

DIURNAL CYCLE OF DEEP

TROPICAL CONVECTION

by

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Submitted to the Department of  
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in Partial Fulfillment of the requirements for the  
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Department of Earth Atmospheric and Planetary Sciences

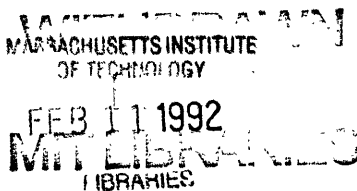
January 18, 1992

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Professor Peter Stone  
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## CONTENTS

|                      |    |
|----------------------|----|
| 1. Abstract.....     | 3  |
| 2. Introduction..... | 4  |
| 3. Data.....         | 11 |
| 4. Result.....       | 15 |
| 5. Conclusion.....   | 26 |
| 6. Figures.....      | 28 |
| 7. References.....   | 53 |

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ABSTRACT

Deep tropical convection has long been recognized to play a central role in both the equatorial Hadley cell of the earth's general circulation and in supplying electric charge to global electrical circuit. It has become common to use cloud data extracted from satellite observations of visible and infra-red radiation as a proxy for tropical convection and condensation. Data from the International Satellite Cloud Climatology Project (ISCCP), which has three-hour time resolution and is therefore adequate for calculating diurnal variations, is becoming available. In this paper, the high cloud cover data from August 1983 to 1987 July are used to determine the diurnal variation of deep convection.

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## INTRODUCTION

Deep tropical convection has long been recognized to play a central role in both the equatorial Hadley cell of the earth's general circulation and in supplying electric charge to the global electrical circuit.

### *Role in General Circulation*

Because of the strong dependence of solar radiation and weak latitude dependence of outgoing infra-red radiation, there is a radiation excess in equatorial region and deficit in the polar region. The tropics is where the majority of the solar energy which drives the atmospheric heat engine is absorbed by the earth and transferred to the atmosphere. Therefore, an understanding of the tropics is very important for understanding the atmospheric system.

The mean rising motion in lower latitudes (the Intertropical Convergence Zone, ITCZ) transports heat upwards which they moves poleward as part of the Hadley cell. But the storage of available potential energy is very small due to the very small temperature gradients.

Riehl and Malkus (1958) showed that the stability of the tropical atmosphere was such that these simple transports would cool the upper troposphere and thus destroy potential energy. In order to satisfy the heat budget of the general circulation, they argued that only motion that followed a moist adiabatic ascent could actually heat the upper atmosphere. This could only be achieved by upward motion taking place through deep penetrative convection cells.

The large scale motions in the equatorial zone are driven primarily by latent heat release and this latent heating occurs primarily through cumulonimbus convection rather than large scale forced ascent. Thus the latent heating associated with condensation in tropical convection is the primary mechanism forcing the general circulation of the atmosphere. This heating drives the low latitude Hadley circulations which in turn are a major source of momentum for the mid-latitude jet stream. And the jet stream is the major source for mid-latitude eddies and weather.

Fluctuations in tropical convection can generate waves which propagate out of the tropics and transport energy to mid-latitudes (Hoskins and Karoly, 1981). The time it takes for wave energy to propagate from the tropics to mid-latitudes is only one to two weeks. So the fluctuations in tropical convection are important for the atmospheric circulations all over world.

Extensive observations of condensation in tropical convection are not available, so it has become common to use cloud data extracted from satellite observations of visible and infra-red radiation as a proxy for tropical convection and condensation. Richards and Arkin (1981) showed a good correlation between precipitation and cloud cover in the tropics. This research was limited to the specific area and may not apply to anomalous rainfall situations. This deficiency may limit its extension to other areas.

Many studies using this proxy data have been done, e.g., interannual variations associated with El Nino, fluctuations associated with the 40-60 day Madden-Julian oscillation. Most of them have focused on long time scales. But there are much short time scales associated with planetary scale features. Thus there is a substantial need to document the climatology of fluctuations in tropical convection on short time scales.

Albright et. al. (1985) found a significant diurnal cycle in tropical convection, particularly over the land, but also over the ocean. At certain hours, the fractional coverage by clouds colder than  $-36^{\circ}\text{C}$  deviated by as much as 40% from the daily mean. The variation was especially large in the South Pacific Convergence Zone (SPCZ). Many studies have been done on the diurnal variation of cloud cover in the tropics, but most of them were about the local time diurnal variation in specific areas. (Reed, Jaffe 1981, Raymond 1983, Richards and Arkins 1981, Rossow, Schiffer 1991 Fu et al. 1990)

Albright and Reed (1985) suggested two convective regimes in SPCZ, a first regime of very deep convection that grows during the night and peaks near sunrise and a second regime of less deep convection that develops rapidly around noontime, peaks in the middle to late afternoon. Rossow and Schiffer (1991) analyzed the diurnal variation of cloud cover for one month (July 1983). They showed that oceanic cloud amount variations are small except at low latitudes. Over the tropical land there is a significant phase difference from the surface temperature, possibly indicating a large semi-diurnal components. Also there is a significant regional variability of phase and amplitude of diurnal cycle in that month.

### *Role in Global Electricity*

It is generally believed that thunderstorm electrical generators provide the source of the fair weather electrification and, in turn, the fair weather electrification is often used as the initial condition in proposed thunderstorm charge generation mechanisms.

The atmosphere is a conductor of electricity as a result of the presence of ions. It is easy to show that the atmospheric condenser, which has a  $130\text{vm}^{-1}$  field, would be discharged by the leakage current, which is about  $3 \times 10^{-2}\text{Am}^{-2}$ , in less than half an hour. Since

the field remains approximately constant, there must exist a supply current equal to the discharge current, which, as stated, is apparently provided by the thunderstorm acting as generator. Because of the low relatively low resistance of the upper conducting layer and the planetary surface, the charge is distributed over the globe in a time that is short compared with the decay time. Thus, the fair weather electric field in all parts of the world is influenced equally and simultaneously by thunderstorm currents regardless of their location, and the ionosphere is at a constant potential throughout the globe.

Wilson(1922) suggested that thunderstorms were the generator that maintained the fair weather field in the face of the conduction current that acts to discharge the field. He pointed out that the maximum potential gradient should occur when the most thundery regions of the earth attain their maximum activity. Brooks (1925) estimated annual, seasonal, and latitudinal frequencies of thunderstorms over the land and oceans from the rather sketchy observations by weather stations and ships. He estimated that 1800 thunderstorms are simultaneously in progress. According to Gish and Wait (1950) conduction currents on the order of 1 ampere are measured over the tops of thunderstorms. This strongly supported Wilson's hypothesis, since a global current of 1,800 amperes is sufficient to balance the conduction current to earth in fair weather regions of the atmosphere (Chalmers, 1967).



The near surface fair weather potential gradient over the oceans, far from land, averages about  $130\text{vm}^{-1}$ . Over land, it changes a lot, depending on aerosol variations. The diurnal variation of the potential gradient is of particular interest. Over the land the diurnal variation also reflect the diurnal changes in the concentration of the aerosol, which are also tied to local time. However, over the ocean, there is a universal time dependent diurnal cycle. This universal diurnal variation presumably occurs over land as well, but is obscured by the effect of aerosols.

The Earth's fair-weather electric field intensity follows universal time (UT) rather than local time. Its variation within each 24 hour period is controlled by the integrated currents from globally distributed thunderstorms. The phase of the universal time diurnal variation of surface electric field (the Carnegie curve) shows a good agreement with the diurnal variation of thunder areas around the world. Mauchly(1923) showed the universal diurnal variation for the oceans on the basis of the measurements made on the several cruises of the R/V Carnegie.

Whipple (1929) refined Brook's estimates and judged that the diurnal variation of the potential gradient was similar to that of the number of thunderstorms in progress over the globe. Trent and Gathman (1972) counted oceanic thunderstorms based on more than 7 million observations made by ships at sea during 1949-1963. There is a general correspondence between the global diurnal variation of the number of thunderstorms and electric field

measurements over the ocean (Mauchly 1926), and this evidence supports the theory that the global circuit is significantly modulated by near-equatorial convection in the Maritime Continent, Africa, and South America. Markson(1986) supported this idea by comparing the variation in area of the America sector highest clouds from a GOES-E satellite analysis with variations of the ionosphere electric potential.

Most researchers consider Wilson's model to be correct because it provides the only reasonable explanation for the atmospheric electric field. The normal 250 kilovolt potential difference between the earth's surface and the conductive upper atmosphere is maintained by the worldwide thunderstorm activity, which is predominantly located within 20° of the equator. Therefore, thunderstorms in the equator appear to be the most significant means for charging the earth.

The deep clouds, or cumulonimbus clouds, are the engine that drives the strong electrical generator manifested in lightning flashes and other electrical phenomena. Roughly speaking, the lateral size of an individual cloud is about the same as its height, and thunderstorms more often occur in groups than singly. The life of a single cell averages about 20min, but the sequence of several cells leads to a storm lifetime of an hour or more. It has been recognized that thunderstorm activity has a pronounced concentration in the tropics, and within the tropical belt, a pronounced concentration over the land areas.

## DATA

The International Satellite Cloud Climatology Project (ISCCP) was established as the first project of the World Climate Research Program (WCRP 1984) to collect and analyze satellite radiance measurements to infer the global distribution of cloud radiative properties and their diurnal and seasonal variations. Operational data collection and processing for ISCCP have been underway since July 1983. To obtain global averages while resolving diurnal variations, the project planned to use data from at least one polar-orbiting and five geostationary weather satellite.

Fig. 1-1 shows the regional coverage provided by satellites used for ISCCP.

The Satellites measured radiances in each pixel for VIS( $0.6\ \mu\text{m}$ ) and IR( $11\ \mu\text{m}$ ) wavelengths which depend on ozone and water abundance. The data have been sampled to a pixel spacing of about 30Km . Hence in the cloud analysis each image pixel is treated as representing a specific scene about 30Km across. Each pixel was separated into cloudy and clear scenes. All image pixels containing cloud are assumed to be completely covered by a single, homogeneous layer.

Original ISCCP plans called for reporting the properties of five cloud types ;low, middle, high, cirrus and deep convective clouds. The latter two types were qualitatively defined to be optically thin and thick high clouds, respectively. The cloud types are identified by their values of cloud top pressure and cloud optical thickness. To allow for diurnal studies and to study the effects of the cloud top adjustment procedure, the cloud top pressure distribution determined by the IR-only algorithm is also reported during the day-time along with the cloud top pressure distribution determined by the VIS/IR algorithm but without the cloud top adjustment.

The deep convections in the tropics, in which we were interested have about 8 - 10 km height. Therefore, the highest cloud data can be the index of deep convection. In this paper, two kinds of cloud type are analyzed. The first is that with the lowest cloud top pressure ( $5\text{mb} < P < 180\text{mb}$ ), which is determined by the VIS/IR algorithm. The second is that with the lowest cloud top pressure and the largest optical thickness( $22.63 < \text{TAU} < 119.59$ ). Because of the need for optical thickness these data were provided only in daytime. Fig. 1-2 shows the area for which visible data can be provided in each GMT hour.

The ISCCP retrieved detailed information about the global cloud properties every three hours throughout the month. The nominal spatial resolution is 250Km. The data was given on a longitude - latitude grid with 2.5 degrees resolution on both longitude and latitude. Thus 10368 grid cells ( $2.5 * 2.5$  degrees longitude latitude)

cover the whole globe. Each such cell contained a certain total number of pixels. "Cloud Cover" in one grid cell for the respective cloud class is defined as follows.

$$\text{Cloud Cover} = \text{Number of cloudy pixels} / \text{Total number of pixels}$$

Fig. 2 shows the number of observations in a 1-year period. The 100% observation number is 2920. In this period the percent of observational coverage is at least 85% from 60N latitude to 60S latitude, except in the Indonesian Area, which is about 30%.

In this paper, the data from August 1983 to July 1987, were analyzed. Because of the Data Tape conditions, some period of the data are not included. Table 1. shows the periods which couldn't be used in this paper, and defines the seasonal means used.

In January 1985, the satellite NOAA-7 was changed to NOAA-9. This satellite is important for the primary which used in the cloud analysis procedure. The data was calibrated to eliminate any discontinuities, to the extent possible (Rossow and Schiffer, 1991).

Table 1.

|      | 1 | 2 | 3  | 4  | 5  | 6 | 7 | 8  | 9 | 10 | 11 | 12 |
|------|---|---|----|----|----|---|---|----|---|----|----|----|
| 1983 |   |   |    |    |    |   |   | O  | O | O  | O  | O  |
| 1984 | O | O | O  | O  | O  | O | O | O  | O | O  | O  | O  |
| 1985 | O | O | O  | O  | O  | O | O | O  | O | O  | X  | O  |
| 1986 | O | O | O  | O  | O  | O | O | 2H | O | O  | 1H | O  |
| 1987 | O | O | 1H | 1H | 2H | X | O |    |   |    |    |    |

O: used    X: unused    1H: first half used    2H: second half used

|        |                        |                        |
|--------|------------------------|------------------------|
| Autumn | 1983(SEP,OCT,NOV)      | 1984(SEP,OCT,NOV)      |
|        | 1986(SEP,OCT,NOV)      |                        |
| Winter | 1983(DEC)1984(JAN,FEB) | 1984(DEC)1985(JAN,FEB) |
|        | 1985(DEC)1986(JAN,FEB) | 1986(DEC)1987(JAN,FEB) |
| Spring | 1984(MAR,APR,MAY),     | 1985(MAR,APR,MAY)      |
|        | 1986(MAR,APR,MAY)      |                        |
| Summer | 1984(JUN,JUL,AUG)      | 1985(JUN,JUL,AUG)      |
|        | 1986(JUN,JUL,AUG)      |                        |

## RESULT

### Mean cloud cover

Fig 4. shows the geographical distribution of mean cloud cover for two different period. In this map we can see 3 major convection areas, America, especially South America, Africa and Asia with the western equatorial Pacific.

### Global diurnal cycle

Fig 5. shows the four years average global diurnal cycle (D line). The percent cloud coverage data were averaged from August 1983 to July 1987 in the tropics (31.25N - 31.25S) at each GMT hour. Also, shown for comparison, in Figure 3-1, is the Carnegie curve for the mean diurnal cycle of the global ionospheric potential. The diurnal cycle of high cloud cover does indeed closely resemble the diurnal cycle in ionosphere potential, thus lending support to Wilson's theory.

Each A,B,C line is the four year average diurnal cycle in the respective sectors shown in Fig 4. Because of the large amount of cloud cover, the Asia-Australia sector ,B, is the major contributor to the global deep cloud cover diurnal cycle.

Fig 6. shows the 4-year mean diurnal cycle over ocean and land. Ocean and land are defined by whether the center of the grid cell is located on land or on ocean from the map. Line A is the total tropical diurnal cycle, while lines B and C are the cycles over land and ocean, respectively. The land cycle has a bigger amplitude, but the ocean cycle is more similar to the total tropical cycle. Fig 6(b) is the same as Fig 6(a) but only the optically thick clouds, based on the visible data, are included. Thus thick, night-time clouds are excluded.(see Fig.1-2)

In section A, the diurnal cycle over ocean and land are very similar. Over land, the maximum is at 15GMT which is 3-4PM in this area. The maximum over ocean is 3 hours later than that over land. This may be because it takes more time to heat the ocean. The diurnal cycle amplitude of this section is very large because the ratio of land area in this section is large,48%.

In section B, The diurnal cycle over the ocean shows two maxima at 9 GMT and 18 GMT. In local time these are about 4-5PM and 1-2AM. Over land, the maxima are at 6GMT and 18GMT. Because of the three hours differences between the land and ocean, we can suggest that the first maximum(1-2PM in the land and 4-5PM in the ocean) is caused by diurnal heating. The second maximum(1-2AM in both) must be caused by larger scale diurnal circulations, e.g. Monsoon circulations.



In section C, the diurnal cycles over both land and ocean have the same shape but different amplitudes. The maximum is at 21GMT which is 2-3PM in the middle of this section. There is a remarkably large diurnal cycle amplitude over land, but because 77% of this section is ocean, there is still a big ocean contribution to the total diurnal cycle.

Fig 7(a). shows the diurnal cycle of the whole tropics and of each section over land. For comparison, Fig 3-2 is the diurnal variation of the world's thunderstorm areas from Brook's 1925 analysis. When we compare diurnal variation of the highest clouds with Brook's analysis, the America section(C) contributes more from 3 to 9GMT than in Brook's analysis. Thus there is no dominant contribution of Asia and Australia, section(B). But there is a big contribution of section B land around 6GMT, as in Brook's analysis. Land in section A is the major contributor from 12GMT to 18GMT. Therefore this figure is very similar to Brook's analysis, but with a 3 hour shift, and a bigger and longer contribution of the America section. Fig 7(b). is for the ocean. The variations are very flat in all sections.

### Seasonal diurnal cycle variation

Fig 8. shows the global and sectional diurnal cycle in each season defined in the DATA section. Line D is the diurnal cycle in whole tropics and line A,B and C represent each section. There is

not much seasonal change in diurnal cycle for the whole tropics except in summer. But, in separate sections there are clear seasonal differences in diurnal cycle.

The diurnal cycle in section A moves up and down seasonally without shape changes. In this section, the major convection area is concentrated in the southern hemisphere. Therefore, the biggest diurnal cycle is in northern spring and winter and the smallest is in summer. In section C, the diurnal cycle changes seasonally without change in shape, too. But there is a big amplitude in winter and very little in summer. In this section, more convection is located in the southern hemisphere than the northern hemisphere as shown in Fig 4. Therefore, there can be a bigger diurnal cycle in northern winter when the southern part of the convection area is stronger.

We can see big differences in the summer season. This is caused by a big change in the section B diurnal cycle and decrease in the section A diurnal cycle. When we look at Fig 4., most of the convection area in section B is located in the northern hemisphere. So in the northern summer, when the ITCZ is located in northern hemisphere, the amount of high cloud cover in section B becomes larger. Therefore, because of the big contribution of section B, the diurnal cycle in summer shows a 9GMT maximum as well as the usual 21GMT maximum.

Fig 9. show the seasonal diurnal cycles over land separately. The diurnal cycles of the whole tropical land area have big amplitudes

but there are very small seasonal changes in either amplitude or shape except in summer.

The diurnal cycles of sections A and C have big amplitudes. And they change seasonally but differently from each other. When we compare these two sections, section A has the biggest diurnal cycle in winter and small diurnal cycle in summer. But in section C, a big diurnal cycle is shown both in spring and autumn. These two diurnal cycles compensate each other except in summer; therefore, we can not see any seasonal change of total diurnal cycle associated with changes of these two sections. Section B is very flat and has not much change except in summer.

In autumn and spring, section C is the major contributor except around 15GMT when the section A is the major contributor. In winter, the major contributor is section A from 12GMT to 18GMT and section B from 3GMT to 9GMT and section C from 18GMT to 3GMT. This is very similar to Brook's(1925) analysis. In summer, section B is the major contributor all the time.

There are unusual changes in summer. Especially, in section B there is a big oscillation, associated with the Monsoon period. There are two maxima which are 6GMT and 18GMT. These are about 1-4PM and 1-4AM in that section. There is also a prominent decrease of the section A cycle.

Over ocean(Fig 10.), all of the diurnal cycles are very flat compared to over land. There are still seasonal changes in the diurnal cycles. Section B is the major contributor to the tropical ocean diurnal cycle in all the seasons. In spring and summer, there are big changes in the convection in section B.

The diurnal cycles of the separate sections are anti-correlated with each other. Therefore, even though there are big changes in diurnal cycles in individual sections, the total diurnal cycle is not changed as much as that of each section.

#### Time series (monthly)

The mean, amplitude and standard deviation of each month's diurnal cycle were calculated for the period of August 1983 to February 1987. November 1985, the missing month, is interpolated from October and December. The mean is the average of the eight 3 hourly values in the diurnal cycle of each month. The amplitude of the diurnal cycle is defined by the difference between the maximum and minimum in that diurnal cycle. The standard deviation is calculated from the eight 3 hour mean data in each month. If the diurnal cycle is complex, this will give a better measure of the daily variation.

Fig 11. shows the mean, amplitude and standard deviation of diurnal cycle for the whole tropical area(31.25N - 31.25S). In the

mean data there is a jump at February 1985. It may be caused by the satellite change described in DATA section. The amplitude may have an annual cycle e.g., the minimum seems to occur every 12 months. The standard deviation data is highly correlated with the amplitude data. This means that most of the diurnal cycles have one maximum and one minimum.

Fig 12. shows the same data but over land and ocean separately. Over land there is a annual cycle in amplitude and mean. They are very well correlated. The maxima occur in October and March and the minimum in July. Thus the high clouds over land are well developed mostly in the transition seasons.

Over ocean, the variations in the diurnal cycle amplitude are smaller than over land, and it is difficult to see any cycles in the ocean data. These time series are more similar to the total, i.e., the monthly change of the global diurnal cycle is dominated by ocean areas.

Fig 13. shows the same data but for each section. In section A, the annual cycle in the mean is more prominent. The amplitude of the diurnal cycle also has an annual cycle which is well matched with the mean's cycle. The maxima are in the southern winter season.

In section B, the mean of the diurnal cycle is very large, i.e, this section is the biggest convection area. But the amplitude of the diurnal cycle is very small compared to the other sections. And

there is a big jump of mean near February 1985. This time is the period when the NOAA satellite is changed, and that satellite covers this B section. This circumstance may affect the cloud cover data in this section. Unusually big amplitudes occurred from June 1984 to September 1984.

In section C, there are bigger annual changes in the diurnal cycle amplitudes. The biggest amplitudes of diurnal cycle occur in February and March. The mean data have a no obvious cycle.

In each sector A,B and C, the same analyses are done for land and ocean separately.(see Fig 14) In section A, land and ocean both have a clear annual cycle. And both have March and April maxima. However their minima are in June or July over land, but in January over ocean. Therefore, land and ocean have different annual cycles but both with maxima in March.

In section B(Fig.15), the land data has a clear annual cycle with an August maximum and January or February minimum. Therefore, it is clear that there is a strong association with the monsoon. The amplitude data are very similar to the mean data. The ocean shows very little annual cycle. An unusual peak is seen in summer 1984, especially over land but also over ocean. In January 1983, there was a very strong El Nino. This meant anomalous heating in the Pacific. This type of event take a year or two to re-equilibriate. This may have affected this period.

Over the ocean in sector C,(Fig.16) we cannot see any specific cycle in the mean data, but, in amplitude there is a clear annual cycle with a maximum in June. Over land, there is a half year period cycle in both amplitude and mean data, with maxima in August and February. In this sector, there are land areas in both hemispheres so that, as the ITCZ moves from one hemisphere to the other, the convection over land is well developed twice each year. Therefore, in winter and summer, when ITCZ is located over land, the diurnal cycle of cloud cover becomes larger.

In the C sector over land the cycles in the mean and amplitude are bigger than those over ocean. But still there is a nonnegligible annual cycle in the diurnal cycle amplitude over ocean, and because of the larger area of ocean than land, the contribution of ocean to total diurnal cycle becomes important. Actually the annual cycle in the total convection in sector C is dominated by the annual cycle over the oceans.

### Correlation

Table 2. shows correlation coefficients of the time series for different areas.

The mean of diurnal cycle for the whole tropics is most correlated with section B, but the amplitude of the diurnal cycle is more correlated with section C. The land area most correlated to

the whole tropics land diurnal cycle section is the diurnal cycle of America (section C). Over ocean, the diurnal cycle of section B is most correlated with total ocean diurnal cycle.

In each section, the diurnal cycle of ocean and land are not much correlated.



**Table 2**

| AREA                  | MEAN  | AMPLITUDE |
|-----------------------|-------|-----------|
| Total : Section A     | 30.1  | 56.5      |
| Total : Section B     | 80.1  | 59.5      |
| Total : Section C     | 60.7  | 63.7      |
| Total : LAND          | 60.9  | 63.6      |
| Total : OCEAN         | 96.2  | 84.3      |
| LAND : OCEAN          | 37.3  | 23.7      |
| Section A : Section B | -18.7 |           |
| Section A : Section C | 34.8  |           |
| Section B : Section C | 11.5  |           |

LAND

|                        |       |       |
|------------------------|-------|-------|
| Section A : Section B  | -30.7 | -48.0 |
| Section A : Section C  | - 3.2 | 48.2  |
| Section B : Section C  | - 1.3 | -31.8 |
| Land Total : Section A | 58.7  | 73.3  |
| Land Total : Section B | 20.3  | -10.7 |
| Land Total : Section C | 63.6  | 72.2  |

OCEAN

|                         |       |       |
|-------------------------|-------|-------|
| Section A : Section B   | 3.1   | 19.5  |
| Section A : Section C   | 3.8   | -65.0 |
| Section B : Section C   | -12.6 | -19.8 |
| Ocean Total : Section A | 24.1  | 8.0   |
| Ocean Total : Section B | 64.8  | 68.3  |
| Ocean Total : Section C | 53.2  | 44.3  |

|              |      |       |
|--------------|------|-------|
| SECTION A    |      |       |
| LAND : OCEAN | 0.4  | -50.9 |
| SECTION B    |      |       |
| LAND : OCEAN | 20.4 | 63.1  |
| SECTION A    |      |       |
| LAND : OCEAN | 38.5 | 11.4  |

## CONCLUSION

1) In tropics there are three major convection areas which are America, especially South America, Africa and Asia with the western equatorial Pacific.

2) The Diurnal cycle of high cloud cover closely resemble the diurnal cycle in Ionosphere potential, thus lending support the Wilson's theory.

3) Asia-Australia region is the major contributor to the global deep cloud cover diurnal cycle.

4) The diurnal cycle of the deep cloud cover over land is similar to the world's thunderstorm area analysis by Brooks, but with a 3 hour shift , and a bigger and longer contribution of the America section.

5) In each sections there are clear seasonal differences in diurnal cycle. But, the seasonal changes of the diurnal cycle of the separate sections are anti-correlated with each other. Therefore, even though there is a big seasonal change in diurnal cycle in individual sections, the total diurnal cycle is not changed as much as that of each section.

But, summer season shows very different diurnal cycle.

6) The monthly mean and amplitude of the diurnal cycle over the land shows a very clear annual cycle. The maxima occur in October and March and minimum in July.

7) In each section, there are more clear annual cycle. In section A, land and ocean both have a clear annual cycle, and both have March

and April maxima. However, their minima are in June or July over land, but in January over ocean. In section B, the land data has a clear annual cycle with an August maximum and January or February minimum. In section C, the land data has a half year cycle with maxima in August and February.

8) The mean of diurnal cycle for the whole tropics is most correlated with section B, but the amplitude of the diurnal cycle is more correlated with section C.

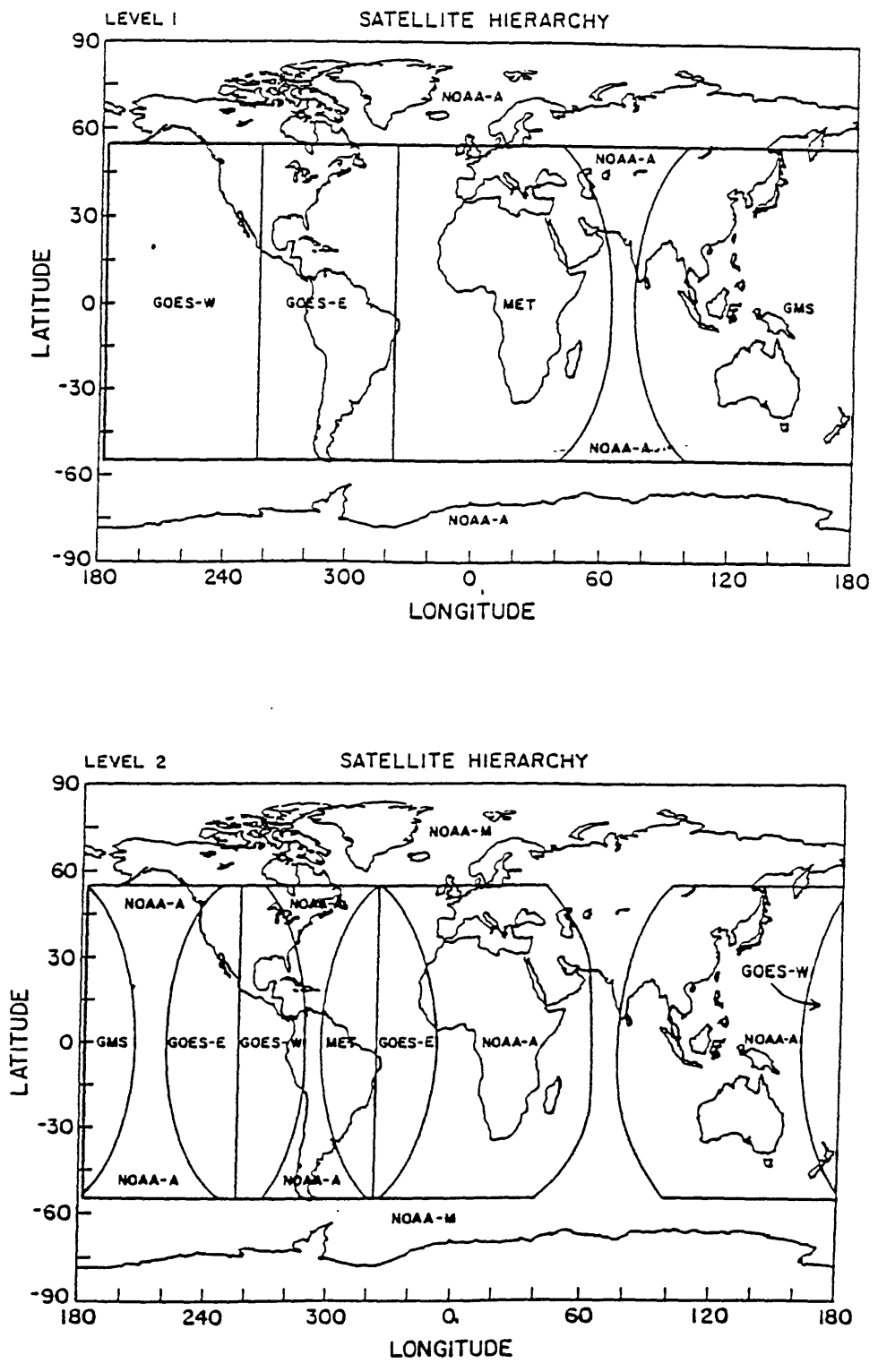


Fig 1-1 Regional coverage provided by satellites used for ISCCP: Level 1 of hierarchy indicates the preferred satellite for each location while Level 2 indicates the second choice used if the preferred satellite is not available.

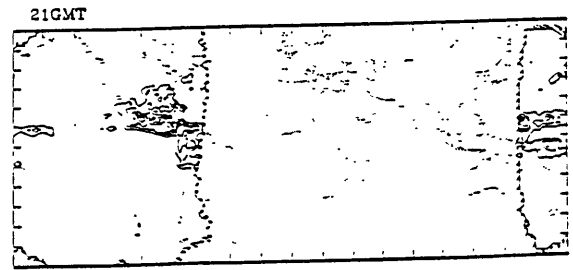
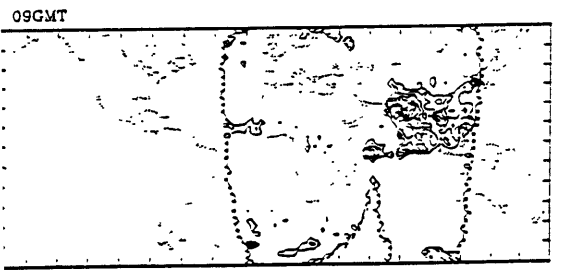
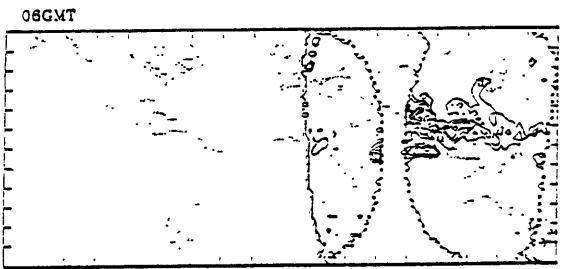
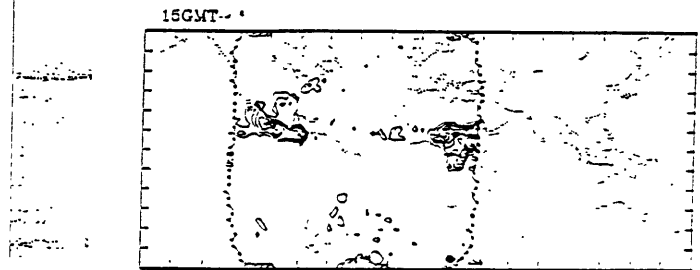
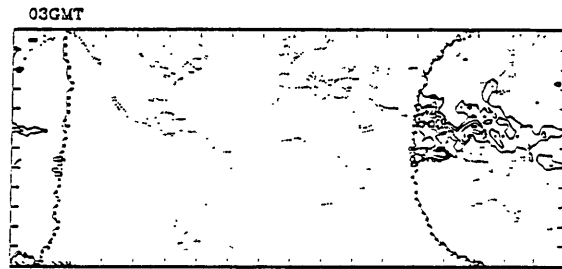
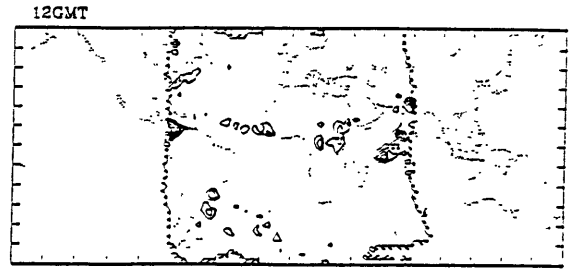
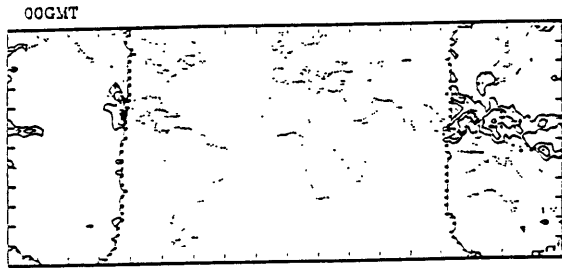
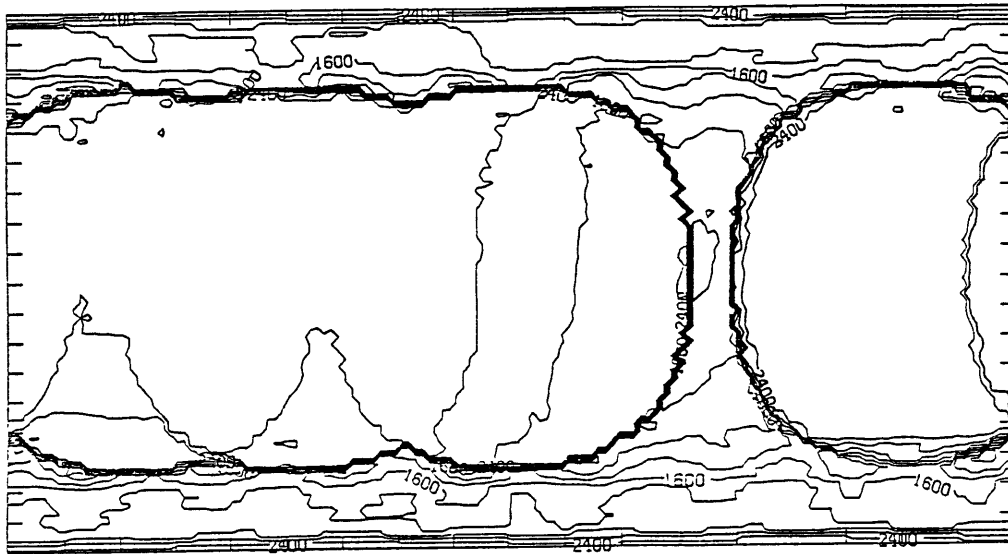


Fig 1-2. The coverage of Visible Data in each GMT hour.

(a)

83 AUG - 84 JUL (3HR INTERVAL OBS)



(b)

84 AUG - 85 JUL (3HR INTERVAL OBS)

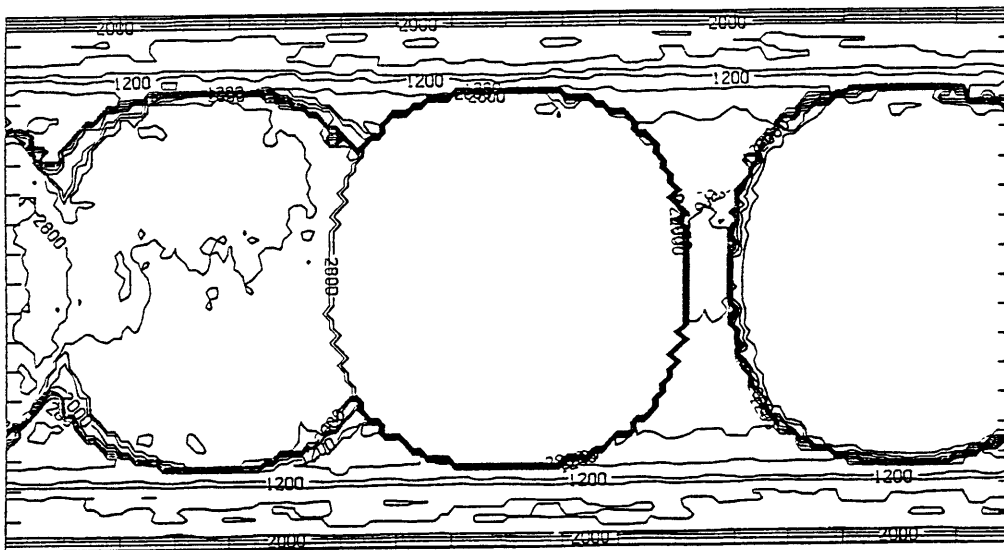


Fig. 2 Number of observation in each one year period (a) August 1983 to July 1984. (b) August 1984 through July 1985. e.g., 2920 will be the complete number of observations.

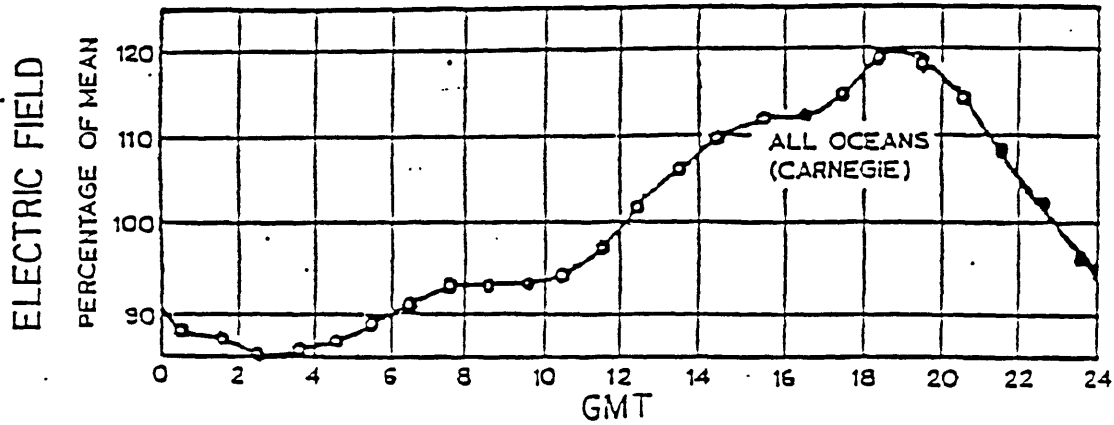


Fig. 3-1 Carnegie curve obtained from the average of electric field measurements made by the Carnegie research vessel during ocean cruises during the 1920's. (After Chalmers, 1957.)

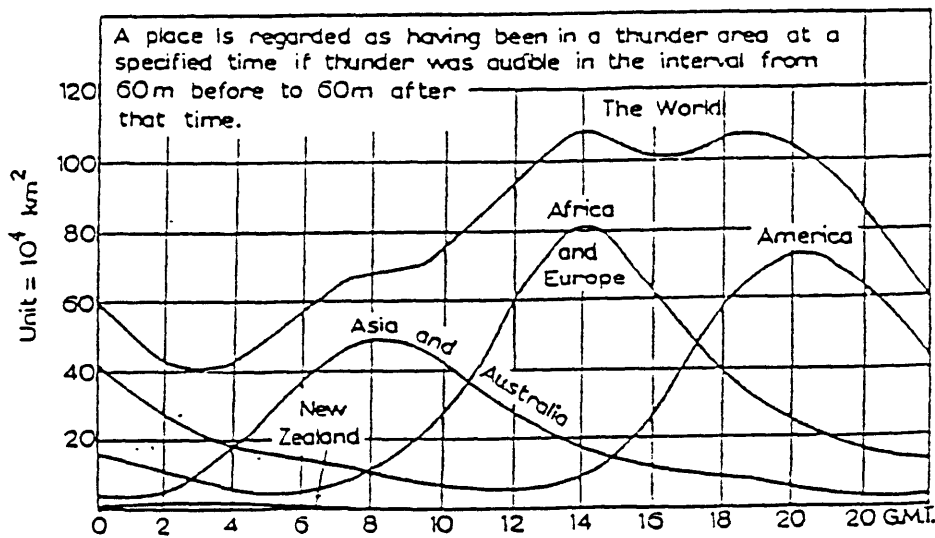
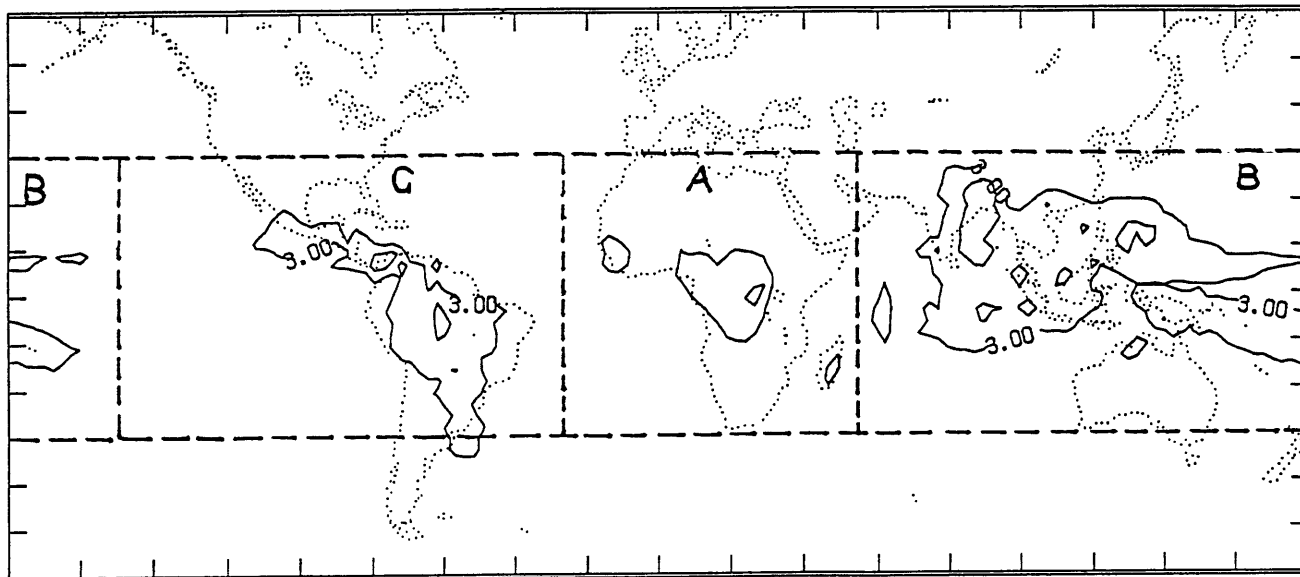


Fig. 3-2 Universal diurnal variation of global electrical circuit and its control by three major zones of convection. (from Chalmers, 1967)

(a)



(b)

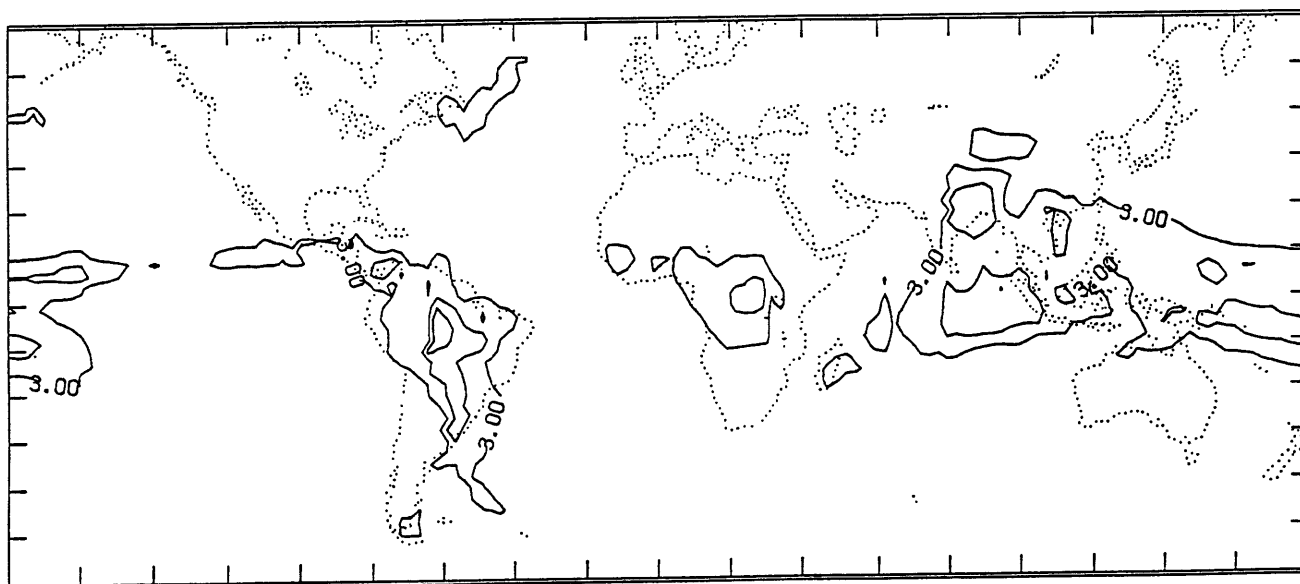


Fig. 4 Mean high cloud (5mb - 180mb cloud top pressure) fraction coverage.(%) (a) August 1983 thru January 1985. (b) February 1985 thru July 1987. Contour intervals are 3%.



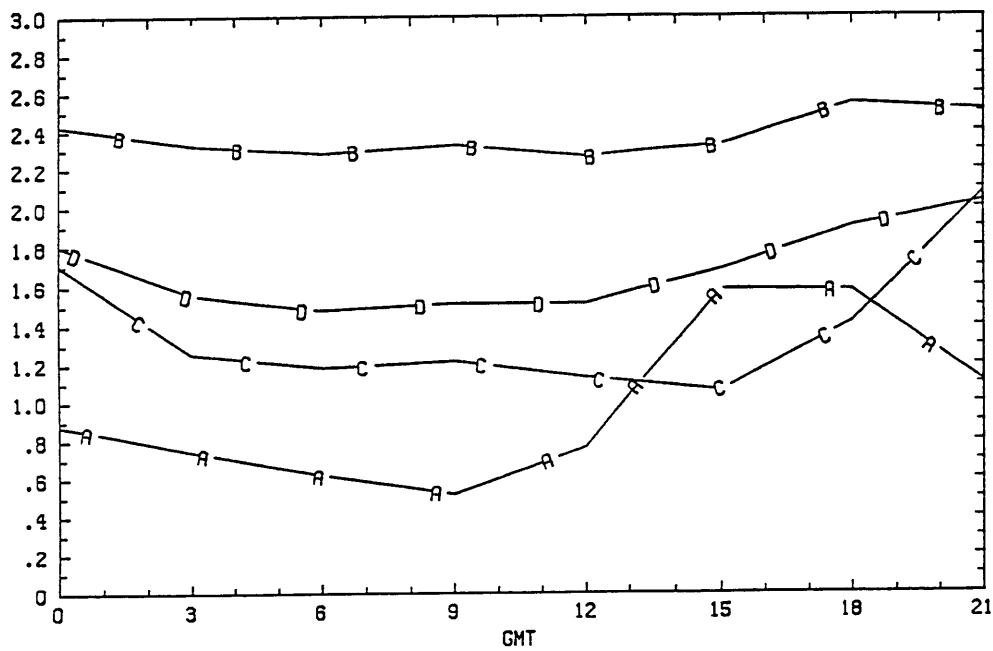


Fig. 5 High cloud diurnal cycle following universal time (August 1983 thru July 1987) . X axis is GMT time. Y axis is cloud fraction coverage(%).  
 Line D is the for total tropics(31.25N-31.25S). Line A,B and C are for section A,B and C.

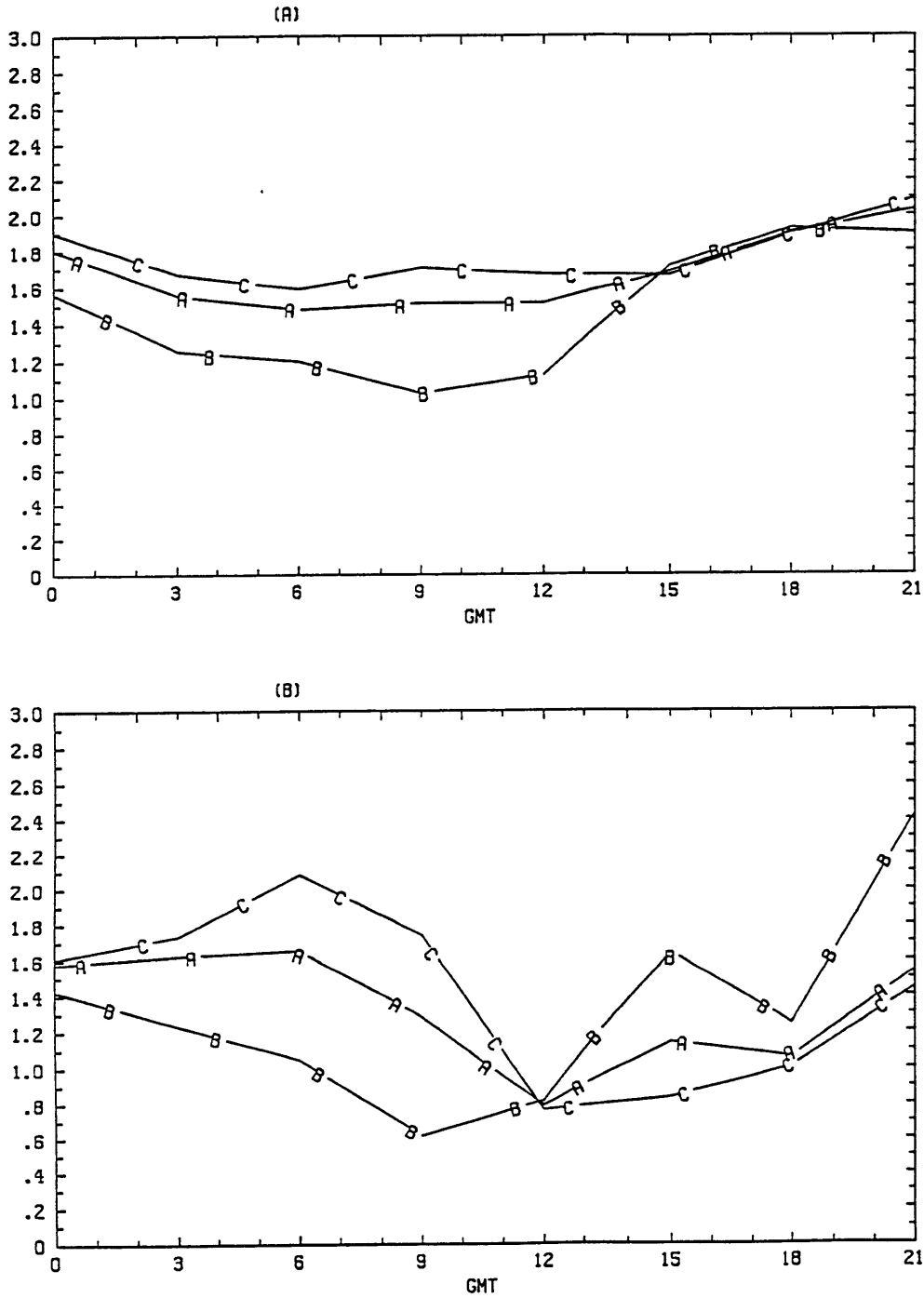
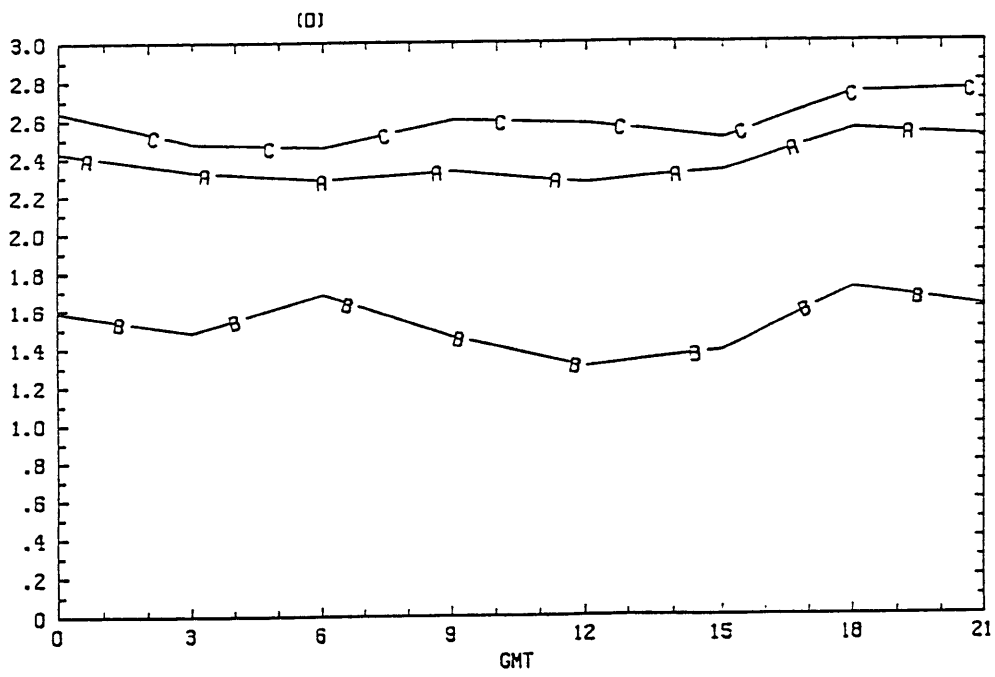
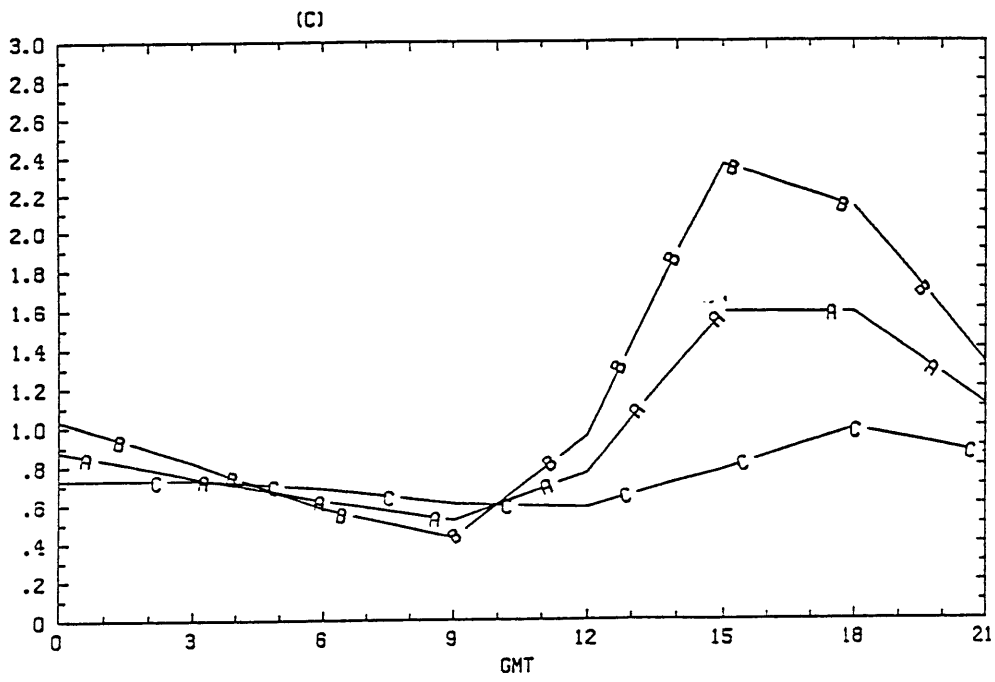
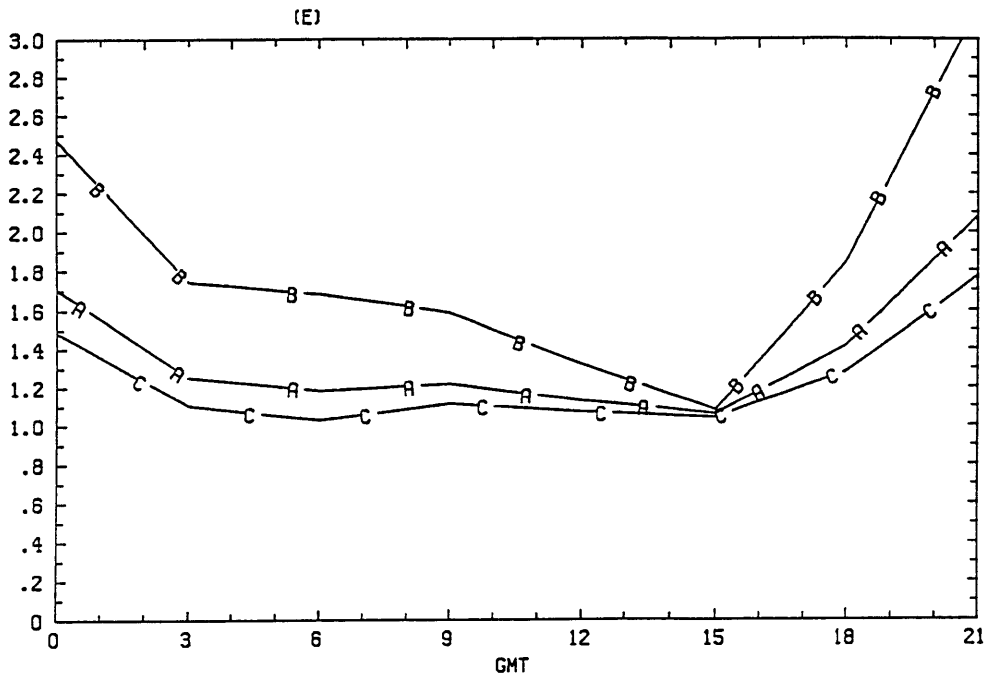


Fig. 6 High cloud diurnal cycle following universal time. Line A is the total for each area, B is for land and C is for ocean. (a) Tropics (b) Tropics but for VIS data only (c) Section A (d) Section B (e) Section C





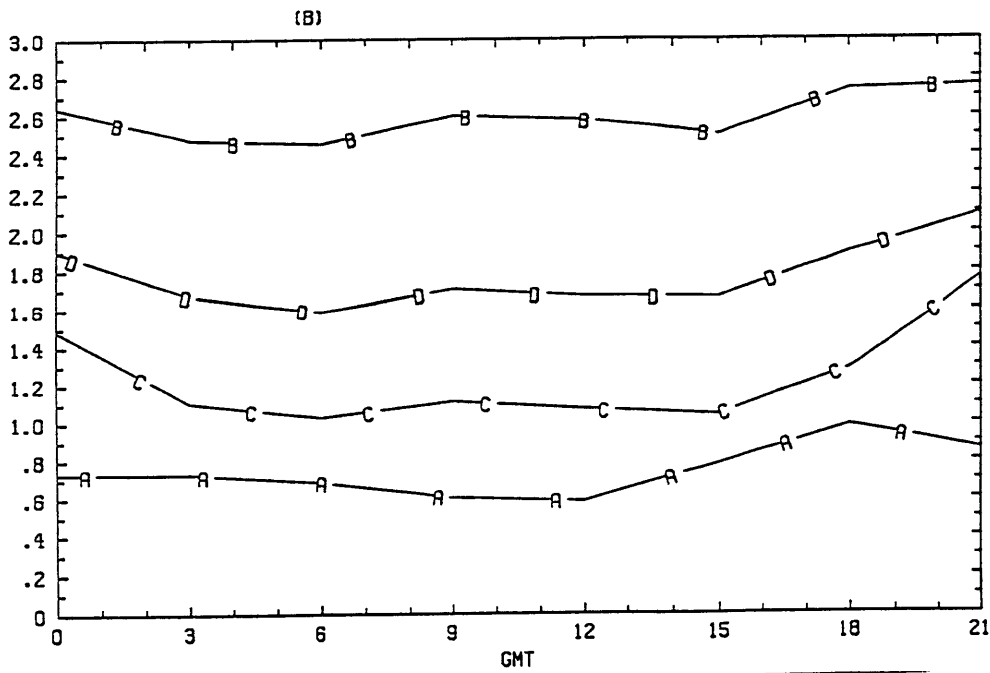
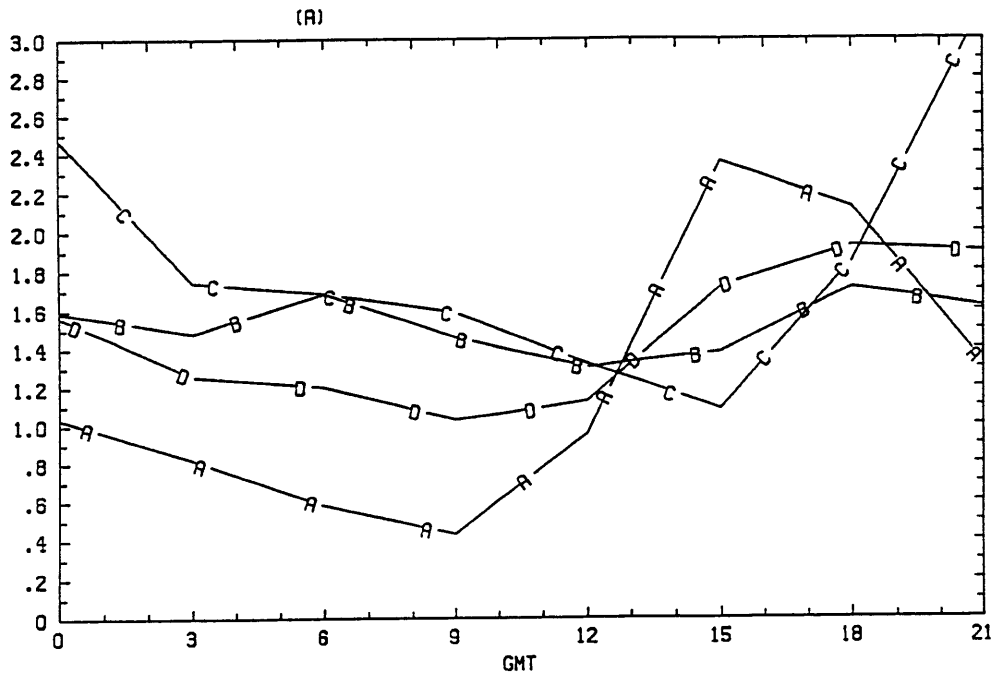


Fig. 7 High cloud diurnal cycle following universal time over land and ocean separately. Line A, B and C are for section A, B and C respectively. Line D is for total. (a) land (b) ocean

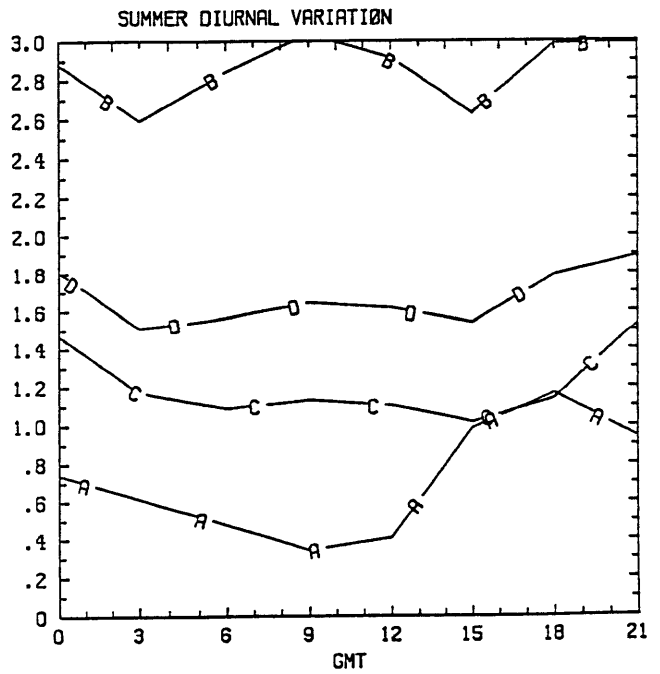
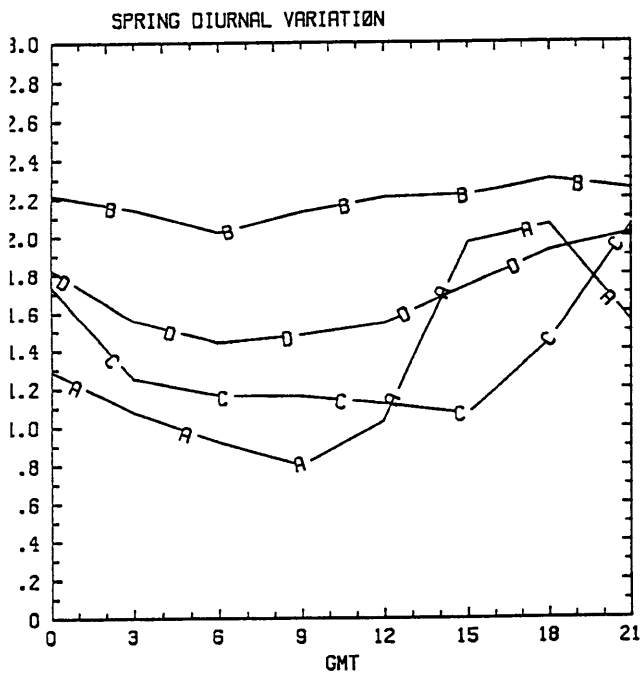
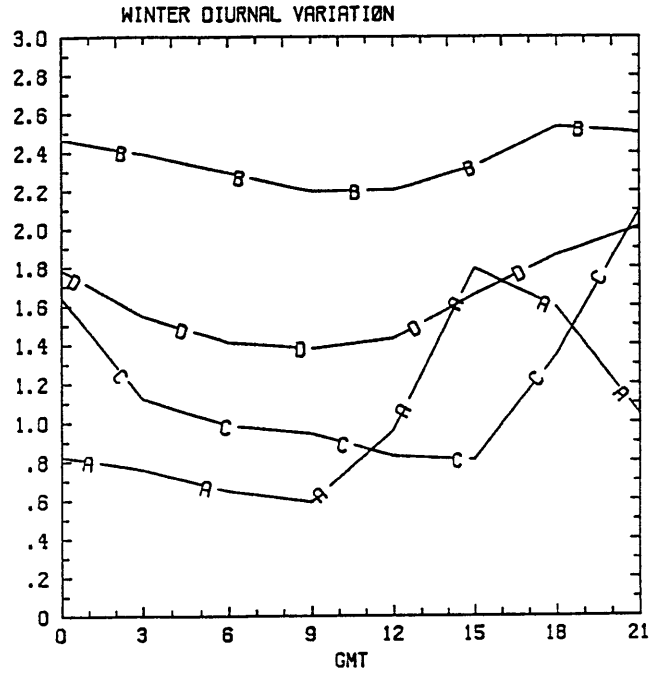
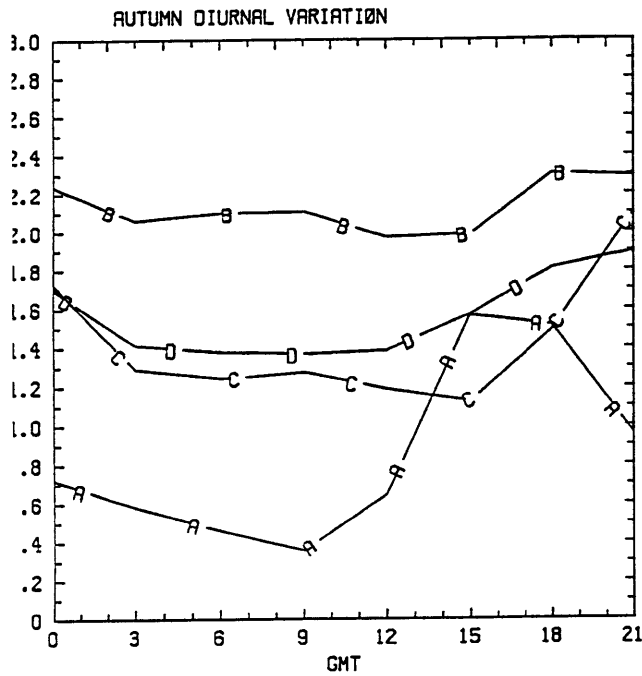


Fig. 8 Seasonal high cloud diurnal cycle. Line A, B and C are for section A, B and C respectively. Line D is for total. (Each season defined in DATA section)

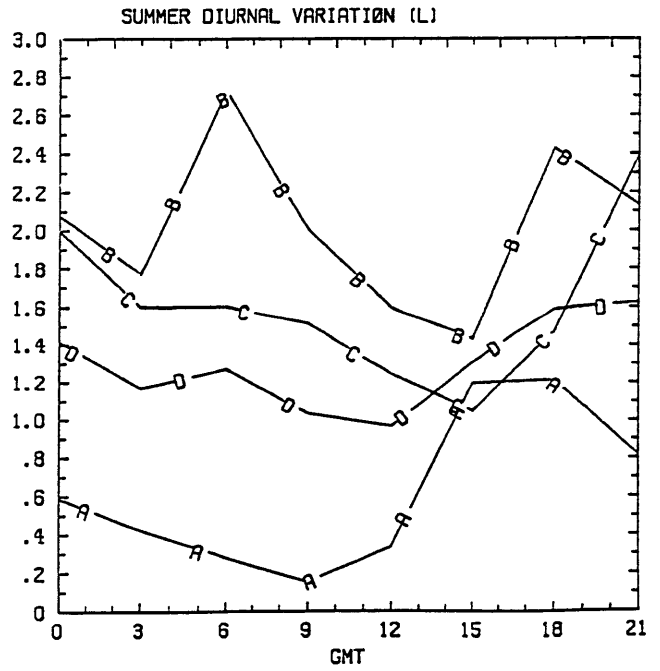
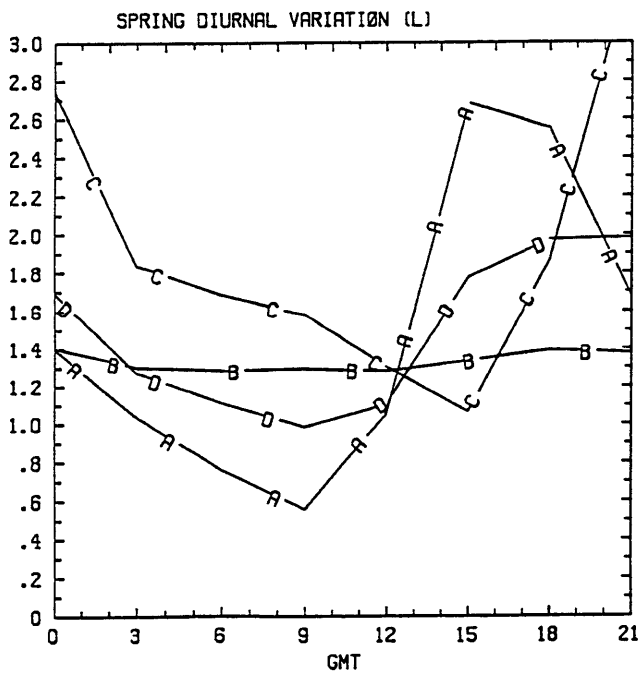
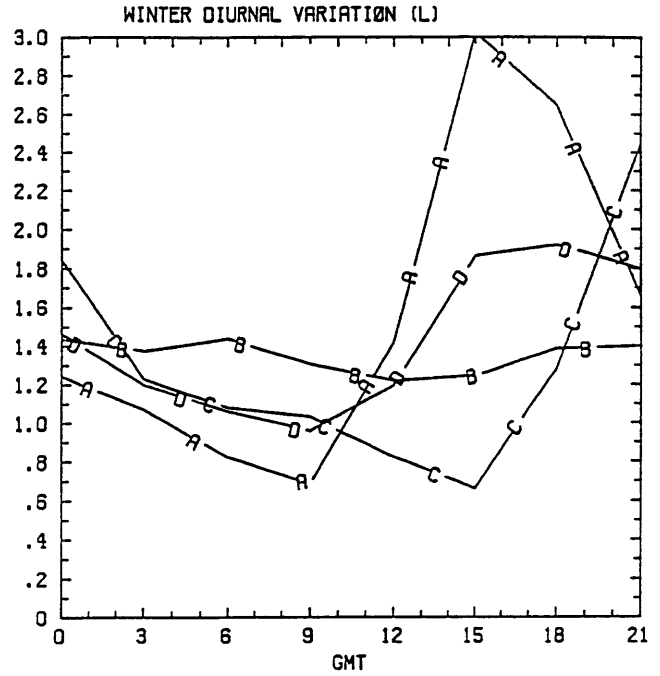
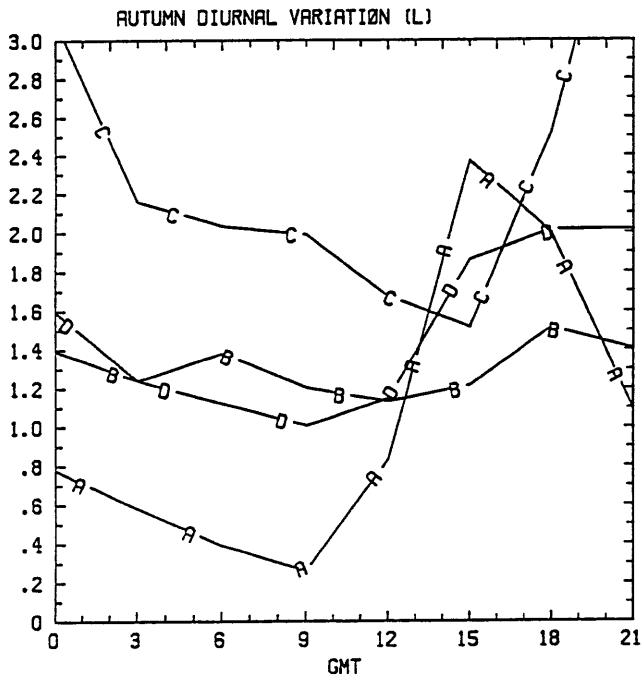


Fig. 9 Same as Fig 8 except for land only.

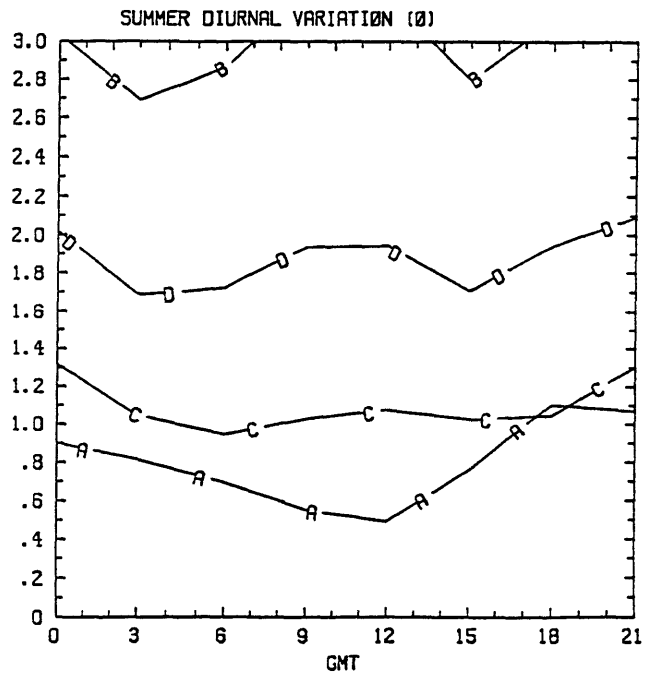
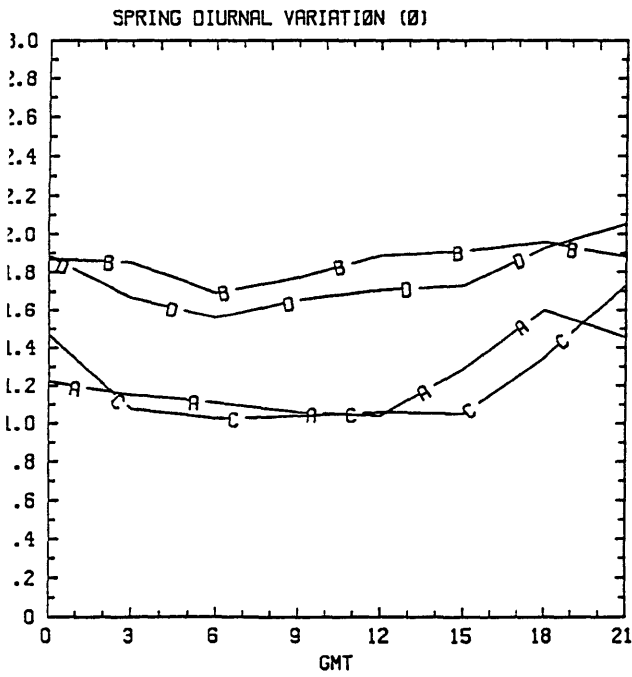
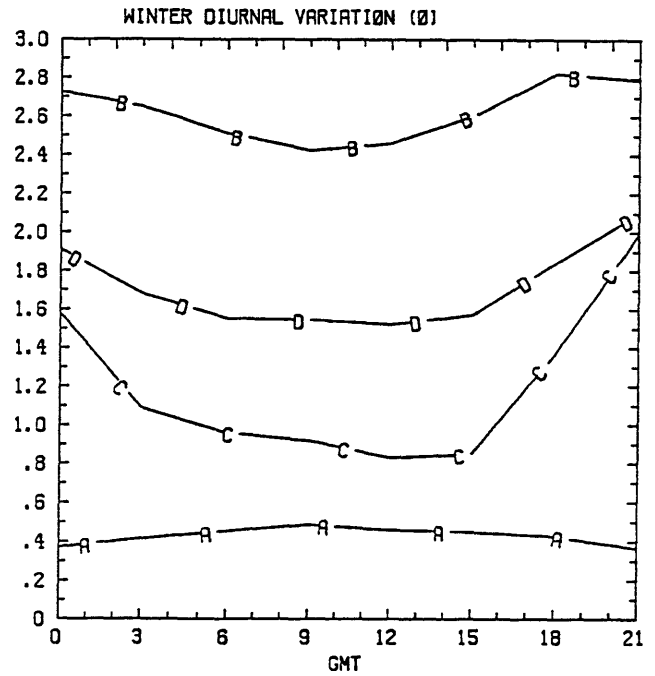
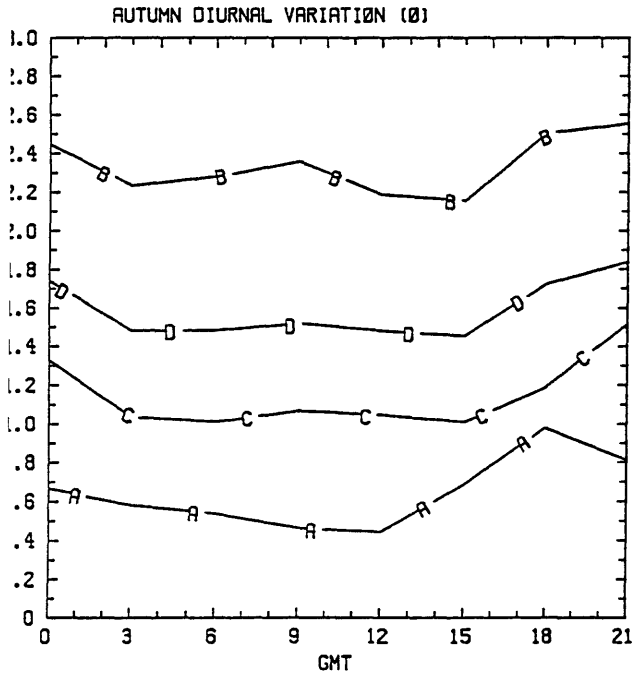


Fig. 10 Same as Fig 8 except for ocean only.



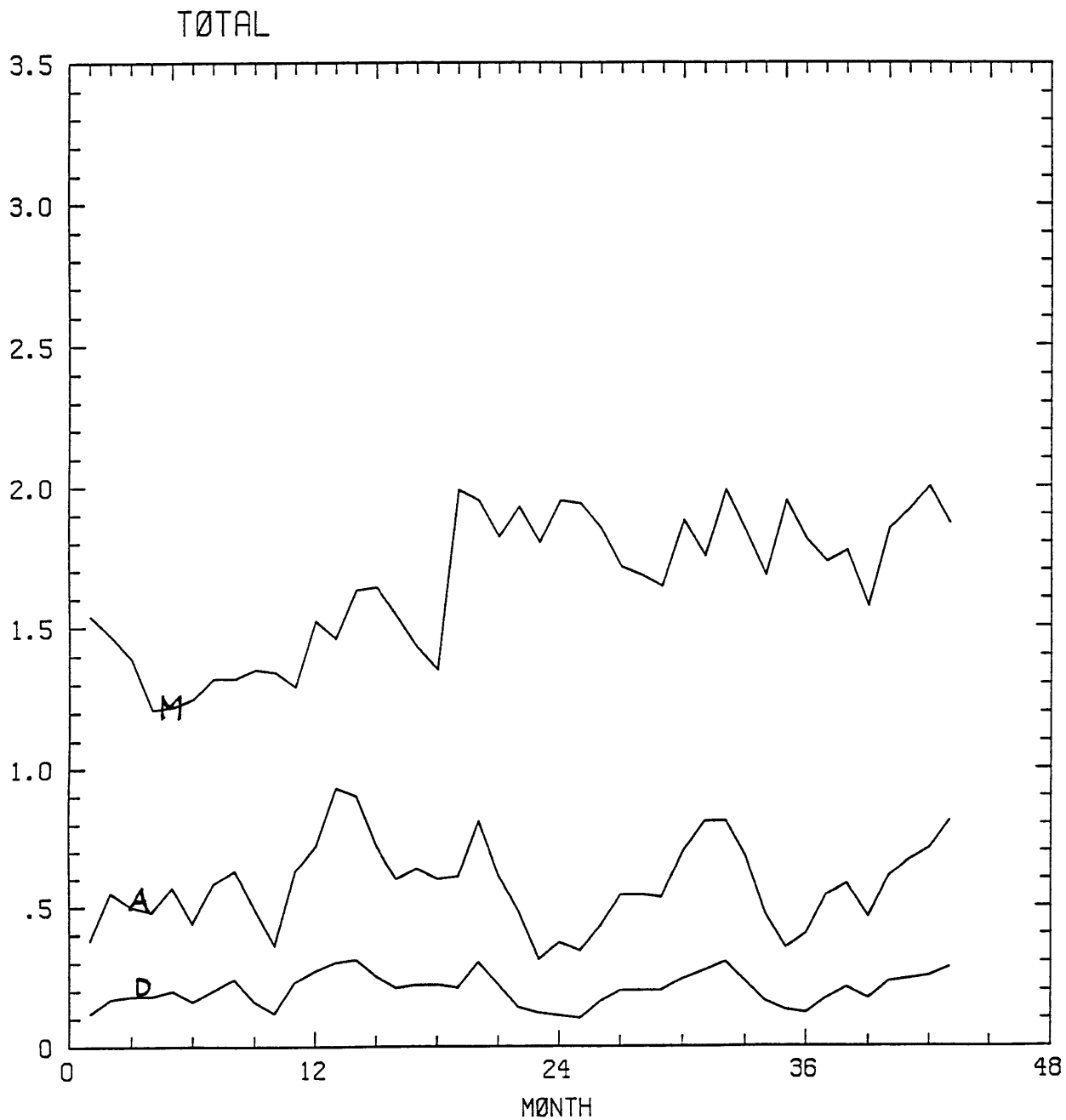


Fig. 11 Monthly changes of diurnal cycle (From August 1983 to February 1987). Line M is the mean, A is amplitude of diurnal cycle and D is standard deviation for diurnal cycle.

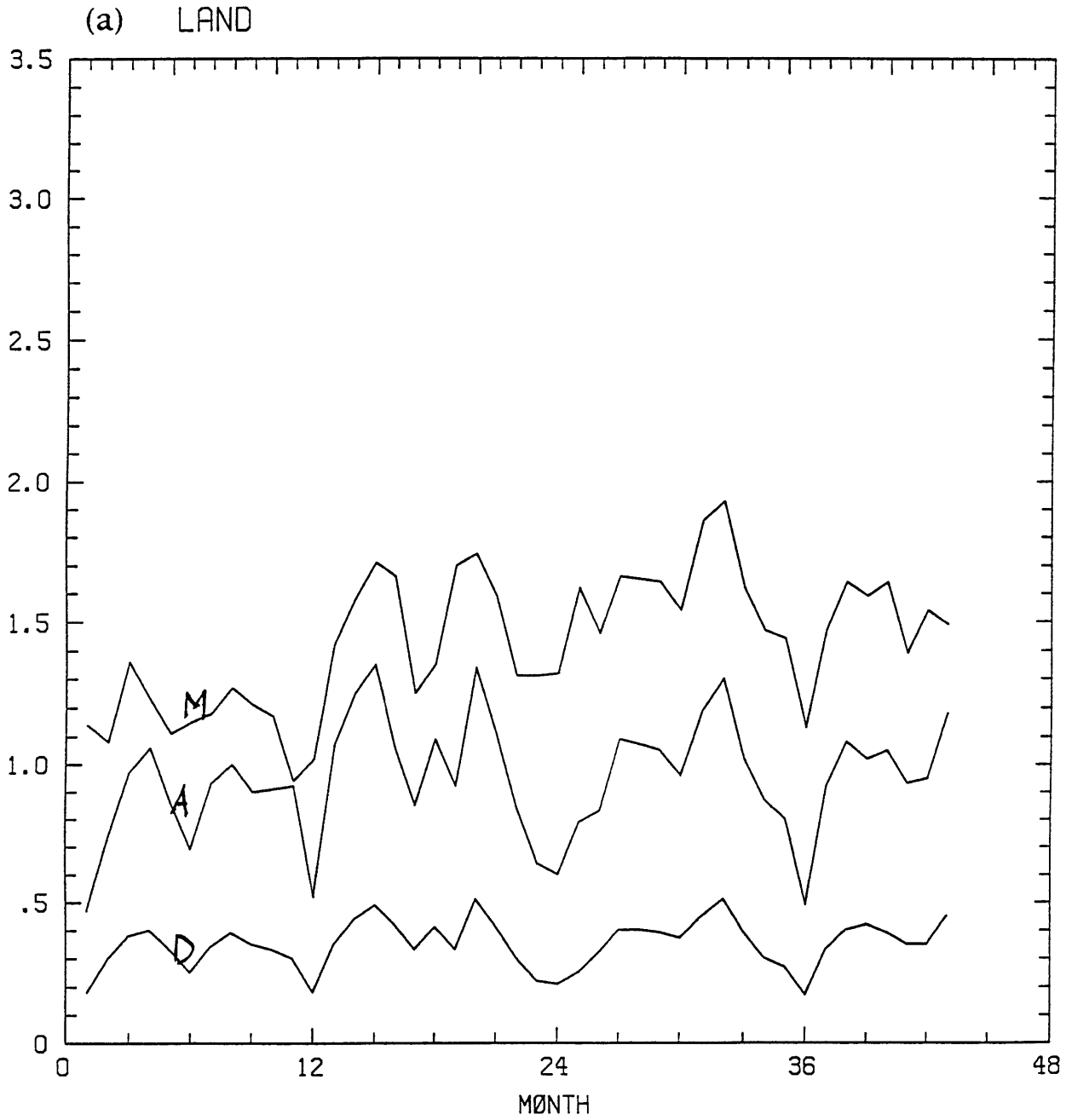
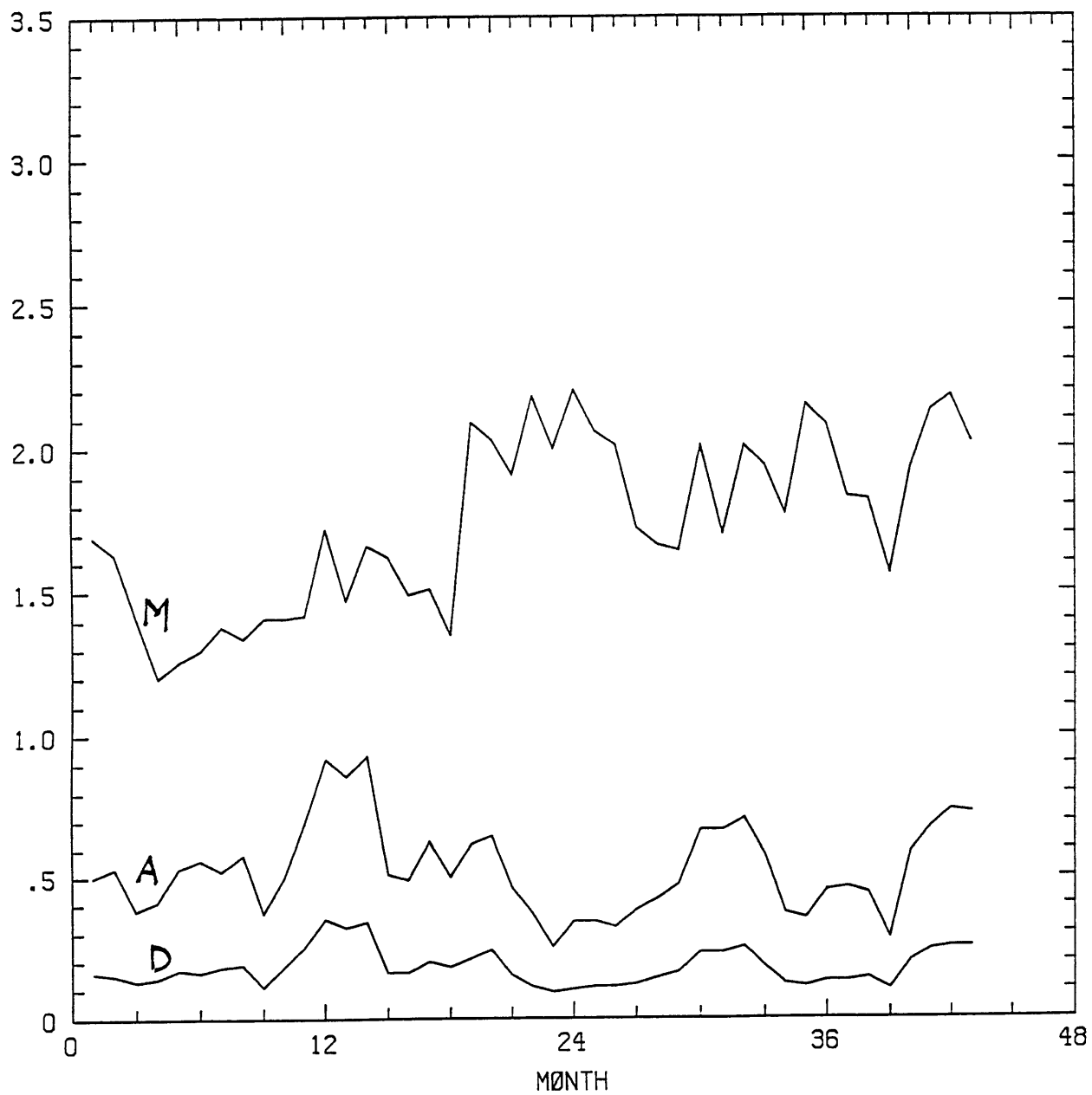


Fig. 12 Same as Fig 11 except for land and ocean seperately. (a) land  
 (b) ocean

(b) OCEAN



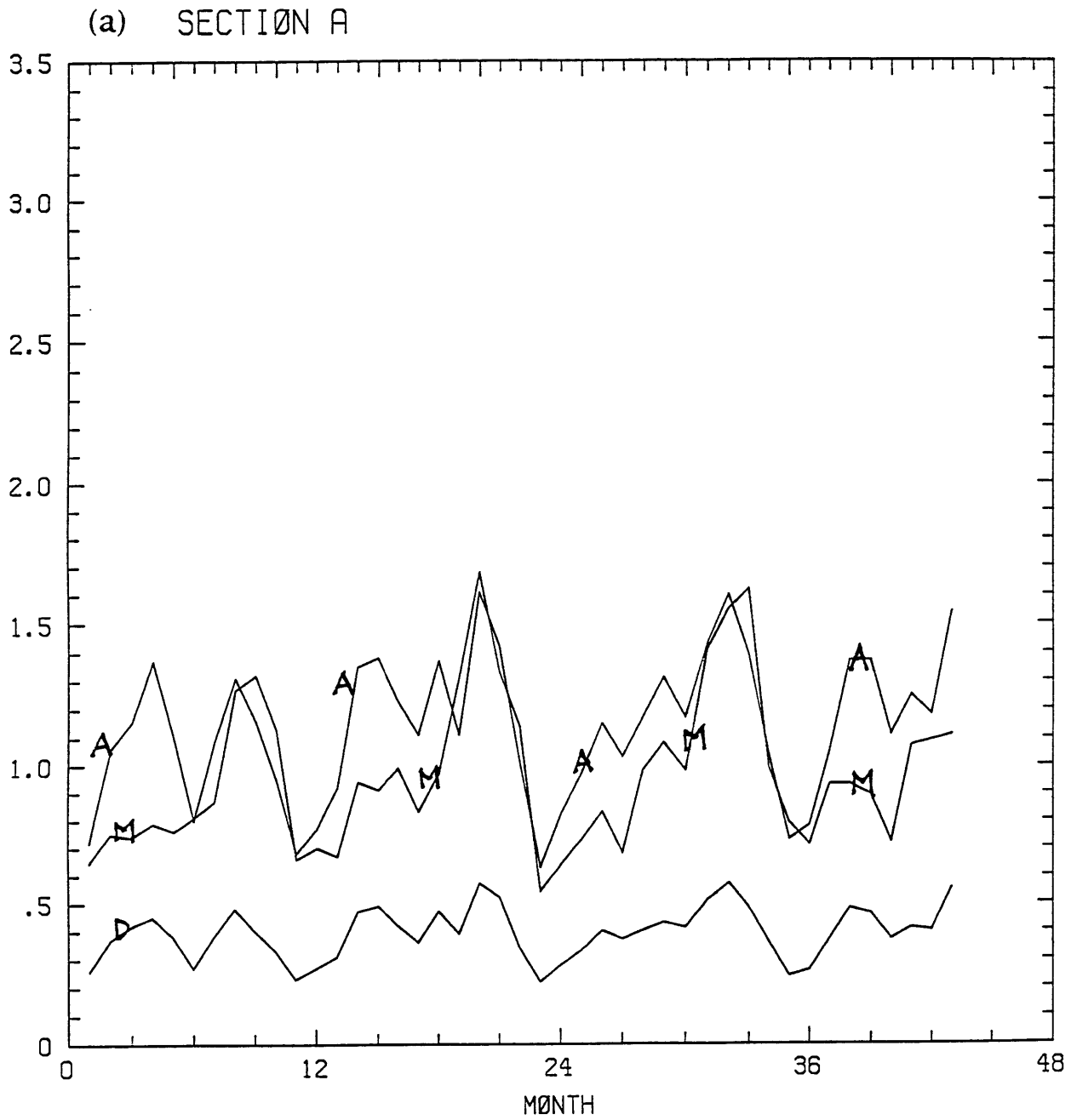
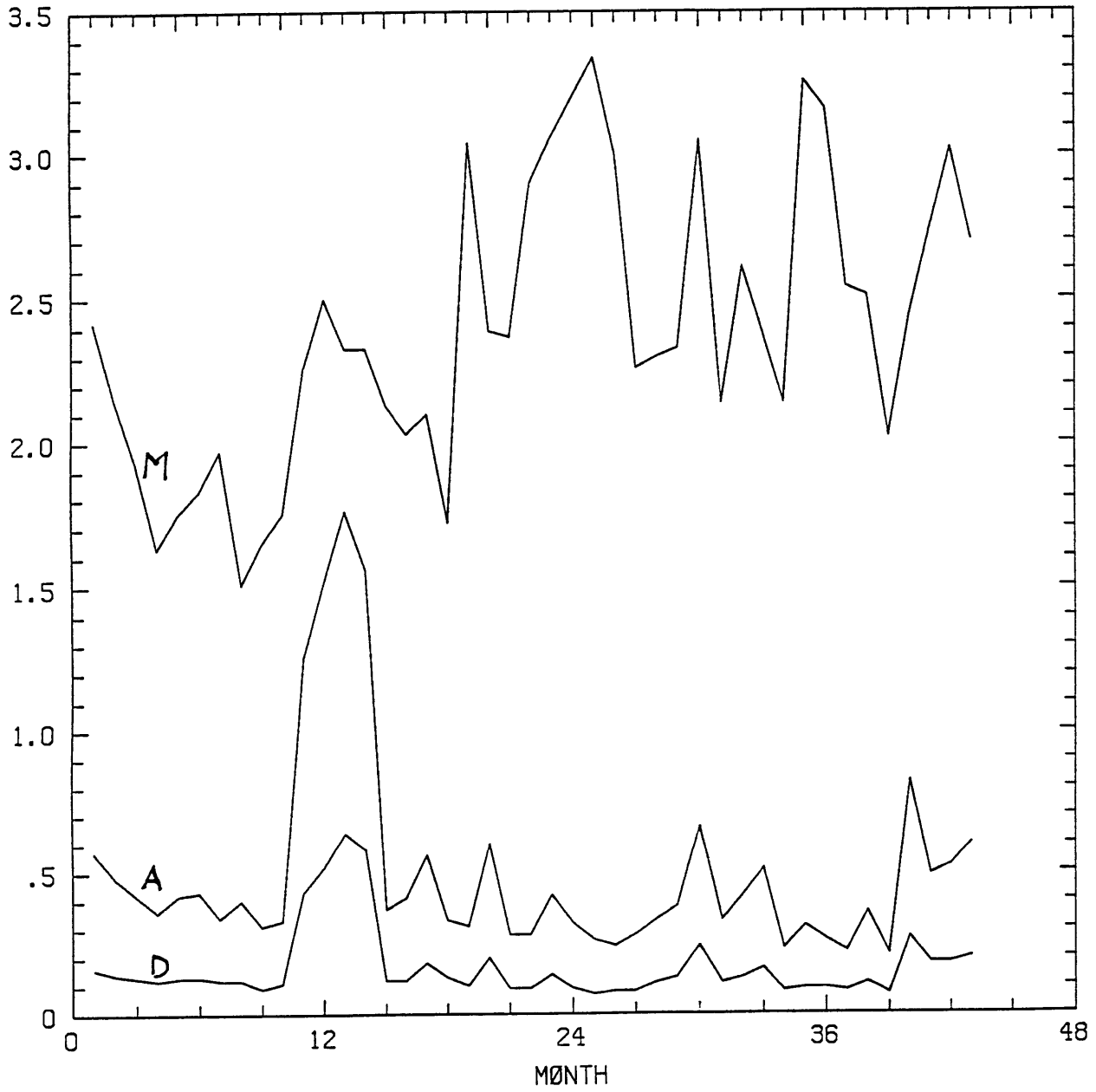
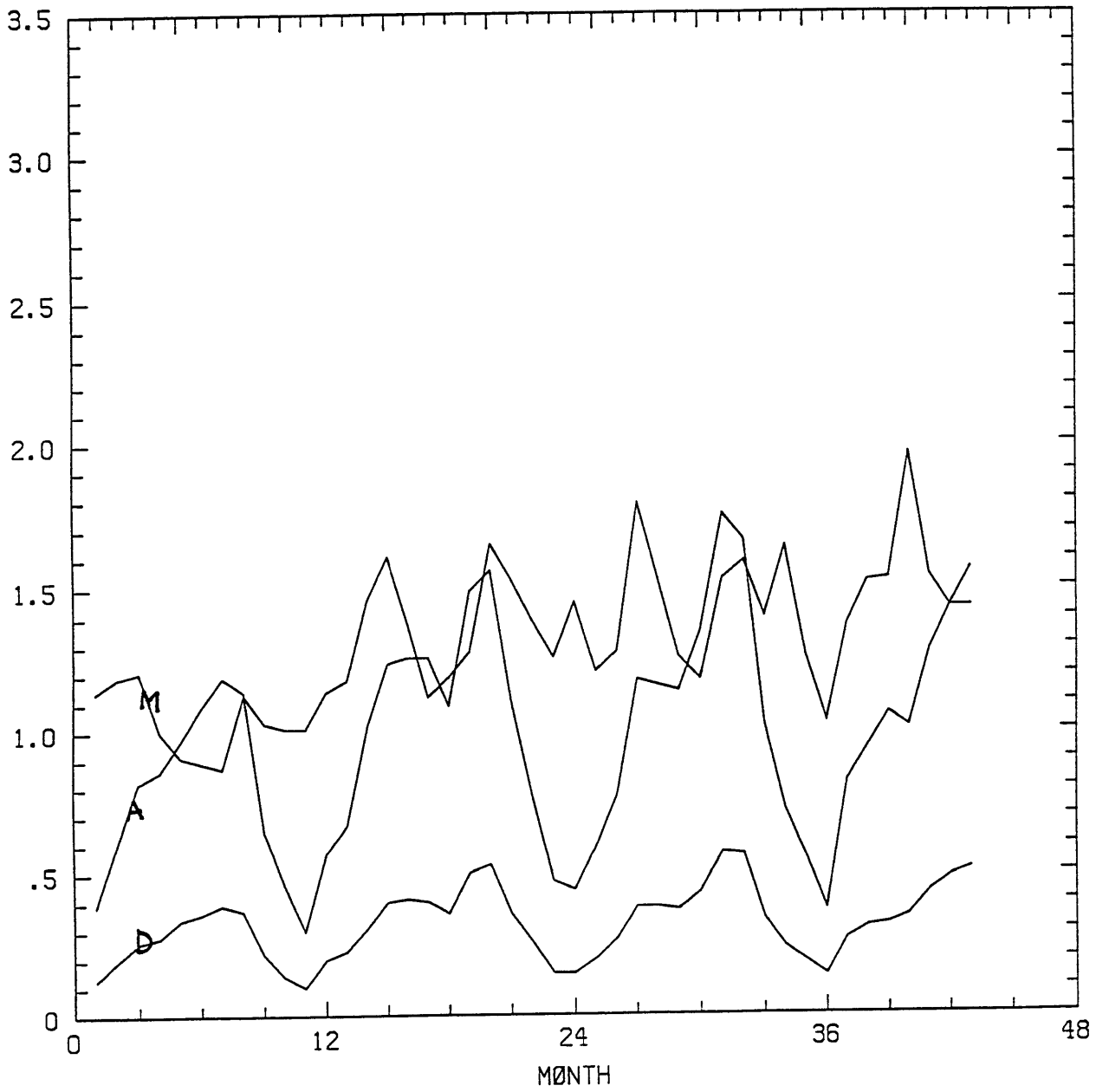


Fig. 13 Same as Fig 11 except for each section. (a) section A (b) section B (c) section C

(b) SECTION B



(c) SECTION C



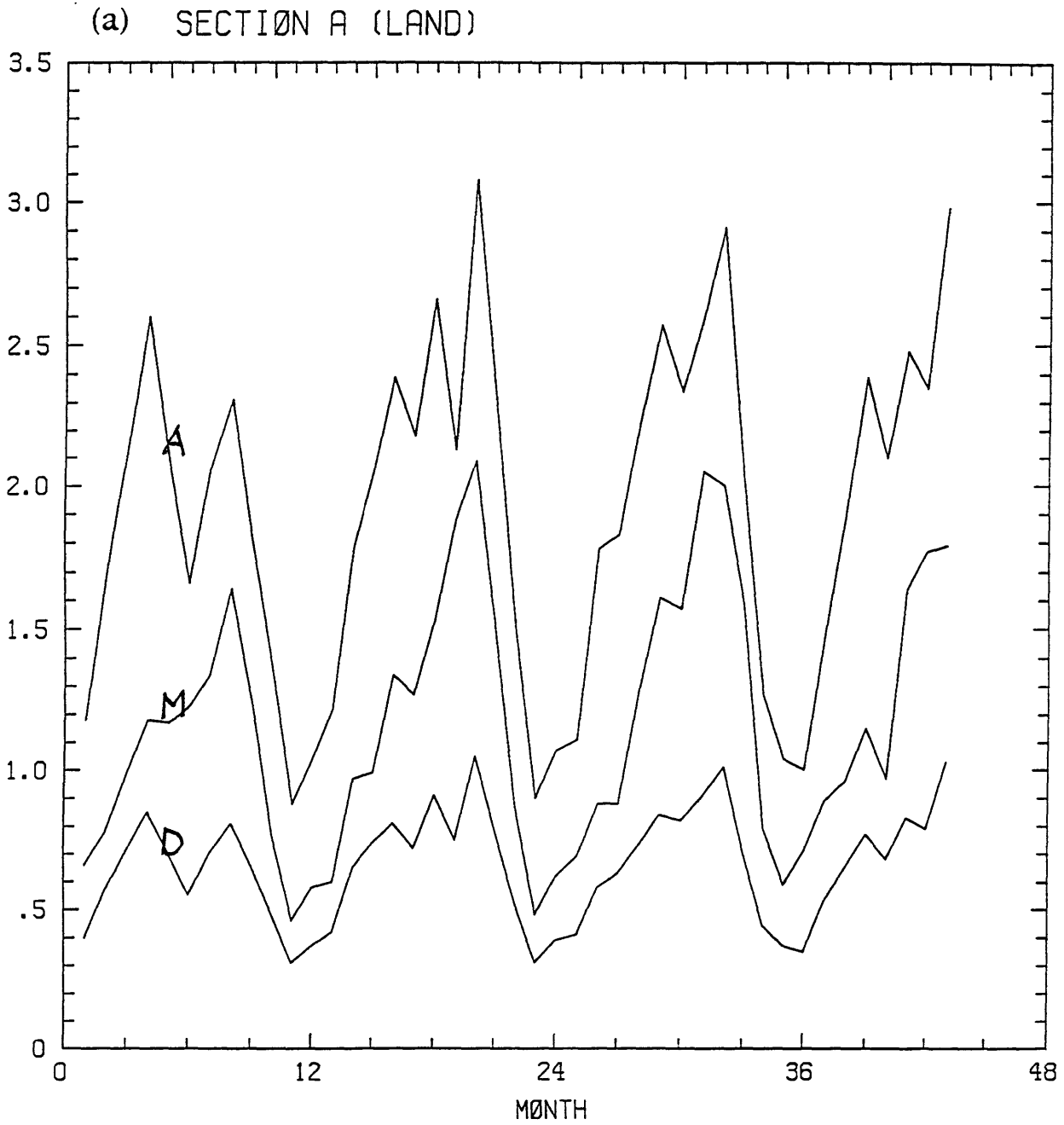
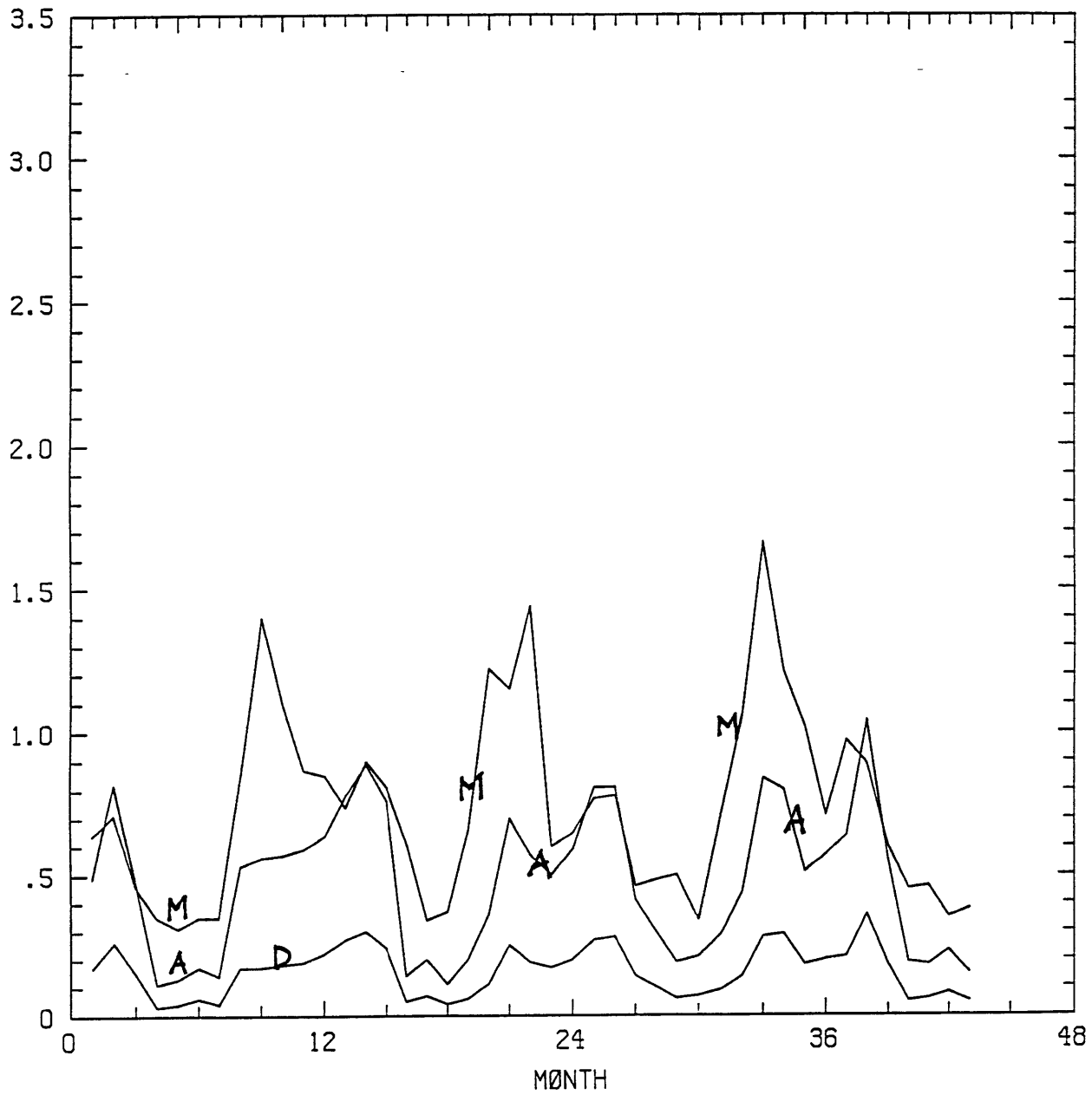


Fig. 14 Same as Fig 11 except for land and ocean separately in section A.  
 (a) land (b) ocean

(b) SECTION A (OCEAN)





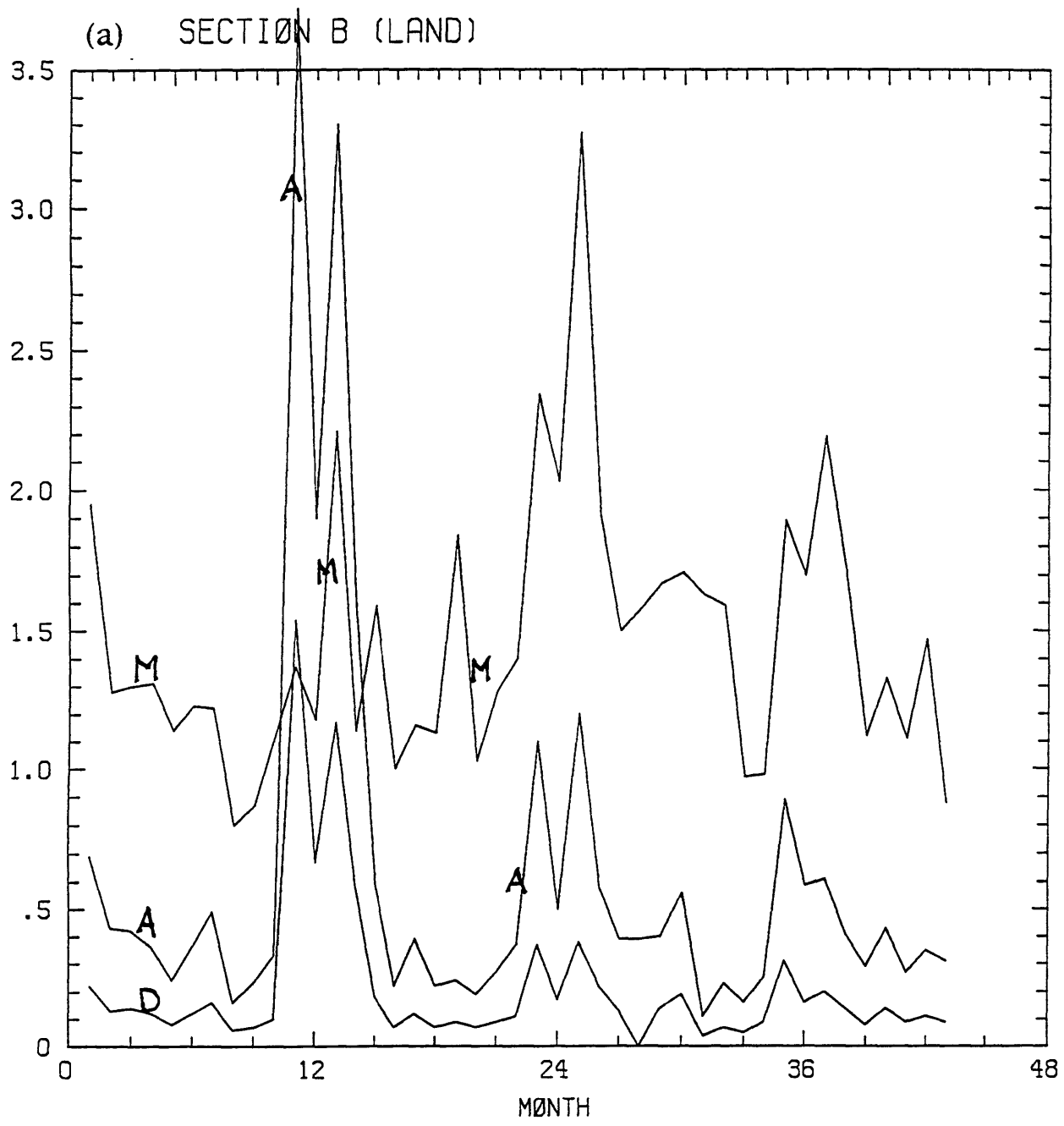
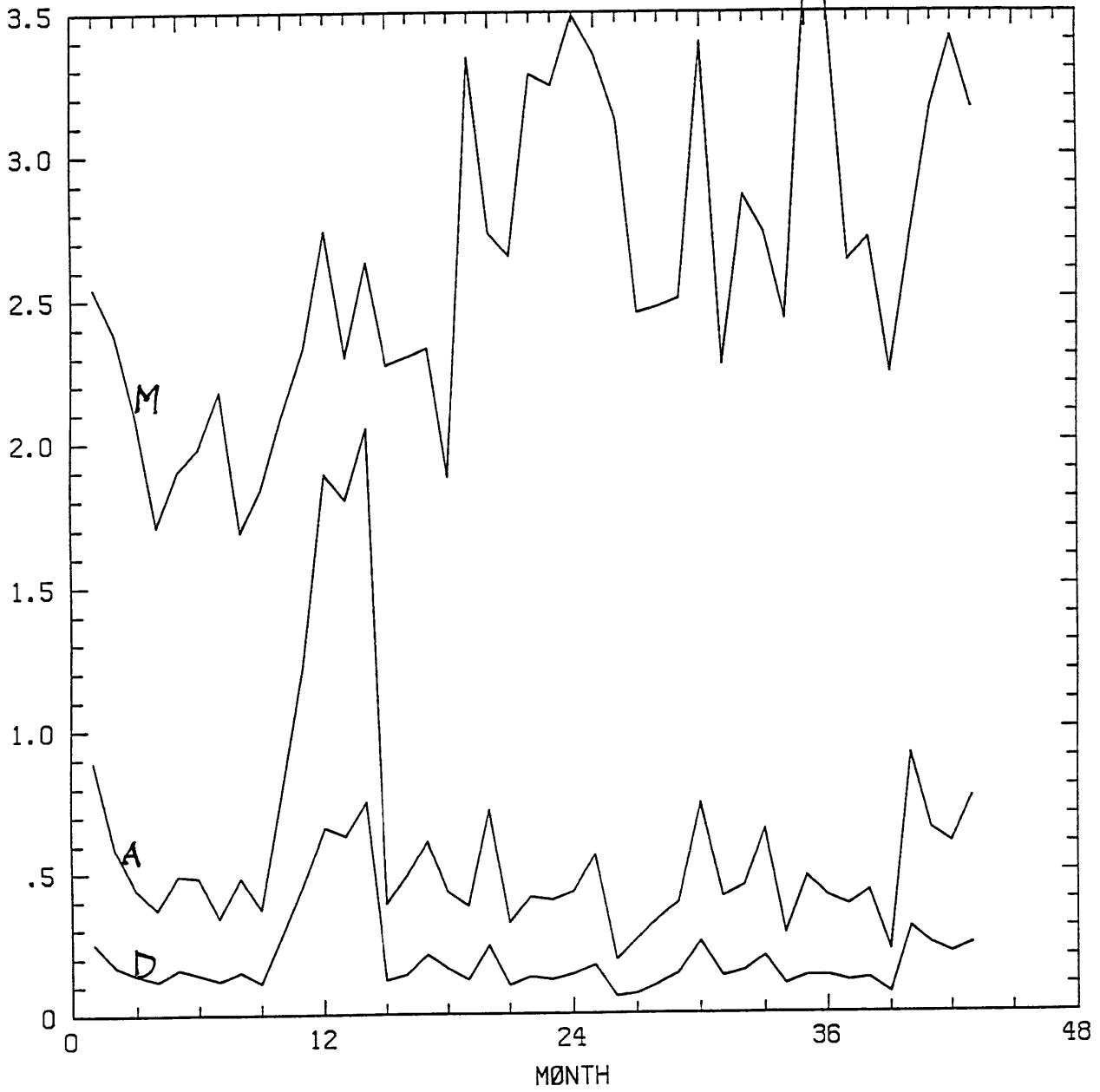


Fig. 15 Same as Fig 14 except for section B  
 (a) land (b) ocean

(b) SECTION B (OCEAN)



(a) SECTION C (LAND)

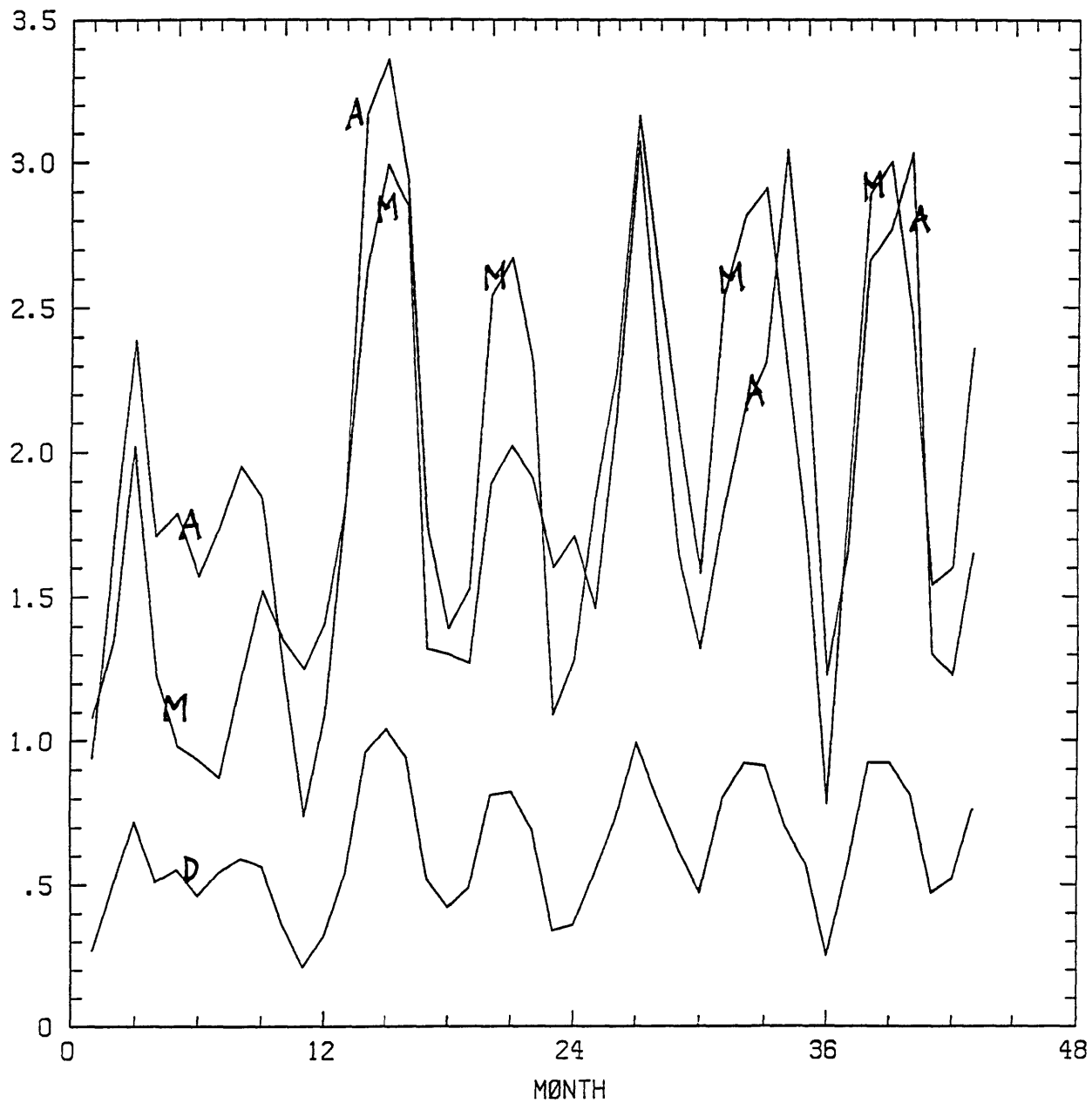
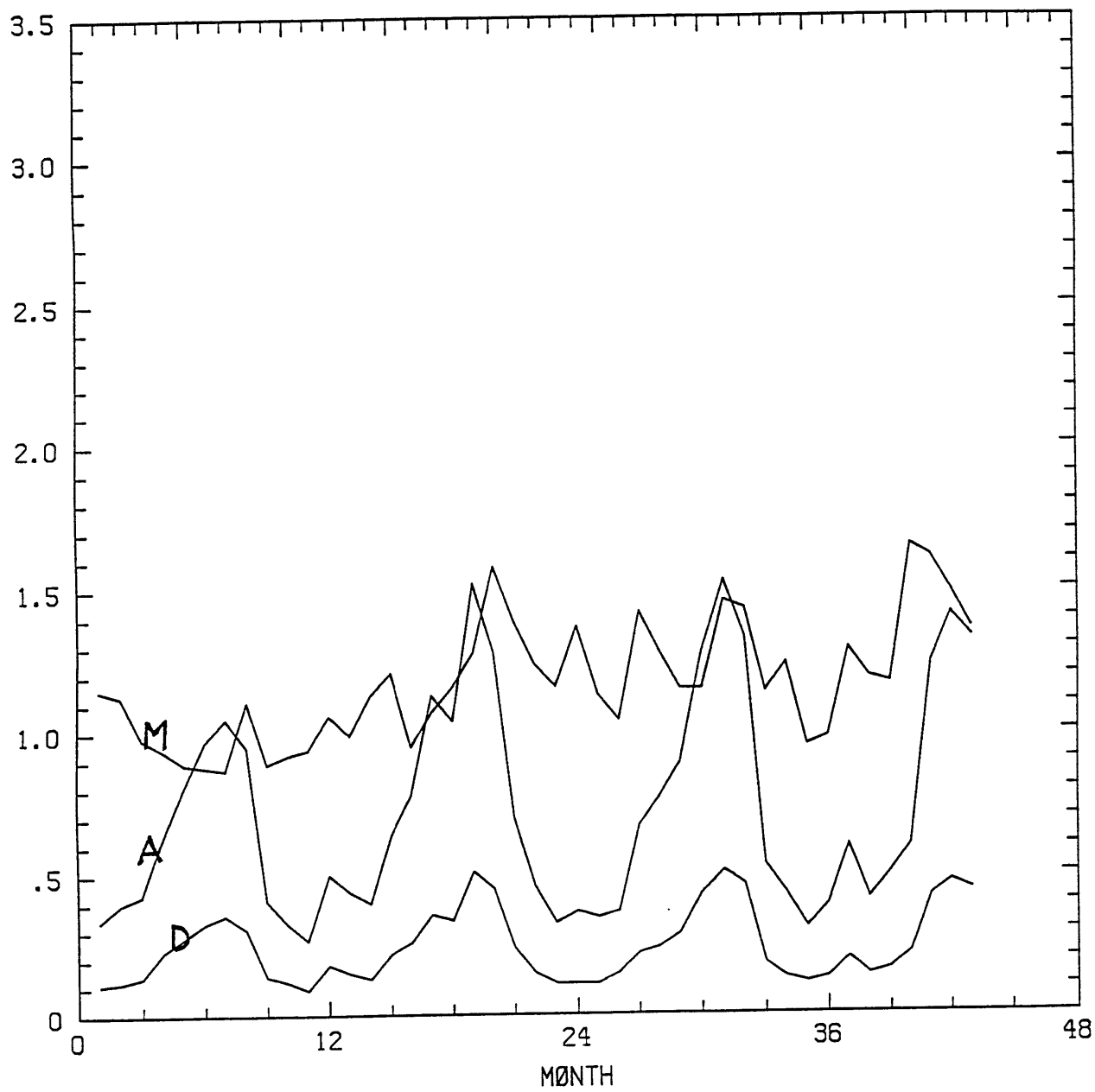


Fig. 16 Same as Fig 14 except for section C  
(a) land (b) ocean

(b) SECTION C (OCEAN)



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