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SOME THOUGHTS ON FUTURE RAIN MAPPING MISSIONS (TRMM FOLLOW-ON)

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INTRODUCTION

The release of latent heat of condensation is the largest internal energy source of the atmosphere. Latent heating is most significant during the precipitation process. Our knowledge of the distribution of precipitation is poor. It is only well observed within limited areas of the globe. Over the oceans, for example, it is known only to within a factor of two. Thus, there are strong scientific requirements for observations of precipitation from instruments on board a satellite. The Tropical Rainfall Measuring Mission (TRMM) will be the first satellite to measure rainfall with adequate accuracy and provide information about the vertical distribution of precipitation, not in only in a tropics and sub tropics, but to plus or minus 35 degrees of latitude. There is a need for the continuity of rain observations for climate modeling purposes and to expand observations to cover more of the globe than simply plus or minus 35 degrees latitude.

TRMM FOLLOW-ON MISSION REQUIREMENTS

One of the requirements that can be met by a TRMM follow-on mission is the need for five additional years of tropical rainfall measurements for short term climate studies. A three year data set simply may not include both normal and El Niño Southern Oscillation (ENSO) conditions. ENSO occurs about twice in a decade, maybe three times, but we need to extend the data set to include El Niño; La Niña which is a cold eastern pacific oscillation; and normal conditions. A total of eight years should achieve this goal. Shukla from the University of Maryland has shown that the results of large scale climate models are immensely sensitive to the amount and vertical profiles of latent heating in the tropics. The only way to obtain adequate quantitative values for latent heating is from TRMM and its hydrometeor profiling. Shukla also showed that the impacts of tropical circulations on mid latitude weather and climate requires a much better knowledge of tropical latent heat release than we have at present.

We also have a need to extend measurements to middle and high latitudes both for analysis of the global hydrological cycle and to understand precipitation and its impact on the environment. Measurements are urgently needed for the Global Energy and Water Cycles Experiment

(GEWEX). We need to begin the measurement of frozen precipitation from space. Over land, only radar can make these measurements. Even radar will have problems detecting light snow fall. The GEWEX Continental Scale Experiment (GCIP) will greatly help testing and validating snow retrievals over land. By the year 2000 we need rainfall measurements in the tropics and mid latitudes on a near real-time basis to assimilate in large scale forecast models. This means rain and latent heat data simulations will have been developed during TRMM-1. This could lead to significant increases in accuracy for one to five day weather forecasts and greatly improved assessment and prediction of global change, particularly global warming, by improving the climate models. We need better models which couple the land surface hydrology with precipitation. Most hydrological studies are on mid latitude sites. (Personal communication from J. Simpson, GSFC, January 1993

Shown in Figure 1 are the satellite data requirements from the World Climate Research Program. The third entry is liquid water. For measuring liquid water, microwave imaging radiometers are needed such as on SSM/I; Eos, which is the MIMR; and TRMM microwave imager TMI. For the liquid water profile, only a rain radar can make that measurement, and of course, the only precipitation radar available will be on TRMM. Therefore, since TRMM is only a three year mission, we need a follow-on in order to fully extend the coverage of GEWEX.

Measurements	Instrument type	Candidate sensor	Mission
Wind profile	Doppler lidar	LAWS	(undetermined)
Temperature & humidity profile	IR & microwave sounder	AIRS, IASI, MSU, AMSU, MHS (1)	EOS, NOAA, POEM, GEWEX (2)
Liquid water (total)	Microwave imaging radiometer	SSM/I, MIMR, TRMM microwave imager (TMI)	DMSP, EOS, TRMM, GEWEX (2)
Liquid water (profile)	Rain radar	Precipitation radar (PR)	TRMM, GEWEX(2)
Cloud amount and cloud top temperature	Imaging radiometer (vis & RI)	AVHRR (3), MODIS	NOAA, EOS, POEM, GEWEX (2)
Cloud particle properties	Polarimeter	POLDER, EOSP	ADEOS, POEM, EOS
Cloud particle profiles	Millimeter wave radar altimeter	(undetermined)	(undermined)
Atmospheric chemistry: minor constituents including ozone	Spectrometer	TOMS, GOME, GOMOS, SCIAMACHY, MOPITT, IMG, ILAS, HIRDLS, TES	NOAA, ERS-2, ADEOS, POEM, EOS
Aerosol: stratospheric	Limb-scanning spectrometer	SAGE, SCIAMACHY, ILAS	EOS, POEM, ADEOS
Aerosol: tropospheric	Multi-directional imager	MISR	EOS
Solar radiation	Solar radiometer	ACRIM	EOS
Earth radiation (top of the atmosphere)	Wide-band scanning radiometer	ScaRaB, CERES	Meteor, TRMM, EOS, POEM, GEWEX(2)
Earth surface/ cloud multi-directional reflectance	Multi-directional imager	ATSR, MISR	ERS, EOS, POEM
Earth surface reflectance and colour	Imaging radiometer (vis & near IR)	AVHRR(3), AVNIR, MODIS	NOAA, ADEOS, EOS, POEM

Figure 1. World Climate Research Program (WCRP) Satellite Data Requirements (From a presentation by P. Morel, Director, WCRP, Hamilton, Bermuda, January 1991).

Ocean surface colour	Imaging radiometer (vis)	SeaWIFS, OCTS, MODIS	SeaWIFS, ADEOS, EOS, POEM
Sea surface temperature	Imaging radiometer or sounder (IR)	AVHRR(3), ATSR, OCTS, MODIS, AIRS, IASI	NOAA, ERS, ADEOS, EOS, POEM
Ocean surface wind vector	Microwave scatterometer	AMI, NSCATT, STIKSCAT	ERS, ADEOS, EOS, POEM
Ocean wave height	Radar altimeter	RA	ERS, EOS, POEM
Ocean surface topography	Precision radar altimeter and orbitometry	Single or 2-frequency altimeter; GPS + water vapour radiometer or DORIS	TOPEX-POSEIDON, ALT(4)
Sea ice cover	Microwave imaging radiometer	SSM/I, MIMR	DMSP, EOS, POEM
Sea ice texture, edge and motion	Imaging radar	AMI, SAR	ERS, RadarSat, JERS-1
Snow cover	Imaging radiometer (vis and microwave)	AVHRR, MODIS, SSM/I, MIMR	NOAA, EOS, POEM, DMSP
Snow water equivalent and soil moisture	(undetermined)	(undetermined)	(undetermined)
Glacial and iceberg discharge	High-resolution imager (vis) and radar altimeter	TM, HRV, ASTER AND RA	LANDSAT, SPOT, EOS and ERS, EOS, POEM

Figure 1 (Continued)

Footnotes: (1) The accuracy and vertical resolution of HIRS in the troposphere are insufficient for climate studies

(2) GEWEX dedicated non-sunsynchronous earth observing mission on a 55-60 degree inclined orbit (undetermined).

(3) AVHRR calibration only marginally adequate for cloud classification, vegetation mapping and sea surface temperature measurements.

(4) TOPEX follow-on high precision ocean altimetry mission (undetermined)

GLOBAL HYDROLOGICAL CYCLE

PROBLEM IS TO COMPLEMENT THE SURFACE-BASED NETWORK FOR DETERMINING GLOBAL PRECIPITATION AND SOIL WETNESS

- GLOBAL PRECIPITATION ESTIMATES EXIST, BASED ON IR CLOUD IMAGES OR PASSIVE μ-WAVE RADIOMETRY AND EMPIRICAL CLIMATIC CORRELATIONS
- VERTICAL DISTRIBUTION OF RAIN DROPS NEEDED FOR DIRECT QUANTITATIVE ESTIMATION
- RESOLVING THE DIURNAL CYCLE IS ESSENTIAL
- TRMM IS ESSENTIAL FIRST STEP. TECHNIQUE TO BE FURTHER DEVELOPED IN FOLLOW-ON "EARTH-SCANNING" MISSION

Figure 2. Global Hydrological Cycle Problem

Figure 2 presents the global hydrological cycle problem. We see that the problem is to compliment the surface based network for determining global precipitation and soil moisture. Global precipitation measurements estimates exist based on infrared cloud images or passive microwave radiometry and empirical climatic correlations. The vertical distribution of raindrops is needed for the direct quantitative estimation of precipitation. Resolving the diurnal cycle is essential which TRMM certainly can do. We need a non-sun-synchronous orbit in order to measure the diurnal cycle. TRMM is the essential first step, but the technique can be further developed in follow-on Earth scanning missions.

TRMM FOLLOW-ON PLANNING

Planning for tropical rainfall measurements to follow TRMM has been a part of the French Space Agency (CNES) planning since Bilan Enegetique du Systeme Tropical (BEST), which means the tropical energy budget, was first proposed in 1989 as a candidate to meet GEWEX space observing system requirements and for an operational mission to begin at the turn of the century. The proposers invited international cooperation, but the mission has never really been approved. In Hamilton, Bermuda where the GEWEX Joint Scientific Steering Group met in January of 1991, the scientific need for continued precipitation measurements from space after the TRMM mission was presented by Professor Pierre Morel, Director of the World Climate Research Program. About that same time the Japanese discussed a plan to begin a TRMM follow-on mission. At the fourth session of Joint Scientific Steering Group for GEWEX, which was held January 1992 in Tokyo, Japan, a resolution was agreed upon that said, "TRMM follow-on missions, that could continue the cooperation between USA and Japan, include discussions of a satellite launched after the year 2000 in a 55 degree inclined orbit with an advanced multi-beam, multi-frequency precipitation radar, and an advanced passive microwave imager." (From presentation by Thomas La Vigna, GSFC, January 1993).

A TRMM follow-on was also discussed at the International Workshop on the Processing and Utilization of the Rainfall Data Measured from Space which was held March 1992 in Tokyo, Japan. At that time it had been established that precipitation is an important component of the Earth system which influences global weather and the climate. Moreover, there now exists strong evidence that rain rates can be measured from space platforms to within the scientific requirements for improving weather forecasting and for improving the models used in the prediction of climate change. Continuation of the measurements is crucial for detecting and monitoring global change of precipitation. In view of these considerations, the workshop participants strongly endorsed the concept of a follow-on mission to TRMM. They urged that the necessary steps be taken by NASA, NASDA, ESA, and CNES to begin pre-phase A studies immediately for such a cooperative mission. A candidate configuration for a 55 degree inclination orbit, which allows sampling over the diurnal cycle and full coverage of the mid-latitude weather, was put forward. The payload was suggested to be similar to that of TRMM except for upgrades in the instruments, such as the dual frequency radar, multi-channel microwave radiometer, and visible and infrared radiometers.

At the International Symposium on Active Sensors and Non-Synchronous Missions Dedicated to GEWEX, held June 1992 in Jouy en Josas, France, strong science recommendations came for the continued measurement of precipitation from space after TRMM. The meeting proposed a non-sun-synchronous mission to extend the results of TRMM beyond the tropics in order to realize the global objectives of GEWEX. The various space agencies were encouraged to define the scope and specification of a TRMM follow-on mission and sensors for appropriate interactions with the scientific community, to coordinate and conduct the corresponding feasibility studies and development, with a view to creating the conditions for a program decision, and accomplish studies and trade-off assessments of several options for the rain radar, for example, dual beam, two-frequency, and dual polarization.

At the Asia-Pacific International Space Year Conference, "The Earth in Space", held November 1992 in Tokyo, Japan, the opening key lecture by Professor P. Morel discussed a follow-on TRMM for continued measurements from space of rainfall and importance to climate models. The opening day lecture by S. Tilford entitled "U. S. Earth Observation Satellite Program" discussed future potential space missions including a TRMM follow-on, TRMM-2.

In the GEWEX Dedicated Space Mission Study Workshop, held November 1992 in Tokyo, Japan, the focus was on a TRMM follow-on mission. The workshop recommendations included unique and essential scientific requirements for GEWEX and global climate science as being the observations of radiation, clouds, and rain which show diurnal variations, and for the latter two parameters, vertical resolutions are indispensable for characterizing relationship among these quantities. In order to meet these requirements, a TRMM follow-on mission is required to provide data continuity over the tropics and to extend coverage to higher latitudes. In view of these considerations NASDA's proposal for a TRMM follow-on mission aiming at a launch in the year 2000 was endorsed as a basis for development. In addition to the original TRMM instruments, inclusion of a cloud profiling radar was recommended to be considered for monitoring the global 3-dimensional distributions of clouds.

At the 6th Standing Senior Liaison Group (SSLG) Meeting, held December 1992 in Washington, D.C., the NASDA presentation entitled "Study on TRMM Follow-On" also recommended that the TRMM follow-on mission to meet GEWEX requirements be started. There are a number of improvements which could be made to the basic TRMM in the TRMM follow-on. However, in order to meet the schedule laid out for continuing the observations, which would mean a launch in the year 2000, it appears that changes for the TRMM follow-on will be minimal. They will include only the increase in the inclination angle to 50 to 60 degrees of latitude, in order to cover the globe more geographically, and an increase in the altitude of the orbit so that the space craft will be able to have a five year lifetime. This basically means that the radar might have to be increased in power and antenna size. The passive microwave imager might also have to be increased in antenna size in order to keep the resolution of the footprint small enough to observe rainfall accurately, especially in convective situations.

Other improvements, such as the inclusion of a radar with multiple frequencies, or a push-broom type scan pattern, or polarization, or all of these, will have to wait until a successor mission to the TRMM follow-on. Likewise, a cloud radar whose feasibility has not been demonstrated yet will also have to await development at the laboratory and aircraft levels to prove the concept. Then, possibly, it can be implemented on a mission sometime after the year 2000.

SUMMARY REMARKS

If we are to maintain data continuity, we need to initiate a TRMM follow-on mission very soon. NASA is considering this action and may fund a study on the subject during this fiscal year. The resources to fund the phase C/D portions of the mission remain to be identified. They will have to compete with all the other ideas that have been proposed for specialized Earth Probe Missions in the years following the turn of the century. The measurement of rainfall from space is and ought to be a high priority in studying the Earth system and global change. It remains to be seen whether we can improve upon the very fundamental measurements that TRMM will make. How we go about this should be the subject of continuing research in the years between now and the end of the decade.

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