Tropical Convective Forcing of the Southern Hemisphere Circulation: Modulation of Polar Regions via Planetary Wave Trains in the UTLS

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1. Planetary wave radiation from Indonesian convection
   * Transition from winter to spring (Hitchman and Rogal, 2010a)
   * August vs. October height anomalies

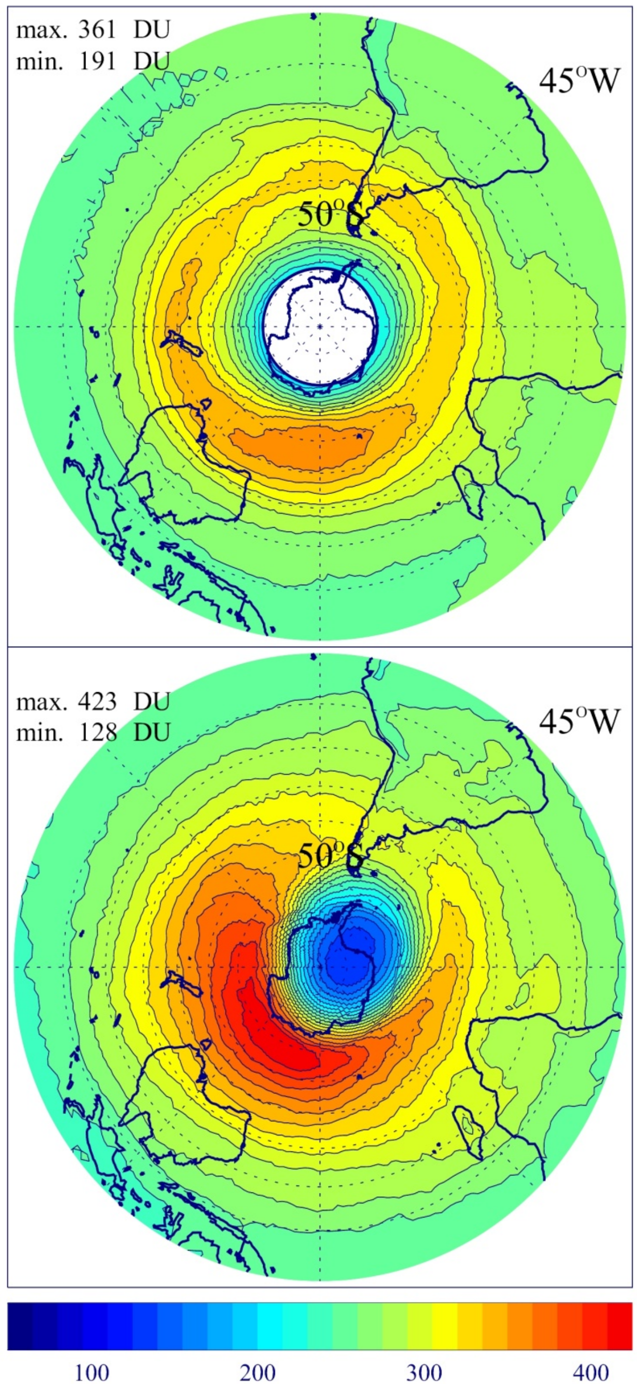
2. Influence of ENSO on SH circulation
   (Rogal and Hitchman 2010b; Rogal et al., 2010)
   * 3d wave activity flux diagnostics (Kinoshita and Sato 2013a,b)
   La Nina: column ozone maximum shifted westward ~50°
   stronger poleward wave activity flux from Indonesia
   stronger polar vortex
   stronger planetary wave one
   enhanced Ross Sea low

3. Cold East Antarctica during La Nina (Welhouse, 2011)
   UWNMS simulations Dec. 1-9, 1988

1. Planetary wave radiation from Indonesian convection
   * Transition from winter to spring (Hitchman and Rogal, 2010a)
   * August vs. October height anomalies

August 2000

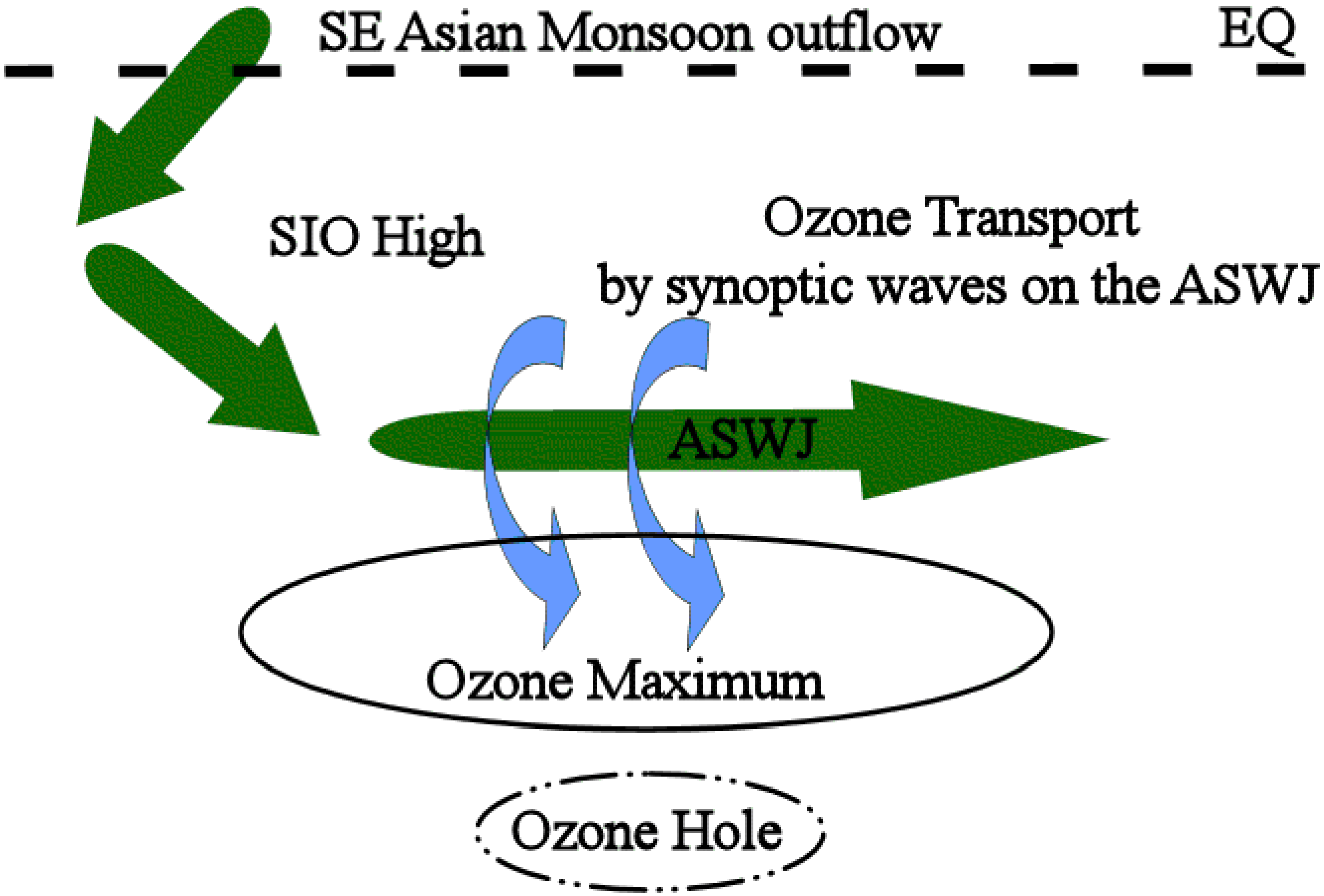
October 2000



What causes the zonal asymmetry in monthly mean column ozone?

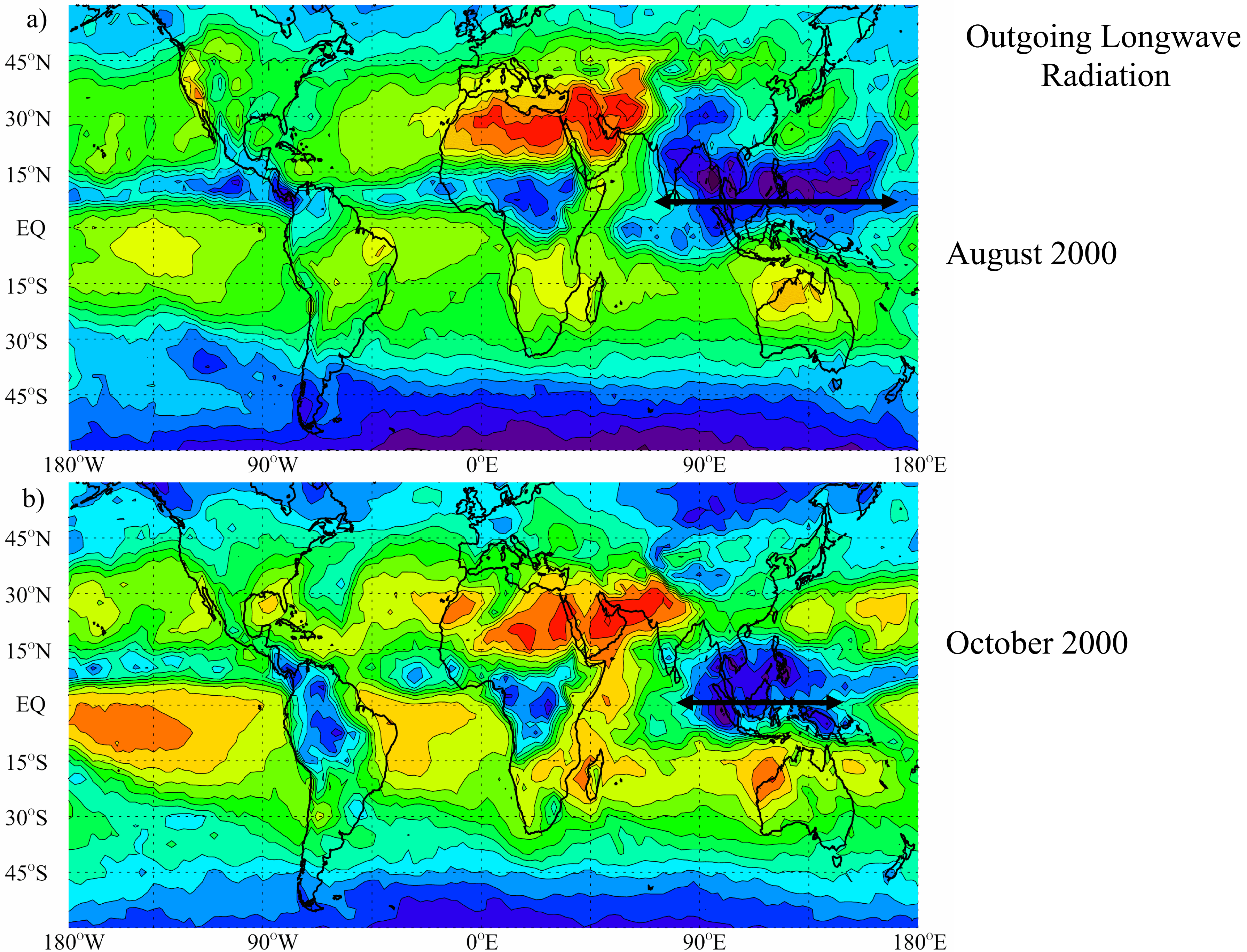
Why is the maximum south of Australia?

What causes the seasonal sharpening of the ozone maximum and its eastward shift during the winter to spring transition?

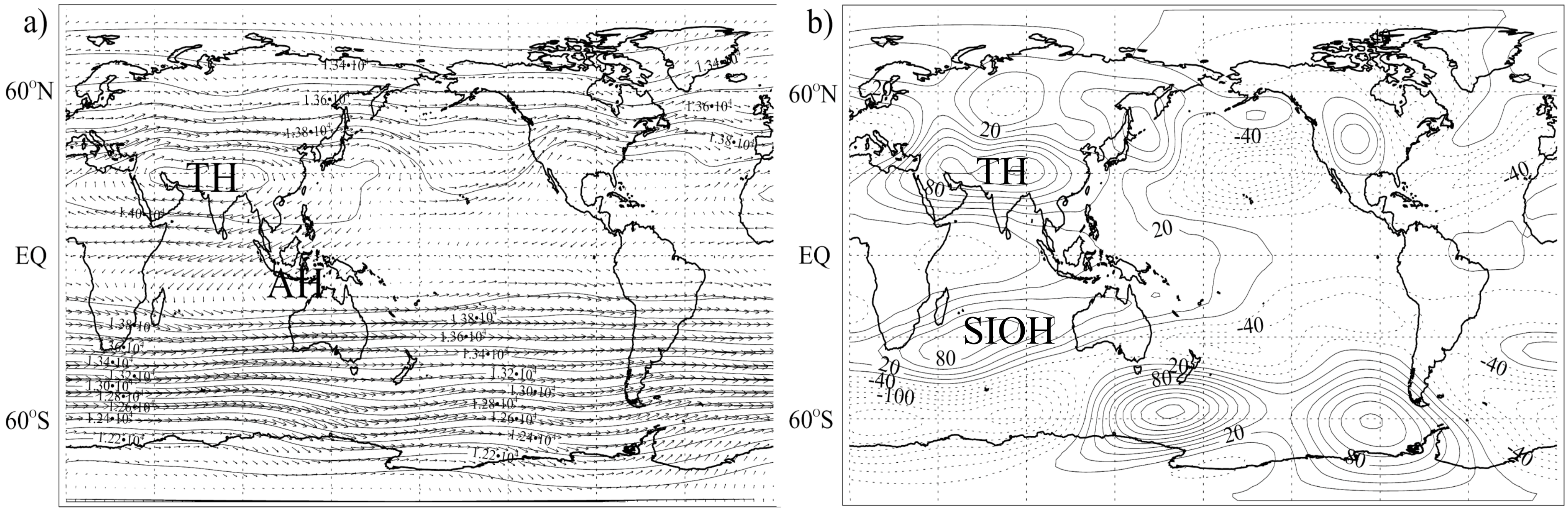


Column ozone maximizes poleward of the Australian Subtropical Westerly Jet in the subsidence warm anomaly (cf. idealized linear model by Wirth, 1993).

The *geographical location* of the ozone croissant and associated wave one structure is partly controlled by convection in Southeast Asia.


Outgoing Longwave Radiation
a)
August 2000
b)
October 2000
45°N
30°N
15°N
EQ
15°S
30°S
45°S
180°W
90°W
0°E
90°E
180°E

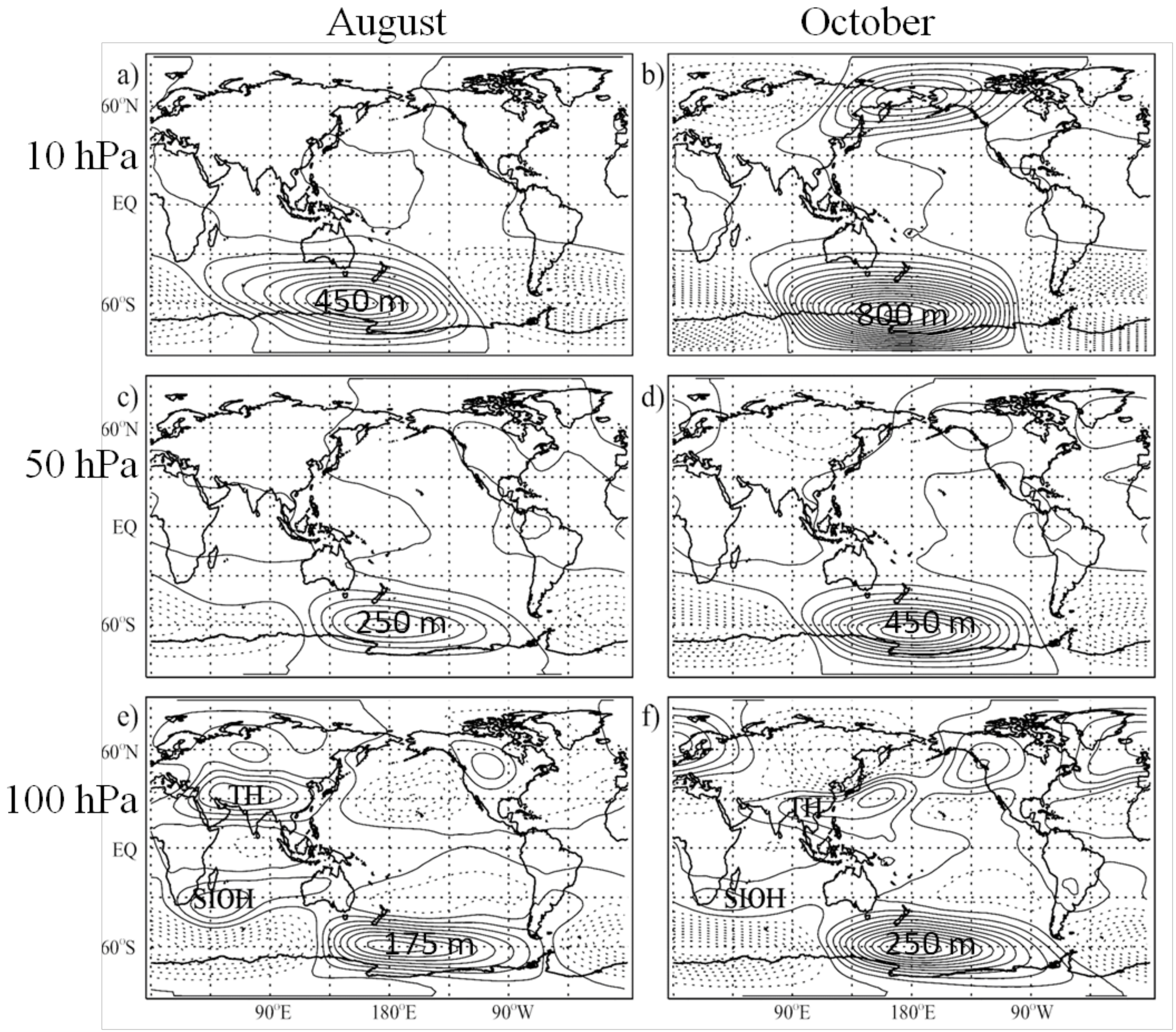
ASO 2000 ECMWF



Z 150 hPa heights and winds
interval 100 m

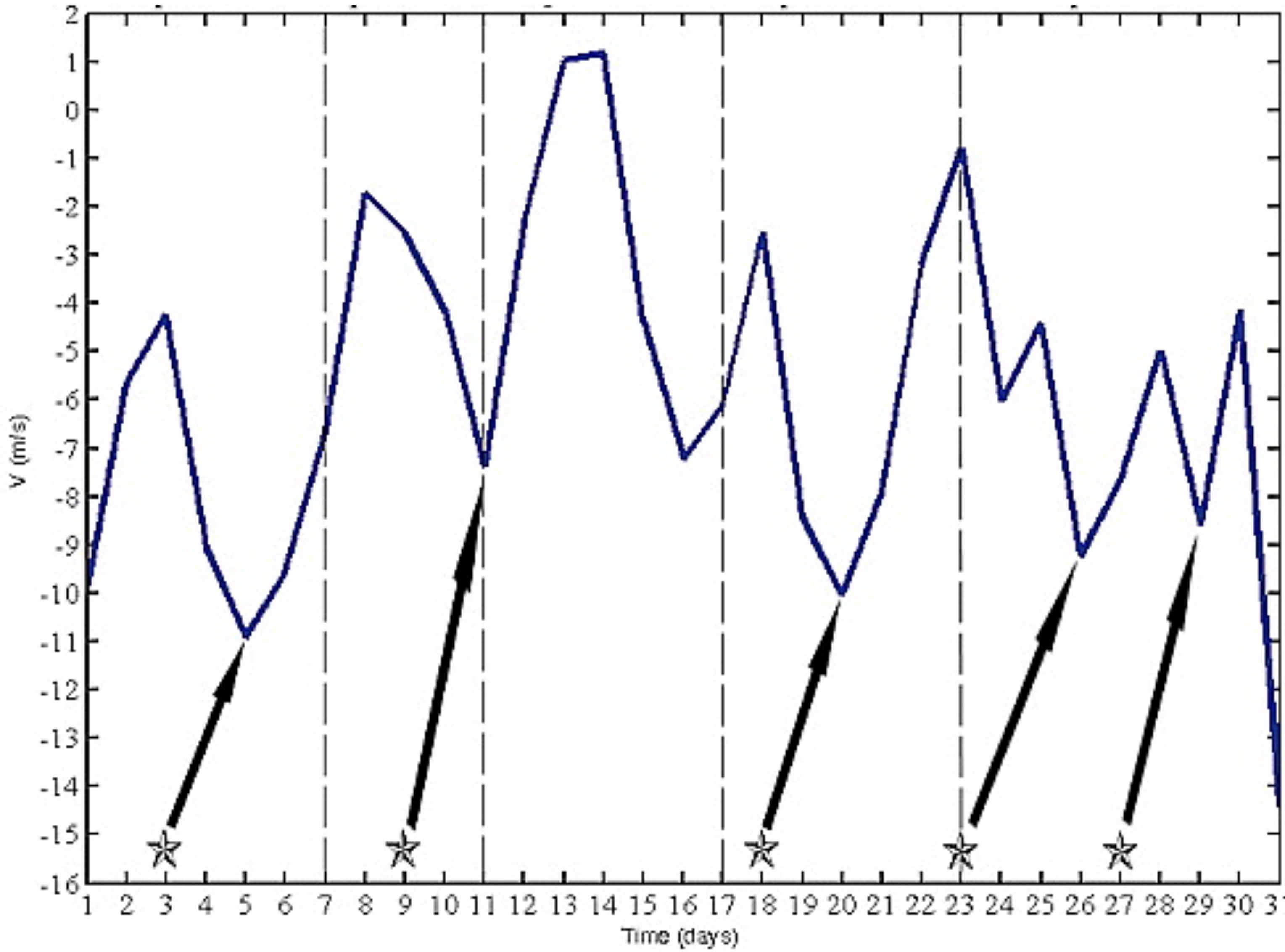
Z' 150 hPa eddy geopotential height
interval 20 m

A planetary wave train emanates from Indonesia into the westerlies of the SH lower stratosphere.



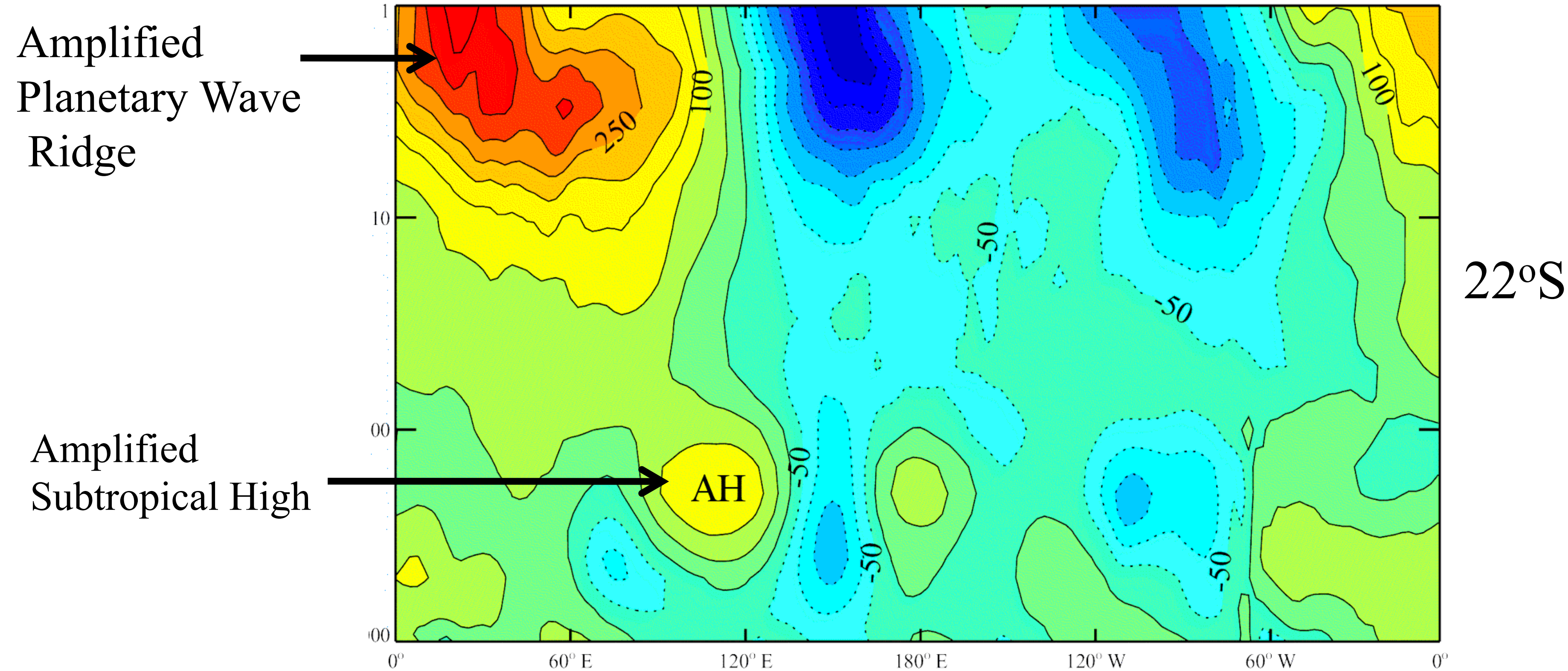
ECMWF monthly mean height anomalies during 1995-2004.

Convective maxima lead to outflow surges into the Southern Indian Ocean UTLS



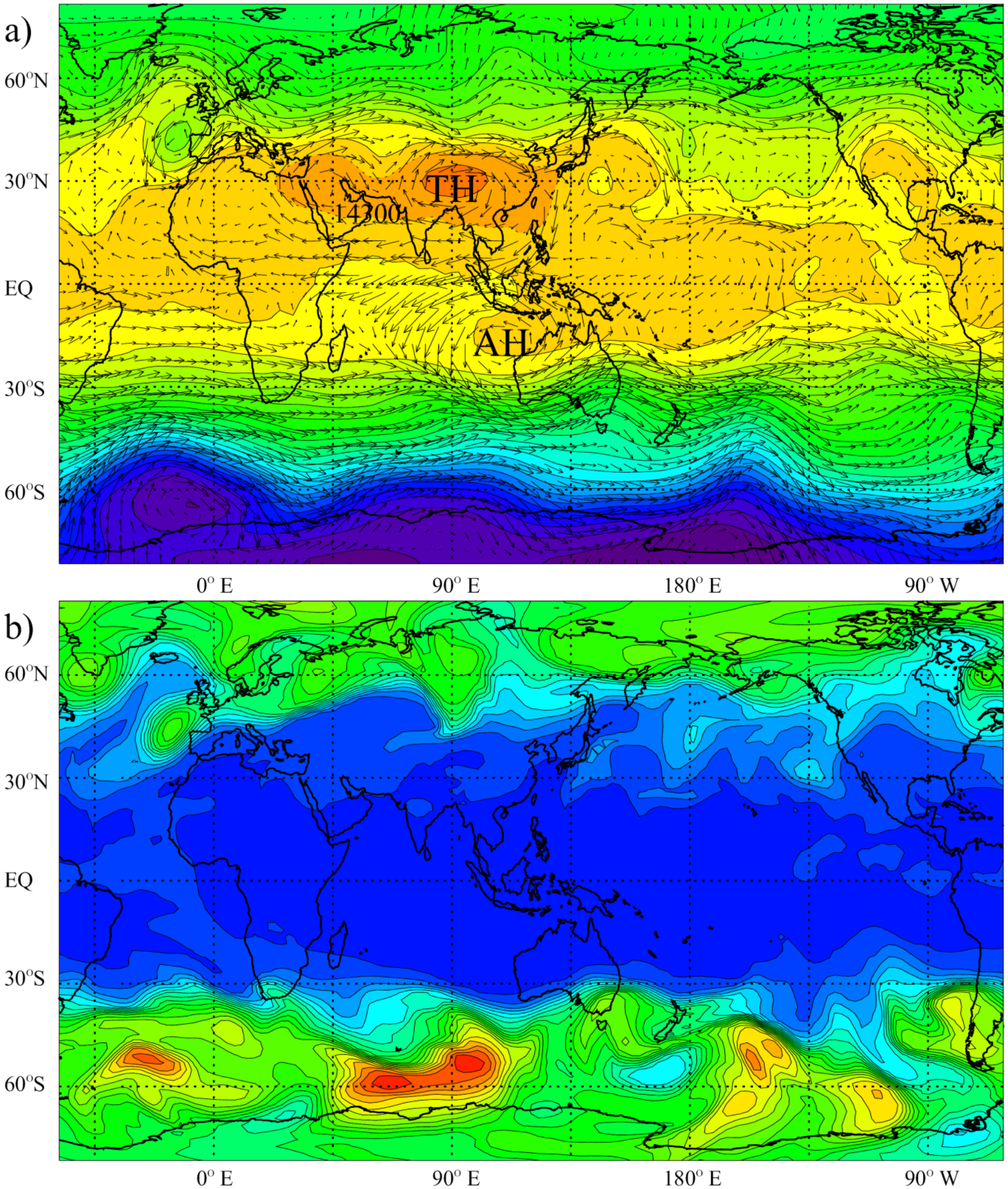
Singapore
150 hPa
Meridional
Wind (m/s)
August 1998

Asterisk = Indonesia OLR minima



Longitude-altitude section from the surface to the stratopause of eddy geopotential height at 22°S (contour interval 50 m) for 24 August 2000.

Outflow surges into the UTLS over the Indian Ocean amplify the Australian High, which merges with a stalling planetary wave ridge in the winter stratosphere.

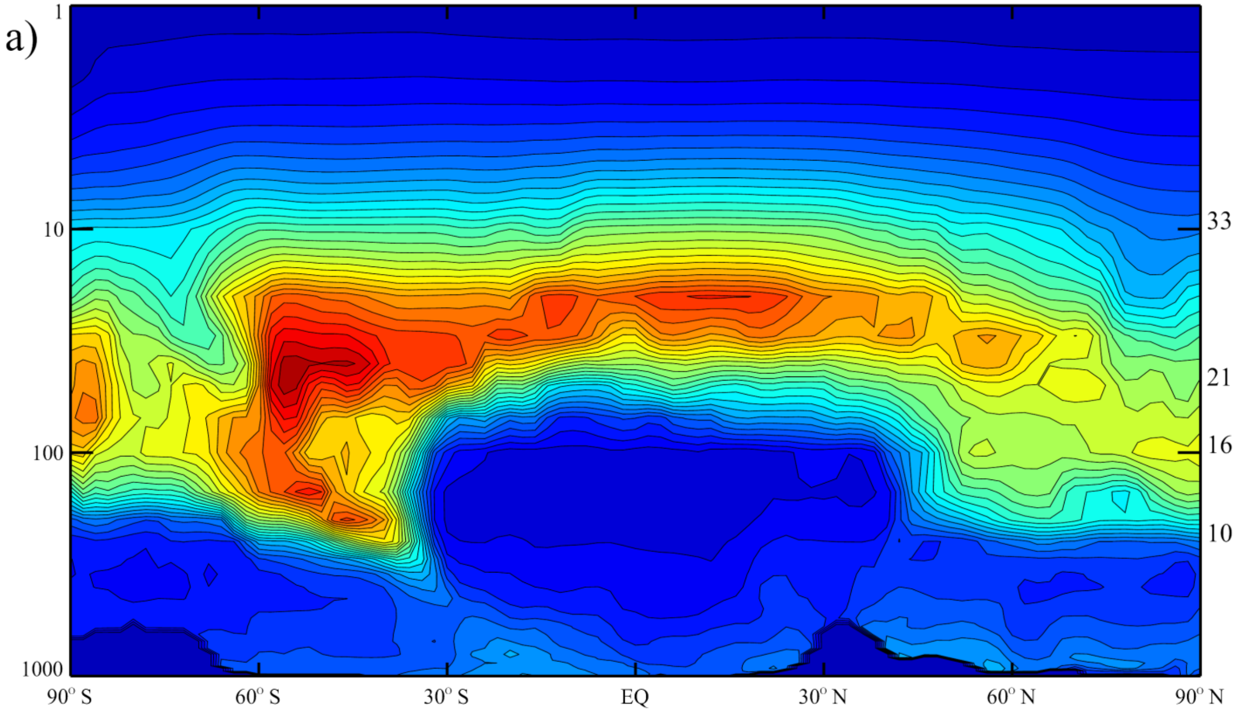


August 24, 2000

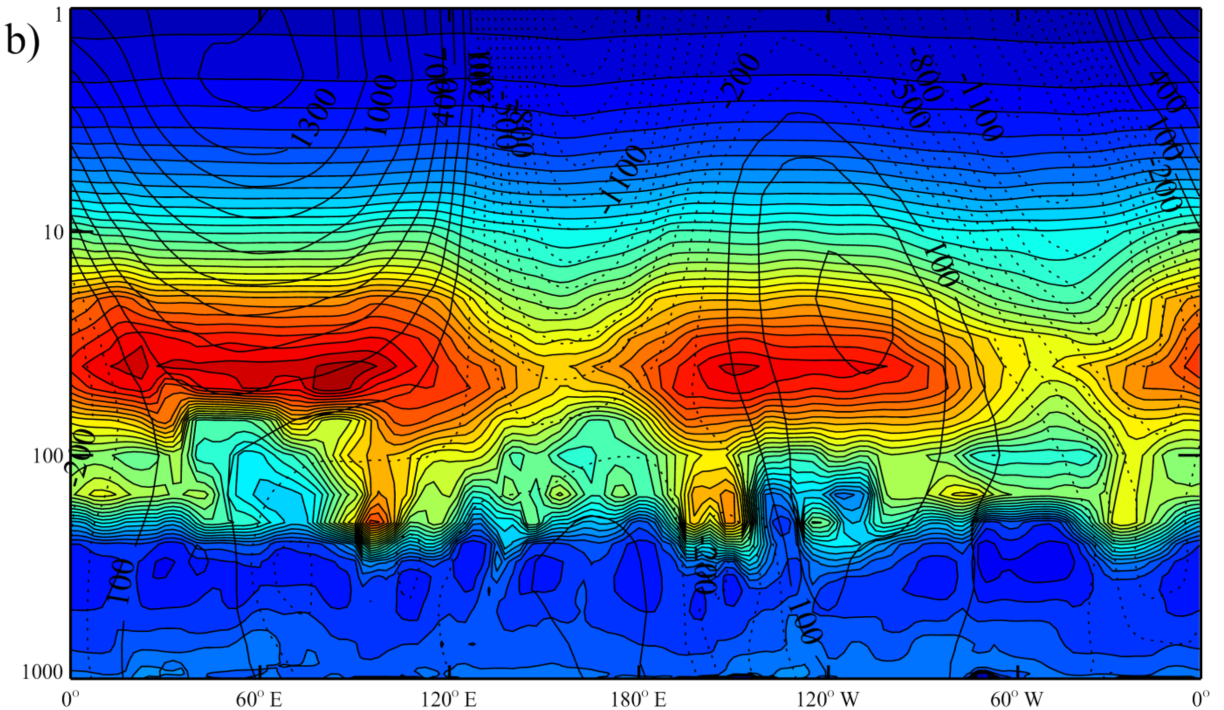
150 hPa Z, winds

150 hPa GMAO ozone mixing ratio.

August 24, 2000



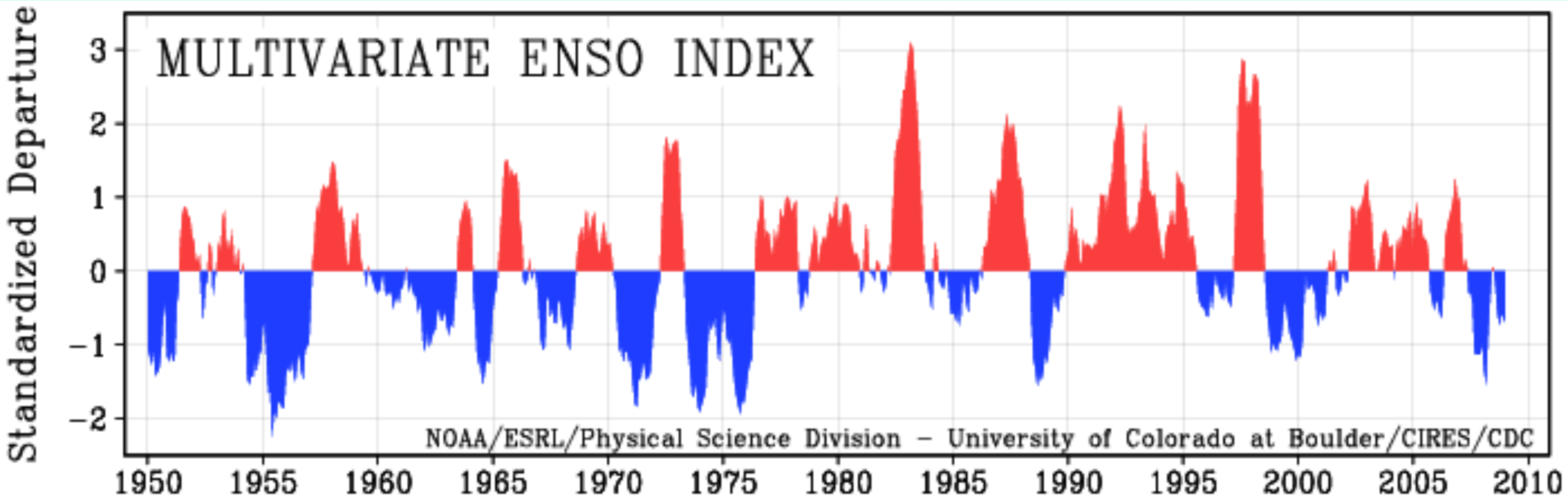
GMAO ozone concentration at 95°E



Eddy geopotential height and Ozone (color) at 47°S

2. Influence of ENSO on SH circulation during SON
   * effects on planetary waves and polar vortex
   * ozone maximum shifted westward during La Nina

ENSO Influences On SH Planetary Waves and Ozone

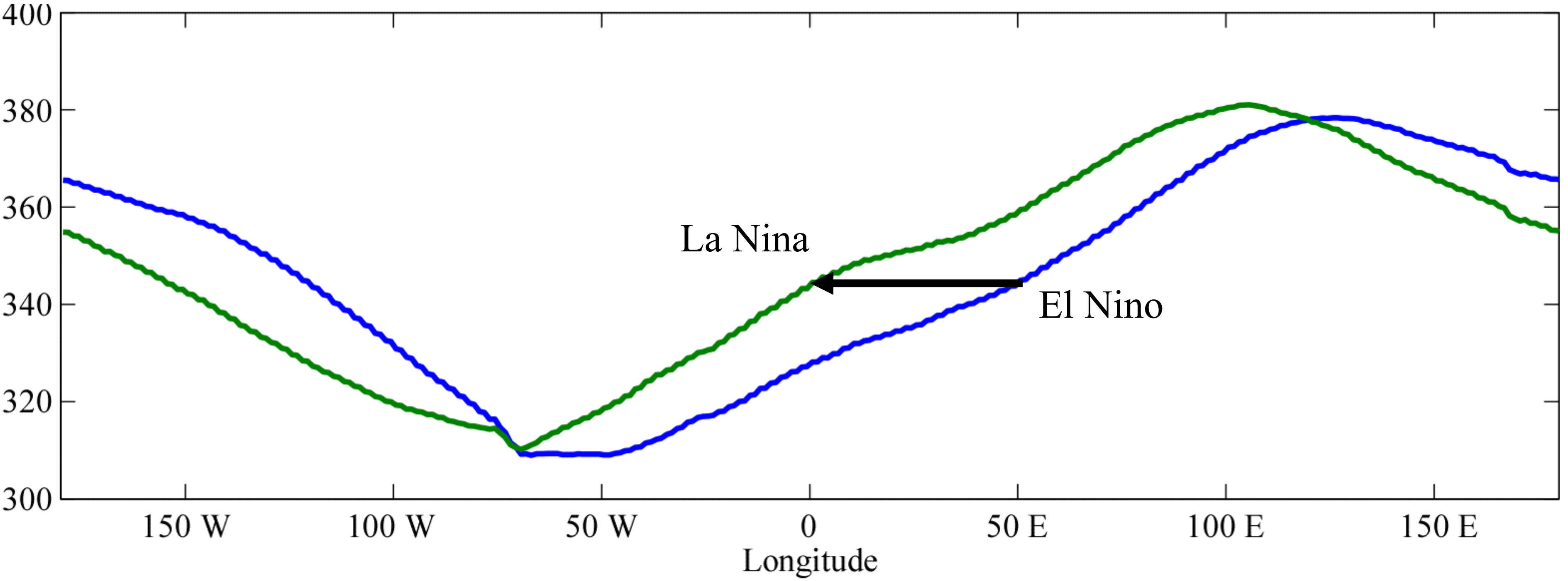


El Nino 1982, 1986, 1987, 1991, 1997, 2002, 2004

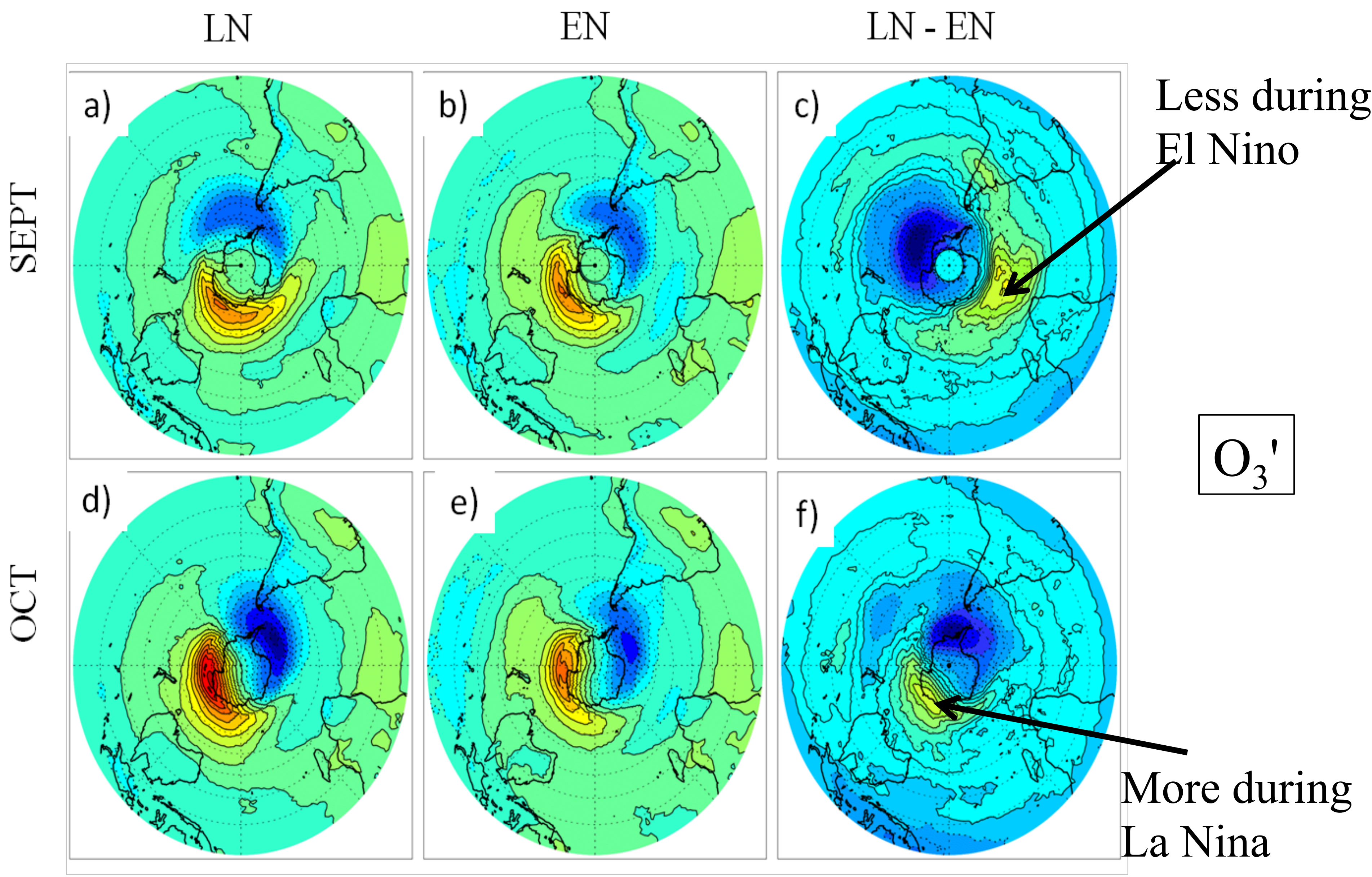
La Nina 1983, 1984, 1988, 1998, 1999, 2000

TOMS column ozone 1982-2004

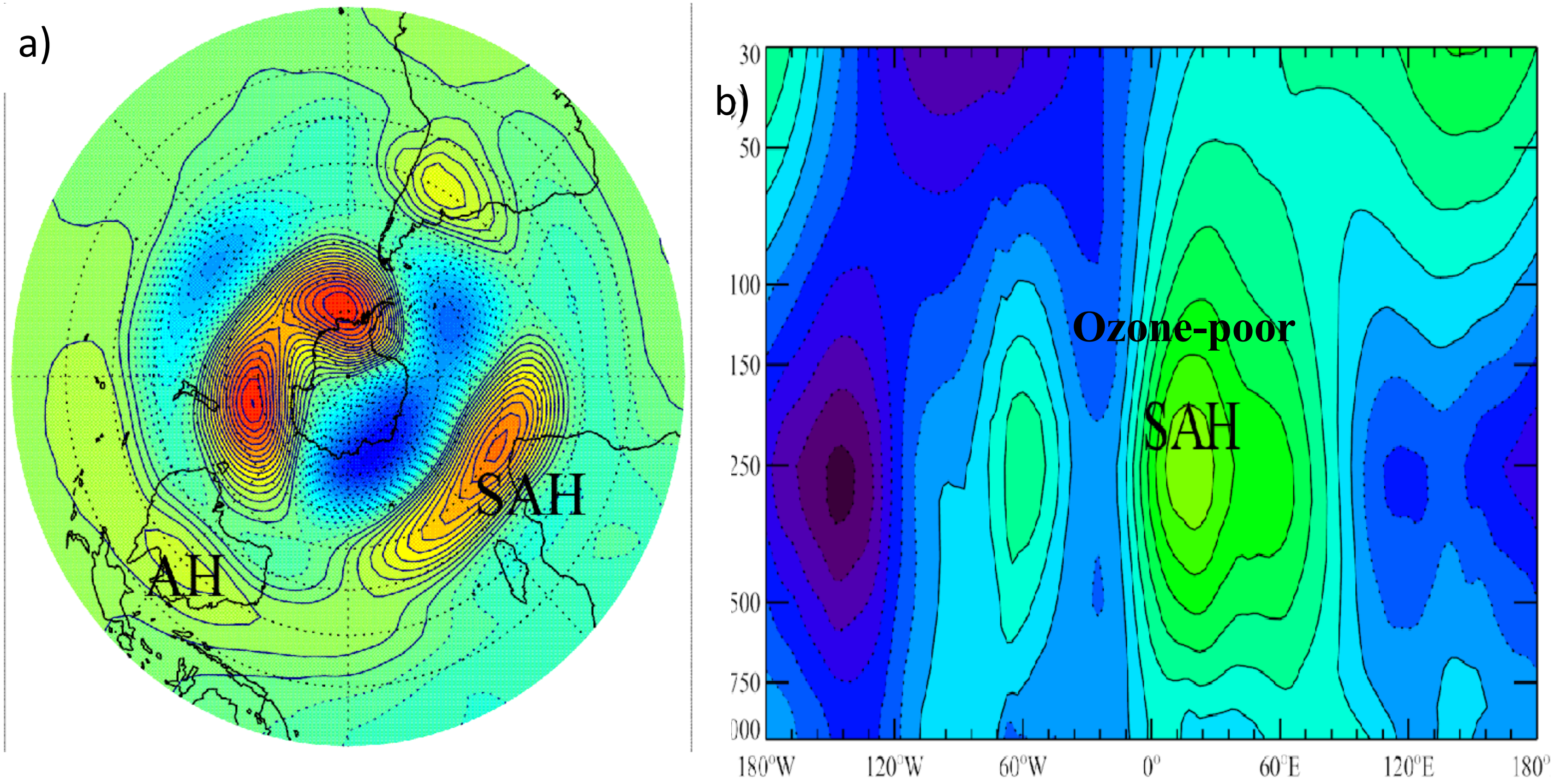
August-September-October 45-60S



SH column ozone shifts westward with convection during La Nina.

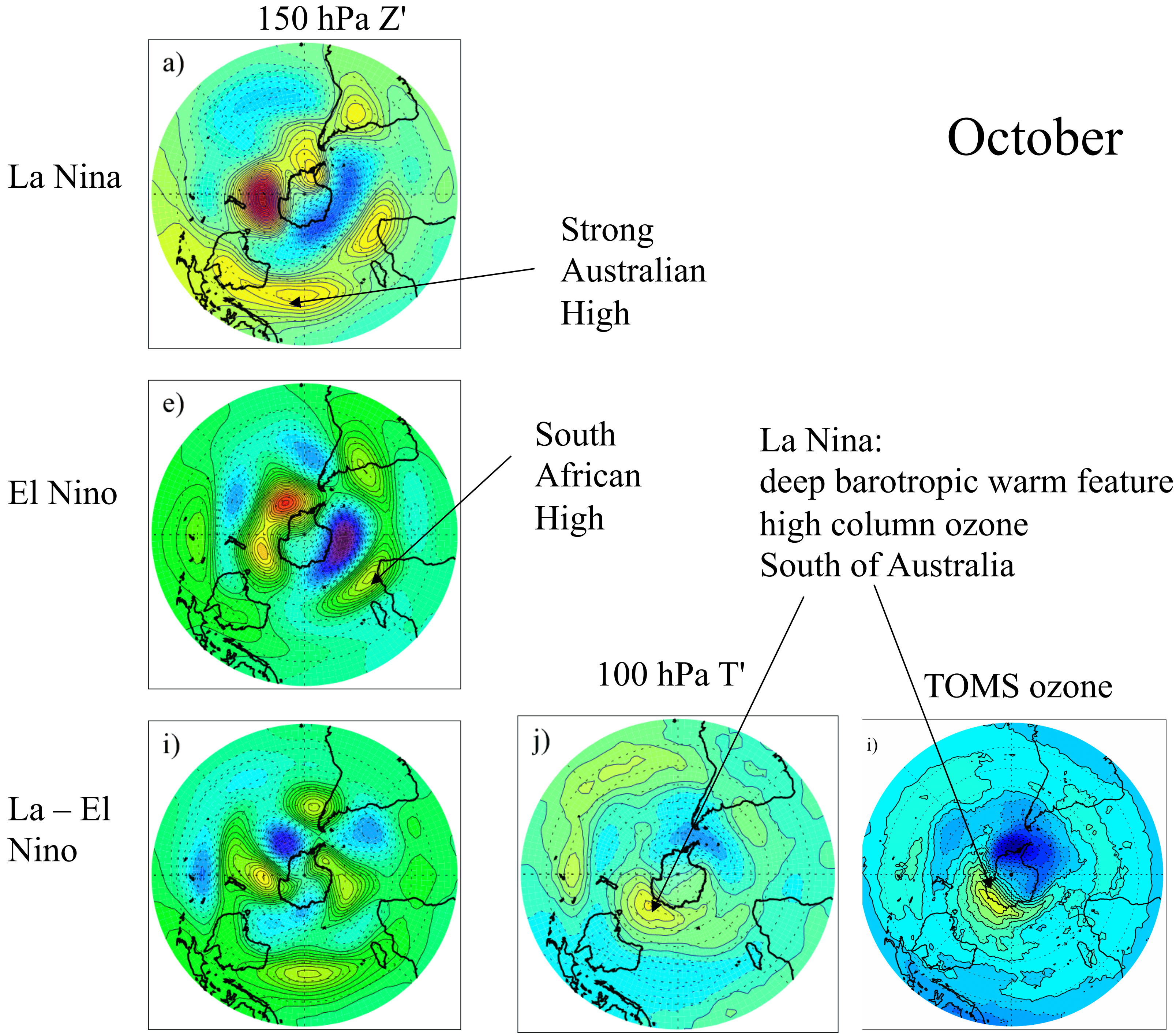


The reason for the westward shift during LN depends on month.



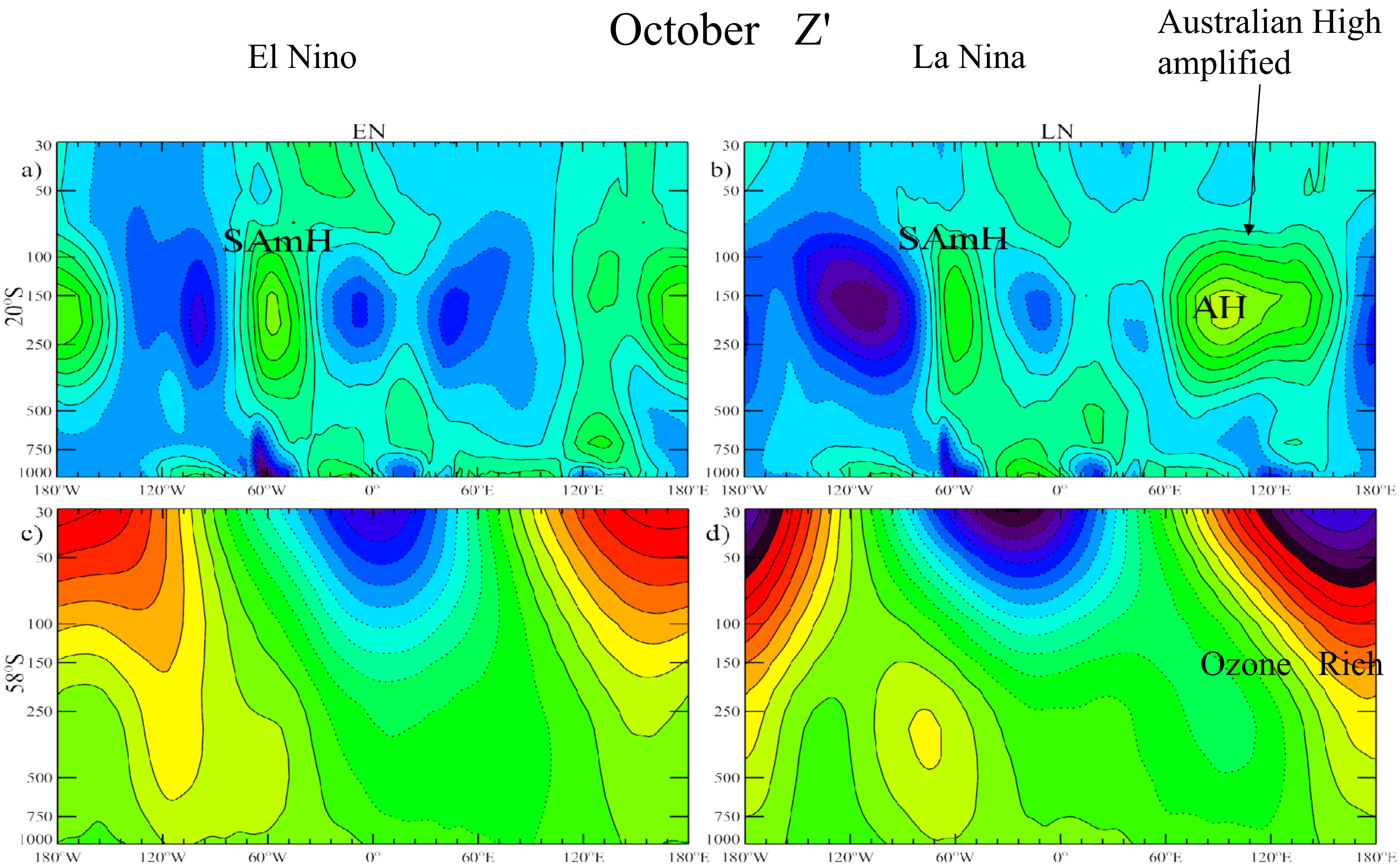
September Z' for El Nino at a) 150 hPa and b) 35°S.

EN favors a stronger South African High (SAH) in the UTLS, which displaces the tropopause upward, causing a cold anomaly in the lower stratosphere and reduced column ozone.



150 hPa Z'
October
La Nina
a)
Strong
Australian
High
El Nino
e)
South
African
High
La Nina:
deep barotropic warm feature
high column ozone
South of Australia
La – El
Nino
i)
100 hPa T'
j)
TOMS ozone
i)

October Z'

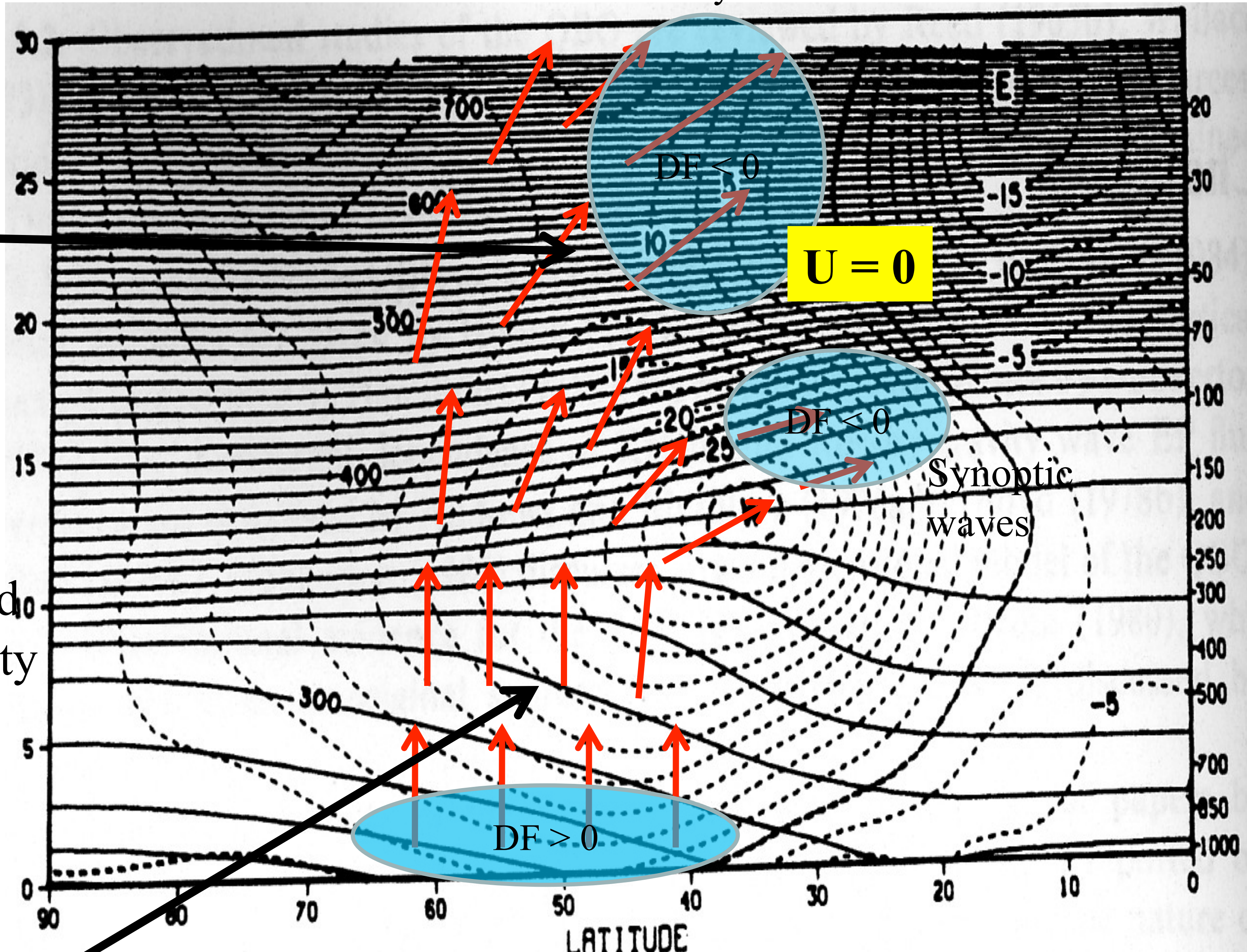


Stronger More Asymmetric Vortex during La Nina

2. Influence of ENSO on SH circulation during SON

* 3d wave activity flux diagnostics (Kinoshita and Sato 2013a,b)

Planetary waves



$F_y \sim - u'v'$
$\sim G_z A$

poleward momentum flux = equatorward wave activity flux

$F_z \sim f\, v'\theta' \sim G_z A$ poleward heat flux = upward wave activity flux

(Kinoshita and Sato 2013a,b) 3D circulation satisfies continuity eqn

3D wave activity flux expressing wave-mean interaction (left) and wave propagations (right)

$$F_{1M(x)} \equiv \rho_0 \left(\overline{u'^2} + \frac{\bar{u}_y - f}{f} \overline{S_{(p)}} - \bar{u}_z \frac{\overline{u'\Phi'_z}}{N^2} \right),$$

$$F_{1M(y)} \equiv \rho_0 \left(\overline{u'v'} - \frac{\bar{u}_x}{f} \overline{S_{(p)}} - \bar{u}_z \frac{\overline{v'\Phi'_z}}{N^2} \right),$$

$$F_{1M(z)} \equiv \rho_0 \left(\overline{u'w'} + \bar{u}_x \frac{\overline{u'\Phi'_z}}{N^2} + (\bar{u}_y - f) \frac{\overline{v'\Phi'_z}}{N^2} \right)$$

$$F_{1W(x)} \equiv \rho_0 (\overline{u'^2 - \tilde{S}}),$$

$$F_{1W(y)} \equiv \rho_0 (\overline{u'v'}),$$

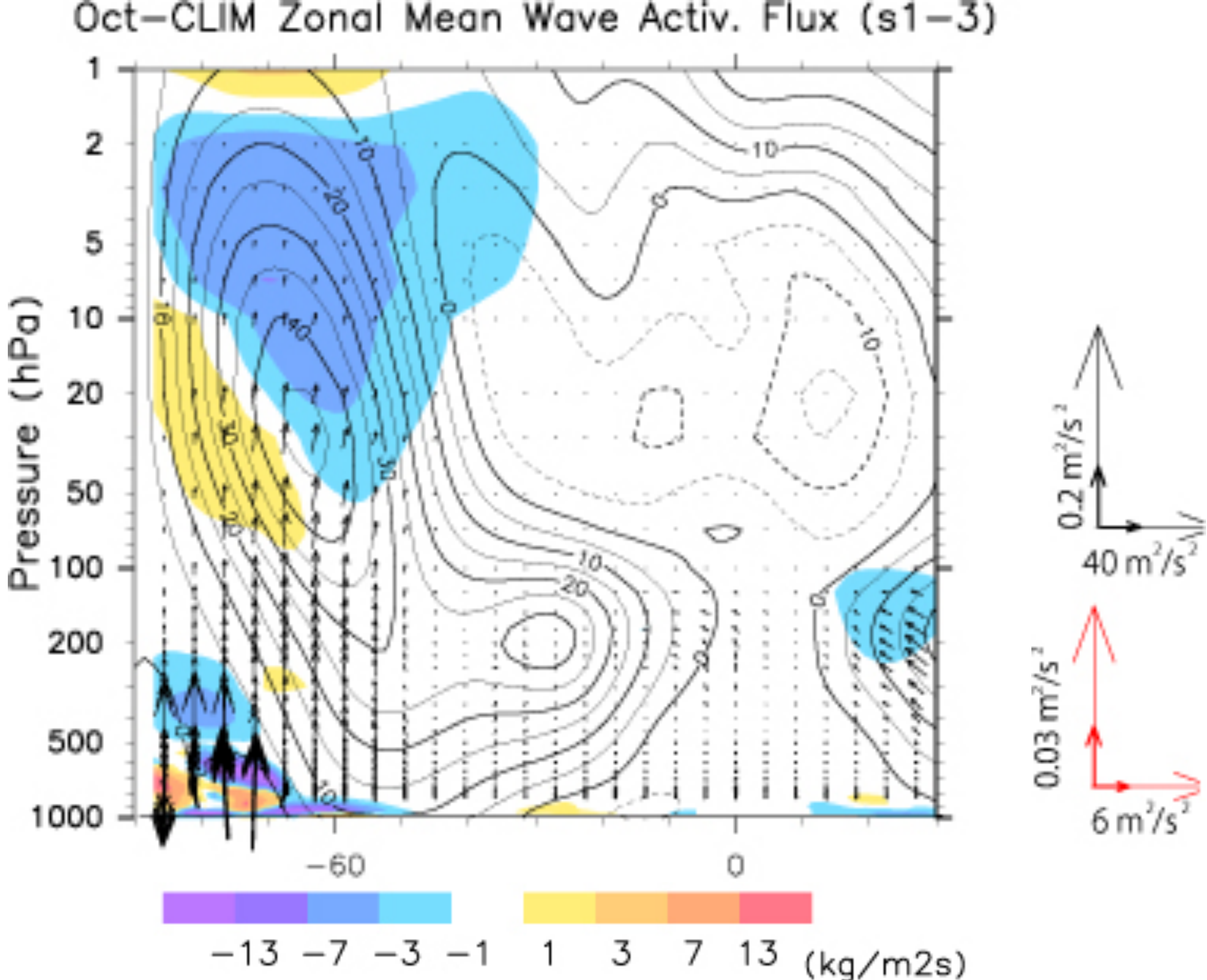
$$F_{1W(z)} \equiv \rho_0 \left(\overline{u'w'} - f \frac{\overline{v'\Phi'_z}}{N^2} \right),$$

$$\mathbf{F_{1W}} = \hat{\mathbf{C}}_g \left(\frac{E'}{\hat{C}_{(x)}} \right)$$

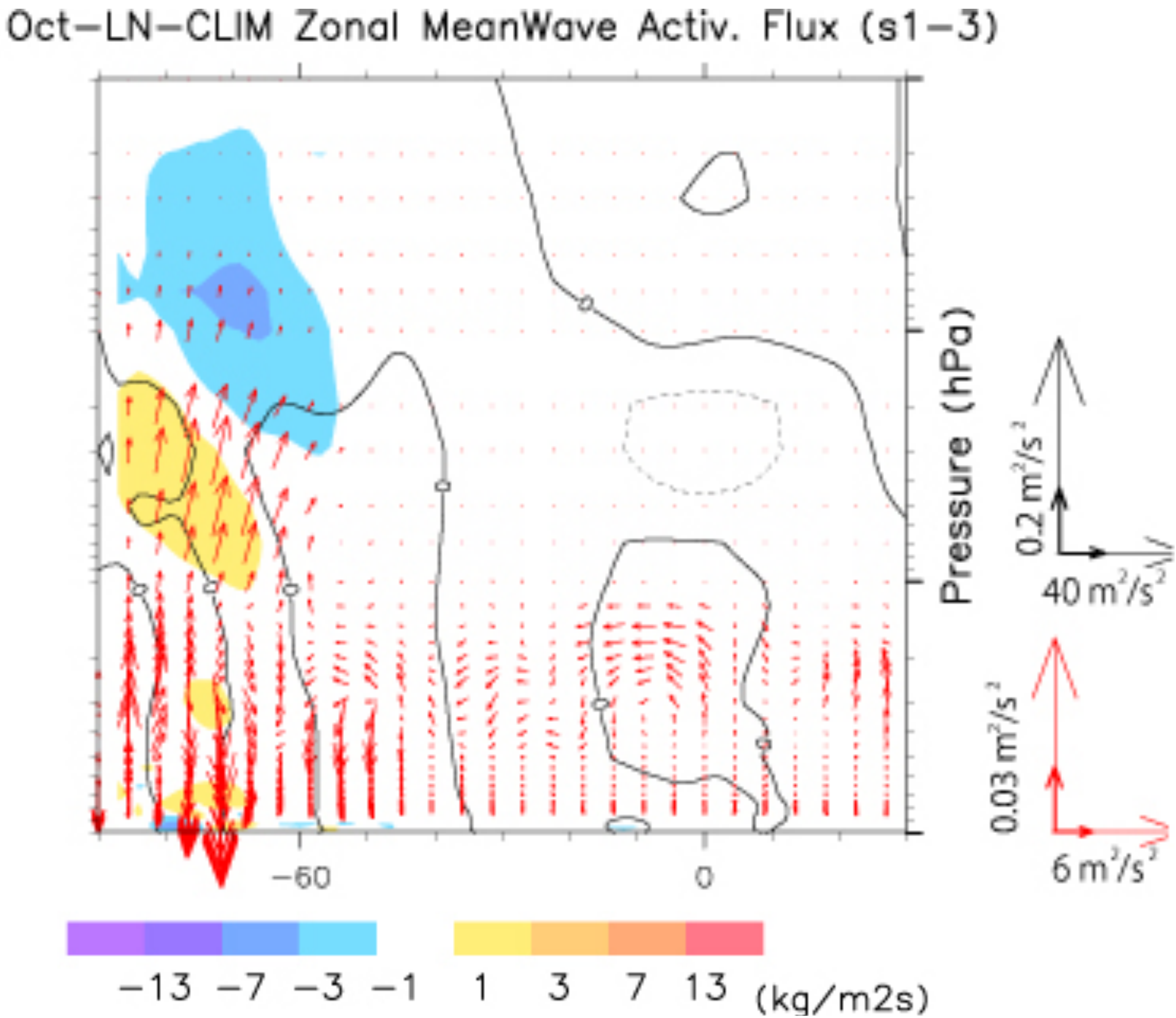
To examine quasi-stationary waves, we use the extend Hilbert transform instead of time mean (Sato et al. 2013)

- Data : ERA-Interim reanalysis data
- Focus on : August ~ October
  - ◆El Nino (EN) : 1991, 1997, 2002, 2004, 2006, 2009
  - ◆La Nina (LN) : 1998, 1999, 2000, 2007

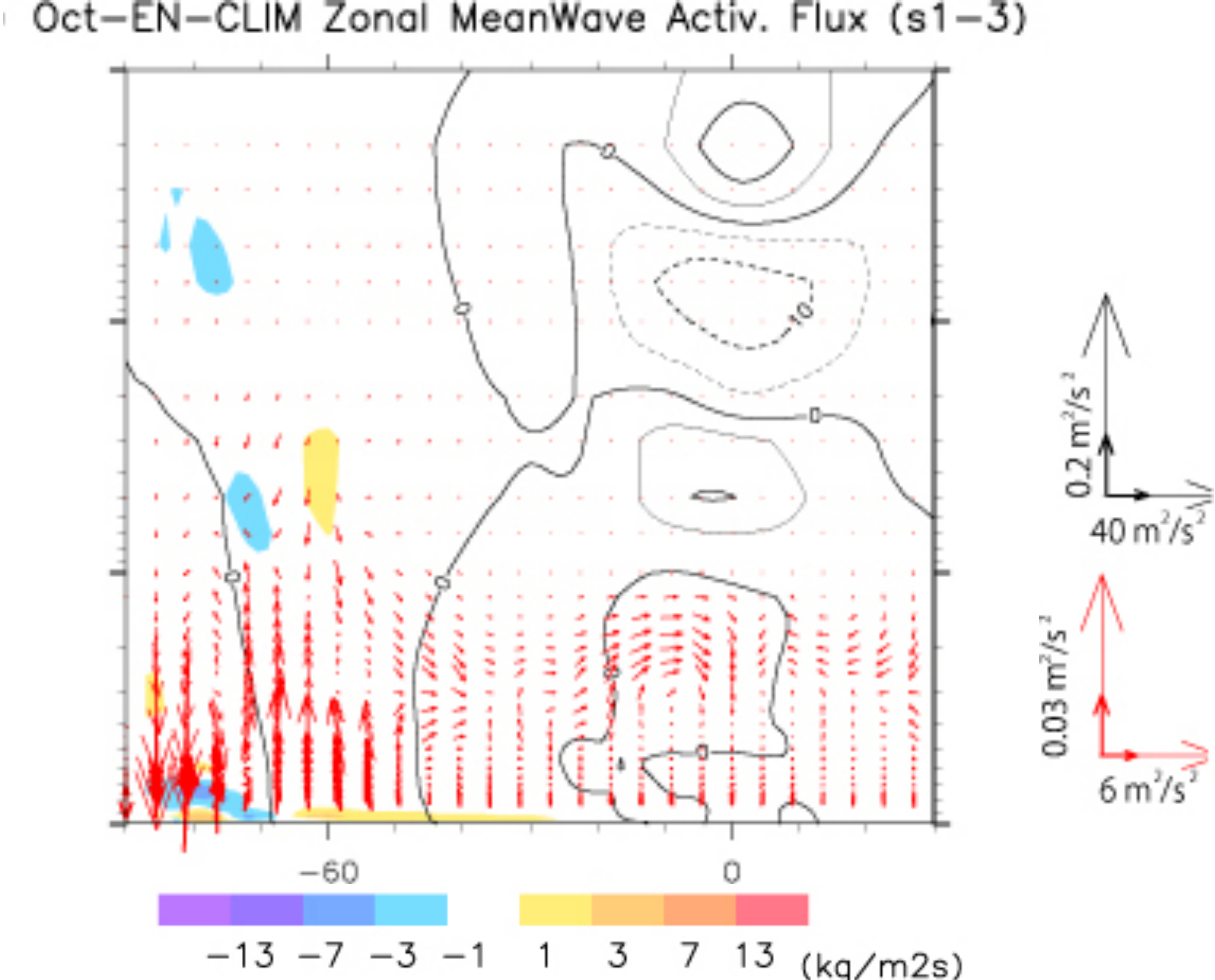
We use Ocean Nino Index (ONI) in NOAA as an index of ENSO.



Oct-CLIM Zonal Mean Wave Activ. Flux (s1-3)
Pressure (hPa)
1
2
5
10
20
50
100
200
500
1000
-60
0
0.2 m²/s²
40 m²/s²
0.03 m²/s²
6 m²/s²
-13
-7
-3
-1
1
3
7
13
(kg/m2s)



Oct-LN-CLIM Zonal MeanWave Activ. Flux (s1-3)
Pressure (hPa)
0.2 m²/s²
40 m²/s²
0.03 m²/s²
6 m²/s²
-60
0
-13 -7 -3 -1 1 3 7 13 (kg/m2s)



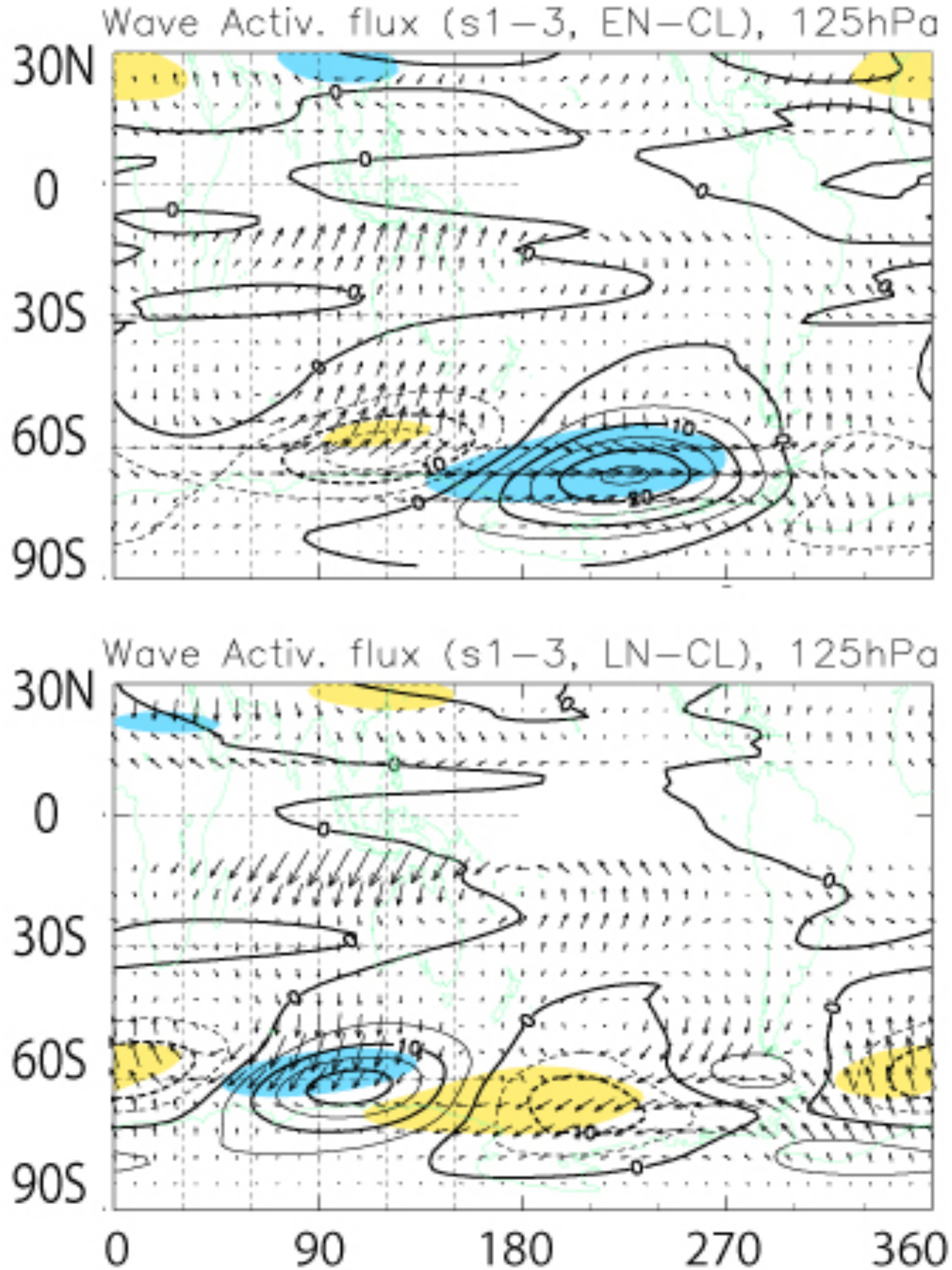
Oct−EN−CLIM Zonal MeanWave Activ. Flux (s1−3)
0
0
0
0
0
0
0
−60
0
0.2 m2/s2
40 m2/s2
0.03 m2/s2
6 m2/s2
−13 −7 −3 −1 1 3 7 13 (kg/m2s)

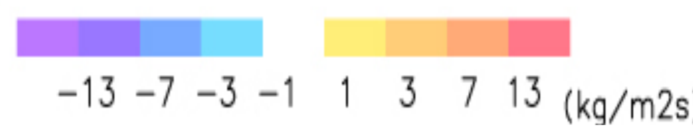
Mid-October

125 hPa

EN - Climatology

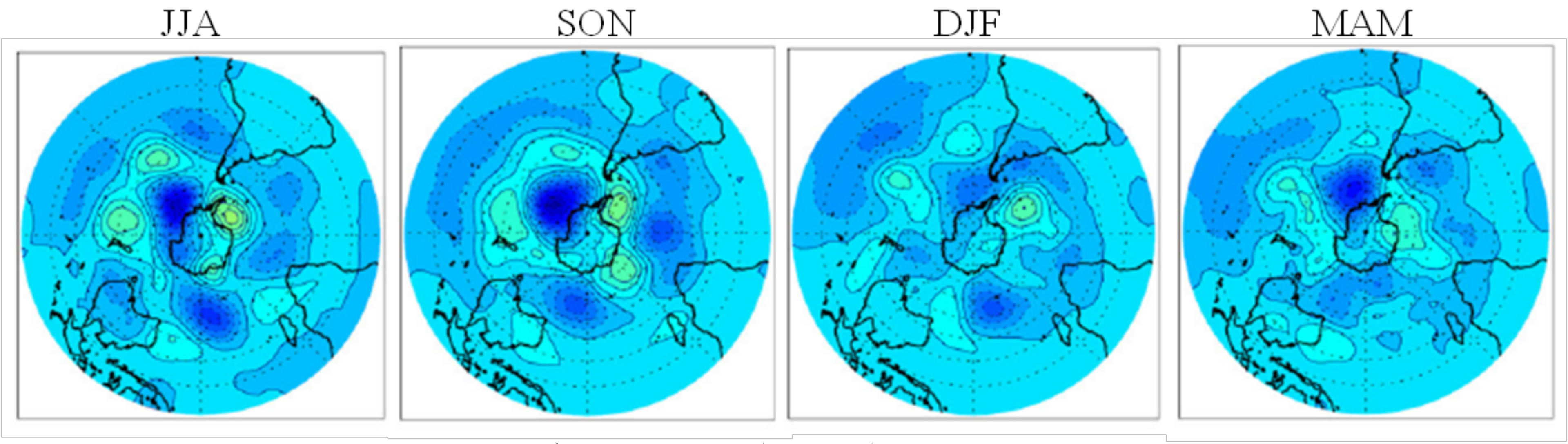
LN - Climatology





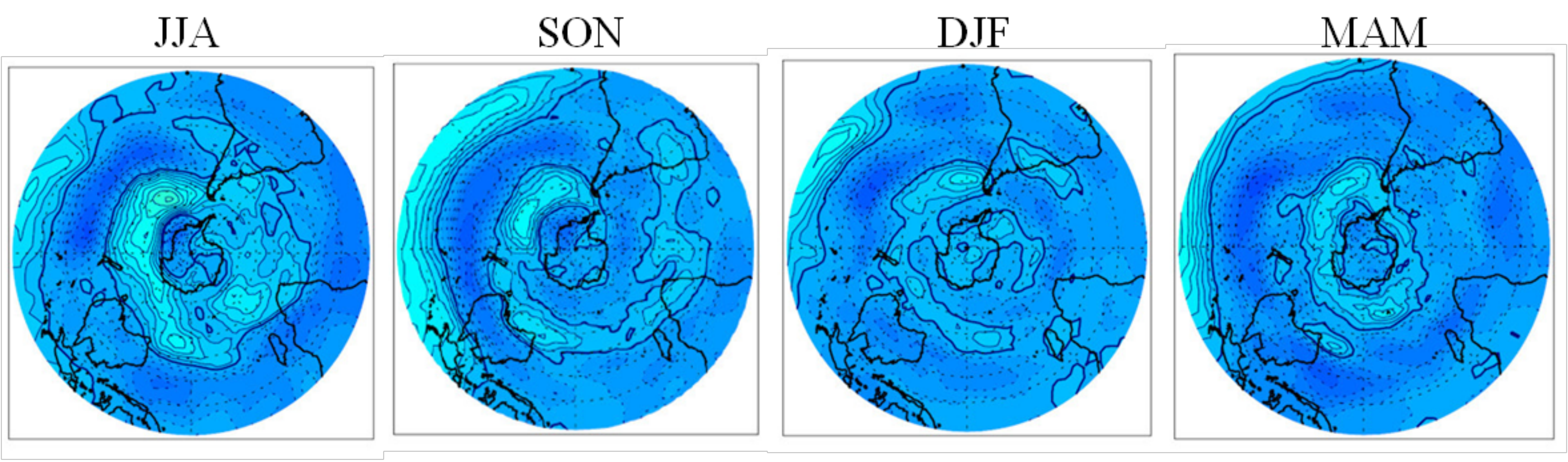
ENSO effects in MAM, JJA, SON, DJF

La Nina: stronger polar vortex
stronger planetary wave one
enhanced Ross Sea low



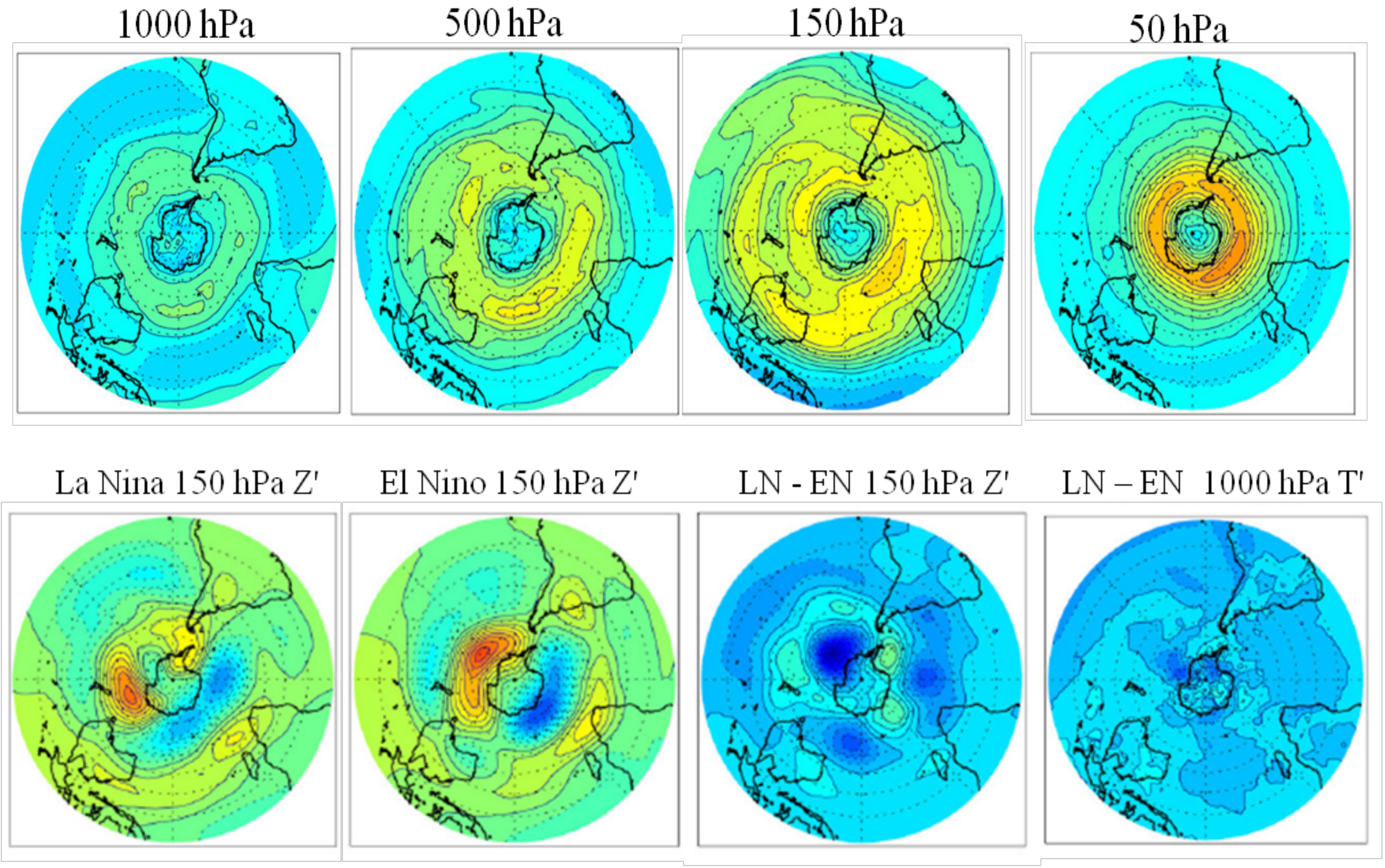
LN – EN 150 hPa Z' (20 m)

ECMWF 1985-2009



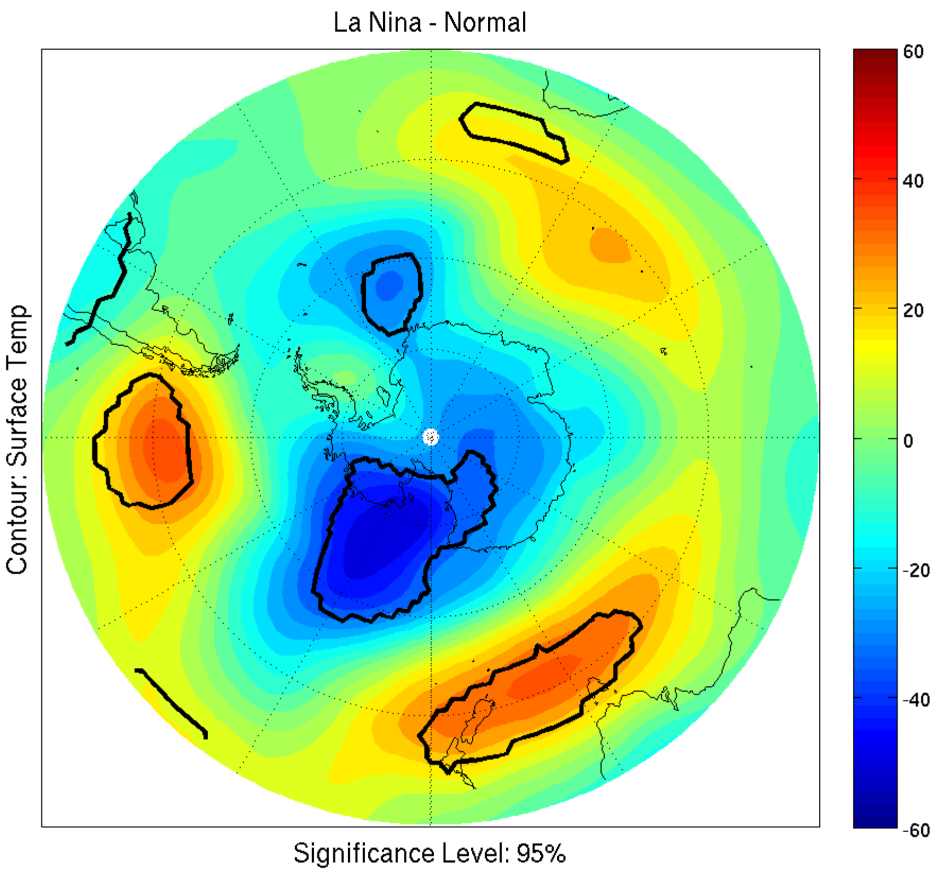
LN – EN 150 hPa zonal wind differences (2 m/s)

Zonal wind speed (contour 5 m/s) during La Nina and SON using daily ECMWF data from 1985-2009.



3. Cold East Antarctica during La Nina

* UWNMS simulations Dec. 1-9, 1988



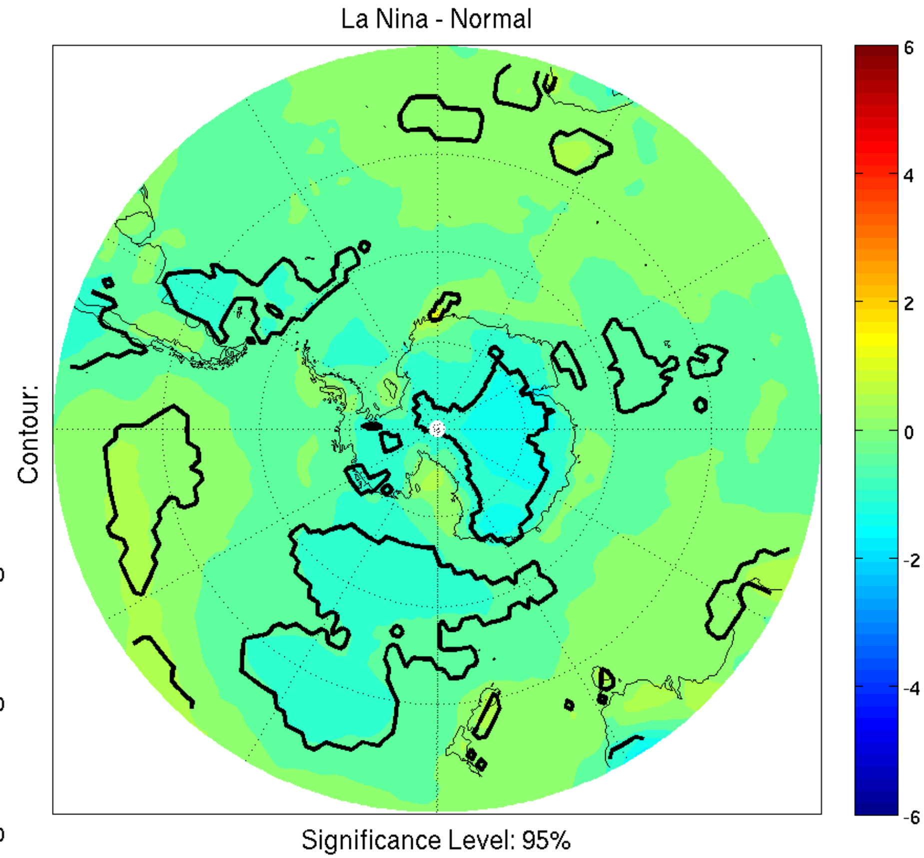
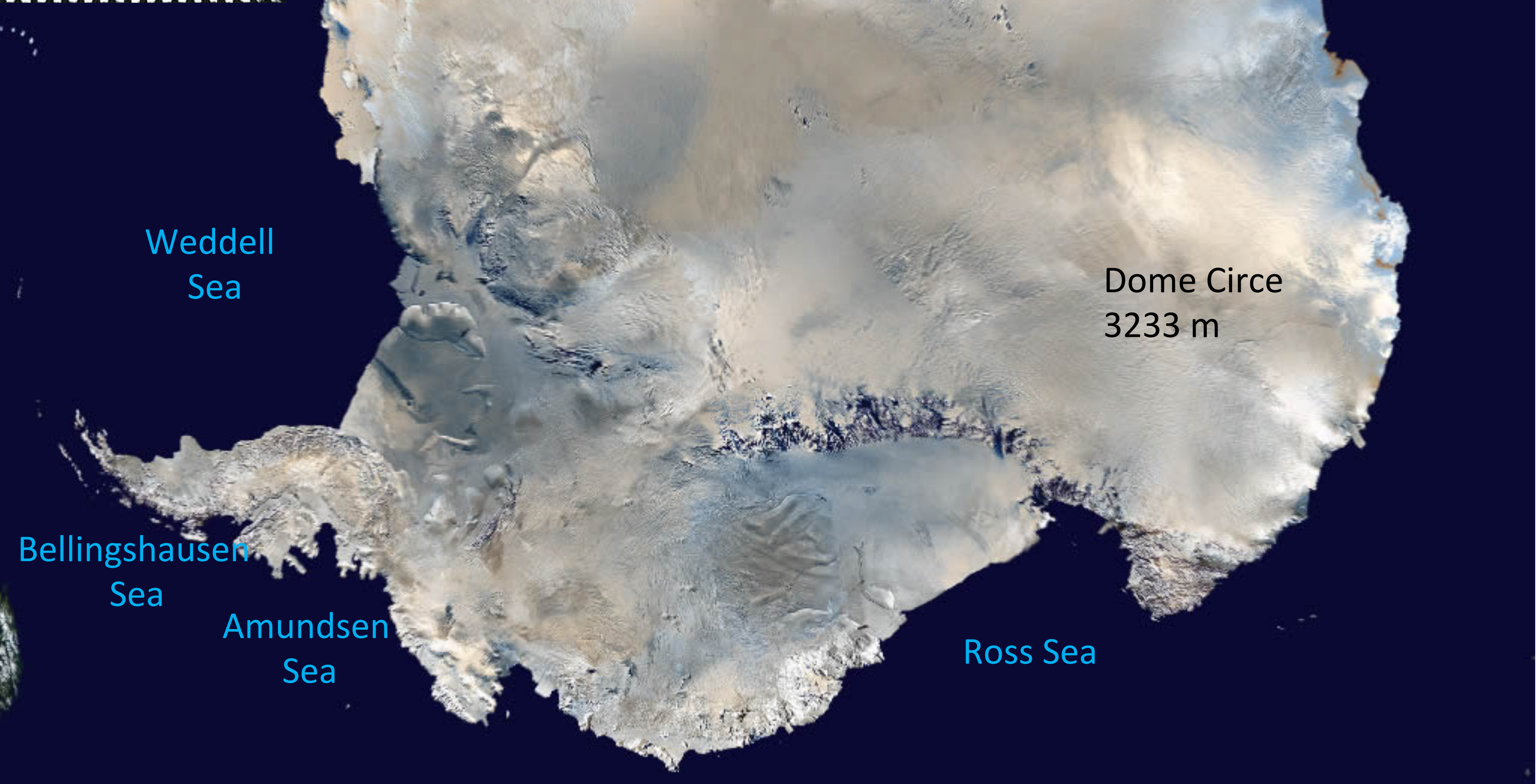


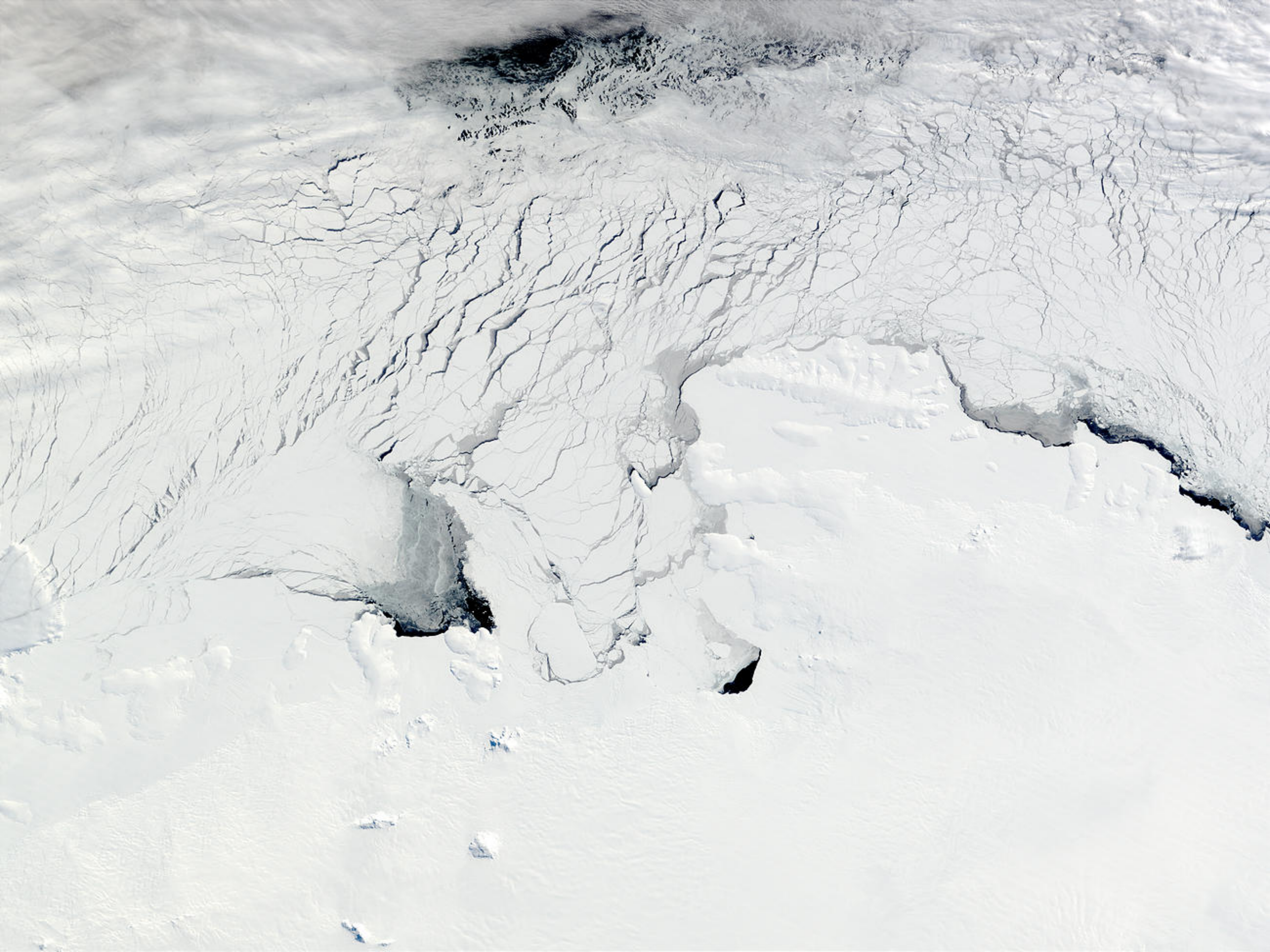
Figure 98: 500 hPa height anomalies for ONI during NDJ of La Niña.

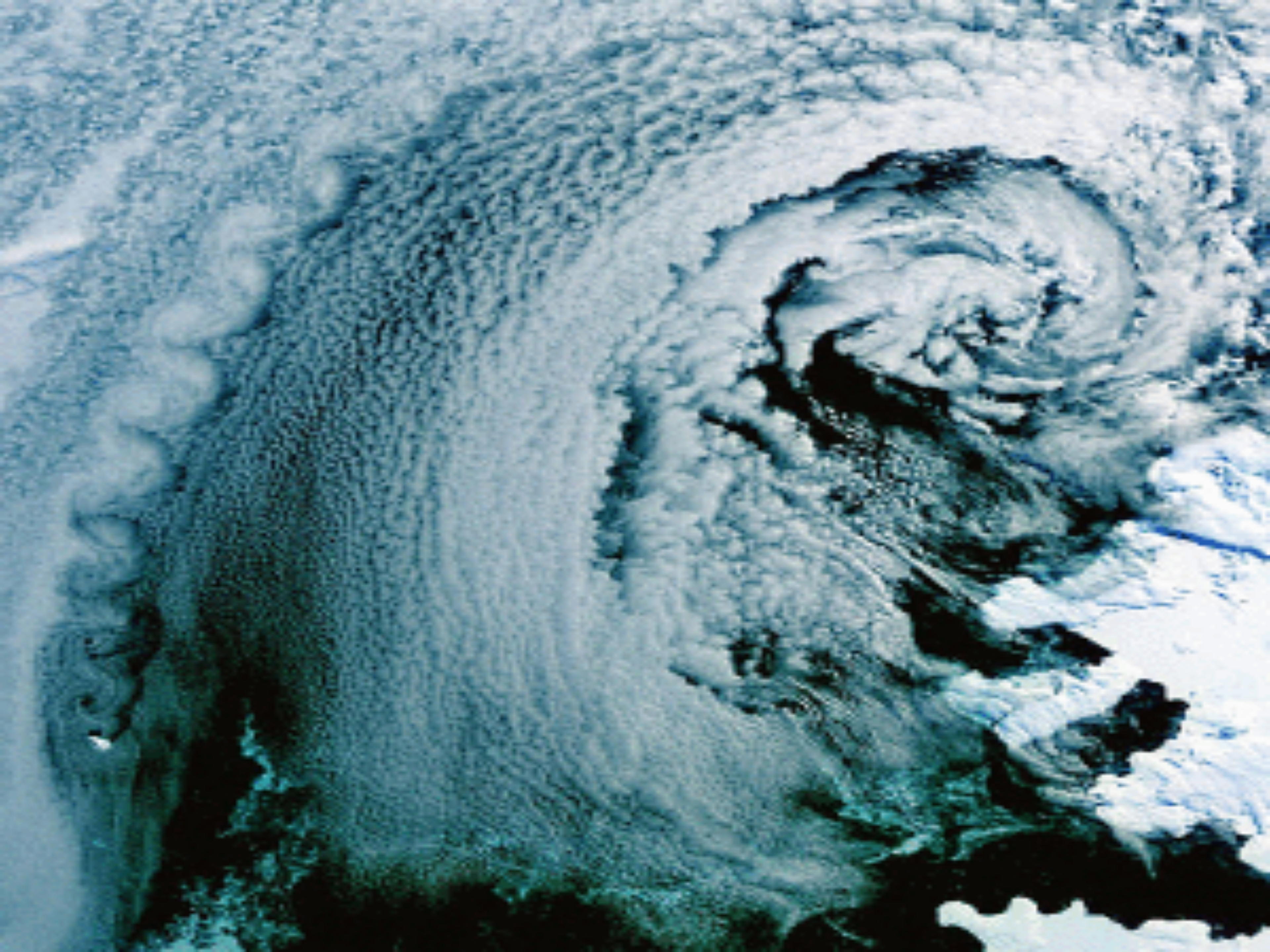
Figure 99: 2 meter temperature anomalies for ONI during NDJ of La Niña.

(Welhouse, 2011)


FABIAN VON BELLINGSHAUSEN
1778-1852
MAGYAR POSTA 2Ft


Weddell
Sea
Dome Circe
3233 m
Bellingshausen
Sea
Amundsen
Sea
Ross Sea

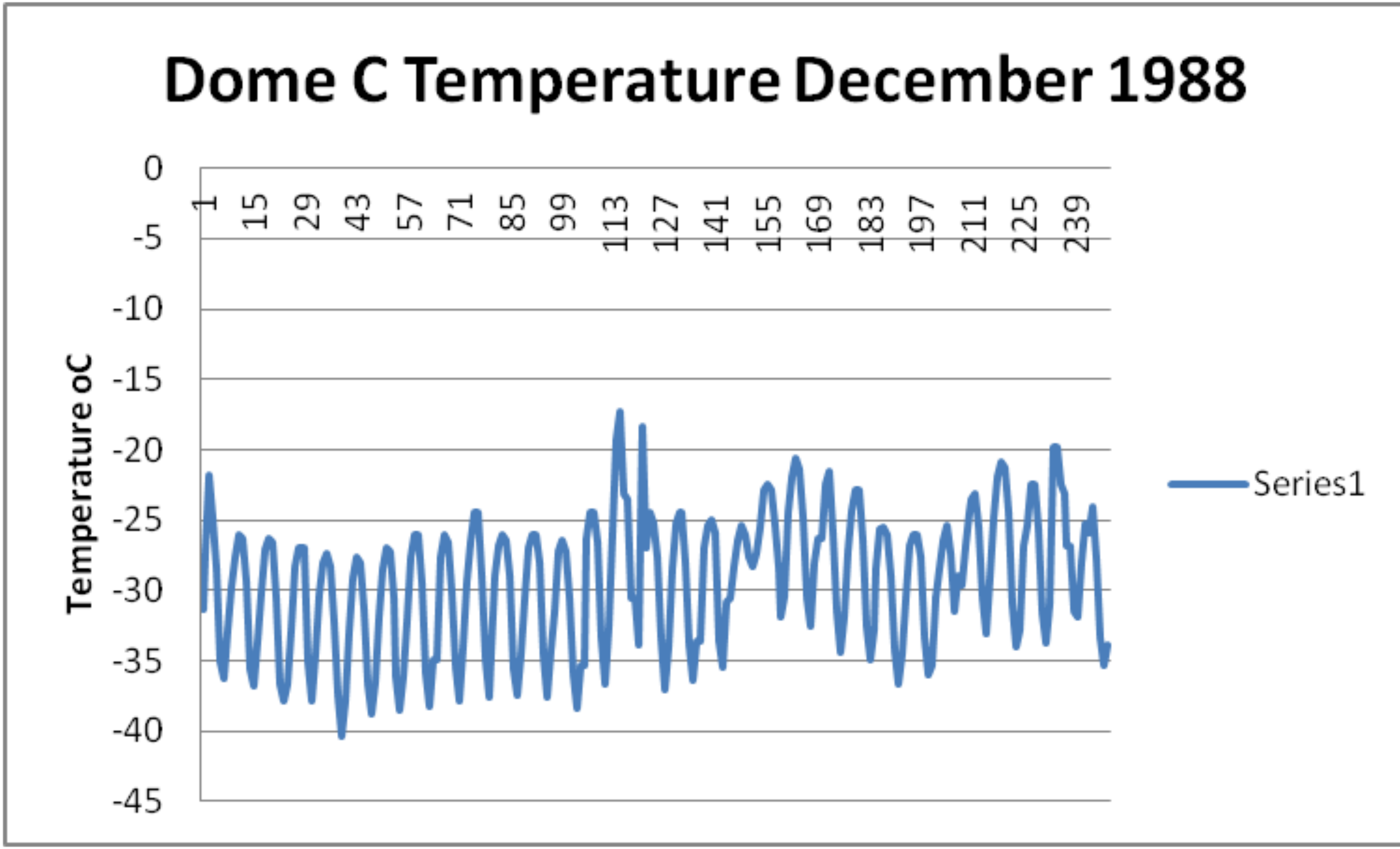




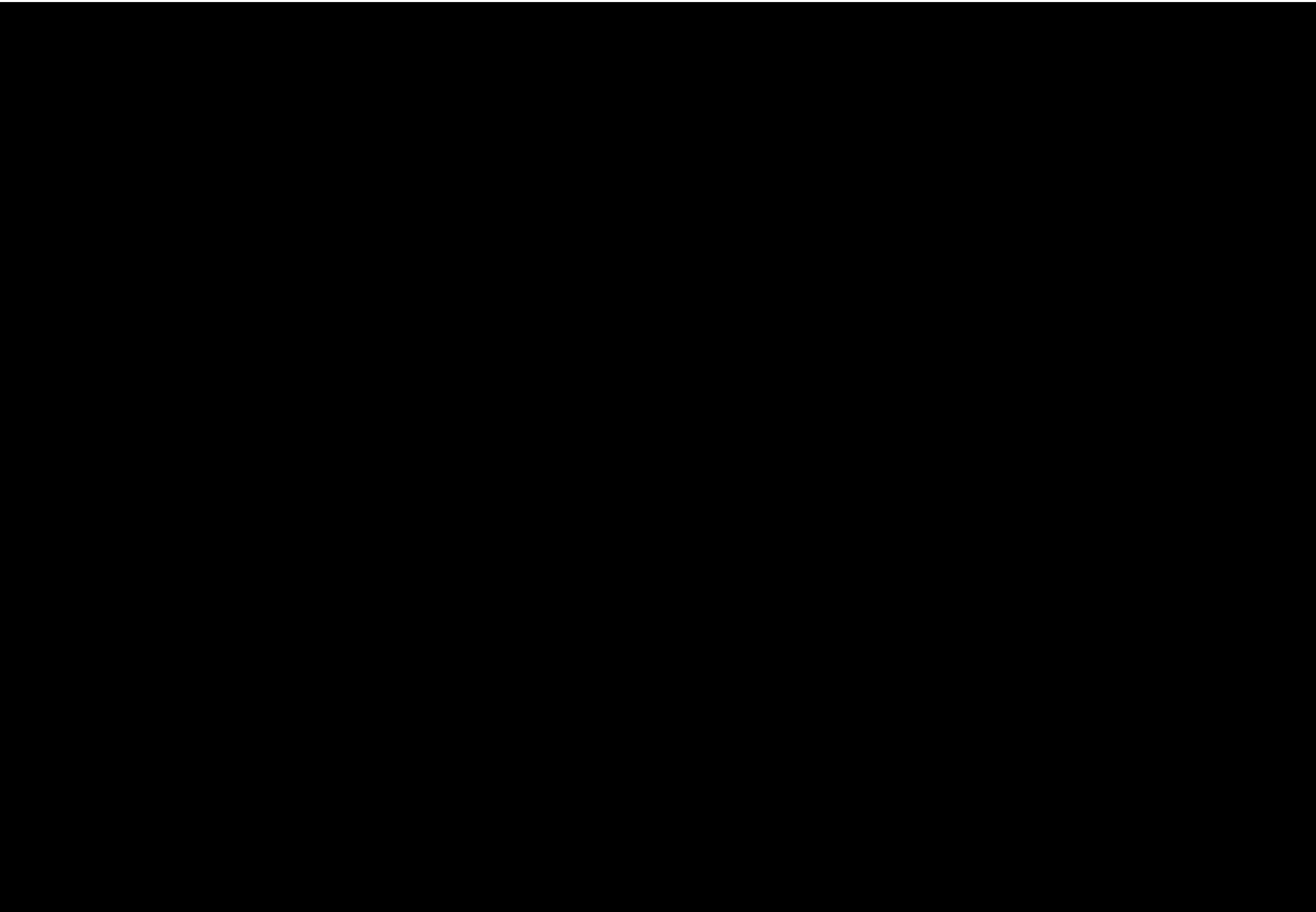
University of Wisconsin Nonhydrostatic Modeling System

Synoptic Case Studies December 1 - 3 and 5 - 9, 1988

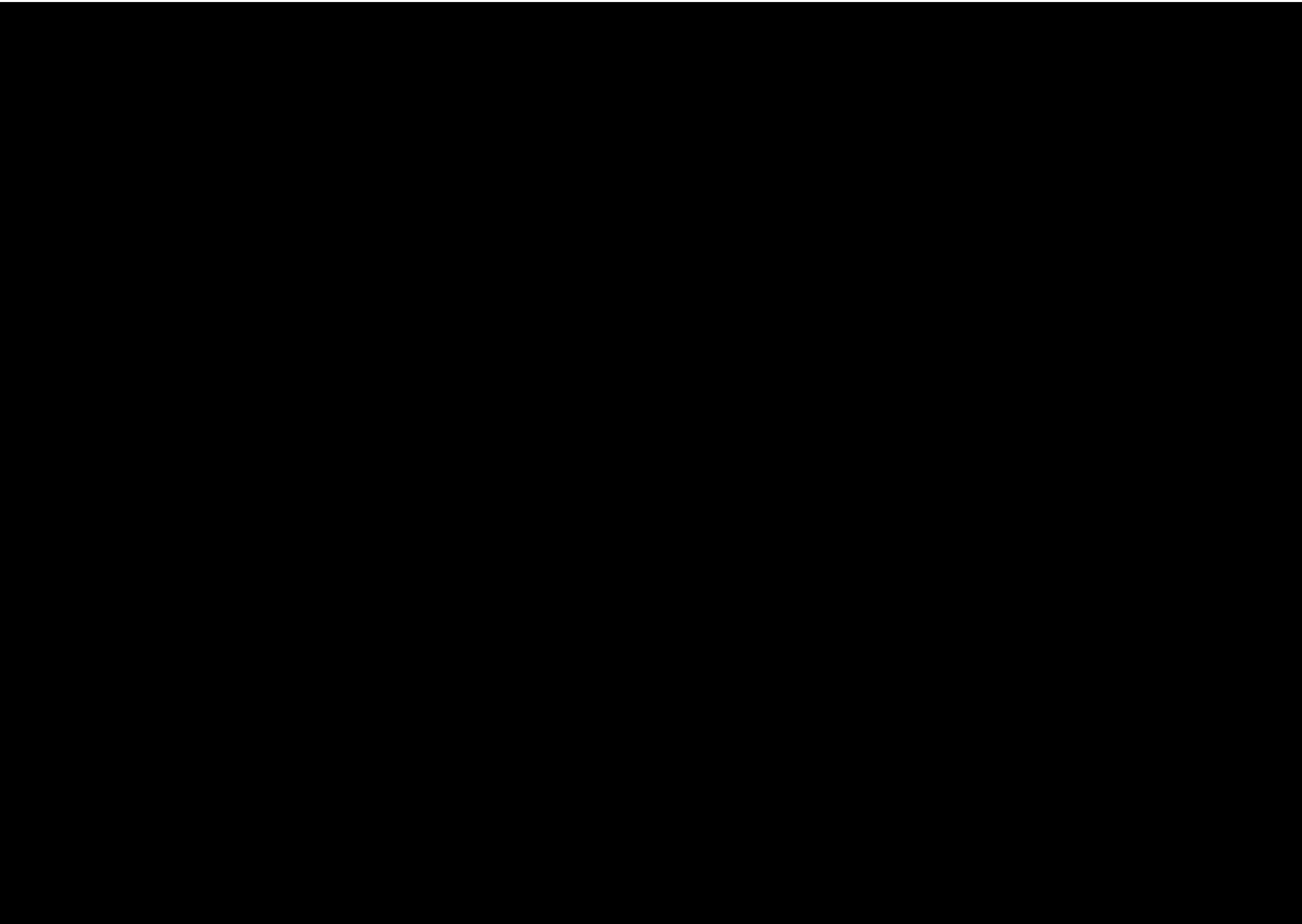
ECWMF initialization
No inflow forcing
Grid Points: 152 x 152 x 60
Outer grid: 100 km x 100 km x 300 m
Inner grid: 20 km x 20 km x 300 m
Model top: 18 km
Vis5d movies of output


Dome C Temperature December 1988
Temperature oC
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
1
15
29
43
57
71
85
99
113
127
141
155
169
183
197
211
225
239
Series1

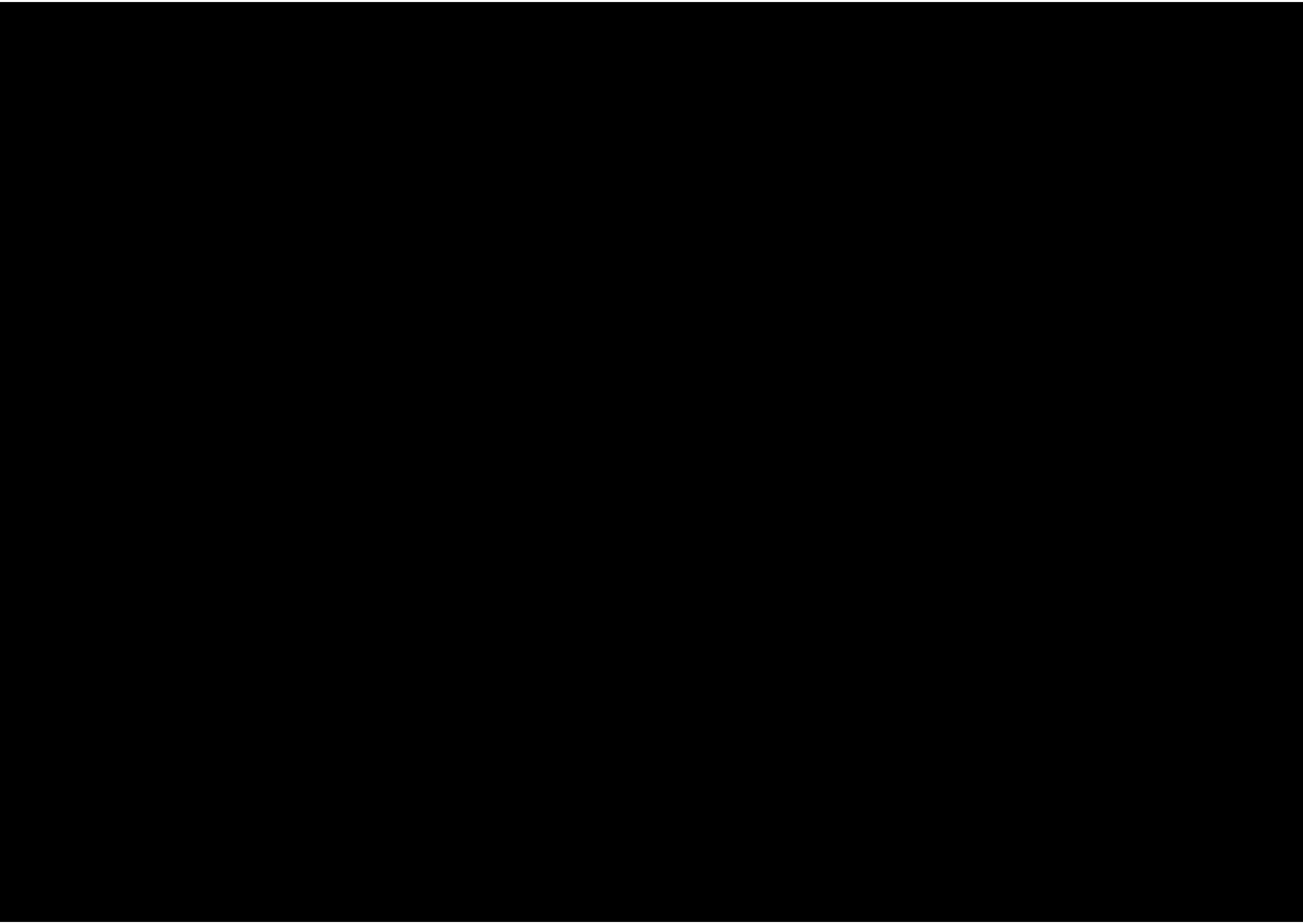
40 m/s isosurface Dec 1-3 1988



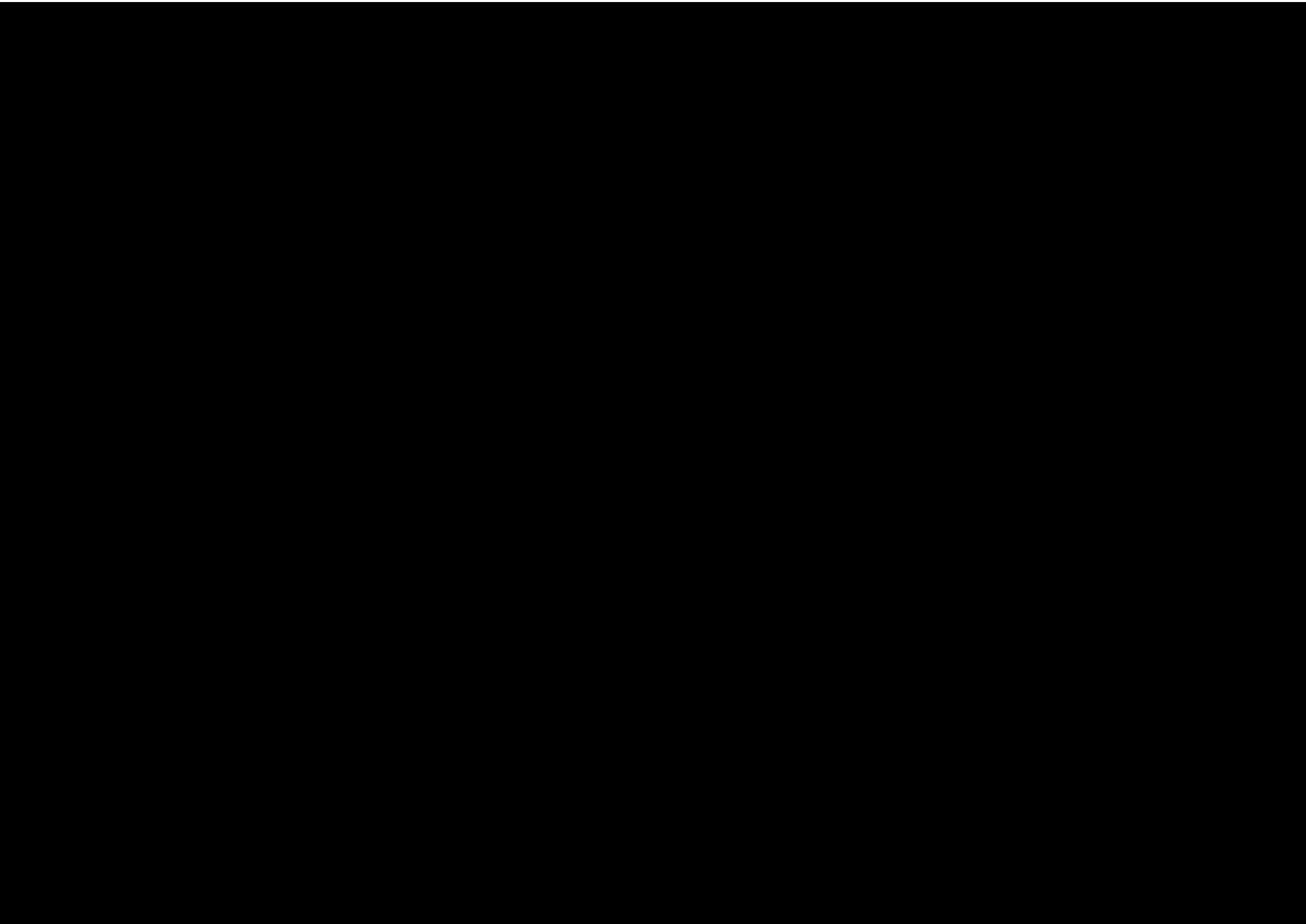
5 km pressure (4 hPa contour interval) outer grid Dec 1-3 1988



10 km pressure (4 hPa contour interval) outer grid Dec 1-3 1988

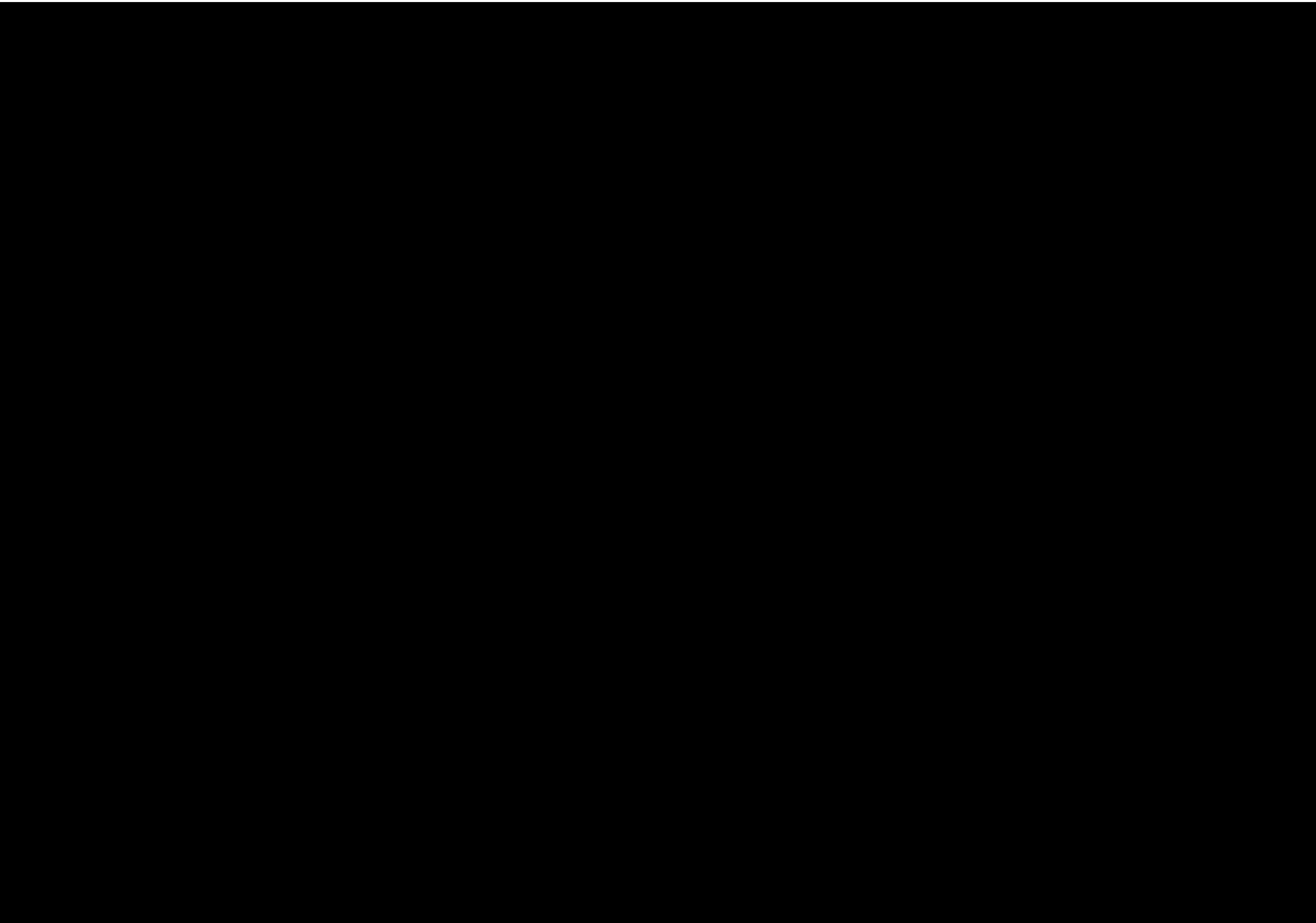


PV section GM – Date Line Dec 1-3 1988

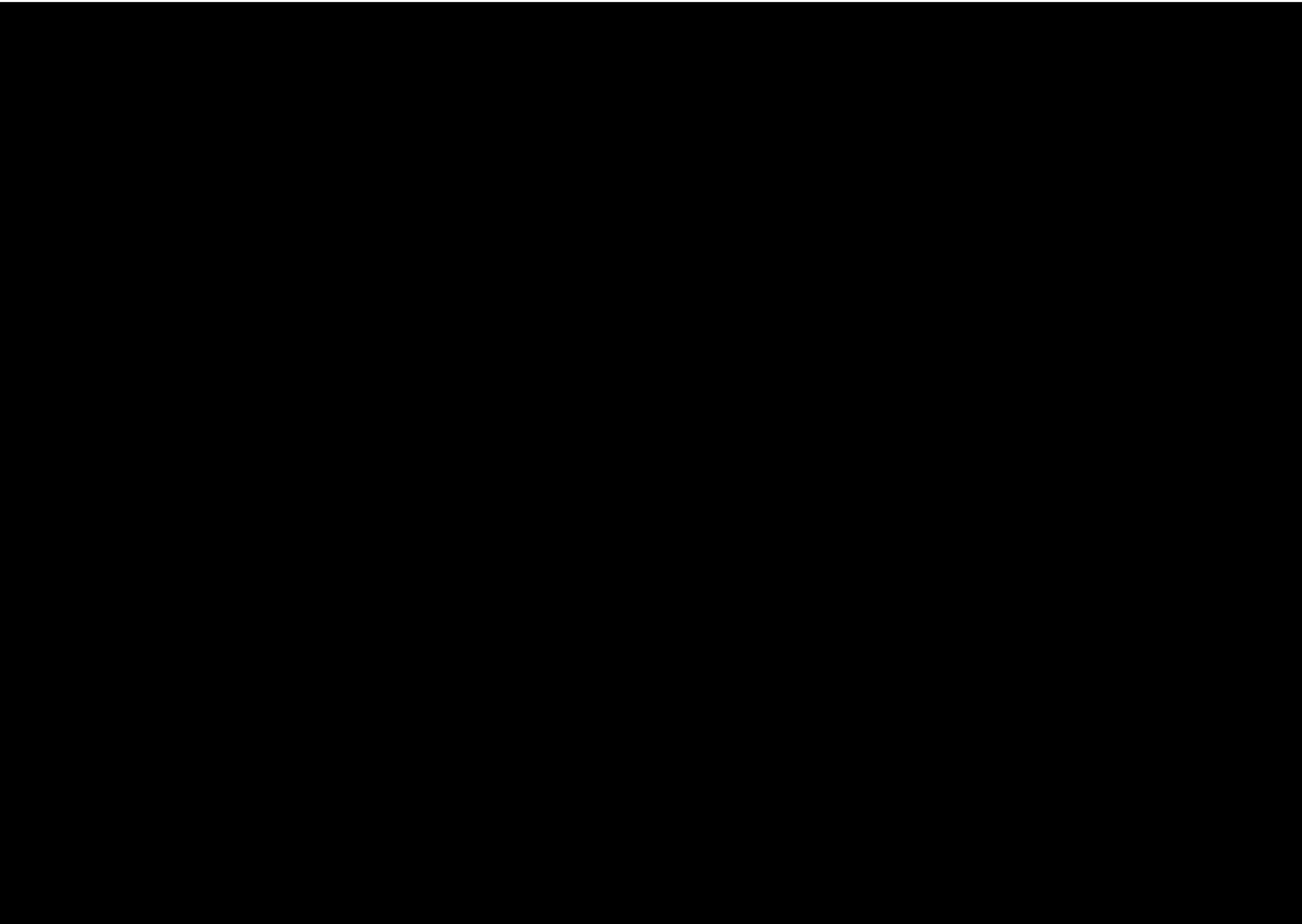


PV = - 2 isosurface colored by Potential Temperature (yellow ~ 340 K) Dec 1-3 1988

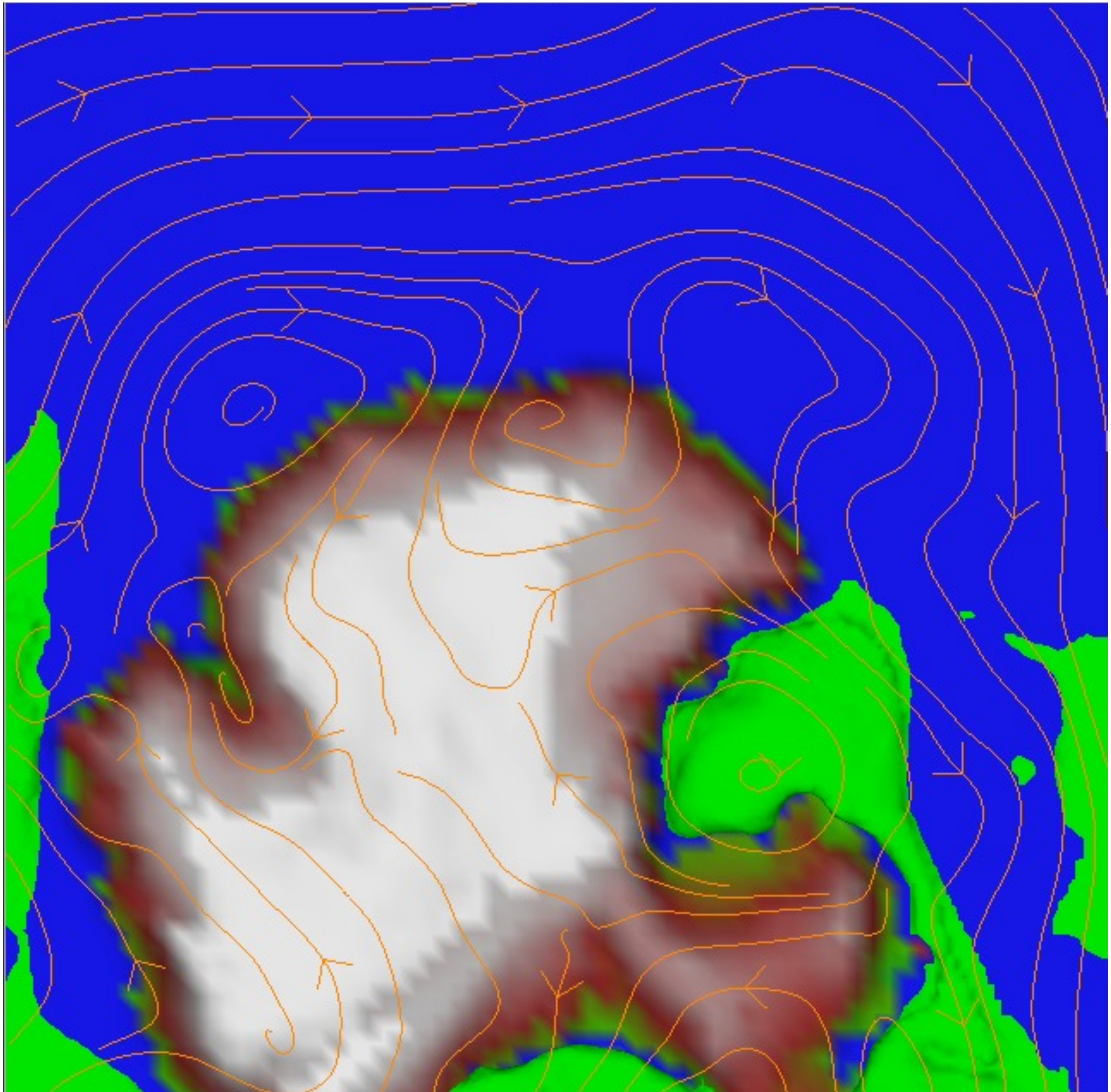
4 km streamfunction inner grid Dec 1-3 1988



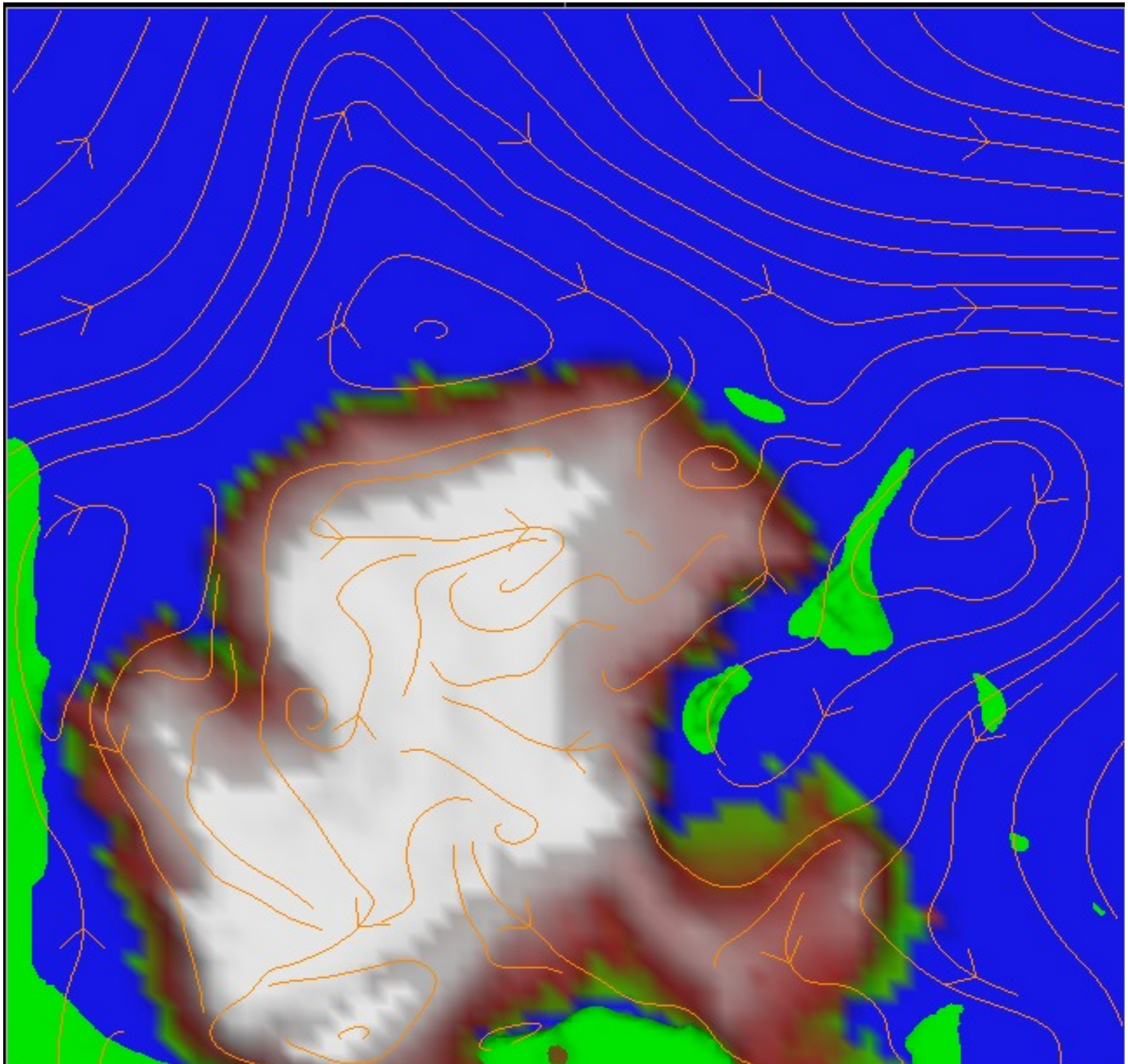
4 km streamfunction 40 km x 40 km x 300 m Dec 5-9 1988



4 km streamfunction Tuesday Dec 6 1988 341



4 km streamfunction Thursday Dec 9 1988 343



Conclusions

During La Nina:

- column ozone maximum shifted westward ~50^o
- stronger poleward wave activity flux from Indonesia
- stronger planetary wave one
- stronger polar vortex
- colder East Antarctica
- enhanced Ross Sea low