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1988 Antarctic Ozone Monitoring Nimbus-7 TOMS Data Atlas

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1988 ANTARCTIC OZONE MONITORING

NIMBUS-7 TOMS DATA ATLAS

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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 ever observed 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). The formation of the ozone hole is believed to be due to chemical reactions with enhanced levels of chlorine monoxide (possibly 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 the surface of the 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.

1.1 1988 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.

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).

2. TOMS TOTAL OZONE DATA

2.1 Chronology of the 1988 Antarctic Ozone Hole

AUGUST 21, 1988

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 west of the Antarctic Peninsula within the normal southern hemisphere winter polar minimum.

AUGUST 22-23, 1988

The minimum west of the Antarctic Peninsula has moved eastward and deepened to form the first observed mini-hole of the season. Values of total ozone below 175 DU are indicated, but could be an artifact if dense clouds are present at stratospheric altitudes in this region.

AUGUST 25, 1988

The minimum noted above has moved east of the Antarctic Peninsula and filled. A new mini-hole has developed in the area west of the Antarctic Peninsula with total ozone values below 200 DU. A large ozone maxima is located south of Africa with maximum total ozone above 475 DU.

AUGUST 27, 1988

The second mini-hole has moved slowly eastward and deepened rapidly. Total ozone values below 150 DU are now noted. The maximum south of Africa has drifted eastward and strengthened to values above 500 DU.

AUGUST 31, 1988

The second mini-hole has drifted east of the Antarctic Peninsula and filled. No value of total ozone below 200 DU currently is present in the southern hemisphere. The ozone maximum which developed south of Africa has expanded and strengthened as it drifts eastward. The expansion of this feature has brought total ozone values above 475 DU to coastal Enderby land. The broad area of minimum values, the embryonic ozone hole has been displaced from the south pole toward the south Pacific and southern Chile.

SEPTEMBER 4, 1988

For the first time in five days, total ozone values below 200 DU have re-appeared, in the Amundsen Sea and over Ellsworth land. The large maxima has weakened, although values above 475 DU are still present along the Indian Ocean coast of Antarctica.

SEPTEMBER 7, 1988

The ozone hole has returned to a position more symmetric about the south pole. Minimum values just below 200 DU persist.

SEPTEMBER 12, 1988

A very strong maxima over the southern Indian Ocean has again displaced the ozone hole away from the south pole. Minimum values of total ozone between 175 and 200 DU exist over the Amundsen Sea.

SEPTEMBER 16, 1988

The maxima off the Indian Ocean coast of Antarctica now exceeds 550 DU. A well defined minima over Ellsworth land and the southern Antarctic Peninsula is close to 175 DU.

SEPTEMBER 18, 1988

As the maxima drifts eastward and builds above the ocean between Australia and Antarctica, the ozone hole becomes elongated along an axis from the Amundsen Sea to Queen Maude land. A large portion of this area has total ozone values between 175 and 200 DU.

SEPTEMBER 25, 1988

With another large maxima along the Indian Ocean coast of Antarctica, the ozone hole is displaced more than 10° of latitude from the pole over Ellsworth land. Minimum values of total ozone just under 175 DU are observed in that region. Values above 500 DU occur above the Antarctic continent over Wilkes land.

OCTOBER 3, 1988

The dominant feature continues to be the strong maxima, now between Australia and Antarctica with total ozone values in excess of 525 DU. Nearly one-half of Antarctica, adjacent to this maxima, sees ozone values in excess of 300 DU. The minimum ozone values continue to be over Ellsworth land and the Amundsen Sea remaining in the 175 to 200 DU range.

OCTOBER 10, 1988

A slight weakening in the persistent ozone maxima permits a trough of ozone to reach the Indian Ocean coast near the Amery Ice Shelf, and minimum values of total ozone less than 200 DU to cover the pole.

OCTOBER 19, 1988

The ozone maxima between Australia and Antarctica remains the dominant feature. The displaced ozone hole continues to be centered over Ellsworth land and the Antarctic Peninsula, but the area covered by total ozone values below 200 DU is diminishing.

OCTOBER 23, 1988

For the first time in nearly six weeks, no total ozone value less than 200 DU exists.

OCTOBER 25, 1988

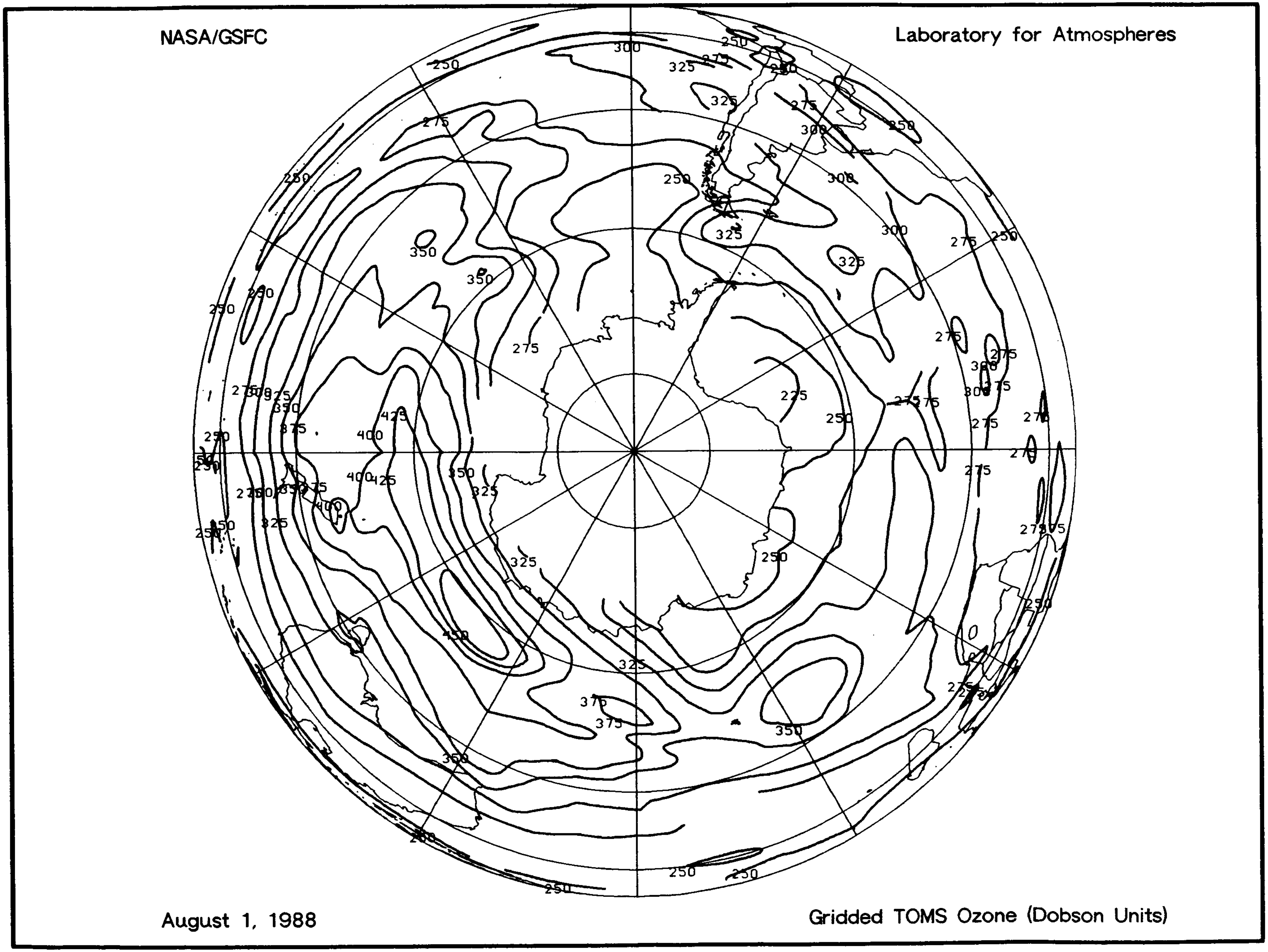
A building ozone maxima south of Africa has begun to raise ozone values rapidly over Queen Maude land, effectively squeezing the ozone hole into an ever-narrower band.

OCTOBER 29, 1988

Rising ozone values over most of Antarctica have brought 300 DU total ozone values to the pole and moved what is left of the hole to a position near the Antarctic Peninsula. Minimum values here are still less than 225 DU. Although the persistent ozone maxima has broadened, the highest value is now less than 475 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 17, 1988, 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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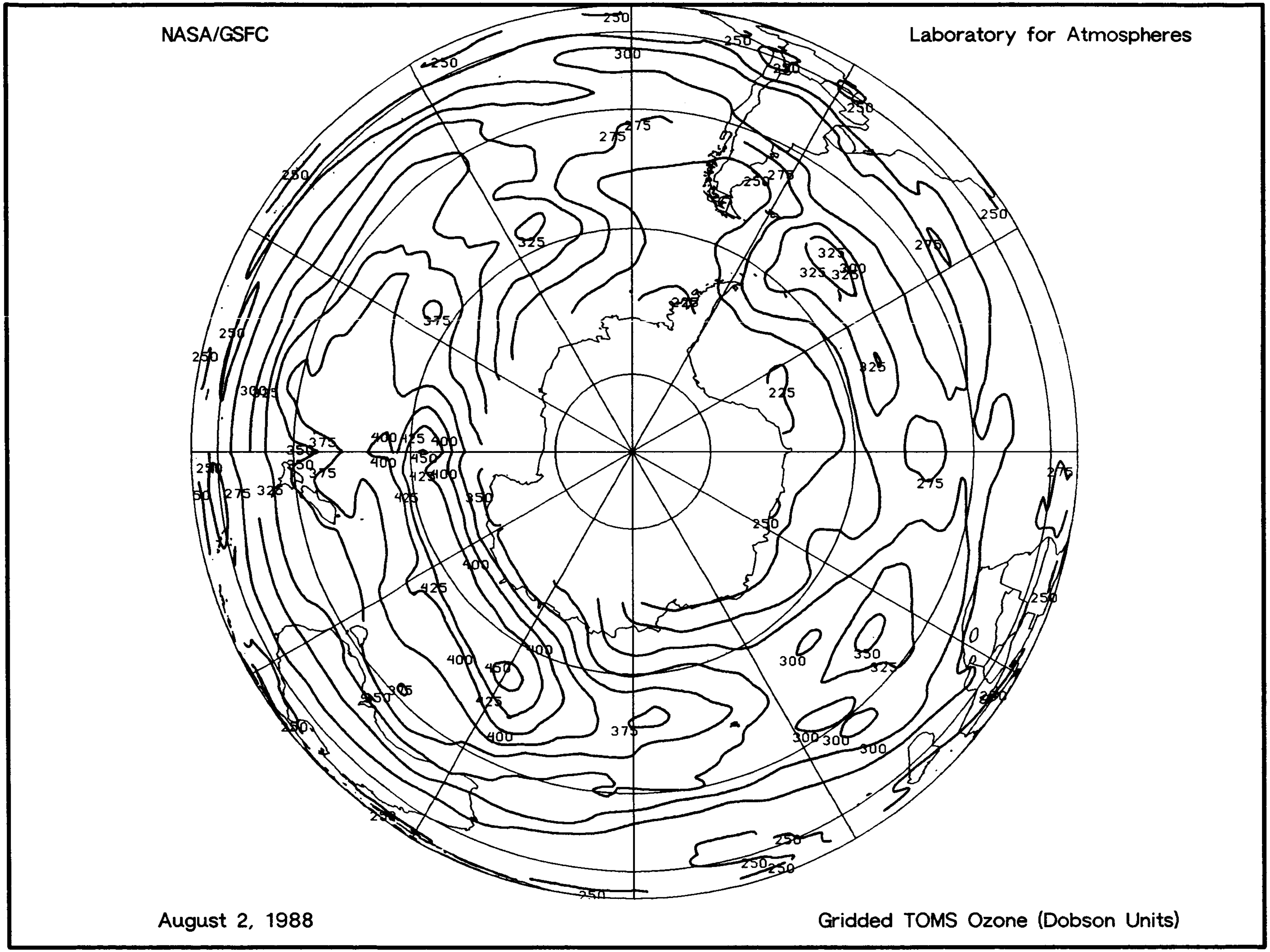
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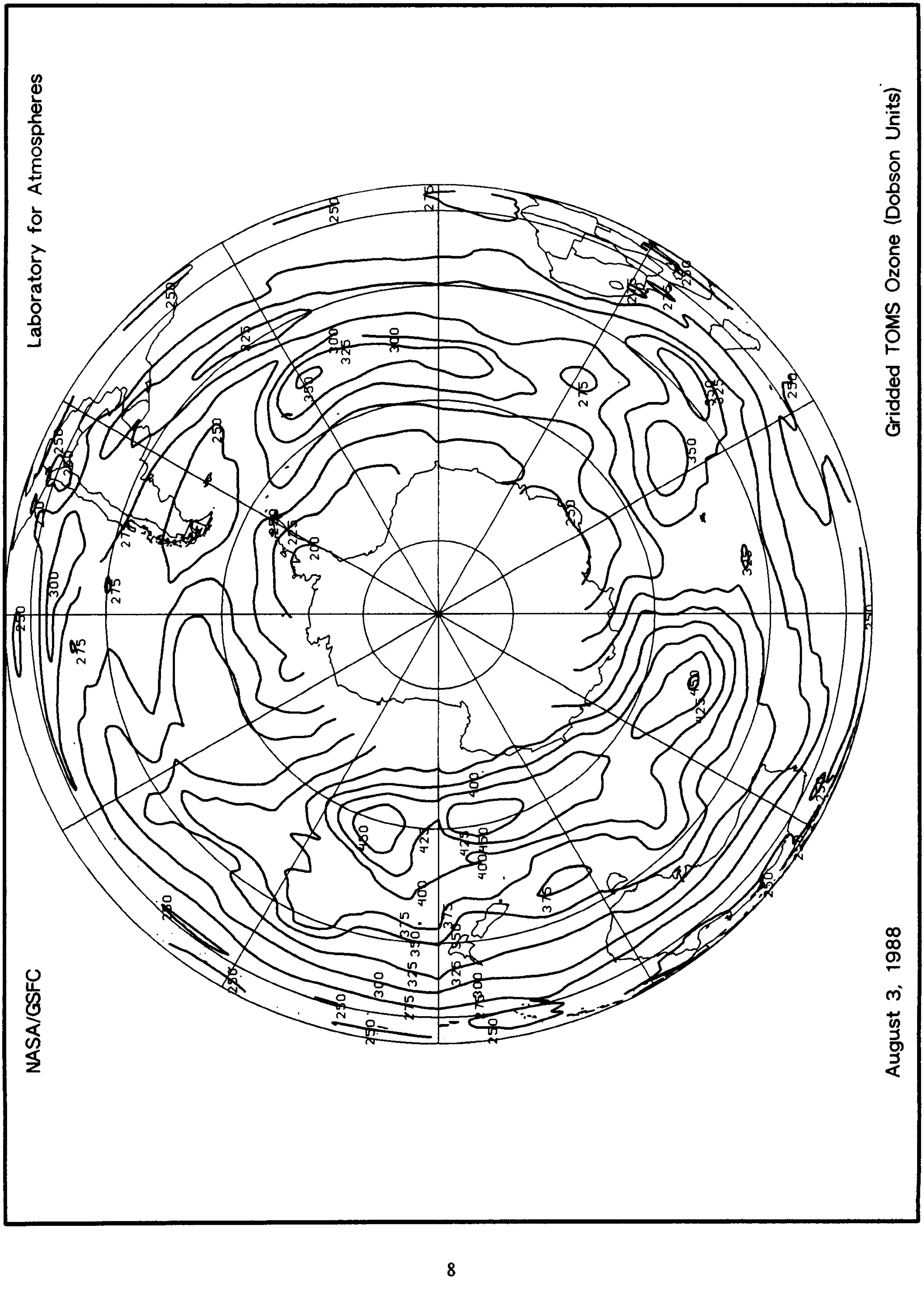

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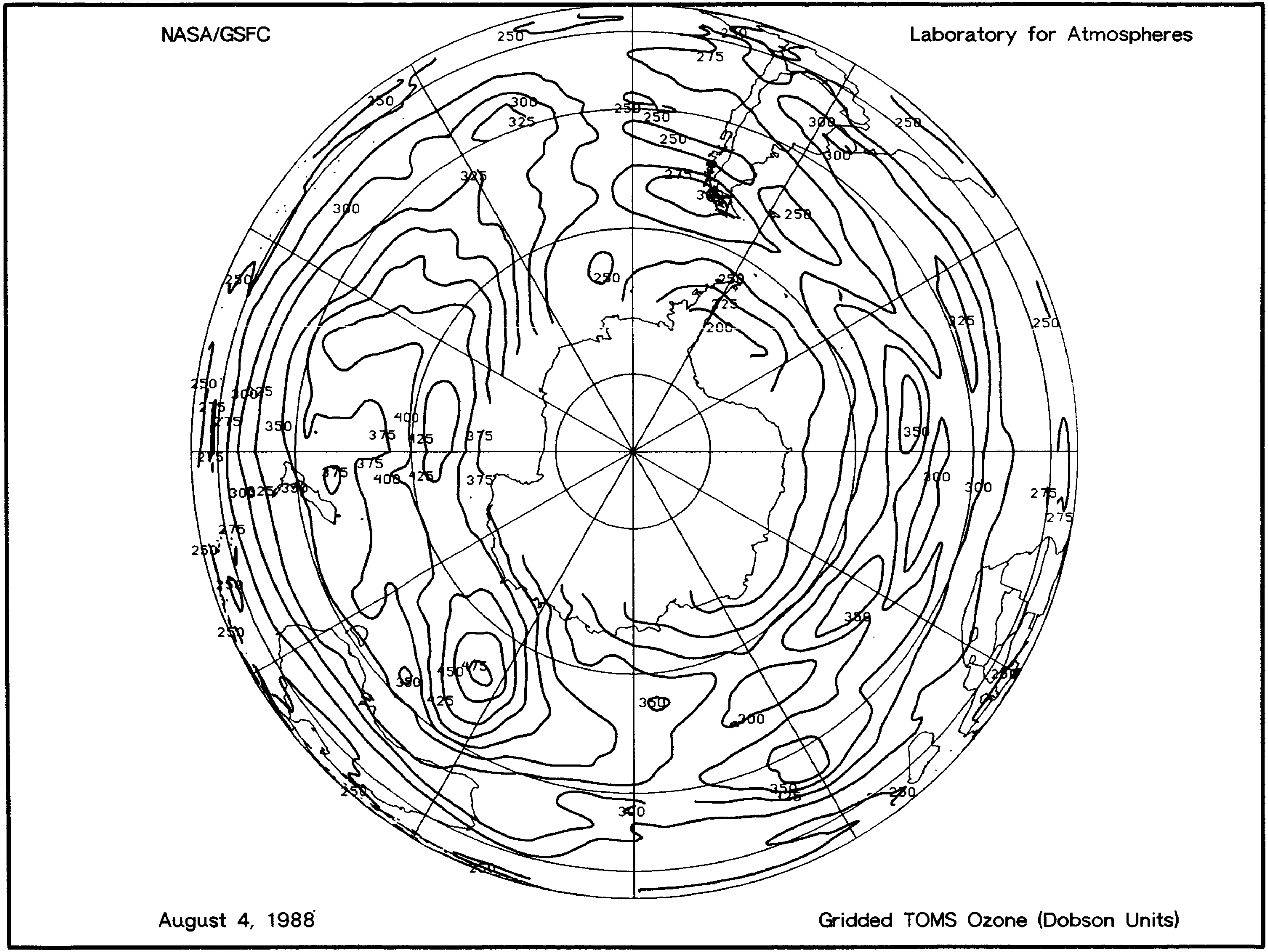
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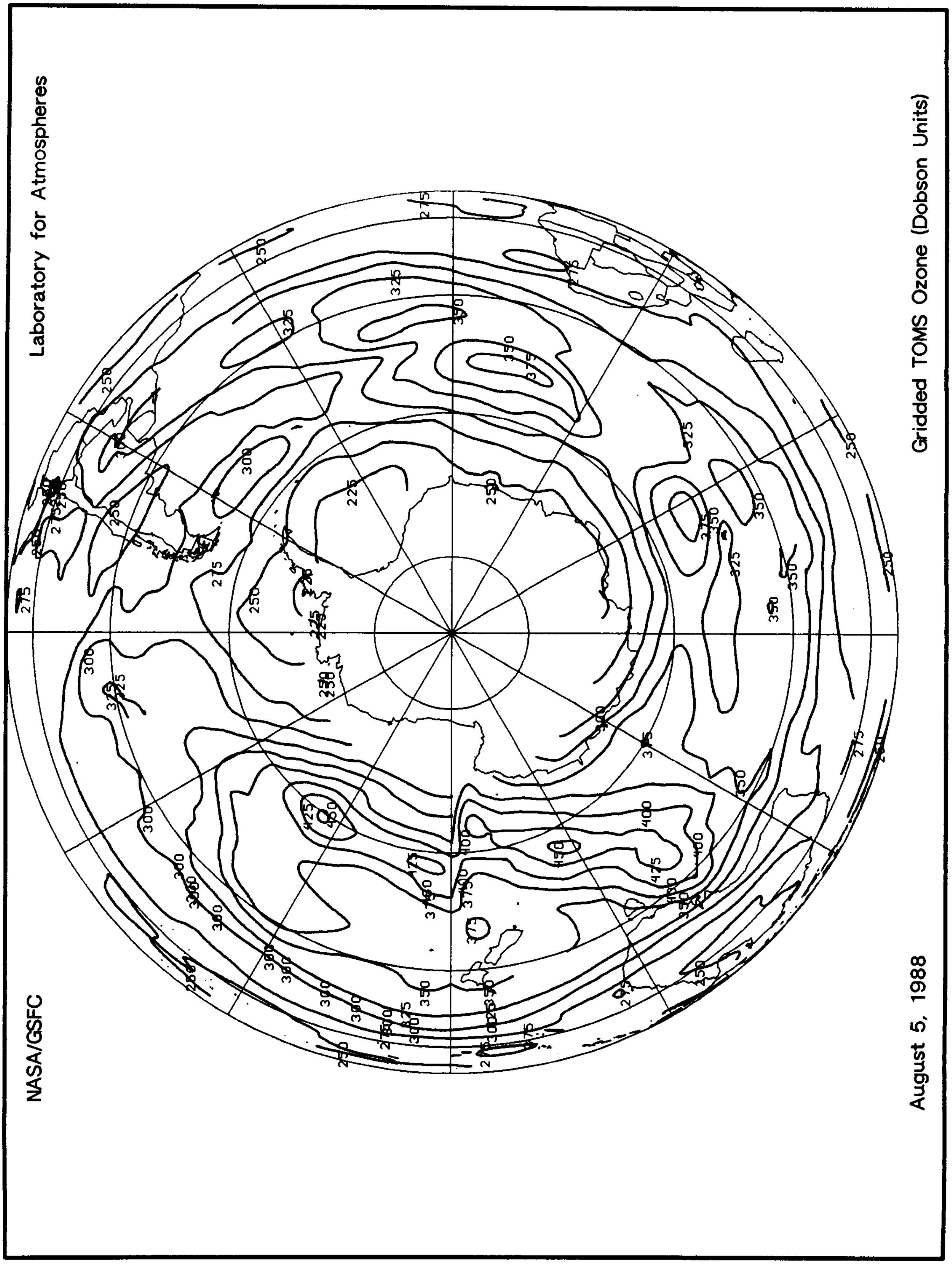

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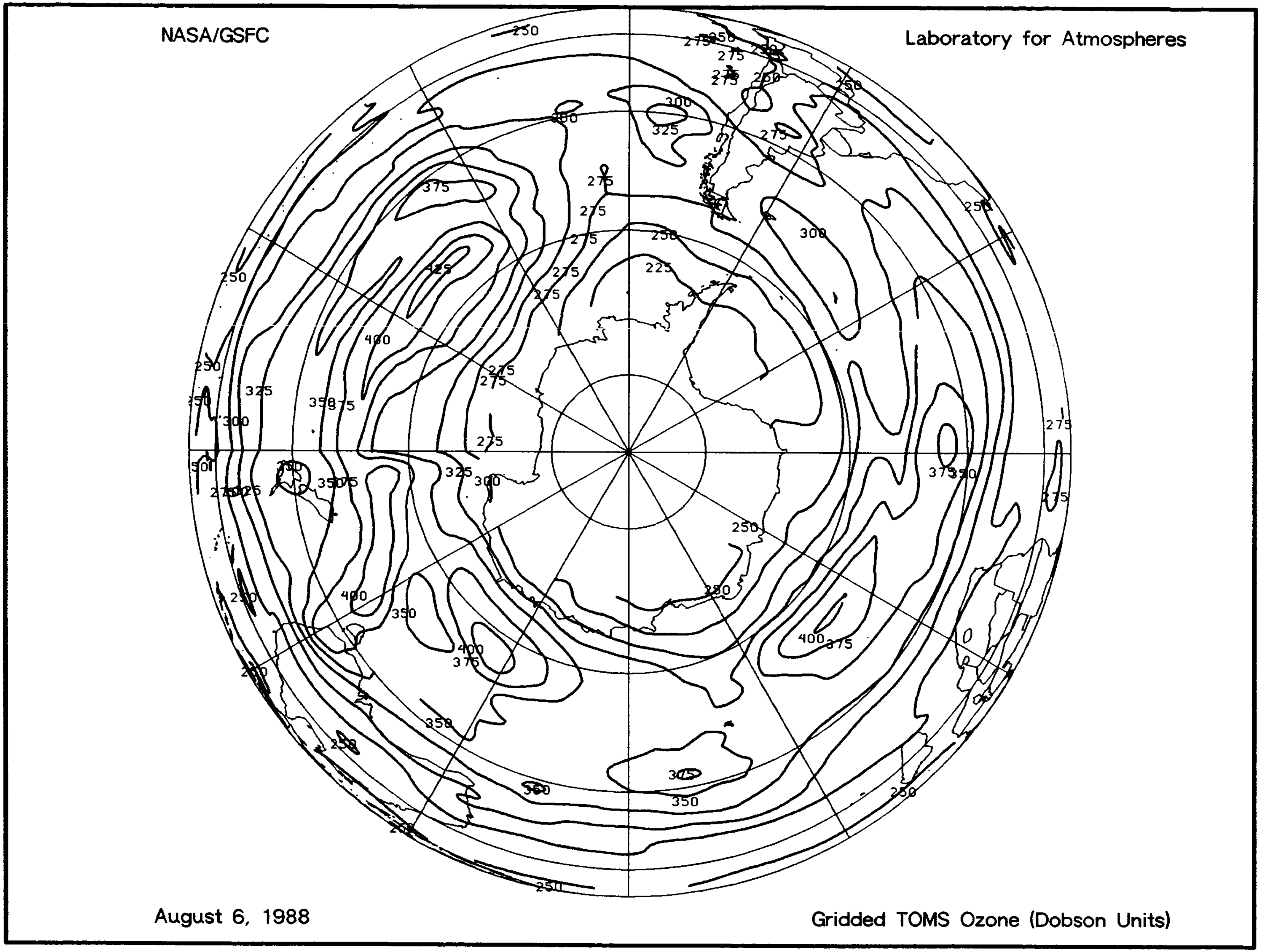

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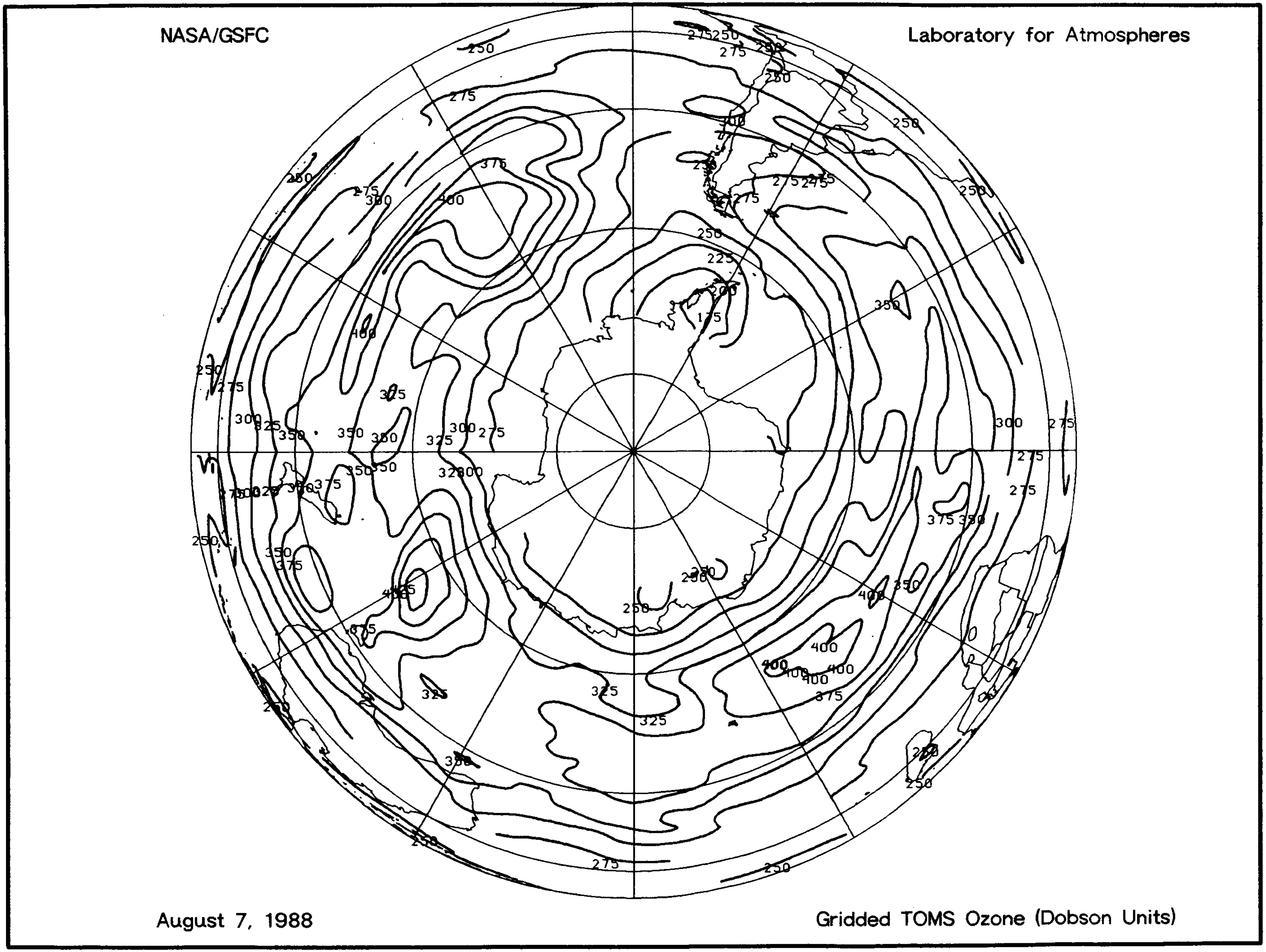
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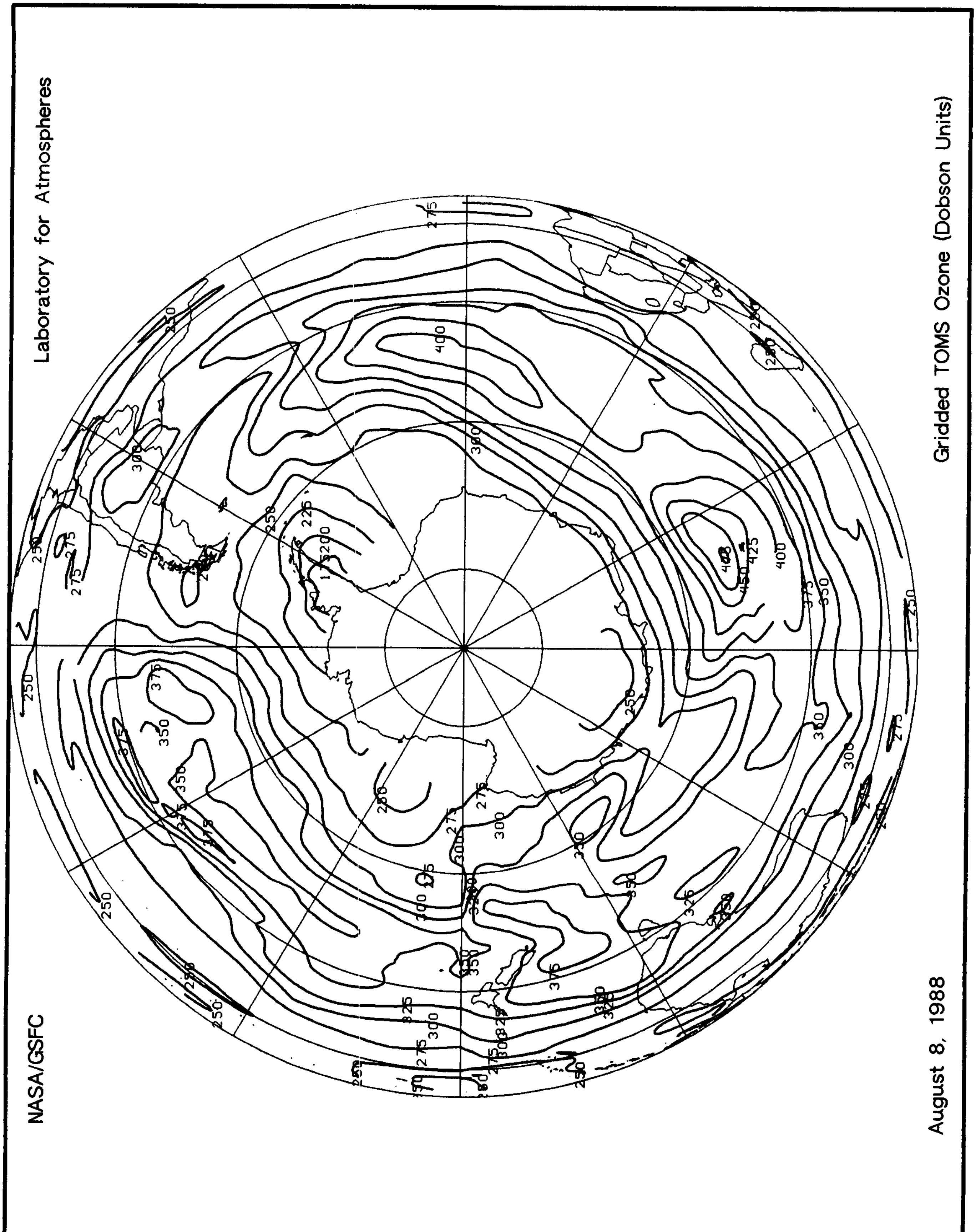
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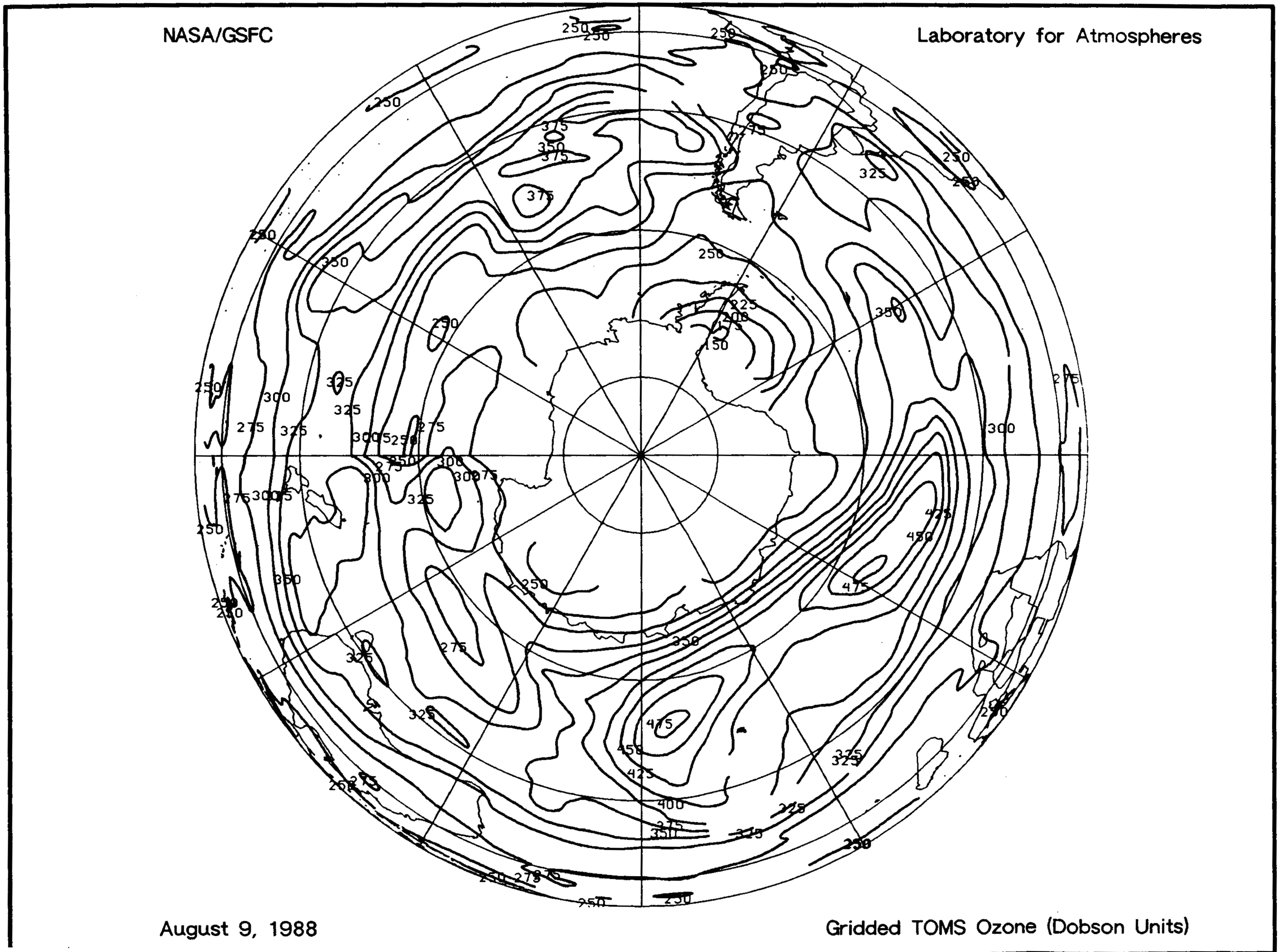
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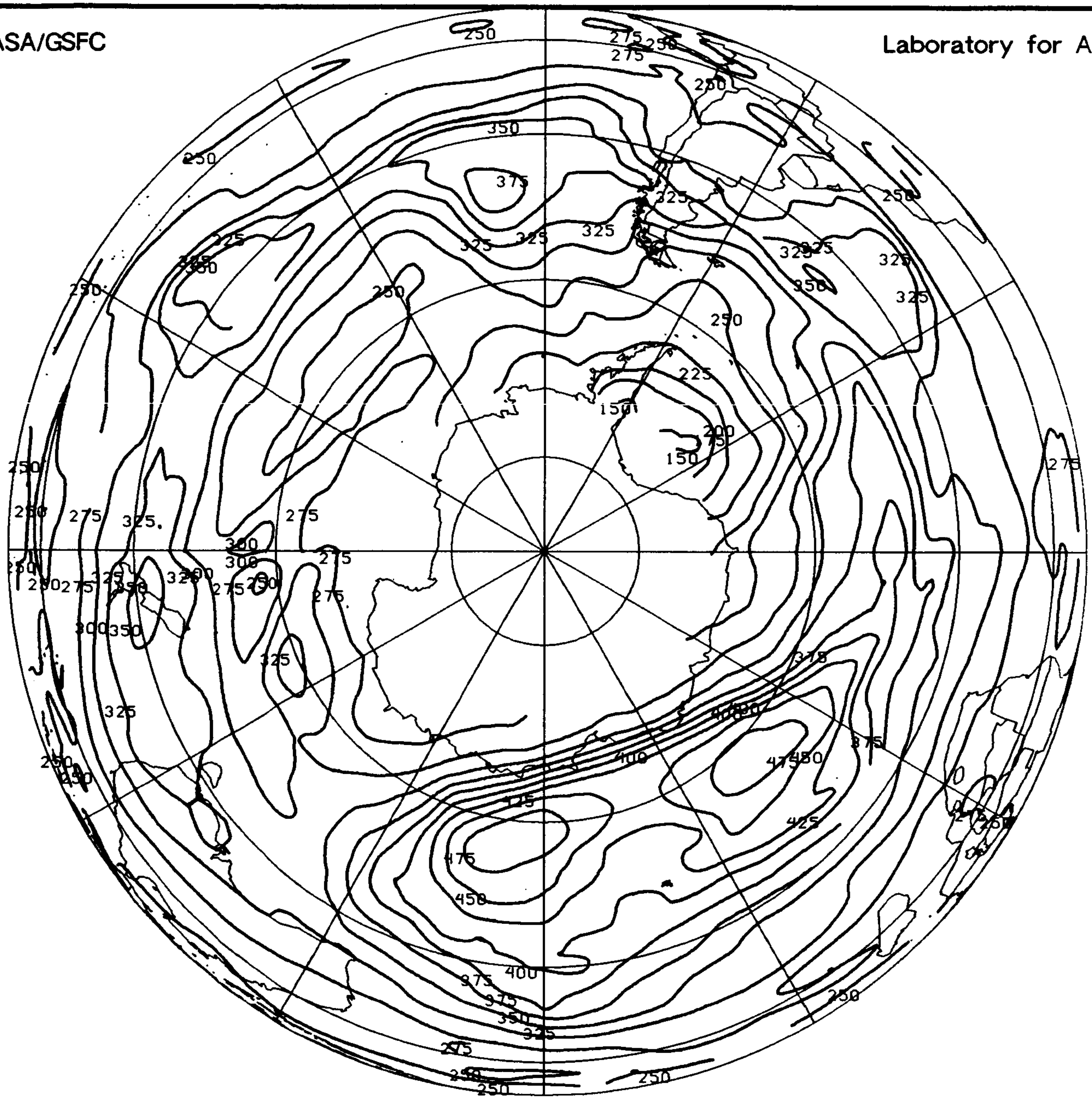

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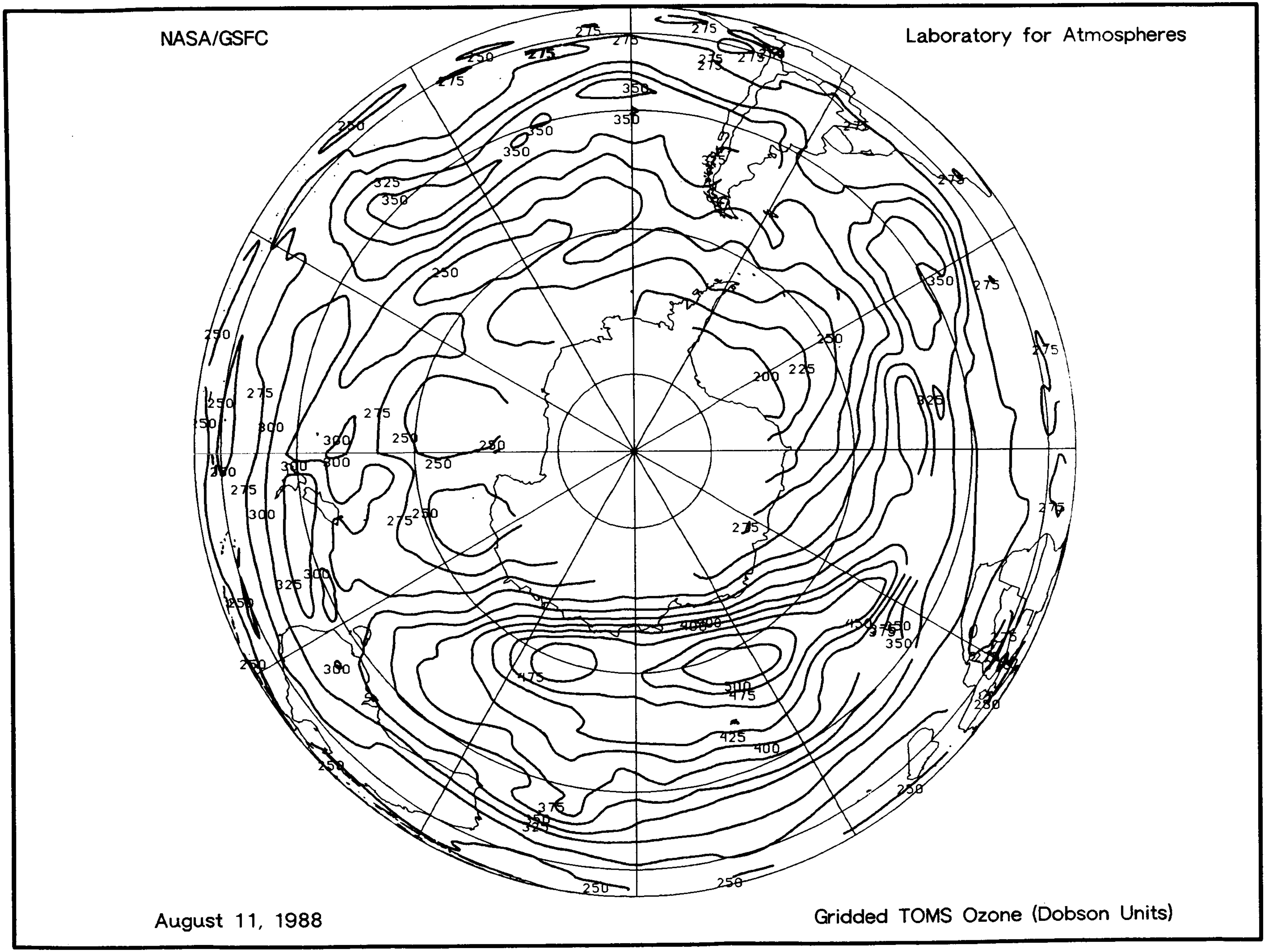
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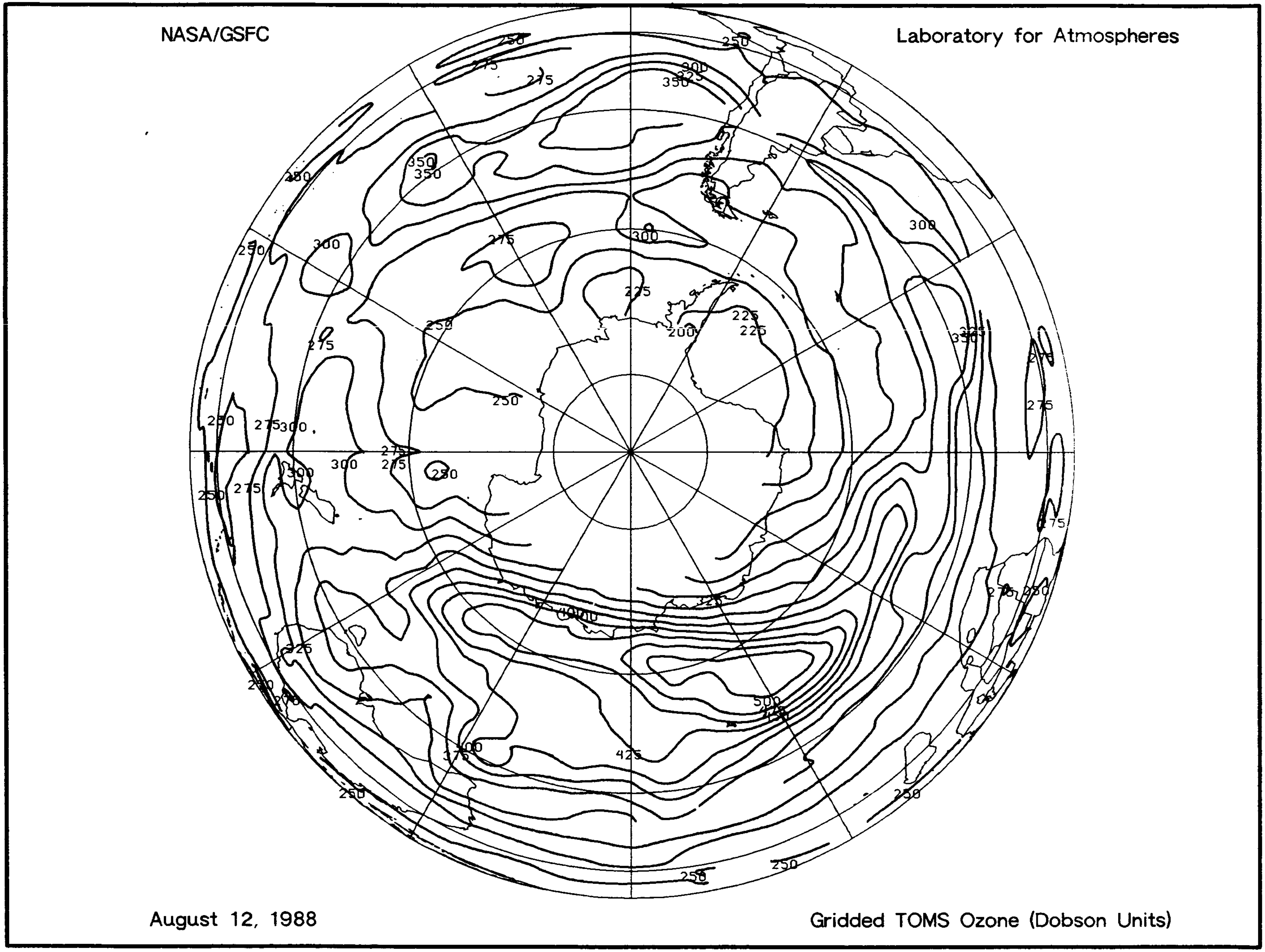

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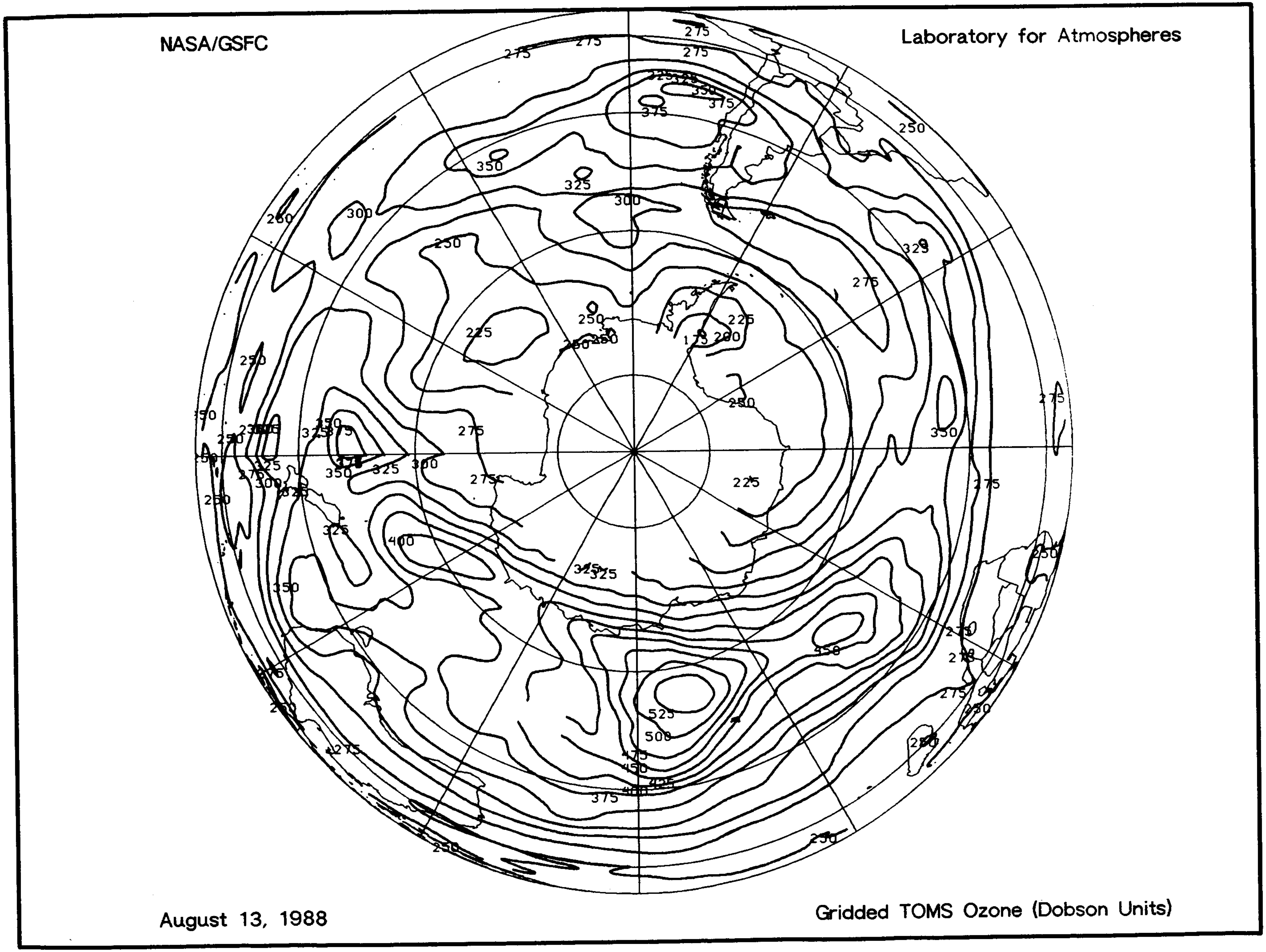
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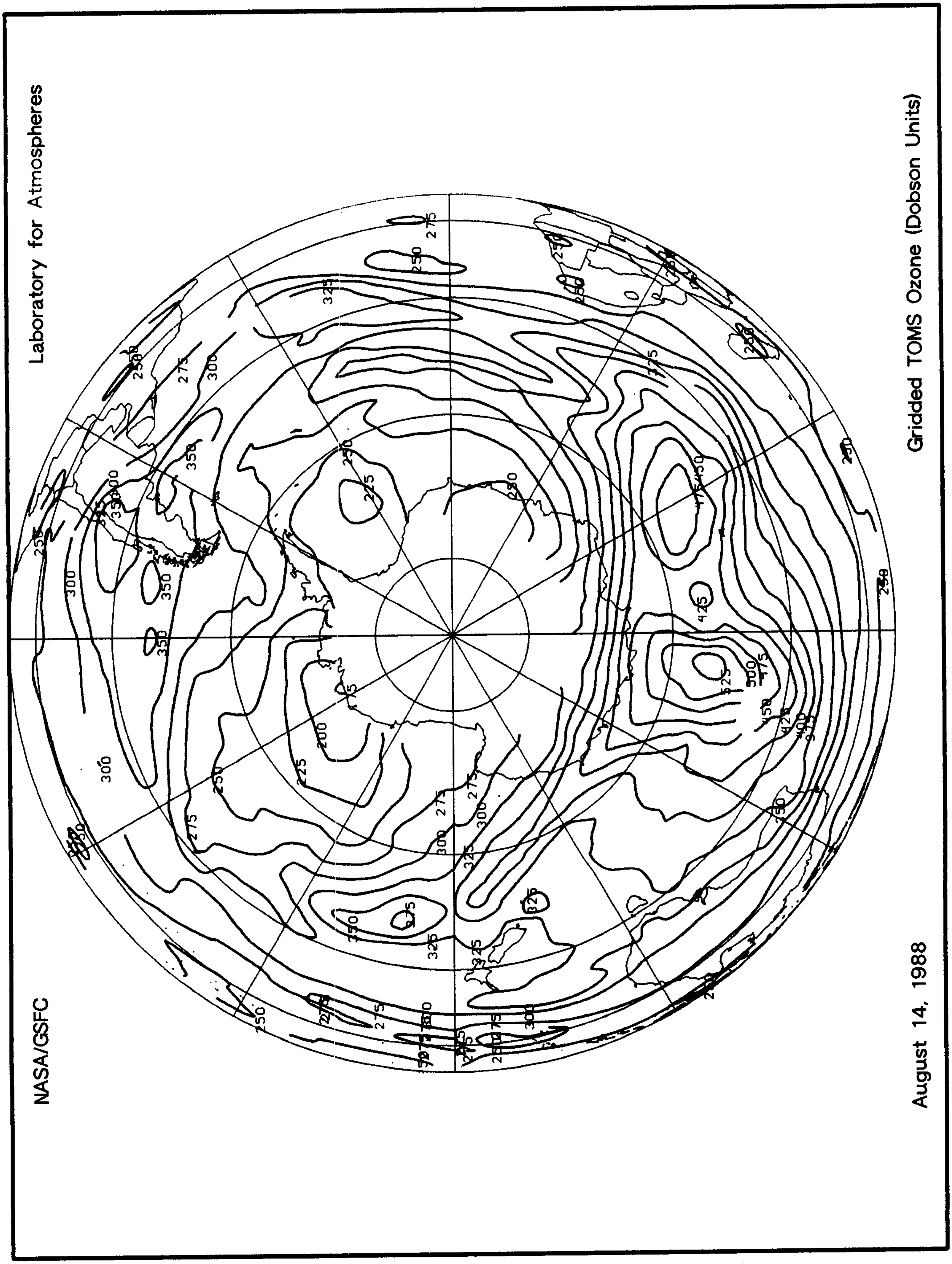
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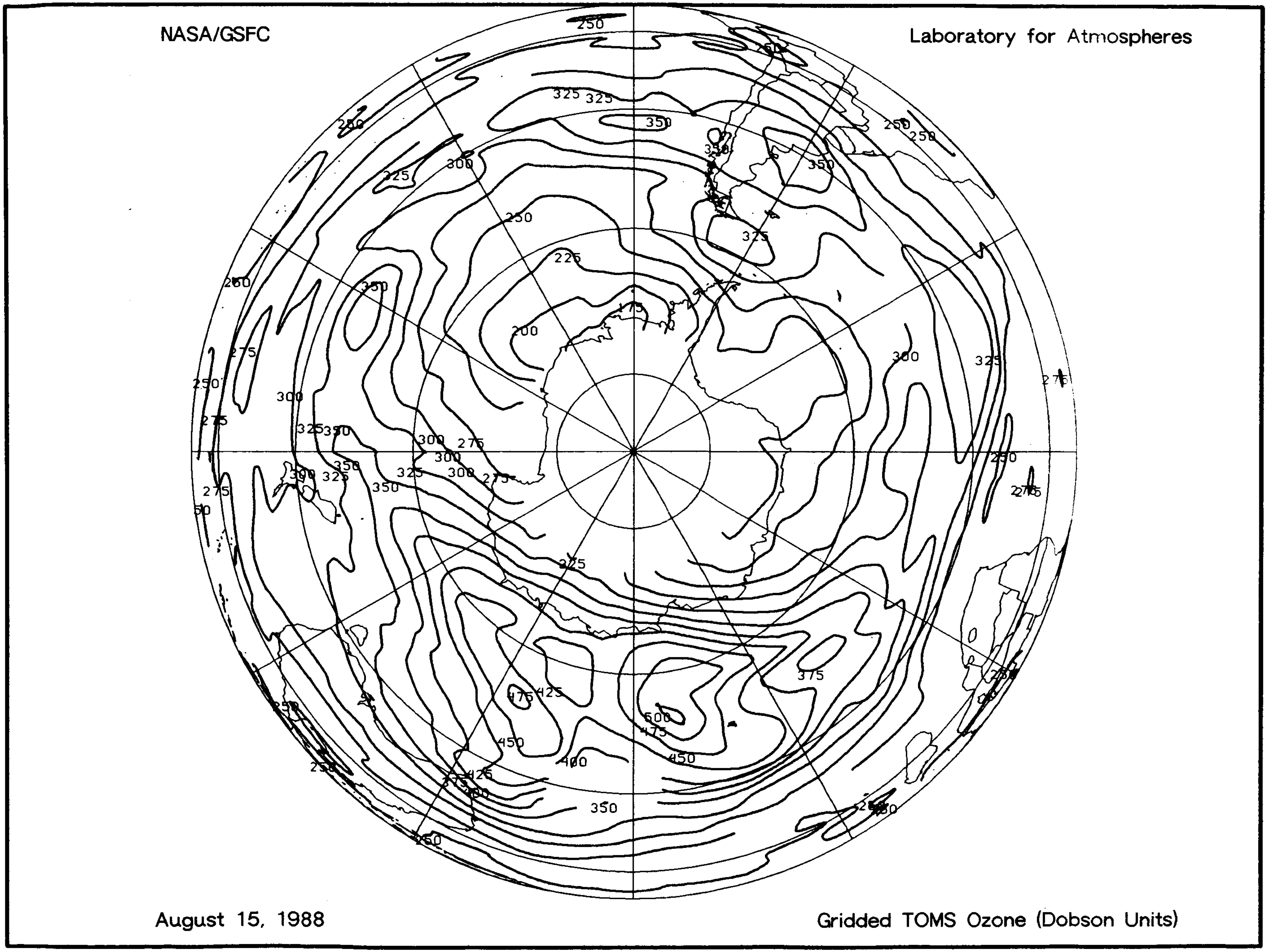
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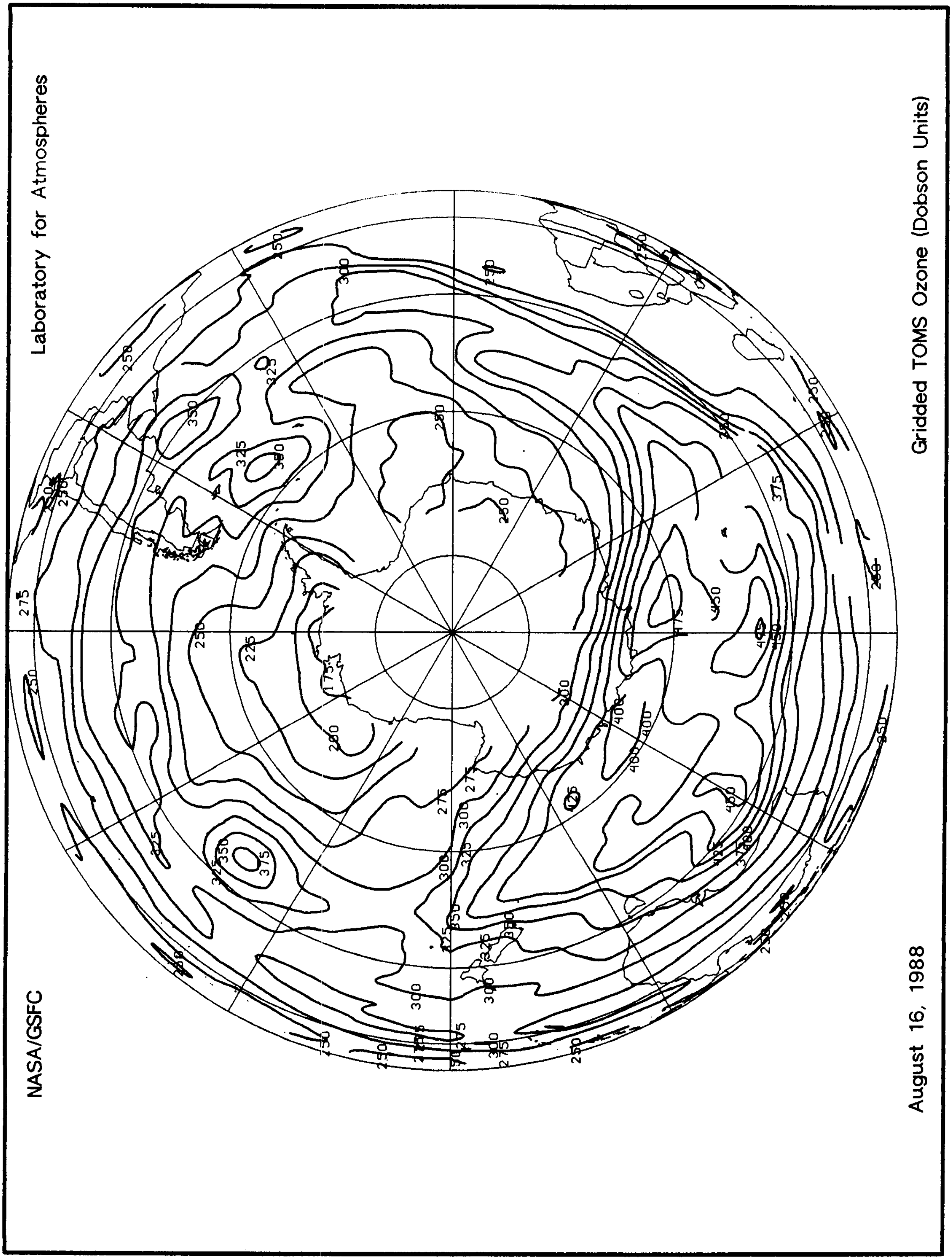

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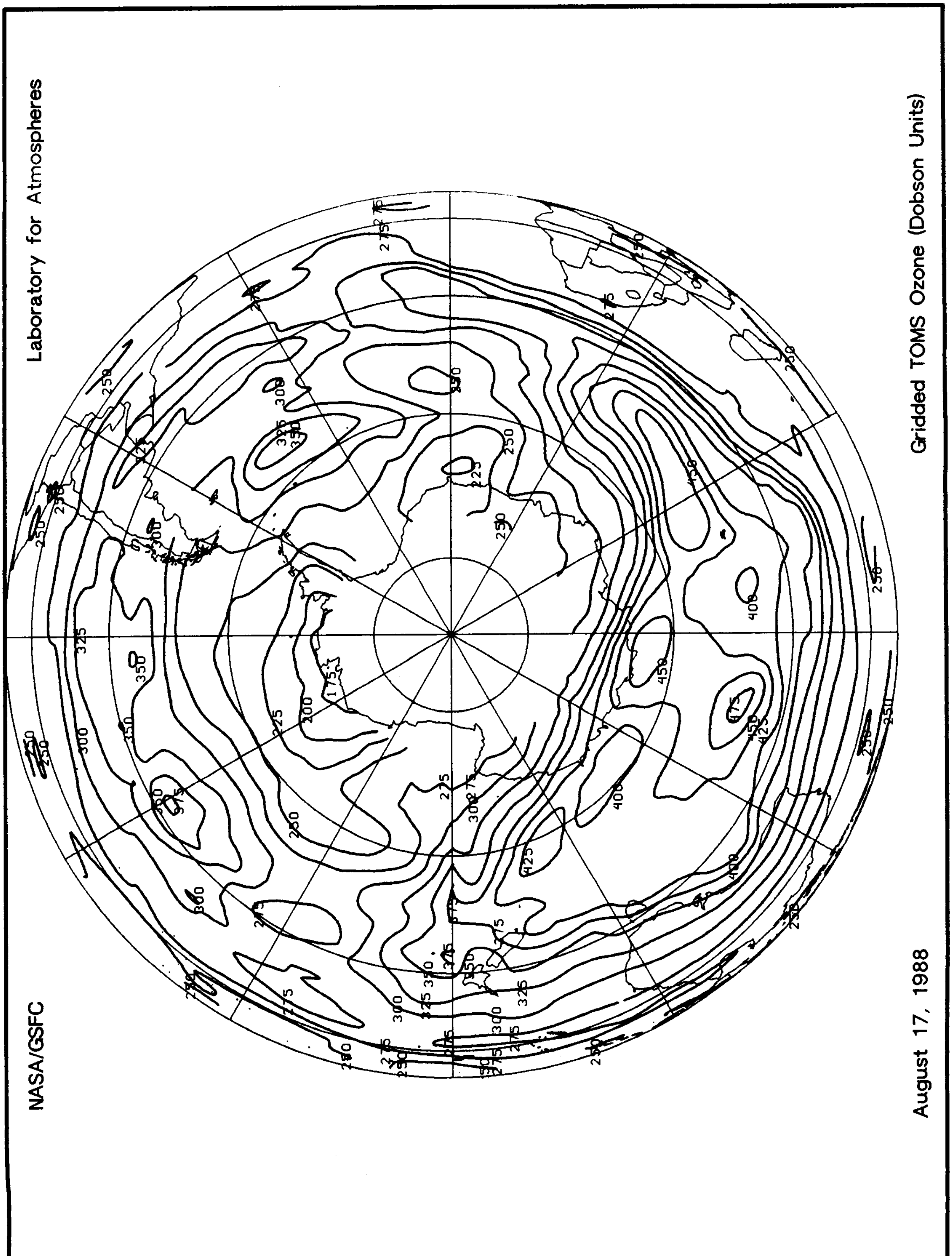
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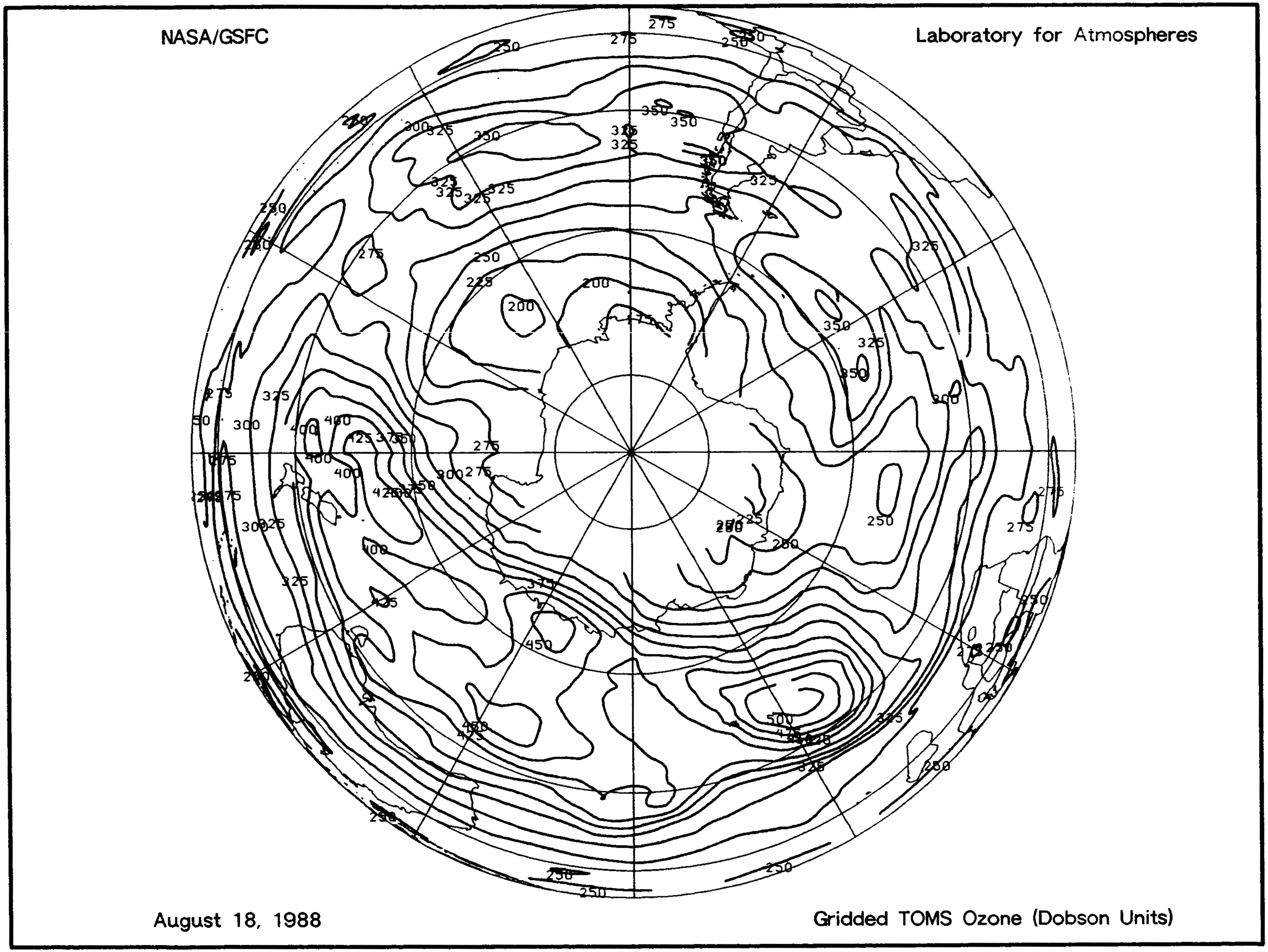
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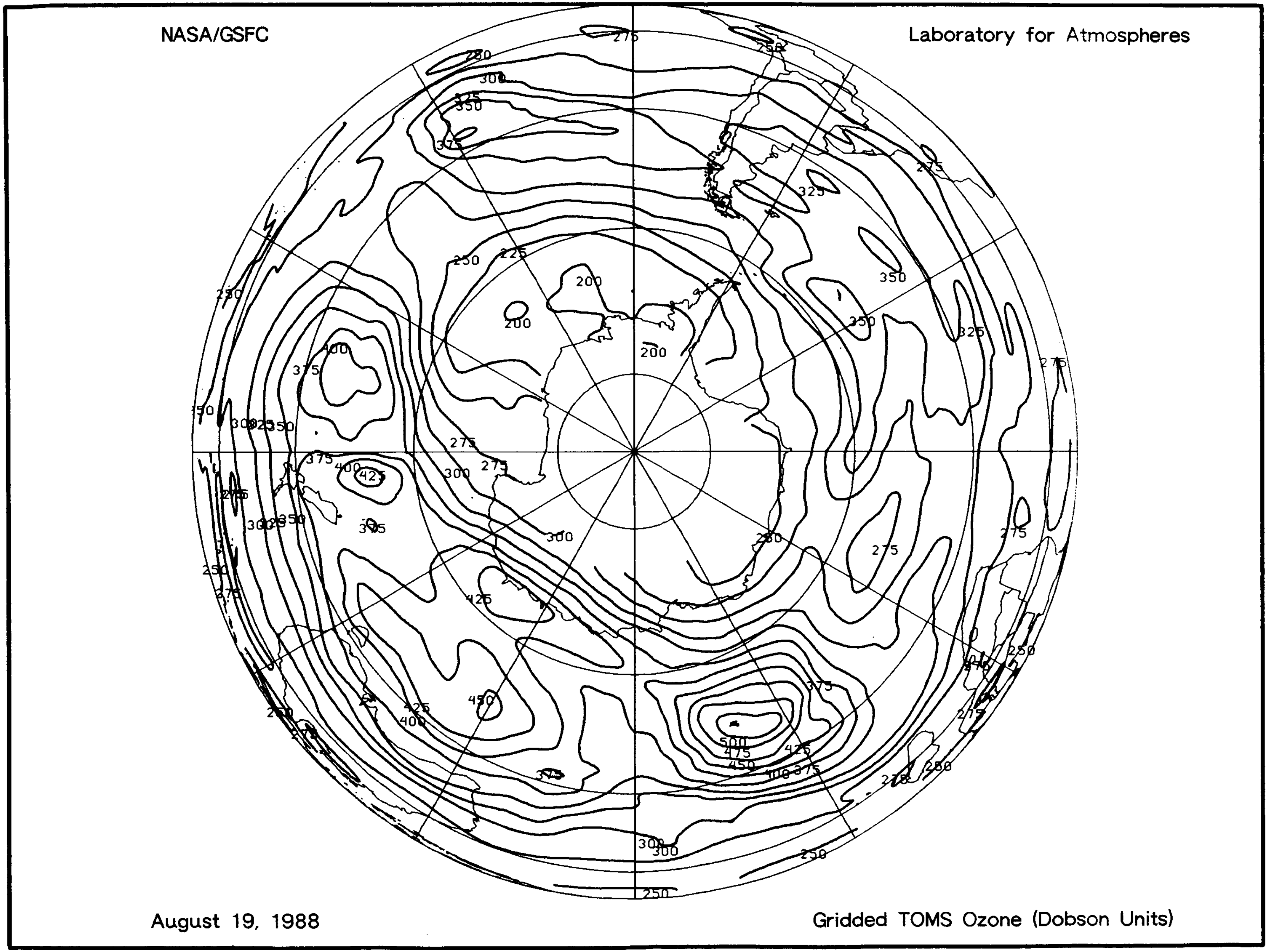
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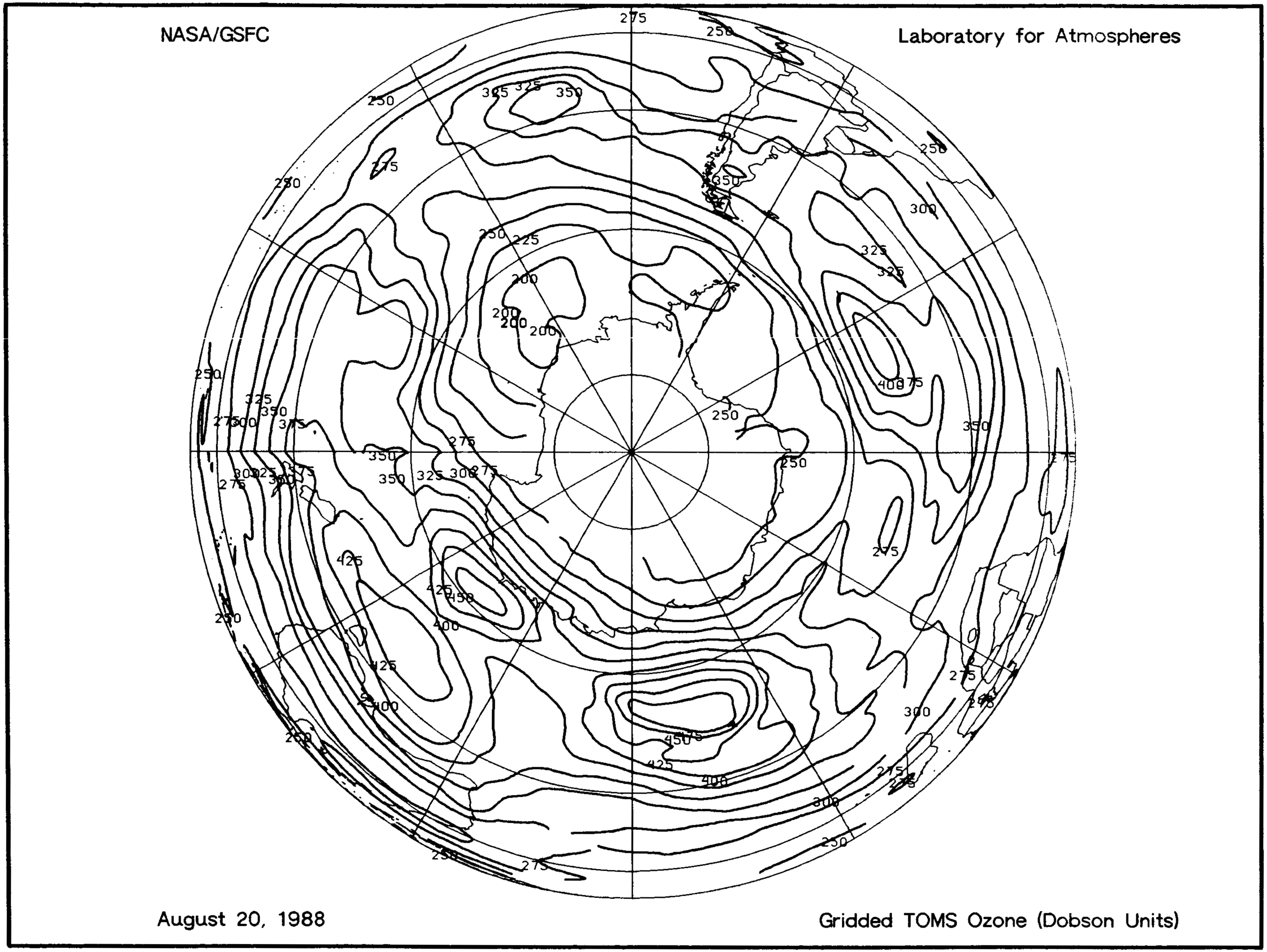
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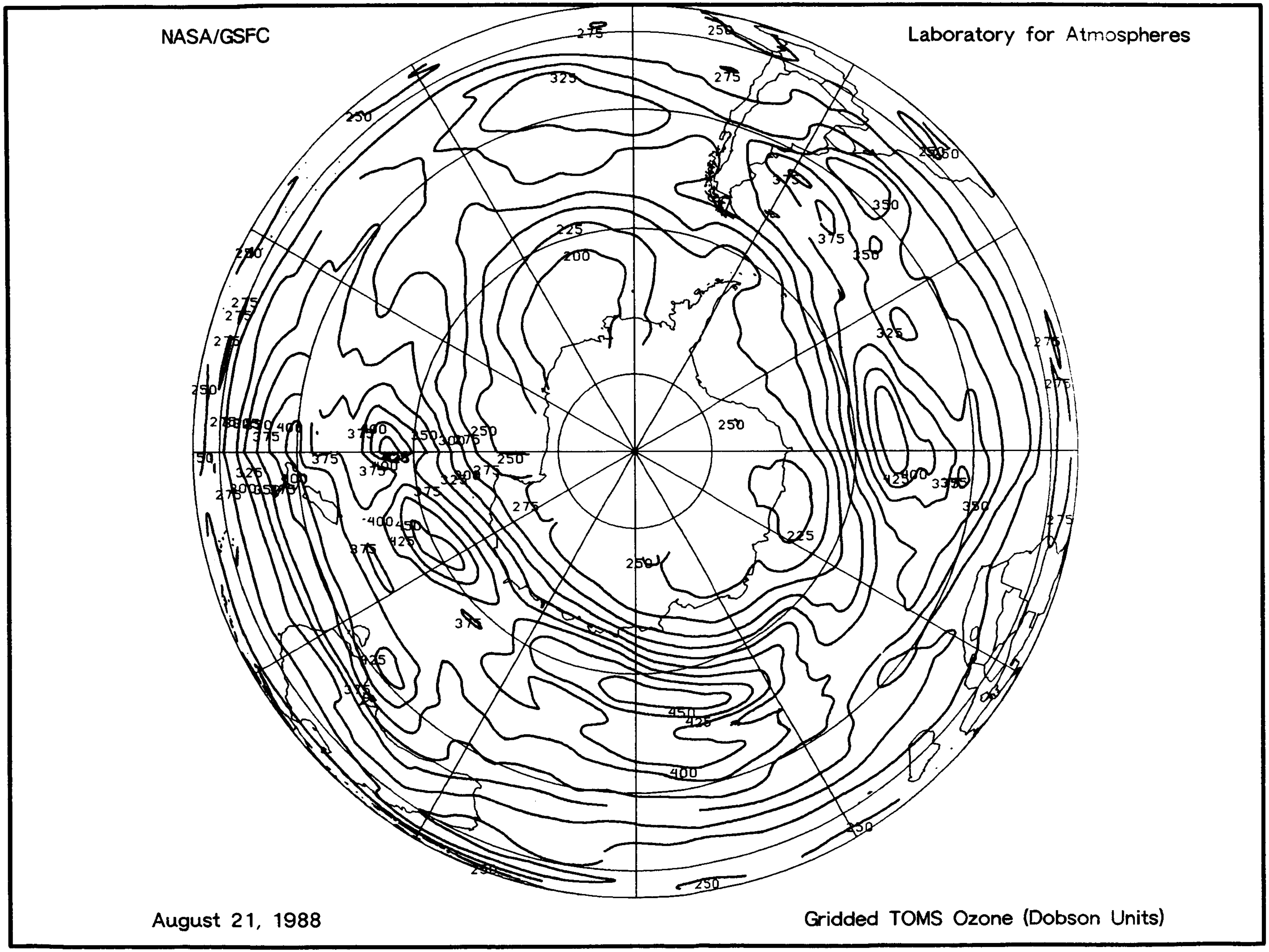
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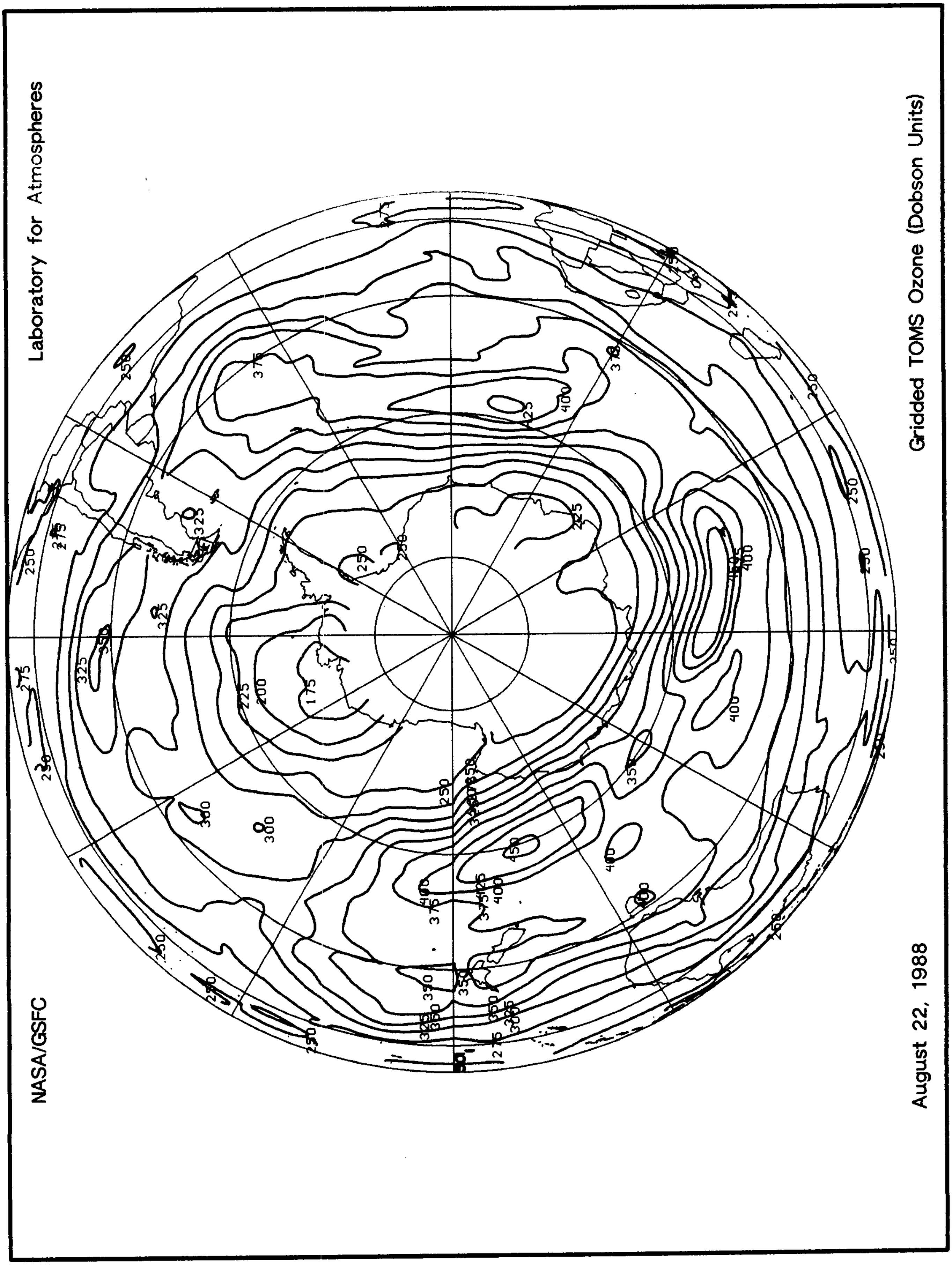
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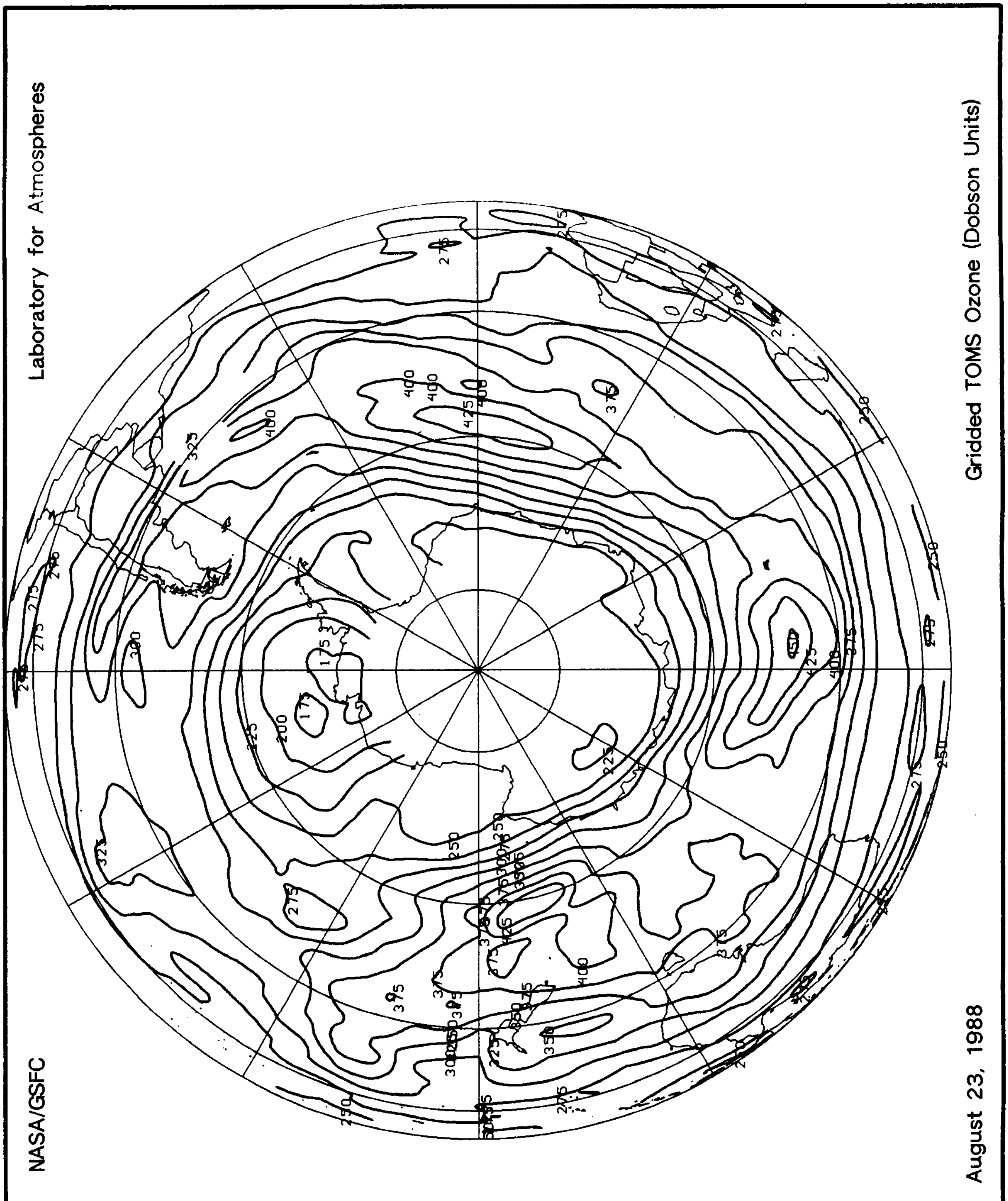
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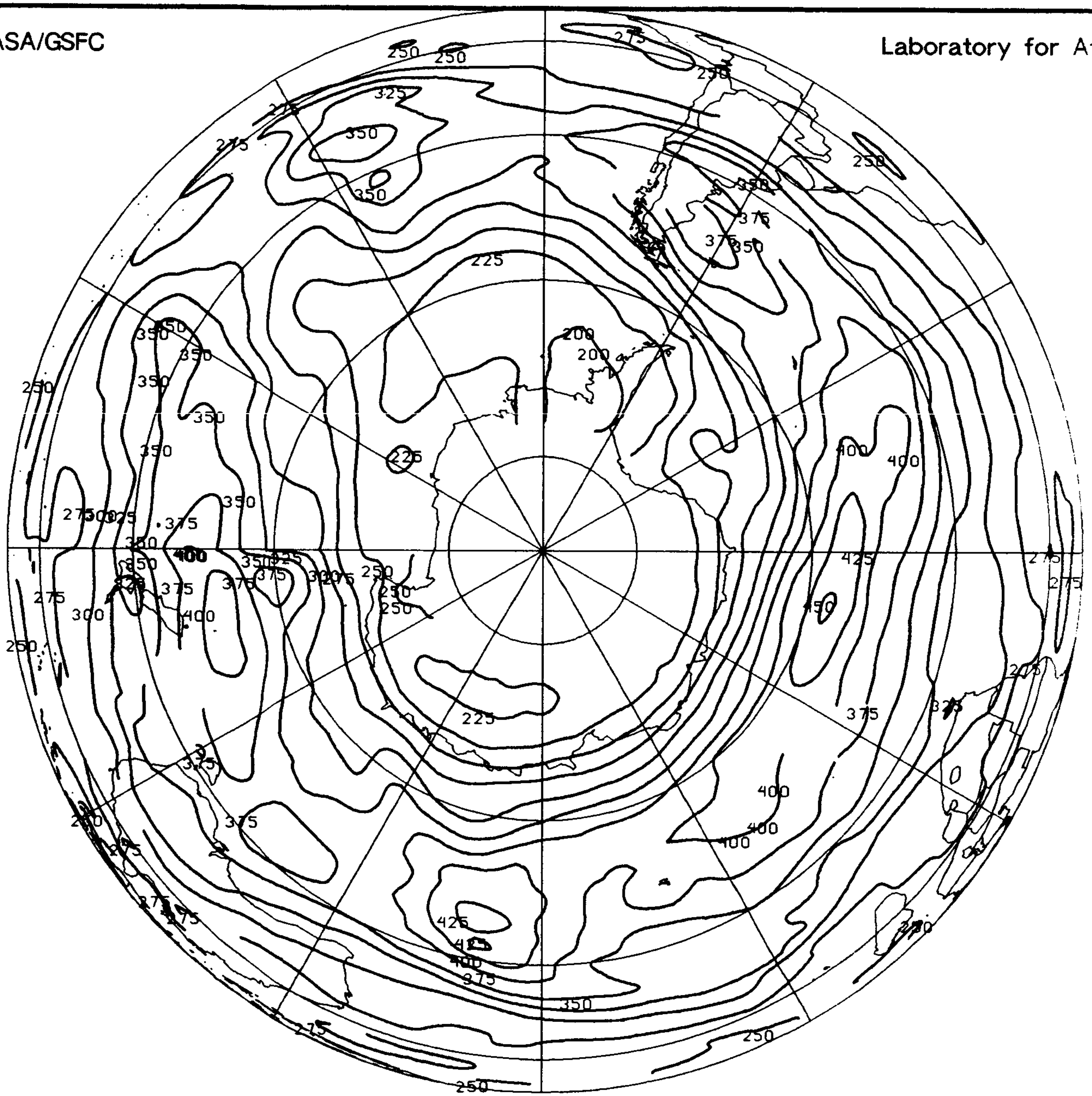

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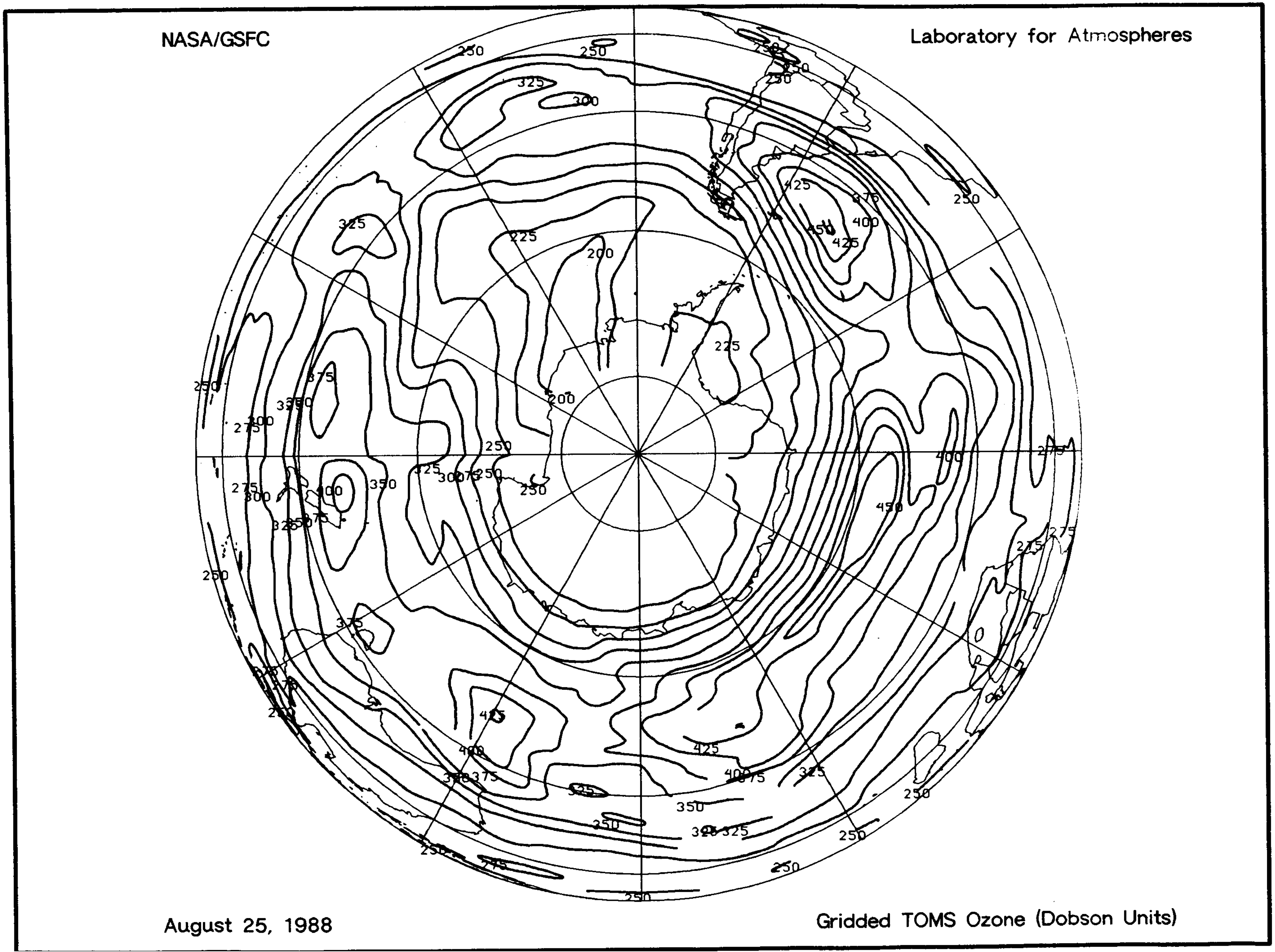
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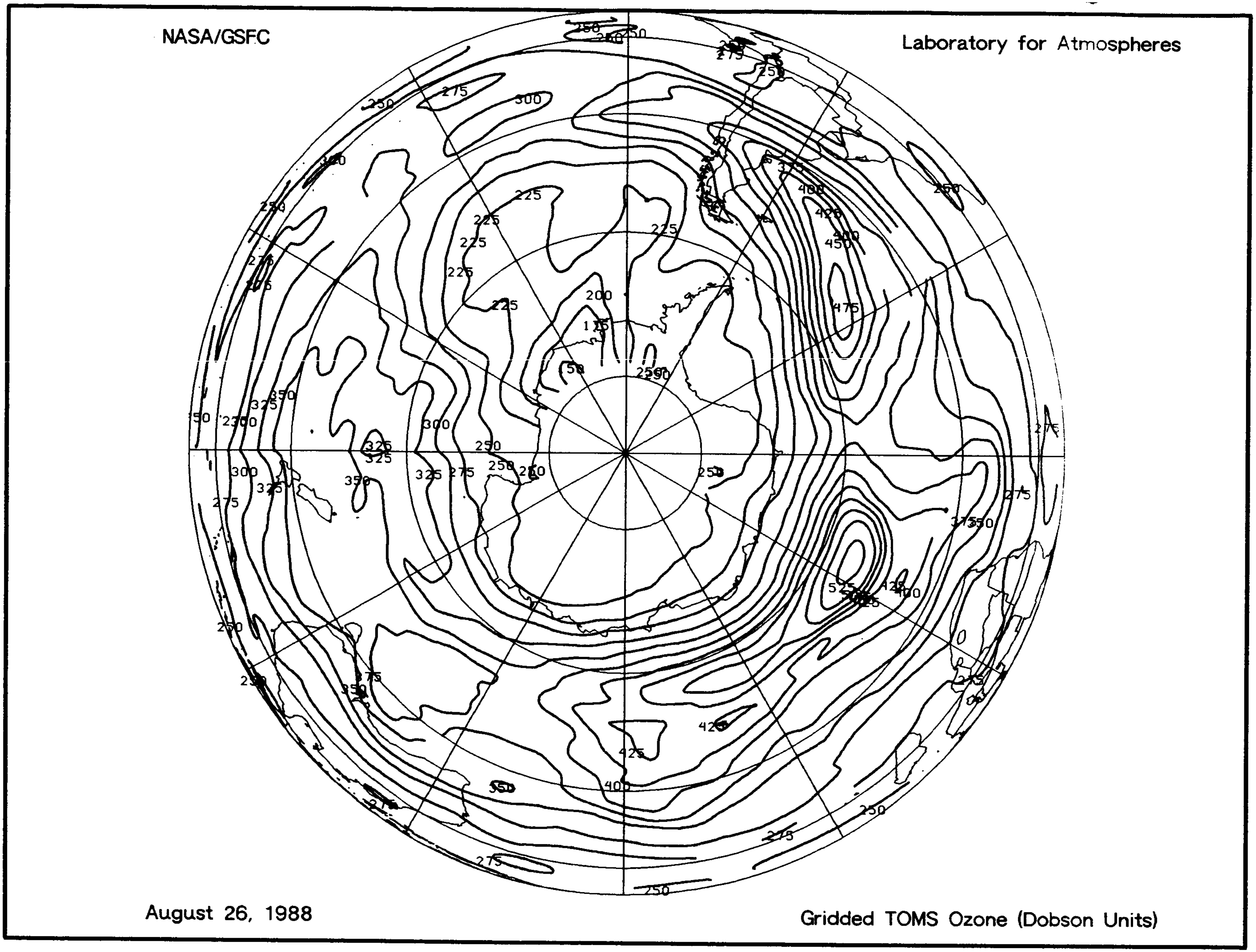
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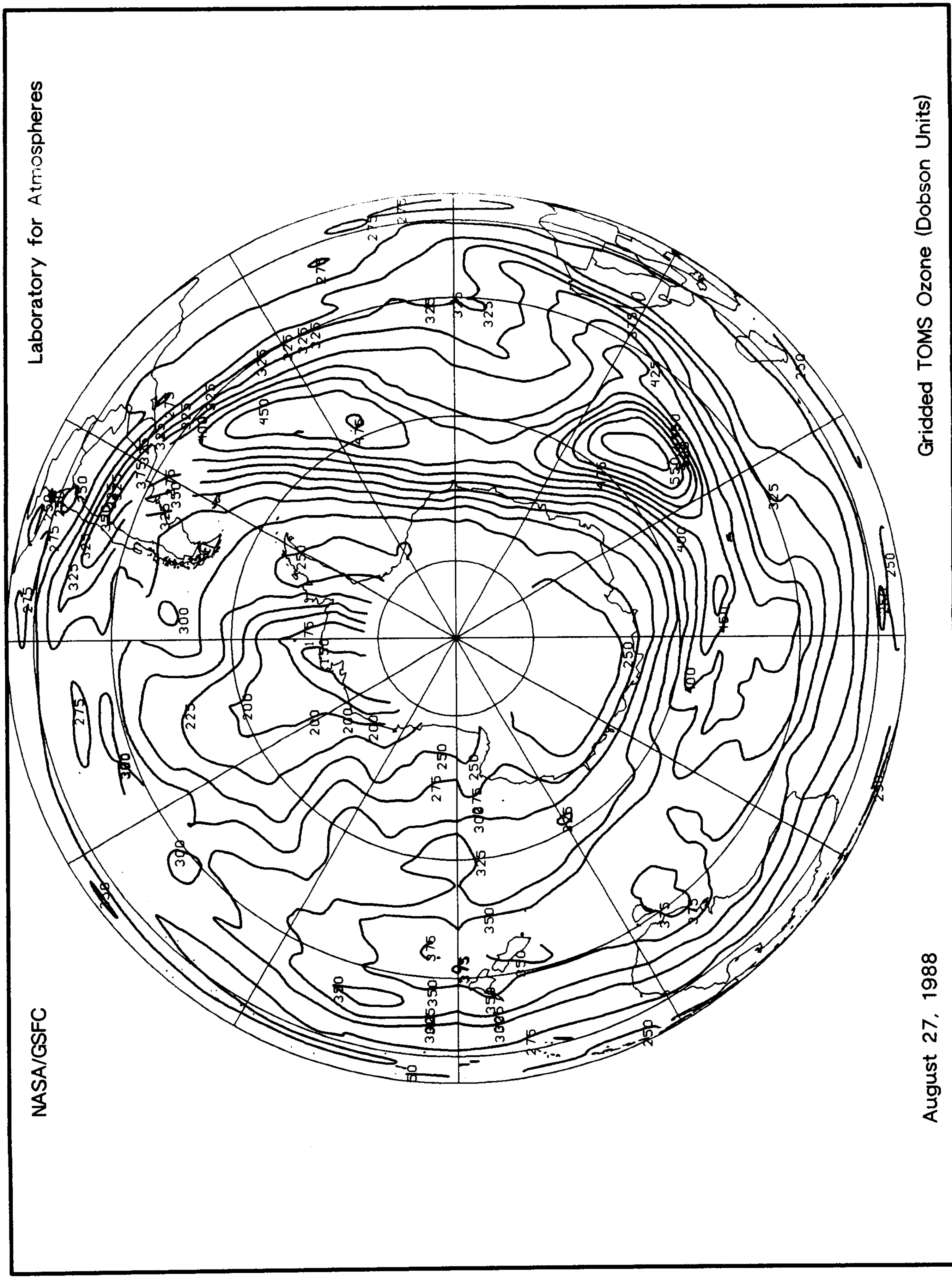
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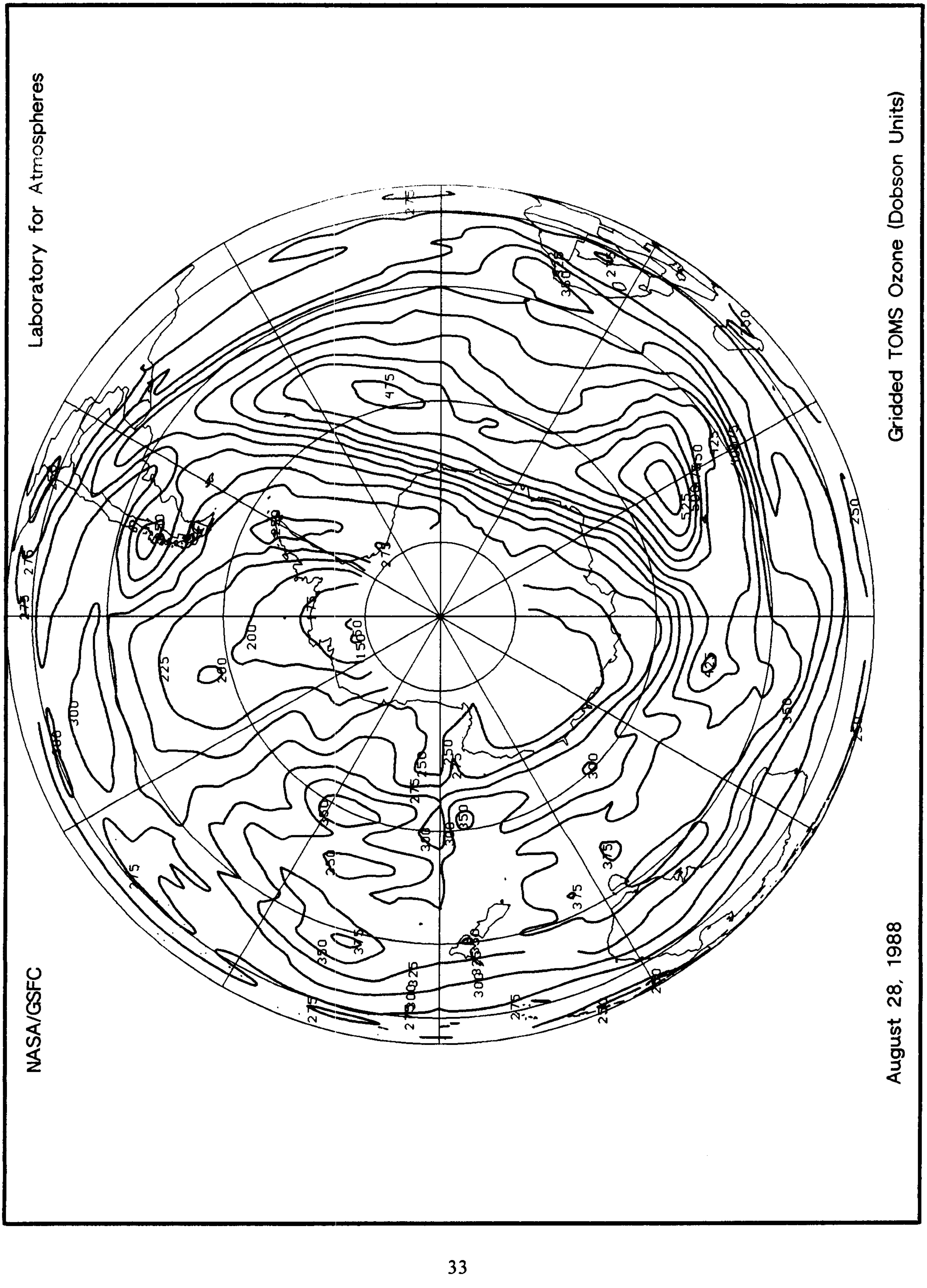
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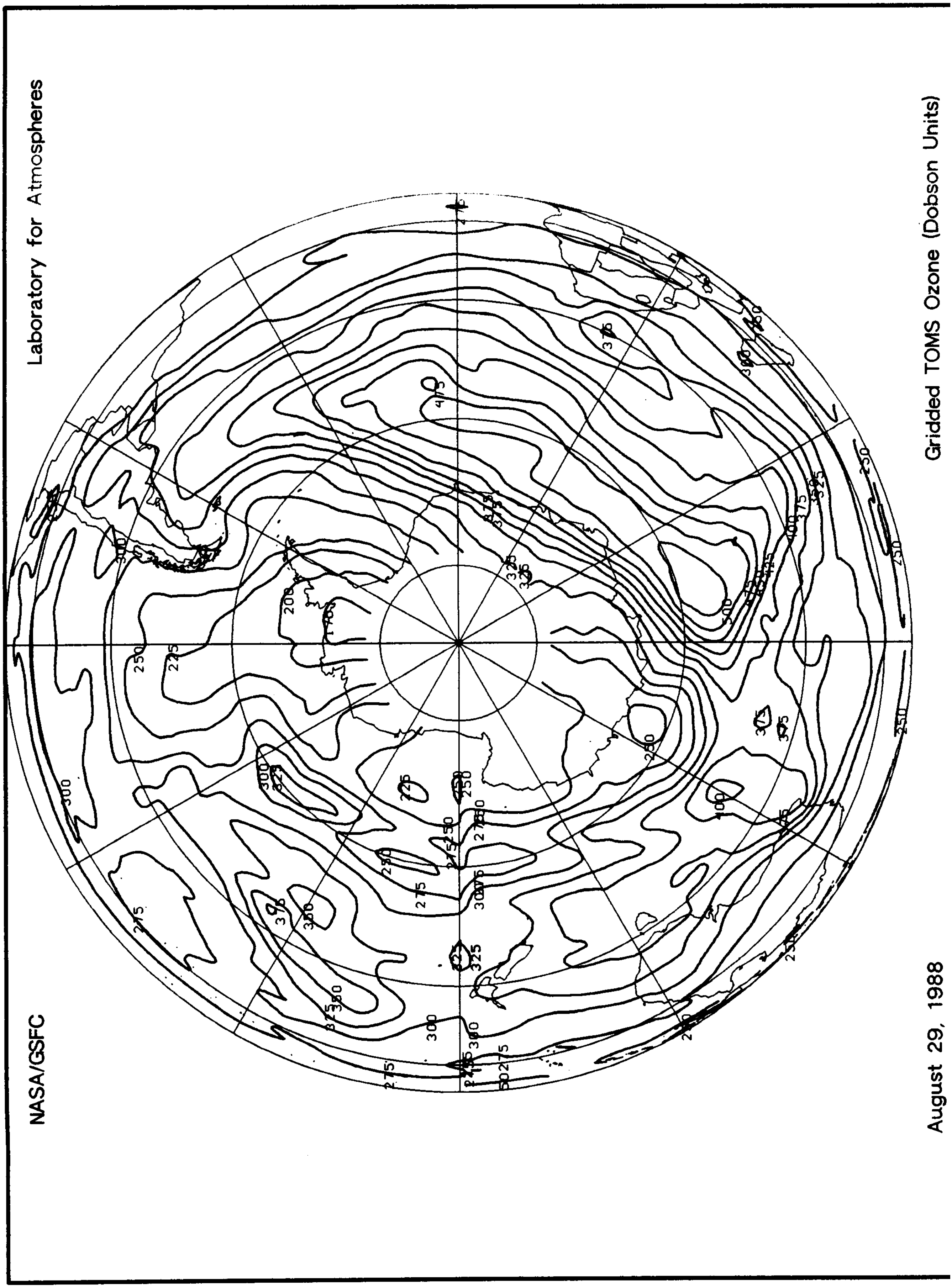
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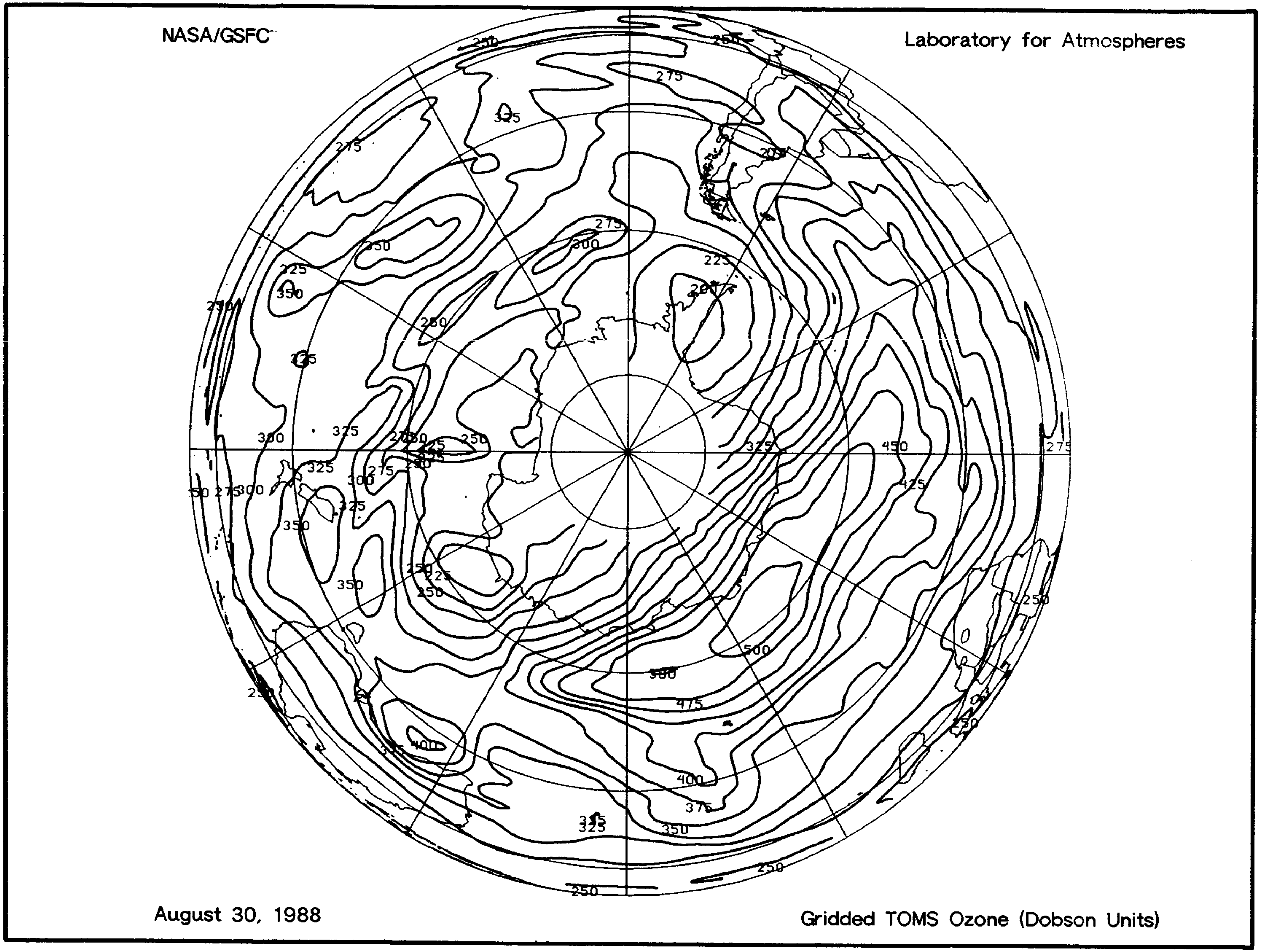
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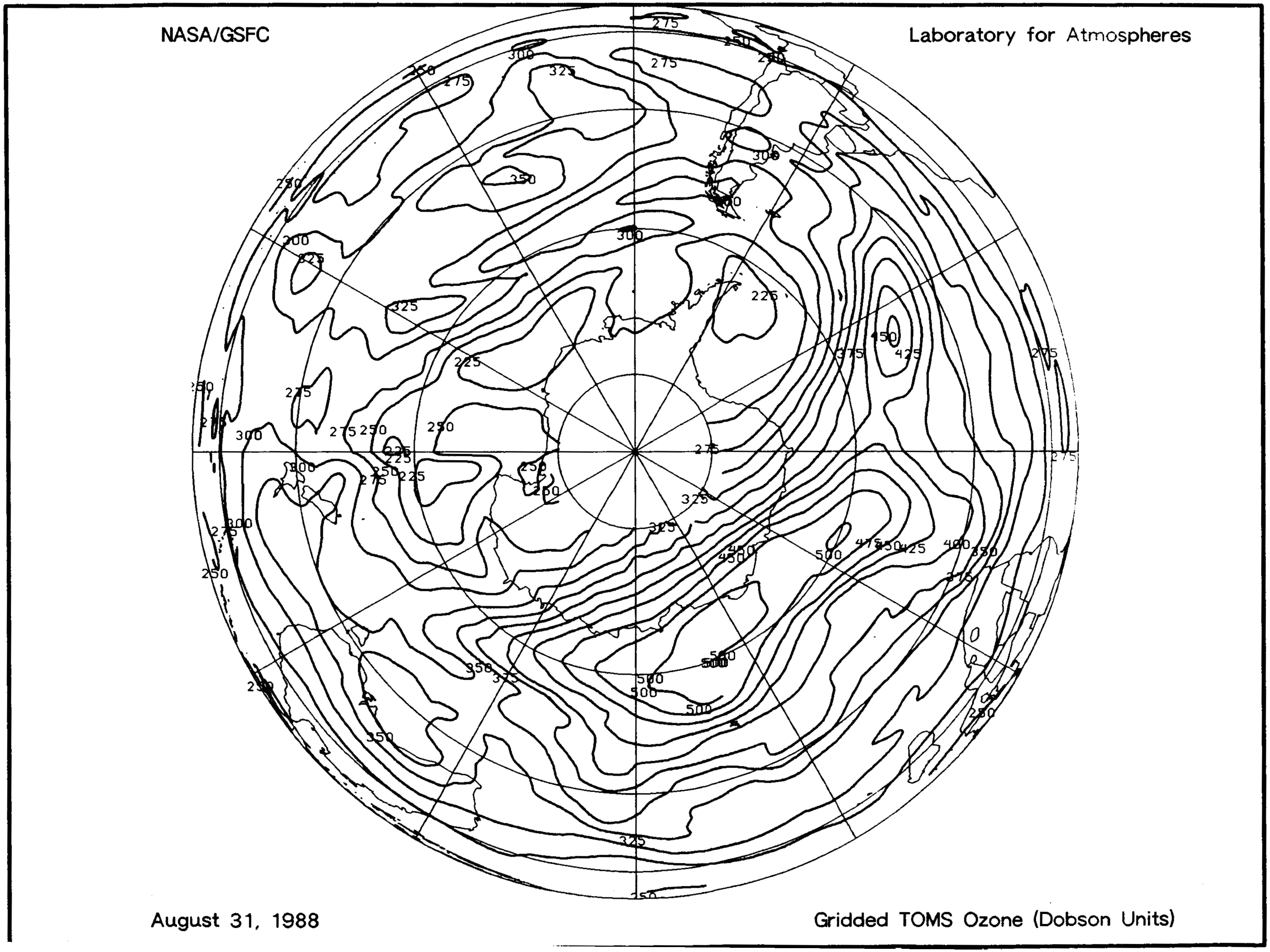
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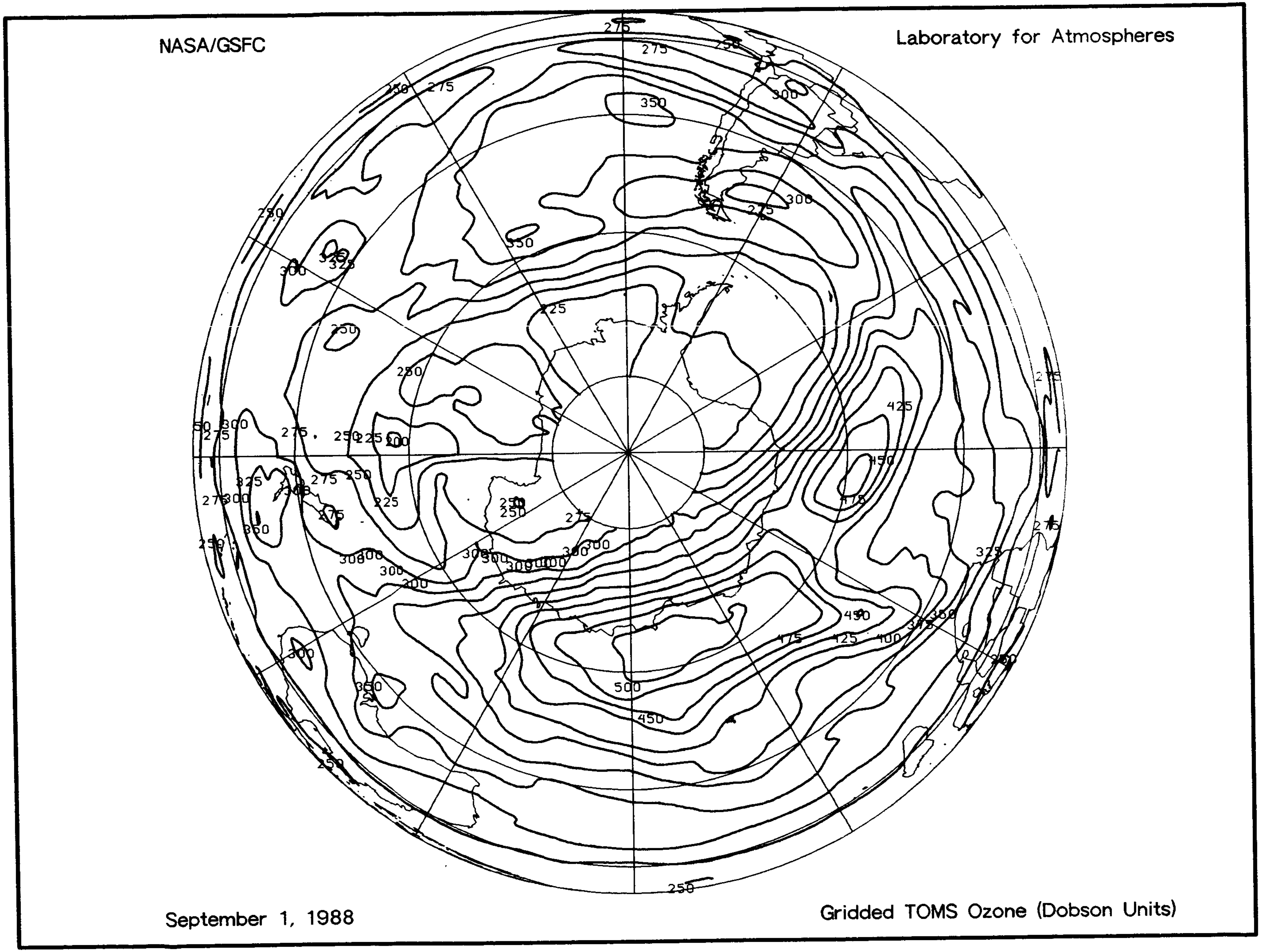
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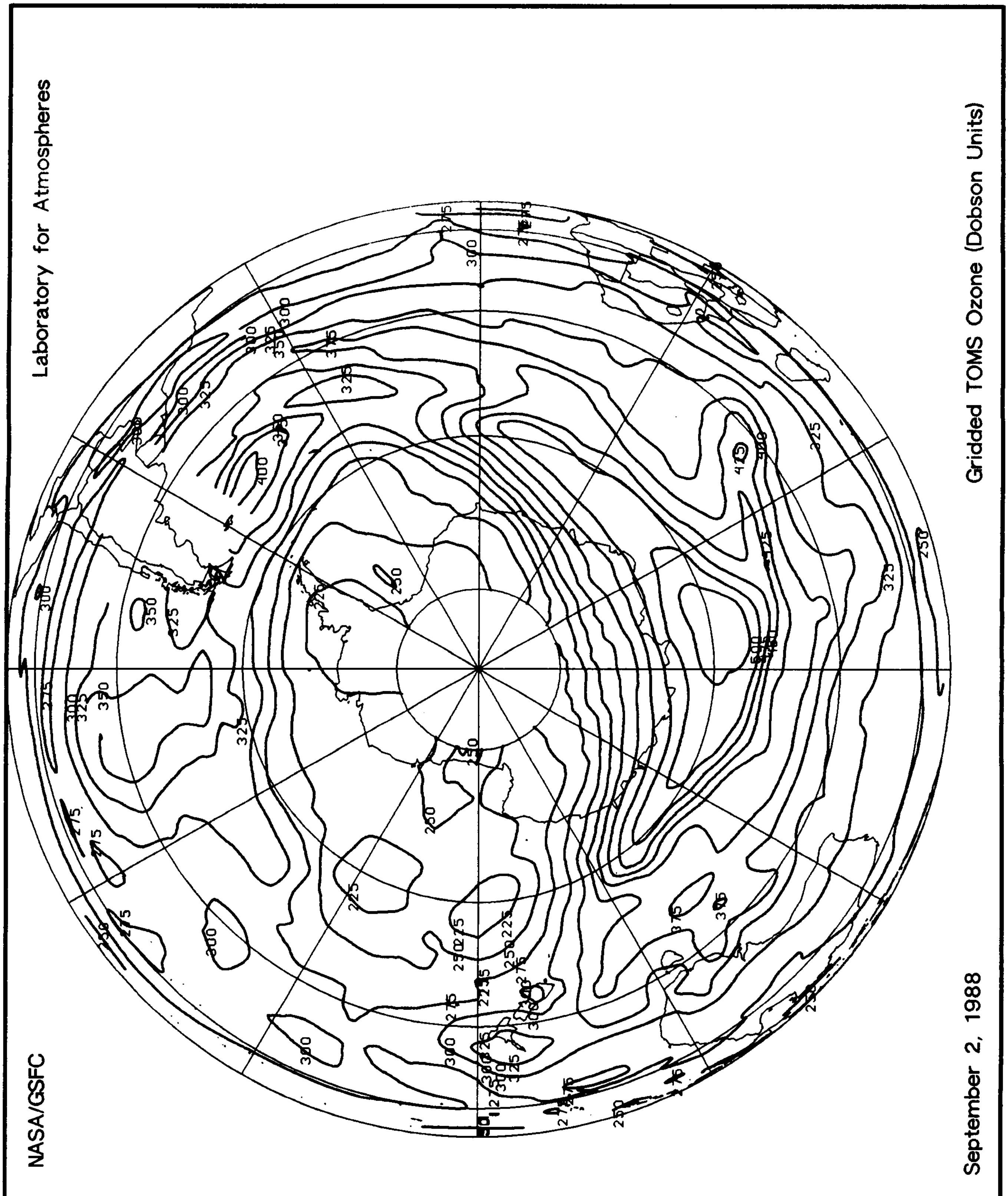
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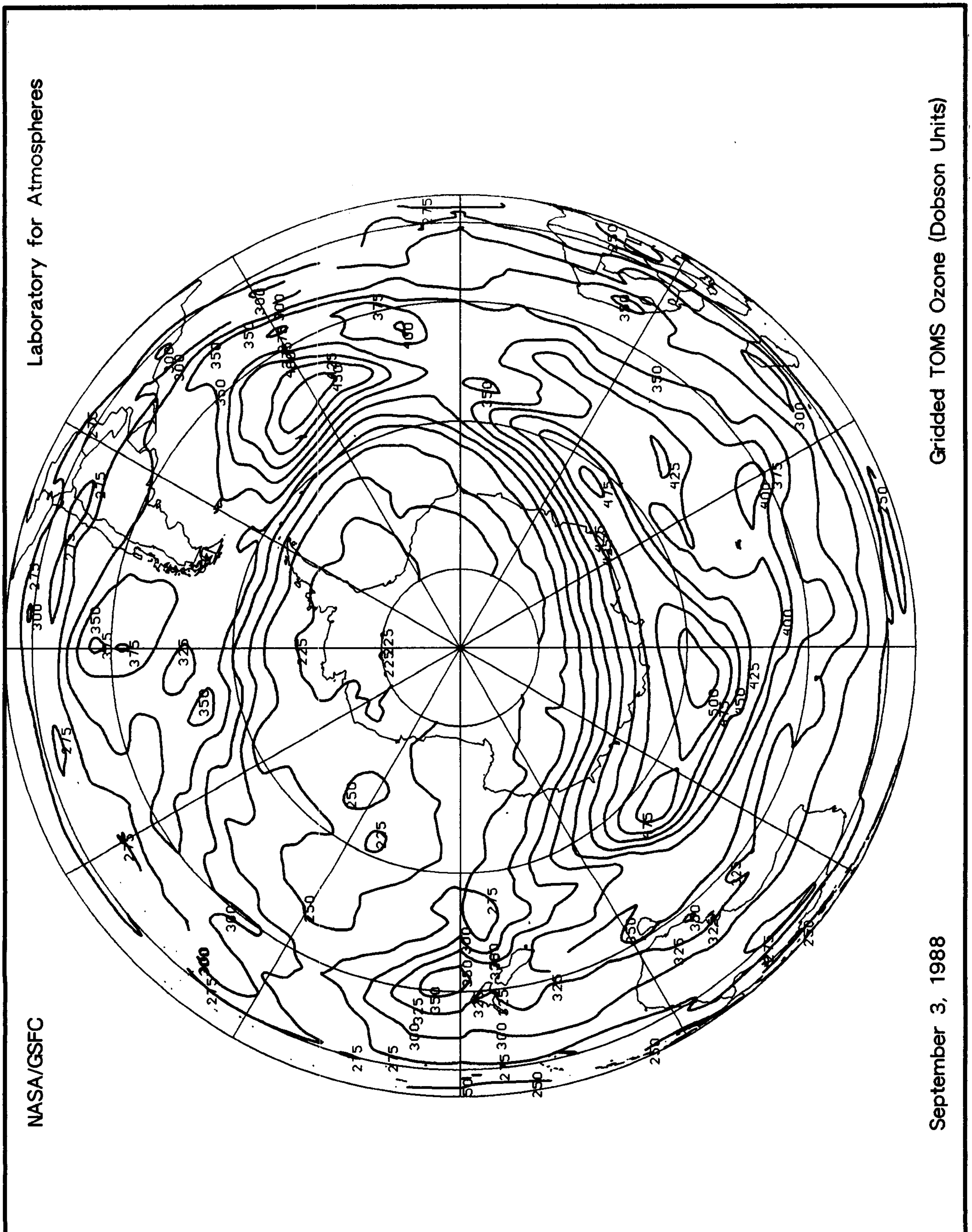

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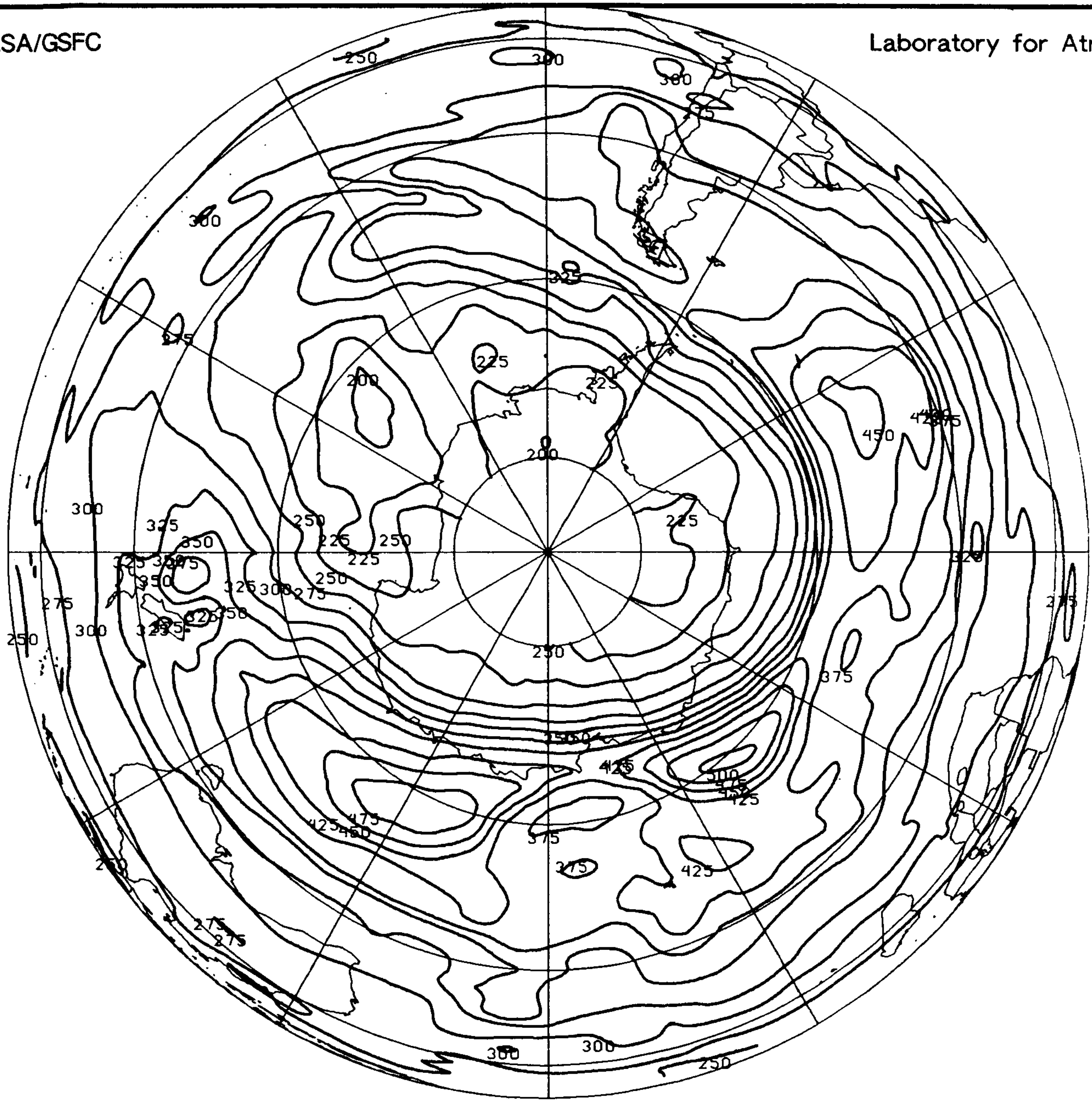
NASA/GSFC

Laboratory for Atmospheres



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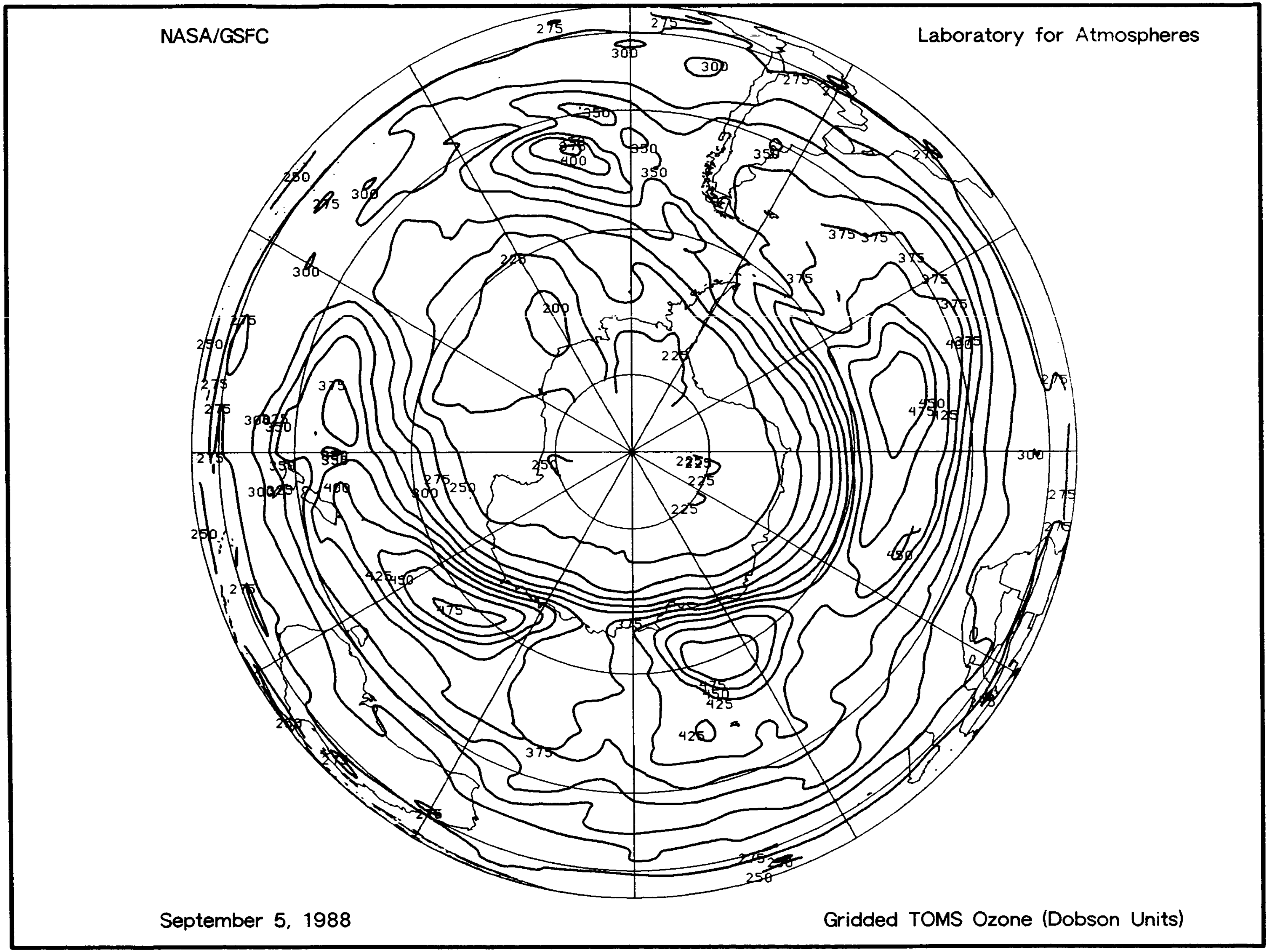
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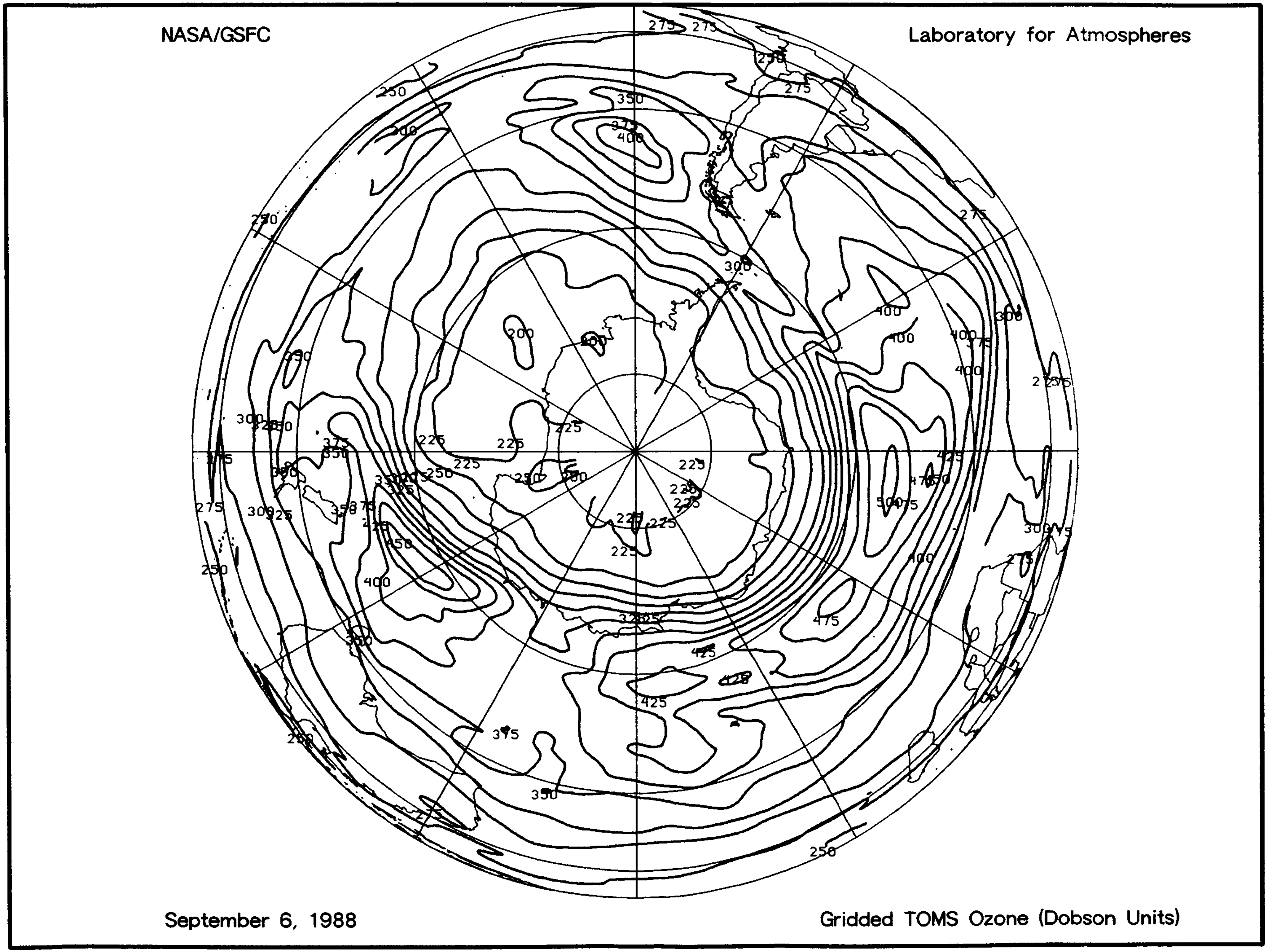
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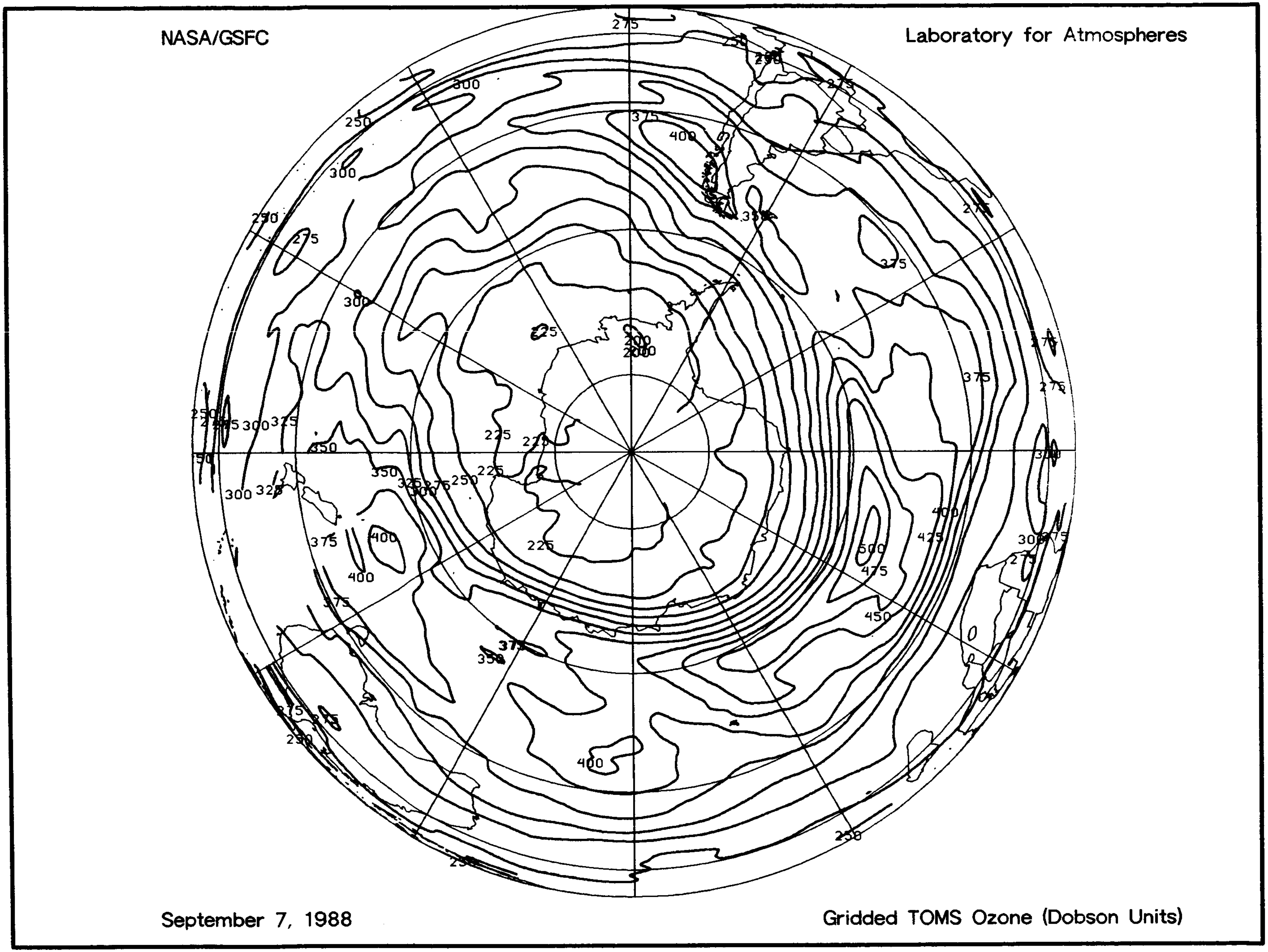
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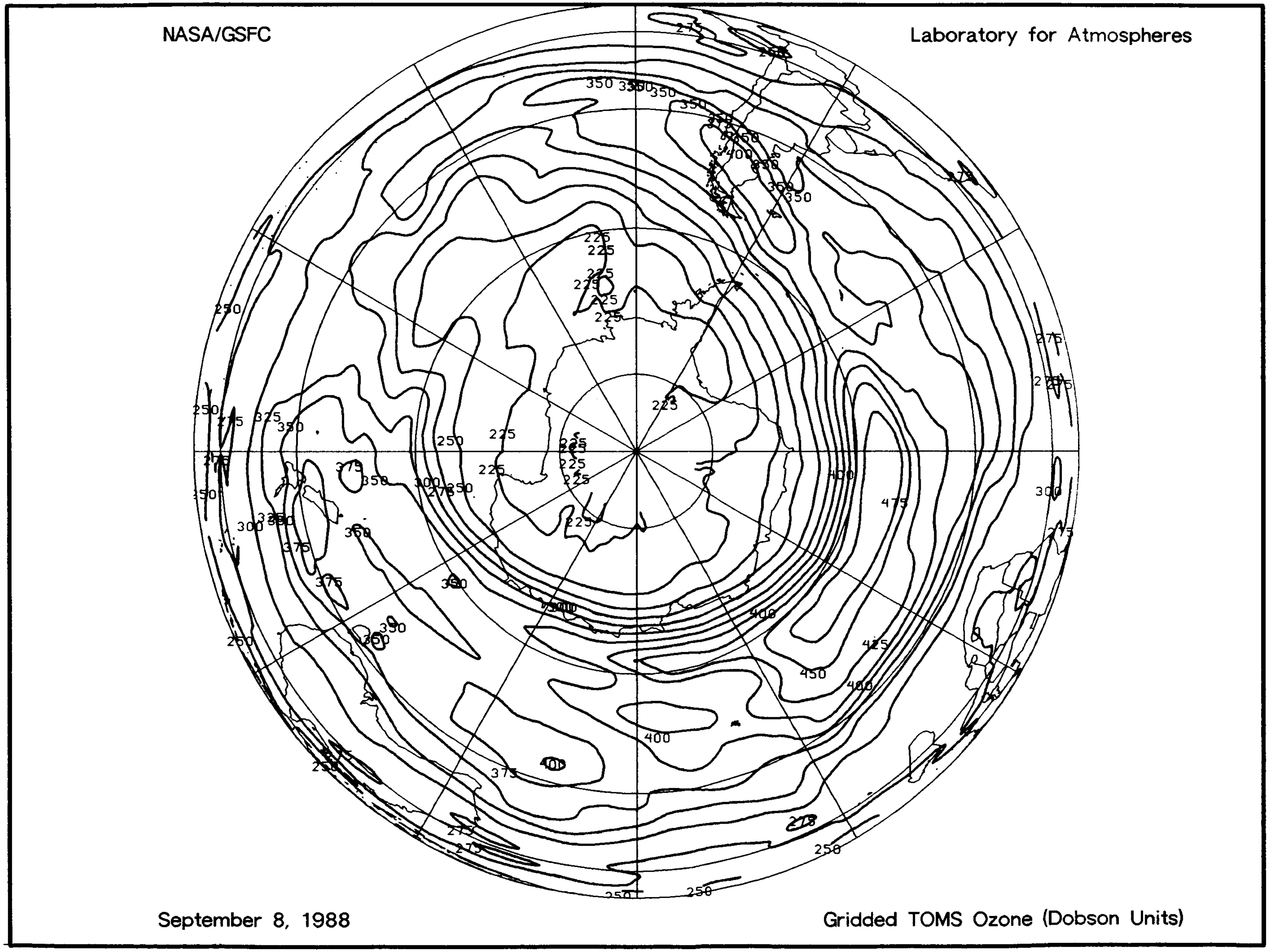
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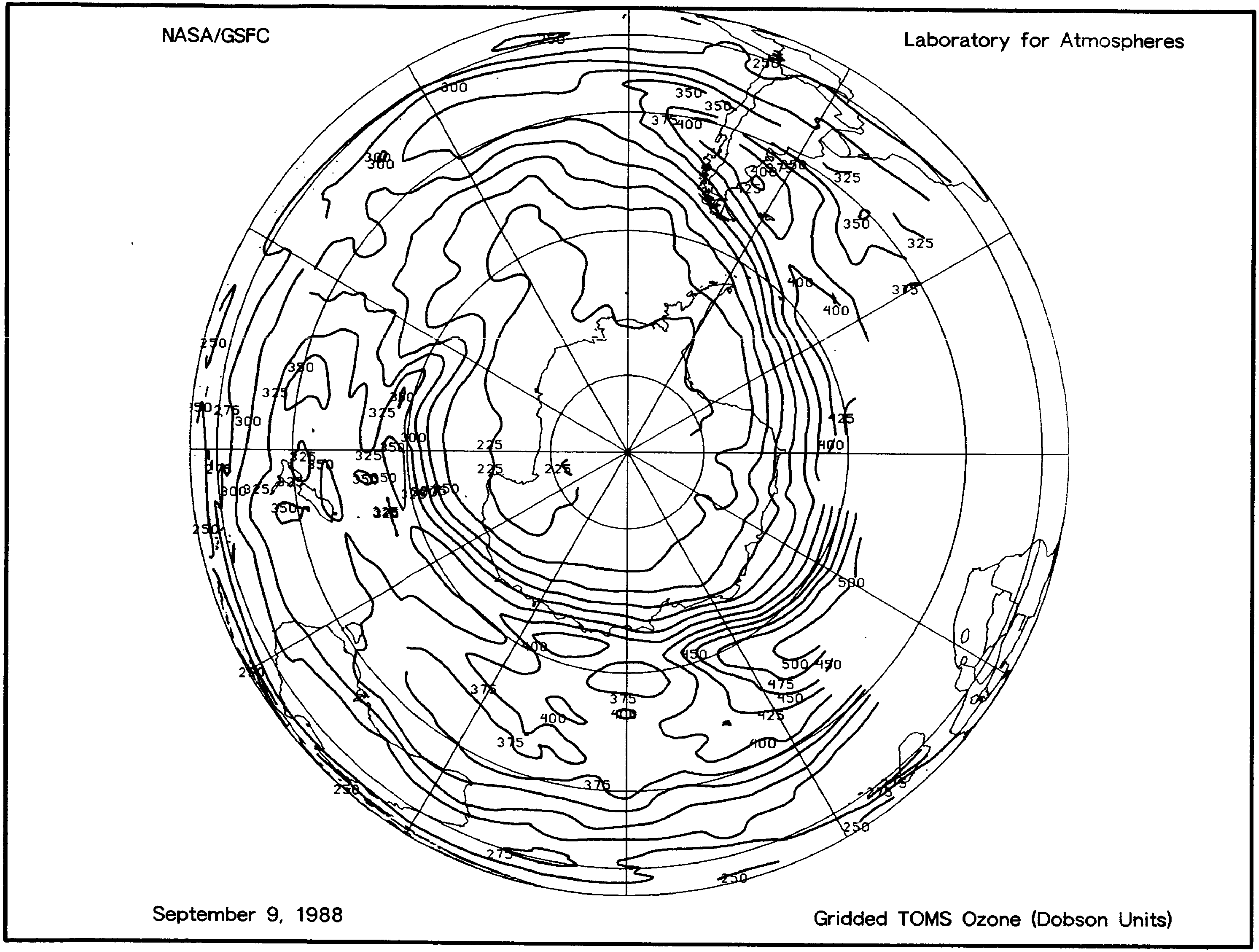
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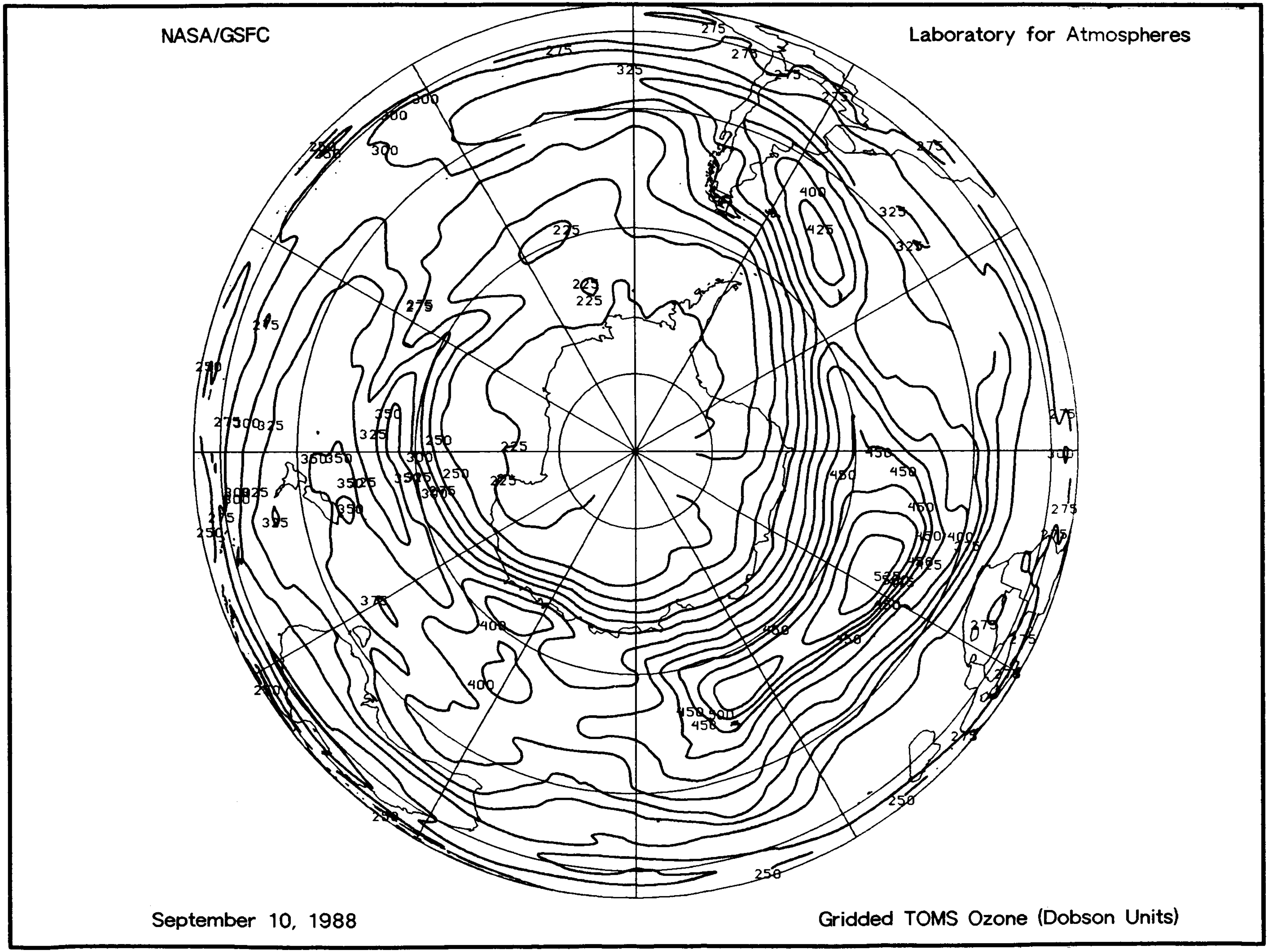
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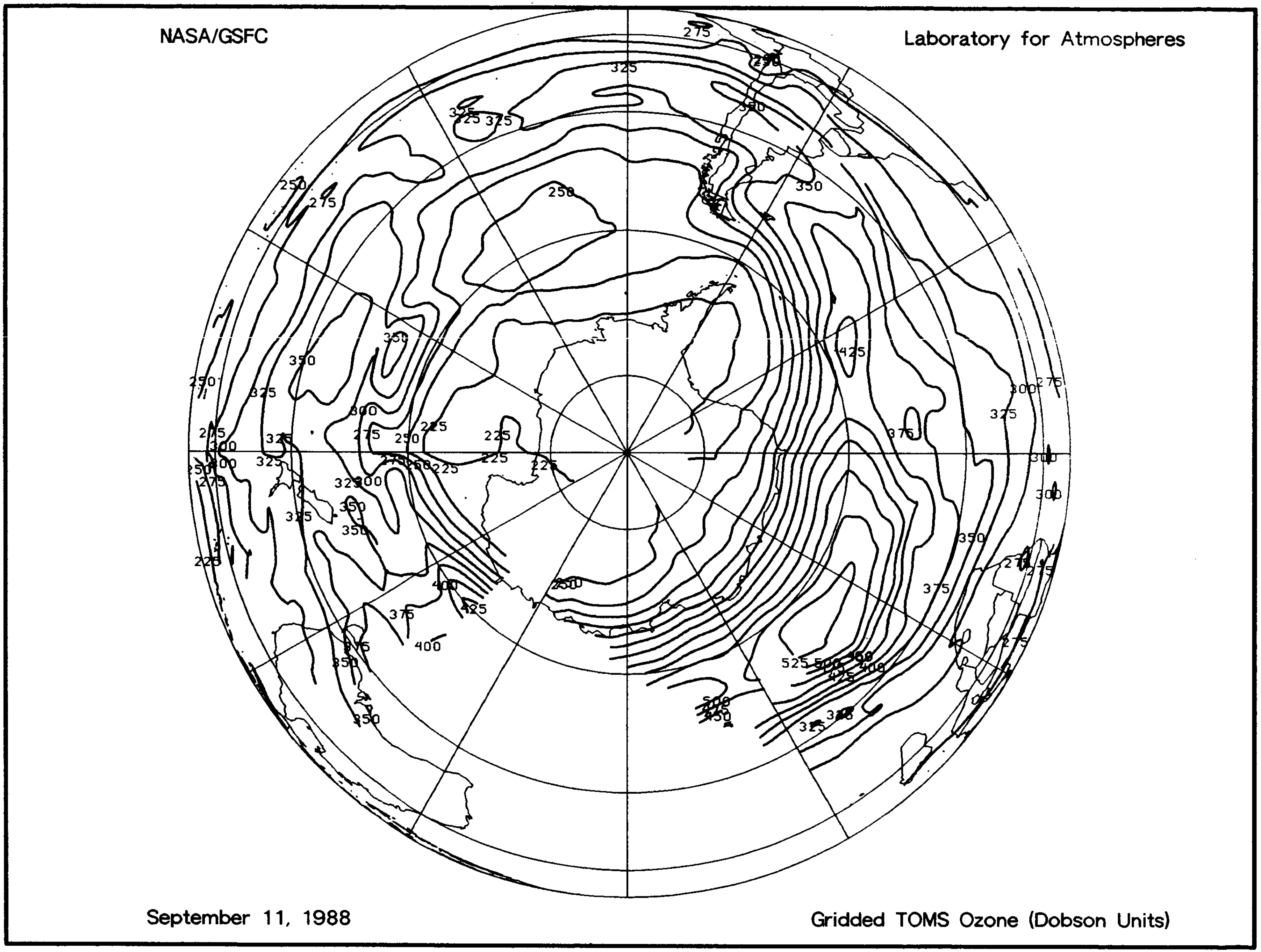
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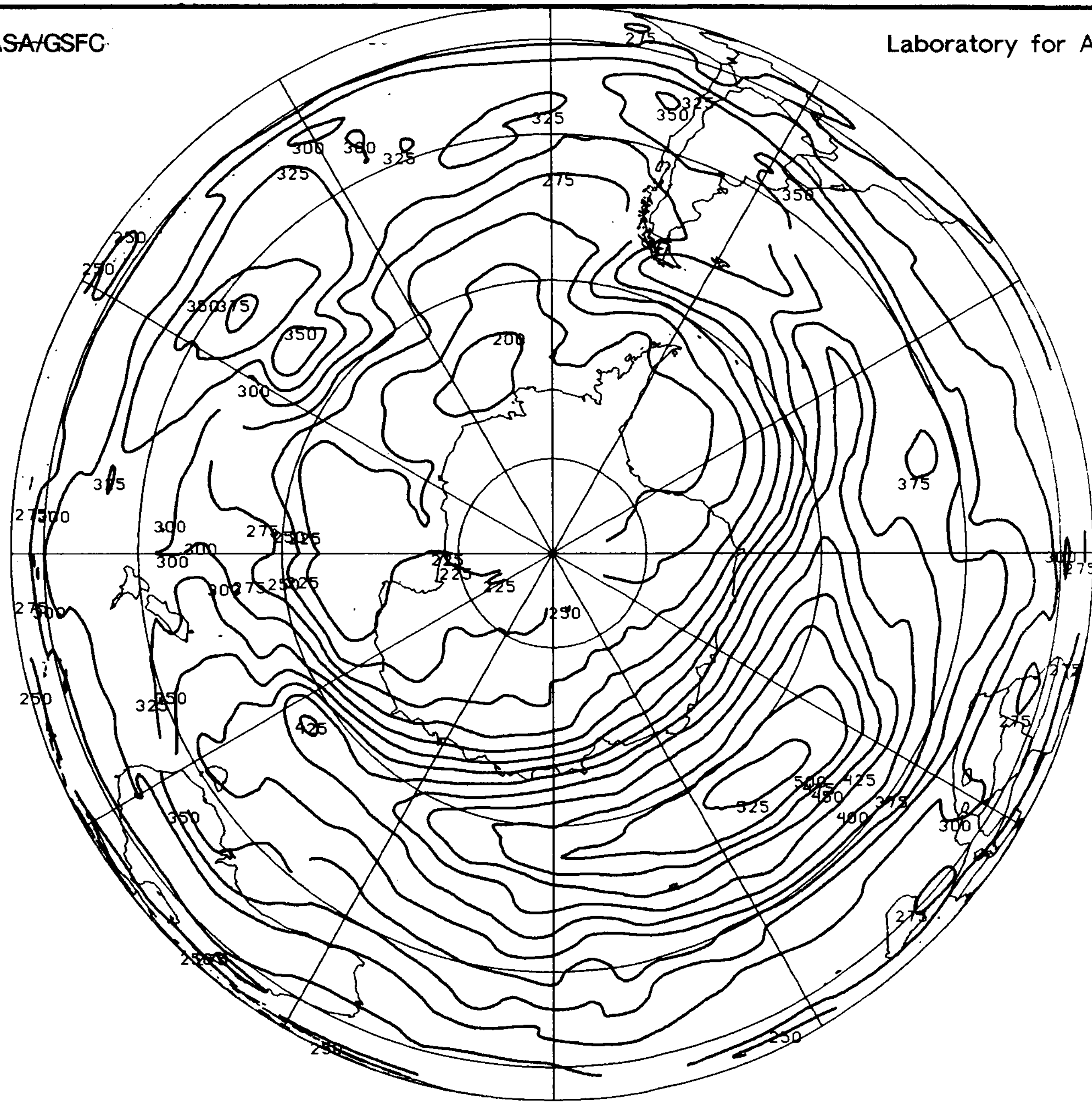

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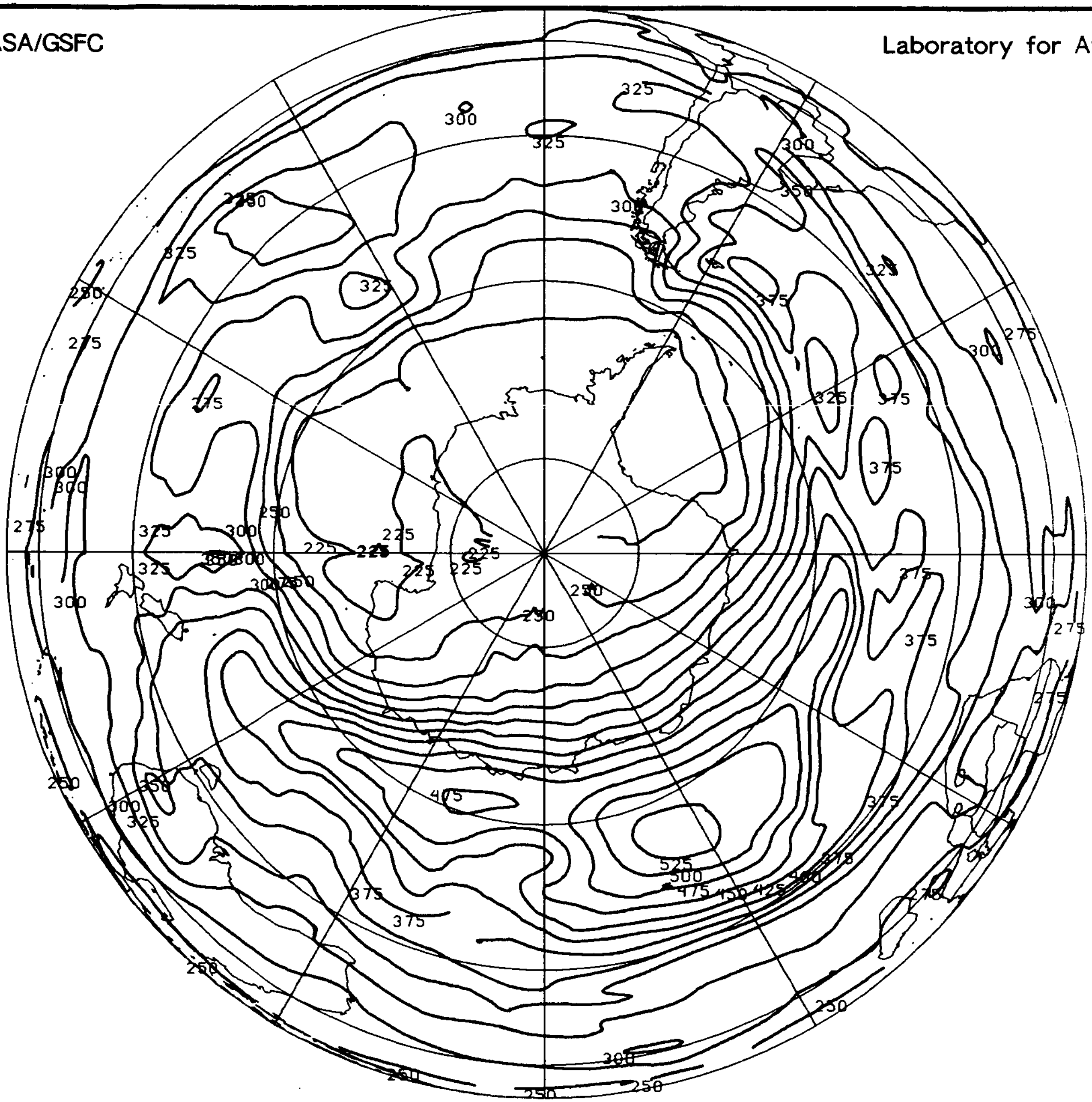
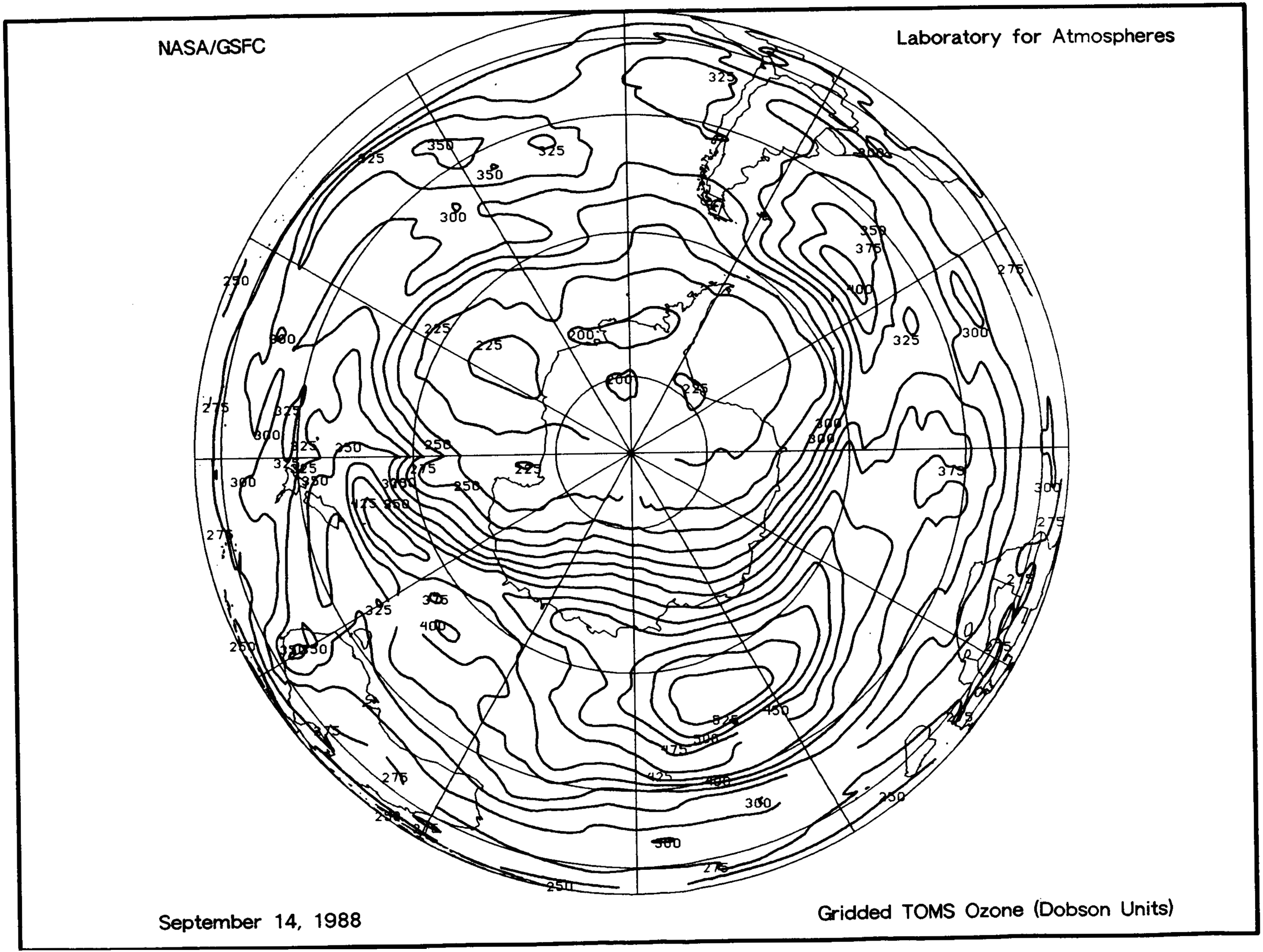


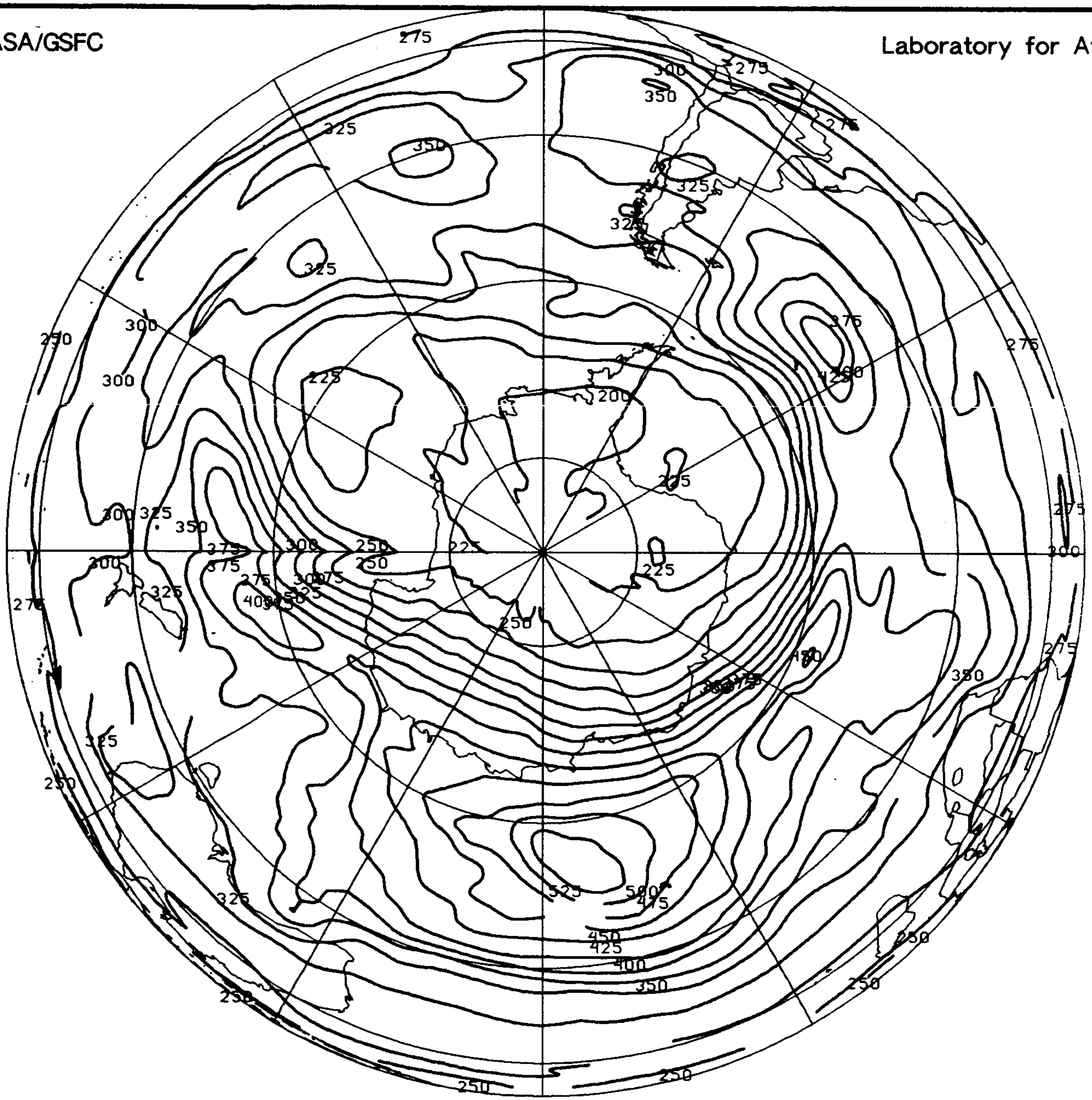
September 13, 1988

Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
September 14, 1988
Gridded TOMS Ozone (Dobson Units)

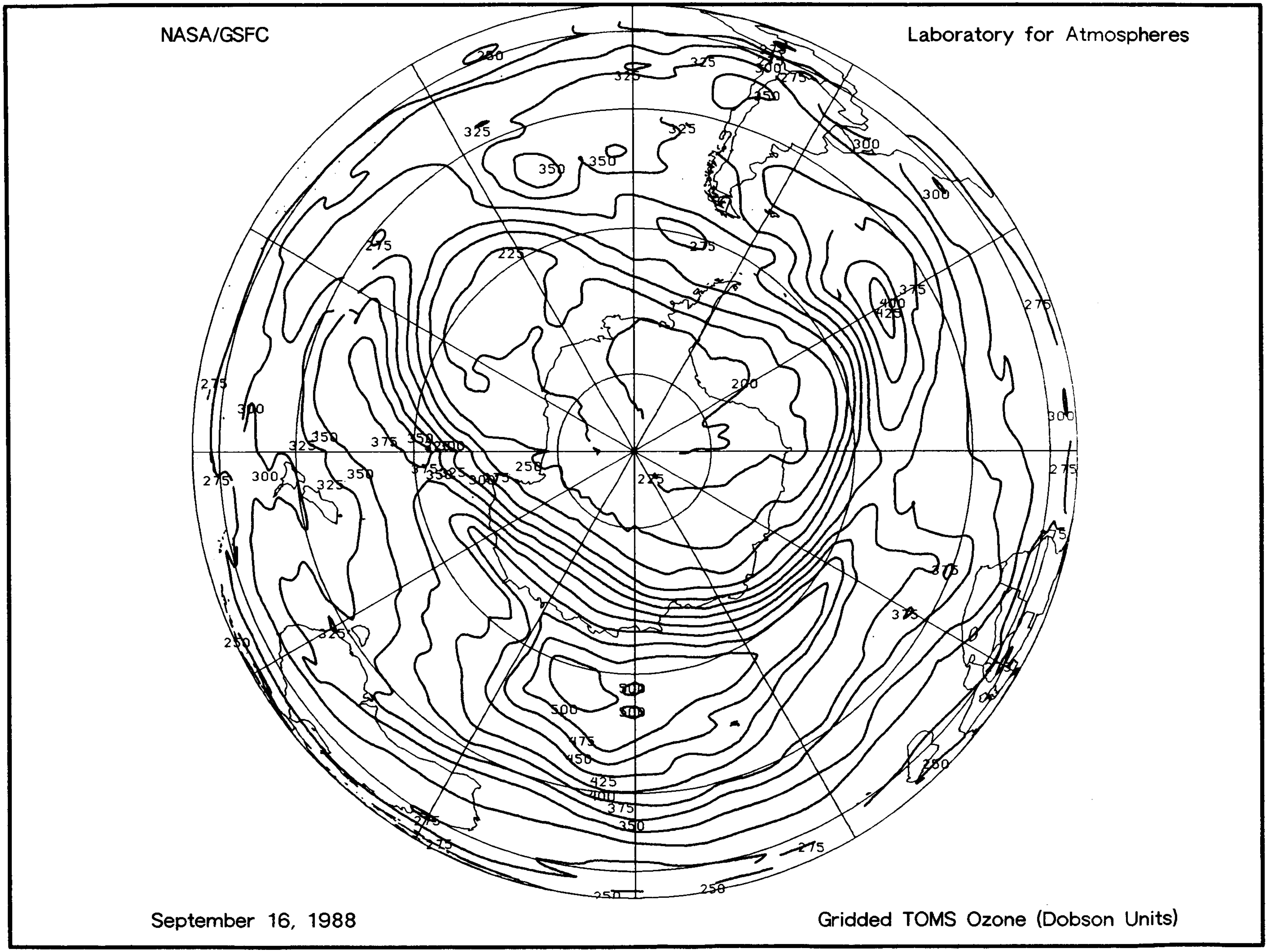
NASA/GSFC

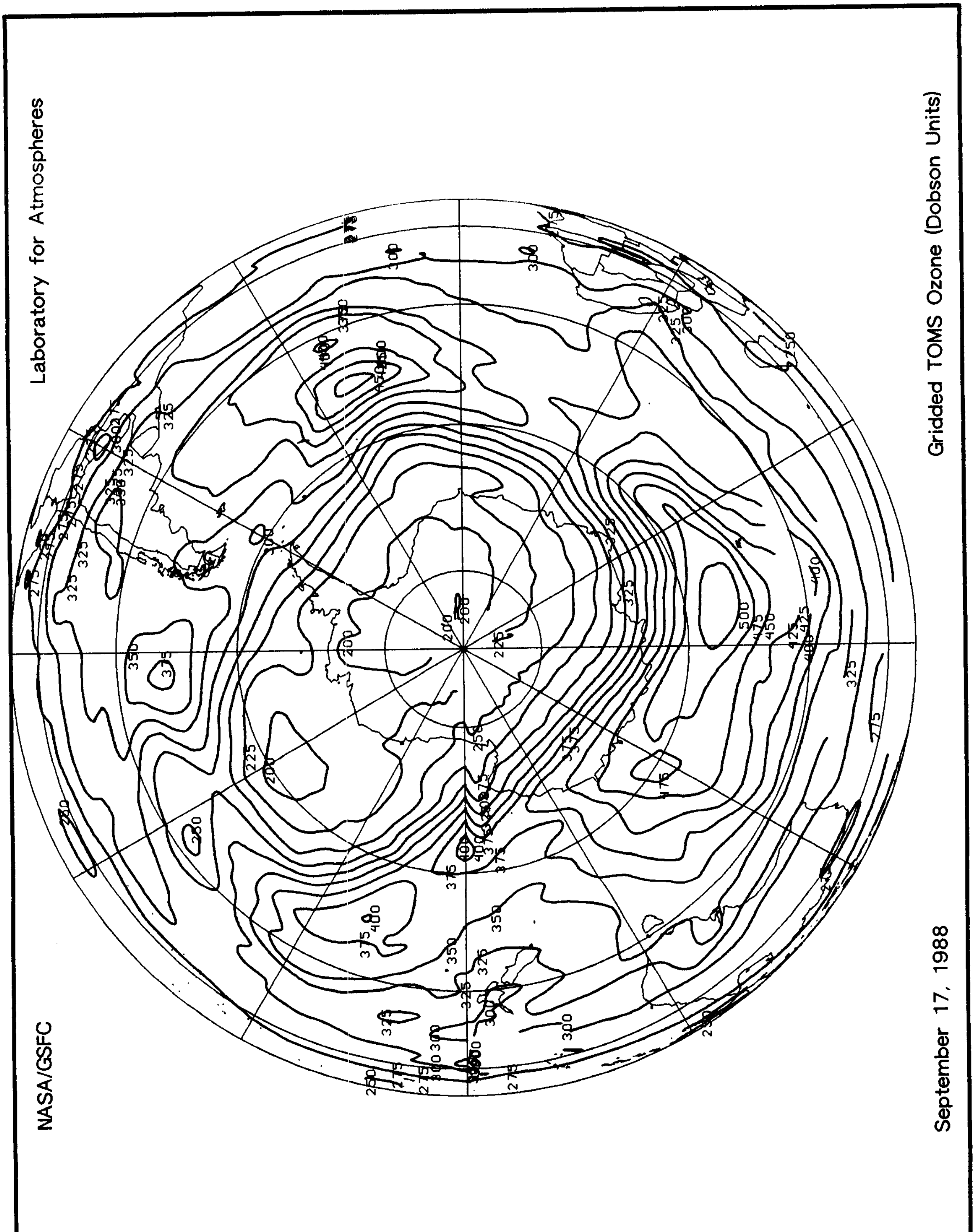
Laboratory for Atmospheres

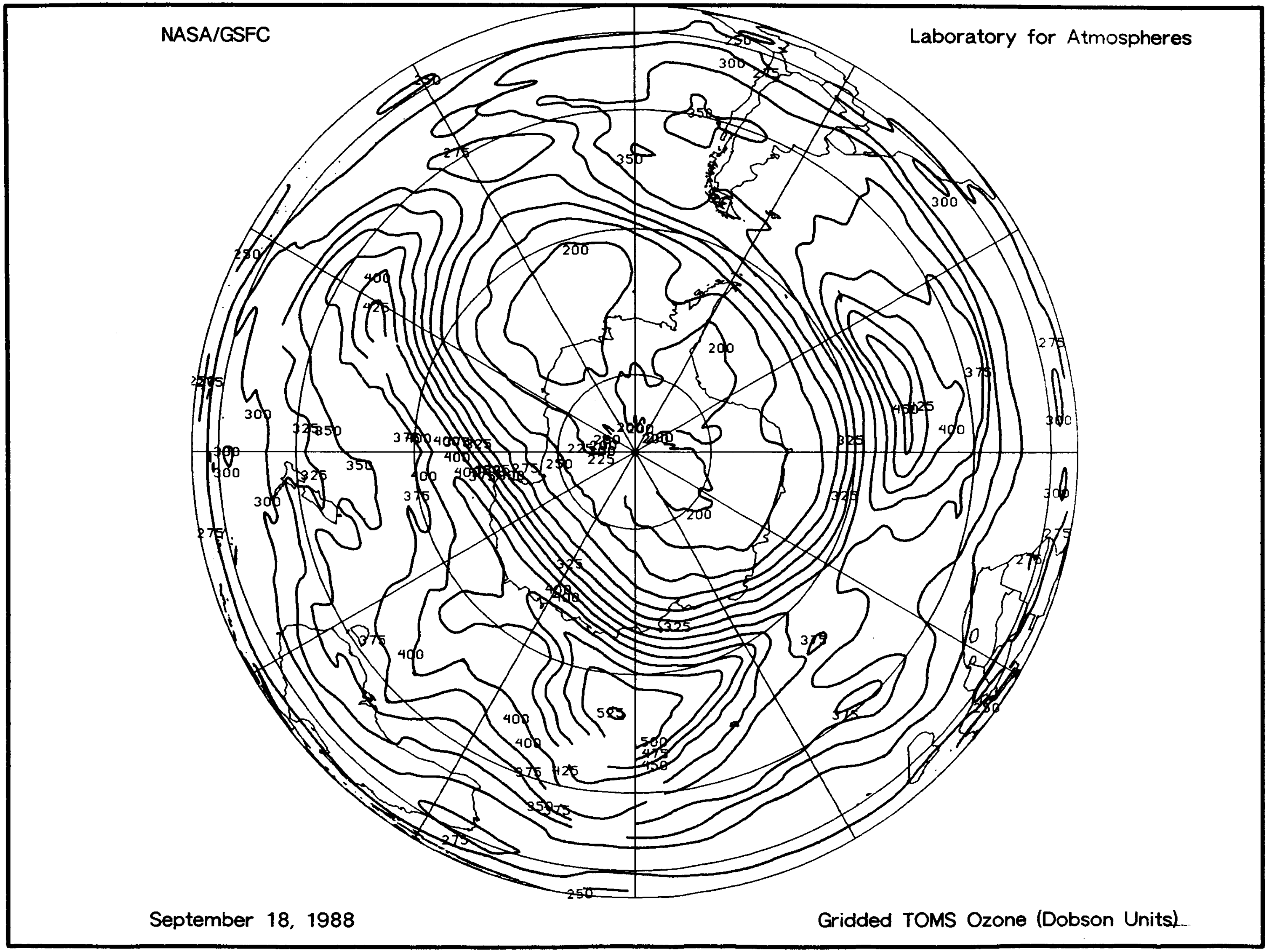


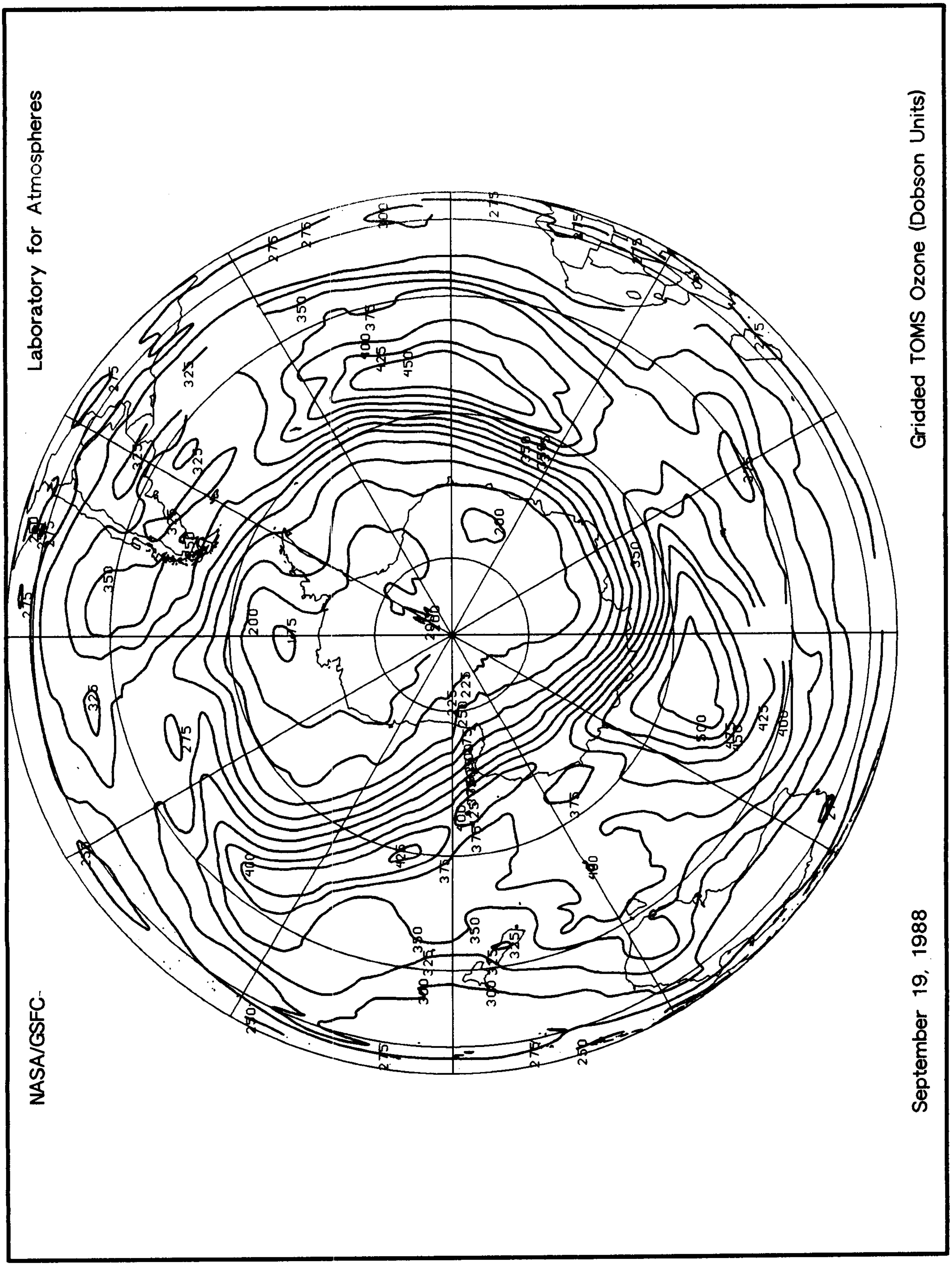
September 15, 1988

Gridded TOMS Ozone (Dobson Units)

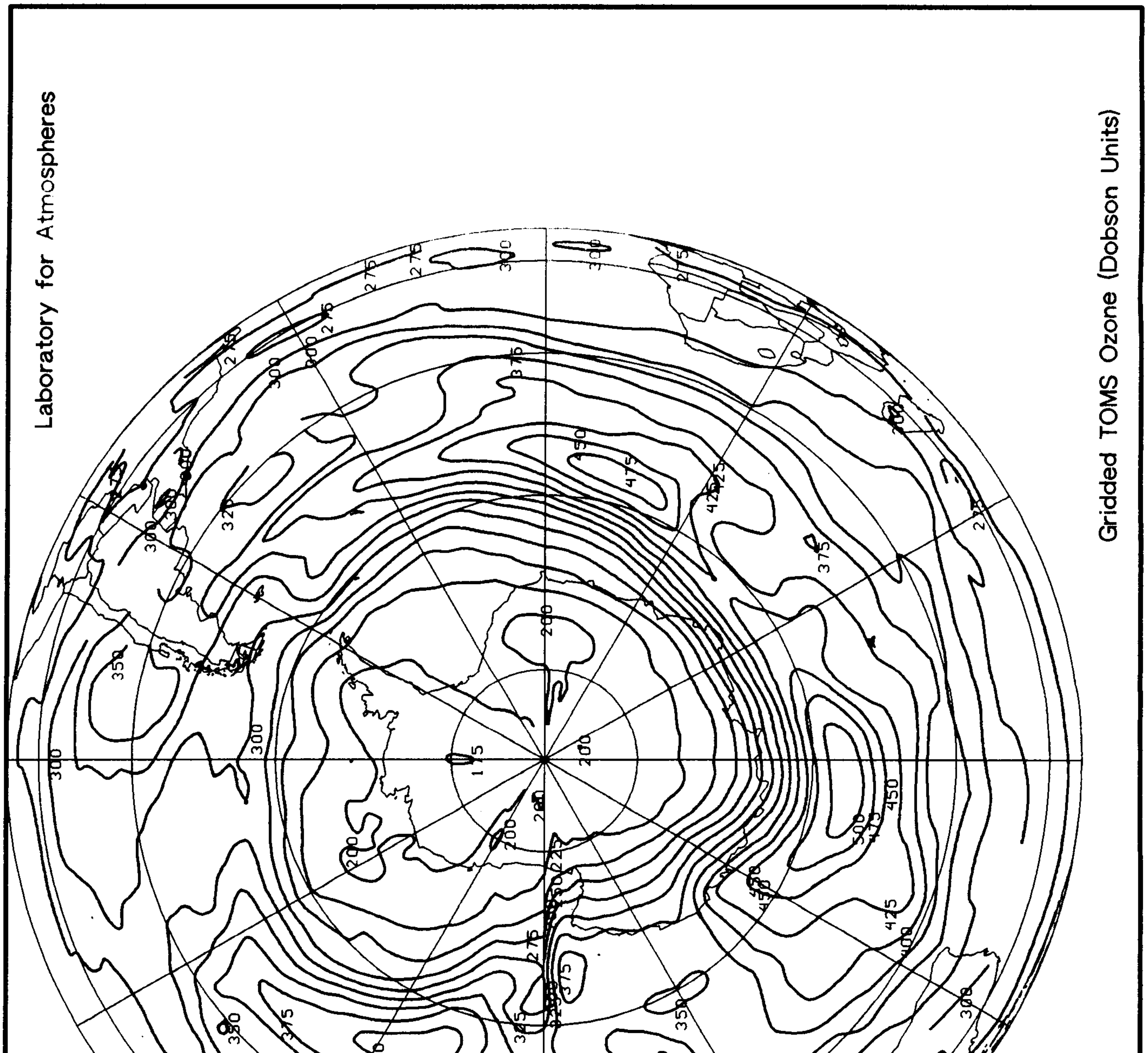

NASA/GSFC
Laboratory for Atmospheres
September 16, 1988
Gridded TOMS Ozone (Dobson Units)


Laboratory for Atmospheres
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
September 17, 1988


NASA/GSFC
Laboratory for Atmospheres
September 18, 1988
Gridded TOMS Ozone (Dobson Units)



NASA/GSFC-
Laboratory for Atmospheres
September 19, 1988
Gridded TOMS Ozone (Dobson Units)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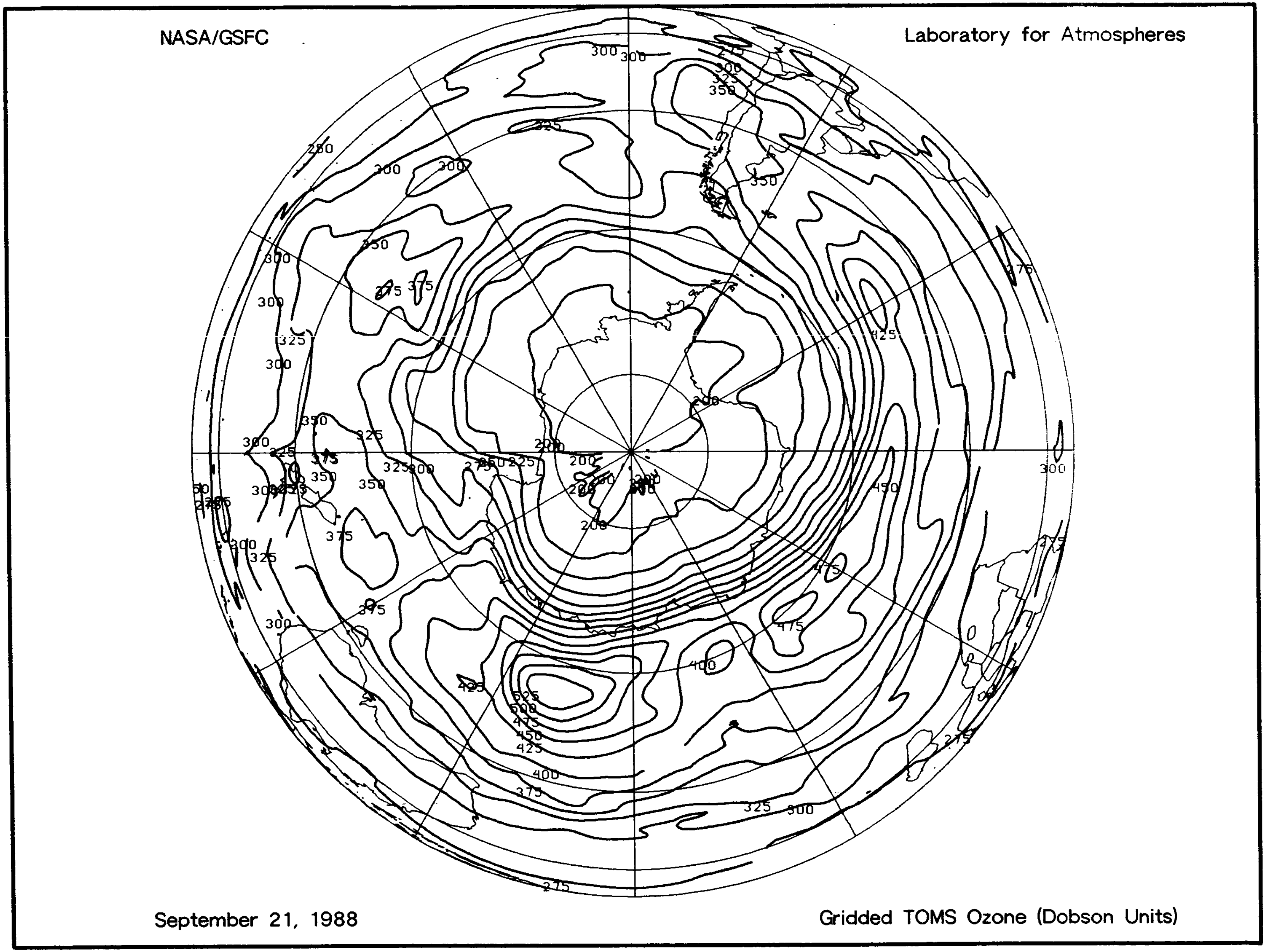
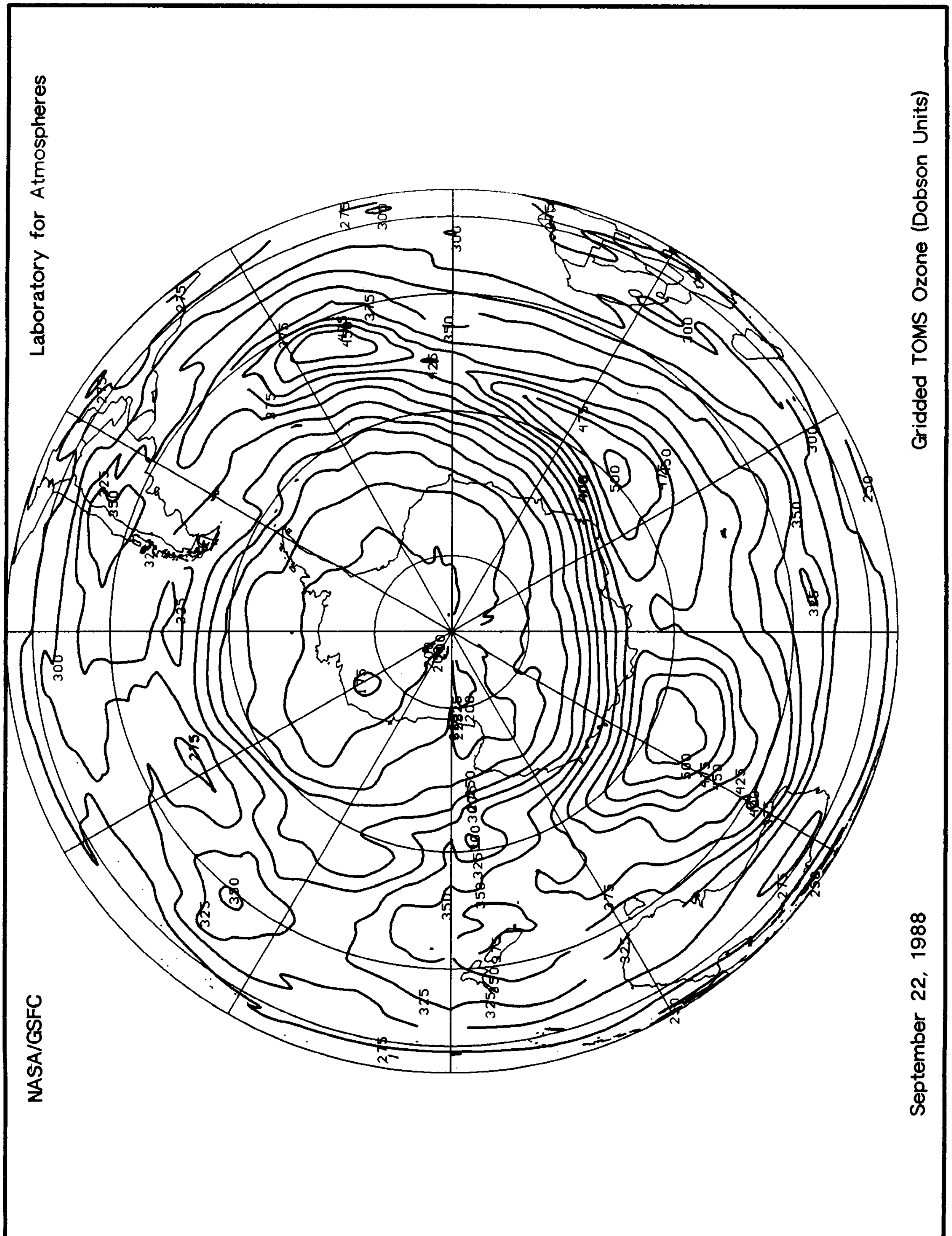
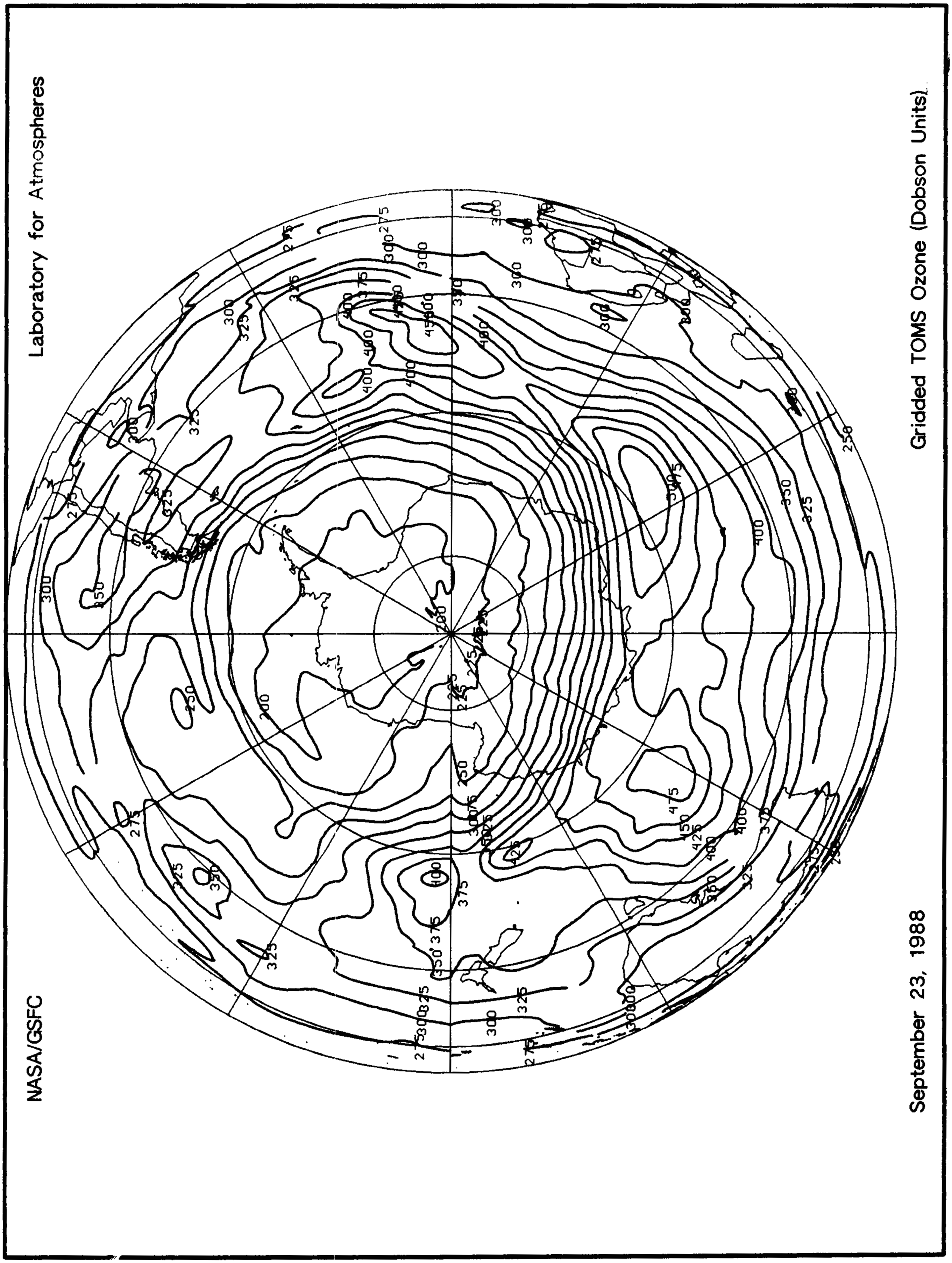
Laboratory for Atmospheres
September 20, 1988
Gridded TOMS Ozone (Dobson Units)

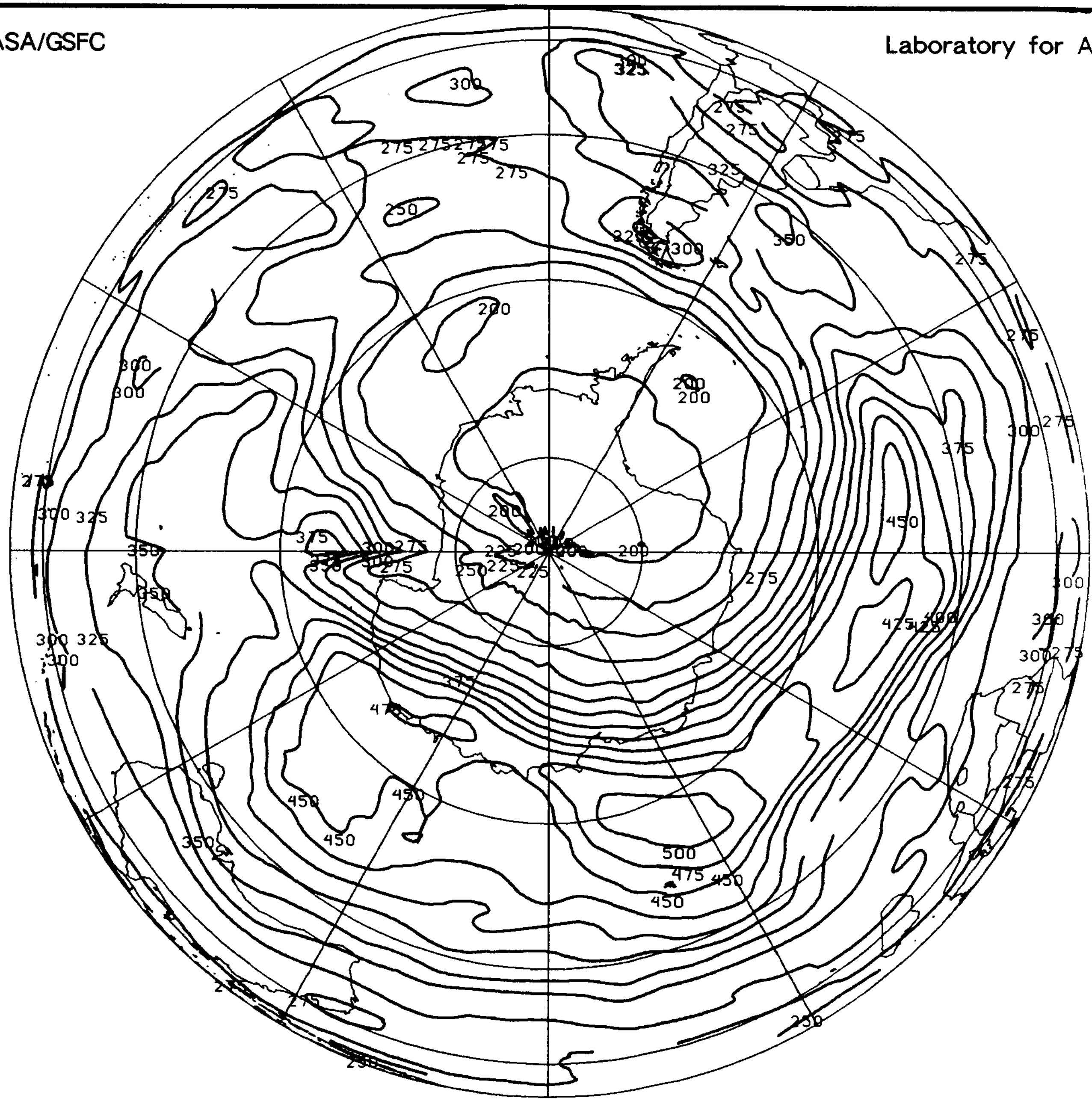

NASA/GSFC
Laboratory for Atmospheres
September 21, 1988
Gridded TOMS Ozone (Dobson Units)


Laboratory for Atmospheres
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
September 22, 1988


Laboratory for Atmospheres
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
September 23, 1988

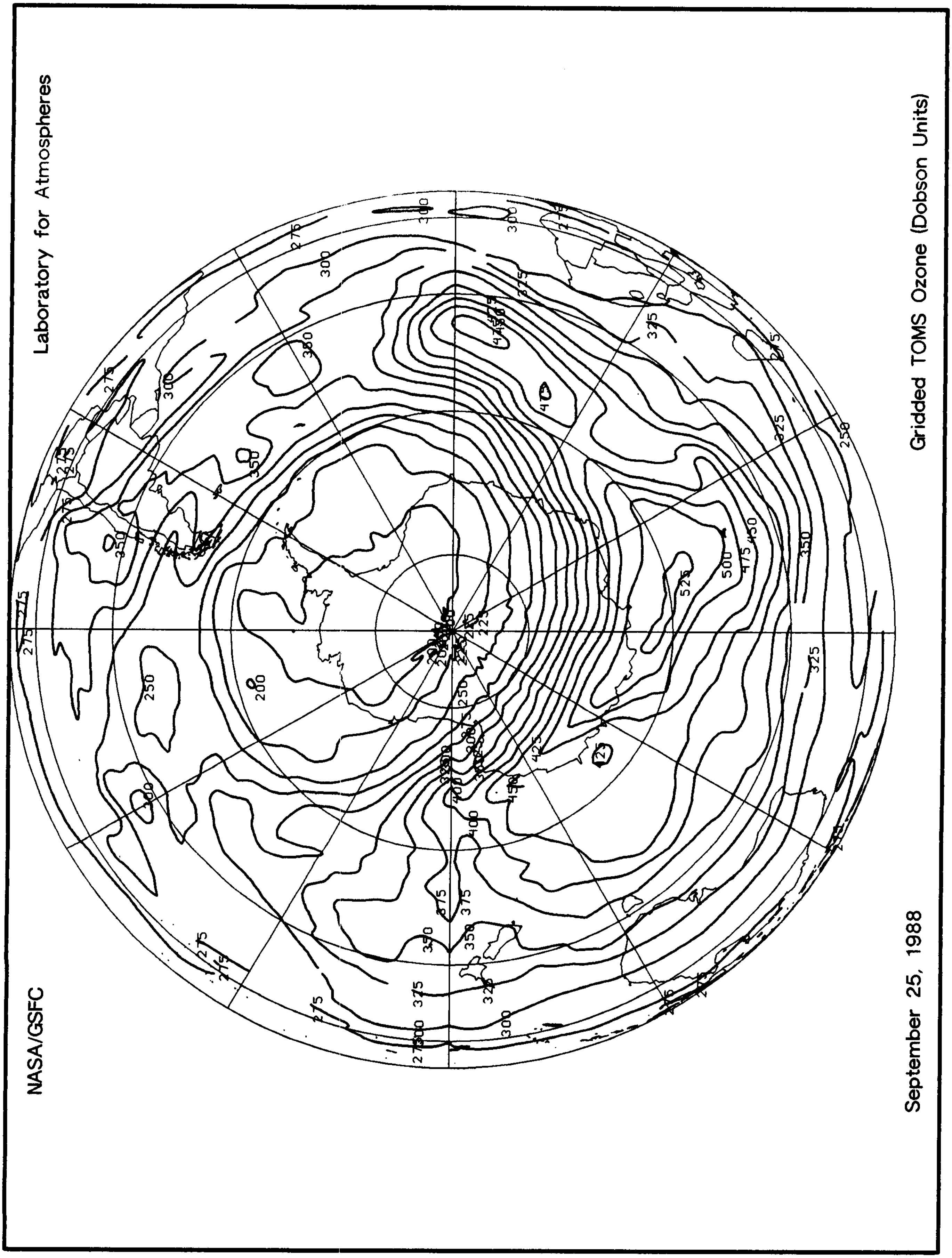
NASA/GSFC

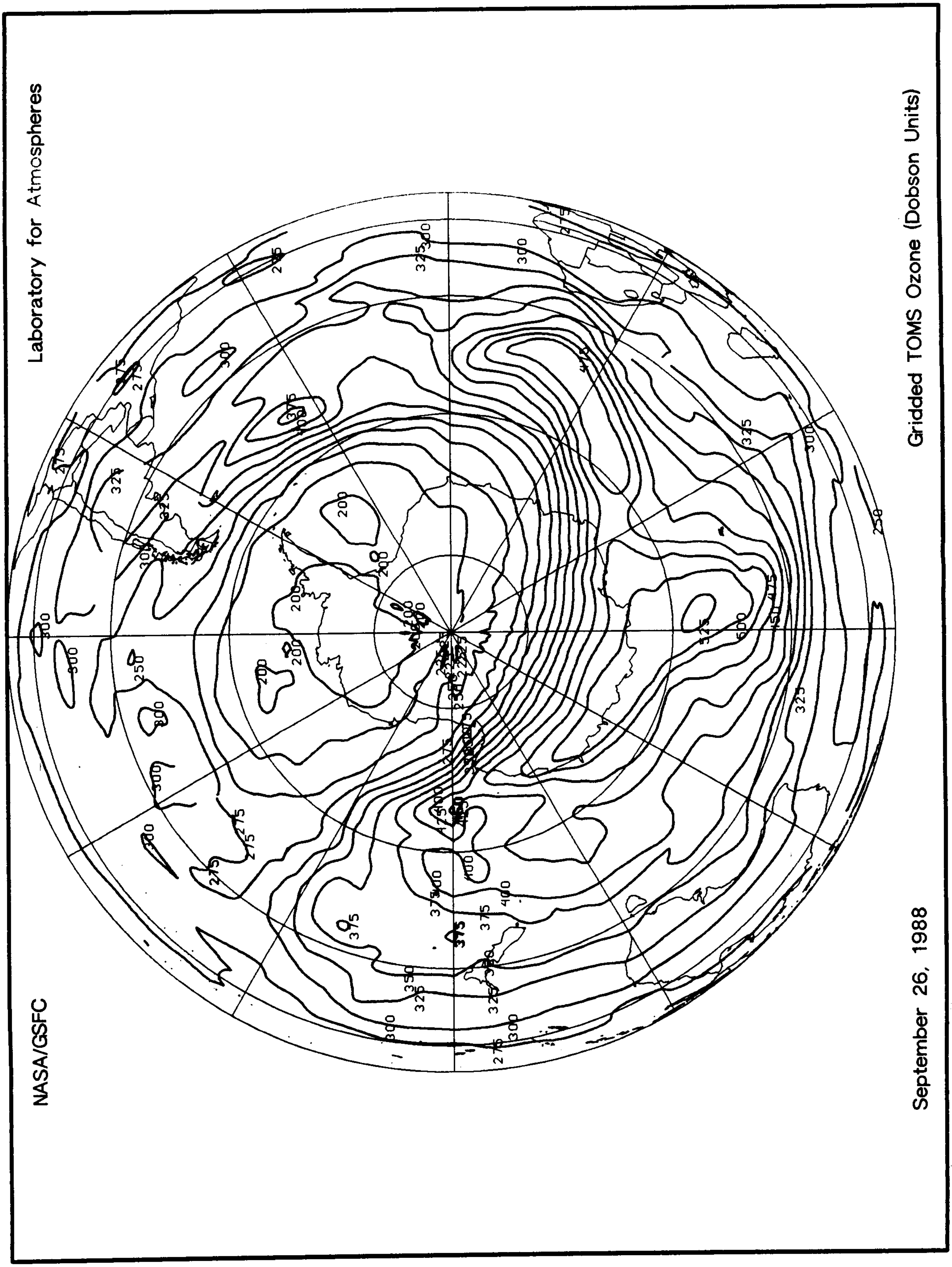
Laboratory for Atmospheres



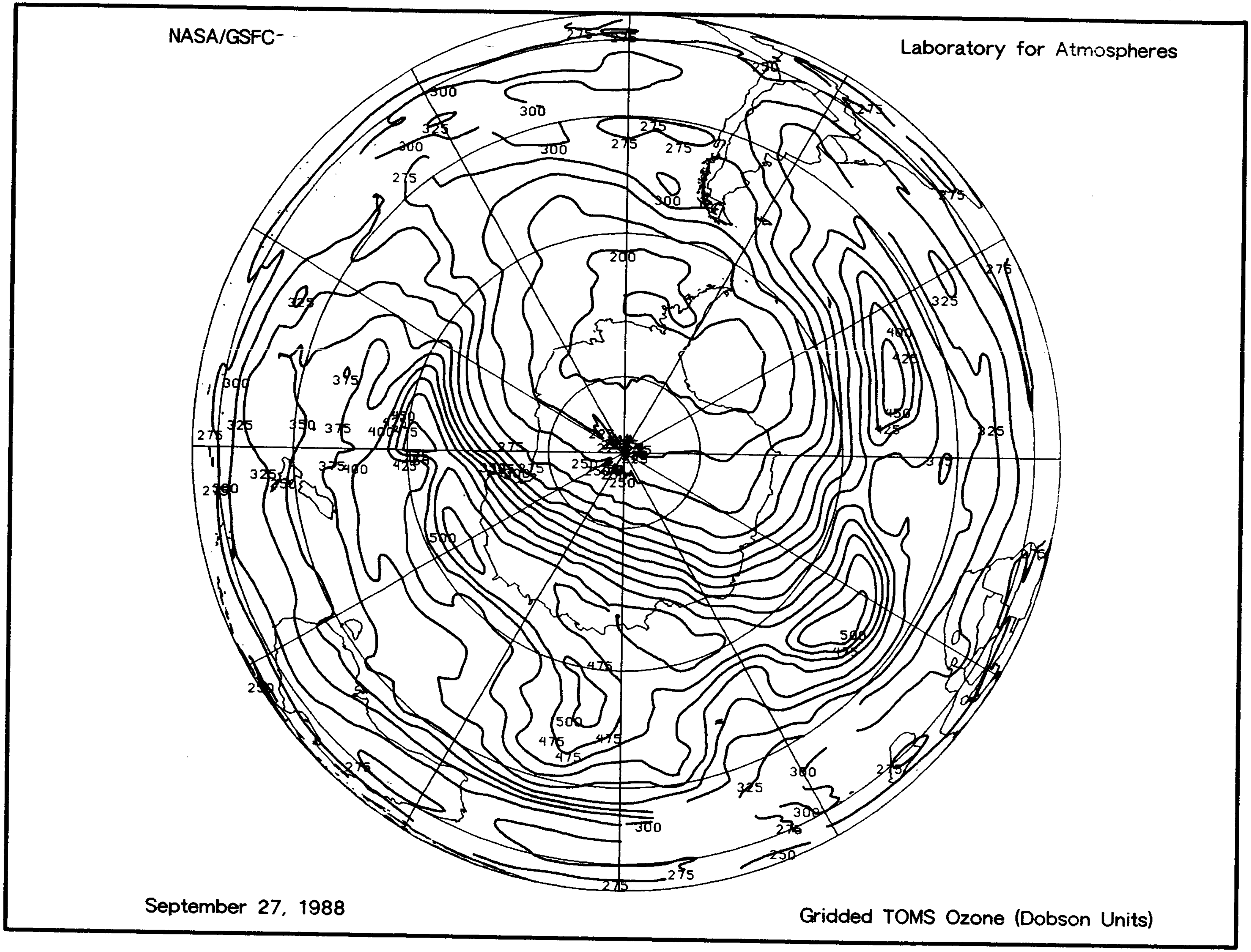
September 24, 1988

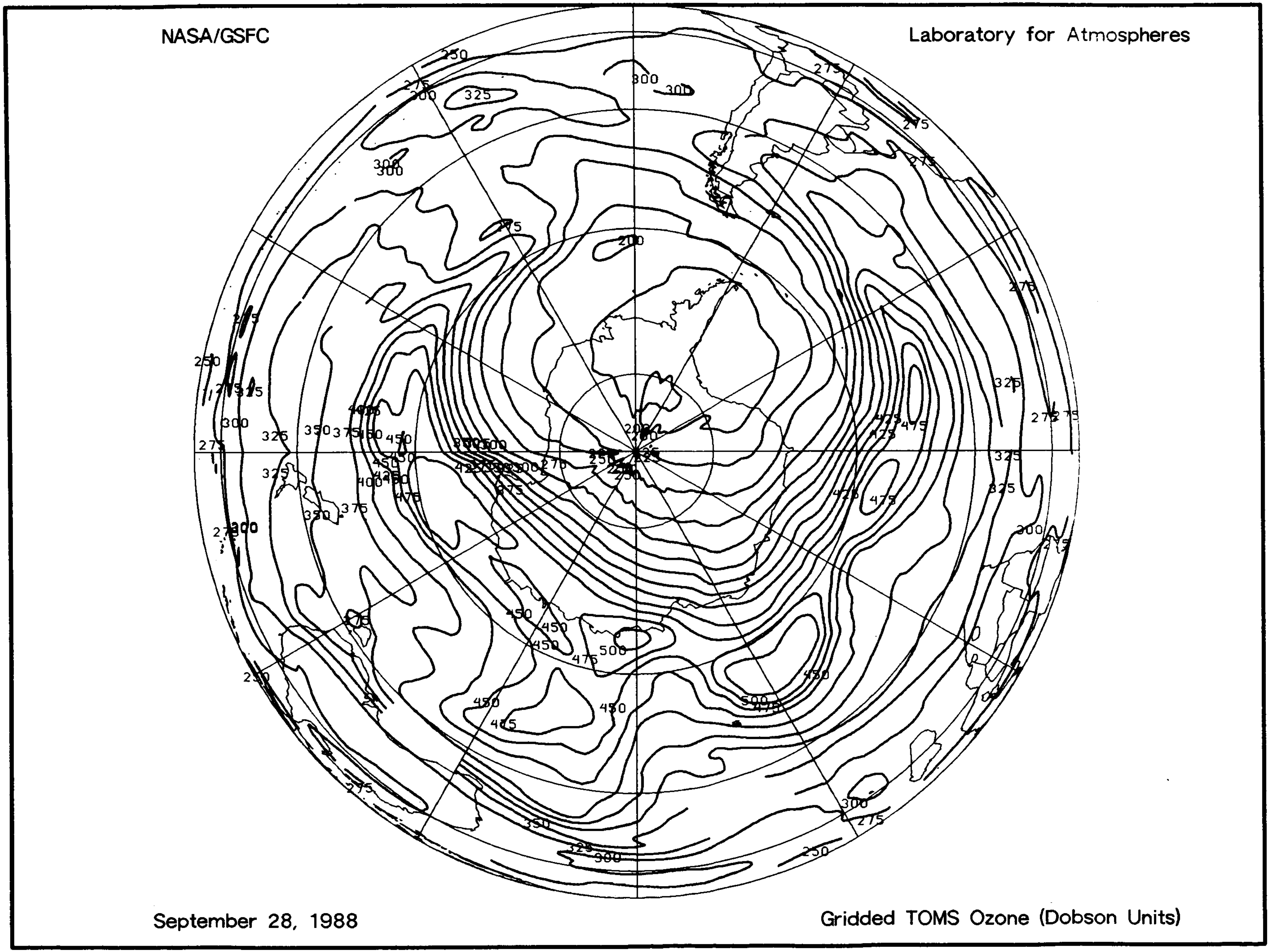
Gridded TOMS Ozone (Dobson Units)

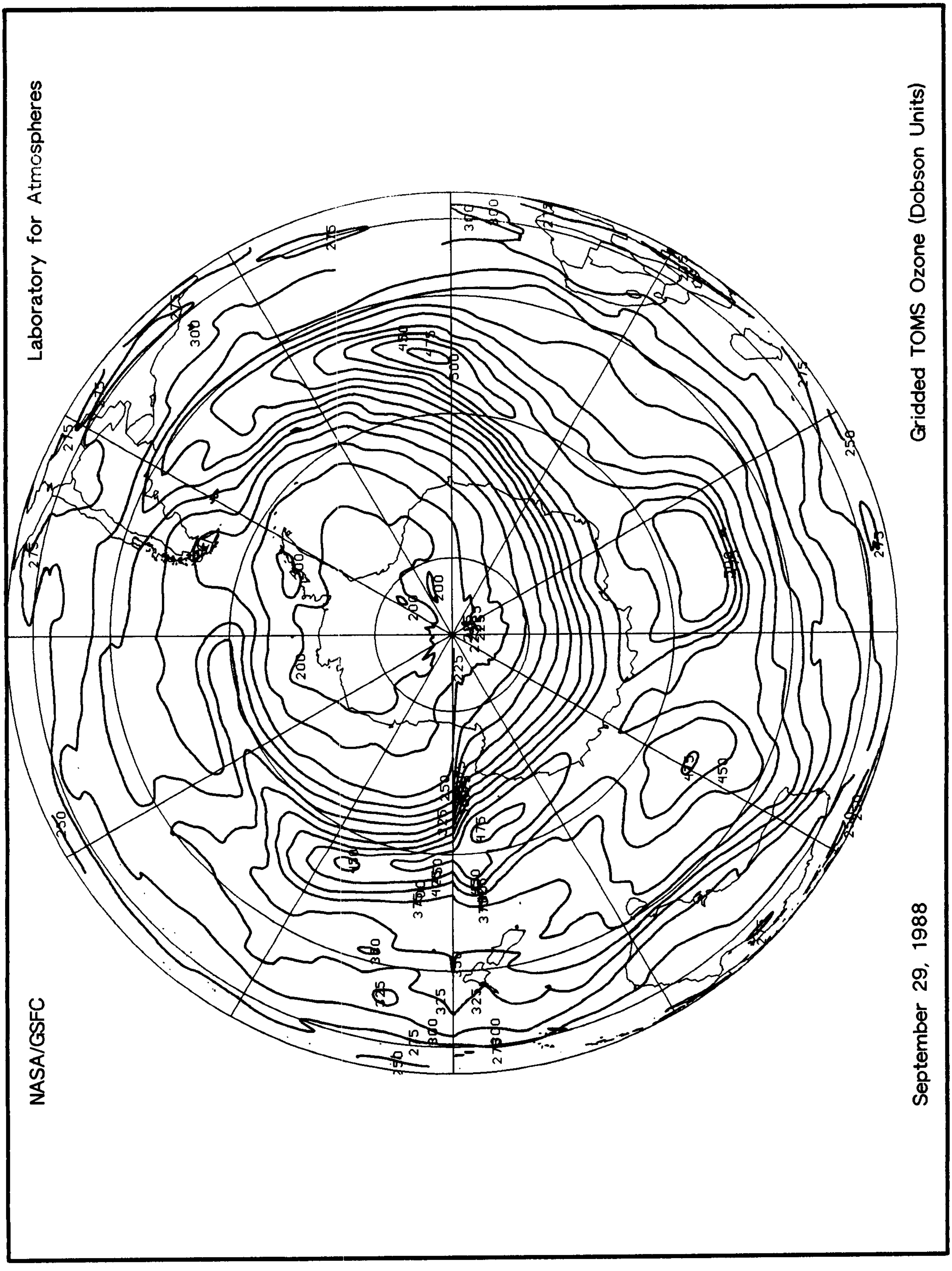

NASA/GSFC
Laboratory for Atmospheres
Gridded TOMS Ozone (Dobson Units)
September 25, 1988



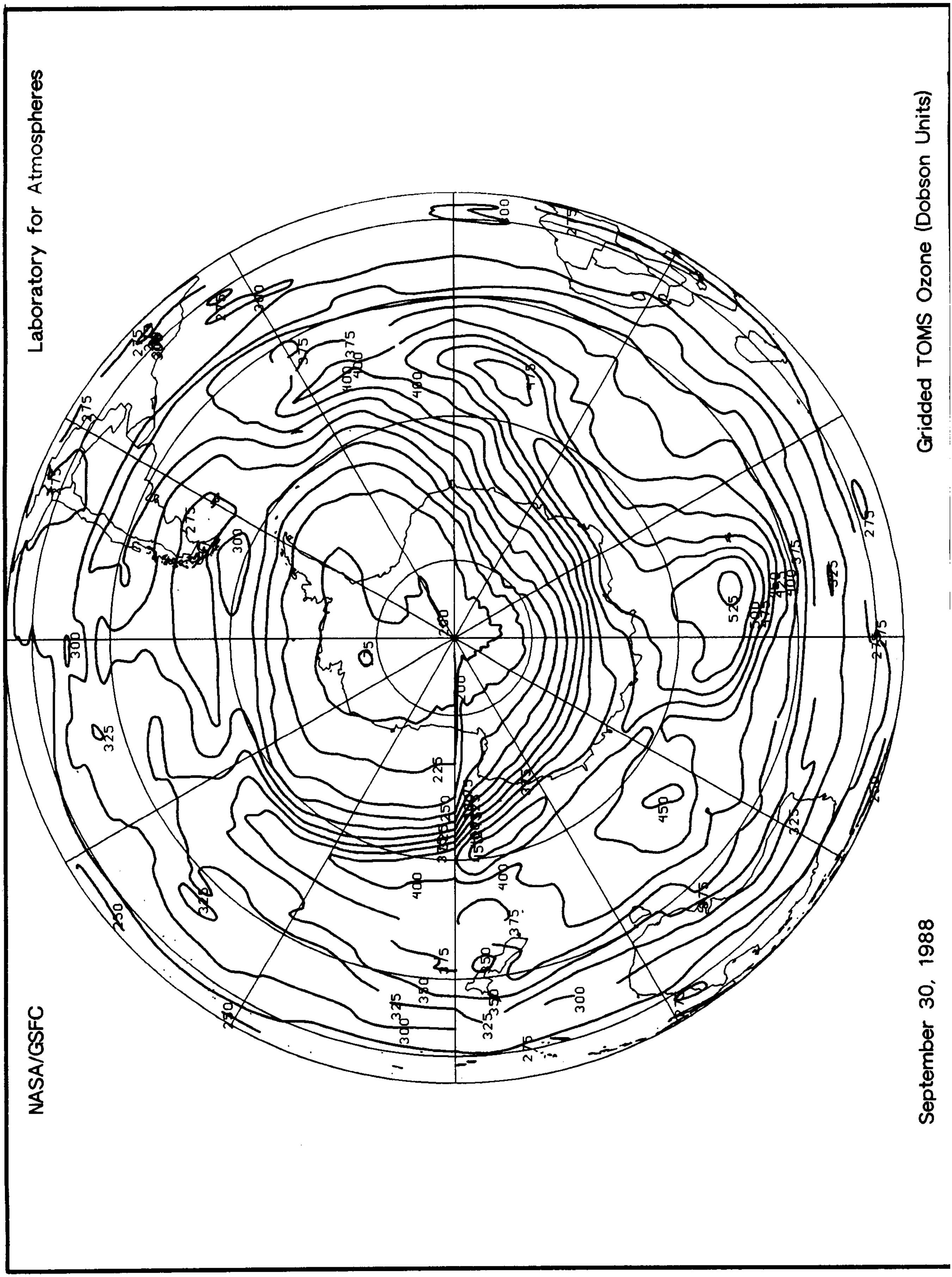
Laboratory for Atmospheres
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
September 26, 1988

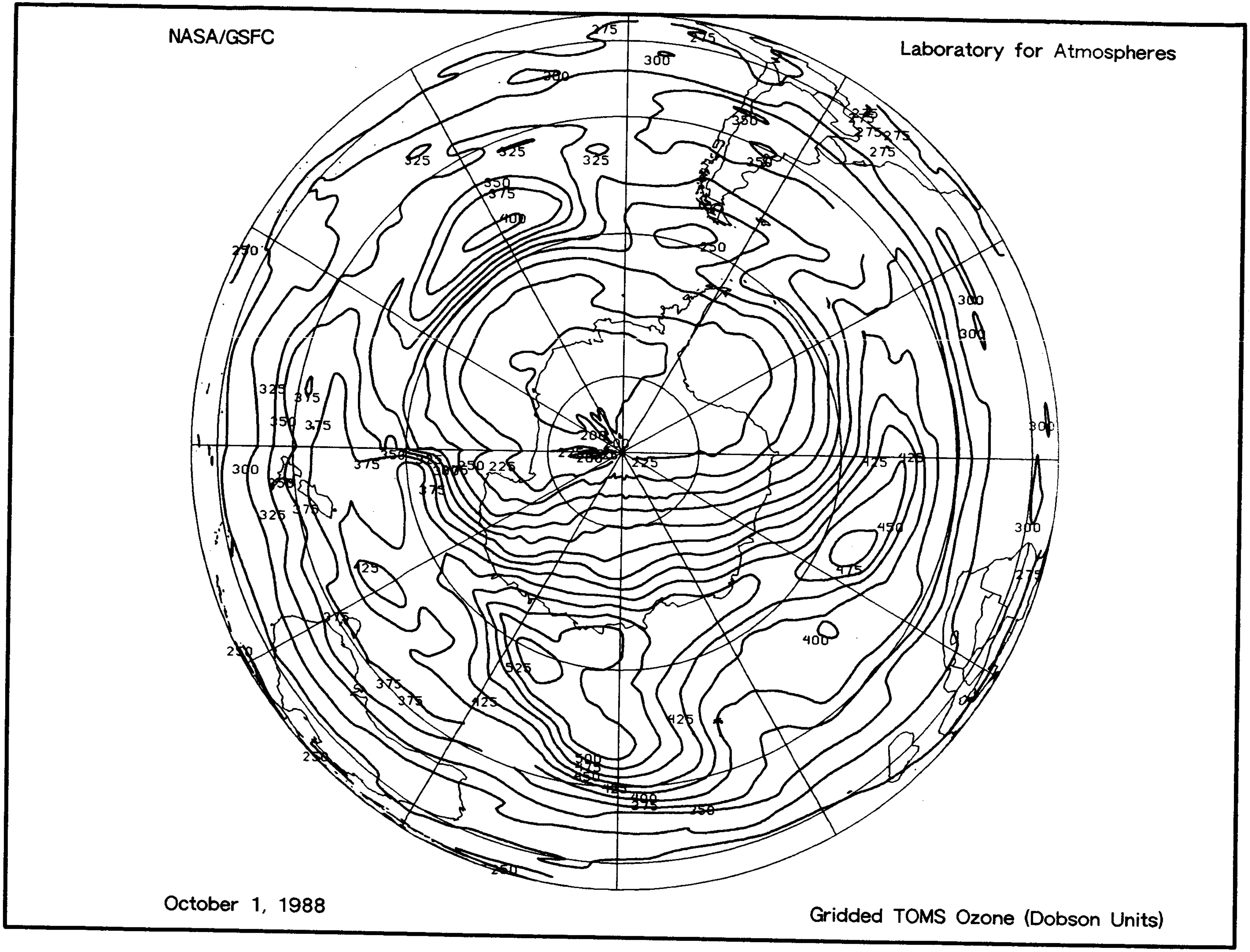

NASA/GSFC
Laboratory for Atmospheres
September 27, 1988
Gridded TOMS Ozone (Dobson Units)

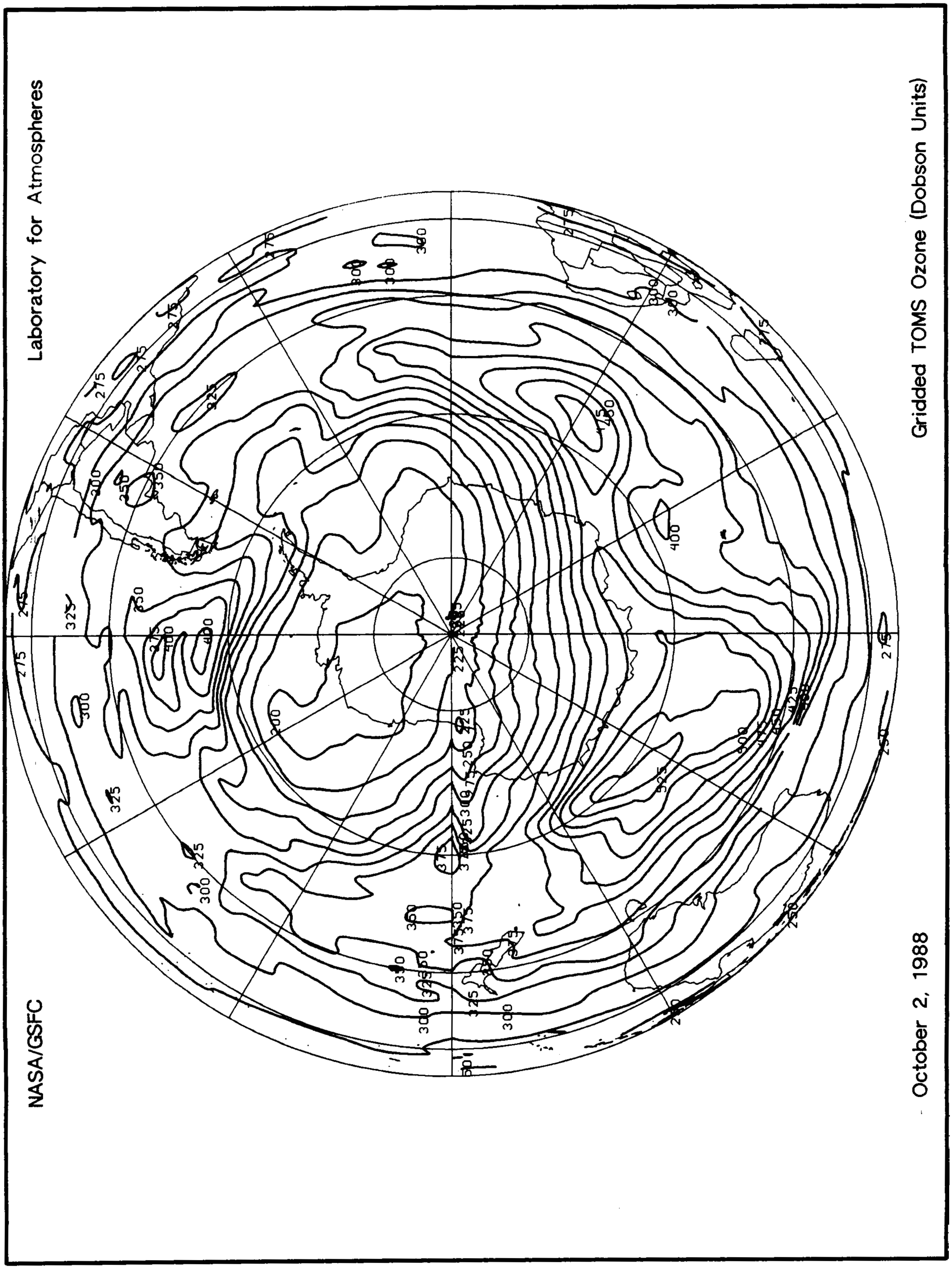

NASA/GSFC
Laboratory for Atmospheres
September 28, 1988
Gridded TOMS Ozone (Dobson Units)

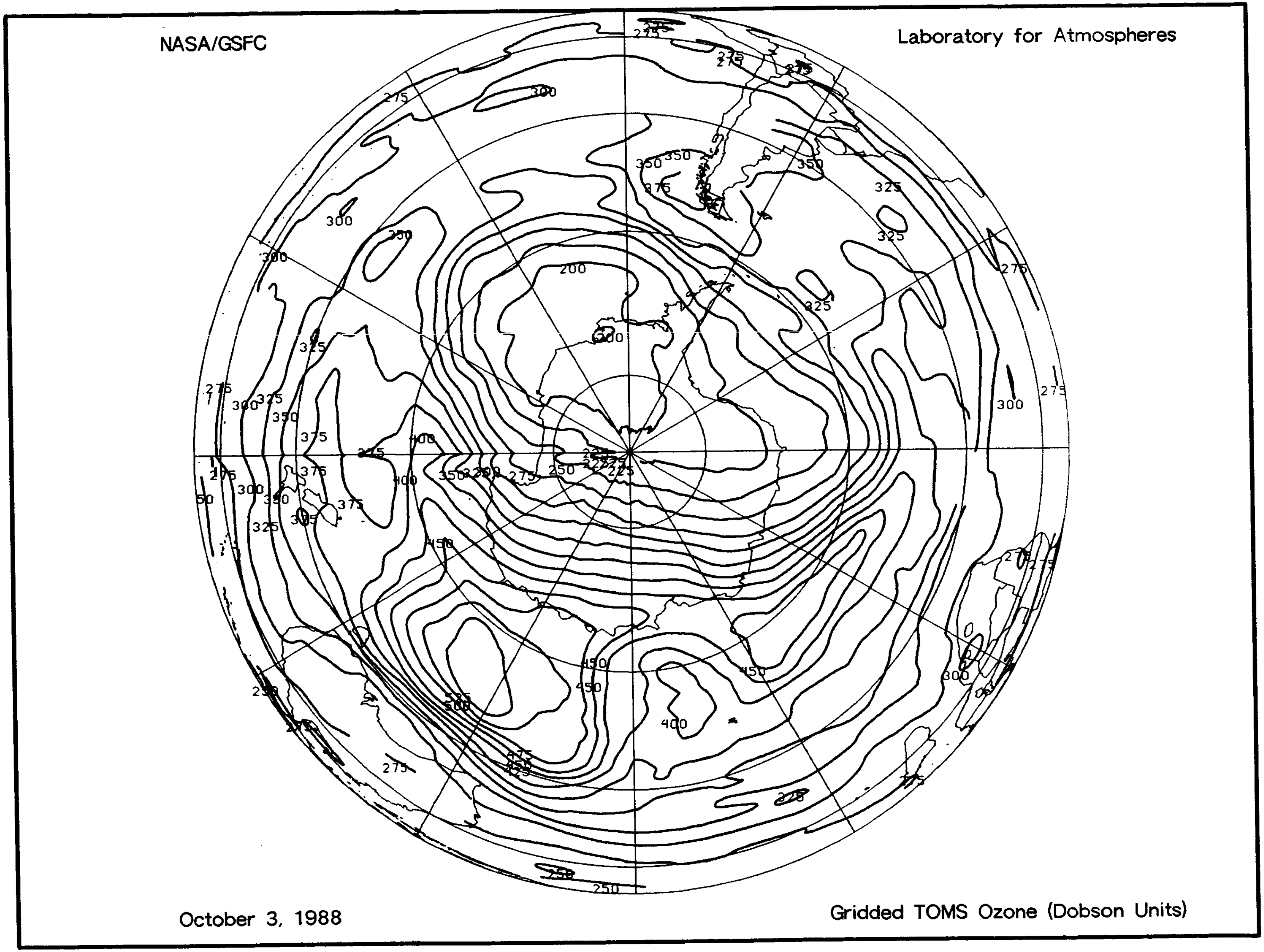


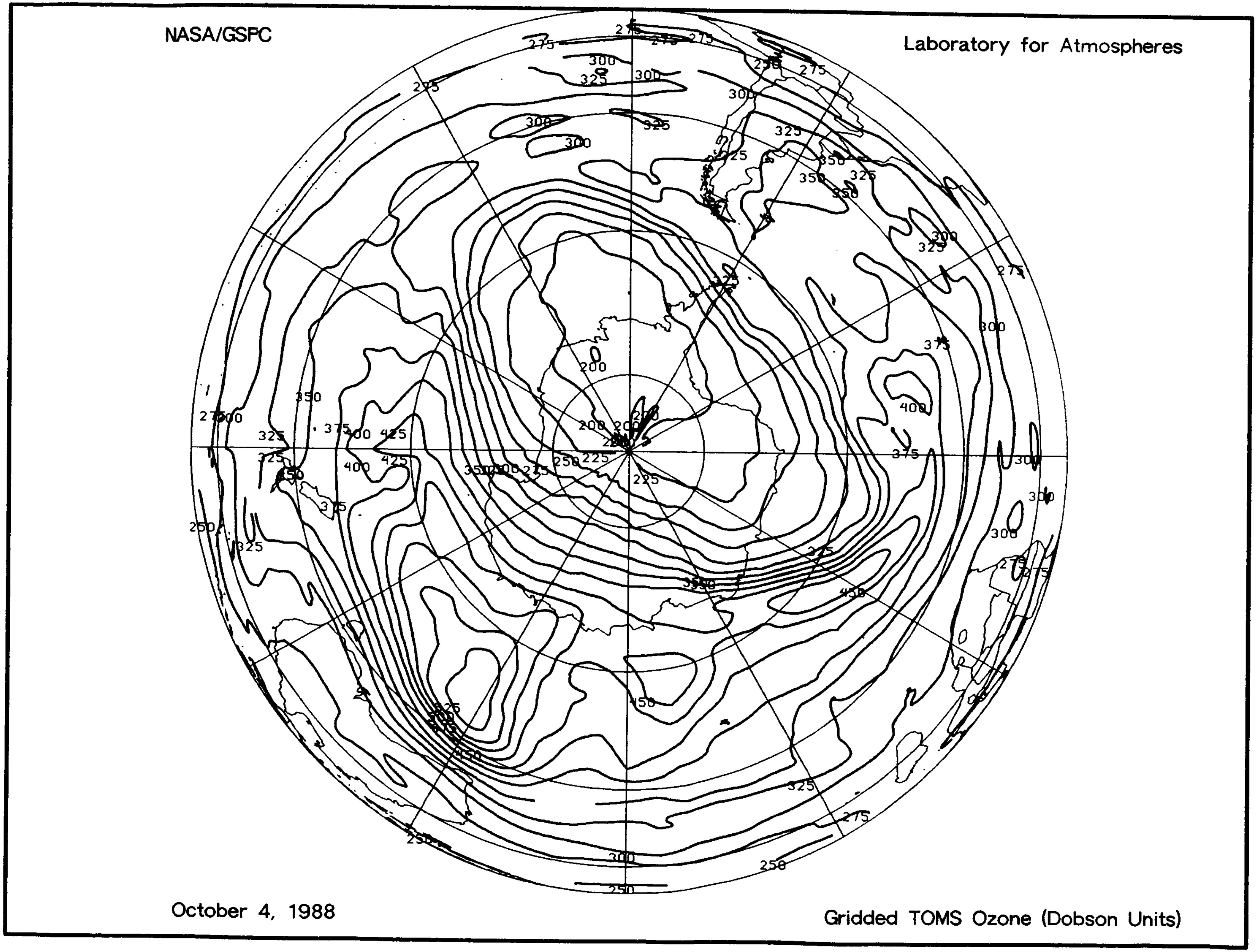
NASA/GSFC
Laboratory for Atmospheres
September 29, 1988
Gridded TOMS Ozone (Dobson Units)

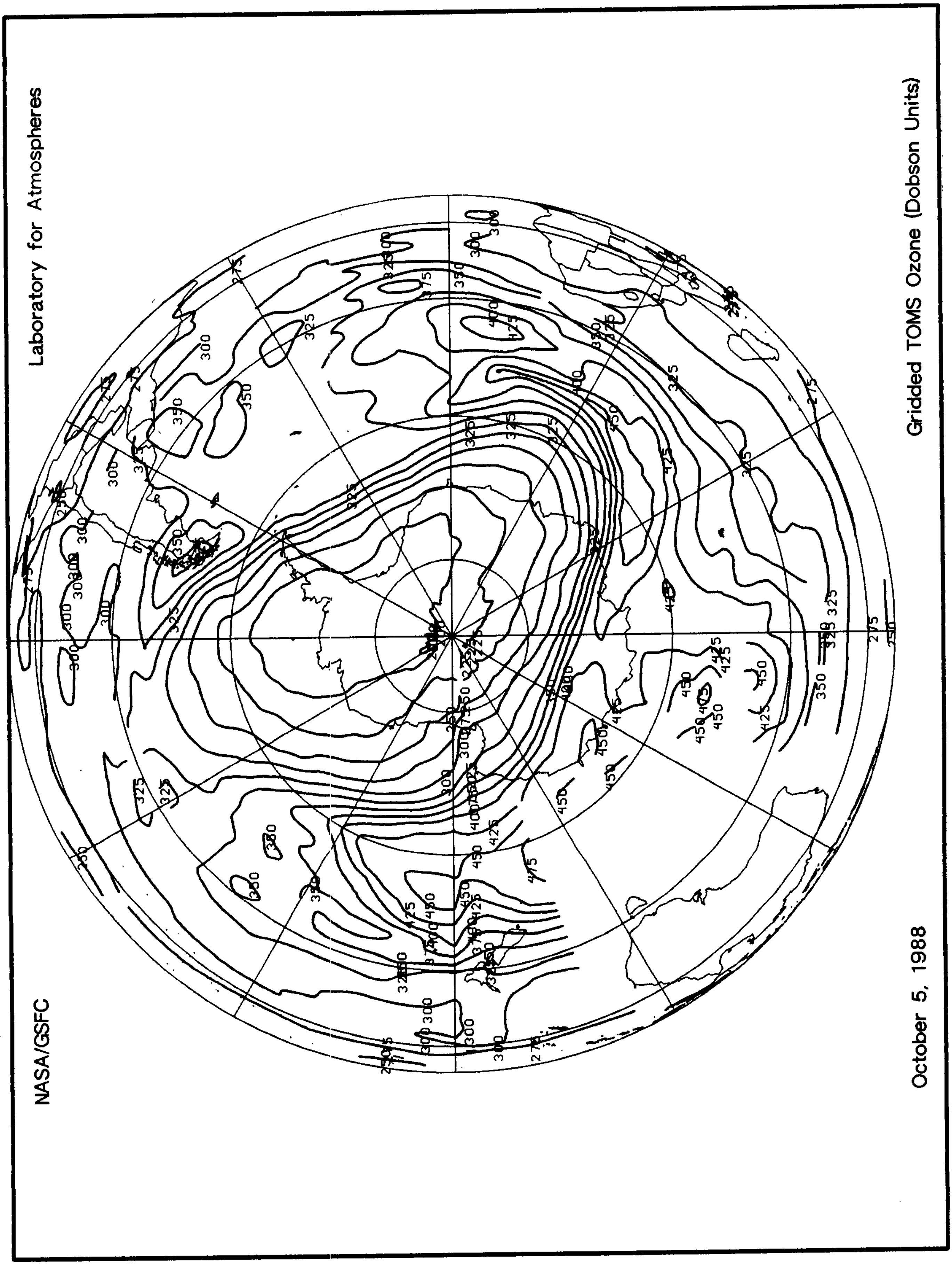

Laboratory for Atmospheres
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
September 30, 1988

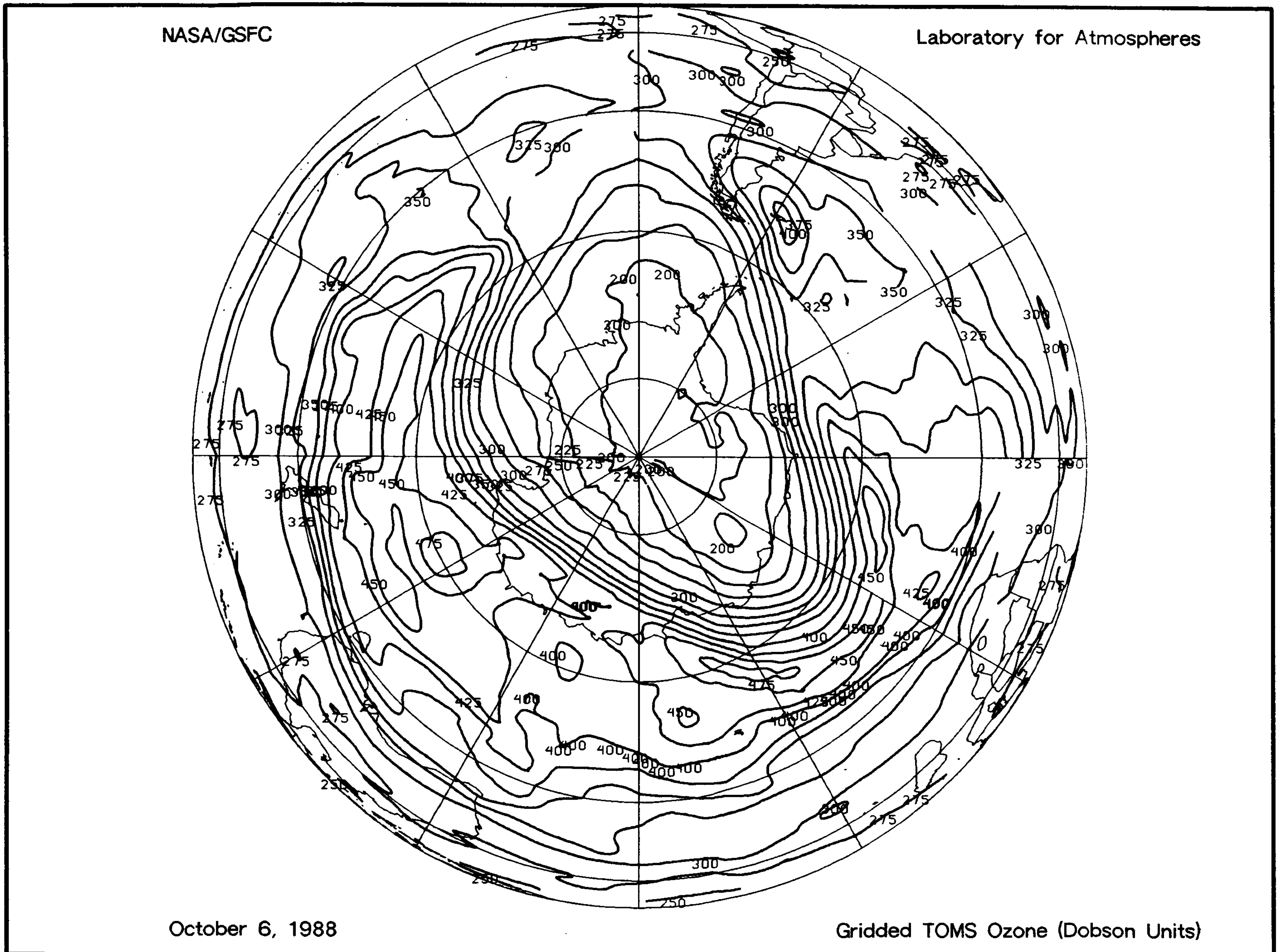

NASA/GSFC
Laboratory for Atmospheres
October 1, 1988
Gridded TOMS Ozone (Dobson Units)

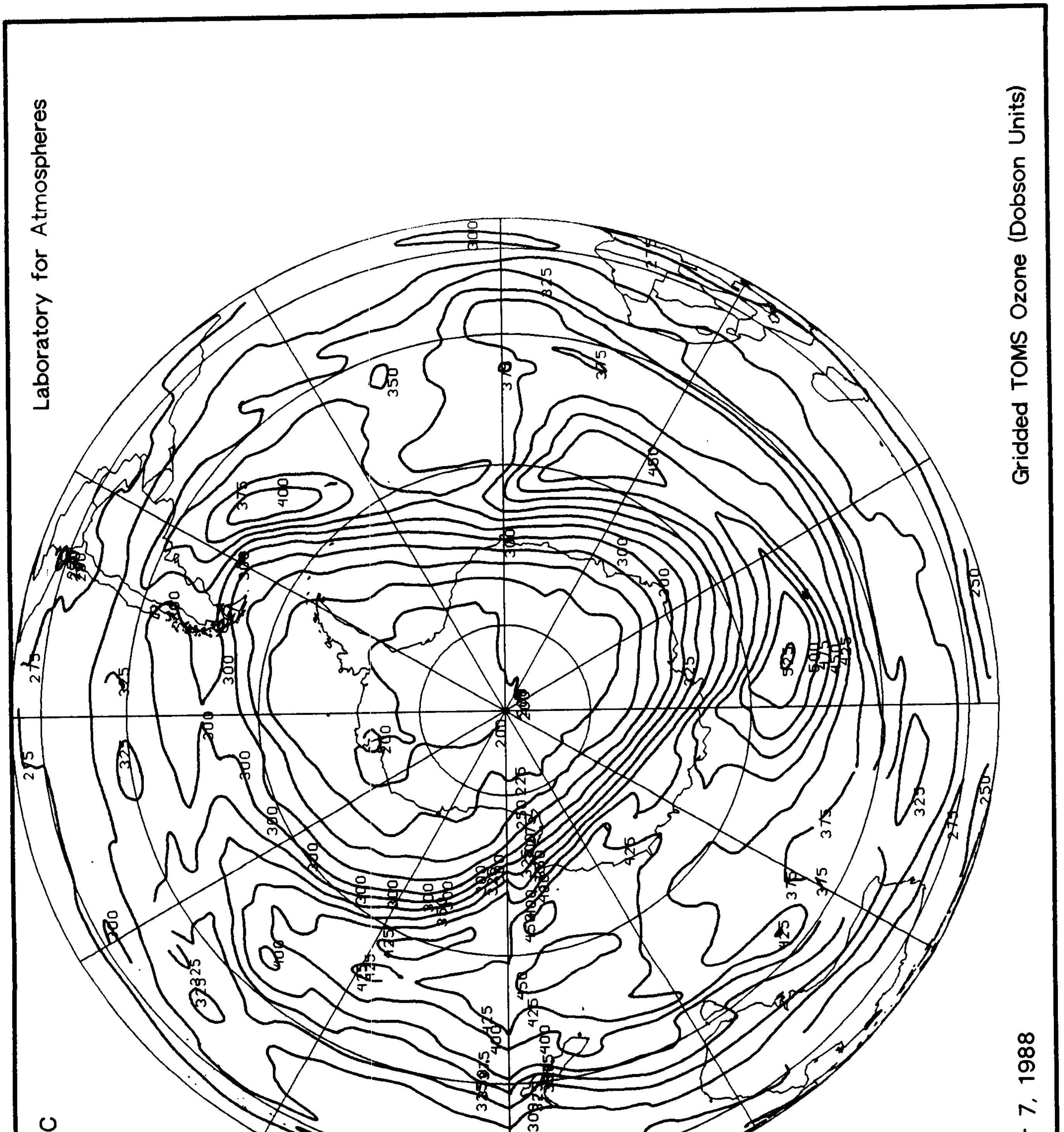

NASA/GSFC
Laboratory for Atmospheres
October 2, 1988
Gridded TOMS Ozone (Dobson Units)

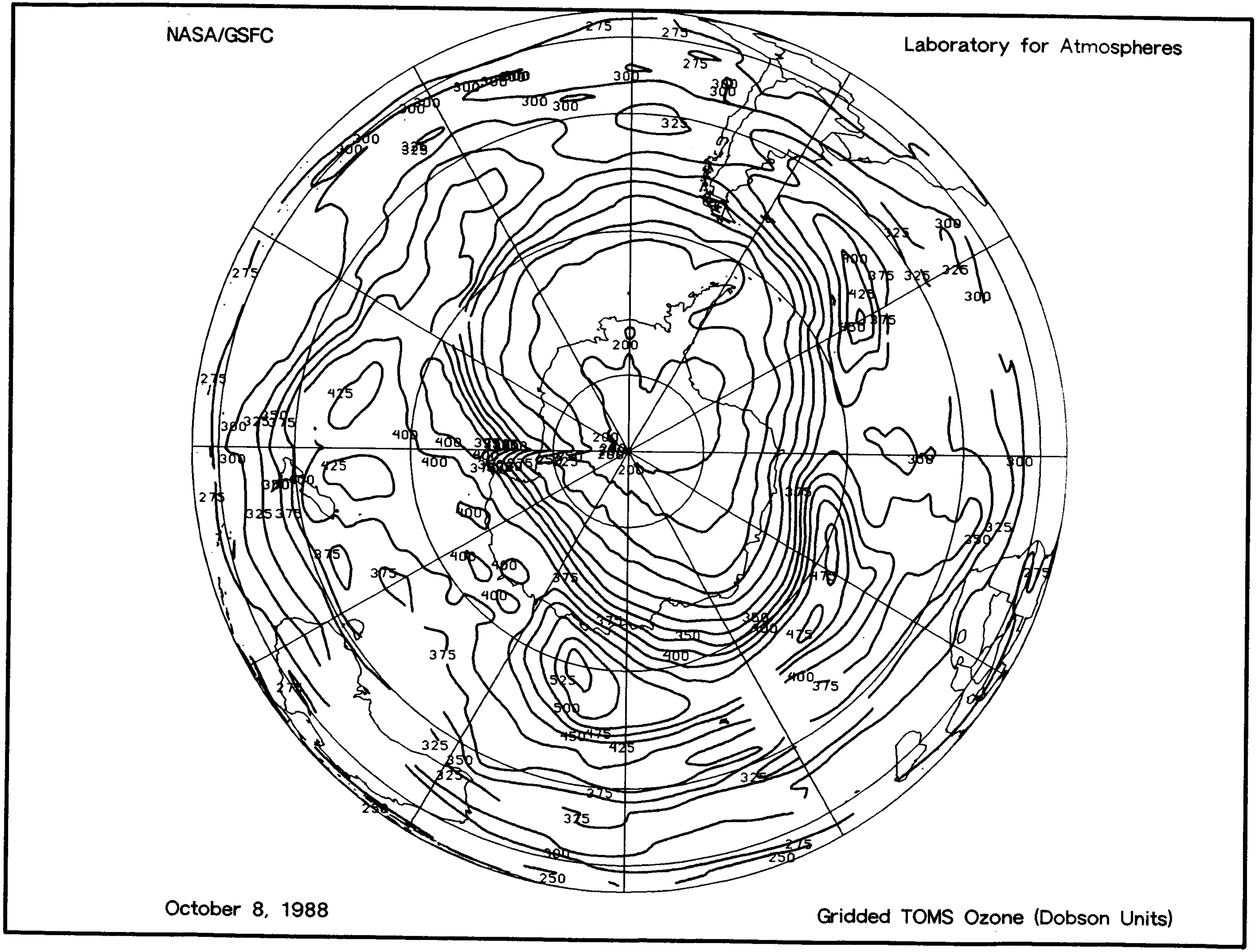

NASA/GSFC
Laboratory for Atmospheres
October 3, 1988
Gridded TOMS Ozone (Dobson Units)

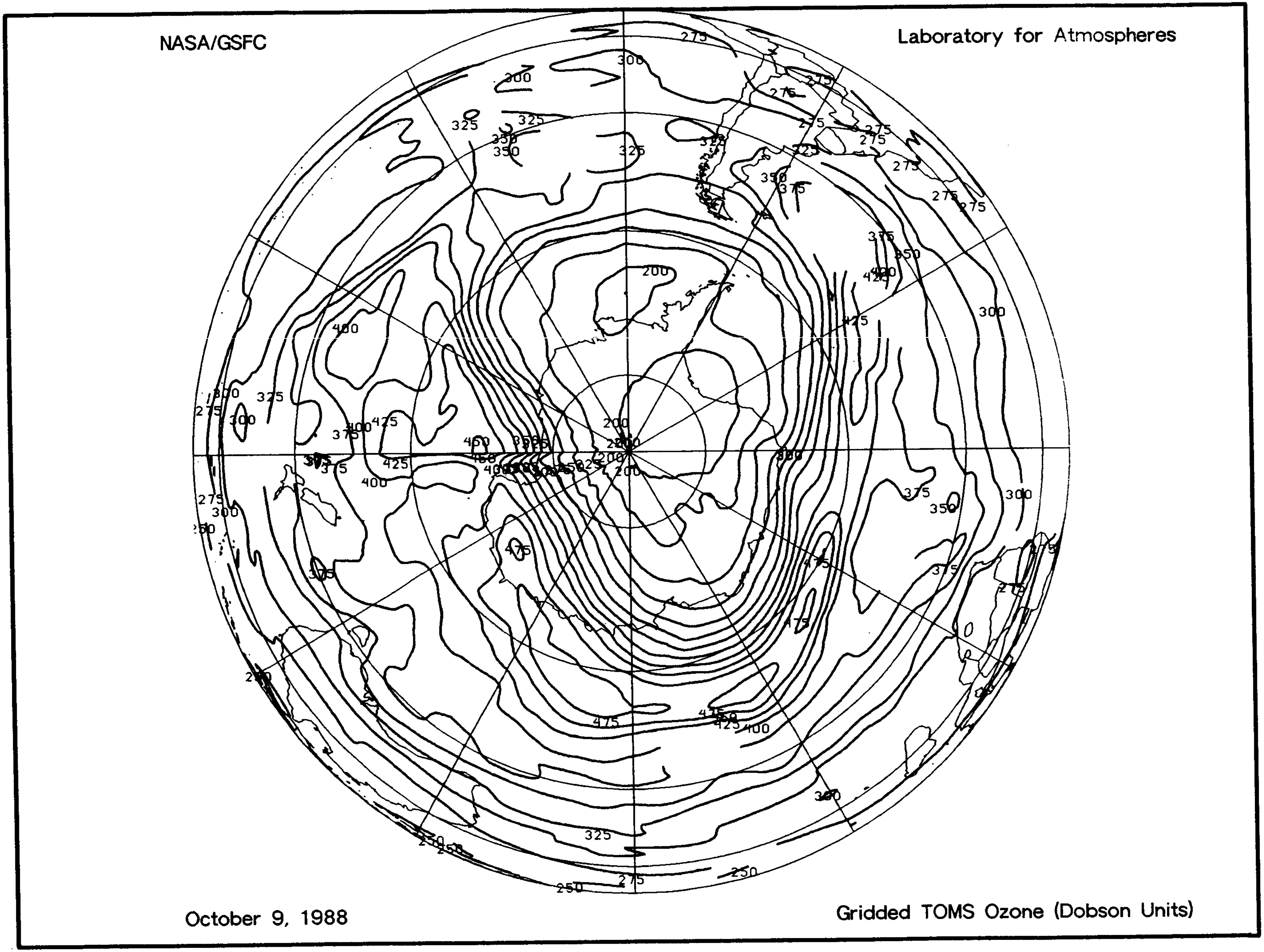

NASA/GSFC
Laboratory for Atmospheres
October 4, 1988
Gridded TOMS Ozone (Dobson Units)

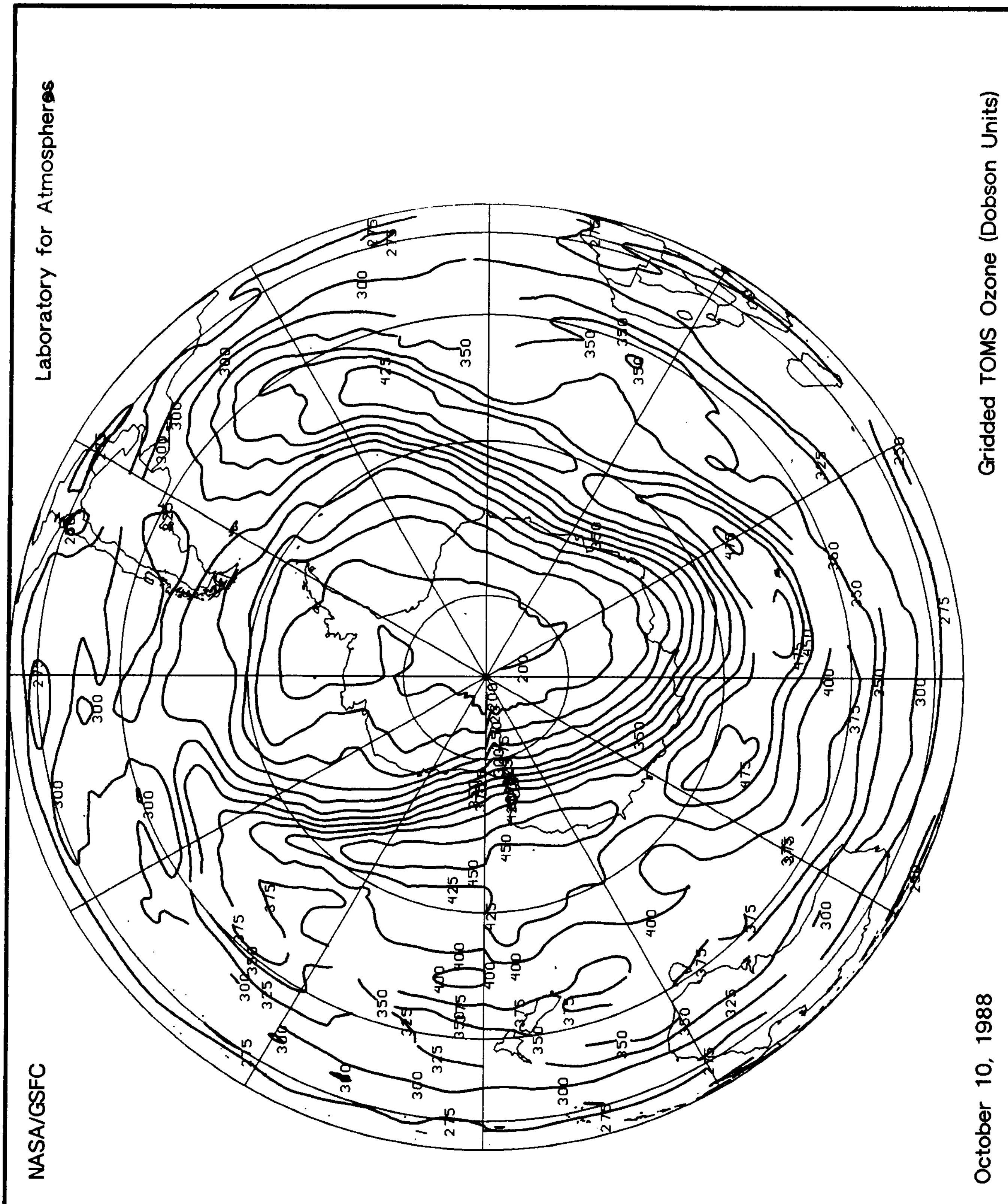

NASA/GSFC
Laboratory for Atmospheres
October 5, 1988
Gridded TOMS Ozone (Dobson Units)

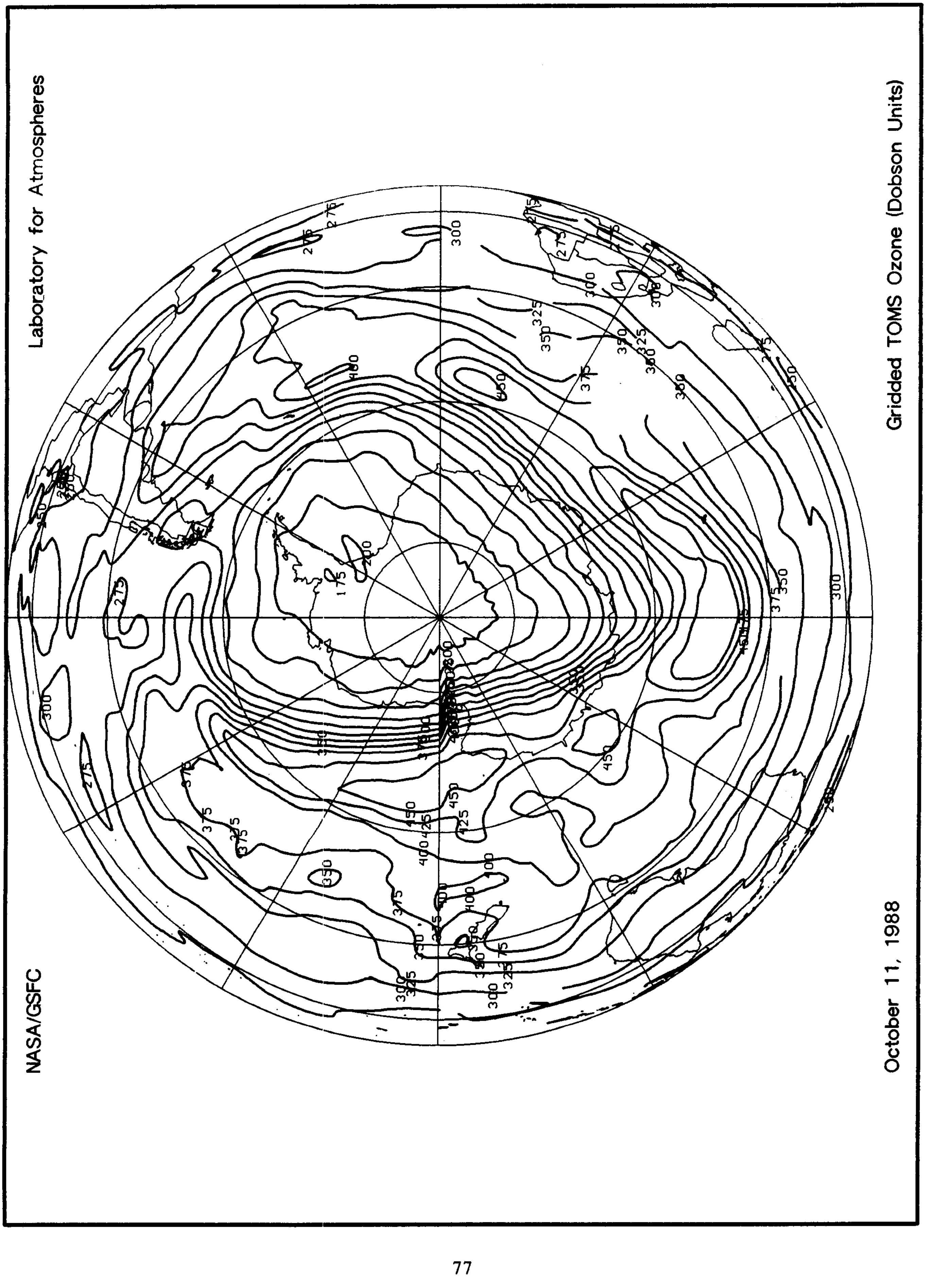

NASA/GSFC
Laboratory for Atmospheres
October 6, 1988
Gridded TOMS Ozone (Dobson Units)

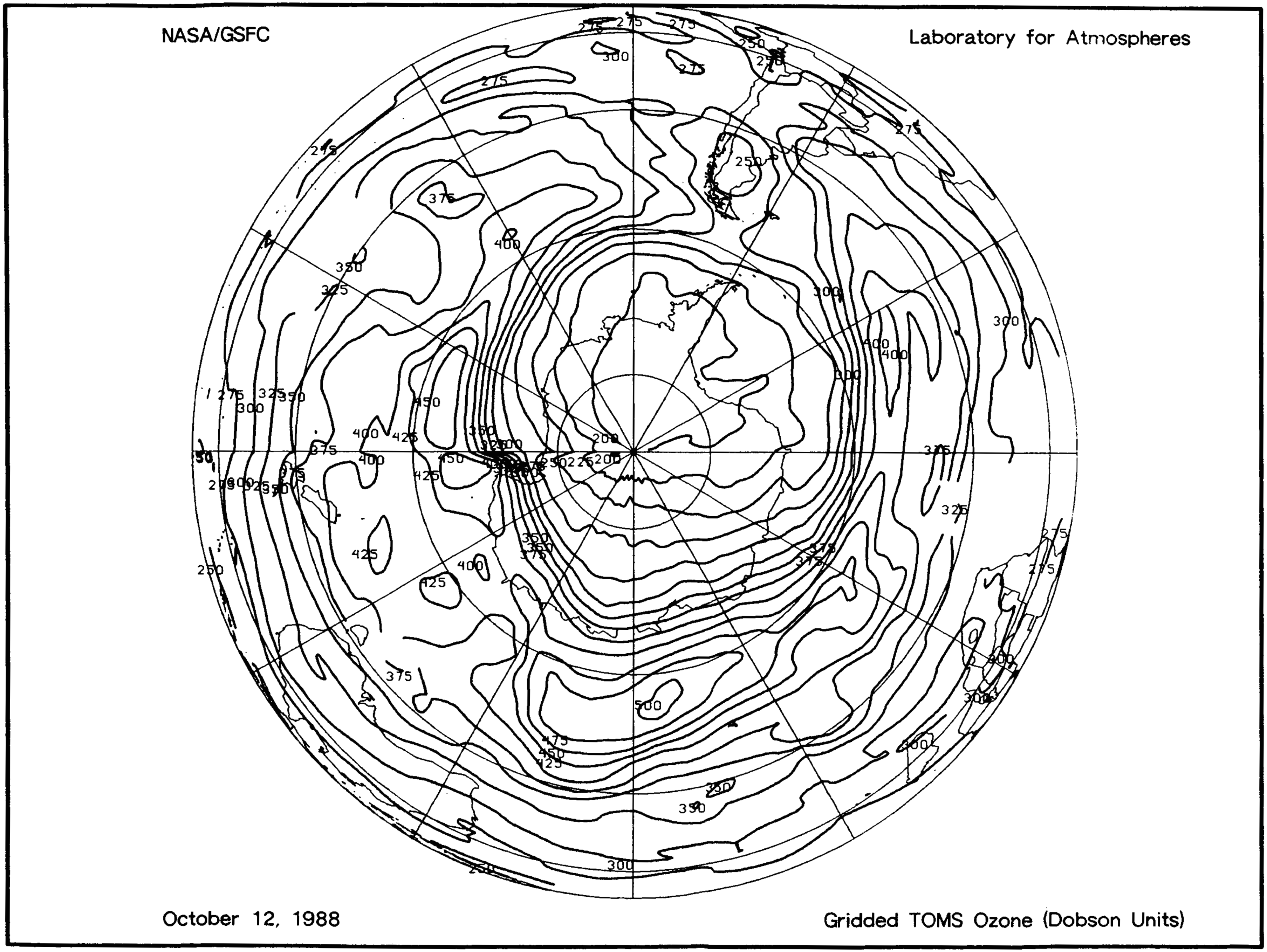

Laboratory for Atmospheres
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
October 7, 1988

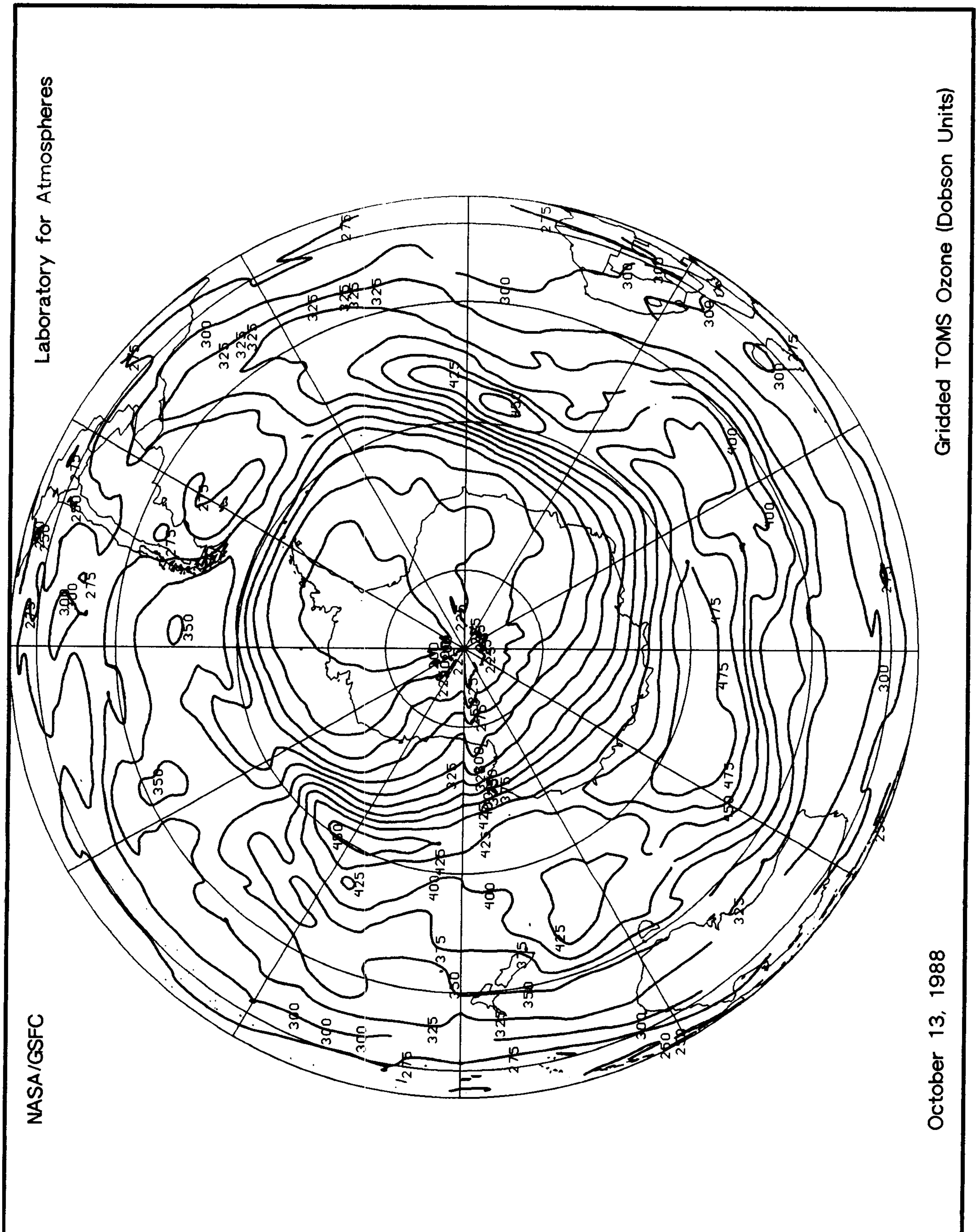

NASA/GSFC
Laboratory for Atmospheres
October 8, 1988
Gridded TOMS Ozone (Dobson Units)

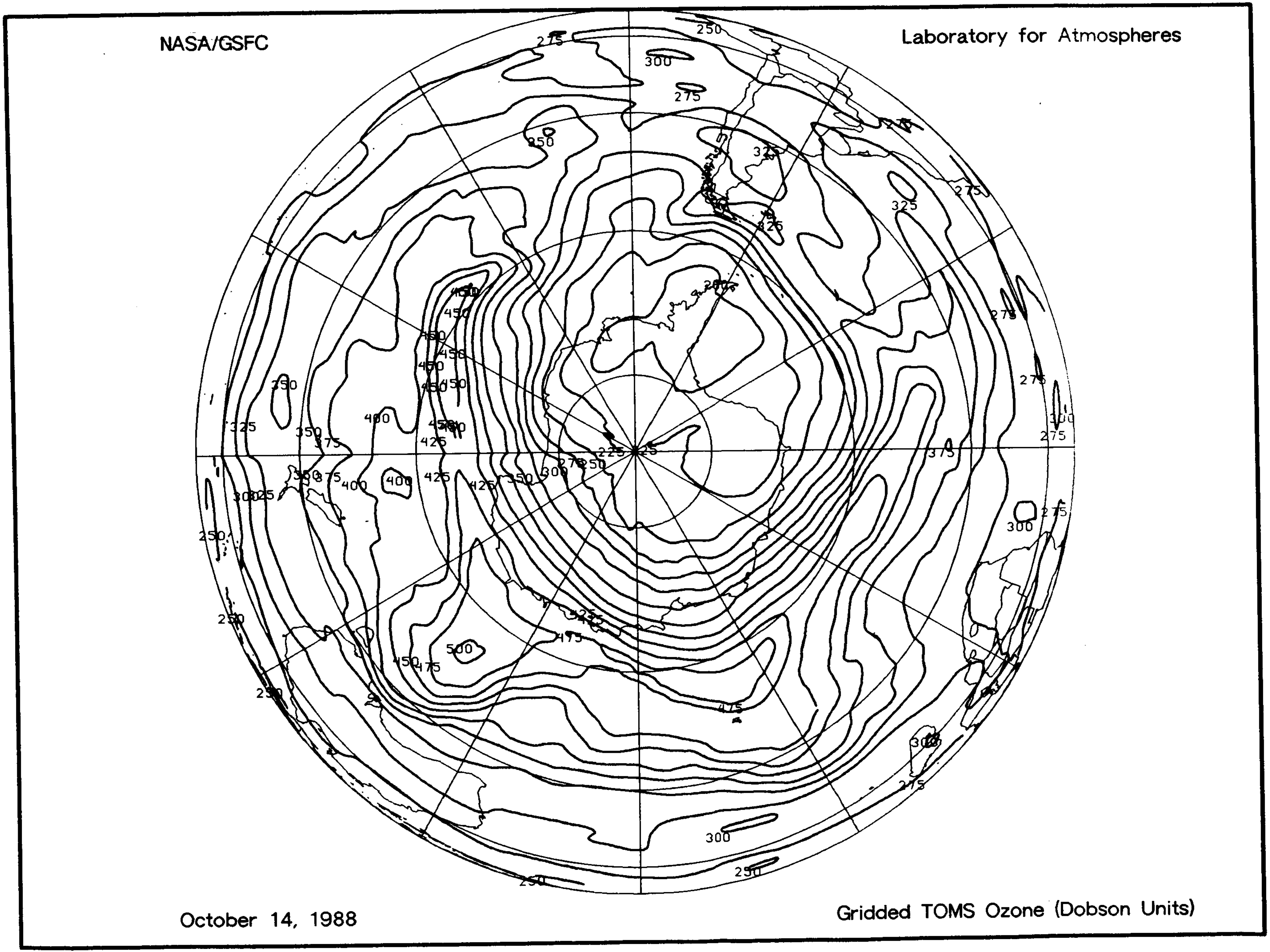

NASA/GSFC
Laboratory for Atmospheres
October 9, 1988
Gridded TOMS Ozone (Dobson Units)

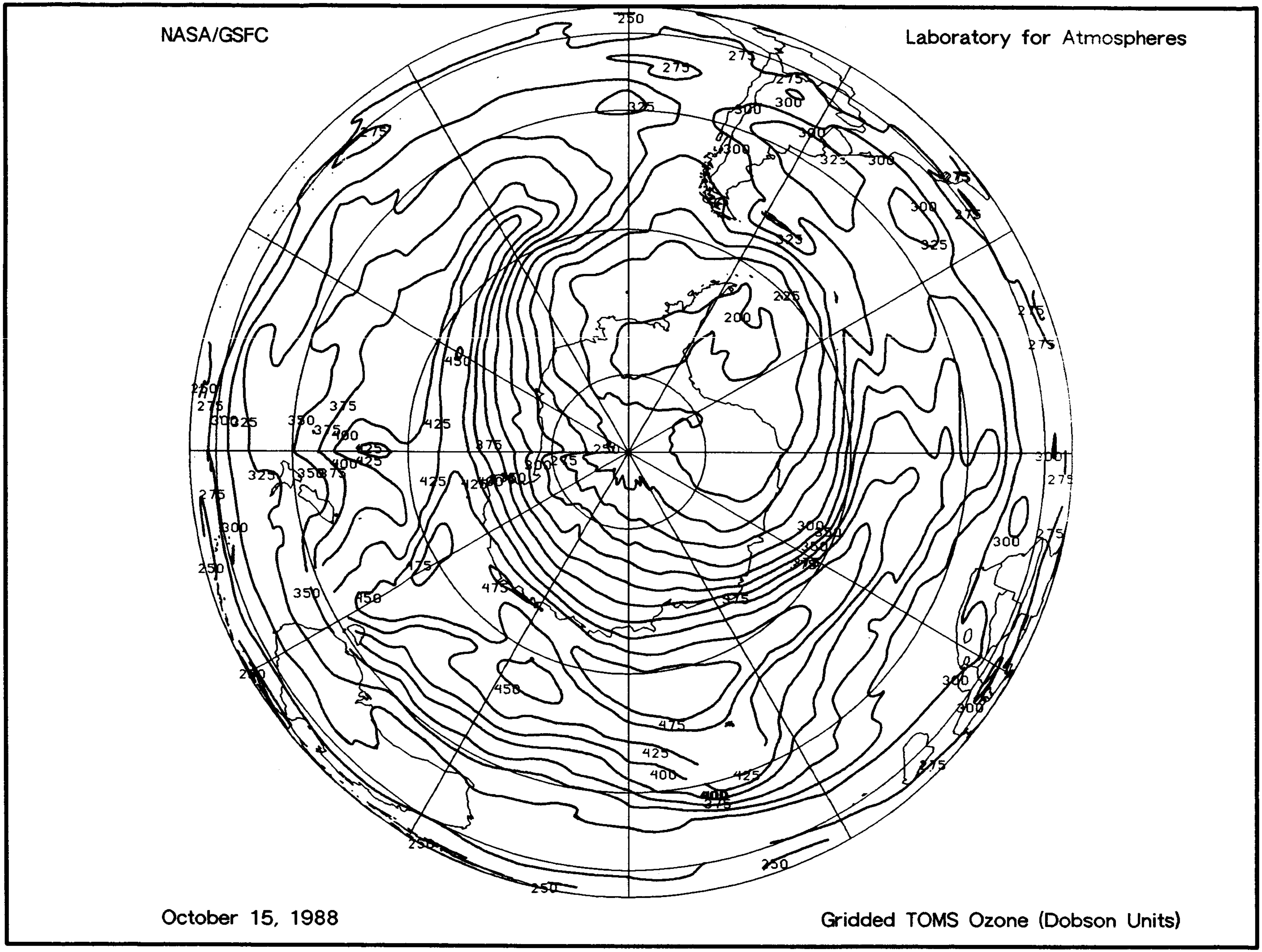

Laboratory for Atmospheres
NASA/GSFC
October 10, 1988
Gridded TOMS Ozone (Dobson Units)

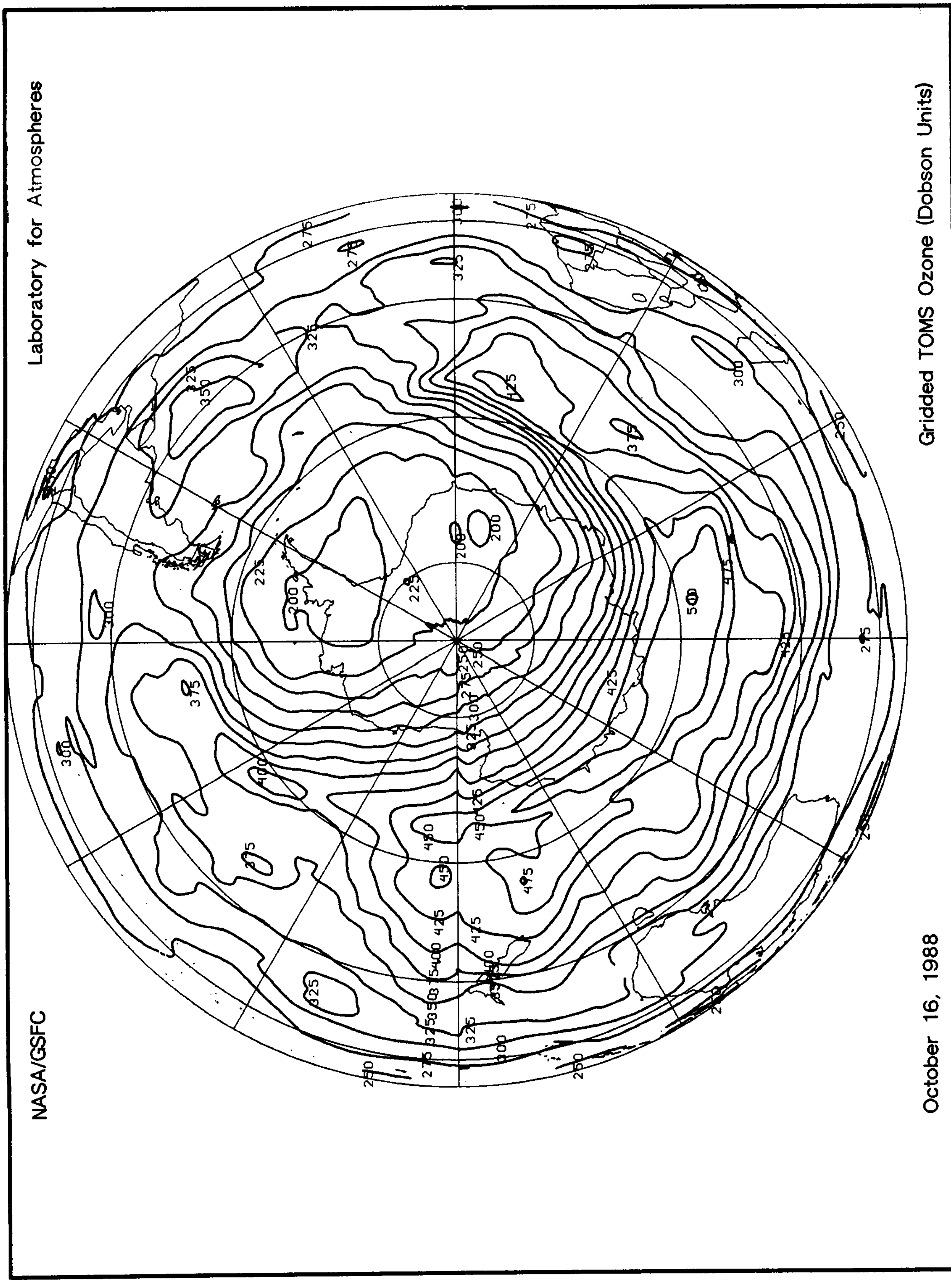

NASA/GSFC
Laboratory for Atmospheres
October 11, 1988
Gridded TOMS Ozone (Dobson Units)

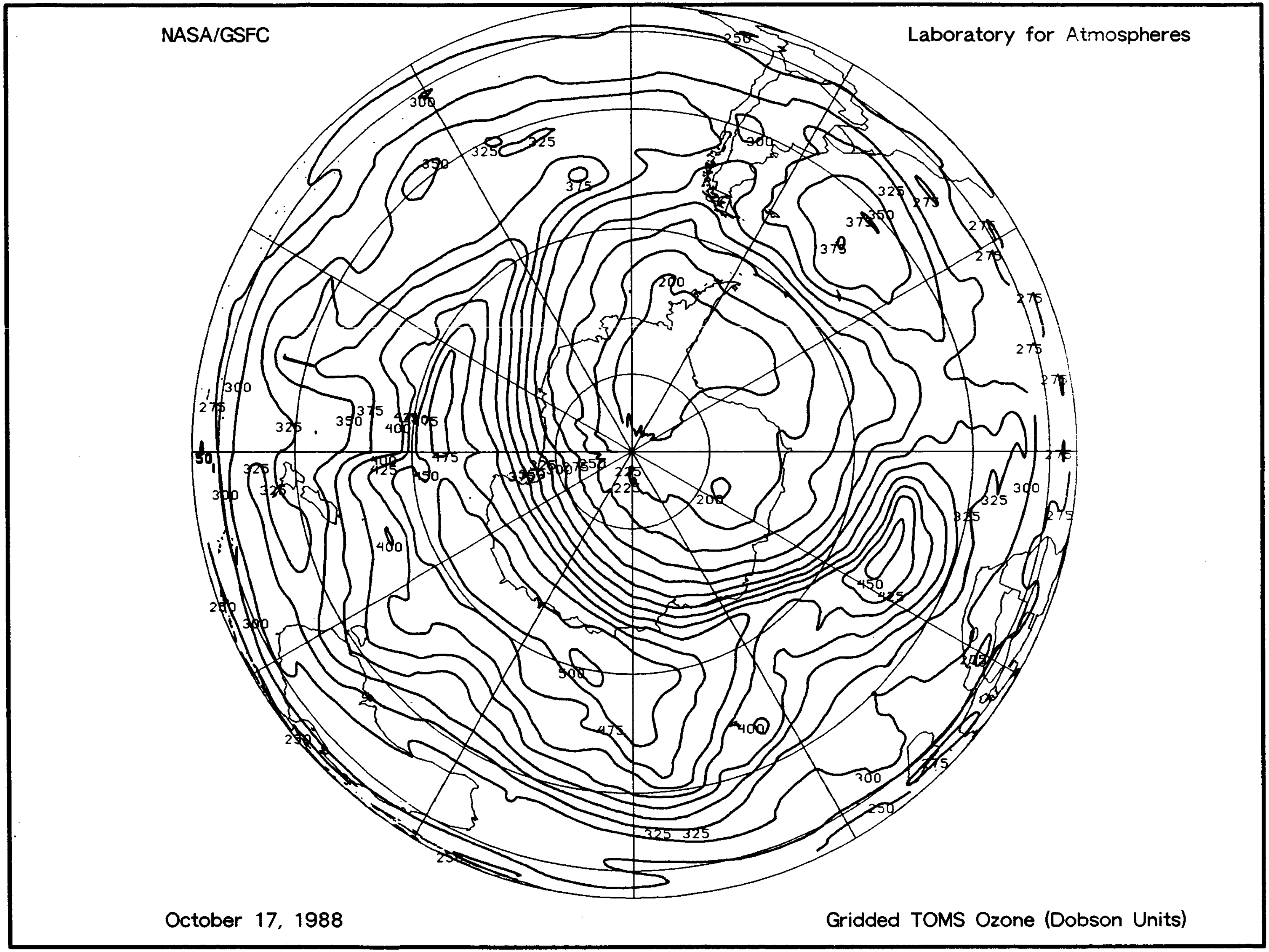

NASA/GSFC
Laboratory for Atmospheres
October 12, 1988
Gridded TOMS Ozone (Dobson Units)

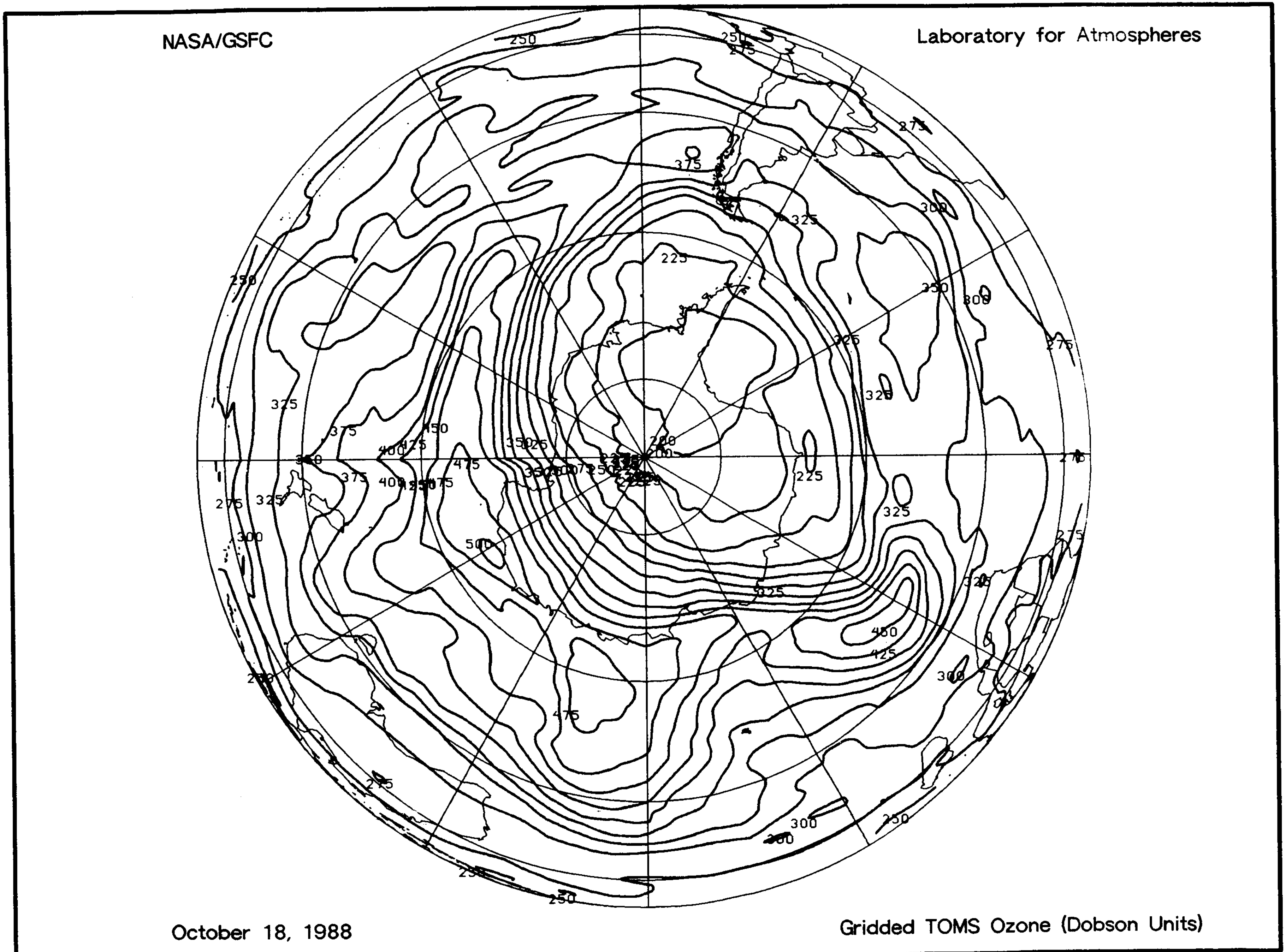

NASA/GSFC
Laboratory for Atmospheres
October 13, 1988
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 14, 1988
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 15, 1988
Gridded TOMS Ozone (Dobson Units)

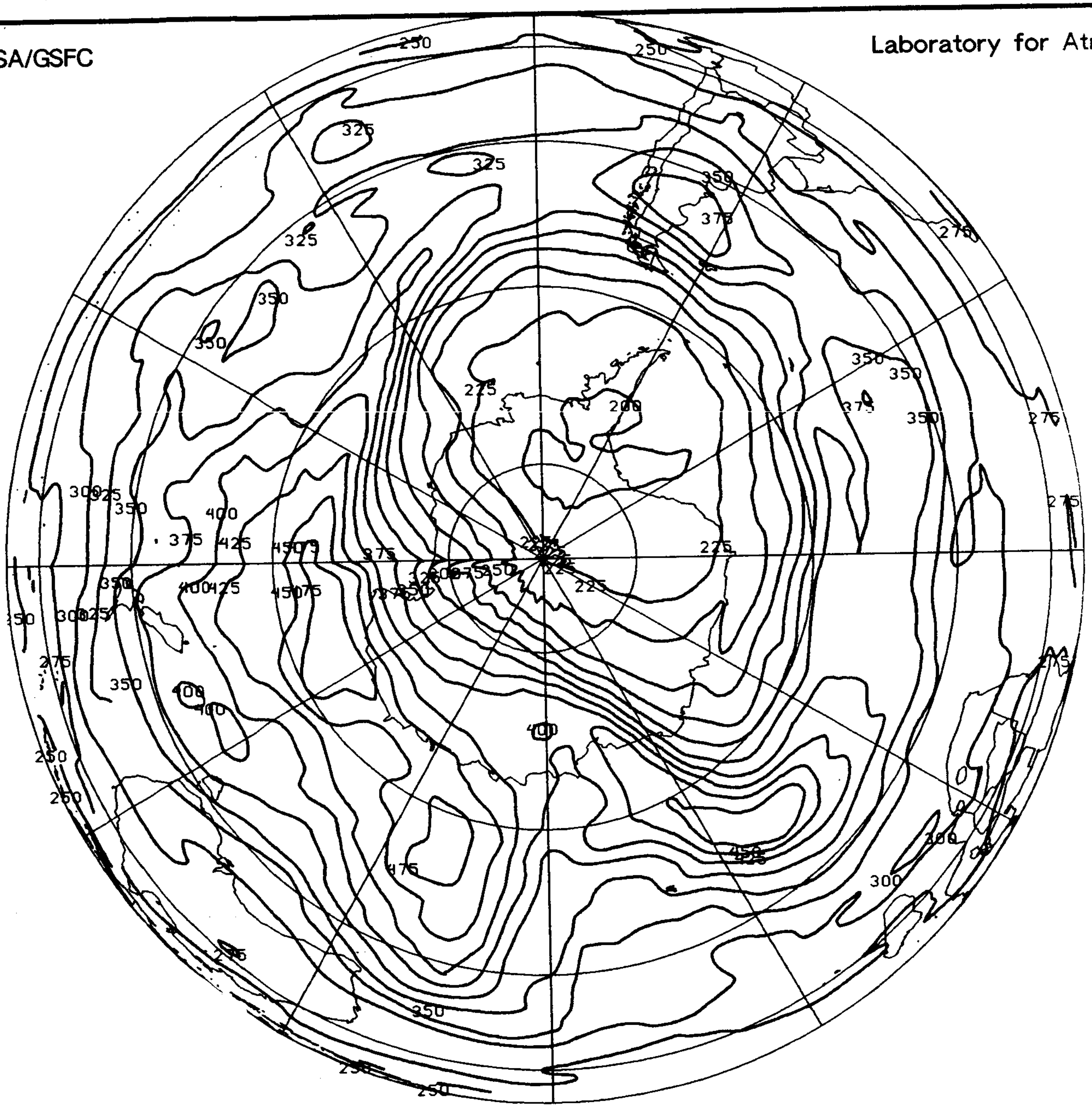

NASA/GSFC
Laboratory for Atmospheres
October 16, 1988
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 17, 1988
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 18, 1988
Gridded TOMS Ozone (Dobson Units)

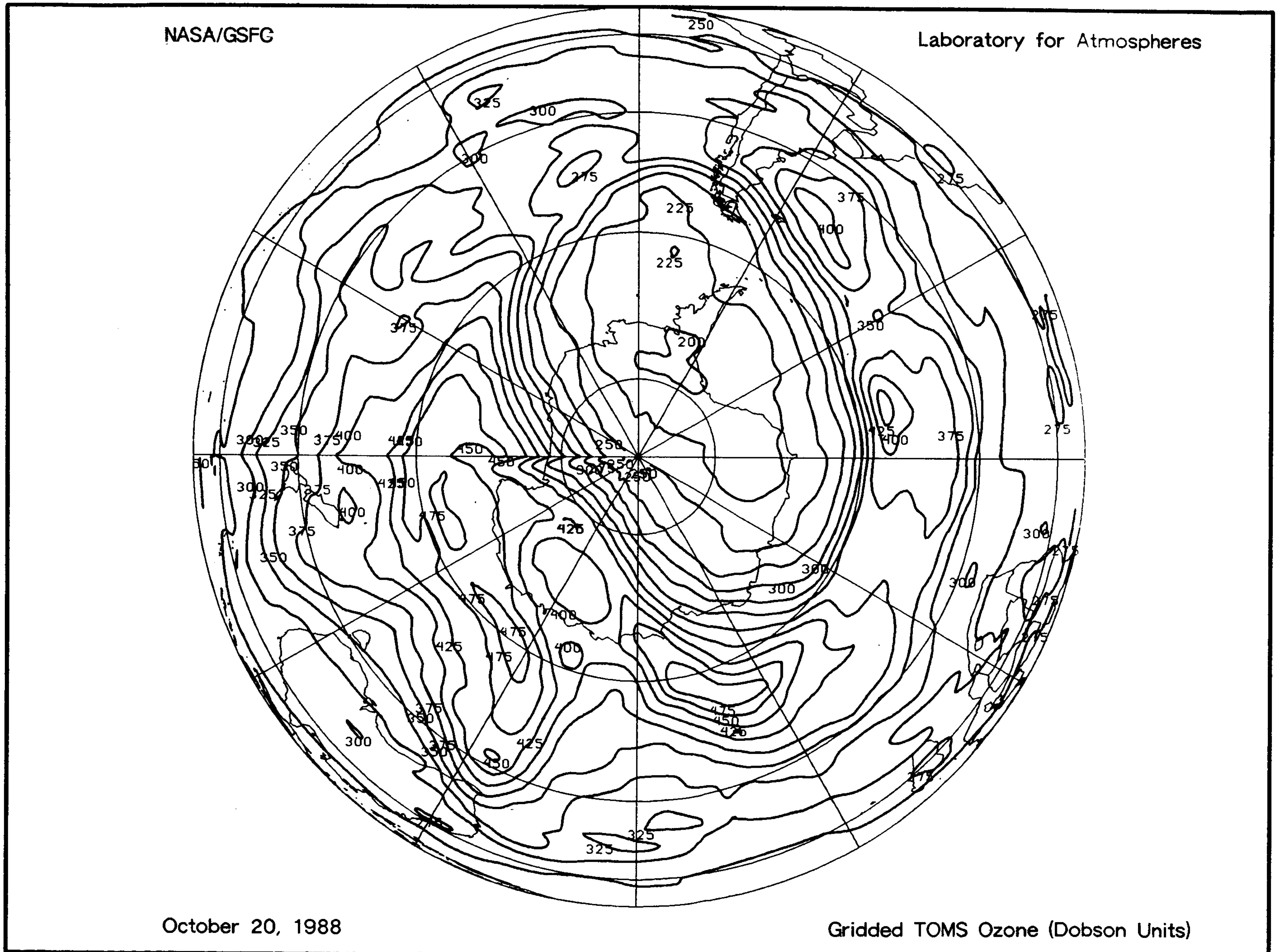
NASA/GSFC

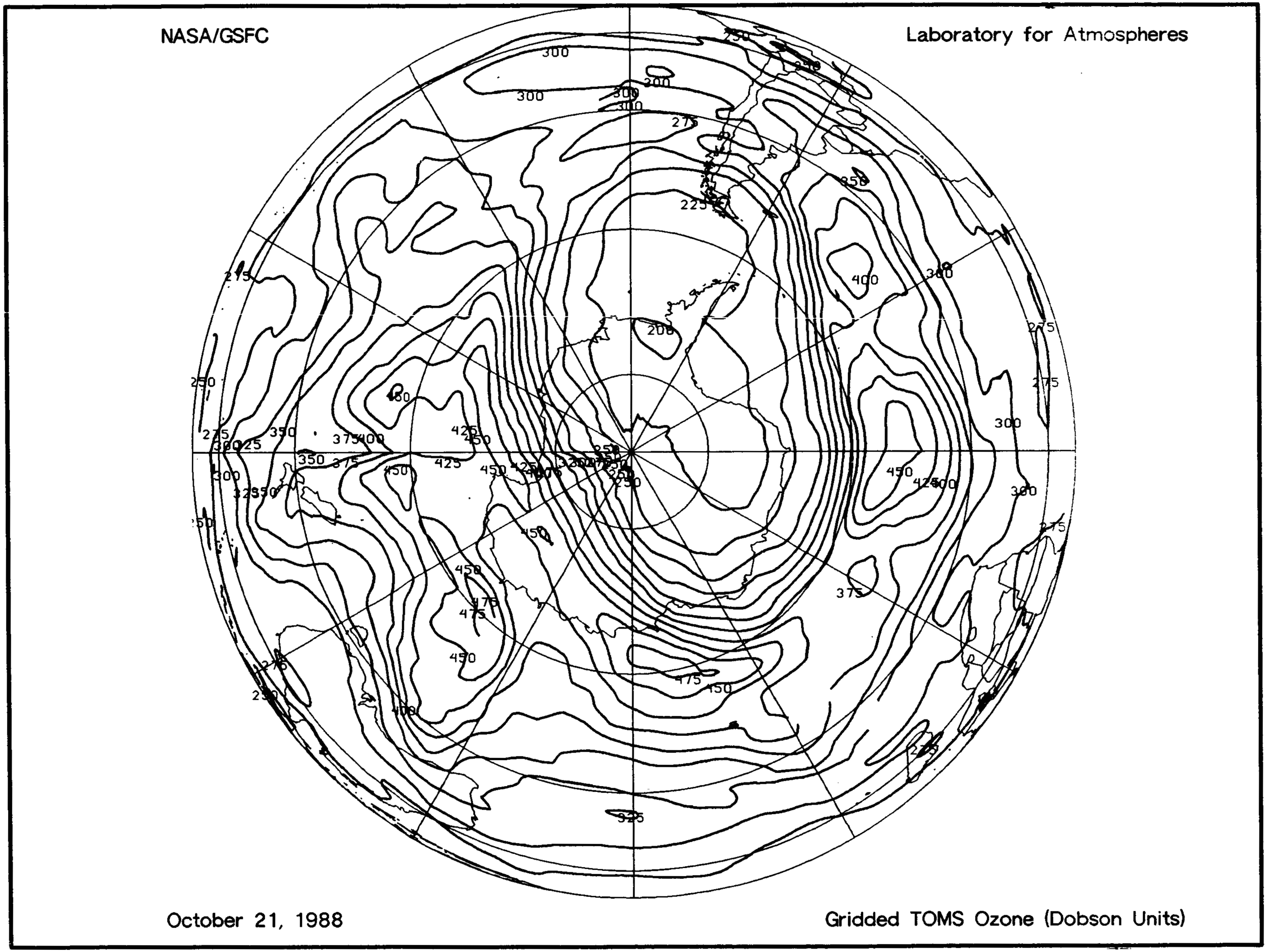
Laboratory for Atmospheres

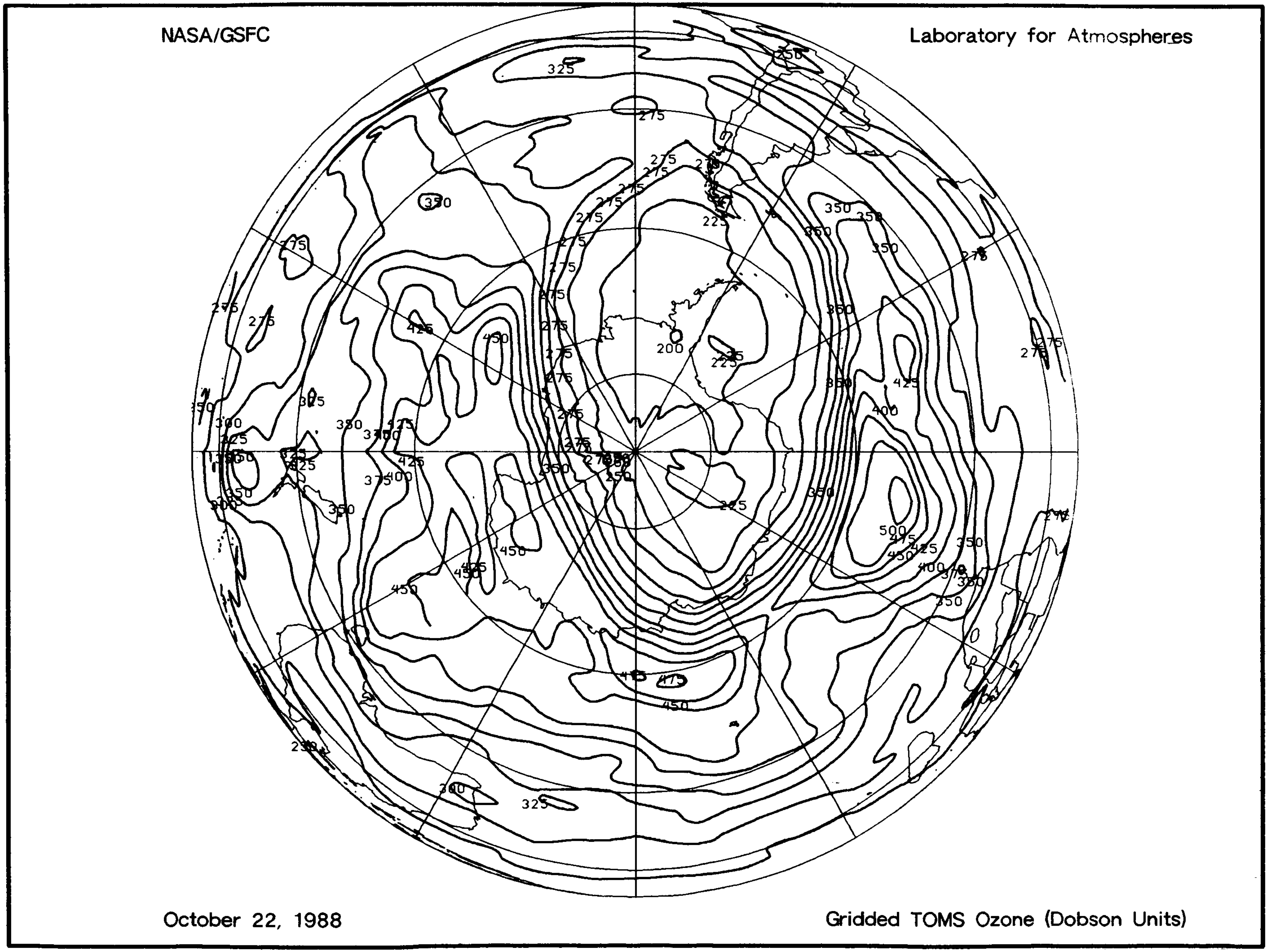


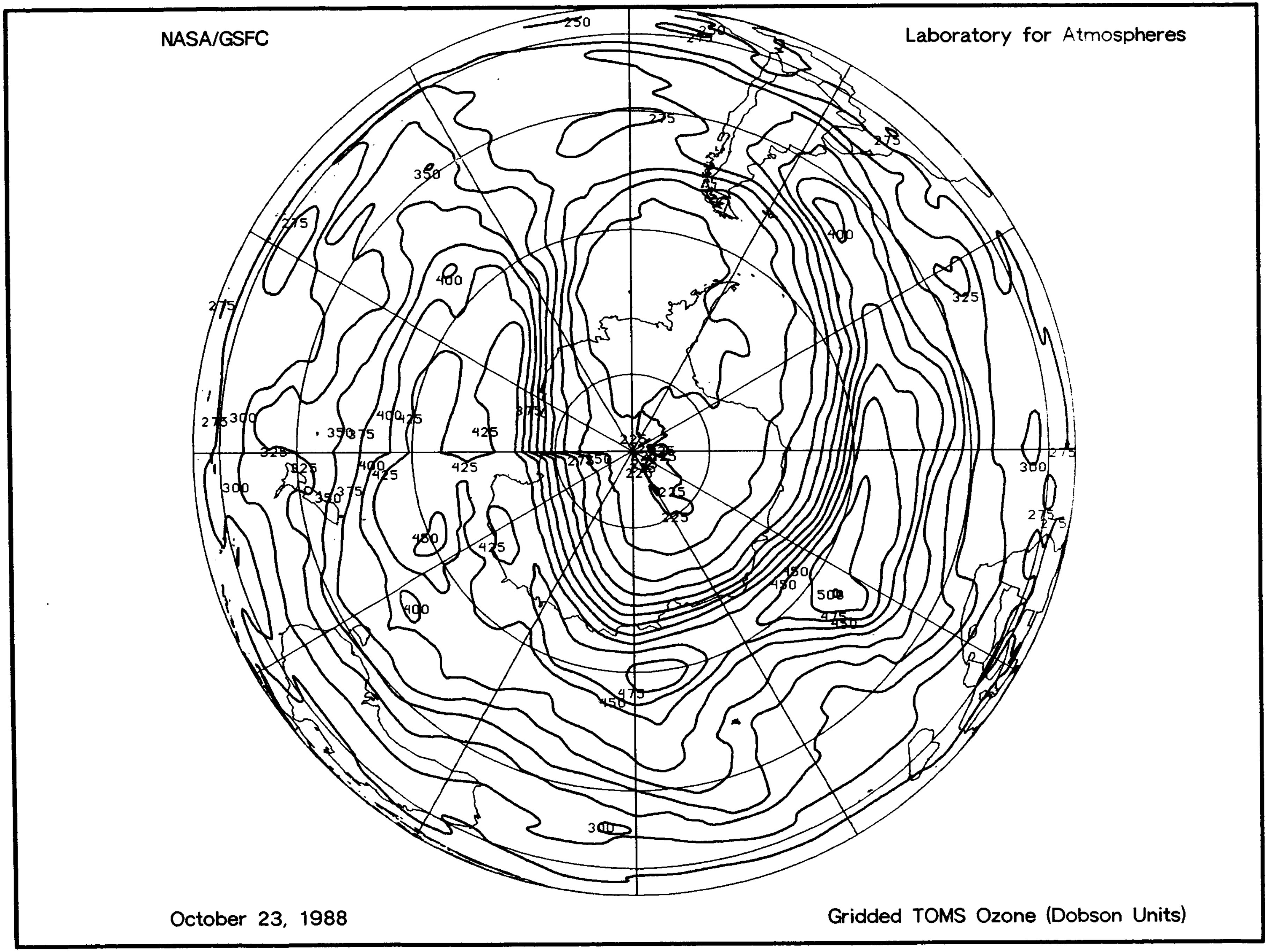
October 19, 1988

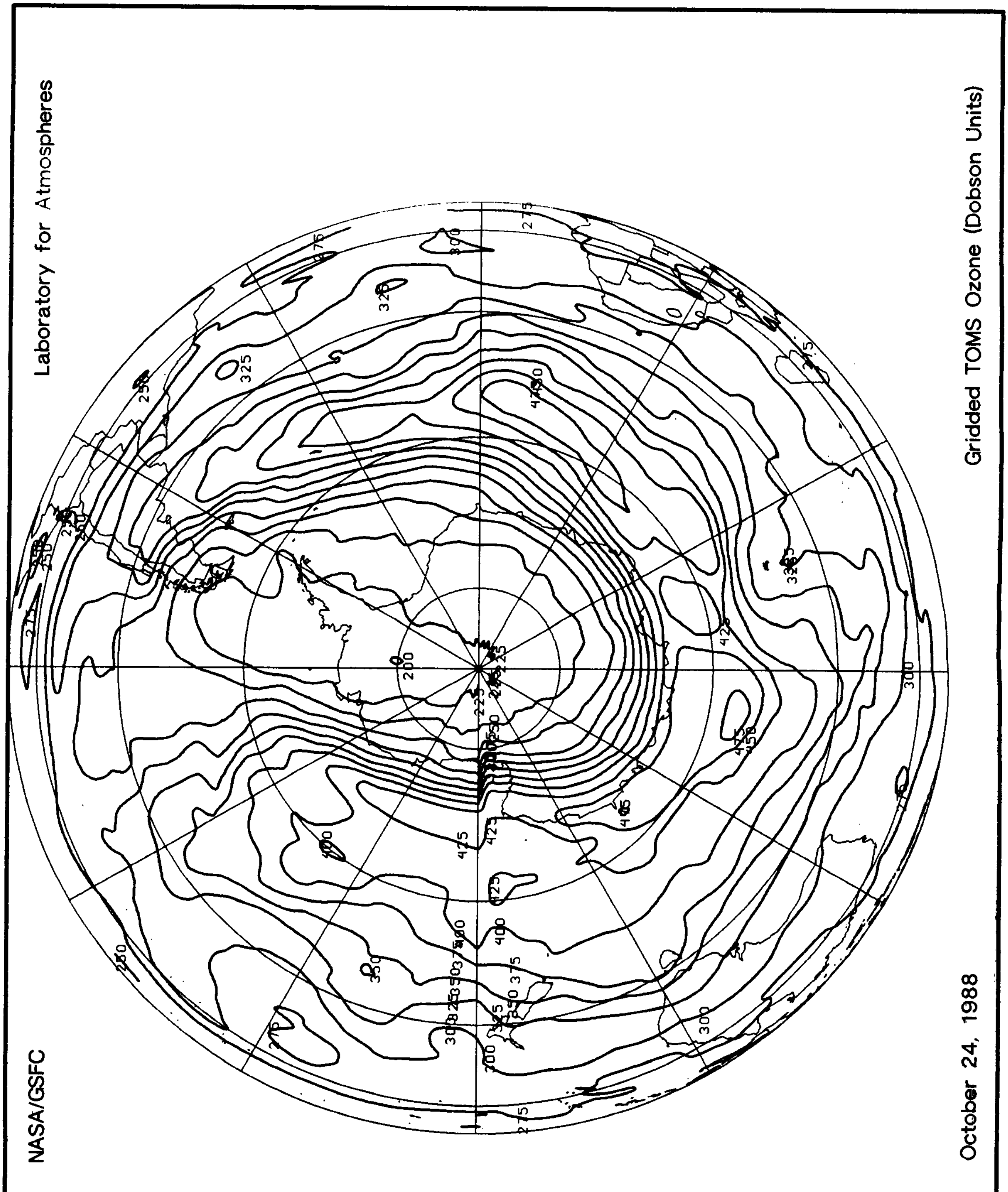
Gridded TOMS Ozone (Dobson Units)

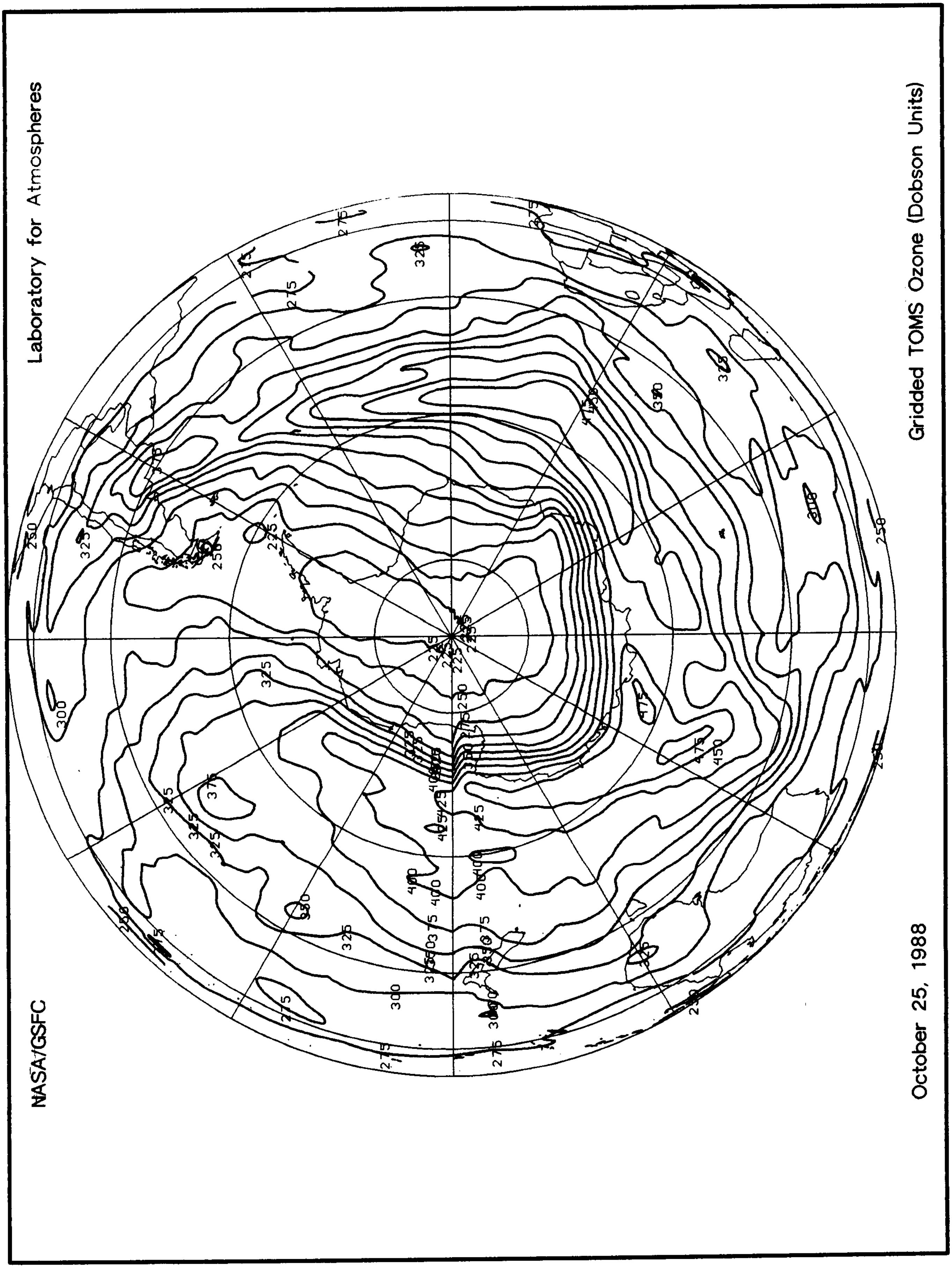

NASA/GSFG
Laboratory for Atmospheres
October 20, 1988
Gridded TOMS Ozone (Dobson Units)

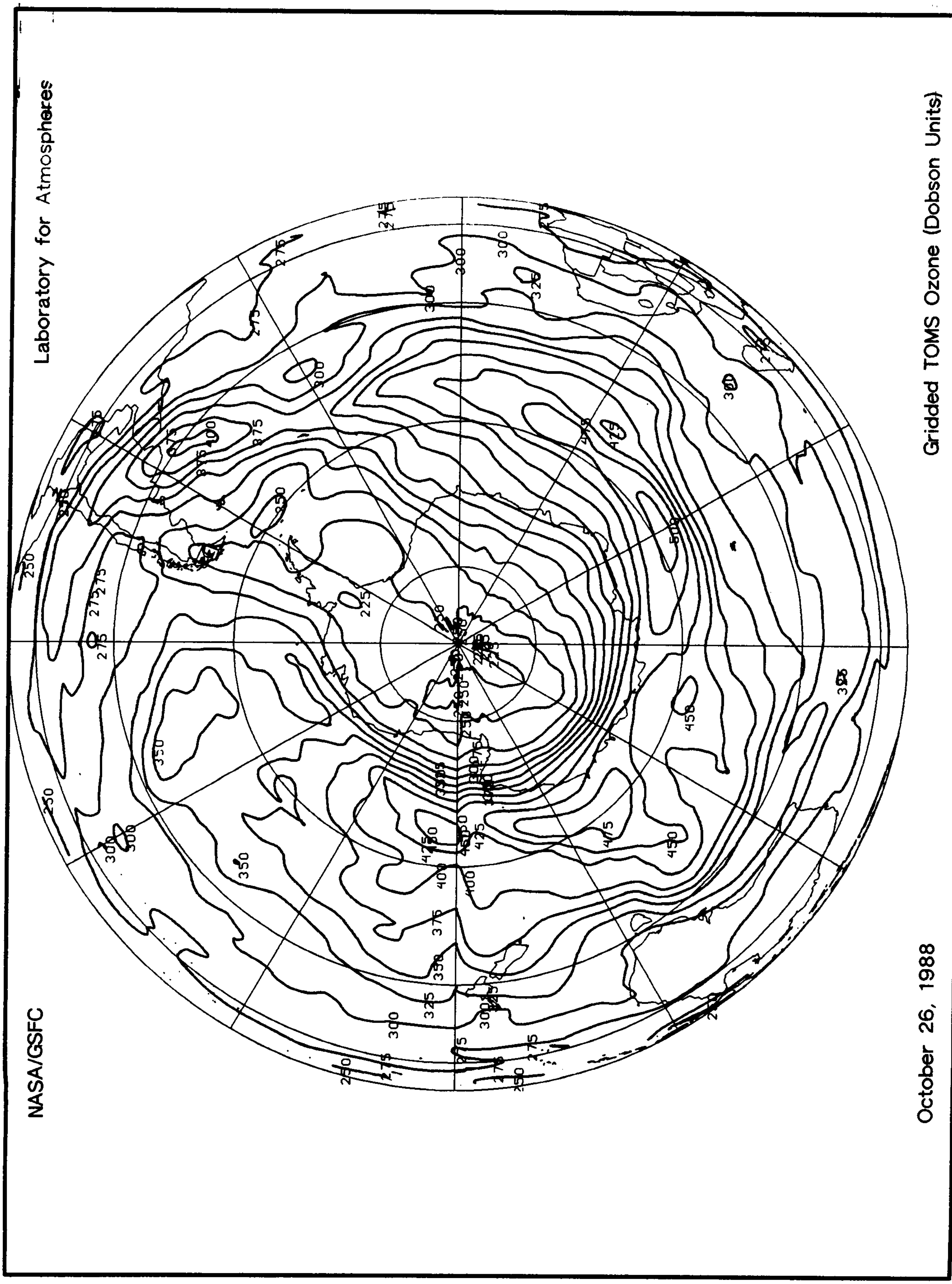

NASA/GSFC
Laboratory for Atmospheres
October 21, 1988
Gridded TOMS Ozone (Dobson Units)

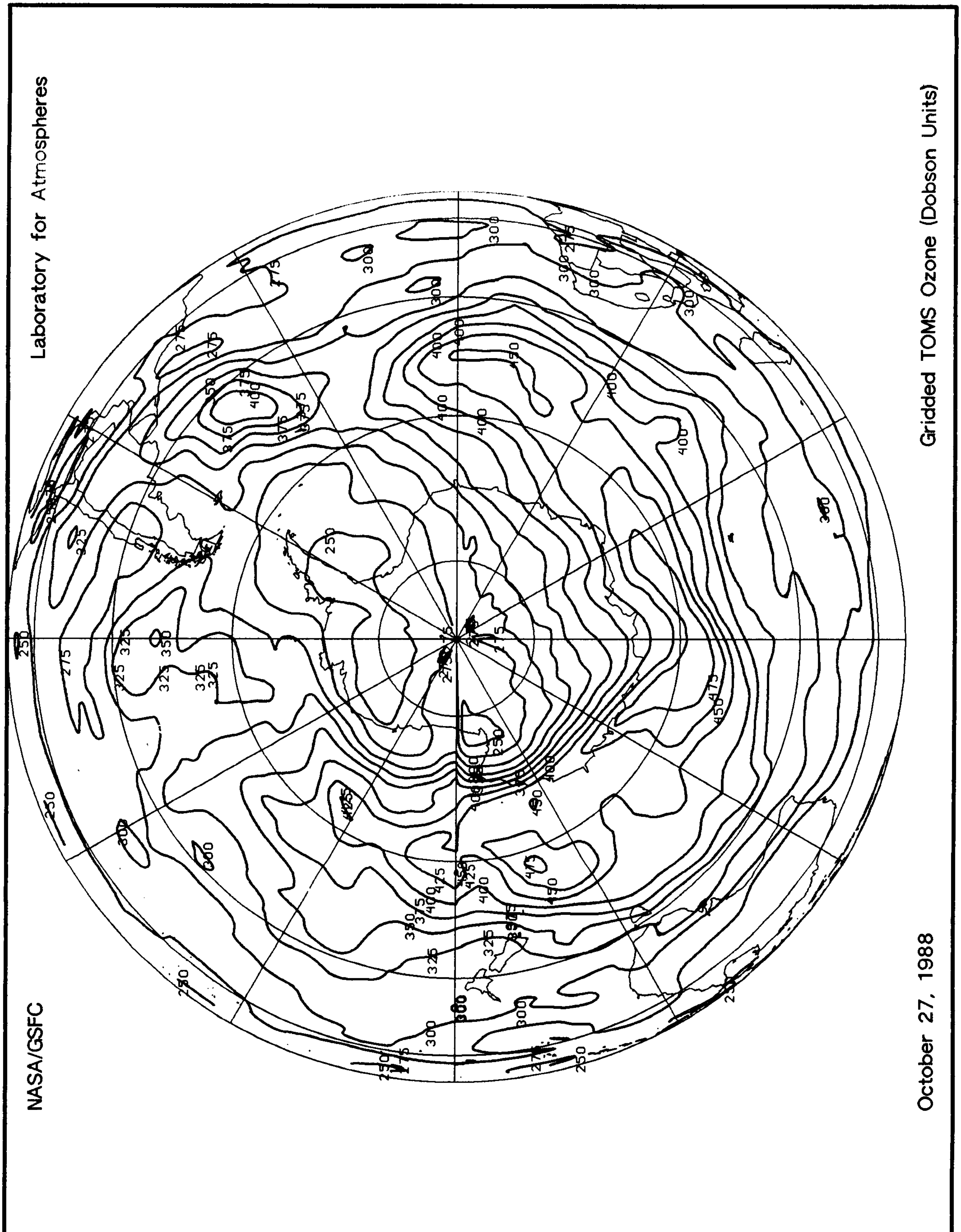

NASA/GSFC
Laboratory for Atmospheres
October 22, 1988
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 23, 1988
Gridded TOMS Ozone (Dobson Units)


Laboratory for Atmospheres
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
October 24, 1988

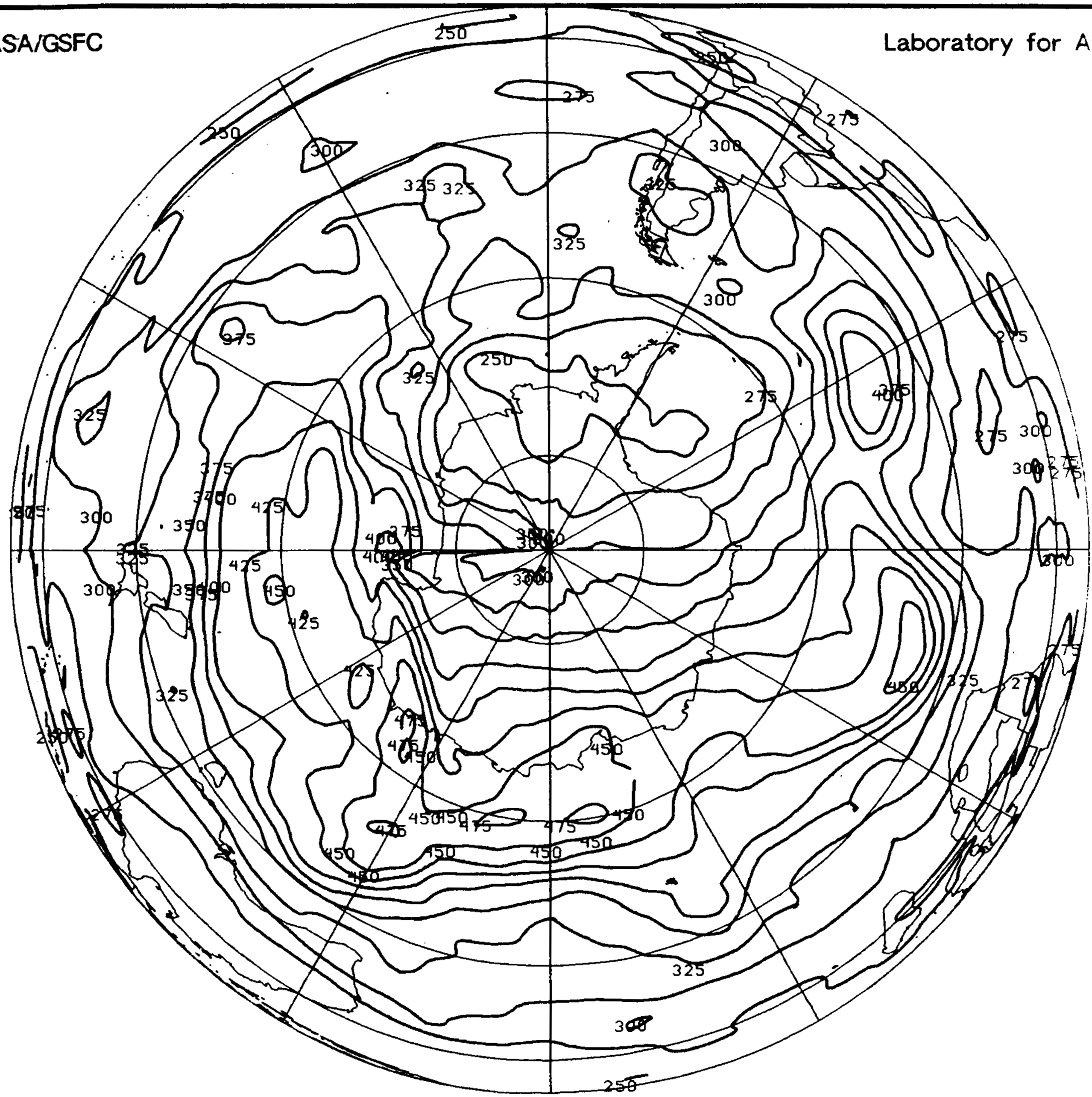

Laboratory for Atmospheres
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
October 25, 1988


Laboratory for Atmospheres
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
October 26, 1988


NASA/GSFC
Laboratory for Atmospheres
October 27, 1988
Gridded TOMS Ozone (Dobson Units)

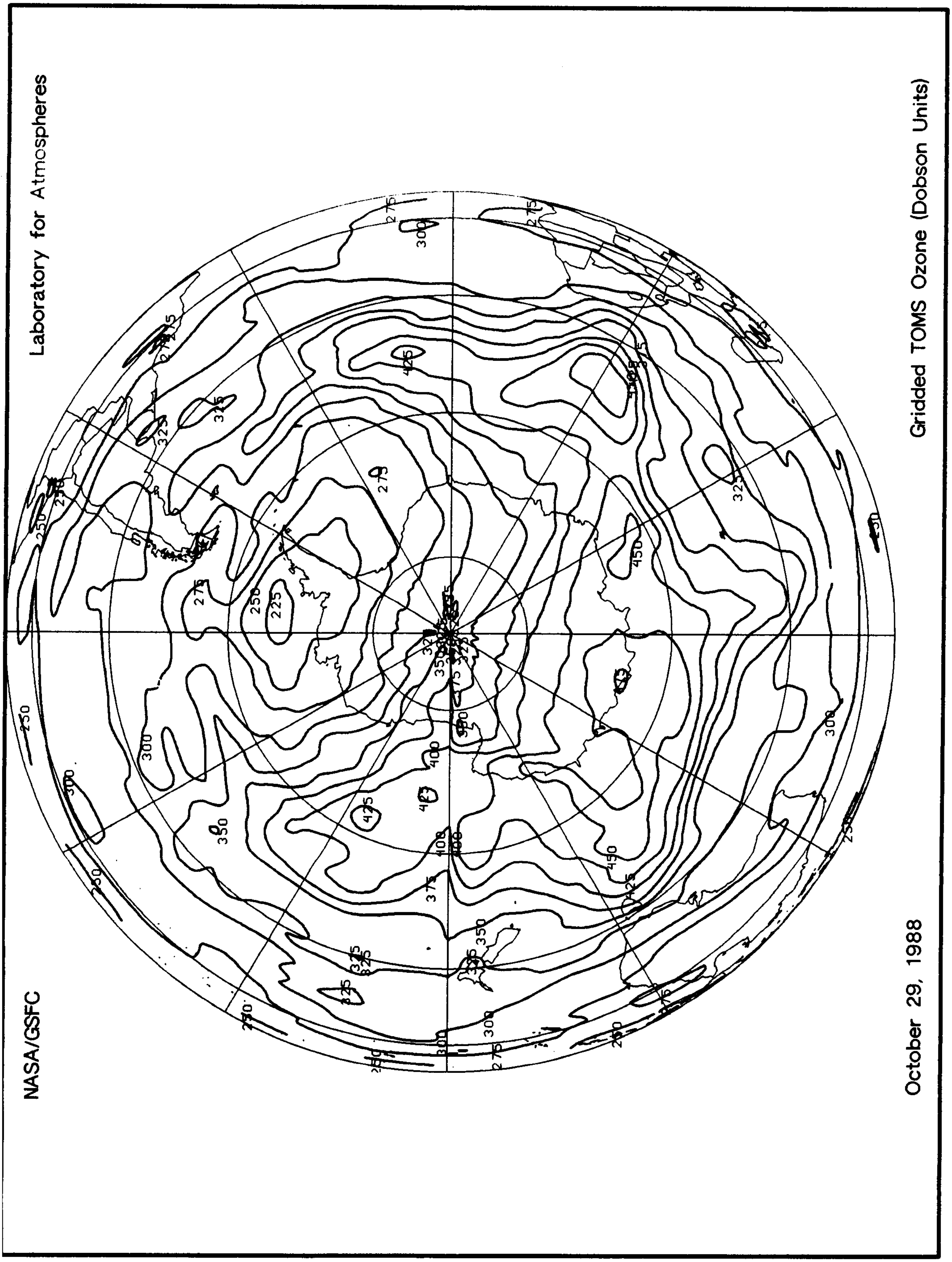
NASA/GSFC

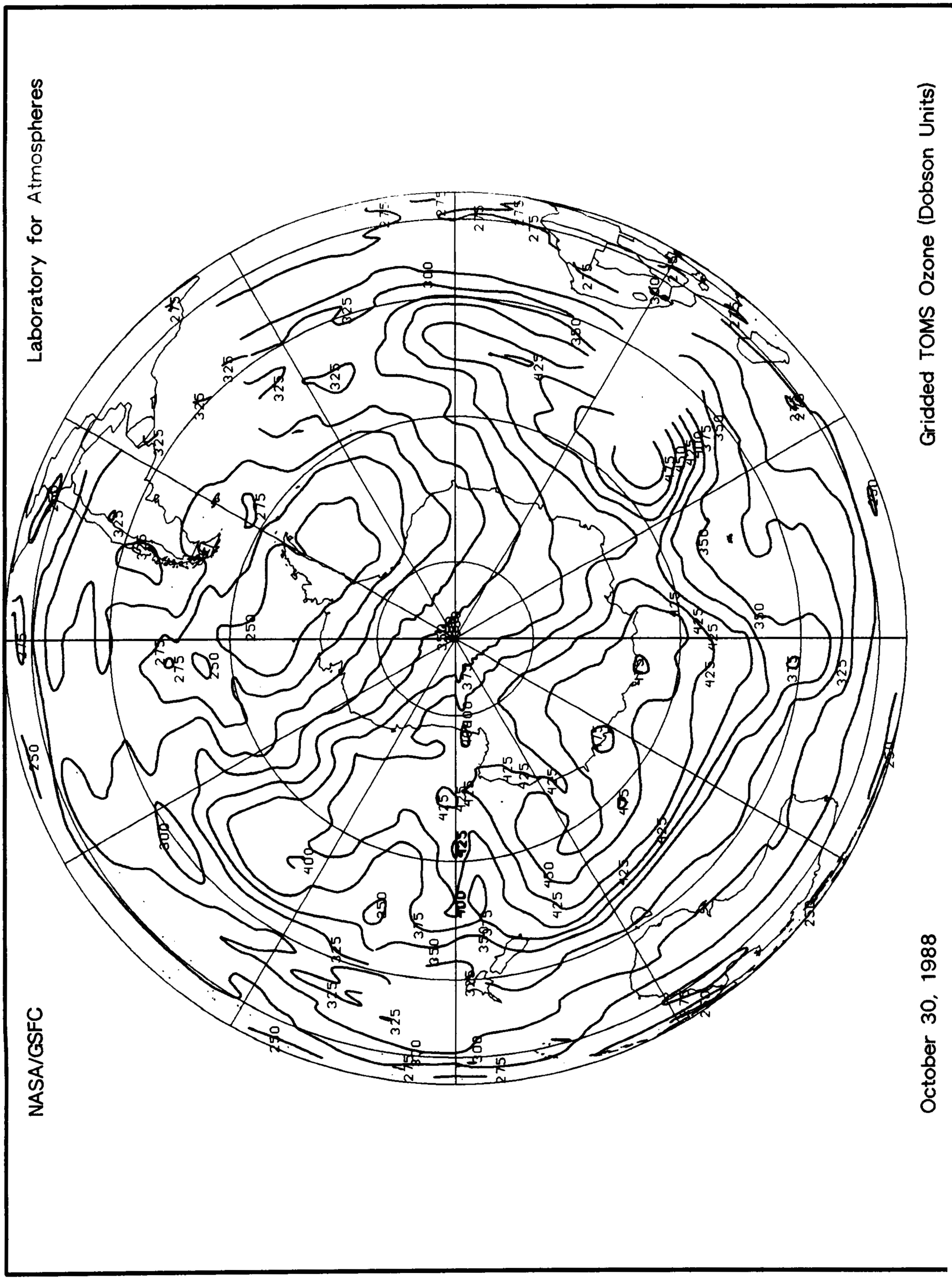
Laboratory for Atmospheres



October 28, 1988

Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
October 29, 1988
Gridded TOMS Ozone (Dobson Units)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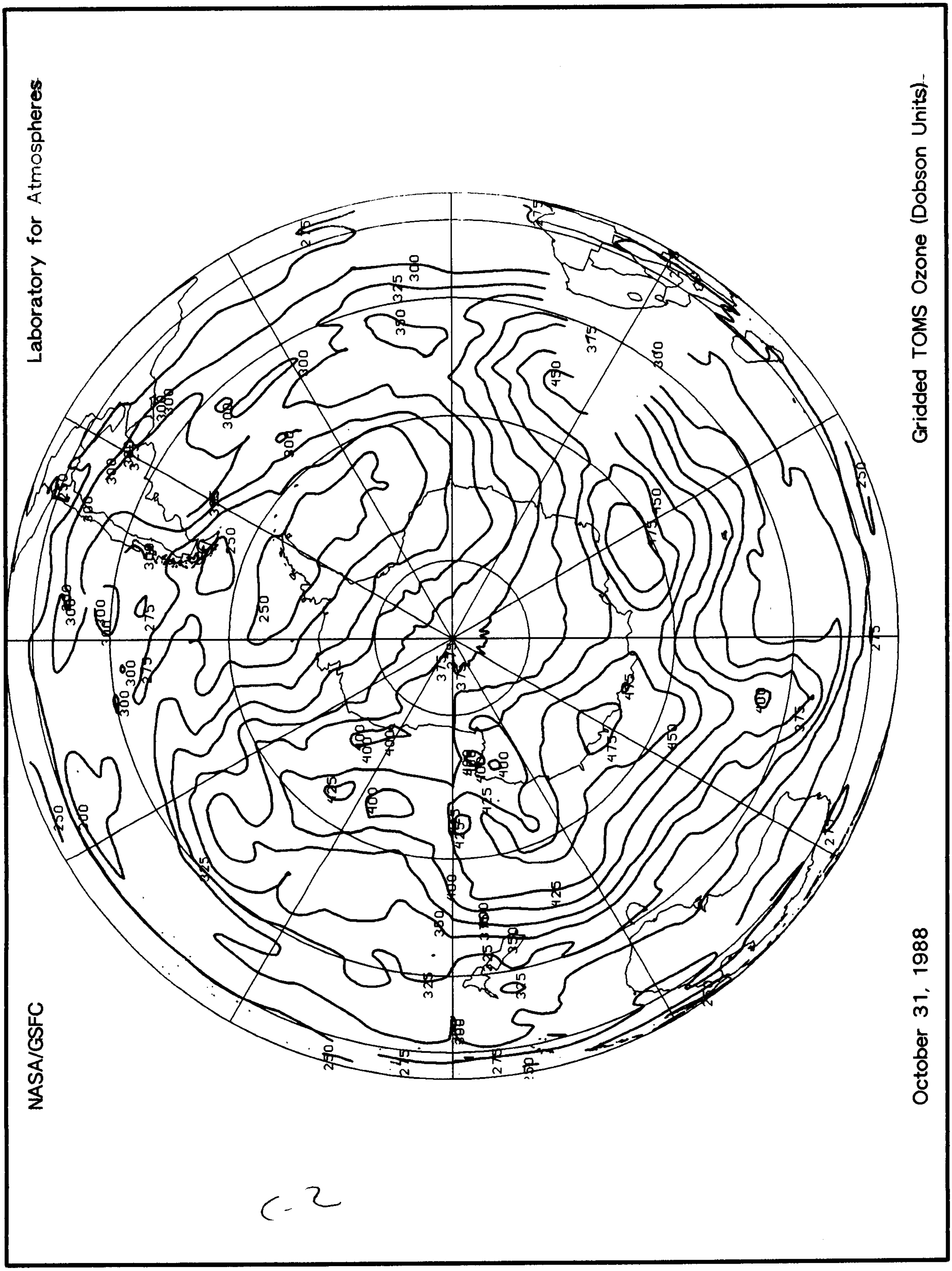
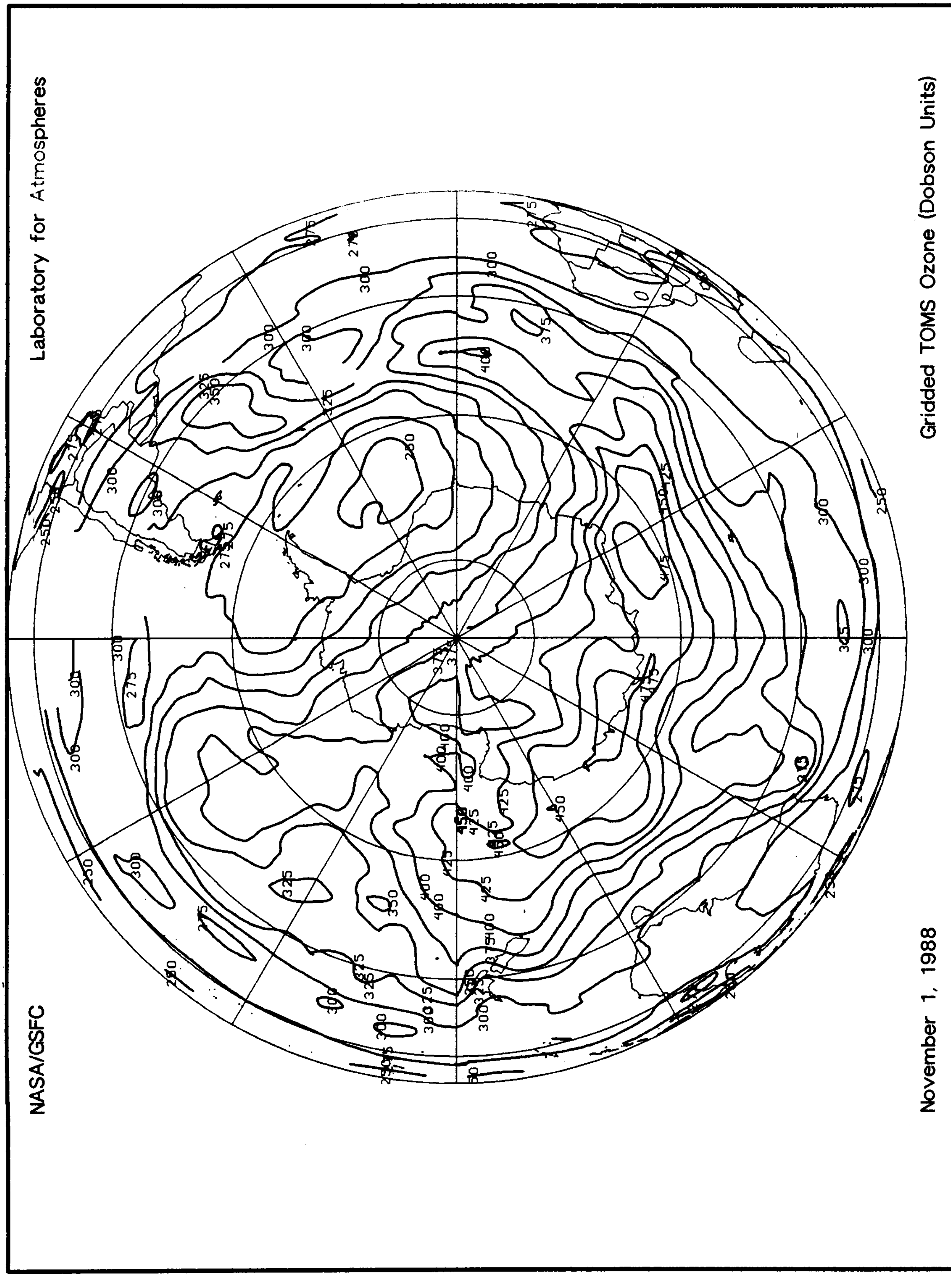
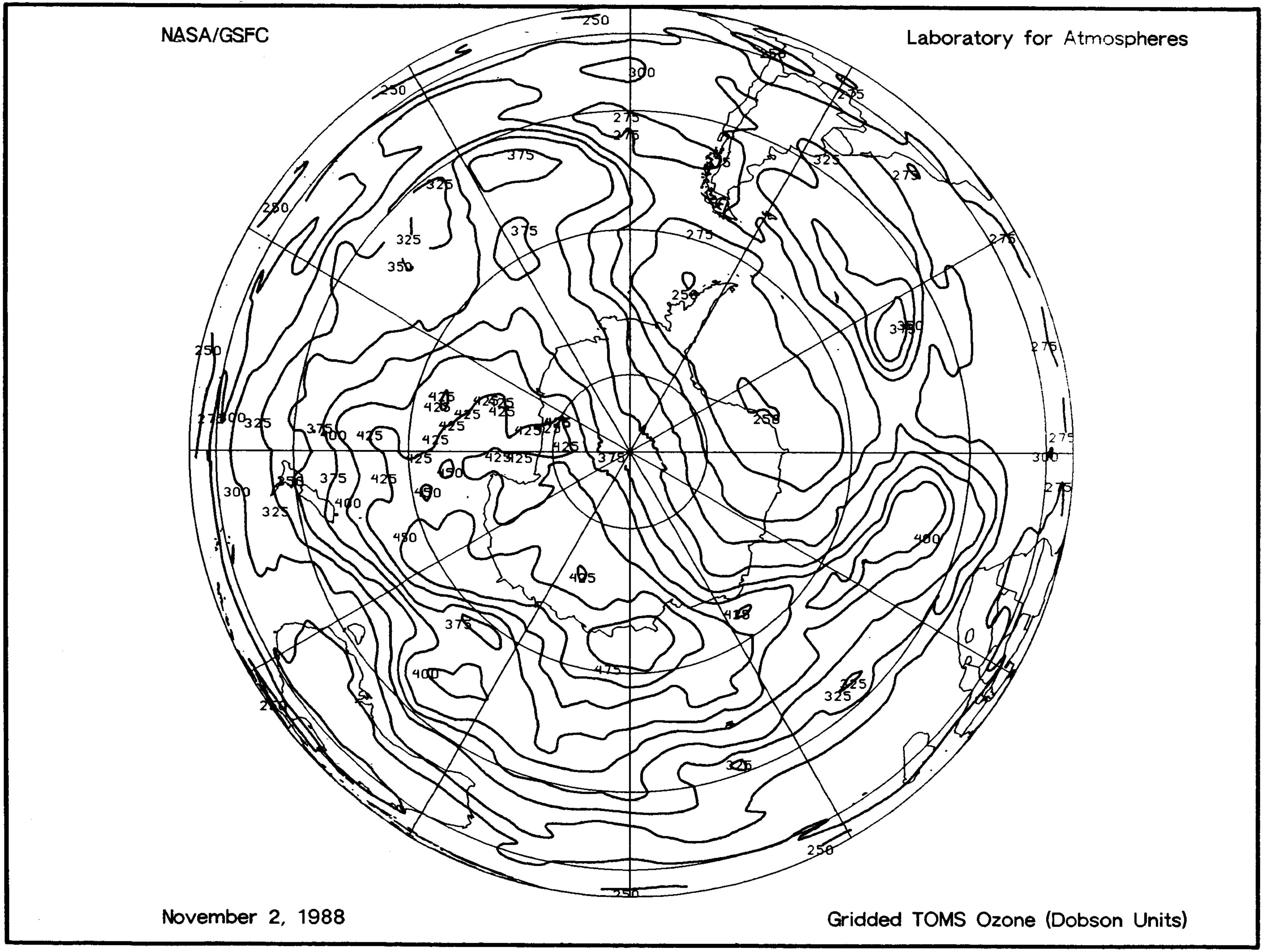
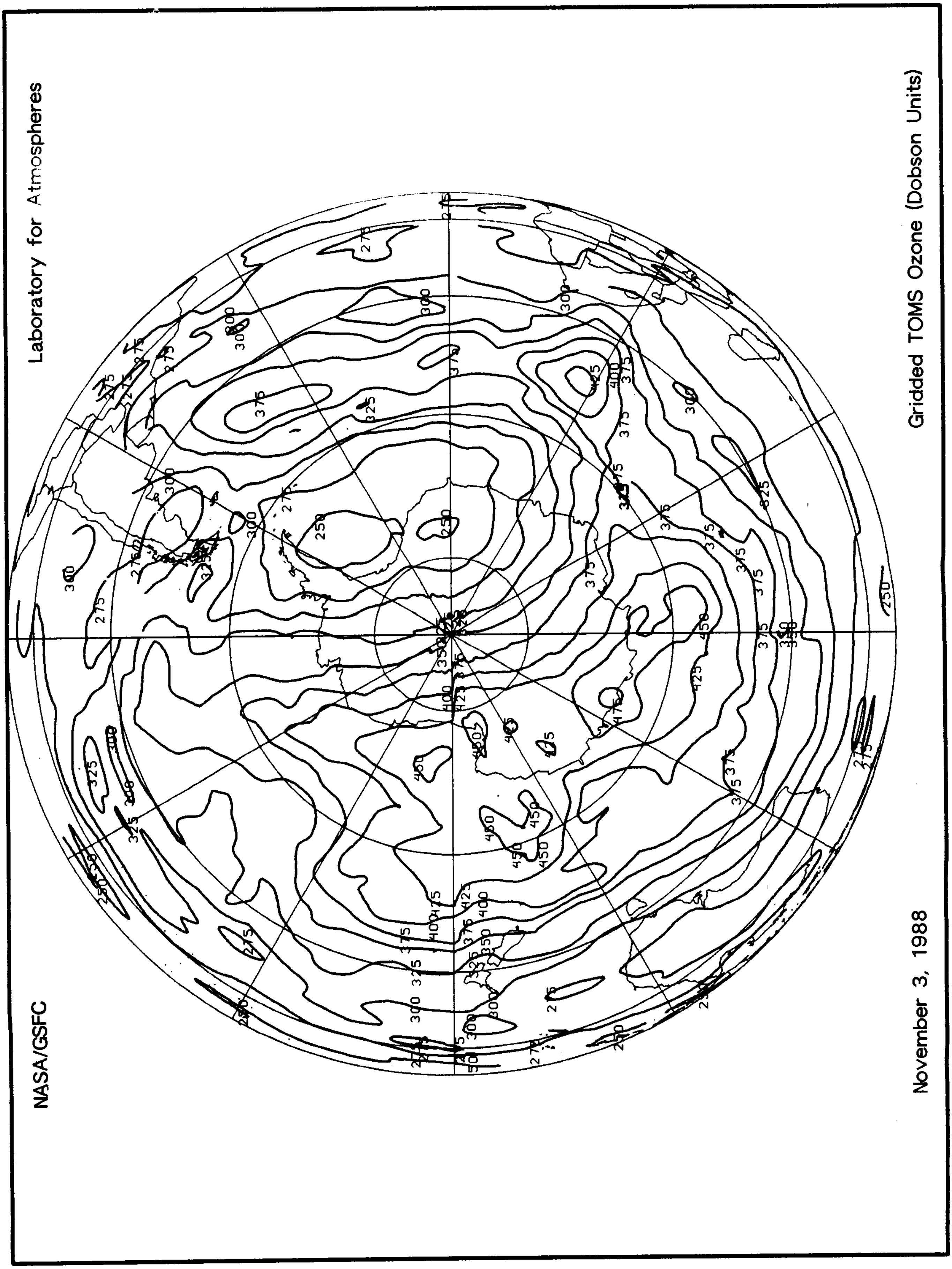
Laboratory for Atmospheres
October 30, 1988
Gridded TOMS Ozone (Dobson Units)


Laboratory for Atmospheres
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
October 31, 1988

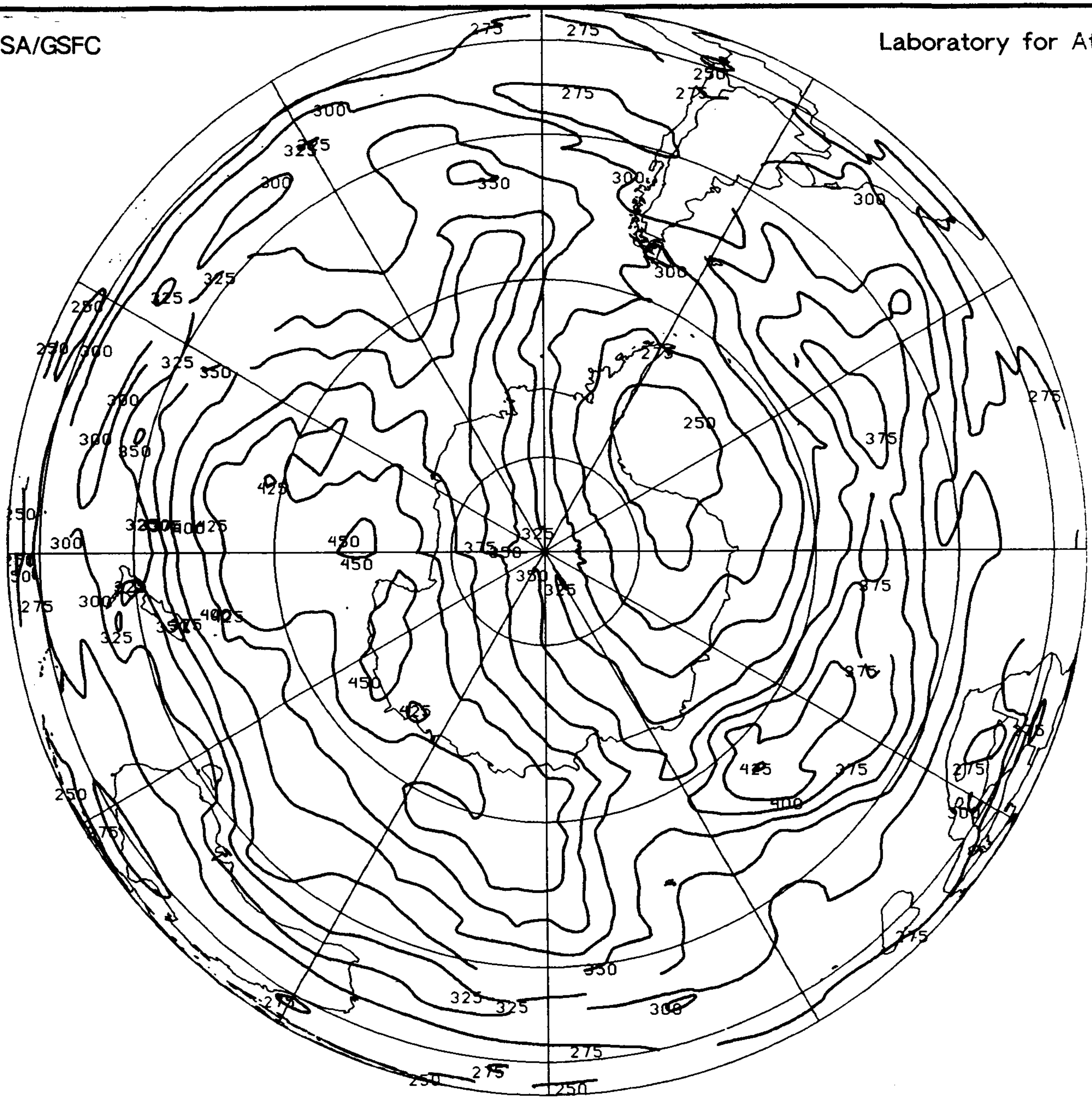

NASA/GSFC
Laboratory for Atmospheres
November 1, 1988
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 2, 1988
Gridded TOMS Ozone (Dobson Units)


Laboratory for Atmospheres
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
November 3, 1988

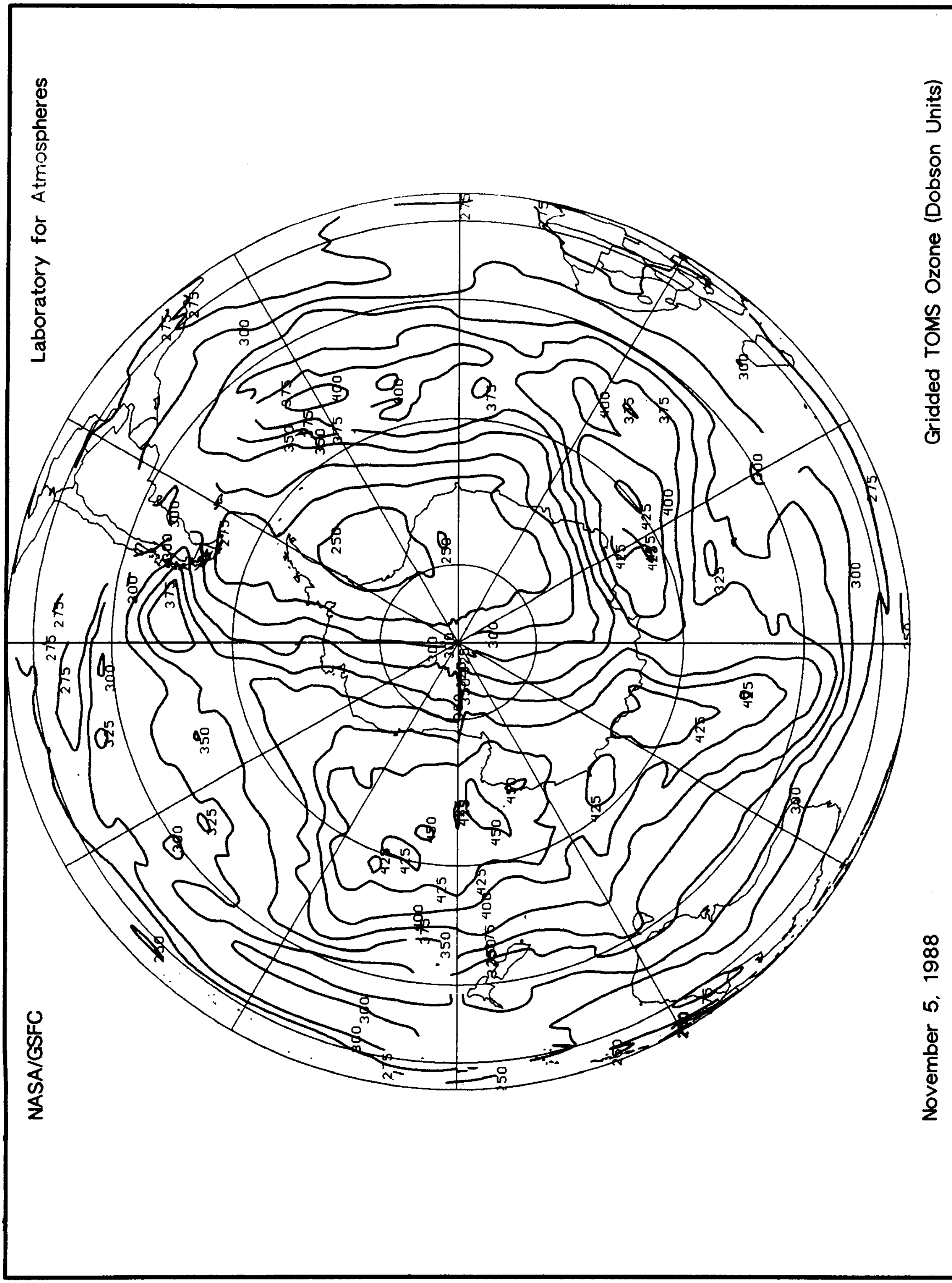
NASA/GSFC

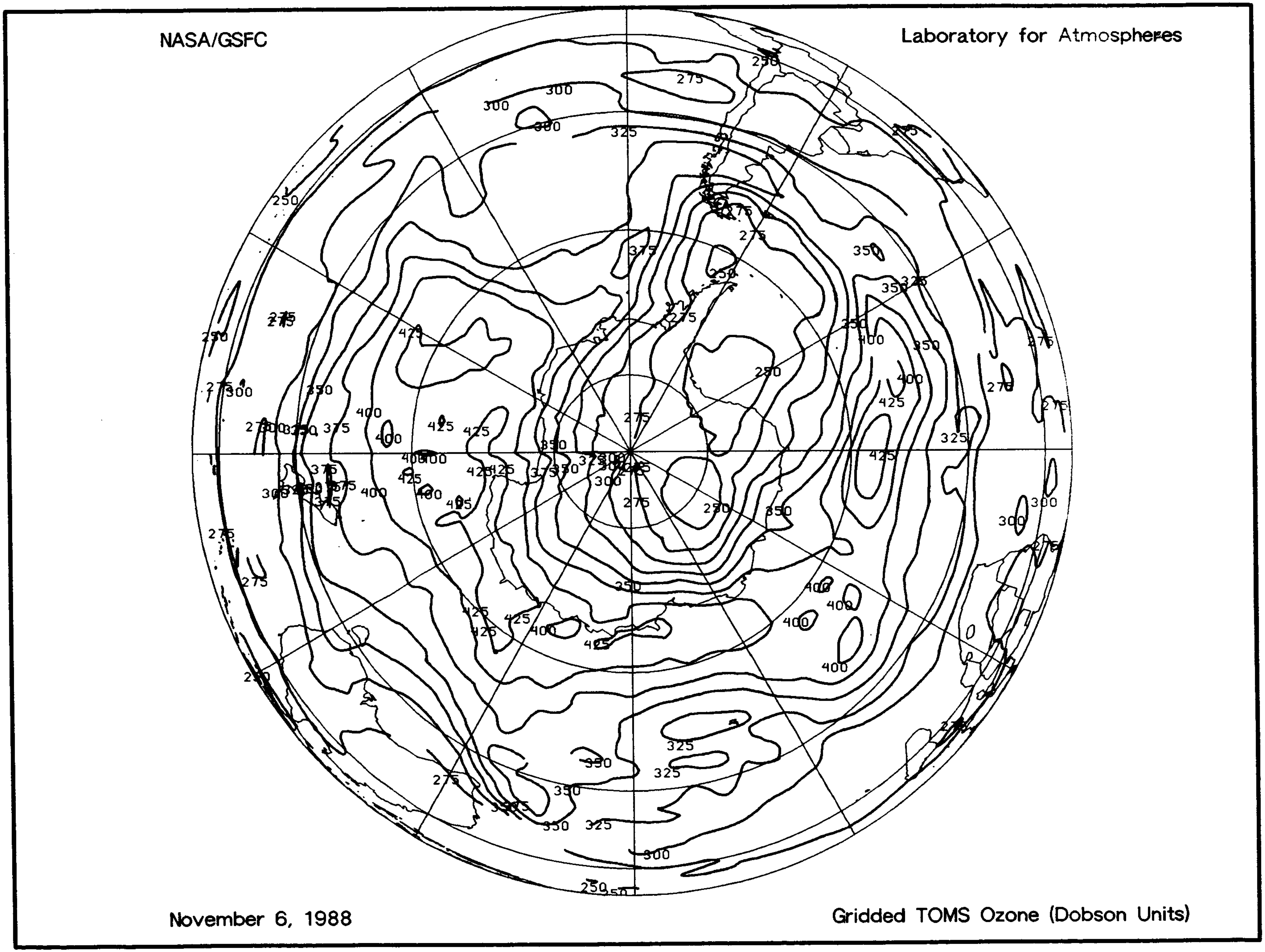
Laboratory for Atmospheres

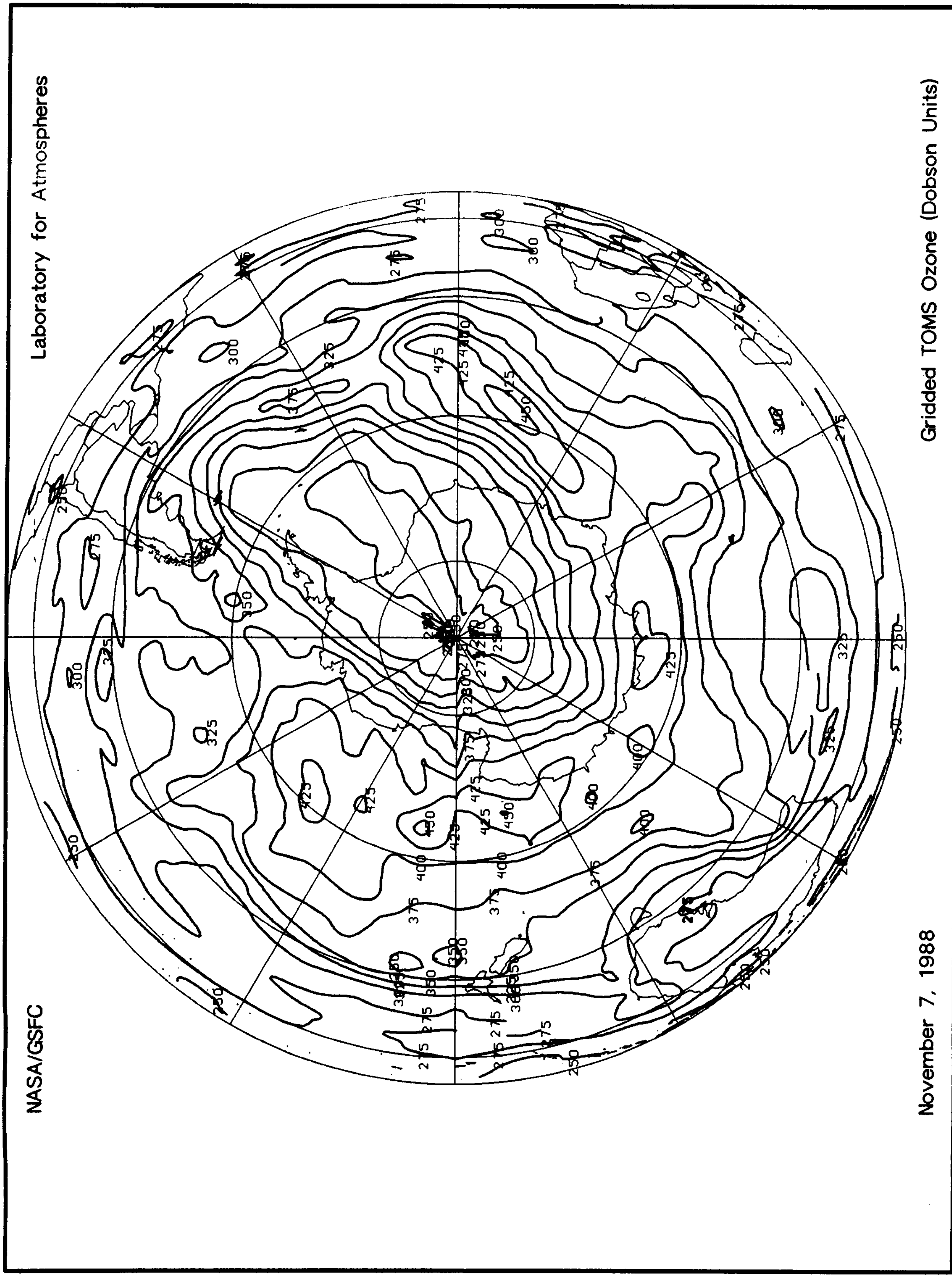


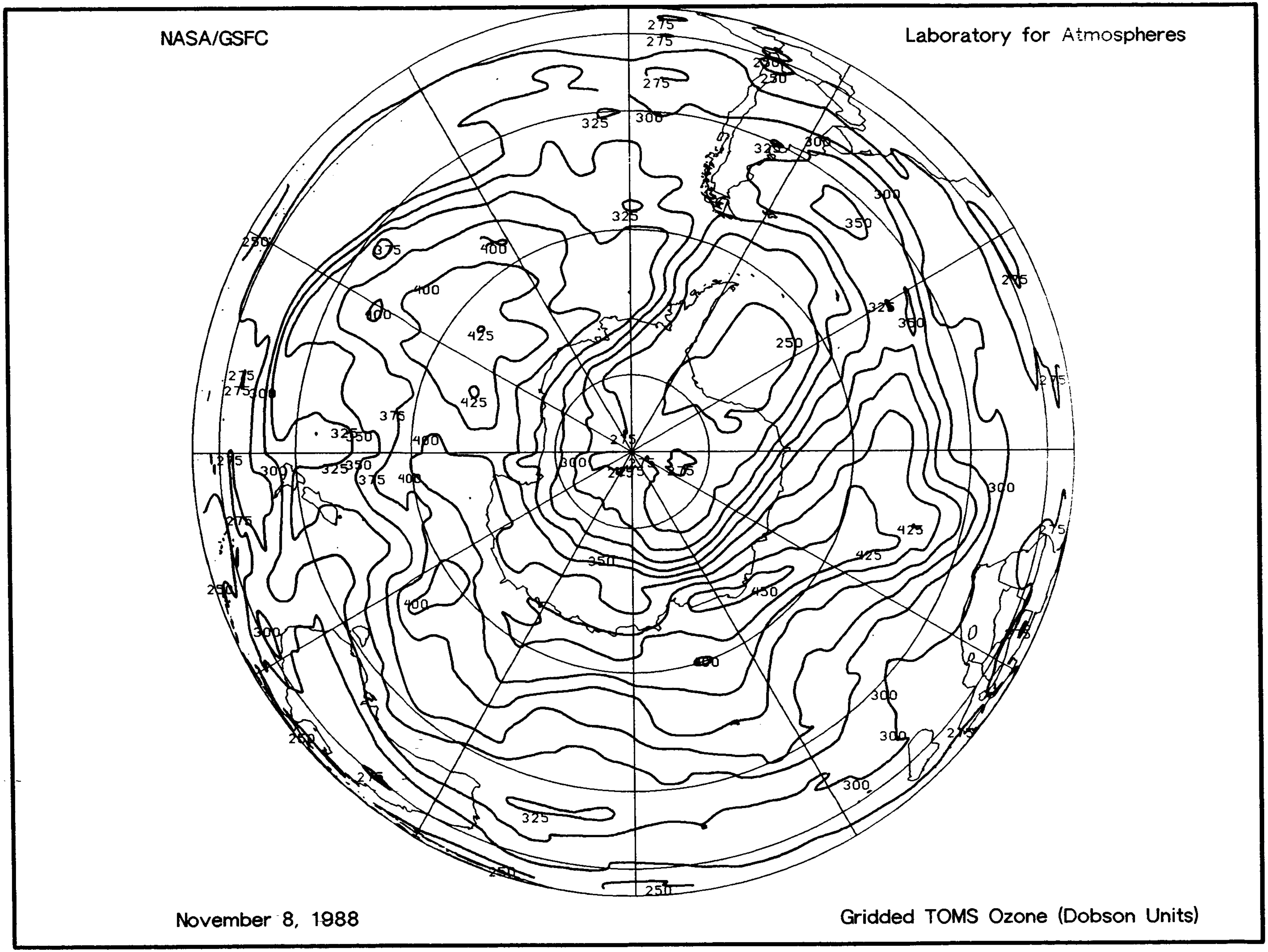
November 4, 1988

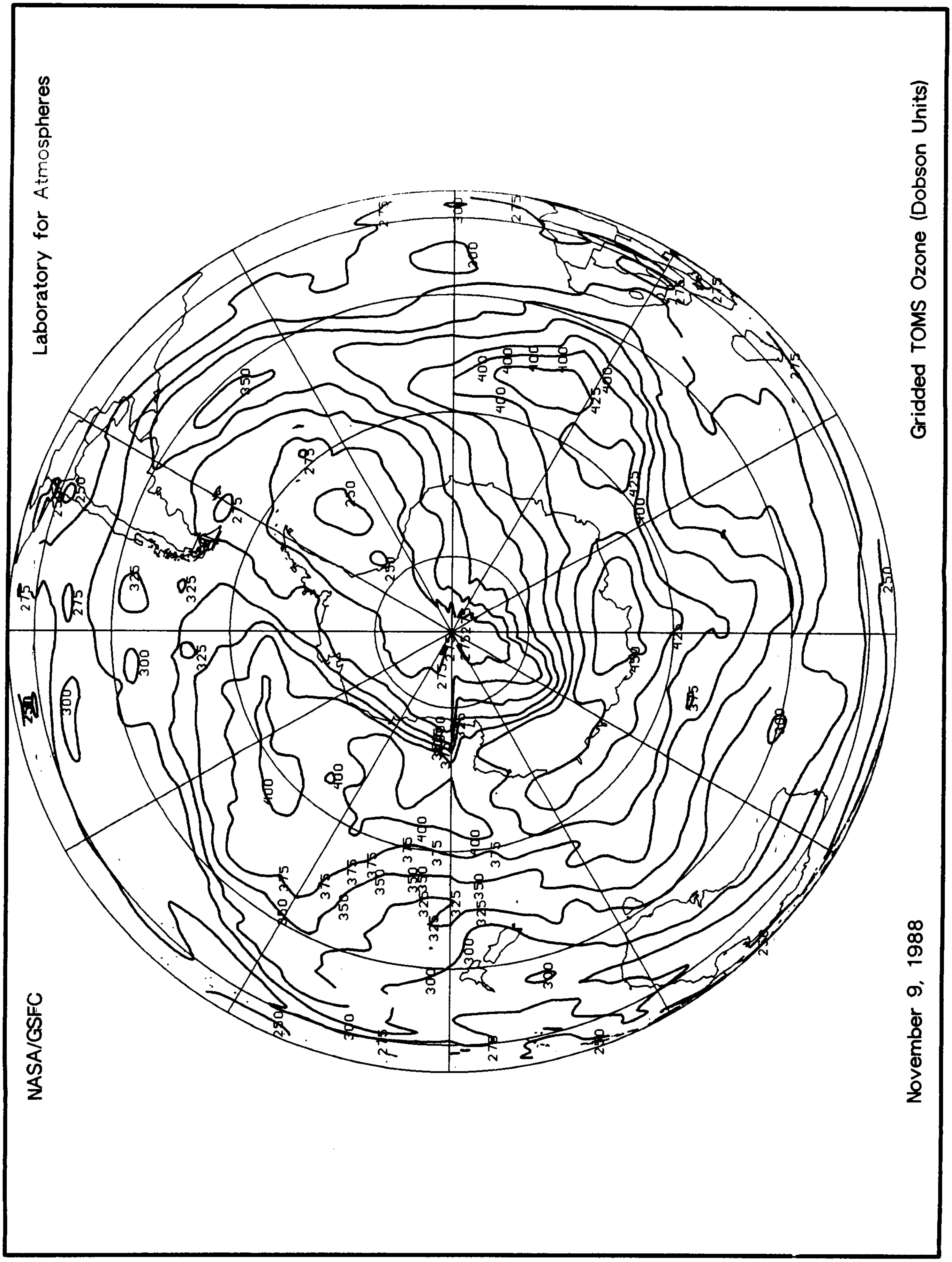
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 5, 1988
Gridded TOMS Ozone (Dobson Units)

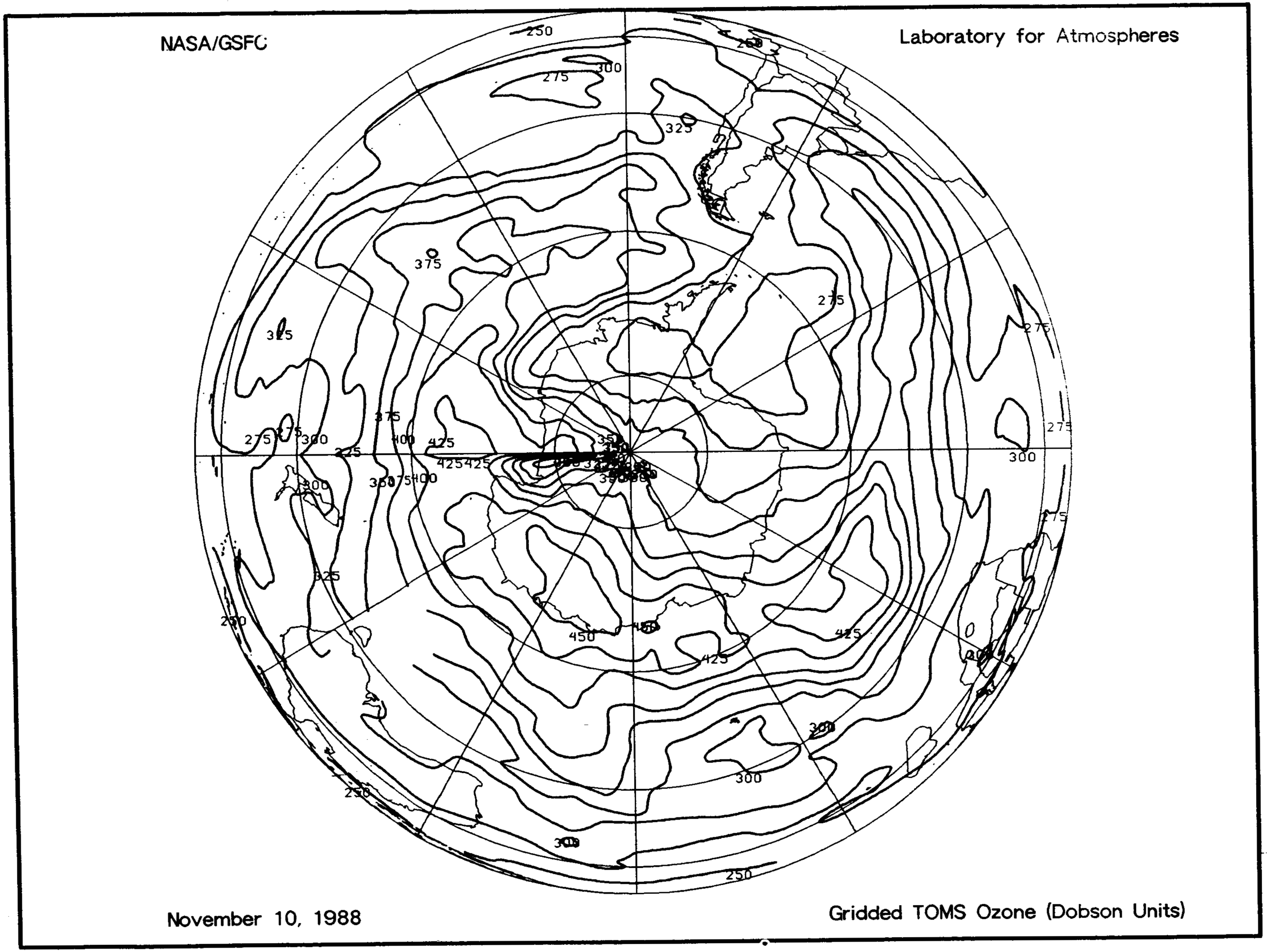

NASA/GSFC
Laboratory for Atmospheres
November 6, 1988
Gridded TOMS Ozone (Dobson Units)

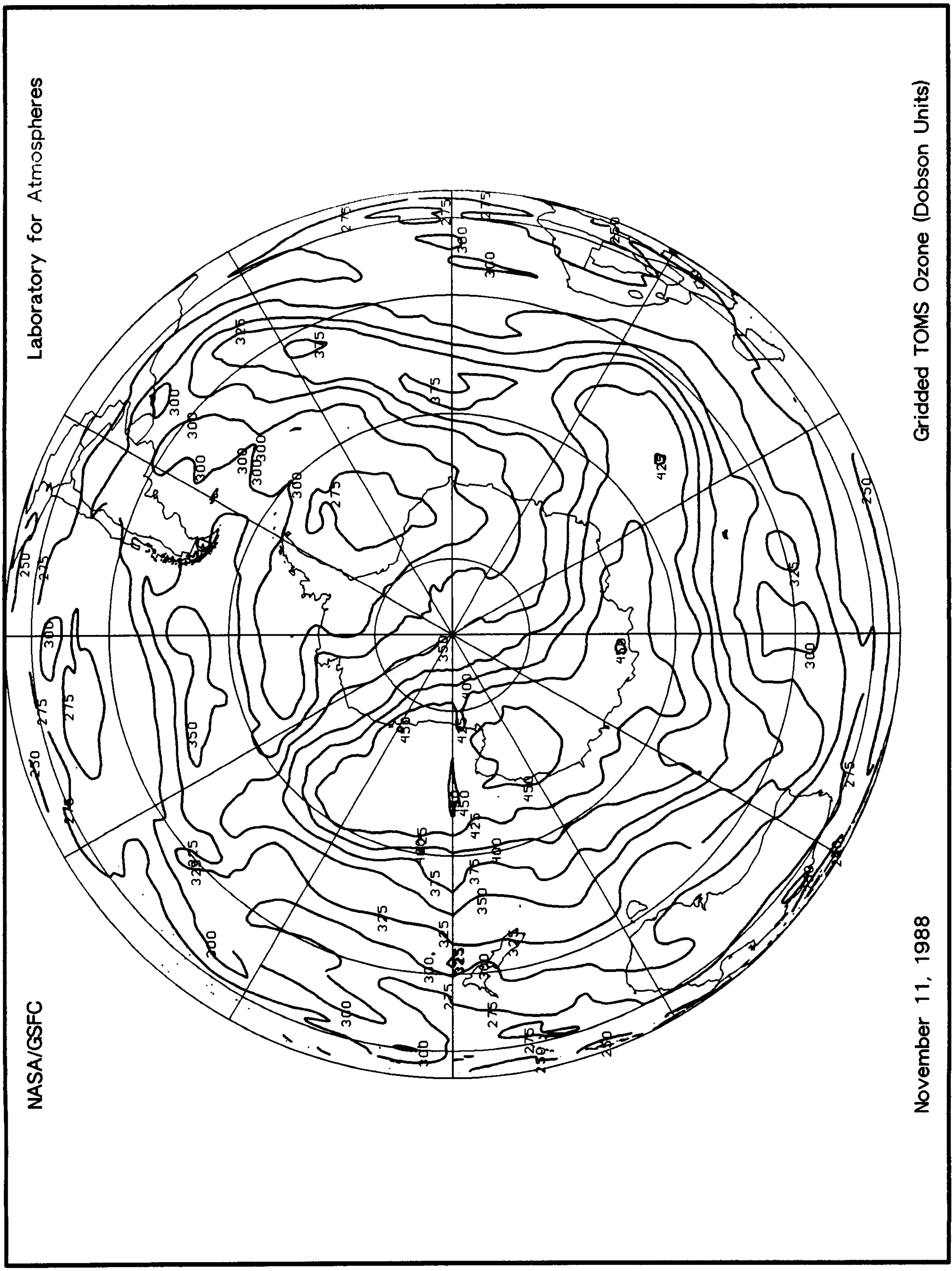

Laboratory for Atmospheres
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
November 7, 1988


NASA/GSFC
Laboratory for Atmospheres
November 8, 1988
Gridded TOMS Ozone (Dobson Units)



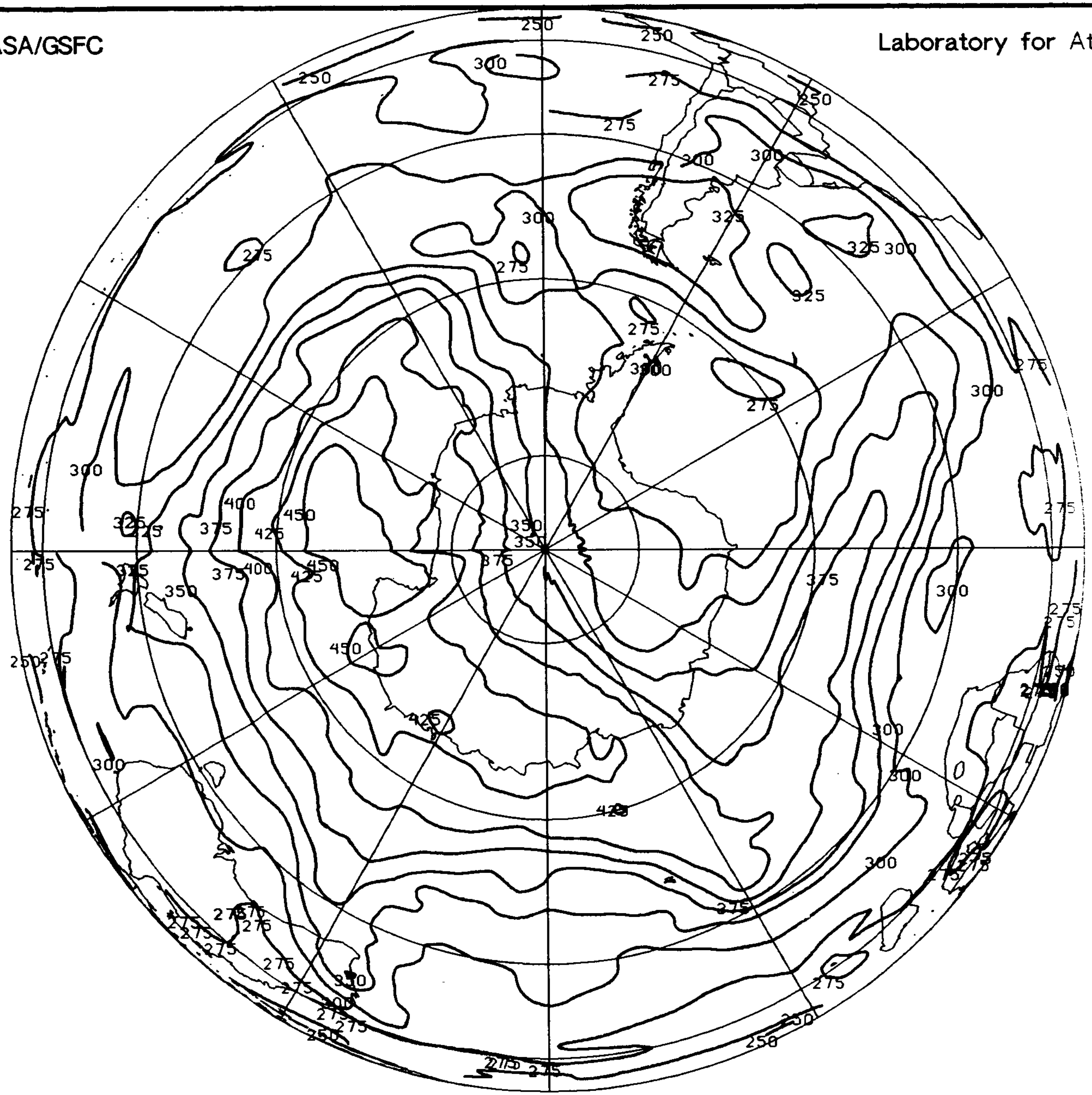
NASA/GSFC
Laboratory for Atmospheres
November 9, 1988
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 10, 1988
Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 11, 1988
Gridded TOMS Ozone (Dobson Units)

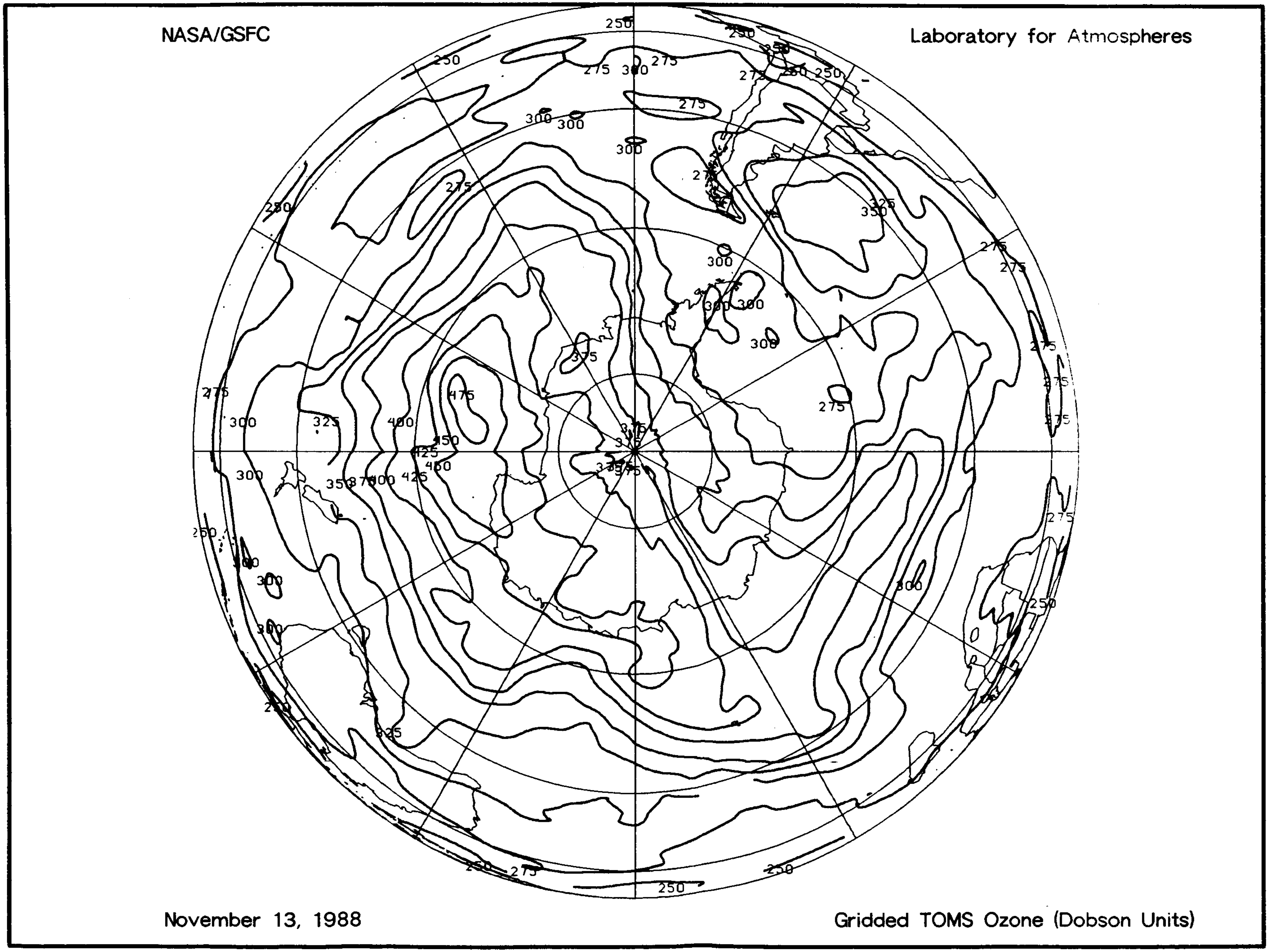
NASA/GSFC

Laboratory for Atmospheres



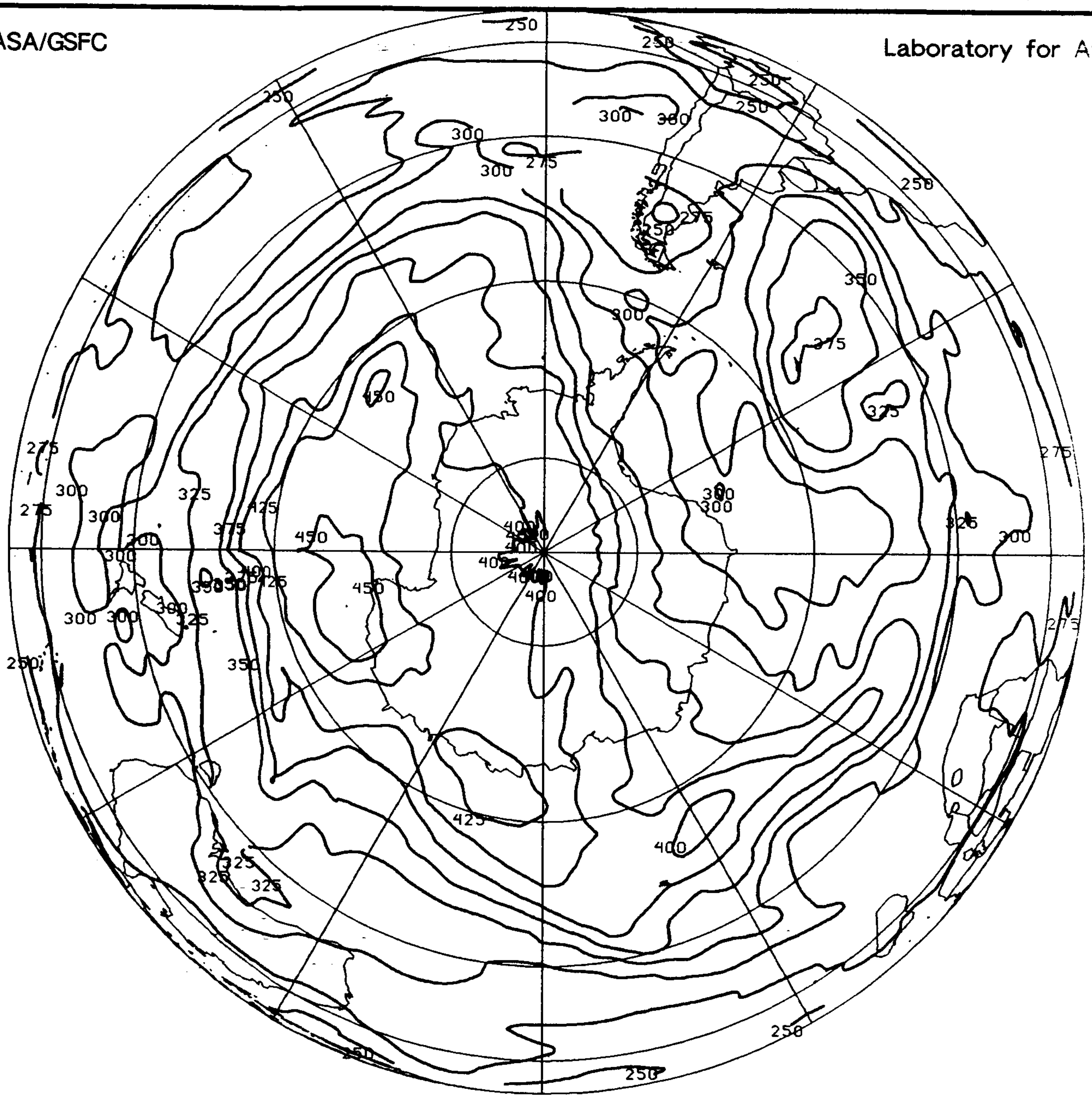
November 12, 1988

Gridded TOMS Ozone (Dobson Units)


NASA/GSFC
Laboratory for Atmospheres
November 13, 1988
Gridded TOMS Ozone (Dobson Units)

NASA/GSFC

Laboratory for Atmospheres

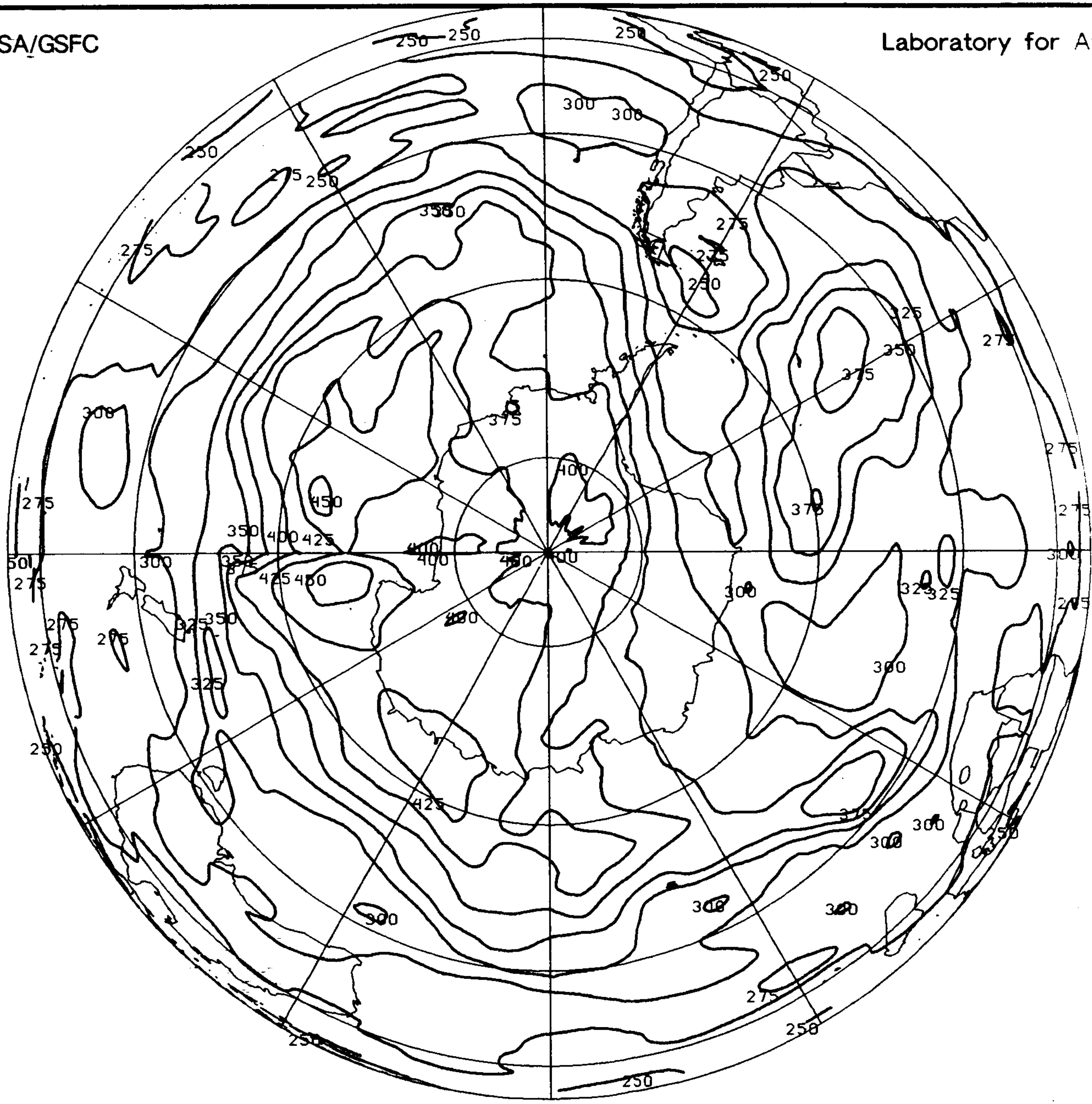


November 14, 1988

Gridded TOMS Ozone (Dobson Units)

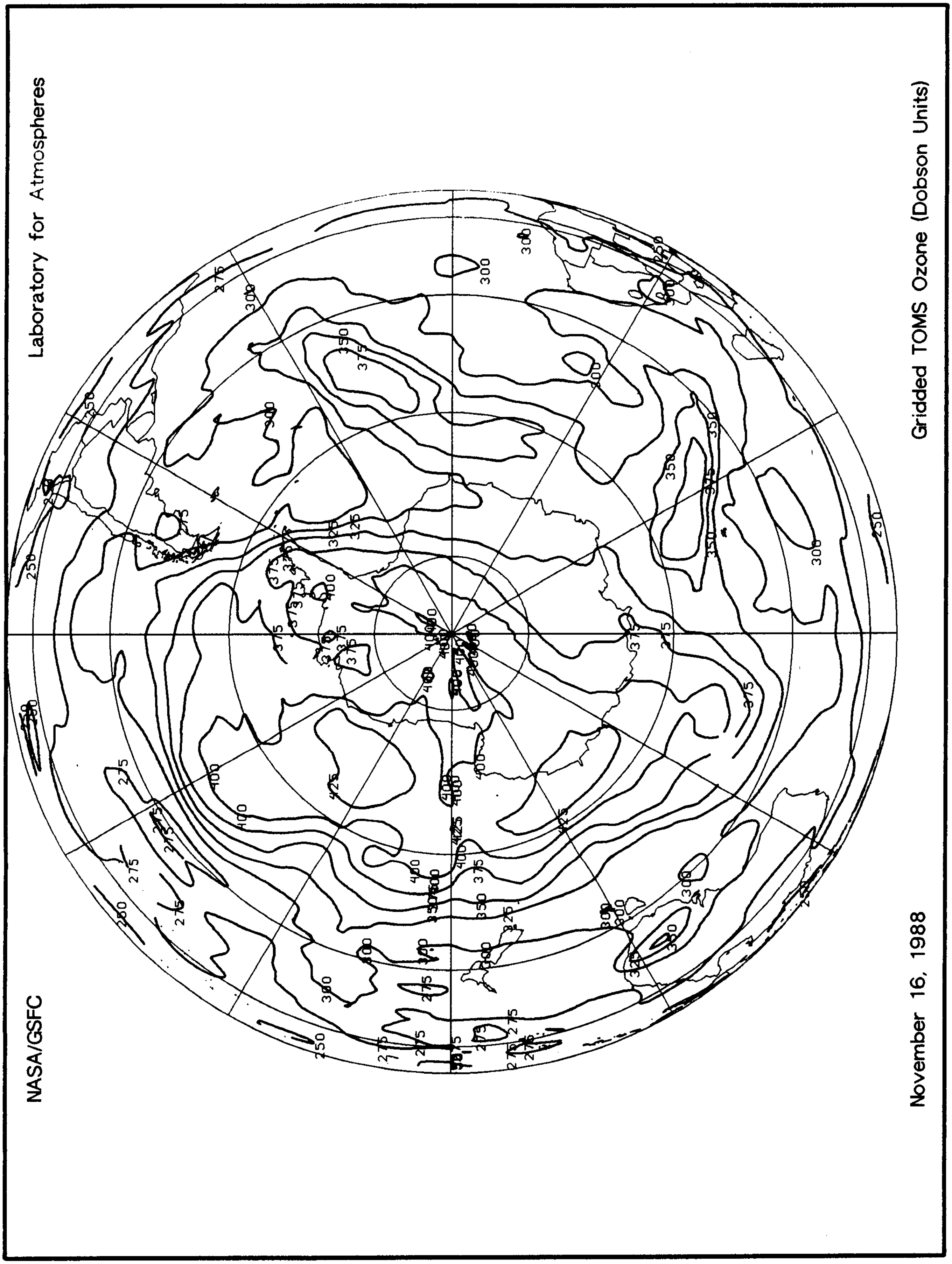
NASA/GSFC

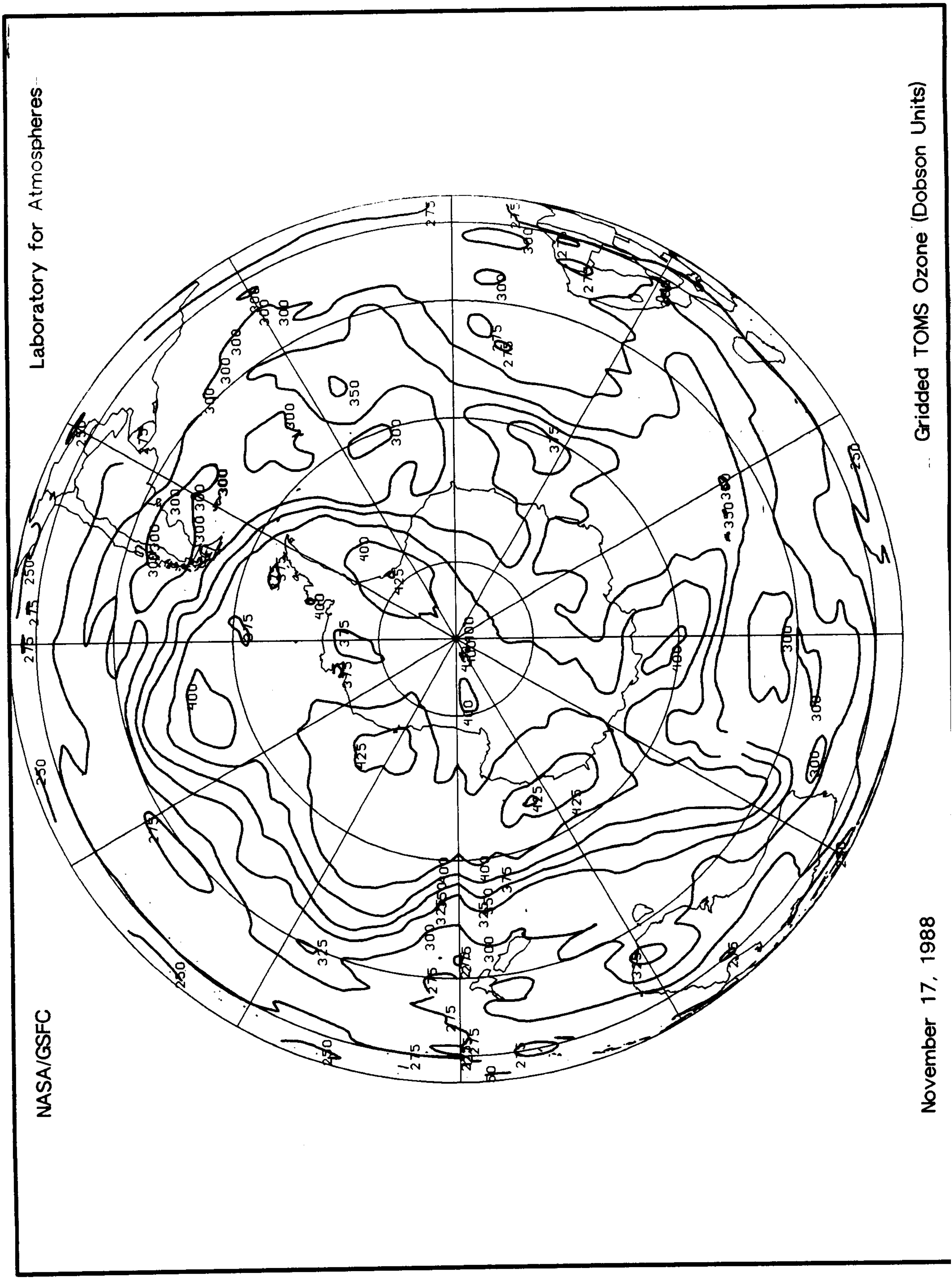
Laboratory for Atmospheres



November 15, 1988

Gridded TOMS Ozone (Dobson Units)


Laboratory for Atmospheres
NASA/GSFC
Gridded TOMS Ozone (Dobson Units)
November 16, 1988


Laboratory for Atmospheres
Gridded TOMS Ozone (Dobson Units)
NASA/GSFC
November 17, 1988

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. A similar time series for the 1987 experiment's base of operations in Punta Arenas was also produced. A list of selected locations, and their coordinates, 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 17, 1988. Note that Palmer Station and Faraday Station, located some 50 km apart, fall within the same grid element and are assigned the same total column ozone values. 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 set to zero.

Table 1

Selected Locations for TOMS Total Ozone Time Series

Location	Abbreviation	Latitude	Longitude
Amundsen-Scott	SPO	90°00'S	00°00'W
B.A. Vice Comodoro Marambio	MAR	64°14'S	56°43'W
Davis	DAV	68°36'S	78°00'E
Dumont D'Urville	DUD	66°42'S	140°00'E
Faraday Station, Argentine Islands	FAR	65°15'S	64°16'W
Halley Bay	HAL	75°30'S	26°39'W
McMurdo	MCM	77°51'S	166°40'E
Molodeznaya	MOL	67°42'S	45°54'E
Palmer Station	PAL	64°46'S	64°04'W
Punta Arenas	PUN	53°02'S	70°51'W
Syowa	SYO	69°00'S	39°36'E
Vostok	VOS	78°30'S	106°54'E

Table 2

Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	MAR	DAV	DUD	FAR	HAL	MCM	MOL	PAL	PUN	SYO	VOS
214	AUG 01	0	276	253	364	274	0	0	240	274	254	247	0
215	AUG 02	0	262	250	379	246	0	0	240	246	231	246	0
216	AUG 03	0	245	254	389	238	0	0	245	238	238	251	0
217	AUG 04	0	242	262	395	237	0	0	229	237	309	237	0
218	AUG 05	0	252	256	339	251	0	0	246	251	276	244	0
219	AUG 06	0	241	257	337	242	0	0	261	242	287	261	0
220	AUG 07	0	205	262	318	198	0	0	268	198	259	273	0
221	AUG 08	0	208	276	309	221	0	0	285	221	247	288	0
222	AUG 09	0	227	304	289	234	0	0	308	234	276	304	0
223	AUG 10	0	224	343	263	230	0	0	317	230	303	303	0
224	AUG 11	0	255	361	305	256	0	0	323	256	326	303	0
225	AUG 12	0	245	363	372	247	0	0	306	247	262	300	0
226	AUG 13	0	242	359	394	243	0	0	302	243	300	291	0
227	AUG 14	0	268	379	397	286	0	0	291	286	323	272	0
228	AUG 15	0	288	362	413	278	0	0	279	278	295	272	0
229	AUG 16	0	258	363	402	254	0	0	286	254	287	283	0
230	AUG 17	0	272	330	397	260	0	0	284	260	274	268	0
231	AUG 18	0	271	304	408	257	0	0	274	257	292	246	0
232	AUG 19	0	246	289	437	242	237	0	256	242	315	258	0
233	AUG 20	0	226	284	413	219	250	0	265	219	323	259	0
234	AUG 21	0	241	269	376	240	243	0	251	240	305	238	0
235	AUG 22	0	254	256	348	259	249	0	223	259	305	224	0
236	AUG 23	0	255	264	302	245	250	0	258	245	331	281	0
237	AUG 24	0	225	268	282	224	247	0	295	224	311	306	0
238	AUG 25	0	232	274	288	228	224	0	301	228	276	305	0
239	AUG 26	0	245	285	265	241	233	252	296	241	264	309	237
240	AUG 27	0	258	272	281	251	248	251	312	251	283	348	231
241	AUG 28	0	245	298	283	246	262	241	405	246	304	436	235
242	AUG 29	0	256	344	265	236	259	242	455	236	274	461	258
243	AUG 30	0	210	422	211	205	241	237	475	205	260	483	272
244	AUG 31	0	218	473	296	232	237	250	491	232	248	481	295
245	SEP 01	0	267	492	336	259	236	252	447	259	288	435	309
246	SEP 02	0	229	413	383	246	235	229	433	246	293	427	305
247	SEP 03	0	250	400	384	272	224	242	404	272	313	363	293
248	SEP 04	0	298	372	370	298	235	235	324	298	319	305	264
249	SEP 05	0	294	358	340	302	240	220	296	302	302	280	245
250	SEP 06	0	298	302	347	297	241	231	279	297	307	278	228
251	SEP 07	0	275	274	314	285	236	198	284	285	373	292	211
252	SEP 08	0	278	283	313	283	225	198	294	283	334	290	226
253	SEP 09	0	247	294	319	262	233	195	300	262	298	306	238
254	SEP 10	0	217	308	342	232	229	198	312	232	302	321	237
255	SEP 11	0	233	333	307	233	233	236	362	233	272	366	235
256	SEP 12	0	238	374	289	226	223	234	389	226	278	390	257
257	SEP 13	0	219	406	327	220	213	232	387	220	272	373	276
258	SEP 14	0	234	409	412	233	218	238	354	233	288	340	305
259	SEP 15	0	259	394	408	259	222	263	334	259	315	311	299
260	SEP 16	0	287	363	440	285	192	255	287	285	316	285	271
261	SEP 17	0	291	327	441	278	187	263	279	278	319	269	273

Table 2 (continued)

Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	MAR	DAV	DUD	FAR	HAL	MCM	MOL	PAL	PUN	SYO	VOS
262	SEP 18	0	249	306	431	242	199	270	252	242	329	243	255
263	SEP 19	0	245	272	380	233	194	271	252	233	332	243	236
264	SEP 20	0	229	300	373	220	207	248	305	220	306	297	210
265	SEP 21	0	240	387	364	242	213	226	338	242	282	316	213
266	SEP 22	0	239	414	350	235	199	210	333	235	321	307	261
267	SEP 23	0	209	431	432	207	197	229	330	207	303	305	281
268	SEP 24	0	207	429	477	217	188	261	351	217	325	321	303
269	SEP 25	0	225	459	431	221	193	292	386	221	293	357	331
270	SEP 26	216	213	486	497	211	203	301	373	211	297	315	352
271	SEP 27	233	217	474	489	207	197	294	341	207	280	314	365
272	SEP 28	232	198	431	440	197	188	302	344	197	261	344	334
273	SEP 29	215	209	457	445	202	195	284	433	202	257	416	302
274	SEP 30	208	239	488	433	250	207	265	466	250	264	440	280
275	OCT 01	220	278	463	427	274	207	214	427	274	291	402	330
276	OCT 02	225	290	466	432	294	210	251	408	294	316	367	330
277	OCT 03	218	292	442	446	286	226	274	361	286	378	329	346
278	OCT 04	216	306	416	450	280	204	283	322	280	329	285	334
279	OCT 05	208	267	440	450	239	192	300	278	239	373	260	312
280	OCT 06	203	242	380	436	222	206	282	234	222	301	229	286
281	OCT 07	197	221	322	432	212	201	263	279	212	309	281	247
282	OCT 08	195	215	314	401	210	200	271	266	210	304	276	273
283	OCT 09	200	226	282	461	216	193	331	273	216	294	289	279
284	OCT 10	196	213	265	446	205	200	338	303	205	278	342	242
285	OCT 11	183	208	310	439	209	191	324	346	209	276	341	225
286	OCT 12	199	222	367	418	223	198	270	337	223	259	311	277
287	OCT 13	213	219	366	450	214	204	304	299	214	323	280	307
288	OCT 14	229	207	351	462	195	209	313	340	195	296	322	292
289	OCT 15	242	208	390	481	216	208	308	317	216	265	296	308
290	OCT 16	239	218	370	482	211	207	332	292	211	283	274	305
291	OCT 17	218	233	362	489	225	210	341	292	225	287	264	291
292	OCT 18	213	234	417	481	222	191	333	292	222	319	258	306
293	OCT 19	231	210	419	458	201	211	330	287	201	310	260	361
294	OCT 20	246	234	380	452	228	213	386	286	228	256	262	382
295	OCT 21	240	212	347	421	204	206	404	287	204	235	273	343
296	OCT 22	239	219	329	440	213	225	397	308	213	242	299	313
297	OCT 23	230	229	360	433	216	228	388	337	216	257	337	269
298	OCT 24	222	228	392	465	216	238	325	385	216	226	367	256
299	OCT 25	220	241	425	441	235	260	279	336	235	239	351	245
300	OCT 26	237	260	395	448	248	252	256	390	248	263	394	246
301	OCT 27	270	262	425	438	257	258	240	413	257	305	408	314
302	OCT 28	299	262	457	458	257	271	316	429	257	316	404	370
303	OCT 29	329	270	439	431	260	276	362	400	260	306	372	409
304	OCT 30	358	250	429	460	240	272	420	385	240	311	378	424
305	OCT 31	365	249	429	465	240	285	427	418	240	261	384	399
306	NOV 01	373	266	445	475	252	282	394	404	252	299	360	427
307	NOV 02	367	262	451	463	254	261	421	352	254	279	332	427
308	NOV 03	345	258	405	441	255	255	454	348	255	308	311	398
309	NOV 04	333	275	375	440	271	241	431	315	271	313	306	374

Table 2 (continued)

Time Series of Daily Total Ozone Values (DU)

DAY	DATE	SPO	MAR	DAV	DUD	FAR	HAL	MCM	MOL	PAL	PUN	SYO	VOS
310	NOV 05	302	267	385	423	265	243	414	351	265	325	318	338
311	NOV 06	280	264	410	438	249	235	377	371	249	327	357	325
312	NOV 07	257	264	403	414	288	230	361	398	288	346	390	294
313	NOV 08	266	261	433	413	260	244	343	434	260	315	415	325
314	NOV 09	274	266	466	427	284	265	354	413	284	317	398	314
315	NOV 10	331	288	440	438	299	281	320	384	299	305	365	418
316	NOV 11	348	299	433	439	296	279	437	377	296	325	350	397
317	NOV 12	347	289	419	440	284	287	444	358	284	335	347	407
318	NOV 13	370	298	407	428	294	296	419	363	294	261	348	417
319	NOV 14	397	303	383	422	292	316	412	350	292	253	341	407
320	NOV 15	397	289	368	435	299	334	413	339	299	294	339	403
321	NOV 16	400	330	356	447	365	357	397	339	365	317	342	394
322	NOV 17	396	378	347	433	376	395	392	351	376	304	351	381
323	NOV 18	381	387	330	393	382	406	396	360	382	326	360	371
324	NOV 19	375	404	343	400	393	408	377	346	393	357	338	357
325	NOV 20	359	395	350	378	396	401	376	327	396	317	323	334
326	NOV 21	360	371	332	388	354	381	366	327	354	360	330	341
327	NOV 22	356	384	346	377	383	367	366	318	383	341	314	341
328	NOV 23	347	373	359	390	358	361	365	313	358	354	343	327
329	NOV 24	343	365	342	367	352	371	360	339	352	354	347	356
330	NOV 25	346	361	334	379	357	366	361	337	357	387	369	354
331	NOV 26	342	367	310	388	349	372	373	367	349	326	384	348
332	NOV 27	337	358	329	382	359	375	357	383	359	323	393	347
333	NOV 28	354	371	343	390	368	373	369	388	368	331	393	332
334	NOV 29	351	357	340	385	363	373	380	371	363	319	382	338
335	NOV 30	347	366	340	386	368	374	388	378	368	328	374	346

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 270) shortly after the autumnal equinox (Figure 1a). Total ozone values between 183 DU and 246 DU continue through October 26 (day 300), as the station is on the boundary of the hole. Thereafter, the hole moves away from the pole and, except for a brief return on November 7 through 9, remains well away from the pole for the remainder of the period.

B.A. Vice Comodoro Marambio (MA)

The Marambio station is located at 64°S, just off the tip of the Antarctic Peninsula. The total ozone amounts at Marambio (Figure 1b) remains below 306 DU until November 16 (day 301), after which values remain continuously above 350 DU. Minimum values of 205 DU (August 7) and 210 DU (August 30) were caused by the passage of short-lived "mini-holes" across the peninsula. The station's absolute minimum, 198 DU on September 28 (day 272), was caused by the mature ozone hole.

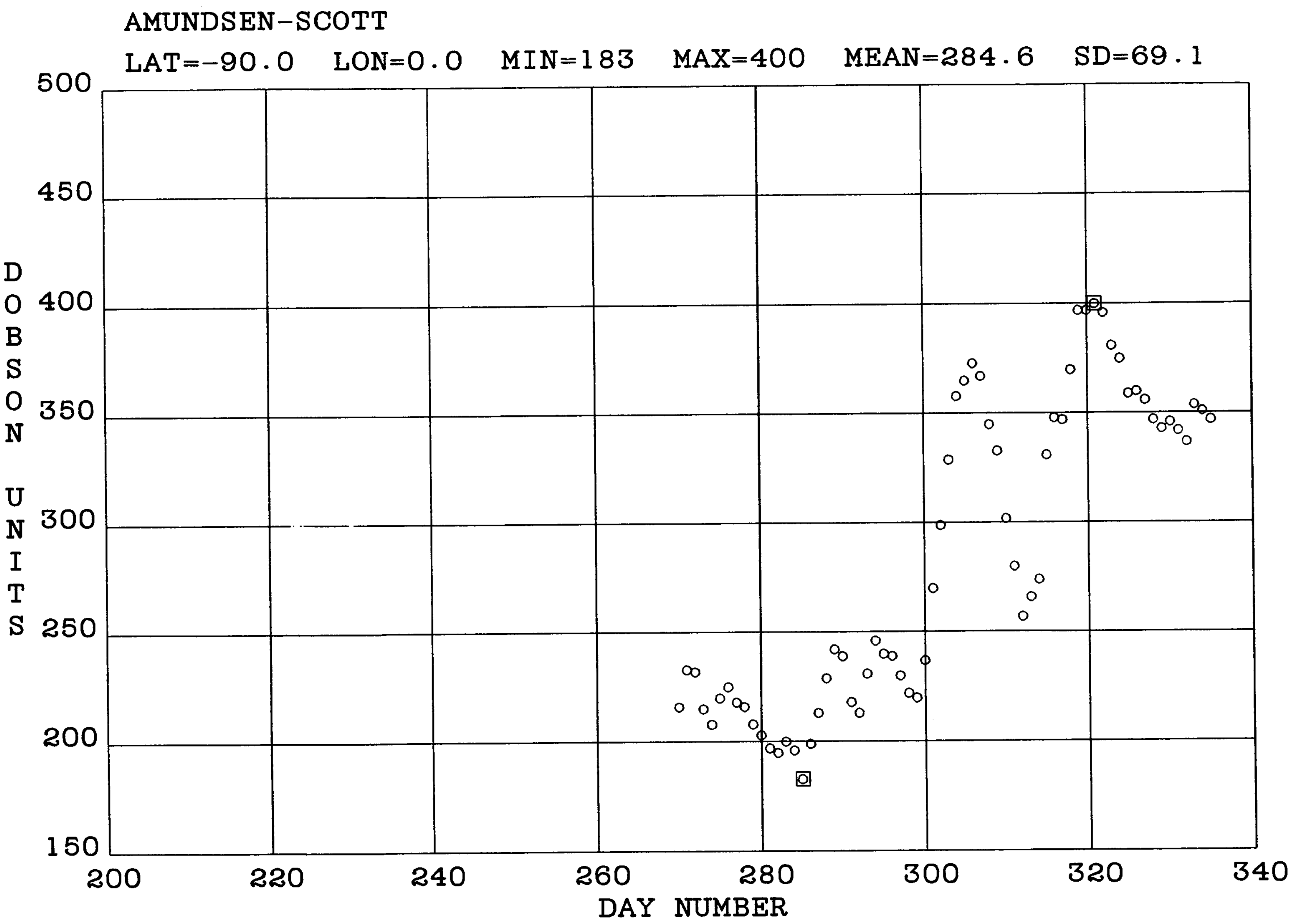


Figure 1a. Daily TOMS Total Ozone Values over Amundsen-Scott (DU).

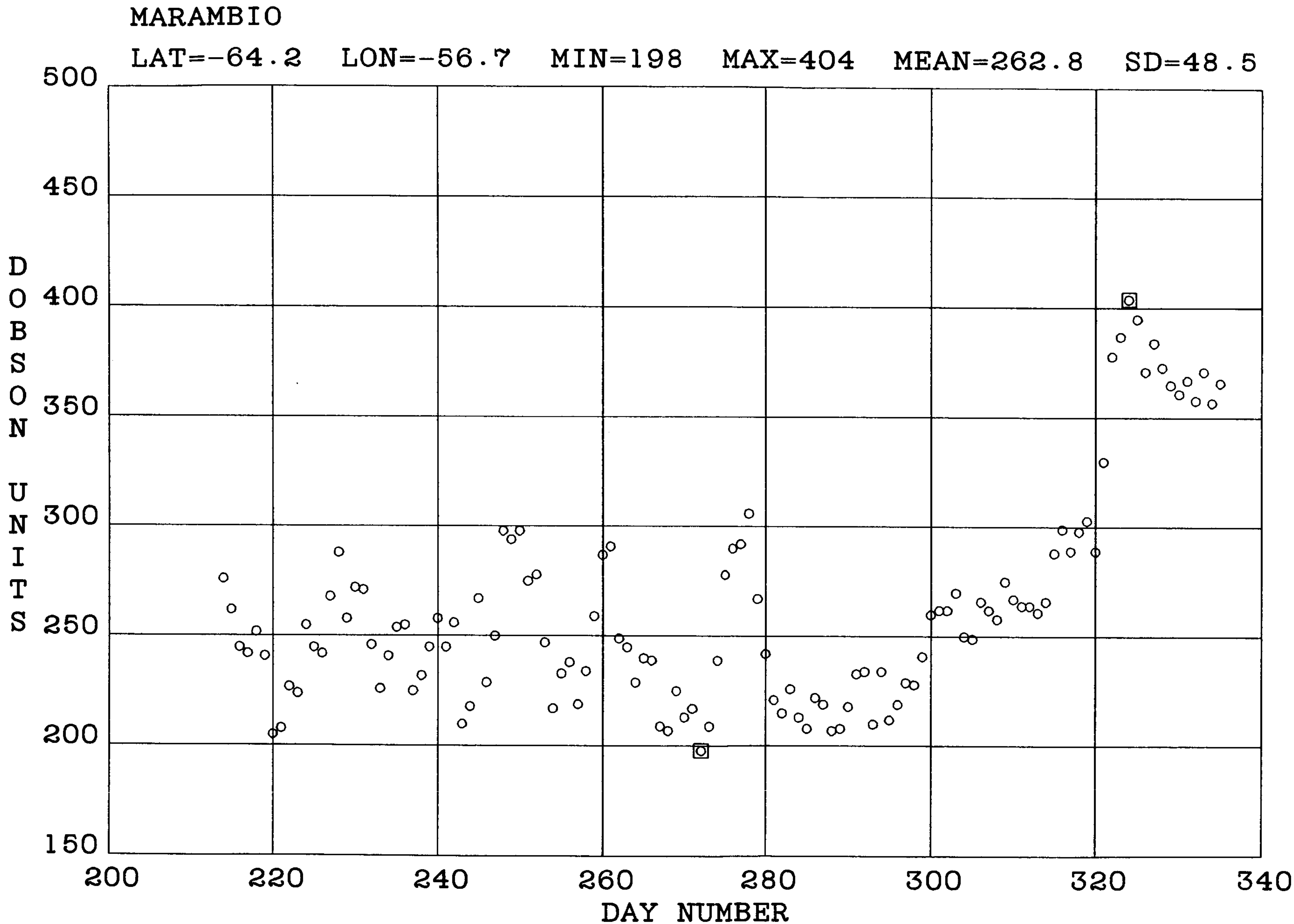


Figure 1b. Daily TOMS Total Ozone Values over Marambio (DU).

Davis (DAV)

The Davis station is located on the coast of Antarctica at 69°S, 78°E. Total ozone above Davis (Figure 1c) fluctuates markedly during the period, ranging from a minimum of 250 DU (August 2) to a maximum of 492 (September 1). The station lies within a steep ozone gradient between the mature hole and a semi-permanent maximum off the Antarctic coast.

Dumont D'Urville (DUD)

The Dumont D'Urville station is located at 67°S on the Antarctic coast almost 180° in longitude away from the Antarctic Peninsula. During the period August 1 through September 13, the station lies within a steep ozone gradient (Figure 1d), varying from a minimum of 211 DU (August 30) to a maximum of 437 DU (August 19). Thereafter, the station falls within the semi-permanent ozone maximum, remaining continuously above 350 DU, with a maximum of 497 DU on September 26 (day 270).

Faraday Station (FAR)/Palmer Station (PAL)

The Palmer and Faraday stations, located at 65°S, lie within the same grid element and are considered jointly. The total ozone for these locations (Figures 1e and 1f) is closely correlated with, though independent of, the TOMS measurements taken over Marambio.

Halley Bay (HAL)

The total ozone measurements over Halley Bay at 76°S first become available on August 19 (day 232). The total ozone above the station (Figure 1g) is initially low (below 260 DU) and declines until a minimum of 187 DU is reached on September 17. The station lies near the mature ozone hole's center until October 25, when the weakening and movement of the hole result in a general rise in total ozone over the station.

McMurdo (MCM)

The McMurdo station is located at 78°S on McMurdo Sound near the dateline. Total ozone measurements (Figure 1h) first become available on August 26 (day 239). After an initial total ozone value of 252 DU, the ozone diminishes rapidly to a minimum value of 195 DU on September 7. Thereafter, as the semi-permanent maximum builds into the area, the total ozone over McMurdo rises to a maximum of 454 DU on November 3. This rise is stepwise, as smaller scale ozone features rotate about the pole, causing alternate rises and falls in total ozone.

Molodeznaya (MOL)

The Molodeznaya station is located in coastal Antarctica at 68°S. This station is highly correlated with Davis station, located within a steep ozone gradient, resulting in large, periodic swings in total ozone (Figure 1i).

Punta Arenas (PUN)

Punta Arenas, located near Cape Horn in extreme southern Chile at 53°S, shows a relatively small variation in total ozone during this period (Figure 1j). Periodically, the fringe of the ozone hole reaches Punta Arenas, producing a minimum value of 235 DU on October 21 (day 295). Since the semi-permanent maximum does not reach this station, its maximum ozone value is only 387 DU on November 25.

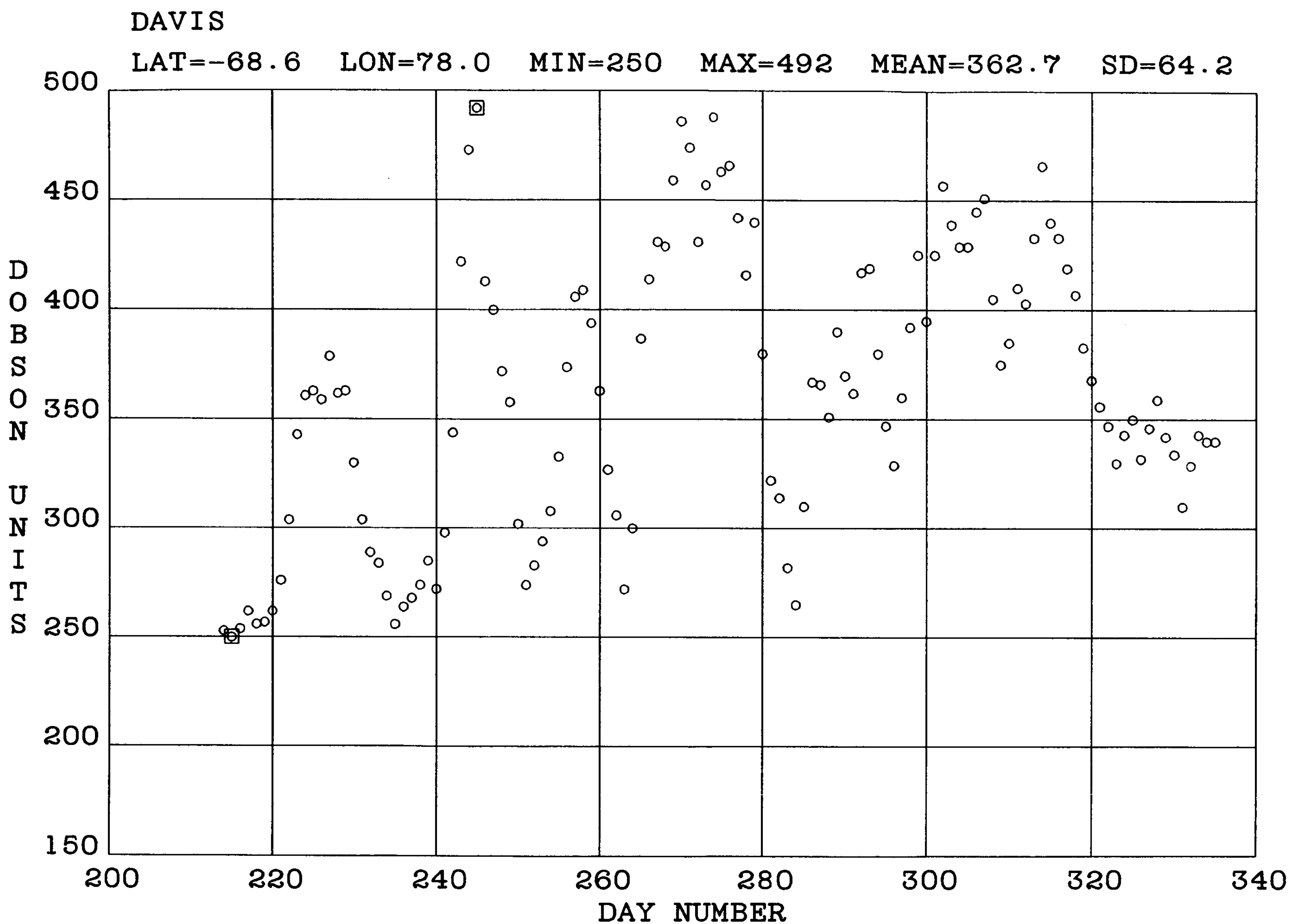


Figure 1c. Daily TOMS Total Ozone Values over Davis (DU).

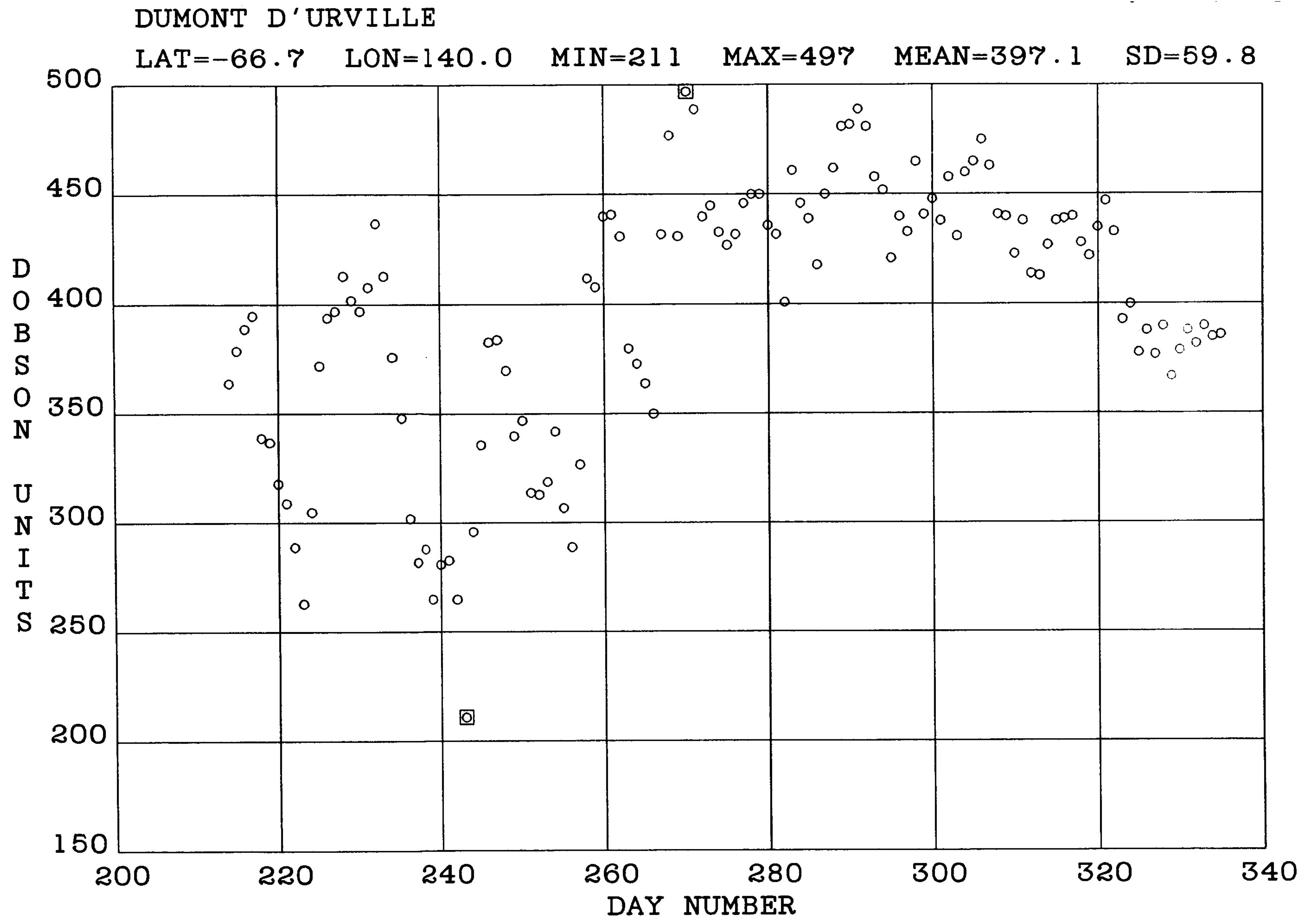


Figure 1d. Daily TOMS Total Ozone Values over Dumont D'Urville (DU).

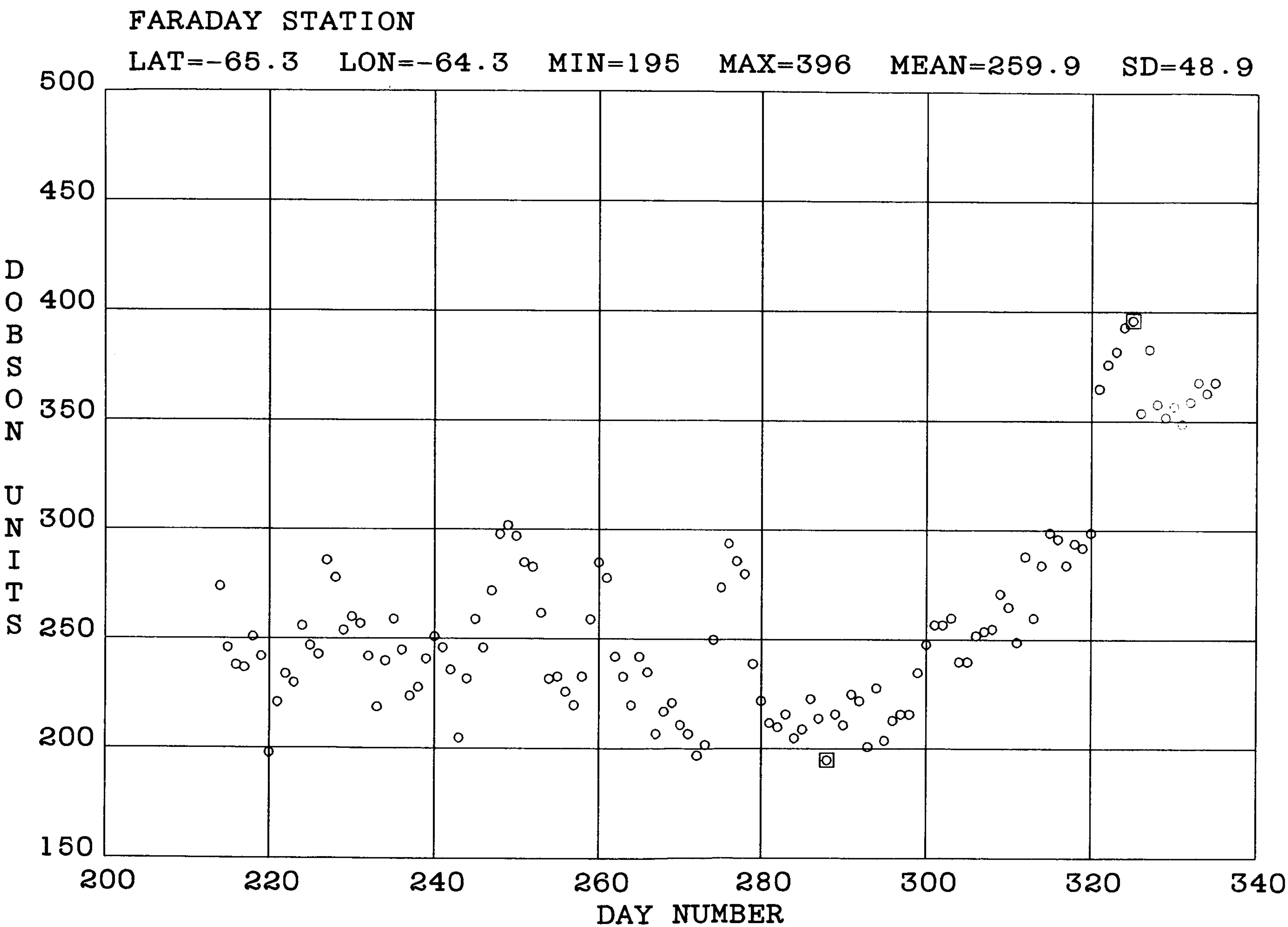


Figure . Daily TOMS Total Ozone Values over Faraday Station (DU)

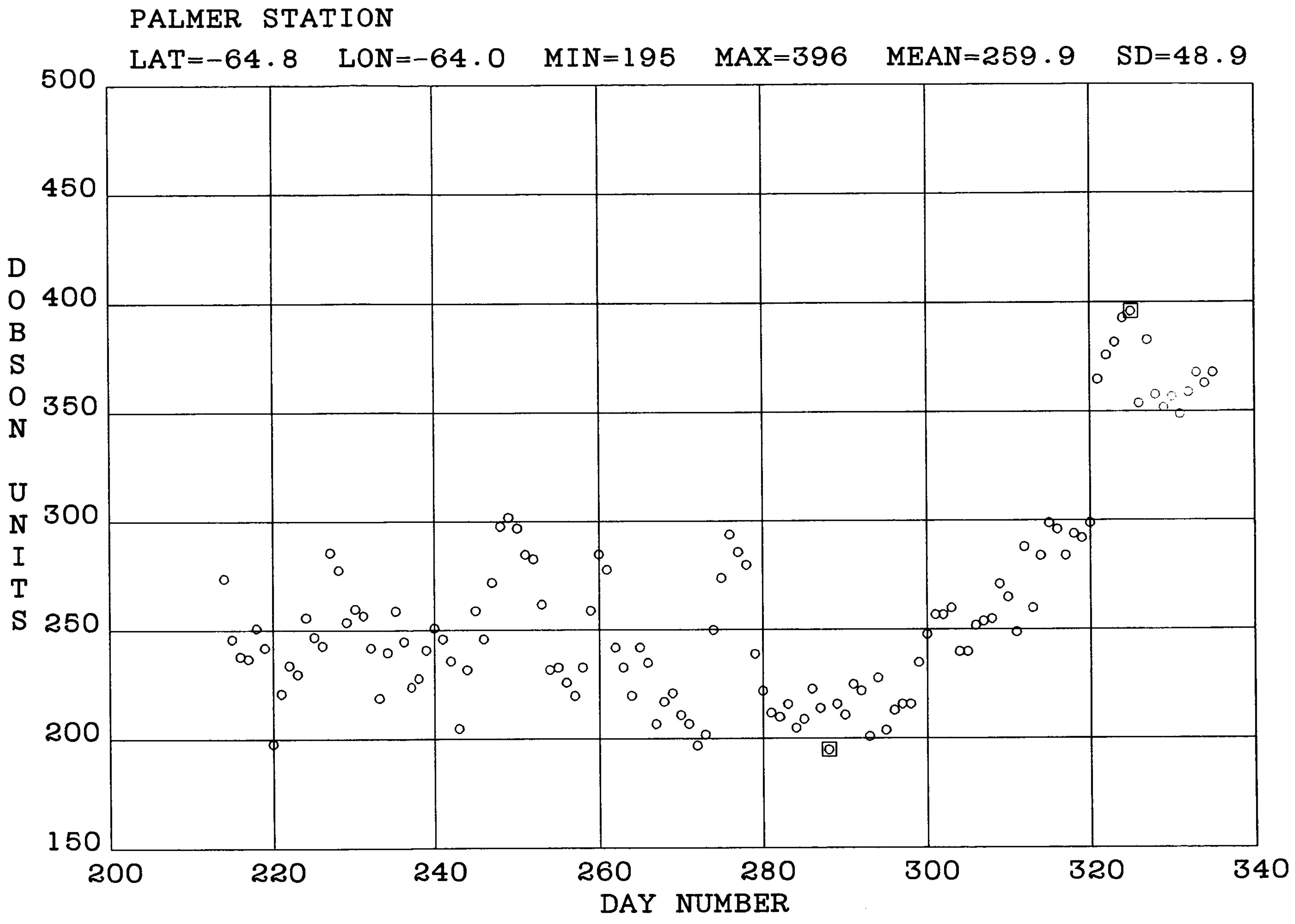


Figure 1f. Daily TOMS Total Ozone Values over Palmer Station (DU).

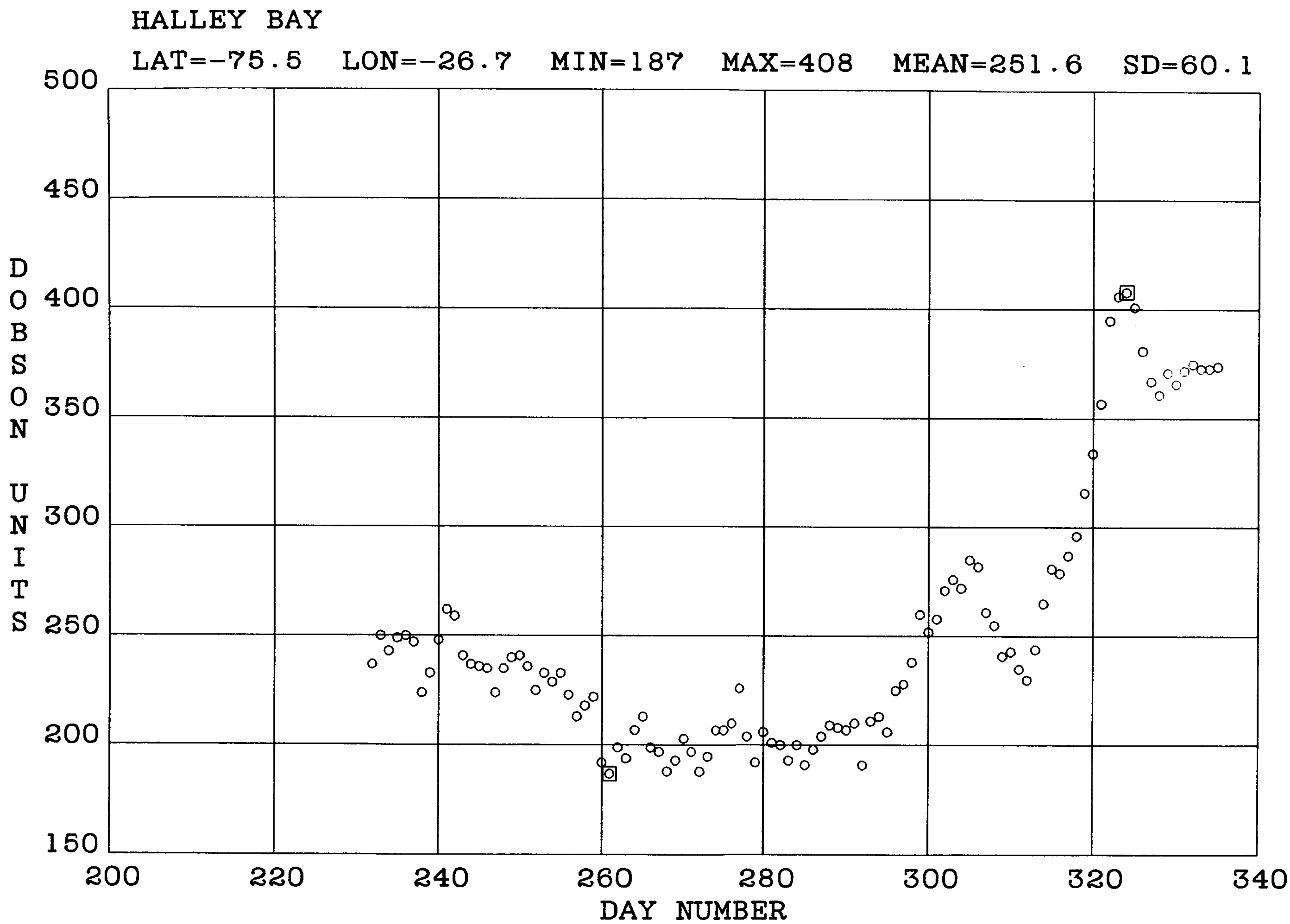


Figure 1g. Daily TOMS Total Ozone Values over Halley Bay (DU).

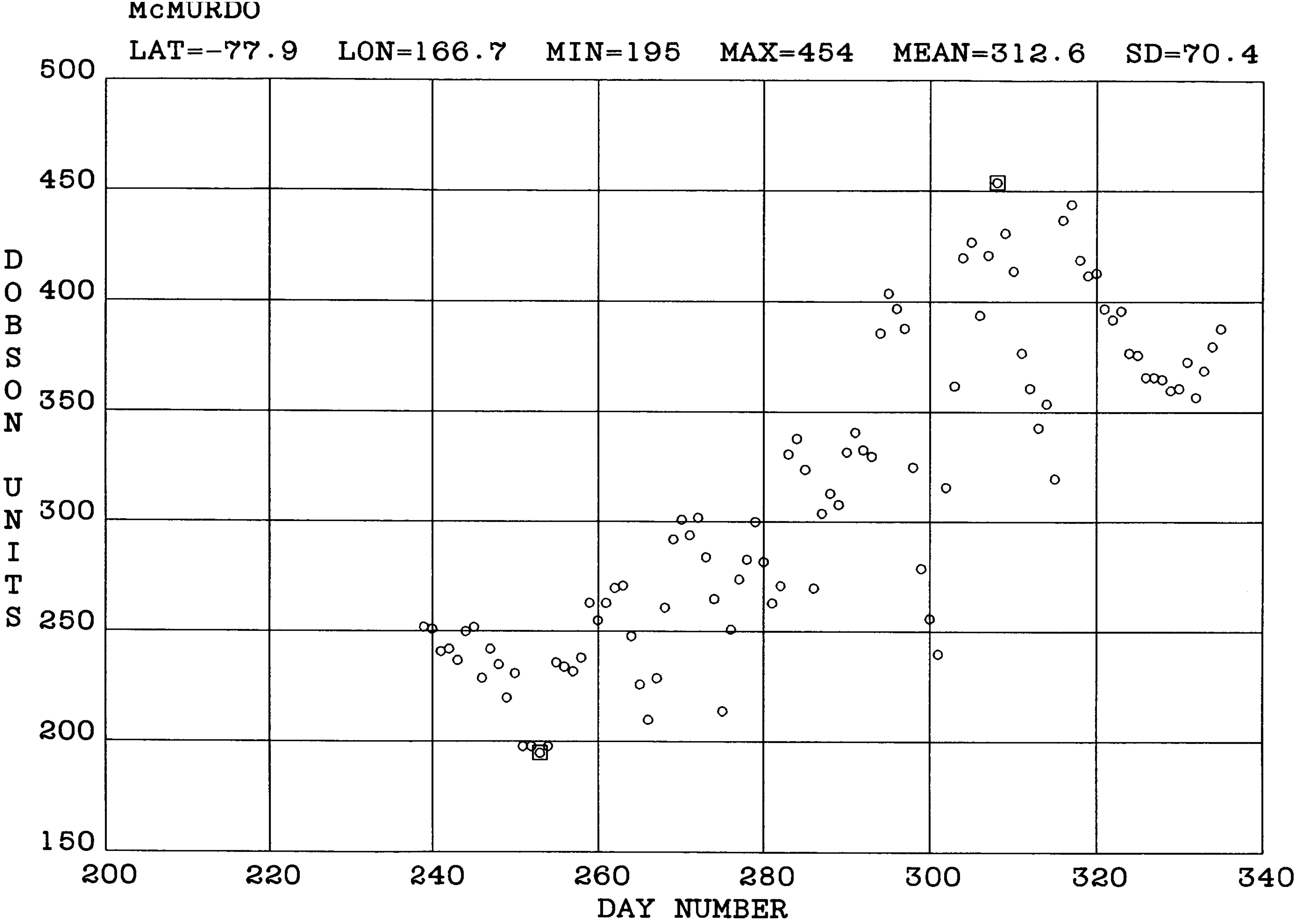


Figure 1h. Daily TOMS Total Ozone Values over McMurdo (DU).

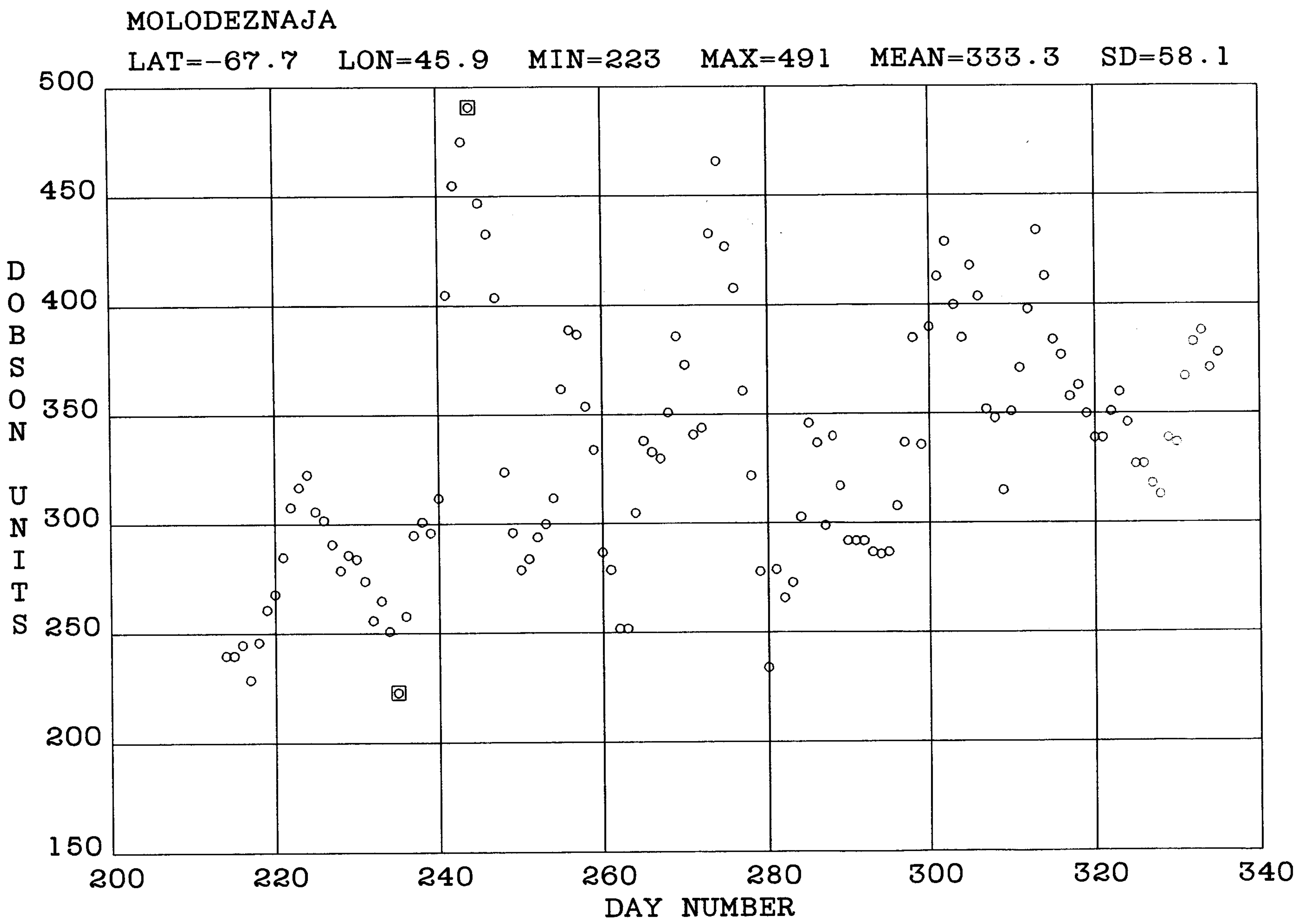


Figure 1i. Daily TOMS Total Ozone Values over Molodeznaya (DU).

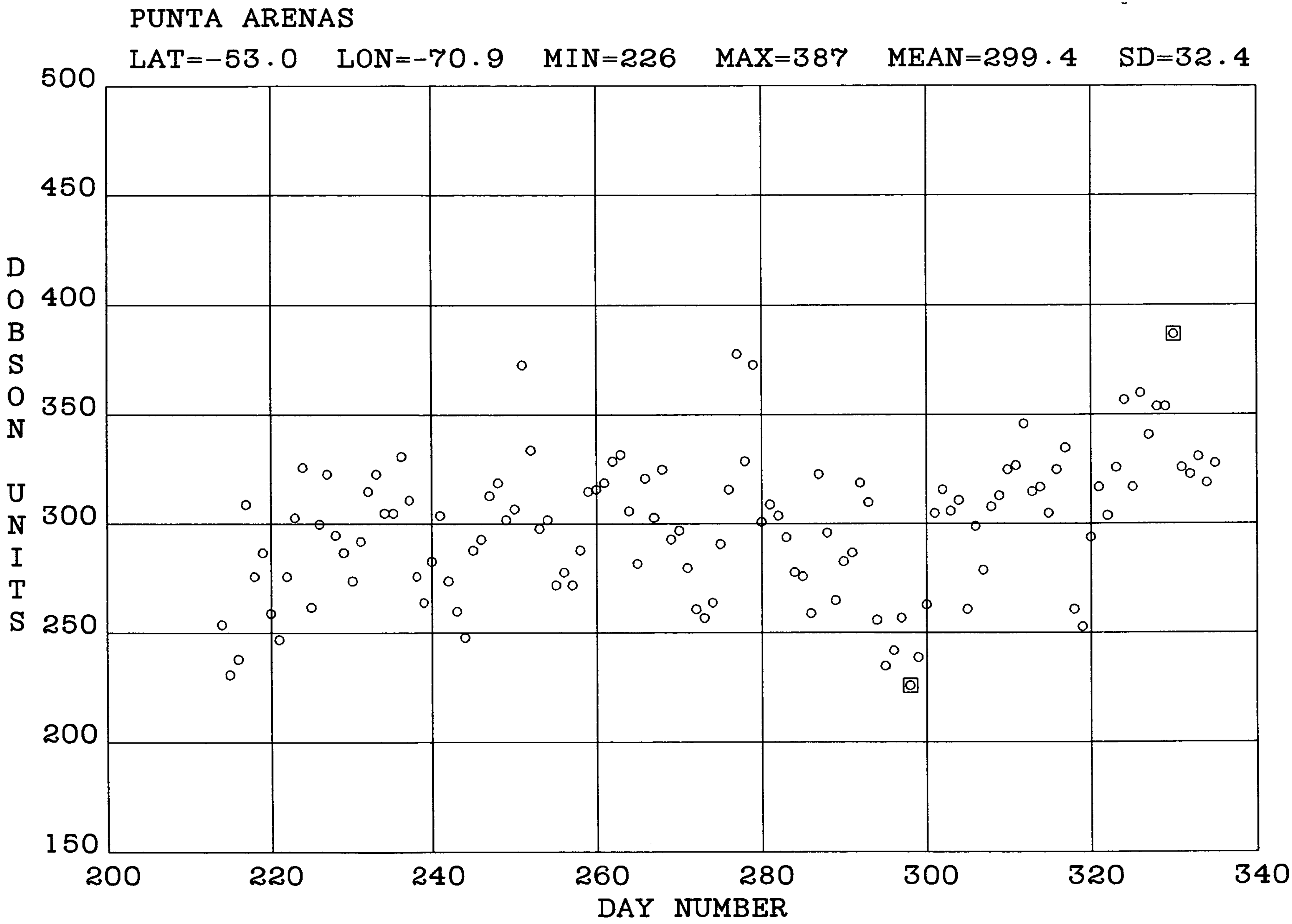


Figure 1j. Daily TOMS Total Ozone Values over Punta Arenas (DU).

Syowa (SYO)

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

Vostok (VOS)

The Vostok station is located deep within continental Antarctica at 78°S. Despite its proximity to the pole, this station does not often find itself within the mature ozone hole (Figure 1l). Located within a developing ozone gradient, Vostok sees the ozone hole alternately cover and then recede from the area. A comparison with Halley Bay (HAL) at a similar latitude, but 130° longitude removed shows the asymmetry of the 1988 ozone hole.

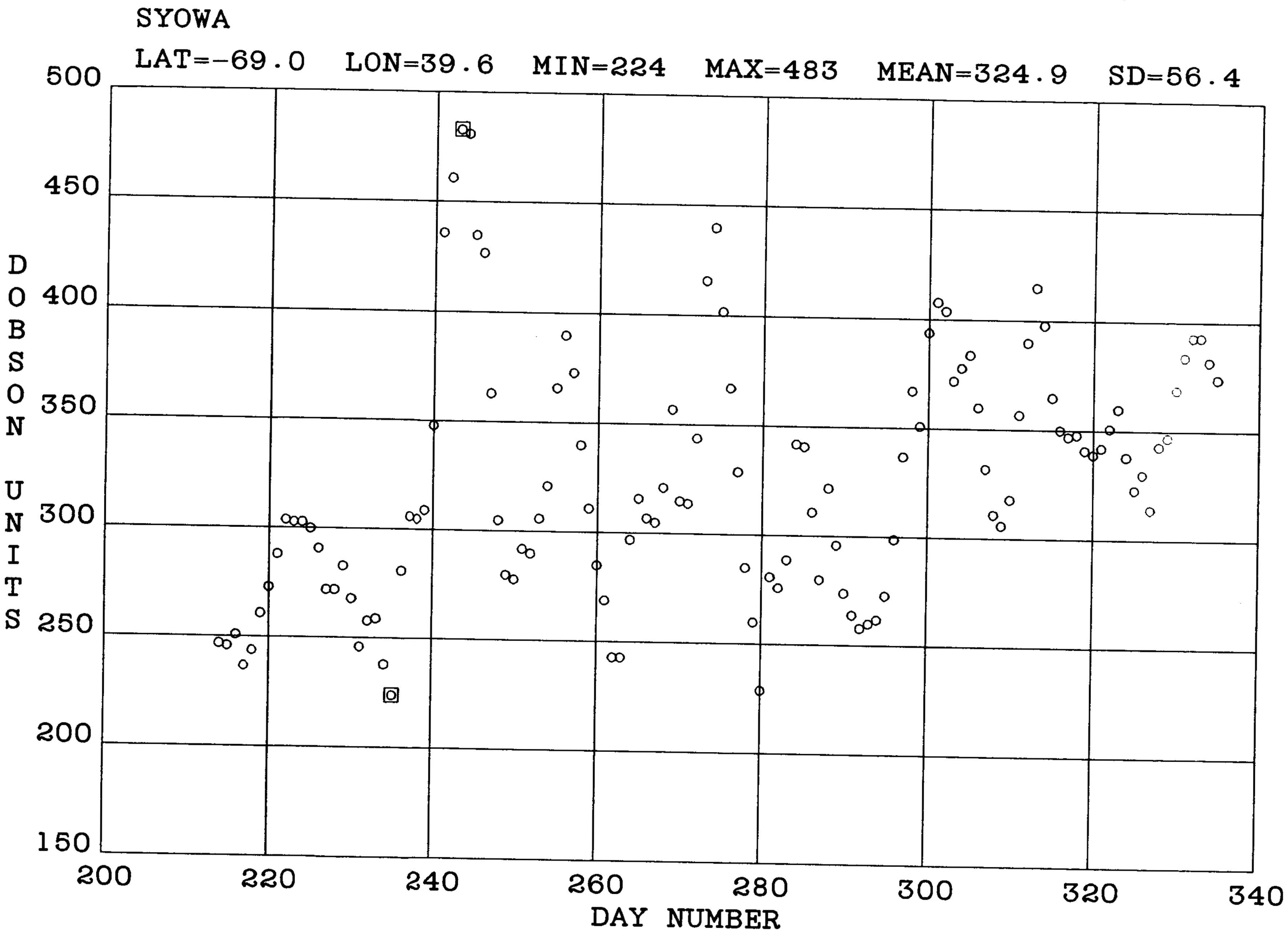


Figure 1k. Daily TOMS Total Ozone Values over Syowa (DU).

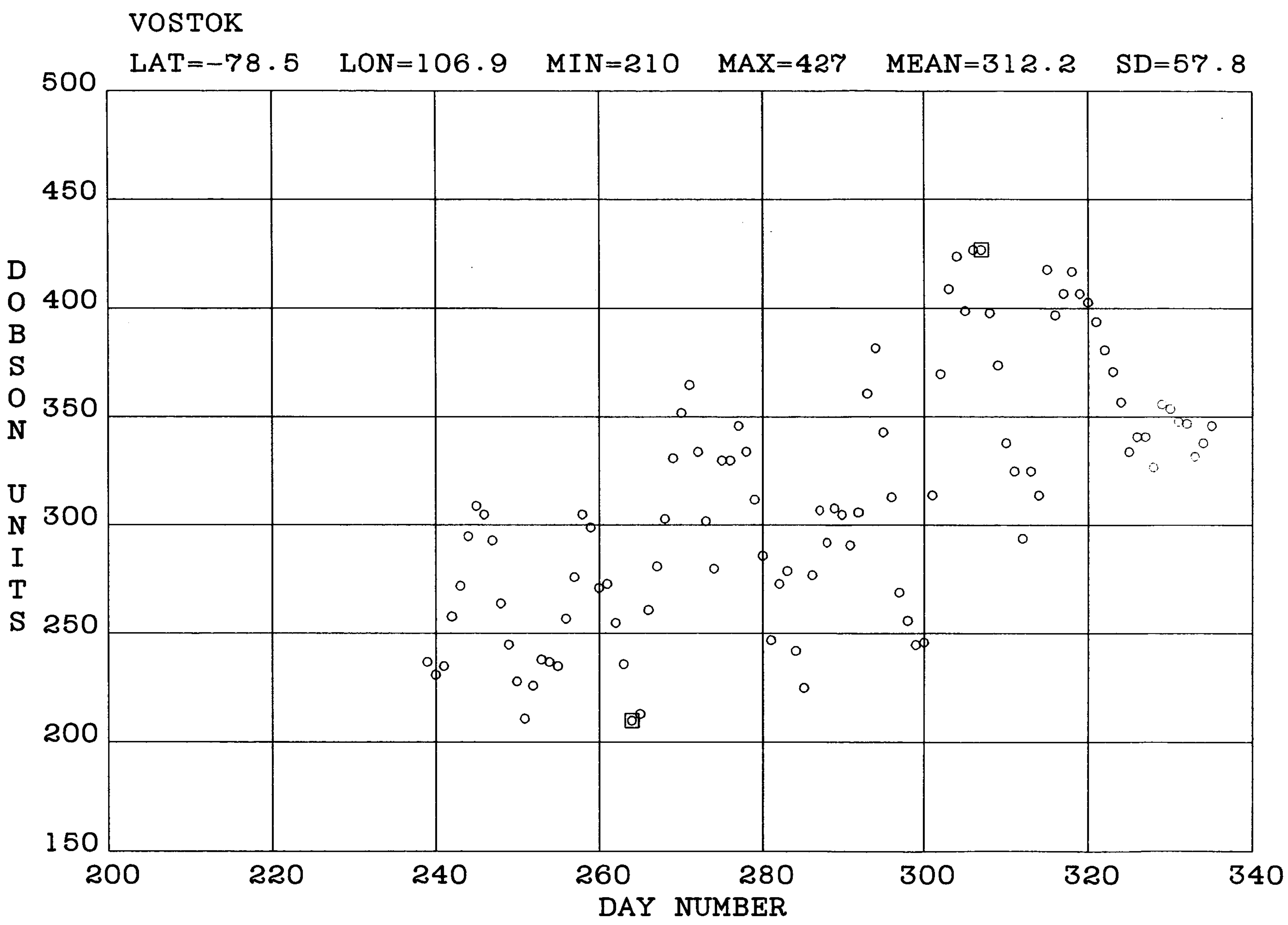


Figure 11. Daily TOMS Total Ozone Values over Vostok (DU).

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, 1986, 1987, and 1988. 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. 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 trend, with values rising from August 1 through mid-September, remaining fairly steady until late October, 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 significant larger than the instrumental drift of about 12 DU. The values in 1986 through 1988 are tightly grouped, although the lowest zonal means after mid-September are in 1988.

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 decline, from mid-October through the end of November is more pronounced than the initial rise. Once again, the values for 1979 are considerably higher than those for the other three years, and again those three years are closely bunched. After mid-October, the lowest zonal means are in 1988.

The 50°S band (Figure 2c) shows the rise and fall characteristic of the lower latitude bands; however, several important differences exist. Although the ozone in 1979 is significantly higher than in the other years after late September, it is indistinguishable from 1986 and 1988 prior to that time. In addition, the ozone in 1987 is significantly lower than in the other three years prior to mid-October. The values for 1988 do not show any characteristics of note.

Figure 2d presents the band averages for 60°S where a steady rise from August 1 through mid-October appears for all years except 1987. After mid-October, the ozone in 1979 declines, while in 1986 and 1988 it remains somewhat steady. The values for 1979 behave in a fashion similar to the 50°S zonal means, rising significantly above the other years after late September. Also similar is the ozone in 1987 which begins significantly lower than in the other years. However, unlike 50°S, it remains lowest throughout the period. The exceptionally symmetric and strong ozone hole of 1987 occasionally extended to this latitude and prevented the significant rise seen in the other years from August 1 until mid-October. In 1988, the ozone, which is initially indistinguishable from 1979 and 1986, has the second highest values after mid-October, about midway between those of 1979 and 1987.

Figure 2e presents the band averages for 70°S. In the years 1979, 1986, and 1988 steady values exist from August 1 through early October, which then rise for the remainder of the period. Although the ozone during the period early October through early November, 1979 is significantly higher than in 1986 or 1988, it is otherwise indistinguishable. These steady initial values, similar to those of 1987 at 60°S are indicative of the fringe of the ozone hole. The stronger ozone hole of 1987 produces a decline in total ozone from August 1 through early October, followed by a gradual rise, which becomes steeper just before the end of the period. After late August, the ozone in 1987 is dramatically lower than the remaining three years, nearly 150 DU lower in mid-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 commence when the sun rises above the horizon

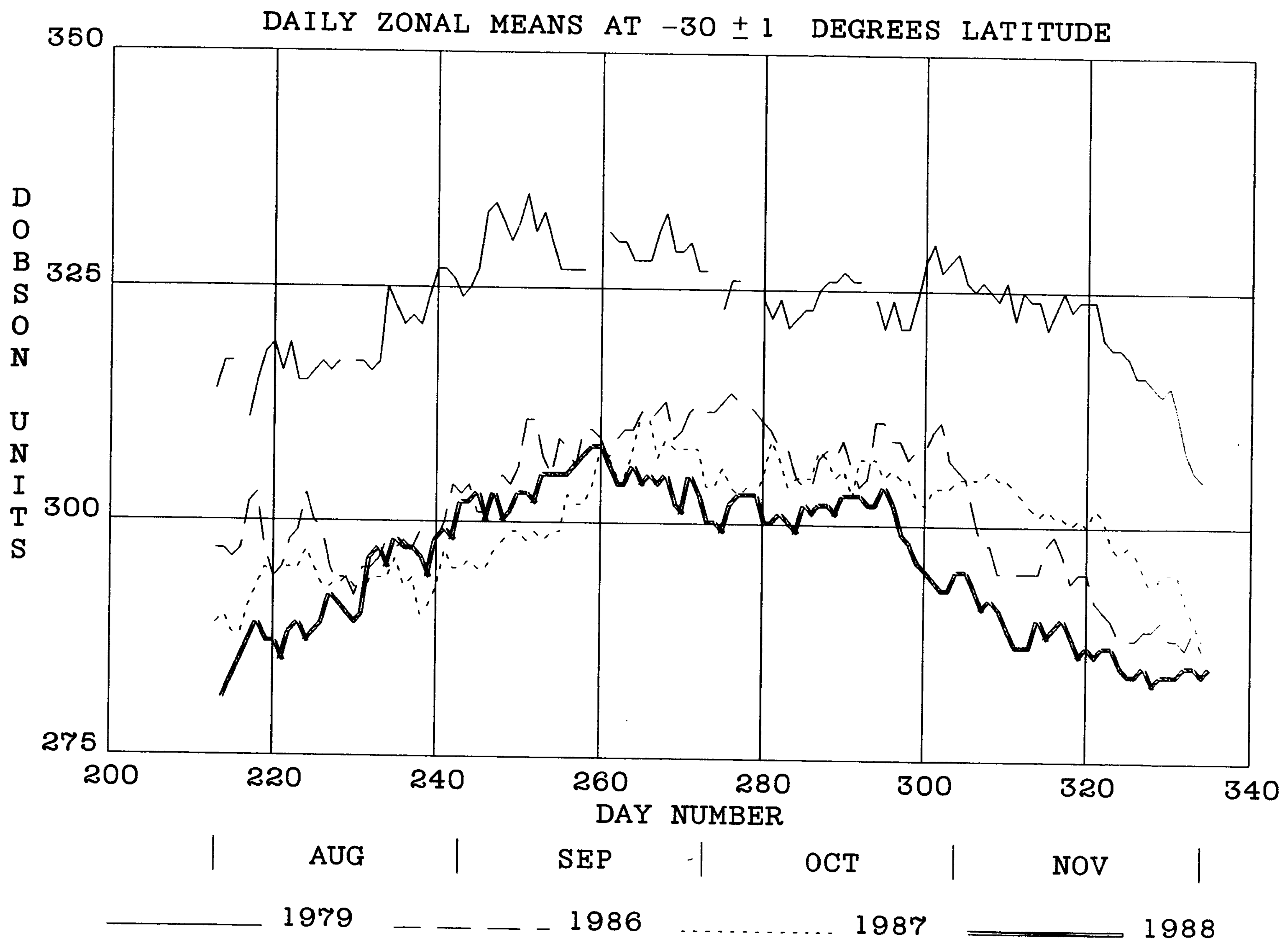


Figure 2a. Mean total ozone for the 2° latitude band centered at 30°S for the period August 1 through November 30 of the years 1979, 1986, 1987, and 1988.

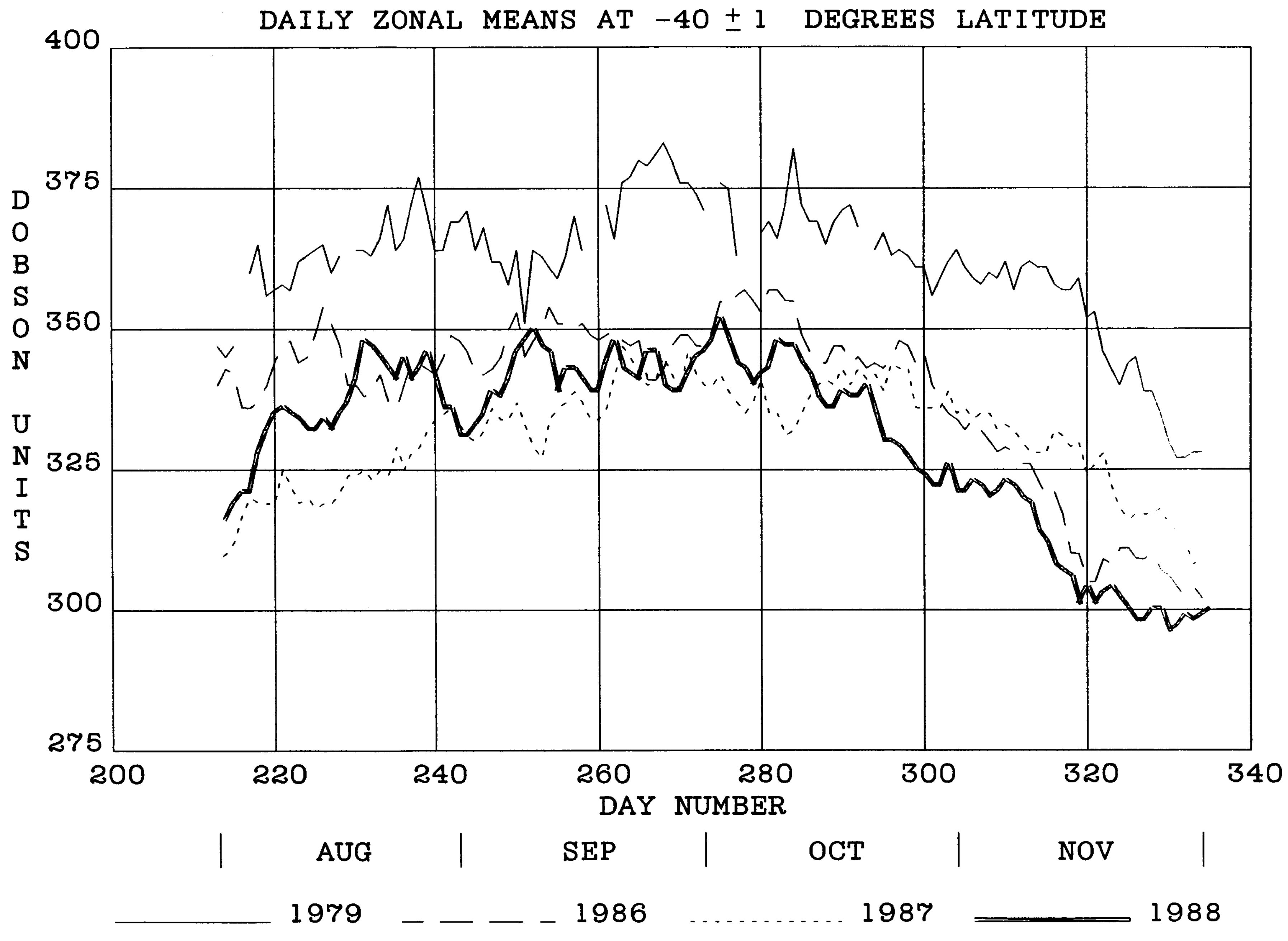


Figure 2b. Mean total ozone for the 2° latitude band centered at 40°S for the period August 1 through November 30 of the years 1979, 1986, 1987, and 1988.

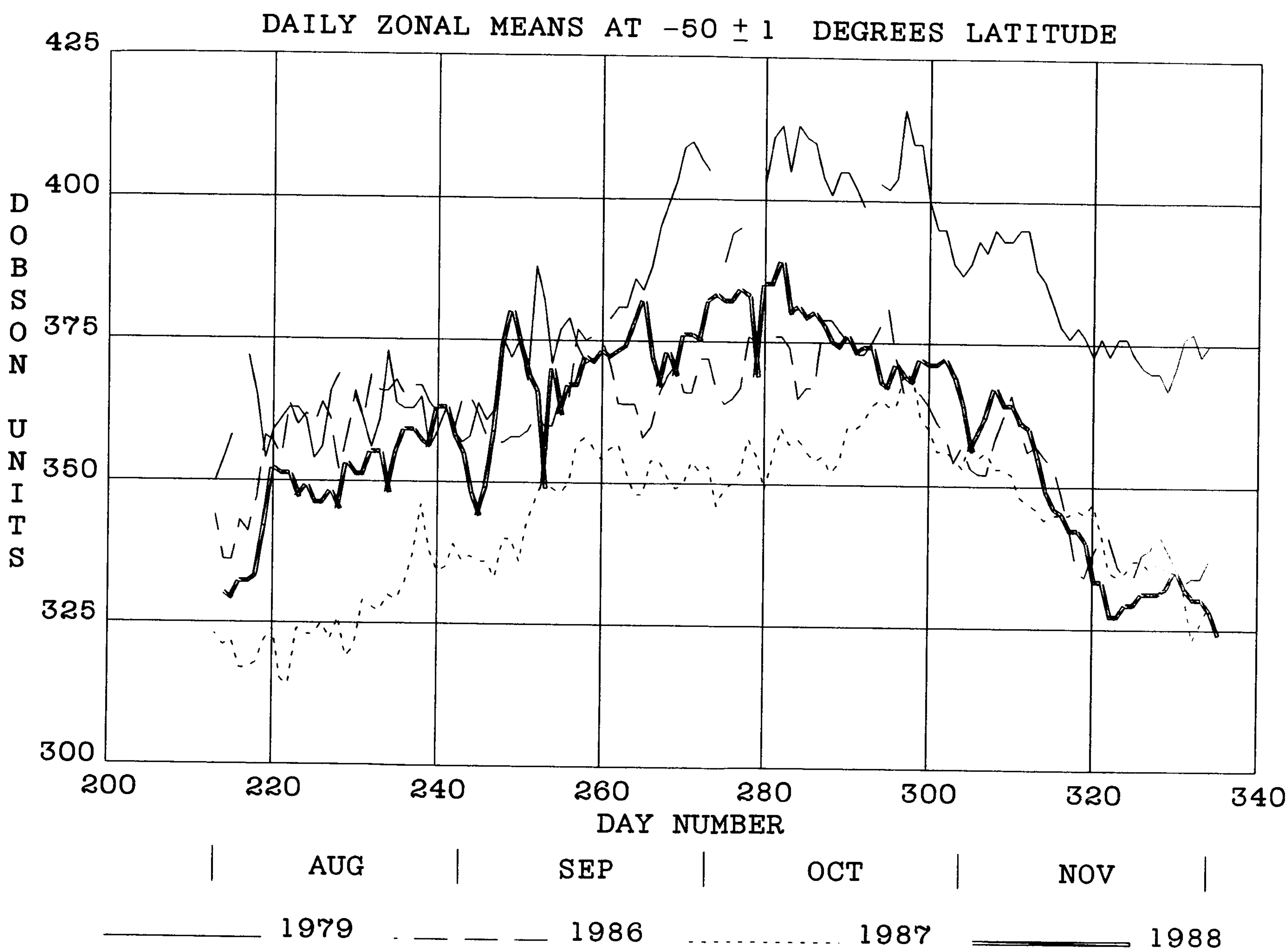


Figure 2c. Mean total ozone for the 2° latitude band centered at 50°S for the period August 1 through November 30 of the years 1979, 1986, 1987, and 1988.

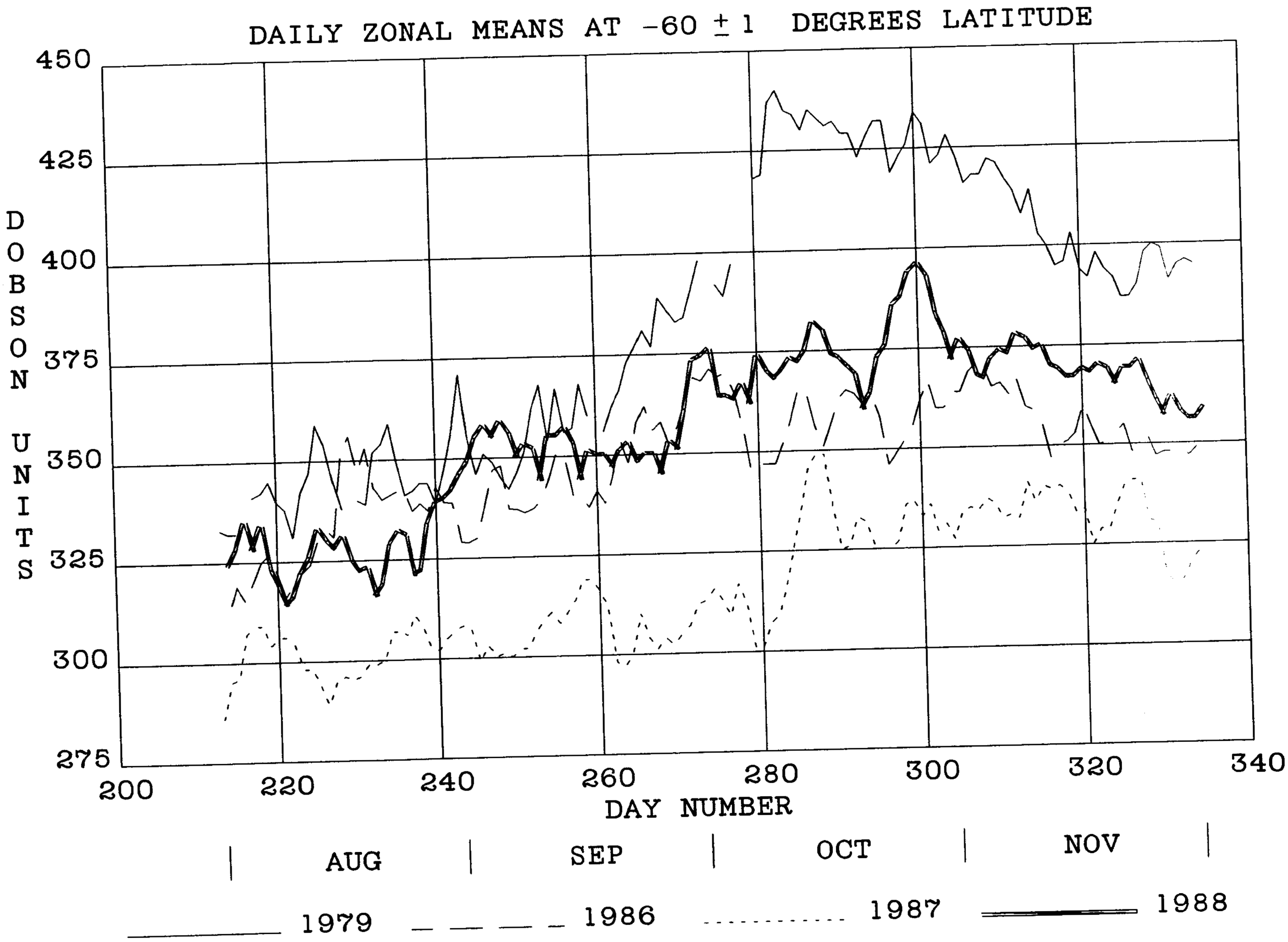


Figure 2d. Mean total ozone for the 2° latitude band centered at 60°S for the period August 1 through November 30 of the years 1979, 1986, 1987, and 1988.

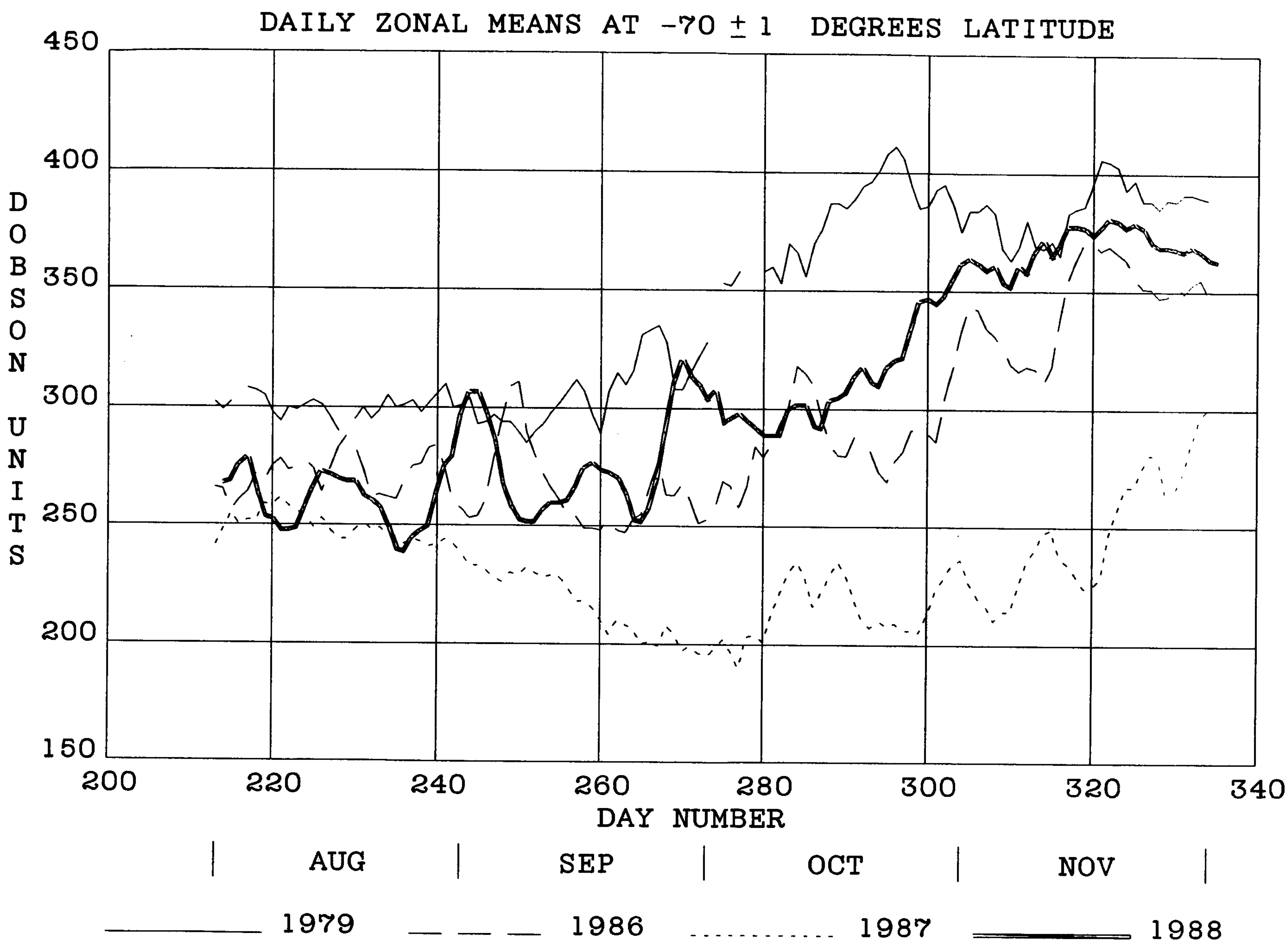


Figure 2e. Mean total ozone for the 2° latitude band centered at 70°S for the period August 1 through November 30 of the years 1979, 1986, 1987, and 1988.

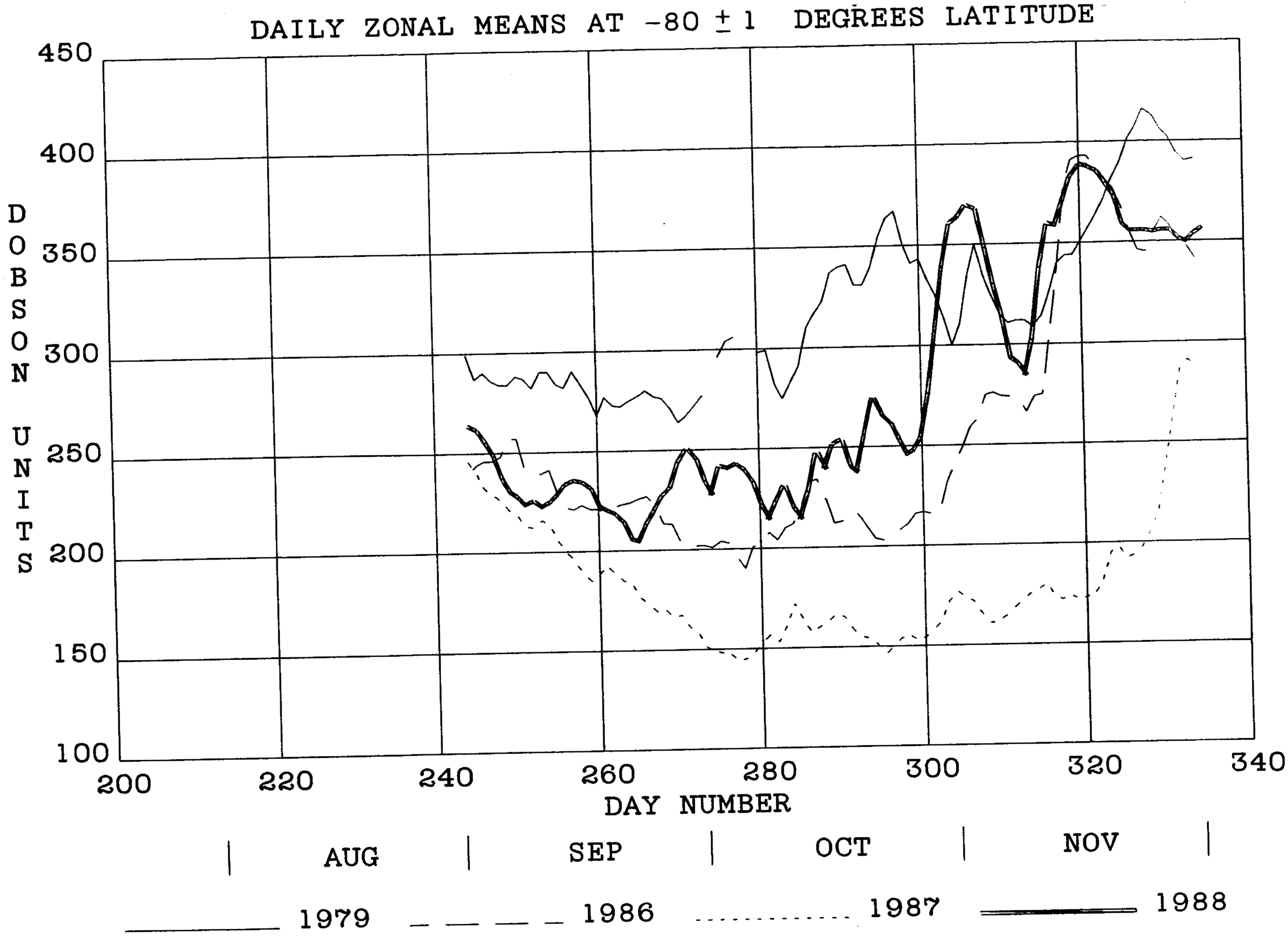


Figure 2f. Mean total ozone for the 2° latitude band centered at 80°S for the period August 1 through November 30 of the years 1979, 1986, 1987, and 1988.

in early September. All years show an initial decline as the ozone hole forms. The decline is not pronounced for any year except 1987. Values rise after early October for all years except 1987 when the rise does not begin until mid-November. At that time, the mean values for 1987 are 175 DU to 200 DU lower than the other three years.

3.2 Monthly Differences

Figures 3a through 3d present the hemispheric differences of total ozone for the months of August through November between the year 1988 and a four-year reference mean (1979 through 1982). Figure 3e presents the difference between October 1987 and the four-year mean. In each case, the values are the month in question minus the four-year mean. Isopleths are solid where this difference is positive and dashed where it is negative. The values are in Dobson Units.

One of the outstanding features of the 1988 Antarctic ozone distribution in August-October was the offset nature of the ozone hole with a semi-permanent maximum located between longitude 30°E and 150°E and a minimum at 90° to 130°W. In the August 1988 differences (Figure 3a) the area of positive difference is centered near 55°S off the east Antarctic coast while an almost mirror-image area of negative differences is centered near 70_0S over the west Antarctic coast.

The peak negative differences (30 DU) are about twice the positive differences. The 1988 ozone hole was seldom symmetric to the pole, and was often displaced toward the western longitudes. Several "mini-holes" formed in early August 1988 in the vicinity of the Antarctic Peninsula. The TOMS measurements can be biased negatively when stratospheric clouds form in the mini-holes. This would slightly exaggerate the differences in the monthly negative differences.

The September differences (Figure 3b) show much the same pattern. The positive differences are somewhat greater (25 DU), cover a slightly larger area, and extend deeper into the Antarctic continent. The region of negative differences is centered near 65°S, 130°W longitude, and clearly extend across the south pole. The maximum negative deviations are about 30 DU, similar to the August values.

By October (Figure 3c) the area of positive differences has shifted eastward and southward, but is greatly reduced in magnitude to about 10 DU. The prominent minimum is centered east of its September position at 90°W, but with comparable magnitude (30 DU).

Figure 3d presents the differences for November. As in the other months, most of the hemisphere shows small, negative differences which could be the result of instrument calibration drifts. However, the area of positive differences now covers most of Antarctica, with the maximum difference (10 DU) centered near the pole. These differences are comparable in magnitude to those of October. The pronounced area of negative differences present in the preceding three months is no longer apparent.

For comparison, Figure 3e presents the differences between October 1987 and the October mean for the years 1979 through 1982. The year 1987 produced a very strong and extensive ozone hole which reached peak intensity in October and which was very symmetric with respect to the pole. Here, all differences are negative, with maximum differences of 45 DU centered at the pole. All isopleths of difference above -5 DU are symmetric with the pole.

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, 1986, 1987, and 1988. The horizontal axis is the day number of the year. In Figure 4a, much variation in the

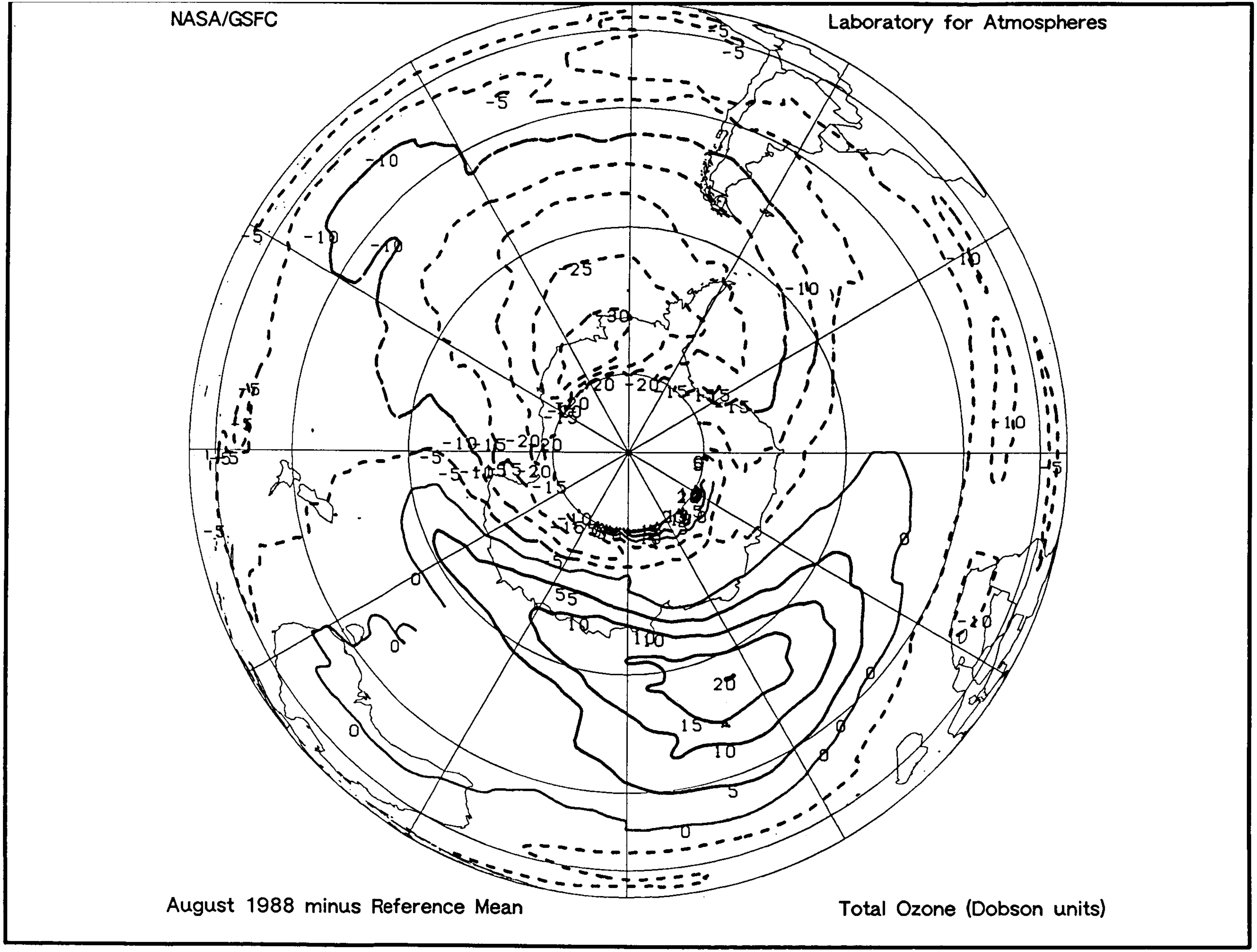


Figure 3a. Monthly mean total ozone difference between August 1988 and a four-year reference mean (August 1979 through 1982).

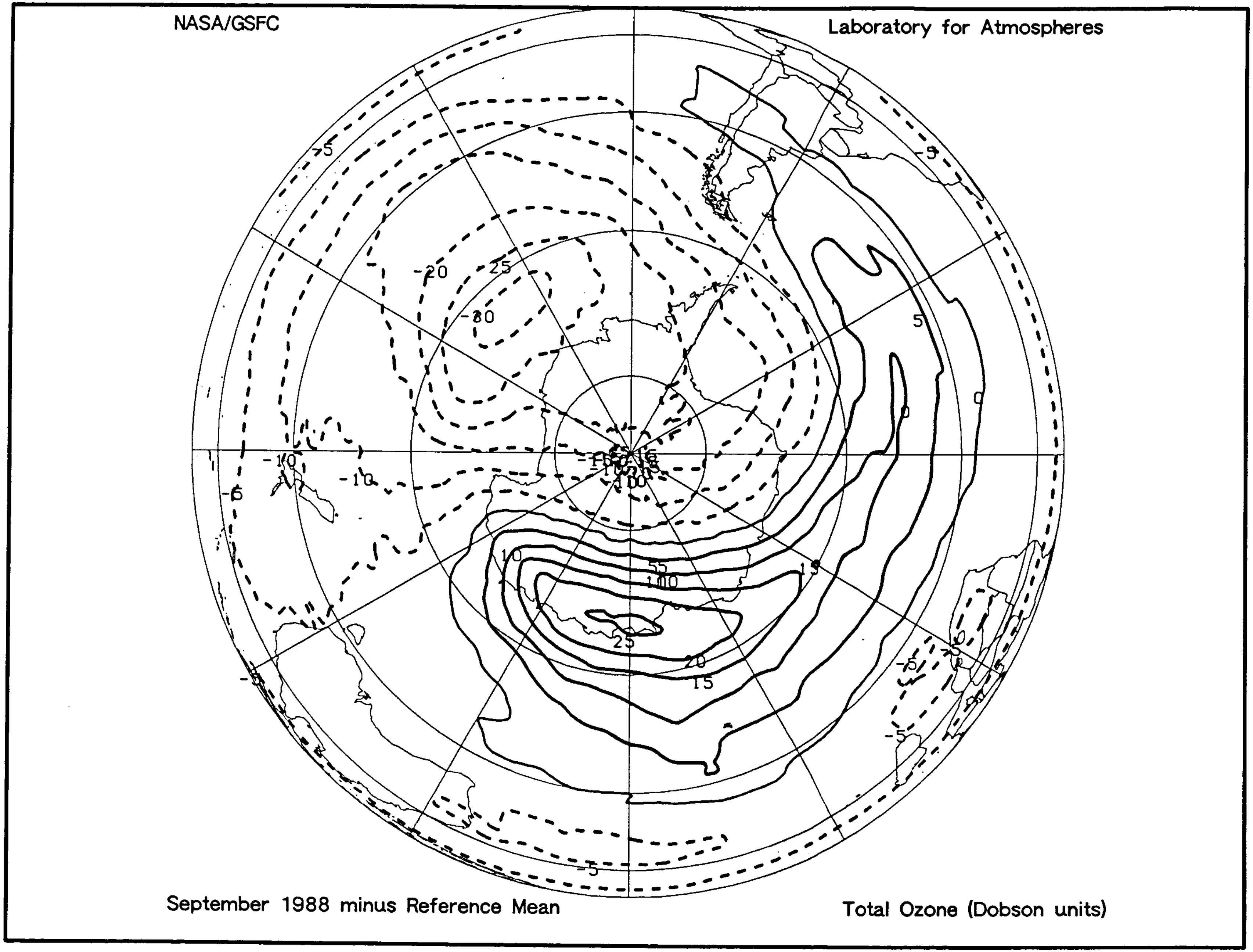


Figure 3b. Monthly mean total ozone difference between September 1988 and a four-year reference mean (August 1979 through 1982).

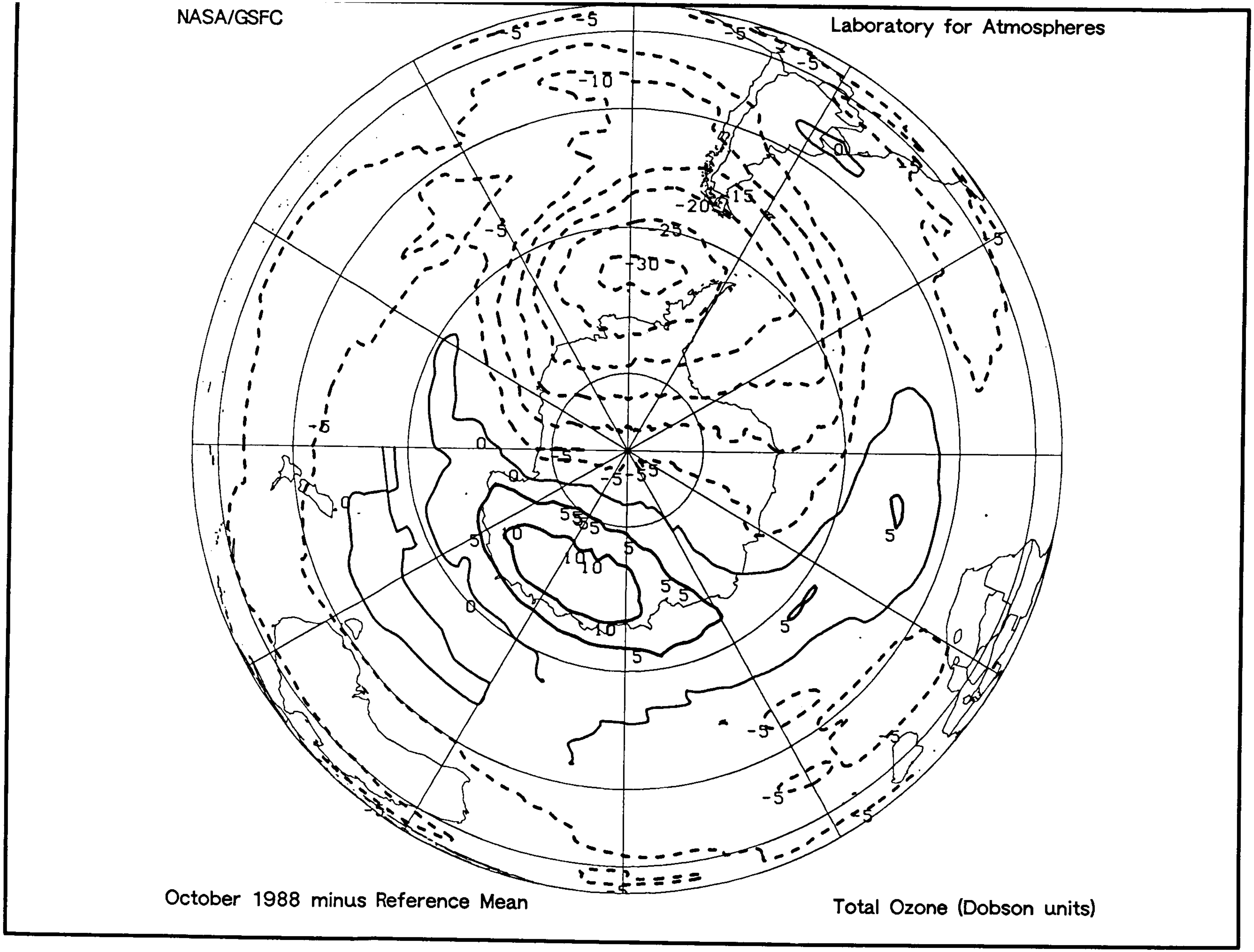


Figure 3c. Monthly mean total ozone difference between October 1988 and a four-year reference mean (August 1979 through 1982).

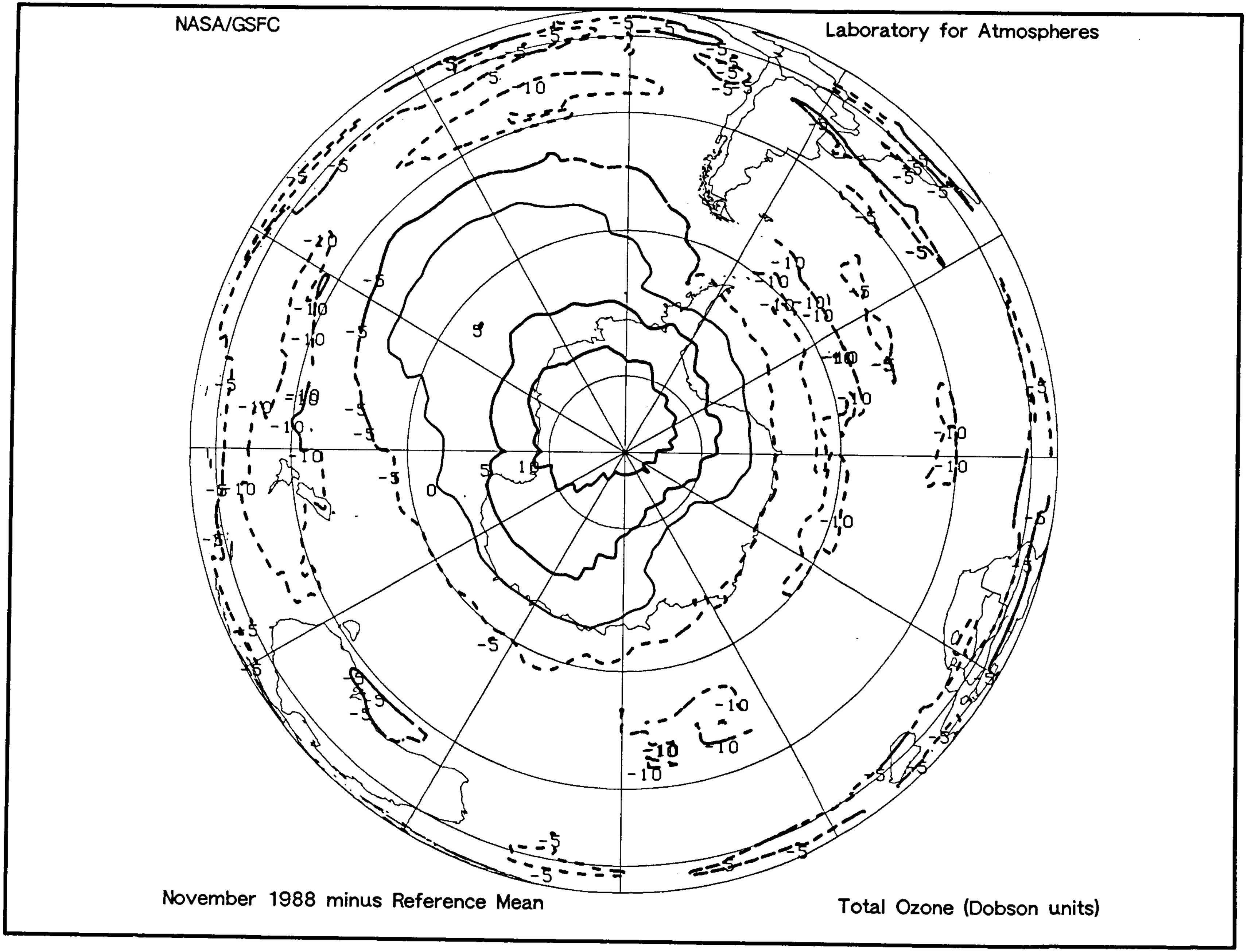


Figure 3d. Monthly mean total ozone difference between November 1988 and a four-year reference mean (August 1979 through 1982).

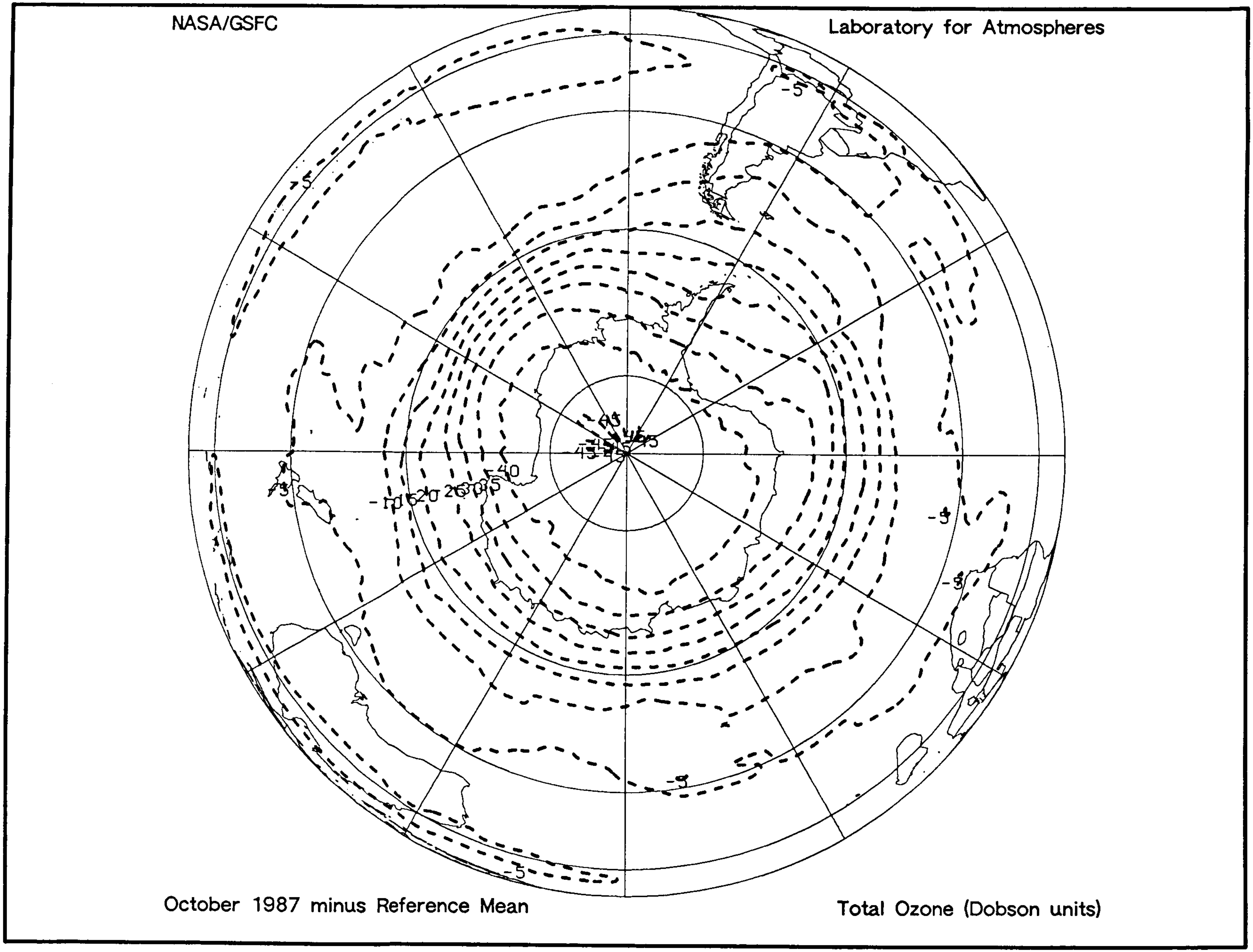


Figure 3e. Monthly mean total ozone difference between October 1987 and a four-year reference mean (August 1979 through 1982).

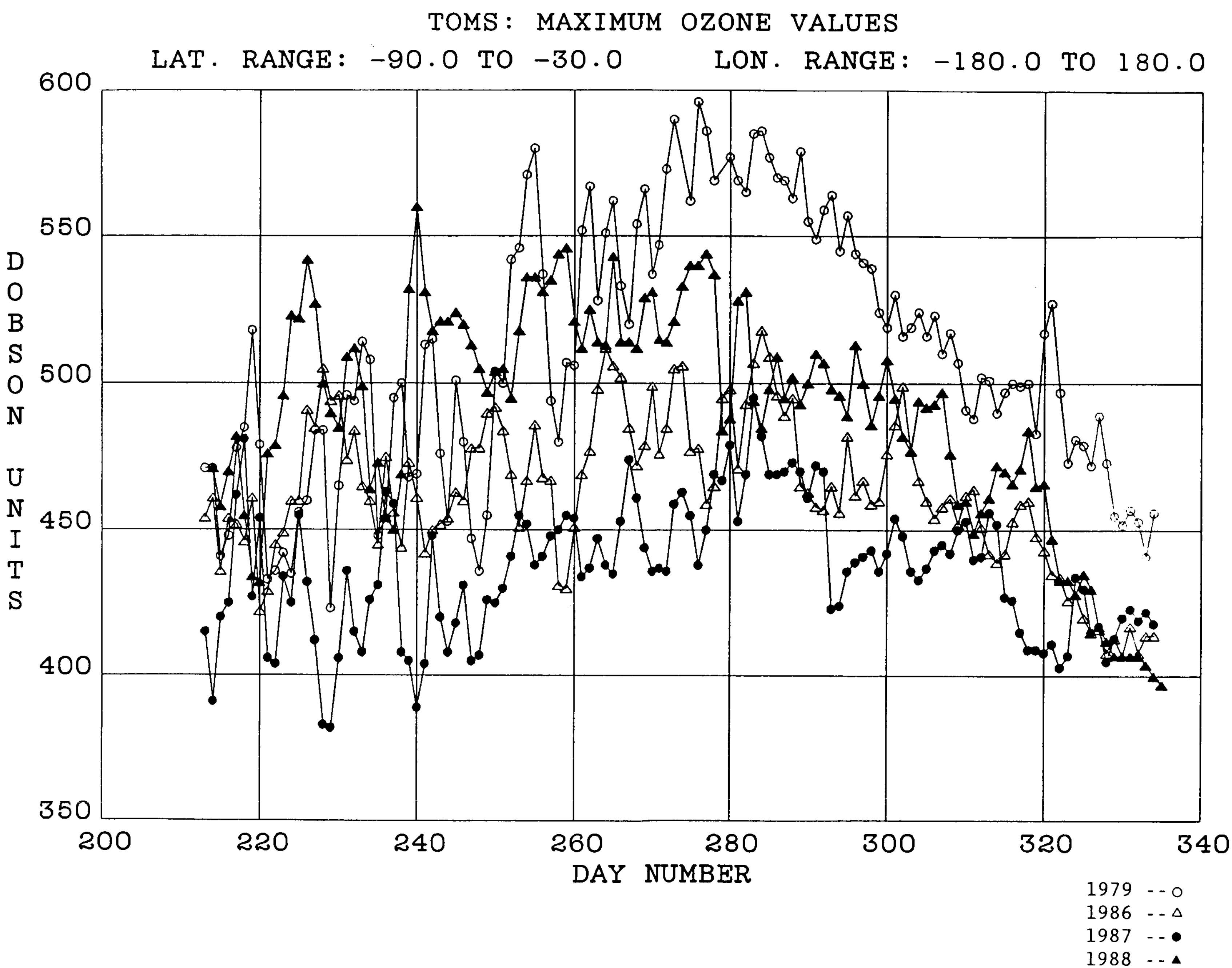


Figure 4a. Daily southern hemisphere ozone maximum for the period August 1 through November 30 of the years 1979, 1986, 1987, and 1988.

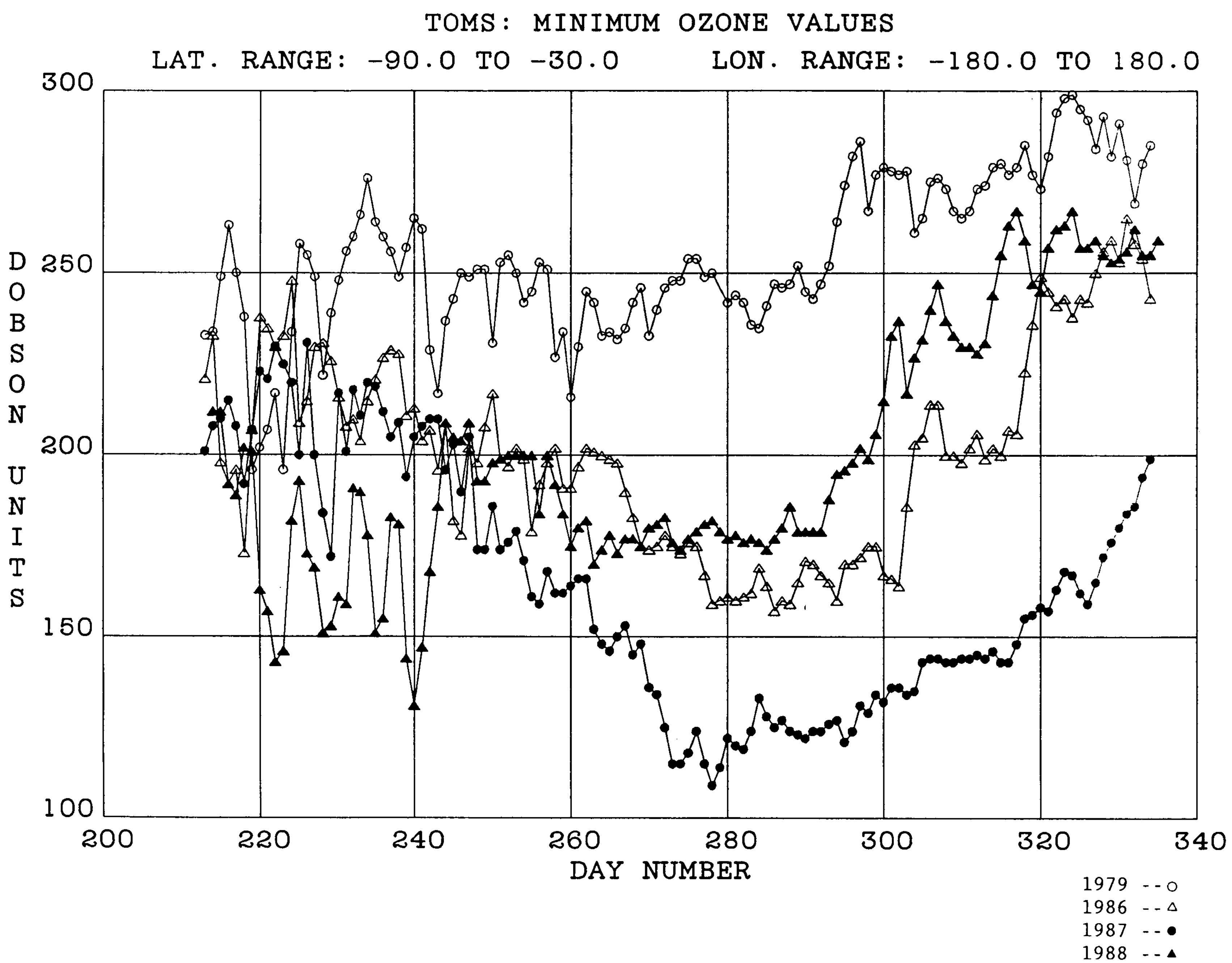


Figure 4b. Daily southern hemisphere ozone minimum for the period August 1 through November 30 of the years 1979, 1986, 1987, and 1988.

maximum values is apparent for all four years. However, in general, after day 250, the maxima for 1979 exceed those for the other three years. The maxima for 1987, the year of the most pronounced ozone hole, are generally lower than those for the other three years. The year 1988 shows stronger maxima early in the period, while after day 300, its maxima almost become indistinguishable from 1986 and 1987.

More pronounced differences are identifiable in Figure 4b, the daily minimum values. Prior to day 245, 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. In fact, 1988 as well as 1979 saw their absolute minimum during this period (day 240). As noted above, these extreme minima in August may be artifacts due to screening of lower stratospheric ozone by high clouds. The minima for 1979 are generally higher than the other three years during this time.

After day 245, the mature ozone hole begins to form. This results in a somewhat steady decline to a minimum value between days 260 and 290, 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. 1986 shows a pronounced decline to a minimum of 157 DU on day 286. The year 1987 drops dramatically to 109 DU on day 278, while 1988 reaches a minimum of 170 DU quite early on day 263. During the recovery phase after day 290, the minimum values for 1979 are greater than those for the other three years, while those for 1987 are lowest. By the end of the period, 1979, 1986, and 1988 have comparable minima, while 1987 is still far below.

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16. Abstract

Because of the great environmental significance of ozone and to support continuing research at McMurdo, Syowa, and other southern hemisphere stations, the development of the 1988 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 17, 1988. Although total ozone in mini-holes briefly dropped below 150 DU in late August, the main ozone hole is seen to be much less pronounced than in 1987. Minimum values, observed in late September and early October 1988, were seldom less than 175 DU. Compared with the same period in 1987, when a pronounced ozone hole whose minimum value of 109 Dobson Units (DU) was the lowest total ozone ever observed, the 1988 ozone hole is displaced from the South Pole, opposing a persistent maximum with values consistently above 500 DU. Daily ozone values above selected southern hemisphere stations are presented, along with comparisons of the 1988 ozone distribution to that of other years.

17. Key Words (Suggested by Author(s))
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