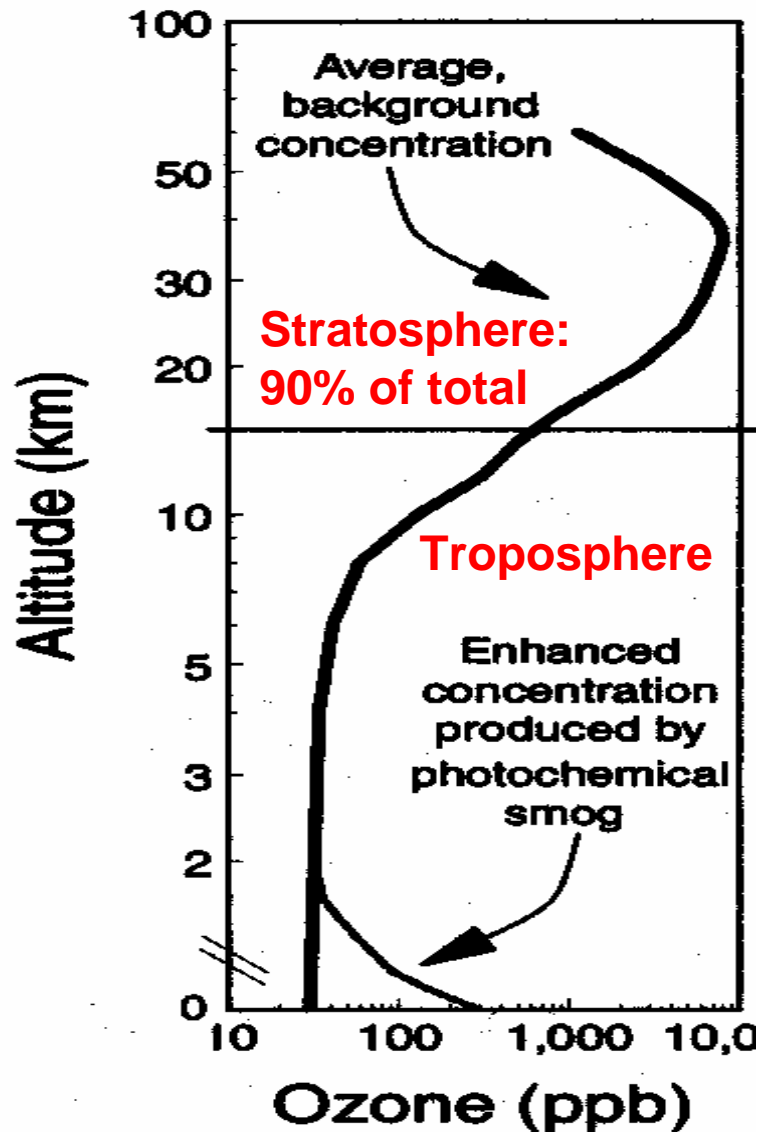


STRATOSPHERIC OZONE & the OZONE HOLE

THE MANY FACES OF ATMOSPHERIC OZONE



In stratosphere: UV shield

In middle/upper troposphere: greenhouse gas

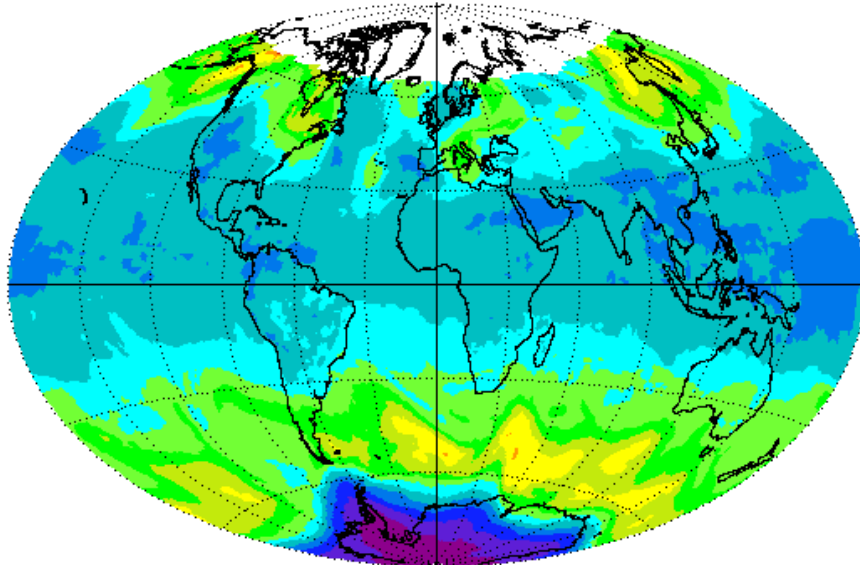
In lower/middle troposphere: precursor of OH, main atmospheric oxidant

In surface air: toxic to humans and vegetation

STRATOSPHERIC OZONE HAS BEEN MEASURED FROM SPACE SINCE 1979

Global Ozone Column Measurements

OMI Total Ozone Nov 17, 2007



NIVR-FMI-NASA-KNMI

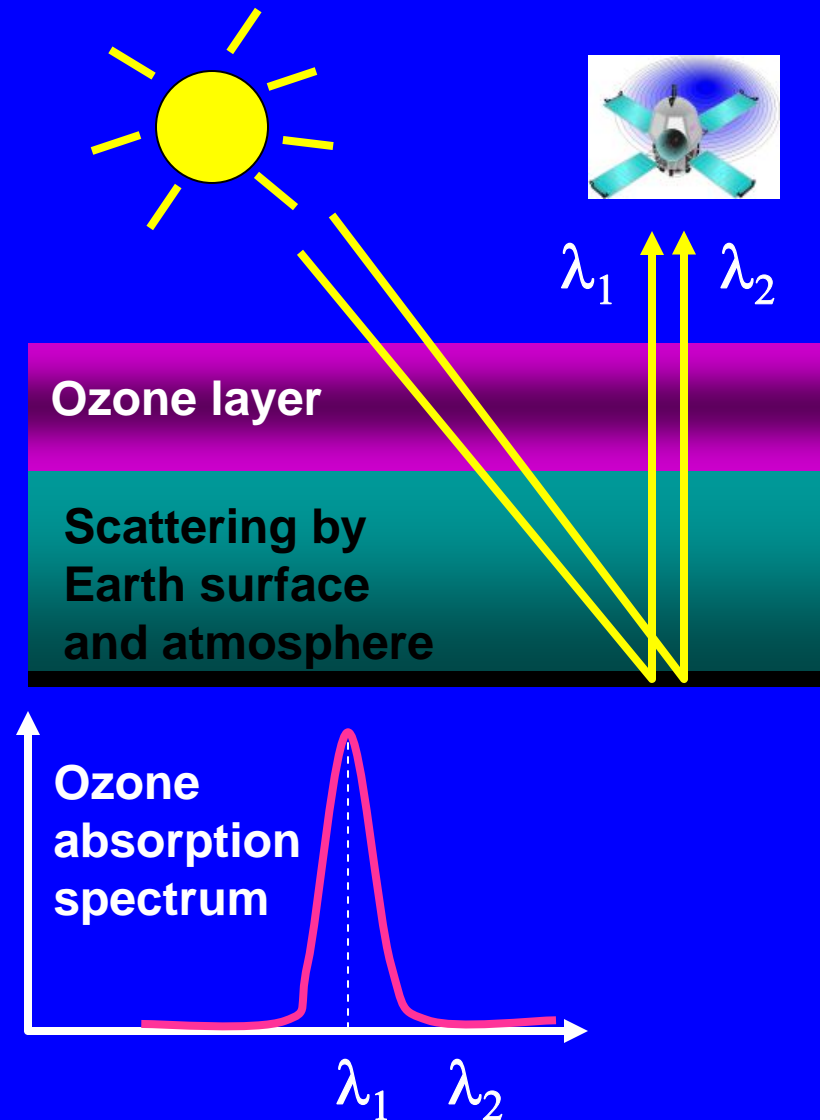


Dark Gray < 100 and > 500 DU

GSFC



Method: UV solar backscatter



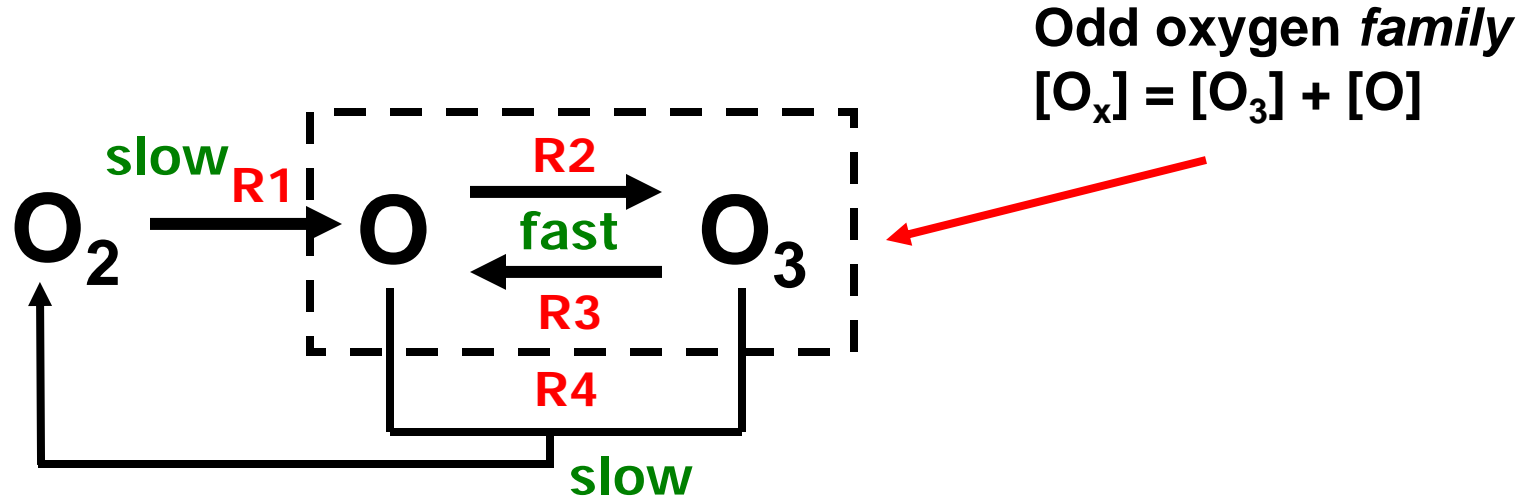
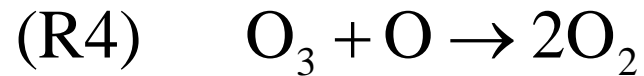
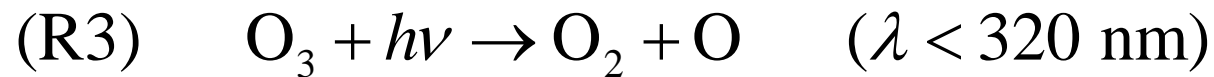
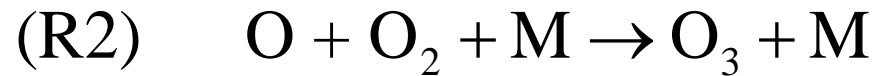
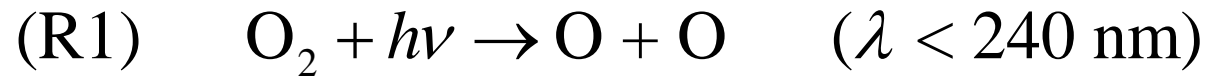
Ozone layer

Scattering by Earth surface and atmosphere

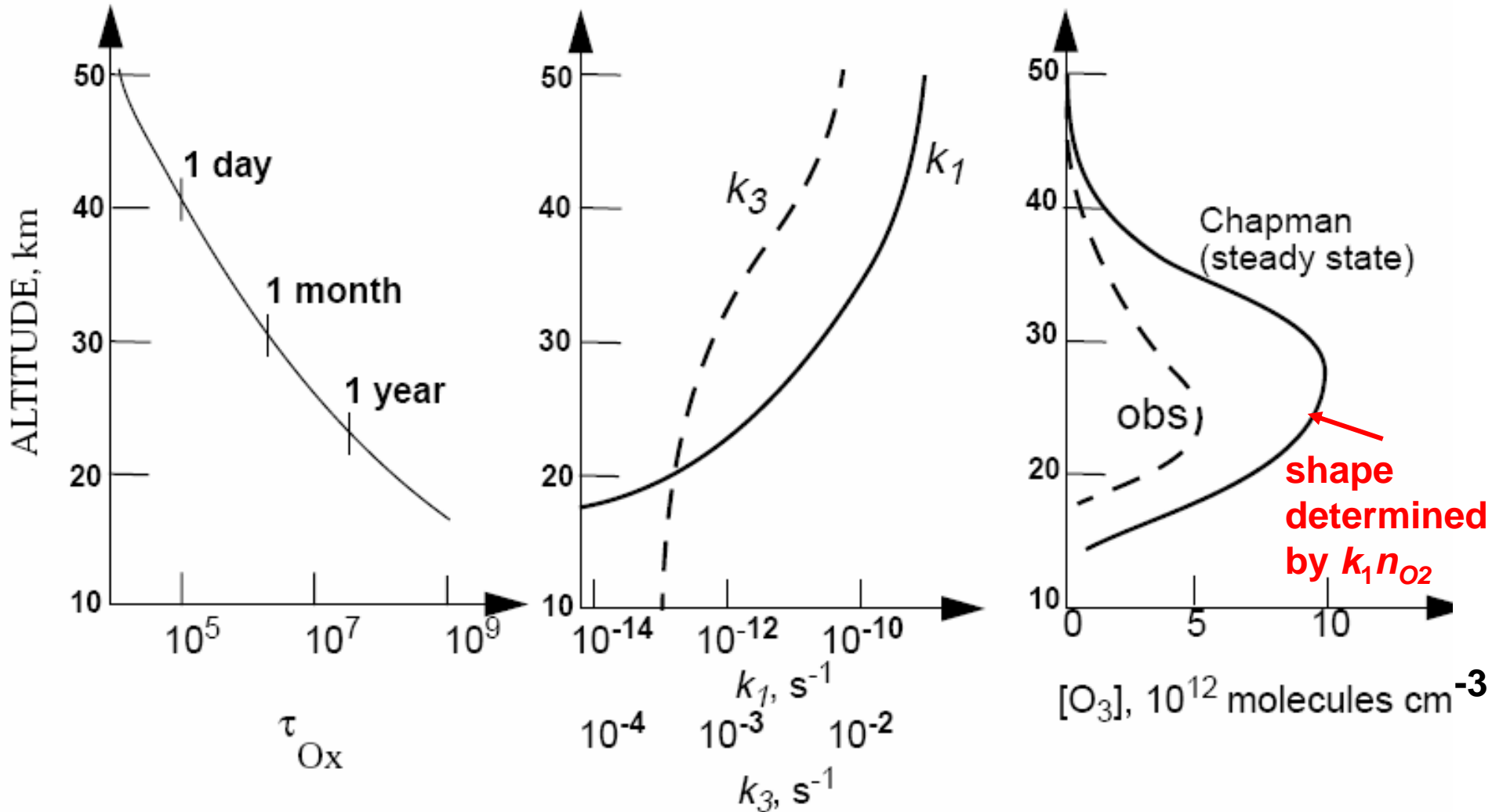
Ozone absorption spectrum

λ_1 λ_2

CHAPMAN MECHANISM FOR STRATOSPHERIC OZONE (1930)



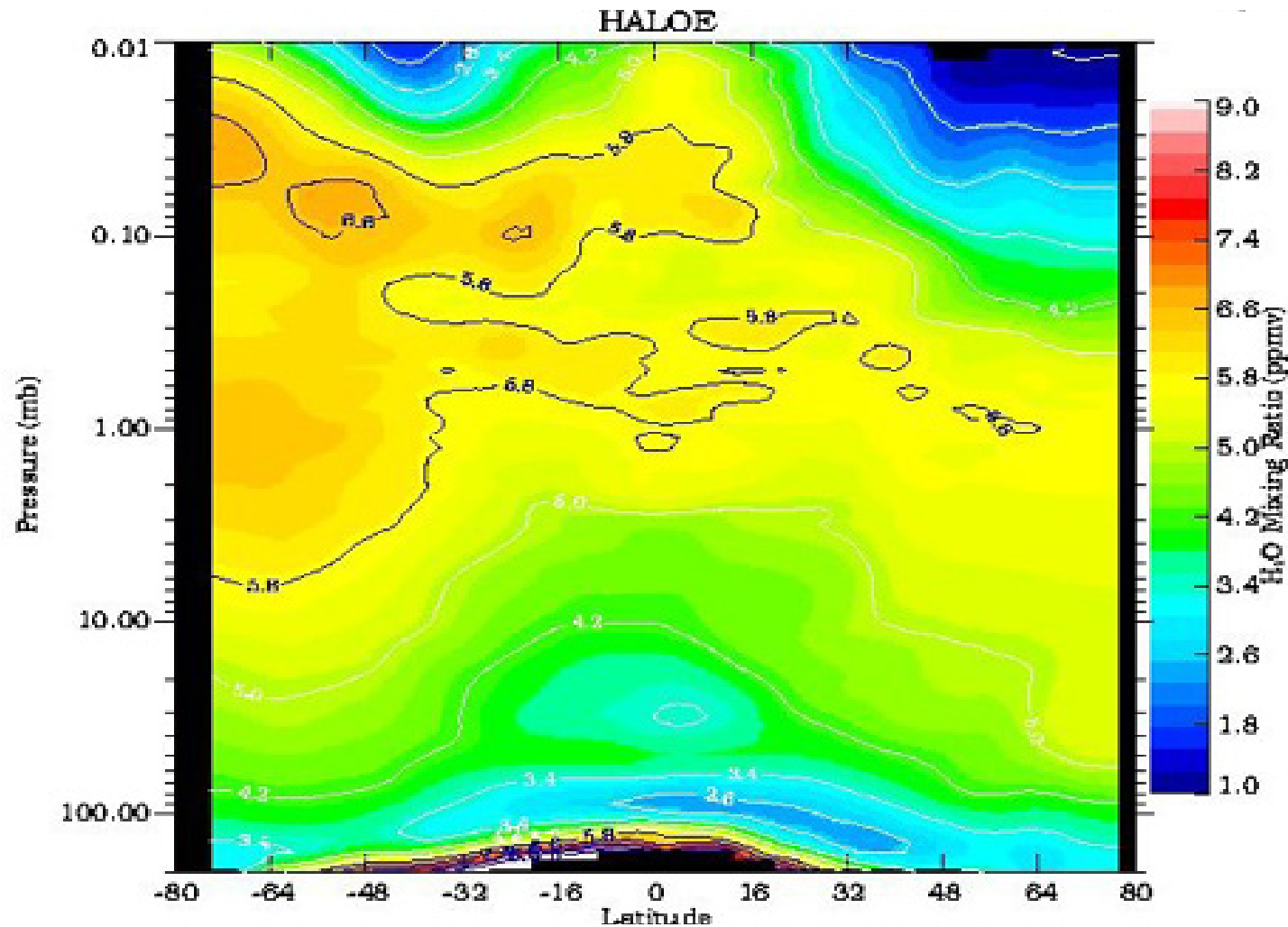
CHAPMAN MECHANISM vs. OBSERVATION



Chapman mechanism reproduces shape, but is too high by factor 2-3

⇒ missing sink!

WATER VAPOR IN STRATOSPHERE AND MESOSPHERE

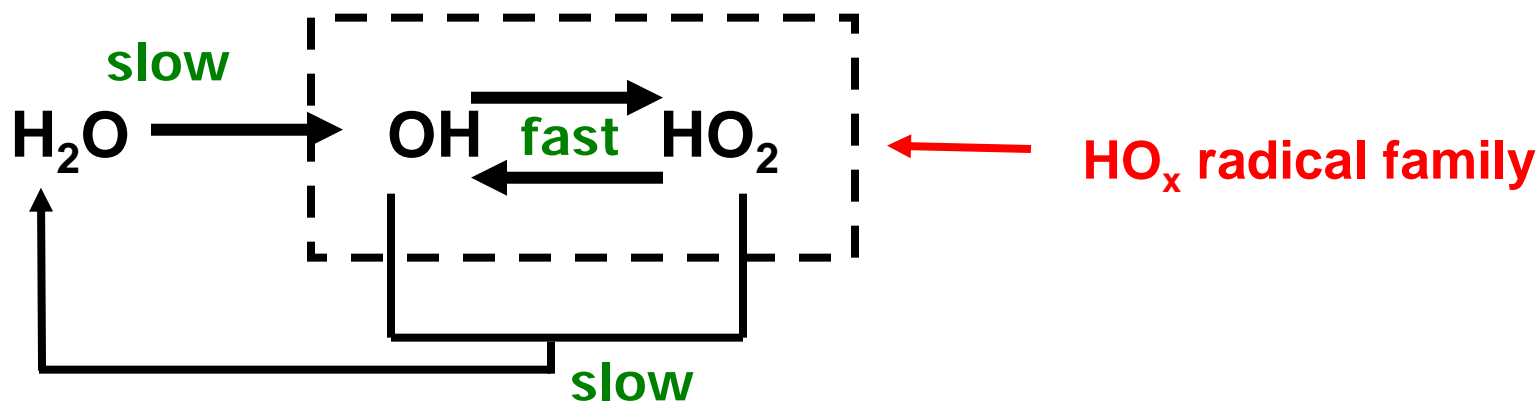
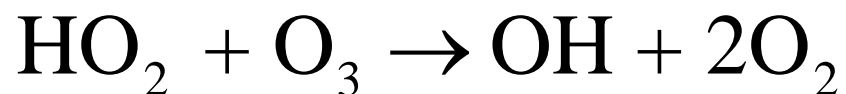
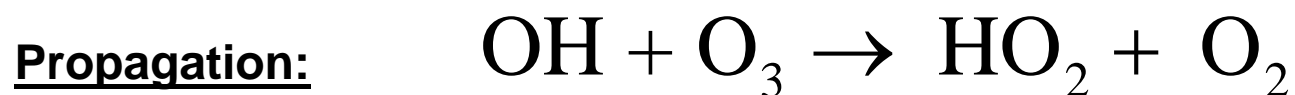
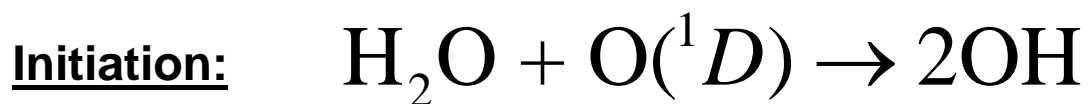


H₂O mixing ratio vs Latitude
Sunset 05-MAR to 10-APR-1993

Source: transport from troposphere and ???

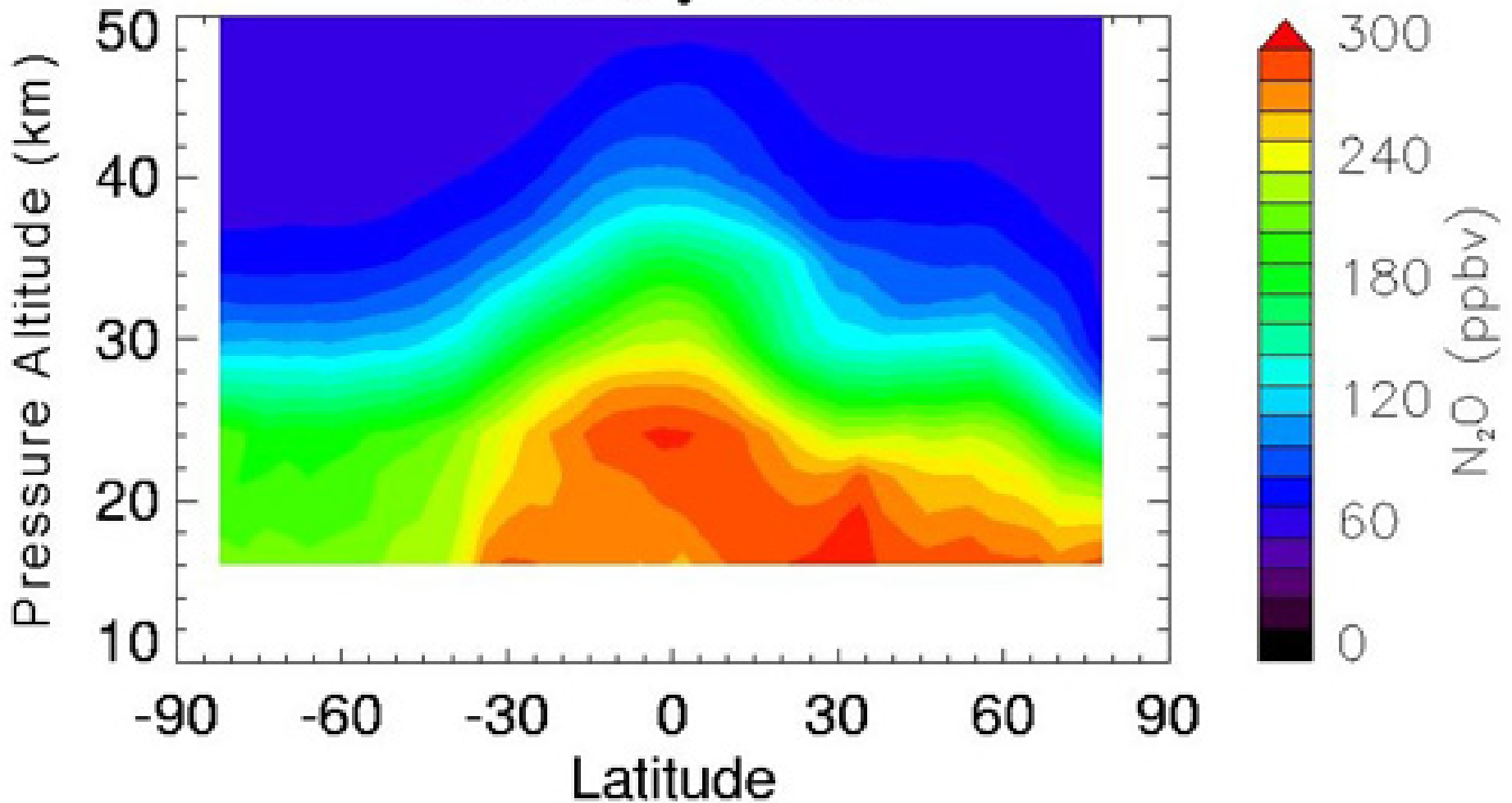
HO_x-CATALYZED OZONE LOSS

HO_x = H + OH + HO₂ hydrogen oxide radical family



NITROUS OXIDE IN THE STRATOSPHERE

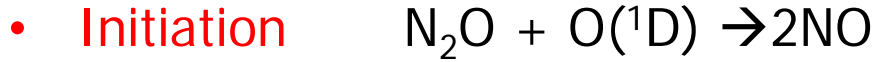
January 1993



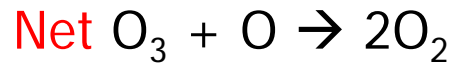
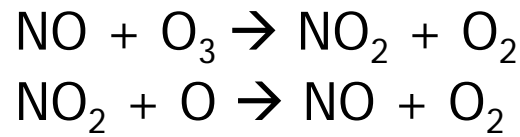
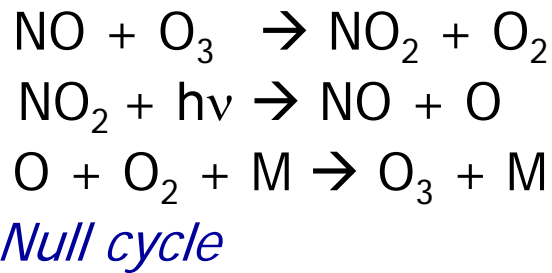
from CLAES satellite instrument

Tropospheric N₂O = 310 ppbv

Nitrogen oxide (NO_x) radicals
(NO_x = NO + NO₂)



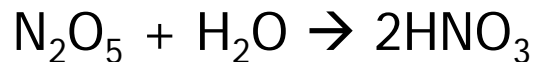
- **Propagation**



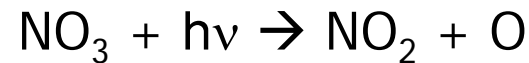
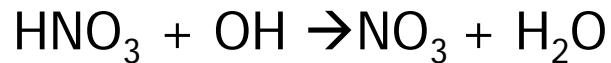
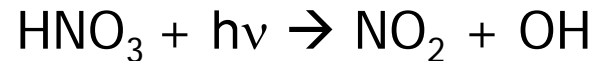
O₃ loss rate:

$$-\frac{d[\text{O}_3]}{dt} = 2k[\text{NO}_2][\text{O}]$$

- **Termination**



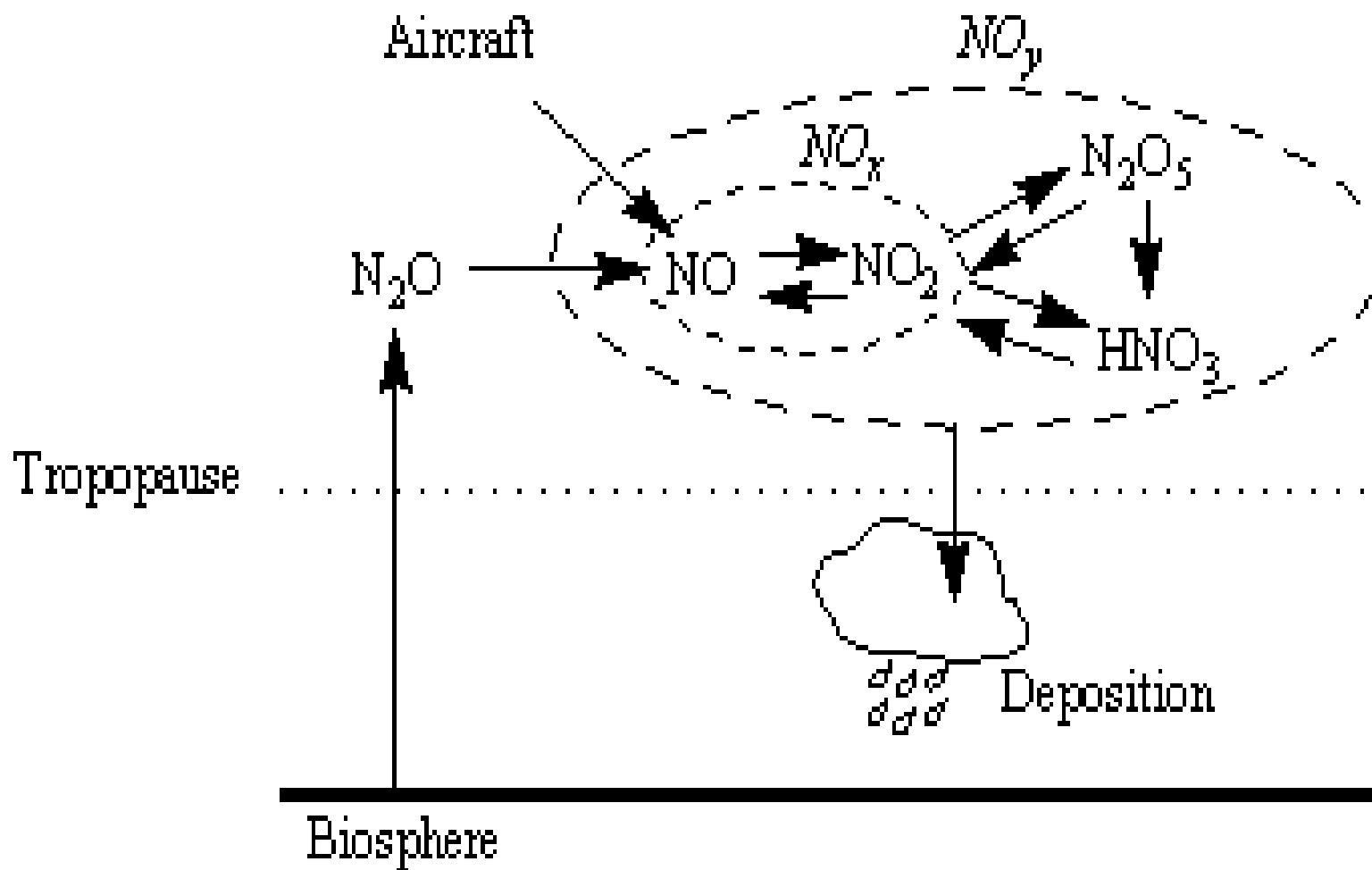
Recycling



HNO₃ is a “reservoir species”

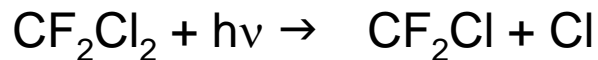
Define NO_y = NO_x + NO_x oxidation products

ATMOSPHERIC CYCLING OF NO_x AND NO_y

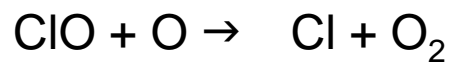
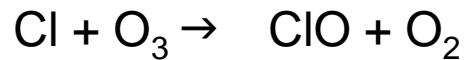


Ozone loss catalyzed by chlorine ($\text{ClO}_x = \text{Cl} + \text{ClO}$) radicals

- Initiation: Cl radical generation from non-radical precursors (e.g., CFC-12)

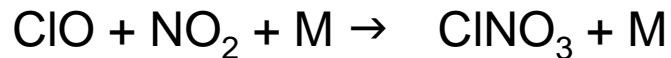
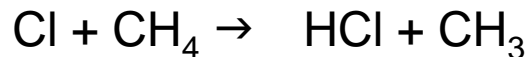


- Propagation:

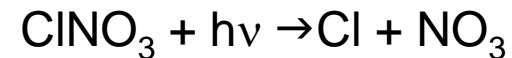
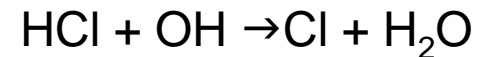


$$\text{O}_3 \text{ loss rate: } -\frac{d[\text{O}_3]}{dt} = 2k[\text{ClO}][\text{O}]$$

- Reservoirs:

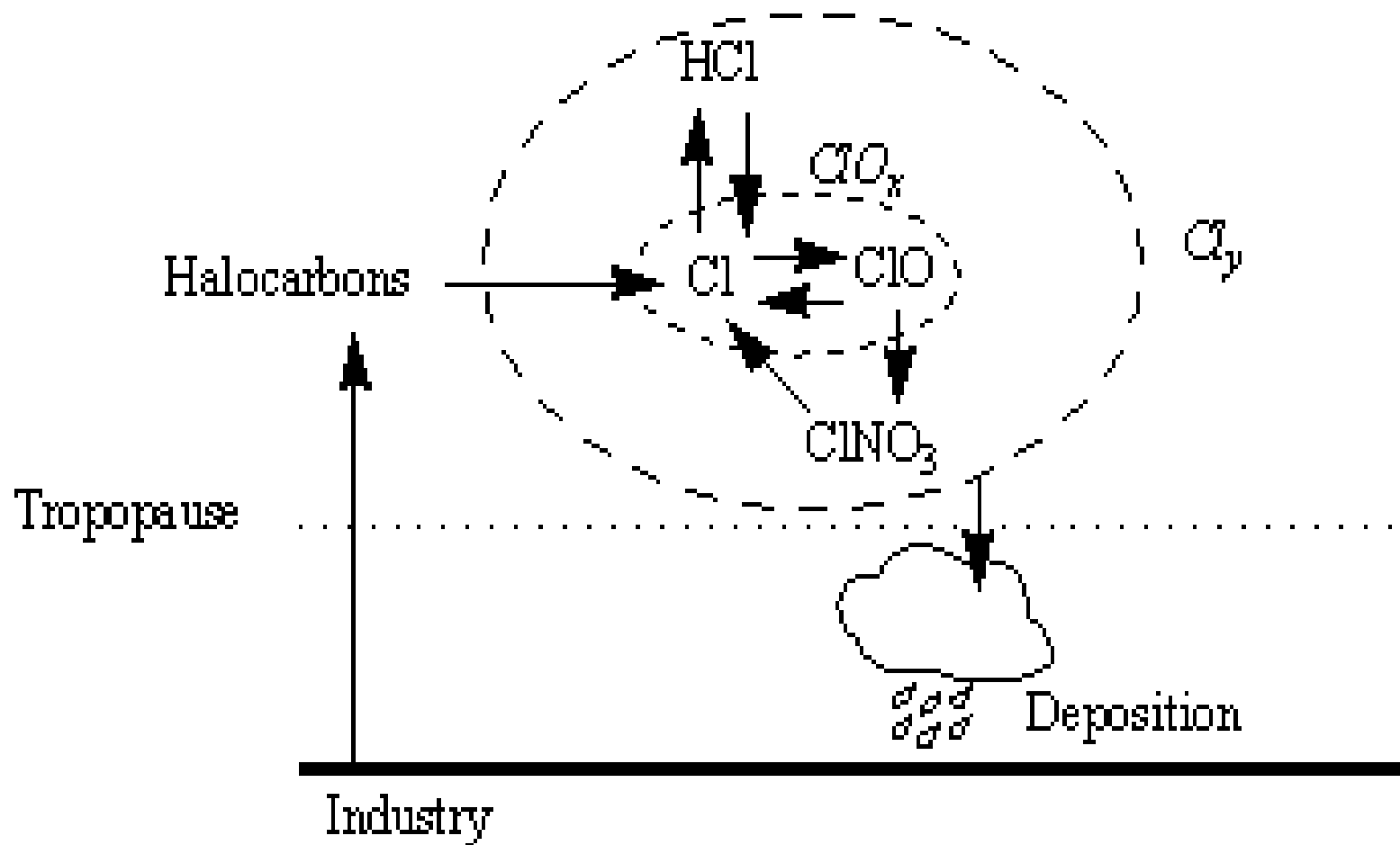


Recycling:

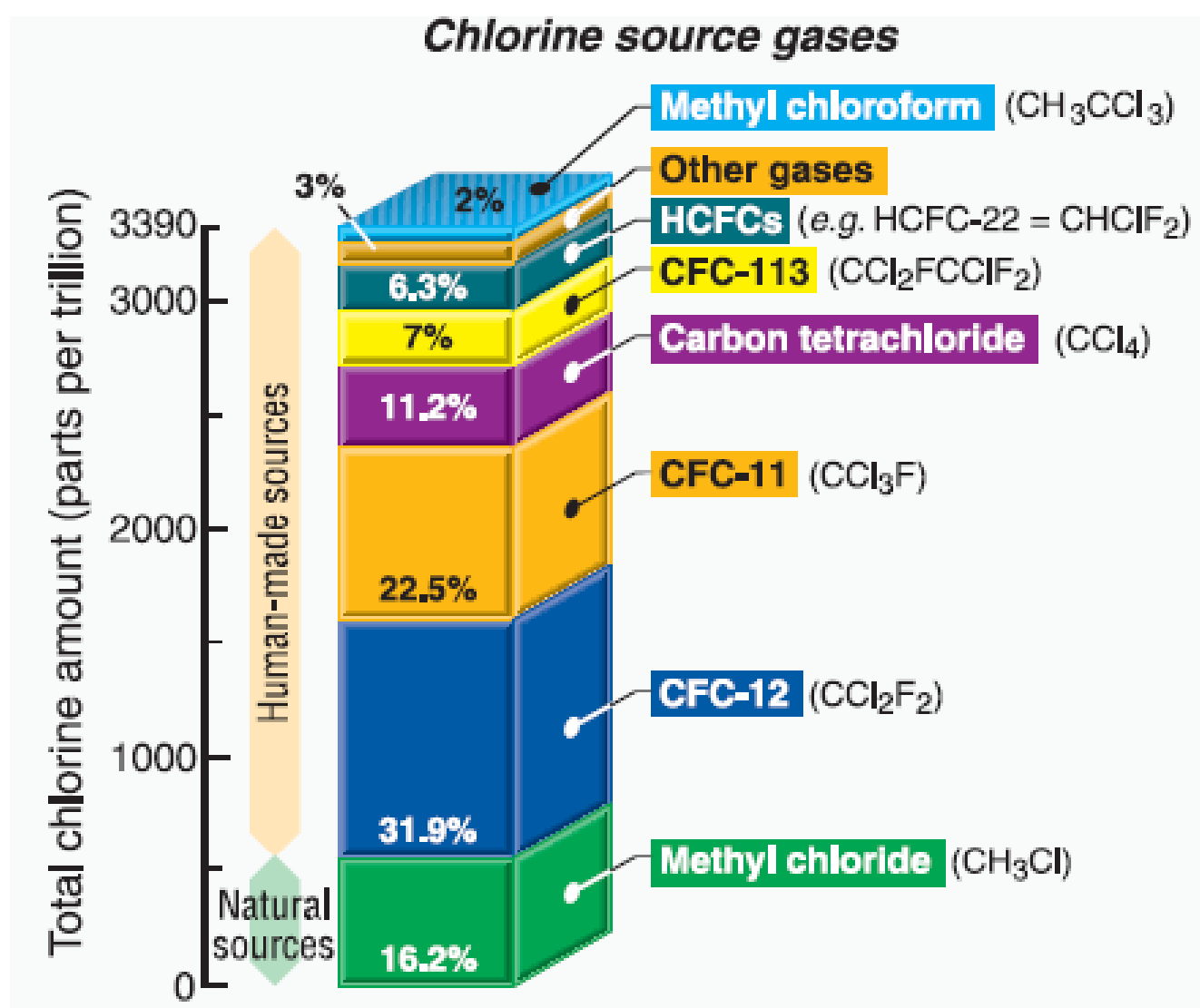


HCl and ClONO_2 are Cl-reservoir species (Cl atoms accumulate in these forms))

ATMOSPHERIC CYCLING OF ClO_x AND Cl_y

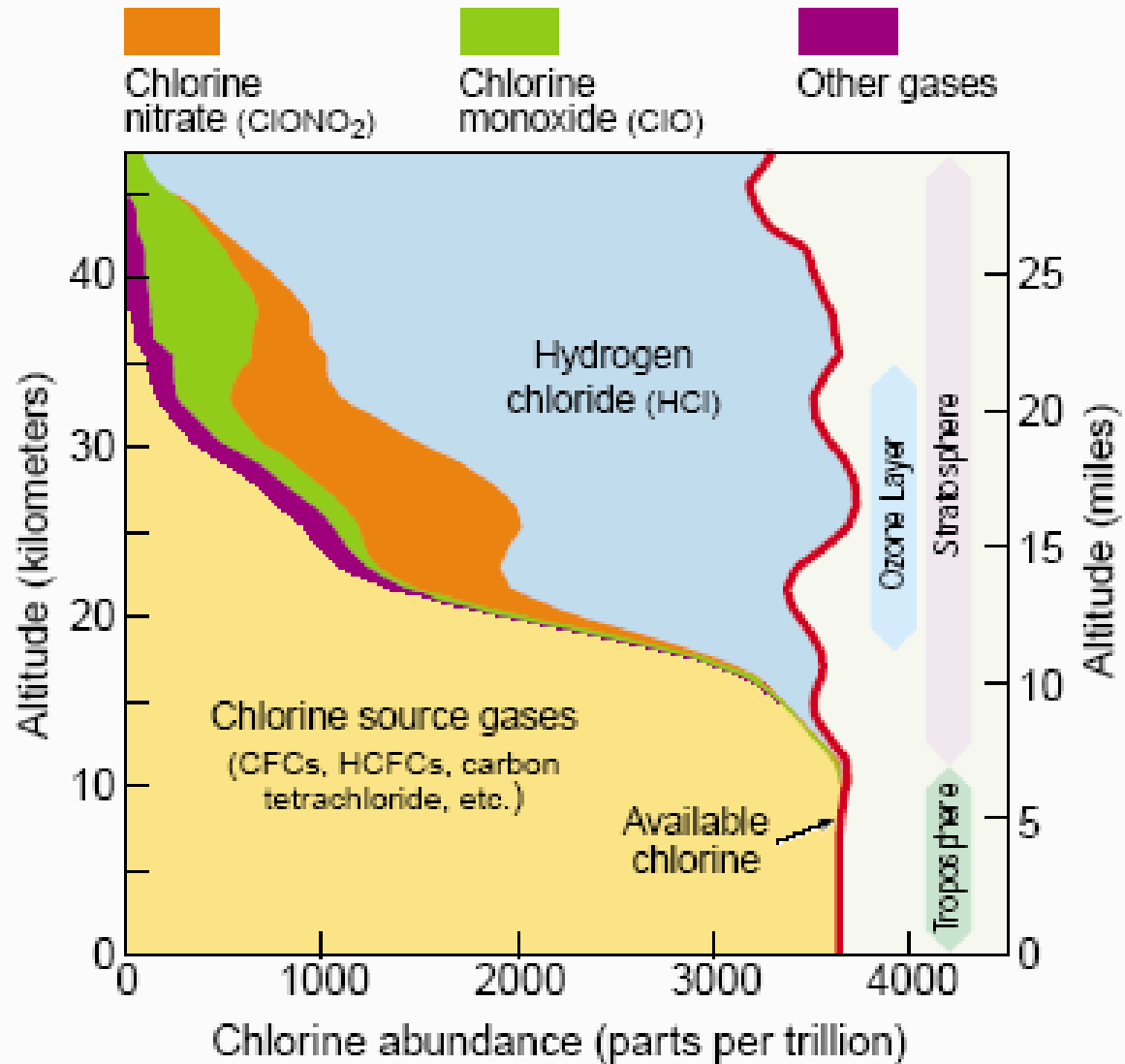


SOURCE GAS CONTRIBUTIONS TO STRATOSPHERIC CHLORINE (2004)

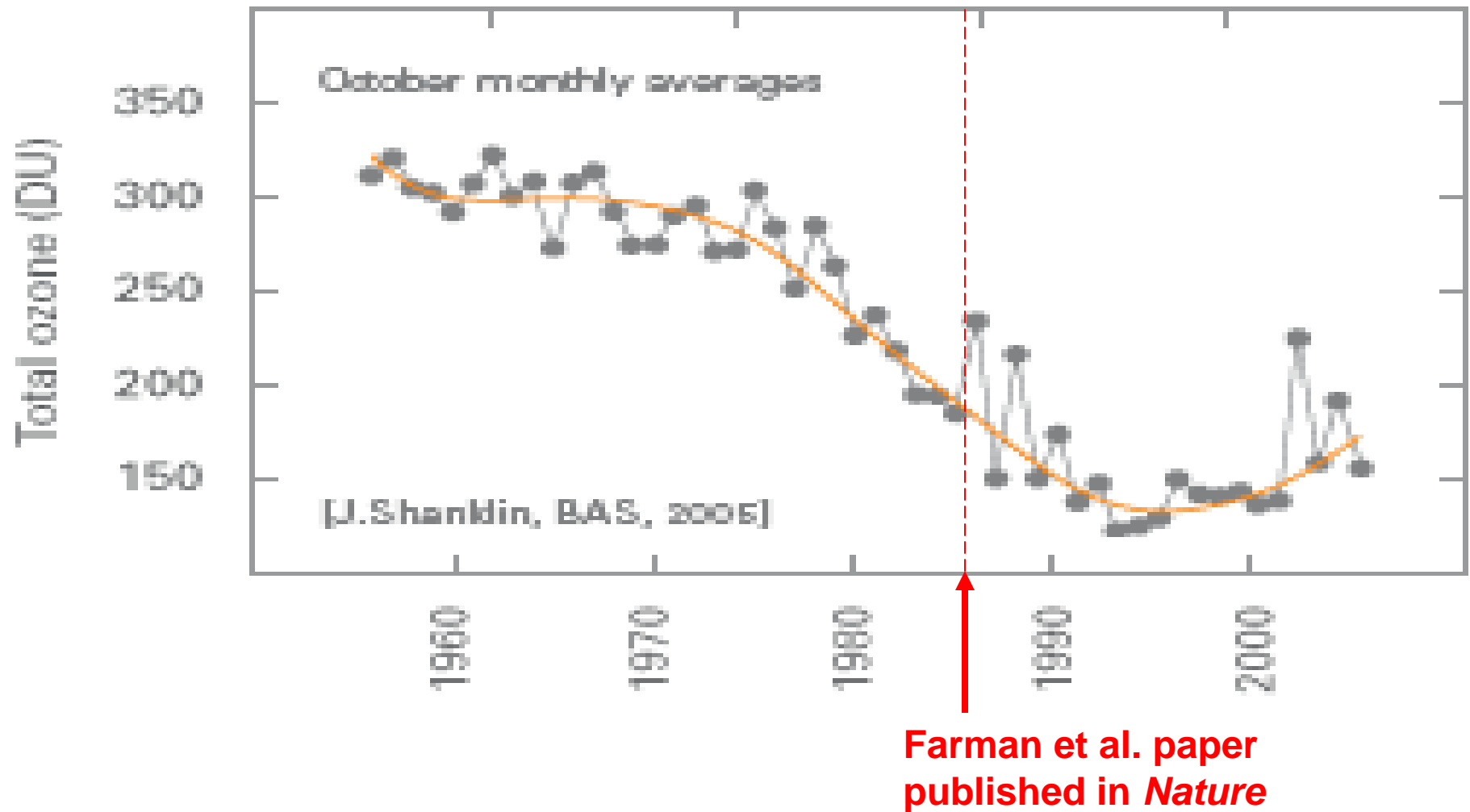


CHLORINE PARTITIONING IN STRATOSPHERE

Measurements of Chlorine Gases from Space
November 1994 (35°-49°N)



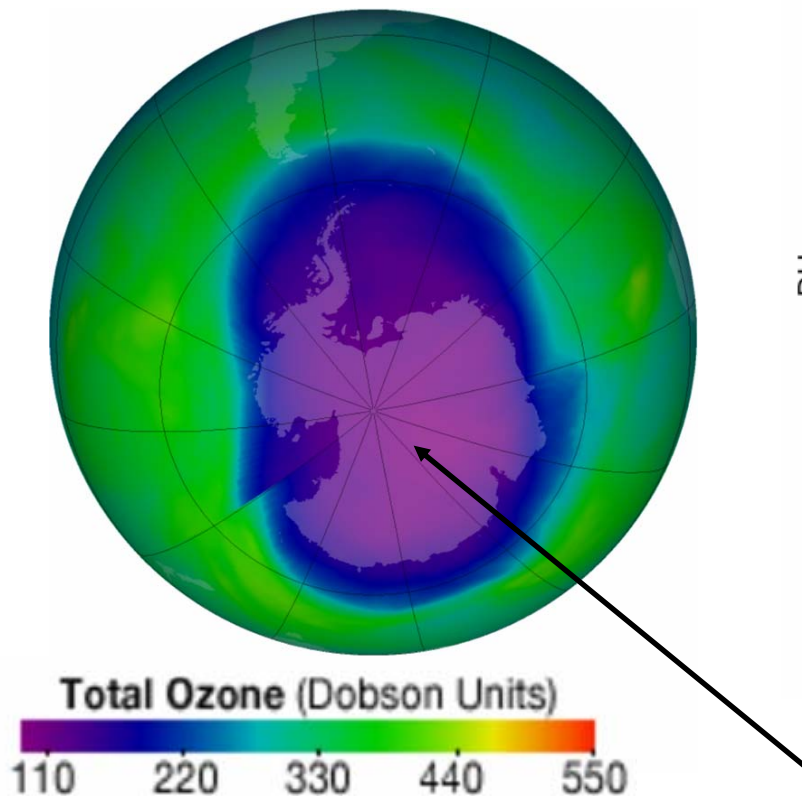
OZONE TREND AT HALLEY BAY, ANTARCTICA (OCTOBER)



1 Dobson Unit (DU) = 0.01 mm O₃ STP = 2.69x10¹⁶ molecules cm⁻²

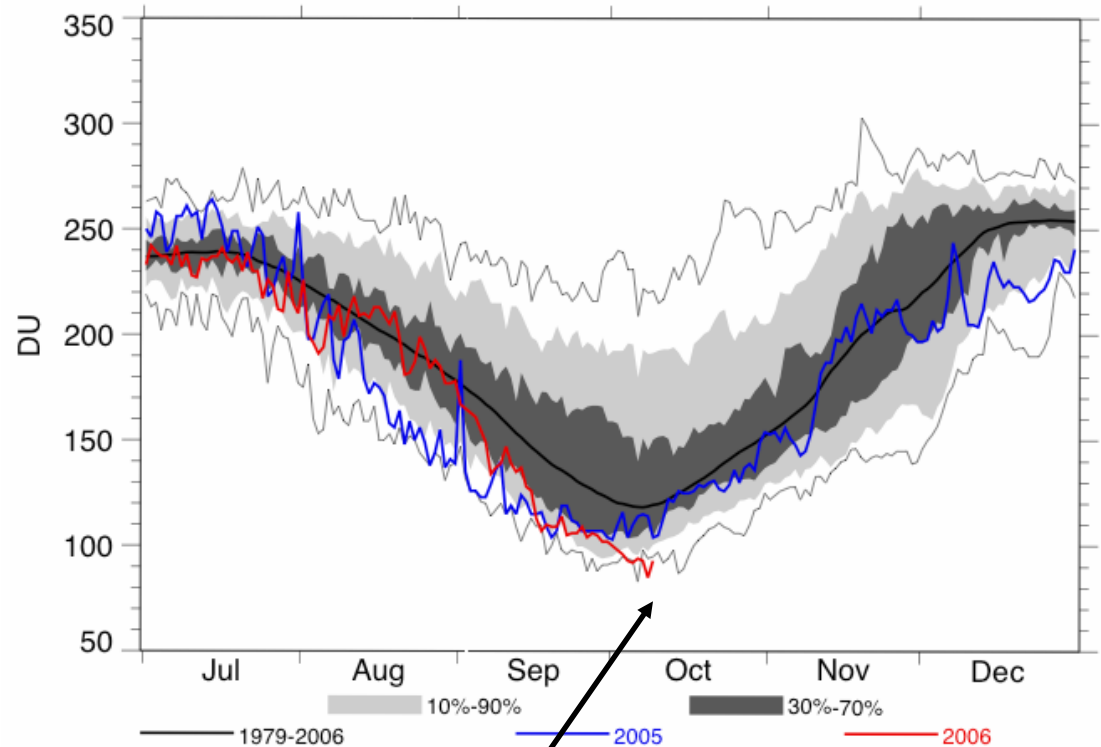
2006 Antarctic Ozone Hole: most severe observed

Aura OMI – 8 Oct 2006



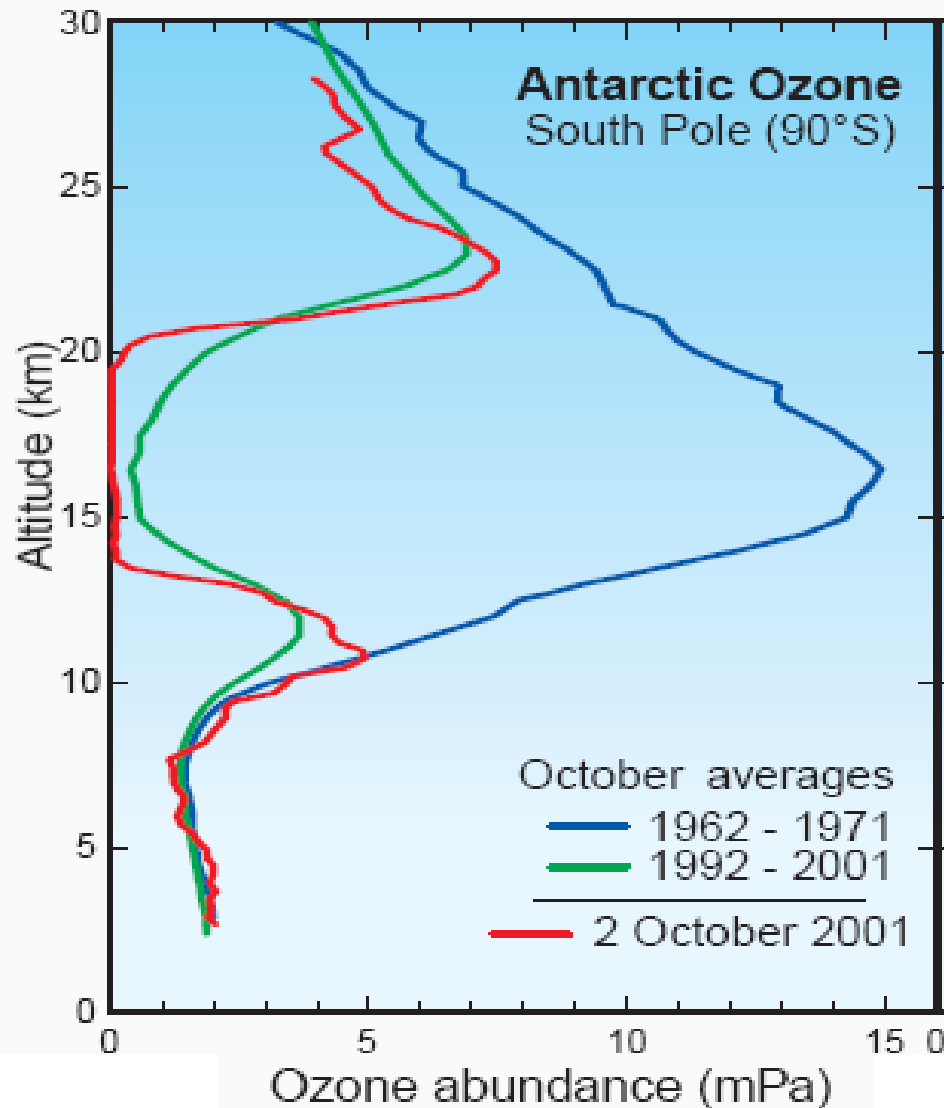
Minimum of 85 DU on 8 Oct 2006

Ozone Hole Minimum



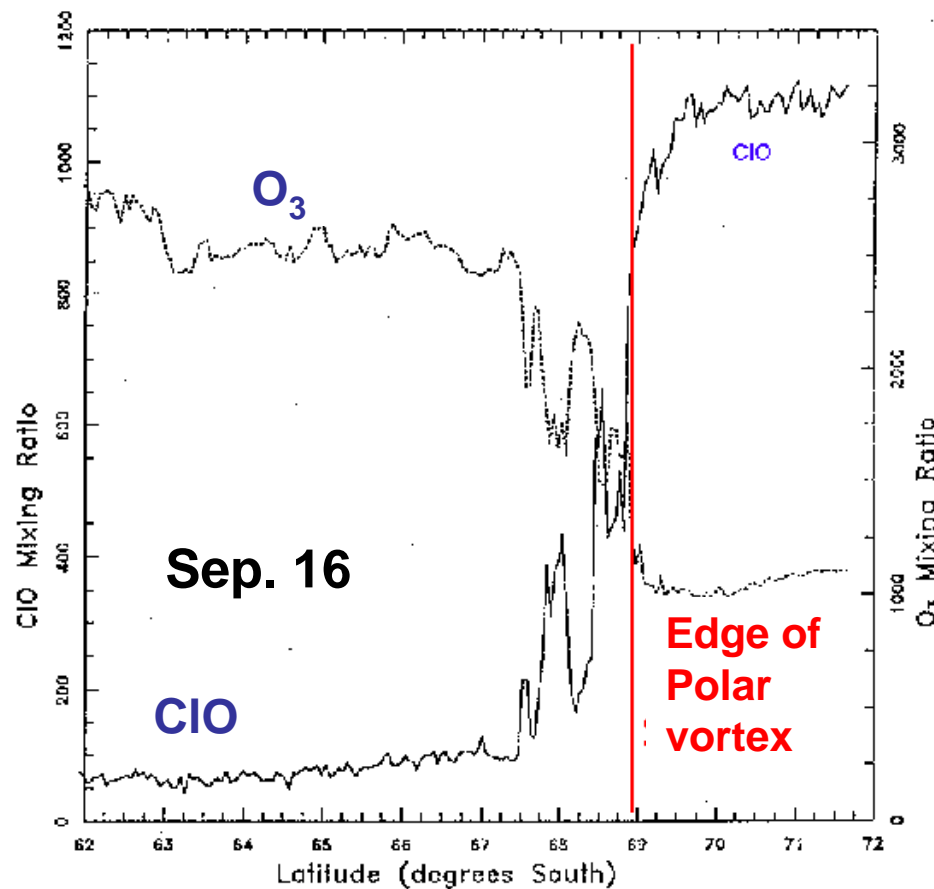
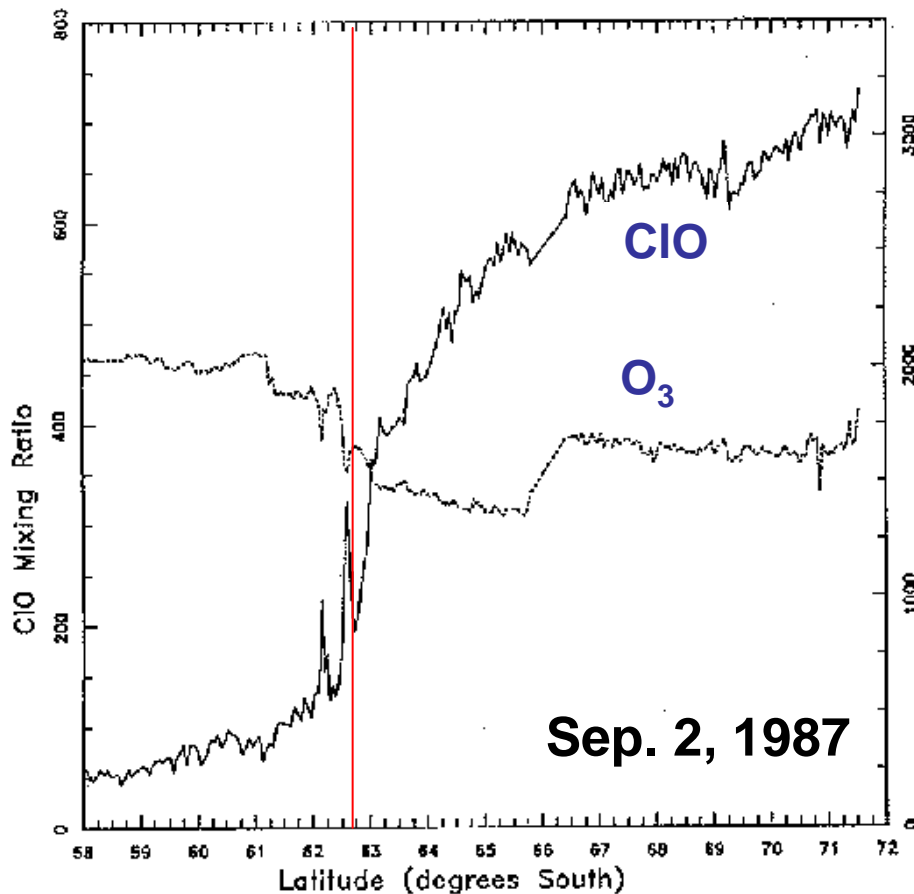
The ozone hole is an austral spring phenomenon – it is not there year-round!

VERTICAL STRUCTURE OF THE OZONE HOLE: near-total depletion in lower stratosphere



ASSOCIATION OF ANTARCTIC OZONE HOLE WITH HIGH LEVELS OF CLO

Sept. 1987 ER-2 aircraft measurements at 20 km altitude S of Punta Arenas



— CIO Mixing Ratio in ppt
 - - - O₃ Mixing Ratio in ppb

20 km
 altitude

— CIO Mixing Ratio in ppt
 - - - O₃ Mixing Ratio in ppb

Measurements by Jim Anderson's group (Harvard)

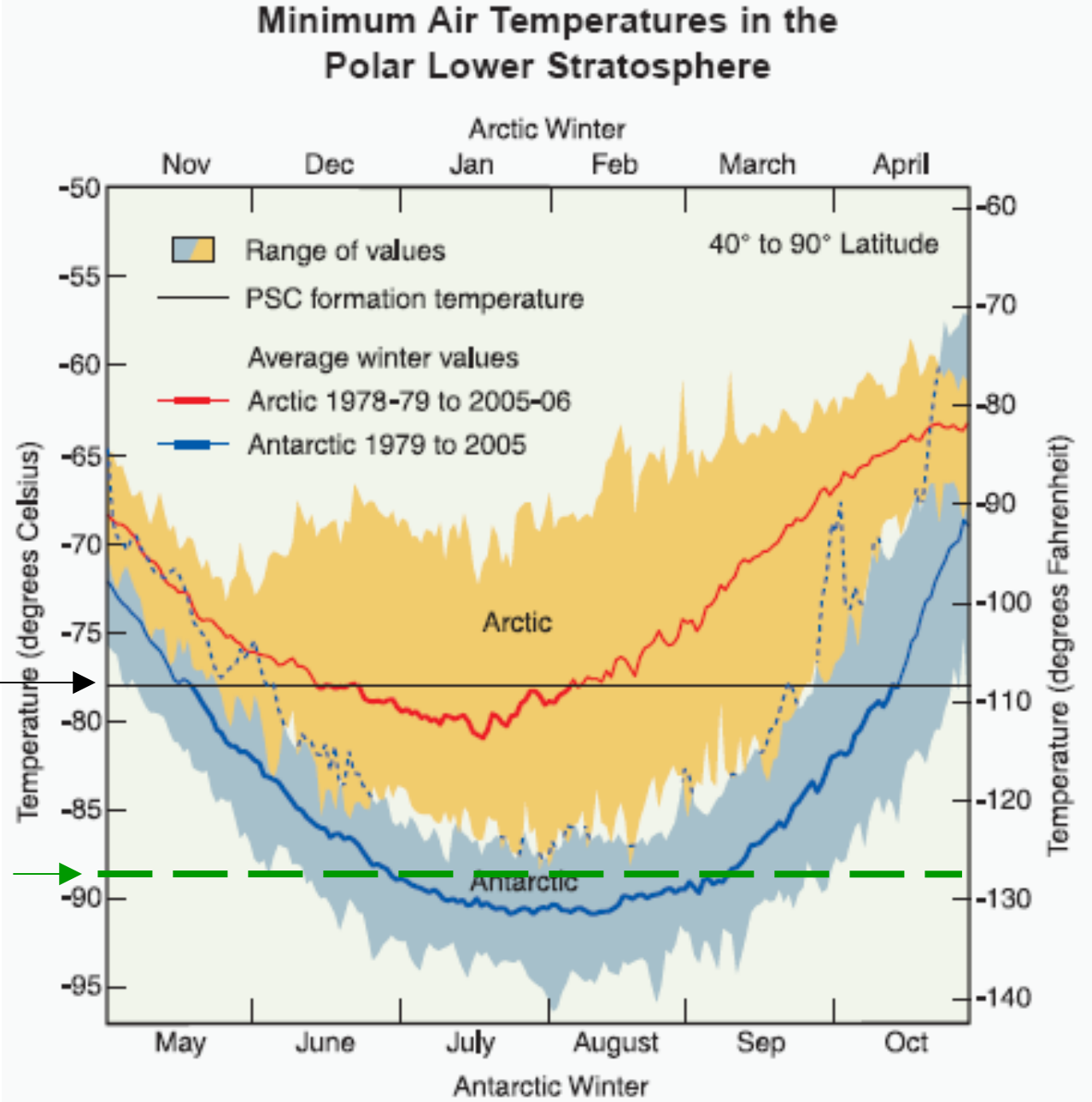


WHY THE HIGH ClO IN ANTARCTIC VORTEX?

Release of chlorine radicals from reactions of reservoir species in polar stratospheric clouds (PSCs)



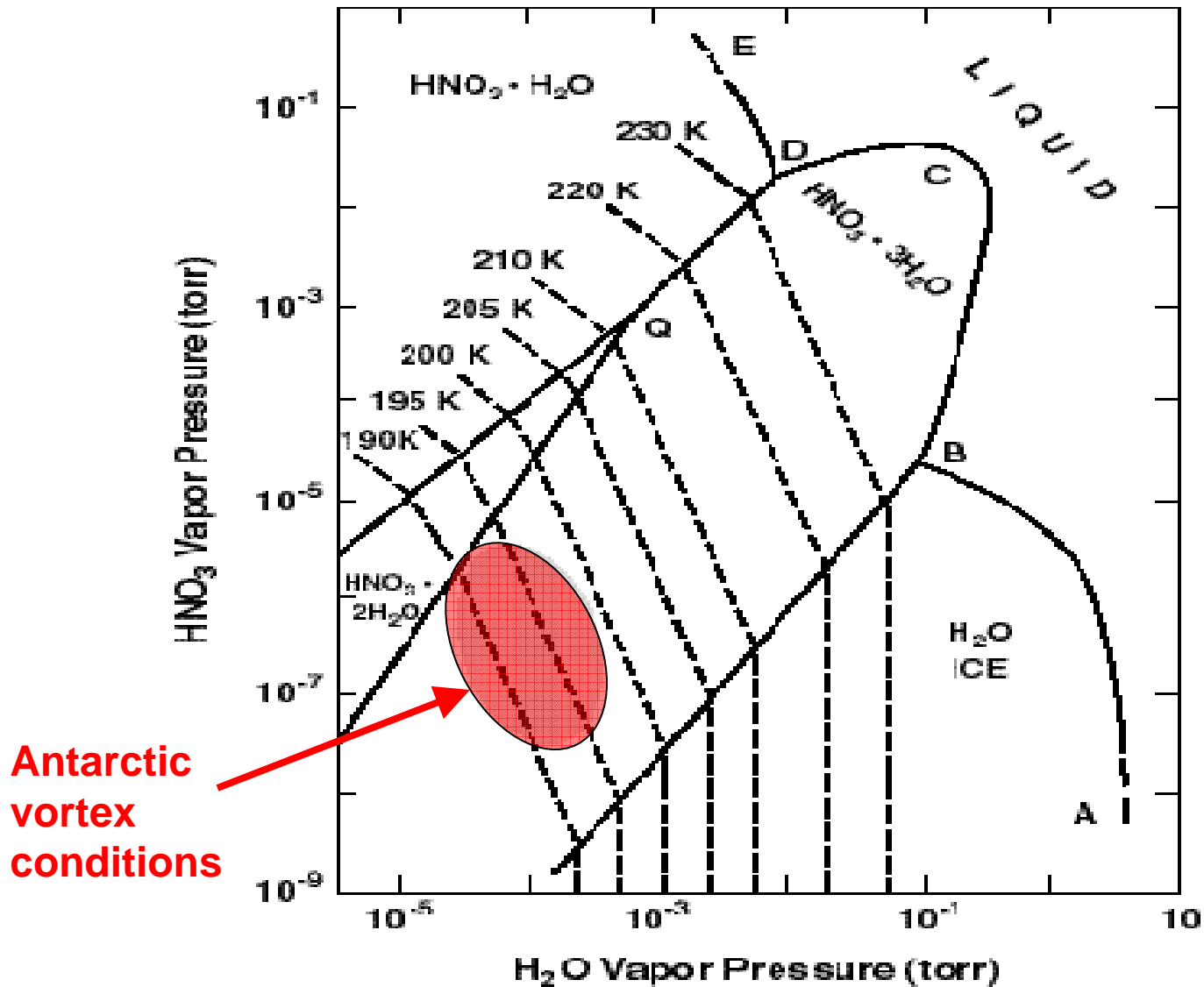
PSC FORMATION AT COLD TEMPERATURES



PSC formation

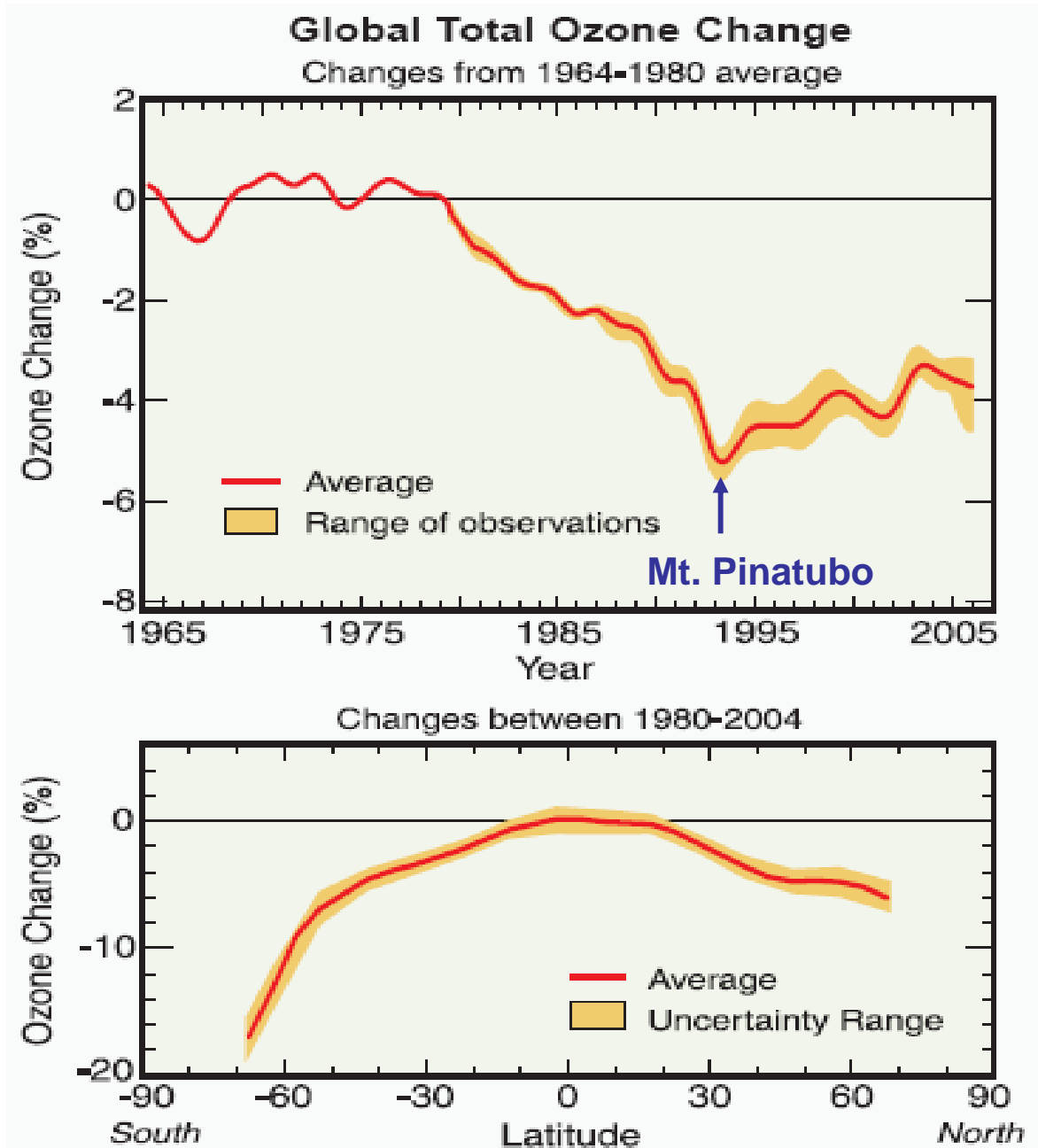
Frost point of water

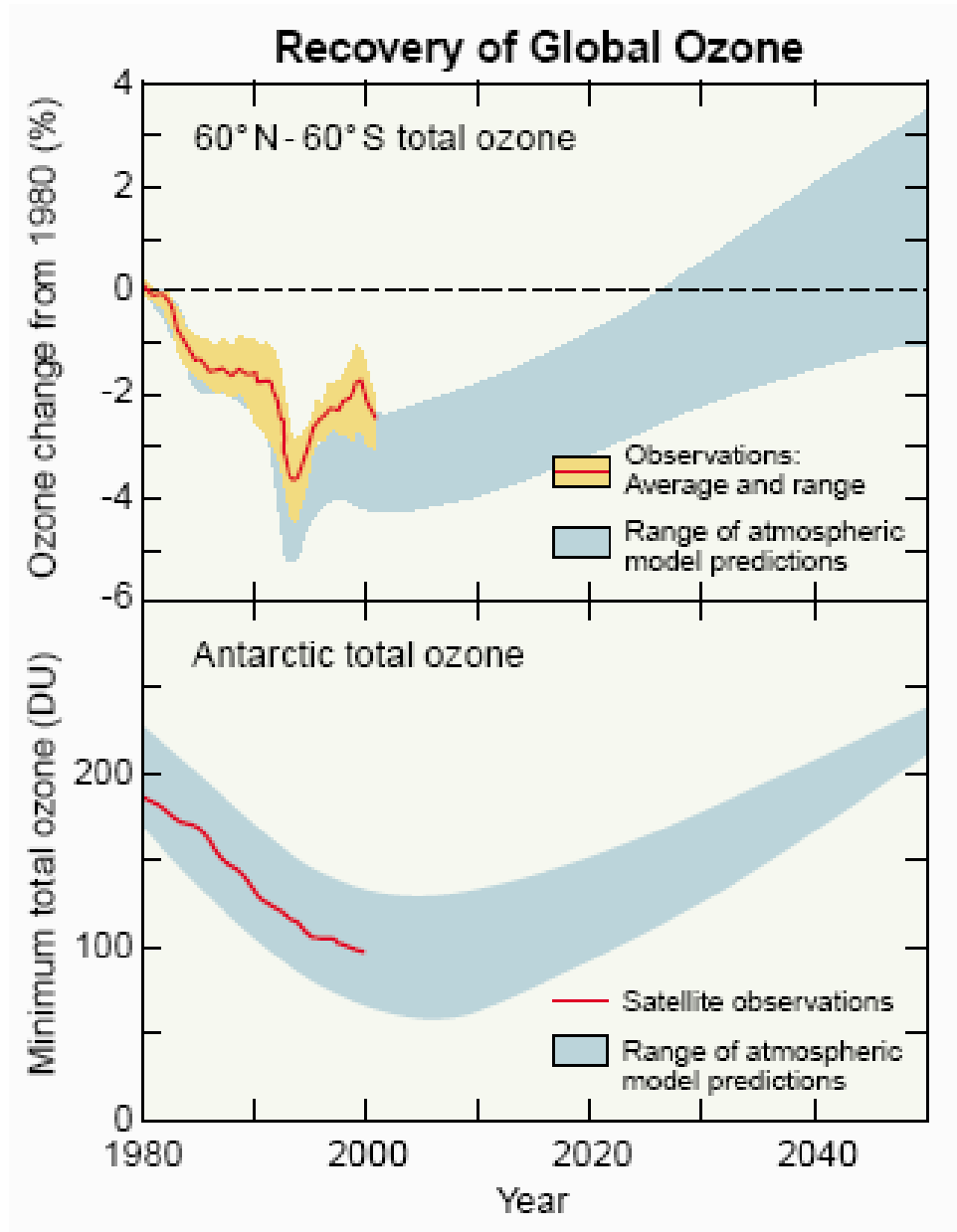
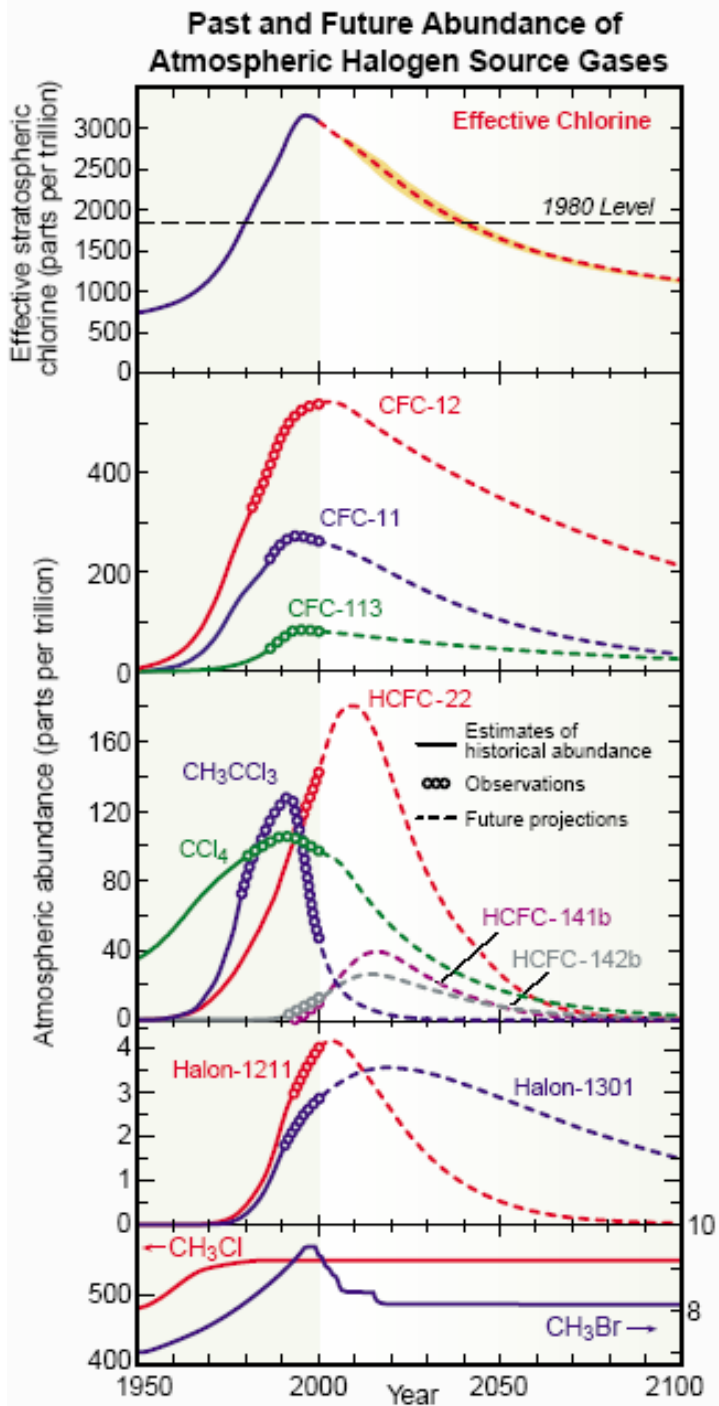
HOW DO PSCs START FORMING AT 195K? HNO₃-H₂O PHASE DIAGRAM



PSCs are not water but nitric acid trihydrate (NAT) clouds

TRENDS IN GLOBAL OZONE





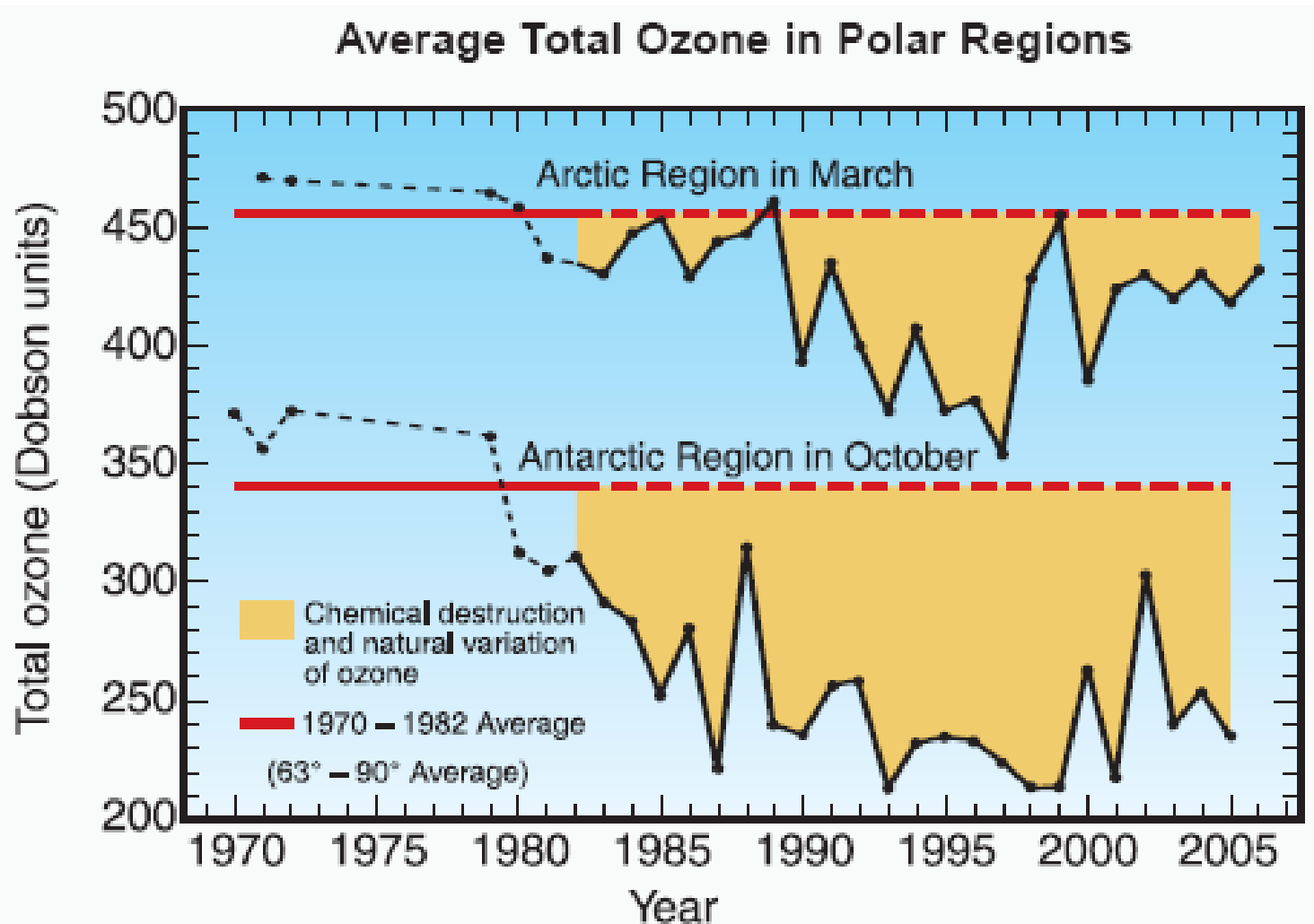
QUESTIONS

1. What would be the effect on chlorine-catalyzed ozone loss of a supersonic aircraft fleet releasing NO_x to the stratosphere?
2. The ozone hole is of limited vertical extent because PSCs form only in the lowest part of the polar stratosphere. Why don't they form at higher altitudes too?

TRENDS IN POLAR OZONE

Could greenhouse-induced cooling of stratosphere produce an Arctic ozone hole over the next decade?

Race between chlorine decrease and climate change



SKIN CANCER EPIDEMIOLOGY PREDICTIONS

