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MORNING-EVENING DIFFERENCES IN GLOBAL AND REGIONAL OCEANIC PRECIPITATION AS OBSERVED BY THE SSM/I

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1. INTRODUCTION

Among the important unanswered scientific questions regarding global precipitation are the following: (1) What is the diurnal cycle of tropical oceanic rainfall and how does it vary in space? and (2) what are the relative contributions of convective and stratiform precipitation, and how does their ratio vary in different regions and in different seasons?

While a definitive answer to these and similar questions may have to await the successful conclusion of the Tropical Rainfall Measuring Mission (TRMM) in the late 1990s, we believe relevant information can already be extracted from the data of an operational satellite sensor, the Special Sensor Microwave/Imager (SSM/I). This view is supported by the following preliminary global SSM/I statistics, which appear to show significant morning-evening differences both in the prevalence of moderate to heavy rain and in the mean intensity of convection within those areas unambiguously identified as raining.

Over the open ocean, meaningful observations of the global-scale spatial distribution and temporal evolution of tropical precipitation are currently feasible from satellites alone. To date, much of what is known about the diurnal cycle of convection located well away from land masses is based on infrared observations of cloud tops. For example, Albright et al. (1985) used the fractional coverage by cloud tops with temperatures colder than −36°C, as observed by the GOES-West geostationary satellite, to demonstrate a pronounced diurnal cycle in deep convection over the Central Tropical Pacific. In the Intertropical Convergence Zone (ITCZ), this cycle was found to have a distinct morning maximum and evening minimum, while in other areas, such as the South Pacific Convergence Zone (SPCZ), an afternoon maximum was observed.

In another study, Hartmann and Recker (1986) used nine years of data from the polar-orbiting NOAA series of satellites to compute the diurnal harmonic in outgoing longwave radiation (OLR) throughout the tropical belt. Because diurnal variations in low-level and high-level clouds tended to be 180° out of phase in regions of intense convection over the ocean, the amplitude of the diurnal variation in OLR was perceived to be "a weak reflection of more substantial variations in cloud type in this area."

All such studies to date, excluding those relying on surface observations from a few widely spaced islands or on data obtained during tropical mesoscale field experiments (e.g., Gray and Jacobsen 1977, and studies cited therein), have provided only an indirect measure of the diurnal variations in precipitation associated with tropical oceanic convection. Infrared and visible satellite sensors observe only cloud top parameters, which in the tropics implies mainly the cirrus anvils and blow-off of convective towers.

Satellite microwave techniques are known to offer a more physically direct indication of precipitation activity, and because of the selection of channels available on current microwave sensors like the SSM/I, various 'modes' of interpreting microwave data (e.g., scattering-based vs emission- or attenuation-based algorithms) are available which can potentially be used to extract independent information concerning certain aspects of a storm's microphysical structure and overall intensity. Microwave brightness temperatures are generally unaffected by the non-precipitating cirrus shields which pervade the tropics and play havoc with infrared remote sensing techniques.

Table 1: Definitions of geographic regions.

Region	Latitude	Longitude
1 Tropics	25° S – 25° N	—
2 TWP	25° S – 25° N	120° E – 170° W
3 TCP	25° S – 25° N	170° W – 130° W
4 TEP	25° S – 25° N	130° W – 80° W
5 ITCZ	0° – 15° N	170° W – 130° W
6 SPCZ	25° S – 0°	170° W – 130° W
7 TIO	25° S – 25° N	40° E – 100° E
8 GATE	5° N – 15° N	30° W – 20° W
9 NML	30° N – 60° N	—
10 SML	60° S – 30° S	—

2. DATA AND METHODOLOGY

The SSM/I carries 19.35, 37.0, and 85.5 GHz channels in dual polarization (22.235 GHz is available only in vertical polarization). The dual polarization brightness temperatures at 19.35 and 37.0 GHz lend themselves to adaptations of the Petty and Katsaros (1990, 1991) attenuation-based algorithm, in which the polarization difference is interpreted as a measure of the visibility of the sea surface and thus of effective rain cloud opacity. Alternatively, using the 37.0 and 85.5 GHz channels, one may seek to isolate the so-called scattering signal (e.g, Spencer 1986, Spencer et al. 1989) associated with moderate to heavy cold-cloud precipitation containing precipitation-size ice particles above the freezing level.

While the twice-daily, non-overlapping sampling of the current SSM/I is not ideal for estimating total daily rainfall nor for studying the entire diurnal cycle of precipitation, its sun-synchronous morning-evening orbit coincides well with the maxima and minima of convective activity observed or inferred over many areas of the tropical ocean.

For the present preliminary analysis of oceanic rainfall statistics, global oceanic SSM/I data were simply scanned for pixels which exhibited a 37 GHz polarization difference (vertically polarized brightness temperature minus horizontally polarized brightness temperature) of less than 15 K. Such a low polarization difference over the open ocean is a completely unambiguous indication of moderate to intense precipitation. Co-located brightness temperatures from all seven channels of the SSM/I were saved for each pixel so identified. Bad scans and geographically mislocated blocks of data were objectively identified and removed from the resulting data base.

Regions of lighter rainfall or isolated convective cells are likely to escape detection using the threshold approach described above. Indeed, the data of Petty and Katsaros (1991) suggest that, in the subtropics at least, the chosen polarization threshold of 15 K will cap-

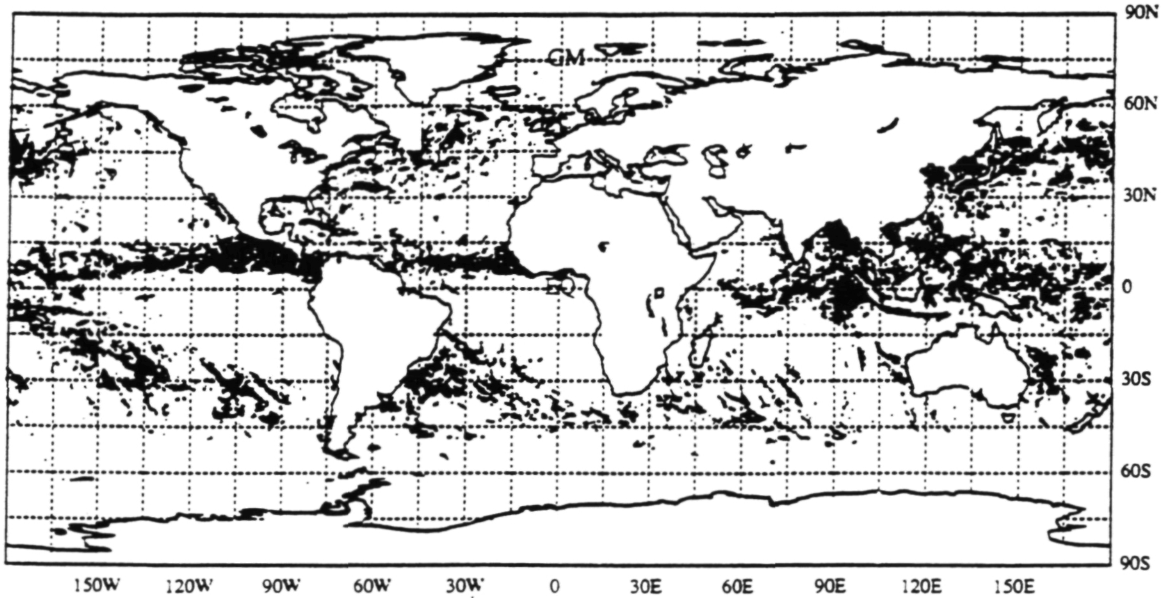
Table 2: Number of SSM/I pixels with 37 GHz polarization differences of less than 15 K, for the period 20 July 1987 — 19 August 1987 (by latitude belt).

Latitude	AM	PM	AM/PM
45°N – 60°N	3,351	2,737	1.22
30°N – 45°N	7,737	4,764	1.62
15°N – 30°N	4,078	3,265	1.25
0° – 15°N	20,927	16,313	1.28
15°S – 0°	6,359	4,463	1.42
30°S – 15°S	6,322	5,054	1.25
45°S – 30°S	7,877	8,037	0.98
60°S – 45°S	769	640	1.20
Total	57,420	45,273	1.27

Table 3: Number of SSM/I pixels with 37 GHz polarization differences of less than 15 K, for the period 20 July 1987 — 19 August 1987 (by region).

Region	AM	PM	AM/PM
1 Tropics	33,971	25,895	1.31
2 TWP	5,978	5,327	1.12
3 TCP	7,428	6,525	1.14
4 TEP	6,524	5,649	1.15
5 ITCZ	3,606	3,094	1.17
6 SPCZ.	3,681	3,389	1.09
7 TIO	7,456	4,352	1.71
8 GATE	772	732	1.05
9 NML	11,085	7,501	1.48
10 SML	8,646	8,677	1.00

MORNING (20 July 1987 -- 19 August 1987)



EVENING (20 July 1987 -- 19 August 1987)

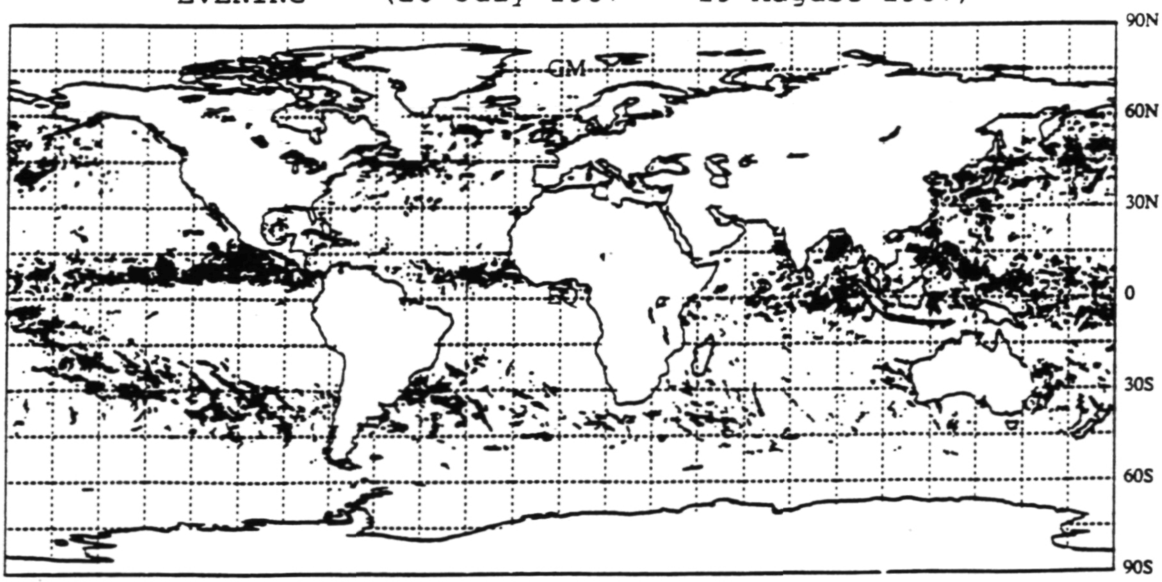


Fig. 1 Locations of SSM/I pixels with 37 GHz polarization differences of less than 15 K, for the period 20 July 1987 — 19 August 1987.

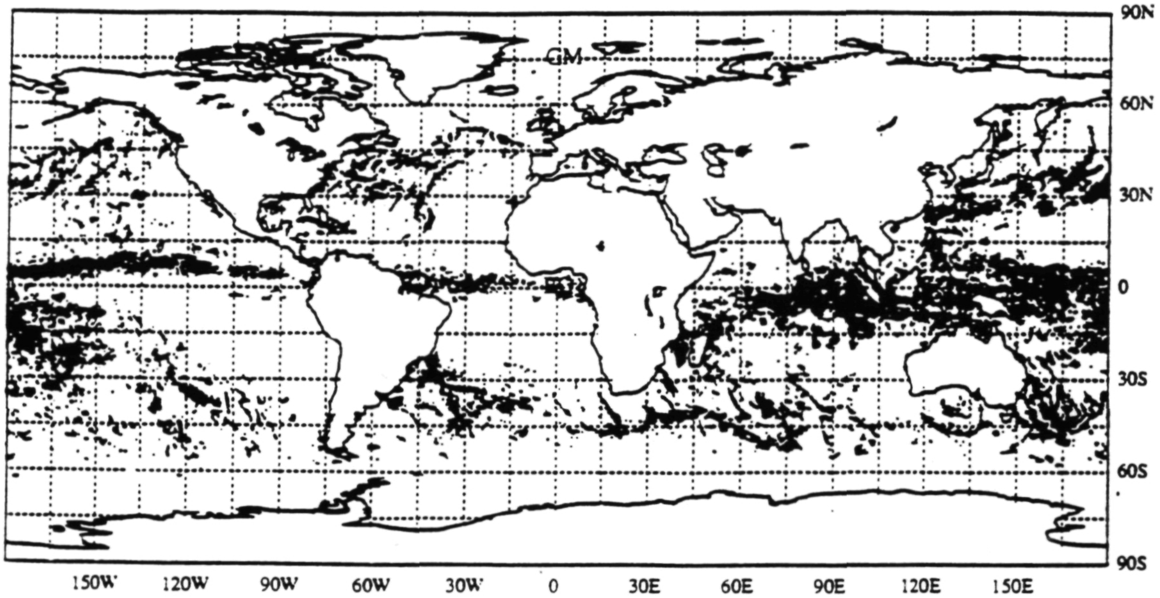
Table 4: Number of SSM/I pixels with 37 GHz polarization differences of less than 15 K, for the period 13 January 1988 — 12 February 1988 (by latitude belt).

Latitude	AM	PM	AM/PM
45°N – 60°N	2,067	2,251	0.92
30°N – 45°N	6,576	6,316	1.04
15°N – 30°N	4,108	3,530	1.16
0° – 15°N	14,476	9,124	1.59
15°S – 0°	16,760	9,810	1.71
30°S – 15°S	7,610	6,646	1.15
45°S – 30°S	10,040	10,161	0.99
60°S – 45°S	3,711	3,782	0.98
Total	65,348	51,620	1.27

Table 5: Number of SSM/I pixels with 37 GHz polarization differences of less than 15 K, for the period 13 January 1988 — 12 February 1988 (by region).

Region	AM	PM	AM/PM
1 Tropics	38,546	24,536	1.57
2 TWP	9,609	4,572	2.10
3 TCP	12,507	7,635	1.64
4 TEP	1,856	1,743	1.06
5 ITCZ	5,332	2,764	1.93
6 SPCZ	6,921	4,666	1.48
7 TIO	9,590	7,005	1.37
8 GATE	0	0	—
9 NML	8,639	8,561	1.01
10 SML	13,751	13,943	0.99

MORNING (13 January 1988 -- 12 February 1988)



EVENING (13 January 1988 -- 12 February 1988)

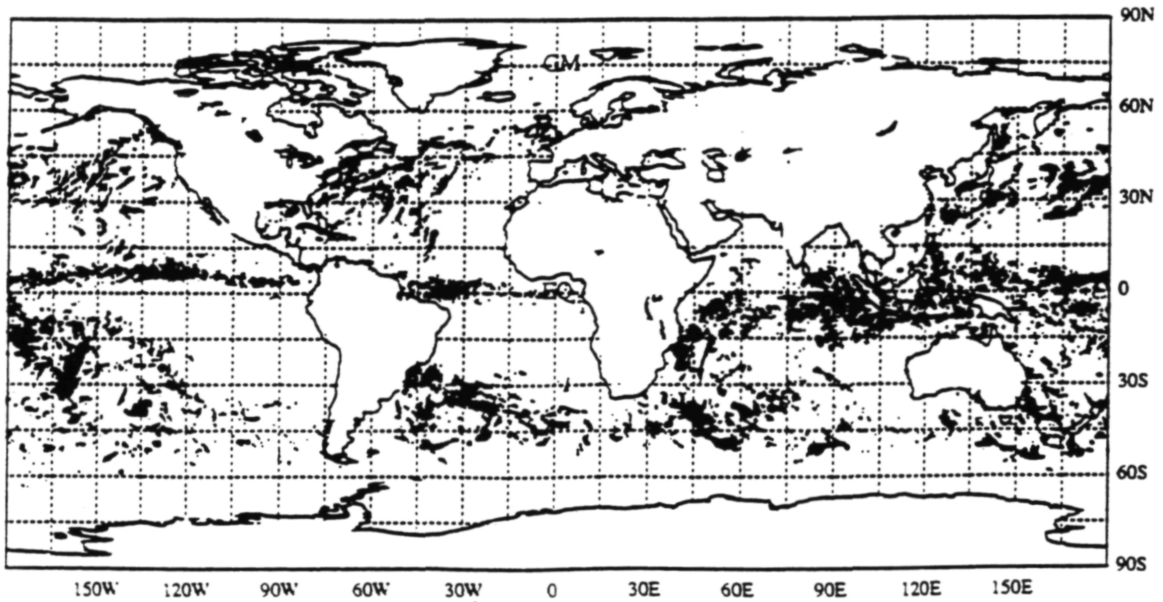


Fig. 2 Locations of SSM/I pixels with 37 GHz polarization differences of less than 15 K, for the period 13 January 1988 — 12 February 1988.

ture only about one fourth (by volume) of the total rainfall sampled by the SSM/I. Moreover, since the polarization threshold was not adjusted to account for regional variations in water vapor amount, surface roughness, and rain layer depth, the percentage of rainfall which escapes detection will vary from one storm to the next and, in particular, from the tropics to the midlatitudes. However, since our initial objective was simply to establish whether significant morning-evening differences could be discerned in the SSM/I data, irrespective of the absolute value of the total rainfall, the obvious limitations of a fixed threshold method can be tolerated.

We collected global oceanic rainfall data for two time periods, each one month in length. The first period (20 July–19 August 1987) coincides with the peak of the Northern Hemisphere summer. Because it also falls in the middle of the June–September season during which the GARP Atlantic Experiment (GATE) was conducted in 1974, results obtained from the SSM/I for the GATE area may be reasonably compared with the earlier GATE results. The second period (13 January – 12 February 1988) coincides with the Northern Hemisphere winter, and SSM/I results for the central tropical Pacific may be compared with those of Albright et al. (1985) obtained for the period January–February 1979.

For each of the two periods, data were classified according to whether they corresponded to a morning pass (approximately 0600 LST at the equator; Figs.1a and 2a) or an evening pass (approximately 1800 LST; Figs. 1b and 2b). The data were further stratified by 15° latitude belts and by specific geographic regions. Regions considered include (1) the Tropics, (2) the Tropical Western Pacific (TWP), (3) the Tropical Central Pacific (TCP), (4) the Tropical Eastern Pacific (TEP), (5) a portion of the Pacific Intertropical Convergence Zone (ITCZ), (6) the Southern Pacific Convergence Zone (SPCZ), (7) the Tropical Indian Ocean (TIO), (8) the GATE region, (9) Northern Midlatitudes (NML), and (10) Southern Midlatitudes (SML). Definitions of these regions are given in Table 1.

3. RESULTS

A simple count of the number of saved pixels gives a consistent and clear picture of significant morning-evening differences in the areal coverage by precipitation that is intense enough and of sufficient horizontal extent to fulfill the 37 GHz polarization criterion. Tables 2 and 4 show that not only are global morning totals 27% larger than evening totals, both for the January–February period and the July–August period, but the morning values are also higher for almost all latitude belts taken individually.

The same picture emerges when the data are considered by region: Table 3 shows that only in the Southern Midlatitudes are the evening totals larger than the morning totals, and then only by an insignificant amount. Elsewhere, the morning total is greater than the evening total by up to a factor of two. A significant morning excess during January-February is observed even in the SPCZ, where Albright et al. (1985) had inferred an afternoon maximum from their infrared satellite observations.

An obvious question to ask in the face of these consistent results is whether the apparent morning-evening differences could be an artifact of a systematic calibration fluctuation in the sensor itself. Since the number of pixels flagged would fall off rather rapidly as the 37 GHz polarization difference threshold is reduced below 15 K, even a modest calibration shift beteen morning and evening could conceivably give rise to the large observed differences in the totals.

Also, since we did not compute the number of pixels saved as a fraction of the total number of pixels falling withing a particular geographic region, it is not yet clear whether any morning-evening biases might have been introduced by systematic differences in the sample size. However, we feel that the weight of the evidence speaks against either a calibration fluctuation or a sampling bias as being the source of the differences.

For example, the 37 GHz polarization thresholds which define various fractions of the archived pixels for selected regions were found to differ by at most 0.5 K from morning to evening, and usually much less. Differences of this size are consistent with random statistical fluctuations in the sample population. *A calibration fluctuation of over 3 K would be required, however, to explain the mean observed difference of 44% between morning and evening totals for the tropics.*

Perhaps even more significantly, 10th-percentile 85.5 GHz brightness temperatures (vertically polarized) are approximately 5 K *lower* for the global AM pixels than for the PM pixels, suggesting that *not only is there a larger fractional coverage by rain in the morning* according to the 37 GHz polarization criterion, but *the average intensity of convection within that rain is also greater.* These results are the opposite of what would be expected if the true morning and evening characteristics of rainfall were in fact identical and a periodic calibration shift had simply biased the sample to include lighter rain events in the morning. Similarly, one would not expect such a large difference in the 85 GHz T_B if the total area sampled by the SSM/I were simply smaller during the evening passes due to missing data.

4. CONCLUSIONS

The data presented here for July-August 1987 and January-February 1988 appear to confirm a tendency toward significantly greater areal extent (based on the number of pixels meeting the 37 GHz polarization criterion) and greater mean intensity (based on the 85 GHz brightness temperature depressions of those pixels) of oceanic rainfall in the early morning (~0600 LST) than in the evening (~1800 LST), over much of the world's oceans. Only poleward of 45° latitude did we in some cases fail to observe a morning maximum. Interestingly, the morning totals were greater even in the South Pacific Convergence Zone, where Albright et al. (1985) had previously found an afternoon maximum, based on an IR brightness temperature threshold technique.

Because of the relatively crude method used here, the data presented must be regarded as preliminary. We plan to refine our approach in the near future, using improved algorithms and a larger SSM/I data set in order to reduce uncertainties related to sampling and in an effort to extract quantitative information concerning the total areal extent, physical characteristics, and temporal and regional variability of global oceanic precipitation.

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References

Albright, M.D., E.E. Recker, R.J. Reed, and R. Dang 1985: The diurnal variation of deep convection and inferred precipitation in the Central Tropical Pacific during January–February 1979. *Mon. Wea. Rev.*, **113**, 1663–1680

Gray, W.M., and R.W. Jacobsen, Jr., 1977: Diurnal variation of deep cumulus convection. *Mon. Wea. Rev.*, **105**, 1600-1616

Hartmann, D.L., and E.E. Recker, 1986: Diurnal variation of outgoing longwave radiation in the tropics. *J. Climate Appl. Meteor.*, **25**, 800–812

Petty, G.W., and K.B. Katsaros 1990: Precipitation observed over the South China Sea by the Nimbus 7 Scanning Multichannel Microwave Radiometer during Winter MONEX. *J. Appl. Meteor.*, **29**, 273–287

Petty, G.W., and K.B. Katsaros 1991: Nimbus 7 SMMR precipitation observations calibrated against surface radar during TAMEX. To appear in *J. Appl. Meteor.*

Spencer, R.W. 1986: A satellite passive 37 GHz scattering-based method for measuring oceanic rain rates. *J. Climate Appl. Meteor.*, **25**, 754–766

Spencer, R.W., H.M. Goodman, and R.E. Hood 1989: Precipitation retrieval over land and ocean with the SSM/I: Identification and characteristics of the scattering signal. *J. Atmos. Ocean. Tech.*, **6**, 254–273