PLANETARY WAVE BREAKING AND THE "SURF ZONE" IN THE VICINITY OF THE MARTIAN POLAR VORTEX.

T. H. McConnochie, *University of Maryland, College Park, MD, USA (Timothy.H.McConnochie@nasa.gov).*

Introduction:

McIntyre and Palmer (1983), studying satellite-derived maps of isentropic Ertel potential vorticity in the terrestrial extra-tropical winter stratosphere, identified breaking planetary waves and introduced the concept of a "surf zone" surrounding the polar vortex and separated from it by a boundary region of steep potential voriticity gradients. Here, we present Mars Global Surveyor Thermal Emission Spectrometer (MGS-TES)-derived maps of isentropic Ertel potential vorticity that show a similar "surf zone" and polar vortex boundary on Mars, complete with evidence for wave breaking.

Isentropic potential vorticity analysis and the "surf zone" paradigm are important because they provide a succinct explanation of the main dynamical features of the terrestrial polar vortex (see, e.g., McIntyre and Palmer, 1983, Schoeberl and Hartmann, 1991, Haynes, 2005). The outer boundary of the polar vortex, as previously mentioned, is defined by a region of steep Ertel potential vorticity ("PV", hereafter) gradients on isentropic surfaces that correspond with the steep gradients in the concentrations of chemical tracers. Outside of the polar vortex boundary lies the "surf zone", a region of very low PV gradients extending into the sub-tropics. Planetary waves propagating upward from the troposphere in the conduit provided by the vortex boundary are constantly breaking in the low PV gradients of the surf zone, providing the mixing that keeps the surf zone PV field homogenized. The same breaking waves are also constantly striping material from the outer edge of the polar vortex and mixing it into the surf zone, but only rarely does a wave amplitude grow so large that it produces a sudden stratospheric warming by breaking all the way through the barrier of the vortex boundary. The tendency of planetary wave breaking to erase weak PV gradients while leaving steeper gradients intact acts to generate and maintain the sharp PV gradient and its associated jet, meaning that the surf zone and vortex pattern is an expected feature of a background PV gradient under the influence of planetary wave forcing (Dritschel and McIntyre, 2008).

The presence of a similar surf zone and vortex pattern in the martian winter polar isentropic PV field, combined with evidence for breaking waves in the martian PV field, suggests that the martian polar vortex is influenced by similar processes. One important implication of this is that a martian chemical tracer with the right production/destruction time scales would tend to show a sharp gradient correlated with the vortex edge PV gradient and thus could be confined within the polar vortex, just as ozone-depleted air is confined within the terrestrial polar vortex. A chemical species that persists for a timescale significantly longer than the PV conservation timescale will be mixed across the vortex boundary by diabatic and/or frictional processes.

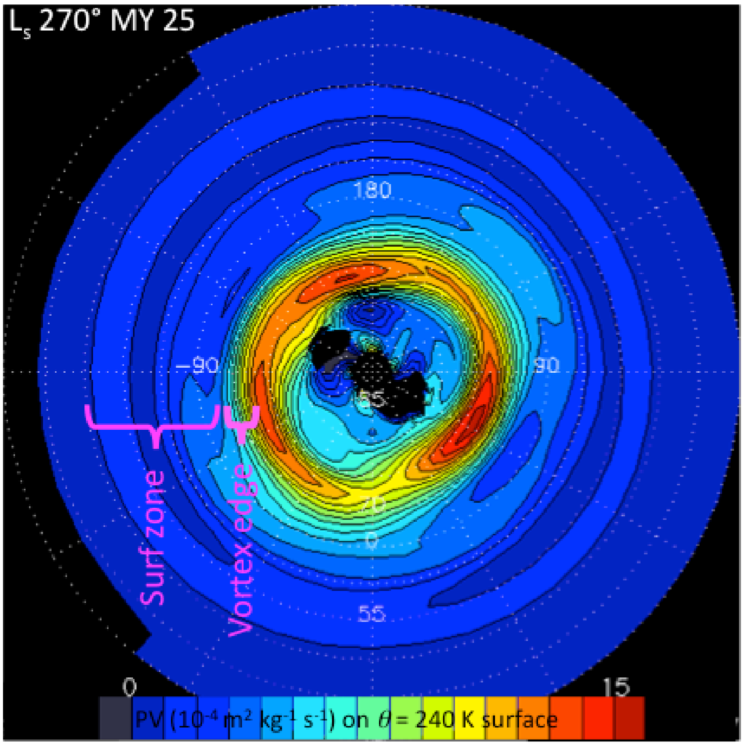

Figure 1: MGS-TES-derived Ertel potential vorticity (PV) on the 240K isentropic surface at martian northern winter solstice. The surf zone and vortex edge region are labeled.

Ertel Potential Vorticity from MGS-TES:

We derive gridded maps of PV on isentropic surfaces starting from MGS-TES nadir temperature soundings.

First we sample the Planetary Data System TES temperature soundings at vertical intervals of ½ scale height, and then at each pressure interpolate the soundings onto a regular grid in longitude, latitude, and time. We do this by smoothing in the latitude direction along each spacecraft orbit track and then performing linear interpolation, first in longitude, and then in time. We use either dayside data exclusively, or nightside data exclusively, yielding snapshots of global conditions at a constant local time of either ~2pm or ~2am.

Next, we calculate both components of the horizontal wind fields on each level by applying a variation of the "balance winds" method suggested by Randel (1987). To do this we necessarily invoke the hydrostatic approximation and chose a lower boundary condition of zero winds on some arbitrary near-surface pressure level. The balance winds method iteratively solves the full non-linear horizontal momentum balance equations, neglecting only time derivatives.

Finally, we calculate PV from the derived winds, and then use linear interpolation to go from the original log-pressure vertical coordinate to the isentroptic vertical coordinate.

Planetary Wave Breaking Defined:

Planetary wave breaking as McIntyre and Palmer (1983) define it means "irreversible deformation" of PV contours. In numerical experiments, Juckes and McIntyre (1987) show that planetary wave breaking begins when the magnitude of the perturbation PV gradient exceeds that of the basic state PV gradient, i.e., when the local total latitudinal PV gradient changes sign. Their experiments also show that the end result of wave breaking, when viewed at the inherently low resolution of satellite measurements, is regions of high PV isolated from the main mass of high-PV, i.e. local maxima in both latitude and longitude. Thus localized transient PV gradient reversals or local maxima suggest wave breaking. A wave breaking event that is well resolved, spatially and temporally, appears as a tendril of high-PV air that gradually extends from the vortex and embays a region of low-PV air which is eventually folder into the interior of the vortex. See Figures 3 and 4 of Juckes and McIntyre (1987) and Figure 2 of McIntyre and Palmer (1983) for numerical and observational (respectively) examples of this process.

Observed Martian Polar Vortex PV-field:

Figure 1 shows MGS-TES-derived daytime isentropic PV for the martian northern winter solstice. The polar vortex edge (labeled in pink) is the region of tightly clustered contours where the PV field *increases* rapidly in the poleward direction. (The persistent poleward-*decreasing* PV, on the inside of the high-PV annulus, i.e., in the interior of the polar vortex, is also a very interesting feature, but is a separate topic from the wave breaking phenomena that we are addressing in this abstract.) The surf zone (labeled in pink) is the region surrounding the polar vortex just equatorward of the polar vortex edge. It is characterized by low PV gradients and localized transient PV gradient reversals the are suggestive of persistent wave breaking. The presence of a sharp polar vortex boundary is further evidence that wave breaking and the associated vortex-stripping/jet-sharpening phenomenon is occurring, because there is no corresponding sharp gradient in the radiative forcing that is the main generator of PV in the winter polar region.

Figure 2 shows that the martian southern winter solstice polar vortex lacks a well organized polar vortex edge, and is instead characterized by localized transient PV gradient reversals throughout the polar region. Thus, the southern winter polar vortex has a very different relationship to planetary wave breaking than does the northern winter polar vortex. Since the southern winter polar vortex is also unlike its terrestrial counterparts, there is not an obvious way to analyze its dynamics by analogy. We can, however, say that the absence of a well defined polar vortex edge region means that breaking planetary waves can more easily mix air into the core of the polar vortex.

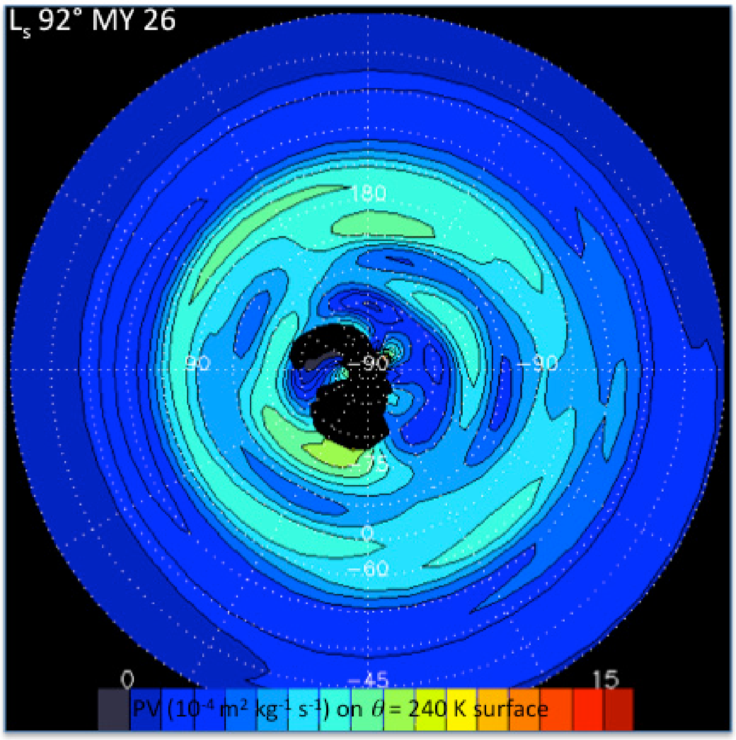

Figure 2: MGS-TES-derived Ertel potential vorticity (PV) on the 240K isentropic surface at martian southern winter solstice. The surf zone and vortex edge region are labeled.

A Major Wave Breaking event:

Figure 3 shows a time series of isentropic PV maps that captures a possible major wave breaking event in the northern winter martian polar vortex. It represents an exception to the rule of a well-organized and intact polar vortex edge in the northern hemisphere, and is thus possibly analogous to a terrestrial major stratospheric warming. The telltale wave-breaking PV configuration is most clearly seen on the third day of the time series, where a thick tendril of high-PV air seems to be extruded from the polar vortex in the vicinity of 0º longitude, and a mass of low-PV air seems to be folded into the polar vortex just north of the high-PV "tendril". This configuration closely resembles the wave breaking simulations of Juckes and McIntyre (1987).

References:

[1] McIntyre and Palmer (1983) Nature 305, 593. [2] Schoeberl and Hartmann (1991) Science 251, 46. [3] Haynes (2005) Annu. Rev. Fluid Mech. 37, 263. [4] Dritschel and McIntyre (2008) Journal of the Atmospheric Sciences 65, 855. [5] Randel (1987) Journal of Atmospheric Sciences 44, 3097. [6] Juckes and McIntyre (1987) Nature 328, 590.

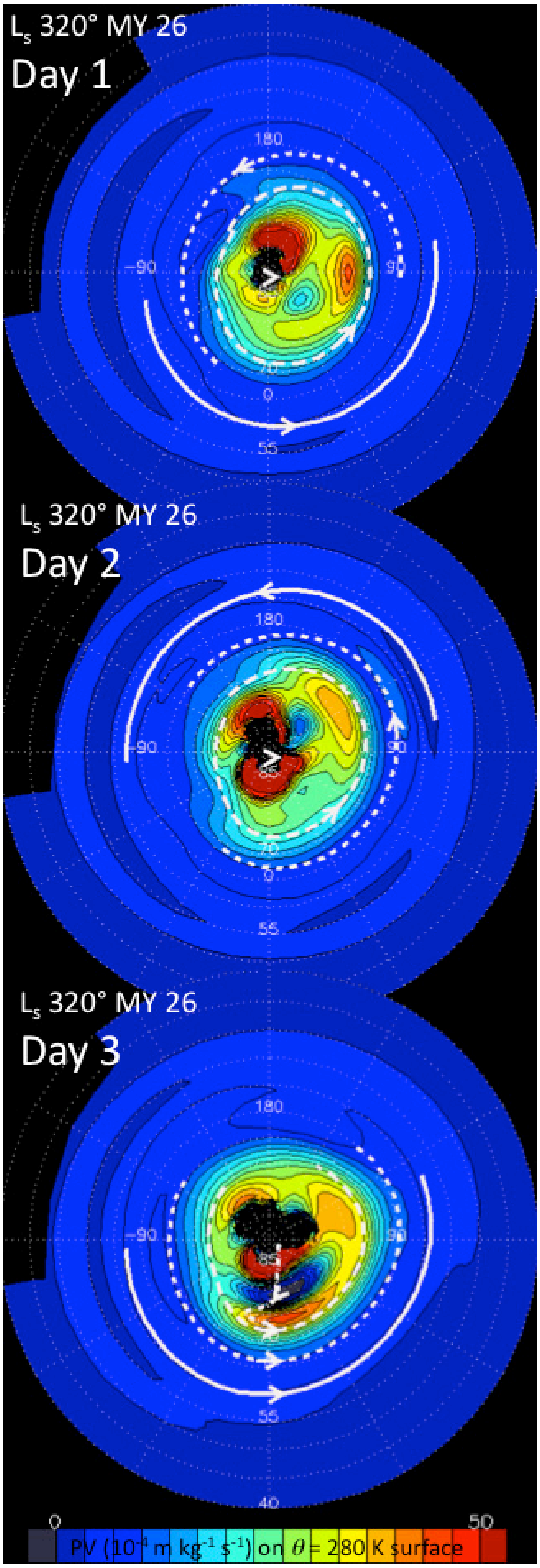

Figure 3: Time series of MGS-TES-derived isentropic Ertel potential vorticity on the 280K isentropic surface in northern winter, showing the development of a major planetary wave breaking event. The white lines show the trajectories of test particles advected by the MGS-TES derived horizontal wind fields.