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Office of Management
Scientific and Technical
Information Division

NIMBUS-7 TOMS ANTARCTIC OZONE ATLAS:
AUGUST THROUGH NOVEMBER 1989

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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 1989 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 November 30, 1989. The 1989 ozone hole developed in a manner similar to that of 1987, reaching a comparable depth in early October. This was in sharp contrast to the much weaker hole of 1988. The 1989 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 1989 ozone distribution to that of other 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. 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. They are processed using Version 5 software which exhibits a drift relative to Dobson network data of about -4% in ten years. Drift-corrected, Version 6 data for 1989 will be archived in 1991.

1.1 1989 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 this near-real-time total ozone data. This work was repeated in 1989.

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).

2. TOMS TOTAL OZONE DATA

2.1 Chronology of the 1989 Antarctic Ozone Hole

AUGUST 12, 1989

This is the first day for which a TOMS hemispheric image is obtained in near-real-time. The lowest polar ozone values are between 200 and 225 DU and are located over eastern Wilkes Land near Mackenzie Bay, within the normal southern hemisphere winter polar minimum.

AUGUST 15, 1989

The minimum over Wilkes Land persists with total ozone values between 200 and 225 DU. A new minimum has developed east of the Antarctic Peninsula of similar depth.

AUGUST 17, 1989

The first total ozone values below 200 DU are observed over a very small area within the Wilkes Land minimum.

AUGUST 21, 1989

The first significant mini-hole of the season develops rapidly over the Antarctic Peninsula with total ozone values between 175 and 200 DU. Values between 200 and 225 DU persist over eastern Wilkes Land.

AUGUST 24, 1989

The mini-hole has moved southeastward, crossing the Weddell Sea, with total ozone values between 175 and 200 DU. Three areas with values between 200 and 225 DU exist over Wilkes Land and the adjacent Pacific Ocean.

AUGUST 28, 1989

Minimum total ozone values are between 200 and 225 DU covering large areas of Wilkes Land, the Antarctic Peninsula and adjacent Marie Byrd Land.

AUGUST 30, 1989

Three regions of total ozone between 175 and 200 DU have appeared over the Amundsen Sea, Weddell Sea, and Wilkes Land. These minima appear to be part of a broad reduction in total ozone across most of the polar region rather than mini-hole events.

SEPTEMBER 4, 1989

Total ozone values below 200 DU have disappeared. However, values between 200 and 225 DU now cover virtually all of Antarctica and much of the Amundsen and Bellingshausen Seas.

SEPTEMBER 8, 1989

During the past four days, two minima of between 175 and 200 DU have developed over Wilkes Land and Marie Byrd Land and increased rapidly in size. On this day, the first total ozone values between 150 and 175 DU have appeared at the base of the Antarctic Peninsula.

SEPTEMBER 13, 1989

The two minima persist, having rotated about 40° eastward. Minimum values between 150 and 175 DU exist in both regions.

SEPTEMBER 17, 1989

The areas of total ozone values between 175 and 200 DU have expanded to cover virtually all of Antarctica. A large area with values between 150 and 175 DU exists over Queen Maude Land. This region is the genesis of the mature ozone hole.

SEPTEMBER 19, 1989

The ozone hole now contains total ozone values between 125 and 150 DU and is located over southern Wilkes Land. The total ozone gradient between 175 and 275 DU is tightening and is nearly circular and symmetric about the pole.

SEPTEMBER 23, 1989

Minimum ozone values continue to be between 125 and 150 DU. However, the area covered by such values has expanded and is now becoming more symmetric with respect to the pole.

OCTOBER 1, 1989

The ozone hole remains quite circular and symmetric with the pole. The area covered by total ozone values between 125 and 150 DU has expanded to cover about 50% of the Antarctic continent. A small area of values between 100 and 125 DU has appeared over southern Wilkes Land.

OCTOBER 7, 1989

After a brief period of elongation along longitude 90°/270°, the ozone hole is again very circular and symmetric with the pole. A fairly large area of total ozone values between 100 and 125 DU covers the immediate vicinity of the pole. It was on this day that the lowest total ozone value of the season (103 DU) was observed.

OCTOBER 13, 1989

A large total ozone maximum has developed over the Indian Ocean and built into the Pacific Ocean south of Australia. This has pushed the ozone hole off the pole and elongated it along longitudes 60°/240°. The lowest values are still between 100 and 125 DU. Values above 400 DU have built over eastern Wilkes Land.

OCTOBER 19, 1989

Over the past six days, the ozone hole has remained elongated and has rotated about 15°/day from west to east. The hole is again symmetric with the pole, with minimum total ozone values between 125 and 150 DU covering a sizeable area.

OCTOBER 24, 1989

A large ozone maximum, with values above 475 DU has again developed south of Australia, pushing the ozone hole off the pole. Minimum total ozone values between 125 and 150 DU persist and are located over the Weddell Sea and adjacent Queen Maude Land.

OCTOBER 29, 1989

The large ozone maximum south of Australia persists, and continues to keep the lowest total ozone values off the pole. Lowest values are now above 150 DU and are located over the Weddell Sea.

NOVEMBER 4, 1989

The ozone maximum has rotated to a position in the Pacific Ocean north of the Ross Sea. The ozone hole, still well off the pole, is now located over Queen Maude Land. A large area with total ozone values between 150 and 175 DU persists there.

NOVEMBER 8, 1989

Although minimum total ozone values between 150 and 175 DU persist over Queen Maude Land, the polar area covered by values less than 250 DU is now decreasing rapidly.

NOVEMBER 12, 1989

The Indian Ocean/Pacific Ocean maxima is building toward the pole, with total ozone values above 400 DU over Marie Byrd Land and the coast of eastern Wilkes Land. Minimum ozone values, now between 175 and 200 DU are over Queen Maude Land and the adjacent Atlantic Ocean.

NOVEMBER 17, 1989

The ozone maximum has rotated eastward and is centered near the Antarctic Peninsula. The ozone hole is now elongated along longitude 160°/340°. Minimum total ozone values are between 175 and 200 DU over a very small area of southern Queen Maude Land.

NOVEMBER 21, 1989

The persistent ozone maximum of the past four weeks has diminished greatly. The ozone hole has gained a more circular appearance and moved back toward the pole. Total ozone values between 175 and 200 DU, absent for the past three days, have reappeared over Queen Maude Land.

NOVEMBER 26, 1989

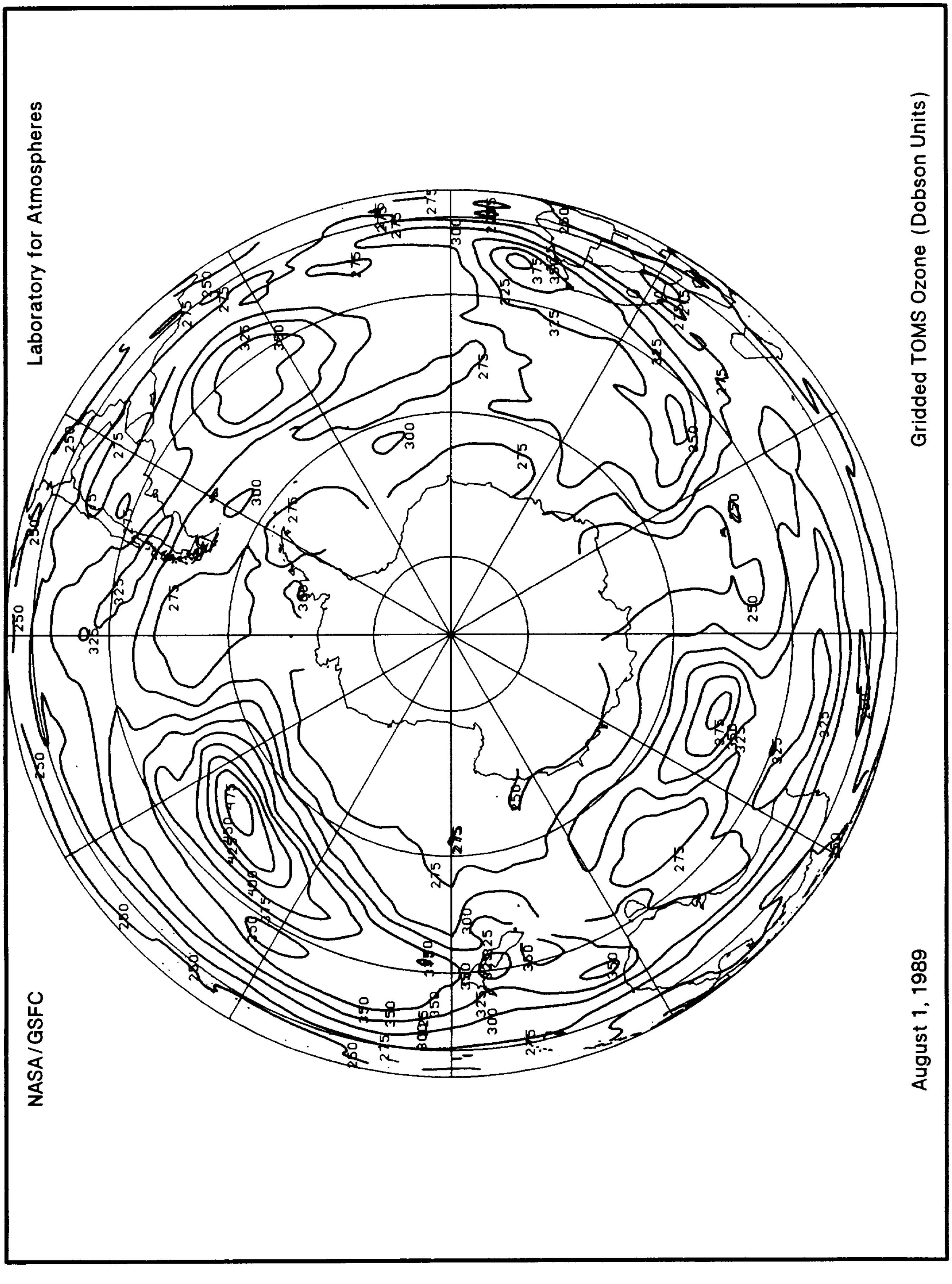
High total ozone values building toward the pole from the Indian Ocean south of Africa have elongated the ozone hole along longitudes 90°/270°. The lowest total ozone values are between 200 and 225 DU and are located over Marie Byrd Land.

NOVEMBER 30, 1989

The elongated ozone hole still contains total ozone values between 200 and 225 DU over Marie Byrd Land and the Ross Sea. The area surrounding the hole contains no prominent ozone maxima above 375 DU.

2.2 Southern Hemispheric Polar Charts

A set of daily TOMS total ozone estimates for the southern hemisphere, over the period August 1 through November 30, 1989, 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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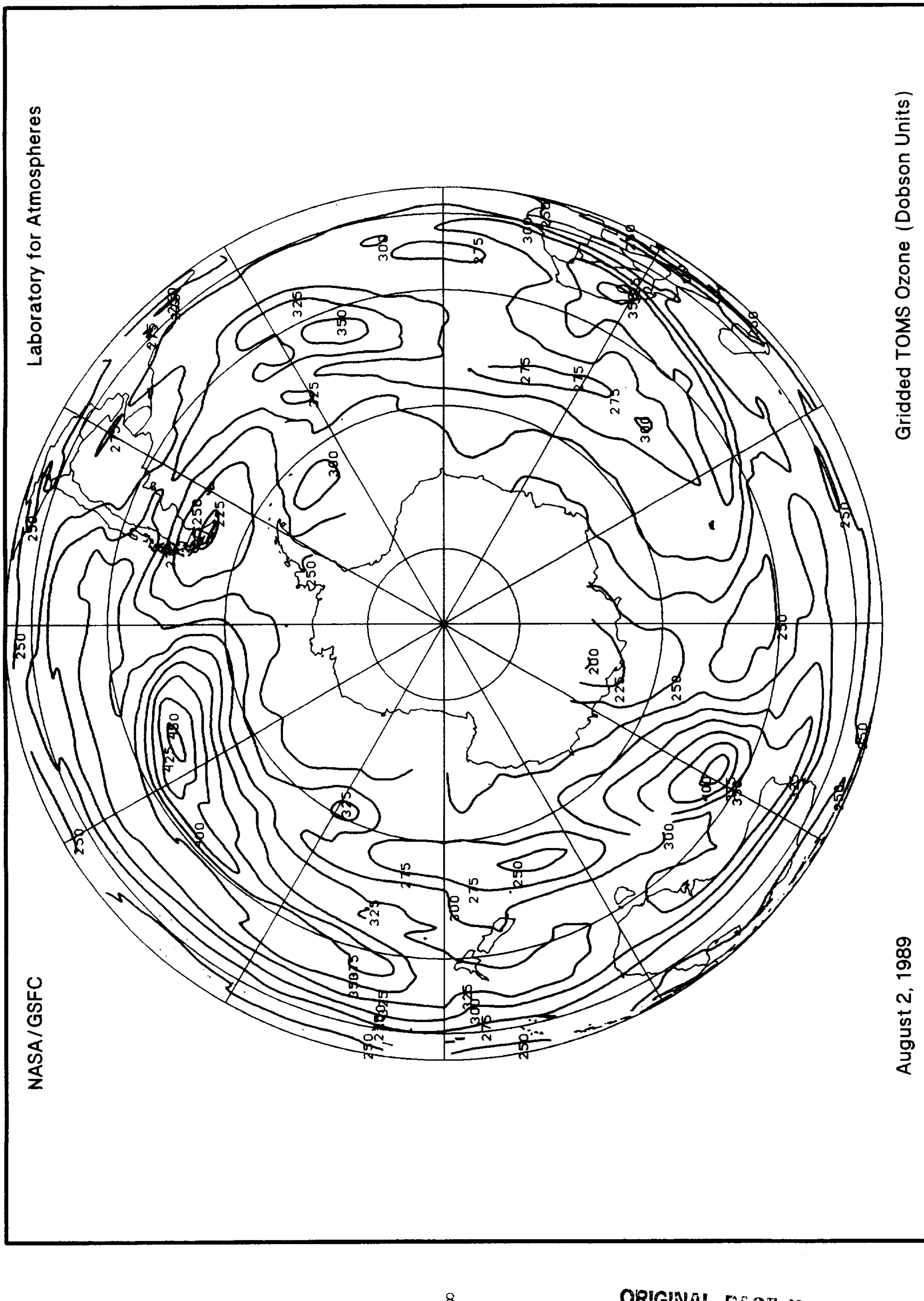
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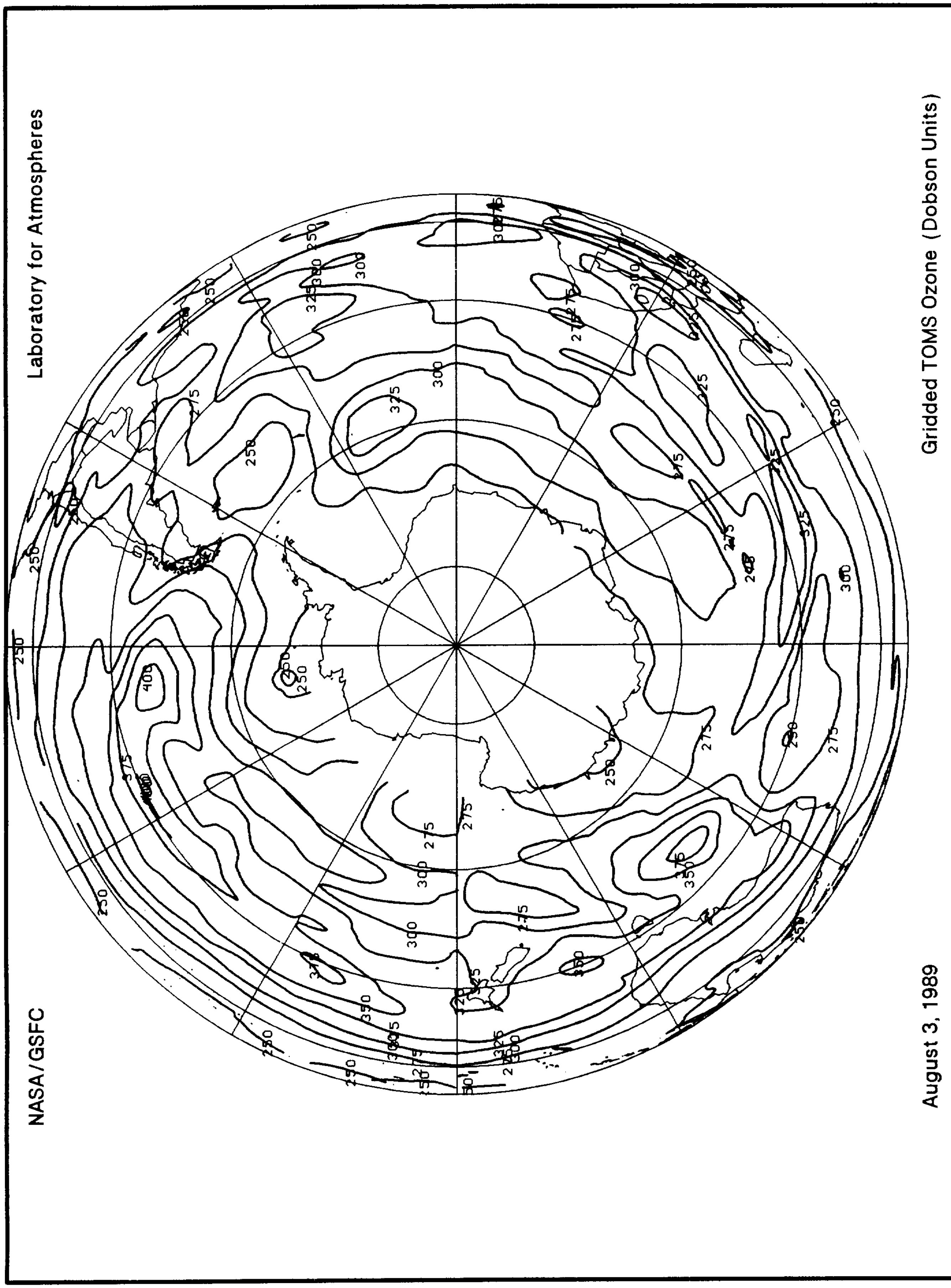
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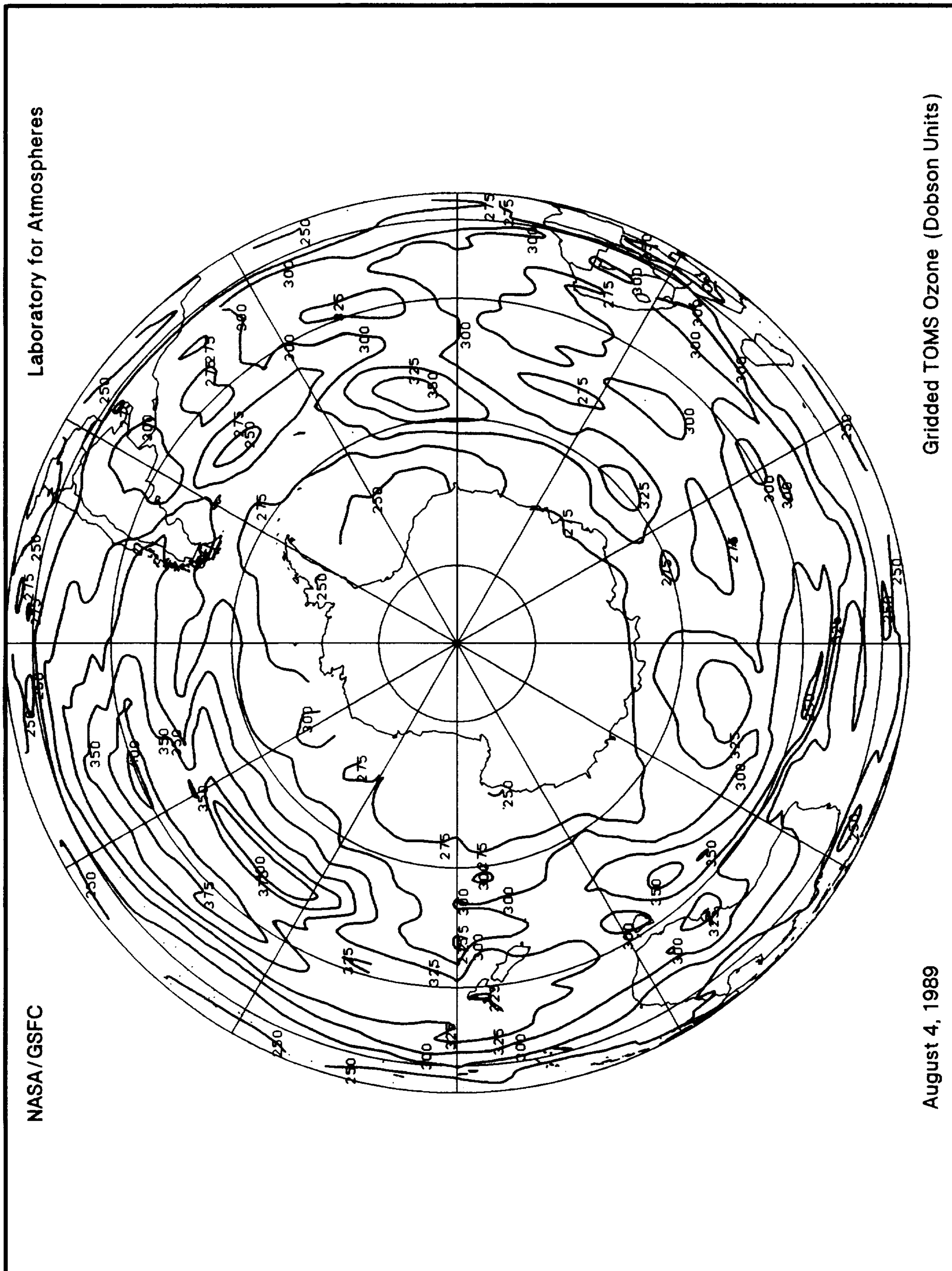
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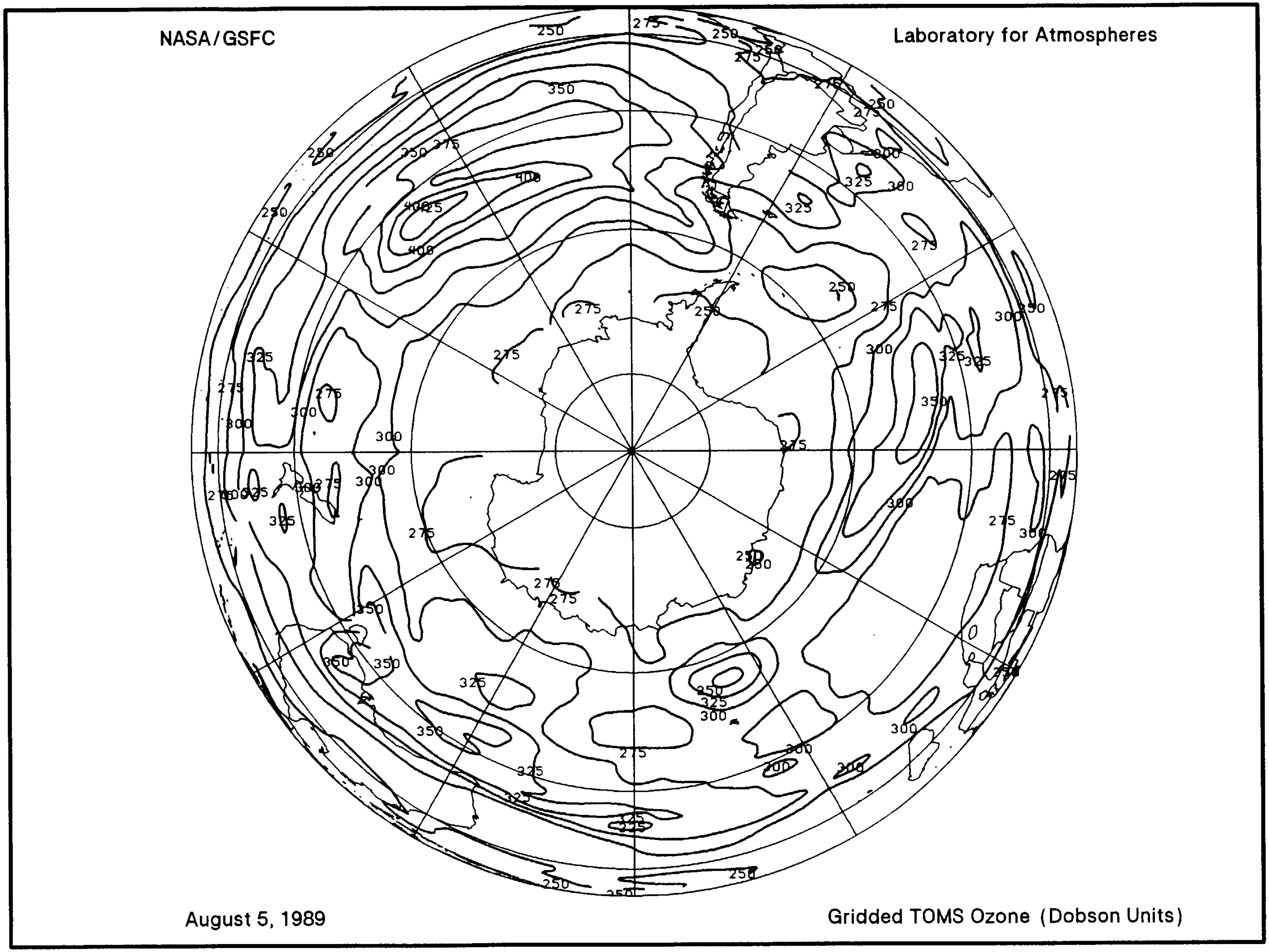
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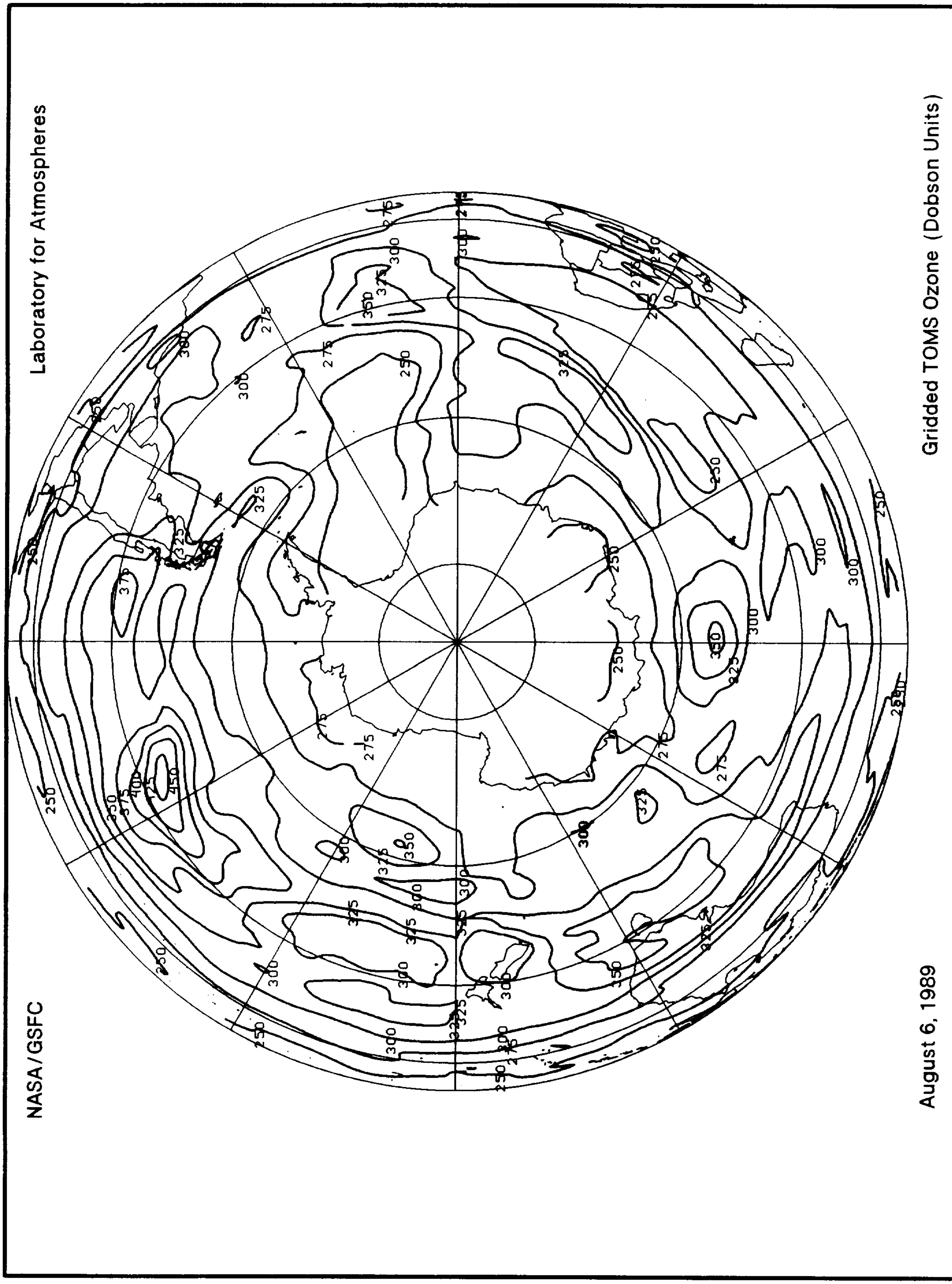

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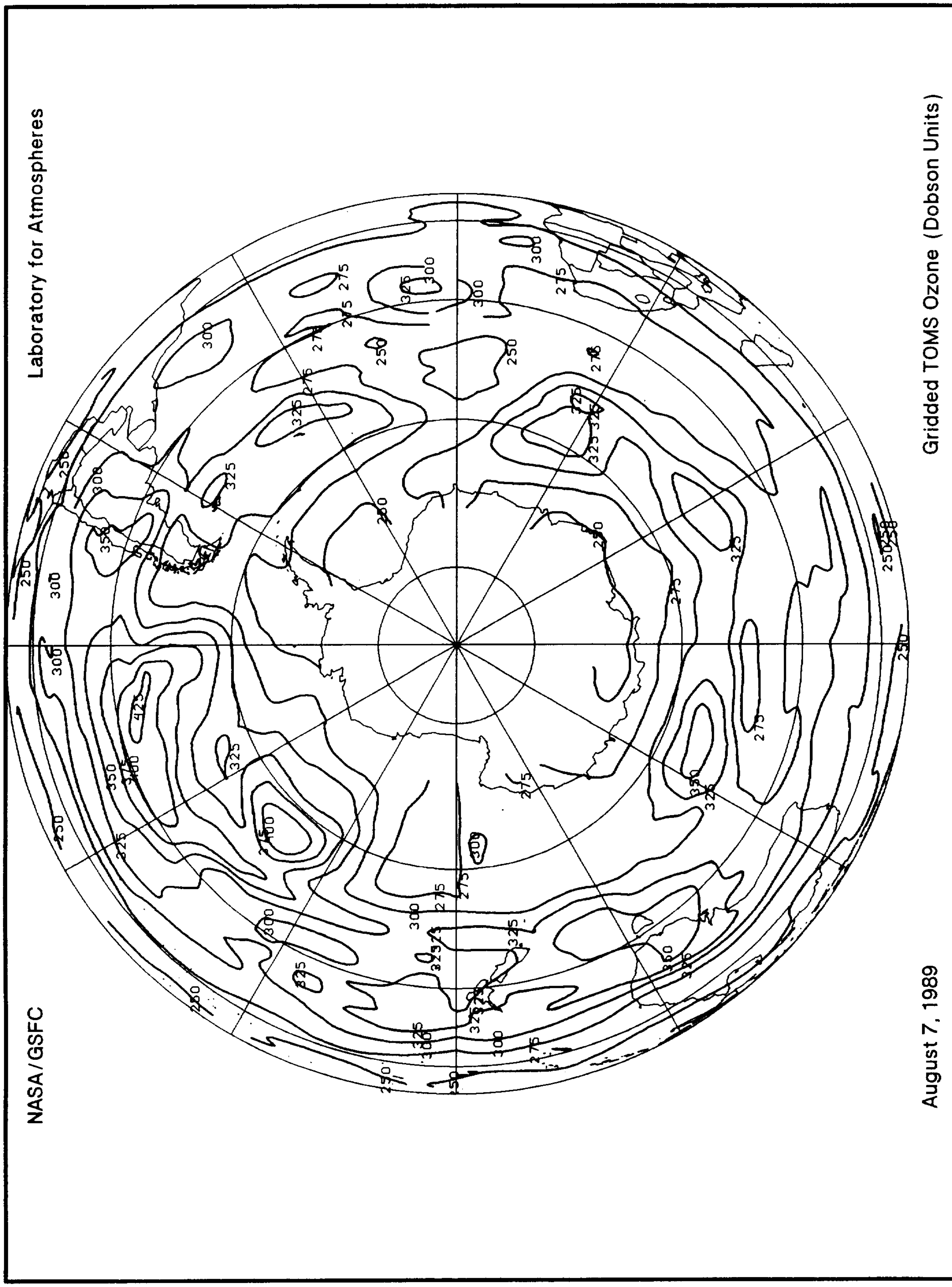
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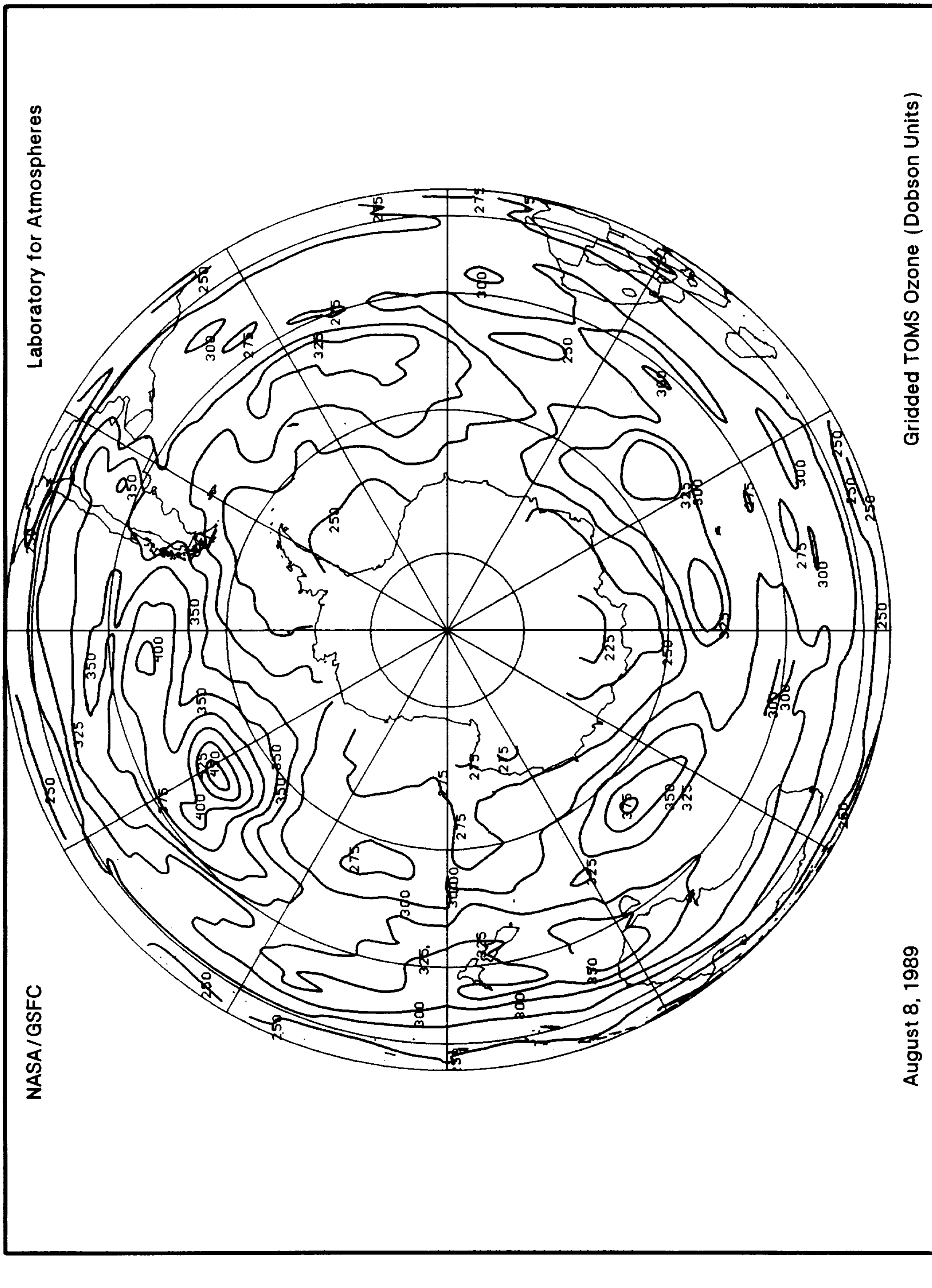
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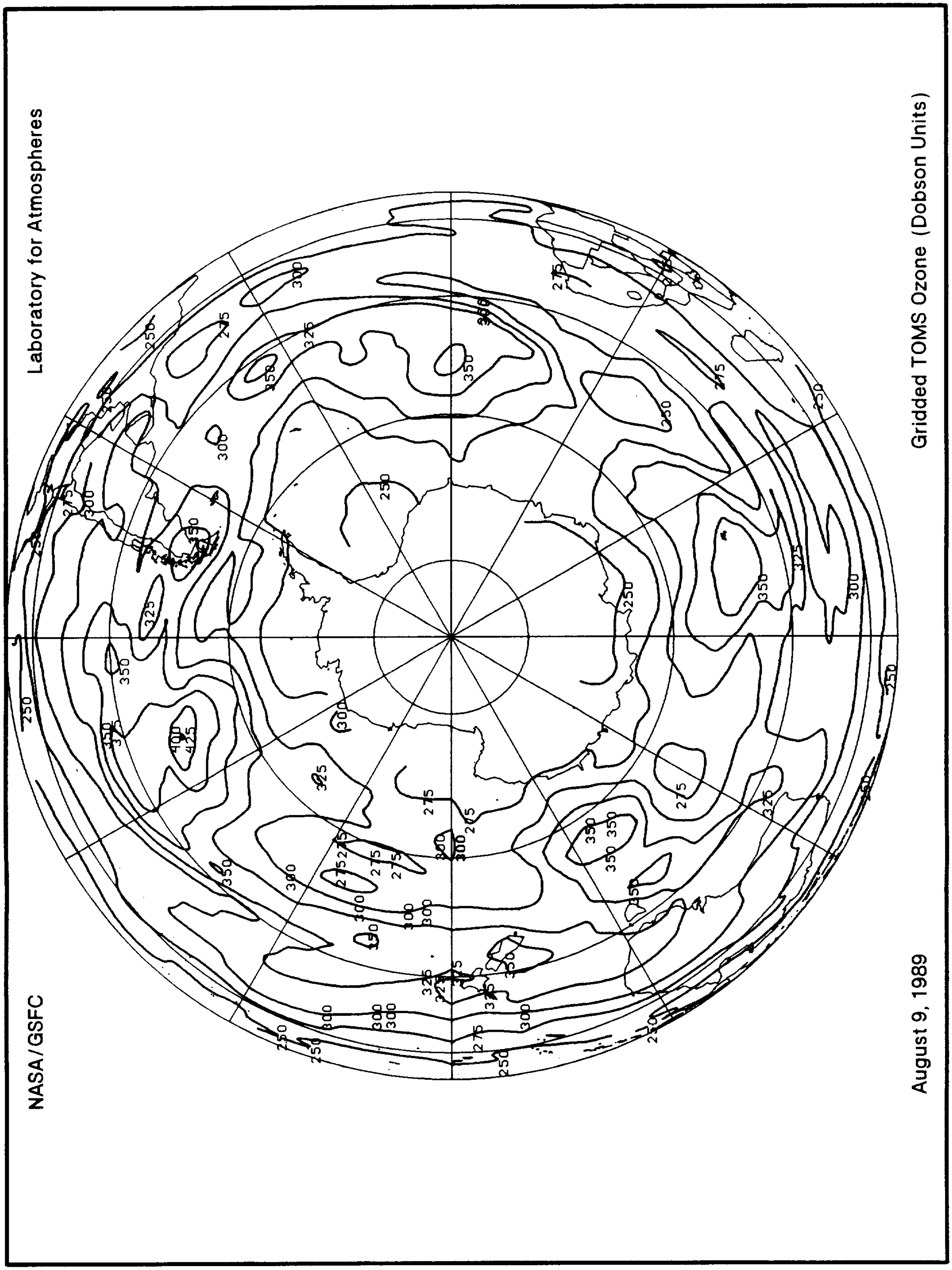
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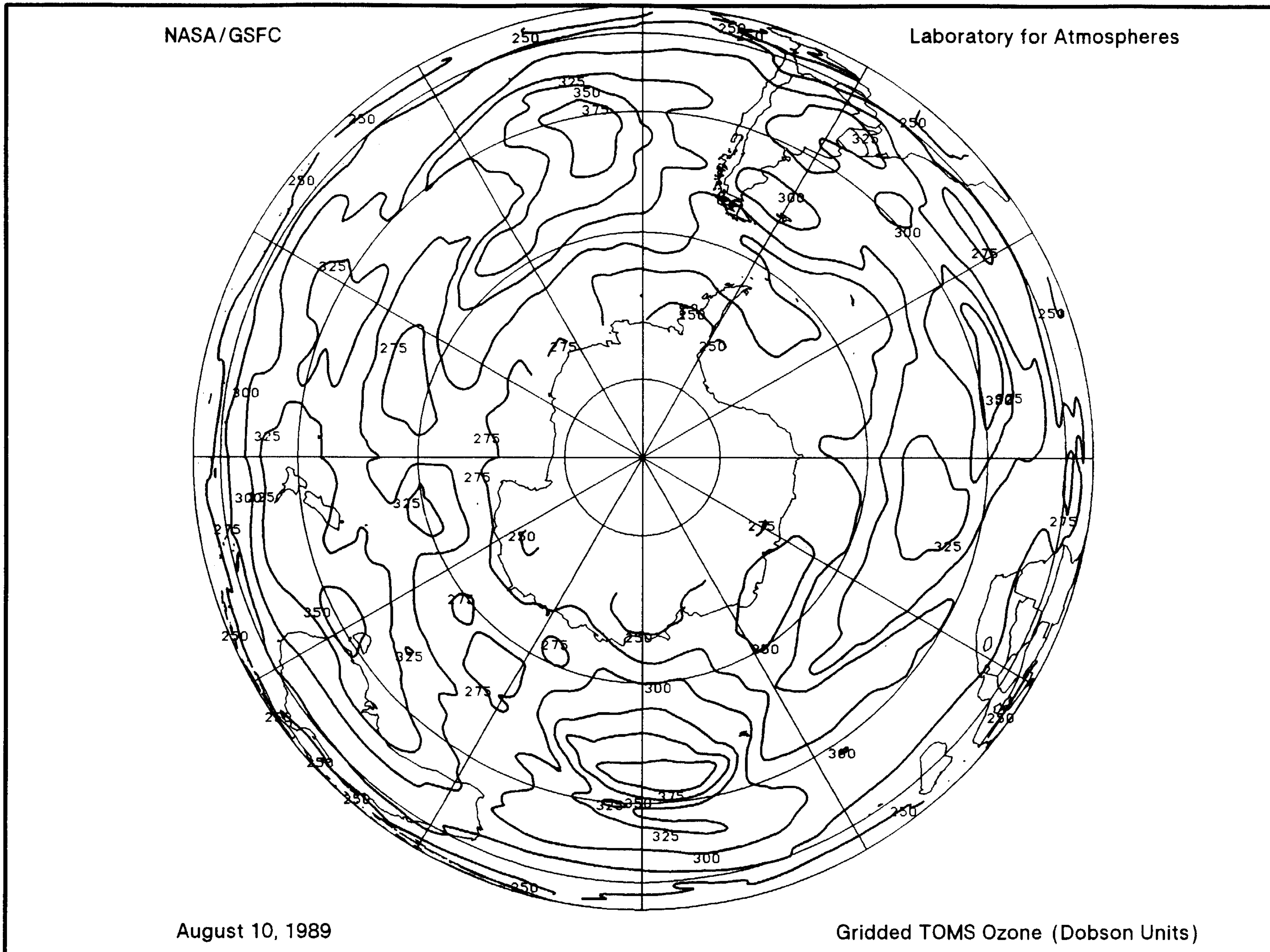
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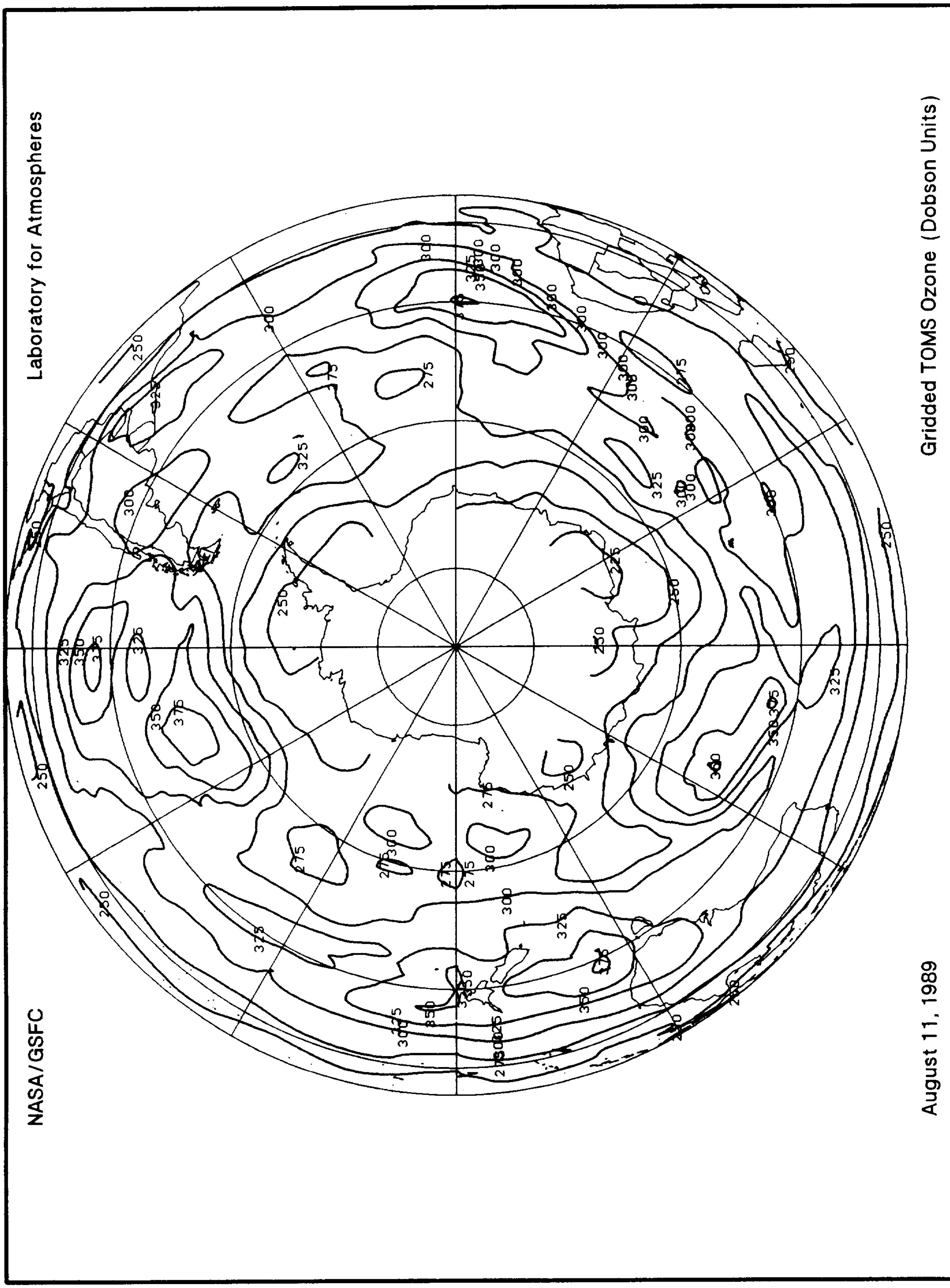
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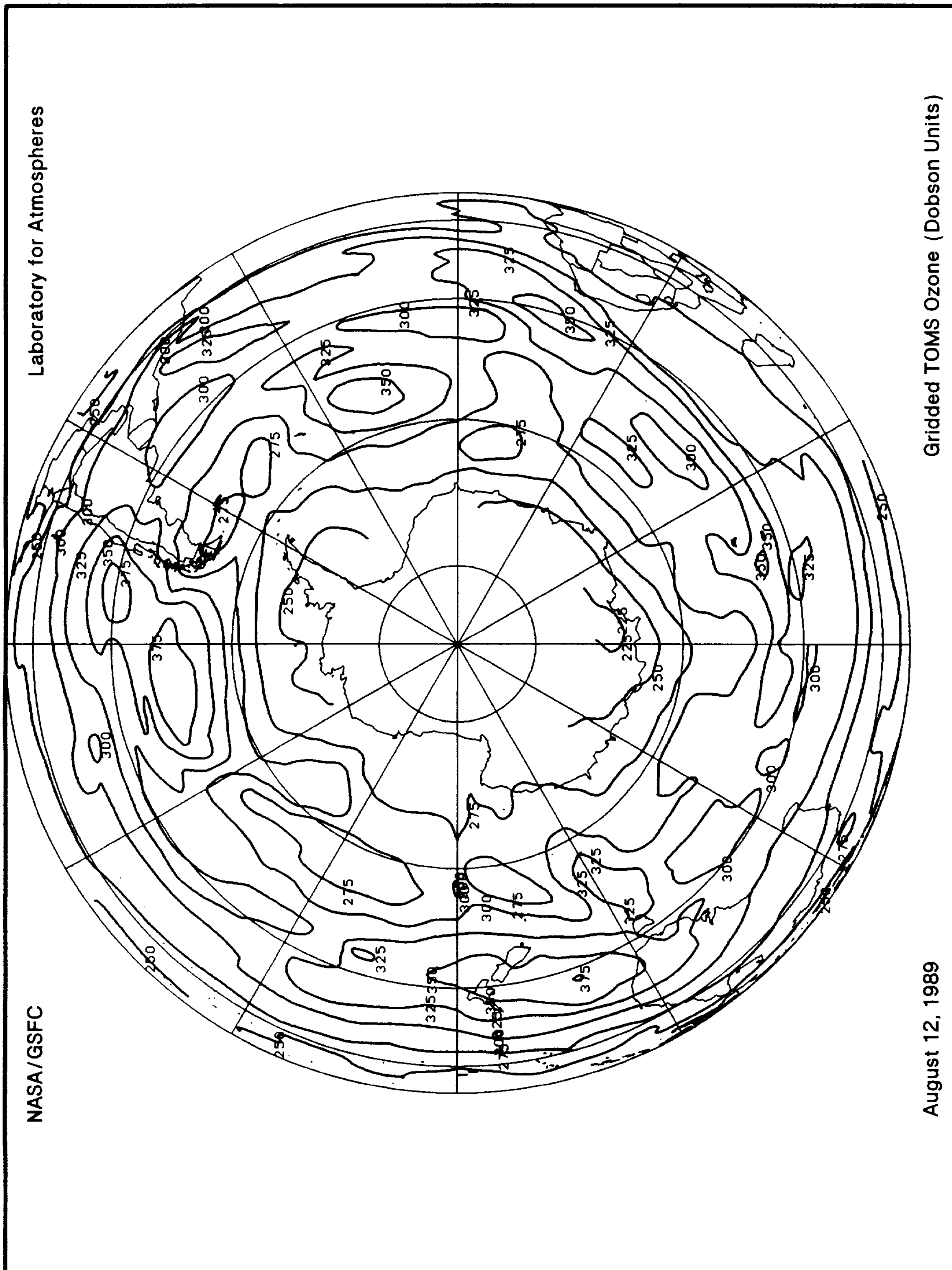
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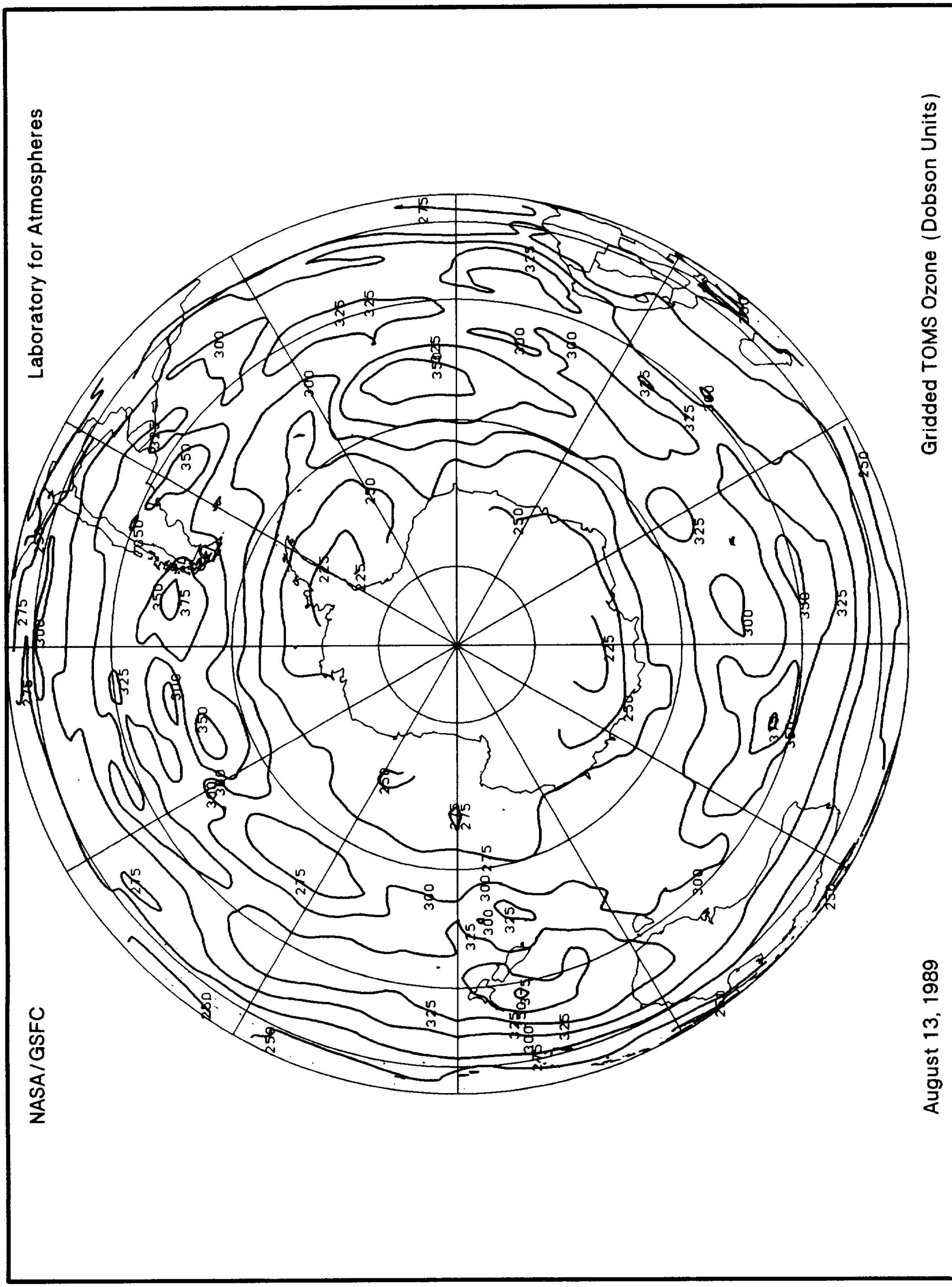
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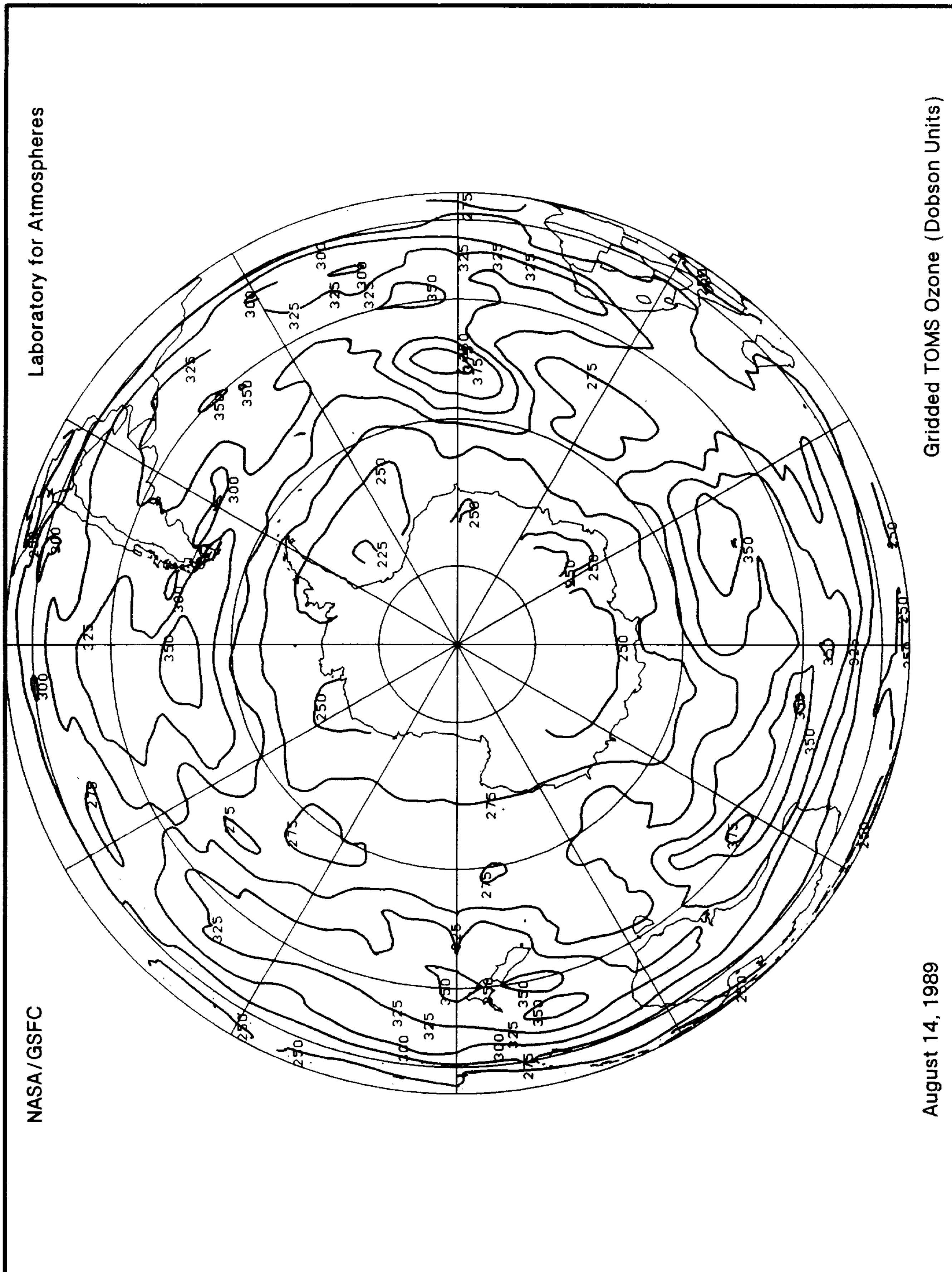
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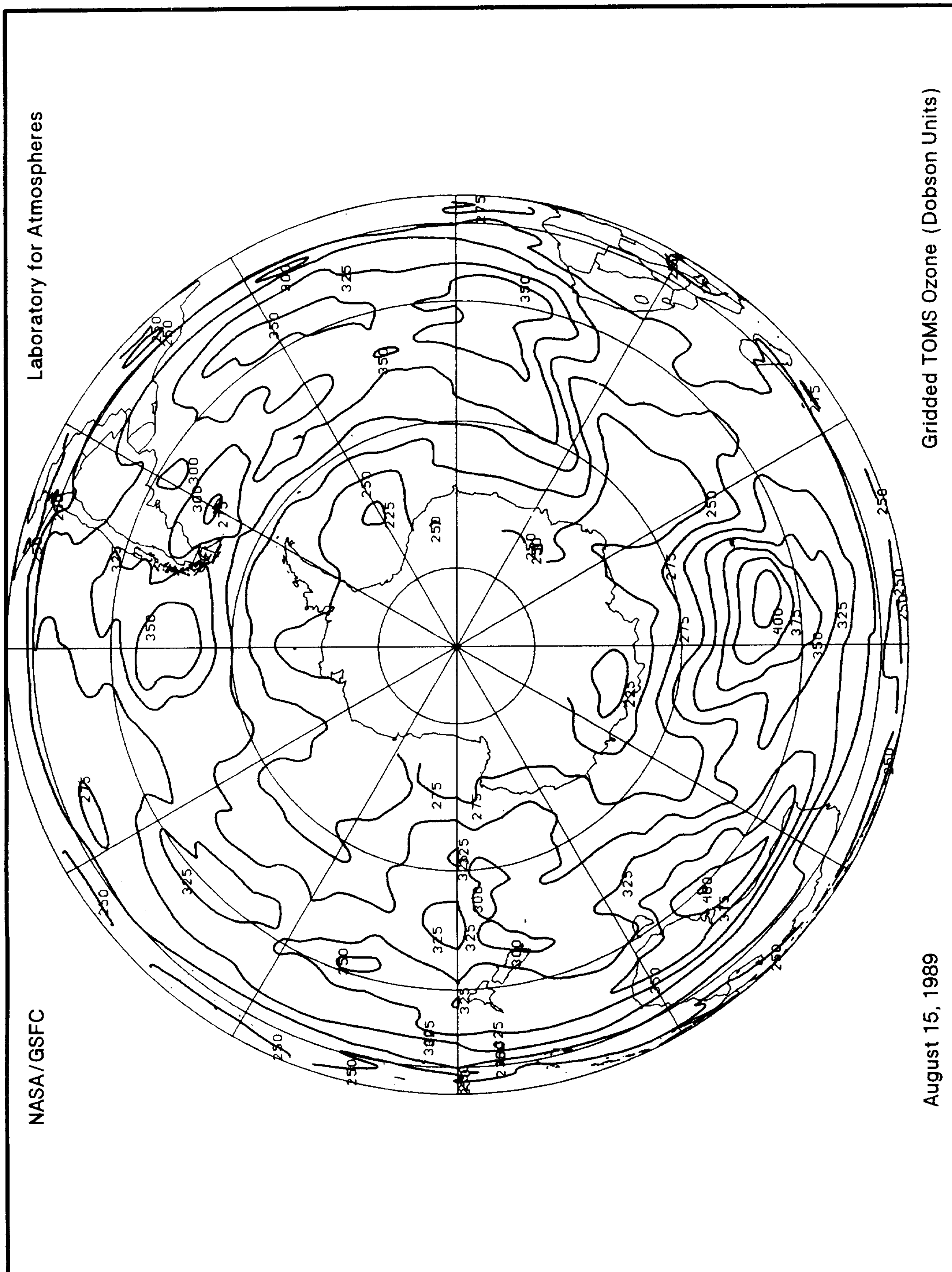
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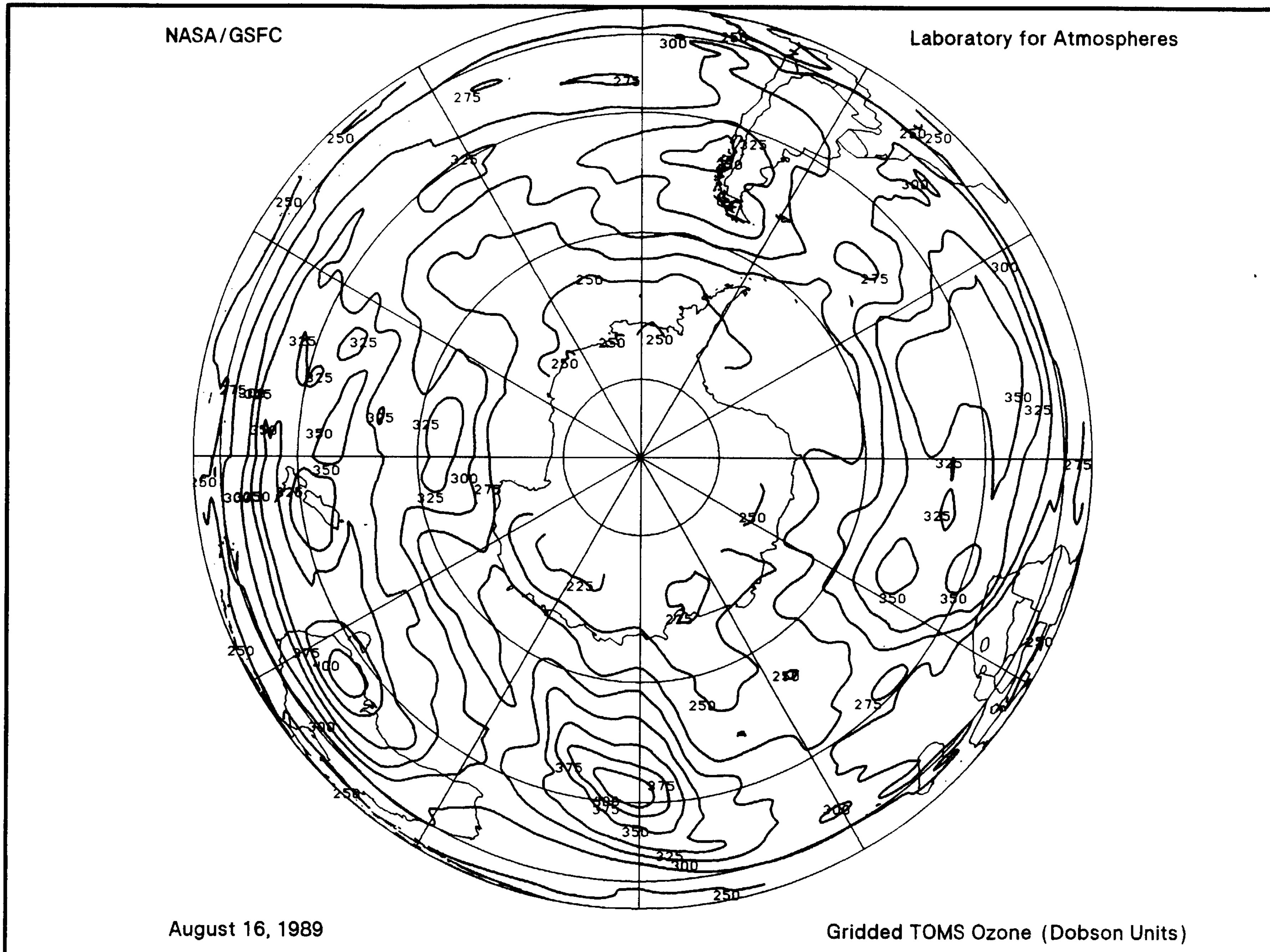
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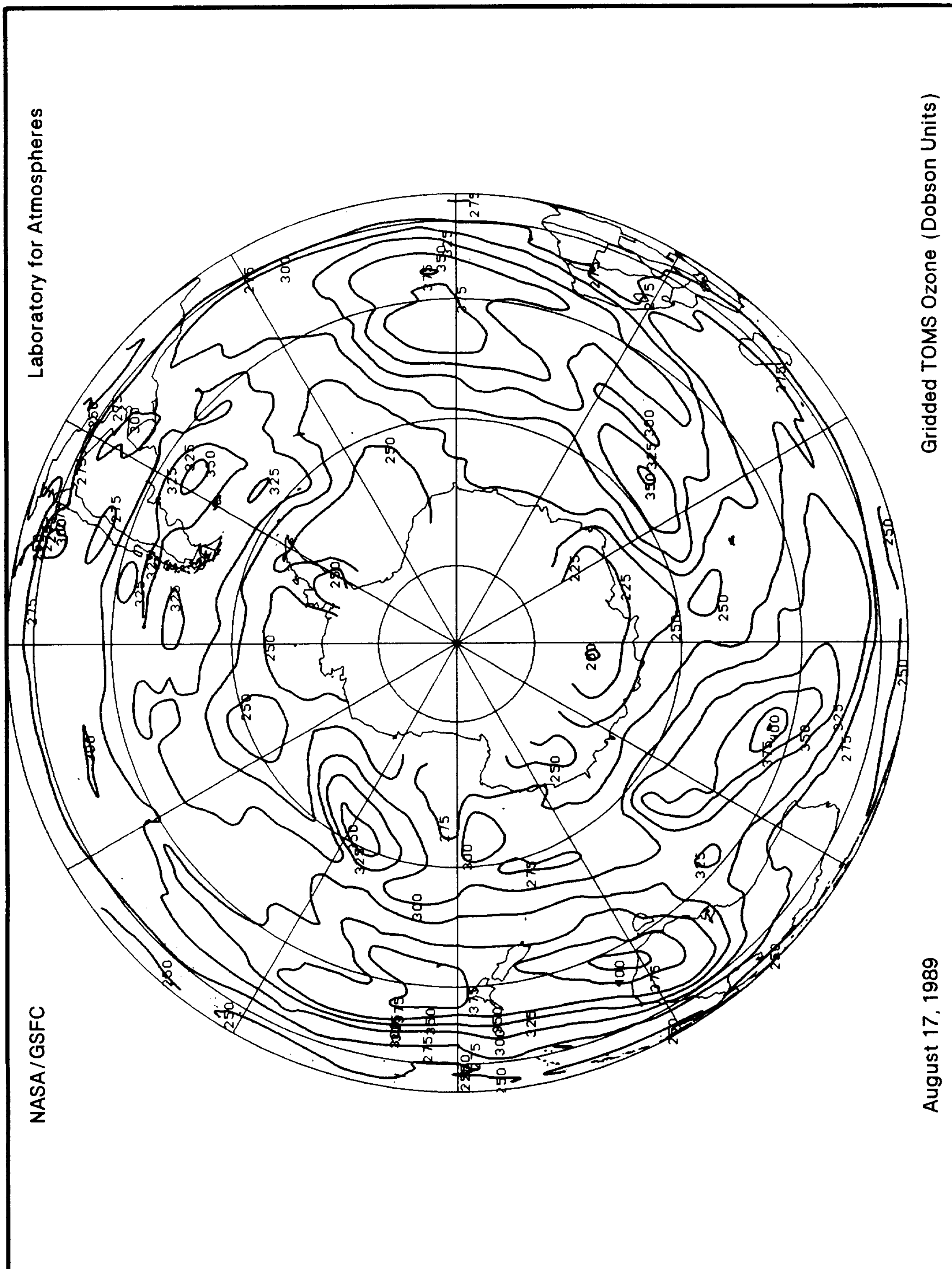

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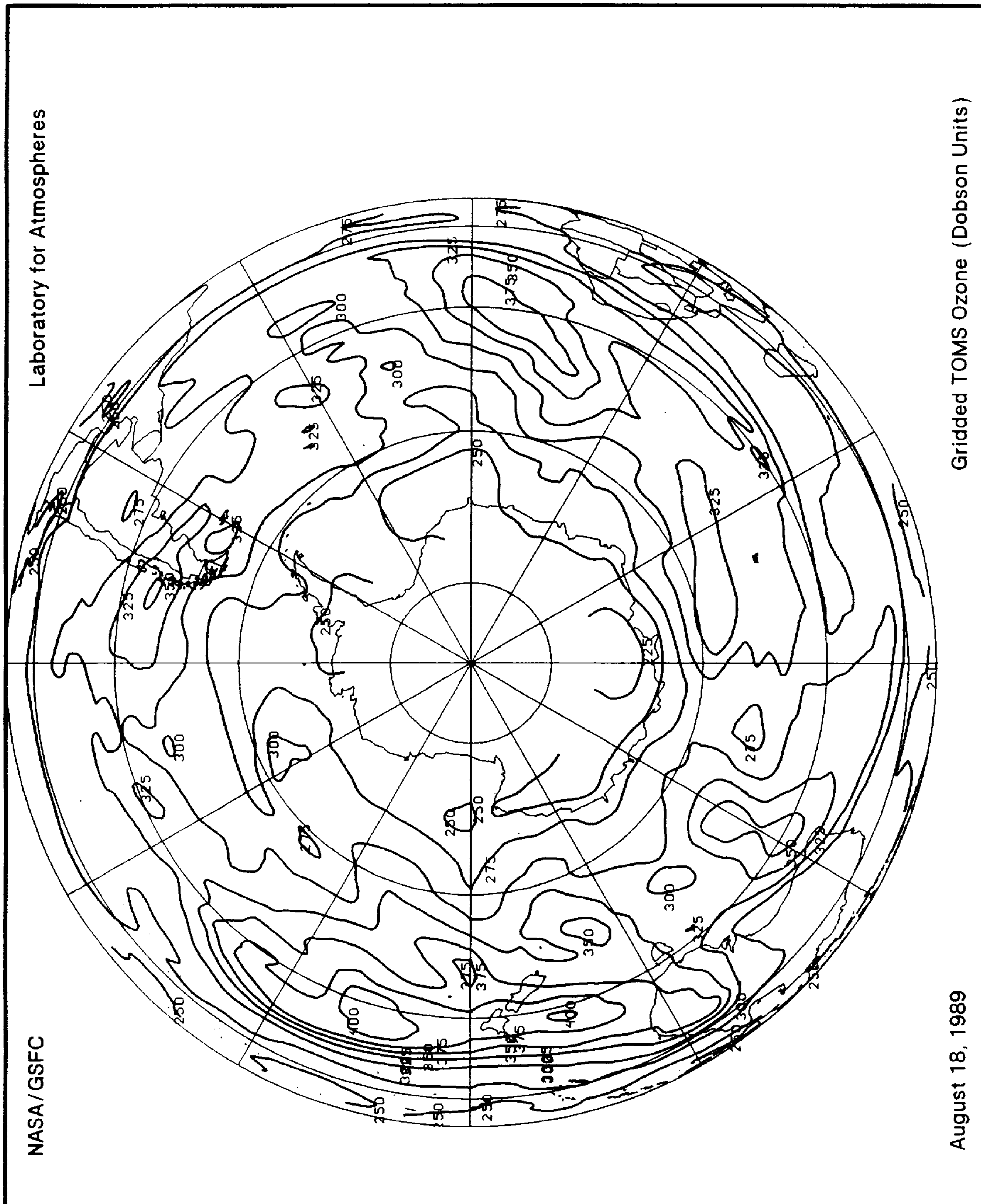

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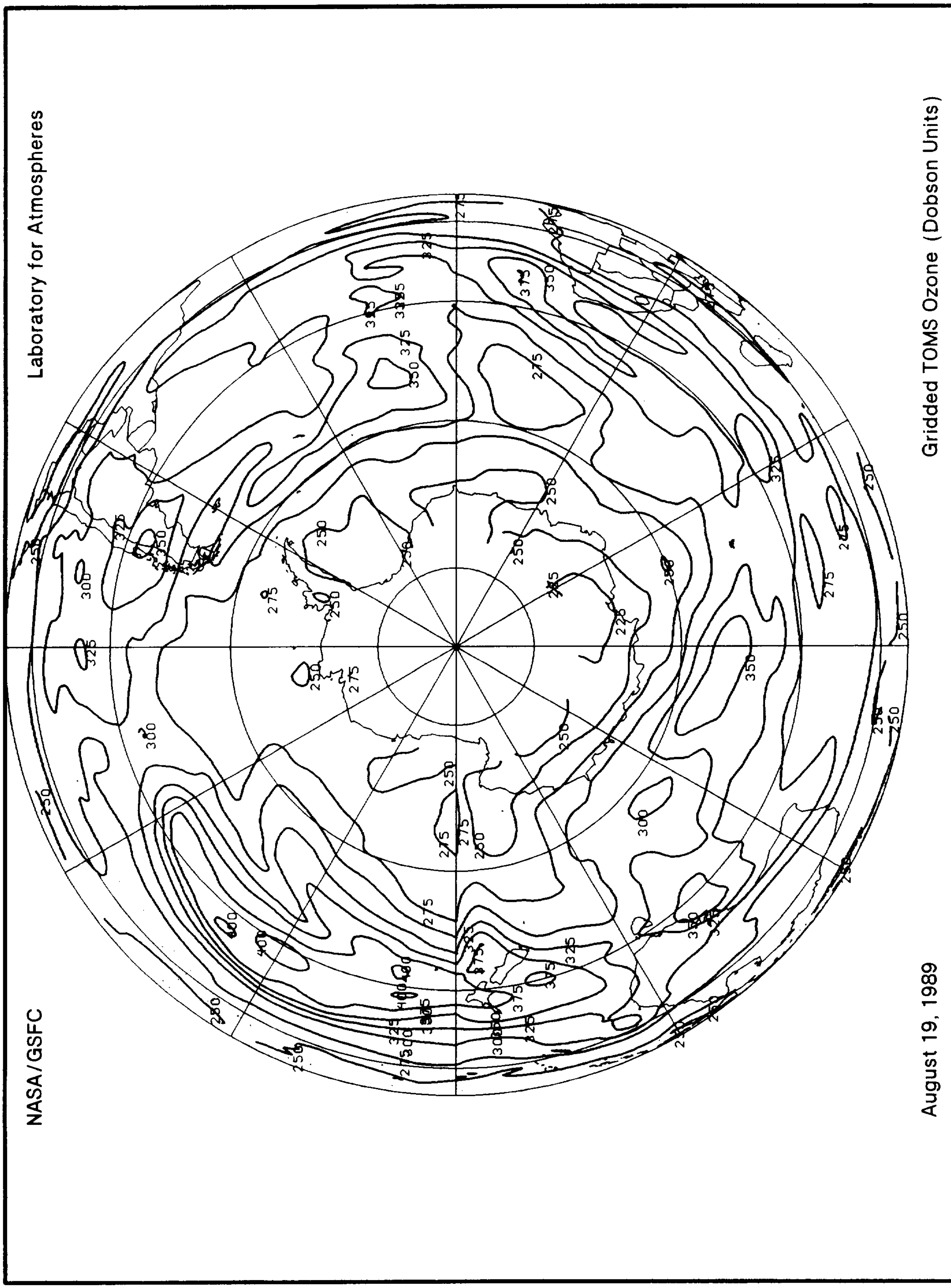
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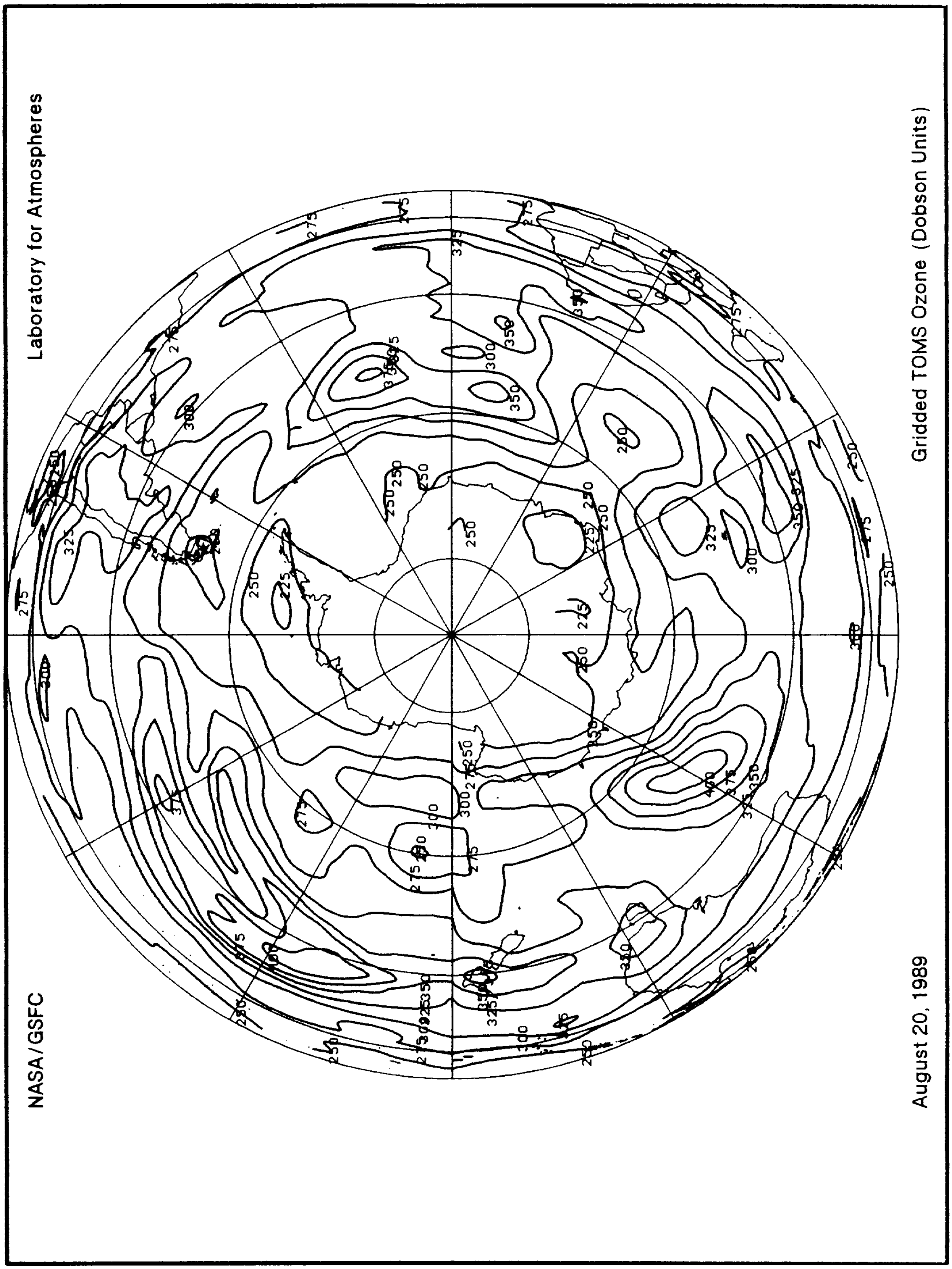
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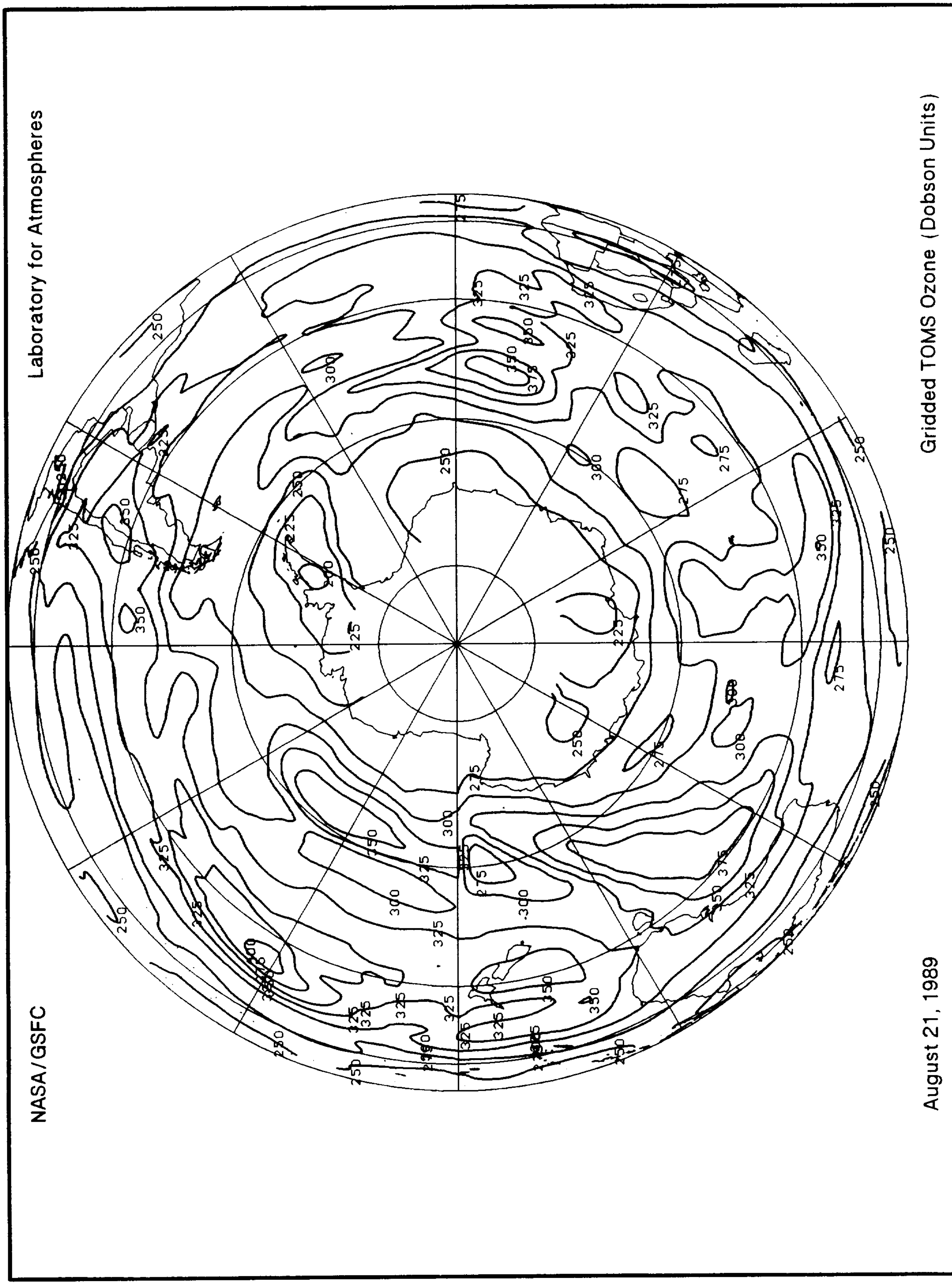
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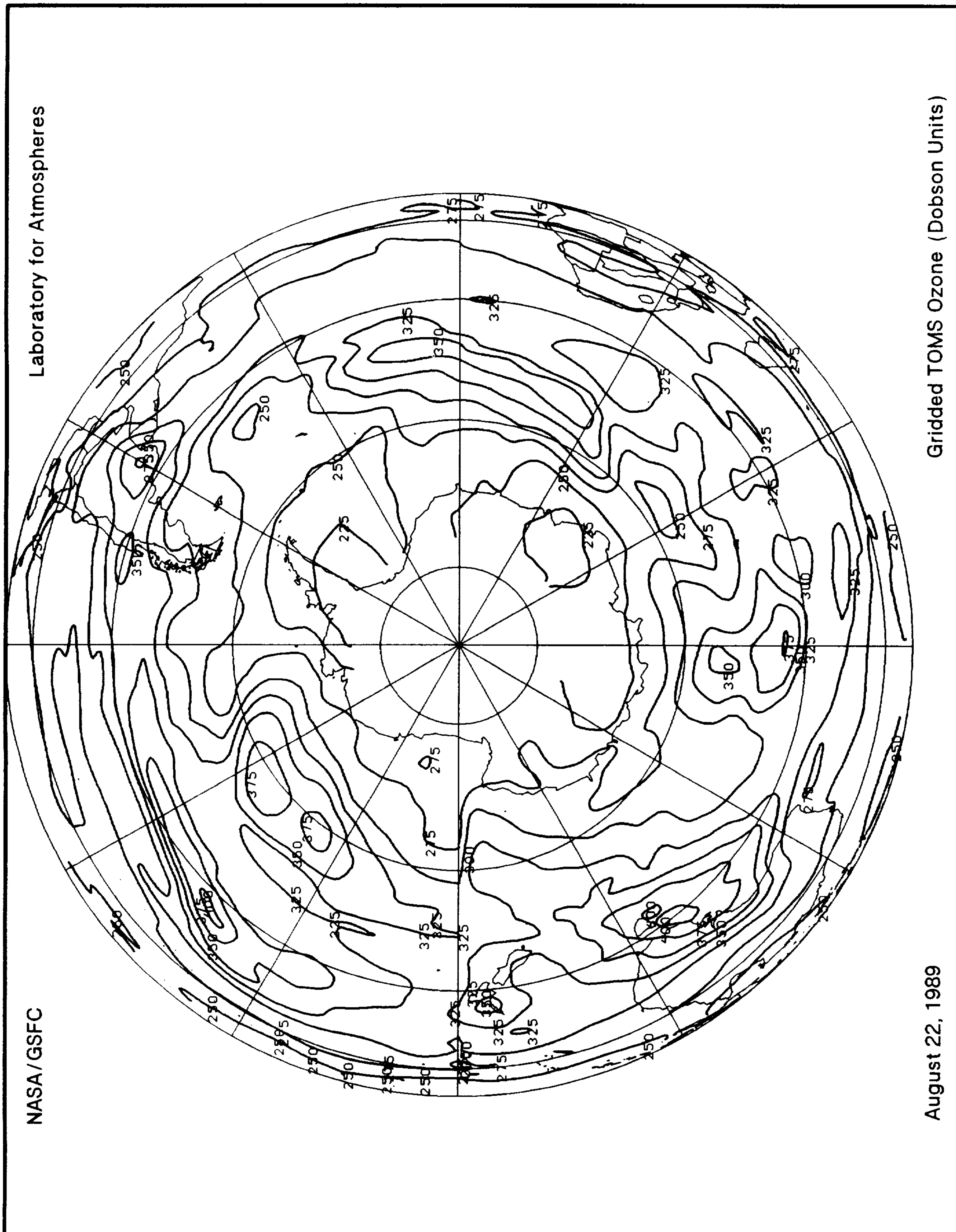
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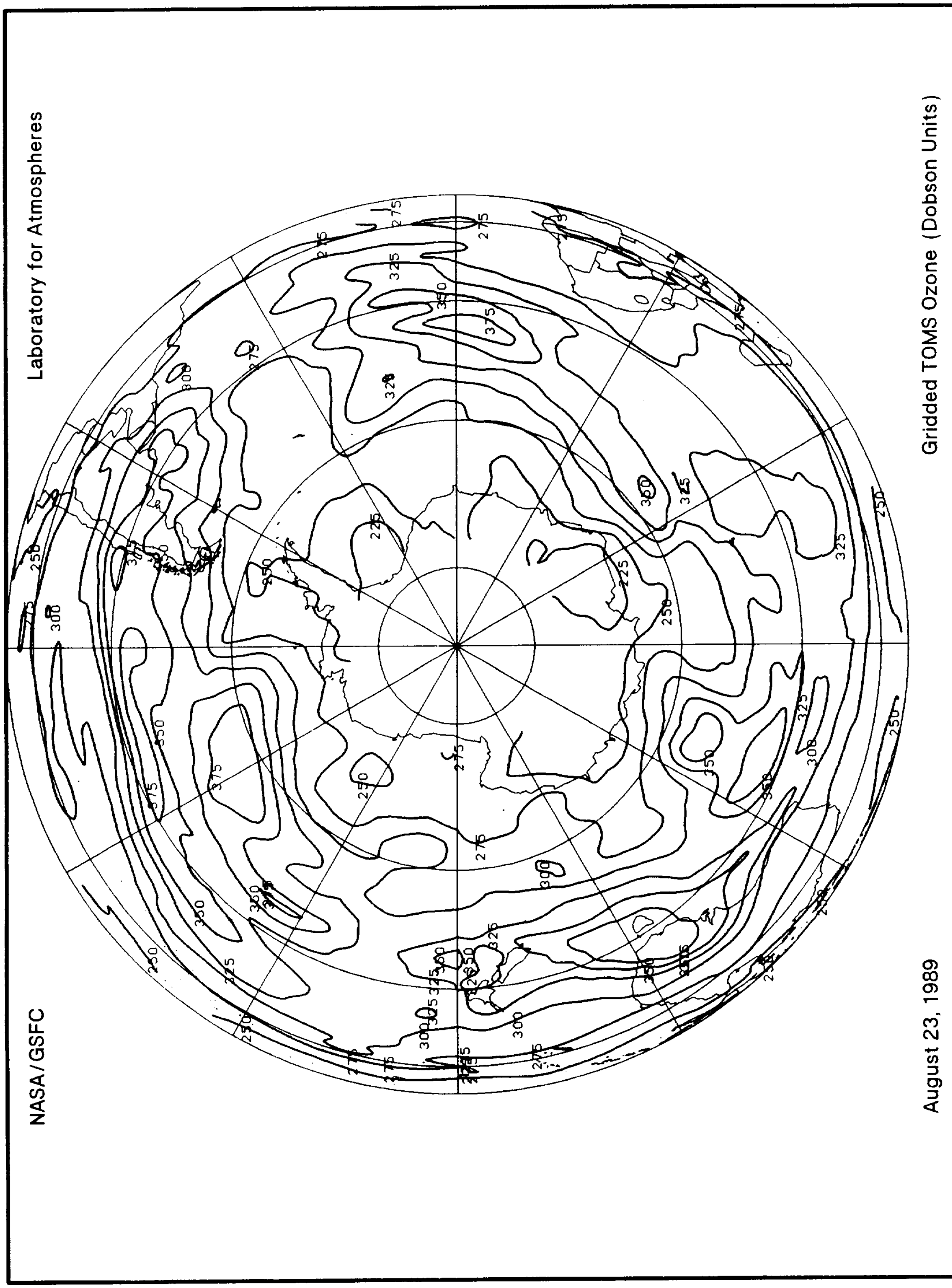
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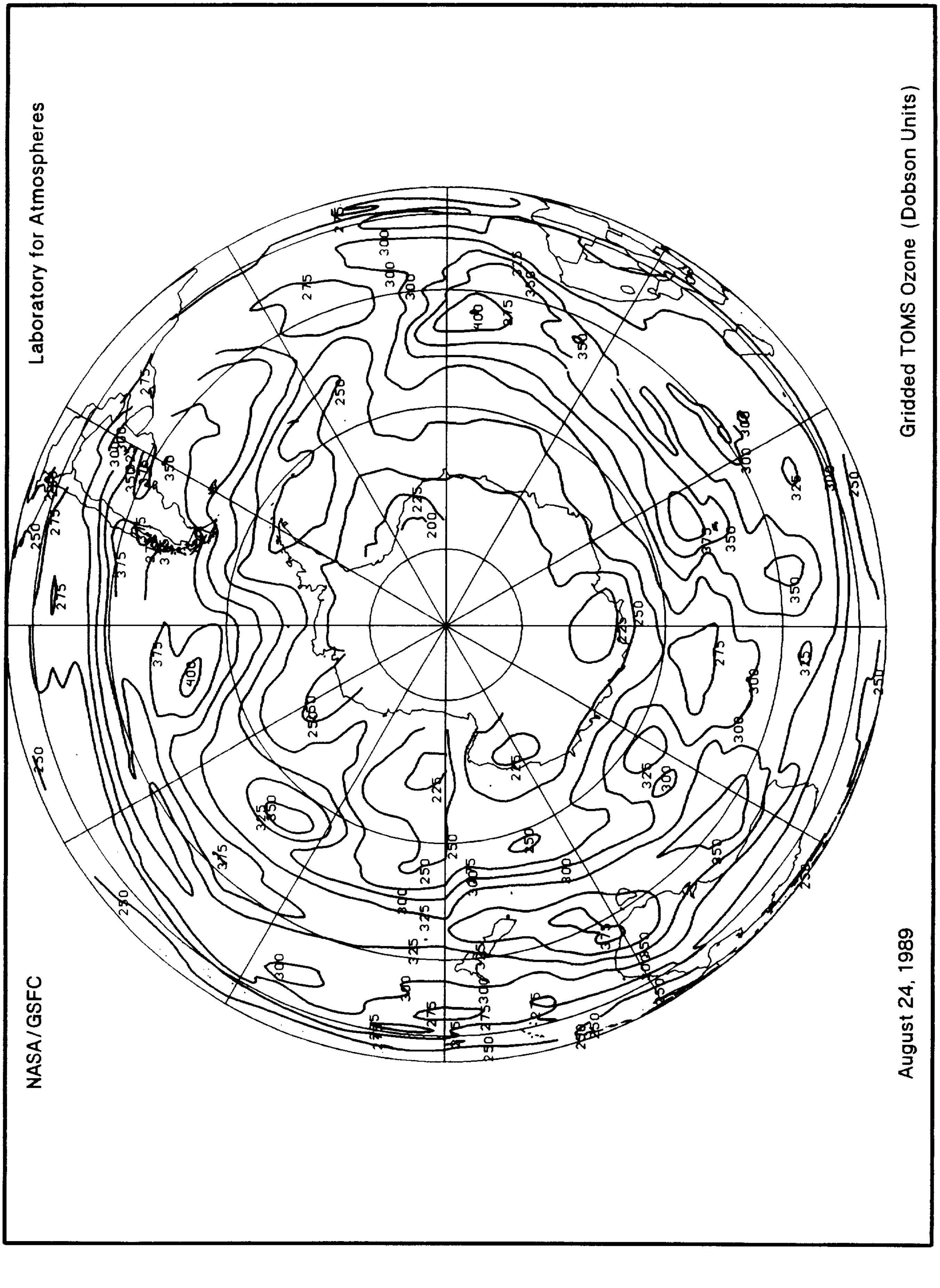
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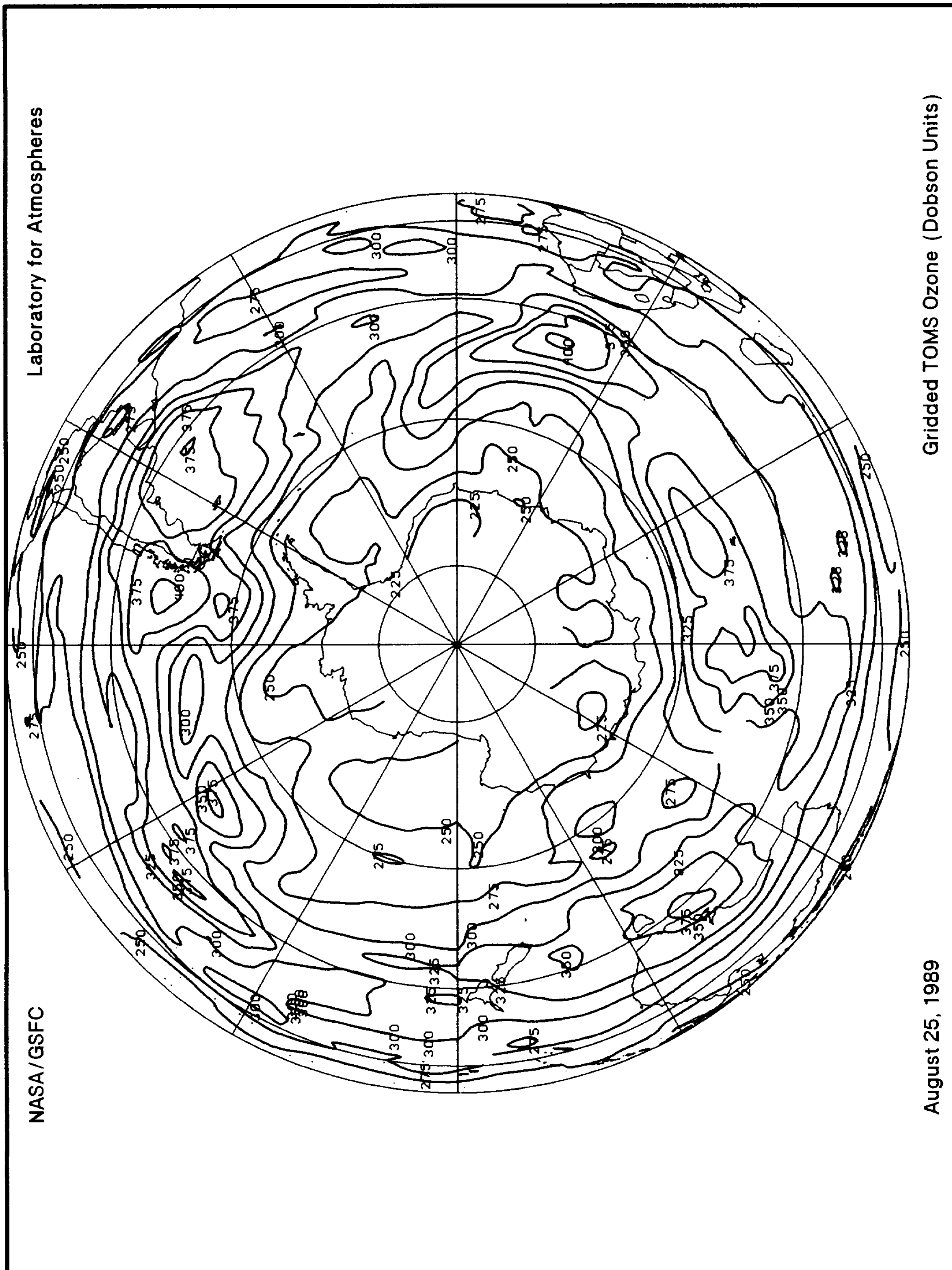
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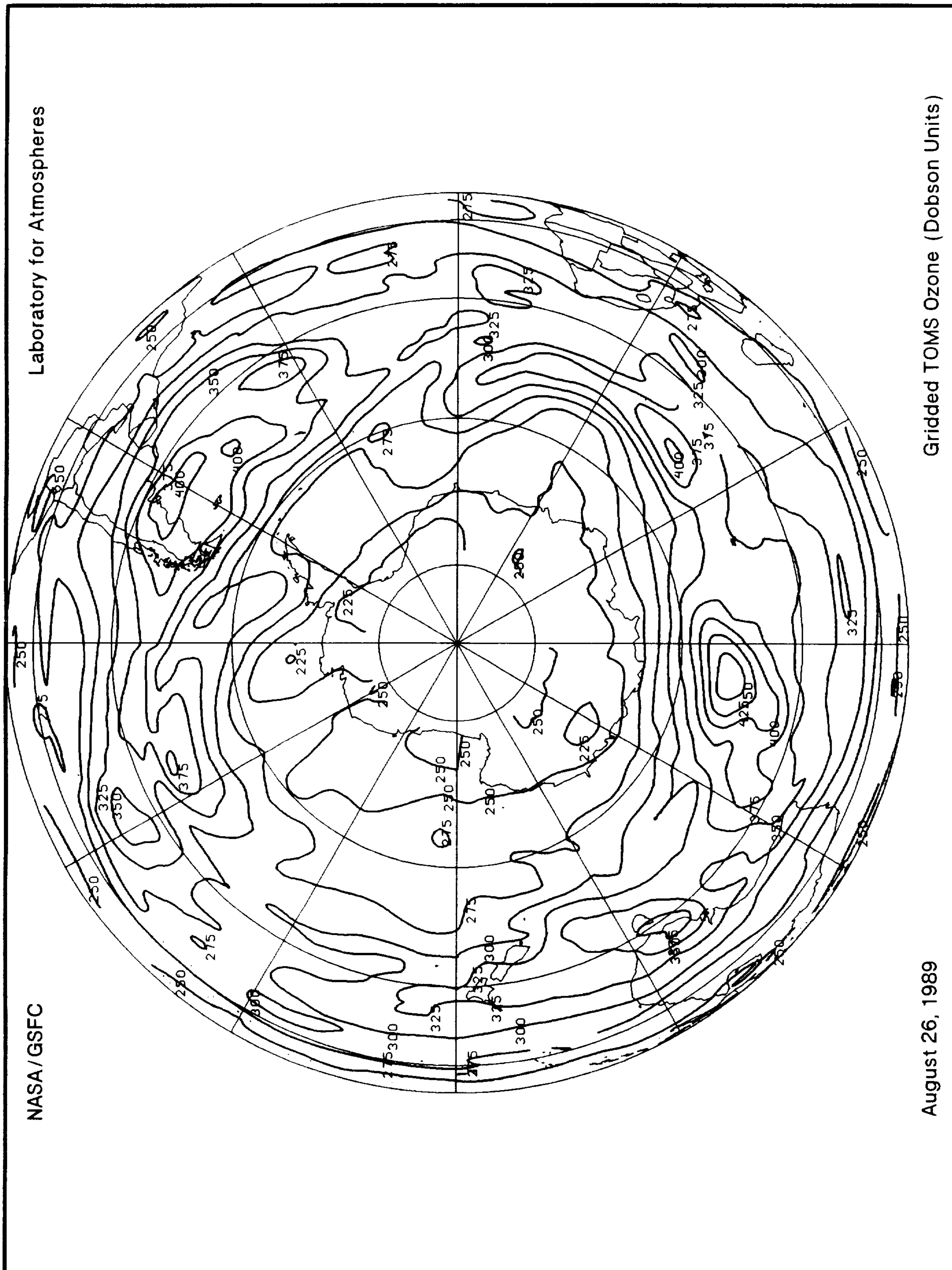
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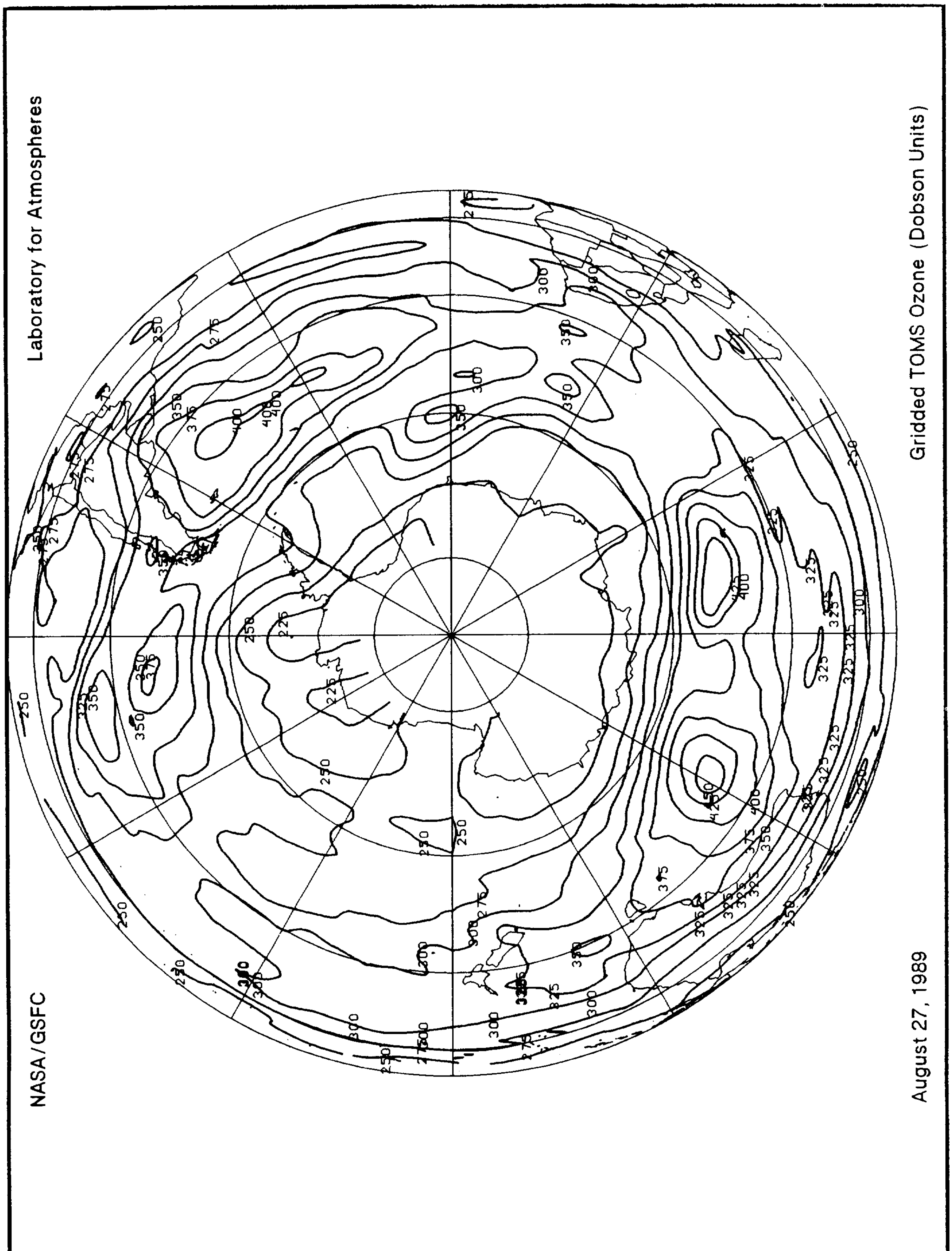

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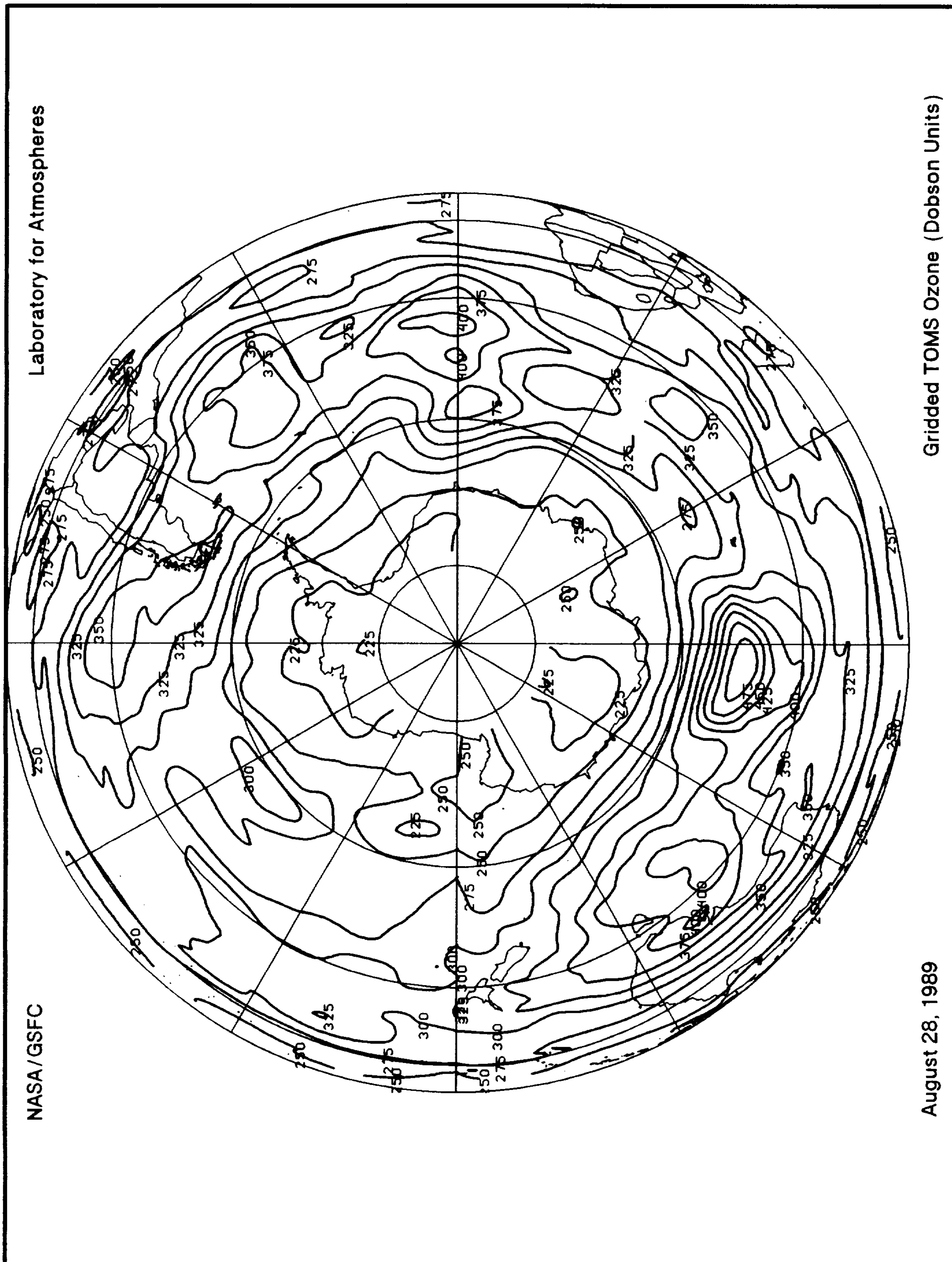
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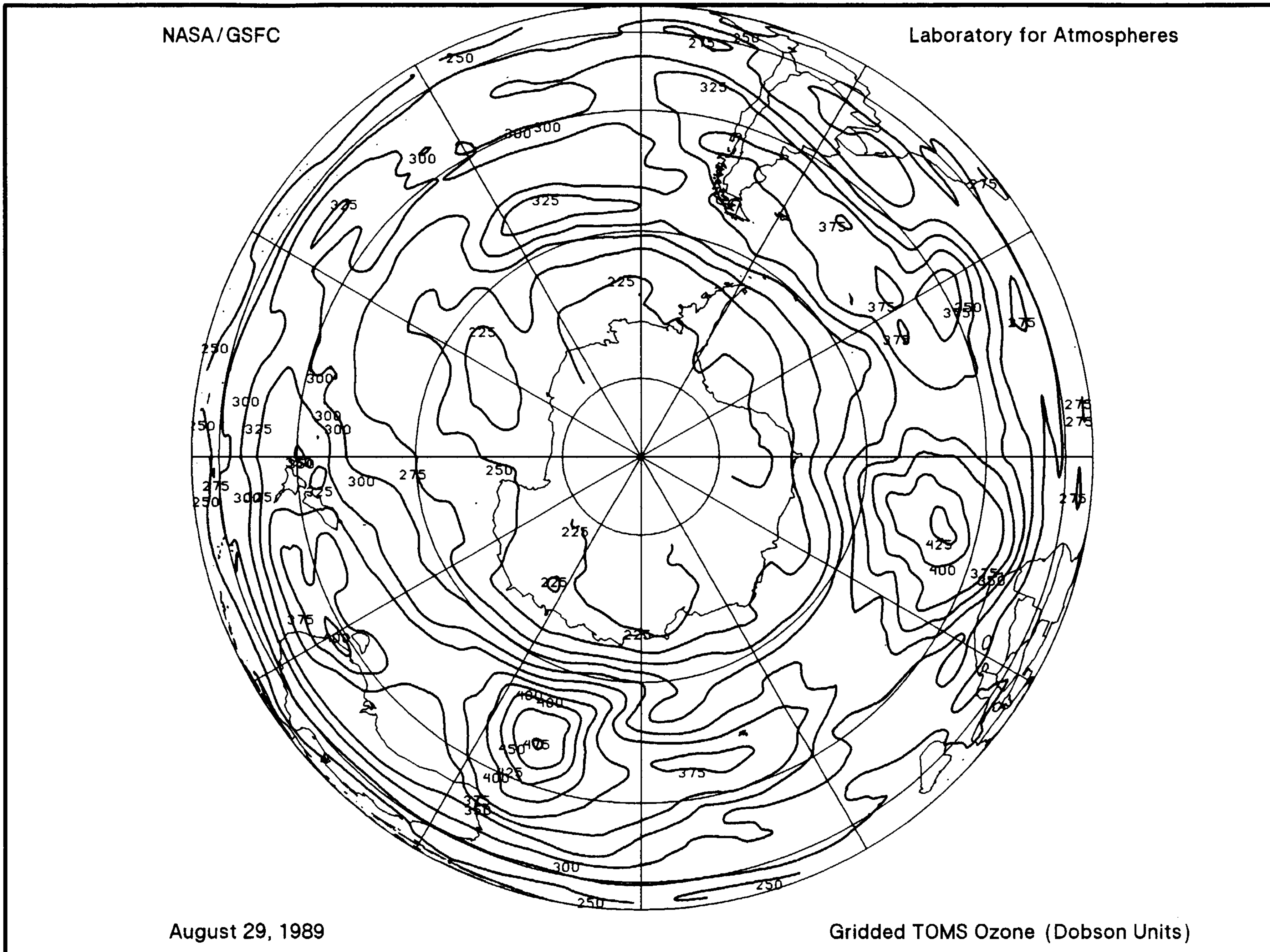
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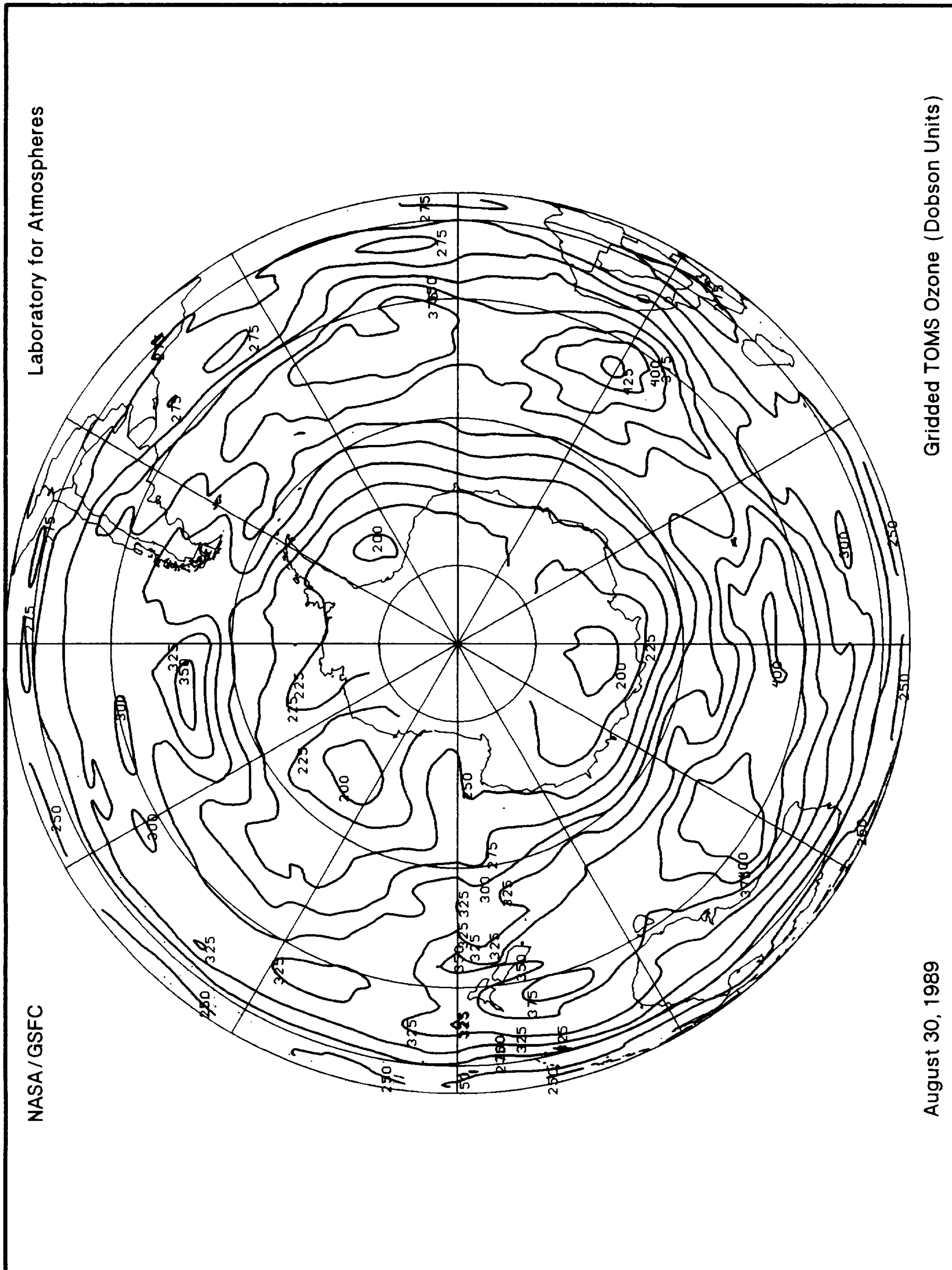
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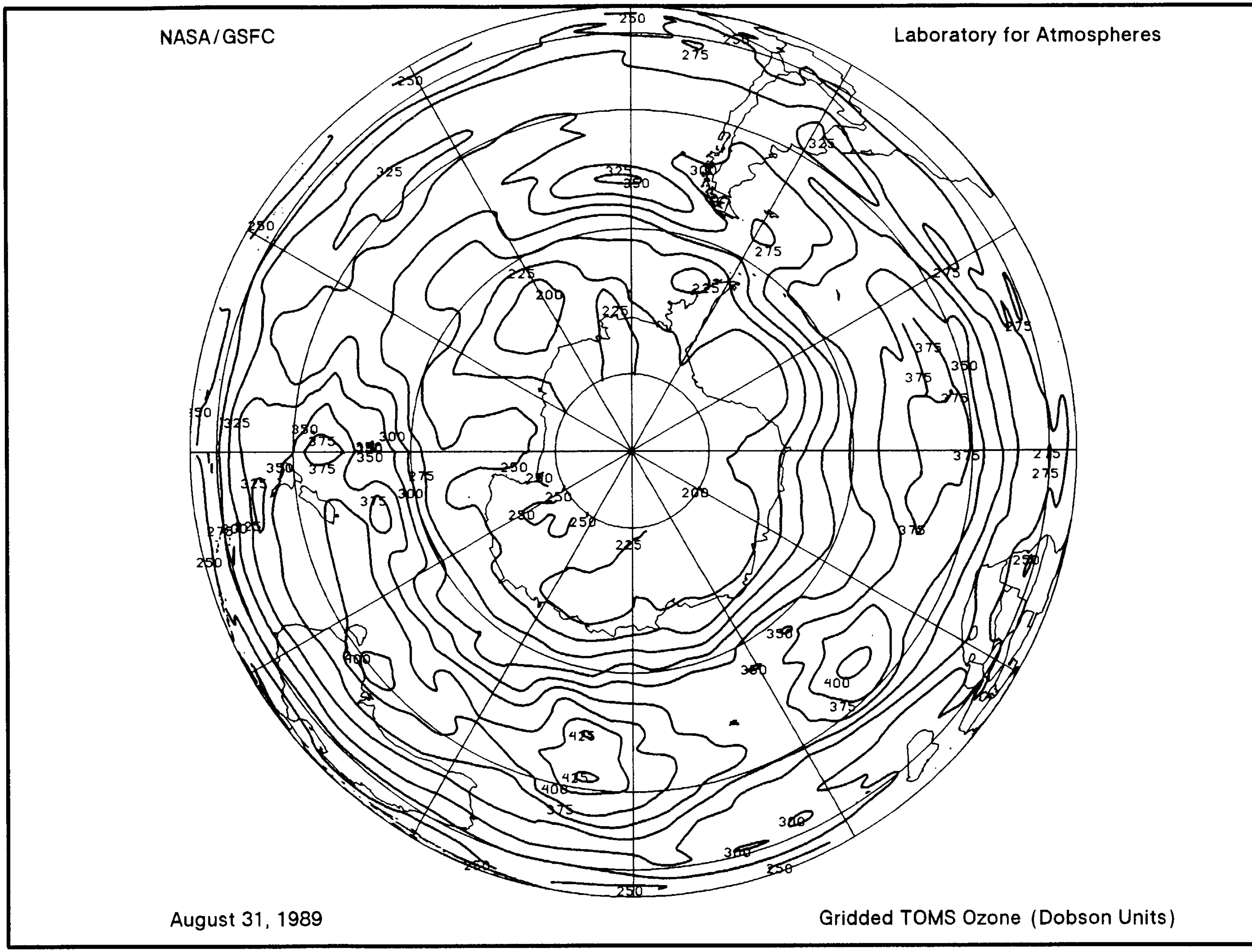

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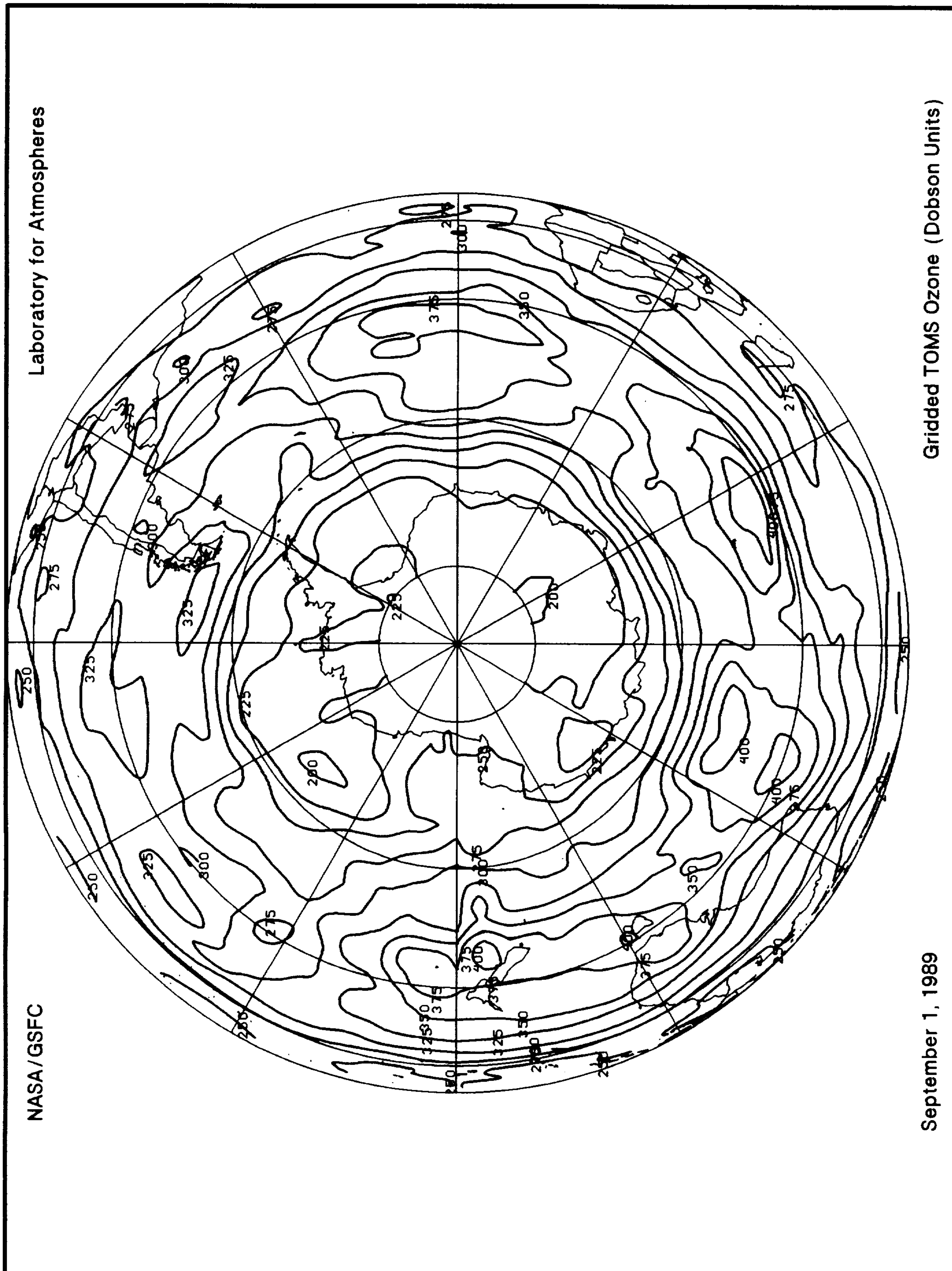
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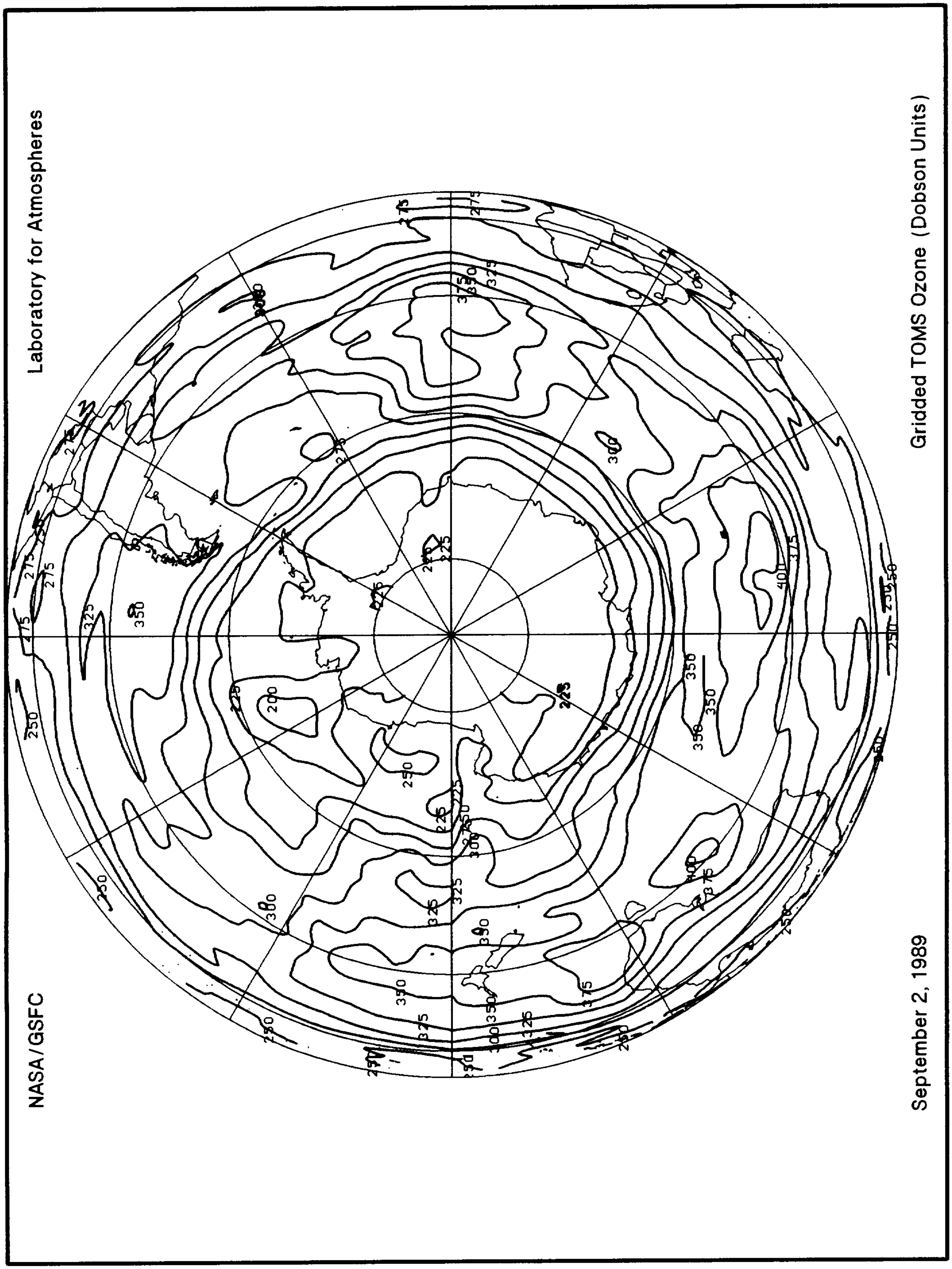
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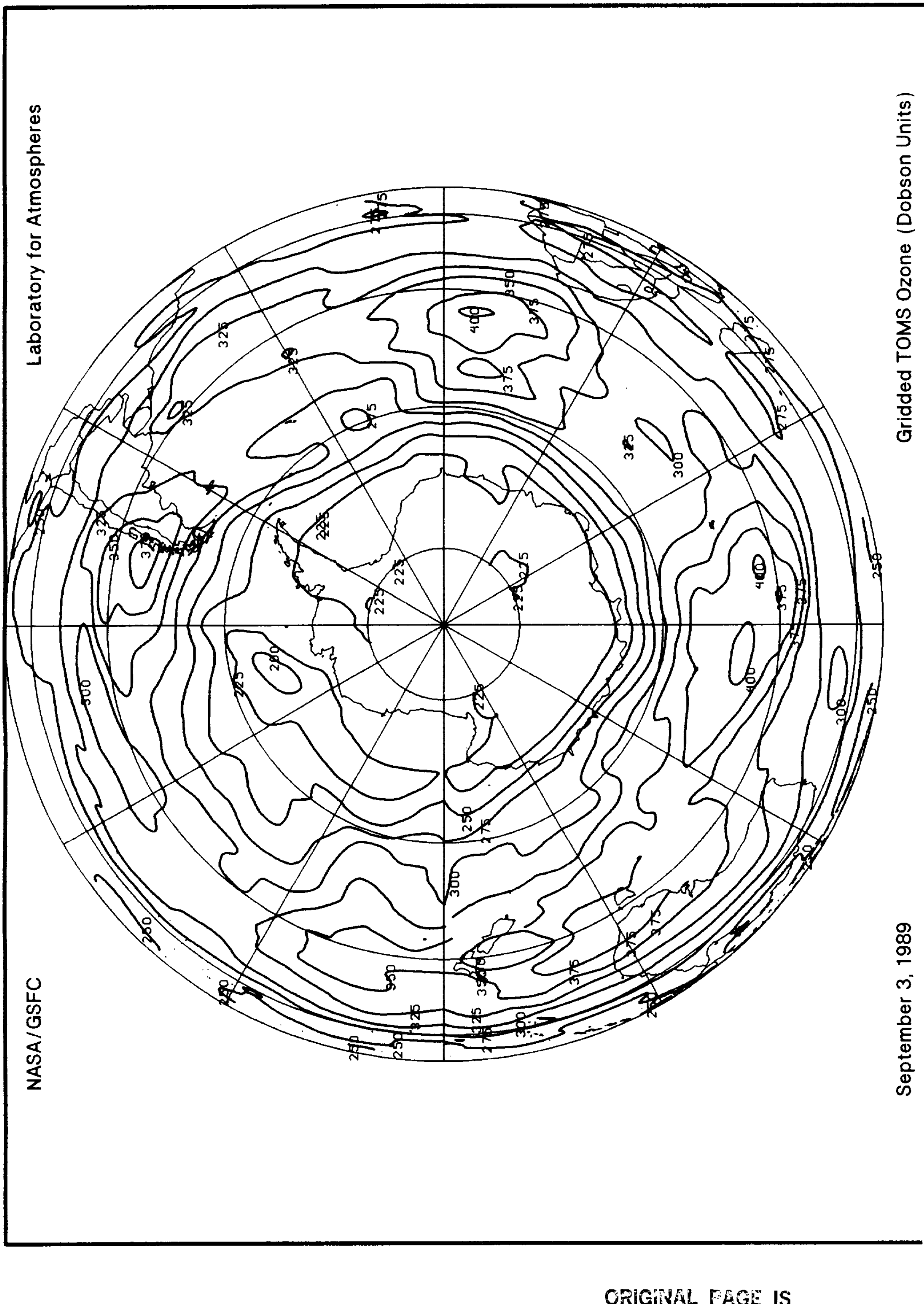
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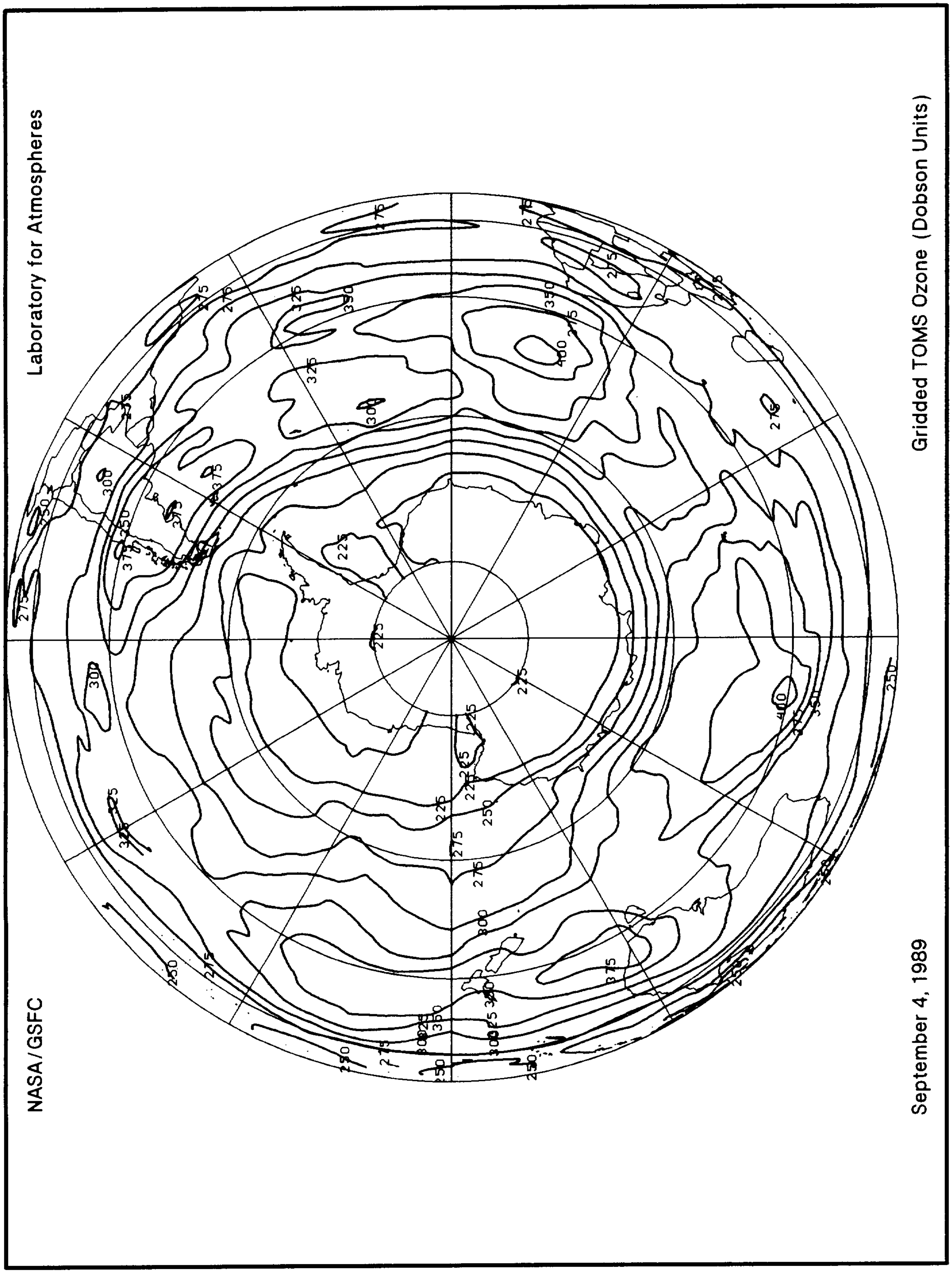
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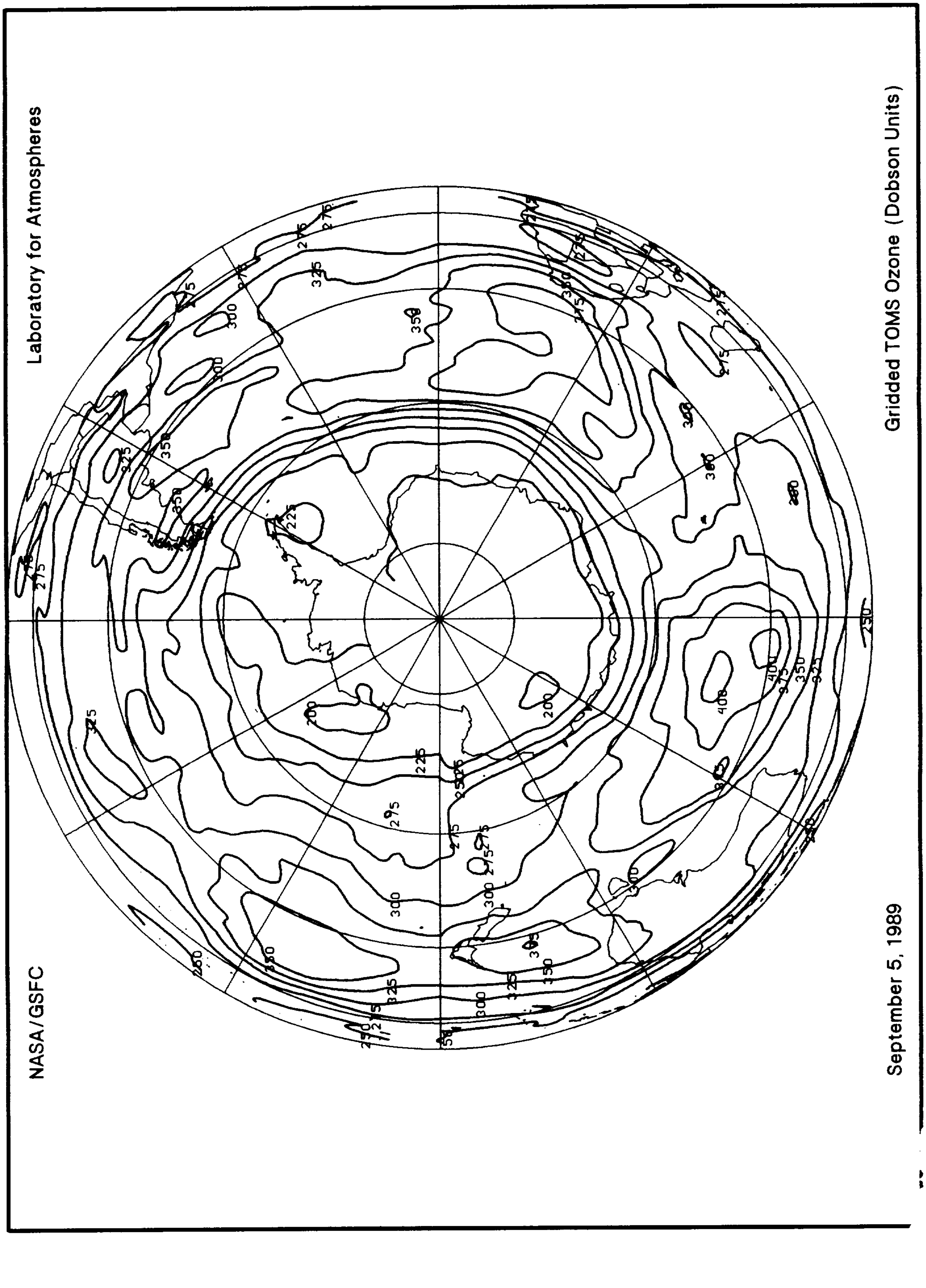
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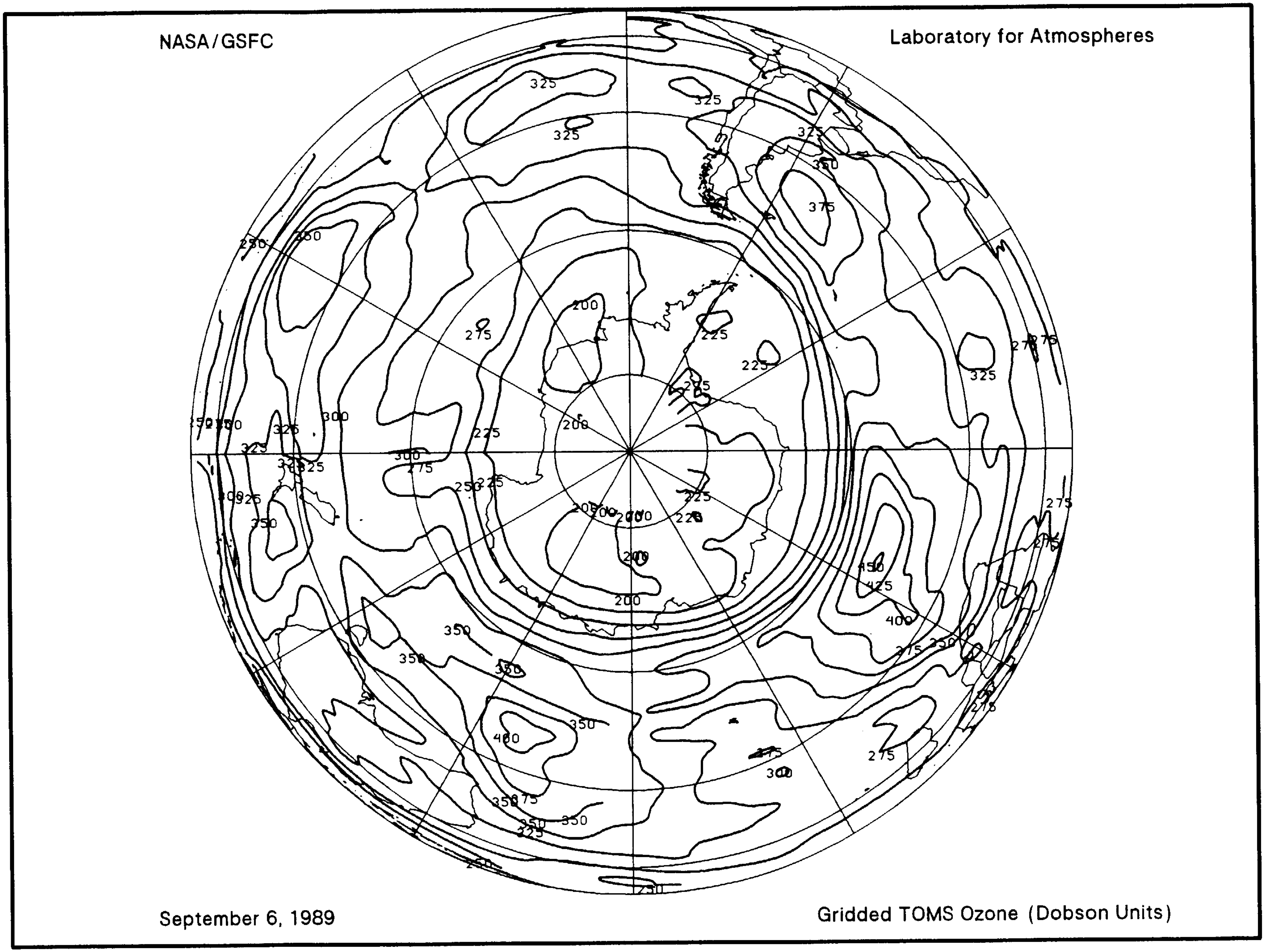
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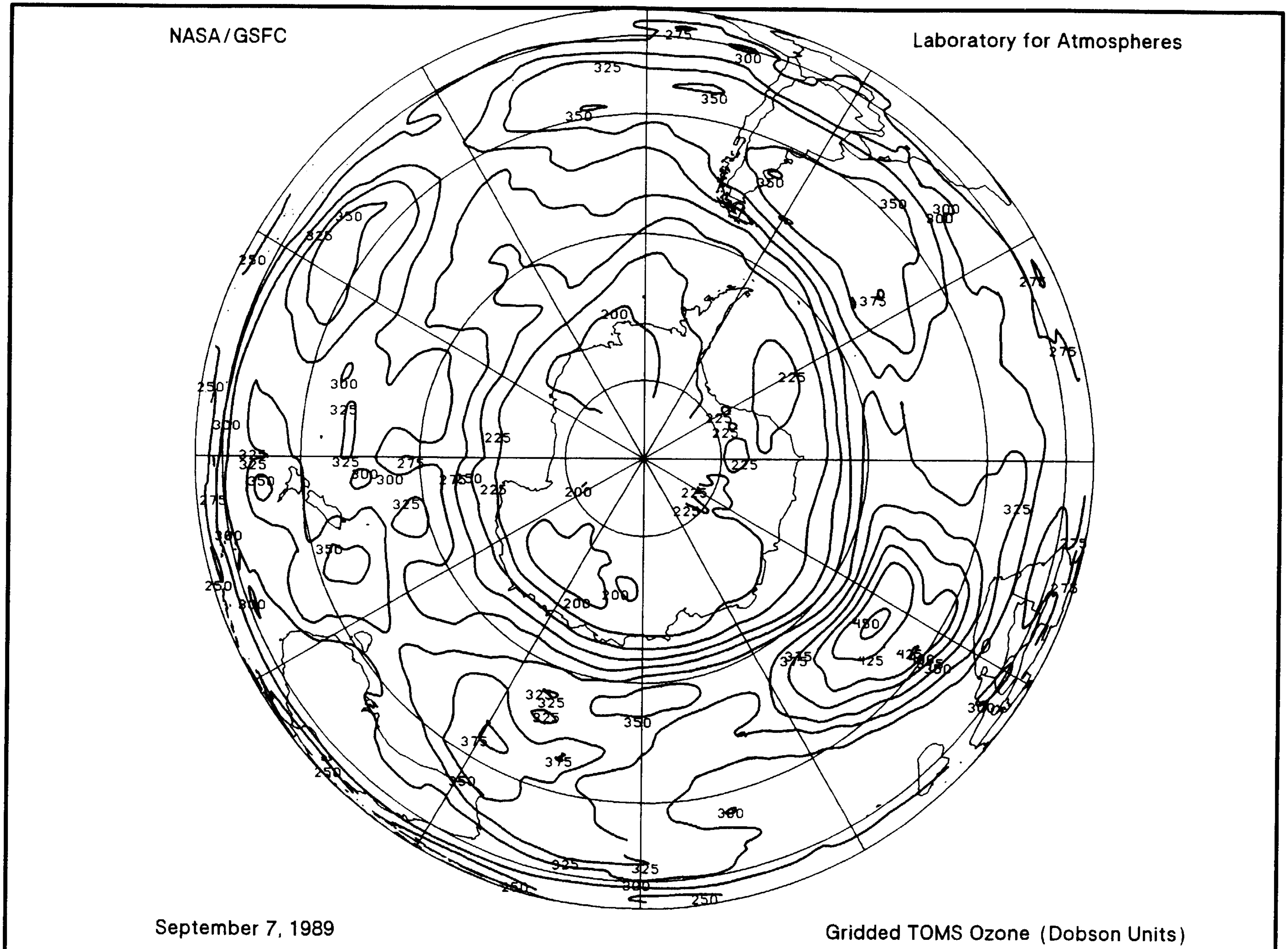
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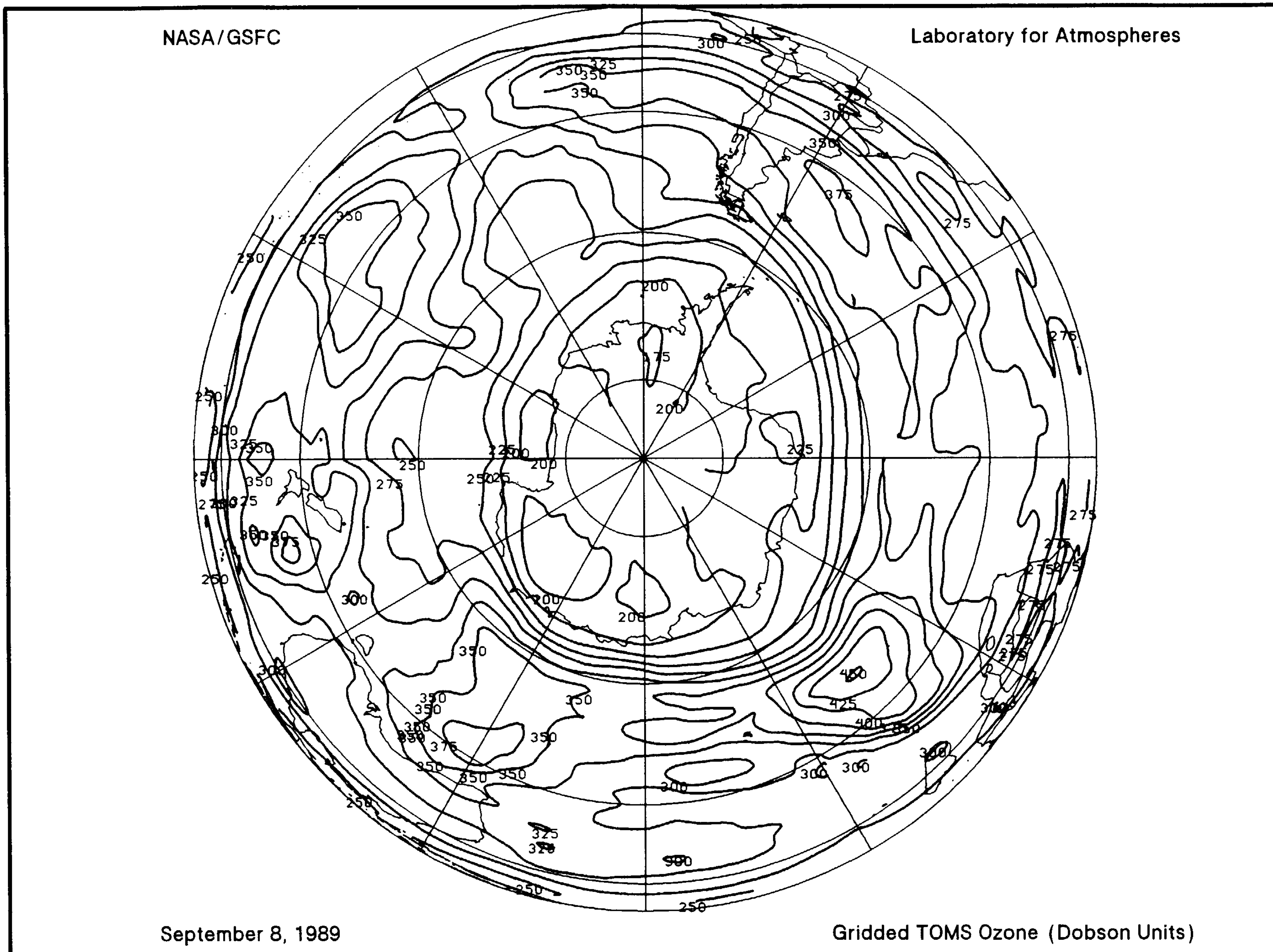
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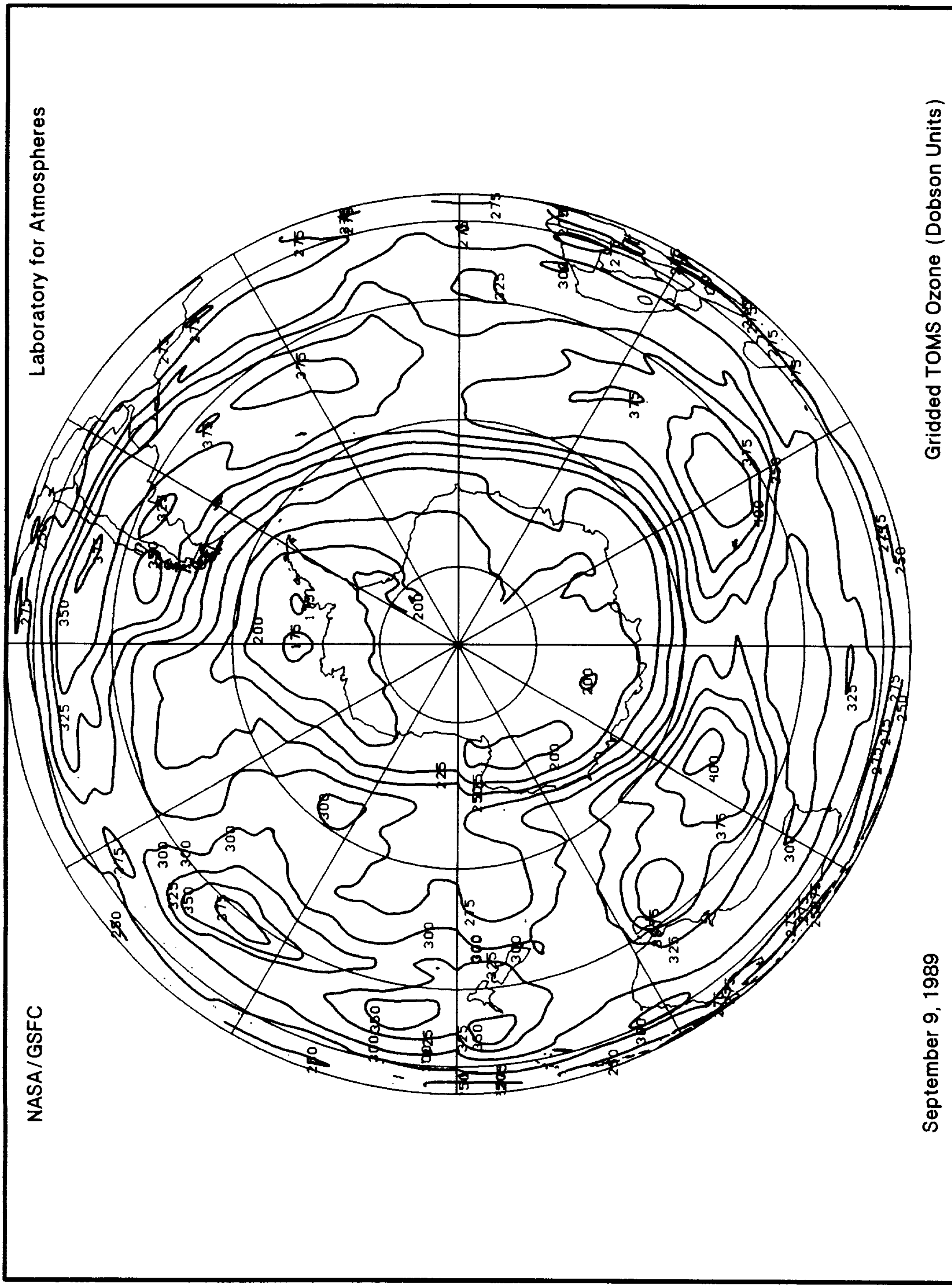
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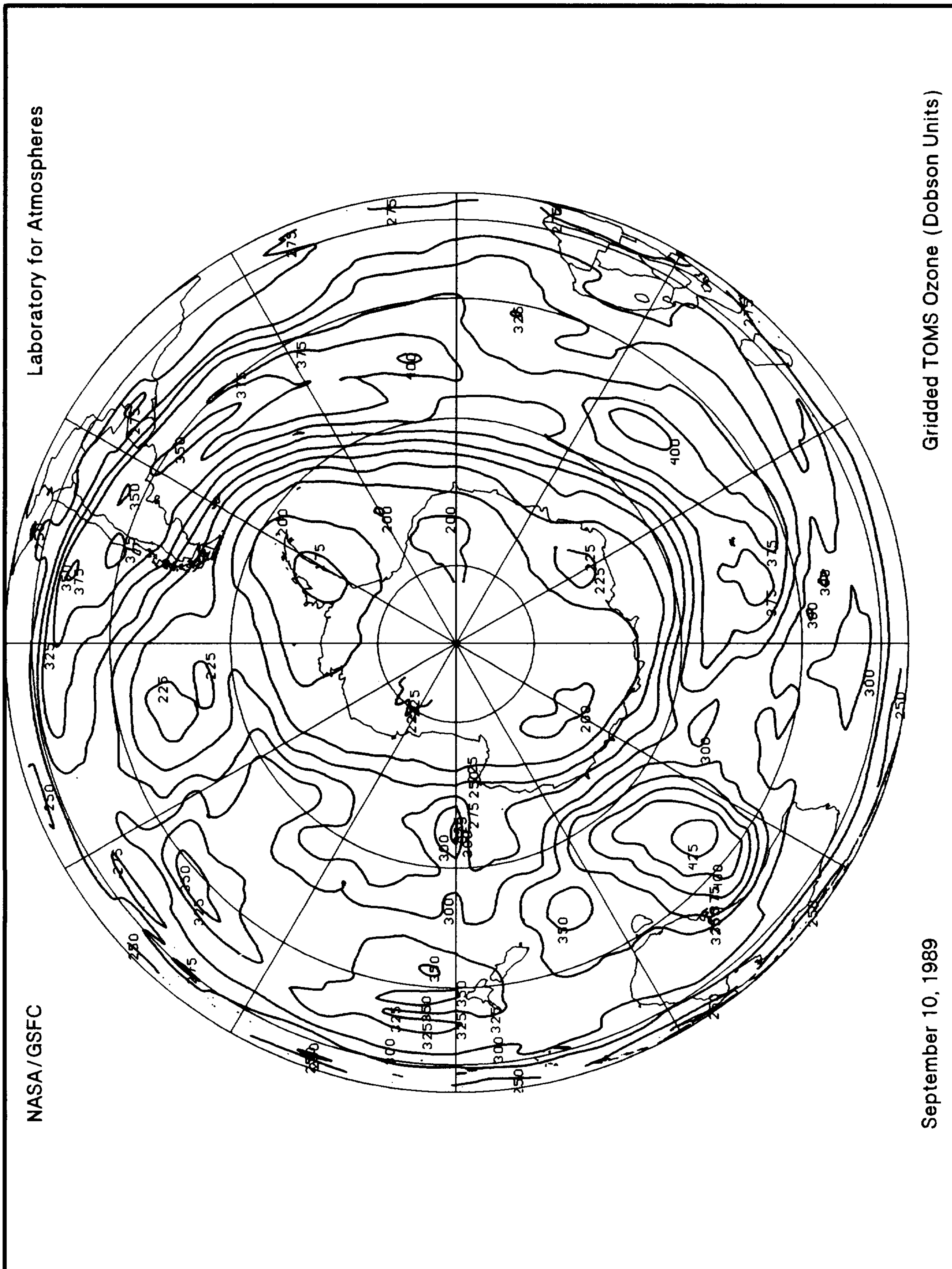
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
September 9, 1989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Laboratory for Atmospheres
September 10, 1989
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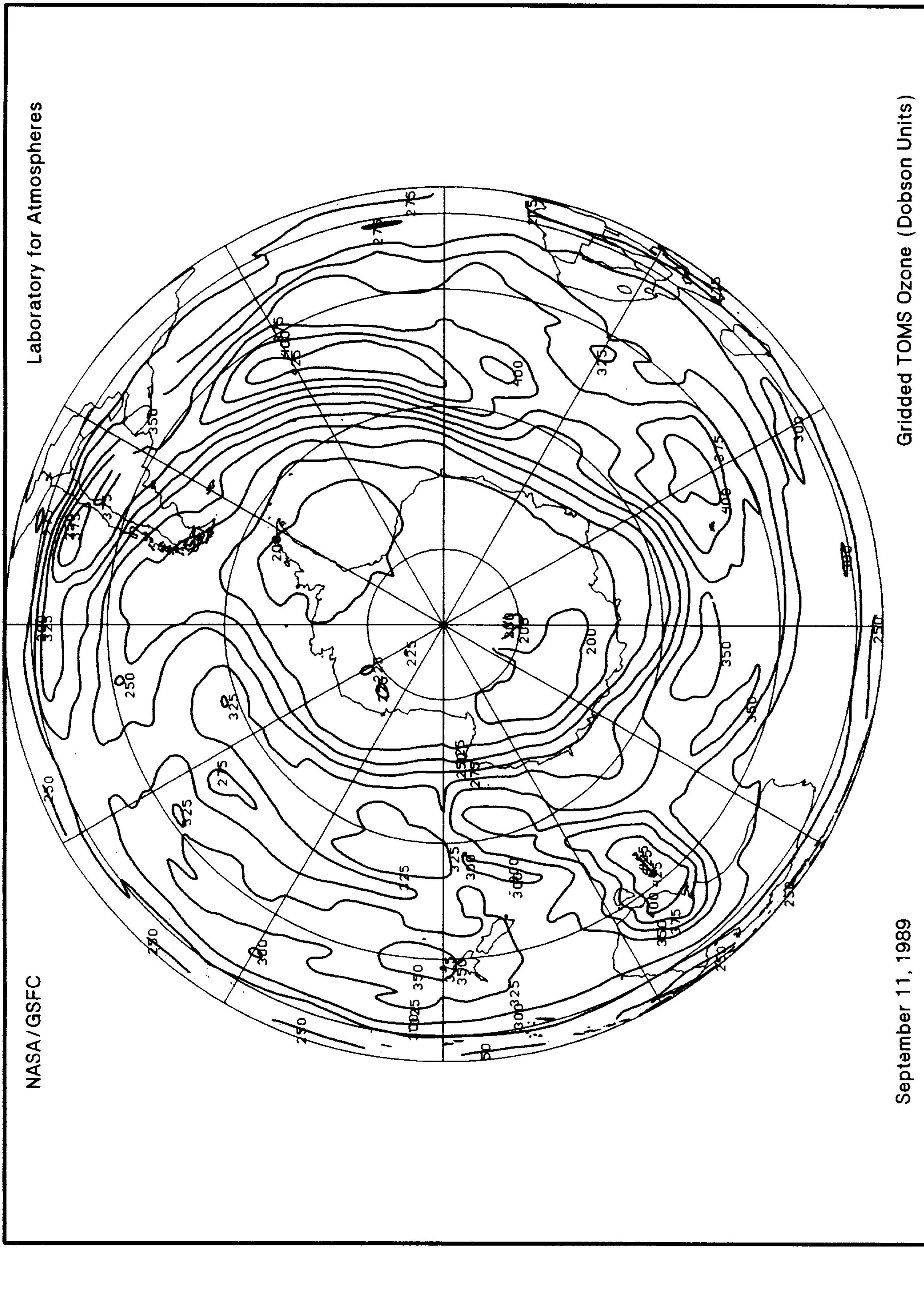
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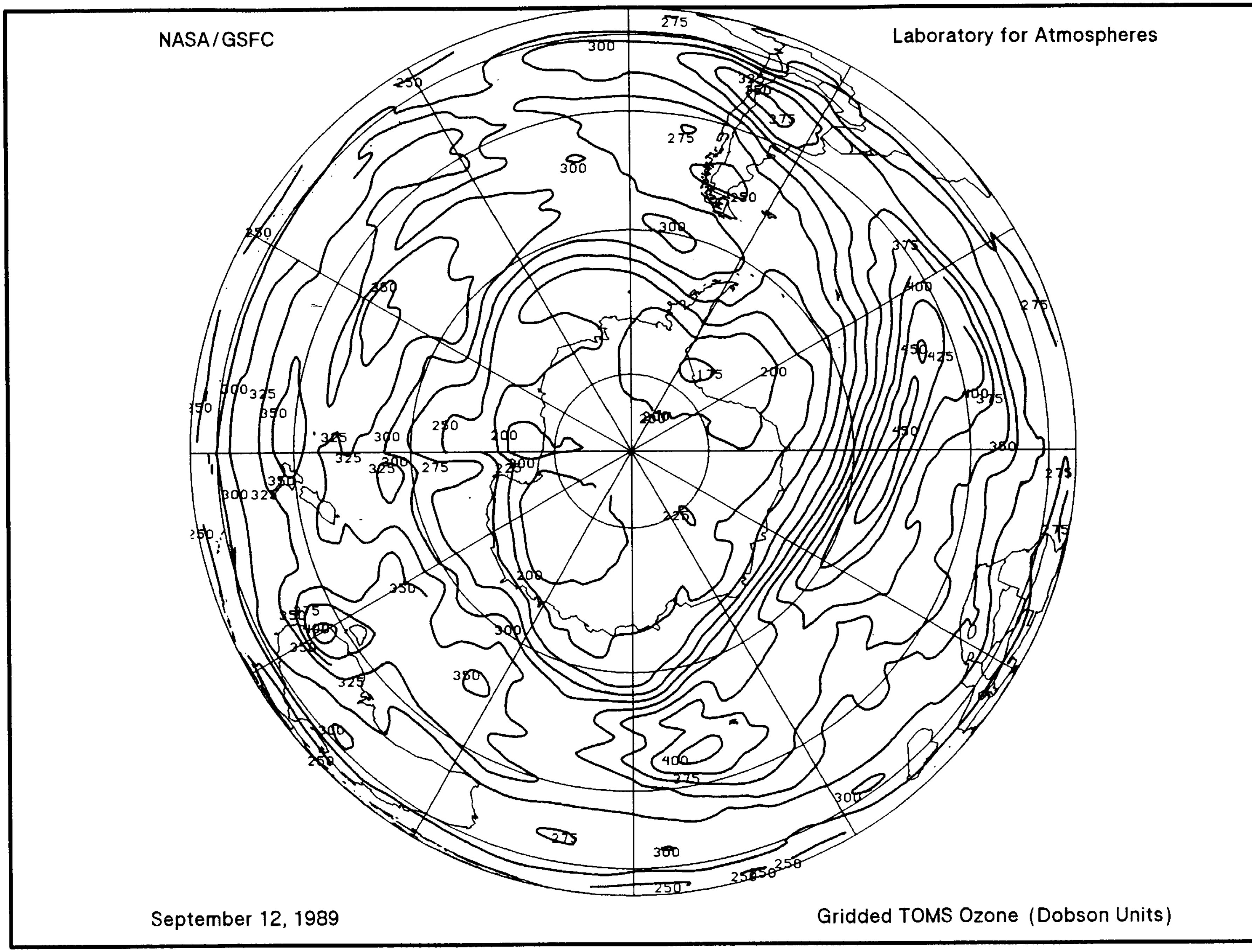
September 11, 1989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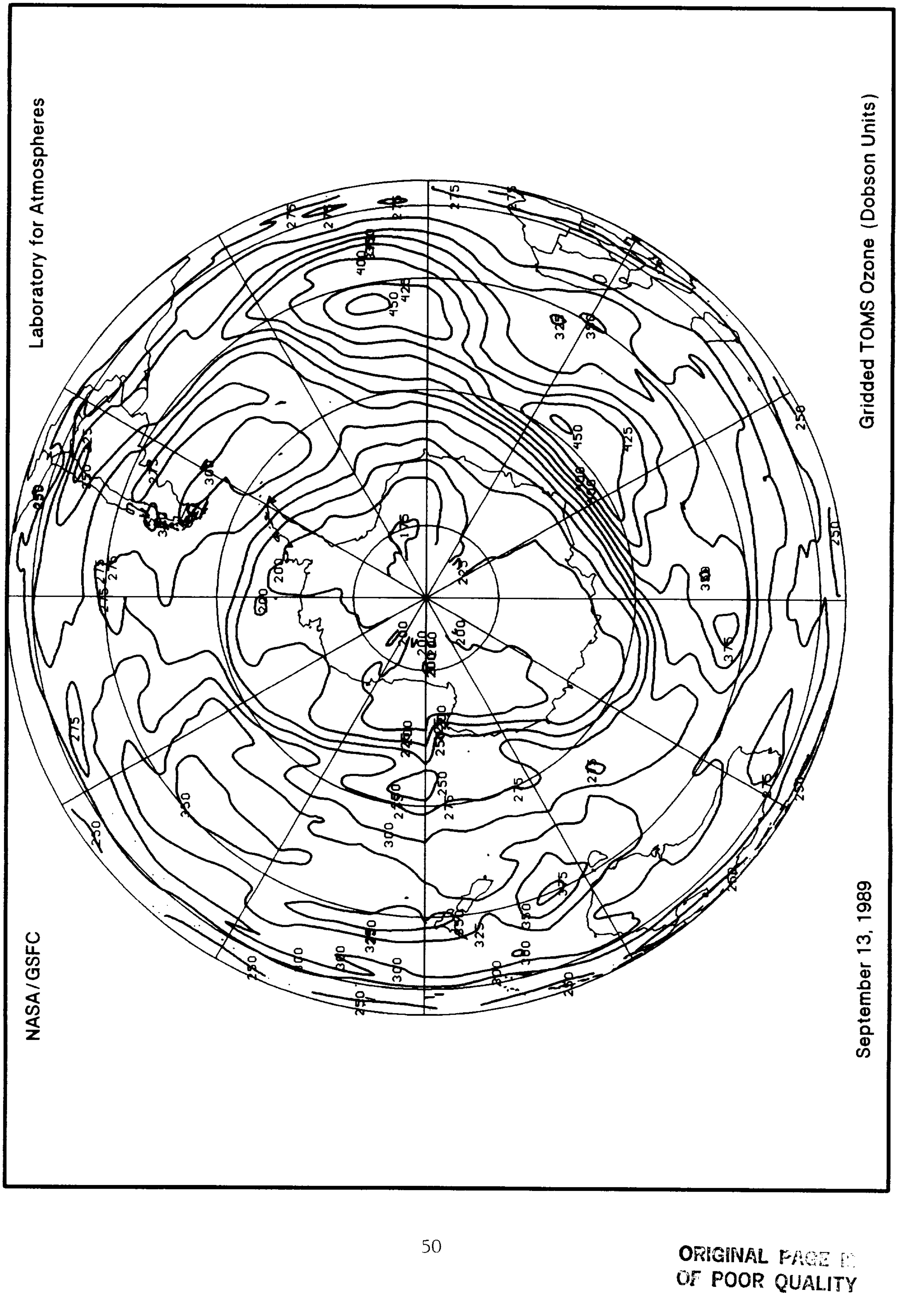
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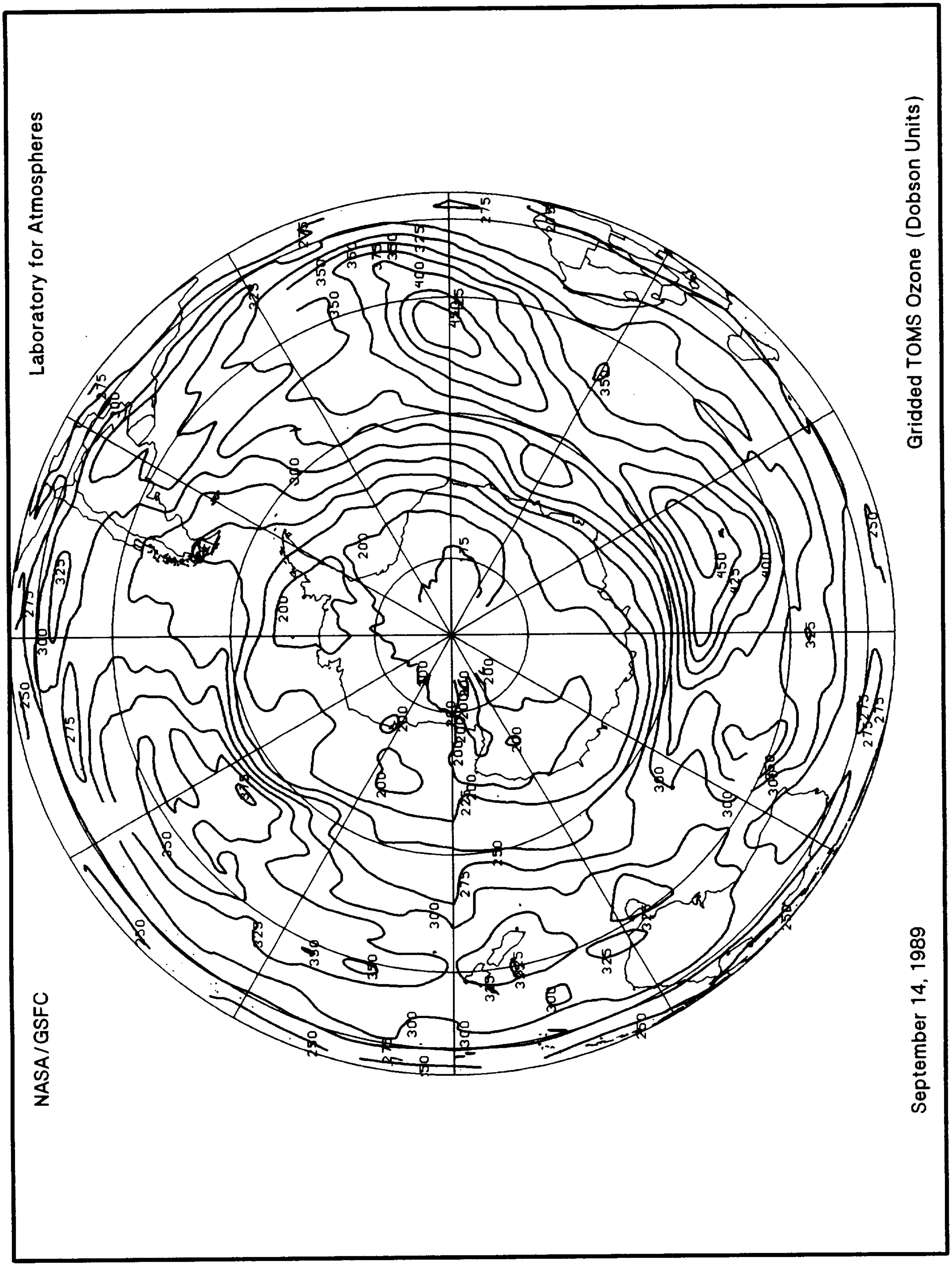
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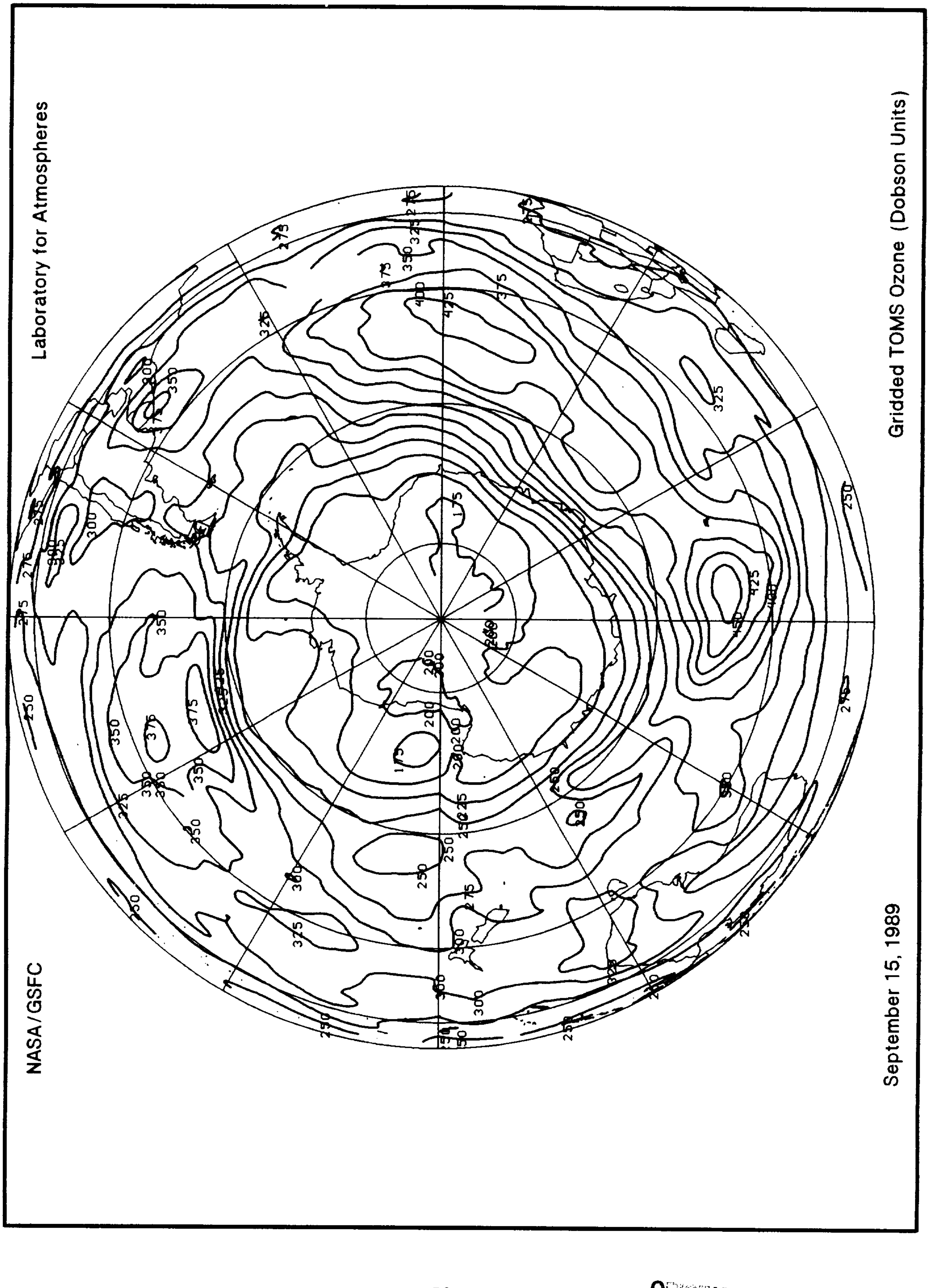
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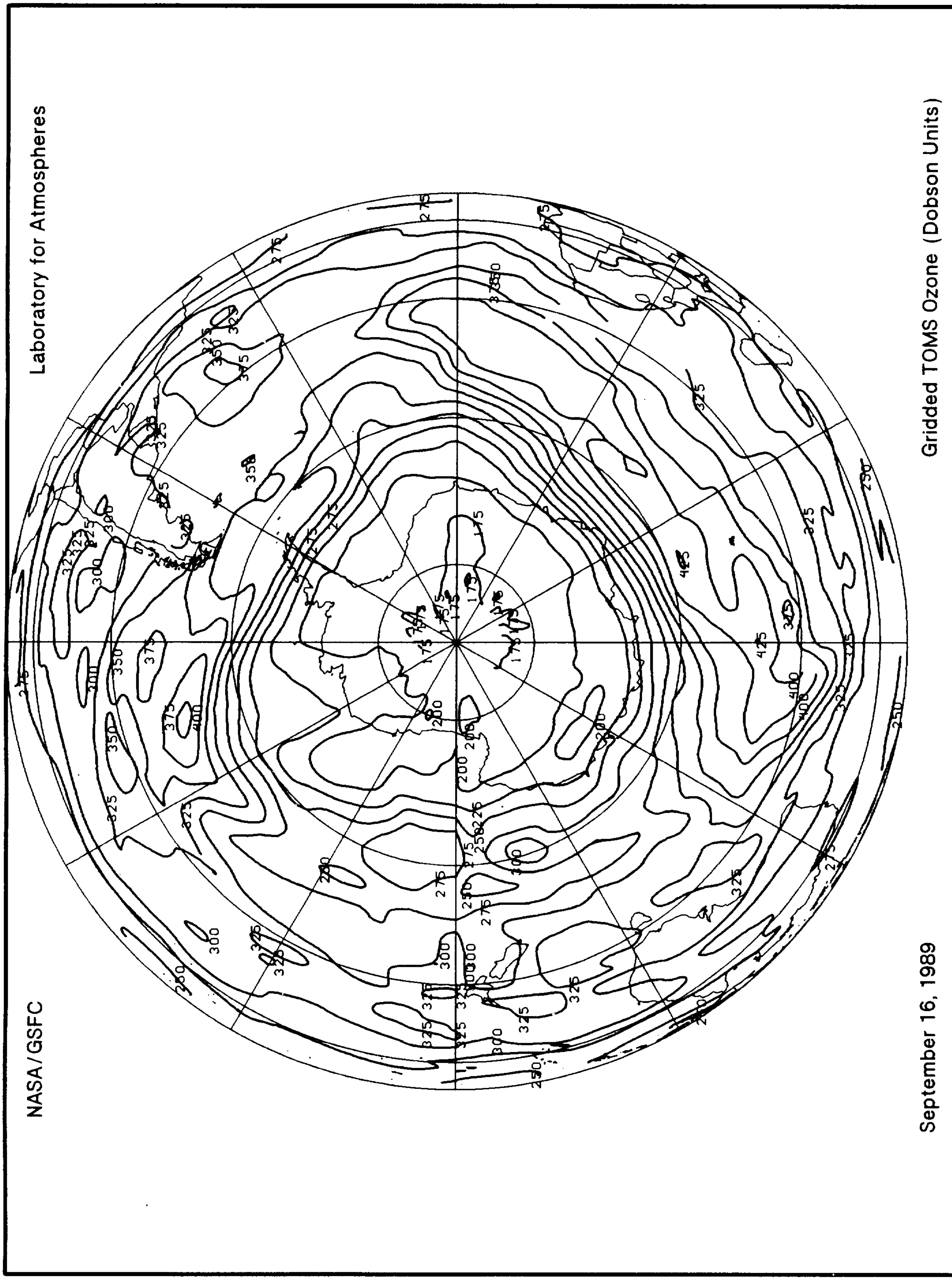
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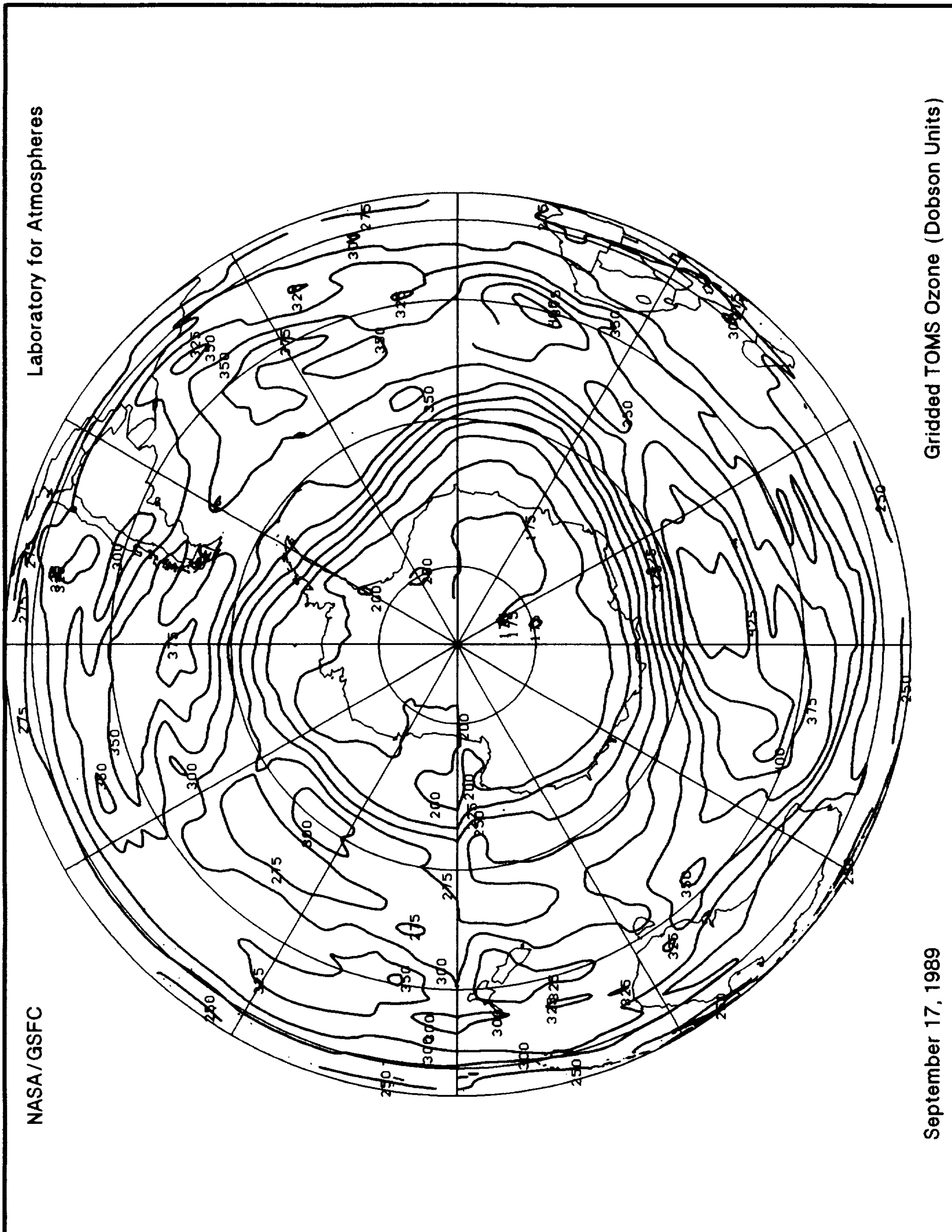
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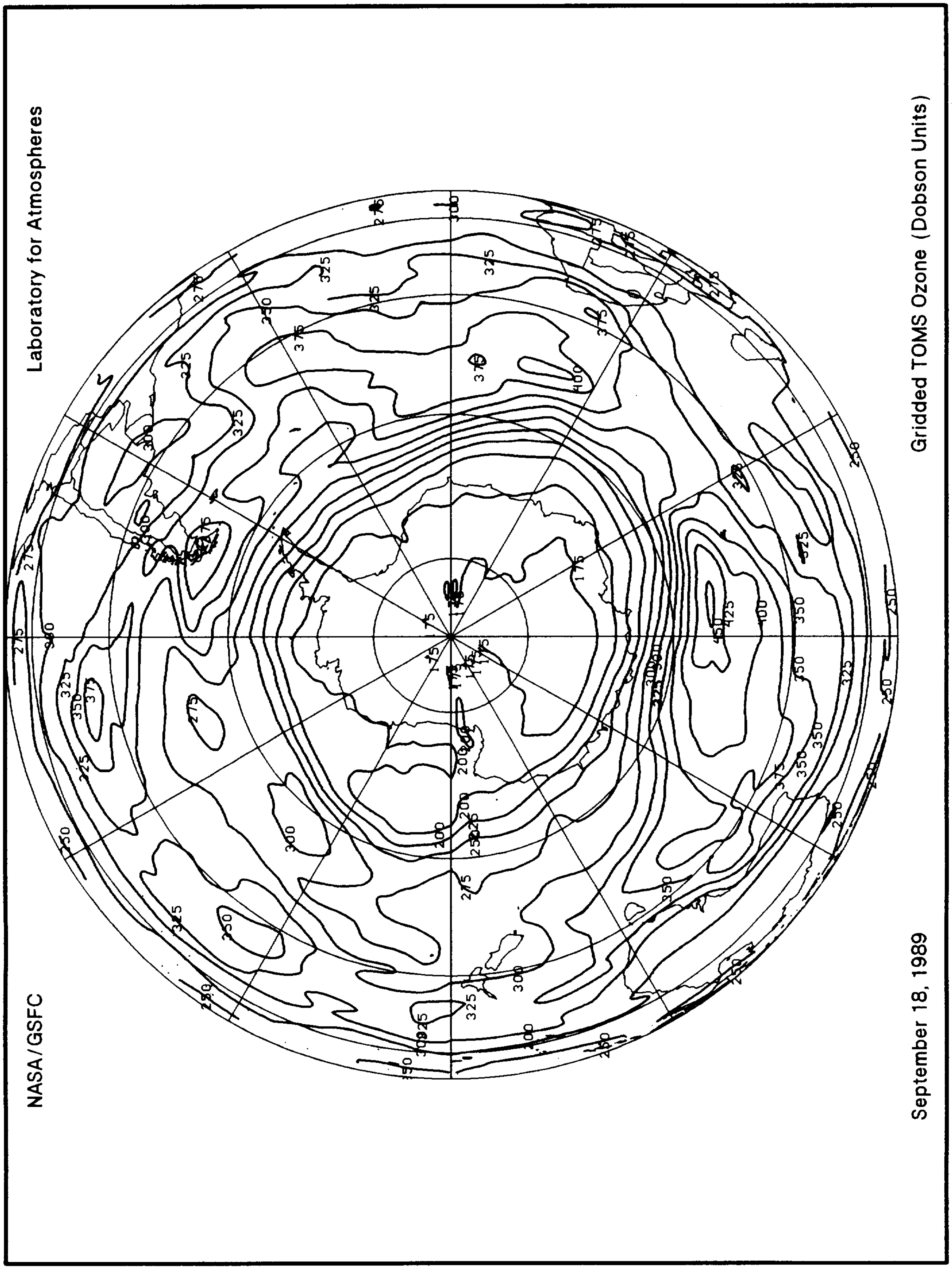
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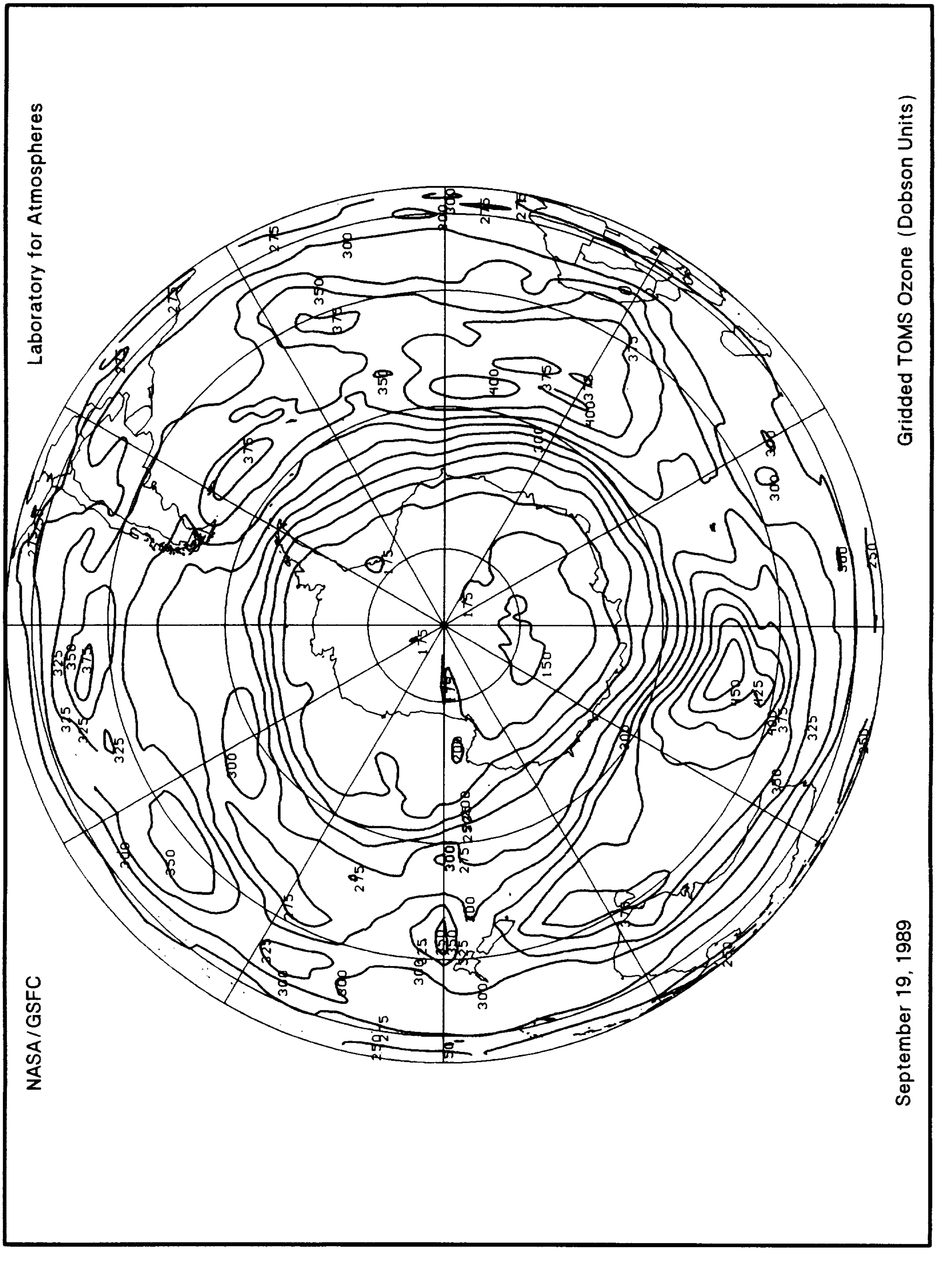
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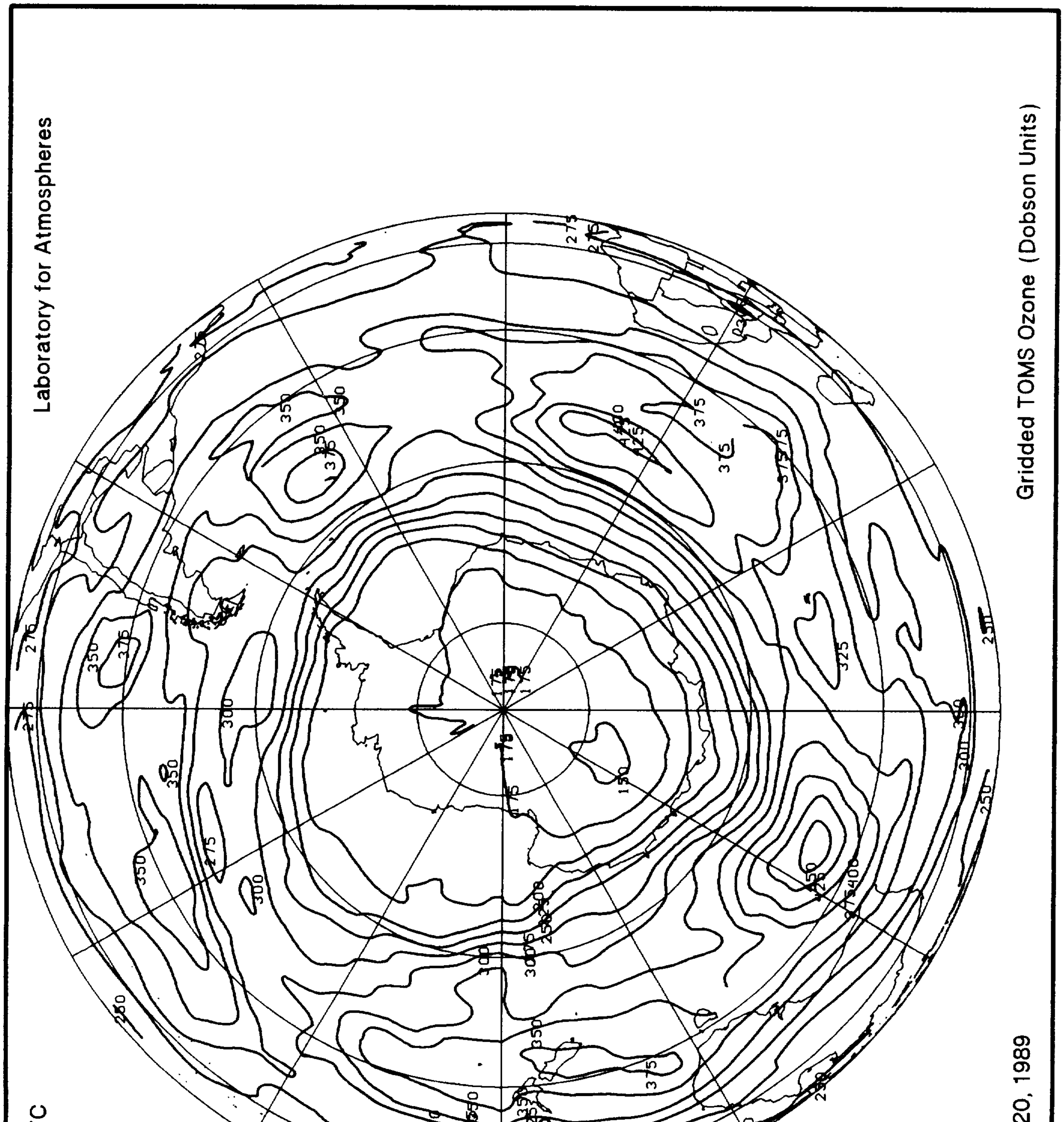

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NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
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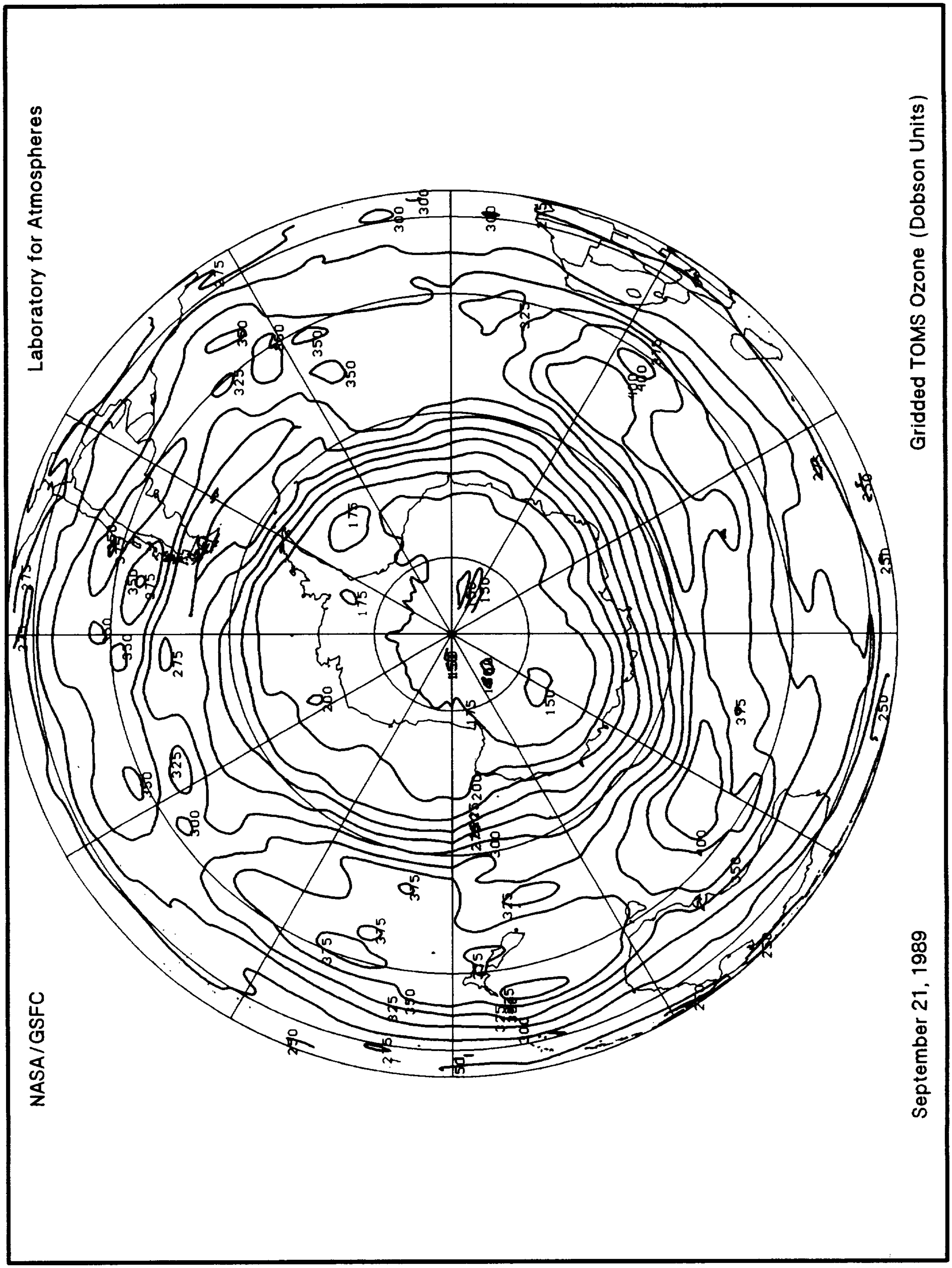
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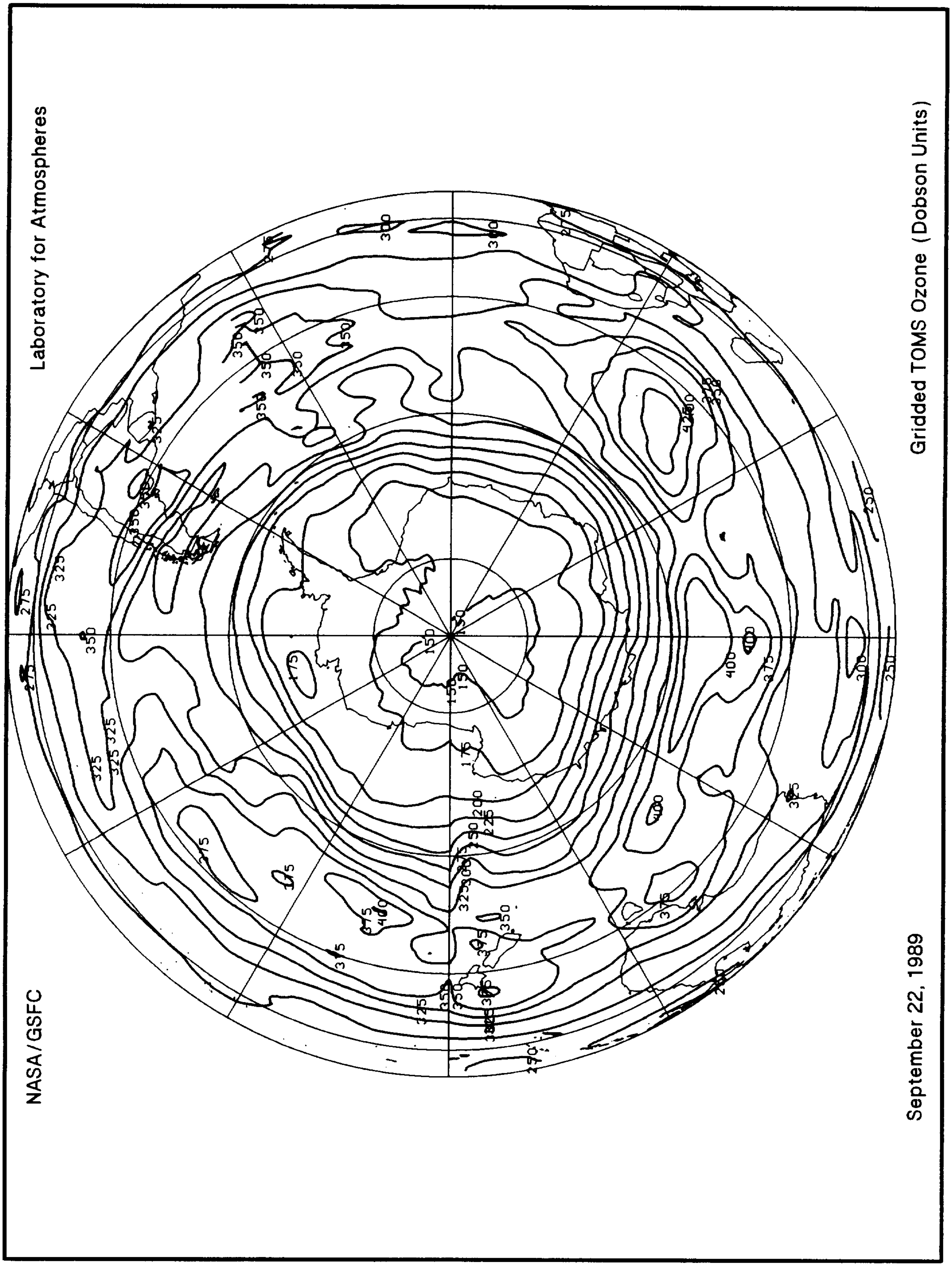

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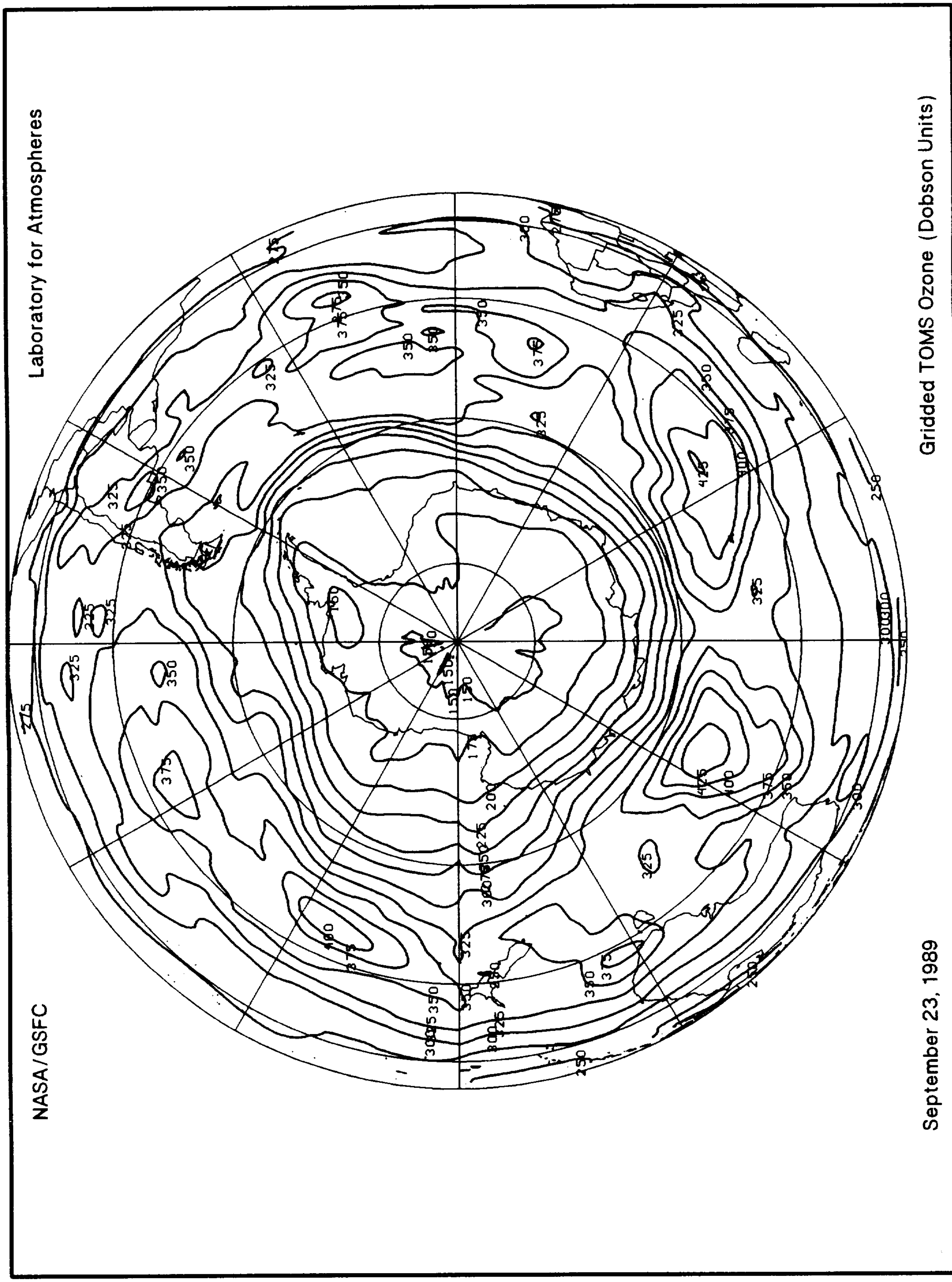
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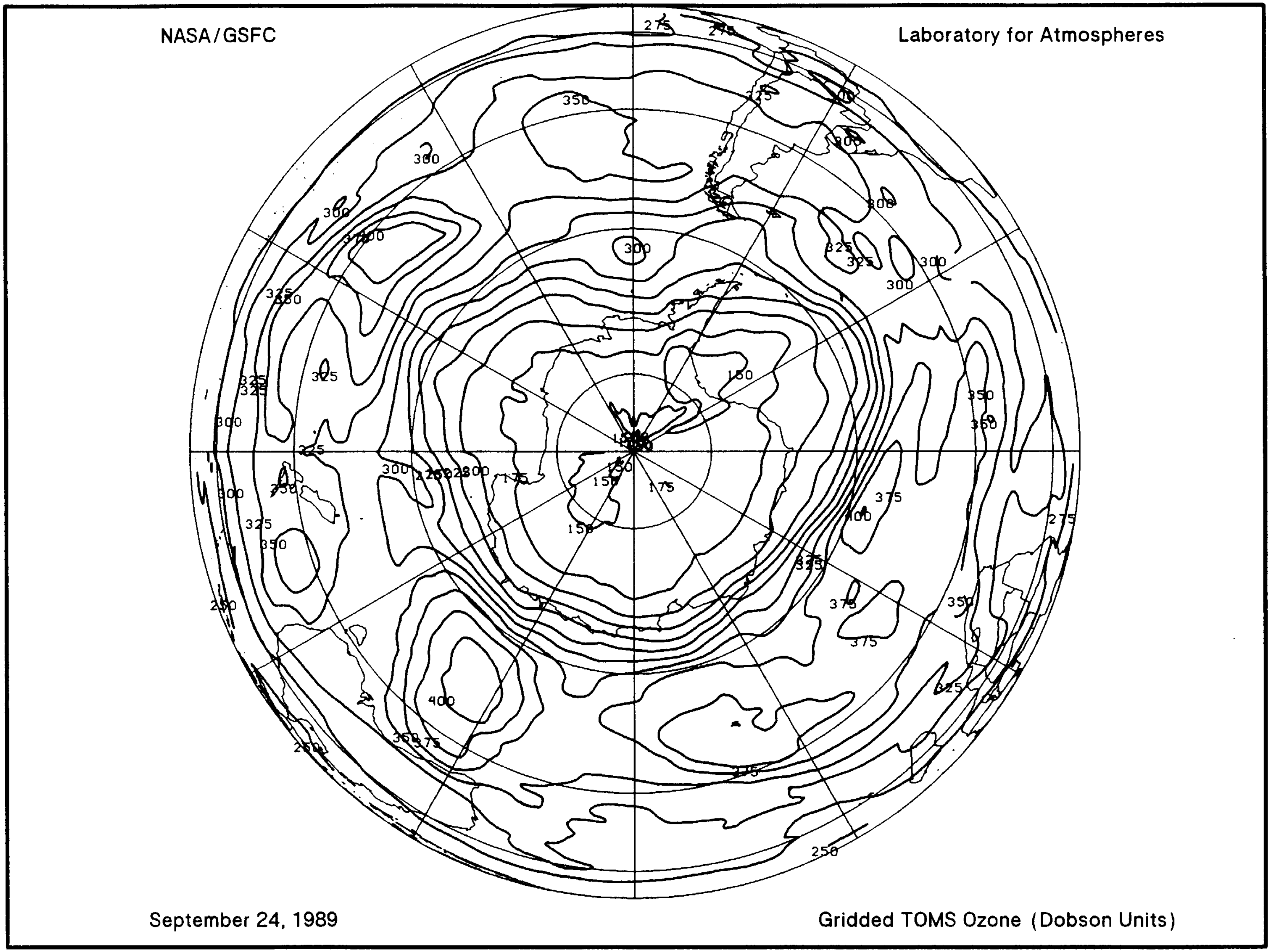
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
September 23, 1989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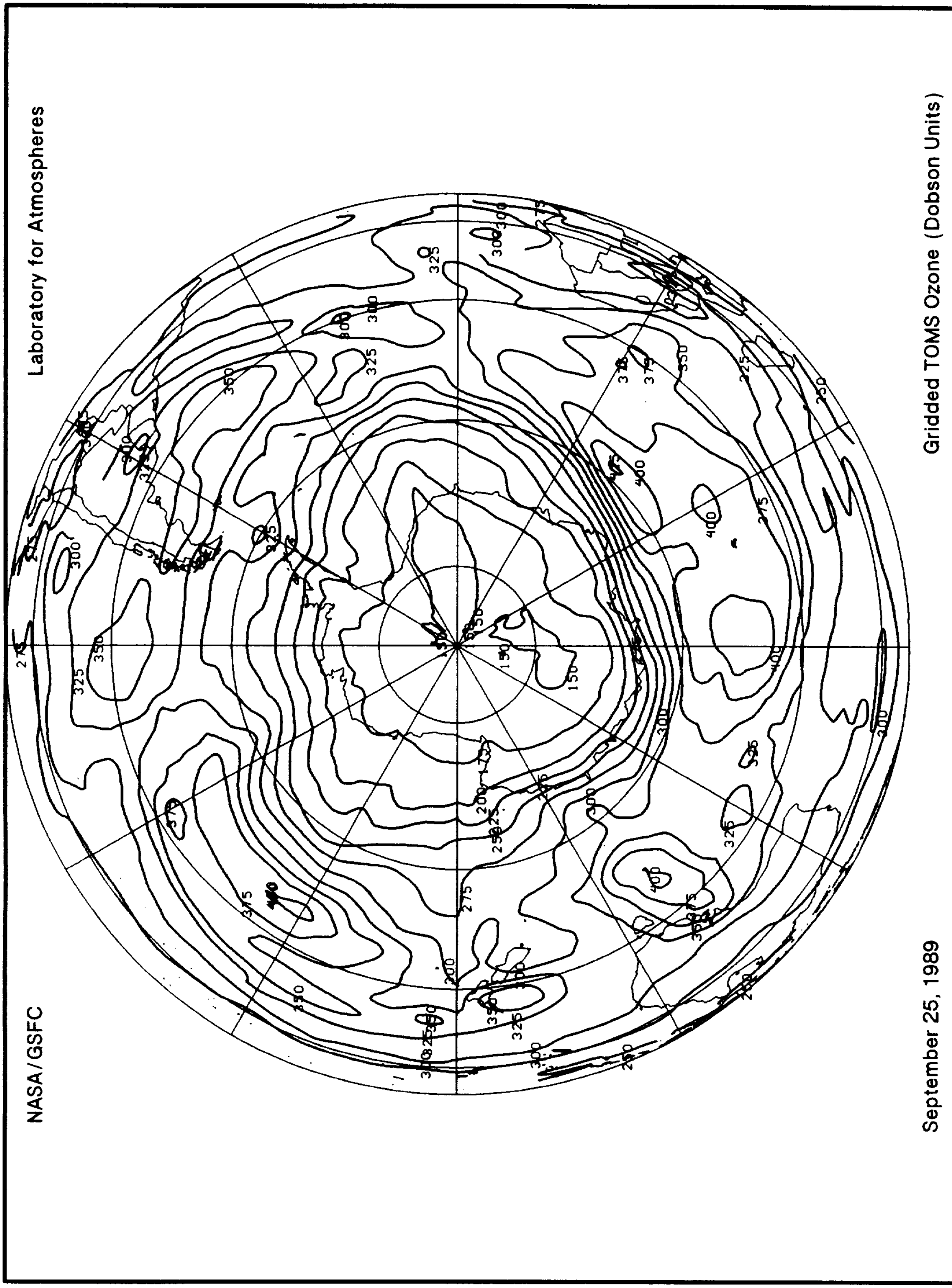
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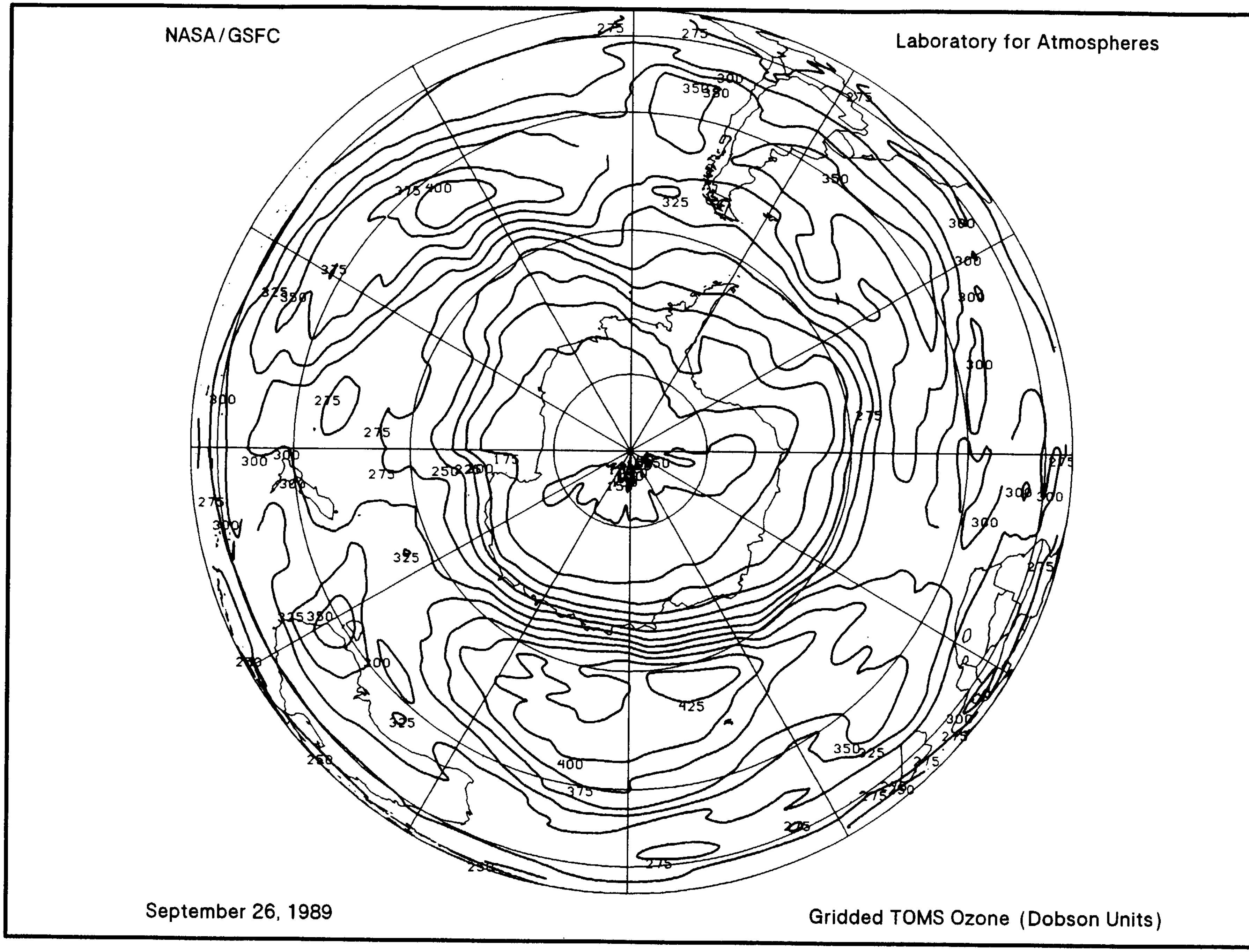
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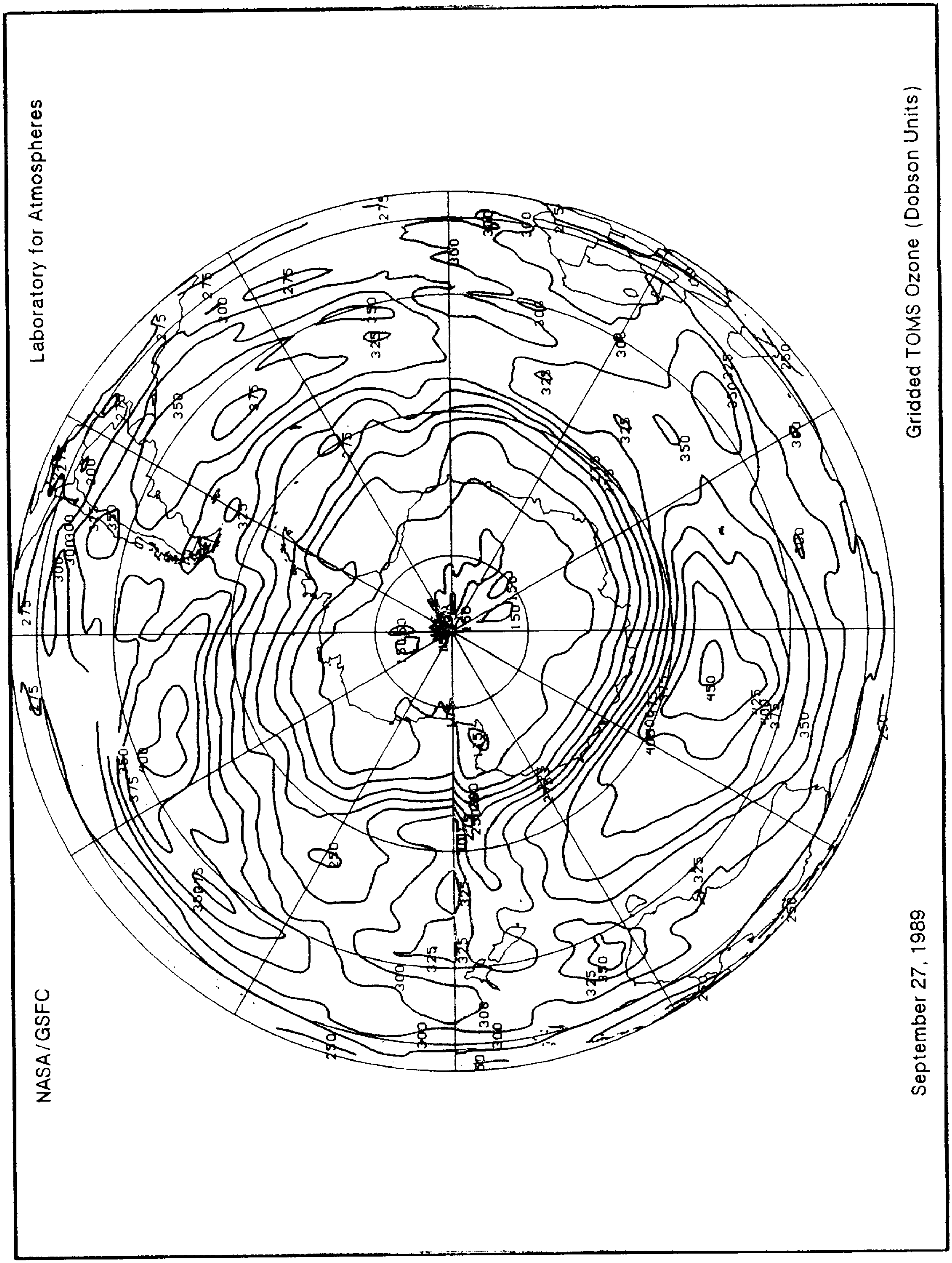
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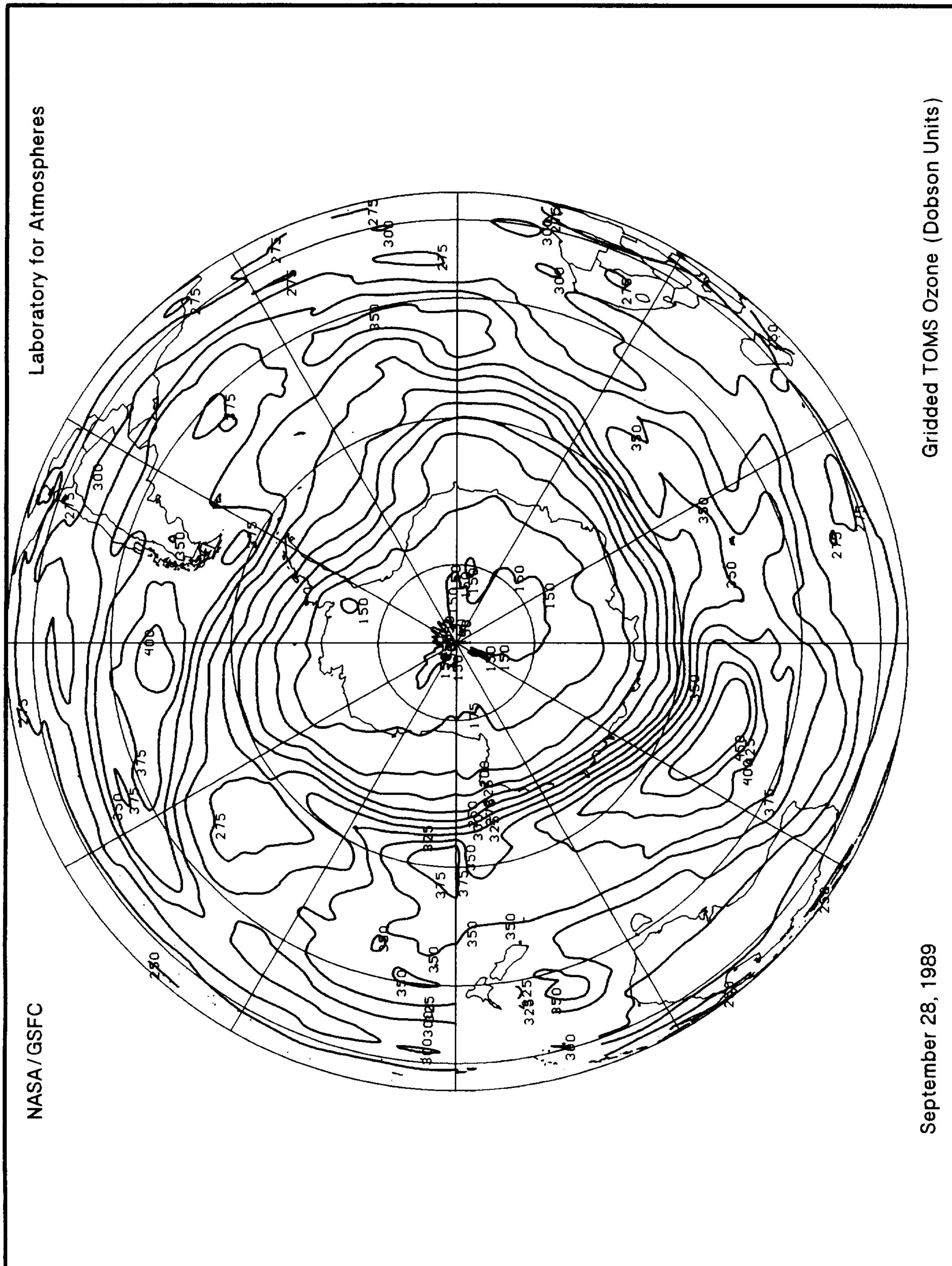
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Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
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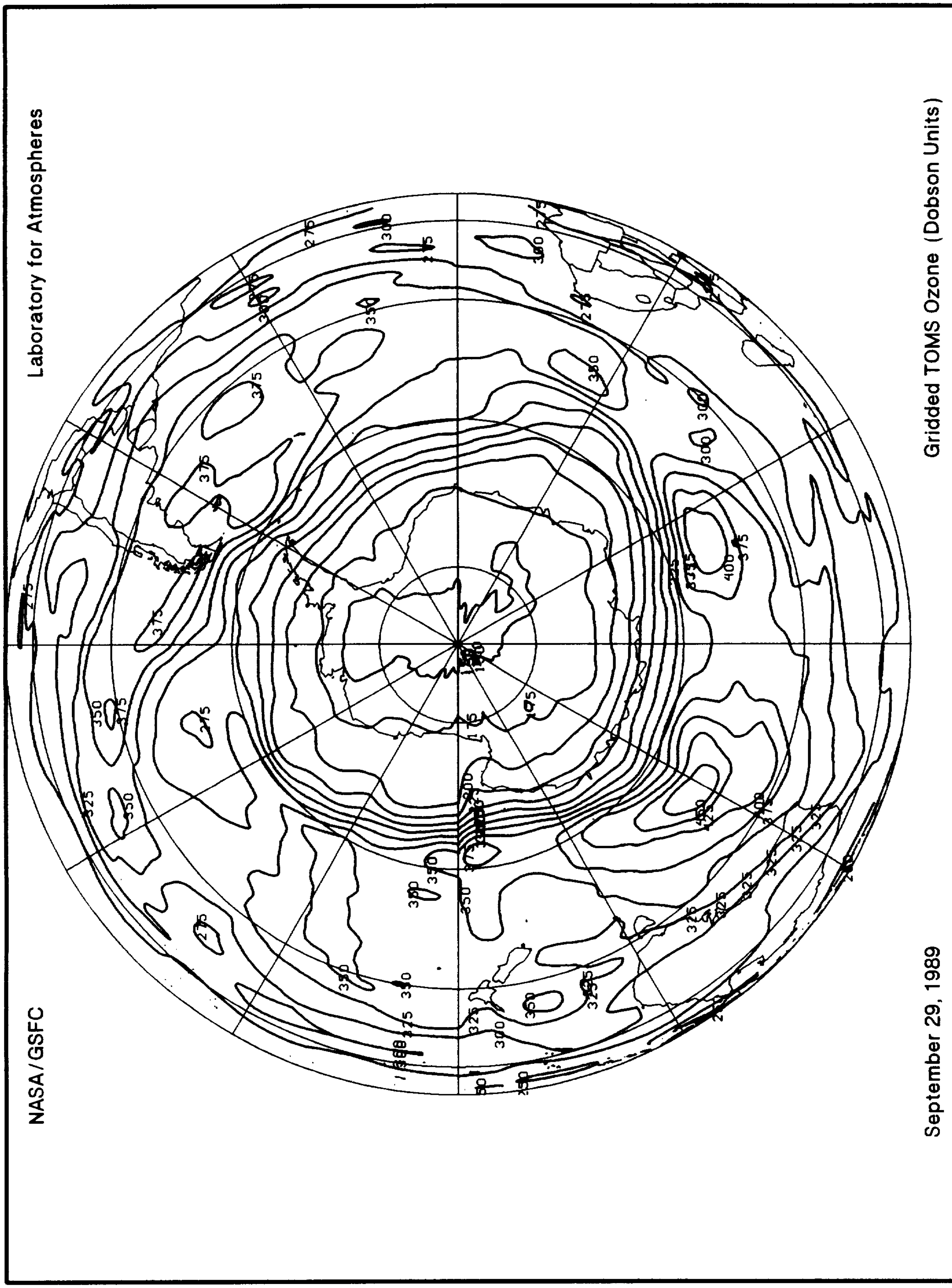
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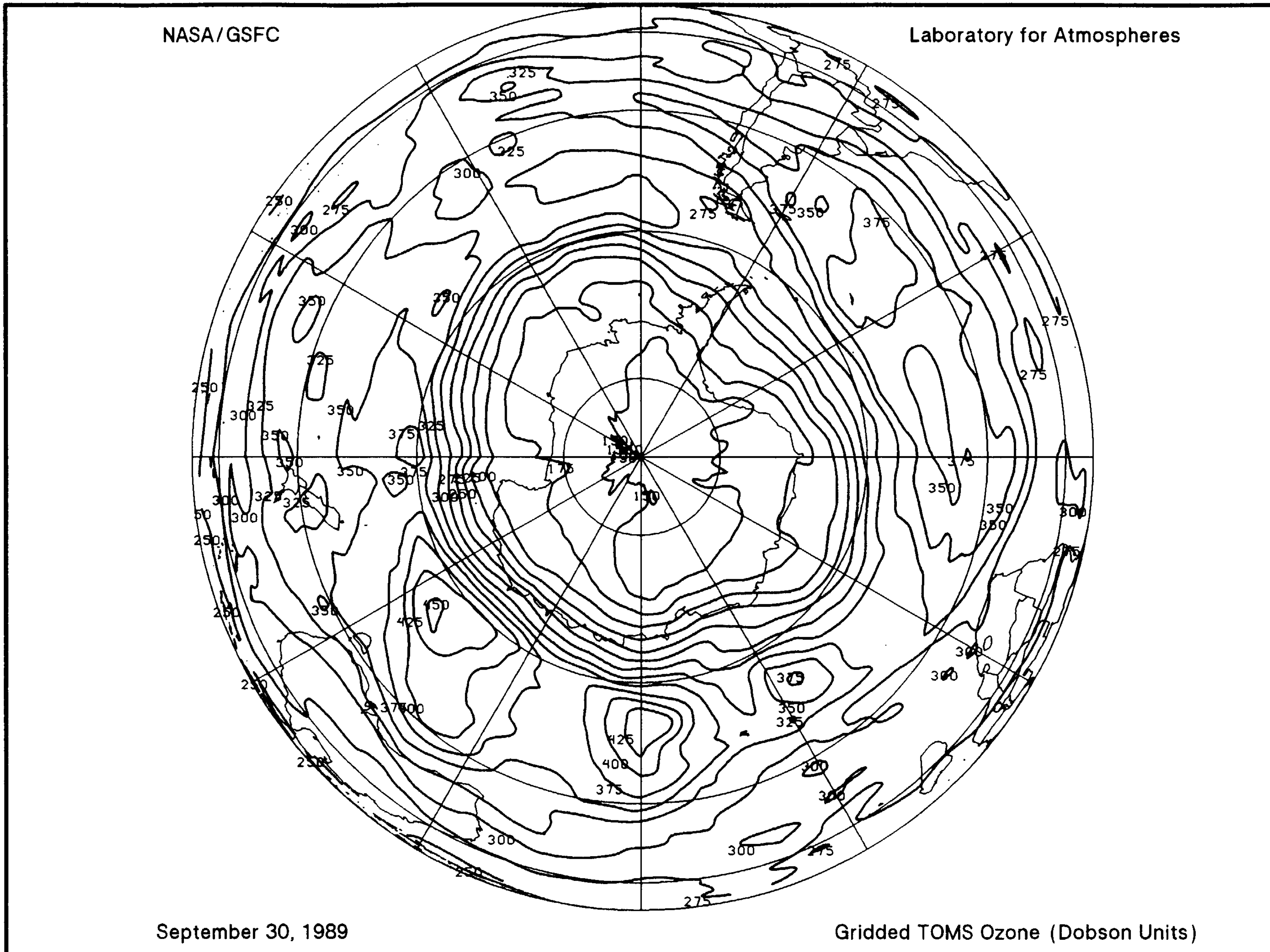
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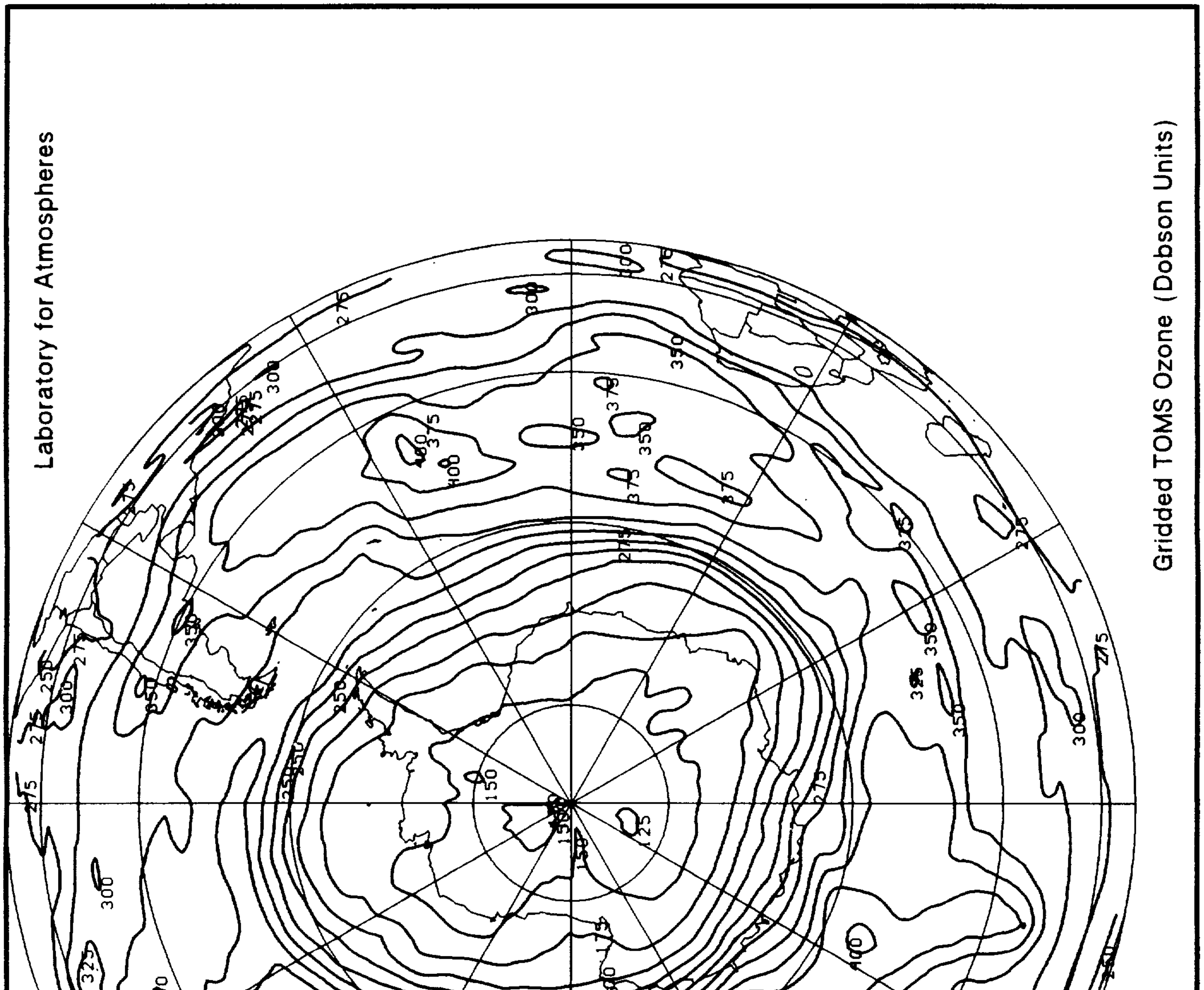
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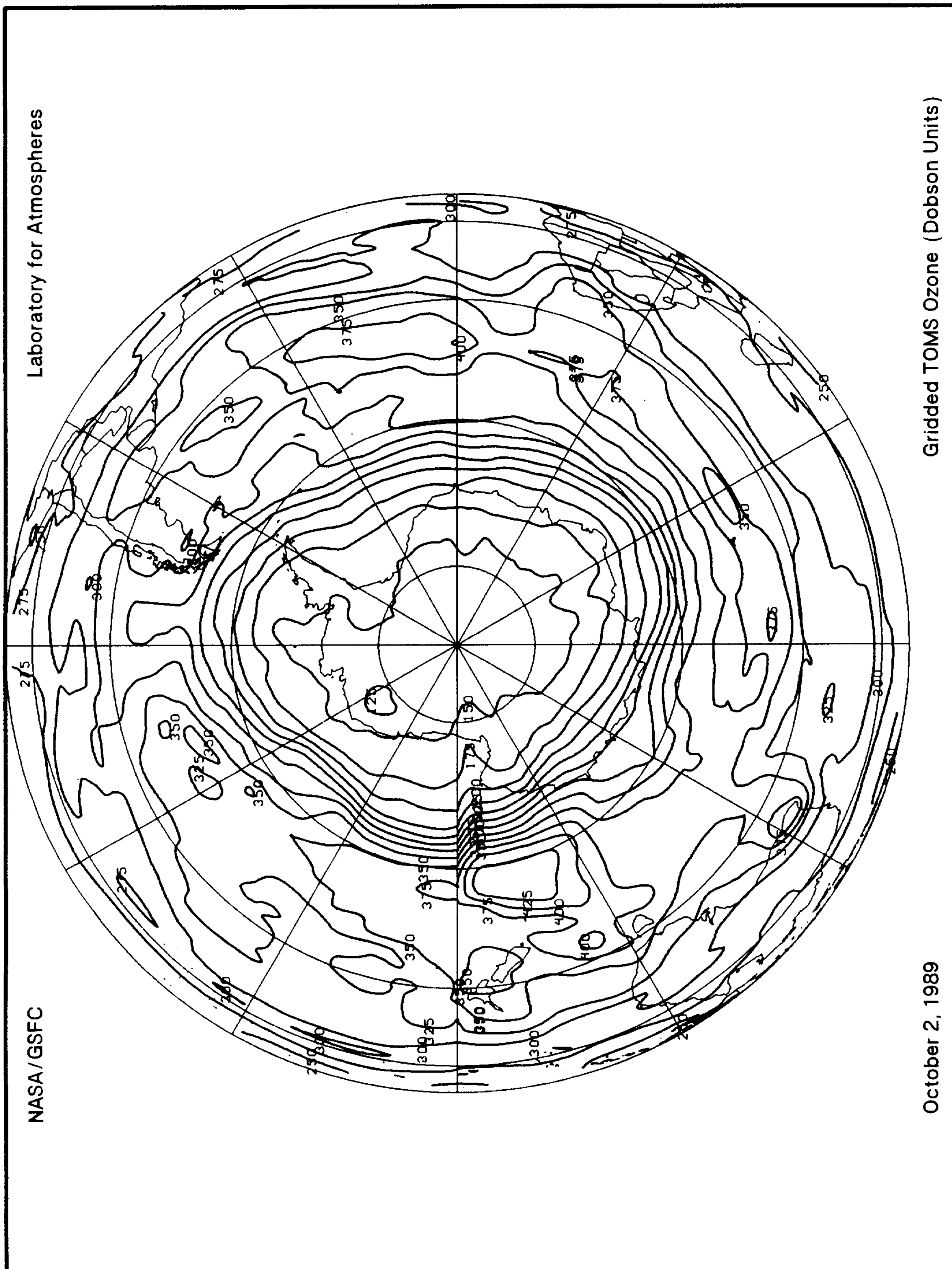
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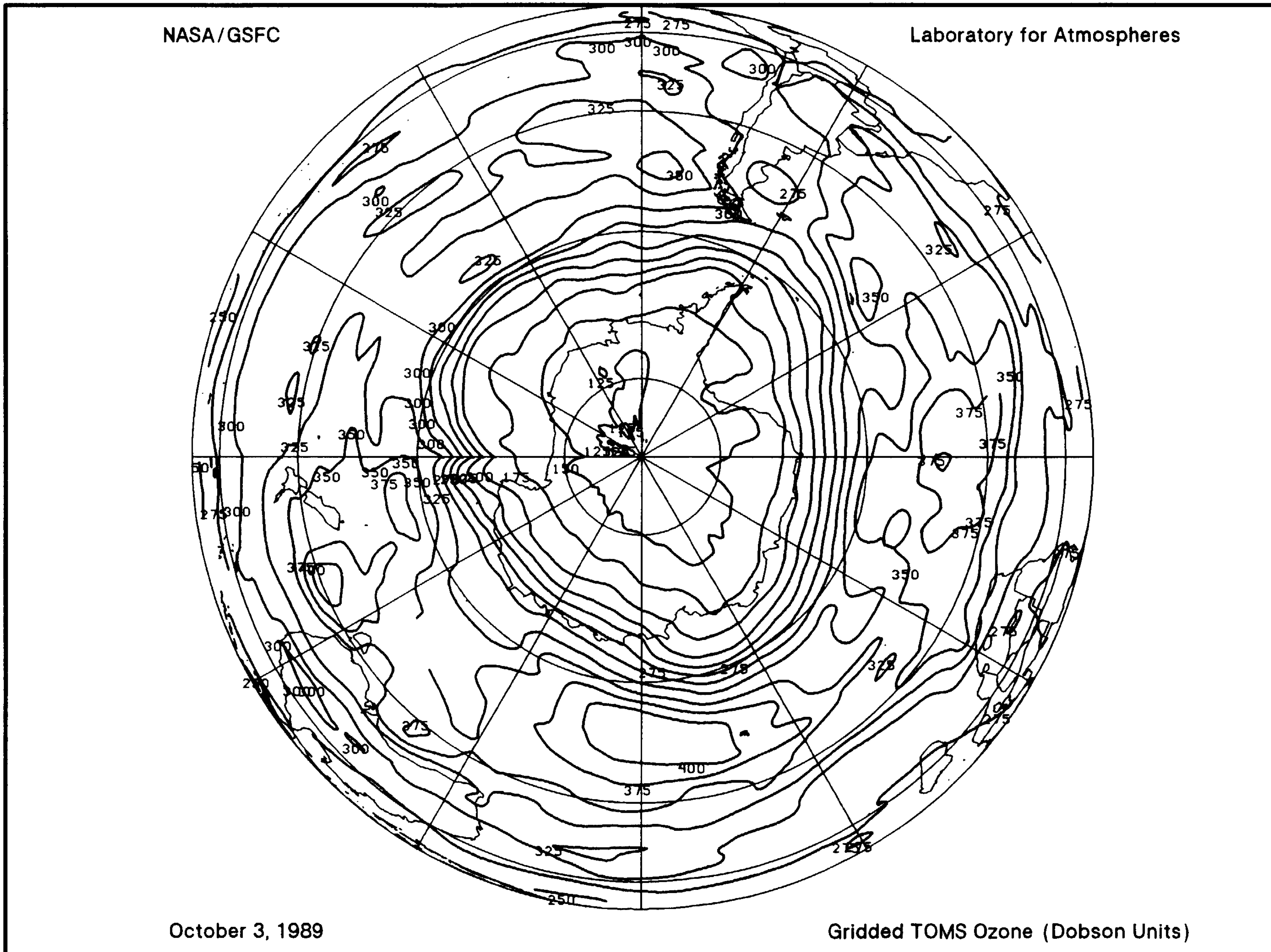
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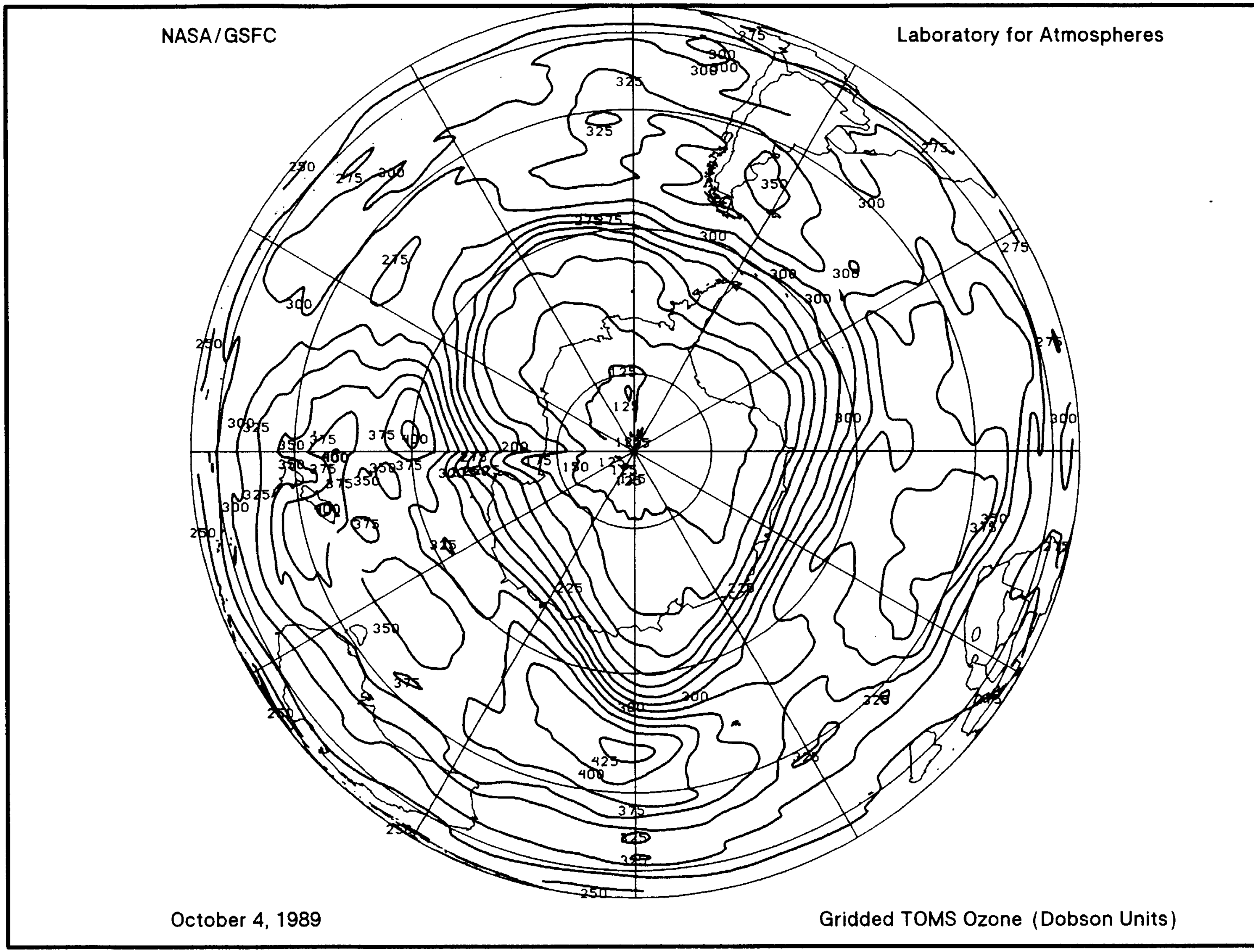
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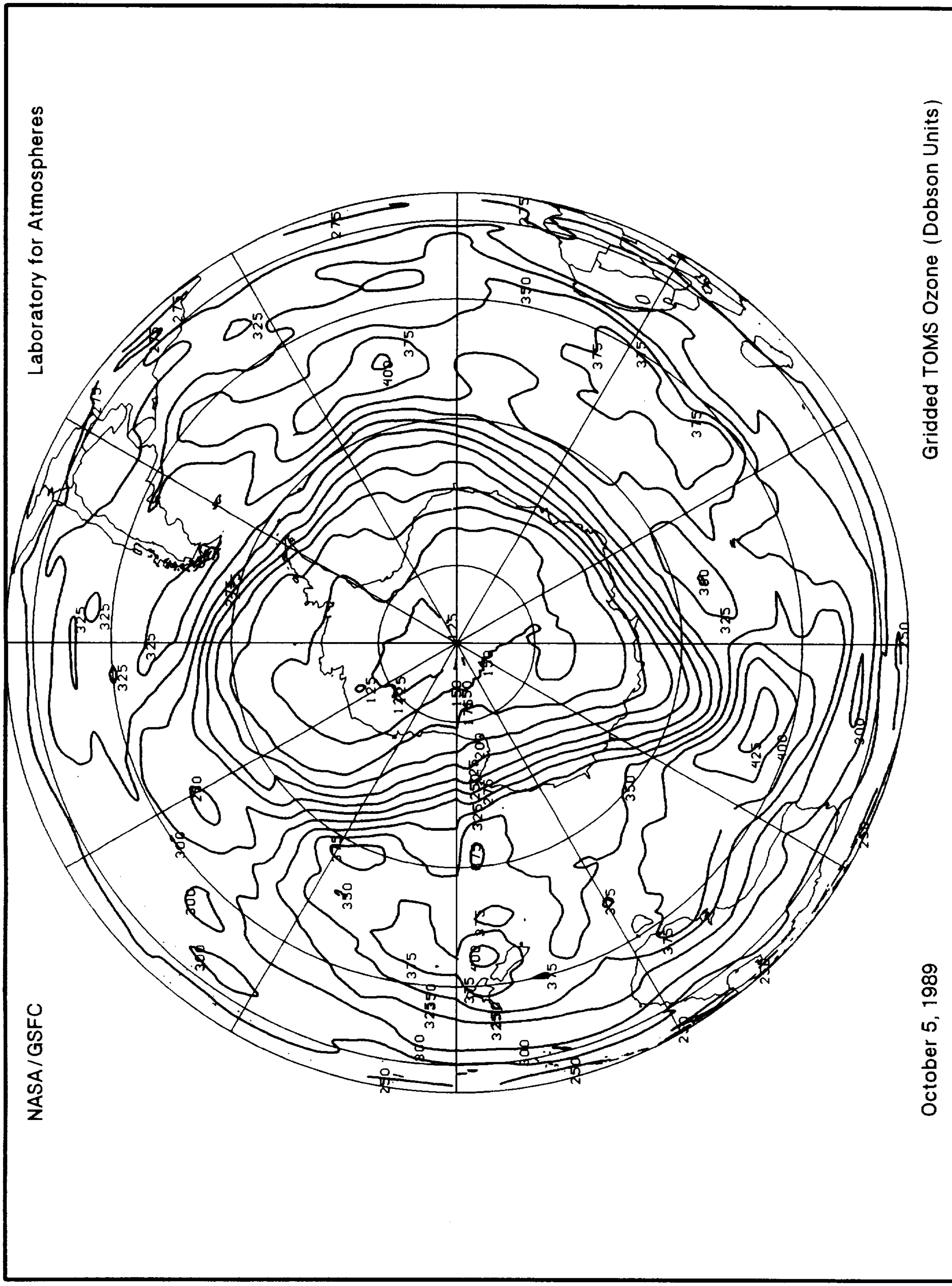

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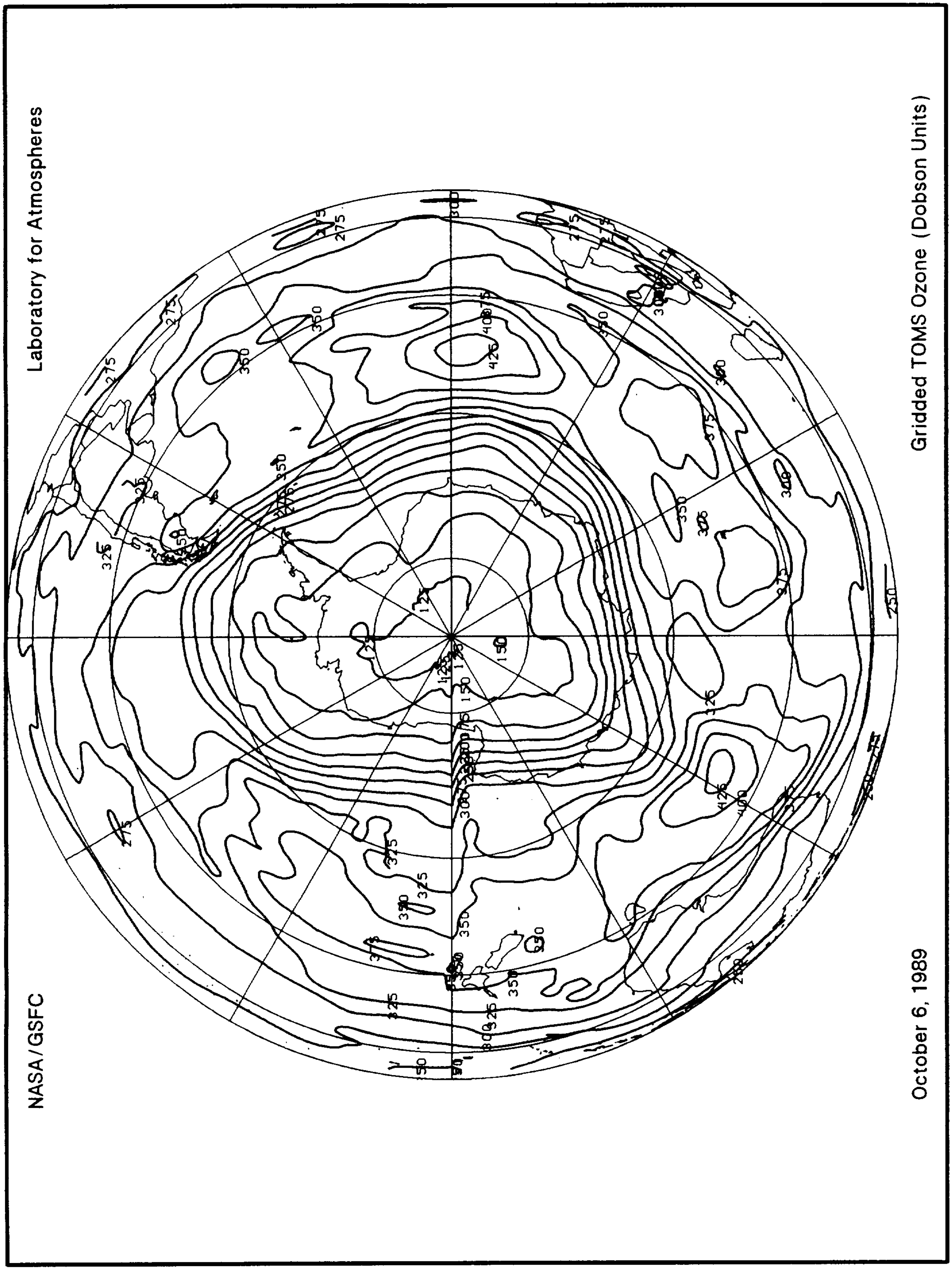
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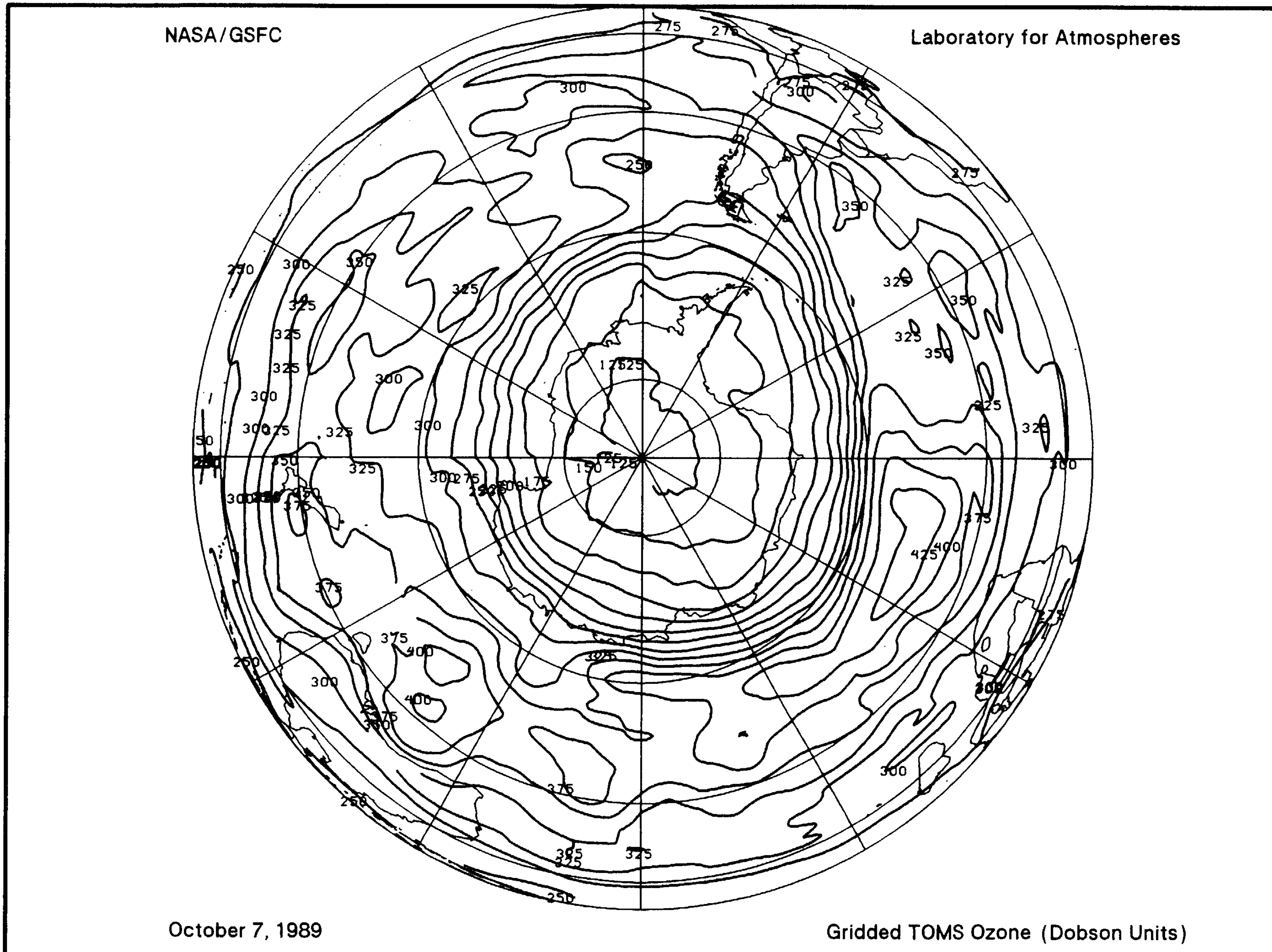
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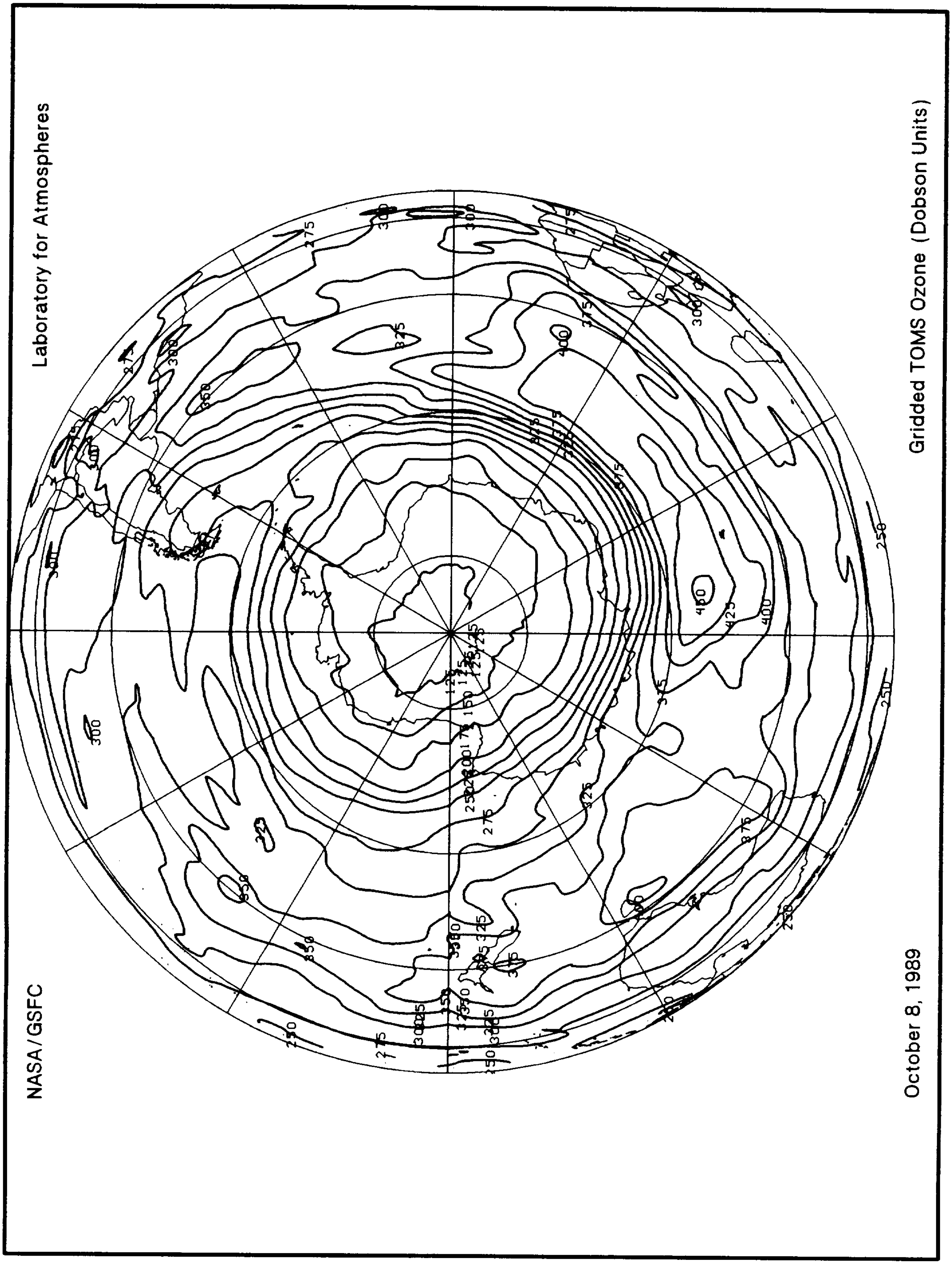

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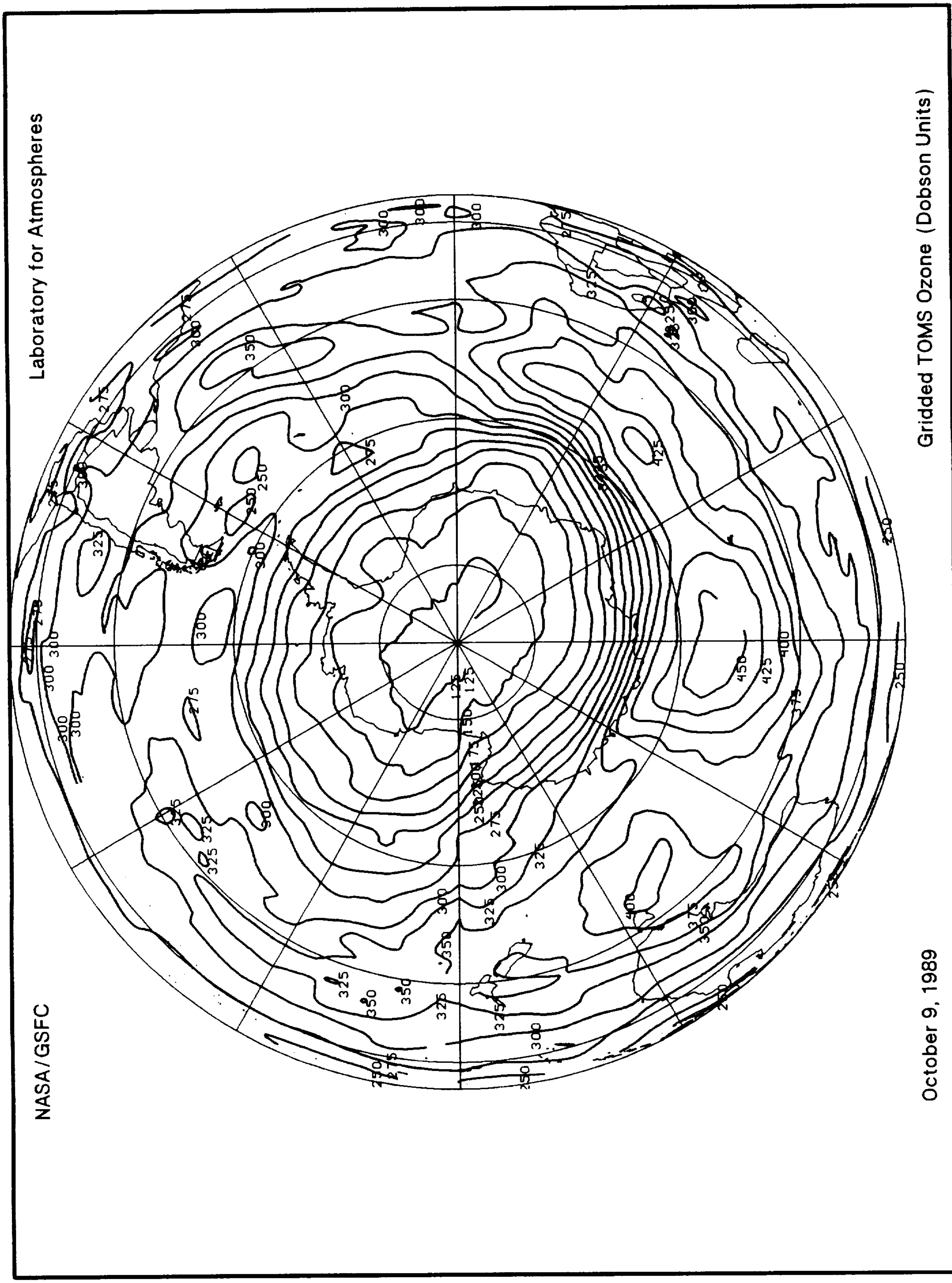
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October 9, 1989
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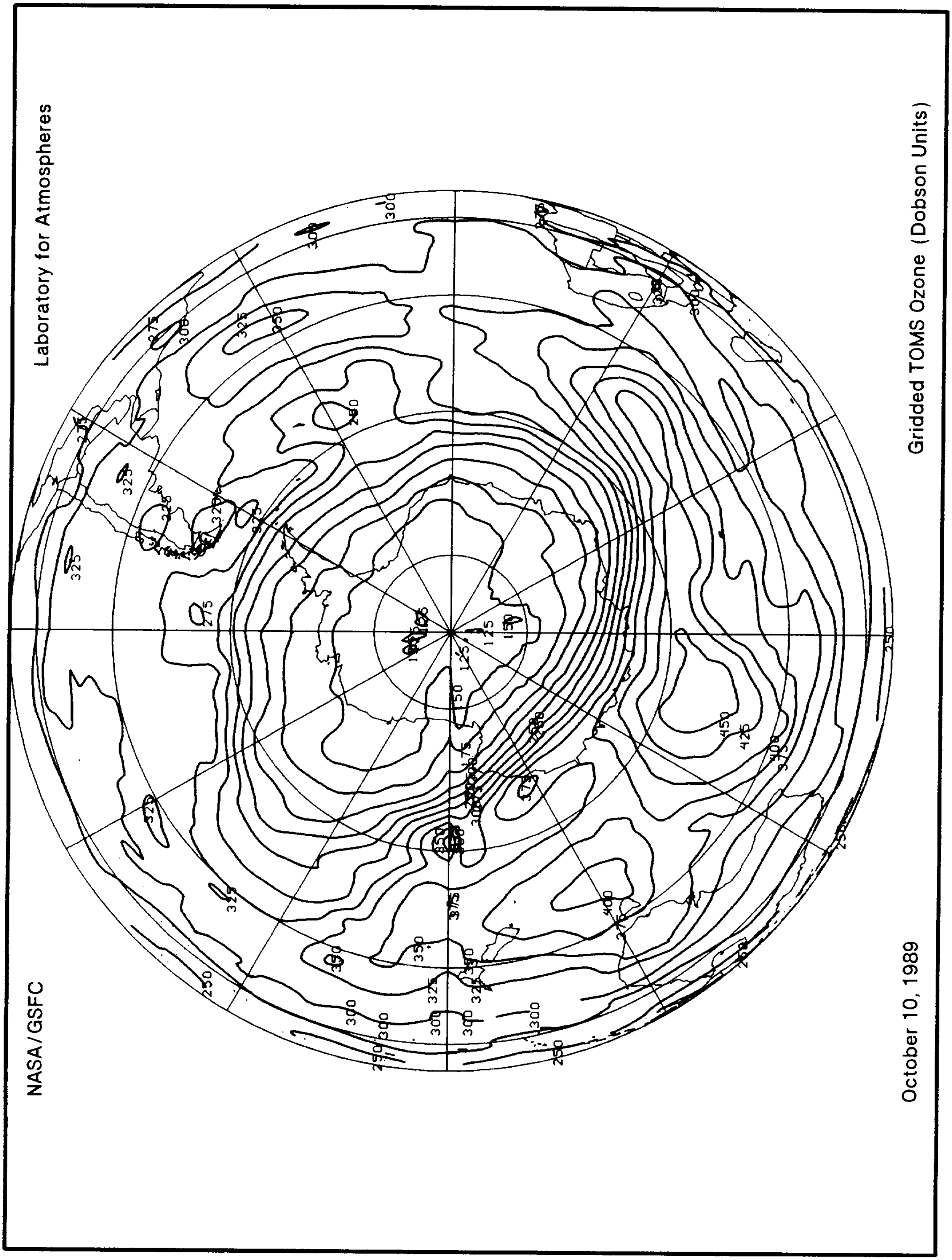
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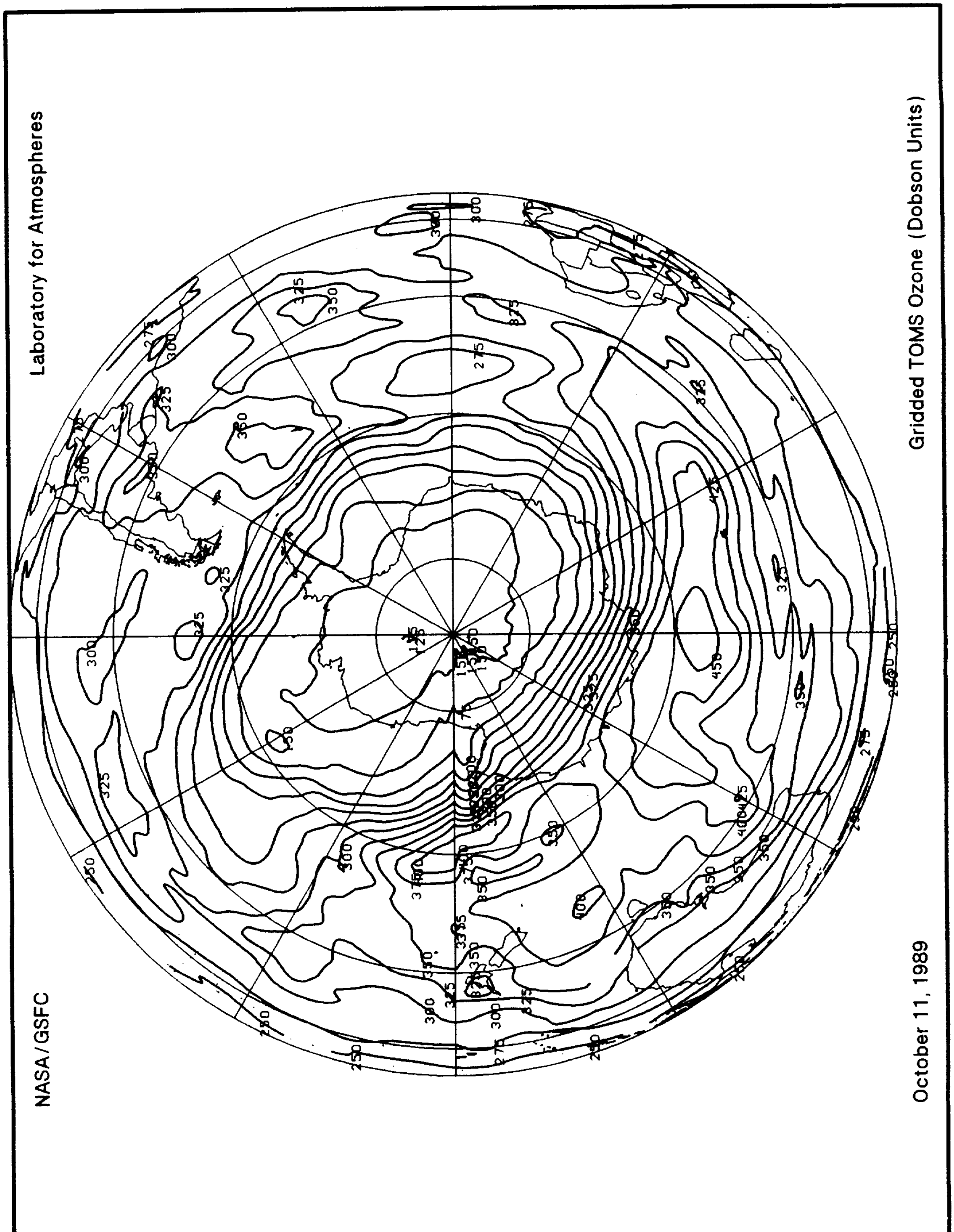
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
October 10, 1989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October 11, 1989
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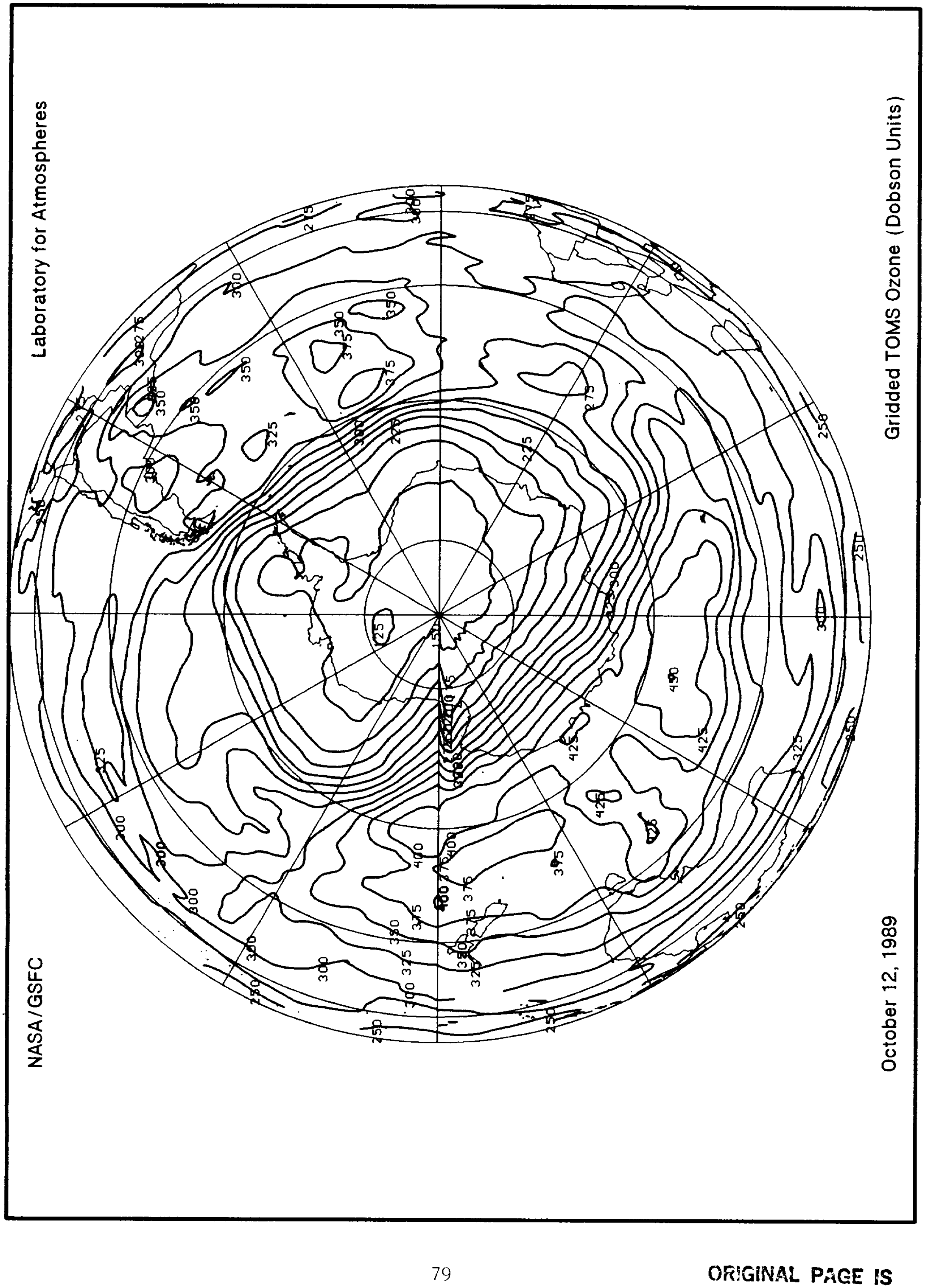
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October 12, 1989
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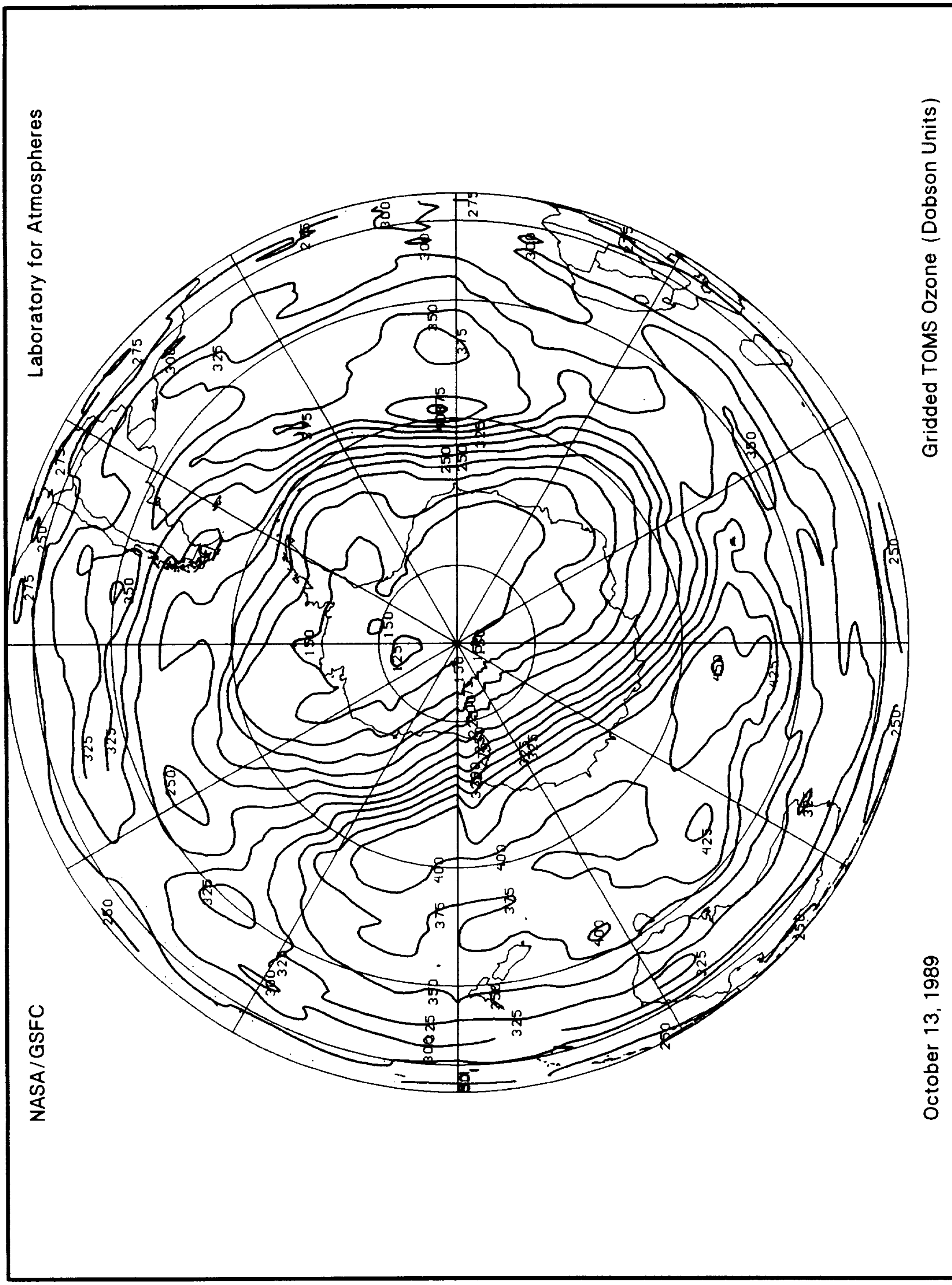
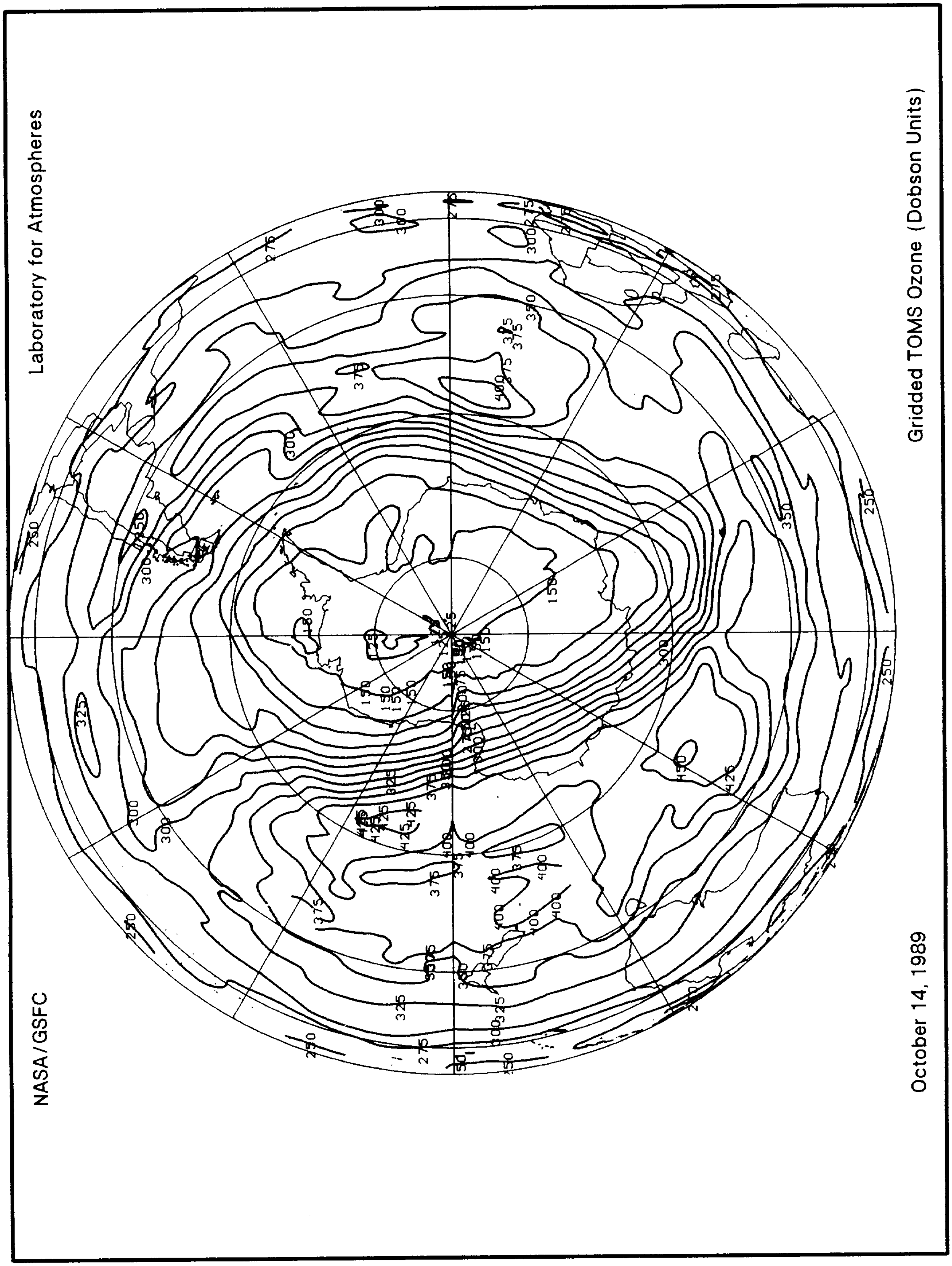


Laboratory for Atmospheres
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
October 13, 1989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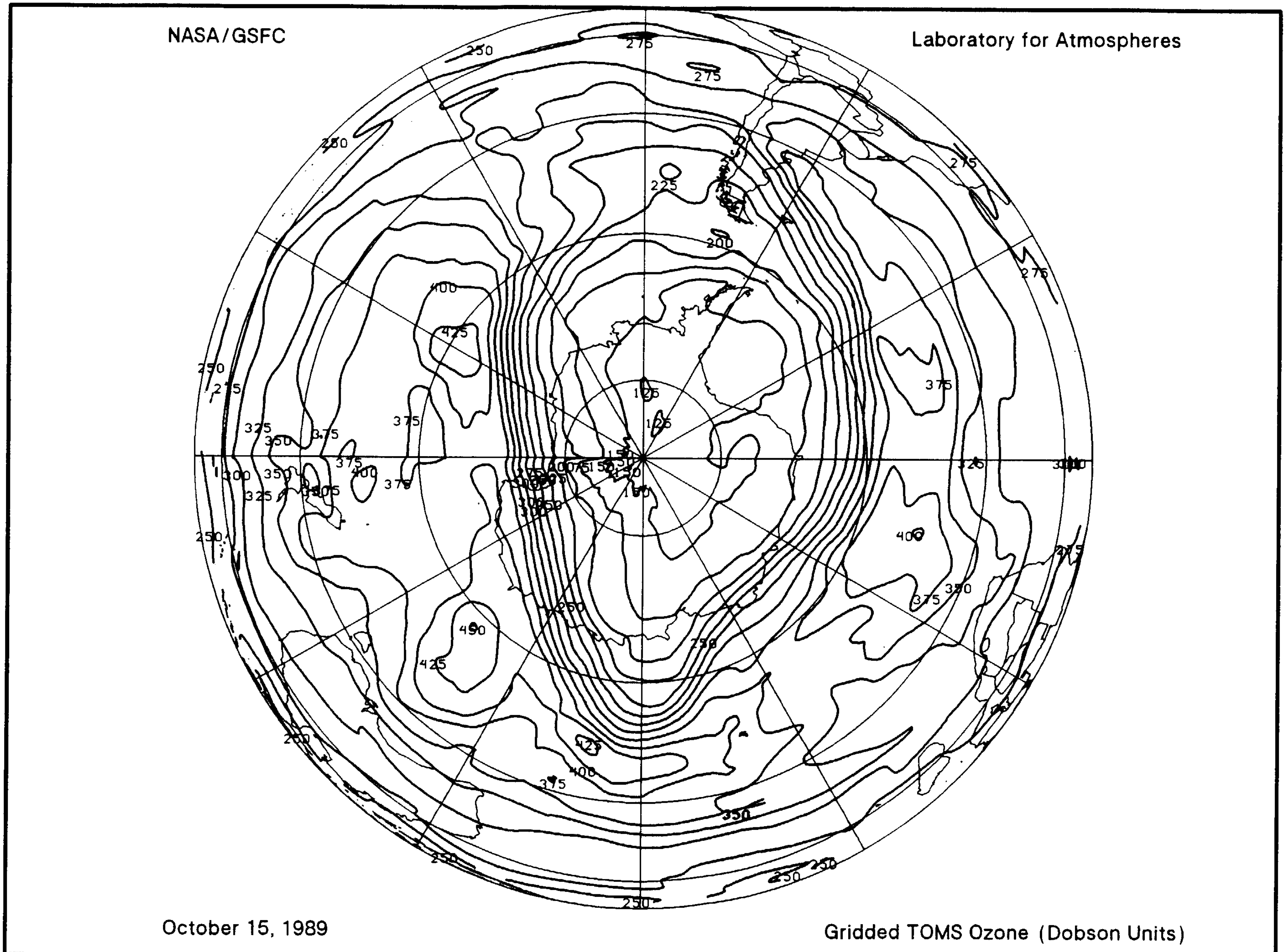

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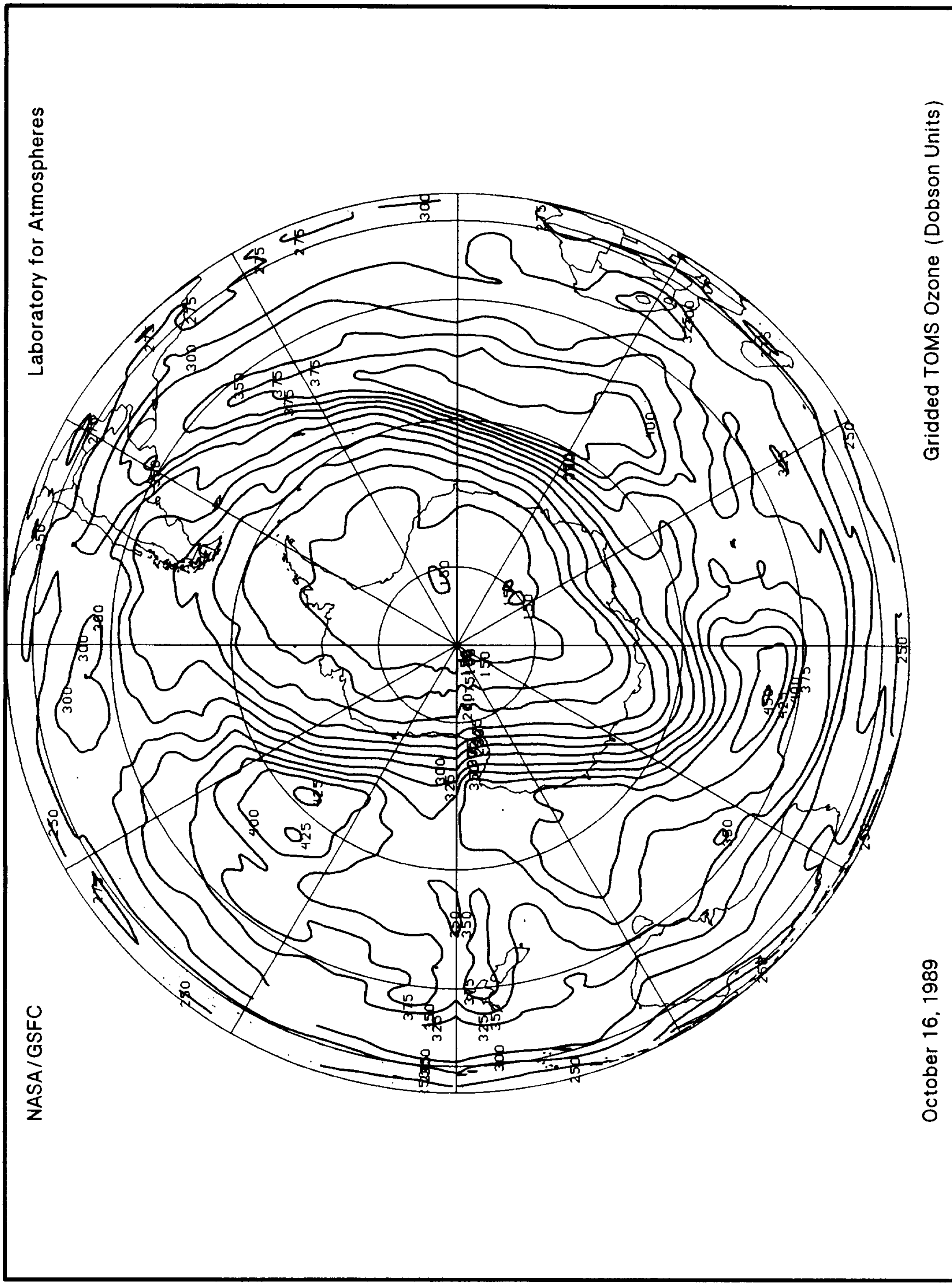

Laboratory for Atmospheres
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
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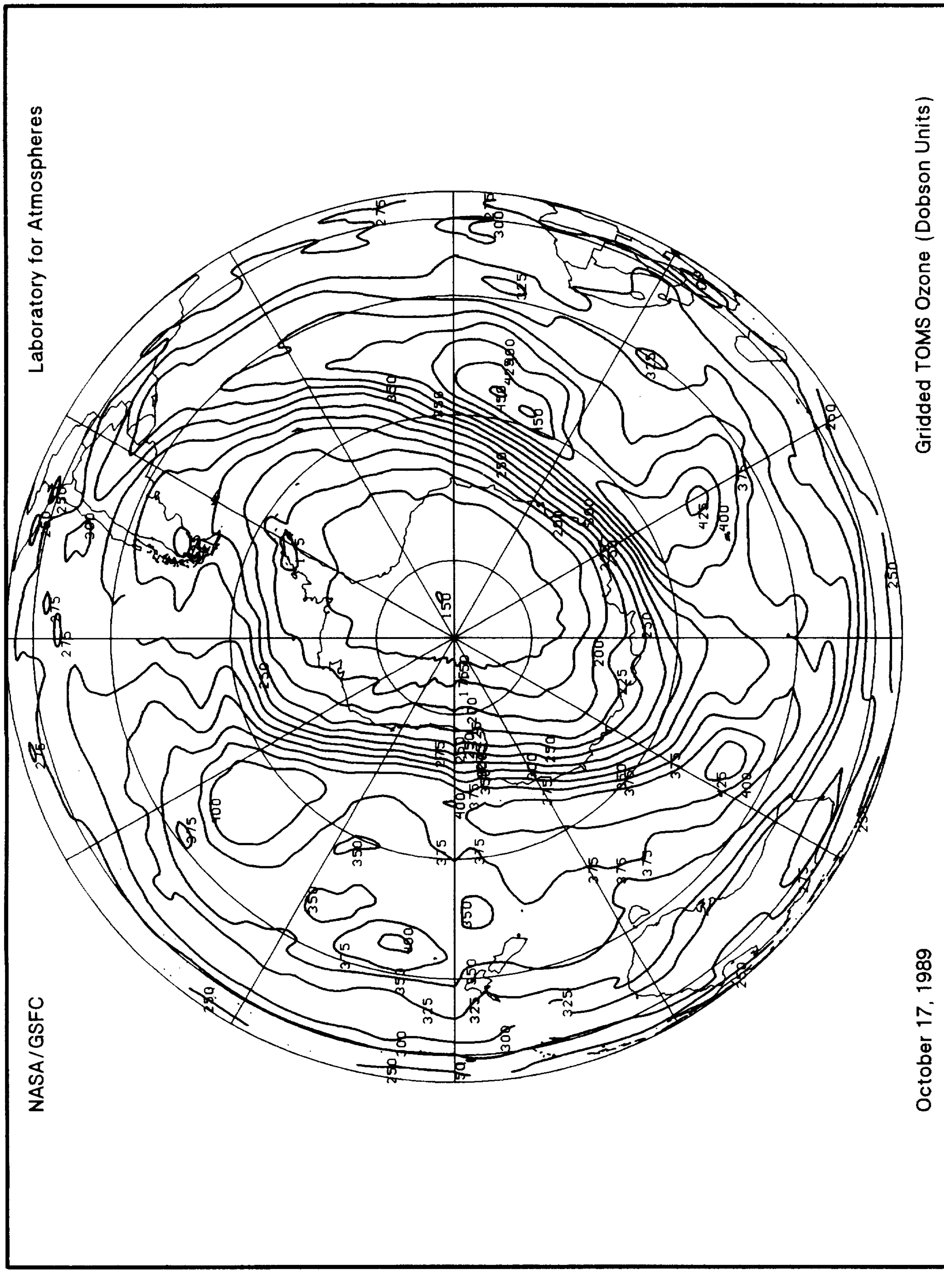
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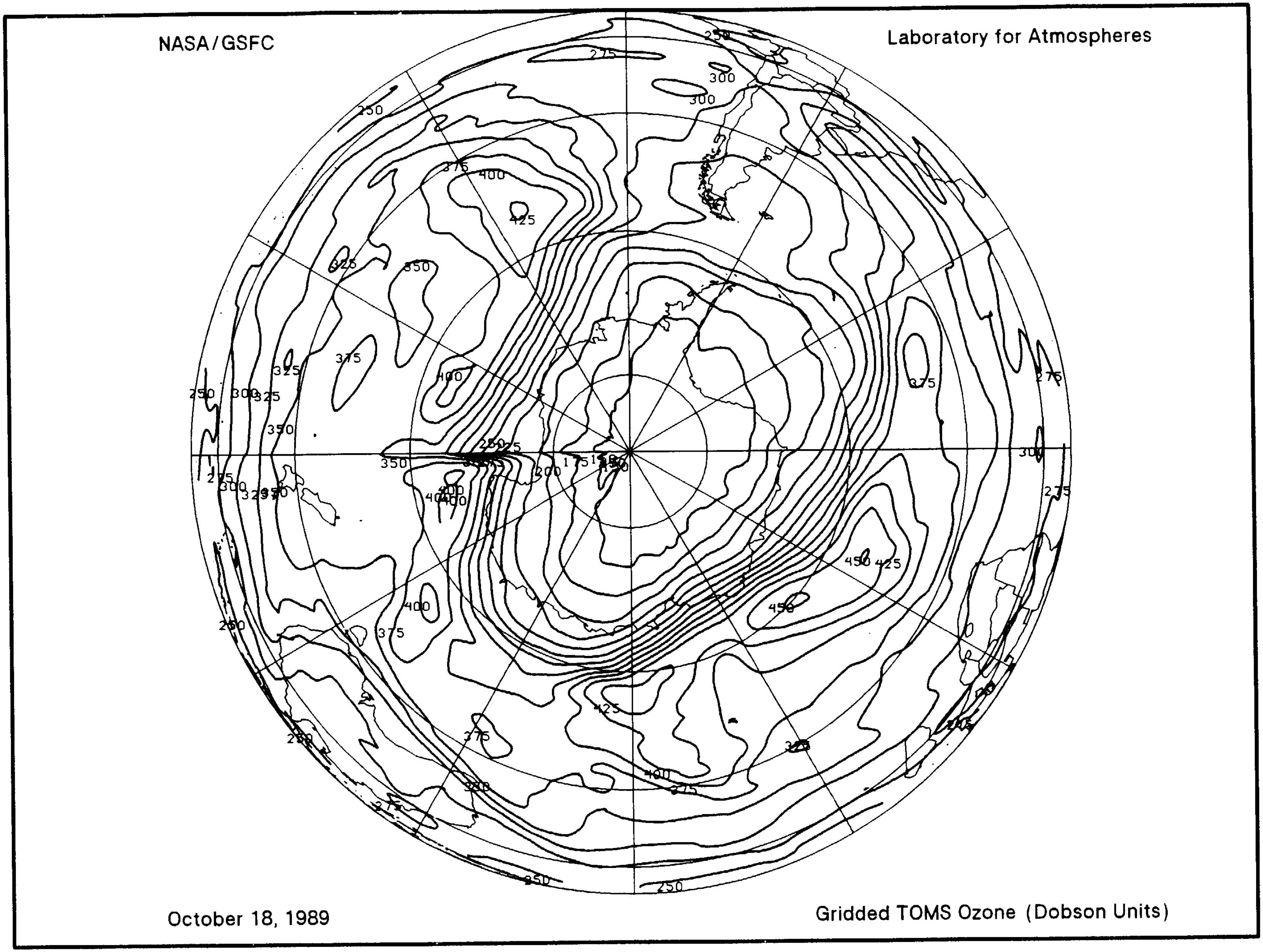
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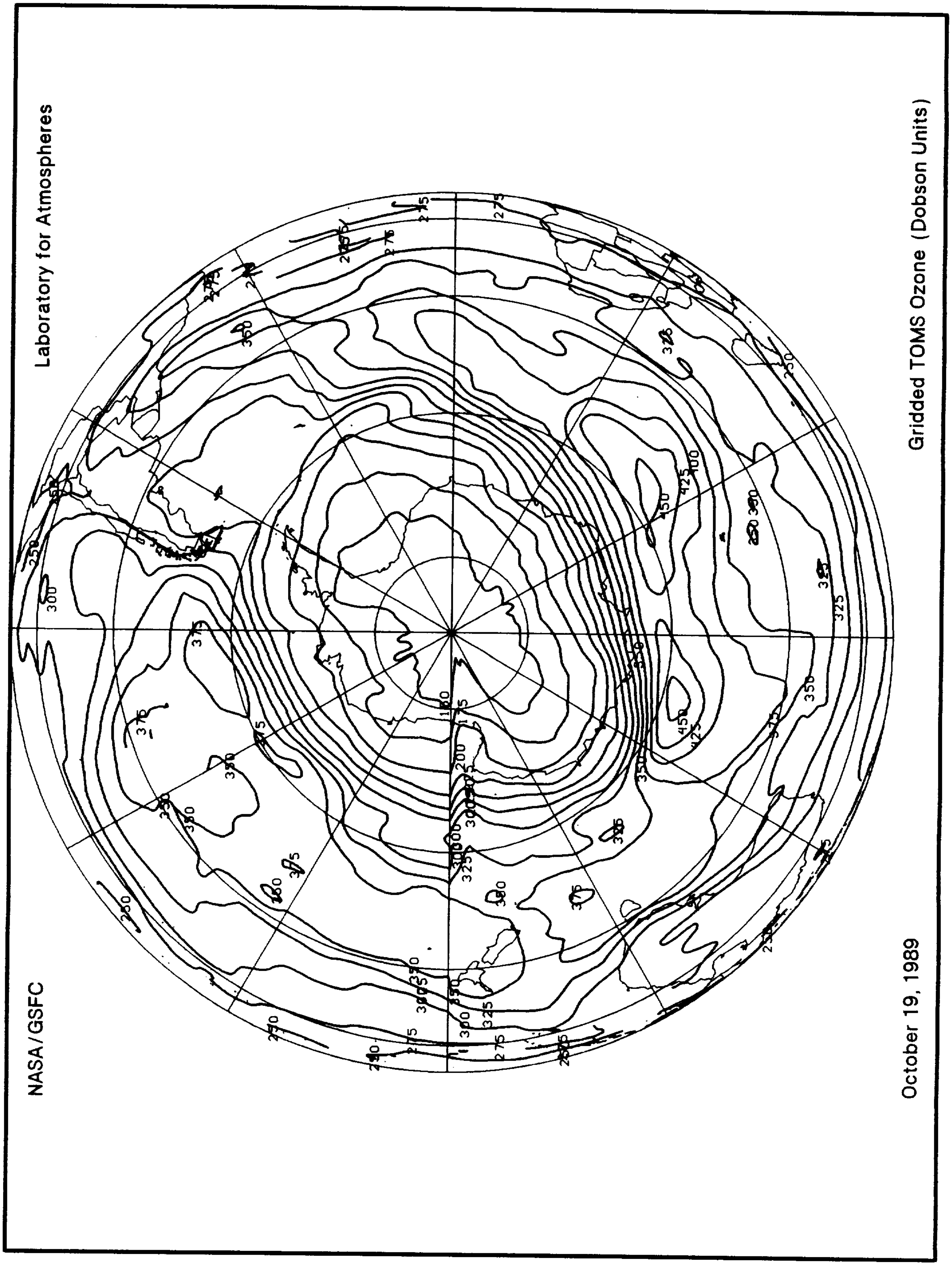
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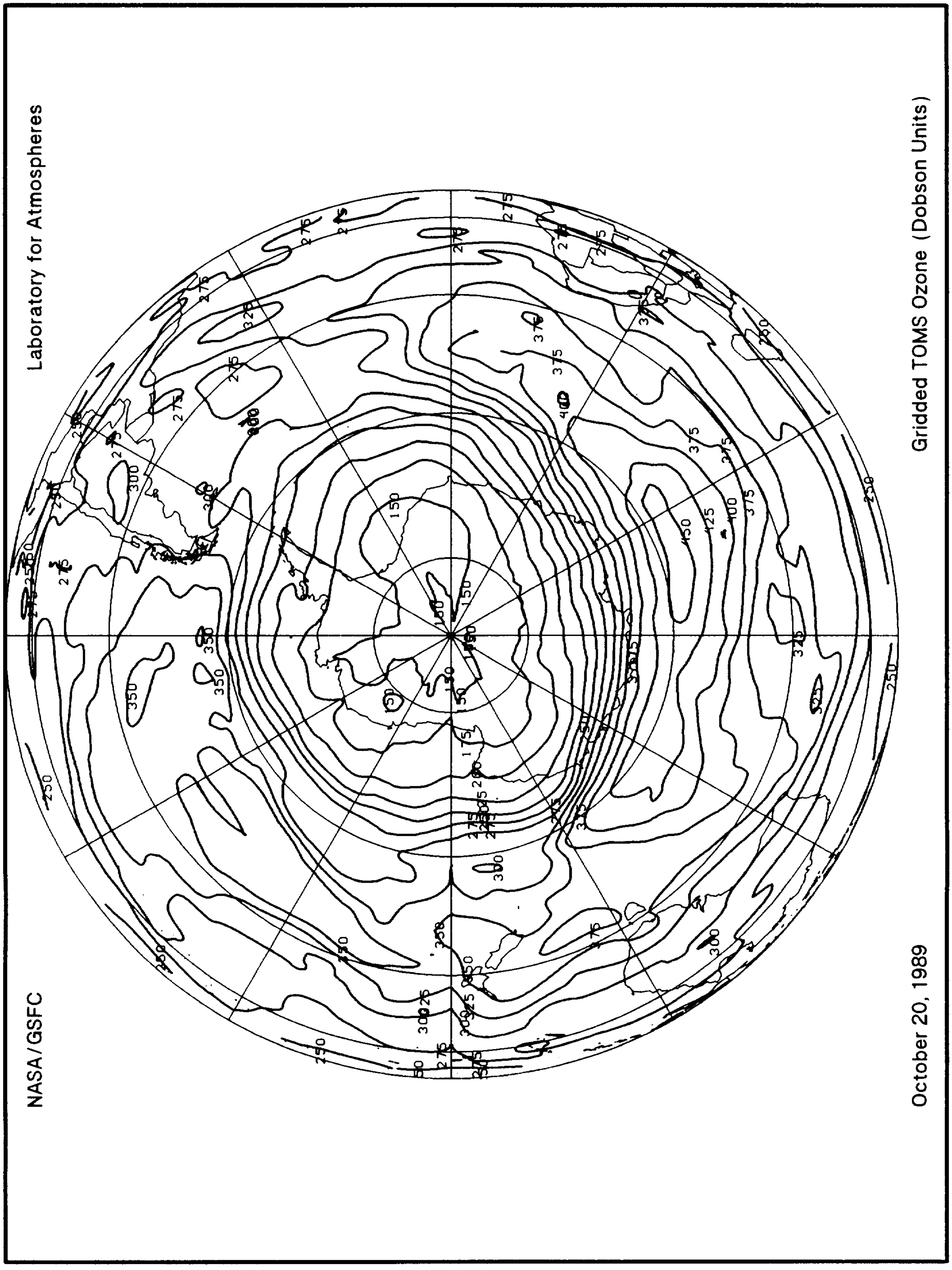
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Gridded TOMS Ozone (Dobson Units)
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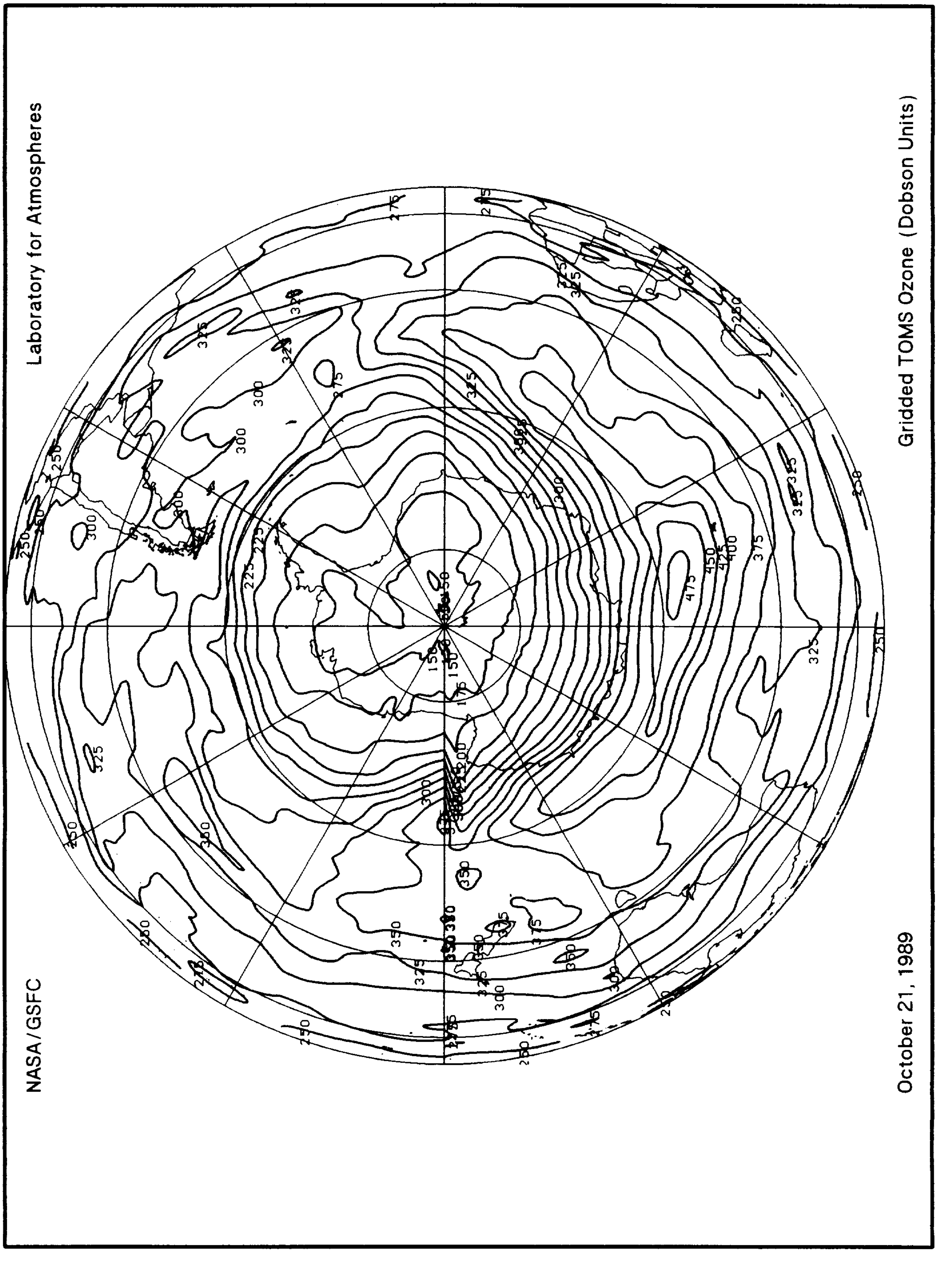

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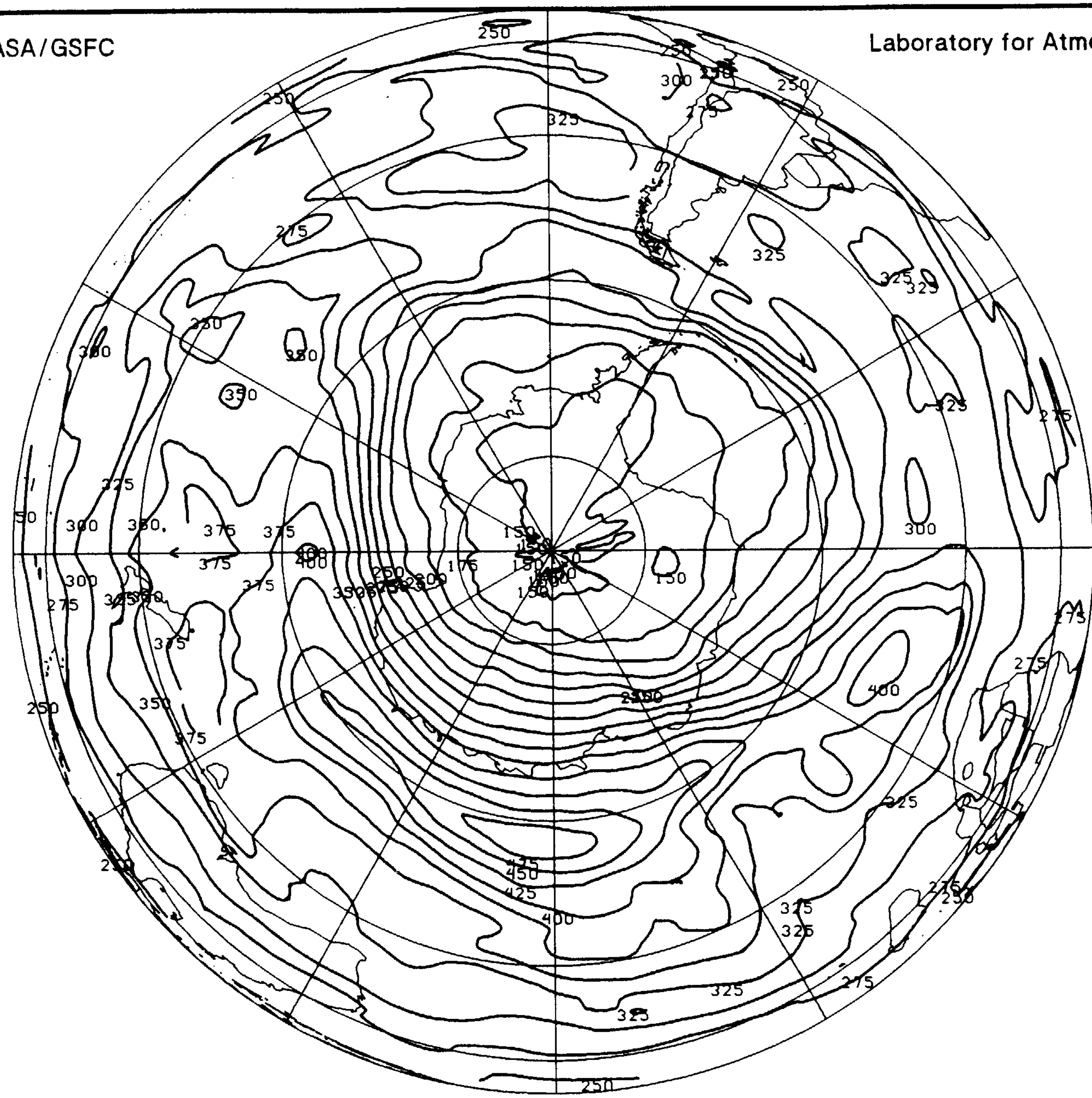
Laboratory for Atmospheres
October 21, 1989
Gridded TOMS Ozone (Dobson Units)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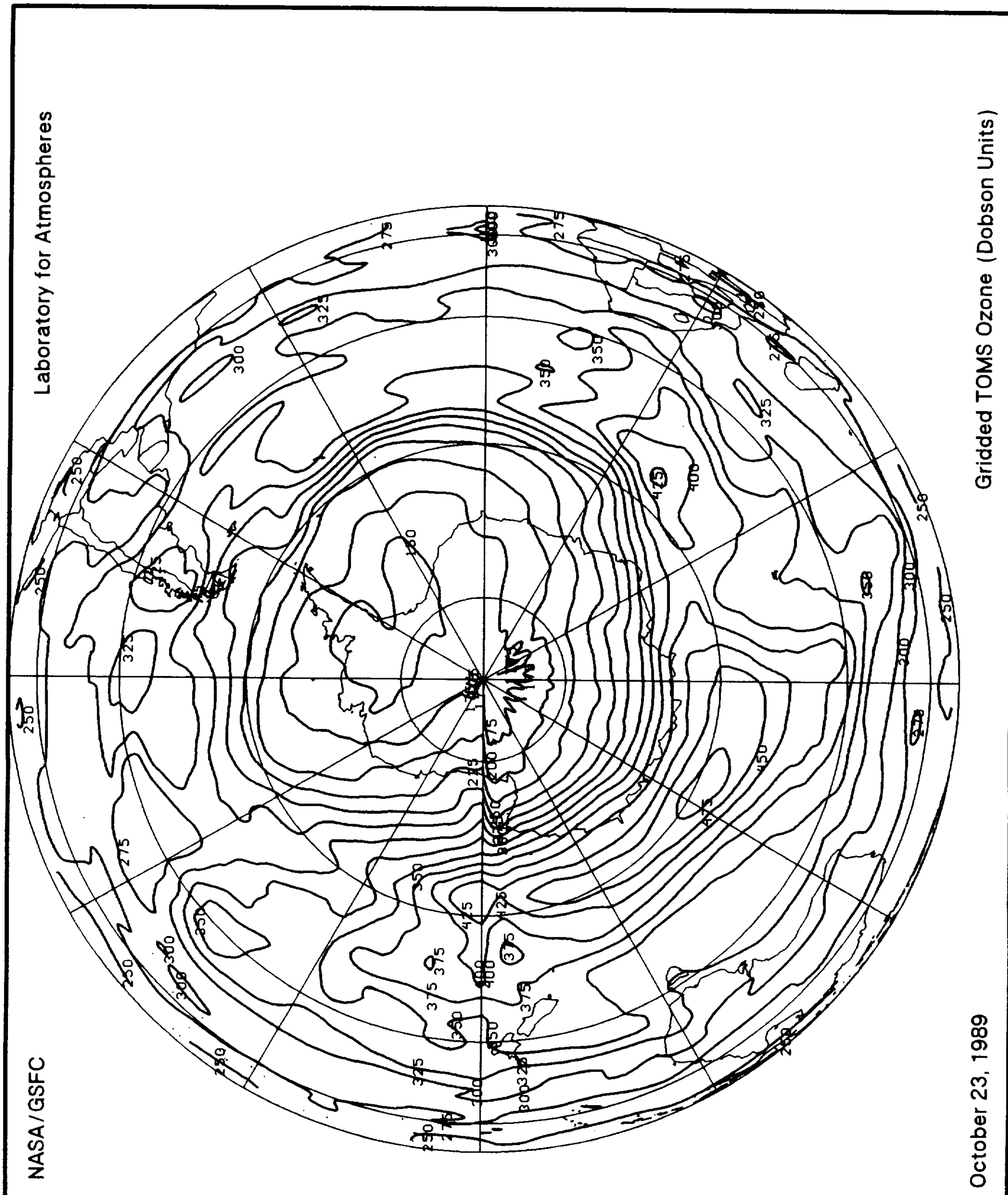
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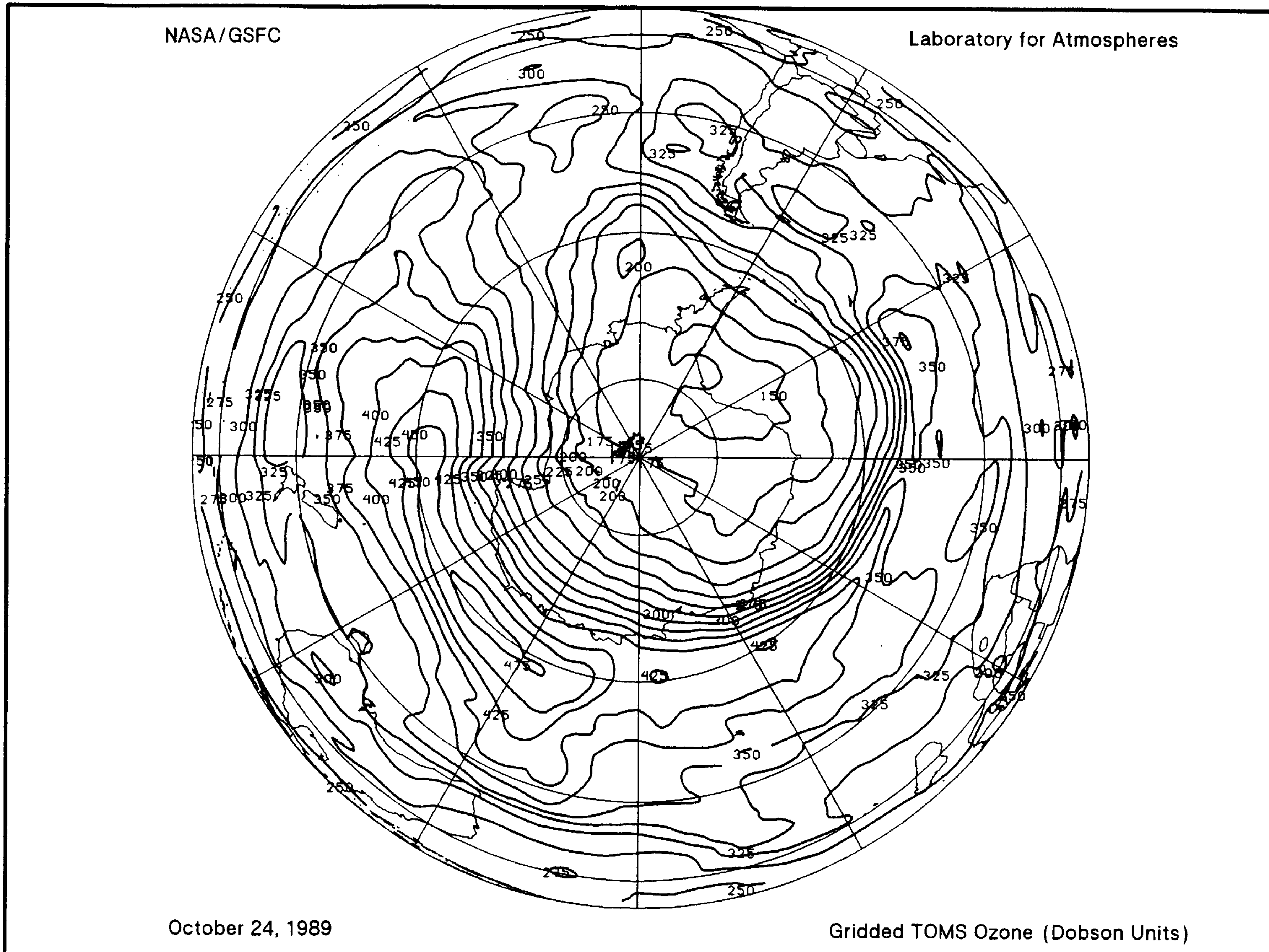
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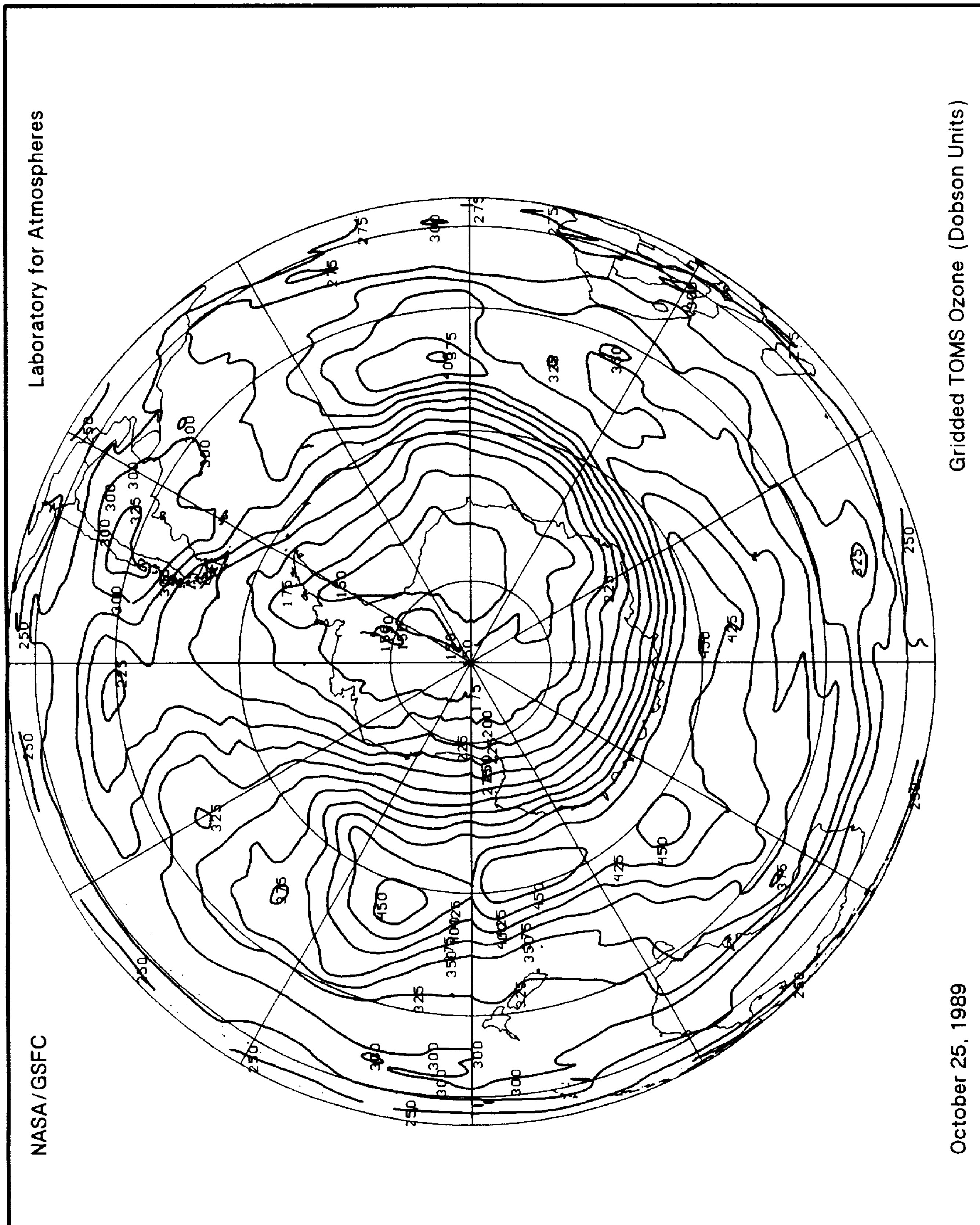
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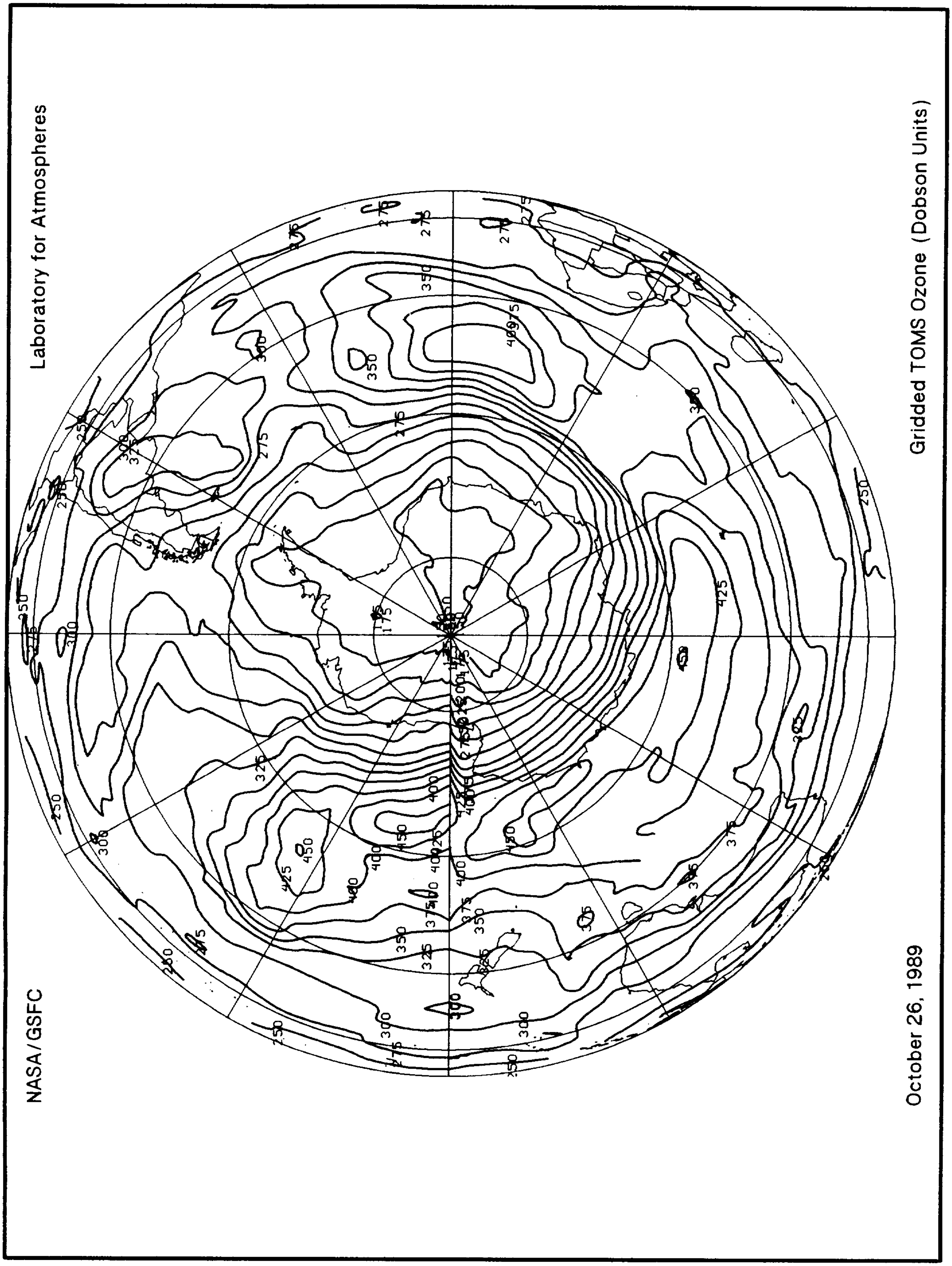
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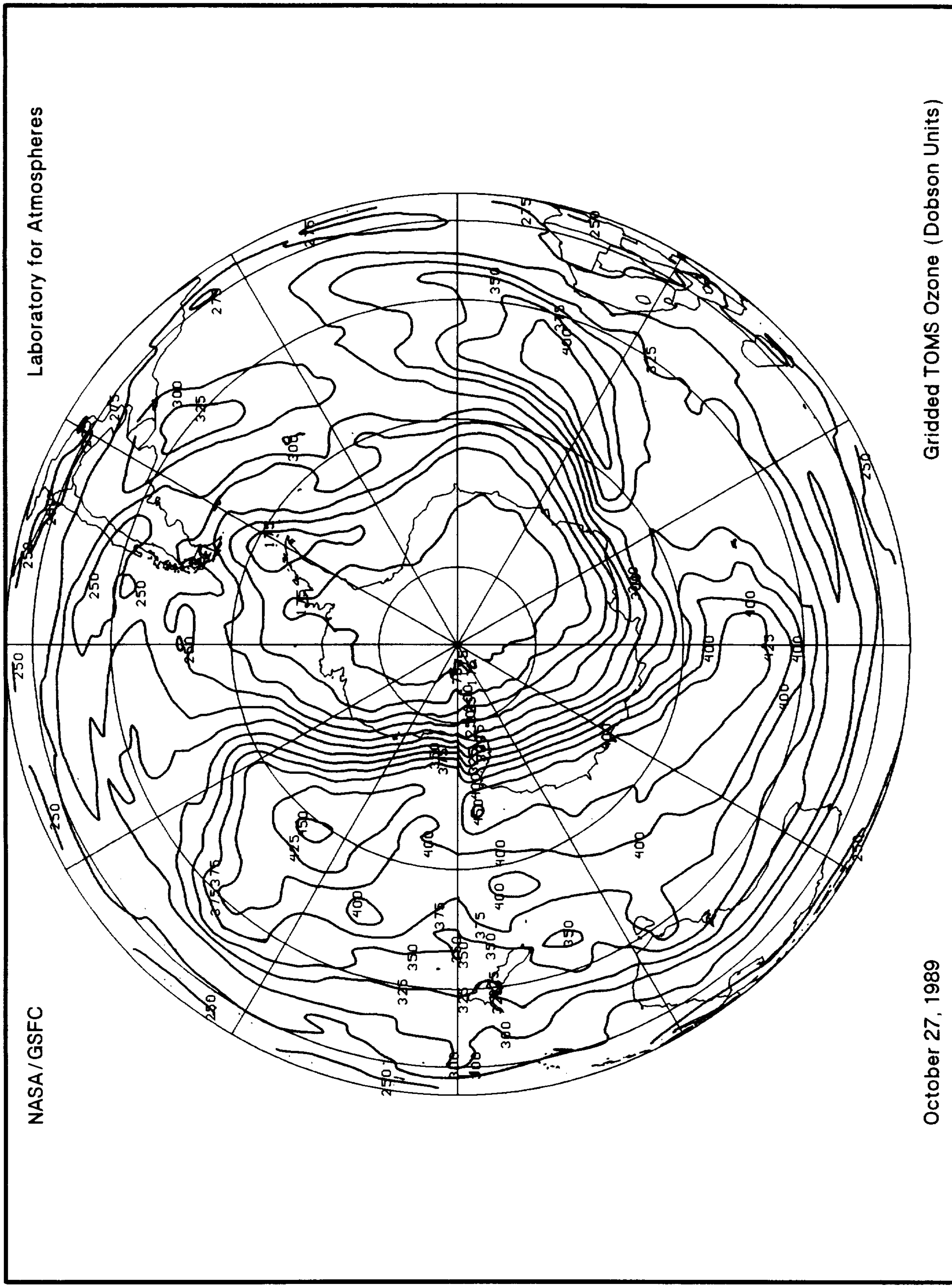
October 26, 1989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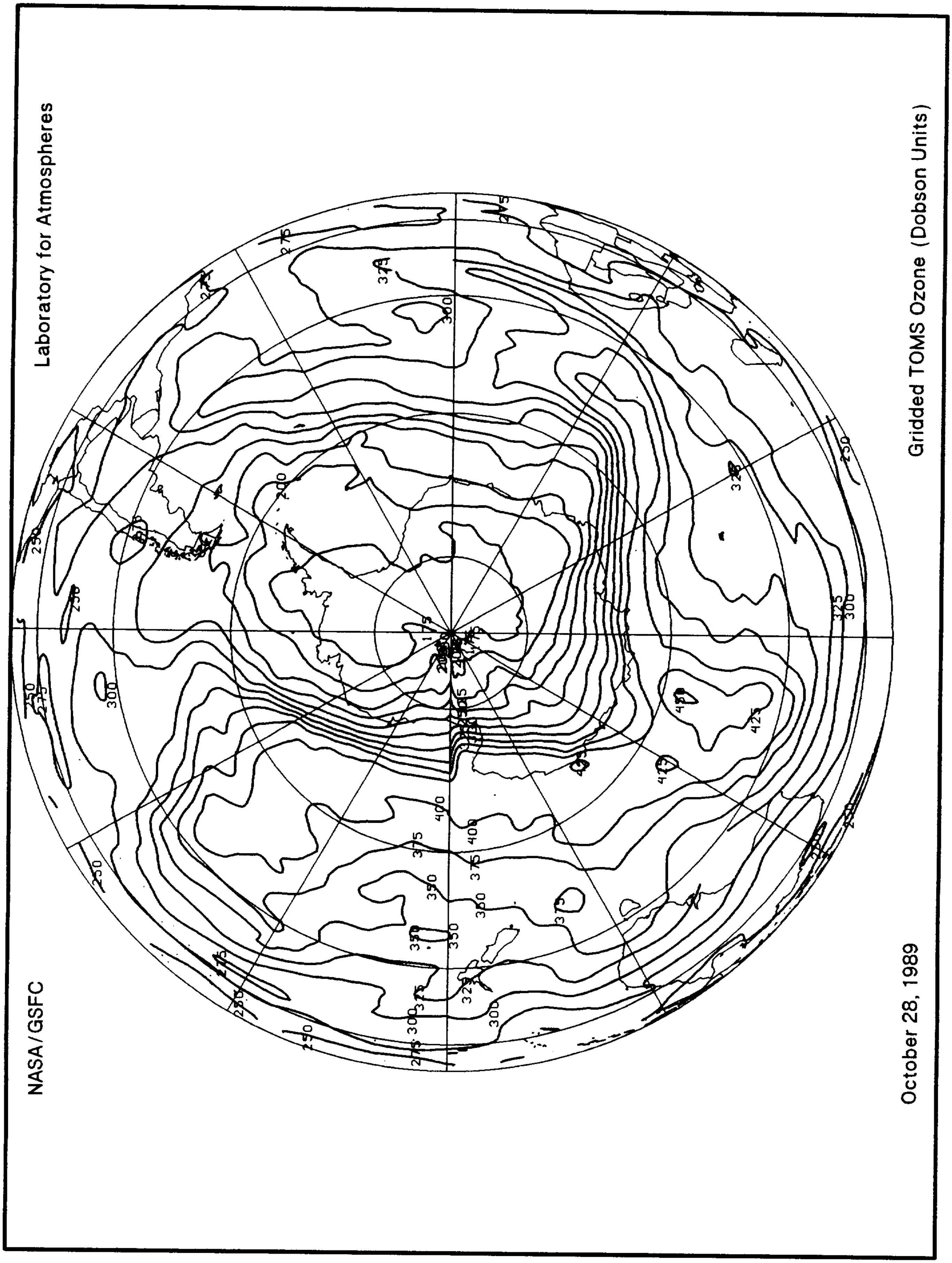

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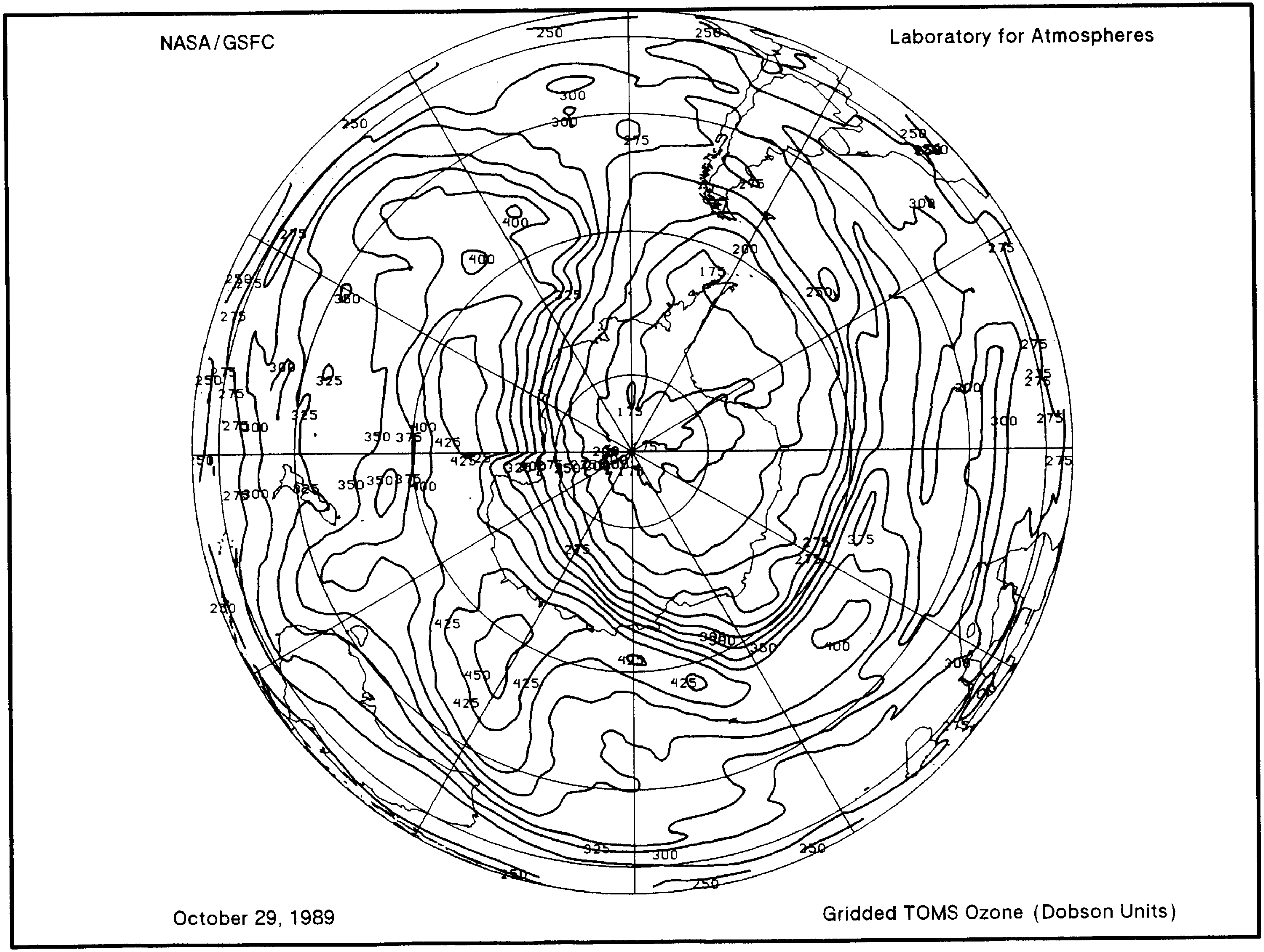

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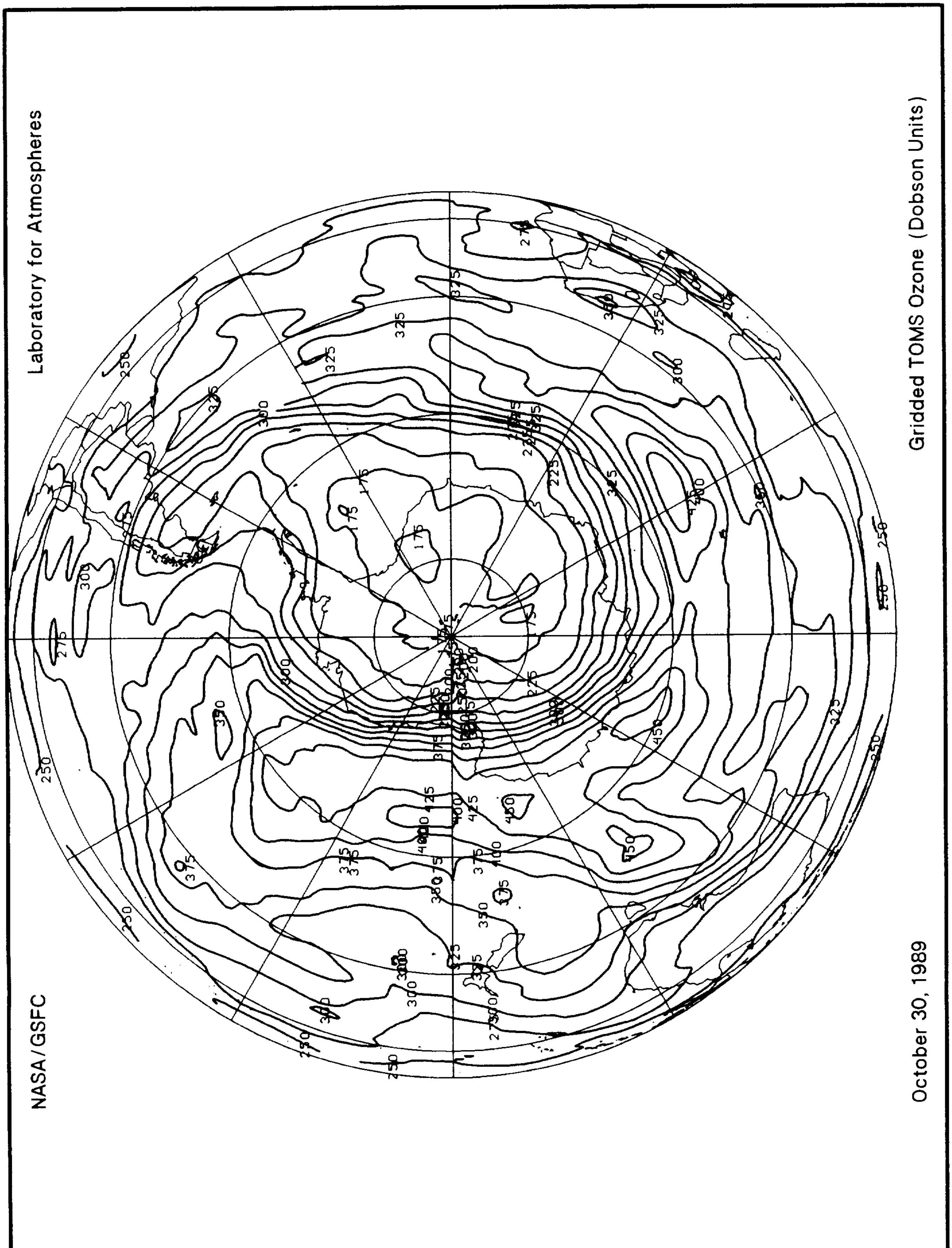
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October 30, 1989
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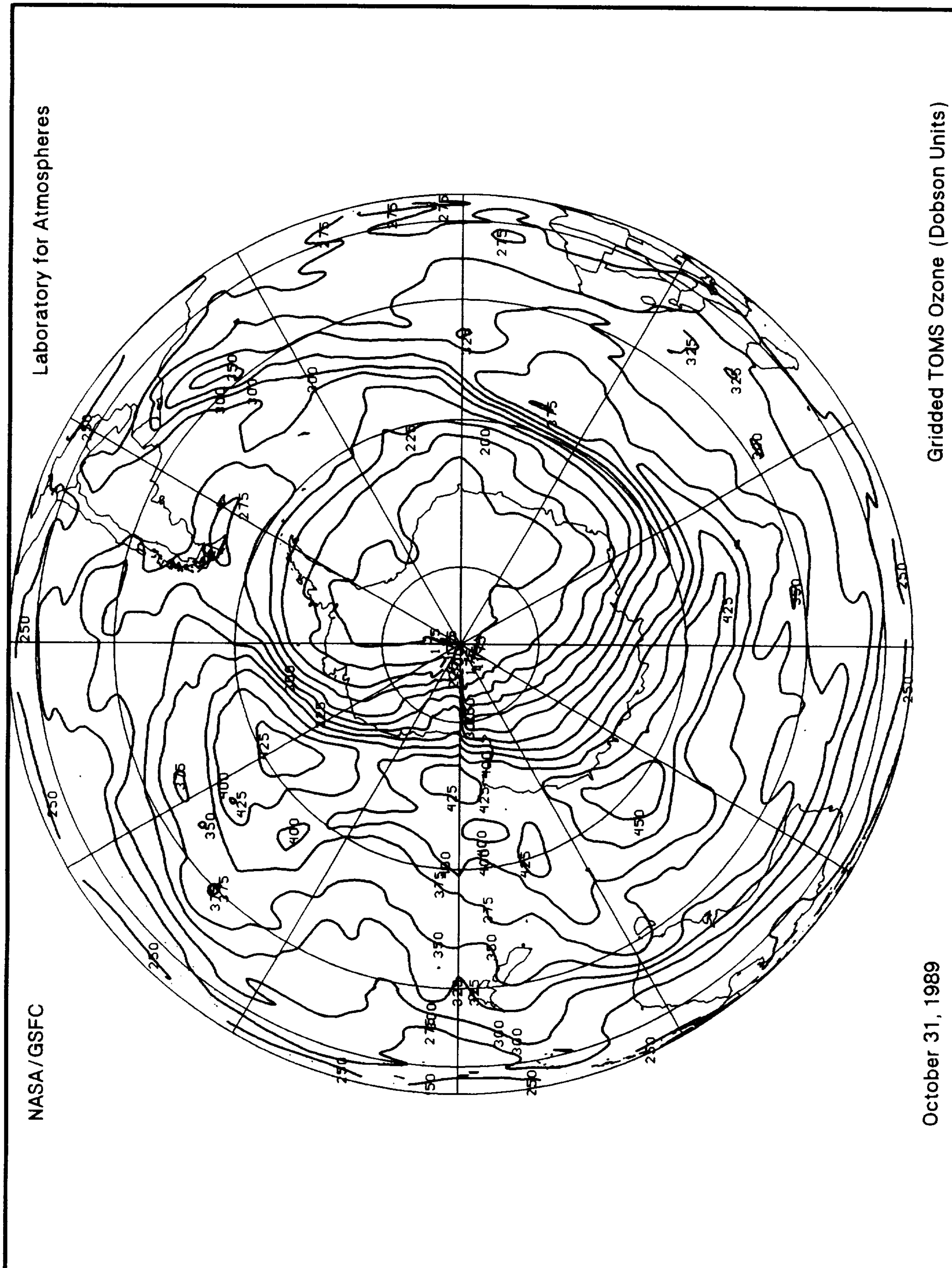

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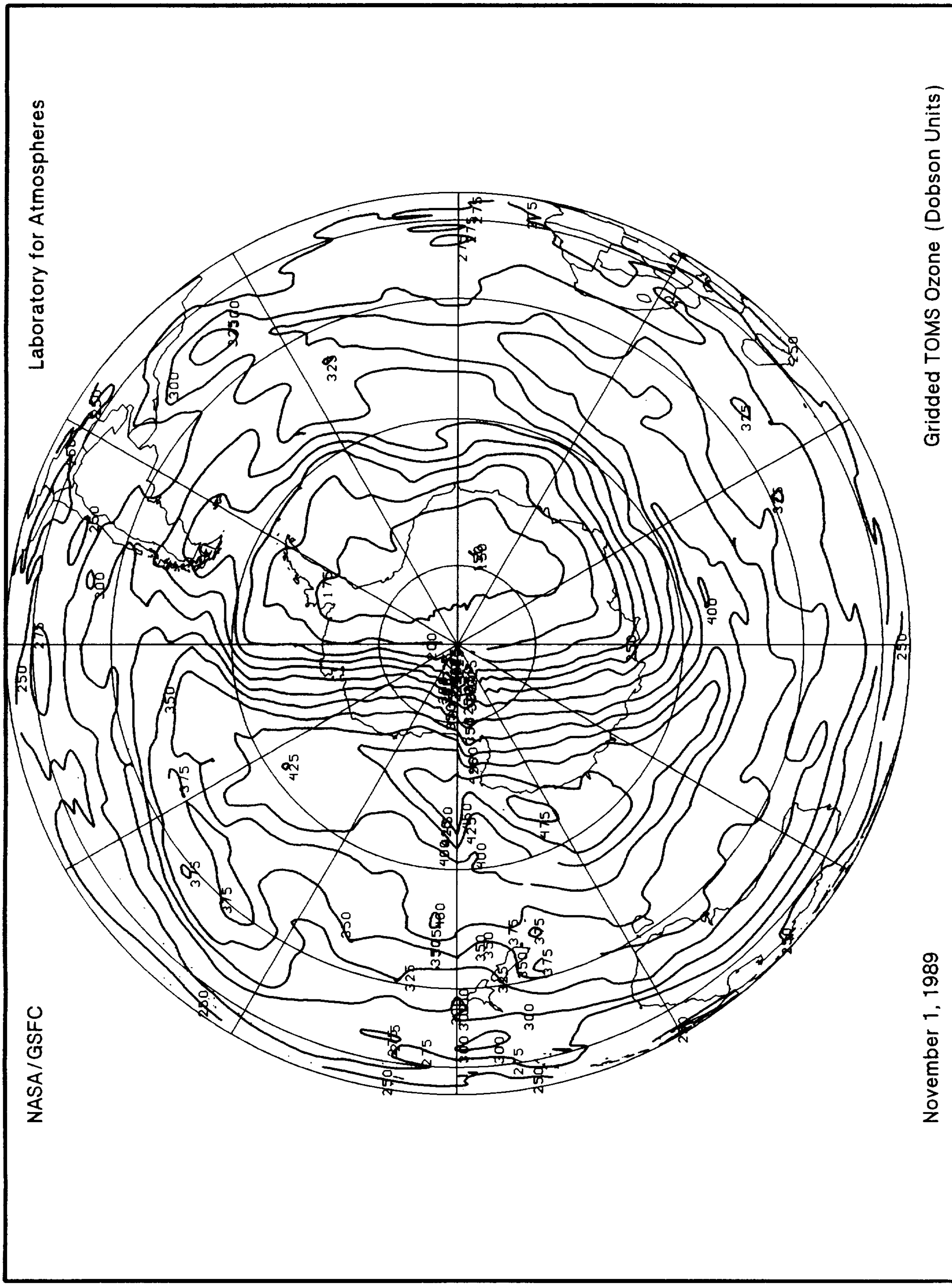
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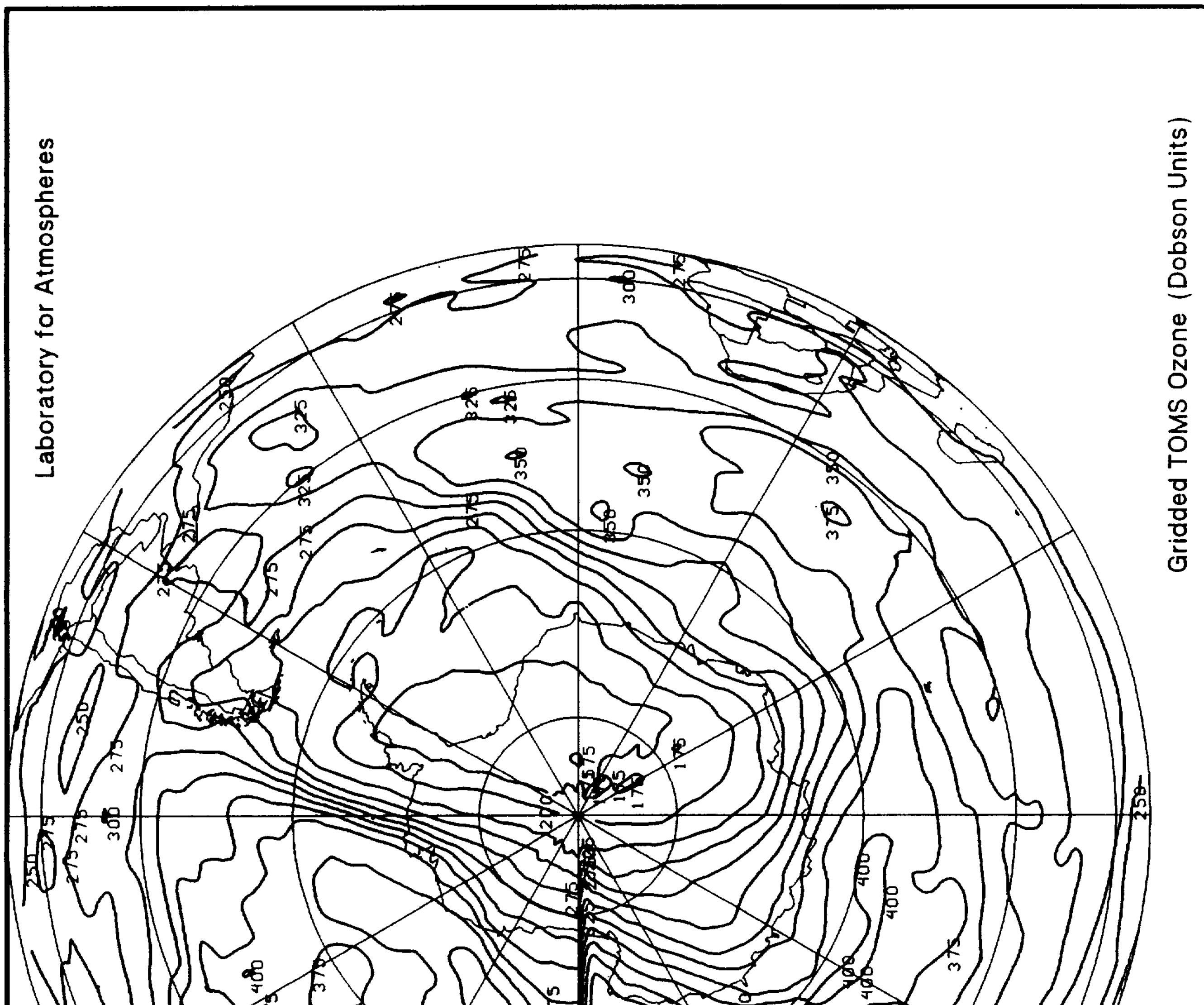
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
November 1, 1989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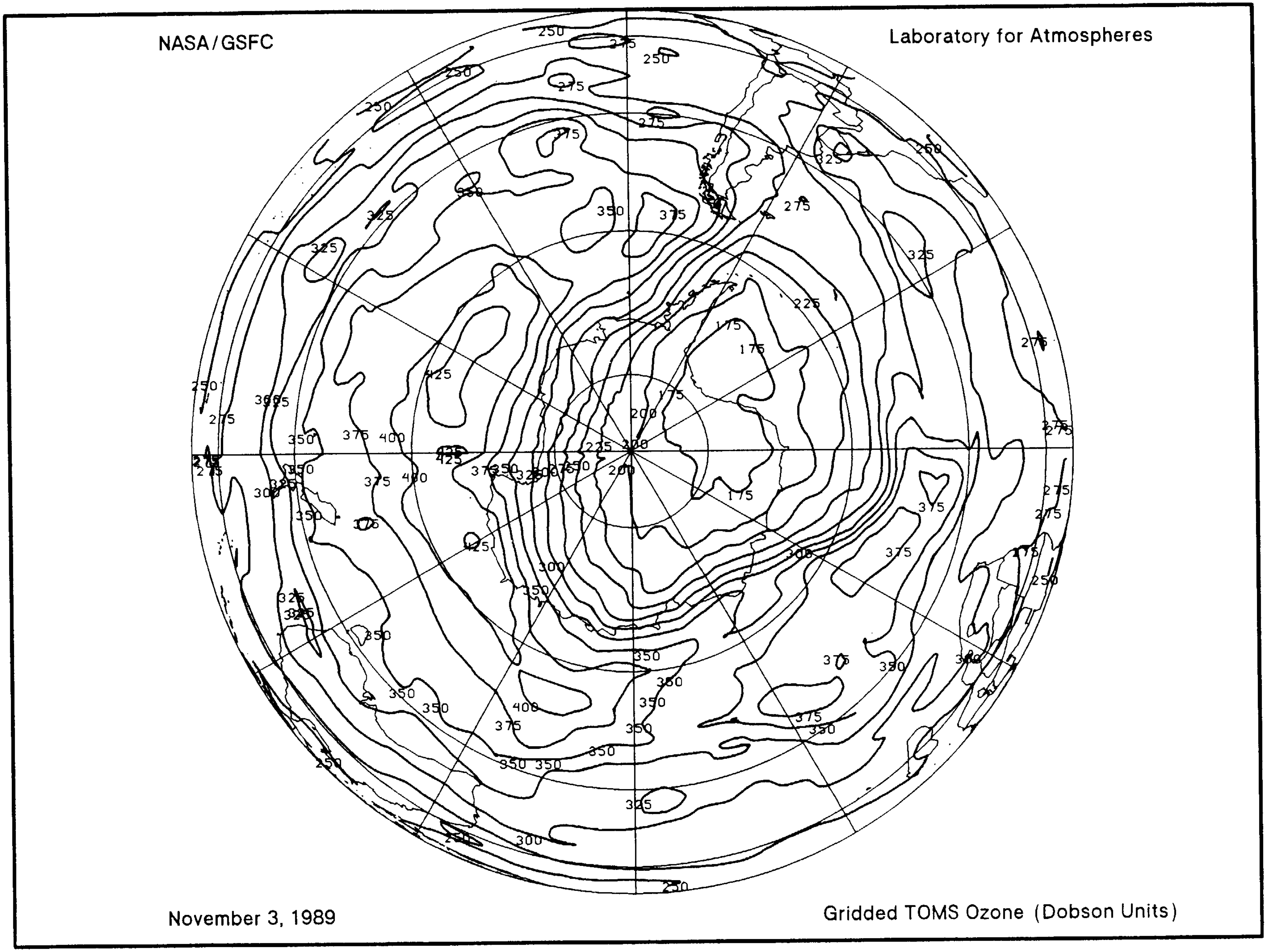
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
November 2, 1989



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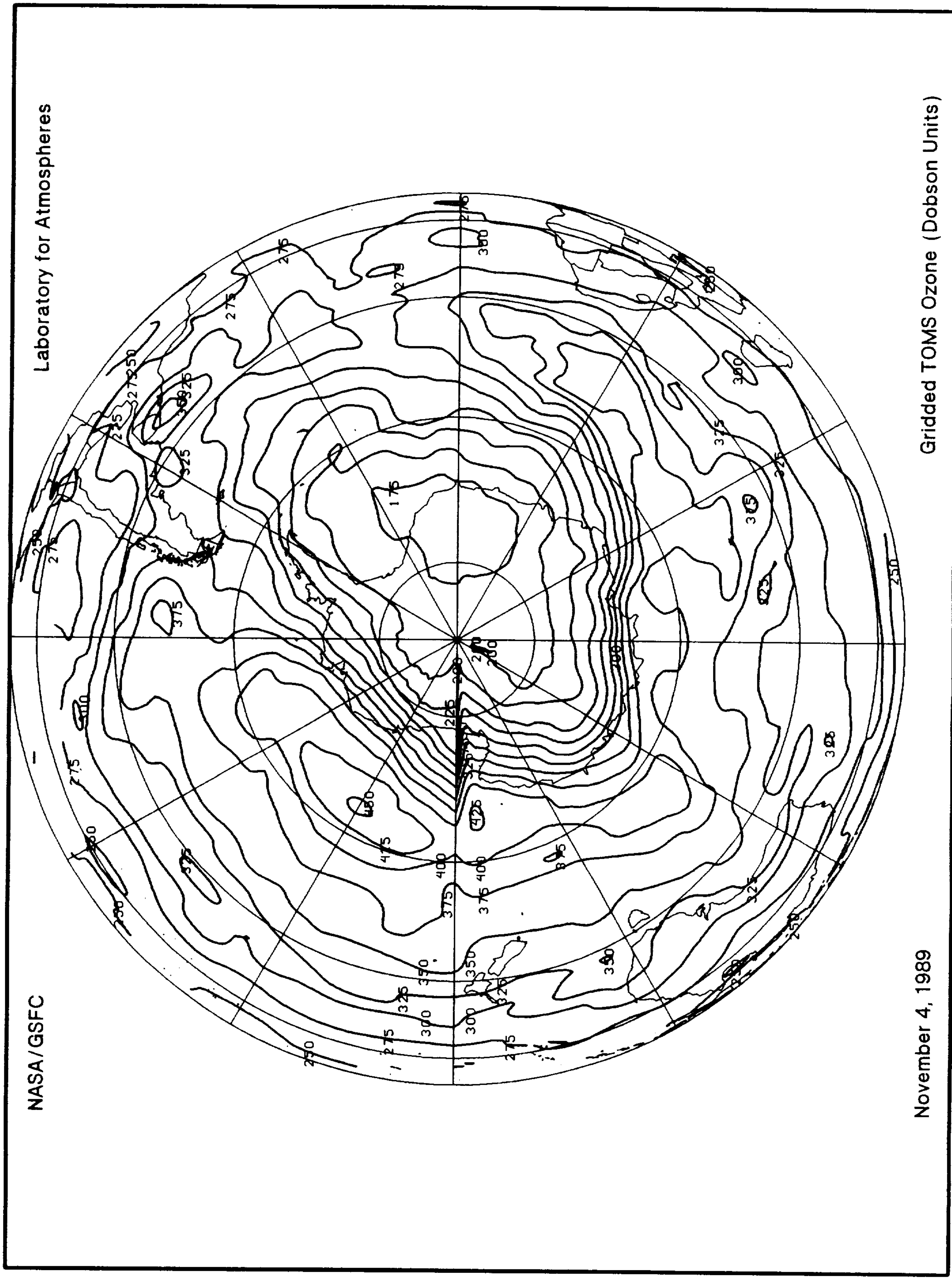
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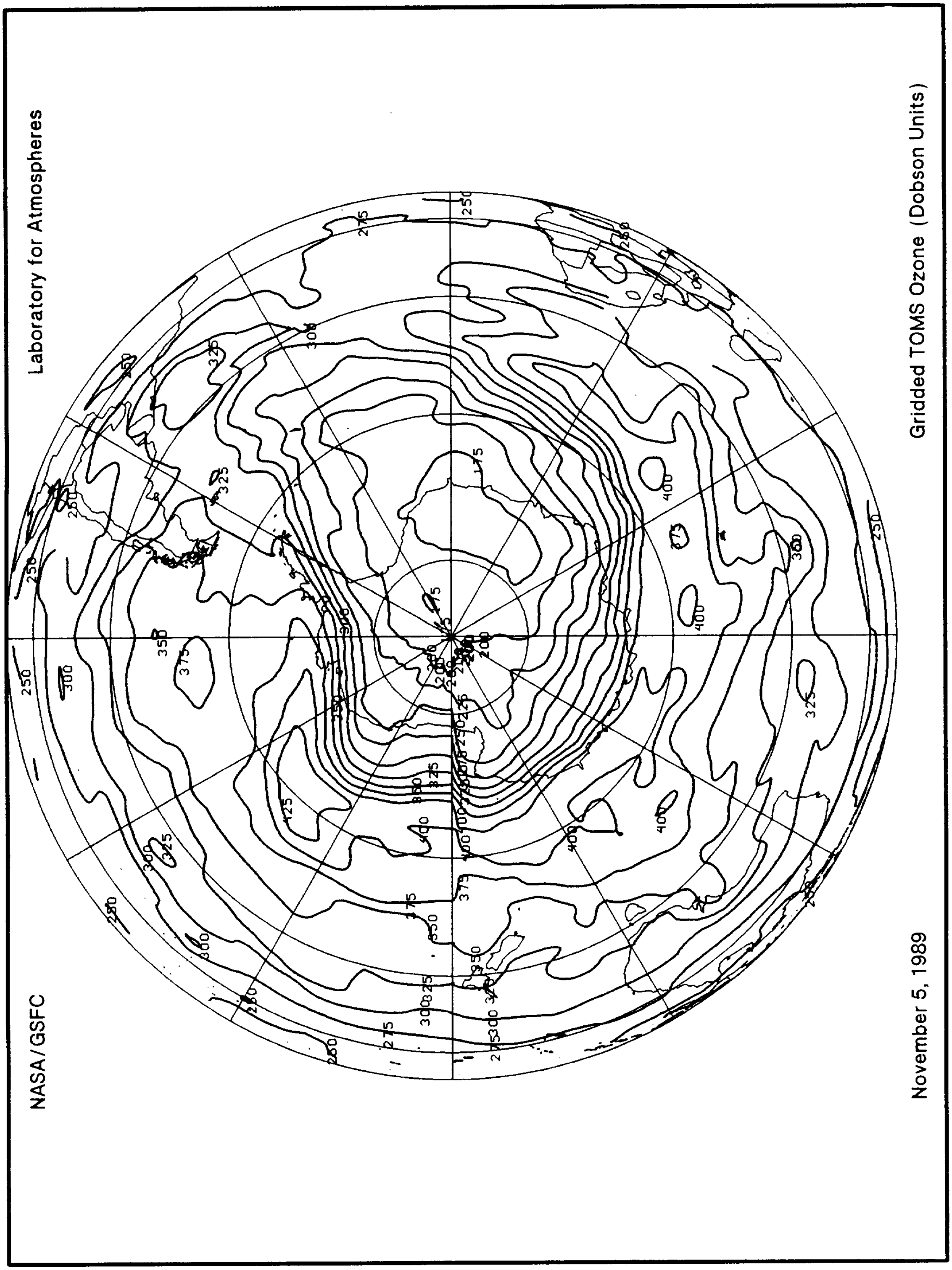
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
November 4, 1989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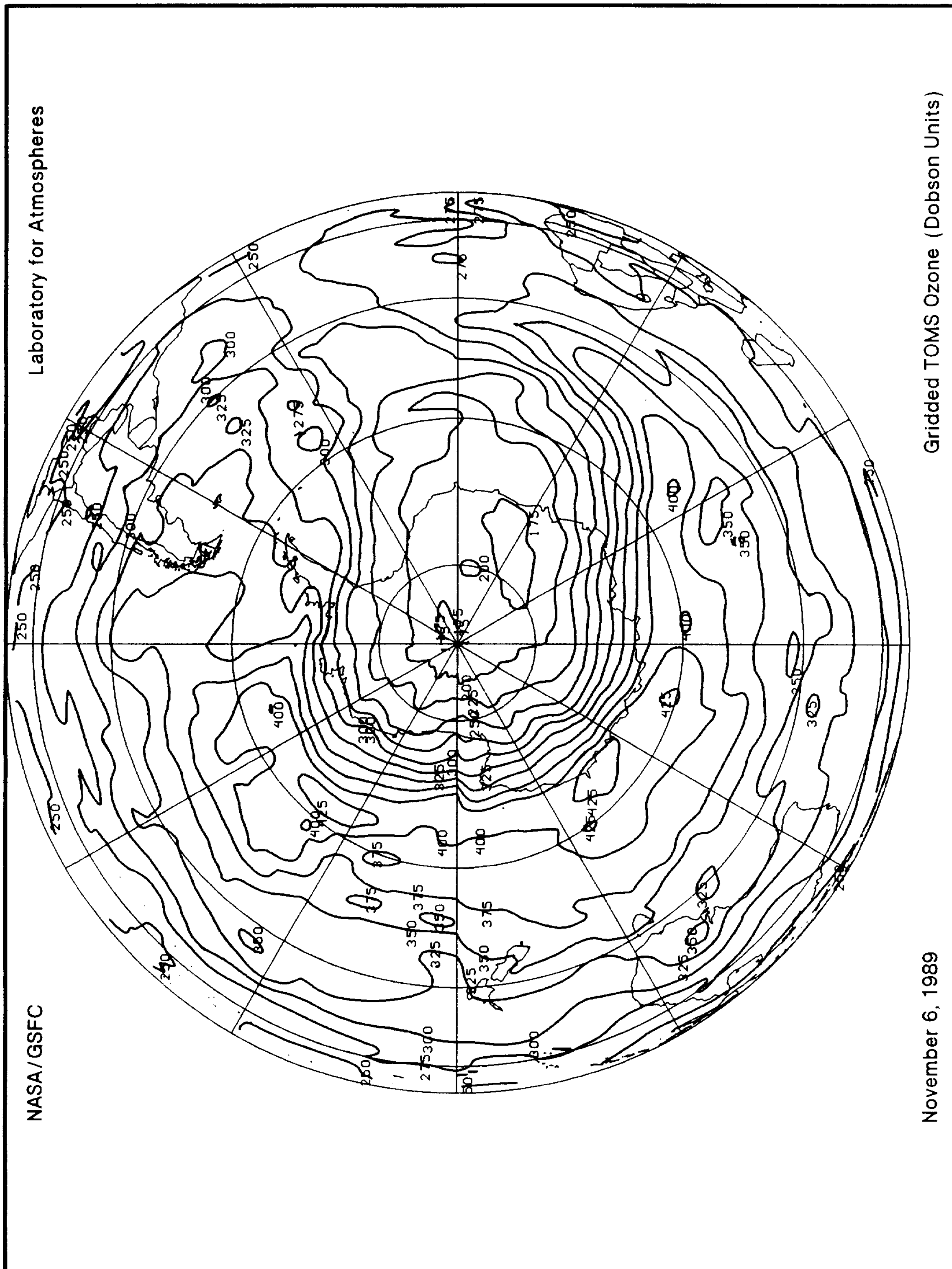
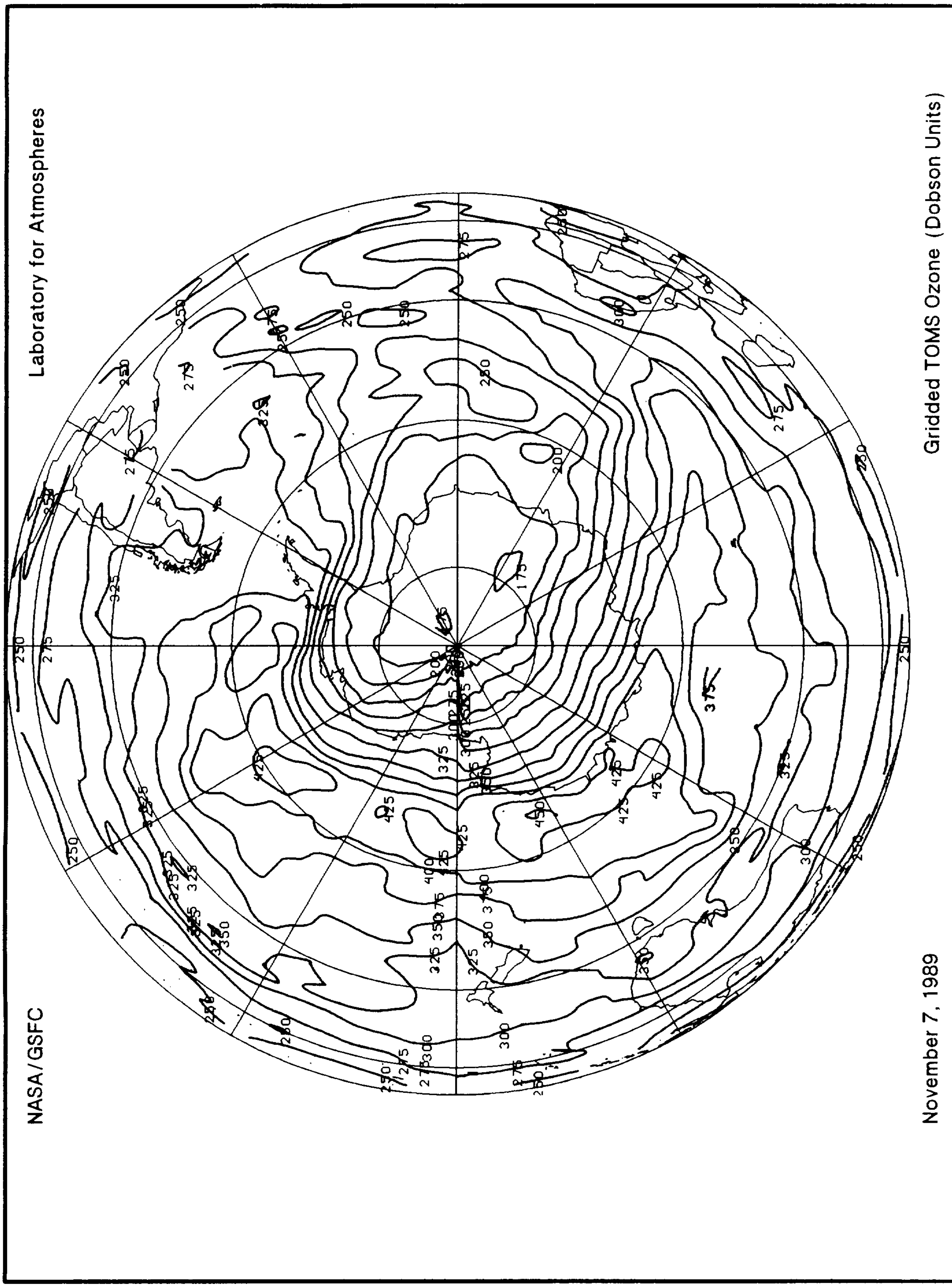
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
November 5, 1989


NASA/GSFC
Laboratory for Atmospheres
November 6, 1989
Gridded TOMS Ozone (Dobson Units)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NASA/GSFC
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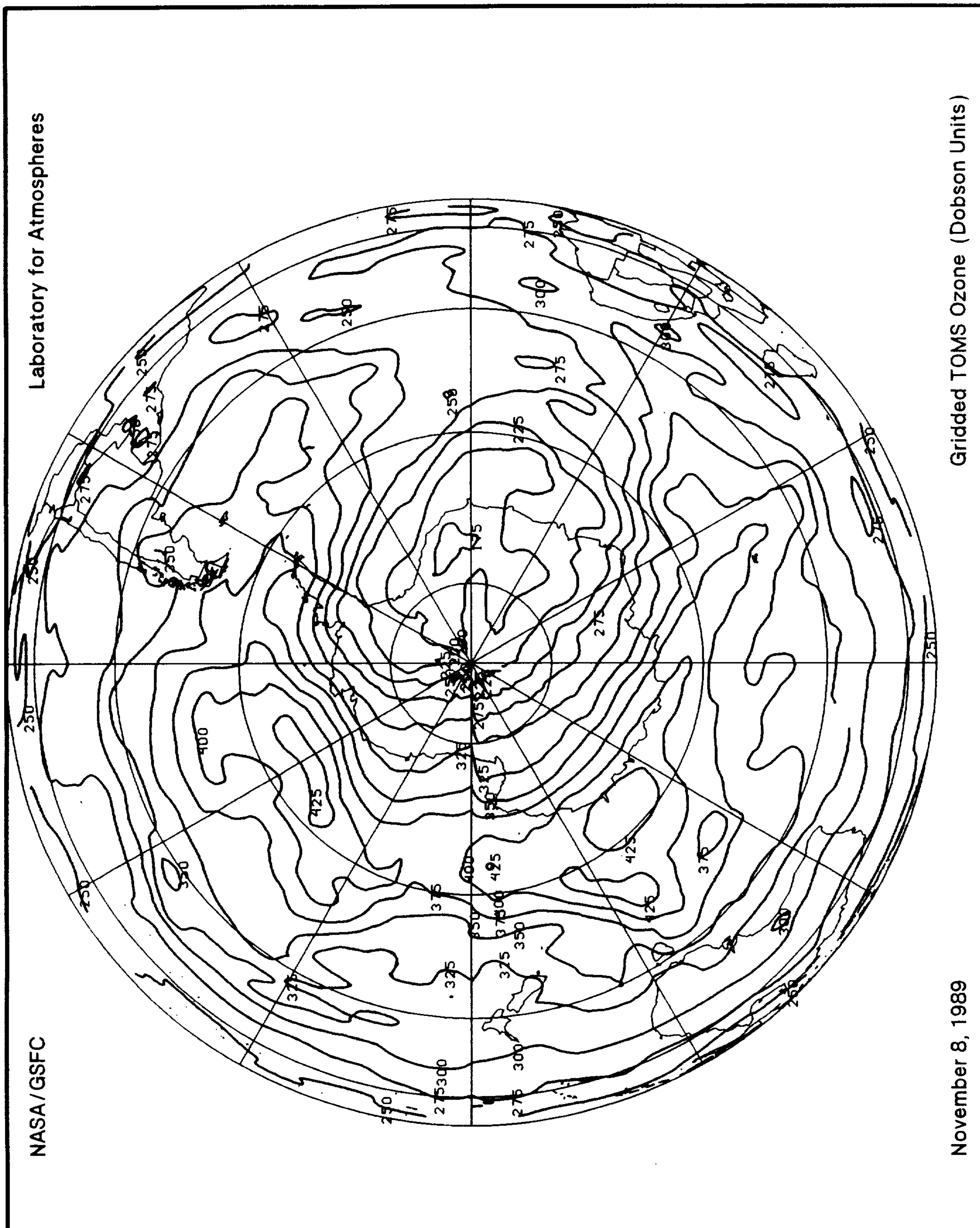
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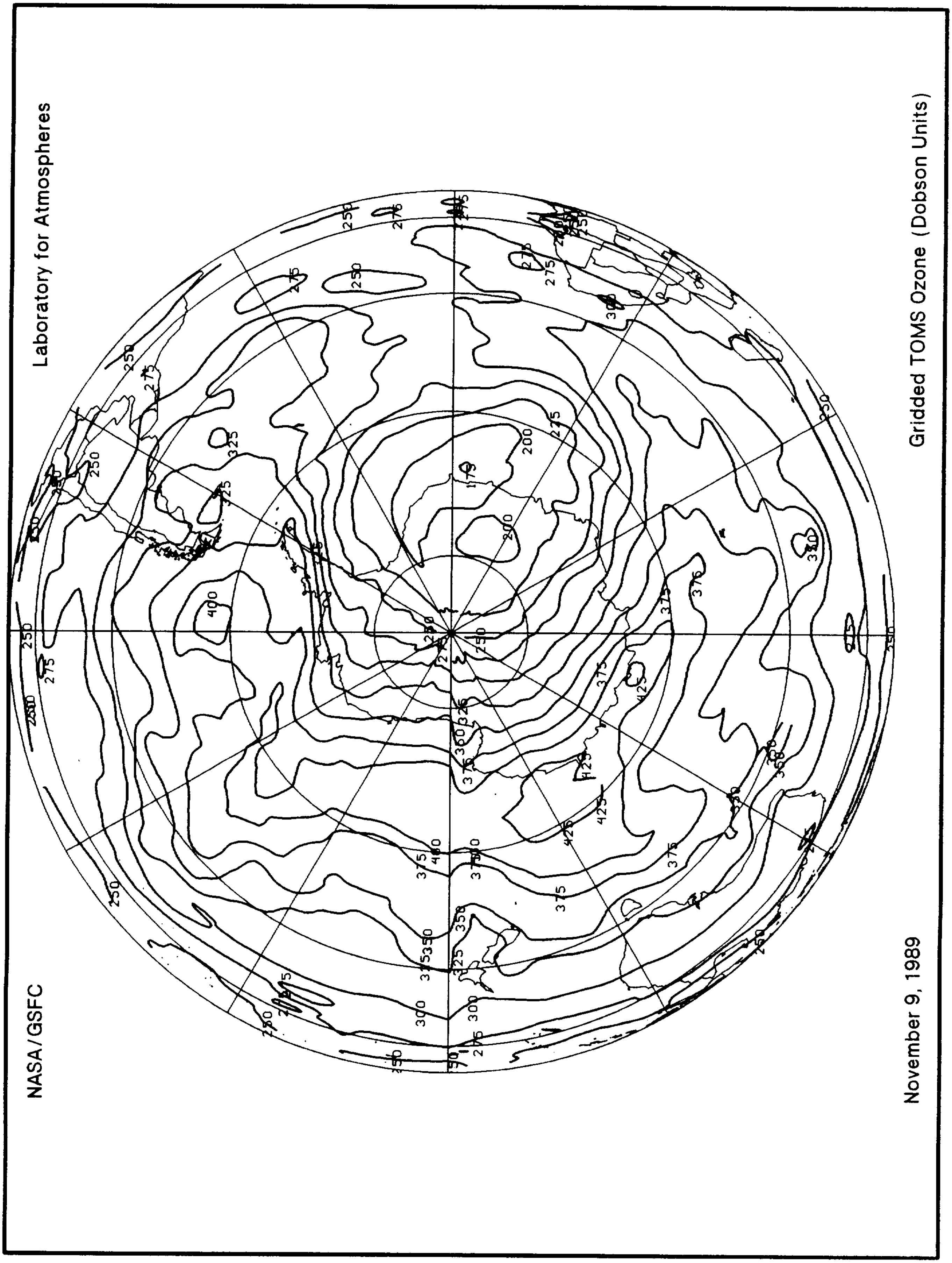
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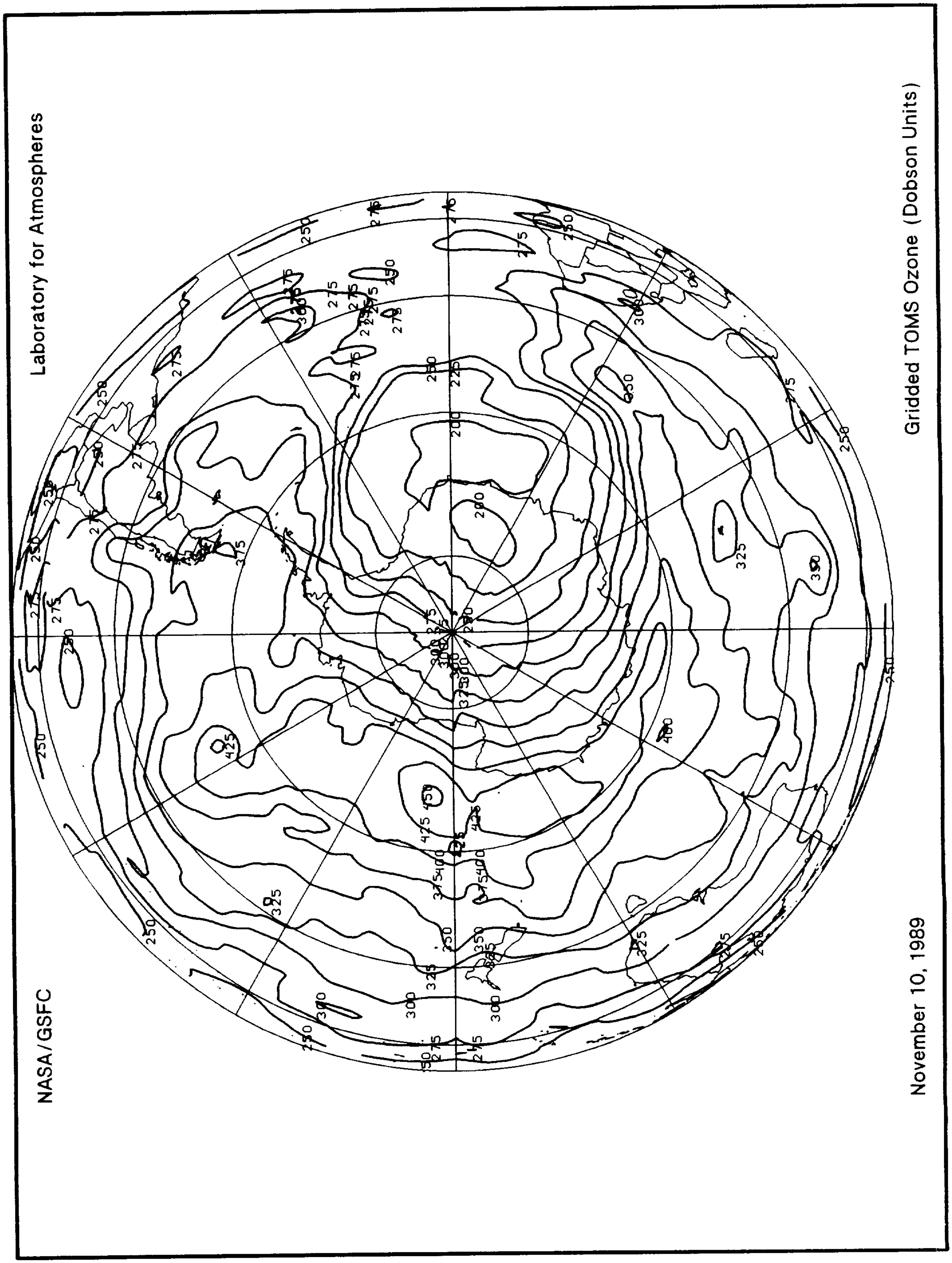
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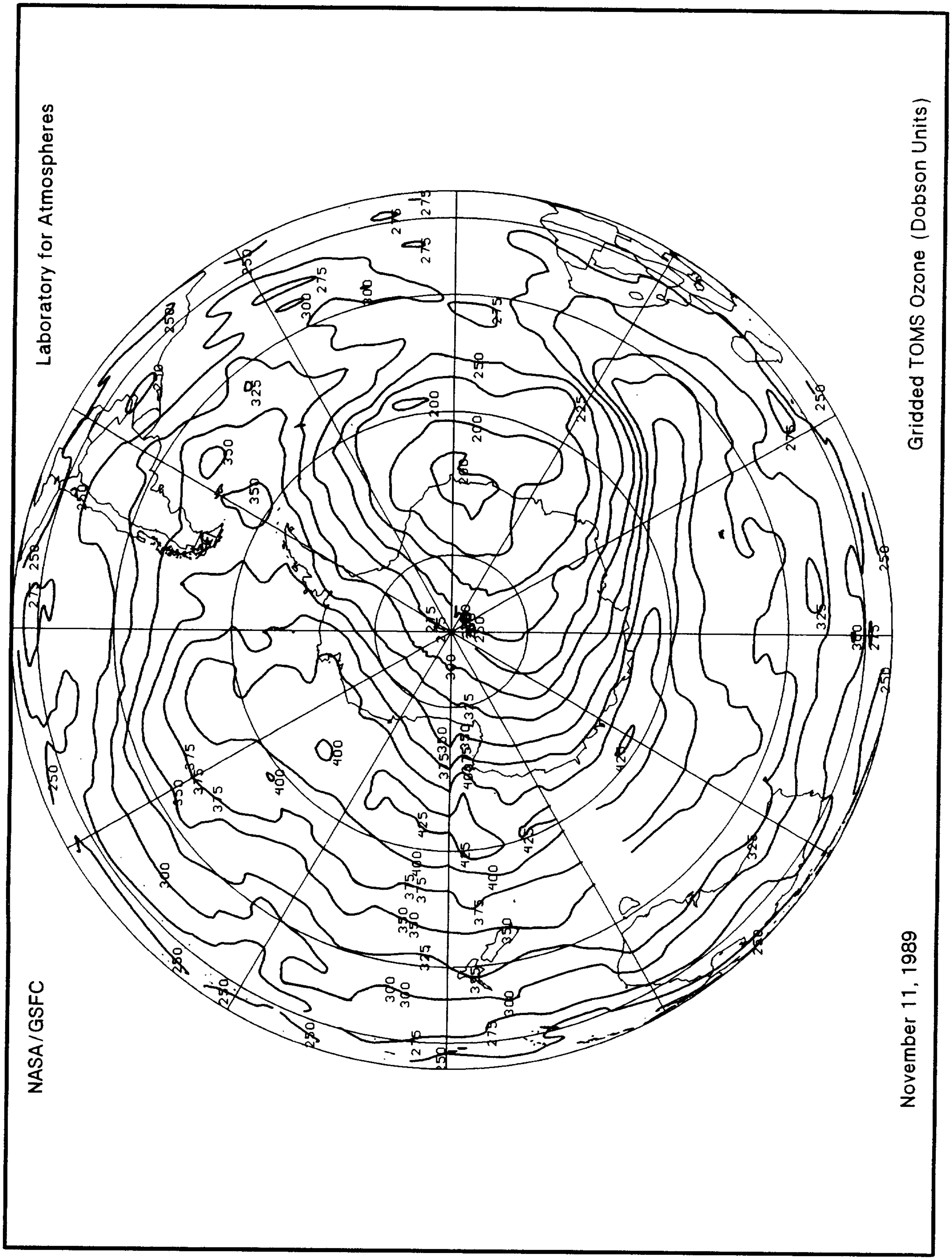
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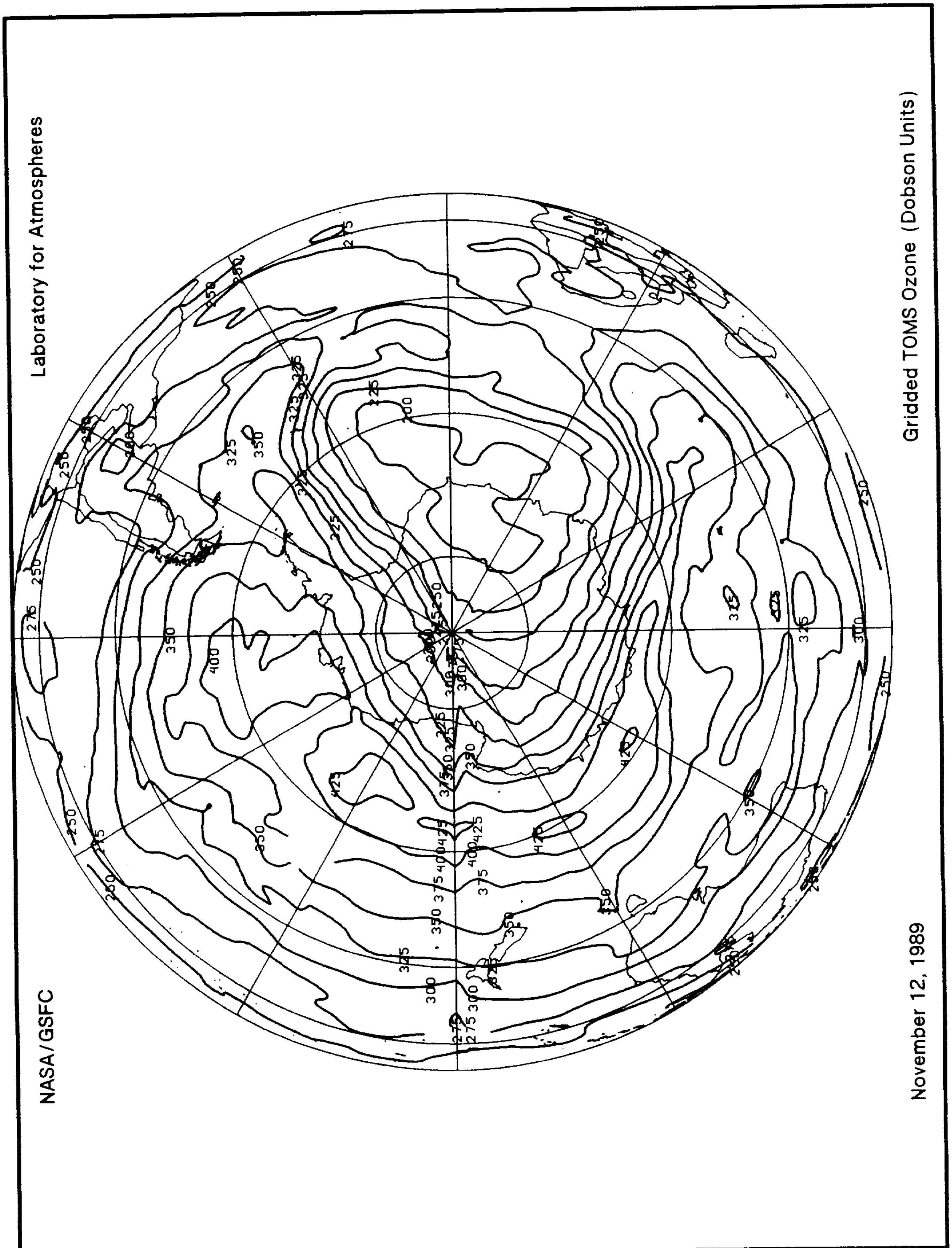

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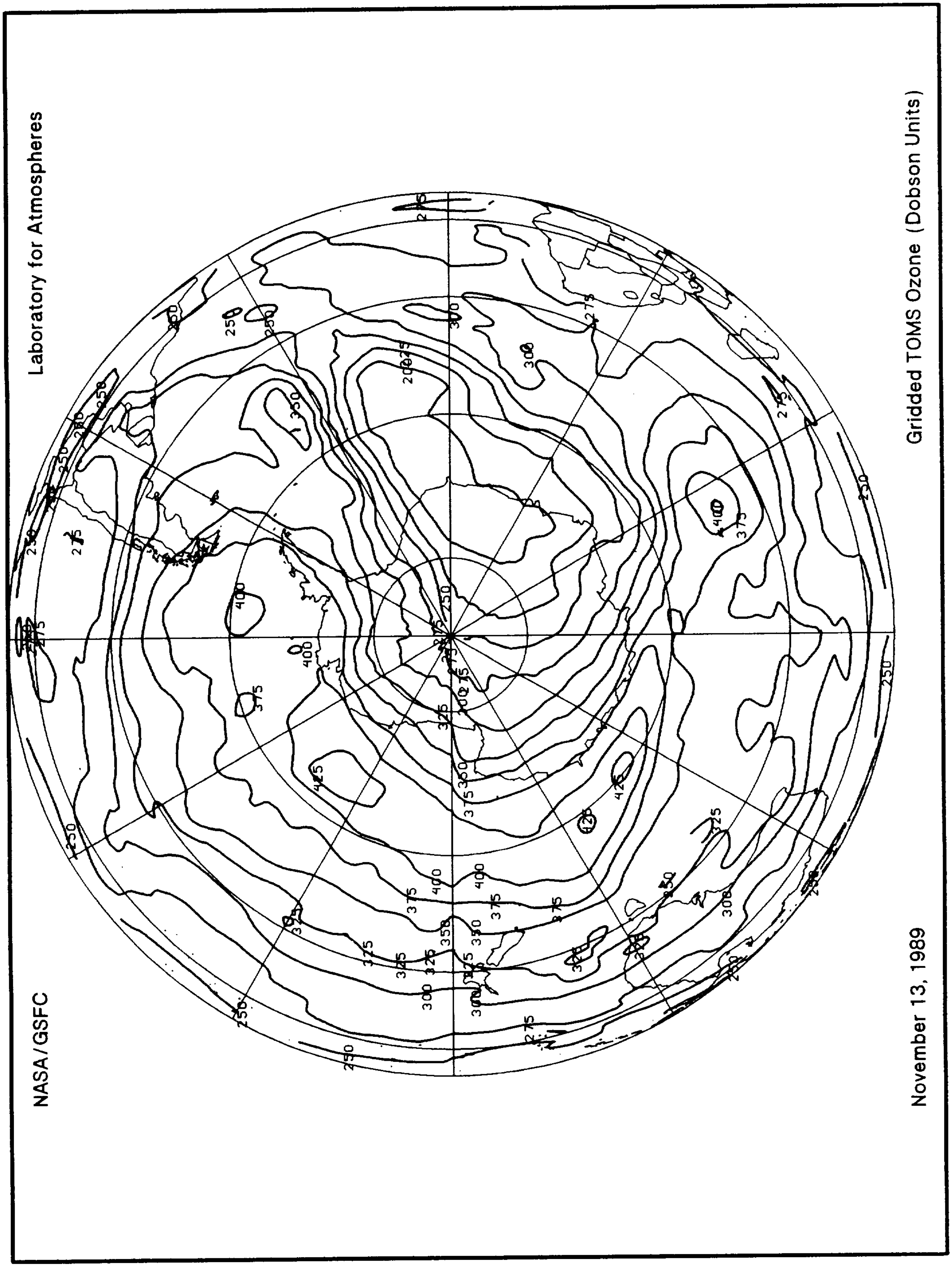
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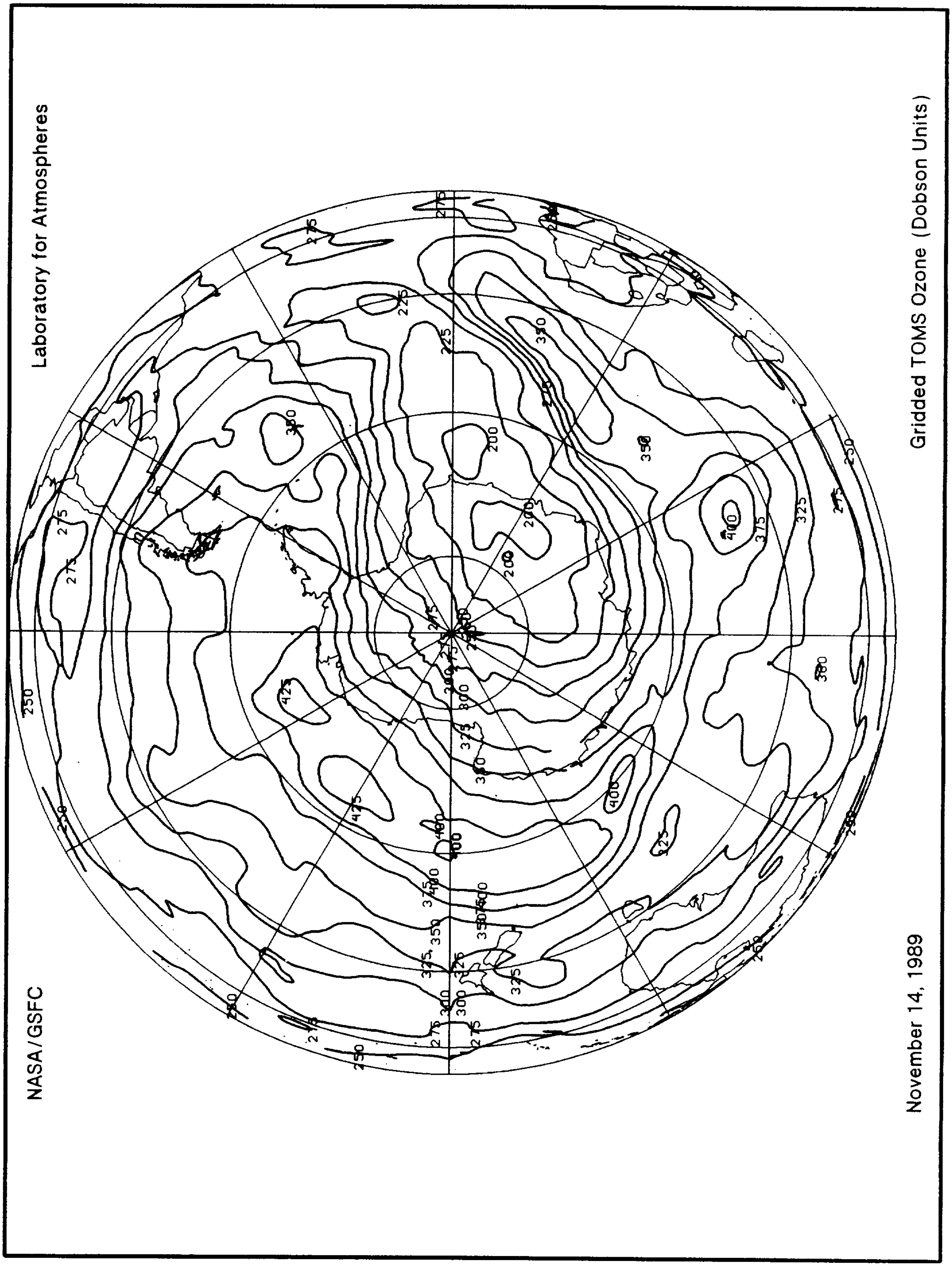
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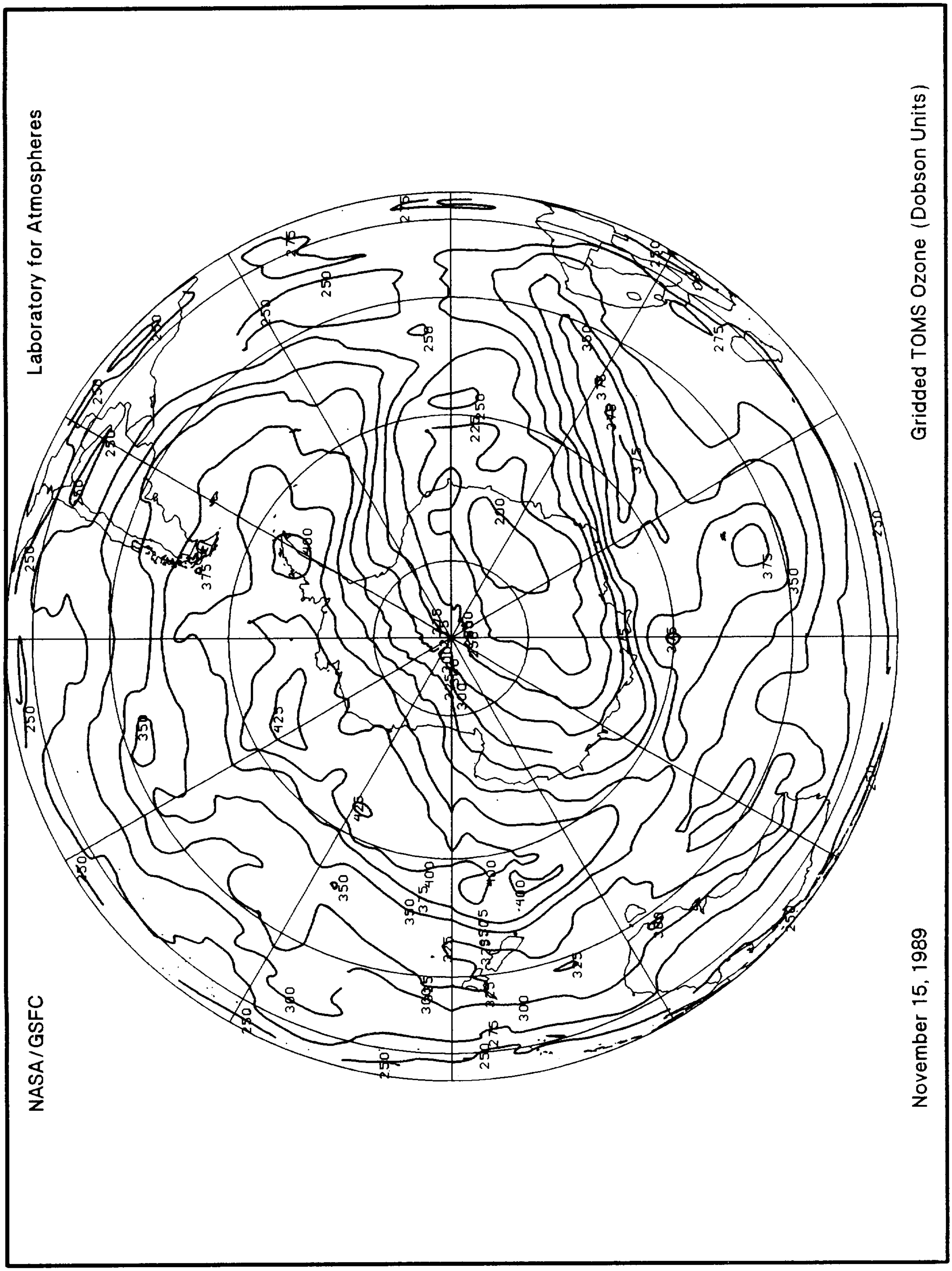
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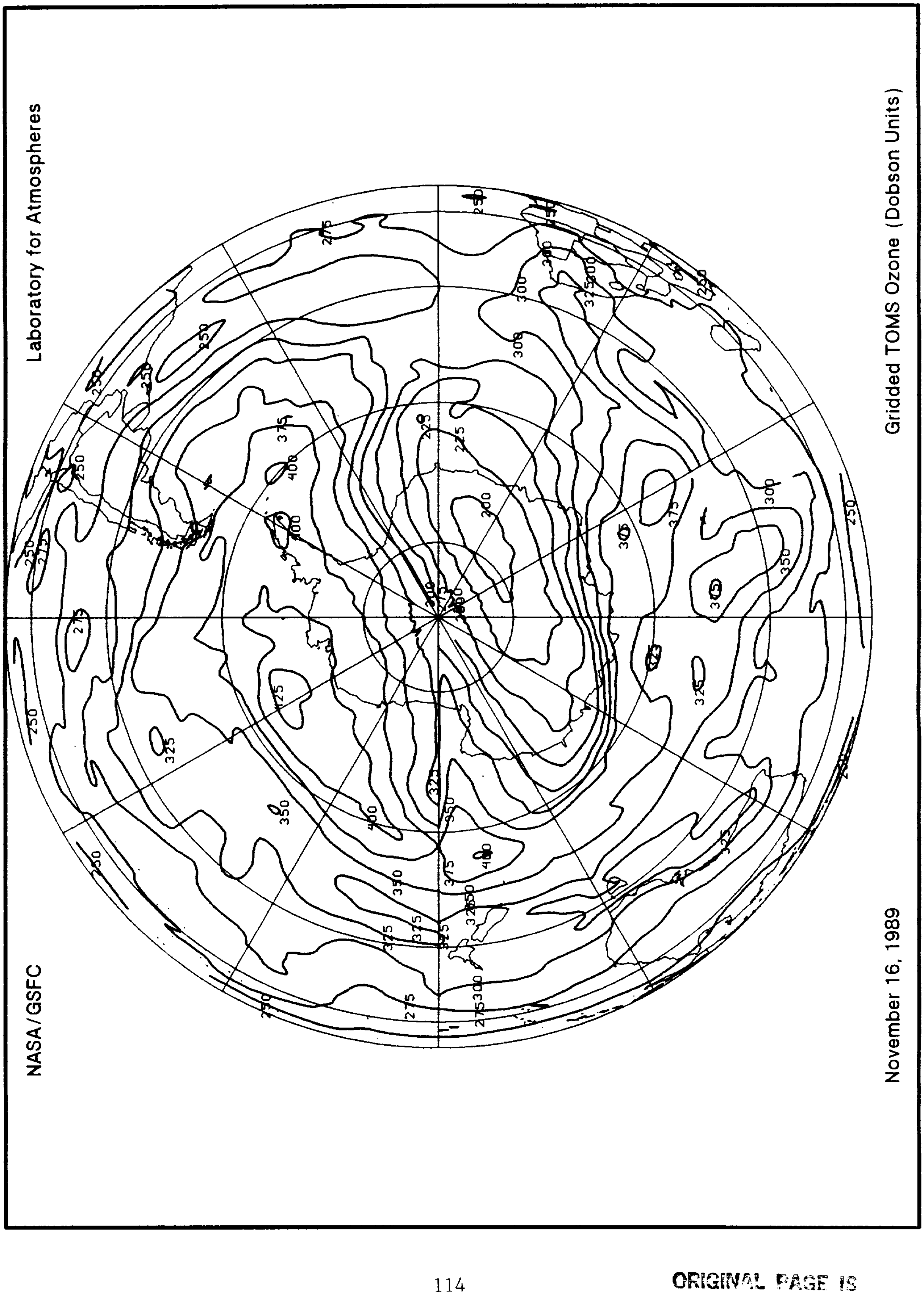

NASA/GSFC
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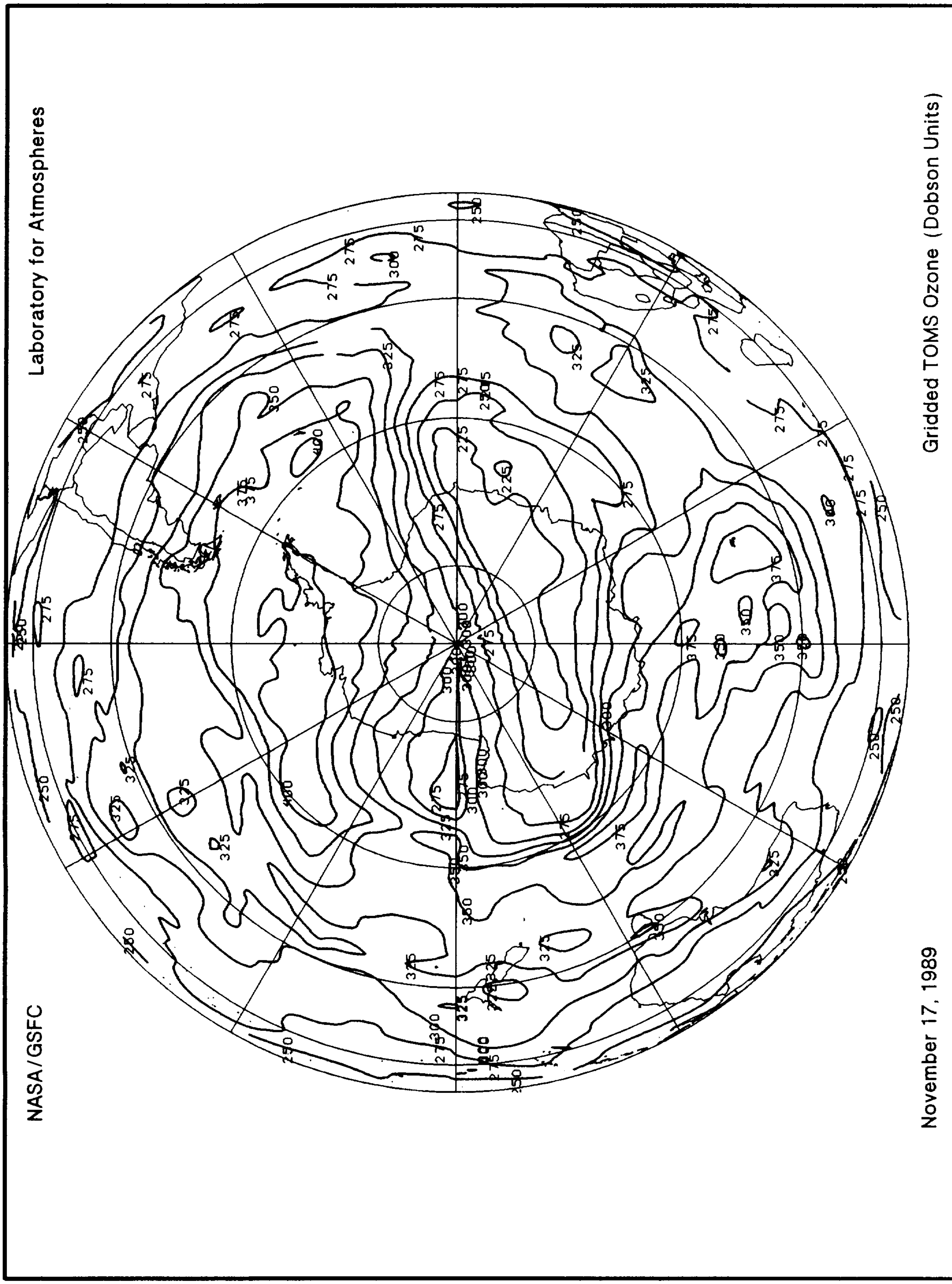

Laboratory for Atmospheres
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
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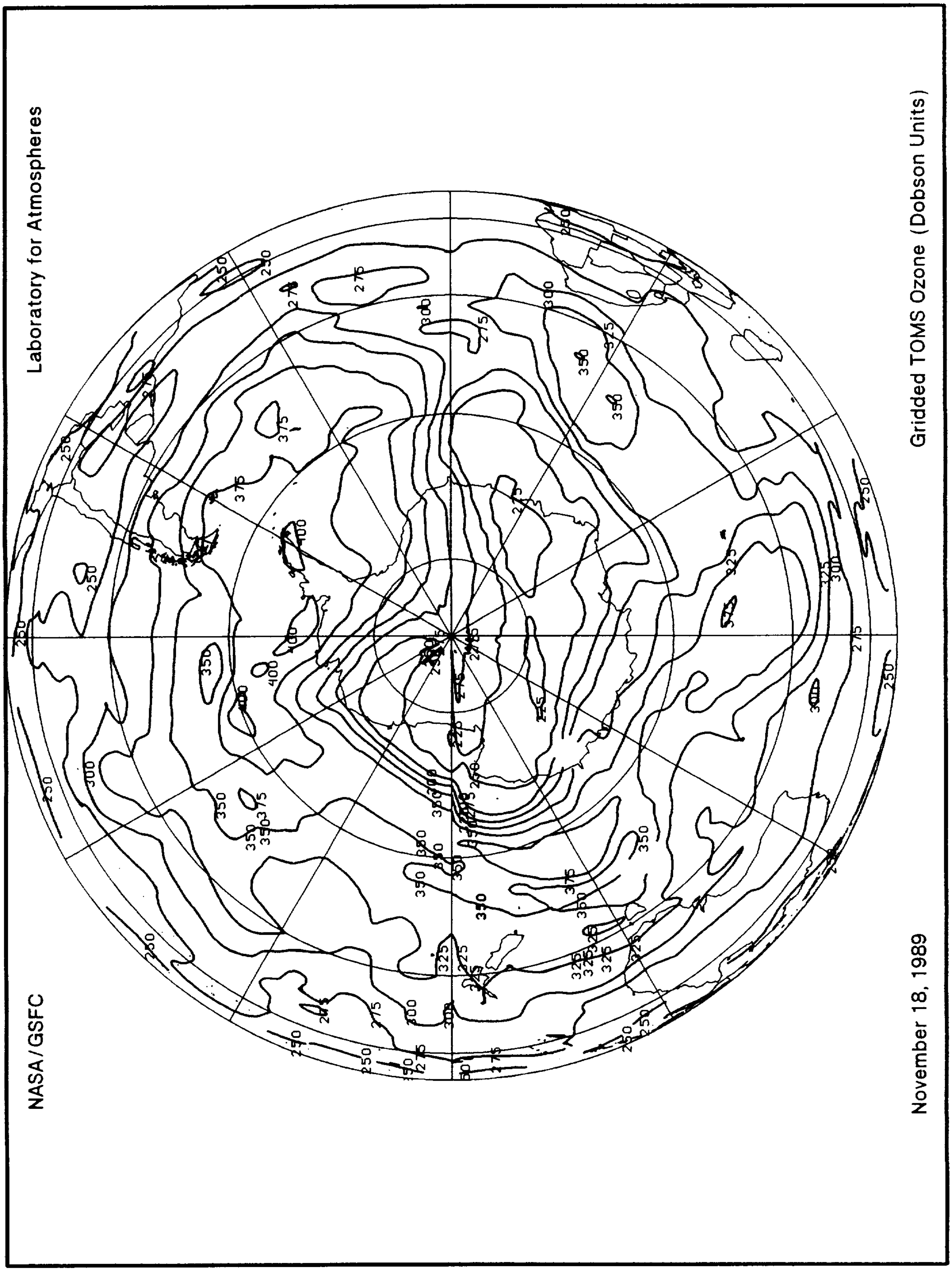
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NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
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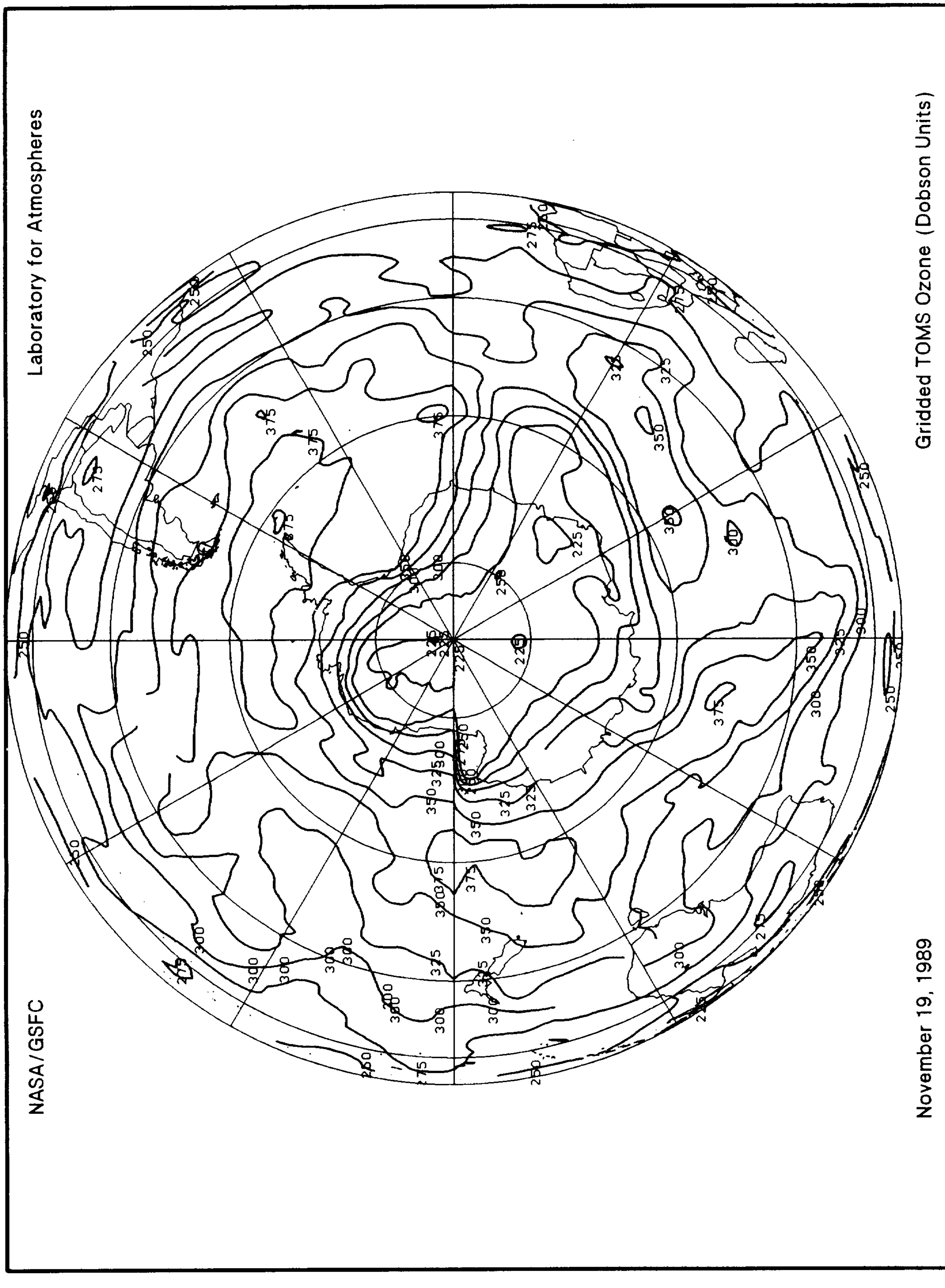
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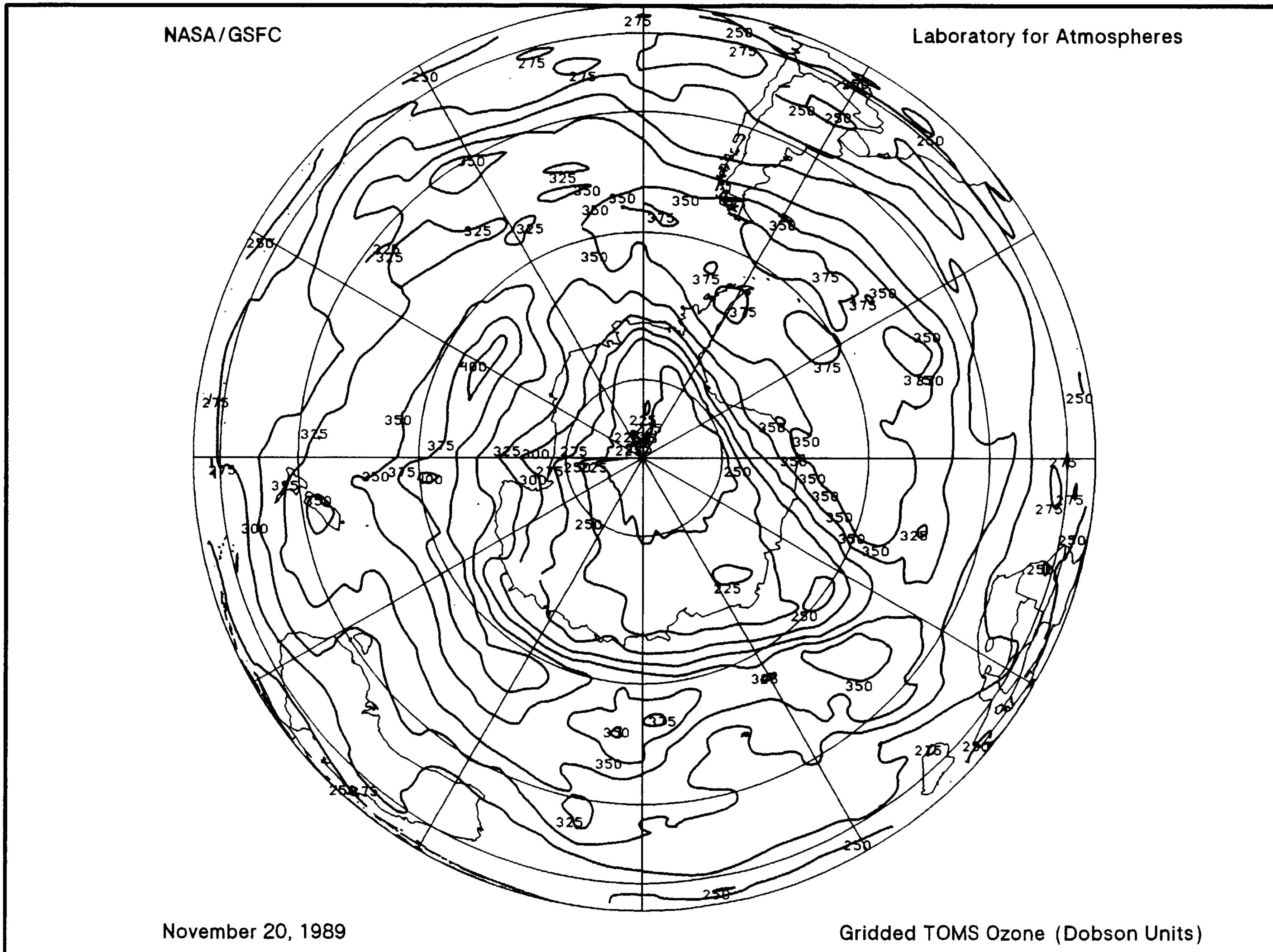
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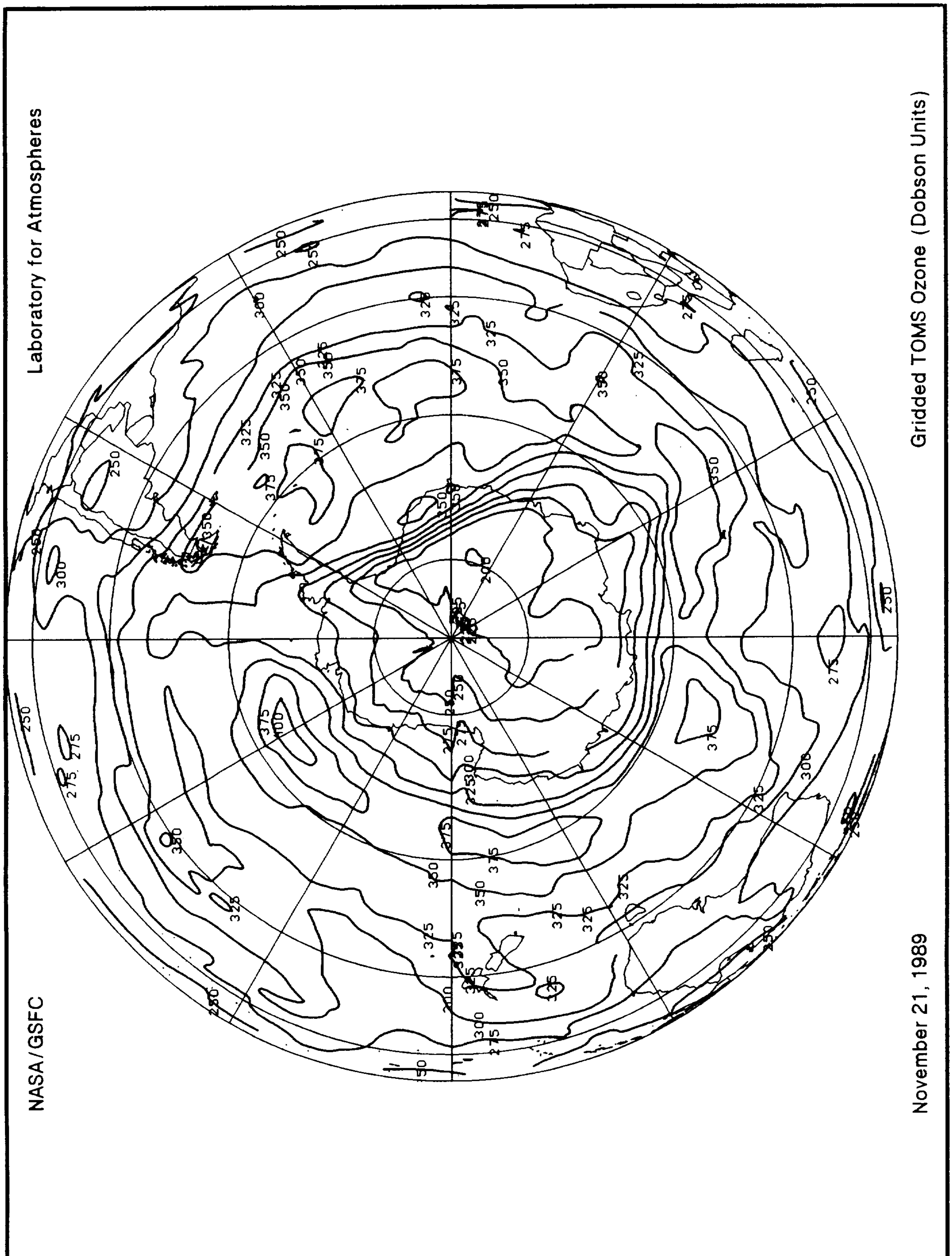
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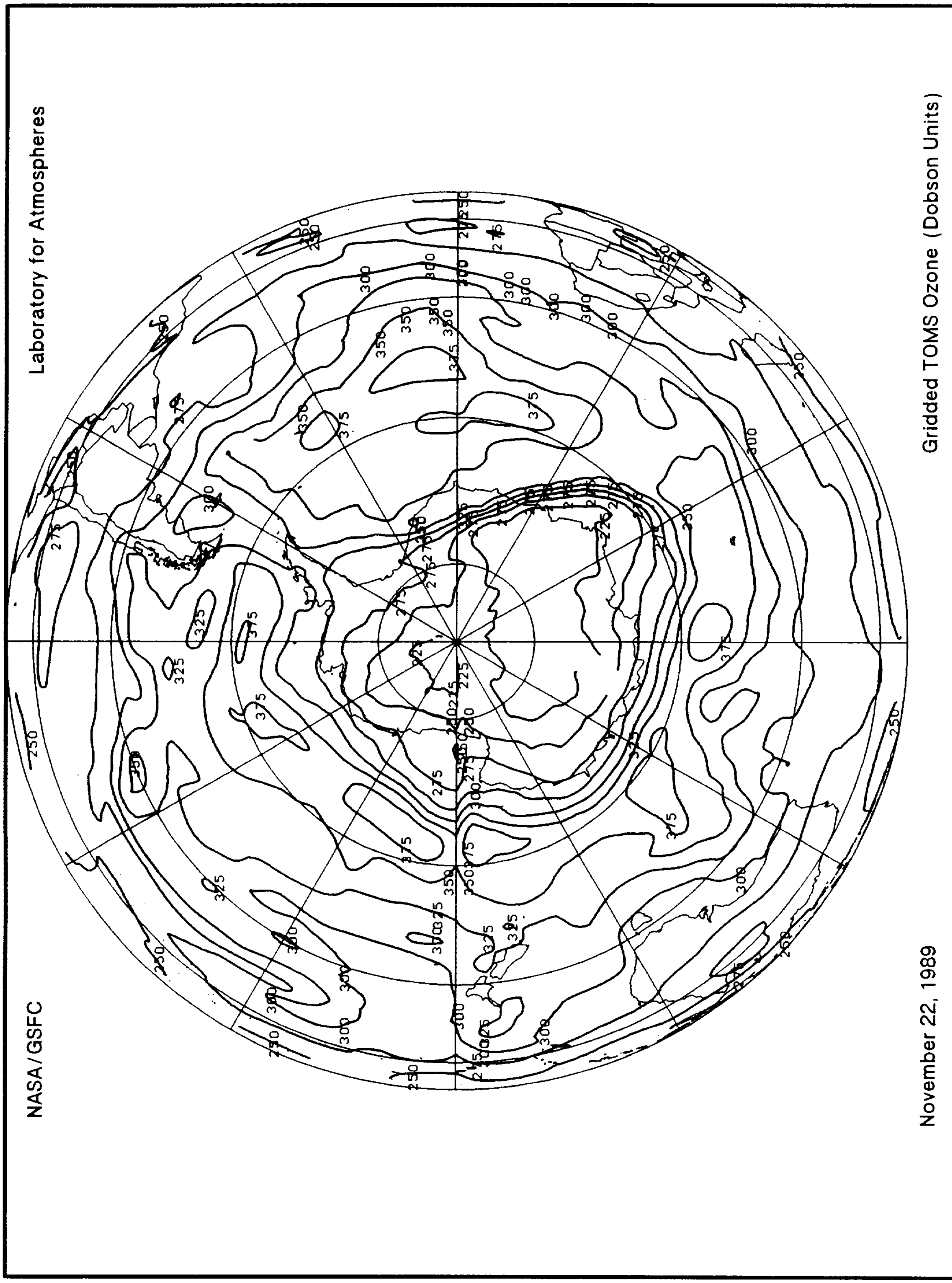
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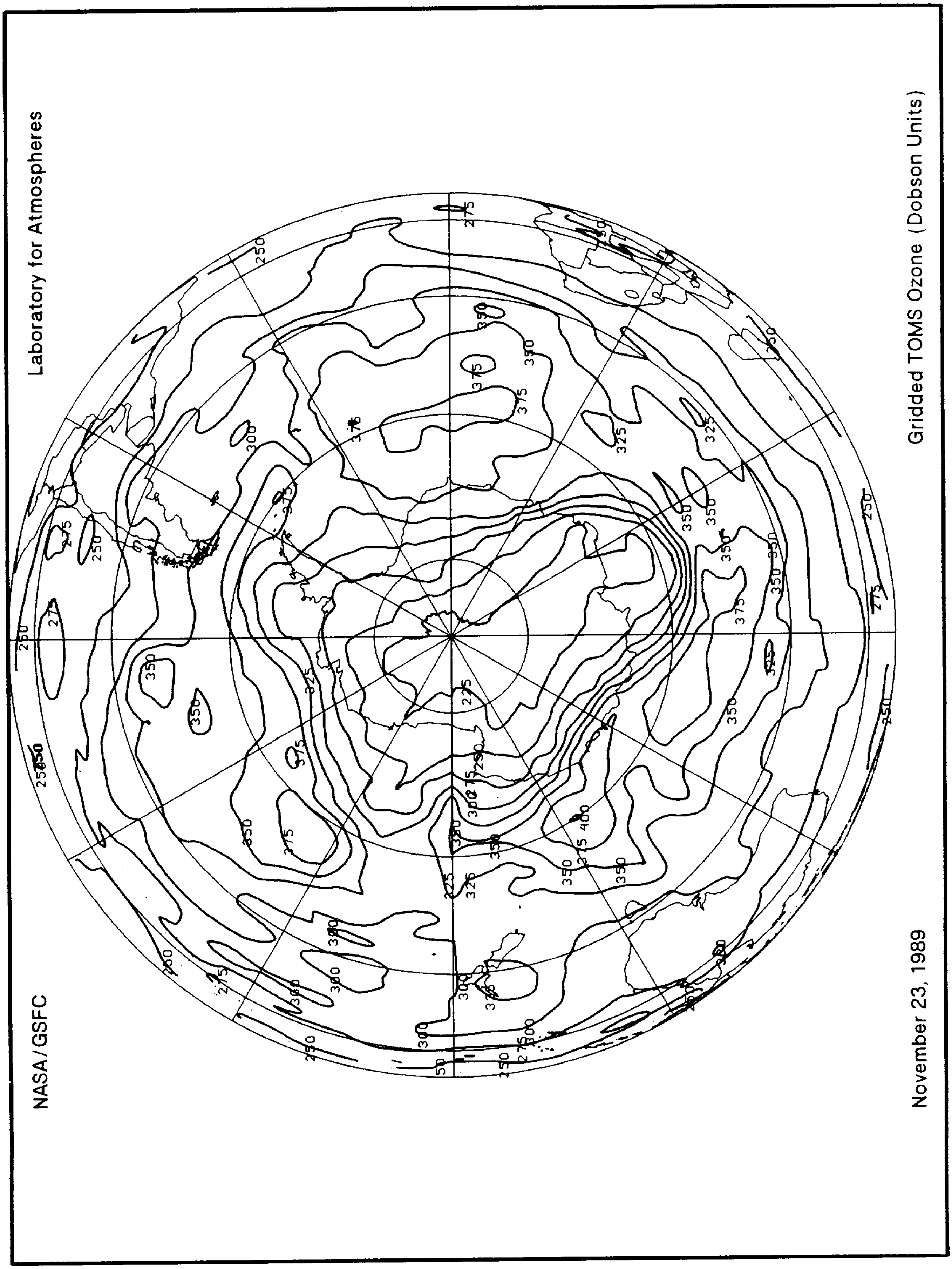
NASA/GSFC
November 22, 1989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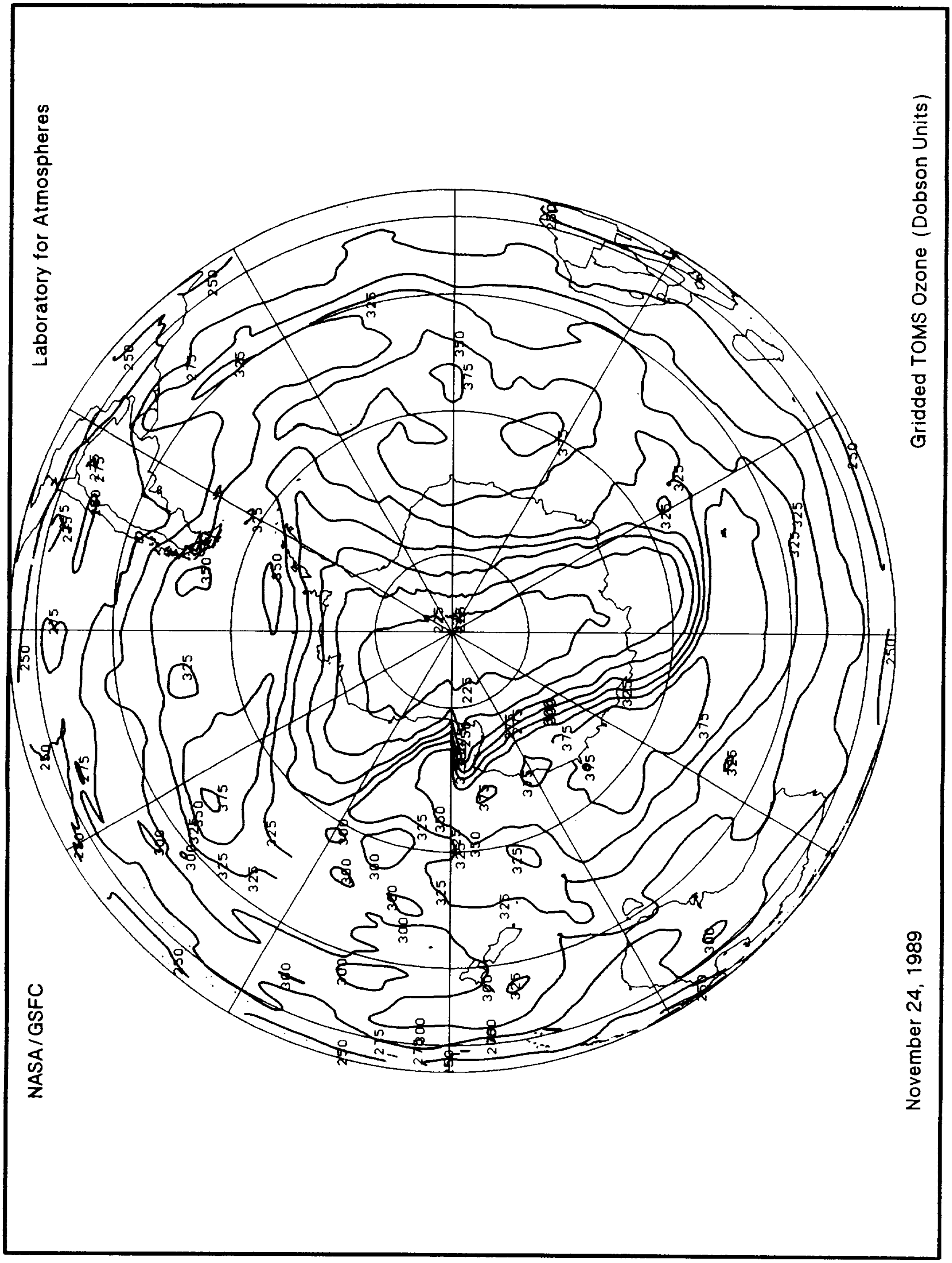
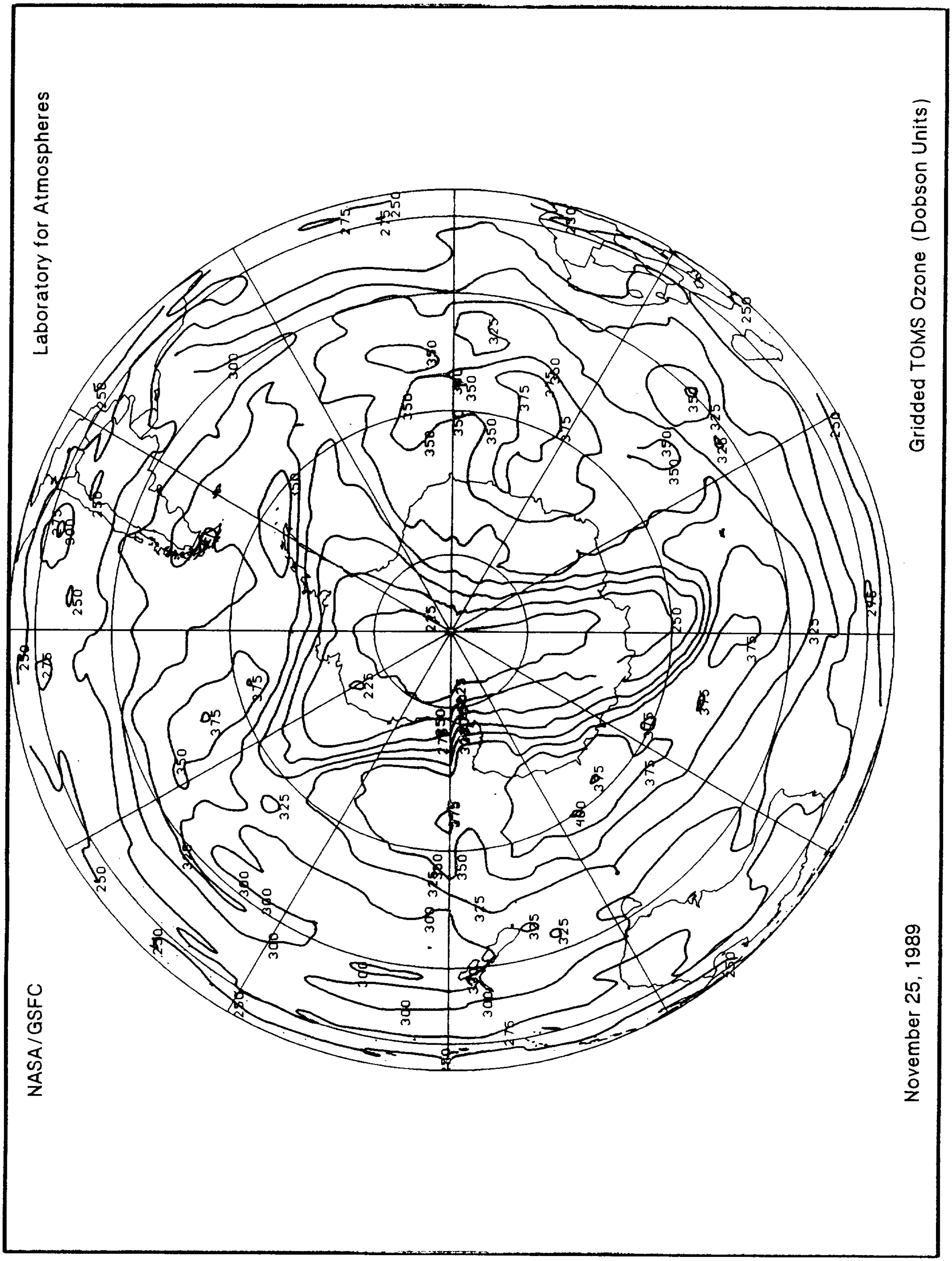
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
November 23, 1989



NASA/GSFC
Laboratory for Atmospheres
November 24, 1989
Gridded TOMS Ozone (Dobson Units)



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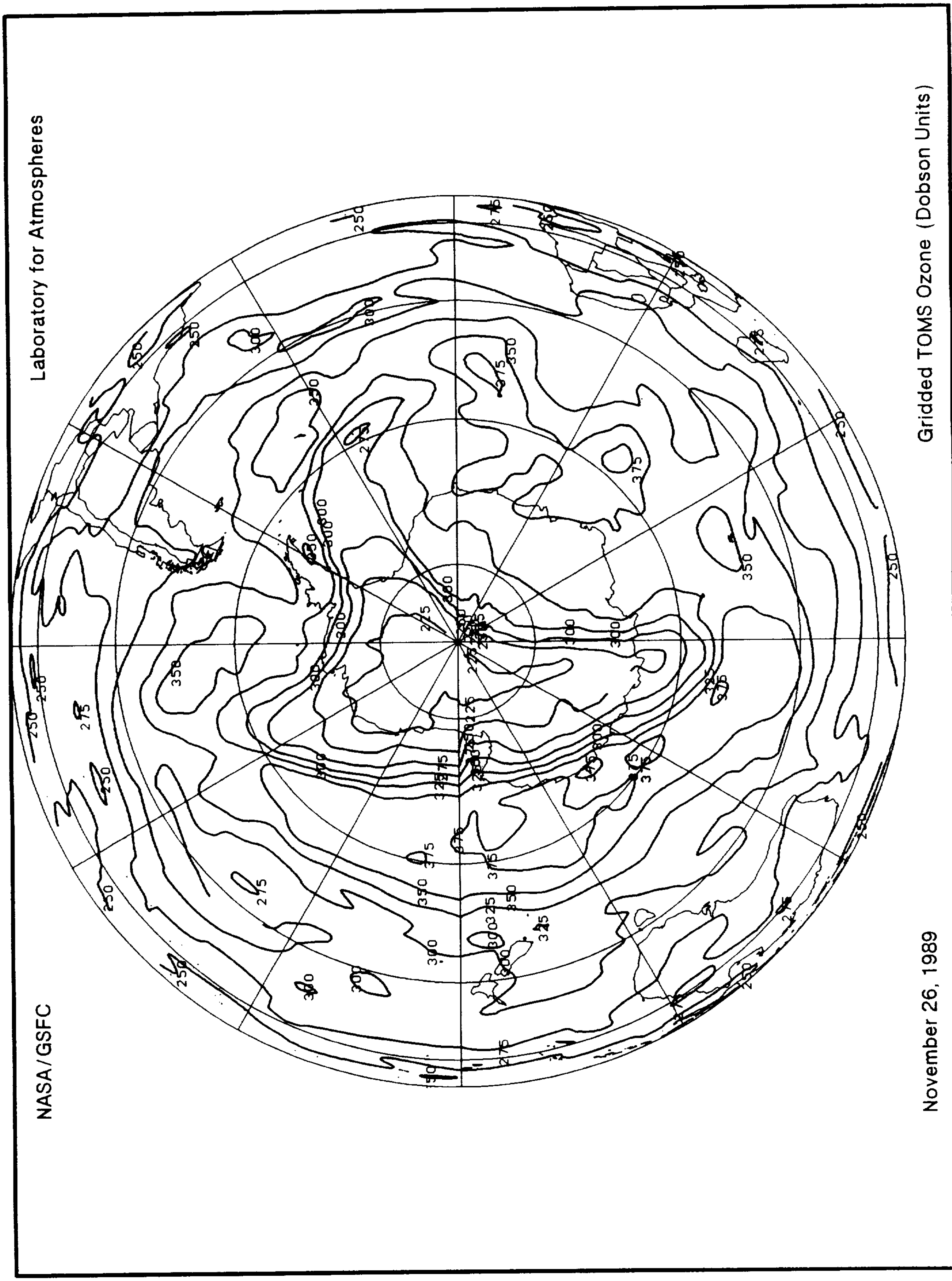
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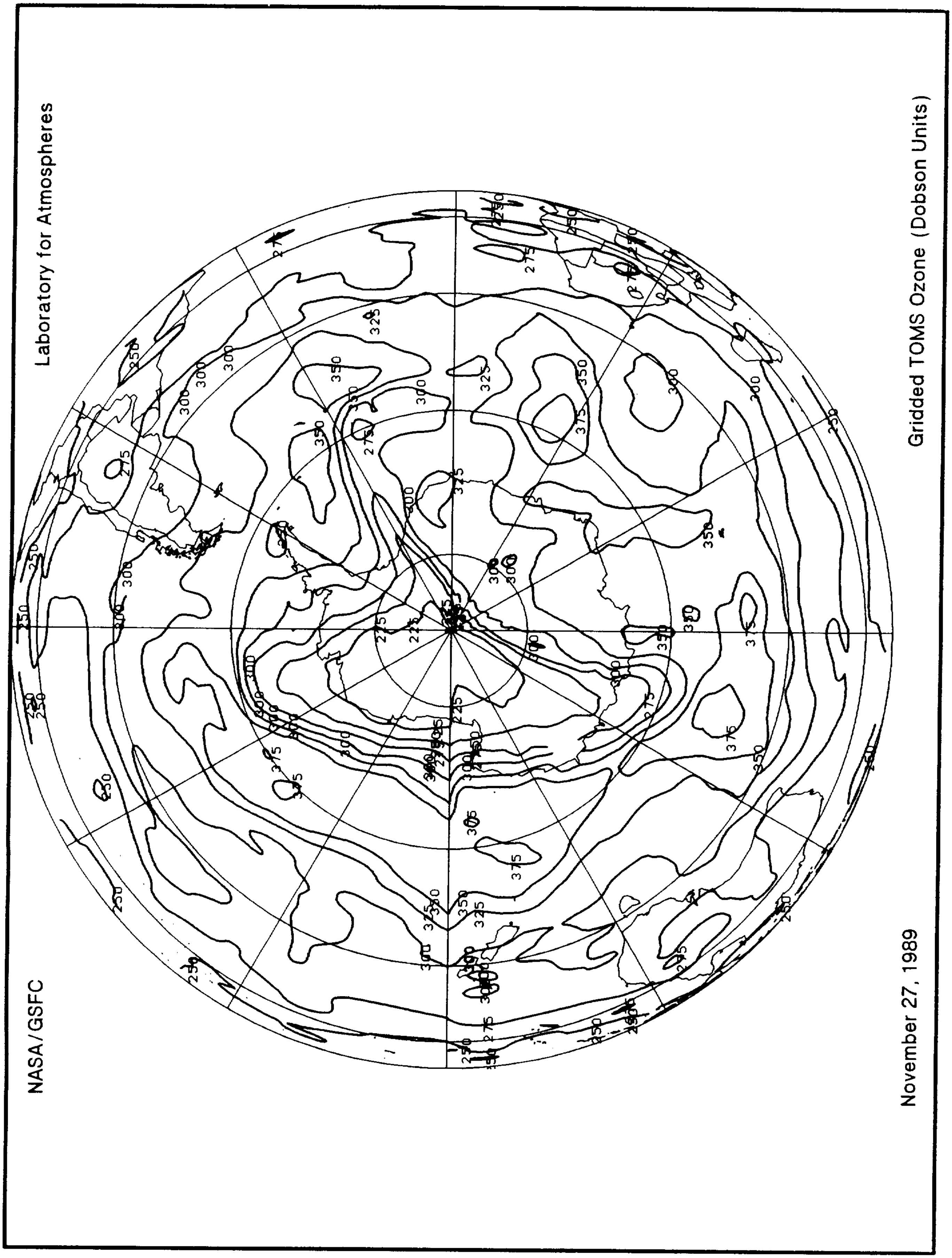
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
November 26, 1989



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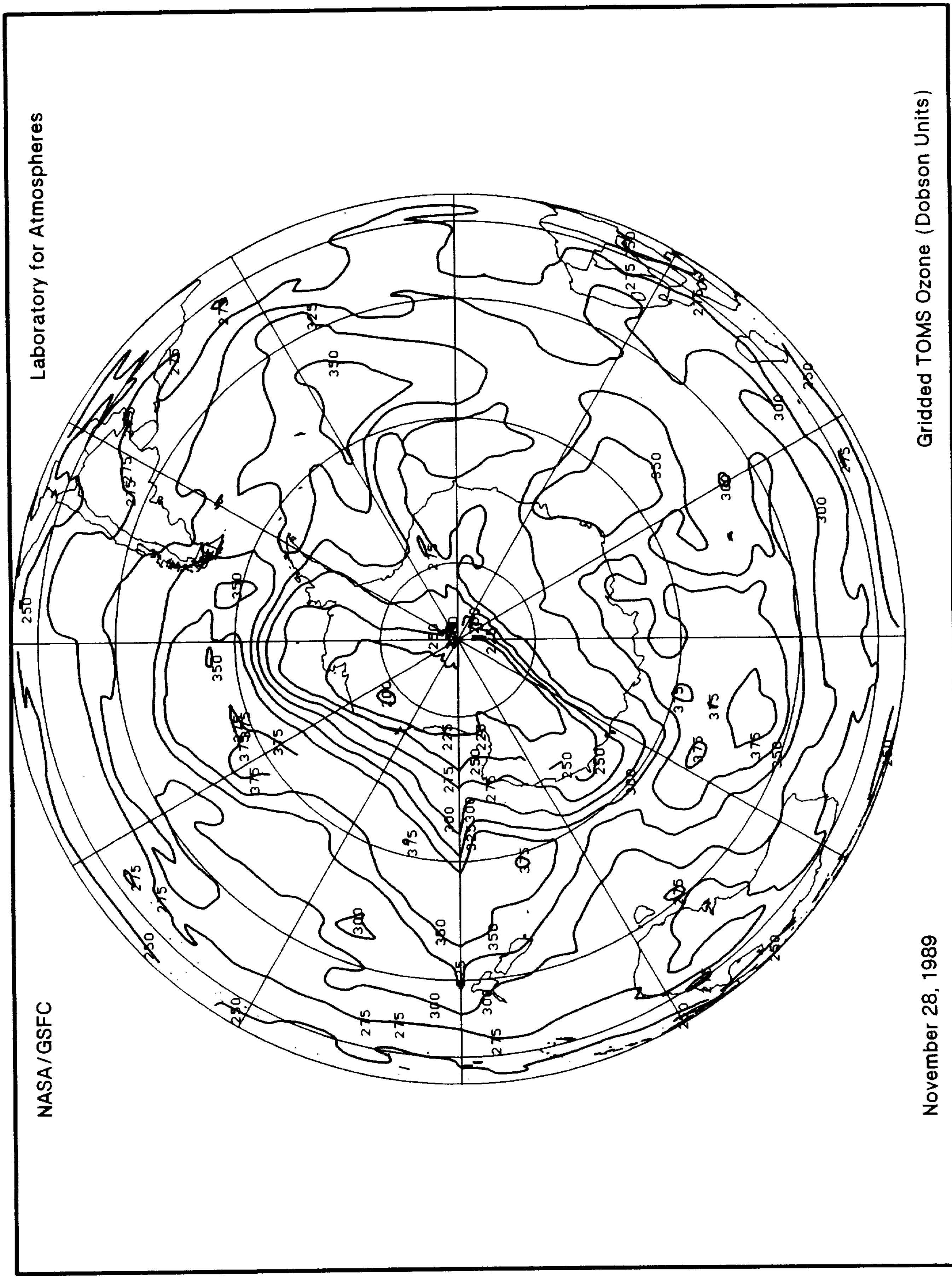
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NASA/GSFC
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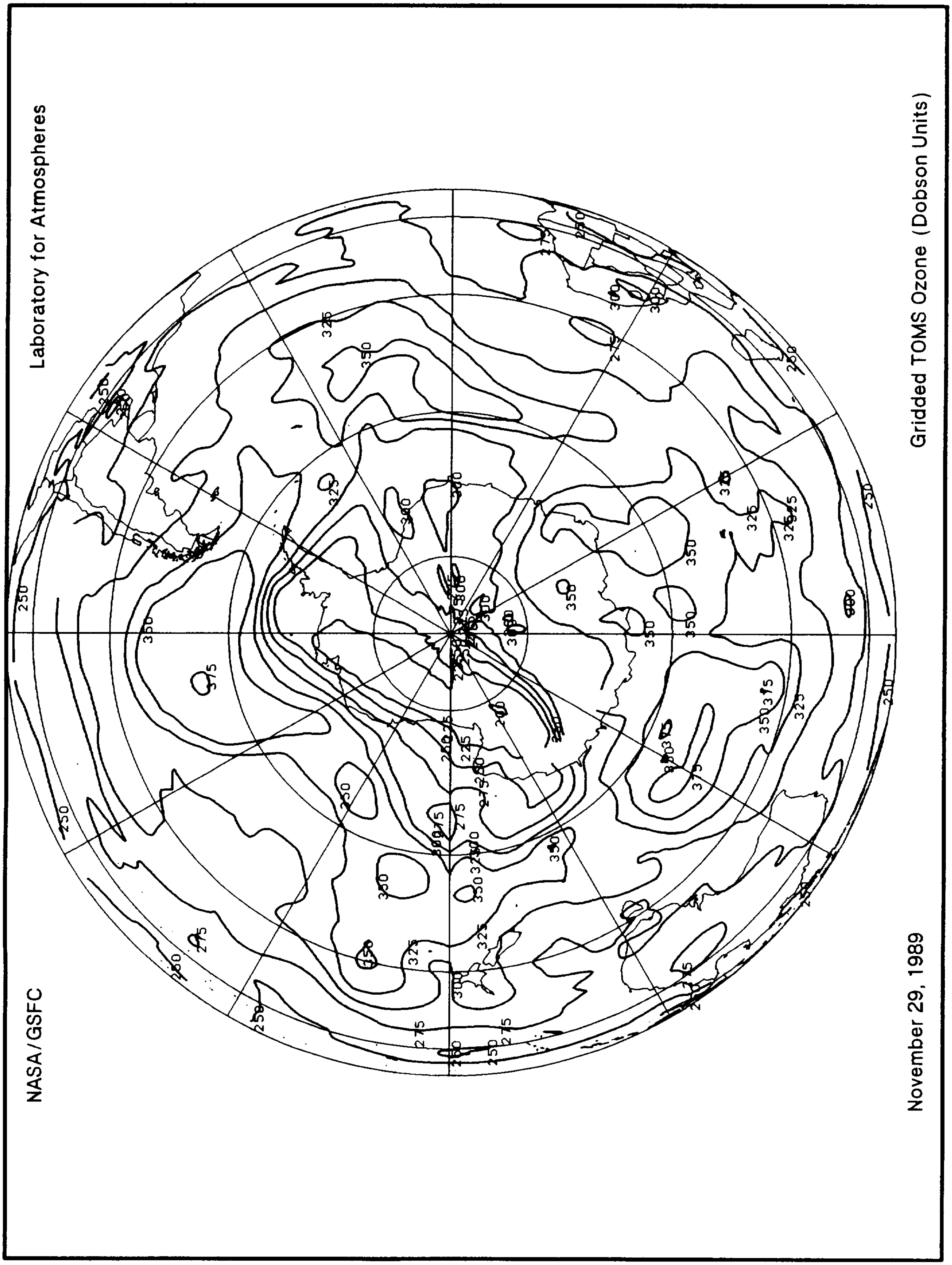
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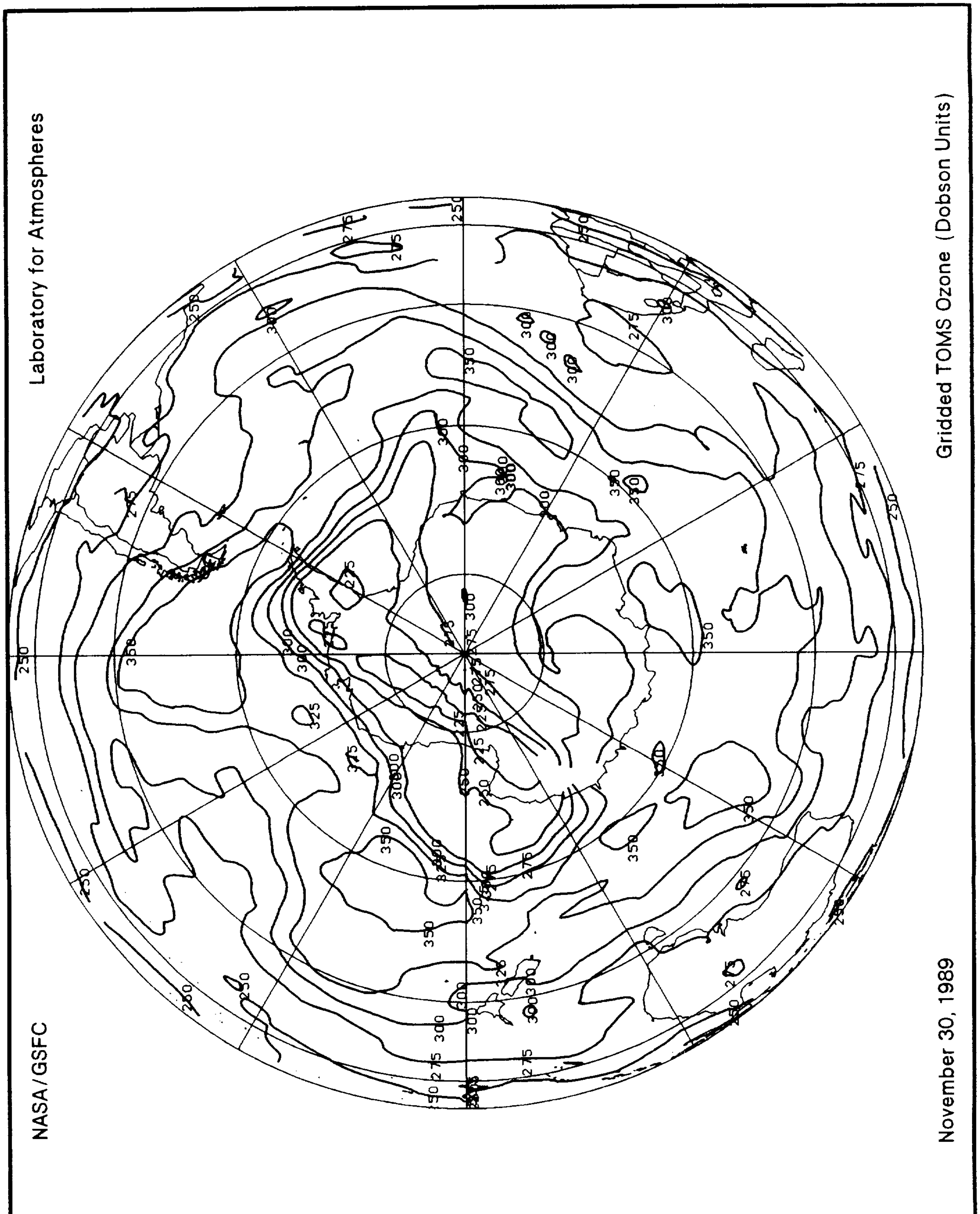
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
November 29, 1989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Laboratory for Atmospheres
November 30, 1989
Gridded TOMS Ozone (Dobson Units)

2.3 Time Series at Locations of Interest

Time series of TOMS total ozone estimates have been constructed for a set of eleven locations in Antarctica and two in South America. A similar time series for the 1987 experiment's base of operations in Punta Arenas was also produced. A list of selected locations, their abbreviations, their coordinates, and the coordinates 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 November 30, 1989. 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 and 1989, the years which have produced the most prominent ozone holes to date. The latitude and longitude provided in Figures 1a through 1m 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 26 (day 269) shortly after the spring equinox. Total ozone values fall steadily (Figure 1a), reaching a minimum of 126 DU on October 4 and 5 (days 277 and 278). The total ozone values for October 6 through October 9 (days 279 through 282) are missing, however, it was during this period that the hemispheric ozone minimum for 1989 was observed. Total ozone values remain below 150 DU until October 23 (day 296), then rise steadily as the ozone hole both weakens and moves off the pole. The ozone hole moves back over the pole during the last week of November causing total ozone values to drop from a maximum of 303 DU on day 321 to 212 DU on day 328.

B.A. Vice Comodoro Marambio (MAR)

The Marambio station is located at 64°S, just off the tip of the Antarctic Peninsula. The station remains below 308 DU from August 1 through November 4 (days 213 through 308) (Figure 1b). During this period, the station experiences significant fluctuation, as the ozone hole builds into and then recedes from the area. The absolute minimum of 157 DU is experienced on October 15 (day 288). A strong ozone maximum moves over the area on November 5 (day 309) raising the total ozone 95 DU in one day. Values remain above 300 DU, with a maximum of 407 DU thereafter. The 1989 October average ozone was 16% lower than in 1987.

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 mid-October (Figure 1c). Total ozone values are continuously below 275 DU during this period, with a minimum value of 173 DU on October 14 (day 287). Thereafter, strengthening ozone maxima north of the station tighten the ozone gradient in the region, causing wide fluctuations in total ozone values for the remainder of the period. A total ozone value of 225 DU on November 23 (day 327) indicates the ozone hole is still not far away even at this late date.

Dumont D'Urville (DUD)

The Dumont D'Urville station is located at 67°S on the Antarctic coast of Wilkes Land almost 180° in longitude away from the Antarctic Peninsula. The station lies within, but on the periphery of the developing ozone hole through early October, reaching a minimum of 211 DU on September 14 (day 257) (Figure 1d). Thereafter, building ozone maxima north of the station causes a general rise in total ozone over the station culminating in a value of 450 DU on November 1 (day 305). An ozone minimum of 222 DU interrupted this rise on October 19 (day 292) as the elongated ozone hole rotated through the area. Ozone maxima off the Antarctic coast weakened in November, causing total ozone values over the station to decline, as the station came under the influence of the still deep ozone hole once again.

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, although the Palmer Station averages 5 to 10 DU greater total ozone (Figures 1e and 1f). Total ozone values are generally steady through August, declining through September to a minimum in mid-October. A rapid rise is noted through early November, with values declining thereafter. The 1989 October average ozone was 20% lower than in 1987.

Halley Bay (HAL)

The total ozone measurements over Halley Bay at 76°S on the Weddell Sea first become available on August 19 (day 231). The total ozone values decrease steadily reaching a minimum of 134 DU on October 25 (day 298) (Figure 1g). Thereafter, the values rise steadily, reflecting the weakening of the ozone hole. A maximum of 364 DU occurs on November 18 (day 322) as an ozone maximum over the Antarctic Peninsula briefly builds into the area.

McMurdo (MCM)

The McMurdo station is located at 78°S on McMurdo Sound near the dateline. Total ozone measurements first become available on August 26 (day 238). Ozone values steadily decline (Figure 1h), reaching a minimum of 159 DU on September 24 (day 267). Values remain steady between 150 and 200 DU until building ozone values over Wilkes Land begin to push the ozone hole away from McMurdo in mid-October. Total ozone values climb to a maximum of 371 DU on November 1 (day 305). Ozone values fall throughout November as the ozone maxima weaken and the hole becomes more symmetric with respect to the pole. Total ozone of 212 DU on November 30 (day 334) is still quite low.

Molodeznaya (MOL)

The Molodeznaya station is located in coastal Antarctica at 68°S in eastern Queen Maude Land. The station remains under the influence of the ozone hole throughout most of the period (Figure 1i), reaching a minimum total ozone value of 162 DU on October 1 (day 274). Values remain below 300 DU until an ozone maxima builds into the area on November 24 (day 328) resulting in a one day rise of 86 DU. Total ozone values remain high for the final week of the period.

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 until November 3 (day 307) (Figure 1j). Periodically, as the hole rotates, total ozone values fall, reaching a minimum of 228 DU on October 28 (day 301). After November 3, the hole ceases to affect the area, and values remain above 300 DU.

Syowa (SYO)

Syowa is located at 69°S, quite close to Molodeznaya. As such, the two time series are highly correlated (Figure 1k).

Ushuaia (USH)

Ushuaia is located at 54°S, 68°W in Argentina. The total ozone observations (Figure 1l) 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 25 (day 237). Values decline steadily (Figure 1m), reaching a minimum of 142 DU on October 6 (day 279). The station thereafter remains under the influence of the weakening ozone hole, although ozone maxima build toward the station on November 7 through 10 and November 27 through 30.

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		-90.0	
Marambio (MAR)	-64.2	-56.7	-64.0	-57.5
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
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	MAR	DAV	DUD	FAR	HAL	MCM	MOL	PAL	PUN	SYO	USH	VOS
213	AUG 1	***	266	233	257	265	***	***	278	271	287	281	288	***
214	AUG 2	***	259	254	271	260	***	***	265	253	238	270	223	***
215	AUG 3	***	254	272	250	254	***	***	281	258	306	281	291	***
216	AUG 4	***	257	272	259	256	***	***	283	263	307	280	302	***
217	AUG 5	***	264	268	286	257	***	***	251	271	289	253	280	***
218	AUG 6	***	272	254	273	264	***	***	251	270	340	266	331	***
219	AUG 7	***	279	247	274	273	***	***	248	278	288	254	294	***
220	AUG 8	***	262	242	274	267	***	***	254	266	333	264	303	***
221	AUG 9	***	279	243	281	276	***	***	259	284	359	262	352	***
222	AUG 10	***	284	252	271	275	***	***	237	283	304	244	294	***
223	AUG 11	***	270	227	260	259	***	***	230	266	307	247	290	***
224	AUG 12	***	264	235	263	256	***	***	258	261	291	258	273	***
225	AUG 13	***	258	255	279	247	***	***	256	263	353	253	337	***
226	AUG 14	***	269	263	283	257	***	***	261	271	319	264	334	***
227	AUG 15	***	259	242	274	260	***	***	249	262	333	264	319	***
228	AUG 16	***	270	224	277	257	***	***	249	266	347	264	343	***
229	AUG 17	***	254	220	260	250	***	***	263	248	317	274	308	***
230	AUG 18	***	268	236	262	280	***	***	264	280	297	263	309	***
231	AUG 19	***	262	230	292	261	250	***	259	269	279	259	298	***
232	AUG 20	***	242	248	302	243	245	***	223	235	250	232	245	***
233	AUG 21	***	213	229	282	210	262	***	252	219	266	256	270	***
234	AUG 22	***	238	247	281	232	251	***	224	240	303	226	294	***
235	AUG 23	***	254	219	247	245	223	***	255	248	327	253	307	***
236	AUG 24	***	247	230	255	250	203	***	265	248	360	261	349	***
237	AUG 25	***	265	263	278	268	233	***	257	273	386	256	355	258
238	AUG 26	***	266	259	259	288	222	240	246	280	364	246	359	253
239	AUG 27	***	306	252	239	292	216	262	246	303	303	254	310	235
240	AUG 28	***	280	258	259	252	221	254	250	268	360	247	352	218
241	AUG 29	***	271	225	237	247	221	233	251	263	323	246	325	211
242	AUG 30	***	277	219	239	245	204	242	251	267	278	252	278	213
243	AUG 31	***	249	230	247	224	217	250	234	233	294	242	286	238
244	SEP 1	***	254	224	241	238	226	244	226	247	315	230	311	213
245	SEP 2	***	249	220	262	232	212	246	215	240	326	217	318	210
246	SEP 3	***	238	227	280	228	217	230	218	234	320	222	303	211
247	SEP 4	***	242	222	288	237	225	224	219	242	309	222	293	208

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

DAY	DATE	SPO	MAR	DAV	DUD	FAR	HAL	MCM	MOL	PAL	PUN	SYO	USH	VOS
248	SEP 5	***	224	242	280	230	227	206	229	226	317	221	296	204
249	SEP 6	***	233	221	254	233	231	216	233	235	304	238	299	196
250	SEP 7	***	239	215	256	236	228	206	227	235	313	235	294	206
251	SEP 8	***	239	212	248	227	221	211	240	226	317	250	294	200
252	SEP 9	***	209	226	272	190	207	207	240	194	314	255	285	208
253	SEP 10	***	181	231	276	177	206	211	248	178	274	264	266	214
254	SEP 11	***	203	219	282	190	197	204	242	201	242	250	248	200
255	SEP 12	***	266	226	264	267	187	197	254	274	258	271	268	198
256	SEP 13	***	272	242	223	240	197	185	270	266	296	275	296	209
257	SEP 14	***	239	255	211	221	190	200	289	234	256	319	244	213
258	SEP 15	***	242	251	230	233	187	199	305	251	306	305	285	203
259	SEP 16	***	308	239	224	278	187	195	255	314	351	252	341	192
260	SEP 17	***	307	230	232	281	196	196	210	298	343	201	345	192
261	SEP 18	***	296	199	241	269	198	193	188	292	378	194	397	161
262	SEP 19	***	275	195	255	236	183	172	203	267	305	211	331	143
263	SEP 20	***	256	210	245	228	177	173	239	263	289	254	289	147
264	SEP 21	***	231	255	225	199	176	179	229	221	285	220	301	151
265	SEP 22	***	212	218	235	213	172	164	197	210	294	195	287	156
266	SEP 23	***	189	194	276	178	182	172	203	203	272	210	278	154
267	SEP 24	***	242	200	231	233	152	159	221	247	328	212	301	156
268	SEP 25	***	287	248	257	260	159	173	217	276	323	222	316	146
269	SEP 26	161	256	223	246	254	180	160	200	260	315	195	307	153
270	SEP 27	156	260	189	298	260	174	170	187	268	320	190	322	170
271	SEP 28	148	289	197	311	268	175	179	188	284	362	197	363	163
272	SEP 29	145	251	205	256	229	164	187	185	242	382	179	370	161
273	SEP 30	144	261	209	294	228	145	176	175	256	287	171	283	148
274	OCT 1	146	228	200	313	202	163	164	162	227	296	179	291	140
275	OCT 2	137	195	192	292	168	155	165	182	182	297	194	281	145
276	OCT 3	129	174	193	294	168	153	163	185	165	323	194	302	165
277	OCT 4	126	226	174	340	218	143	181	226	222	328	241	326	167
278	OCT 5	126	236	213	336	184	167	194	249	220	332	247	328	148
279	OCT 6	***	180	261	271	172	150	180	209	176	281	210	300	142
280	OCT 7	***	169	223	298	162	150	168	195	168	253	194	239	164
281	OCT 8	***	225	233	310	205	137	174	208	225	260	201	256	162
282	OCT 9	***	252	258	334	233	143	169	199	252	283	178	267	166

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

DAY	DATE	SPO	MAR	DAV	DUD	FAR	HAL	MCM	MOL	PAL	PUN	SYO	USH	VOS
283	OCT 10	135	236	264	356	222	147	160	200	236	318	190	330	159
284	OCT 11	139	243	272	389	216	143	193	202	240	314	187	305	193
285	OCT 12	140	208	275	427	167	145	205	196	176	303	197	330	223
286	OCT 13	141	206	217	413	200	158	254	169	221	262	167	263	222
287	OCT 14	131	172	173	409	153	157	255	197	170	280	208	260	167
288	OCT 15	136	157	185	409	150	145	246	244	151	221	237	207	180
289	OCT 16	142	164	250	367	164	143	245	236	165	223	224	205	161
290	OCT 17	140	176	216	308	179	135	224	251	173	229	260	232	152
291	OCT 18	139	194	265	251	182	137	208	280	193	238	256	227	149
292	OCT 19	141	213	318	222	206	144	185	288	213	289	263	265	153
293	OCT 20	146	229	330	291	218	142	161	301	232	304	275	292	200
294	OCT 21	149	195	342	392	182	157	191	287	190	308	261	298	213
295	OCT 22	146	197	359	399	185	163	196	286	204	304	256	288	219
296	OCT 23	164	191	359	409	174	143	202	273	191	288	254	260	234
297	OCT 24	179	205	318	415	186	146	247	234	201	304	217	300	233
298	OCT 25	171	191	301	407	181	134	242	220	191	236	200	234	210
299	OCT 26	155	184	285	449	165	156	250	206	171	235	197	234	211
300	OCT 27	162	161	258	443	183	188	286	246	164	256	216	236	222
301	OCT 28	171	185	338	425	188	185	285	225	184	228	219	225	218
302	OCT 29	178	178	266	435	175	174	298	239	171	249	216	232	223
303	OCT 30	181	243	268	443	254	175	307	224	259	258	219	233	209
304	OCT 31	174	230	292	433	217	179	312	209	232	289	195	276	245
305	NOV 1	194	203	227	450	192	174	371	213	192	257	210	233	250
306	NOV 2	194	202	253	363	183	164	363	269	202	273	276	232	240
307	NOV 3	200	215	277	409	224	165	312	277	226	337	244	330	222
308	NOV 4	200	234	347	353	257	177	292	243	268	332	206	320	199
309	NOV 5	190	329	304	417	337	182	230	213	326	359	209	345	219
310	NOV 6	179	317	316	436	325	203	265	228	321	349	201	334	215
311	NOV 7	185	336	316	421	339	188	282	223	333	339	204	343	257
312	NOV 8	215	352	313	428	340	192	314	239	345	345	217	342	290
313	NOV 9	240	350	317	428	352	200	340	229	350	348	221	348	296
314	NOV 10	266	347	301	410	354	214	353	238	359	358	214	372	292
315	NOV 11	271	341	313	390	348	234	331	219	341	339	210	327	263
316	NOV 12	258	349	302	387	358	251	320	224	348	353	209	350	267
317	NOV 13	255	371	272	384	387	264	300	211	384	364	206	368	263

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

DAY	DATE	SPO	MAR	DAV	DUD	FAR	HAL	MCM	MOL	PAL	PUN	SYO	USH	VOS
318	NOV 14	263	385	248	349	388	256	310	219	392	376	217	378	241
319	NOV 15	266	407	272	319	413	269	310	247	399	367	244	365	230
320	NOV 16	289	403	325	265	403	293	316	262	395	348	247	353	212
321	NOV 17	303	401	321	258	402	332	301	253	394	363	232	368	208
322	NOV 18	283	399	275	339	403	364	256	244	390	353	233	378	222
323	NOV 19	237	378	246	342	387	359	236	235	378	348	231	345	238
324	NOV 20	221	374	241	292	378	320	281	235	370	342	252	359	238
325	NOV 21	233	363	233	296	348	310	268	244	347	354	244	354	224
326	NOV 22	231	316	245	287	323	286	249	216	316	316	231	324	212
327	NOV 23	213	343	225	374	327	302	231	244	332	323	330	325	215
328	NOV 24	212	325	229	379	319	305	257	332	339	339	344	326	221
329	NOV 25	222	360	254	385	351	296	293	350	360	324	362	321	223
330	NOV 26	225	340	325	381	331	283	260	347	323	305	362	305	224
331	NOV 27	216	344	332	313	345	249	236	346	356	319	357	326	285
332	NOV 28	233	328	345	247	311	303	226	348	323	335	360	322	305
333	NOV 29	260	328	335	293	309	296	214	360	329	327	324	322	310
334	NOV 30	276	349	338	333	269	254	212	315	341	352	308	346	321

Table 3 Monthly Mean Comparisons								
Station Name	August		September		October		November	
	1987	1989	1987	1989	1987	1989	1987	1989
Amundsen-Scott	***	***	134*	151*	137	149	182	234
Marambio	273	263	242	248	240	201	277	336
Davis	248	243	229	221	233	261	286	288
Dumont D'Urville	273	267	258	256	315	364	319	358
Faraday Station	261	257	230	233	234	189	255	333
Halley Bay	247*	228*	190	193	157	153	193	256
McMurdo	243*	247*	202	194	186	216	217	284
Molodeznaya	244	253	226	225	214	227	272	261
Palmer Station	275	263	243	246	246	199	272	336
Punta Arenas	326	313	308	310	315	277	326	338
Syowa	246	257	227	229	209	218	267	257
Ushuaia	316	306	307	304	305	268	327	335
Vostok	244*	232*	190	183	166	187	216	247

*Calculated from partial month of data.

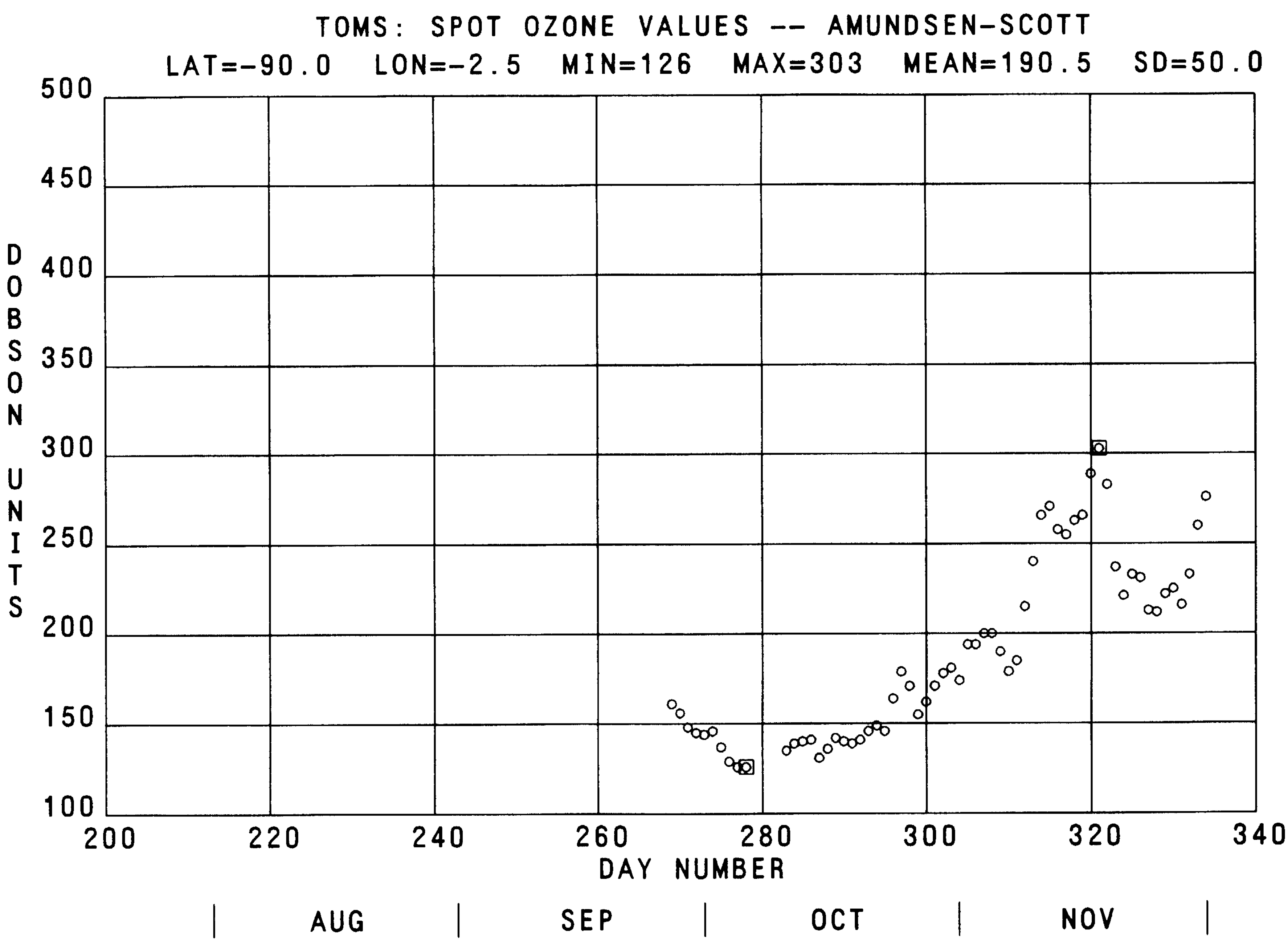

Figure 1a. Daily TOMS Total Ozone Values over Amundsen-Scott (DU) for 1989.

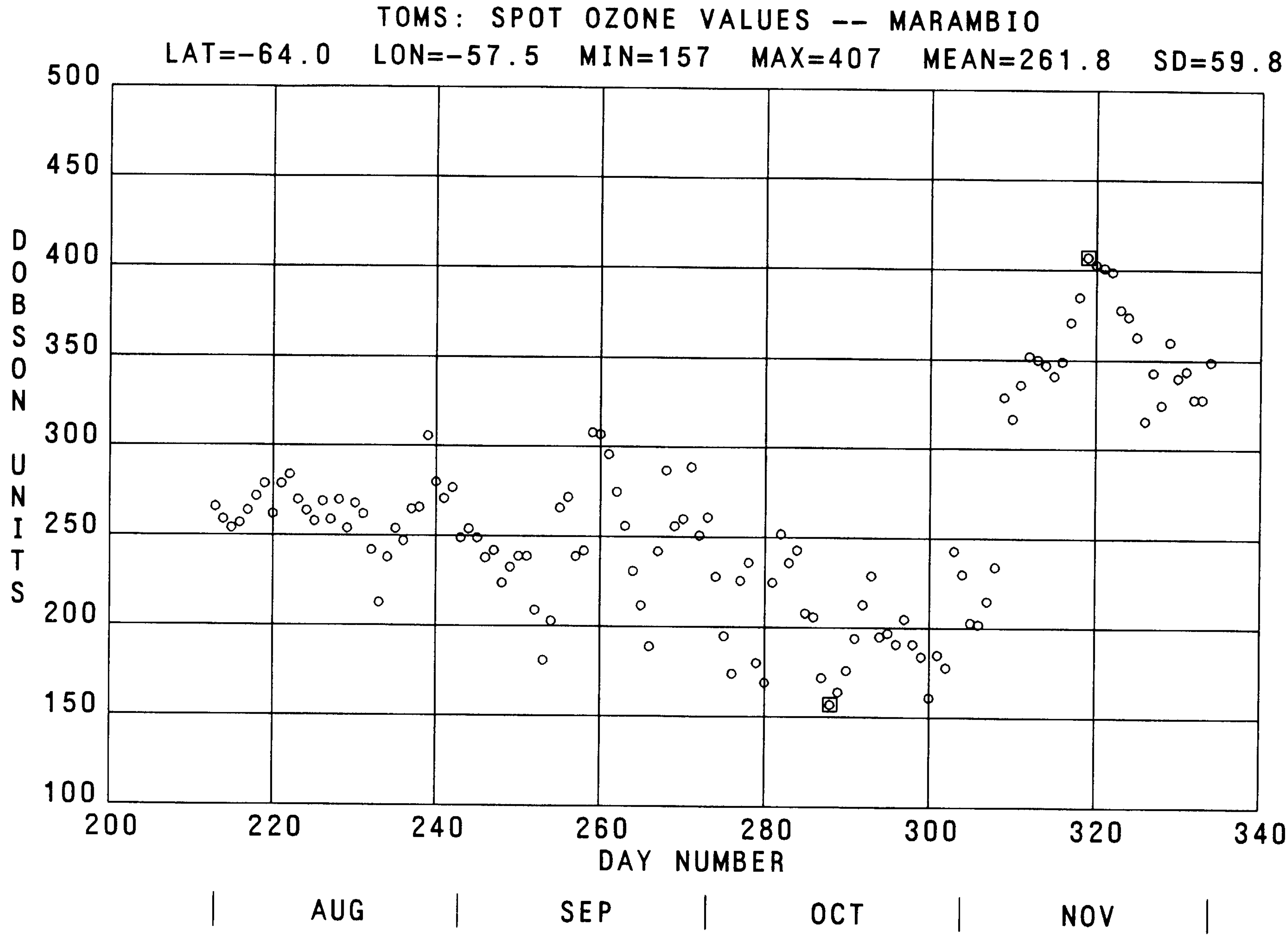

Figure 1b. Daily TOMS Total Ozone Values over Marambio (DU) for 1989.

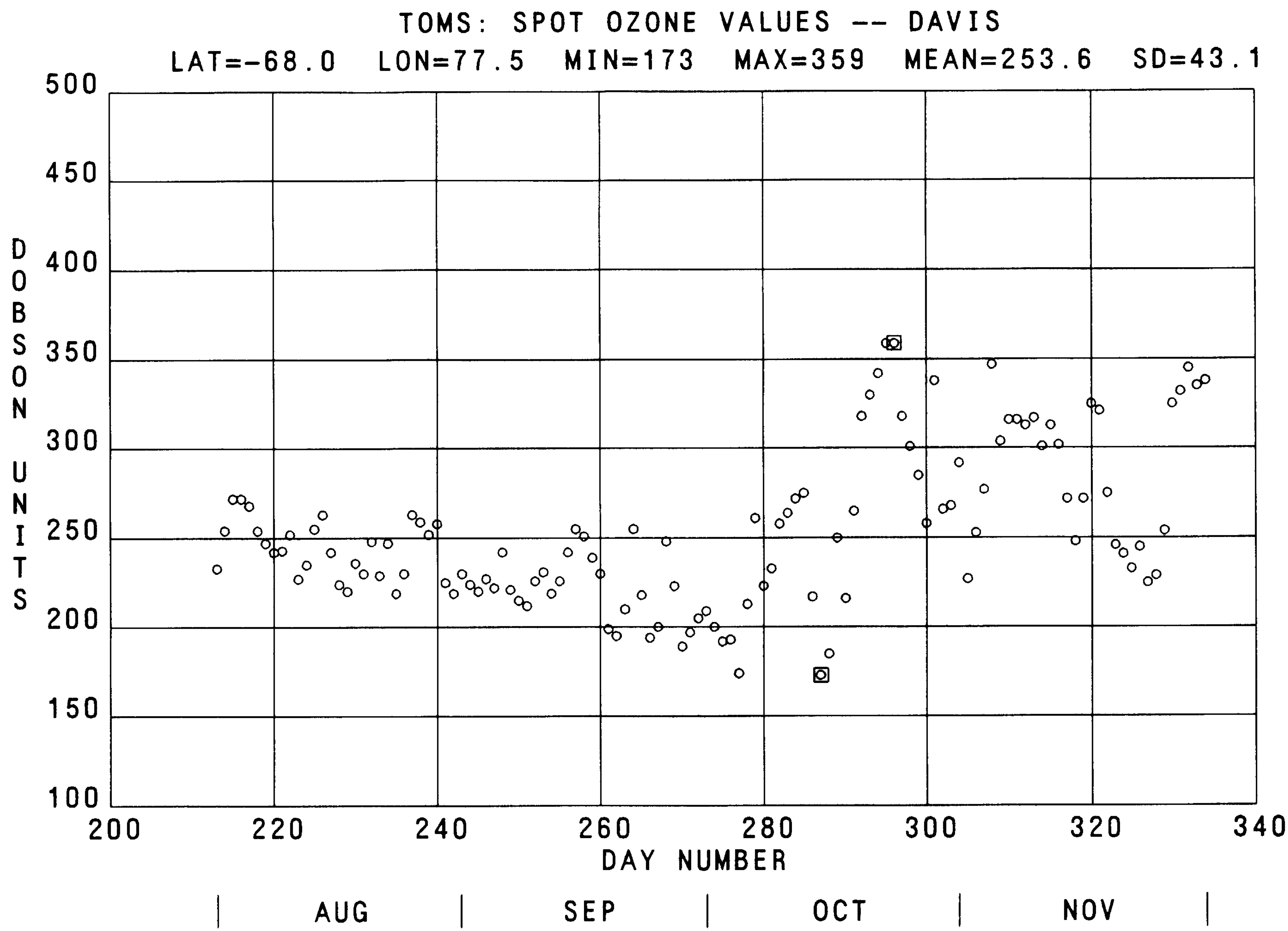

Figure 1c. Daily TOMS Total Ozone Values over Davis (DU) for 1989.

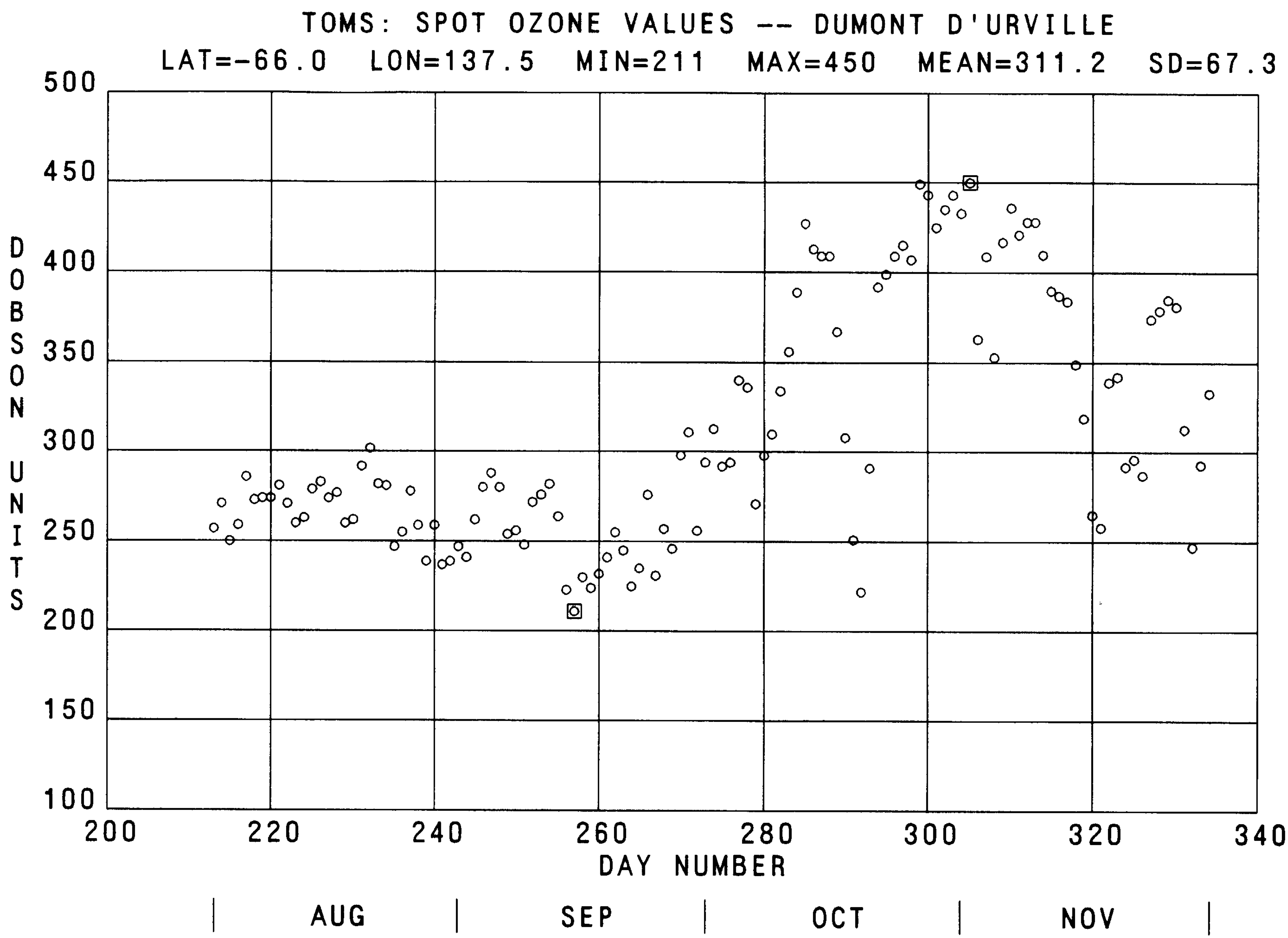

Figure 1d. Daily TOMS Total Ozone Values over Dumont D'Urville (DU) for 1989.

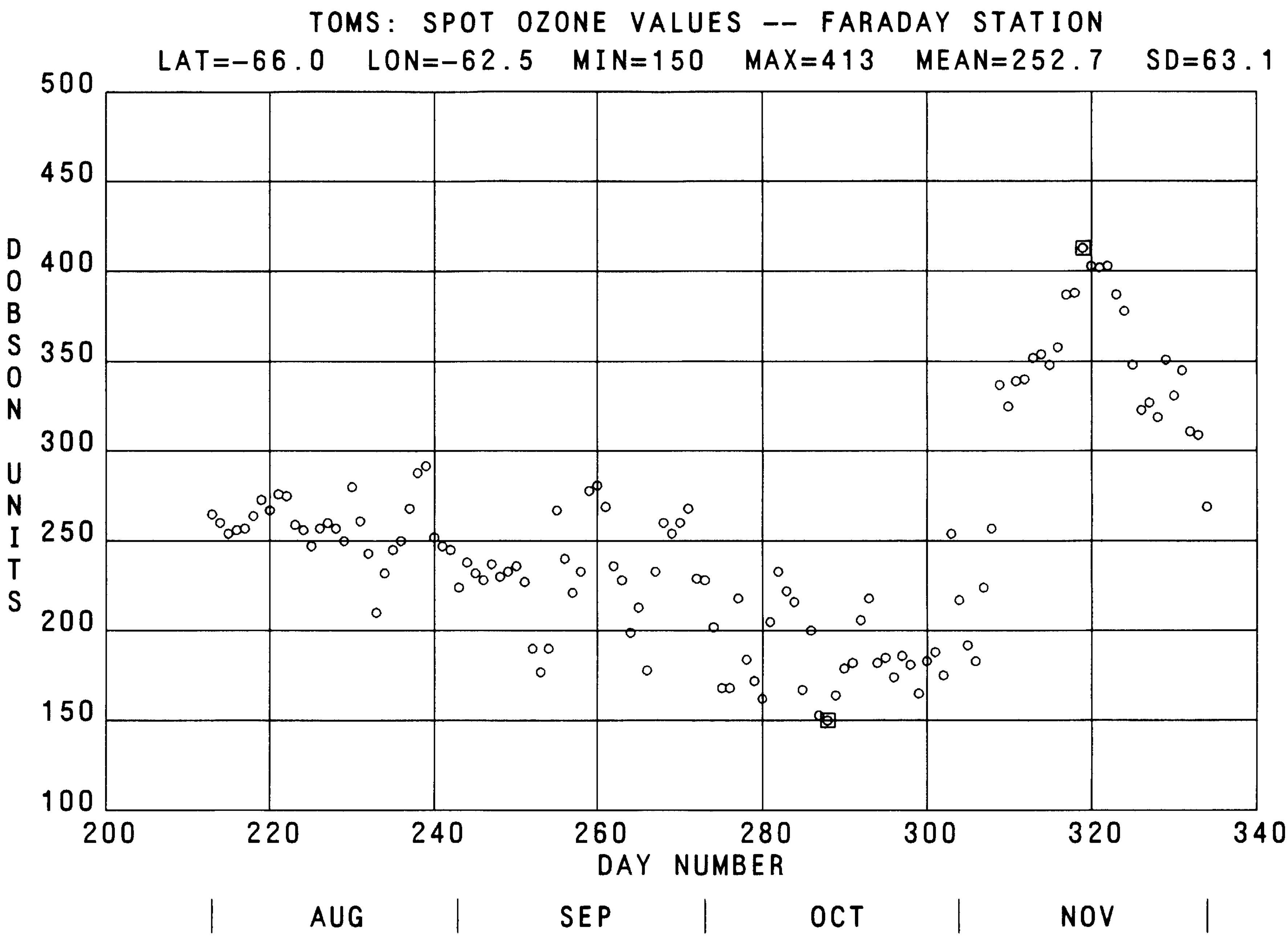

Figure 1e. Daily TOMS Total Ozone Values over Faraday Station (DU) for 1989.

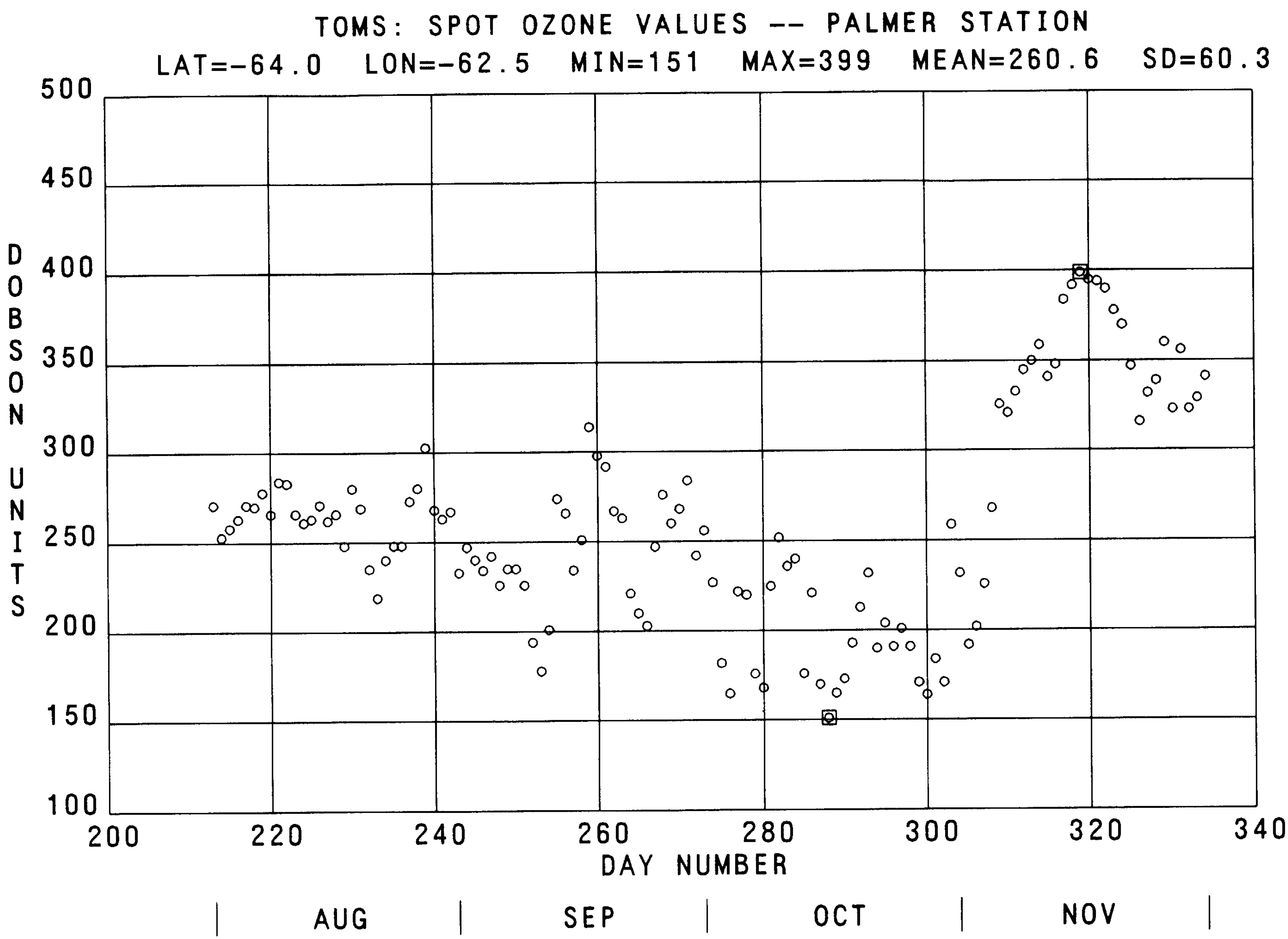

Figure 1f. Daily TOMS Total Ozone Values over Palmer Station (DU) for 1989.

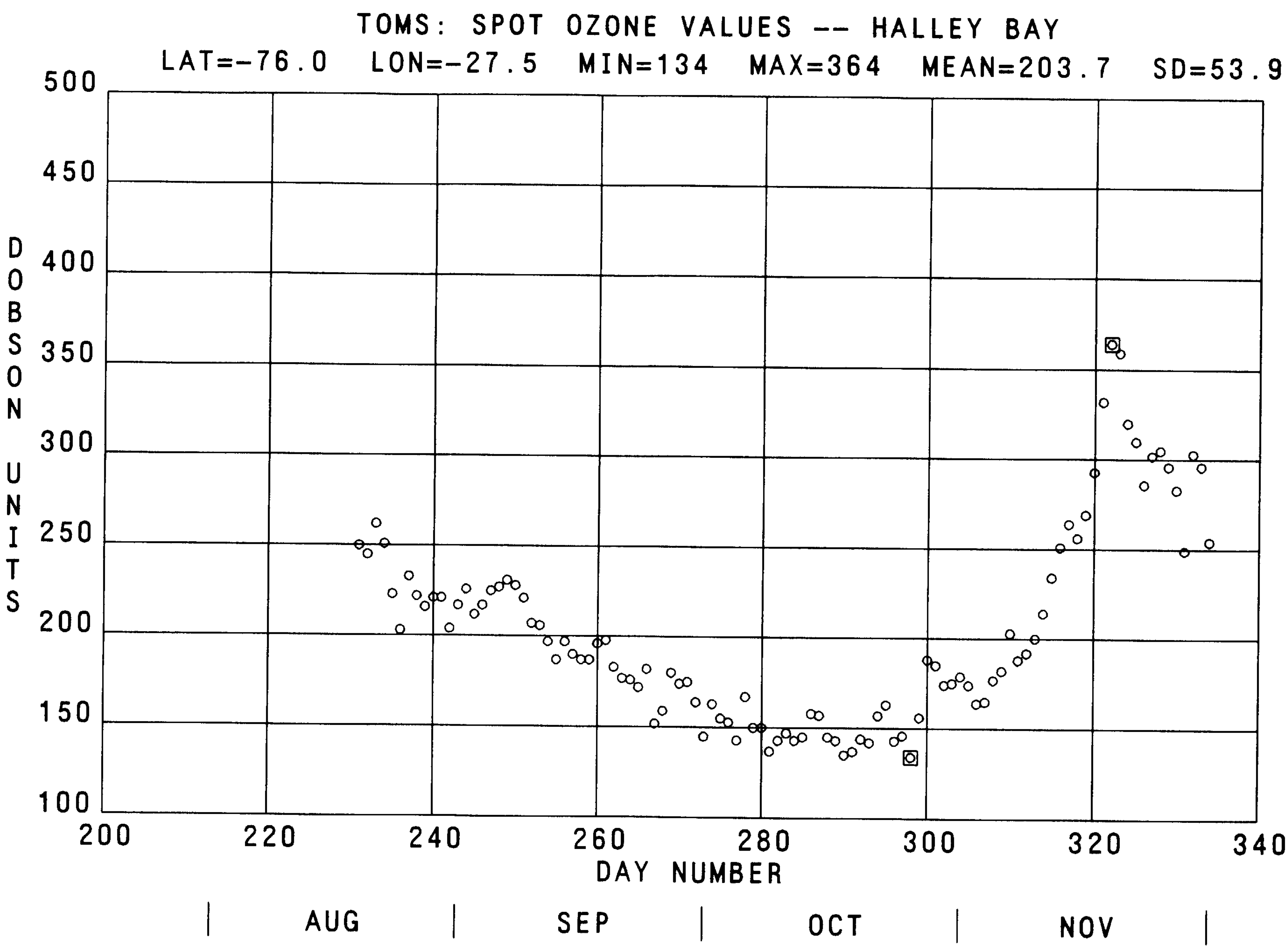

Figure 1g. Daily TOMS Total Ozone Values over Halley Bay (DU) for 1989.

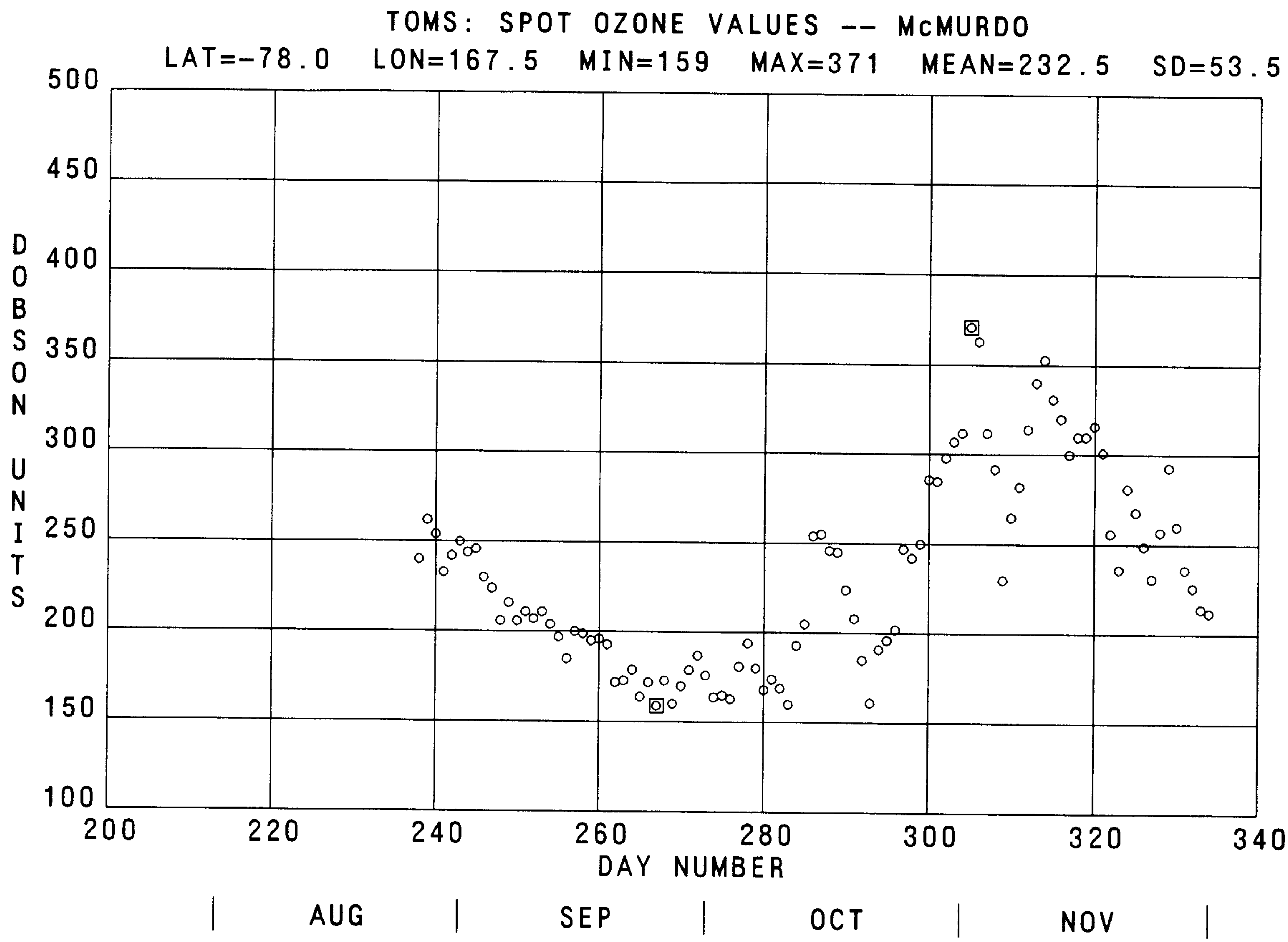

Figure 1h. Daily TOMS Total Ozone Values over McMurdo (DU) for 1989.

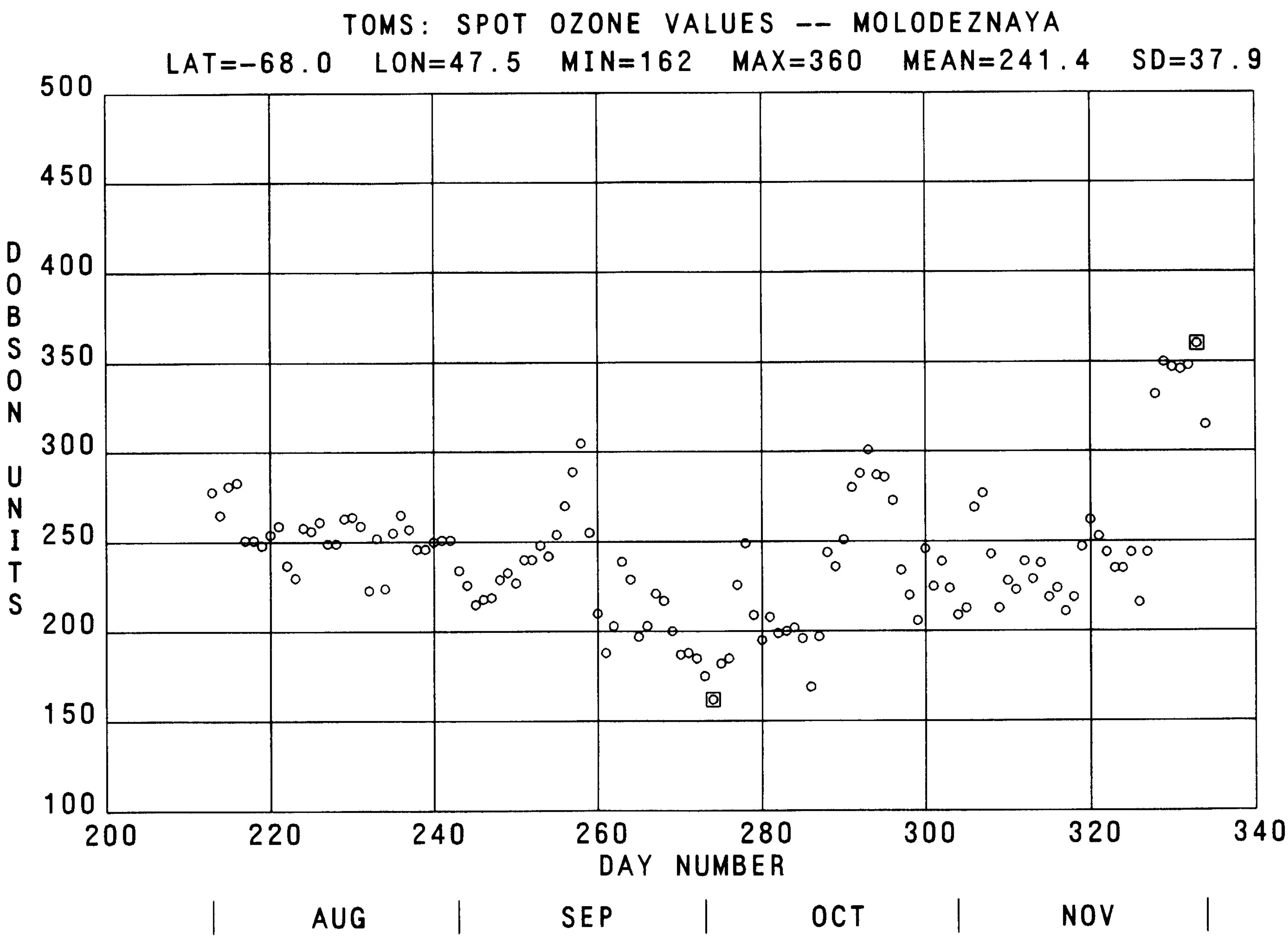

Figure 1i. Daily TOMS Total Ozone Values over Molodeznaya (DU) for 1989.

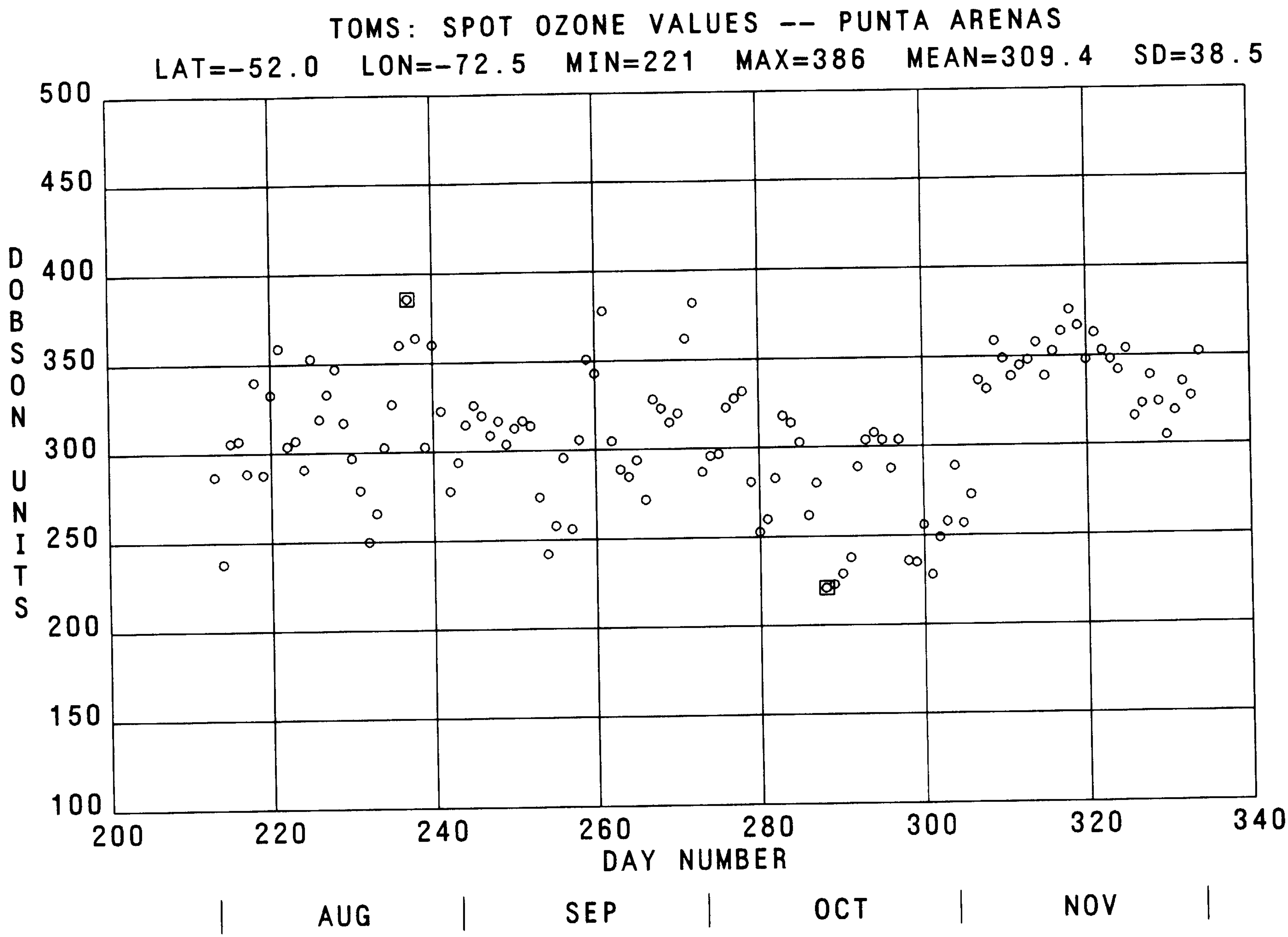

Figure 1j. Daily TOMS Total Ozone Values over Punta Arenas (DU) for 1989.

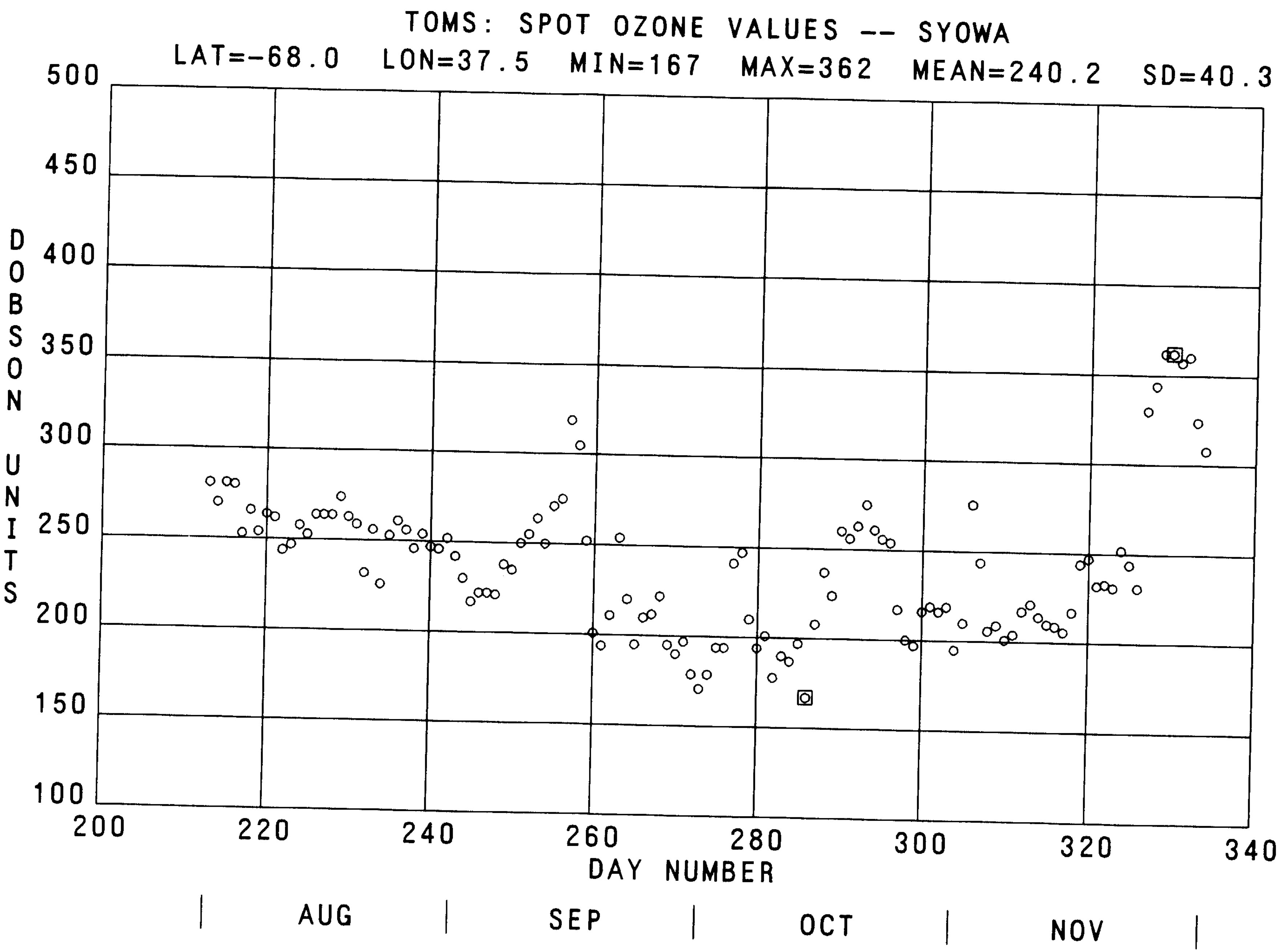

Figure 1k. Daily TOMS Total Ozone Values over Syowa (DU) for 1989.

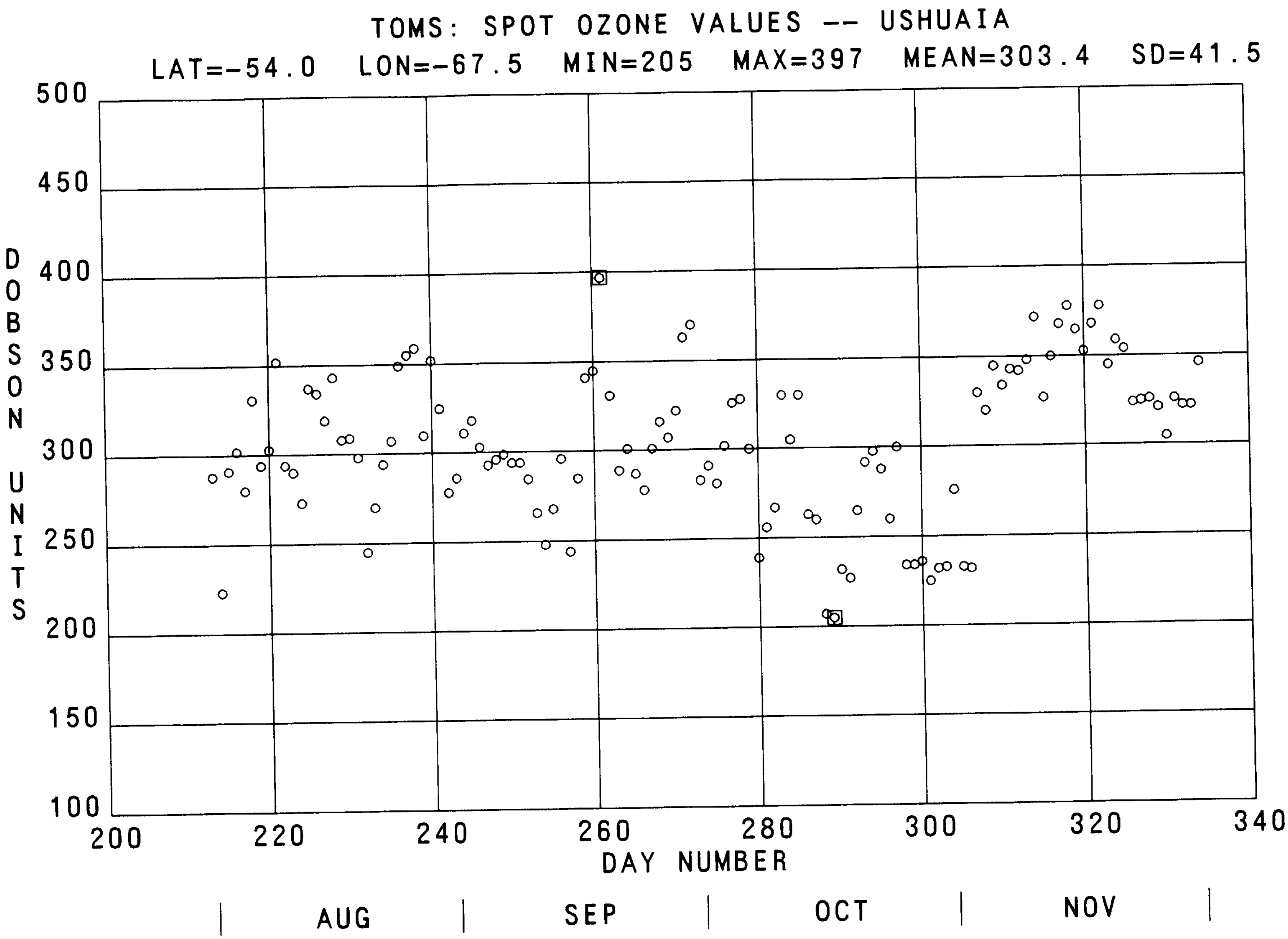

Figure 11. Daily TOMS Total Ozone Values over Ushuaia (DU) for 1989.

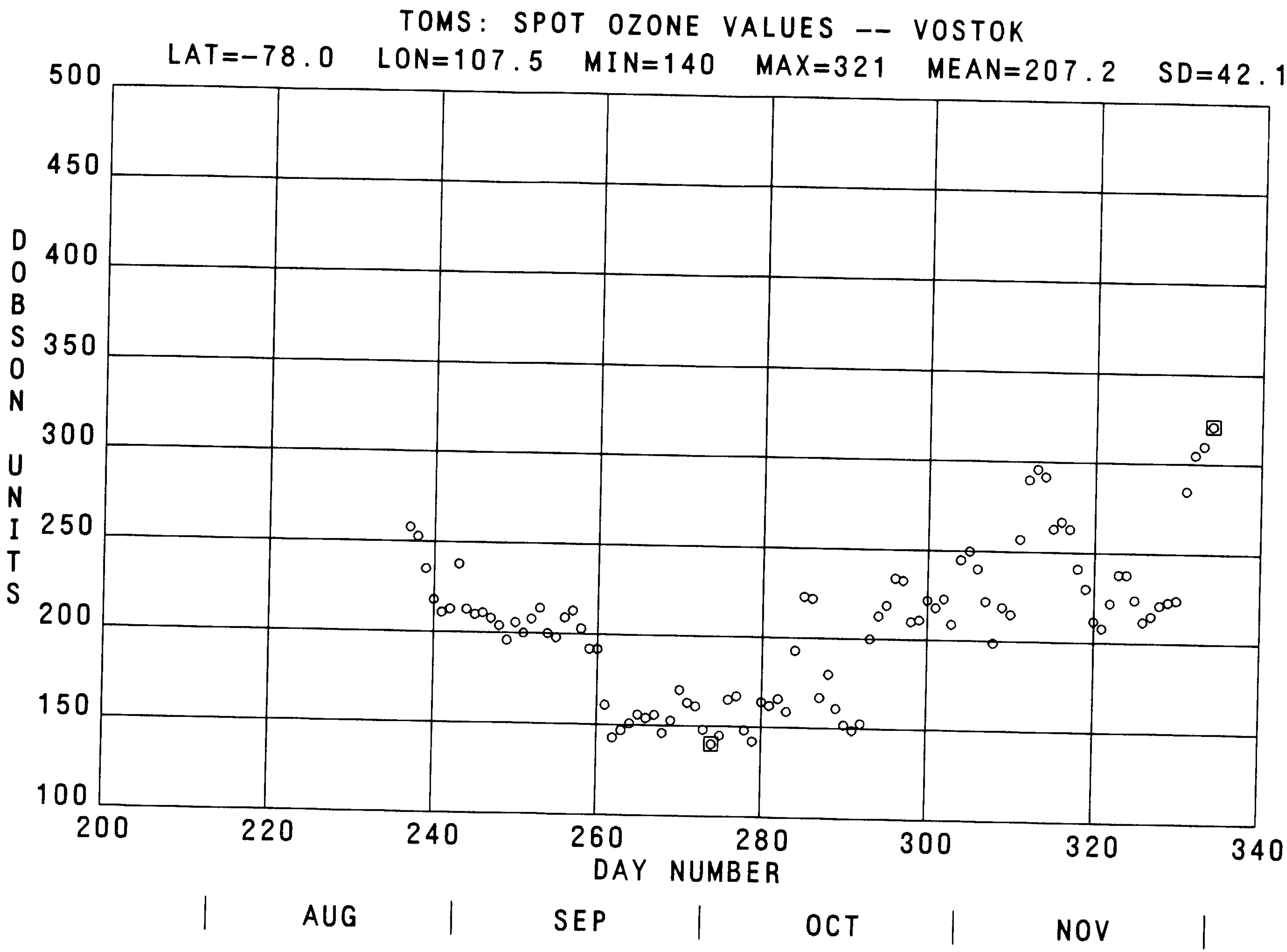

Figure 1m. Daily TOMS Total Ozone Values over Vostok (DU) for 1989.

3. COMPARISONS WITH PAST OZONE HOLE EVENTS

3.1 Zonal Means

Figures 2a through 2f present the mean total ozone values for each of six latitude bands for the period August 1 through November 30 of the years 1979, 1987, 1988, and 1989. 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 2g presents the mean total ozone for the band 30°S to 90°S. The instrumental drift relative to Dobson station data has not been corrected but is approximately -4% after ten years.

Figure 2a presents the total ozone zonal means for the subtropical latitude of 30°S. All years display the same seasonal trend, with values rising from August 1 through mid-September, remaining fairly steady until mid-October, and then falling through the end of the period. Throughout, the mean values from 1979 are 20 to 30 DU higher than the other three years and significantly larger than the instrumental drift of about 12 DU. The values in 1987 through 1989 are tightly grouped, although the values for 1989 are the highest of the three until mid-September and the lowest during November.

In Figure 2b, the zonal means for 40°S are presented. As with the 30°S band, an initial rise, a period of steadiness, and a decline are apparent. The values for the end of November are lower for all four years than those in early August. Once again, the values for 1979 are considerably higher than those for the other three years, and again these three years are closely bunched. The values for 1989 are generally indistinguishable from those of 1987 or 1988.

The 50°S band (Figure 2c) shows the rise and fall characteristic of the lower latitude bands; however, several important differences exist. Although mean ozone in 1979 is significantly higher than the other three years after mid-September, it is similar to 1988 prior to that time. These two years are significantly higher than 1987 or 1989 prior to mid-September. By mid-November, the mean values for 1988 have dropped to the level of 1987 and 1989. The mean values for 1987 and 1989, the two most significant ozone depletion years, are very similar, although 1989 appears to be slightly lower.

Figure 2d presents the band averages for 60°S. As in the case of 50°S, the mean ozone for 1979 is significantly higher than the other three years after mid-September. Values for 1988 are comparable to those of 1979 prior to mid-September and remain well above those of 1987 and 1989 thereafter. Both 1987 and 1989 behave similarly, remaining fairly steady at the fringe of the ozone hole until early October and rising slowly thereafter. While these years are slowly rising, 1979 begins to decline in early October while 1988 begins a decline in late October. Although very close, the mean values for 1987 exceed those of 1989 early in the period and then fall below 1989 in November.

Figure 2e presents the band averages for 70°S. The mean values for 1979 are steady on the fringe of the ozone hole from August 1 through late September, rise until late October, and are rather steady thereafter. The values for 1988 follow a similar pattern although their rise does not begin until early October and extends through mid-November. The values for 1979 are generally higher than those of 1988. The zonal means for 1987 and 1989 are indistinguishable through mid-October. During this time a steady decline is observed as the ozone hole extends beyond this latitude. The ozone values for 1989 recover after mid-October much faster than those of 1987 although they are comparable by the end of the period. Mean ozone for 1987 and 1989 remains nearly 100 DU lower than 1979 at the end of November.

The zonal means for 80°S are presented in Figure 2f. This latitude band falls substantially within the ozone hole for all four years. Data 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 for 1987 and 1989. A general rise commences for all years by mid-October, although the rise is very slight during 1987 until late November. The values for 1987 and 1989 are again indistinguishable until mid-October, and recover much sooner during 1989. Although generally higher than the other three years, the values for 1979 are similar to those of 1988 after late October.

Figure 2g shows the mean latitude-weighted total ozone for that portion of the southern hemisphere south of 30°S for 1979, 1987, 1988, and 1989. The values for 1979 are higher than the other three years throughout, ranging from 340 to 385 DU. The values for 1988 range from 310 to 340 DU. The values from 1987 and 1989 are closely grouped and lie between 300 and 320 DU. The mean values for 1979 rise sharply from mid-September to mid-October, the time of the lowest values for 1987 and 1989. The only distinction between the two lowest years is during the period from late October to late November, when the values from 1989 are up to 10 DU higher, indicating the more rapid filling of the 1989 ozone hole. Expressed as a percent, the 1979 to 1989 differences ranges from 12 percent in August and early September to nearly 20 percent in early October.

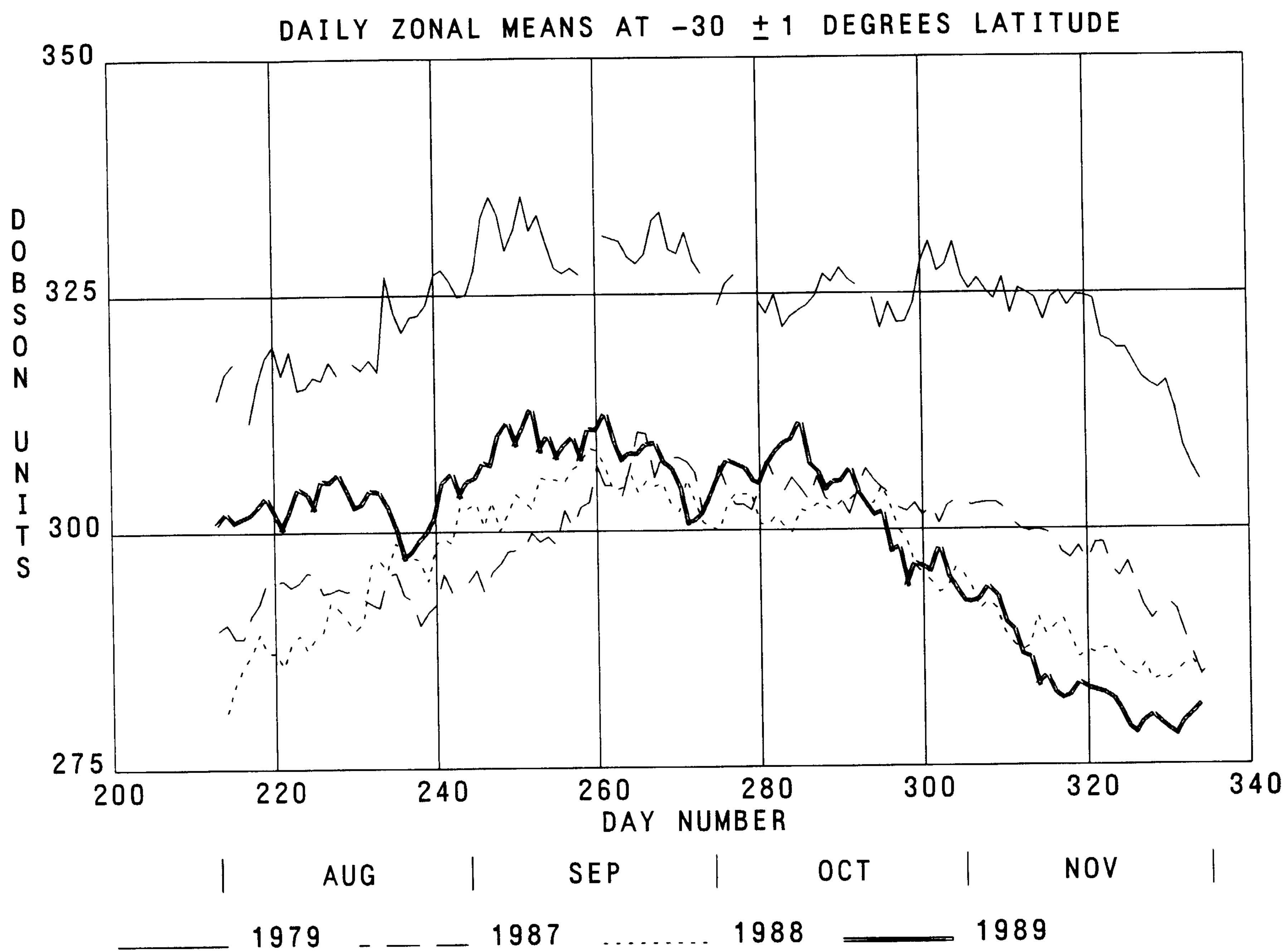

Figure 2a. Mean total ozone for the 2° latitude band centered at 30°S for the period August 1 through November 30 of the years 1979, 1987, 1988, and 1989.

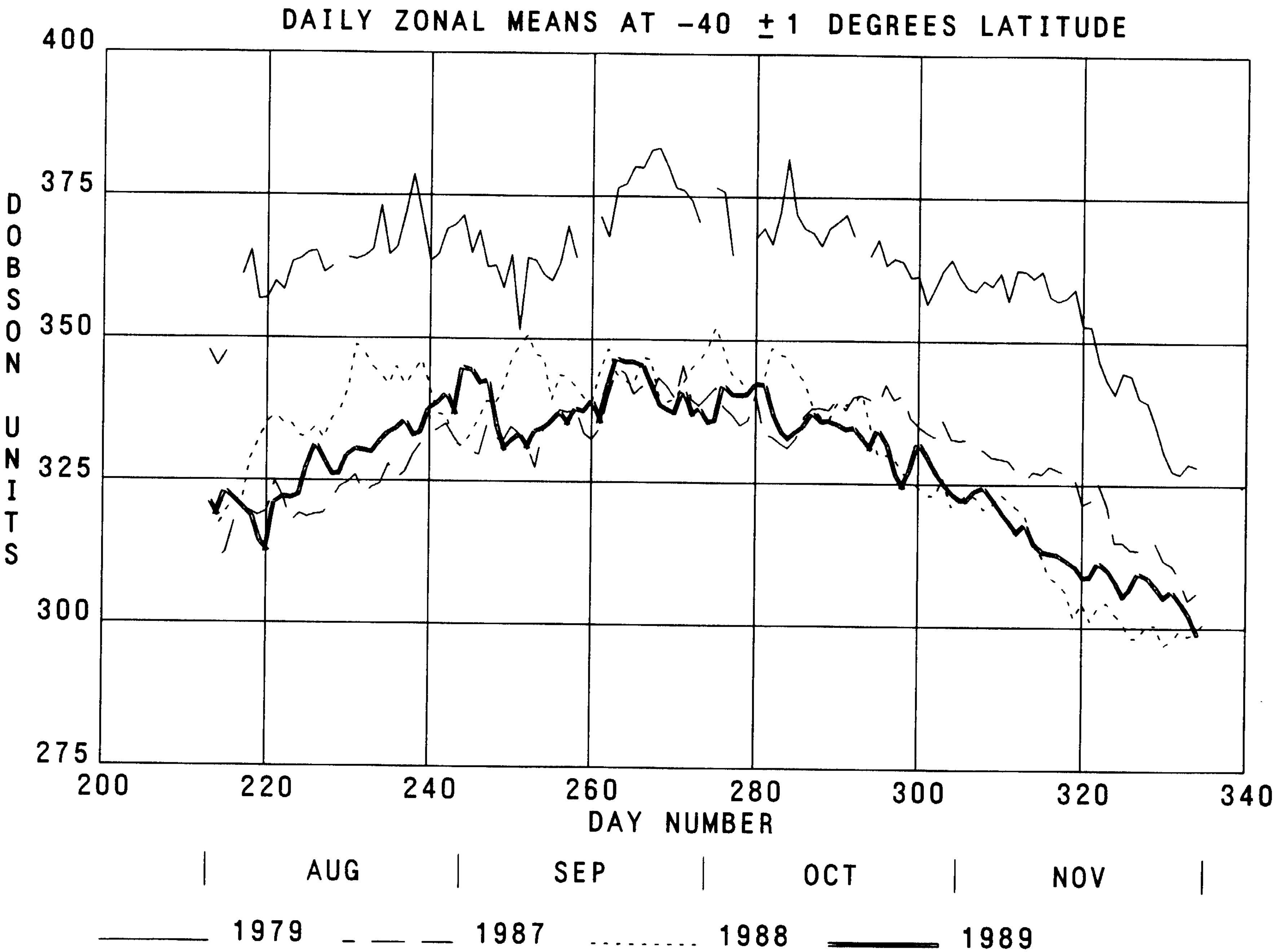

Figure 2b. Mean total ozone for the 2° latitude band centered at 40°S for the period August 1 through November 30 of the years 1979, 1987, 1988, and 1989.

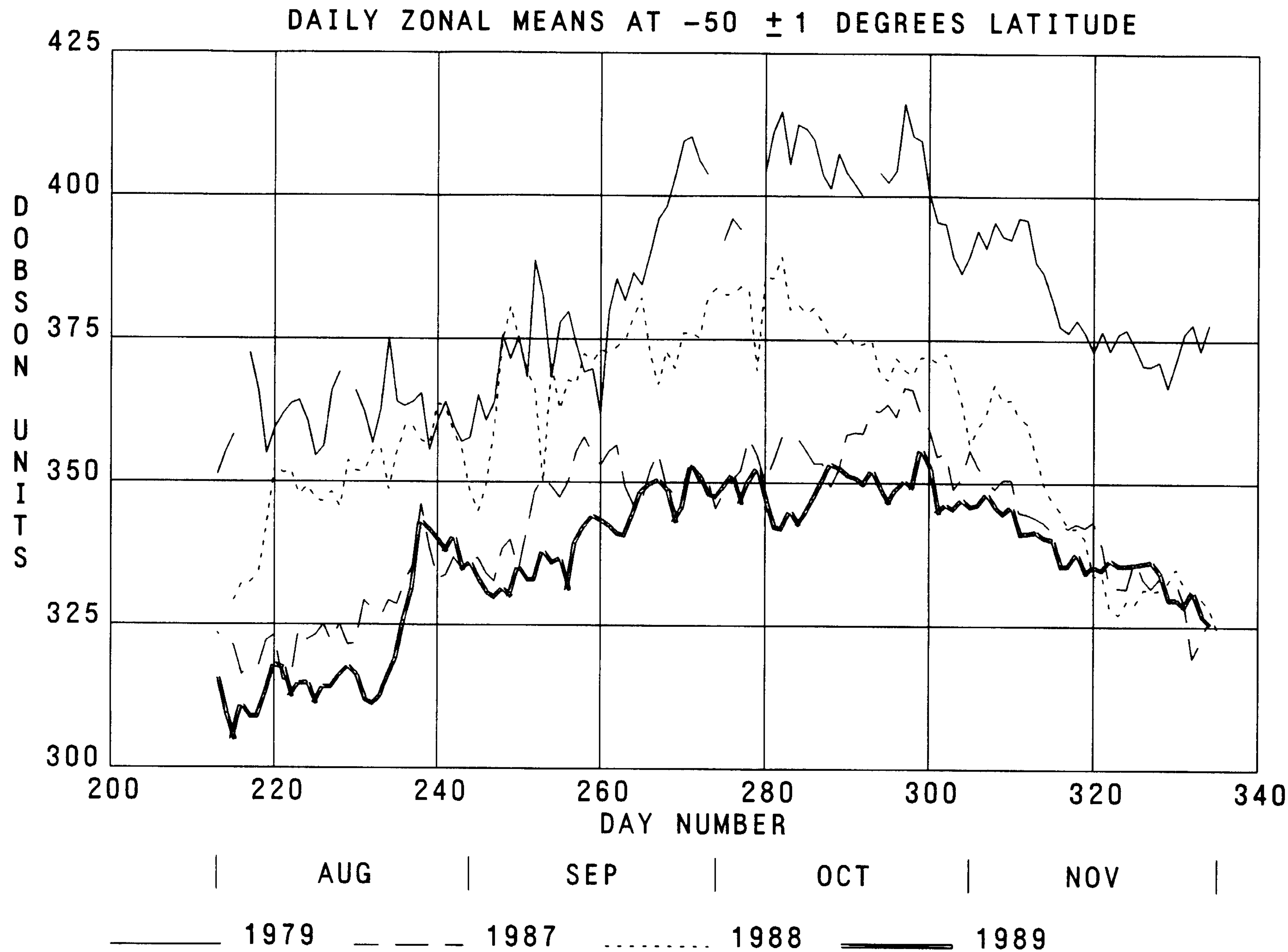

Figure 2c. Mean total ozone for the 2° latitude band centered at 50°S for the period August 1 through November 30 of the years 1979, 1987, 1988, and 1989.

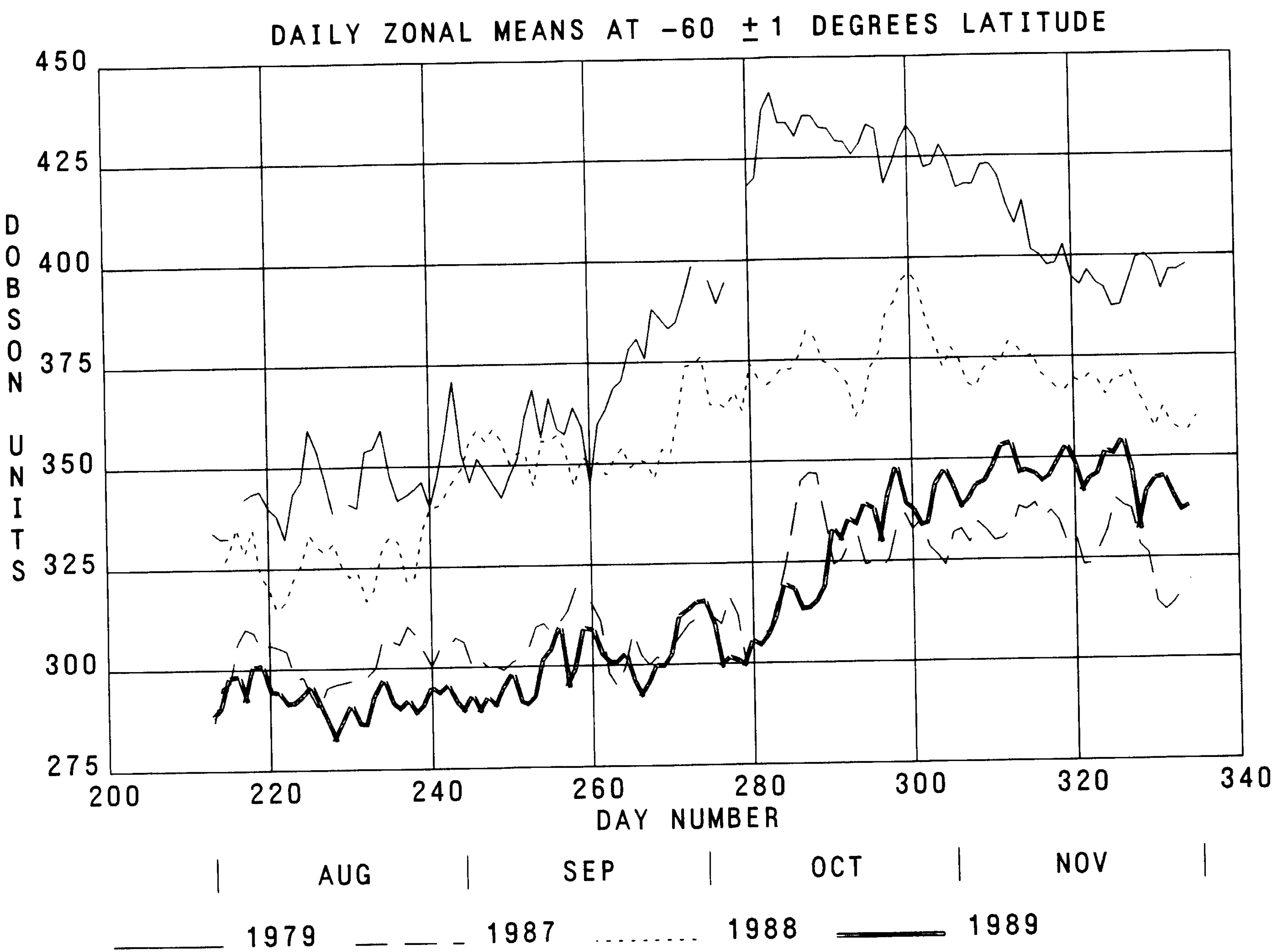

Figure 2d. Mean total ozone for the 2° latitude band centered at 60°S for the period August 1 through November 30 of the years 1979, 1987, 1988, and 1989.

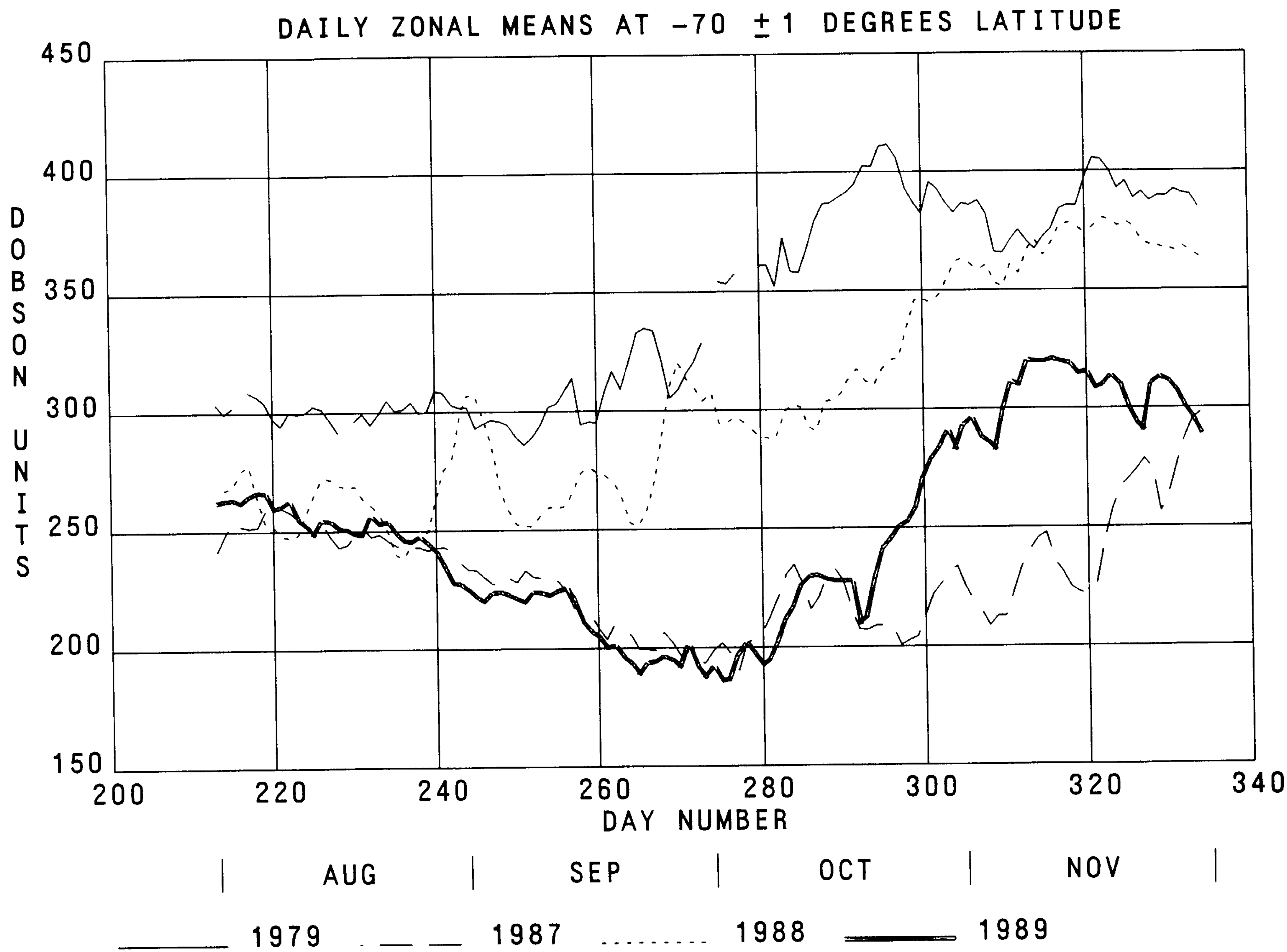

Figure 2e. Mean total ozone for the 2° latitude band centered at 70°S for the period August 1 through November 30 of the years 1979, 1987, 1988, and 1989.

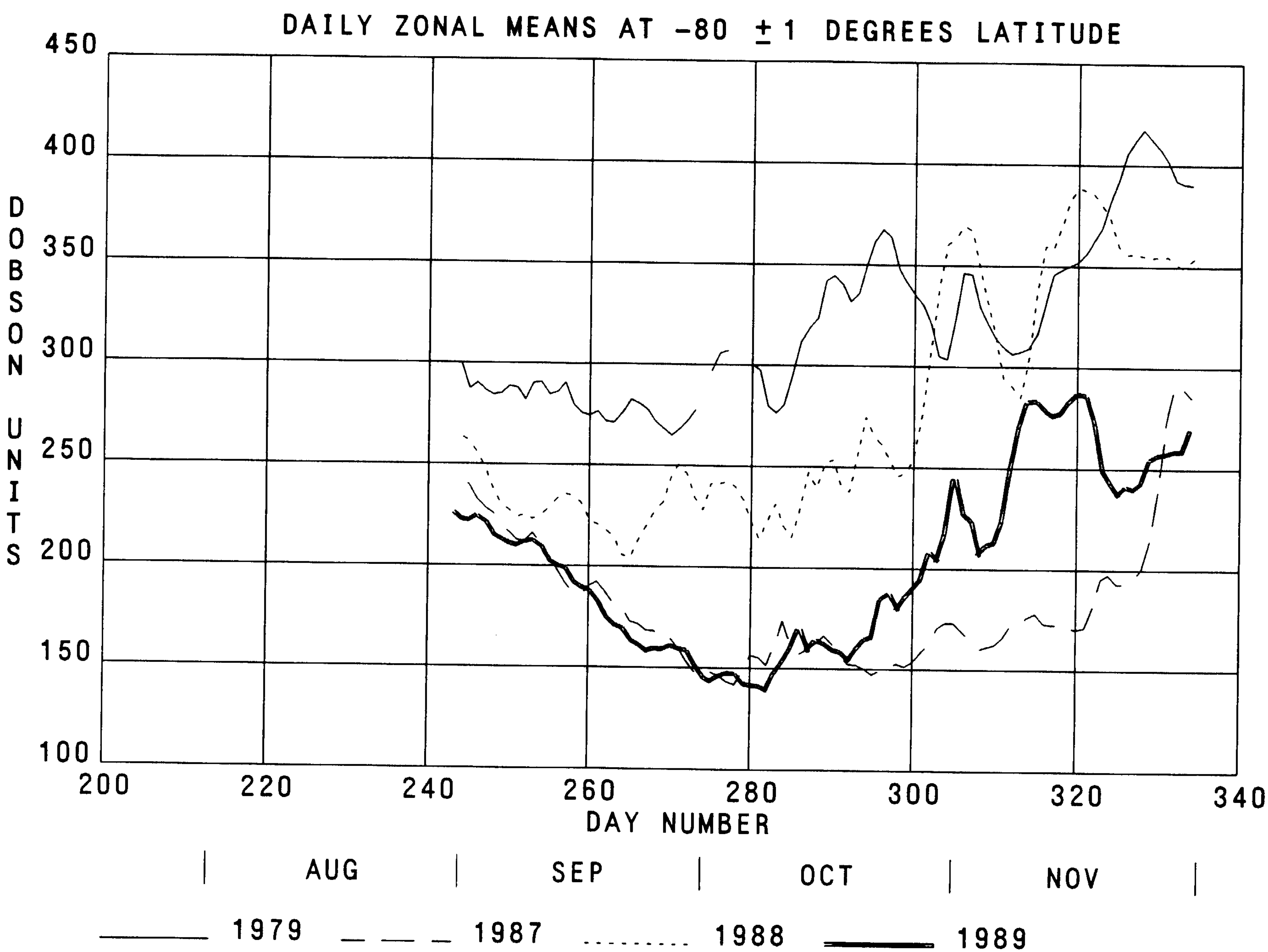

Figure 2f. Mean total ozone for the 2° latitude band centered at 80°S for the period August 1 through November 30 of the years 1979, 1987, 1988, and 1989.

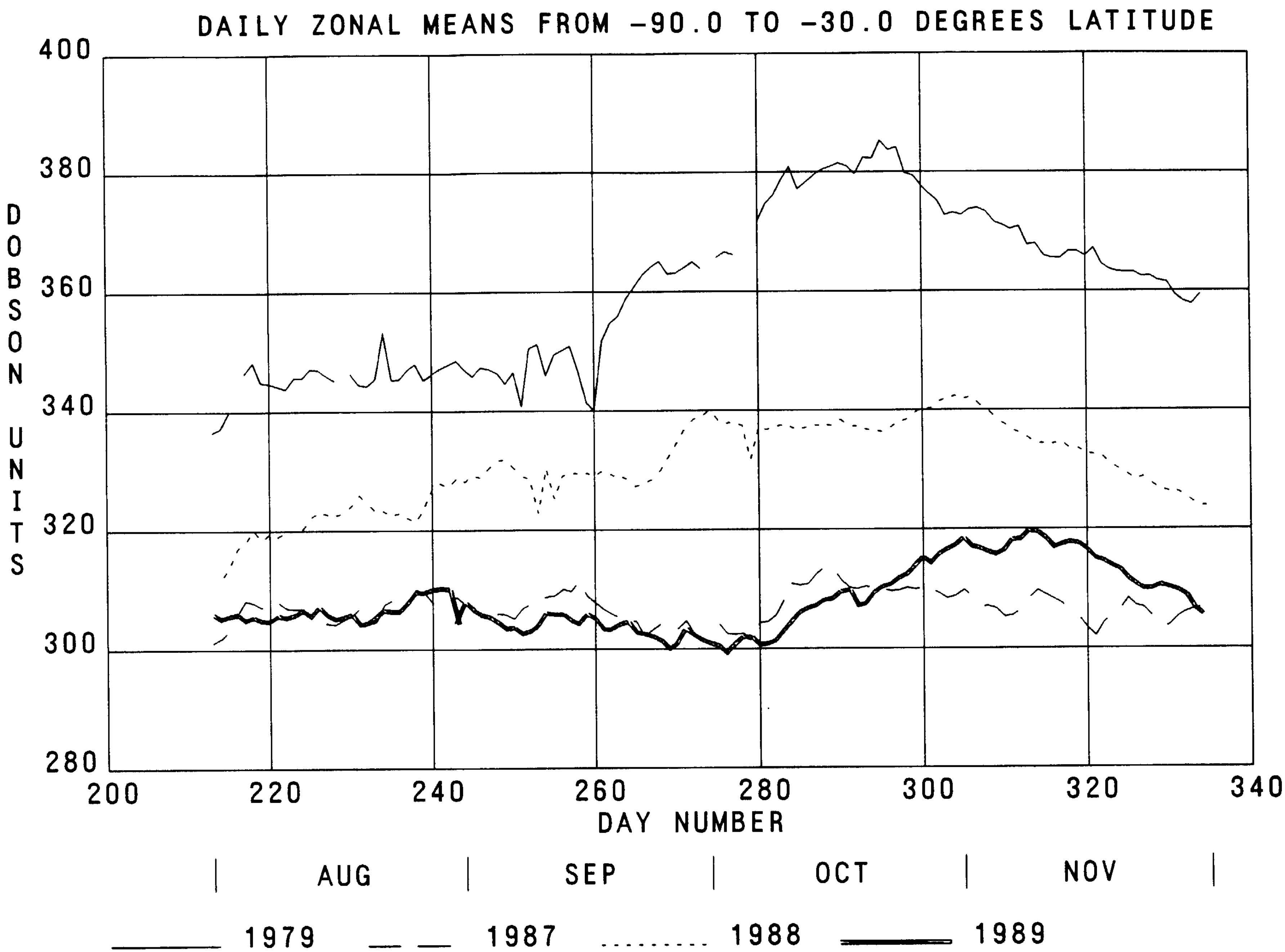

Figure 2g. Mean total ozone for the latitude band -30°S to -90°S for the period August 1 through November 30 of the years 1979, 1987, 1988, and 1989.

3.2 Monthly Differences

Figures 3a through 3d present the hemispheric differences of total ozone for the months of August through November 1989 and a four-year reference mean (1979 through 1982). Figures 3e through 3g present the differences between September through November 1989 and the same three months of 1987. The years 1987 and 1989 have experienced the most pronounced ozone depletion to date. Isopleths are solid where the difference is positive and dashed where it is negative or zero. The values are in percent difference.

During August 1989 (Figure 3a), total ozone is lower than the reference mean virtually throughout the hemisphere, although differences less than about 5% are within the error due to instrument drift. The exceptions are small areas in the mid-latitudes, the largest over Australia. The negative differences increase toward the pole, reaching 20 to 30 percent at the terminator. A local minimum of negative 20 percent exists near 60°S over the Pacific Ocean.

Figure 3b displays a similar pattern for September. Negative differences dominate, and increase toward the pole, reaching 40 percent in the immediate polar region. Negative 20 percent differences extend out to 50°S to 60°S. The only positive differences are found near 40°S over South America and adjacent portions of the Atlantic and Pacific.

During October 1989 (Figure 3c), the entire hemisphere contains negative differences, again increasing toward the pole. The area of negative 20 percent difference has shrunk to the area within 60°S to 70°S. A large area of Antarctica is covered by negative 40 percent differences.

Negative differences still predominate in November 1989 (Figure 3d). However, the minimum values have been offset from the pole and are located over Queen Maude Land and adjacent waters. The minimum values are now above 35 percent. Although, in general, the differences become more negative as one moves poleward, the isopleths are no longer concentric with the pole. A fairly large area of positive differences is seen over the southeast Pacific, an area with a persistent ozone maximum in November 1989.

In comparing September 1987 to September 1989 (Figure 3e), one finds more modest differences. The total ozone values for 1989 exceed those of 1987 over most of the hemisphere, but by less than 10 percent. A large area of negative differences exists over the South Pacific, with a smaller area exceeding 15 percent. A very small area of negative differences exceeding 5 percent exists over eastern Queen Maude Land, near the genesis point of the 1989 ozone hole.

By October 1989 (Figure 3f), a more coherent pattern exists. North of 40°S, small differences of -5 percent to +5 percent exist. However, south of 40°S, two large and roughly equal sized areas exist, one of positive and one of negative differences. The negative differences, indicating lower total ozone in 1989 fall below 20 percent, centered just west of the Antarctic Peninsula. The area of positive differences reaches a maximum of 25 percent near McMurdo Sound. Here the 1987 ozone hole was deeper. The differences are the result of a displacement of the ozone hole toward the Antarctic Peninsula in 1989.

The 1989 ozone hole, though as deep or deeper than that of 1987, filled more quickly. This is apparent in the November differences (Figure 3g). The polar region within 60°S is dominated by a huge positive difference maxima approaching 65 percent west of the Antarctic Peninsula. This was an area dominated by ozone maxima in 1989, which did not exist in 1987. The only significant negative differences are in the south Atlantic near 60°S.

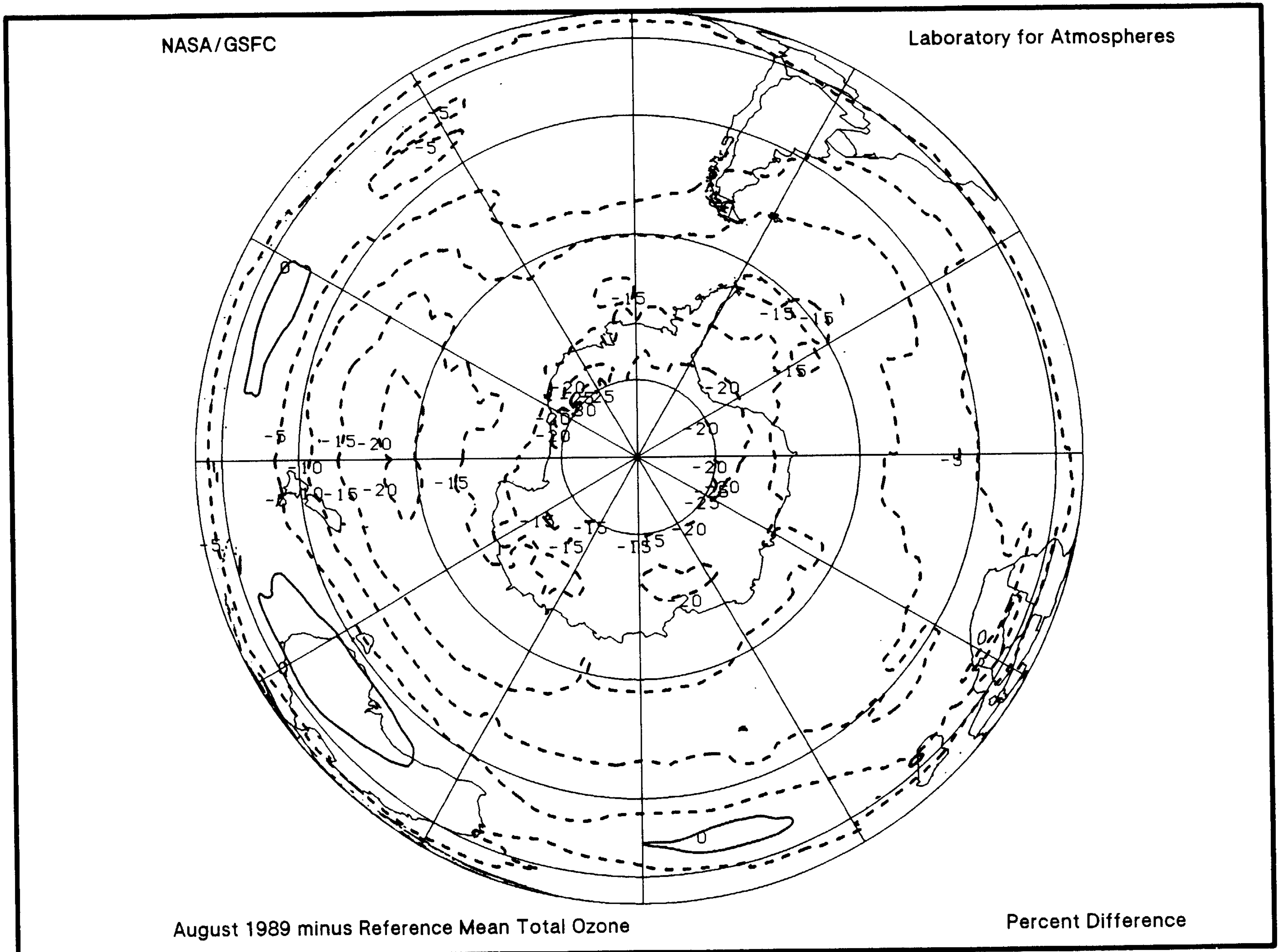

Figure 3a. Monthly mean total ozone difference between August 1989 and a four-year reference mean (August 1979 through 1982).

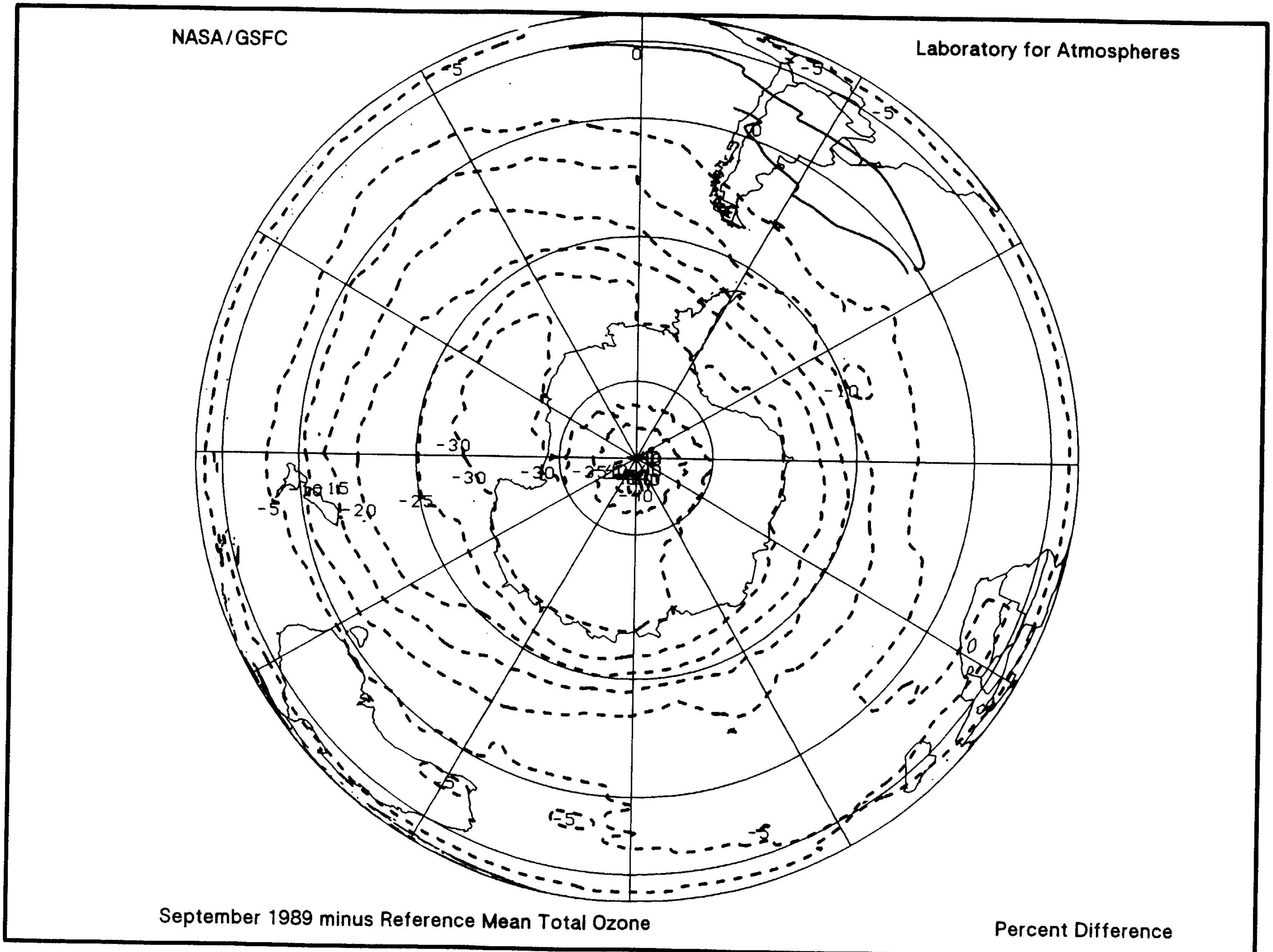

Figure 3b. Monthly mean total ozone difference between September 1989 and a four-year reference mean (August 1979 through 1982).

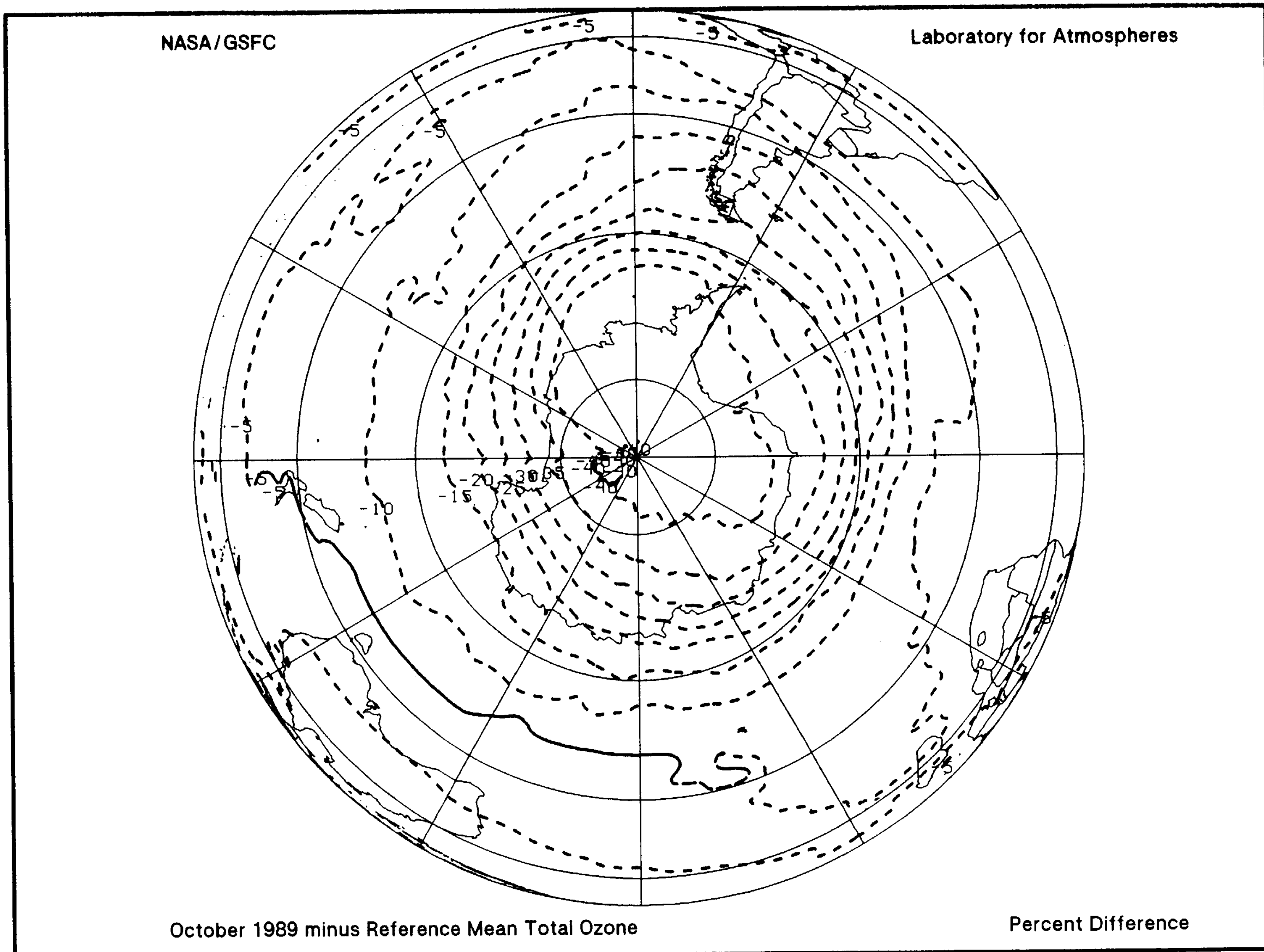

Figure 3c. Monthly mean total ozone difference between October 1989 and a four-year reference mean (August 1979 through 1982).

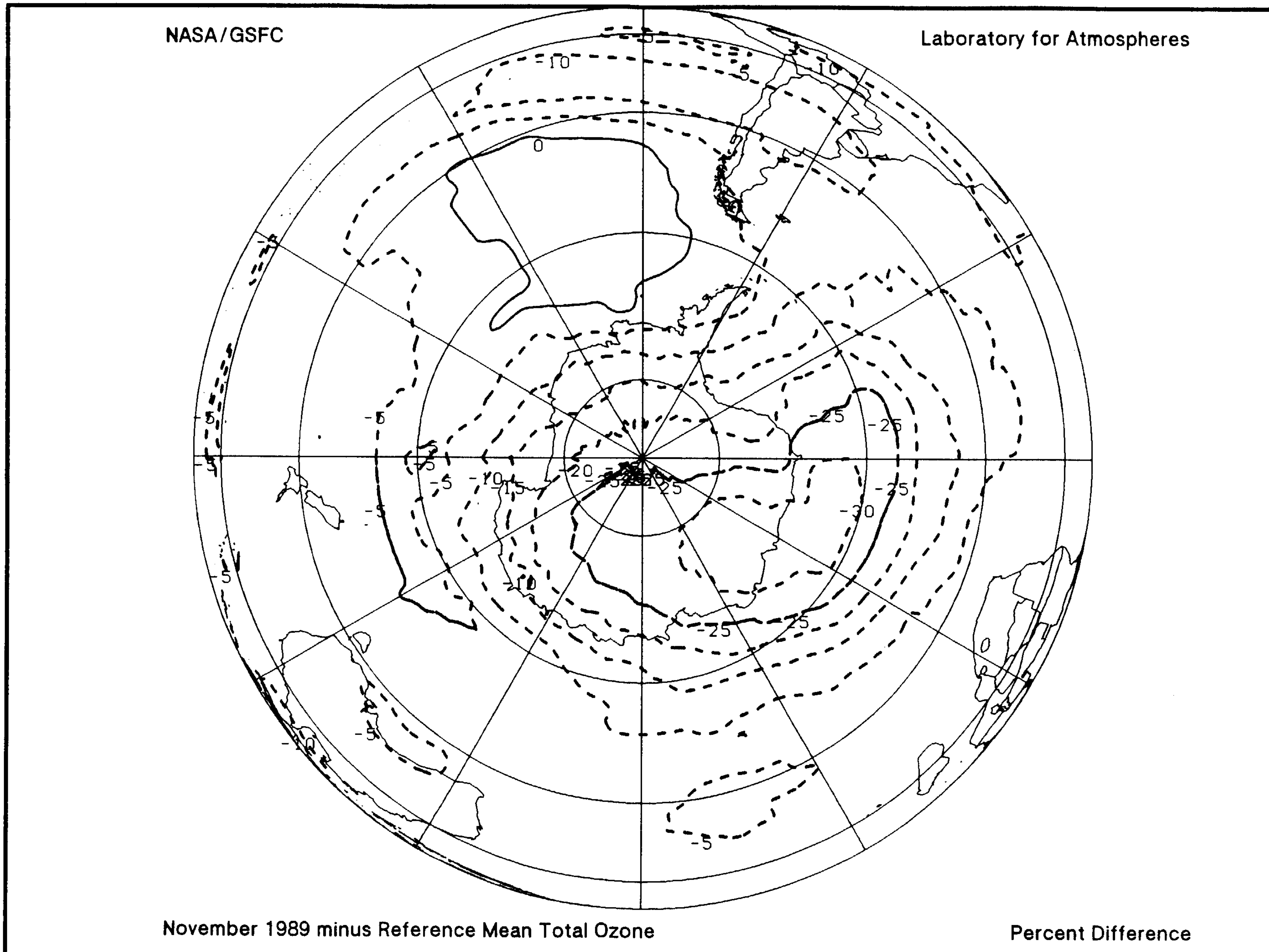

Figure 3d. Monthly mean total ozone difference between November 1989 and a four-year reference mean (August 1979 through 1982).

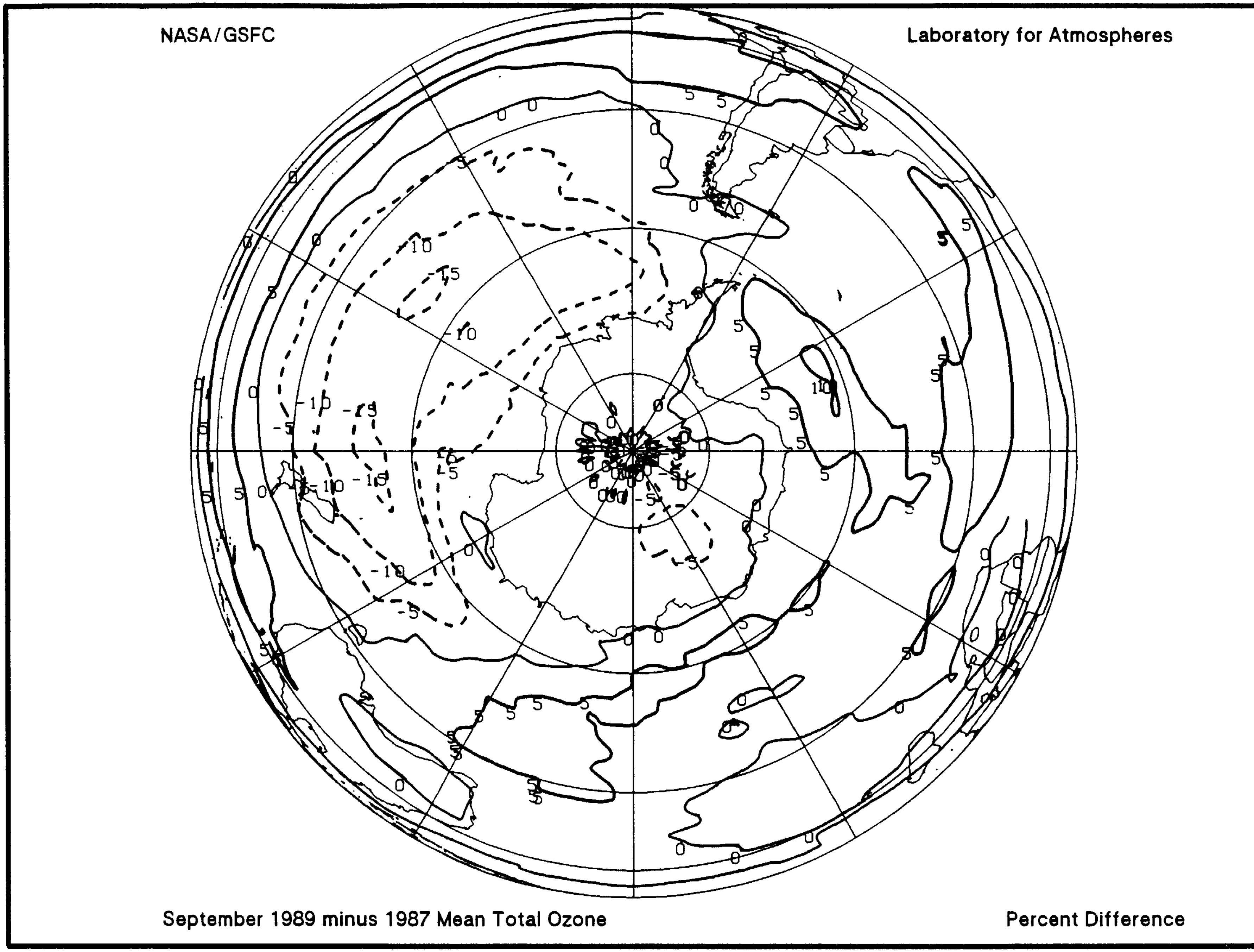

Figure 3c. Monthly mean total ozone difference between September 1989 and September 1987.

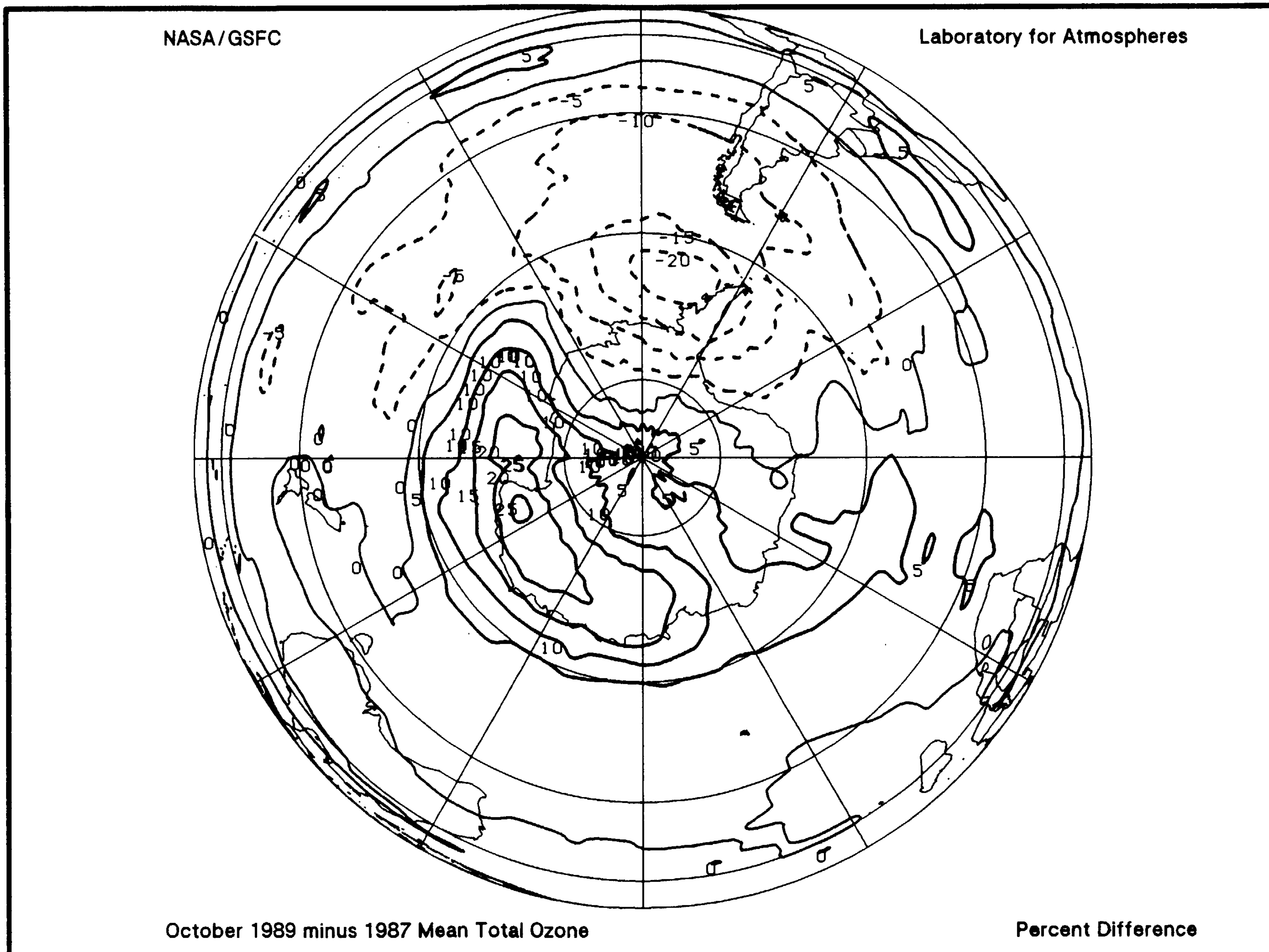

Figure 3f. Monthly mean total ozone difference between October 1989 and October 1987.

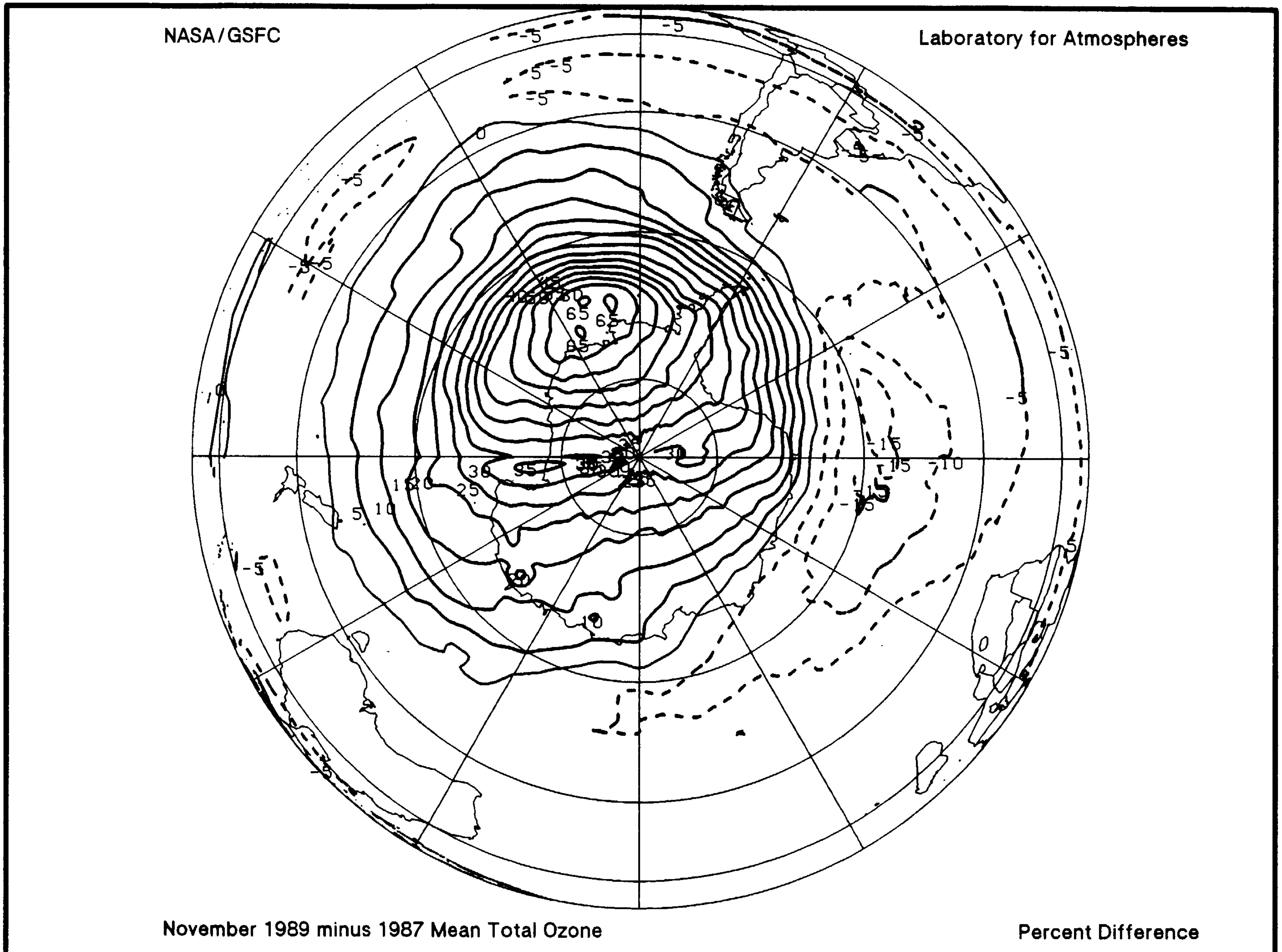

Figure 3g. Monthly mean total ozone difference between November 1989 and November 1987.

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3.3 Comparisons of Daily Maxima and Minima

Figures 4a and 4b present the daily maximum and minimum ozone values over the southern hemisphere for the period August 1 through November 30 during the years 1979, 1987, 1988, and 1989. The horizontal axis is the day number of the year. In Figure 4a, much variation in the maximum values is apparent for all four years.

The maxima for 1979 exceed those for the other three years. However, in general, after day 260, the maxima for 1987 and 1989, the years with the most pronounced ozone holes, are lower than 1979 and 1988 throughout and are closely bunched. The maxima for 1988 are similar to 1979 until early October, after which they decline, reaching the level of 1987, 1989 by late November. It appears that for all four years daily maxima reach a peak in late September/early October, and decline thereafter.

More pronounced differences are identifiable in Figure 4b, the daily minimum values. Prior to early September (day 250), all four years show significant day-to-day variation. This is the period prior to the development of the mature ozone hole, when smaller minima, known as "mini-holes" develop and dissipate quite rapidly. During this period, the minima for 1988 are noticeably lower than the other three years. Both 1979 and 1988 saw their absolute minimum during this period. The depth of these extreme minima in August may be exaggerated due to the screening of lower stratospheric ozone by high clouds. The minima for 1979 are generally higher than the other three years during this period.

After day 250, the mature ozone hole begins to form. This results in a somewhat steady decline to a minimum value between days 260 and 280, followed by a steady rise until the end of the period. The year 1979 shows very little decline, with daily minima seldom below 225 DU. The year 1988 reaches a minimum of 170 DU quite early on day 263. The minimum ozone in both 1987 and 1989 drops dramatically to minima of 106 and 103 DU, respectively, on days 278 and 280. Previous minimum of 109 DU for October 5, 1987 reported earlier was revised due to a slight correction of the algorithm. During the recovery period, after day 280, all years show a steady increase in minimum values. The values for the year 1989 diverge from 1987 and recover more rapidly. However, a steady period of 1989 minima during the final 10 days of the period results in comparable 1987 and 1989 values by the end of the period.

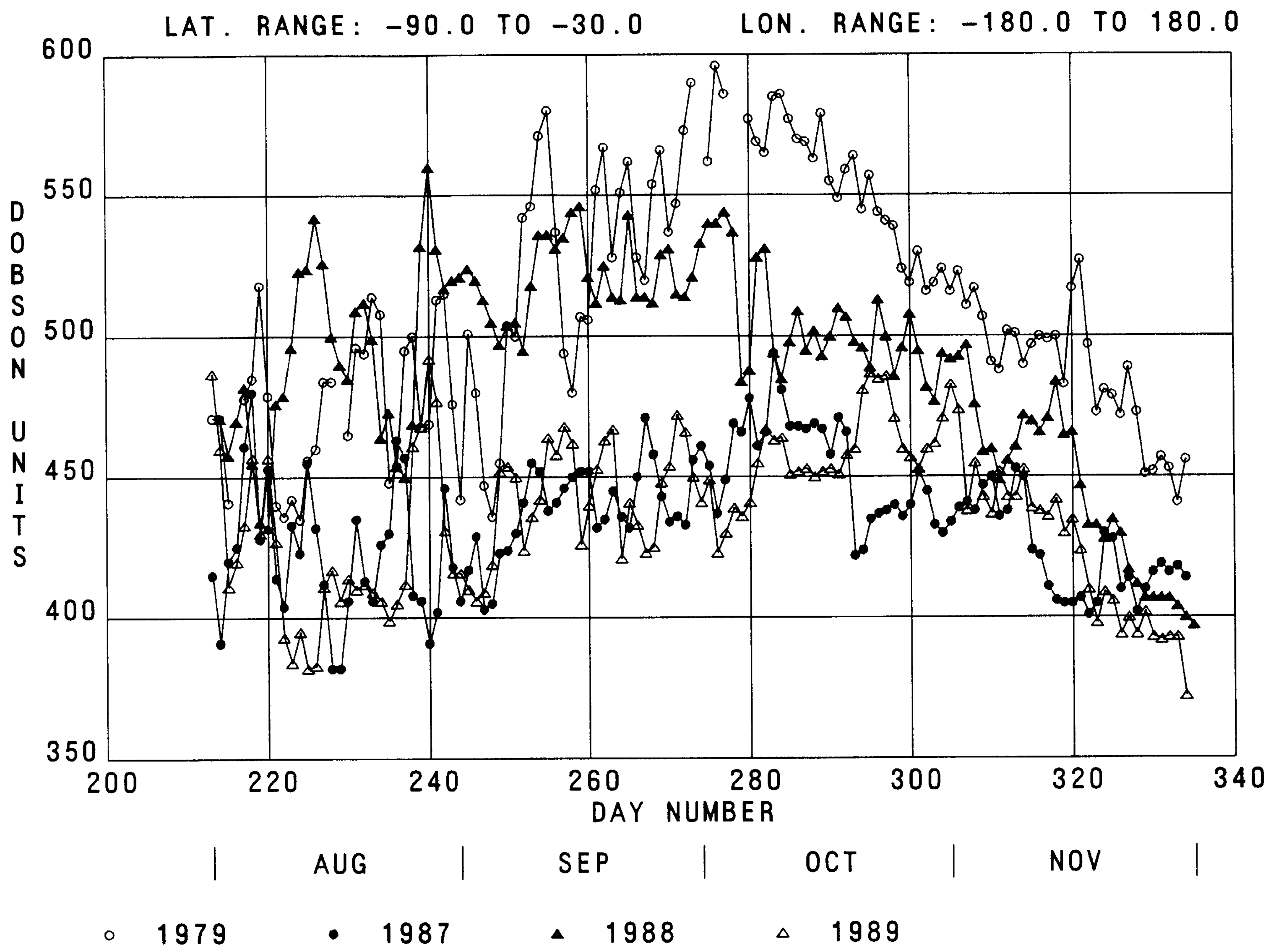

Figure 4a. Daily southern hemisphere ozone maximum for the period August 1 through November 30 of the years 1979, 1987, 1988, and 1989.

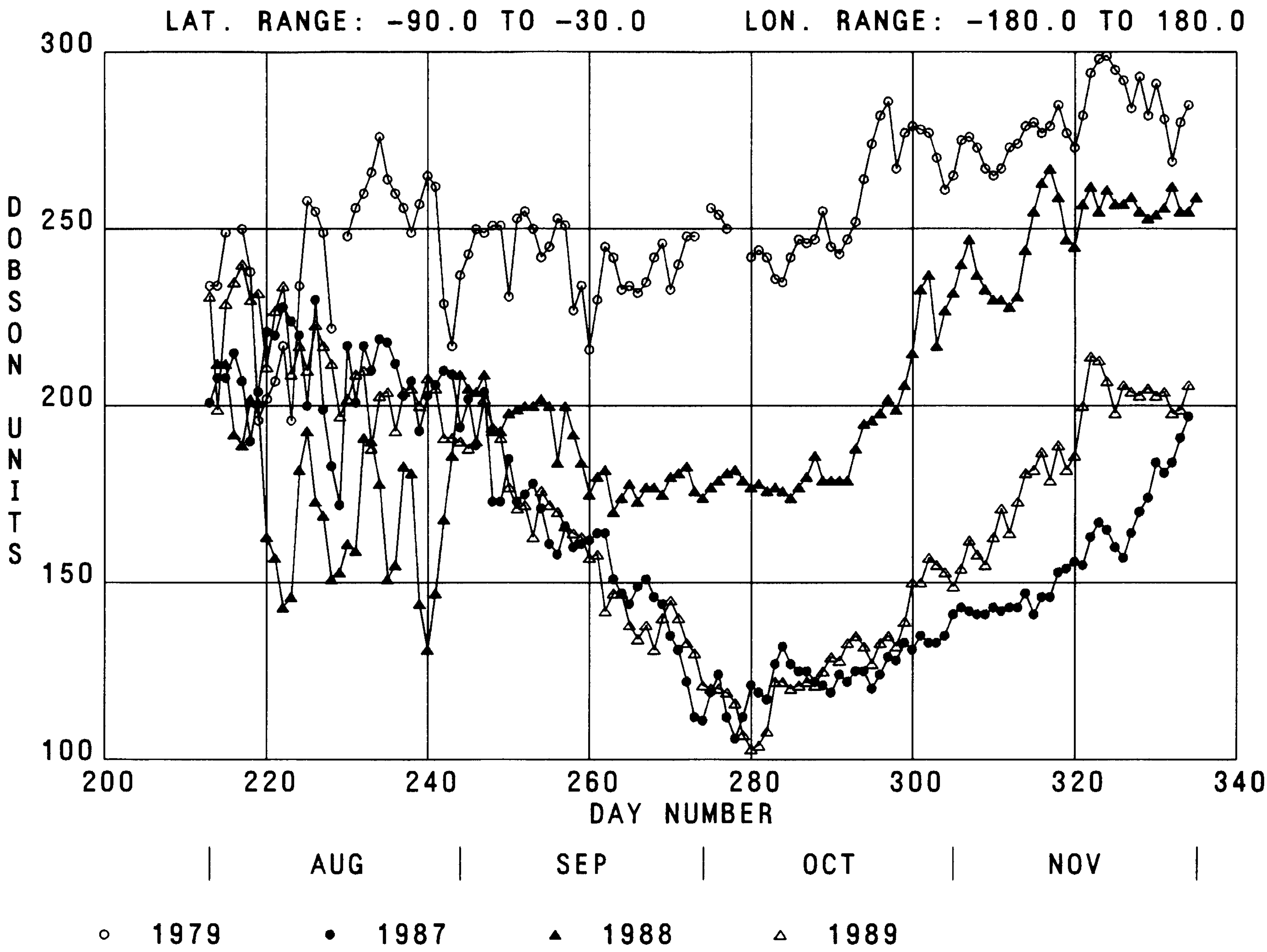

Figure 4b. Daily southern hemisphere ozone minimum for the period August 1 through November 30 of the years 1979, 1987, 1988, and 1989.

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15. Supplementary Notes

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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 1989 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 November 30, 1989. The 1989 ozone hole developed in a manner similar to that of 1987, reaching a comparable depth in early October. This was in sharp contrast to the much weaker hole of 1988. The 1989 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 1989 ozone distribution to that of other years.

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