The Global Distribution of the Annual and Semiannual Cycles in Surface Temperature

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ABSTRACT

The annual march of surface temperature is documented on a global basis by mapping the amplitudes and phases of the annual and semiannual cycles in a vectorial format. The annual cycle in Northern Hemisphere geopotential heights is discussed and the amplitude of the annual cycle in 300 mb geopotential height is presented.

1. Introduction

Two recent papers by Hsu and Wallace (1976a,b) documented the annual and semiannual cycles of precipitation and sea level pressure on a global basis by mapping the amplitudes and phases in a vectorial format. This paper uses the same means to examine the annual cycles of surface temperature and tropospheric geopotential heights.

The annual cycle of surface temperature on the continents was extensively examined by Kendrew (1927) who emphasized the role of the land-sea distribution in determining the observed geographical pattern of annual temperature range. Kirk (1953) investigated the seasonal cycle of surface temperature in the North Atlantic. He found that the amplitude of the annual cycle is largest just off the North American coast and decreases eastward. Prescott and Collins (1951) documented the lag of surface temperature behind solar radiation on a global basis. The smallest lags were found to occur on continental basins and highlands and the largest lags over the eastern oceans near the equator. van Loon (1972a) published separate maps of the amplitude and phase of the yearly wave of surface air temperature (Figs. 3.21 and 3.23) in the Southern Hemisphere, based on the same data as this paper. In middle latitudes the amplitude of the annual temperature cycle was found to be about twice as large over the continents as over the oceans with the peak temperatures occurring at least a month earlier over the continents. van Loon (1972b) also examined the annual and semiannual cycles in upper atmospheric geopotential heights and temperatures in the Southern Hemisphere.

The present study is based on the long-term mean monthly grid-point data assembled by Crutcher and Meserve (1970) for the Northern Hemisphere and Taljaard et al. (1969) for the Southern Hemisphere. The data were obtained on magnetic tape from the National Center for Atmospheric Research. The amplitudes and phases of the annual and semiannual cycles at each grid point were obtained by harmonic analysis of the 12 monthly means. In presenting the results, we used the same vectorial format as in Hsu and Wallace (1976b). The length of the arrow indicates the amplitudes of the annual cycle while the direction indicates the phase. An arrow from north to south represents a maximum in the annual cycle on 1 January, while an arrow from the east indicates a maximum on 1 April. For the semiannual cycle, the arrows are plotted without heads; a line running north-south indicates maxima on 1 January and 1 July.

2. Surface temperature

Figs. 1 and 2 show the amplitude and phase of the annual cycles in surface air temperature over the entire globe. The plots of the first harmonic of mean monthly surface air temperature confirm the results of the previous investigators mentioned above, while presenting the annual cycle in a compact, objective format. The following characteristics are observed:

1) Over land, in all but the equatorial latitudes, the annual cycle is clearly larger and its peak occurs at least a month earlier than over the oceans, as observed by Prescott and Collins (1951).
2) The largest annual cycles in the Northern Hemisphere are observed near 60°N rather than further poleward, as noted by Kendrew (1927).
3) The amplitude increases gradually eastward across Europe into eastern Russia, in contrast to the situation in western North America where the increase is more abrupt, as Kendrew (1927) observed.
4) In the Northern Hemisphere mid-latitude oceans, the amplitude decreases from west to east, as described by Kirk (1953). Such a pattern is not nearly as readily apparent in the Southern Hemisphere.
5) The largest phase lags relative to the annual cycle...
Fig. 1. Amplitude and phase of the annual cycle in surface temperature, for (a) Northern Hemisphere, (b) Southern Hemisphere, and (c) belt centered on equator. Amplitude is indicated by the length of the arrows according to the scale shown. Phase is depicted by the orientation of the arrows. An arrow pointing from north to south indicates a maximum on 1 January, while one pointing from the east shows a maximum on 1 April. Amplitudes smaller than 0.5°C are plotted as points.

in insolation are observed over the eastern oceans in low latitudes, as noted by Prescott and Collins (1951) and van Loon (1972a).

6) The effects of the summer monsoon are evident in the early maxima over much of the land area near 15° latitude in both hemispheres, reflecting the arriva

Fig. 2. As in Fig. 1 except for the semianual cycle. A line directed north–south indicates maxima on 1 January and 1 July.
of clouds and rain in early summer which causes cooler temperatures than before the monsoon.

Among the most noticeable features of the semiannual cycles are the large amplitudes in the polar regions where the phase vectors for the second harmonic tend to be parallel to those for the first harmonic, especially over Antarctica. Thus in these regions the maxima of the semiannual cycle coincide with the maximum and the minimum of the annual cycle, which is equivalent to saying that the annual temperature cycle has a sharp summertime maximum and a broad wintertime minimum. This phenomenon in the Antarctic has been discussed by van Loon (1972a) who referred to it as the “coreless winter.”

At lower latitudes the semiannual cycles over land and ocean tend to behave in opposite manner. Over land the phase vectors of the second harmonic tend to be perpendicular to those of the first, particularly at lati-
tudes around 30°, indicating a sharp minimum and a broad maximum in the annual surface temperature cycle. The second harmonic in surface temperature over the oceans tends to be quite small, except poleward of 30°N in the Atlantic and Pacific, where the vectors for the first and second harmonics tend to be parallel, indicating a sharp maximum and a broad minimum in the annual cycle.

A possible explanation for the pronounced phase difference in the semiannual cycle between land and oceans involves the difference in the character of the energy transfer mechanisms in the two regions. During the summer, a shallow oceanic mixed layer is present, and downward heat transfer into the oceans is strongly inhibited by the seasonal thermocline, whereas during winter convective overturning exists through a much deeper layer of the ocean. Hence it seems plausible that the late summer maximum in sea surface temperature should be sharper than the late wintertime minimum. Over land the situation is somewhat the opposite; convective instability tends to be most efficient as a heat transfer mechanism during the warm season.

3. Upper level geopotential heights

We also examined the annual cycles in geopotential height at various levels in the Northern Hemisphere troposphere [van Loon (1972a,b) has extensively documented the Southern Hemisphere]. The prominent wintertime maxima in sea level pressure over the Northern Hemisphere continents noted by Hsu and Wallace (1976b) were found to extend upward to about 700 mb in the geopotential height field. At the 500 mb level and above, the annual cycle in geopotential height exhibits a summertime maximum both over land and sea and the distribution of amplitude of the annual cycle is related to that of wintertime mean geopotential height. The largest amplitudes are observed where the wintertime geopotential height is lowest, as shown in Fig. 3. Hence, at upper tropospheric levels, the annual cycle in geopotential height may be viewed as the alternation between a distinctive wintertime pattern and a relatively flat summertime pattern.

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REFERENCES


Comments on "A Z−R Relationship for the GATE B-Scale Array"

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ABSTRACT

It is shown that the Z−R relationship determined by Cunning and Sax (1977) includes additional useful information of cloud physics. The physical processes by which the tropical rainshaws were formed was simple, probably with a single method of drop formation. Comparable Z−R relationships from the Marshall Islands are given. It is shown that the selection of R as the independent variable usually results in a larger coefficient and a smaller exponent than when Z is taken as the independent variable.

Additional very useful cloud physics information is implied in the paper by Cunning and Sax (1977). This information interestingly results from the analytical process they used to obtain a drop-size sample sufficient for meaningful distributions from tropical cumuli rainshaws.

First, Cunning and Sax found that they could combine the drop-size distributions from consecutive samples taken in flights through a rainshaft to obtain one distribution. In other words, very little difference was found in varying parts of the rainshaft. This single combined distribution was then used to determine a rainfall rate for that pass through the rainshaft. A common concept of a rate distribution in a rainshaft is of a low rate near the edges increasing to a maximum near the center of the shaft. Cunning and Sax acknowledge that this is the norm for the GATE data (Cunning and Sax, 1977, p. 1336). However, since they attempted to sample through the rain core for each rainshaft, most of the impacted drops would have been recorded in the rain core. Thus, the predominating rainfall rate sampled in each pass was the rainfall rate for the core. The fact that the several penetrations of the same rainshaft resulted in series of rainfall rates with relatable drop-size distributions means that the physical process by which the showers were formed was simple, probably with a single method of drop formation.

Second, after studying their data Cunning and Sax, found that the drop-size distributions of most rainshaws, when separated into rainfall rates, could be grouped and averaged by rainfall rate. The high correlation of derived rainfall rates with drop-size distributions noted within the individual rainshaws was also found in the grouped data. This likely means that there was a single method of drop production for all rainshaws on all days. Midlatitude rains do not maintain that simplicity of rainfall rate—drop-size distribution relationships (Nicholass and Larke, 1976). Therefore, tropical rainshaws should prove to be a valuable "laboratory" for future cloud physics experiments.

These facts appear important in the understanding and modeling of the warm-rain processes. The distributions are much simpler than those measured in mid-latitude showers involving the ice phase and also in continuous rains with imbedded showers falling from altostratus and altocumulus in the deep tropics. Raindrop-size distributions measured in 1959–60 in the Marshall Islands resulted in a relationship of $Z = 184R^{1.40}$ (Mueller and Sims, 1967). This is to be compared with $Z = 170R^{1.52}$ determined by Cunning and Sax. When only trade wind showers in the Marshall Islands were analyzed, the study resulted in a relationship of $Z = 126R^{1.47}$. Similarly, continuous rains resulted in $Z = 226R^{1.46}$. The Marshall Island relationships were determined with R as the dependent variable and Z as the independent variable. Mathematically, the Marshall Island Z−R relationships should be expressed as $R = cZ^b$. This was desired, as with the GATE experiment, to determine the rainfall rate from the radar echo information. Inquiry into the procedures of least-square regression by most authors including Cunning and Sax, unless otherwise stated, has shown that R is taken to be the independent variable. The selection of R as the independent variable usually results in a larger coefficient and a smaller exponent than when Z is taken as the independent variable.

The Marshall Island data were collected using a raindrop camera which sampled one-seventh of a cubic meter volume 2 m above sea level every 1.5 s, usually limited to only 1 m² min⁻¹. Raindrop sizes were strati-