Stratospheric ozone & Arctic ozone losses

1. Background

The stratosphere, ozone and UV radiation

3. The ozone balance in the stratosphere

2. Antarctic ozone hole observations

4. Theory of the Antarctic ozone hole

5. Global ozone, Arctic ozone, & SOLVE

6. Ozone and the future

General Ozone Facts

1. Ozone = O_3

2. Ozone is mainly in the stratosphere.

3. Ozone concentrations are small (at STP would form a layer 3 mm in depth).

4. Absorbs ultraviolet light.

5. Heats the stratosphere.

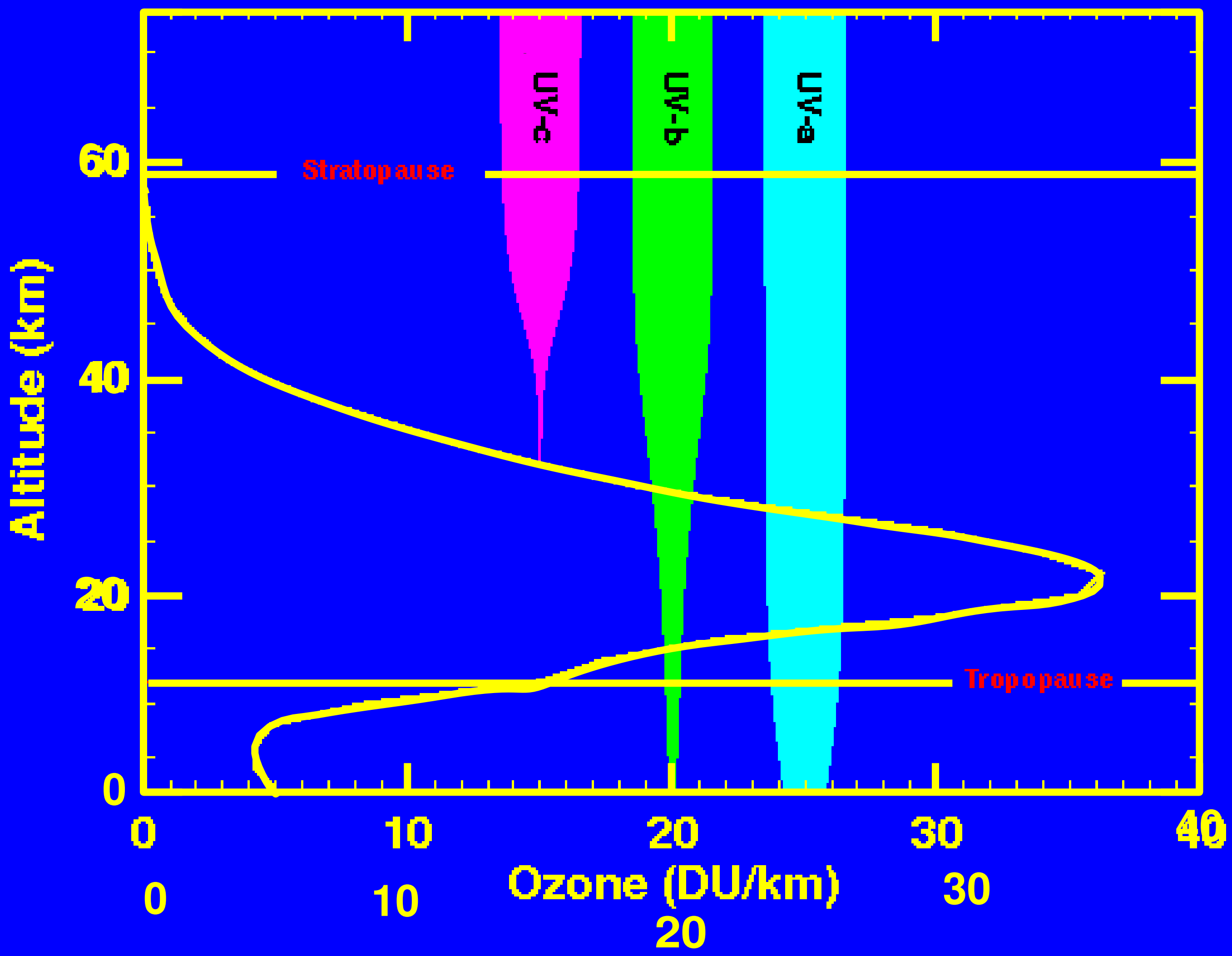
6. Absorption of UV by ozone is necessary for life.

Why do we care about stratospheric ozone levels?

Ozone absorbs nearly all the biologically damaging solar ultraviolet radiation before it reaches the Earth's surface.

Ozone and trace gases such as methane, nitrous oxide, and the chlorofluorocarbons profoundly influence the habitability of the Earth even though together they comprise less than one percent of the Earth's atmosphere.

NASA is congressionally mandated to study atmospheric ozone by the Clean Air Act of 1977.



UV–c is completely absorbed by ozone
UV–b is almost completely absorbed by ozone
UV–a is weakly absorbed by ozone and scattered.

Results of Ozone Depletion

1. More skin cancer

2. Damaged immune systems

3. Crop damage

4. Decrease of phytoplankton (affects the ocean food chain)

Note: Increase ozone and other pollutants in the troposphere (lower atmosphere) can offset some of these effects, but with unhealthful side effects.

Ozone historical timeline

1840: Ozone discovered by Schönbein

1879: Cornú discovers the solar spectrum UV cutoff at 300 nm

1880: Hartley shows that the UV cutoff results from ozone

1913: Fabry and Buisson deduce the amount of ozone in the atmosphere from the UV cutoff

1918: Strutt shows that most ozone is located above the surface in the upper atmosphere

1926: Dobson builds simple spectrophotometers that begin making regular observations

1930: Midgley discovers the Chlorofluorocarbon (CFC)

1930: Chapman proposes the first theory on the vertical distribution of ozone (UV production, O_X loss mechanism)

1949: Brewer and Dobson separately propose a circulation that explains the latitudinal distribution of ozone.

1964: Hampson proposes ozone loss mechanism by HO_X

1970: Crutzen proposes ozone loss mechanism by NO_X

1974: Stolarski and Cicerone propose ozone loss by Cl_X

1974: Molina and Rowland suggest CFCs can lead to ozone loss

1985: Farman, Gardiner, and Shanklin discover the Antarctic ozone hole

http://hyperion.gsfc.nasa.gov/Personnel/people/Stolarski,_Richard_S./history.html

The ozone balance

☛ Ozone is produced when UV radiation breaks apart oxygen molecules.

☛ Ozone absorbs ultraviolet radiation & converts this radiation into heat.

☛ Ozone is catalytically destroyed by reactions which involve the oxides of chlorine, hydrogen, nitrogen, and bromine*.

* Increasing the oxides of chlorine, hydrogen, nitrogen, and bromine removes more ozone, leading to smaller concentrations of ozone. Likewise, decreasing the concentrations of the oxides, increases ozone

The ozone balance

- ☞ Oxygen molecules are broken apart by UV radiation (200–220 nm)

$$O_2 + h\upsilon \text{ (a photon)} \Rightarrow O + O$$

- ☞ Ozone is formed by these oxygen atoms:

$$O + O_2 \Rightarrow O_3$$

- ☞ Ozone removes UV in a cyclic process by:

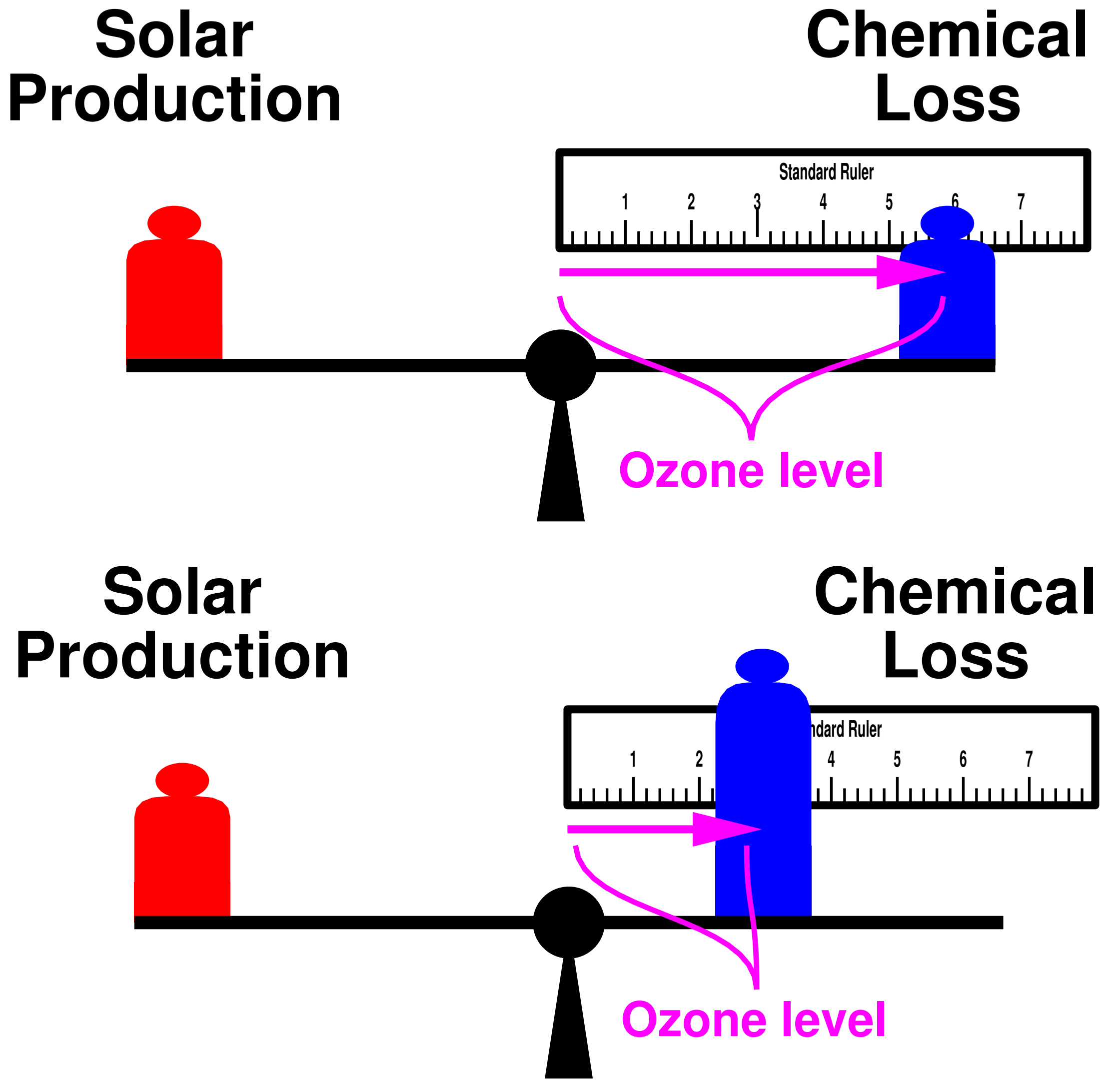
$$O_3 + h\upsilon \text{ (a photon)} \Rightarrow O + O_2$$
$$O + O_2 \Rightarrow O_3$$
$$\text{Net = removal of } h\upsilon \Rightarrow \text{heats stratosphere}$$

- ☞ Ozone is destroyed by:

$$O_3 + X \Rightarrow XO + O_2$$
$$O + XO \Rightarrow O_2 + X$$
$$\text{Net: } O_3 + O \Rightarrow 2 \cdot O_2$$

✧ X can be either Cl, NO, Br, OH.
✧ Increasing X removes more O_3

Ozone Balance



1. production and loss approximately balance.

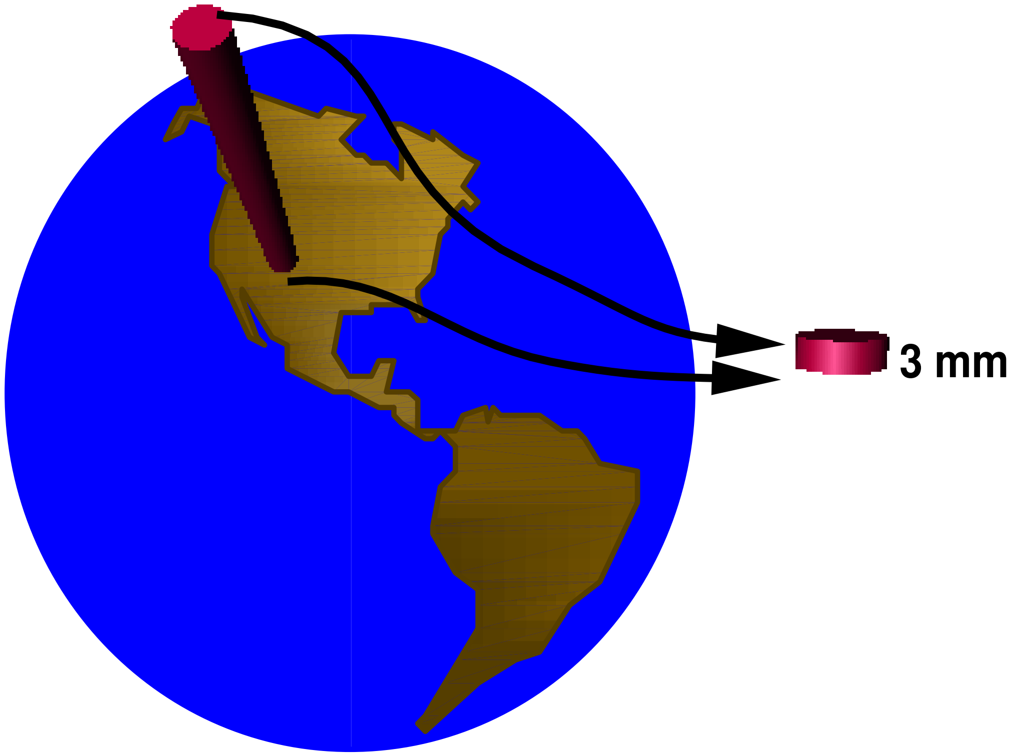
2. As the Cl_X level increases the O_3 level must decrease to maintain the balance

1. $P = k\, O_3\, Cl_X$ ➡ 2. $P/(k\, Cl_X) = O_3$

What are CFCs?

- CFC stands for ChloroFluoroCarbon.
- Their DuPont trade name is Freon. Their Allied Chemical trade name is Genetron
- They are methane or ethane with hydrogen replaced by chlorine and fluorine.
- CFC–12 is CF_2Cl_2. It has been the predominant refrigerant in automobile air conditioners.
- They are remarkably stable compounds invented in the 1930s by Midgley at DuPont. They are not soluble, don’t react, and don’t absorb visible or near UV radiation.

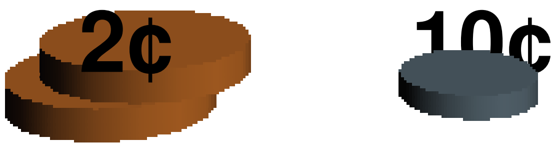
Dobson Units



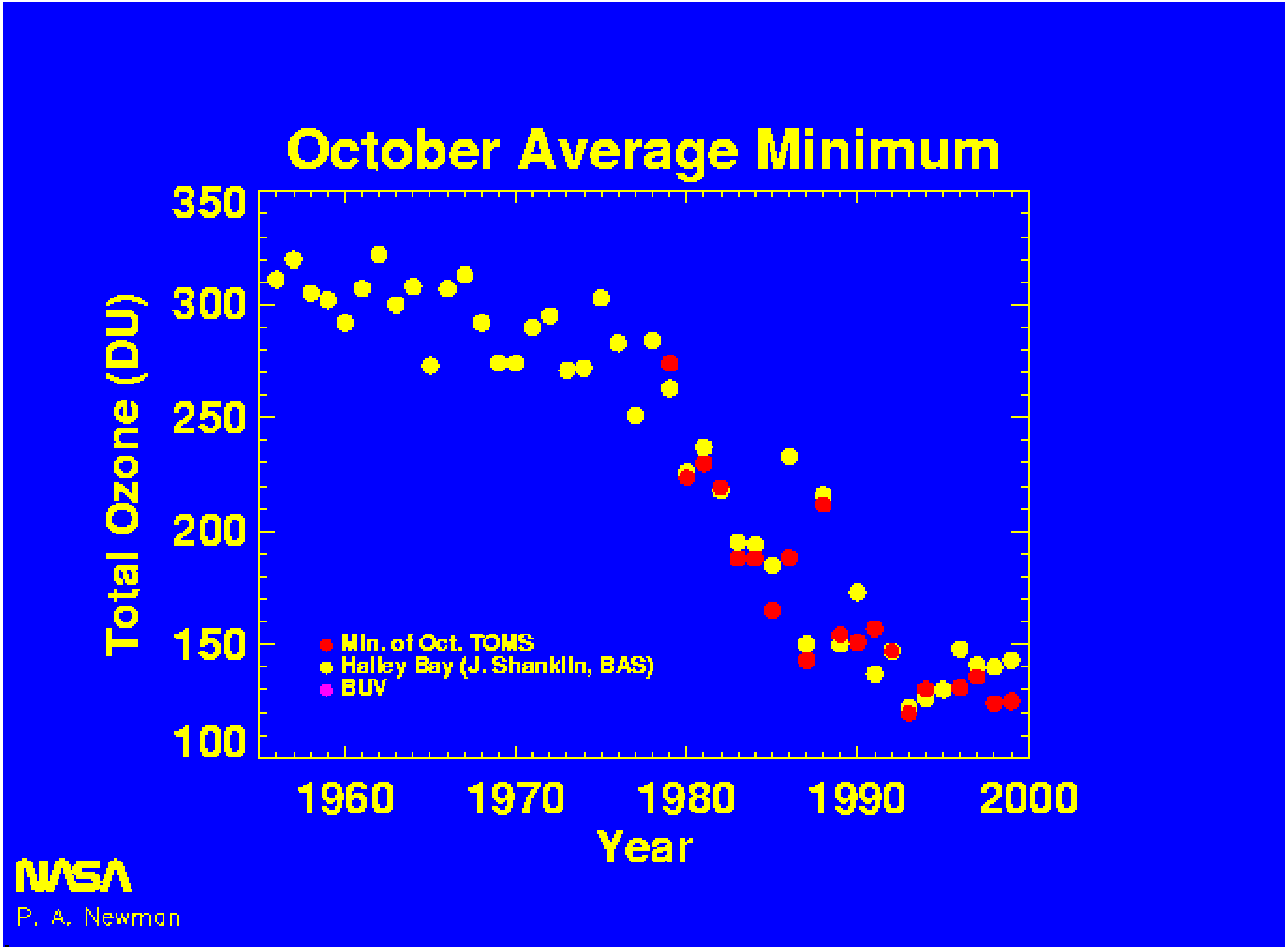
- Imagine that we could bring all ozone above a certain location down to the ground, at $0^{\circ}C$ and 1 atmosphere pressure.

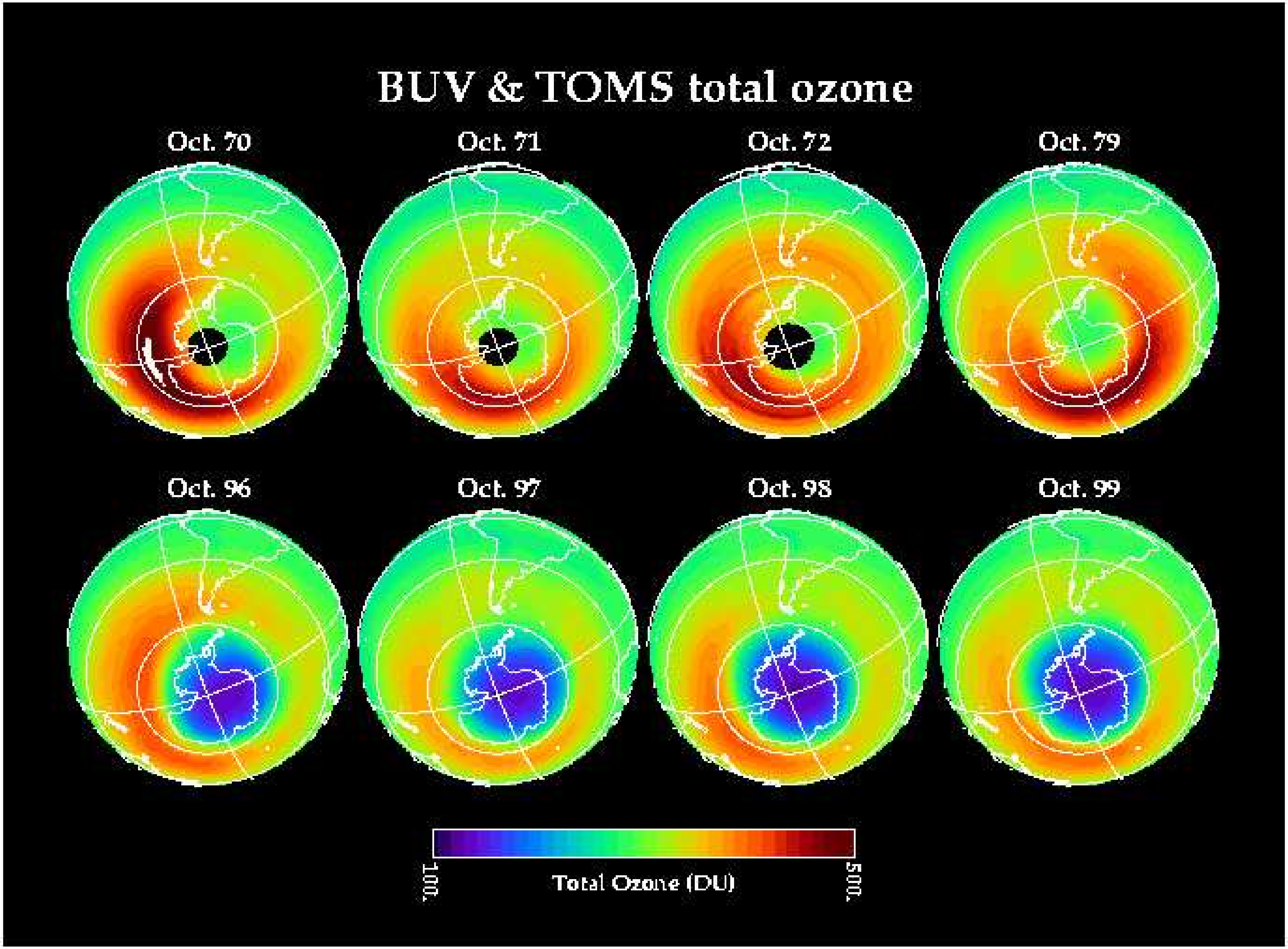
- The thickness of this layer is about 3 millimeters (~ 0.1 inch), the thickness of two stacked pennies. This corresponds to 300 Dobson Units (approximately the global average).

- 100 Dobson Units is 1 millimeter thick (approximately the thickness of ozone in the Antarctic ozone hole), the thickness of one dime.

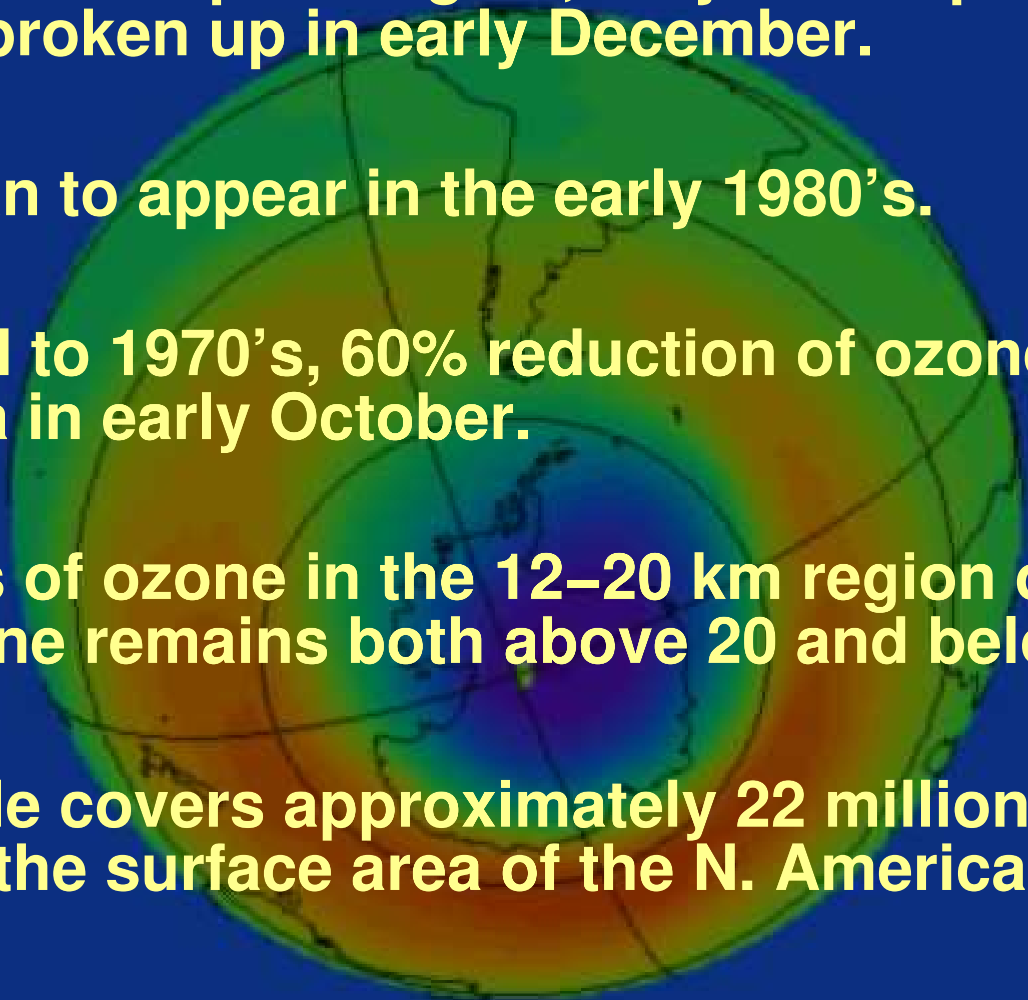


☞ **The Dobson Unit is a convenient unit of measurement for total column ozone.**


October Average Minimum
Total Ozone (DU)
350
300
250
200
150
100
1960
1970
1980
1990
2000
Year
Min. of Oct. TOMS
Halley Bay (J. Shanklin, BAS)
BUV
NASA
P. A. Newman


BUV & TOMS total ozone
Oct. 70
Oct. 71
Oct. 72
Oct. 79
Oct. 96
Oct. 97
Oct. 98
Oct. 99
100.
Total Ozone (DU)
500.

Ozone Hole Observations



- Begins to develop in August, fully developed by early October, broken up in early December.
- First began to appear in the early 1980’s.
- Compared to 1970’s, 60% reduction of ozone over Antarctica in early October.
- 100% loss of ozone in the 12–20 km region over Antarctica, some ozone remains both above 20 and below 12 km.
- Ozone hole covers approximately 22 million km^2 (slightly less than the surface area of the N. American continent).
- Ozone hole associated with cold Antarctic stratospheric temperatures.

Ozone Hole Theory

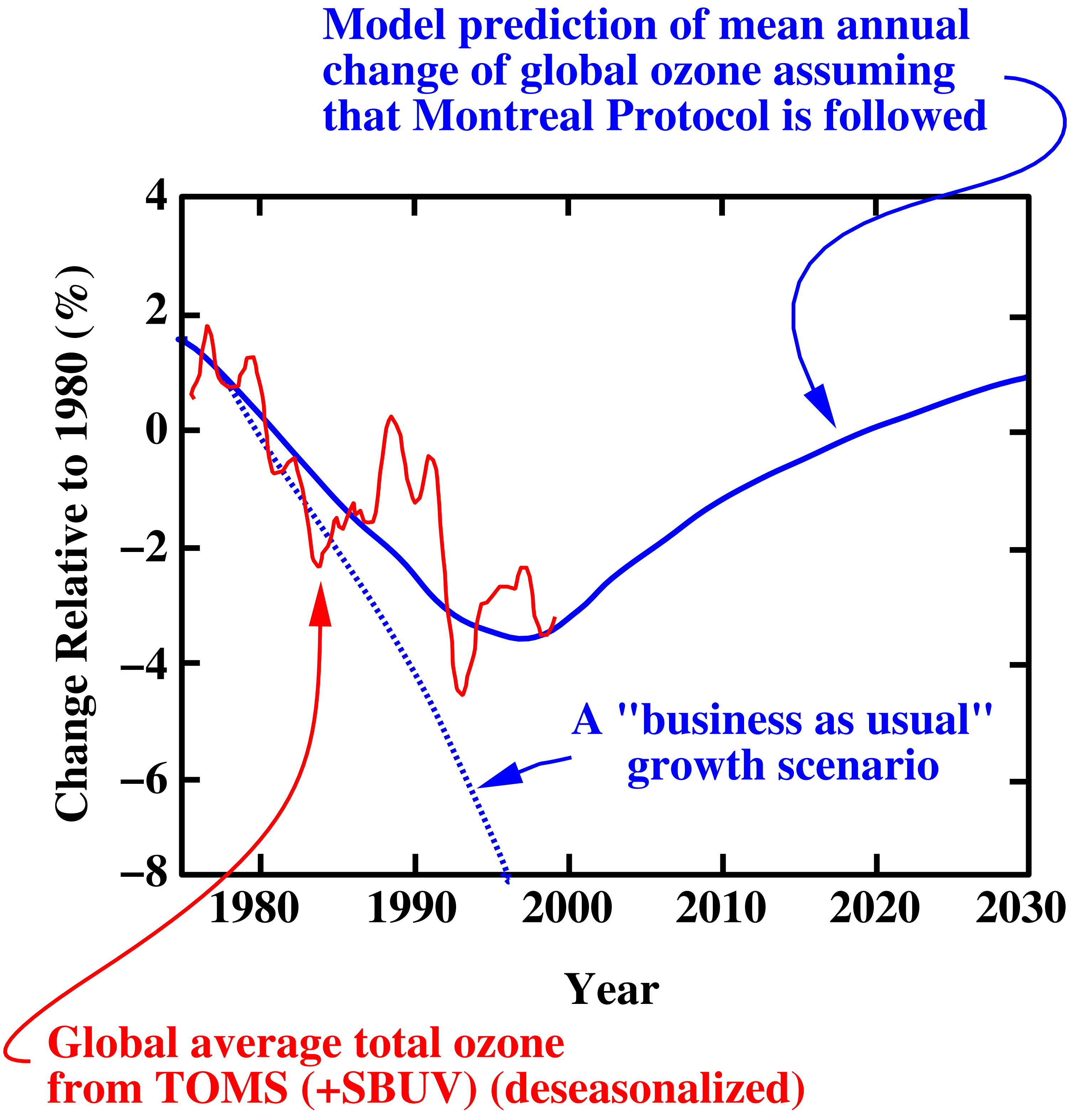
- Most chlorine in the stratosphere comes from CFCs and is in the form of HCl (hydrochloric acid) and $ClONO_2$ (chlorine nitrate). HCl and $ClONO_2$ do not react with ozone.

- Polar stratospheric clouds (PSCs) form in the cold winter conditions, and HCl and $ClONO_2$ react on the surfaces of these PSC particles to form Cl_2 (chlorine gas) and HNO_3 (nitric acid).

- Visible radiation breaks apart Cl_2 as the sun rises over Antarctica in the spring, and ozone is rapidly destroyed by Cl and Br catalytic reactions.

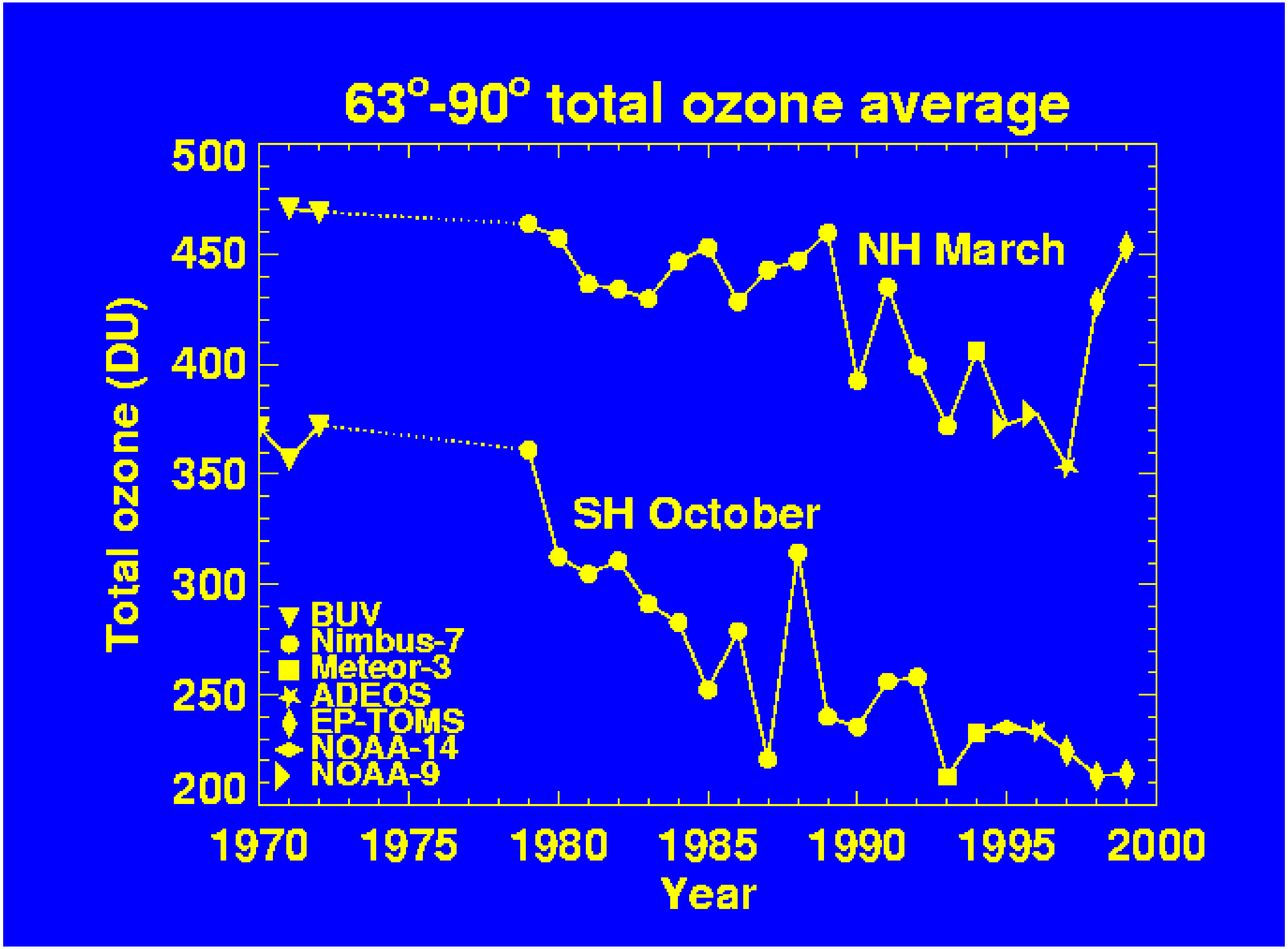
- O_3 loss continues until: 1) spring to summer warming halts formation of PSCs, 2) HNO_3 photolyzes in sunlight and NO_2 reacts with ClO to form $ClONO_2$, or 3) O_3 is completely gone.

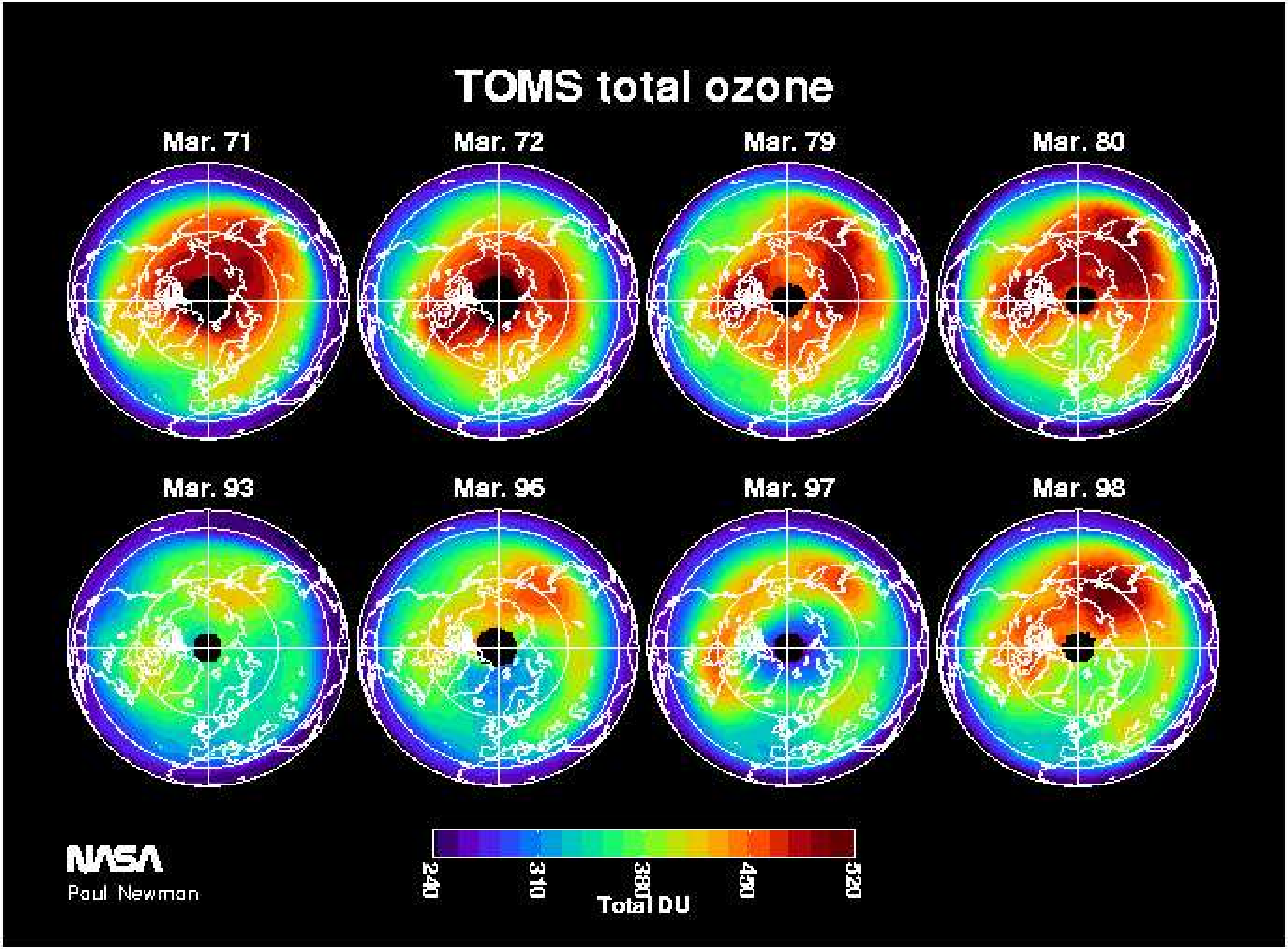
Illustration of the trend–reversal detection problem

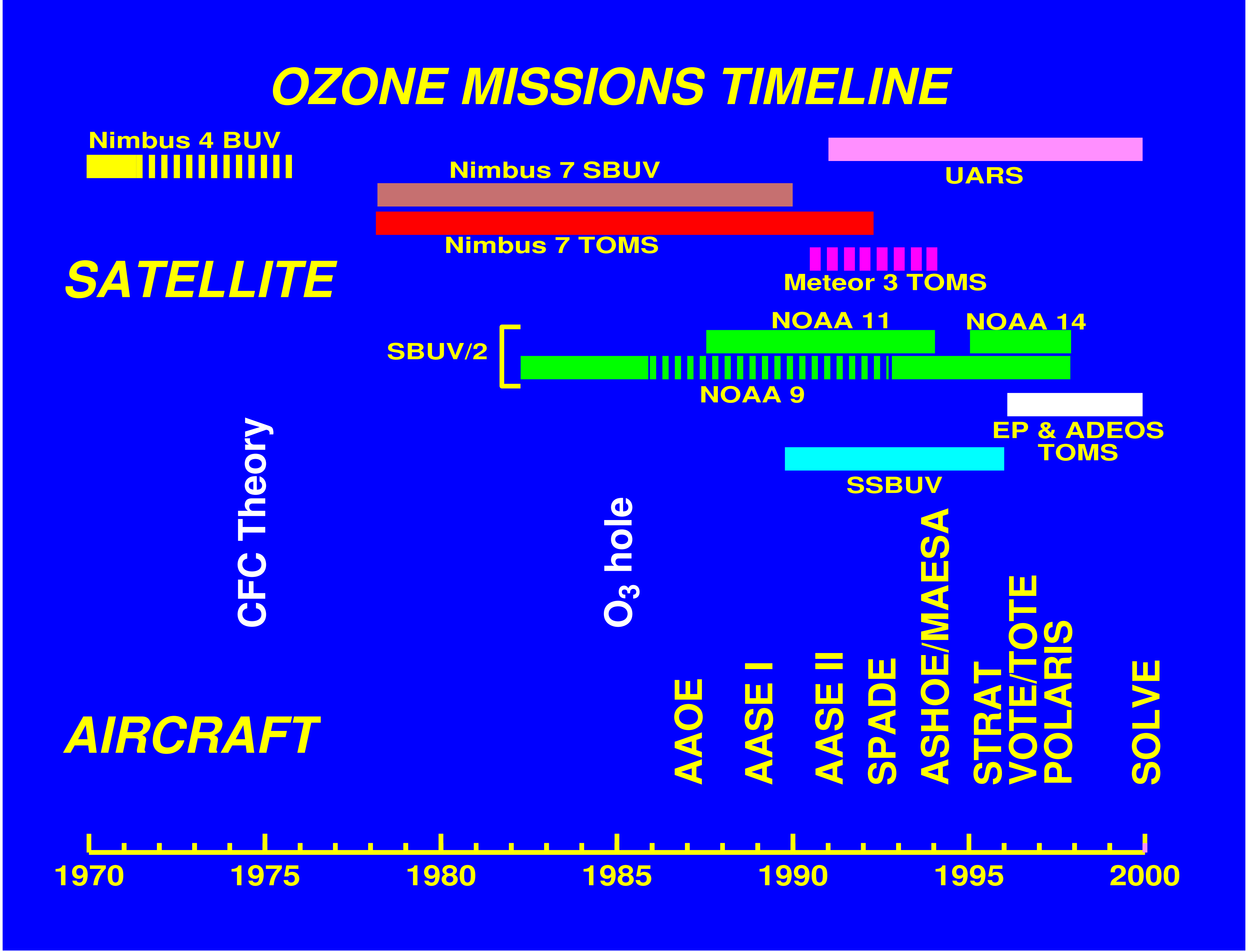


The Montreal Protocol

- Originally passed in Montreal in 1978
- Since amended in London, Copenhagen and Montreal
- Signed by more than 100 countries
- Phases out, then bans numerous long–lived CFCs
- Allows substitution of replacement HCFCs for a specified period of time, then phases them out
- Contains specific provisions for developing countries (slower phase outs, funding)

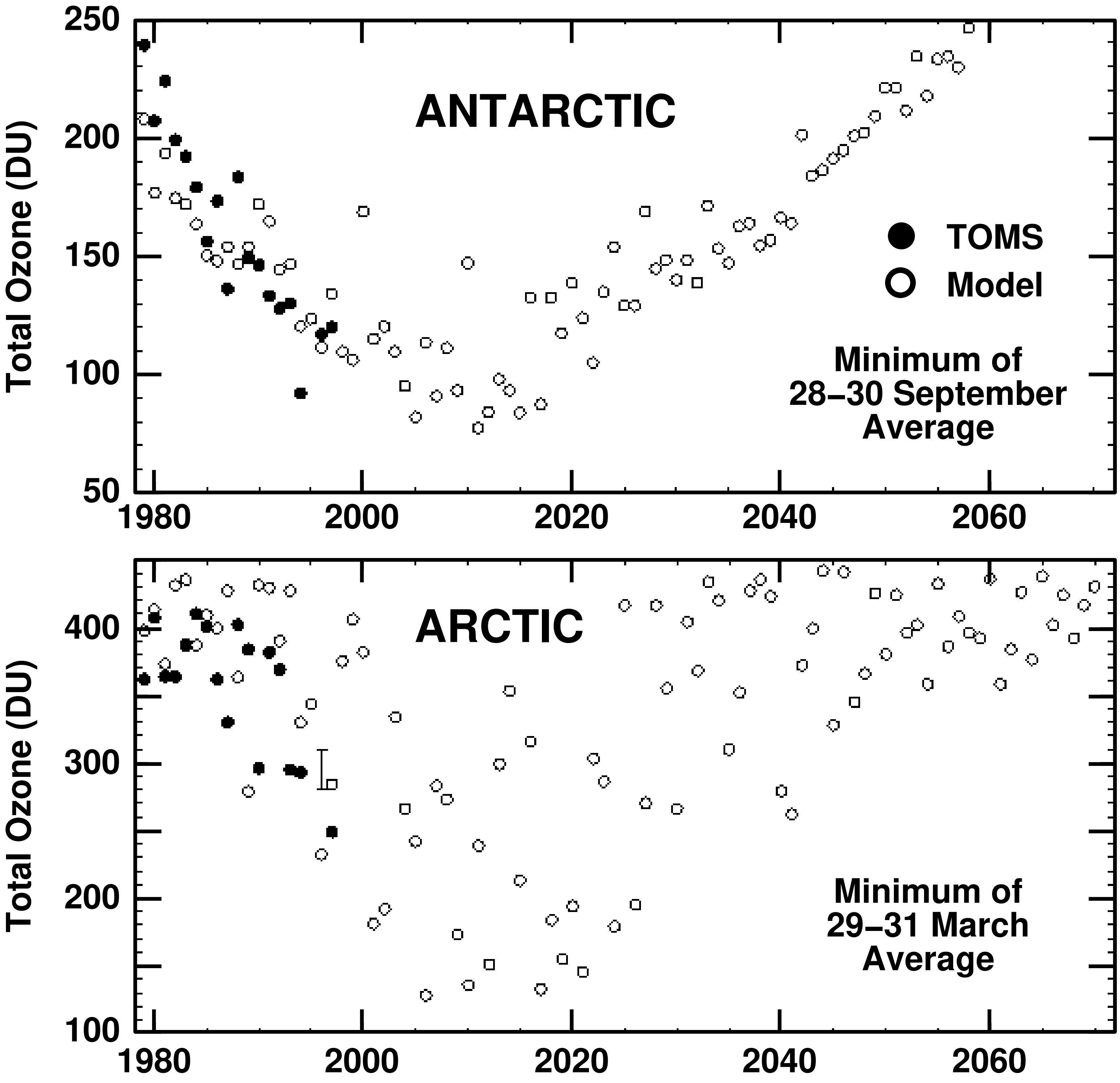

63°-90° total ozone average
Total ozone (DU)
500
450
400
350
300
250
200
1970
1975
1980
1985
1990
1995
2000
Year
NH March
SH October
BUV
Nimbus-7
Meteor-3
ADEOS
EP-TOMS
NOAA-14
NOAA-9


TOMS total ozone
Mar. 71
Mar. 72
Mar. 79
Mar. 80
Mar. 93
Mar. 96
Mar. 97
Mar. 98
240
310
380
450
520
Total DU
NASA
Paul Newman


OZONE MISSIONS TIMELINE
Nimbus 4 BUV
UARS
Nimbus 7 SBUV
Nimbus 7 TOMS
SATELLITE
Meteor 3 TOMS
NOAA 11
NOAA 14
SBUV/2
NOAA 9
EP & ADEOS
TOMS
SSBUV
CFC Theory
O_3 hole
AIRCRAFT
AAOE
AASE I
AASE II
SPADE
ASHOE/MAESA
STRAT
VOTE/TOTE
POLARIS
SOLVE
1970
1975
1980
1985
1990
1995
2000

2000–01–27 PSC at Kiruna

McGee lidar image



Adapted from Shindell et al. (Nature, 1998)

Antarctic:

- Temperatures are always extremely cold because of a lack of strong stratospheric weather dynamics.
- PSCs form every year over extensive regions.
- Chlorine is converted into reactive forms on the PSC particles, leading to large ozone loss.
- With reduction of Cl in the stratosphere, the ozone hole should disappear.

Arctic:

- Temperatures are marginally cold because of strong stratospheric weather dynamics.
- PSCs generally form every year over small regions.
- As in Antarctica, chlorine is converted into reactive forms on the PSC particles, leading to ozone loss, but considerably less because of the reduced extent of PSCs.
- With greenhouse gas cooling of the polar stratosphere (by direct radiative effects, and reduction of weather dynamics), more PSCs will form leading to much greater ozone loss.

The future of stratospheric ozone

There are two major issues on stratospheric ozone:

- Will the ozone layer recover as predicted due to the restrictions of the Montreal Protocol on the release of ozone–depleting substances? How soon will we be able to definitively say that recovery is occurring?

- How will the Arctic (and Northern midlatitudes) respond to, and influence, future climate change? What specific properties of the Arctic stratosphere govern the amplification of future human–caused changes?