NOTES AND CORRESPONDENCE

Diurnal Variations in the Western Atlantic Trades during the BOMEX

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1. Introduction

The diurnal variations of wind, temperature and pressure in the troposphere have been studied by many authors. Harris *et al.* (1962) analysed diurnal variations for 30 levels from the surface to 10 mb at Azores (38°44′N, 27°04′W). Hering and Borden (1962) studied the diurnal wind variations over the central United States and found three oscillation regimes which have the maximum amplitude of a few m $\sec^{-1}$. They concluded that these diurnal variations are organized by the summer wind field over the central United States. Wallace and Hartranft (1969) examined global distributions of diurnal wind variations from the surface to 30 km and concluded that the diurnal wind variations at low and middle latitudes are strongly related to topography, land-sea contrasts and terrain slope. Recently Hastenrath (1972) examined the daily wind, pressure and temperature variations up to 30 km over the tropical western Pacific.

However, there are few observational studies of the diurnal variations of large-scale horizontal divergence and the vertical motion. Wallace and Hartranft (1969) found the diurnal cycle of the horizontal divergence in the layer below 700 mb in the western Pacific which has an amplitude of the order of $5\times10^{-7}\sec^{-1}$. Recently Nitta and Esbensen (1974) analysed large-scale mass, heat and moisture budgets over the Atlantic trade wind region. In their results of areal averaged vertical velocity, a large amplitude diurnal variation is clearly seen but a detailed analysis of this variation was not given in their paper. In this paper we examine the diurnal variations of horizontal divergence, vertical velocity, wind and temperature over the western Atlantic trade wind region. Since the large-scale divergence field is strongly coupled with cumulus activity, accurate knowledge of diurnal variations is important for large-scale heat and moisture budget analyses.

2. Data and method of analysis

In this study we use the same rawinsonde data used by Nitta and Esbensen (1974) for BOMEX Phase 3 from 22 to 30 June 1969. Fig. 1 shows the fixed ship locations during the analysed period. The rawinsonde observations extend from the sea surface to 500 mb above the surface with a vertical resolution of 10 mb. The time interval between soundings is $1-1/2$ hours with the exception of the 0000 GMT and 0300 GMT observations. Since there are no observations on 27 June, the data on 27 June is linearly interpolated from the data at the same observational hour on 26 June and 28 June.

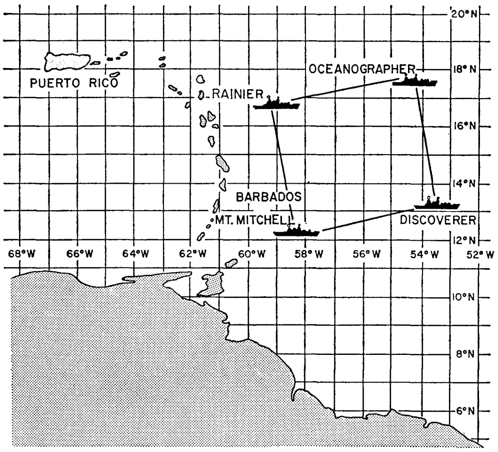

Fig. 1. BOMEX fixed-ship array during Phases 1, 2 and 3.

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Areal averaged horizontal divergence, relative vorticity and vertical velocity are computed by the usual kinematic method. We use a p^*-coordinate system where $p^*=p_s-p(p_s$: surface pressure). Fig. 2 shows the time-height section of the vertical p^*-velocity. Within the dominant downward motion, diurnal variations are clearly seen. Nitta and Esbensen (1974) subdivided the whole period into the undisturbed period (22–26 June 1969) and the disturbed period (28–29 June 1969) for large-scale budget analyses. The diurnal variation during the undisturbed period is more clearly found than that during the disturbed period in general, but the analysed period is too short to discuss the difference between two periods. In this paper we examine the diurnal variation averaged through the whole period. We apply a band-pass filter which has a response amplitude larger than 0.5 in the period range between 16 and 46 hours to the original time series. The 1−1/2 hourly, filtered data are averaged over the 7 days from 1330 GMT on 22 June to 1200 GMT on 29 June to obtain the mean amplitude for each observation time.

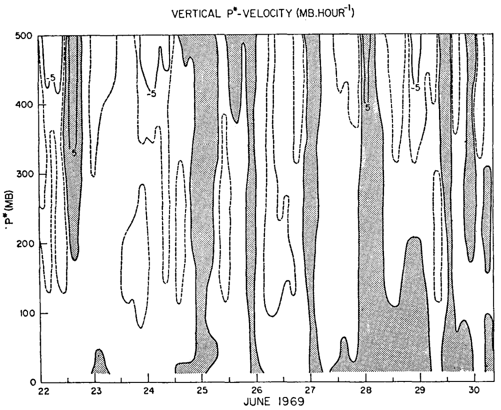

Fig. 2. Vertical p^*-velocity (ω^*) cross section. Shaded areas are upward motions.

3. Horizontal divergence and vertical velocity

Figs. 3 and 4 show the diurnal variations of horizontal divergence and vertical velocity. The variation of horizontal divergence has a layer structure. In the lower layer below $p^*\sim 200$ mb, maximum convergence and maximum divergence occur at 00 GMT (20 LMT) and at 12 GMT (08 LMT) respectively. In the middle layer between $p^*=200$ mb and $p^*=400$ mb, the phase is reversed, and in the upper layer the phase is reversed again. The maximum amplitude is about $3\times10^{-6}\text{sec}^{-1}$ which is one order of magnitude larger than that estimated in the western Pacific by Wallace and Hartranft (1969). Maximum rising motion occurs at 00 GMT (20 LMT) and maximum sinking motion at 12 GMT (08 LMT) near $p^*=200$ mb. The amplitude is about 1 mb hour^{-1}.

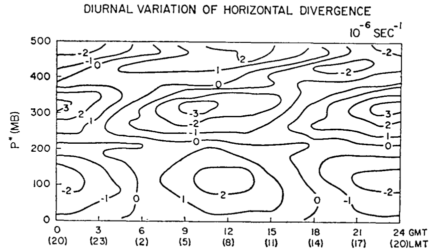

Fig. 3. Diurnal variation of horizontal divergence.

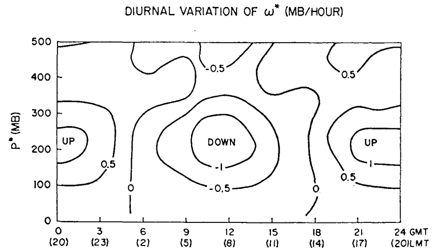

Fig. 4. Diurnal variation of vertical p^*-velocity.

Lindzen (1967) theoretically investigated the diurnal tide in the atmosphere which is thermally driven by the absorption of solar radiation by ozone and water vapor. In his model, the heat sources have no longitudinal dependence and topography is neglected. The computed amplitude of the vertical velocity in the lower troposphere is one order of magnitude smaller than that of this study.

There also exists a diurnal variation of relative vorticity (not shown). The maximum amplitude is about $3\times10^{-6}\text{sec}^{-1}$. Maximum relative vorticity occurs at about 06 GMT–09 GMT (02 LMT–05 LMT) and minimum relative vorticity occurs at about 18 GMT–21 GMT (14 LMT–17 LMT) in almost the whole layer.

4. Wind

Diurnal variations of the u-component and the v-component of the wind for the *Oceanographer*

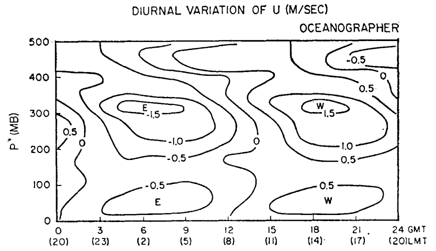

Fig. 5. Diurnal variation of eastward wind component for *the Oceanographer.*

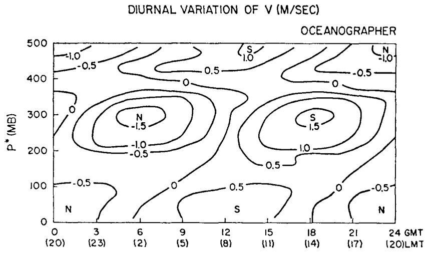

Fig. 6. Diurnal variation of northward wind component for *the Oceanographer.*

are shown in Figs. 5 and 6. In the lower layer below $p^*=100$ mb, the phase of the u-component and that of the v-component are different from each other by 6 hours. However, in the upper layer above $p^*=200$ mb, the phases of the u-component and the v-component are almost identical with each other. Wind directed from southwest to northeast dominates during the daytime and reverse wind flows during nighttime near $p^*=300$ mb. The maximum amplitude of the u- and v-components is about 1.5 m sec^{-1} and is nearly one order of magnitude larger than that obtained by Hastenrath (1972) over the western Pacific and that computed theoretically by Lindzen (1967).

Fig. 7 shows the diurnal variations of the wind vector at $p^*=90$ mb for the four ships. The variations of the wind vector for northern ships are similar to each other but the variations for the southern ships are different from those for the northern ships and are also different from each other. It is expected from Fig. 7 that maximum convergence occurs near 00 GMT (20 LMT) and maximum divergence occurs near 12 GMT (08 LMT) at $p^*=90$ mb. The wind vector does not show a simple uniform flow but appears to be affected largely by local influences. These non-uniform flows are seen through the whole layer. Wallace and Hartranft (1969) found a similar complex behavior of diurnal wind vector in the lower troposphere over the North America and the Carribean Sea. They concluded that land-sea contrast and terrain slope appear to be the controlling influences upon the diurnal wind variations at low and middle latitudes.

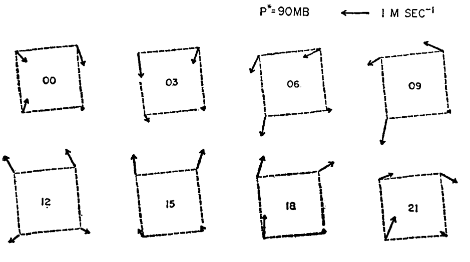

Fig. 7. Diurnal variation of wind vector for the four corner ships as a function of GMT.

There also exist diurnal variations of temperature (not shown). Maximum temperature occurs near 18 GMT (14 LMT) and its amplitude is about 0.5°C.

5. Conclusions

The diurnal variations of the large-scale horizontal divergence, large-scale vertical velocity and wind over the Atlantic trade wind region are examined. Maximum amplitude of the diurnal variation of the vertical velocity is 1 mb hour^{-1} which is nearly the half of the mean downward velocity under the undisturbed weather situation (22–26 June, 1969). The amplitude of diurnal variations in this study is one order magnitude larger than that of the diurnal tide obtained theoretically by Lindzen (1967). We conclude that the diurnal variations in this study are largely affected by the land-sea contrast.

The GARP Tropical Experiment (GATE) will be held in the eastern Atlantic Ocean near Africa in 1974 and large diurnal variations may also exist over this area. We should carefully choose the time interval of measurements and the method for data analysis.

The large amplitude of the diurnal variations in the large-scale divergence field may affect the activity of cumulus convection. Brier and Simpson (1969) demonstrated the relation between tropical cloudiness and rainfall and the semidiurnal solar atmospheric tide. Hudlow (1970) obtained the average diurnal variation in radar echo occurrences during the BOMEX period. A maximum in echo activity is observed during early morning which is about 6 hours later than the occurrence of the maximum upward motion. The minimum echo activity occurs during midday which is about 4 hours later than the occurrence of the maximum downward motion. Since the cumulus activity may be controlled also by the diurnal change of heat and moisture supply from the ocean and related to the structure of the mixed layer, the diurnal variations of cumulus activity may be produced through complex response to large-scale divergence fields, energy supply from the sea surface and the mixed layer structure. A diagnostic study of the diurnal change of the mixed layer heat and moisture budgets will be performed by one of the authors.

Acknowledgments

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BOMEX のデータを用いた西大西洋貿易風帯における日変化の解析

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