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11. Orbit and Sampling Requirements: TRMM Experience

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Introduction. The Tropical Rainfall Measuring Mission (TRMM) concept originated in 1984 (Simpson *et al.*, 1988). Its overall goal is to produce datasets that can be used in the improvement of general circulation models. A primary objective is a multiyear data stream of monthly averages of rainrate over 500 km boxes over the tropical oceans. Vertical distributions of the hydrometers, related to latent heat profiles, and the diurnal cycle of rainrates are secondary products believed to be accessible. The mission is sponsored jointly by the U.S. and Japan. TRMM is an approved mission with launch set for 1997. There are many retrieval and ground truth issues still being studied for TRMM, but here we concentrate on sampling since it is the single largest term in the error budget.

The TRMM orbit plane is inclined by 35° to the equator, which leads to a precession of the visits to a given grid box through the local hours of the day, requiring three to six weeks to complete the diurnal cycle, depending on latitude. For sampling studies we can consider the swath width to be about 700 km. Figure 11.1 shows a visit sequence (local time versus day of month) for a month for the TRMM satellite (Shin and North, 1989). This illustrates the latitude dependence of the sampling sequence.

Types of Sampling. TRMM sampling studies have been of three types:

1) Given a dataset of rainrates collected from a ground site or for a special observing period, such as the GATE, we can "fly" an ensemble of imaginary TRMM satellites over the data and see how the sampling by the satellite ensemble agrees with the actual average rainrate for the month. This approach was pursued by McConnell and North (1987) and Kedem *et al.* (1990), who found that the errors for a 280 km square box over a three week period were of the order of 10%.

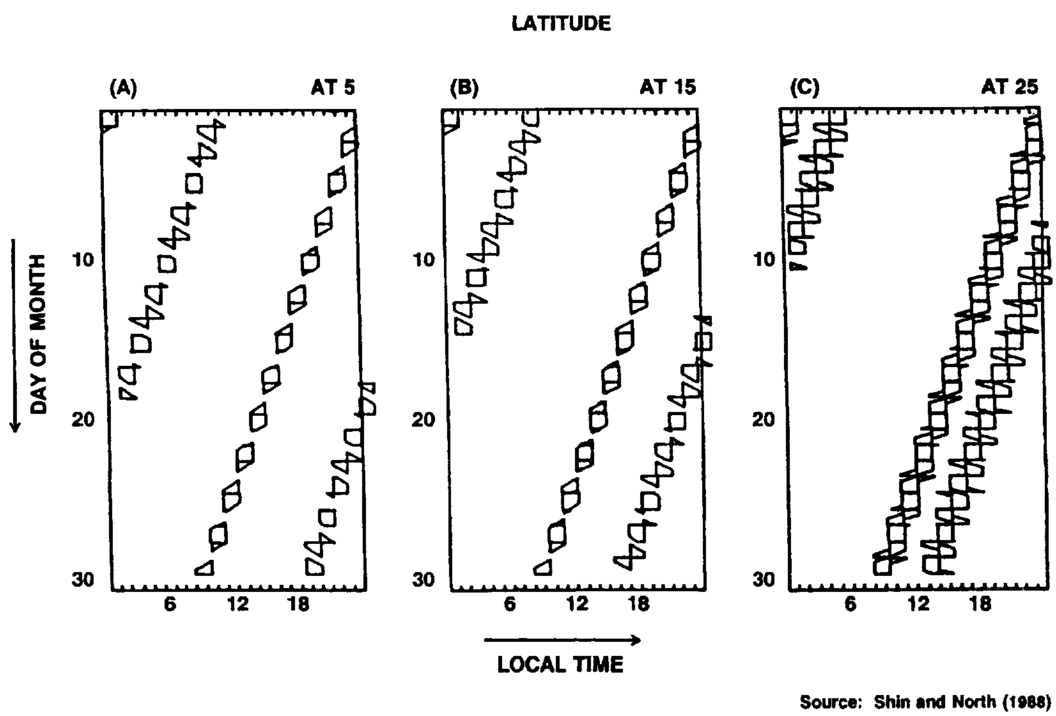

Fig. 11.1. The visiting sequences and fractional coverages through a month for the TRMM orbit (300 km altitude and 35° inclination) for different latitudes [(a) at 5°, (b) at 15°, (c) at 25°].

2) We can make models of the rainrate field, tuning them to the GATE data, then "fly" ensembles of satellites over the data field to check the error. The advantage of the models is that we can make the gridbox larger and we can change parameters to represent the differences in climatology over different regions and seasons. The first such model was formulated by Laughlin (1981) as a simple first order autoregressive model of the area averaged rainrates. An extension of Laughlin's method was presented with many numerical results for TRMM by Shin and North (1989). A very comprehensive rainfield model was constructed by Bell (1987) and TRMM calculations were presented later by Bell *et al.* (1990). Bell's model is a fully two dimensional random field simulation which includes all the spatial-temporal second moment statistics and the correct probability distribution function for the rainrates as tuned from GATE.

3) The last class of studies makes use of the spectral form of the mean square error (MSE). North and Nakamoto (1989) showed that the MSE can be written as an integral of the space-time spectral density of the rainrate field, weighted by a filter which depends only on the sampling design, be it single or multiple satellite or rain gauges (North *et al.*, 1991; North *et al.*, 1992). This last formulation is particularly useful since we can imagine optimally weighting the data from different sources to form the best estimate of the space-time averages.

Root mean square error results (monthly average rainrate) for various satellite orbit parameters are shown in Fig. 11.2 as percent of the mean. We see that the errors for TRMM (inscribed box) are 10 to 12%. A sun-synchronous satellite at 800 km altitude would give only 10% errors. (TRMM has a low altitude to achieve high resolution of the individual field-of-views and to conservé radar power.)

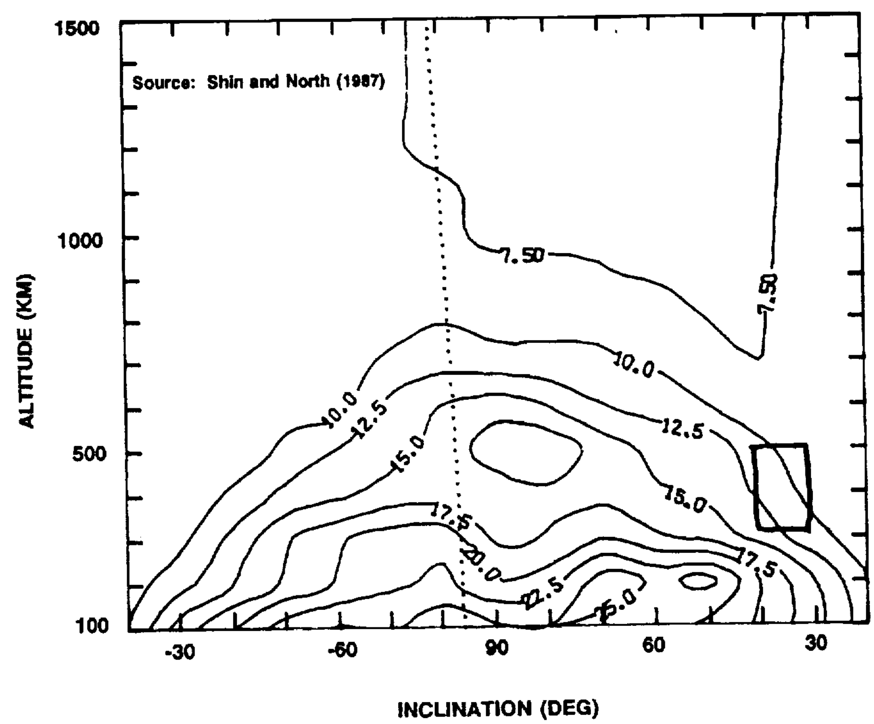

Fig. 11.2. Distribution of rms sampling errors in monthly mean rainfall rate (percent of mean value) as a function of satellite altitude and orbit inclination (Shin and North, 1987).

Main factors determining sampling errors. The studies so far have indicated that the main factors determining sampling error are the autocorrelation time of the grid-box area averaged rainrate field and the variance of the grid-box averaged rainrate. Autocorrelation times for rainrates for 500 km boxes tend to be about 10 or 12 hours which is comparable to the revisit time for the satellite (at the equator). Revisit configurations of this type will lead to approximately 10% errors. The errors can obviously be reduced substantially by introducing data from a separate satellite, say a polar orbiter. North *et al.* (1992) showed that optimally combining data from the DMSP microwave radiometer with TRMM leads to errors of the order of 6%, which is probably comparable to other errors in the measurement process. The root mean square error in percent is proportional to the ratio of standard deviation to the mean for the area averages. Hence, we prefer areas with small fluctuations in their area averages. For GATE this ratio appears to be about 1.25.

The autocorrelation time increases with grid box area in the tropics (e.g., Bell *et al.*, 1990). Similarly the variance of area averages decreases smoothly as a function of grid box size (Shin and North, 1989). Hence, use of large averaging boxes reduces sampling error in several ways, including the fact that small boxes are missed more often by the swath. While this has not been thoroughly studied, there are likely to be useful tradeoffs between larger areas and shorter averaging times, especially when two or more satellites are used.

Outstanding estimation issues. Most of the TRMM studies are tuned in one way or another to the GATE dataset. Two studies (Shin *et al.*, 1990; Shin and North, 1991) suggest that GATE is reasonably representative of the important statistical quantities over the tropical Pacific. However, both studies were essentially qualitative and clearly more work needs to be done.

Extraction of the diurnal cycle is not a trivial matter, since there are severe sampling errors in trying to estimate its amplitude. Bell and Reid (1993) have provided some preliminary indication of these difficulties.

Various aliasing problems arise because of the interaction between the sampling of the diurnal cycle and some natural oscillations in the tropics such as the Madden-Julian waves which have a period of 40-50 days. It appears that to correct for these we will need to introduce other data on the phase and amplitude of the waves.

TRMM and Climsat. TRMM and Climsat have several sampling properties in common: inclined orbit, use of data from multiple sources. My preliminary very crude estimate is that Climsat will have smaller sampling errors than TRMM because the fields being measured have longer autocorrelation times. For example, Cahalan *et al.* (1979) showed that the outgoing IR has autocorrelation times of the order of a day or two for 250 km boxes. Nevertheless, it is advisable to construct random field models of the desired field and conduct observing system simulation experiments. While using data from GCMs is useful, it is not helpful for some of the issues at scales that are smaller in space than the grid size of the GCM. These smaller scales will have smaller autocorrelation times and this could be crucial. Hence, I recommend the construction of specific random field models for the several hundred km scale. These can be stochastic models as opposed to real dynamical mesoscale numerical models. The main concern is that the space-time correlation properties be faithfully simulated.