Planetary waves and zonal asymmetry in ozone distribution above Antarctica

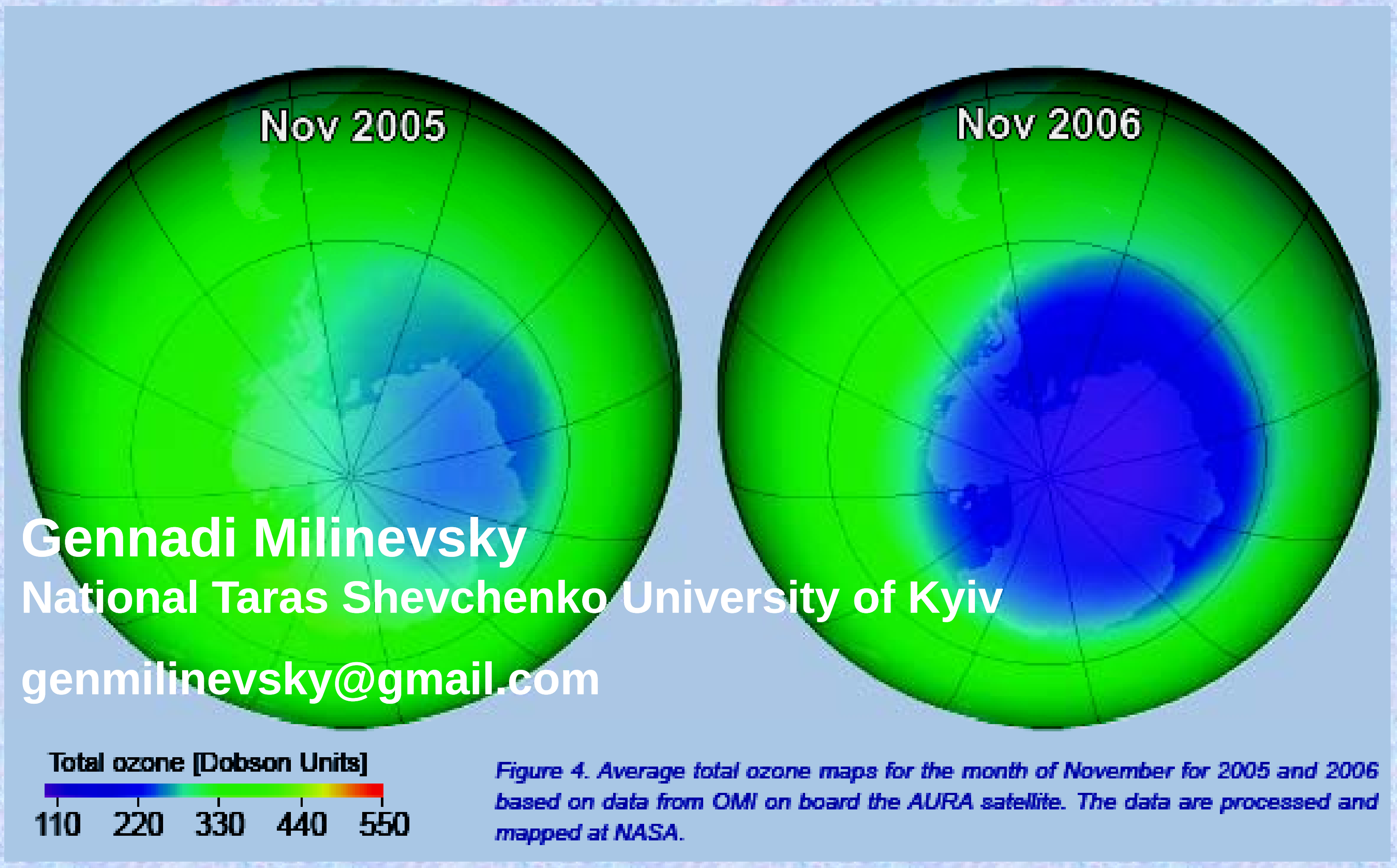
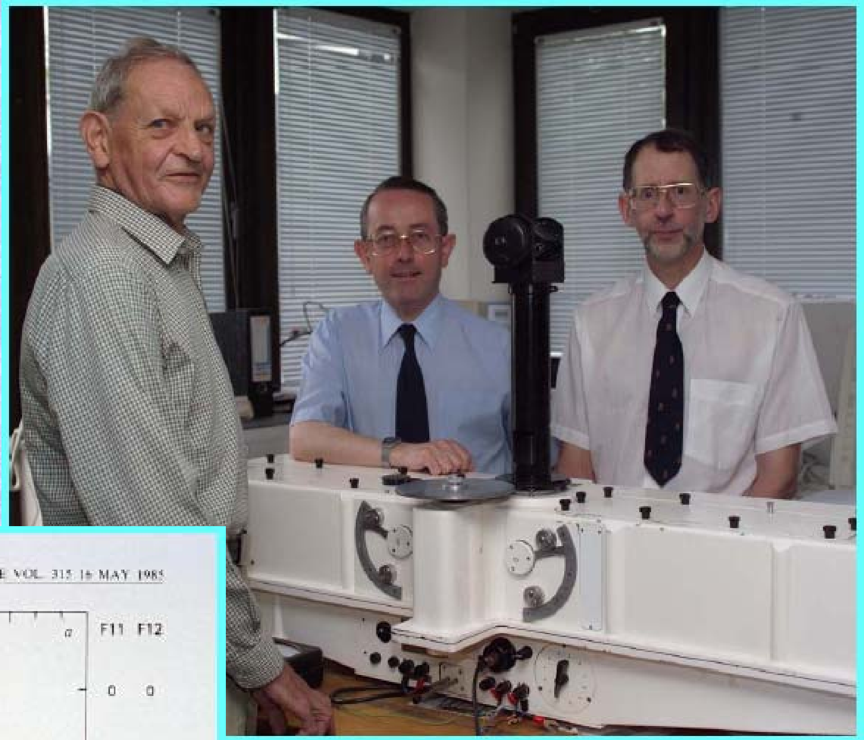


Figure 4. Average total ozone maps for the month of November for 2005 and 2006 based on data from OMI on board the AURA satellite. The data are processed and mapped at NASA.

Gennadi Milinevsky
National Taras Shevchenko University of Kyiv
genmilinevsky@gmail.com

Summer school "Atmosphere researches. Challenge for Ukraine",
Kyiv, 15-17 September 2008 (17 Sep, Wed 11.45-12.30)

Ozone hole discovery



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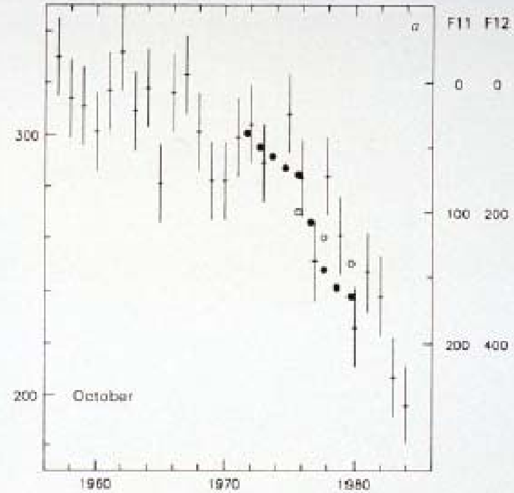
Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction

J. C. Farman, B. G. Gardiner & J. D. Shanklin

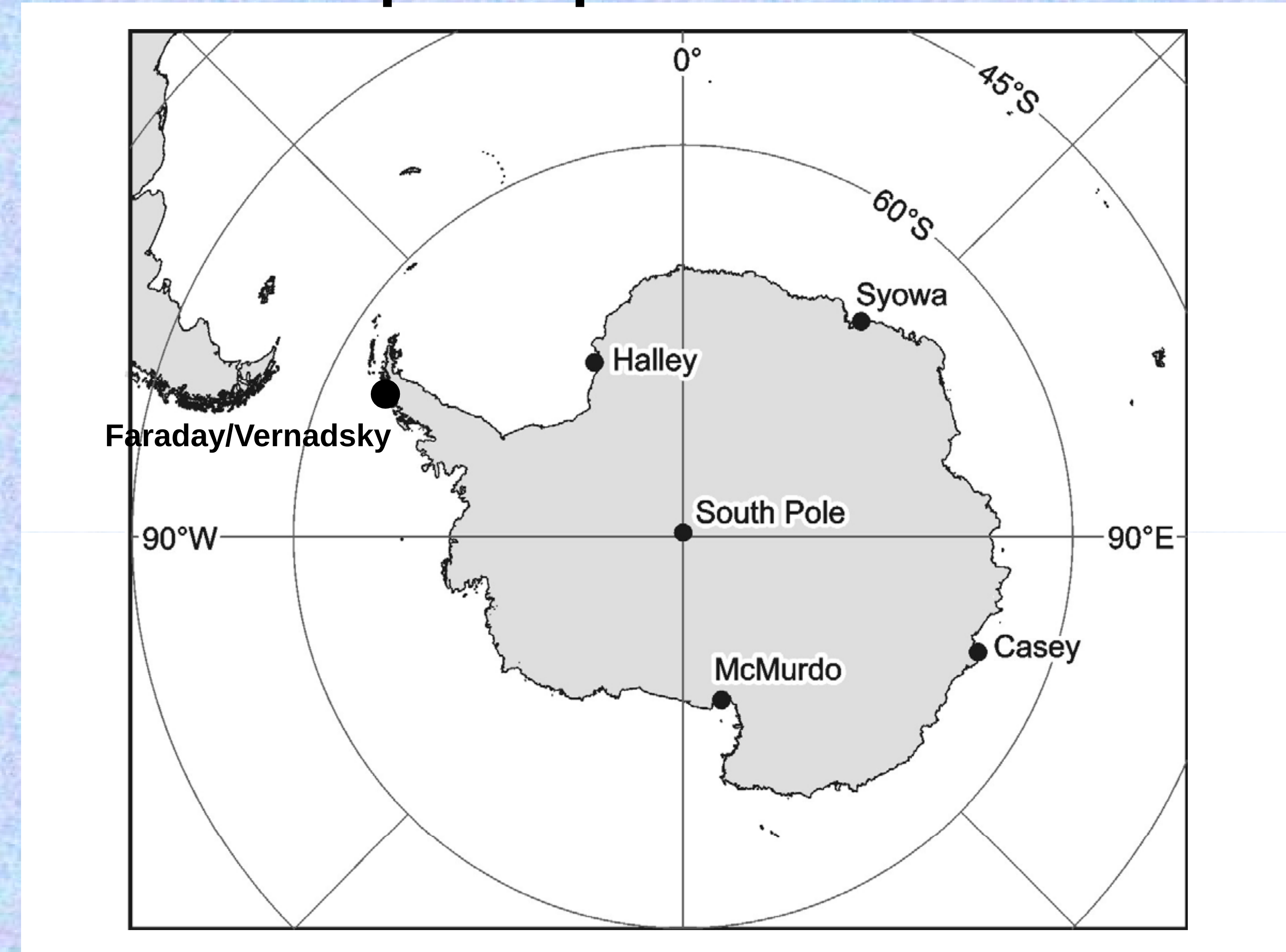
British Antarctic Survey, Natural Environment Research Council, High Cross, Madingley Road, Cambridge CB3 0ET, UK



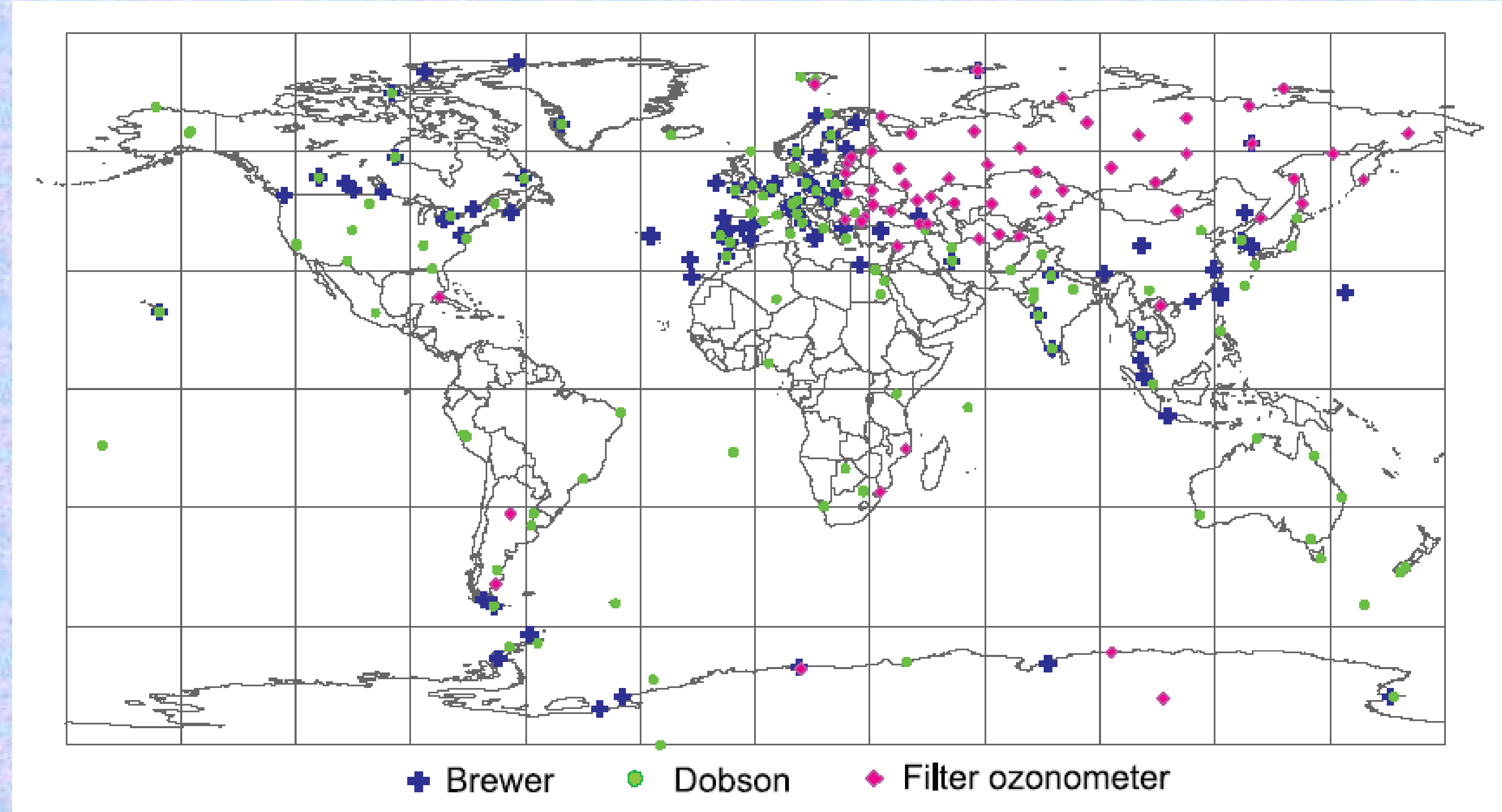
Recent attempts[1,2] to consolidate assessments of the effect of human activities on stratospheric ozone (O_3) using one-dimensional models for 30° N have suggested that perturbations of total O_3 will remain small for at least the next decade. Results from such models are often accepted by default as global estimates[3]. The inadequacy of this approach is here made evident by observations that the spring values of total O_3 in Antarctica have now fallen considerably. The circulation in the lower stratosphere is apparently unchanged, and possible chemical causes must be considered.

May 1985

Antarctic total ozone ground based measurements with Dobson, Brewer spectrophotometers

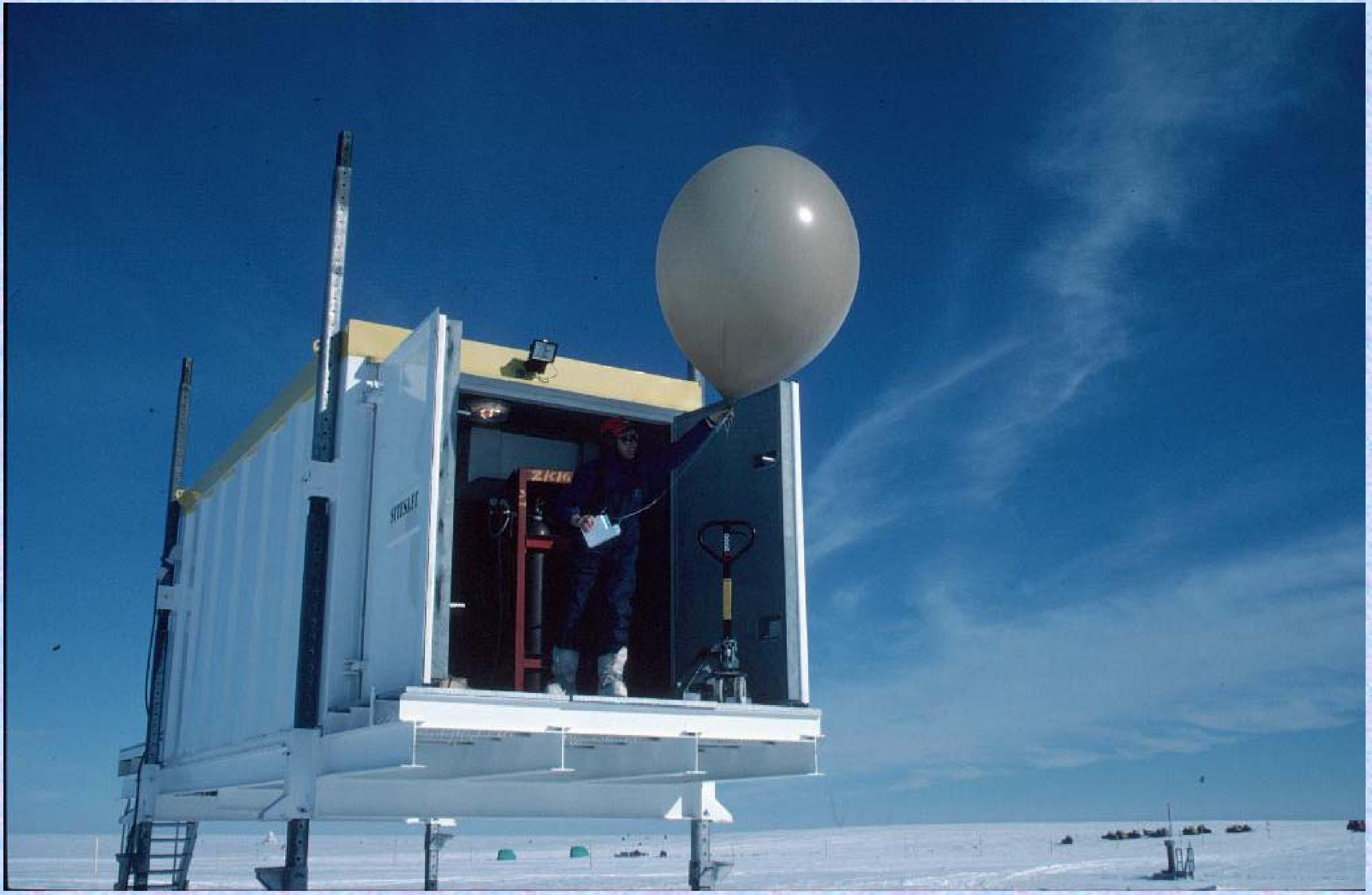


Total ozone ground based measurements with Dobson, Brewer spectrophotometers and filter ozonometers



Fioletov et al., JGR, 2008

Ozonesonde at Halley Station, Antarctica



Shanklin, 2006

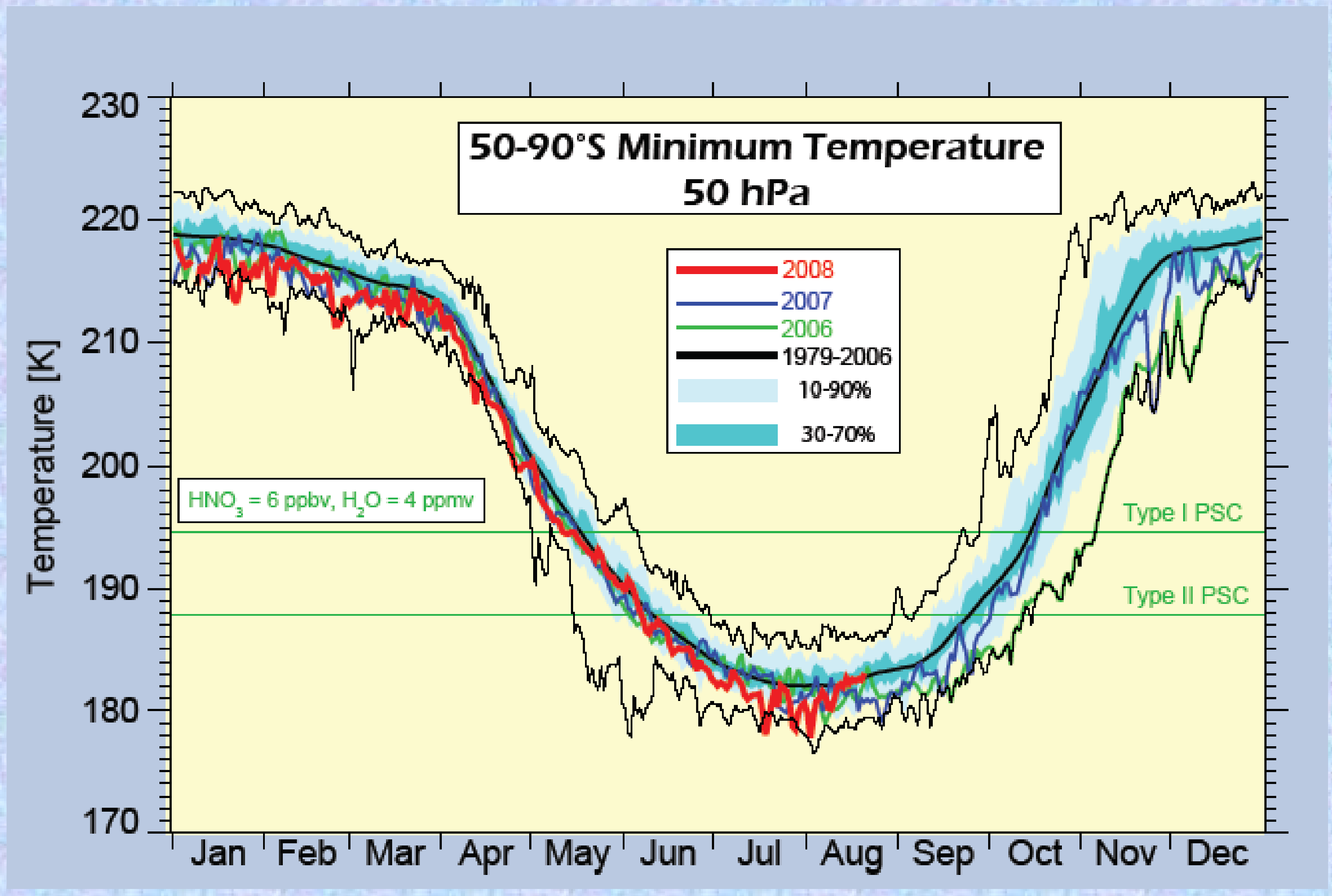
Noctilucent ('night-shining') Clouds are an indicator of extremely cold conditions in the upper atmosphere

Shanklin, 2006

2008: 50 hPa minimum temperature

-78C

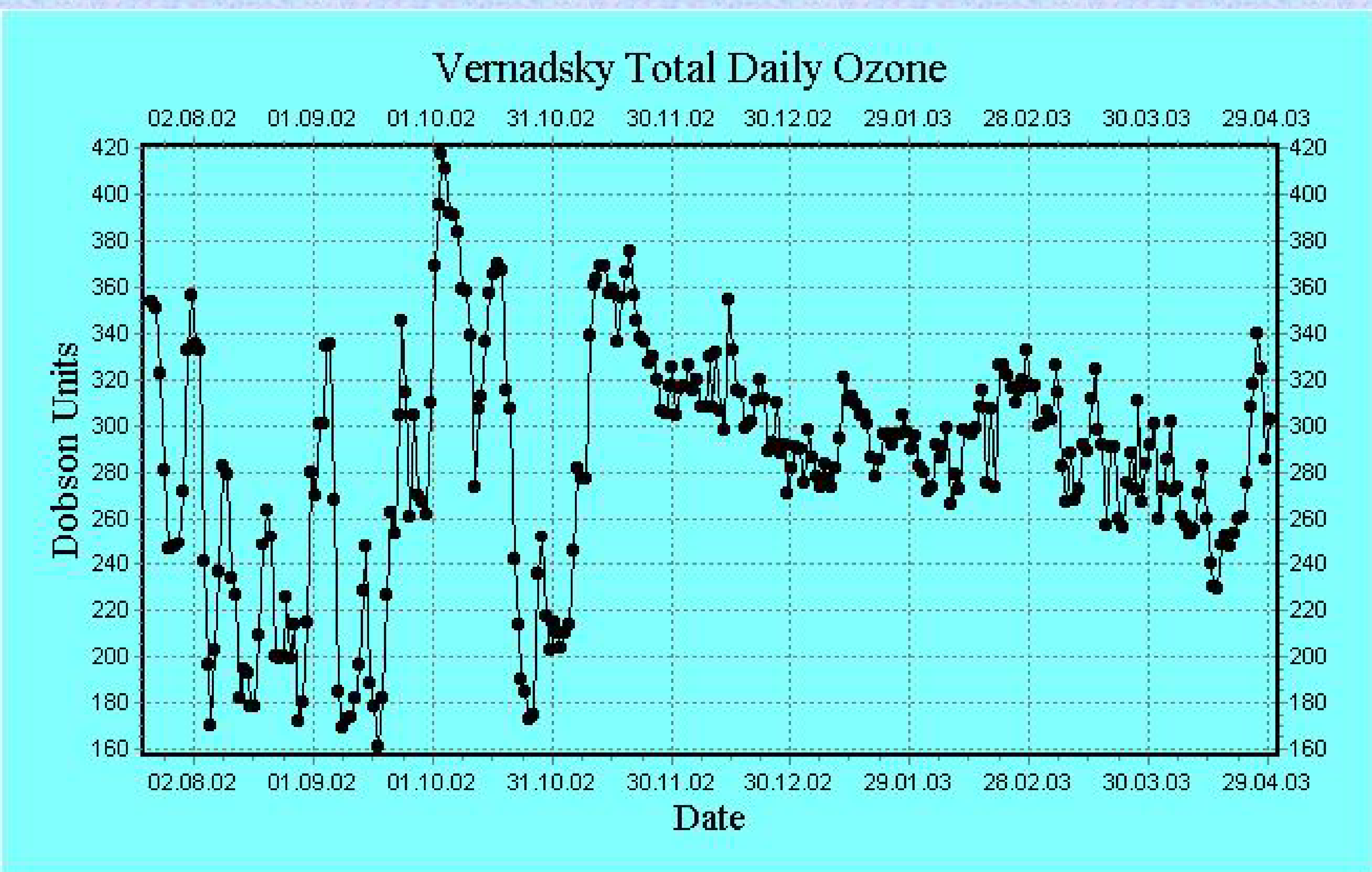
-85C



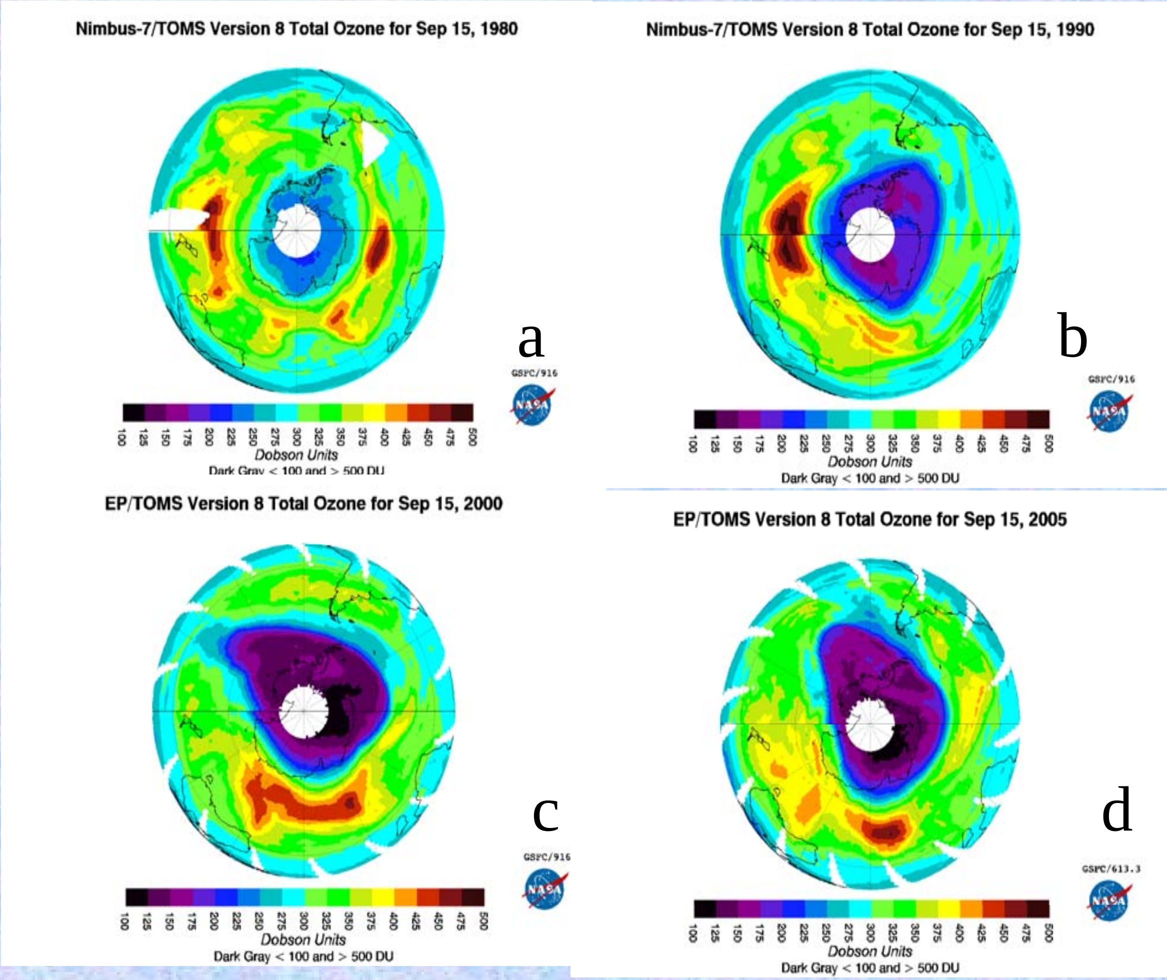
NASA

Total ozone measurements by Dobson spectrophotometer at Vernadsky

Ozone measurements 2002-2003 season



Ozone hole development



Total ozone content by Total Ozone Mapping Spectrometer measurements

Nimbus-7,

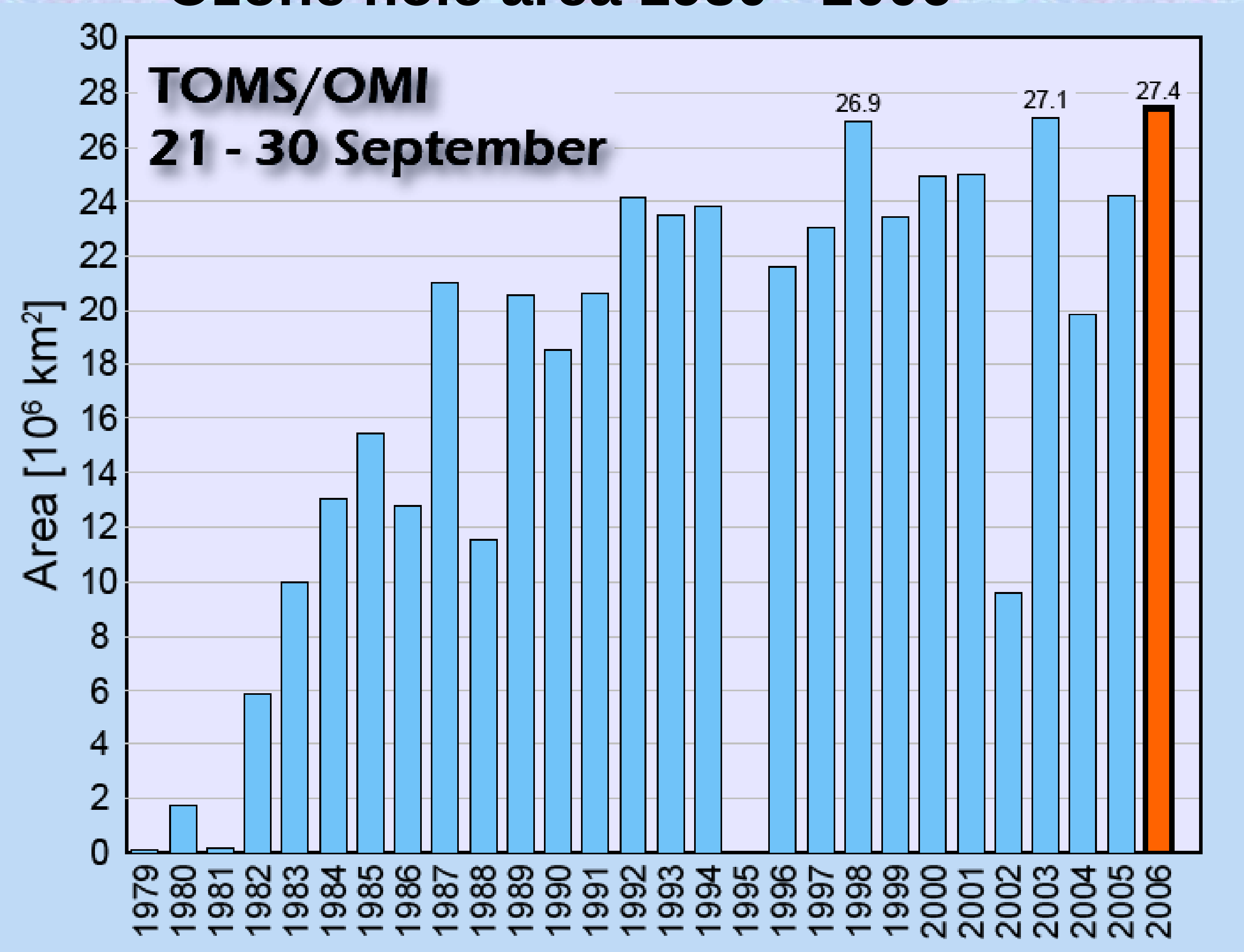
Meteor-3,

Earth Probe

(Aura, OMI since 2004)

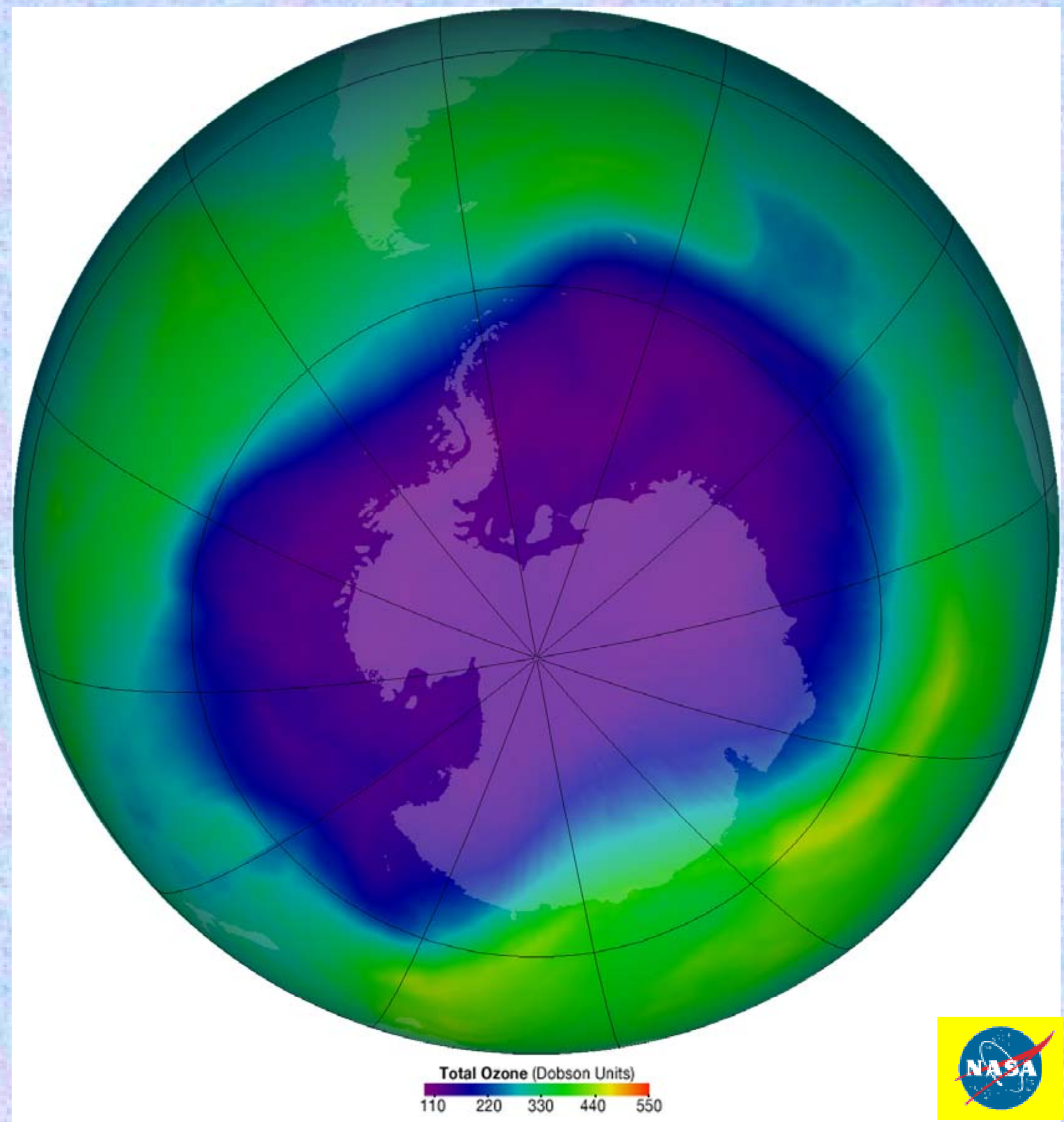
Ozone 15 September: a) 1980; b) 1990; c) 2000; d) 2005.

Ozone hole area 1980 - 2006

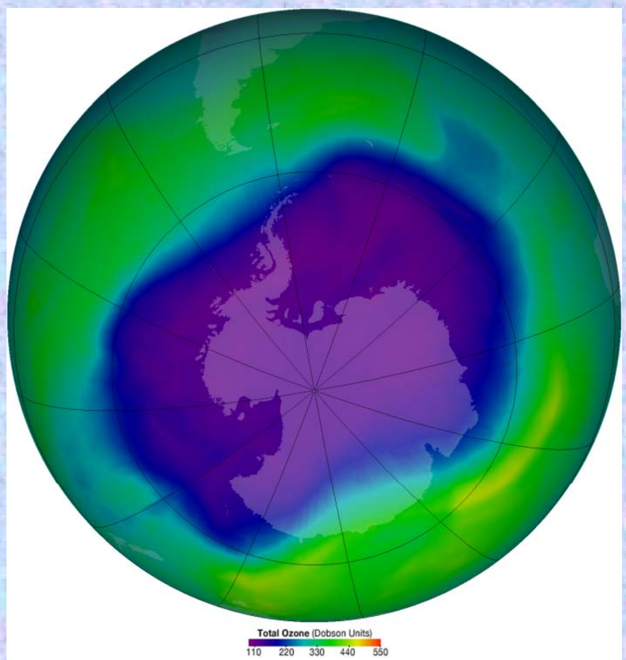


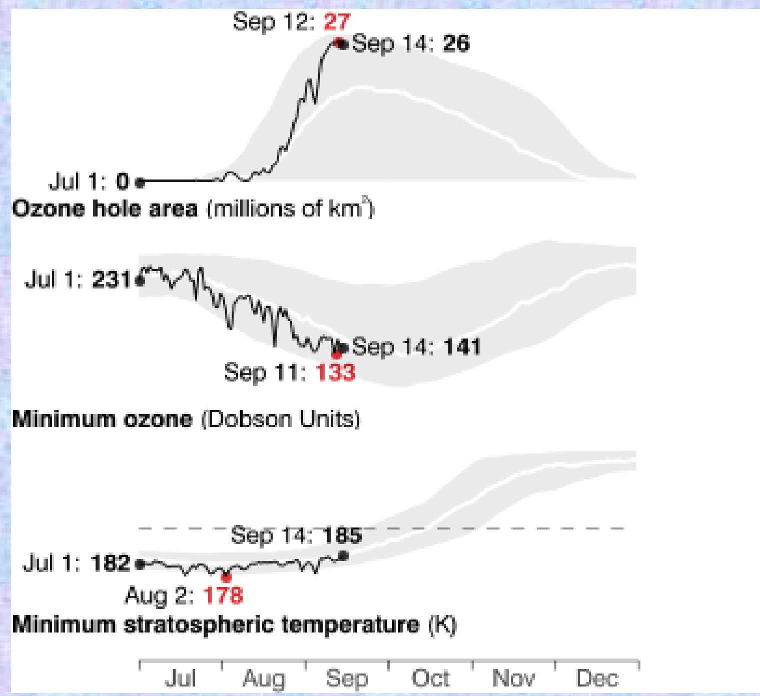
WMO, 2006

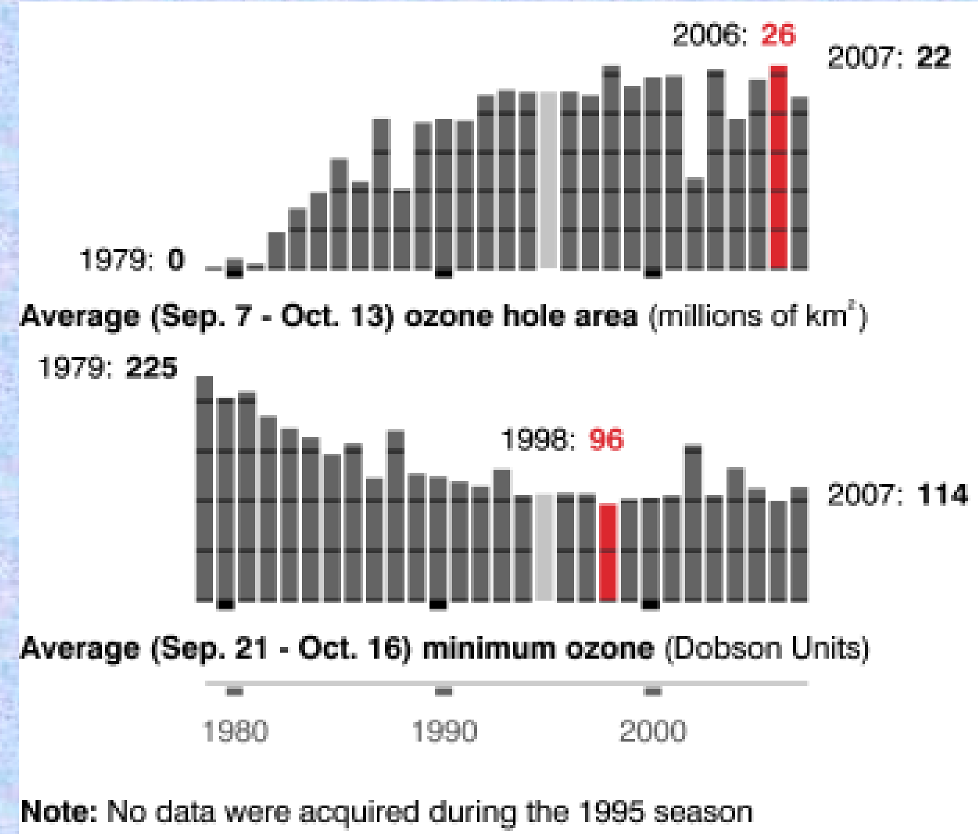
Biggest in area ozone hole 24 Sept 2006



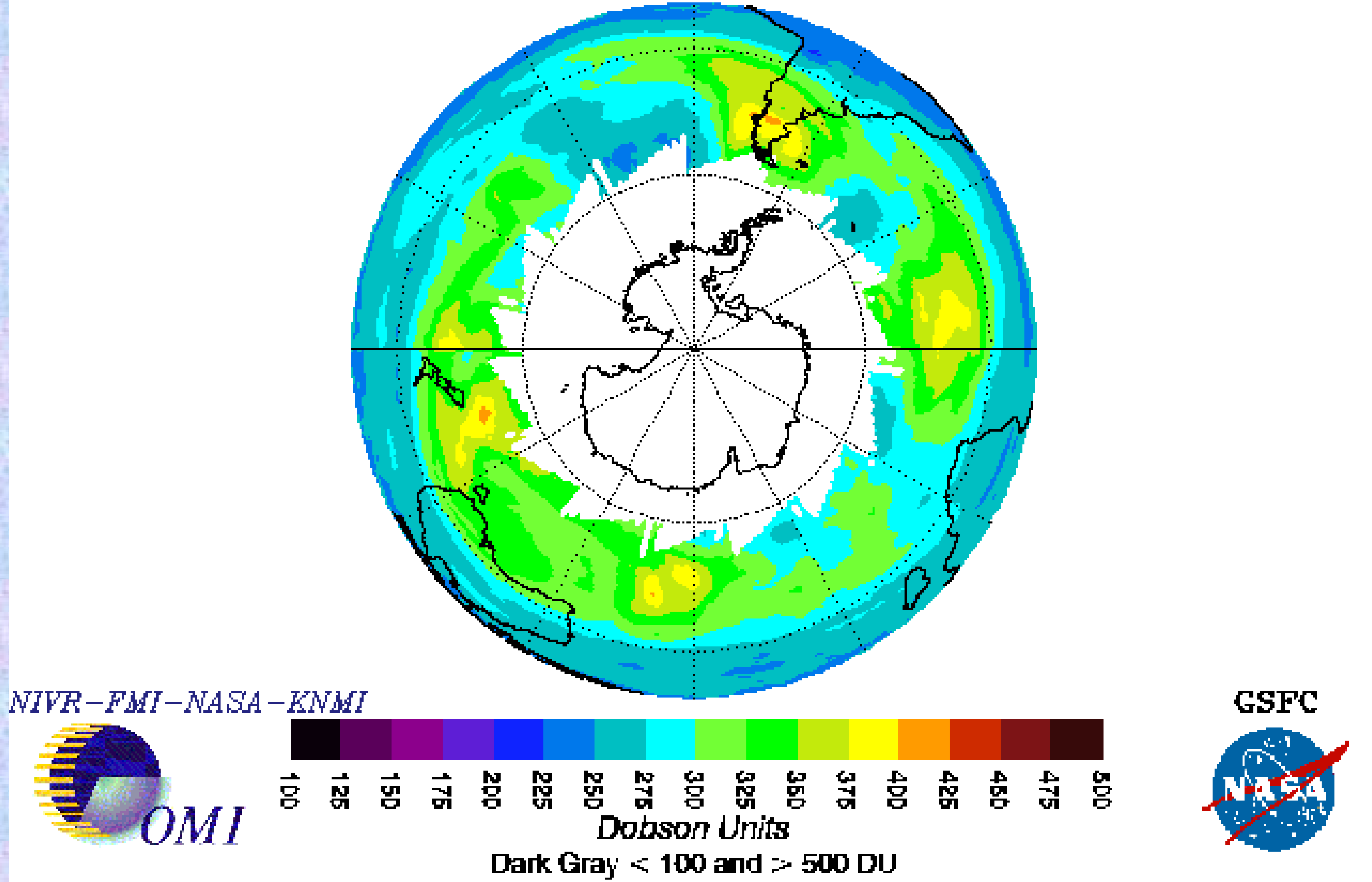
Ozone hole
14 September 2008



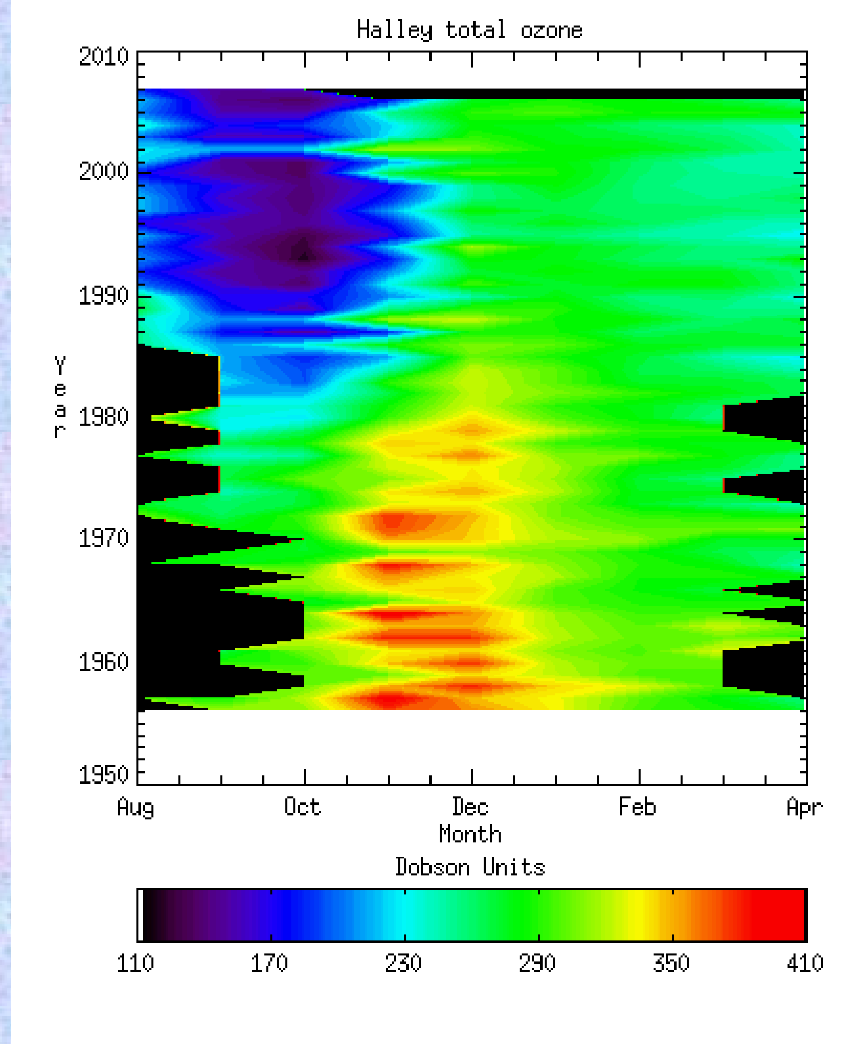


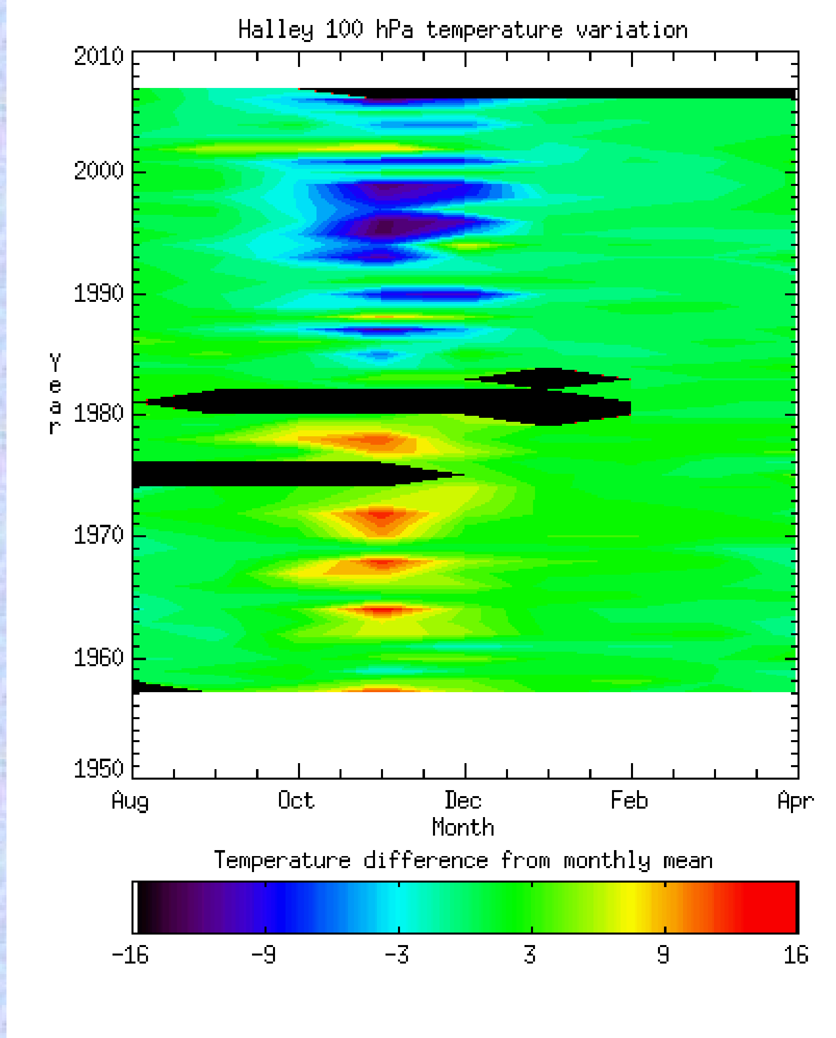


OMI Total Ozone for Jun 21, 2007



Halley total ozone and 100 hPa temperature 1957 - 2007

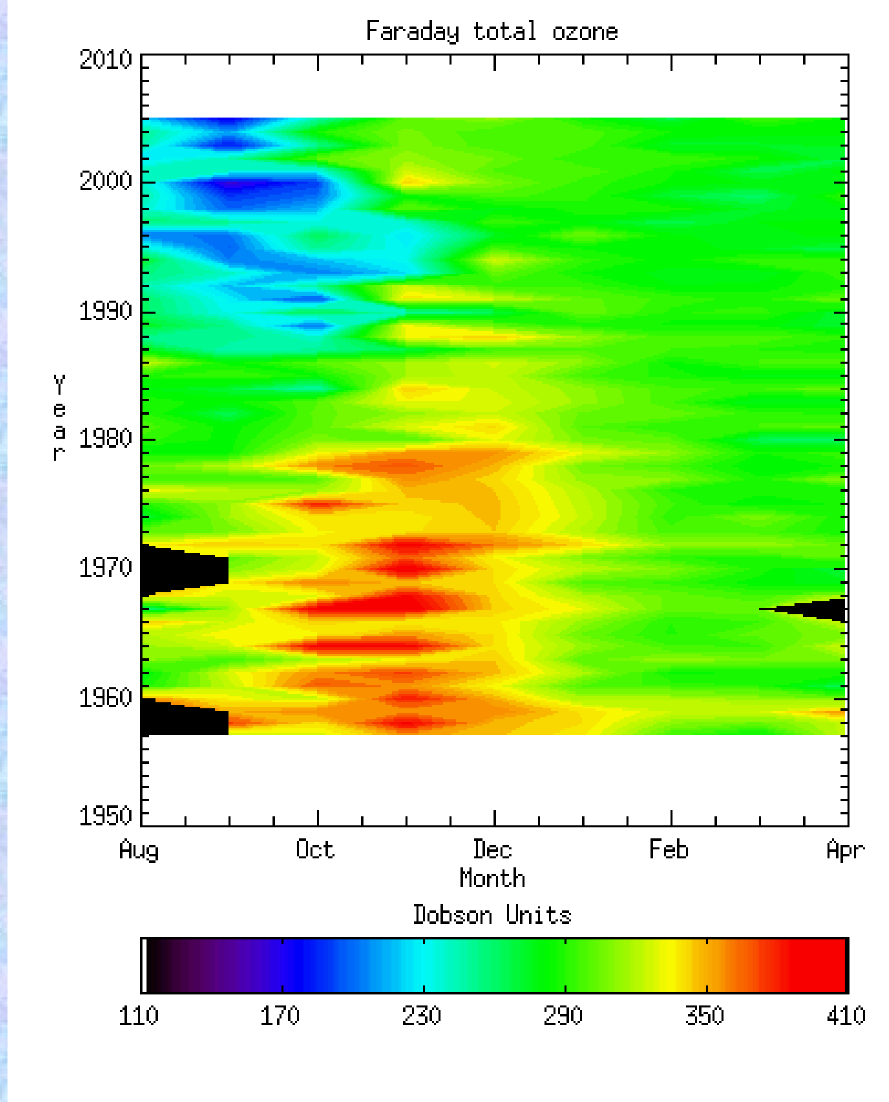




Shanklin, 2007

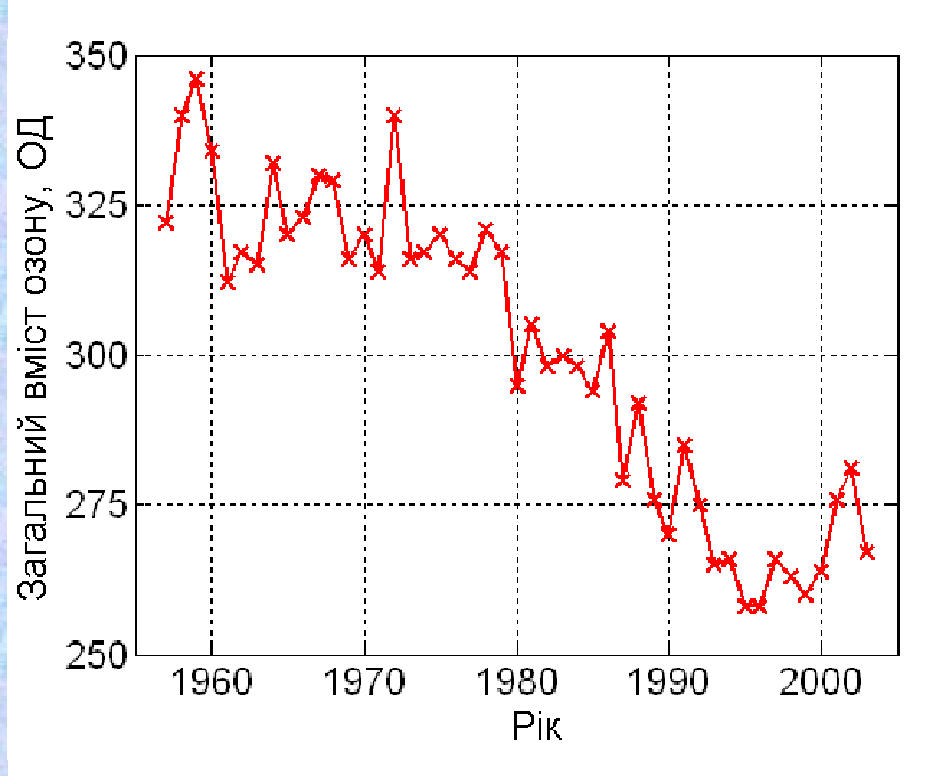
100 hPa – 16 km

Faraday/Vernadsky total 1957 - 2005



Shanklin, 2007

Total ozone content trend according Faraday/Vernadsky observations



Season mean data: decreasing since 1980 is observed

Main idea: Planetary waves impact on long-term total ozone distribution in Antarctica

Task:

Analysis of interannual and decadal changes of the quasi-stationary wave amplitude and structure of zonal ozone distribution using the TOMS and partly Dobson Vernadsky station data.

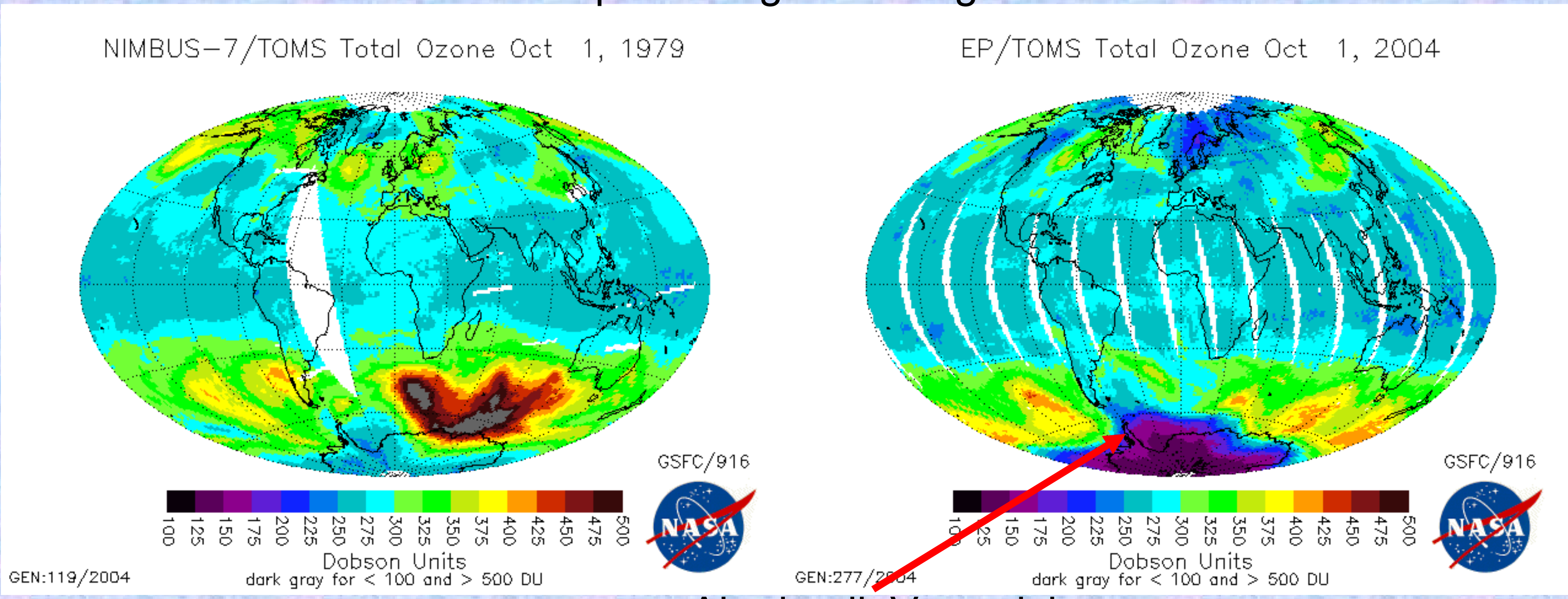
Time interval: 1979-2005.

Season: the spring months September-November.

Analysis method: zonal wave parameters determination using longitudinal distribution of the total ozone at individual latitude circles within 50°S-80°S.

Dataset:
TOMS measurements of total ozone content

http://toms.gsfc.nasa.gov



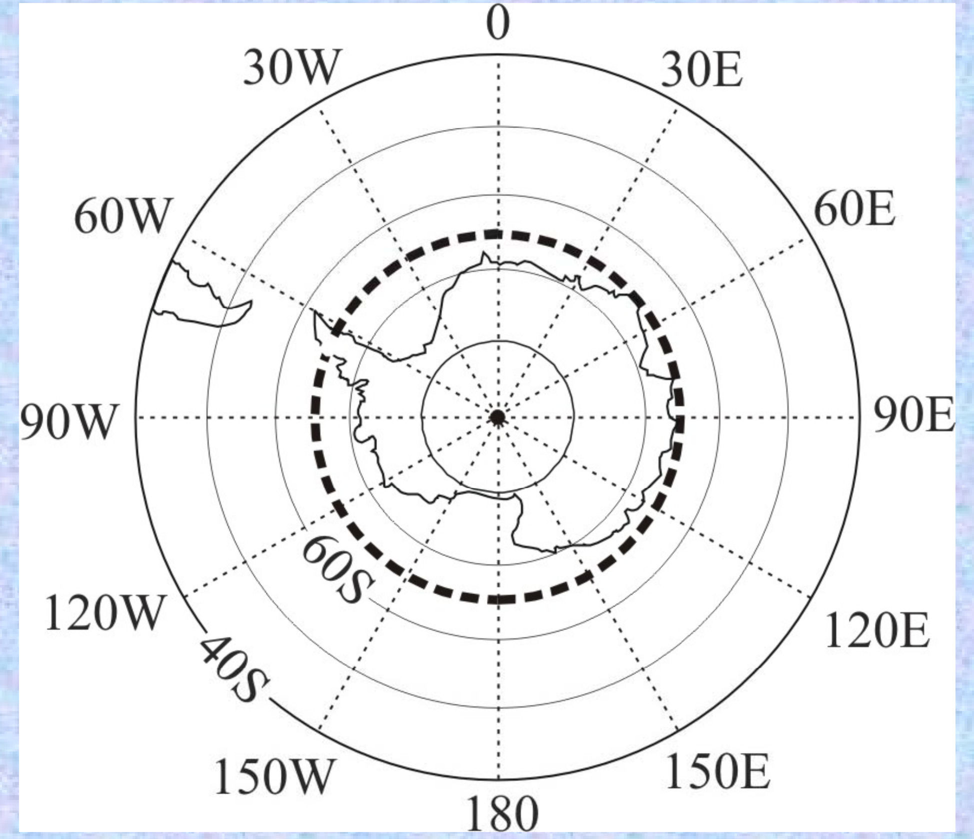
Total ozone distribution on 1.10.1979 and 1.10.2004

Regular satellite measurements of total ozone content (TOC) have been carried out using TOMS (Total Ozone Mapping Spectrometer) since 1978 (with a gap in 1993-95). Spatial resolution is equal 1° on latitude and 1.25° on longitude.

Data base

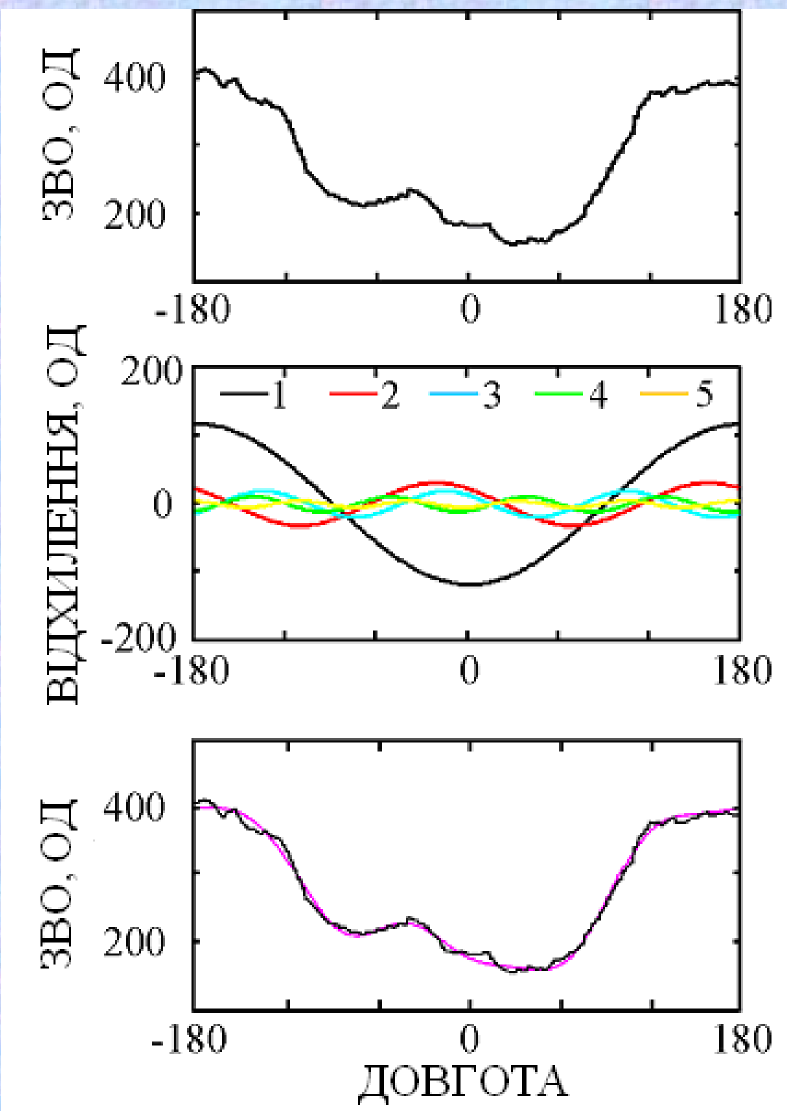
1. Matrix-type database produced from TOMS measurements

2. Database of secondary ozone distribution characteristics (TOC zonal distribution, amplitudes, phase of planetary waves)



Longitude –time visualization method

Fourier analysis



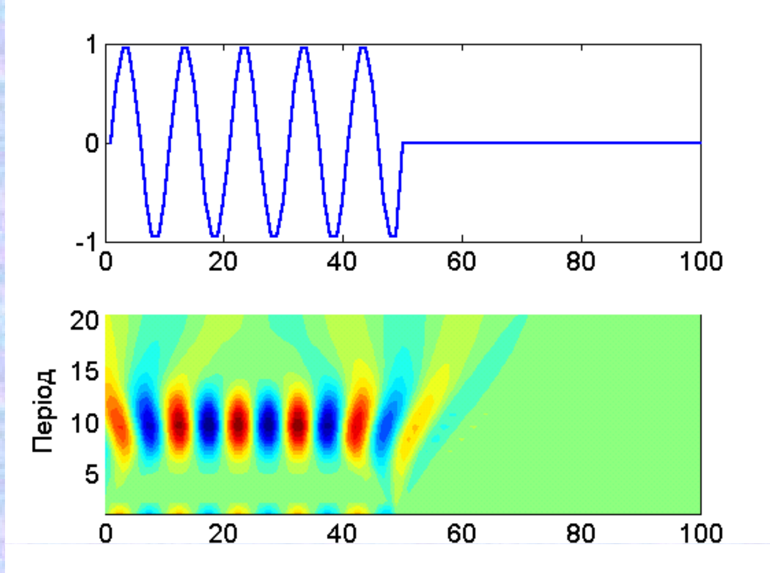
a TOC according TOMS data along 65°S, 15 October 1996

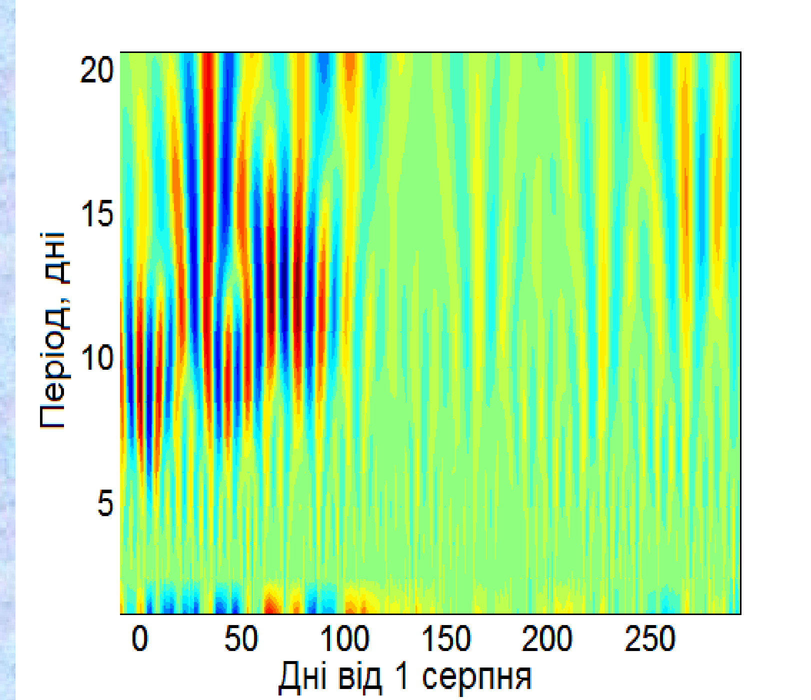
b Zonal number m = 1 – 5

c Observed and restored total ozone distribution

The first five harmonics give error less then ~3%.

Wavelet analysis





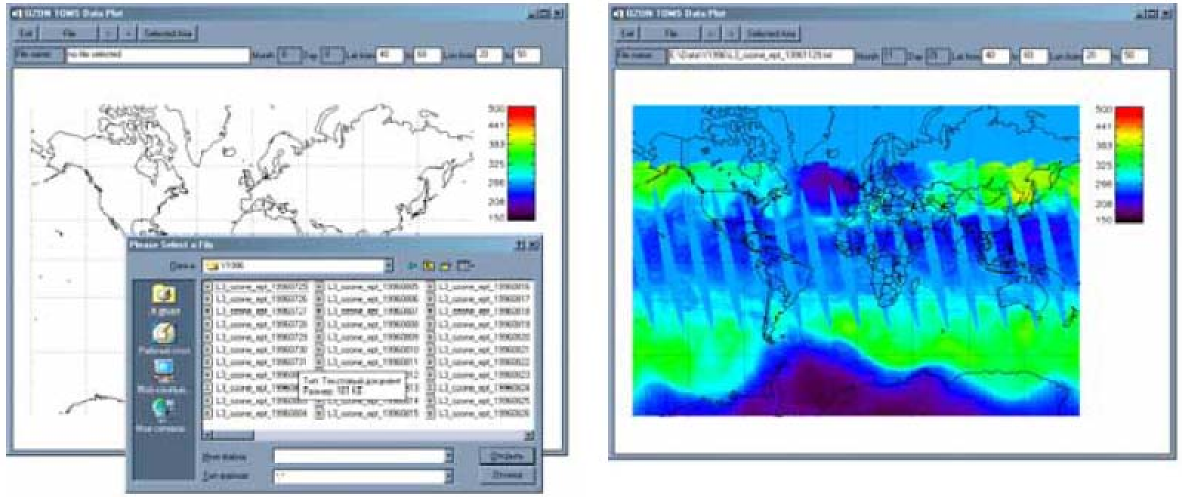
Time localization of periodicity

TOC periodicity, 2002/03 season June - May

Mother wavelet – Morlet function:

$$\psi(t) = e^{-t^2/2} \cdot \cos 5t$$

Software for visualization of daily and monthly mean ozone TOMS measurements



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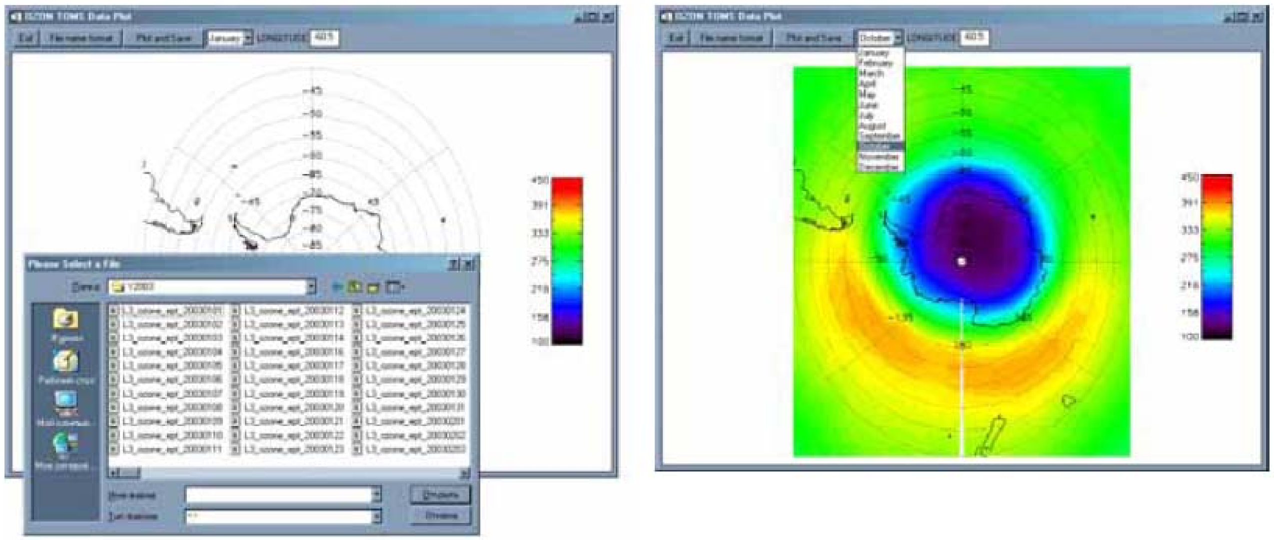

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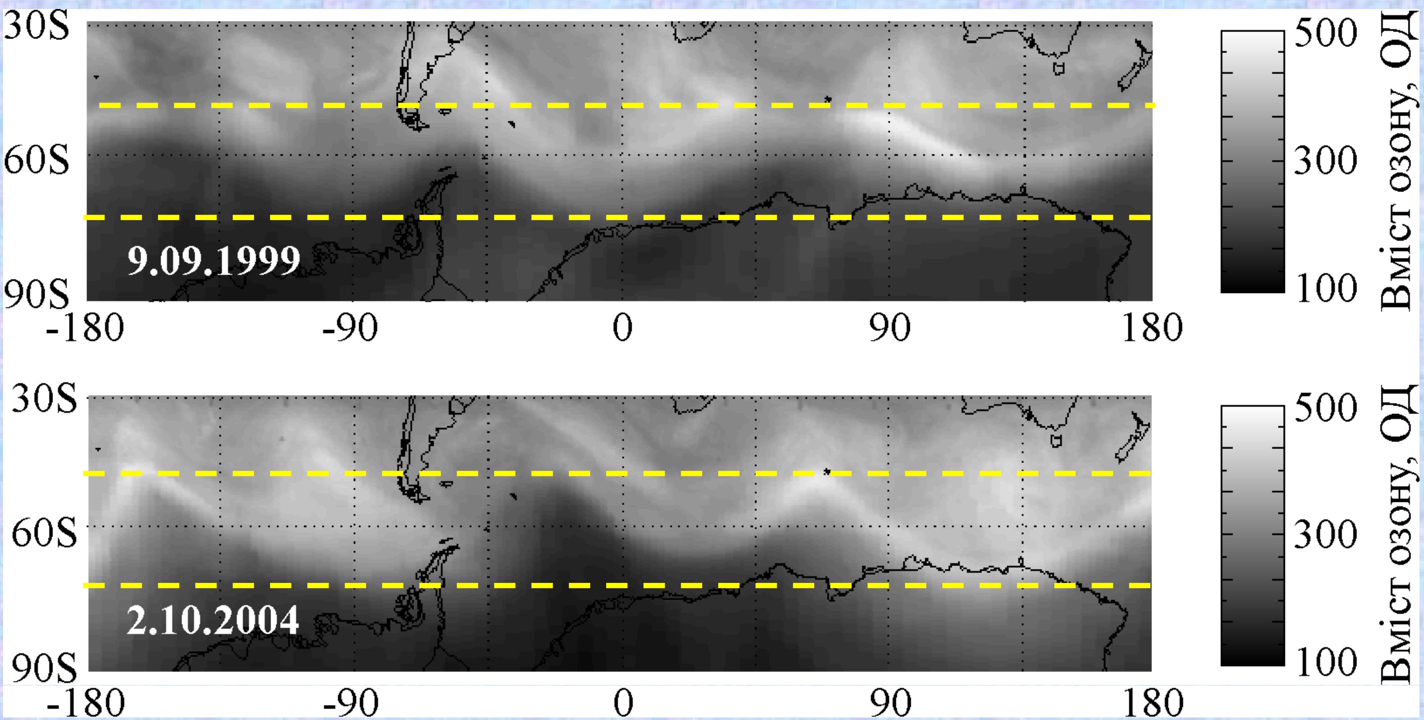
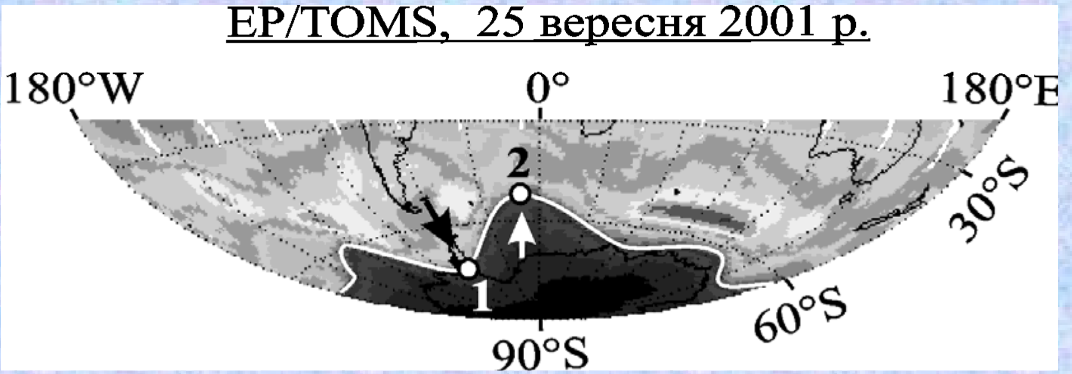
Ozone hole edge deformation by planetary waves

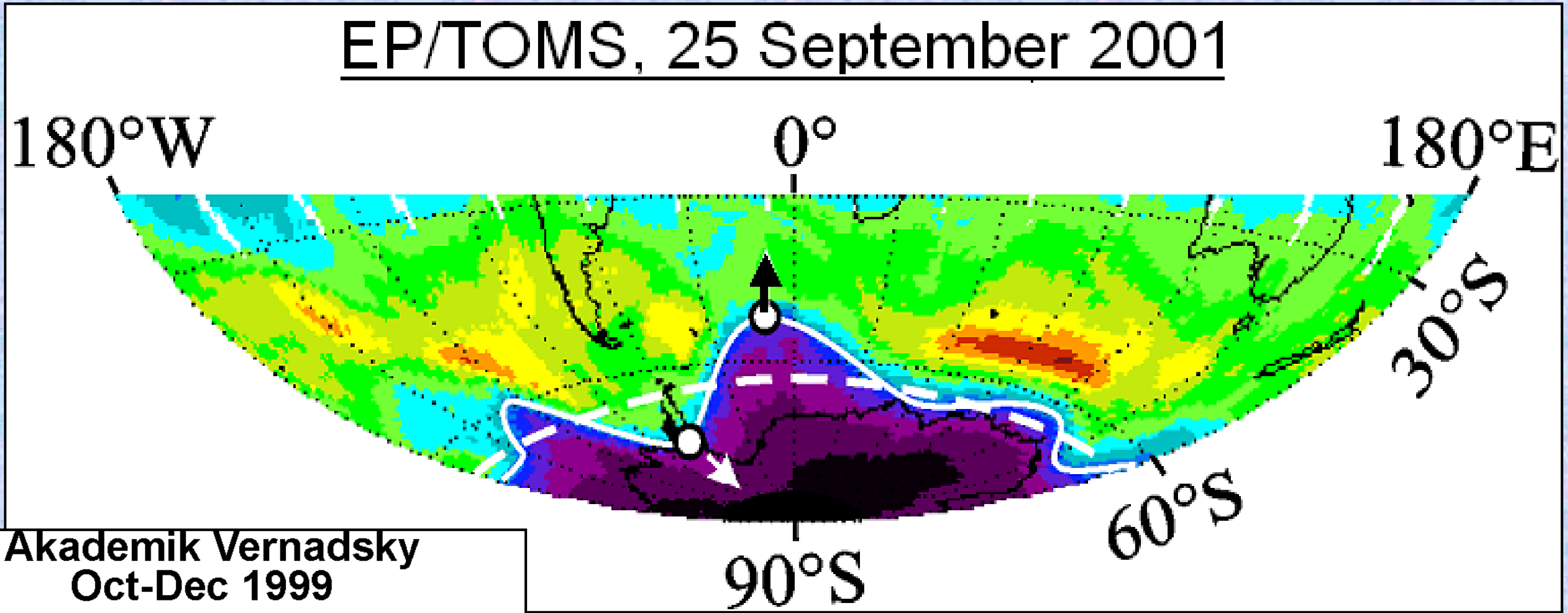


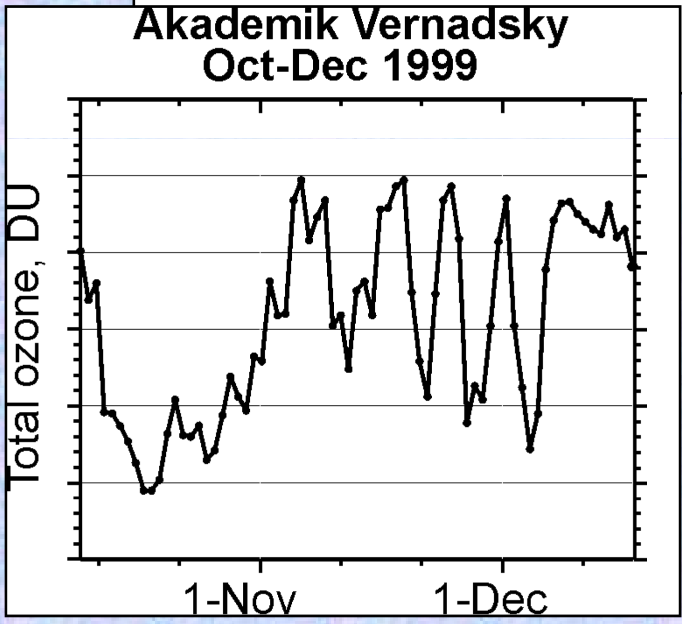


55 – 70°S latitudes – edge of polar vortex, ozone hole edge

Significant zonal asymmetry due to planetary wave activity is observed

Planetary waves in total ozone

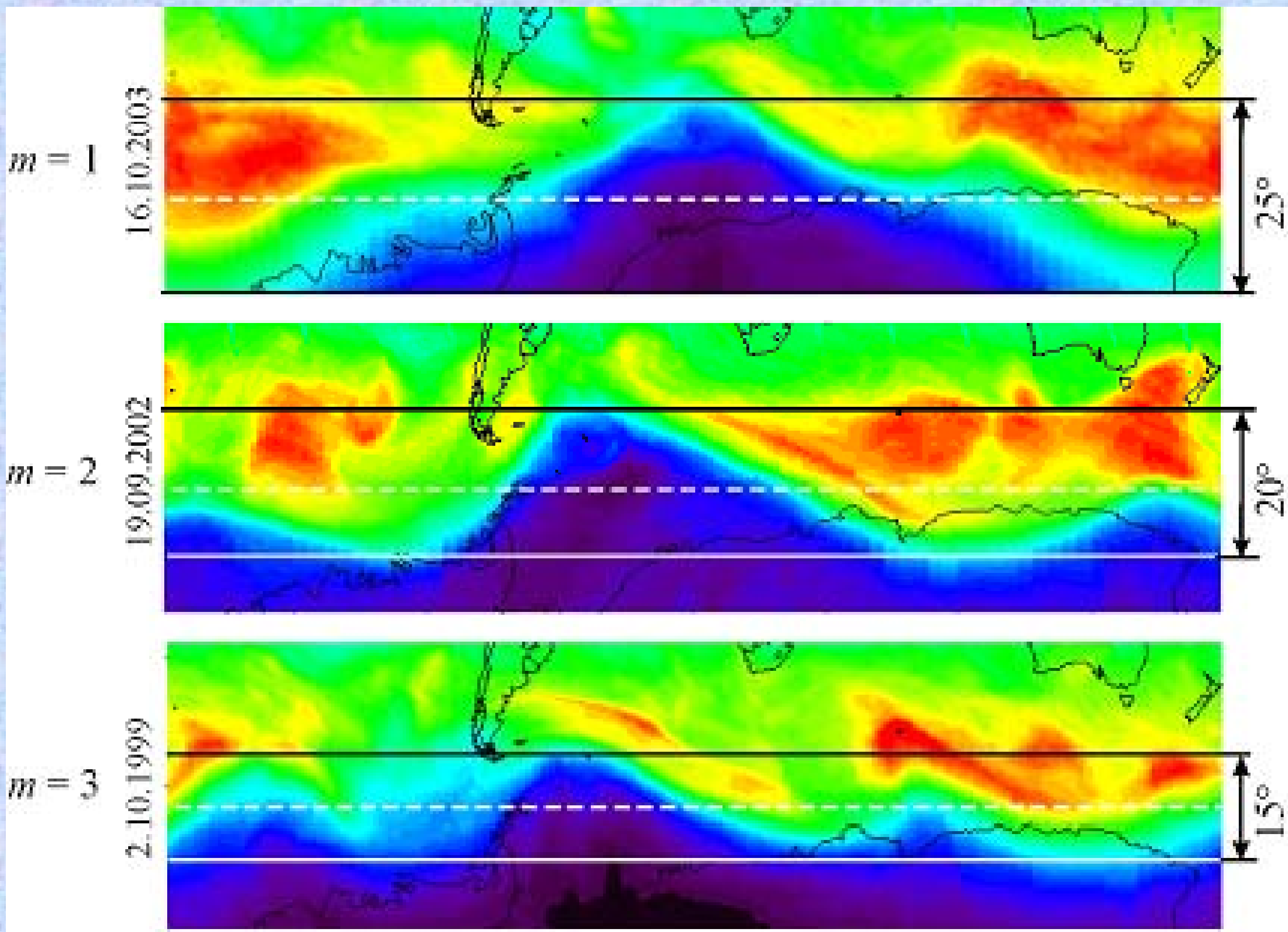




Total ozone distribution to the south of 30°S, 25.09.2001. Dashed line marks the latitude circle 65°S.

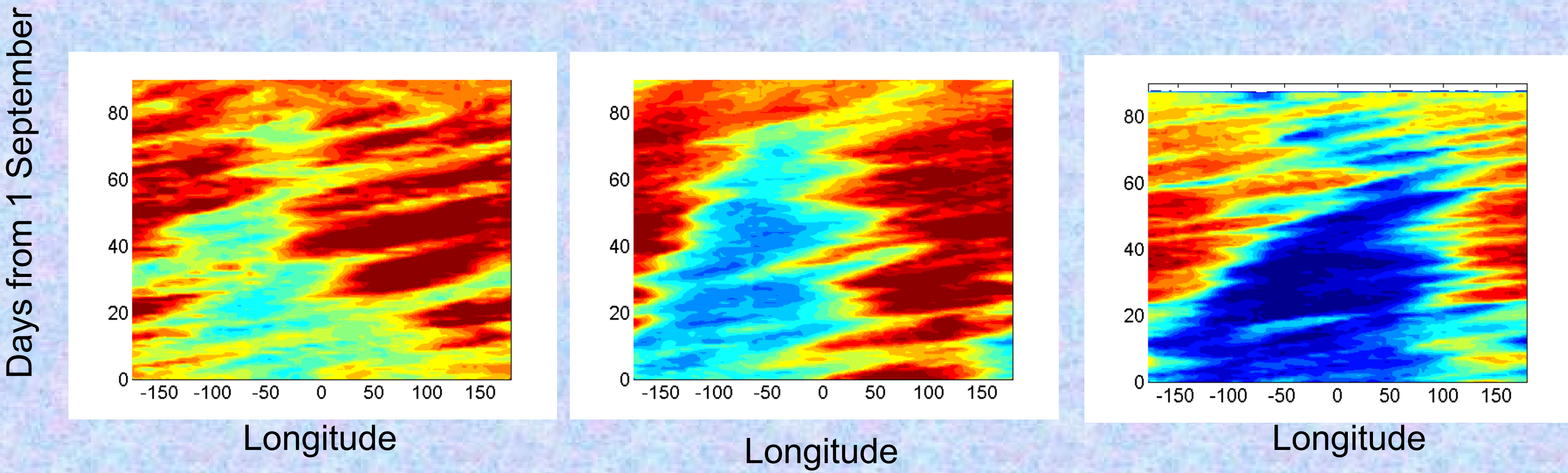
Traveling wave from ground-based observations.

Planetary waves in total ozone distribution (ozone hole edge deformation)



Planetary waves with zonal wave numbers m = 1, 2, 3

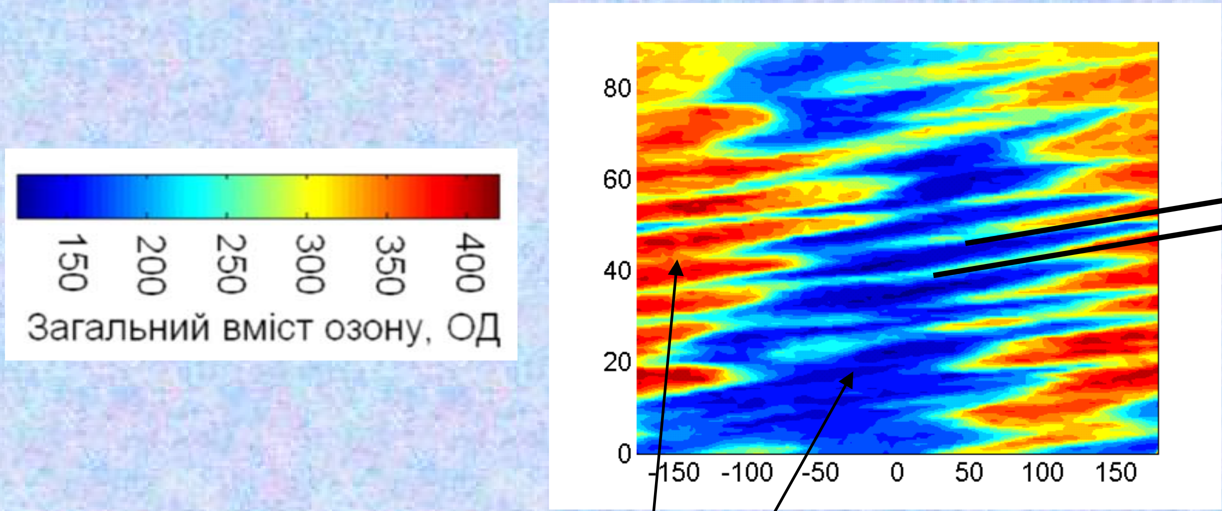
Planetary waves in total ozone



1979 **1988** **2003**

Longitude – time visualization of ozone distribution (65°S) (Hovmöller diagram)

Quasi stationary and traveling waves



Traveling wave

TOC for 65 S, September - November 1996

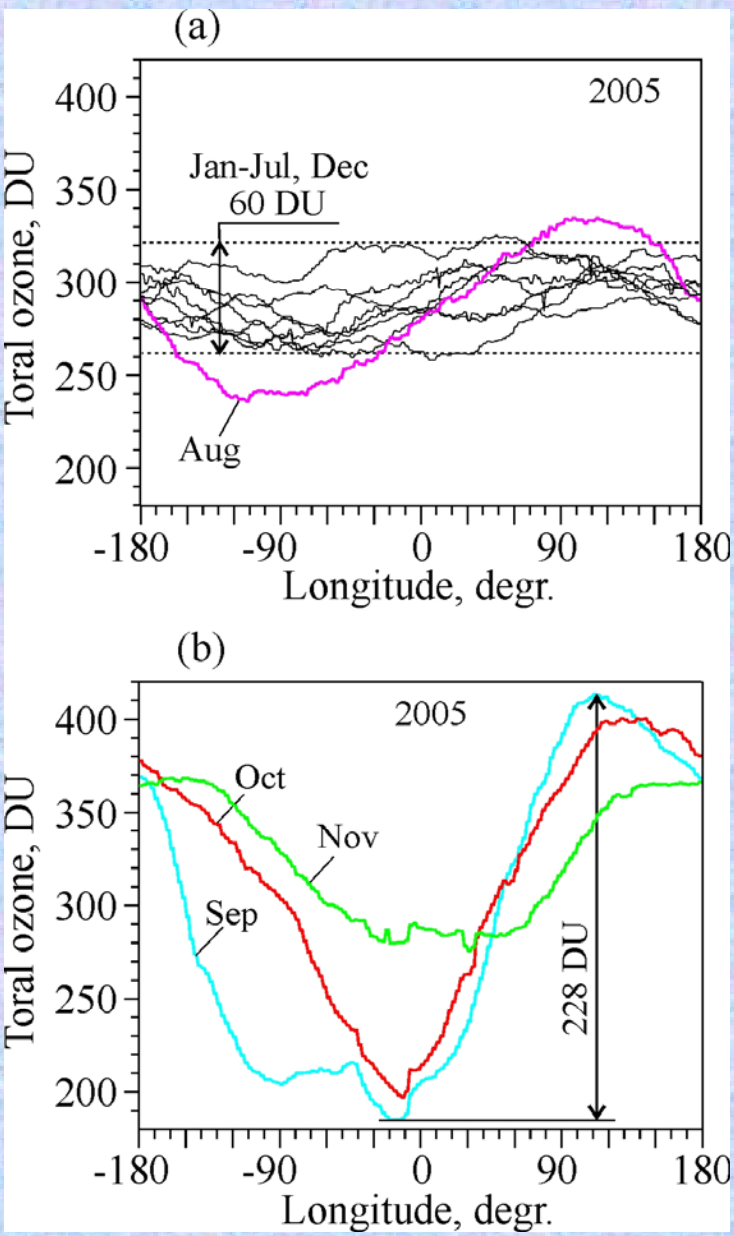
Quasi stationary wave

Increasing of ozone asymmetry in spring

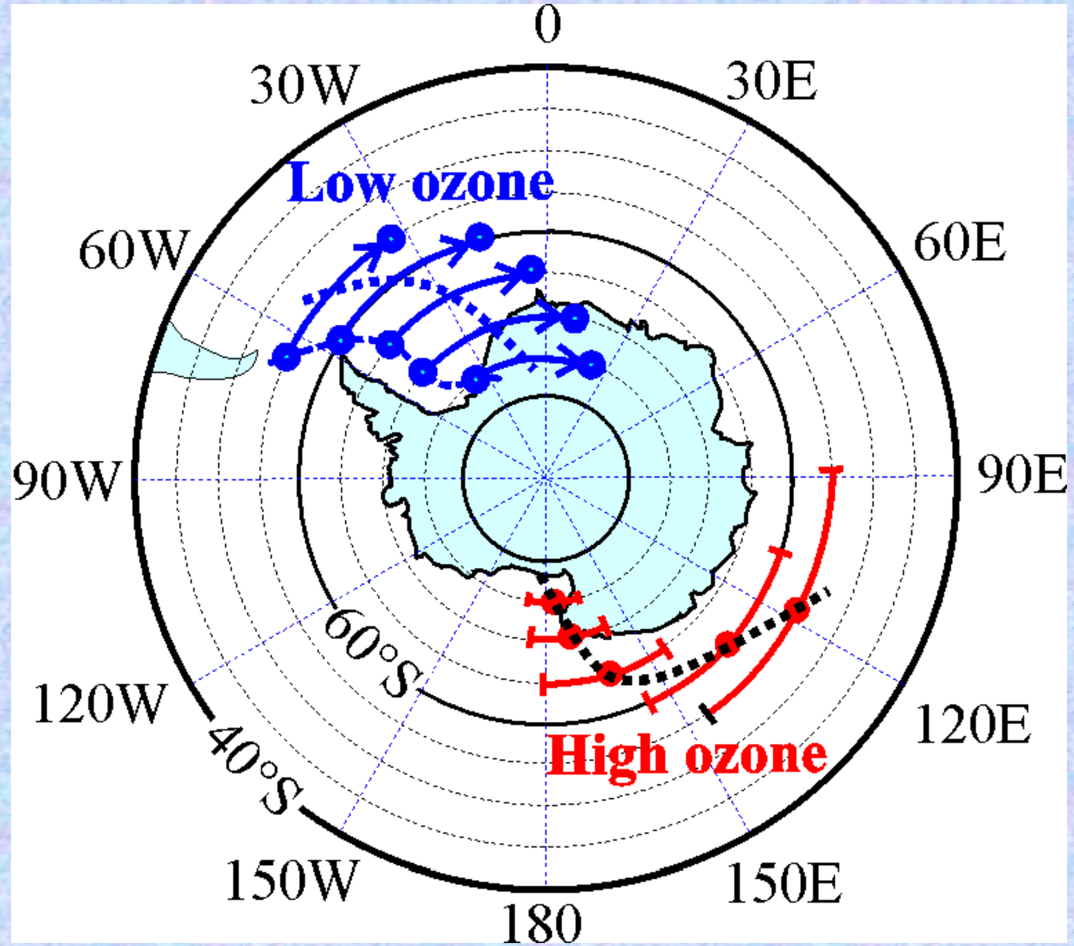
Monthly mean longitudinal distributions of the total ozone by the TOMS data for

(a) the 9 months of the southern summer, autumn and winter 2005 at 60°S;

(b) the spring months September, October and November 2005 at 60°S.

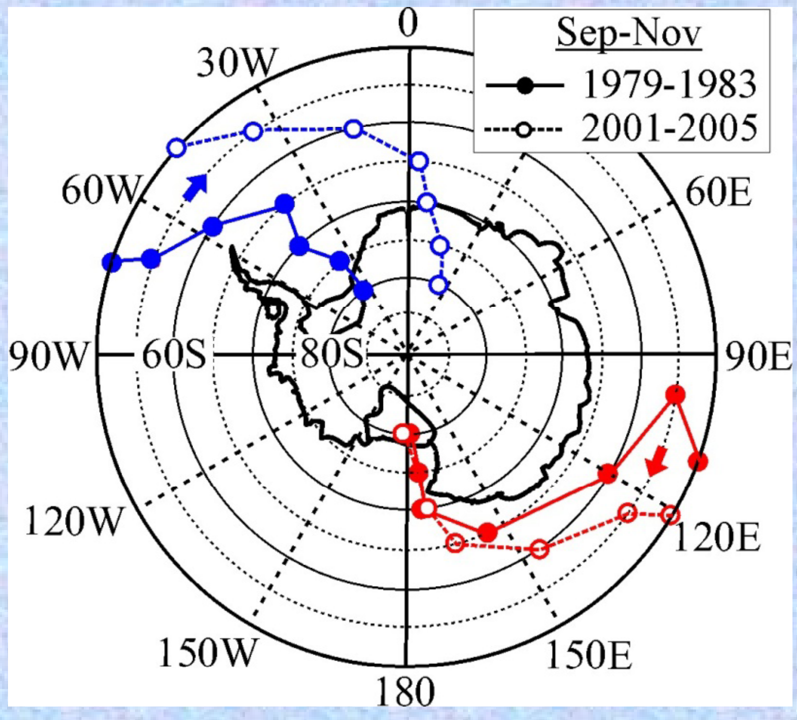


Climatology of the total ozone asymmetry over Antarctica, 1979-2005



- the polar low ozone anomaly;
- eastward shift by about 45° in ozone minimum position (blue) and relatively stable position of zonal maximum (red)

Geographical position of zonal extremes in total ozone



The average positions of the quasi-stationary extremes in September-November 1979-2005 (left) and the 5-year means for 1979-1983 and 2001-2005 (right). At high latitudes the positions of maximum outline the continent boundary in region of Victoria Land and Wilkes Land. Minima are located along Antarctic Peninsula in average data of 1973-1983 and shift eastward during last decades. Shift distance is about 45°, or ~ 2000 km at 65 °S.

Ozone distribution asymmetry in the Southern Hemisphere

Ozone hole (blue) and ozone rich collar (red) take typically asymmetric positions relative to the South pole due to quasi-stationary planetary waves influence.

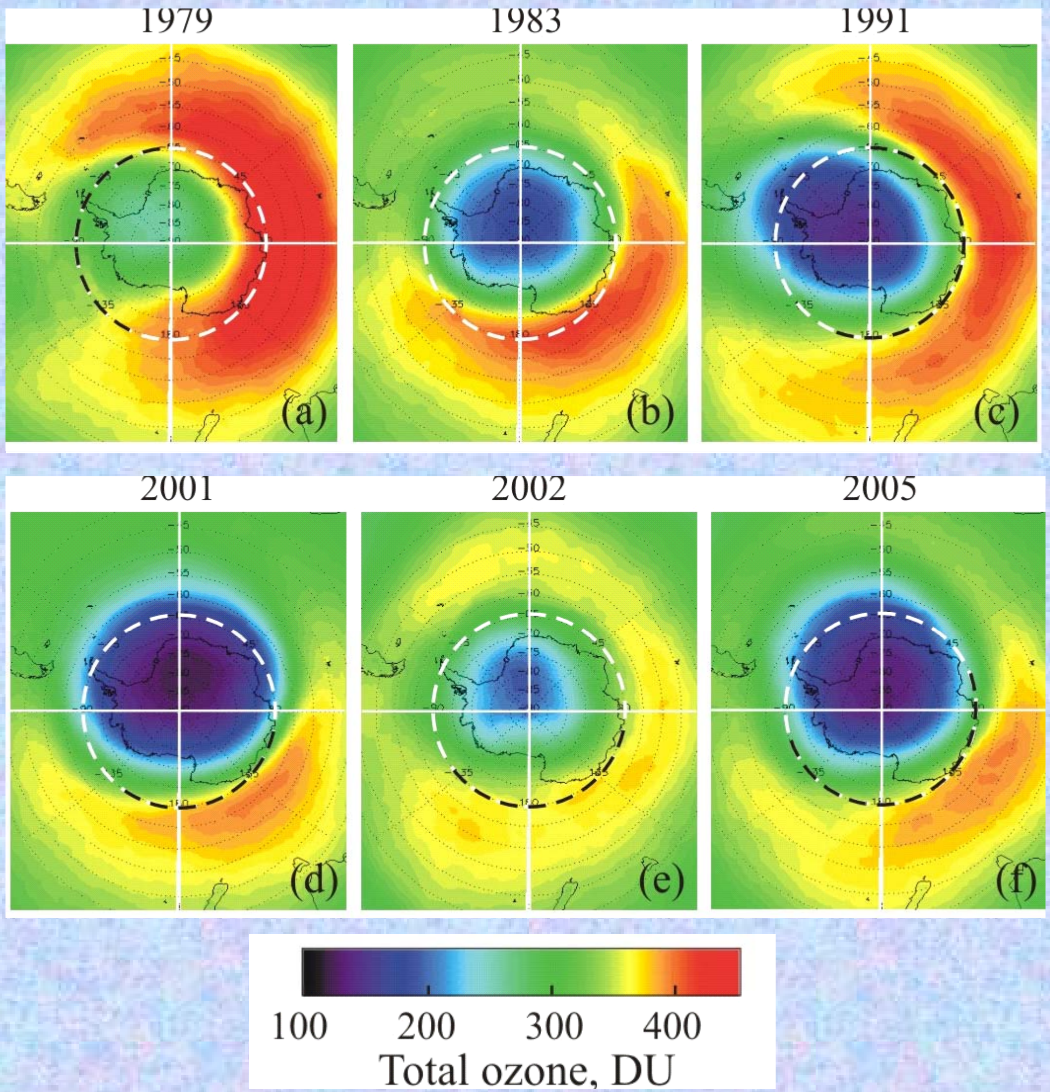
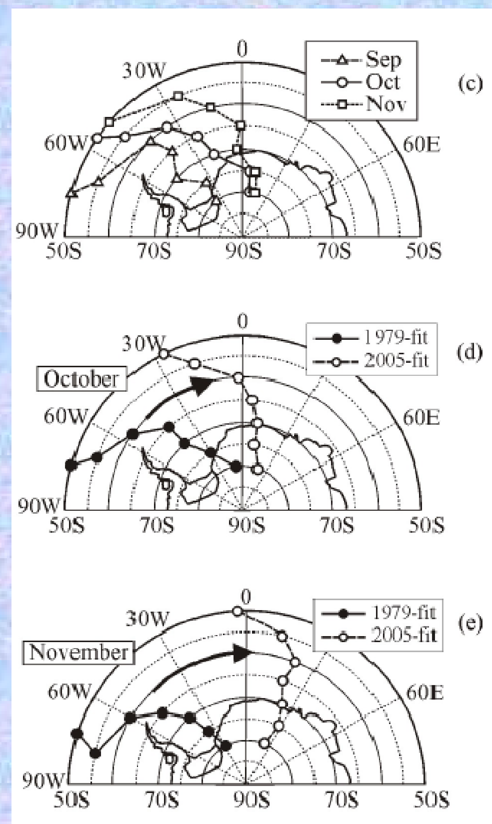
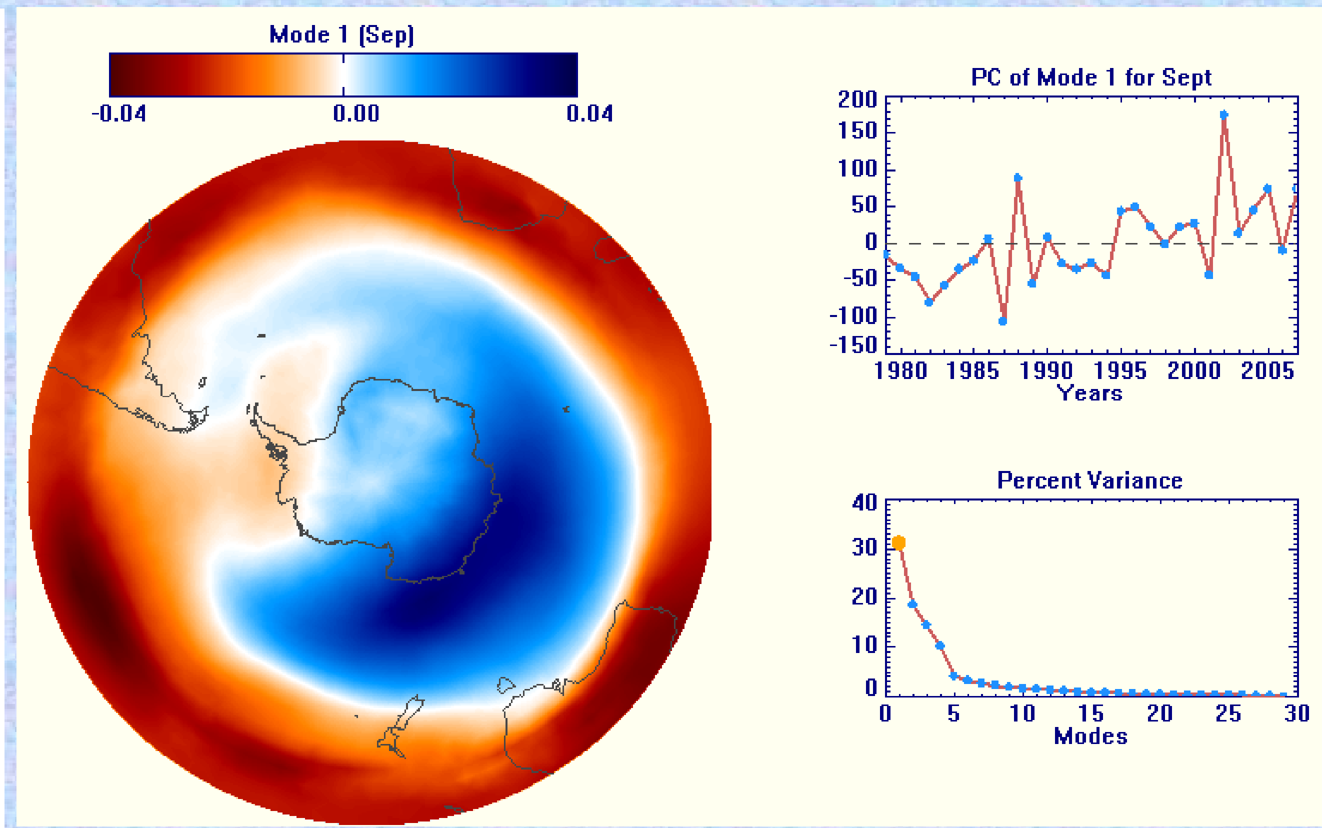


Fig. 1. October mean fields of the total ozone, 45°S -90°S,TOMS data. The dashed circle marks the latitude 65°S.

By Grytsai et al. (2007), Ann. Geophys., 25 (2), 361–374, Fig. 1.

Empirical Orthogonal Function (EOF) analysis of NCEP tropopause temperature





1979-2007 September

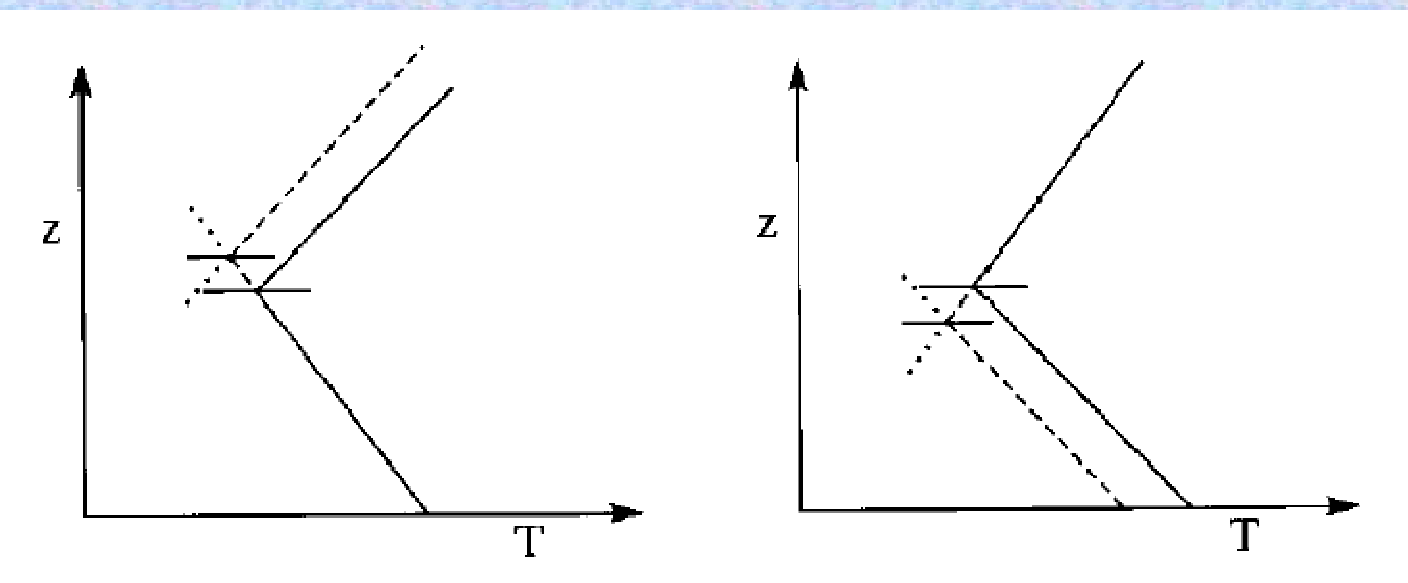
the spatial variability of the leading EOF

in monthly mean tropopause temperature

Definitions

Tropopause is a boundary between turbulent troposphere, in which the temperature **decreases** with height, and stratified stratosphere where temperature **increases** with height.

Tropopause elevation takes place when **stratosphere cools (left)** or **troposphere warms (right)**.



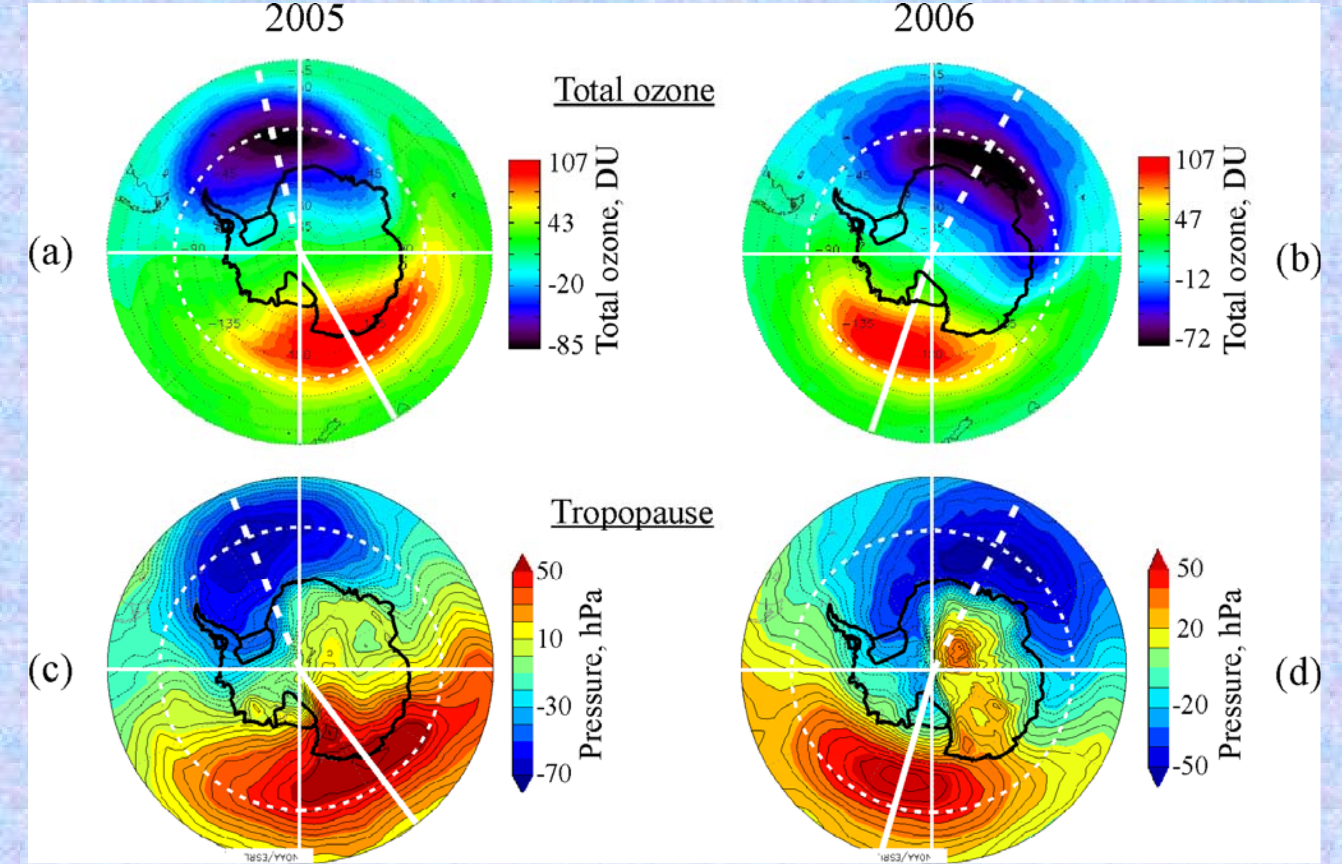
Stratosphere impact **Troposphere impact**

by (Shepherd, JMS of Japan, 2002)

Total ozone and tropopause zonal anomalies

Total ozone content and tropopause height anti-correlates.

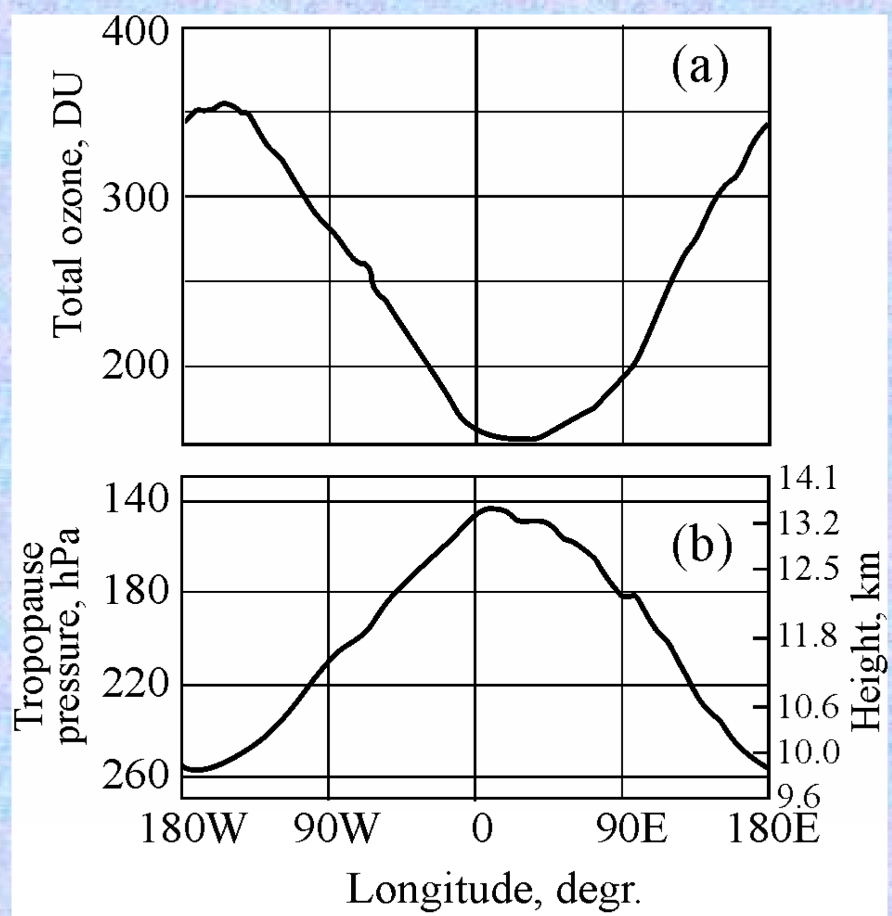
Spring Antarctic tropopause is influenced by the lower stratosphere temperature formed by ozone distribution.



Monthly mean eddy fields of (a, b**) total ozone** and (c, d) **tropopause height** by TOMS/OMI data and NCEP-NCAR reanalysis data, respectively.

Stratospheric impact on tropopause position

Longitudinal distribution of (a) total ozone, (b) tropopause pressure/height along the latitude circle 65°S for October 2006.



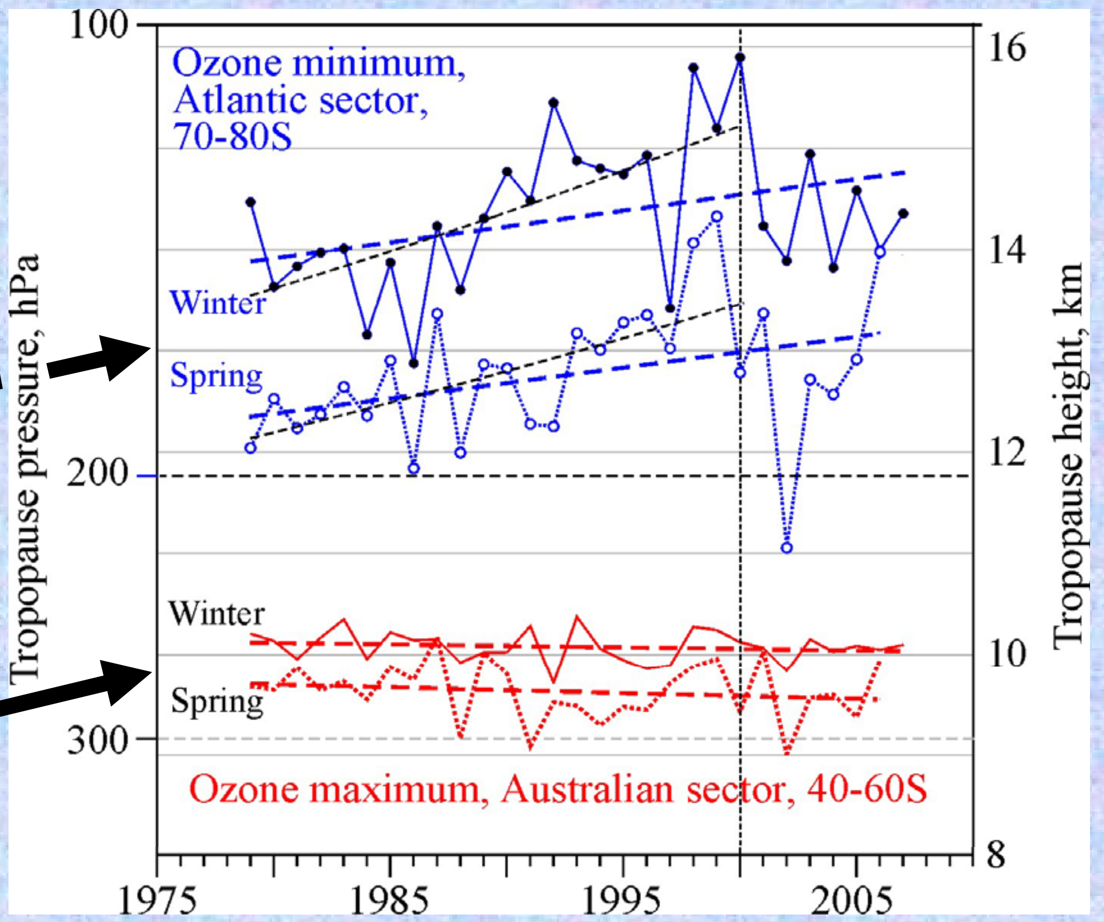
Strong **anti-correlation** between **tropopause height** and **total ozone** content shows that ozone losses are a cause of the spring tropopause elevation in Antarctic region.

Tropopause trend asymmetry

In average, the highest tropopause pressure trends are

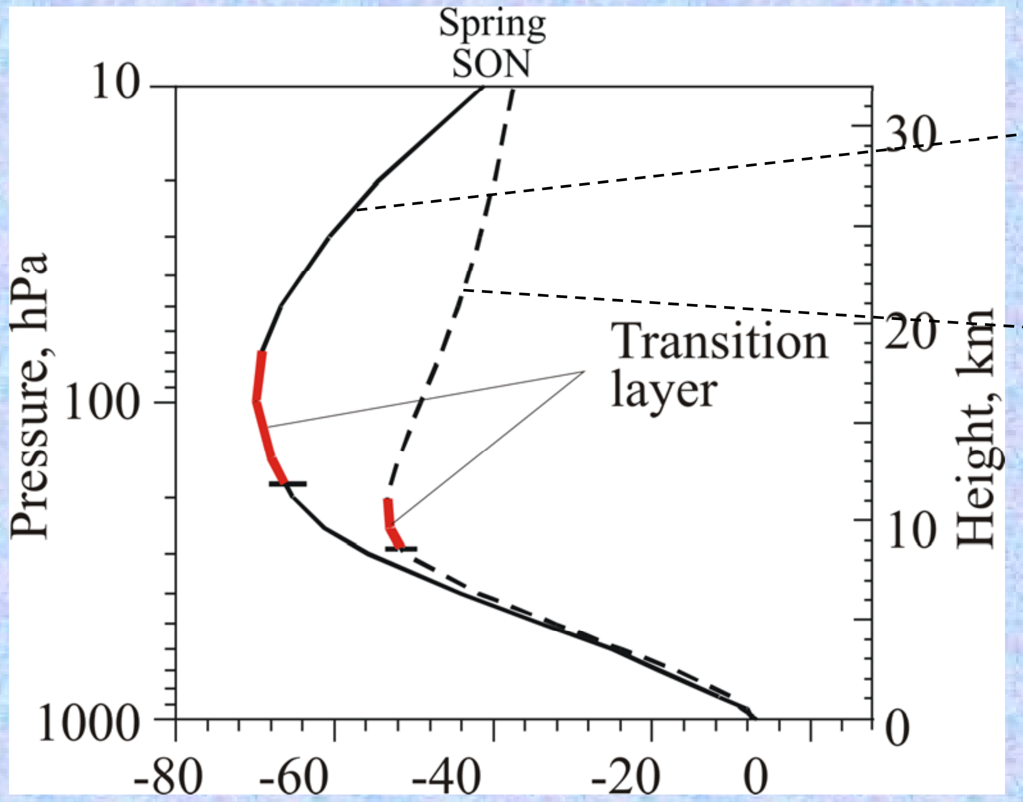
1979-2006: -7±3 hPa/dec.
1979-2000: -17±4 hPa/dec.
or ~0.5 km/dec.
(at the level of ±1σ).

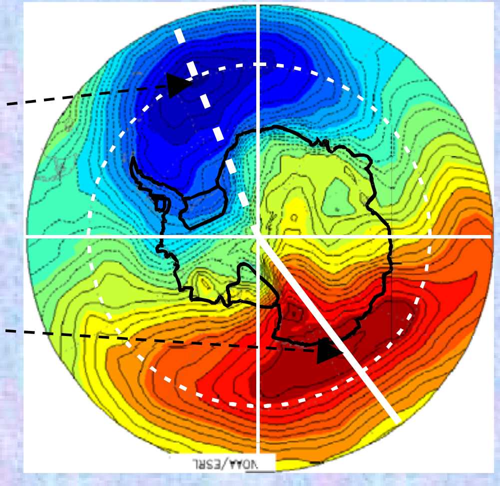
About zero trends are observed in ozone collar region.



Difference in tropopause pressure/height trends over the regions of total ozone extremes.

Tropopause sharpness decrease in spring in TOC min region

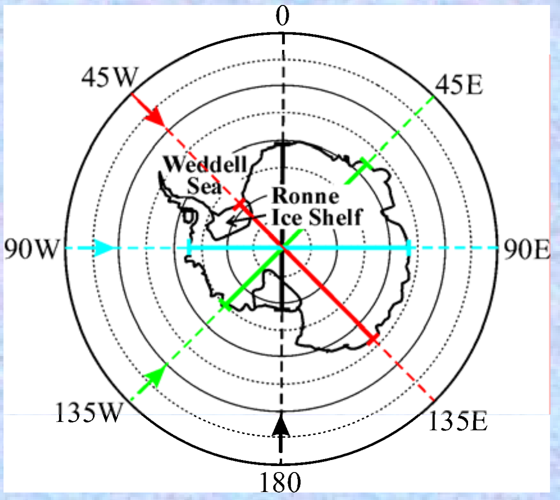




Eddy tropopause pressure monthly mean, Oct 2005

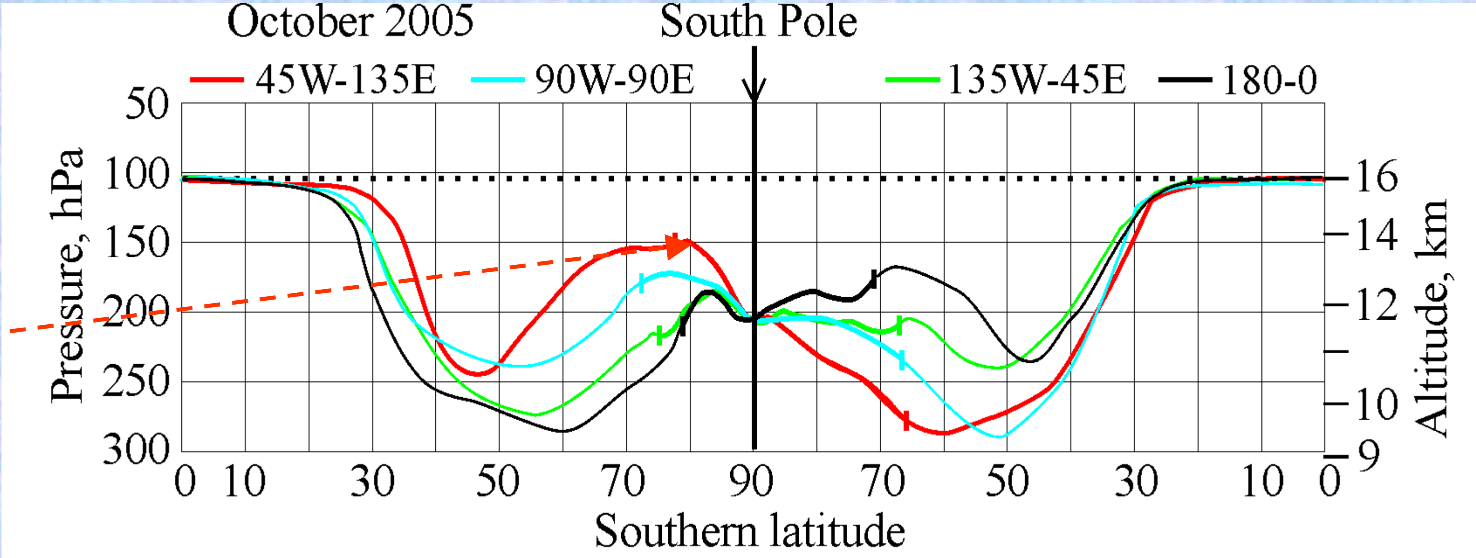
Vertical temperature profiles in spring 2005 for the tropopause zonal extremes at latitude 65°S, longitudes 30°W (tropopause height maximum) and 150°E (tropopause height minimum).

Meridional tropopause structure



Four meridional planes along which tropopause profiles "equator-pole-equator" for Southern Hemisphere have been obtained.

Anomalous tropopause height

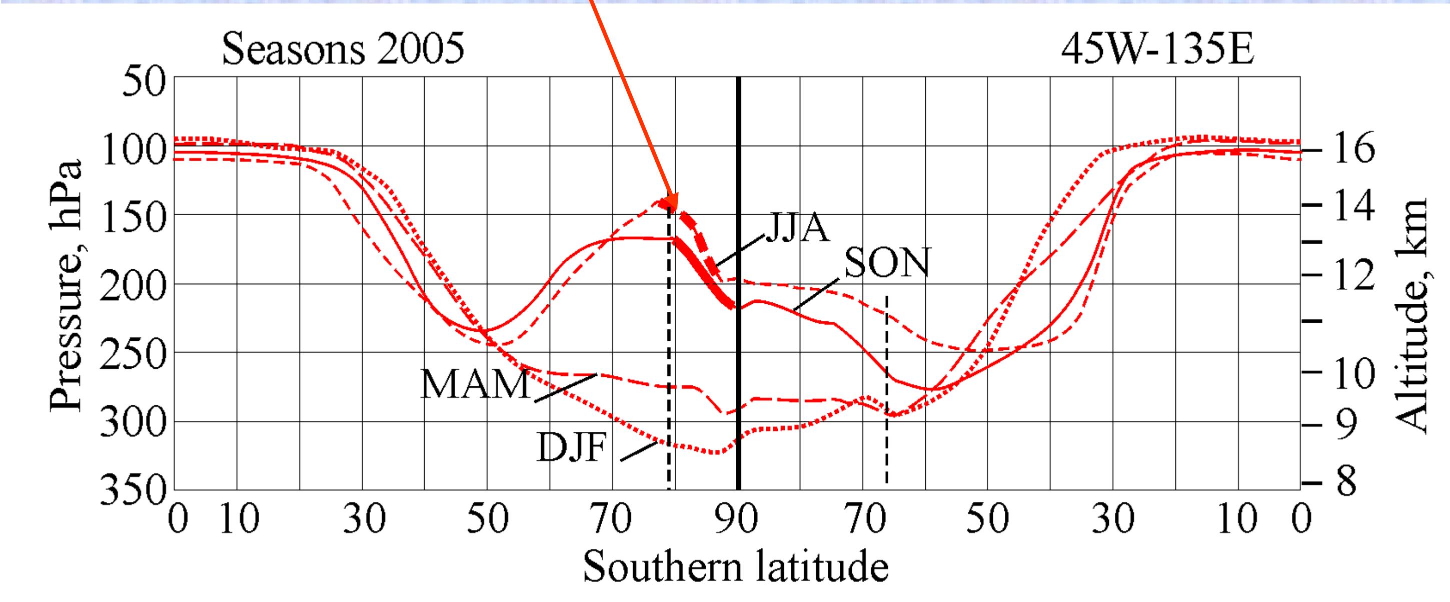


The tropopause elevation is observed in Atlantic sector.

Tropopause pressure/height profiles for October 2005 in the four meridional directions.

Tropopause seasonal variations

Anomalous tropopause height

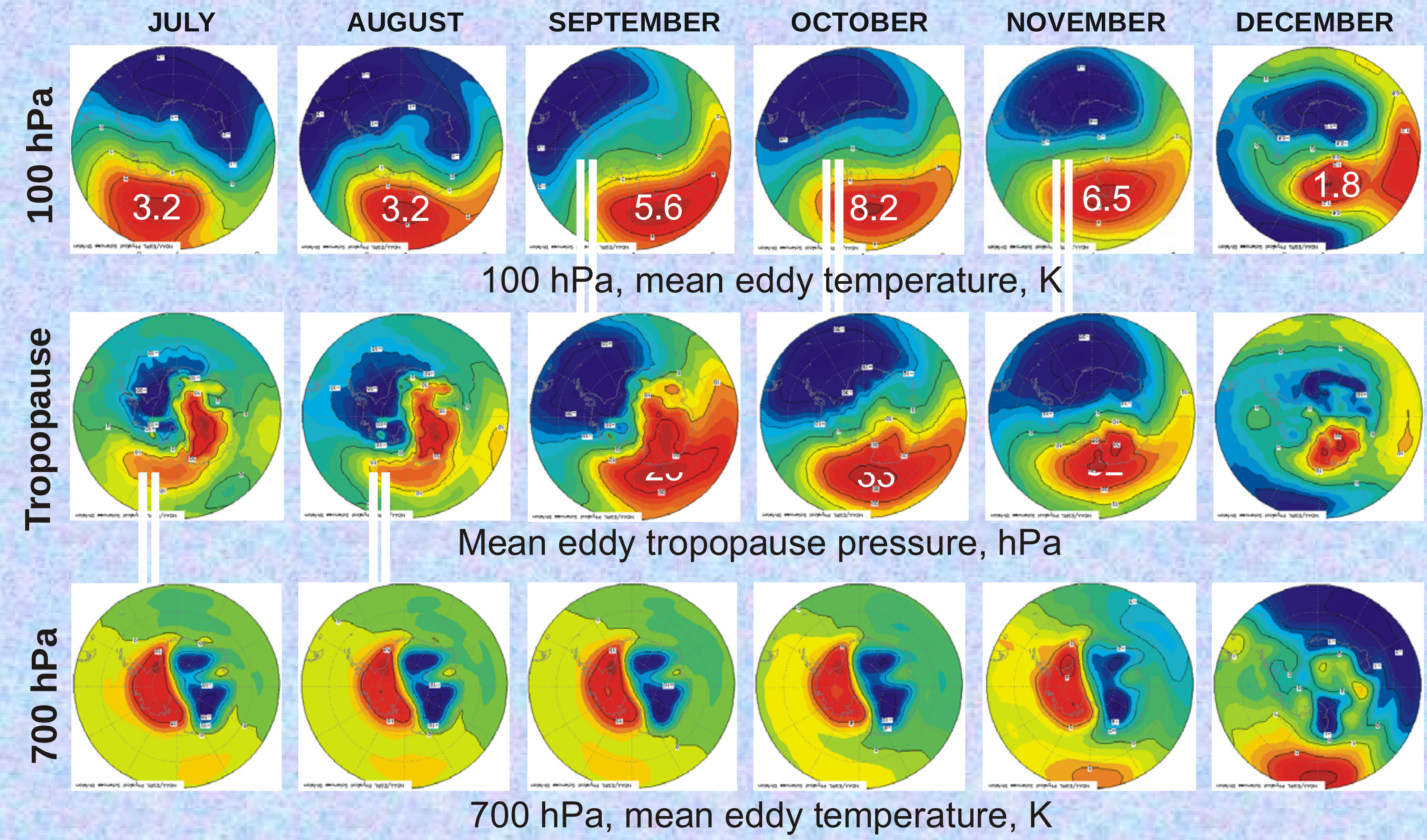


Tropopause pressure/height profiles for 4 seasons of 2005 meridional section 45°W-135°E

Anomalous tropopause elevation occurs during winter and spring. Other seasons are characterized by uniform tropopause height distribution over Antarctic Region.

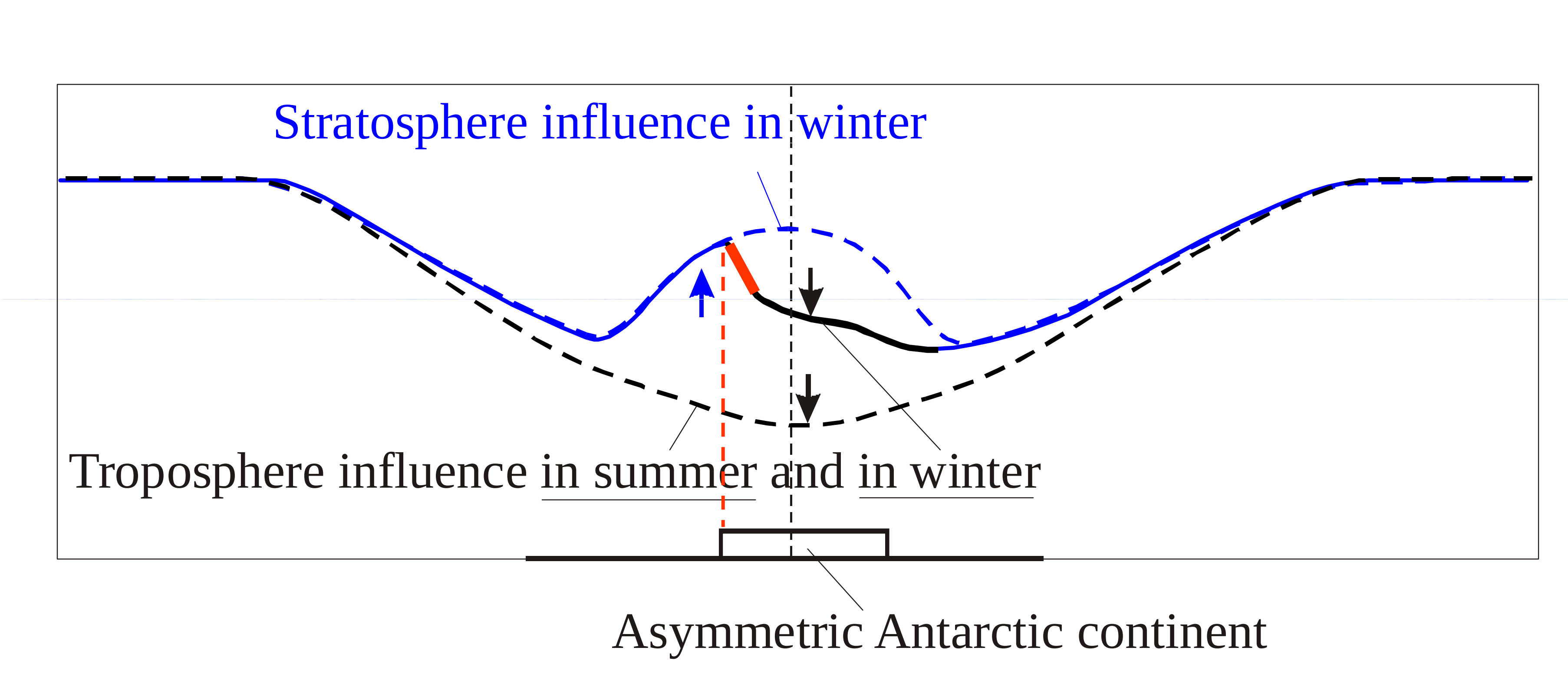
Disturbed tropopause height equals 13-14 km (JJA, SON). Typical undisturbed values reach only 9 km (DJF, MAM).

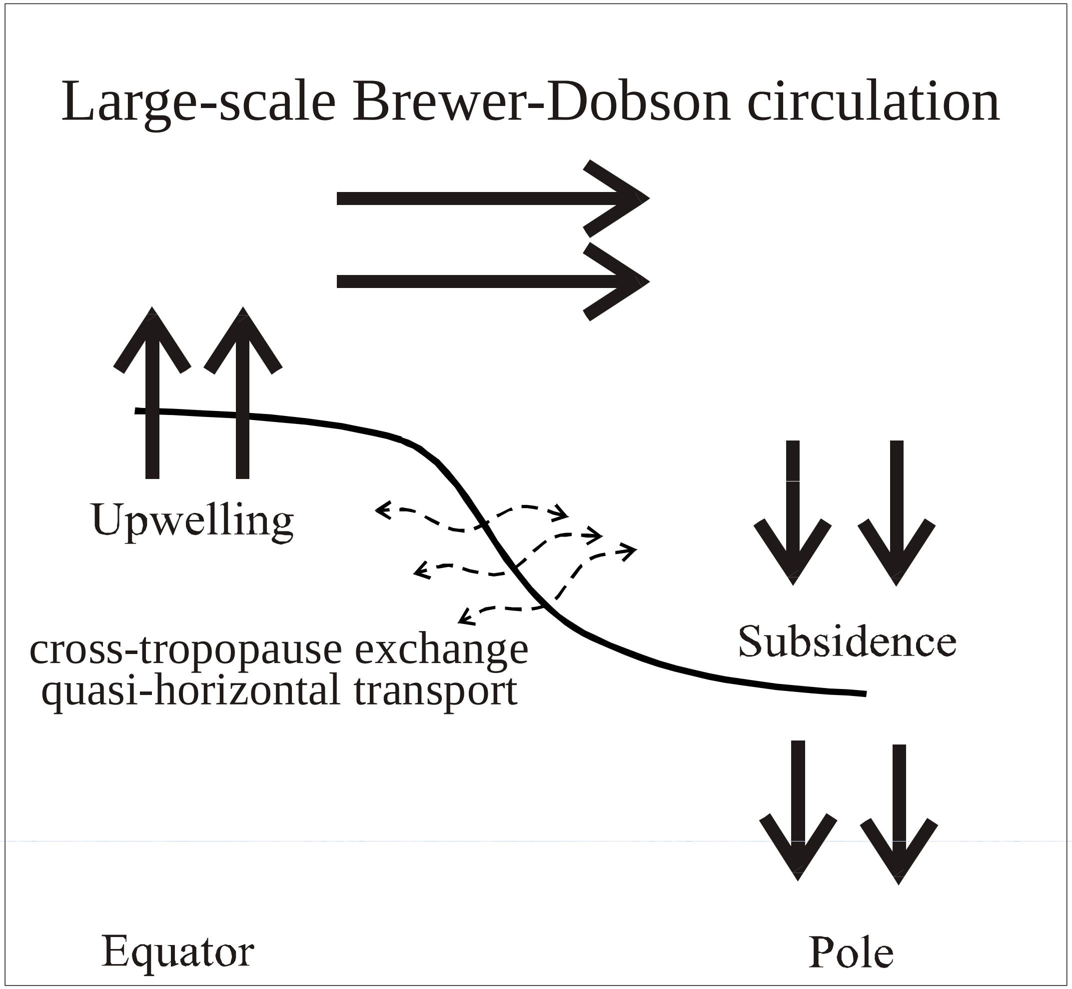
Long-term means 1968-1996
July-December eddy fields by NCEP-NCAR reanalysis



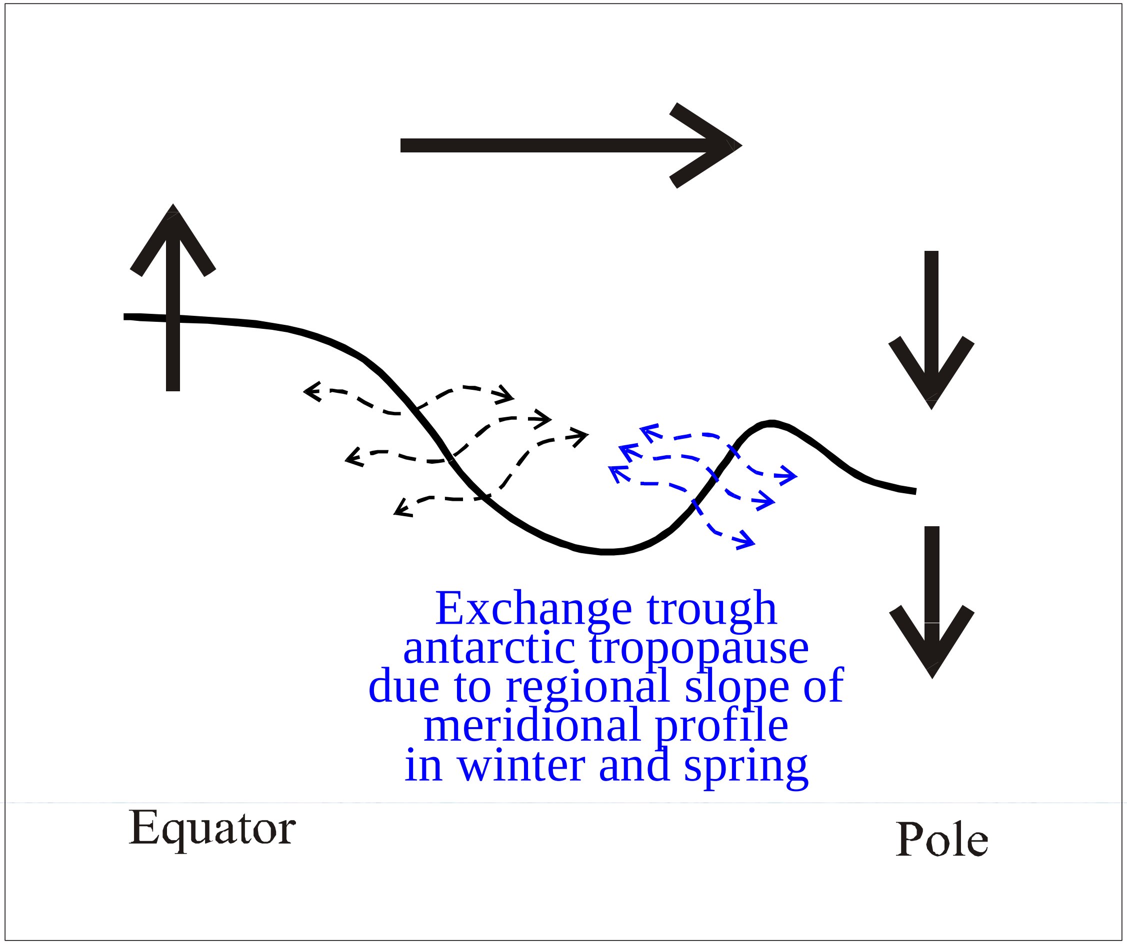
Winter-spring zonal anomalies in troposphere temperature (bottom), tropopause pressure (middle) and lower stratosphere temperature (top) by the long-term means of 1968-1996.

Scheme of Antarctic troposphere and stratosphere contribution to formation of tropopause meridional profile





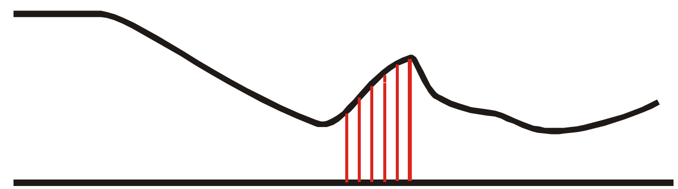
Normal Brewer-Dobson circulation (North Hemisphere, by Holton et al., 1995)



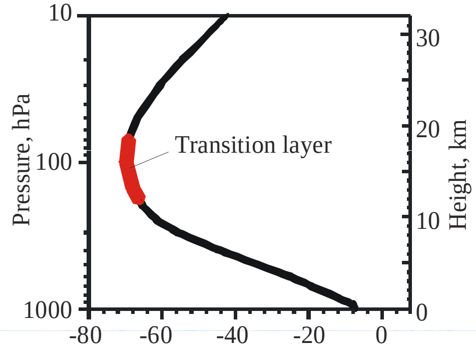
Possibility of horizontal cross-tropopause exchange in the region of elevated tropopause over West Antarctica

Conclusions: tropopause

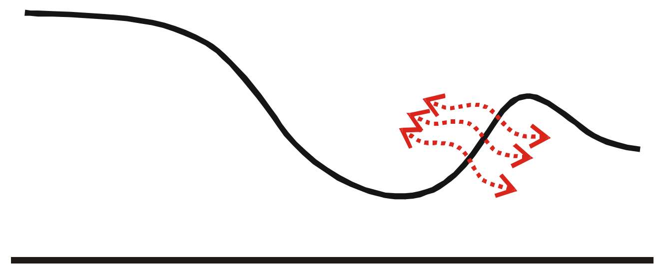
In combination with surface conditions, the changes of tropopause structure could impact to regional troposphere state:



- increase of troposphere thickness



- decrease of tropopause sharpness and modification of vertical troposphere/stratosphere exchange



- increase of possibility the cross-tropopause horizontal transport

- modification of planetary wave propagation

Task-home message - ozone

Changes in ozone max and min positions:

- how impact on ecosystem due to redistribution of UV radiation at sea level

- how influence on regional climate

- what is the future of ozone hole