Claus

GOME Ozone Fast Delivery and value-Added Products

Validation Document

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Contents

1 Introduction

This document gives an overview of the results of the validation of the Fast Delivery level 2 data (vertical ozone columns). Validation is an important part of the the GOFAP project and involves the assessing of the quality of the Fast Delivery vertical ozone columns by independent means and provides an estimate of the random and systematic errors. The first logical step in the validation of the Fast Delivery processor is a comparison with the GOME Data Processor (GDP) run by the German Processing and Archiving Facility (D-PAF) at DLR. Hence, comparisons have been made of the ozone slant column densities, the Air Mass Factors and the total ozone columns between the two processors. These comparisons give a good insight in the differences between the Fast Delivery and GDP ozone columns and provides an indication of the inaccuracies of both processors. However, this comparison involves the same instrument and therefore it is important to compare the Fast Delivery ozone columns with measurements of other satellite and ground-based instruments as well. For this reason, the Fast Delivery and GDP ozone columns have also been compared with TOMS total ozone measurements and with Brewer measurements at De Bilt (The Netherlands).

In Chapter 2 the comparisons between the Fast Delivery processor and the GDP are described. Chapter 3 discusses the comparisons with the TOMS total ozone measurements and Chapter 4 describes the comparison with the Brewer measurements at the Bilt. The conclusions of the validation are summarised in Chapter 5.

2 Comparison with the GOME Data Processor

This chapter describes the comparison between the the Fast Delivery data and the GDP data for the months February and July 1998 (a description of the Fast Delivery processor is given in the Algorithm Specification Document [1], the GDP algorithm is described in [2]). The differences in the DOAS slant column densities, the Air Mass Factors and the vertical ozone columns have been analysed; the results of these analyses are described in the next sections.

2.1 Slant column comparison

In the Figure 2.1a, the relative difference between the FD and GDP ozone slant column densities are plotted for three successive orbits on February 16, 1998 (roughly covering Europe and Africa). Each asterisk denotes a single GOME measurement: centre pixels are plotted in black, east pixels in red and west pixels in green. From this comparison it can be seen that the FD slant column is about 1-3% higher than the GDP slant column, depending on the latitude. It is likely that this difference is caused by a difference in the (climatological) temperature used in the calculation of the ozone absorption spectrum. Figure 2.1a shows jumps in the slant column differences at certain latitudes. A reason for these jumps could be that the temperature used in the GDP DOAS slant fit is not interpolated as a function of latitude (in the FD processor, the fit-temperature is linearly interpolated). The comparison shows not much scatter in the slant column difference (<1%), indicating that the longitudinal variation in the slant column difference is small.

In Figure 2.2a, the relative difference between the FD and GDP ozone slant column densities are plotted for three successive orbits on August 16, 1998. In this month, the FD slant column is about 3-6% higher than the GDP slant column. The latitudinal variation is different from February (more or less reverse) and is, as explained above, probably due to differences in the fit-temperature. The jumps in the slant column are also clearly visible in August, but occur at different latitudes.

2.2 Air Mass Factor comparison

Figure 2.1b shows the relative difference between the FD and GDP Air Mass Factors for the three orbits in February. For this comparison, the AMF "to the ground" is used and therefore the effect of clouds is not taken into account. This figure shows that between the equator and 60°S, the FD Air Mass Factors are about 2-5% lower than the Air Mass Factors calculated with the GDP. This systematic difference is possibly caused by differences in the assumed ozone- and temperature in both processors. There is not much scatter in the AMF difference at these latitudes. However, the AMF difference for the west pixels vary systematically from the AMF difference for the centre and east pixels. A clear explanation for this pixel type dependence can not (yet) be given, but it could be due to inaccuracies in one or both processors in the treatment of the azimuth, solar zenith and line-of-sight angles in the AMF calculations or in the averaging of the Air Mass Factors over a pixel.

Figure 2.1b shows that when going from the equator to the northern mid- and high latitudes, the FD Air Mass Factor becomes somewhat larger (1-5%) than the GDP Air Mass Factor and the scatter in the AMF difference increases. The main reason for this scatter in the Air Mass Factors is the difference in the surface albedo climatology. In the Fast Delivery processor, the monthly reflectivity climatology from 340-380 nm TOMS data is used in which sea-ice and snow cover is taken into account (for a description of the TOMS reflectivity climatology see [3]). In the GDP, however, sea-ice and snow cover is not taken into account. This causes significant differences in the calculated AMF for northern mid- and high-latitudes in February. The large scatter at the southern high-latitudes is probably caused by differences in the assumed surface albedo around and above Antarctica.

In Figure 2.2b the relative difference between the FD and GDP Air Mass Factors are plotted for the three orbits in August. Between the equator and 70°N, the FD Air Mass Factors are about 2-5% lower than the Air Mass Factors calculated with the GDP. As already explained above, these systematic differences are probably caused by differences in the assumed ozone- and temperature climatology in both processors. Between the equator and 60°S, the differences are small but south of 60°S, the differences increase strongly due to the surface

albedo effect above the sea ice around Antarctica. At high northern latitudes the AMF difference shows increasing scatter due to surface albedo effects above snow-covered areas.

2.3 Vertical ozone column comparison

Figures 2.1c and 2.2c show the relative difference between the FD and GDP vertical ozone columns for the three orbits in February and August. The ozone columns are retrieved by dividing the slant column density by the appropriate Air Mass Factor (see [1] and [2]). Hence, the difference between the FD and GDP ozone columns is a consequence of the slant column and AMF differences discussed in the previous sections. For February this results in a FD ozone column that is about 5-8% higher than the GDP ozone column between the equator and 60°S. North of the equator the difference decreases, but at northern mid- and high latitudes (and the southern high latitudes) the scatter in the differences increases due to a surface albedo effect. Due to the effects of clouds, the scatter in the ozone column differences is larger than the scatter in the AMF differences (in the GDP, the effects of clouds are accounted for via the Initial Cloud Fitting Algorithm and the use of a clear and cloudy Air Mass Factor, while in Fast Delivery processor, the effects of clouds are not yet taken into account).

In August, the FD ozone column is about 10% higher than the GDP ozone column between the equator and the northern mid-latitudes. South of the equator the difference decreases but south of 60°S the FD ozone column becomes increasingly smaller than the GDP ozone column (as described in the previous section, this is probably due to the surface albedo effect). At high northern latitudes, the scatter in the ozone column differences increases presumably due the surface albedo effect and the effect of clouds.

Figure 2.3 shows the difference between the FD and GDP vertical ozone columns for the nine Kiruna orbits of February 16, 1998. The somewhat higher differences in the west pixel ozone columns compared to the east and centre pixels are visible (as explained in the previous section, this is due to the AMF dependence on the pixel type). The figure clearly shows the higher FD ozone columns between the equator and 60°S and the abrupt change over Antarctica (presumably due to a surface albedo effect). North of the equator, the difference

decreases, but at the northern mid- and high latitudes there is a strong longitudinal dependence (due to a cloud- and surface albedo effect) clearly showing the snow covered areas above northern America and Asia.

Figure 2.4 shows the difference between the FD and GDP vertical ozone columns for all orbits of August 16, 1998. The generally higher FD ozone columns on the Northern Hemisphere and the decreasing difference between the equator and 60°S are visible. The effect of sea-ice around Antarctica and the ice in the North Pole and Greenland area on the ozone column difference can also clearly be seen.

3 Comparison with TOMS total ozone measurements

The vertical ozone columns calculated with the Fast Delivery processor and the GDP have been compared with EP-TOMS total ozone measurements for February and August 1998 (a description of the TOMS instrument and algorithm can be found in [4]). Section 3.1 describes the comparison between the Fast Delivery processor and TOMS, in section 3.2 the comparison between the GDP and TOMS is described. In section 3.3 the conclusions of these comparisons are discussed.

3.1 Comparison between the Fast Delivery processor and TOMS

The monthly average FD ozone fields have been calculated for February and July 1998 and interpolated to the TOMS grid-size. In Figure 3.1, the relative difference between the Fast Delivery and TOMS ozone fields is plotted for February (for the Kiruna orbits). This figure shows that the FD total ozone column is about 2-4% higher than TOMS between 30°S and 30°N (the higher difference around the equator in the Pacific ozone west of South America is due to persistent cloud cover, which is not yet taken into account in the Fast Delivery processor). At the southern mid-latitudes, the FD total ozone column is slightly lower (0-4%) than TOMS. Over Antarctica, the difference between the FD and TOMS ozone column increases sharply to about 10% and is presumably a result of the high surface albedo (the effect of high surface albedo on the retrieved ozone columns will be discussed in more detail at the end of this section). In the Northern Hemisphere, the difference between FD and TOMS decreases to about 1.5% at 40-50°N, but increases again over the northern Europe and the northern Atlantic Ocean. Over the snow covered areas in northern America and Asia, the FD ozone values are 5-10% lower due to the high surface albedo.

Figure 3.2 shows the relative difference between the FD and TOMS ozone fields for August. At low-latitudes, the FD ozone column is about 5% higher than TOMS. Northwards this difference decreases slowly to about 3% at the northern mid-latitudes with the exception of the Himalayas, where the FD ozone column is about 8% higher than TOMS. This is due to an

orography effect: in the FD processor the surface elevation (pressure) is not yet taken into account. Above Greenland and north of about 70°N, the FD ozone column becomes smaller than TOMS due to a surface albedo effect above the (sea) ice. On the Southern Hemisphere, the difference between FD and TOMS is generally small at the mid-latitudes. However, above the sea-ice around Antarctica, the FD ozone column is considerably smaller than TOMS.

To further analyse the effects of high surface albedo on the retrieved FD and TOMS ozone fields, the average ozone fields for February have been studied in more detail. Figure 3.3 shows the average FD ozone field for this month and the TOMS ozone field is shown in Figure 3.4. The general pattern of the two ozone fields is similar, but over Antarctica the different effect of high surface albedo on the retrieved ozone column can clearly be seen. The TOMS ozone column does not show a sudden change in the total ozone column above Antarctica (as one should expect), however, the FD ozone column changes abruptly. The effect above the snow covered areas in northern America and Asia is also visible, but not as clearly as above Antarctica. Although a realistic surface albedo climatology is used in the Fast Delivery processor, the effect on the retrieved ozone column seems to be to large. A possible explanation could be that in the Fast Delivery algorithm the calculated Air Mass Factor is to large over high surface albedo areas. The inclusion of the cloud cover effect in the FD algorithm could reduce the abrupt change in the ozone columns over high surface albedo areas somewhat, but (probably) not enough to resolve the problem. The effect of high surface albedo and cloud cover on the calculated AMF and ozone column will therefore be an important subject of further study.

3.2 Comparison between the GDP and TOMS

Figure 3.5 shows the relative difference between the GDP and TOMS ozone fields for February (for the Kiruna orbits). On the Southern Hemisphere, the GDP total ozone columns is lower than TOMS with differences of about 4% at the equator and 8% at the southern mid- and high-latitudes. Like the comparison between FD and TOMS, the difference increases abruptly above Antarctica due to the high surface albedo. In the Northern Hemisphere, the difference between the GDP and TOMS are smaller: at the northern mid-latitudes the GDP ozone column is about 2% higher than TOMS. At high-latitudes the difference varies

strongly, presumably due to high surface albedo (e.g. above Greenland). An other reason could be that the calculated Air Mass Factors in the GDP is inaccurate for high solar zenith angles.

Figure 3.6 shows the relative difference between the GDP and TOMS ozone fields for August. In contrast to the FD ozone columns, the GDP columns are generally lower than TOMS. The difference around the equator is about 5% and increases to about 8% at the northern mid- and high latitudes (with the exception of the Himalayas, where due to an orography effect, the GDP is higher than TOMS). South of the equator, the difference between GDP and TOMS decreases to about 3%, but at the southern mid-latitudes the increases again to about 6%. Above the sea-ice around Antarctica, the GDP ozone column becomes larger than TOMS (in the surface albedo climatology used in the GDP, sea-ice is not taken into account, resulting in higher total ozone columns).

Figure 3.7 shows the average ozone field for February calculated with the GDP. The general pattern of the GDP ozone field is similar to the FD and TOMS ozone fields, however, just as for the FD ozone column, the GDP ozone column changes abruptly over Antarctica. Since the GDP algorithm assumes a (realistic) high surface albedo above Antarctica, the effect of high surface albedo on the calculated Air Mass Factor could be overestimated in the GDP as well.

3.3 Conclusions

To give an overview of the comparisons of the FD and GDP ozone columns with the TOMS ozone columns, the zonally average differences for February and August are plotted in Figures 3.8 and 3.9. In February the GDP ozone column is generally lower than TOMS (except for the northern mid-latitudes). The FD ozone column is generally somewhat higher or comparable to the TOMS ozone column at low- and mid-latitudes, but smaller at high-latitudes (due to a surface albedo effect).

In August, the GDP ozone column is also generally lower than TOMS, while the FD ozone columns is about 3-5% higher at low-latitudes and northern mid-latitudes but smaller at high-latitudes and southern mid-latitudes.

From these comparisons one can conclude that the absolute differences between the FD ozone column and TOMS are smaller than 5% (except above Antarctica). The absolute differences between the GDP ozone column and TOMS exceed 5% over large parts of the world.

4 Comparison with ground-based Brewer measurements

The Fast Delivery and GDP ozone columns have been compared with Brewer measurements at De Bilt in The Netherlands as shown in Figure 4.1. This figure shows the relative difference between coincident GOME and Brewer measurements as a function of the solar zenith angle (as a 5 point running mean). There are 77 coincident measurements (within one hour) in the period from February 1998. The solid lines show the difference for the Fast Delivery processor (for each pixel type), the dashed lines show the difference for the GDP. The comparison shows that the FD ozone column is higher than the Brewer measurements, with an average difference of about 4%. The GDP ozone columns are lower than the Brewer measurements, with an average difference of about 2.5%.

To analyse the effect of clouds on the comparison, the cloud free situations (<10%) have been selected from the coincident measurements shown in Figure 4.1. The average difference for the cloud free situations are given in Table 4.1. From this table, it follows that the difference between the FD ozone column and the Brewer measurements are considerably smaller for the low cloud situation, with an average difference of about 2%. This implies that if a cloud algorithm is included in the Fast Delivery Processor, it is likely that the average difference becomes smaller for all coincident measurements

5 Conclusions

From the comparisons between the FD and GDP data one can conclude that the FD ozone column is generally 0-10% higher than the GDP ozone column. This is a result of differences in the temperatures used in the calculation of the ozone absorption spectrum and differences in the assumed ozone- and temperature climatology. The scatter in the ozone column differences at mid- and high latitudes is due to a surface albedo effect and the effect of clouds.

From the comparison with TOMS total ozone one can conclude that the FD ozone column is generally higher at low and mid-latitudes and smaller at higher latitudes. The absolute differences between the FD ozone column and TOMS are smaller than 5% (except above Antarctica). It is to be expected that the differences above areas with high surface albedo (like Antarctica) will become smaller if a cloud algorithm is included in the Fast Delivery Processor. The GDP ozone column is generally lower than TOMS with differences up to 5-10%.

The comparison between the Fast Delivery and GDP ozone columns show that the FD ozone columns are higher than the Brewer measurements (an average difference of about 4%), while the GDP ozone columns are lower (an average difference of about 2.5%). The comparison for the FD ozone columns is much better, with a average difference of about 2%, if the cloud free measurements are selected. It is therefore likely that the comparisons between the FD ozone columns and Brewer becomes better if a cloud algorithm is included in the Fast Delivery processor.

References

[1] GOME Ozone Fast Delivery and value-Added Products, Algorithm Specification Document, GOFAP-KNMI-ASD-01, 1998.

[2] GOME Level 1 to 2 Algorithm Description, ER-TN-DLR-GO-0025, 1994.

[3] Herman, J.R., E.A. Celarier, Earth surface reflectivity climatology at 340-380 nm from TOMS data, *Journal of Geophysical Research, Vol. 102*, p. 28,003-28,011, 1997.

[4] Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) Data Products User's Guide, NASA Reference Publication 1384, April 1996.

Captions

Figure 2.1 Relative difference of the ozone slant column density, Air Mass Factor and vertical ozone column calculated with the Fast Delivery processor and the Gome Data Processor. The data is plotted for three successive orbits on February 16, 1998 (roughly covering Europe and Africa). Each asterisk denotes a single GOME measurement (black: centre pixels, red: east pixel, green: west pixel).

Figure 2.2 Same as Figure 2.1, but for three successive orbits on August 16, 1998.

Figure 2.3 Relative difference between the Fast Delivery and GDP vertical ozone columns for the Kiruna orbits of February 16, 1998.

Figure 2.4 Relative difference between the Fast Delivery and GDP vertical ozone columns for the orbits of August 16, 1998.

Figure 3.1 Relative difference between the monthly average Fast Delivery and TOMS ozone fields for the Kiruna orbits of February, 1998 (the FD ozone fields are interpolated to the TOMS grid).

Figure 3.2 Relative difference between the monthly average Fast Delivery and TOMS ozone fields for August, 1998 (the FD ozone fields are interpolated to the TOMS grid).

Figure 3.3 Monthly average Fast Delivery ozone fields for the Kiruna orbits of February, 1998 (the ozone fields are interpolated to the TOMS grid).

Figure 3.4 Monthly average TOMS ozone fields (for the GOME Kiruna orbits) of February, 1998

Figure 3.5 Relative difference between the monthly average GDP and TOMS ozone fields for the Kiruna orbits of February, 1998 (the GDP ozone fields are interpolated to the TOMS grid).

Figure 3.6 Relative difference between the monthly average GDP and TOMS ozone fields for August, 1998 (the GDP ozone fields are interpolated to the TOMS grid).

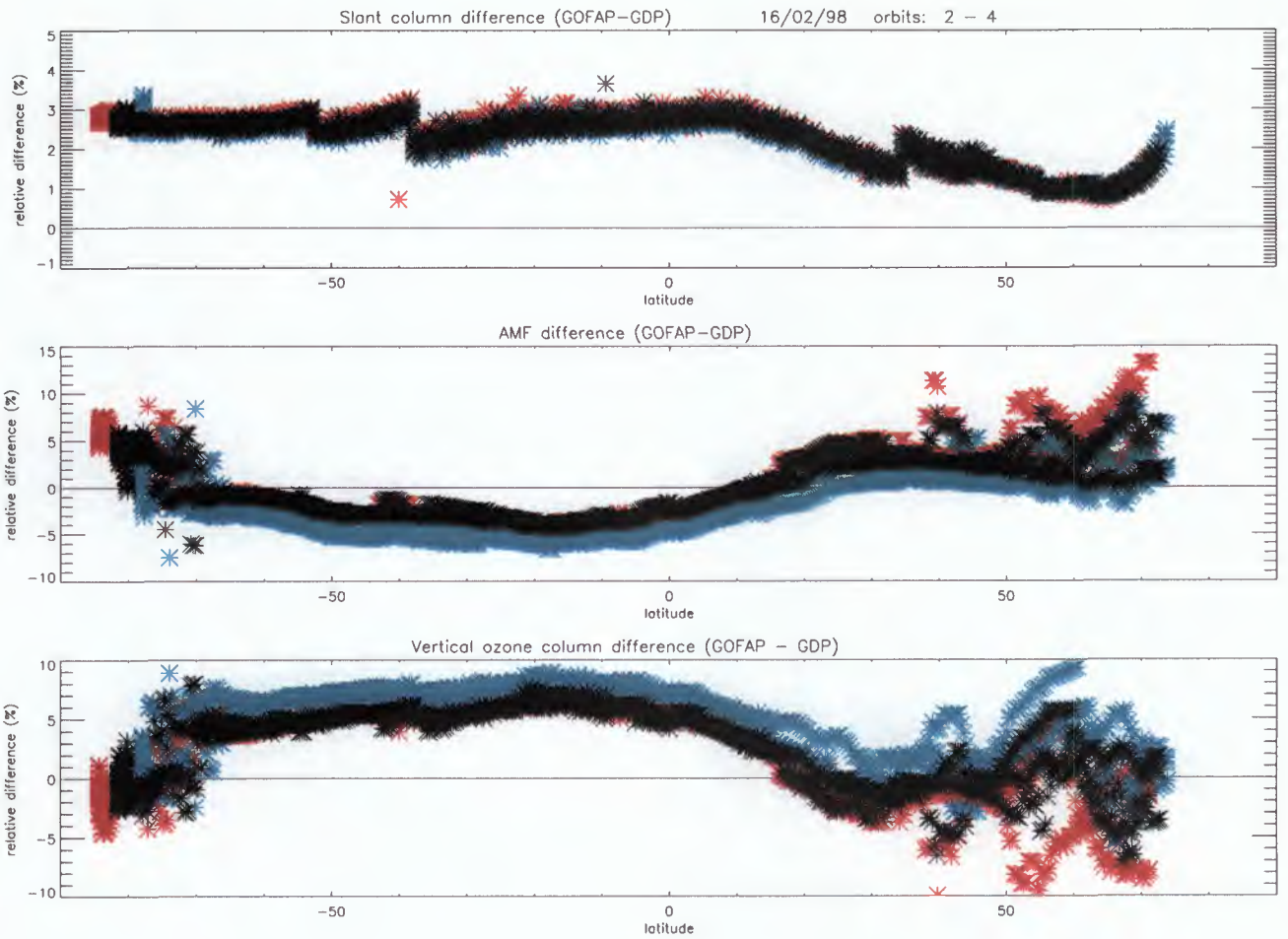
Figure 3.7 Monthly average GDP ozone fields for the Kiruna orbits of February, 1998 (the ozone fields are interpolated to the TOMS grid).

Figure 3.8 Zonally averaged difference between the Fast Delivery and TOMS ozone columns (solid line) and between the GDP and TOMS ozone columns (dashed line) for February, 1998.

Figure 3.9 Same as Figure 3.8, but for August, 1998.

Figure 4.1 Relative difference between coincident GOME and Brewer measurements as a function of the solar zenith angle (as a 5 point running mean). There are 77 coincident measurements (within one hour) in the period from February 1998. The solid lines show the difference for the Fast Delivery processor , the dashed lines show the difference for the GDP (black: east pixel, red: centre pixel and green: west pixel)

Table 4.1 Average relative difference between GOME (Fast Delivery and GDP) and Brewer measurements. Values are given for all coincident measurements and for the cloud free situations.

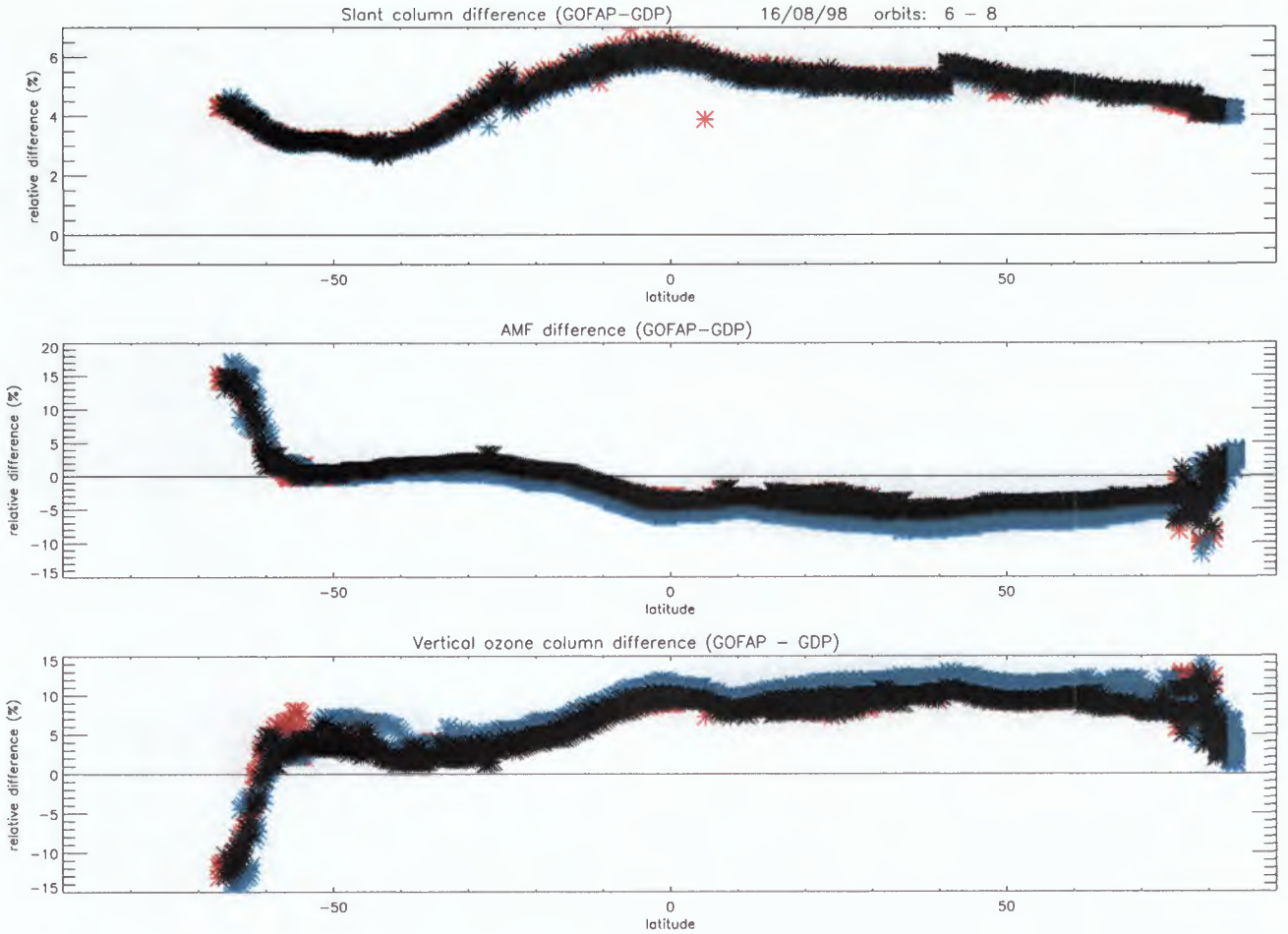

Slant column difference (GOFAP–GDP) 16/02/98 orbits: 2 – 4
relative difference (%)
latitude
AMF difference (GOFAP–GDP)
relative difference (%)
latitude
Vertical ozone column difference (GOFAP – GDP)
relative difference (%)
latitude

a

b

c

Fig 2.1


Slant column difference (GOFAP–GDP) 16/08/98 orbits: 6 – 8
relative difference (%)
6
4
2
0
−50
0
50
latitude
AMF difference (GOFAP–GDP)
relative difference (%)
20
15
10
5
0
−5
−10
−15
−50
0
50
latitude
Vertical ozone column difference (GOFAP – GDP)
relative difference (%)
15
10
5
0
−5
−10
−15
−50
0
50
latitude

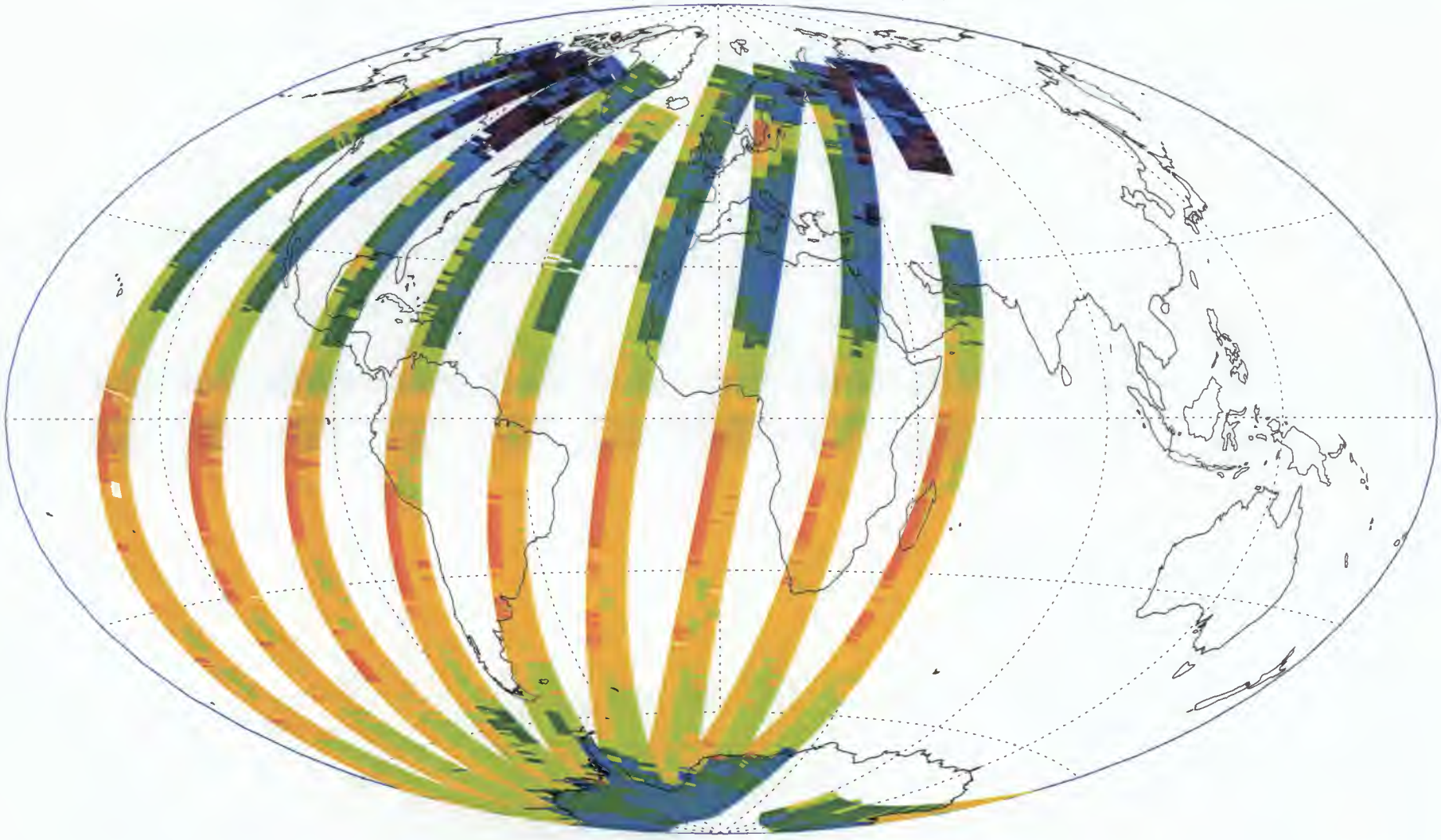
a

b

c

Fig 2.2

Vertical ozone column difference (GOFAP–GDP) 16/02/98 orbits: 1 – 9



< −10 | −10/−7.5 | −7.5/−5 | −5/−2.5 | −2.5/0 | 0/2.5 | 2.5/5 | 5/7.5 | 7.5/10 | > 10

Relative difference (%)

Fig 2.3

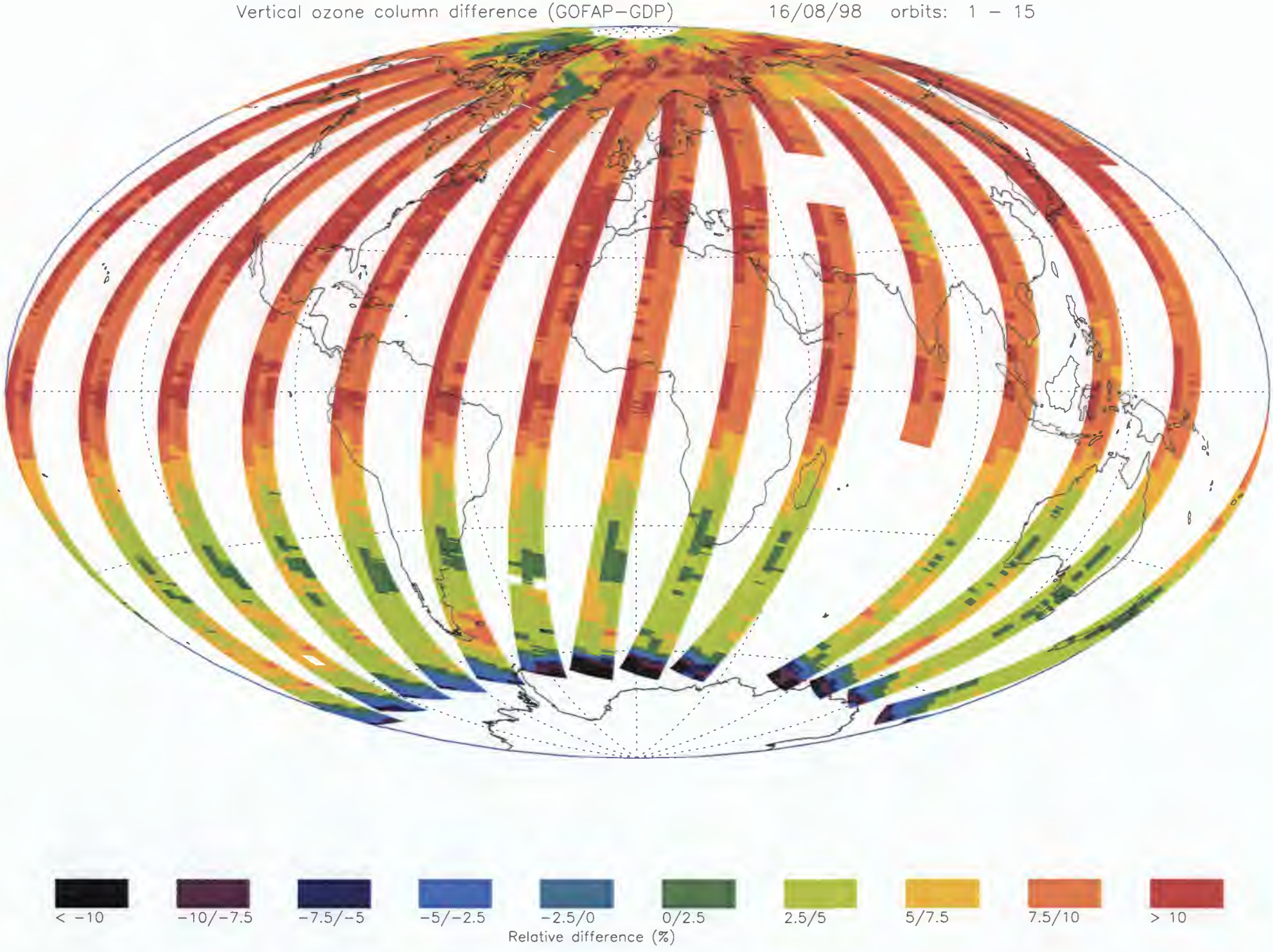

Vertical ozone column difference (GOFAP−GDP) 16/08/98 orbits: 1 – 15
< −10
−10/−7.5
−7.5/−5
−5/−2.5
−2.5/0
0/2.5
2.5/5
5/7.5
7.5/10
> 10
Relative difference (%)

Fig 2.4

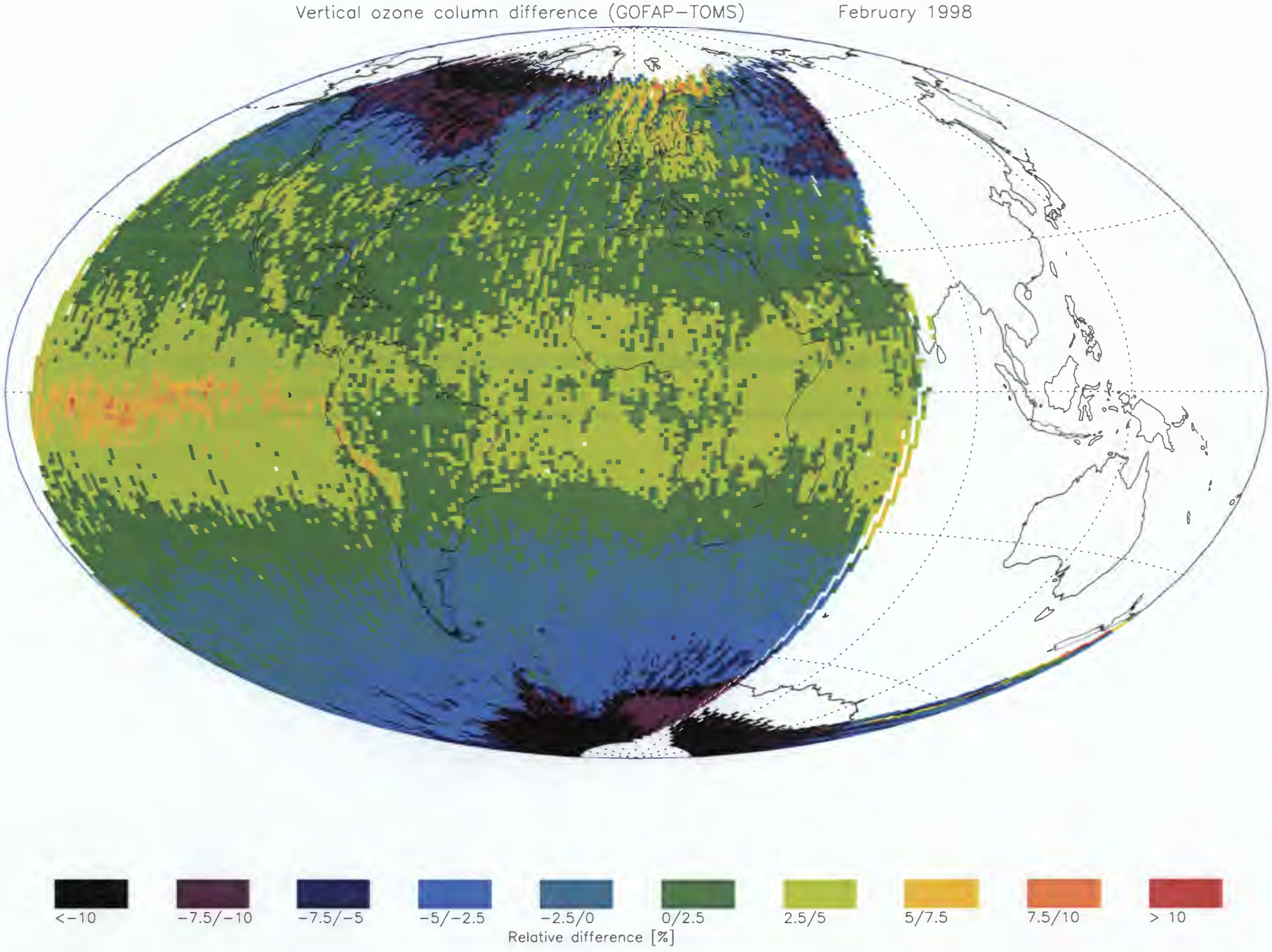

Vertical ozone column difference (GOFAP–TOMS)
February 1998
<–10
–7.5/–10
–7.5/–5
–5/–2.5
–2.5/0
0/2.5
2.5/5
5/7.5
7.5/10
> 10
Relative difference [%]

Fig 3.1

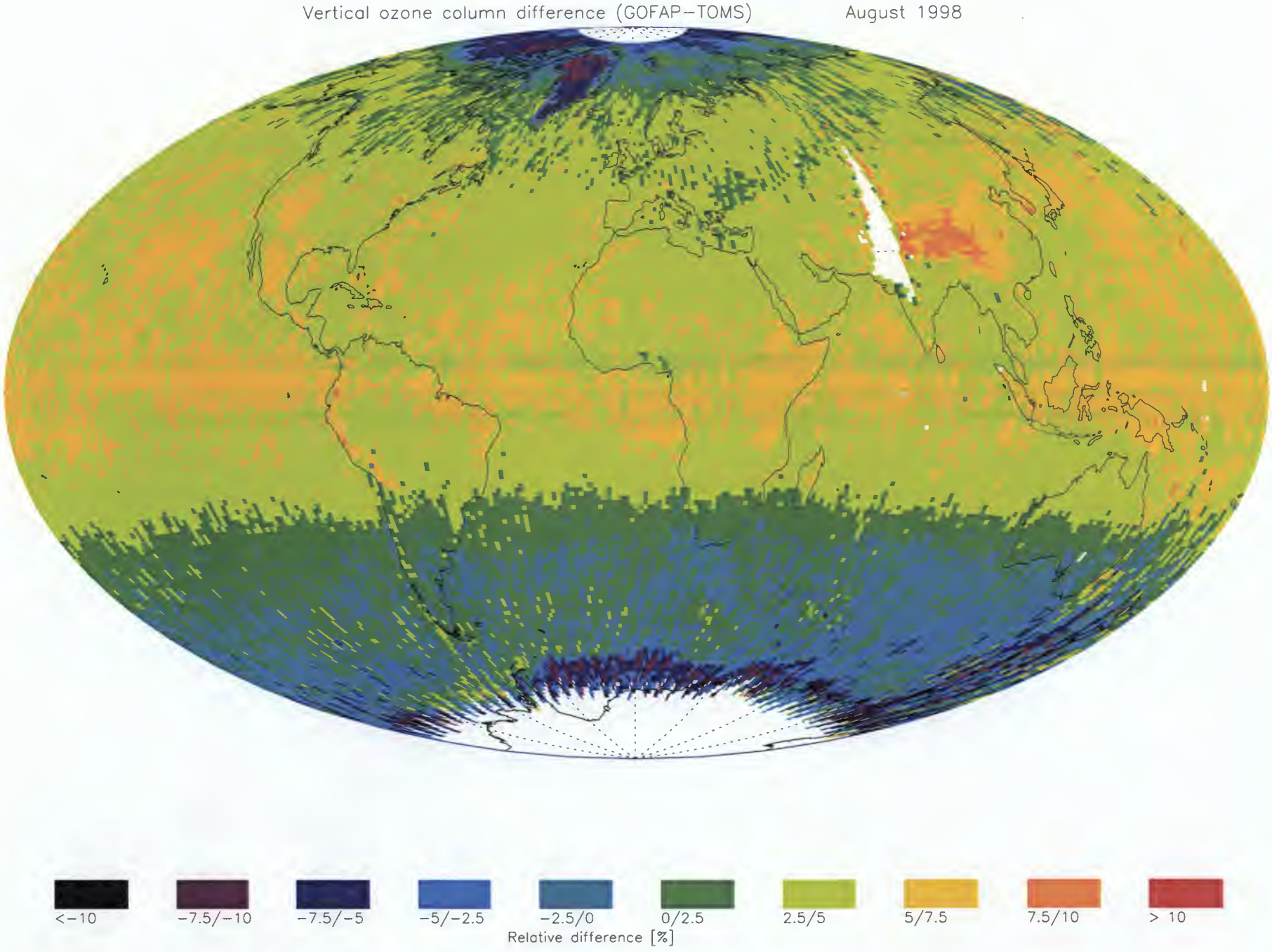
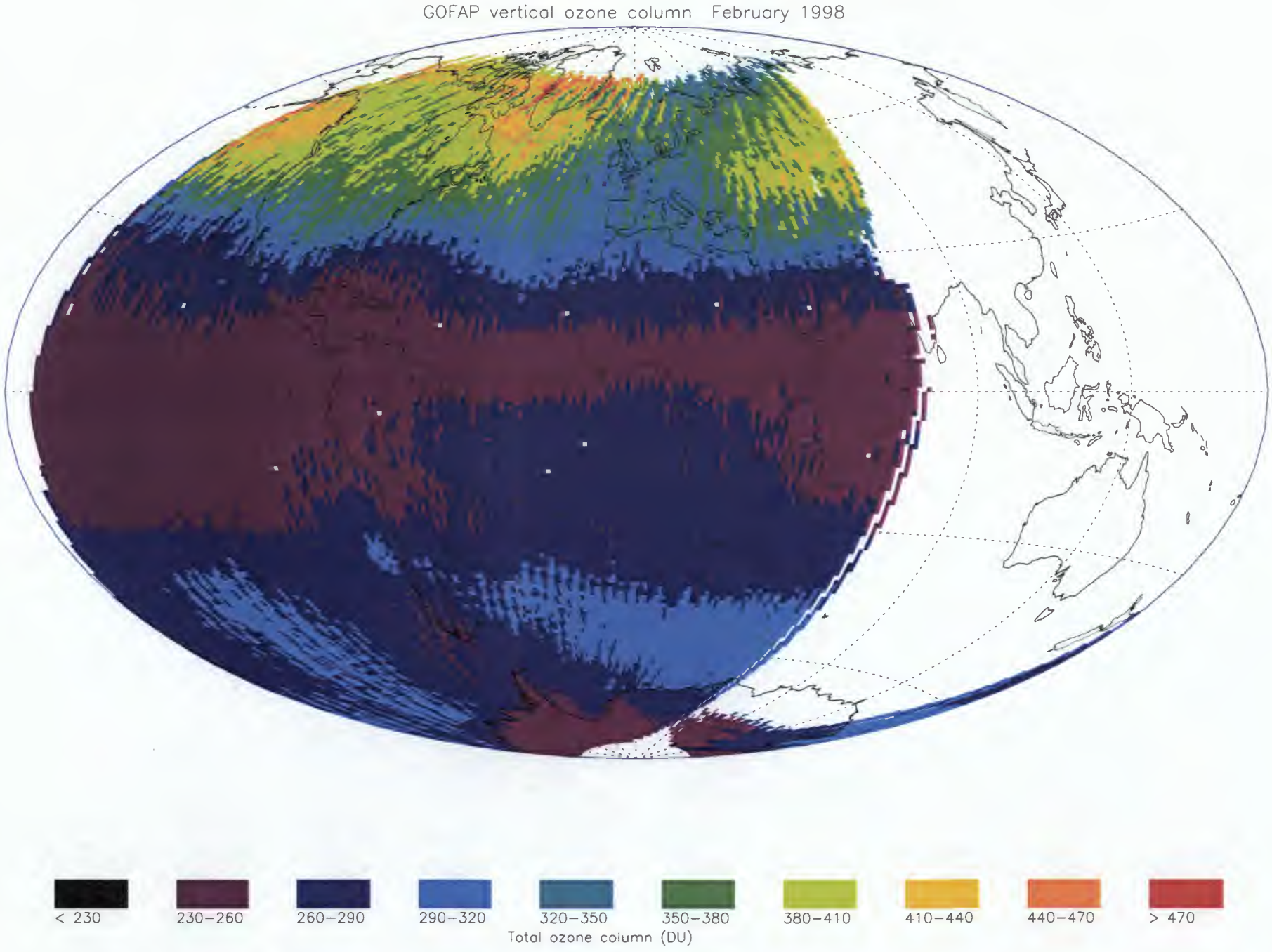

Vertical ozone column difference (GOFAP–TOMS)
August 1998
<–10
–7.5/–10
–7.5/–5
–5/–2.5
–2.5/0
0/2.5
2.5/5
5/7.5
7.5/10
> 10
Relative difference [%]

Fig 3.2

Fig 3.3


GOFAP vertical ozone column February 1998
< 230
230–260
260–290
290–320
320–350
350–380
380–410
410–440
440–470
> 470
Total ozone column (DU)

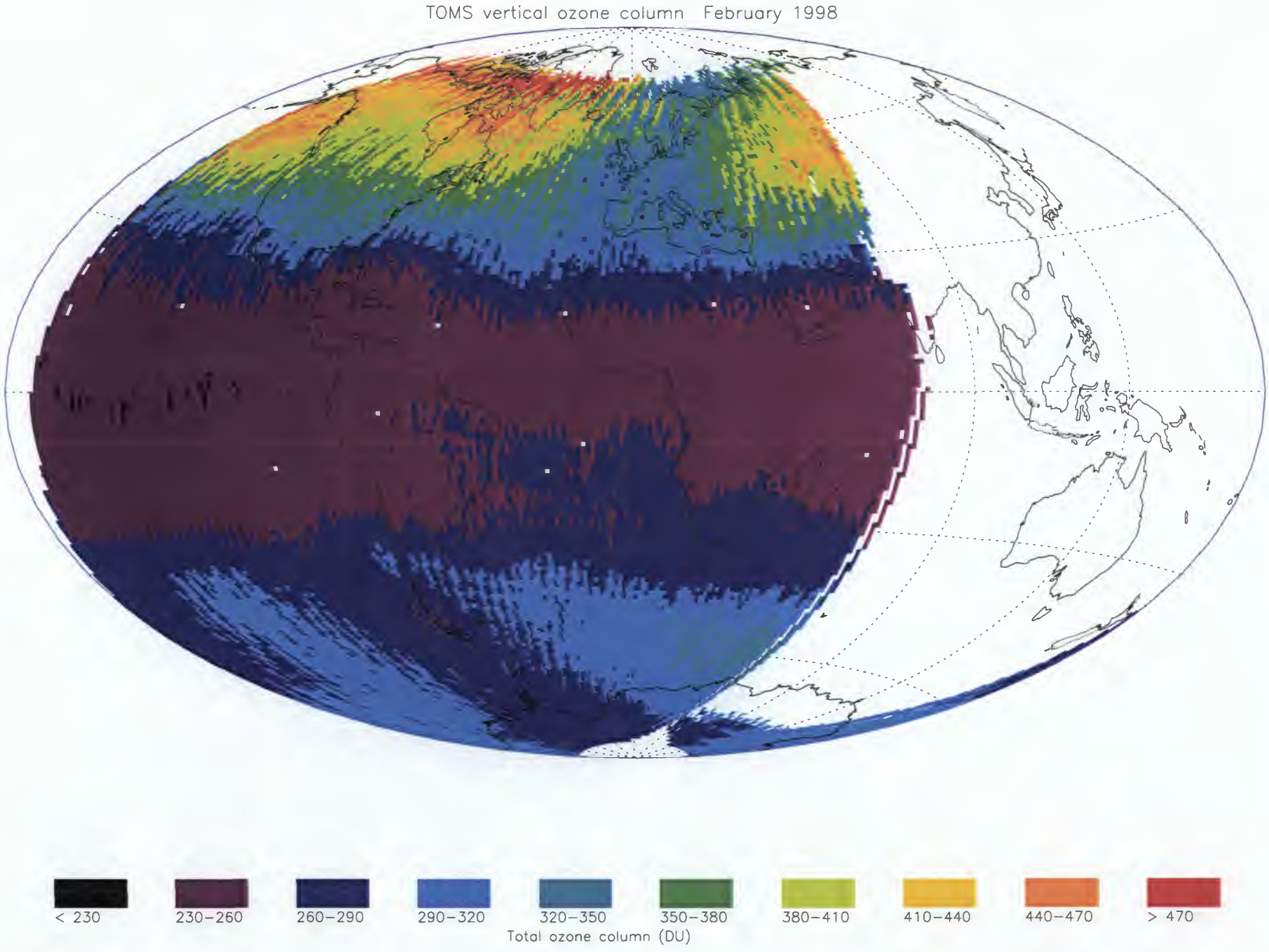

TOMS vertical ozone column February 1998
< 230
230–260
260–290
290–320
320–350
350–380
380–410
410–440
440–470
> 470
Total ozone column (DU)

Fig 3.4

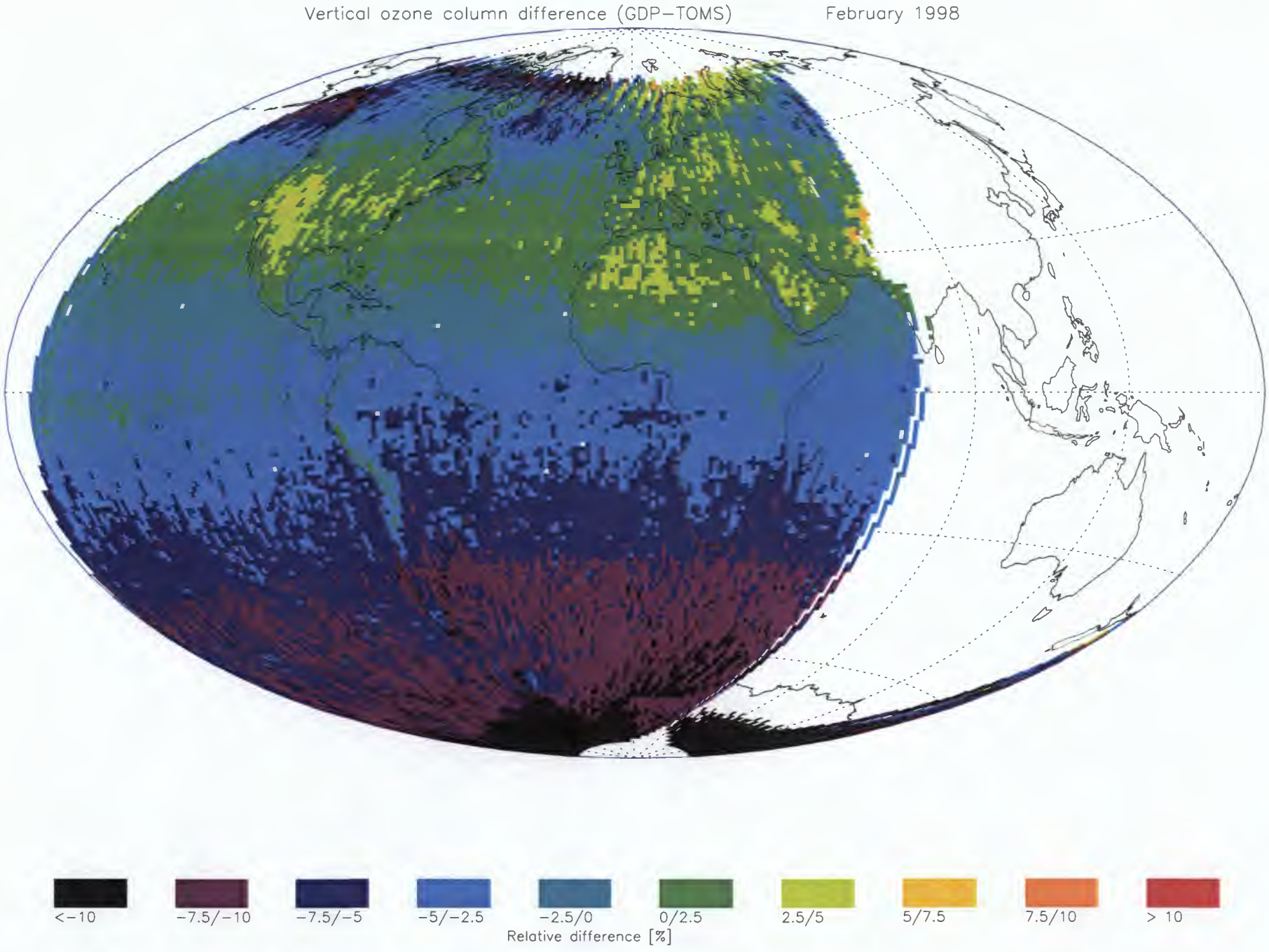

Vertical ozone column difference (GDP–TOMS)
February 1998
<–10
–7.5/–10
–7.5/–5
–5/–2.5
–2.5/0
0/2.5
2.5/5
5/7.5
7.5/10
> 10
Relative difference [%]

Fig 3.5

Vertical ozone column difference (GDP–TOMS) August 1998

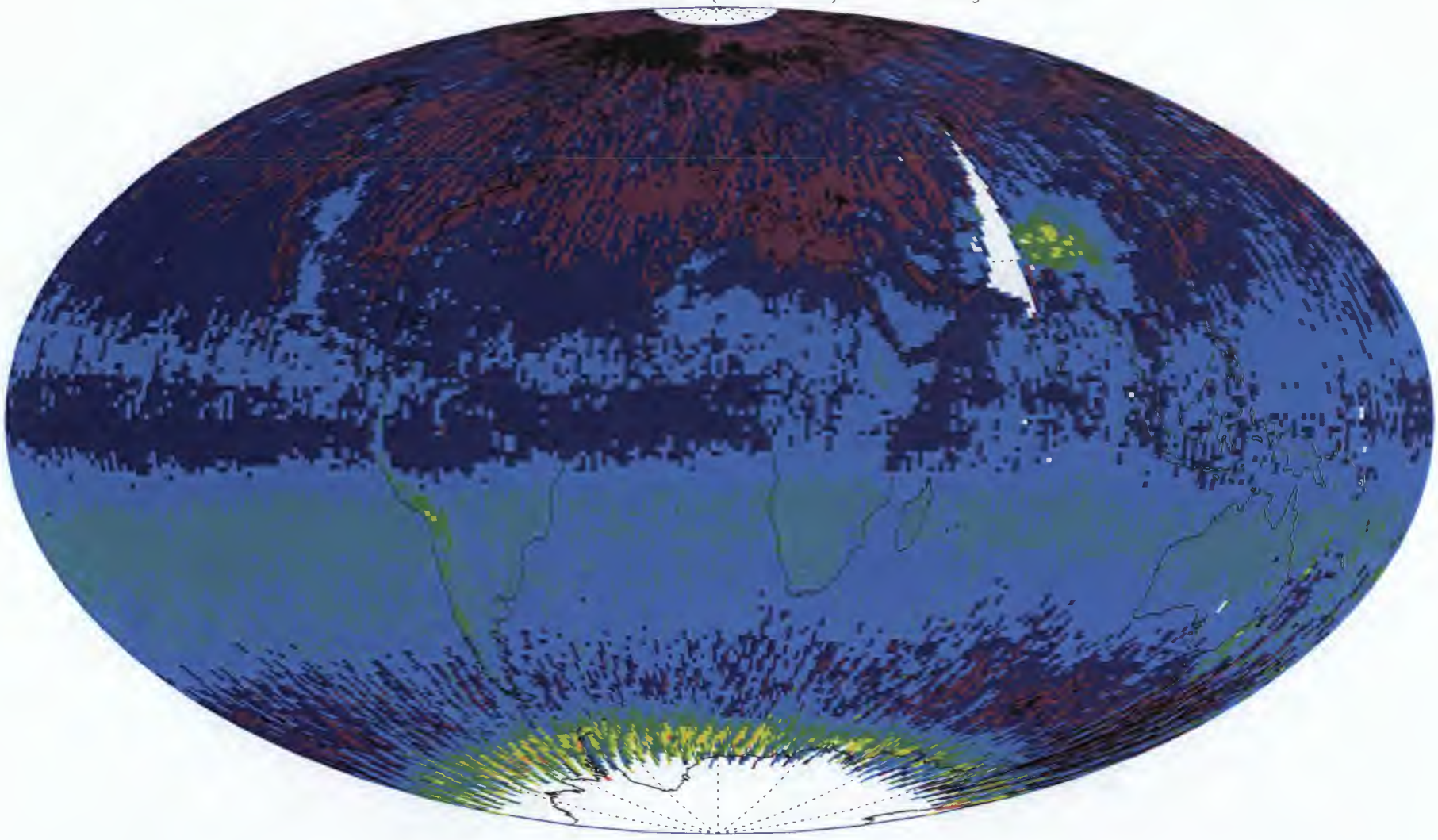


Fig 3.6

Fig 3.7

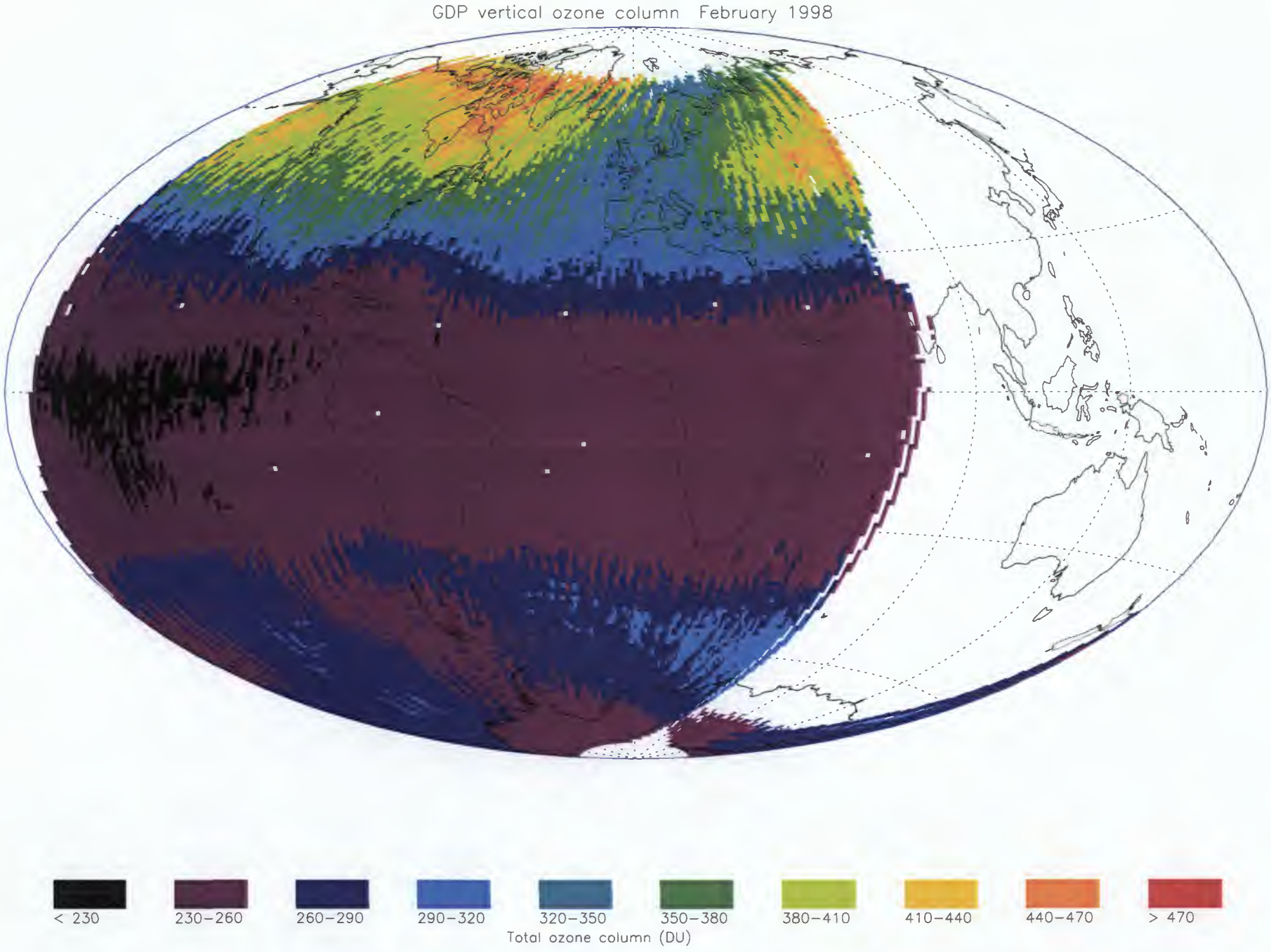
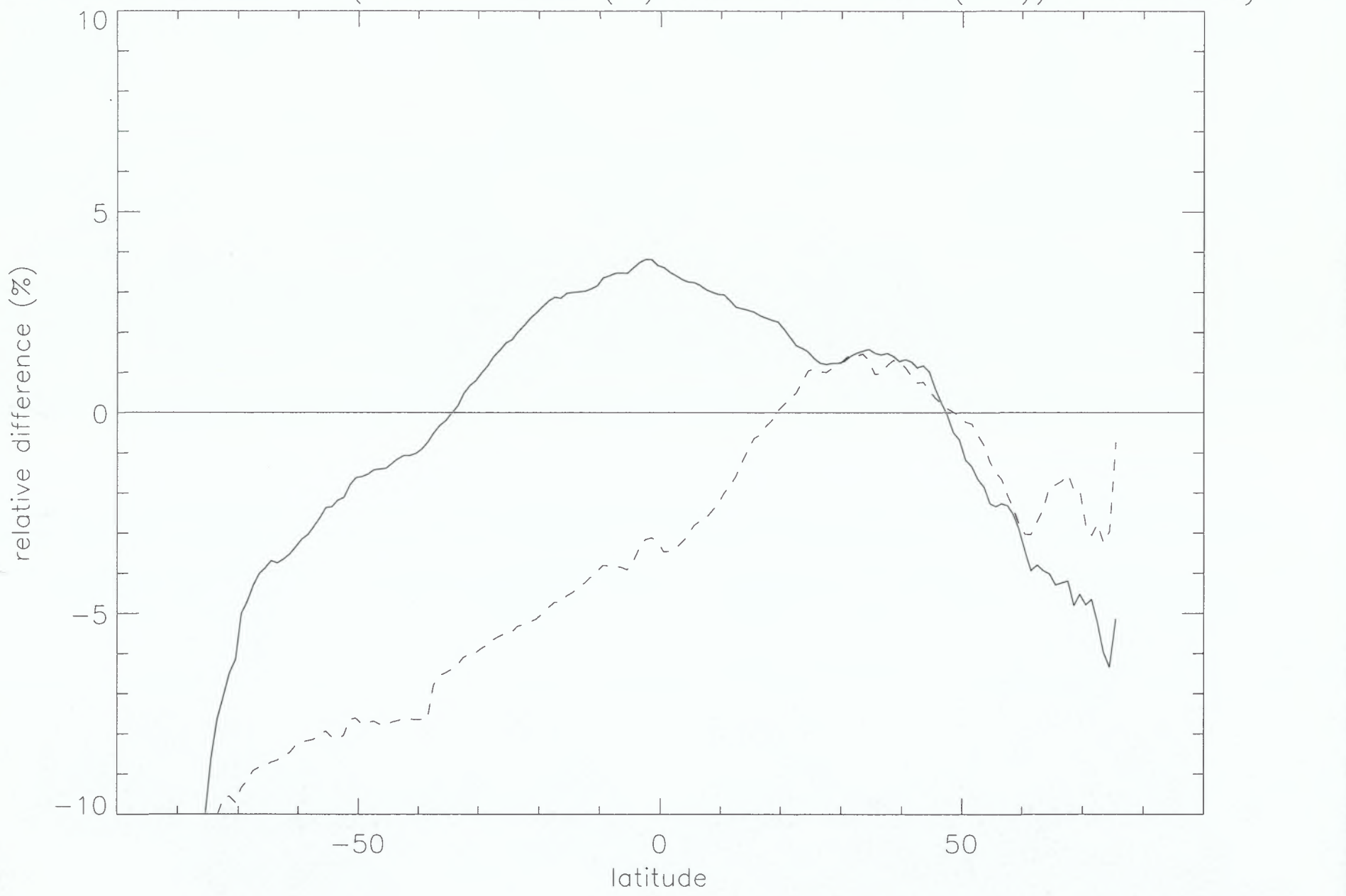

GDP vertical ozone column February 1998
< 230
230–260
260–290
290–320
320–350
350–380
380–410
410–440
440–470
> 470
Total ozone column (DU)

Fig 3.8


Total ozone difference (GOFAP−TOMS (−) and GDP−TOMS (−−))
February 199
10
5
0
−5
−10
relative difference (%)
−50
0
50
latitude

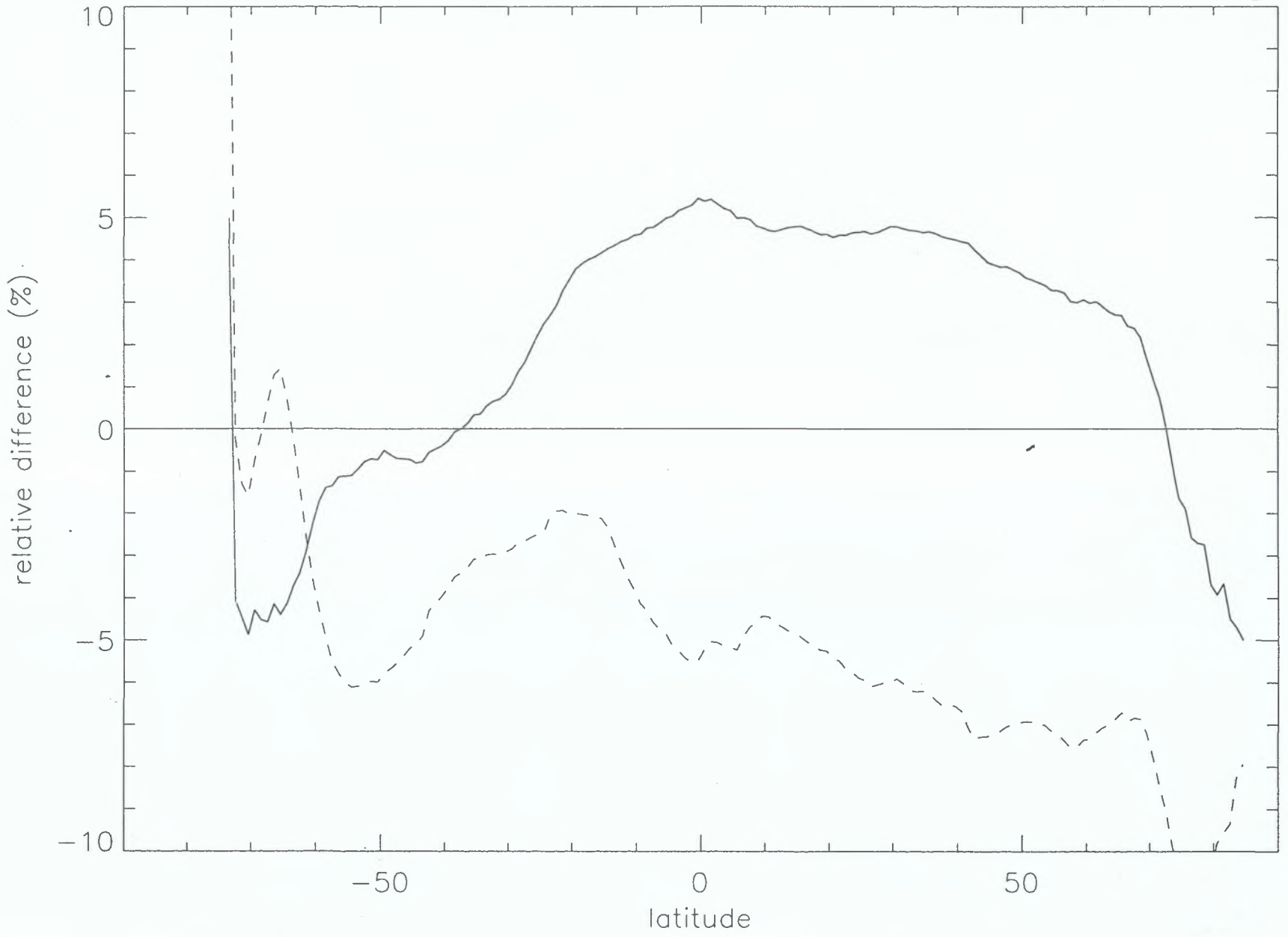

Total ozone difference (GOFAP−TOMS (−) and GDP−TOMS (−−))
August 1998
10
5
0
−5
−10
relative difference (%)
−50
0
50
latitude

Fig 3.9

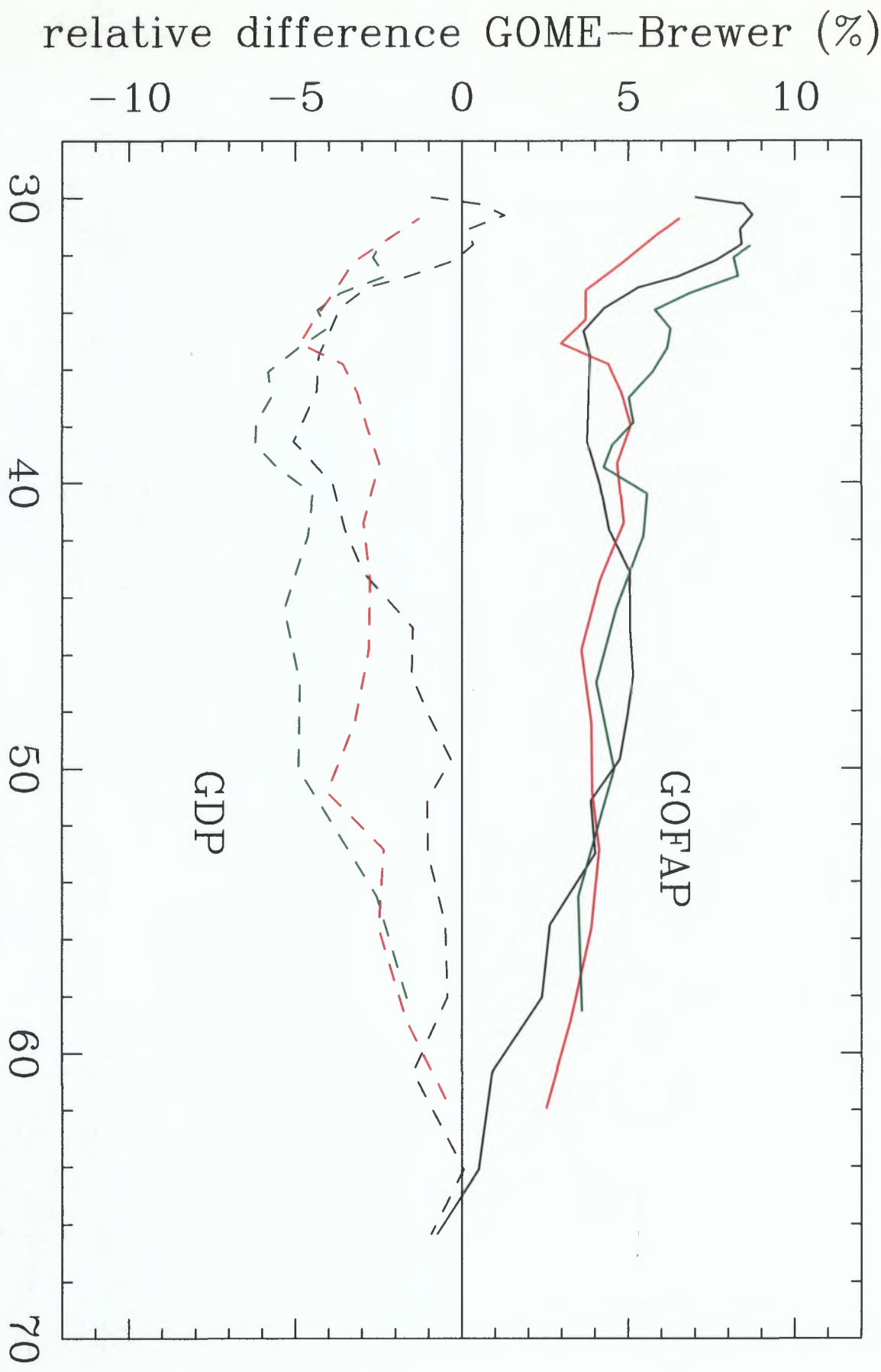

relative difference GOME–Brewer (%)
−10
−5
0
5
10
30
40
50
60
70
GDP
GOFAP
5 point running mean
olar zenith angle

Fig 4.1

		GOME(GOFAP)-Brewer	GOME(GDP)-Brewer
clouds < 10%	E(n=8)	3.4 +/- 1.1 %	-2.6 +/- 1.7 %
	C(n=4)	**1.8 +/- 0.4 %**	-3.3 +/- 1.8 %
	W(n=5)	**3.5 +/- 0.9 %**	-4.3 +/- 3.3 %
all	E(n=31)	4.4 +/- 0.6 %	-1.6 +/- 0.6 %
	C(n=23)	**4.2 +/- 0.5 %**	-2.5 +/- 0.6 %
	W(n=23)	**5.7 +/- 0.6 %**	-3.7 +/- 0.8 %

Table 4.1