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AND ATMOSPHERIC PHYSICS (IAMAP)

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PREFACE

This collection of extended summaries is intended to provide the essential results and figures of the papers presented at the ICMUA Symposia at the IAGA/IAMAP Joint Assembly, August 22 to September 3, 1977, Seattle, Washington. The two sessions on Winds were arranged jointly with IAGA Commission VIII, and presented as part of Joint Symposium A.

The short time allowed for the presentation of papers and the large number of papers at such meetings makes it difficult to take notes or to examine figures carefully. These summaries are therefore reproduced here to allow participants to review the findings more thoroughly and to allow those who were unable to attend to also learn of the latest work in the fields of stratospheric-mesospheric circulation. To make this available as quickly as possible, papers are photoreproduced as they were received. Unfortunately, some figures submitted were not suitable for reproduction and may be even less legible here. Nothing has been edited, but most figures have been reduced to save space.

It is hoped this informal reproduction will prove useful in the interval before many of the papers eventually appear in the standard journals.

Thanks are extended to all the authors who took the extra effort to prepare these summaries so promptly, and to the other members of the Program Committee: Professor I. Hirota, Professor K. Labitzke, R. Quiroz, and Professor J. Taubenheim. Their cooperation made this volume possible.

A. D. Belmont
Chairman,
Program Committee
25 October 1977

CONTENTS

WAVES I

Presiding: R. A. Plumb, CSIRO, Aspendale, Victoria, Australia

WAVES II

Presiding: I. Hirota, Geophysical Institute, Kyoto University, Japan

Note - missing paper number indicates paper given but not included here.

DYNAMICS

Presiding: B. Boville, Atmospheric Environment Service, Downsview, Ontario, Canada

14	Harwood, R. S.	Measurements of the flux of potential vorticity in the stratosphere
15	DeVore, J. Venkateswaran, S.V.	Mesospheric response to modifications in ozone photo-chemistry
16	Kao, S. K. Okrasinski, R. Lordi, N. J.	Horizontal eddy diffusivities in the northern hemispheric stratosphere and lower mesosphere
17	Barnett, J. J. Alyea, F. N. Cunnold, D. M.	Comparison between satellite radiance observations and those derived from a stratospheric numerical model
18	Johnson, K. W.	Variations in static stability in the stratosphere and lower mesosphere during a winter disturbance
19	Weisman, M. L. Olivero, J. J.	Vertical motions in the equatorial middle atmosphere
20	Rose, K. Klinker, E.	The stratospheric circulation in terms of the balance of angular momentum squared

WINDS I

Presiding: R. Roper, Georgia Institute of Technology, Atlanta, Georgia

21	Geller, M. A.	Planetary waves
--	Glass, M. Bernard, R. Fellous, J. L. Massebeuf, M.	The zonal circulation at meteor altitudes
22	Manson, A. H. Meek, C. E.	Gravity waves in the lower thermosphere at 35^{o}S (South Australia)
23	Stening, R. J. Manson, A. H. Meek, C. E. Stephenson, D. G.	Tidal winds from 60 to 110 km at Saskatoon, Canada (52^{o}N)
24	Gregory, J. B. Manson, A. H.	Atmospheric circulation, 60-110 km, autumn-winter-spring, 1974-75, at 52^{o}N, 107^{o}W
25	Belmont, A. D. Nastrom, G. D.	Long-period waves in mesospheric winds at Saskatoon (52^{o}N)
26	Clark, R. R. Wand, R. H.	Tidal comparisons between incoherent scatter and meteor wind measurements
--	Glass, M.	Coordinated meteor measurements

27	Hernandez, G. Roper, R. G.	A comparison between radio meteor and airglow winds
28	Rind, D.	Lower thermosphere tidal effects and circulations observed with natural sound
29	Hung, R. J. Smith, R. E.	Speculation of the dynamics of severe storms through the study of thermospheric-tropospheric coupling

WINDS II

Presiding: M. Glass, Centre National D'etudes des Telecommunications, 92131 Issy les Moulineaux, France

--	Bauer, P.	Incoherent scatter observations of lower thermospheric tidal motions
30	Harper, R. M.	Tidal winds at a low latitude station for solar cycle minimum conditions
31	Lysenko, I. A. Orlyanskii, A. D. Portnyagin, Yu. I.	Results of wind velocity measurements at middle latitudes by the meteor radar method
32	Petrosyantz, M. A. Minina, L. A. Portnyagin, Yu. I.	Circular systems in the mesopause of the northern hemisphere
33	Iljichev, Yu. D. Portnyagin, Yu. I.	Schemes of the global height-latitude cross-sections of the wind field up to 100 km
34	Kazimirovsky, K.	Coordinated measurement of E layer drifts
35	Ebel, A.	Scales of macroturbulence in the atmosphere around 100 km altitude
36	Zimmerman, S. P. Murphy, E. A.	Fine scale dynamics of the middle atmosphere

TEMPERATURE AND OZONE VARIATIONS

Presiding: A. Belmont, Control Data Corporation, Minneapolis

--	Barnett, J. J. Houghton, J. T. Kirkman, R. J. D. Rodgers, C. D.	Global measurements of the temperature of the mesosphere and upper stratosphere
37	Sekihara, K. Ikeda, H. Kikuchi, N. Tamura, T.	A long term trend of stratospheric temperature
38	Zerefos, C. S. Mantis, H. T.	Variations in northern hemisphere stratospheric temperatures from 1957 to 1972
39	Ghazi, A.	Stratospheric thermal wave-ozone field interactions

40	Grasnick, K. H. Entzian, G.	Long and short period variations of ozone over central Europe
41	Hilsenrath, E. Dunn, P. J. Mateer, C. L.	Standard ozone profiles from balloon and rocket data for satellite and theoretical model input
42	Kidiyarova, V. G. Tarasenko, D. A. Sheherba, I. A.	Statistical characteristics of temperature and wind in the stratosphere and mesosphere
43	Koshelkov, Yu. P.	Analysis of temperature and geopotential fields in the lower mesosphere
44	Kantor, A. J. Cole, A. E.	Thermodynamic properties of the Arctic and Sub-arctic atmosphere to 90 km

SUDDEN WARMINGS I

Presiding: R. Harwood, University of Edinburgh, Edinburgh, UK

45	Labitzke, K.	Interannual variability of the winter stratosphere in the northern hemisphere
46	Coy, L. Leovy, C.	A comparison of midwinter stratospheric warmings in the southern and northern hemisphere
47	Matsuno, T. Nakamura, K.	Dulerian view vs. Lagrangian view of the mean meridional circulation on the occasion of a sudden warming
48	Hsu, C. F. Holton, J. R.	Stratospheric sudden warmings: The role of wave-wave interactions
49	Johnson, K. W. Rodenhuis, D. R.	Potential vorticity transport during a stratospheric warming

SUDDEN WARMINGS II

Presiding: J. Holton, University of Washington, Seattle, Washington

50	O'Neill, A. Newson, R. L.	Studies of stratospheric sudden warmings simulated by a general circulation model of the atmosphere
51	Grose, W. L. Haggard, K. V.	Simulation of a sudden stratospheric warming with a three-dimensional spectral circulation model
52	Balachandran, N.K. Donn, W. L. Rind, D.	Stratospheric warmings and Concorde sonic boom propagation
53	Crane, A. J. Barnett, J. J.	Energetics of the upper stratosphere during a sudden warming
54	Klinker, E.	Energetics of major and minor warmings
55	Rind, D. Donn, W.L.	Observation of upper atmosphere warmings using natural infrasound

AUTHOR LIST

SEMIANNUAL VARIATION OF THE EQUATORIAL ZONAL WIND AND PLANETARY WAVES IN THE MESOSPHERE

Isamu Hirota (Geophysical Institute, Kyoto University,
Kyoto, Japan)

1. Introduction

Since the earlier discovery of Reed (1965) for the semiannual oscillation of the zonal wind in the equatorial upper stratosphere, there have been many statistical studies based on high altitude meteorological rocket observations for the mean zonal wind behaviour. Results of these studies indicate that the semiannual variation of the zonal wind is global in extent with its maximum amplitude near the stratopause level over the equator: maximum westerlies of the semiannual component appear just after the equinoxes at the level and propagate downward into the lower stratosphere.

Regarding the mechanism of this phenomenon, however, no satisfactory explanation has been given yet. One of the most important aspects may be, similar to that of the quasi-biennial oscillation of the zonal wind in the lower stratosphere, the generation of equatorial zonal westerlies. To account for the westerly accelerations over the equator, a kind of eddy momentum flux convergence should be required.

From the statistical analysis of rocketsonde data for about 10 years, Hopkins (1975) found that the zonal wind variance after the solstices is due mainly to extra-tropical planetary waves, by showing that zonal wind anomalies in the easterly regime of tropical semiannual cycle are positively correlated with those in the higher latitude winter hemisphere.

However, the global analysis of seasonal variation of planetary-scale waves with use of the Nimbus 5 Selective Chopper Radiometer (SCR) observations reveals that the wave amplitudes at the stratopause level show a notable six-month cycle in tropical latitudes with maxima after the equinoxes (Hirota, 1976).

Thus the main objectives of this study are to find the evidence of equatorial waves in the upper stratosphere and mesosphere and to describe their characteristic features in relation to the semiannual oscillation of the zonal wind.

2. Monthly mean zonal wind

Preceding the discussion of wave disturbances, we briefly describe the seasonal variation of the mean zonal wind in the equatorial stratosphere and mesosphere.

Fig.1 shows a vertical-time section of the monthly mean zonal wind at Ascension Island (8S,14W) for the period from July 1970 to December 1972. Wind data of special observations for the range between 60 and 90km are available during the period from October 1970 to December 1971. In order to make clear the semiannual variation, the mean and annual component are removed.

It can be seen from this figure that the semiannual variation of the zonal wind is predominant above 30km: the amplitude has two maxima at 47 and 81km with the value slightly exceeding 30m/sec and a minimum of about 5m/sec at 64km, and the phase propagates downward with an average speed of about 10km per month.

3. Spectral analysis of equatorial waves

Meteorological rocket observations at Ascension Island of zonal wind component U, meridional wind component V, and temperature T are used for 4 years from 1969 to 1972. The data of rockets launched at around the local noon are selected to remove the effect due to the mixture of diurnal variations in various phases. Observed values at every 1km between 25 and 59km are picked up, so that we have 35 data of each component for each observation day. The data density in time is about 10 days per month or less. Therefore it is not adequate in general to make a conventional time-series analysis based on such a coarse time resolution.

The procedure of the present analysis is in a following manner:

(1) From the data set mentioned above, we choose a pair of days with a time interval of 2 days. Total number of pairs thus selected is about 40 per year in average.

(2) Next we compute the 2-day difference of each component for each level. This process removes the mean field, on which the wave is superposed, the long-term trend due to annual and semiannual variations, and short-period tidal waves. In other words, the making of 2-day difference is equivalent to a kind of "band-pass filter" suitable for the wave with a time-scale of 10 days.

(3) Then a power spectral analysis is applied to the 2-day difference with respect to the altitude, for each component, to determine predominant vertical wavelengths and their power spectral densities. The maximum entropy method (MEM) is used in this study. Because of the excellent properties of the MEM, the predominant vertical wavelength is significantly detected in spite of the short data length.

4. Results

Fig.2 shows an example of the result of such an analysis for a pair of days February 17 and 19, 1971. Strong concentration of power spectral density can be seen at the wavelength of 17km (U), 15km (T) and 11km (V) respectively, corresponding to the vertical distribution of local time change of each component. The power spectral density around the dominant wavelength thus obtained should be regarded as a measure of the wave activity in the whole region under consideration, i.e., the upper stratosphere and lower mesosphere.

As is seen in Fig.2, the vertical wavelengths L(U), L(V) and L(T) are not always coincident with one another. From the scatter diagrams of L(U) vs. L(V) and L(U) vs. L(T), it is found that the correlation between L(U) and L(V) is very poor while L(U) and L(T) are well correlated with each other.

The seasonal variation of power spectral density of each wavelength is shown in Fig.3 for the zonal wind component. Inspection of this figure reveals that the wave with the vertical scale of 15-20km shows a remarkable semiannual oscillation. A Fourier analysis indicates that the maximum contribution to the semiannual component comes from L(U)=17km. On the other hand, the power of meridional wind component is highly dispersive throughout the year and does not show an apparent six-month cycle, whereas the temperature variation with season seems to be similar to that of zonal wind, though the amplitude is rather weak.

Since the mean zonal wind in the middle and lower stratosphere is characterized by the predominance of quasi-biennial oscillations (QBO), it will be of interest to separate the analysis into two periods in accordance with the westerly and easterly regime of the QBO. From the result of the analysis for 4 years 1969 through 1972, it can be said that the wave activity is significantly stronger in the easterly wind phase of the QBO (1970 & 1972) than in the westerly wind phase (1969 & 1971) for both annual and semiannual variations.

5. Discussion

In view of the result of observational and theoretical studies so far made on large-scale wave disturbances in the tropical lower stratosphere (Wallace, 1973: Holton, 1975), the waves under consideration in the present study are identified as Kelvin waves.

Apart from the detailed mechanism of the excitation of Kelvin waves in the lower stratosphere, the upward propagation of the wave into the upper stratosphere and mesosphere can be accounted for in terms of their vertical wavelengths: generally speaking, the larger the vertical scale, the weaker the attenuation due to Newtonian cooling in the upper level. The fact that the preferred vertical scale (=15~20km) in the upper stratosphere is twice as large as that of Kelvin waves observed in the lower stratosphere (=6~10km) is plausible in this sense to account for the penetration of Kelvin waves into the upper atmosphere.

Regarding the east-west wavelength and the period associated with the passage of waves, however, the present analysis at one station gives no direct information at all. If we fix the east-west wavenumber, the wave frequency must be proportional to the square root of vertical scale of the wave. Using the observed values of period (=15days) in the lower stratosphere, we have a period of about 10 days for the Kelvin wave in the upper stratosphere and mesosphere.

As was discussed by many authors in relation to the QBO, Kelvin waves have a property of transporting a considerable amount of westerly momentum vertically through the easterly phase of the oscillation to produce the mean westerly current over the equator. Hence a similar mechanism to the wave-zonal flow interaction in the QBO can be expected also for the semiannual oscillation, by supposing the vertical transport of ample westerly momentum into the upper stratosphere and mesosphere due to shorter period, slowly damping Kelvin waves.

With regards to the semiannual variation in the upper mesosphere, however, the source of westerly momentum is still open to the question, although semiannually varying planetary waves have been detected at the mesopause level by the Nimbus 6 Pressure Modulator Radiometer (PMR). Since the upper mesosphere is out of the target of conventional meteorological rockets, new observational techniques with a fine vertical resolution will be of great importance in the future.

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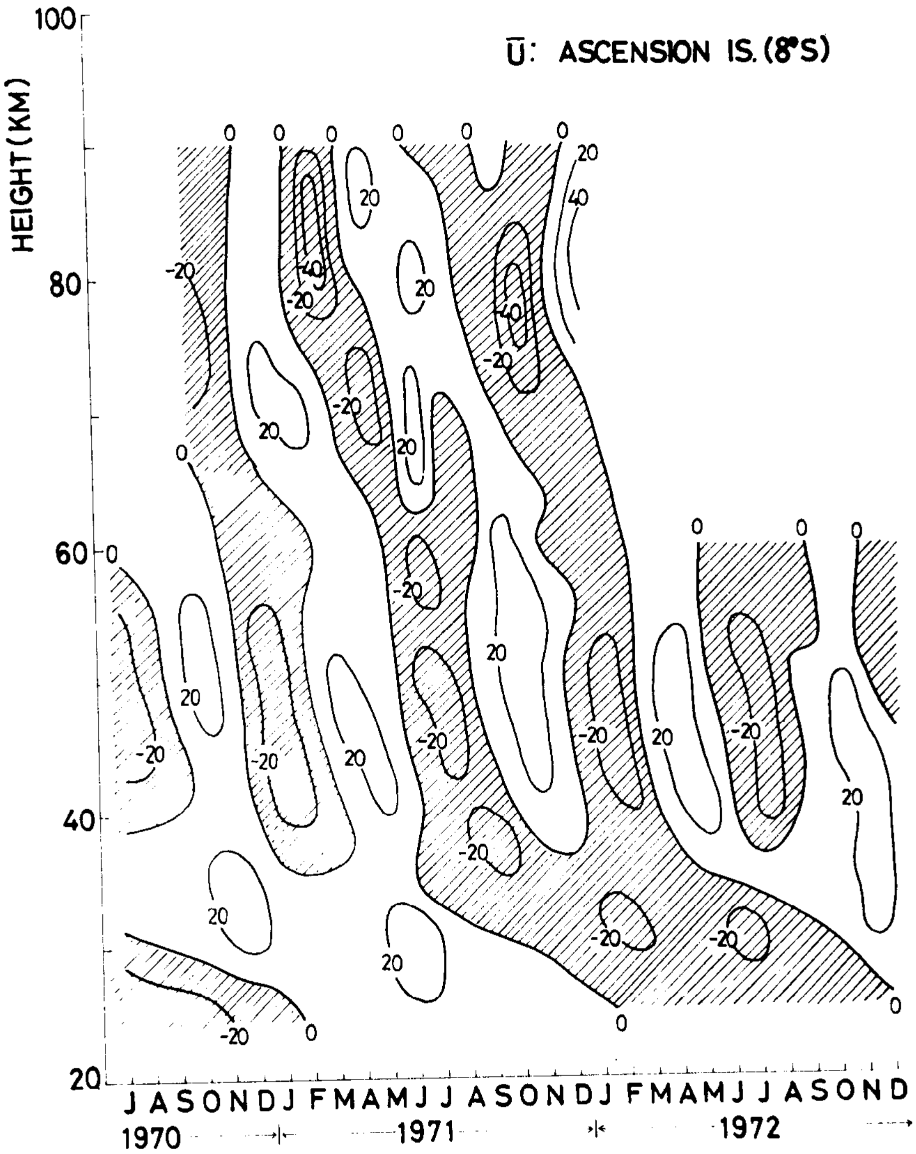

Fig.1 Vertical-time section of the monthly mean zonal wind at Ascension Island for the period July 1970 through December 1972. The annual cycle is removed. Units are m/sec and the easterlies are shaded.

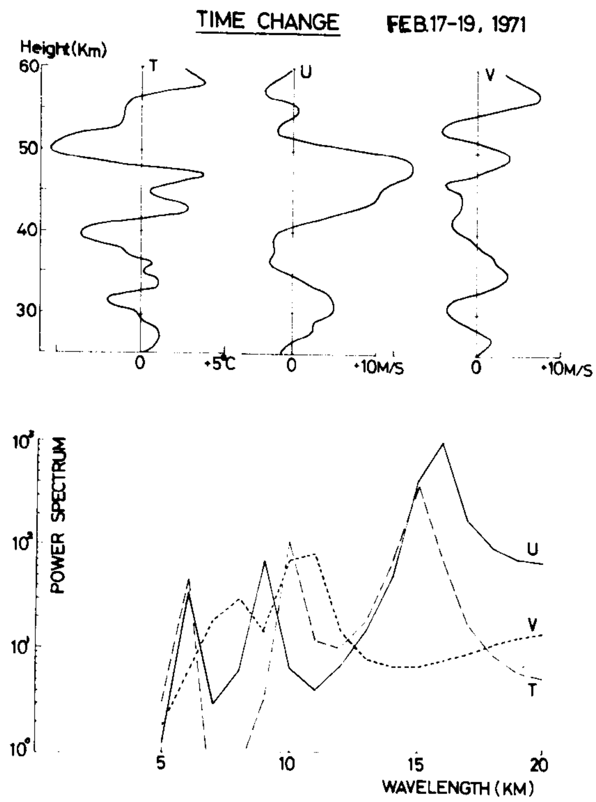

Fig.2

(upper) An example of 2-day difference of temperature (T) and zonal (U) and meridional (V) wind component at Ascension Island for February 17-19, 1971. Units are K/day and (m/sec)/day. (lower) Power spectra of each component as a function of vertical wavelength. Units are $(K/day)^2 \cdot km$ and $((m/sec)/day)^2 \cdot km$.

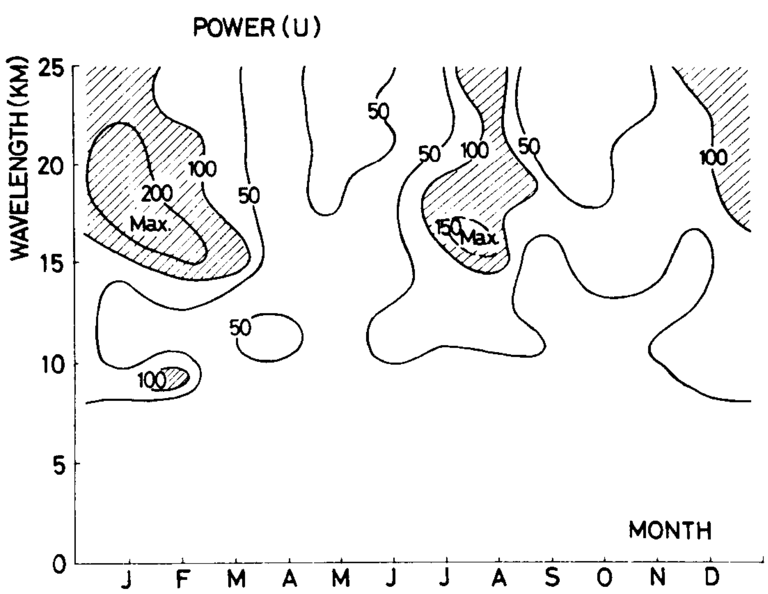

Fig.3 Seasonal variation of power spectral density for the zonal wind component as a function of vertical wavelength during the period of 1971 and 1972.

EQUATORIAL WAVES IN THE UPPER STRATOSPHERE

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Equatorial waves have been identified in upper stratosphere radiance measurements by Barnett (1975) and Hirota (1975). The waves considered were of vertical wavelength $\gtrsim 20$ km since they were visible in the nadir-viewing satellite measurements. Both investigators considered variations of zonal wave-number 1 as estimated from radiance in the Selective Chopper Radiometer (SCR) channel B_{12}, the channel measuring the uppermost stratospheric levels, and both were concerned with 30-day average properties of the waves. Barnett found maximum wave activity during spring and fall when the upper stratospheric zonal winds are in the west-to-east phase of the semi-annual oscillation. The latitudinal phase and amplitude variations were shown by Barnett to be consistent with the predictions of planetary wave propagation theory (Eliassen and Palm, 1961, Charney and Drazin, 1961, Dickinson, 1968). That is, they transport wave energy from the active hemisphere toward the passive one. Hirota suggested that these planetary waves, which act to extract westerly momentum from the equatorial zone, are responsible for the transitions from the westerly to the easterly phase of the semi-annual oscillation. By contrast, Hopkins (1975) found maximum wave activity in the equatorial upper stratosphere within the easterlies in rocket wind data. Hirota (1977), in his paper presented at this session, presents evidence that Hopkins' disturbances are Kelvin waves of period $\sim$10 days, vertical wavelength $\sim$15-20 km, and zonal wave-number 1 or 2. He suggests that vertical momentum transport by these waves may be responsible for the transition to the westerly phase of the semi-annual oscillation.

In this research, we examine further the satellite radiance variations in the equatorial zone, using Nimbus 5 SCR data from channels B_{23} and B_{34}. Wave-number 2, lower stratosphere radiance, and the higher frequency time-dependent behavior of the upper stratosphere radiance waves are investigated. Our results are as follows: (1) Averaged over 30 day periods, upper stratosphere wave 2 behaves in much the same way as does wave 1. (2) There is some evidence that radiance variations in the lower stratosphere (100-10 mb) are modulated by the quasi-biennial oscillation in the sense expected from wave-propagation theory, but further analysis is needed to confirm this. (3) There are higher frequency fluctuations in upper stratosphere radiance waves 1 and 2 which resemble Kelvin waves of 5-7 day period and vertical wavelength $\sim$ 30 km. Thus, if Hirota's suggestion is correct, there may be a spectrum of equatorial upper stratospheric Kelvin waves, some of which can be seen in the radiance data.

The figures reveal some of these features.

Fig. 1: Amplitudes of radiance waves on the equator and at high latitudes. The striking anti-correlation between equatorial and high latitude waves is illustrated (30 day averages, wave 2). Heavy bars represent periods when the combined energy of equatorial waves 1 and 2 is high.

Fig. 2: Amplitudes of wave 1 and 2 on the equator and their combined energy, compared with combined high latitude amplitude. The semi-annual variation with equinoctial westerlies is shown (30 day averages).

Fig. 3: Amplitudes and combined energy of equatorial waves 1 and 2 in the lower stratosphere compared with the 50 mb zonal wind. Peak energy occurs with westerly winds occurring at this level but not at higher levels.

Fig. 4: Monthly averaged equatorial zonal winds showing the QBO through 1975: total. (top); with annual variation removed (bottom).

Fig. 5: Vector plot of 100 days of wave 1 wave 2 amplitude. Vectors point to 0°lon. on the left, 90°W at the top, latitudes 28°S to 28°N. Wave 2 (top), wave 1 (bottom). In both waves, disturbances of constant phase and amplitude and ∿ 5-7 day recurrence periods occur, especially early in N.H. spring; there are also disturbances extending from southern high latitudes in late spring. The former are interpreted as Kelvin waves, the latter as high latitude Rossby waves.

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