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Analysis of 200 mbar zonal wind for the period 1958–1997

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Abstract. The value of the analyses of the 200 mbar zonal winds is proposed as a particularly effective tool to assess variability and trends in atmospheric circulation. Using the thermal wind relation, the 200 mbar zonal wind results from the vertically integrated north-south temperature gradient between the Earth's surface and 200 mbar. We found a tendency for the 200 mbar winds to become somewhat stronger at higher latitudes since 1958.

1. Introduction

The monitoring of troposphere weather trends using available global weather observations is difficult as a result of changes in measurement platforms over time, although useful results are possible [*Angell*, 2000; *Chase et al.*, 2000; *Pielke et al.*, 1998a, 1998b; *Stendel et al.*, 1998, 2000]. Nonetheless, some have suggested that global-scale data such as the NCEP Reanalysis or satellite measurements should be used cautiously or not at all to assess long-term trends [e.g., *Hurrell and Trenberth*, 1998; *NCEP Conference Summary*, 1997; *Santer et al.*, 1999].

There are particular weather observations, however, that are best suited to evaluate trends. These are observations in which the atmosphere itself performs the integration. As is well known, integration of data reduces the effect of random errors, although systematic errors, if any, would still persist. *Chase et al.* [2000] and *Pielke et al.* [1998a, 1998b] used the thickness between pressure surfaces in order to assess trends in depth-integrated temperatures around the Earth. In the work of *Chase et al.* [2000], different levels of error in the data were assumed in order to reduce the role of systemic errors, so that real trends could be more realistically evaluated. *Pielke et al.* [1998a, 1998b] compared the thickness data with satellite-derived equivalent data on an interannual basis, in order to provide confidence in the results.

In this paper, an alternate integrated trend measurement is evaluated. The 200 mbar zonal winds (u component) for the period 1958–1997 are analyzed using observational data. From the thermal wind relation (discussed in the next section) the winds at 200 mbar are a very effective integrator of the tropospheric meridional temperature gradient averaged from the surface up to the altitude of the 200 mbar pressure surface. The monitoring of trends in the 200 mbar winds, therefore, provides an effective procedure to look for long-term changes and variability in the atmospheric circulation. This paper explores this issue using the NCEP Reanalysis.

2. Analysis

The westerly winds at 200 mbar, $u_{200\text{ mbar}}$, are directly related to the magnitude of the horizontal, north-south, gradient in temperature averaged from the Earth's surface to the height of the 200 mbar winds [*Bluestein*, 1992]. This relation can be expressed as the thermal wind equation;

$$u_{200\text{ mbar}} = \frac{R_d}{f} \ln\left(\frac{1000\text{ mbar}}{200\text{ mbar}}\right)(\mathbf{k} \times \nabla_p \overline{T}) \cdot \mathbf{i}, \qquad (1)$$

where the surface geostrophic wind (the surface is defined to be at 1000 mbar) is assumed to be negligible compared to the 200 mbar winds. The quantity $\nabla_p \overline{T}$ is the horizontal temperature gradient averaged from 1000 to 200 mbar. R_d is the dry air gas constant, and f is the Coriolis parameter. An increase in wind speeds, for example, would be expected if this layer warmed at lower latitudes and/or cooled at higher latitudes, and/or the horizontal difference in temperature occurred over a shorter distance. An increase in the layer-mean horizontal temperature gradient of 1°C per 1000 km at a latitude of 43°, for example, would produce a geostrophic 200 mbar wind speed increase of 4.6 m s^{-1}; an effect which should be easily detectable in observational data. An advantage of using (1) is that the atmosphere itself performs the vertical integration of the layer-averaged horizontal temperature gradient. The accuracy of (1) has been repeatedly confirmed through independent calculations of the term $\nabla_p \overline{T}$ and comparison with observed winds [*Pielke*, 1995].

We analyzed the 200 mbar annual westerly (u component) wind anomaly for the period 1958–1997 from the National Center for Environmental Prediction (NCEP) Reanalysis. *Kalnay et al.* [1996] describes the Reanalysis product. The Reanalysis data were obtained as monthly averages from the National Center for Atmospheric Research (NCAR). Winds in the Reanalysis are heavily constrained by observational data and are considered as one of the most reliably analyzed fields [*Kalnay et al.*, 1996; *Kistler et al.*, 2001].

The 200 mbar wind anomalies were analyzed in 15° latitude bands. Figures 1a–1l present the observed wind anomalies for each latitude band, and their corresponding linear trends and significance p values over the time period 1958–1997 are given in Table 1. No adjustment for serial autocorrelation has been made to these significance estimates as we are interested in the overall sign of wind changes rather than a detailed assessment of trend significance. Despite the large interannual variability, the linear trends for several of the latitude bands are statistically significant. Since 1958, the latitude bands 0°–15°N, 45°–60°N, 60°–75°N, 0°–15°S, 45°–60°S, 60°–75°S, and to a lesser extent, 75°–90°S show an increase in wind speed. The latitude

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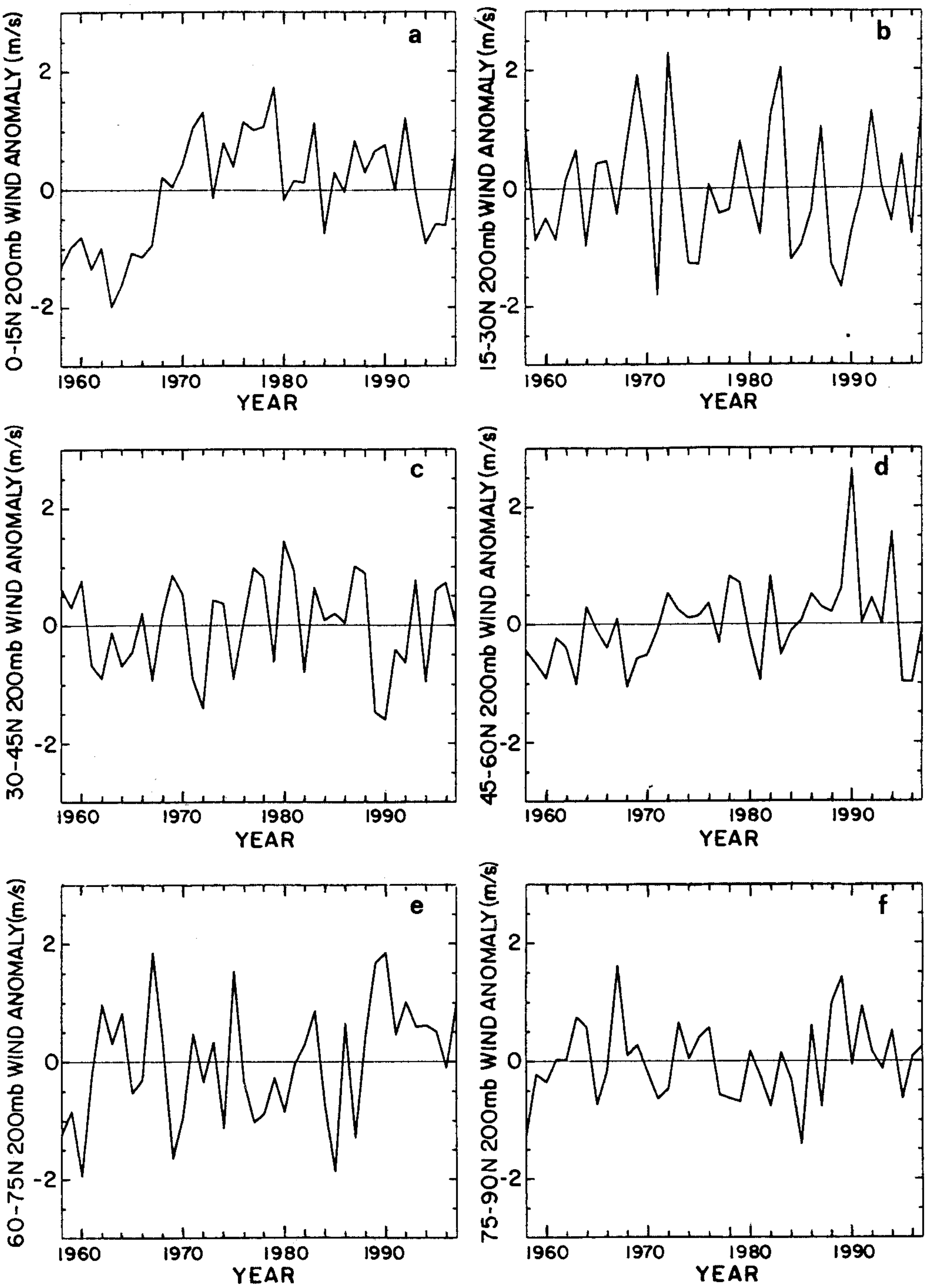

Figure 1. The 200 mbar westerly wind anomaly from the NCEP Reanalysis for 1958–1997. (a) 0°–15°N, (b) 15°–30°N, (c) 30°–45°N, (d) 45°–60°N, (e) 60°–75°N, (f) 75°–90°N, (g) 0°–15°S, (h) 15°–30°S, (i) 30°–45°S, (j) 45°–60°S, (k) 60°–75°S, and (l) 75°–90°S. Equation (1) can be used to convert these values to north-south temperature gradients. A value of 1 m s^{-1} corresponds to a difference in temperature across a distance of 1000 km of 0.04°C, 0.12°C, 0.19°C, 0.25°C, 0.29°C, and 0.31°C for the latitudes of 7.5°, 22.5°, 37.5°, 52.5°, 67.5°, and 82.5°, respectively.

bands 15°–30°S and 30°–45°S show significant decreases in speed. The interpretation of these results is that there has been some tendency for the 200 mbar westerlies to become stronger at higher latitudes since 1958. This is to some degree consistent with the observational findings of *Kodera and Koide* [1997], who found increased 500 mbar zonal winds at ~50°–70°N for the period 1965–1993 and decreased winds centered at 40°N in northern winter and early spring though little change elsewhere. Trends averaged over the globe show a weak and highly insignificant increase (Table 1).

We also examined the 500 mbar westerly wind anomalies in the Reanalysis in order to completely remove the stratospheric

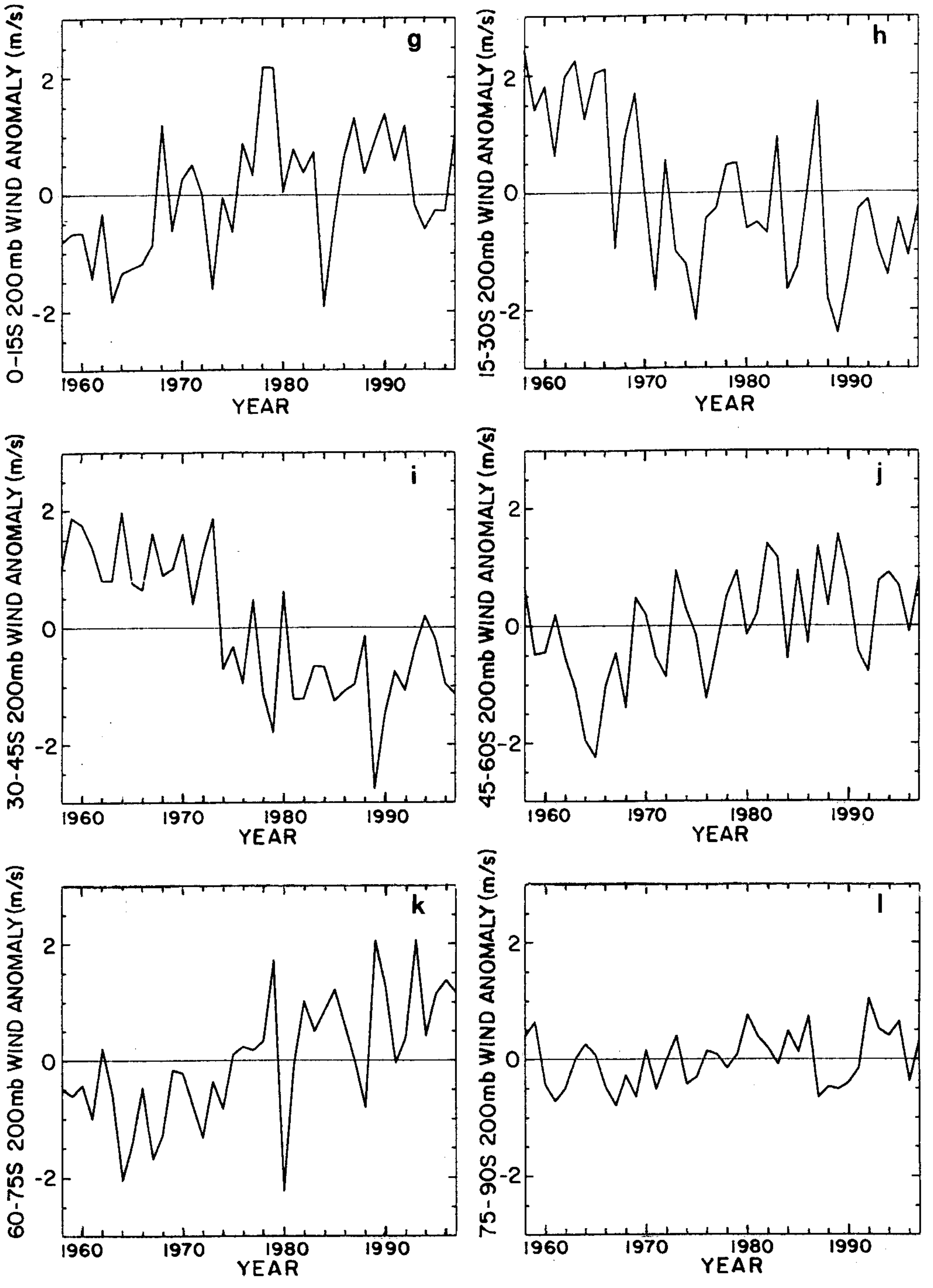

Figure 1. (continued)

influence at high latitudes and obtained similar results as those found in the 200 mbar analysis, indicating the 200 mbar winds at all latitudes are still dominated by the tropospheric horizontal temperature gradient and that these results are robust.

3. Conclusion

Observed trends in 200 mbar westerly flow suggest that the vertically averaged horizontal gradient in global tropospheric temperatures at most higher latitudes has increased since 1958. We emphasize that changes in the vertically averaged horizontal temperature gradient are a more appropriate circulation diagnostic (through the thermal wind relation) than changes in the horizontal temperature gradient at the surface. Analysis of winds as a tropospheric averaging technique is less affected by biases than temperature analyses and provides an effective method for assessing atmospheric variability and change. Because future shifts in wind regimes are likely under both natural and anthropogenically caused climate change, identifying the robustness of the simulated wind changes in many models

Table 1. The 1958–1997 200 mbar Observed Westerly Wind Trends and Significance Level p From NCEP Reanalysis[a]

	Observed	
	Trend	p
Globe	0.03	0.58
0°–15°N	0.35	<0.01
15°–30°N	−0.03	0.86
30°–45°N	0.03	0.82
45°–60°N	0.22	0.02
60°–75°N	0.27	0.05
75°–90°N	0.06	0.50
0°–15°S	0.41	<0.01
15°–30°S	−0.72	<0.01
30°–45°S	−0.76	<0.01
45°–60°S	0.38	<0.01
60°–75°S	0.59	<0.01
75°–90°S	0.11	0.09

[a] Units of trends are in m s^{-1} $decade^{-1}$.

and the monitoring of this quantity in observations is expected to become more important in coming years as a test of the predictive capability of climate change models and as one means for resolving the discrepancy between model simulations which show large upper tropospheric warming, and observations which show large surface warming but little change above the surface [*Panel on Reconciling Temperature Observations*, 2000].

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