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NASA/MSFC FY92 Earth Science and Applications Program Research Review

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NASA/MSFC FY92 Earth Science and Applications Program Research Review

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N93-20068

Title: Global Temperature Variations

Investigators: Roy W. Spencer/MSFC
John R. Christy/UAH

Significant Accomplishments for the Past Year:

Lower stratospheric temperature anomalies from MSU channel 4 were compared to ten years of radiosonde data to validate the satellite record, and the results were submitted for publication. Various assumed stratospheric weighting profiles were tested to determine whether the theoretical channel 4 weighting function had significant errors. It was found that the real weighting function is slightly sharper than the theoretical weighting function. We also found evidence for a step-function cooling in the radiosonde record during 1982, a period when two satellites were operating with no evidence of changes in the satellites. Lower tropospheric bulk temperature datasets continue to be sent to climate researchers and modelers, as well as to the Climate Analysis Center (CAC). The CAC is also implementing our MSU software to be able to do the MSU processing at their site. Drift in MSU channel 3 is being qunatified and corrected to allow it to be used together with channel 2 for a better lower-tropospheric gridpoint temperature product. A new global oceanic precipitation dataset has been produced from MSU channel 1 data, and compared to ten years of global raingage data. A manuscript has been submitted to J. Climate describing this work.

Focus of Current Research and Plans for Next Year:

Monthly updates of MSU data from NOAA will be processed at the end of each month and the derived datasets will be updated, along with satellite intercomparison statistics relating to noise and drift. Datasets are routinely accessed electronically by NCAR, GISS, CAC, and other climate research centers.

Publications:

Spencer, R.W. and J.R. Christy, 1990: Precise monitoring of global temperature trends from satellites. *Science*, **247**, 1558-1562.

Spencer, R.W., J.R. Christy, and N.C. Grody, 1990: Global atmospheric temperature monitoring with satellite microwave measurements: Method and results, 1979-84. *J. Climate.*, **3**, 1111-1128.

Spencer, R.W., and J.R. Christy, 1991a: Precison and radiosonde validation of satellite gridpoint temperature anomalies, Part I: MSU channel 2. In press.

Spencer, R.W., and J.R. Christy, 1991b: Precison and radiosonde validation of satellite gridpoint temperature anomalies, Part I: A tropospheric retrieval and trends during 1979-90. In press.
Spencer, R.W., and J.R. Christy, 1992: Precision lower stratospheric temperature monitoring with the MSU: Technique, validation, and results 1979-1991. Submitted to J. Climate.
Spencer, R.W., 1992: Global temperatures, satellite measures. Encyclopedia of Earth System Science, Vol. II, Academic Press.
Spencer, R.W., 1992: Global oceanic precipitation estimation from the MSU during 1979-91. Submitted to J. Climate.
Spencer, R.W., 1992: Monitoring of global tropospheric and stratospheric temperature trends. Atlas of Satellite Observations, Cambridge University Press. In press.

N93-20069

Global Rainfall Monitoring by SSM/I

E.C. Barrett, C. Kidd and D. Kniveton

Background of the Investigation

Rainfall is a key environmental parameter for which *in situ* observational data has always been generally inadequate. Today, the need for rainfall data is even greater than before, not least because of growing concerns for global weather and climate change, improved evaluations of the global hydrological cycle, and the significance of rainfall for water supplies, crop growth, industry and commerce. Since the 1970s many techniques have been tested for improved rainfall monitoring using satellite visible and/or infrared data in support of ground observations. However, problems exist with all such methods because the radiances measured by the satellite emanate almost exclusively from the tops of clouds. Passive microwave data afford fresh hope for more physically direct monitoring of rainfall by satellites, especially for climate time scales.

The WetNet Project, "a pilot programme...designed to enhance scientific analysis and encourage an interdisciplinary approach to research problems" is based on the DMSP-SSM/I sensor, and therefore holds particular promise for rainfall monitoring. The activity described in this Report is part of the WetNet effort, which embraces a total of 42 laboratories, 7 outside the USA. A key element of WetNet is ..."cooperative research among teams of scientists..."; the WetNet Precipitation Working Group is the biggest of its teams. Since early 1991 E.C.Barrett has served (at NASA's request) as WetNet PrecipWG Chairman. In this capacity he has organised a global algorithm precipitation intercomparison project (PIP-1) as outlined below.

Significant Accomplishments in the last year

During 1991, three main activities were undertaken:

1. <u>Development and testing of a preliminary global rainfall algorithm</u>, based on frequency differencing over land and polarization differencing over coasts and oceans. Initial results (including both global maps and mean latitudinal profiles of estimated rainfall) have been compared qualitatively with climatology, and areas of difficulty identified. The latter include areas of strong surface

scattering, most notably sand and snow.

2. Researching areas of strong surface scattering in attempts to reduce or even remove related global rainfall algorithm ambiguities. Results for selected desert areas (Sahara, Great Australian Desert) confirm that use of horizontally-polarized brightness temperatures in such areas instead of the more generally approved vertically-polarized data largely eliminate the sand/rainfall ambiguity problem. Meanwhile, studies in selected snow-covered areas (Great Britain) confirm that rain/snow ambiguities are likely to be more difficult to resolve, although evaluations of diurnal temperature variations of snow surfaces may be helpful in some situations. Global tests have begun with a modified global rainfall algorithm incorporating the above findings, and the results from possibly the first such algorithm to eschew a sand mask are encouraging.

3. Formulation of a program of work for the WetNet PrecipWG, primarily the Precipitation Intercomparison Project, PIP-1, to be undertaken during 1992. Recognising that present SSM/I rainfall algorithms are not yet mature, but increasing calls are being made for such algorithms to be implemented operationally, PIP-1 was proposed by E.C.Barrett.

   (a) to facilitate intercomparison of existing algorithms (including SSM/I, GPCP infrared, Spencer MSU, and ECMWF forecast model outputs) and through requested results conforming to a careful set of specifications for a chosen period of time (August through November 1987, for which data from all seven SSM/I channels were available);

   (b) to permit validation of these results through reference to selected surface data sets (GPCC continental raingauge, and Morrisey's Pacific atoll, data sets);

   (c) to enable elucidation of the physical reasons for differing results from different algorithms; and

   (d) to move towards the development of a "community algorithm" for optimum performance on a global scale.

A sub-committee of ECB (Chair), J.Dodge (NASA, HQ), J.Janowiak (CAC, NOAA), M.Goodman (NASA, MSFC) and E.Smith (FSU) was set up to prepare the "rules of combat", and to determine how the results will be evaluated. Invitation letters to possible PIP-1 participants were sent out in December 1991, and ancillary and validation data sets were obtained. A subsequent case-study oriented PIP-2 is now being advanced from seed to embryo.

Focus of Present Research and Plans for Next Year

Presently, we are preparing our own results for submission to PIP-1 by the deadline of 31 July 1992, and designing the statistical package by which results from all participating laboratories will be judged. From 1 August until 4 January 1993 we will, in liaison with MSFC, process and analyse these results.

It is our intention in 1993 to prepare a detailed Report on the intercomparison in time for a Participant's Workshop provisionally set for 13-14 April 1993. After this we will complete and edit a special edition of the refereed journal Remote Sensing Review (approx. 200pp) to describe PIP-1, its need, its components, and its results and their implications. For the second half of the year we hope to participate in the planned PIP-2 (case studies) exercise, and follow-on activities from PIP-1 as its results recommend, it is expected that ECB will continue to Chair the PrecipWG through this period.

Publications

Barrett, E.C. (1991): Diagnostic, historic & predictive analyses of rainfall using passive microwave image data. Palaeogeography, Palaeoclimatology & Palaeoecology, 90, 1991, p.99-106.

Barrett, E.C. & Bellerby, T.J. (in press): A strategy for the calibration by collateral data of satellite rainfall estimates for shorter periods. Accepted for publication in Journal of Applied Meteorology.

Barrett, E.C., Kidd, C. and Kniveton, D. (1992): Global Rainfall Monitoring by the SSM/I: Products, Problems and Intercomparison Projects. Final Report to USRA, Columbia, MD., RSU, Univ. Bristol, 83pp + 27pp of Plates.

Barrett, E.C., Kidd, C. & Xu, Hui. "Snow monitoring by AVHRR-HRPT and DMSP-SSM/I data analyses". In Proceedings of the Vth AVHRR Users Meeting, Tromso, Norway, 1991, p.103-108.

GLOBAL SATELLITE DATA ANALYSIS

John R. Christy
Assistant Professor, Atmospheric Science
University of Alabama in Huntsville
and
Roy W. Spencer, NASA/MSFC

1. Microwave Sounding Unit Research (with Roy Spencer)

Papers in press:

Spencer, R.W. and J.R. Christy, 1992: Precision and radiosonde validation of satellite gridpoint temperature anomalies. Part I: MSU Channel 2. *J. Climate*, **5**.

Spencer, R.W. and J.R. Christy, 1992: Precision and radiosonde validation of satellite gridpoint temperature anomalies. Part II: A tropospheric retrieval and trends during 1979-90. *J. Climate*, **5**.

Trenberth, K.E., J.R. Christy and J.W. Hurrell, 1992: Monitoring global monthly mean surface temperatures. *J Climate*, **5**.

Papers in review

Spencer, R.W. and J.R. Christy, 1993: Precision lower stratospheric temperature monitoring with the MSU: Technique, Validation, and Results 1979-90. *J. Climate*.

Contributions to books:

Christy, J.R., "Monitoring Global Temperature Changes from Satellites". Chapter 11. *Global Climate Change: Implications, Challenges and Mitigation Measures*. Eds: S.K. Majumdar, L.S. Kalkstein, B. Yarnal, E.W. Miller, and L.M. Rosenfeld. The Pennsylvania Academy of Science.

Conference Presentations:

(invited) Spencer, R.W. and J.R. Christy, 1991: A physical interpretation of brightness temperatures observed by the Microwave Sounding Units based upon Raobs. *Fifth Symposium on Climate Variations*, American Meteorological Society, 14-18 Oct. 1991, Denver CO.

Christy, J.R. and K.E. Trenberth, 1991: Monitoring global monthly surface temperatures. *Fifth Symposium on Climate Variations*, American Meteorological Society, 14-18 Oct. 1991, Denver CO.

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(invited) Christy, J.R., 1991: The MSU data, 1979 to the present. *First Demetra Meeting on Global Change,* 28 Oct. 1991, Chianciano Italy.

Other

Invited Contributor, *Climate Change 1992: IPCC,Supplementary Report (Section C,Observed Climate Variability and Change).* Melbourne Australia, 24-26 Nov. 1991.

Research areas:

Working with Spencer to develop a multi-channel retrieval for increased tropospheric precision. The problem area concerns the instability of channel 3 on at least three of the MSUs.

Using footprint data, I am constructing global synoptic maps of MSU temperatures (daily means at this point) for identification of variability over data sparse regions on the synoptic scale.

2. Earth Observing System

(In addition to papers listed above)
Papers presented:

Christy, J.R., R.T. McNider, F.R. Robertson and D. Fitzjarrald, 1991: Comparison of MSU and CCM1 tropospheric temperatures for 1979-86. *Fifth Symposium on Climate Variations,* American Meteorological Society, 14-18 Oct. 1991, Denver CO.

Christy, J.R., 1992: Climate model validation using MSU global temperatures. Workshop on Atmospheric Model Intercomparison Project. 21 Feb. 1992, Berkeley, CA.

Research Areas

One result from the multi-year run of the CCM1 using prescribed (observed) SSTs (1978-86) indicated that the model's tropospheric temperature responds to SST warming almost exactly as does the real atmosphere as measured by MSU temperatures. However, during periods of cooling, the CCM1 did not return to the levels seen in the real atmosphere so that a warm bias slowly was built in the model results. At present the net downward solar flux in the tropics is being examined and found to vary in the opposite sense from atmospheric temperature (warmer troposphere indicates more cloudiness).

This seems to be a negative feedback on temperature, though not to the extent experienced in the real world.

D. Fitzjarrald, J. Srikishen and I are studying the predictability of global stratospheric and tropospheric temperatures using neural network theory.

N93-20070

TITLE: Interactive Access and Management for Four-Dimensional Environmental Data Sets Using McIDAS

INVESTIGATORS: William L. Hibbard and Gregory J. Tripoli

BACKGROUND OF THE INVESTIGATION:

The development of McIDAS (Man-computer Interactive Data Access System) has been a long term project at the Space Science and Engineering Center for managing, displaying and processing earth science data. This grant is part of a series of NASA funded projects to explore technological opportunities to extend the capabilities of the McIDAS system, including animated three-dimensional displays, the use of computing standards such as UNIX and X Windows, the use of commercial workstations, interactive three-dimensional graphics, graphical user interfaces, and visual interaction with computations. The systems developed by these NASA funded projects have either become part of McIDAS, or access data in McIDAS file formats.

The McIDAS-X system released in April 1992 evolved from an experimental version of McIDAS running under UNIX and X Windows, and developed by this NASA funded technology exploration. The VIS-5D (VISualization of 5-Dimensional data sets) system, available as freeware and widely used by atmospheric modelers, was developed as part of this NASA funded technology exploration. VIS-5D provides highly interactive visual exploration of large data sets in McIDAS grid files, such as those produced by numerical simulations and volume scanning radars. The user interface of VIS-5D is specifically designed for earth scientists and, for a given size of workstation, it allows exploration of much larger data sets than other visualization packages.

VIS-5D is being used by scientists at UW-SSEC as a routine diagnostic tool for their model developments, and has had a real effect on the content of their science. It is also being used by scientists at NASA/MSFC and at NASA/GSFC. In addition to the support from NASA for the development of VIS-5D, the French Meteorology Bureau and INPE/CPTEC in Brazil have both funded visiting scientists for periods of six months who contributed to its development.

We have implemented a distributed version of VIS-5D, supported by the Gigabit Testbed Project. This version of VIS-AD accesses very large data sets (10^10 grid points) residing on remote super computers, although it requires extraordinary computational and communications resources.

The current NASA grant combines support for this exploration of technology with support for atmospheric modeling, recognizing the importance of cooperation between scientists and system developers.

SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

Enhancements to VIS-5D

During the last year, enhancements to VIS-5D include

A) a significant decrease in the response time to user selection of new iso-level contour surfaces for depicting fields
B) the ability to render plane slices as pseudo-colored images, which is useful for visualizing highly textured radar data
C) the ability to render topographical map backgrounds from user-supplied topography data files
D) a port of VIS-5D to run on almost all models of SGI workstations
E) a port of VIS-5D to run on the IBM RISC 6000 workstations.

Implementation of the VIS-AD system

We have implemented an initial version of the VIS-AD (VISualization for Algorithm Development) system and have demonstrated it at the American Meteorological Society conference in Atlanta in January 1992. VIS-AD lets scientists visualize the results of experiments with their algorithms. It functions somewhat like an interactive debugger, except that it presents graphics of high-level data objects rather than just printing lists of numbers. Its focus is on tracing high-level algorithm behavior rather than on tracking down low-level bugs. VIS-AD provides

A) an editor, compiler and interpreter for a programming language similar to C
B) management of user-defined data structures, accessible as data objects from the programming language

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C) support for MISSING data in the programming language
D) an elegant and flexible mechanism for managing finite samplings of continuous quantities, such as the way a satellite image samples earth locations
E) interactive execution controls for setting breakpoints and executing single steps in programs
F) a means to display any combination of data objects in a program.

Scientists at Wisconsin are beginning to use VIS-AD to help them develop algorithms for the GOES Pathfinder project. VIS-AD accesses image data and gridded data in McIDAS data files, so that it can easily be used to access data from the GOES archive and other sources at SSEC.

In order to demonstrate the flexibility of VIS-AD, we have applied it to an algorithm for discriminating clouds in GOES images using infrared and visible data. These image data may be displayed as pseudo-colored images, as two-dimensional contours of pixel values, as three-dimensional surfaces, as two- and three-dimensional scatter diagrams of infrared temperature versus visible brightness versus variance of temperature, and as other formats. These display formats are not hard-wired, but are defined by the user in a flexible language.

Numerical Modeling Applications

The University of Wisconsin Regional Atmospheric Modeling System (UW-RAMS) is being used as a prototype model to test the usefulness of VIS-5D to numerical simulation. The output infra-structure of the UW-RAMS model output was modified to write output of any variable or function within in a large menu of possible functions, to McIDAS grid format where it could be easily picked up by the VIS-5D software for immediate visualization of results. Model output formats for numerical model runs on non-McIDAS computers was also modified to create files which are easily converted to McIDAS files for VIS-5D applications.

As a result, essentially all numerical model runs are capable of being visualized routinely, and most, in fact, are. The visualization has become a primary tool for understanding complex dynamical systems. Problems encountered with the prototype visualization software are relayed to the Hibbard-Paul development group, where improvements are made. The visualization has used also for presentation graphics for publication, at conferences, seminars and even graduate student exams. Several examples of its use as an interactive model diagnostic tool and then as a presentation graphics tool are mentioned below.

As an interactive diagnostic tool, the VIS-5D has become a software of central importance. Both numerical studies of tropical cyclogenesis and polar low cyclogenesis used VIS-5D to investigate the details of scale interaction processes, by finding and defining the existence and movement and vertical trapping of outward and inward propagating spiral gravity wave bands, showing the development of a hurricane eye structure, the coexistence of microphysical quantities, the relationship between isentropic surface and momentum surfaces throughout the storm with regard to the existence of conditional symmetric stability, the development of the Ekman boundary layer and so on. Trajectory analysis has been useful in revealing major differences between the dynamical structure of the tropical cyclone at the tropical depression, storm and hurricane stages.

Numerical studies of large eddies in the boundary have used the VIS-5D to demonstrate the tendency toward organized bands in unlikely situations. The animation instills the viewer with a sense of how and why the organization must occur and on what it must depend.

Numerical studies of thunderstorm clouds with UW-RAMS have utilized VIS-5D to depict the updraft organization, existence and development of the mesocyclone and the role of the different microphysical components of the system. Numerical studies of downbursts by Dr. J. Anderson have also utilized VIS-5D to visualize downbursts simulated by an independent model.

The VIS-5D graphics have been employed as a tool for conveying the simulated dynamics to an informed audience at scientific conferences. Presentations of the visualized hurricane at the Miami National hurricane conference and the Atlanta Mesoscale conference were well received and enabled the speaker to demonstrate dynamical principles of scale interaction otherwise difficult to understand or explain. The visualized hurricane was also used in the classroom to explain hurricane dynamics to a senior level undergraduate class.

The visualized polar low simulation was presented at the Atlanta mesoscale conference to demonstrate the influence of inertial stability on CISK induced arctic cyclogenesis and was successful in driving home points which would have difficult to show with two-dimensional graphics. Several papers have been submitted or in preparation utilizing full color or gray shaded VIS-5D illustrations.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

Continued development and application of the VIS-AD system

Because of its ability to display user-defined data structures and because of its support for user-written algorithms accessing those data structures, VIS-AD is an extremely flexible tool for visualizing data and algorithms. It is the appropriate software context for most further work under this NASA sponsored exploration of technology. The development of VIS-AD replaces our earlier plans for continued development of VIS-GI and for providing interactive diagnostics as part of VIS-5D. The most immediate areas for continued development of VIS-AD include

A) labeling display axes with application values
B) labeling the current frame in an animation sequence with application values
C) supporting a variety of map projections
D) supporting satellite navigation and calibration
E) extending the library of intrinsic functions for image processing
F) implementing McIDAS commands as intrinsic functions
G) supporting user-written external functions written in C or Fortran
H) improving the efficiency of the language interpreter
I) providing a translator from the VIS-AD language to C.

We will also continue to support scientists at Wisconsin and at NASA who apply VIS-AD to their algorithm development problems, such as those developing product generation algorithms for GOES Pathfinder.

Further enhancements to VIS-5D

We will respond to scientists' needs to make VIS-5D more useful for exploring atmospheric simulation data sets. Some possible new features include

A) interactive retrieval of field values using the 3-D cursor
B) providing more flexible map projections in the 3-D box.

Plans for Modeling Applications

We plan to continue to utilize the Stellar GS-2000 as a primary modeling workstation and to utilize the visualization capability both for locally run model simulations and runs made on other machines. In this coming year, we will be simulating much more real data including an observed mid-latitude snow storm, the killer tornado of Plainfield, Illinois and several mesoscale convective complexes including one with a strong Derecho. We will also accelerate the tropical cyclone research to investigate external scale interactions with the surrounding circulations and again, VIS-5D will play a central role. In addition, we are beginning plans to develop an operational model of mesoscale weather for which there will be application of VIS-5D. Most likely, VIS-5D will be used as a presentation tool in many more conference papers and publications since we have learned to depend on its presentation power. Because the quality of the presentation and published presentation graphics is a permanent record of the VIS-5D product, we would strongly suggest that the development of VIS-5D should be continued to improve the appearance of the visualizations under these circumstances.

PUBLICATIONS:

Aune, R., G. Callan, and W. Hibbard, 1991; A 4D visualization of a 4D assimilation system. Preprint, 9th Conference on Numerical Weather Prediction, Oct. 14-18, Denver, AMS, 614-615.

Hibbard, W., and B. Paul, 1991; El Nino Satellite Observations and Downburst Simulation. SIGGRAPH Video Rev., No. 74.

Hibbard, W., 1991; Access - end user (scientist) view and environment subgroup. Part of the SIGGRAPH '90 workshop report: Data structure and access software for scientific visualization. Edited by Lloyd A. Treinish. Computer Graphics 25(2), 104-118.

Hibbard, W., 1992; A highly parallel approach for satellite archive processing. Preprints, Conf. Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology. Atlanta, AMS, 82-83.

Hibbard, W., C. Dyer and B. Paul, 1992; A development environment for data analysis algorithms. Preprints, Conf. Interactive Information and Processing Systems for Meteorology, Oceanography, and Hydrology. Atlanta, AMS, 101-107.

Tripoli, G. J., 1992; An explicit three-dimensional non-hydrostatic numerical simulation of a tropical cyclone. Meteor. in Atmos. Phys., accepted for publication.

N93-20071

Title: Planetary Circulations in the Presence of Transient and Self-Induced Heating

Investigators:

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Rolando R. Garcia
National Center for Atmospheric Research
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Background: The research program focuses on large-scale circulations and their interaction with the global convective pattern.

Progress: An 11-year record of global cloud imagery and contemporaneous fields of motion and temperature have been used to investigate organized convection and coherent variability of the tropical circulation operating on intraseasonal time scales. This study provides a detailed portrait of tropical variability associated with the so-called "Madden-Julian Oscillation" (MJO). It reveals the nature, geographical distribution, and seasonality of discrete convective signal, which is a measure of feedback between the circulation and the convective pattern. That discrete spectral behavior has been evaluated in light of natural variability of the ITCZ associated with climatological convection.

A composite signature of the MJO, based on cross-covariance statistics of cloud cover, motion, and temperature, has been constructed to characterize the lifecycle of the disturbance in terms of these properties. The composite behavior has also been used to investigate the influence the MJO exerts on the zonal-mean circulation and the involvement of the MJO in transfers of momentum between the atmosphere and the solid Earth.

The aforementioned observational studies have led to the production of two animations: One reveals the convective signal in band-pass filtered OLR and compares it to climatological convection. The other is a 3-dimensional visualization of the the composite lifecycle of the MJO.

Current Research: With a clear picture of the MJO in hand, feedback between the circulation and the convective pattern can be diagnosed meaningfully in numerical simulations. This process is being explored in calculations with the linearized primitive equations on the sphere in the presence of realistic stability and shear. The numerical framework represents climatological convection as a space-time stochastic process and wave-induced convection in terms of the vertically-integrated moisture flux convergence.

In these calculations, frictional convergence near the equator emerges as a key to feedback between the circulation and the convective pattern. At low latitudes, nearly geostrophic balance in the boundary layer gives way to frictional balance. This shifts the wave-induced convection into phase with the temperature anomaly and allows the attending heating to feed back positively onto the circulation. The calculations successfully reproduce the salient features of the MJO. They are being used to understand the growth and decay phases of the composite lifecycle and the conditions that favor amplification of the MJO.

Publications:

Salby, M. and H. Hendon, 1992: Intraseasonal behavior of clouds, temperature, and motion in the tropics. *J. Atmos.* (to be submitted).

Hendon, H. and M. Salby, 1992: The structure and evolution of the Madden-Julian oscillation. *J. Atmos.* (to be submitted).

Hendon, H. and M. Salby, 1992: Vertical momentum transfer associated with the Madden-Julian oscillation. *J. Geophys. Res.* (to be submitted).

Salby, M. and R. Garcia, 1992: Planetary circulations in the presence of climatological and wave-induced heating. *J. Atmos. Sci.* (to be submitted).

Tanaka, K., Hendon, H., and M. Salby, 1992: Intraseasonal Behavior of Convection in the Tropics. Computer animation, SVHS video, 10 mins. Available from CATA.

Callaghan , P., Tanaka, K., Salby, M., and H. Hendon, 1992: Structure and Evolution of the Madden-Julian Oscillation. Computer animation, SVHS video, 5 mins. Available from CATA.

N93-20072

TITLE: Cloud Radiative Forcing Effects on Observed and Simulated Global Energetics

INVESTIGATORS: B. J. Sohn, USRA/MSFC (Principal Investigator)
Franklin Robertson, MSFC

RESEARCH OBJECTIVES:

1. To examine how cloud-radiation processes generate/destroy available potential energy by altering both meridional and zonal temperature gradient.
2. To investigate how the atmospheric dynamic fields respond to the cloud-altered mass distributions through the energy conversion circuit.
3. To examine how the improved version of CCM1 simulates observationally obtained cloud-radiative forcing and its associated energetics and circulations.

SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

This is the first year of an effort to understand cloud radiative effects on atmospheric energetics. As an initial part of this study, an intercomparison of cloud forcing determined by the ERBE clear sky scene identification method and two regression methods has been made for the time period of February and March, 1985. This period was selected because of coexisting satellite radiation budget and cloudiness data sets from ERBE, Nimbus 7 and ISCCP. The intercomparison is motivated by substantial differences in magnitudes of the annual global mean of cloud forcing; recent estimates of net cloud forcing range from -2 Wm^{-2} to -27 Wm^{-2} depending on methods, data sources, and analysis period. Different cloud forcing estimates will bring about different results in diabatic heating estimation. Because we intend to use the satellite-estimated cloud forcing as a constrained top boundary condition of the radiative transfer model in order to obtain cloud-induced atmospheric heating, it is essential to clarify why there are differences in order to obtain reliable heating distributions. Here we intercompare three recent cloud forcing estimation methods using the same data sources and analysis period.

The three methods each support the conclusion that in the global mean the increased reflection of SW radiation induced by clouds is greater than the reduced outgoing longwave energy loss by clouds. The estimates of net effects obtained from the three methods are in near agreement on a global average basis. On the basis of error analysis of LW and SW cloud forcing, it appears that all estimates differ by less than their uncertainties. Based on the close agreement of the global average of net cloud forcing between five estimates, we conclude that large differences between published cloud forcing estimates are mainly due to substantially different data sources as well as analysis period rather than to deficiencies in methods.

Since global means of net forcing from two regression methods are close to the ERBE value we further conclude that a best estimate of global annual mean of net cloud forcing would be close to that of the ERBE estimate, i.e., -17.3 Wm^{-2}. However, the systematic bias of the ERBE estimate toward larger magnitudes in both LW and SW would bring in uncertainties examining the role of clouds in regional and planetary atmospheric energetic processes or the general circulation. Errors in either LW or SW cloud forcing induce errors in vertical diabatic heating profiles as well as surface radiation fluxes. Since

LW-induced heating errors cannot counterbalance those induced by SW, the close agreement between net cloud forcing estimates does not necessarily imply the same quality of agreement in net heating profiles or net surface radiation flux. Because diabatic heating is one of most important factors of clouds in modulating global climate, additional work is necessary to improve our ability to precisely measure the effects of clouds and their role in regulating regional and global climate.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

In order to examine radiative impact of clouds upon atmosphere as well as surface, we are retrieving atmospheric diabatic heating profiles and surface radiation budget components. The direct simulation of the radiative transfer processes relevant to the atmosphere and surface radiation budget is used for the retrieval. Input data to drive the model include satellite-estimated clear and cloudy sky TOA fluxes of both solar and infrared radiation. Retrieval strategies consist of 4 steps and are following:

1. LW clear sky run: In determining atmospheric contribution to the TOA LW flux, we insert ECMWF temperature and moisture data at 1000, 850, 700, 500, 300, 200, 100 mb into LW radiative transfer model. Since the calculated TOA flux is usually different from satellite-measured clear sky LW flux, we minimize the difference between these two fluxes by perturbing temperature and moisture profiles. The resultant T and q profiles now will yield the satellite-estimated TOA LW flux.

2. SW clear sky run: Atmospheric temperature and moisture data yielding LW clear sky flux will then be used for SW clear sky calculation. By perturbing surface albedo in the radiative transfer calculation and minimizing the flux difference at the TOA we will obtain surface albedo which produces satellite-measured clear-sky SW flux.

3. SW cloudy sky run: The areal coverage of low, middle, high cloudiness from ISCCP cloud climatology will be inserted into the SW radiative transfer model. Considering the influences of cloud liquid water content and effective radius of cloud droplets on SW radiation, the SW cloud forcing will be redistributed vertically.

4. LW cloudy sky run: Same as in step 3, LW cloud forcing will be redistributed by specifying low, middle, and high cloudiness.

The obtained cloud-induced heating profiles through steps 1 - 4 will then be used for diagnosing the global and regional APE and KE balance with a particular focus on the generation of APE by cloud-induced radiative heating. The calculation will be performed for a Dec. - Jan. period and a Jun. - Aug. period.

PUBLIATIONS:

Sohn, B.J., and F.R. Robertson, 1992: Intercomparison of observed cloud radiative cloud forcing. To be submitted to *Bull. Amer. Meteor. Soc.* for publication.

N93-20073

Basic Studies of Baroclinic Flows

Investigators:

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H.-I. Lu, USRA/MSFC
K. A. Butler, NTI/MSFC

a. STRATEGY: The combination of differential heating and rotation can result in numerous regimes of fluid flow, depending upon boundary conditions, etc. Of particular interest are baroclinic instabilities, including nonlinear behavior. Laboratory experiments and numerical models will be jointly used to study basic physical processes that are important in the Earth's atmosphere with the objective of contributing toward a better understanding of the requirements for and application of space-based sensor measurements and to develop a better understanding of methods for modeling the behavior of the Earth system, especially the atmosphere.

b. PROGRESS: A fully nonlinear 3-dimensional numerical model (GEOSIM), previously developed and validated for several cases of geophysical fluid flow, has been used to investigate the dynamical behavior of laboratory experiments of fluid flows similar to those of the Earth's atmosphere. The phenomena investigated are amplitude vacillation, and the response of the fluid system to uneven heating and cooling. The previous year's work included hysteresis in the transition between axisymmetric and wave flow. Investigation is also continuing of the flows in the Geophysical Fluid Flow Cell (GFFC), a low-gravity Spacelab experiment.

Much of the effort in the past year has been spent in validation of the model under a wide range of external parameters including nonlinear flow regimes. With the implementation of a 3-dimensional upwind differencing scheme (using a weighted average of upwind and centered differencing), higher spectral resolution, and a shorter time step, the model has been found capable of predicting the majority of flow regimes observed in one complete series of baroclinic annulus experiments of Pfeffer and co-workers. Detailed analysis of amplitude vacillation has revealed that the phase splitting described in the laboratory experiments occurs in some but not all cases. Through the use of animation of the model's output, a vivid 3-dimensional view of the phase splitting was shown to the audience of the Southeastern Geophysical Fluid Dynamics Conference in March of this year.

A study on interannual variability was made using GEOSIM with periodic variations in the thermal forcing. Thus far, the model has not predicted a chaotic behavior as observed in the experiments, although there is a sensitivity in the wavenumber selection to the initial conditions. Work on this subject, and on annulus experiments with non-axisymmetric thermal heating, will continue.

The comparison of GEOSIM's predictions with results on the Spacelab 3 GFFC experiments continued over the past year, on a "back-burner" basis. At this point, the study (in the form of a draft of a journal article) is nearly completed. The results from GEOSIM compared very well with the experiments, and the use of the model allows the demonstration of flow mechanics that were not possible with the experimental data. For example, animation of the model output shows that the forking of the spiral bands is a transient phenomenon, due to the differential east-west propagation of convection bands from different latitudes.

c. PLANS: The numerical model will continue to be used to investigate amplitude vacillation and nonaxisymmetric heating. Publications will be developed. The investigators will also begin to investigate shape vacillation, and hysteresis in wavenumber and other transitions. Comparison between model predictions and flows observed in the GFFC experiment on Spacelab 3 will be completed, and suggestions for future experiments on USML-2 will be developed.

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N93-20074

LABORATORY AND THEORETICAL MODELS OF PLANETARY-SCALE INSTABILITIES AND WAVES

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RECENT PROGRESS

Research work is proceeding in theoretical, numerical, and experimental geophysical fluid dynamics leading up to a reflight of the GFFC (Geophysical Fluid Flow Cell Experiment) on USML - 2. The work is intended not only to generate ideas for future space experiments, but to provide fundamental results concerned with nonlinear and chaotic properties of thermal convection and baroclinic waves in terrestrial and planetary atmospheres. The major efforts are focussed on thermal convection in a rapidly rotating annulus relevant to Jovian atmospheric dynamics, and on the chaotic behavior of baroclinic waves relevant to the Earth's atmosphere. The approach, in preparation for USML - 2, is primarily theoretical and numerical.

Mechanistic process models are solved numerically in order to identify physical mechanisms that may be observed in the GFFC, and which are important in real geophysical applications. The results from numerical simulations of geophysical fluid flow (subject to rotation and stratification) are compared with previous GFFC experiments on Spacelab-III and with existing and proposed terrestrial laboratory experiments of various types. Pattern recognition algorithms have been employed to generate low-dimensional descriptions of the the highly nonlinear and turbulent numerical simulations. Such empirically truncated descriptions provide for simplified but robust physical interpretations of the dynamics, as well as yielding highly efficient computations of these chaotic flows.

Our most important new results are:

1) The completion and exploration of a fully nonlinear computational model of thermal convection in the presence of strong basic rotation which varies with latitude. The model assumes the thermal convection takes place on cylinders parallel to the axis of planetary rotation, but is influenced by the spherical topography (the β effect). The resulting thermal convection is composed of banana cells, as observed on Spacelab III flight of the GFFC, but the computation is simplified by using an equatorial annulus geometry. Thus very high Rayleigh and Taylor numbers can be studied on workstations.

The results are most interesting. The turbulence at high Rayleigh numbers is associated with extremely strong, even dominating, mean zonal jets. A scaling of the model results with the observed heat flux of Jupiter, for example, leads to zonal jets with velocities of order 100 meter per second. This number is similar to Voyager observations. The turbulence can have isolated spots imbedded in the self-induced zonal jets. At very high Rayleigh number and large β the whole system pulsates. The differential rotation and the turbulent convection patches oscillate almost-periodically. If an effective eddy viscosity appropriate to solar convection is used, the pulsation period is about 11 years - the observed period of the solar cycle. All our work so far has been with unit Prandtl number, and one consequence of this is that the associated solar convective heat flux is much too small. We propose to correct this deficiency and to study further properties of this system at low Prandtl number in the second year.

2) Accurate simulations of the way in which baroclinic atmospheric instabilities become chaotic were completed. It was discovered that almost all previous numerical simulations intending to look at the transition to baroclinic chaos were in error, or at least very slowly convergent. Pseudo-spectral models must employ some lateral viscosity to arrest the enstrophy cascade to small scales. However, with small lateral viscosity present the standard Phillips' condition on the zonal flow at the sidewalls is slightly inconsistent. This small inconsistency has a strong effect on the bifurcation sequence, even when the lateral viscosity is small.

The new model has a different spectral representation that avoids these problems. The baroclinic waves become weakly chaotic for Froude numbers about a factor of 2 smaller than in previous models. However, the degree of chaos is small, when compared with terrestrial laboratory experiments. It is thought that this may be due to the presence of rigid walls in terrestrial and GFFC space experiments, and we propose to rewrite our codes to look at this important problem. For example, the lateral shears induced by the walls will allow for critical layers that will have a significant effect on the baroclinic waves. Although walls are not relevant to atmospheres (though they are to oceans), the transition to chaos with meridional mean shear is a key unsolved problem in atmospheric dynamics.

3) Algorithms to do pattern recognition on both the β - convection and baroclinic wave simulations were competed and tested. Pattern recognition extracts empirical orthogonal functions (nonlinear eigenfunctions) which can be used as basis functions for constructing low order models of the highly nonlinear and fully resolved simulations. In some circumstances modest (e.g. 10 mode) sets of ordinary differential equations can mimic numerical solutions requiring over 10^4 degrees of freedom.

PROPOSED RESEARCH

Our successful numerical model of banana cell convection subject to the β effect will be expanded. The goals are to understand the heat flux and the 11 year cycle on the Sun, and the reason for prograde equatorial jets on Jupiter and Saturn, but retrograde jets on Uranus and Neptune. The hypothesis for the latter difference is that the distance to the inner core (which is significantly larger on Jupiter and Saturn) plays a key dynamical role. We shall:

a) Determine the effect of small ($\simeq 0.01$, as in the Sun) and modest ($\simeq 8$, as in GFFC) Prandtl number on β - convection.

b) Compare full numerical simulations of β - convection with asymptotically derived nonlinear amplitude equations. These comparisons will allow us to understand the conditions under which multiple zonal jets may arise, as in Jupiter, vs. the single jet on Uranus and Neptune.

c) Determine the effect of deep anelastic compressibility on the liquid GFFC type models. The convection and zonal jets must extend some distance into the giant planets and the effect of penetration through many scale heights must be addressed before truly quantitative comparisons with the Voyager data will be possible. Our code will be for a rectilinear geometry (retaining β effects) and will run much faster than full spherical shell models. Thus we will be able to pursue questions about scaling and banana cell breakup at very high Rayleigh and Taylor numbers.

d) Determine the effect of core depth on zonal jets. Simulations with β increasing or decreasing with latitude, or with a singularity at subtropical latitudes, will be run to investigate the effect of variable β on zonal jet sign (prograde vs. retrograde) and structure.

e) Complete a rigid sidewall boundary model of baroclinic instability. Investigate the transition to chaos and compare with the previous free slip models. The results are of fundamental interest and important for generating baroclinic wave experiments on GFFC - USML2.

f) Perform pattern recognition and EOF analyses on the above simulation results. Analyse the resulting projected low order models as predictive and interpretive tools in nonlinear geophysical fluid dynamics.

g) Construct a simple rapidly rotating - convection experiment using centrifugal buoyancy. Compare with anaytical and numerical results. Verify the existence of pulsating turbulent states.

Publications and Submittals:

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N93-20075

RESEARCH ON DIABATIC INITIALIZATION

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The objective of this research is to contribute to the improvement of the analyses of irrotational wind and moisture fields in the tropics through advancement in the technique of initialization, incorporating diabatic effects and use of satellite-derived, radiometric imagery data that are not used currently by operational centers.

Significant Accomplishments in the Past Year (May 1991–April 1992)

Impact of tropical initialization upon the spin-up of precipitation forecasts

Kasahara, Mizzi and Donner (1992) investigated the impact of various steps of data initialization on precipitation forecasts in the tropics. The data initialization is divided into three components: 1) application of diabatic nonlinear normal mode initialization (NNMI), 2) modification of the initial divergence by incorporation of satellite imagery data [Kasahara *et al. Mon. Wea. Rev.*, **116** (1988), 866–883], 3) modification of the moisture and temperature fields by the cumulus initialization schemes [Donner, *Mon. Wea. Rev.*, **116** (1988), 377–385]. Numerical experiments were conducted by running 10.5 hour forecasts (42 time steps), starting from various initial conditions after application of some combination of the three initialization components. A triangular-42 version of the NCAR global spectral model (CCM1) and its associated NNMI package were used. The results of a case study from reanalyzed FGGE Level III data show that 1) even if a good estimate of diabatic heating rates were available, diabatic NNMI alone would not solve the spin-up problem, 2) the adjustments of moisture and temperature using the cumulus initialization are essential to ameliorate the spin-up problem, and 3) the divergence adjustment, assisted by satellite imagery data, is beneficial when used in conjunction with the cumulus initialization and diabatic NNMI procedures.

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A unified approach to diabatic initialization for improvement in the analysis of divergence and water vapor fields in the tropics

The knowledge gained from the previous study enables us to develop a unified initialization to adjust the analyses of the horizontal divergence, moisture, and temperature fields simultaneously, rather than in the three separate steps described earlier, using "observed" precipitation rates as input. The regions of cumulus convection (upward motion) and cloud-free regions (downward motion) are identified in the tropics by using infrared and visible radiometric imagery data. The horizontal divergence and moisture in the ascending area are then adjusted based on a cumulus parameterization formulation using "observed" precipitation rates as a constraint. The details of this adjustment process based on the Kuo cumulus parameterization are described in Kasahara, Mizzi and Donner (1991). The adjustment procedures use a quadratic optimization algorithm with nonlinear and linear constraints and are tested using the ECMWF FGGE Level IIIb analyses. The horizontal divergence in the descending area is calculated from the estimate of vertical velocity based on the dynamical balance between adiabatic warming by advection and descending motion and radiative cooling, since the local time rate of change of the temperature in the tropics is small. At present, the vertical moisture distribution in the descending area is left unchanged.

Focus of Current Research and Plans for Next Year

Controlling the precipitation overshoot during the early part of a numerical forecast

In connection with our impact study of various steps of data initialization on precipitation forecasts described earlier, we observed that the evolution of a precipitation forecast during the early part of some forecast runs is not completely smooth, so that the reduction of the spin-up time is accompanied by an overshoot of precipitation. We will continue to investigate the cause of precipitation overshoot during the early part of a numerical forecast, as initiated by Mizzi, Kasahara and Donner (1991). It was noticed that this phenomenon is associated with an overshoot of the horizontal divergence. Therefore, a method was developed to adjust the vertical distribution of the horizontal divergence over convective areas to control the overshoot of precipitation and divergence. This adjustment procedure requires the information on an upper bound of the vertically-integrated convective heating rate and is applied during the first few time steps of the numerical forecasts. While this adjustment procedure can control the overshoot of precipitation, the first and second derivatives of horizontal divergence D with respect to time, $\partial D/\partial t$ and $\partial^2 D/\partial t^2$ over the convective region at the initial time are still large, despite the initial reduction of D. Currently, work continues to diagnose the budget of $\partial D/\partial t$ and $\partial^2 D/\partial^2 t$ to understand the nature of dynamical balance under the influence of convective heating.

Use of satellite imagery data for improvement of the tropical analysis

The unified diabatic initialization, described earlier, is intended to be used to check the quality of the first-guess fields and to modify them, particularly the horizontal divergence and moisture, by incorporating information concerning convective activity in the tropics and proxy data for precipitation. We plan to test this initialization scheme for precipitation forecasts using the ECMWF analysis data with a Kuo-parameterization version of the NCAR Community Climate Model (CCM1). A period of January 1988 will be selected to coordinate our forecast experiments with the global analyses of water vapor and precipitation by Dr. F.R. Robertson (NASA/MSFC), who has been using the SSM/I moisture data for comparison with the ECMWF moisture analysis.

Key to our forecast experiments is the global distribution of precipitation. Actually, we are interested in such information only in the tropics, say $\pm 30°$. Since no daily analyses of precipitation are available, we must first construct the proxy data of daily tropical precipitation for the month of January 1988. Through efforts of the Global Precipitation Climatology Project (GPCP), five-day and monthly precipitation data have been constructed starting January 1986 for 40°S–40°N [Janowiak and Arkin, *J. Geophys. Res.*, **96** (1991), 3359–3373]. Data on 2.5° lat-long grids are archived at NCAR by the Data Support Section of the NCAR Scientific Computing Division. Since daily outgoing longwave radiation (OLR) data from NOAA-9 are available for the same period, we will estimate a daily precipitation distribution in the tropics by means of a regression relationship between the pentad GPCP precipitation and daily OLR data.

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N93-20076

Title: Nonlinear Dynamics of Global Atmospheric and Earth System Processes

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Background:

During the past eight years, we have been engaged in a NASA-supported program of research aimed at establishing the connection between satellite signatures of the earth's environmental state and the nonlinear dynamics of the global weather and climate system. Co-investigators over this period, including postdoctoral associates and graduate students, are W. Ebisuzaki, A. R. Hansen, K. A. Maasch, R. L. Nagle, R. J. Oglesby, L. Pandolfo, and C.-M. Tang. Thirty-five publications and four theses have resulted from this work, which include contributions in five main areas of study: 1) Cloud and latent heat processes in finite-amplitude baroclinic waves, (2) application of satellite radiation data in global weather analysis, (3) studies of planetary waves and low-frequency weather variability, (4) GCM studies of the atmospheric response to variable boundary conditions measurable from satellites, and (5) dynamics of long-term earth system changes.

Significant Accomplishments:

Three main lines of investigation were pursued during the past year:

1) Planetary Atmospheric waves and Low-Frequency Variability. A study showing that Rossby waves can be confined to middle latitudes on a spherical earth due to the "localizing" property of a fluctuating zonal mean flow was completed (publication [6]). This provides a significant justification for the use of a mid-latitude beta-plane in treating simple models of planetary wave behavior, at the same time pointing to possible errors in studies in which a fixed zonal wind profile is prescribed. Since the results are dependent on spatial resolution of the zonal flow, some suggestions are made concerning a possible source of systematic error in low resolution models. In addition, a major review of observational studies of low-frequency, intraseasonal, planetary wave variability is made in publication [5],and some important insights concerning the energy source of traveling planetary waves in the atmosphere is obtained in publication [1], based on an observational and theoretical study of the vertical tilts of these waves.

2) GCM Studies of the Atmospheric Response to Changed Boundary Conditions. Two studies aimed at helping establish the sensitivity of the atmosphere to satellite signature of soil moisture, sea-surface temperature, snow cover, and sea ice cover were completed, some of the results of which appeared in publications [2] and [4].

3) Dynamics of Long-Term Changes in the Global Earth-System. Significant strides were made in developing a dynamical systems framework for treating the evolution

of the slower-response parts of the earth-systems (e.g., the ice sheets, deeper ocean, carbon-dioxide content of the atmosphere). Two publications were completed in which a model of the ice-age fluctuations of the past few million years were accounted for as a combined response to radiative and tectonic forcing and free internal variability of the atmosphere - hydrosphere - cryosphere - biolithospheric components of the complete earth-system (publications [7] and [8]).

Focus of Current Research and Plans for Next Year:

Systematic studies are continuing to determine the transitivity properties of a GCM (the NCAR CCM), particularly the very long term (greater than 150 years) equilibration properties including long period fluctuations and the possibility for multi-modal states. In this latter connection, we are exploring the possibility for modelling abrupt changes in weather and climate as a consequence of possible instabilities in the climate system implied by such multi-modal states. We are also continuing our program of using the GCM to establish parameterizations and sensitivity functions that can be used to formulate and improve low-order dynamical models for the evolution of the full climatic system over secular (multi-year) time scales and for a range of externally imposed conditions (e.g., CO_2, solar radiation) much wider than are presently imposed. The role of stochastic forcing as a proxy for unrepresented or unrepresentable physics in the complete system is being studied.

Publications: (1991-1992)

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N93-20077

Title: Life Cycles of Transient Planetary Waves

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Background

In recent years there has been an increasing effort devoted to understanding the physical and dynamical processes that govern the global-scale circulation of the atmosphere. This effort has been motivated, in part, from i) a wealth of new satellite data, ii) an urgent need to assess the potential impact of chlorofluorocarbons on our climate, iii) an inadequate understanding of the interactions between the troposphere and stratosphere and the role that such interactions play in short and long-term climate variability, and iv) the realization that addressing changes in our global climate requires understanding the interactions among various components of the earth system.

The research currently being carried out represents an effort to address some of these issues by carrying out studies that combine radiation, ozone, seasonal thermal forcing and dynamics. Satellite and ground-based data that is already available is being used to construct basic states for our analytical and numerical models.

Significant Accomplishments (1991-1992)

Ozone-Dynamics Interaction

During the past year we have been examining the role of radiative transfer and ozone-dynamics interaction in the genesis, maintenance and decay of free waves in the atmosphere. Our studies have employed both analytical and numerical methods. We have shown, for example, that meridional ozone advection may produce wave growth or decay depending on the wave and basic state vertical structures, whereas vertical ozone advection is locally (de)stabilizing when the vertical ozone gradient is (positive) negative, *irrespective* of the wave or basic state vertical structures. For all of the cases considered we have found that photochemically accelerated cooling, which predominates in the upper atmosphere, augments the Newtonian cooling and is stabilizing.

Using zonal mean basic states constructed from satellite and ground-based data characteristic of each season, we have shown that ozone heating generated by ozone-dynamics interaction in the stratosphere can reduce (enhance) the damping rates due to Newtonian cooling by as much as 50% for planetary waves of large vertical scale and maximum amplitude in the lower (upper) stratosphere. For waves with relatively large vertical scale and maximum amplitude in the lower to mid stratosphere and small Doppler shifted frequency, we have obtained the particularly striking result that ozone - dynamics interaction in the stratosphere can significantly influence the zonally rectified wave fluxes in the troposphere!

For the summer basic state, adiabatic eastward and westward-propagating neutral modes having the same zonal scale were shown to emerge; both are confined to the lower stratosphere and troposphere. For these modes ozone heating dominates over Newtonian cooling, and the modes amplify with growth rates comparable to those of baroclinically unstable waves of similar spatial scale.

Periodic Local Forcing and Low Frequency Variability

In a medium that is unbounded in the horizontal and subjected to localized, time periodic forcing, disturbances may amplify downstream from the source. In such situations the flow is said to be spatially unstable. In the atmosphere, tropical convection and wind fluctuations over mountains have been suggested as possible sources of spatial instability.

In this study the linear and nonlinear stability characteristics of spatially growing, long, low frequency baroclinic waves were examined in a continuous atmosphere on a β-plane channel in the presence of Ekman friction and Newtonian cooling. For the low frequency waves considered in this study, the ratio of mechanical energy flux to baroclinic energy conversion was shown to decrease in direct proportion to β. The convergence of mechanical energy flux was shown to be maximized in the mid-troposphere, whereas the baroclinic energy conversion was shown to be maximized in the lower troposphere where it becomes increasingly dominant as the ratio of the surface wind to β increases.

The nonlinear evolution of the wave amplitude and (time-averaged) mean field were shown to be characterized by either a damped oscillatory approach to a steady (space - independent) state or a weak finite amplitude destabilization. Irrespective of the form of the dissipation, the spatial vacillations and corresponding wave fluxes, which are maximized near the source, were shown to increase with forcing frequency. For sufficiently large Newtonian cooling, it was shown that the wave amplitude is maximized in the far field where the wave asymptotically approaches an equivalent barotropic structure.

Steady Forcing and Low Frequency Variability

In recent years several studies have presented evidence suggesting that topographic instability may be one of several potentially important mechanisms by which low frequency motions can be generated at middle latitudes in the Northern Hemisphere. We have recently demonstrated using a two-layer baroclinic model of the atmosphere that zonally asymmetric potential vortcity (PV) forcing can produce dramatic changes in the baroclinic topographic instability properties of the flow. The PV forcing may act to enhance, suppress, or catalyze the topographic instability depending on the phase of the PV forcing with respect to the topography. These changes result from the alteration of the zonal mean flow produced by the interaction between the resonant wave and the stationary (PV) forcing. To the extent that the PV forcing mimics the diabatic heating in a continuous atmosphere, land-sea heating contrasts may play a more important role in the dynamics of topographically induced low frequency instabilities than previously thought.

Focus of Current Research and Plans for Next Year

Current research:

1. *Examination of the nonlinear interactions among radiation, ozone, and dynamics.* A self-consistent set of equations governing the weakly nonlinear interactions between ozone and the dynamical circulation has been developed. These equations are currently being analyzed to provide a better understanding of zonally rectified transports of ozone, heat, and vorticity in a continuously stratified model of the troposphere-stratosphere coupled system.

2. *Examination of the role of seasonal forcing in short-term climate variability.* A two-layer, nonlinear baroclinic model was recently developed in order to study the combined effects of topography, zonal mean and zonally asymmetric seasonal forcing, and wave-wave and wave-mean flow interactions on short - term climate variability.

Plans for next year:

1. We plan to examine the linear stability of free planetary waves in the presence of radiative - photochemical feedbacks for two different cases: 1) using *instantaneous* rather that climatological distributions of wind, temperature and ozone; and 2) using ozone distributions based on recent WMO projections of reduced ozone in the stratosphere.

2. We plan to continue work on the role of seasonal forcing in short-term climate variability. Particular emphasis will be placed on examining the influence of seasonal variations in land-sea heating contrasts.

Publications (1991-1992)

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N93-20078

TITLE: Global Water Cycle

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RESEARCH OBJECTIVES:

This research is the MSFC component of a joint MSFC / Pennsylvania State University Eos Interdisciplinary Investigation: "The Global Water Cycle: Extension Across the Earth Sciences". The primary long-term objective of this investigation is to determine the scope and interactions of the global water cycle with all components of the Earth system and to understand how it stimulates and regulates change on both global and regional scales.

Thre integrating priorities characterize the organization of research our research tasks: (1) Documentation of Earth System state and change, (2) Focused studies on controlling processes, and (3) Integrated conceptual and predictive modeling.

SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR:

(1) Water vapor variability

Last year we reported on initial efforts at analyzing higher frequency modes of variability in SSM/I data, particularly the column integrated water vapor. We have now conducted a more complete analysis of synoptic to intraseasonal variability of column integrated water vapor and liquid water. Bandpass analyses, 1-point lag correlation maps, and power spectra have been produced which document moisture variability. Middle latitude oceanic storm tracks are defined by high 2-8 day bandpass variance maxima in the water vapor and liquid water fields. Moisture variability has proven an especially useful tool in documenting Southern Hemisphere oceanic systems because of the paucity of data there. In the tropics we have noted the largest variance in water vapor on all time scales is found on the periphery of the Western Pacific warm SSTs. Along the SST maxima water vapor variability is at a minimum and liquid water variability a maximum.

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(2) Multi-phase water analysis

At present, global data sets of moisture have rather poor determinations of vertical structure. We are continuing our investigation of combining SSM/I integrated water vapor with kinematic constraints (u,v,and omega) from gridded analyses (e.g. ECMWF) as a means of reconstituting vapor, cloud and precipitation in 3-D and in time. The basic formalism for this 4-dimensional multi-phase water analysis (4-DMPW) is what we term a diagnostic assimilation procedure. Wind fields from ECMWF gridded analyses have been used to drive conservation equations for vapor, liquid and ice. These equations, which also use bulk parameterizations of microphysics (e.g. condensation, autoconversion, collection, precipitation evaporation and fallout) are updated, or constrained in such a way that where SSM/I observations are available, the evolving model vapor is nudged to those values.

We have formulated a parameterization of convection which now allows us to explore the role of vertical moisture transport by subgrid processes. At present we are examining the production of cirrus originating from convective detrainment. We will be comparing these diagnostic results to available climatology such as ISCCP.

Because the 3-D structure of moisture is strongly constrained by vertical transport processes, we have spent some effort this year evaluating the consistency between ECMWF omega fields and SSM/I vapor, liquid water, and ice. For features of scales >1500 km we find substantial agreement in patterns of large-scale ascent and positive anomalies of water vapor and condensate--even on a daily basis.

(3) Global Modeling

We have been examining the thermal response of the CCM1 atmosphere to forcing by observed SST anomalies during 1979-1986. We have seen that the global response to warming events shows very good agreement with elevations in MSU tropospheric temperature anomalies. However, subsequent cooling when SSTs return to normal is not well captured by the model. A warm bias has thus accumulated in the model in comparison to MSU measurements.

(4) Optimal Precipitation and Streamflow Analysis and Hydrologic Processes

Observed precipitation analyses (Chang's SSM/I, Spencer's MSU, Jaeger, Legates and Arkin precipitation climatologies) have been assembled at MSFC in order to make comparisons with the CCM1 model integrations (including the Genesis version). We are especially targeting an interomparison of ENSO warm event and cold event years (e.g. DJF 1986-1987 versus 1989-1990) to understand the model's response to natural climate variations.

In addition, a land climatology is still immature so high resolution data from the CaPE field program will be compared with satellite estimates to develop a method to calibrate and scale up the rainfall estimate procedure over land areas (particularly the Southern Hemisphere) to produce an optimal global blended analysis. In a related activity, a version of the Biosphere-Atmosphere Transfer Scheme (BATS) has been linked to the LAMPS mesoscale model. This model version is being used to study regional scale aspects of hydrologic processes.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR:

We are currently producing an integration of a modified version of the CCM1 in collaboration with Penn State University. This integration uses observed SSTs as our earlier effort but includes a more realistic treatment of land surface processes. The robustness of the various rainfall climatologies will be assessed to help produce an optimally blended rainfall analysis for model verification.

Our plans for the next year include: (1) Completion of our analysis of the water and heat balances of the CCM using as verification our SSM/I moisture and MSU temperature analyses, (2) Analysis of vertical cloud and moisture structure produced by our 4-D Multi-phase Water Analysis. This will be compared further to ISCCP data and should yield insight into the dynamics of global and regional cloud patterns, preciupitation, and water vapor anomalies, (3) Regional and global modeling experiments with lower boundary temperature and soil moisture anomalies, (4) Regional analyses of hydrologic cycle budgets over the CaPE domain.

The analysis of SSM/I moisture variability is currently focusing on the analysis of synoptic-scale variability. An analysis of intraseasonal behavior has also been started and will be completed this summer. The focus of the 4-dimensional multiphase water analysis will continue to be on diagnostic treatment of convection and the treatment of surface fluxes.

CCM-related research will encompass: (1) sensitivity studies with imposed SST anomalies, (2) experiments with observed SST forcing, (3) comparison of CCM moisture lag-correlation relationships to those from SSM/I, and (4) diagnostics of cloud radiative forcing and its associated generation of available potential energy.

PUBLICATIONS:

Robertson, F. R., 1992: An examination of transient moisture anomalies over the global oceans as revealed by SSM/I. (Manuscript to be submitted to J. Geoph. Res.)

Robertson, F. R. and J. R. Christy, 1992: Structure, propagation, and growth rates of transient anomalies in the tropospheric temperature field as depicted by MSU. Preprints Sixth AMS Conference on Satellite Meteorology and Oceanography, Atlanta, GA. Jan, 1992.

N93-20079

TITLE: COORDINATED FIELD STUDY for CaPE: Analysis of Energy and Water Budgets

INVESTIGATORS: Steven Goodman/MSFC
Claude Duchon/Univ. of Oklahoma
Ed Kanemasu/UGA
Eric Smith/FSU
Bill Crosson/USRA
Chip Laymon/USRA
Jeff Luvall/MSFC

1. BACKGROUND:

The objectives of this hydrologic cycle study are to understand and model 1) surface energy and land-atmosphere water transfer processes, and 2) interactions between convective storms and surface energy fluxes. A surface energy budget measurement campaign was carried out by an interdisciplinary science team during the period July 8 - August 18, 1991 as part of the Convection and Precipitation/Electrification Experiment (CaPE) in the vicinity of Cape Canaveral, FL. Among the research themes associated with CaPE is the remote estimation of rainfall. Thus, in addition to surface radiation and energy budget measurements, surface mesonet, special radiosonde, precipitation, high-resolution satellite (SPOT) data, geosynchronous (GOES) and polar orbiting (DMSP SSM/I, OLS; NOAA AVHRR) satellite data, and high altitude airplane data (AMPR, MAMS, HIS) were collected.

2. SIGNIFICANT ACCOMPLISHMENTS IN PAST YEAR:

Initial quality control of the seven surface flux station data sets begun. Ancillary data sets being collected and assembled for analysis. Browsing of GOES and radar data begun to classify days as disturbed/undisturbed to identify the larger scale forcing of the pre-convective environment, convection storms and precipitation. The science analysis plan has been finalized and tasks assigned to various investigators.

3. FOCUS OF CURRENT RESEARCH AND PLANS:

The surface, airplane, and satellite data sets will be used in process studies and model development. Present emphasis is to study the recovery of the boundary layer after a rain event and to determine the magnitude of the atmospheric components of the daily hydrologic cycle during the CaPE experiment. The calculation of the rain budget has begun and employs radars and rain gauges to produce an optimal rainfall data base on hourly and daily time scales. There are over 100 gauges in the 100 x 100 km^2 budget study area. The Ex-BATS model development has begun, and testing of a GIS for integrating data sets is under evaluation. SPOT-derived NDVI will be produced with the GIS.

4. PUBLICATIONS:

Cooper, H. J., and E. A. Smith, 1992. The importance of short term forecasting of thunderstorms to launch operations at Cape Canaveral, Bull. Am. Meteor. Soc., submitted.

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Investigation of the Role of Thermal Boundary Layer Processes in Initiating Convection under the NASA SPACE Field Program.

Strategies:
The current NWS ground based network is not sufficient to capture the dynamic or thermodynamic structure leading to the initiation and organization of air mass moist convective events. Under this investigation we intend to use boundary layer mesoscale models (McNider and Pielke (1981) to examine the dynamic triggering of convection due to topography and surface thermal contrasts. VAS and MAM's estimates of moisture will be coupled with the dynamic solution to provide an estimate of the total convective potential. Visible GOES images will be used to specify incoming insolation which may lead to surface thermal contrasts and IR skin temperatures will be used to estimate surface moisture (via the surface thermal inertia) (Wetzel and Chang (1988))which can also induce surface thermal contrasts.

Plans:
We will use the SPACE-COHMEX data base to evaluate the ability of the joint mesoscale model satellite products to show skill in predicting the development of air mass convection. We will develop images of model vertical velocity and satellite thermodynamic measures to derive images of predicted convective potential. We will then after suitable geographic registration carry out a pixel by pixel correlation between the model/satellite convective potential and the "truth" which are the visible images.

Accomplishments:
During the first half of the first year of this investigation we have concentrated on two aspects of the project. The first has been in generating vertical velocity fields from the model for COHMEX case days. We have taken June 19 as the first case and have run the mesoscale model at several different grid resolutions. We are currently developing the composite model/satellite convective image. The second aspect has been the attempted calibration of the surface energy budget to provide the proper horizontal thermal contrasts for convective initiation. We have made extensive progress on this aspect using the FIFE data as a test data set. The calibration technique looks very promising.

Bibliography:
McNider, R.T. and R.A. Pielke , 1981: Boundary layer development over sloping terrain. *J. Atmos. Sci.*, 10, 2198-2212

Wetzel,P.J. and J. Chang,1988: evaoptranspiration from non uniform surfaces: a first approach for numerical weather prediction. *Mon. Wea. Rev.*, 116,600-62

Key Personnel: Richard T. McNider, Associate Professor, UAH
Aaron Song, Senior Research Associate, UAH
Dan Casey, Graduate Assistant, UAH
Bill Crosson, Research Asso. USRA/MSFC (in kind FIFE data)
Peter Wetzel, Goddard Space Flight (Scientific Collaborator)

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N93-20081

Title: AMPR/SSMI Data Comparisons

Investigators: Roy W. Spencer/MSFC
Robbie Hood/MSFC
Mark James/MSFC
Eric Cantrel/MSFC
Dave Simmons/Sverdrup Technology, Inc.
John Jackson/Sverdrup Technology, Inc.
Frank LaFontaine/USRA

Significant Accomplishments for the Past Year:

The AMPR was flown during CAPE and STORMFEST, during which some good data were gathered. Significant instrument noise problems were encountered in both deployments which appear to be temperature related. These are being fixed before the TOGA COARE deployment. New calibration loads have also been manufactured for the TOGA COARE configuration. Eric Smith at FSU had been analyzing the AMPR data and has written a journal article to be submitted early this summer. The emphasis of his work is on the interpretation of low resolution microwave data from space, based upon what we have learned from the high-resolution AMPR signatures.

Focus of Current Research and Plans for Next Year:

The AMPR is being thoroughly checked out before the TOGA COARE deployment. New calibration loads have been completed, and will be integrated this summer. Because they were designed to exactly replace the existing loads, this is a low risk modification. While a new data system has been designed, the existing data system is also being thoroughly checked out since it will likely be the primary system that will be used for COARE.

Publications:

Galliano, J.A., and R.H. Platt, 1990: Advanced Microwave Precipitation Radiometer (AMPR) for Remote Observation of Precipitation. Final Report, NASA Contract NAS8-37142.

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N93-20082

TITLE: WetNet: Using SSM/I data interactively for global distribution of tropical rainfall and precipitable water

INVESTIGATORS: Edward J. Zipser
James P. McGuirk
Department of Meteorology
Texas A&M University
College Station, TX 77843

RESEARCH OBJECTIVES:

1. Use SSM/I to categorize, measure and parameterize effects of rainfall systems around the globe, especially mesoscale convective systems.
2. Use SSM/I to monitor key components of the global hydrologic cycle, including tropical rainfall and precipitable water, and links to increasing sea surface temperatures.
3. Assist in the development of efficient methods of exchange of massive satellite data bases and of analysis techniques, especially their use at a university.

SIGNIFICANT ACCOMPLISHMENTS IN FY 91/92:

Numerous tasks have been initiated. First and foremost has been the integration and startup of the WetNet computer system into the TAMU computer network. Scientific activity was infeasible before completion of this activity. Final hardware delivery was not completed until October 1991, after which followed a period of identification and solution of several hardware and software and software problems. The following accomplishments represent approximately four months work with the WetNet system.

1. A synoptic hydrological study has been planned and initiated to use SSM/I, GOES and operational synoptic information to document cold frontal intrusion into Central America. The "North American Cold Surge" has been defined in terms of its more intense Asian counterpart. A climatology of several years of events has been completed. Radiosonde and special surface observations have been obtained from the U.S.A.F. Environmental Technical Applications Center. Preliminary case studies are being identified and examined through GOES and SSM/I products available through the WetNet.

2. Planning activity has commenced on a project to define and document the hydrological variability of the Pacific ITCZ region. Our university library of OLR and TOVS has been augmented to overlap the SSM/I operational period commencing in 1987. The goal of this project is to resolve and correlate the

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variability of cloud, precipitable water and precipitation variability along the equatorial trough and convergence zone of the Pacific. Linkages to and between synoptic, meso and planetary circulation systems are sought, as well as the mutual variability of satellite observed features. Use of Dennis Chesters' TOVS "water vapor data set " has been investigated. This work has been inspired by intercomparisons of satellite observations of tropical plumes, supported by the NASA Global Scale Program, and motivated by the data and analytical tools available through the WetNet.

3. A working hypothesis has been developed relating the frequency of lightning in mesoscale convective systems (MCSs) to the convective intensity. EJZ has reported preliminary results from a study of lightning frequency in the tropics, noting that during the GATE program, monthly rainfall was over 300 mm/month despite one thunderstorm day per month, on average. A more specific hypothesis is that vertical velocity in storm cores in the range of 4-8 m/s is the threshold necessary for lightning. We participated in plans for an atmospheric electricity component of TOGA-COARE.

4. We have initiated data collection with the TAMU 10-cm Doppler radar, and will be archiving data for providing to other WetNet PIs. Through our closely related work with NASA/TRMM, we are ready to archive data from the Houston WSR-88D radar. We have initiated case studies with Eric Smith (FSU), starting with well-documented hurricanes, like Hugo (1989), for the purpose of using SSM/I algorithms to identify the convective regions of MCSs.

FOCUS OF CURRENT RESEARCH AND PLANS FOR FY 92/93:

1. The study of the "North American Cold Surge" should be completed. Key findings should be the description of the interaction of synoptic and meso scale systems associated with frontal systems that approach the equator. Of particular interest is the rate of deterioration (air mass modification) of the synoptic features, both hydrological and kinematic, as the systems move southward.

2. Descriptive statistics should be collected for the Pacific ITCZ variability from SSM/I, OLR, TOVS and ECMWF analysis. Preliminary intercomparisons should be complete. A computational plan for detailed diagnostics should be complete. One component of this plan will be the quantitative definition of observed systems as well as the quantification of their behavior and mutual interaction.

3. The preliminary study of lightning frequency in the GATE and West African regions will be completed. The results should include quantitative documentation of the low lightning frequency in the tropical Atlantic oceanic air masses, and further refinement of the "threshold vertical velocity" hypothesis. The

remainder of the year will be devoted to obtaining direct measurements in TOGA COARE from lightning DFs, field mills on the DC8 and ER2, and radar data from the ships and turboprop aircraft. These data shouuld allow us to accept, reject or modify the hypothesis.

4. We shall undertake several case studies jointly with Eric Smith, using surface based and aircraft radar data to identify convective and stratiform regions of MCSs. We will then assess the ability of several SSM/I algorithms to distinguish between convective and stratiform regions. In addition, we will begin archiving data from the TAMU and Houston 10-cm Doppler radars for similar purposes. If we succeed in validating one or more algorithms with this "reality check", we plan to initiate surveys of MCS structure over a wide area of the tropics.

PUBLICATIONS:

Presentations:

McGuirk, J.P., 1991: Long term climatology of precipitable water from space, WetNet Science and Analysis Colloquium, Univ. of Calif.-Santa Barbara, February 19-22, 1991.

Zipser, E.J., 1991: High precipitation, no thunder (HPN) storms; How such "none-der-storms dominate tropical oceanic rainfall, Abstract, American Geophysical Union, p. 97, San Francisco, December, 1991.

----- and E. Smith, 1992: Hurricanes as viewed by SSM/I and radar: Preliminary look at case study opportunities, WetNet Science Meeting, Florida State Univ., Tallahassee, April 1992.

N93-20083

Title: Improvement and Further Development of SSM/I Overland Parameter Algorithms Using the WetNet Workstation

Investigators: Christopher M. U. Neale and Jeffrey J. McDonnell
Co-investigators: Douglas Ramsey, Lawrence Hipps and David Tarboton

Background of the Investigation:

Since the launch of the DMSP Special Sensor Microwave/Imager (SSM/I), several algorithms have been developed to retrieve overland parameters. These include the present operational algorithms resulting from the Navy calibration/validation effort such as land surface type (Neale et al. 1990), land surface temperature (McFarland et al. 1990), surface moisture (McFarland and Neale, 1991) and snow parameters (McFarland and Neale, 1991). In addition, other work has been done including the classification of snow cover and precipitation using the SSM/I (Grody, 1991).

Due to the empirical nature of most of the above mentioned algorithms, further research is warranted and improvements can probably be obtained through a combination of radiative transfer modelling to study the physical processes governing the microwave emissions at the SSM/I frequencies, and the incorporation of additional ground truth data and special cases into the regression data sets.

We have proposed specifically to improve the retrieval of surface moisture and snow parameters using the WetNet SSM/I data sets along with ground truth information namely climatic variables from the NOAA cooperative network of weather stations as well as imagery from other satellite sensors such as the AVHRR and Thematic Mapper. In the case of surface moisture retrievals, the characterization of vegetation density is of primary concern. The higher spatial resolution satellite imagery collected at concurrent periods will be used to characterize vegetation types and amounts which, along with radiative transfer modelling should lead to more physically based retrievals. Snow parameter retrieval algorithm improvement will initially concentrate on the classification of snowpacks (dry snow, wet snow, refrozen snow) and later on specific products such as snow water equivalent.

Significant Accomplishments in the Past Year:

The project initiated mid-November 1991. The following tasks have been accomplished since that date:

1) Inventory of all SSM/I and climatological ground truth data presently available in-house. Identification of additional SSM/I data needs covering precipitation and snow accumulation events of interest (in progress).

2) Development and programming of a radiative transfer model (RTM): A working model has been coded in Quickbasic for the PC

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and is presently being tested against actual SSM/I brightness temperatures for different uniform surface types i.e. dense vegetation, deserts, water bodies. The model is a non-coherent, first order RTM. The complex dielectric constants of the soil matrix, the canopy and the leaves are calculated using de Loor's mixing formula (de Loor, 1968). The model allows for the simulation of SSM/I footprints with different proportions of surfaces (soils at different moisture content, water bodies, snow and vegetation cover at different densities). Several simulation options are possible by varying incidence angle, frequency, vegetation density, surface soil moisture or the proportions of different surface types. The output is presently in graphical form on-screen. The model has been able to reproduce brightness temperatures at different frequencies, under different surface emissivity conditions described in several papers in the literature. We will further test the model with more complex scenes as our research progresses.

3. Establishment of a link to the Soil Conservation Service SNOTEL network. We have obtained a two year data set from more than 80 stations in the Great Basin area to compare with SSM/I brightness temperatures. Though we realize the complications that large footprints entail over the mountains, we are looking to monitor the onset of snow melt, an important hydrological parameter.

4. In cooperation with the Central Sierra Snow Laboratory, U.S. Forest Service, we are examining the possibility of using time domain reflectometry (TDR) to obtain snow liquid water content for future field studies on this project. An experiment was conducted by comparing capacitance meter measurements with TDR measurements in snow pits during a week in February, 1992. The data has been analyzed and a report is presently being written.

Focus of Current Research and Plans for Next Year:

We see the development of the above mentioned RTM as being crucial for the proper understanding of the processes governing the overland microwave emissions at the SSM/I frequencies. In this way, we plan to develop more physically based algorithms for some of the overland parameters which are complicated by the large footprint size of the SSM/I and the heterogenous nature of the earth's surface.

During the next year we will concentrate on further building our database of SSM/I and ground truth climatic data to support algorithm development. We plan to conduct several comparisons of actual SSM/I and simulated SSM/I brightness temperatures under different surface moisture conditions resulting from large precipitation events over the central plains of the United States. The effect of vegetation density on the microwave emissions will be studied. We plan to conduct similar comparative studies with snow covered surfaces using surface climatic and snowpack information as ground truth.

Publications:

We plan to publish a paper on the RTM in the near future after further testing has been completed. A paper on the use of TDR for monitoring snow wetness is forthcoming.

References:

de Loor, G.P. 1968. Dielectric properties of heterogenous mixtures containing water. J. Microwave Power, Vol. 3, pp. 67-73.

Grody, N.C. 1991. Classification of snow cover and precipitation using the special sensor microwave imager. J. of Geophysical Research, Vol. 96, No. D4, pp 7423-7435.

Hollinger et al. 1991. DMSP Special Sensor Microwave/Imager Calibration/Validation, Final Report, Volume II. Naval Research Laboratory, Washington, D.C.

McFarland, M.J. and C.M.U. Neale. 1991. Surface Moisture Retrieval Algorithms for the SSM/I. Section 9.3, and Snow retrieval algorithms, section 9.4, DMSP Special Sensor Microwave/Imager Calibration/Validation, Final Report, Volume II. James Hollinger, editor. Naval Research Laboratory, Washington, D.C.

McFarland, M.J., R.L. Miller and C.M.U. Neale. 1990. Land surface temperature derived from SSM/I passive microwave brightness temperatures. IEEE Transactions on Geoscience and Remote Sensing, Vol 28, No.5, pp 839-845.

Neale, C.M.U., M.J. McFarland and K. Chang. 1990. Land-surface-type classification using microwave brightness temperatures from the Special Sensor Microwave/Imager (SSM/I). IEEE Transactions on Geoscience and Remote Sensing, Vol 28, No.5, pp 829-838.

N93-20084

Climatic Variation of Storms

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Significant Accomplishments, August 91 - April 92

Long-term variation of U.S. tornadoes were studied by obtaining the best possible data during the 75 years, 1916-90. The most difficult task was to estimate the number of early tornadoes in 1916-50 when the reporting efficiency was very bad, resulting in undercounting of the incidents. In generating the best possible data, Fujita's Tornado Tape produced at the University of Chicago, the book "Significant Tornadoes, 1880-1989" by Thomas P. Grazulis, and the NSSFC Tornado Tape were combined.

First, the "Annual Number of Tornadoes" were smoothed to obtain the "Smoothed Number of Annual Tornadoes" which was normalized to the "Standard Number of Tornadoes" defined as the mean number in the recent 30 years, 1960-89. The "Normalization Factor" was obtained by computing the ratio of smoothed and standard number. In the early years, the factor was in excess of 7.

Thereafter, the "Normalized Number of Annual Tornadoes" was computed and plotted, finding that the results are very satisfactory.

In order to visualize the variation of tornado activities, the "Tornado Activity Number (TAN)" was initiated and computed. The TAN including all annual tornadoes show certain periodicity. For climatological evaluation, the peak-activity day of each year, such as Superoutbreak day, 3 April 1974, Palm Sunday, 11 April 1965 were eliminated. The TAN, excluding peak-day tornadoes, is of extreme interest.

Plans for Next Year

This study will continue in an attempt to relate tornado activities with other climatological events such as El Niño, La Niña, sunspots, etc.

Meanwhile, individual case studies and synoptic analyses of special cases will be performed for better understanding of tornado climatology.

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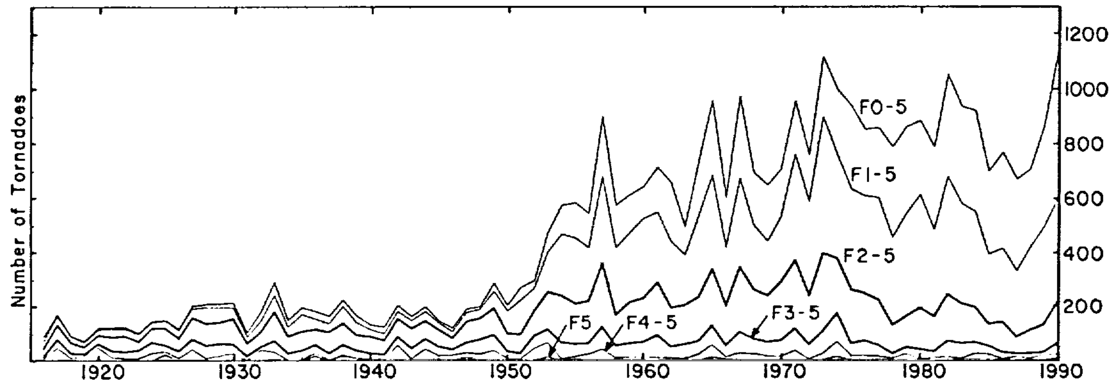
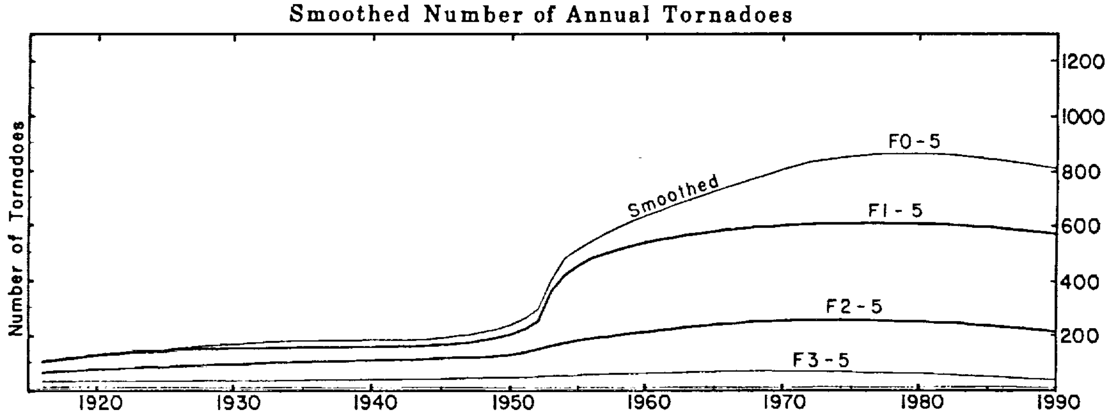
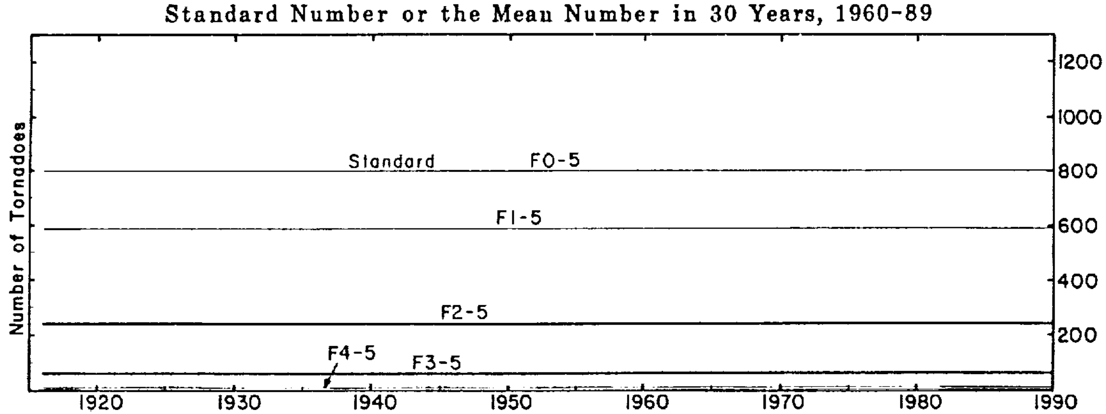
Annual Number of Tornadoes



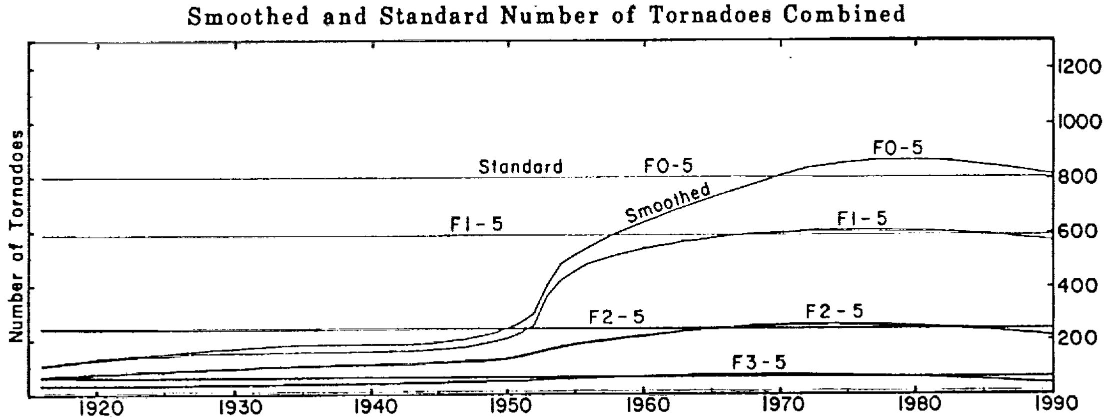
Smoothed Number of Annual Tornadoes



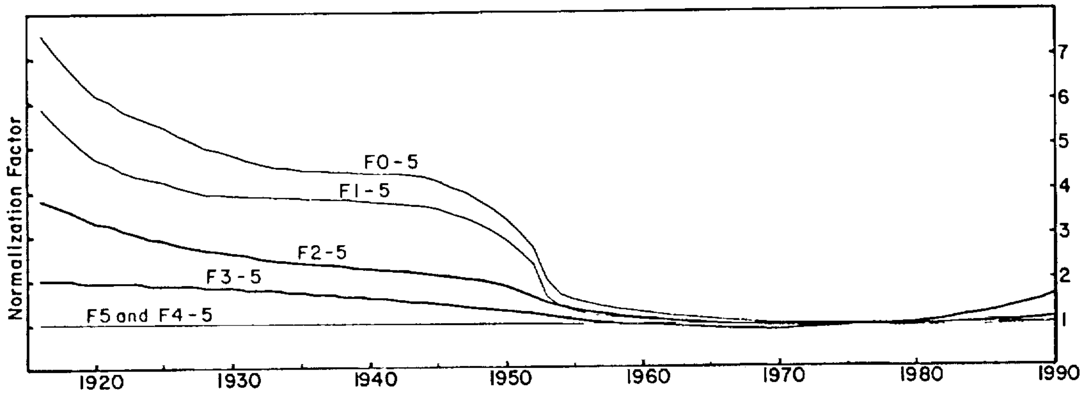
Standard Number or the Mean Number in 30 Years, 1960-89



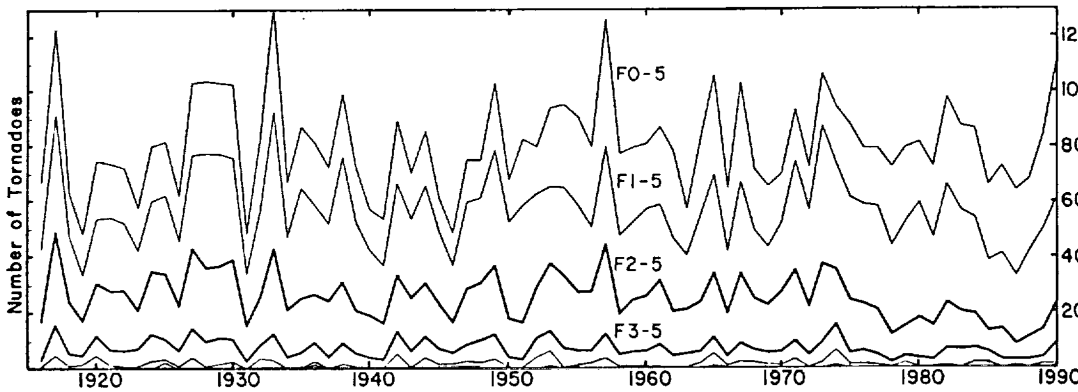
Smoothed and Standard Number of Tornadoes Combined



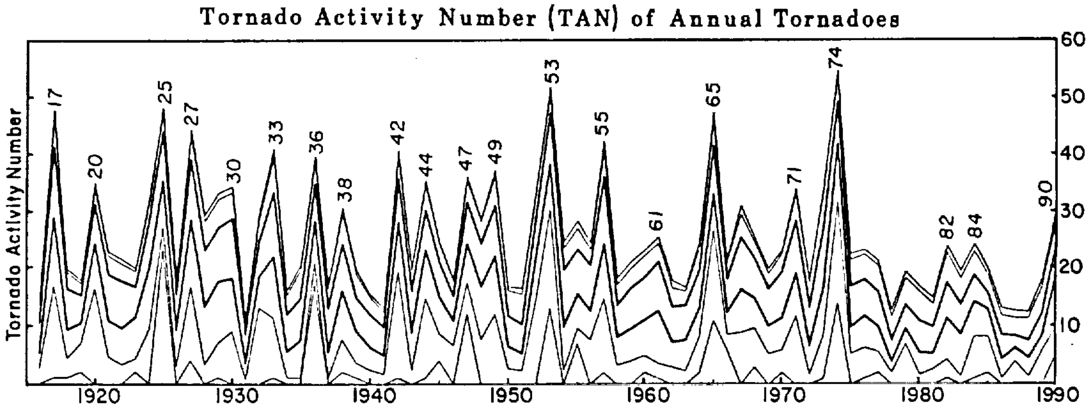
Normalization Factor



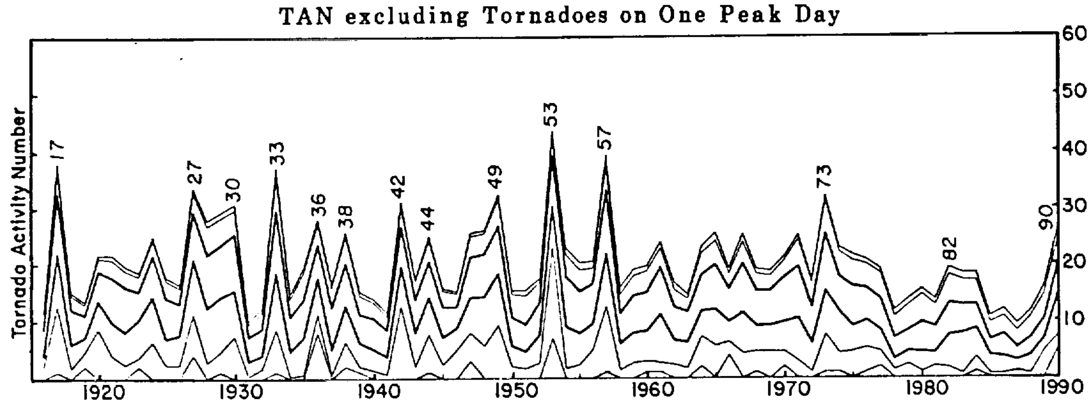
Normalized Number of Annual Tornadoes



Tornado Activity Number (TAN) of Annual Tornadoes



TAN excluding Tornadoes on One Peak Day



TITLE: OLS DATA SYSTEM/ GLOBAL SURVEY OF LIGHTNING

INVESTIGATORS: Steven Goodman/MSFC
Hugh Christian/MSFC
Pat Wright/USRA
Greg Scharfen/NSIDC

1. BACKGROUND:

A global lightning climatology is being assembled from the nighttime imagery of the DMSP Optical Linescan Sensor (OLS). Lightning saturates the visible channel of the OLS at nighttime and can be identified as a horizontal streak on the order of 50-100 km in horizontal extent. Lightning streaks apparent in the film strips located at the National Snow and Ice Data Center (NSIDC) prior to 1991 are being digitized.

2. SIGNIFICANT ACCOMPLISHMENTS IN PAST YEAR:

An initial survey was completed for the F7 satellite observation period January 1986-October 1987 and for the Q satellite for the period June-July 1973. Comparisons between the OLS lightning climatology with the Arkin GPI data set during the 1986-87 El Nino event shows similar regional variations in convective activity. The digital archive of global DMSP data began at the end of February. Software is being developed at both MSFC and NSIDC to extract, navigate, and view the OLS fine and smooth imagery.

3. FOCUS OF CURRENT RESEARCH AND PLANS:

With the demise of the OLS instrument on F8 and F9, digital lightning extraction will concentrate on F10 and F11. Digital F8, F9, and F10 data collected over Florida during July-August 1991 will be processed. Limited ground truthing of the OLS lightning signatures will be performed with the 1991 data. During the period June-August 1992 in central Florida and November 1992 to February 1993 in the Solomon Islands (during TOGA/COARE), partial ground truth data will be collected from ground-based sensors and from the Global Positioning Satellite (GPS) NDS instrument. OLS lightning data from F7, F8, and F9 are being processed for comparison with WETNET precipitation algorithms. The first routinely available global OLS Exabyte tapes in a standard format will not be available from NSIDC until summer 1992 due to the need for extensive software development to ramp-up the operational processing software. For this reason, we will extract lightning signatures from Exabyte tape copies at MSFC.

4. PUBLICATIONS

Goodman, S. J., and H. J. Christian, 1992. Lightning. Chapter to appear in Global Change Atlas, to be published in 1992 by Cambridge University Press.

Christian, H. J. and S. J. Goodman, 1992. Global observations of lightning from space, Preprints, 9th Int. Conf. on Atmospheric Electricity, St. Petersburg, Russia, June 13-17.

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N93-20086

TITLE: ATMOSPHERIC ELECTRICITY/METEOROLOGY ANALYSIS

INVESTIGATORS: Steven Goodman/MSFC
Richard Blakeslee/MSFC
Dennis Buechler/UAH

1. BACKGROUND:

This activity focuses on Lightning Imaging Sensor (LIS)/Lightning Mapper Sensor (LMS) algorithm development and applied research. Specifically we are exploring the relationships between 1) global and regional lightning activity and rainfall, and 2) storm electrical development, physics, and the role of the environment. U.S. composite radar-rainfall maps and ground strike lightning maps are used to understand lightning-rainfall relationships at the regional scale. These observations are then compared to SSM/I brightness temperatures to simulate LIS/TRMM multi-sensor algorithm data sets. These data sets are supplied to the WETNET project archive. WSR88-D (NEXRAD) data are also used as it becomes available. The results of this study allow us to examine the information content from lightning imaging sensors in low-earth and geostationary orbits.

2. SIGNIFICANT ACCOMPLISHMENTS IN PAST YEAR:

Analysis of tropical and U.S. data sets continues. A neural network/sensor fusion algorithm is being refined for objectively associating lightning and rainfall with their parent storm systems. Total lightning data from interferometers are being used in conjunction with data from the national lightning network. A 6-year lightning/rainfall climatology has been assembled for LIS sampling studies.

3. FOCUS OF CURRENT RESEARCH AND PLANS:

The LIS/LMS neural network clustering algorithm development will continue using satellite/radar/lightning data acquired and examined from different climatological regions including TRMM ground truth sites (primarily Central Florida and Solomon Islands). Intercomparisons with other rainfall estimates (VIS, IR, SSM/I) will continue. Collaborative efforts are planned with 1) the cloud modeling group at UMIST to better understand the relationship between precipitation and lightning, and 2) the USDA Forest Service to better understand the role of the environment and lightning occurrence in the ignition of forest fires in Boreal forests.

4. PUBLICATIONS:

Goodman, S. J., and K. R. Knupp, 1992. Tornadogenesis via squall line and supercell interaction: The 15 November 1989 Huntsville, AL tornado. To appear in the AGU Monograph concerning the results of Tornado Symposium III, Norman, OK April 2-5.

Buechler, D. E., and R. J. Blakeslee, 1992. Cloud-to-ground lightning observations used to simulate observations from a low-earth orbiting lightning sensor, Preprints, 9th Int. Conf. on Atmos. Elec., St. Petersburg, Russia, June 15-19.

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Title: Electrification in Winter Storms and The Analysis of Thunderstorm Overflight Data

N93-20087

Principal Investigator: Marx Brook
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Background of the Investigation: We have been focusing our study of electrification in winter storms on the lightning initiation process, making inferences about the magnitude of the electric fields from the initial pulses associated with breakdown, i.e., with the formation of the initial streamers.The essence of the most significant findings is as follows: 1) Initial breakdown radiation pulses from stepped leaders prior to the first return stroke are very large, reaching values of 20-30 Volts/meter, comparable to return stroke radiation. 2) The duration of the stepped leader, from the initial detectable radiation pulse to the return stroke onset, is very short--ranging from a minimum 1.5 ms to a maximum of 4.5 ms. These values should be contrasted with the published durations of stepped leaders from summer storms which fall in the range from 6-20 ms. The difference in duration is significant in that the radiosonde soundings for summer and for winter storms show only a 20-30% difference in the height of the -10 degC to -20degC region which is where the lightning charge is found to accumulate. This difference in height cannot account for the difference in duration of the stepped leader (a factor of 2-3) between winter and summer storms. Obviously, the velocity of the leaders in winter storms must be greater by a factor of 2-3 than the leaders in summer storms.

This past summer (June-August of 1991) we participated in the CAPE program at the Kennedy Space Center in order to acquire data on stepped leaders in summer storms with the same equipment used to get the winter storm data. Our efforts were certainly worth while, because we discovered that the vigorous leaders seen in winter so frequently were present in summer storms, although not as large in amplitude and certainly not as frequent. The analysis of the large amplitude radiation pulses from these summer storms continues at this time, and the conclusions cited earlier with regard to the differences between summer and winter leaders remain unaltered.

It is reasonable to attribute the striking difference in the two types of leaders to the value of the breakdown electric field inside the cloud, i.e., the maximum value of the electric field which can be sustained without the initiation of a discharge. In looking for a different set of in-cloud conditions between summer and winter which might have a major role in influencing the breakdown field we are immediately drawn to the hypothesis that it is the precipitation mix that determines, almost exclusively, the value of the breakdown electric field. Many laboratory studies have been done on the influence of water drops on the breakdown field, and an elegant theoretical and laboratory study was published by G. I. Taylor in 1965. The size of water drops affects the breakdown electric field: larger drops lower the breakdown potential gradient; a factor of 2 increase is acheived in going from 2.4 mm rad drops to 1.2 mm rad. A temperature dependence, though less noticeable, is also present. Surface tension is a function of temperature, and increases with decreasing T.

Ice crystals, also present in the -10 degC to -20 degC region, are not as active in lowering the breakdown potential gradient. Although ice crystals may provide corona, their resistivity is too high to maintain the electric field at the tip after the emission of charge. In

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general, it has been found that ice crystals initiate breakdown at much higher fields than do water drops. The subject of the influence of ice crystals on the electric breakdown is far from complete and is in need of further study.

A check on the above hypothesis was possible for the Albany winter storm during which time a sounding was taken at the Albany Airport. We were able to determine that in the region of -10 degC to 20 degC the vapor pressure was saturated with respect to ice. Thus there was no liquid water present to lower the breakdown potential gradient; only the ice phase populated the charge accumulation region! This result has important implications related to electric charge separation in clouds, as well as implying that charge storage per unit volume in winter storms can exceed that possible in summer storms.

Significant Accomplishements of the Past Year: We have been able to strengthen our original hypothesis that electric fields in winter storms are higher than they are in summer storms by considering the influence of the precipitation environment in the region of electric charge accumulation. We have been able to propose a reasonable rationale for the observed fact that lightning strokes from winter storms are more destructive and carry larger currents than do the stokes in summer. Stronger fields imply greater charge density, and since the energy stored is proportional to the square of the electric field, we would expect more destructive currents. This result is completely consistent with both aircraft-triggered lightning-damage statistics, and with powerline-damage statistics.

We participated in the analysis of an unusual video photograph (Boeck,et.al.1992) taken from the space shuttle at night which shows an enhancement in the luminosity of the airglow layer directly above a lightning flash which occurred simultaneously within the uncertainty of a video frame. This is the only observed occurence of apparent ionospheric ionization produced by thunderstorm activity 100 km below the airglow layer. If it is not spurious, it demonstrates the existance of an energy coupling mechanism from the troposphere to the ionosphere. We were able to show that the enhancement did not result from return stroke radiation but more likely from one of the horizontally oriented vigorously radiating stepped leaders discussed earlier in this report.

At KSC we also recorded lightning flashes as ground truth for the ER-2 and the Lear jet aircraft doing cloud overflights as part of the CAPE program. As a result of the large amount of good electrical data we obtained it will be possible to get good correlations with the New Mexico Tech Wideband Noise and Coherent Radar and with the NCAR CP-2 Radar. The NMTech interferometer was also operated at the same time, making these data an unusual set for the analysis of electrical-precipitation interactions. All of the 7500 lightning flashes have now been plotted for cursory examination. We are also in the process of looking at the triggered lightning data, correlating that set with the excellent streak camera photographs of Dr. Vincent Idone of the State University of New York at Albany.

Focus of Current Research and Plans for Next Year: If funding is forthcoming, we plan to continue with several activities already in progress.

1) continue the analysis of both winter and summer initial leader data to further clarify the role of precipitation in limiting the maximum value of electric field strength in clouds. We should also like to collaborate with John Latham of the University of Manchester and with Alan Blythe of NMTech in designing laboratory experiments to study the role of ice crystals in in initiating electrical breakdown in clouds.

2) We plan to correlate our lightning measurements with the NMTech Radar and Interferometer data. A particular question of interest to be addressed is: How does a lightning discharge in a volume seen by the radar and the interferometer affect precipitation growth? This is an important question which can now finally be addressed with our dual polarization radar. This radar sees the ionized lightning channels without significant precipitation background clutter in the crosspolar channel, while the copolar channel sees the precipitation echo as normal. We have seen the growth of an echo after lightning, and with circular polarization it has been possible to watch the crystals align with the electric field (induced dipoles) and to see them disalign after lightning. We have not yet put all the data together to see whether electric fields provide enhanced forces for accelerated coalescence of droplets, thus promoting droplet growth. We intend to use these data to study this question.

3) As a result of a workshop discussing the possible role of lightning measurements in the TOGA-COARE program in the South Pacific, we are preparing one of our instrumental systems for use in Kavieng, New Guinea in conjunction with a 3 or 4 station array of LLP direction finders. The direction finders will be modified by LLP to higher sensitivity for use up to distances of 900-1000 km. I have prepared lightning waveforms recorded from those approximate distances to test the modified instruments. We shall be working with Drs. E. Phillip Krider and Charles Weidman to synchronize time between the direction finders and my waveform recorder. Although the instrumentation is NASA funded, a proposal for travel expenses and some analysis has been submitted to NSF by Drs. Ed Zipser and Dick Orville of Texas A&M. I have agreed to donate about three weeks time to setting up the instruments in Kavieng and training a student to operate them.

4) Finally, we want to return to finish the study of the origin of the 'slow tails' to identify the type of lightning flash which produces them. This requires 2 stations, and we hope to operate a pair in either Albany or Socorro with a station in Huntsville. The slow tails may be a unique identifier of continuing current lightning which is estimated to start about 95% of all forest fires.

Publications

1) A paper entitled "Electric Fields in Winter Storms" was given at a US-JAPAN workshop on 'Lightning in Winter Storms' and will be published in "Letters in Atmospheric Electricity, a Japanese journal.

2) A paper entitled "Breakdown Electric Fields in Summer and Winter Storm-Clouds: Inferences Based on Initial Lightning Leader Waveforms" has been submitted for presentation at the St. Petersburg International Conference on Atmospheric Electricity. It will be presented for me by Dr. John Latham. The paper is being expanded to include additional work on the role of precipitation in breakdown and to include better statistics of summer-storm stepped leaders.

3) Boeck,W.L.,O.H.Vaughan,Jr., R. Blakeslee, B. Vonnegut, and M. Brook, Lightning Induced Brightening in the Airglow Layer, Geophys. Res. Lett., 19, 99-102,1992.

N93-20088

Title: ER-2 Investigations of Lightning and Thunderstorms

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Background of the Investigation: The primary objective of the ER-2 lightning program is to investigate relationships between lightning and storm electrification and a number of underlying and interrelated phenomena including the structure, dynamics, and evolution of thunderstorms and thunderstorm systems, precipitation distribution and amounts, atmospheric chemistry processes, and the global electric circuit. This research is motivated by the desire to develop an understanding needed for the effective utilization and interpretation of data from the Lightning Imaging Sensor (LIS), the Lightning Mapper Sensor (LMS), and other satellite-based lightning detectors planned for the late 1990's and early 2000's. These satellite lightning detection systems will be characterized by high detection efficiencies (i.e., 90%) and the capability to detect both intracloud and cloud-to-ground discharges during day and night. The Lightning Imaging Sensor (LIS) is being developed by NASA for the Tropical Rainfall Measuring Mission (TRMM) satellite. In the ER-2 and related investigations, the emphasis is on establishing quantitative relationships and developing practical algorithms that employ lightning data, such as could be derived from satellite observations of optical lightning emissions, as the independent variable.

Presently, the ER-2 aircraft provides the best means to fly above thunderstorms since the ER-2 can be vectored over regions of interest. The ER-2 platform also provides a cloud top perspective similar to that viewed by a space sensor, albeit much closer. The proposed ER-2 lightning instrumentation will detect total storm lightning and differentiate between intracloud and cloud-to-ground discharges. It should be noted that the ER-2 lightning instrument package will generally be flown with other sensor systems (e.g., infrared, passive microwave, EDOP Dopplar radar, etc.) that will provide new understanding of thunderstorms and precipitation and support detailed satellite simulations of storm measurements through the acquisition and analysis of multiparameter data sets. By developing and maintaining the capability to monitor lightning and thunderstorms with the ER-2, NASA will also be able to provide important ground truth verifications and calibrations when the LIS and other lightning detectors begin operations in the late 1990's.

The emphasis, now, is to "quantify" the lightning relationships that have been determined. It is hoped that as a result of these kinds of investigations, lightning data alone and/or in conjunction with other remote sensing techniques will provide quantitative information about such storm characteristics as the occurrence and location of embedded convection, the strengths of updrafts and downdrafts, thermodynamic and electrical energy budgets, precipitation amounts and distributions, and the storm type, dimensions, and life cycle. Lightning rates, distribution, and characteristics (i.e., number of strokes per flash, ratio of intracloud to cloud-to-ground lightning, discharge energy, etc.) are all factors that may prove useful in devising quantitative algorithms, and these factors can be studied appropriately with the ER-2.

Significant Accomplishments in the Past Year: During May 1991, we integrated the Lightning Instrument Package (LIP) onto the ER-2 aircraft. This integration was required since the U-2 aircraft on which the lightning package flew in the past have been phased out of NASA's high altitude aircraft fleet and replaced by the larger ER-2 aircraft. We are now able to conduct atmospheric electrical investigations above thunderstorms for the first time since the COoperative Huntsville Meteorological EXperiment (COHMEX) in 1986. An independent subset of LIP was integrated earlier onto the ER-2. This sensor subset consists of electric field mills, conductivity probes, and an associated data system.

During July and August 1991, ER-2 science flights were conducted as part of the Convective and Precipitation/Electrification (CaPE) experiment. CaPE will provide extensive multiparameter data sets referred to above. More importantly, two of the major scientific goals of CaPE (1. the identification and investigation of the relationships among the co-evolving wind,

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water, and electrification within the convective cloud and 2. rainfall estimation) coincide with primary objectives of the ER-2 investigations and NASA's overall lightning program. A large number of storm overflights were obtained during CaPE including a number of cases of multiple storm passes. In February and March 1992, the ER-2 participated in the STORM-Fronts Experiment Systems Test (STORM-FEST) experiment. STORM-FEST provided an opportunity to study wintertime thunderstorms.

Working with Kevin Driscoll, an Auburn Univ. Ph.D. student participating in the NASA sponsored Graduate Students Research Program (GSRP), a finite difference numerical model that incorporates the full Maxwell equations was developed and used to investigate how thunderstorm currents and fields are related to the storm's electrical generator and associated lightning (including lightning type, rate, charge exchange, ratio of ic to cg, etc.). We have demonstrated that by using time-averaged electrical properties of a thunderstorm, including the effects of lightning, the electrical behavior of the atmosphere in the vicinity of the storm can be examined with a simple analytical formulation. Also we have had some success in using the model to simulate and investigate U-2 lightning observations obtained during COHMEX.

Focus of Current Research and Plans for Next Year: Analysis of ER-2 data from CaPE and STORM-FEST is a high priority and underway. In addition, some of the U-2 COHMEX lightning data may be reexamined as well. As noted earlier, the emphasis is on storm characterization and algorithm development (particularly precipitation algorithms) that utilize lightning measurements. Some other areas of interest include the effect of thunderstorms on the global electric circuit and the relationship of thunderstorms to atmospheric chemistry processes involving trace gases (e.g., NO_x).

Preparations for participation in the TOGA-COARE field program are well underway. These include providing an improved LIP for the ER-2 and a small lightning package for the DC-8, and deploying lightning ground stations near the Intensive Flux Array (IFA) This latter activity is being conducted in cooperation with scientist from the Univ. of Arizona (C. Weidman and P. Krider), Texas AM Univ. (R. Orville and E. Zipser), and New Mexico Tech.(M. Brook).

Although not part of the ER-2 effort, an investigation of LIS statistics using lightning direction finder data from the MSFC LLP network and TRMM orbit characteristic to simulate LIS observations has been initiated and is providing valuable insights. This research on simulated LIS statistics using direction finder lightning data will continue and it is hoped that the data sets employed for this study can be expanded (with D. Buechler). We will also explore the possibility of using shuttle video lightning images to simulate Lightning Imaging Sensor (LIS) data in the LIS algorithm development effort (with W. Boeck).

Publications:

Blakeslee, R.J., H.J. Christian, and B. Vonnegut, Electrical measurements over thunderstorms, J. Geophys. Res., 94(D11), 13135-13140, 1989.

Christian, H.J., R.J. Blakeslee, and S.J. Goodman, The detection of lightning from geostationary orbit, J. Geophys. Res., 94(D11), 13329-13337, 1989.

Boeck, W.L., O.H. Vaughan,Jr., R. Blakeslee, B. Vonnegut, and M. Brook, Lightning induced brightening in the airglow layer, Geophys. Res. Letters, 19, 99-102, January 24, 1992.

Blakeslee, R.J., and E.P. Krider, Ground level measurements of air conductivity under Florida thunderstorms, accepted for publication J. Geophys. Res. - Atmos., 1992.

Driscoll, K.T., R.J. Blakeslee, and M.L. Baginski, A modeling study of the time-averaged electric currents in the vicinity of isolated thunderstorms, accepted for publication J. Geophys. Res. - Atmos., 1992.

Vaughan, O.H., R. Blakeslee, W.L. Boeck, B. Vonnegut, M. Brook, and J. McKune, Jr., A cloud-to-space lightning as recorded by space shuttle payload bay TV cameras (picture of the month), Mon. Wea. Rev., 120, 1992.

The following papers will be presented at the St. Petersburg 9th International Conference on Atmospheric Electricity and will be included in the Preprint volume for that conference.

Driscoll, K.T. and R.J. Blakeslee, A simple analytic method to estimate a thunderstorm's contribution to the global electric circuit.

Geis, P.B., R.J. Blakeslee, A.A. Few, E.K. Stansbery, and H.J. Christian, A global model of thunderstorm electricity

Buechler, D., and R. Blakeslee, Cloud-to-ground lightning observations used to simulate observations from a low earth orbit lightning sensor.

Boeck, W.L., O.H. Vaughan, R.J. Blakeslee, B. Vonnegut, M. Brook, and J. McKune, Observations of vertical lightning in the stratosphere.

N93-20089

Airborne Full Polarization Radiometry Using the MSFC Advanced Microwave Precipitation Radiometer (AMPR)

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The applications of vertically and horizontally polarized brightness temperatures in both atmospheric and surface remote sensing have been long recognized by many investigators, particularly those studying SMMR and SSM/I data. Here, the large contrast between the first two Stokes' parameters (T_V and T_H) can be used for detection of sea ice, measurement of ocean surface wind speed, and measurement of cloud and water vapor opacity. High-resolution aircraft data from instruments such as the NASA/MSFC AMPR is crucial for verifying radiative transfer models and developing retrieval algorithms. Currently, the AMPR is outfitted with single-polarization channels at 10, 18, 37 and 85 GHz. To increase its utility, it is proposed that additional orthhogonal linearly-polarized channels be added to the AMPR. Since the AMPR's feedhorns are already configured for dual orthogonal linearly polarized modes, this would require only a duplication of the currently existing recievers. To circumvent the resulting polarization basis skew caused by the cross-track scanning mechanism, the technique of Electronic Polarization Basis Rotation [1-3], developed by the authors with support from NASA/MSFC and NASA/GSFC, is proposed to be implemented. Implementation of EPBR requires precise measurement of the third Stokes parameter $T_U = \langle E_V E_H^* \rangle$, and will eliminate polarization skew by allowing the feedhorn basis skew angle to be corrected in software. In addition to upgrading AMPR to dual polarization capability (without skew), the modifications will provide an opportunity to demonstrate EBPR on an airborne platform. This is a highly desirable intermediate step prior to satellite implementation.

However, only recently have potential remote sensing applications of the third Stokes parameter T_U been investigated [3-6]. Laboratory measurements by the authors using a full polarization radiometer and a rotatable wave tank have shown values of T_U of amplitude up to ± 5 K that are directly related to the orientation of small gravity waves [6]. This effect, which has been corroborated using radiative transfer calculations based on the Kirchoff method, is observed at both extreme incident angles ($\sim 65^\circ$) and near nadir. In order to further investigate the use of T_U for remote sensing of surface state variables such as ocean surface wave direction, airborne experiments are needed. As modified for EBPR, the AMPR would have the capability to accurately measure T_U throughout its entire scan range, thus providing important scientific field data on these radiation-polarizing phenomena.

As previously proposed to NASA by the authors, EPBR modifications to AMPR are suggested to proceed via two phases: (1) First, the 37-GHz channel would be modified. A polarized calibration load would be constructed for ground-based referencing, but would not be used during flight. The 37-GHz channel would provide initial information on the potential of airborne T_U measurements. (2) Pending successful modification of the 37-GHz channel the 10, 18 and 85-GHz channels would be modified. The total time required for the modifications and subsequent aircraft experiments would be approximately three years. (Further details concerning this proposal are

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available from the authors.) Modifications would be performed by the author and students within the Laboratory for Remote Sensing at the Georgia Tech School of Electrical Engineering. These individuals are uniquely qualified for airborne investigations involving polarimetric radiometry.

References

[1] Gasiewski, A.J. "A Technique for Measuring Vertically and Horizontally Polarized Brightness Temperatures Using Electronic Polarization Basis Rotation", Proceedings of the 1990 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp. 1569-1572, May, 1990.

[2] "Laboratory Demonstration of Electronic Polarization Basis Rotation", Proceedings of the 1992 IEEE MTT-S International Microwave Symposium (IMS), vol. 1, pp. 329-332, Albuquerque NM, June 1-5 1992.

[3] Gasiewski, A.J., and D.B. Kunkee, "Calibration and Applications of Polarization-Correlating Radiometers", submitted for publication to *IEEE Trans. Microwave Theory Tech.*, May 1992.

[4] Dzura, M.S., Etkin, V.S., A.S. Khrupin, M.N. Pospelov, M.D. Raev, "Radiometers-Polarimeters: Principles of Design and Applications for Sea Surface Microwave Emission Polarimetry", Proceedings of the 1992 IEEE International Geoscience and Remote Sensing Symposium (IGARSS), pp. 1432-1434, June, 1992.

[5] Veysoglu, M.E., "Polarimetric Passive Remote Sensing of Periodic Surfaces and Anisotropic Media", S.M. Thesis, Department of Electrical Engineering and Computer Science, Massachusetts Institute of Technology, Cambridge, MA, 1991.

[6] Gasiewski, A.J., and D.B. Kunkee, "Laboratory Measurements of Gravity Wave Characteristics Using Full Polarization Microwave Radiometry", To be submitted to *IEEE Trans. Geosci. Remote Sensing.*

N93-20090

Title: Nonhydrostatic Effects in Numerical Modeling of Mesoscale Convective Systems and Baroclinic Waves

Investigator: Charles Cohen, USRA, MSFC

Background:

The present investigation is concerned with the role of convection upon mesoscale modeling results, particularly when the grid resolution becomes small enough that there is not a clear scale separation between the explicitly resolved circulations and the parameterized clouds. In those situations, the vertical accelerations in explicitly resolved circulations become strong enough that the hydrostatic assumption may no longer be valid. These concerns arise from interests in improving mesoscale modeling *per se* and in improving the subgrid-scale parameterizations in global models.

Significant accomplishments in the past year:

The hydrostatic and the nonhydrostatic options of the Colorado State University Regional Atmospheric Modeling System were used to simulate dry gravity currents in two dimensions, using several different horizontal grid sizes. With horizontal grid intervals of 10 km or less, nonhydrostatic simulations produce wider and colder heads and weaker but wider forced updrafts than do the hydrostatic simulations. Comparing the hydrostatic and nonhydrostatic models shows that the difference between the vertical mass fluxes is much less than the difference between the vertical velocities.

When the grid is fine enough to resolve the head of the gravity current, horizontal convergence at the gust front extends upwards almost to the head of the cold air. Vertical mass flux in the forced updraft at the front varies with horizontal grid size mainly as a function of the height of the simulated head. For coarser grids, which do not resolve the head, vertical mass flux at all heights decreases with increasing horizontal grid size.

A comparison of nonhydrostatic simulations with horizontal grid intervals of 1 km and 2 km illustrates how decreasing the grid size does not necessarily increase the intensity of the resolved circulation. The smaller grid enables the simulated gravity current to entrain a bubble of warm air behind the head, which results in a weaker circulation with a shorter head and a weaker updraft.

Focus of current research:

The hydrostatic and nonhydrostatic versions of the RAMS model will be used to simulate deep moist convection using horizontal grid intervals between 20 km and 50 km, with parameterized cumulus convection. The magnitudes of the vertical velocities will be compared for the hydrostatic and nonhydrostatic models and the individual terms in the vertical momentum equation will be examined in the nonhydrostatic model, in order to document the effects of relaxing the hydrostatic assumption in numerical modeling of mesoscale circulations.

The nonhydrostatic model will be used, with a horizontal grid interval of 1 km, to simulate the formation of mesoscale convective systems which include nimbostratus anvils. By alternatively including and excluding ice processes, an examination of the role of mesoscale downdrafts in forming and organizing mesoscale convective systems will be made.

Publication:

Cohen, C., 1992: The effects of the hydrostatic assumption and of horizontal grid size on numerical simulations of low-level mass convergence. Submitted to *J. Atmos. Sci.*

N93-20091

Title: Synoptic/Planetary-Scale Interactions and Blocking Over the North Atlantic Ocean

Investigators: Phillip J. Smith (PI)
Anthony R. Lupo (Graduate Research Assistant)
Melinda L. Hunter (Graduate Teaching Assistant)
David R. Stettner (Undergraduate Honors Student)

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Background of the Investigation:

The central theme of this project has been the diagnosis of blocking anticyclogenesis and the corresponding interactions with synoptic-scale circulations. To that end an extensive investigation of the dynamics and energetics of a major blocking anticyclone and two upstream cyclones, all of which occurred over the North Atlantic Ocean and the United States in January 1979, was undertaken. Data for the study were provided by Goddard Laboratory for Atmospheres (GLA) 4° LAT by 5° LON FGGE analyses. The methodology has primarily focused on the diagnosis of circulation forcing mechanisms using the modified forms (referred to as the extended forms) of the height tendency and Zwack-Okossi equations developed by our research group. Calculations use routine second-order finite differencing with boundary layer friction and sensible heating and latent heat release represented as parameterized quantities. Of particular interest are the latent heat release estimates, which combine convectional parameterized values with estimates derived from satellite IR data. The latter were obtained using an algorithm derived by Dr. Franklin R. Robertson of NASA's Marshall Space Flight Center. Results are contained in project reports, theses and publications identified in previous review summaries and reports, and publications listed at the end of this summary.

Significant Accomplishments in the Past Year

1) The cyclone diagnostic study, using the Zwack-Okossi (Z-O) equation, and the application of these results as lower boundary conditions in the solution of the height tendency equation, both of which were summarized in last year's annual review, have been accepted for publication in refereed journals (Lupo, et al., and Uhl et al.). In addition, the cyclone study was presented at a national conference (Lupo and Smith). Included in this paper was one added feature. Using the 950 geostrophic vorticity tendencies diagnosed by the Z-O equation, predictions of the vorticity fields were made by simply extrapolating these tendencies for 6 and 12 hours. This resulted in remarkably good forecasts for both cyclone cases, thus suggesting that reliable Z-O equation diagnoses can provide the basis for useful short-range predictions and for the evaluation of mechanisms responsible for the predicted states.

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2) Undergraduate student David Stettner completed an Honors degree thesis in which he examined the importance of vorticity and temperature advection, two terms that often dominate in the Z-O equation, in seven winter extratropical cyclones. He found that for these two quantities positive correlations with cyclone development occurred for vertically-averaged advections, from 850 to 100 mb for vorticity and from 300 to 100 mb for temperature.

3) The comparison of SAT and NOSAT versions of the GLA FGGE analyses was completed (M.S. thesis, Gregory Lamberty). The comparison strategy was to examine correlation coefficients, RMS differences, and standard deviations first for basic variable fields (sea level pressure, temperature, geopotential height, and wind speed) and then for higher-order derived fields (gradient magnitudes, advections, vorticity, and height tendencies). The comparisons were done over two areas, one encompassing North America and the North Atlantic Ocean and a second encompassing only the ocean region.

Mean value statistics show that the SAT field had a low (high) level cold (warm) temperature bias that resulted in lower, low-level heights and higher, upper level heights. The SAT fields also consistently exhibited, at most levels, stronger height gradients and wind speeds and exaggerated the dominance of cyclonic vorticity and warm air advection in the region by producing a cyclonic geostrophic vorticity bias and a warm air advection bias. Other quantities possessed less consistent differences. Also, differences in the analysis means and standard deviations were larger over the ocean area than over the total domain. The basic variables examined exhibited correlation coefficients (CC) in excess of .90 for both domains. These correlations then decreased for successively higher order parameters. The smallest CC's, with values generally near or below .85, occurred for the horizontal advection quantities. While significant differences were often not apparent in the correlation statistics, such differences did emerge more often in the root mean square differences, which were normalized by dividing by the respective mean standard deviations. Except for the sea level pressure, the normalized root mean square differences (NRMSD) were consistently above 20% of their respective mean standard deviations, with higher-order parameters often in excess of 50%. Furthermore, both the CC and NRMSD statistics revealed that for all variables, the analyses compared most poorly over the ocean area.

<u>Focus of Current Research and Plans for Next Year</u>

We are currently engaged in two studies which will carry through next year.

1) To complete our tests of the Z-O equation, M.S. student Melinda Hunter is diagnosing the evolution of a surface anticyclone that occurred in January 1979 over North America. Data for this study are provided by the GLA FGGE analyses.

2) Ph.D. student Anthony Lupo has began a study of ten blocking episodes that occurred over the North Atlantic and Pacific Oceans. The objective is to examine dynamical relationships between block development and upstream cyclones. While the general dynamics of these cases will be examined, focus will be on

(a) the jet streak link between block formation and upstream cyclone activity, as noted in the single case study of Tsou and Smith (1990, Tellus, 42A, 174-193);

(b) the role of northward warm air advection in block formation;

(c) the importance of cooperative participation of several forcing mechanisms during explosive cyclone development;

(d) the significance of the vertical distribution of forcing processes during cyclone/anticyclone development.

For this study, we expect to use GLA 2° LAT by 2.5° LON analyses. In addition, as in previous studies, GOES satellite IR data will be used to augment conventional latent heat release estimates.

Publications

a. Refereed papers

Lupo, A.R., P.J. Smith, and P. Zwack, 1992: A Diagnosis of the Explosive Development of Two Extratropical Cyclones. Monthly Weather Review, in press.

Smith, P.J., and C.-H. Tsou, 1992: Energy Transformations Associated with the Synoptic and Planetary Scales During the Evolution of a Blocking Anticyclone and an Upstream Explosively-Developing Cyclone. Tellus, in press.

Uhl, M.A., P.J. Smith, A.R. Lupo, and P. Zwack, 1992: The Diagnosis of a Pre-Blocking Explosively-Developing Extratropical Cyclone System. Tellus, in press.

b. Conference preprint

Lupo, A.R., and P.J. Smith: A Comparison of Synoptic-Scale Development Characteristics for Over-Water and Over-Land Cases of Explosive Cyclone Development. Preprint volume of the Symposium on Weather Forecasting, January 6-9, 1992, Atlanta, GA, 72-79.

c. M.S. thesis

Lamberty, G.L.: A Study of the Influence of Satellite Data on Goddard Laboratory for Atmospheres' Analyses. M.S. completed August 1991.

N93-20092

Observational and Modeling Studies of Heat, Moisture, Precipitation, and Global-Scale Circulation Patterns

Dayton G. Vincent, Purdue University: Principal Investigator
Franklin "Pete" Robertson, MSFC/NASA: Scientific Collaborator

Annual Review for Period, June 1991 - June 1992

A. Background of the Investigation

The research sponsored by this grant is a continuation and an extension of the work conducted under a previous contract, "South Pacific Convergence Zone and Global-Scale Circulations". In the prior work, we conducted a detailed investigation of the South Pacific convergence zone (SPCZ), and documented many of its significant features and characteristics. We also conducted studies of its interaction with global-scale circulation features through the use of both observational and modeling studies. The latter was accomplished toward the end of the contract when Dr. James Hurrell, then a Ph.D. candidate, successfully ported the NASA GLA general circulation model (GCM) to Purdue University.

In our present grant, we have expanded our previous research to include studies of other convectively-driven circulation systems in the tropics besides the SPCZ. Furthermore, we have continued to examine the relationships between these convective systems and global-scale circulation patterns. Our recent research efforts have focused on three objectives: (1) determining the periodicity of large-scale bands of organized convection in the tropics, primarily synoptic to intraseasonal time scales in the Southern Hemisphere; (2) examining the relative importance of tropical versus mid-latitude forcing for Southern Hemisphere summertime subtropical jets, particularly over the Pacific Ocean; and (3) estimating tropical precipitation, especially over oceans, using observational and budget methods. A summary list of our most significant accomplishments in the past year is now given.

B. Significant Accomplishments (June 1991 - June 1992)

1. In July 1991, a final report on our previous contract, "South Pacific Convergence Zone and Global-Scale Circulations", was submitted.

2. In August 1991, Dr. Vincent presented two papers at the IUGG/IAMAP meetings in Vienna, Austria. These were: (1) "Mean monthly precipitation rates over tropical oceans", by Vincent, North (former M.S. graduate) and Velasco (former B.S. Honors graduate), presented at the Workshop on Precipitation Measurements, and (2) "The relationship between tropical heating and subtropical wind maxima: Observational and modeling study", by Hurrell (former Ph.D. graduate) and Vincent, presented at the Symposium on Large-Scale Flow and Atmospheric Variability.

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3. In October 1991, Dr. Vincent presented a paper, "Relationship between intraseasonal oscillation and subtropical wind maxima over the South Pacific Ocean", by Vincent, Hurrell (former Ph.D. graduate), and Dr. Speth and Messrs. Sperling, Fink and Zube (Dr. Vincent's colleagues at the University of Cologne, Germany). This paper was given at the Fifth Conference on Climate Variations, held in Denver, Colorado.

4. In January 1992, Dr. Vincent presented a paper, "A case study of analyzed versus satellite-derived water vapor distributions over the Atlantic Ocean", for which he was the sole author. This paper was given at the Sixth Conference on Satellite Meteorology and Oceanography, held in Atlanta, Georgia.

5. In January 1992, three Ph.D. students on the project (Messrs. Bourassa, Ko and Ramsey) and former B.S. Honors graduate, Mr. Velasco, were awarded partial support from the American Meteorological Society to participate in the conference on Global Change Studies, held at Atlanta, Georgia.

6. In April 1992, Dr. Speth from the Institute for Geophysics and Meteorology, University of Cologne, Germany, visited Dr. Vincent at Purdue University for one week. They conducted research and discussed plans for the continued collaboration between their research groups.

7. Several refereed papers and conference preprints were published which contained research sponsored by the grant. These are listed in section E.

C. <u>Focus on Current Research (summer 1992)</u>

By the time this review takes place (July 1992), we will be in the midst of a busy summer of research activities. At the time of this writing (April 1992), Mr. Bourassa is preparing to take his Ph.D. preliminary examination. If all goes well, he will become the second Ph.D. candidate on the project (Mr. Ramsey is the other). Both Mr. Bourassa and Mr. Ramsey, as well as the other two graduate students on the project (Messrs. Ko and Sliwinski), are looking forward to the summer period when it is possible to focus most of their attention toward research. Dr. Vincent, together with his colleagues and students, will spend much of the summer preparing conference presentations, invited lectures, and manuscripts for publication in the coming year. These are listed below in section D.

D. <u>Plans for Next Year (July 1992 - July 1993)</u>

1. In August 1992, Mr. Ramsey will present a paper, "Improvements in Q_1 budget derived precipitation estimates: Calculation of radiation terms using operational analyses and ISCCP C1 cloud statistics", at the Eleventh International Conference on Clouds and Precipitation, held in Montreal, Canada.

2. In August 1992, our project will welcome a new M.S. student, Mr. Jon Schrage, who is a graduate of Creighton University. He received a fellowship from the American Meteorological Society for his first year of graduate study.

3. In November - December 1992, Dr. Vincent will present an invited 6-week course in "Tropical Meteorology" at the Institute for Geophysics and Meteorology, University of Cologne, Germany. The course is currently being prepared.

4. In January 1993, Dr. Vincent, and perhaps one or more of his graduate students, will attend the meetings associated with the AMS Annual Meeting in Anaheim, California. One or more preprint paper(s), is (are) currently in preparation.

5. In March - April 1993, Dr. Vincent will present a review paper on the South Pacific convergence zone (SPCZ) at the Fourth International Conference on Southern Hemisphere Meteorology and Oceanography in Hobart, Australia. An Abstract is currently in preparation and the paper will be written in the coming fall-winter period. In addition, Dr. Vincent has been invited to chair a session at the conference.

6. In April - May 1993, Dr. Vincent and perhaps one of his graduate students plan to present papers at the Twentieth Conference on Hurricanes and Tropical Meteorology to be held at a yet-to-be-named location in the Southwest U.S.A. Abstracts and preprints would be prepared during the coming fall-winter period.

7. Dr. Vincent will prepare his contribution to two manuscripts he is co-authoring with his colleagues at the University of Cologne, Germany (Dr. Speth and Ph.D. students, Messrs. Fink and Sperling).

8. Dr. Vincent will continue to act in an advisory capacity to two of Dr. Speth's Ph.D. students (Messrs. Fink and Sperling) at the University of Cologne, Germany.

E. Publications (June 1991 - June 1992)

1. Refereed

Hurrell, J.W. and D.G. Vincent, 1991: On the maintenance of short-term subtropical wind maxima in the Southern Hemisphere during SOP-1, FGGE. Journal of Climate, 4, 1009-1022.

Vincent, D.G., K.H. North, R.A. Velasco and P.G. Ramsey, 1991: Precipitation rates in the tropics based on the Q_1-budget method: 1 June 1984 - 31 May 1987. Journal of Climate, 4, 1070-1086.

Hurrell, J.W. and D.G. Vincent, 1992: A GCM case study on the maintenance of short-term subtropical wind maxima in the summer hemisphere during SOP-1, FGGE. Quarterly Journal Royal Meteorological Society, 118, 51-70.

2. Preprint papers

Vincent, D.G., J.W. Hurrell, P. Speth, T. Sperling, A. Fink and S. Zube, 1991: Relationship between intraseasonal oscillation and subtropical wind maxima over the South Pacific Ocean. Preprint from the Fifth Conference on Climate Variations, October 14-18, 1991, Denver, CO, American Meteorological Society, Boston, MA, 240-243.

Vincent, D.G., 1992: A case study of analyzed versus satellite-derived water vapor distributions over the Atlantic Ocean. Preprint from the Sixth Conference on Satellite Meteorology and Oceanography, January 5-10, 1992, Atlanta, GA, American Meteorological Society, Boston, MA, 329-332.

N93-20093

TITLE: Tropical Pacific Moisture Variability

INVESTIGATOR: James P. McGuirk
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RESEARCH OBJECTIVES:

1. To describe synoptic scale variability of moisture over the tropical Pacific Ocean and the systems leading to this variability.
2. To implement satellite analysis procedures to accomplish (1).
3. To incorporate additional satellite information into operational analysis/forecast systems at NMC.
4. To synthesize knowledge gained from satellite observations through diagnosis and numerical models.

SIGNIFICANT ACCOMPLISHMENTS IN FY 91/92:

1. Satellite forecast applications.

A case study in which additional signals were extracted from TOVS and inserted into the NMC Global Spectral Model is complete. A report has been submitted to NMC for evaluation and a manuscript has been submitted for publication. The key results are that modest improvements in tropical analysis and forecasting on the synoptic scale can be achieved by making use of horizontally coherent temperature and moisture signatures currently available in operational TOVS observations.

2. Satellite data analysis.

i. A draft of a thesis by Fink intercomparing SMMR, TOVS, OLR and ECMWF estimates of tropical oceanic column precipitable water is being prepared for publication. The key results are that infrared observations have a positive impact on estimated precipitable water by ECMWF analysis, even when moisture retrievals from TOVS are used as estimators in the ECMWF analyses. The infrared information is merged with ECMWF through simple regression and the results are compared with SMMR estimates (assumed as a ground truth). Negative results are that most of the predictability seems to appear on the large scale in association with climatological features. Impact on analyzed synoptic structure appears to be minimal.

ii.Fink's study is the basis for extending interpretive analysis of infrared precipitable water estimation. A study has been initiated using many of the TOVS channels (including MSU, window channels, and channels in the 14 micron band) to estimate precipitable water. Sensitivity of precipitable water to sea surface temperatures and atmospheric stability is also being considered. A new data set is being used and ground truth will be raobs and SSM/I estimates. At this point, planning is complete and two tasks have been completed:

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a. A radiative model has been used to define and quantify the sensitivity of numerous TOVS channels to vertical moisture structure.
b. Data sets of several hundred pairs of observations have been constructed for collocated SSM/I-TOVS observations, TOVS-Raob observations and SSM/I-Raob observations.

Interpolations of OLR and ECMWF fields are also being prepared.

3. Tropical plume mechanisms.

iii. Interpretation of the kinetic energy calculations of Lee is continuing. He has computed kinetic energy budgets comparing 1983 (El Nino) and 1984 (El Nino cold phase) in both the NMC and ECMWF analyses. He intercompares regional energetics over the eastern Pacific during tropical plume events and hemispheric wide tropical spectral energetics. He finds systematic biases in the two analyses which change as climate conditions (El Nino) change. Local random wind differences exceeding 20 m/s occur almost daily. Important findings are:

a. During ENSO, source regions of KE move dramatically.
b. During plume events, barotropic and baroclinic processes suggest stability, although locally, generation of KE by cross contour flow is large.
c. Spectrally, planetary waves dominate, especially during ENSO. During most plume events, there is a transfer of KE from the planetary scale to the synoptic scale.

iv. Development of a spherical global model and a two layer baroclinic model, appropriate for tropical plume diagnostics and study of tropical/extratropical interaction continues. Tropical plume simulation during ENSO continues. There are no results yet beyond Askue's modelling of normal mode interaction and Blackwell's modelling of tropical plumes forced by subsidence.

FOCUS OF CURRENT RESEARCH AND PLANS FOR FY 92/93:

1. Completion of the prediction of precipitable water from ECMWF analysis and infrared observations is anticipated (ii above). The long range goal is to document a technique for retrieving daily precipitable water fields for the decade of the 1980's from infrared based techniques. From 1987 onward, SSM/I has solved much of this problem (except vertical moisture structure and structure between tropical DMSP passes).

2. We anticipate revisiting the estimation of TOVS radiances from ECMWF and NMC analyses. This procedure is to be used as a diagnostic tool of the operational analyses.

3. Finally, interpretive modelling of tropical mid latitude interactions with barotropic and simple baroclinic models will continue (item iv). Expected results are a description of the interaction of baroclinic and barotropic fields in synoptic systems forced diabatically. Also of interest is the correspondence between satellite observations (OLR, TOVS 11 and 12, and SSM/I fields) and dynamically predicted quantities in simple models (related to focus 2).

PUBLICATIONS (since July 1991):

Refereed:

McGuirk, J.P., 1992: Impact of increased TOVS signal on the NMC global spectral model: A tropical plume case study,submitted to *Weather and Forecasting*, April 1992.

_____, and J.D. Fink: Tropical precipitable water estimates from SMMR, TOVS, OLR and ECMWF analysis, to be submitted to *J. Applied Meteorology*, July 1992.

Blackwell, K.G., and J.P. McGuirk, 1992: Sensitivity of TOVS moisture channels to upper tropospheric moisture, to be submitted to *J. Applied Meteorology*, August 1992.

Presentations:

-----, 1991: Transient tropical-extratropical interaction observed and simulated in a barotropic model, Accepted at the IUGG/IAMAP Symposium on Large-Scale Atmospheric Flow and Variability, Vienna, Austria, August 1991.

-----, 1991: Improved satellite signals in tropical forecasts in the NMC Medium Range Forecast Model, submitted to the AMS 9th Conf. on Numerical Weather Prediction, Denver, October 1991.

-----, K.G. Blackwell and Y. Zhang, 1991: Divergently-forced transient tropical response in a shallow water model with a realistic basic state, submitted to the AMS 8th Conf. on Atmospheric and Oceanic Waves and Stability, Denver, October 1991.

Theses/ Dissertations:

Lee, J.G., 1991: Comparative tropical synoptic scale kinetic energy budgets, PhD., Texas A&M Univ., (August 1991).

Winton, S.E., 1991: Eastern Pacific and Central American tropical systems as viewed from satellite, MS. Texas A&M Univ., (December 1991).

[Totaling 10 refereed publications, 35 conference papers, 11 MS. theses, 6 PhD. dissertations under 8 yrs. of NASA sponsorship, commencing April 1983.]

N93-20094

Investigation of Cloud/Water Vapor Motion Winds from Geostationary Satellite

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Work has been primarily focussed on three tasks: (A) comparison of wind fields produced at MSFC with the CO2 autowind/autoeditor system newly installed in NESDIS operations, (B) evaluation of techniques for improved tracer selection through use of cloud classification predictors, and (C) development of height assignment algorithm with water vapor channel radiances. The contract goal is to improve the CIMSS wind system by developing new techniques and assimilating better exisitng techniques. The work reported here was done in collaboration with the NESDIS scientists working on the operational winds software, so that NASA funded research can benefit NESDIS operational algorithms.

(A) Comparison of A Wind Set Produced by MSFC with the New Operational CO2 Autowind/Autoeditor (C. Hayden, NOAA/NESDIS, C. Velden, CIMSS)

In the early spring of 1990 a team from the Cooperative Institute for Satellite Studies (CIMSS) joined with the NESDIS Interactive Processing Branch and the Satellite Analysis Branch in introducing and testing at the VAS Data Utilization Center a new software system for automated cloud motion winds with pressure altitude assignment using the CO_2 slicing method. Wind vectors generated during this demonstration were given to the NMC to investigate forecast impact. One of the highlights of this effort occurred on April 24 and 25 when the new pressure assignment method succeeded in correctly locating the altitude of thin cirrus tracers off the coast of California associated with a shortwave which would later affect the weather over the U.S. (Merrill,et al. 1991). The success of this venture breathed new life into applied research for improving the vectors obtainable from satellite imagery, and one consequence was an agreement with Marshall Space Flight Center (MSFC) that they use the April test case with their vector generating software for comparison with the new NESDIS system, the eventual goal being the amalgamation of better aspects of the two methods. MSFC agreed to this task, and subsequently delivered a data set to CIMSS which included vectors from visible, infrared window, and water vapor (6.7 micrometer) imagery for April 25, 00 UT. CIMSS evaluation of these data was conducted under this contract and the results are briefly highlighted here.

CIMSS has developed a system for objective quality control of the winds generated from tracers. This quality control includes both pressure altitude reassignment by objective assimilation with other data and ojective editing (Hayden, 1991; Hayden and Velden, 1991). It is a part of the new wind generating system which became operational at NESDIS on February 12, 1992. The MSFC wind data were evaluated by this quality control system.

The principal conclusion from examination of the MSFC data set is that NESDIS should be paying more attention to visible data to improve vector coverage. A second conclusion is that MSFC seems to have a superior technique for obtaining targets in the water vapor imagery. Certainly their density is much higher. Finally, the NESDIS assimilation system was quite successful in blending the MSFC winds into the analysis, despite the deficiencies of the

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initial height assignment. Although an obvious bias to the NMC forecast is enforced by the reassignment, the end result in comparison to rawinsondes shows an rms improvement over the forecast.

Hayden, C. M. and C. S. Velden, 1991: Quality control and assimilation experiments with satellite-derived wind estimates. *Preprint Volume, 9th Conference on Numerical Weather Prediction*, Denver, CO. Amer. Meteor. Soc., 19-23 October.

Hayden, C. M. 1991: Research leading to operational methods for wind extraction. *Proceedings of the Workshop on Wind Extraction from Operational Meteorological Satellite Data*, Washington, DC, 17-19 September, Eumetsat ISBN 92-9110-007-2.

Merrill, R. T., W P. Menzel, W. Baker, J. Lynch, and E. Legg, 1991. A report on the recent demonstration of NOAA's upgraded capability to derive cloud motion satellite winds. *Bull. Amer. Meteor. Soc.*, **72**, 372-376.

(B) Use of Cloud Classification Predictors for Cloud Tracer Selection in Operational Winds Algorithms (C. Moeller, CIMSS)

The utility of cloud feature characteristics as additional information to the operational automated cloud tracking wind algorithm is being investigated. This effort is aimed at improving the quality of operationally produced cloud tracked winds while eliminating computational time spent trying to produce vectors from cloud targets which are not likely to yield good quality vectors. Automated wind vectors can be improved by limiting cloud tracer selection to tracers that are, more often than not, accurately tracked (via correlation technique) through time. A goal of this work is to base cloud tracer selection on cloud feature characteristics as well as the usual pixel brightness and gradient thresholds. The characteristics for describing cloud tracers include cloud albedo, fraction, multilayering, height of base and top, spatial distribution and orientation, connectivity (cloud and background), and type (Garand, 1988). These cloud characteristics are being compared to cloud tracers and vectors produced by the operational cloud tracking procedure in an effort to identify the conditions under which good (and bad) quality wind vectors are produced. Those characteristics demonstrating skill in identifying good (and bad) cloud tracers will be retained; those not demonstrating skill will be removed from the algorithm to reduce computational time.

Garand, L., 1988: Automated Recognition of Oceanic Cloud Patterns. Part I: Methodology and Application to Cloud Climatology. *Jour. of Clim.*, Vol.1, No.1, 20-39.

(C) Compariosn of Several Techniques to Assign Heights to Cloud Tracers (S. Nieman, CIMSS, P. Menzel, NOAA/NESDIS, J. Schmetz, ESOC)

In the current operational use of four geostationary satellites, satellite derived cloud motion vector (CMV) production has been troubled by inaccurate height assignment of cloud tracers, especially in thin semi-transparent clouds. At the recent Workshop on Wind Extraction from Operational Meteorological Satellite Data (Eumetsat, 1991) there was a consensus that the present techniques for height assignment needed further review and that greater commonality in techniques should be encouraged.

Presently heights are assigned by any of three techniques when the appropriate spectral radiance measurements are available. In opaque clouds, infrared window (IRW) brightness temperatures are compared to forecast temperature profiles to infer the level of best agreement which is taken to be the level of the cloud. In semi-transparent clouds or sub-pixel clouds, since the observed radiance contains conributions from below the cloud, this IRW technique assigns the cloud to too low a level. Corrections for the semi-transparency of the cloud are possible with the carbon dioxide (CO_2) slicing technique (Menzel, 1983) where radiances from different layers of the atmosphere are ratioed to infer the correct height. A similar concept is used in the water vapor (H_2O) intercept technique (Szejwach, 1982), where the fact that radiances influenced by upper tropospheric moisture (H_2O) and IRW radiances exhibit a linear relationship as a function of cloud amount is used to extrapolate the correct height. These three techniques are being compared at CIMSS through this contract and other NESDIS supported work.

There is an added impetus to this work. The European community is sharing one of its satellites with the United States, METEOSAT 3; understanding the relative performance of the NESDIS (National Environmental Satellite and Data Information Service) operational CO_2 slicing heights and the ESOC (European Satellite Operations Center) operational H_2O/IRW intercept heights is necessary for the United States to begin production of CMVs with M3. Furthermore, GMS 5 will be supplemented with a water vapor channel so that international commonality of height assignment is closer, if viable H_2O/IRW height performance can be verified.

Evaluations so far suggest that the H_2O/IRW intercept technique is a viable alternative to the CO_2 slicing technique for inferring the heights of semi-transparent cloud elements. On a given day the heights from the two approaches compare to within 60 to 110 mb rms; drier atmospheric conditions tend to reduce the effectiveness of the H_2O/IRW intercept technique. The infrared window channel technique consistently places the semi-transparent cloud elements too low in the atmosphere by 100 mb or more; only in more opaque clouds does it perform adequately. Comparison of the heights produced operationally at NESDIS (with the CO_2 slicing technique) and ESOC with their version of the H20/IRW intercept technique) reveal that the cloud height algorithms are approaching an international commonality.

EUMETSAT, 1992: Workshop on wind extraction from operational meteorological satellite data, 17-19 September 1991. EUM P 10, ISBN 92-9110-007-2.

Menzel, W. P., W. L. Smith, and T. R. Stewart, 1983: Improved cloud motion wind vector and altitude assignment using VAS. *J. Clim. Appl. Meteor.*, 22, 377-384.

Szejwach, G., 1982: Determination of semitransparent cirrus cloud temperatures from infrared radiances: application to METEOSAT. *J. Appl. Meteor.*, 21, 384.

N93-20095

TITLE: Microwave Radiative Transfer Studies of Precipitation

INVESTIGATORS

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Dr. J. Vivekanandan, National Center for Atmospheric Research, Research Applications Program, Boulder, CO (303) 497-8402.
Dr. F. Joseph Turk, Department of Electrical Engineering, Colorado State University, Ft. Collins, CO (303) 491-7678.

BACKGROUND OF THE INVESTIGATION

This proposal was submitted to NASA in 1990 as a proposed extension to the previous NASA contract NAG8-643. Since the deployment of the DMSP SSM/I microwave imagers in 1987, increased utilization of passive microwave radiometry throughout the 10-100 GHz spectrum has occurred for measurement of atmospheric constituents and terrestrial surfaces. Our efforts have focused on observations and analysis of the microwave radiative transfer behavior of precipitating clouds. We have focused particular attention on combining both aircraft and SSM/I radiometer imagery with ground-based multiparameter radar observations. As part of this and the past NASA contract, we have developed a multi-stream, polarized radiative transfer model which incorporates scattering. The model has the capability to be initialized with cloud model output or multiparameter radar products. This model provides the necessary "link" between the passive microwave radiometer and active microwave radar observations. This unique arrangement has allowed the brightness temperatures (T_B) to be compared against quantities such as rainfall, liquid/ice water paths, and the vertical structure of the cloud. Quantification of the amounts of ice and water in precipitating clouds is required for understanding of the global energy balance.

SIGNIFICANT ACCOMPLISHMENTS IN THE PAST YEAR

During July and August 1991, we as well as investigators from NASA Marshall Space Flight Center (Ms. Robbie Hood, Ms. Vanessa Griffin, Mr. Frank LaFontaine) participated in the collection of aircraft radiometer observations during the Convection and Precipitation/ Electrification (CaPE) experiment, held near Kennedy Space Center, Florida. The experiments involved overflights of the NASA ER-2 high-altitude aircraft over large precipitating complexes concurrently being scanned by the NCAR CP-2 dual-frequency, dual-polarization radar. The ER-2 carried, among other instruments, the new Advanced Microwave Precipitation Radiometer (AMPR), a 4-channel (10.7, 19.35, 37.1, and 85.5 GHz) scanning microwave radiometer system. The latter three frequencies coincide with those on the SSM/I. The AMPR was conceived and is operated by NASA/MSFC, and was built by the Georgia Tech Research Institute. The AMPR scans ±45° across-track, giving a ground swath width of about 40 km, with individual ground resolutions ranging from 0.7 km to 2.4 km at 10.7 and 85.5 GHz, respectively. Since that time, we have been analyzing both the radar and radiometer datasets, first checking data quality and calibration, and then developing color graphics software to facilitate the display and quantitative analysis of both datasets. We have produced maps of the radar-derived products rainfall and integrated ice and water paths for comparison with the AMPR T_B in preparation for attempts to

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quantify retrieval techniques via multifrequency T_B relations. Existing relations are hindered by the lack of available ground verification data. The earth resolution of the AMPR is finer than that of the SSM/I by a factor of about 20, so factors such as partial beam-filling are mitigated to a large extent.

FOCUS OF CURRENT RESEARCH AND PLANS FOR NEXT YEAR

There are several groups in the US performing microwave radiative transfer studies, employing different techniques or approaches to the problem of quantifying the precipitation process via passive microwave data. Several of these approaches complement each other and are mutually beneficial. During the next year, in addition to collaborating with the Remote Sensing Branch at NASA/MSFC, we will collaborate with scientists at Florida State University (Eric A. Smith) and the Atmospheric Physics Institute in Italy (Alberto Mugnai). The latter's studies have involved the use of a detailed microphysical cloud model to study the effects of the vertical distribution of rain, cloud water, snow, etc. on the top-of-atmosphere T_B, as well as development of an inversion scheme which attempts to reproduce the SSM/I-measured T_B by perturbing cloud model vertical hydrometeor profiles. Similarly, using the radar data, we are attempting to reproduce the AMPR-measured T_B over the actual storm by inverting the radar data products. The link here is that the cloud model is a simulator which provides separate rain, snow, etc. categories, whereas the radar data is an actual measurement from all of the different categories in its resolution volume, separation of which can be improved with the multiparameter capabilities of the CP-2 radar. We all have agreed to work on a 3-part effort as follows: 1) Demonstrate the utility of the AMPR instrument for diverse geophysical applications including precipitation, surface characterization, etc., 2) combine the AMPR and CP-2 radar data from CaPE into our detailed radiative transfer model to identify plausible hydrometeor vertical profiles including rainfall, and to separate the ice and water contents for use by others interested in energy budget studies, and, 3) test the Smith and Mugnai inversion scheme using their cloud model dataset along with SSM/I measurements from CaPE. This will reveal how the fine-scale ($\simeq$2 km) microphysical processes observed by the AMPR/CP-2 combination manifest themselves when viewed by the coarser resolution SSM/I channels. In sum, these efforts will be guided by the belief that improved quantification of rainfall from space may be possible when one considers the physical processes within the cloud that lead to rain production.

PUBLICATIONS

J. Turk, J. Vivekanandan, and V.N. Bringi (1992), "Studies of microwave radiative transfer model results using multiparameter radar observations", *Specialists Meeting on Microwave Radiometry and Remote Sensing*, E.R. Westwater, Chairman, 14-16 January, Boulder, CO.

J. Vivekanandan, J. Turk, R.E. Hood, V.L. Griffin, F.J. LaFontaine, V.N. Bringi, and R.W. Spencer (1992), "Multiparameter radar and Advanced Microwave Precipitation Radiometer observations of tropical convection", *Int. Geoscience and Remote Sensing Symposium*, 26-29 May, Houston, TX.

J. Vivekanandan, J. Turk, and V.N. Bringi (1991), "Ice water path estimation and characterization using passive microwave radiometry", *J. Applied Meteorology,* **30**, 1407-1421.

N93-20096

A SATELLITE-BORNE RADAR WIND SENSOR (RAWS)

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BACKGROUND

Modeling global atmospheric circulations and forecasting the weather would improve if worldwide information on winds aloft were available. Accurate prediction of weather is important to agriculture, shipping, air traffic, and many other fields. Global system models of climate are of great importance. Current global atmospheric models use pressure measurements and thermodynamic properties to calculate the effects of wind for use in Numerical Weather Prediction (NWP) models. Inputs to the NWP models are temperature, pressure and wind velocities at different heights. Clearly direct wind measurements could significantly improve the NWP model performance.

The RAdar Wind Sounder (RAWS) program at the University of Kansas is a study of the feasibility and the trade-offs in the design of a space-based radar system to measure wind vectors. This can be done by measuring the Doppler shift of cloud and rain returns from three or more points and calculating the components of the wind vector. The primary tasks related to the RAWS program are to determine:

1. scattering and attenuation models,
2. required radar sensitivity,
3. optimal frequencies,
4. needed antenna size,
5. suitable scan pattern,
6. ways to remove the ambiguity imposed by range and Doppler frequency,
7. spectrum measurements,
8. system configuration,
9. performance as a rain sensor,
10. performance as an ocean-surface wind sensor.

Xin's dissertation treated all items listed above except items 9-10. He developed a candidate system used throughout the study as a baseline. Our research shows that such an instrument could measure winds at about 1-km height intervals in denser clouds and rain using a large scanning parabolic antenna (8-m diameter in our example), with power comparable to a spaceborne SAR (6 kW). A conical scan pattern with two pointing angles allows for multiple independent looks at the same observation point. So far the study has treated sensitivity and Doppler measurements in detail.

ACCOMPLISHMENTS FOR THE PAST YEAR

The RAWS study to date uses the candidate system selected after preliminary study of frequencies and sensitivities. Two frequencies chosen, 10 and 35 GHz, allow higher sensitivity for clouds and more penetration for rain. The past year was devoted to modeling the signal-to-noise ratio (SNR) achievable for the two frequencies. The determination of SNR versus cloud penetration depth used a cloud backscattering and attenuation model in the appropriate radar equation. Calculations assumed reasonable losses in reception and transmission, in addition to the atmospheric attenuation. We discovered that ice clouds provide a higher SNR than previously calculated, but some water clouds give lower SNRs than we calculated before.

One of the primary issues in the SNR calculation was the choice of the drop size distribution. Although Xin used several distributions (e.g., log normal, Khrigian and Mazin), this year we used the Deirmendjian cloud model. SNR versus cloud penetration plots were generated to validate the candidate system. Rain, which appears in the cloud models at the lower altitudes, provides ample SNR, as do the higher clouds composed of ice particles. However, in some cloud situations we found the sensitivity for the clouds was marginal or inadequate. At 35 GHz, two of the cloud models characterized by 1 to 2 g/m^3 of water content at altitudes extending from 150 to 1500 meters, produced a sufficient SNR. Other models, however, with water contents ranging from 0.5 to 4 g/m^3 and altitudes up to 4000 meters, exhibit SNR of -3 to -23 dB, largely because of attenuation in the upper cloud layers. These results coupled with the lower SNR at 10 GHz, led to an investigation of alternate frequencies. The rain present beneath these clouds provides adequate SNR at 10 GHz, and in most cases, at 35 GHz.

CURRENT AND FUTURE RESEARCH

Analysis is underway to determine the best frequencies for the system. We need a stronger received signal to get a larger-than-unity SNR for all cloud depths. Operating at 94 GHz, for example, would increase SNR for clouds with smaller water content at the cost of more attenuation. The use of a 17- or 24-GHz frequency would increase the backscatter with a possibly acceptable increase in attenuation.

A larger antenna is under consideration to increase SNR and improve vertical resolution. A rectangular antenna may be used, as this would allow for independent selection of vertical and horizontal beamwidths. The antenna scan pattern is also being reviewed for optimization. With the present conical scan, few individual points will be illuminated for the required three measurements. We will explore an alternate scan or scan rate, such as an adaptive shot pattern, to control slew rates and schedule pulse suppression in regions of low information potential. Such an approach may require use of electronically scanned arrays, which we will also examine.

The Doppler tracker, briefly discussed in Xin's dissertation, will be studied further. This function is critical to achieve the wind speed accuracy required. A phase-lock loop (PLL) will probably be used for this purpose.

The RAWS is potentially a multipurpose instrument: wind aloft, rain, and ocean-surface winds. Once we are more certain of the feasibility of the first use, we plan to examine the other two. Since the wind-aloft task is more demanding than the others, use of RAWS for these applications will be easy. However, such use may require small modifications to the wind-aloft system.

PUBLICATIONS

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The M.S. thesis by Mr. Timothy Propp is still being written.

N93-20097

MAMS - High Resolution Atmospheric/Surface Properties

Gary J. Jedlovec (NASA), Anthony R. Guillory (NASA),
Grant S. Carlson (USRA), and Robert J. Atkinson (GE)

Background. The Multispectral Atmospheric Mapping Sensor (MAMS) has been used for a number of investigations over the last 8 years. It has served as the basis for retrieval technique development, for atmospheric process studies, and to retrieve geophysical parameters at the surface (land and ocean). It was used most recently to collect high resolution visible and infrared imagery for the CaPE and STORMFEST experiments during FY91 and FY92. The Wildfire spectrometer (similar to MAMS but with different infrared channels) was also used during STORMFEST. The goals of MAMS during CaPE were:

1) to collect MAMS data to support the overall CaPE science objectives,
2) refine techniques for the retrieval of atmospheric moisture and surface geophysical parameters,
3) map the moisture distributions associated with the sea breeze front over Florida with MAMS ancillary satellite data on a case study basis,
4) identify surface features which may serve as local sources of heat and moisture and influence preferential convective regions over Florida, and
5) process MAMS data and derived relevant geophysical parameters to support other CaPE investigators.

For STORMFEST both the MAMS and Wildfire spectrometers were used to collect unique multispectral data to study atmospheric processes. The Wildfire objectives were:

1) to collect high quality Wildfire data in conjunction with other in situ and remote measurements available during the STORMFEST field phase (1 February - 15 March 1992),
2) to develop algorithms to retrieve total ozone content and compare with those from TOMS and HIRS (IR), and
3) along with water vapor imagery, use the ozone data to better understand the 3-dimensional structure and dynamics of jet streaks and frontal systems in a case study investigation.

The MAMS objectives were::

1) collect MAMS data to support a GSFC investigation of gravity waves,
2) process the MAMS data to locate gravity wave features, and produce various moisture products in support of the gravity wave investigation.

Significant Accomplishments Over the Last Year: The research activities have focused on analyzing the CaPE data sets and collecting and starting preliminary analysis of the STORMFEST MAMS and Wildfire data.

CaPE: The MAMS data from the first 8 flights during CaPE are plagued by numerous data problems. Data problems were finally eliminated for the last three flights by utilizing a new scan head and digitizer which was made available by Ames research center. A vast amount on MAMS data was collected which captured some interesting features relevant to this RTOP research. A NASA Technical Memo has been produced which describes the MAMS data collected for CaPE.

The following 5 cases (days) have been selected for investigation. Much time has been spent on pre-processing the data for the case studies, including the calibration and navigation of the data sets in preparation for quantitative analysis.

Case Studies:

30 July 91: This day has been selected to study the flux of heat and moisture from the surface. This activity supports other work at MSFC under RTOP 460-23-34 (Surface Hydrologic Analysis for CaPE). MAMS flew repeatedly over the surface flux network to collect time dependent data sets. Data quality is fair on this day as some line drop-outs and calibration noise was present. Reasonable surface temperatures and land scene information will be

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available in the cloud free regions.

6 Aug 91: This was an outstanding day for a sea breeze mapping mission. MAMS collected data for 2 hours over the Cape with repeated flight tracks over the developing sea breeze front. The MAMS data for this day has some roll correction problems which is taking extra time to fix. These data are also coincident with in situ thermodynamic measurements from the NCAR and Wyoming King-Airs, and with interferometer data from the HIS. These additional data sets will be used along with the VAS data in a case study analysis.

16 Aug 91: Predominantly clear skies prevailed during the MAMS flight and an extremely high quality data set was collected. It will be used for moisture mapping and surface flux investigations.

17 Aug 91, MAMS data for this flight includes repeated passes over the outer rain bands from tropical storm Bob (when it was off the coast of Florida). The cloud top information will be processes to support the lightning investigations. INS failed on aircraft and additional work is necessary to navigate MAMS imagery.

19 Aug 91, MAMS, HIS, and MTS data was collected over portions of Hurricane Bob. The data has been processed to locate the eye of the hurricane, however, a clear view of the ocean below in the eye was obscured by cirrus at that time. No further activities are planned for this data set.

STORMFEST

Both MAMS and Wildfire data were collected during the STORMFEST experiment period. A NASA Technical Memo has been produced which describes the Wildfire and MAMS data collected for STORMFEST.

Wildfire. Wildfire data was collected on 5 ER2 flights during STORMFEST IOP. Two of these flights were made in direct support of the Wildfire ozone mapping objectives. The data from these flights is of very good quality. These two days (14 and 17 February) will serve as the basis for this research investigation. Additionally, the flight on 25 February will be used to intercompare Wildfire data with that synthesized from coincident HIS data. The 14 February case will also be used to support the GSFC gravity wave investigation.

Calibration and navigation of the Wildfire data for the case studies has begun. The data is consistently of very good quality throughout both flight days. Refinement of existing split window techniques for the retrieval of column ozone content below the aircraft has begun.

Ancillary data required for the investigation has been ordered.

MAMS

Four flights were made with the MAMS during the latter part of the STORMFEST IOP. These flights were either in support of the gravity wave objectives or for other instrument investigations. The objective in processing this data further has not been determined.

Current and Future Work:

CaPE:

Processing of the data sets on the 4 remaining cases will continue. Surface geophysical parameters will be derived for the 30 July and 16 August cases. Modifications to both the split window variance ratio (SWVR) and the physical split window (PSW) techniques for the retrieval of integrated water content (IWC) will be finalized and the techniques applied to the MAMS data of 6 and 16 August. VAS data will be used and new retrievals will be made to support a more detailed mesoscale analysis. Products derived from the HIS data will be evaluated as well as the thermodynamic and wind data from the King Airs.

STORMFEST:

The refined techniques to retrieve integrated ozone content of the atmosphere below the aircraft will be applied to the case study data. The results will be verified against other ancillary data. The 0-20km ozone values will be combined with satellite estimates to derived two layers (0-20 km and 20-TOA) of ozone.

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N93-20098

INFRARED BACKSCATTER CLIMATOLOGY AND MACAWS

M. J. Post/NOAA

During FY91 NOAA's research activities funded under NASA's RTOP program were centered on two areas -- infrared backscatter climatology and MACAWS.

The climatology of vertical backscatter profiles at λ = 10.59 μm over Boulder, Colorado continued at a normal pace (1-2 calibrated profiles per week) through the end of July. During this period we observed 45 typical "clean period" profiles, which ranged from several times 10^{-8} m^{-1} sr^{-1} in the PBL to about 10^{-12} m^{-1} sr^{-1} at 10 km ASL. On July 27, 1991 the first stratospheric clouds from Mt. Pinatubo appeared over Boulder, and we increased the frequency of attempted data taking to daily. Since August 1, 1991 and through March 1992, we have averaged 2 profiles every 3 days, despite field trips to Utah, Kansas, and New Mexico, and the Christmas holidays. The high frequency of observation comes at high cost of manpower and expendables, but it has enabled us for the first time to accurately depict the build up of debris in the stratosphere following a major volcanic eruption. This build up centered on 16 km ASL and grew both upward and downward with time. Simultaneous with the first appearance of stratospheric debris, backscatter in the troposphere increased markedly, and has remained at levels well above the "clean period" profiles. At first there appeared to be no correllation between height of the local tropopause and the bottom of the main stratospheric/tropospheric cloud. However, after about 60 days this correllation increased significantly to the point where specific tropopause folding events, for example, were easily seen in the data. The cloud now reaches to altitudes of 27 km ASL. These results are summarized on the enclosed color figure.

On numerous occasions we observed backscatter profiles in conjunction with other lidars of shorter wavelengths, such as NOAA's dye lidar at Fritz peak or NOAA's ruby lidar, which was at times co-located with the CO_2 system. We also attempt to take data with all lidars whenever the University of Wyoming flies its stratospheric balloons with in situ particle counters. From such data sets we can retrieve size distributions remotely, and for the first time calibrate the CO_2 lidar at long ranges.

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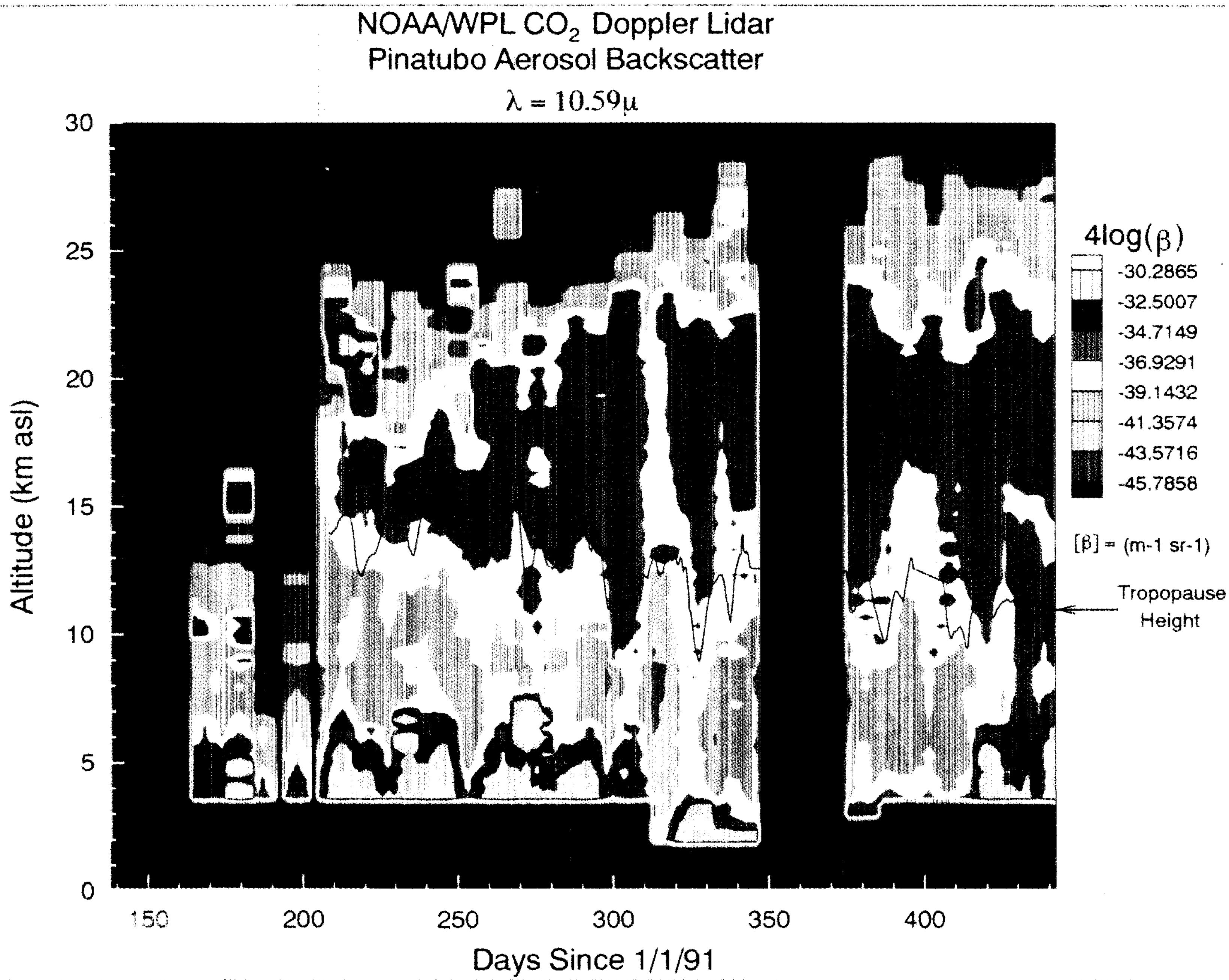
During FY 91 NOAA received about $40K for its backscatter climatology work, but we have received nothing for FY 92. Unless NASA provides some support for FY 92, it will be difficult for NOAA to continue data acquisition and processing at the current feverish pitch, and valuable information on the dissipation of the Pinatubo event will be lost.

The other area of activity was developing the scientific rationale and technical plans to install NOAA's CO_2 Doppler lidar in NASA's DC-8, as part of a multi-agency joint proposal labels MACAWS (Multi-Agency Coherent Atmospheric Wind Sounder). This work entailed considerable debate over the scientific merit of various scanning geometries possible from the DC-8, and the importance of the scientific contribution of MACAWS to such other programs as TOGA, STORM, GEWEX, GLOBE, and LAWS. A great deal of time was spent both internally and in collaboration with STI Optronics planning and costing the hardware modifications necessary for moving the lidar from NOAA's trailer to the DC-8. Considerable time was also spent soliciting proposals and awarding a contract to procure the computing/control/display systems required by NASA and NOAA for MACAWS.

MACAWS is now funded over 4 years, with checkout flights scheduled for FY95. A large percentage of future RTOP funding from NASA to NOAA likely will be spent on implementing the proposed hardware and software modifications. NOAA is pursuing the acquisition of additional funds from NOAA to assist in the high cost of these modifications.

NOAA also attended and contributed to the 1991 workshop put together by NASA Headquarters to review the status of solid-state lidar technology. We plan to attend the upcoming 1992 workshop as well, but again have received no support (even for travel) to do so.



NOAA/WPL CO2 Doppler Lidar
Pinatubo Aerosol Backscatter
λ = 10.59μ
Altitude (km asl)
0
5
10
15
20
25
30
Days Since 1/1/91
150
200
250
300
350
400
4log(β)
-30.2865
-32.5007
-34.7149
-36.9291
-39.1432
-41.3574
-43.5716
-45.7858
[β] = (m-1 sr-1)
Tropopause Height

N93-20099

MOUNTAIN TOP MEASUREMENTS OF BETA(9.2μ)

Investigator: R. M. Schotland

Background of the Investigation:

The purpose of this program is to obtain statistical information on the variability of Beta(9.2μ) in clean air on mountain top locations.

Accomplishments in the Past Year:

C.W. CO_2 Lidar

A bistatic C.W. homodyne lidar was assembled using a Synrad, nominal 9.2μ, laser as a source. Even though this laser scanned between 9.2 and 9.3μ, the baseband spectral width of the lidar signal scattered from a target at 100 meters was less than 20 kHz.

A serious problem that became apparent in the operation of the lidar was the difficulty in achieving reliable alignment of the receiving and transmitting optics. The scattering volume formed by the intersection of these optic axes could not be well defined. This point is important because the objective of the program is the measurement of the atmospheric scattering cross-section. Because of this problem, the bistatic lidar approach has been abandoned and a more conventional monstatic lidar is under development.

The monstatic lidar, shown as Figure 1, utilizes most of the components of the bistatic lidar. However, the design requires the use of $\lambda/2$ and $\lambda/4$ waveplates operating in the 9.2-9.3μ spectral range. These are non standard zero order devices and delayed the assembly of the lidar. Final testing of the lidar is now in process.

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Data Processor

The Lidar signal processor is basically a four band power spectrum analyzer. Three bands, each 500 kHz wide, pass the doppler shifted back scattered signals corresponding to wind speeds in the range between 2 and 15 m/s. The fourth band is used to establish the noise level of the lidar system.

The signal in each spectral range, suitably conditioned, passes through a wide band, wide dynamic range squaring circuit (AD834). The outputs of each of the circuits is simultaneously integrated, and then periodically sampled and stored in an IBM 286 computer. The average power level in each channel, taking into account system noise from the forth channel is the determined by software.

The system has been tested using digitally generated incoherent pseudo-random noise sources and is able to detect narrow band noise powers of less than 0.1 picowatt in the presence of wide band (full channel) 10 picowatts.

Focus of the Current Research and Plans for the Next Year:

The research plans for the next period center have two objectives;

1. Calibration of the lidar system, and
2. Mountain top observations on Mount Lemmon.

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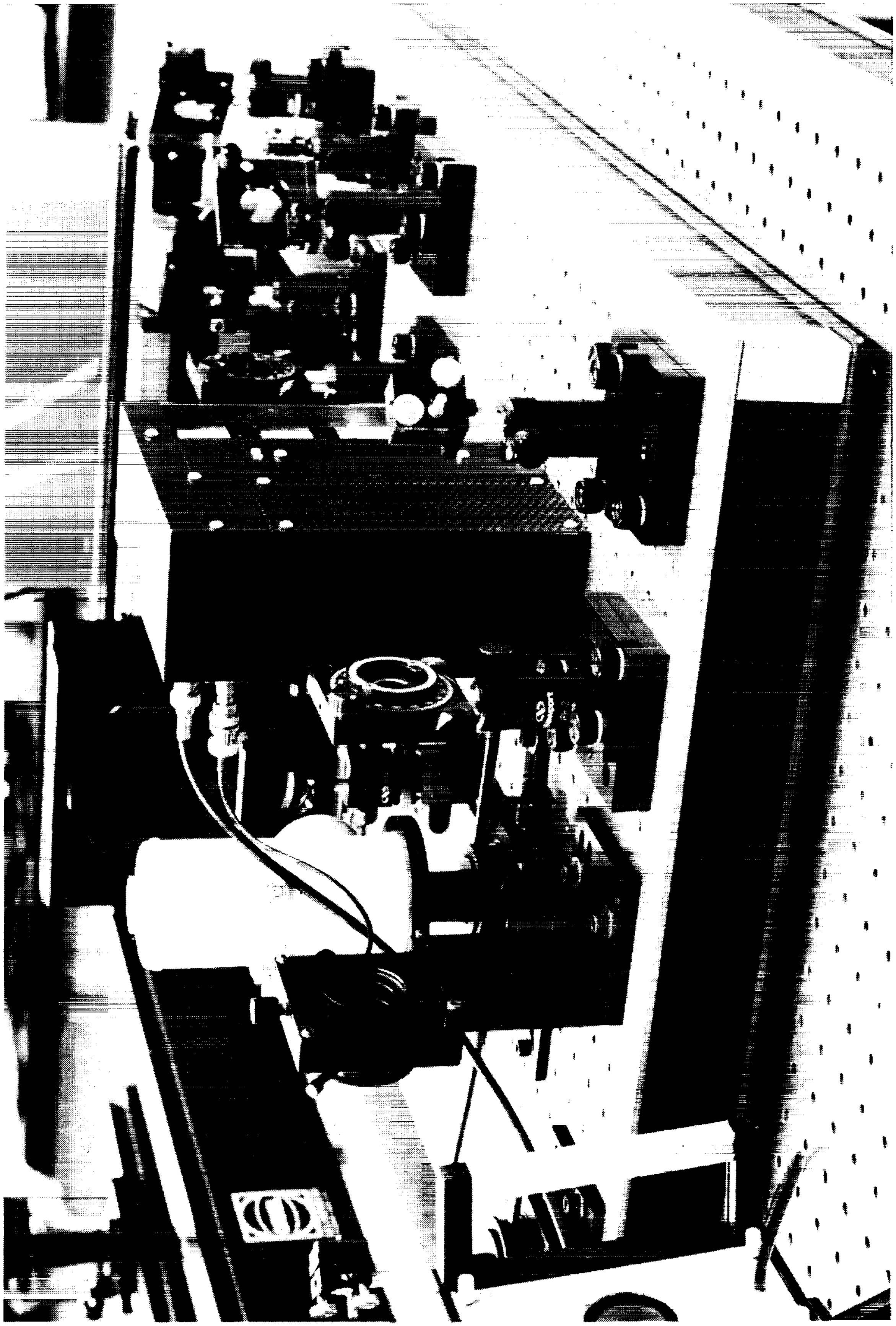

Fig. 1. Monstatic lidar.

N93-20100

Title: Development of a 100 mJ, 5 Hz, Flashlamp-Pumped, Cr,Tm:YAG Coherent Lidar Transmitter

Investigators: S. Henderson/CTI, S. Johnson/MSFC/EB23

Background of Investigation:

A contract to develop a 100 mJ, 5 Hz, flashlamp-pumped Cr,Tm:YAG coherent lidar transmitter has been awarded to Coherent Technologies, Inc. (CTI). The lidar transmitter will operate at an eyesafe wavelength of 2.01 microns. The development complements work being performed under an SBIR Phase II with Electro-Optics Technology (EOT). EOT is developing continuous wave, low and medium power Tm:YAG oscillators of a unique design. One of the low power oscillators will be used as the injection seeder/local oscillator in the CTI lidar transmitter. The lidar transmitter will require the addition of a receiver section. Once completed, the lidar will be used in atmospheric performance studies, allowing comparison with that of the more mature CO_2 lidar technology.

Significant Accomplishments in the Past Year:

The CTI contract was awarded in December, 1991. The final design should be completed during FY92.

Focus of Current Research and Plans for Next Year:

The CTI contract has an 18 month period of performance. Delivery of the transmitter to MSFC is scheduled for June, 1993. Installation of a receiver section and lidar performance tests are planned for the remainder of FY93. The low and medium power, continuous wave, Tm:YAG oscillators should be delivered in August, 1993.

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N93-20101

Title: MULTI-CENTER AIRBORNE COHERENT ATMOSPHERIC WIND SENSOR (MACAWS)

Investigators: J. Rothermel/ES43 (PI), W.D. Jones/EB23, J.A. Dunkin/EB23,
Marshall Space Flight Center
E.W. McCaul, Jr./USRA/ES43,
Universities Space Research Association

Background of the Investigation:
Funding began in April 1992. This effort involves development of a calibrated, pulsed, coherent CO_2 Doppler lidar, followed by a carefully-planned and -executed program of multi-dimensional wind velocity and aerosol backscatter measurements from the NASA DC-8 research aircraft. The lidar, designated as the Multi-center Airborne Coherent Atmospheric Wind Sensor (MACAWS), will be applicable to two research areas. First, MACAWS will enable specialized measurements of atmospheric dynamical processes in the planetary boundary layer and free troposphere in geographic locations and over scales of motion not routinely or easily accessible to conventional sensors. The proposed observations will contribute fundamentally to a greater understanding of the role of the mesoscale, helping to improve predictive capabilities for mesoscale phenomena and to provide insights into improving model parameterizations of sub-grid scale processes within large-scale circulation models. As such, it has the potential to contribute uniquely to major, multi-institutional field programs planned for the mid-1990's. Second, MACAWS measurements can be used to reduce the degree of uncertainty in performance assessments and algorithm development for NASA's prospective Laser Atmospheric Wind Sounder (LAWS), which has no space-based instrument heritage. Ground-based lidar measurements alone are insufficient to address all of the key issues.

To minimize costs, MACAWS is being developed cooperatively by the lidar remote sensing groups of the Jet Propulsion Laboratory, NOAA Wave Propagation Laboratory, and MSFC using existing lidar hardware and manpower resources. Several lidar components have already been exercised in previous airborne lidar programs (for example, MSFC Airborne Doppler Lidar System (ADLS) used in 1981,4 Severe Storms Wind Measurement Program; JPL Airborne Backscatter Lidar Experiment (ABLE) used in 1989,90 Global Backscatter Experiment Survey Missions). MSFC has been given responsibility for directing the overall program of instrument development and scientific measurement.

Significant Accomplishments in the Past Year:
None; this is a new effort.

Focus of Current Research and Plans for Next Year:
Three primary activities are being conducted during the remainder of this fiscal year. The first involves definition and acquisition of the MACAWS data system, which must orchestrate in real time all functions and subsystems, including: user interface; basic input/output of the transmitter/receiver; constant adjustment of germanium wedge scanner to compensate for changes in aircraft attitude and speed using inputs from a dedicated inertial navigation unit; acquisition and use of measurements from the DC-8 digital aircraft data system; calculation and display of moment estimates; and calculation and display of two-dimensional wind vectors for various scan patterns. The second activity involves development and execution of a flight qualification test plan for existing MSFC germanium optical windows through which the MACAWS lidar beam is to be directed to the atmosphere. Development of the plan involves cooperation with flight safety personnel at the NASA Ames Research Center. The third activity involves upgrading the aircraft software simulator to emulate with the DC-8 operating environ-

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ment. The aircraft simulator is required for data system development and MACAWS performance simulation.

Instrument development is planned for FY92-5, with first flights on the NASA DC-8 in FY95. Activities planned at MSFC for the next fiscal year include: (1) continued coordination of overall MACAWS development, (2) development or refurbishment of lidar hardware subsystems and corresponding mechanical and electrical interfaces for which MSFC is directly responsible, and (3) refinement of science objectives and flight plans in cooperation with MACAWS co-investigators.

Publications:
An airborne Doppler lidar system of similar design but with more modest capability was first developed and demonstrated by MSFC researchers in the early 1980's. The following references provide examples of the scientific utility of such a system:

Bilbro, J.W., G.H. Fichtl, D.E. Fitzjarrald and M. Krause, "Airborne Doppler lidar wind field measurements," *Bull. Amer. Meteor. Soc.*, **65**, 348-359 (1984).

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N93-20102

Aerosol Chemistry in GLOBE

Strategy:
This task addresses the measurement and understanding of the physical and chemical properties of aerosol in remote regions that are responsible for aerosol backscatter at infrared wavelengths. Because it is representative of other clean areas, the remote Pacific is of extreme interest. Emphasis is on the determination of size dependent aerosol properties that are required for modeling backscatter at various wavelengths and upon those features that may be used to help understand the nature, origin, cycling and climatology of these aerosol in the remote troposphere. Empirical relationships will be established between lidar measurements and backscatter derived from the aerosol microphysics as required by the NASA Doppler Lidar Program. This will include the analysis of results from the NASA GLOBE Survey Mission Flight Program. Additional instrument development and deployment will be carried out in order to extend and refine this data base. Identified activities include participation in groundbased and airborne experiments.

Progress:
Progress to date includes participation in, analysis of, and publication of results from Mauna Loa Backscatter Intercomparison Experiment (MABIE) and Global Backscatter Experiment (GLOBE). See references below.

Plans:
More extensive analysis of GLOBE data is presently underway. This includes in-situ comparisons with MSFC lidar data and assessment of climatological features in the aerosol and backscatter. Airborne measurements in the Atlantic and South Pacific are also being planned for 1992 and 1993.

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Clarke, A.D., "Atmospheric nuclei in the remote mid-troposphere," submitted to J. Atmos. Chem. (1992)

Clarke, A.D., "Aerosol physicochemistry in the remote Pacific troposphere," 7th CACGP/IGAC Meeting, Chamrousee, France, September 1990.

Clarke, A.D. "Condensation nuclei in the remote free troposphere," 20th General Assembly, IUGG/IAMAP, Vienna, August 1991.

Porter, J.N., A.D. Clarke, and F.F. Pueschel, "Aircraft studies of size-dependent aerosol sampling through inlets," J. Geophys. Res. (1992)

Personnel

FUNCTION	NAME	ORGANIZATION
1. PI	A. Clarke	Univ. Hawaii
2. Rsch Asst.	TBD	Univ. Hawaii
3. Scientist	J. Rothermel	NASA/MSFC
4. Engineer	M. Jarzembski	NASA/MSFC

N93-20103

CO_2 LIDAR BACKSCATTER EXPERIMENT

Investigators: M. Jarzembski
J. Rothermel
D.A. Bowdle
V. Srivastava
D. Cutten
E.W. McCaul, Jr.

Background of the Investigation:

The Aerosol/Lidar Science Group of the Remote Sensing Branch engages in experimental and theoretical studies of atmospheric aerosol scattering and atmospheric dynamics, emphasizing Doppler lidar as a primary tool. Activities include field and laboratory measurement and analysis efforts by in-house personnel, coordinated with similar efforts by university and government institutional researchers. The primary focus of activities related to understanding aerosol scattering is the GLObal Backscatter Experiment (GLOBE) program. GLOBE was initiated by NASA in 1986 to support the engineering design, performance simulation, and science planning for the prospective NASA Laser Atmospheric Wind Sounder (LAWS) managed by MSFC. Designed and scientifically directed by MSFC, GLOBE is a multi-element multi-institutional effort to develop a global aerosol model to describe the "background" tropospheric backscatter conditions that LAWS is likely to encounter. The accuracy of LAWS wind estimates will depend on the strength of the backscattered signals, which in turn will depend on the spatial distribution and physicochemical and optical properties of aerosols. Survey missions were flown in the NASA DC-8 in November 1989 and May-June 1990 over the remote Pacific Ocean, a region where backscatter values are low and where LAWS wind measurements could make a major contribution. The instrument complement included: pulsed and continuous-wave (CW) carbon dioxide gas lidars and solid state lidars measuring aerosol backscatter in the 0.53-10.6 micrometer range; optical particle counters measuring aerosol concentration, size distribution and chemical composition in the 0.1-43 micrometer range; a filter/impactor system collecting aerosol samples for subsequent analysis; and integrating nephelometers measuring visible scattering coefficients in the 0.45-0.7 micrometer range. Personnel from the MSFC Remote Sensing and Optical Systems Branches and supporting contractors obtained backscatter measurements at close range using MSFC-developed CW lidars operating at 9.1 and 10.6 micrometers, the former being the primary design wavelength for LAWS. Supporting measurements included satellite observations of tropospheric extinction profiles in the near-infrared, surface observations of aerosols and dust transport, coordinated observations by airborne and ground-based lidars and aerosol samplers, and visible and infrared satellite imagery. The GLOBE instrument configuration and survey missions were carefully planned to achieve complementary measurements under background backscatter conditions. Special flight maneuvers were made periodically throughout the GLOBE survey missions to allow inter-comparisons between the *in situ* and remote sensing instruments. Measurements of backscatter at 9.1 and 10.6 micrometers and aerosol physicochemical and optical properties were made routinely at flight level. The airborne measurements were coordinated with ground-based aerosol samplers and satellite based extinction profilers in order to relate the airborne observations to these long-term, global-scale climatologies of physicochemical and optical properties. The processing of each measurement

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set has been the responsibility of the investigators or institutions which developed and operated the instrument. MSFC has responsibility for synthesizing the various measurements into a wavelength-dependent global tropsphere backscatter model for LAWS design, simulation, and science planning. Periodic meetings of the GLOBE Science Working Group have been convened to identify data processing priorities and case studies, assess instrument performance, present preliminary findings, and assess overall progress.

Significant Accomplishments in the Past Year:

The most important GLOBE scientific result has been identification of a background aerosol mode with a surprisingly uniform backscatter mixing ratio (backscatter normalized by air density) throughout a deep tropospheric layer. The backscatter magnitude of the background mode evident from the MSFC CW lidar measurements is remarkably similar to that evident from ground-based backscatter profile climatologies obtained by JPL in Pasadena CA, NOAA/WPL in Boulder CO, and by the Royal Signals and Radar Establishment in the United Kingdom. Similar values for the background mode have been inferred from the conversion of *in situ* aerosol microphysical measurements to backscatter using Mie theory. Little seasonal or hemispheric variation is evident in the survey mission data, as opposed to large variation for clouds, aerosol plumes, and the marine boundary layer. Additional features include: localized aerosol residues from dissipated clouds, occasional regions having mass concentrations of nanograms per cubic meter and very low backscatter, and aerosol plumes extending thousands of kilometers and several kilometers deep. Preliminary comparisons with meteorological observations thus far indicate correlation between backscatter and water vapor under high humidity conditions. Limited intercomparisons with the Stratospheric Aerosol and Gas Experiment (SAGE) limb extinction sounder shows differences in the troposphere, however, it should be noted that in general SAGE measurements have not yet been validated in the troposphere.

Focus of Current Research and Plans for Next Year:

1. Aerosol data analysis activities. processed GLOBE data sets continue to be incorporated into the GLOBE data base at MSFC. Measured size distributions and chemical composition long with established valued of refractive index are being used to calculate aerosol backscatter coefficients at desired wavelengths using Mie theory, taking into account instrument limitations. Conversion functions are being developed to relate one aerosol property to another, for example, 1.06 micrometer extinction to 9.1 micrometer backscatter. Key checks of the Mie theory calculations are being made by comparing calculated aerosol properties with direct measurements. In support of GLOBE aerosol analyses, laboratory studies continue to characterize scattering features of aerosols generated in the MSFC Aerosol Optical Properties Laboratory (AOPL) using the MSFC CW lidars. Aerosol particles with known size, shape and refractive index are generated under controlled laboratory conditions. Chemical compositions are selected for analysis which reflect what was encountered in several locations during the survey missions. Meteorological model outputs from the European Center for Medium-range Weather Forecasting (ECMWF) continue to be compared to composite backscatter profile measurements from the pulsed lidars to better classify the conditions under which a correlation may exist between backscatter and one or more meteorological variables, e.g., water vapor, and to quantify the degrees of correlation. Progress in this area will greatly benefit Observing System Simulation

Experiments (OSSEs), which rely heavily on global meteorological datasets--and which represent the principal means thus far--to assess LAWS performance. Specific future in-house tasks include: 1) completion of GLOBE MSFC CW lidar data processing, 2) study of optical properties of aerosols generated in the MSFC AOPL and transfer of findings to interpretation of GLOBE results, 3) use of GLOBE aerosol size distribution and chemistry measurements to extend theoretical backscatter predictions to wavelengths at which no direct measurements have as yet been made, 4) incorporation of GLOBE findings into simulation studies to assess impacts of measured and modeled backscatter levels on LAWS performance, 5) refinement of global tropospheric backscatter model at LAWS primary and alternate design wavelengths using GLOBE program data sets, 6) modifications to CW lidar systems to enhance sensitivity and operating capabilities both in the laboratory and in the field, 7) intercomparison of backscatter and meteorological measurements for the remainder of the GLOBE survey mission flights, 8) development and initiation of research plan to address discrepancies between SAGE extinction and GLOBE survey mission measurements, and 9) development of science rationale for future GLOBE missions.

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N93-20104

Simulations of Satellite Doppler Wind Observations

Strategy:
This study will involve two objectives: 1) To develop, through computer simulations, optimal satellite-based sensor scanning techniques for direct measurement of tropospheric winds on the meso-- and synoptic scales. 2) construct simulations of remotely measured wind fields for assessing impact of such fields on the diagnosis and prognosis of atmospheric phenomena through the use of Observing System Simulation Experiments (OSSE).

Progress:
Using the LAWS Simulation Model (LSM), various global coverage scenarios have been investigated as part of an effort to define the optimal orbit, configuration and sampling strategies for observations of winds for use in global circulation models. Simulated data sets have been provided to GSFC, FSU and several LAWS team members. Particular emphasis has been on providing realistic cloud cover, cirrus backscatter, aerosol distribution and wind variance on scales <600 km. Progress is currently being made to incorporate other remote sensors (AIRS/AMSU, STIKSCAT) into the global OSSEs.

Plans:
OSSEs at FSU, GSFC, Suny and MSFC will continue to be supported in the upcoming year. Additional emphasis will be given to assessing the relative contribution from clouds to LAWS performance, as well as the impacts of modifications to LAWS design parameters.

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Personnel

FUNCTION	NAME	ORGANIZATION
1. PI	G. Emmitt	Simpson Weather
2. Programmer/Scin.	S. Wood	Simpson Weather
3. Programmer/Scin.	L. Wood	Simpson Weather
4. Scientist	O. Vaughan	NASA/MSFC

N93-20105

A Modeling Study of Marine Boundary Layer Clouds

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1. Background

Marine boundary layer(MBL) clouds are important components of the earth's climate system. These clouds drastically reduce the amount of solar radiation absorbed by the earth, but have little effect on the emitted infrared radiation on top of the atmosphere. In addition, these clouds are intimately involved in regulating boundary layer turbulent fluxes. For these reasons, it is important that general circulation models used for climate studies must realistically simulate the global distribution of the MBL. While the importance of these cloud systems is well recognized, many physical processes involved in these clouds are poorly understood and their representation in large-scale models remains an unresolved problem.

The present research aims at the development and improvement of the parameterization of these cloud systems and understand of physical processes involved. This goal is addressed in two ways. One is to use regional modeling approach to validate and evaluate a two-layer marine boundary layer model using satellite and ground-truth observations; the other is to combine this simple model with a high-order turbulence closure model to study the transition processes from stratocumulus to shallow cumulus clouds.

2. Progress

A regional model of marine boundary layer has been developed. Compared to the one-dimensional version of the model, surface flux parameterization is improved by including the factor of stability. The input of this model are sea surface temperature, wind fields in the boundary layer, large-scale vertical velocity and thermodynamic structure above the boundary layer, which can be derived from ECMWF analyses or other sources. With given large-scale conditions, the regional model predicts turbulent fluxes, thermodynamic structure, cloud fraction and cloud-top heights. This model is applied to the region of 20°N-42°N and 117°W-145°N for the period of the First International Satellite Cloud Climatology Project Regional Experiment (FIRE) marine stratocumulus intensive field observation. The simulated steady-state cloud-top height and fractional cloudiness are compared with available satellite data. The model predicts a realistic pattern of cloud-top height. The overall simulated cloudiness is qualitatively realistic, but the model give excessive cloudiness over cold ocean surfaces. This discrepancy is believed to be due to the exclusion of diurnal variability in the model. The model results also show that marine stratocumulus clouds are sensitive to large-scale subsidence and light precipitation (drizzle).

A one-dimensional third-order turbulence closure model with the parameterization of long and short-wave radiation and precipitation has been developed. The model predicts not only boundary layer mean wind and thermodynamic structure, but also second and third turbulent correlations. Solar warming and drizzle have been suggested to be processes that can decouple the boundary layer and decrease cloud fraction. Thus this high-order model is used to study the MBL decoupling process due to solar warming and drizzle. The sensitivity of simulated clouds to the subgrid-scale condensation scheme is also evaluated.

The simulation of the decoupled structure observed in FIRE show that both solar warming and drizzle contribute to the decoupling process, although solar absorption appears to have larger influence on the modeled mean structure. The effects of drizzle on turbulent structure also depend on the large-scale conditions such as sea surface temperature and wind. Under low sea surface temperature and light wind conditions, drizzle may very effectively decouple the MBL. High SST and strong wind shear increase turbulent kinetic energy production so that the decoupling effect is significantly reduced. Our study also shows that the simulated decoupling and cloud formation process in a high-order model may be sensitive to subgrid-scale condensation scheme.

3. Focus of current research and plans for next year

In the process of developing the two-layer boundary layer model, we have found some undesired features of the model. For example, the model is extremely sensitive to the cloud-base transition layer and mass flux parameter (pointed out by other researchers). Thus we currently try to improve the model formulation to account for the characteristics of different convective regimes. The GLOBE data has been processed to obtain cloud-top and cloud-base heights. The model is being used to simulate these data from the GLOBE observation. This application is intended to verify the model formulation.

We plan to use the regional boundary layer model to study the diurnal variation of stratocumulus clouds. In this practice, we will use ECMWF analyses to provide time-dependent large-scale conditions and SSM/I precipitable water observation to give better estimation of moisture above the cloud-top height. Then we can simulate the diurnal variation of MBL observed during FIRE and study its effects on surface fluxes and cloud albedo. We will also try to extend the one-dimensional high-order turbulence closure model to three dimensional version. Then we can study meso-scale variability of marine boundary layer clouds and compare the results from two type of three-dimensional models.

4. Publications and reports

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N93-20106

TITLE: Computer Modeling of Pulsed CO_2 Lasers for Lidar Applications

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BACKGROUND OF THE INVESTIGATION:

The object of this effort is to develop code to enable the accurate prediction of the performance of pulsed transversely excited (TE) CO_2 lasers prior to their construction. This is of particular benefit to the NASA Laser Atmospheric Wind Sounder (LAWS) project. A benefit of the completed code is that although developed specifically for the pulsed CO_2 laser much of the code can be modified to model other laser systems of interest to the lidar community.

SIGNIFICANT ACCOMPLISHMENTS:

During the past year the following tasks have been completed:-

1) A Boltzmann equation solver has been developed which enables the electron excitation rates for the vibrational levels of CO_2 and N_2, together with the electron ionisation and attachment coefficients to be determined for any CO_2 laser gas mixture consisting of a combination of CO_2, N_2, CO, He and CO. The validity of the model has been verified by comparison with published material.

2) The results from the Boltzmann equation solverhave been used as input to the laser kinetics code which is currently under development.

3) A numerical code to model the laser induced medium perturbation (LIMP) arising from the relaxation of the lower laser level has been developed and used to determine the effect of LIMP on the frequency spectrum of the LAWS laser output pulse. The enclosed figures show representative results for a laser operating at 0.5 atm. with a discharge cross-section of 4.5 cm to produce a 20 J pulse with aFWHM of 3.1 μm. The first four plots show the temporal evolution of the laser pulse power, energy evolution, LIMP frequency chirp and electric field magnitude. The electric field magnitude is taken by beating the calculated complex electric field and beating it with a local oscillator signal. The remaining two figures show the power spectrum and energy distribution in the pulse as a function of the varying pulse frequency. The LIMP theory has been compared with experimental data from the NOAA Windvan Lidar and has been found to be in good agreement.

FOCUS OF CURRENT AND PLANNED RESEARCH:

Emphasis is currently being placed on completing the kinetics module of the code. Once this is completed and verified, it will be intergrated with the Boltzmann solver code into a single package. Following on from this, the combined code will be refined and improved in preparation for the development and inclusion of code for the laser optical field development and gas fluid dynamics. It is hoped to start work on inclusion of the gas discharge chemistry and laser catalyst chemistry to enable long term prediction of the output from a sealed CO_2 laser.

At all stages of the process, the model will be verified by comparison with experimental results obtained from the LAWS breadboards and from the published literature.

PUBLICATIONS:

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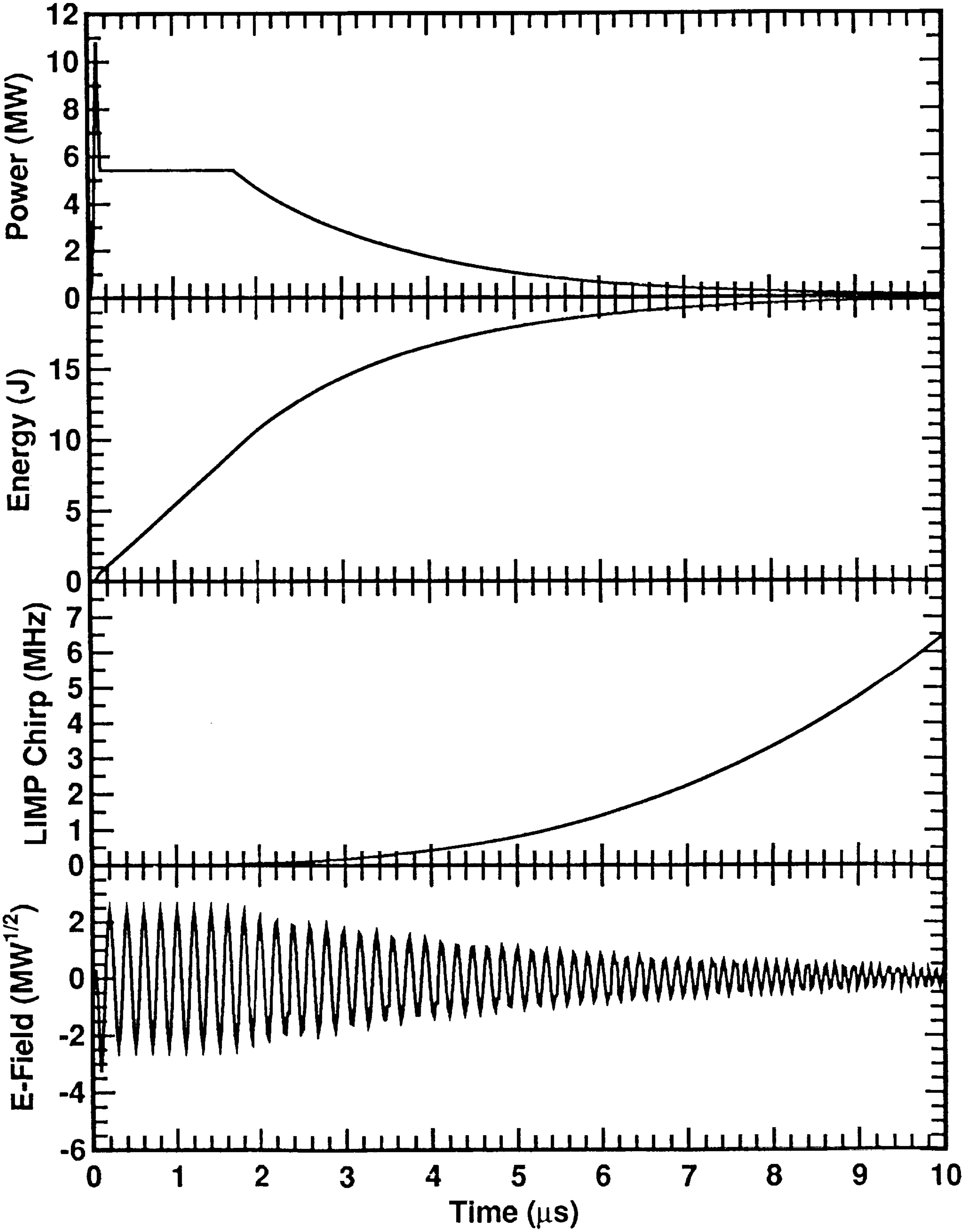
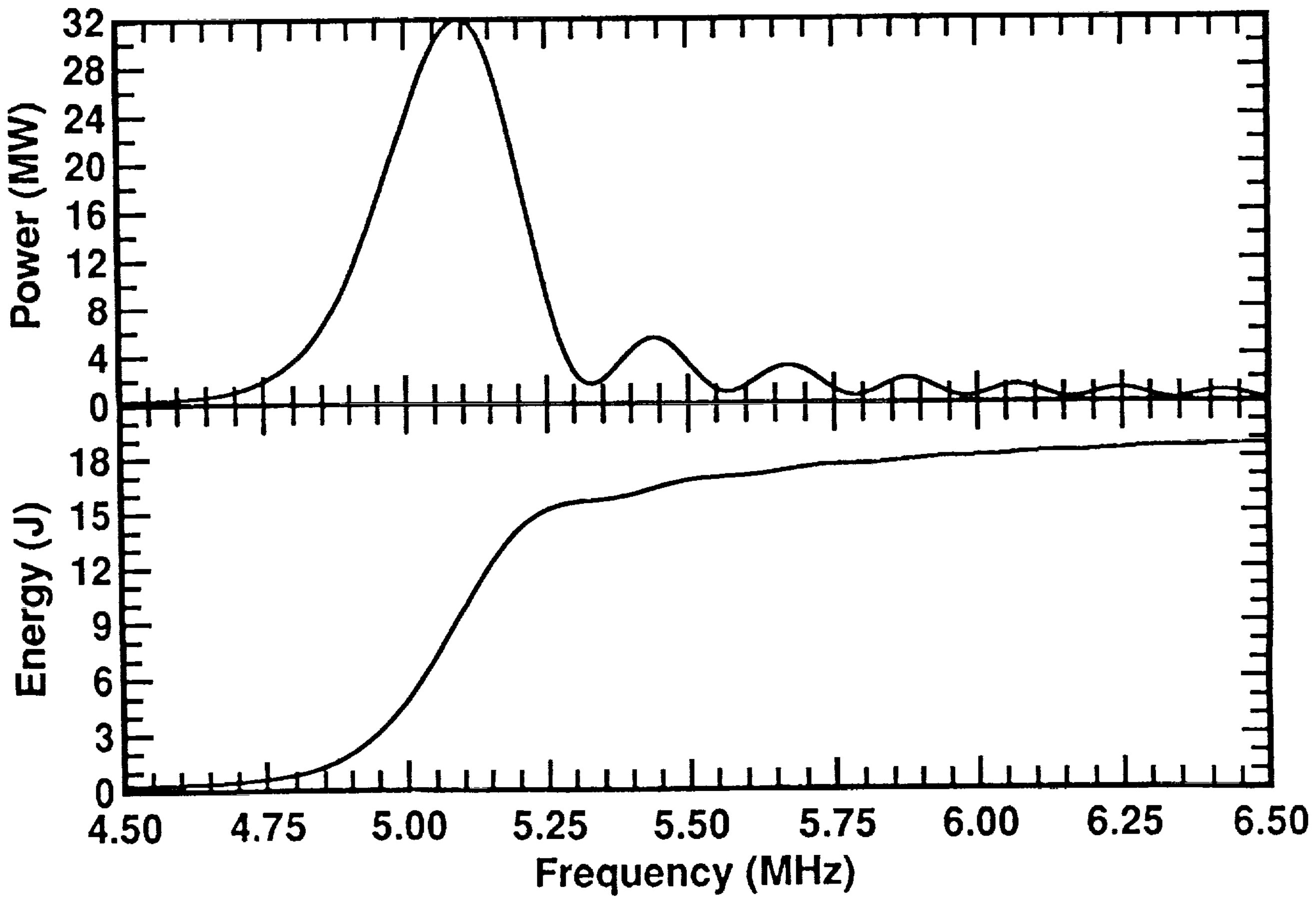


3.1 μs FWHM pulse, GSS , 4 μs tail decay and frequency chirp



N93-20107

REMOTE SENSING OF WATER VAPOR FEATURES

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Background

Water vapor plays a critical role in the atmosphere. It is an important medium of energy exchange between air, land, and water; it is a major greenhouse gas, providing a crucial radiative role in the global climate system; and it is intimately involved in many regional scale atmospheric processes. Our research has been aimed at improving satellite remote sensing of water vapor and better understanding its role in meteorological processes. Our early studies evaluated the current GOES VAS system for measuring water vapor and have used VAS-derived water vapor data to examine pre-thunderstorm environments. Much of that research was described at the 1991 Research Review. A second research component has considered three proposed sensors--the High resolution Interferometer Sounder (HIS), the Multispectral Atmospheric Mapping Sensor (MAMS), and the Advanced Microwave Sounding Unit (AMSU). Future research will use GOES I water vapor data.

The Past Year's Efforts

We have focussed on MAMS and AMSU research during the past year.

1) CONVECTIVE CASE. Graduate student Rick Knabb is utilizing MAMS data collected over the Florida peninsula on 16 October 1990. Split window channel radiances are being used to analyze mesoscale moisture variations. The split window variance ratio (SWVR) technique developed by Dr. Gary Jedlovec is being employed. It takes advantage of MAMS' fine spatial resolution (100 m) to calculate the ratio of the variances of split window channel brightness temperatures. Since the split window channel transmittance ratio has been shown to be similar to the SWVR, a regression between transmittance ratio and PW can be determined and used with the imagery to retrieve PW.

Most of the work to date has been to develop the regression between transmittance ratio and PW for this particular case. That relationship shows a strong inverse logarithmic fit to the data, with a standard error less than 1 mm of PW. There is some uncertainty (scatter) in the relation, and extensive sensitivity testing has shown that this is attributable to variations in the vertical distribution of temperature, and most importantly, dew point. That is, for a given value of PW, there is an infinite number of possible dew point profiles. These differing distributions affect the split window transmittances, and ultimately the PW determined by regression. The transmittances and PW are much less affected by temperature. The sensitivity analysis indicates that the MAMS/SWVR technique provides PWs that are accurate to within 3 mm. Based on these efforts, we believe that we have a good understanding of the strengths and weaknesses of the SWVR algorithm.

Rick is just beginning to use the MAMS/SWVR technique on the October 1990 case over Florida. He has written code to make the PW calculations on our PC McIDAS, with a man-in-the-loop selecting the retrieval locations. There are several interesting mesoscale features on the case day. A large area of thunderstorms over Cape Canaveral initiates outflow to its southwest, including a series of arc cloud lines. The MAMS flight crosses the outflow boundary and appears to be in a good position to document moisture differences on its two sides. Another area of interest is northeastern Florida, which experiences rapidly decreasing dew points during the MAMS overflights. The high resolution MAMS-derived PWs likely will yield a detailed analysis of this dry advection event. The research on this period will document the utility of the SWVR technique as applied to high resolution MAMS data.

2) LAND SURFACE CASE. Graduate student Mike Nichols is exploiting MAMS imagery to study how land surface characteristics relate to cumulus cloud formation. The MAMS-derived characteristics include land surface temperature (LST), normalized difference vegetation Index (NDVI), and soil moisture. The case being studied is the 18 August 1988 MAMS overflight of the Tennessee River Valley.

LSTs are calculated using a statistical split window technique similar to that used to obtain sea surface temperatures. Regression coefficients are developed based on radiative transfer calculations. The resulting equations give LSTs that are similar to those derived by Jedlovec for a previous case. LSTs over the area are found to vary greatly in both time and space. NDVI is calculated from MAMS data using standard procedures. The relation between LST and NDVI is being explored. Correlation coefficients between these terms are near -0.75 during the case study. Soil moisture is obtained from time changes in MAMS-derived surface temperatures. The MAMS-derived values have been compared with those from observed rainfall data using the Antecedent Retention Index (ARI). Results indicate that areas receiving the least rainfall during the preceding two months experience the greatest LST changes during the morning MAMS overflights, thereby implying lowest soil moisture content.

The Oregon State University Planetary Boundary Layer (PBL) Model is being used to calculate cloud fractions for comparison with those from MAMS. Soil moisture, one of the key inputs to this one dimensional model, is obtained from MAMS as described above. Model runs are made at numerous locations on the case study day. An older version of the PBL cloud model component has been found to give results that are superior to those from a newer version.

The role that terrain plays in cloud development also is being investigated. Results show that where terrain is a factor, only the steepest gradients produce cloud lines. Conversely, where topographic changes are small, boundary layer clouds form initially over areas with the highest soil moisture. Finally, precipitable water is being calculated using the SWVR technique (see above). Initial results indicate only small variations across the study area.

3) AMSU EFFORTS. Graduate student Brad Muller is sponsored by a NASA Graduate Student Researchers Program. However, since his efforts are so closely related to those sponsored by the RTOP, it is appropriate to comment on them briefly. Brad has assembled and modified existing numerical algorithms into a multiple scattering microwave radiative transfer model. He is using this code to perform sensitivity studies to understand the effects of temperature, water vapor, and liquid and ice clouds on upwelling AMSU brightness temperatures. He also is applying the code to mesoscale model (LAMPS)-derived atmospheres to calculate patterns of AMSU moisture channel brightness temperatures. The LAMPS output is then used to quantify processes that create the mid- to upper-level dry band/moisture boundaries that will be seen in AMSU water vapor imagery.

Current Focus and Future Plans

The current grant will expire at the end of calendar year 1992. All of the research described above will be completed by that time. New research, to be conducted with Dr. Gary Jedlovec of NASA/MSFC, will begin in late 1992. Those efforts will involve the upcoming GOES I-M satellite series. Our goals are to 1) Understand features in GOES I water vapor imagery and their relationships to atmospheric processes, 2) Quantify the information content of GOES I imagery and derived products, 3) Develop new procedures for examining water vapor that take advantage of GOES I's enhanced capabilities, and 4) As a result, improve our understanding of the role of atmospheric water vapor. An important point is that much of the research will be conducted using simulated imagery. Thus, it will not be impacted by delays in the launch of the satellite.

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N93-20108

An Investigation of the Role of Current and Future Remote Sensing Data Systems in Numerical Meteorology

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I. Background

The goals of this research endeavor have been to develop a flexible and relatively complete framework for the investigation of current and future satellite data sources in numerical meteorology. In order to realistically model how satellite information might be used for these purposes, it is necessary that Observing System Simulation Experiments (OSSEs) be as complete as possible. It is therefore desirable that these experiments simulate in entirety the sequence of steps involved in bringing satellite information from the radiance level through product retrieval to a realistic analysis and forecast sequence. In this project we have worked to make this sequence realistic by synthesizing raw satellite data from surrogate atmospheres, deriving satellite products from these data and subsequently producing analyses and forecasts using the retrieved products.

II. Accomplishments in 1991

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The emphasis in 1991 has been on examining atmospheric soundings and microphysical products which we expect to produce with the launch of the Advanced Microwave Sounding Unit (AMSU), slated for flight in mid 1994. We have accomplished several OSSEs in the past year for a mesoscale forecast environment in which we have examined the impact of the atmospheric soundings of temperature and water vapor which will be produced from this instrument, in combination with its companion infrared sounder, the HIRS. The OSSEs have all produced very similar results showing that in this sort of forecast environment the impact of the AMSU on the prediction of atmospheric temperature will be small but positive. More impact has been noted, however, in the prediction of fields of water vapor. This is not unexpected, since the AMSU will include new water-vapor-sensitive microwave channels, which have some capability for sounding through non-precipitating clouds. Future plans involve a closer examination of situations where the AMSU has advantages over the current HIRS-MSU instrument suite, cases where there are large areas of non-precipitating cloud.

The large frequency range of the suite of microwave channels which comprise the AMSU instrument means a range of sensitivities to the presence of cloud liquid water and other atmospheric microphysical parameters, which may be useful in the retrieval of these quantities from AMSU radiances. Cloud liquid water (CLW) is a fundamental quantity in the transfer of solar, microwave and infrared radiation in the atmosphere and work in the past year has concentrated on methods for retrieving this quantity from the AMSU and applying it to various facets of atmospheric modelling. Last year we reported on the development of a "Microwave Slicing" algorithm for the retrieval of the height and "effective" fraction of cloud appropriate for microwave radiation and also the first results of retrievals of total-column CLW amounts from the AMSU. The retrieval method was a non-linear maximum-likelihood type algorithm which simultaneously derives infrared and microwave cloud parameters as well as atmospheric soundings, developed by John Eyre (current affiliation, ECMWF) while he was a visiting scientist at the CIMSS. In the past year we have gained considerable experience in retrieving CLW from the AMSU and have run several experiments involving the retrieval of CLW using the CIMSS mesoscale model to produce realistic cloud water features. The "Microwave Slicing" algorithm has been incorporated as a preprocessing step in the full simultaneous non-linear retrieval algorithm to improve the character of the "first guess" of CLW for the full retrieval methodology. Results of the retrieval of cloud liquid water will be presented at the review meeting.

In order to more effectively examine the retrieval and modeling of CLW and other microphysical parameters, we have been steadily increasing the sophistication of the microphysical parameterizations in the CIMSS Mesoscale Model (the Subsynoptic-Scale Model, SSM). Cloud liquid water and an elementary ice form were added to the model based on similar parameterizations used in the Limited Area Mesoscale Prediction System (LAMPS), which is used by our MSFC colleagues. This system has proven to be remarkably accurate in the prediction of the location of cloud water and several examples will be shown at the review meeting of these predictions compared to satellite images and also in a "VIS-5D" (four dimensional display) environment. During the NOAA Stormfest experiment of early 1992, we ran the SSM in real time and gained much experience on the character of the microphysical predictions. We are continuing to run the model daily in real time to increase this experience base. We are also looking at increasing the complexity of the basic microphysics of the model to include a more complete treatment of ice and better representation of convective cloud and ice water. We have coupled the explicit microphysics in the model into its solar and infrared radiative transfer parameterization and the resulting radiation fields show definition and structure not present in the previously employed more basic scheme.

We are currently examining the coupling of retrieved CLW amounts into the initialization of short and medium-range forecast models. In the "explicit " cloud and rain water physics coming into use in forecast models, cloud water is a "reservoir" which must be filled to a critical value before precipitation can occur. In addition to the general "spin-up" problem inherent in these models, the time required to generate cloud water to the precipitation threshold may be detrimental to short-term precipitation forecasting. We are finding that cloud water initialization is of some help in reducing this spin-up if the model water vapor field is also modified in a consistent fashion. In the past year, we have also done some investigation of the initialization of latent heating fields in the model (presumably from satellite or surface-measured rainfall rates) within the framework of the model "vertical mode initialization" scheme, which has also helped in reducing spin-up effects.

III. Focus of Current and Future Research

The goals current and future research in the coming year are:

1. Continue to improve the microphysical parameterizations in the SSM so that OSSEs can be made more realistic and comprehensive. This will include better representations of ice phases and improved parameterizations for water and ice phases from convective processes.
2. Examine in more detail the cloud liquid water information available from the AMSU and whether the suite of channels on the satellite platform will provide any profile information on this quantity. Two complementary methods will be investigated and these will be discussed at the review meeting.
3. Examine cloudy situations and the potential improvement of atmospheric soundings provided over current systems by the AMSU. Continue to evaluate cloud water and latent heating initialization in short and medium-range forecasts.

IV. Recent Publications

Huang, H. L. and G. R. Diak, 1992: Retrieval of nonprecipitating liquid water cloud parameters from microwave data: a simulation study. J. Atmos. Ocean. Tech., June issue.

Diak, G. R., D. Kim, M. A. Whipple and X. H. Wu: Preparing for the AMSU. Bull. Am. Meteor. Soc., In review.

Huang. H. L. and G. R Diak, 1992: Estimation of liquid water cloud height and fraction using simulated AMSU-A and MHS data. Preprint volume, AMS Sixth Conference on Satellite Meteorology and Oceanography, Atlanta, GA, Jan. 5-10, 1992, 219-222.

Huang, H. L., W. L. Smith, G. R. Diak and H. M. Woolf, 1991: Future hybrid infrared and microwave satellite system- A theoretical analysis of its capability. AMS Seventh Conf. on Meteorological Observations and Instrumentation, New Orleans, LA, Jan. 14-18, 428-430.

Diak, G. R., H. L. Huang and D. Kim, 1990: Observing system simulations using synthetic radiances and atmospheric retrievals derived for the AMSU and HIRS in a mesoscale model. AMS Fifth Conf. on Satellite Meteorology and Oceanography, London, England, Sept. 3-7, 1990.

AGENDA
NASA/MSFC EARTH SCIENCE AND APPLICATIONS PROGRAM
FY92 REVIEW

Tuesday, July 7, 1992
Radisson Suites Hotel

8:30	*Welcome and Introduction*	**James E. Arnold** **Fred W. Leslie**
8:45	*HQ Program Overview*	**John Theon, Robert Schiffer, Jim Dodge, Ramesh Kakar, Ken Bergman, Ming-Ying Wei**
9:00	*Global Temperature Variations*	**Roy W. Spencer**
9:30	*Tri-Spectral SSM/I Analysis*	**Eric C. Barrett**
10:00	*Global Satellite Data Analysis*	**John Christy**
10:30	**BREAK**	
10:45	*4-D Data/Model Output Visualization*	**Bill Hibbard**
11:15	*Heating in Global Circulation*	**Murry L. Salby**
11:45	*Cloud-Radiative Forcing*	**Byung-Ju Sohn**
12:15	**LUNCH**	
1:15	*Studies of Baroclinic Flows*	**Timothy L. Miller**
1:45	*Geophysical Fluid Flow Studies*	**John E. Hart**
2:15	*Diabatic Initialization*	**Akira Kasahara**
2:45	*Data Applications Satellite*	**Barry Saltzman**
3:15	*Life Cycles of Transient Planetray Waves*	**Terrence R. Nathan**
3:45	**BREAK**	
4:00	*MSFC/ESAD Programs*	**H. Michael Goodman/DAAC** **Richard Beranek/LAWS** **James E. Arnold/GCIP**

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Wednesday, July 8, 1992
Radisson Suite Hotel

8:30	*Global Water Cycle*	**Franklin R. Robertson**
9:00	*Surface Hydrologic Analysis/CaPE*	**Steven J. Goodman**
9:30	*Role of Boundary Layer in Convection*	**Richard T. McNider**
10:00	**BREAK**	
10:15	*AMPR Measurements/Science*	**Robbie E. Hood**
10:45	*WetNet SSM/I for Global Rainfall*	**E. Zipser**
11:15	*WetNet SSM/I Surface Moisture*	**Christopher M. Neale**
11:45	**LUNCH** - *Climate Variations of Storms*	**Ted Fujita**
1:15	*OLS Data System/Lightning Survey*	**Steven J. Goodman**
1:45	*Atmospheric Electricity/Meteor. Analysis*	**Steven J. Goodman**
2:15	*Lightning in Winter Storms*	**Marx Brook**
2:45	*LIP/Lightning Mapping Technology*	**Richard J. Blakeslee**
3:15	*Mesoscale Convection Systems*	**Charles Cohen**
3:45	**BREAK**	
4:00	*Elect. Polarization Basis Rotation at 90 GHz*	**Al Gasiewski**
4:15	*Global Weather Energetics*	**Phillip J. Smith**
4:45	*South Pacific Convergence Zone*	**Dayton G. Vincent**
5:15	*Tropical Pacific Moisture Variability*	**James P. McGuirk**
5:45	*Automated Winds From Geo Satellite*	**Paul Menzel**
6:15	ADJOURN	

Thursday, July 9, 1992
Radisson Suites Hotel

8:00	*Microwave Radiative Transfer Studies*	**V. N. Bringi**
8:30	*Radar Wind Sounder Simulations*	**Richard K. Moore**
9:00	*HIS Participation in CaPE*	**William L. Smith**
9:30	*MAMS (HI-Res. Atmospheric Sur. Rel.)*	**Gary J. Jedlovec**
10:00	**BREAK**	
10:15	*Backscatter Obs. with the NOAA Lidar*	**R. Hardesty/M.J. Post**
10:45	*Mountain Top Measurements of Backscatter*	**R. M. Schotland**
11:15	*Aerosol Backscatter Studies*	**S. Henderson**
11:45	*Aerosol Chemistry in GLOBE*	**Antony Clarke**
12:15	**LUNCH**	
1:15	*Airborne Scanning Doppler Lidar*	**Jeffry Rothermel**
1:45	CO_2 *Lidar Backscatter Experiment*	**Maurice Jarzembski**
2:15	*Simulations of Satellite Doppler Wind Obs.*	**George D. Emmitt**
2:45	**BREAK**	
3:00	*Modeling Study of MBL Clouds*	**Shouping Wang**
3:30	*Advanced Doppler Lidar Techniques*	**Gary D. Spiers**
4:00	*VAS Humidity/Convection*	**Henry Fuelberg**
4:30	*VAS Algorithm Development*	**George Diak**
5:00	ADJOURN	

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13. ABSTRACT *(Maximum 200 words)*

This report summarizes the research presented at the annual Marshall Research Review of Earth Science and Applications. A large amount of attention has recently been given to global issues such as the ozone hole, tropospheric temperature variability, etc. A scientific challenge is to better understand atmospheric processes on a variety of spatial and temporal scales in order to predict environmental changes. Measurements of geophysical parameters such as wind, temperature, and moisture are needed to validate theories, provide analyzed data sets, and initialize or constrain numerical models. One problem is that measurements are concentrated near large cities or airports of which virtually all are located on land (and mostly northern hemisphere) representing only a small part of the Earth's surface. One way to gain more understanding of the atmosphere is to make measurements on a global scale from space. One of NASA's initiatives is the Mission to Planet Earth Program comprised of an Earth Observation System (EOS) and the scientific strategy to analyze these data. This series of new sensors will measure globally (and in some cases, simultaneously) atmospheric parameters such as temperature, moisture, wind, lightning, etc. Analysis of satellite data by developing algorithms to interpret the radiance information improves our understanding and also defines requirements for these new sensors. This work describes these efforts in the context of satellite data analysis and fundamental studies of atmospheric dynamics which examine selected processes important to the global circulation.

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