The edge region of the Antarctic stratospheric vortex: existence and importance

H.K. Roscoe
British Antarctic Survey
Presented to Concordiasi Workshop
Toulouse, March 2010

1. History of discovery

2. Definition of edge region from dynamical models

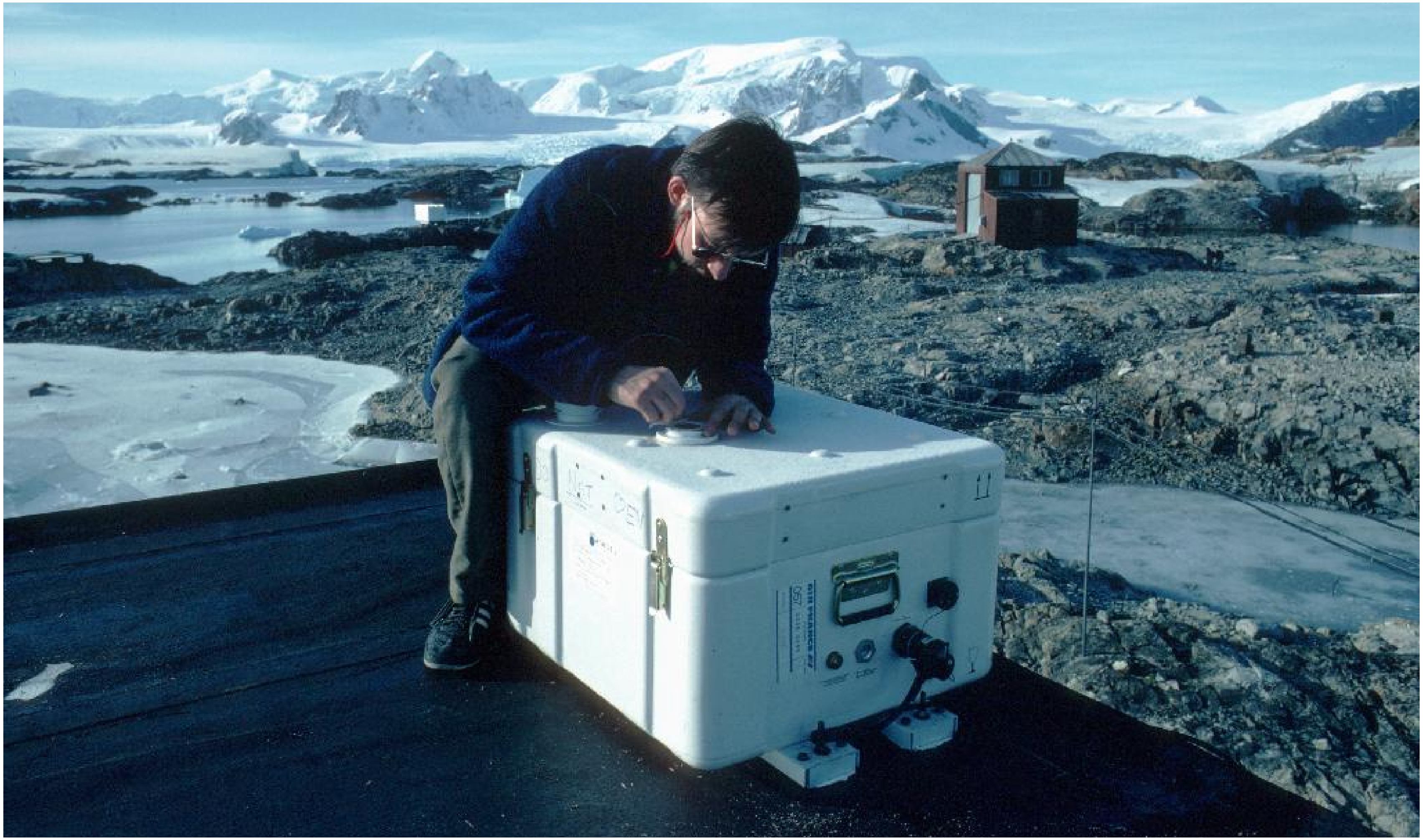
3. Evidence for its existence from chemical models

4. Evidence for its existence from chemical measurements

5. Evidence from dynamical measurements (balloons)

6. Why is it important?

1. History of discovery



The SAOZ zenith-sky spectrometer for measuring total O3 & NO2, being installed at Faraday (65°S) by Derek Oldham in March 1990

1. History of discovery

Midwinter Start to Antarctic Ozone Depletion: Evidence from Observations and Models
H. K. Roscoe, Anna Jones, Adrian Lee (Science 1997)

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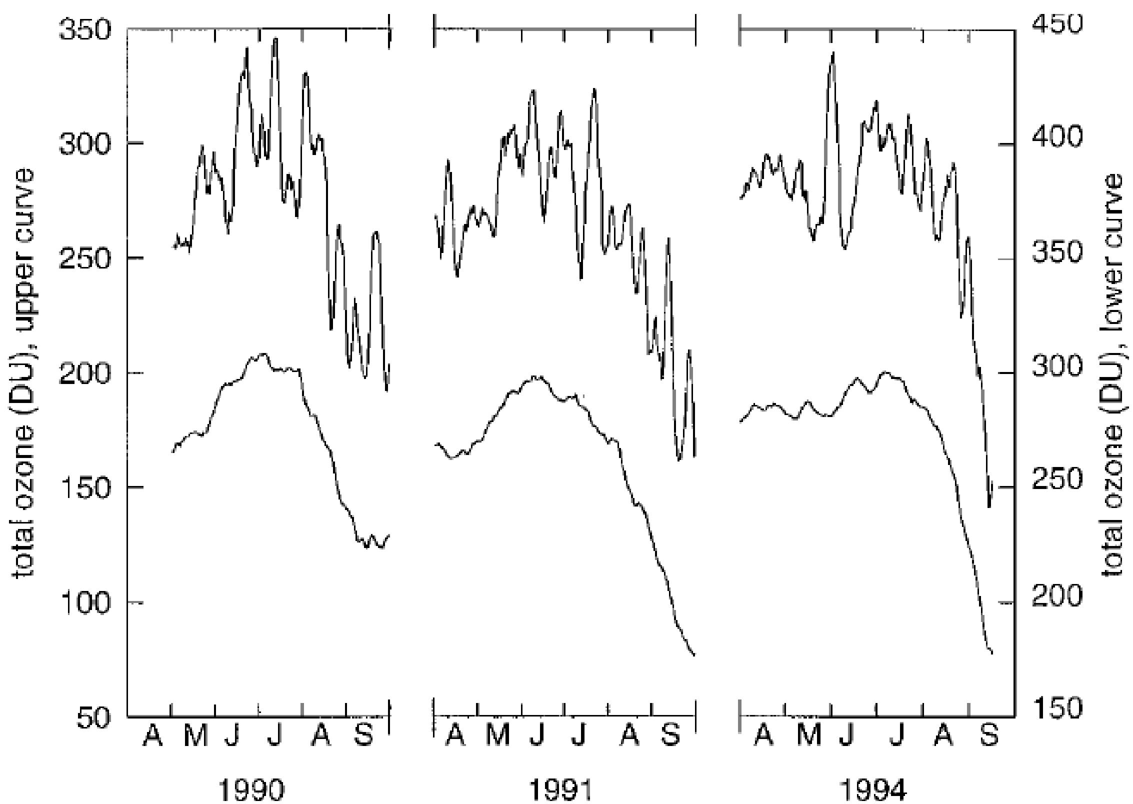

Fig. 1. Daily total ozone measured by SAOZ at Faraday at 65°S, using calculated AMFs specific to each month. The upper curves are smoothed by a 5-day running mean for clarity; the lower curves are the same data smoothed by a 41-day running mean. The short time-scale variability in the upper curves, which is even greater in unsmoothed data, agrees with Dobson measurements when available; it is dynamical variability, not noise in the measurements. A winter maximum is discernible in the upper curves, despite this variability, and is more discernible in the lower curves. AMJJAS: April, May, June, July, August, September.

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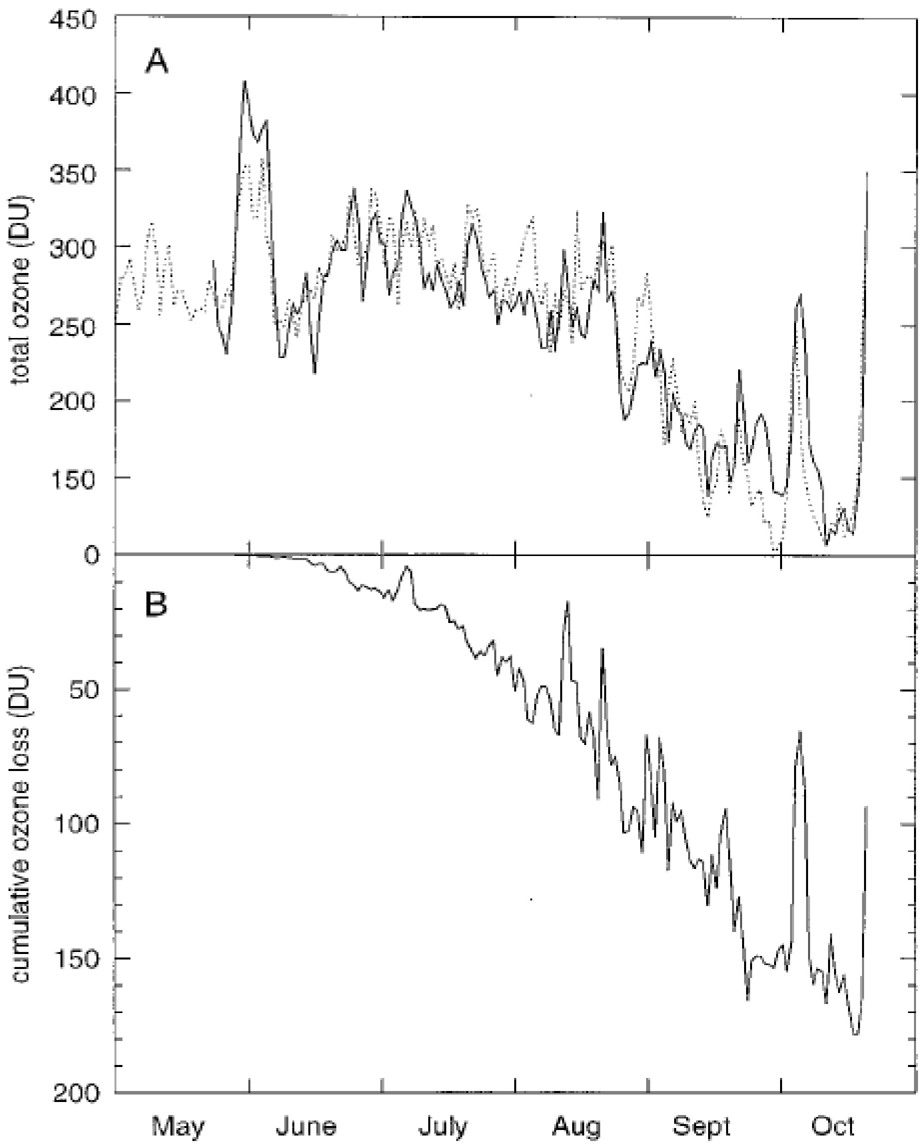
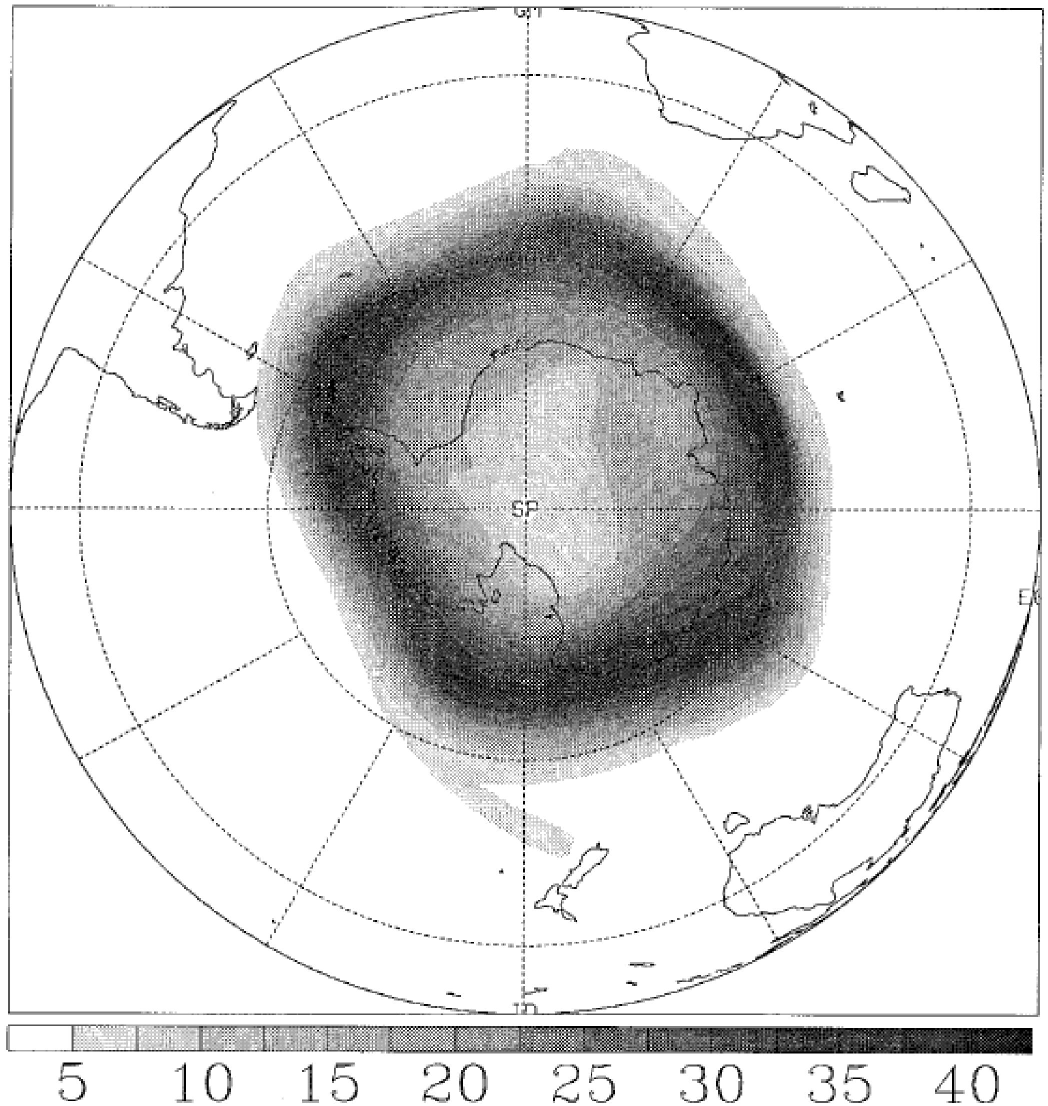
1. History of discovery

Fig. 2. (**A**) Daily total ozone measured by SAOZ at Faraday in 1994 (dashed line), compared to total ozone above potential temperature 350 K, calculated by a 3D chemical-transport model (solid line). Neither measured nor calculated ozone values have been smoothed. The model reproduces the large ozone depletion starting in mid-August and reproduces many of the short time-scale dynamical features of the measurements. (**B**) Accumulated loss in total ozone above 350 K at Faraday in 1994, calculated by the model from cycles involving the formation of the ClO dimer plus the two pathways of ClO + BrO that lead to ozone loss. By mid-August, the calculated depletion frequently exceeds 60 DU.



1. History of discovery

Fig. 3. Accumulated loss in total ozone calculated by the model from cycles involving the formation of the ClO dimer plus both the pathways of ClO + BrO that lead to ozone loss, as in Fig. 2B, but for the whole Southern Hemisphere on 23 July 1994. Significant ozone loss is confined to a ring at the sunlit edge of the vortex, occupying about 5° of latitude centered between 59°S and 72°S and exceeding 35 DU for over half of the ring's circumference. This confinement, more than a month after the start of ozone depletion, illustrates that mixing within the vortex is weak. The gray scale shows the accumulated ozone loss in Dobson units.



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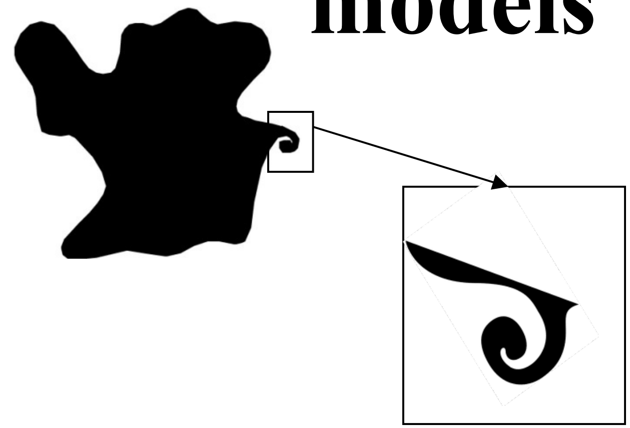
2. Definition of edge region from dynamical models

• mixing in a fluid is enhanced by stretching and folding:



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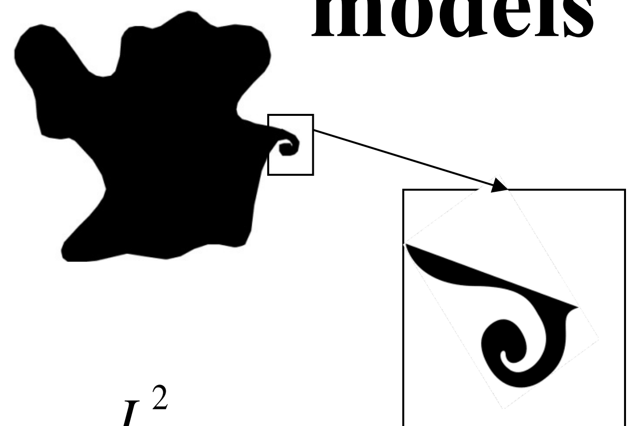

- mixing in a fluid is enhanced by stretching and folding:

- this is quantified by “effective diffusivity” κ_{eff}
  (Nakamura 1996, Haynes & Shuckburgh 2000)

- it uses the enhancement of a tracer contour above its minimum possible length
  (how convoluted a tracer contour has become)

$$\kappa\kappa_{eff} = k \frac{L_{eff}^2}{L_{min}^2}$$

where k is the actual diffusivity

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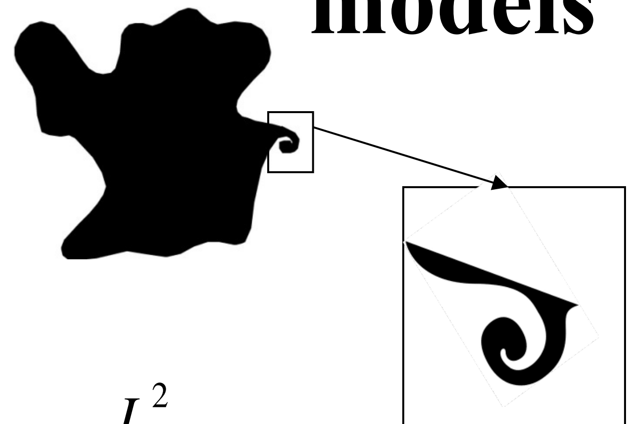

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- for presentation purposes we sometimes use "log-normalised equivalent length of effective diffusivity": $L_{eq} = \ln\frac{L_{eff}^2}{L_{min}^2}$

2. Definition of edge region from dynamical models

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 106, NO. D3, PAGES 3203–3211, FEBRUARY 16, 2001

The impact of the mixing properties within the Antarctic stratospheric vortex on ozone loss in spring

Adrian M. Lee,[1] Howard K. Roscoe,[2] Anna E. Jones,[2] Peter H. Haynes,[3] Emily F. Shuckburgh,[3] Martin W. Morrey,[4] and Hugh C. Pumphrey[4]

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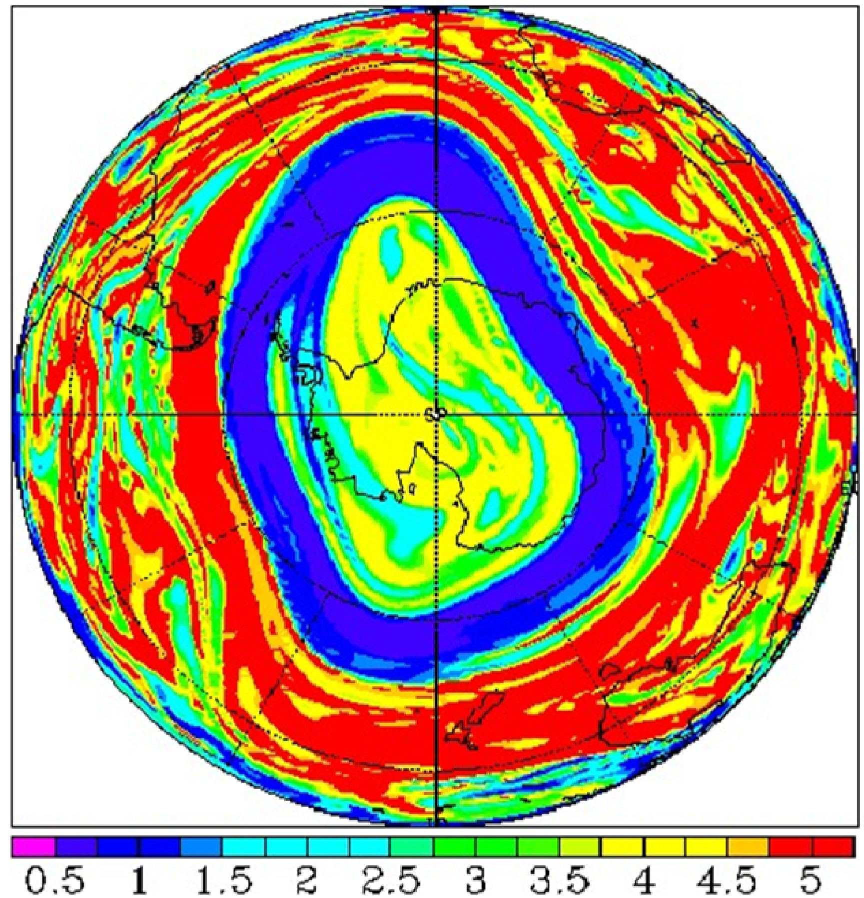
Effective diffusivity for mixing and stirring in mid-September 1996, where small values are less mixing. The edge region of the vortex is isolated from its core, and is about half the total area of the vortex. Co-ordinates are log-normalised equivalent length, the tracer was PV advected by horizontal winds from UKMO-UARS analyses.



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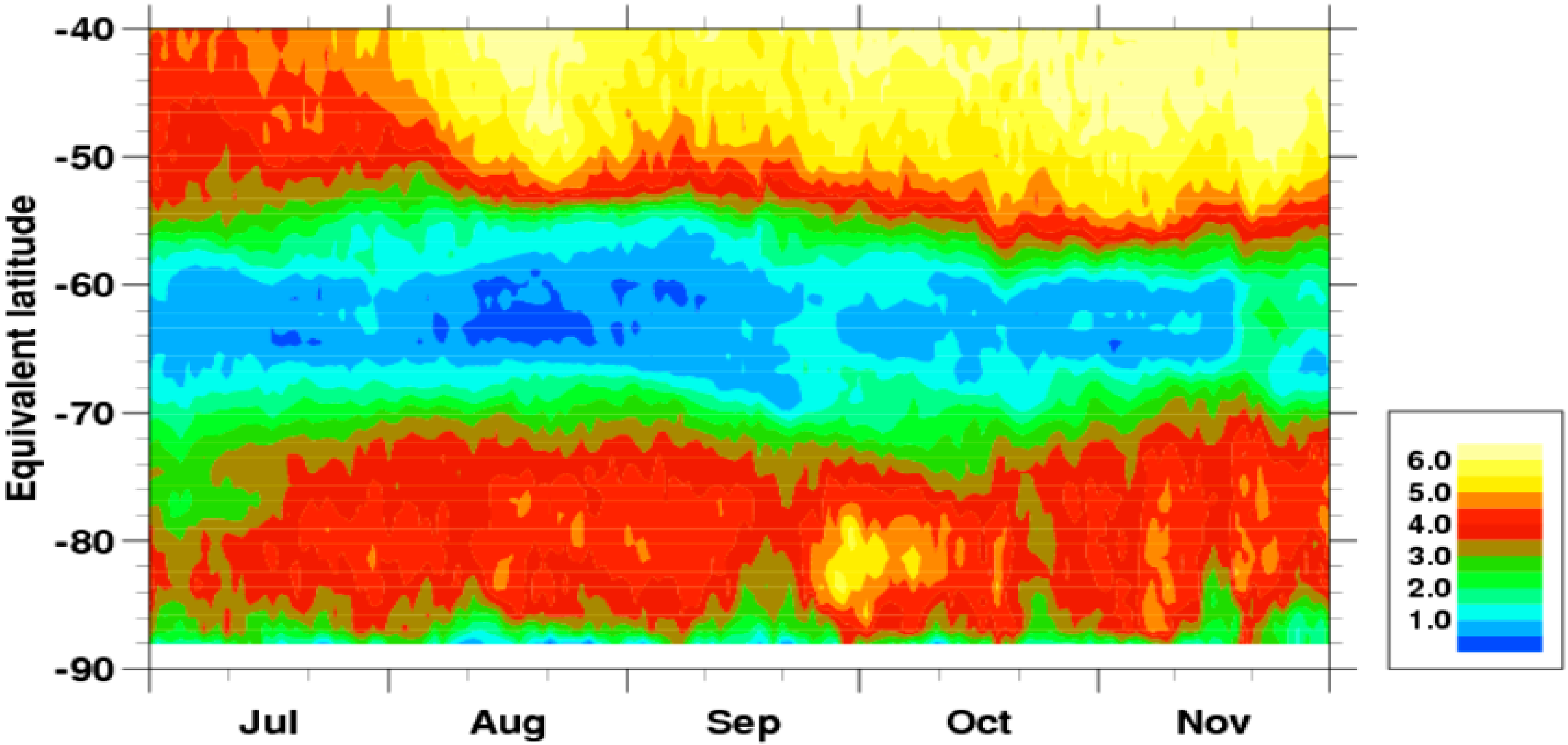
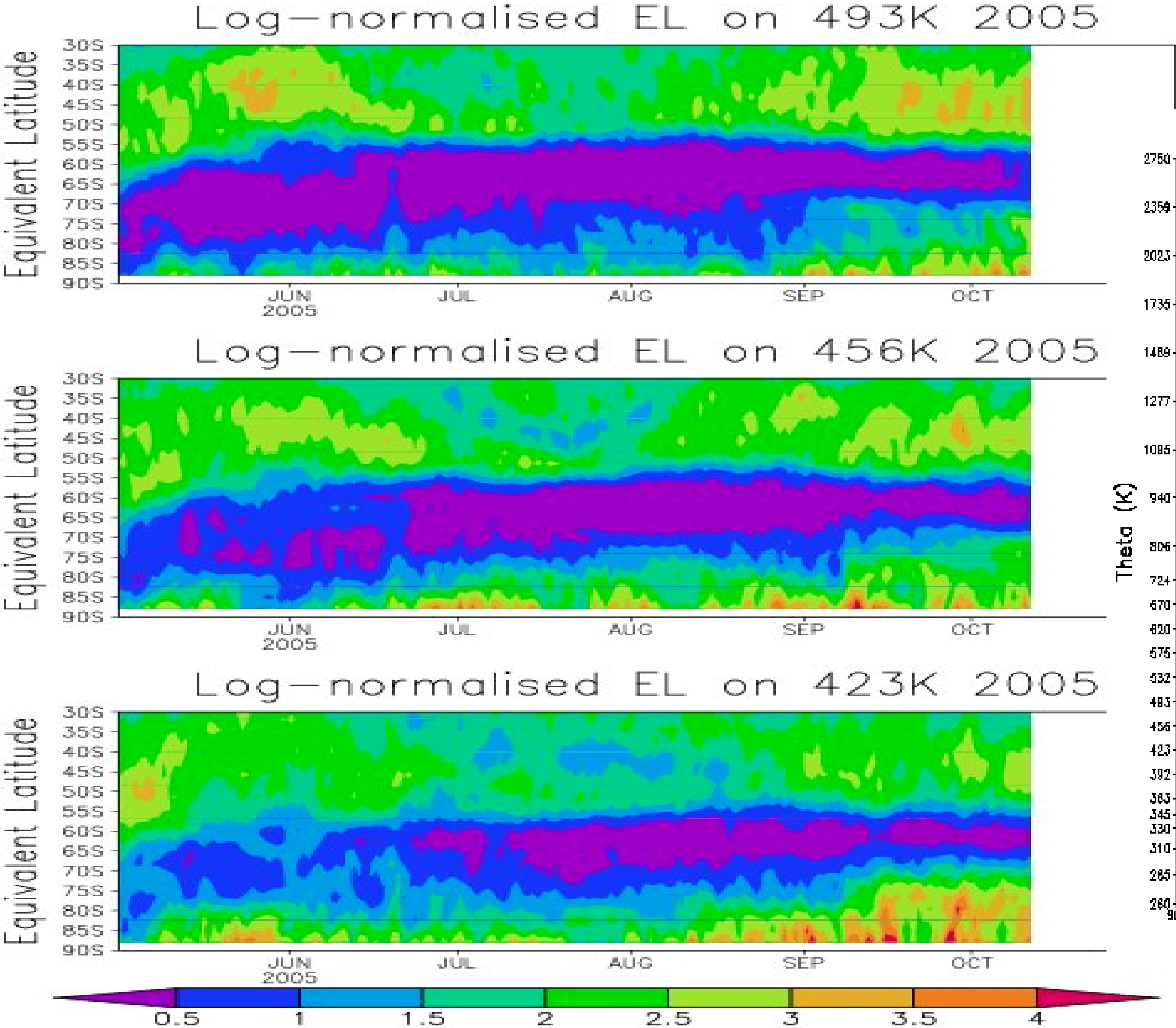
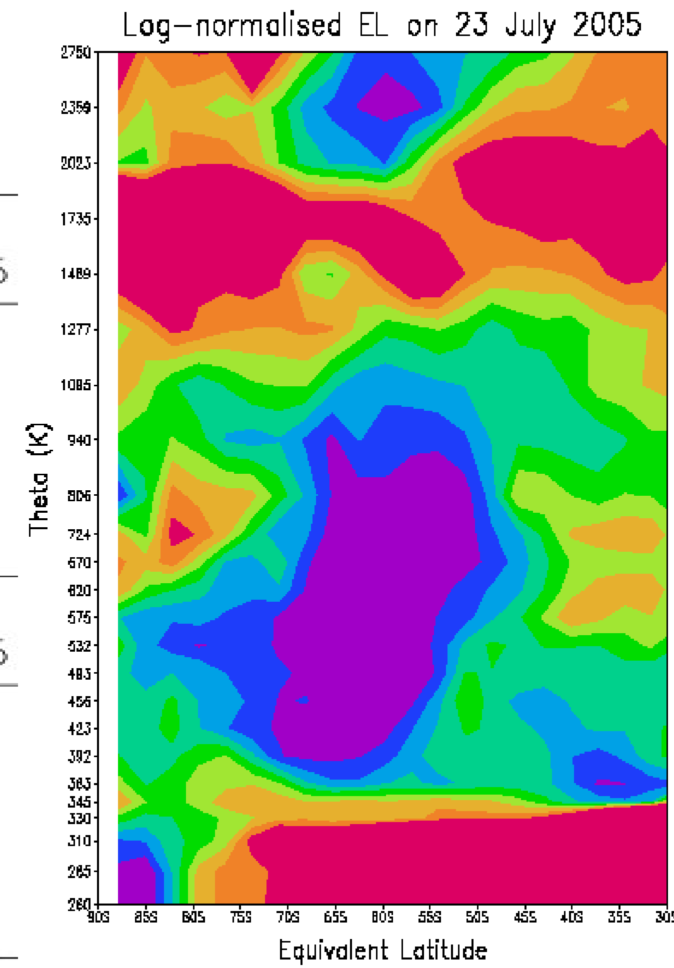


Figure 1. The evolution of lognormalized equivalent length as a function of equivalent latitude on the 480 K isentropic surface during the 1996 winter and spring. The broad region of weak mixing centered at around 63°S equivalent latitude will act as a significant transport barrier preventing the mixing of air in the vortex core with air in the middle latitudes.

2. Definition of edge region from dynamical models





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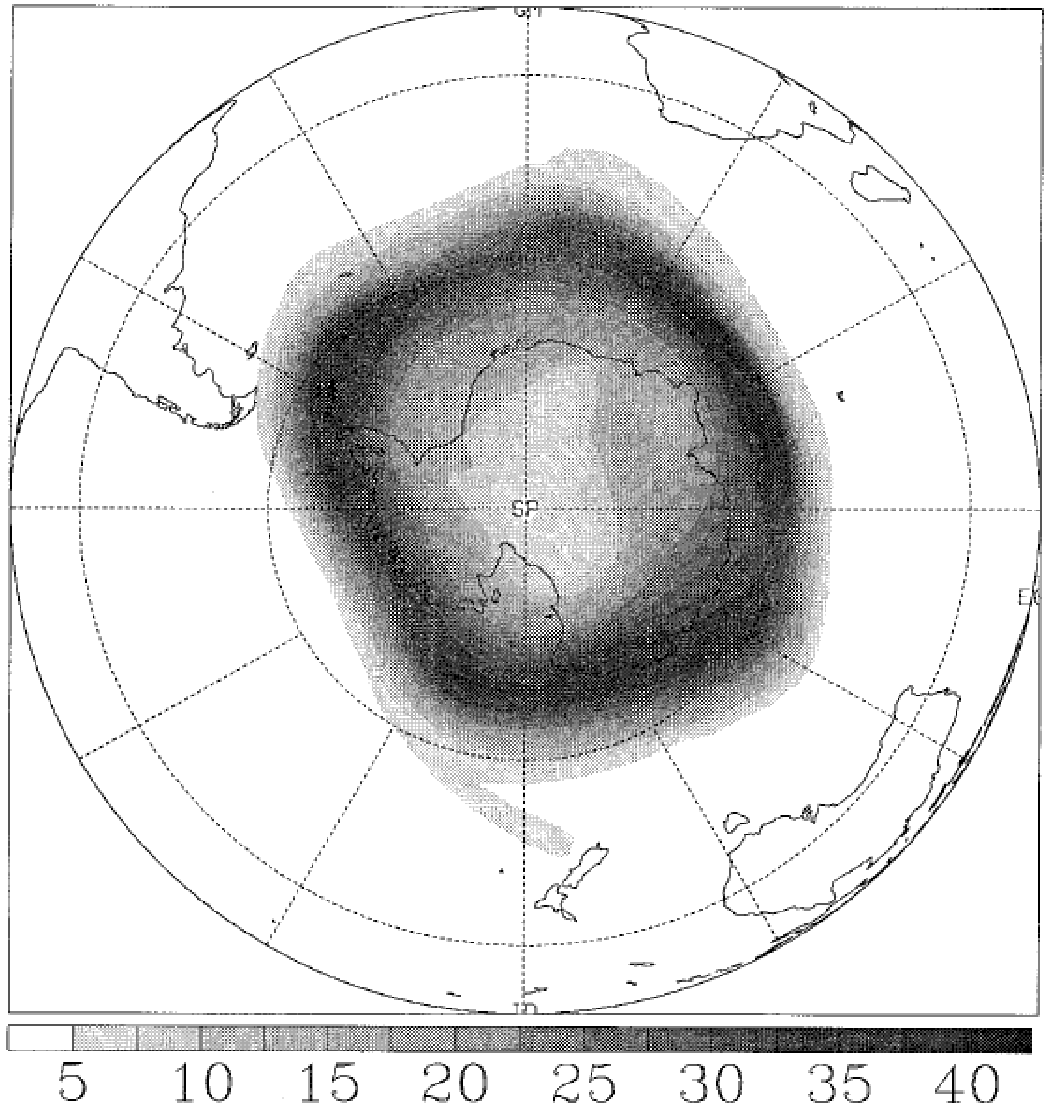
3. Evidence for its existence from chemical models

Fig. 3. Accumulated loss in total ozone calculated by the model from cycles involving the formation of the ClO dimer plus both the pathways of ClO + BrO that lead to ozone loss, as in Fig. 2B, but for the whole Southern Hemisphere on 23 July 1994. Significant ozone loss is confined to a ring at the sunlit edge of the vortex, occupying about 5° of latitude centered between 59°S and 72°S and exceeding 35 DU for over half of the ring's circumference. This confinement, more than a month after the start of ozone depletion, illustrates that mixing within the vortex is weak. The gray scale shows the accumulated ozone loss in Dobson units.



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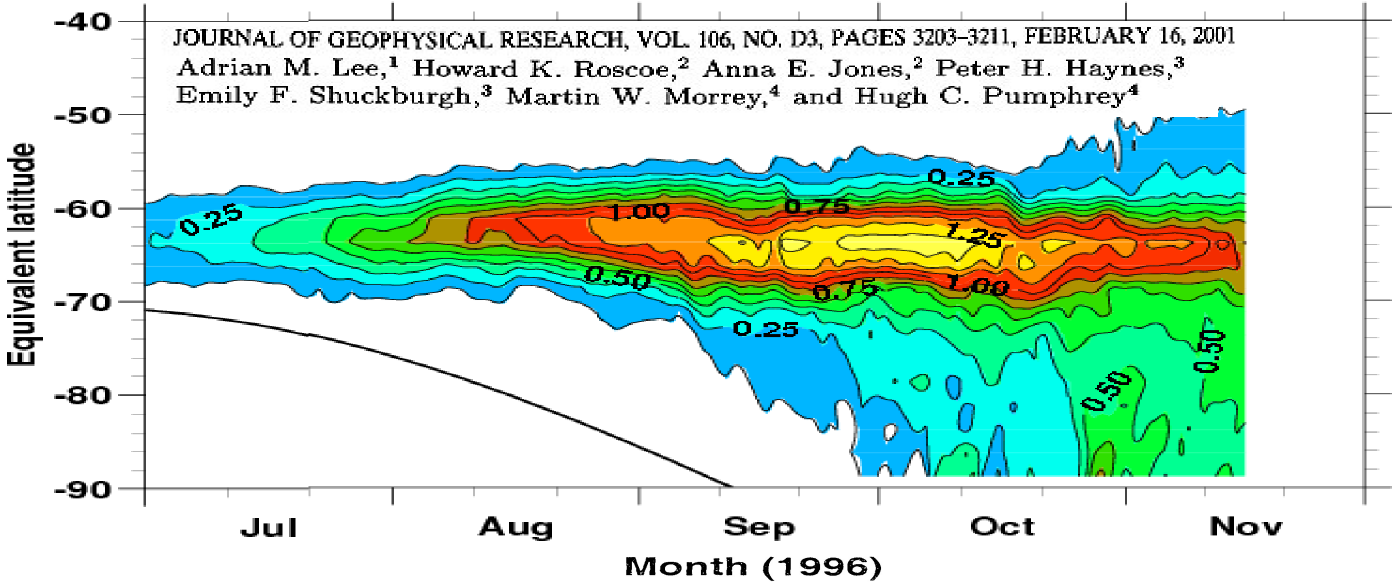

Figure 6. The evolution of accumulated model ozone loss that occurred within the 60° to 65°S equivalent latitude band as a function of equivalent latitude on the 480 K isentropic surface. The ozone loss has been averaged within 2.5° equivalent latitude bands. Contours of ozone loss are labeled as mixing ratios (ppmv). The bold line shows the approximate latitudinal position of the terminator on the 480 K isentropic surface. The ozone loss remains largely confined to the region of weak mixing until at least mid-spring.

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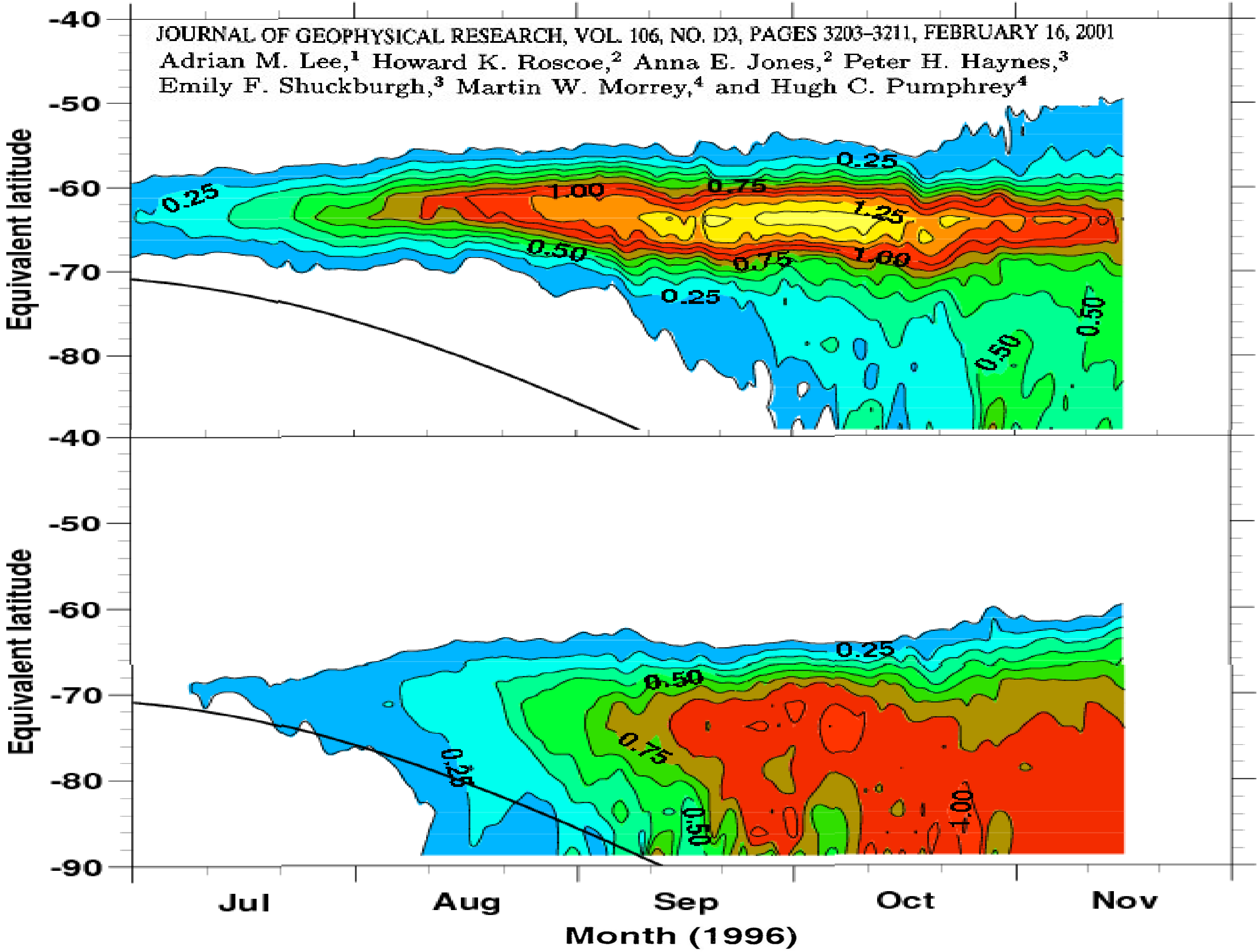

Figure 7. As Figure 6, but for ozone loss that occurred within the 70° to 75°S equivalent latitude band. Transport of ozone loss southward soon after it occurs at these latitudes in early spring (August) is clearly evident, unlike Figure 6. This illustrates the comparatively well-mixed nature of the vortex core.

4. Evidence for its existence from chemical measurements

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from MLS
on UARS

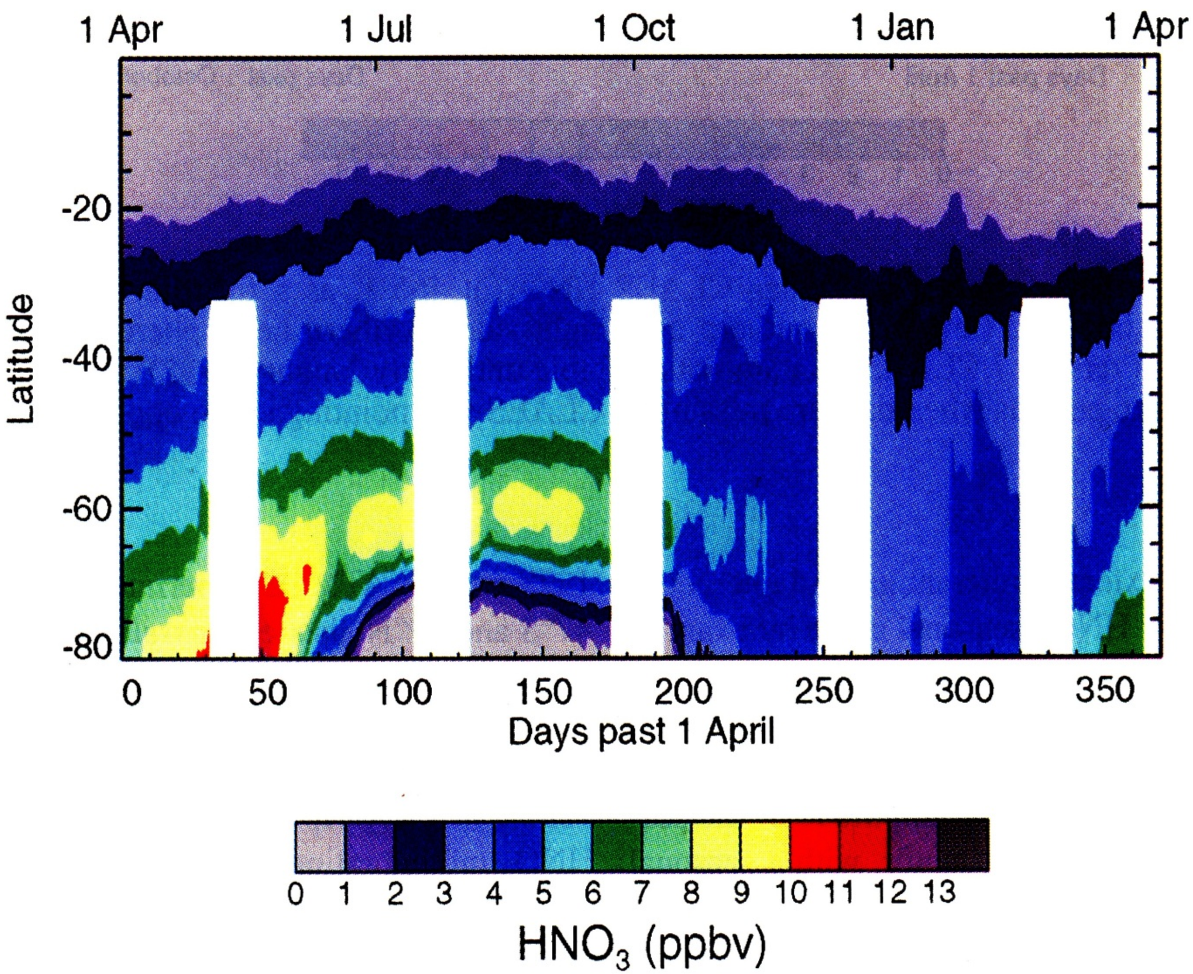

Plate 7. Southern hemisphere daily zonal-mean climatology of MLS HNO_3 at 465 K 'unction of latitude, obtained by averaging together for the respective hemispheres the results for the 6 ındividual years shown in Plate 5 plus the partial year 1997–1998.

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4. Evidence for its existence from chemical measurements

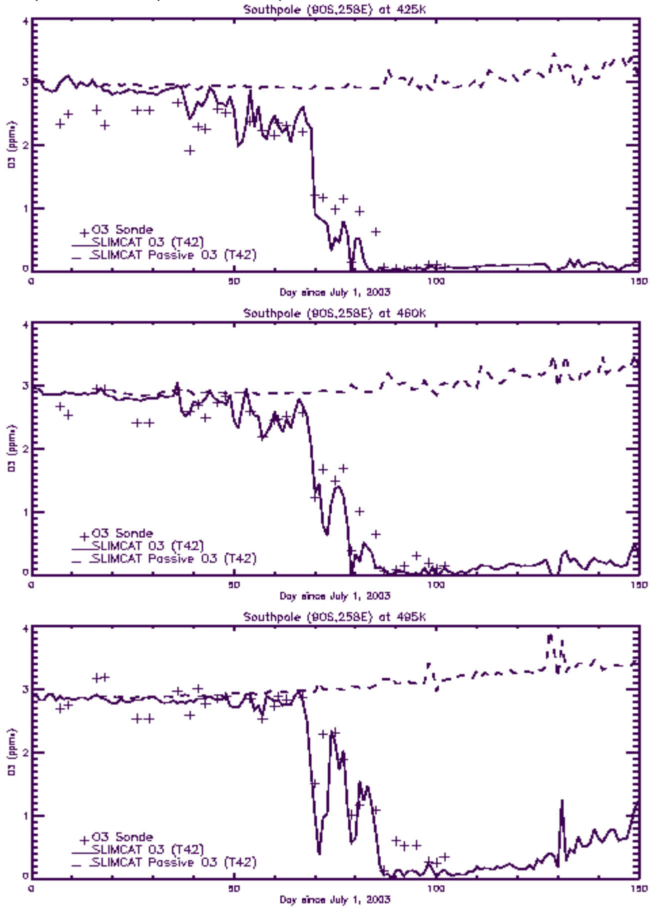
from QUOBI EC project

1 July ↓ 1 Aug ↓ 1 Sept ↓ South Pole

425 K

460 K

495 K



Chemically active & passive O_3 from SLIMCAT model (lines), and O_3 from sondes (points), in 2003

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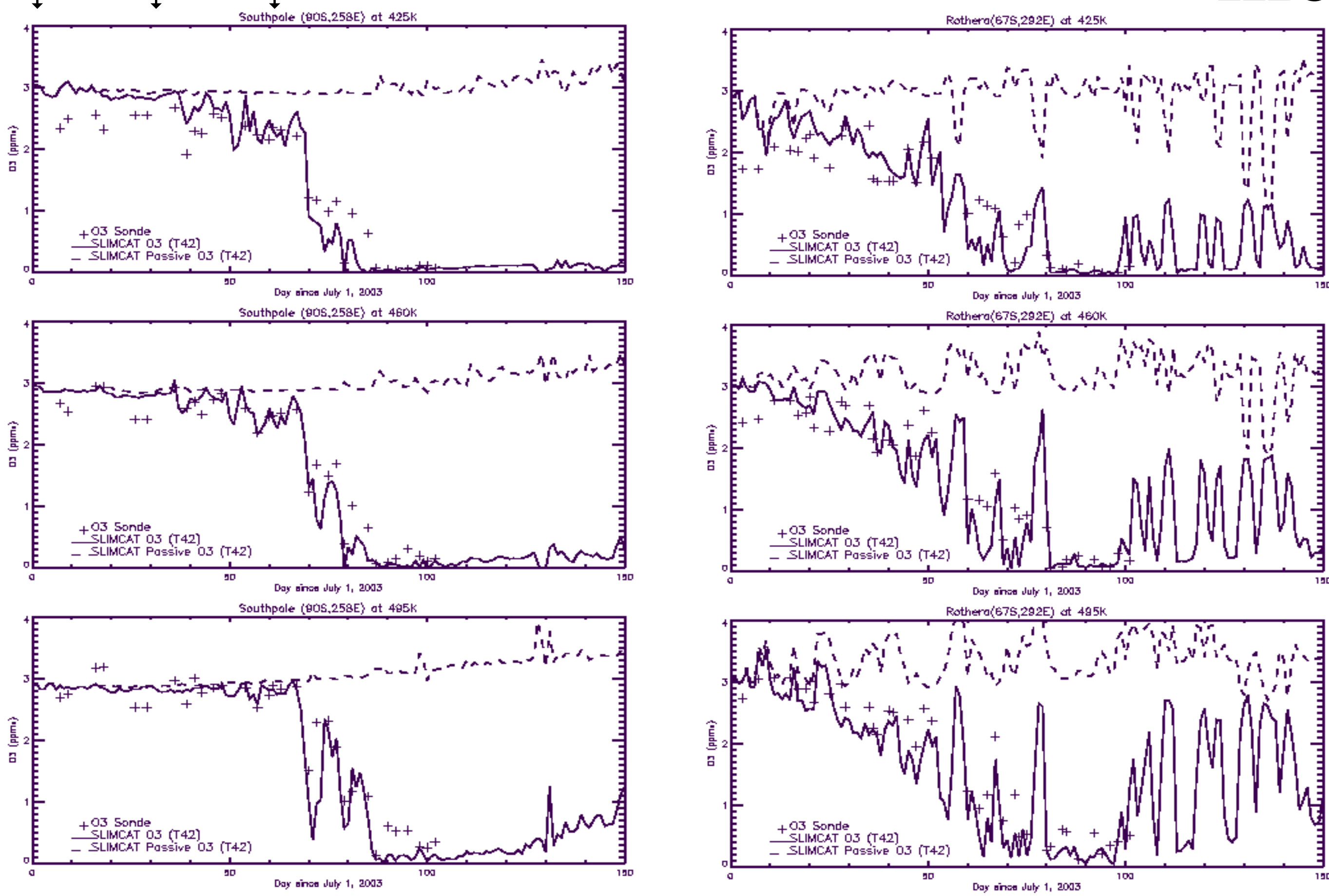
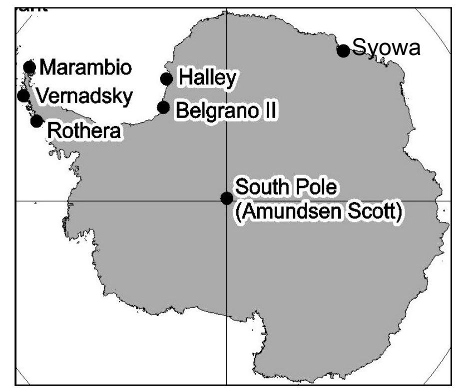
1 July ↓ 1 Aug ↓ 1 Sept ↓

South Pole | Rothera (67°S)

425 K
460 K
495 K





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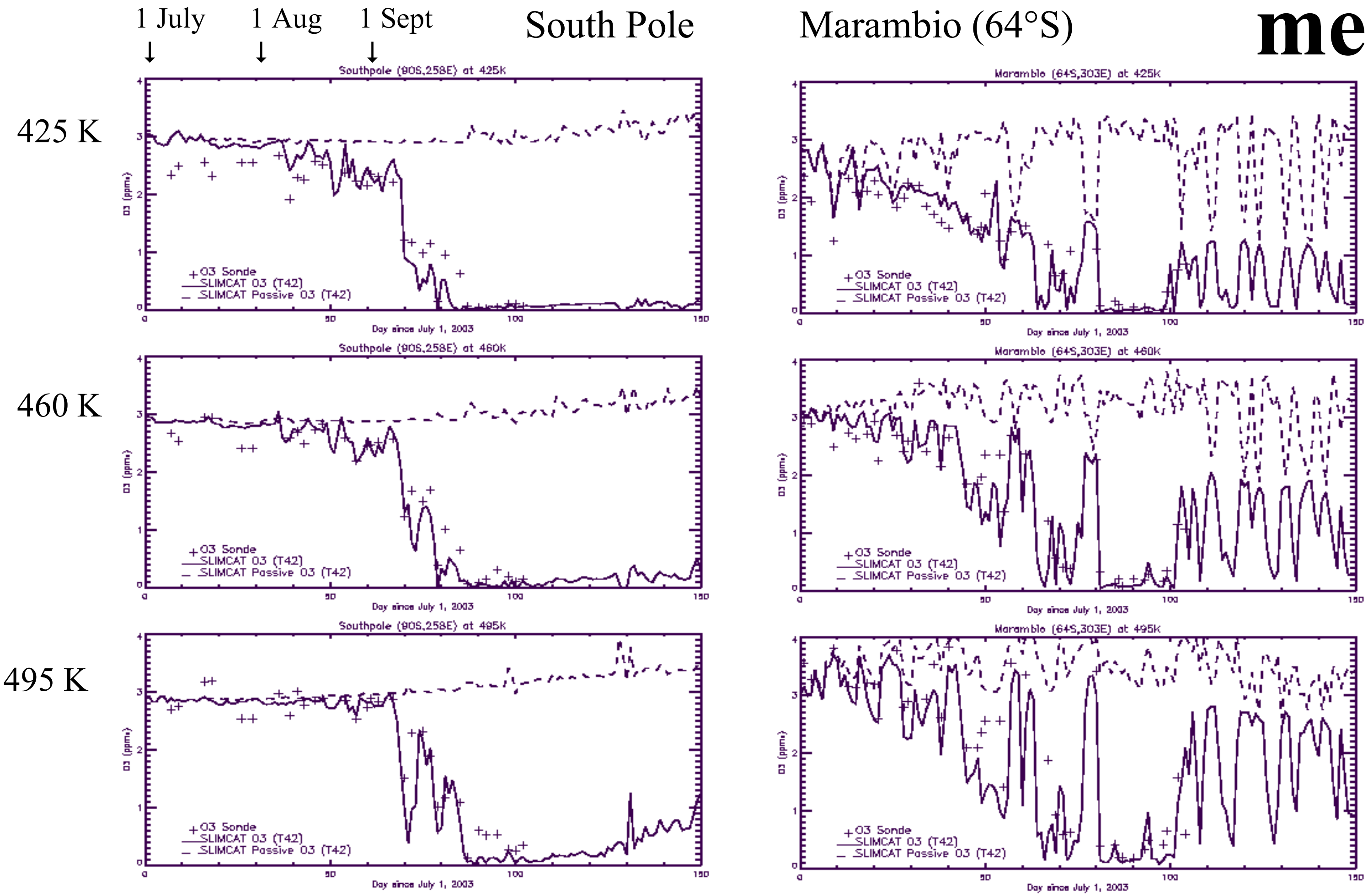

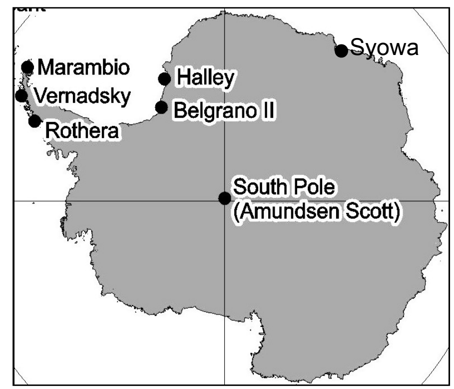

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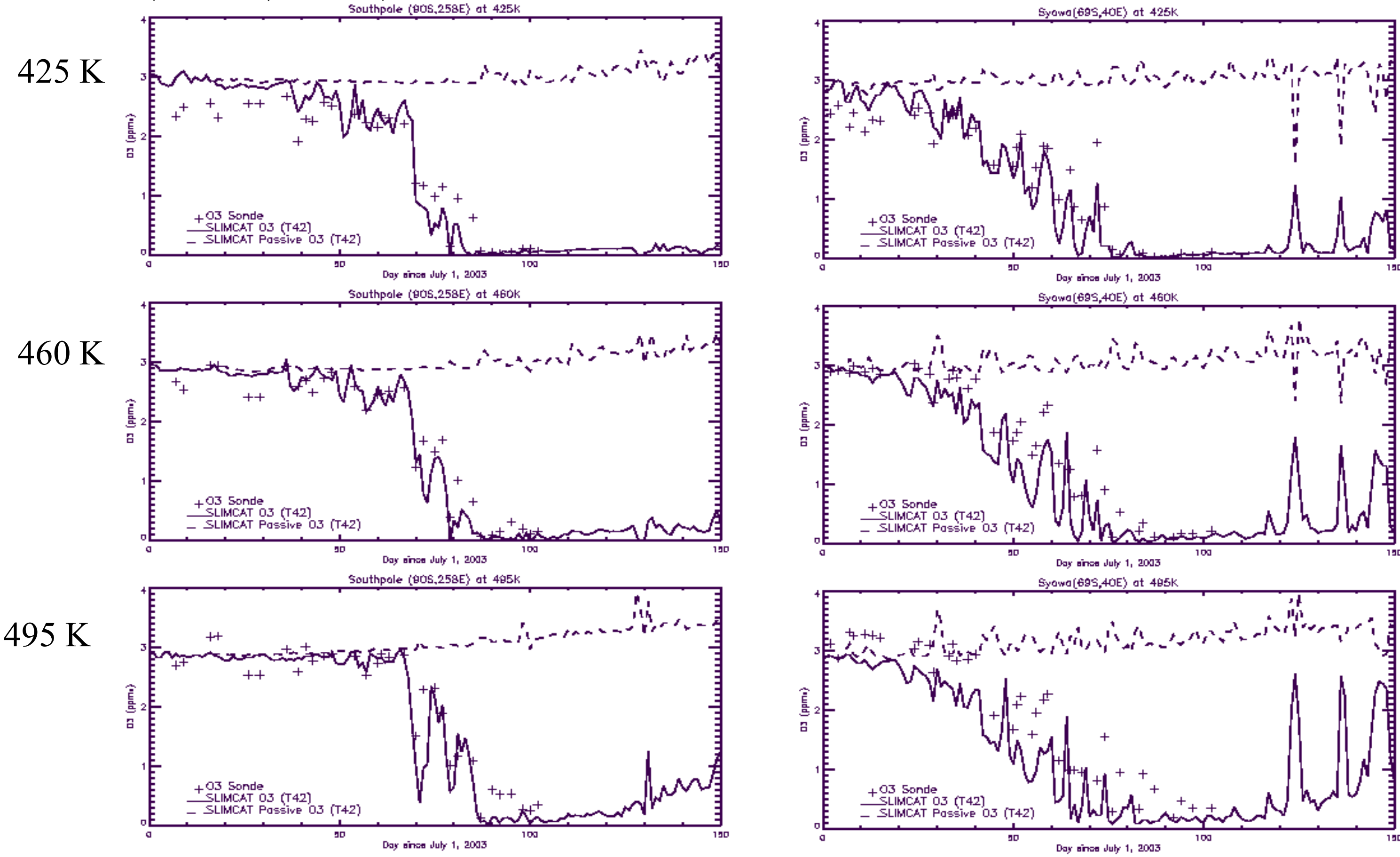
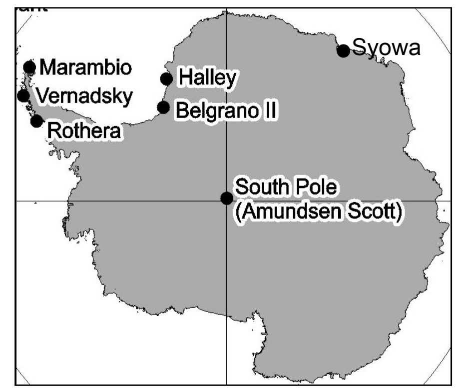
1 July ↓ 1 Aug ↓ 1 Sept ↓ South Pole Syowa (69°S)





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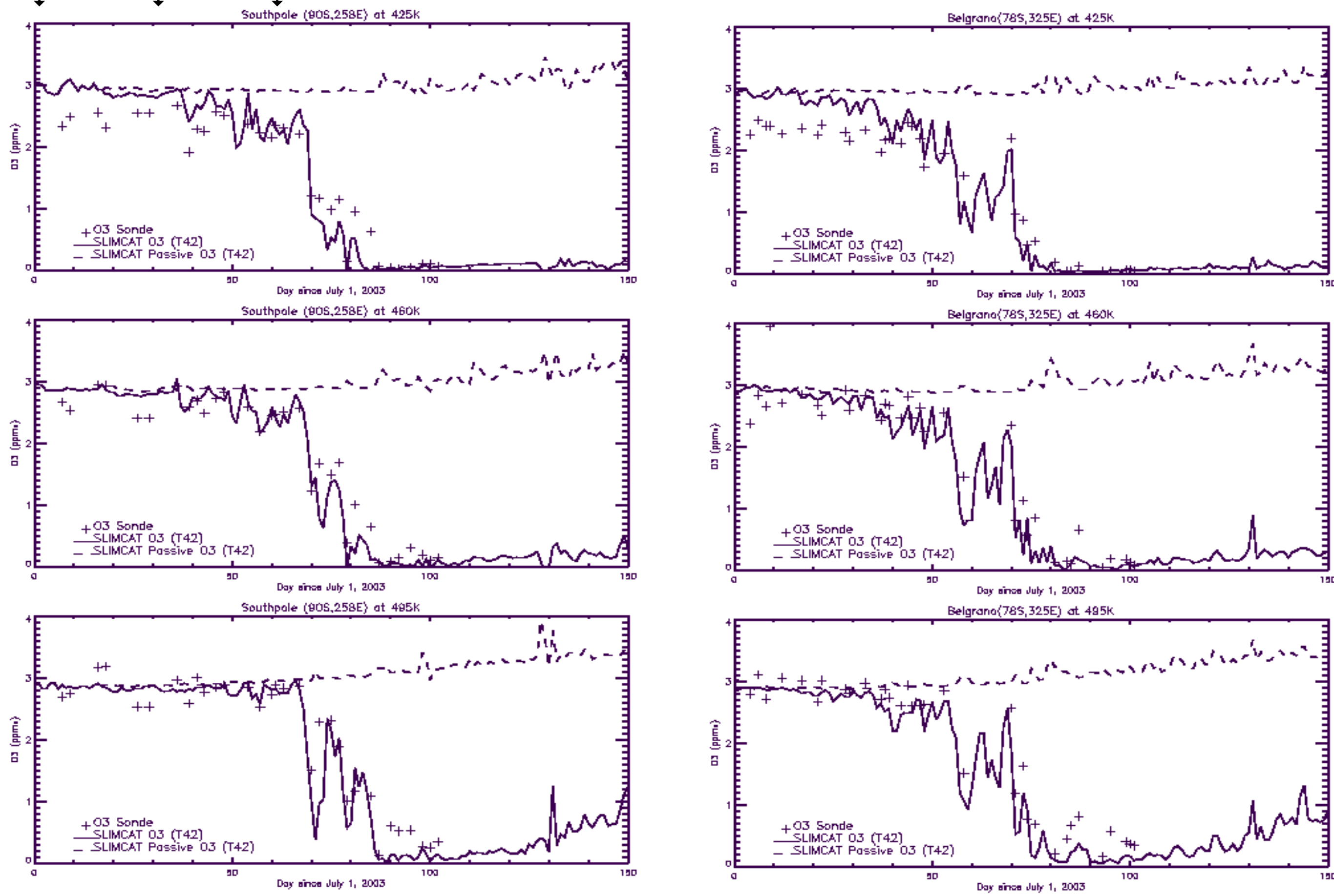
1 July ↓ 1 Aug ↓ 1 Sept ↓

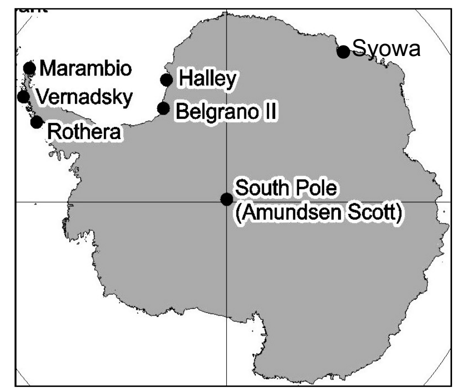
South Pole | Belgrano (78°S)

425 K

460 K

495 K





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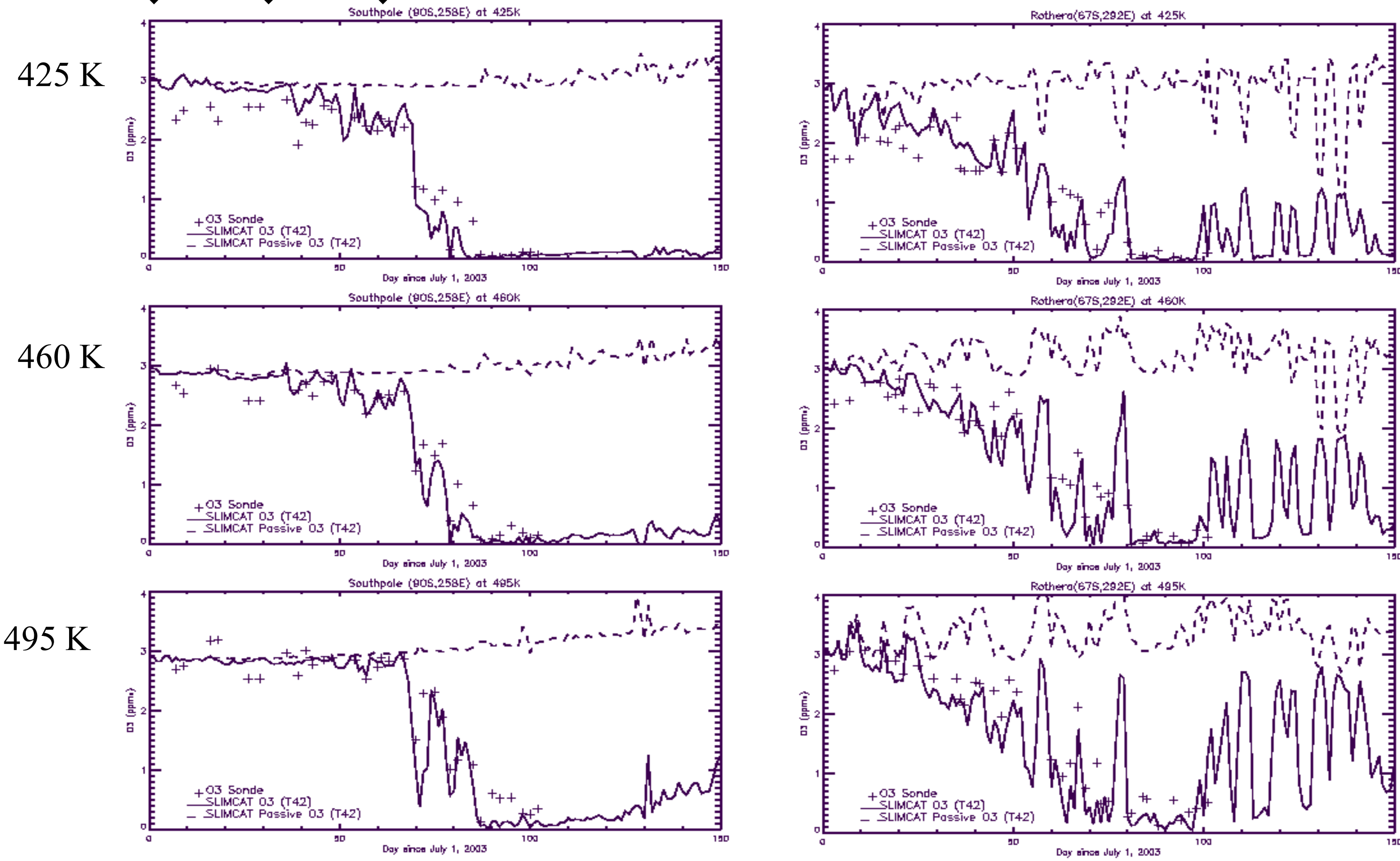

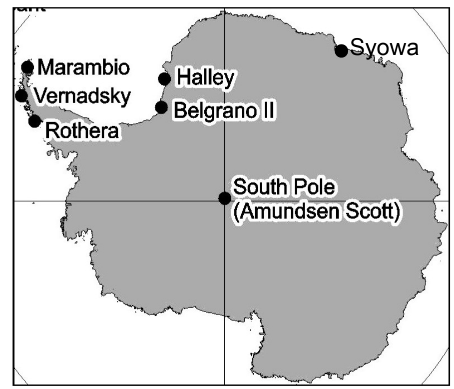

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5. Evidence from dynamical measurements (balloons)

from VORCORE project

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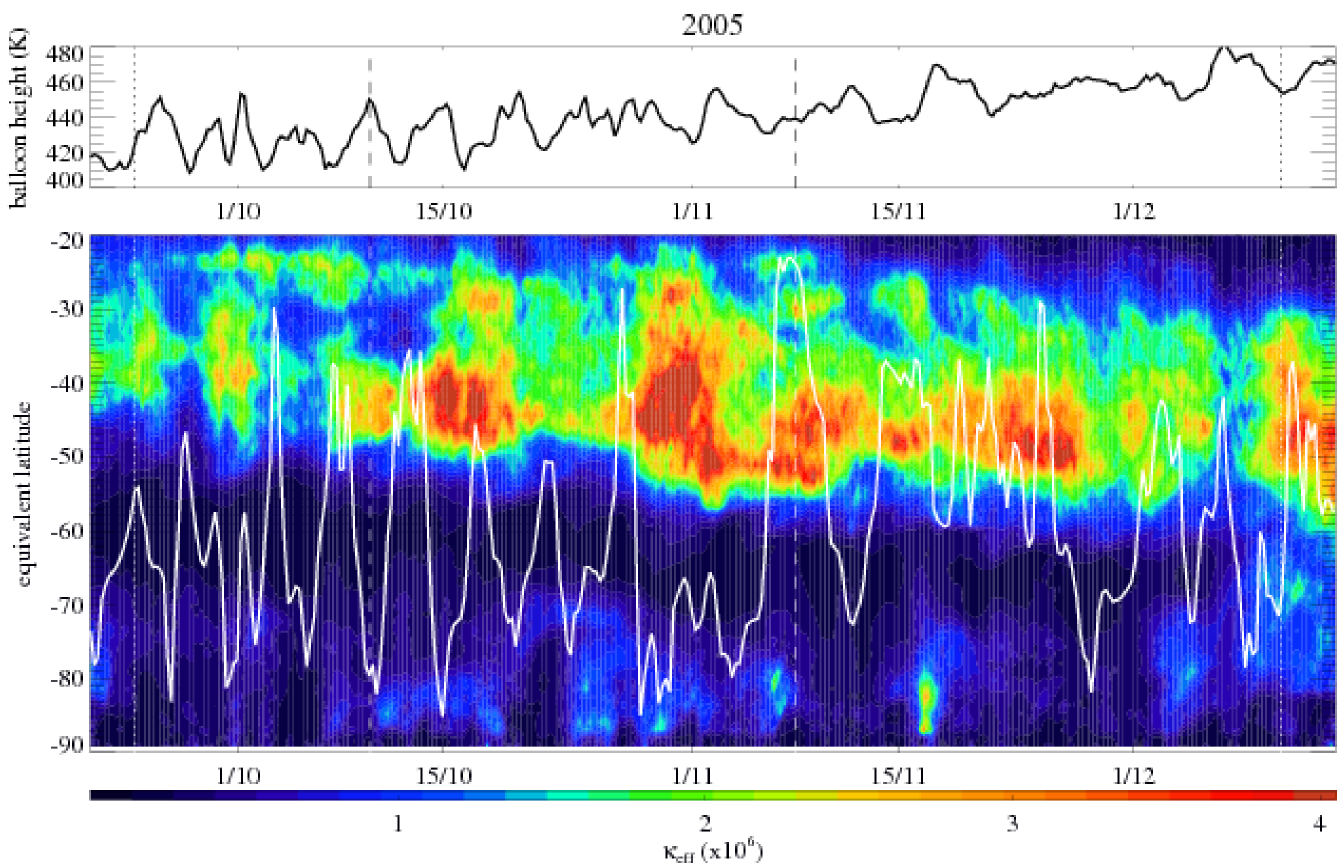

Top:
Height (potential temperature) of the balloon launched on 20 September 2005

Bottom:

Colours: effective diffusivity at the height of the balloon

White: location of the balloon, in PV-equivalent latitude

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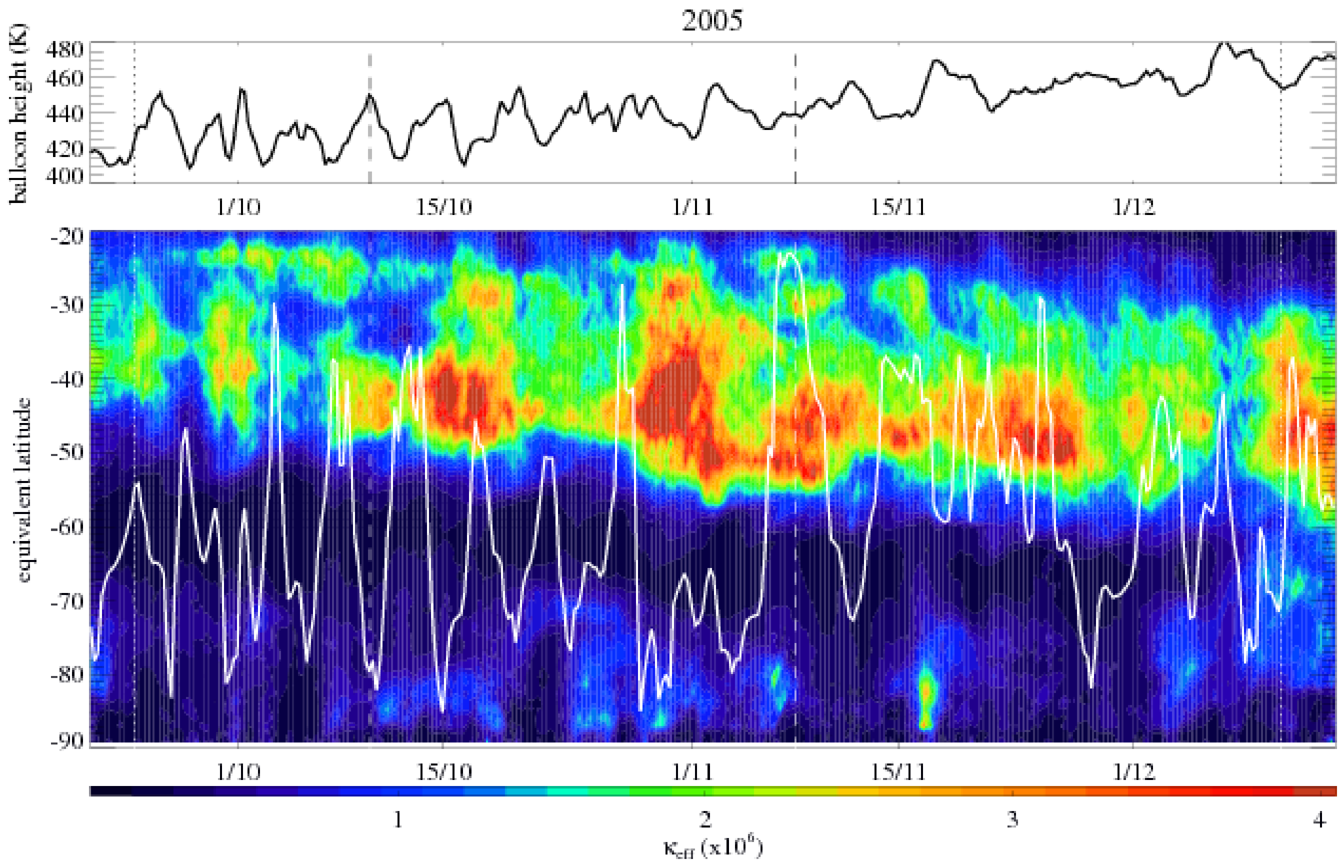

Top:
Height (potential temperature) of the balloon launched on 20 September 2005

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Colours: effective diffusivity at the height of the balloon

White: location of the balloon, in PV-equivalent latitude

Problem: the calculation of PV-equivalent latitude of the balloon is wrong
- probably because of the poor vertical and horizontal resolution of the model used
Also: the balloon is rather low for a well defined edge region, particularly at the start

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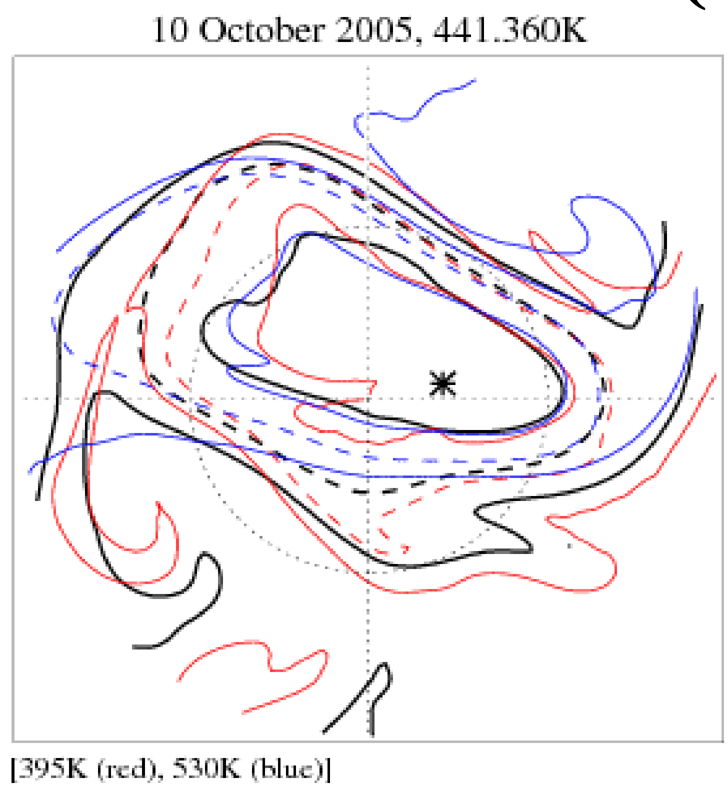

Contours of 50°, 60° and 70° equivalent latitude, at 395K (red), 530K (blue) and interpolated to balloon level (black).

Contours at T106 resolution

* location of the balloon

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5. Evidence from dynamical measurements (balloons)

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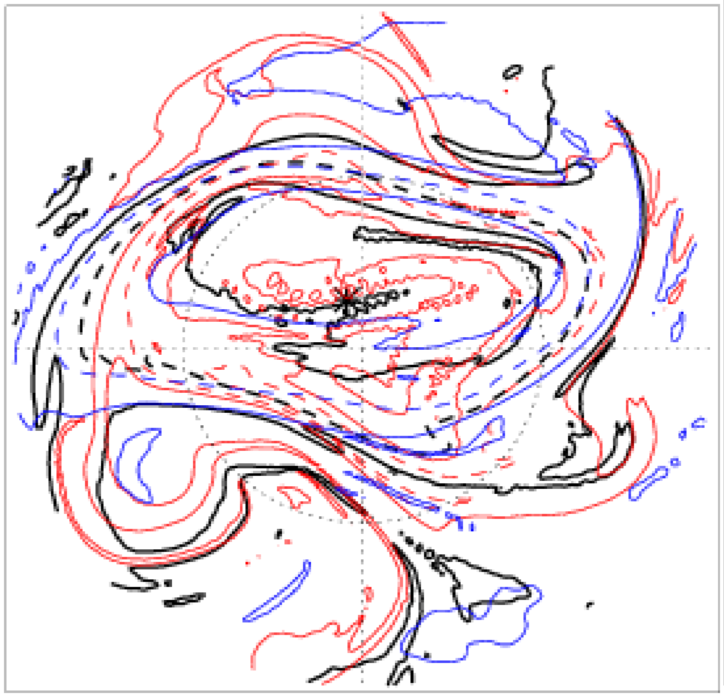
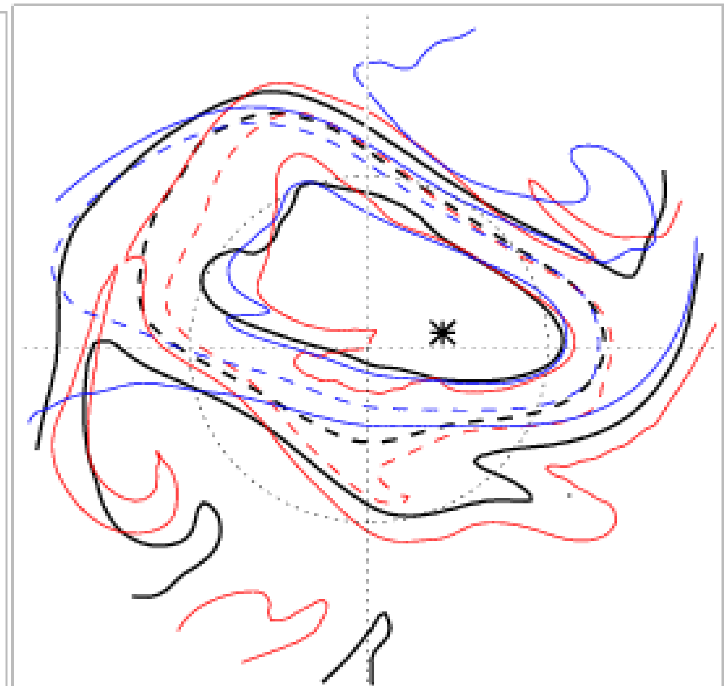
Contours at T213 resolution



10 October 2005, 441.360K



[395K (red), 530K (blue)]

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It should allow climate and chemistry to interact, delaying the recovery of the ozone hole

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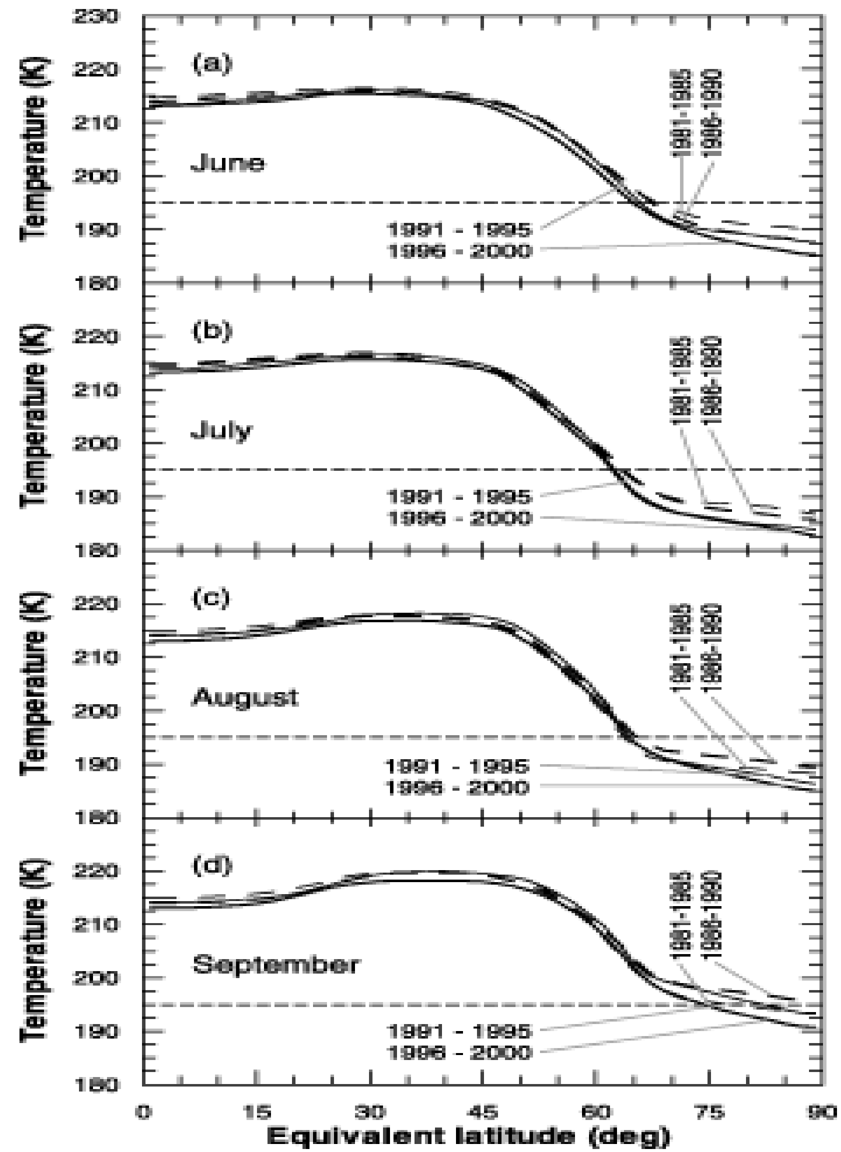

Monthly-mean zonal-mean T at 550 K
(from met. analyses, Bodeker et al. 2002)

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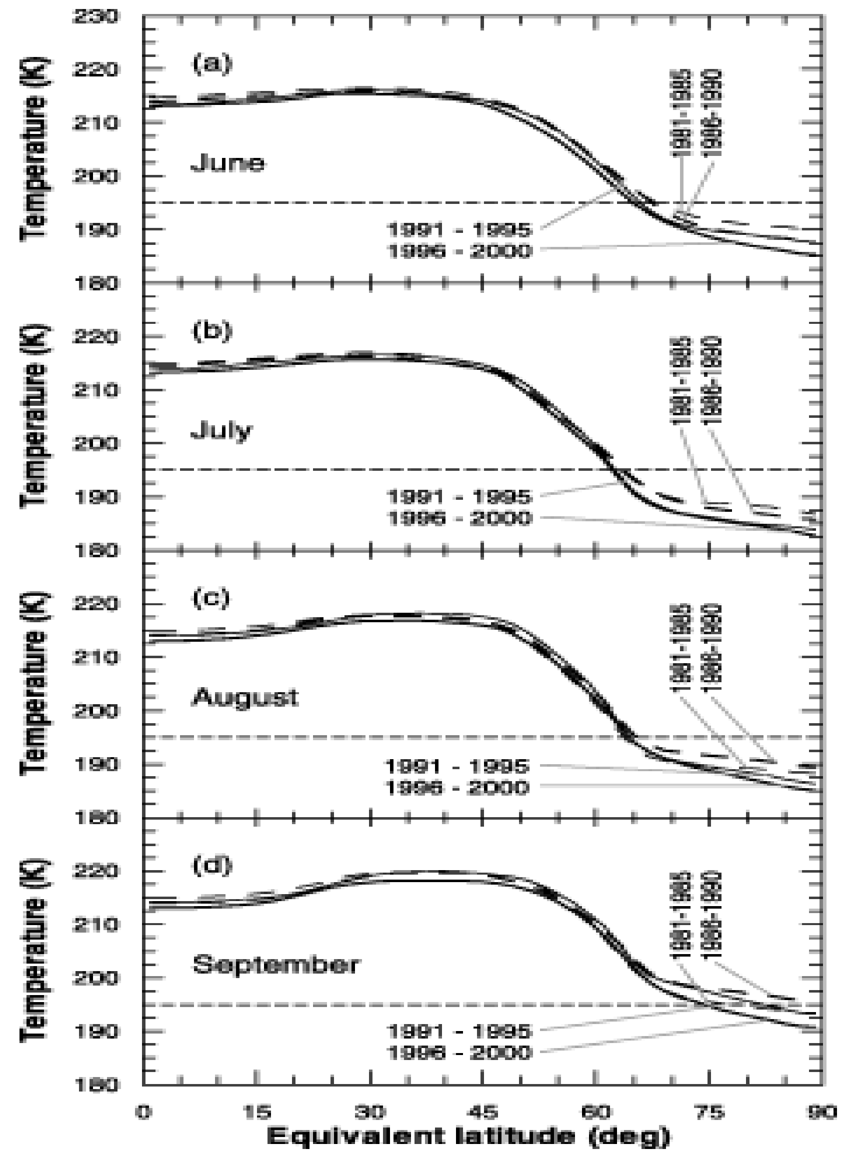
- **increased greenhouse gases (CO_2, stratospheric H_2O) & reduced O_3 are cooling the stratosphere**
- **about 2 K globally since 1980**
- **a colder stratosphere will increase ozone loss in the edge region by forming more PSCs**
- **the vortex core is full of PSCs in winter, so there would be no effect on ozone loss if the core mixed with the edge region**



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- about 2 K globally since 1980
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- the vortex core is full of PSCs in winter, so there would be no effect on ozone loss if the core mixed with the edge region

Ratio of ozone loss with different Cly & T to ozone loss in the model's control run. Equiv lat 60-65°S at 480 K in mid-Oct 96 (Lee, Roscoe et al. 2001)

	Cly (ppbv)			
ΔT, K	3.6	3.0	2.5	2.0
0	1.00	0.92	0.83	0.72
-2	1.09	1.02	0.93	0.82
-4	1.15	1.09	1.00	0.89
-6	1.18	1.13	1.05	0.94
-8	1.20	1.15	1.08	0.96

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Is the ozone hole getting bigger despite the maximum in Cly in the 1990s?

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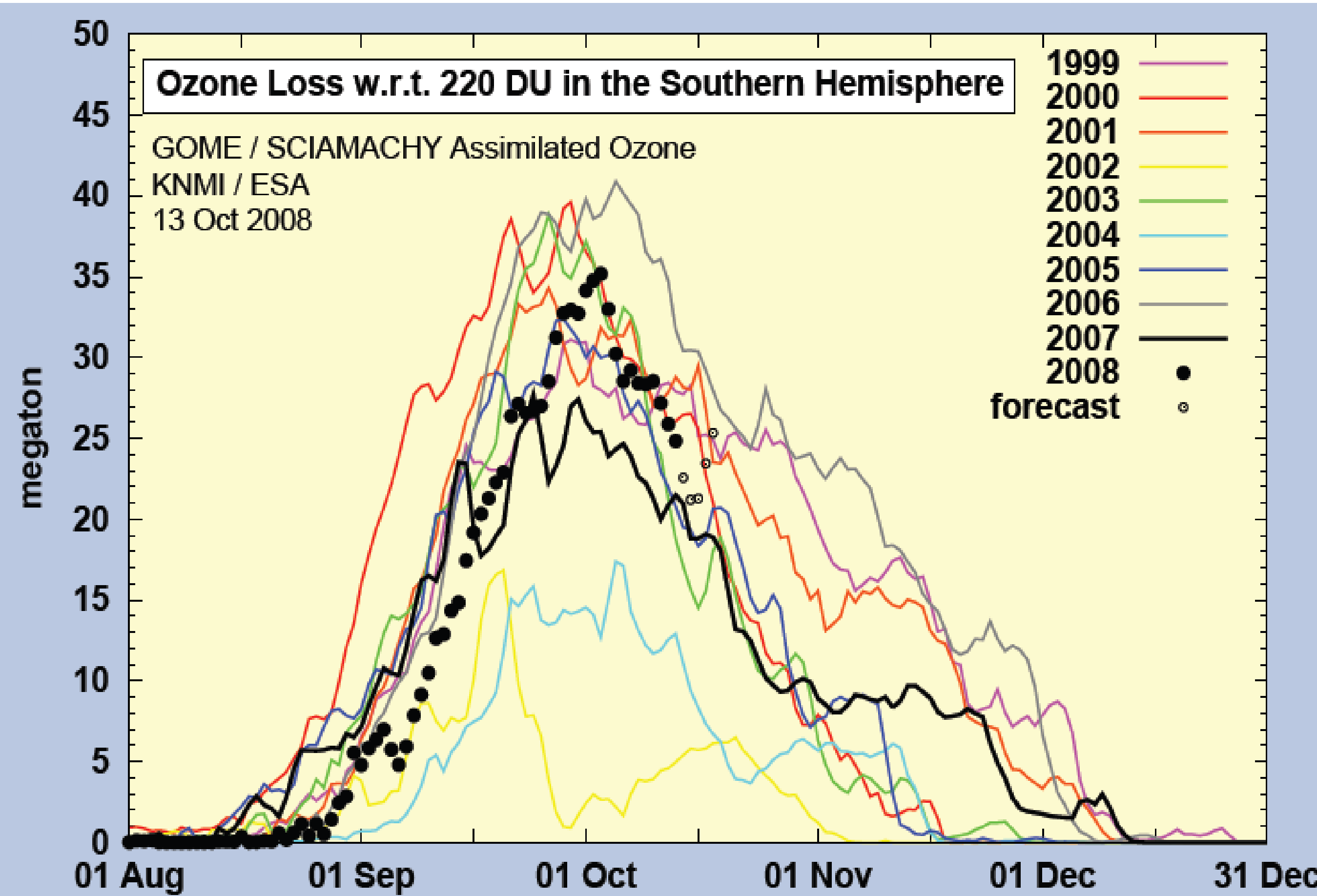

Figure 22. Ozone mass deficit (megatonnes) for the years from 1999 to 2008 (black dots). The mass deficit is the amount of ozone that would have to be added to the ozone hole in order to bring the total column up to 220 DU in those regions where the total column is below this threshold. The open circles represent a forecast for the next five days. This plot is produced by KNMI and is based on data from the GOME and SCIAMACHY satellite instruments.

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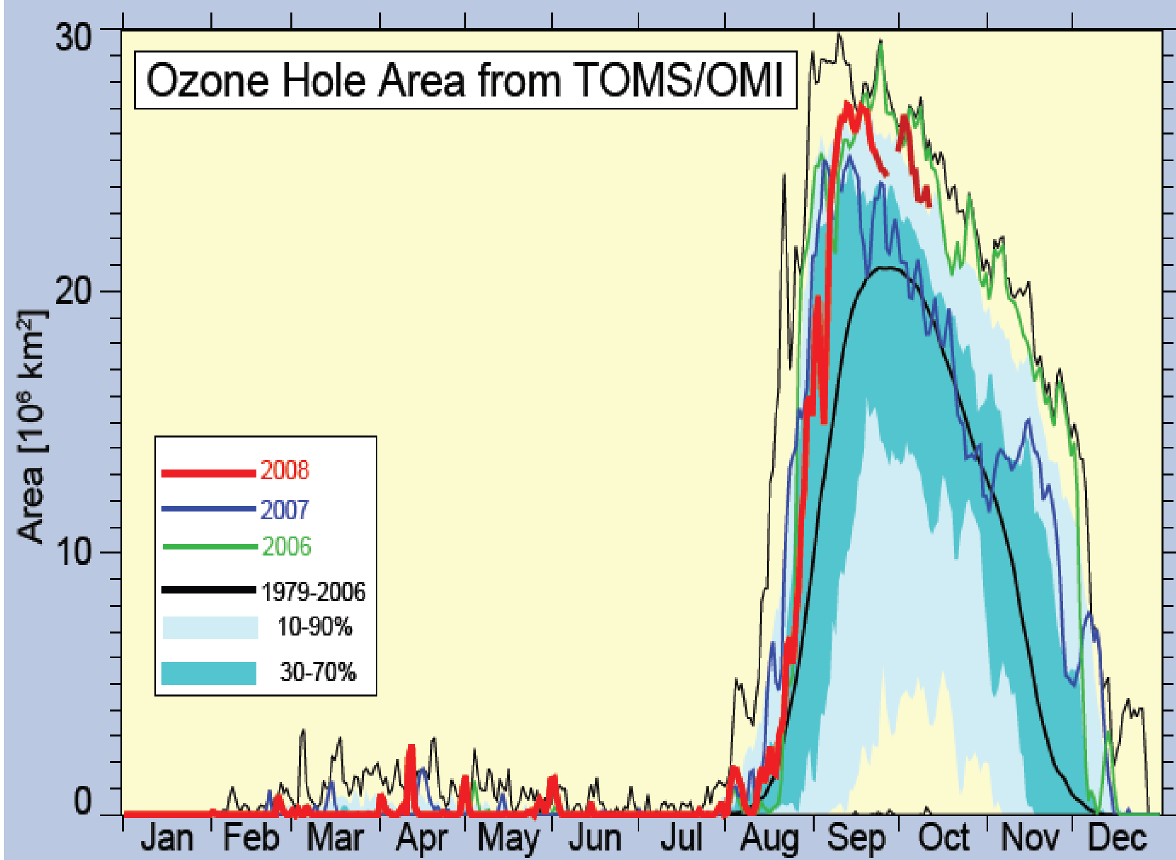

Figure 21. Area (millions of km^2) where the total ozone column is less than 220 Dobson units. 2008 is showed in red (until 22 September). The development since the last Bulletin is shown with a deeper red colour. 2007 is shown in blue and 2006 in green. The smooth black line is the 1979-2007 average. The dark green-blue shaded area represents the 30th to 70th percentiles and the light green-blue shaded area represents the 10th and 90th percentiles for the time period 1979-2007. The plot is adapted from a plot downloaded from the NASA Ozonewatch web site and is based on data from the OMI instrument on AURA and various TOMS instruments.

The edge region of the Antarctic stratospheric vortex: Conclusions

Howard Roscoe, BAS

Acknowledgements:
M Chipperfield & W Feng
M Trainic & VORCORE
E Shuckburgh

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E Shuckburgh

- **Strong evidence for existence from calculated effective diffusivity**
  - **area equal to the vortex core, unmixed with core for most of the spring**
- **Strong evidence for existence from chemical models with prescribed transport**
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The edge region of the Antarctic stratospheric vortex: Conclusions

British Antarctic Survey
NATURAL ENVIRONMENT RESEARCH COUNCIL

Howard Roscoe, BAS

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