The non-repeating variations of the observed wind in the equatorial stratosphere

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ABSTRACT

To assist in interpretation of large-scale trajectories of fallout, the resultant wind in the stratosphere arising from the interaction of annual and quasi-biennial waves is described in the equatorial zone from 40° N to 40° S for a 3½-year period (July 1957 to December 1960). To illustrate the *non-repeating* horizontal migrations of the flow patterns from month to month and year to year, 50 mb maps of the zonal component of the mean monthly wind are presented. Meridional cross sections from 100 mb to 10 mb along 180° and also 80° W for the same period show how the zero wind surface and the associated easterly and westerly regimes oscillate across the equator, as functions of height and time.

1. Introduction

In the earlier days of concern about radioactive fallout, it was hoped meteorologists could predict accurately where the winds would transport the debris. Without sufficient wind data in space and time, especially in the stratosphere at low latitudes, and because transport processes are complicated, it is difficult to get even horizontal trajectories on a mean monthly basis, let alone the actual three-dimensional trajectories (Danielsen, 1961). In understanding how these large-scale transports occur we must at least be aware of the general behavior of the wind field on a monthly basis. At high and middle latitudes, there is a well recognized seasonal reversal of the stratospheric flow. The winter westerlies are reasonably reliable although the dates of the spring reversal may vary over a few months, and despite regional and erratic sudden warnings which bring temporary easterlies (Belmont, 1961, 1963). At low latitudes, however, because of the existence of another wind cycle, there are no consistent monthly mean or even seasonal winds which can be expected each year. It is the purpose of this paper to demonstrate the monthly and yearly variation of the mean monthly zonal wind in the tropical stratosphere.

The tropical stratospheric wind field is complicated by the still unexplained quasi-biennial component superimposed on the normal annual wave. Many papers have appeared in the past five years on the quasibiennial stratospheric wind oscillation (QBW), but although the average features of this component are now well described (Reed, 1965), the horizontal and vertical properties of the actual, *observed* wind in the tropical stratosphere are quite irregular and not generally appreciated. This is because the QBW is of variable period (20 to 30 months) and is not a simple sine wave (Dartt & Belmont, 1964). Further, the annual cycle, caused by seasonal variations of insolation, has its maximum amplitude at mid-latitudes (although its corresponding thermal wave has its maximum range at the poles), while the amplitude of the biennial wave is a maximum near the equator and decreases with increasing latitude in both hemispheres.

The annual wave is of opposite phase in each hemisphere corresponding to the opposite seasons, but the phase of the biennial wave is apparently symmetric to the equator. While the annual wave has relatively little lag with height, the quasi-biennial wave's phase progression appears to be from highest levels downward and at the same time equatorward from both hemispheres simultaneously. The annual wave progresses from high northern to high southern latitudes and back again, crossing the equator twice a year. These two major waves interact in such a manner that the resulting zero zonal

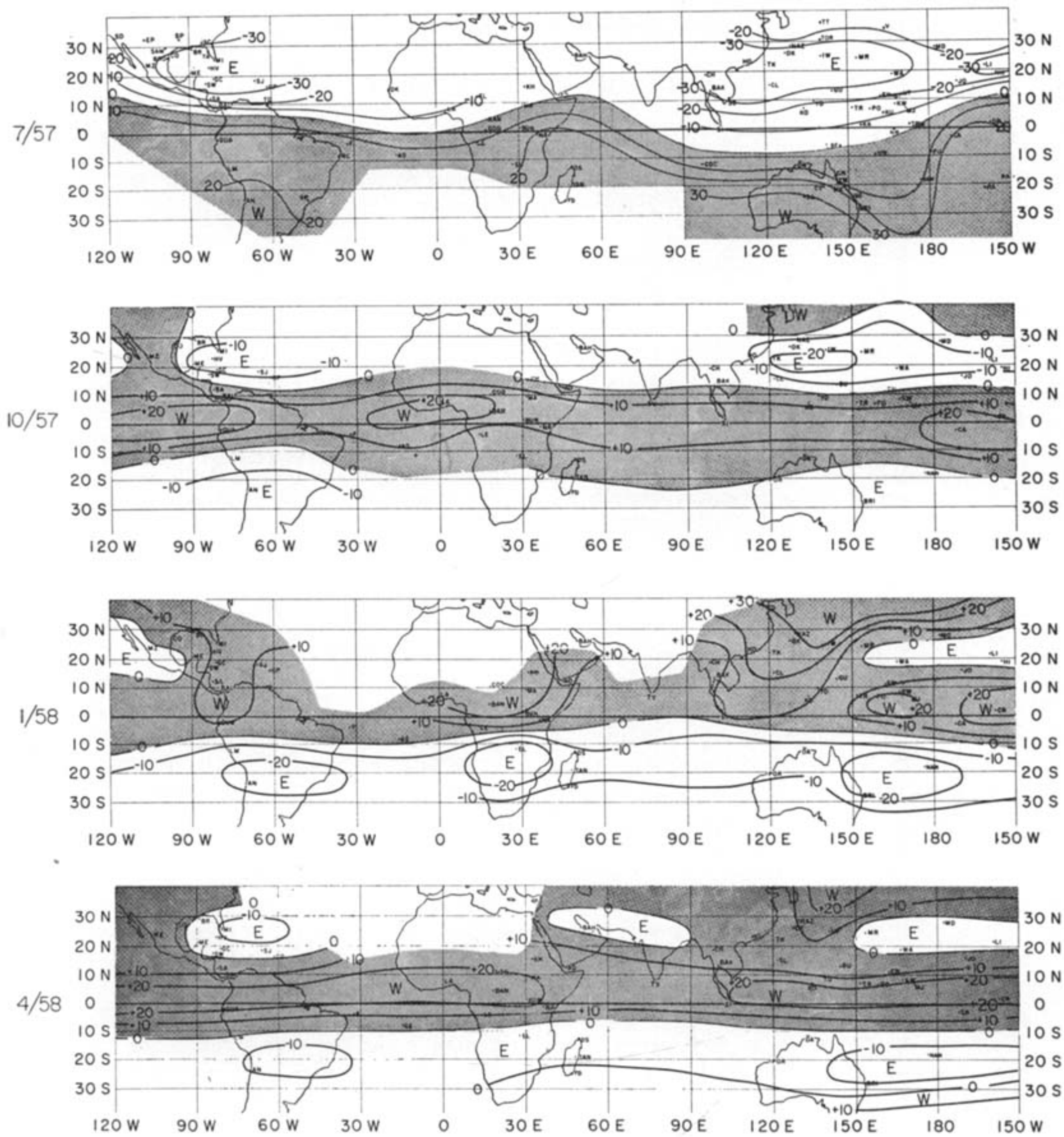

FIG. 1*a*. Mean monthly zonal wind isotachs at 50 mb, at 10 knot intervals. Shaded area denotes winds from the west, July 1957–April 1958.

wind surface (separating east winds from west winds) behaves in an irregular oscillatory pattern, moving from northern to southern hemispheres and back, on a time scale which may never repeat, but if so, in not less than 13 years, (12×13 months) depending upon the variability of the biennial wave period.

In a previous paper, the interference pattern of the two waves, seen as time variations with height at a given station, showed at least two prominent waves, each of which progresses upward from one biennium to the next. As this caused westerlies where easterlies might have been expected, the meridional interference pattern is investigated here to see how cross-equatorial phase interference affects the resultant, observed zonal wind (BELMONT & DARTT, 1963). This paper describes the resultant wind

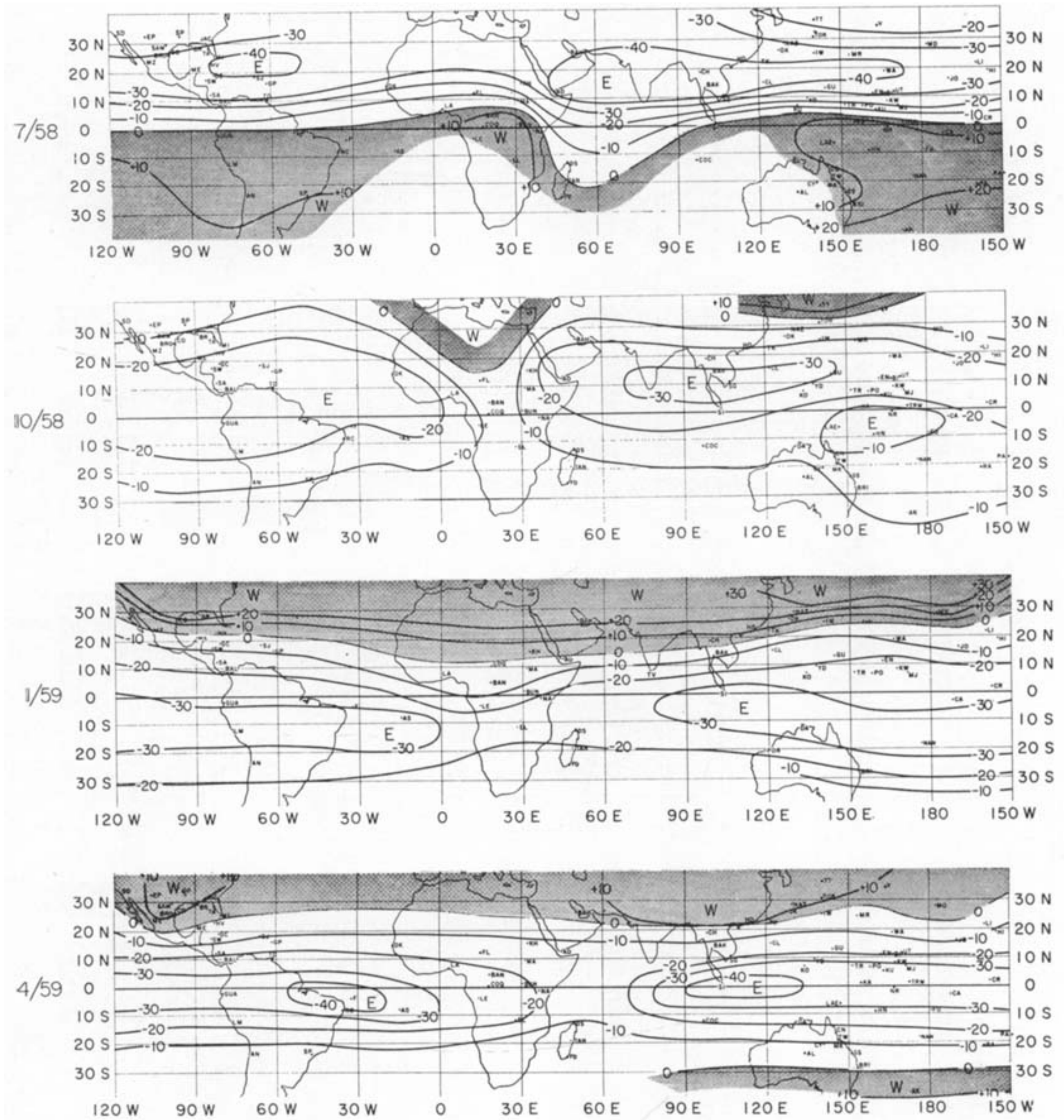

FIG. 1*b*. Same as Fig. 1*a*, for July 1958–April 1959.

field arising from the interaction of the annual and biennial waves in the equatorial zone from 40° N to 40° S in the stratosphere for a 3½-year period. The first part presents 50 mb maps of the zonal component of the mean monthly wind to illustrate the large scale horizontal migrations of the flow patterns. The second part gives meridional cross sections from 100 mb to 10 mb for the same period along 180° and also 80° W, to illustrate how the zero wind surface, and its associated easterly and westerly regimes, oscillates across the equator.

2. Equatorial 50 mb maps

The quasi-biennial wave apparently is simultaneous at all longitudes within the time resolution now possible with monthly mean data. To

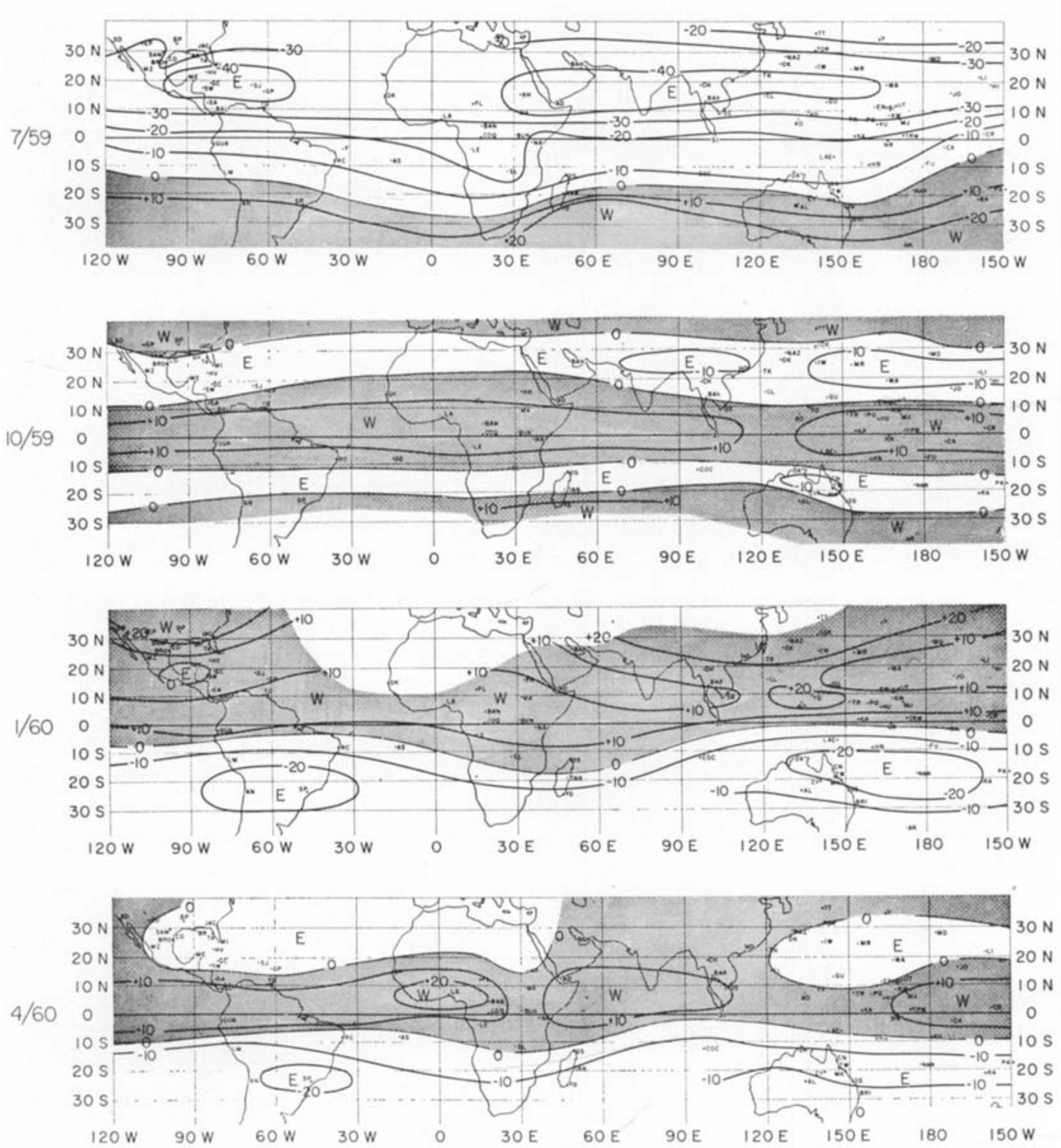

FIG. 1c. Same as Fig. 1a, for July 1959–April 1960.

see how the horizontal patterns of these winds are organized and changed, a series of 42 mean monthly equatorial maps at 50 mb was prepared. It is only possible to show every third map here (Figs. 1a–1d). The maps show isotachs of the mean monthly zonal wind at 10-knot intervals. Regions of winds from the west are shaded. Areas of no data are indicated by ends of isolines and by reference to the data availability chart (Figure 2) which shows all stations used and also serves as an example of about the best coverage available in a single month. Few stations could be used every month.

The first feature to note is that the zonal winds appear to be organized in latitudinal bands rather than to have definite longitudinal patterns. However, there is often evidence of a continental-ocean influence, shown by the cellular organization of primary centers west and east of Africa (Figs. 1b and 1c, for example).

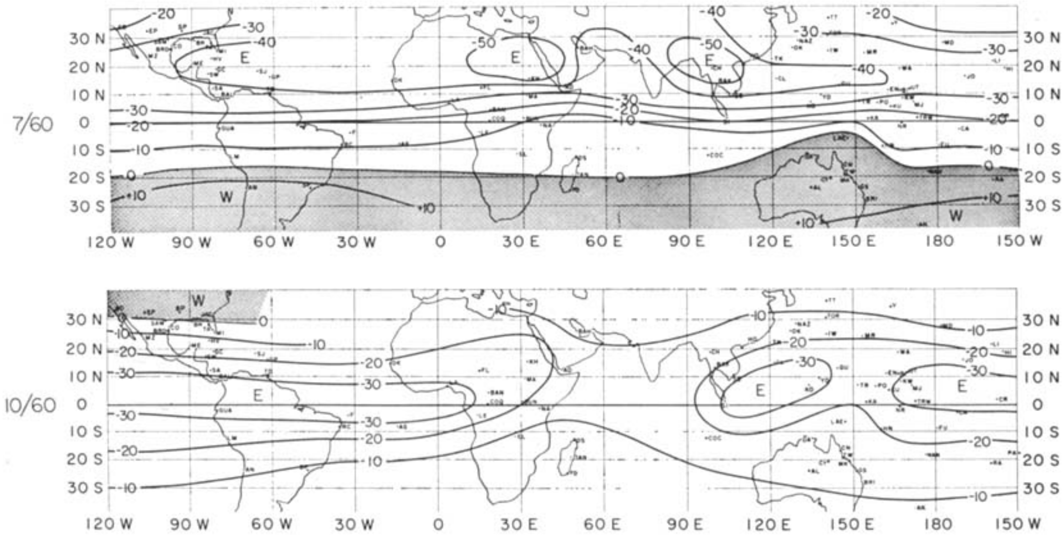

FIG. 1*d*. Same as Fig. 1*a*, for July 1960–October 1960.

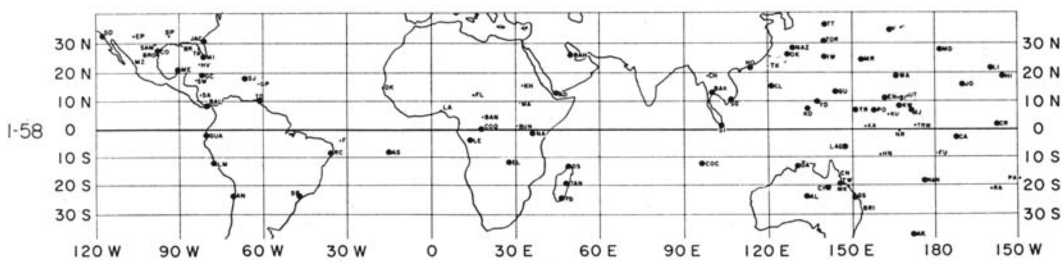

FIG. 2. Stations used. Large dots indicate data available for January 1958, representing best coverage during the series.

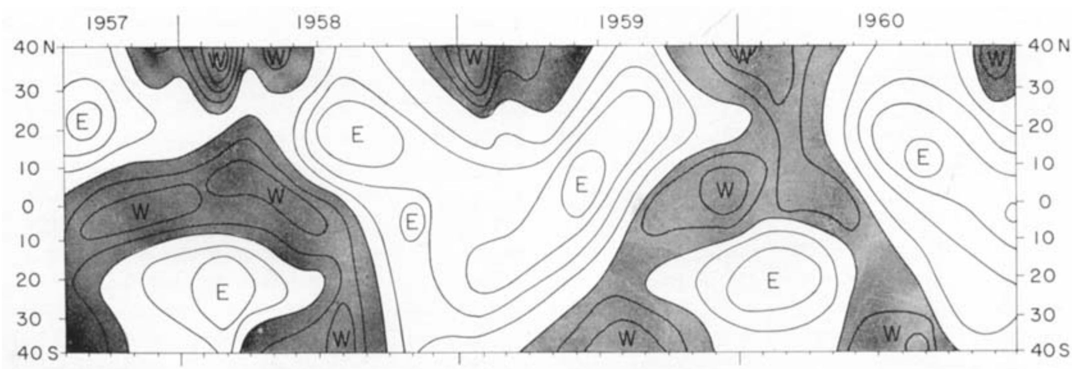

FIG. 3. Time section along 180° of the mean monthly zonal wind isotachs at 50 mb.

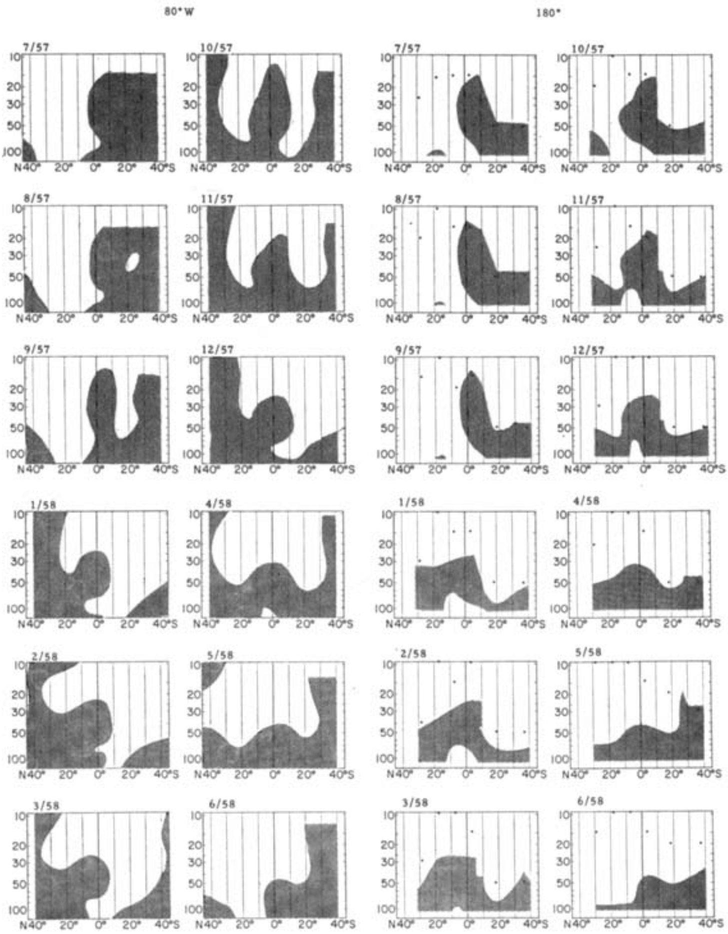

FIG. 4*a*. Cross sections of the zero wind surface along 80° W and 180°, July 1957–June 1958. Shaded area is from the west. Dots show stations and highest levels available.

This may be due in part to the distribution of available data, but also occurs frequently over SE Asia and the western Pacific where data are relatively plentiful.

If we are satisfied that the broad-scale isotach patterns are generally zonal, then Fig. 3 conveniently represents how these bands of winds change along the 180th meridian with time. This meridian was chosen to represent oceanic conditions and also an area of most reliable analysis. The figure shows that the component QBW is sufficiently stronger than the annual wave in a band from about 10° N to 10° S to cause a reversal of the circulation about each two years. Presumably easterly flow would exist in this belt were it not for the component biennial wave. The usual annual cycle prevails at higher latitudes. Notice that the equatorial westerlies occasionally do not merge with the higher latitude westerlies and that the patterns do not repeat closely from biennium to biennium. Differences from this time section are to be expected at other longitudes, especially along coastal and continental meridians. However, sufficient data were not available to prepare other time-meridian graphs for the same range of latitudes for which data were available at 180 degrees. It is clear that there are cellular patterns of maximum wind within each narrow latitudinal band, but details can only be revealed by additional and more representative data.

The monthly maps show large changes from season to season and year to year. Used with height-latitude cross sections and height-time

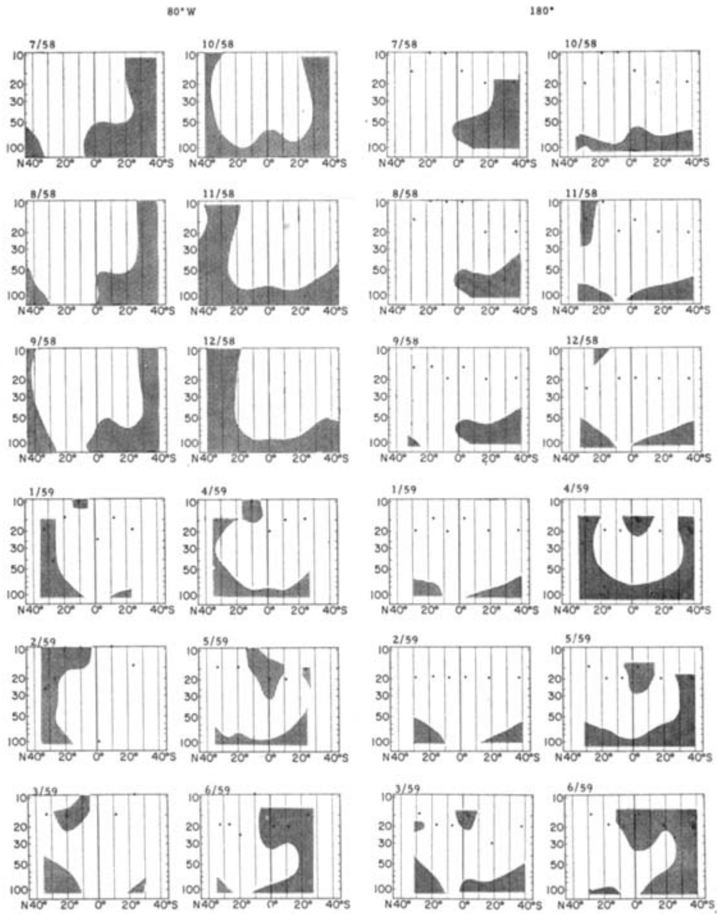

FIG. 4b. Same, July 1958–June 1959.

sections, the movement of the mean monthly zero wind surface can be well described to hasten its eventual explanation. As with any phenomenon, the more that is known about it, the more detail becomes apparent. This is only a first estimate to be improved as additional data are provided.

3. Meridional cross sections of the zero wind surface

For the same period as the previous maps, cross sections were also constructed along the 180th and 80° W meridians to examine the differences in latitudinal patterns with height.

The charts are shown in groups of twelve months, for each meridian, (Figs. 4a–4d). To avoid unnecessary duplication, the zero wind positions along 80° W for the IGY period were taken from existing cross sections (U. S. WEATHER BUREAU, 1961). As this reference shows no data and draws its analysis over most of the chart area, the analysis here for these months extends over greater area than in the remaining ones which have been rather strictly limited to areas for which data were available. To distinguish regions for which no data were available from those with data, a dot has been placed at the highest level reported by the stations on each chart. Shaded regions indicate westerlies and blank areas below the dots are easterly. Extrapolation of shaded regions is indicated whenever the zero wind boundary has not been drawn around the shaded area. The stations used were:

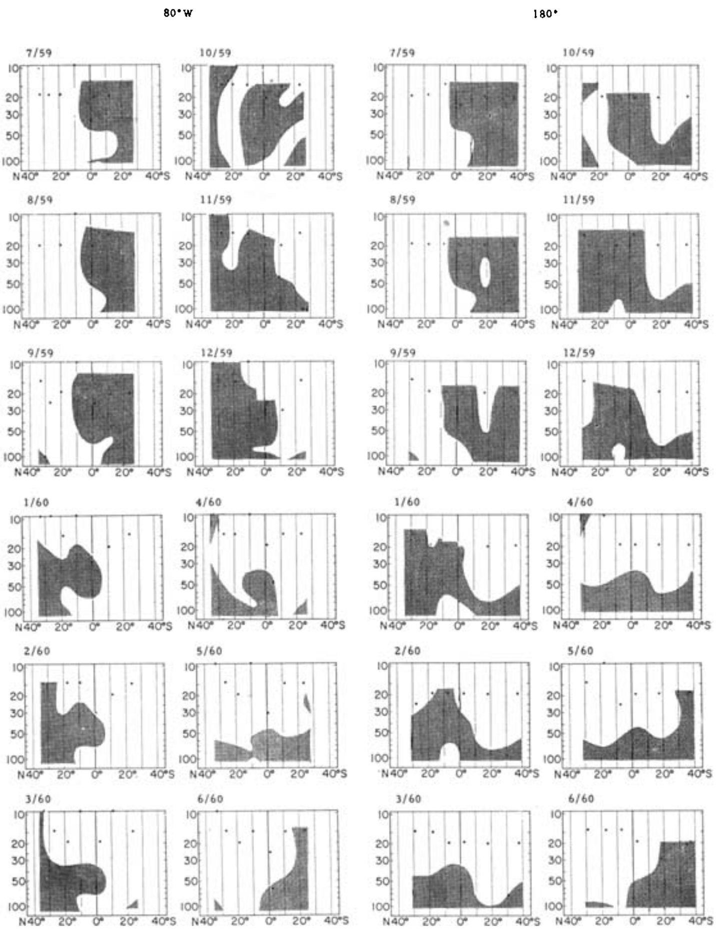

FIG. 4c. Same, July 1959–June 1960.

80° W (1/59–12/60)

Station	Latitude
Charleston	33° N
Miami	26
Grand Cayman (1/59–12/59)	19
Swan Island (1/60–12/60)	17
Balboa	9
Guayaquil	2° S
Lima	12
Antofagasta	23

180° (7/57–12/60)

Station	Latitude
Midway	28° N
Johnston	17
Majuro	7
Canton	3° S
Nandi	18
Auckland	37

The source of all the above data is the National Weather Records Center, Asheville, N.C.

The general agreement of the two series of sections is good when it is remembered that the different location of stations along the two meridians of course yield different resolution of details, and the use of IGY cross-section analysis makes it impossible to know how much of the wind field has been implied rather than observed. The latter difference probably accounts for the areas of westerlies which frequently are shown to 10 mb along 80°W.

The vertical meridional interference pattern of the annual wave and quasi-biennial wave is generally the same at these two longitudes, and gives no evidence to expect significant variations at other longitudes in either wave, al-

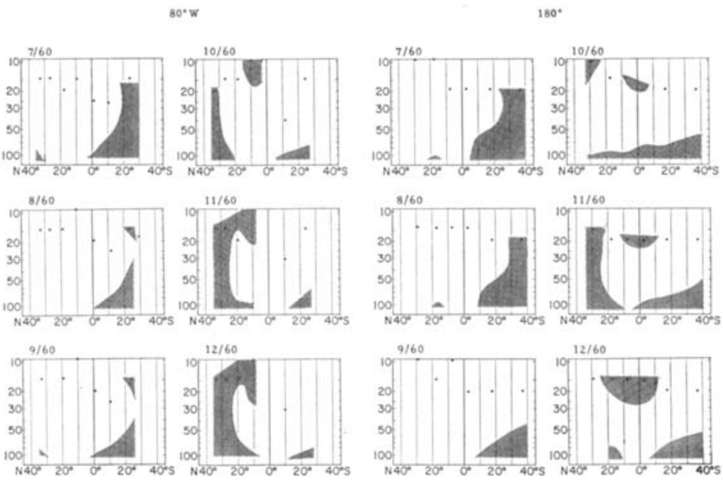

Fig. 4*d*. Same, July 1960–December 1960.

though the previous maps show some differences of horizontal pattern with longitude.

Note that Fig. 4*a* agrees reasonably well with Fig. 4*c* which is two years later, and similarly, Figs. 4*b* and 4*d* agree. However, consecutive years (Figs. 4*a* and 4*b*, 4*c* and 4*d*, etc.) are quite dissimilar. For these pairs of corresponding years it appears that the quasi-biennial wave is the primary control on the wind field at latitudes below about 15°, in agreement with the 50 mb maps.

During the period of these charts, the QBW westerlies appear at highest levels near the equator, descend and alternately merge with the westerlies of the winter hemisphere. In July 1957, the westerly phase of the QBW has al eady reached down to 80 mb and extends southward (July–September 1957), northward (December 1957–March 1958), southward (June 1958–September 1958), and northward (November 1958–January 1959), when the original westerly phase has disappeared from view and a new westerly area appears at highest levels. The second series progresses as the first and gradually fades from the section from about June 1960. By October 1960, a third series has started.

The corresponding months in successive years (e.g., July 1959 and July 1960) are quite different due to the presence in the first of the equatorial westerlies which combine with the winter westerlies to produce a large extent of westerlies on the section. However, in the next year the easterly phase of quasi-biennial wave is found near the equator and thus the westerlies are confined to much higher latitudes.

Had a much longer period of these sections been prepared, the similarity from one calendar biennium to the next would gradually be lost because of the variations in the period of the quasi-biennial wave and because its period is neither constant nor 24 months.

We bring these large scale changes in zonal wind patterns in the tropics to the attention of those who are concerned with global scale transport and distribution of non-homogenic atmospheric constituents. Of even greater importance would be the corresponding changes in the meridional component of the wind as this would apply to cross-equatorial flow problems. We hope to start this in the near future, and also, to extend the patterns upward using recent meteorological rocket data.

Acknowledgements

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НЕВПОВТОРЯЮЩИЕСЯ ВАРИАЦИИ НАБЛЮДАЕМОГО ВЕТРА В ЭКВАТОРИАЛЬНОЙ СТРАТОСФЕРЕ

Интерпретируя крупномасштабные траектории радиоактивной пыли авторы описывают ветер в экваториальной зоне стратосферы 40° N–40° S, возникающий в результате взаимодействия одно- и двухгодичных волн, за период в 3,5 года (июль 1957–декабрь 1960).

Для иллюстрации неповторяющегося от месяца к месяцу и от года к году горизонтального переноса частиц представлена карта зональной компоненты среднемесячного ветра для 50 mb. Представлены за тот же самый период меридиональные сечения вдоль 80° и 180° от 100 mb до 10 mb показывают колебания на экваторе как функции высоты и времени поверхности нулевого ветра и разделяемых ее областей восточного и западного ветров.