# An Overview of the Impact of Energetic Particle Precipitation on the Stratosphere and Mesosphere

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# Acknowledgments:

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# Outline

I. Introduction

II. $HO_x$ [H, OH, $HO_2$] impacts

III. $NO_x$ [N, NO, $NO_2$] impacts

IV. Ozone impacts

V. Conclusions

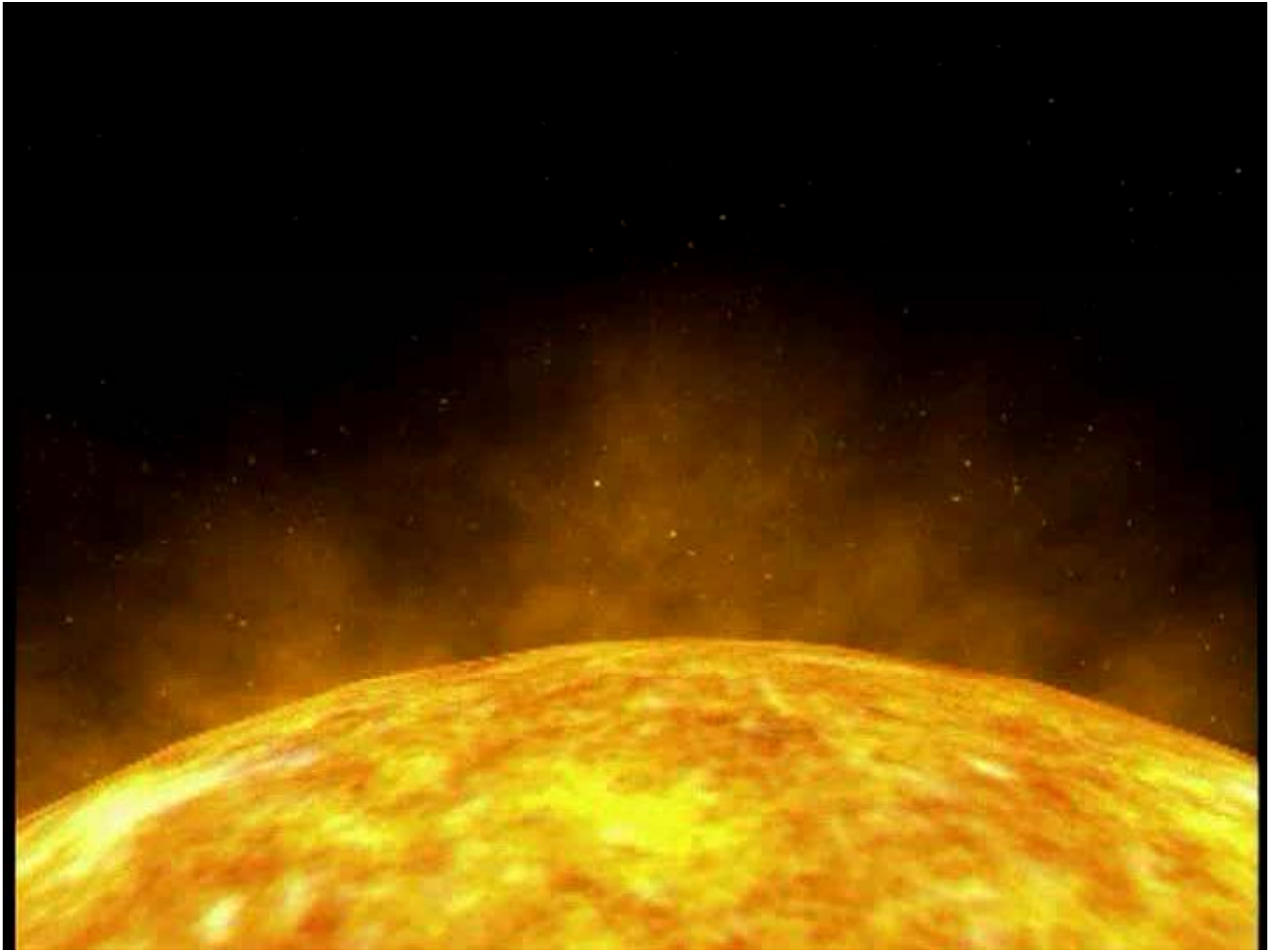
# I. Introduction

**Focus on Electrons and Protons**

Comprise most (~90% or so) of Energetic Particles

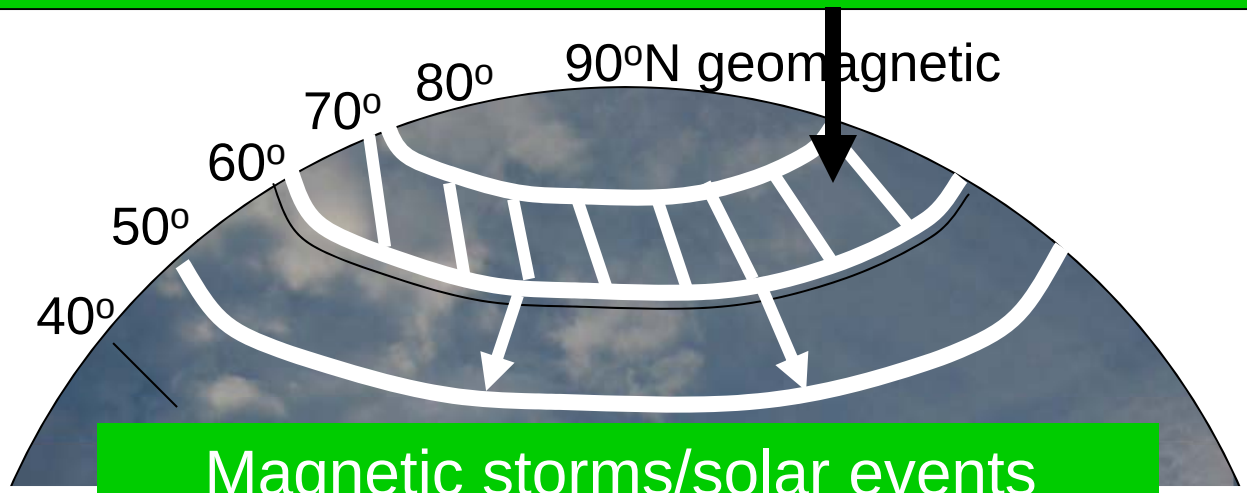
**Ultimate origin of Energetic Particles is the Sun**

# Animation of Coronal Mass Ejection



# Electron Precipitation

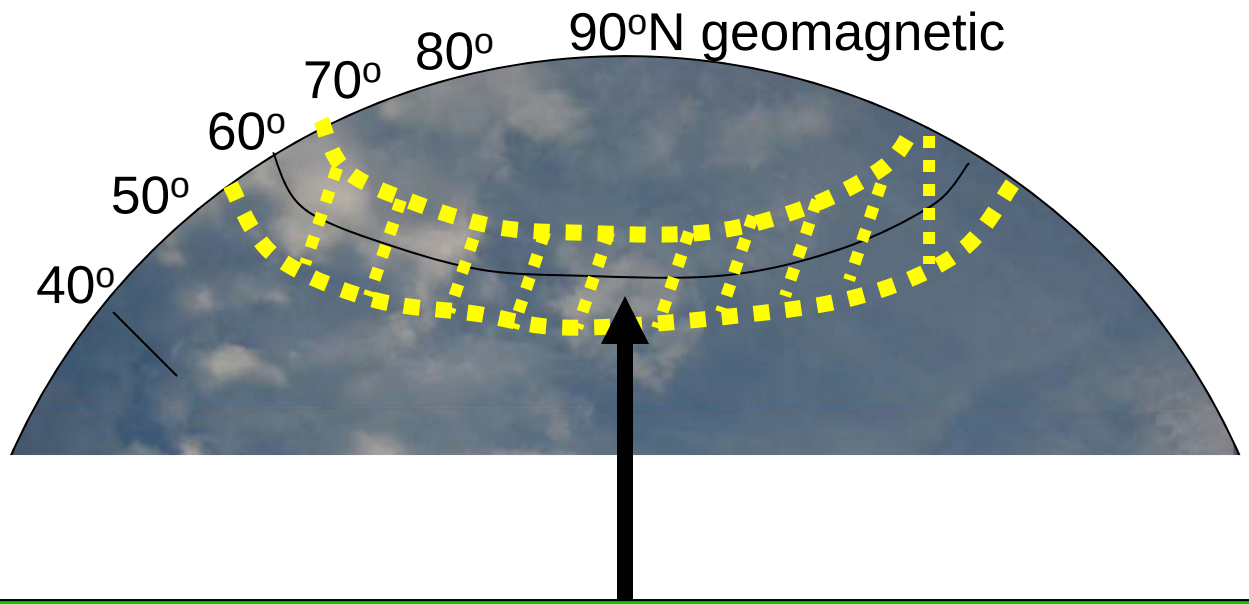
Auroral electrons → auroral zone [~62-75º geomag. lat.]




Magnetic storms/solar events
push auroral boundary Equatorward

Large dependence:
1) Diurnally - day, night
2) Seasonally
3) With magnetic/solar activity

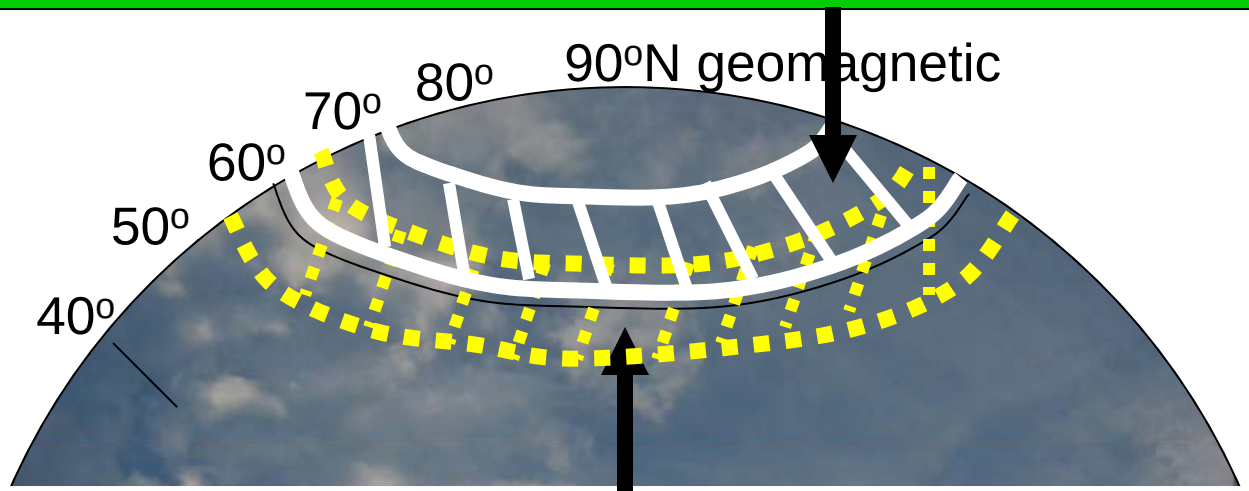
# Electron Precipitation




Medium & high energy electrons
→ subauroral (diffuse, relativistic) [~55-65º geom. lat.]

# Electron Precipitation

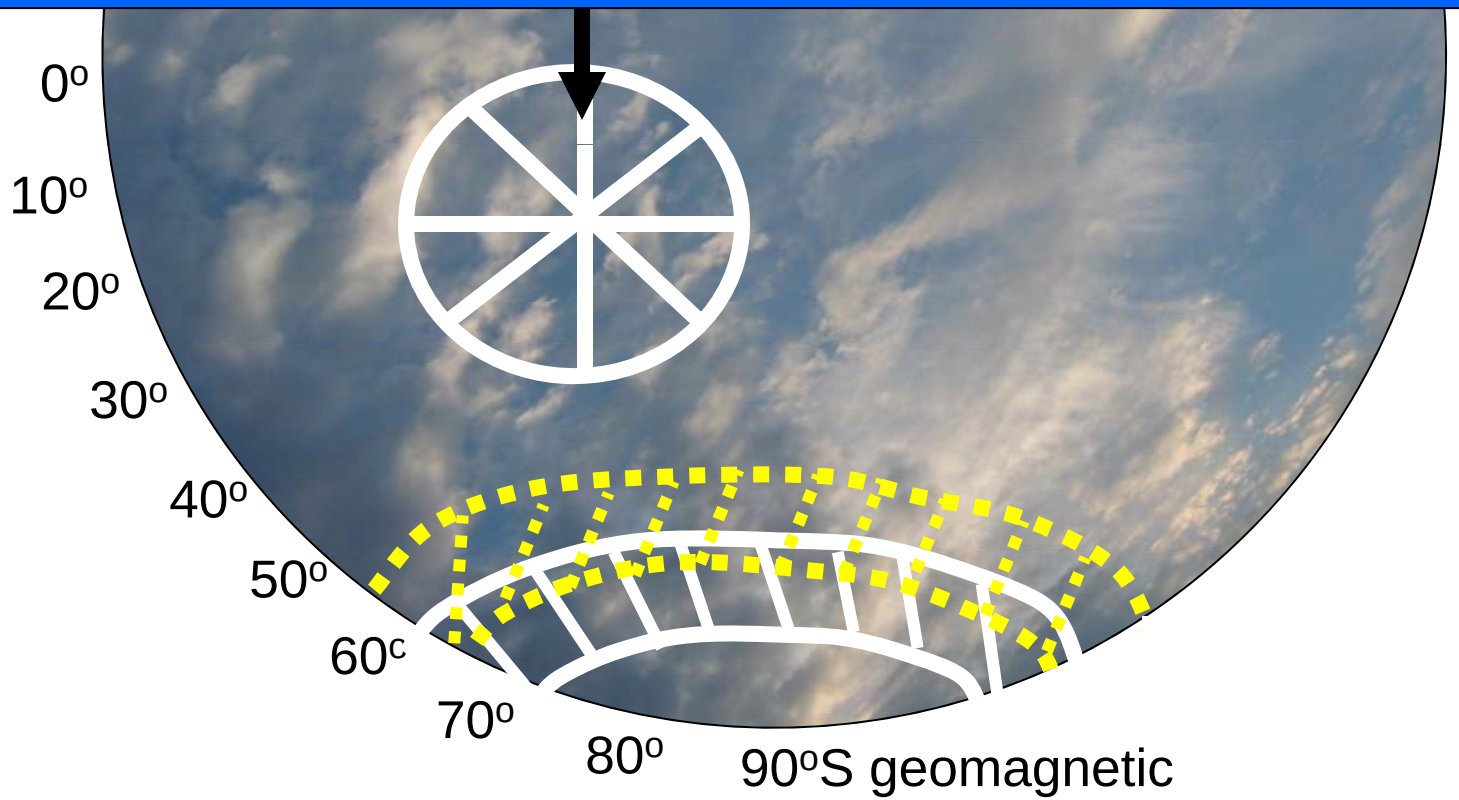
Auroral electrons → auroral zone [~62-75º geomag. lat.]

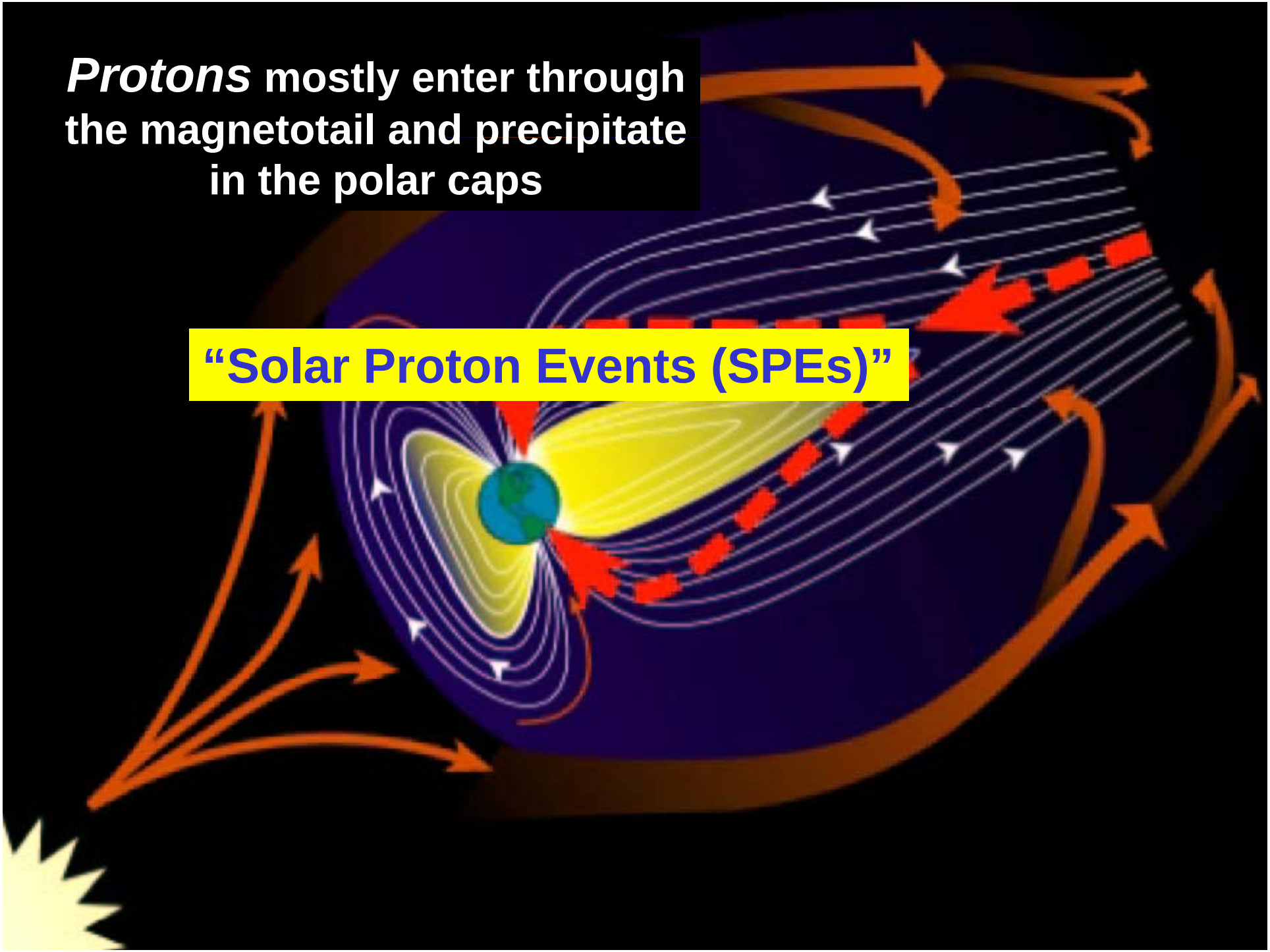



Medium & high energy electrons
→ subauroral (diffuse, relativistic) [~55-65º geom. lat.]

# Electron Precipitation

Also: South Atlantic Anomaly – weak field – all electrons
→ low latitude [~0-30°S geom. lat., ~0-45°E geom. lon.]




*Protons* mostly enter through the magnetotail and precipitate in the polar caps
"Solar Proton Events (SPEs)"

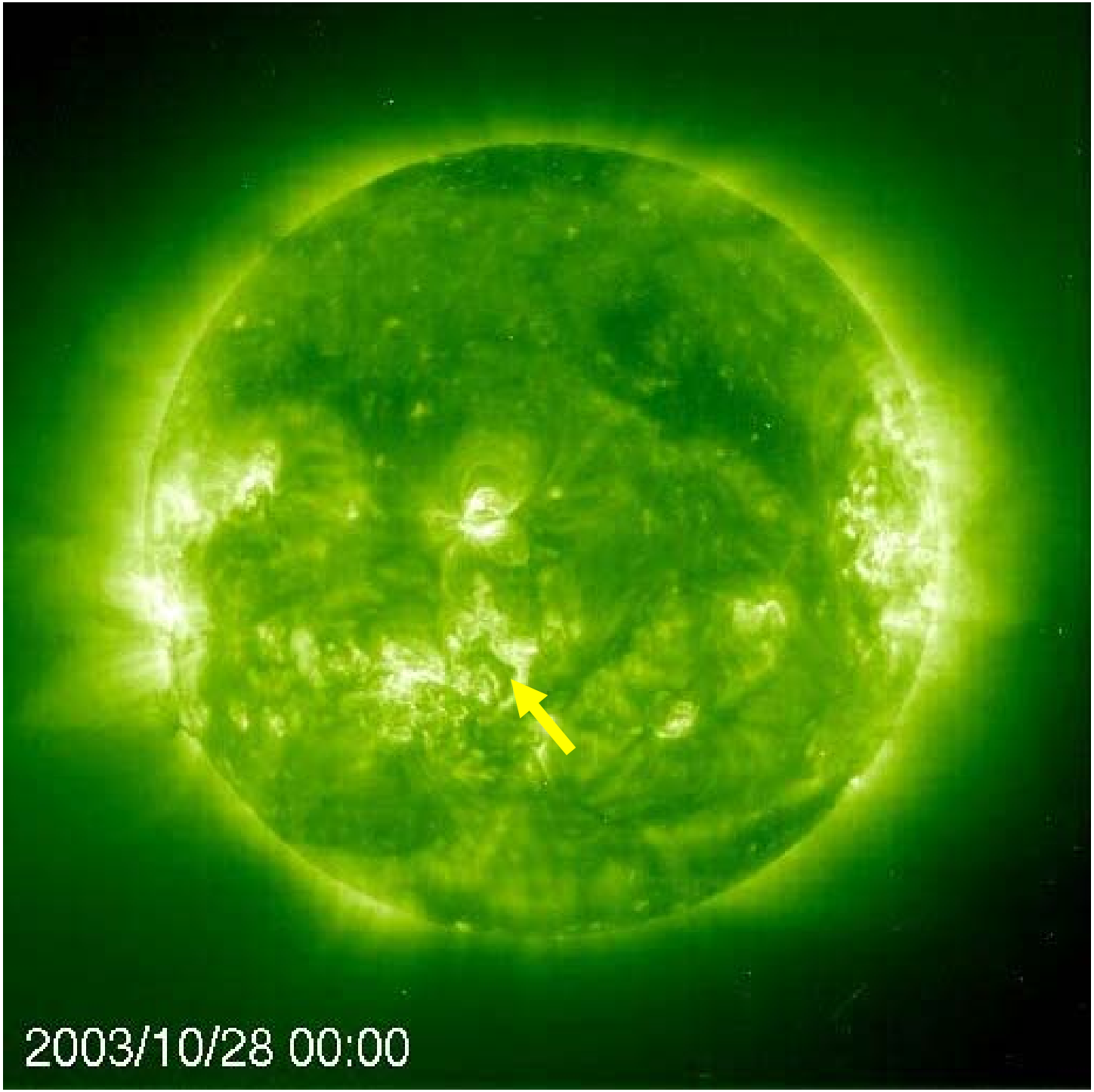
# Impulsive Flare Event on October 28, 2003

## "Halloween Storms"

***View with SOHO***

***(Solar and Heliospheric Observatory)***

***Extreme UV Imaging Telescope***


2003/10/28 00:00

# Proton Precipitation

Solar protons


Very intense solar events
push polar cap boundaries Equatorward

# Energetic Particle Precipitation

(of interest here)

**Electrons**

- **Auroral (~1-30 keV)**
- **Medium energy (~30-300 keV)**
- **High energy (~300-3000 keV)**

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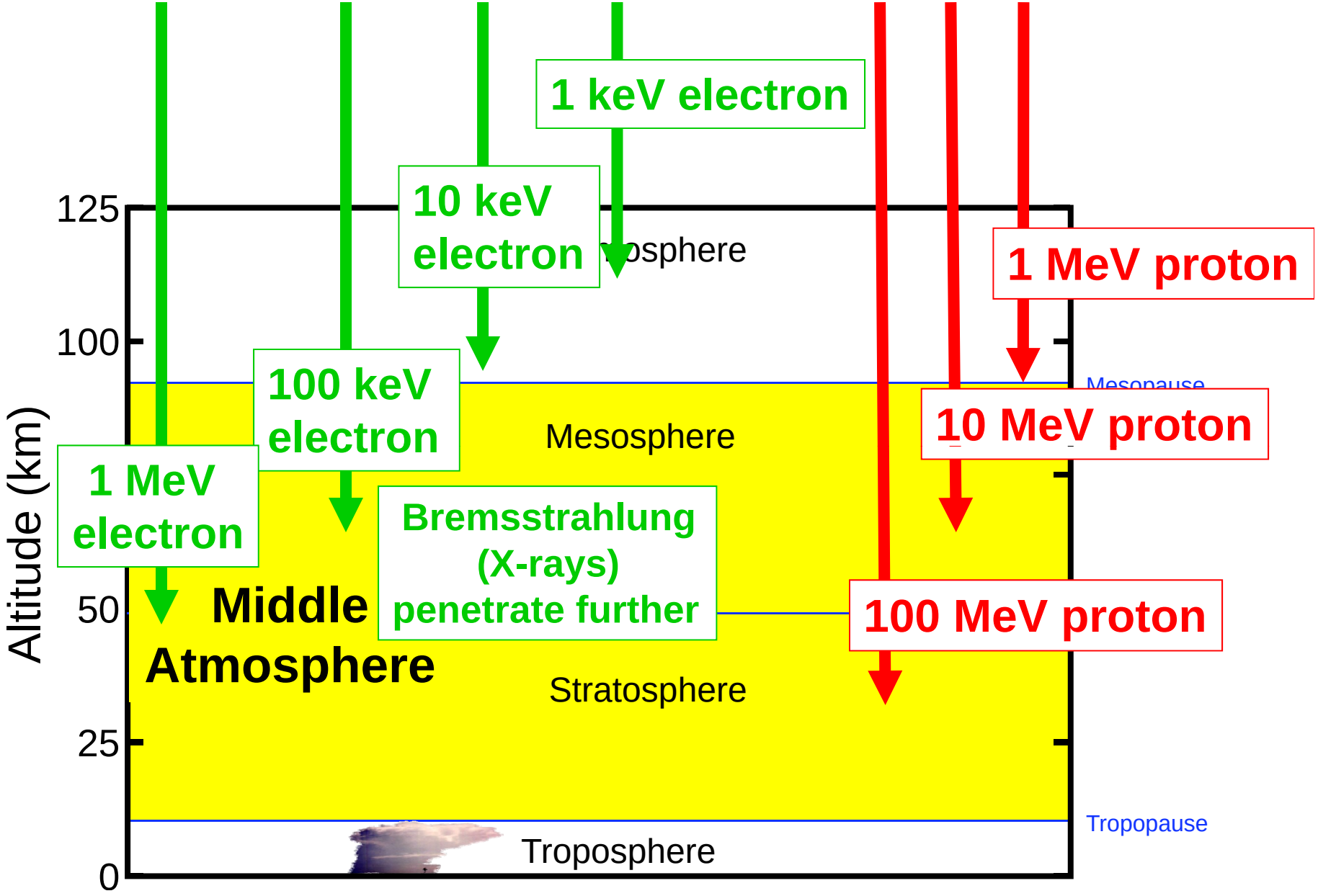
**Solar Protons**

- **Medium to High energy (~1-300 MeV)**



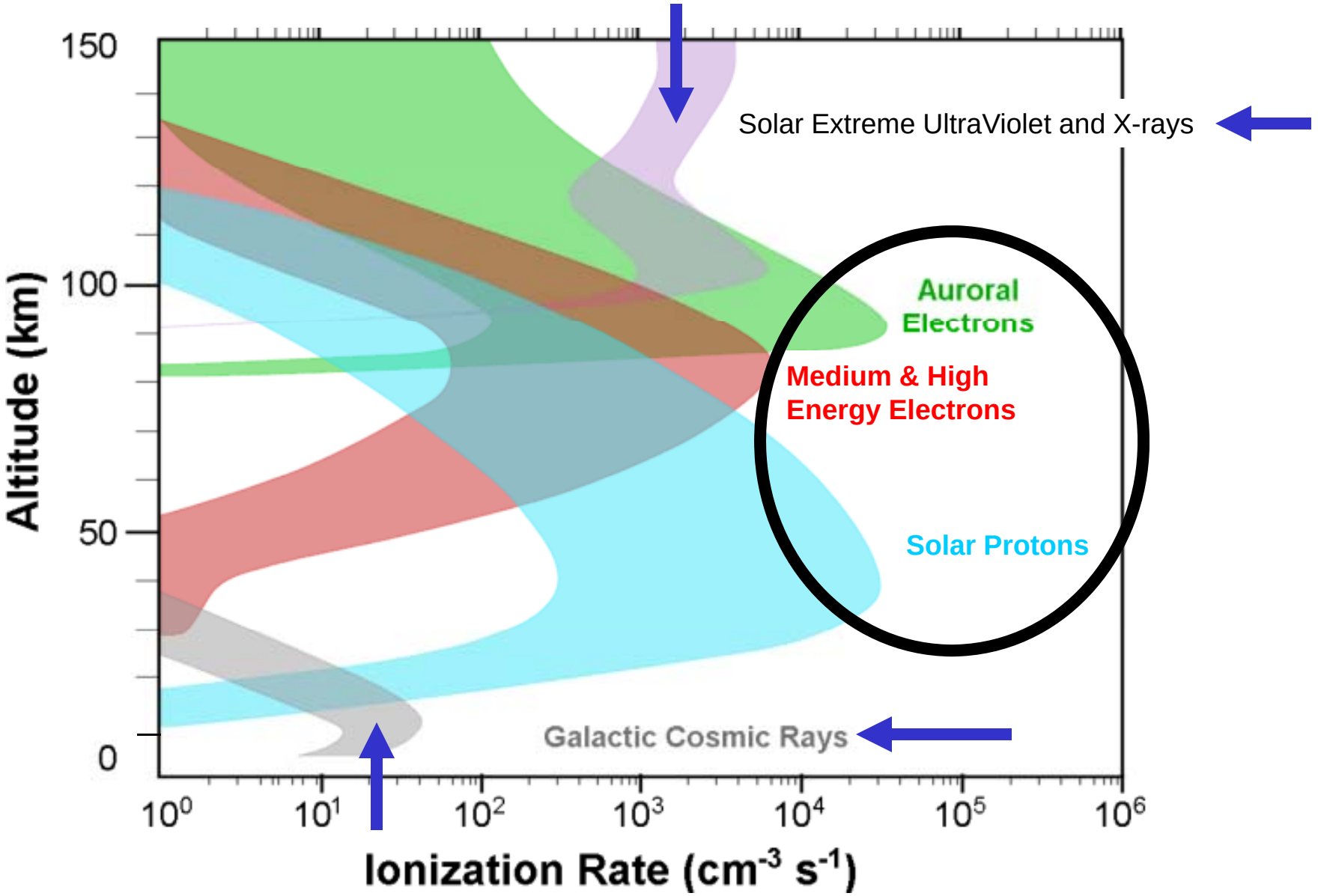

**Atmospheric Structure**

# Energetic Particle Precipitation

**Much of the energy deposited**
**by energetic particles creates ion pairs:**

→ **free Electron & positive Ion**

# Energetic Particle Precipitation



**Energetic Particles also Produce $HO_x$ and $NO_x$**

***Both of which can destroy Ozone***

# II. $HO_x$ [H, OH, $HO_2$] impacts

# Energetic Particles Enhance $HO_x$ (H, OH, $HO_2$)

- **Swider and Keneshea (1973)** first proposed that $HO_x$ constituents produced by solar protons *(November 1969 Solar Proton Event)*

- $HO_x$ constituents are produced through water cluster ion formation & neutralization
  - Primarily short-term effects (during and for a few hours after a Solar Proton Event)

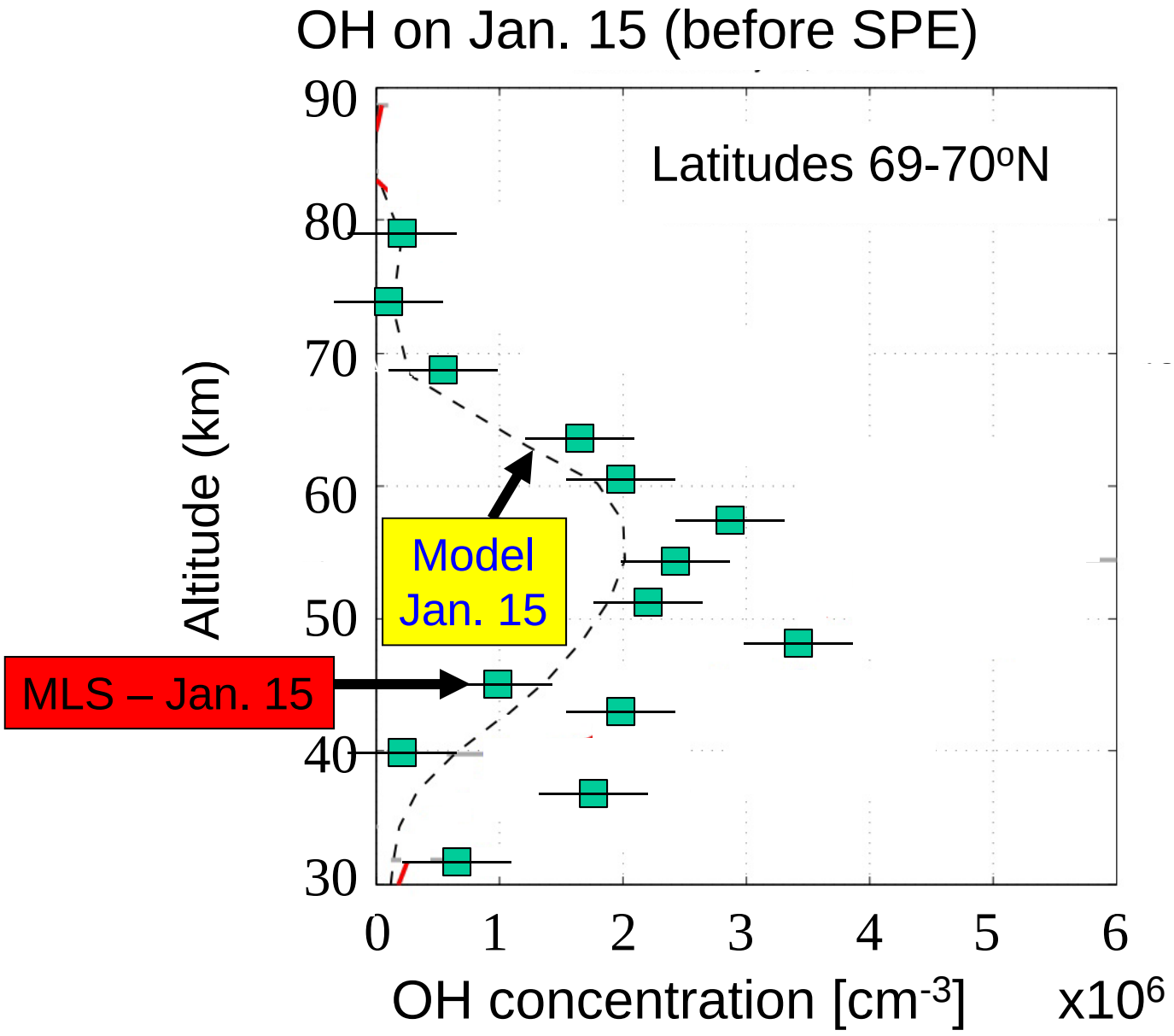
- Predictions of $HO_x$ production by energetic particles not confirmed up through 2004

# $HO_x$ Production

– **January 2005 SPEs**

**NASA Aura Microwave Limb Sounder (MLS) providing first global OH observations**

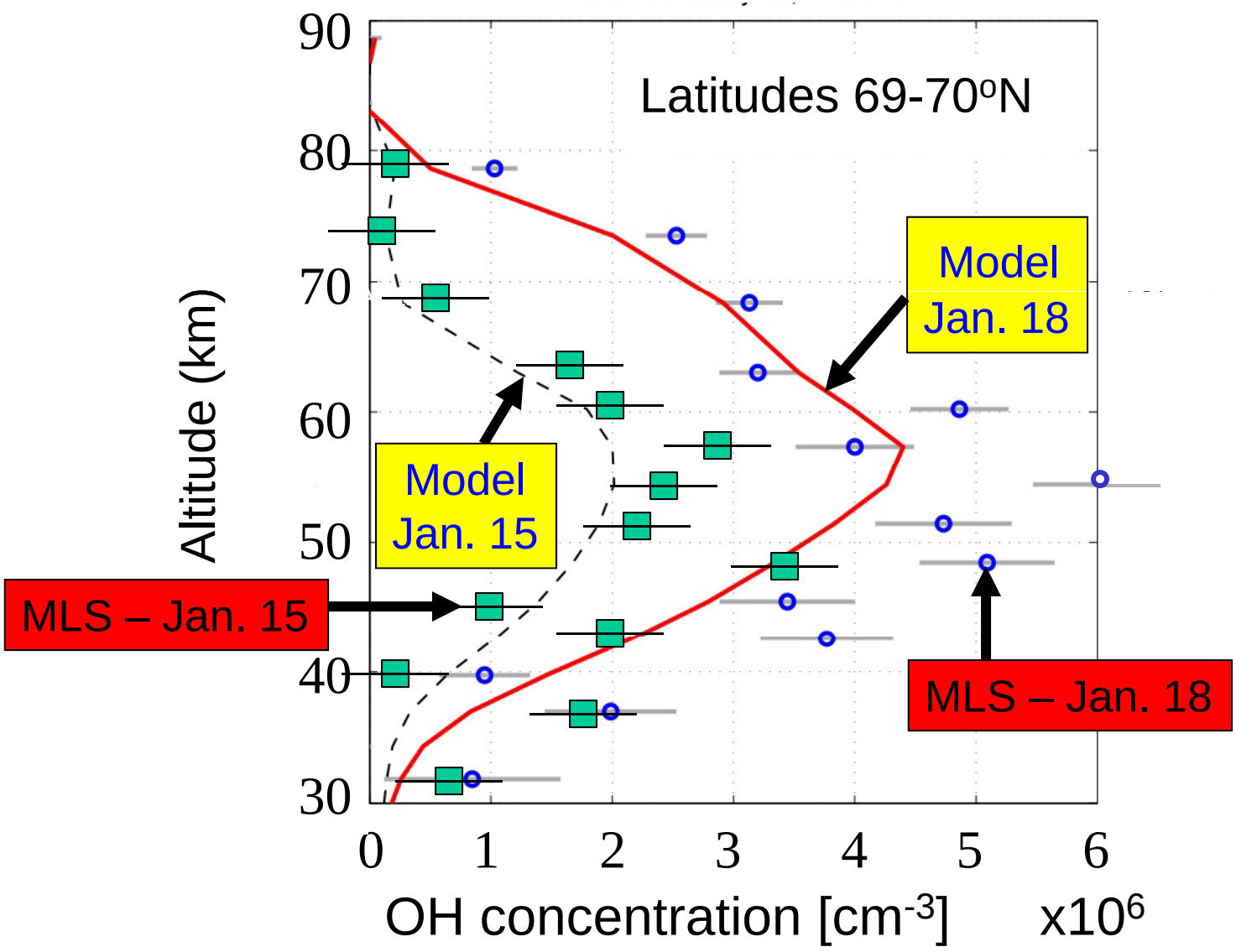
# Aura MLS & Model Predictions




from Verronen et al. [2006]

# Aura MLS & Model Predictions

OH on Jan. 15 (before SPE) & Jan. 18 (during SPE)




from Verronen et al. [2006]

# III. $NO_x$ [N, NO, $NO_2$] impacts

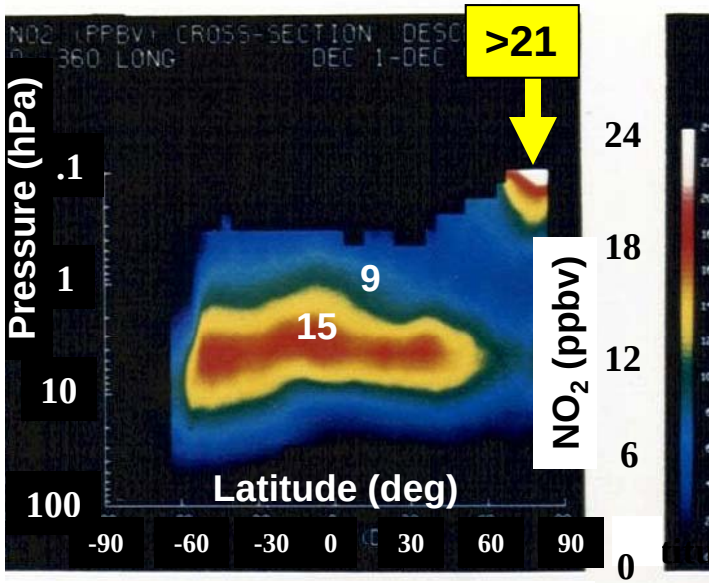
# Energetic Particles Enhance $NO_x$ (N, NO, $NO_2$)

- $NO_x$ constituents are produced by primary electrons and protons (and associated secondary electrons) dissociating $N_2$
  - Short- and long-term effects as $NO_x$ constituents can last for weeks

- Downward transport (especially in winter) of thermospheric $NO_x$ (electrons, extreme UV, X-rays)

  → First proposed in 1970s

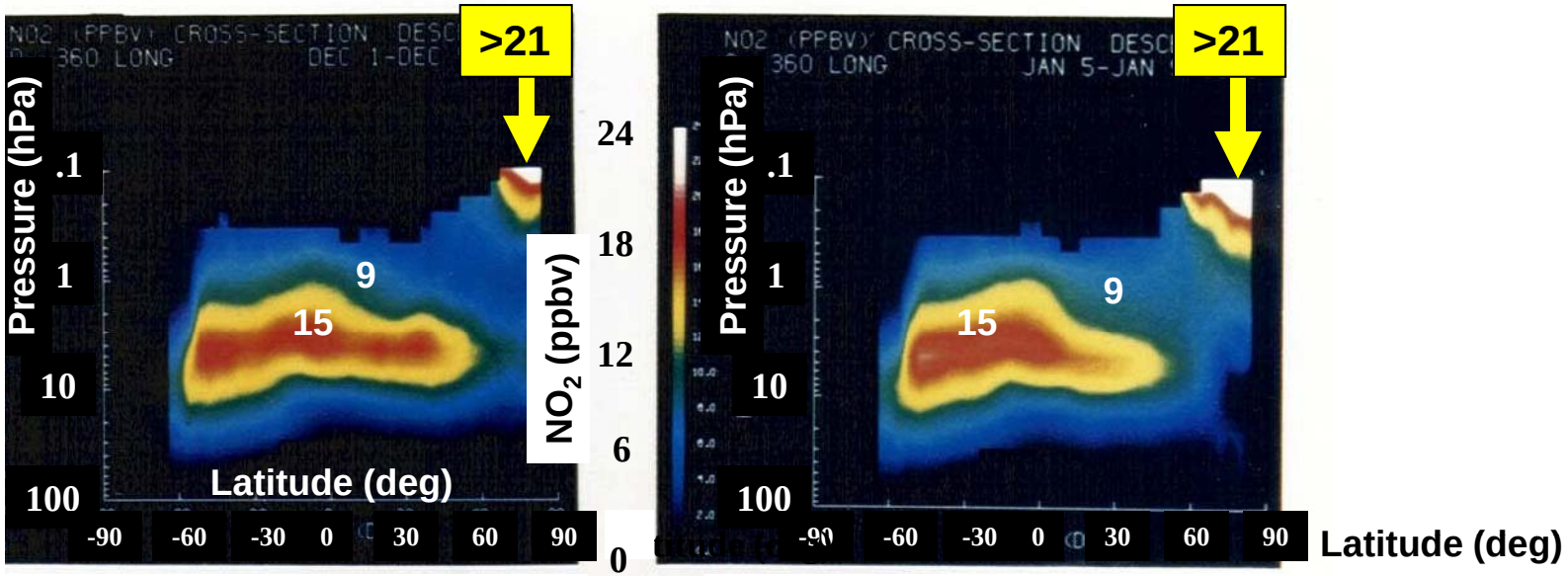
  → Observed in the 1980s.




**December 1-5, 1978**

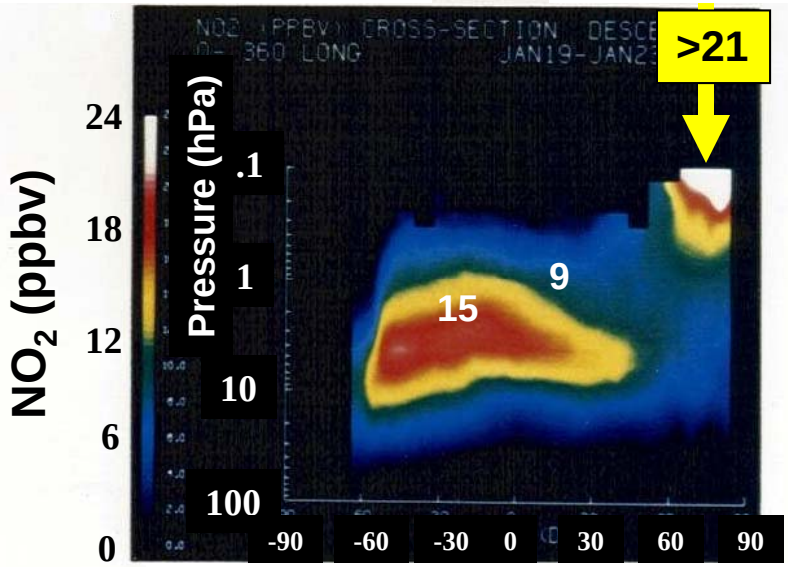
## NASA Limb Infrared Monitor of the Stratosphere (LIMS) $NO_2$ obs.

from Russell et al. (1984)




**December 1-5, 1978**

**January 5-9, 1979**




**January 19-23, 1979**

# LIMS $NO_2$ obs.

from Russell et al. (1984)

# Electrons Enhance $NO_x$ (N, NO, $NO_2$)

- ***Canadian Space Agency*** ***Atmospheric Chemistry Experiment*** observations (and several other instruments)

  → Good evidence of downward transport of thermospheric $NO_x$ to middle atmosphere in winter

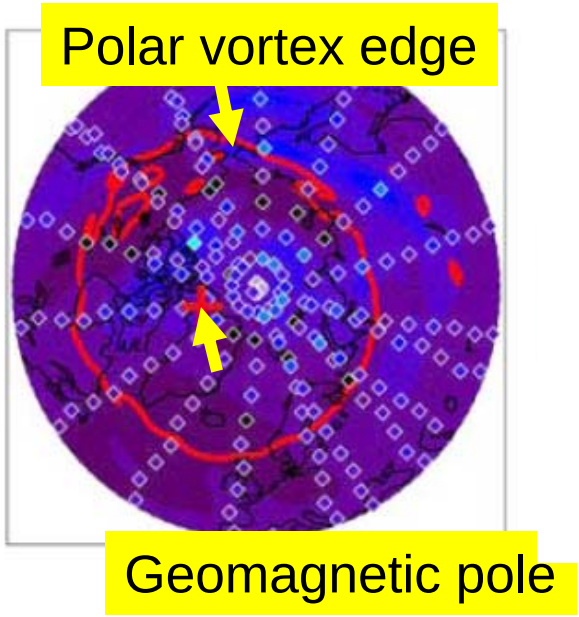
- **Cora Randall to show some of this in her talk**

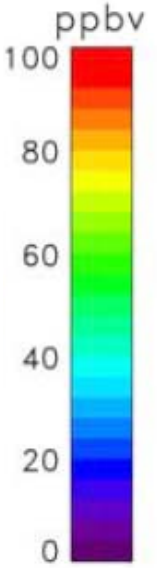
# Solar Protons Enhance $NO_x$ (N, NO, $NO_2$)

- Mesospheric & stratospheric $NO_x$ (NO, $NO_2$) constituents increased due to solar protons

  → Observed by several satellite instruments

**27-Oct-2003**

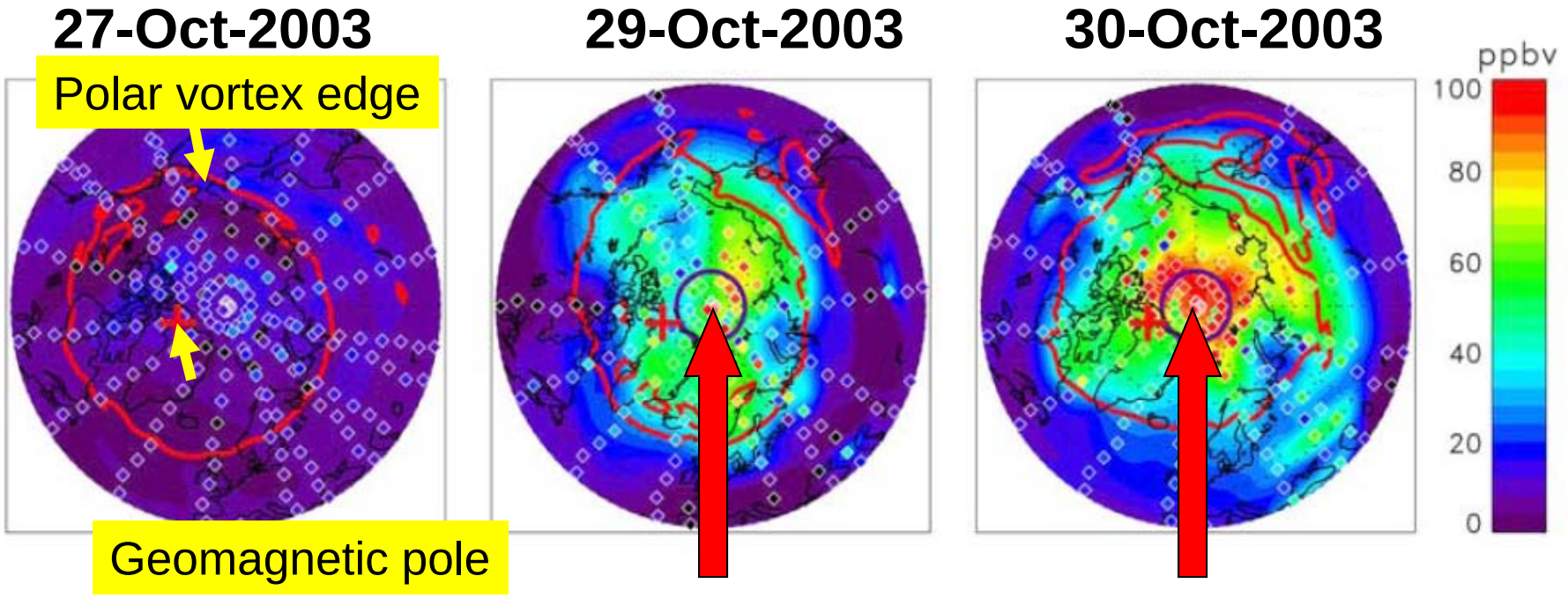



***European Space Agency Michelson Interferometer for Passive Atmospheric Sounding* (MIPAS)**

**$NO_x$ ($NO+NO_2$) in 50-55 km (Northern Hemisphere)**

**from López-Puertas et al. [2005]**




# MIPAS $NO_x$ ($NO+NO_2$) in 50-55 km (No. Hem.)

## Enhanced by Oct. 2003 Solar Proton Events (Halloween Storms)

**from López-Puertas et al. [2005]**

# Model

- **Whole Atmosphere Community Climate Model (WACCM) – Dan Marsh, Rolando Garcia, & Francis Vitt (NCAR)**

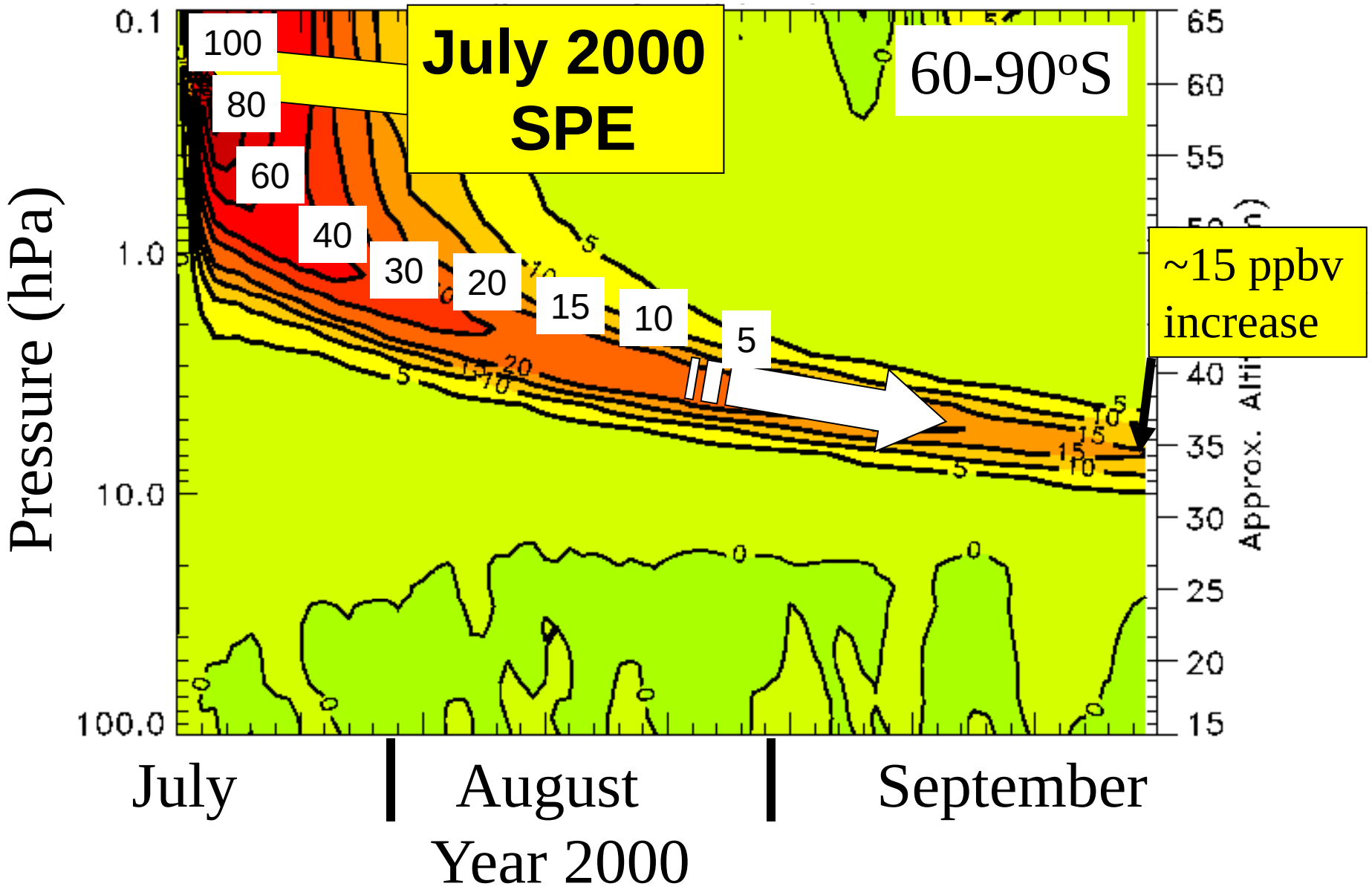
  - Domain [90°S – 90°N, 0 - 145 km]
  - Atmospheric physics & photochemistry
  - Interactive dynamics

→ Simulations: **'With'** and **'Without'**
Solar Proton Events (SPEs) over years 1963 – 2004

# WACCM Comparisons

- **Average four realizations 'With' SPEs**
  - **Perturbed result**
- **Average four realizations 'Without' SPEs**
  - **Base result**
- **Difference Perturbed and Base results to compute SPE-caused change**

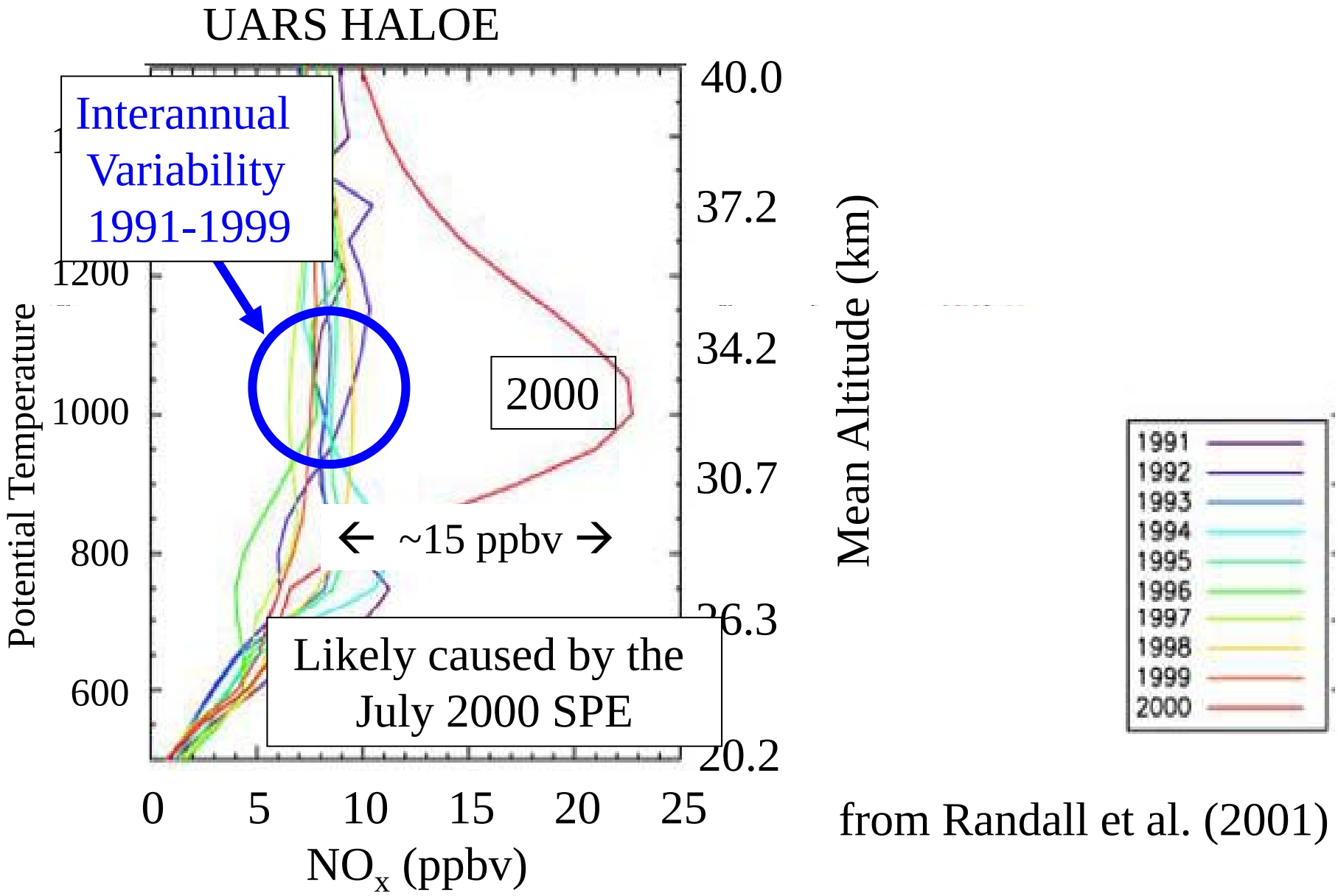
# WACCM - $NO_x$ ($NO+NO_2$) change (ppbv)



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

**Yes, Randall et al. (2001)**

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

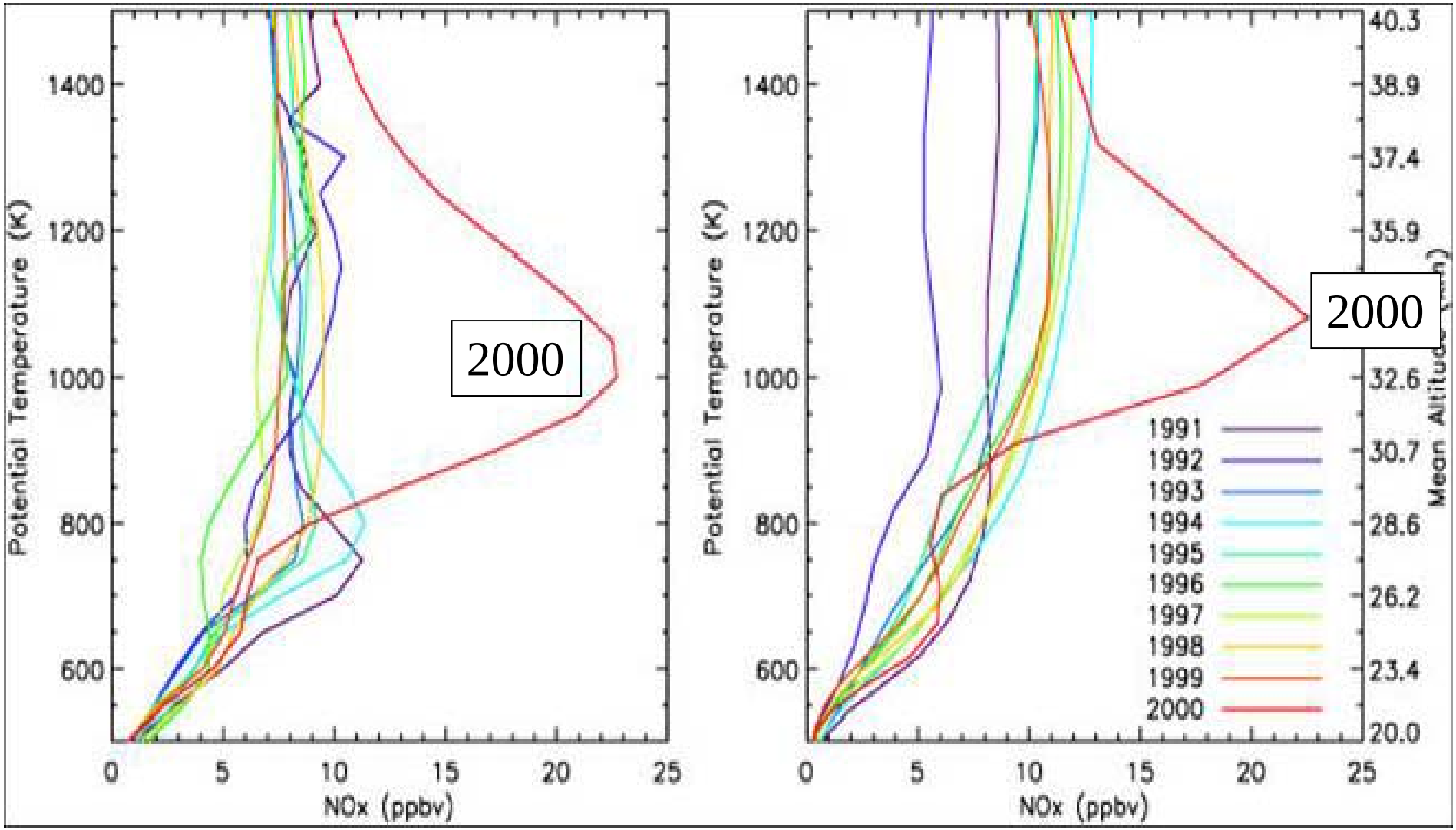



from Randall et al. (2001)

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

UARS HALOE

WACCM (with SPEs)

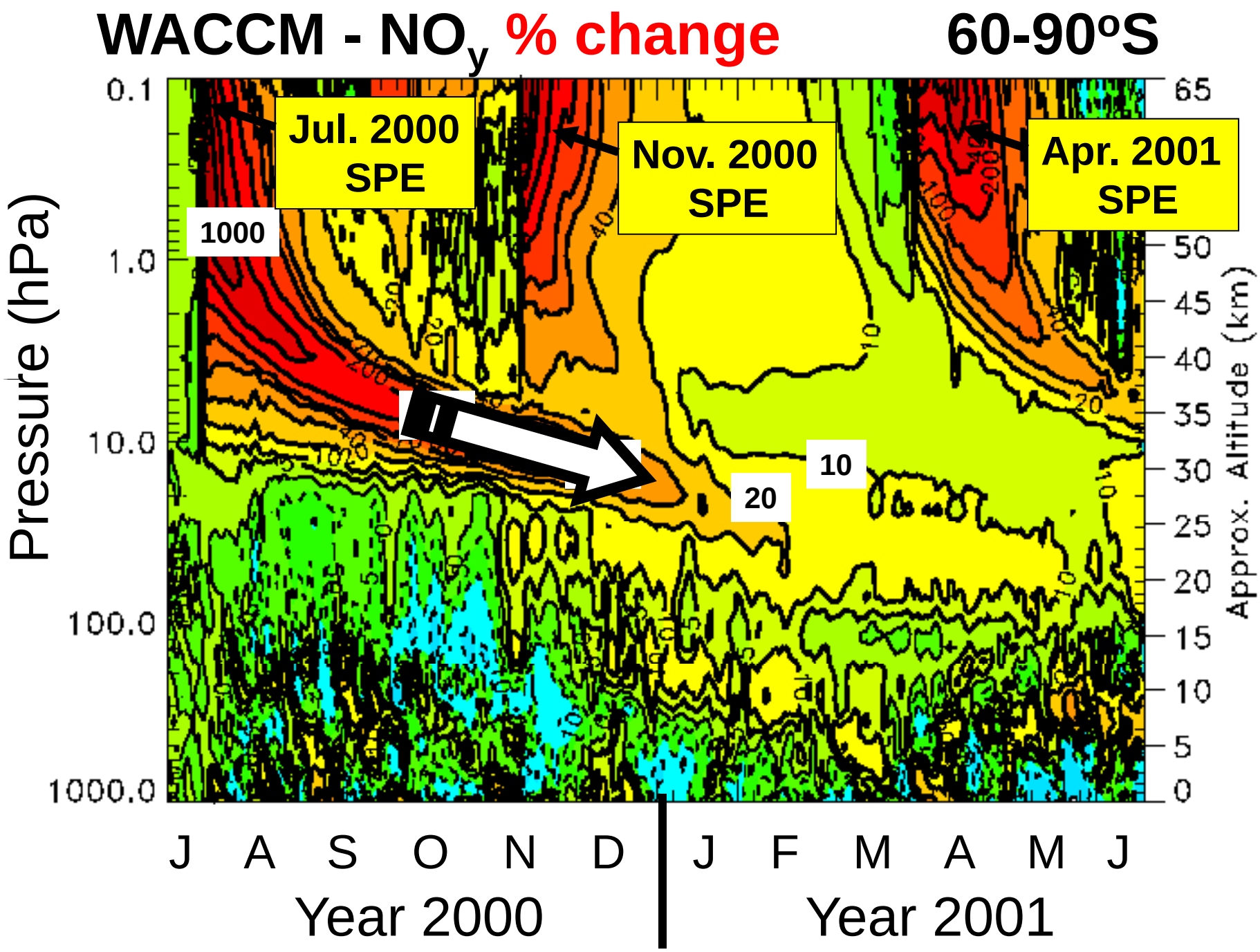



from Jackman et al. (2008)

# $NO_x$ 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
60-90ºS
Jul. 2000 SPE
Nov. 2000 SPE
Apr. 2001 SPE
1000
10
20
Pressure (hPa)
0.1
1.0
10.0
100.0
1000.0
Approx. Altitude (km)
65
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

# IV. Ozone impacts

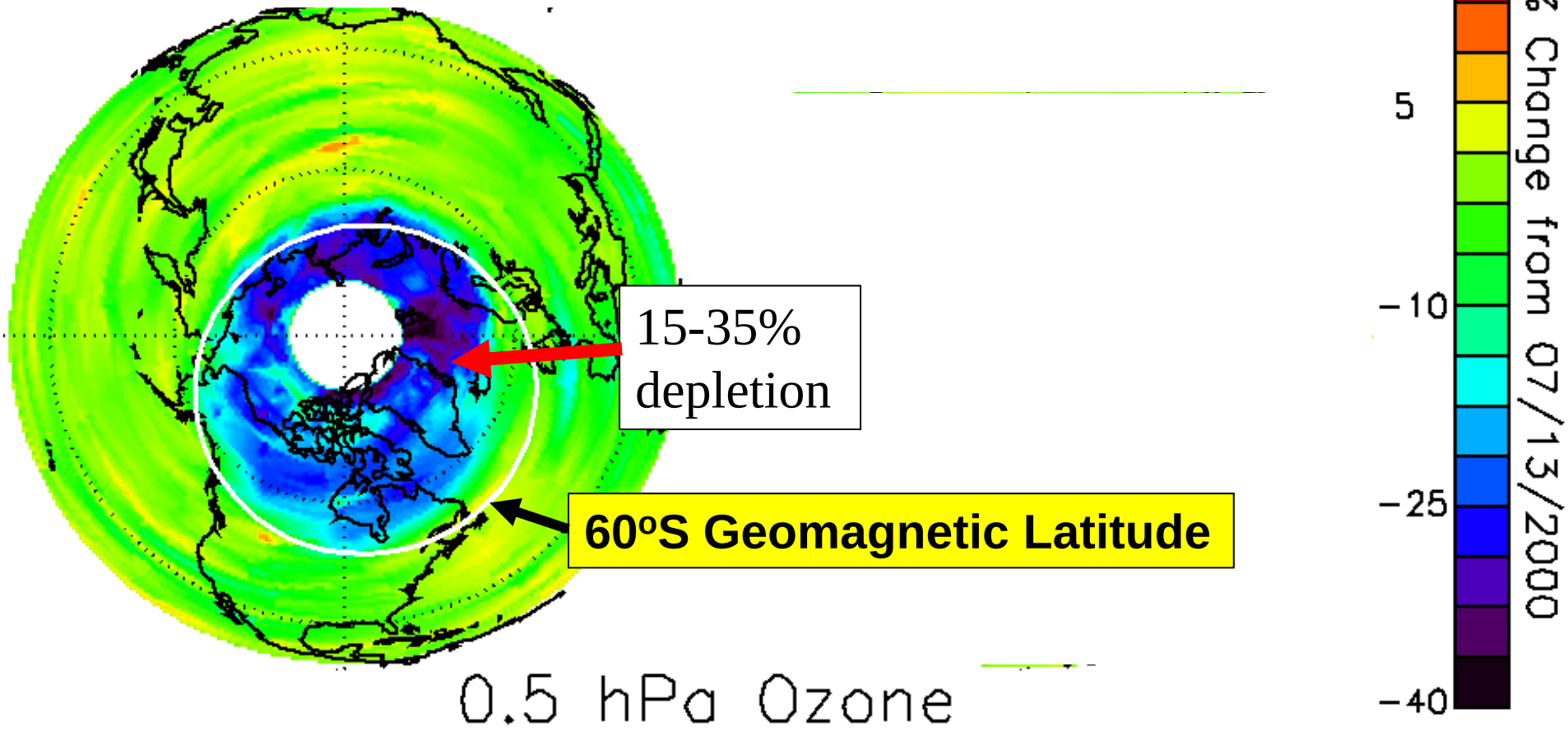
# How does Energetic Particle Precipitation-produced $HO_x$ and $NO_y$ impact Ozone?

- **$HO_x$ reduces mesospheric & upper stratospheric ozone**
  - → Also, impacts mesospheric temperature & winds
  - → Short-lived effects (~days)

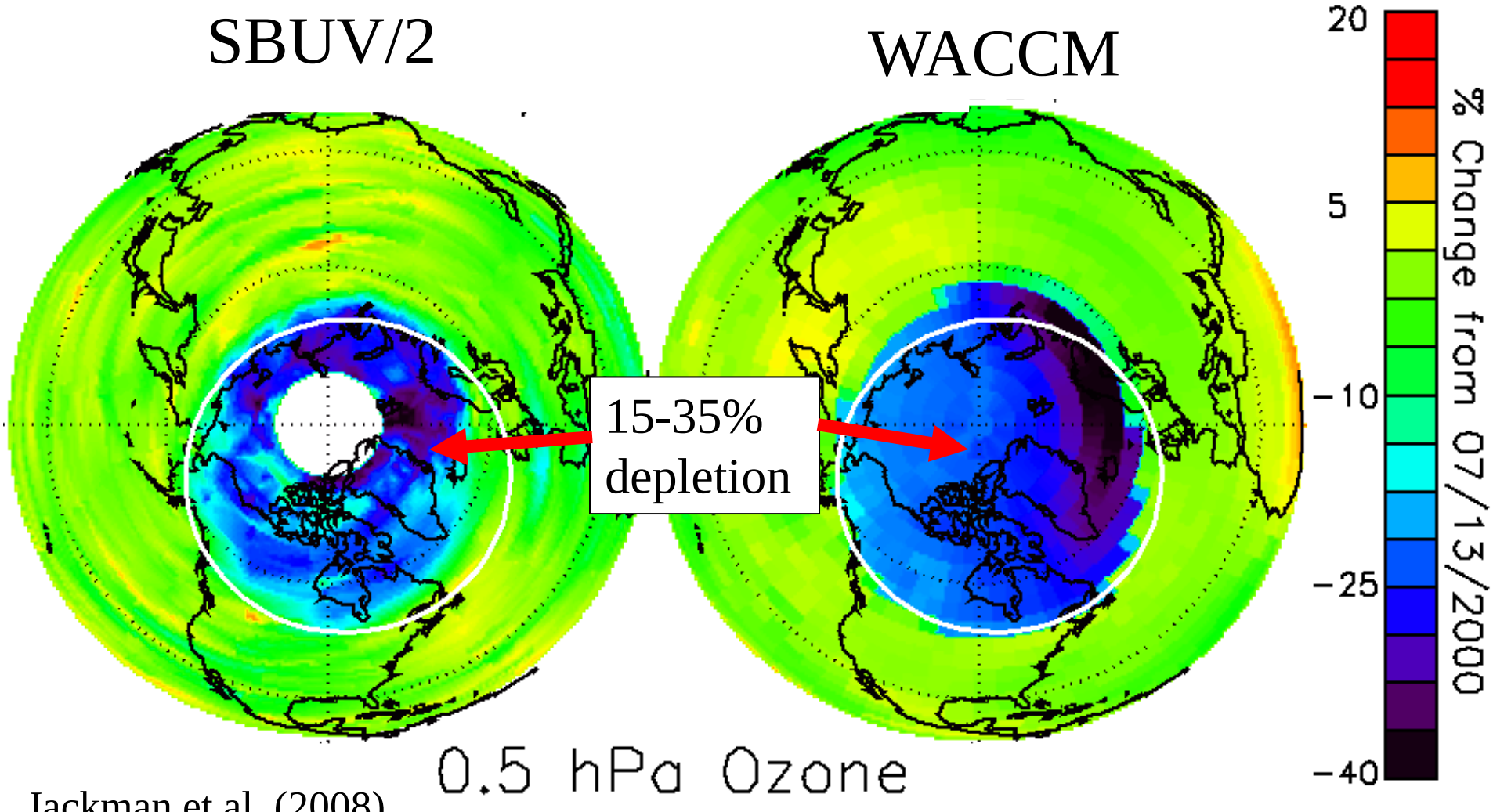
- **$NO_y$ impacts stratospheric & lower mesospheric ozone**
  - → Also, may impact stratospheric temperature & winds
  - → Short to long-lived effects (~days to months)

# Percentage Change in Ozone at 0.5 hPa (~55 km) from July 13, 2000 to July 14/15, 2000 – Northern Hemisphere

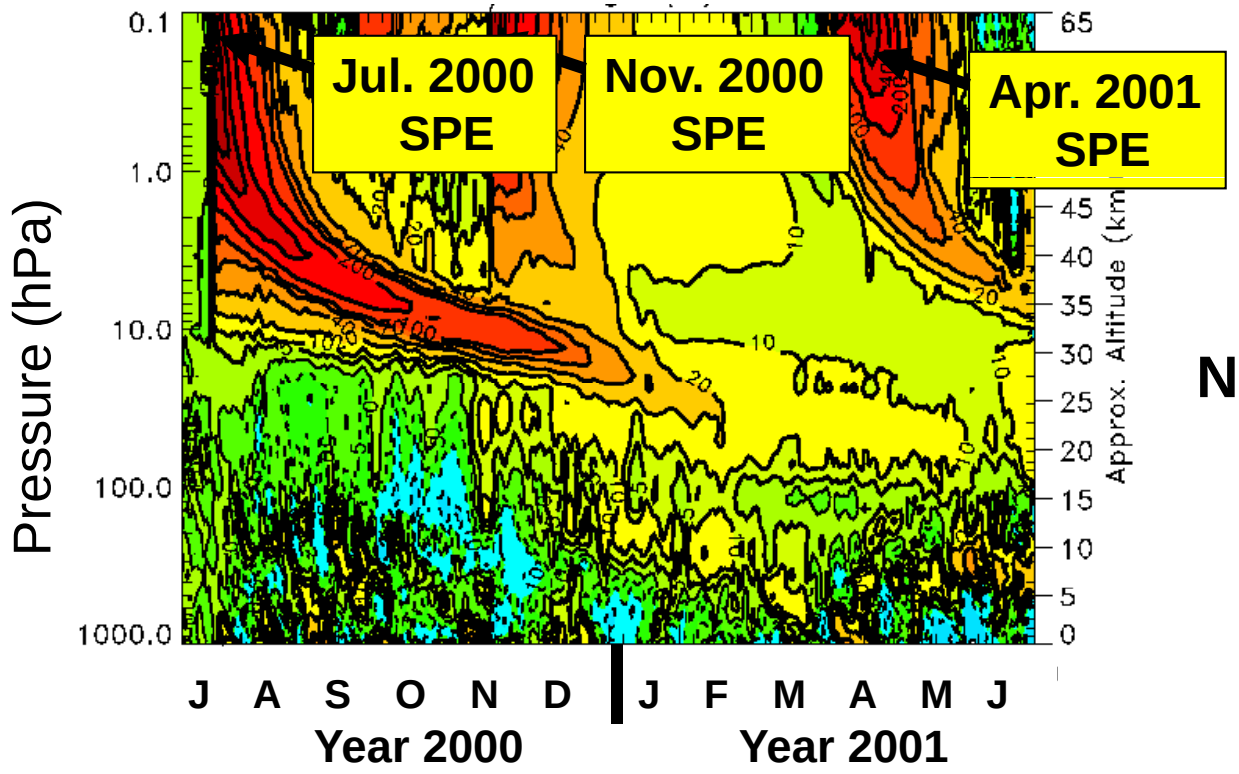
Solar Backscatter Ultraviolet 2 (SBUV/2)



# Percentage Change in Ozone at 0.5 hPa (~55 km) from July 13, 2000 to July 14/15, 2000 – Northern Hemisphere



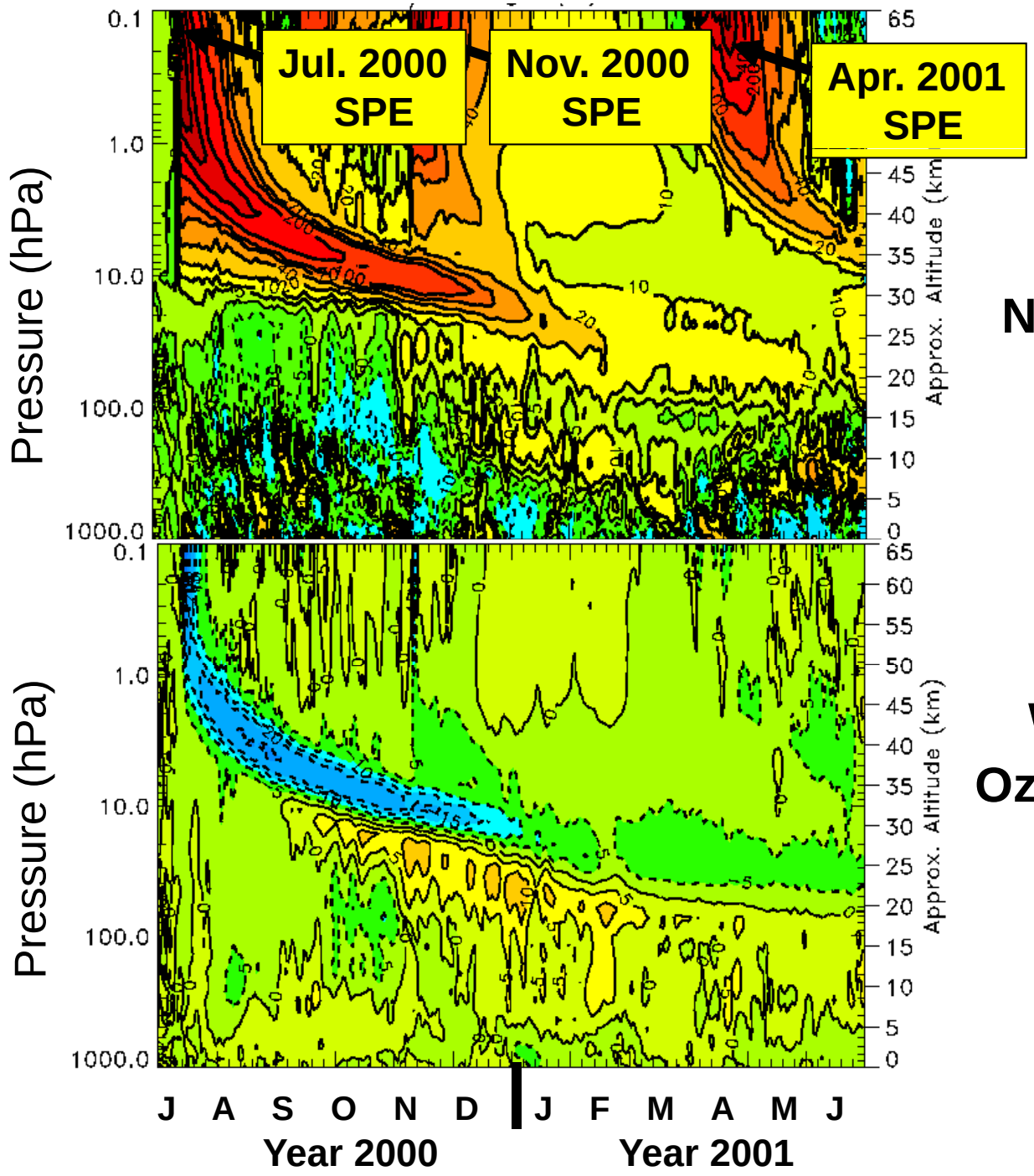

Jackman et al. (2008)




**60-90°S**

**WACCM**

**$NO_y$ % change**



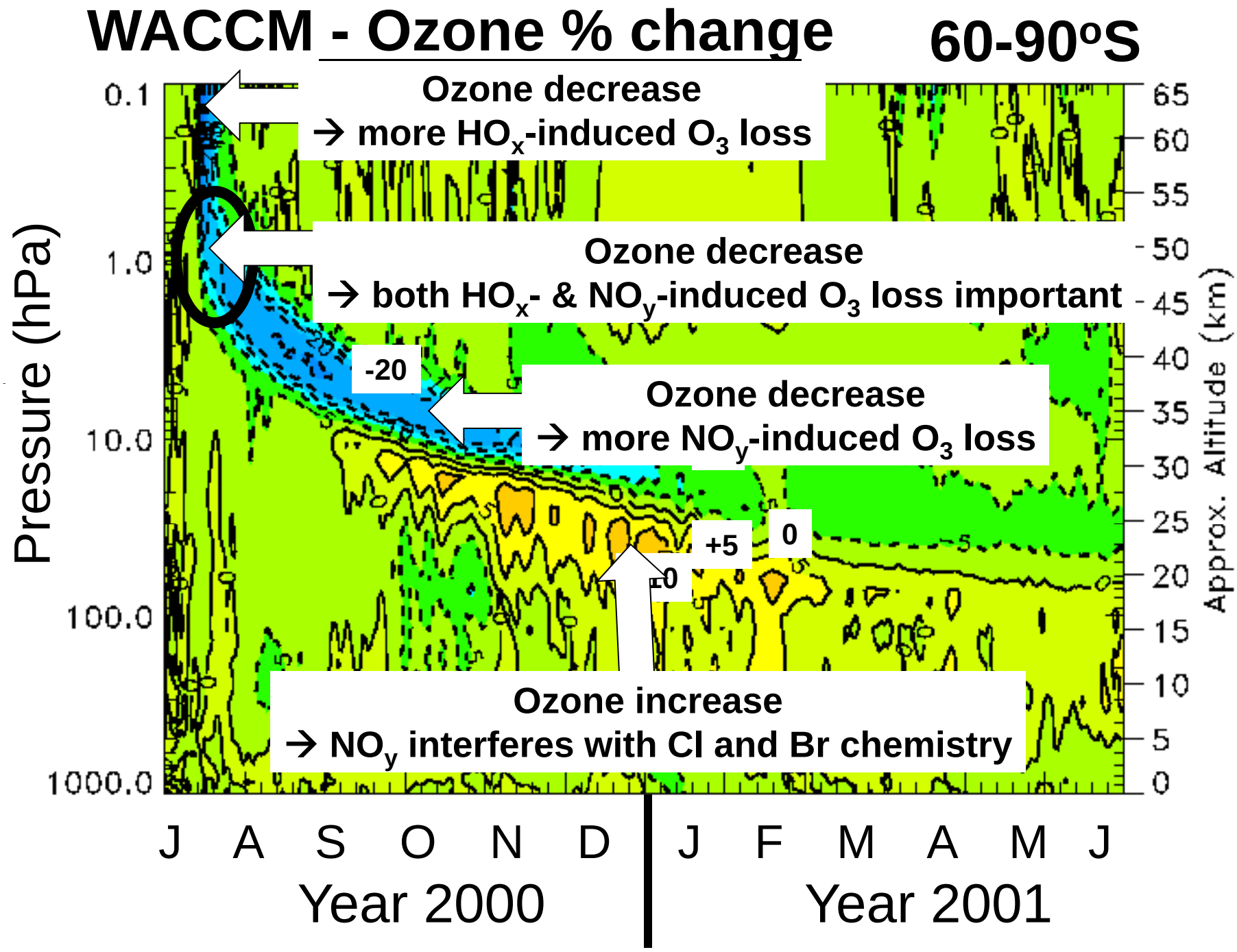

**60-90°S**

**WACCM**

**$NO_y$ % change**

**WACCM**

**Ozone % change**


WACCM - Ozone % change
60-90°S
Ozone decrease
→ more HOx-induced O3 loss
Ozone decrease
→ both HOx- & NOy-induced O3 loss important
-20
Ozone decrease
→ more NOy-induced O3 loss
+5
0
-0
Ozone increase
→ NOy interferes with Cl and Br chemistry
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

# Ozone Production by SPEs

## (Interaction between Manmade & Natural Influences)

- **$NO_y$ from July 2000 SPEs transported to lower stratosphere and interfere with $Cl_y$ and $Br_y$ via**

$ClO + NO_2 \rightarrow ClONO_2$

Normally chlorine destroys ozone:

$Cl + O_3 \rightarrow ClO + O_2$

$ClO + O \rightarrow Cl + O_2$

Net: $O_3 + O \rightarrow O_2 + O_2$

- **Chlorine (& bromine) losses for Ozone are reduced**

**→ thus Ozone is increased**

# V. Conclusions

- **Both electrons and protons influence the polar mesosphere and stratosphere – particularly during certain years**

  → *e.g., Near solar max; Large geomagnetic activity; Unusual meteorology*

- **$HO_x$ produced is short-lived, but depletes ozone**

- **$NO_x$ produced is long-lived, and affects ozone (both decrease and increase)**

- **Solar protons influence mesospheric & stratospheric ozone, but is not observable in total ozone**

**Thank you for your attention!**