THE ROLE OF THE QINGHAI-XIZANG PLATEAU IN FEEDBACK MECHANISMS AFFECTING THE PLANETARY CIRCULATION*

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3. *Observational Evidence.*

Figure 7 shows the Line Island precipitation index from 1910 to 1975. This index was computed and combined for the precipitation stations of Fanning Island, Washington Island and Christmas Island. It is defined by assigning the value of 100 to the wattest in a long series of months, say January, and the value 0 to the driest month in the same series. The interval between the wettest and driest month of January is thus divided into 100 units. The procedure is repeated for the other months of the year (Solot, 1950). This procedure eliminates the seasonal cycle and gives equal weight to dry and wet stations, as well as dry and wet seasons.

Similar data are shown for Nauru (Fig. 8) which lies much farther to the west. The agreement between the two sets of curves is demonstrated by the lag-correlation analysis of Fig. 9. There is also reasonable agreement with sea-surface temperature anomalies at Puerto Chicama (Fig. 4), as demonstrated by the lag correlations shown in Fig. 10.

From the agreement between the convergence of the Pacific trade winds and Line Island precipitation (Fig. 2) we are encouraged to conclude that during precipitation surges in the equatorial Pacific the Hadley circulation is stronger than normal in its surface component, namely the equatorward flow in the trade-wind region. A numerical general circulation model (GCM) experiment by Julian and Chervin (1978) suggested that another manifestation of the Hadley cell intensity, namely the strength of the subtropical jet stream over the Mexican Pacific coast, increases at the same time.

The Walker circulation, which represents the wind anomalies (Fig. 11) associated with the much larger southern oscillation of surface pressures indicates a rising branch over the equatorial East Pacific when waters are warm there, as they are during El Niño and heavy precipitation surges. Sinking motions are enhanced over Port Darwin and Djakarta during such periods (compare Figs. 3 and 4 with each other).

Our own investigations showed similar shifts in the equatorial Walker circulation

Manuscript received June 6, 1980.

* Following the first part on page 309, SCIENTIA ATMOSPHERICA SINICA, Vol. 4, No. 4, December, 1980.

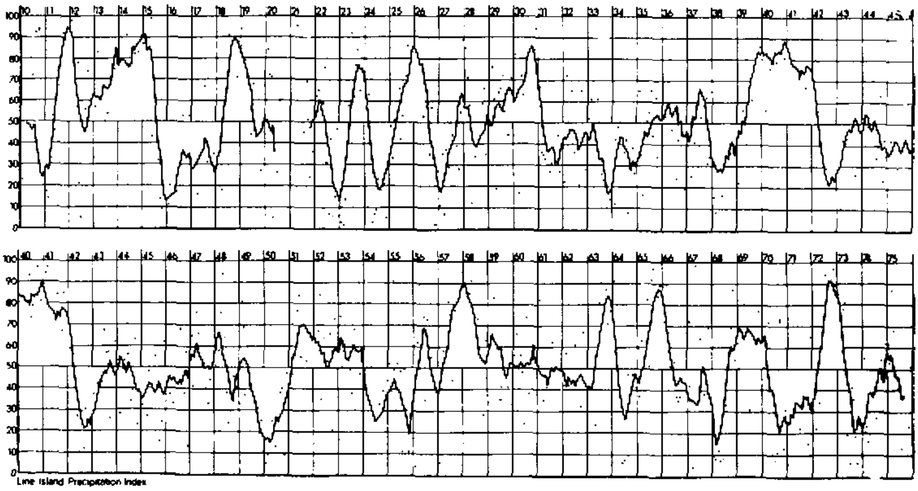

Fig. 7 Line Lsland precipitation index for the years 1910 to 1975. Dots indicate monthly values, the heavy line stands for a 7-month running average. (Data from Meisner, 1976.)

associated with SST anomalies in the eastern North Pacific north of the equator (Figs. 12 and 13). Such an association would indicate a connection between El-Niño related SST changes in the Humboldt and South Equatorial currents with SST changes in the California and North Equatorial currents. Furthermore, important teleconnections between South and North Pacific regions would be indicated through the actions of the equatorial Walker circulation and the Hadley cells in that region. Such interhemispheric relationships, therefore, are not confined to the cross-equatorial monsoon flow over the Indian Ocean.

A negative correlation between equatorial Pacific precipitation surges and rainfall during the Indian summer monsoon becomes apparent from Fig. 11.

A negative correlation between snow accumulation over the Himalayas during winter and the subsequent monsoon rainfall has been noted by Walker (1923) (see WMO-ICSU, 1975). In agreement with this, Chen and Yan (1978) report that with abnormally high and long-lasting snow cover over the Qinghai-Xizang plateau the establishment of the summer heat low and the upper tropospheric anticyclone appears to be delayed and weakened. The advance of the ITCZ trough from the Bay of Bengal into northern India is delayed accordingly, leading to a late commencement of the monsoon season. The tropical easterly jet stream over India during such years is found to the south of its normal position, so is the West Pacific subtropical high which, furthermore, extends farther to the west than normal. All these indicators mentioned by Chen and Yan (1978) point towards a Walker circulation as depicted in the lower portion of Fig. 11, indicative of a warm equatorial East Pacific. As shown by Figs. 12 and 13, such a Walker circulation also favors above-normal frequency of typhoon generation during the summer months (see Table 1) (Ding and Reiter, 1980a). This particular teleconnection is again in excellent agreement with statements by Chen and Yan (1978) pertaining to an increase of summer rainfall in Southern China subsequent to snow-

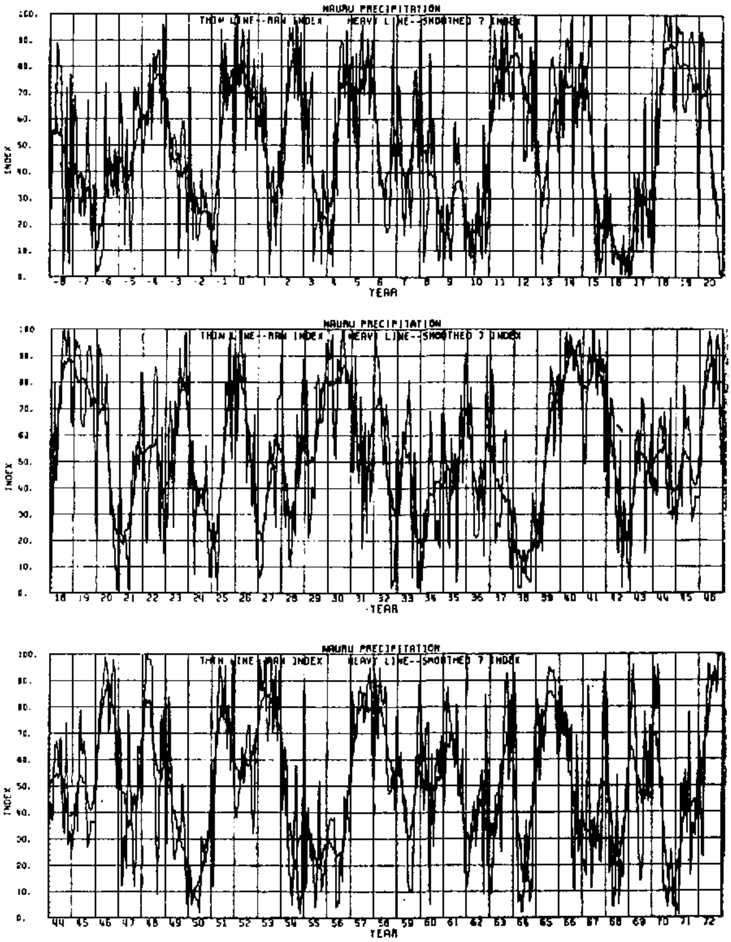

Fig. 8. Precipitation index for Nauru for the years 1892 (= -8) to 1972. Thin lines indicate monthly values, heavier lines stand for a 7-month running average. (Data courtest H. Flohn.)

rich winters in the Qinghai province. After all, typhoons contribute significantly to rainfall in southern China.

In line with what has been said in Chapter 2 we should not expect a perfect and consistent year-by-year match in the afore-mentioned teleconnections because of the complex responses of planetary waves to orographic and thermal forcing. With what little data we have, we attempted to match the anomalous number of days with snow cover at Heihe Station (dashed line in Fig. 14) with the Line Island precipitation index (Fig. 15). A time lag of the order of one year, with snow at Heihe leading

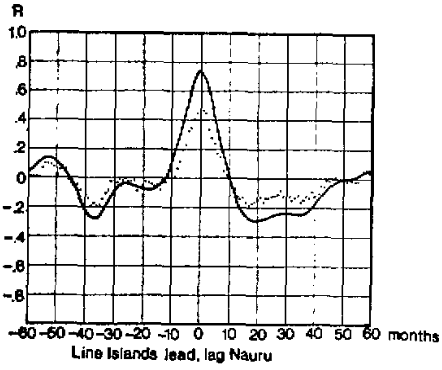

Fig. 9 Lag correlations between monthly precipitation index values for Line Island and Nauru. Dots indicate correlations obtained from individual monthly values, the solid curves give correlations between 7-month smoothed data sets.

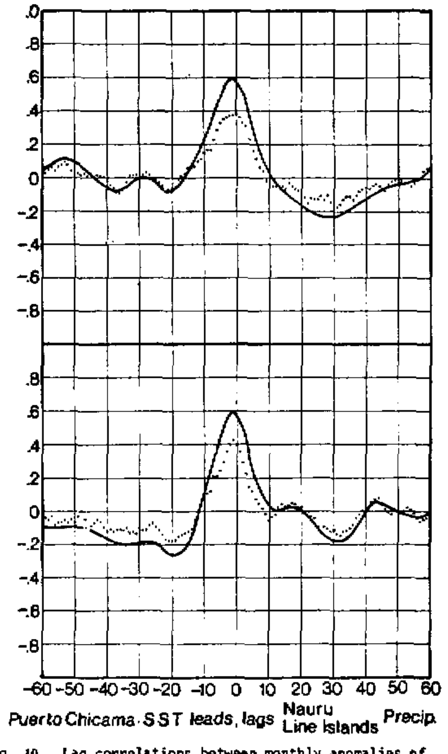

Fig. 10. Lag correlations between monthly anomalies of sea surface temperature (SST) for Puerto Chicama and precipitation index for Nauru (upper panel) and Line Islands (lower panel).

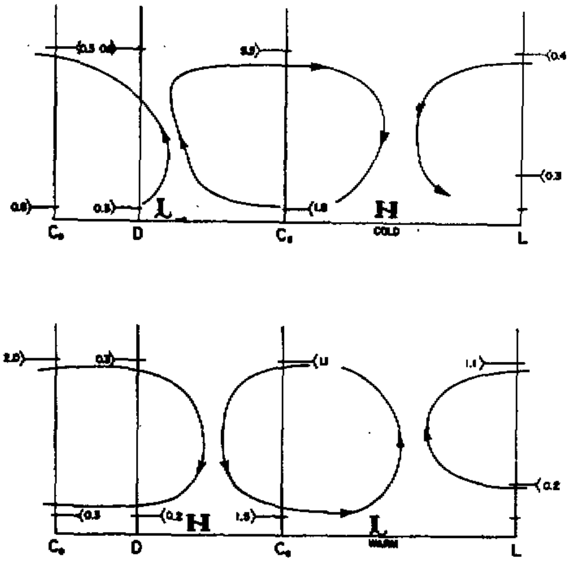

Fig 11. Schematic representation of the Walker Circulation. The top panel applies with normal cold water off the South American coast. The wind arrows denote actual average departures from normal of the zonal winds at 200 and 850 mb (or 700 mb) for Cocos Island, Port Darwin, Canton Island and Lima, Peru. The departures from normal are in meters per second. The bottom panel indicates the composite anomalies during the El Niño warm water months. (Julian and Chervin, 1978.)

precipitation in the equatorial Pacific, seems to yield the best match of peaks in the two sets of curves, with a notable exception in 1972/73. This time lag is quite bothersome because we cannot think of a physical mechanism, especially for a continental region, that would provide for such a long "memory".

We have attempted another crude comparison, by superimposing the (inverse of the) Heihe snow-cover day anomalies over SST anomalies in the Atlantic, this time without a time lag (Fig. 16). Again, there is a hint of a correspondence in the two sets of curves. Rowntree (1976) has commented on possible European weather pattern responses to Atlantic SST anomalies in the tropics. The SST anomalies shown in Fig. 16 were observed at higher latitudes than Rountree's and most likely are indicators of interaction between the ocean and atmospheric flow patterns, similar to those found over the Pacific (Reiter, 1978a, b, c, 1979a, b, c, d). We do not yet have positive proof of this hypothesis, but we are encouraged to speculate that Atlantic SST anomalies might affect planetary wave patterns even over the Asian continent. These SST anomalies might provide the "memory" affecting the correlation between snow cover on the Qinghai-Xizang plateau and the atmospheric circulation patterns over China during the subsequent summer.

Even though we have not yet attempted to quantify planetary-wave adjustments

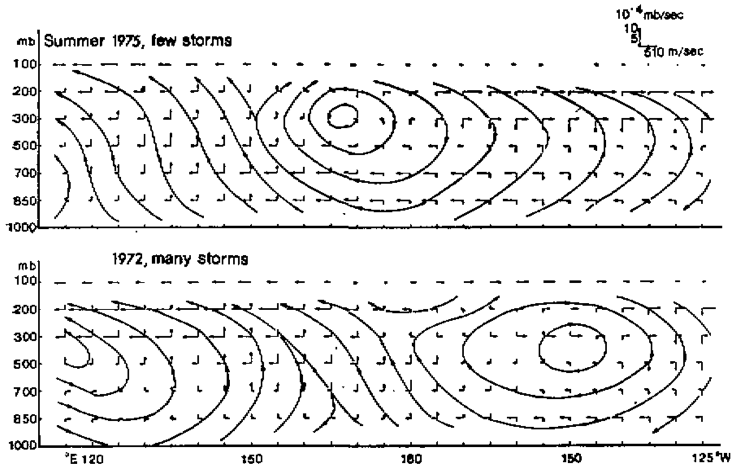

Fig. 12a. The equatorial Walker circulation over the Pacific ocean, averaged over the latitude band 5°S to 5°N. Upper panel is for 1975, a year with few typhoons. Lower panel is for 1972, a year with many typhoons.

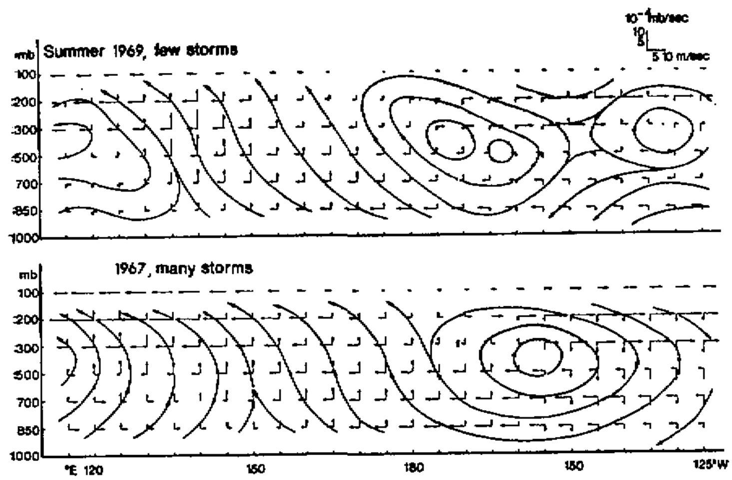

Fig. 12b. Similar to Fig. 12a, except for 1969 and 1967.

to the interannual variability of heat sources and sinks over oceans and continents, preliminary indications are that such adjustments may be significant. How else could one explain the large interannual variability in planetary-wave characteristics, unless one assumed random processes to dominate the long-term behavior of the atmosphere?

In a priliminary attempt to relate the activity of planetary wave numbers 1, 2, 3

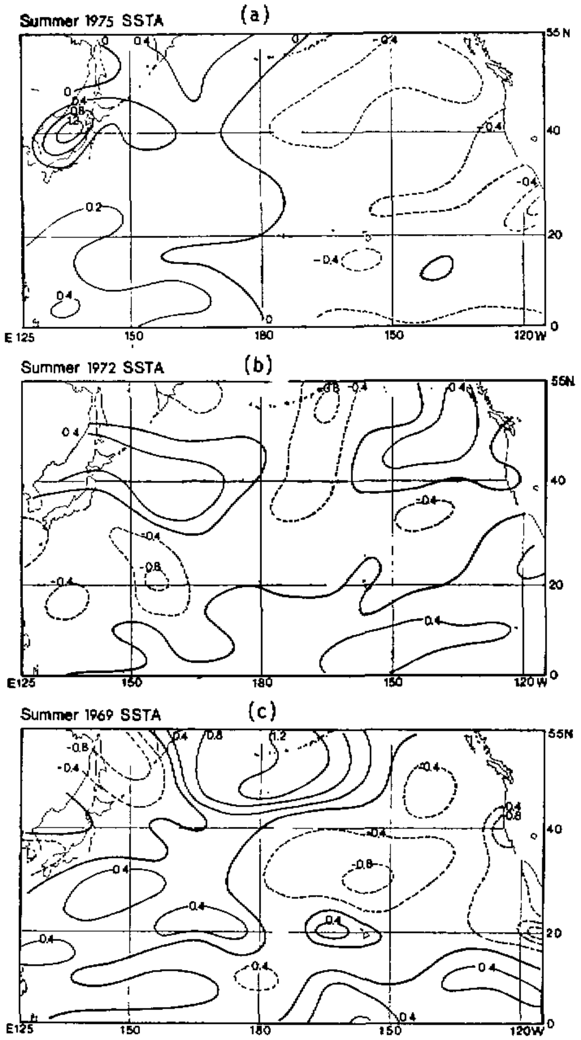

Fig. 13. Sea-surface temperature anomaly (SSTA) patterns for (a) summer of 1975; (b) summer of 1972; (c) summer of 1969; (d) summer of 1967; Dashed lines denote negative anomalies, thin solid lines denote positive anomalies, and slightly thicker lines are zero-isolines of SSTA.

and 4 to typhoon activity over the Pacific, we show in Fig. 17 the time sections of 500-mb height anomalies at 30°N for two years with many typhoons (1967, 1972) and two years with few typhoons (1969, 1975). It becomes evident from these diagrams that the suppression of typhoon activity in the Pacific is associated with a strong and stable ridge near the date line. During the two years with many typhoons shown here the mid-Pacific trough is weak and is interrupted several times. The Atlantic ridge appears to

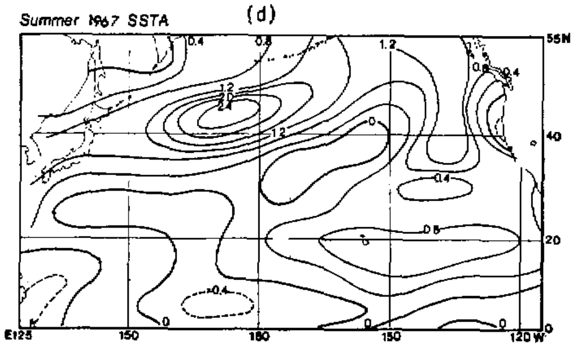

Fig. 13 (continued)

be more stable than the Pacific ridge in the two examples shown here. It appears, that the relative westward shift of the equatorial Walker circulation during years with few typhoons (Fig. 12) is matched by a westward migration of the East Pacific long-wave trough. A coupling of SST anomalies, low latitude Walker circulation and planetary long waves, therefore, seems to be suggested by observational evidence.

Also shown in Fig. 17 are time-sections for the years 1962 and 1968 which, according to Fig. 14, were characterized by excessive snow cover in the Qinghai region and, according to Fig. 16, by relatively cold SST in the central North Atlantic. These two sections should be compared with the time sections for 1967 and 1972. During these years little snow prevailed on the Qinghai-Xizang plateau and the central North Atlantic was relatively warm. During the early part of 1967 and 1972 a strong and persistent planetary long-wave ridge covered the Atlantic warm-water region, indicative, perhaps, of blocking anticyclonic activity in that longitude sector. On the other hand, during the early part of 1968, with above-normal snow in Qinghai, the high pressure ridge near 120°—110°W (Rocky-Mountain region) appeared to be more dominant. From Fig. 18 we find that relatively warm SST's prevailed off the coast of California during the winter of 1967/68, more so than during the winters of 1966/67 and 1971/72. The

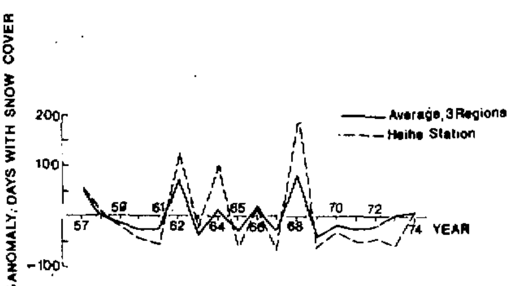

Fig. 14. The interannual variability in the anomaly of the number of days with snow cover (%) over the Tibetan plateau (averaged for 3 regions with much snow cover) and at Heihe Station. Years are indicated for each January of respective winter season. (Chen and Yan, 1978.)

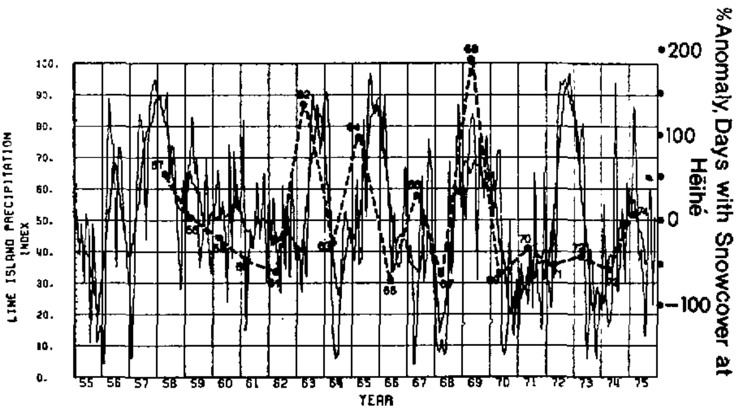

Fig. 15. Percent anomaly of days with snow cover at Heihe Station (dashed line with years marked near dots) and Line Islands precipitation index (thin line: monthly values; slightly heavier line: 7-month running mean).

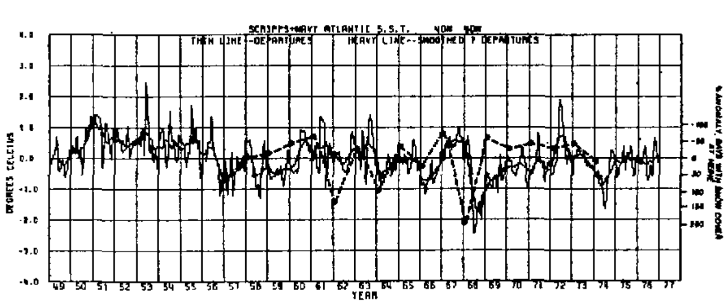

Fig. 16. Percent anomaly of days with snow cover at Heihe Station (dashed line and dots plotted in the corresponding winter season) and Atlantic sea-surface temperature anomalies at 40°N 40°W, showing monthly data (thin line) and 7-month running means (slightly heavier line).

Qinghai-Xizang region (80°E) shows relatively more cyclonic (trough) activity during January 1962 and 1968 than during the same month in 1967 and 1972. Moreover, relatively strong troughs prevailed during the early part of 1967 and 1972 over central and eastern Europe, downstream from the Atlantic blocking high, suggesting a planetary wave pattern of considerable amplitude west of the Qinghai region, and prevailing southwest winds aloft in the region between 30°E and 60°E. In the early part of the snow-rich years 1962 and 1968, on the other hand, the European trough was weak. During February and March anticyclonic conditions extended well into southeastern

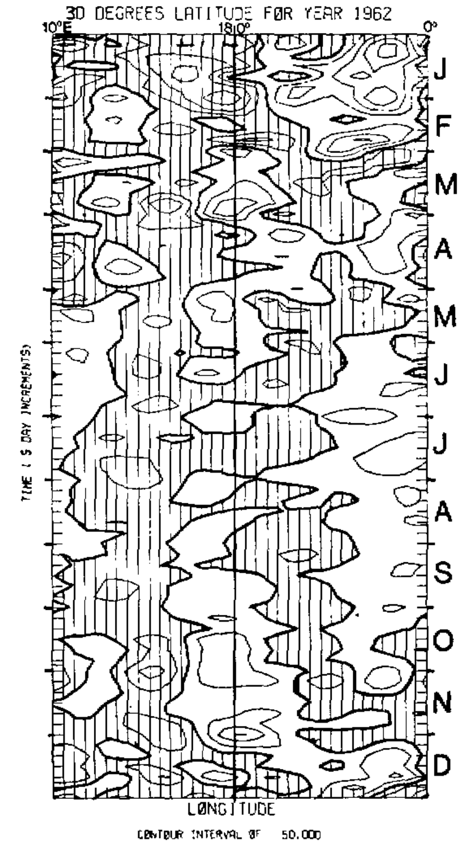

Fig. 17. Time section of 500 mb-heights, truncated after planetary-wave number 4, at 30°N. Abscissa is marked for every 10° of longitude; each dash along the ordinate corresponds to a five-day period. Months are labelled on the right side of each diagram. The year is given on top of each diagram. Isolines are drawn at intervals of 50 m of geopotential height. Low-pressure anomalies are shaded.

Europe. Figure 17 suggests that a zonal to northwesterly flow component by long planetary waves was the dominant feature of the 1967/68 winter along the western border of the Qinghai region.

We thus have preliminary evidence that SST anomalies in the Atlantic and Pacific oceans can interact in a significant way with planetary long-wave patterns, as postulated in Chapter 2. Furthermore, snow-cover characteristics on the Qinghai-Xizang plateau appear to respond to planetary long-wave characteristics. The albedo and atmospheric energy-budget modifications by a snow-covered plateau might conceivably produce an important feedback process with planetary-wave behavior. It might be more than coincidence that in March/April 1967 and 1972, following a snow-poor winter in the Qinghai region, anticyclonic conditions were established rapidly in the Asian sector (Fig. 17), whereas in April 1962 and 1968, following a snow-rich winter, relatively

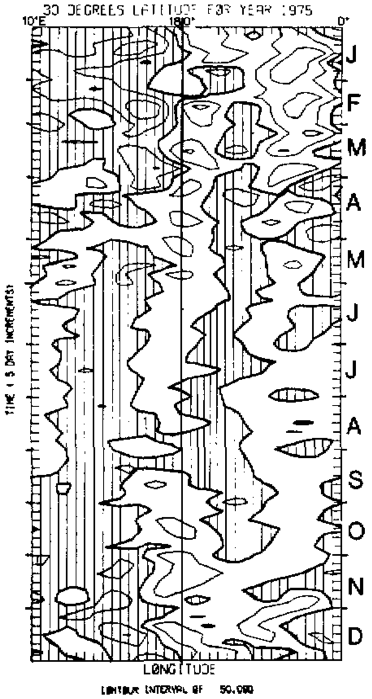

Fig. 17 (continued)

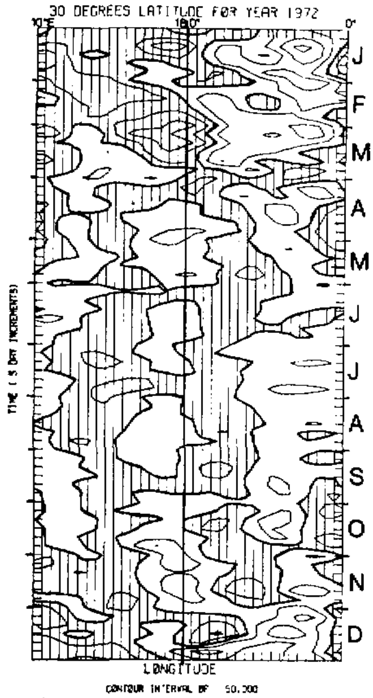

Fig. 17 (continued)

cyclonic conditions prevail in the same longitude sector. We, therefore, find ourselves in agreement with the important work conducted by several of our Chinese colleagues (Chen and Yan, 1978).

4. *Conclusions*

The main results of our study can be summarized as follows:

(a) Long and ultra-long planetary waves in the atmosphere are forced not only by the large mountain ranges but also by heat sources and sinks.

(b) Interannual variability in these long-wave patterns, hence in seasonal and regional weather anomalies, can be produced by changes in the heat-source distribution, notably by shifts in SST anomaly patterns and by changes in the albedo characteristics of the Qinghai-Xizang plateau.

(c) Planetary-wave adjustments are not confined to a limited region but produce "teleconnections" between weather anomalies over distant parts of the globe. Snow cover in the Qinghai region seems to be linked to SST anomalies over the central North Atlantic, blocking activity in that region, and trough intensity over Europe. In agreement with earlier conclusions by Chinese scientists, the development of an anticyclone over Tibet during spring seasons following snow-rich winters appears to be delayed and weakened. Shifts in long-wave patterns also affect the Pacific longitude sector and are directly reflected in the typhoon activity.

(d) Pacific typhoon frequency is also modulated by SST anomalies in tropical

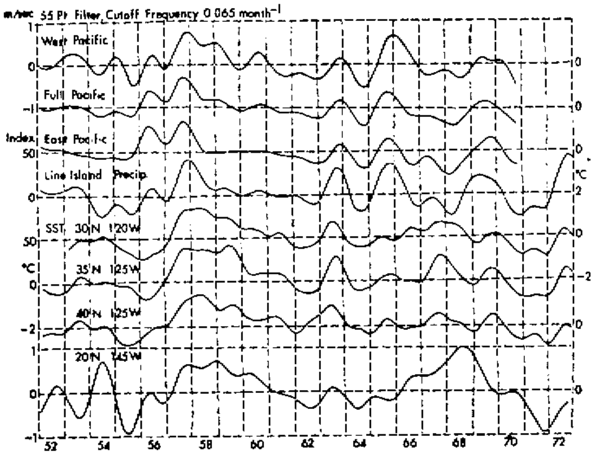

Fig. 18'. Filtered time series (cut-off period ca. 15 months) of the trade wind convergence $(-v_{N.H.} + v_{S.H.})/2$ in m/sec in the West Pacific (5°N-19PN, T°S-15°S; west of 160°W), the full Pacific (same latitude bands), and the East Pacific (same latitude bands, east of 160°W); filtered series of the Line Islands precipitation Index expressed as ranging from -50 (dry) to +50 (wet), and of SST anomalies (°C) at various grid points as indicated. Years are plotted along the abscissa. (Filter design and computations by J. Middleton.)

and subtropical regions of the East Pacific. Walker and Hadley circulations appear to be linked to these SST anomalies as well.

(e) Shifts in Walker and Hadley circulations are reflected in phase shifts of the long and ultra-long planetary waves. A feedback mechanism between these waves and SST anomalies is indicated. Interannual variability of planetary wave characteristics appears to be the cause of snowfall variability on the Qinghai-Xizang plateau which, in turn, also can exercise a feedback effect on planetary waves. Thus a complex pattern of interactions between continents and mountain ranges, oceans, and the atmosphere evolves.

(f) These interactions are by no means fully explained by our study but have to remain the target of further exploration using observational data, laboratory experiments and numerical modelling approaches.

(g) The Qinghai-Xizang plateau not only is a forceful *source* of perturbations affecting the global atmospheric circulation; its meteorological characteristics also *respond* to forcing processes that occur elsewhere on the globe.

Acknowledgments

The research work reported in this paper was supported under Department of Energy Contract DE-AS02-76EV01340 and National Science Foundation Grant ATM17835.

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