Stratospheric-Tropospheric Interaction and the 2002 Ozone Hole

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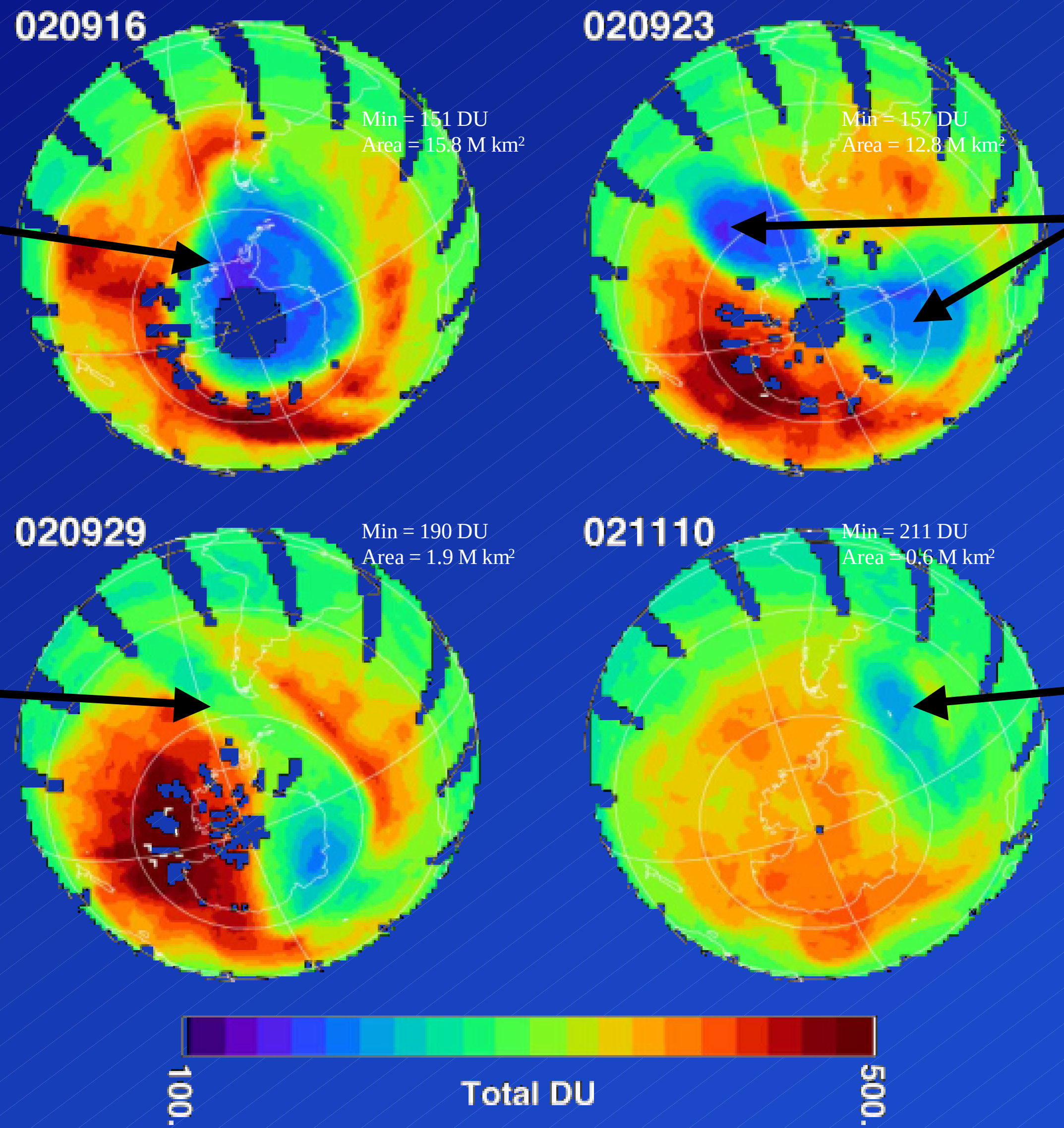
Outline

1. TOMS total ozone observations
2. Basic meteorological fields
3. Tropospheric anomalies
4. Summary

2002 Ozone Hole Evolution

Hole was smaller than normal

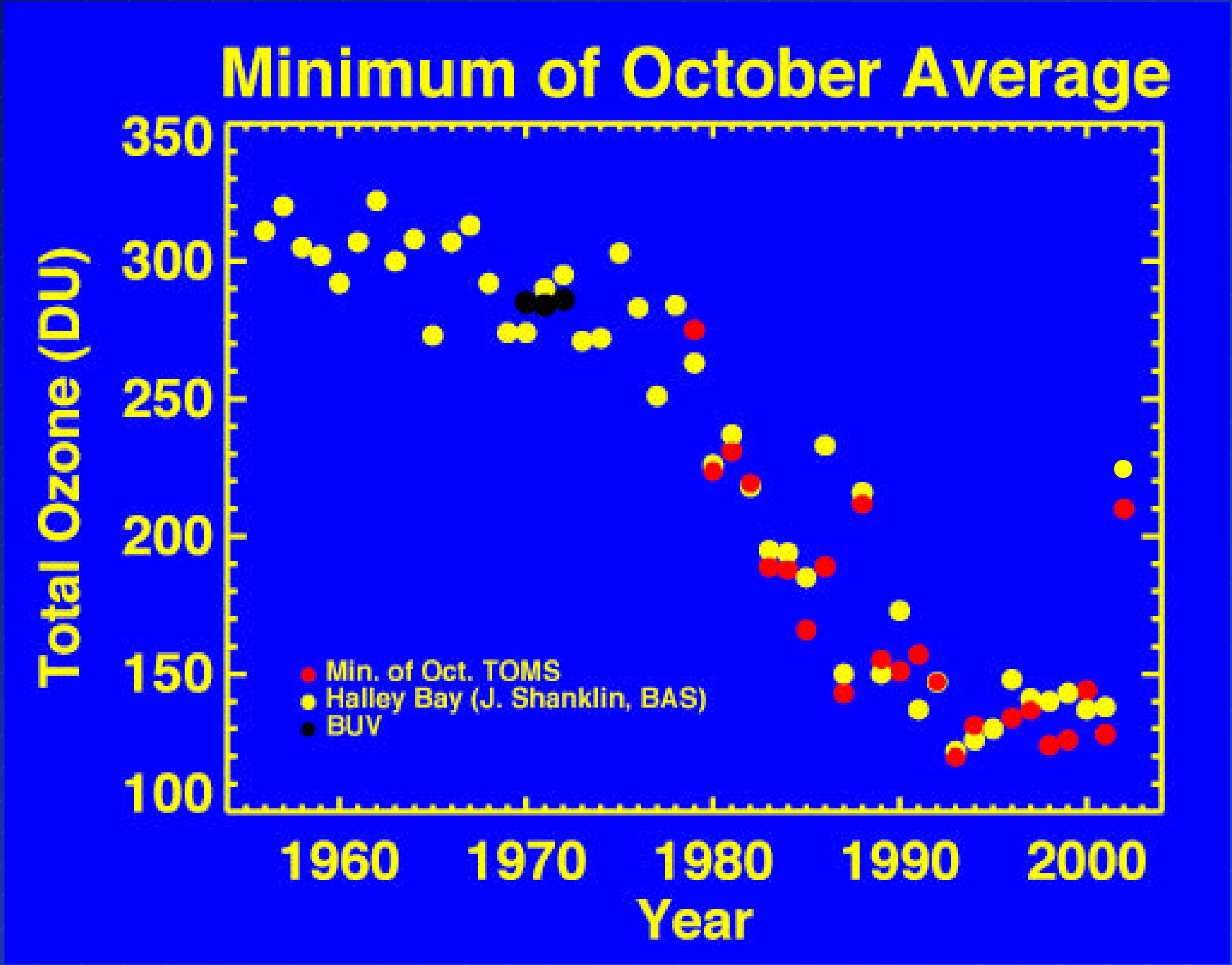
Hole splits



Western Hem lobe decays

Hole dissipates in early November

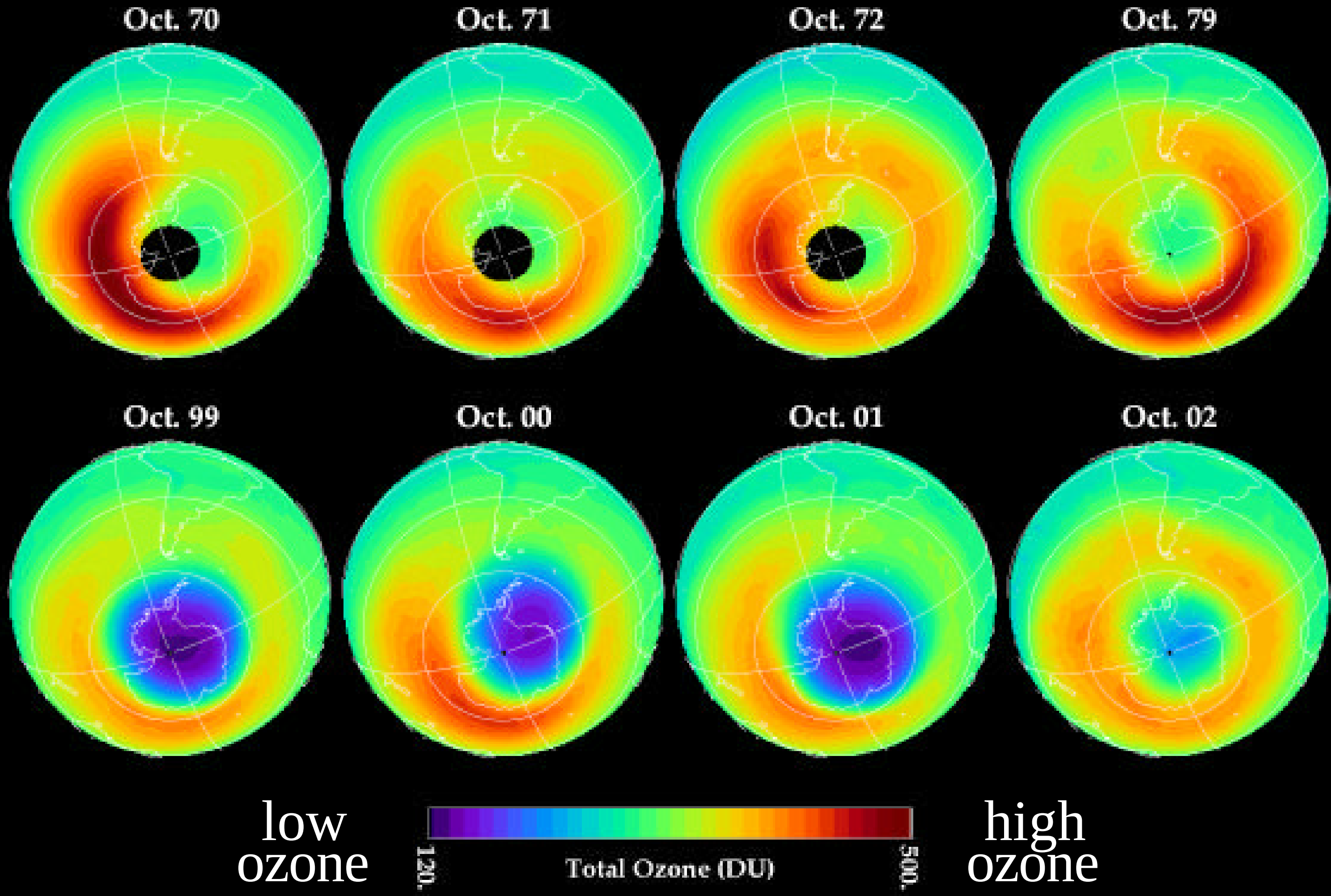
Antarctic Ozone Losses



October Average Ozone Hole

Nimbus-4 BUV | **Nimbus-7 TOMS**

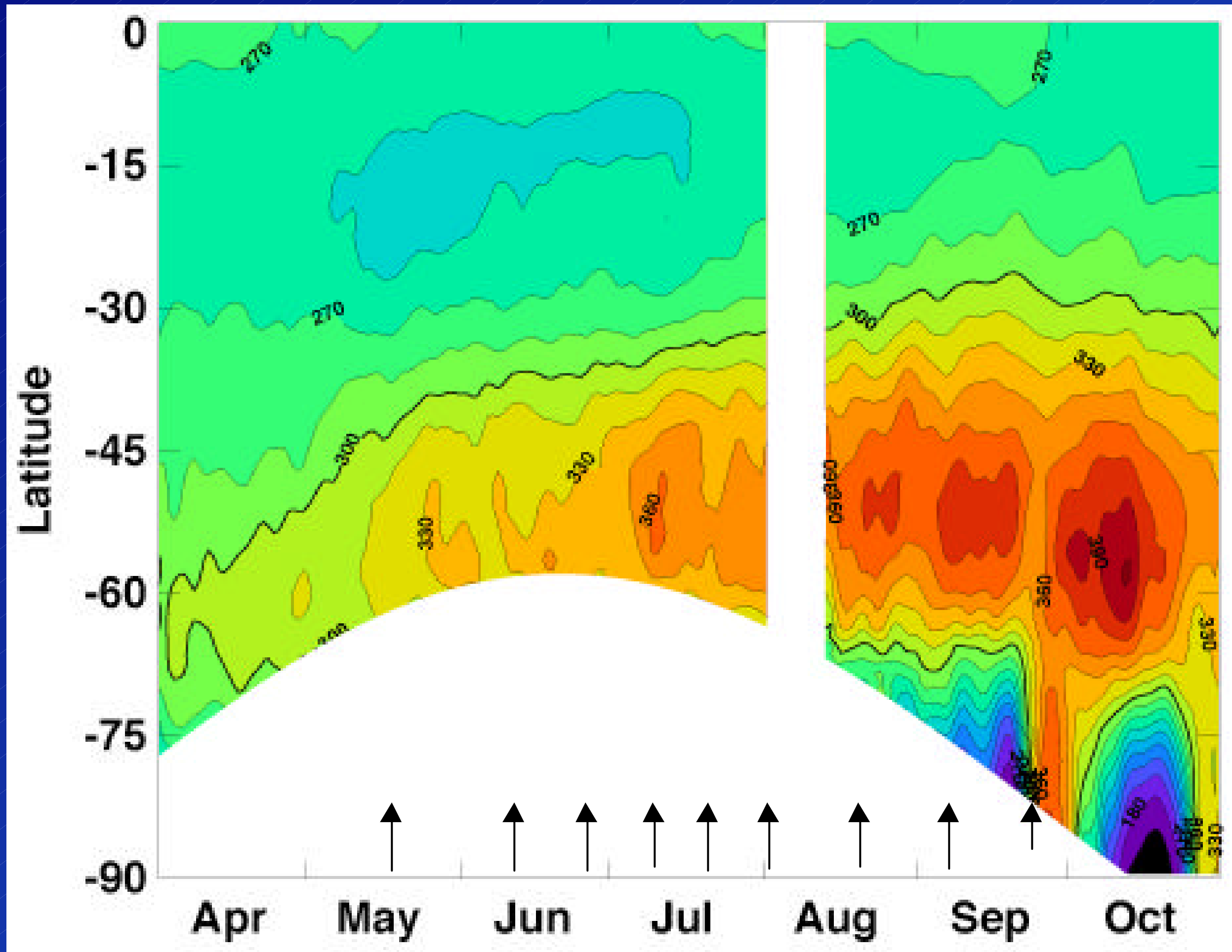
Earth Probe TOMS



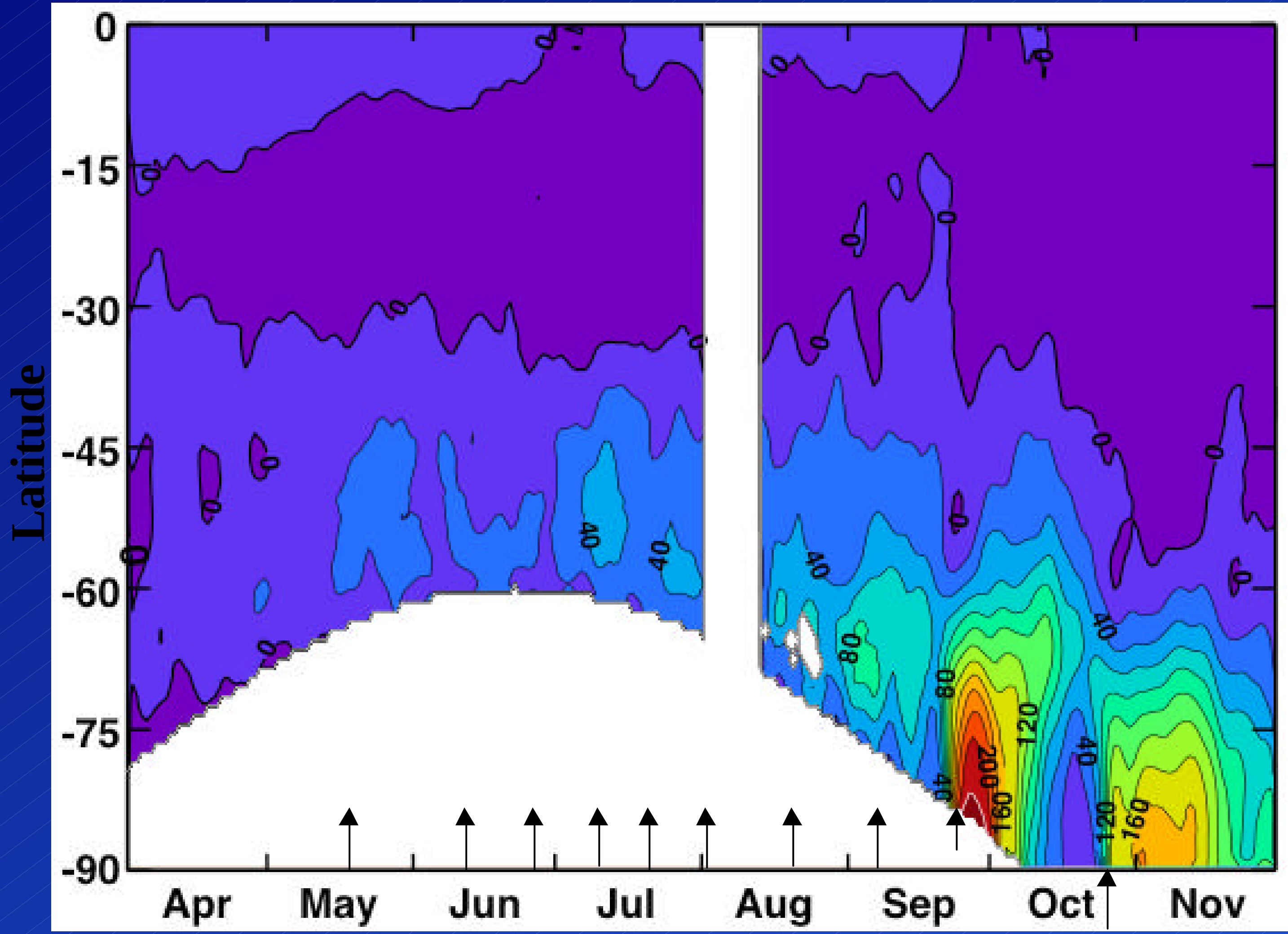
low ozone

high ozone

Zonal Mean vs. Time plot



Zonal mean ozone deviations



2002 Total ozone minus EP-TOMS climatology (1997-2001)

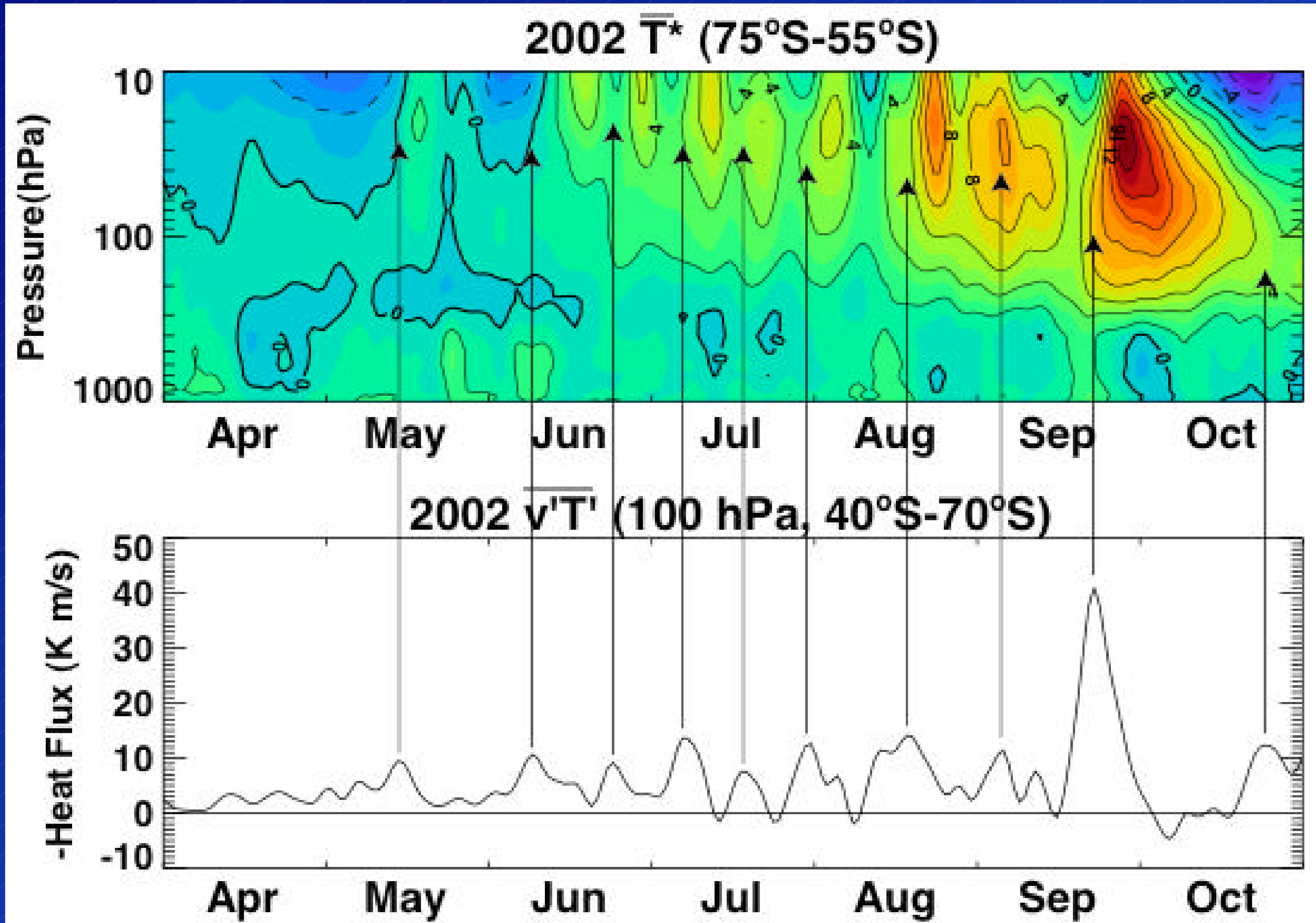
Ozone observations summary

- Ozone hole split into 2 pieces in late September, sized decreased dramatically, and minimum stopped decreasing.
- Ozone hole was the smallest, weakest, and had earliest breakup since 1988.
- Profiles of ozone did not show the expected decrease to near zero over the expected layer from 14-20 km, and ozone above 22 km was much higher than normal
- Mid-to-high latitude total ozone was higher than normal over the course of the winter, and low latitude ozone was somewhat lower than normal

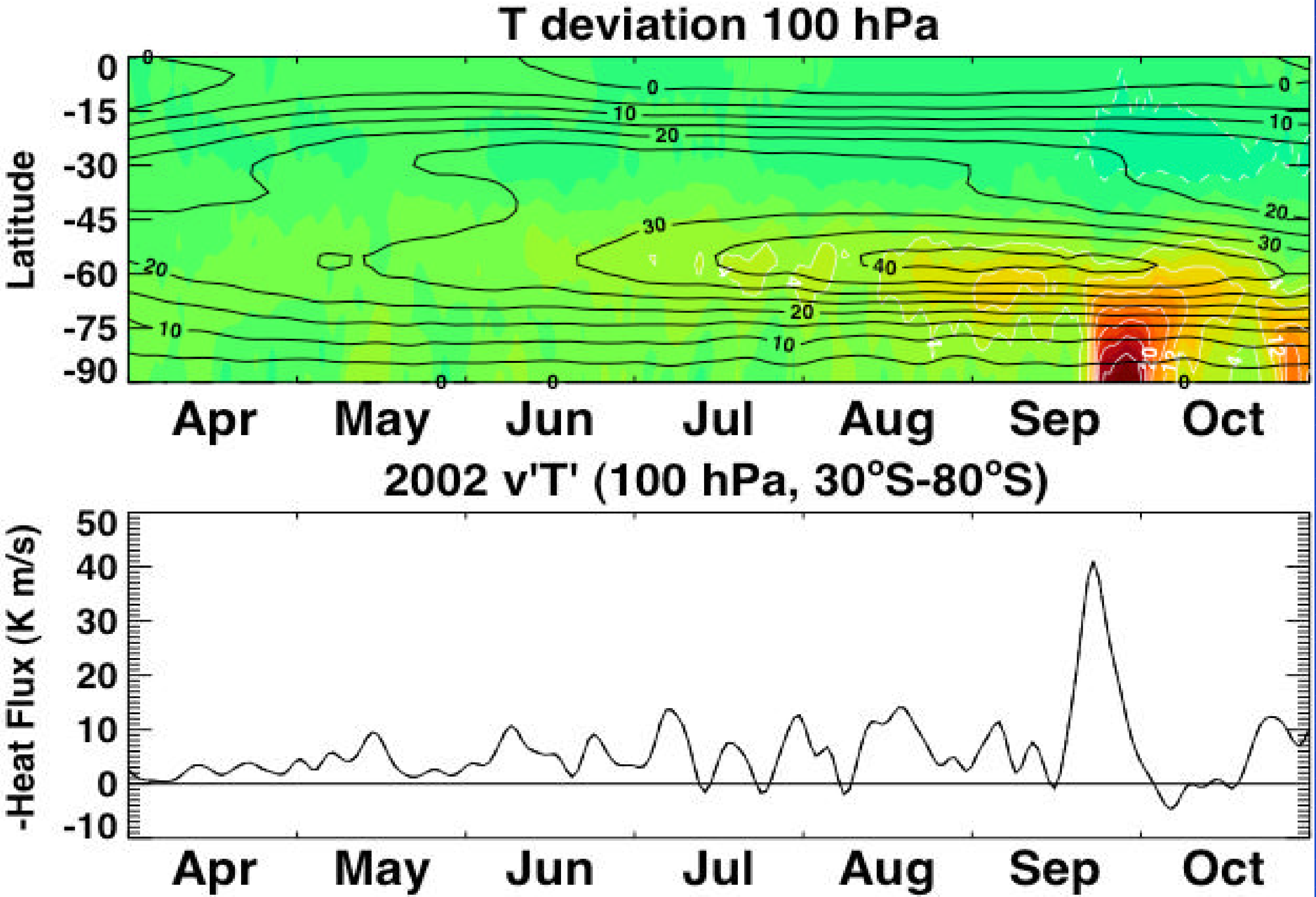
2002 Meteorology

- Temperatures
- Winds and vortex behavior
- Wave activity
- Wave forcings?

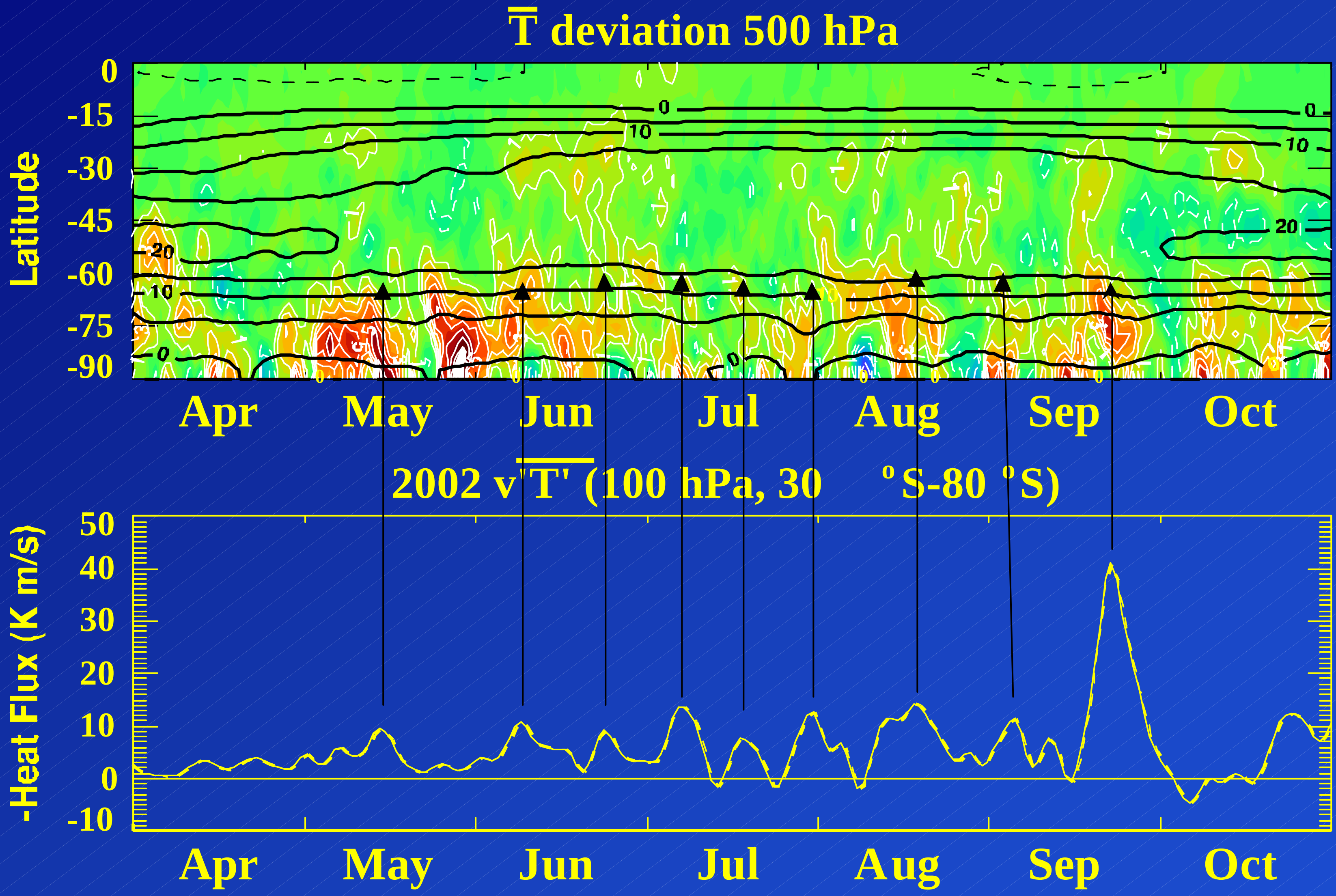
Climatology Temp departures



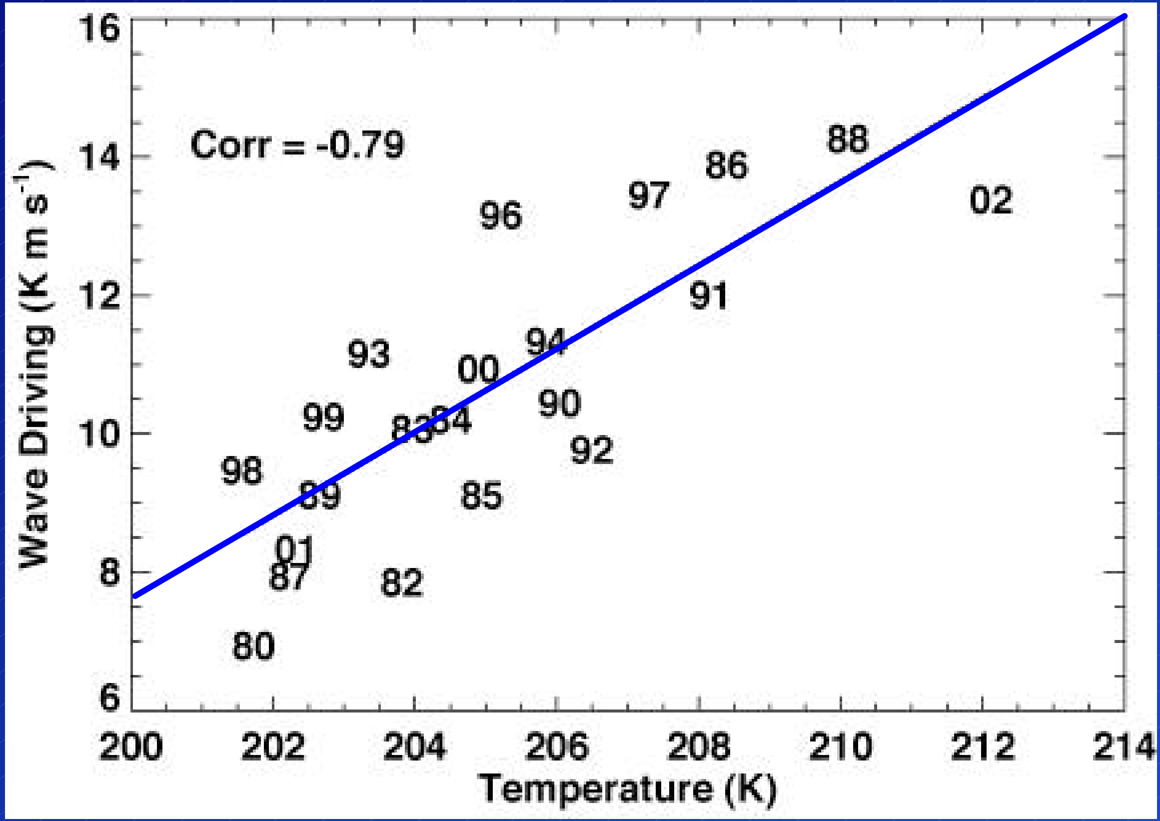
100 hPa Temp. Deviations



500 hPa Temp Deviations



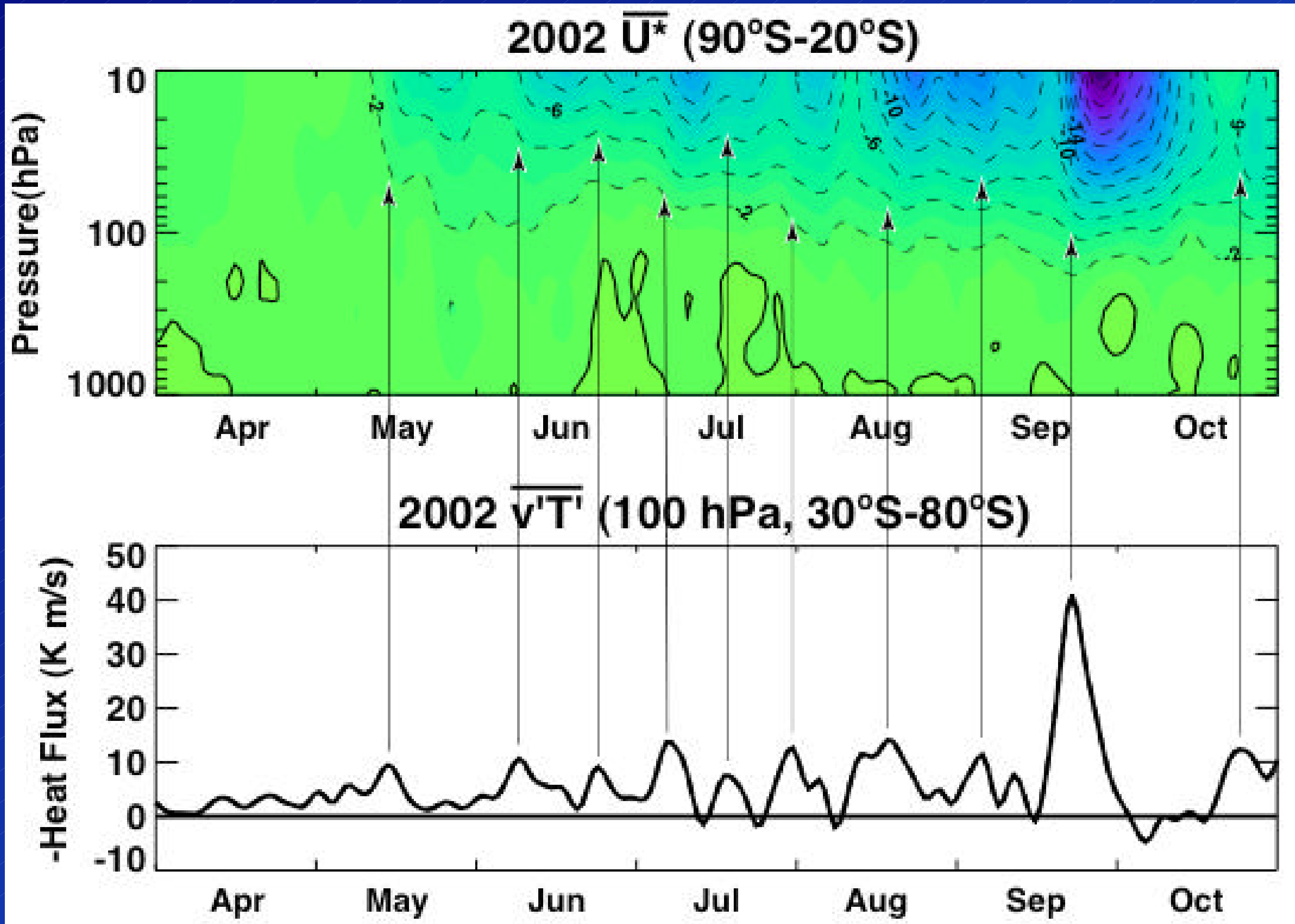
Heat flux vs. Temperature



- The higher heat flux of 2002 led to warmer temperatures, while the low heat flux of 1998, 1999, 2000, and 2001 led to colder temperatures. A 10% increase of $-\overline{v'T'}$ increases $\overline{T}$ by 1.8 K, and consequently decreases the area by about 2 Million km^2.

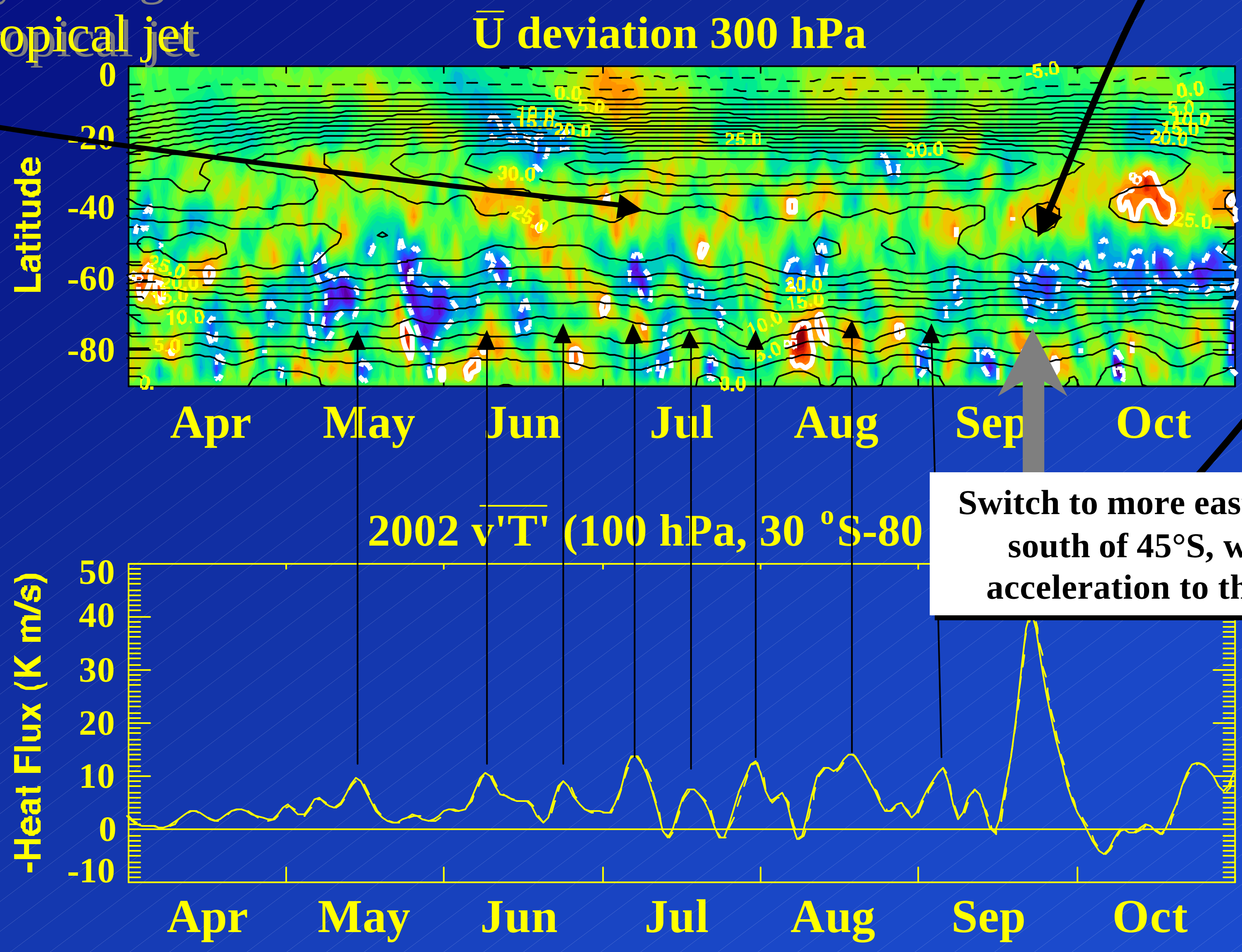
Temperature:	55-75°S	50 hPa	09/11-09/20
Wave Driving: $-\overline{v'T'}$,	45-65°S	100 hPa	07/01-09/10

Climatology Wind Departures



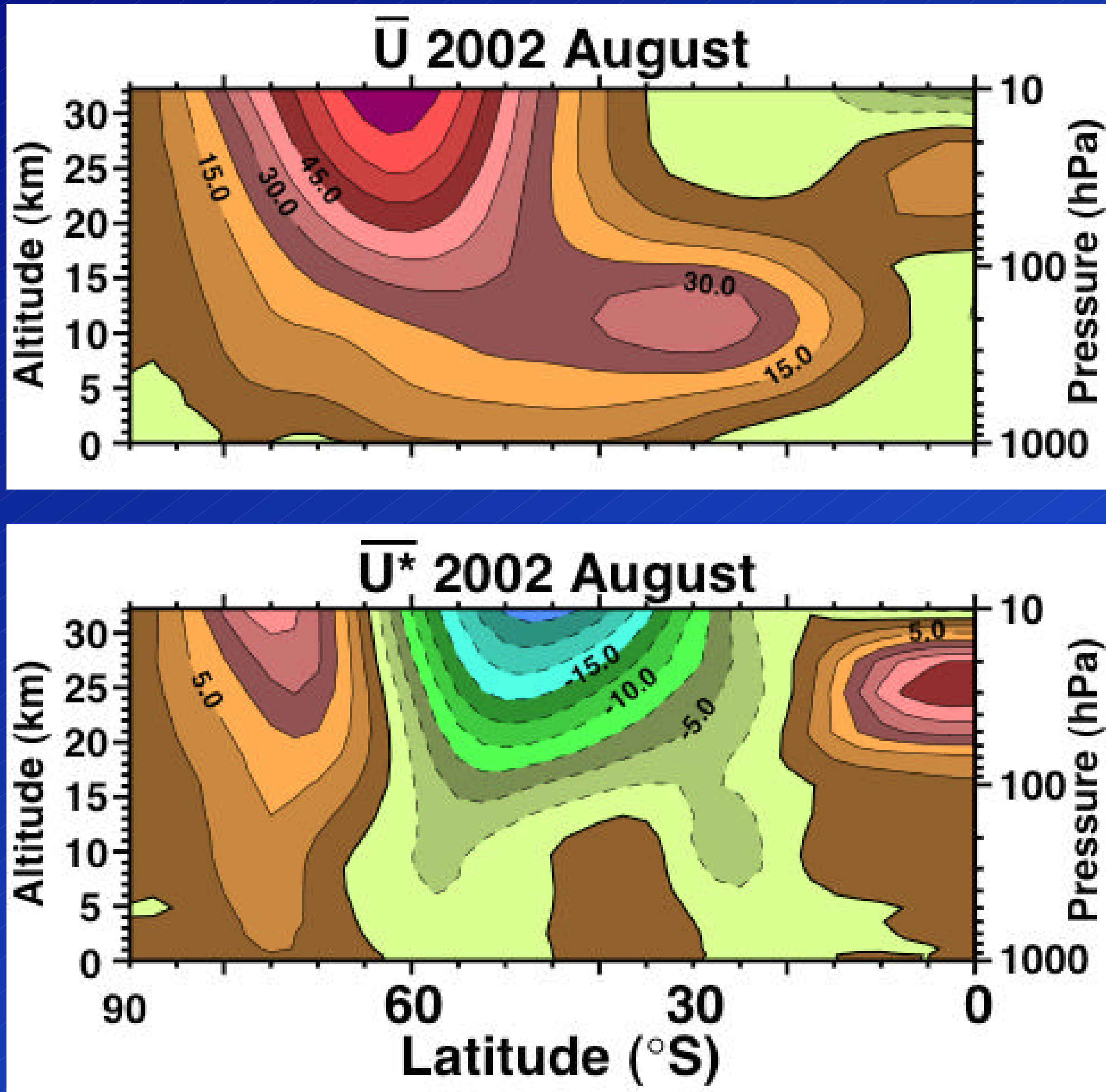
Wind Deviations

Slightly stronger sub-tropical jet

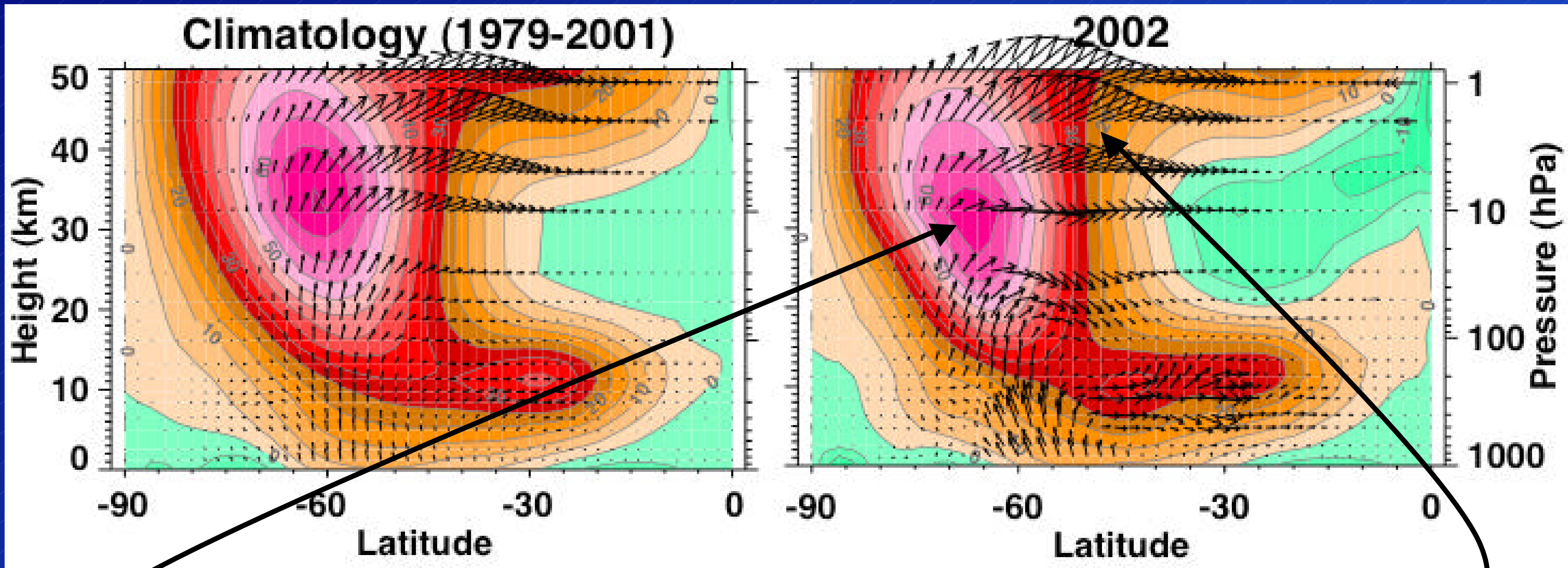


Switch to more easterly flow south of 45°S, with an acceleration to the north

August zonal mean wind

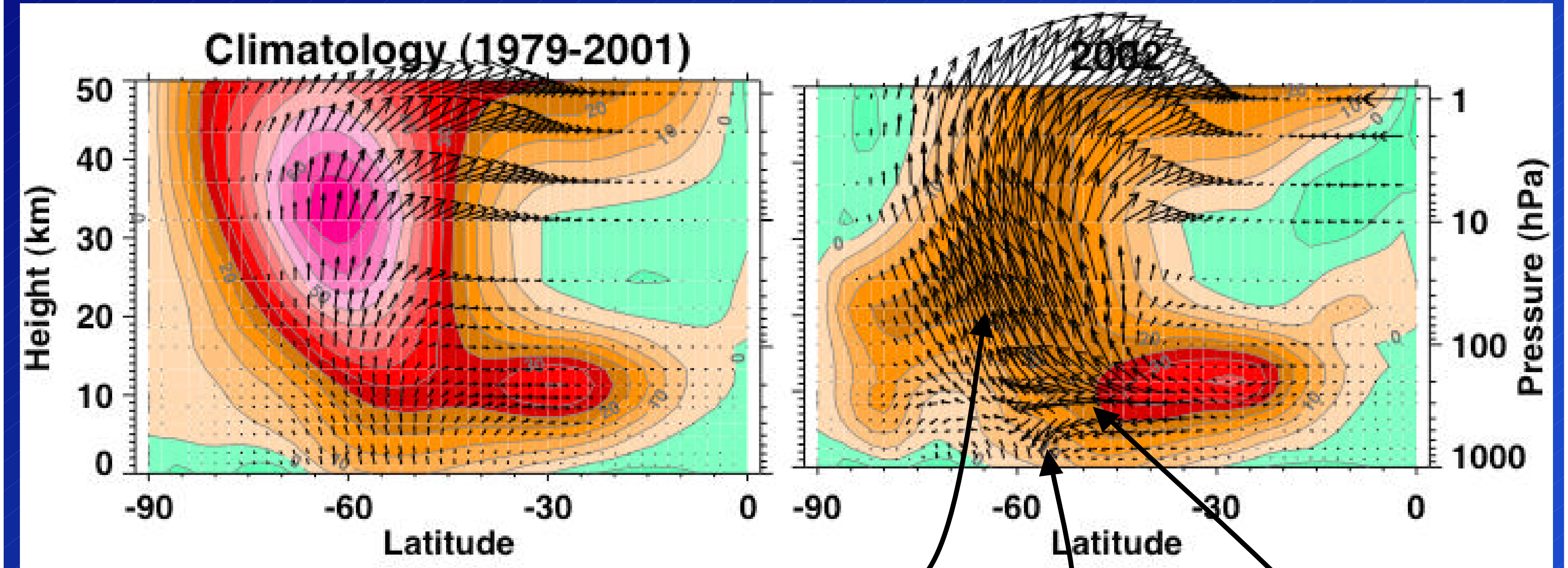


Sep. 17, 2002



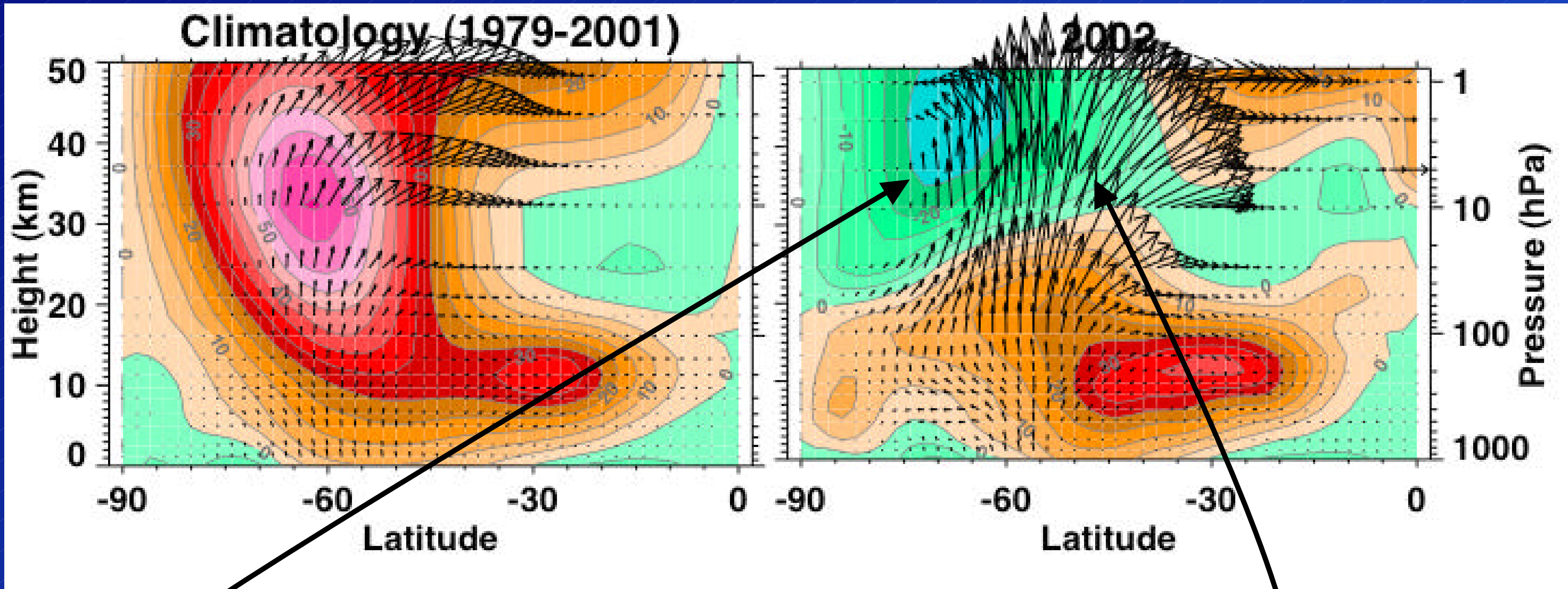
- Slightly higher E-P flux in upper stratosphere
- Jet somewhat weaker than normal

Sep. 22, 2002



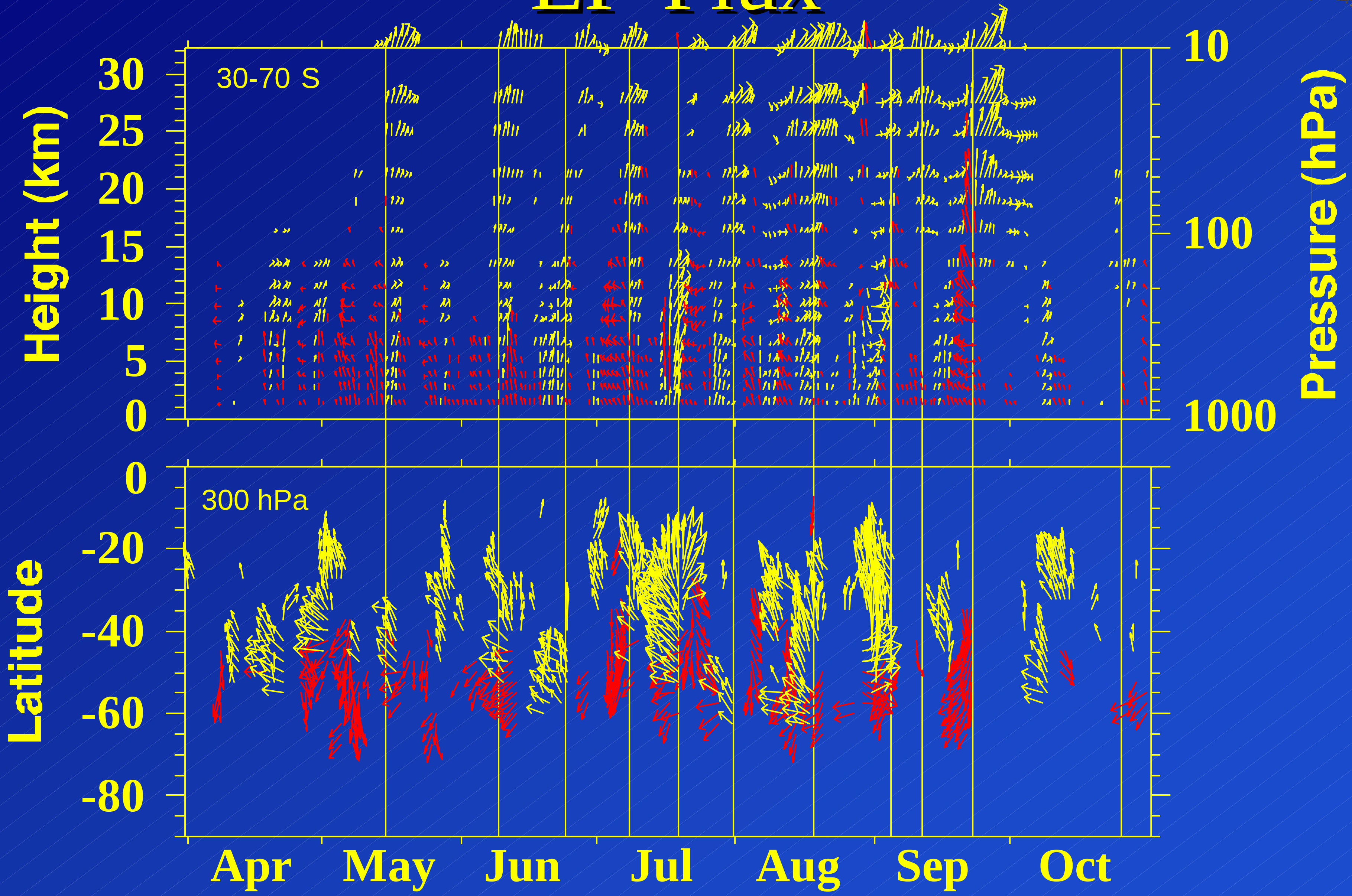
Strong upward E-P flux
Downward focusing of flux
Strong poleward E-P flux from subtropical jet

Sep. 26, 2002



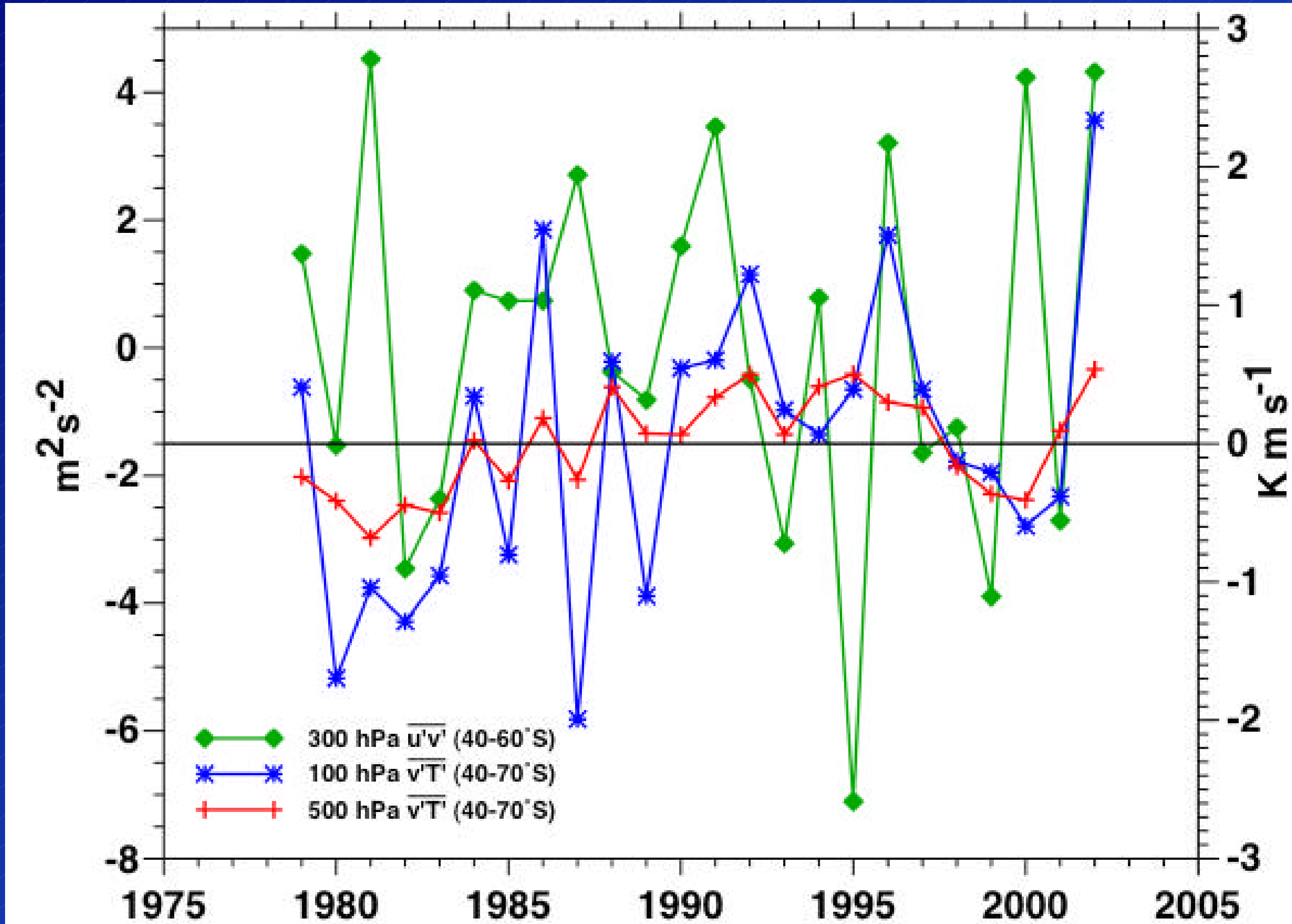
Strong jet deceleration
Strong upward and equatorward flux

EP-Flux

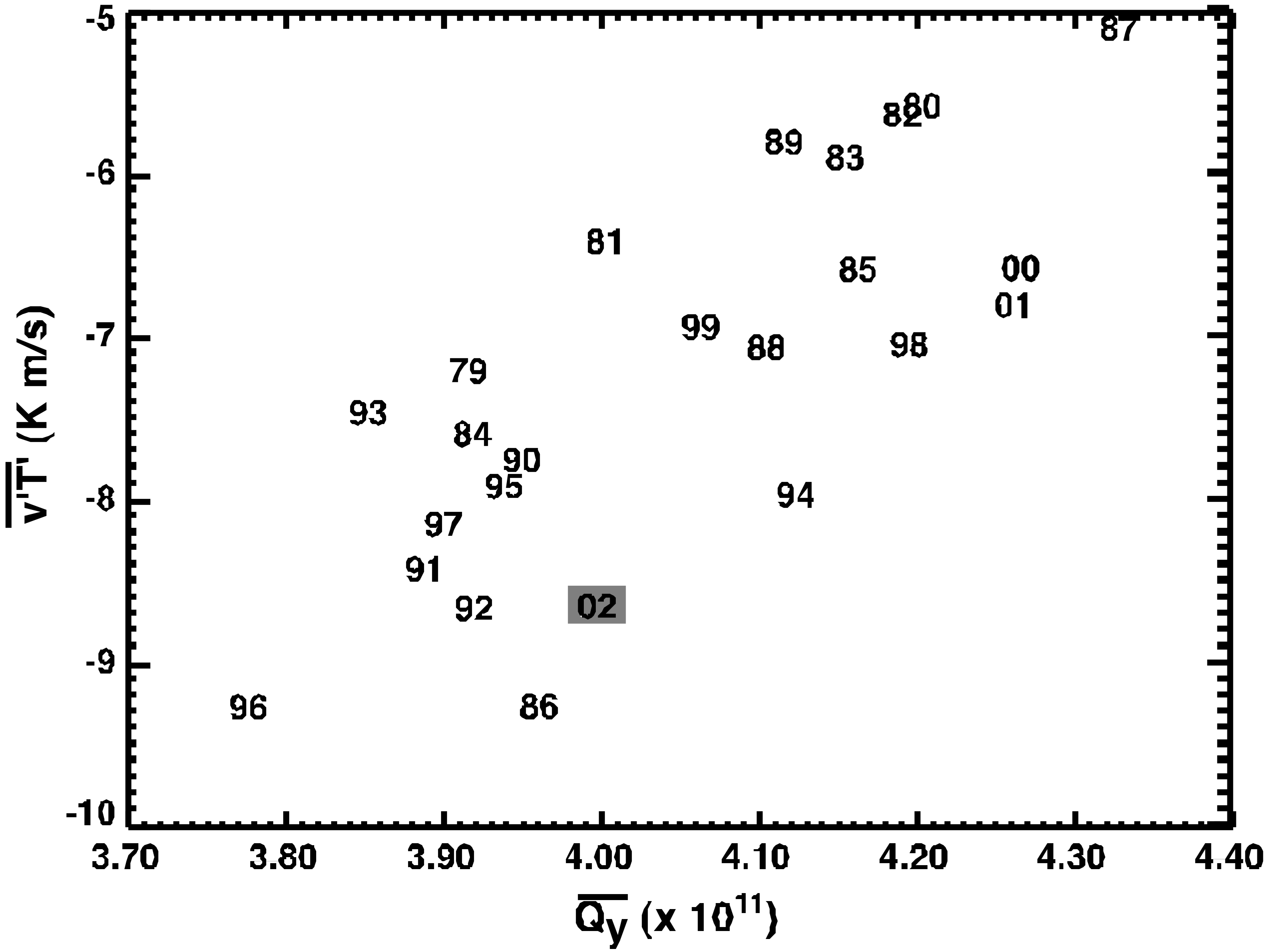


30-70 S
300 hPa
Height (km)
30
25
20
15
10
5
0
Latitude
0
-20
-40
-60
-80
Pressure (hPa)
10
100
1000
Apr
May
Jun
Jul
Aug
Sep
Oct

Tropospheric forcing



Index of refraction



$\overline{Q_y}$ = 40°-60°S, 200-400 hPa, May 1- Sept. 15
$\overline{v'T'}$ = waves 1-3, 45°-75°S, 100 hPa, May 1-Sept. 15

Wave Propagation Analysis

Use coherency to analyze vertical wave propagation:

$\Psi(\lambda,\phi,z,t) = ?_{m} [S_m(\phi,z,t) \sin(m \lambda) + C_m(\phi,z,t) \cos(m\lambda)]$

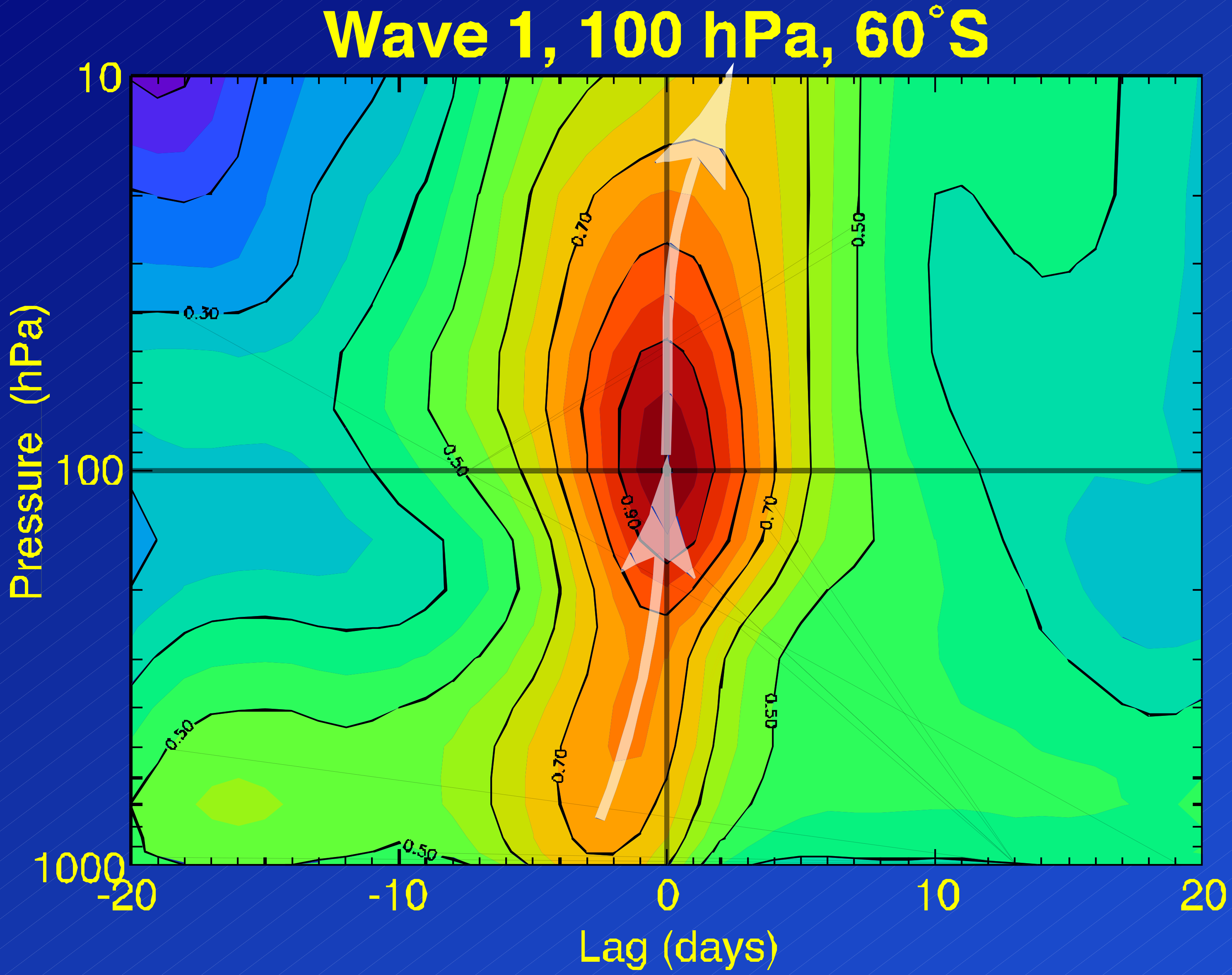
Choose $S_1(\phi_0,z_0,t)$ and $C_1(\phi_0,z_0,t)$ - Wave-1 at position ϕ_0,z_0

$Coh(\phi,z)$ = linear correlation of variance of Wave-1 at position (ϕ_0,z_0) with Wave-1 at all other points (ϕ,z)

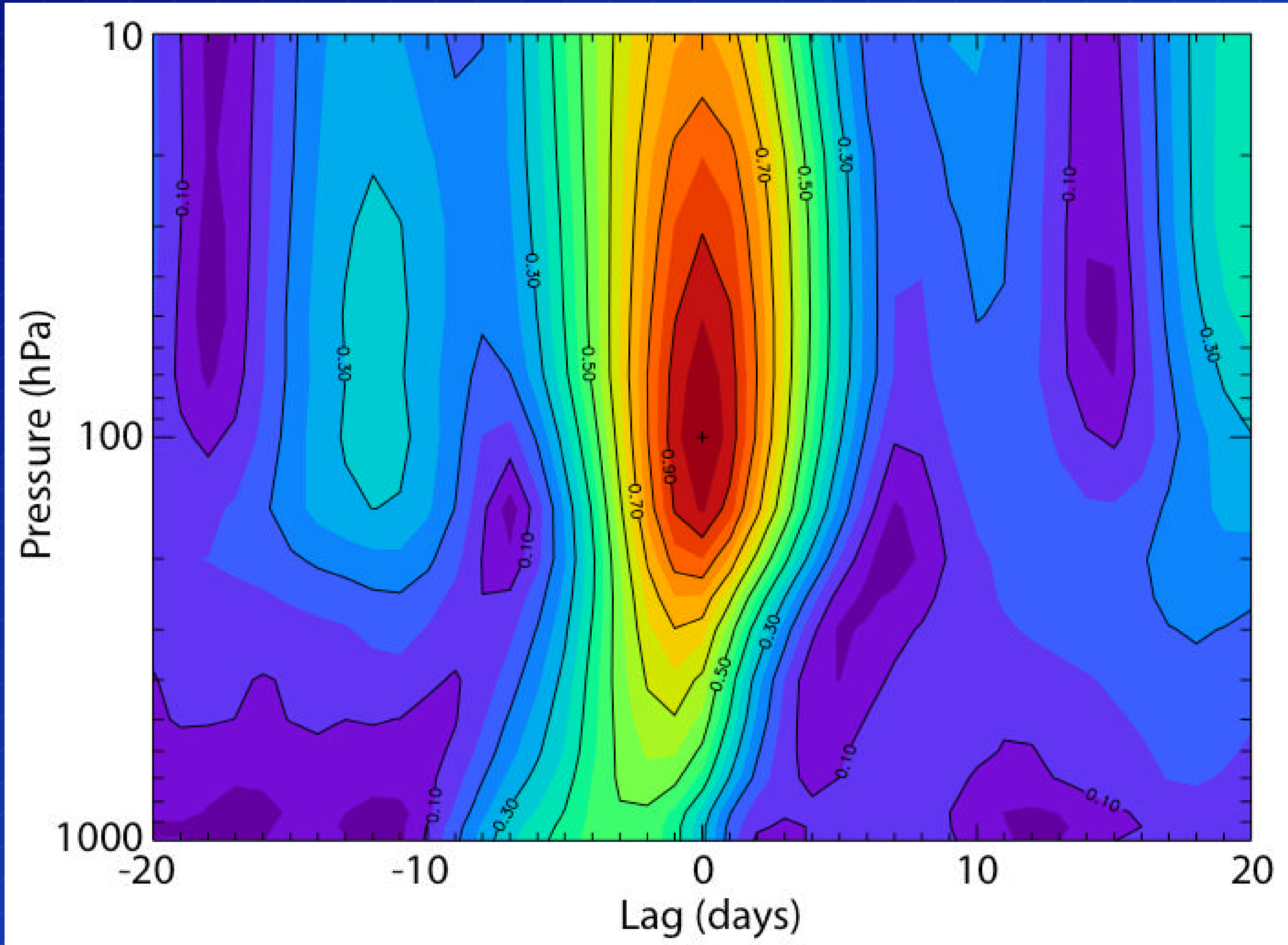
See Randel (1987) for an analysis of 1983 and 1984

Use May 1- Sep. 15, 2002 non-divergent stream function derived from wind observations

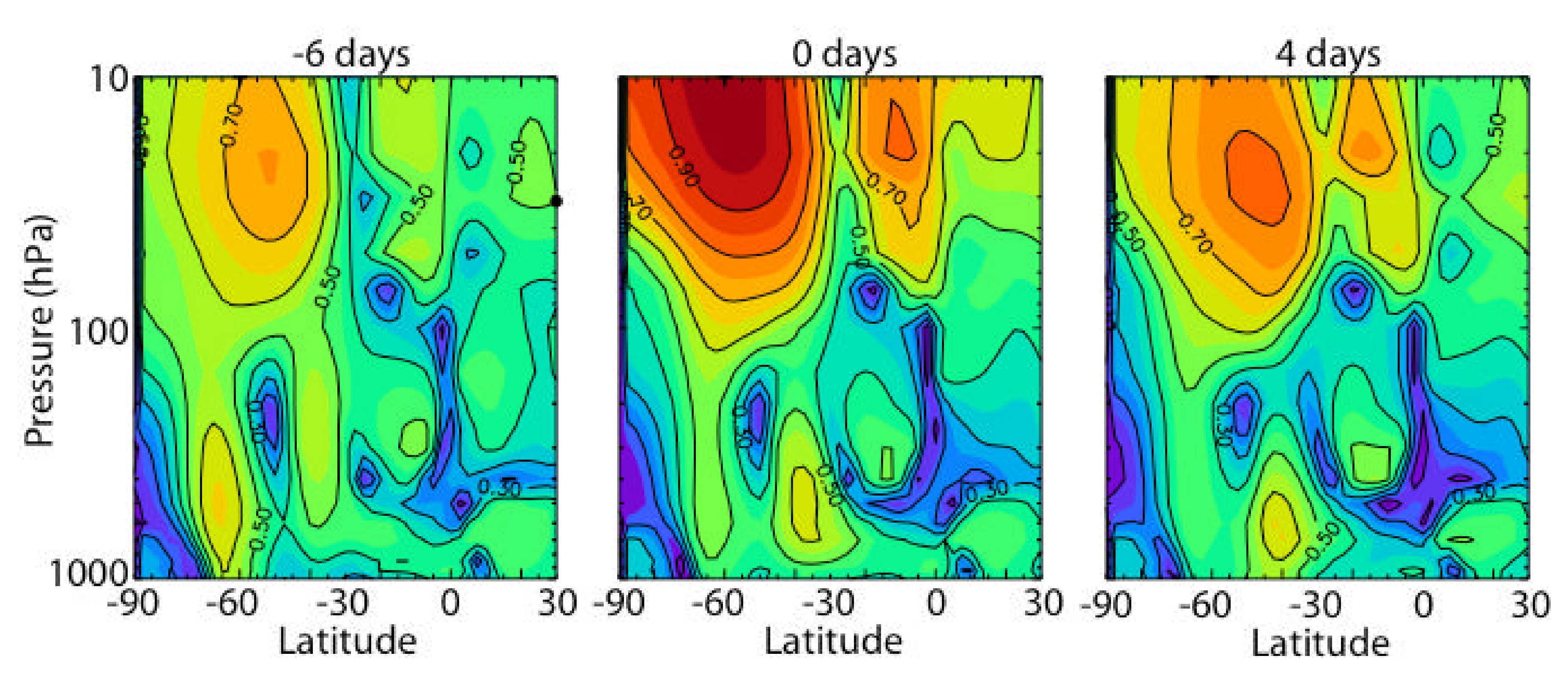
Vertical wave-1 coherence



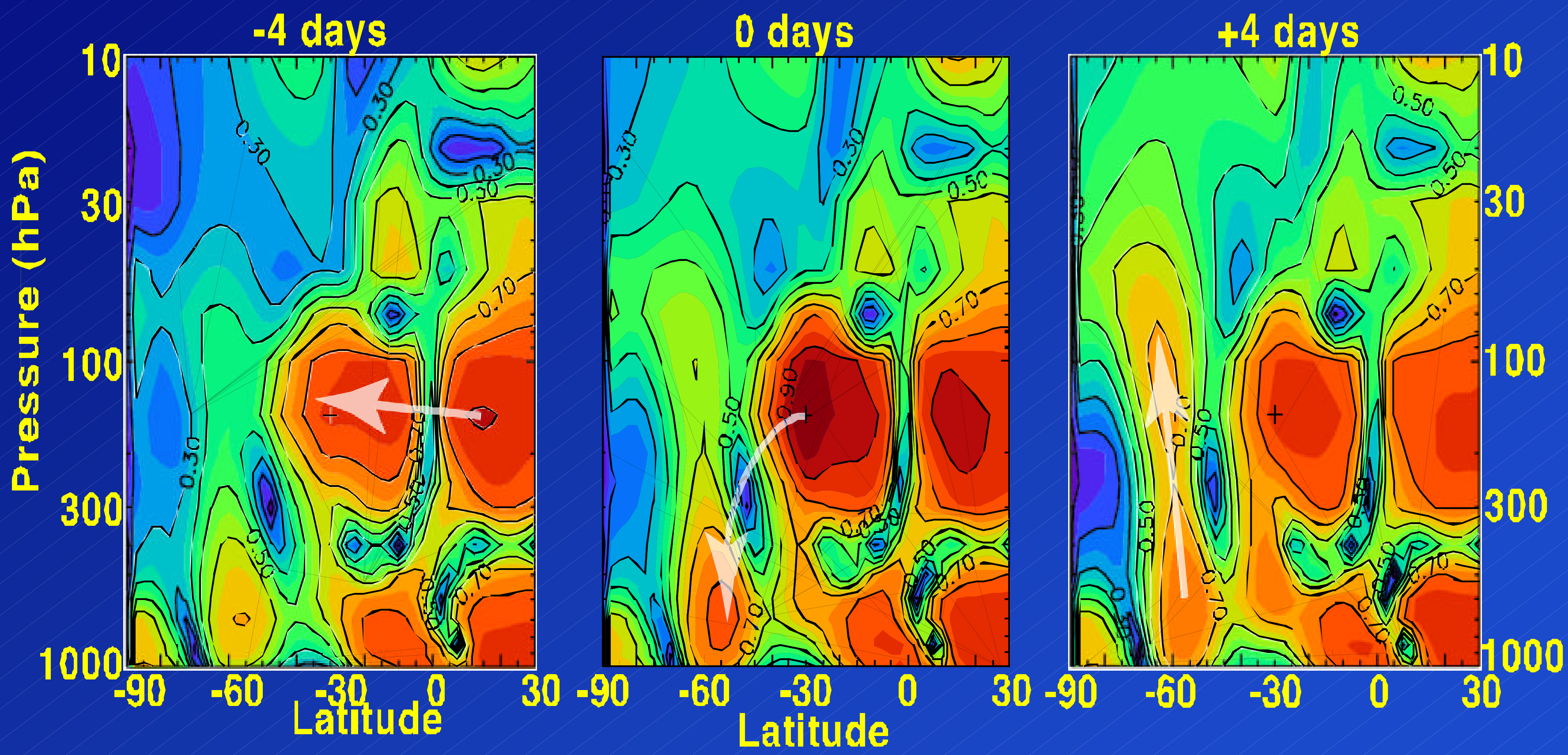
Vertical wave-2 coherence
50°S, 100 hPa



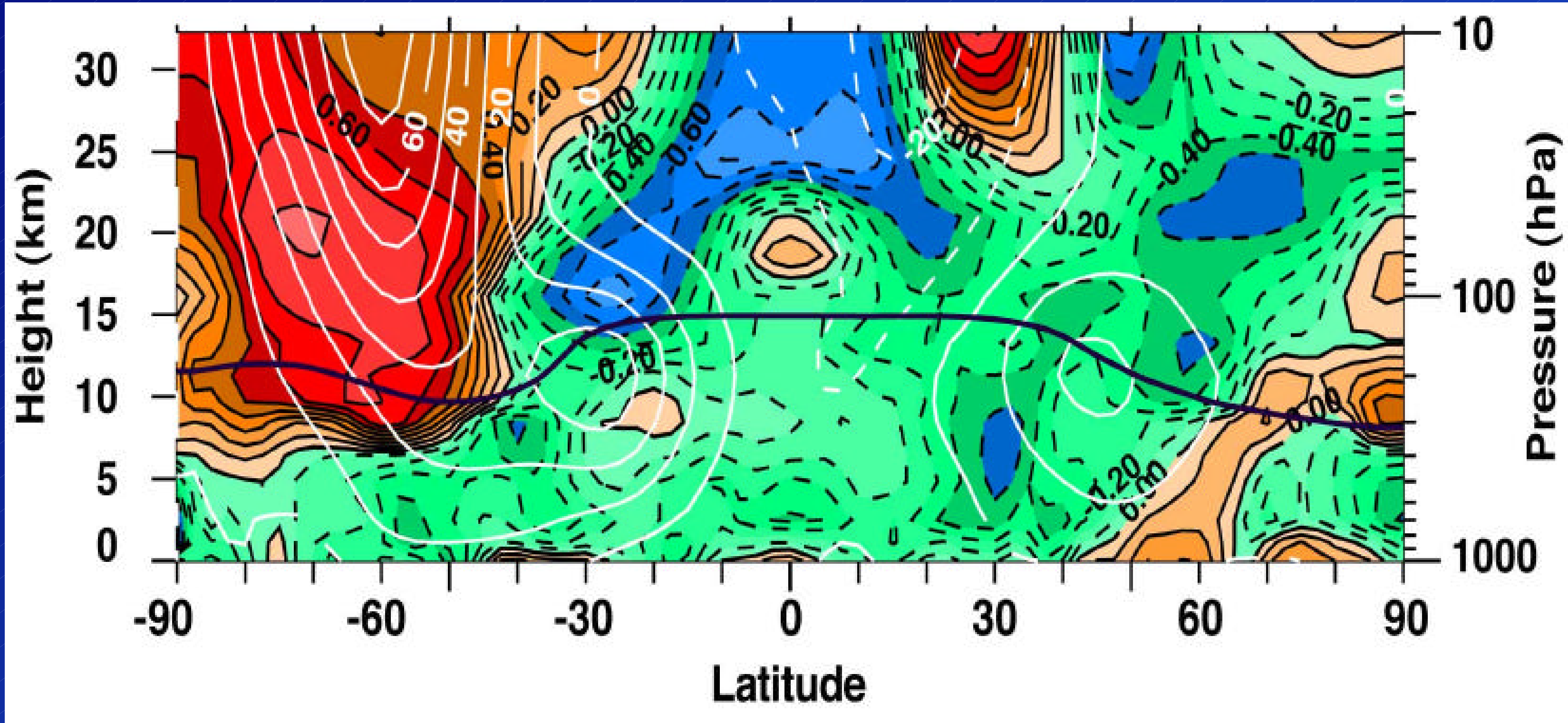
Wave-1 coherence
10 hPa, 60°S



Horizontal & Vertical propagation



Tropical Upper Stratospheric wind is strongly correlated with polar temperatures



- Gray et al. (2001) suggest equatorial winds at mid-upper stratosphere may act as a waveguide. Supported by Gray et al. (2001b) and Scott and Haynes (1998) modeling work.
- $\overline{U}$ (5 hPa, 20S-20N, July 16-September 15 average) correlated with $\overline{T}$ (1979-2002)

Summary & Conclusions

- The 2002 ozone hole was small because of wave events that warmed the vortex collar region. The September 22 major warming split the hole, cuting the size 5 Mkm^2 (normally about 25 Mkm^2). The small size of the ozone hole was ***not a result of the Montreal Protocol.***
- Higher wave activity propagating into the stratosphere and a disturbed mean flow field was evident as early as mid-May 2002. The vortex was already substantially perturbed by early September - preconditioned.
- Tropospheric mean flow showed clear anomalies throughout the winter that strengthened after the major warming. Little evidence for downward wave propagation
- The active winter was most probably due to 2 factors:
  - Increased tropospheric eddy activity - most probably from anomalous tropical wave-1 forcing
  - An unusual upper stratospheric tropical wind pattern