The Relationship between the Gradient of Satellite-Derived Radiance and Upper Tropospheric/Lower Stratospheric Winds

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ABSTRACT

It is shown that the gradient of satellite-derived radiance is proportional to a certain vertical integral of the geostrophic wind. The radiance gradient is shown to be useful in locating the upper tropospheric jet maxima in middle latitudes; the major uncertainty results from lack of specific knowledge of the lower stratospheric winds above the area in question. At high latitudes, the radiance gradient delineates regions of stratospheric jet maxima.

1. Introduction

Gradients of satellite-derived radiance fields have been found empirically to be useful in determining middle and upper tropospheric flow patterns, particularly with regard to the strength and location of jet stream axes at these altitudes. For example, Brodrick (1978) showed that good correspondence existed between radiance gradients and 300 mb wind fields in midlatitudes. Fig. 1, which is adapted from Brodrick's analysis, shows that the 300 mb jet axes coincide well with radiance gradients from about 30 to 50°N over North America. However, the analysis also reveals that the *strongest* radiance gradients (located near 60°N) show *poor correlation* with the 300 mb jet.

In this note, the partial success of the radiance gradient as a locator of upper tropospheric jet maxima is explained rigorously. For a radiometer channel similar to that used by Brodrick and normal winter wind structure, it is shown that the *radiance gradient is useful* in identifying the *upper tropospheric jet* in *middle latitudes,* while at *high latitudes* it is the *lower stratospheric jet* which is located. These uses are demonstrated in the case studied by Brodrick.

2. Theory

To an approximation sufficient for the present purposes, the radiance R measured by a 15 μm infrared radiometer provides a measure of atmos-

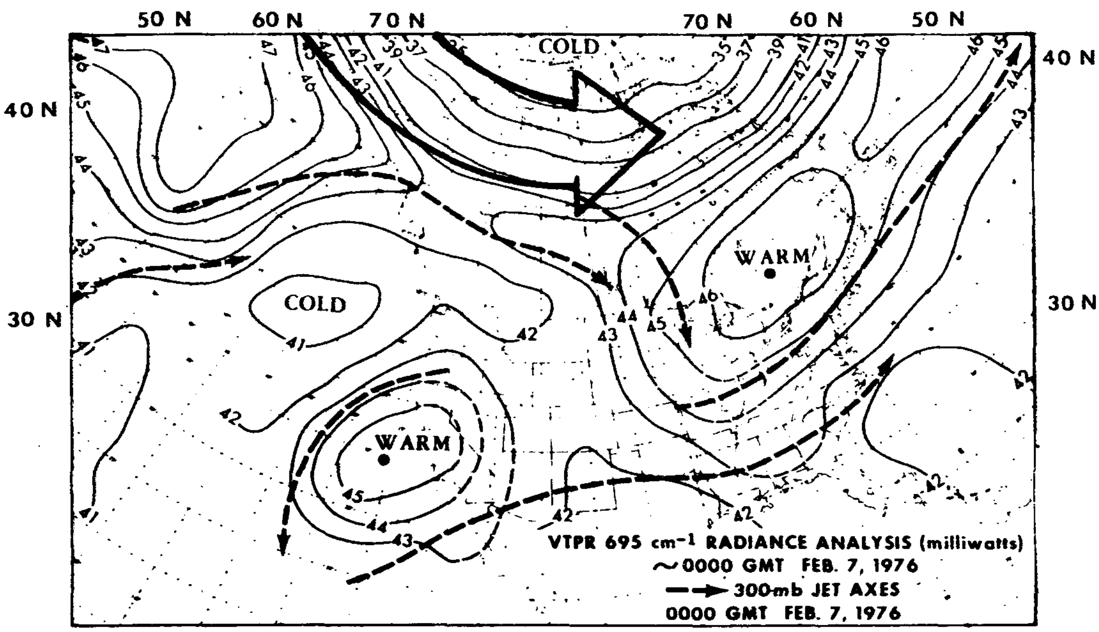

FIG. 1. Comparison of satellite-derived radiance field and 300 mb jet axes (from Brodrick, 1978). Also shown is 50 mb jet maximum (50 m s^{-1}, large arrow) from data in *Meteorologische Abhandlungen* (1976).

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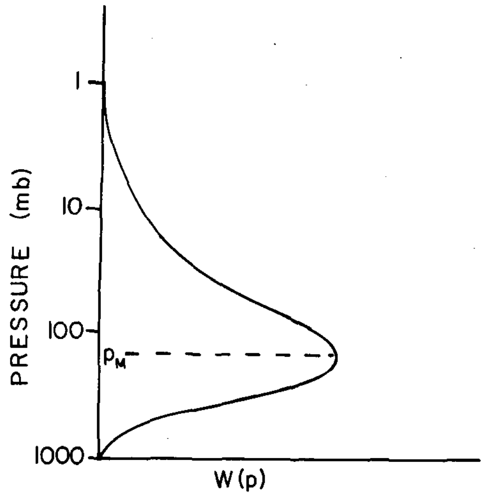

FIG. 2. Typical instrumental weighting function $W(p)$ for a satellite radiometer.

pheric temperature which may be written (see, e.g., Stanford, 1979)

$$R - R_0 \approx C_1 \int_{p_{00}}^{0} T'(\theta,\phi,p)W(p)d\ln p. \quad (1)$$

Here R_0 is the horizontal mean radiance, C_1 a constant, p_{00} the surface pressure, $W(p)$ the instrumental weighting function (see Fig. 2), and $T'(\theta,\phi,p)$ the deviation of temperature T from the background horizontal mean $T_0(p)$. θ and ϕ are latitude and longitude, respectively. $W(p)$ is the vertical derivative of optical depth $\tau(p)$ seen from the satellite down to atmospheric pressure p (see, e.g., Houghton, 1977) and may be written

$$W(p) = d\tau(p)/d\ln p. \quad (2)$$

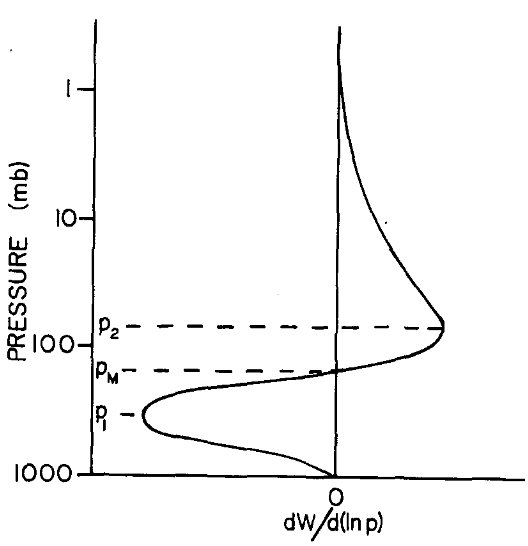

FIG. 3. Variation of $dW/d\ln p$ with pressure.

Since $W(p)$ is a continuous and well-behaved function of p, Eq. (1) can be integrated by parts to obtain

$$R(\theta,\phi) - R_0 = C_1[\overline{T'}W]_{p=p_{00}}^{p=0} - C_1 \int_{p_{00}}^{0} \overline{T'} \frac{dW}{d\ln p} d\ln p, \quad (3)$$

where

$$\overline{T'} = \int_{p_{00}}^{p} T'd\ln p.$$

The first term on the right in Eq. (3) is zero because $W(0) = W(p_{00}) = 0$ for the radiometer channel considered here (Fig. 2).

We now consider $\partial R/\partial y$, where y is the northward coordinate on the spherical earth. From Eq. (3) we may write

$$\partial R/\partial y = -C_1 \int_{p_{00}}^{0} \left(\frac{\partial}{\partial y}\overline{T'}\right)\frac{dW}{d\ln p} d\ln p. \quad (4)$$

By the thermal wind relation and recalling that $T' \equiv T - T_0(p)$, the term in parentheses inside the integral in Eq. (4) is proportional to the Coriolis parameter times $[u_g(\theta,\phi,p) - u_g(\theta,\phi,p_{00})]$, where u_g is the zonal component of geostrophic wind. The integral containing $u_g(p_{00})$ vanishes and the northward component of the gradient of radiance is

$$\frac{\partial R(\theta,\phi)}{\partial y} = K_1 \sin\theta \int_{p_{00}}^{0} u_g(\theta,\phi,p) \frac{dW}{d\ln p} d\ln p, \quad (5)$$

where K_1 is a constant.

It is apparent from Fig. 2 that the variation of $dW/d\ln p$ will be that shown in Fig. 3, a function peaking at the inflection points of $W(p)$. If the latter were a perfect "rectangular" function of $\ln p$, $dW/d\ln p$ would be proportional to the difference of two delta functions, $\delta(p - p_2) - \delta(p - p_1)$. For such an idealized weighting function, Eq. (5) shows that $\partial R/\partial y$ would be proportional to the zonal component of thermal wind between the layers at p_2 and p_1. Because of the smoothly varying nature of $W(p)$, $\partial R/\partial y$ is actually proportional to the difference between the mean geostrophic wind in a layer centered about p_2 and that in a layer centered about p_1, as depicted in Fig. 3.

By reasoning similar to that used in obtaining Eq. (5), it can be shown that

$$\frac{\partial R(\theta,\phi)}{\partial x} = -K_1 \sin\theta \int_{p_{00}}^{0} v_g(\theta,\phi,p) \frac{dW}{d\ln p} d\ln p, \quad (6)$$

where x is the eastward coordinate and v_g the northward geostrophic wind component. Eqs. (5) and (6) show that *the radiance gradient is proportional to the geostrophic wind averaged over the vertical, weighted by* $dW/d\ln p$. For 15 μm infrared radiometer channels, this result is further limited

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because Eq. (1) is contingent on approximations which are most valid in middle latitudes (Stanford, 1979). On the other hand, for microwave radiometers such as SCAMS (Nimbus 6) or MSU (TIROS N/NOAA A series), Eq. (1) holds to a high approximation for all latitudes.

3. Discussion and conclusions

The use of the radiance gradient to obtain quantitative information about the upper tropospheric or lower stratospheric flow pattern is limited to those situations in which the wind in one layer is dominated by that in the other. This result may be used to explain Brodrick's (1978) observations, and to suggest other possible uses of the wind-radiance gradient relationship.

In northern middle latitudes, the lower stratospheric wind field is generally weak throughout the year. Therefore, the radiance gradient, for a channel similar to that used by Brodrick, primarily measures the upper tropospheric wind field, and the correlation of the jet maxima with the radiance gradient as illustrated in Fig. 1 is anticipated. In the Southern Hemisphere winter, the stratospheric winds are usually weak in the vicinity of 50 mb near 25–30°S (Phillpot, 1962; Hartmann, 1976). Climatological studies of van Loon *et al.* (1971) show a jet maximum near 200 mb at these latitudes. Thus, a radiance channel with a weighting function whose inflection points occur in these regions of the atmosphere could be used to locate this jet. This would be advantageous for forecasting as well as for climatological studies, since sufficient conventional data are not readily available in the Southern Hemisphere.

Limitations of this method must also be noted: van Loon *et al.* (1971) also report a second upper tropospheric jet maximum near 45–50°S which could be misinterpreted with this technique, due to interference with the stratospheric jet.

At higher latitudes, ~60°, Brodrick's (1978) results show that the radiance gradient does not correlate well with upper tropospheric jet maxima (Fig. 1). This occurs because at these latitudes the stratospheric jet is considerably stronger than the upper tropospheric wind, and makes the dominant contribution in Eqs. (5) and (6). Although the approximations used in deriving Eq. (1) are less valid at high latitudes, a good correlation is observed between the stratospheric jet and the radiance gradient. As shown in Fig. 1, the 50 mb jet axis is clearly indicated by the radiance gradient poleward of ~60°N. This suggests the possibility of using the radiance gradient to study the stratospheric jet at high latitudes in either hemisphere. This would be particularly feasible for regions where some conventional data are available so that the approximate strength of the upper tropospheric winds could be taken into account.

Both of these applications would be enhanced by the use of a microwave radiometer, for which Eq. (1) is accurate for all latitudes.

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REFERENCES

Brodrick, H. J., 1978: The relationship between vertical sounder radiances and mid-latitude 300 mb flow patterns. *J. Appl. Meteor.*, **17**, 477–481.

Free University of Berlin, 1976: Tägliche Höhenkarten der 50 mb Fläche sowie monatliche Mittelkarten für das Jahr 1976. *Meteor. Abhand.*, **B8**, p. II/7.

Hartmann, D. L., 1976: The structure of the stratosphere in the Southern Hemisphere during late winter 1973 as observed by satellite. *J. Atmos. Sci.*, **33**, 1141–1154.

Houghton, J. T., 1977: *The Physics of Atmospheres*. Cambridge University Press, 203 pp.

Phillpot, H. R., 1962: Mean westerly jet streams in the Southern Hemisphere. *Antarctic Research, Geophys. Monogr.*, No. 7, U.S. Nat. Res. Coun., 128–148.

Stanford, J. L., 1979: Latitudinal-wavenumber power spectra of stratospheric temperature fluctuations. *J. Atmos. Sci.*, **36**, 921–931.

van Loon, H., J. J. Taljaard, R. L. Jenne, and H. L. Crutcher, 1971: Climate of the upper air: Southern Hemisphere. Vol. II: Zonal geostrophic winds. NCAR TN No. 57, NAVAIR 50-1C-56, 80 pp.

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