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INVESTIGATION OF ADAPTIVE-THRESHOLD APPROACHES FOR DETERMINING AREA-TIME INTEGRALS FROM SATELLITE INFRARED DATA TO ESTIMATE CONVECTIVE RAIN VOLUMES

PERIOD: 1 MARCH 1995 - 29 FEBRUARY 1996

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The principal goal of this project is to establish relationships that would allow application of area-time integral (ATI) calculations based upon satellite data to estimate rainfall volumes. The research is being carried out as a collaborative effort between the two participating organizations, with the satellite data analysis to determine values for the ATIs being done primarily by the STC-METSAT scientists and the associated radar data analysis to determine the "ground-truth" rainfall estimates being done primarily at the South Dakota School of Mines and Technology (SDSM&T). Synthesis of the two separate kinds of data and investigation of the resulting rainfall-versus-ATI relationships is then carried out jointly.

The research has been pursued using two different approaches, which for convenience can be designated as the "fixed-threshold approach" and the "adaptive-threshold approach". In the former, an attempt is made to determine a single temperature threshold in the satellite infrared data that would yield ATI values for identifiable cloud clusters which are most closely related to the corresponding rainfall amounts as determined by radar. In this respect the approach resembles the GOES Precipitation Index (GPI), but we make no assumption of a fixed rainfall rate for each cloudy pixel. Results thus far (Johnson *et al.*, 1994) have indicated that a strong correlation exists between the rain volumes and the satellite ATI values, but the optimum threshold for this relationship seems to differ from one geographic location to another. The difference is probably related to differences in the basic precipitation mechanisms that dominate in the different regions. The average rainfall rate associated with each cloudy pixel is also found to vary across the spectrum of ATI values.

Work on the second, or "adaptive-threshold", approach for determining the satellite ATI values has explored two avenues. The initial attempt involved choosing IR thresholds to match the satellite ATI values with ones separately calculated from the radar data on a case by case basis. Comparison of the resulting thresholds with the corresponding minimum cloud-top temperatures (CTT) suggested that a fixed temperature offset of 7.3°C from the CTT could provide a suitable adaptive threshold for the satellite ATI calculation. The ATIs possess spatial characteristics similar to those of the rainfall. A second attempt involved a straightforward screening analysis to determine the (fixed) offset that would lead to the strongest correlation and lowest standard error of estimate in the relationship between the satellite ATI values and the corresponding rainfall volumes. However, neither of these attempts to devise an adaptive threshold proved as satisfactory as the initial fixed-threshold approach. A paper summarizing these results was presented at the International GEWEX Workshop on Cold-Season/Region Hydrometeorology in May 1995 (Smith *et al.*, 1995); Attachment A provides the abstract of this presentation.

Most of the previous ATI work dealt with cloud clusters from the Lagrangian, or "floating-target", point of view. For many purposes, however, the Eulerian, or "fixed-target", perspective is more appropriate. For a very large target area encompassing entire cluster life histories, the rain volume-ATI relationship would obviously be the same with either reference frame. The important question for the Eulerian perspective is: How small can the fixed area be made while maintaining consistency in that relationship? To investigate this question, a sample of radar data for echo clusters from southeastern Montana was partitioned by dividing the radar surveillance area into successively smaller sectors. If sectors receiving more than 50% of their rainfall from echoes below the threshold (25 dBz) used for the radar ATI calculation are excluded, the rain volume-ATI relationship remains essentially the same from the overall radar surveillance area of 75,000 km^2 down to a grid with sectors of 73.4 km^2. The cases with weaker echoes could presumably be incorporated by repeating the ATI computation with a lower reflectivity threshold. Irregular sub-areas corresponding to county boundaries were used in another similar analysis, with essentially the same results. A paper describing this work was presented at the XXI General Assembly of the IUGG held in Boulder, Colorado, July 1995; Attachment B provides a copy of the abstract of this presentation.

Investigations of the Probability Density Functions of rainfall rate (or of a surrogate, the radar reflectivity factor) continued. The results have indicated that the PDFs for different echo clusters can usually be described by a common mathematical expression, but the parameters appear to differ substantially from one cluster to another. This contradicts the hypothesis of a universal PDF, which has been advanced to account for the observed rain volume/ATI correlation. Efforts are in progress to establish a statistical test procedure that can put this indication on a more rigorous basis. A paper summarizing part of this work was presented at the 27th Conference on Radar Meteorology (Larsen *et al.*, 1995); Attachment C provides a reprint of the paper.

The advent of GOES-8 and the NEXRAD (WSR-88D) radars provides new and higher-quality data that can be used in studying the relationships between rain volumes and satellite area-time integrals. Work to explore the utility of these new data is in progress on two fronts. A new Graduate Research Assistant is investigating the radar ATIs and rain volumes for a sample of NEXRAD data from St. Louis. The data were already in hand from another study, and software for ingesting and processing the data were also available. A preliminary report on this work has been accepted for presentation at the Second International Scientific Conference on the Global Energy and Water Cycle this coming June. The other approach

involves looking at some of the additional channels in the GOES-8 data to determine whether extra information about cloud particle types, sizes or optical depths can be derived. This information might help to improve the correlation between the rain volumes and the satellite-derived variables (including the ATIs).

Efforts at STC-METSAT were initially directed toward finding reasons for the weaker correlations found in the adaptive-threshold rain volume/satellite ATI relationships. The work included re-examination of satellite images for the "outlier" cases and study of the spatial and temporal gradients in the IR cloud-top-temperature structure. Soundings from the COHMEX time periods used in the ATI study were also examined for possible clues about the thermal structure near the cloud-top levels. However, these efforts were to little avail. More recently, the effort has concentrated examining available SSM/I microwave data along with the geostationary satellite data, and on screening GOES-8 data to find cases that can be correlated with coincident NEXRAD data. A structural comparison of the GOES and SSM/I images has also been initiated. Copies of status reports from STC are attached.

To coordinate efforts on this project, the STC-METSAT scientists visited the School of Mines campus on 17-18 April 1995 for discussion of progress and plans for further work. At the time of the IUGG presentation (see Attachment B), the lead author visited the STC-METSAT staff in Ft. Collins to provide further interactions. A copy of his trip report is included as Attachment D.

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Smith, P. L., L. R. Johnson, T. H. Vonder Haar and D. Reinke, 1995: An adaptive-threshold approach for relating area-time integrals based on satellite infrared data to convective rainfall volumes. In Krauss, T. W. and T. R. Carroll (eds), *Int'l GEWEX Workshop on Cold Season/Region Hydrometeorology, Summary Report and Proceedings*, IGPO Publication Series No. 15, p. 141.

ATTACHMENT A

An Adaptive-Threshold Approach for Relating Area-Time Integrals Based on Satellite Infrared Data to Convective Rainfall Volumes

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Satellites, with near-global observations, offer an attractive approach for estimating precipitation. Some satellite estimation schemes attempt to distinguish between raining and non-raining cloud while others take a broader view and simply try to correlate rainfall with cloud cover. The latter methods cannot pinpoint exact locations of specific rainfall amounts but may be useful at the regional or global spatial scale for time periods of climatological interest. The area-time integral (ATI), part of the latter category, has been shown to be strongly correlated with rain volume at the individual-storm level. Calculation of the ATI usually requires data for the storm life history and employs a Lagrangian frame of reference centered on the storm. Present research shows promising results for extension of the approach to fixed areas, which will prove more meaningful for many hydrological and climatological purposes.

Initial application of the ATI concept to satellite infrared (IR) data considered a fixed IR temperature threshold, analogous to the GOES Precipitation Index. The threshold was optimized to improve the correlation between storm rainfall (estimated from radar) and the satellite ATI. A threshold of -22.5°C ($r=0.93$) was found for convective storms in the northern Great Plains, while 8.5°C was the optimized value ($r=0.85$) for the southeastern U.S. The cloud area included in the ATI calculation is several times that of the raining portion of the cloud. Therefore two items restrict applicability of the ATI approach based on such a "fixed" IR threshold: 1) The raining portion of the cloud is not identified; and 2) the threshold is dependent on geographical location. Our recent research has focused on a search for an adaptive-threshold approach that might alleviate one or both of these restrictions.

The problems of a calibration requirement to establish the local threshold and of raining-area identification could be alleviated by forcing the satellite-derived ATI to be equal to the equivalent ATI based on radar data (which, in effect, includes only the raining area). A comparison of minimum cloud-top temperature (CTT) to the temperature threshold for each storm that matches a satellite ATI to the radar ATI suggests an adaptive threshold can be determined by simply adding 7.3°C to the minimum IR temperature reached by the storm during its lifetime. The satellite ATI determined from the area of the cloud enclosed by this threshold should be comparable to the radar ATI, which in turn is well correlated to the rain volume. However, the correlation between the rain volumes and these adaptive-threshold ATI's was found to be unsatisfactory ($r = 0.49$). Examination of the scatter plots showed poor results for a group of storms for which the appropriate offset from CTT was much greater than 7.3°C, and another group for which it was essentially zero. Consequently, use of the average difference does not yield satisfactory results.

This difficulty led us to abandon the attempt to match the radar ATI. The alternative threshold, differing by a fixed amount from the CTT, that gives the best rain volume/ATI correlation involves an offset of 4.5°C; however, the correlation still remains unsatisfactory ($r = 0.55$). Results of a multiple linear regression analysis intended to identify a combined-feature approach will be reported at the Workshop.

ATTACHMENT B

Fixed-Target Area-Time Integrals as Estimators of Rainfall

L R Johnson and P L Smith, (Both at the Institute of Atmospheric Sciences, South Dakota School of Mines and Technology, Rapid City, SD 57701-3995; 605-394-2291; e-mail: lron@dust.ias.sdsmt.edu)

Gridded estimates of rainfall amounts are useful quantities for hydrologists, mesoscale meteorologists and others involved in modeling, water-budget analyses and forecasting. The estimates can be even more useful if they represent a specific watershed or a geopolitical boundary, which is possible if the grid sector is allowed to vary in size and shape. The area-time integral (ATI) concept has evolved mainly using a Lagrangian reference frame that is centered on the storm through time, although some fixed-area techniques (such as the GOES Precipitation Index) are equivalent to an ATI analysis. It was reported earlier that the ATI-rainfall correlation holds for areas whose boundaries do not change with time, if the areas remain large enough ($\geq$4700 km^2) that many storms of average size and duration would play out their lifetimes within the sector. The extension to smaller areas, where the average storm would be expected to cross the boundary during its lifetime, and to irregular-shaped areas requires resolution and is the subject of this paper.

The strong correlation between radar estimated rain volume (RERV) and ATI in log-log space was maintained for uniform grids when the sector areas were reduced to as small as 73.4 km^2, with only slight deterioration in the correlation coefficient (0.987-0.971) as the sector size decreased. The boundaries of 14 counties were used to define another grid of irregular shapes and sizes. The applicability of the ATI-rainfall relationship to this scenario was also supported by a strong correlation (0.977).

In these studies the RERV calculations included all reflectivities $\geq$ 10 dBz while the ATI threshold was 25 dBz, to insure that the low-level radar echoes corresponded to precipitation that would reach the ground. The difference allowed some sectors to have a reportable rainfall but no ATI. Any sectors that received more than 50% of their rainfall from reflectivities < 25 dBz were not included in the comparisons, to minimize the effects of this difference. The effect of lowering the ATI threshold to 10 dBz would be to degrade the correlation coefficient (0.988-0.954), while the regression slope and standard error of estimate increase substantially.

1. 1995 IUGG Meeting
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4. IAMAS
5. H JW3 "Water Balance"
6. O = Oral
7. None
8. No

ATTACHMENT C

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P6.9 PROBABILITY DENSITY FUNCTIONS OF OBSERVED RAINFALL IN MONTANA

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1. INTRODUCTION

The determination of convective rainfall volumes independent of rain gage networks is important in areas where such coverage is sparse. A procedure utilizing a relationship between volume and horizontal areal coverage of precipitation would provide a method for estimating rainfall based solely on areal coverage. Doneaud *et al.* (1981) developed one such procedure at the South Dakota School of Mines and Technology. Their work explicitly defined a coverage-based method that eventually came to be known as the Area Time Integral, or ATI. If the average rain rate R is known, the rain volume V follows from

$$V = \bar{R} \iint_{At} dAdt \quad , \qquad (1)$$

where the ATI is the double integral over both area A and time t:

$$ATI = \iint_{At} dAdt \quad . \qquad (2)$$

The ratio of Radar Estimated Rain Volume (RERV) to the ATI gives the average rain rate. There is no need to determine the structure for the area of precipitation activity, provided an average rain rate is known (Doneaud *et al.*, 1984). The area of integration can be specified with respect to the precipitation itself ("floating target") or a fixed surface area (Doneaud *et al.*, 1984). Doneaud *et al.* (1981) initially presented the fixed surface integration, while Johnson *et al.* (1994) examined the floating target integration.

The ATI depends, in theory, on a combination of a deterministic and statistical distribution of rain rate over area (Atlas *et al.*, 1990). The rain rate probability density function (PDF) is believed to be unimportant as long as the distribution remains constant -- either for all rain events or for a uniform variation between events. The exact PDF has never been explicitly presented, although studies have shown a log-normal distribution (Doneaud *et al.*, 1984; Atlas *et al.* 1990; Sauvageot, 1994) and modified gamma distribution (Doneaud *et al.*, 1979) provide reasonable rain rate distribution fits.

In the ATI sense, a universal PDF (one that fits all cases) would show a relationship between rain rate and area-time coverage. For a low ATI value, the probability of heavy rain would be small. An increase in the probability would be supported by a corresponding increase in area and/or duration of the event (Larsen, 1994).

This paper examines the question of whether a rain rate PDF can vary uniformly between precipitation events (hereafter called "storms" with the understanding that precipitation is falling although it may not be severe). Image analysis on large samples of radar echoes is possible because of advances in technology. The data provided by such an analysis easily allow development of radar reflectivity factor (and by extension rain rate) distributions. Finding a PDF becomes a matter of finding a function that describes the curve approximating the resulting distributions. Ideally, one PDF would exist for all cases; or many PDF's that have the same functional form with only systematic variations in parameters (such as size or shape) exist. Satisfying either of these cases will, according to Atlas *et al.* (1990) validate the theoretical basis of the ATI.

2. ANALYSIS

The floating target analysis requires following a storm through its entire lifetime. This was not practical in the past because the storm lifetime could last several hours and contain thousands of reflectivity factor values. With faster digital equipment, true image processing has become a reality and the

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capability to easily study storm lifetime distributions now exists.

The Interactive Radar Analysis Software running on Sun workstations (Sun-IRAS) (Priegnitz and Hjelmfelt, 1993) was used to generate the storm distributions. The Sun-IRAS echo area statistics option allows distribution function analysis. The Sun-IRAS user selects a radar echo on a Plan Position Indicator (PPI) display and outlines the area to be analyzed. Sun-IRAS then analyzes the pixels contained in the enclosed area and determines echo region properties such as area above a reflectivity threshold, maximum and mean reflectivities, and corresponding maximum and mean rain rates. A frequency distribution is generated for each echo region showing the number of pixels for a particular range of reflectivity factor. A sample echo-area statistics display is shown in Fig. 1.

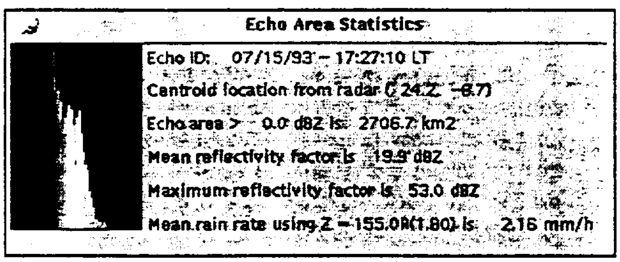

Fig. 1. Sun-IRAS Echo-Area Statistics Display.

The total number of scans analyzed depends on the length of the storm. Once all scans had been analyzed, the time dependency was removed. This involved totaling the number of pixels at a given reflectivity factor value throughout the storm duration and dividing by the total number of pixels encountered throughout the storm's life. The result was a lifetime frequency distribution of reflectivity factor values.

The data for this research came from the CCOPE experiment of 1981 (Knight, 1982). Radar data from the Skywater 5-cm radar located near Miles City, MT, was used because it produced the full-volume scans necessary for studying the storms through their lifetime (Johnson and Hjelmfelt, 1990).

Storms selected for this study had to be easily identified and followed through their lifetime. They were categorized according to duration and seasonal dependence. Duration classes were short (lasting between 0.5 and 2.0 hours), medium (between 2.0 and 4.0 hours), and long (between 4.0 and 8.0 hours). Seasonal classes were roughly two-week intervals throughout the CCOPE experiment: May (18-31 inclusive), June 1-15, June 16-30, July 1-15, July 16-31, and August (1-7 inclusive). A total of 54 storms were analyzed, with an equal number of storms selected for each class (Larsen, 1994).

3. RESULTS

The method-of-moments procedure was used to produce indicators for selecting a mathematical relationship to fit the distributions. Curve selection criteria based on moment generated parameters (Elderton, 1953) were then applied to determine the form of the PDF equation. A Pearson Type I curve was found to fit 48 of the 54 selected storms. Since this one equation is indicated as the choice for 89% of the cases, the Type I equation appears to be a very good prospect for a universal function. The term universal is used with some caution since only one season-location was examined (Larsen, 1994).

The shape of a Type I curve ranges from a closed, positively skewed curve to an open, asymptotic curve. The shape is J, U, or twisted-J, depending on shape parameters. Typical Type-I curves are shown in Fig. 2. Duration and seasonal curve shape relationships are shown in Table 1 and 2, respectively.

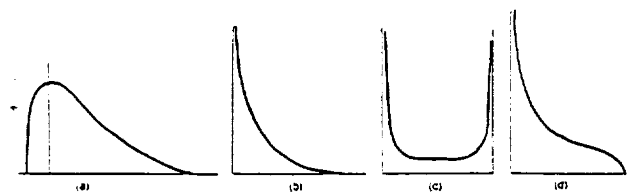

Fig. 2. Typical Pearson Type I curves: a) bell shaped; b) J-shaped; c) U-shaped; d) twisted J-shape.

TABLE 1. Duration-Curve Shape Relationships

	J-Shape	Bell-Shape	U-Shape
Short	14	3	1
Medium	7	9	0
Long	6	9	0

TABLE 2. Seasonal-Curve Shape Relationships

	J-Shape	Bell-Shape	U-Shape
May	5	3	0
1-15 Jun	4	3	0
16-30 Jun	3	6	0
1-15 Jul	6	3	0
16-31 Jul	5	2	1
Aug	3	4	0

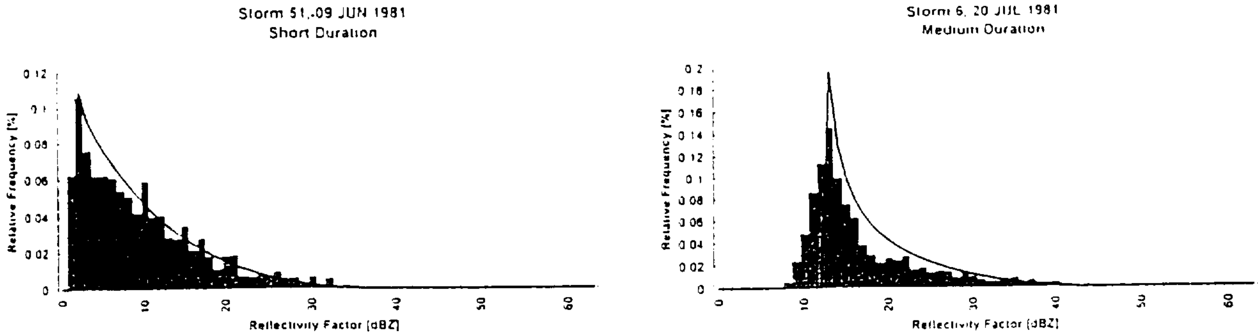

Fig. 3. Type-I curve fit to rain-rate distribution: a) 9 June 1981; b) 20 July 1981.

By inspection, the generql shape of many of the curves is approximated. However, a chi-square goodness-of-fit test indicates the majority of the curves do not provide a fit with 95% confidence. Of the 54 distributions, the chi-square statistic at a 5% level of significance favored rejection of the null hypothesis ("the Type I curve approximates the shape of all the distributions") for 52 cases. One case where the test statistic met the criteria, as well as another example where the criteria was not satisfied, are shown in Fig. 3.

4. CONCLUSION

This paper examined whether a universal PDF of rainfall rate exists, supporting the theoretical basis for the ATI proposed by Atlas *et al.* (1990). Using the method of moments and Elderton's (1953) curve selection criteria, the Pearson Type 1 equation was identified as a potential fit for 89% of the observed distributions. Further analysis indicates that the Type I curve does approximate the shape of the distributions but quantitatively does not produce a great fit (Larsen, 1994).

There is evidence to show that the method-of-moments may not be the most effective estimator of parameters available (Brooks and Carruthers, 1953; Elderton, 1953). With that said, another method may produce better parameters and curve fits. This is a starting point, however, and at the very least, opens the door for further discussion of curve fitting techniques (Larsen, 1994).

Since one type of curve was identified to fit 89% of the storms researched, there does appear to be some type of universal distribution present. Whether the distribution can be applied to all seasons and climates, or simply to the data of the CCOPE project is subject for further study.

Acknowledgments. This research was conducted as a thesis requirement for the degree Master of Science in Meteorology at the South Dakota School of Mines and Technology. Financial support was provided by the National Aeronautics and Space Administration (Grant NAG 5-386) and the State of South Dakota.

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ATTACHMENT D

7 August 1995

MEMORANDUM FOR THE RECORD

FROM: L. R. Johnson

SUBJECT: Trip Report

I traveled to Fort Collins, Colorado by private vehicle on 9 July 1995 to attend the second week of the International Union of Geodesy and Geophysics (IUGG) conference in Boulder, Colorado and to present a paper, and to confer with NASA Rain Volume Estimation project participants at Colorado State University. The paper entitled, "Fixed-Target Area-Time Integrals as Estimators of Rainfall," was the fourth paper presented during the joint session of the International Association of Hydrological Sciences and the International Association of Meteorology and Atmospheric Sciences. This session entitled, "Dynamic Monitoring and Estimation of the Water Balance of the Globe and Its Continents," convened on Monday morning and continued throughout the day.

Tony Smith picked me up at the hotel in Fort Collins at 7:00 a.m. as prearranged and drove me to the University of Colorado campus in Boulder where the conference was being held. Neither of us had experience with the University campus and several moments were utilized in finding our way. Registration was being held at the field house and you were required to walk to reach the session location at the basketball arena, which was referred to as the Events Center. The second paper presentation was in progress by the time I located the correct meeting room. The brave session chair, Dr. Kendal McGuffie, University of Technology, Sydney, Australia, introduced the fourth paper and took several steps in my direction in anticipation. Delivery of the paper went very smoothly; but, no questions were asked from the floor. Two papers later, a 30 minute break was called and then many questions came from several interested individuals. Frank Adam with the South African Weather Bureau requested information concerning implementation of fix area ATI to estimate rainfall from radar data for a specific watershed.

Topics for the session were broad in scope and covered the measurement of glacier thickness by radar to the development of an extended global river discharge database for GCM validation while most dealt with precipitation, evaporation and runoff. Several authors demonstrated that GCMs are too wet and another indicated that the NMC Eta-model is too dry for the Mississippi River Basin. Flow in the Mississippi was decreasing for many decades but the present decade shows a large

uptick. The increased flow still remains behind flows measured earlier this century. It is estimated that 0.6 Mkm^3 of water is involved in the Earth's hydrologic cycle each year as reported by A. O. Selivano of the Water Problems Institute, Moscow, Russia. Rainfall estimation schemes based on remote sensed data using a properly tuned threshold are found to be adequate if the time scale is not small (i.e. monthly). Other techniques such as microwave may be applicable to a much shorter time scale but the spatial resolution suffers.

I met Norman Miller of Lawrence Livermore National Laboratory, Livermore, CA who gave two papers at the end of the session. He is in global climate research and specifically is simulating precipitation on the local scale and using the limited NWS point data to keep the model on track. The simulated rainfall is then applied to a hydrology model to predict stream flow and runoff. He asked about Harry Orville. The day's activities concluded with a poster session and a social hour.

On Tuesday, attention turned to the effects of Pinatubo, which was the second day of a two-day specialty segment of the International Global Aerosol Program. The aerosol produced by the eruption of Mt. Pinatubo on June of 1991 was sensed by many different instruments at the Earth's surface, on aircraft, supported by balloon and especially from the satellite perspective. Instruments and platforms included in the reports I observed covered AVHRR, SAGE and GMS satellites, ER-2 aircraft, special radiometers, ozone concentration, condensation counters, optical counters, impactors and lidars. All the various measurements appeared to present a consistent picture of the evolution of particle size and particle dispersion. In the first month following the eruption, particle numbers increased by orders of magnitude but effective size remained about 0.2 µm radius for stratospheric aerosol. Effective size increased to about 0.5 µm over the next 3 to 6 months. Increases in effective size continued for about a year. The peak wavelength of optical depth spectra increased from initial values of <0.42 µm to values between 0.78 and 1 µm. The plume was spatially inhomogeneous for the first 4-5 months while spreading to higher latitudes. Both condensation nuclei and aerosol mass mixing ratio became spatially uniform above 18 km in the winter of 1992. Mixing ratios peaked at values more than 100 times background values. Gradual removal via sedimentation followed and proceeded at a rate of about an order of magnitude per 400 days. Below 18 km height, dilution by cleaner, tropical air from the troposphere was sporadic and disorderly. The increase of

particle surface area in the stratosphere reinforces ozone depletion because of the modified conditions for heterogeneous chemical reactions. During the winter seasons of 1992 and 93 ozone concentration between 12 and 20 km height at 50^{o}north latitude decreased 20 to 50% from the long term mean. Three Dimensional dispersion models were found incapable of describing the observed dispersion.

I returned to Fort Collins before the session ended to meet with Don Reinke and discuss data issues for the ATI project. The WSI NEXRAD product for Atlanta indicated most days in June experienced rainfall in the southeast. Don agreed to recall images for that period of time and area from the GOES 8 archive and look for days of opportunity. I agreed to order NEXRAD data for the month of June for radars located at Atlanta, Birmingham and Jackson. Mobile, Tallahassee, Jacksonville and Charleston will also be ordered, if available.

I returned to Rapid City on Wednesday, 12 July.

LRJ:clh
cc: P. L. Smith
R. J. Gowen

STC PROPRIETARY DATA

STC Technical Report 2846(4)
6333

Rain Volumes

Quarterly R&D Status Report

Prepared for
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As Quarterly Progress Report
Under Subcontract IAS–STC94–02
For the period 1 January – 31 March 1995

March 1995

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Rain Volumes
Principal Investigator(s): Dr. Thomas Vonder Haar
Period of Performance: 1 May 1994 through 30 April 1995
Reporting Period: 1 January 1995 – 31 March 1995

Work accomplished during this reporting period:

1. COHMEX case study analysis:

   The analysis of the COHMEX satellite imagery has provided little, if any, new insights into the identification of "outlayer" cells in the regression plot of ATI versus coldest IR temperature. The imagery used in the study (the COHMEX data set) for this phase of the satellite ATI investigation is extremely "noisy" in the vicinity of the large cold cells. I believe that our discussions regarding the use of microwave sensor data to identify the precipitating portion of the cells is essential. Doing the gradient/coldest IR temperature analysis modifies our original ATI analysis scheme to the point that it becomes more like several contemporary precipitation estimation techniques - most notably the Scofield-Oliver.

   As a result, we recommend that a modified ATI technique, involving the use of SSM/I imagery be used as described in item 2 below.

2. Satellite "moisture" ATI (SATMATI) analysis plan:

   It has become apparent that the most significant drawback to the satellite ATI (SATATI) analysis is the inability to determine, from the infrared imagery alone, the exact aerial extent of the precipitating portion of the cloud mass. For the next phase of the ATI study, STC-METSAT will add microwave imagery to the ATI process. This addition of the moisture variable, cloud liquid water, will be referred to as the Satellite Moisture ATI (SATMATI) analysis.

   In addition, the next phase will take advantage of improved radar and satellite data sets. Both the NEXRAD radar and DMSP SSM/I microwave imager data will be used, along with GOES-7 or GOES-8 satellite imagery, to identify precipitating cells and produce SATMATI estimates.

The specific plan is as follows:

(a) SDSMT/AS will provide STC-METSAT with a list of potential sites and dates for which NEXRAD data is available. The target data set is a fifteen day period that contains frequent rainfall events.

(b) STC-METSAT will obtain the corresponding SSM/I and GOES imagery to compliment the NEXRAD data. The SSM/I imagery will be processed to identify the precipitating

portion of the convective cells. This analysis will be compared with the raining areas determined by radar and used to compute an ATI estimate of rainfall. The GOES infrared imagery will then be processed independently to produce an ATI estimate. Finally, the SSM/I imagery will be used to identify the portion of the cloud mass, on the GOES infrared image, that corresponds to the precipitating portion of the cloud. The SSM/I and infrared analysis will then be used to produce a SATMATI on successive GOES infrared images where SSM/I data is not available.

Due to the overflight times of the SSM/I sensor, the cases will be confined to precipitation events that occur in the early morning and late evening hours. This will limit the dates of this study to the spring and/or late summer convection periods over the continental United States.

(c) It is also suggested that STC-METSAT will also perform a structure analysis of the collocated (in space and time) SSM/I and GOES infrared images. The purpose of this analysis will be to determine a link between the cloud-top structure in the infrared imagery in the portion of the cloud mass that is identified as precipitating by the SSM/I overflight. The purpose of this analysis will be to determine if there is a significant signature in the infrared imagery that will help identify the area to be used in the ATI calculation.

3. Tom Vonder Haar and Don Reinke will try to visit SDSM&T in mid-April to discuss the details of the next phase of the ATI investigation.

STC PROPRIETARY DATA

STC Technical Report 2846(5)
6333

Rain Volumes

Semi-Annual R&D Status Report

Prepared for
Dr. Paul Smith, Mr. Ron Johnson
Institute of Atmospheric Sciences
South Dakota School of Mines and Technology
501 E. St. Joseph Street
Rapid City, SD 57701–3995
As Semi-Annual Progress Report
Under Subcontract IAS–STC94–02
For the period 1 May – 31 July 1995

July 1995

STC
Science and Technology Corporation
101 Research Drive, Hampton, Virginia 23666–1340

Rain Volumes

Principal Investigator(s): Dr. Thomas Vonder Haar

Period of Performance: 1 May 1995 through 30 April 1996

Reporting Period: 1 May – 31 July 1995

Work during this period centered around the collection and identification of potential case study periods. Mr. Don Reinke met with Mr. Ron Johnson in Fort Collins during the week of 10 July to discuss the direction we would go with this next phase. Ron indicated that the NEXRAD radar data was available, however there was a three-month lag time until the digital data is available. Based on this lag time, Don and Ron decided to try for the June 1995 data. These data should be available in September. It would be preferable to wait until July or August data are available; however, that only delays the processing until much later in the fall of this year.

Based on that discussion, STC-METSAT processed a set of GOES-8 images to identify days during the month of June that have good convective days. A sector over the southeast U.S. was extracted for the 1800-2100 UTC time period for each day of the month that data were available. A graphic was produced to geolocate clouds on the images, and the images were converted to TIFF format and made available to SDSMT on an anonymous ftp account.

Mr. Johnson will review the images to identify "good" days. NEXRAD data will then be ordered for the selected days. At the same time, STC-METSAT will order the satellite imagery and begin processing Satellite ATI's.

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February 1996

RAIN VOLUMES

Principal Investigator(s): Dr. Thomas Vonder Haar

Period of Performance: 1 May 1995 – 30 April 1996

Reporting Period: 1 August 1995 – 31 January 1996

A. Summary of Project Objectives - Satellite "Moisture" ATI

The most significant drawback to the Satellite ATI (SATATI) analysis has been the inability to determine, from the infrared imagery alone, the exact areal extent of the precipitating portion of the cloud mass. For this phase of the ATI study, *STC*-METSAT has been tasked with the objective of: (1) processing additional satellite case study days that will be compared with NEXRAD radar data (to be processed by SDSM&T) and (2) adding microwave imagery to the ATI process. This addition of the moisture variable, cloud liquid water retrieved from SSM/I data, is referred to as the Satellite Moisture ATI (SATMATI) analysis.

This phase will take advantage of improved radar and satellite data sets. Both the NEXRAD radar and DMSP SSM/I microwave imager data will be used, along with GOES-7 or GOES-8 satellite imagery, to identify precipitating cells and produce SATMATI estimates.

b. Project Plan Items, and the Status of Each:

1) SDSMT/AS will provide *STC*-METSAT with a list of potential sites and dates for which NEXRAD data is available. The target data set is a fifteen-day period that contains frequent rainfall events.

Status: STC-METSAT provided SDMS with a set of sample GOES-8 satellite images for period of 1-May through 1-June of 1995. One image per day was processed to provide a means for determining which days will provide the best opportunity for analyzing simultaneous satellite and radar coverage of convective rainfall events. The 2145 UTC image was processed (except for several days where it was not available, in which case the nearest time was used).

2) *STC*-METSAT will obtain the corresponding SSM/I and GOES imagery to compliment the NEXRAD data. The SSM/I imagery will be processed to identify the precipitating portion of the convective cells. This analysis will be compared with the raining areas determined by radar and used to compute an ATI estimate of rainfall. The GOES infrared imagery will then be processed independently to produce an ATI estimate. Finally, the SSM/I imagery will be used to identify the portion of the cloud mass, on the GOES infrared image, that corresponds to the precipitating portion of the

cloud. The SSM/I and infrared analysis will then be used to produce a SATMATI on successive GOES infrared images where SSM/I data is not available.

Status: SSM/I imagery has been obtained, and pre-processed for all of the dates in May and June of 1995. These data will only provide one "pass" per day (assuming the maximum convection occurs during the late afternoon/early evening), however, it will provide a unique calibration of the infrared satellite imagery to pinpoint the location of the raining portion of the image. (Due to the overflight times of the SSM/I sensor, the cases will be confined to precipitation events that occur in the early morning and late evening hours. As stated in the initial processing plan, this will limit the dates of this study to the spring and/or late summer convection periods over the continental United States.)

3) *STC*-METSAT will also perform a structure analysis of the collocated (in space and time) SSM/I and GOES infrared images. The purpose of this analysis will be to determine a link between the cloud-top structure in the infrared imagery in the portion of the cloud mass that is identified as precipitating by the SSM/I overflight. The purpose of this analysis will be to determine if there is a significant signature in the infrared imagery that will help identify the area to be used in the ATI calculation.

Status: This study is progressing independently of the case studies involving radar data, until specific radar case days are identified. To perform this study, *STC*-METSAT processed a series of days from a 1994 data set produced for the CHANCES project (Vonder Haar et al., 1995). At this point, approximately 48 cases have been processed and saved. *STC*-METSAT will process approximately 60 cases (2/day for a full month). The cases are taken from the month of July, 1994, the eastern U.S. (over water only). Figure 1 is an example of GOES Infrared imagery for one of the case study days, and Figure 2 is the same image with SSM/I-derived cloud liquid water data superimposed on the image.

c. Travel

Dr. Tom Vonder Haar and Mr. Don Reinke will visit SDSM&T in early May to discuss the ATI project and outline a plan for the next phase of the ATI investigation.

REFERENCE

Vonder Haar, T. H., D. L. Reinke, K. E. Eis, J. L. Behunek, C. R. Chappel, C. L. Combs, J. M. Forsythe and M. A. Ringerud, 1995: Climatological and Historical Analysis of Clouds for Environmental Simulations (CHANCES) Database - Final Report. Report PL-TR-95-2101, Phillips Laboratory, Hanscom AFB, MA.

Figure 1. GOES infrared satellite image.

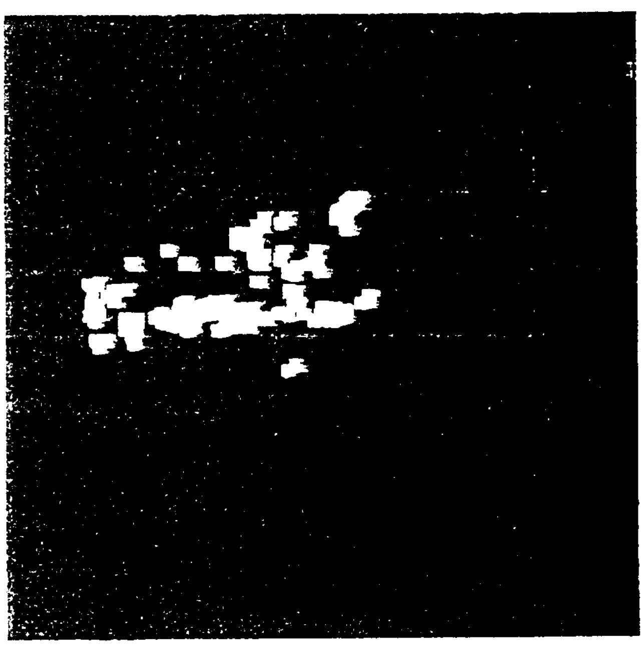

Figure 2. GOES infrared satellite image with SSM/I - derived cloud liquid water superimpoesd on the image (lighter colored 'squares').