The Influence of Very Large Solar Proton Events on the Mesosphere and Stratosphere

Charles Jackman

NASA Goddard Space Flight Center, Greenbelt, MD

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Acknowledgments:

Cora Randall
University of Colorado, Boulder, CO

Eric Fleming
NASA Goddard Space Flight Center, Greenbelt, MD

Daniel Marsh, Francis Vitt, and Rolando Garcia
National Center for Atmospheric Research, Boulder, CO

Manuel López-Puertas and Bernd Funke
Instituto de Astrofisica de Andalucia, CSIC, Granada, SPAIN

Outline

I. Overview

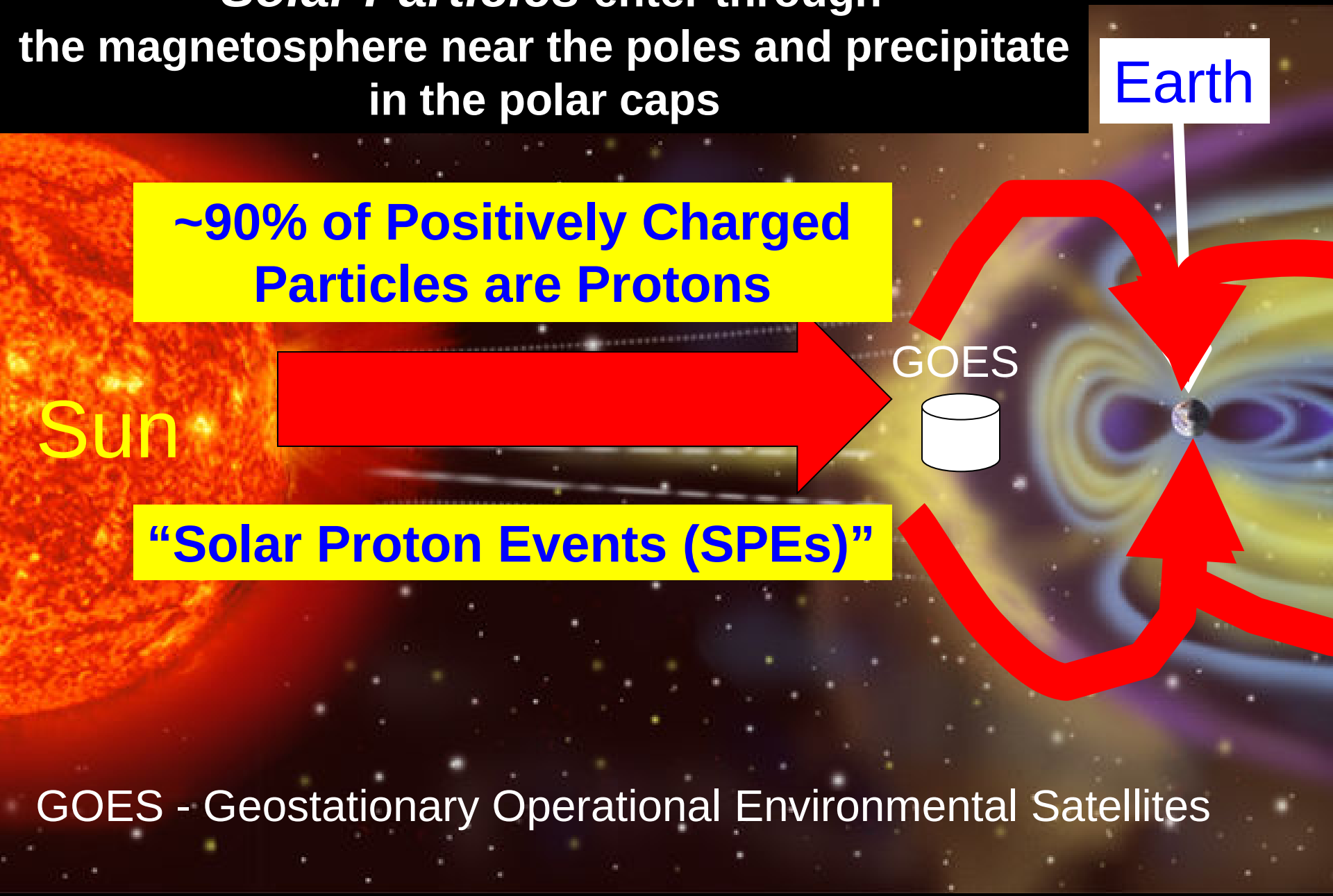
II. January 2012 & July 2000 Solar Proton Events

III. Total Ozone Impacts

IV. Conclusions

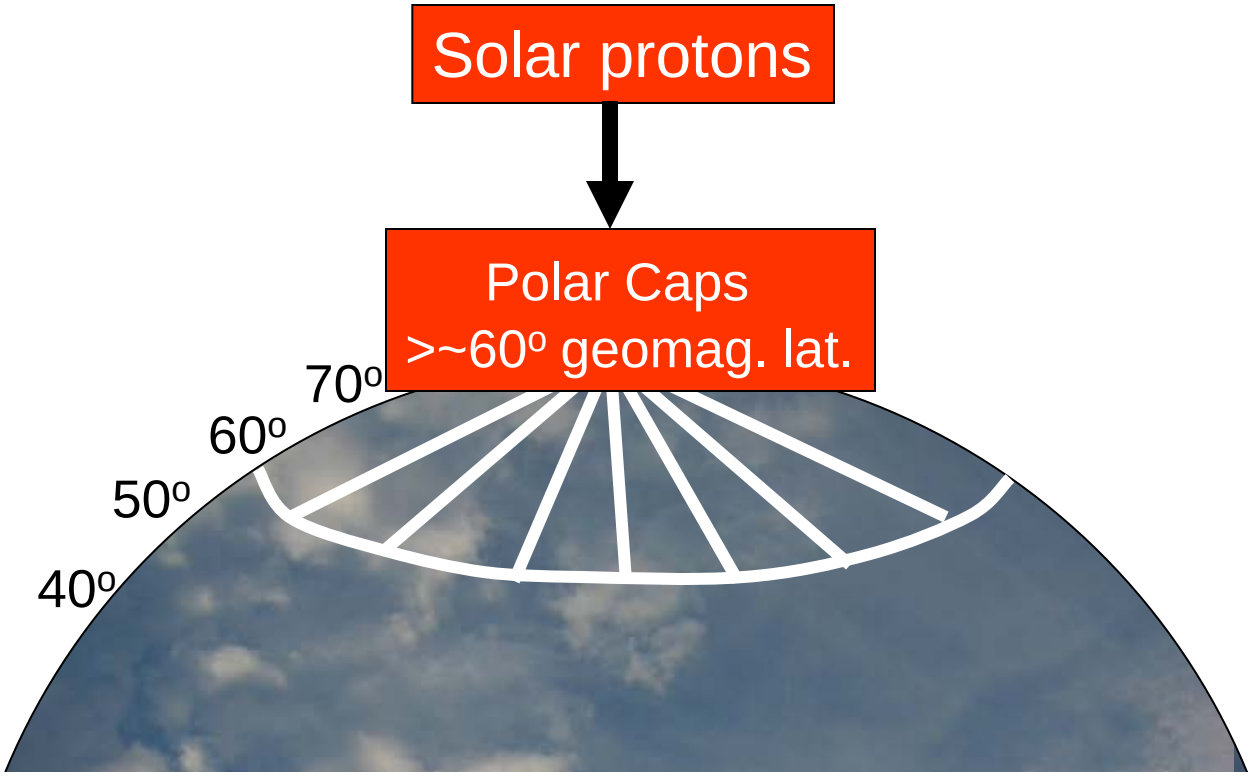
I. Overview

Solar Particles **enter through the magnetosphere near the poles and precipitate in the polar caps**



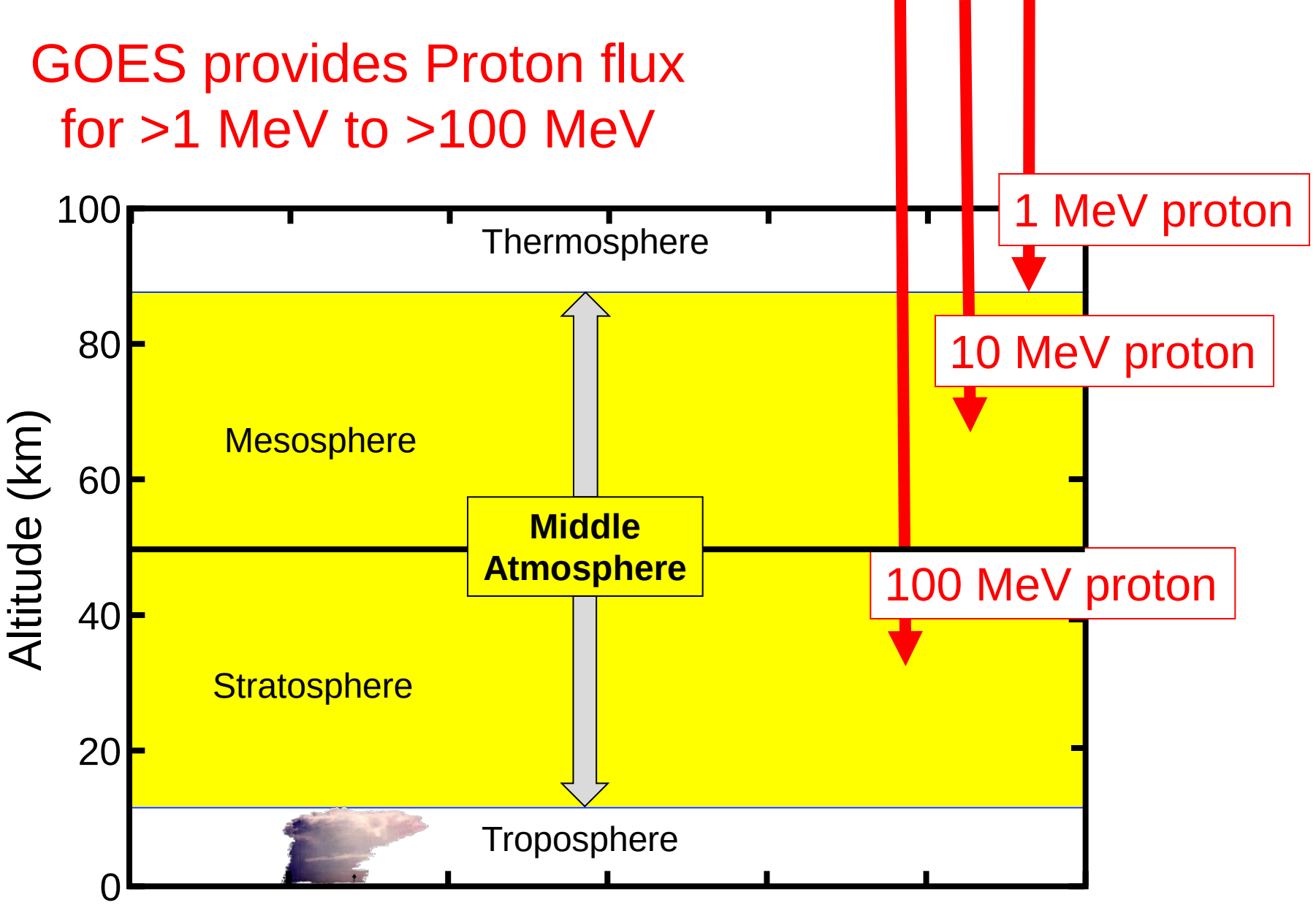
GOES - Geostationary Operational Environmental Satellites

Proton Precipitation



About 14% of Earth is affected during solar proton events.

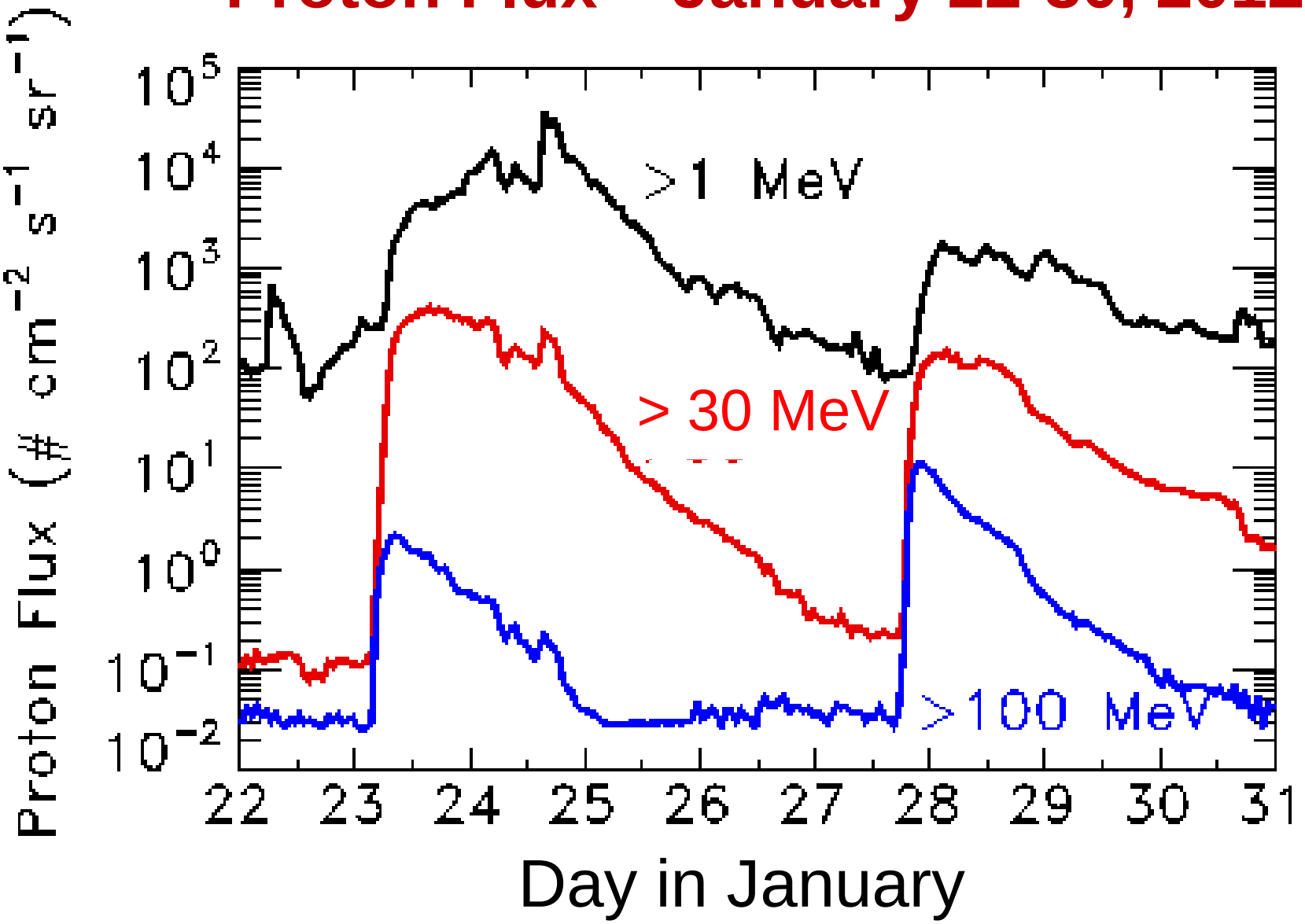
GOES provides Proton flux for >1 MeV to >100 MeV



II. January 2012 & July 2000 Solar Proton Events

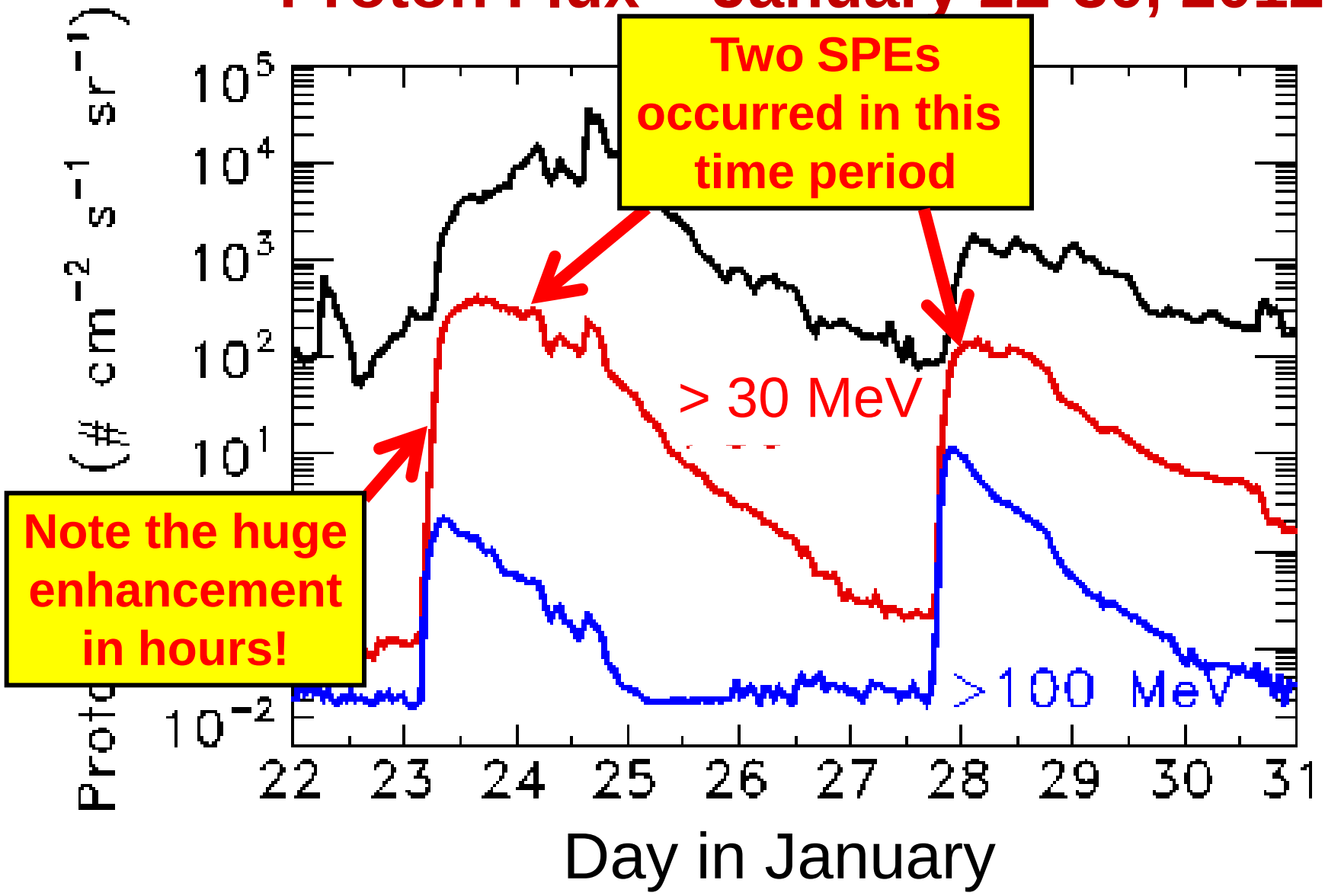
The January 2012 Solar Proton Events

Proton Flux – January 22-30, 2012



The January 2012 Solar Proton Events

Proton Flux – January 22-30, 2012

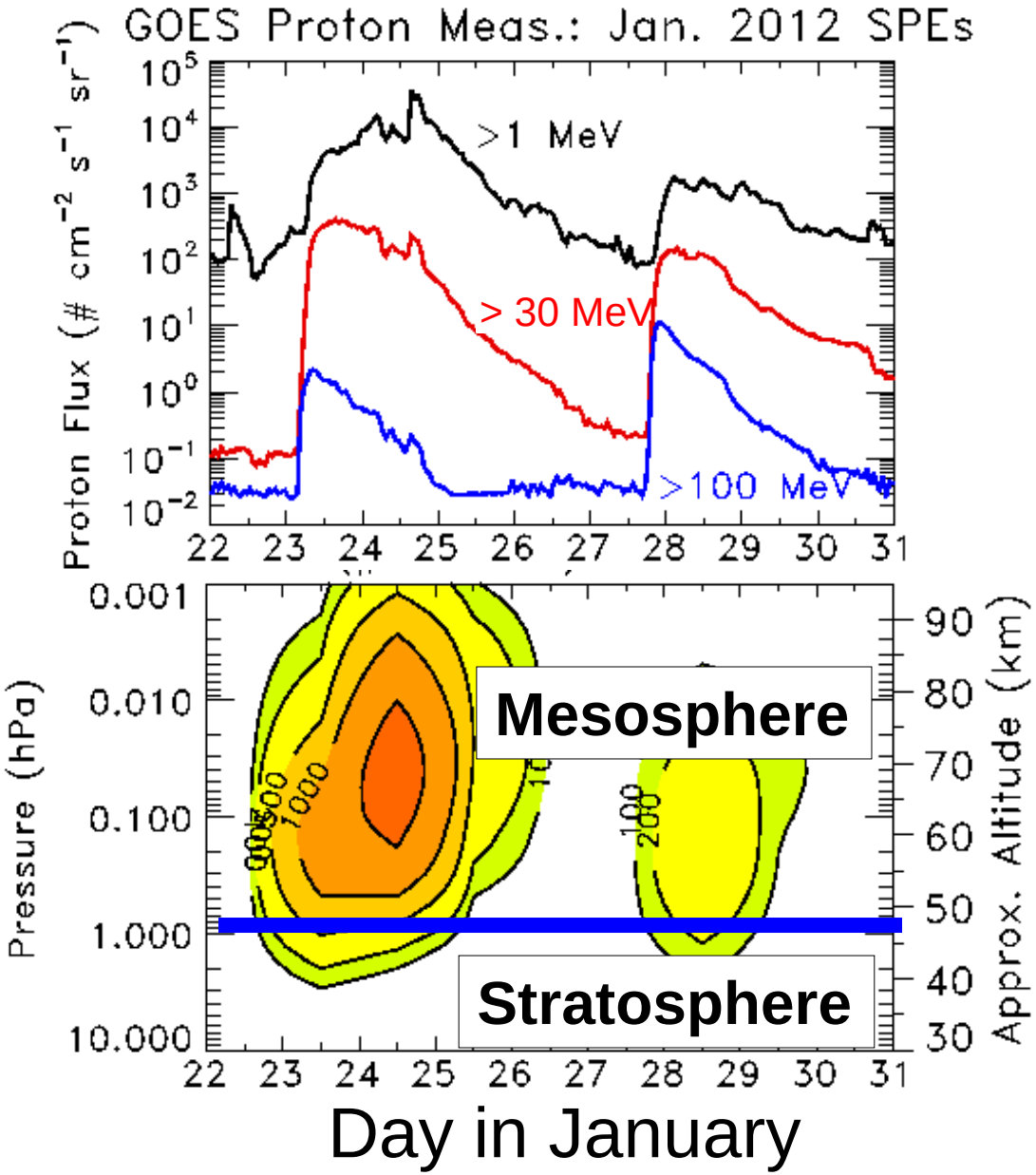


Atmospheric Influences

Most (70-80%) of the Energy Deposited by Protons Creates Ion Pairs:

→ free Electron & positive Ion

Proton Flux & Ion Rates – January 22-30, 2012



Contour levels: 100, 200, 500, 1000, & 2000 (#cm^{-3} s^{-1})

Solar Protons also Produce HO_x and NO_x

Both of which can destroy Ozone

- HO_x (H, OH, HO_2) produced via ion chem. H_2O impact
  - Primarily short-term effects (~hours after SPE)

- **NO_x (N, NO, NO_2) produced by protons & associated secondary electrons dissociating N_2**
  - **→ N rapidly produces NO & NO_2**
  - **→ Short- & long-term effects as NO_x lasts for weeks**

Envisat MIPAS measured NO & NO_2 (essentially NO_x)

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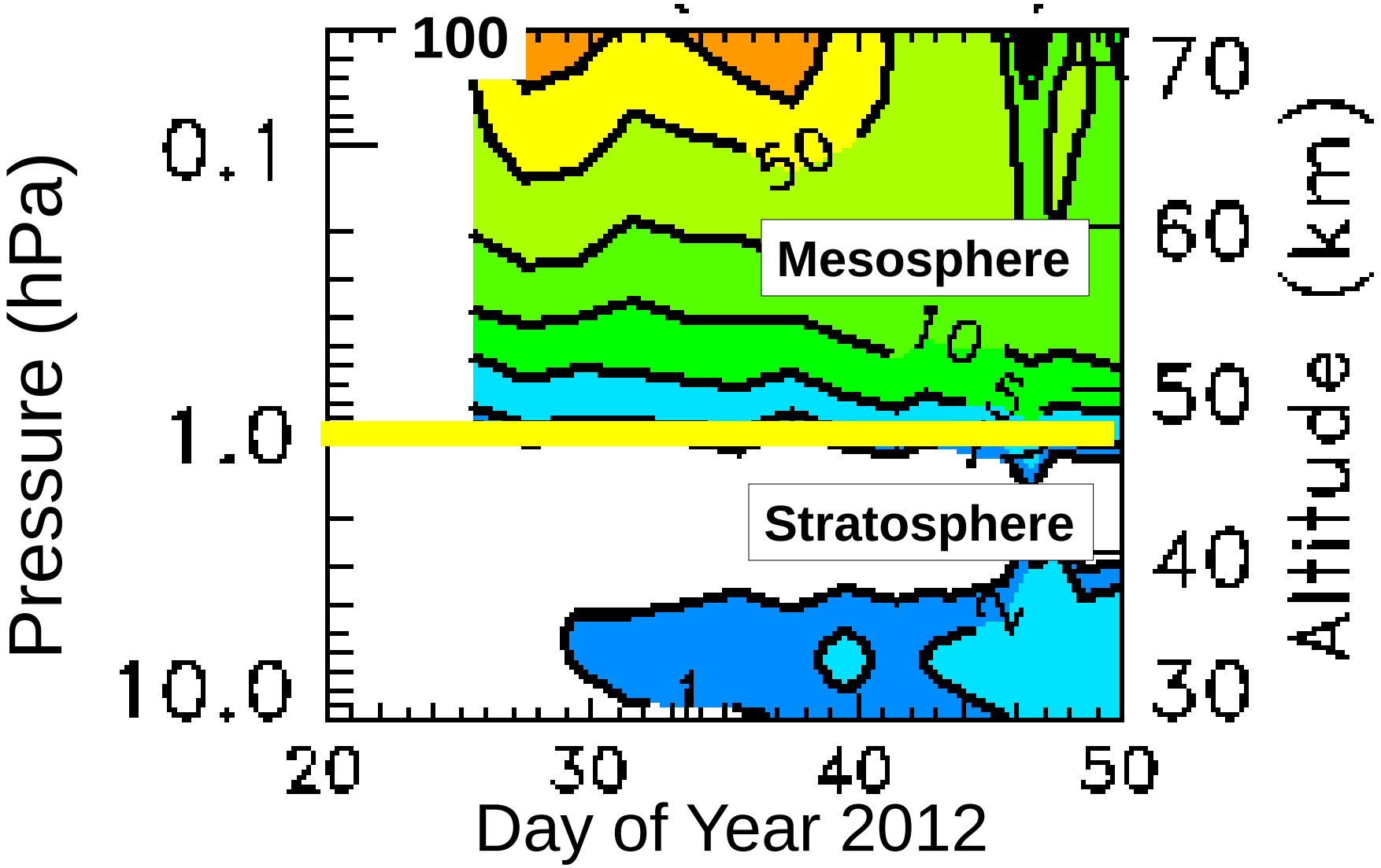
  - **→ N rapidly produces NO & NO_2**
  - **→ Short- & long-term effects as NO_x lasts for weeks**

Envisat MIPAS NO_x (ppbv change)

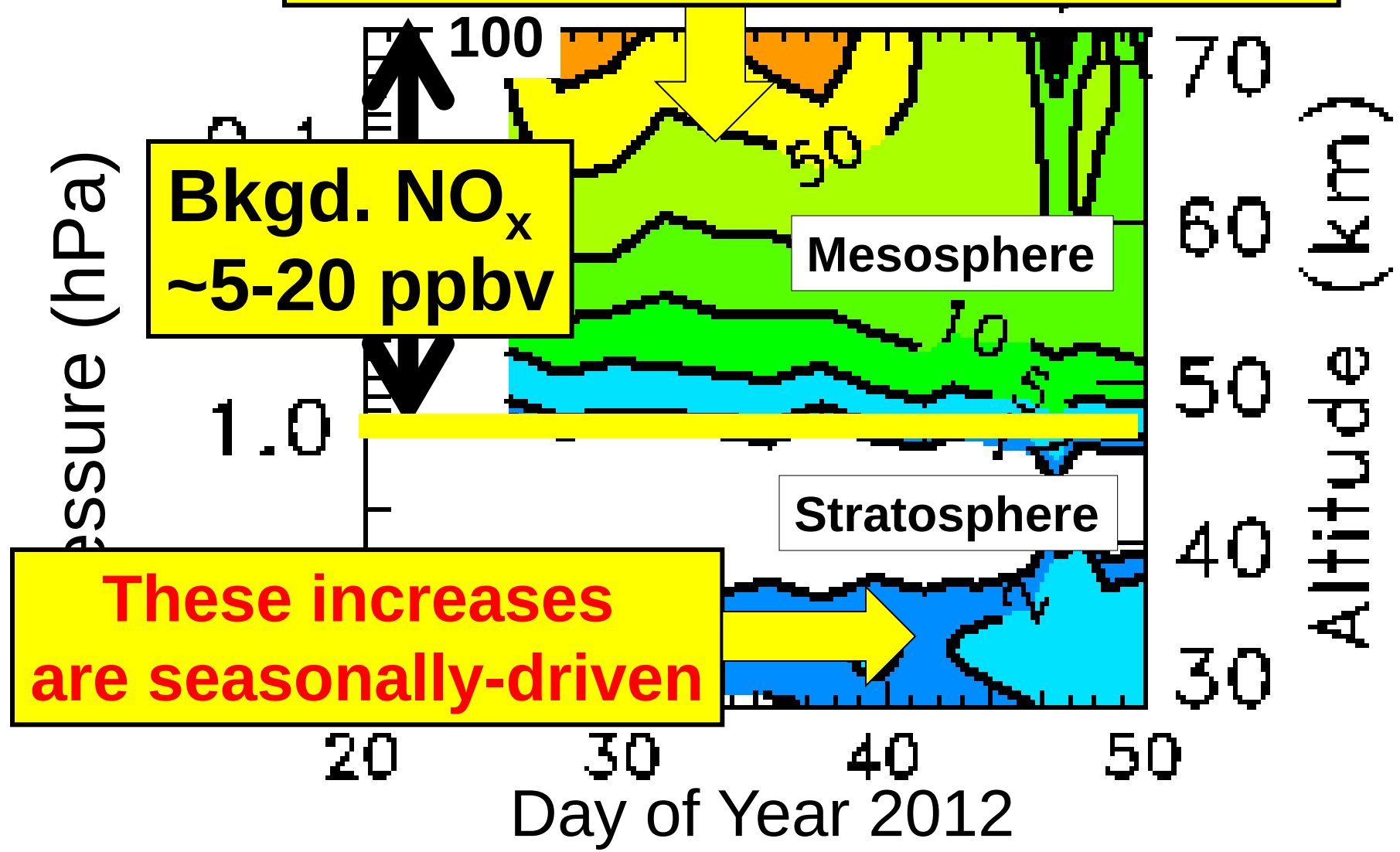
for 60-90ºN Lat. Band [subtract Day 22 values]



Envi ... **ge)**

for 60- ... **ues]**

Large NO_x increases mainly caused by SPEs



Bkgd. NO_x ~5-20 ppbv

These increases are seasonally-driven

These SPE-caused NO_x increases are primarily in the Mesosphere.

Stratospheric NO_x increases are needed for longer-term impacts on Ozone.

Largest 15 SPEs in Past 50 Years

Date of SPEs	*Computed Rank (NO_x Production)*	*GMoles NO_x*
October 1989	1	7.2
August 1972	2	6.1
July 2000	3	6.0
October 28-31, 2003	4	5.7
November 5-7, 2001	5	5.3
November 2000	6	4.3
September 2001	7	3.1
August 1989	8	3.1
November 23-25, 2001	9	2.9
March 2012	10	2.1
September 1966	11	2.0
January 2012	12	1.9
January 2005	13	1.9
Sep. 29 – Oct. 3, 1989	14	1.7
Jan. 28 – Feb. 1, 1967	15	1.6

GigaMole = 6.02×10^{32} atoms and molecules

Largest 15 SPEs in Past 50 Years

Date of SPEs	*Computed Rank (NO_x Production)*	*GMoles NO_x*
October 1989	1	
August 1972	2	
July 2000	3	6.0
October 28-31, 20		
November 5-7, 20		
November 2000		
September 2001		
August 1989		
November 23-25, 2001	9	
March 2012	10	
September 1966	11	
January 2012	12	1.9
January 2005	13	
Sep. 29 – Oct. 3, 1989	14	
Jan. 28 – Feb. 1, 1967	15	

July 2000:

~ a factor of three larger than the ***January 2012*** SPEs

GigaMole = 6.02 x 10^{32} atoms and molecules

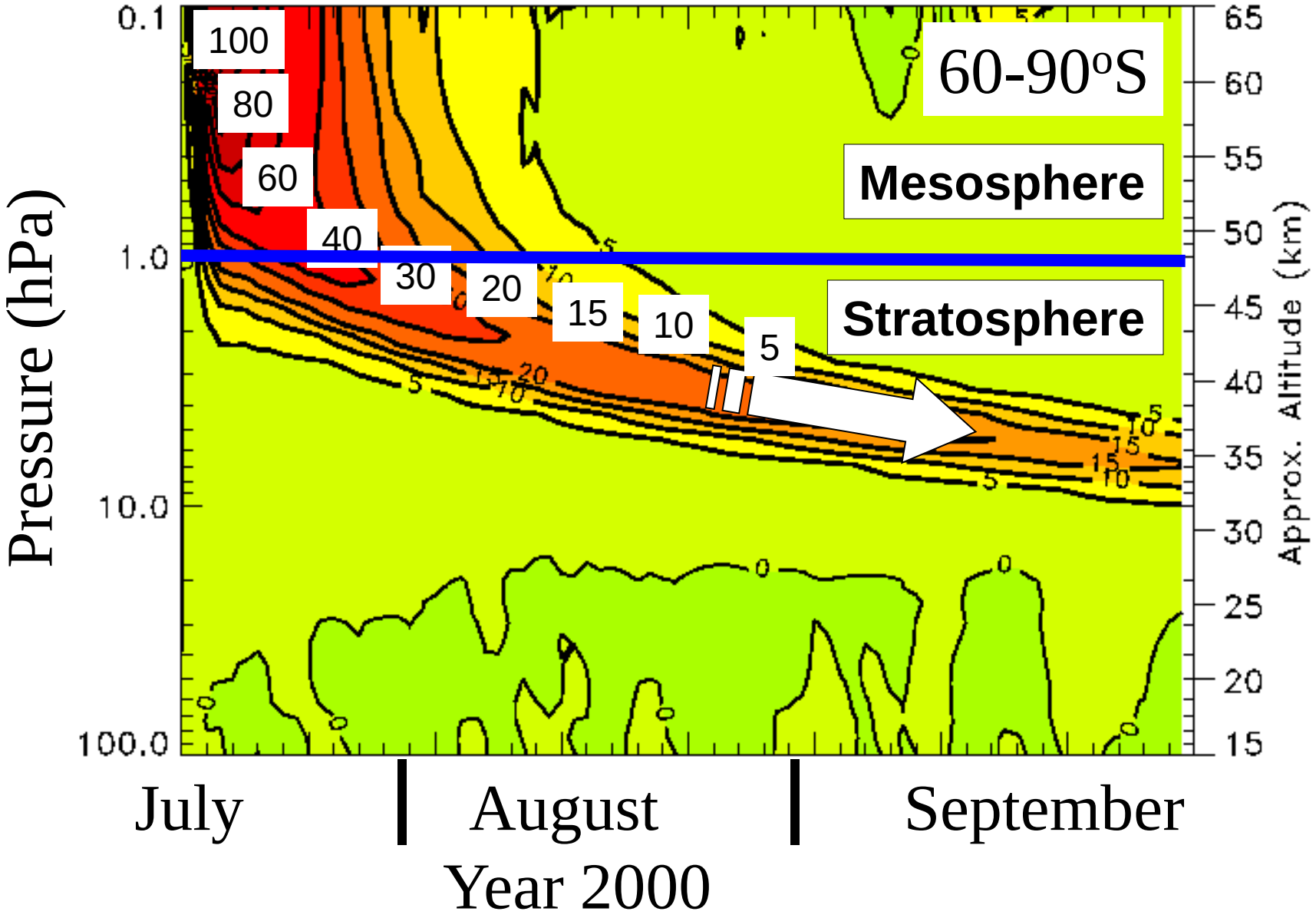
Model Simulations

- **Whole Atmosphere Community Climate Model (WACCM)**

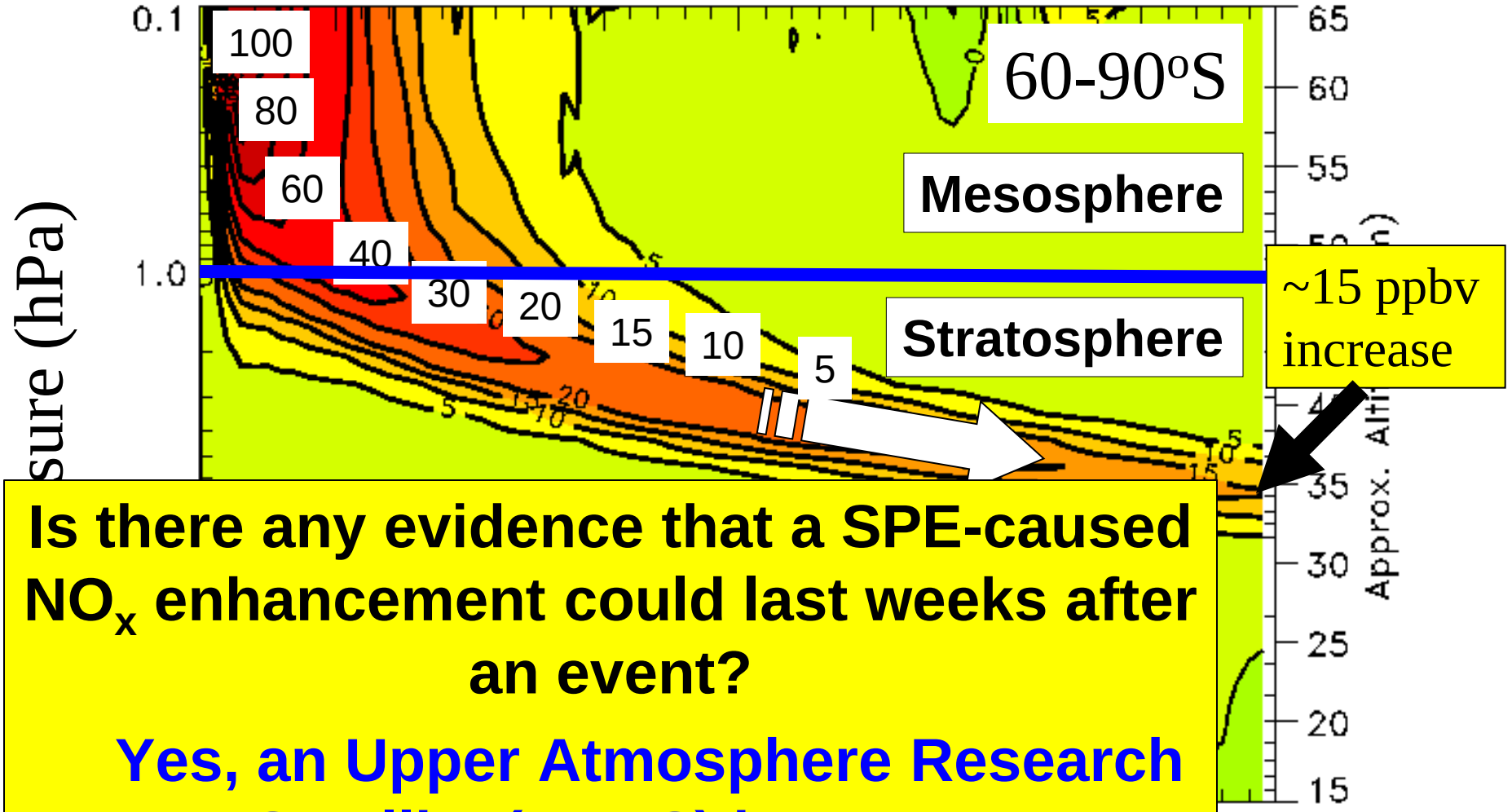
- **Simulations over years 2000 - 2001:**
  - **Perturbed 'With SPEs'**
  - **Base 'Without SPEs'**

- **Difference Perturbed and Base simulations to compute SPE-caused change**

WACCM - NO_x ($NO+NO_2$) change (ppbv)



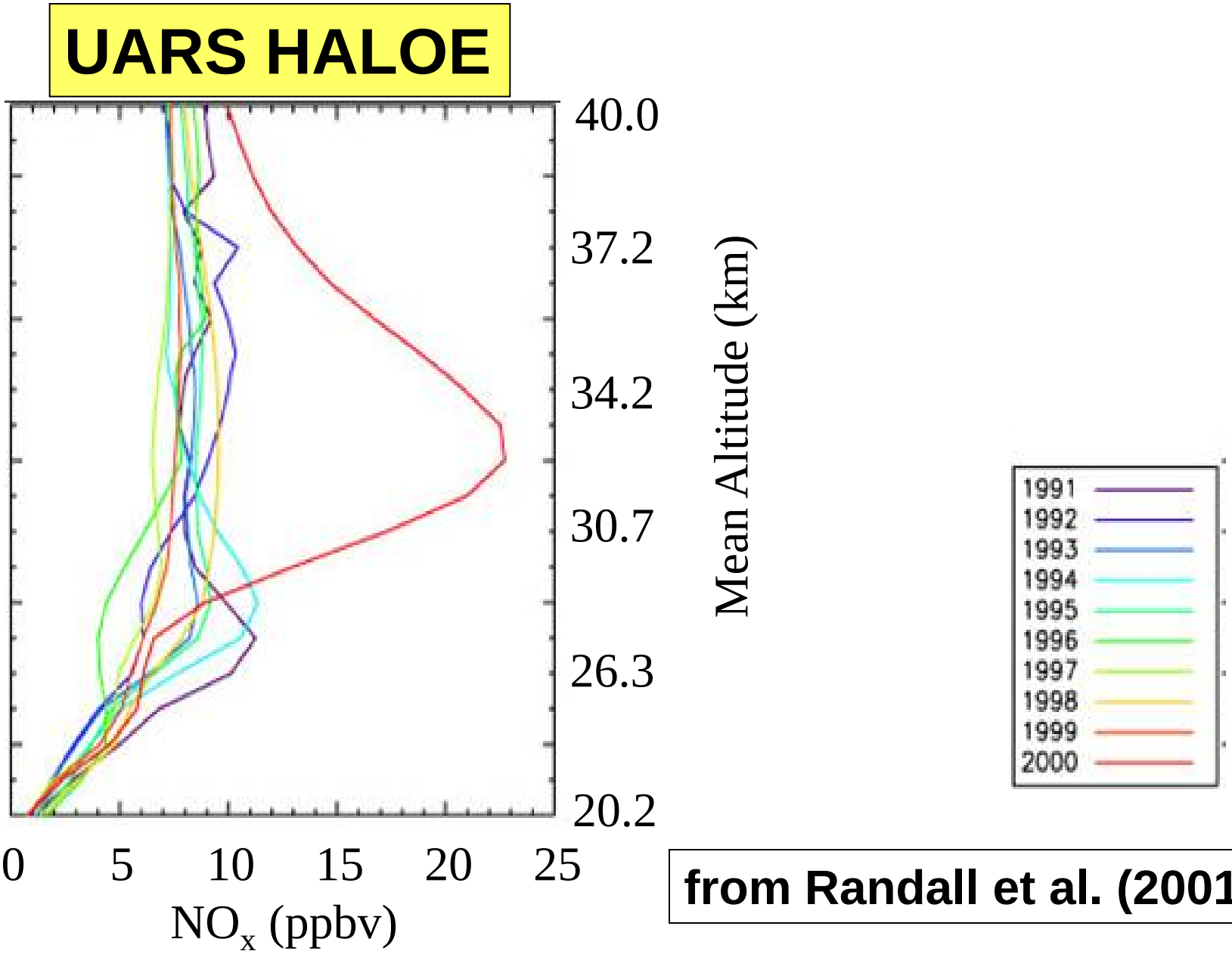
WACCM - NO_x ($NO+NO_2$) change (ppbv)



Is there any evidence that a SPE-caused NO_x enhancement could last weeks after an event?

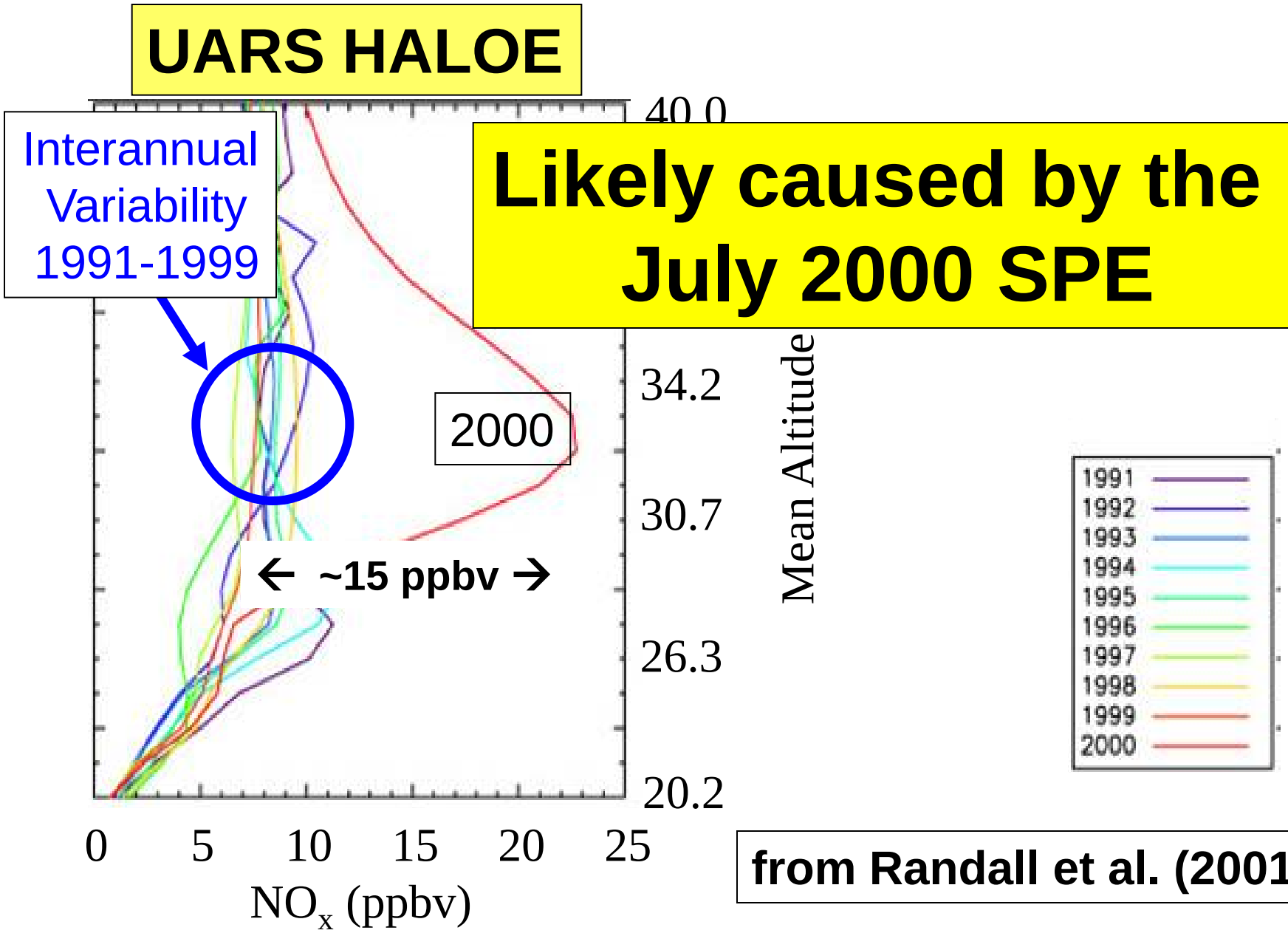
Yes, an Upper Atmosphere Research Satellite (UARS) instrument measured NO_x changes

NO_x ($NO+NO_2$) in SH Polar Vortex in Sep./Oct.



from Randall et al. (2001)

NO_x ($NO+NO_2$) in SH Polar Vortex in Sep./Oct.



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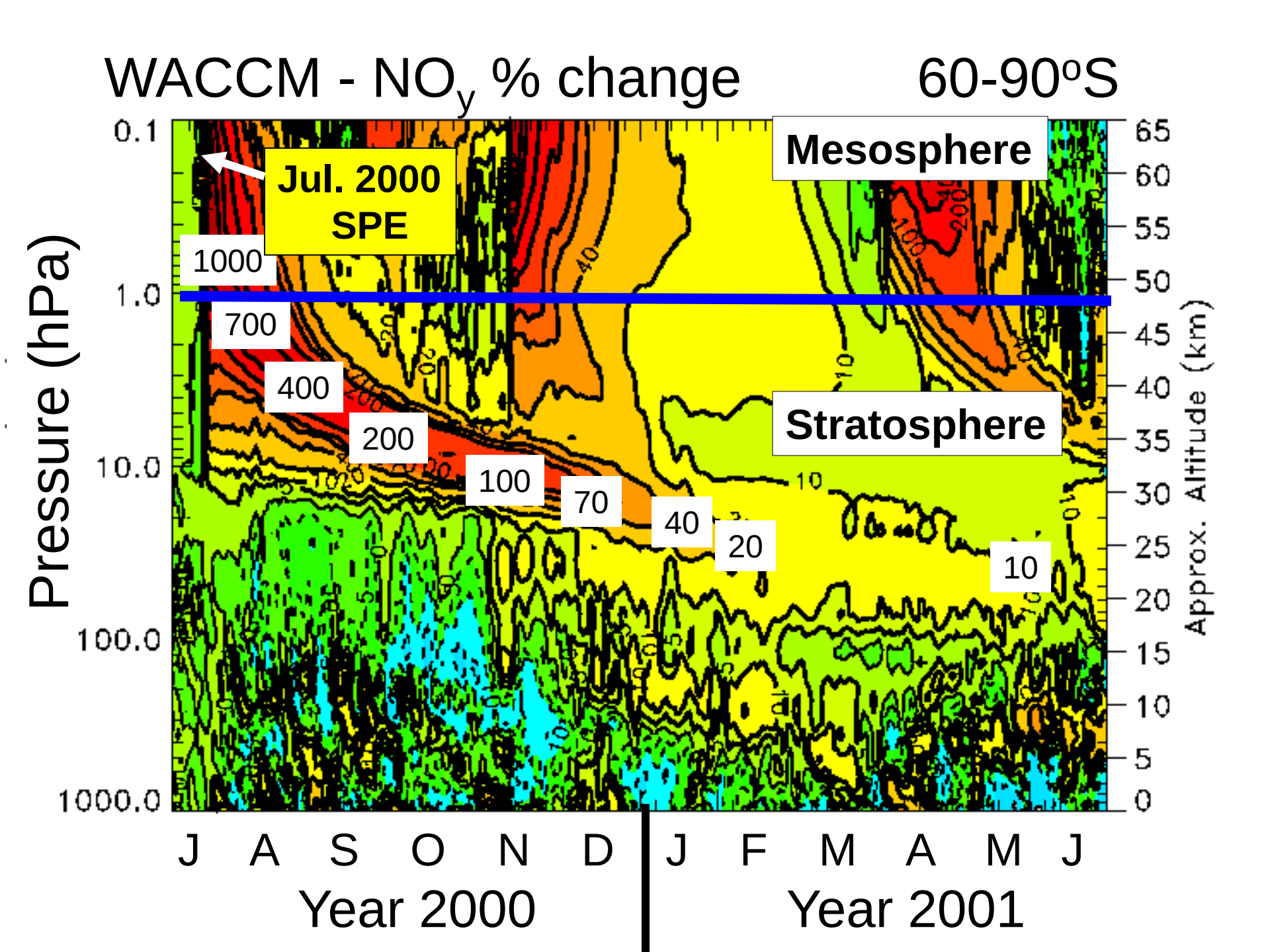
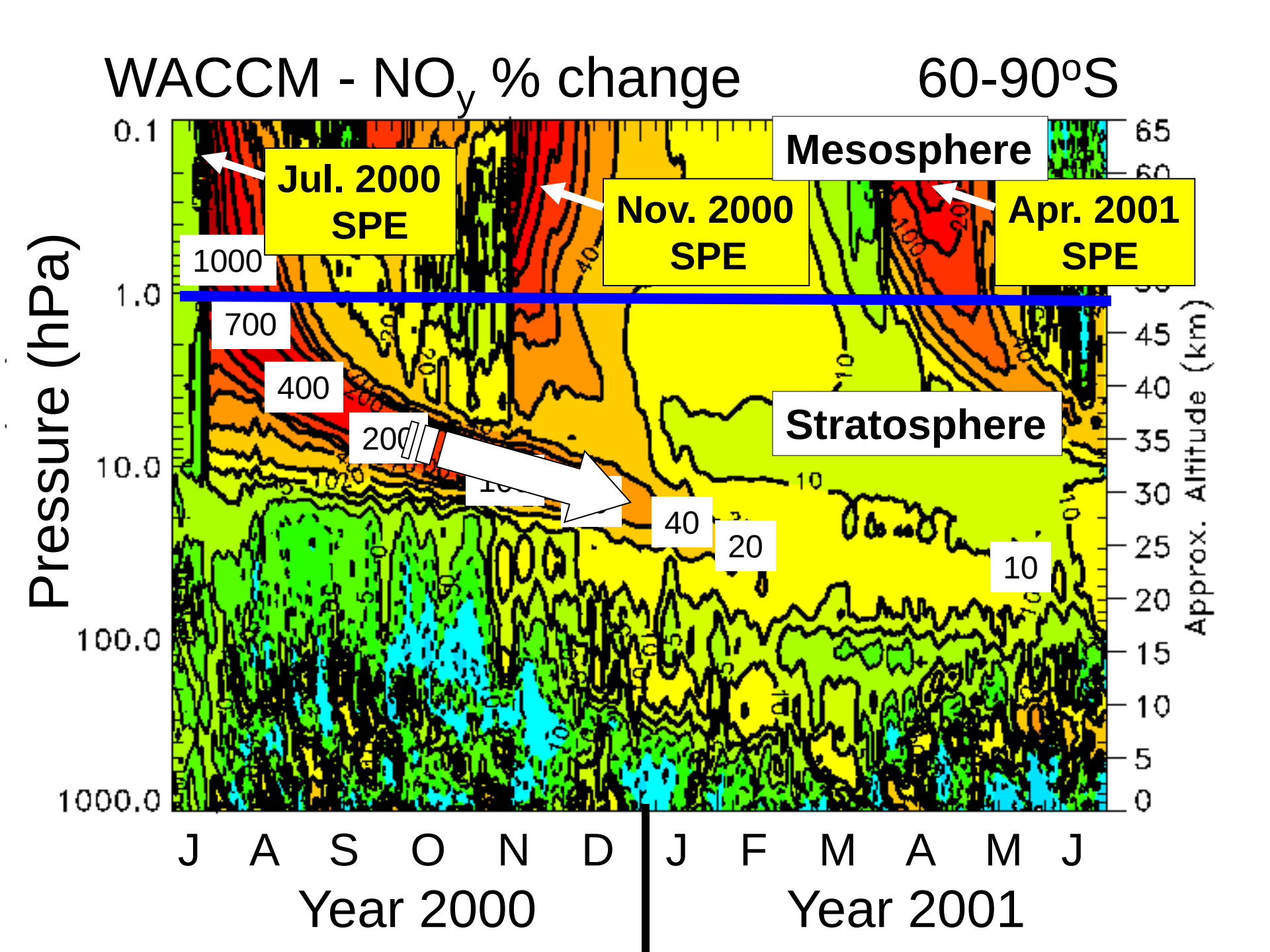
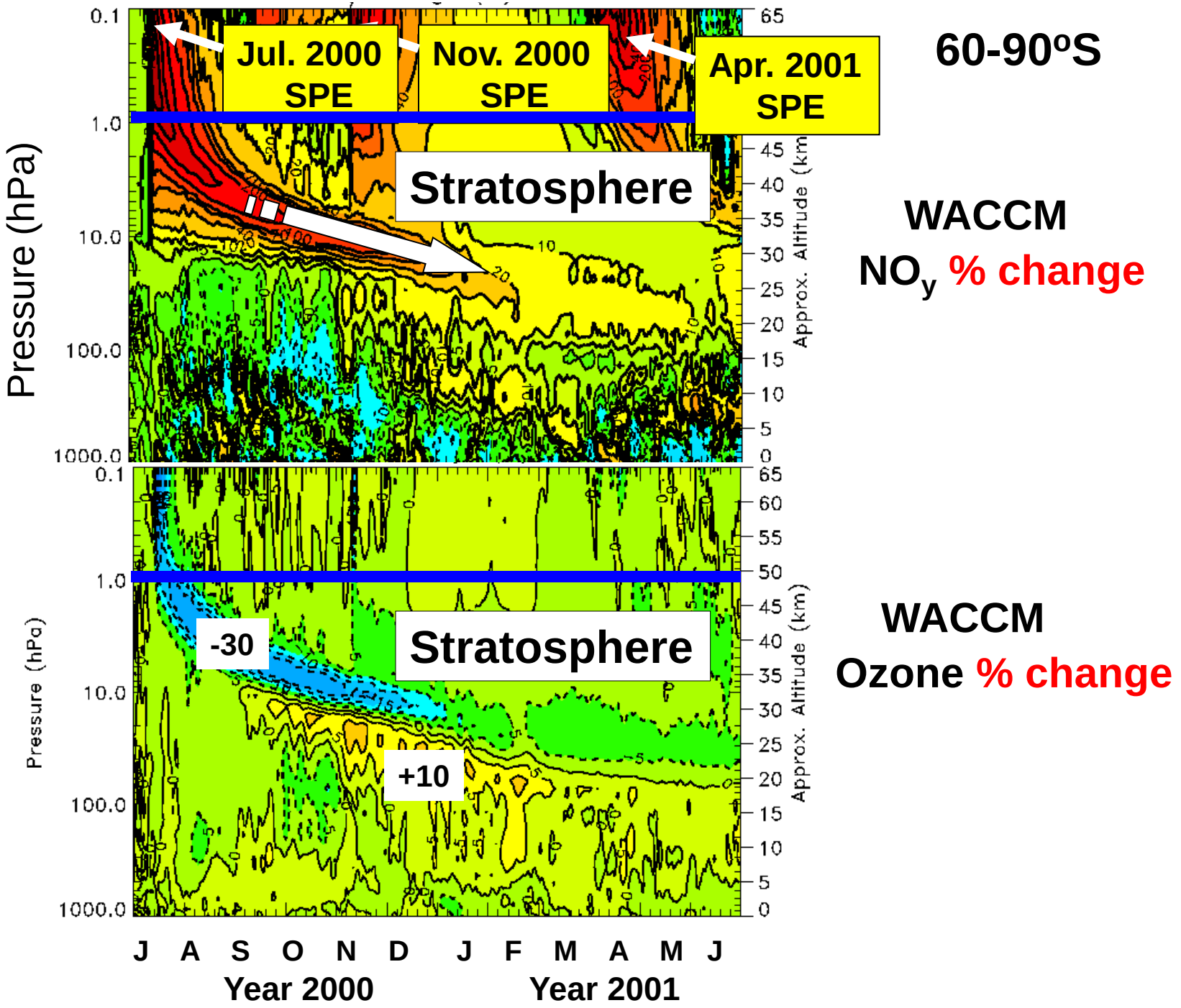
NO_x enhances larger family NO_y

(N, NO, NO_2, NO_3, N_2O_5, HNO_3, HO_2NO_2, $ClONO_2$, $BrONO_2$)

– Whose lifetime can be long (~months to years)

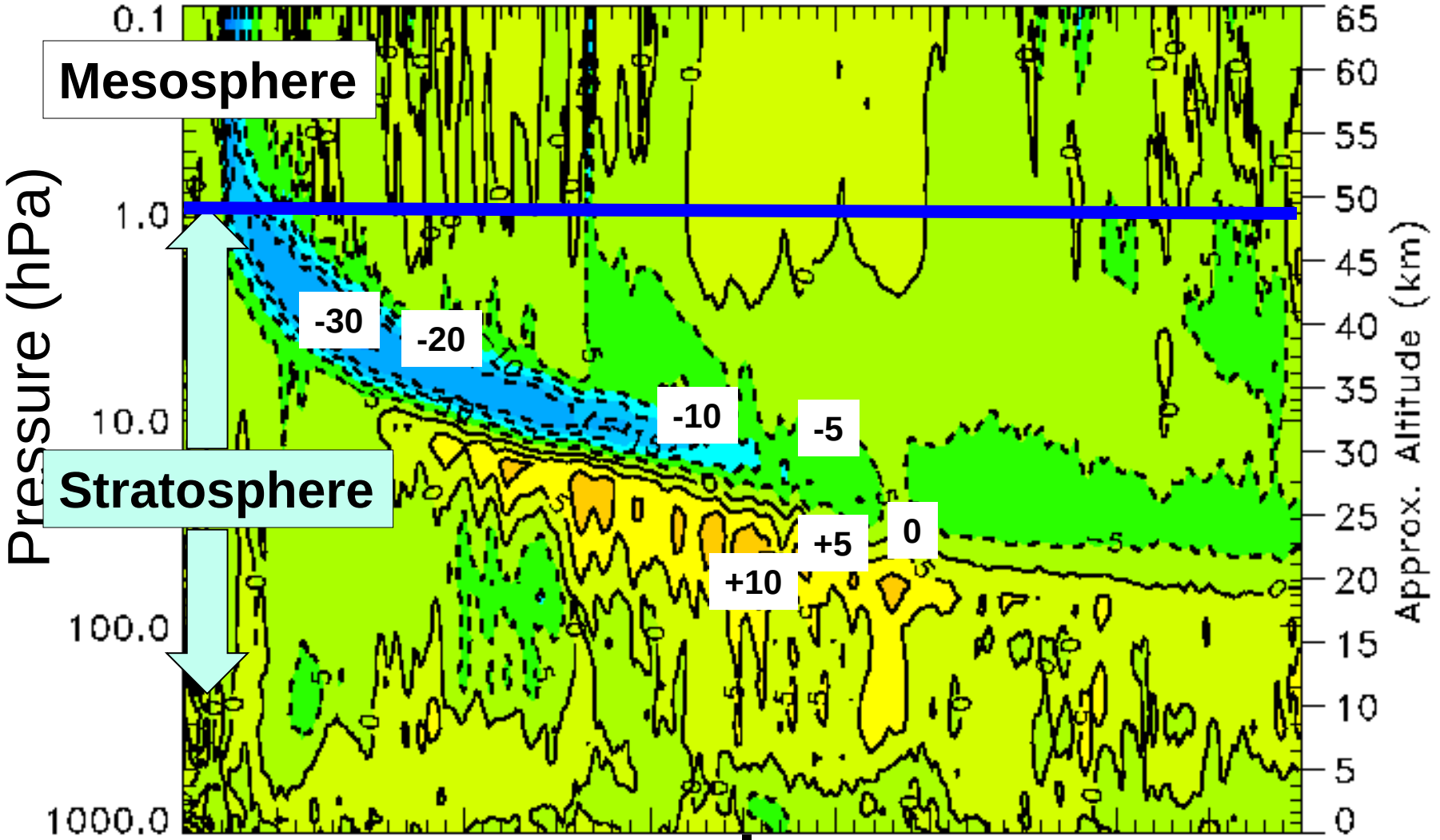

WACCM - NOy % change
60-90°S
Jul. 2000 SPE
Mesosphere
Stratosphere
1000
700
400
200
100
70
40
20
10
Pressure (hPa)
0.1
1.0
10.0
100.0
1000.0
Approx. Altitude (km)
65
60
55
50
45
40
35
30
25
20
15
10
5
0
J A S O N D J F M A M J
Year 2000
Year 2001

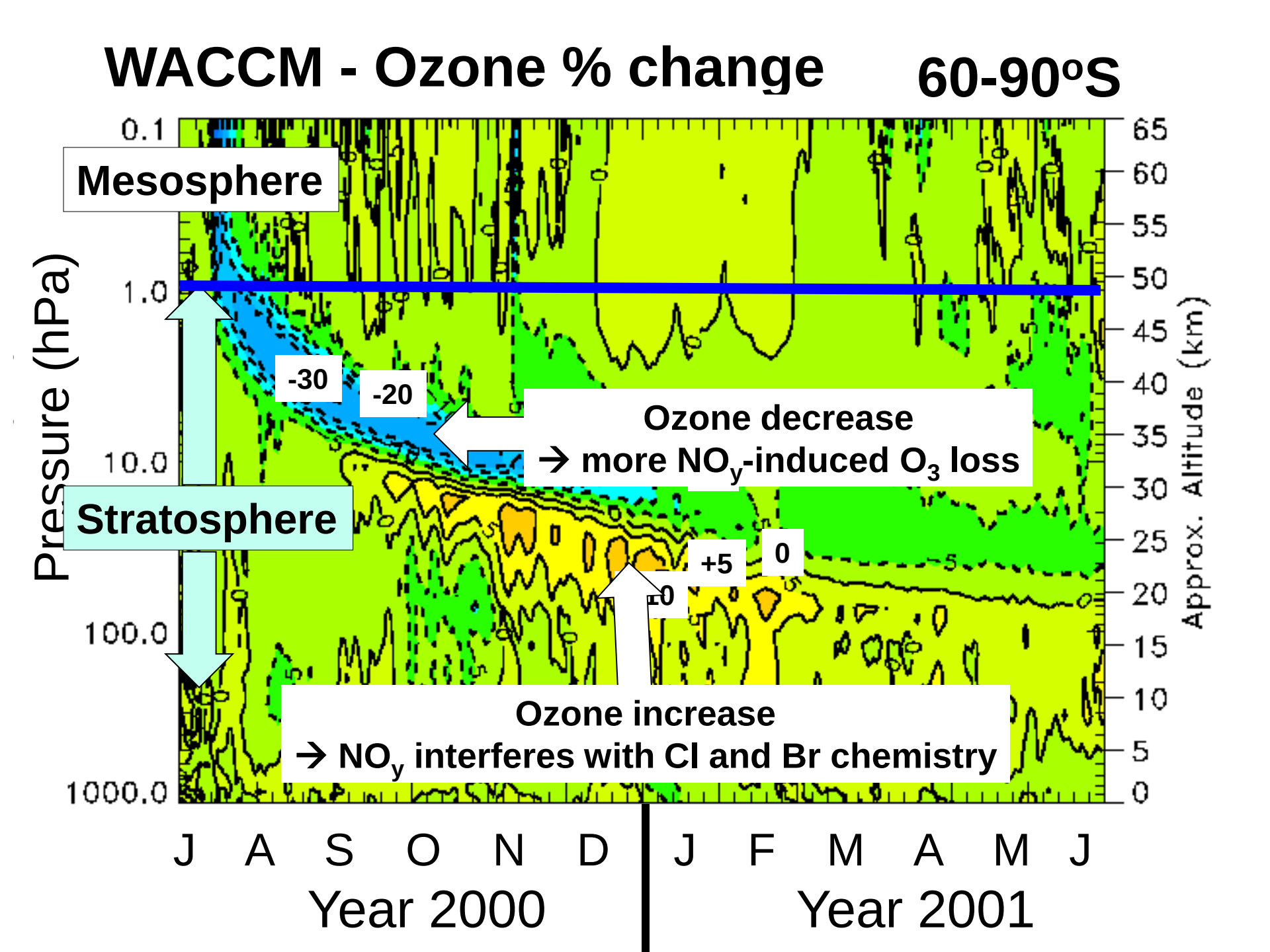

WACCM - NOy % change
60-90°S
Jul. 2000 SPE
Nov. 2000 SPE
Apr. 2001 SPE
Mesosphere
Stratosphere
1000
700
400
200
40
20
10
Pressure (hPa)
0.1
1.0
10.0
100.0
1000.0
Approx. Altitude (km)
65
60
45
40
35
30
25
20
15
10
5
0
J A S O N D J F M A M J
Year 2000
Year 2001


Jul. 2000 SPE
Nov. 2000 SPE
Apr. 2001 SPE
60-90ºS
Stratosphere
WACCM
NOy % change
Pressure (hPa)
Approx. Altitude (km)
-30
Stratosphere
+10
WACCM
Ozone % change
J A S O N D J F M A M J
Year 2000
Year 2001

WACCM - Ozone % change

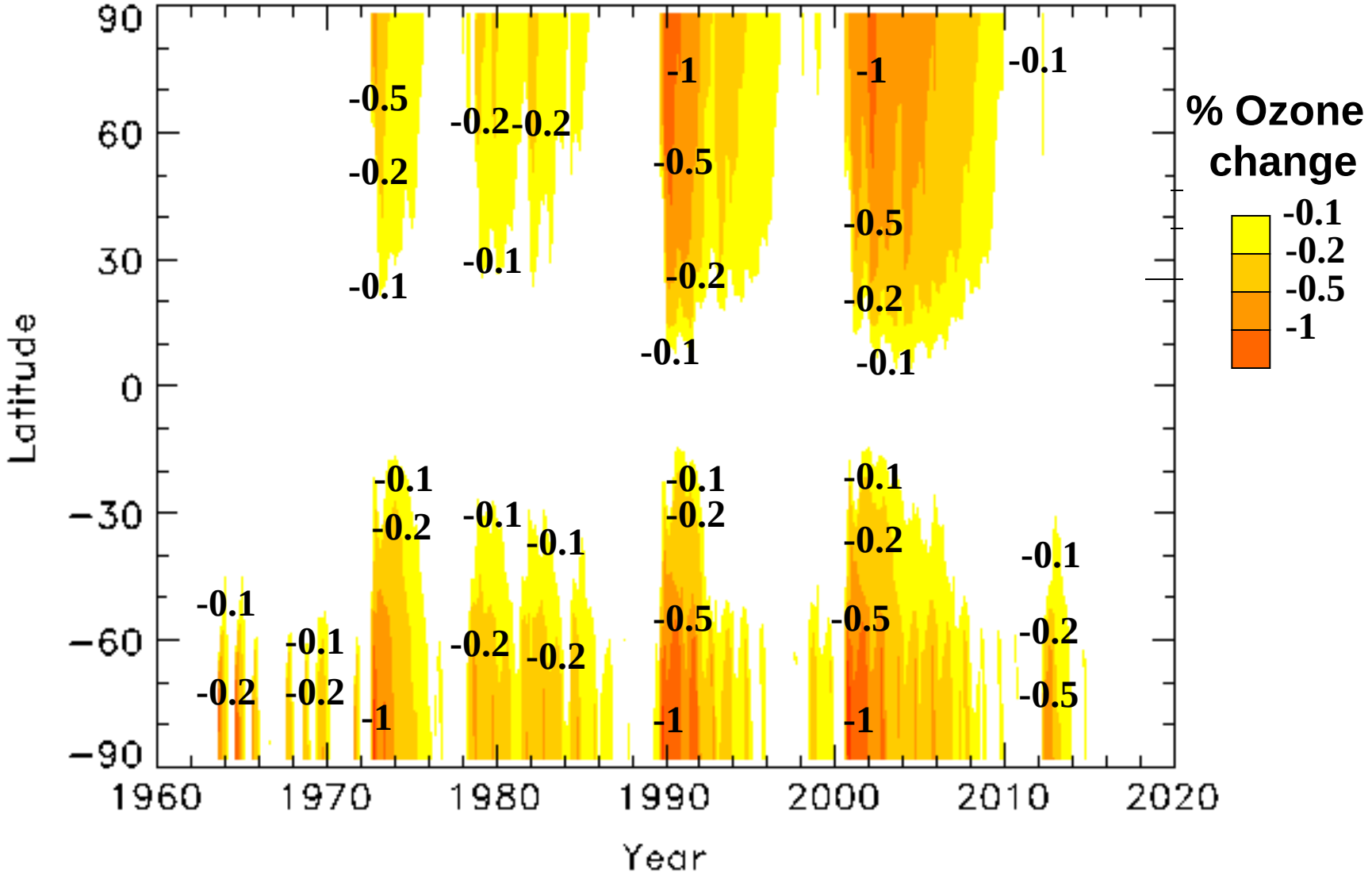
60-90°S




WACCM - Ozone % change
60-90°S
Mesosphere
Stratosphere
Pressure (hPa)
0.1
1.0
10.0
100.0
1000.0
Approx. Altitude (km)
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-30
-20
Ozone decrease
→ more NOy-induced O3 loss
+5
0
-0
Ozone increase
→ NOy interferes with Cl and Br chemistry
J A S O N D
J F M A M J
Year 2000
Year 2001

III. Total Ozone Impacts

Predicted Impact (GSFC 2D Model) of Solar Protons on Total Ozone (%)



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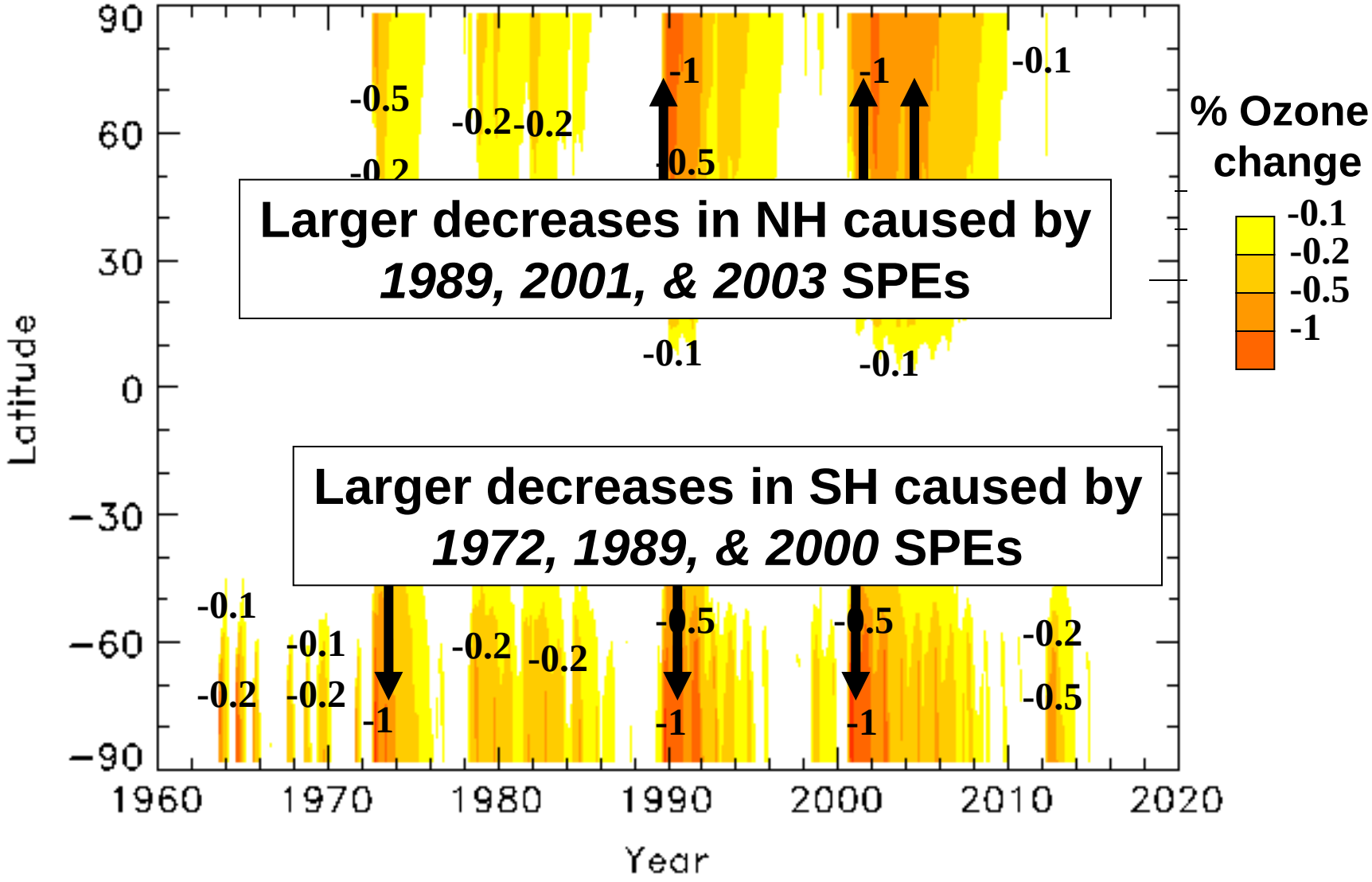
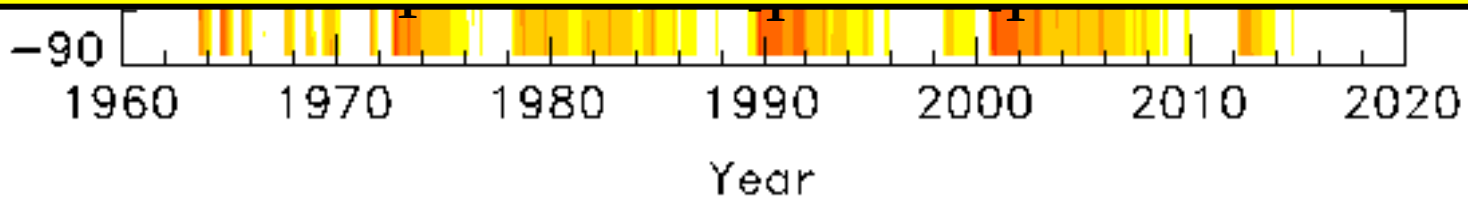


Predicted Impact (GSFC 2D Model) of Solar Protons on Total Ozone (%)

Computed Total Ozone decreases from SPEs are maximum of ~3%.

Measured interannual variability up to ~10%, thus difficult to observe.

Such changes are competitive with high latitude variations caused by Solar photons over a Solar Cycle (1-2%).



IV. Conclusions

A. Very Large SPEs do Influence the Polar Mesosphere and Stratosphere

B. SPEs Produced Large Amounts of *Polar NO_y* in 1972, 1989, 2000, 2001, & 2003

C. *Polar NO_y Impacted Ozone*:

- → **Caused months-long impacts**
- → **Led to both stratospheric decrease & increase**
- → **Total ozone decreases up to ~3%**

Thank you for your attention!