A FORTRAN PROGRAM TO CACULATE DESCRIPTIVE STATISTICS OF SATELLITE-DERIVED TROPICAL PRECIPITATION

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1. Introduction

Precipitation can be calculated using satellite observations. Satellites can estimate cloud-tops by measuring the outgoing longwave radiation (OLR). After getting the daily OLR data we change it to daily precipitation estimates for the tropics. The focus of this paper is to examine and calculate spatial and temporal statistics for this daily precipitation. The calculations are done using a FORTRAN program. The results are important because they determine the precipitation climatology and inter annual variability for the tropics.

2. Methods

a. OLR

The average temperature near ground surface is 288K. Between 0-12 km, temperature decreases with altitude. This part of the atmosphere is called the troposphere. Above the troposphere, there is a layer where temperature increases with height. This layer of the atmosphere is the stratosphere. It is found between altitudes 10km-50km. The transition between troposphere and stratosphere is called tropopause. At this level the average temperature is 220K. Clouds form in the lower troposphere and grow in height. The upper limit on the cloud is the tropopause. Satellites locate cloud-tops by measuring the longwave radiation emitted by the cloud-top.

To calculate precipitation, we change the radiation measured to black-body temperature with the Stefan-Boltzmann relationship. We assume that clouds are near black-body emitters. Black-Bodies are substances that emit the maximum amount of radiation for their measured temperature in all wavelengths. The amount of radiation emitted by a black-body is proportional to the fourth power of its absolute temperature i,e $E=\sigma T^4$ this is the Stefan-Boltzmann relationship, where σ is the Stefan-Boltzmann constant T is the equivalent black-body temperature and E is the OLR. We use this relationship to change radiation data to equivalent black-body temperature data.

b. Precipitation

Since deeper clouds have cooler cloud-top temperature and generally produce larger amount of precipitation, we can relate precipitation amount to the cloud-top temperature using regression techniques. Using such a technique we obtain

$$P=a+bT+cT^2+dT^3 \qquad \text{eq (1)}$$

where a= 3.3931*10e-4

b= .5399*10e-6

c=.-2391*10e-8

d=.3447*10e-11

a,b,c and d are constants. T is equivalent black-body temperature and P is precipitation in cm/day.

This formula is used to convert equivalent black-body temperature to precipitation.

c. Data

In this study we use radiation data from the NOAA polar orbiting satellites. We use data from January, April, July and October in the year 1987-1991. We use the first 30 days from the months with 31 days. In the following discussion temporal statistics refer to monthly statistics and ensemble statistics refer to yearly statistics. The following section describes the FORTRAN program that does this calculations.

3. Description of the FORTRAN program

We have modified a FORTRAN program that read horizontal slice tapes from the CCM processor and calculated descriptive statistics for pentad data to read daily OLR radiation data, convert it to precipitation and calculate the same descriptive statistics.

a. Data Input

The input tapes have 30 unformatted records that are read with the FORTRAN statement

READ (IUNT) OLR,ALB,TEQV where IUNT is input tape unit number, OLR is outgoing longwave radiation, TEQV is equivalent black-body temperature and ALB is albedo. The last three variables are arrays with dimensions NLN-number of longitude points and NLT-number of latitude points.

The OLR and TEQV arrays are related through the Stefan-Boltzmann relationship and ALB is not used. The temperature is converted to precipitation using eqn (1) and the units of precipitation is cm/day. This is the raw data used in this study. From this data we had to calculate descriptive statistics.

There are four subroutines in the FORTRAN program to calculate the descriptive statistics. The first subroutine calculates spatial and temporal statistics over the whole tropics. The second one calculates spatial statistics over land and ocean separately. The third, calculates ensemble mean of spatial statistics, ensemble variance of spatial statistics, ensemble mean of temporal statistics and ensemble variance of temporal statistics. The fourth subroutine calculates the same statistics as the third one except that it calculates it over land and ocean separately. We present the mathematical formulas for this statistics in the following section.

b. Calculation of Statistics

After converting black-body temperature to precipitation, we calculate the descriptive statistics. These are the spatial and temporal parameters i,e., mean and variance. The spatial mean is defined by the following formula

Spatial mean:

$$\mu_t = \sum_{i=1}^{NLN} \sum_{j=j1}^{j2} \cos(ANG(j))\, P_t(i,j)/TWT \qquad \text{eq (2)}$$

where

$$TWT = \sum_{i=1}^{NLN} \sum_{j=j1}^{j2} \cos(ANG(j)). \qquad \text{eq (3)}$$

The ANG is array with dimension NLT containing the latitude information in radians, j1 is Southern boundary of the tropics while j2 is the Northern boundary. The symbol P_t denotes precipitation on a particular day, cos (ANG(j)) is the cosine weight, that is added to account for the curvature of the earth. Equation (3) defines the total weighting which is the normalization for eqn (2).

Spatial variance is defined by

Spatial variance:

$$\sigma_t^2 = \sum_{i=1}^{NLN} \sum_{j=j1}^{j2} \cos\,(ANG(j))\,(\,P_t(i,j)-\mu_t)^2\,/TWT \qquad \text{eq (4)}$$

where this symbols are defined as in eqn (2). These formulas define the spatial statistics.

The temporal statistics are defined in the same way as the spatial statistics except that here we use a uniform weight. The temporal mean is defined by

$$\eta(i,j) = \sum_{t=1}^{30} P_t(i,j)/30 \qquad \text{eq (5)}$$

and temporal variance is defined by

$$\varepsilon^2(i,j) = \sum_{t=1}^{30} (P_t(i,j)-\eta(i,j))^2/30 \qquad \text{eq (6)}$$

where the symbols are as defined previously and the 30 represents the 30 days from any month in the study period. These formulas define the temporal statistics and together with eqns (2) and (4) we have the descriptive statistics. But the individual statistics are not enough to find the precipitation climatology and inter annual-variability for the tropics, therefore we have to calculate the ensemble statistics (which are the average statistics for the five year study period for each of the 4 months).

For the calculation of ensemble statistics the operators are defined as

$$\langle \xi \rangle = \sum_{n=1}^{5} \xi_n/5 \qquad \text{eq (7)}$$

$$v^2(\xi) = \sum_{n=1}^{5} (\xi_n - \langle \xi \rangle)^2/5 \qquad \text{eq (8)}$$

where $\langle\ \rangle$ is the ensemble mean operator and $v^2()$ is the ensemble variance operator. The subscript n denotes a particular ensemble member and 5 denotes the 5 years in the study period. The operators in eqns (7) and (8) represent one of the descriptive statistics defined by eqns (2) to (6).

For example, by substituting $\eta(i,j)$ instead of ξ into eqn (7), we get the ensemble mean of the temporal mean i,e., which is the tropical precipitation $\langle\eta(i,j)\rangle = \sum_{n=1}^{5} \eta(i,j)_n/5$. Similarly we may apply the same technique for the $v^2()$ to get ensemble variance of the temporal mean which is the inter annual variability $v^2(\eta(i,j)) = \sum_{n=1}^{5} (\eta(i,j)_n - \langle\eta(i,j)\rangle)^2/5$. In a similar manner we may also apply those operators for the ensemble spatial statistics . These ensemble statistics provide useful information about the temporal and spatial statistics of tropical precipitation as discussed in section 5.

4. Special Considerations

As with any experimental program, analysis of the results is complicated by missing data. Here the month of October is complete however other remaining months have missing data.

In January 1991, the OLR measurements are missing for days 11 and 12 therefore we consider only 28 days when calculating spatial and temporal statistics. In April 1987, the OLR data is missing for day 7 so we consider only 29 days. In July 1987 OLR data for day 27 and 28 as well as the whole July 1988 is missing. Consequently for calculations of spatial and temporal statistics of July we consider only 28 days. For the ensemble statistics of July we consider only 4 years.

For example, to calculate the spatial mean and variance for January 1991, we write a FORTRAN statement to skip the missing days. To calculate temporal mean and variance for January 1991, we have to divide by 28 days instead of 30 in eqn (5).

Similar corrections are done for the month of April 1988 and July. Recall that July 1988 is missing therefore we divide by 4 instead of 5 in eqns (7) and (8). Since the four months need different corrections, we had to write four different separate FORTRAN program codes.

After making these corrections for the missing days, we then use the FORTRAN program to calculate ensemble mean and variances. We present the spatial statistics in tabular form and the temporal statistics as contour plots of the results in the tropics.

5. Results

In this discussion we are only going to look at the ensemble mean of the spatial mean, the ensemble variance of the spatial mean, the ensemble mean of the temporal mean and the ensemble variance of the temporal mean.

a. The average of the ensemble spatial statistics

Table 1 shows the ensemble mean and variability of the tropical mean precipitation for the study period. The average of ensemble mean of spatial mean $\langle\mu\rangle$ show the total amount of precipitation that fall over the tropics. We calculate the above statistics over the total area and then over land and ocean separately. The average of the ensemble variance of the spatial mean $(v^2(\mu))$ show us the variability in total precipitation around the tropics. We expect it to be very small because there should be little change in the average tropical precipitation from year to year. Notice that the largest amount of precipitation occurs in January and the minimum in July. During the last two months most of the precipitation occurs in ocean. In January, April and October the variability over the land is three times than over the ocean whereas in July it is only two times larger. These calculations are average calculations over the tropics, therefore they do not show the distribution of precipitation over the tropics. In the next sections we see the distribution of the above calculations over the whole tropics.

b. Ensemble mean of the temporal mean

The ensemble mean of the temporal mean shows the precipitation climatology for the five year study. These results are shown in Figs 1a and b. Figure 1a displays the tropical precipitation climatology for the Eastern hemisphere for each of the four months. Figure 1b is the same as Fig 1a except it displays results for the western hemisphere.

The upper most panel of Fig1a shows precipitation maxima over Southern Africa, Northern India and Indonesia. Notice the minimum precipitation over central Africa that is associated with deserts of Sudan, Ethiopia and Somalia. In April, the second panel of Fig 1a shows that the maxima over Africa has moved northward and the precipitation maxima over the Himalayas have increased. For the third panel of Fig1a there is precipitation minima in Southern Africa and a dramatic increase of precipitation over India which is associated with the Indian summer monsoon. The maximum precipitation over South Africa has moved northward due to the position of the Inter Tropical Convergence Zone (ITCZ). The intensity of precipitation in Indonesia has not changed. The last panel of Fig 1a displays results for October. Here we see precipitation maxima over South Central Africa, Northern India, and Indonesia. This figure shows a transition from the Northern hemisphere summer precipitation pattern to the winter manner. As with previous months we have precipitation minima over North Central Africa associated with Sahara desert.

Figure 1b shows the precipitation climatology for the western hemisphere of the tropics. The upper most panel of Fig 1b shows precipitation maxima over Northwest South America and over regions of Southwest Pacific due to the South Pacific Convergence Zone (SPCZ). In April, the maxima over Northwest South America have decreased. The maxima over Southwest Pacific regions have moved further east. The third panel of Fig 1b shows no precipitation over Southeast South America and the precipitation over Northwest South America has moved Northward. The precipitation maxima in the South equatorial pacific regions is due to the ITCZ. The last panel of Fig 1b displays results for October. Here the precipitation maximum has returned back to Northwest South America and precipitation minimum observed over Southeast South America during July has become a maximum suggesting a transition from Northern hemisphere summer to the winter season. In all of the four months we notice precipitation maxima over South America.

c. Ensemble variance of the temporal mean

In Figures 1a and 1b we saw tropical precipitation maxima and minima. But what about when there is variability between years in the amount of precipitation ? In other words, it is possible that a precipitation maxima that is observed in one year can be minima in another year. Ensemble variance of the temporal mean plots show which part of the tropics have higher variation of the annual mean for this study. This is a measure of the inter annual variability. Figure 2a shows variability for the Eastern hemisphere of the tropics while Fig 2b shows variability for the Western hemisphere.

The upper most panel in Fig 2a shows high variability over Southern Australia and parts of Indonesia and Indian ocean. This suggests that the precipitation maxima over this regions may vary from year to year. There is low variability of precipitation over Africa, India and parts of Australia. For April, the low variability over North Central Africa combined with Fig 1a are associated with the Sahel desserts. The high variability over Australia have moved Northward and the high variability over Indian Ocean and Indonesia has decreased, this results may be associated with the Northward migration of the ITCZ. From the third panel we see that July has low variability over Africa and Northern Australia due to the summer monsoon. Here, Southern India has a very high variability which indicates that the setting up of the monsoon change from year to year. For October, the lowest panel of Fig 2a, the high variability over Southern India has decreased to the ending of the July summer monsoon and a transition to the Northern hemisphere winter pattern. Similarly the low variability over Australia , India and most parts of Africa suggests transition to the Boreal winter season. The low variability over North Central Africa is the feature of the 4 months.

Fig 2b shows inter annual variability for the Western hemisphere of the tropics. The first panel shows high variability over the West Pacific ocean associated with the SPCZ. There is low variation over South America. Notice the small variability in Fig 2b over West Pacific ocean and an increase over Atlantic ocean . In July, the variability maxima over the pacific ocean have moved further east and northward with the migration of the ITCZ. The last panel in Fig 2b shows an increase in variability over the South west pacific ocean due to the SPCZ. In all of the four months we see low variability in Southern America and we have already noticed that there is high precipitation around this regions which indicates that the high precipitation around this regions is constant. Consequently these places are called the tropical Rain forests.

The calculations for all of the above results are done using eqns (7) and (8). The results for Fig 1a and Fig 1b are done using the examples in section 3a. The calculations for ensemble spatial statistics are also done by the above equations using the appropriate operators.

6. Conclusions

From this project we see that the OLR data measured from satellites can be realistic estimates of tropical precipitation. We were able to calculate statistics for precipitation around the tropics. The calculations have helped us to determine climatology and inter annual variability for the tropics. We notice that the movement of the ITCZ has great effect on the rate of precipitation over most regions of Eastern hemisphere of the tropics and over the Equatorial Pacific regions. Similarly the SPCZ has a huge effect on the rate of precipitation over the Western hemisphere of the tropics. We have noticed low precipitation and low variability around North Central Africa which is associated with the Sahara desert. The July monsoon has a dramatic effect in the low precipitation around most parts of Africa and high precipitation around Southern India during July. We have also noticed a high precipitation and low variability over South America which is associated with the South America Tropical Rain forests.

Acknowledgements

I acknowledge many people in the Climate and Global Dynamics Division at NCAR for helping me in a lot ways during my 10 weeks stay. I specially thank my supervisor Dr. Arthur Mizzi for explaining my project and for the patience he had to answer every question I had about my project. My knowledge about Atmospheric science and its applications to society has greatly expanded because of his help. I thank Dr. Akira Kasahara for helping me in debugging the FORTRAN program. I also thank Andrew Mai for answering my questions about many FORTRAN and UNIX commands. The UNICOS orientation class was very helpful in finishing my project. The technical writing class was very helpful in writing my paper. I thank Lydia Harper for helping me in preparing my table. I give special thanks to Anna-Arcos, Chryl Brunner, Valeri Sodaitis, and many people in the Human resources department for giving us their time for entertainments and different activities. Summer would not have been fun without them. I also thank Mary, Harvey and Joann for editing my paper. Last but not least I thank NCAR and NSF for sponsoring our program.

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Figure Captions

Figure 1 a). Shows Eastern hemisphere ensemble mean of the temporal mean for tropical precipitation in January, April, July and October.

Figure 1 b). Shows the same result as Fig 1a except that it is for the Western Hemisphere.

Figure 2a). Shows the same geographical location as Fig 1a except that it shows ensemble variance of the temporal mean.

Figure 2b). Shows the same statistics as Fig 2a except that it is for the Western hemisphere.

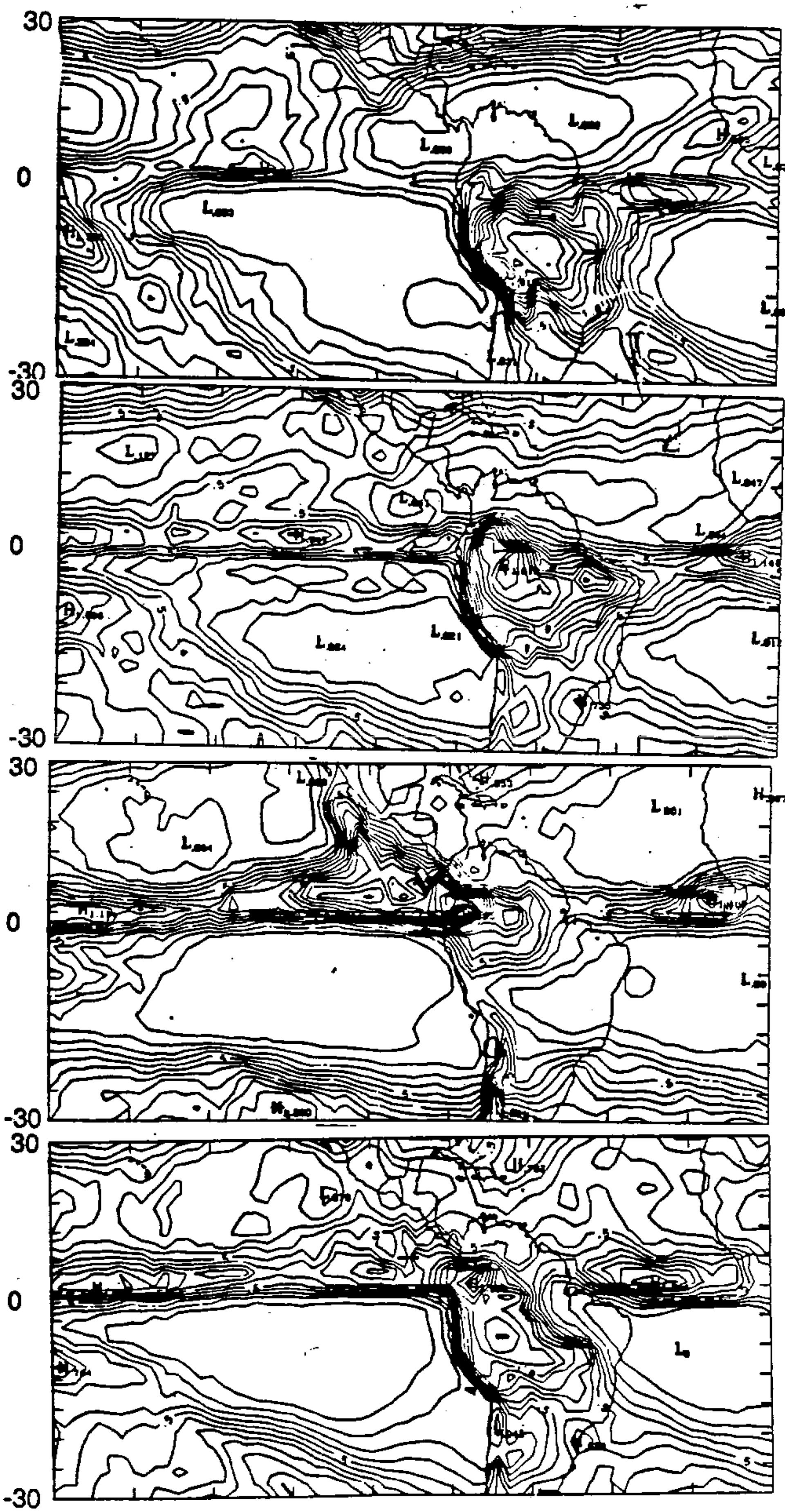
Table 1

OLR PRECIP

Jan	TA	LN	OC
$<\mu>$	0.4840	0.5857	0.4494
$\nu^2\mu \times 10^{-4}$	9.166	33.61	9.818
Apr			
$<\mu>$	0.4440	0.5116	0.4210
$\nu^2\mu \times 10^{-4}$	10.8	47.2	14.67
Jul			
$<\mu>$	0.4121	0.3990	0.4165
$\nu^2\mu \times 10^{-4}$	5.7	19.73	8.836
Oct			
$<\mu>$	0.4274	0.4212	0.4295
$\nu^2\mu \times 10^{-4}$	12.71	42.95	14.85

$<\mu>$ = Average of the ensemble mean of the spatial mean (cm/day)
$<\nu^2\mu>$ = Average of the ensemble variance of the spatial mean (cm^2/day^2)
TA = Total $<\mu>$ and $\nu^2 <\mu>$
LN = Land $<\mu>$ and $\nu^2 <\mu>$
OC = Ocean $<\mu>$ and $\nu^2 <\mu>$

Figure 1 b). Shows the same result as Fig 1a except that it is for the Western Hemisphere.



JAN

Contour from .1 to 1.8 by .1

APR

Contour from .1 to 1.6 by .1

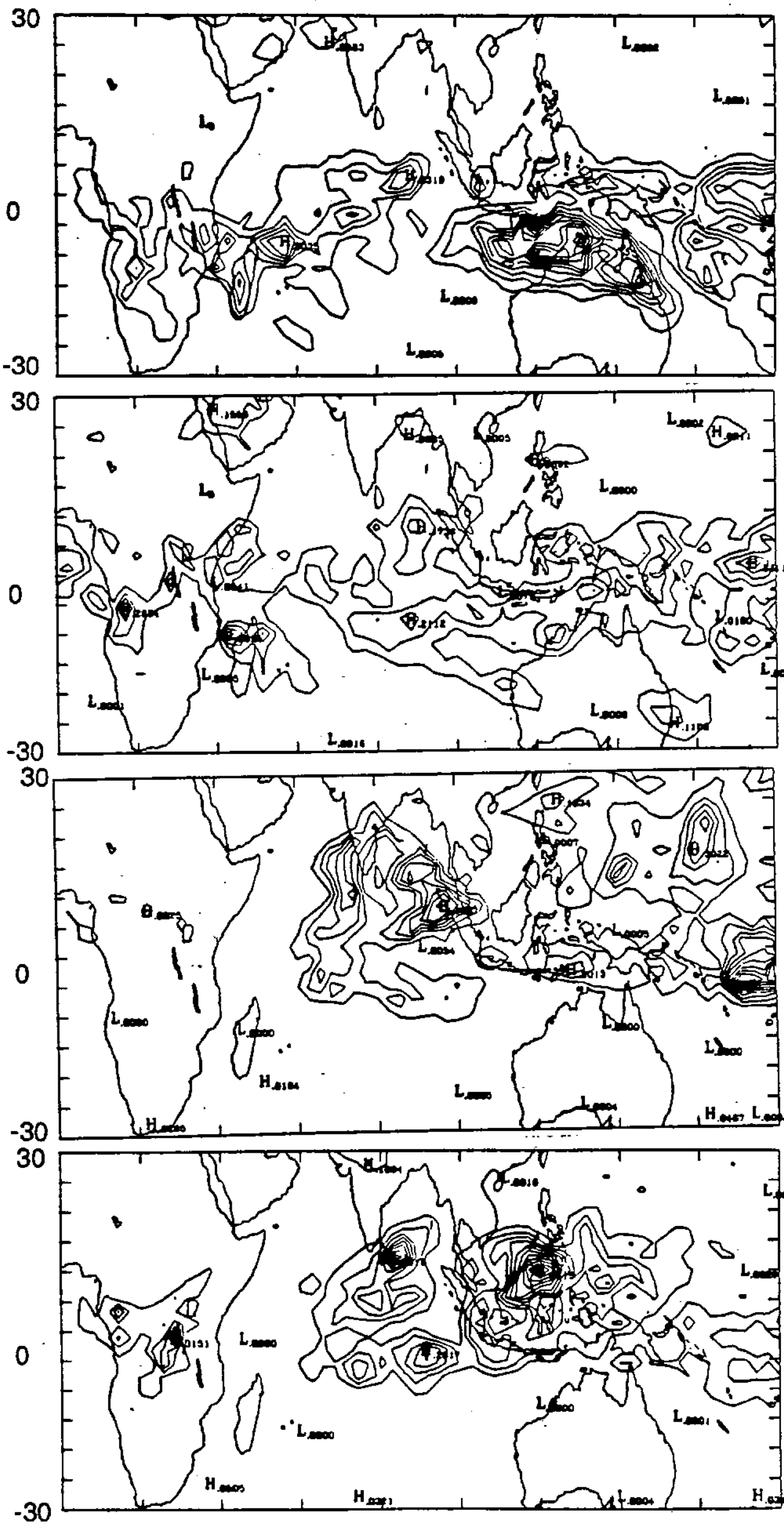
JUL

Contour from .1 to 2.1 by .1

OCT

Contour from .1 to 1.5 by .1

Figure 2a). Shows the same geographical location as Fig 1a except that it shows ensemble variance of the temporal mean.



JAN — Contour from .05 to .55 by .05

APR — Contour from .05 to .3 by .05

JUL — Contour from .05 to .56 by .05

OCT — Contour from .05 to .6 by .05

Figure 2b). Shows the same statistics as Fig 2a except that it is for the Western hemisphere.