The Relationship Between Stability and Boundary Layer Winds in the Trades

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ABSTRACT

Surface winds over the oceans are an essential component in the computation of wind stress and energy exchanges between the atmosphere and ocean. One technique to determine winds over large, uninstrumented oceanic regions is the tracking of the movement of cloud patterns from geosynchronous satellites. These low-level cloud drift vectors often correlate poorly with surface winds, partly because of wind shear in the boundary layer.

In this study, data from a small island station located in the southeast trade wind regime was used to show the influence of stability on the boundary layer winds. There was stronger low-level shear on stable days; thus on stable days cloud drift winds are likely to be poorer estimates of surface winds than on unstable days, when deep easterlies were found to characterize both the cloud and subcloud layers. It is shown that synoptic charts can be used to assess the low-level stability. By taking the stability into account, it should be possible to better extrapolate satellite winds to the surface.

1. Introduction

Surface winds over the oceans are an essential component in the computation of wind stress and energy exchanges between the atmosphere and ocean. One technique to determine winds over large, uninstrumented oceanic regions is the tracking of the movement of cloud patterns from geosynchronous satellites (e.g., Hubert and Whitney, 1971; Gaby and Poteat, 1973; Hubert and Thomasell, 1979). Low-level cloud motion vectors have for many years been routinely computed by NOAA's National Environmental Satellite Service. Cloud motions have been found to correspond most closely with the winds at cloud base (Hasler et al., 1976), but the winds are a priori assigned to 900 mb because of the uncertainties in determining actual cloud height. These wind vectors often correlate poorly with surface winds (e.g., Halpern, 1978, 1979), in part because of wind shear in the boundary layer. In comparing low-level satellite wind estimates with aircraft measurements in a disturbed situation, Smith and Hasler (1976) found these observations to agree with different accuracy depending upon their location relative to the disturbance (i.e., in an area of convergence, divergence, or trade flow north of the disturbance). They postulated that environmental factors peculiar to the regions influenced the movement of the cloud targets. In this study, data from a small island station located in the southeast trade wind regime was used to show the influence of stability on the boundary layer winds. By taking the low-level stability into account, it should be possible to improve estimates of surface winds from satellite data.

2. Data

Willis Island (150°E, 16°S) is a tiny, low coral cay located 450 km east of Australia. An observing station was established there in 1921, and since then detailed meteorological records have been maintained. Data were generously made available by the Australian Bureau of Meteorology through B. Neal and U. Radok.

Daily (~0900 LT) temperature and moisture
soundings and corresponding wind data taken in April and May 1974 have been used for this study. From the soundings, stability was assessed by bringing a parcel to its Lifting Condensation Level (LCL) and then raising it moist adiabatically; if it intersected the sounding at some low level the day was defined as stable; if not, as unstable. Included in the analysis were several disturbed days in May when a tropical front approached the vicinity of Willis Island. Of the 59 days (1 April and 10 May were omitted because of missing data), 31 were stable, 23 were unstable, and 5 were undetermined.

3. Discussion

The most significant differences between composite soundings for the stable and unstable days (Fig. 1) were, not unexpectedly, the moisture content from 885 to 710 mb and also the moisture at the surface. The composite relative humidity at the surface was 67% for the stable cases compared to 78% for the unstable cases. Composite cloud base (i.e., LCL) and top (i.e. the level of zero buoyancy) were ~900 m (910 mb) and 1780 m (820 mb), respectively, for the stable cases, and cloud base was ~530 m (950 mb) for the unstable cases.

Fig. 2. Wind profiles for the stable and unstable days. Envelopes have been sketched around the U and V components to show the extent of the scatter.
Table 1. Stable or unstable days with an approaching ridge or trough.1

<table>
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<tr>
<th></th>
<th>Approaching ridge</th>
<th>Approaching trough</th>
<th>Undetermined</th>
</tr>
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<tbody>
<tr>
<td>Stable days</td>
<td>19 (15)</td>
<td>4 (8)</td>
<td>8</td>
</tr>
<tr>
<td>Unstable days</td>
<td>7 (11)</td>
<td>9 (5)</td>
<td>7</td>
</tr>
<tr>
<td>Undetermined</td>
<td>2</td>
<td>3</td>
<td>0</td>
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1 Underlined values indicate “correct” determination of stability. Numbers in parentheses are days expected by chance.

Fig. 2 shows the composite wind profiles for the stable and unstable situations. Envelopes were sketched around the curves of the $u$ and $v$ components to show the extent of the scatter, which was large in both cases. In spite of the sizeable overlap in the scatter, the differences between the two situations were significant at the 95% level, except for the $v$ component at heights $>1800$ m.

The observed wind profile with a low-level wind speed maximum is typical for trade wind regimes (e.g., Richl et al., 1951; Sheppard and Omar, 1952), and is the result of the combined effects of thermal wind shear and the surface frictional force. However, the stability also has a modifying effect. In both the stable and unstable cases, the wind speed maximum occurred at or very near cloud base, the level best represented by satellite wind vectors. Thus without any reduction at all, the cloud motion vectors are likely to be poor estimates of the surface wind. However, because of the deep easterlies (i.e., smaller vertical shear) on unstable days, the satellite-derived cloud winds are probably more accurate representations of wind in the cloud layer, and also at cloud base. A scheme which attempts to reduce satellite winds to the surface should take this into account. The magnitude of the vector difference, and the wind turning between cloud base and surface winds was 6.4 kt, 4.5° for the stable cases, and 6.7 kt, 0.6° for the unstable cases. If this small wind turning is typical, it explains why satellite estimates of wind direction are better than those of wind speed in the trades. The strong backing of the wind between surface and 300 m, particularly evident in the unstable case, may be an artifact of the radar balloon tracking (Neal, 1973a).

Another important factor to consider is the cloudiness itself. While there were low-level trade cumulus on all but one day, 9 out of the 23 unstable days had $>6/8$ middle or upper level cloudiness compared with 8 of the 31 stable days. Even so, because of the overriding easterly movement in the trades, the sky would have to be nearly completely overcast for satellite low-level cloud tracking to be impossible (Frank Smiglielski, NESS; personal communication). Cumulonimbus were reported on just two of the un-

Fig. 3. Wind profile, sounding and synoptic analyses for a typical stable day.
stable days. On days sufficiently disturbed to generate cumulonimbus, the wind shear can be large through the extent of the clouds, but these no longer qualify as "low" clouds, and so are not a major concern here.

An important remaining question is: can the stability be determined by means available to an analyst (or model) whose task it is to reduce satellite winds to the surface? Streamline analyses at 200 mb, 500 mb, and the surface have been examined to determine how well the synoptic conditions indicate low-level stability. The 200 mb chart was the most useful of these. Results are shown in Table 1. The numbers in parentheses indicate the frequencies in each category expected by chance. Using Yates continuity correction for $2 \times 2$ contingency tables and applying the $x^2$ test, the differences were found to be significant at the 95% level. Sixty-eight percent of the days with an approaching ridge were found to be stable and 56% of the days with an approaching trough were found to be unstable. The low-level divergence or convergence implied by the synoptic situation at 200 mb must serve to reinforce or weaken, respectively, the normally stable conditions one expects in the trades. In total, correct determination of the boundary layer stability based on the 200 mb analyses was made $\sim 52\%$ of the time, incorrect identification was made $\sim 20\%$ of the time, and another 28% was undetermined.

Figs. 3 and 4 illustrate soundings, winds and streamline analyses on representative stable and unstable days. Fig. 5 shows these parameters for another type of wind profile which was occasionally observed. That is, light winds almost directly from the south at the surface, changing to weak southerlies or southwesterlies above. Though this type of wind profile usually occurred under stable conditions, the surface chart shows southerly flow resulting from a weak depression east of Willis Island. This is an instance when the SLP analysis may be of use, corroborating the southerly cloud motion which would probably be observed by satellite.

4. Conclusion

In conclusion, the effect of atmospheric stability on the boundary layer winds in the trades provides a tool by which the agreement between satellite wind vectors and surface winds may be assessed and improved. Surface winds on the mean stable and unstable days were similar, but the stronger southerly and weaker easterly components in the cloud layer in the stable case may lead to an incorrect estimate of these quantities at the surface. In addition, the apparent speed of the cloud is influenced by the shear in the cloud layer. The presence of deep easterlies and small vertical shear implies that little correction for direction is necessary on unstable days, though a correction for speed is still needed. On stable days, the shear through the cloud layer is greater even though the cloud is shallower. These factors could be taken into account by an analyst reducing satellite
winds to the surface with the aid of synoptic charts to determine stability. A more extensive study, such as that which could be done using Global Weather Experiment data, might include refinements such as variation with latitude and season or month.

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REFERENCES