Rossby Wave Breaking and Cross-Tropopause Ozone Flux Using the Two-Scale Method Over the North Pacific During July 2004

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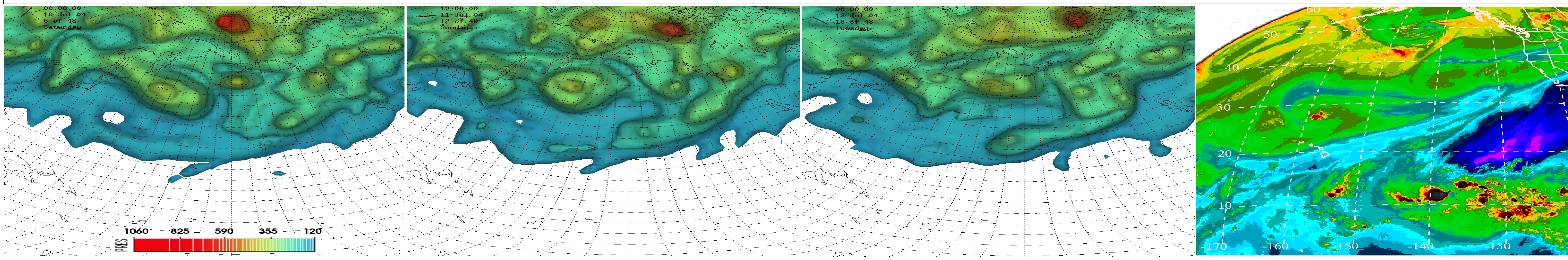
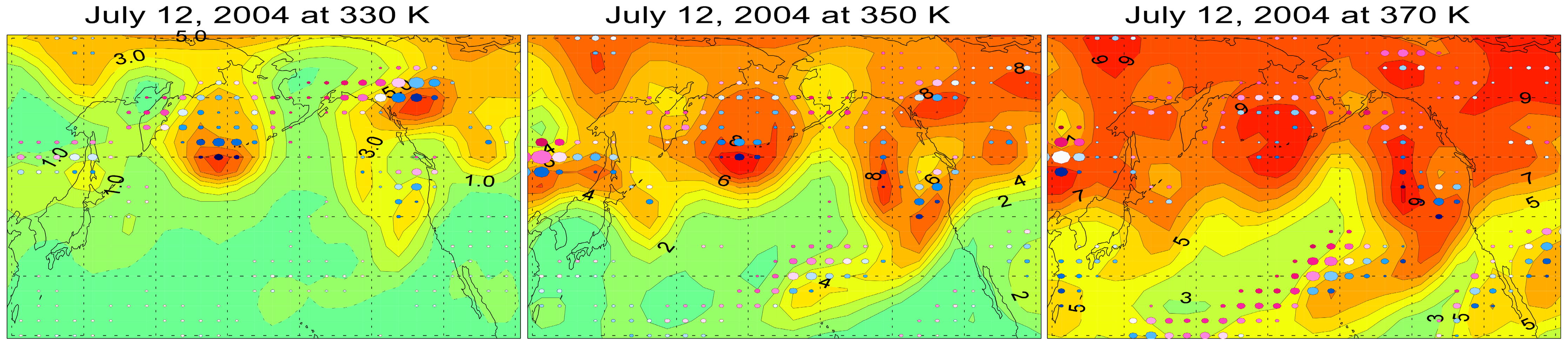
Rossby Wave Breaking (RWB) statistics and high resolution simulations with the Regional Air Quality Modeling System (RAQMS) are employed to quantify the contribution of stratospheric ozone to observed tropospheric amounts over the North Pacific during the INTEX-NA flights of July 2004, as polluted air made its way from Asia toward North America. Our new two-scale method calculates local ozone fluxes across the tropopause. Particle trajectories illuminate pathways by which polluted tropospheric air comes into juxtaposition with air from the stratosphere. A point is flagged as a local RWB event if the northward gradient of potential vorticity (PV) reverses sign. A future goal of this work is to use the two-scale method to calibrate RWB events. Then RWB statistics can be used to estimate regional, seasonal, and interannual differences in ozone flux based on where the PV gradient reverses sign.



Pressure on the 1.5 PVU surface (near the tropopause) is shown in color for 00Z July 10, 12Z July 11, 00Z July 13, from NCEP Global Forecasting System data analyzed in the University of Wisconsin Nonhydrostatic Modeling System (UWNMS), the regional component of RAQMS. Rossby wave energy disperses eastward from the large cyclone near the tip of Kamchatka, with subsequent development of the ridge and trough downstream. A classic RWB event develops, with somewhat polluted tropospheric air extending northeastward, while ozone-rich stratospheric air extends southwestward near Hawaii. GOES-10 water vapor imagery (far right) from 12Z July 11 verifies the rich structure of the tropopause.

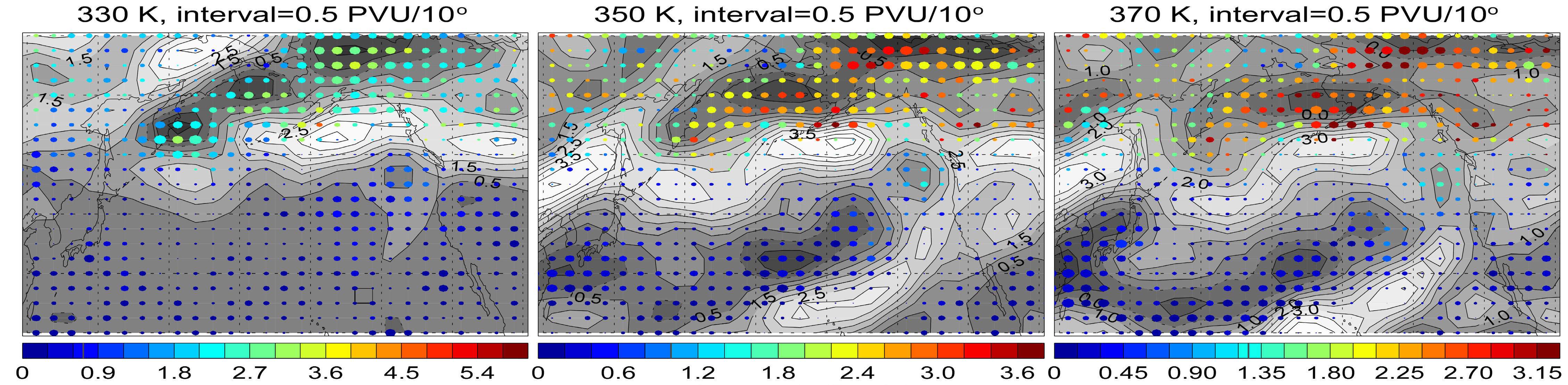
July 12, 2004 at 330 K | July 12, 2004 at 350 K | July 12, 2004 at 370 K



PV (contours, interval=1 PVU with extra at 0.5 PVU), flag PV-climatological PV (color, pink/blue=more -/+, climatology is from 1979-2004), strength (size)

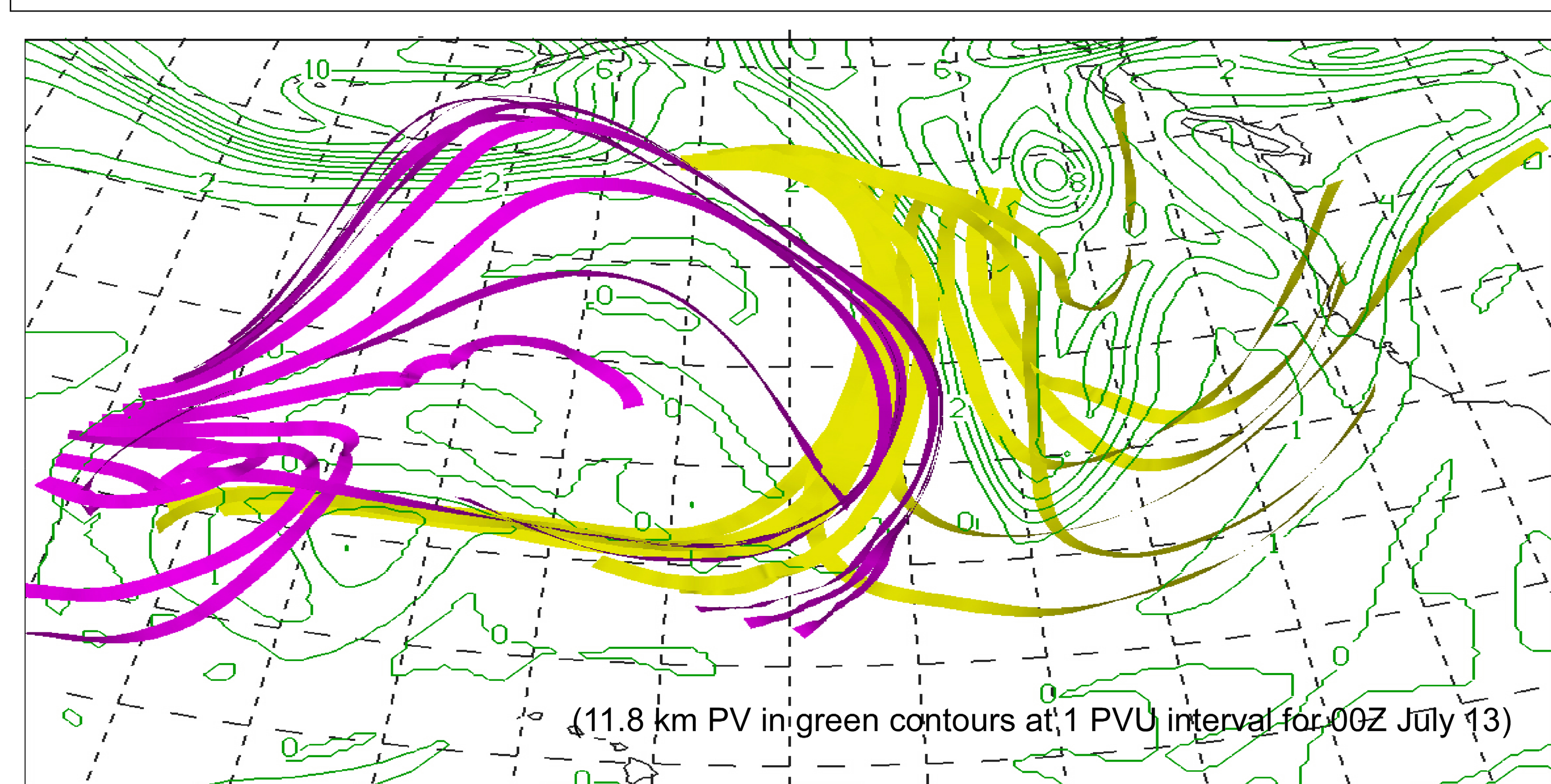
July, 2004 dPV/dy

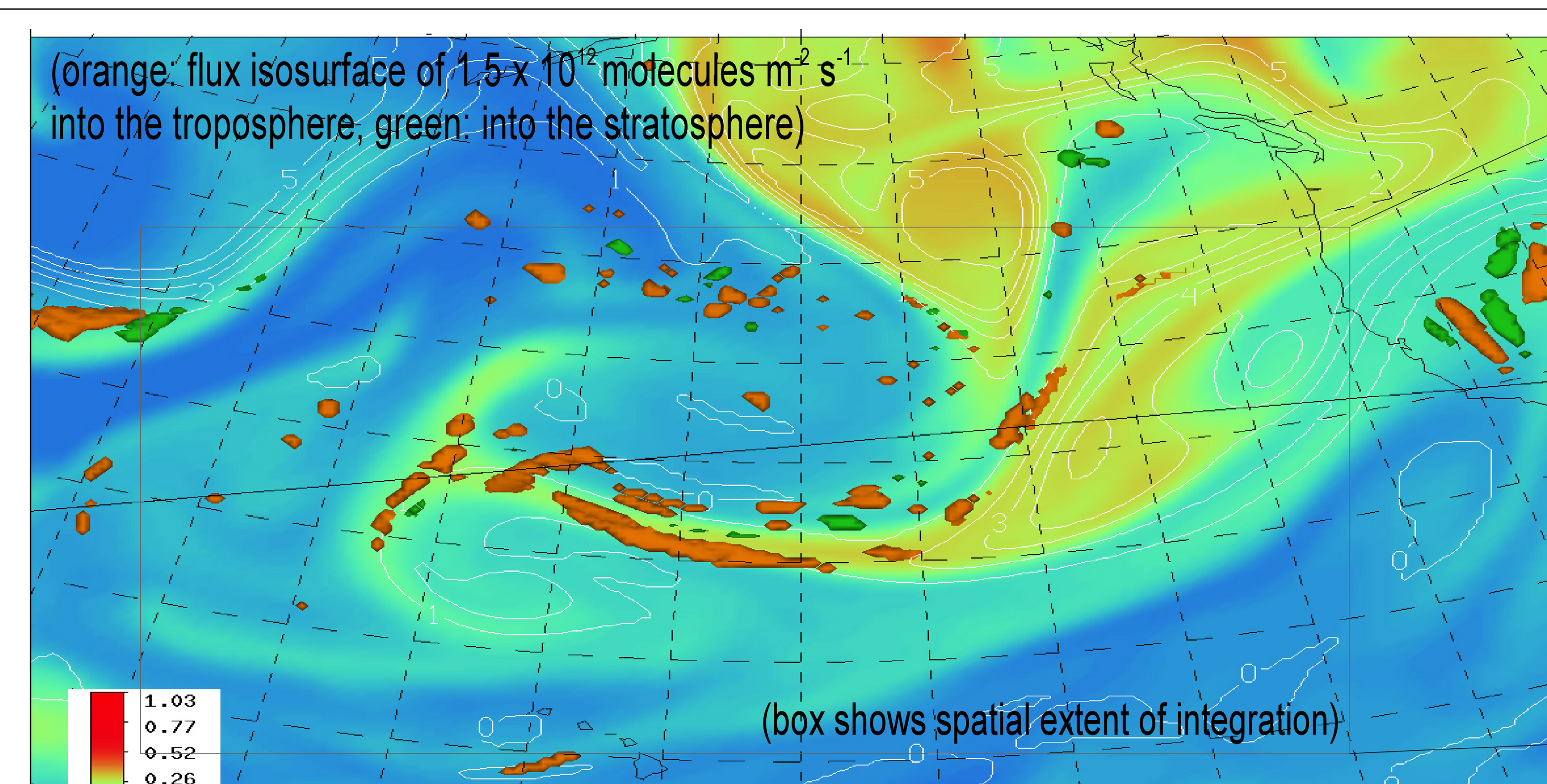
330 K, interval=0.5 PVU/10° | 350 K, interval=0.5 PVU/10° | 370 K, interval=0.5 PVU/10°

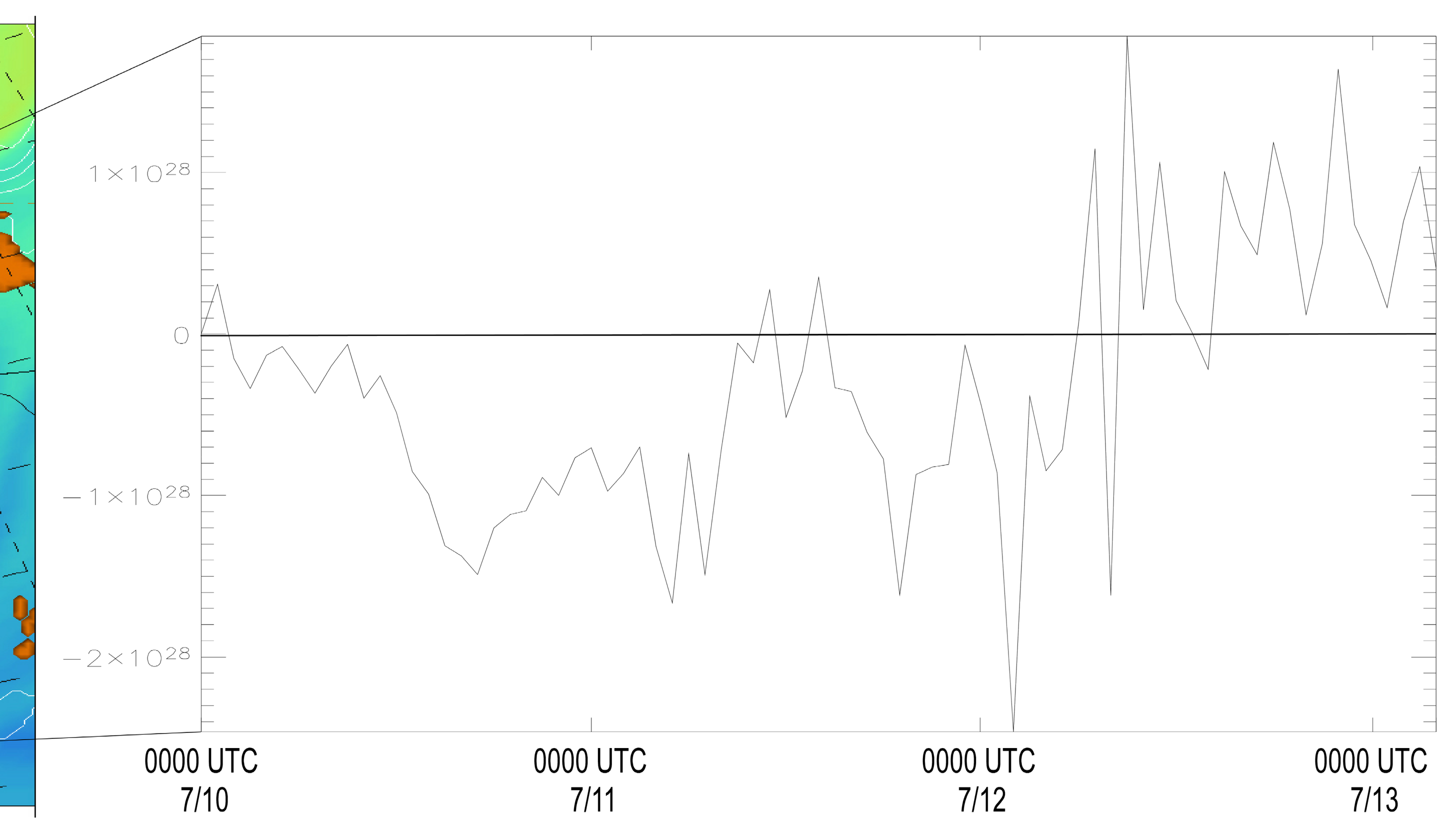


reversal strength (PVU/10°)
(thick gray line indicates global average dPV/dy for July, 2004)

Daily maps of PV and RWB occurrence were calculated at a variety of theta surfaces during July. An example is shown for July 12 at the 330, 350, and 370 K levels. The circle size corresponds to the strength of the PV reversal, while the color of the circle corresponds to the departure of local PV from the climatological value of PV at that point (pink bigger, blue smaller). The cyclonic structures near Kamchatka and the Pacific Northwest extend down to the 330 K surface, with RWB flags indicating an irreversible cascade of mixing to small scales. The primary RWB feature north of Hawaii also suggests that mixing is occurring near the elongated stratospheric filament. The three panels at the right shows the PV gradient and RWB statistics for all of July 2004, where the color indicates the strength of the reversed PV gradient. .







Three-day trajectories (initialized at 11.8 km altitude) in the UWNMS ending at 00Z July 13 show how upper tropospheric air (purple) comes into juxtaposition with stratospheric air (yellow) in the RWB event north of Hawaii. A map of instantaneous ozone flux calculated using the two-scale method in the UWNMS at 30 km resolution (Büker et al., 2005) for 17Z July 11 highlights specific regions of ozone exchange. Ozone (color index) and PV (white contours, 1 PVU interval) at 11.8 km are also shown. The two-scale method is based on the principle that winds at scales larger than the Rossby radius of deformation merely advect the tropopause along, while winds at scales smaller than that cause irreversible mixing across the tropopause. Note the areas of ozone flux (and likely tropospheric air) into the stratosphere. The evolution of the partial domain-integrated ozone flux (in total molecules) across the 1.5 PV surface is shown at the right. Note the contribution from the central Pacific system developing with time, with flux generally negative (into the troposphere) until the end of the RWB event. Stratospheric ozone flux contributes significantly to tropospheric ozone amounts prior to reaching North America.