Response of the Middle Atmosphere to Energetic Particle Precipitation

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Outline

1) Introduction

2) Energetic Particle Precipitation

A) HO_x Production → Ozone depletion

B) NO_x Production → Ozone depletion

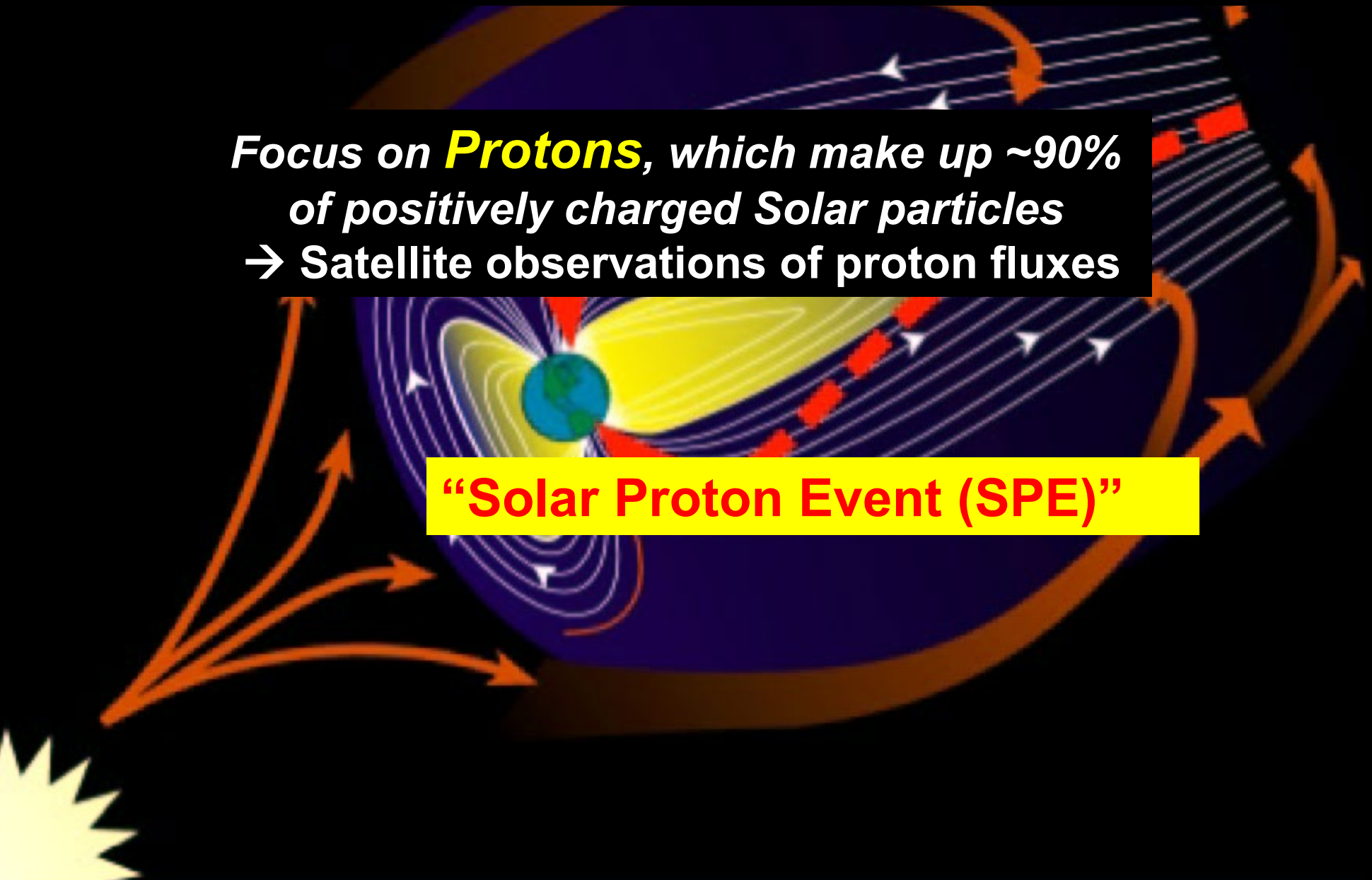
3) Energetic Particles & Ozone Trends

1) Introduction

→ Energetic particles released from Sun

during Coronal Mass Ejections
& Solar Flares

Positively Charged Particles penetrate deeper into the atmosphere than Electrons



*Focus on **Protons**, which make up ~90% of positively charged Solar particles*
→ Satellite observations of proton fluxes

"Solar Proton Event (SPE)"

Energy Deposition by Solar Protons in both Polar Caps (>60° Geomag. Lat.)

Most (70-80%) energy of protons creates ion pairs:
→ free Electron & positive Ion

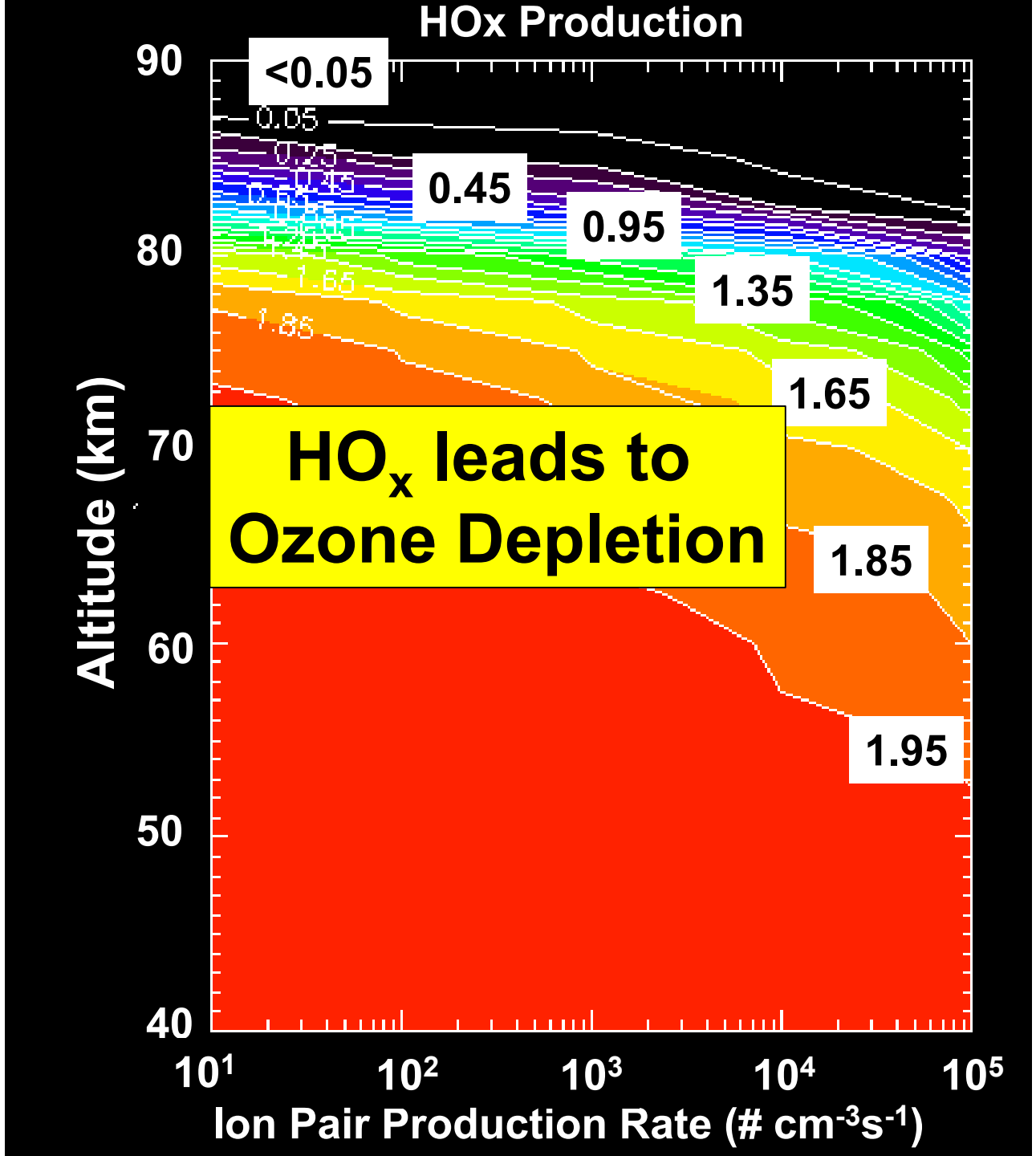
HO_x (H, OH, HO_2) made via ion chemistry (H_2O)
→ Primarily short-term effects
(during and for a few hours after SPE)

NO_x (N, NO, NO_2) made by protons (etc.) dissoc. N_2
→ Short- and long-term effects as NO_x constituents can last for days to months in the middle atmosphere

2) Energetic Particle Precipitation
A) HO_x (H, OH, HO_2) Production

- **Swider and Keneshea (1973) first proposed that HO_x constituents produced by solar protons decreased ozone.**

- **Solomon et al. (1981)** ***first quantified the production of HO_x constituents as a function of altitude and ion pair production.***

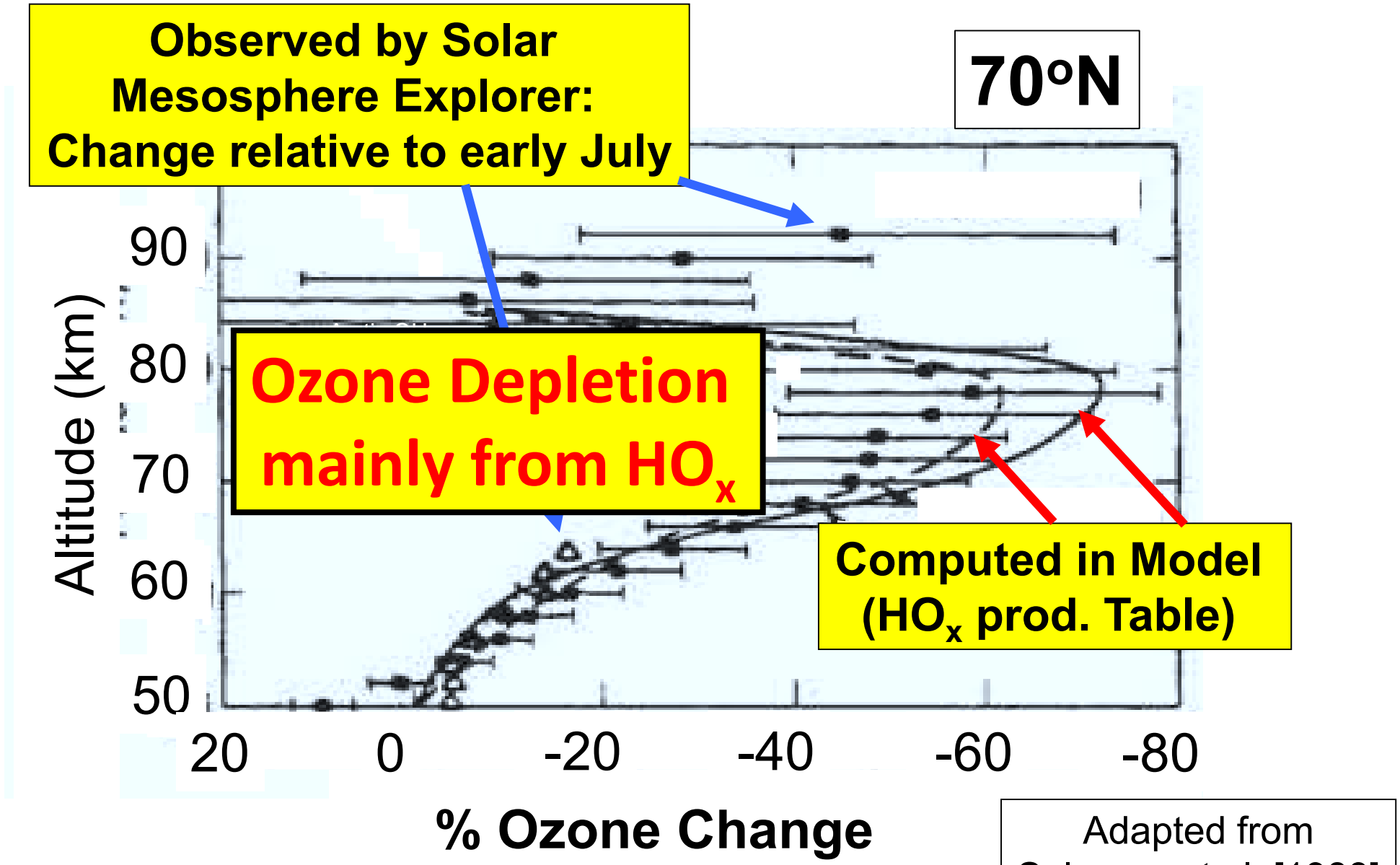


HO_x production per ion pair from incoming protons

from Solomon et al. (1981)

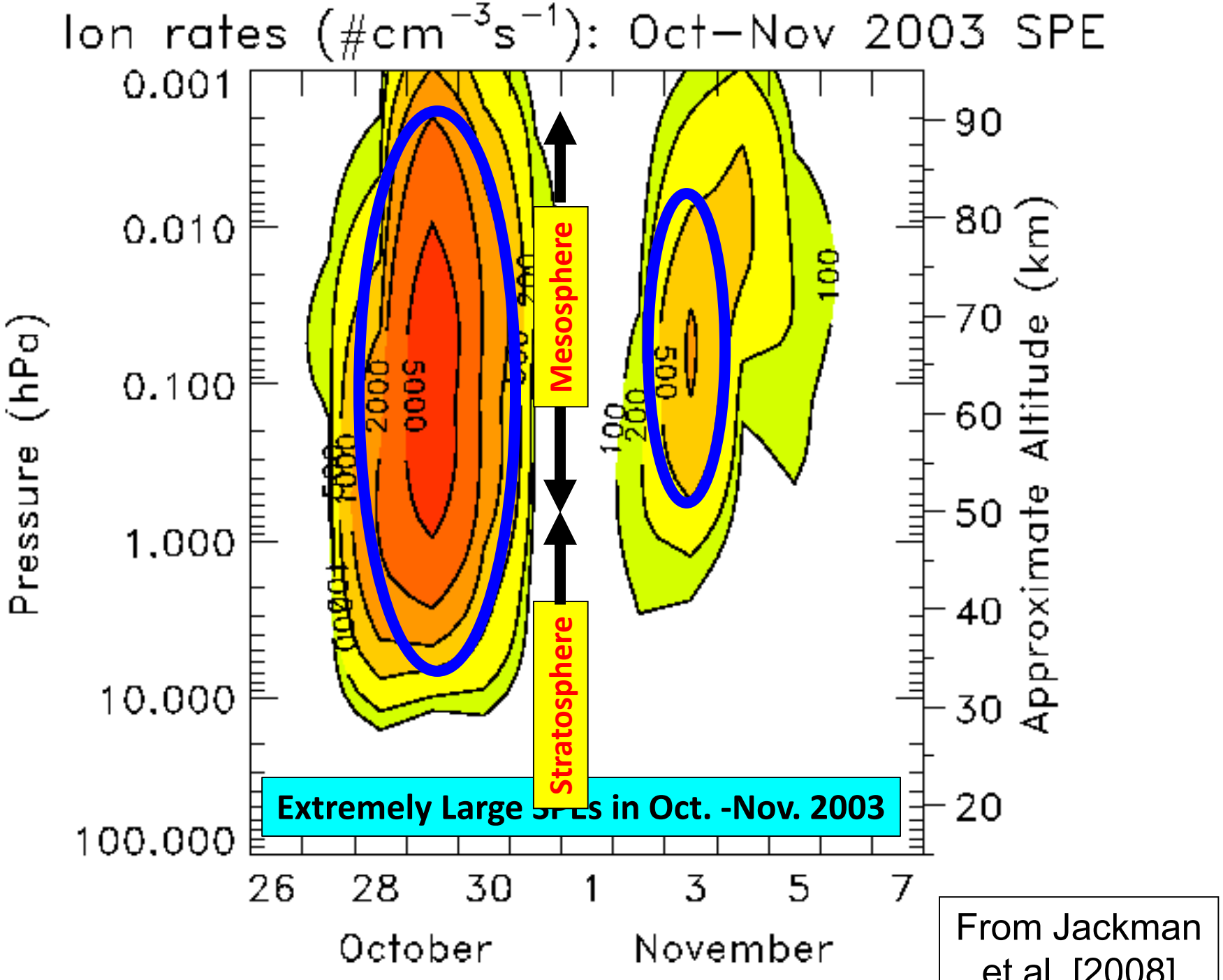
Thanks to Dan Marsh for colorizing this Figure.

Ozone Depletion from July 13, 1982 SPE



Adapted from Solomon et al. [1983]

Impacts of
Extremely Large SPEs in Oct. -Nov. 2003



From Jackman et al. [2008]

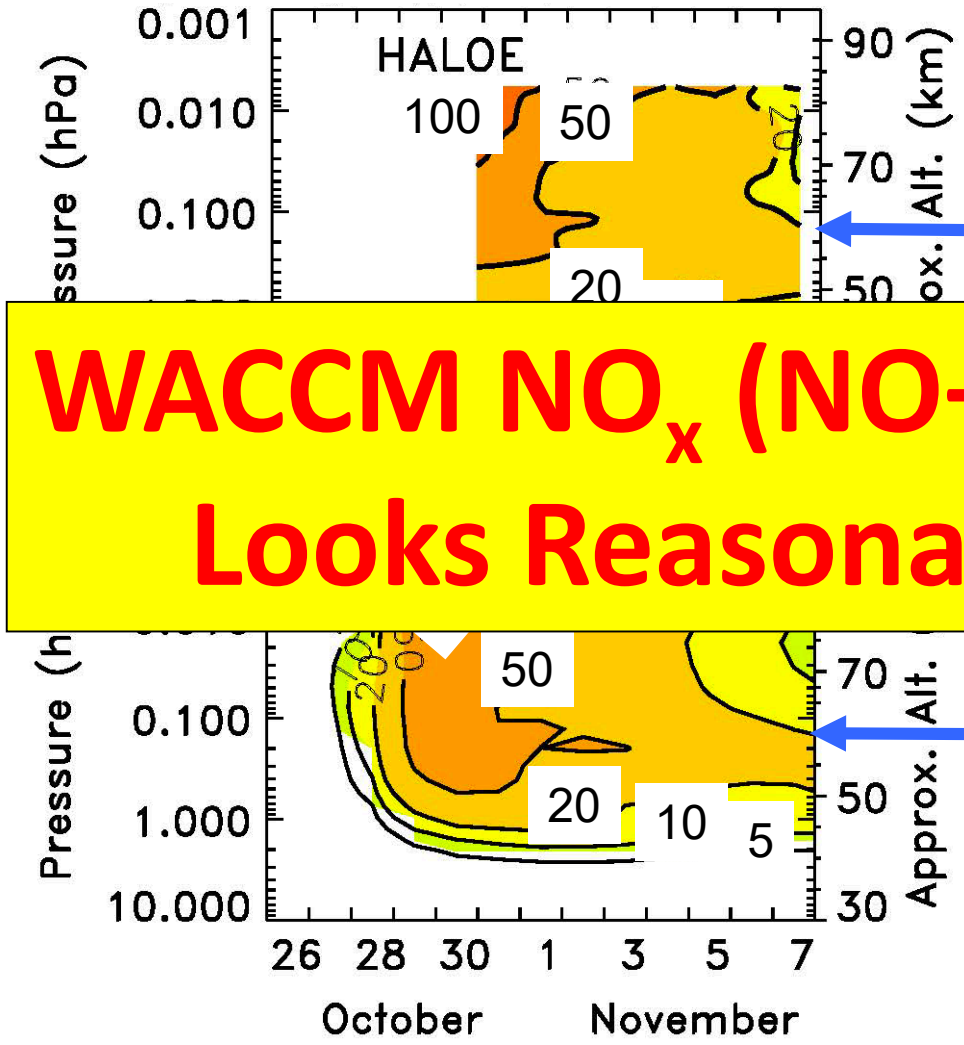
2) Energetic Particle Precipitation
B) NO_x (N, NO, NO_2) Production

- **Crutzen et al. (1975) first proposed that NO_x constituents were produced by solar protons & would decrease ozone.**

- **Solomon & Crutzen (1981)** ***modeled the SPE production of NO_x & ozone loss including chlorine chemistry & temperature feedback for the first time.***

- **~1.25 NO_x constituents produced per ion pair in the middle atmosphere**

NO_x ($NO+NO_2$) Increase (ppbv) Caused by Extremely Large SPEs in Oct. -Nov. 2003



75°S – 64°S

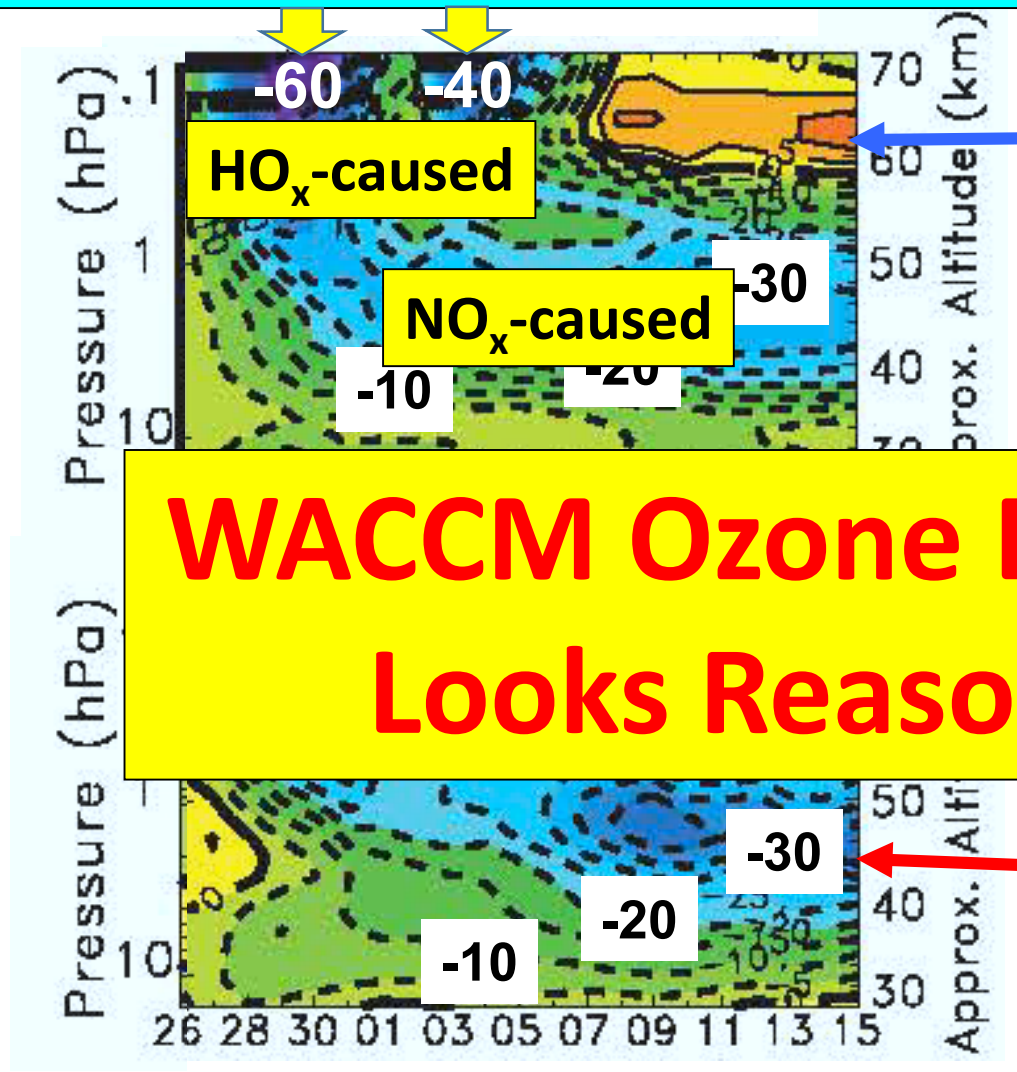
UARS HALOE: Change relative to early Oct.

WACCM NO_x ($NO+NO_2$) Looks Reasonable

WACCM (Whole Atmosphere Com. Climate Model)

Adapted from Jackman et al. [2008]

Ozone Depletion (%) in 70-90°N Band Caused by Extremely Large SPEs in Oct. -Nov., 2003



Ozone observed by Envisat MIPAS: Change relative to Oct. 25

WACCM Ozone Depletion Looks Reasonable

Ozone computed in WACCM

Adapted from Jackman et al. [2008]

WACCM NO_x Increase & Ozone Depletion from Huge 2003 SPEs Mostly Agree with Observations

3) Energetic Particles and Ozone Trends

PAPER: On the Identification of Ozone Recovery,
Kane Stone, S. Solomon, & D. Kinnison, GRL, (2018)

A) Ozone trends in upper stratosphere at polar latitudes in autumn/winter were impacted by HUGE SPEs in years 2000-2003

B) Analyses including WACCM NO_2 accounts for SPEs

→ Better quantifies the ozone recovery signature

Thank you,
Susan Solomon and colleagues,

**for ground-breaking contributions
to understanding the influence
of energetic particle precipitation
on the middle atmosphere!**