Stratospheric and Upper Tropospheric Circulation in the Equatorial Region

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ABSTRACT

A study has been made of the possible relationships between the time variations of winds at one level and those at another in the stratosphere and upper troposphere, on either side of the equator, using the rocket meteorological data of Fort Sherman ($9^{\circ}20'N$) and Ascension Island ($7^{\circ}59'S$) for the seasons June solstice (j), equinox (e) and December solstice (d), and for the years 1967–68. A good positive correlation exists among the zonal winds at different levels over both Fort Sherman and Ascension Island, between the time variations of winds at 40 km and those at 36, 28 and 20 km, in all the seasons; that is, an increase of wind speed at 40 km is accompanied by an increase of wind speed at 36, 28 and 20 km. At Fort Sherman a negative correlation exists between the time variations of winds at 32 km and 24 km in the e season, and between those of 32 and 20 in the d season. Over Ascension Island negative correlation exists between wind variations at 36 and 20 km and also between 32 and 20 km in the e and j seasons. From these negative correlations, it is inferred that zonal circulation cells may generally exist between 32 and 24 km and between 32 and 20 km. There is no correlation of any type among the meridional component of winds, suggesting that the stratospheric circulation in the equatorial region is mostly confined to zonal winds only. The circulations in the stratosphere and in the troposphere are independent systems. The zonal wind variations near the stratonull are always negatively correlated with wind variations at other levels, suggesting that the stratonull lends itself as an easy path for completion of the circulation cell.

1. Introduction

It is recognized that the most striking feature of atmospheric motion is its coherence in a complex fluid in which each part eventually interacts with all other parts. The laws governing the interaction, in particular those governing vertical motions, are still not clearly understood. The impact of solar changes is first felt at high levels; but whether it is faithfully communicated to lower levels, and if so, how, is yet to be established. Gudiksen *et al.* (1968) studied the roles of mean circulation and eddy mixing in determining the spread of tungsten 185 injected into the lower stratosphere in the Hardtac test series of 1958 and inferred that the mean meridional circulation is found to play a minor role in the transport process. The mean residence time for a tracer injected between 18 and 20 km was found to be 10 months, most of the transport into the troposphere occurring in mid-latitudes.

In order to see how the wind variations at one level are related to those at another level over the same region, a study has been made of the rocket wind data for Ascension Island and Fort Sherman, two stations symmetrically situated on either side of the equator (although at different longitudes). It is found that there is very little correlation between the meridional winds at one level and those at another, over these stations. From an examination of the correlation between the zonal winds at one height and those at another in the

height range from 12 to 40 km, it is suggested that a zonal circulation cell may exist between 36 and 24 km. There does not appear to be complete symmetry with respect to the equator.

2. Data and analysis

The coordinates of the two stations over which the wind structure has been studied are given below together with the number of rocket soundings.

Station	Latitude	Longitude	Number of rocket firings used
Ascension Island	$07^{\circ}59'S$	$14^{\circ}25'W$	344 (J126, D109, E109)*
Fort Sherman	$09^{\circ}20'N$	$79^{\circ}59'W$	305 (J113, D88, E104)*

The wind data for these stations were taken from the Meteorological Rocket Network data publications of the Environmental Science Services Administration for 1967–68. Meteorological rocket results with supplementary radiosonde data for two years for these stations give the zonal and meridional winds from ground level to 55 km and above.

For seasonal grouping the year is divided into three groups—June solstice (j), equinox (e) and December

* J = May, June, July and August; E = March, April, September and October; D = November, December, January and February.

FIG. 1. Zonal winds and correlations over Fort Sherman and Ascension Island.

solstice (*d*)—as it is thought that the stratospheric winds depend more on the declination of the sun than on the conventional seasons used in the meteorological studies of tropospheric phenomena.

The time variations of the zonal wind in each of the seasons *j*, *e* and *d* at eight discrete levels from 12 to 40 km altitude at 4-km height intervals form eight random series. One such set of eight series for zonal or meridional wind observations over a station in any one season can be represented by:

- 1) $Z_{1,1} \quad Z_{1,2} \quad Z_{1,3} \quad Z_{1,4}, \dots, Z_{1,n}$
- 2) $Z_{2,1} \quad Z_{2,2} \quad Z_{2,3} \quad Z_{2,4}, \dots, Z_{2,n}$
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- 8) $Z_{8,1} \quad Z_{8,2} \quad Z_{8,3} \quad Z_{8,4}, \dots, Z_{8,n}$

The correlation coefficient between any two of the eight series is represented by C_{MN} (where *M* and *N* take values from 1 to 8, $M \neq N$). For example, the correlation coefficient between series 1 and 3 is repre-

sented by $C_{1,3}$. The correlations $C_{M,N}$ have been worked out for the seasons *j*, *e* and *d* for the observed zonal and meridional winds for Fort Sherman and Ascension Island. The wind vectors have been used in the computation following the usual convention in which a wind blowing from west to east or south to north is positive and a wind blowing from east to west or north to south is negative. A correlation coefficient is considered significant if it is equal to or greater than 0.5. The significant correlations obtained in the case of zonal winds are summarized in Table 1. No significant correlations (either negative or positive) resulted from any of the meridional winds.

3. Discussion

a. Model circulation cells

A significant positive correlation between winds at two levels is interpreted to mean that these two levels are under the influence of the same or similar driving mechanisms.

In the *j* season over Fort Sherman, positive correlation exists between the wind at 40 km and that at each of the other levels down to 20 km. A significant negative correlation between winds at two levels is interpreted in the following way. If the time variations of the zonal wind speeds at two levels A and B are negatively correlated, an increase in the westerly winds at level A, for example, means that the variation at level B is such that the westerly winds have decreased or the easterly increased. From Table 1, it is seen that at Fort Sherman in the *e* season there is a negative correlation between the winds at 32 and 28 km and 32 and 24 km; and between winds at 32 and 20 km in the *d* season. We interpret this to indicate a zonal vertical circulation cell between 32 and 24 km in the *e* season and between 32 and 20 km in the *d* season. Over Ascension Island also we find such circulation cells between 36 and 20 km and 32 and 24 km in the *e* season; and between winds at 36 and 20 km and 32 and 20 km in the *j* season.

While there is no such circulation cell in the *j* season over Fort Sherman, there is such a cell between 32 and 24 km in the *d* season over Ascension Island. These circulations are represented in Fig. 1.

The lack of significant correlation, either negative or positive, between meridional winds at any two levels indicates that the stratospheric circulation is mainly latitudinal, unlike the troposphere, where we have meridional circulations such as the well-known Hadley cell. This type of tropospheric circulation is confined to levels much below the tropopause [see, for example, Fig. 1 of Teweles (1965)].

Gudiksen *et al.* (1968) concluded from a study of the spread of tungsten 185 injected in the lower stratosphere in the Hardtac test series of 1958 that the mean meridional circulation plays a minor role in the transport process. This observation supports the view expressed by the present authors that the stratospheric circulation

TABLE 1. Zonal wind correlations.

Heights at which correlations were made (km)	Stations					
	Ascension Island			Fort Sherman		
	Correlation coefficient for the season			Correlation coefficient for the season		
	<i>j</i>	<i>e</i>	<i>d</i>	<i>j</i>	<i>e</i>	<i>d</i>
40 and 36	0.5	0.7	0.6	0.7	0.6	0.6
40 and 32	0.5	0.5	0.7	0.5	—	0.6
40 and 28	0.5	0.8	0.7	0.5	0.7	—
40 and 20	0.6	0.5	0.7	0.6	0.7	0.5
40 and 12	—	—	0.7	—	—	—
36 and 24	—	−0.5	−0.5	—	—	—
36 and 20	—	−0.5	—	—	—	—
36 and 12	—	—	—	—	0.5	—
32 and 28	—	—	—	—	−0.5	—
32 and 24	—	—	—	—	−0.5	−0.6
32 and 20	—	−0.6	—	—	—	−0.6

FIG. 2. Mean monthly zonal wind velocities (m sec^{-1}) at the 24- and 32-km levels over Fort Sherman and Ascension Island.

is mainly latitudinal in the equatorial region. This model cell will necessarily presume vertical currents in the equatorial region.

b. Seasonal variations

From Fig. 1 it is clear that in the ϵ season over both Fort Sherman and Ascension Island the circulation cell is practically the same except that it comes down to 20 km over Ascension Island. In the d season over Fort Sherman and in the j season over Ascension Island we have the circulation cell between 32 and 20 km and between 36 and 20 km, respectively. But over Fort Sherman in the j season there is no such cell at all, while over Ascension Island in the d season there is a weak cell between 32 and 24 km. These seasonal variations at the two stations suggest a lack of symmetry about the equator. This can be due to the longitudinal asymmetry of the two stations considered; or it may be real and can perhaps be attributed to the fact that in the Southern Hemisphere there are large areas of ocean, giving rise to a thermal structure of the stratosphere over the oceans which is different from that over land.

c. Relation between tropospheric and stratospheric circulations

In an earlier paper the present authors (1969) examined the relation between upper tropospheric jets and the stratospheric and lower mesospheric winds over Sonmiani ($25^{\circ}12'N$, $66^{\circ}45'E$) and Thumba ($8^{\circ}30'N$, $76^{\circ}52'E$) and concluded that there was no direct relationship between the upper tropospheric jets and wind systems in the stratosphere or mesosphere. The

region below the tropopause receives its energy principally from surface heating which is then distributed throughout the troposphere by convective motion. Above the tropopause, energy is absorbed in bulk by atmospheric interactions with solar and terrestrial radiant flux. Webb (1966) conceives of the tropopause as a perfect seal for certain purposes, although it is only a leaky barrier for many other purposes.

This evidence supports the view expressed here that the stratospheric circulation cell is quite different from that of the troposphere.

d. Stratonull and QBW in zonal wind

It is believed that the quasi-biennial wave (QBW) in the zonal wind has maximum amplitude in the vicinity of the stratonull, which is defined as the stratospheric level at which the meridional temperature gradient is a minimum (Webb, 1966, p. 67). Fig. 2 shows the mean monthly zonal winds at 24 and 32 km over Ascension Island and over Fort Sherman during 1967-68. These figures indicate that the QBW is more predominant at 32 km than at 24 km over both the stations. It may be noted that the zonal wind variations at 24 km (the stratonull) are always negatively correlated with those of other levels where the correlation is significant. This negative correlation is interpreted to mean that the stratonull itself completes the circulation cell.

4. Conclusions

Lack of significant correlation between meridional winds at any two levels indicates that the stratospheric

circulation is mainly latitudinal, unlike that in the troposphere. Significant negative correlations between wind variations at two levels suggest that zonal circulation cells may exist between 32 and 24 km in the *e* season and between 32 and 20 km in the *d* season to the north of the equator, and between 36 and 24 km and 32 and 20 km in the *e* and *j* seasons to the south of the equator. The seasonal variations in the pattern of circulation cells over Fort Sherman and over Ascension Island suggest asymmetry about the equator.

The stratospheric circulation is thus quite different from that of the troposphere. The maximum amplitude of the quasi-biennial wave in the stratospheric winds in the equatorial region appears to exist near 32 km and not near 24 km as is generally believed. The correlations between wind variations at the stratonull and those of other levels are always negative, suggesting that the stratonull level itself completes the circulation cell.

The authors are aware of the hazards of such a generalization from a study of the data of only two

stations. Further work in this direction is in progress to support the view expressed here.

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