Rain Systems of Amazonia
Grant ATM-9001269

Report on the Second Year

David W. Martin
25 November 1992

1. Progress

The project concerns moisture over Amazonia. It has two parts, a classification of rain systems and an estimate of evapotranspiration (ET). Classification is the more important of the two parts.

The estimate of ET was carried over from an earlier grant and was to have been completed during the first year. The classification of rain systems was to proceed along two paths, an Eulerian analysis and a Lagrangian analysis. The Eulerian analysis involves fixed areas and definite periods. The Lagrangian analysis is keyed to individual rain systems. The Eulerian analysis, in turn, consists of two parts, an analysis of events and an analysis of clouds. The events analysis depends on sequential measurements of rain and some other variables at a handful of stations and is being done mainly at Western Michigan University. The clouds analysis depends on sequences of geostationary satellite images and is being done mainly at the University of Wisconsin.

Over the period since the report on the first year of the project we expected to install the University of Washington cloud cluster tracking program on a local work station, to construct a Geostationary Operational Environmental Satellite (GOES) data set for the period of the Amazon experiment FLUAMAZ and to revise the ET manuscript which we had submitted to the *Journal of Geophysical Research.* After testing the tracking program, we expected to apply it to the FLUAMAZ cloud clusters. (FLUAMAZ took place in 1989, during the transition from dry to wet seasons.) The results of the cluster tracking then were to be related to results from the station analysis. Building on earlier studies, from this comparison we expected to construct a tentative model of the rain systems of the dry-to-wet transition.

Madison's analysis of station rainfall has focused on periodic behavior. We constructed continuous hourly records at two of the rain stations, Careiro (near Manaus) and Federal University of Para (UFPa, in Belem). The continuous records, each spanning the years 1988 through 1990, support searches for periodicities at scales of hours through months. At Careiro now we do find a diurnal signal. In both records there also appears to be a signal corresponding to the Madden/Julian (30 to 60 day) oscillation. Otherwise, spectra for both stations are remarkably flat.

Through the continuous record for Careiro, we also have explored the relationship between hourly rainrate and GOES temperature. Cold temperatures lag high rainrates by one to two hours. Peak correlation increases as the rainrate series is smoothed, but remains disappointingly small (less than 0.5) even for substantial smoothing factors.

There now are four computer-compatible databases of geostationary satellite infrared images for use with the cluster tracking program. Three date from the last report. The first of the new databases covers the last three weeks of FLUAMAZ. It is composed of images from the GOES-7. The other two databases are composed of images from the Meteosat-3 satellite, which affords a much better look angle than did GOES-7 during FLUAMAZ. The first of the Meteosat archives covers the month of March 1992; the second, the period from 13 September through 3 October of 1992. The September/October archive overlaps two coordinated field campaigns conducted in and near South America, the Rondonia Boundary Layer Experiment (RBLE) and the Transport and Air Chemistry Experiment-Atlantic (TRACE-A). From this archive we have supplied data to Prof. Garstang's group.

We have installed the University of Washington cloud cluster tracking algorithm on RISC work stations at both UW-Madison and Western Michigan University. Using the UW-Madison work station and the Man-computer Interactive Data System (McIDAS), we have processed the March set of Meteosat infrared images. In checking output from the program we found that cluster areas are in error by up to 20% because of a mistake in our input values. It may be possible to correct the error rather than reprocessing the set of images. This error notwithstanding, the analysis to date suggests that Amazonia's clusters may be rather different from those of the warm pool of the western Pacific.

Unexpectedly, the *Journal of Geophysical Research* rejected the ET manuscript. Since then we have revised the manuscript and resubmitted it for possible publication in a special issue of *Remote Sensing Reviews*.

The transcription of GOES images (from videocassette to computer-compatible tape) proved to be expensive--about $12 per image pair. To cut costs and at the same time exploit a superior view angle, twice this year we archived real-time images of Meteosat-3. The first archive (month of March) suffered from nine percent missed images. At substantial expense to the project, we purchased missed infrared images (but not visible or water vapor images) from the European Space Operations Center. The second archive (three weeks in September and October) was virtually complete. We will not purchase any of the three missing images.

Finding a local work station with power to run the Washington cluster tracking program and at the same time with a link to McIDAS proved to be difficult. Presently we are running the tracking program on a RISC machine belonging to the High-resolution

Interferometer Spectrometer (HIS) project at UW-Madison, with backup on a SUN SPARC at Western Michigan University.

We have not yet tried to relate satellite and station views and have just begun to synthesize the various station analyses. Therefore, our present model of Amazon rain systems is one-dimensional.

2. Research Plans

We will monitor the progress of the ET paper as it moves through the review process. Coordinating with Western Michigan, we also will consolidate and document the station analysis of rainrate. The documentation will culminate in one or two manuscripts, which will be submitted for publication in the refereed literature.

Our main effort will focus on the cluster analysis. Once we are satisfied the program is working as intended, we will analyze output from the March data set. For cluster elements (the cloud components of each cluster) as well as for clusters themselves the analysis will include bulk statistics, maps, frequency distributions and time series plots. Matters of particular interest to us are size distribution, geographic distribution, diurnal variability, trends and behavior. Using ground observations we will relate cluster structure and behavior to rain and tropospheric circulation. From this synthesis of satellite and ground views we will try to distill conceptual models of the two or three main Amazon wet season rain systems. If time and resources permit, we will run the tracking program on the September/October data set as well. Results from this survey of dry-season clusters will be compared with results from the wet-season survey. Wet-season conceptual models will be modified or extended to embrace dry-season rain systems. We also expect this part of the project to yield one or two publishable manuscripts.

3. There have been no changes in project personnel.

4. The manuscript we have submitted to *Remote Sensing Reviews* is entitled, "A Satellite-Based Estimate of Evapotranspiration over Amazonia". With partial support from the present grant, we have prepared a second manuscript, "A Non-Linear Algorithm for Estimating 3-Hourly Rain Rates over Amazonia from GOES/VISSR Observations", for *Remote Sensing Reviews*. In the proceedings of the International Workshop on the Processing and Utilization of the Rainfall Data Measured from Space, which was held in Tokyo last March, we published an extended abstract, "Phenomenology of Amazon Rain and Its Impact on TRMM". A copy of this paper is attached.

5. A table of funding support for the PI is attached.

6. Wen-Seh Lin receives support from the grant. Ms. Lin is a candidate for the Master of Science degree. In September the PI gave an invited talk, "Observations of Anthropogenic Change and Climate Change in Amazonia", to a graduate seminar in the Oceanic and Atmospheric Science department. The PI also serves on a campus advisory committee for a Brazil/Wisconsin socio-agricultural project which focuses on Amazonia.

7. A summary budget form is attached. This budget differs from the original budget in requesting additional funds for data, in particular, the September/October archive of Meteosat-3 data.

CURRENT SUPPORT

Principal Investigator

Rain Systems of American	NSF	Renewable through January 1994	2.5
Application of Satellite Data Bases to Determine the Influence of Vegetation and Moisture on Clouds and Regional Energy Budgets	NOAA	Renewable through August 1994	2.3
British Columbia Hydroelectric	Atmospheric Dynamics Inc.	December 1992	1

Project Scientist

A Facility Team Member for a Tropical Rainfall and Energy Analysis Experiment	NASA	May 1993	2.3

Note: Support is in man-months per project year.

Conclusion

We have analyzed rainfall at two stations in Amazonia, one central and one coastal. In the range of periods ordinarily associated with tropical disturbances there was little structure in the rain records for either station. At the central station (Careiro) this statement holds down to a period of one day. Rain at Careiro also was significantly more variable than rain at UFPa.

At Careiro hourly rain rate was weakly (inversely) related to hourly window radiance observed by a geosynchronous satellite. This result implies that infrared image sequences alone would not be effective in describing the spacial character of Amazonia rainfall on scales of tens of kilometers. Visible image sequences might complement infrared sequences in describing rainfall on such scales. Plausibly, the best combination would be a geosynchronous visible/infrared image sequence with radar and microwave images from TRMM.

The absence of strong periodicities in the rain records for the two stations suggests a regime of rain which is different from those with which we are familiar. This in turn may imply a need for an additional measure of flexibility in TRMM algorithms. TOGA/COARE, which shares Amazonia's equatorial siting, may go far towards resolving this issue.

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Harriss, R. C., S. C. Wofsy, M. Garstang, E. V. Browell, L. C. B. Molion, R. J. McNeal, J. M. Hoell, Jr., R. J. Bendura, S. M. Beck, R. L. Navarro, J. T. Riley and R. L. Snell, 1988: The Amazon Boundary Layer Experiment (ABLE 2A): Dry season 1985. J. Geophys. Res., 93, 1351-1360.

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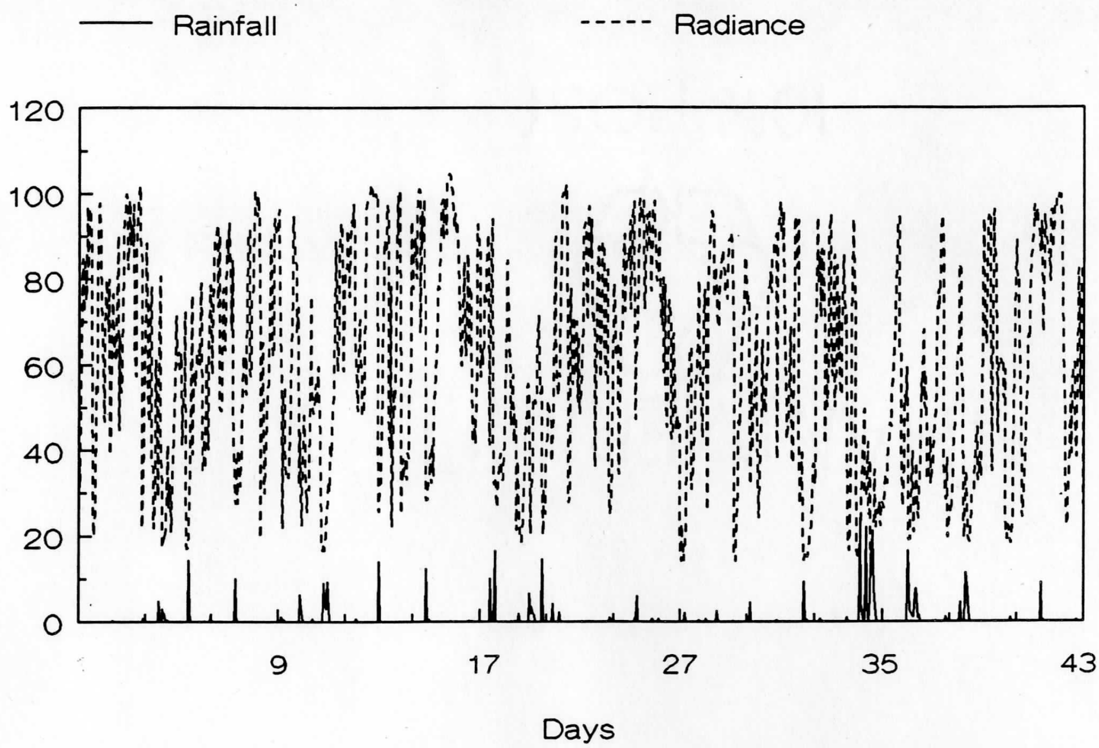
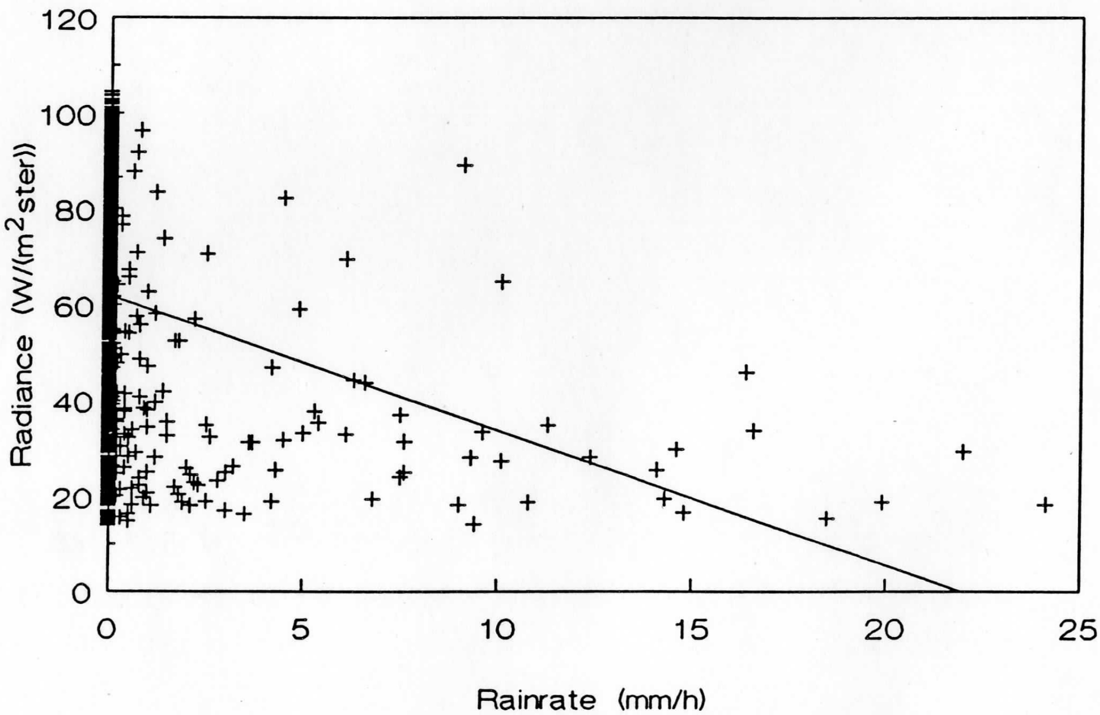
Wei, M. Y., D. R. Johnson and R. D. Townsend, 1983: Seasonal distributions of diabatic heating during the First GARP Global Experiment. Tellus, 35A, 241-255.



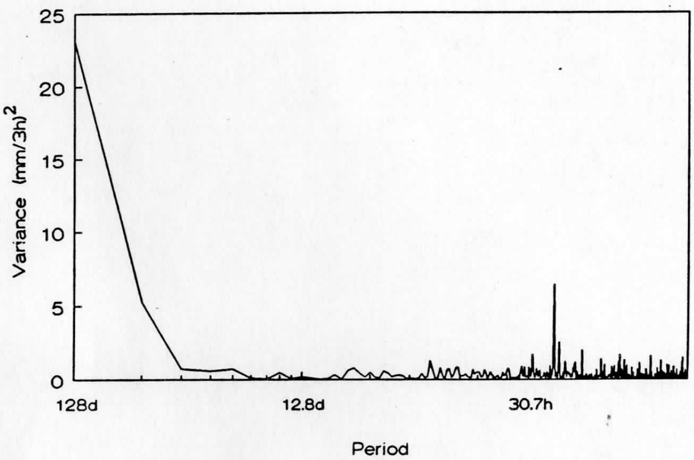
5. Time series of rainfall (mm/h; solid line) and satellite infrared radiance ($W/(m^2$ ster); dashed line) at Careiro. The period covered is 00 UTC on 1 January 1990 through 15 UTC on 11 February 1990; the sample size is 1024.



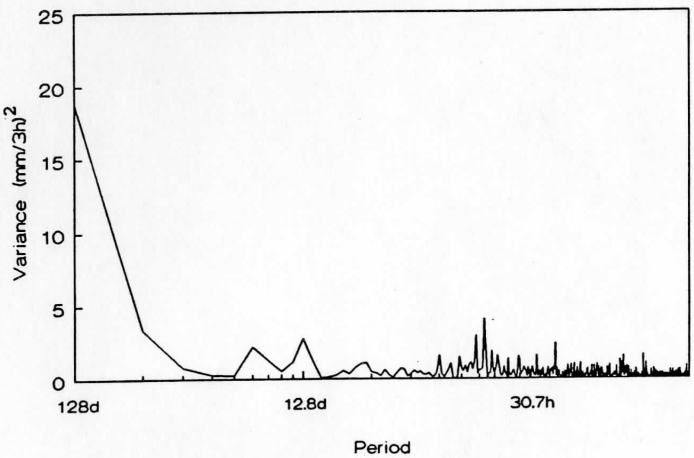
6. Scatterplot of radiance versus rainrate for the sample shown in Figure 5. Also shown is the least-squares linear regression line of radiance on rainrate.

In three other respects, Careiro differed significantly from UFPa. First, despite its lower annual rainfall, rain was recorded on five out of ten days (not shown). Second, a larger fraction of rain fell at heavier rates (note in the table the factor two difference in skewness). Finally, as the spectrum of 3 h rainfall for January, February and March of 1989 shows (Figure 4), there is at best a modest spike at 24 hours. (This was the case for a dry-season spectrum as well.) As at UFPa, variance in rain at Careiro was dispersed across a broad range of frequencies.

3. Spectrum of 3 h rainfall at UFPa. The period covered is 1 January 1989 through 31 March 1989. A period of 128 days corresponds to a frequency of one.



4. Spectrum of 3 h rainfall at Careiro. Otherwise, as for Figure 3.



Radiance

Preliminary work with the rain/radiance time series underscores the difficulties many have experienced in using infrared images to estimate rainrate. We show time series of hourly radiance and hourly rainrate for the first 1024 h (43.7 days) of 1990 in Figure 5. Apparently, large rainrates were associated with low radiances. However, at times low radiances occurred in the absence of rain.

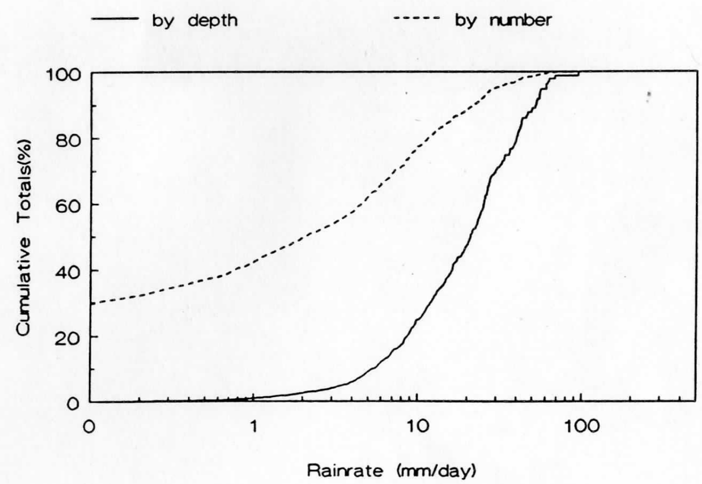
This relationship is easier to see in Figure 6. Indeed, rain and radiance were anticorrelated. For this set of data the coefficient is -0.25.

The predominant periodicity in daily rainfall was one year (Figure 2). Its amplitude was small (about 200 mm, which is <10% of the annual rainfall).

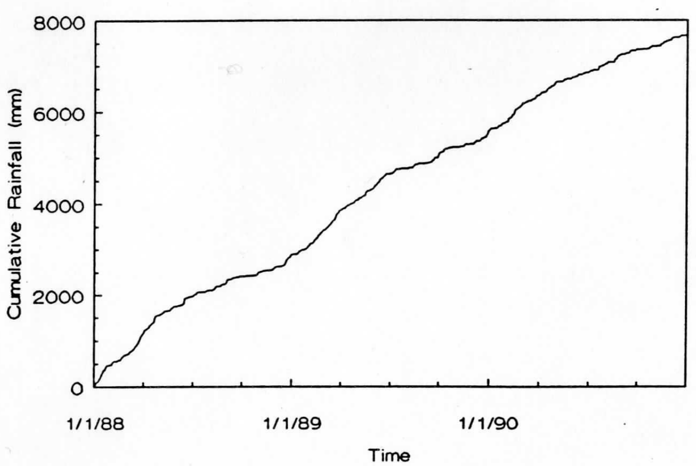
The cumulative rainfall curve (Figure 2) implies structure at all periods from one year down to two days. To test this inference we calculated the spectrum of power in 3 h rainrates covering two different periods from 1989. The spectrum for January, February and March, a wet-season period, is shown in Figure 3 (that for the dry-season period, July, August and September, is similar). As expected (e.g., see Kousky 1980), there is a spike at a period of 24 hours. Otherwise, the variance up to and including the period of 30 to 60 day waves is dispersed.

At Careiro, a river station 25 km east of Manaus, the daily mean rainfall over the three years was 12% less than that of UFPa (Table). Nevertheless, the variance was greater. In respect to the ratio of standard deviation to mean (2.3), Careiro is not typical of tropical stations.

1. Cumulative probability as a function of rainrate for daily rainrate at UFPa over the years 1988, 1989 and 1990. The dashed line shows cumulative (percent) fraction of days; the solid line, cumulative (percent) fraction of rainfall.



2. Cumulative daily rainfall for UFPa. The abscissa runs from 1 January 1988 through 31 December 1991.



Proc. International Workshop on the Processing and Utilization of the Rainfall Data Measured from Space
Tokyo
16-19 March 1992

Phenomenology of Amazon Rain and Its Impact on TRMM

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B. B. Hinton[1], W.-S. Lin[1] and V. E. Suomi[1]

Despite recent atmospheric campaigns (e.g., Harriss et al., 1988, 1990; Garstang et al., 1990), and recent studies of large systems (Cohen 1989, Greco et al. 1990, Halverson et al. 1992), in respect to rain Amazonia remains nearly as much a mystery as any tropical ocean. We do not understand the character of Amazonia's rain, much less the mechanisms which produce it. Yet as one of the troposphere's three main centers of diabatic heating (Wei, et al., 1983) it cannot be ignored.

We can expect a leap in our understanding of Amazonian rain from TRMM alone. But for steps we can draw on existing observations, including those from the ground as well as from space. By focussing attention on critical questions these incremental steps could enhance the value of observations from TRMM. They also should help to construct a context for the mission.

For more than a decade the Federal University of Para has operated a small network of autographic raingauges near the cities of Manaus and Belem in Brazilian Amazonia. At hourly resolution, for two stations we have digitized three years of data. The stations are Careiro (3° 5'36"S, 59°45'W) and the Federal University of Para (UFPa; 1° 28' 18"S, 48° 27' 09"W); the years are 1988, 1989 and 1990. Through the course of one year (July 1989 into June 1990) the University of Wisconsin-Madison collected hourly GOES infrared radiances coincident with the gauge at Careiro. In this paper we use these observations to describe the character of rain at the stations and its relation at one station to infrared radiance.

Rainfall

At UFPa 7.7 m of rain fell over the three-year period beginning in January 1988. This averages to falls of 7.0 mm/day (Table), a large number even for a tropical site. The variability of this rainfall was typical of tropical sites (e.g., see Simpson 1988, pp 34-35). For daily falls the standard deviation is 1.6 times the mean.

Rain (of 0.1 mm or more) was recorded on three out of ten days (Figure 1). Only 10% of the total rain fell at daily rates equal to or less than the median (6 mm/day); 10% of the rainy days supplied nearly 40% of the total.

Rainfall
1988-1990
mm

Careiro

Accumulation Period	Mean Value	Standard Deviation	Skewness
One Day	6.0	13.7	5.0
One Month	182	112	0.54
One year	2184	---	---

Federal University of Para

Accumulation Period	Mean Value	Standard Deviation	Skewness
One Day	7.0	11.1	2.6
One Month	213	113	0.88
One year	2561	---	---

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(SEE INSTRUCTIONS ON REVERSE BEFORE COMPLETING)

SUMMARY PROPOSAL BUDGET

1February 1993 thru 31 January 1994

ORGANIZATION	FOR NSF USE ONLY		
University of Wisconsin Space Science and Engineering Center	PROPOSAL NO.	DURATION (MONTHS) Proposed	Granted
PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR: David W. Martin	AWARD NO.		

A. SENIOR PERSONNEL: PI/PD, Co-PI's, Faculty and Other Senior Associates (List each separately with title; A.6. show number in brackets)	NSF FUNDED PERSON-MOS. CAL.	ACAD	SUMR	FUNDS REQUESTED BY PROPOSER	FUNDS GRANTED BY NSF (IF DIFFERENT)
1 PI-Martin	2.9			$ 12,111	
2	0			0	
3	0			0	
4	0			0	
5. ( ) OTHERS (LIST INDIVIDUALLY ON BUDGET EXPLANATION PAGE)					
6. (1) TOTAL SENIOR PERSONNEL (1-5)	2.9			$ 12,111	
B. OTHER PERSONNEL (SHOW NUMBERS IN BRACKETS)					
1. (0) POST DOCTORAL ASSOCIATES	0			0	
2. (0) OTHER PROFESSIONALS (TECHNICIAN, PROGRAMMER, ETC.)	4.7			12,385	
3. (1) GRADUATE STUDENTS				8,435	
4. ( ) UNDERGRADUATE STUDENTS				0	
5. (1) SECRETARIAL-CLERICAL				354	
6. ( ) OTHER					
TOTAL SALARIES AND WAGES (A+B)				33,285	
C. FRINGE BENEFITS (IF CHARGED AS DIRECT COST)				8,391	
TOTAL SALARIES. WAGES AND FRINGE BENEFITS (A+B+C)				41,676	
D. PERMANENT EQUIPMENT (LIST ITEM AND DOLLAR AMOUNT FOR EACH ITEM EXCEEDING $1,000:)					
TOTAL PERMANENT EQUIPMENT				0	
E. TRAVEL 1. DOMESTIC (INCL. CANADA AND U.S. POSSESSIONS)				1,000	
2. FOREIGN				0	
F. PARTICIPANT SUPPORT COSTS					
1. STIPENDS					
2. TRAVEL					
3. SUBSISTENCE					
4. OTHER					
TOTAL PARTICIPANTS COSTS				0	
G. OTHER DIRECT COSTS					
1. MATERIALS AND SUPPLIES INCL. METEOSAT-3 DATA				2,375	
2. PUBLICATION COSTS/PAGE CHARGES				1,050	
3. PURCHASE OF SOFTWARE				0	
4. COMPUTER (ADPE) SERVICES				5,000	
5. SUBCONTRACTS				0	
6. OTHER Tuition Remission				2,193	
TOTAL OTHER DIRECT COSTS				10,618	
H. TOTAL DIRECT COSTS (A THROUGH G)				53,294	
I. INDIRECT COSTS (SPECIFY) 44% of A, B, C, E, F and G1-G4					
TOTAL INDIRECT COSTS				22,485	
J. TOTAL DIRECT AND INDIRECT COSTS (H+I)				75,779	
K. RESIDUAL FUNDS (IF FOR FURTHER SUPPORT OF CURRENT PROJECTS SEE GPM 252 AND 253)				0	
L. AMOUNT OF THIS REQUEST (J) OR (J MINUS K)				$ 75,779	

PI/PD TYPED NAME & SIGNATURE*	DATE	FOR NSF USE ONLY		
David W. Martin [signature]	23Nov92	INDIRECT COST RATE VERIFICATION		
INST. REP. TYPED NAME & SIGNATURE*	DATE	Date Checked	Date of Rate Sheet	Initials-DGC
Robert W. Erickson [signature]				Program

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