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ESTIMATING TROPICAL CYCLONE OUTER SURFACE WINDS FROM SATELLITE MICROWAVE DATA

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ABSTRACT

Warm temperature anomalies over tropical cyclones are sensed by the 55.45 GHz channel of the Nimbus 6 Scanning Microwave Spectrometer (SCAMS). Radial brightness temperature gradients are related to radial surface pressure gradients through the hydrostatic and radiative transfer equations. Surface wind speeds outside of the radius of maximum wind are calculated from the pressure gradients and compared with observations.

1. INTRODUCTION

One of the most important measurements to be made on tropical cyclones is that of surface wind speed. In this paper a simple technique for estimating outer surface winds using data from the 55.45 GHz channel of the Nimbus 6 Scanning Microwave Spectrometer (SCAMS) or from the 54.96 GHz channel of the Tiros-N Microwave Sounding Unit (MSU) is proposed. The advantages of the technique are that it is physically based, it requires little computation time, and it is not affected by clouds.

2. THEORY

The brightness temperature measured by a satellite-borne radiometer is given by

$$T_B = \epsilon T_s \tau_o + \int_o^H W(z)T(z)dz \tag{1}$$

where ϵ is surface emittance, T_s surface temperature, τ_o transmittance from the surface to the satellite, T(z) atmospheric temperature, and W(z) a weighting function (Fig. 1). For a frequency such as 55.45 GHz (SCAMS) or 54.96 GHz (MSU) which have a vanishingly small τ_o, the brightness temperature is a weighted mean upper tropospheric temperature. Coincidentally, tropical cyclones are driven by upper tropospheric warm temperature anomalies (Fig. 2). Because these temperature anomaly curves have very similar shape,

$$T'(r,z) \approx \alpha(r)\hat{T}(z), \tag{2}$$

where $\hat{T}(z)$ is a standard anomaly profile, a relationship between brightness temperature gradient and surface pressure gradient can be derived, assuming hydrostatic balance (see Kidder, 1979):

$$\frac{\partial T_B}{\partial r} = -A \frac{\partial \ell n P_S}{\partial r}, \quad (3)$$

where A is given by

$$A = \frac{\frac{g}{R}\int_o^H \frac{\hat{T}(z)}{\cdot T_o^2(z)}\,dz}{\int_o^H W(z)\hat{T}(z)dz}, \quad (4)$$

and $T_o(z)$ is the temperature profile of the storm's environment. In the western North Pacific A is $0.95 \times 10^{-2}\ K^{-1}$ and $0.84 \times 10^{-2}\ K^{-1}$ for 55.45GHz and 54.96GHz, respectively. In the Atlantic the values are $1.02 \times 10^{-2}\ K^{-1}$ and $0.61 \times 10^{-2}\ K^{-1}$, respectively.

The surface wind speed is related to the radial surface pressure gradient by

$$\frac{v^2}{r} + f\ v \sec\beta = \frac{1}{\rho}\frac{\partial p}{\partial r} = -ART_s \frac{\partial T_B}{\partial r} \quad (5)$$

where R is the gas constant and β is the inflow angle, roughly 22.5° on the average (Frank, 1977). Friction is implicit in this equation. Because there is noise in the brightness temperature field (±0.5K) it is useful to know the functional form of the wind to use as a smoothing tool. Such a function, suggested by Hughes (1952), Riehl (1954, 1963), and others, is

$$V = Cr^{-x}. \quad (6)$$

Inserting Equation (6) into (5) and integrating holding, A, f, β, C, and $\dot{X}$ constant gives

$$T_B(r) - T_C = (ART_S)^{-1} \left[-\frac{C^2}{2X} r^{-2X} + \frac{f\sec\beta}{1-X} Cr^{1-x} \right], \quad (7)$$

where T_C is an integration constant. To calculate wind speeds, one calculates the average brightness temperature in radial bands around the center of the storm. Then one calculates the C for a given X, which gives the least squares best fit to the observed brightness temperatures. The wind at any radius (outside the radius of maximum wind) is given by Equation (6).

It is important to note that clouds and precipitation have virtually no effect at the two frequencies mentioned here (Kidder, 1979); thus, these measurements can be made regardless of weather conditions.

3. OBSERVATIONS

Two types of data were used to examine the theory. First simulated satellite data was calculated using soundings constructed from multi-level aircraft penetrations. Figure 3 shows the calculated surface wind speed and the observed vortex average relative wind at 95kPa for hurricane Inez on 28 September, 1966 (Gray and Shea, 1976). In this calculation, X was set equal to 0.5 which has been shown to be the best value for low level winds in the inner core region by Riehl (1963) and Shea and Gray (1972). Because the wind of the surface is less than at 95 kPa, the calculated surface winds are somewhat too high, but the shape of the curve is good, and some sort of correction could produce accurate surface winds.

The second type of data used was from the 55.45GHz SCAMS channel. The brightness temperatures were averaged in 56km bands about the storm center, and the radius of $15 ms^{-1}$ (30kt) and $26 ms^{-1}$ (50kt) winds were calculated for eight typhoons during 1975 using X = 0.7 which is a reasonable choice for r greater than 100km (Kidder, 1979). These data are compared with best track estimates in Figure 4. There are, unfortunately, very few data points, but there does seem to be a relationship between the observed and predicted radii. That the slopes of the regression lines are less than one is somewhat disturbing, but it may be explained in part by the inclusion of "safety factors" in official estimates. The uncertainty (one standard deviation) in estimates made from the regression line is 63km for the radius of $26 ms^{-1}$ winds and 82km for $15 ms^{-1}$ winds.

4. CONCLUSIONS

While this technique is not ready for operational use, it shows enough promise that more research should be undertaken. The first step in this process should be testing the technique using Tiros–N MSU data. Because of the smaller A for 54.96 GHz, the MSU data give about a 70% greater signal for an individual storm than the SCAMS data. Also, aircraft observations could be useful.

5. ACKNOWLEDGEMENT

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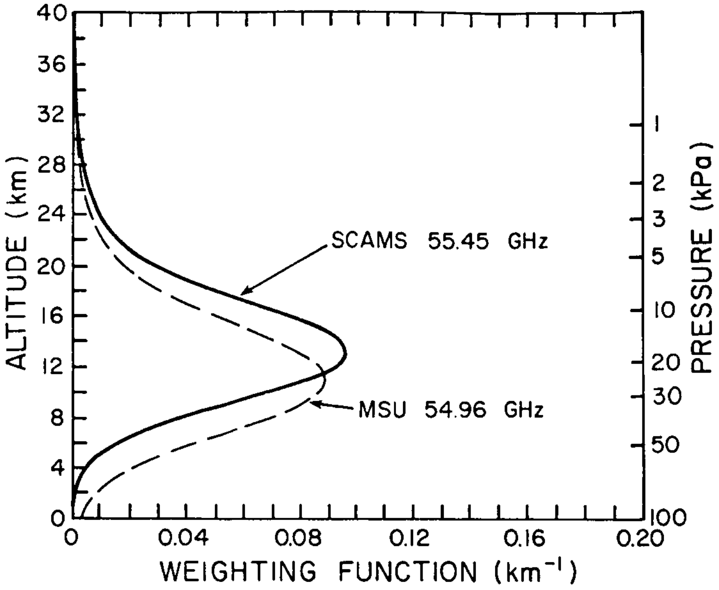

Fig. 1–Weighting functions.

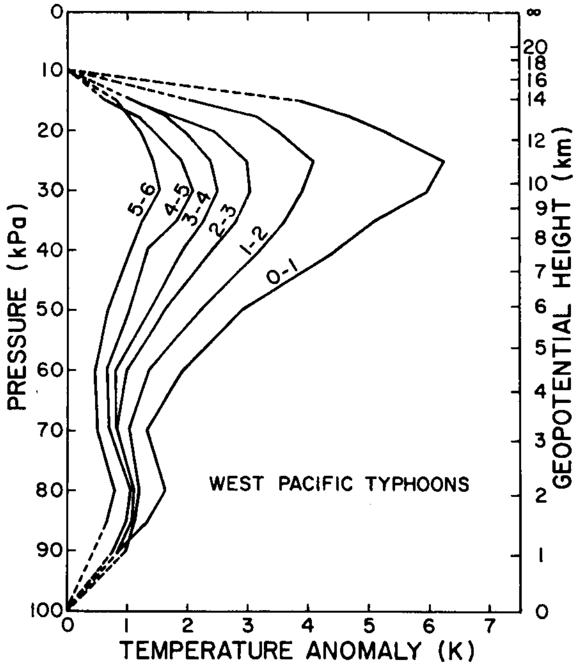

Fig. 2–Temperature anomalies (difference from environment) for the mean typhoon in one degree radial bands.

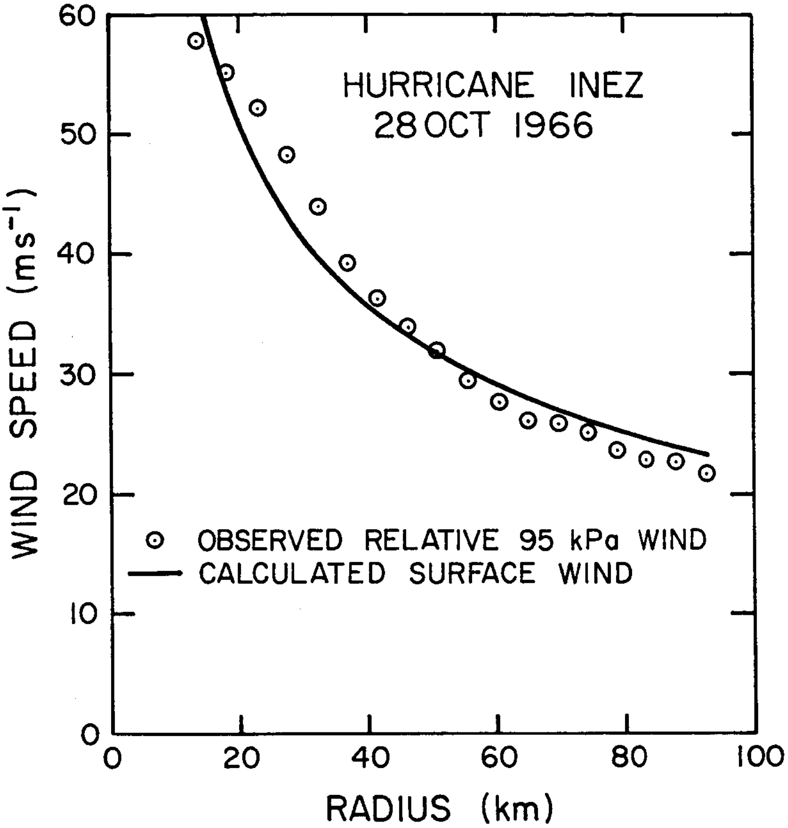

Fig. 3–Observed 95 kPa wind speeds compared with surface winds calculated from simulated satellite data.

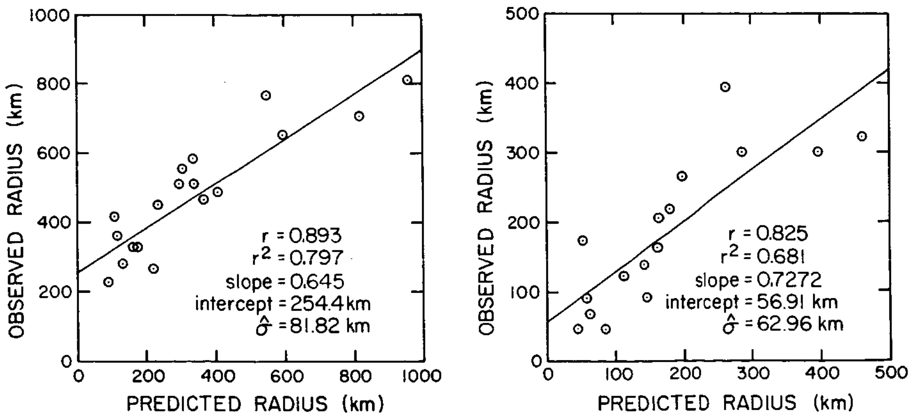

Fig. 4–Radii of (a) 15 ms^{-1} (30 kt) and (b) 26 ms^{-1} (50 kt) wind calculated from SCAMS 55.45 GHz data compared with observations.