The Ozone Hole . . . Montreal Protocol

GEOG/ENST 3331 – Lecture 17

Ahrens: Chapter 18; Turco: Chapter 13

The Ozone Hole

- **Polar stratospheric clouds**
  - **Polar vortex**
  - **Cloud formation**
- Chlorine at the poles
- Remediation

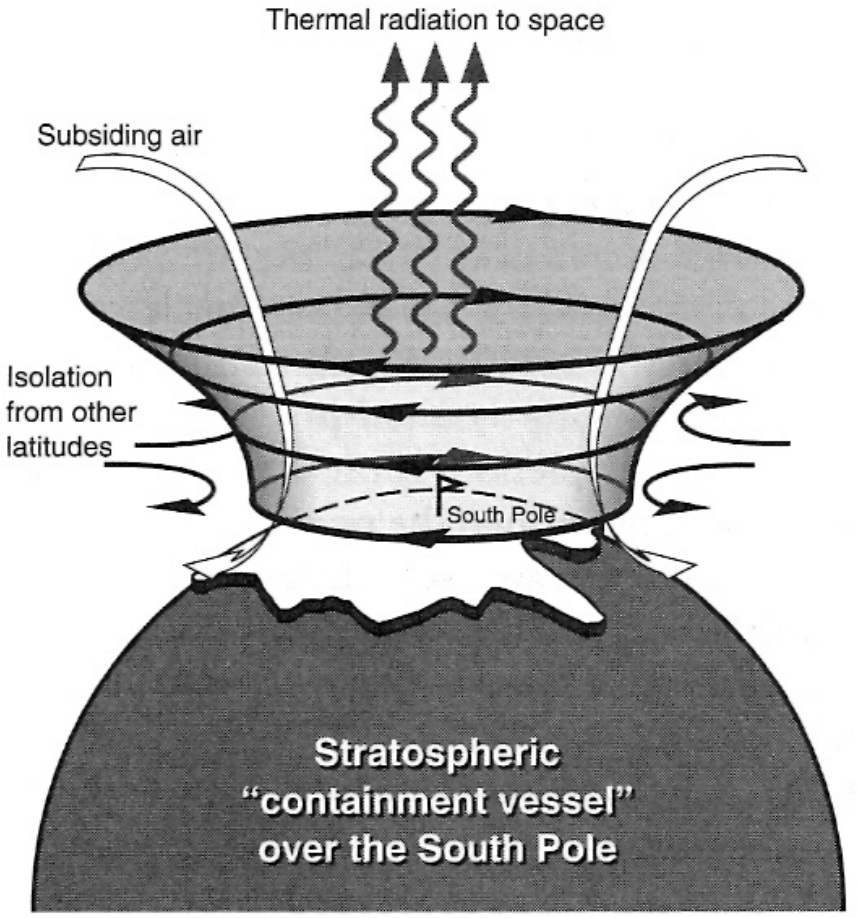
Polar stratosphere

- No insolation during the winter
  - Large temperature gradient develops
  - Large pressure gradient results

- Low pressure over poles in stratosphere
  - Geostrophic winds circle the pole
  - Intensifies all winter

Polar vortex

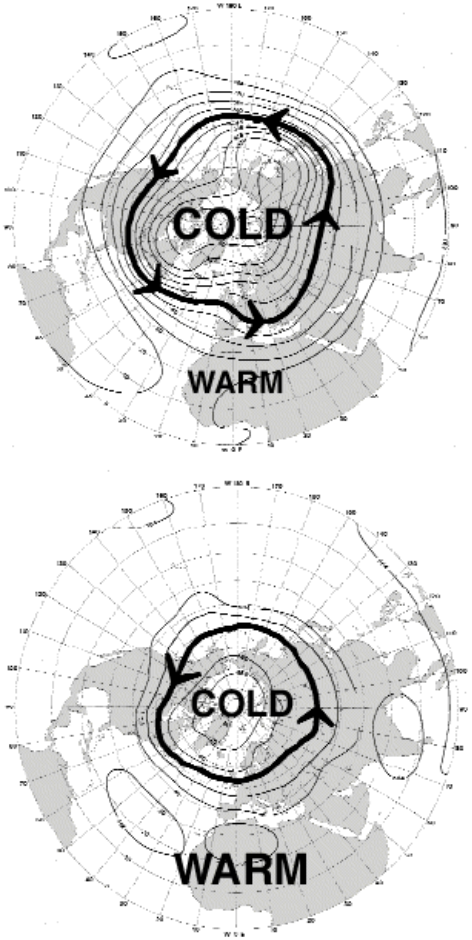
- Barrier to mixing
- Antarctic vortex is particularly strong
  - -93°C
  - Winds up to 300 km/hr
  - Arctic vortex is somewhat weaker because of alternating land and ocean below



Turco: Figure 13.24

Polar vortex

- Pole is isolated until spring
  - No warm air can mix in
- Winds reverses direction in summer (much weaker)
- During the reversal, rapid mixing can occur



Polar stratospheric clouds (PSC)

- Composed of :
  - Type 1: Frozen nitric acid (HNO_3)
  - Type 2: Ice
- Caused by extreme cooling:
  - < -73°C (Type 1)
  - < -78°C (Type 2)

Nacreous cloud

Chlorine in the stratosphere

$$Cl + O_3 \rightarrow ClO + O_2$$
$$ClO + O \rightarrow Cl + O_2$$

Net: $O + O_3 \rightarrow 2O_2$

- But eventually:

  $$Cl + CH_4 \rightarrow HCl + CH_3$$
  $$ClO + NO_2 \rightarrow ClONO_2 \text{ (chlorine nitrate)}$$

- 99% of chlorine in the stratosphere is HCl or $ClONO_2$

Polar stratospheric clouds

1. Suck HNO_3 out of air
   - Draws down NO_2 concentration
   - Less chlorine nitrate production to remove Cl
2. Provide solid surfaces for chemical reactions:

$HCl + ClONO_2 \rightarrow Cl_2 + HNO_3$

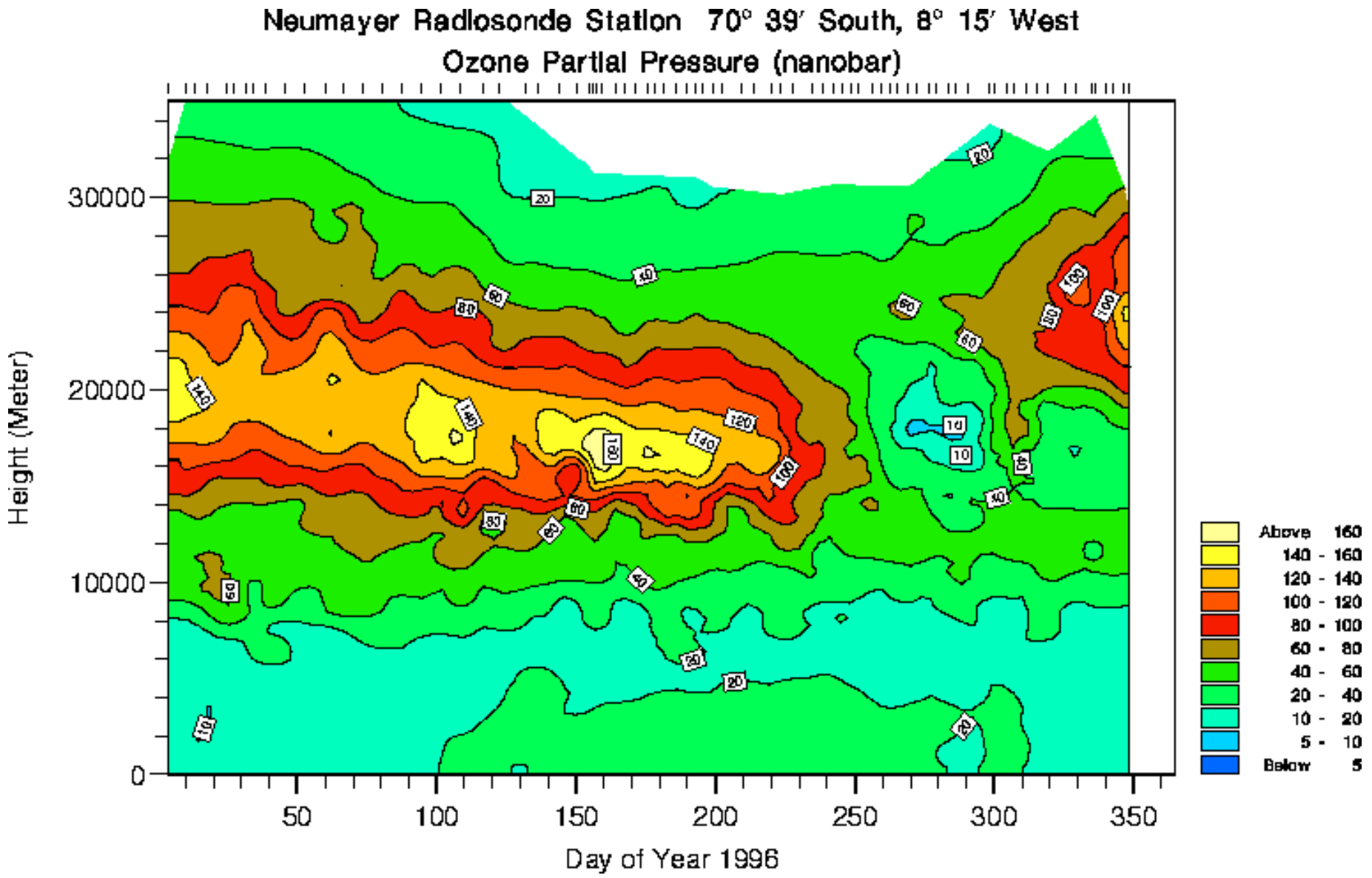
- *When sunlight returns*:

$Cl_2 + UV \rightarrow Cl + Cl$

  - Concentration of reactive Cl increases 100 times in the polar spring

The Ozone Hole

- Antarctic winter: high levels of Cl_2
- Antarctic spring:
  - Cl_2 split into Cl
  - O_3 concentration drops 90% in a few weeks
- Eventually:
  - Polar vortex breaks down
  - O_3 and NO_2 replenished from lower latitudes


Neumayer Radiosonde Station 70° 39′ South, 8° 15′ West
Ozone Partial Pressure (nanobar)
Height (Meter)
30000
20000
10000
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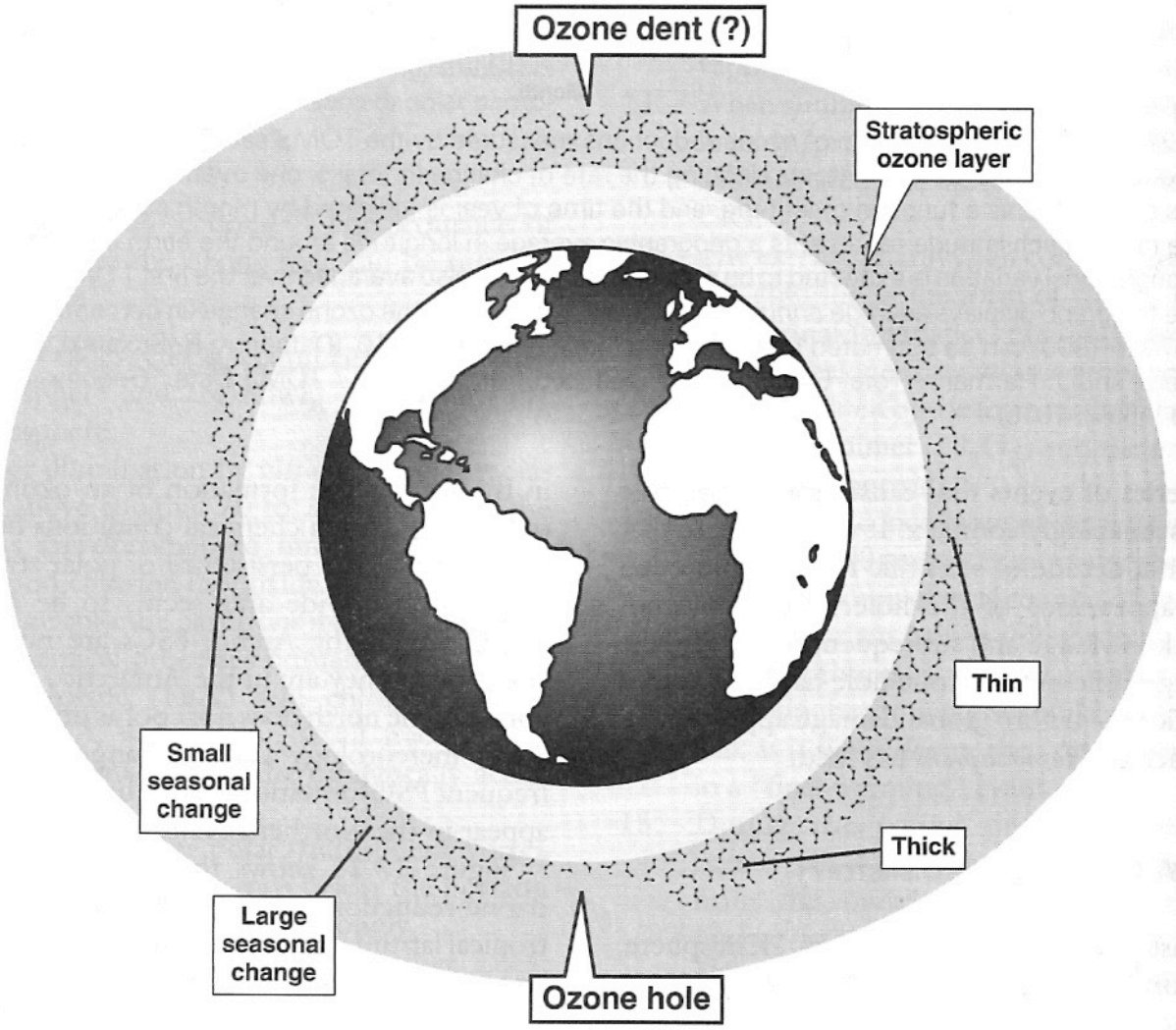
Day of Year 1996
Above 160
140 - 160
120 - 140
100 - 120
80 - 100
60 - 80
40 - 60
20 - 40
10 - 20
5 - 10
Below 5

Lecture outline

- Polar stratospheric clouds
- Chlorine at the poles
- **Remediation**
  - **The Montréal Protocol**

Global ozone depletion



Turco: Figure 13.29

International negotiation

- 1985 Vienna Convention for the Protection of the Ozone Layer

- 1987 Montréal Protocol on Substances that Deplete the Ozone Layer
  - Reduce CFC emissions by 50% by 2000
  - Further cuts to be negotiated

1987 Montréal Protocol

- Agreed on 16 September 1987; entered into force on 1 January 1989
  - Reduce CFC emissions by 50% by 2000
  - Further cuts to be negotiated
- Eight revisions to date
  - As a result of the international agreement, the ozone hole in Antarctica is slowly recovering.
  - Climate projections indicate that the ozone layer will return to 1980 levels between 2050 and 2070

Substitution for CFCs

- Some easy
  - Aerosol propellants
  - Fire extinguishing
  - Solvents (e.g. dry cleaning)
- Some more difficult
  - Coolants
    - HCFCs, HFCs

Montreal Protocol Multilateral Fund

- To assist developing country parties to the Montreal Protocol to comply with the control measures of the Protocol.
- whose annual per capita consumption and production of ozone depleting substances (ODS) is less than 0.3 kg

1987 Montréal Protocol

- Two ozone treaties have been ratified by 197 parties, which making them the first universally ratified treaties in United Nations history
- Between the basic scientific research discovery in 1973 and the international agreement signed 1987 only 14 years lapsed.

The path taken

- 1985 Vienna Convention for the Protection of the Ozone Layer

- 1987 Montréal Protocol on Substances that Deplete the Ozone Layer
  - Reduce CFC emissions by 50% by 2000
  - Further cuts to be negotiated

International negotiation

However, the hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) contribute to anthropogenic global warming. On a molecule-for-molecule basis, these compounds are up to 10,000 times more potent as greenhouse gases than carbon dioxide. The Montreal Protocol currently calls for a complete phase-out of HCFCs by 2030, but does not place any restriction on HFCs. Since the CFCs themselves are equally powerful greenhouse gases, the mere substitution of HFCs for CFCs does not significantly increase the rate of anthropogenic global warming, but over time a steady increase in their use could increase the danger that human activity will change the climate.

Treaty on ozone depleting substances

- Club-within-a-club:
  - 1987: Montréal Protocol has 24 parties
    - 1989: small group of countries move from 50% reduction to 100%
  - 1990: London Amendments
    - 93 countries agree to new targets

Montréal Protocol

- Continued ratcheting:
  - 1992: Copenhagen Amendments
    - Sped up targets, especially bromine compounds (halons)
    - Cap on HCFCs
  - 2007 adjustment:
    - 200 countries agreed to eliminate HCFCs by 2020

Montréal Protocol

- Differential obligations
  - Article 5 countries (LDCs) have delayed targets
  - Eg. 2030 for HCFCs

- Multilateral fund:
  - Direct and indirect funding
  - Over 1991-2005, US$2.1 billion

Outcomes

Very successful treaty

- High compliance
- CFC production has almost ceased
- CFC concentrations have decreased
- Ozone layer shows some signs of recovery

Action

- Sources – easily identifiable – DuPont
- Replacements readily available
  - CO2 as propellant in aerosols
  - HFCs, HCFCs used as coolants
  - Lemon juice as solvent for cleaning electronics
- Economically inexpensive

The Road not Taken

- "The Road Not Taken", featured in *Mountain Interval* (1916) a collection of poems by Robert Frost, seems to be a fairly simple homily about making choices:

"Two roads diverged in a yellow wood,

…

I took the one less traveled by,

And that has made all the difference."

A Road avoided

- **As of the end of 2009, the Parties to the Protocol had phased out the consumption of 98% of all of the chemicals controlled by the Protocol**

Health benefits

It is estimated that the global community avoids millions of cases of fatal skin cancer and tens of millions of cases of non fatal skin cancer and cataracts.

A Road avoided (cont.)

Health benefits

In the United States the EPA estimates that by the

year 2165 more than 6.3 million skin cancer deaths will have been avoided and saved it an estimated $4.2 trillion in health care costs during 1990–2165.

Health benefits

more than 22 million additional cataract cases will be avoided for Americans born

between 1985 – 2100 due to Montreal Protocol

What would have happened to the ozone layer if CFCs had not been regulated?

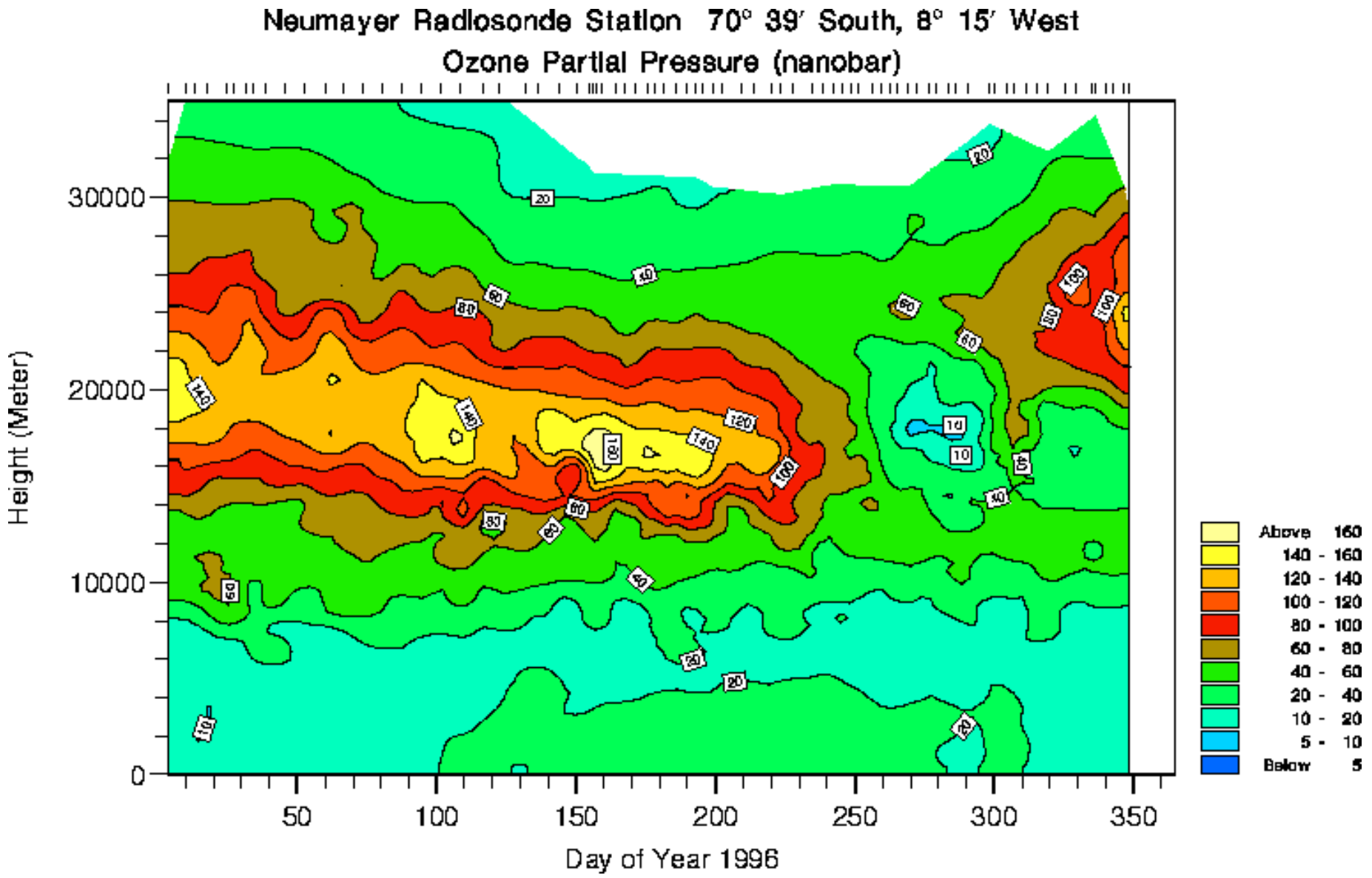
"We simulated a world avoided, and it's a world we should be glad we avoided."

"The Montreal Protocol is a remarkable international agreement that should be studied by those involved with global warming and the attempts to reach international agreement on that topic."

Source: Newman, Stolarski et al. (2009). What would have happened to the ozone layer if chlorofluorocarbons (CFCs) had not been regulated? Atmospheric Chemistry and Physics, 9(6), 2113-2128.

Remaining causes for concern

- CFCs will still be present for a long time
- Very high altitude aircraft would exacerbate the problem
- Stratosphere is cooling as a result of increasing CO_2
  - Could lead to Arctic ozone hole
  - Could also lead to decreased ozone levels over heavily populated areas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Ozone Partial Pressure (nanobar)
Height (Meter)
30000
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Day of Year 1996
Above 160
140 - 160
120 - 140
100 - 120
80 - 100
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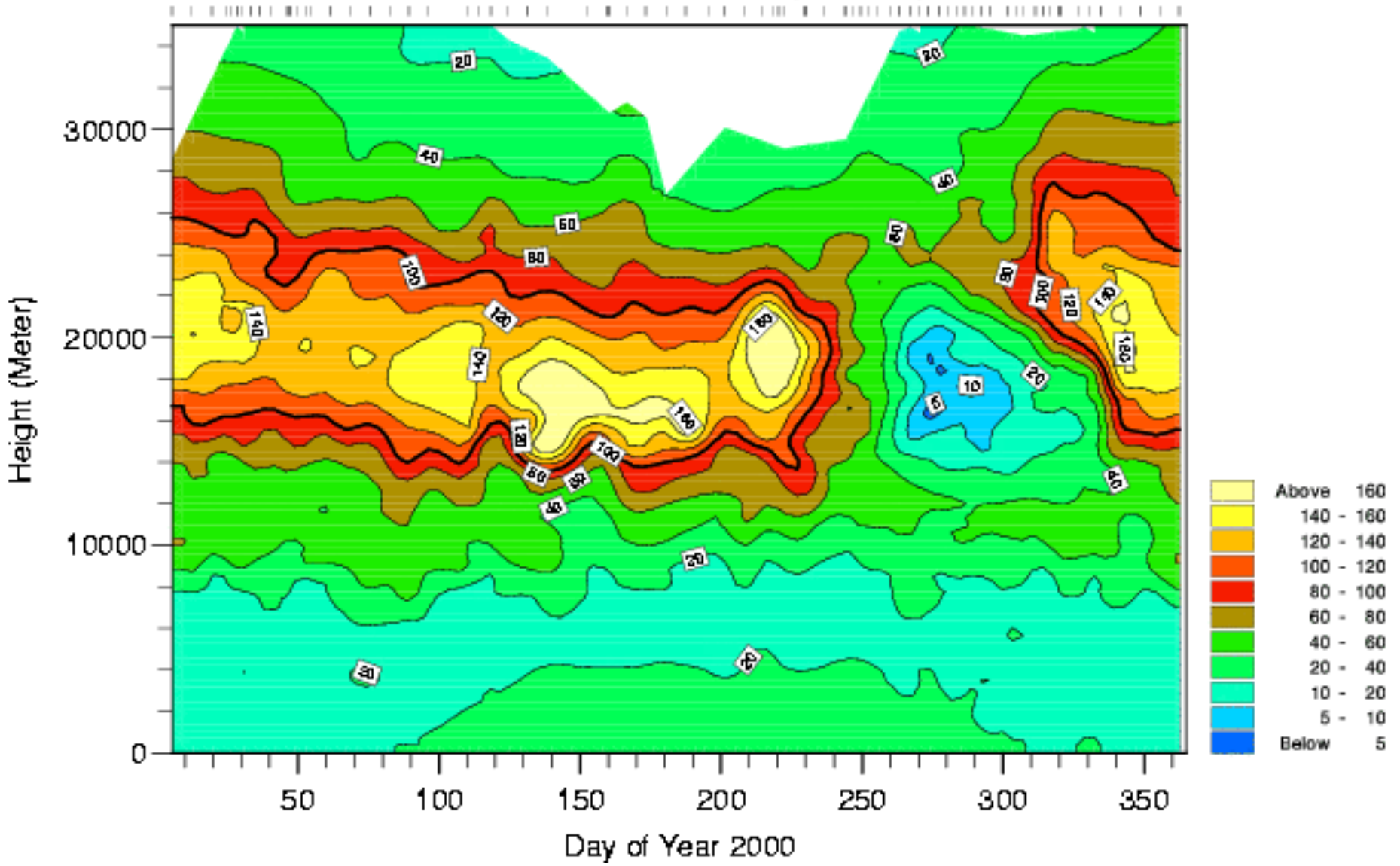
5 - 10
Below 5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Ozone Partial Pressure (nanobar)
Height (Meter)
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Day of Year 2000
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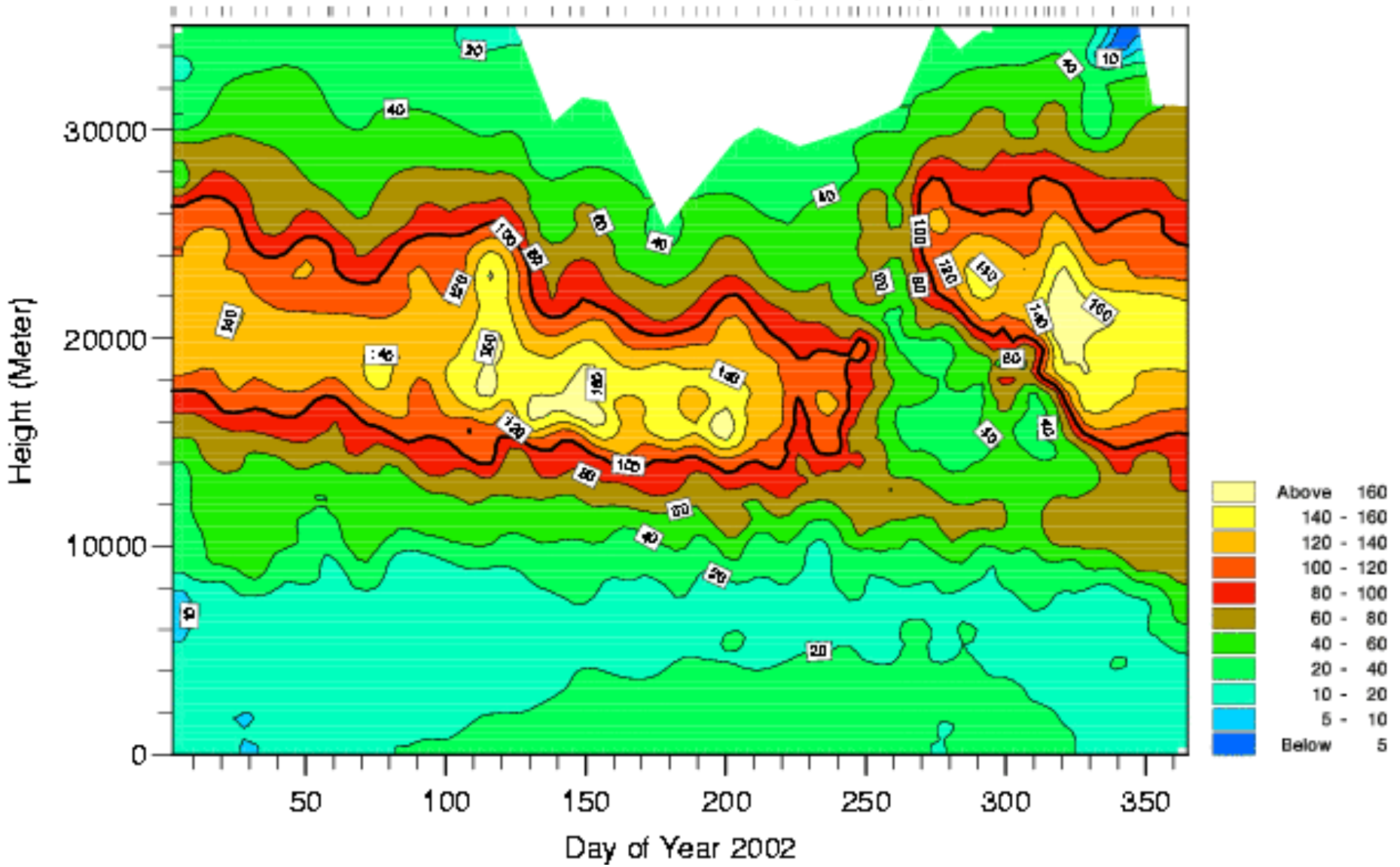
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Ozone Partial Pressure (nanobar)
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Day of Year 2002
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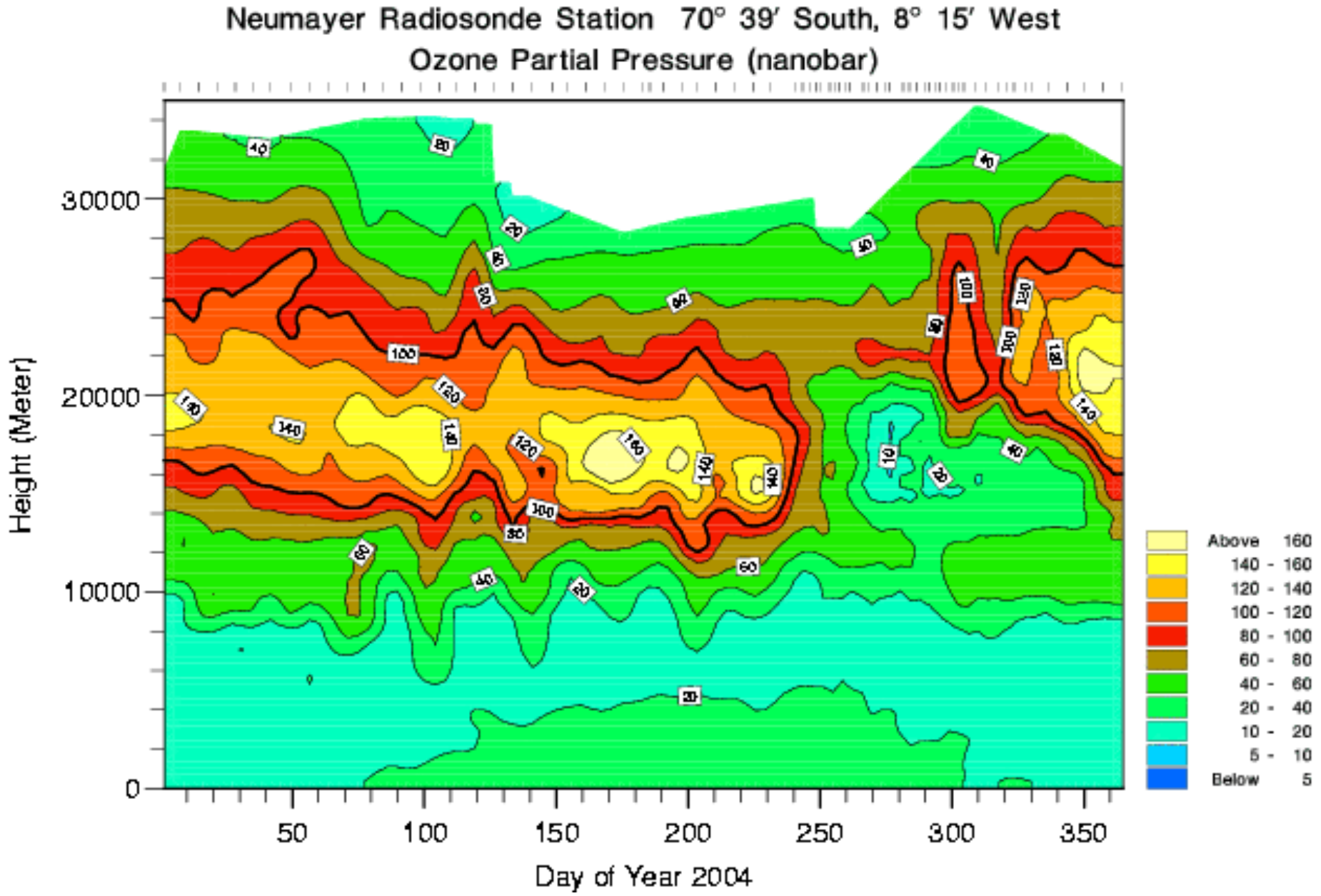
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Ozone Partial Pressure (nanobar)
Height (Meter)
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Day of Year 2004
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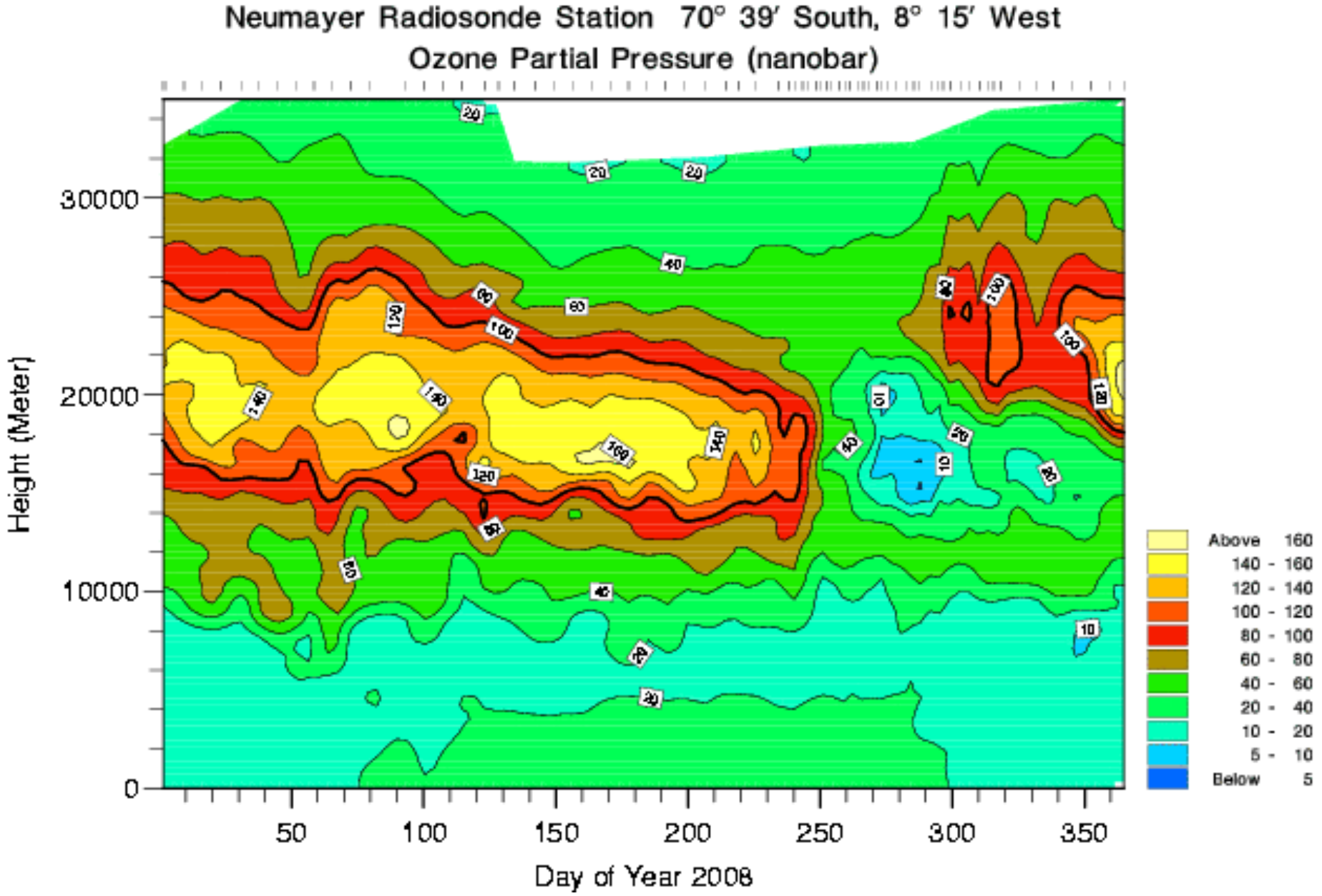
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Ozone Partial Pressure (nanobar)
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Day of Year 2008
Above 160
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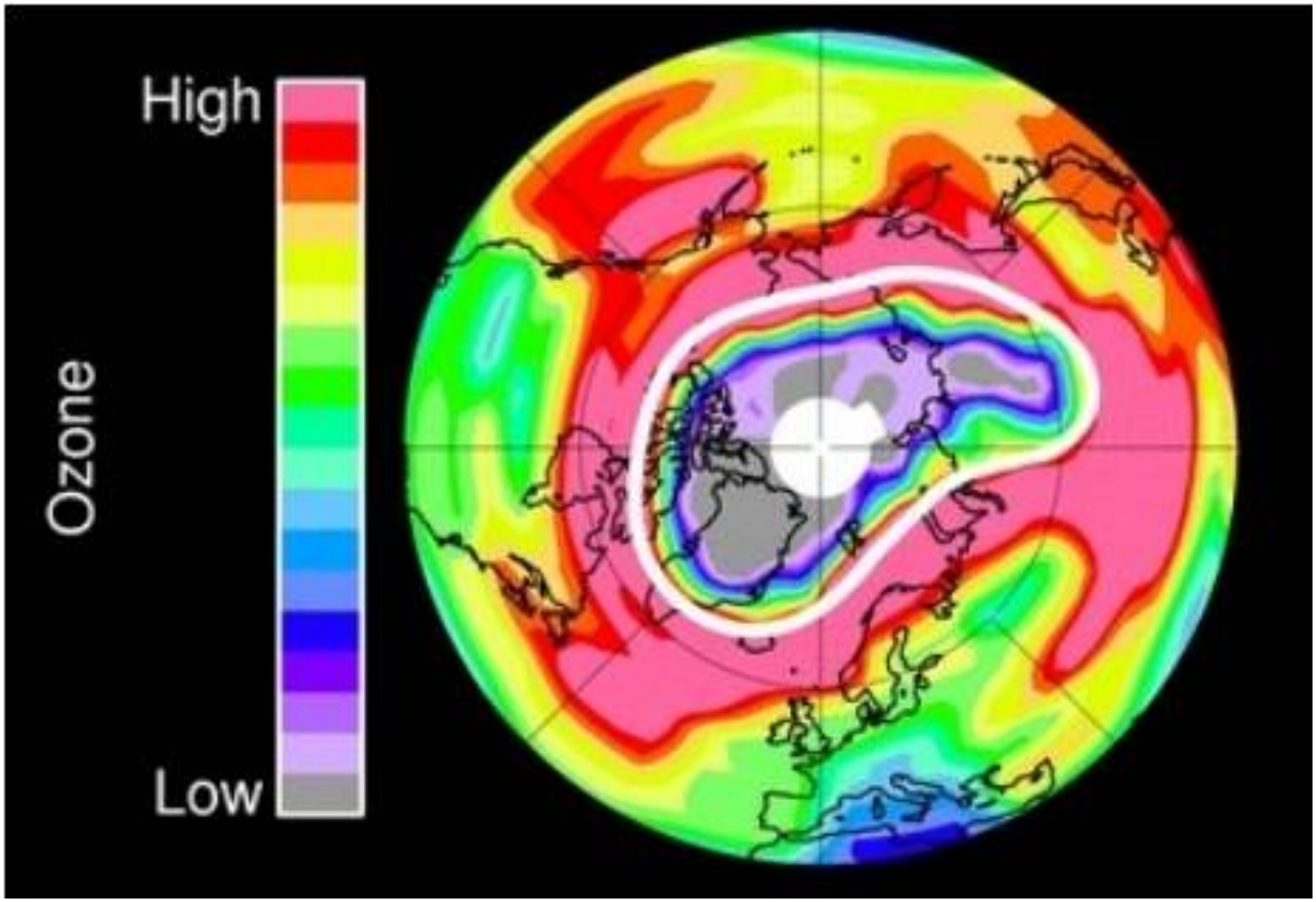
5 - 10
Below 5

2011: Arctic Ozone Hole



Arctic Ozone Hole

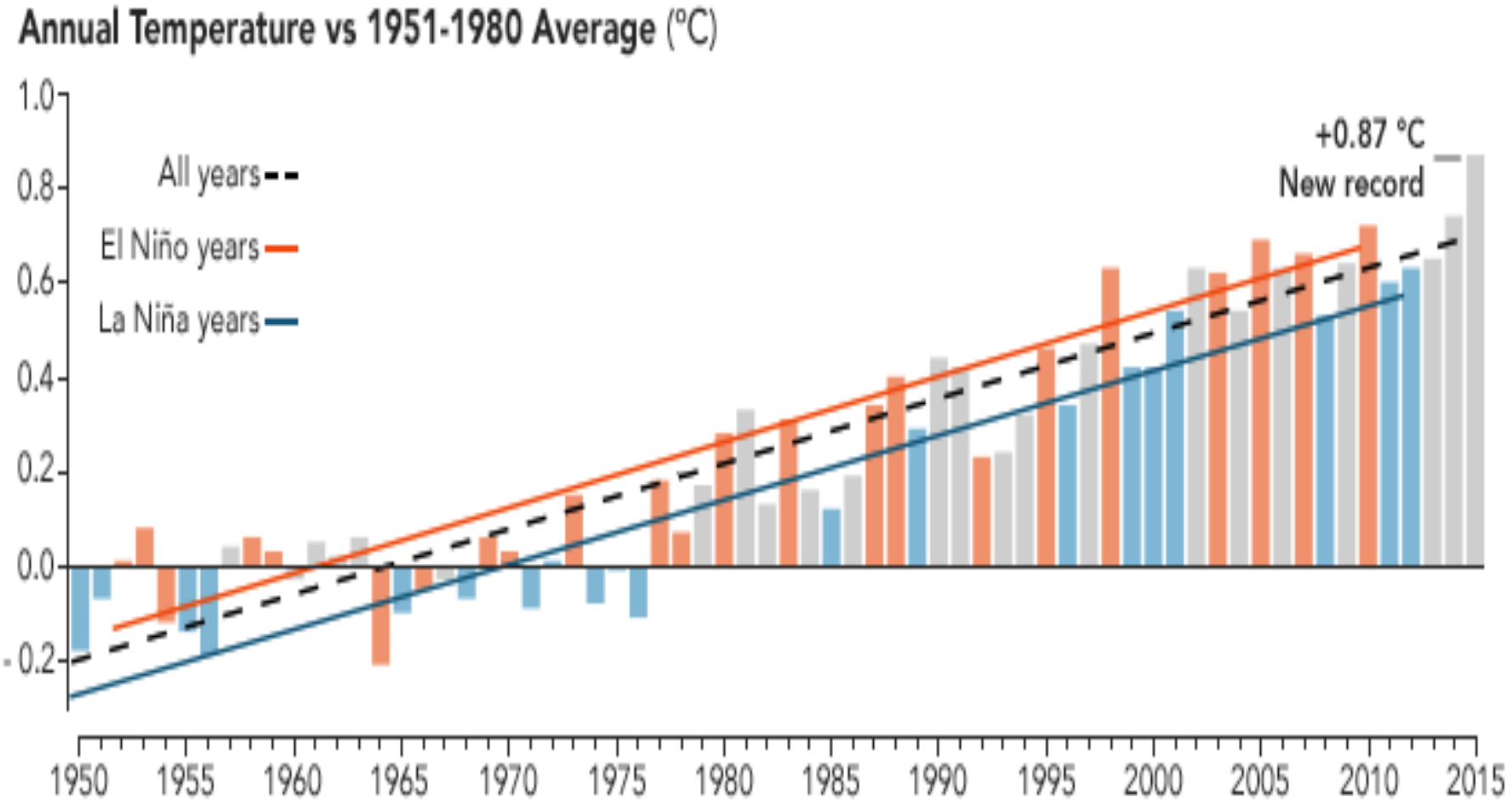
- Ozone levels dropped by 80%
  - Comparable to Antarctic hole
  - Twice as much as ever recorded previously
- 2 million km^2
  - Twice the area of Ontario
- Product of unusually cold stratosphere

Other concerns

- CFCs are potent greenhouse gases
- HCFCs and HFCs are *also* potent greenhouse gases
  - Also have long atmospheric residence times

- Alternatives that are friendly to both the ozone layer and climate have yet to be developed

Instrumental temperature record 1950-2015



Zero line is 1951-1980 average global temperature

Coming up!

Global

Climate Change

1800: 13.6° C

1880: 13.7° C

1920: 13.7° C

1965: 14.0° C