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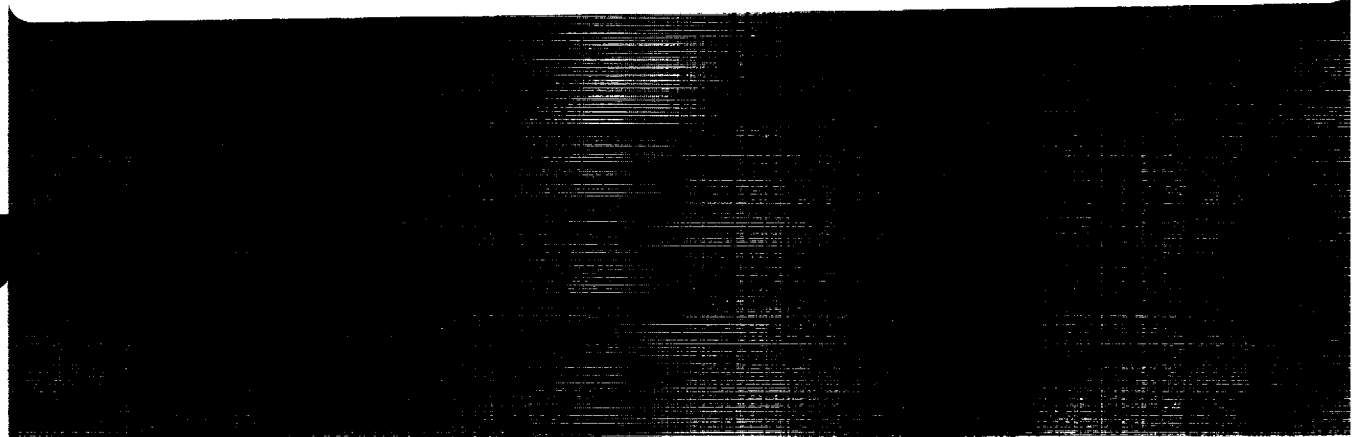

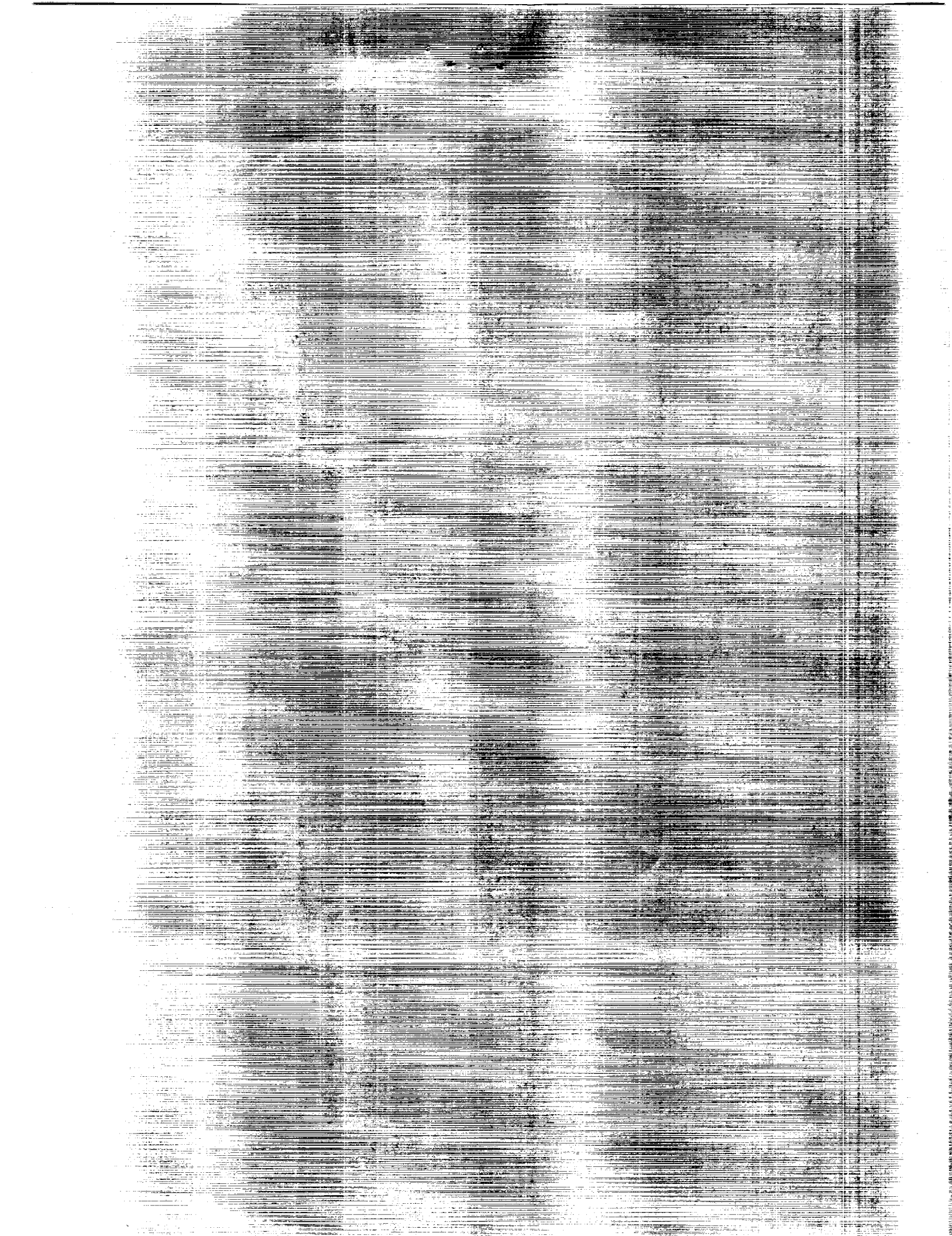

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NIMBUS-7 TOMS ANTARCTIC OZONE ATLAS: AUGUST THROUGH DECEMBER 1990

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ABSTRACT

Because of the great environmental significance of ozone and to support continuing research at the Antarctic and other southern hemisphere stations, the development of the 1990 ozone hole was monitored using data from the Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) instrument, produced in near-real-time. This Atlas provides a complete set of daily polar orthographic projections of the TOMS total ozone measurements over the southern hemisphere for the period August 1 through December 31, 1990. The 1990 ozone hole developed in a manner similar to that of 1987 and 1989, reaching a comparable depth in early October. This was in sharp contrast to the much weaker hole of 1988. The 1990 ozone hole remained at polar latitudes as it filled in November, in contrast to other recent years when the hole drifted to mid-latitudes before disappearing. Daily ozone values above selected southern hemisphere stations are presented, along with comparisons of the 1990 ozone distribution to that of other years. A new calibration scheme (Version 6) was used to process 1990 ozone values, as well as to reprocess those of previous years.

1. INTRODUCTION

Both ground-based (Farman et al., 1985; Komhyr et al., 1989) and satellite (Stolarski et al., 1986; Schoeberl and Krueger, 1986; Krueger et al., 1987; Krueger et al., 1988a) observations have documented a startling downward trend in the total column ozone amounts over Antarctica. This decrease, which occurs seasonally during September and October, has resulted in a depletion in the column ozone amounts by as much as 50%. The Antarctic ozone minimum, termed "the ozone hole," reached the lowest values observed to that point in 1987 (Krueger et al., 1988a). The 1988 ozone hole was displaced from the South Pole and far weaker than in 1987 (Krueger et al., 1989). However, the 1989 ozone hole was comparable to the 1987 event (Krueger et al., 1990). The 1990 ozone hole seemed to break a trend which had seen the lowest polar ozone values during odd numbered years. Values during 1990 were comparable to the lowest values of 1987 and 1989. The formation of the ozone hole is believed to be due to chemical reactions with enhanced levels of chlorine monoxide (caused by the introduction of chlorofluorocarbons into the atmosphere) (e.g., Farman et al., 1985). Observations from the Satellite Aerosol Measurement (SAM II) instrument (McCormick and Trepte, 1986) and the Limb Infrared Monitor of the Stratosphere (LIMS) instrument (Austin et al., 1986) on board the Nimbus-7 spacecraft have revealed the presence of Antarctic Polar Stratospheric Clouds (PSC's). These PSC's are present in the Antarctic lower stratosphere with cloud tops of from 15 to over 20 km throughout September. It has been suggested that heterogeneous reactions on cloud particles may be related to the formation of the ozone hole (Toon et al., 1986; Crutzen et al., 1986). The preliminary data in this report are normally quite close to the final archived data. Drift-corrected Version 6 data were used for all years in this atlas.

1.1 1990 Antarctic Ozone Monitoring

Following the dramatic decline in total ozone over the southern hemisphere observed during the 1987 Airborne Antarctic Ozone Experiment, it was decided to gather, in near-real-time, hemispheric total ozone during the same period in 1988. The 1988 ozone hole was the subject of study by scientists in Antarctica, who were provided with near-real-time total ozone data. This work was repeated in 1989 and 1990.

An atlas of the TOMS coverage of the 1987 ozone hole and background information on the Nimbus-7 TOMS Experiment, as well as the processing used to produce hemispheric total ozone contour plots, may be found in Krueger et al. (1988b). Details of the project operations and the communications network used in the 1987 ozone expedition can be found in Ardanuy et al. (1988). An atlas of the TOMS coverage of the 1988 ozone hole may be found in Krueger et al., (1989); of the 1989 ozone hole in Krueger et al., (1990).

1.2 Version 6 Data

The TOMS instrument has been functioning since October 31, 1978, and the data have been used to estimate global ozone trends over this time period. The TOMS Version 5 archived data showed a 9% decrease in the weighted global average (-70°S to +70°N latitude) of ozone from November 1978 to November 1988 (Herman et al., 1990). An estimate for the same time period using data from the ground-based Dobson network shows about a 3.5% decrease

(Watson, 1988, 1990). It was determined after examining solar irradiance measurements that the diffuser plate calibrations common to TOMS and SBUV had been incorrectly maintained (Hudson et al., 1988; Herman et al., 1990). It was demonstrated that these calibrations could be partially corrected for long wavelength pairs of radiance-irradiance ratios (Bhartia et al., 1988). This correction was extended and is referred to as the Pair Justification Method (PJM) (Herman et al., 1991).

Using the PJM to revise the diffuser calibrations and reprocessing the TOMS total ozone yielded a global average trend of -2.9% $\pm$ 1.3% for November 1978 to November 1989 (Herman et al., 1990). After these errors were corrected, several other more minor errors such as determining spacecraft attitude, synchronization problems with the wavelength chopper wheel, and sunglint contamination of boundary reflectivity data were discovered and corrected or minimized. For a complete description of these corrections, the authors refer the reader to Herman et al. (1991).

All of these corrections led to a new version (Version 6) of the TOMS dataset. During the TOMS real-time processing effort of August to December 1990, Version 6 data were produced. All plots and listings for all years included in this atlas are from Version 6 data. It should be noted that these data show similar trends but with less divergence than the Version 5 data used in earlier atlases (Krueger et al., 1988b, 1989, and 1990).

Figure 1 displays the daily zonal mean ozone for the latitude band extending from 60° to 90°S latitude for the period August through December 1989, for Versions 5 and 6. The difference, about 8%, can be attributed to the new calibration and an updated ozone profile for Antarctica used by the Version 6 algorithm. This difference would be lower for years prior to 1989.

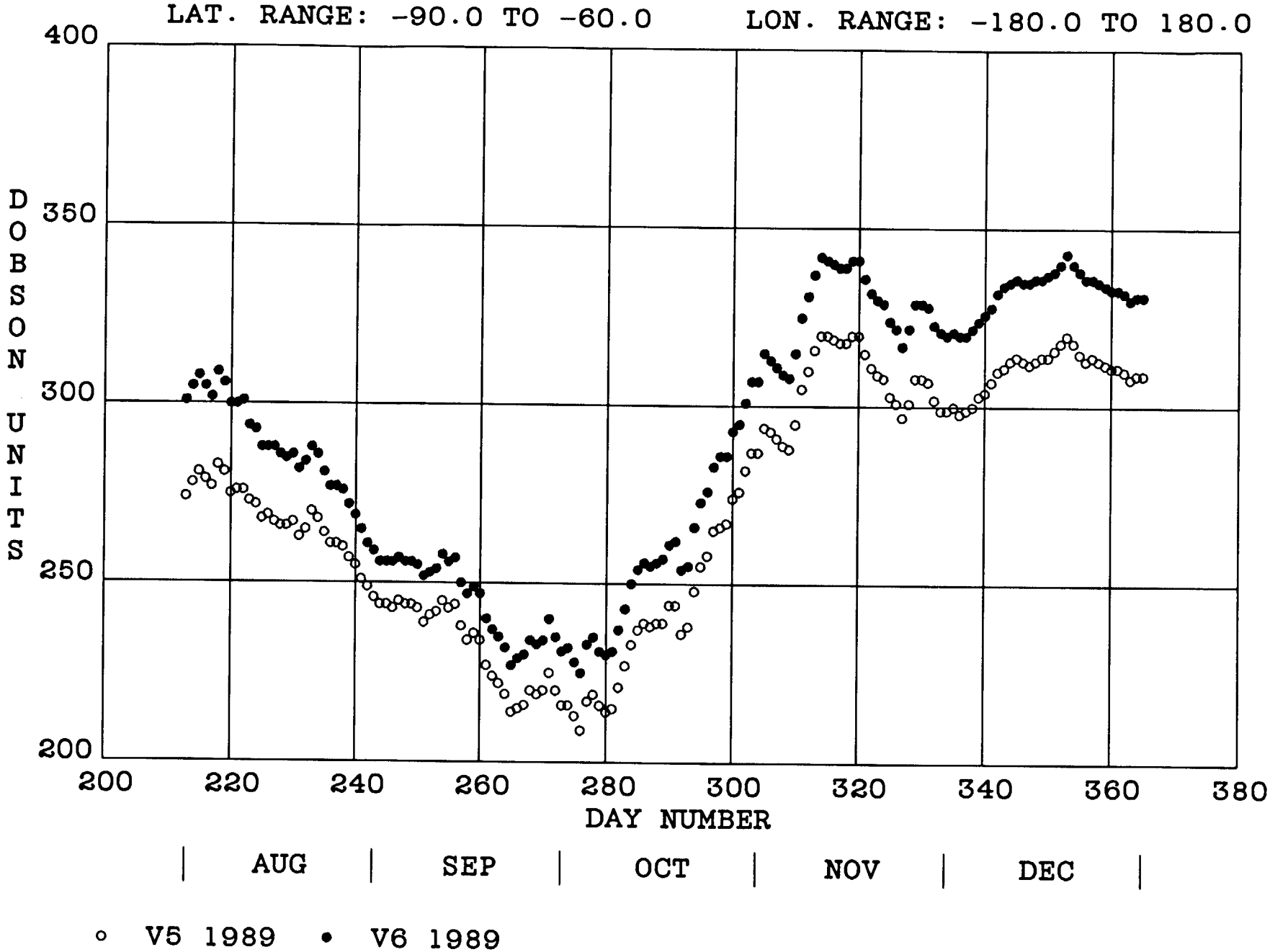


Figure 1. Daily Mean Ozone for Latitude Band 60° to 90°S for Versions 5 and 6 for the Period August Through December 1989.

2. TOMS TOTAL OZONE DATA

2.1 Chronology of the 1990 Antarctic Ozone Hole

AUGUST 19, 1990

This is the first day for which a TOMS hemispheric image is obtained in near-real-time. The lowest polar ozone values are between 175 and 200 DU and are located in a mini-hole over the Amundsen Sea.

AUGUST 22, 1990

The mini-hole has rotated eastward to a position over the Antarctic Peninsula and total ozone within the hole remains between 175 and 200 DU. A sizeable maximum with total ozone values approaching 450 DU exists off the coast of Enderby Land.

AUGUST 25, 1990

The normal southern hemisphere winter polar minimum is developing and is relatively circular, with three local minima symmetrically distributed about the pole. The lowest total ozone values in these minima are near or slightly below 200 DU. The maximum cited above has rotated to a position off the coast of western Wilkes Land, with total ozone values approaching 500 DU.

AUGUST 29, 1990

The area of total ozone below 225 DU has grown, now almost encircling the pole. Within that region, several small areas of total ozone between 175 and 200 DU grow and dissipate. No maximum above 450 DU currently exists.

AUGUST 31, 1990

The southern hemisphere winter polar minimum has abruptly ceased to be nearly circular, and has begun to elongate along longitude 140°W/40°E. Total ozone values below 250 DU extend equatorward to latitude 45°S near South Africa. A significant mini-hole with ozone values below 150 DU has developed suddenly in the Bellinghausen Sea, a favored area for such development.

SEPTEMBER 5, 1990

The mini-hole has rotated eastward to a position in the Weddell Sea, with a large area of total ozone values between 150 and 175 DU. The southern hemisphere winter polar minimum has regained its circular appearance with all areas south of 70°S latitude exhibiting total ozone values below 225 DU.

SEPTEMBER 8, 1990

The mature ozone hole appears to be forming as a rapidly growing area of total ozone values below 200 DU now nearly encircles the pole. A small minimum between 150 and 175 DU persists over the Weddell Sea. The polar minimum remains roughly circular.

SEPTEMBER 12, 1990

The area of total ozone values less than 200 DU now covers roughly half of the Antarctic Continent. The ozone hole has become elongated along longitude 100°W/80°E. The small area of total ozone between 150 and 175 DU has rotated eastward and is now over Queen Maude Land. An ozone maximum above 450 DU rotating eastward off the coast of Victoria Land appears to be responsible for the elongation of the ozone hole.

SEPTEMBER 15, 1990

The ozone maximum cited above has moved further offshore and strengthened to 500 DU. The ozone hole, however, is regaining its circular appearance with most of Antarctica exhibiting total ozone values below 200 DU, with several growing areas between 150 and 175 DU.

SEPTEMBER 18, 1990

The nearly circular ozone hole is deepening rapidly, with most of the region within 70°S below 200 DU. For the first time this season, total ozone values within the mature ozone hole have dipped to between 125 and 150 DU. This minimum is located near the pole over the Whitmore Mountains.

SEPTEMBER 22, 1990

A strong ozone maximum of 500 DU north of Wilkes Land has developed. The ozone hole has been pushed off the pole toward the Weddell Sea. No ozone value below 150 DU currently is observed.

SEPTEMBER 26, 1990

The ozone maximum cited above has rotated eastward and expanded to cover nearly 180° of longitude over the Pacific and Indian Oceans. The ozone hole has become elongated along longitude 110°W/70°E. Total ozone values between 125 and 150 DU have re-appeared over southern Queen Maude Land.

SEPTEMBER 29, 1990

The ozone maximum has rotated eastward as has the elongated ozone hole, now oriented along longitude 70°W/110°E. A small area of total ozone values below 150 DU exists over southern Wilkes Land.

OCTOBER 2, 1990

Values in the ozone maximum have diminished greatly, exceeding 400 DU over a very small area. The ozone hole has regained its circular appearance and resumed deepening. A growing area of total ozone values between 125 and 150 DU is roughly centered on the pole.

OCTOBER 4, 1990

The nearly circular and symmetric ozone hole reached its minimum value of 125 DU. At this time, total ozone values less than 150 DU cover all of the polar region south of 80°S latitude.

OCTOBER 12, 1990

The ozone hole began to elongate on October 5 and has rotated to the east 20° to 25° longitude per day for the past week. It is now elongated along longitude 90°W/90°E. A large area of total ozone values between 125 and 150 DU persists near the pole.

OCTOBER 16, 1990

Evidence of rotation of the ozone hole continues, although it has become more circular. A large area of total ozone values between 125 and 150 DU persists near the pole.

OCTOBER 21, 1990

A somewhat elongated ozone hole has continued to rotate eastward at about 20° longitude per day. For the first time since September 24, no total ozone value below 150 DU is present.

OCTOBER 25, 1990

The ozone hole has regained its circular appearance. Minimum ozone values between 150 and 175 DU still cover a significant portion of Antarctica centered on the pole.

OCTOBER 28, 1990

The ozone hole is once again elongated, now along longitude 180°/0° and is rotating eastward at between 20° and 25° longitude per day.

NOVEMBER 4, 1990

The rotation of the ozone hole has diminished and it has once again become roughly circular. A significant area is still covered by total ozone values between 150 and 175 DU.

NOVEMBER 8, 1990

The still roughly circular ozone hole has begun to fill. Only a small area of southern Queen Maude Land displays total ozone values below 175 DU.

NOVEMBER 12, 1990

The ozone hole has once again become elongated. No total ozone value below 175 DU currently exists.

NOVEMBER 19, 1990

The elongated ozone hole continues to rotate eastward, now at about 15° longitude per day. A small area of total ozone values between 150 and 175 DU has re-appeared over southern Queen Maude Land.

NOVEMBER 26, 1990

A severely elongated ozone hole is now oriented along longitude 90°W/90°E. The hole has been filling rapidly, with only a very small area possessing total ozone values below 200 DU. Rotation of the hole has slowed to about 5° longitude per day.

DECEMBER 5, 1990

The weakening ozone hole is no longer centered near the pole. Minimum total ozone values between 200 and 225 DU are now located over the Ellsworth Mountains. No ozone maximum above 400 DU exists.

DECEMBER 12, 1990

The ozone hole is still identifiable over the Weddell Sea with total ozone values between 225 and 250 DU.

DECEMBER 19, 1990

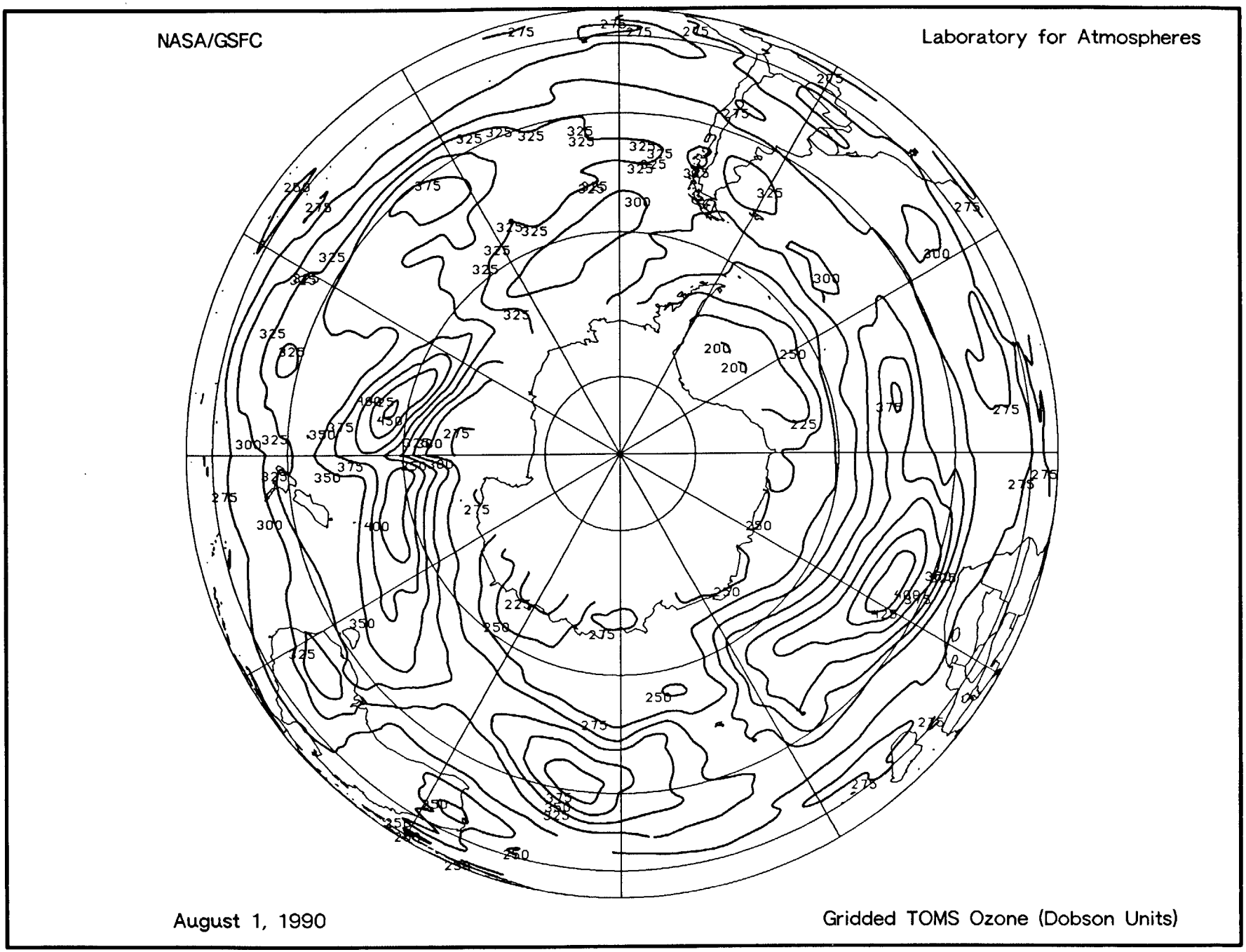
What was once the 1990 Antarctic ozone hole is now nothing more than a series of minima over Queen Maude Land, the Weddell and Bellinghausen Seas with total ozone values between 250 and 275 DU.

DECEMBER 29, 1990

The ozone hole ceases to be identifiable within a very flat ozone field.

2.2 Southern Hemispheric Polar Charts

A set of daily TOMS total ozone estimates for the southern hemisphere, over the period August 1 through December 31, 1990, is presented here. The daily data are resolved on a uniform 2° latitude by 5° longitude grid for each day, and displayed using a south-polar orthographic projection. The advantage of this projection is that emphasis is placed over precisely those high-latitude regions of interest to the Antarctic experiment.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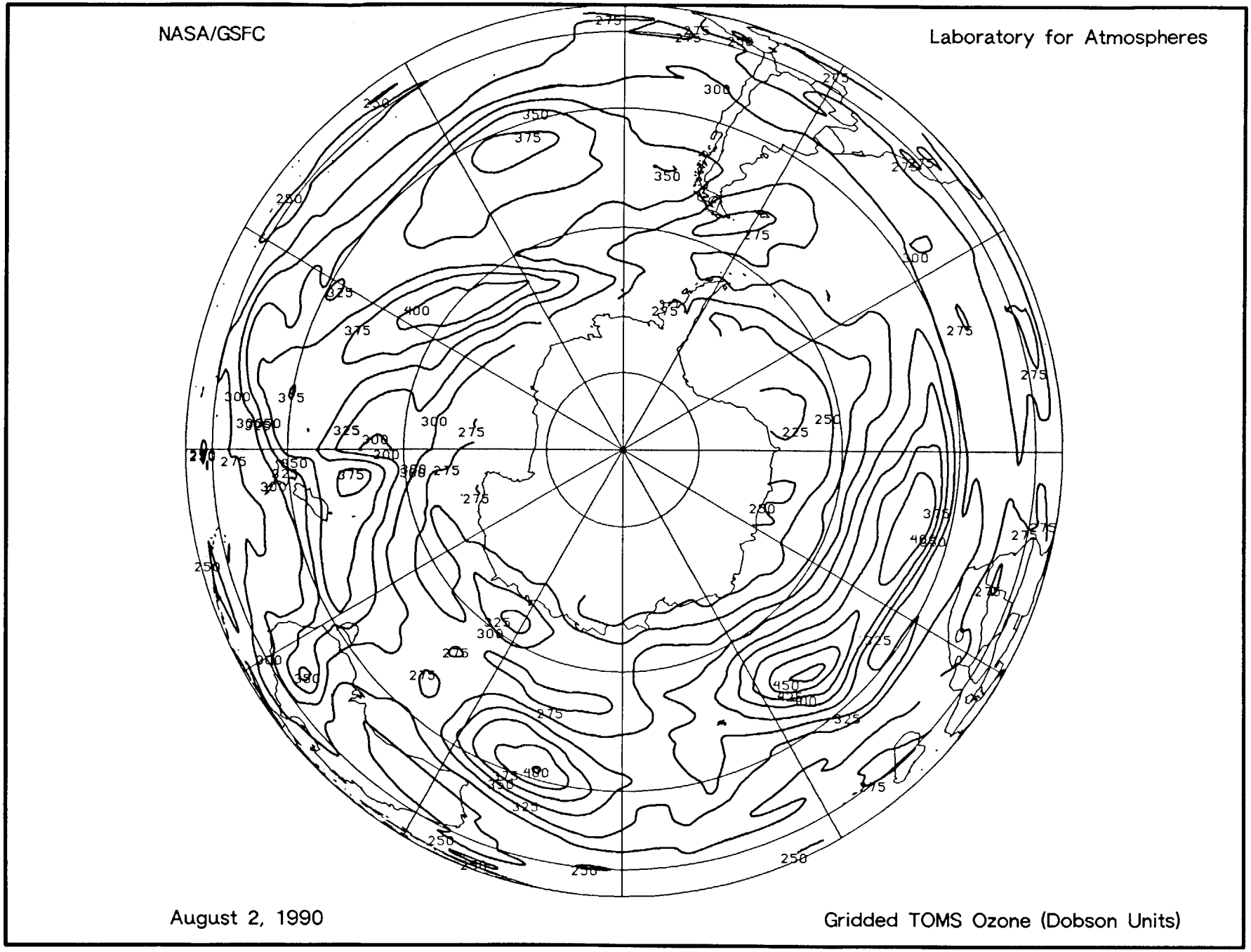
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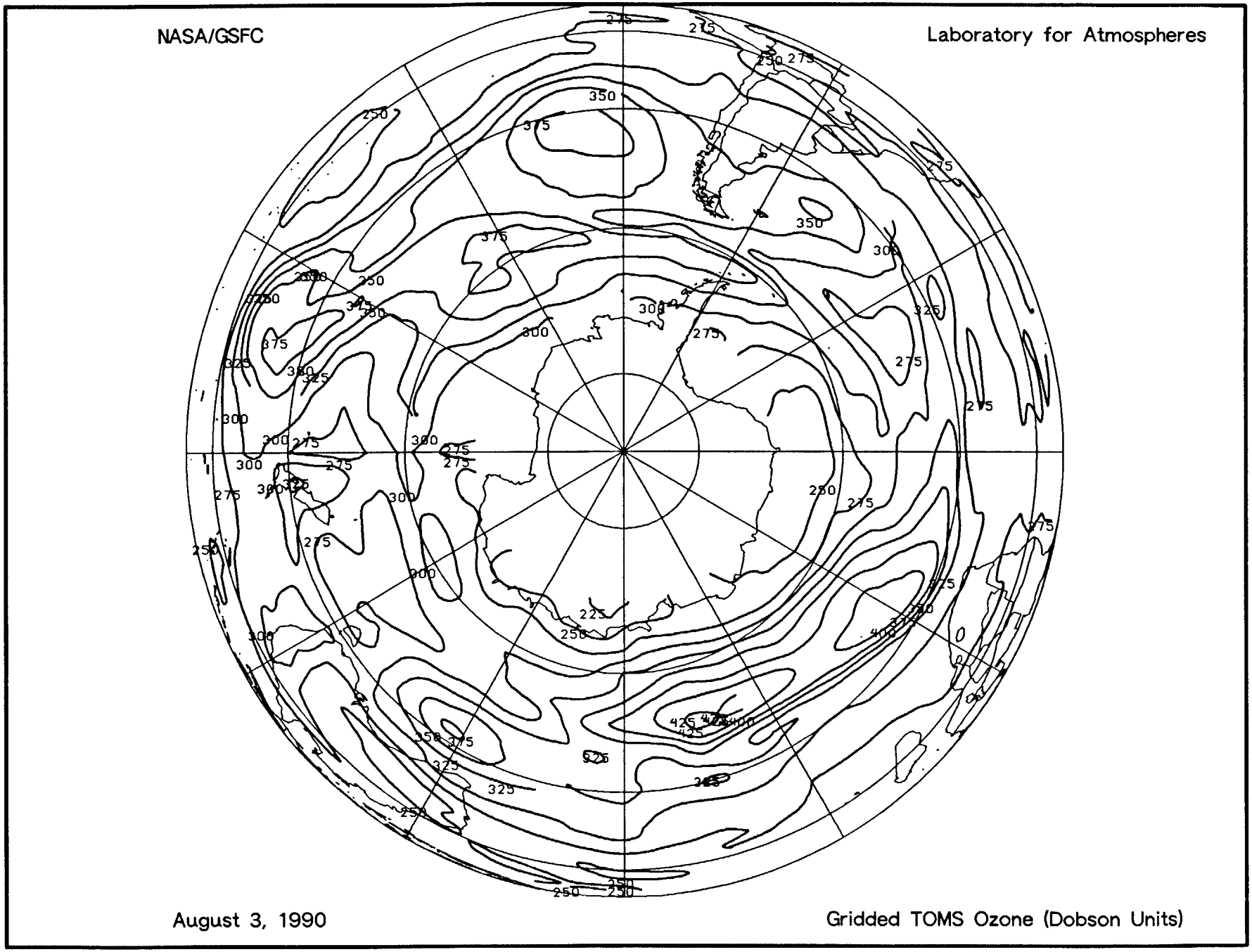
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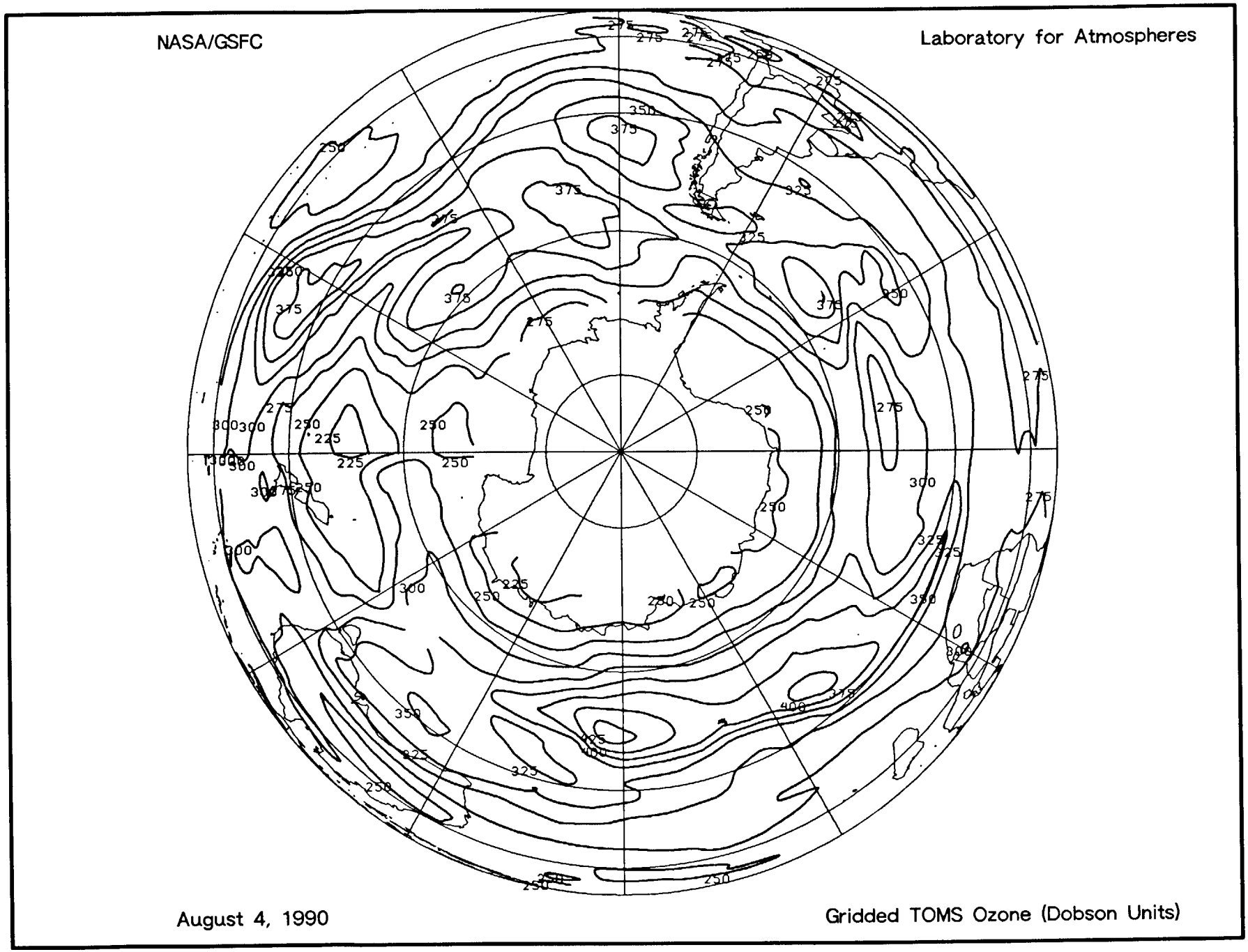
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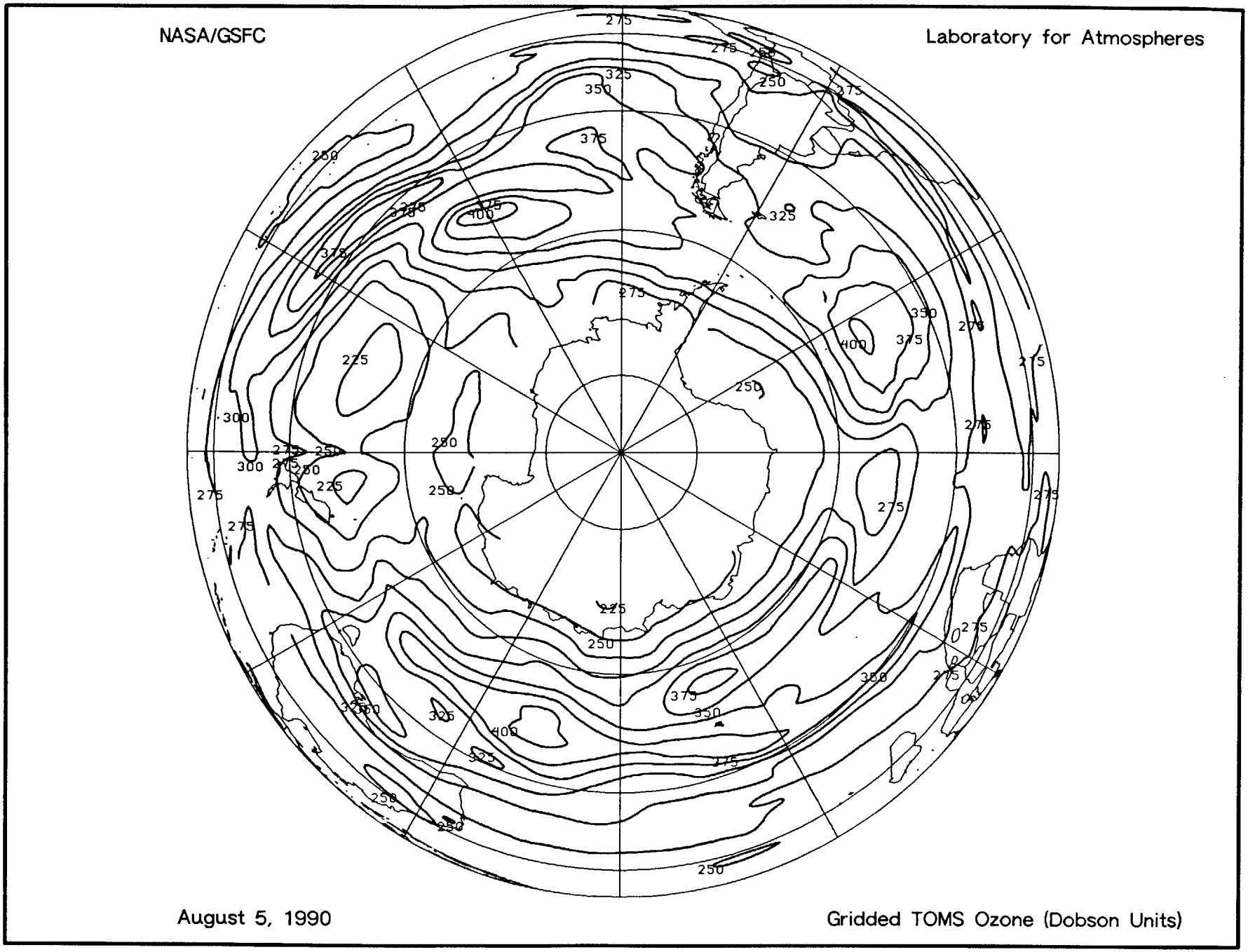
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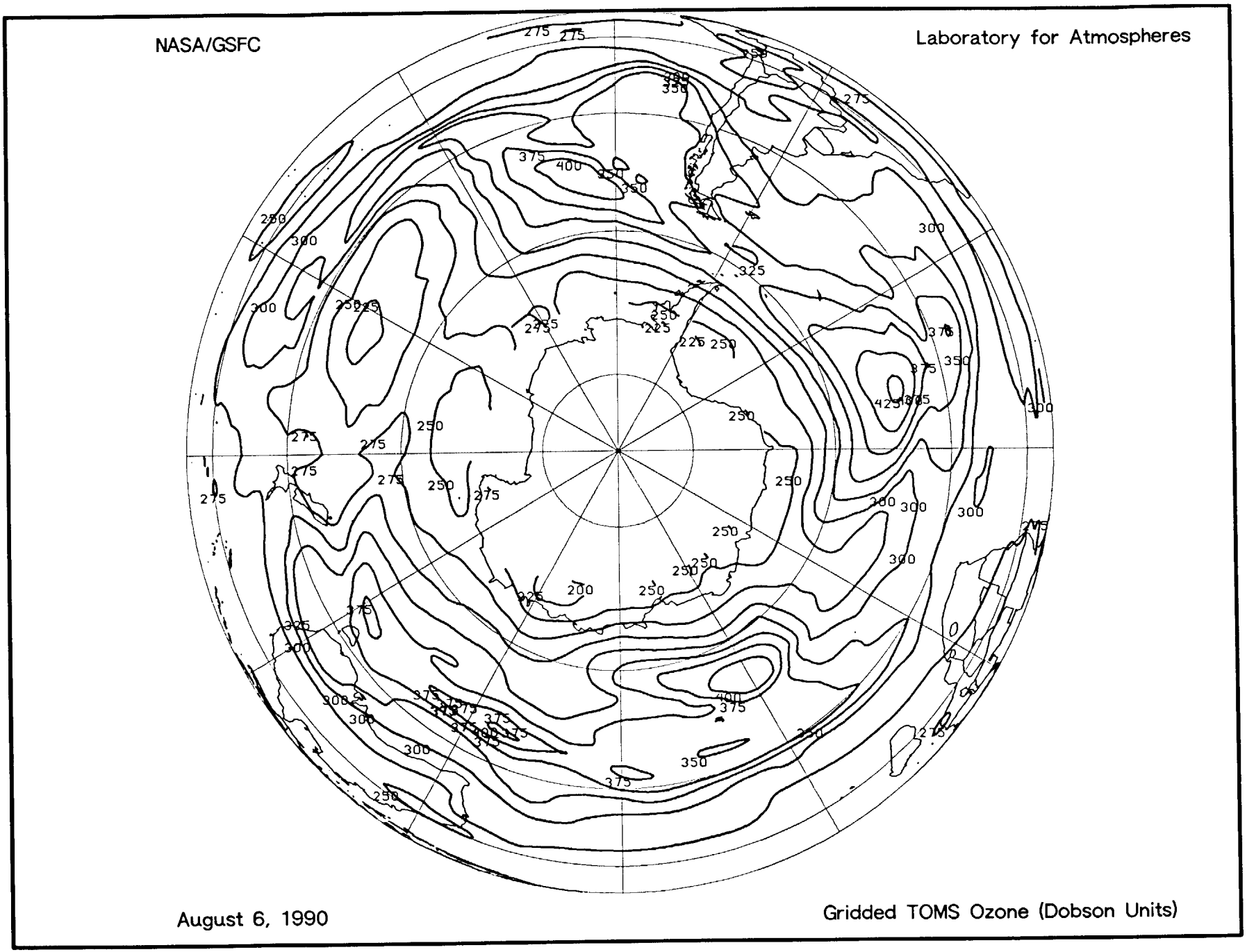
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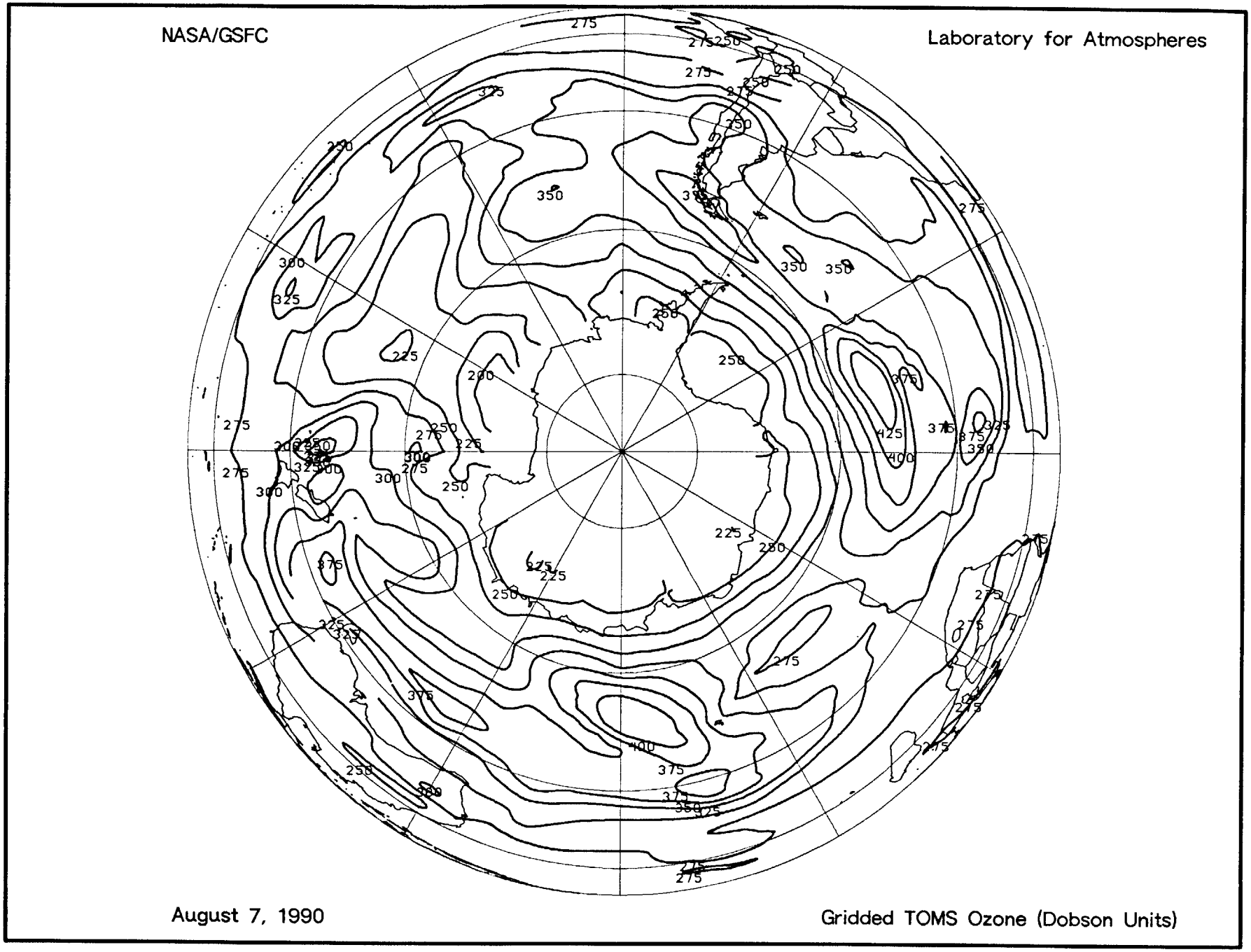
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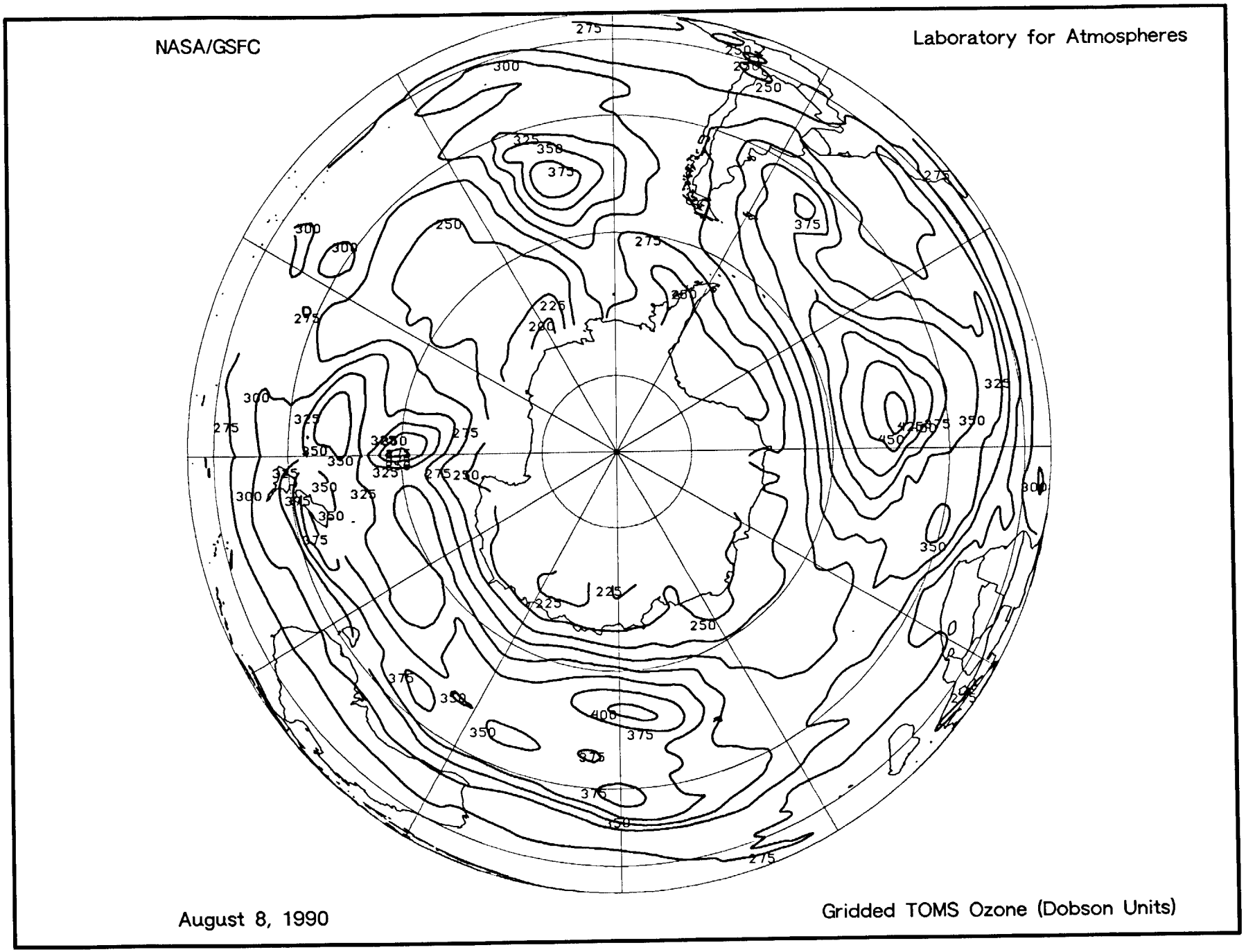
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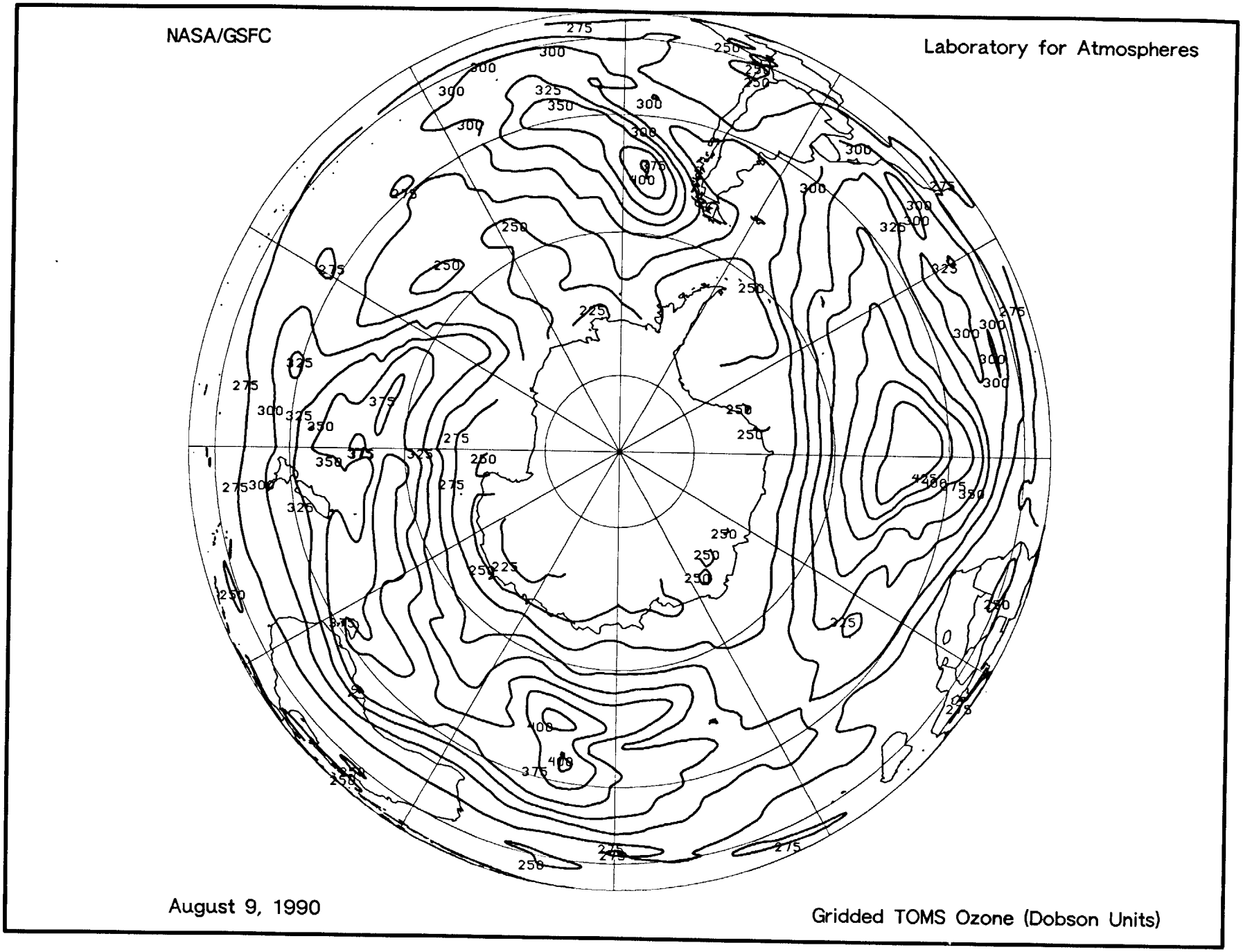
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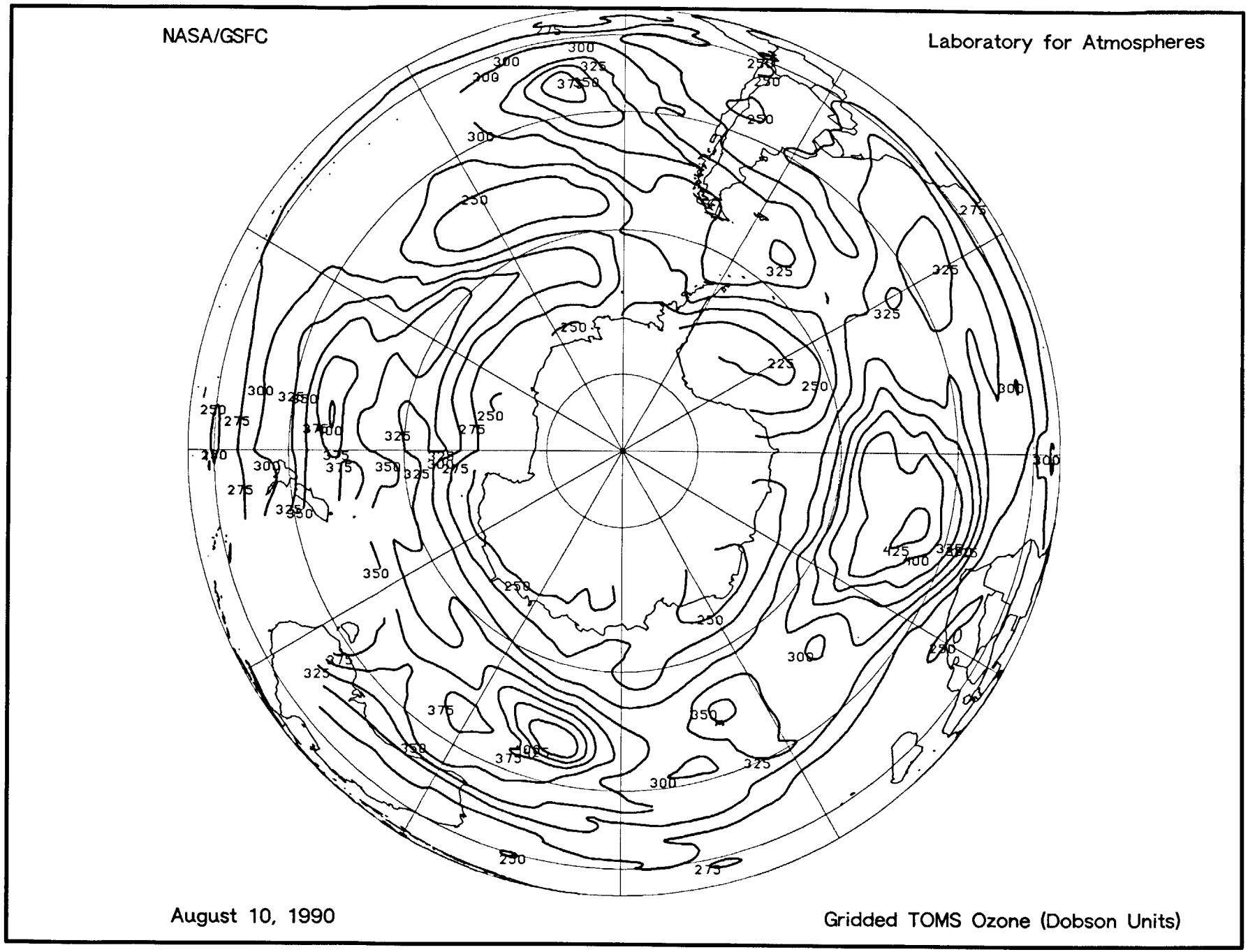
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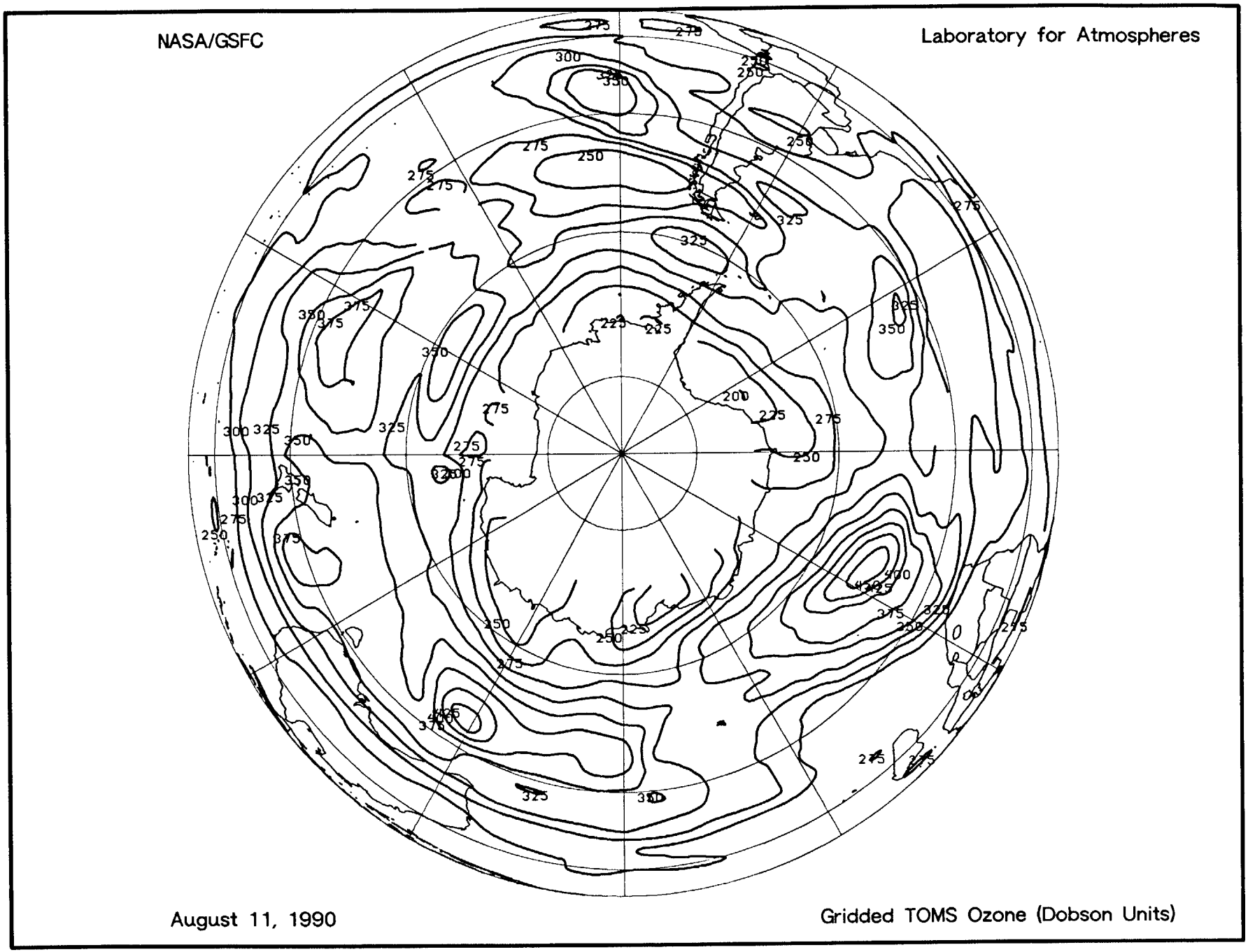
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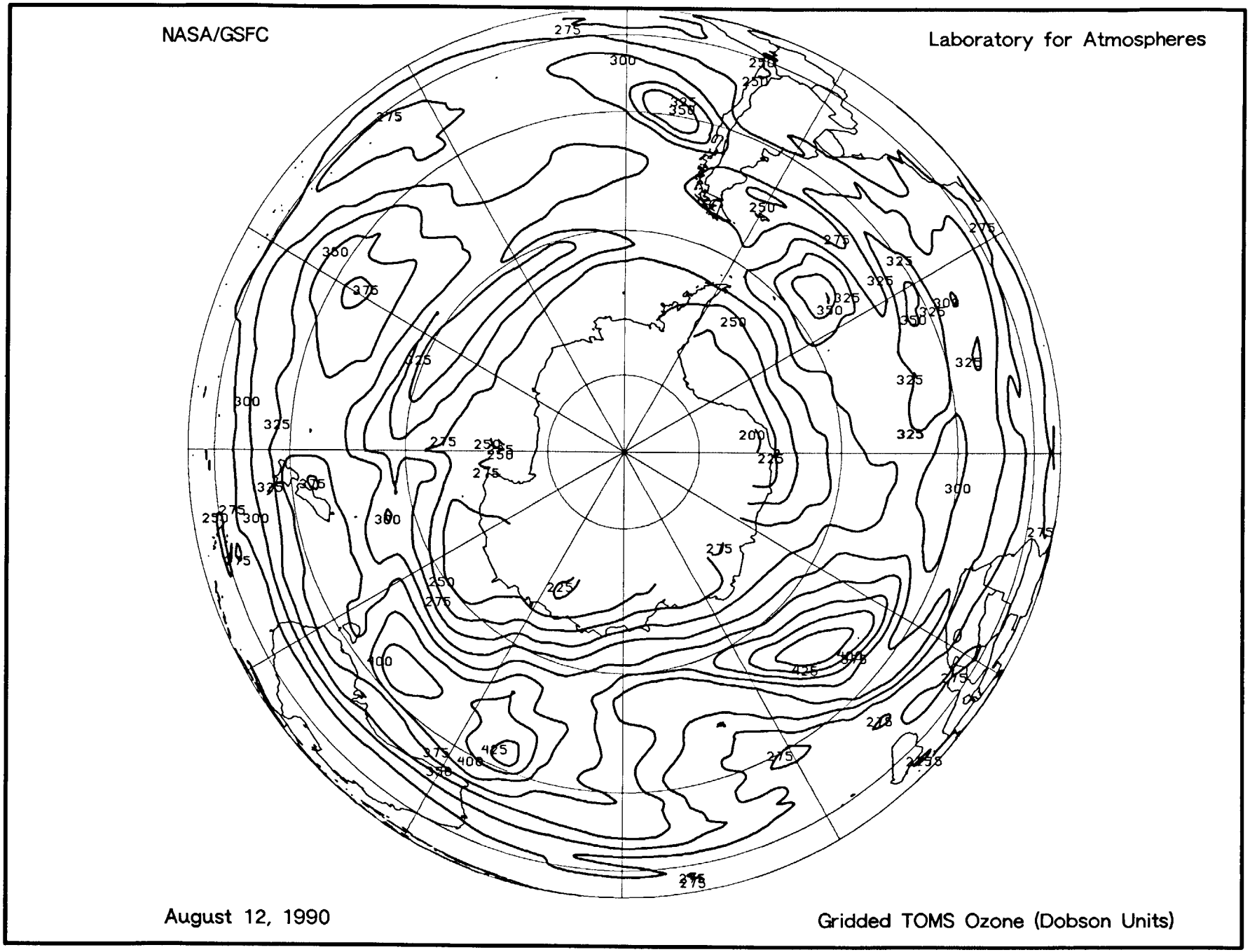
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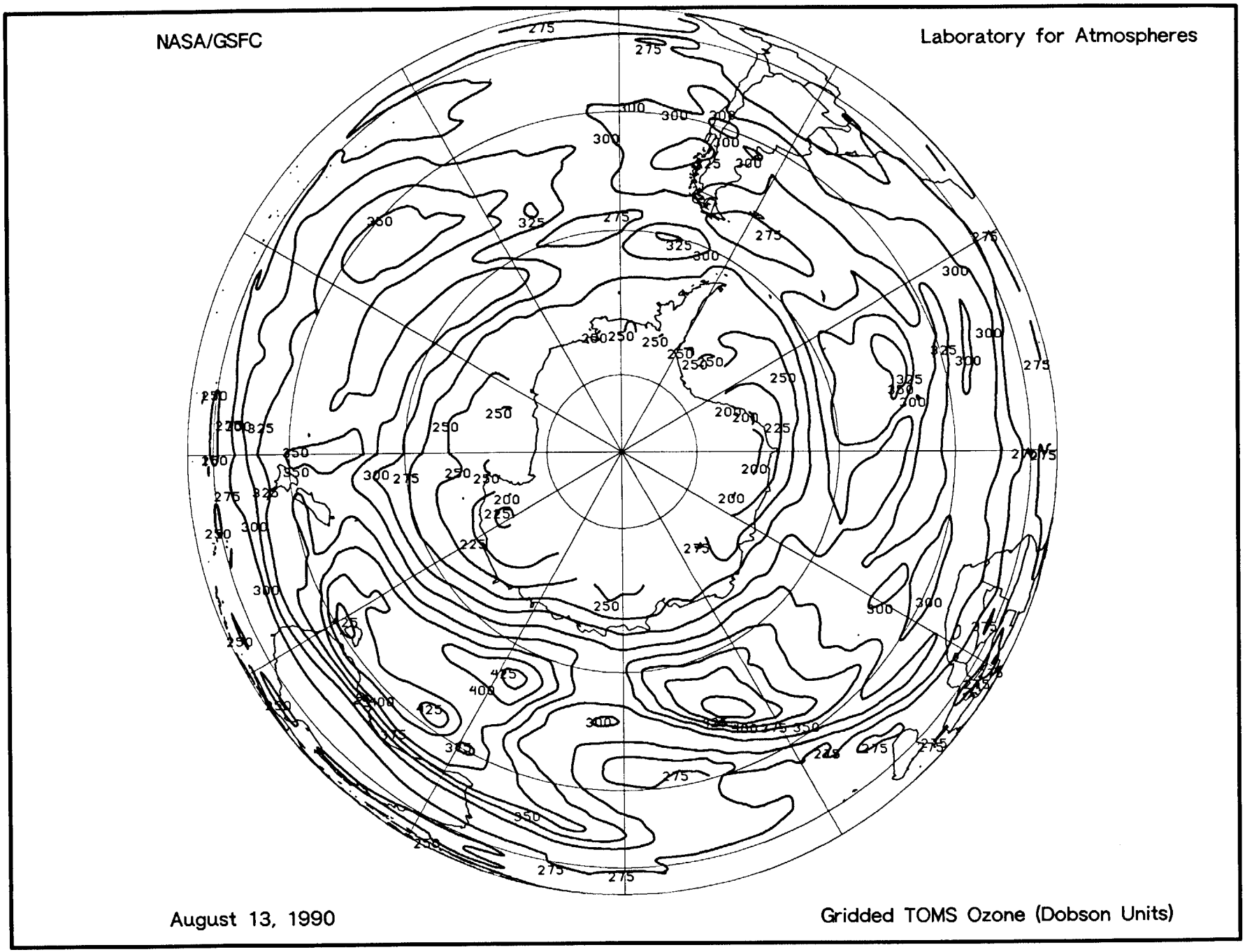
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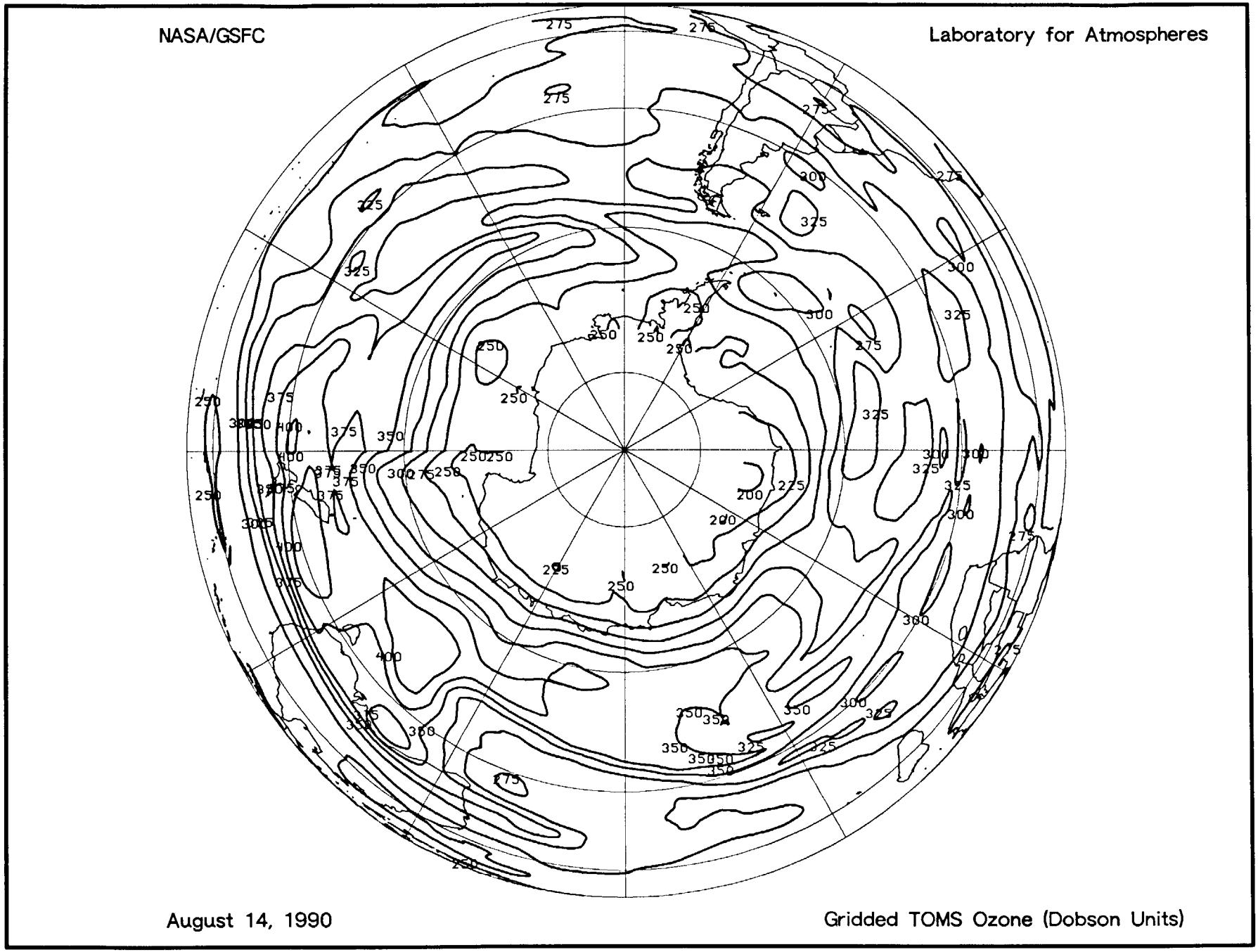
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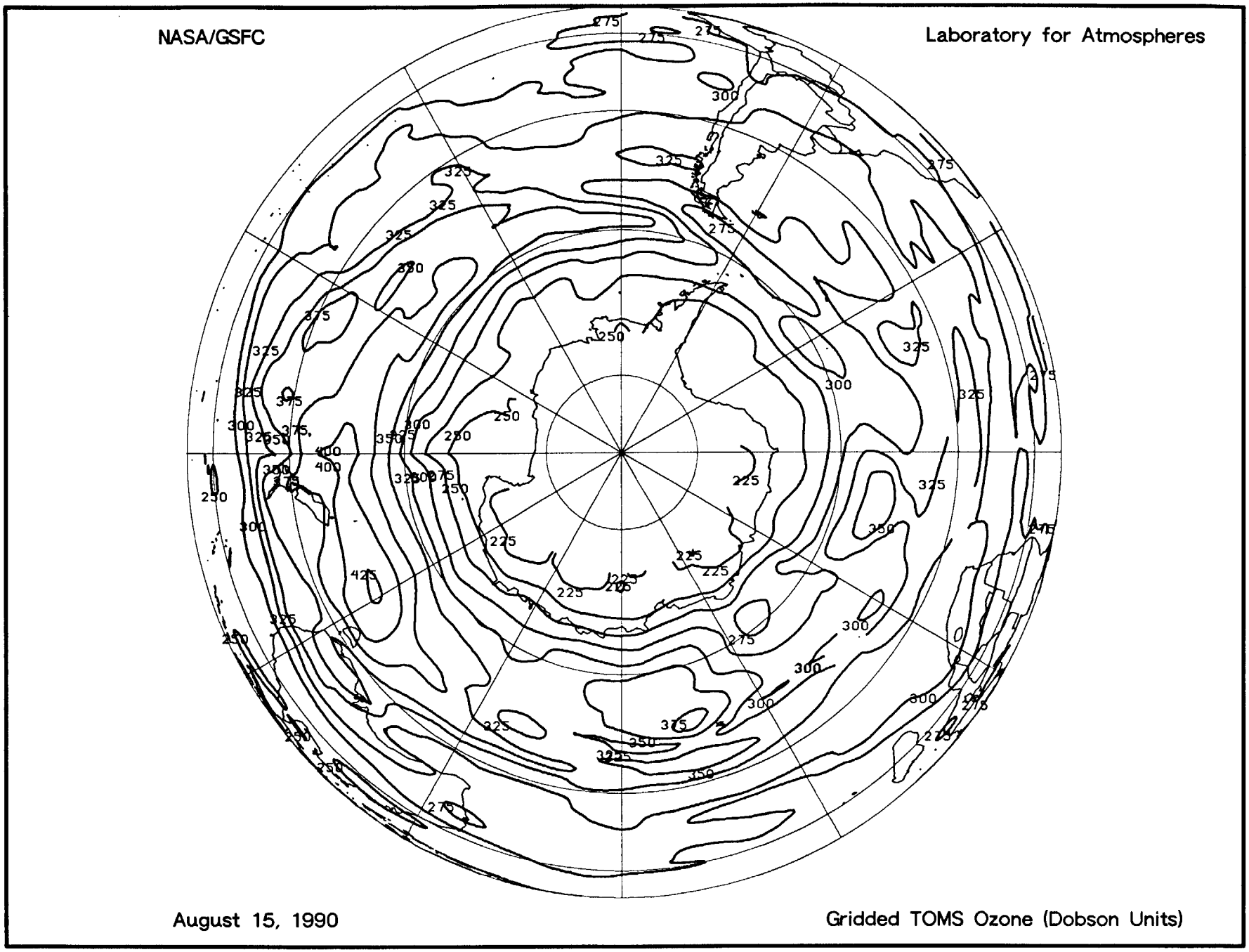
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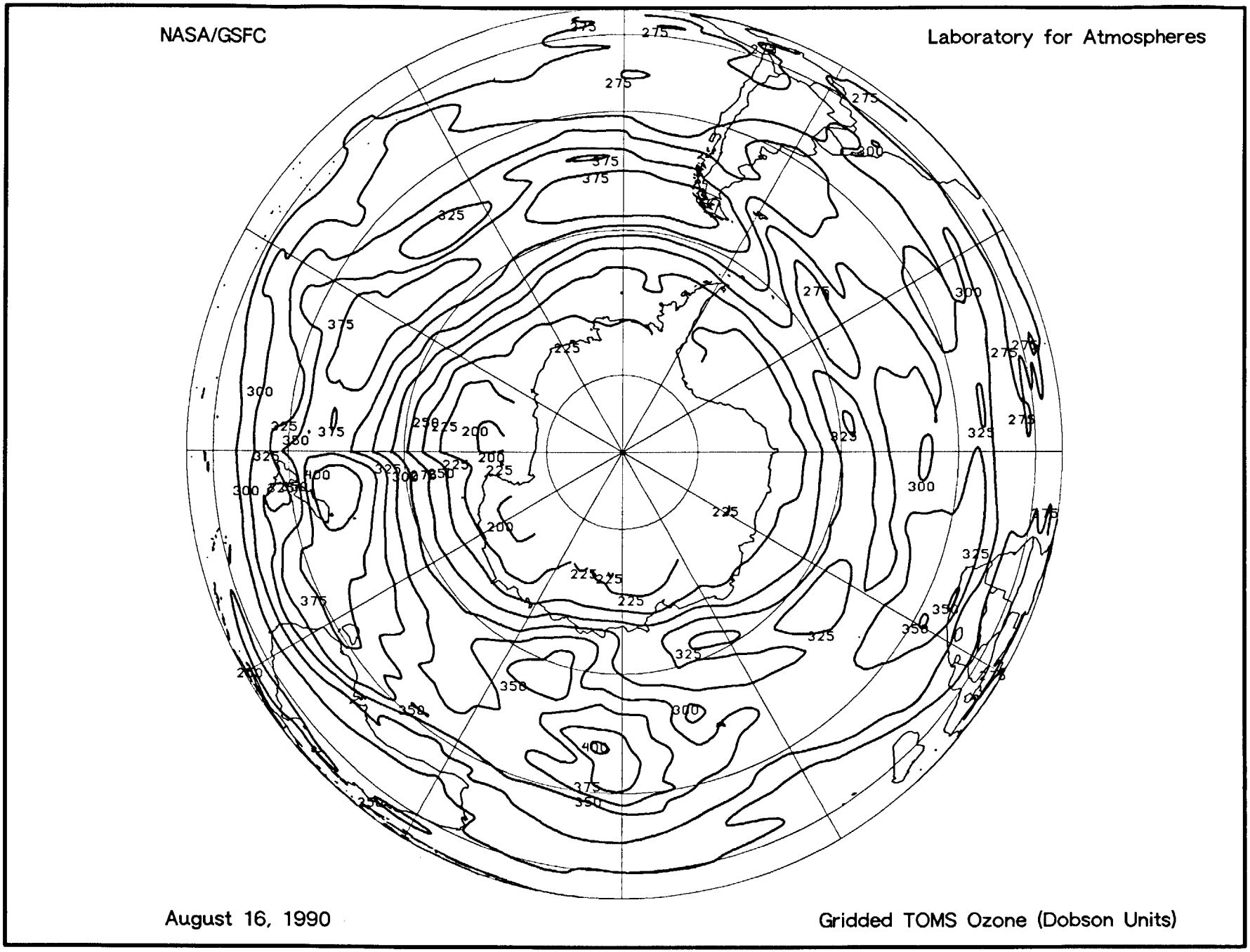
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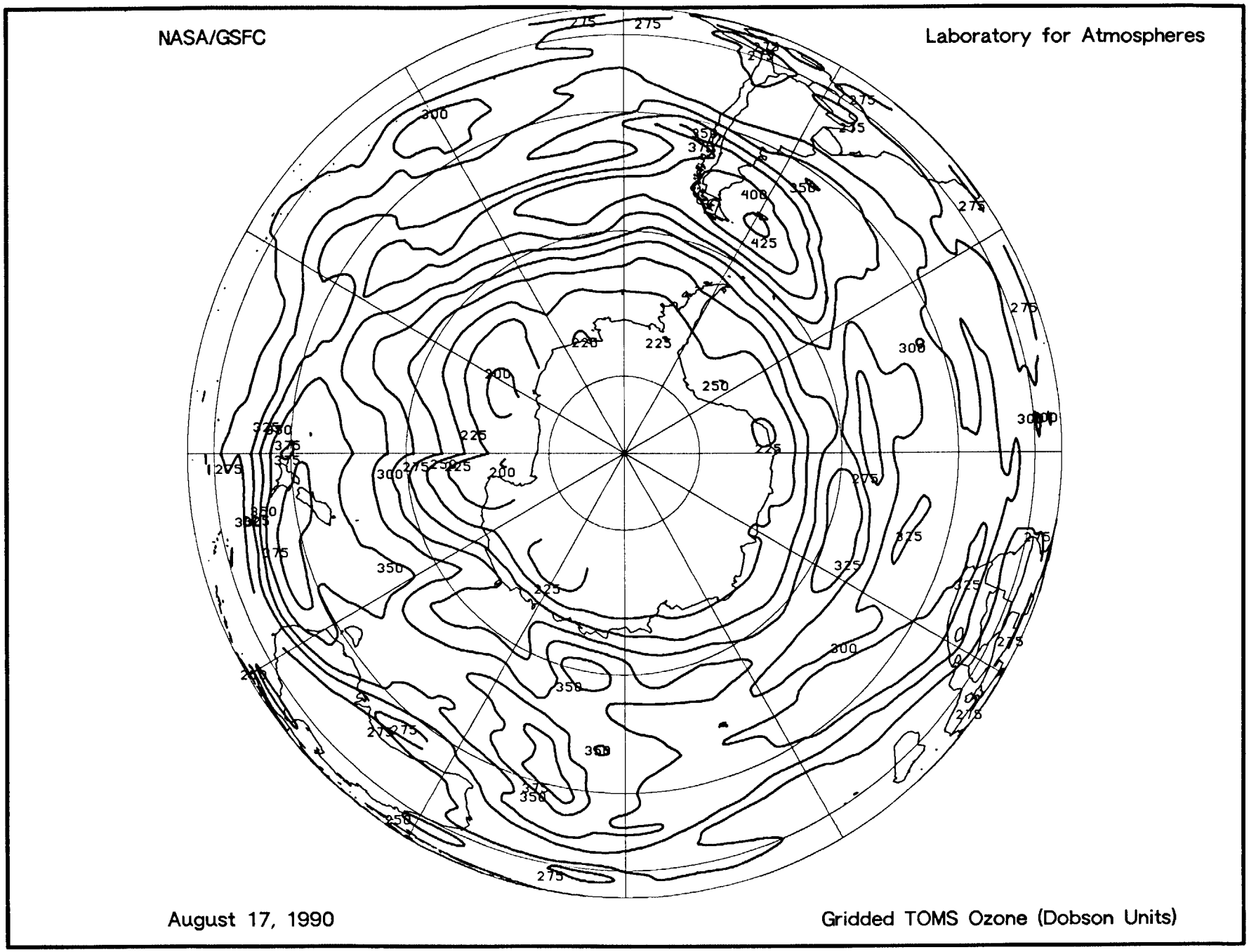
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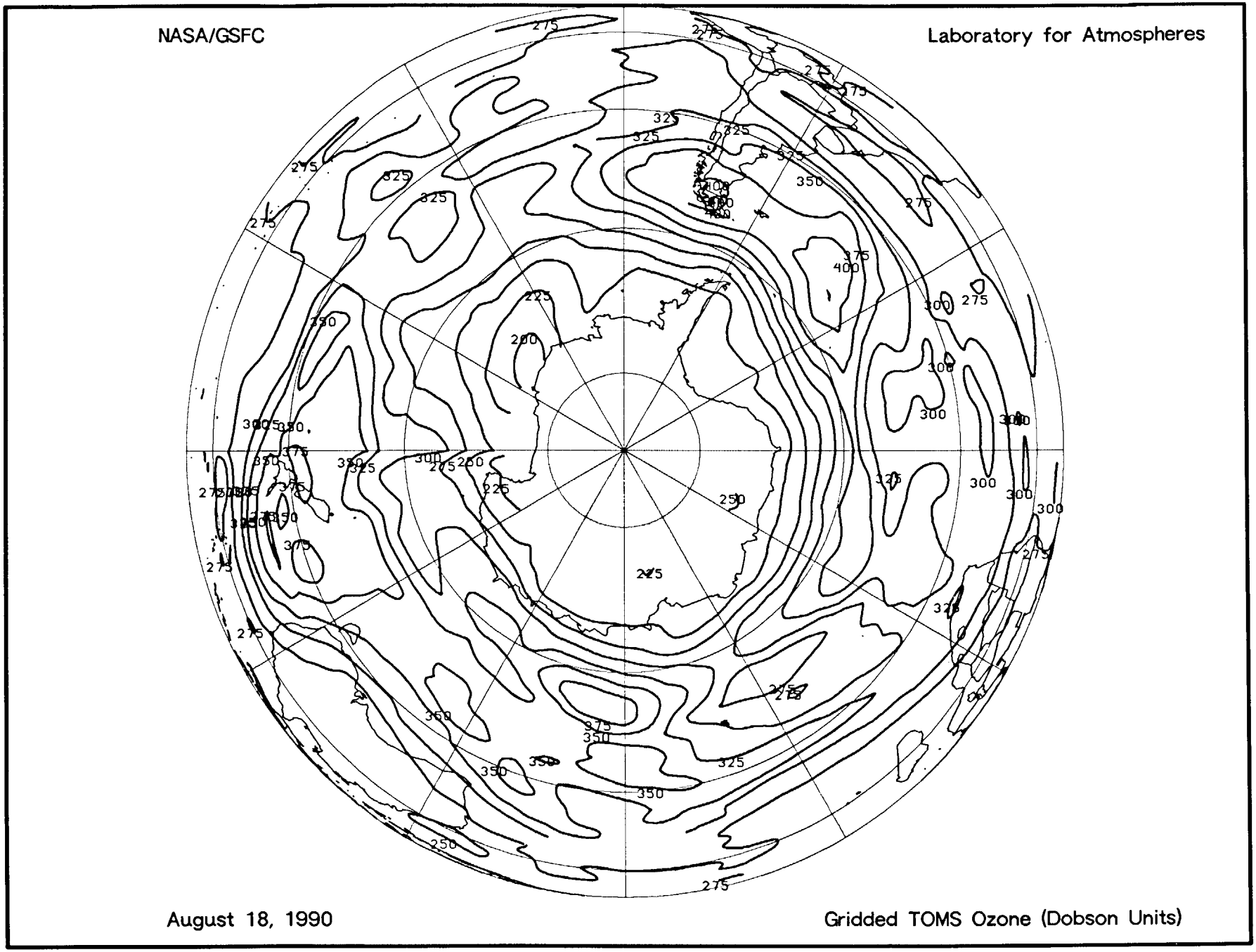
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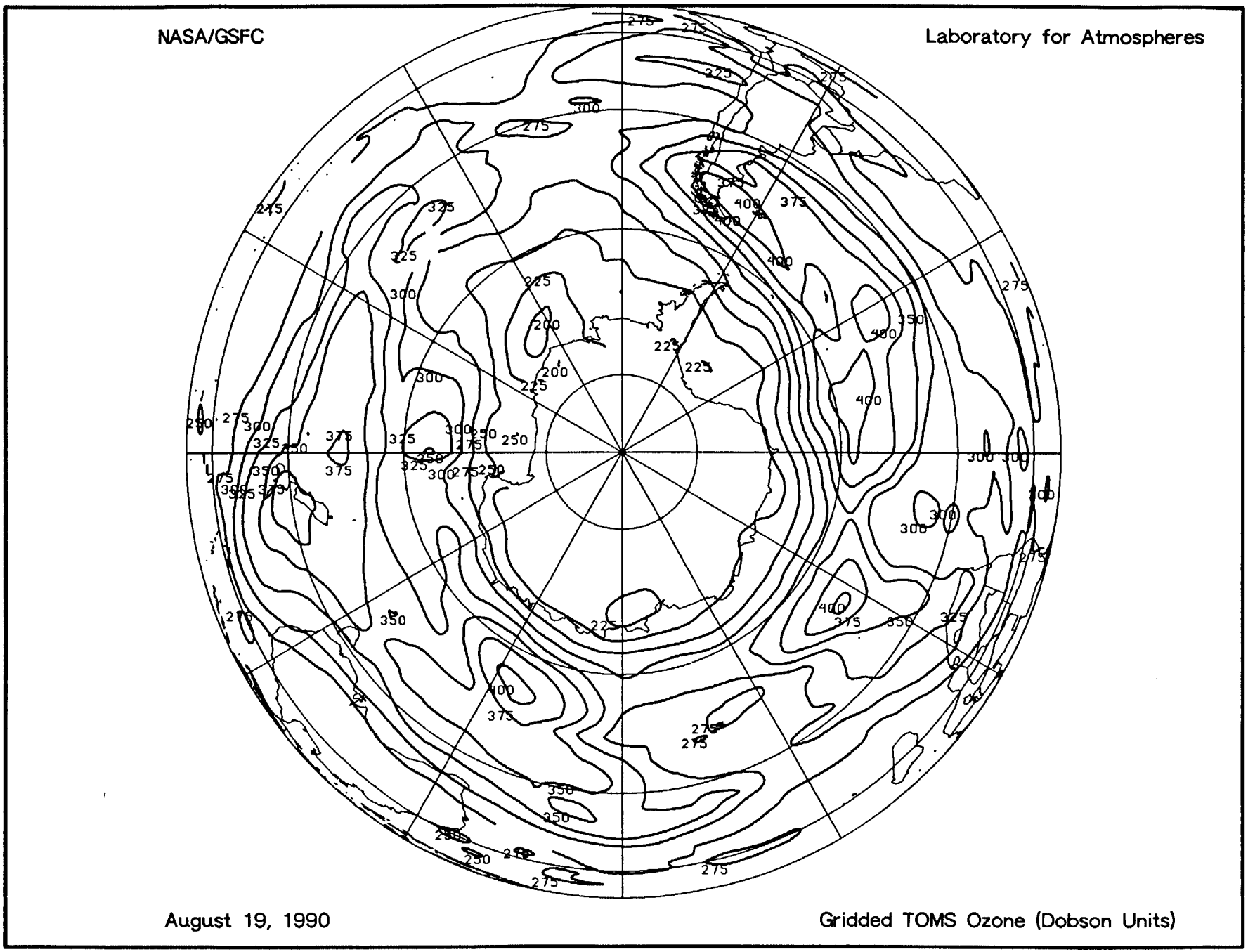
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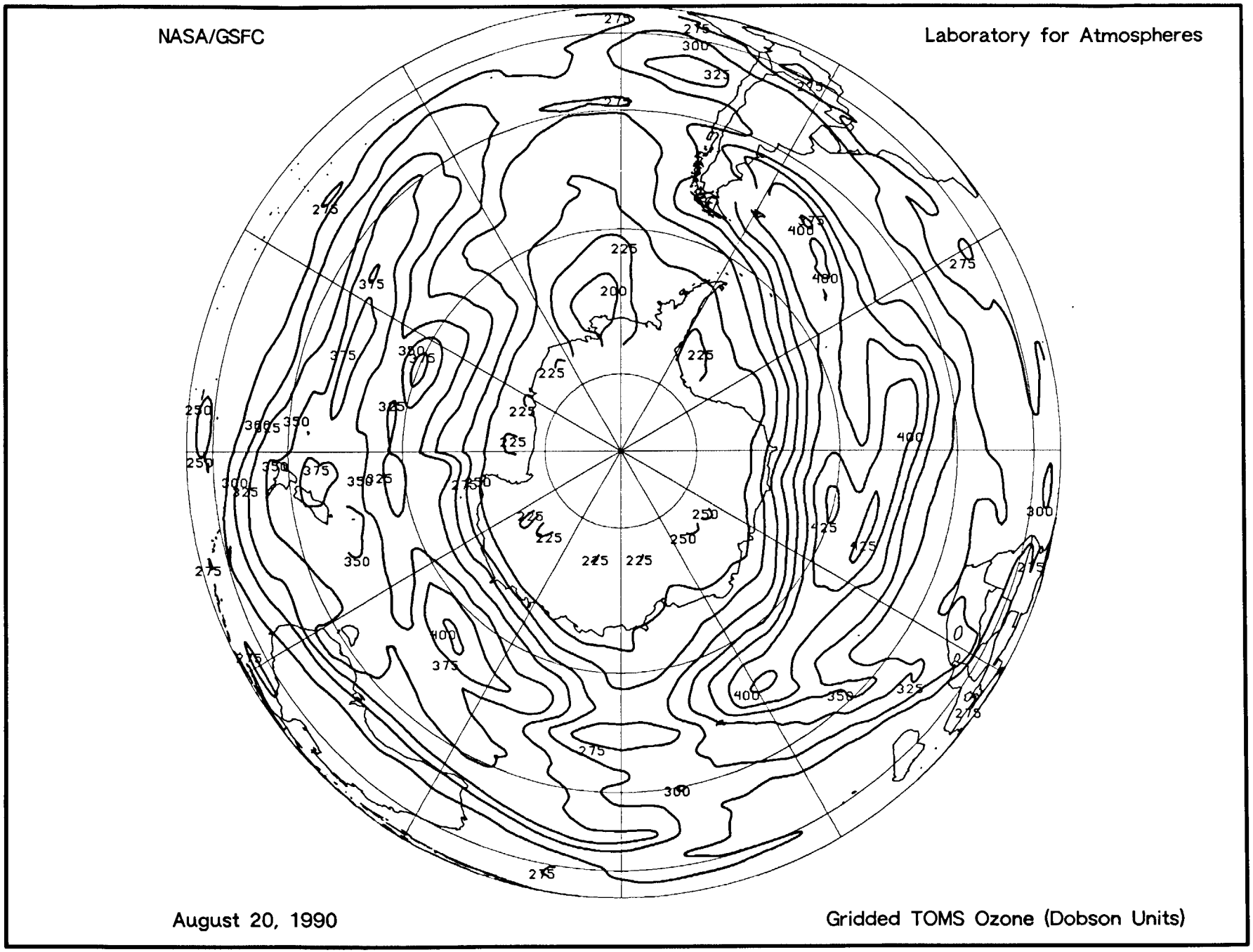
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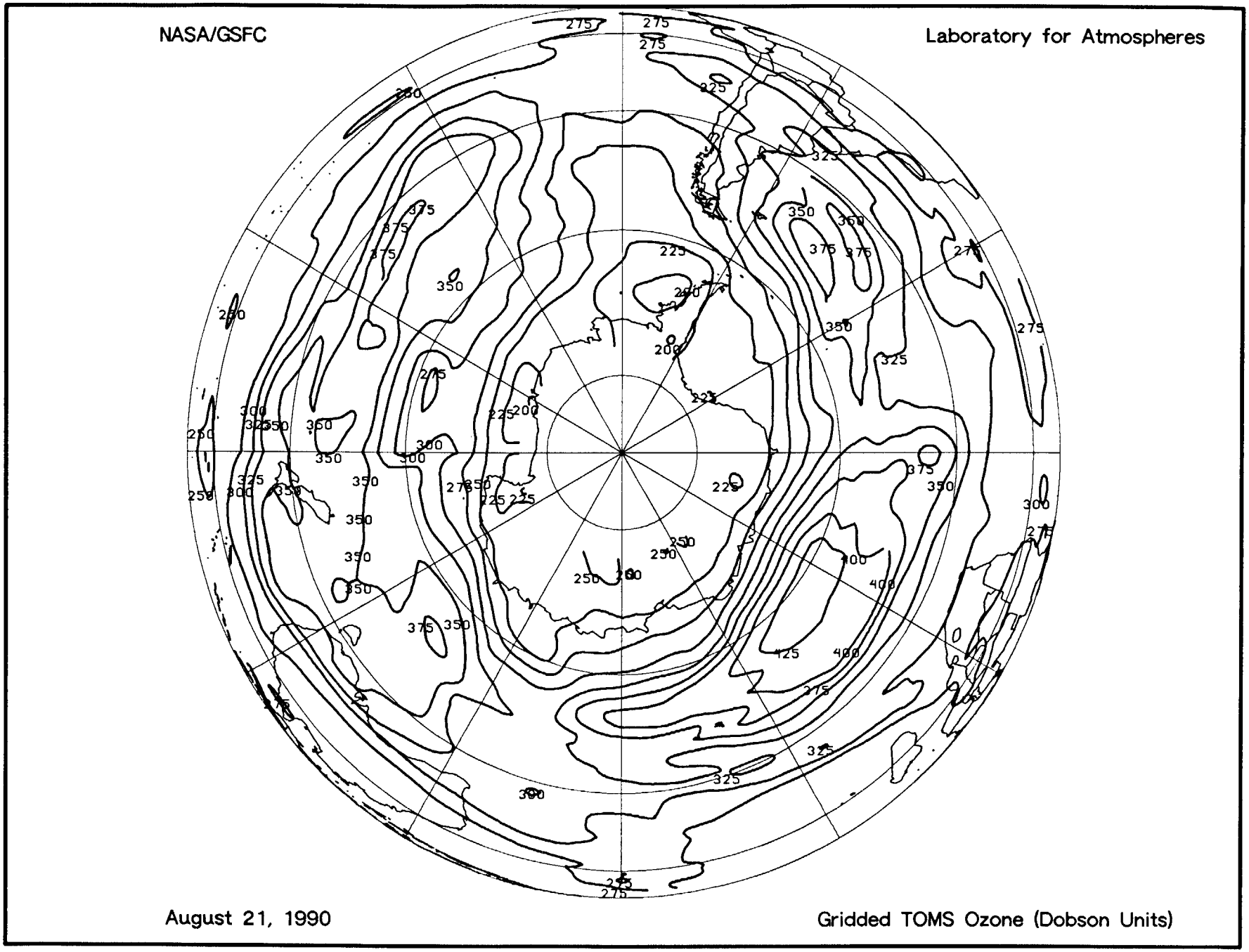
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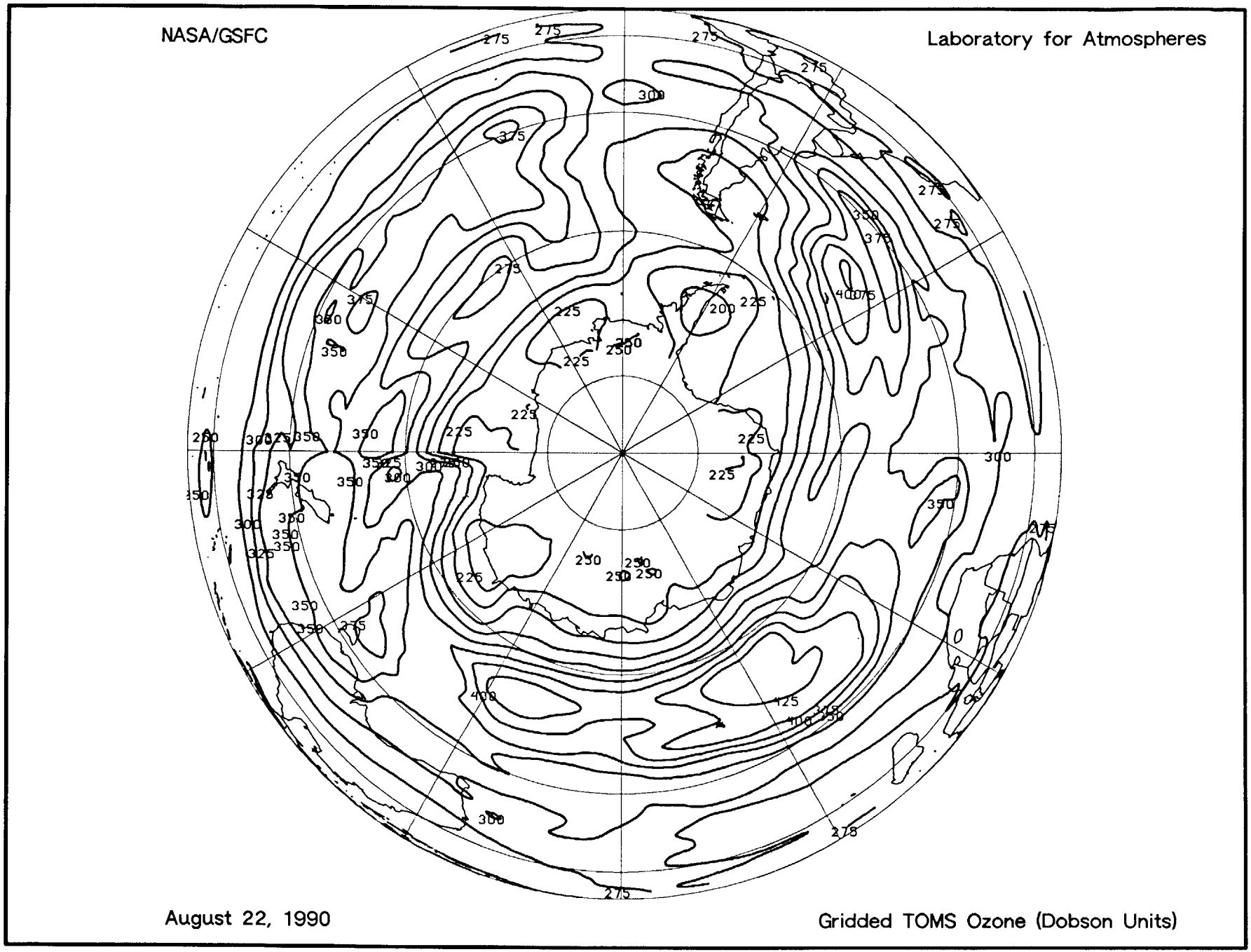
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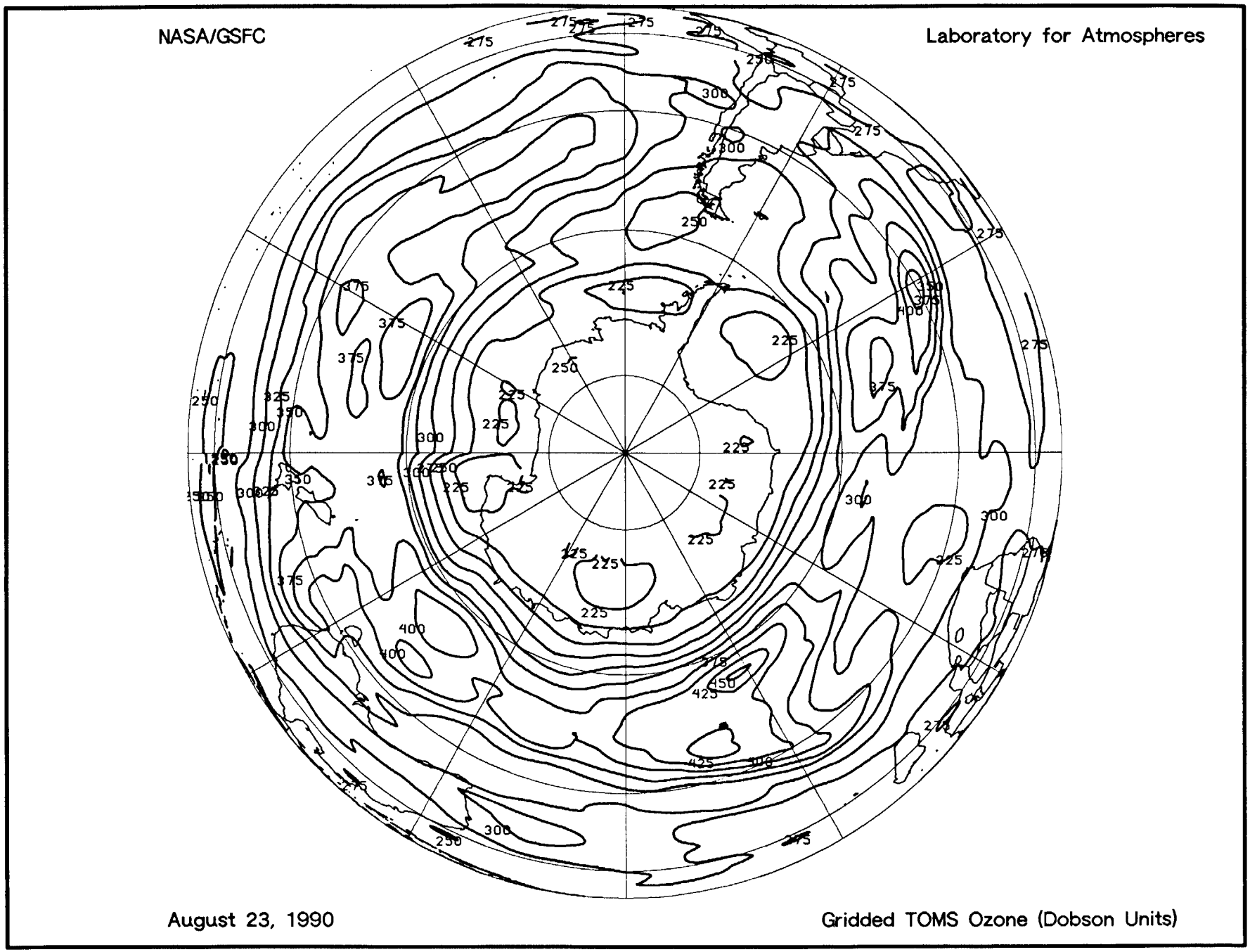
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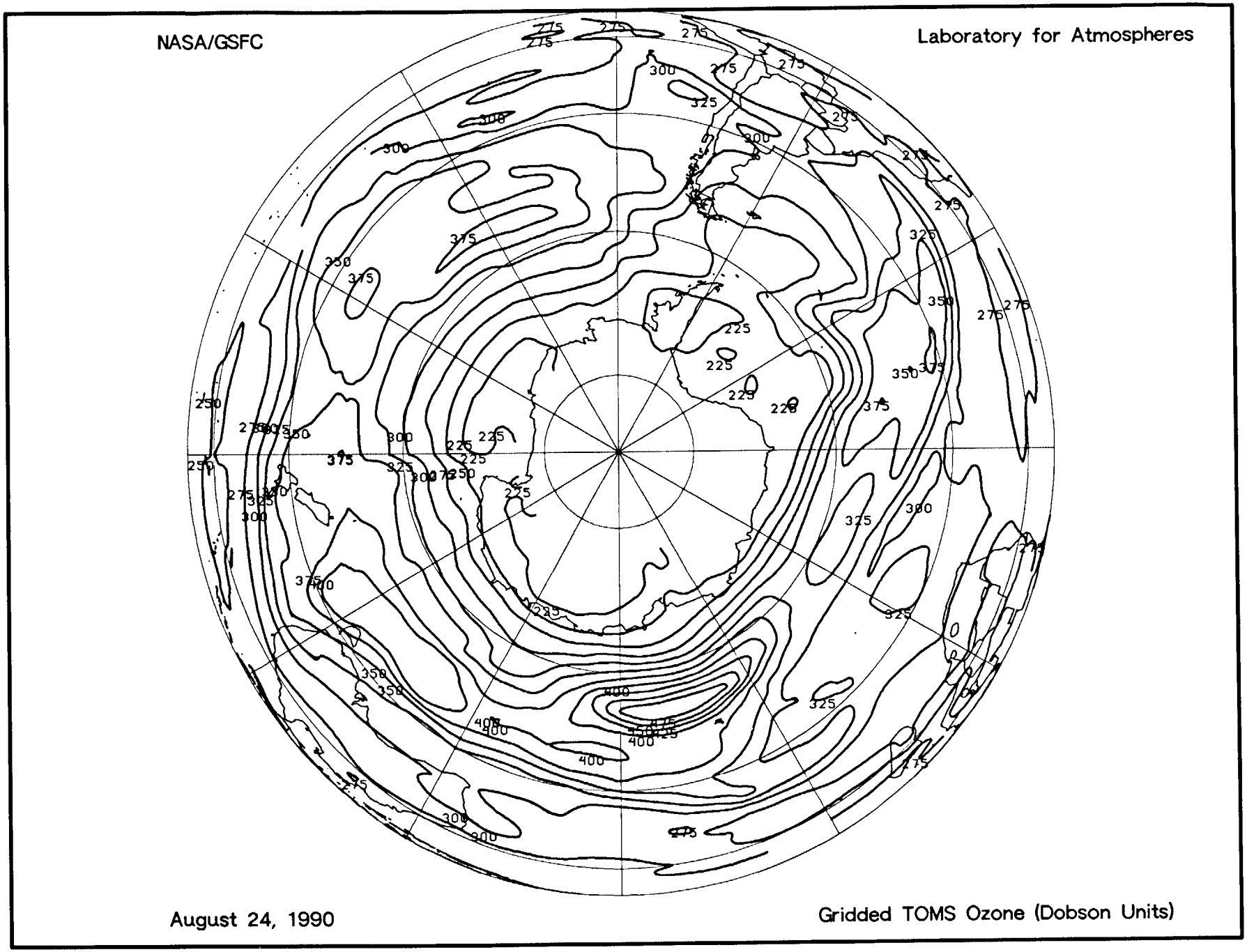
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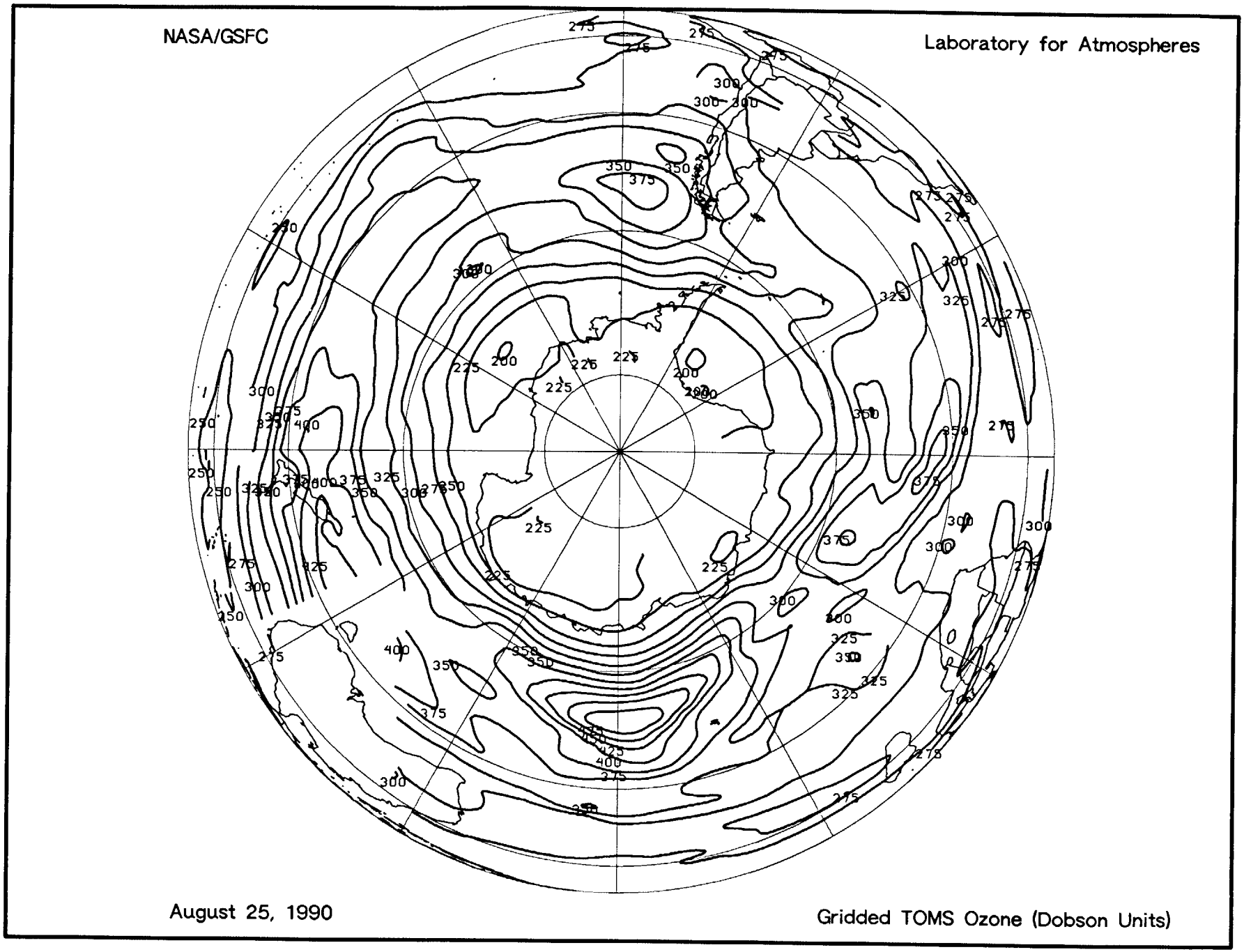
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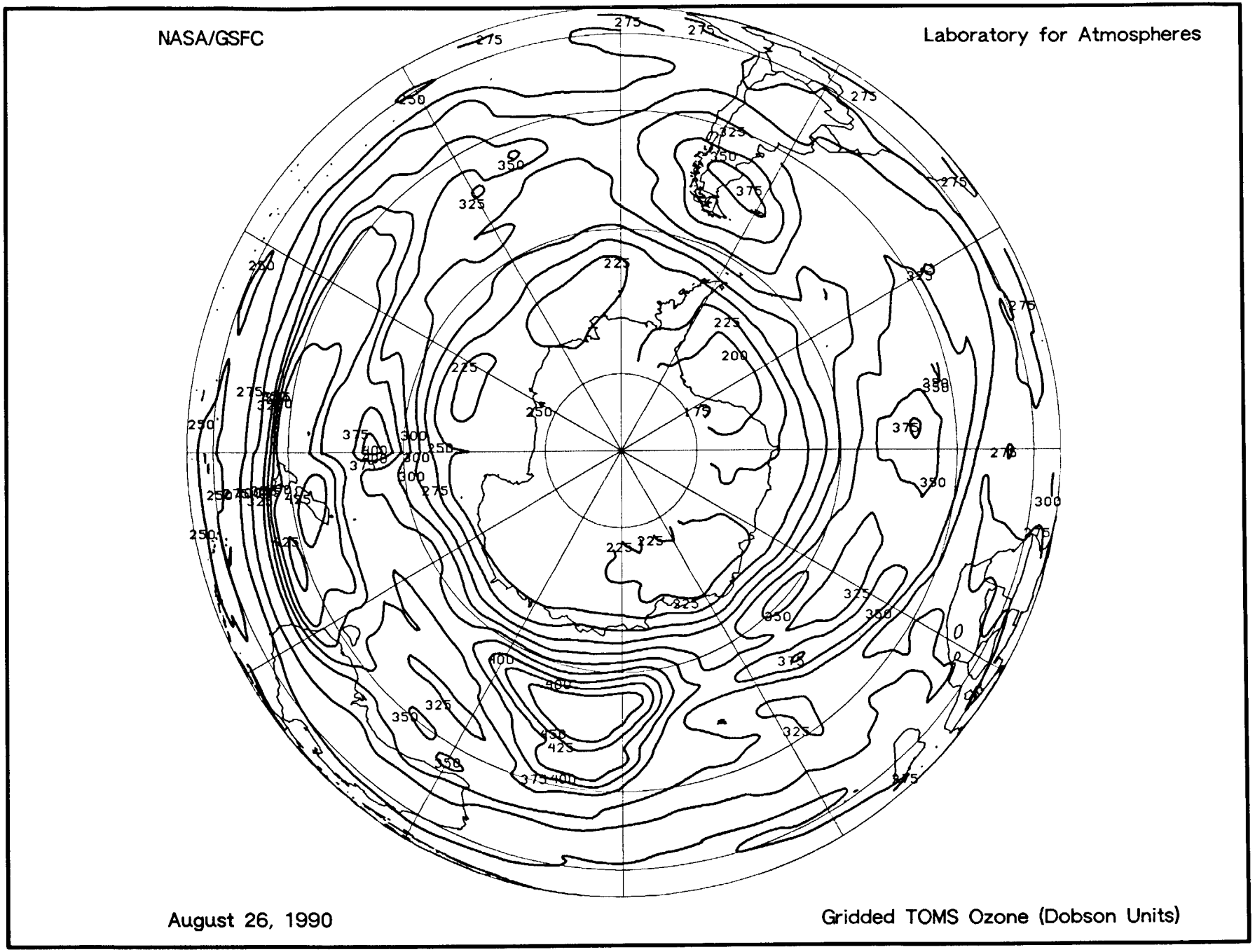
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August 26, 1990
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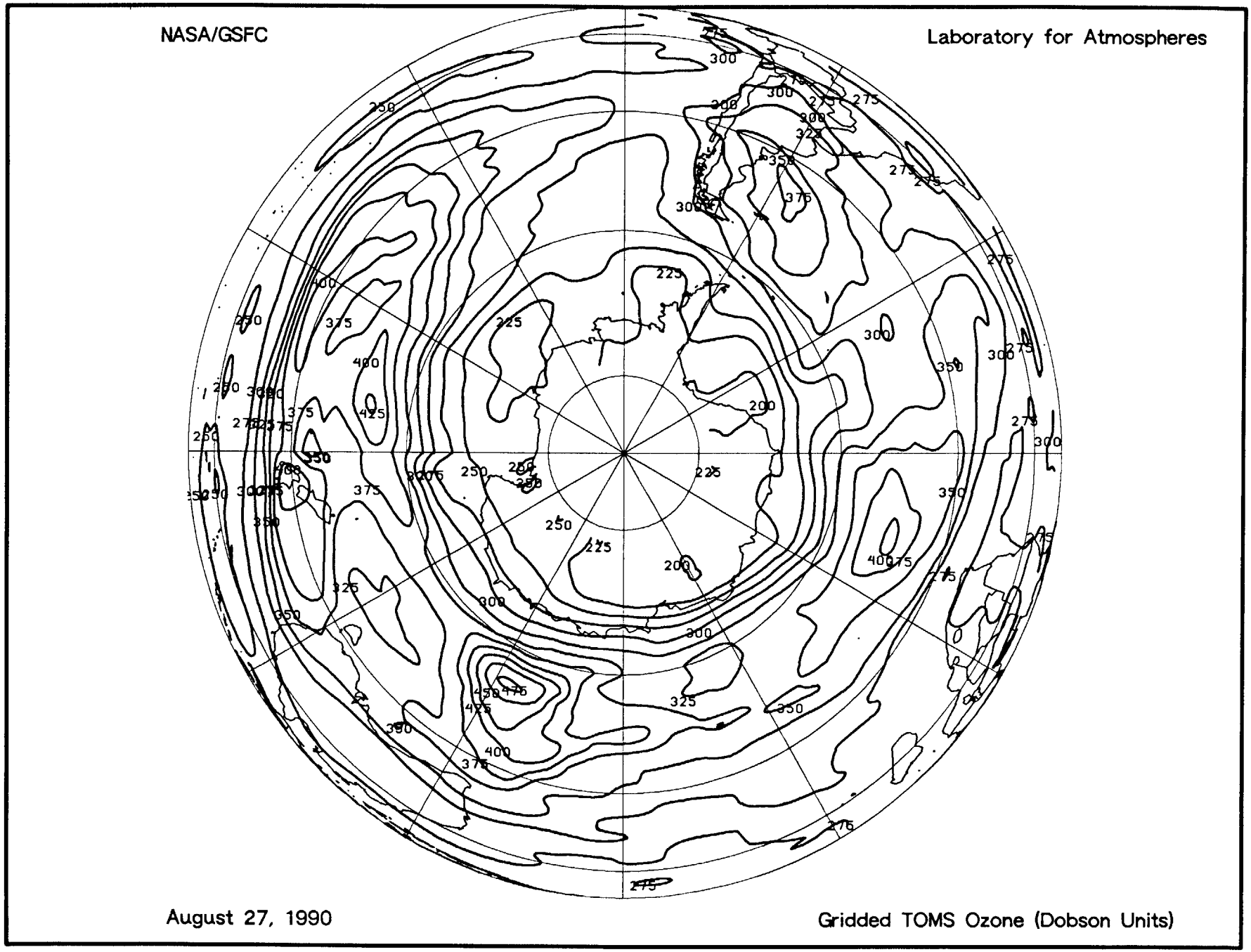
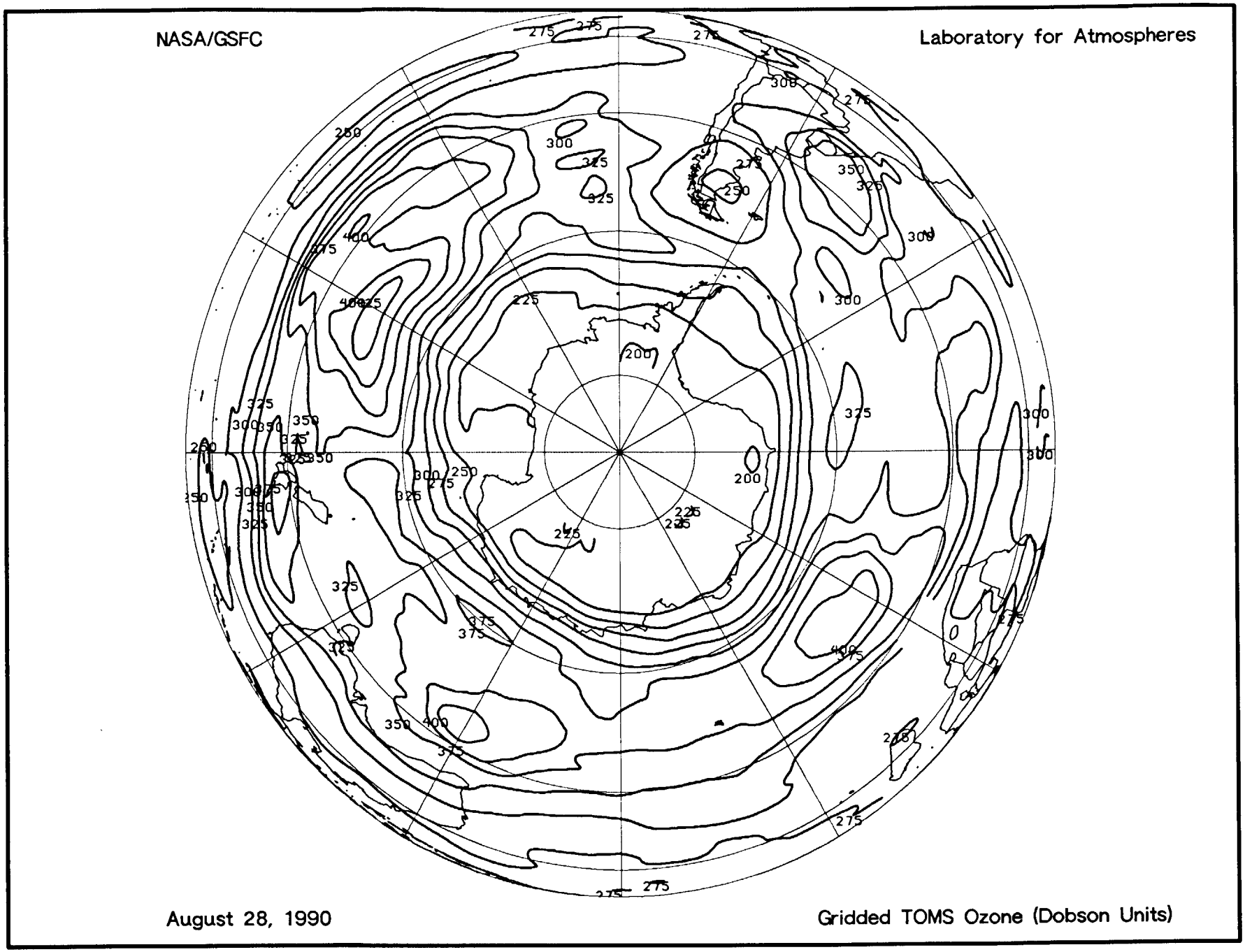
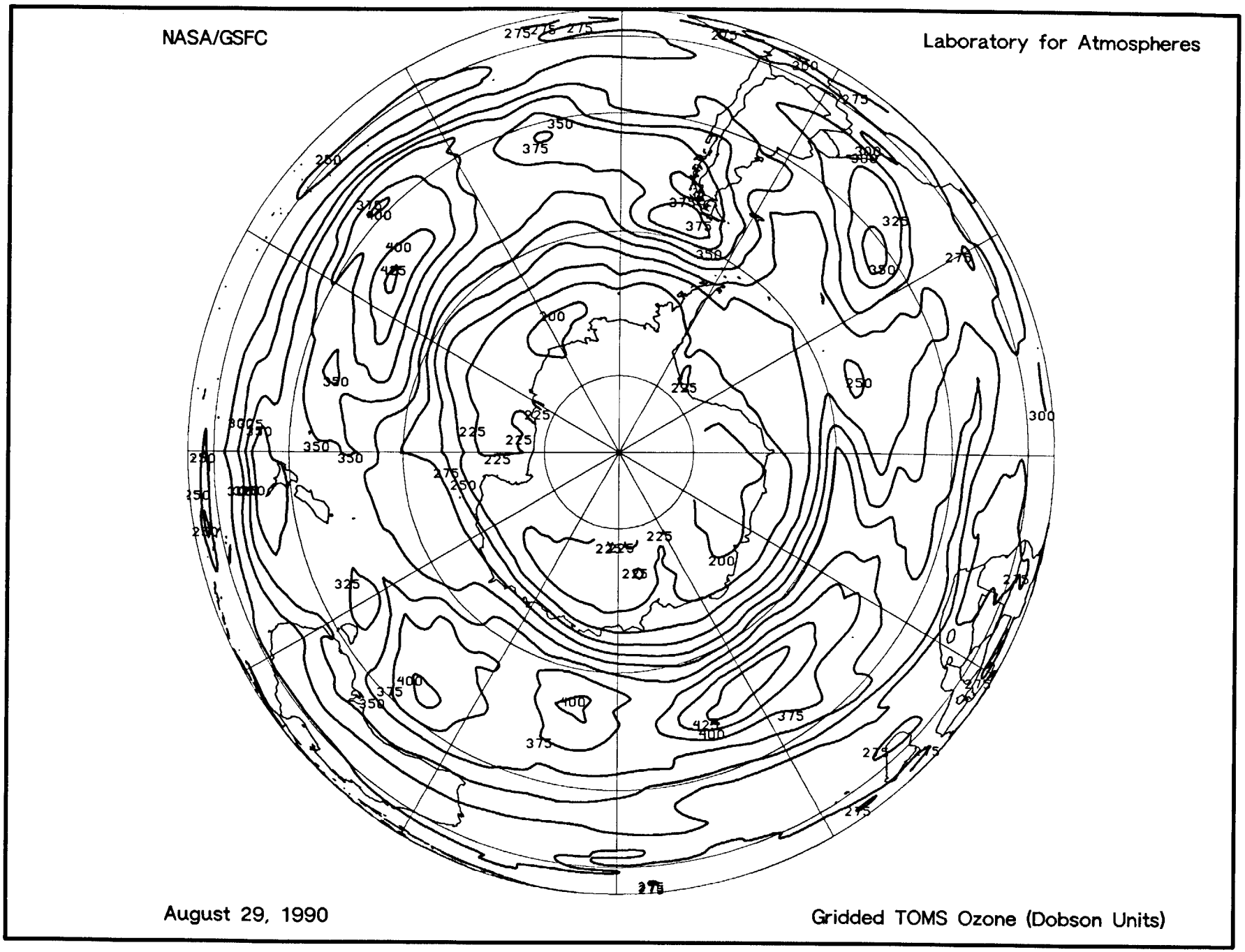
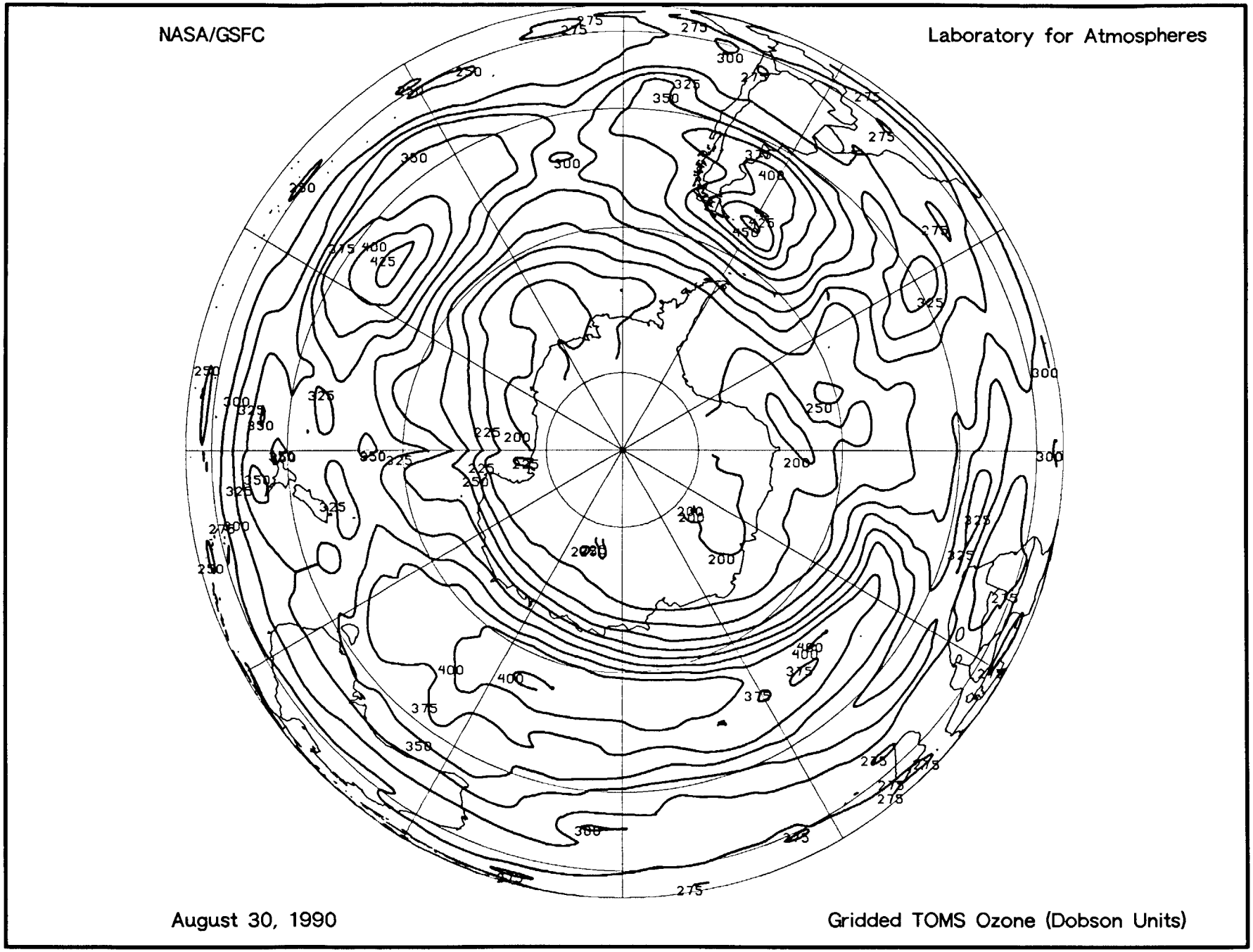
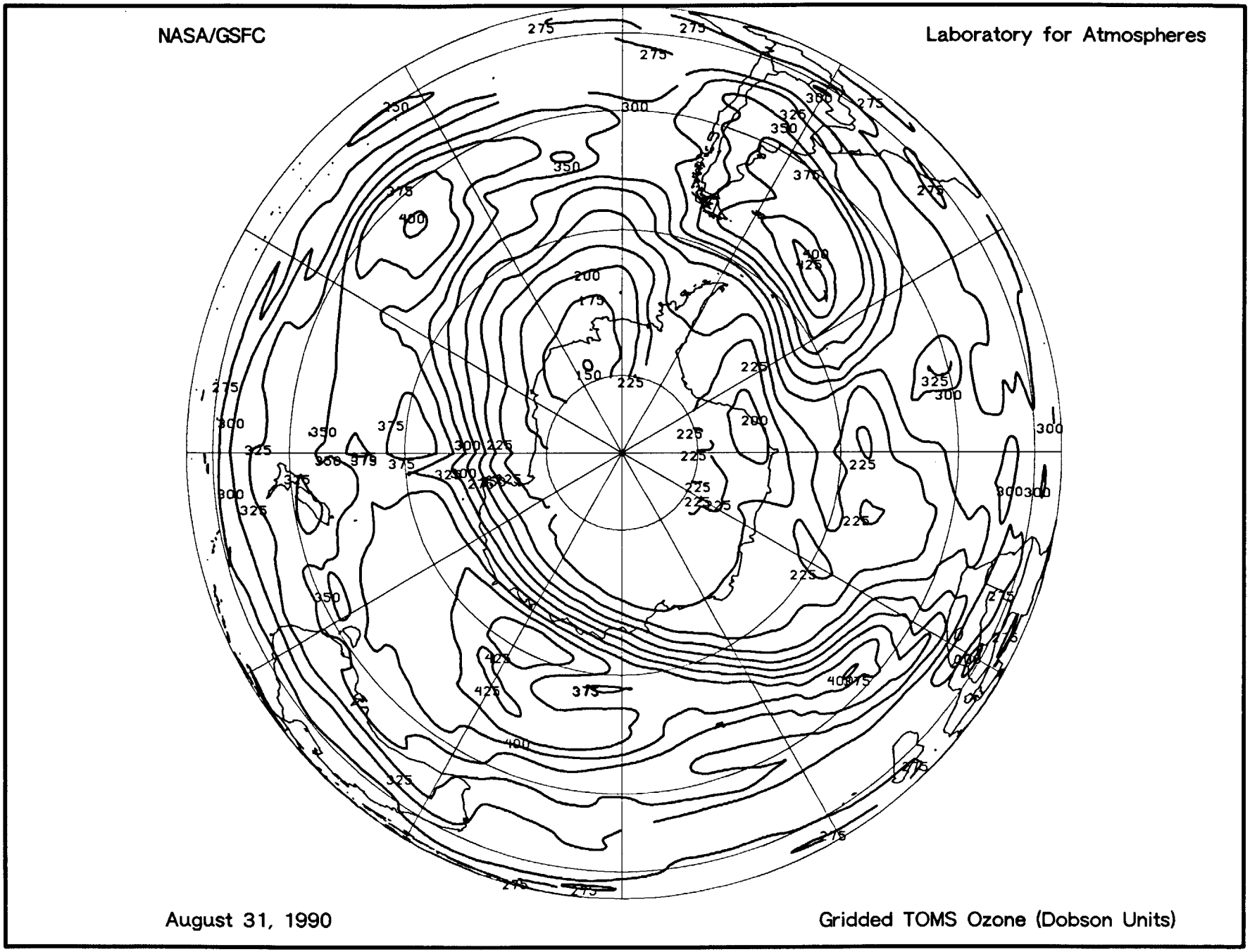
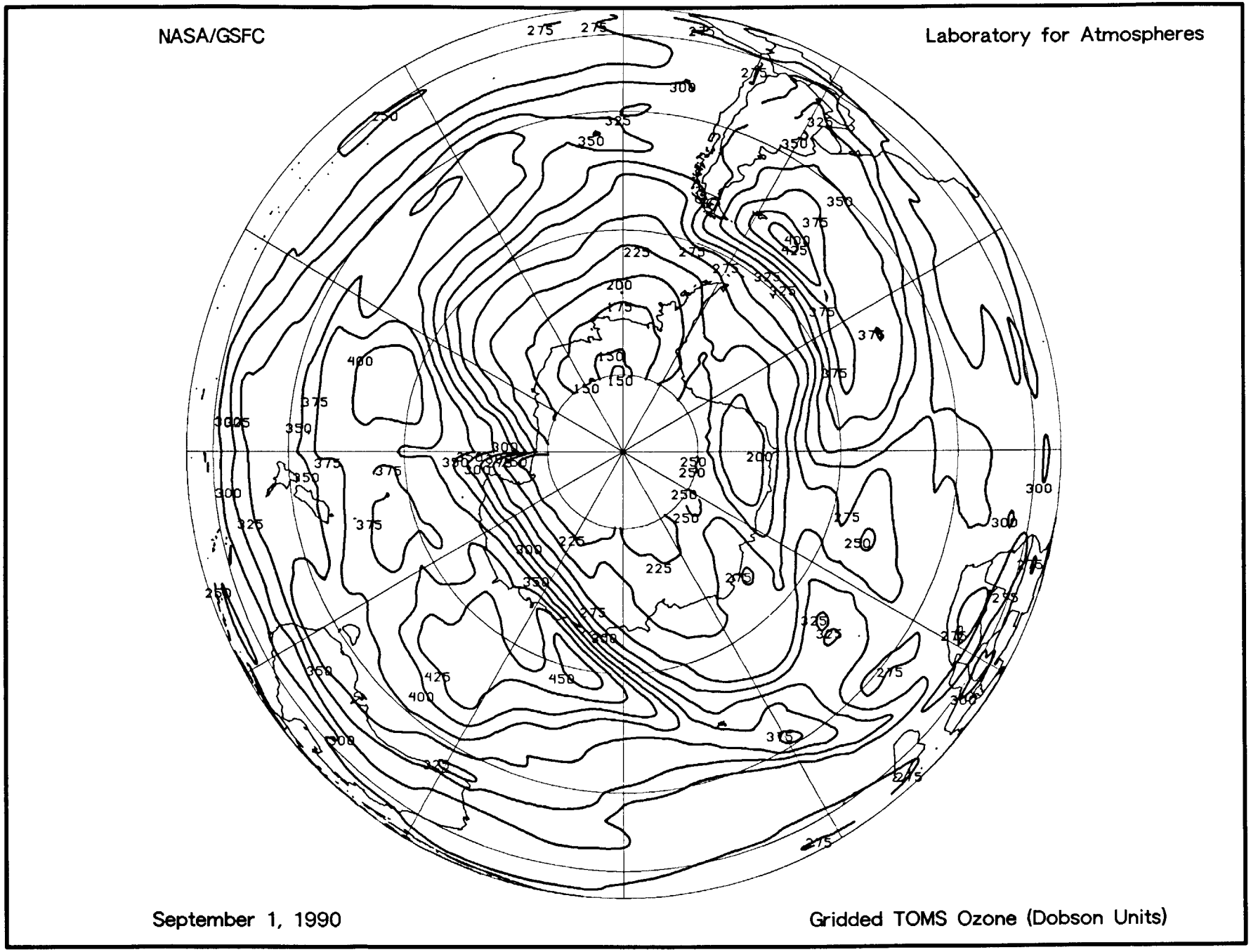

NASA/GSFC
Laboratory for Atmospheres
August 27, 1990
Gridded TOMS Ozone (Dobson Units)

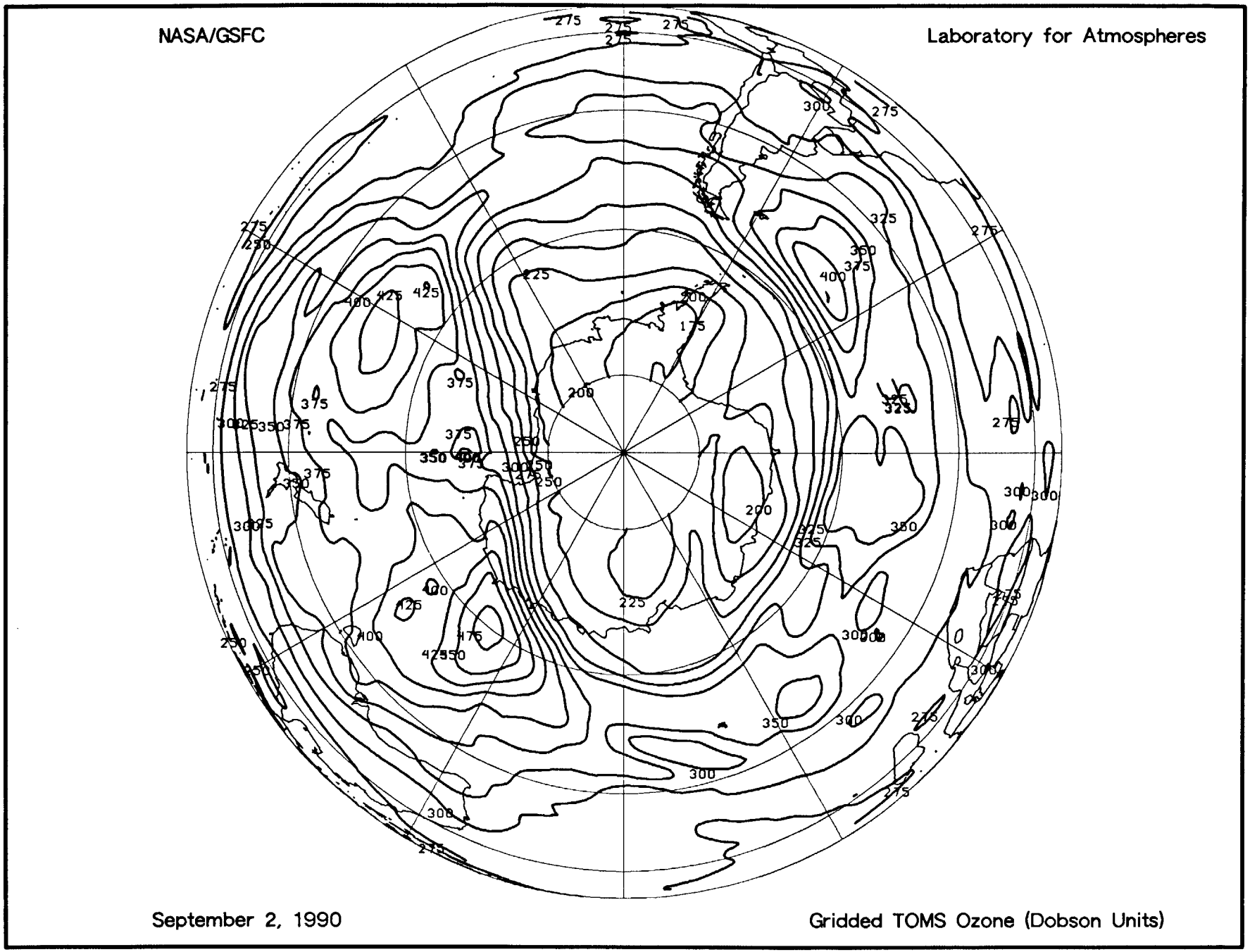

NASA/GSFC
Laboratory for Atmospheres
August 28, 1990
Gridded TOMS Ozone (Dobson Units)

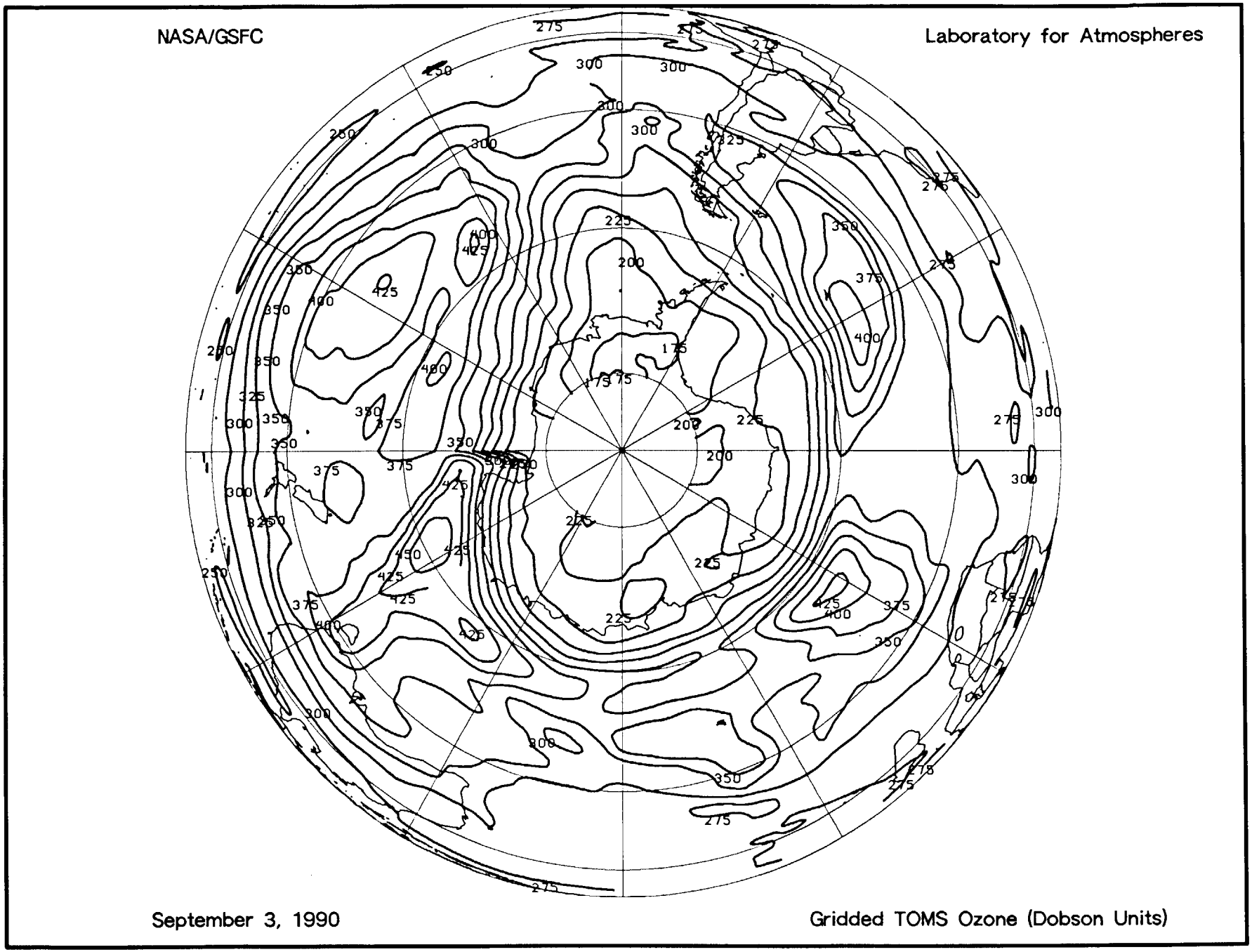

NASA/GSFC
Laboratory for Atmospheres
August 29, 1990
Gridded TOMS Ozone (Dobson Units)

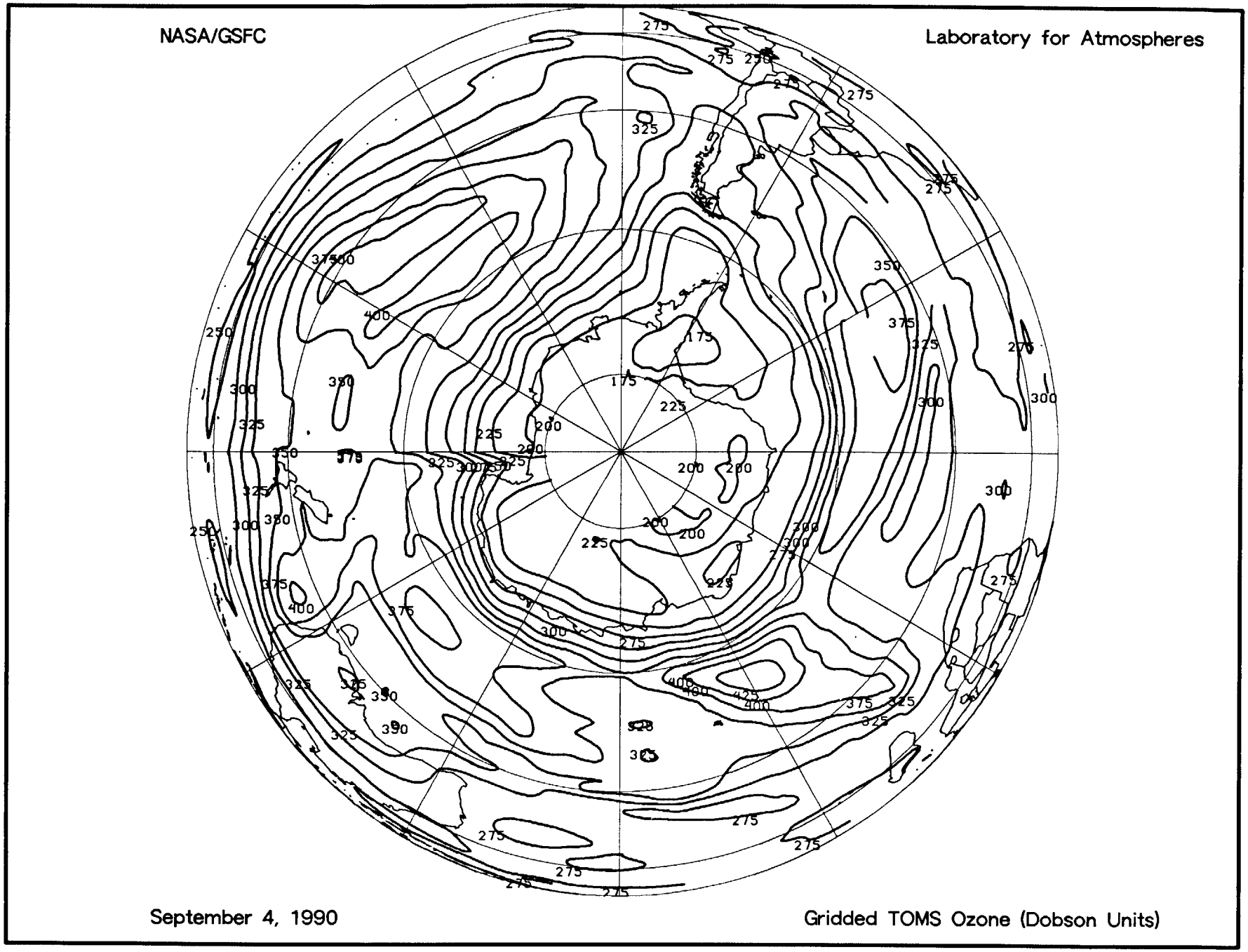

NASA/GSFC
Laboratory for Atmospheres
August 30, 1990
Gridded TOMS Ozone (Dobson Units)

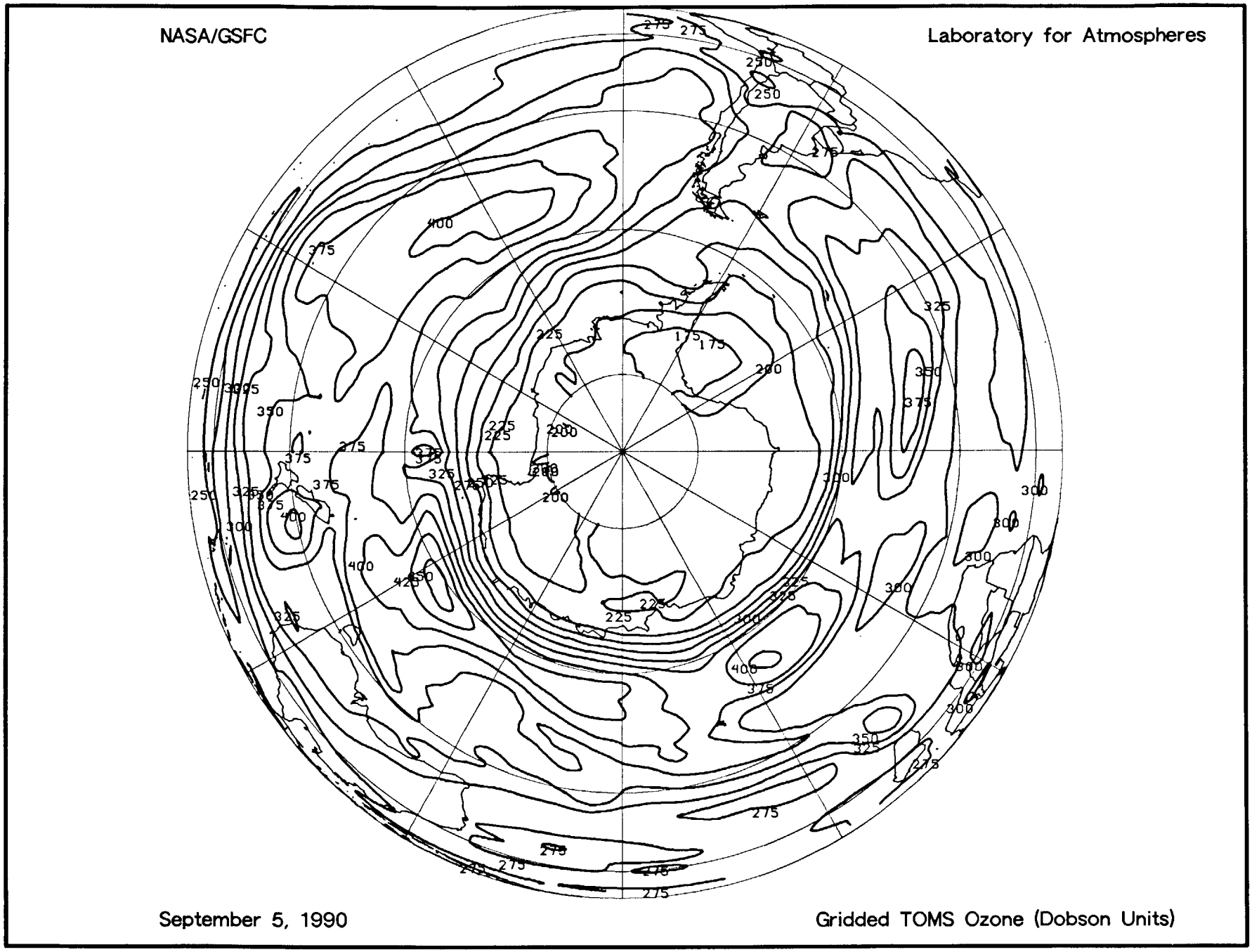

NASA/GSFC
Laboratory for Atmospheres
August 31, 1990
Gridded TOMS Ozone (Dobson Units)

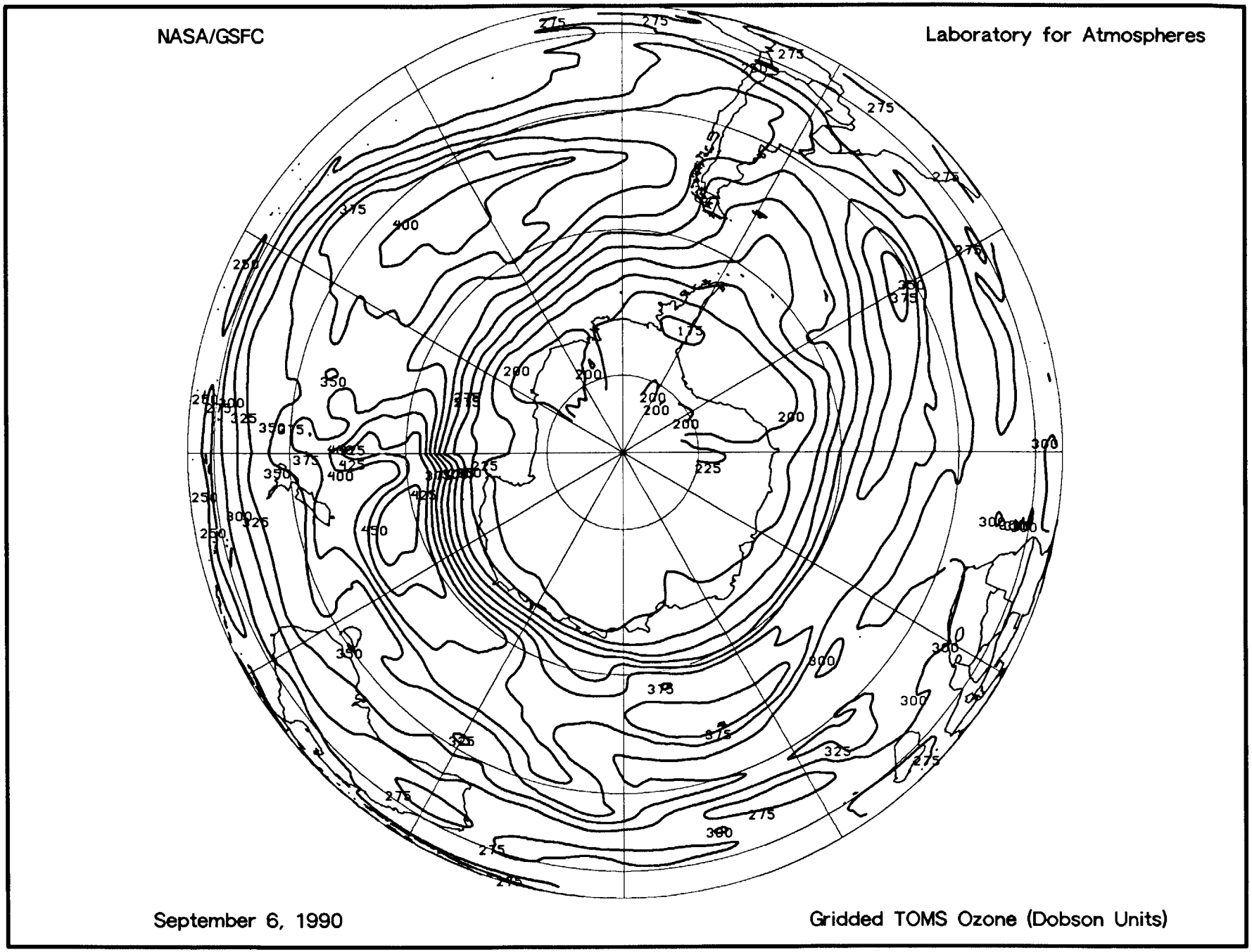

NASA/GSFC
Laboratory for Atmospheres
September 1, 1990
Gridded TOMS Ozone (Dobson Units)

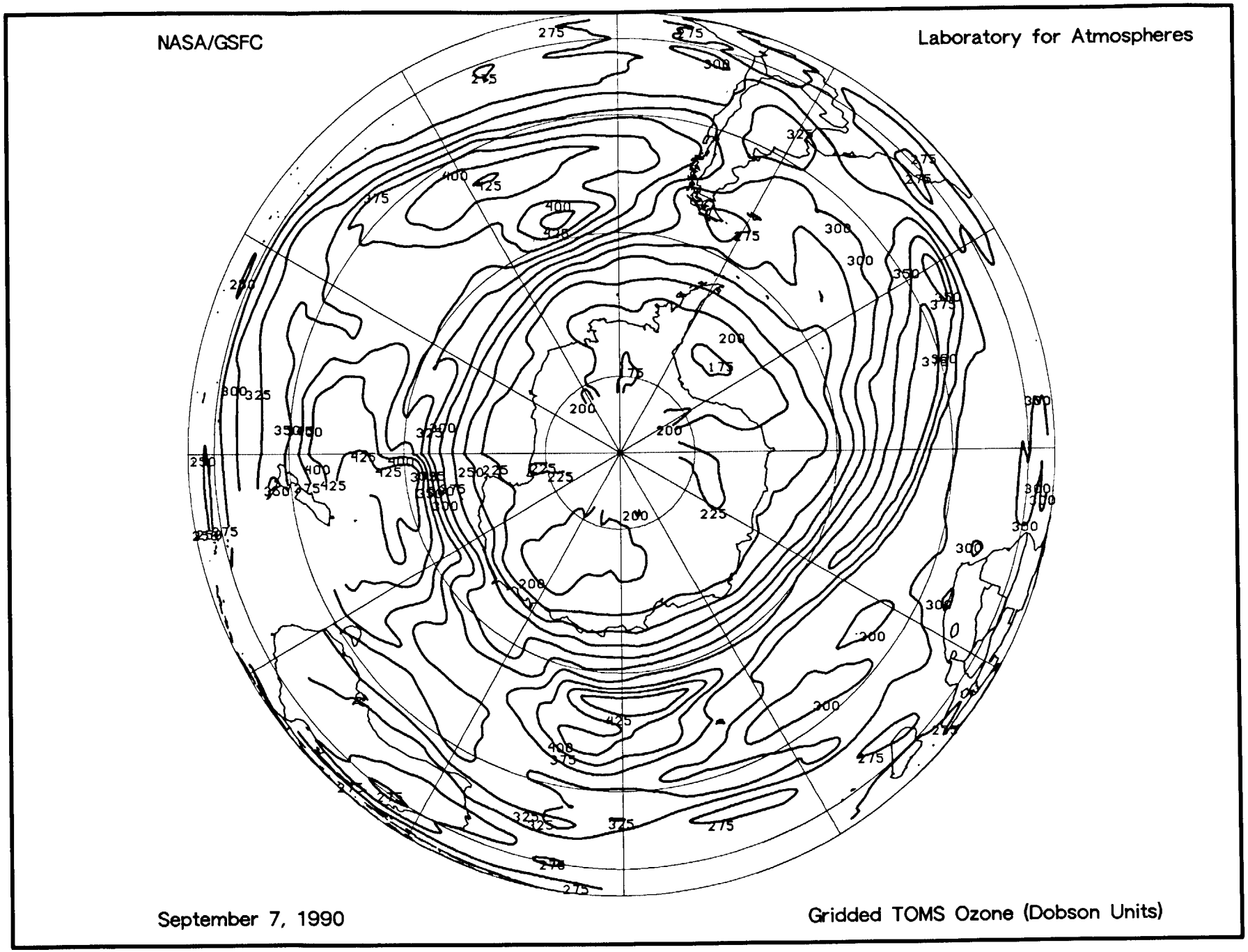

NASA/GSFC
Laboratory for Atmospheres
September 2, 1990
Gridded TOMS Ozone (Dobson Units)

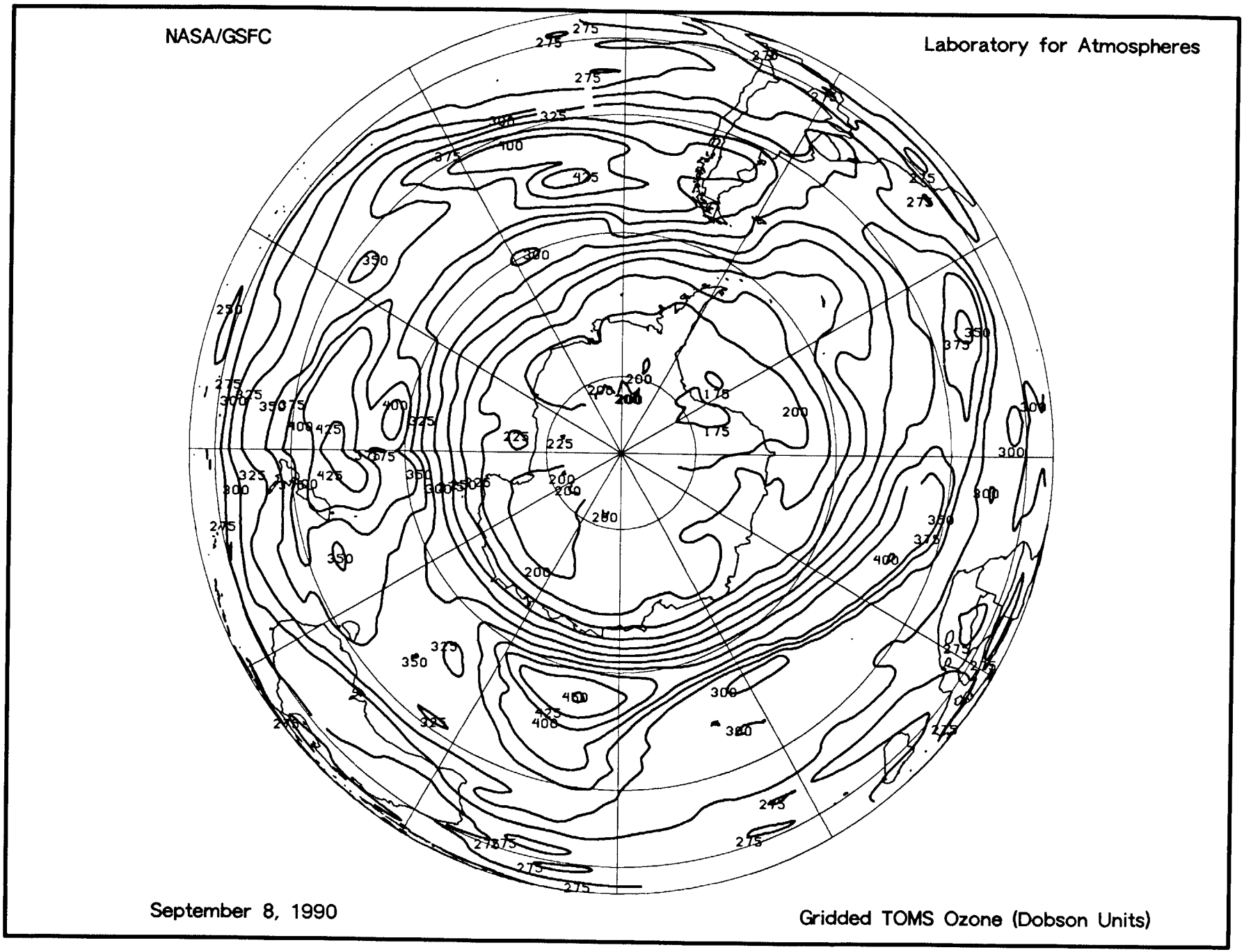

NASA/GSFC
Laboratory for Atmospheres
September 3, 1990
Gridded TOMS Ozone (Dobson Units)

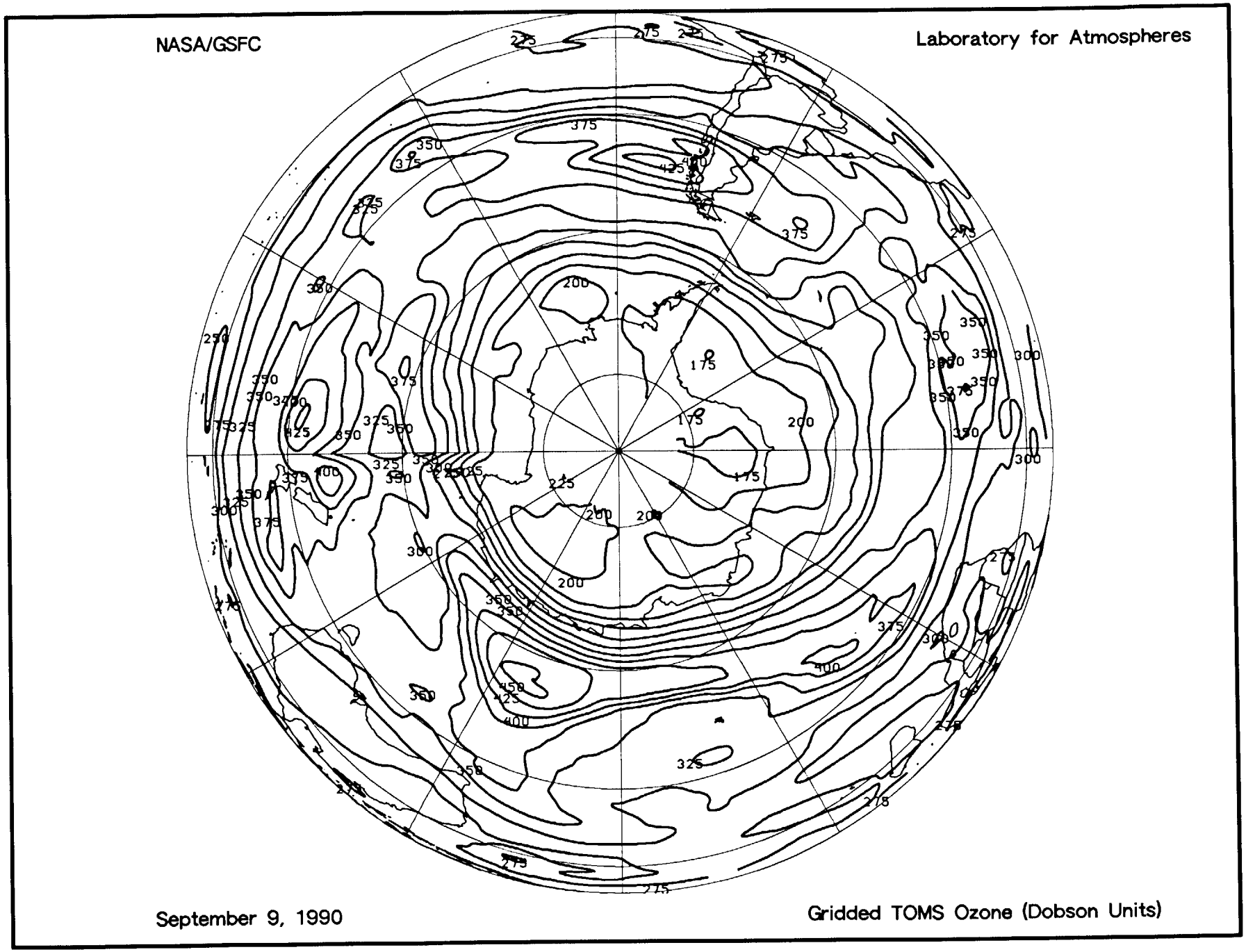

NASA/GSFC
Laboratory for Atmospheres
September 4, 1990
Gridded TOMS Ozone (Dobson Units)

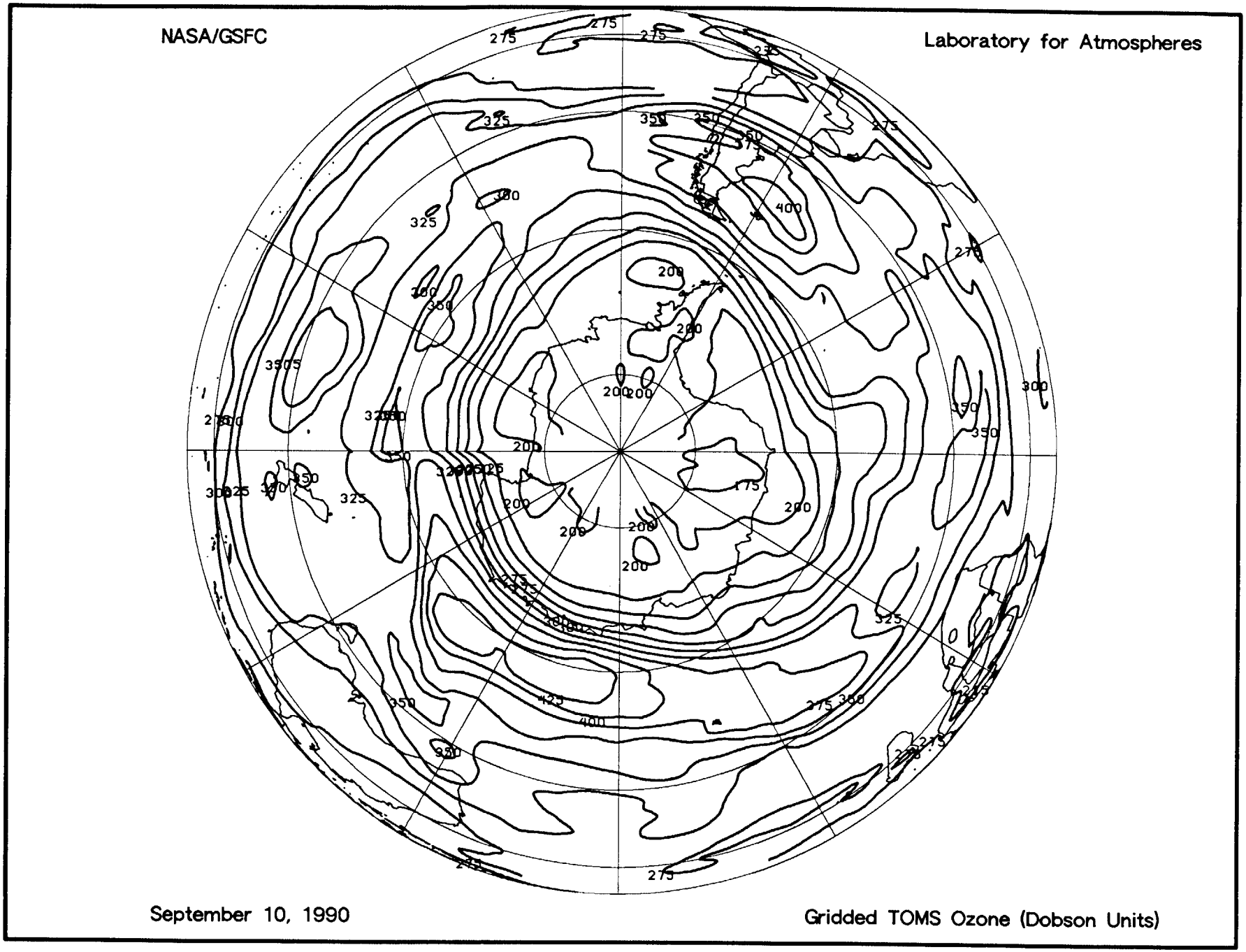

NASA/GSFC
Laboratory for Atmospheres
September 5, 1990
Gridded TOMS Ozone (Dobson Units)

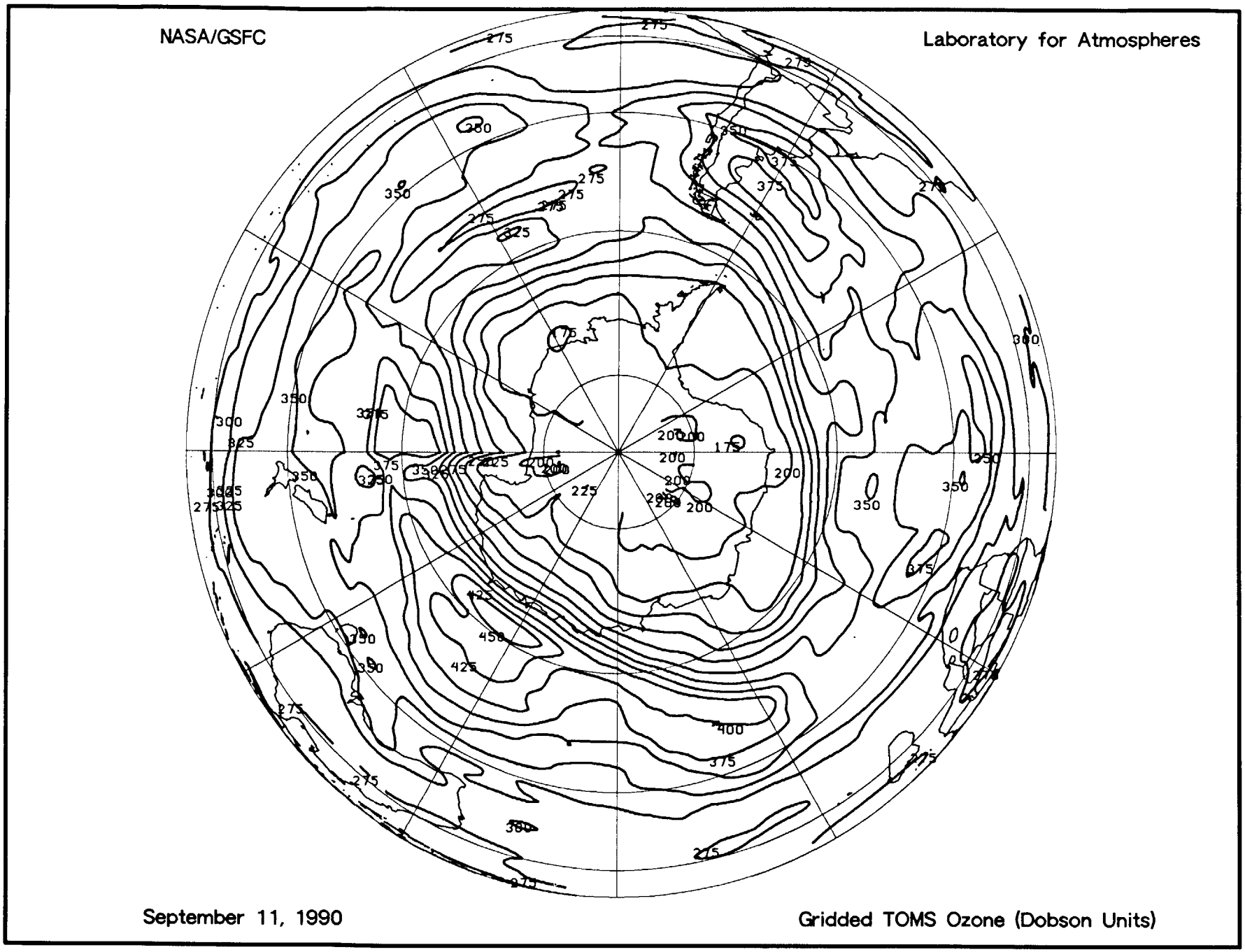

NASA/GSFC
Laboratory for Atmospheres
September 6, 1990
Gridded TOMS Ozone (Dobson Units)

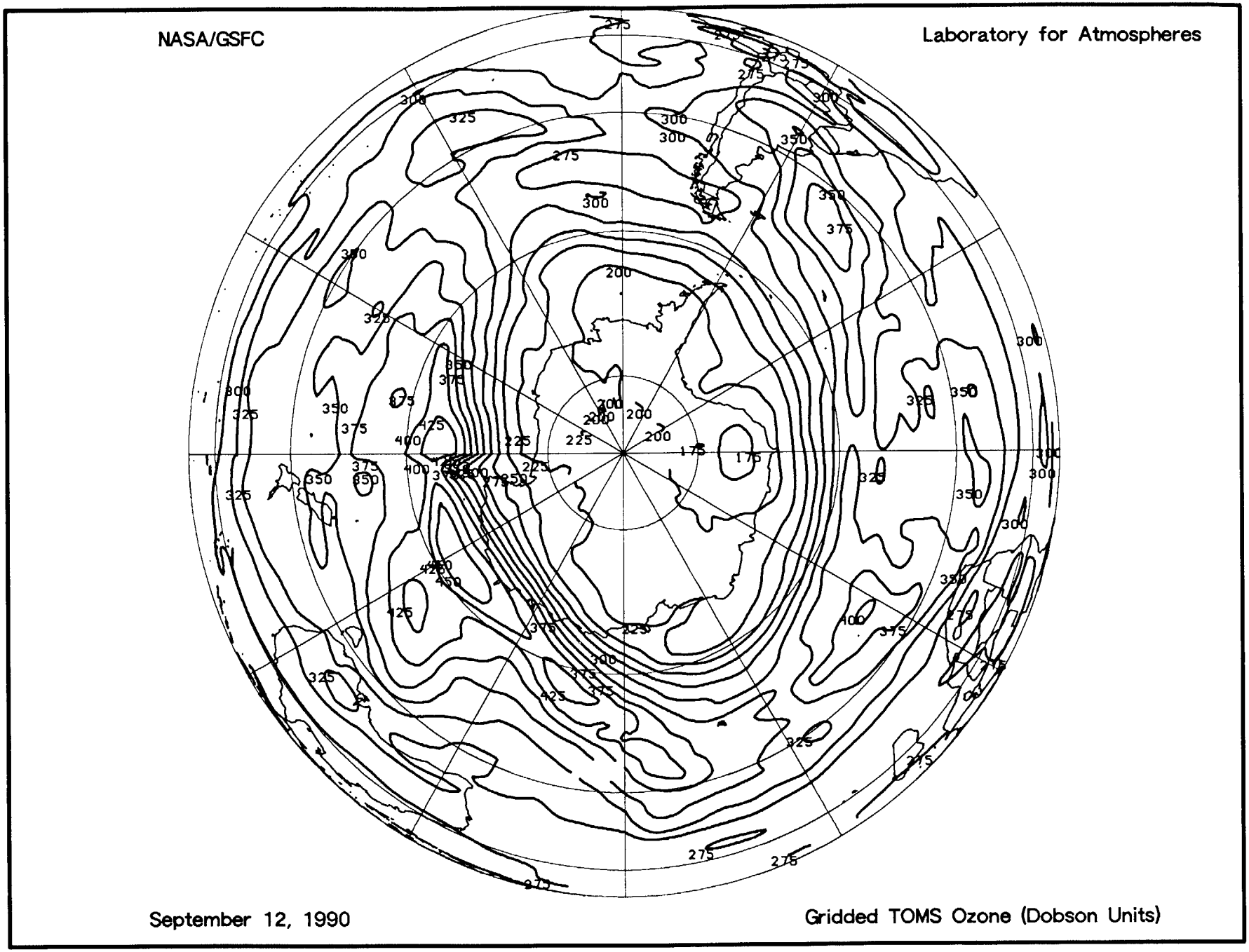

NASA/GSFC
Laboratory for Atmospheres
September 7, 1990
Gridded TOMS Ozone (Dobson Units)

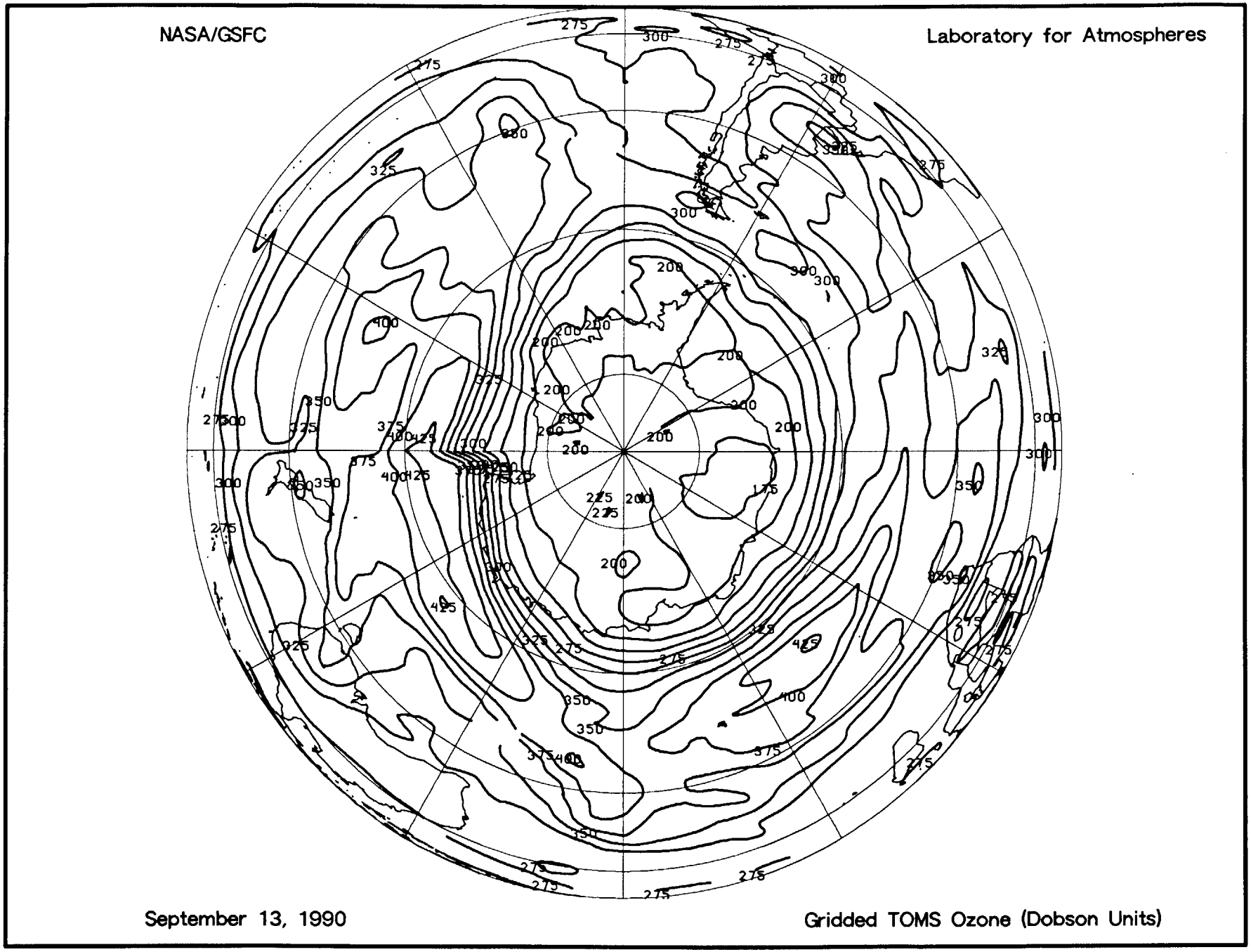

NASA/GSFC
Laboratory for Atmospheres
September 8, 1990
Gridded TOMS Ozone (Dobson Units)

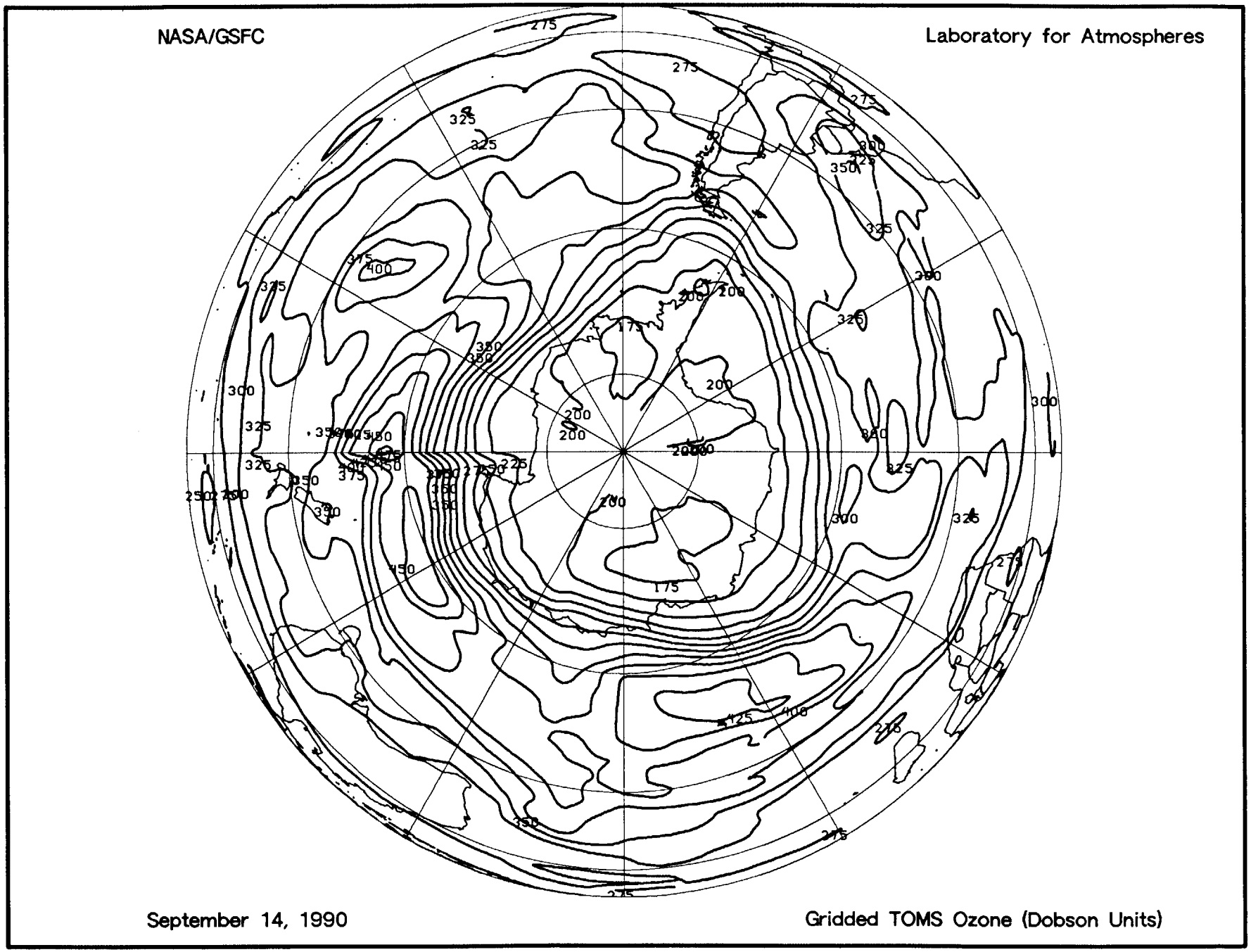

NASA/GSFC
Laboratory for Atmospheres
September 9, 1990
Gridded TOMS Ozone (Dobson Units)

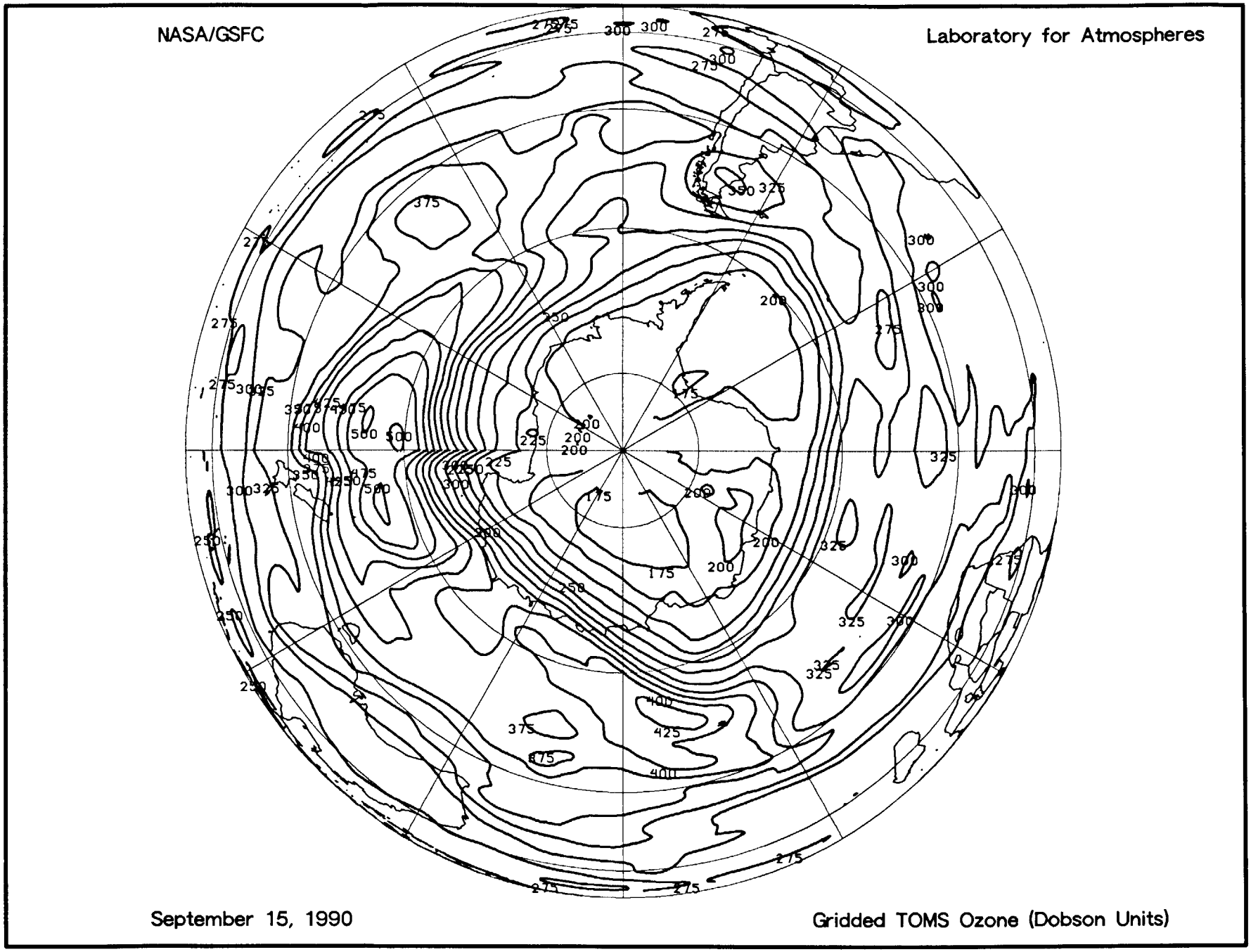

NASA/GSFC
Laboratory for Atmospheres
September 10, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 11, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 12, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 13, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 14, 1990
Gridded TOMS Ozone (Dobson Units)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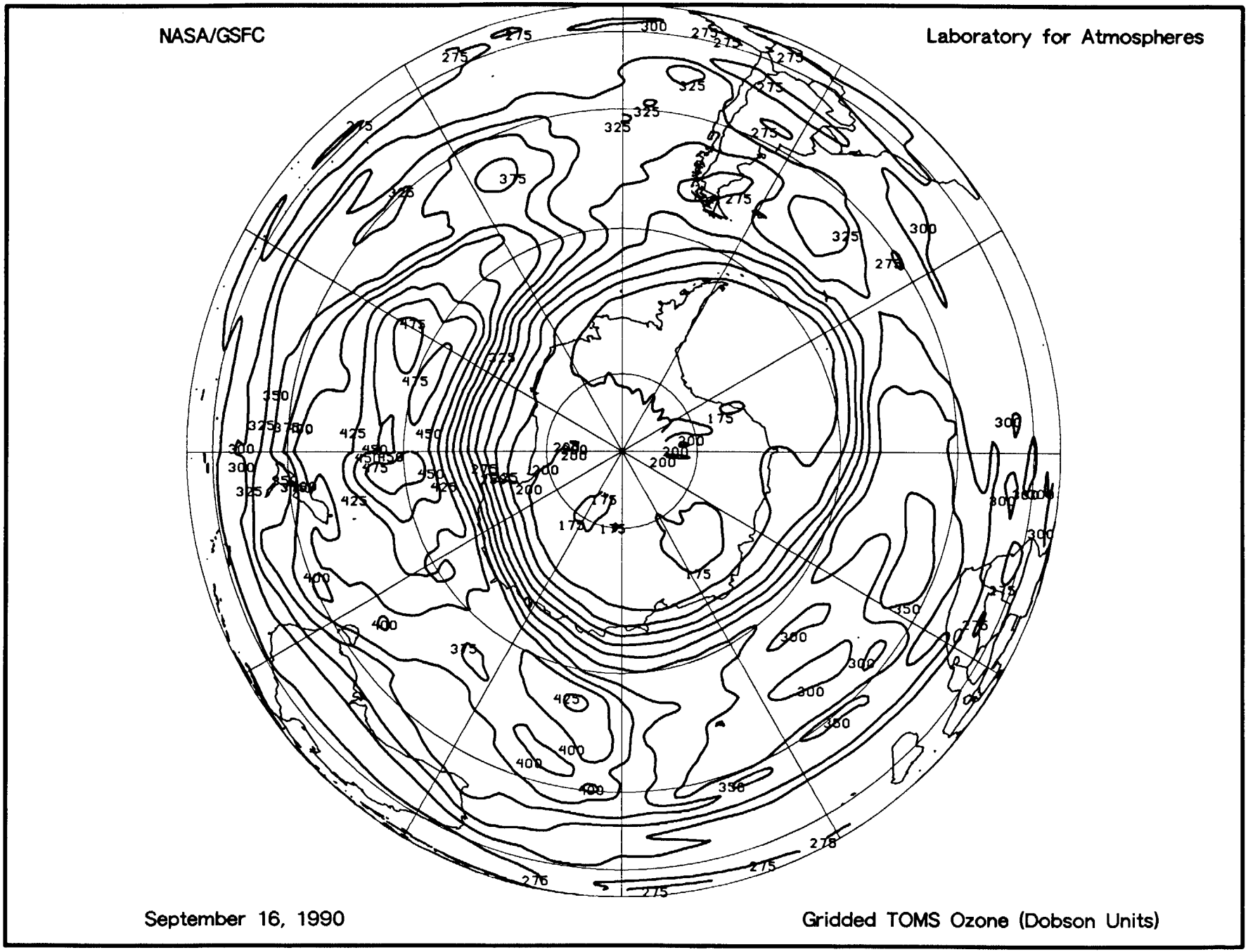
Laboratory for Atmospheres
September 15, 1990
Gridded TOMS Ozone (Dobson Units)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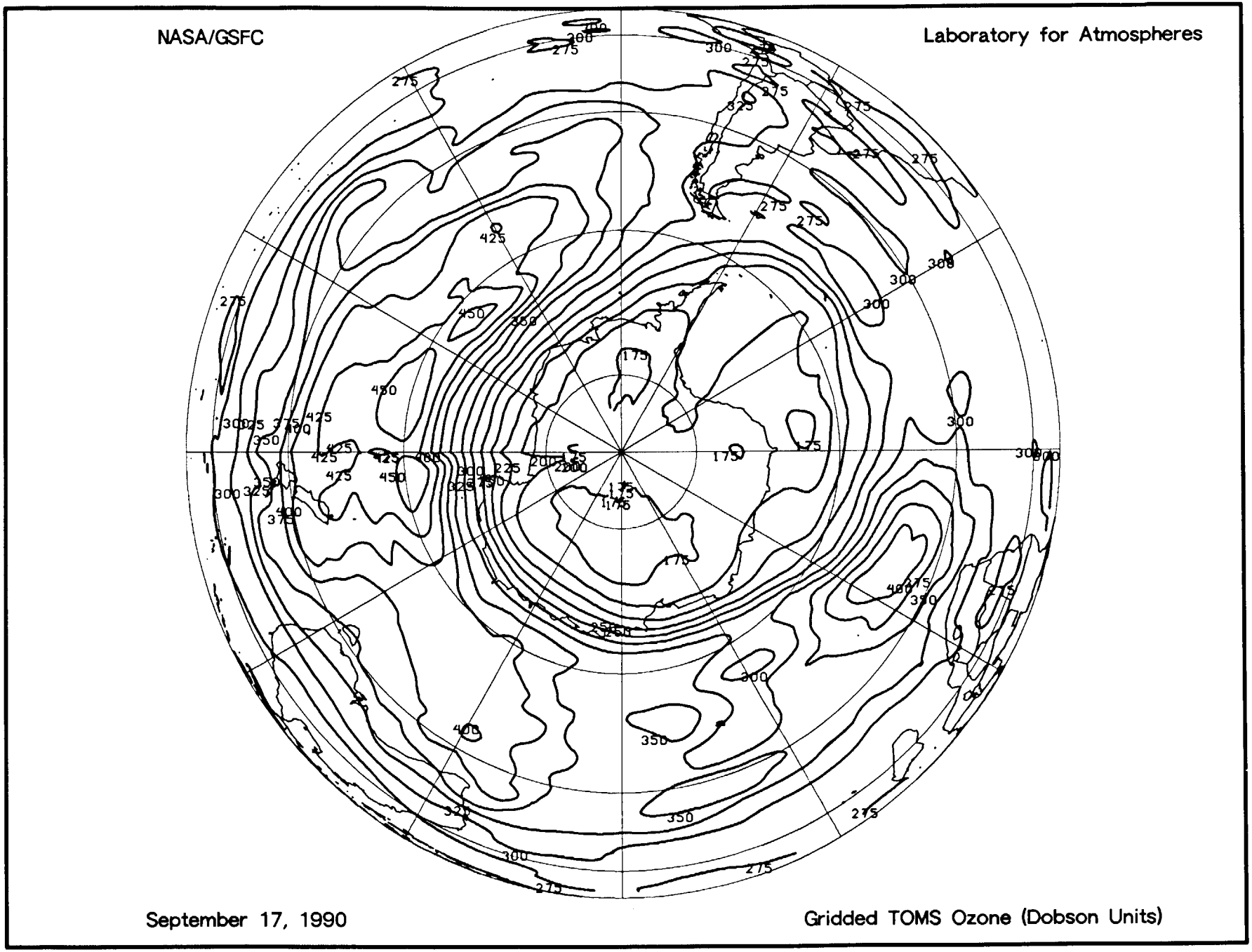
Laboratory for Atmospheres
September 16, 1990
Gridded TOMS Ozone (Dobson Units)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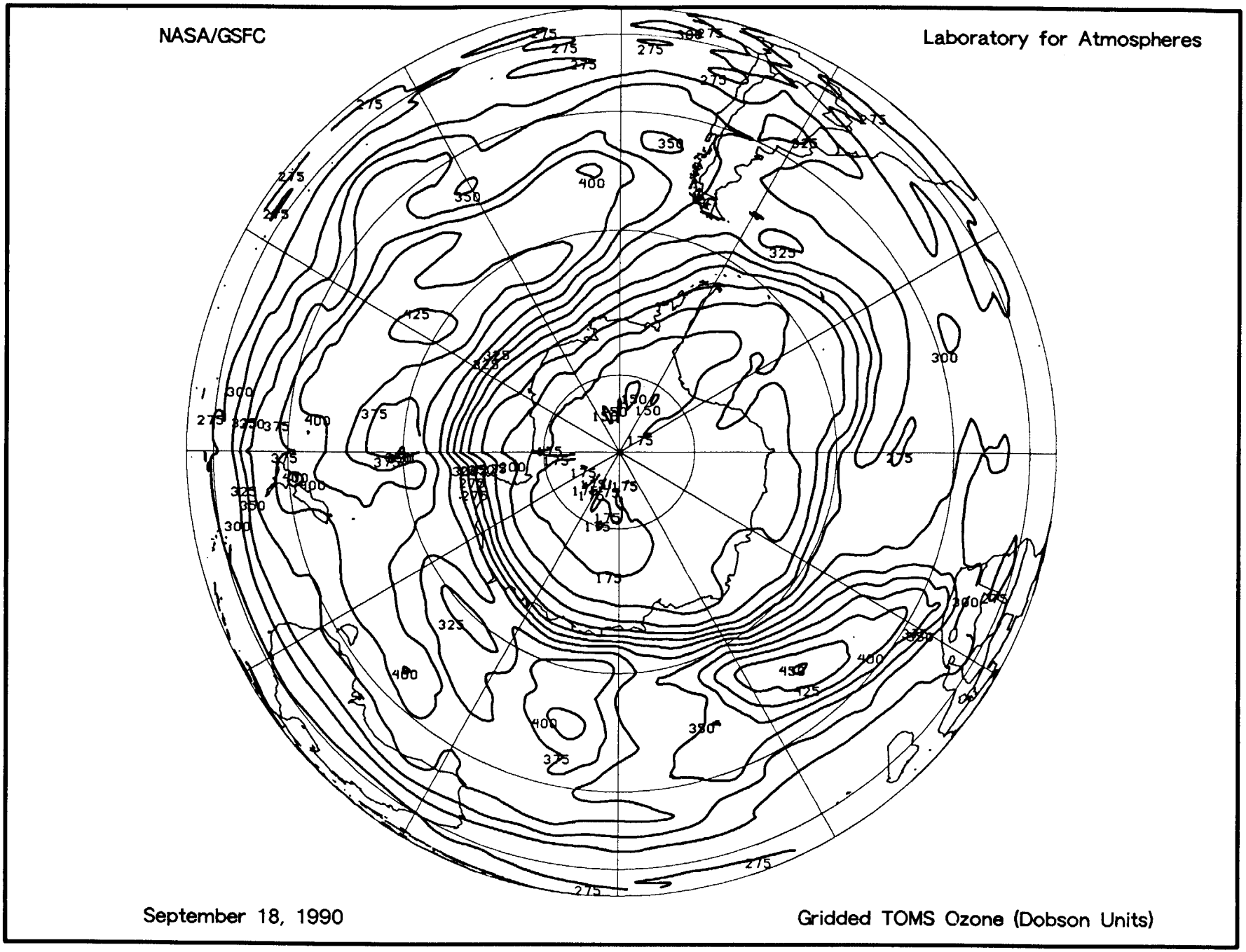
Laboratory for Atmospheres
September 17, 1990
Gridded TOMS Ozone (Dobson Units)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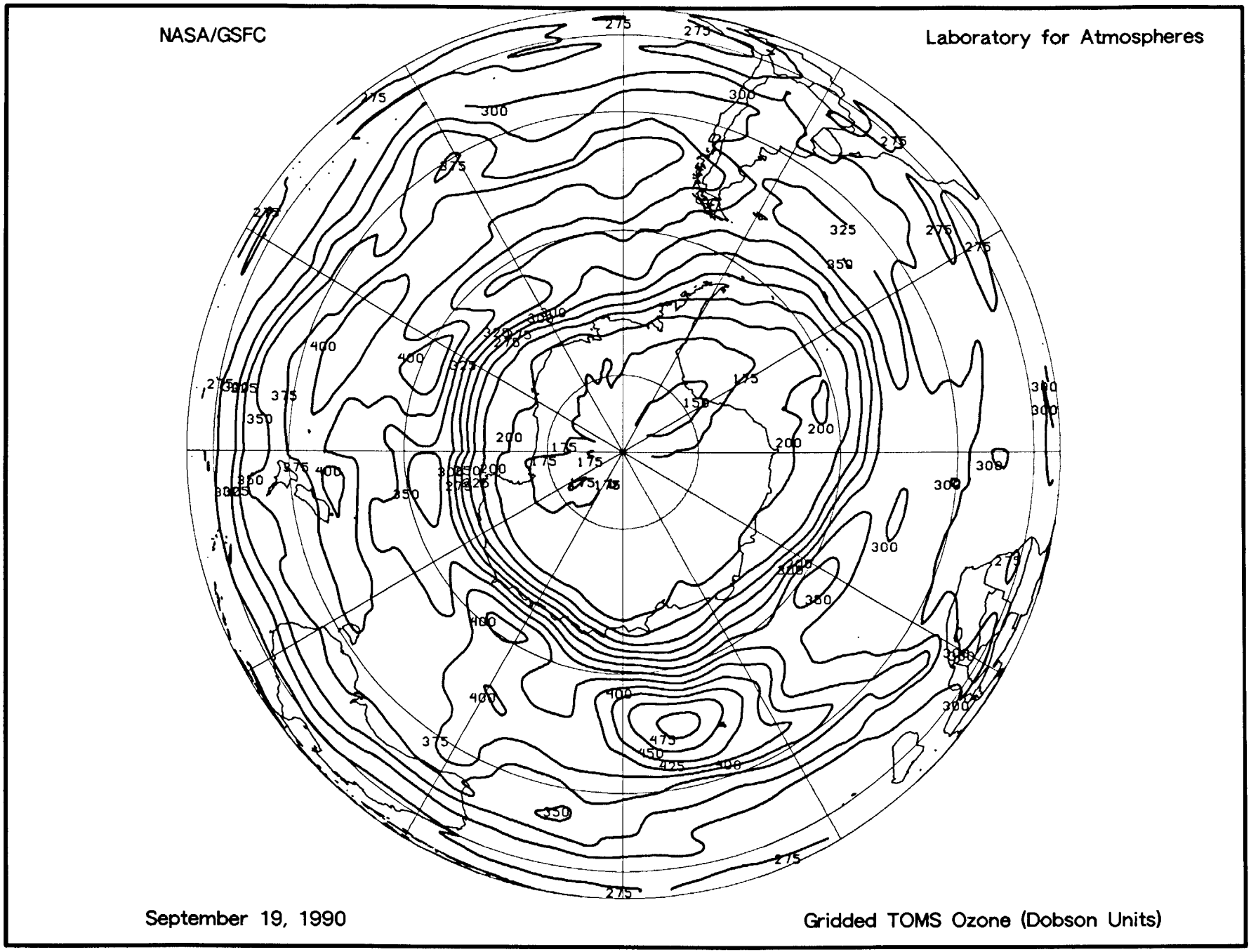
Laboratory for Atmospheres
September 18, 1990
Gridded TOMS Ozone (Dobson Units)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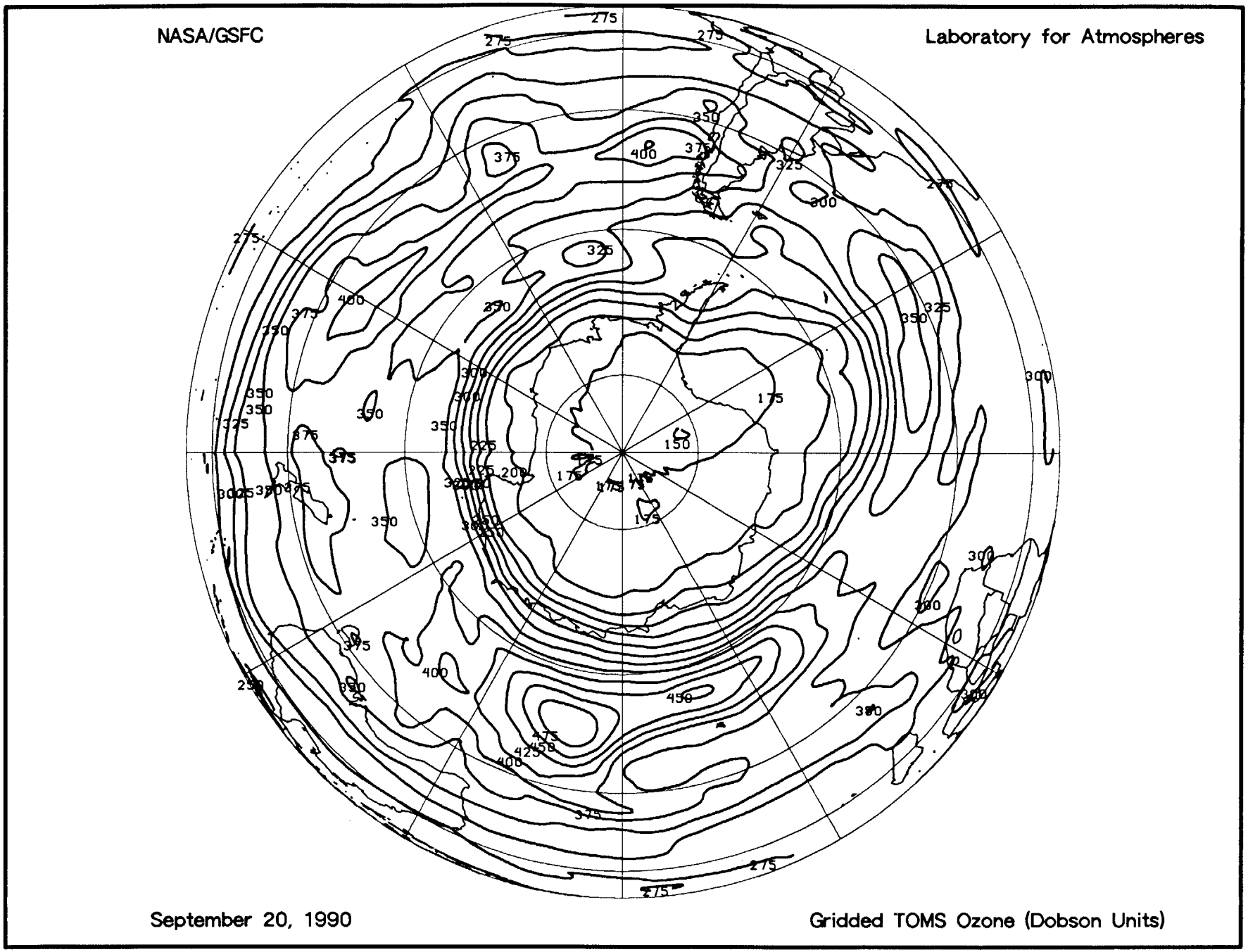
Laboratory for Atmospheres
September 19, 1990
Gridded TOMS Ozone (Dobson Units)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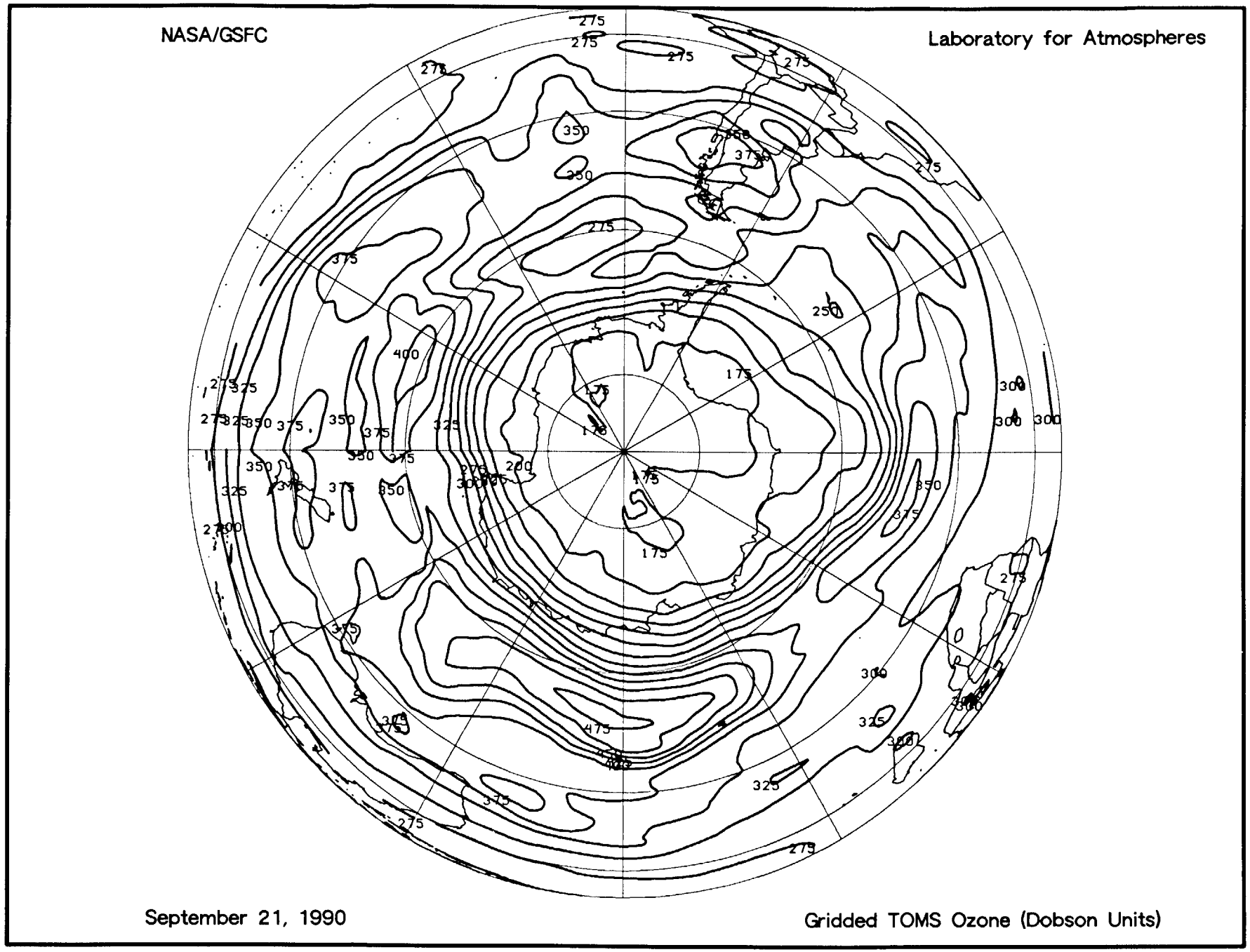
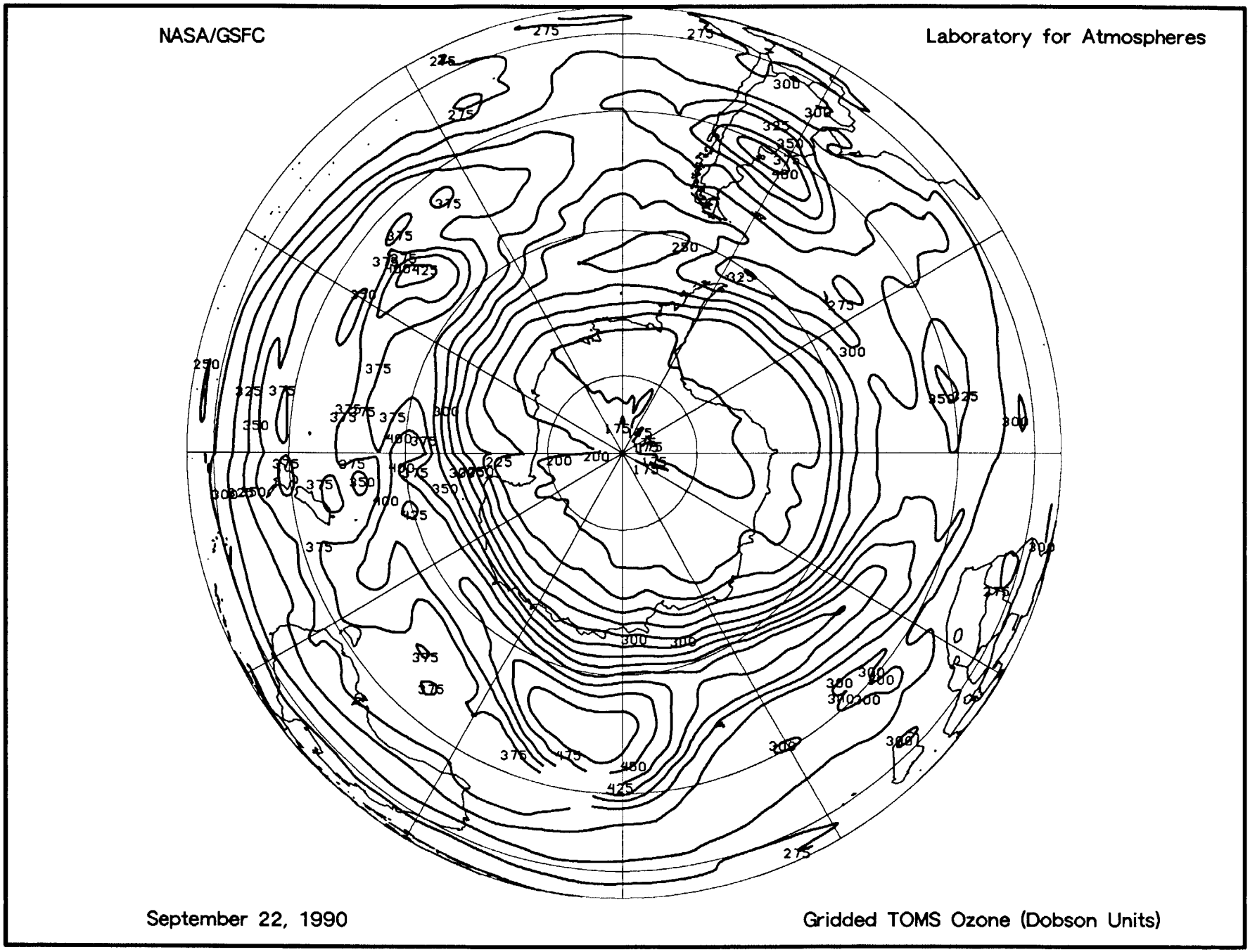
Laboratory for Atmospheres
September 20, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 21, 1990
Gridded TOMS Ozone (Dobson Units)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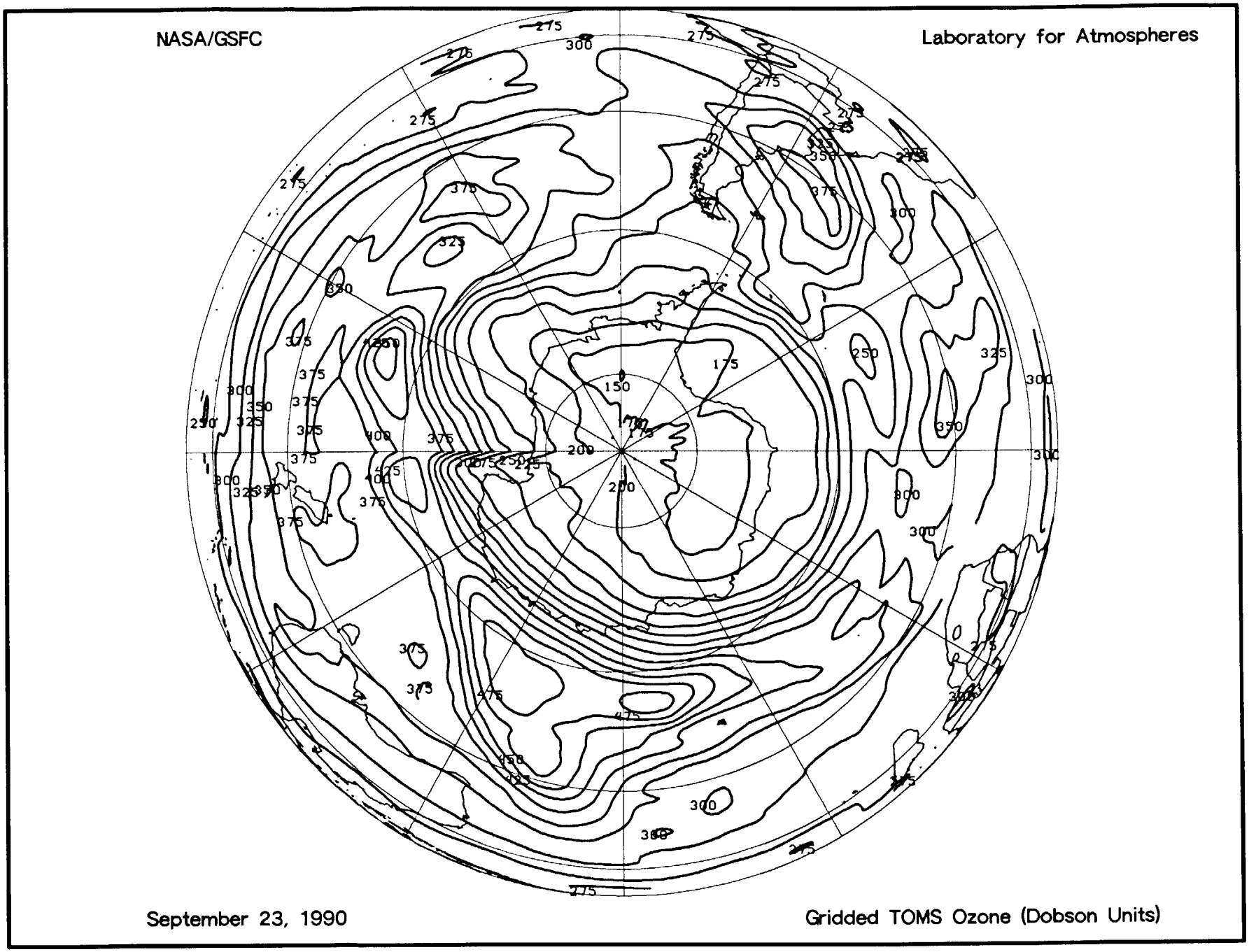
Laboratory for Atmospheres
September 22, 1990
Gridded TOMS Ozone (Dobson Units)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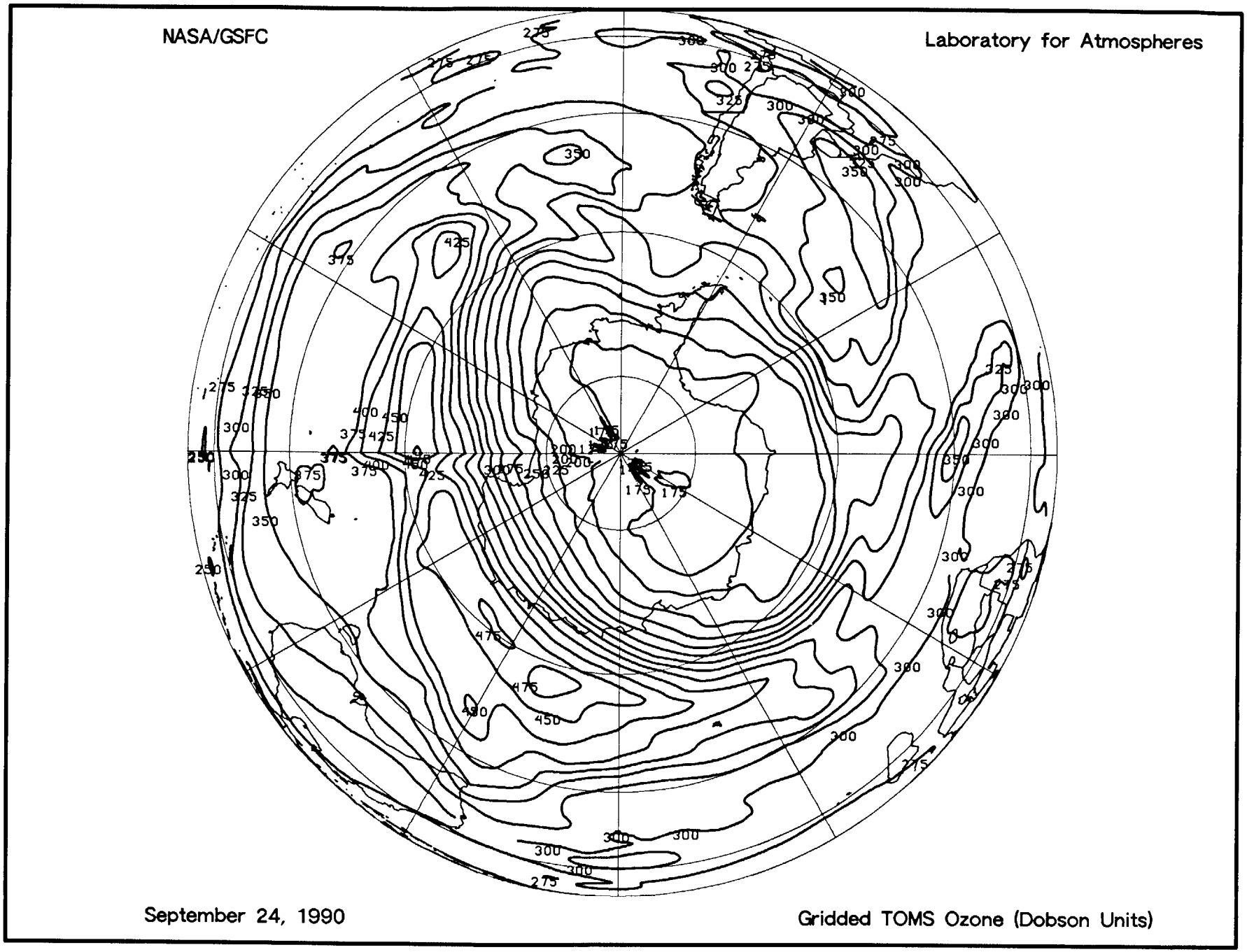
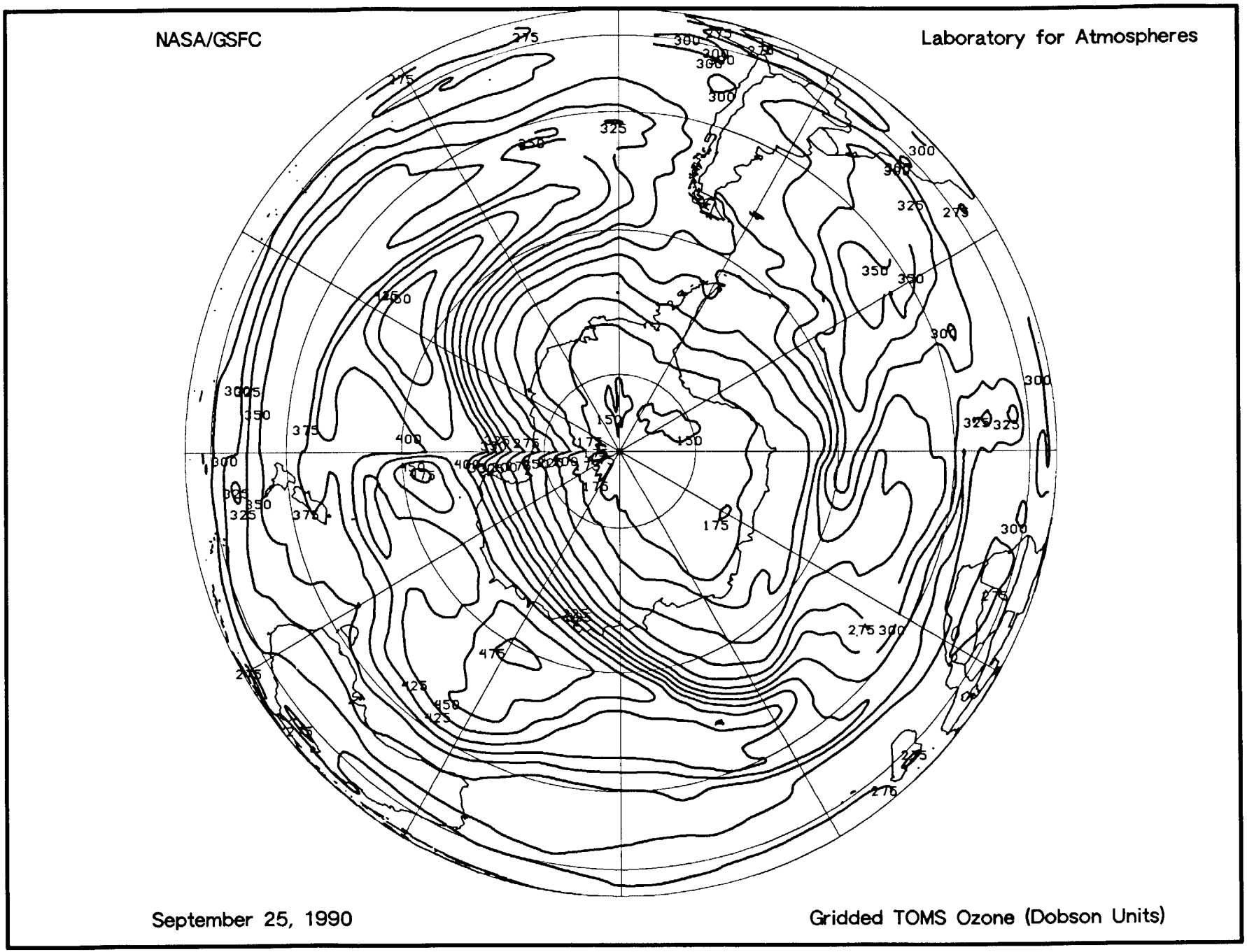
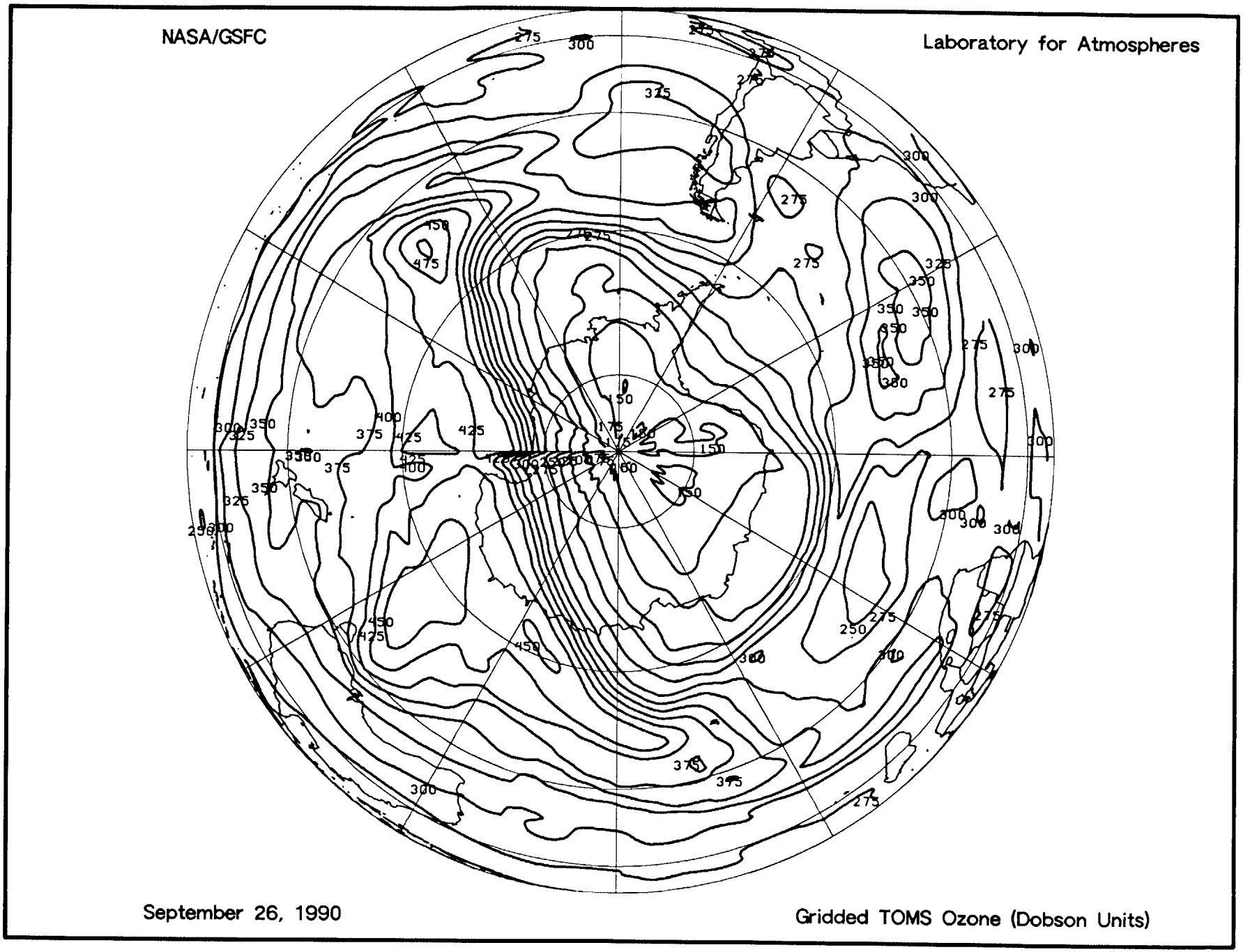
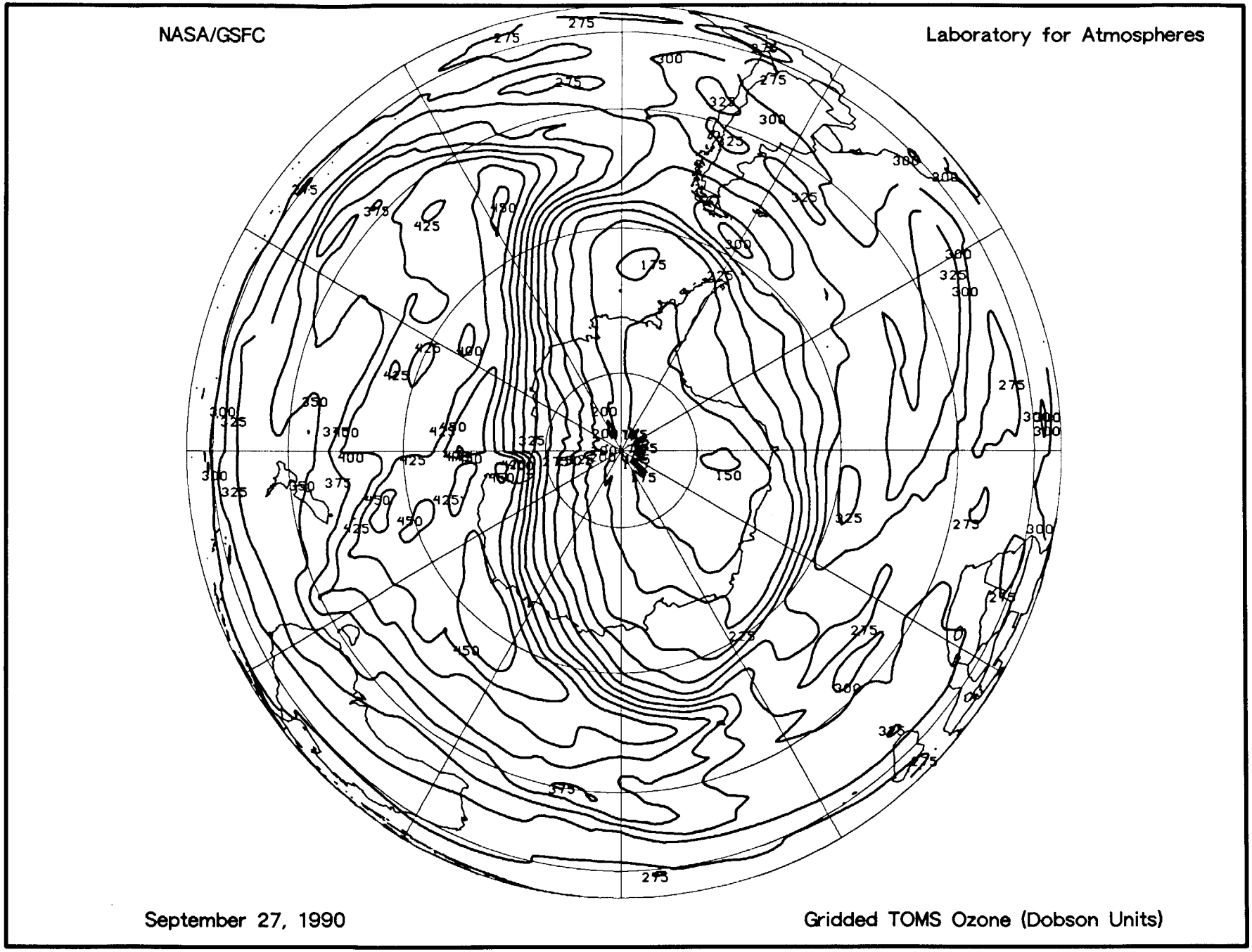
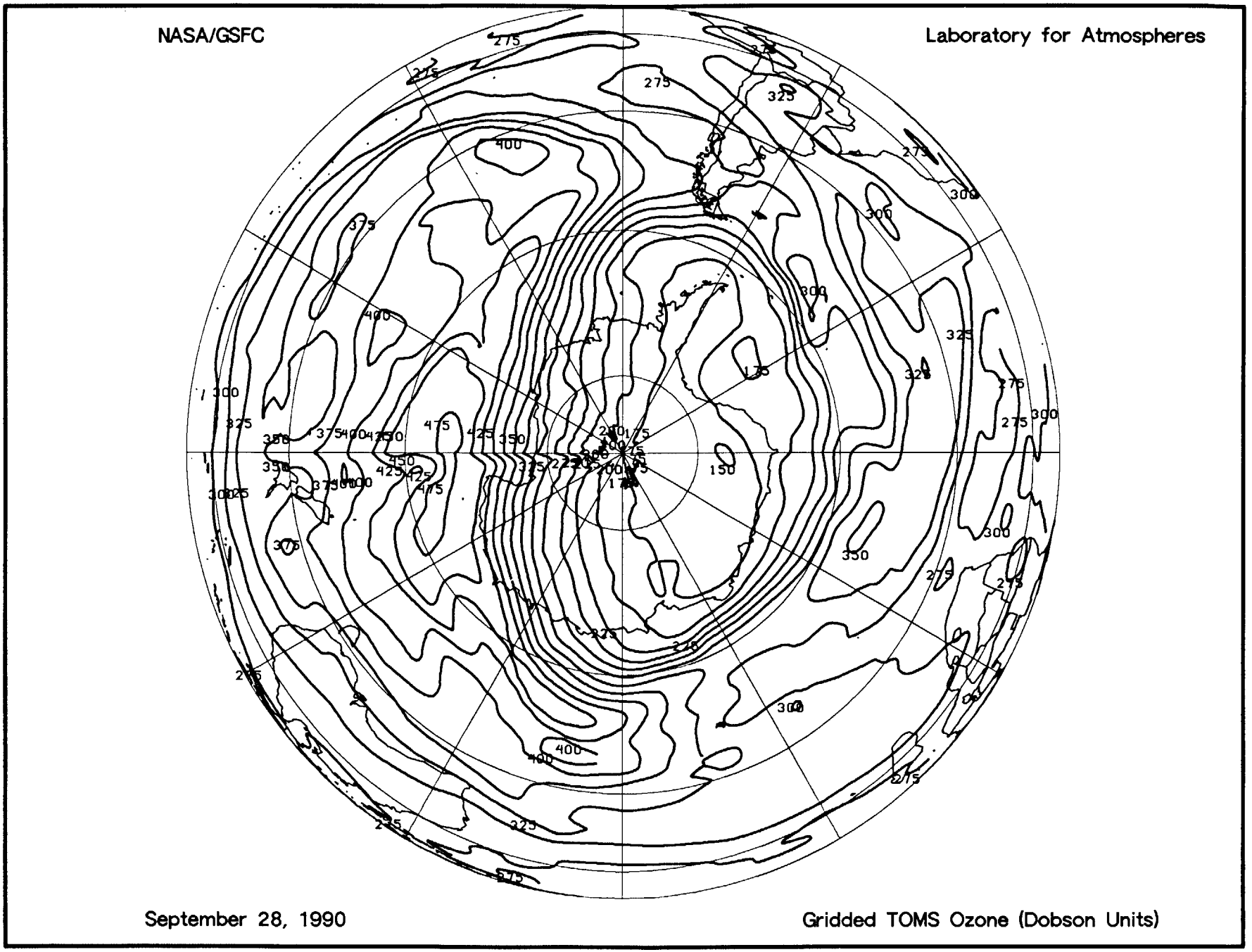
Laboratory for Atmospheres
September 23, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 24, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 25, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 26, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 27, 1990
Gridded TOMS Ozone (Dobson Units)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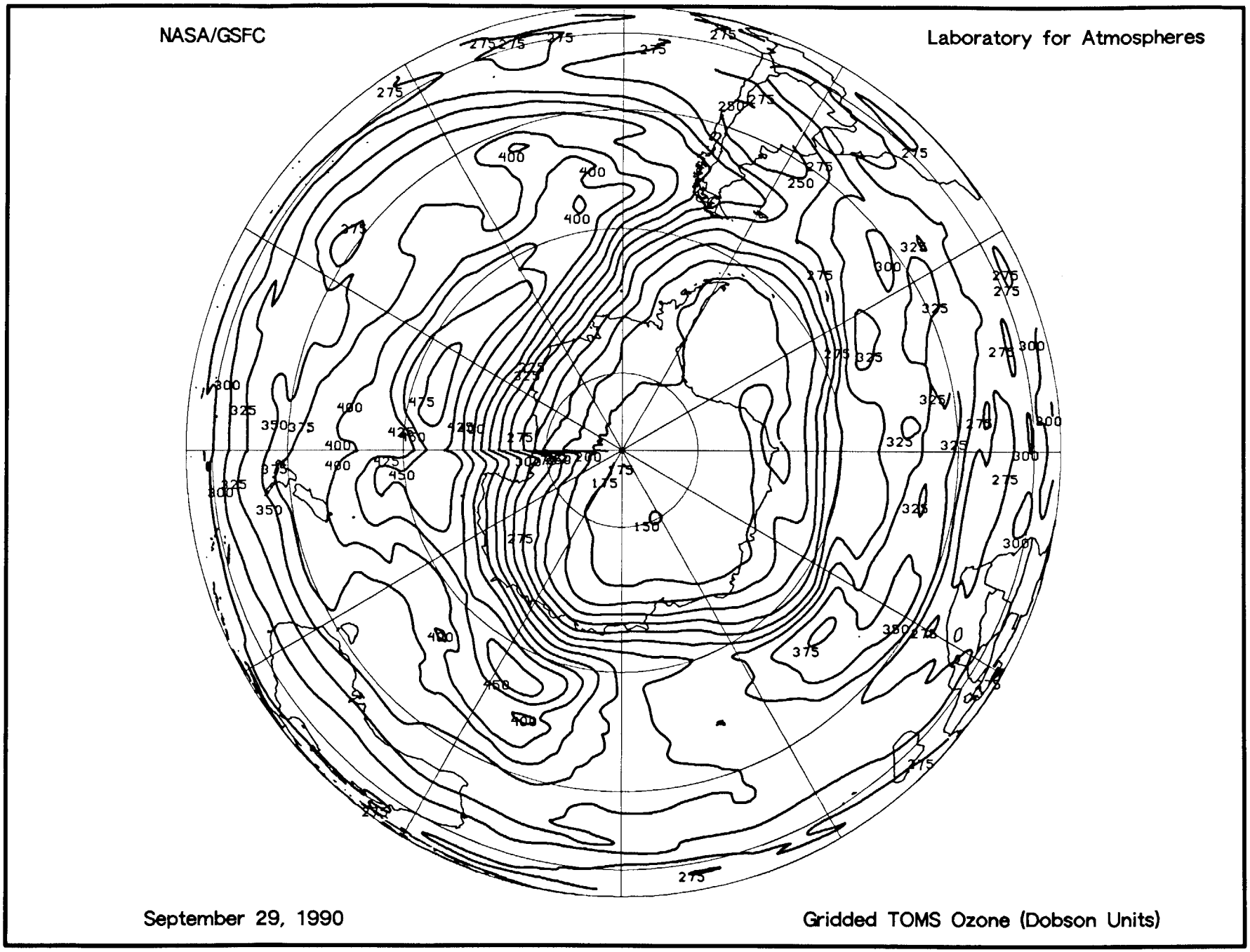
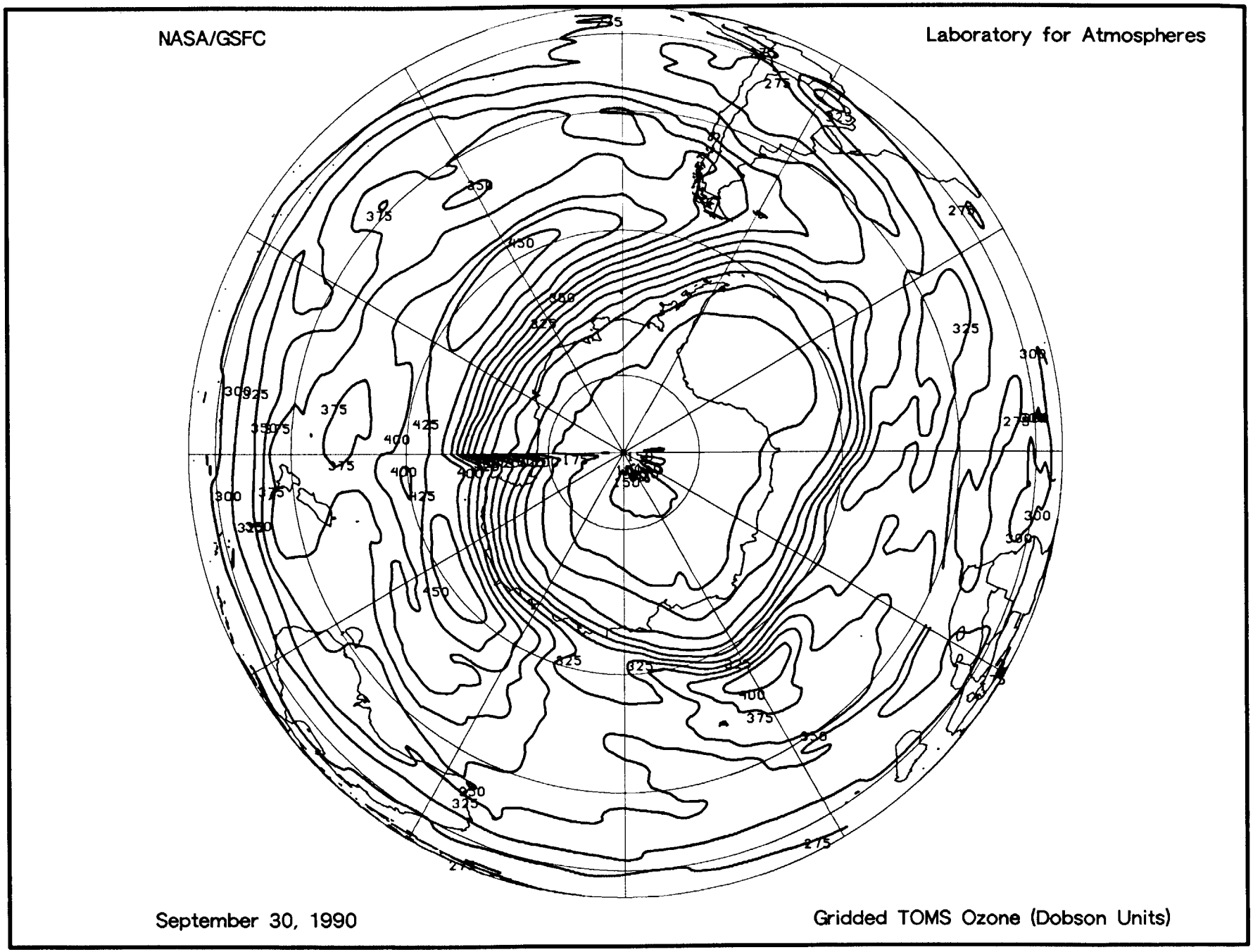
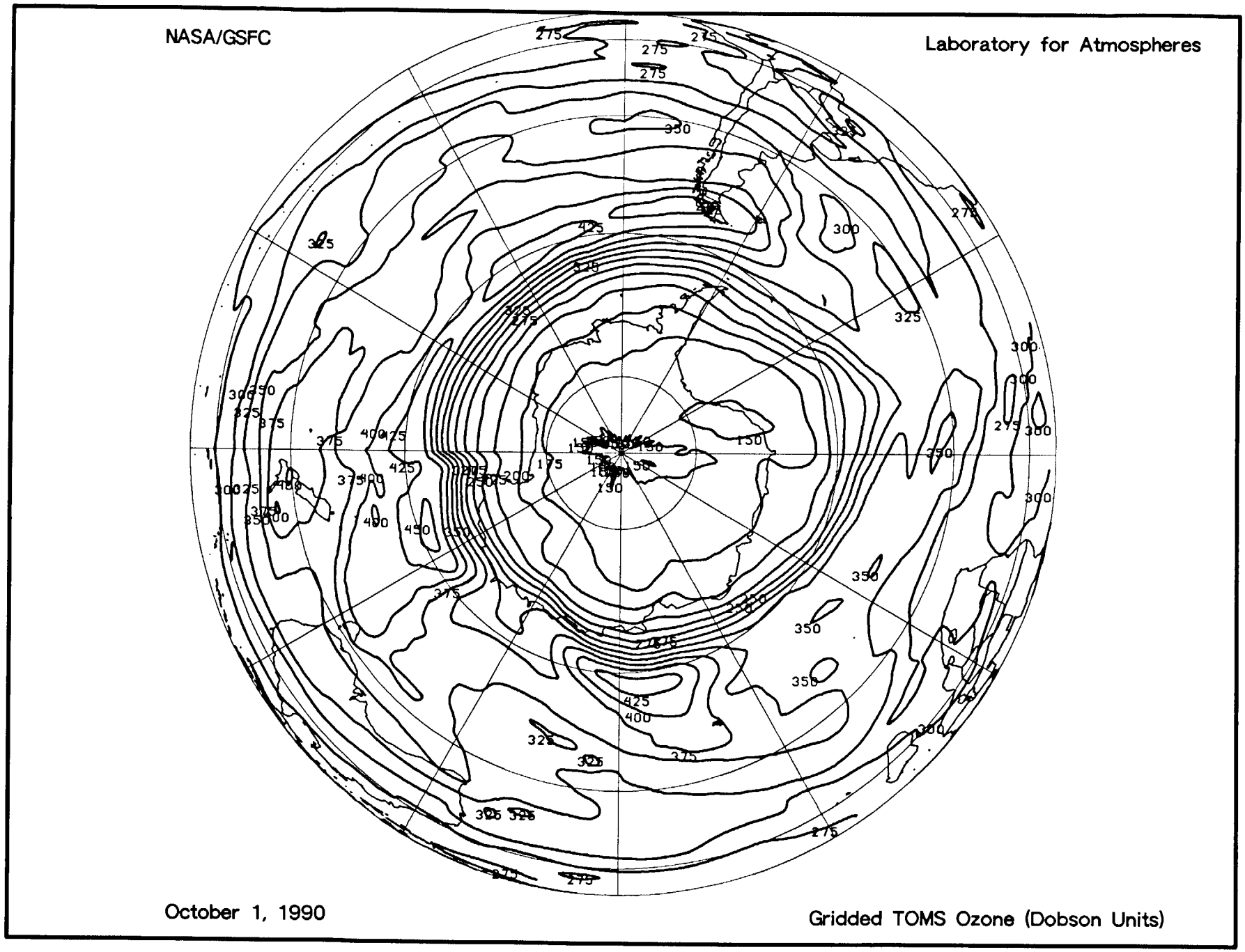
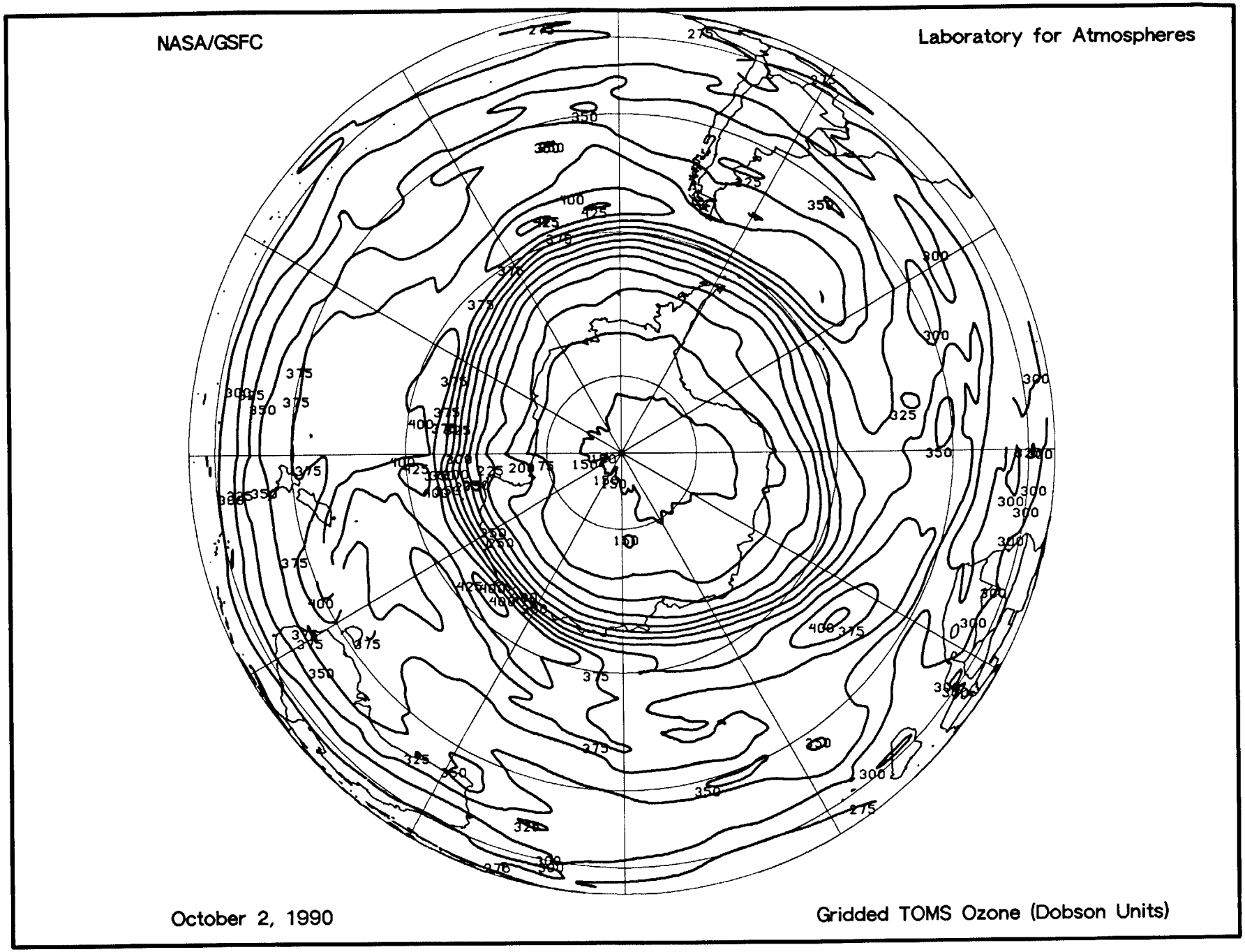
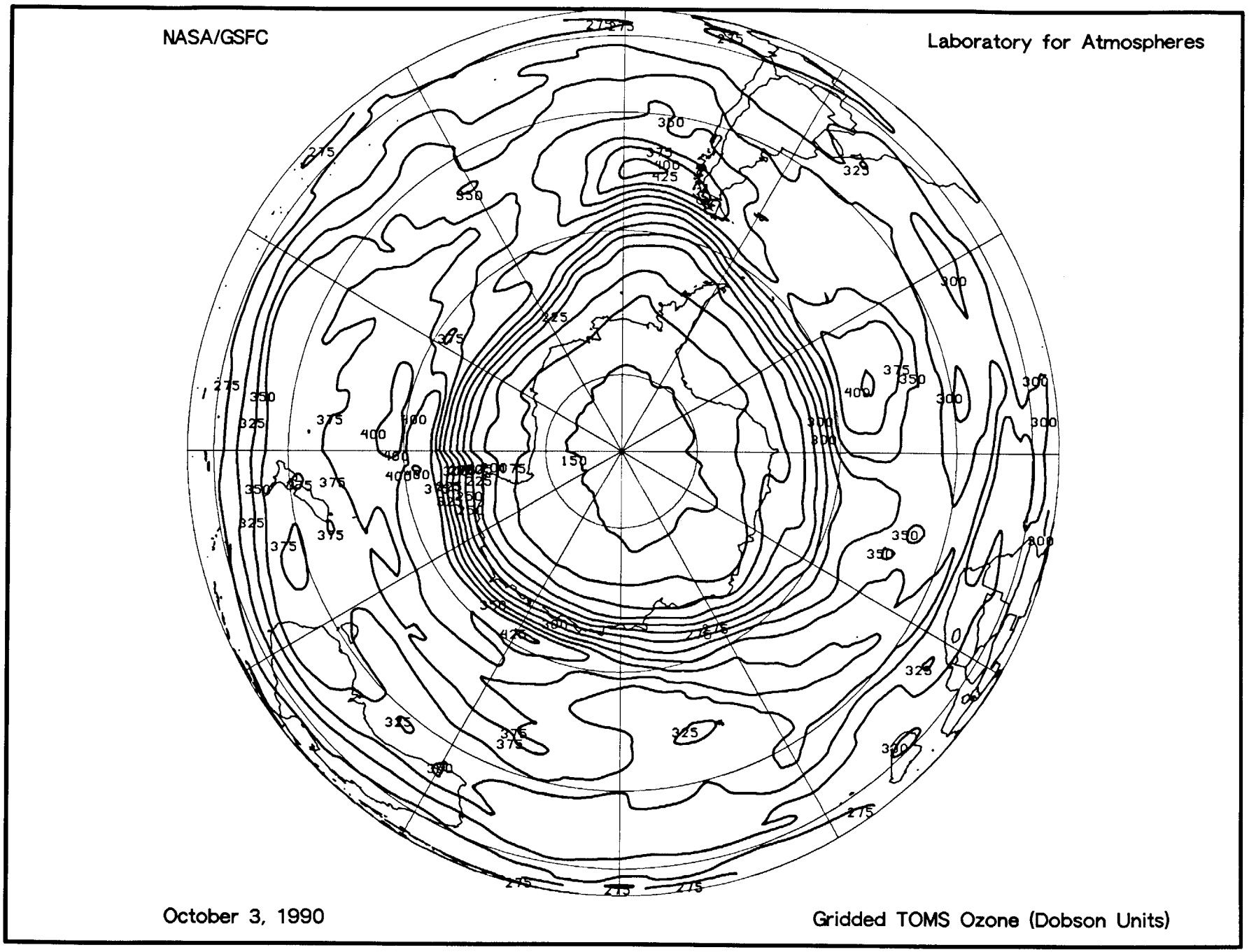
Laboratory for Atmospheres
September 28, 1990
Gridded TOMS Ozone (Dobson Units)

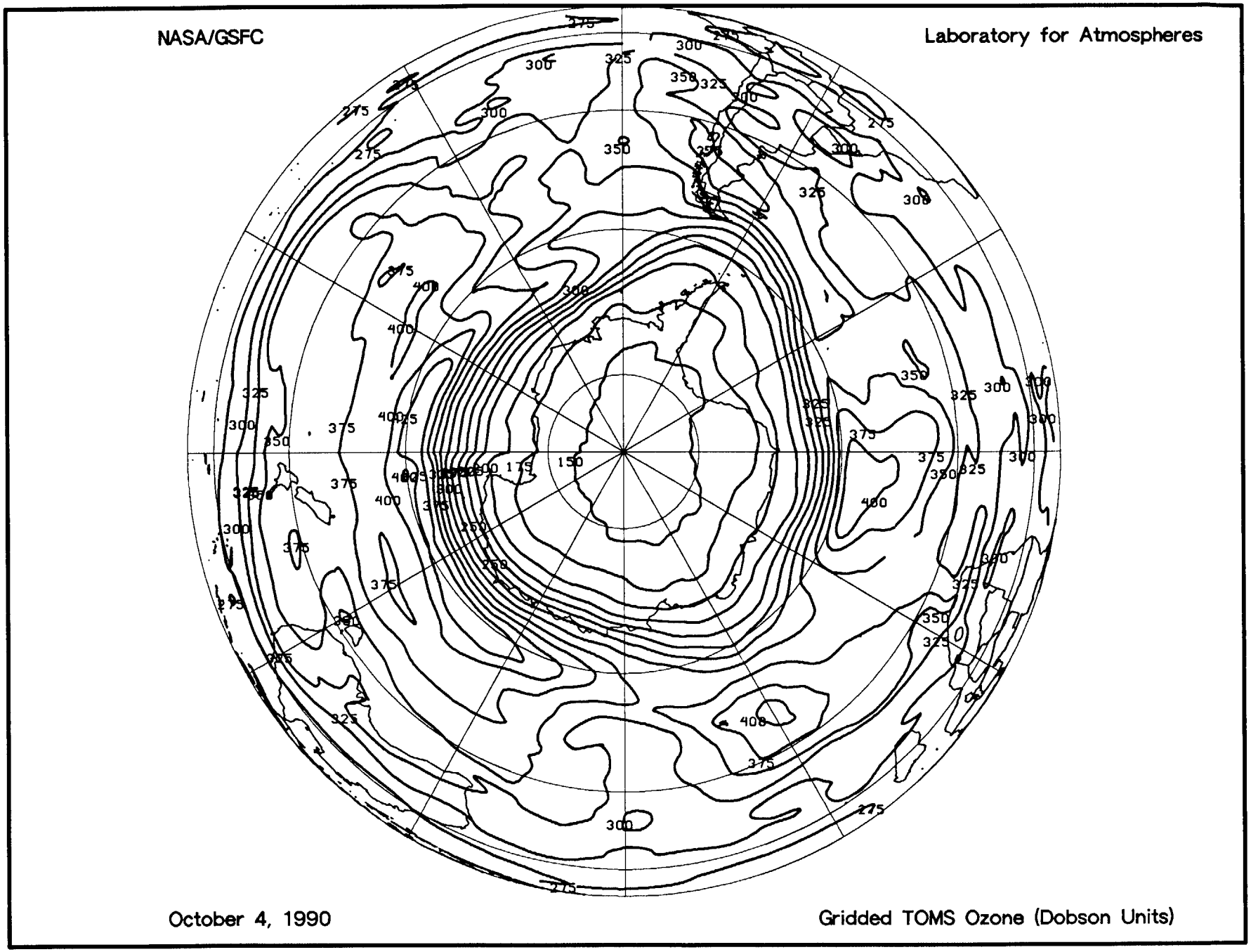

NASA/GSFC
Laboratory for Atmospheres
September 29, 1990
Gridded TOMS Ozone (Dobson Units)

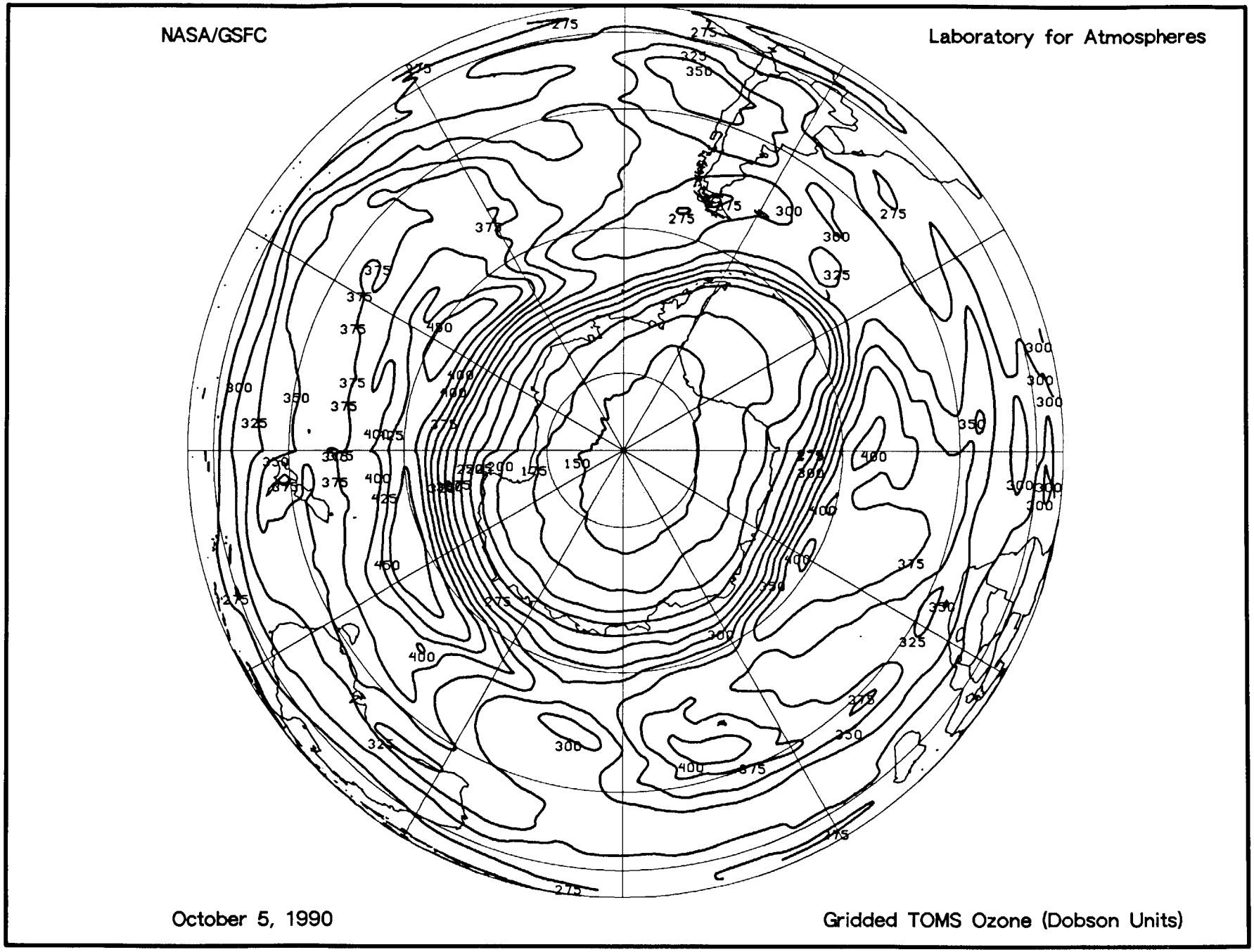

NASA/GSFC
Laboratory for Atmospheres
September 30, 1990
Gridded TOMS Ozone (Dobson Units)

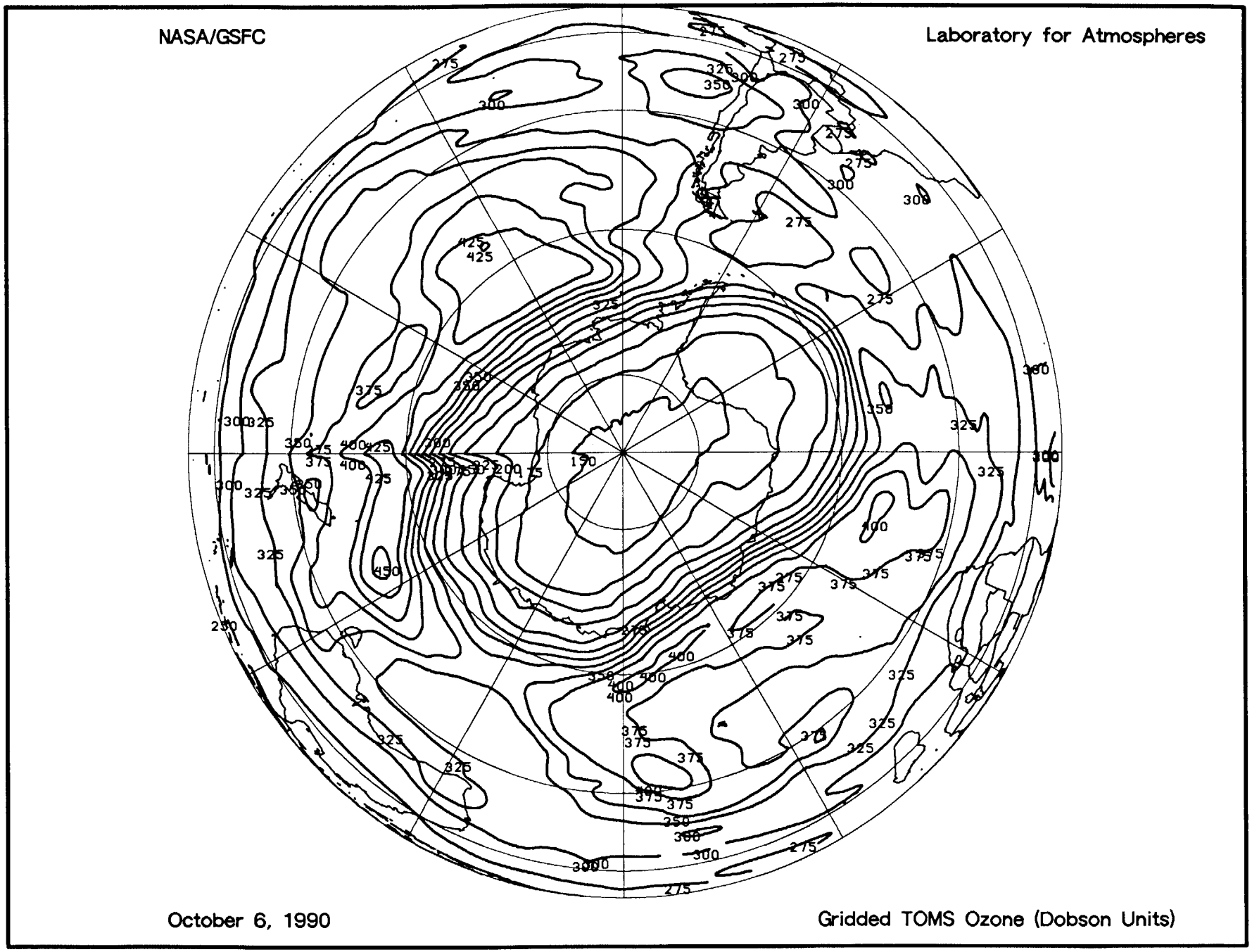

NASA/GSFC
Laboratory for Atmospheres
October 1, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 2, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 3, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 4, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 5, 1990
Gridded TOMS Ozone (Dobson Units)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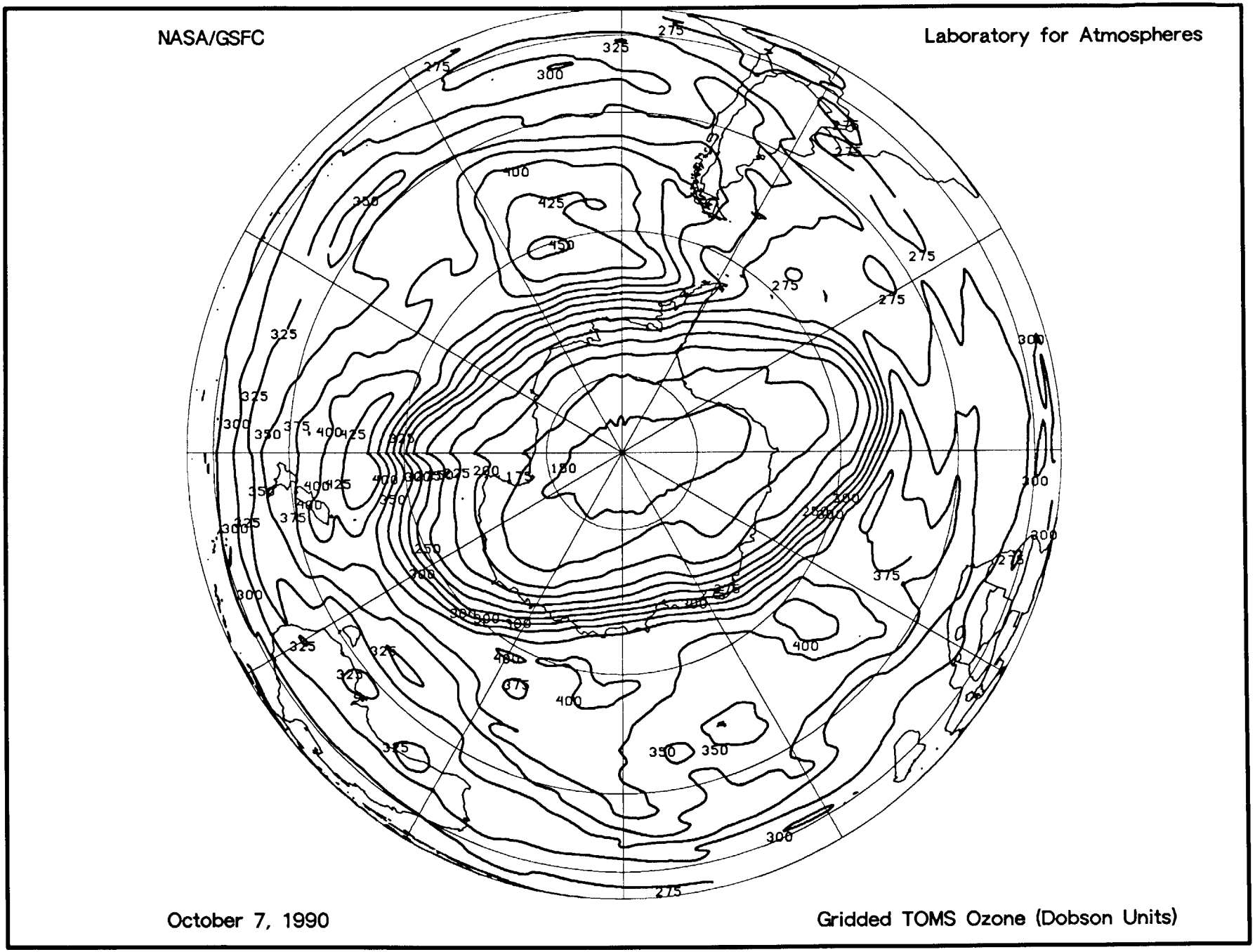
Laboratory for Atmospheres
October 6, 1990
Gridded TOMS Ozone (Dobson Units)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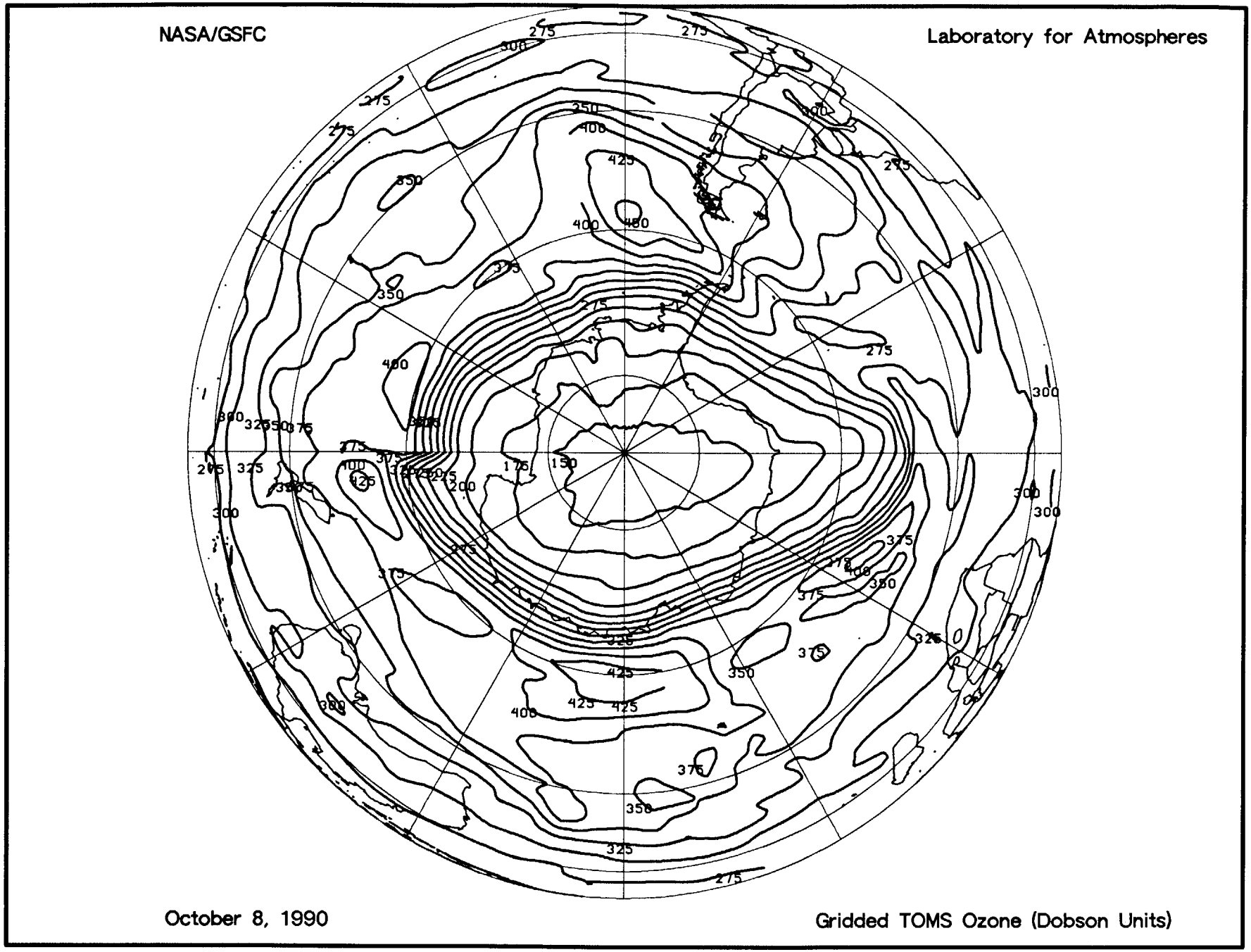
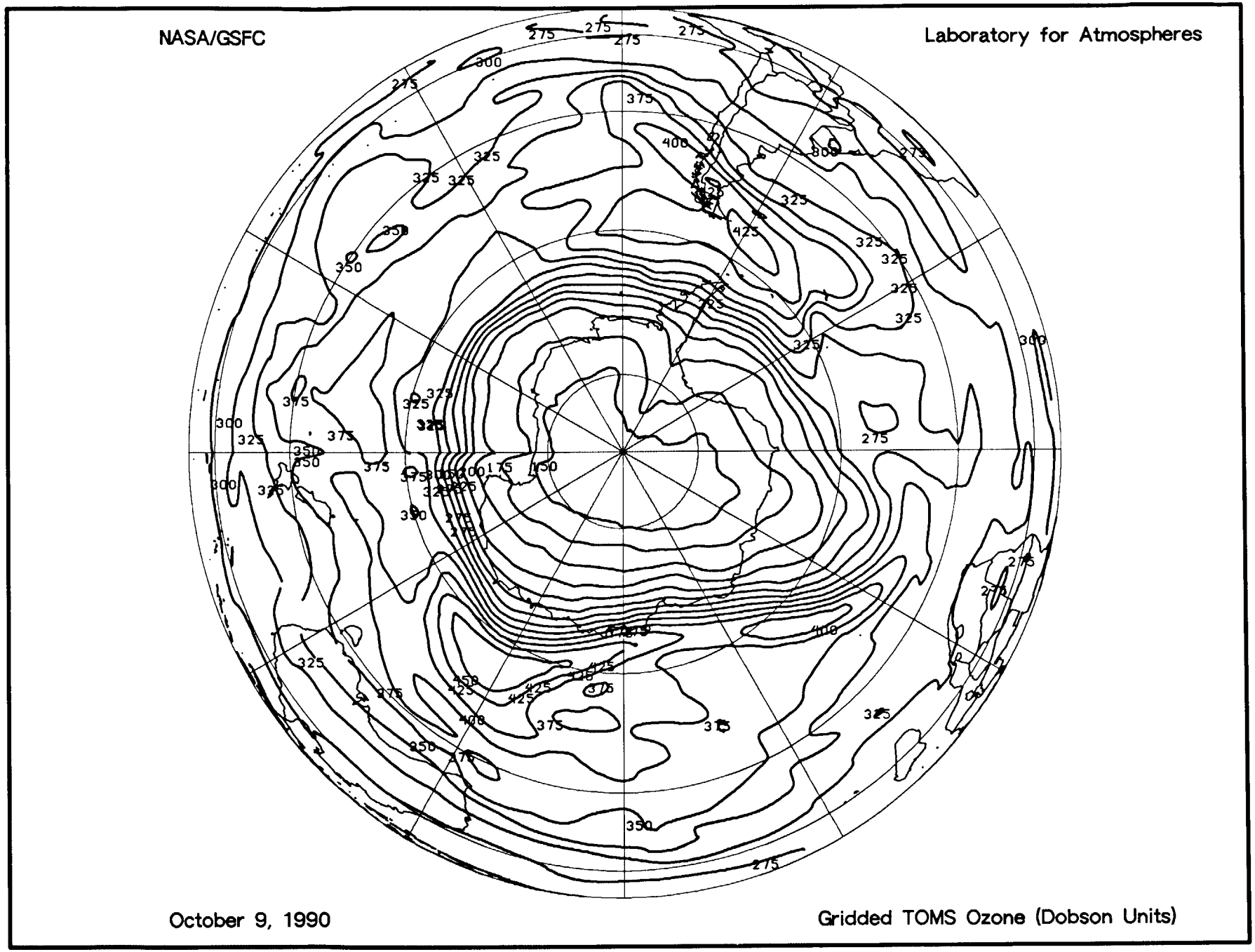
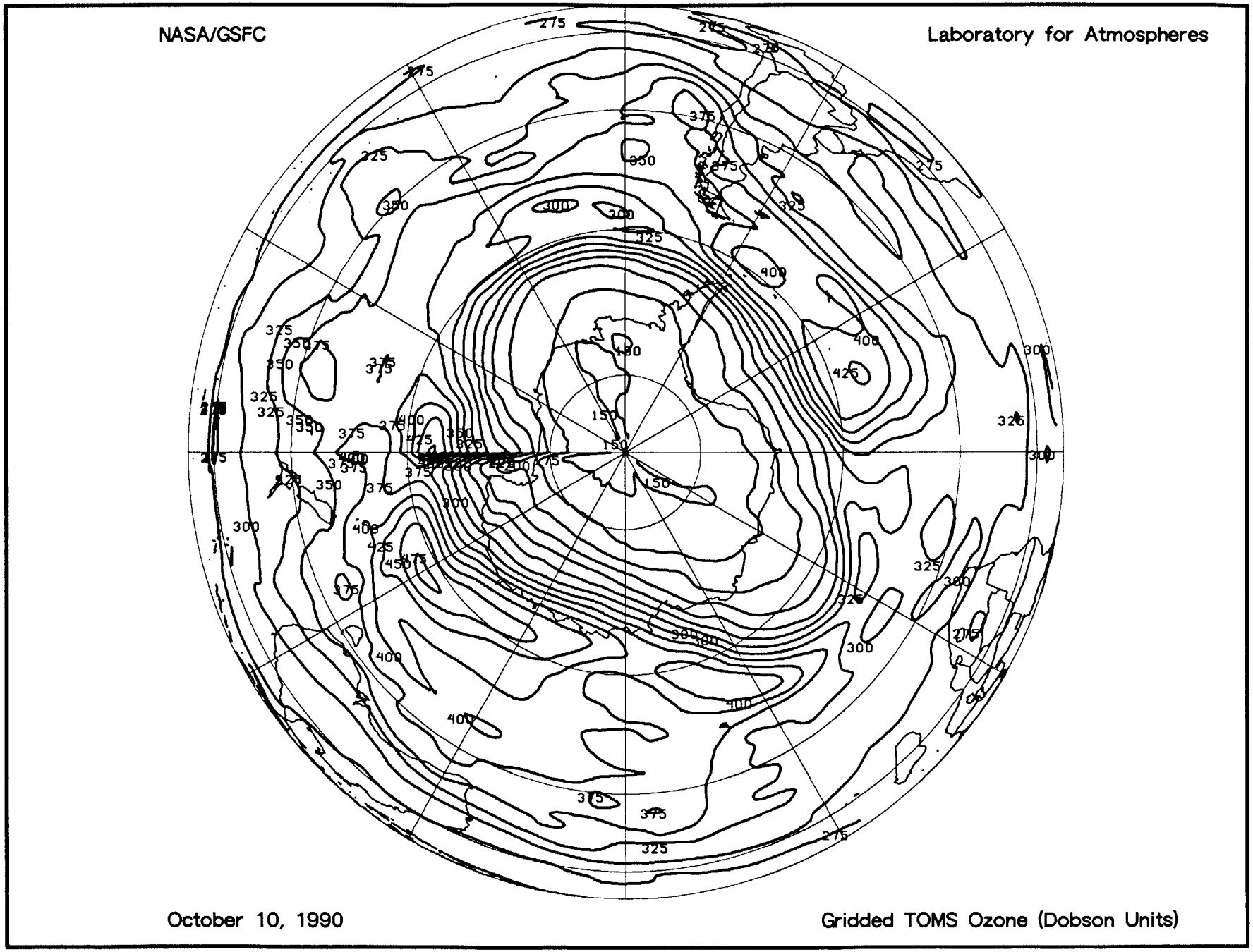
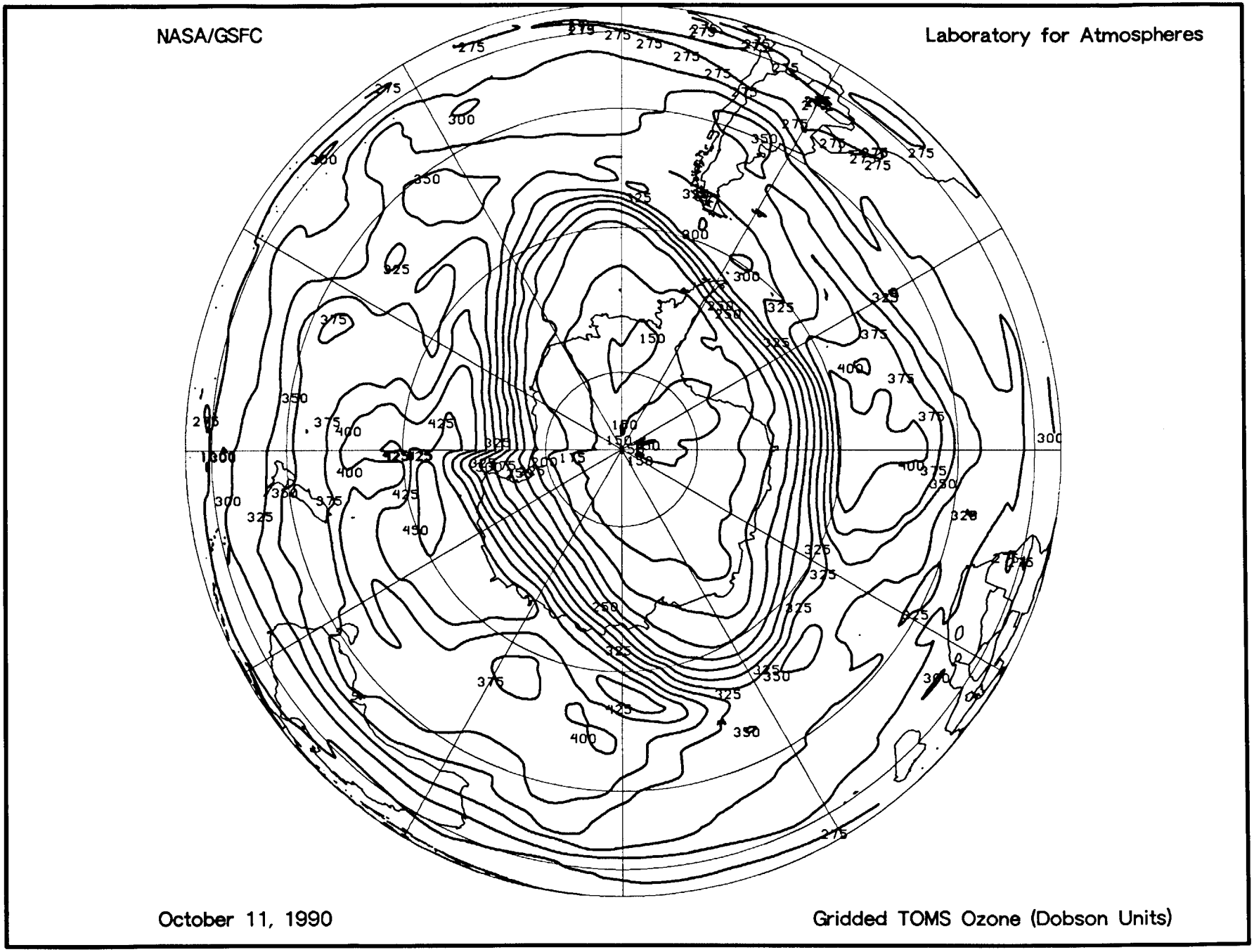
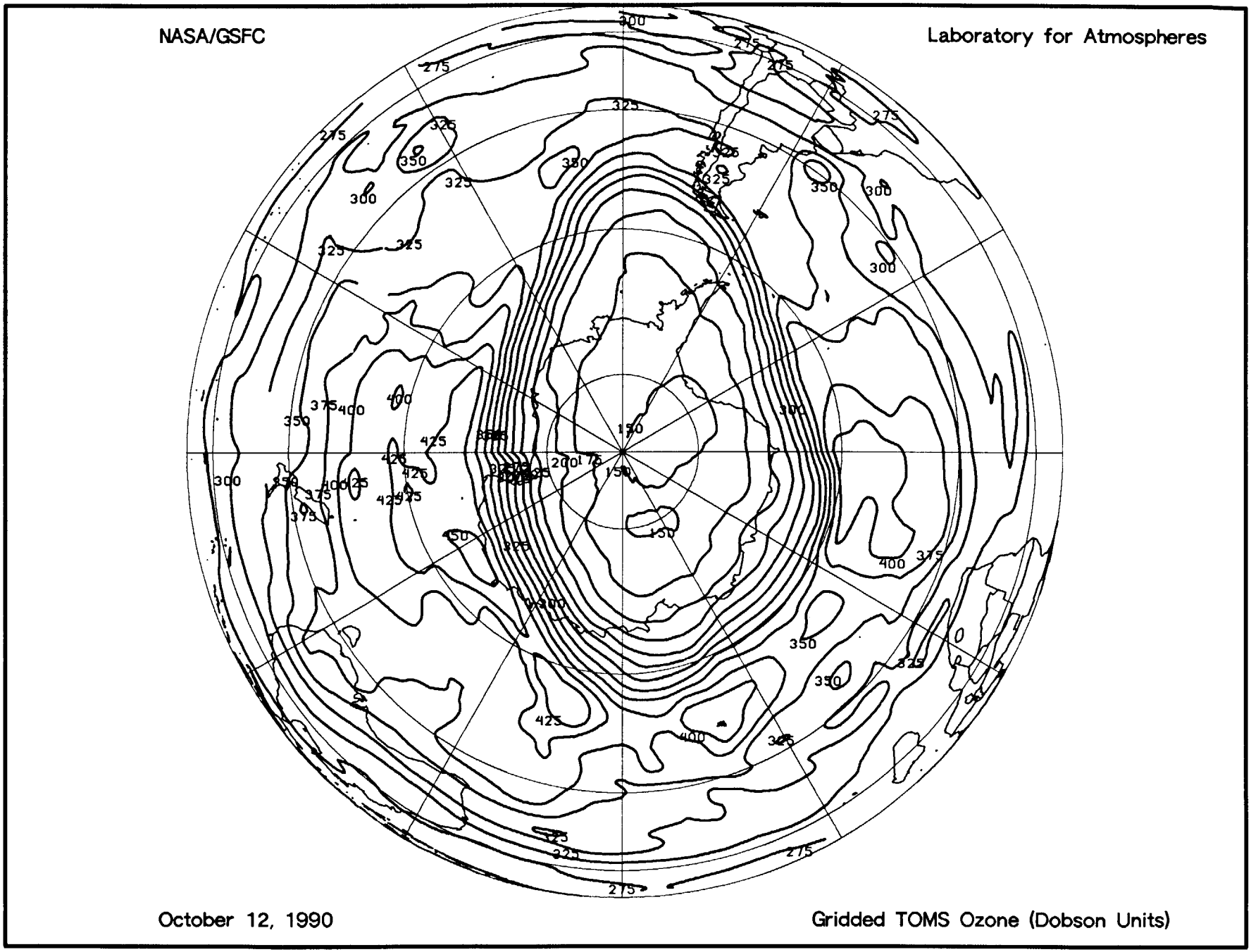
Laboratory for Atmospheres
October 7, 1990
Gridded TOMS Ozone (Dobson Units)

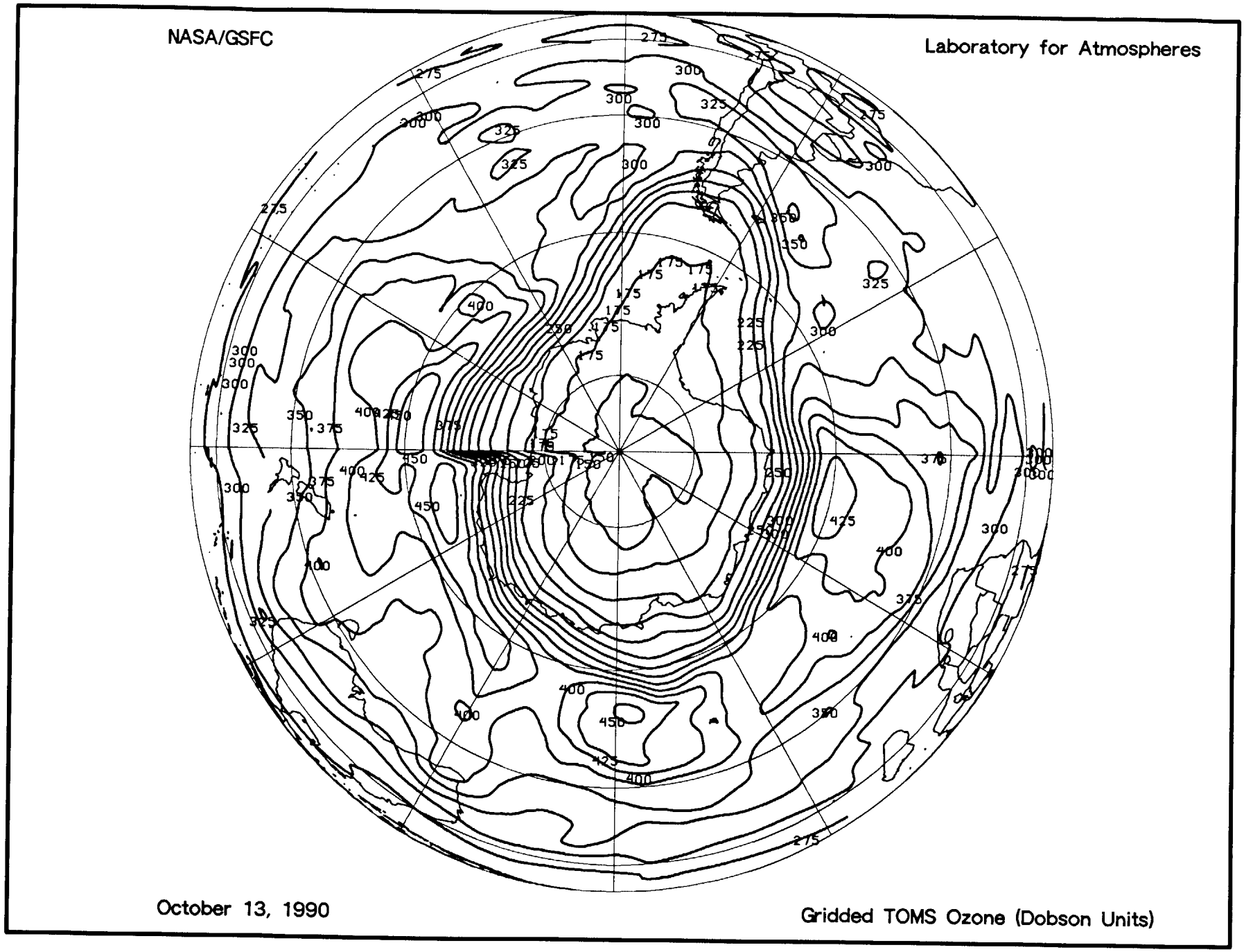

NASA/GSFC
Laboratory for Atmospheres
October 8, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 9, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 10, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 11, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 12, 1990
Gridded TOMS Ozone (Dobson Units)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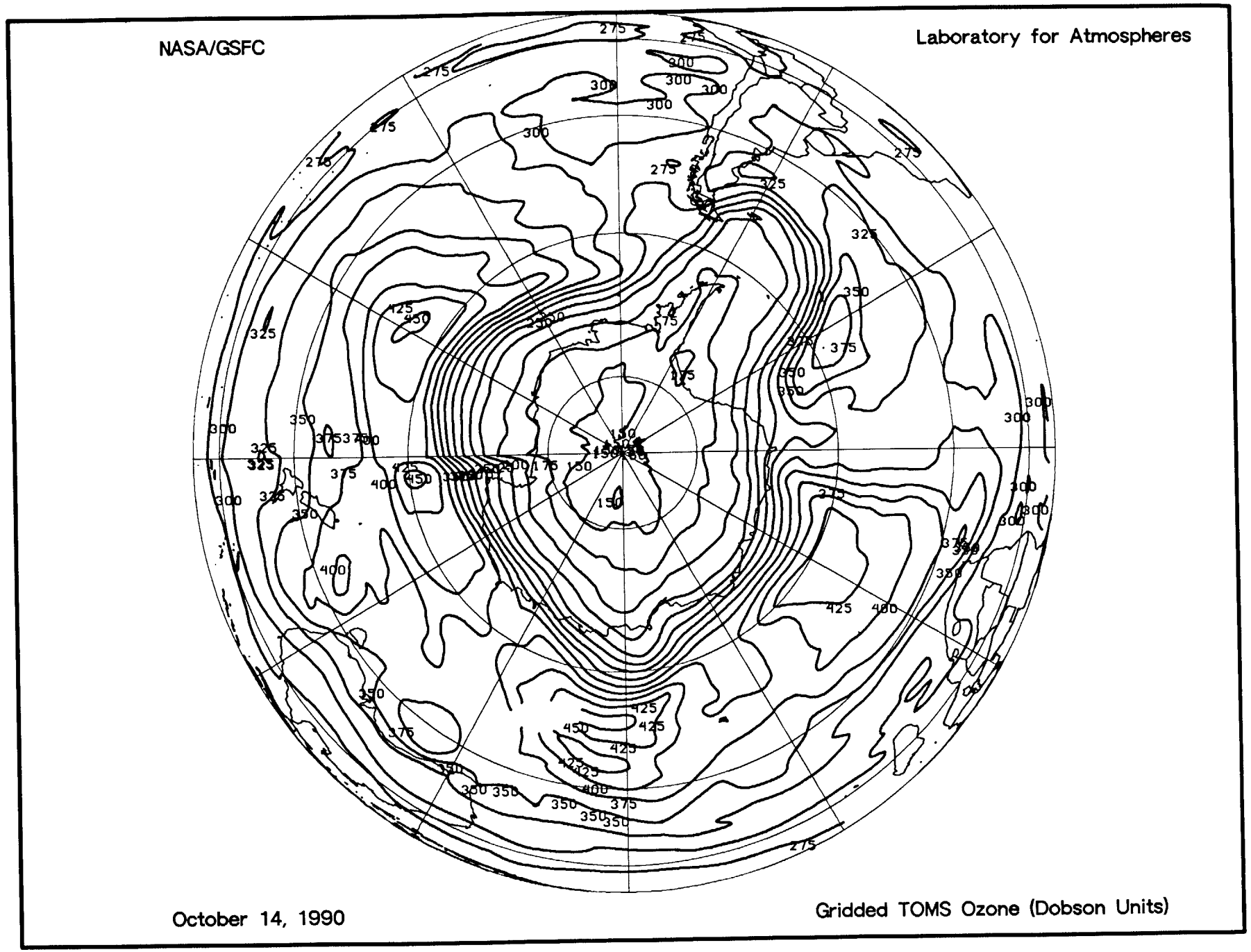
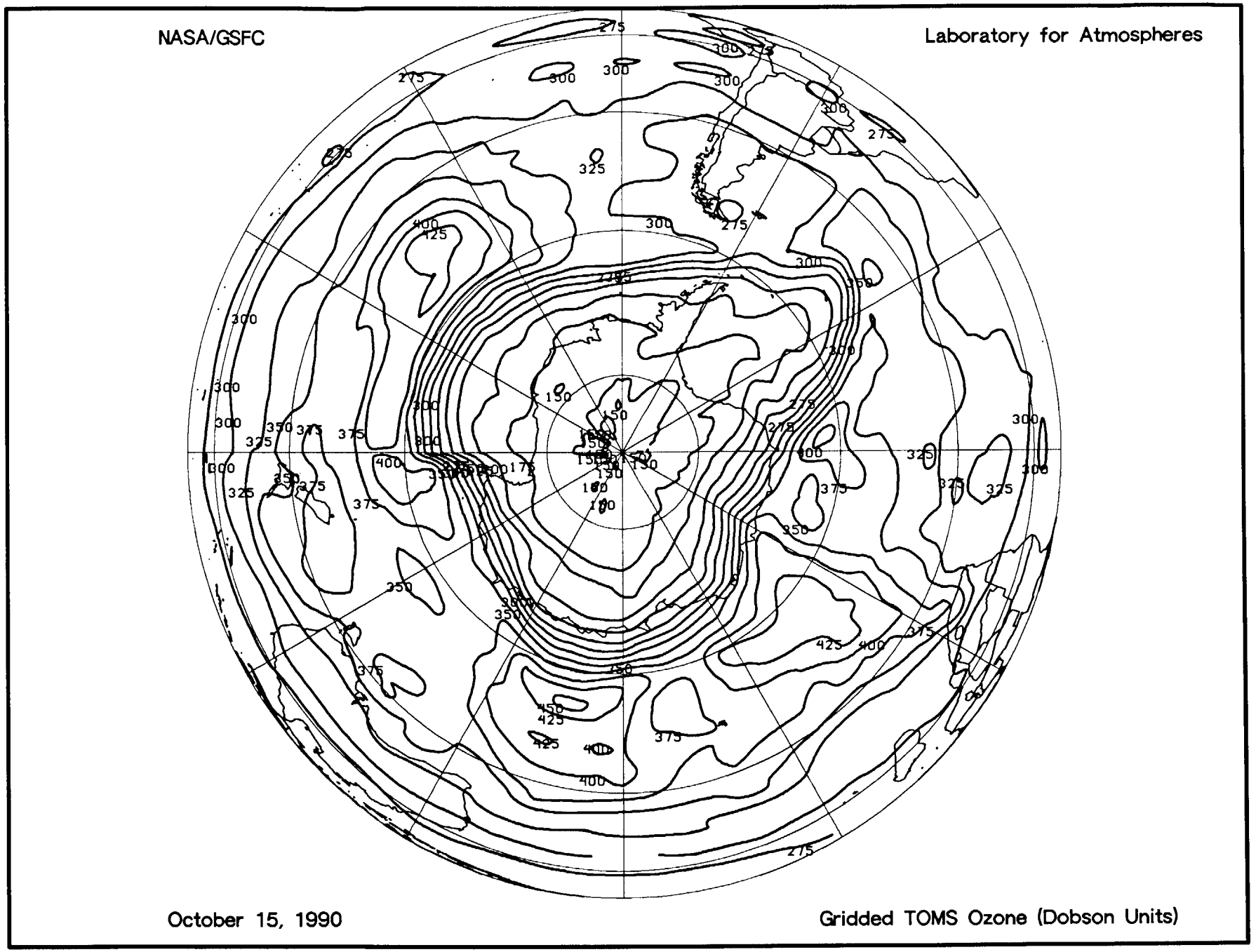
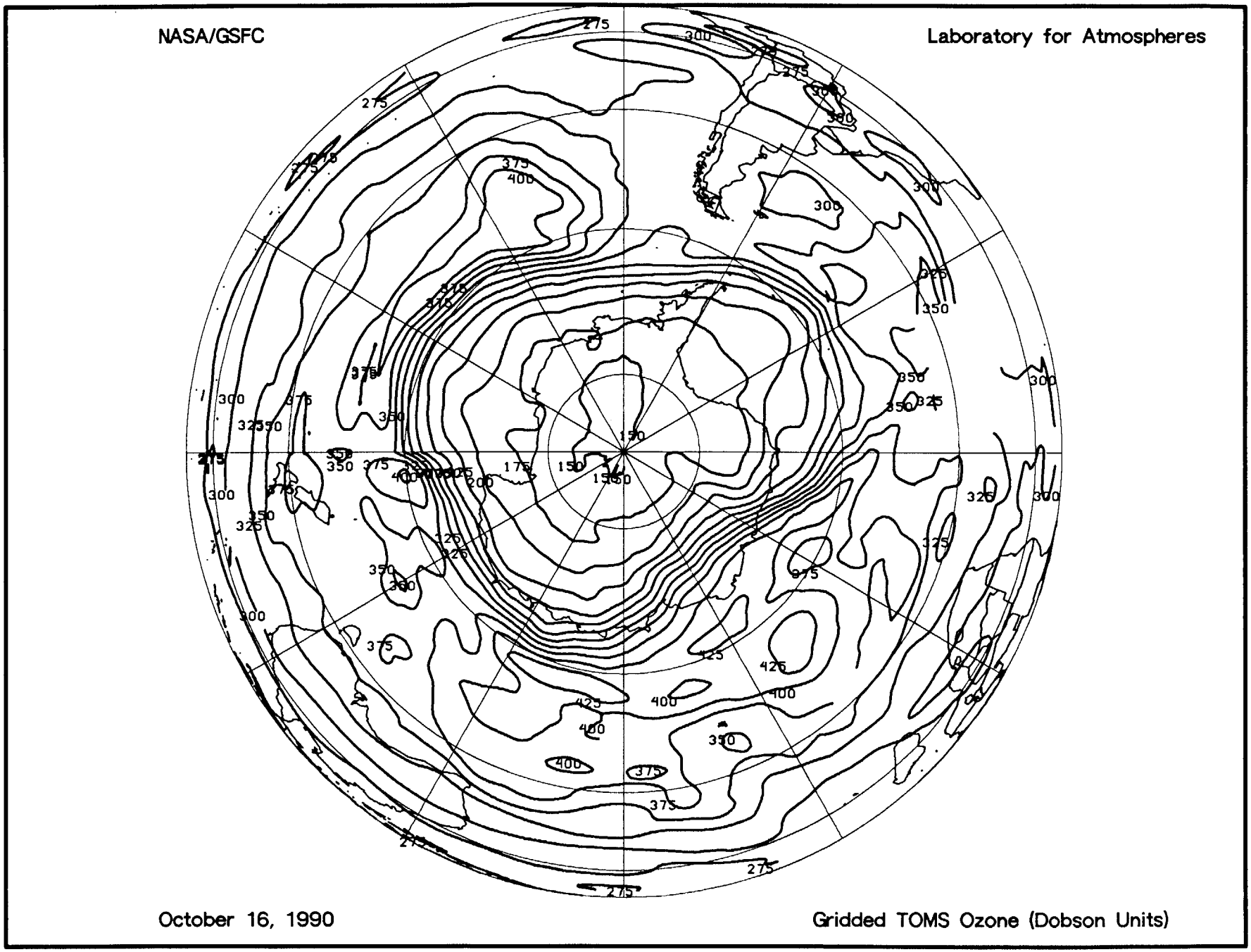
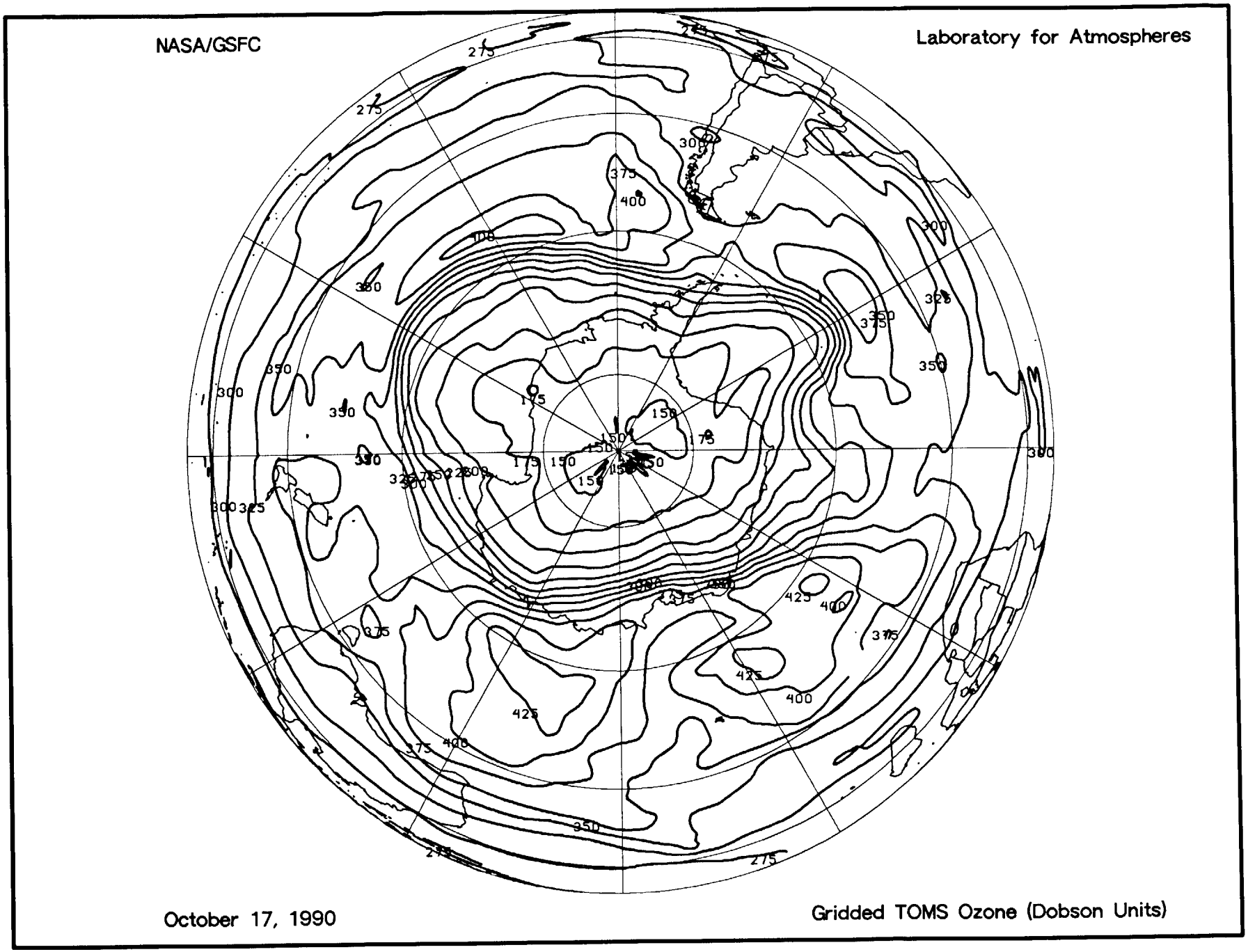
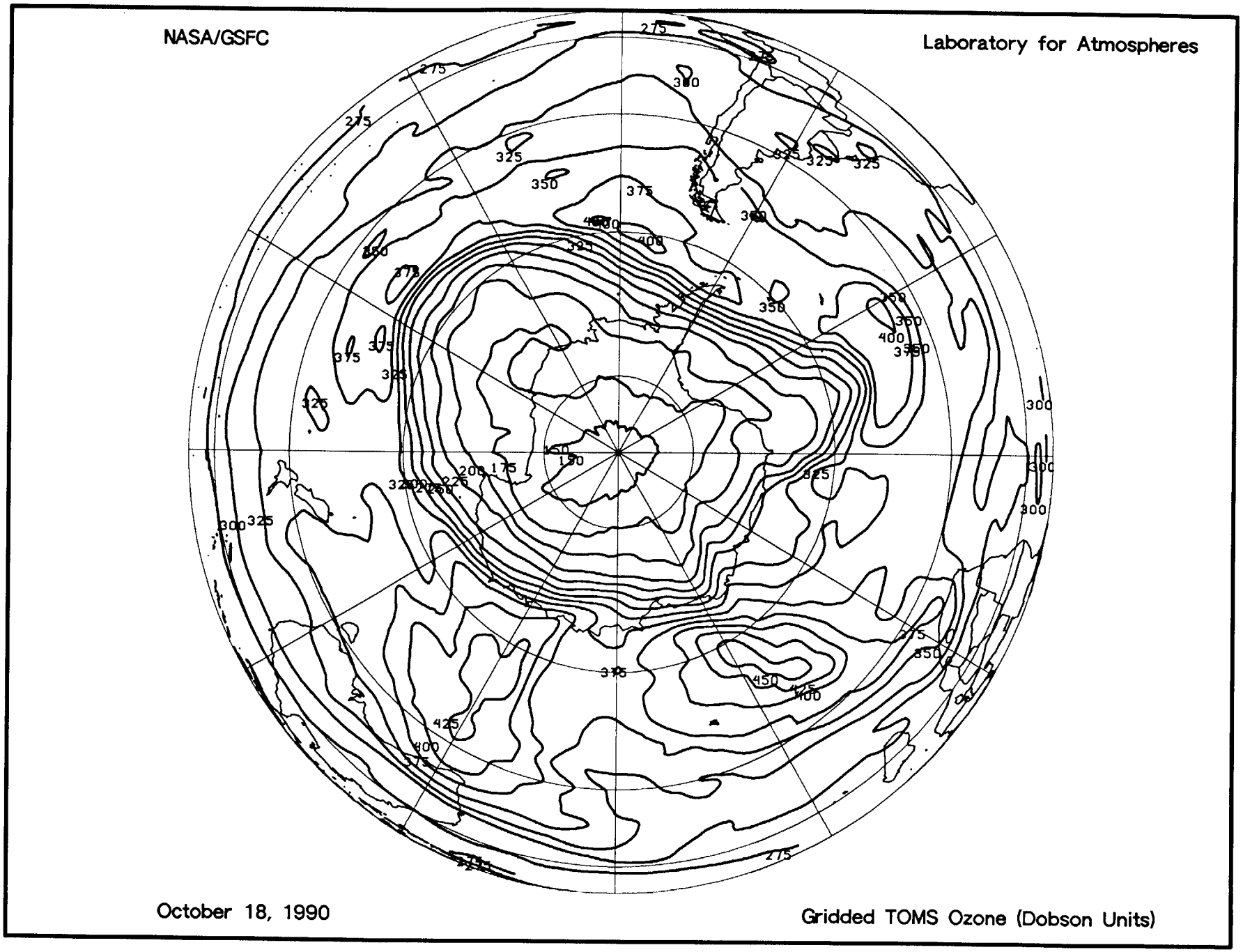
Laboratory for Atmospheres
October 13, 1990
Gridded TOMS Ozone (Dobson Units)

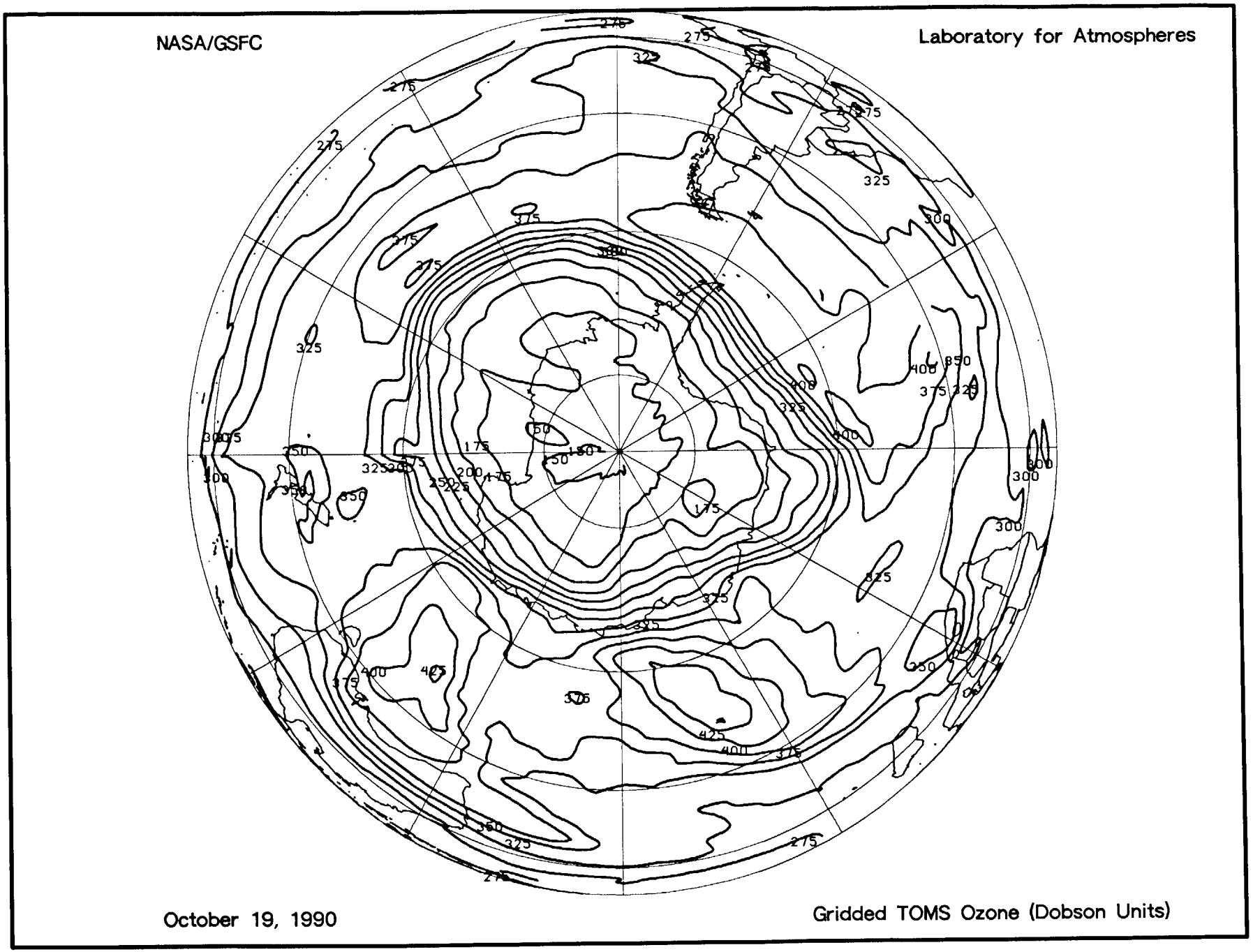

NASA/GSFC
Laboratory for Atmospheres
October 14, 1990
Gridded TOMS Ozone (Dobson Units)

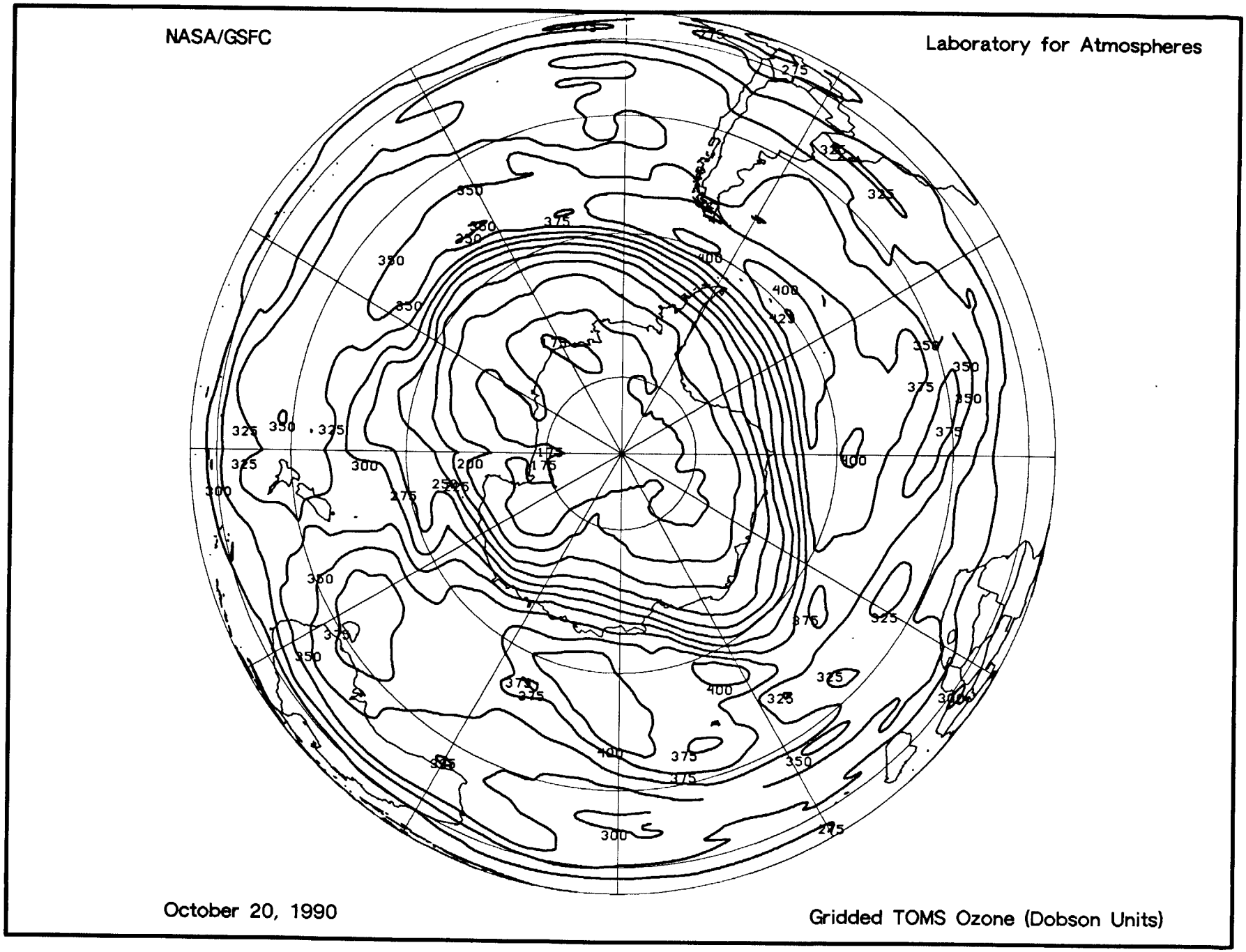

NASA/GSFC
Laboratory for Atmospheres
October 15, 1990
Gridded TOMS Ozone (Dobson Units)

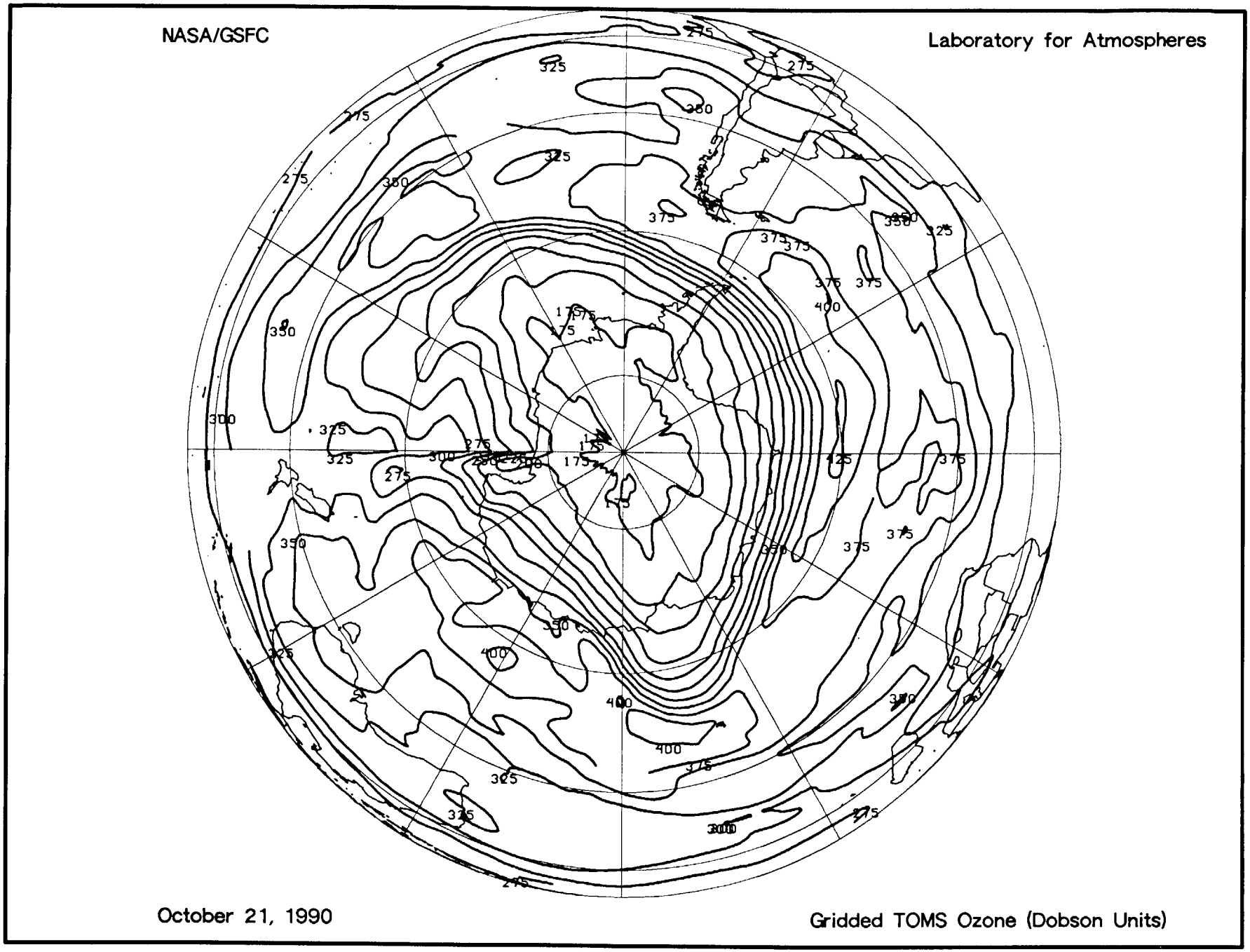

NASA/GSFC
Laboratory for Atmospheres
October 16, 1990
Gridded TOMS Ozone (Dobson Units)

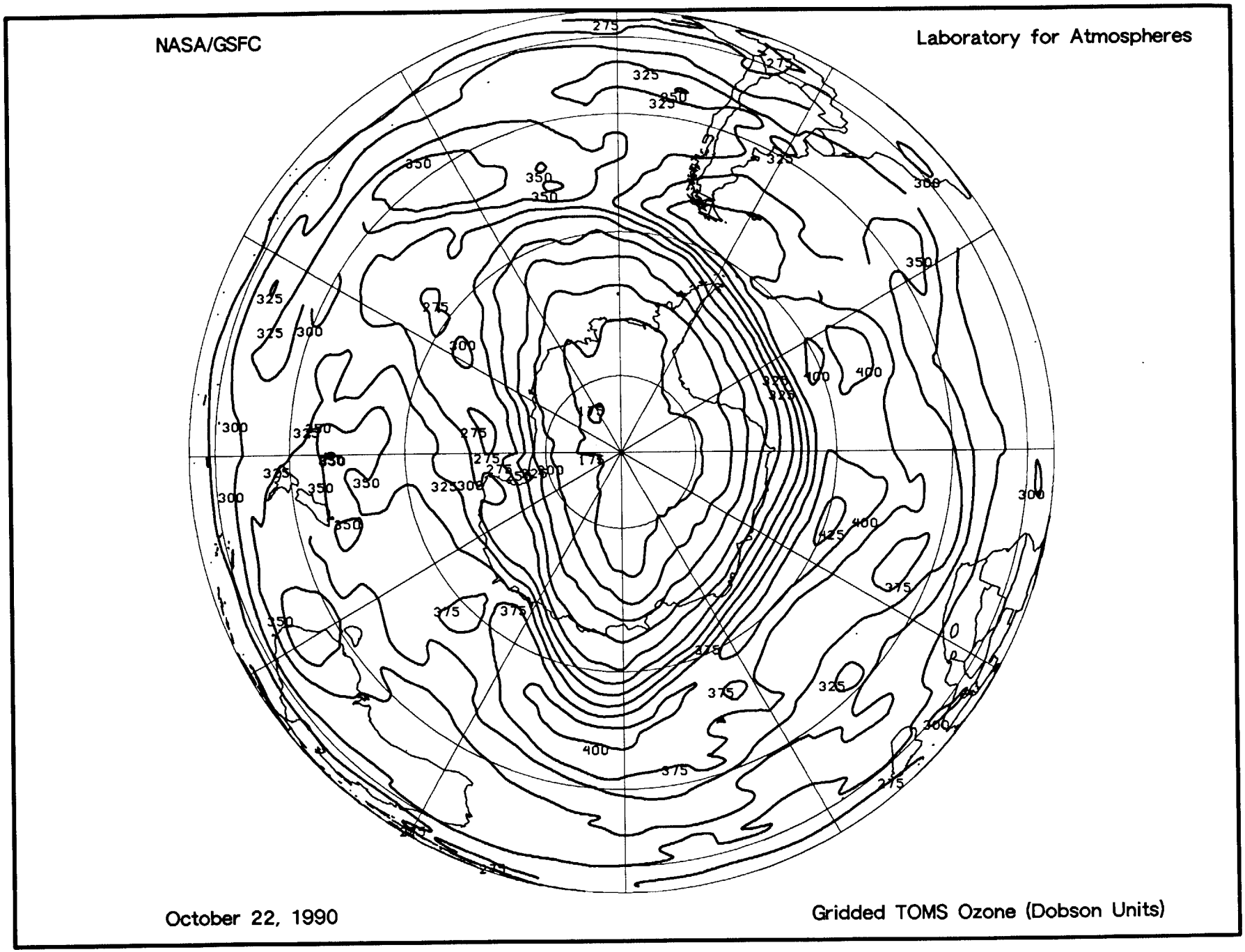

NASA/GSFC
Laboratory for Atmospheres
October 17, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 18, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 19, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 20, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 21, 1990
Gridded TOMS Ozone (Dobson Units)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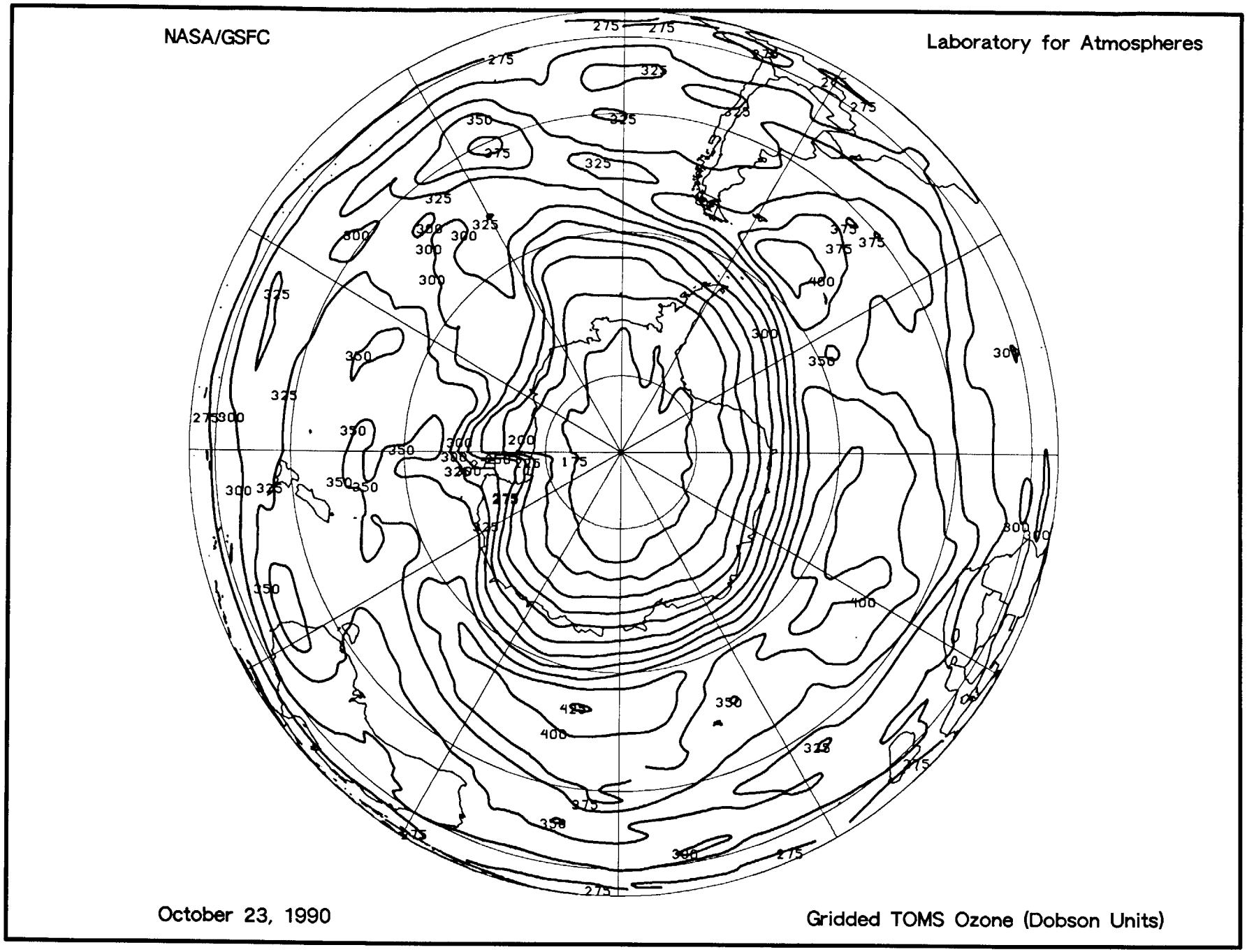
Laboratory for Atmospheres
October 22, 1990
Gridded TOMS Ozone (Dobson Units)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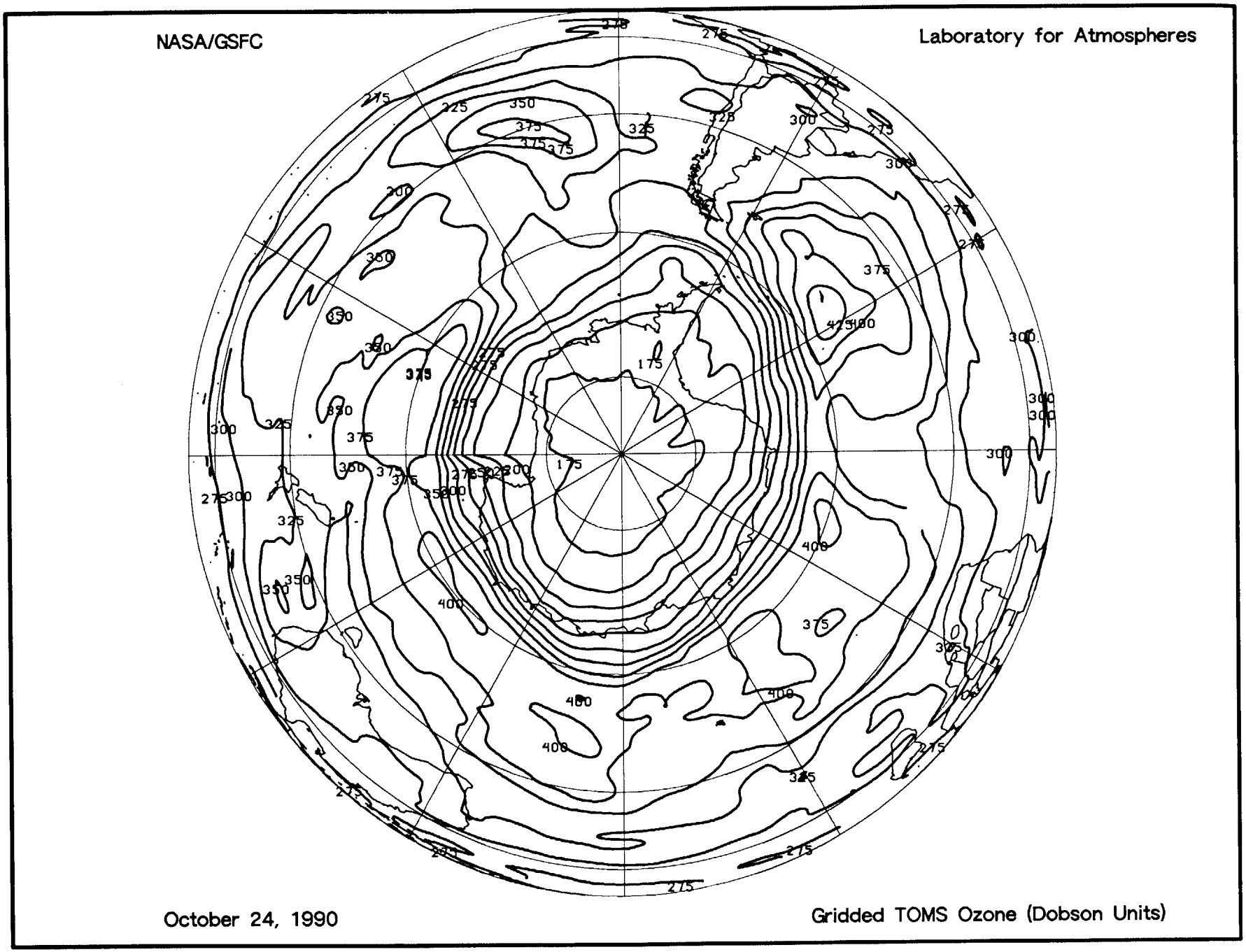
Laboratory for Atmospheres
October 23, 1990
Gridded TOMS Ozone (Dobson Units)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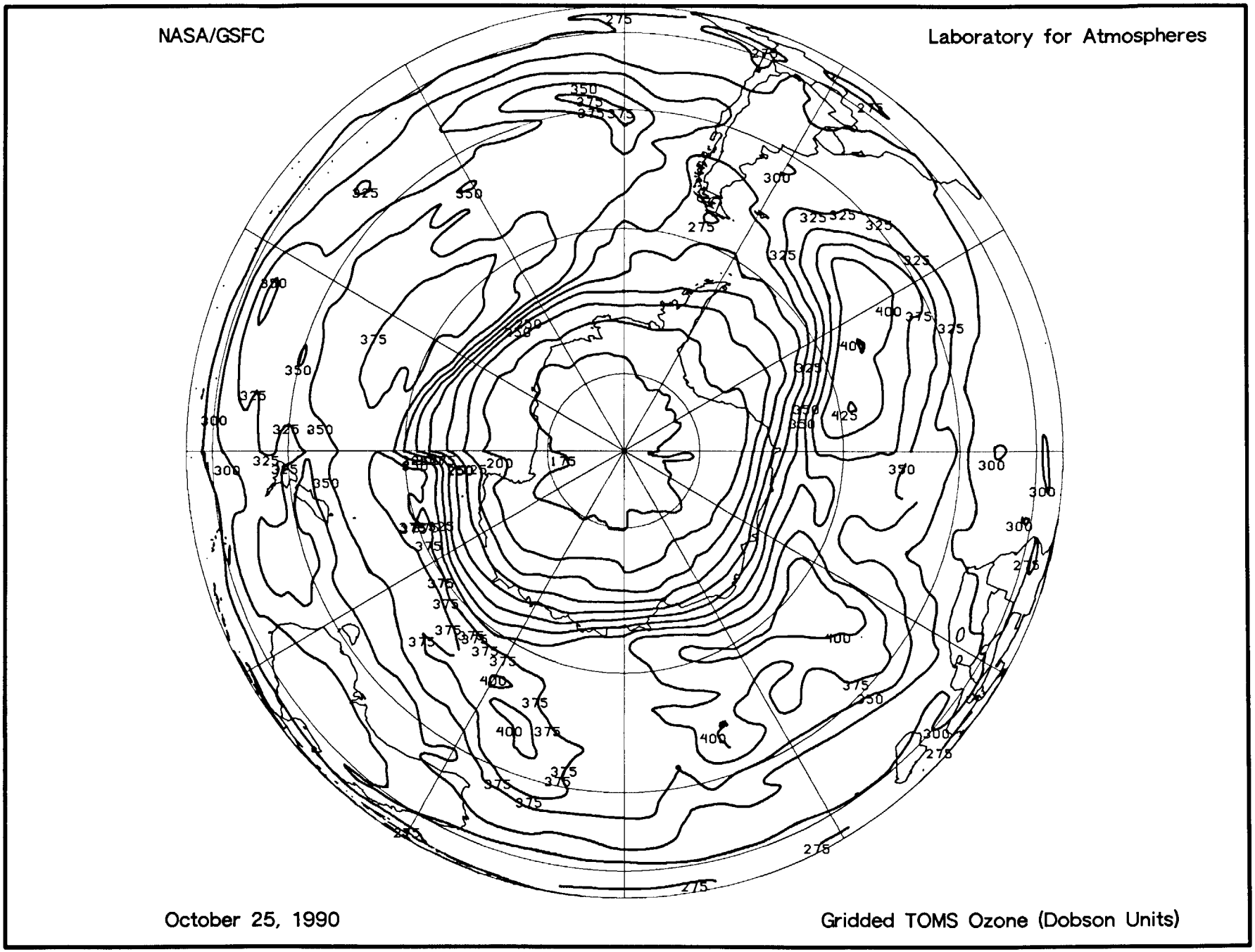
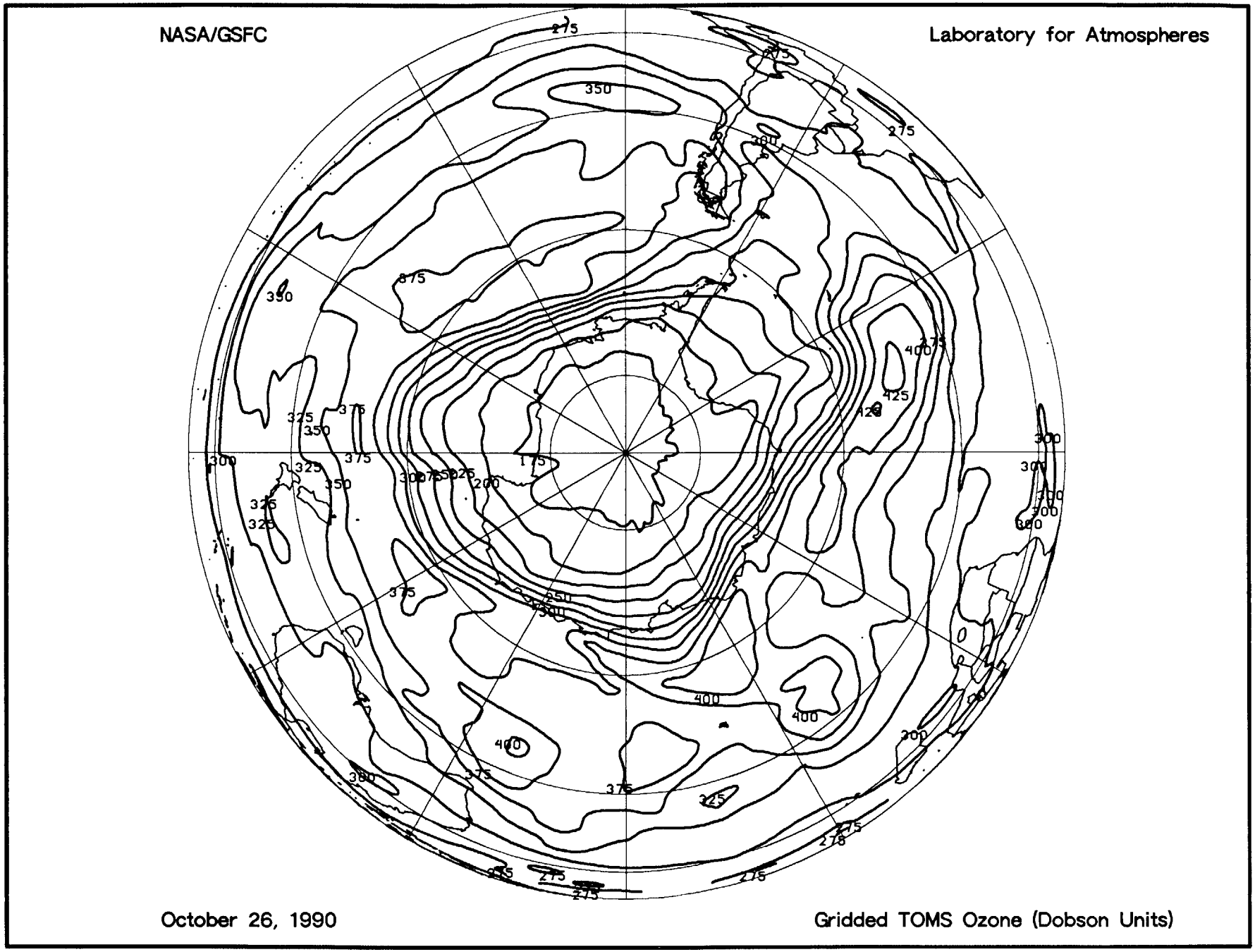
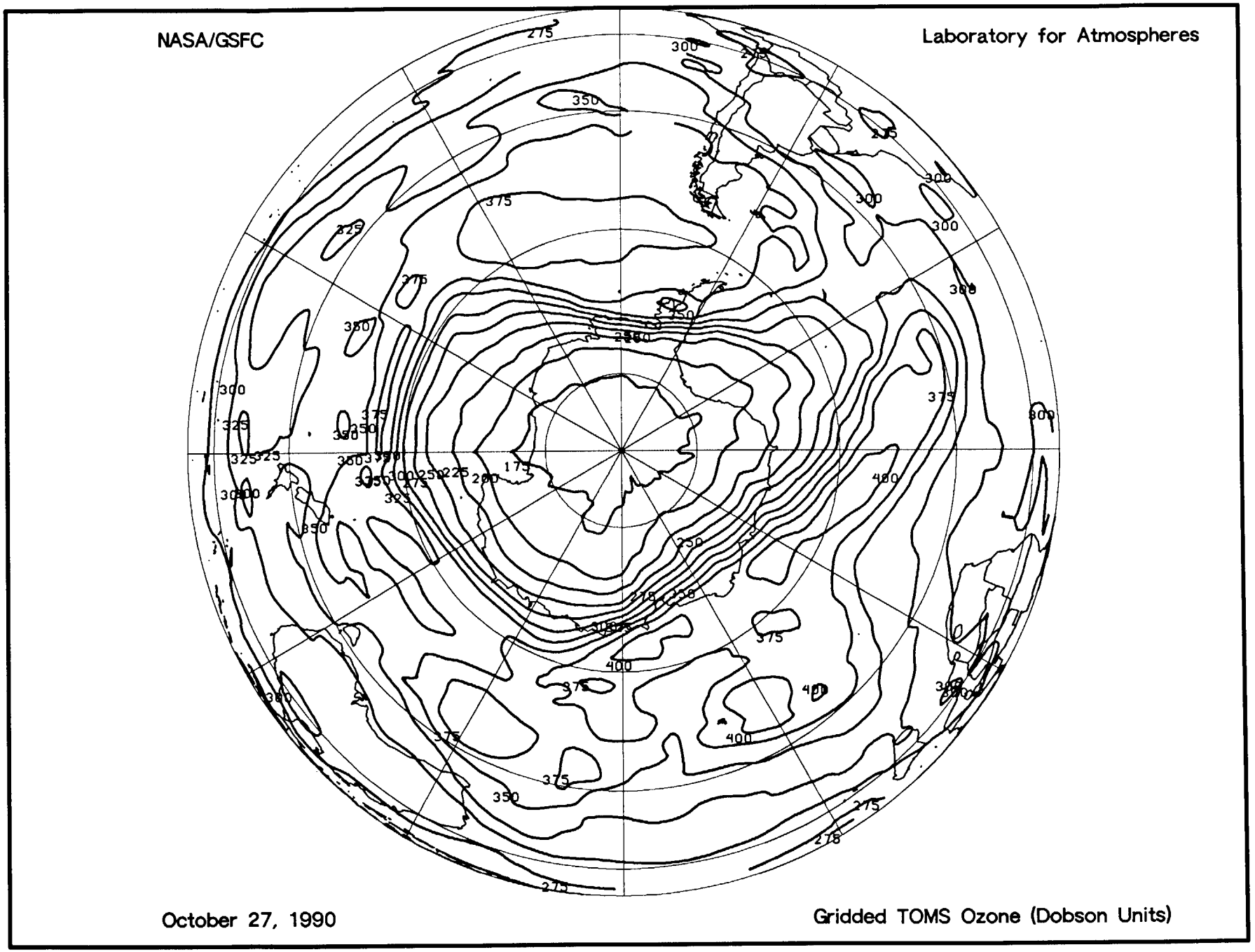
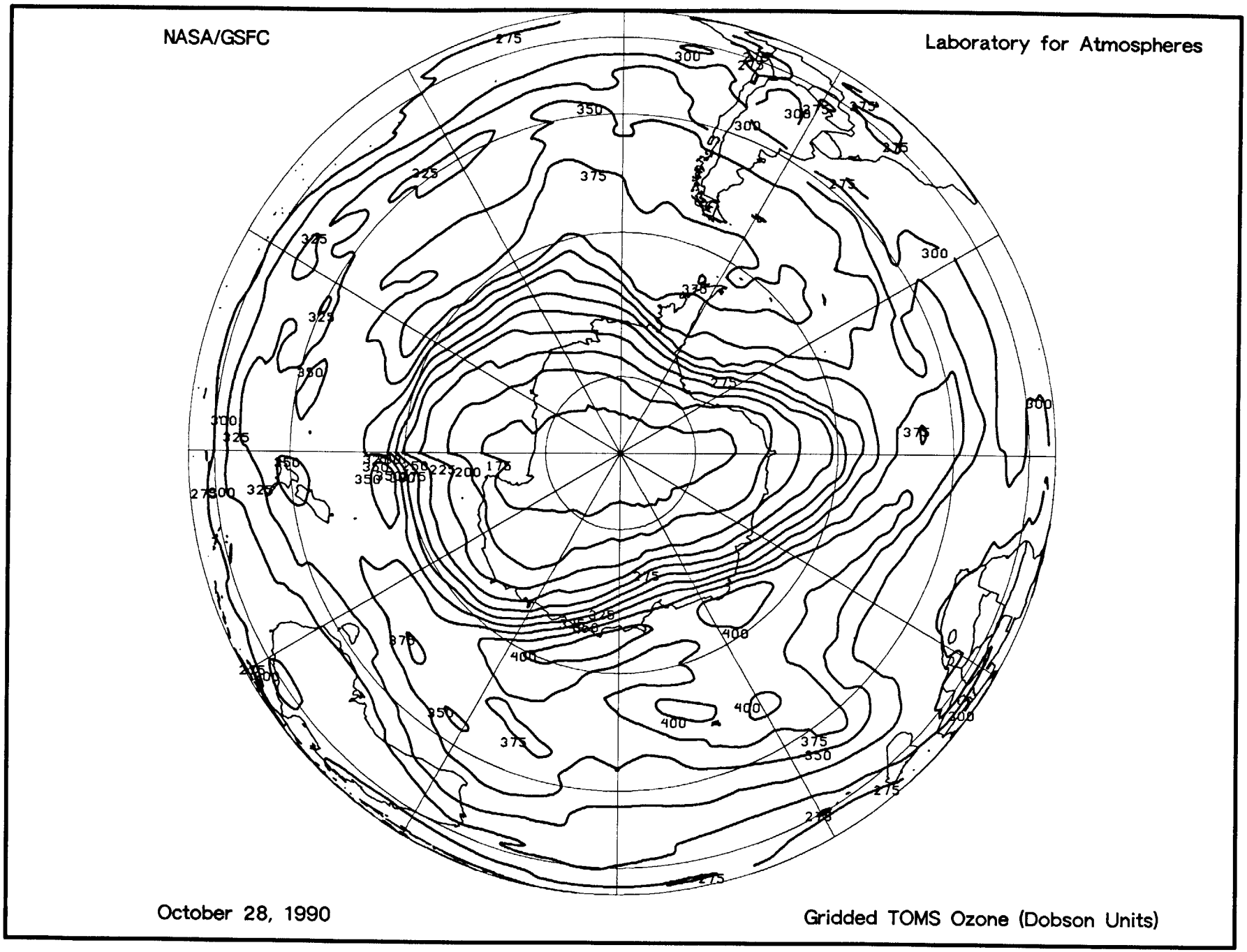
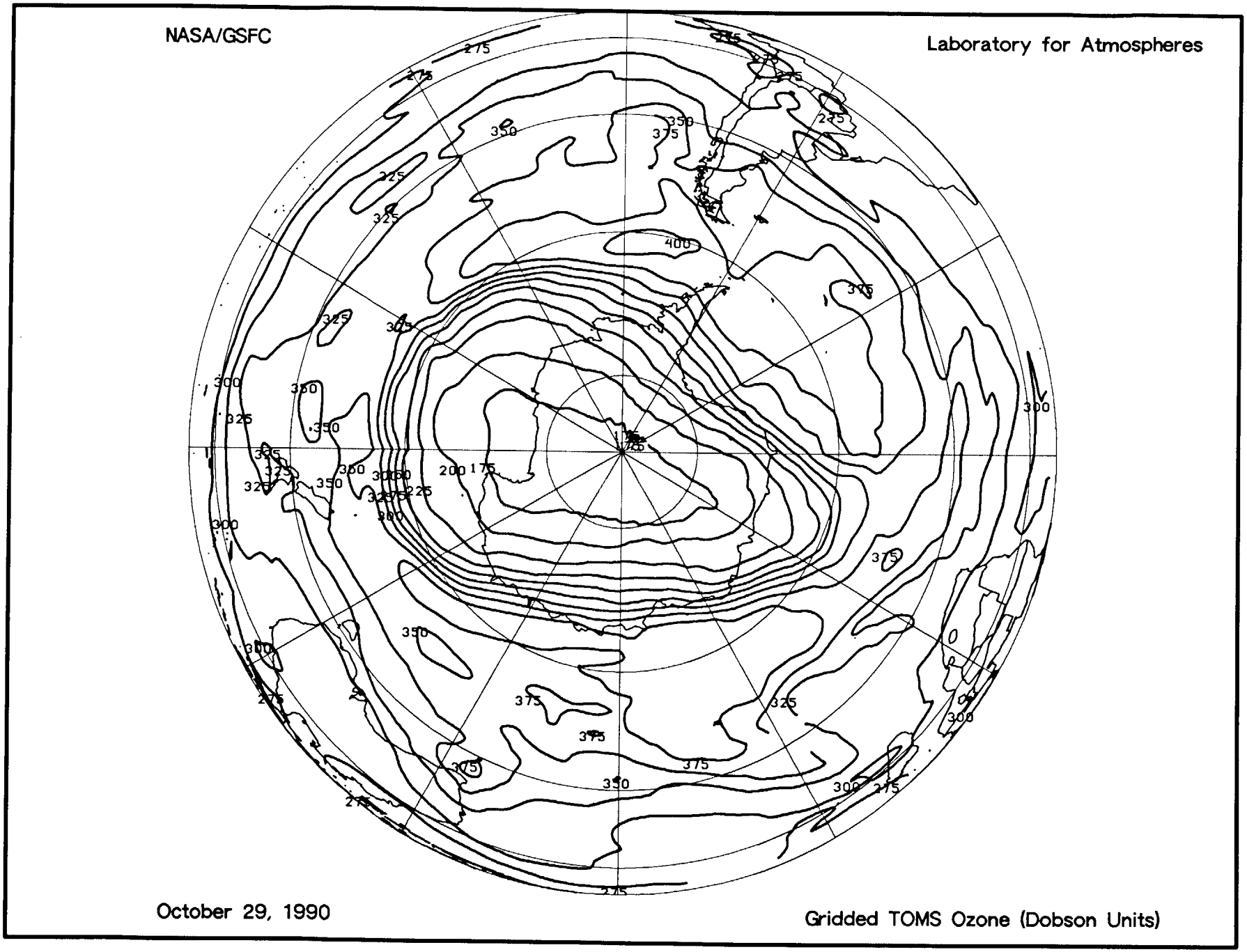
Laboratory for Atmospheres
October 24, 1990
Gridded TOMS Ozone (Dobson Units)

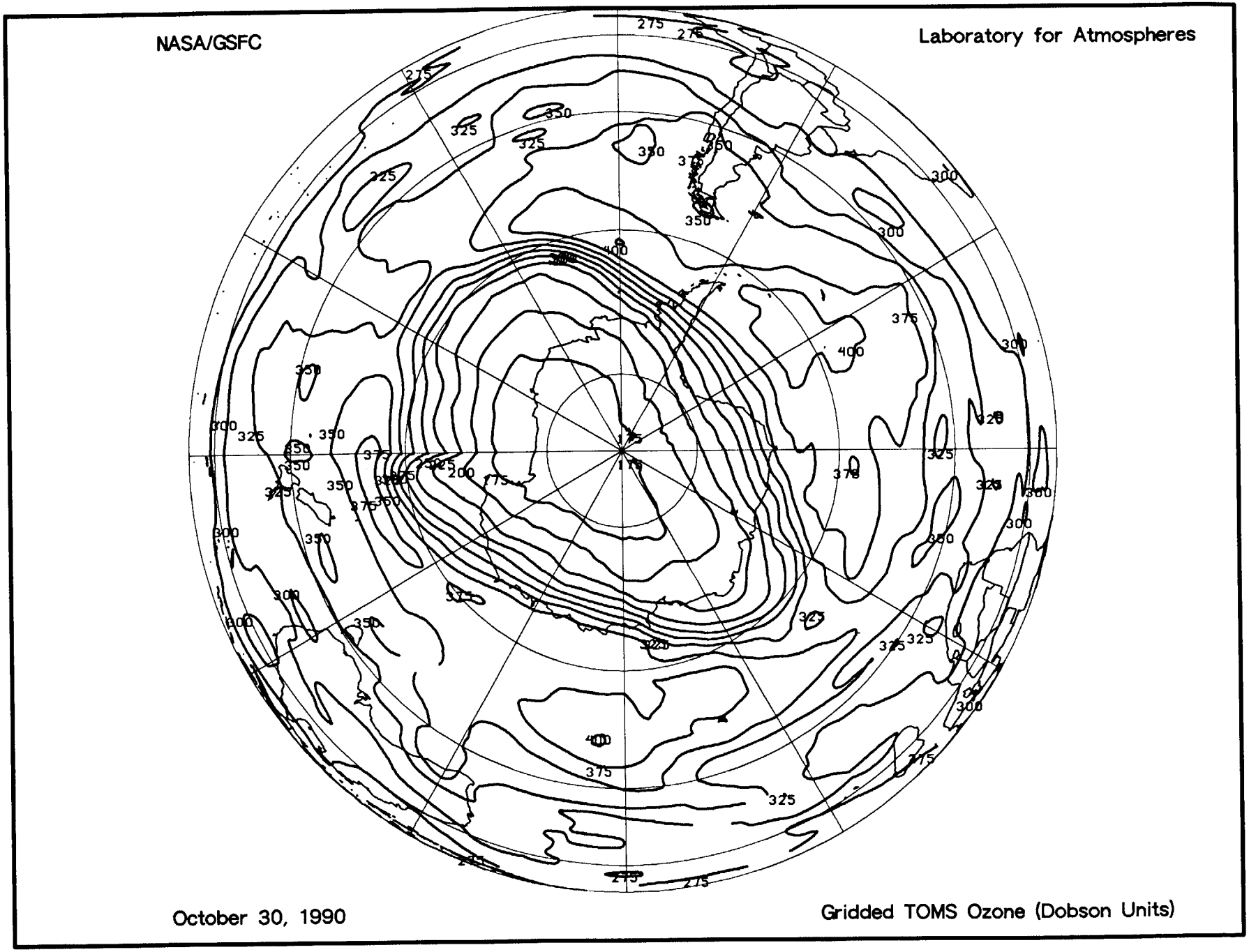

NASA/GSFC
Laboratory for Atmospheres
October 25, 1990
Gridded TOMS Ozone (Dobson Units)

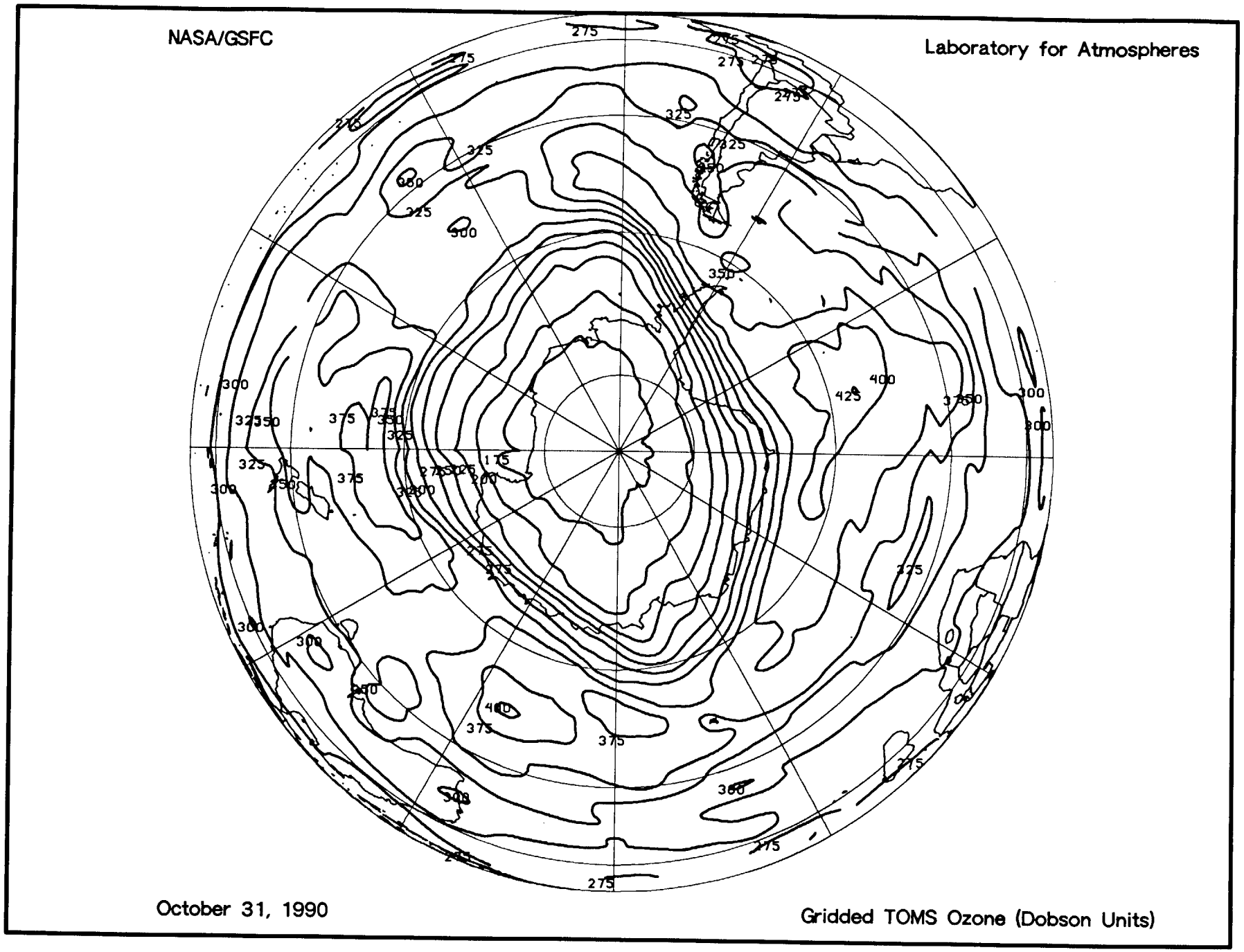

NASA/GSFC
Laboratory for Atmospheres
October 26, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 27, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 28, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 29, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 30, 1990
Gridded TOMS Ozone (Dobson Units)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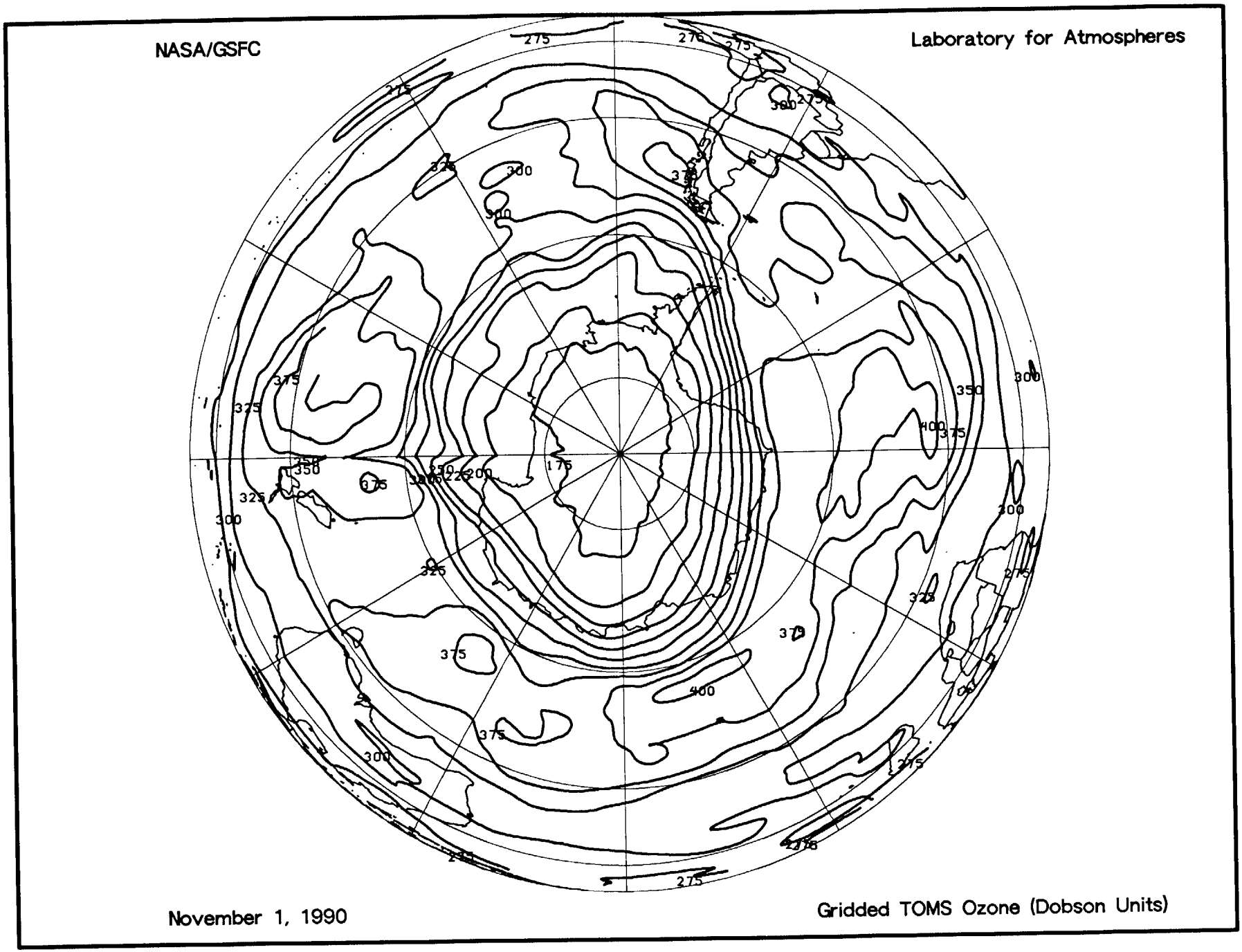
Laboratory for Atmospheres
October 31, 1990
Gridded TOMS Ozone (Dobson Units)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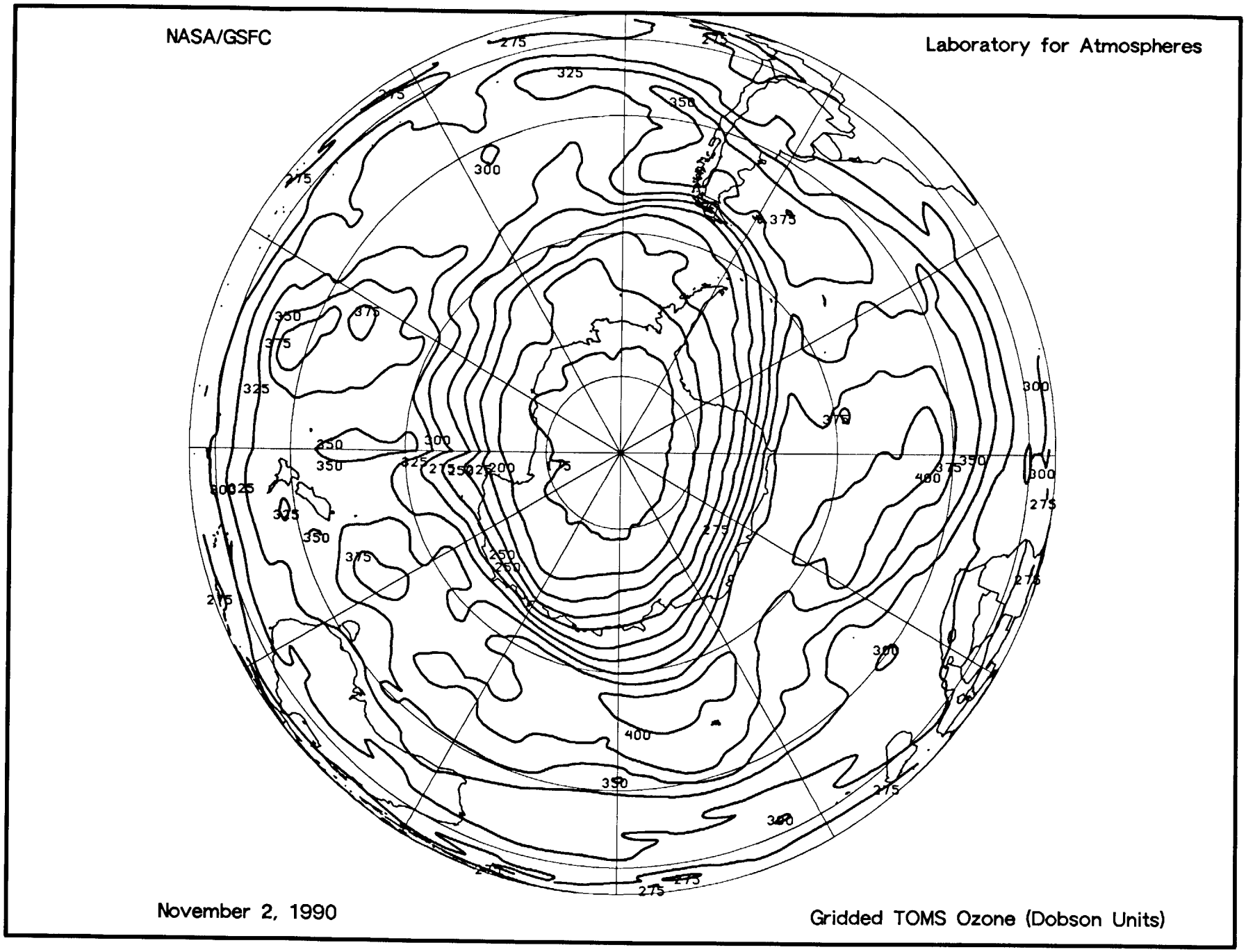
Laboratory for Atmospheres
November 1, 1990
Gridded TOMS Ozone (Dobson Units)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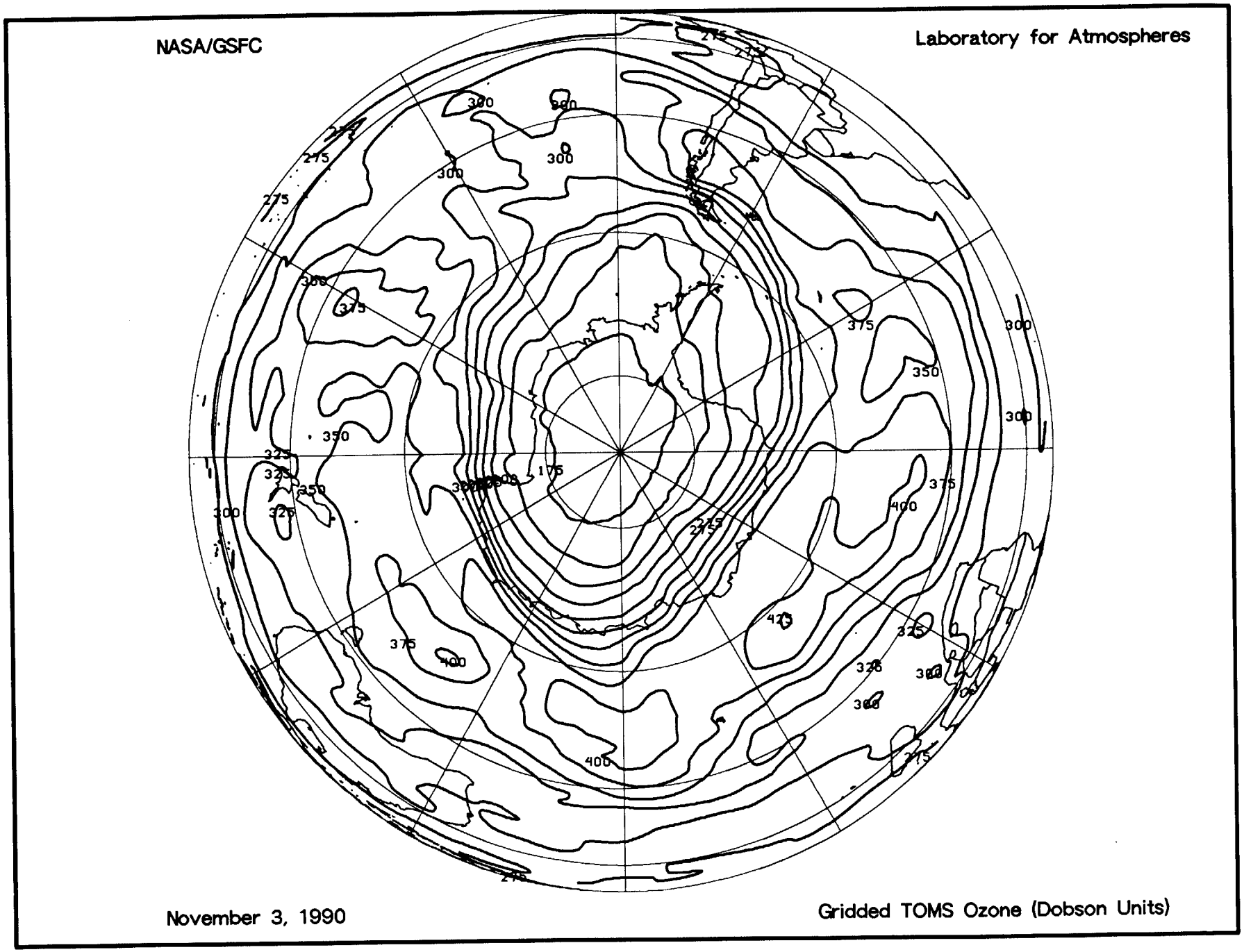
Laboratory for Atmospheres
November 2, 1990
Gridded TOMS Ozone (Dobson Units)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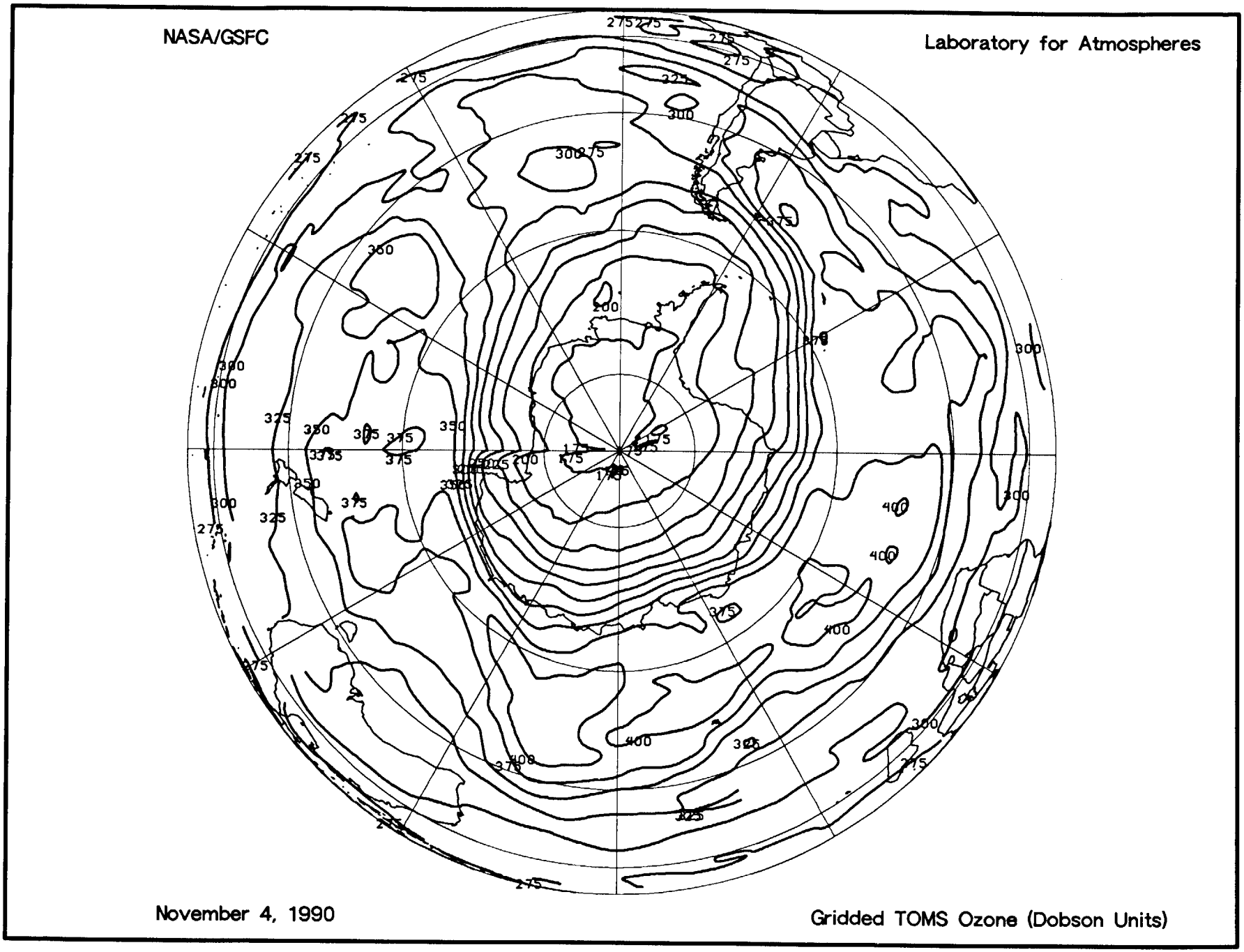
Laboratory for Atmospheres
November 3, 1990
Gridded TOMS Ozone (Dobson Units)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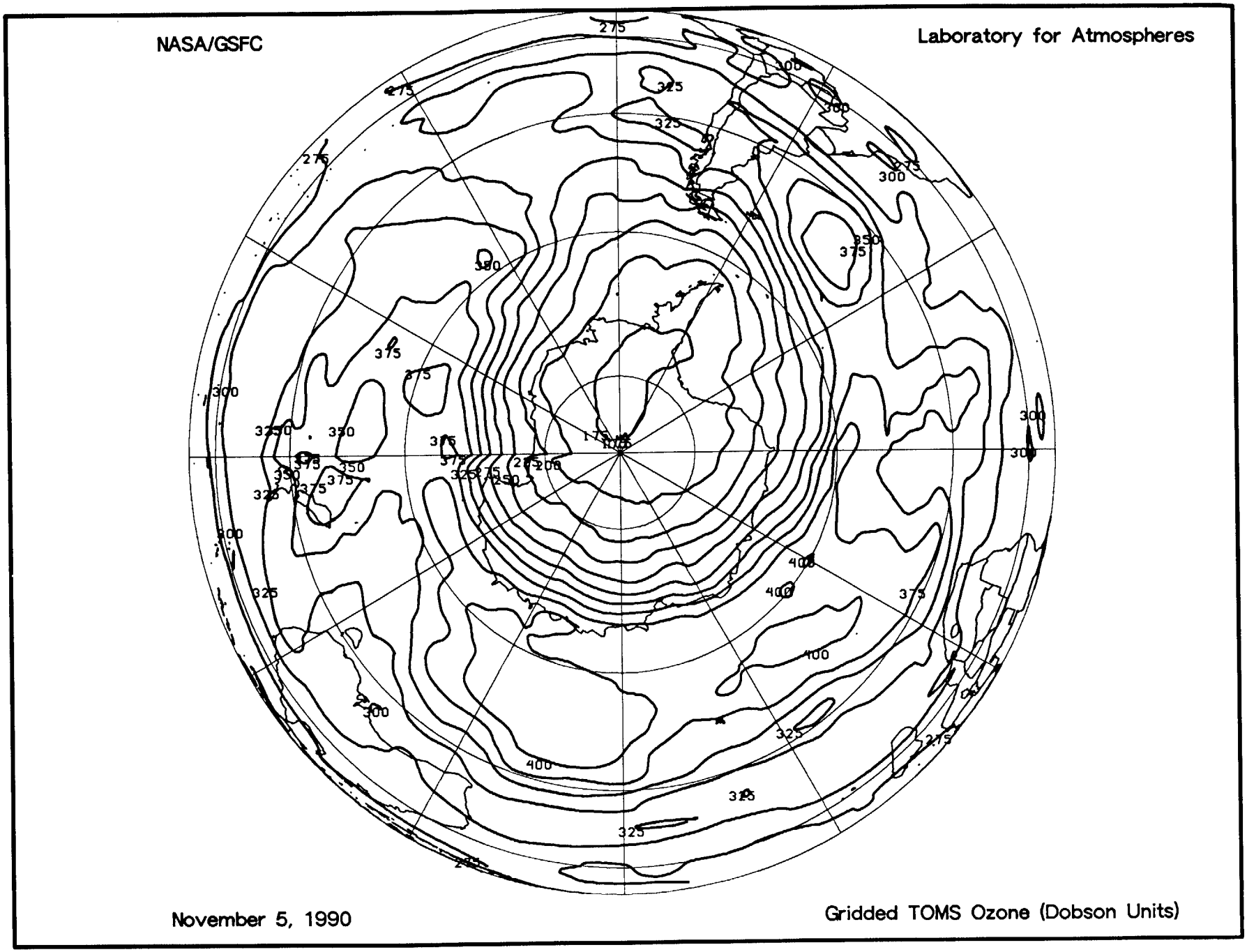
Laboratory for Atmospheres
November 4, 1990
Gridded TOMS Ozone (Dobson Units)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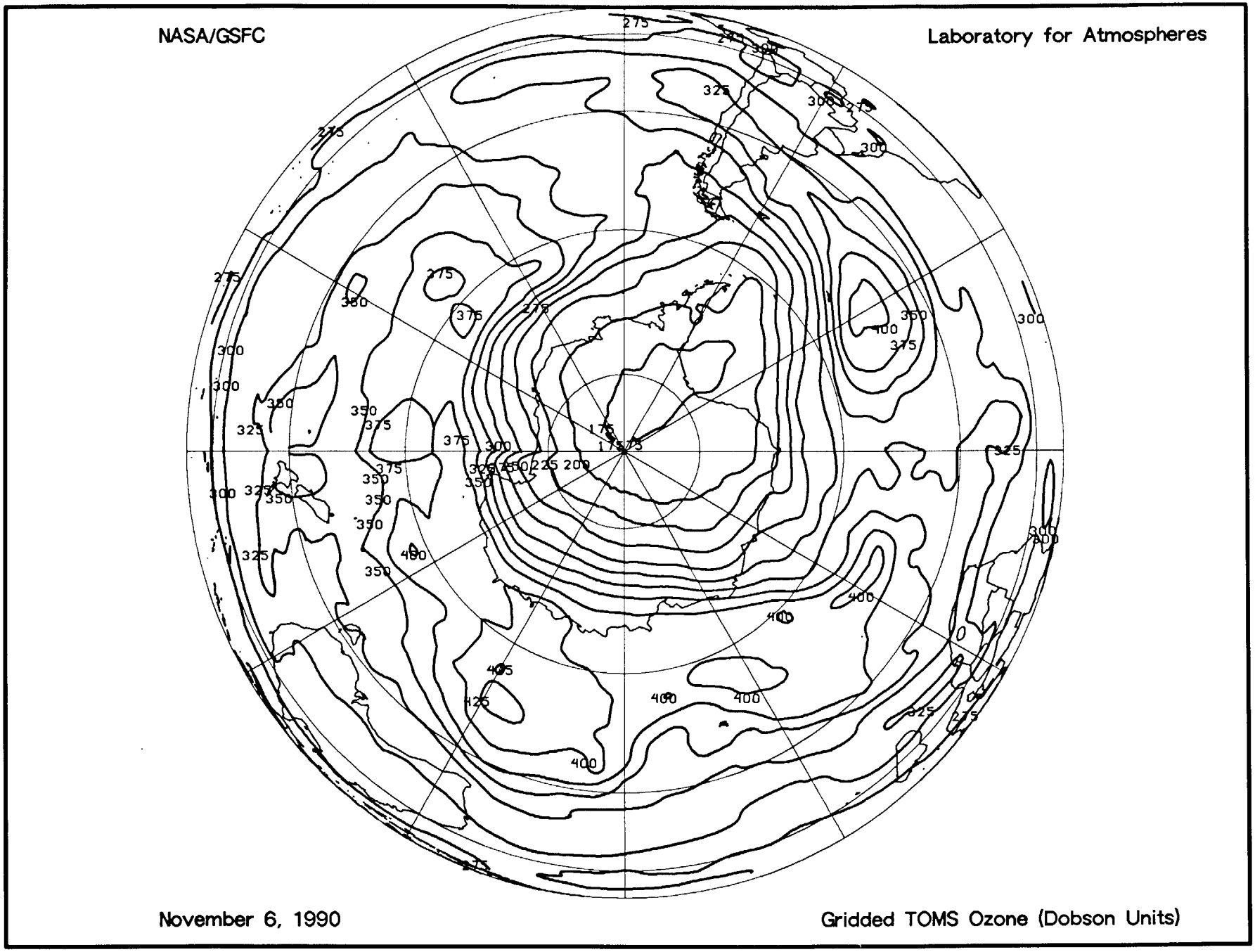
Laboratory for Atmospheres
November 5, 1990
Gridded TOMS Ozone (Dobson Units)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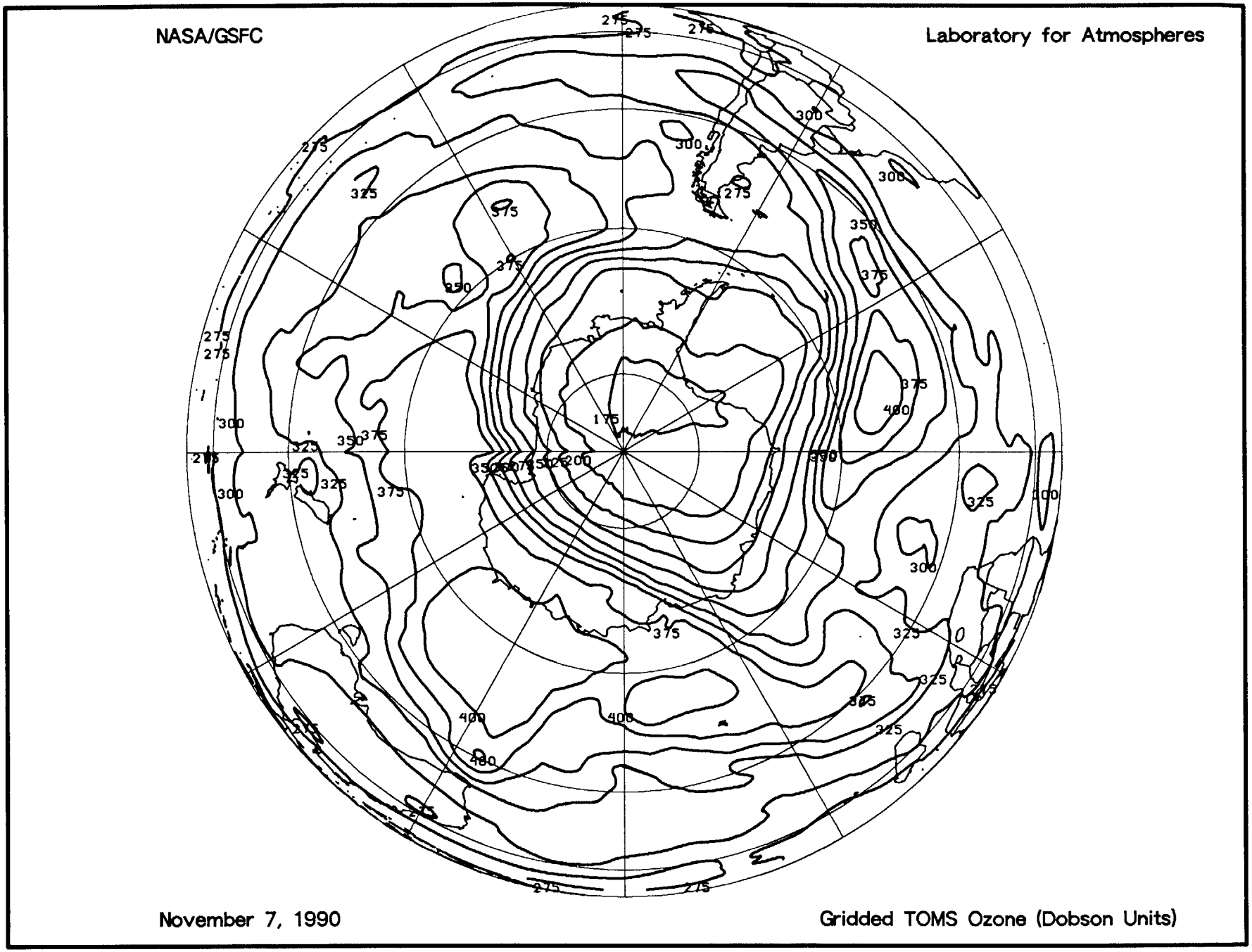
Laboratory for Atmospheres
November 6, 1990
Gridded TOMS Ozone (Dobson Units)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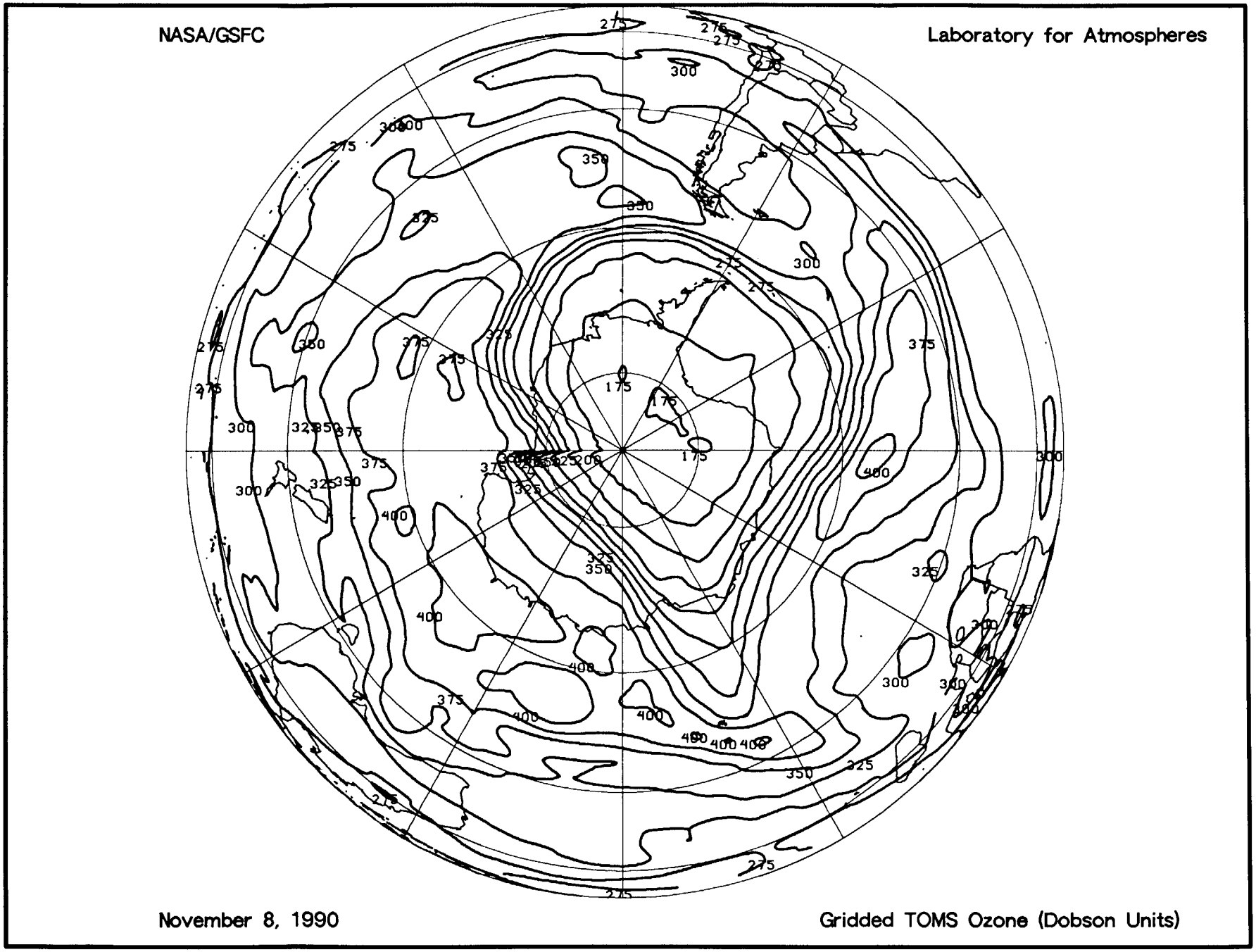
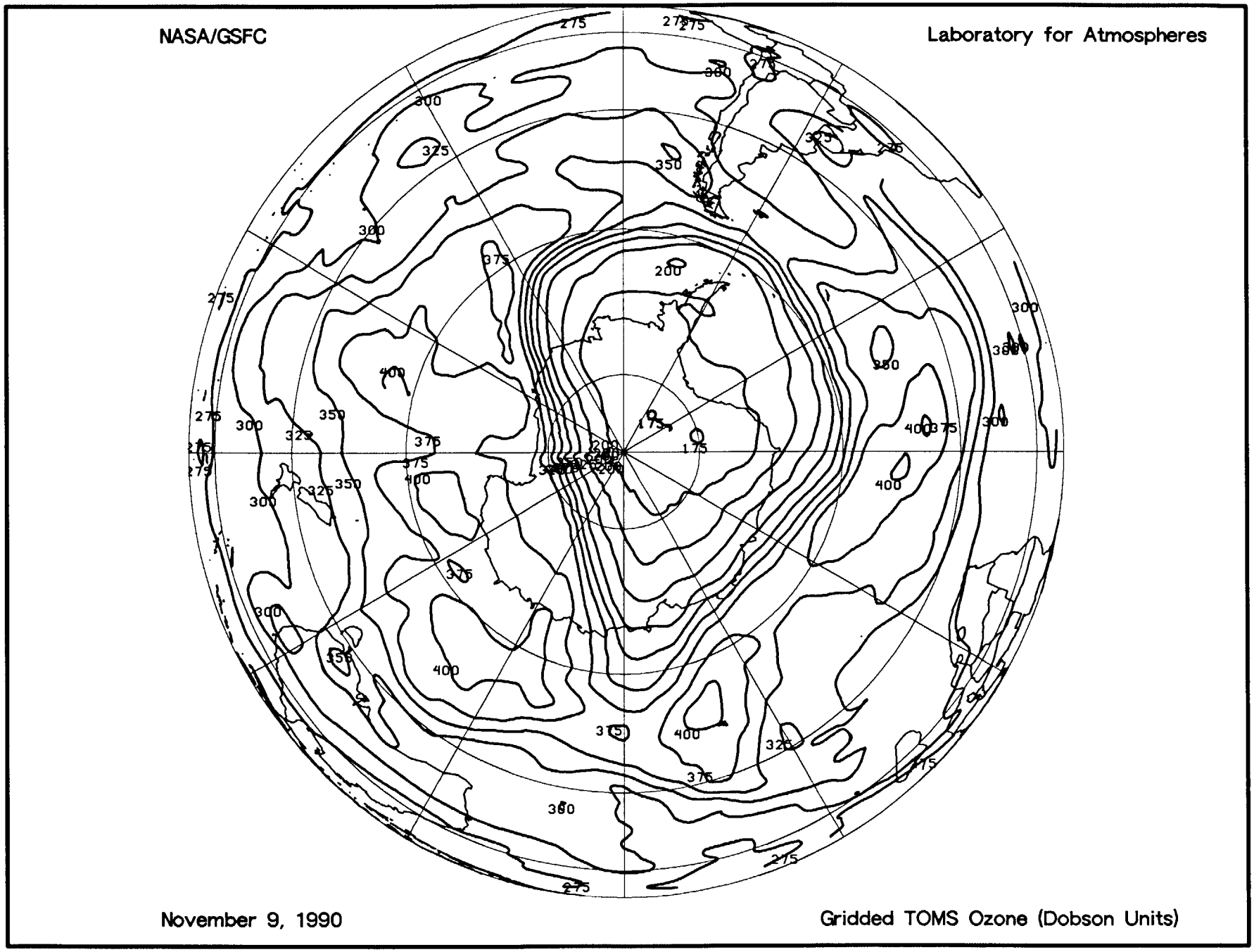
Laboratory for Atmospheres
November 7, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 8, 1990
Gridded TOMS Ozone (Dobson Units)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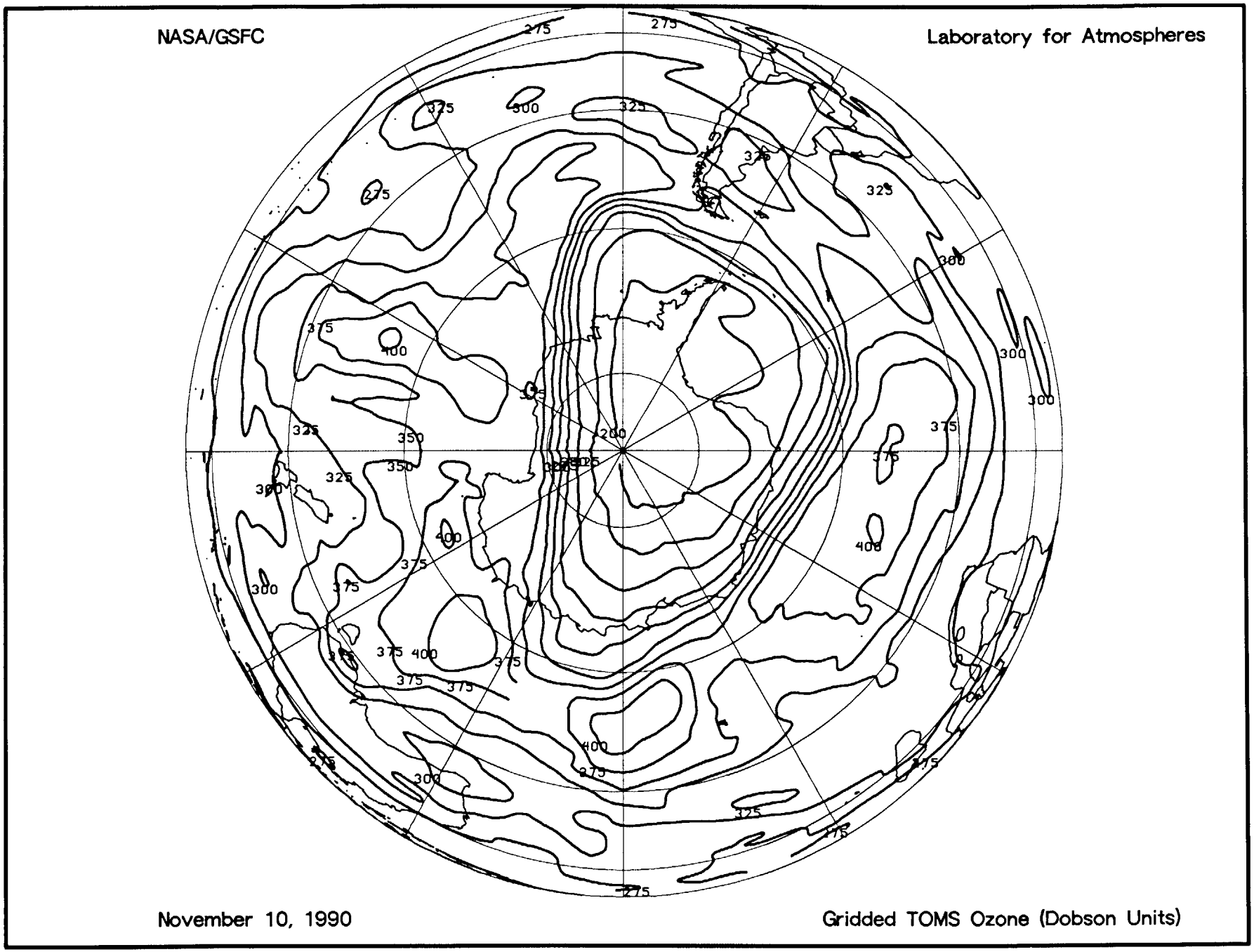
Laboratory for Atmospheres
November 9, 1990
Gridded TOMS Ozone (Dobson Units)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November 10, 1990
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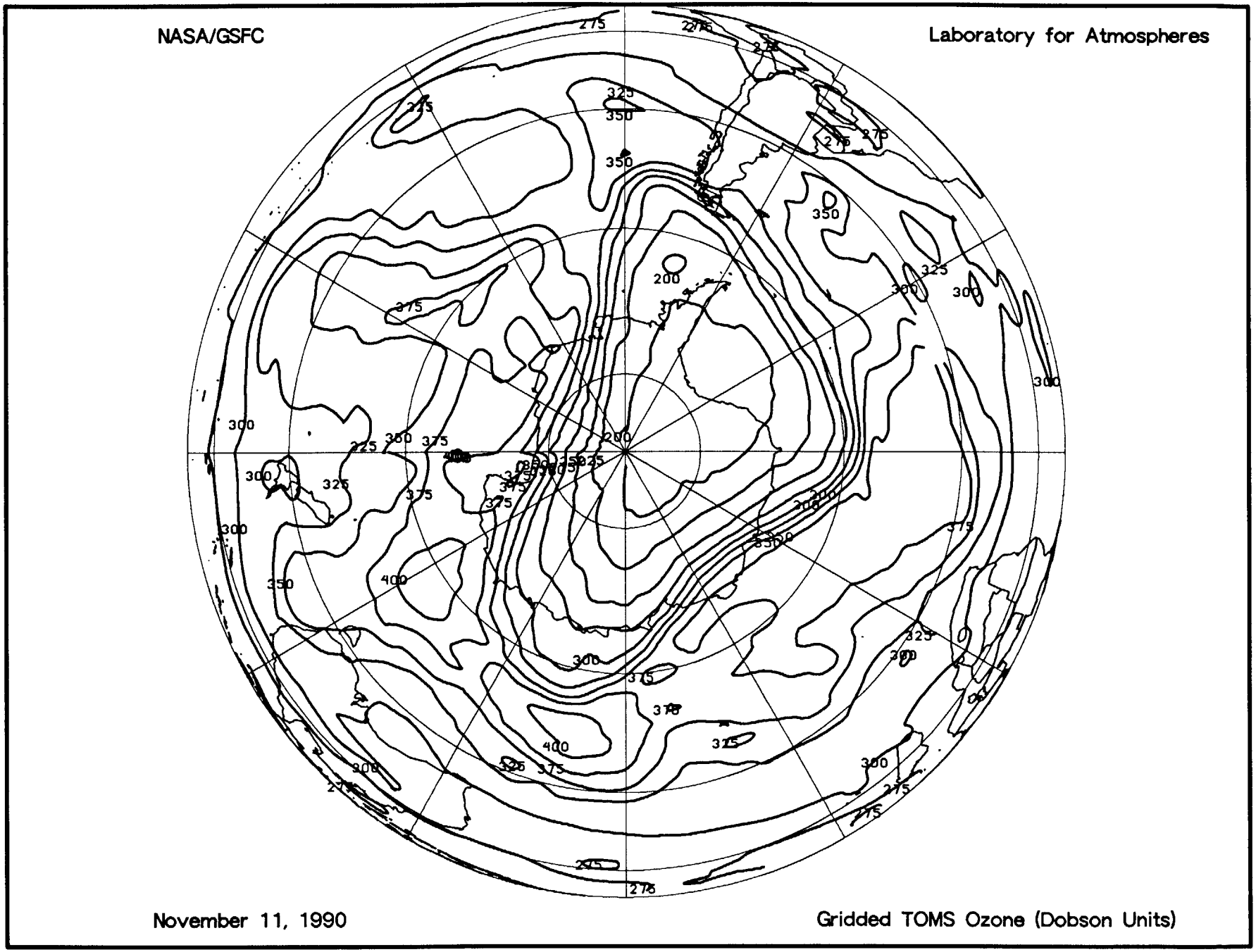
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Laboratory for Atmospheres
November 11, 1990
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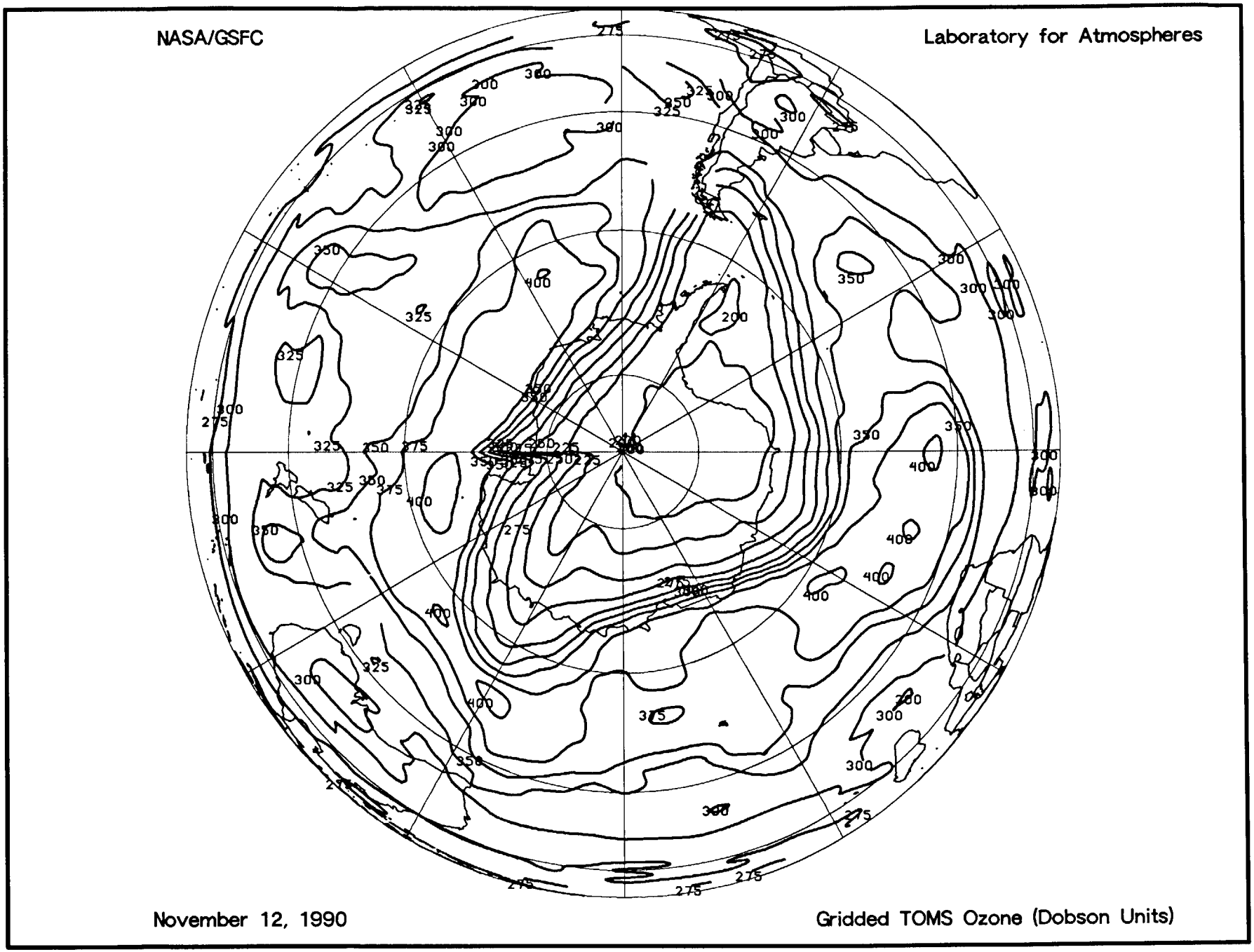
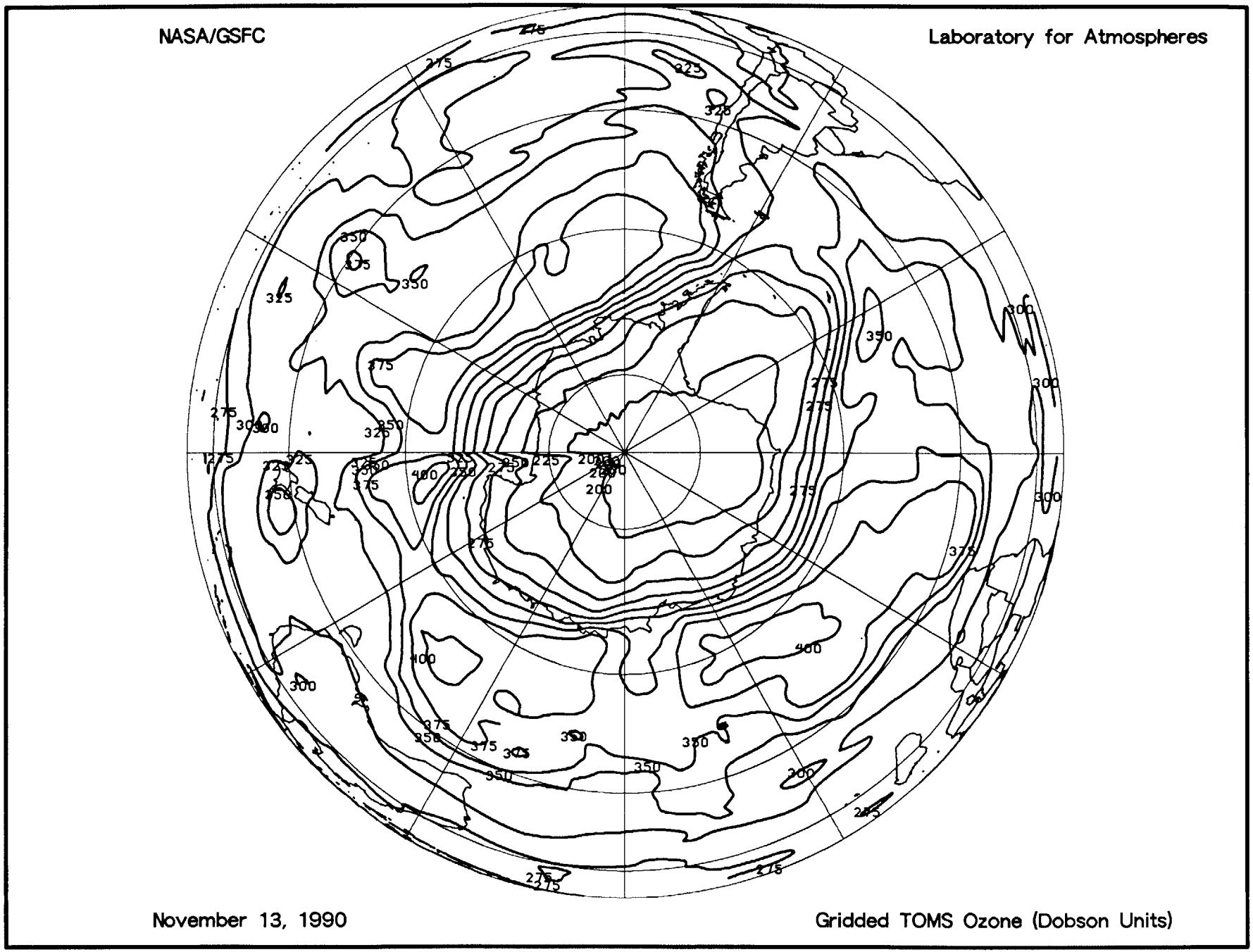
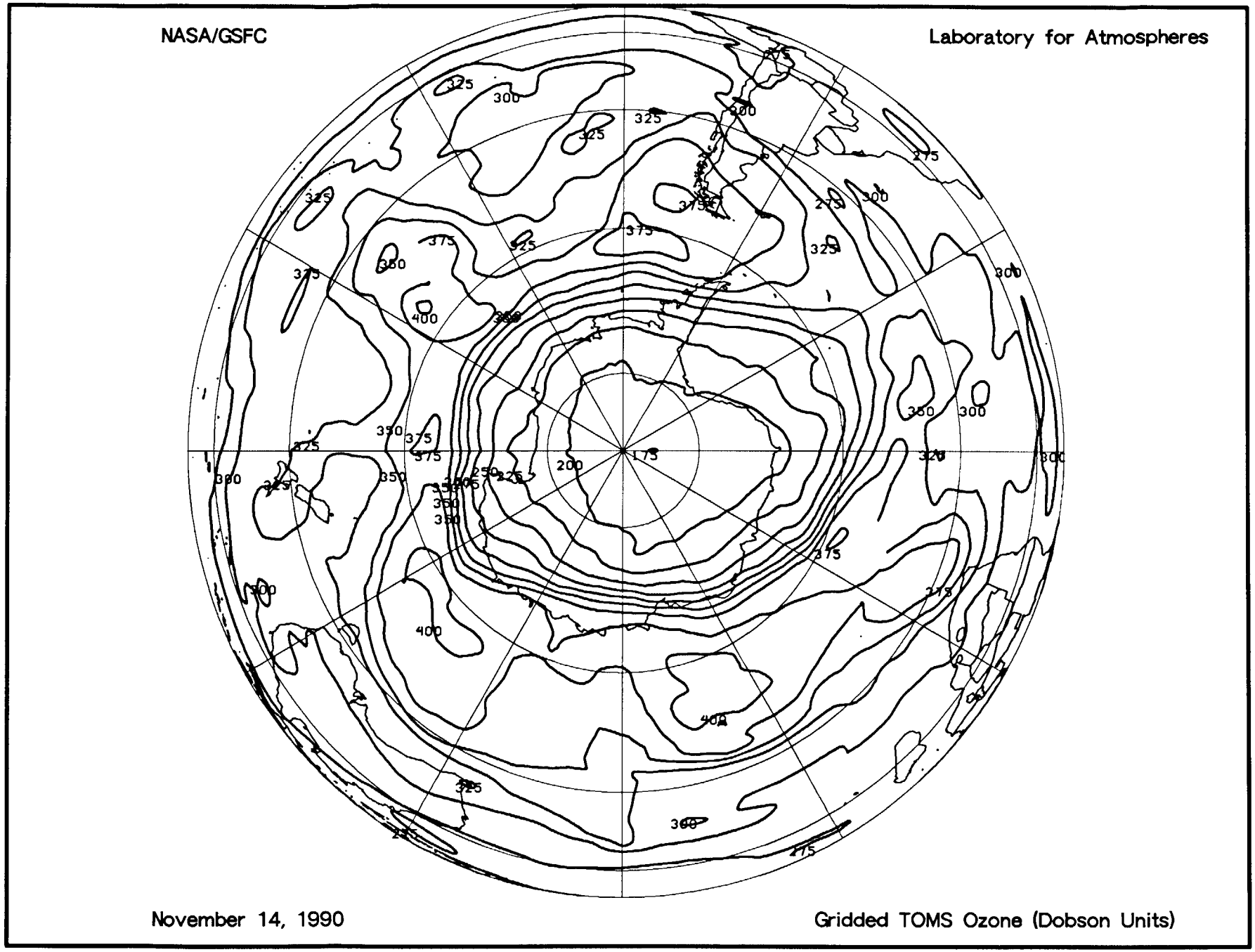

NASA/GSFC
Laboratory for Atmospheres
November 12, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 13, 1990
Gridded TOMS Ozone (Dobson Units)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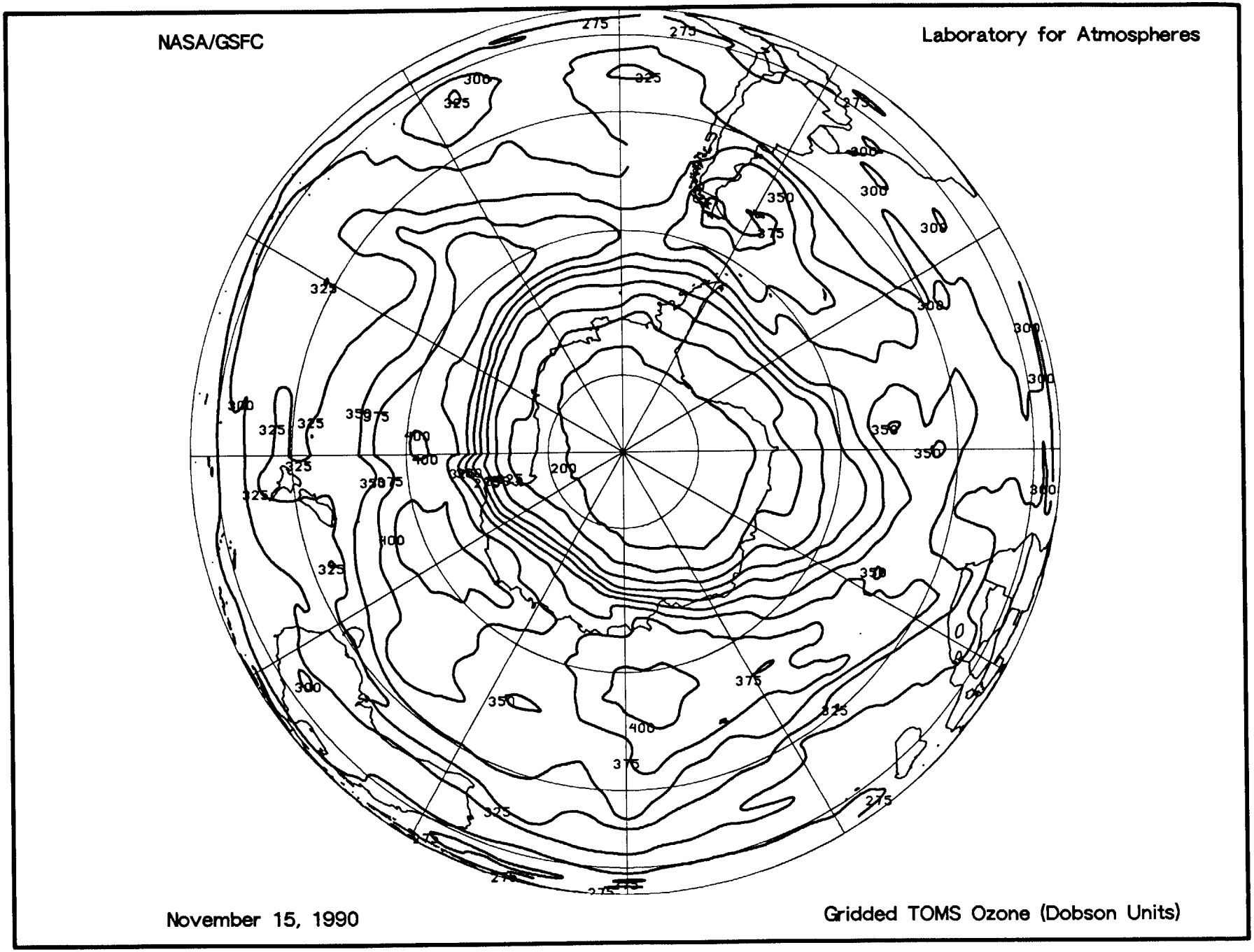
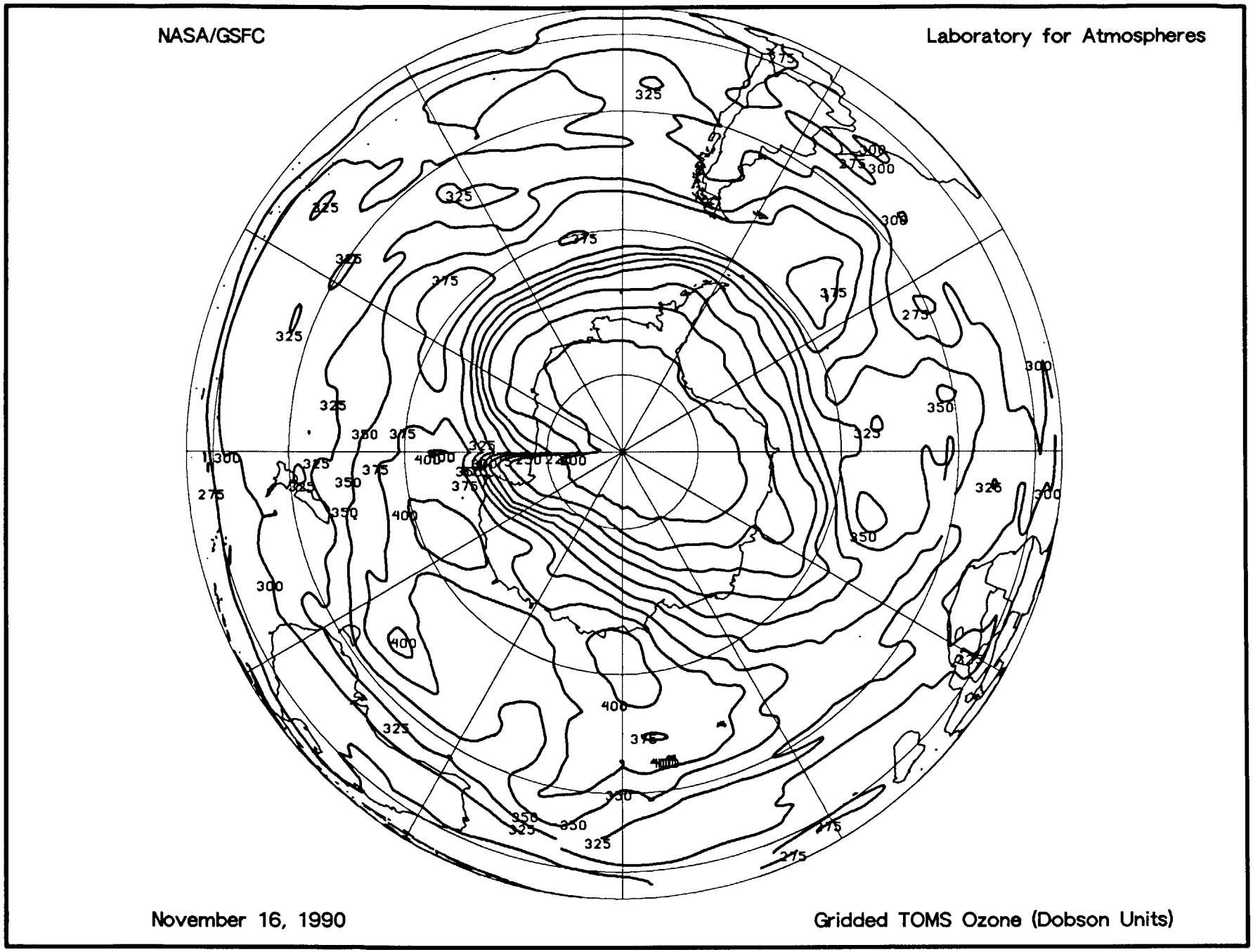
Laboratory for Atmospheres
November 14, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 15, 1990
Gridded TOMS Ozone (Dobson Units)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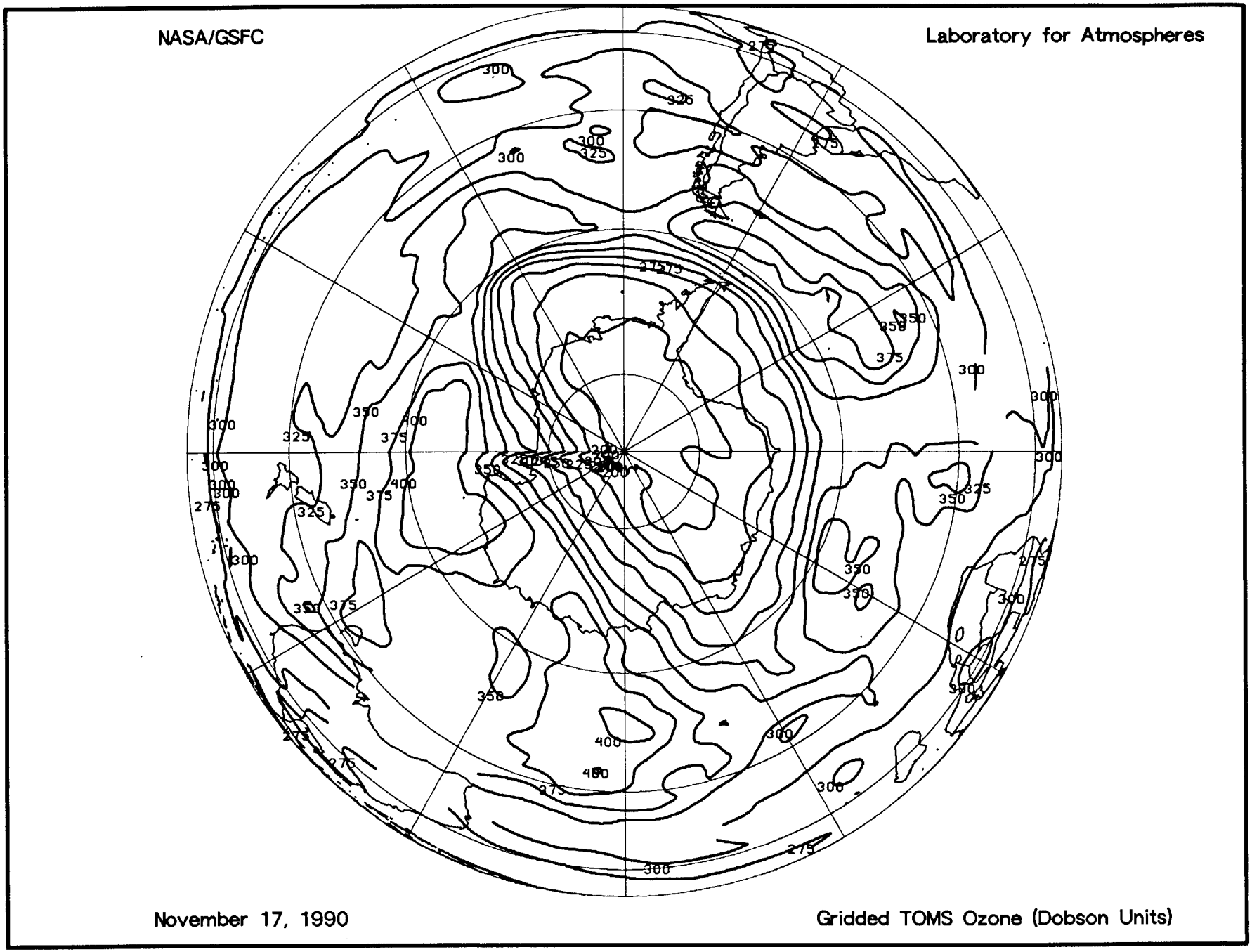
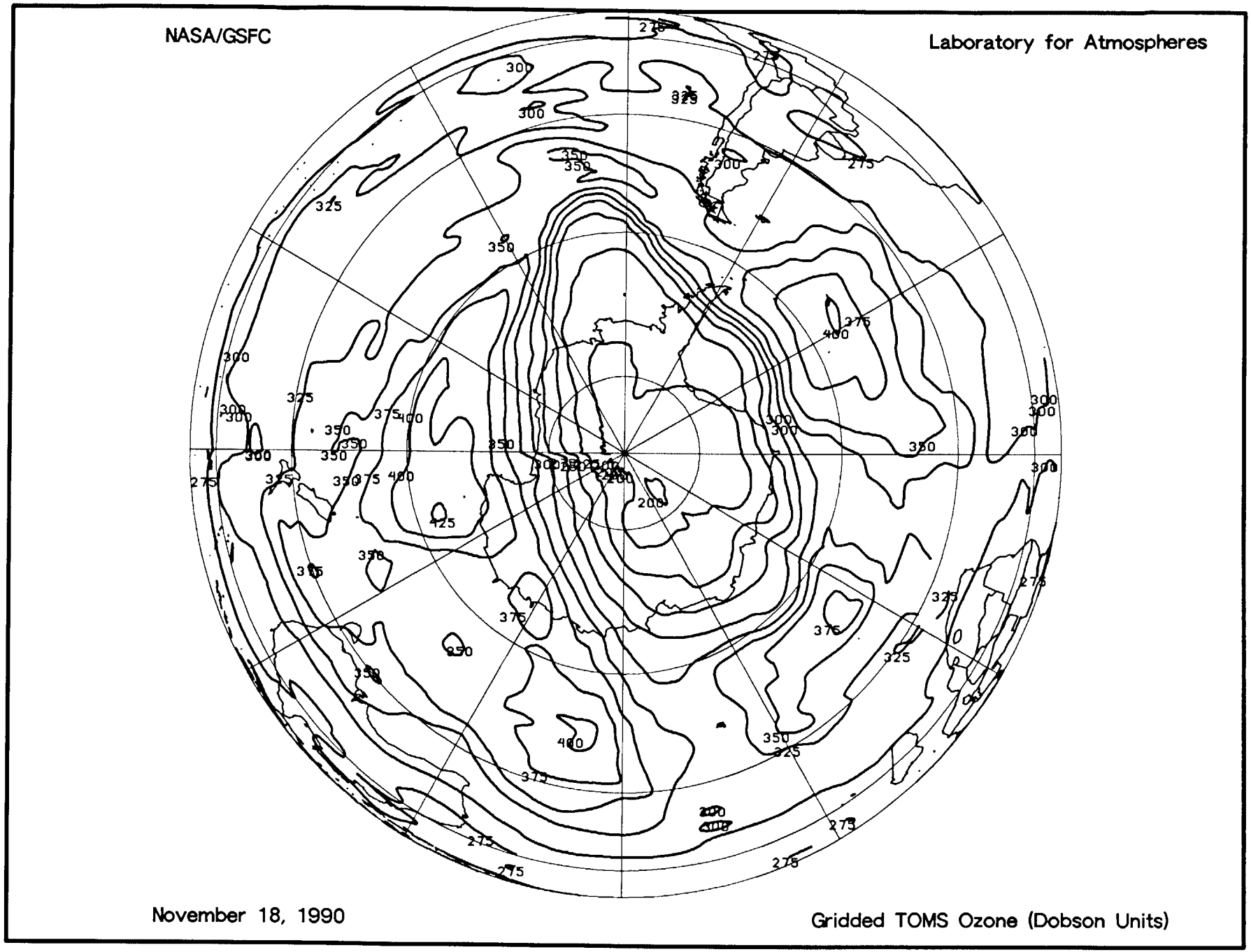
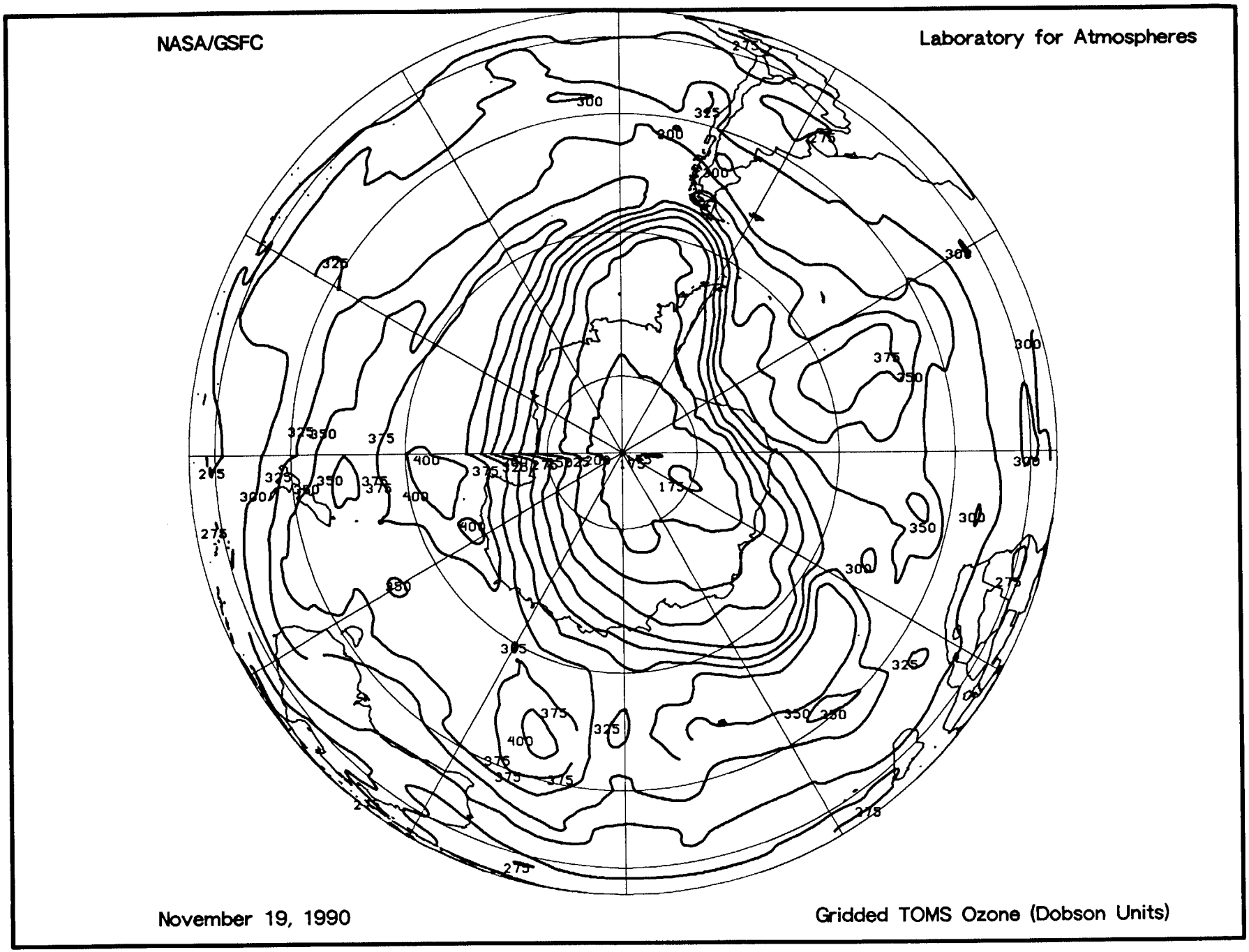
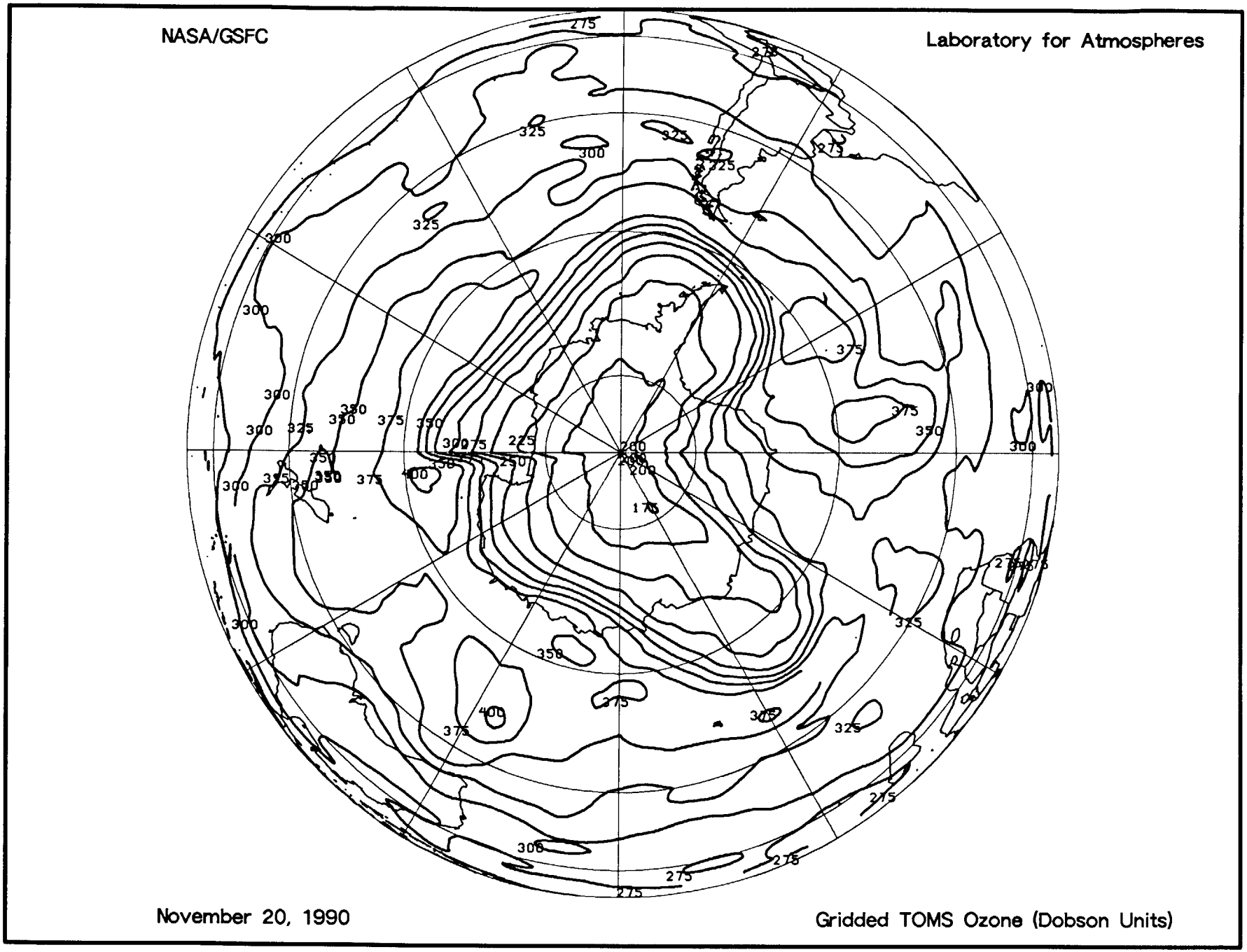
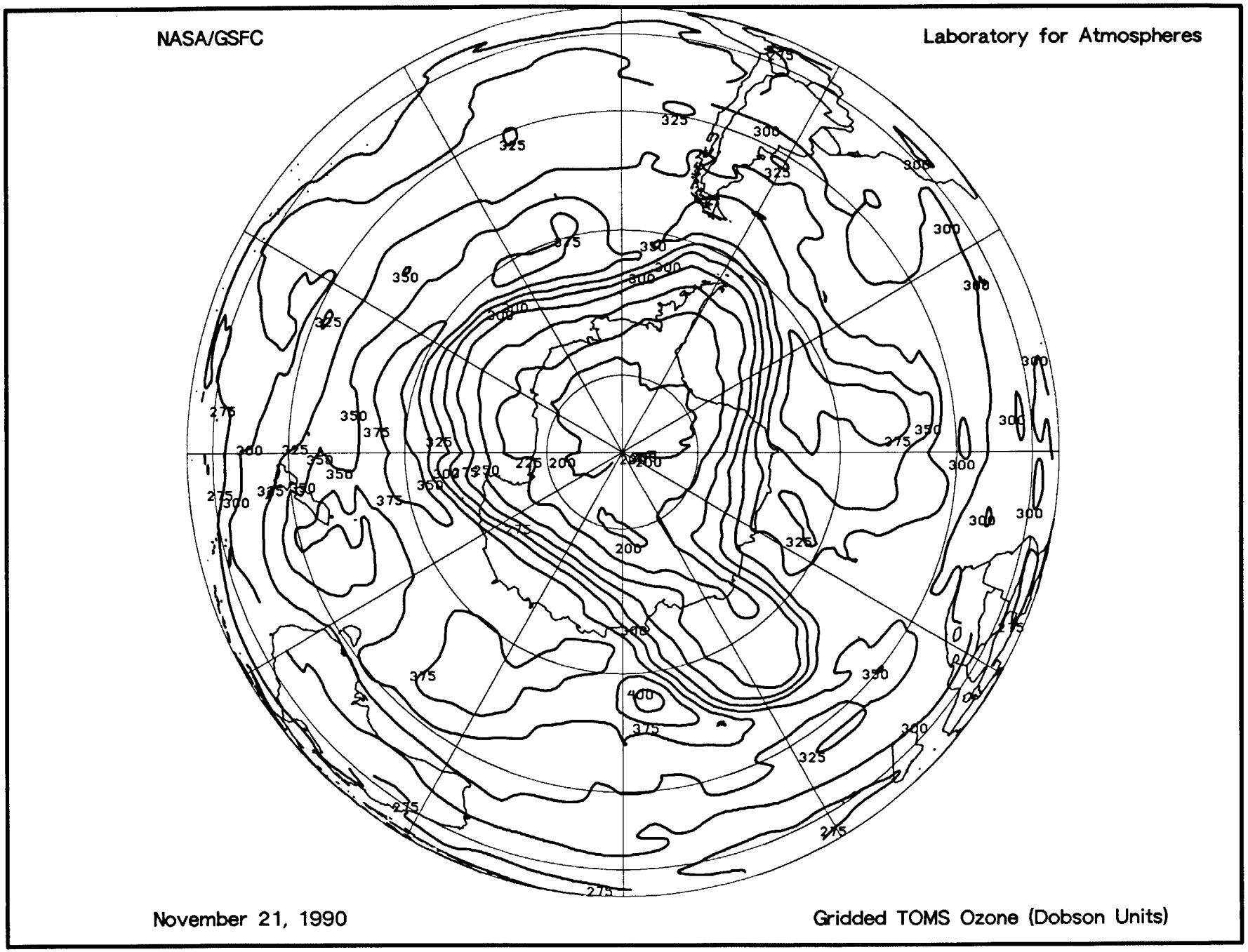
Laboratory for Atmospheres
November 16, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 17, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 18, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 19, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 20, 1990
Gridded TOMS Ozone (Dobson Units)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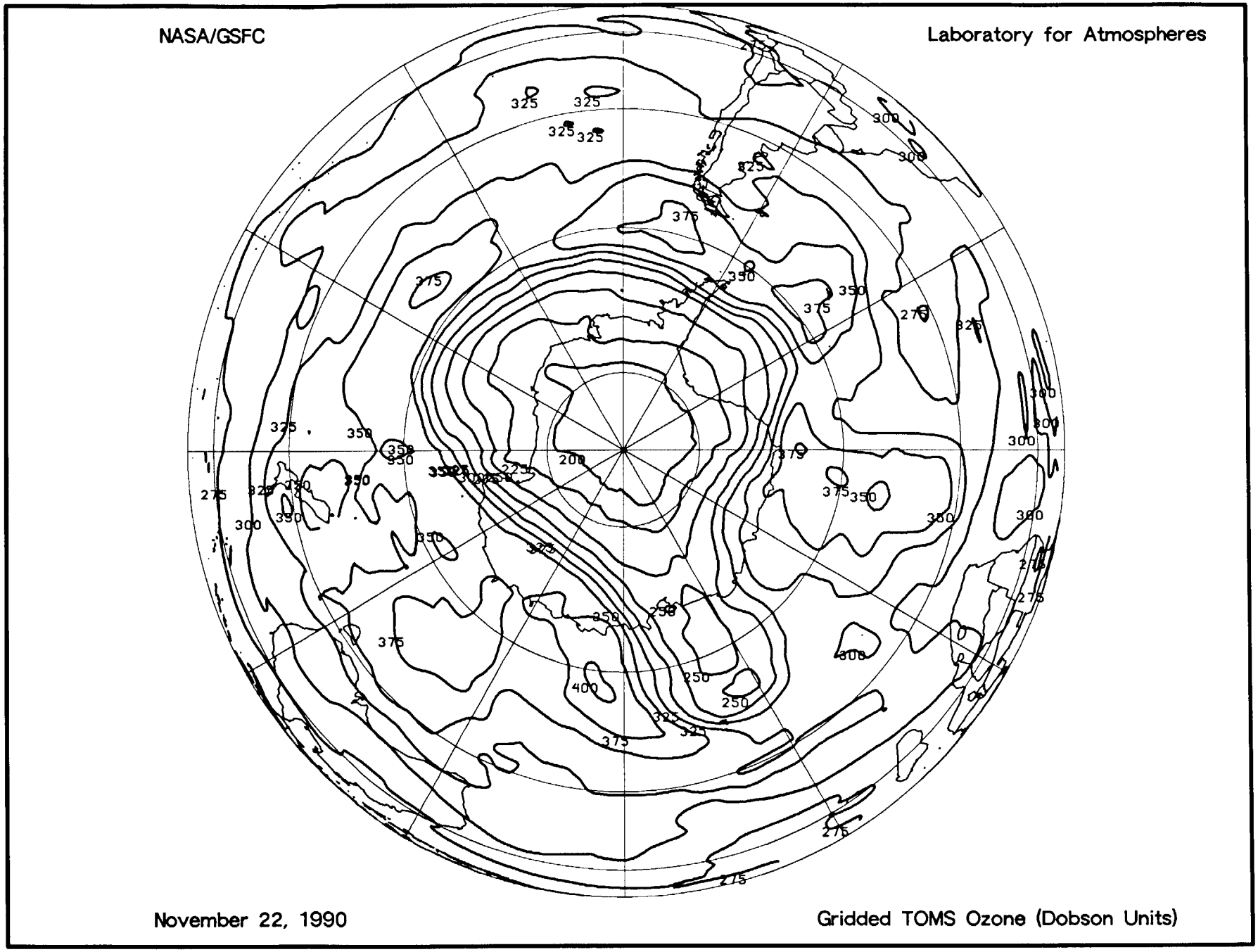
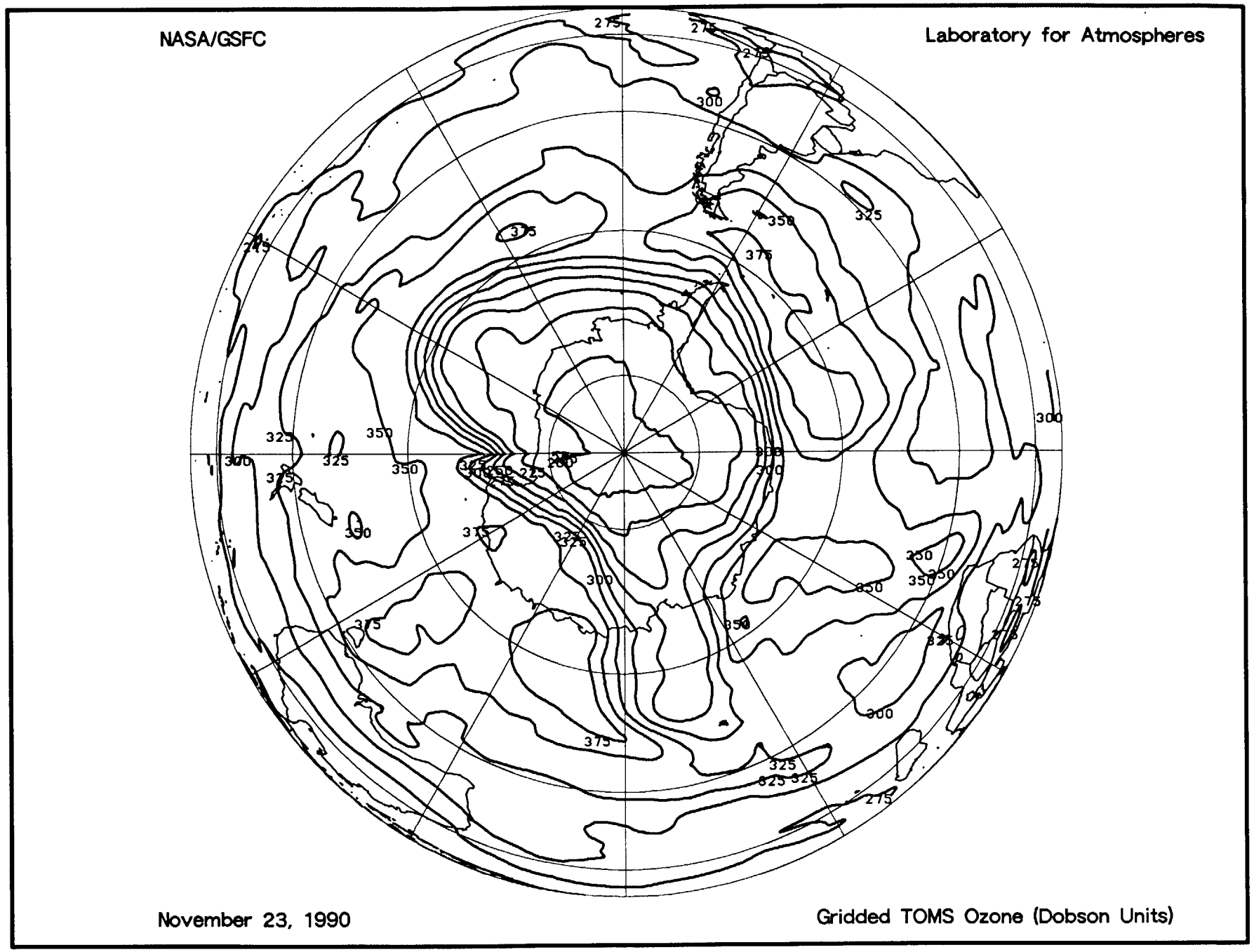
Laboratory for Atmospheres
November 21, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 22, 1990
Gridded TOMS Ozone (Dobson Units)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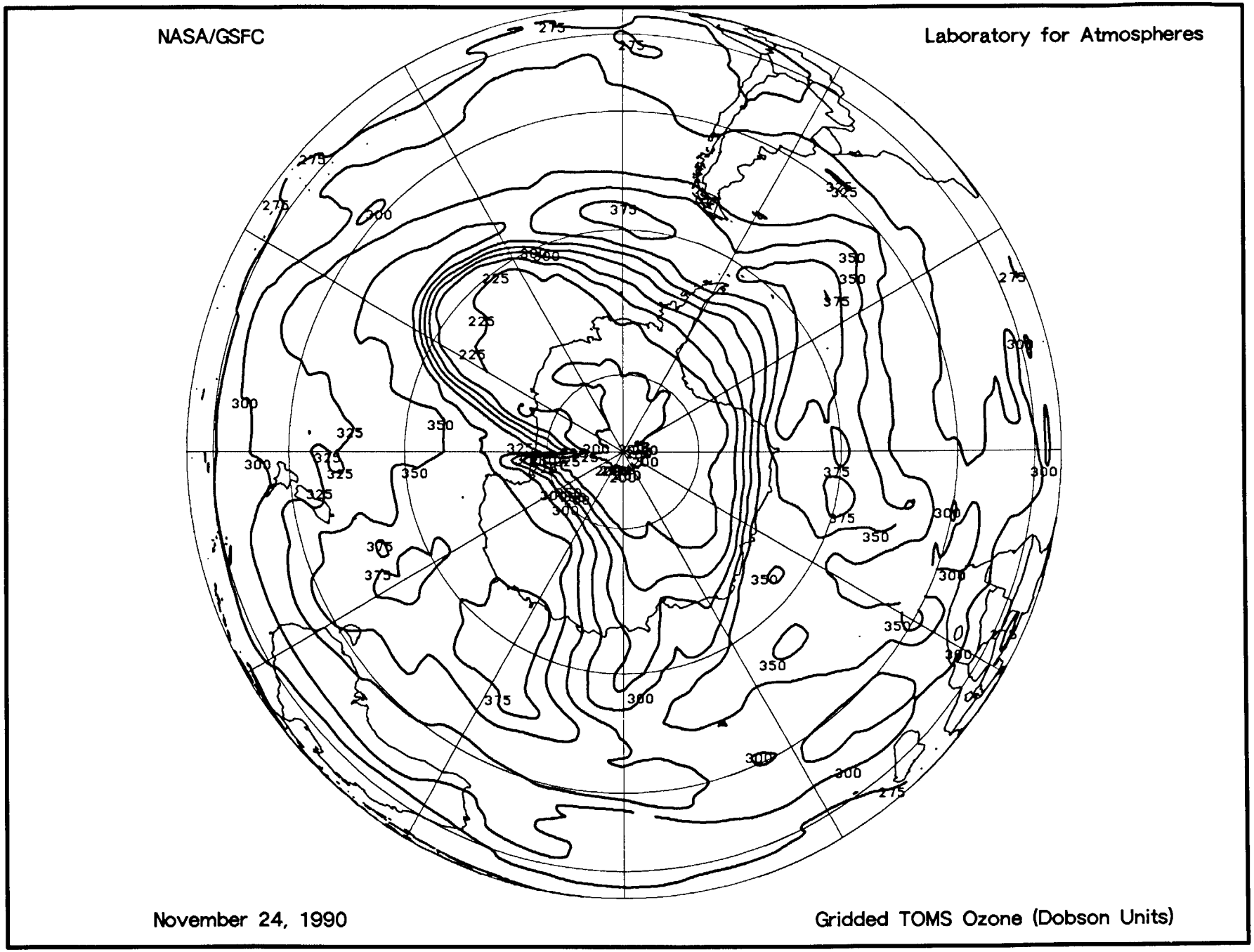
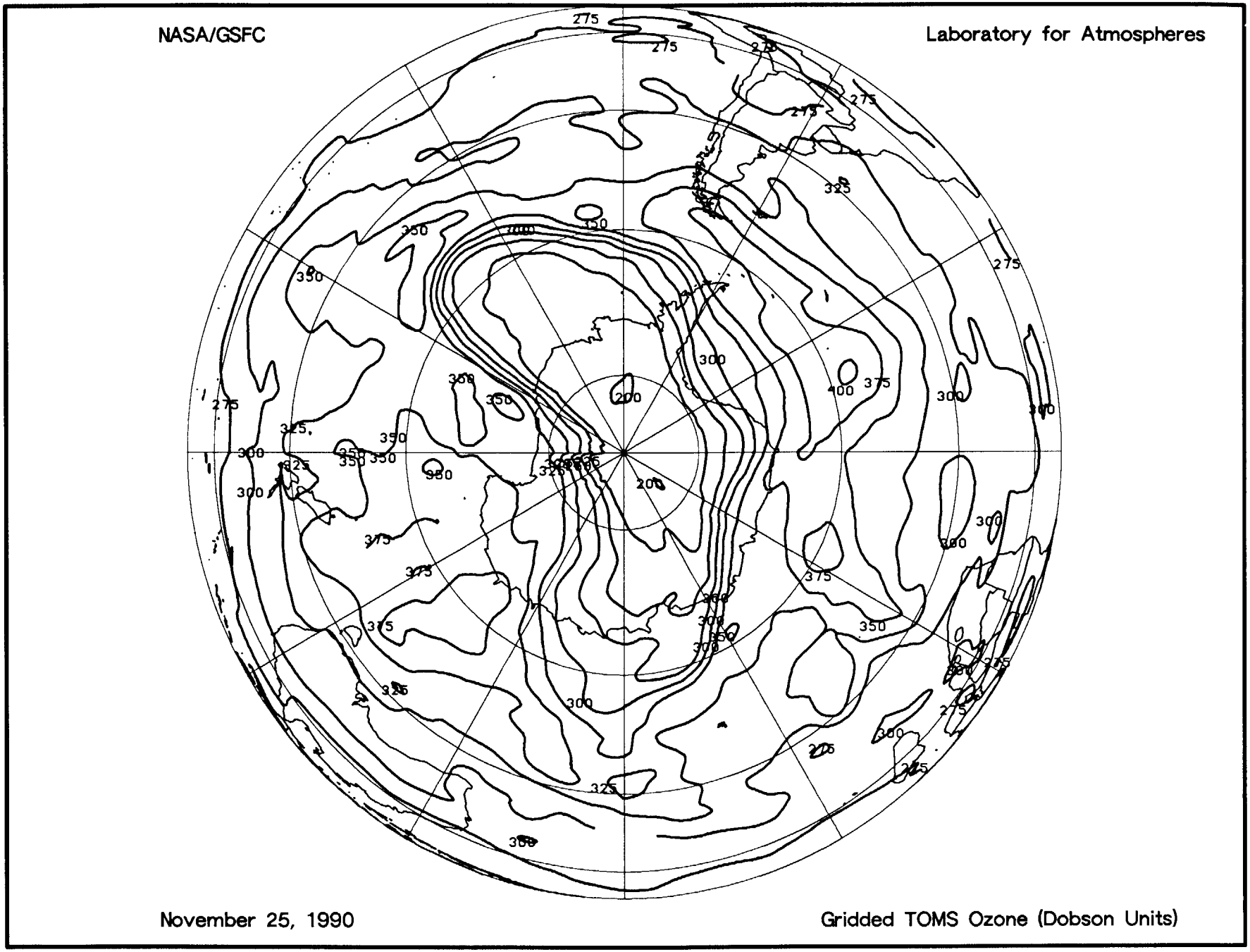
Laboratory for Atmospheres
November 23, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 24, 1990
Gridded TOMS Ozone (Dobson Units)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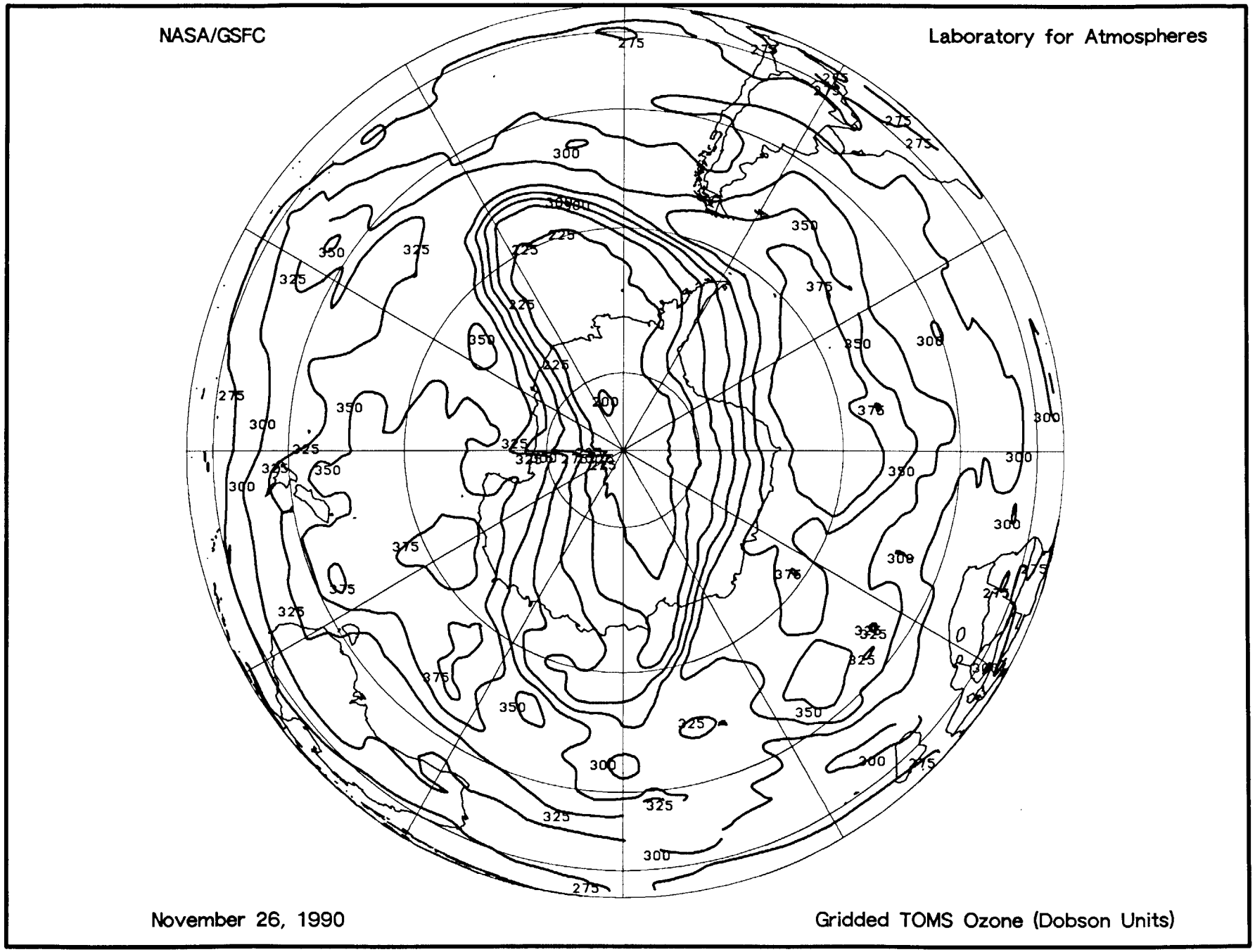
Laboratory for Atmospheres
November 25, 1990
Gridded TOMS Ozone (Dobson Units)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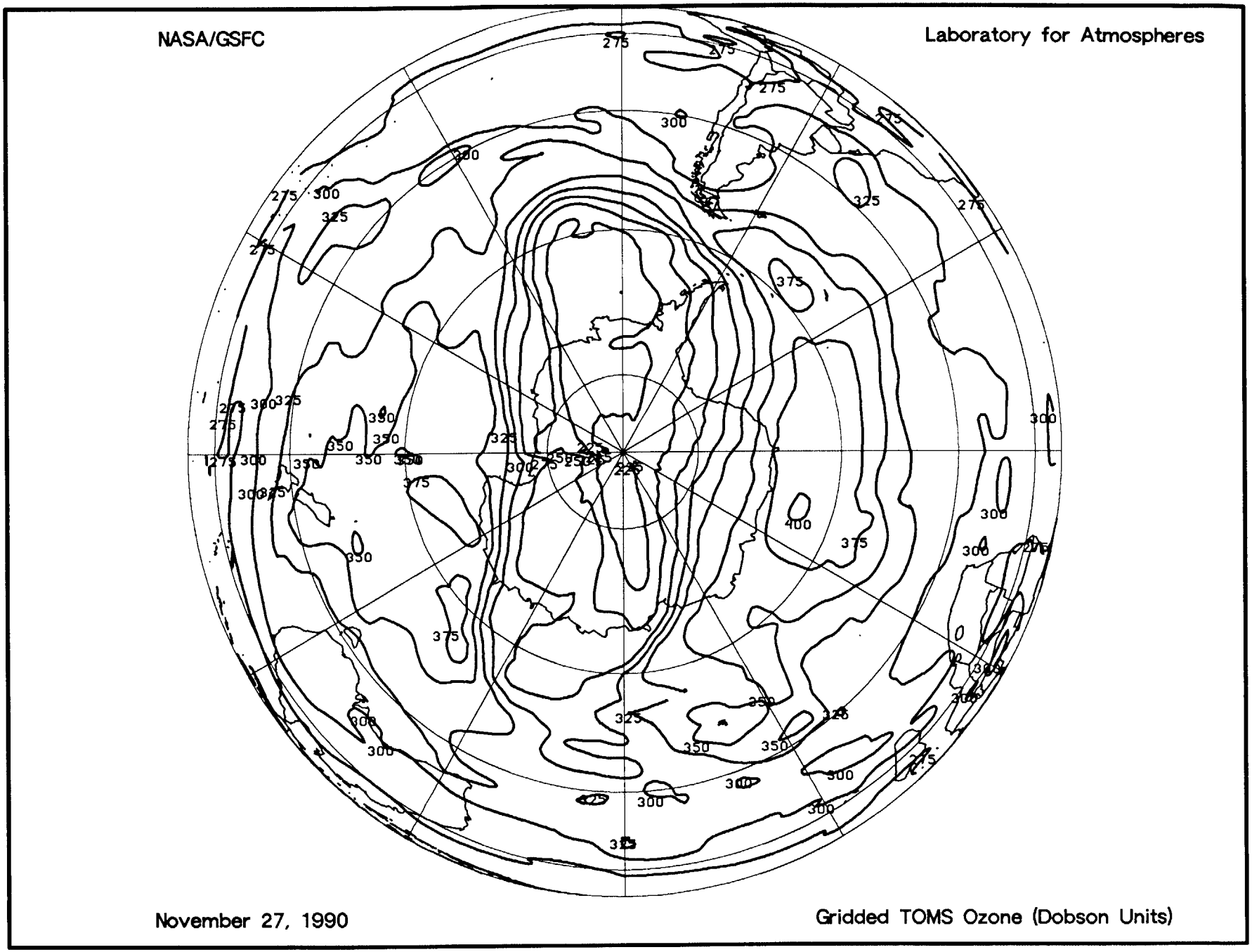
Laboratory for Atmospheres
November 26, 1990
Gridded TOMS Ozone (Dobson Units)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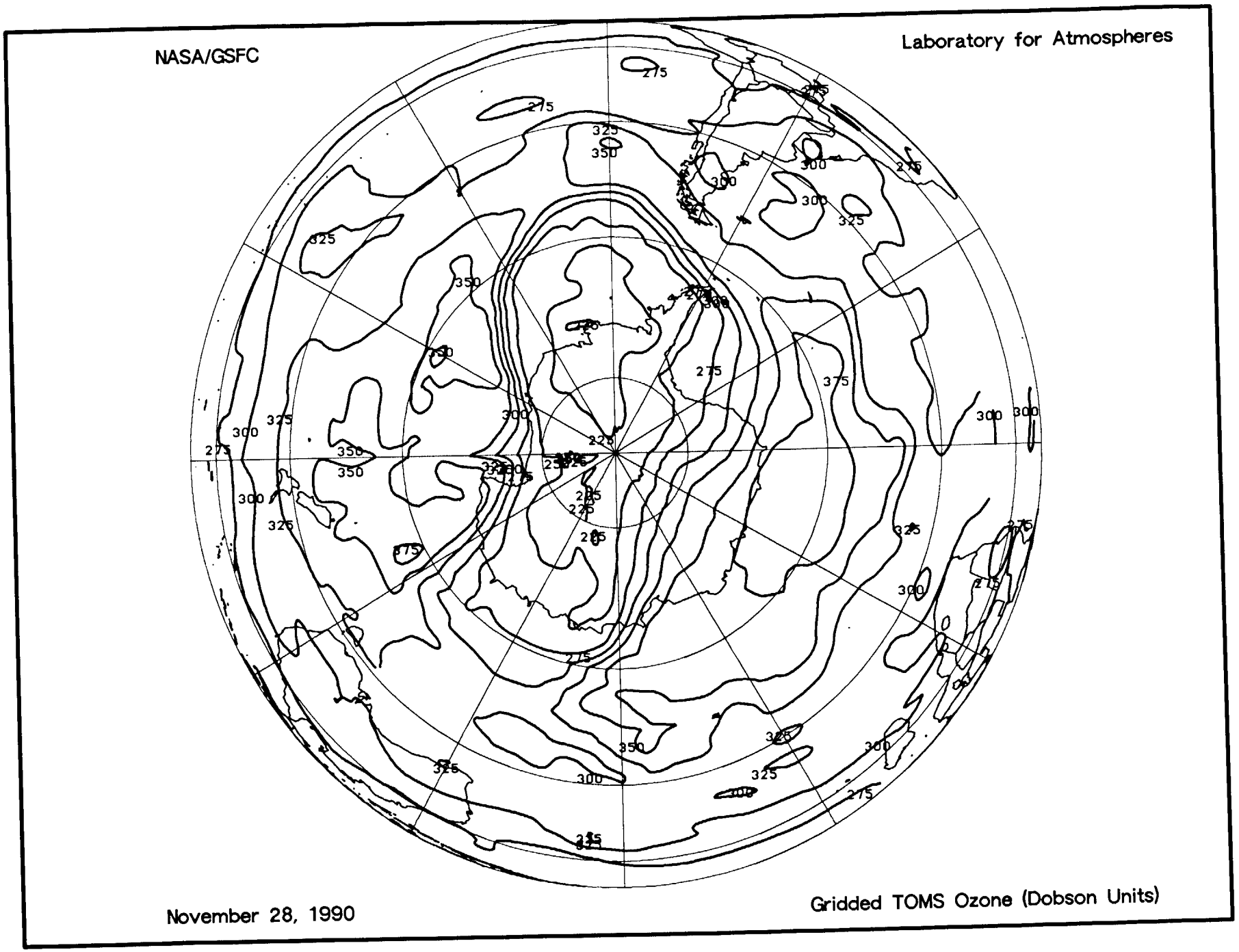
Laboratory for Atmospheres
November 27, 1990
Gridded TOMS Ozone (Dobson Units)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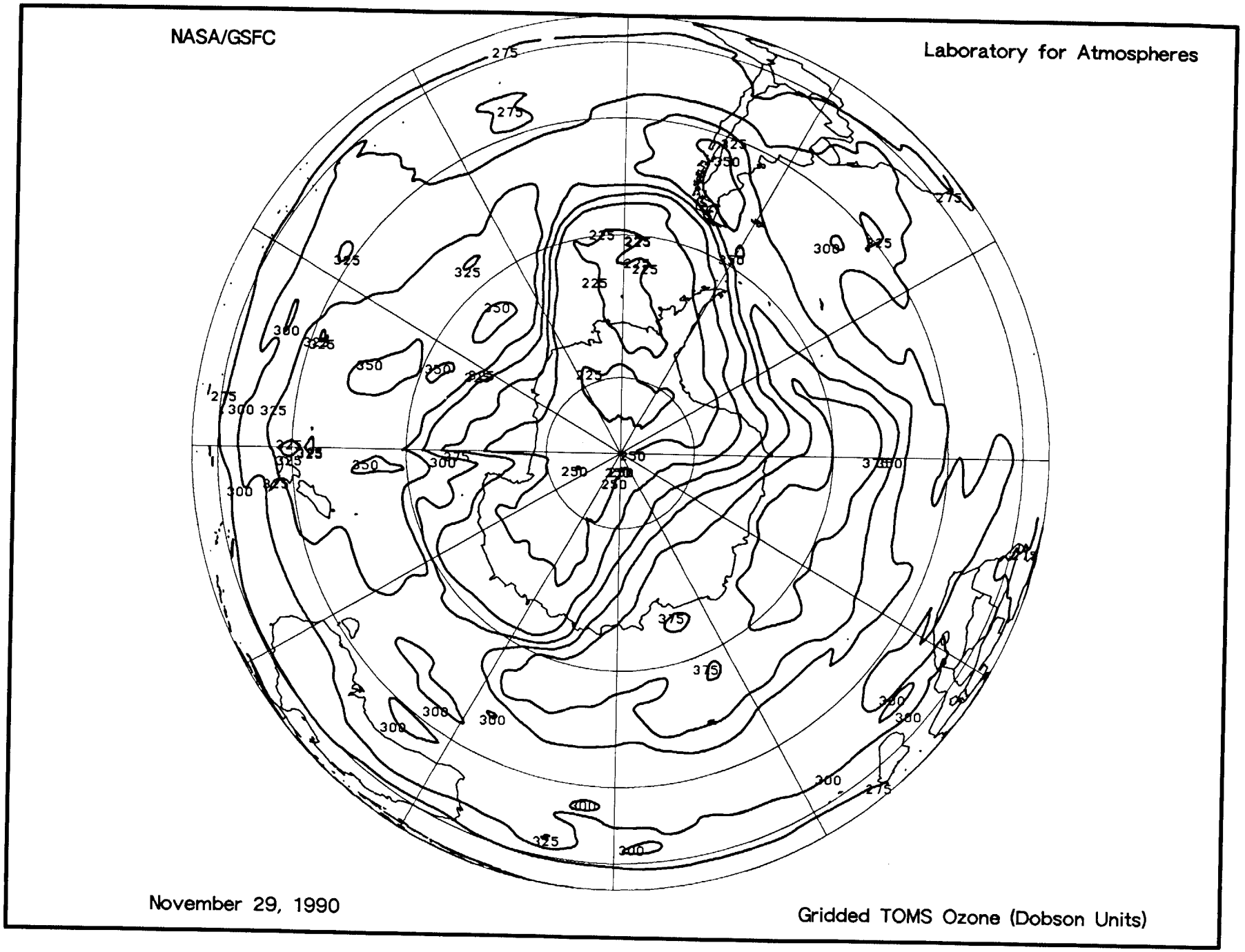
Laboratory for Atmospheres
November 28, 1990
Gridded TOMS Ozone (Dobson Units)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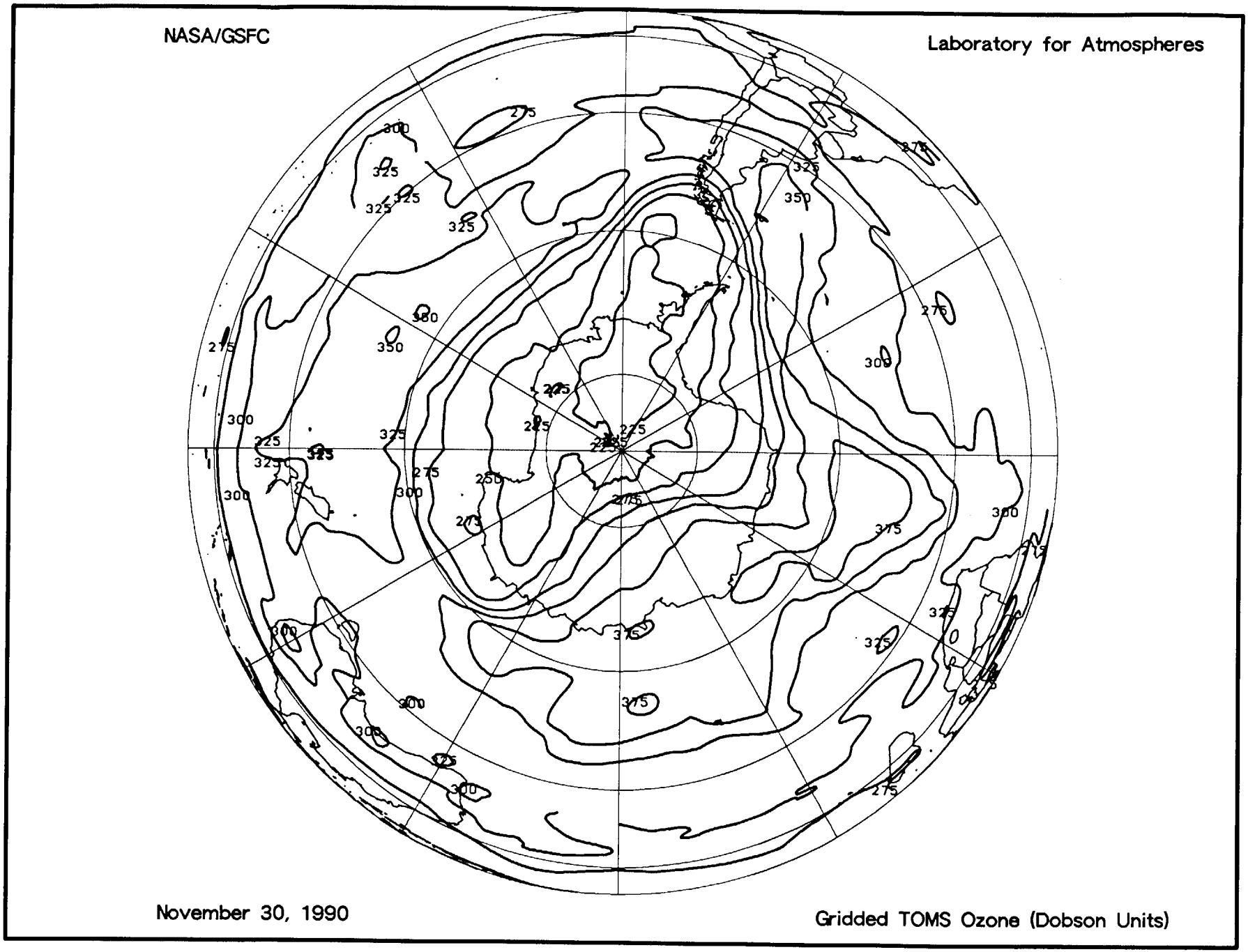
Laboratory for Atmospheres
November 29, 1990
Gridded TOMS Ozone (Dobson Units)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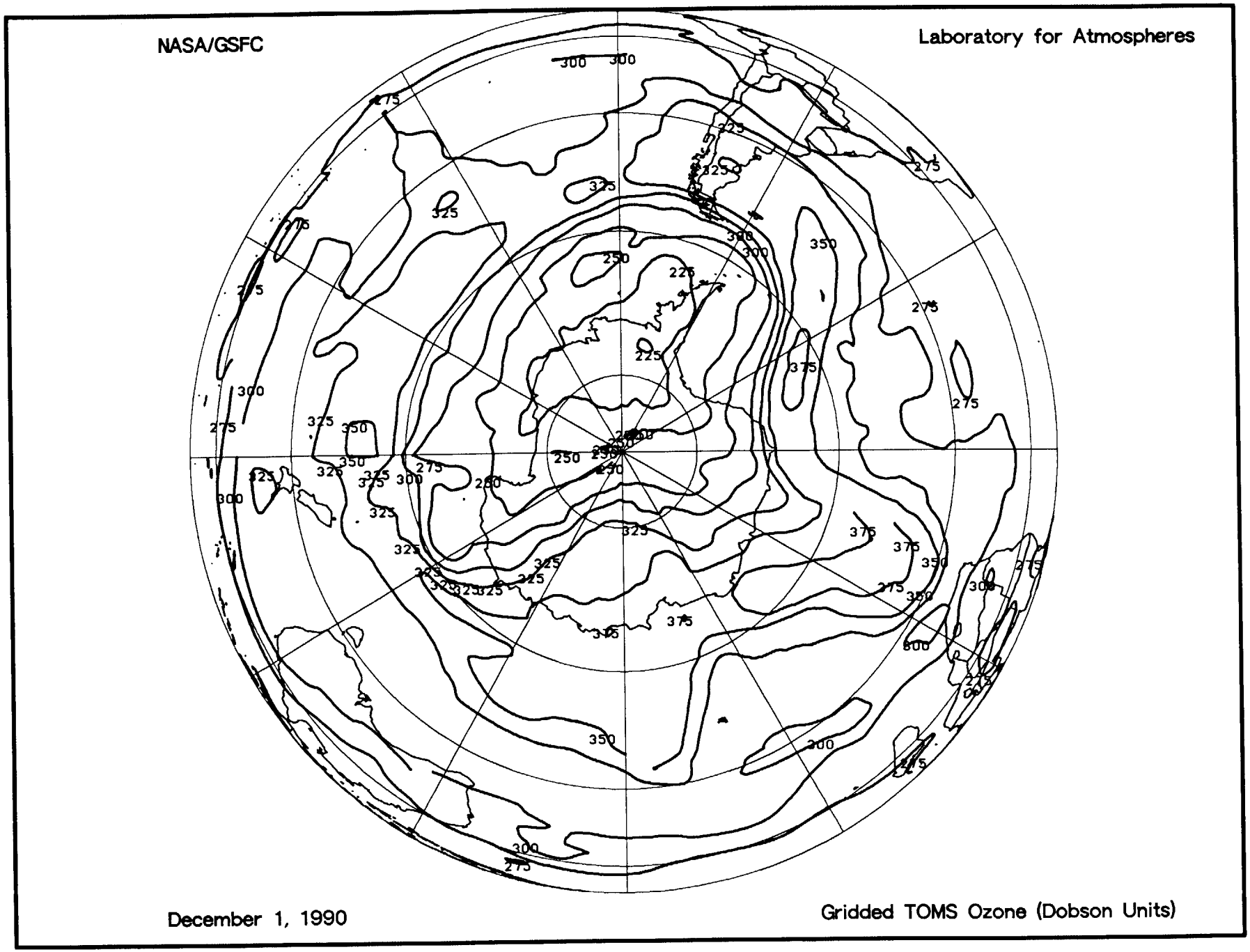
Laboratory for Atmospheres
November 30, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
December 1, 1990
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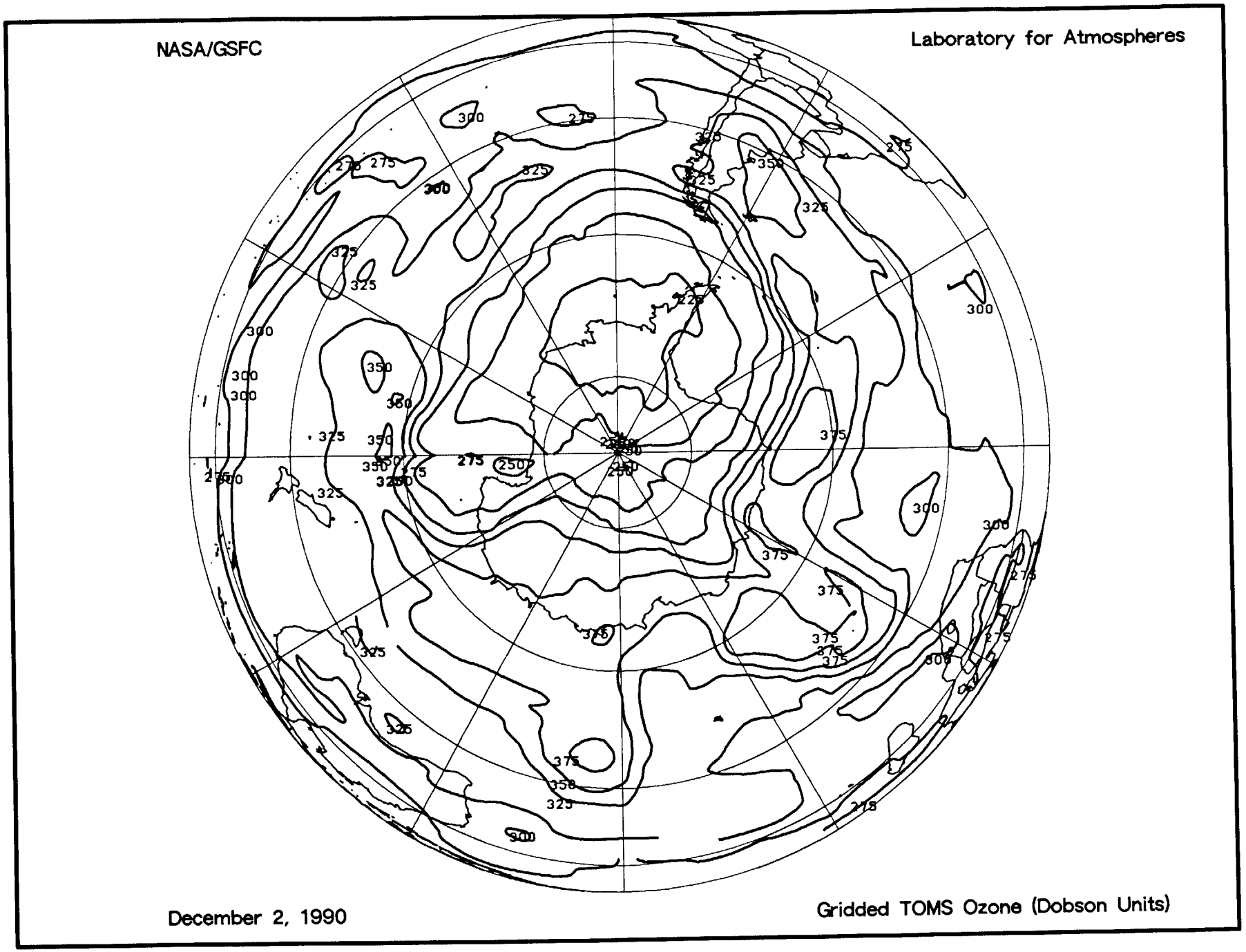
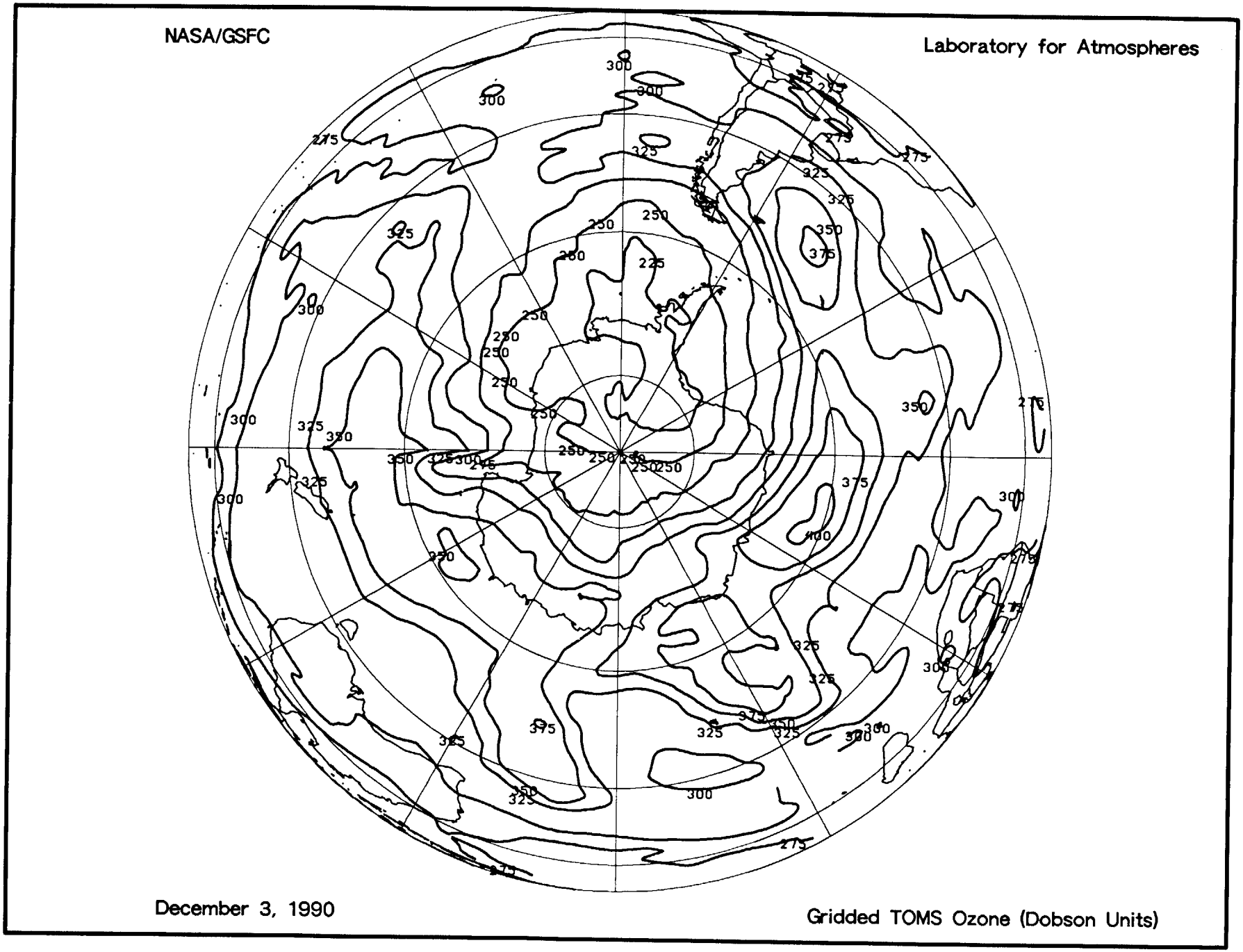

NASA/GSFC
Laboratory for Atmospheres
December 2, 1990
Gridded TOMS Ozone (Dobson Units)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Laboratory for Atmospheres
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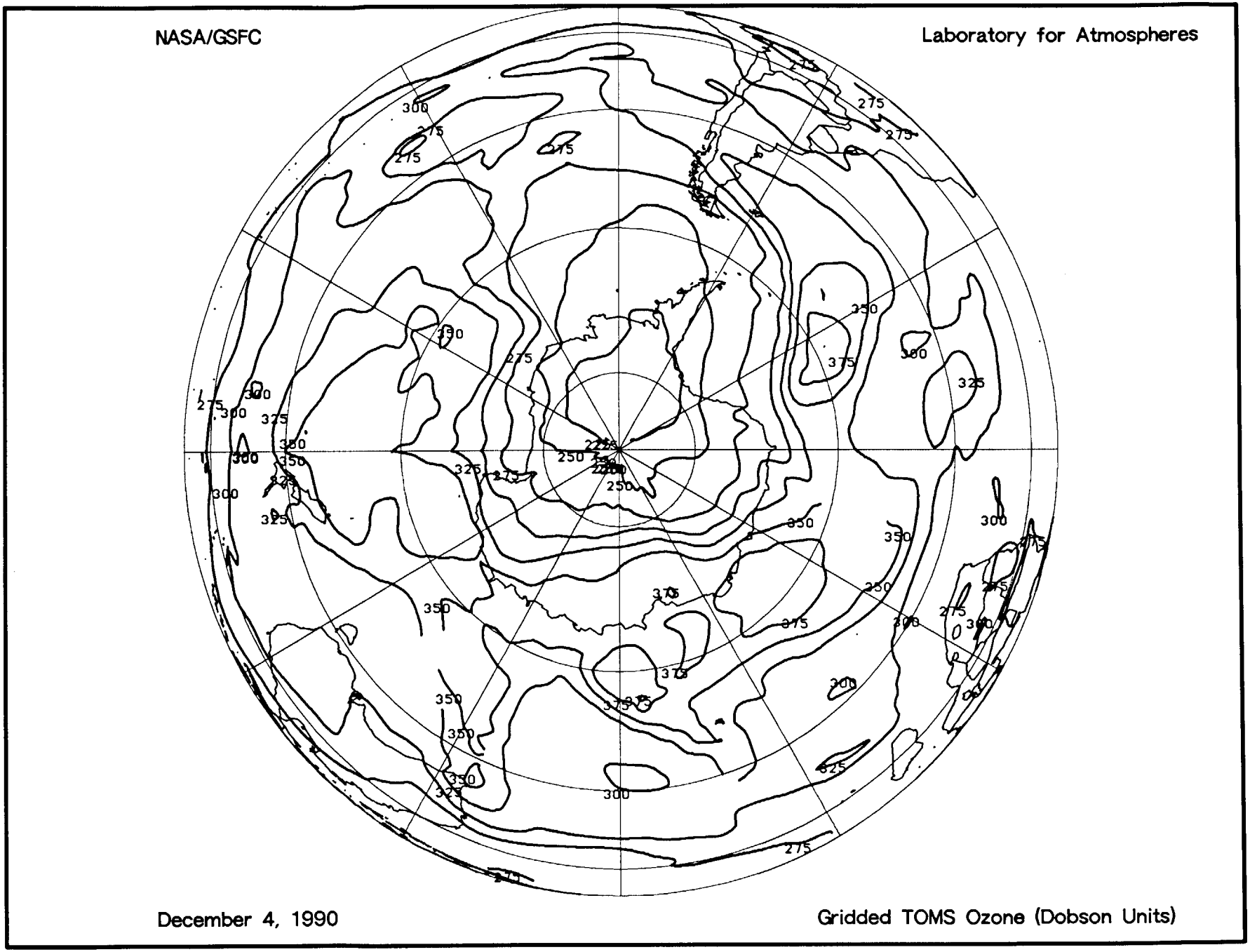
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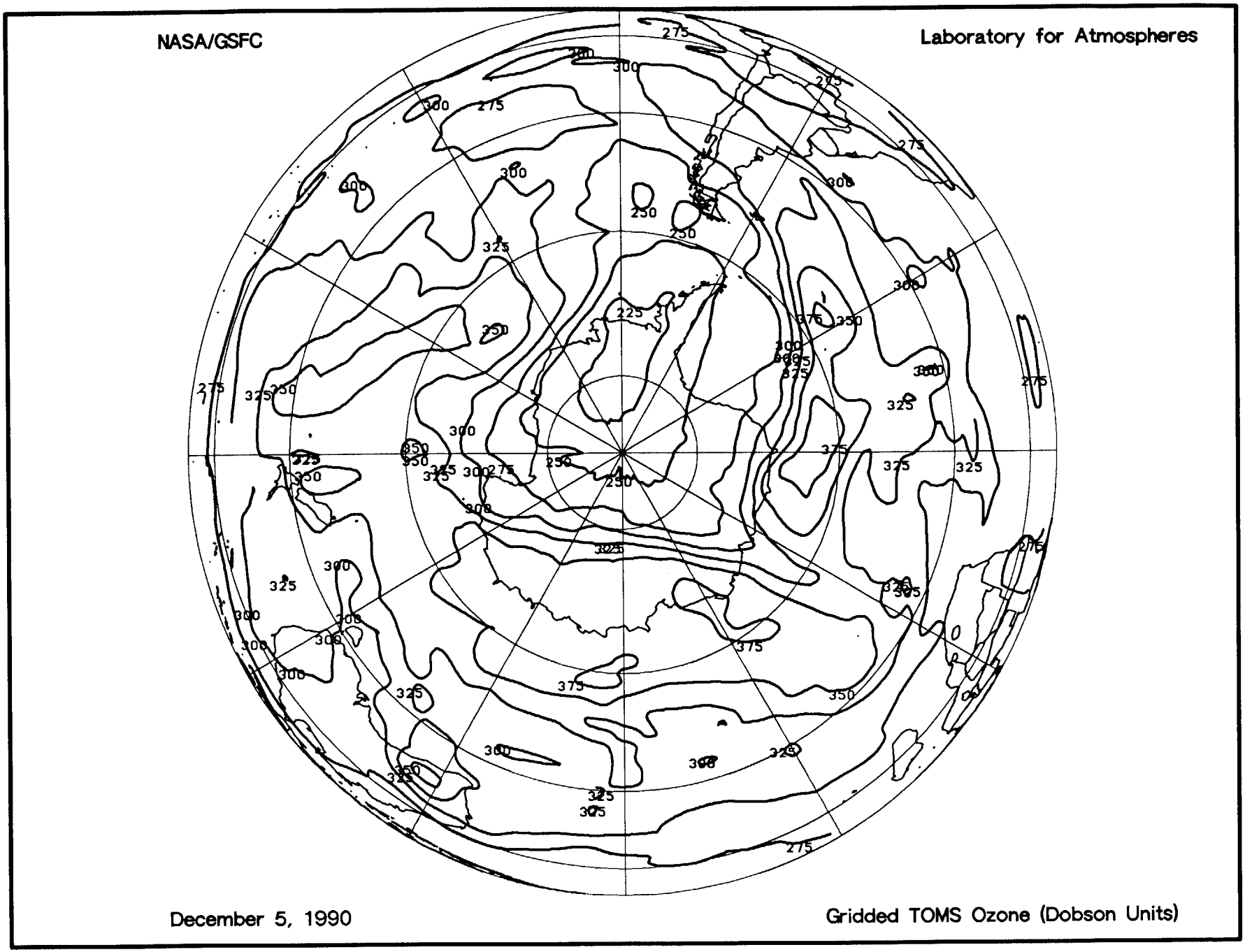
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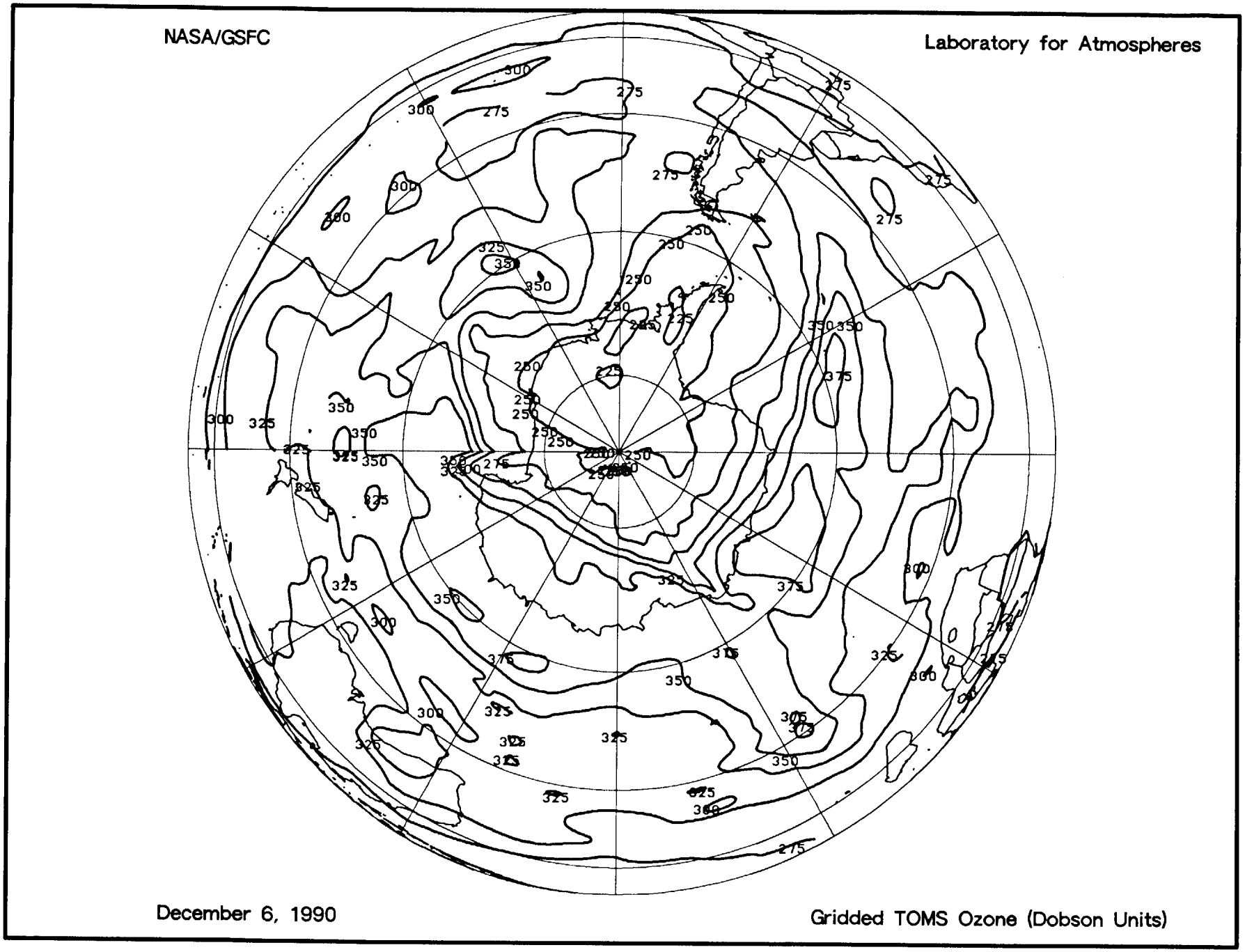
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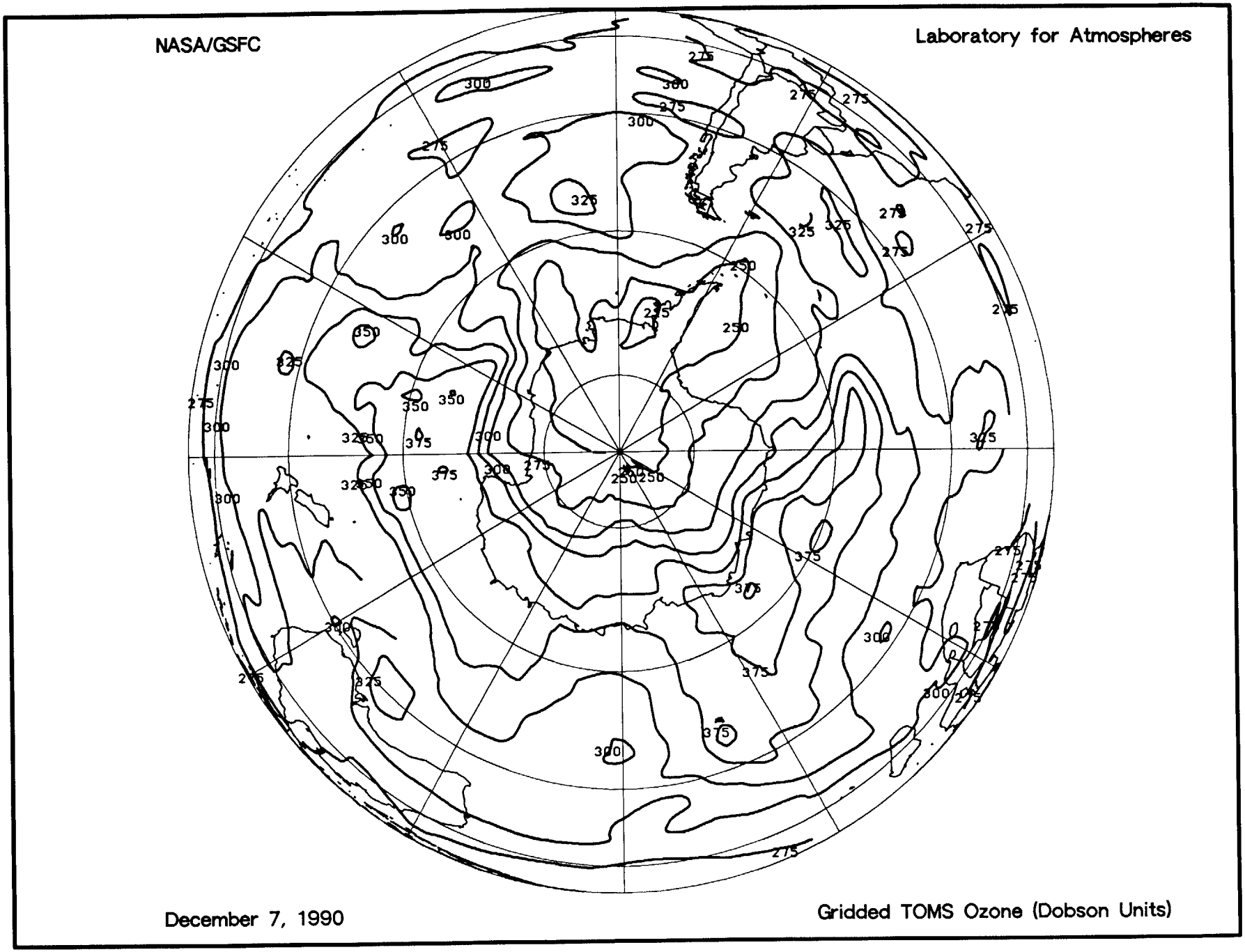
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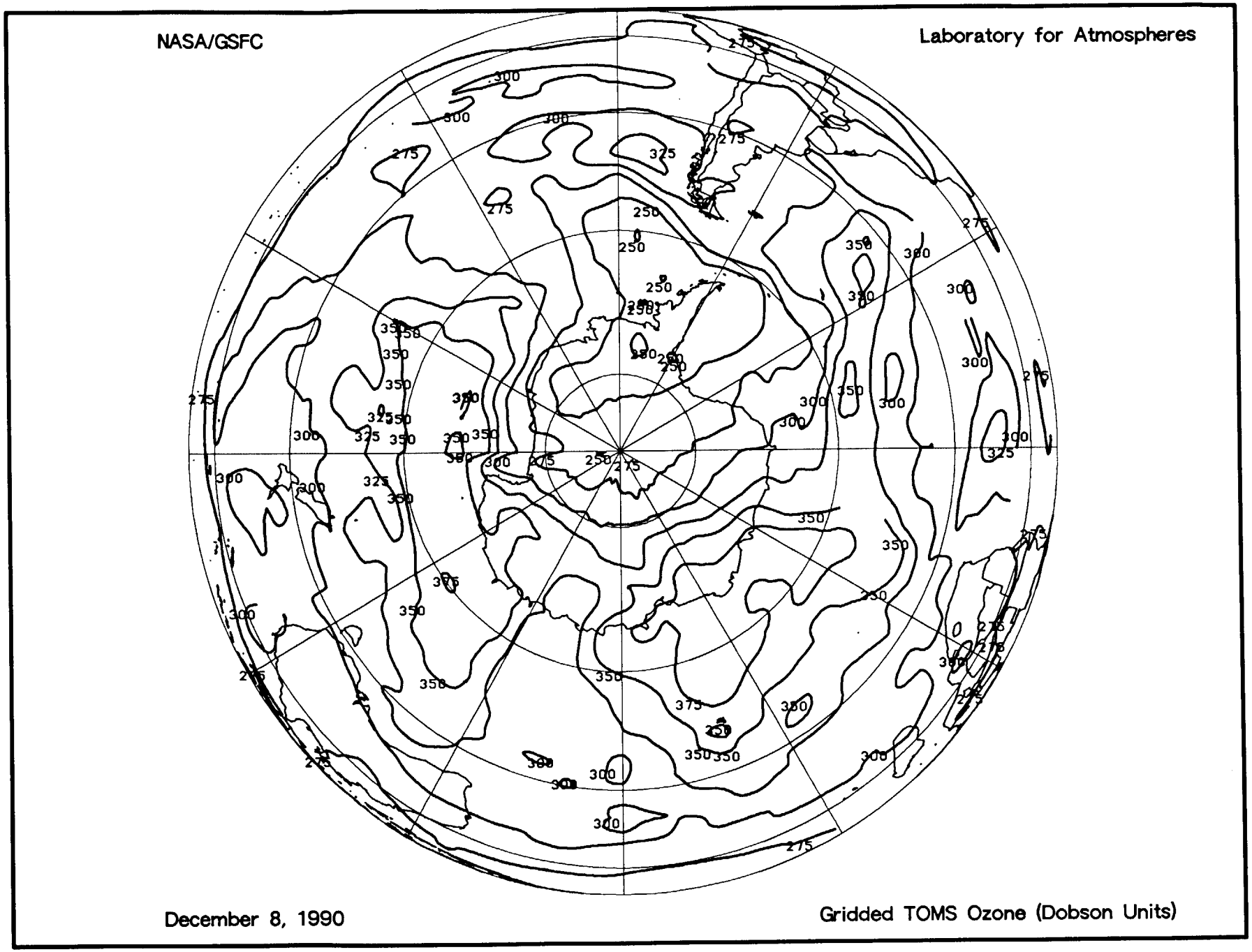
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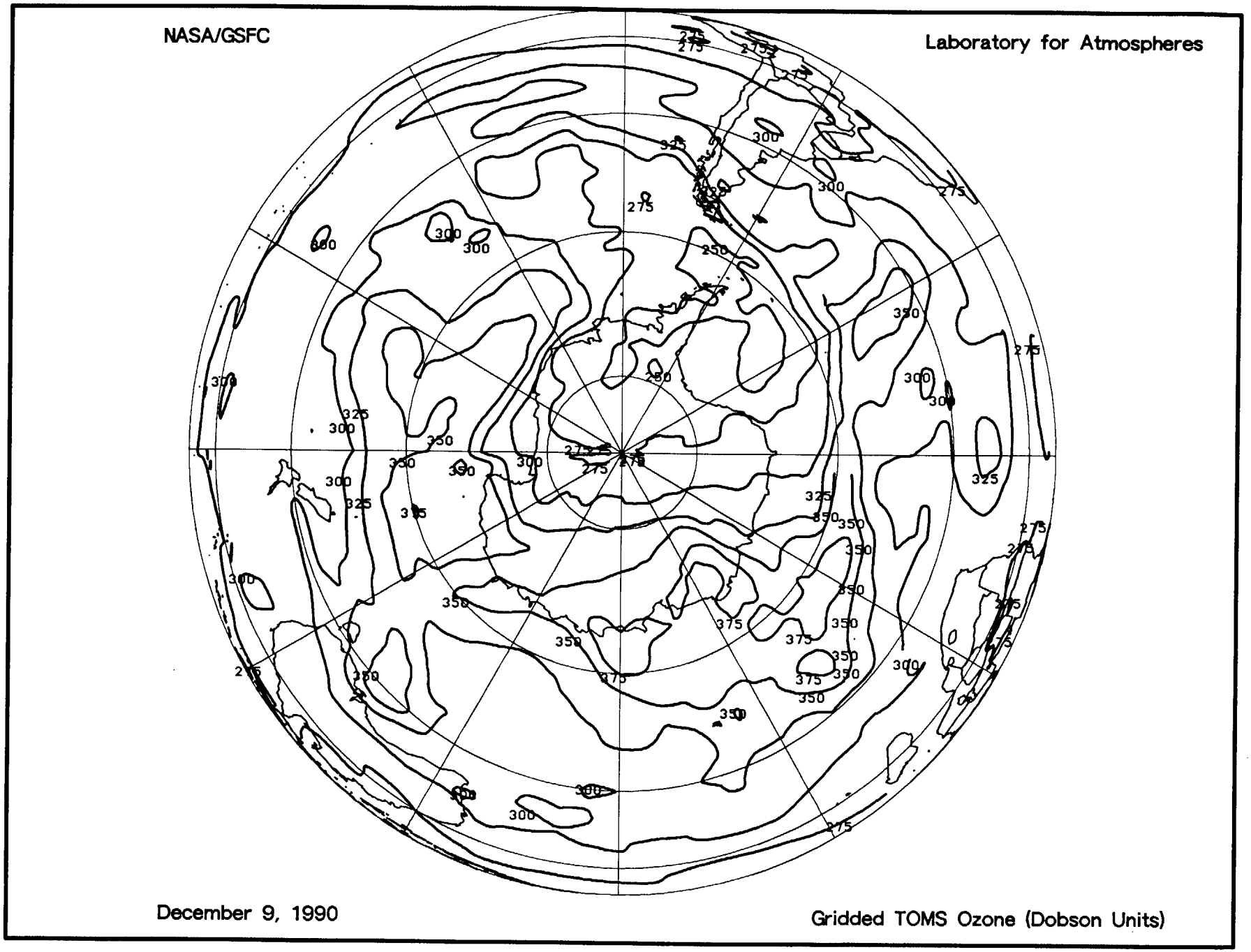
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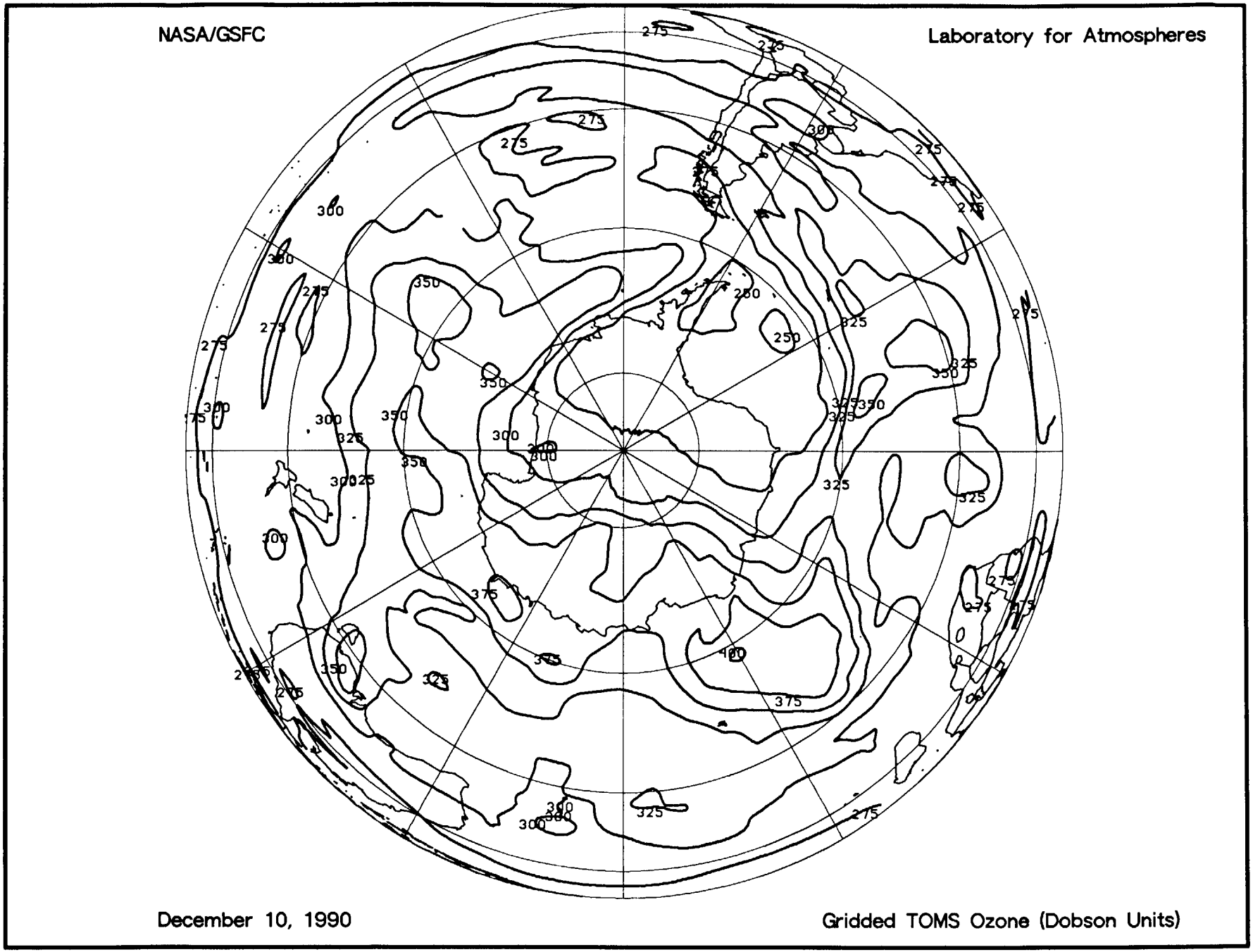
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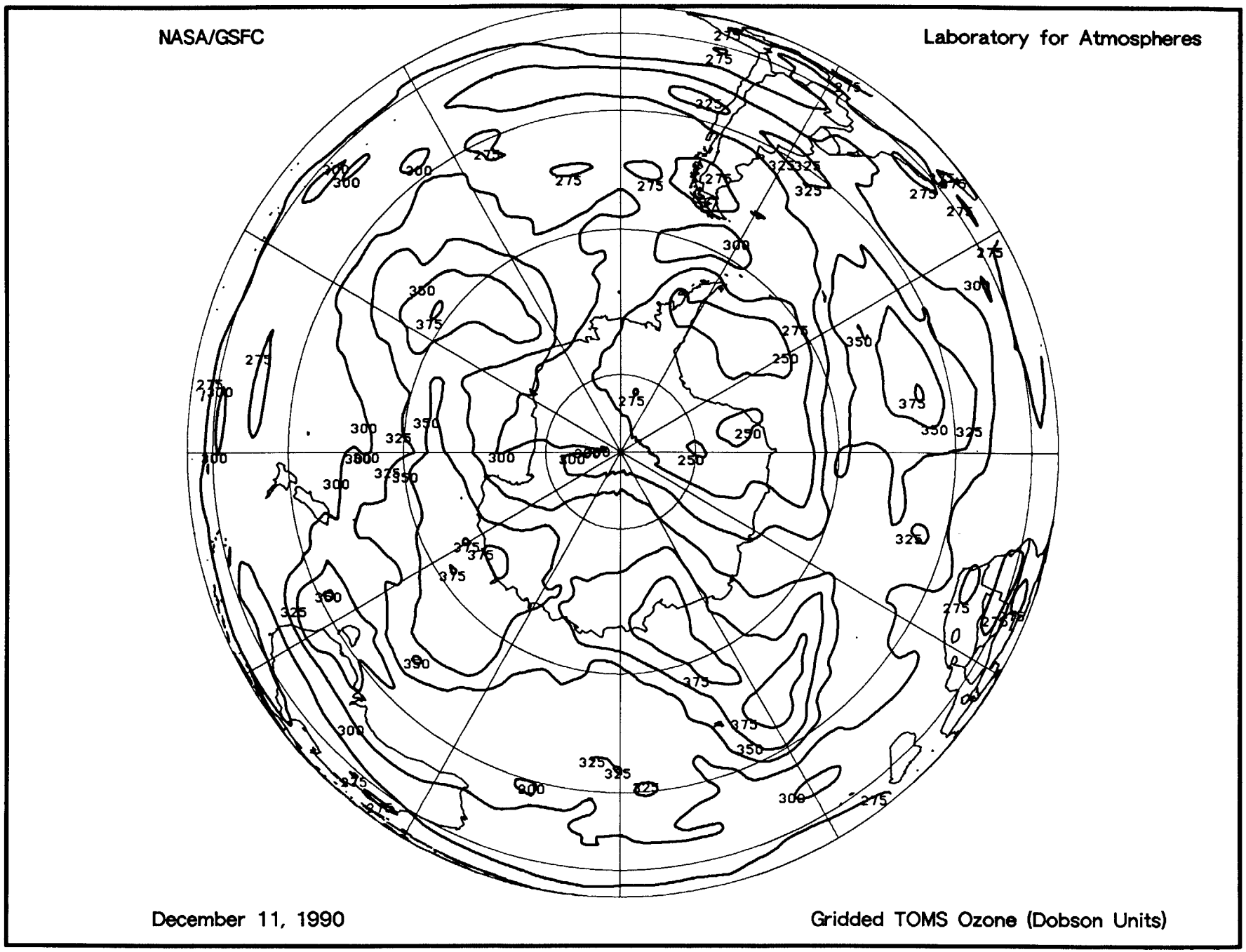
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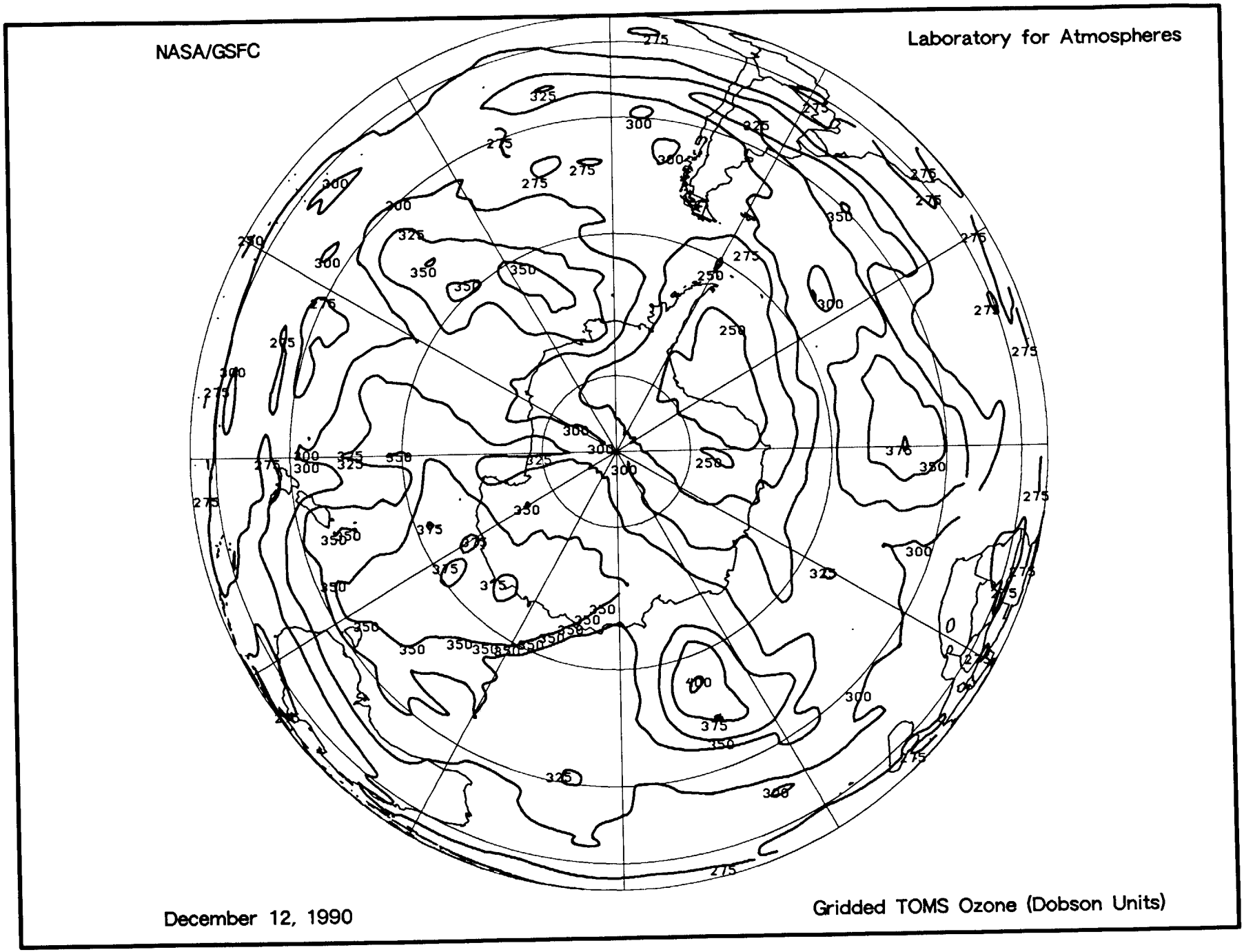
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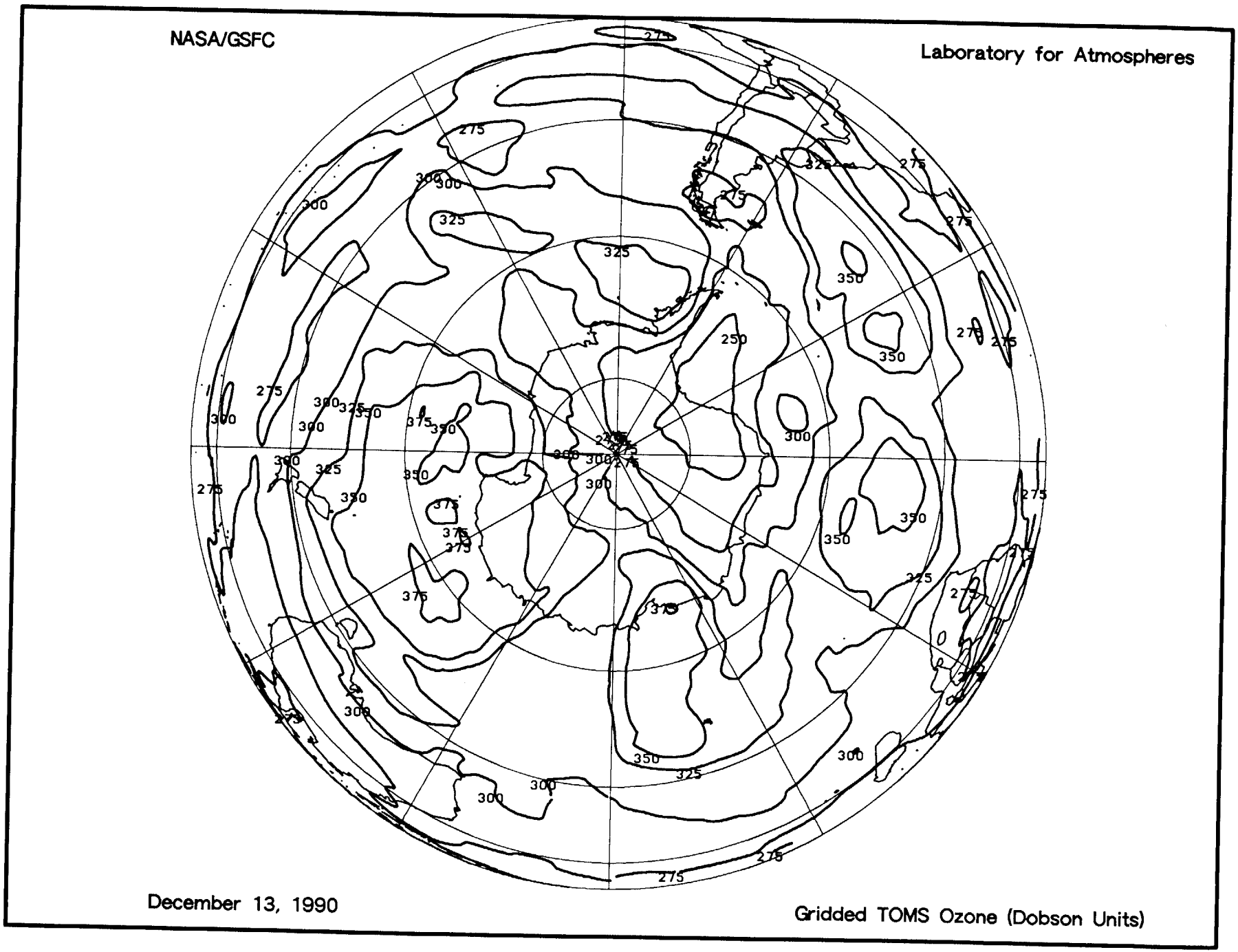
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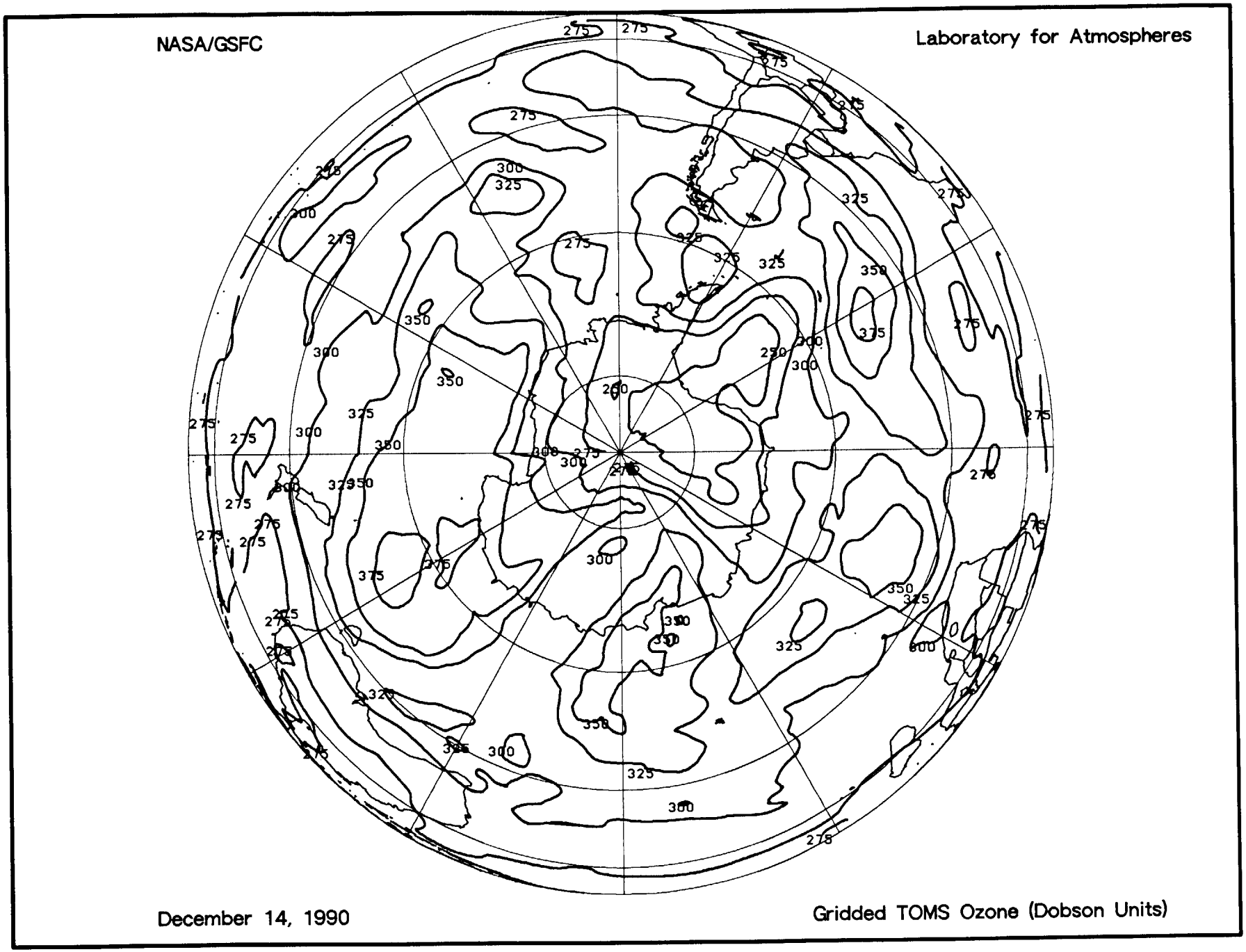
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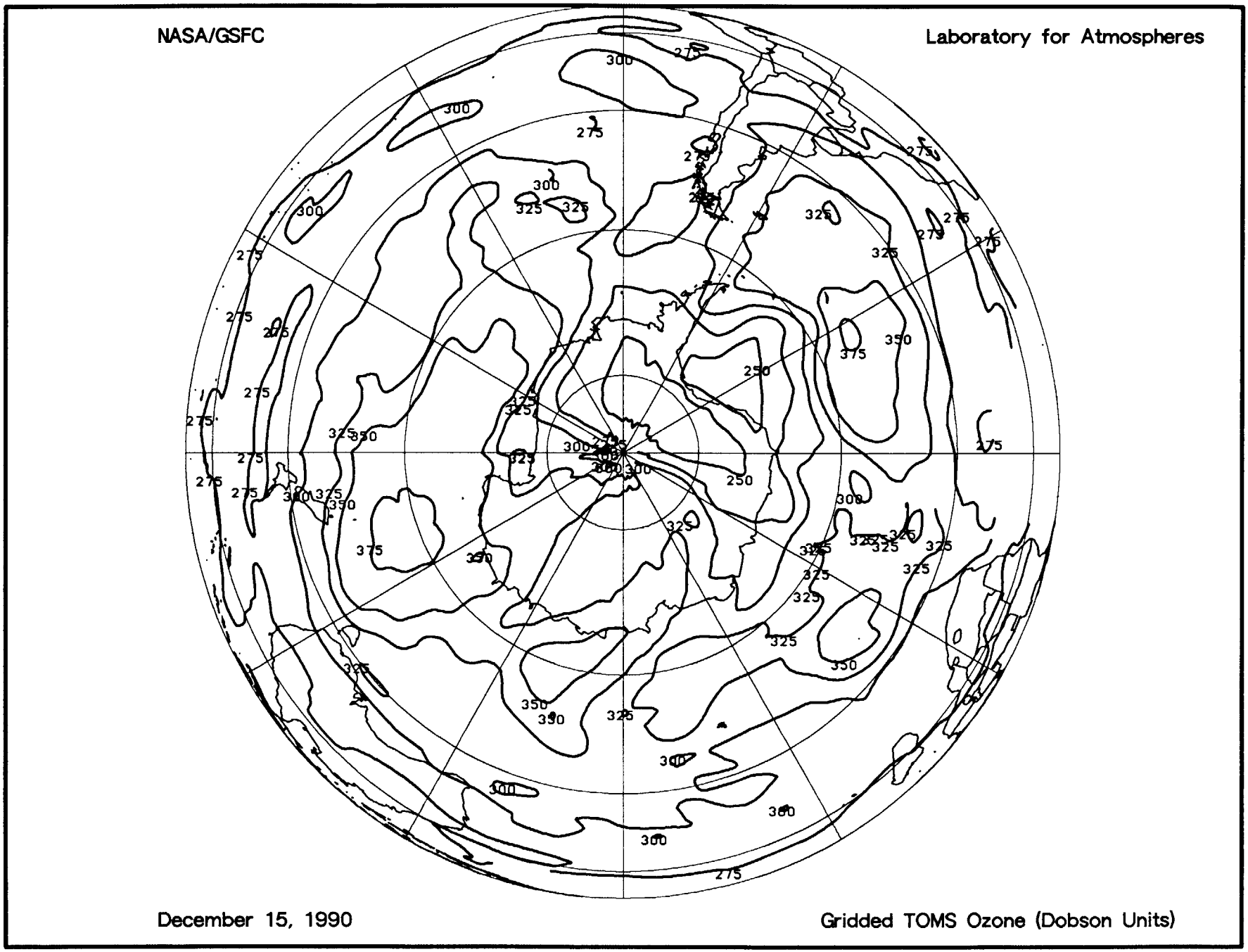
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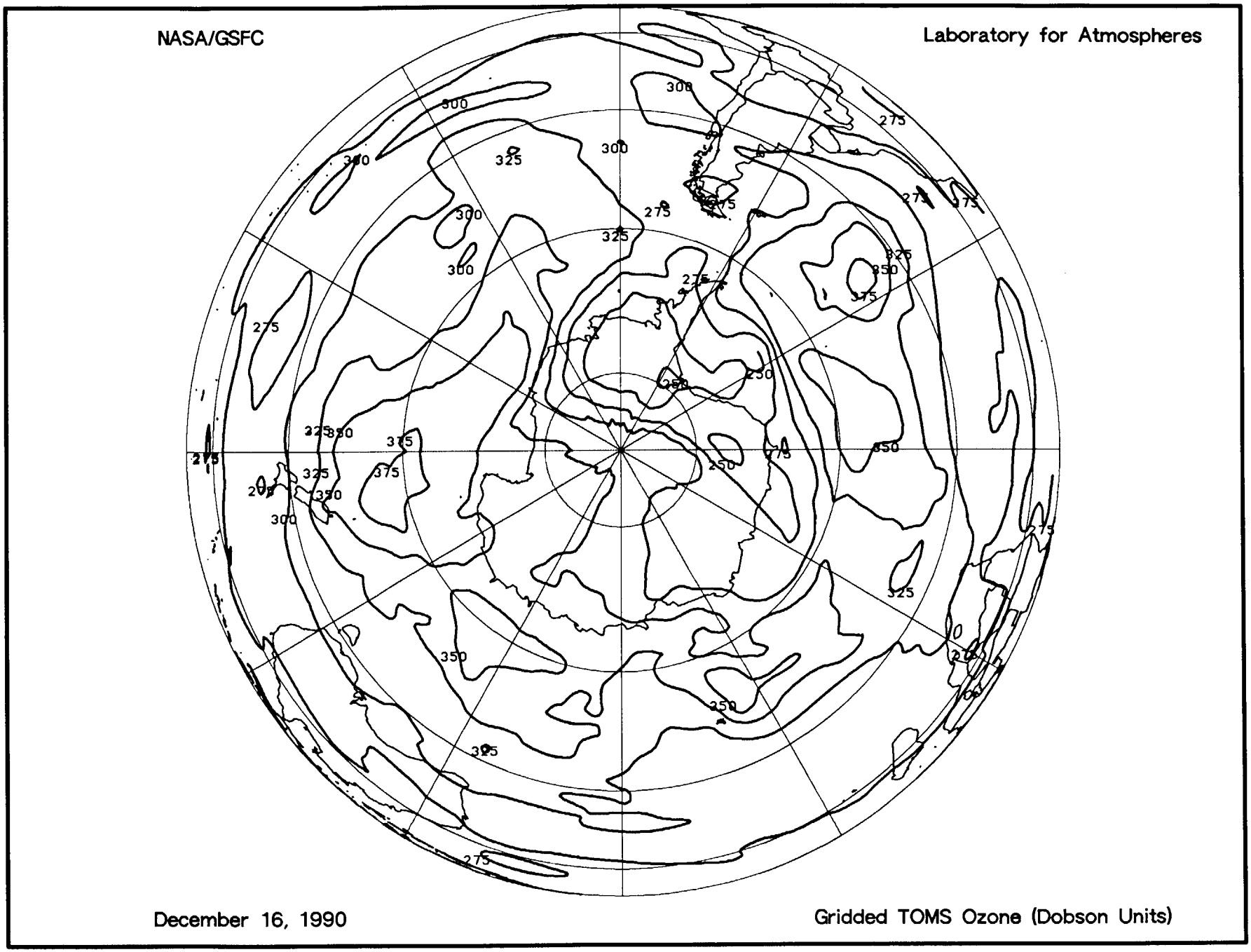
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Laboratory for Atmospheres
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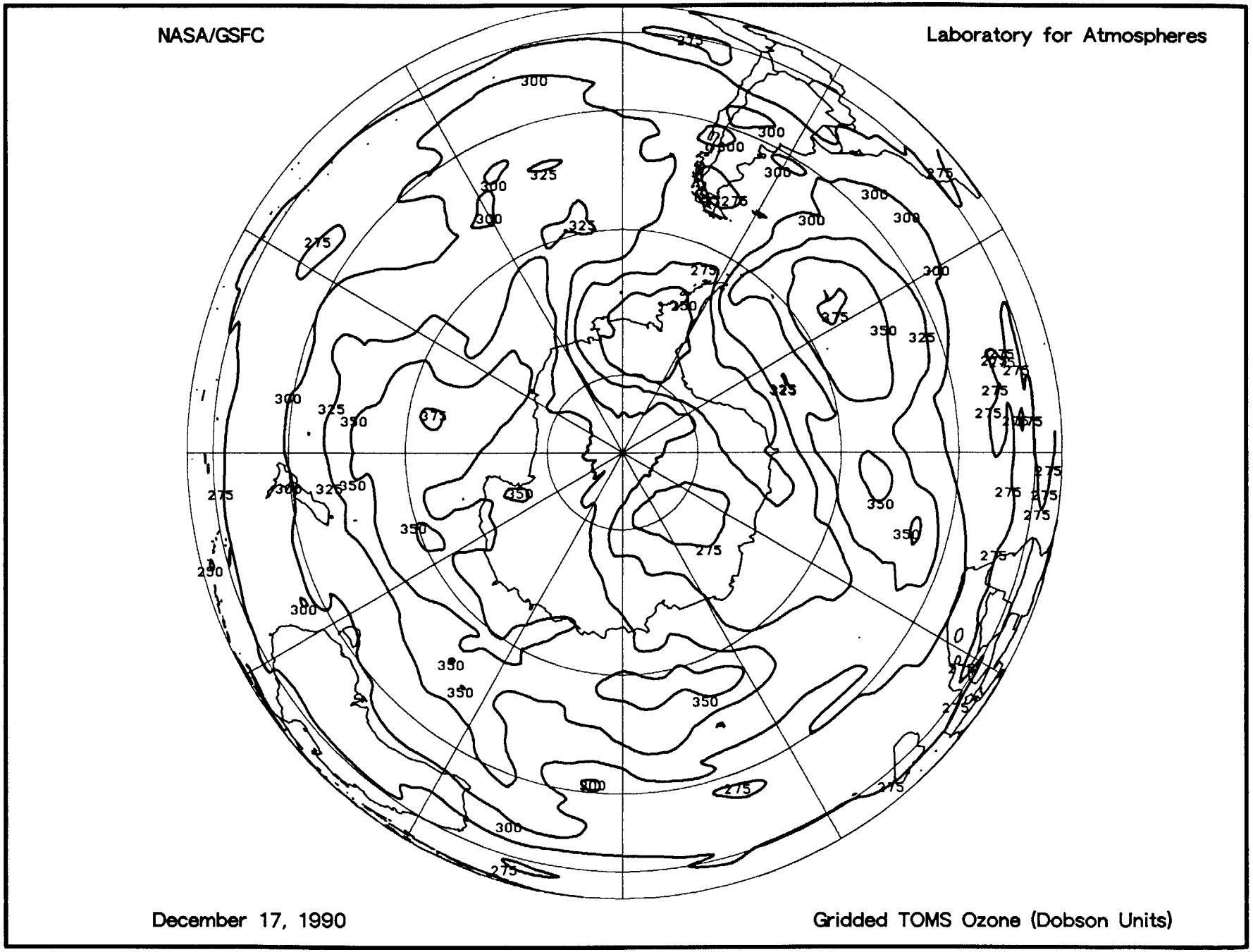
Gridded TOMS Ozone (Dobson Units)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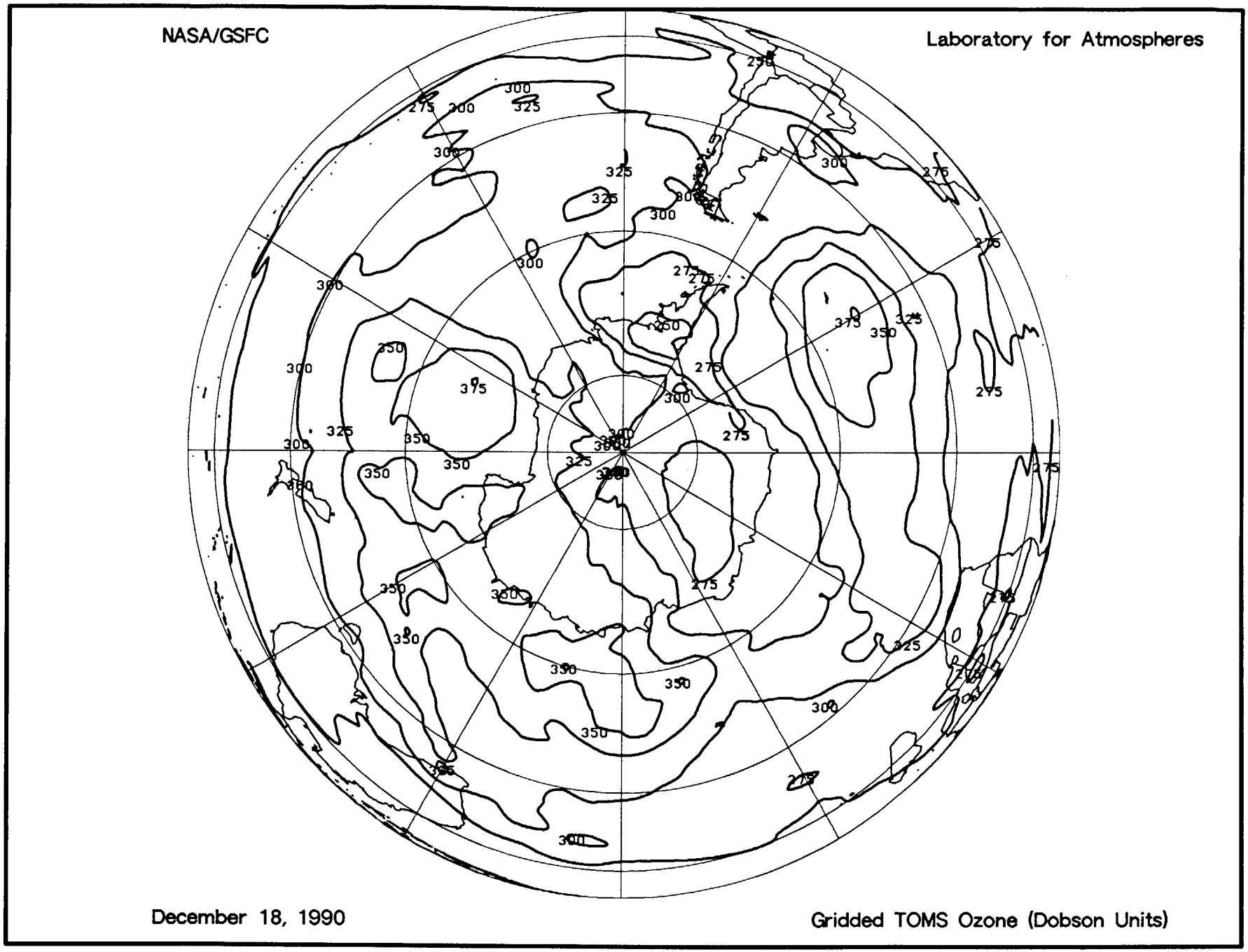
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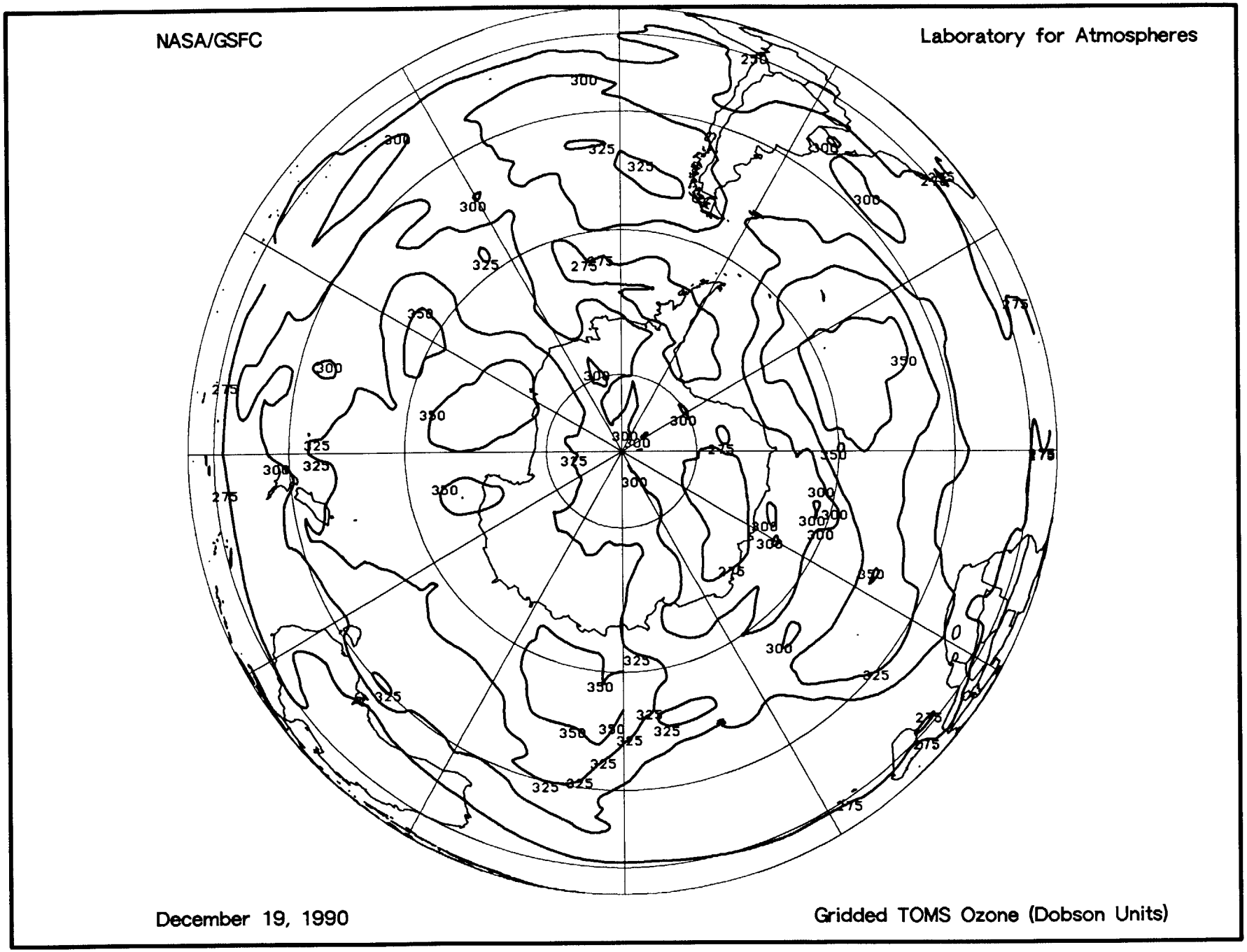
Gridded TOMS Ozone (Dobson Units)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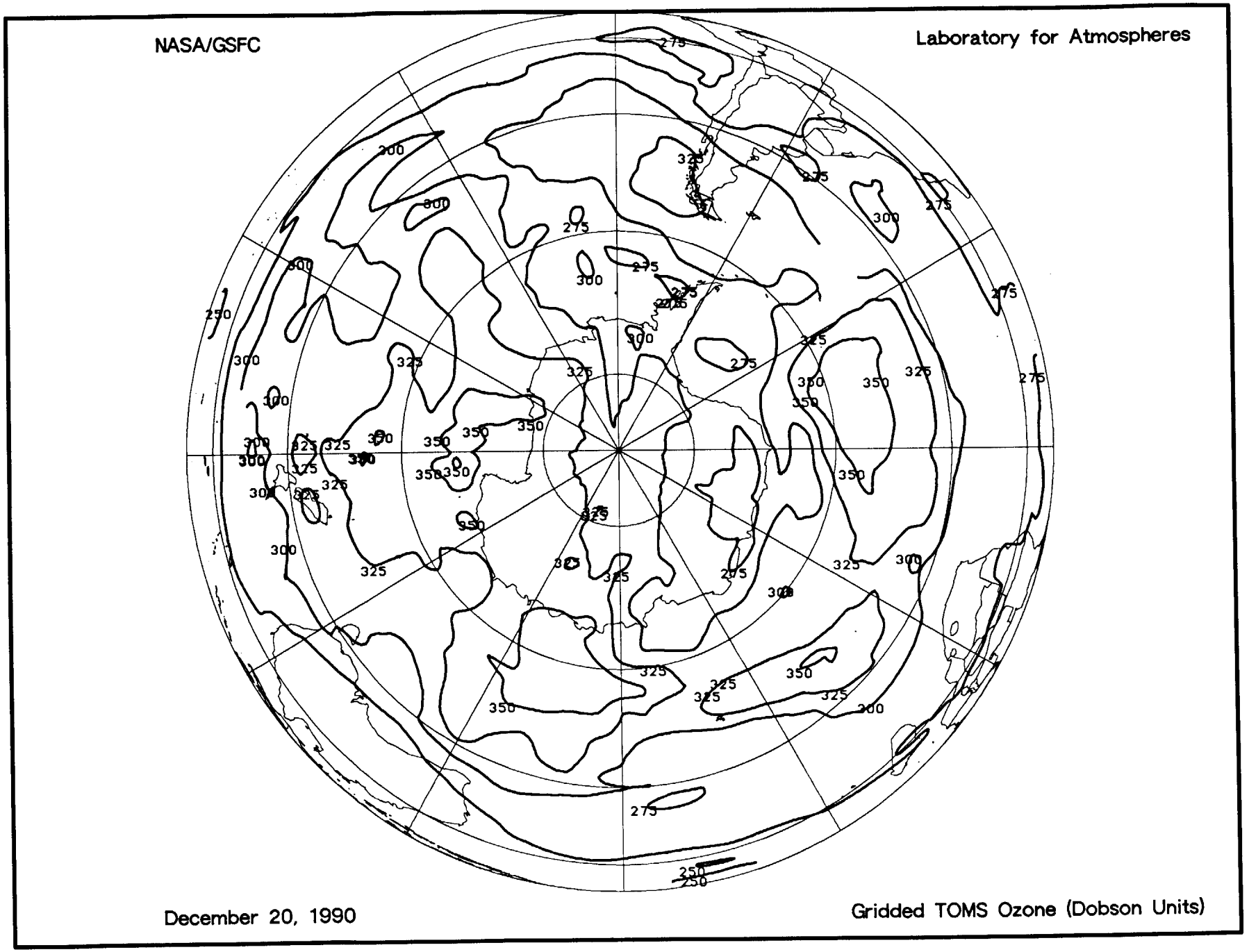
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December 20, 1990
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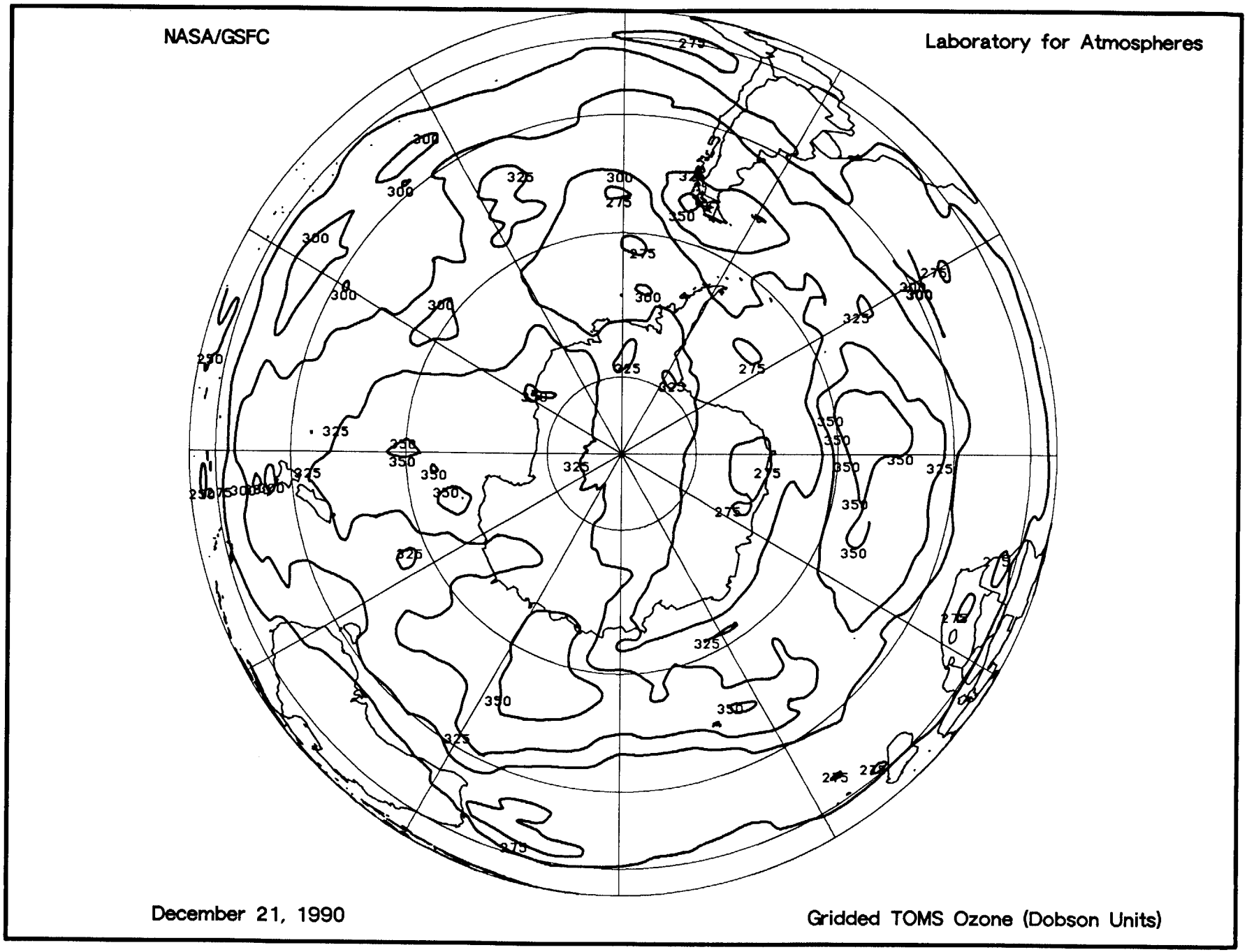
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Laboratory for Atmospheres
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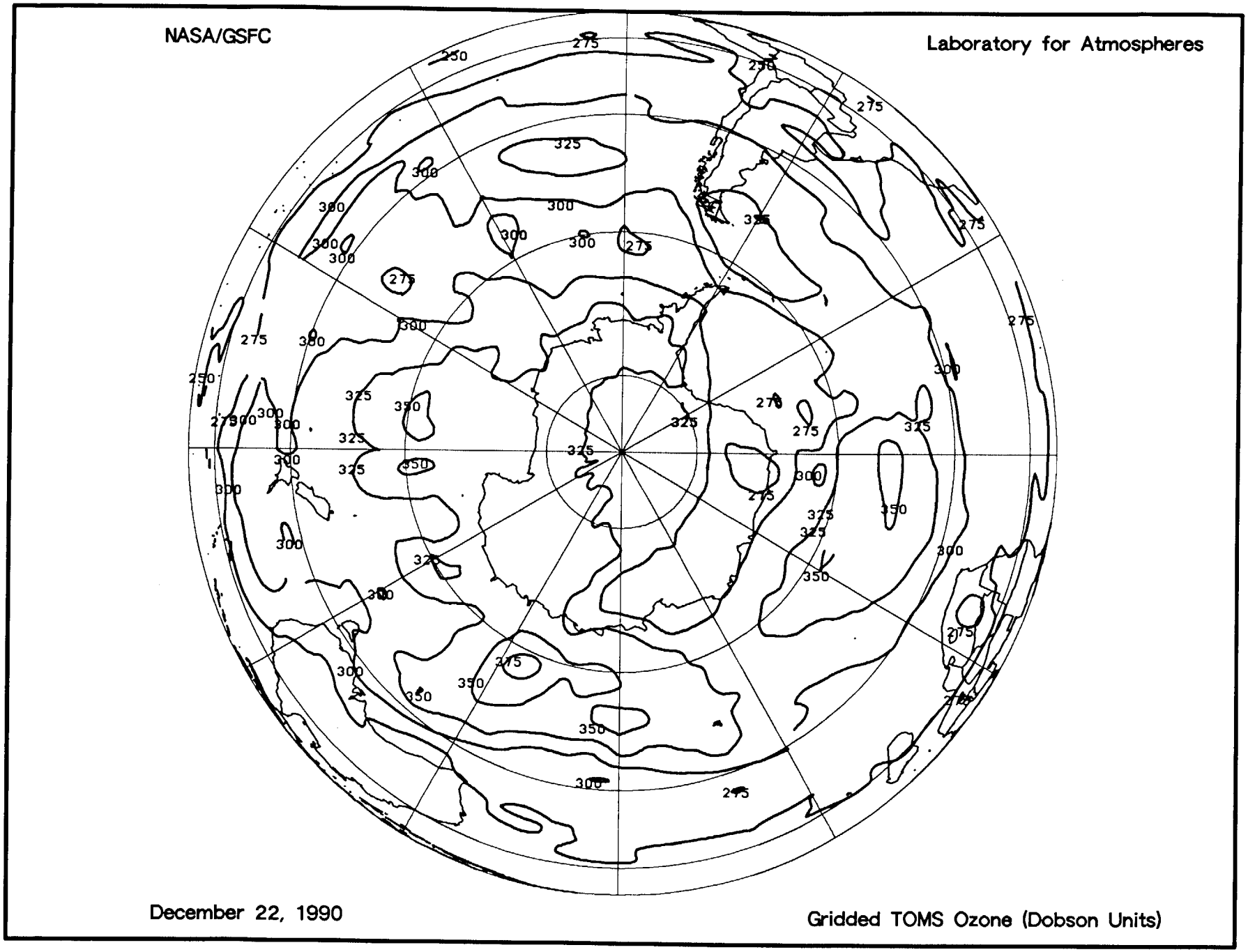
Gridded TOMS Ozone (Dobson Units)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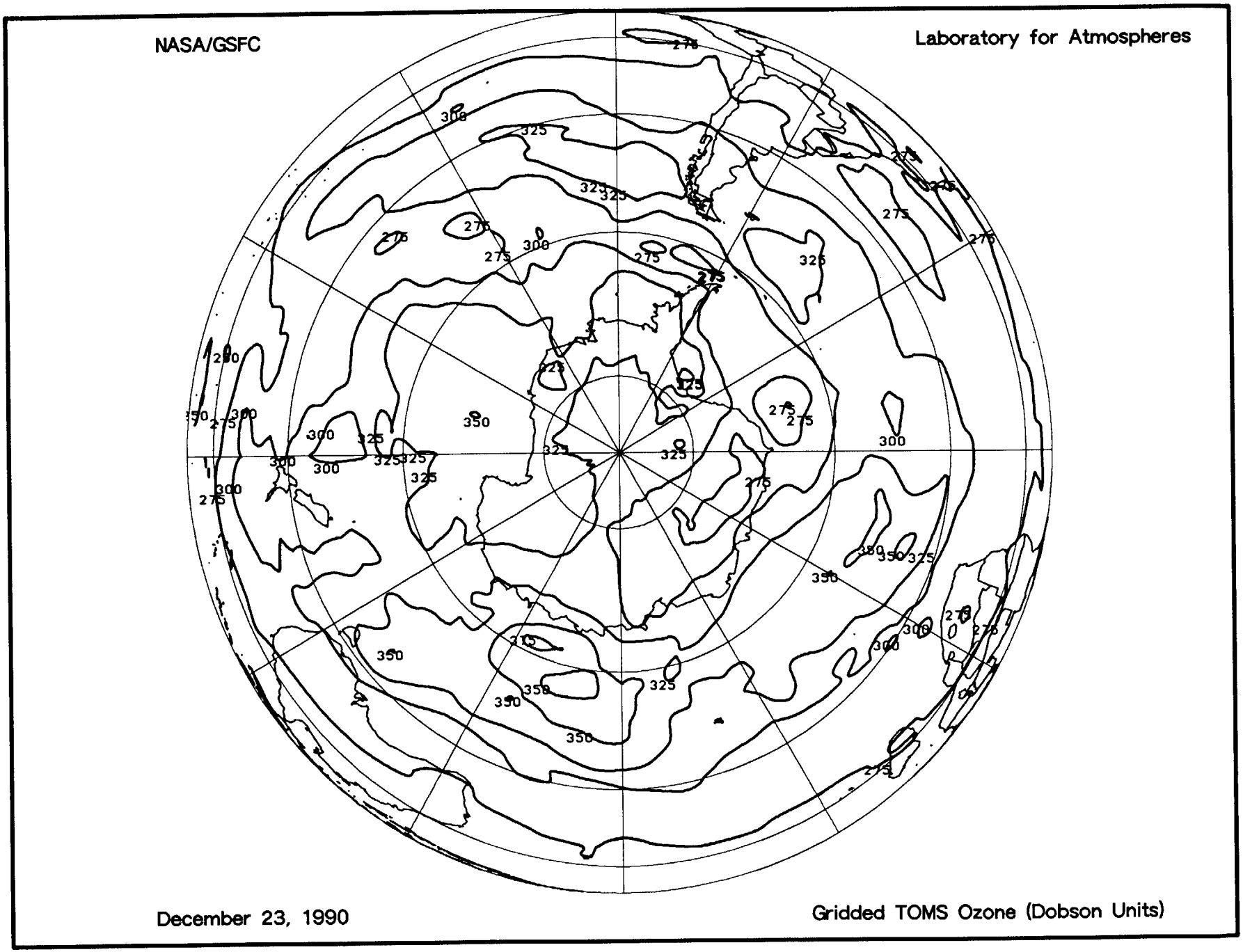
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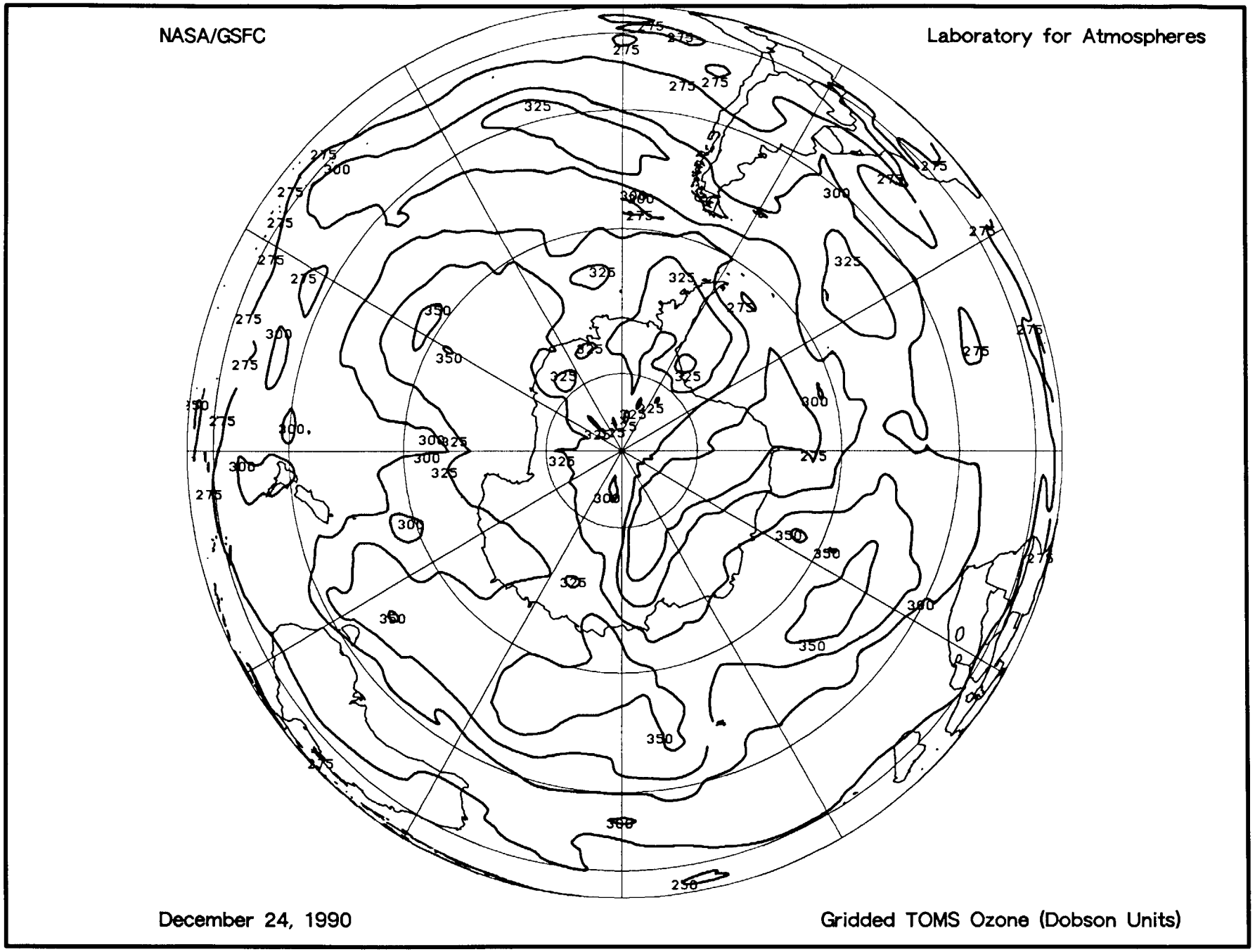
Laboratory for Atmospheres
December 23, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
December 24, 1990
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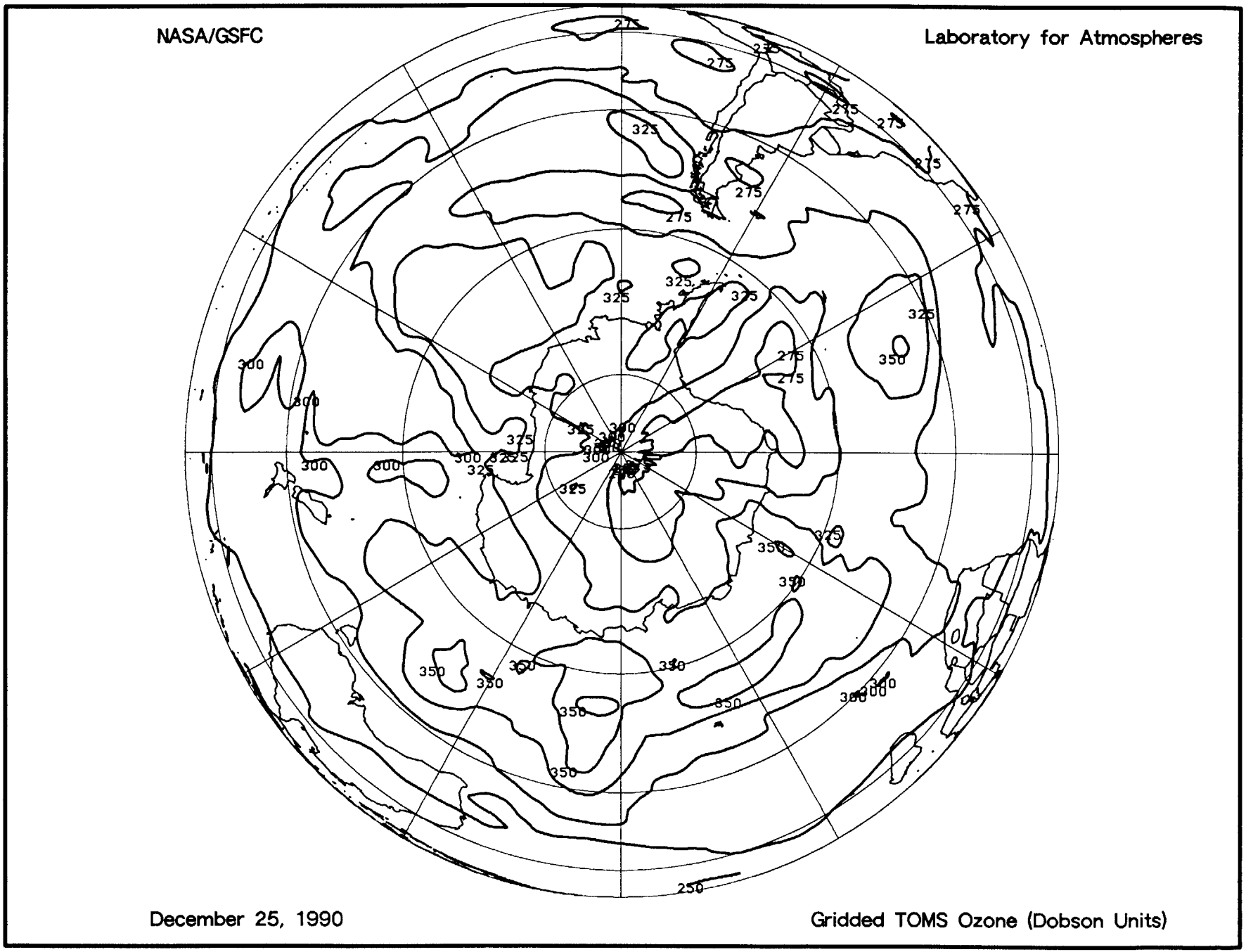
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Laboratory for Atmospheres
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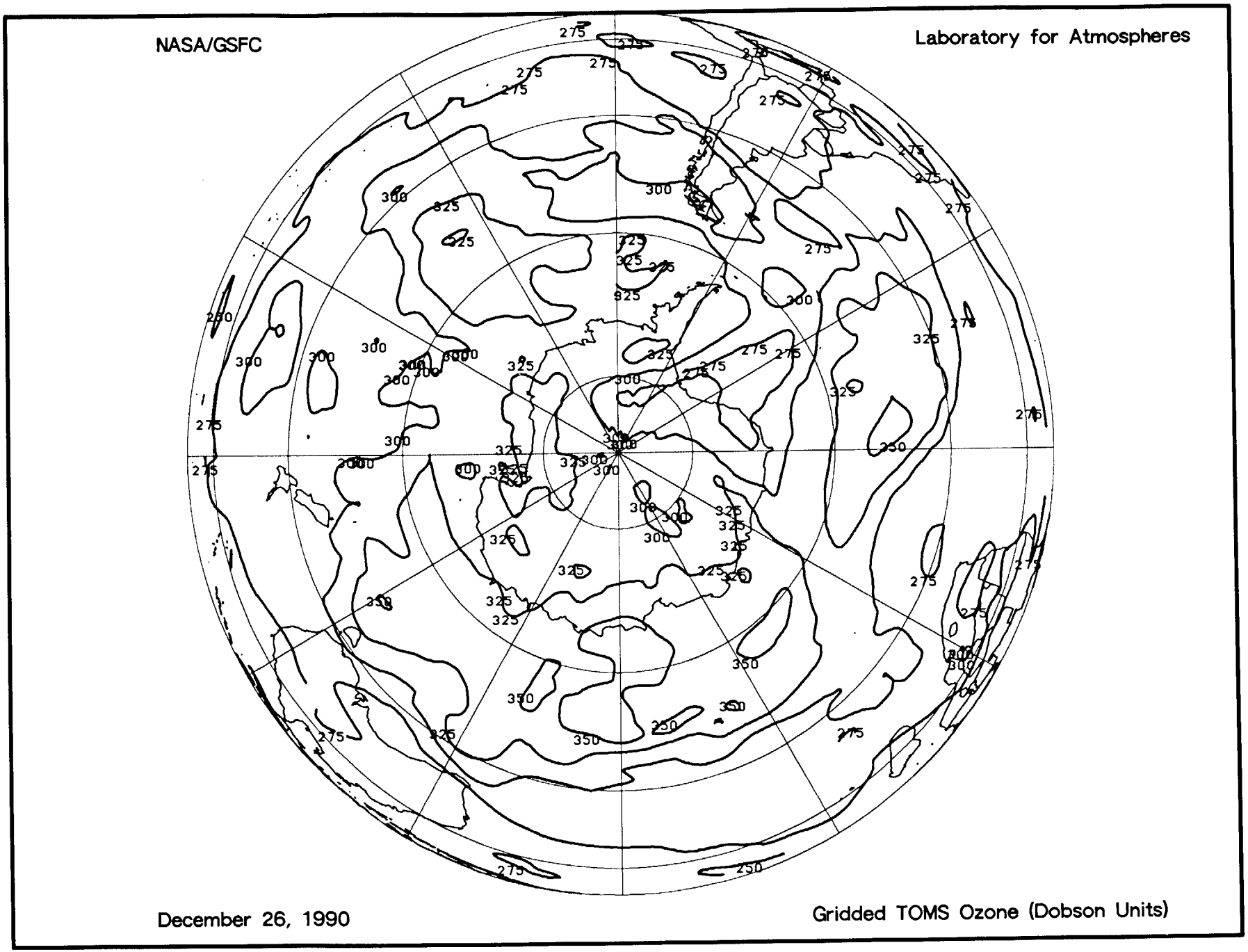
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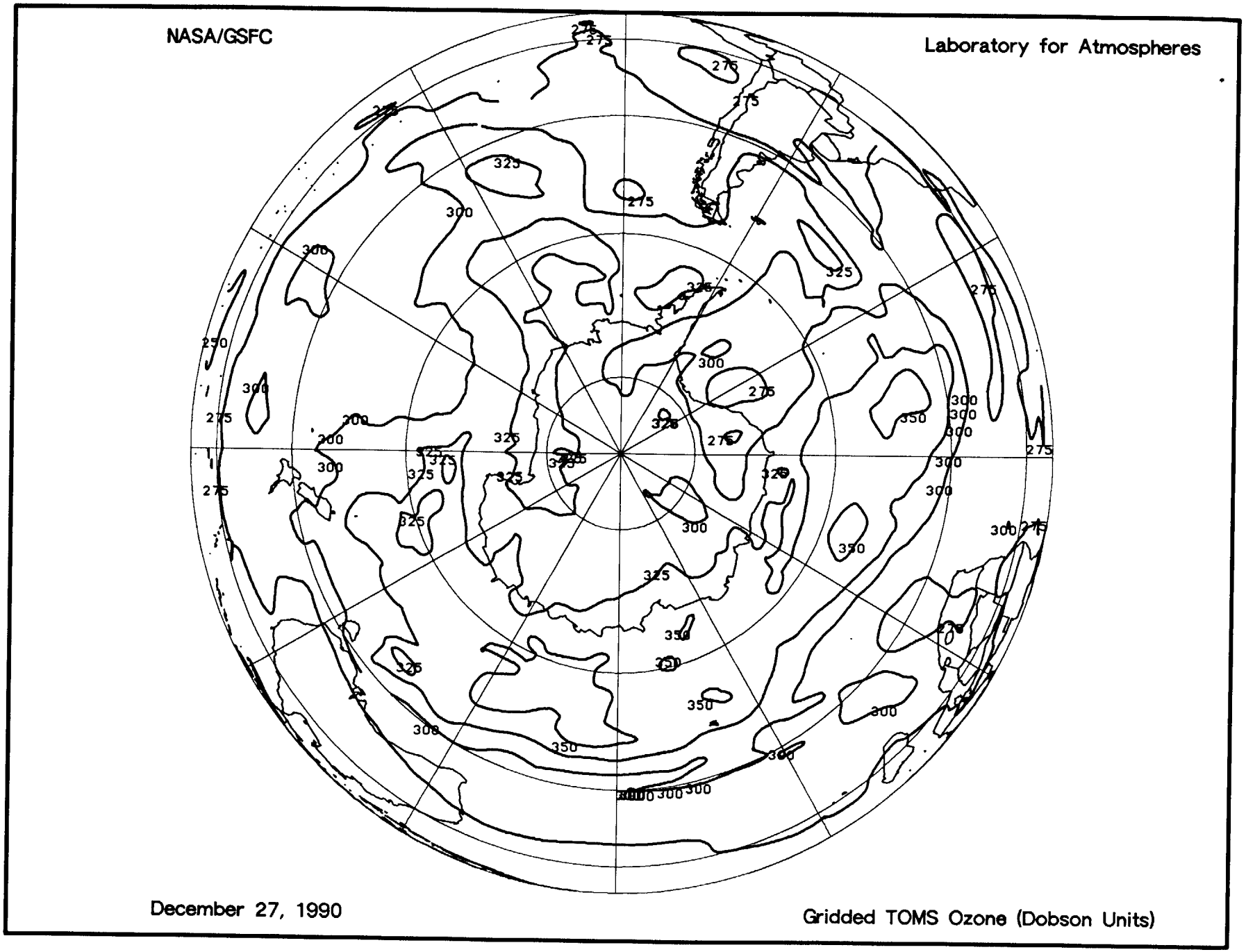
Laboratory for Atmospheres
December 26, 1990
Gridded TOMS Ozone (Dobson Units)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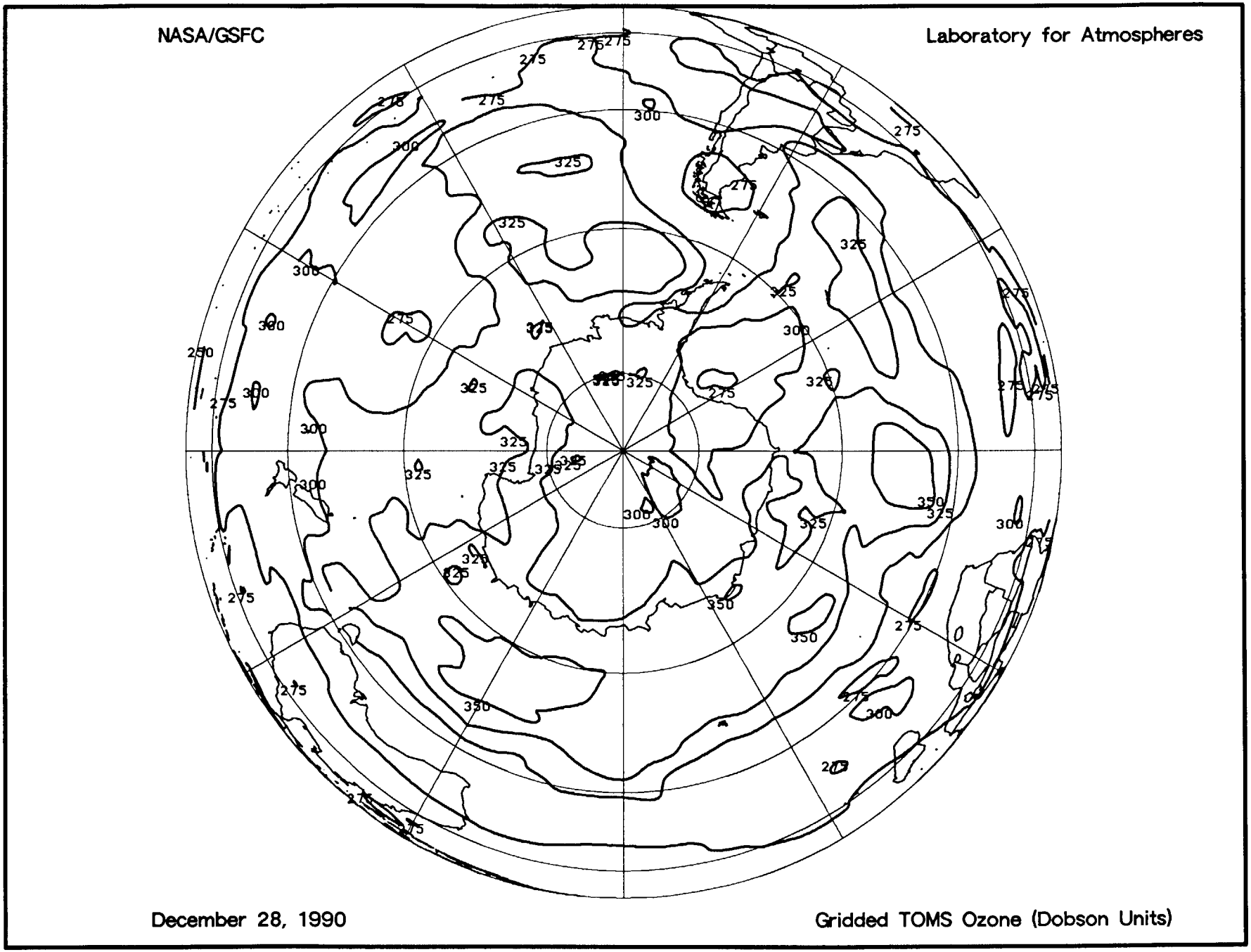
Laboratory for Atmospheres
December 27, 1990
Gridded TOMS Ozone (Dobson Units)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December 28, 1990
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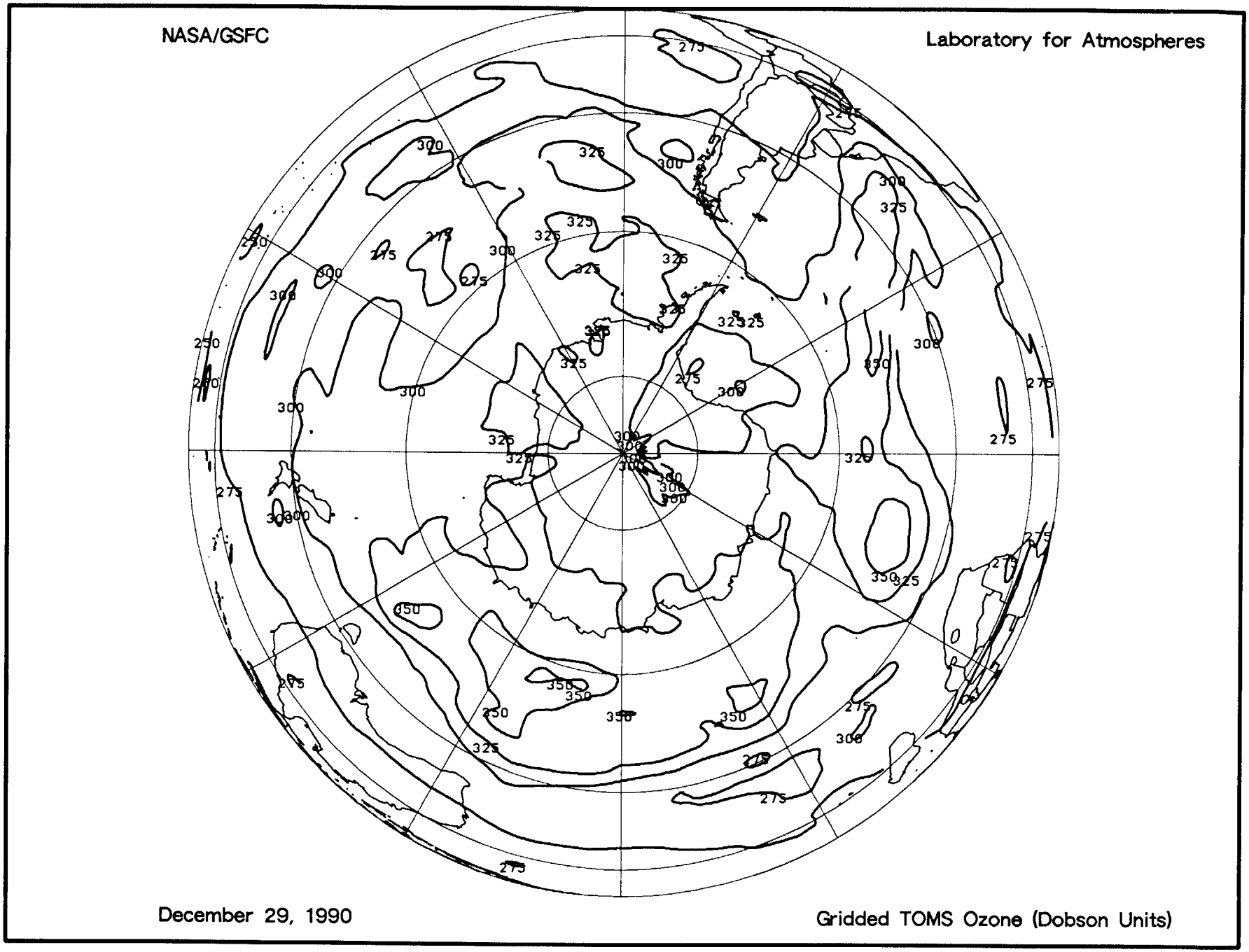
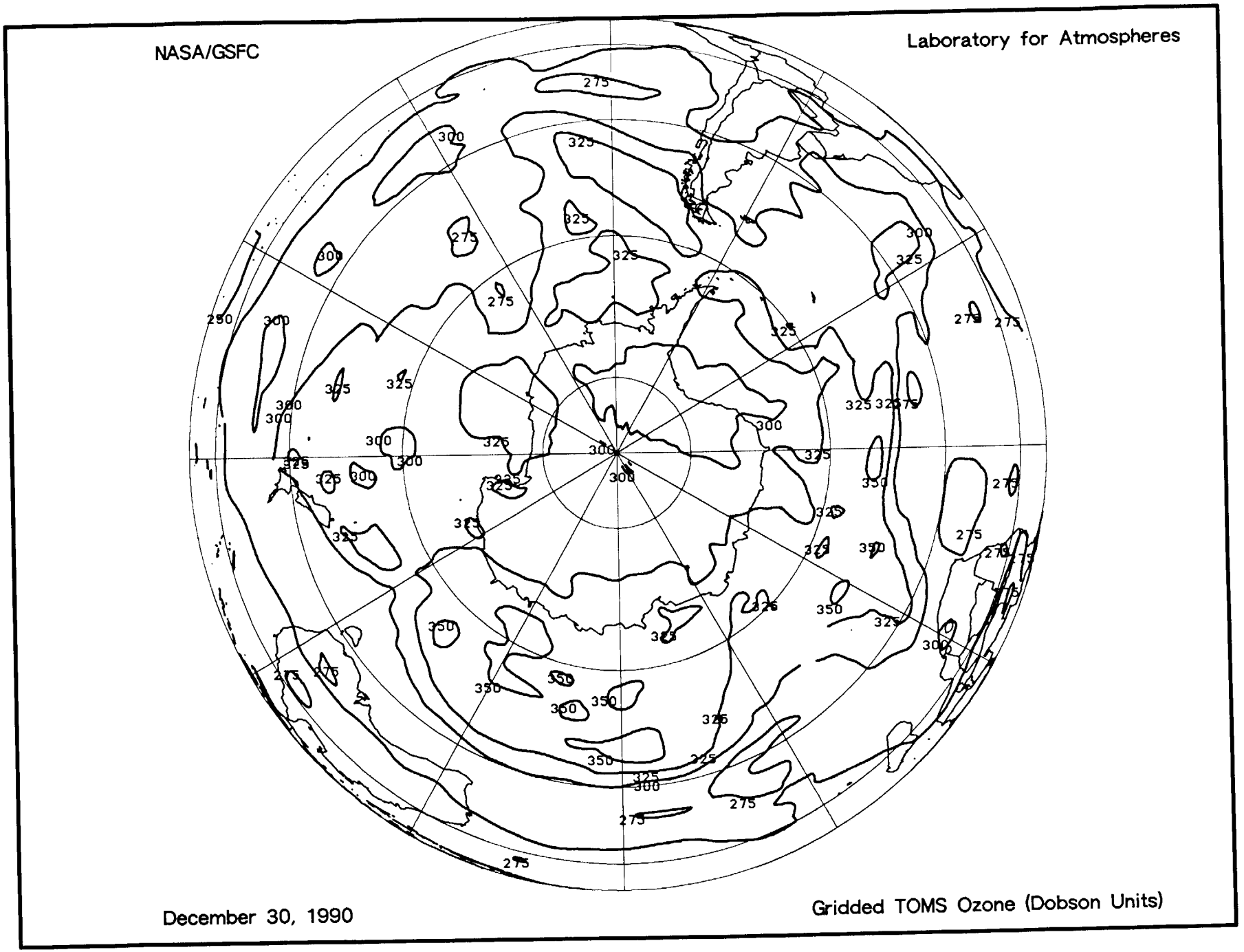

NASA/GSFC
Laboratory for Atmospheres
December 29, 1990
Gridded TOMS Ozone (Dobson Units)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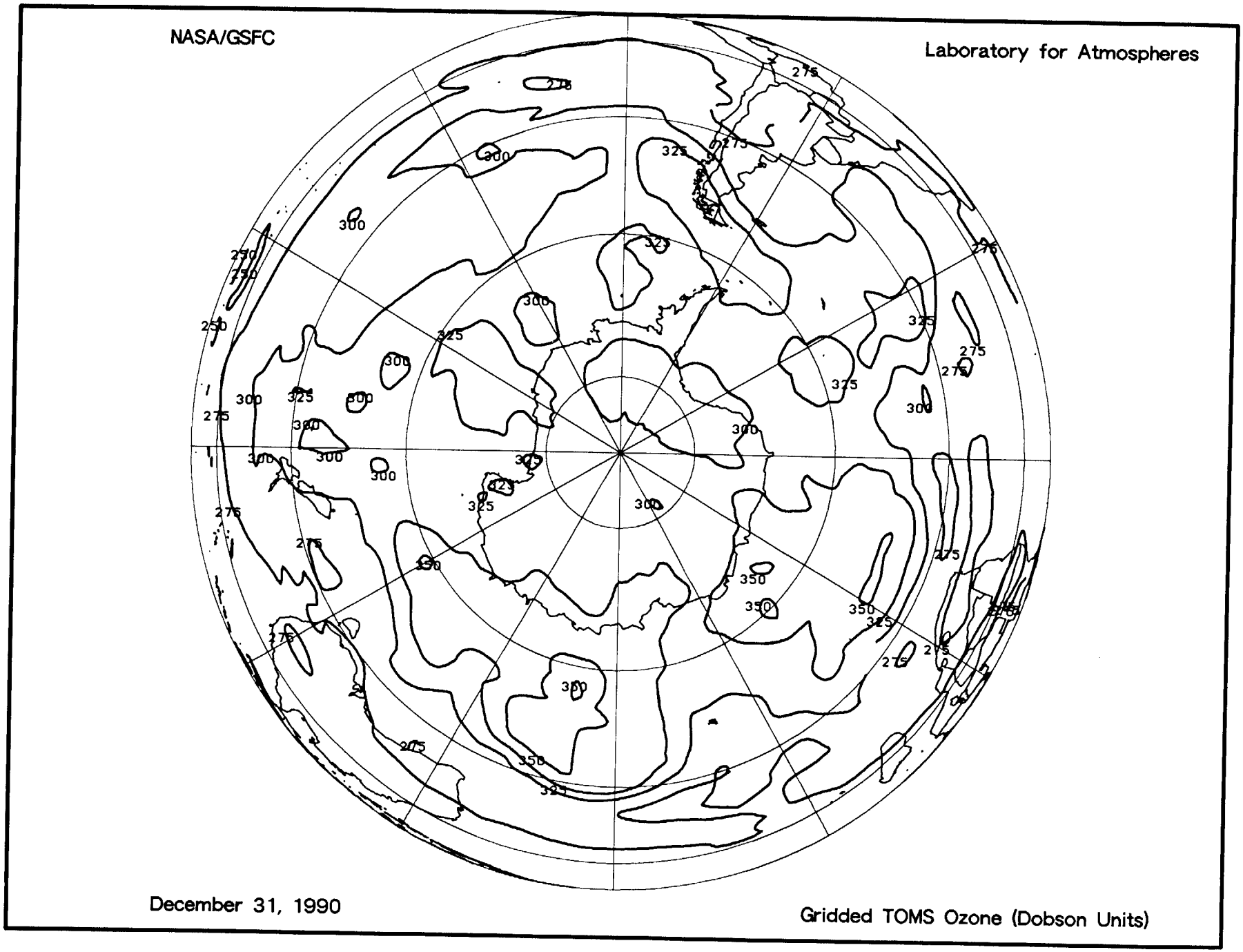
Laboratory for Atmospheres
December 30, 1990
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
December 31, 1990
Gridded TOMS Ozone (Dobson Units)

2.3 Time Series at Locations of Interest

Time series of TOMS total ozone estimates have been constructed for a set of twelve locations in Antarctica and two in South America, including the 1987 experiment's base of operations in Punta Arenas. A list of selected stations, their abbreviations, their coordinates, and the coordinates of the center of the grid cell within which the station lies is provided in Table 1. The time series incorporate daily gridded measurements from the southern hemispheric grids (Section 2.2), and are extracted from the 2° (latitude) by 5° (longitude) grid element within which each station resides. At the mean latitude of 70°S, this corresponds to spatial average over an area of 222 km by 189 km. Table 2 presents the time series for the period August 1 through December 31, 1990. Of course, a number of the stations are located south of the Antarctic circle and experience 24-hour night during a portion of the experiment. During these periods, the TOMS total ozone estimates at these stations, which include Amundsen-Scott, Halley Bay, McMurdo Sound, and Vostok, are not available, and are represented by asterisks. Table 3 presents monthly mean comparisons for each of the stations for 1987 through 1990, and includes the years which have produced the most prominent ozone holes to date. The latitude and longitude provided in Figures 2A through 2N are for the midpoint of the grid cell in which the station is located, not for the station itself.

Amundsen-Scott (SPO)

The Amundsen-Scott station is located at 90°S on the south pole. At this extreme location, total ozone observations do not become available until September 27 (day 270), shortly after the spring equinox. Total ozone values fall steadily (Figure 2A), reaching a minimum of 133 DU on October 4 and 5 (days 277 and 278). Total ozone values rise steadily thereafter.

B.A. Vice Comodoro Marambio (MAR)

The Marambio station is located at 64°S, just off the tip of the Antarctic Peninsula. Total ozone values drop steadily (Figure 2B) over the station until mid September. Thereafter, the values oscillate with a periodicity of 10 to 15 days as the elongated ozone hole rotates about the pole. During this period a minimum value of 166 DU is observed on September 28 (day 271) and a maximum value of 396 DU is observed on October 29 (day 302). Total ozone values rise steadily during December as the ozone hole fills.

Davis (DAV)

The Davis station is located on the coast of Antarctica at 69°S, 78°E near Mackenzie Bay. The station lies continuously within the ozone hole through early October (Figure 2C), reaching a minimum of 185 DU on September 28 (day 271). Thereafter, total ozone values over the station oscillate as the elongated ozone hole rotates about the pole.

Dumont D'Urville (DUD)

The Dumont D'Urville station is located at 67°S on the Antarctic coast of Wilkes Land, almost 180° of longitude away from the Antarctic Peninsula. The station remains on the periphery of the ozone hole throughout the period (Figure 2D), briefly entering the hole only when the axis

of elongation passes through the station. The minimum total ozone value of 214 DU occurs on August 22 (day 234) during the passage of a mini-hole.

Faraday Station (FAR)/Palmer Station (PAL)

The Faraday and Palmer stations, located at 65°S on the Antarctic Peninsula, lie within adjacent grid elements and display the same ozone trends (Figures 2E and 2F). Total ozone values decline steadily until mid-September. Thereafter, values oscillate due to the rotation of the elongated ozone hole until early December. Total ozone values rise fairly steadily during December as the ozone hole fills.

Halley Bay (HAL)

The total ozone measurements at Halley Bay at 76°S on the Weddell Sea first become available on August 19 (day 231). The station remains in the ozone hole for the remainder of the period. Total ozone values decline steadily (Figure 2G) reaching a minimum value of 146 DU on October 6 (day 279). Thereafter a steady rise is observed until the end of the period, interrupted only slightly by the more dramatic elongations of the ozone hole.

McMurdo (MCM)

The McMurdo station is located at 78°S on McMurdo Sound near the dateline. Total Ozone measurements first become available on August 27 (day 239). A decline in total ozone values to a minimum of 151 DU on October 9 (day 282) is followed by increasing values through mid-December (Figure 2H). This steady trend is interrupted briefly but dramatically on several occasions as the rotation of the elongated ozone hole causes the station to cease to be under the influence of the ozone hole.

Maitri (MAT)

The Maitri station is located at 70°S on the coast of Queen Maude Land. The station experiences a steady decline in total ozone (Figure 2I) until reaching a minimum of 166 DU on October 8 (day 281). Thereafter, total ozone values over the station oscillate dramatically as the elongated ozone hole rotates into and out of the area. During December, the station remains within the filling ozone hole.

Molodeznaya (MOL)

The Molodeznaya station is located in coastal Antarctica at 68°S in eastern Queen Maude Land. The station lies within the developing ozone hole and reaches a minimum total ozone value of 175 DU on September 29 (day 272). The station then experiences rapid and dramatic oscillations in total ozone (Figure 2J) as the elongated ozone hole rotates about the pole. December is characterized by a steady decline in total ozone through mid-month, with a steady rise thereafter.

Punta Arenas (PUN)

Punta Arenas, located near Cape Horn in extreme southern Chile at 53°S is one of two populous areas of this analysis. The station remains on the fringe of the ozone hole throughout the period (Figure 2K). Total ozone values observed over the station oscillate significantly throughout the period, with the amplitude of the oscillation reaching a peak in early October, and declining thereafter. The minimum total ozone value observed was 226 DU on October 13 (day 286). Total ozone values below 300 DU continue to occur periodically through the end of the period.

Syowa (SYO)

Syowa is located at 69°S, quite close to Molodeznaya. As such, the two time series are highly correlated (Figure 2L).

Ushuaia (USH)

Ushuaia is located at 54°S, 68°W in Argentina. The total ozone observations (Figure 2M) are well correlated with those of Punta Arenas.

Vostok (VOS)

The Vostok Station is located deep within continental Antarctica at 78°S in southern Wilkes Land. Total ozone values first become available on August 27 (day 239). The station remains within the ozone hole until late November (Figure 2N), reaching a minimum of 148 DU on October 5 (day 278). After late November, as the ozone hole moves toward the Weddell Sea, total ozone remains continuously above 300 DU.

Table 1
Selected Locations for TOMS Total Ozone Time Series

Station Name	Location		Center of Cell	
	Latitude	Longitude	Latitude	Longitude
Amundsen-Scott (SPO)	-90.0	0.0	-90.0	0.0
Davis (DAV)	-68.6	78.0	-68.0	77.5
Dumont D'Urville (DUD)	-66.7	140.0	-66.0	137.5
Faraday Station (FAR)	-65.3	-64.3	-66.0	-62.5
Halley Bay (HAL)	-75.5	-26.7	-76.0	-27.5
Maitri (MAT)	-70.0	12.5	-70.0	12.5
Marambio (MAR)	-64.2	-56.7	-64.0	-57.5
McMurdo (MCM)	-77.9	166.7	-78.0	167.5
Molodeznaya (MOL)	-67.7	45.9	-68.0	47.5
Palmer Station (PAL)	-64.8	-64.0	-64.0	-62.5
Punta Arenas (PUN)	-53.0	-70.9	-52.0	-72.5
Syowa (SYO)	-69.0	39.6	-68.0	37.5
Ushuaia (USH)	-54.9	-68.3	-54.0	-67.5
Vostok (VOS)	-78.5	106.9	-78.0	107.5

Table 2
Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	DAV	DUD	FAR	HAL	MAT	MAR	MCM	MOL	PAL	PUN	SYO	USH	VOS
213	AUG 1	***	266	262	254	***	251	265	***	246	273	307	256	304	***
214	AUG 2	***	248	286	293	***	241	295	***	238	304	334	246	298	***
215	AUG 3	***	247	251	330	***	235	341	***	246	343	338	246	334	***
216	AUG 4	***	246	237	301	***	242	313	***	251	316	342	247	325	***
217	AUG 5	***	247	248	314	***	256	337	***	253	335	335	261	328	***
218	AUG 6	***	257	266	293	***	236	318	***	252	316	362	241	350	***
219	AUG 7	***	256	255	296	***	243	318	***	242	315	383	242	384	***
220	AUG 8	***	246	260	251	***	272	275	***	249	265	283	257	294	***
221	AUG 9	***	249	248	227	***	266	226	***	252	234	309	255	291	***
222	AUG 10	***	255	266	291	***	275	299	***	240	301	294	259	292	***
223	AUG 11	***	222	233	289	***	271	307	***	277	311	250	287	279	***
224	AUG 12	***	279	235	258	***	219	281	***	291	278	270	288	268	***
225	AUG 13	***	277	250	262	***	217	257	***	271	276	309	275	284	***
226	AUG 14	***	258	291	262	***	205	284	***	255	274	289	262	290	***
227	AUG 15	***	259	266	267	***	232	290	***	247	290	307	240	282	***
228	AUG 16	***	256	243	271	***	239	292	***	250	285	377	248	368	***
229	AUG 17	***	248	302	274	***	239	290	***	241	285	401	249	407	***
230	AUG 18	***	240	310	251	***	241	258	***	239	263	403	246	407	***
231	AUG 19	***	228	288	253	240	242	285	***	252	269	372	254	372	***
232	AUG 20	***	250	296	246	236	290	254	***	255	252	316	260	329	***
233	AUG 21	***	255	251	206	223	258	234	***	280	210	265	302	270	***
234	AUG 22	***	249	214	198	223	247	209	***	266	216	245	257	239	***
235	AUG 23	***	244	280	229	230	241	253	***	248	249	254	244	250	***
236	AUG 24	***	248	265	235	234	225	246	***	250	251	299	252	258	***
237	AUG 25	***	253	254	251	206	234	264	***	249	269	345	239	319	***
238	AUG 26	***	245	262	241	178	230	268	***	237	259	354	232	350	***
239	AUG 27	***	243	288	242	195	225	259	250	219	242	298	216	315	227
240	AUG 28	***	224	313	254	215	211	254	228	227	256	258	227	259	223
241	AUG 29	***	234	307	242	211	202	276	241	212	276	385	209	367	224
242	AUG 30	***	226	323	250	228	216	283	223	205	273	369	208	406	226
243	AUG 31	***	227	377	261	218	208	264	213	225	262	334	232	361	205
244	SEP 1	***	241	409	221	222	211	244	218	272	230	289	241	314	226
245	SEP 2	***	254	444	206	214	212	226	273	220	223	298	214	300	230
246	SEP 3	***	237	324	219	202	212	237	237	242	231	266	223	266	210
247	SEP 4	***	224	271	184	207	223	184	230	229	177	253	230	262	226
248	SEP 5	***	224	282	251	190	221	231	209	226	255	295	222	279	219

Table 2
Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	DAV	DUD	FAR	HAL	MAT	MAR	MCM	MOL	PAL	PUN	SYO	USH	VOS
249	SEP 6	***	229	267	225	192	219	227	206	231	238	322	226	287	211
250	SEP 7	***	233	271	221	193	220	233	224	221	235	292	226	276	192
251	SEP 8	***	233	268	223	177	224	236	198	234	235	364	238	359	204
252	SEP 9	***	238	337	218	178	184	242	216	218	239	382	236	345	196
253	SEP 10	***	241	341	205	199	176	216	201	227	207	362	222	335	210
254	SEP 11	***	245	366	218	193	195	223	201	216	230	313	206	307	208
255	SEP 12	***	221	429	206	195	187	227	235	218	225	259	214	268	217
256	SEP 13	***	191	338	202	204	172	223	210	208	213	289	210	298	212
257	SEP 14	***	217	299	200	209	187	197	213	194	199	309	189	276	187
258	SEP 15	***	211	368	191	202	197	197	209	196	198	330	195	320	170
259	SEP 16	***	204	380	191	182	203	196	203	204	206	267	200	279	177
260	SEP 17	***	208	320	222	196	191	218	201	206	231	294	213	283	163
261	SEP 18	***	203	335	225	192	188	228	178	207	239	334	204	315	169
262	SEP 19	***	206	324	238	159	192	241	173	214	248	349	208	332	186
263	SEP 20	***	238	325	268	161	195	273	197	219	272	326	212	312	182
264	SEP 21	***	221	342	254	167	187	270	193	204	281	318	205	335	194
265	SEP 22	***	251	371	266	173	186	288	204	219	285	298	208	287	201
266	SEP 23	***	246	393	238	180	186	256	232	198	246	286	194	269	212
267	SEP 24	***	231	437	251	156	185	251	260	193	257	297	188	293	212
268	SEP 25	***	222	434	244	166	191	252	271	187	251	294	193	287	211
269	SEP 26	***	213	432	255	182	184	277	314	191	271	306	192	333	235
270	SEP 27	187	208	443	189	194	173	203	351	185	191	268	187	276	218
271	SEP 28	185	185	417	166	178	187	166	314	177	165	304	182	269	204
272	SEP 29	171	214	375	177	163	181	171	289	175	183	328	179	304	171
273	SEP 30	157	205	356	209	158	182	211	221	195	234	380	187	365	166
274	OCT 1	145	219	328	228	152	181	254	189	193	253	411	191	425	167
275	OCT 2	145	214	378	222	159	169	250	197	179	249	371	175	365	157
276	OCT 3	137	206	289	211	166	202	227	166	175	222	413	190	395	152
277	OCT 4	133	205	297	185	156	194	200	169	207	191	335	211	334	150
278	OCT 5	133	214	258	204	154	217	210	177	228	242	293	242	273	148
279	OCT 6	137	296	228	280	146	185	282	171	330	287	309	290	301	149
280	OCT 7	137	341	219	341	160	171	329	164	244	336	378	220	361	162
281	OCT 8	137	278	299	333	167	166	385	162	248	379	405	213	401	167
282	OCT 9	134	323	270	320	173	169	364	151	205	356	395	192	404	170
283	OCT 10	148	278	386	228	186	193	302	183	185	279	358	182	368	188
284	OCT 11	157	206	437	200	152	208	279	234	182	251	323	213	310	193

Table 2
Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	DAV	DUD	FAR	HAL	MAT	MAR	MCM	MOL	PAL	PUN	SYO	USH	VOS
285	OCT 12	147	192	452	181	155	197	200	237	207	185	279	212	268	171
286	OCT 13	142	219	362	163	167	211	184	218	219	168	226	237	202	157
287	OCT 14	143	237	373	180	173	287	172	188	252	173	281	268	271	159
288	OCT 15	148	257	337	212	169	331	211	174	351	226	284	401	281	156
289	OCT 16	145	353	271	213	158	232	224	168	413	239	318	412	304	176
290	OCT 17	152	389	304	281	168	224	297	184	309	297	322	277	323	186
291	OCT 18	142	310	345	360	176	253	392	158	302	390	362	285	358	181
292	OCT 19	150	303	313	306	205	205	367	157	307	345	351	255	373	159
293	OCT 20	158	273	311	289	203	253	341	179	220	324	354	235	375	208
294	OCT 21	162	208	368	264	202	279	321	210	269	315	346	288	356	185
295	OCT 22	163	235	360	244	197	269	299	235	292	272	362	305	378	176
296	OCT 23	160	263	302	233	194	274	271	221	262	262	338	282	357	162
297	OCT 24	158	257	319	223	192	266	243	197	301	230	302	307	299	168
298	OCT 25	160	287	262	256	196	294	261	182	292	257	298	306	281	183
299	OCT 26	160	275	295	265	202	293	275	175	382	275	341	364	346	186
300	OCT 27	162	368	264	356	184	246	357	180	388	360	367	372	368	175
301	OCT 28	159	382	224	376	215	213	380	163	332	374	370	289	372	197
302	OCT 29	162	338	278	379	276	220	396	160	231	386	356	214	353	194
303	OCT 30	167	231	322	392	277	316	390	163	219	379	362	233	348	183
304	OCT 31	166	224	324	378	259	325	369	172	284	373	349	316	343	179
305	NOV 1	161	234	288	247	220	353	296	183	313	258	368	341	363	170
306	NOV 2	159	273	313	231	213	364	236	184	371	231	337	382	297	175
307	NOV 3	162	315	348	214	204	325	227	187	388	217	289	385	274	185
308	NOV 4	170	366	342	190	202	283	200	192	345	194	277	326	256	222
309	NOV 5	180	357	384	188	189	258	188	222	328	185	276	326	249	229
310	NOV 6	180	373	397	216	180	234	208	235	292	207	267	285	262	253
311	NOV 7	180	373	406	229	173	238	234	271	258	233	286	257	284	273
312	NOV 8	184	292	416	214	181	239	221	304	284	216	313	291	314	307
313	NOV 9	188	261	384	205	185	236	209	357	297	204	333	295	317	264
314	NOV 10	196	279	396	197	198	249	199	370	295	200	306	309	290	237
315	NOV 11	199	299	345	202	189	234	209	346	371	205	285	363	266	222
316	NOV 12	200	366	288	213	185	209	207	303	282	209	***	255	230	231
317	NOV 13	191	320	302	259	191	214	251	241	263	278	345	253	332	207
318	NOV 14	182	337	340	326	197	200	345	219	263	358	372	247	371	215
319	NOV 15	180	338	394	286	206	213	318	214	258	306	343	248	379	216
320	NOV 16	180	326	389	254	208	223	274	213	251	268	312	230	323	271

Table 2
Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	DAV	DUD	FAR	HAL	MAT	MAR	MCM	MOL	PAL	PUN	SYO	USH	VOS
321	NOV 17	189	282	379	245	210	237	279	307	229	275	321	234	348	278
322	NOV 18	191	248	373	297	197	222	335	328	232	319	324	243	323	243
323	NOV 19	185	233	375	240	267	268	274	298	222	235	346	233	354	215
324	NOV 20	190	234	356	227	258	317	243	249	212	237	342	256	344	204
325	NOV 21	196	257	357	249	215	330	269	222	267	265	330	316	359	222
326	NOV 22	183	249	375	328	220	348	354	229	315	349	347	337	352	244
327	NOV 23	185	268	367	290	222	306	321	237	338	315	331	338	357	259
328	NOV 24	192	281	375	345	224	344	366	312	311	361	331	337	336	284
329	NOV 25	207	252	382	316	273	356	370	346	338	350	348	345	369	272
330	NOV 26	208	234	349	271	286	361	307	337	340	295	309	356	330	238
331	NOV 27	223	272	312	257	281	367	285	276	361	269	310	369	321	254
332	NOV 28	234	348	266	239	273	377	283	265	373	257	339	384	335	222
333	NOV 29	240	364	262	257	241	359	276	258	370	264	337	373	335	262
334	NOV 30	234	370	260	238	262	319	249	242	371	236	262	371	254	304
335	DEC 1	248	368	319	228	257	315	239	241	366	229	332	353	300	329
336	DEC 2	254	357	351	222	246	369	250	263	332	235	302	358	273	321
337	DEC 3	255	356	363	237	230	322	253	279	364	246	273	383	266	287
338	DEC 4	233	367	358	242	256	308	257	275	380	243	275	367	262	301
339	DEC 5	240	361	361	237	262	366	246	271	343	236	269	301	254	320
340	DEC 6	248	353	358	232	255	329	245	283	373	233	288	384	275	310
341	DEC 7	246	361	372	253	268	343	240	289	359	257	287	379	283	304
342	DEC 8	260	377	357	229	266	324	234	295	386	238	304	387	301	315
343	DEC 9	272	369	352	251	266	306	243	300	382	246	267	336	266	336
344	DEC 10	283	351	377	256	257	273	244	300	339	262	268	311	268	357
345	DEC 11	284	381	374	253	254	269	268	305	320	259	266	303	270	339
346	DEC 12	301	340	374	267	244	271	257	335	309	265	279	303	276	343
347	DEC 13	290	368	373	312	234	272	276	357	290	308	271	302	271	335
348	DEC 14	272	348	361	331	244	285	333	324	301	340	308	289	315	306
349	DEC 15	279	329	359	289	250	259	315	313	299	291	268	289	285	310
350	DEC 16	315	310	343	274	251	266	295	338	289	276	274	287	275	319
351	DEC 17	318	315	342	256	266	269	279	342	289	265	285	291	277	314
352	DEC 18	303	303	338	270	272	290	285	339	285	270	300	284	294	317
353	DEC 19	301	298	339	277	287	292	284	334	277	286	320	282	307	319
354	DEC 20	307	288	327	277	295	284	292	342	273	291	335	275	326	320
355	DEC 21	310	285	330	291	293	276	305	338	286	300	347	283	341	324
356	DEC 22	314	289	333	290	297	272	301	339	298	293	318	307	334	329

Table 2
Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	DAV	DUD	FAR	HAL	MAT	MAR	MCM	MOL	PAL	PUN	SYO	USH	VOS
357	DEC 23	312	295	326	311	320	276	296	337	313	293	326	312	312	312
358	DEC 24	314	307	321	325	300	292	295	340	335	317	315	334	308	319
359	DEC 25	295	325	324	318	275	292	321	331	330	323	305	335	283	316
360	DEC 26	302	325	325	313	280	294	307	331	327	306	290	332	286	313
361	DEC 27	308	330	331	324	274	324	319	333	332	325	281	327	285	317
362	DEC 28	309	327	333	295	278	328	287	328	334	298	266	327	269	318
363	DEC 29	304	324	334	319	290	322	321	325	337	321	293	336	299	316
364	DEC 30	303	324	336	320	296	316	332	323	344	323	324	342	316	310
365	DEC 31	309	333	325	316	293	318	323	323	330	317	342	337	333	308

Table 3
Monthly Mean Comparisons

Station Name	August				September				October				November				December			
	1987	1988	1989	1990	1987	1988	1989	1990	1987	1988	1989	1990	1987	1988	1989	1990	1987	1988	1989	1990
Amundsen-Scott	***	***	***	***	140	216	161	175	146	241	159	150	189	363	249	192	325	343	323	287
Davis	261	328	262	248	234	407	234	223	241	403	280	270	296	395	309	300	345	361	346	334
Dumont D'Urville	287	359	286	272	266	404	272	357	325	466	386	315	330	431	379	351	358	375	344	346
Faraday Station	271	244	274	261	236	245	247	219	242	239	206	268	264	343	355	249	311	361	324	278
Halley Bay	253	250	236	218	188	214	199	186	164	229	168	185	200	339	274	218	310	347	319	270
Maitri	257	299	284	239	214	284	224	195	190	290	200	234	244	350	268	286	328	353	339	301
Marambio	283	2566	281	277	249	261	264	228	249	252	219	291	287	340	359	268	308	365	324	282
McMurdo	247	264	266	231	201	260	202	229	191	332	230	183	225	404	303	265	349	355	333	315
Molodeznaya	256	318	274	247	231	357	238	211	222	347	243	265	282	376	280	305	340	362	353	327
Palmer Station	285	254	282	276	251	257	263	230	255	244	217	286	282	339	360	260	309	361	324	280
Punta Arenas	337	299	334	322	319	323	331	309	327	306	299	341	338	339	363	320	315	351	339	296
Syowa	257	318	278	250	232	342	242	208	216	333	234	264	277	370	276	310	339	360	356	324
Ushuaia	327	296	327	319	318	322	326	301	317	298	290	338	340	339	361	317	310	353	336	291
Vostok	255	272	247	221	192	284	192	201	173	324	201	172	226	381	265	239	340	350	332	319

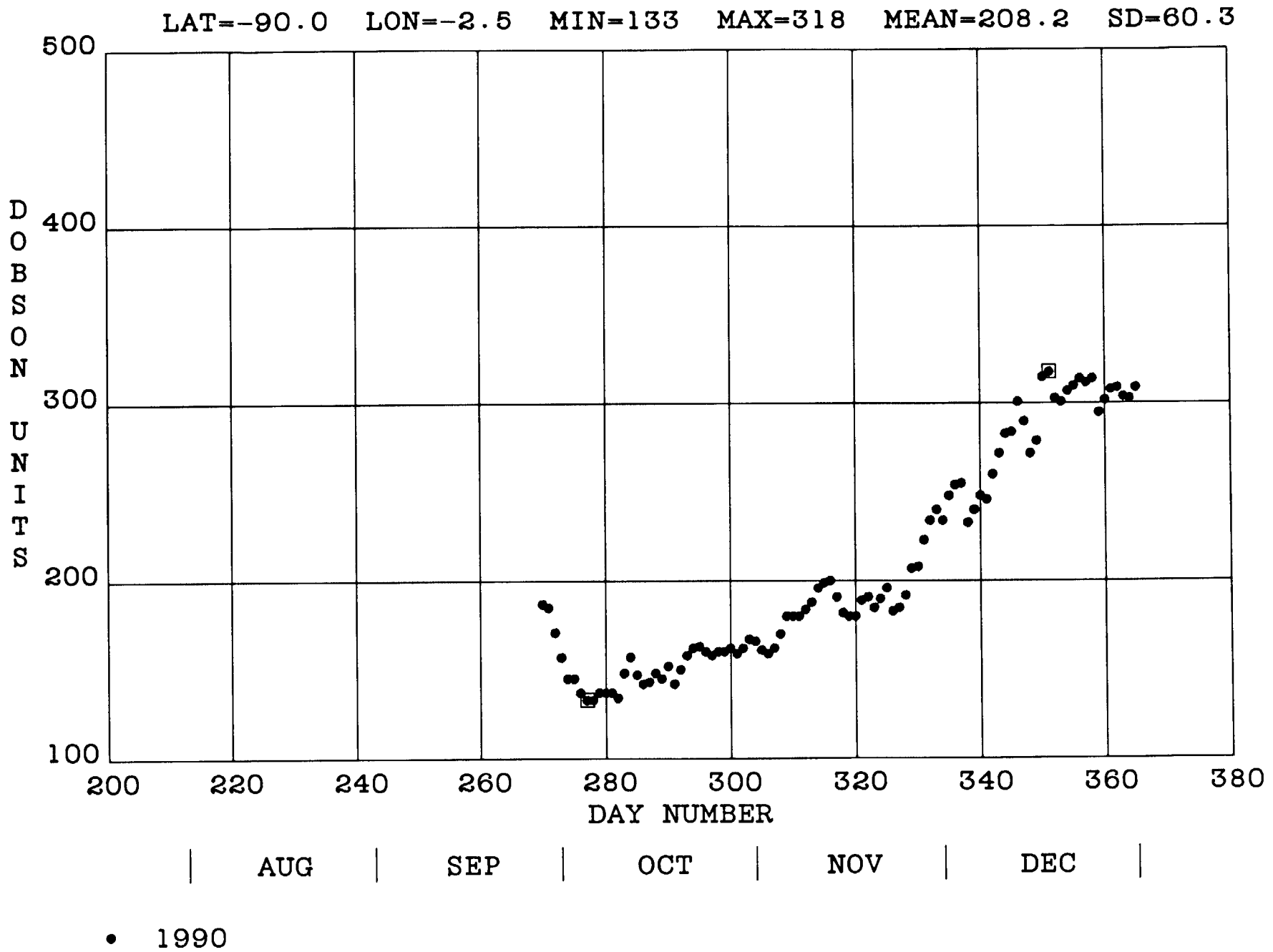


Figure 2A. Daily TOMS Total Ozone Values Over Amundsen-Scott (DU) for 1990.

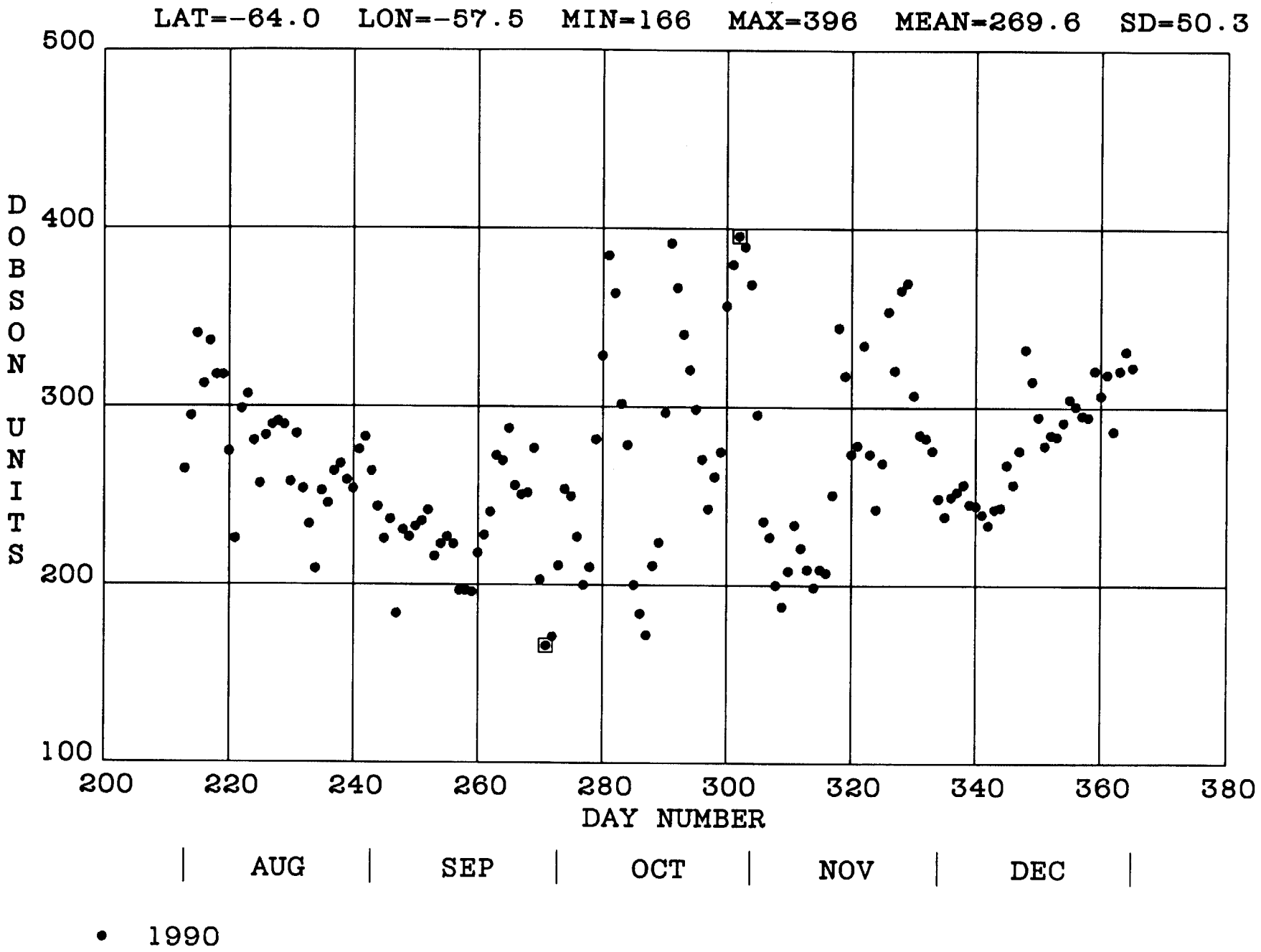


Figure 2B. Daily TOMS Total Ozone Values Over Marambio (DU) for 1990.

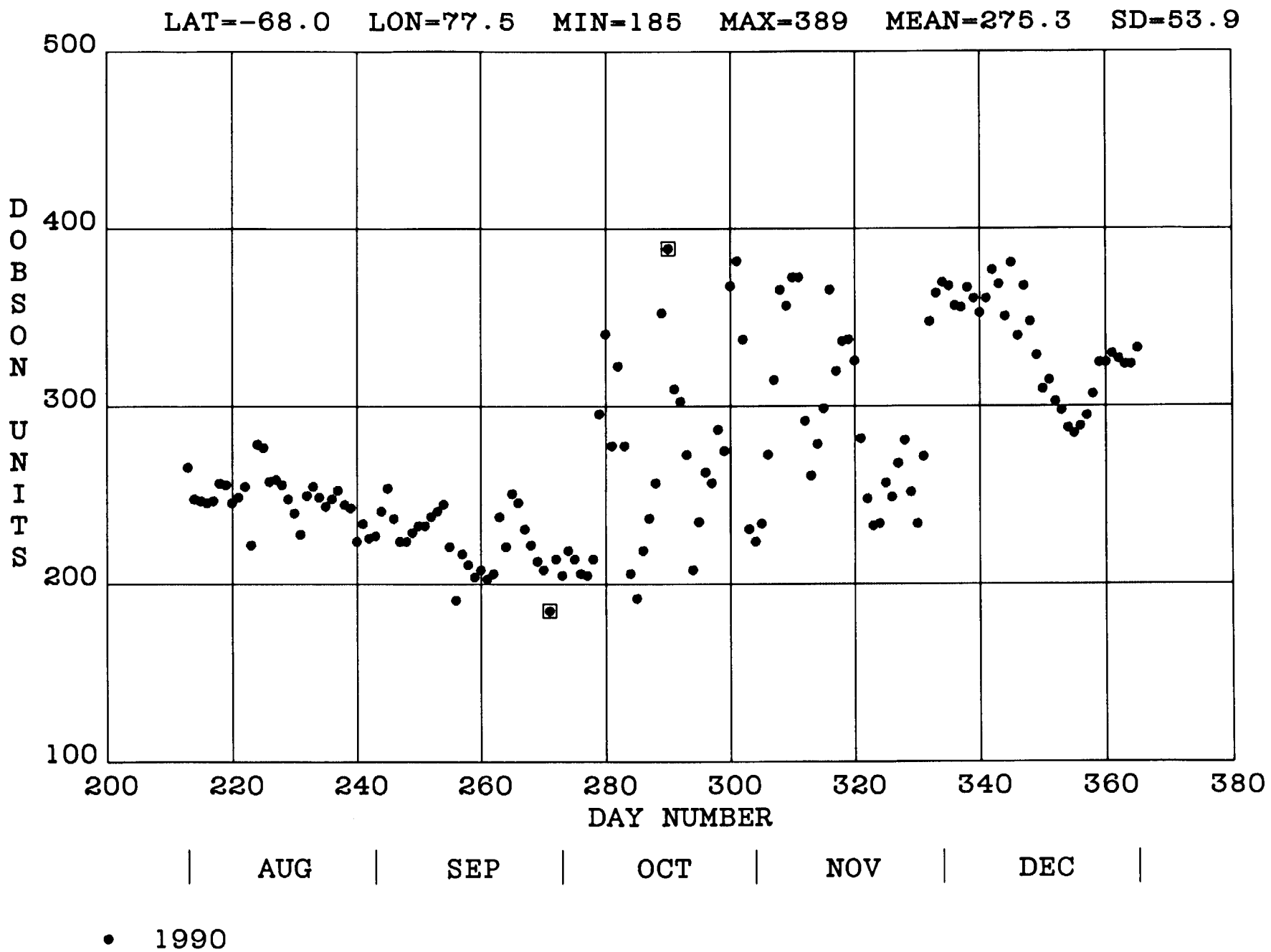


Figure 2C. Daily TOMS Total Ozone Values Over Davis (DU) for 1990.

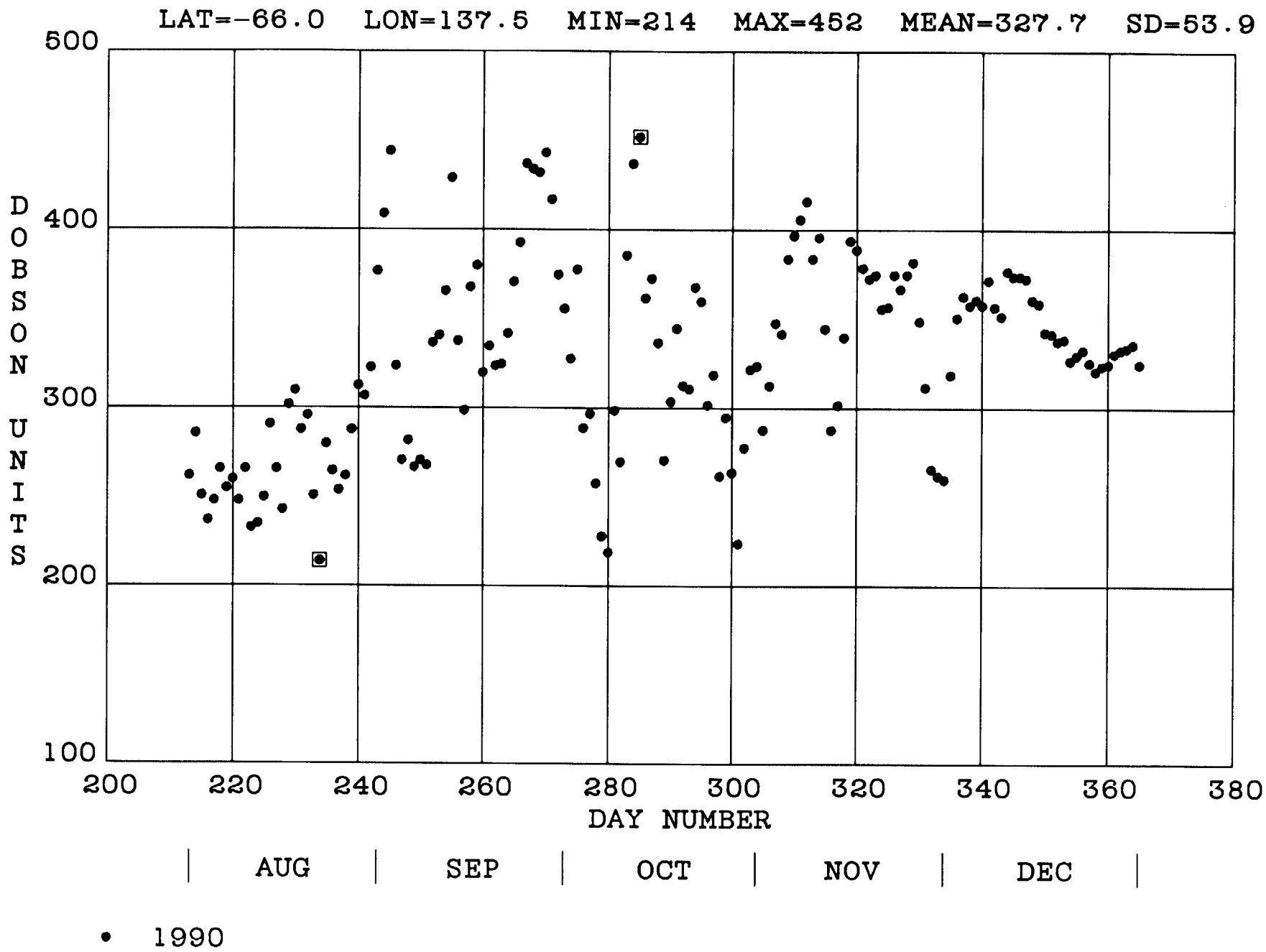


Figure 2D. Daily TOMS Total Ozone Values Over Dumont D'Urville (DU) for 1990.

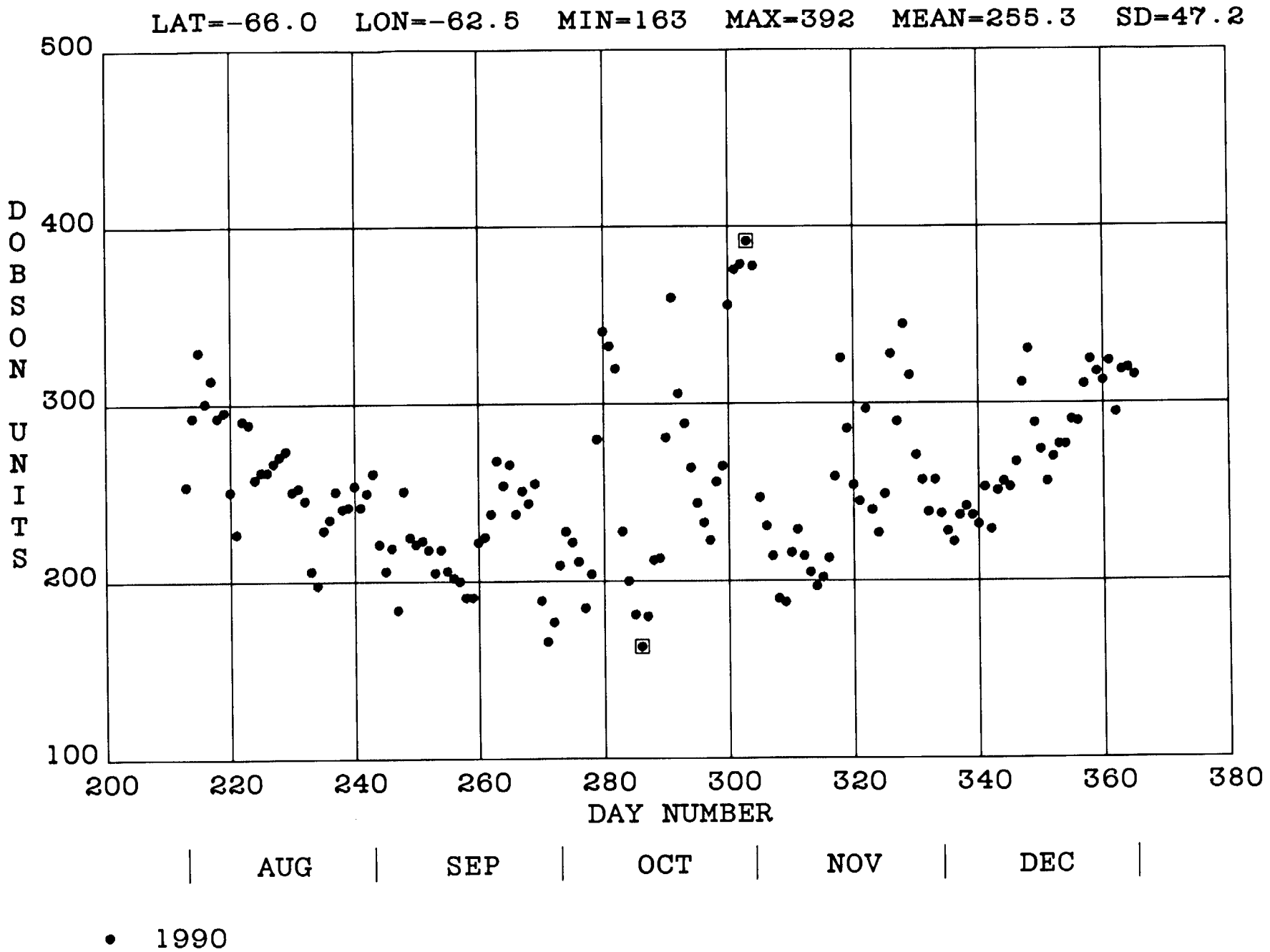


Figure 2E. Daily TOMS Total Ozone Values Over Faraday Station (DU) for 1990.

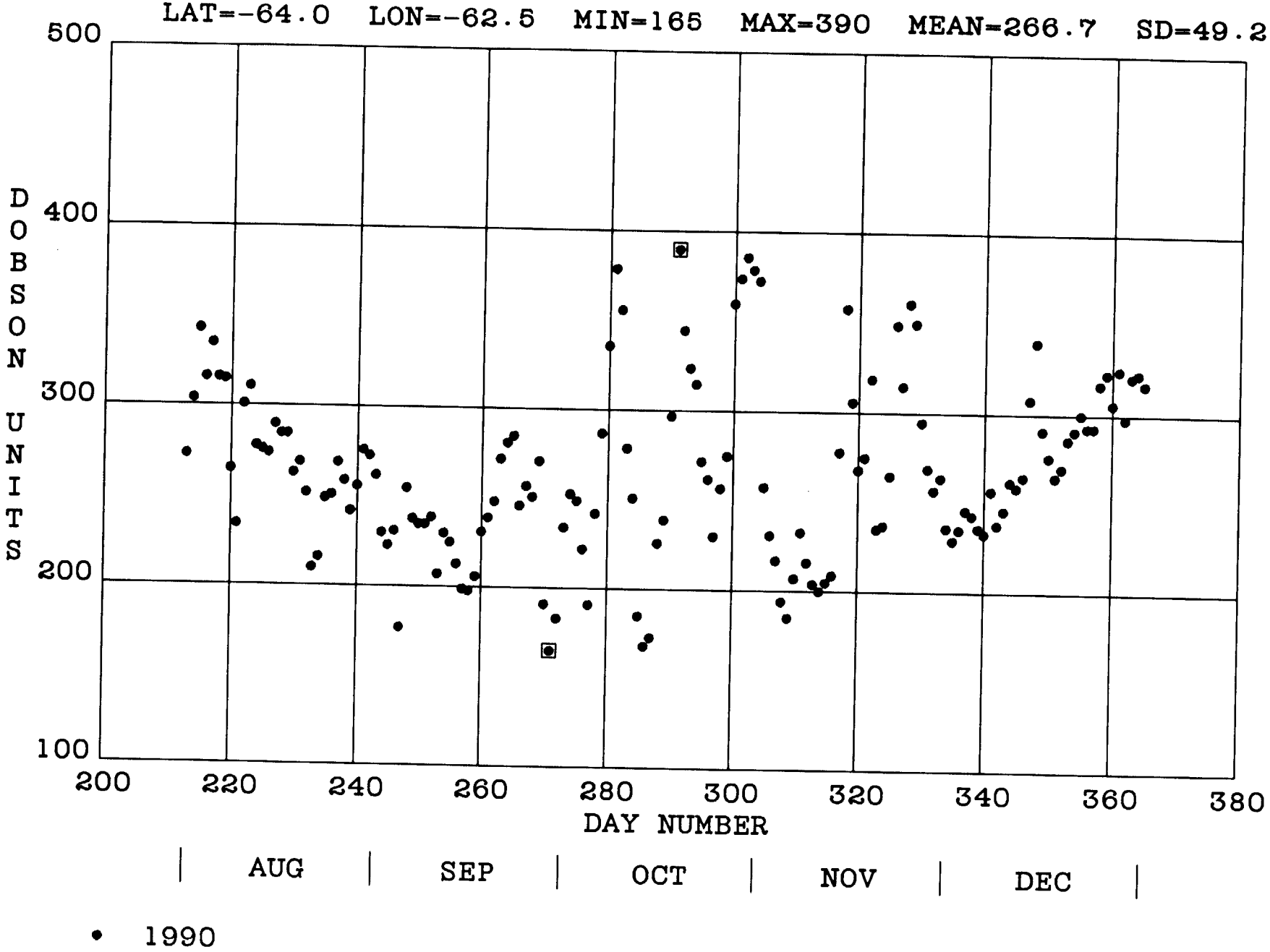


Figure 2F. Daily TOMS Total Ozone Values Over Palmer Station (DU) for 1990.

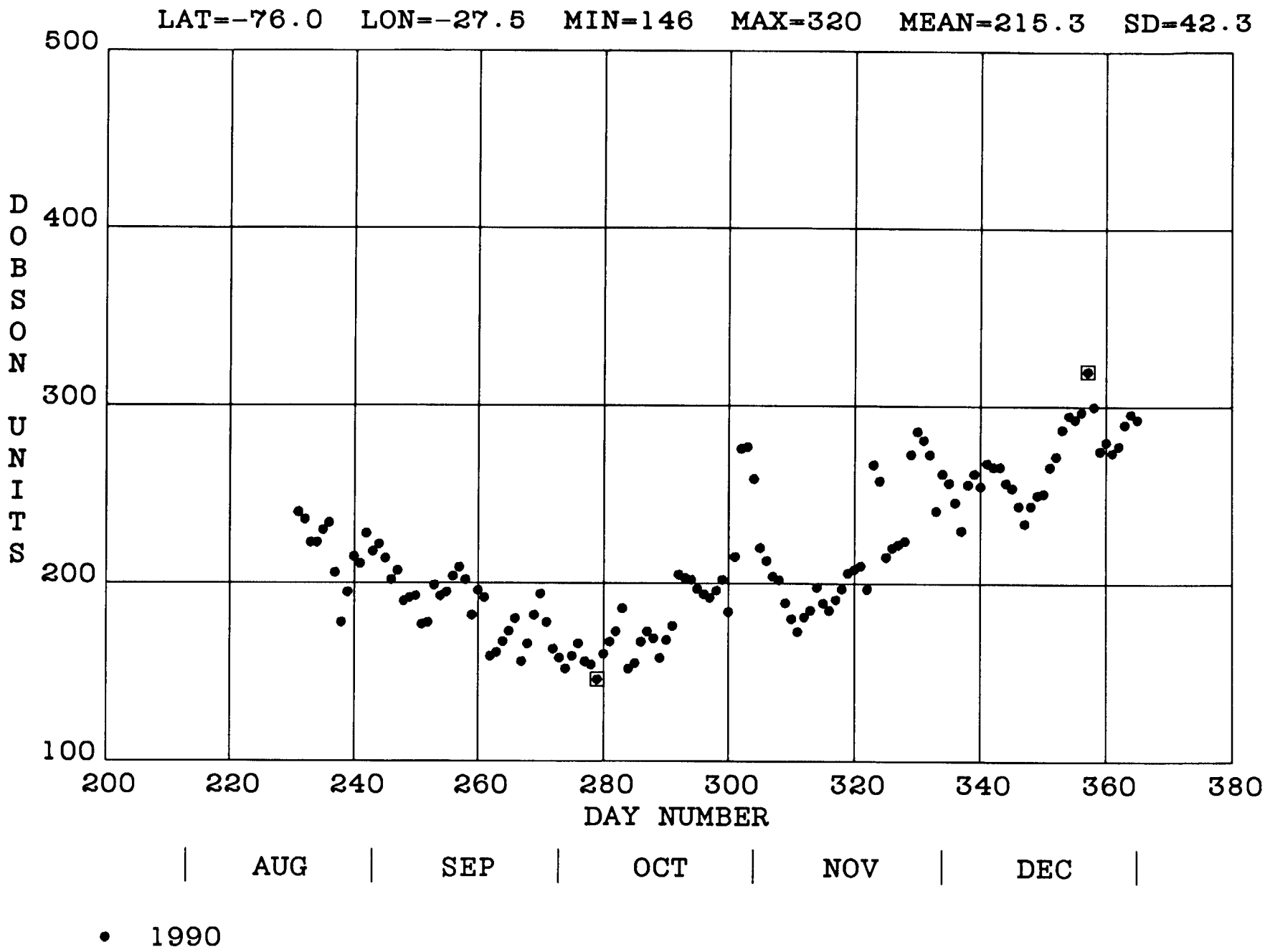


Figure 2G. Daily TOMS Total Ozone Values Over Halley Bay (DU) for 1990.

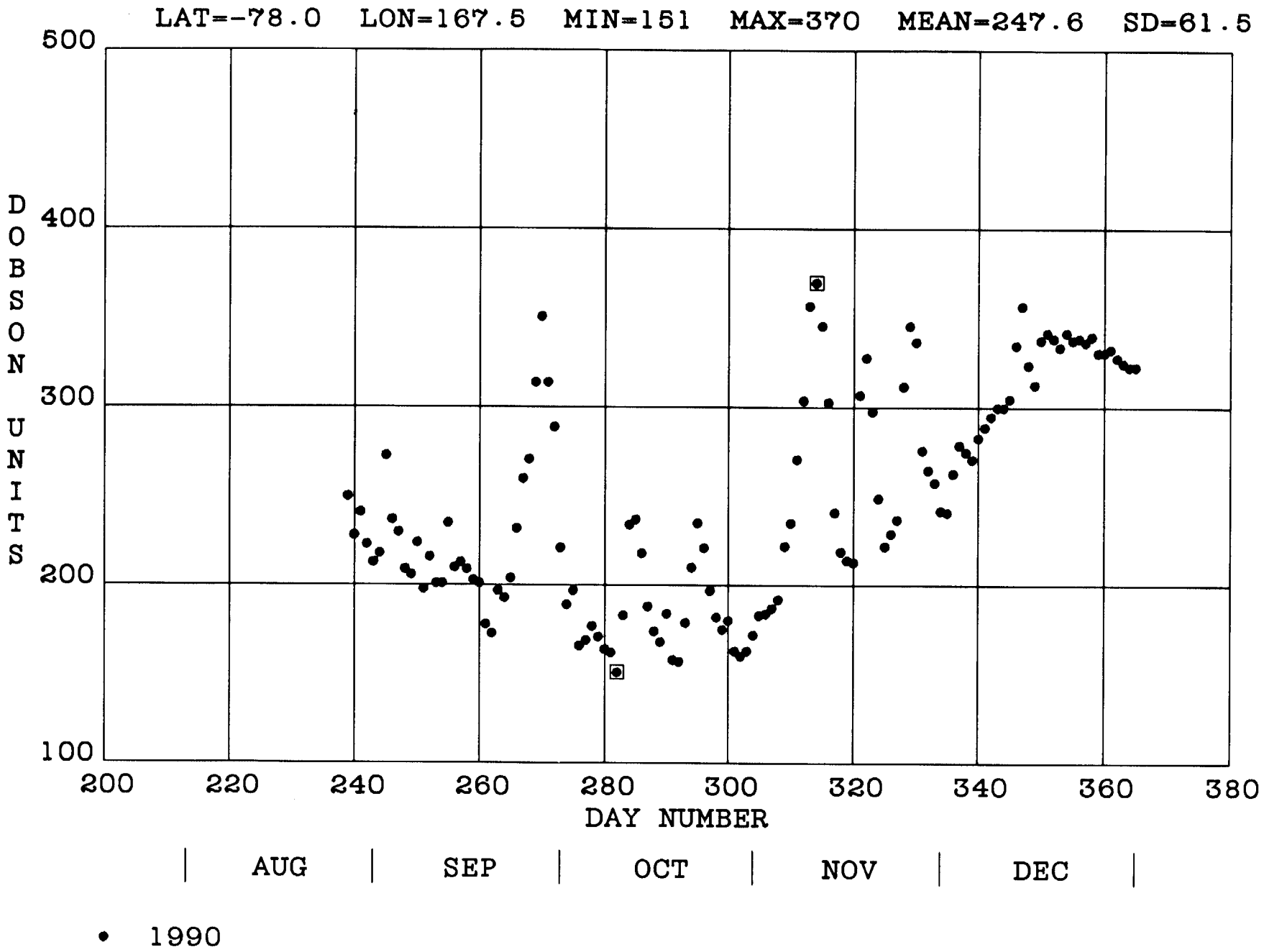


Figure 2H. Daily TOMS Total Ozone Values Over McMurdo (DU) for 1990.

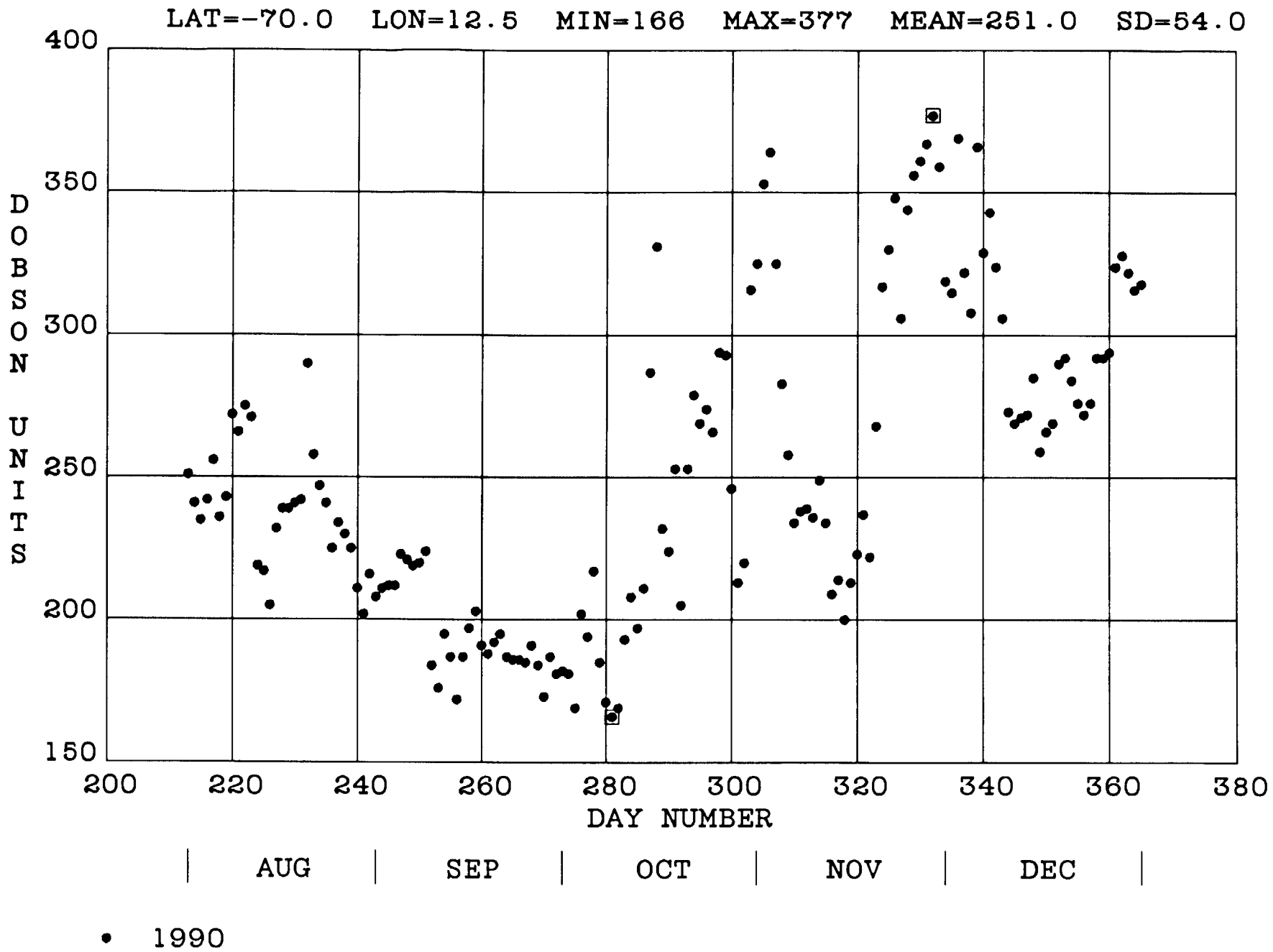


Figure 2I. Daily TOMS Total Ozone Values Over Maitri (DU) for 1990.

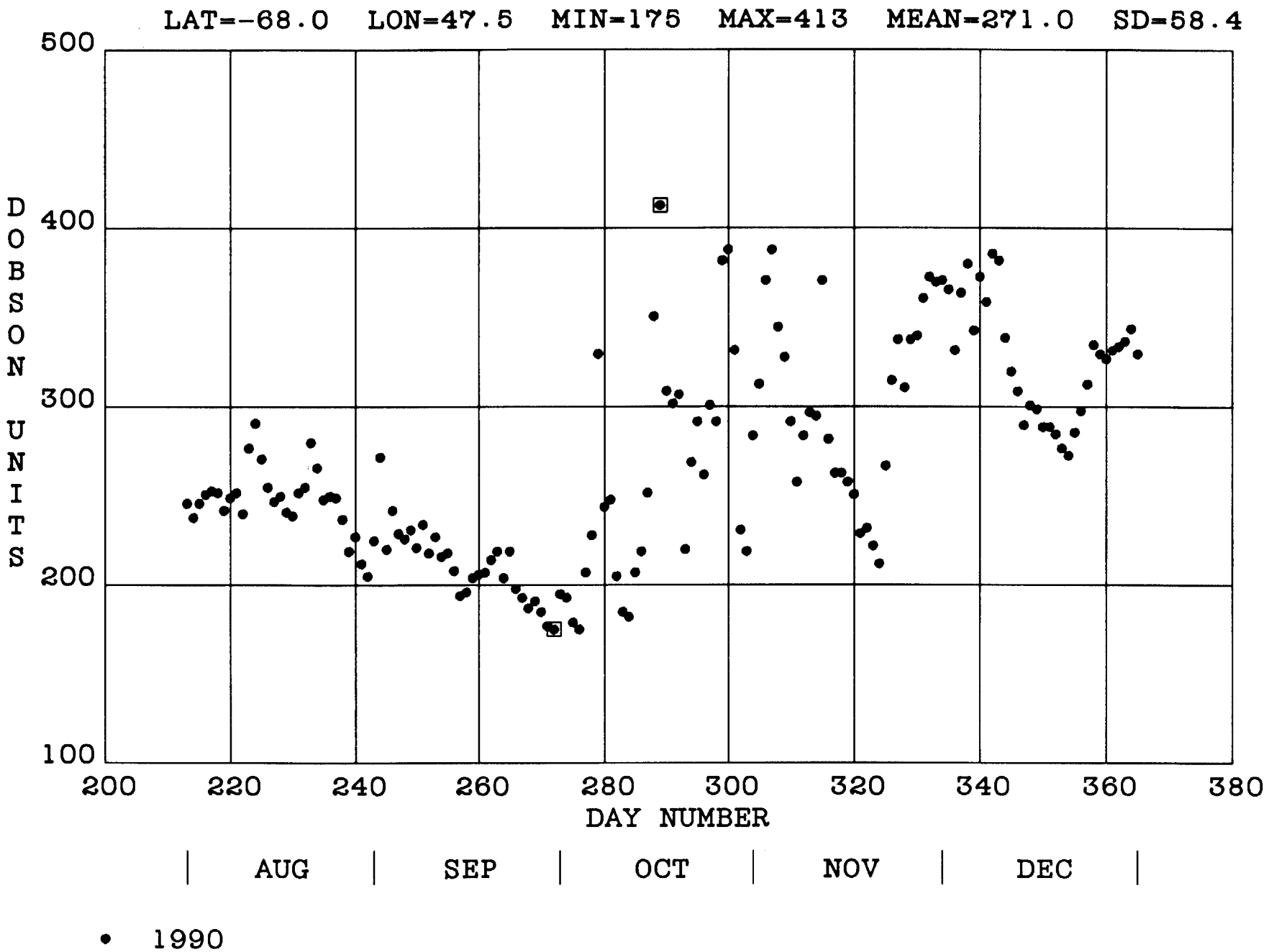


Figure 2J. Daily TOMS Total Ozone Values Over Molodeznaya (DU) for 1990.

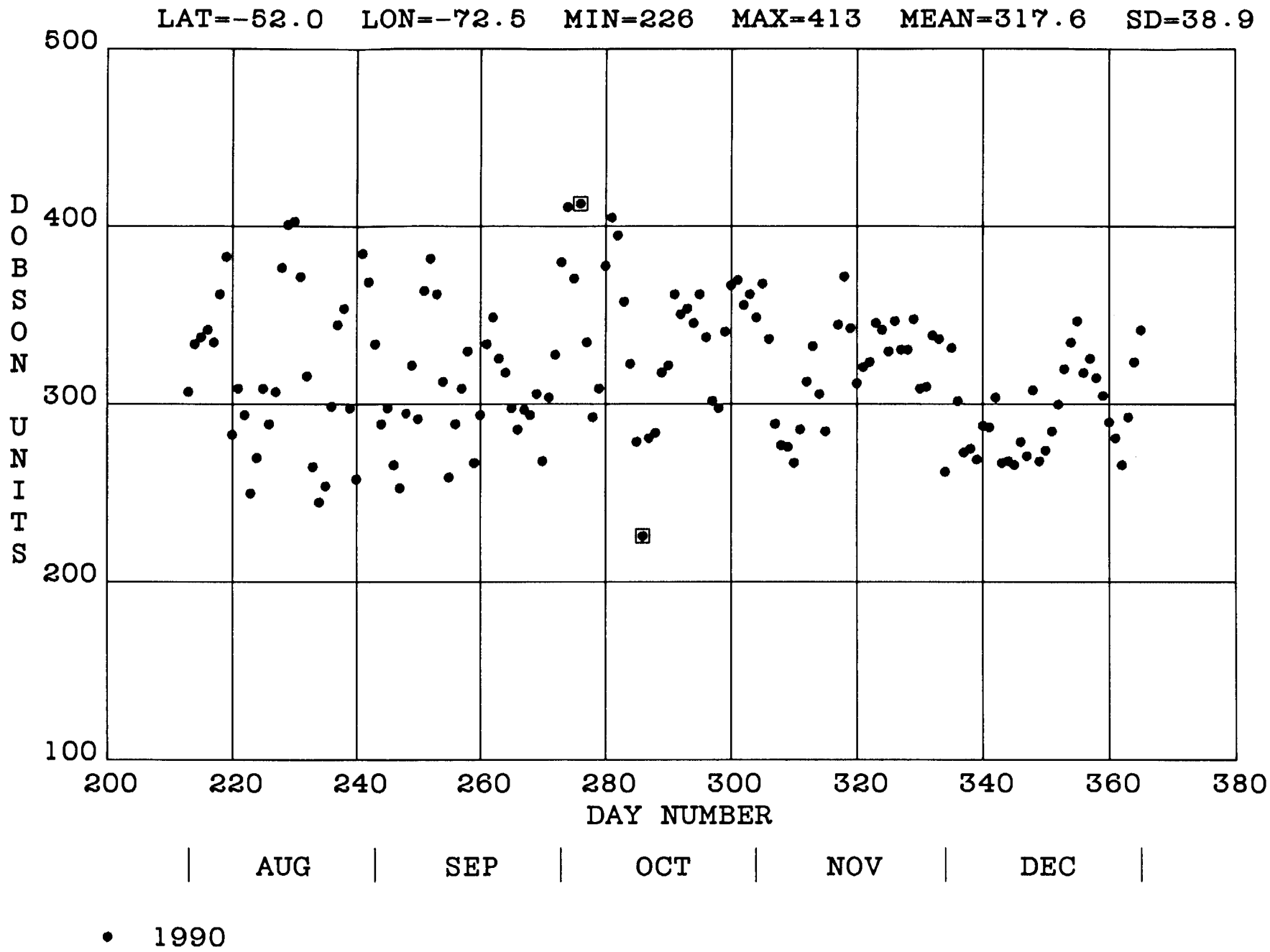


Figure 2K. Daily TOMS Total Ozone Values Over Punta Arenas (DU) for 1990.

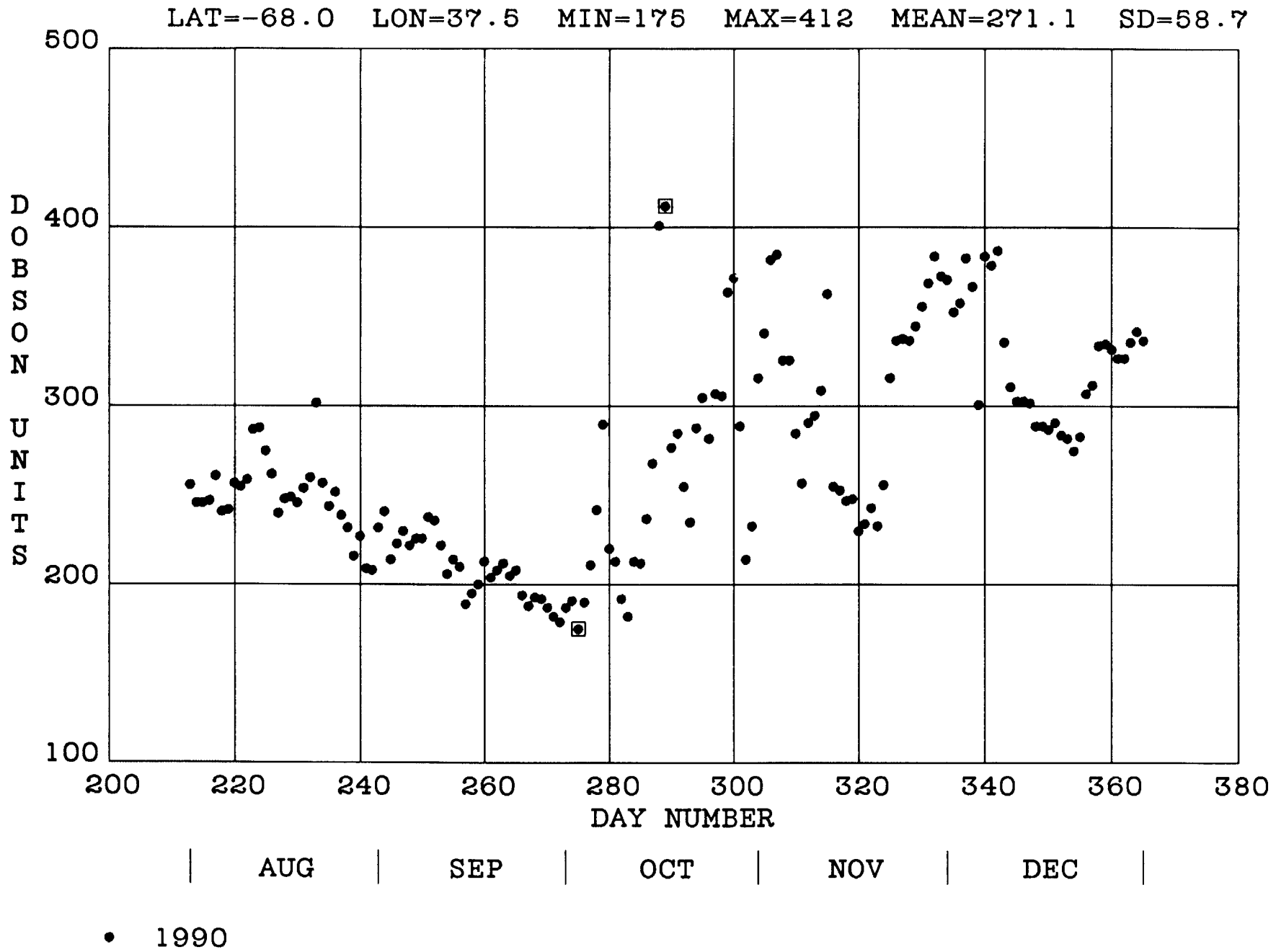


Figure 2L. Daily TOMS Total Ozone Values Over Sywoa (DU) for 1990.

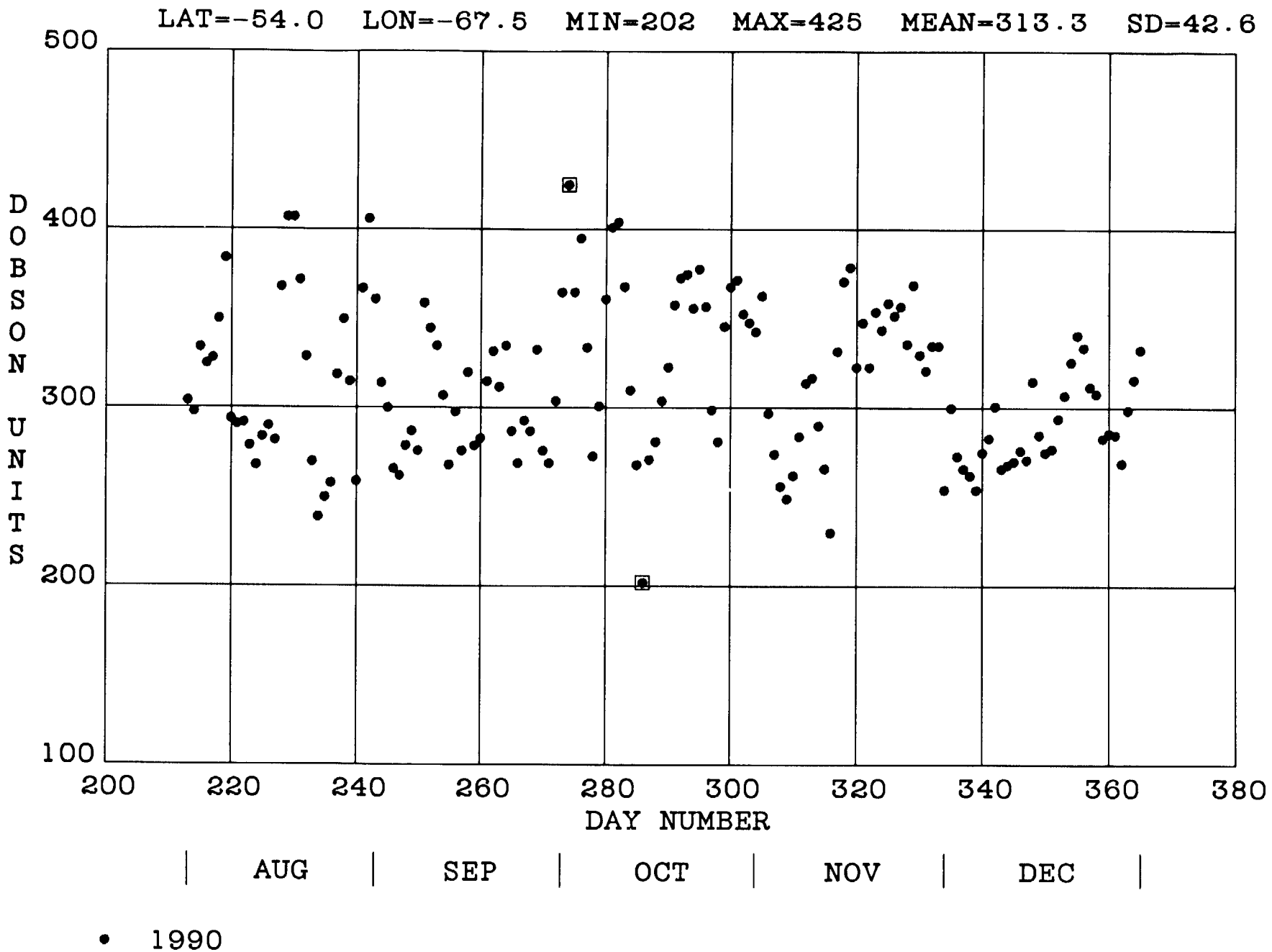


Figure 2M. Daily TOMS Total Ozone Values Over Ushuaia (DU) for 1990.

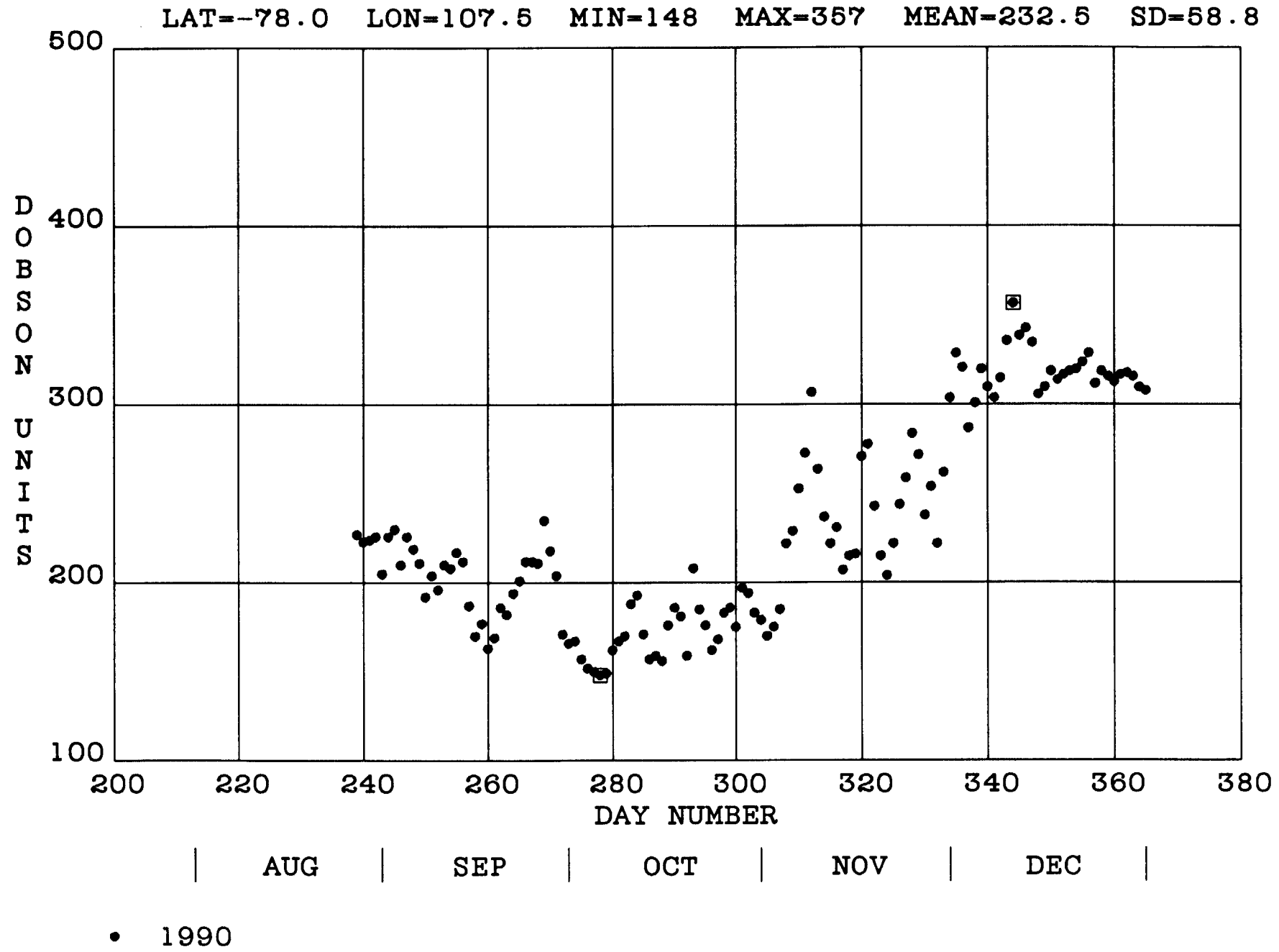


Figure 2N. Daily TOMS Total Ozone Values Over Vostok (DU) for 1990.

3. COMPARISONS WITH PAST OZONE HOLE EVENTS

3.1 Zonal Means

Figures 3A through 3F present the mean total ozone values for each of six latitude bands for the period August 1 through December 31 of the years 1979, 1987, 1988, 1989, and 1990. The latitude bands are 2° wide centered at 30°S, 40°S, 50°S, 60°S, 70°S, and 80°S. In general, only the bands at 70°S and 80°S fall within the area affected by the mature ozone hole, except when it is exceptionally asymmetric with respect to the pole. It should be noted that the ozone scale varies from plot to plot. Figure 3G presents the mean total ozone for the band 70°S to 90°S. It should once again be noted that all ozone data in this atlas have been processed using the Version 6 algorithm.

Figure 3A presents the total ozone means for the subtropical latitude of 30°S. All years display the same seasonal trend, with values rising from August 1 through mid-October, and falling thereafter. The time of the peak ozone value varies from year to year, occurring earliest in 1979, and latest in 1990. During August and September, up to 40 DU separates the highest years (1979 and 1989) and the lowest year (1990). This difference is reduced to approximately 10 DU during late October. Through November and December, the highest values are those for 1979, while the lowest values are for 1990 in November and 1987 in December. The difference between the highest and lowest values in November and December averages 15 DU.

In Figure 3B, the zonal means for 40°S are presented. As with the 30°S band, an initial rise and a subsequent decline are apparent. The range between the highest (1979) and lowest (1990) values averages 40 DU through early October and 30 DU thereafter. Unlike the 30° band, the values for December are significantly lower than those of August for all five years. The values for 1990 are lowest throughout the period with the exception of two weeks in early December when the values of 1987 are lowest.

The 50°S band (Figure 3C) shows the rise and fall characteristic of the lower latitude bands. The range of total ozone values between the highest and lowest years averages 40 DU, although it approaches 60 DU during parts of September and October. During August and September, the highest values are observed for 1979 and 1988. Thereafter, 1979 is well above the other four years. The lowest values are those of 1987 and 1990. The values for 1989 are briefly lowest in late August and mid-December.

Figure 3D presents the band averages for 60°S. This latitude is still not sufficiently close to the pole to experience the mature ozone hole, thus the total ozone values show the rise and fall characteristic of the lower latitude bands. During August, the range between the highest values (1979 and 1988) and the lowest (1987 and 1989) is about 50 DU. This difference grows to nearly 100 DU during early October, indicating some influence of the larger and deeper ozone holes of recent years (1987,1989,1990). During November and December, total ozone values steadily decline, and the range between the highest (1979) and the lowest (1990) declines to about 60 DU. The ozone values for 1990, while somewhat higher than those of 1987 and 1989 through mid-October, are clearly the lowest by early December.

Figure 3E presents the band averages for 70°S. All five years fall under the influence of the mature ozone hole and thus show an initial decline in total ozone values. For the most part, the years 1979 and 1988 are higher throughout than 1987, 1989 and 1990, the years with significant ozone hole events. The range between the highest and lowest years varies from about 50 DU during August and December to nearly 200 DU during late October. The values for the years 1979 and 1988 peak during late October or early November and then decline through December. The years 1987 and 1990 show a steady increase from early October through early December. The year 1989 seems to be intermediate. The absolute lowest values occur in 1990 from August 1 through early September, 1987 and 1989 during September, 1987 during October and November and 1990 again during December.

The zonal means for 80°S are presented in Figure 3F. This latitude band falls substantially within the ozone hole for all years. Data acquisition commences when the sun rises above the horizon in early September. All years show an initial decline as the ozone hole matures. The decline is far more pronounced in 1987, 1989 and 1990, with the absolute minimum values for these three years very similar in magnitude and time of occurrence. The minimum values for 1979 and 1988 occur several weeks earlier. The total ozone values for 1987, 1989 and 1990 are essentially similar until mid-October. Thereafter, the values for 1987 are lowest until mid-November. During the time period from mid-November through December, the ozone values for the year 1990 are lowest. The years 1979 and 1988 feature a peak during November which is absent from the other three years.

Figure 3G shows the mean latitude-weighted total ozone for that portion of the southern hemisphere south of latitude 70° for 1979, 1987, 1988, 1989 and 1990. All years display an initial decline, indicating the deepening of the ozone hole. Minimum values for 1979 and 1988 occur in September, while the lower minima for 1987, 1989, and 1990 occur in very early October. The years 1979 and 1988 values reach a maximum in late November and decline through December. The remaining years rise steadily from early October. The 1987 ozone hole fills very slowly through mid-November, but then fills very rapidly thereafter. The ozone values for 1990 are the lowest of the five years until mid-September and after mid-November, the time least influenced by the ozone hole.

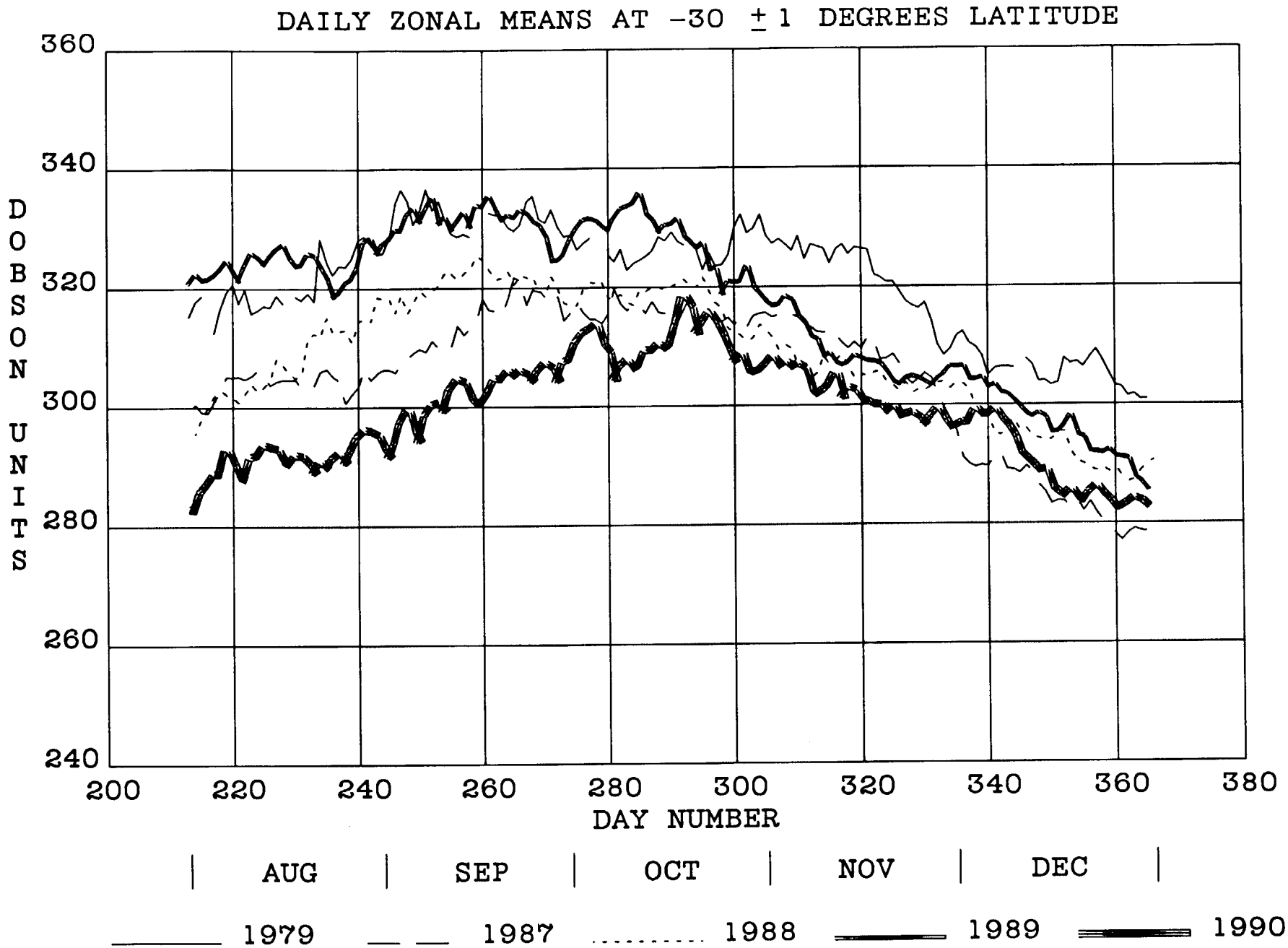


Figure 3A. Mean Total Ozone for the 2° Latitude Band Centered at 30°S for the Period August 1 Through December 31 of the Years 1979, 1987, 1988, 1989, and 1990.

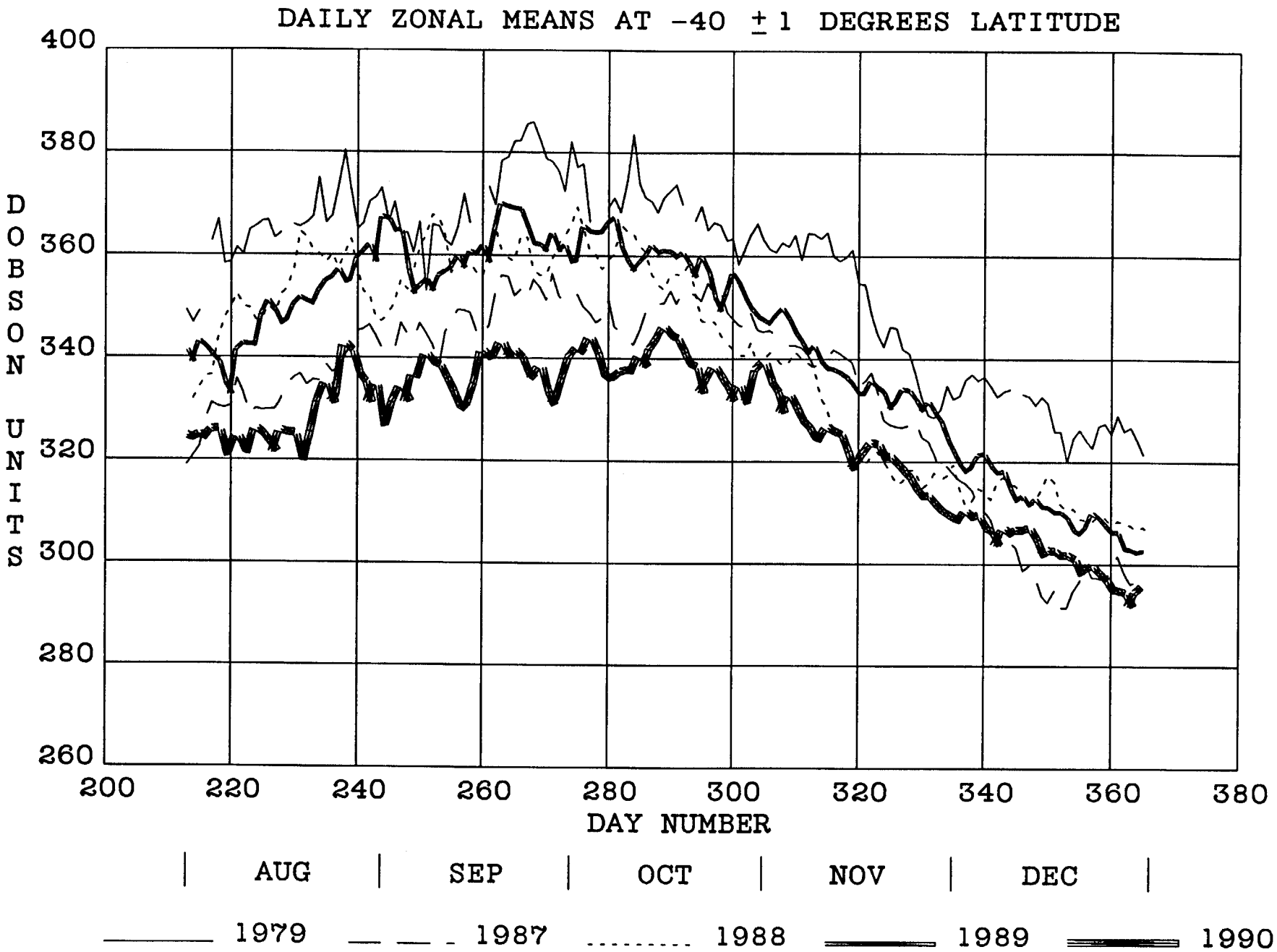


Figure 3B. Mean Total Ozone for the 2° Latitude Band Centered at 40°S for the Period August 1 Through December 31 of the Years 1979, 1987, 1988, 1989, and 1990.

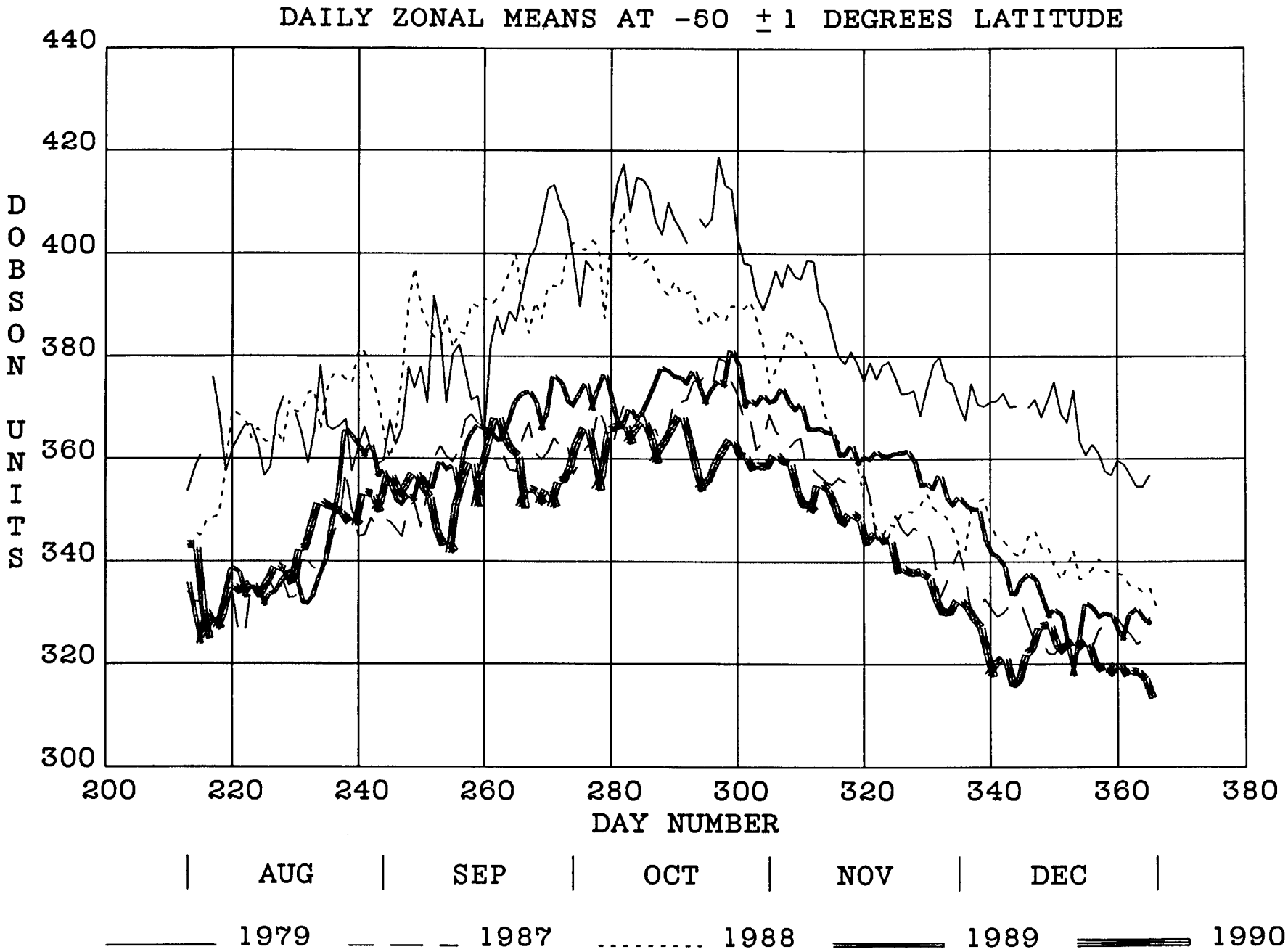


Figure 3C. Mean Total Ozone for the 2° Latitude Band Centered at 50°S for the Period August 1 Through December 31 of the Years 1979, 1987, 1988, 1989, and 1990.

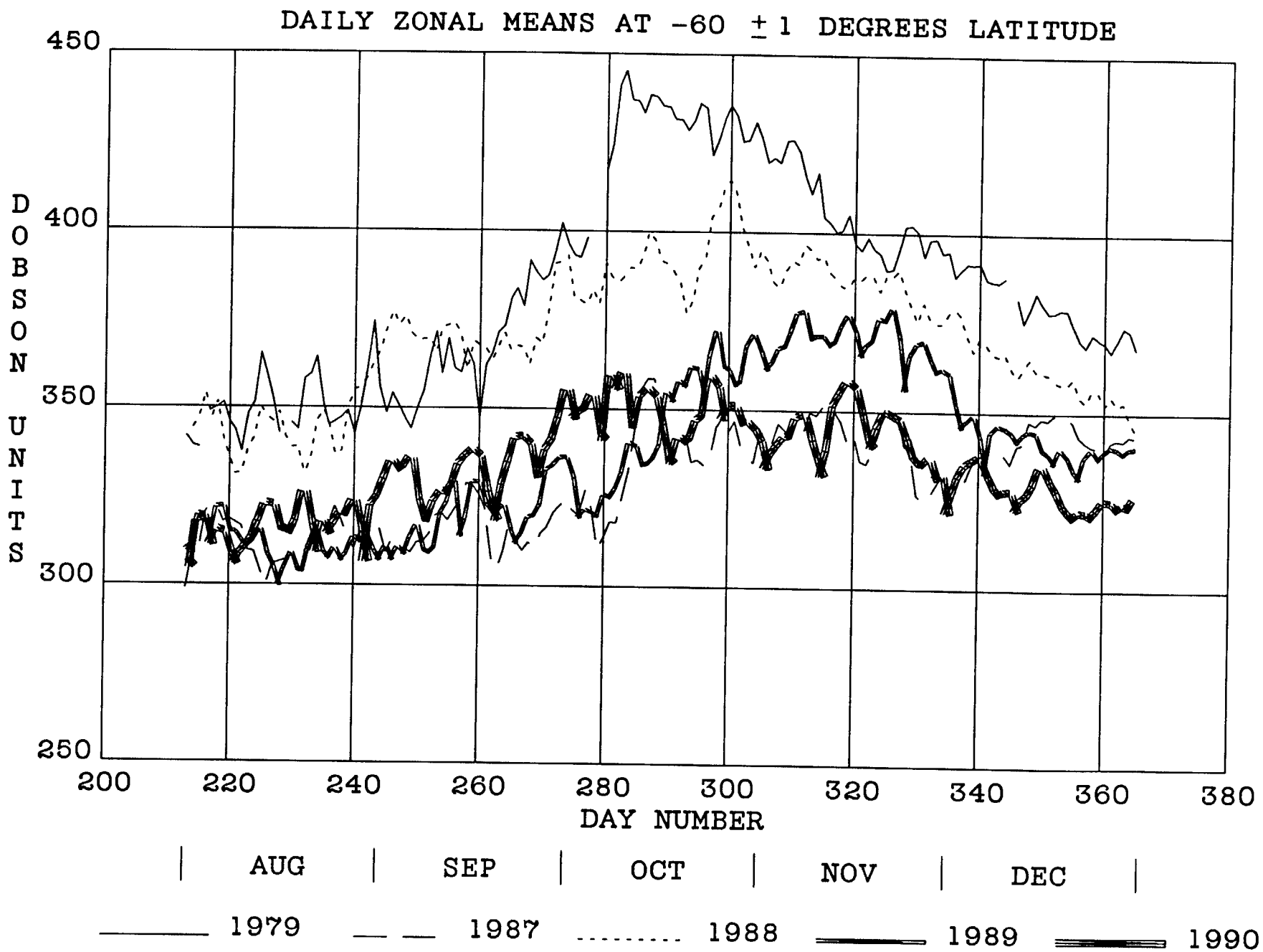


Figure 3D. Mean Total Ozone for the 2° Latitude Band Centered at 60°S for the Period August 1 Through December 31 of the Years 1979, 1987, 1988, 1989, and 1990.

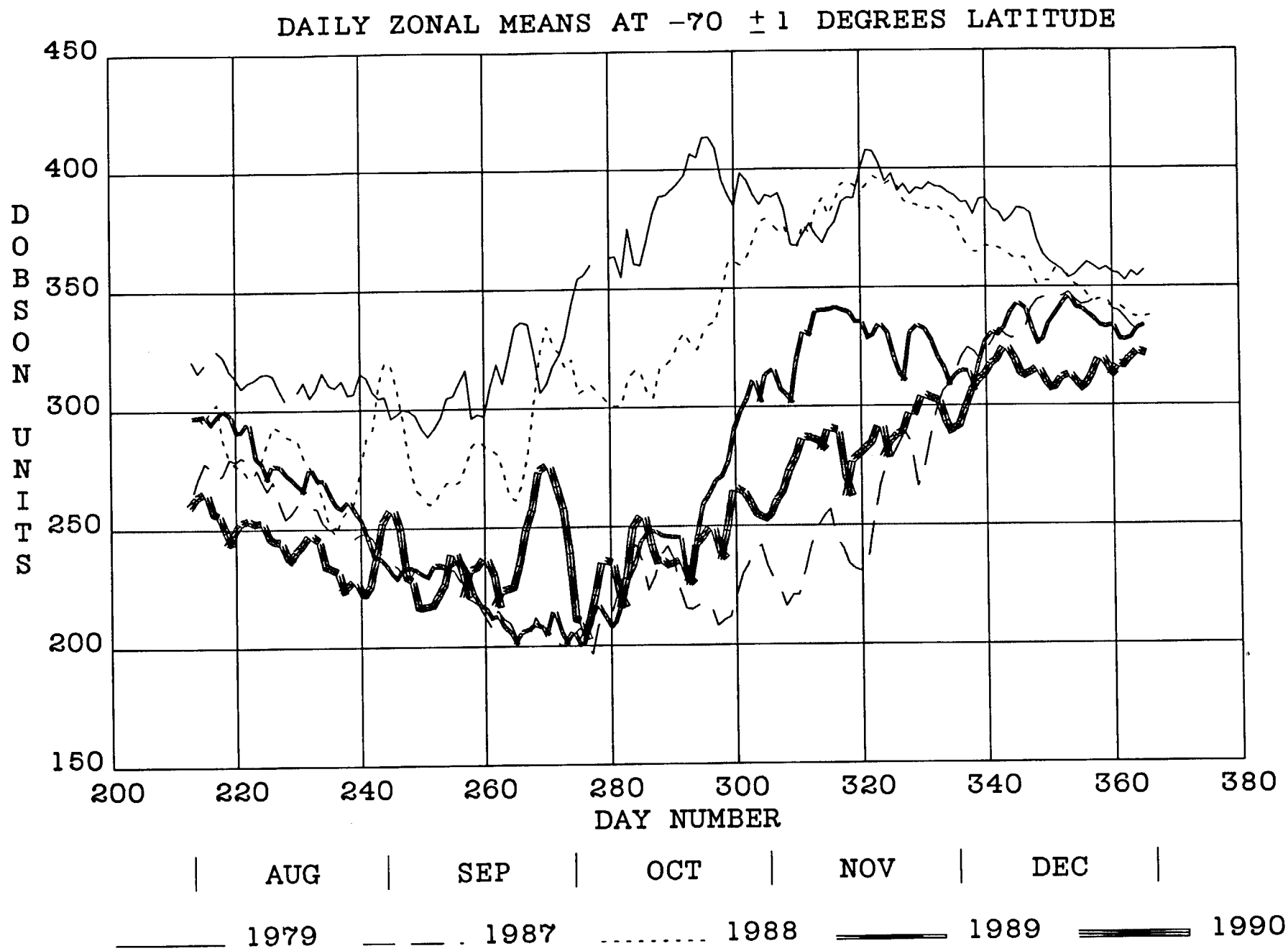


Figure 3E. Mean Total Ozone for the 2° Latitude Band Centered at 70°S for the Period August 1 Through December 31 of the Years 1979, 1987, 1988, 1989, and 1990.

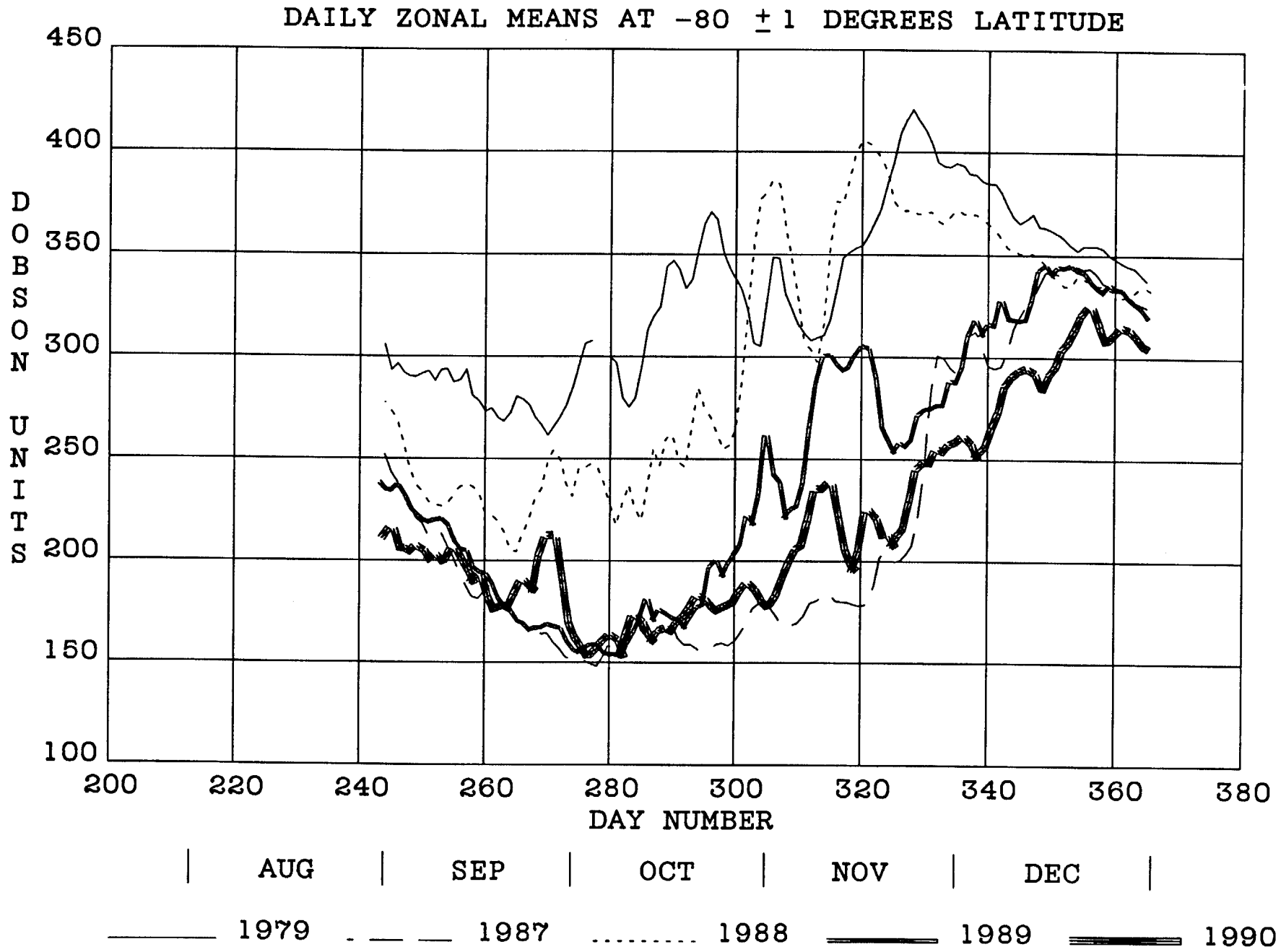


Figure 3F. Mean Total Ozone for the 2° Latitude Band Centered at 80°S for the Period August 1 Through December 31 of the Years 1979, 1987, 1988, 1989, and 1990.

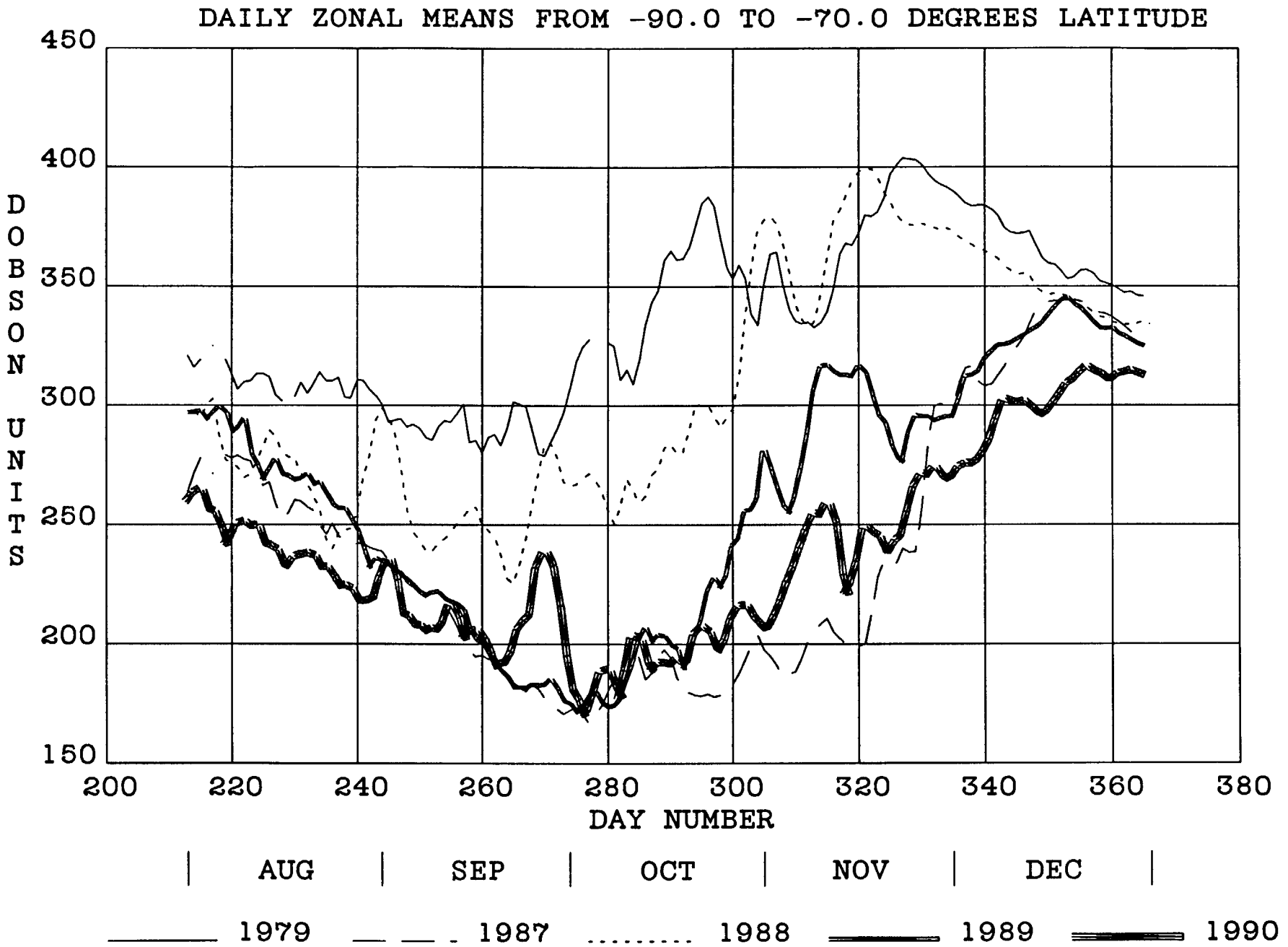


Figure 3G. Mean Total Ozone for the Latitude Band 70°S to 90°S for the Period August 1 Through December 31 of the Years 1979, 1987, 1988, 1989, and 1990.

3.2 Monthly Differences

Figures 4A through 4E present the hemispheric differences of total ozone between the months of August through December, 1990 and a four-year reference mean (1979 through 1982). Figures 4F through 4J present the differences between August through December, 1990 and the same five months in 1987. The years 1987 and 1990 have experienced the most pronounced ozone depletion to date, although the year 1989 falls close behind. Isopleths are solid where the difference is positive, and dashed where it is negative.

During August 1990 (Figure 4A), total ozone is lower than the reference mean throughout the hemisphere. The differences are 10% or less until one reaches latitude 60°S. From there poleward, the negative differences increase to a maximum of from 25 to 30% near the terminator.

During the month of September (Figure 4B), negative differences again predominate. However, unlike August, an area of positive differences exists, and the overall pattern is not symmetric about the pole. The area of positive differences is in the Pacific, north of Wilkes Land and the Ross Sea, possessing a magnitude of only 5%. Regions of negative difference exceeding 30% exist over Queen Maude Land and in the immediate polar region.

Figure 4C displays a pattern again differing from the preceding month. During October, the pattern is again asymmetric, but now the center of the negative differences is on the opposite side of the pole, over the Ross Ice Shelf. Here, a large area of negative differences exceeding 40% exists. There is only the smallest area of slight positive differences over the eastern Pacific west of Cape Horn.

During the month of November (Figure 4D), negative differences exist for the entire hemisphere. These differences increase toward, and are symmetric about, the pole. The maximum negative differences exceed 35%.

During the month of December (Figure 4E), negative differences again exist for the entire hemisphere. The pattern once again has become asymmetric with the pole, with maximum negative differences exceeding 25% over the Weddell Sea, the final location of the 1990 ozone hole.

In comparing August 1987 to August 1990 (Figure 4F) one finds the ozone values for 1990 to be lower over much of the hemisphere. A broad area of slight positive differences exists between latitude 30°S and 60°S over the Atlantic, Indian and western Pacific Oceans. Negative differences approaching 15 to 20% exist near the terminator.

During September (Figure 4G), the area of positive differences covers about half of the hemisphere, with positive differences exceeding 40% centered near the coast of eastern Wilkes Land. The largest negative differences exceed 10% and are located in the South Atlantic and Eastern Pacific Oceans.

During October (Figure 4H), the hemisphere is again nearly equally divided between areas of positive and negative differences, but geographically, these areas are reversed. A large area of

positive differences, with maximum differences exceeding 30%, exists over the South Atlantic Ocean. A diffuse area of small negative differences can be seen over the Indian and western Pacific Oceans. The majority of the Antarctic continent shows slight positive differences.

It is apparent from Figure 4I that during November, the ozone hole was deeper in 1987 than in 1990. Significant positive differences dominate the area south of latitude 60°S. A small area of negative differences exceeding 10% exists near the tip of the Antarctic Peninsula.

The pattern of November is reversed in December (Figure 4J). During December 1990, ozone values in the filling ozone hole were lower than during 1987, and negative differences exceeding 10% dominate the polar region. Very slight positive differences may be seen over the mid-latitudes.

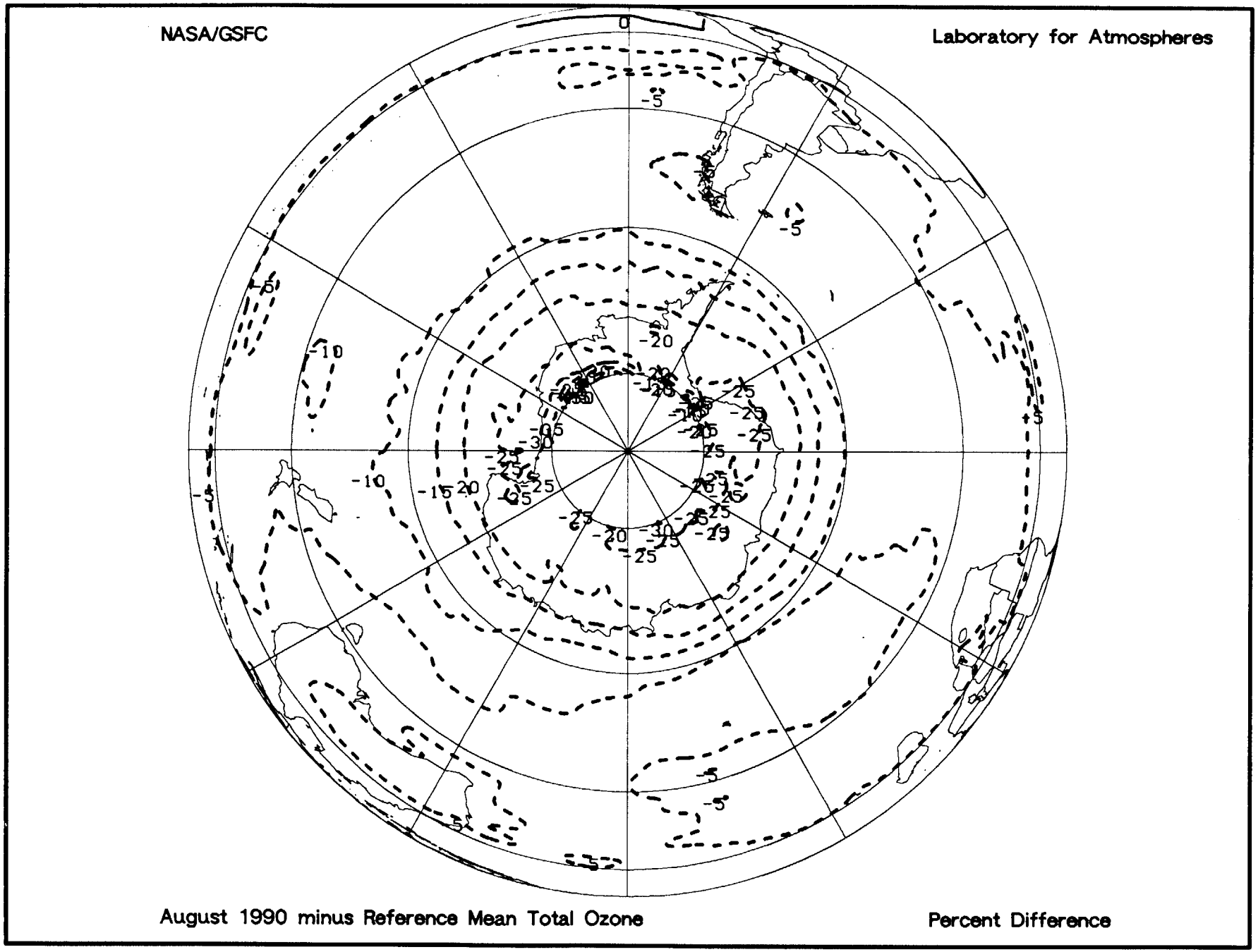


Figure 4A. Monthly Mean Total Ozone Difference Between August 1990 and a 4-Year Reference Mean (August 1979 Through 1982).

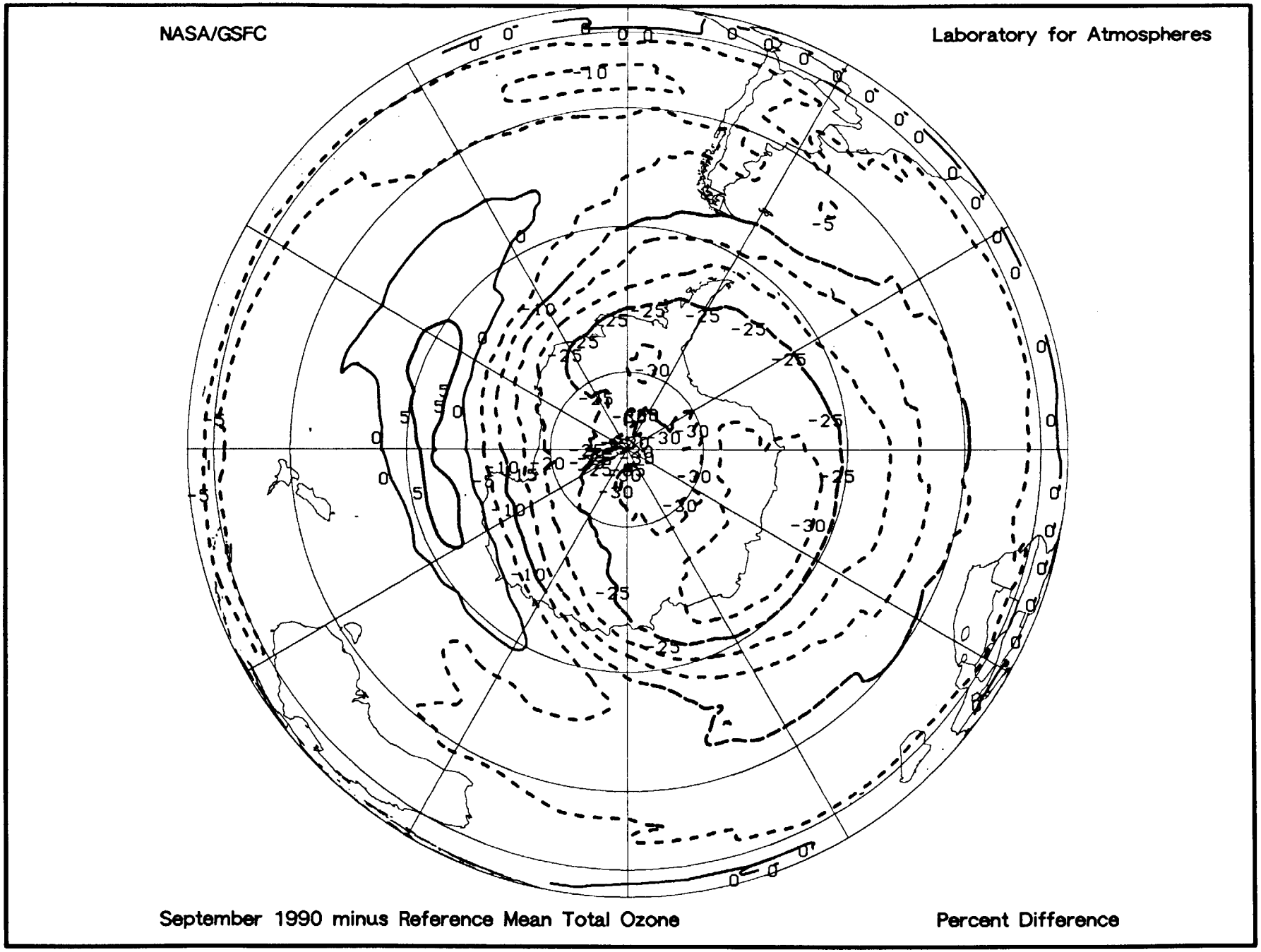


Figure 4B. Monthly Mean Total Ozone Difference Between September 1990 and a 4-Year Reference Mean (September 1979 Through 1982).

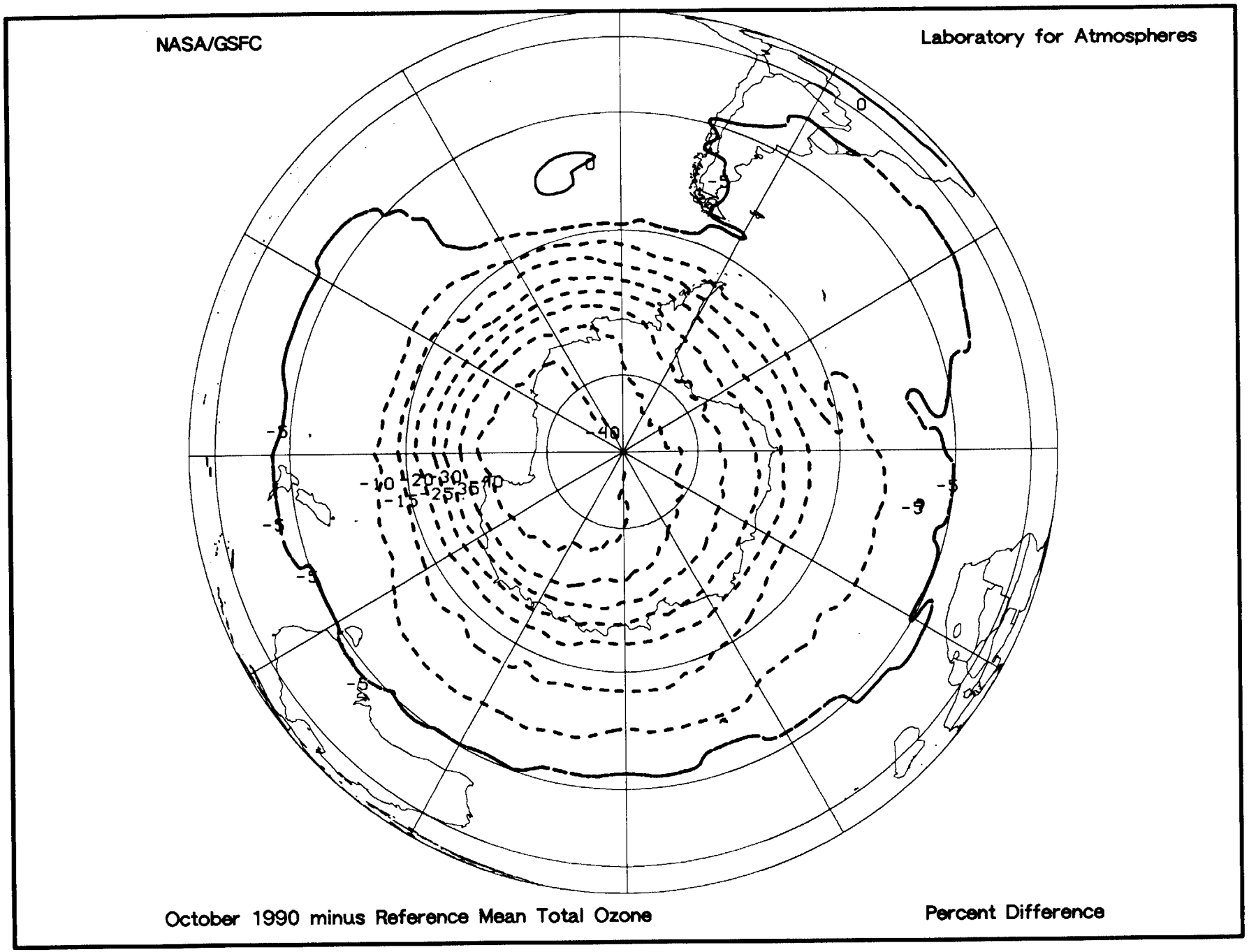


Figure 4C. Monthly Mean Total Ozone Difference Between October 1990 and a 4-Year Reference Mean (October 1979 Through 1982).

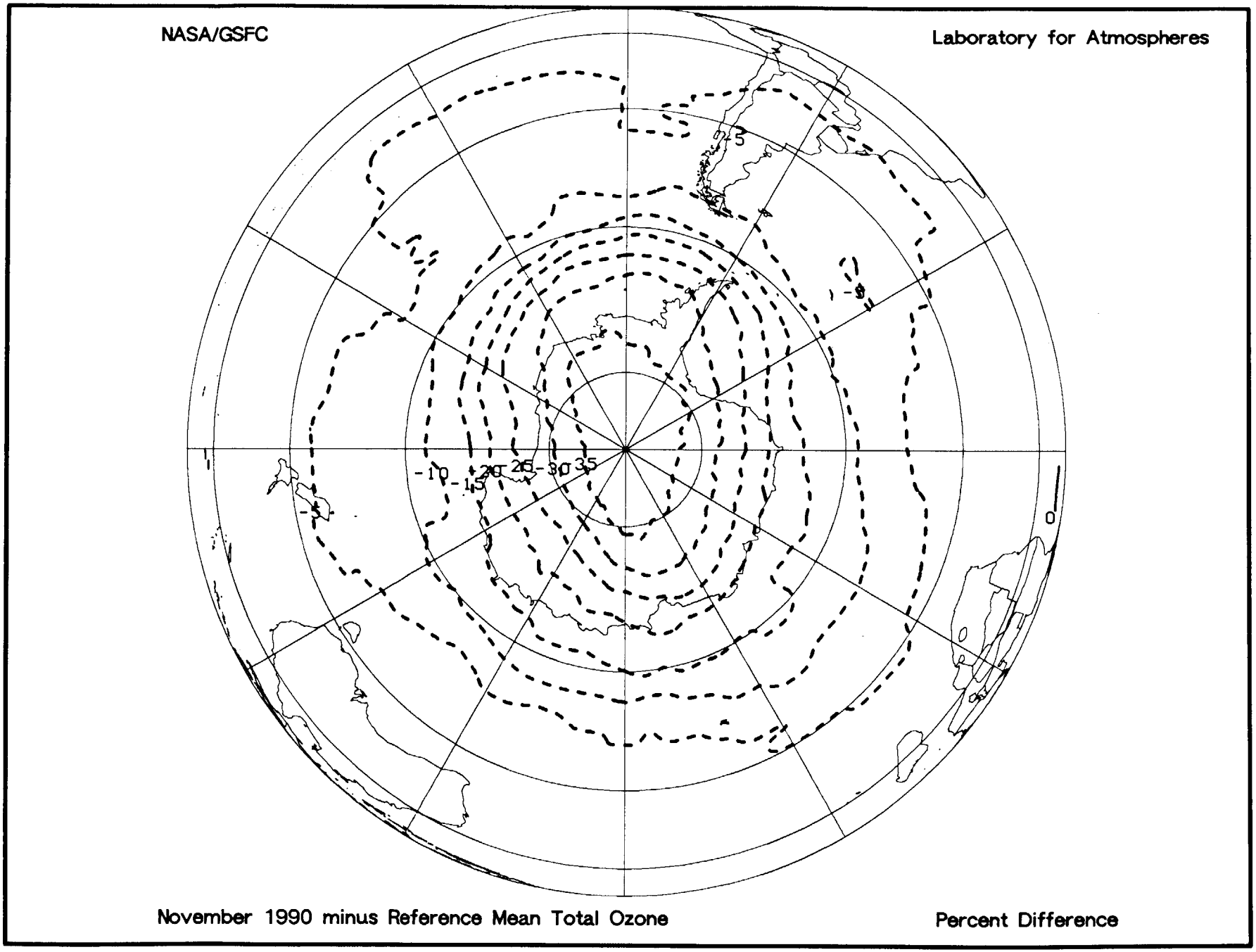


Figure 4D. Monthly Mean Total Ozone Difference Between November 1990 and a 4-Year Reference Mean (November 1979 Through 1982).

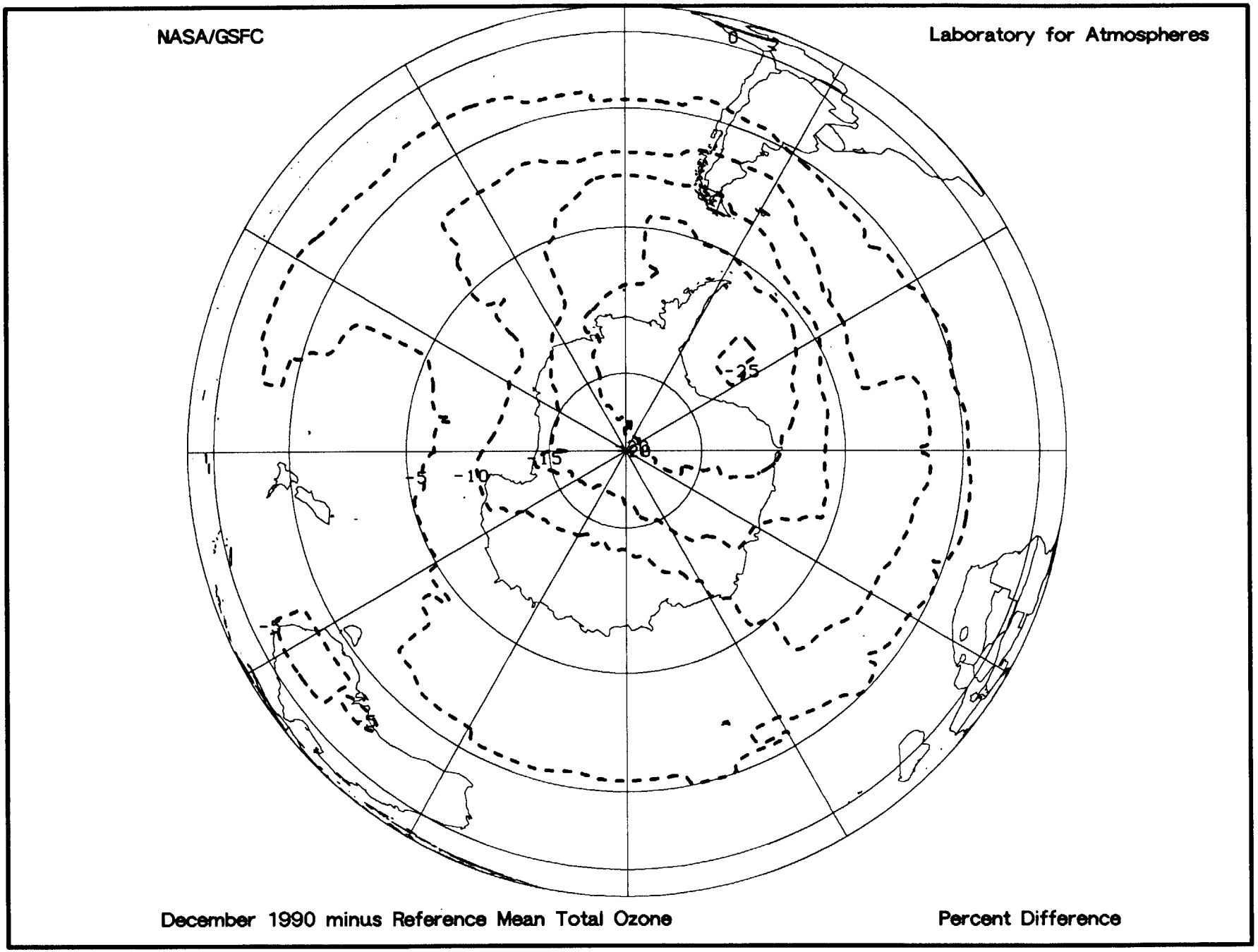


Figure 4E. Monthly Mean Total Ozone Difference Between December 1990 and a 4-Year Reference Mean (December 1979 Through 1982).

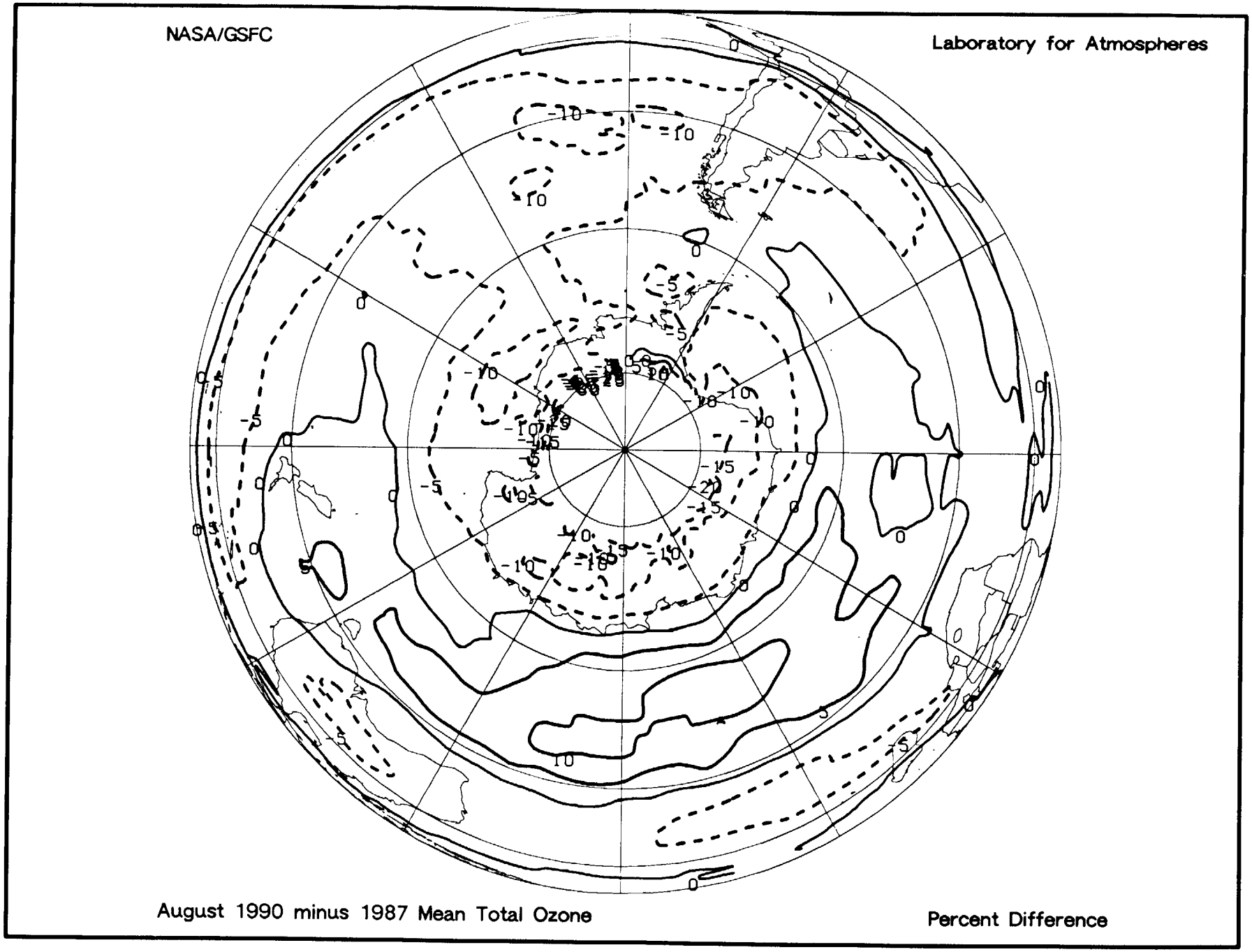


Figure 4F. Monthly Mean Total Ozone Difference Between August 1990 and August 1987.

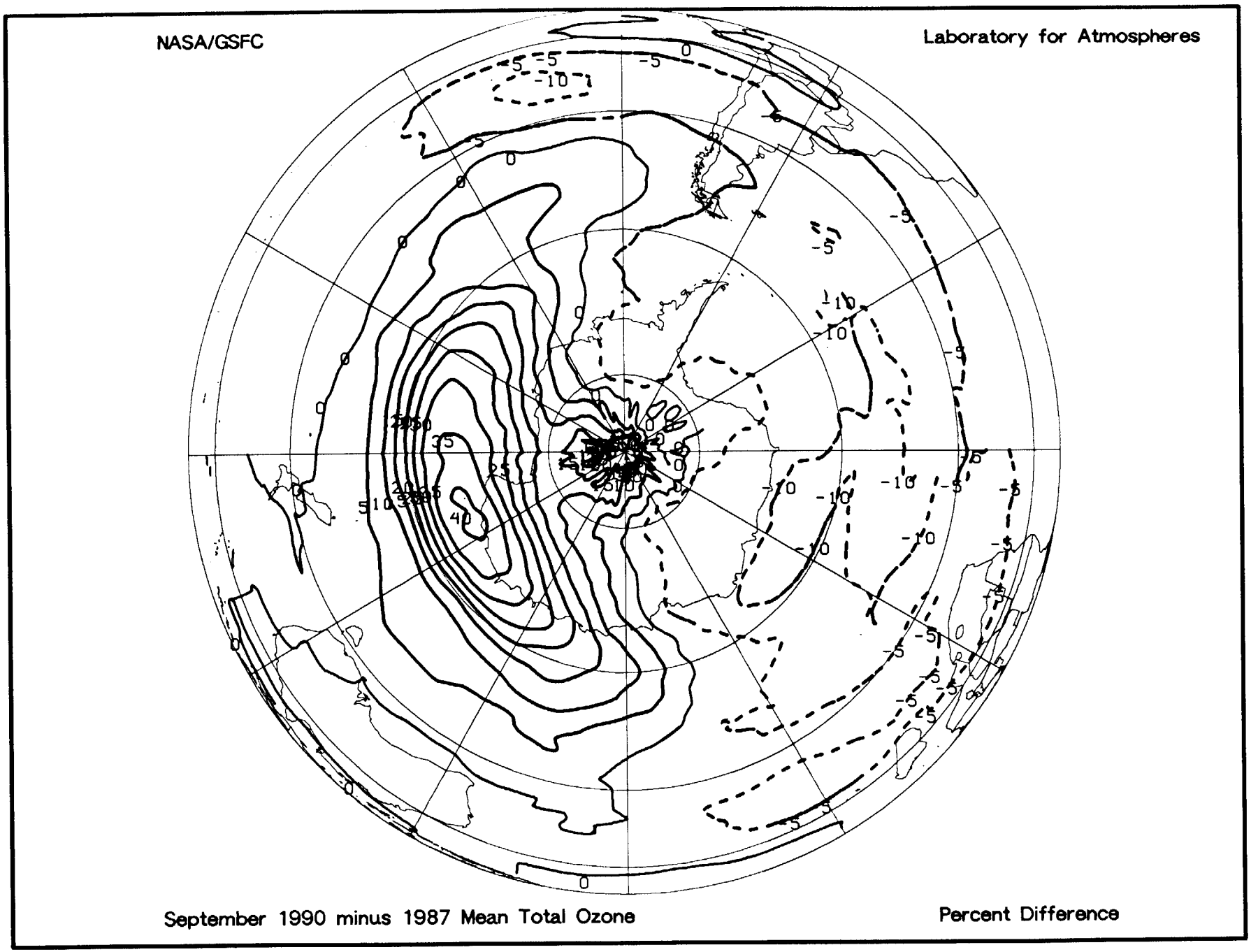


Figure 4G. Monthly Mean Total Ozone Difference Between September 1990 and September 1987.

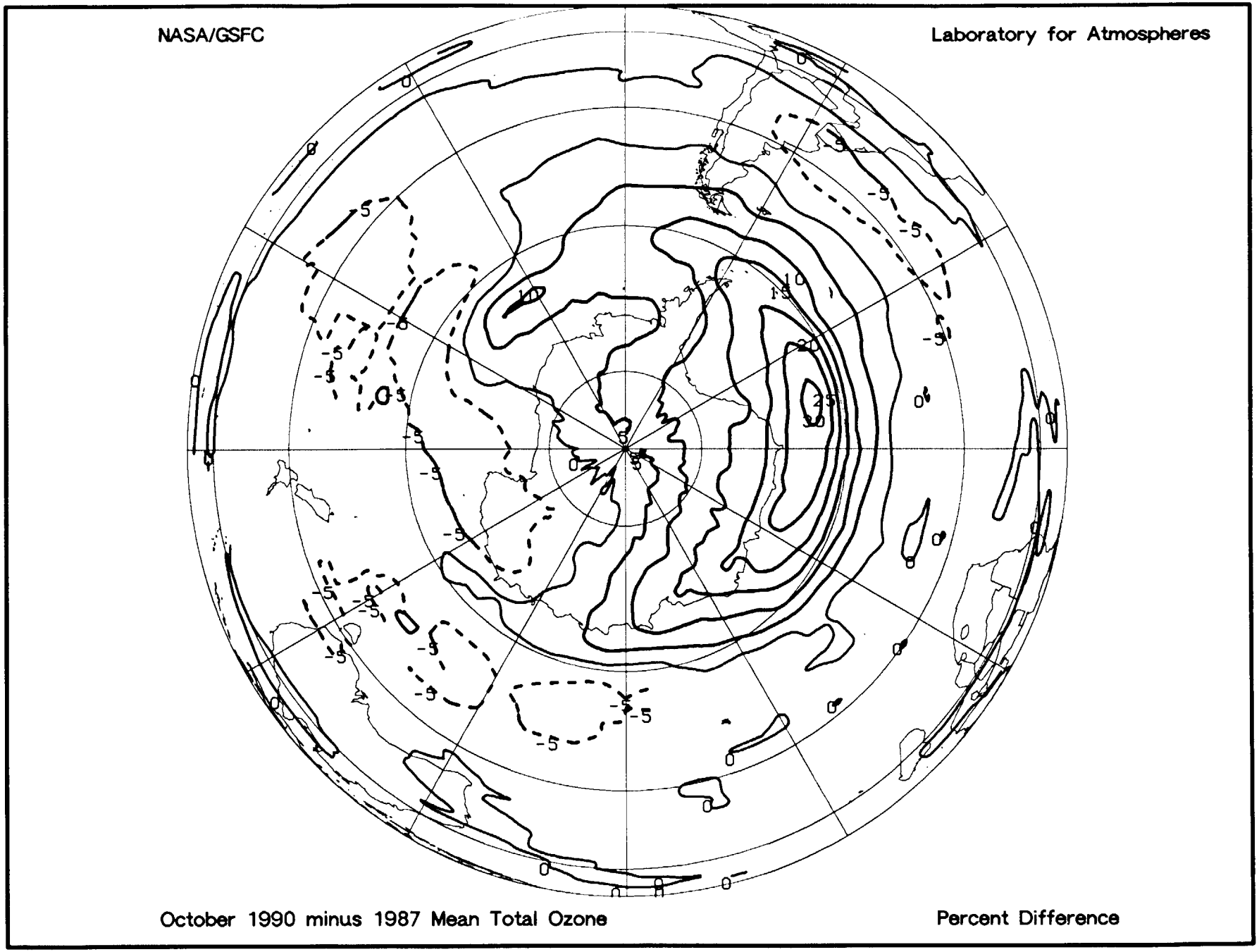


Figure 4H. Monthly Mean Total Ozone Difference Between October 1990 and October 1987.

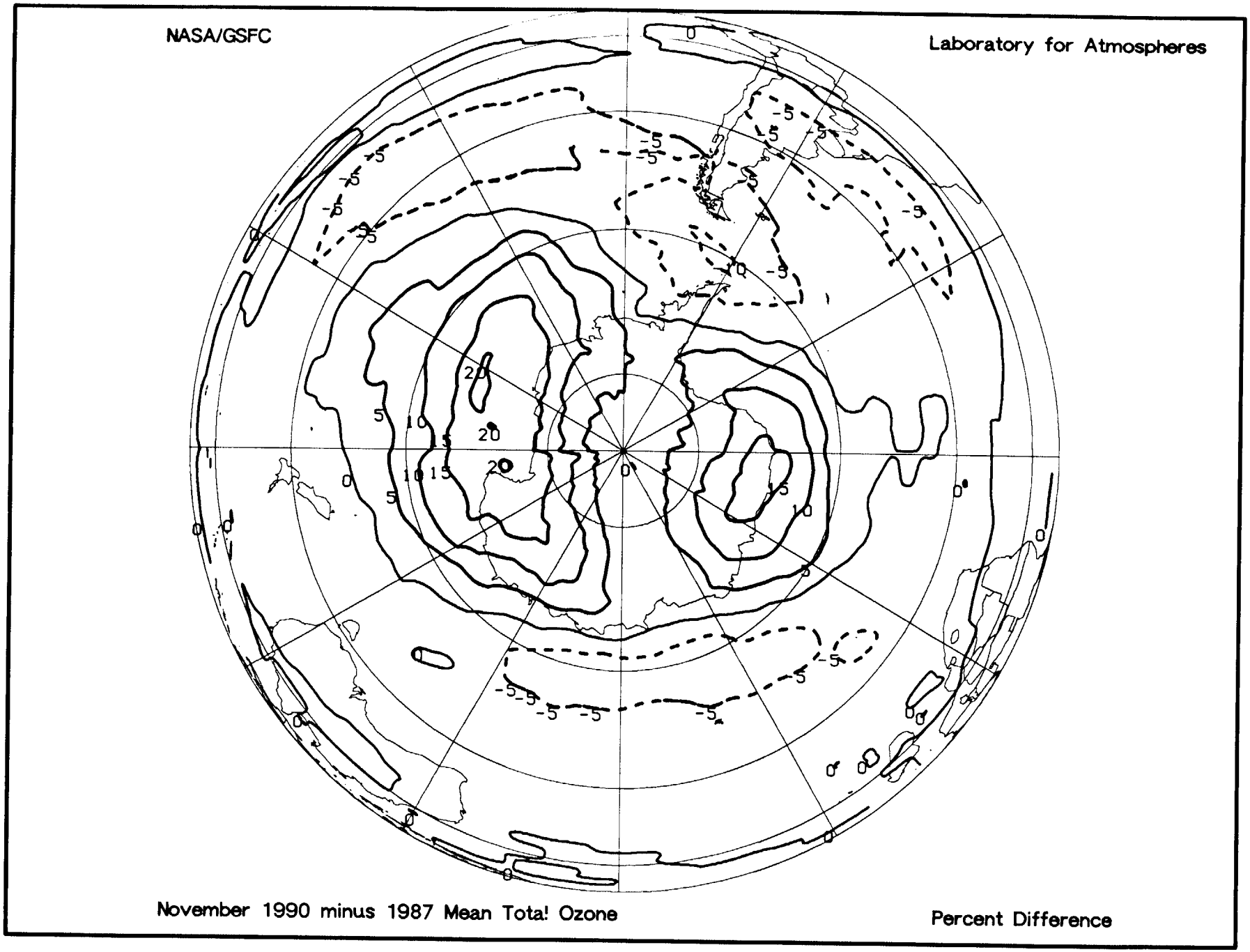


Figure 4I. Monthly Mean Total Ozone Difference Between November 1990 and November 1987.

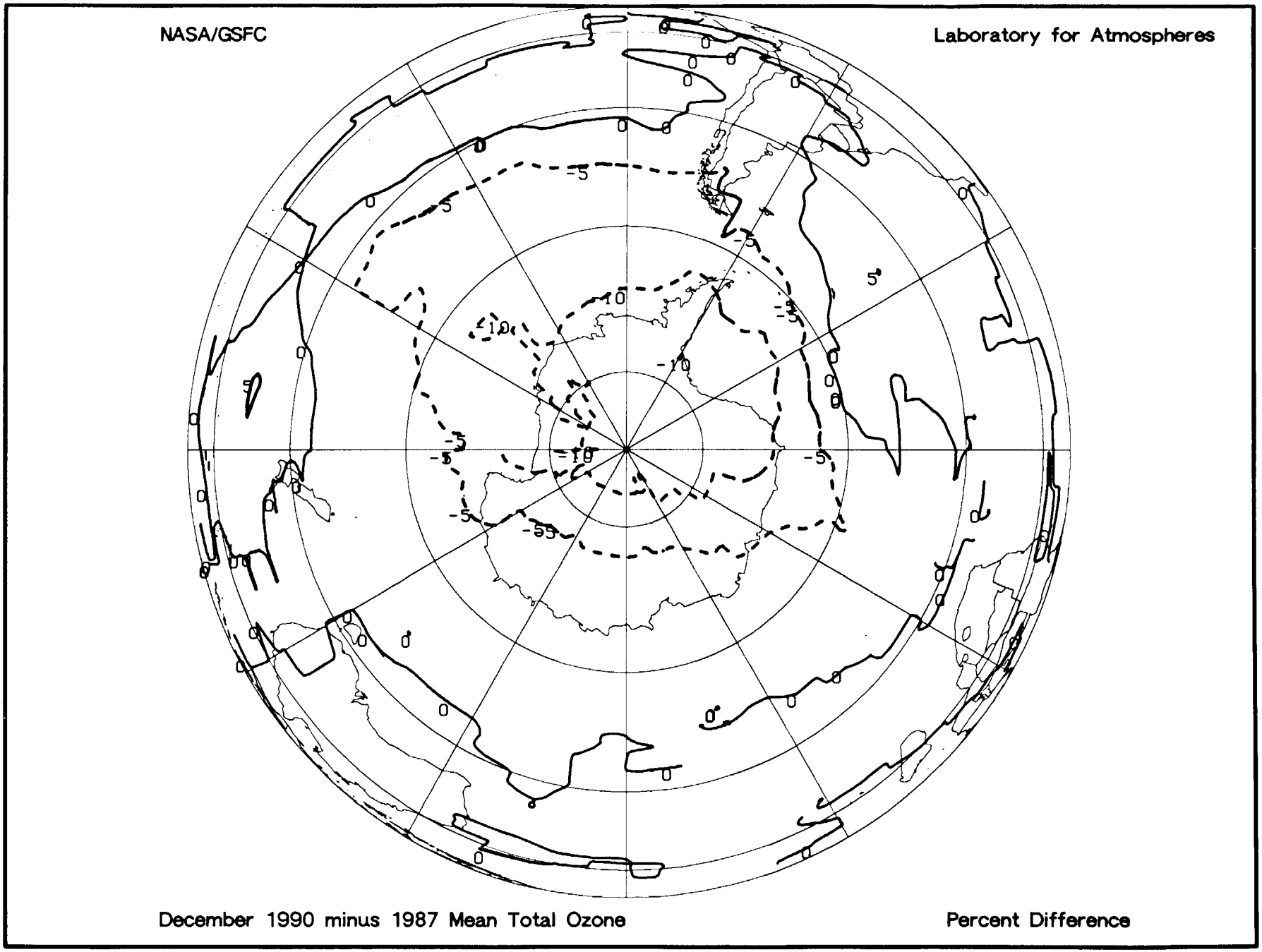


Figure 4J. Monthly Mean Total Ozone Difference Between December 1990 and December 1987.

3.3 Comparisons of Daily Minima

Figure 5 presents the daily minimum ozone values over that portion of the southern hemisphere south of latitude 60°S for the period August through December for the years 1979, 1987, 1988, 1989 and 1990.

Prior to early September, there is significant day-to-day variation within all years, and little coherent pattern. The absolute lowest values during this period were in 1988 and occurred in the many significant mini-holes which developed that year. These were, in fact, the lowest values of 1988, exceeding in depth the mature ozone hole.

As we go beyond early September (day 250), throughout the remainder of September and October, a coherent pattern develops. The minimum values for 1979 are significantly higher than those of the other four years, remaining above 200 DU. The values for the years 1987, 1989, and 1990 are clustered together, reaching minimum values in the vicinity of 125 DU during early October. The year 1988 falls between 1979 and the three-year cluster.

As November progresses, the values for 1979 and 1988 converge, and reach a peak late in the month. The values for 1987, 1989 and 1990 rise steadily. During December, the values for all five years converge at about 300 DU.

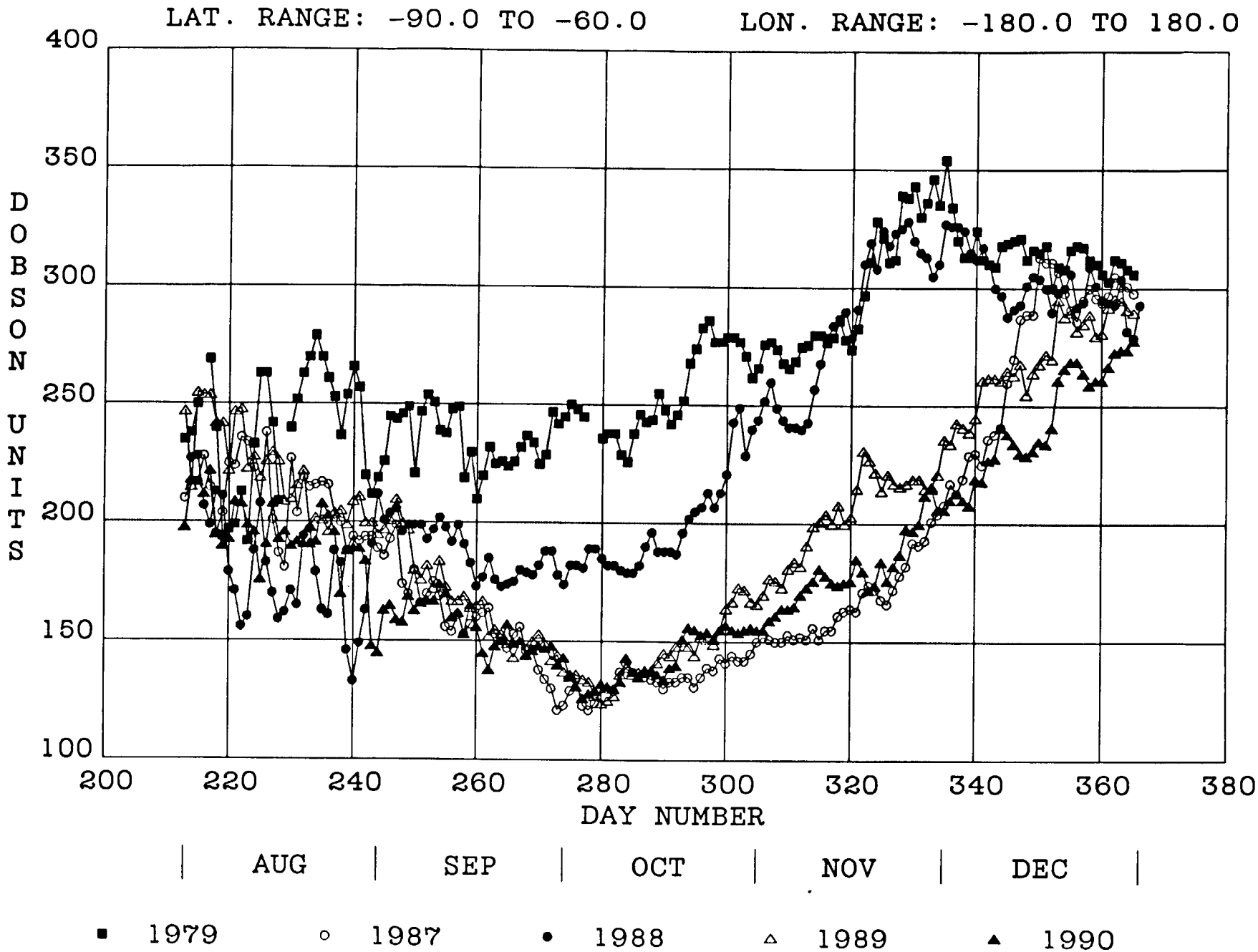


Figure 5. Daily Southern Hemisphere Ozone Minimum for the Period August 1 Through December 31 of the Years 1979, 1987, 1988, 1989, and 1990.

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16. Abstract

Because of the great environmental significance of ozone and to support continuing research at the Antarctic and other southern hemisphere stations, the development of the 1990 ozone hole was monitored using data from the Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) instrument, produced in near-real-time. This Atlas provides a complete set of daily polar orthographic projections of the TOMS total ozone measurements over the southern hemisphere for the period August 1 through December 31, 1990. The 1990 ozone hole developed in a manner similar to that of 1987 and 1989, reaching a comparable depth in early October. This was in sharp contrast to the much weaker hole of 1988. The 1990 ozone hole remained at polar latitudes as it filled in November, in contrast to other recent years when the hole drifted to mid-latitudes before disappearing. Daily ozone values above selected southern hemisphere stations are presented, along with comparisons of the 1990 ozone distribution to that of other years. A new calibration scheme (Version 6) was used to process 1990 ozone values, as well as to reprocess those of previous years.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Antarctic ozone hole, Nimbus-7, ozone hole, total ozone, Total Ozone Mapping Spectrometer	Unclassified - Unlimited Subject Category 47

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