Long-term Middle Atmospheric Influence of Very Large Solar Proton Events in the 1963-2004 Period

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Outline

- **Introduction**
- **Focus on Solar Cycle 23:**
  → especially Years 2000-2004
- **Polar Total Ozone Change (1965-2004)**
- **Conclusions**

Introduction

Solar Protons Produce HO_x and NO_x - *Both of which can destroy Ozone*

- HO_x (H, OH, HO_2) produced through water cluster ion formation & neutralization
  - Primarily short-term effects (during and for a few hours after SPE)

- **NO_x (N, NO, NO_2) produced by protons & associated secondary electrons dissociating N_2**
  - **Short- and long-term effects as NO_x constituents can last for weeks**

Largest 12 Solar Proton Events (SPEs) in Past 45 Years

Date of SPEs	Computed NO_x Production Rank	(in Gigamoles)
October 1989	**1**	(11.)
August 1972	**2**	(6.0)
July 2000	**3**	(5.8)
October 28-31, 2003	**4**	(5.6)
November 5-7, 2001	**5**	(5.3)
November 2000	**6**	(3.8)
September 2001	**7**	(3.3)
August 1989	**8**	(3.0)
November 23-25, 2001	**9**	(2.8)
September 1966	**10**	(2.0)
January 2005	**11**	(1.8)
Sep. 29 – Oct. 3, 1989	**12**	(1.7)

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

Focus on Solar Cycle 23:
→especially Years 2000-2004

Model

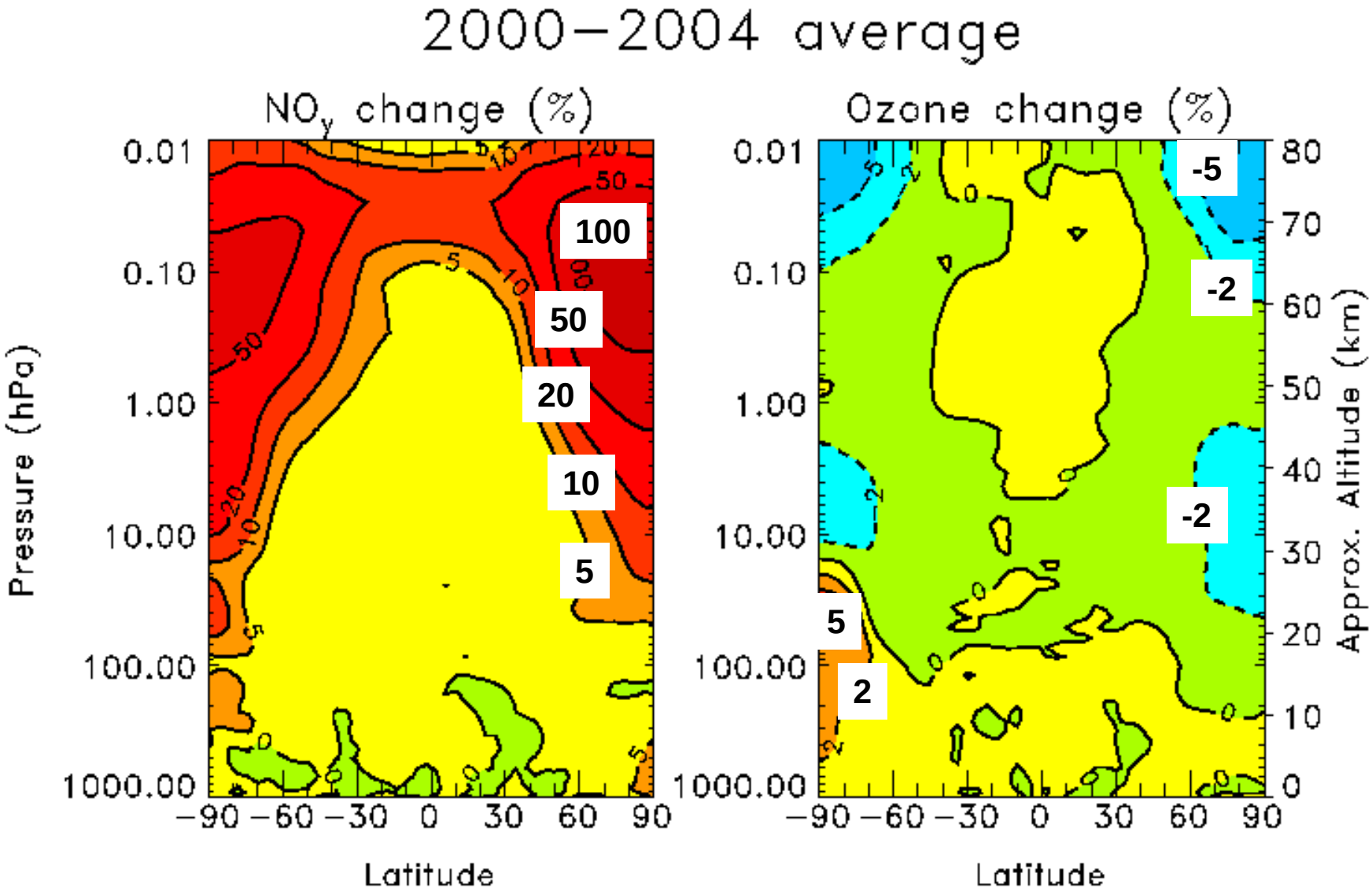
- **Whole Atmosphere Community Climate Model (WACCM) – Dan Marsh, Rolando Garcia, & Francis Vitt (NCAR)**
  - Domain [90°S – 90°N, 0 - 145 km]
  - Atmospheric physics & photochemistry
  - Interactive dynamics

→ Simulations: **'With'** and **'Without'** SPEs over years 1963 – 2004

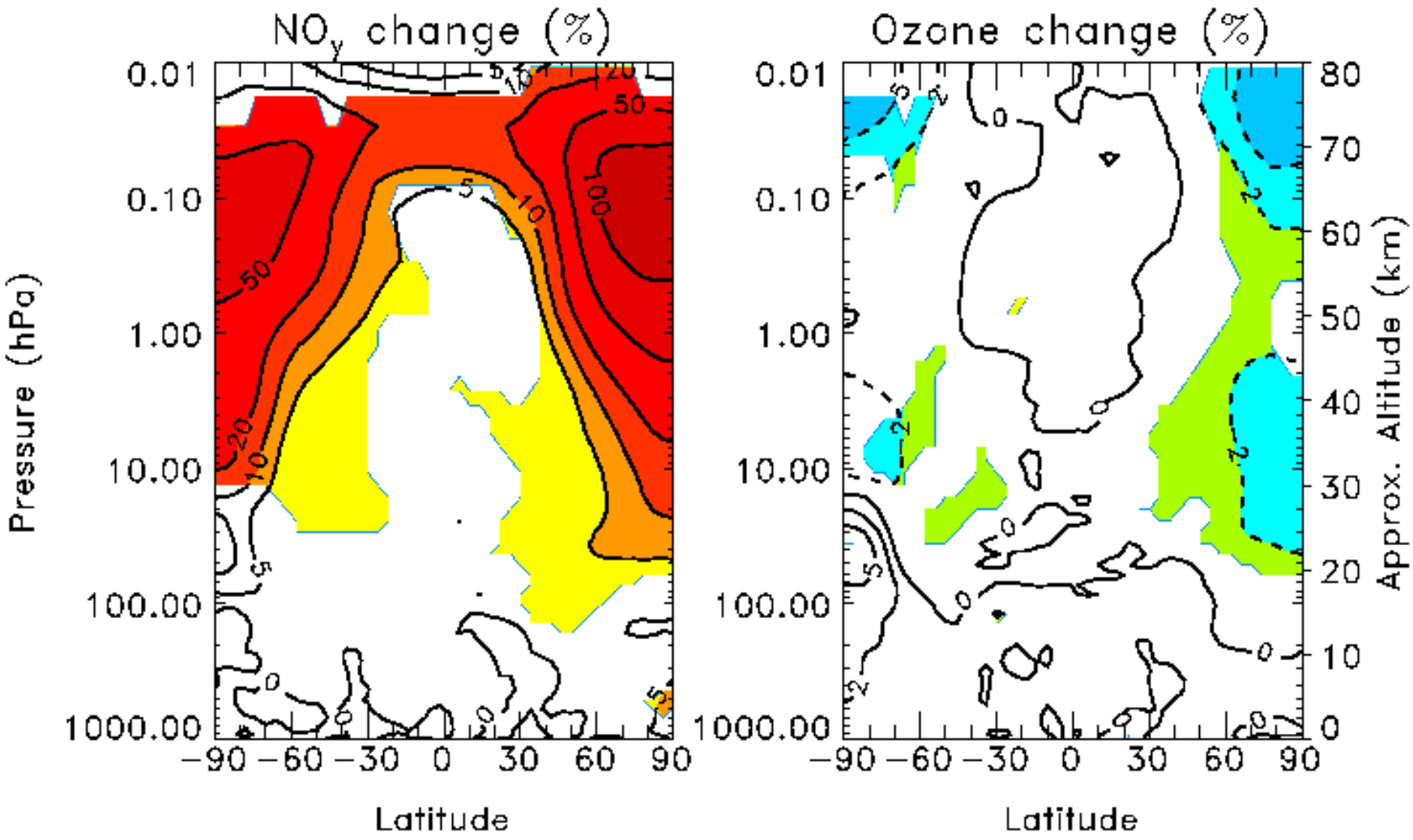
WACCM Comparisons

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

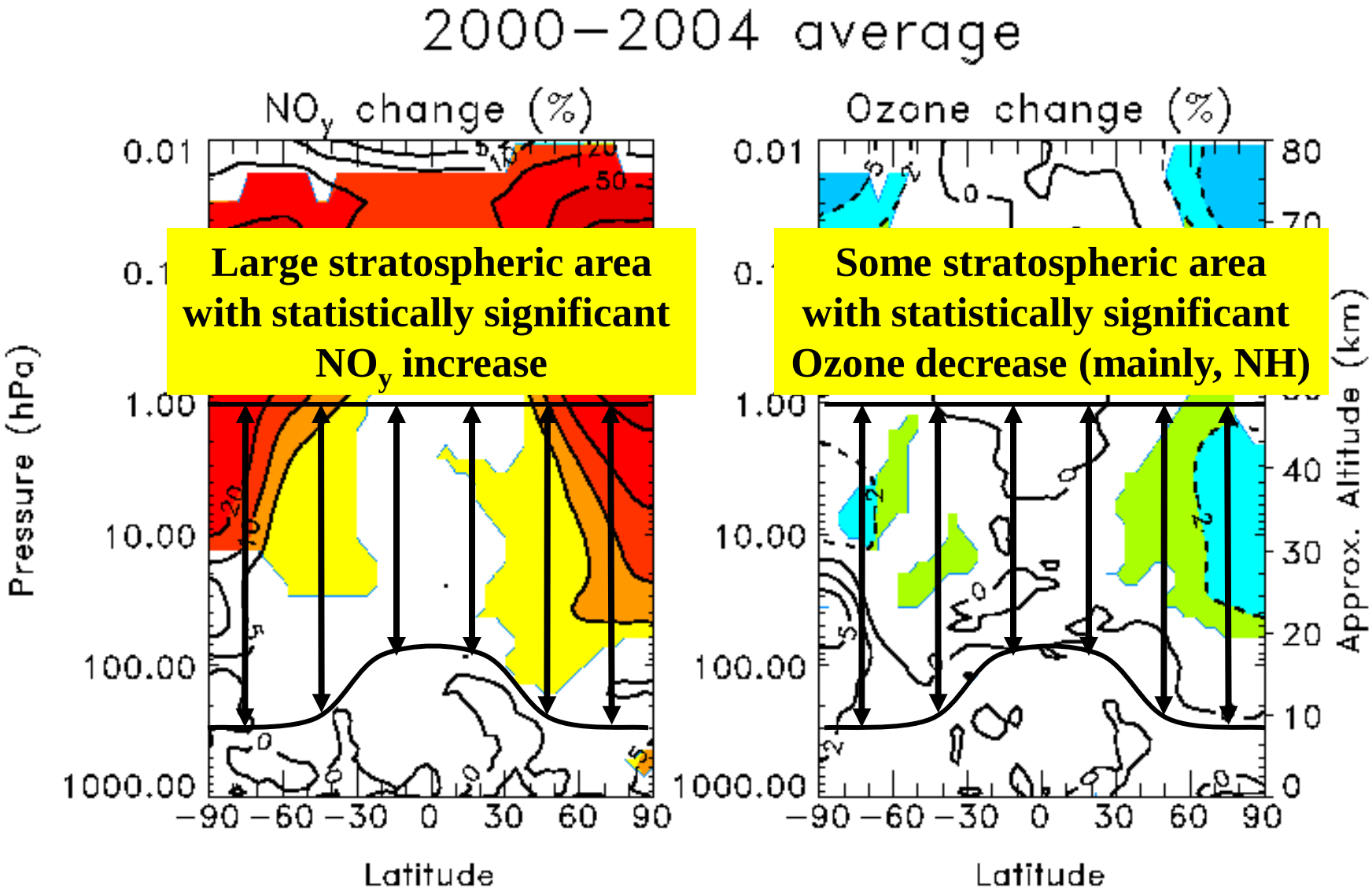
Look at Average for Years 2000-2004



Very Large SPEs in 2000, 2001, & 2003



Colored Regions are Statistically Significant to 95% (Student's t-test)



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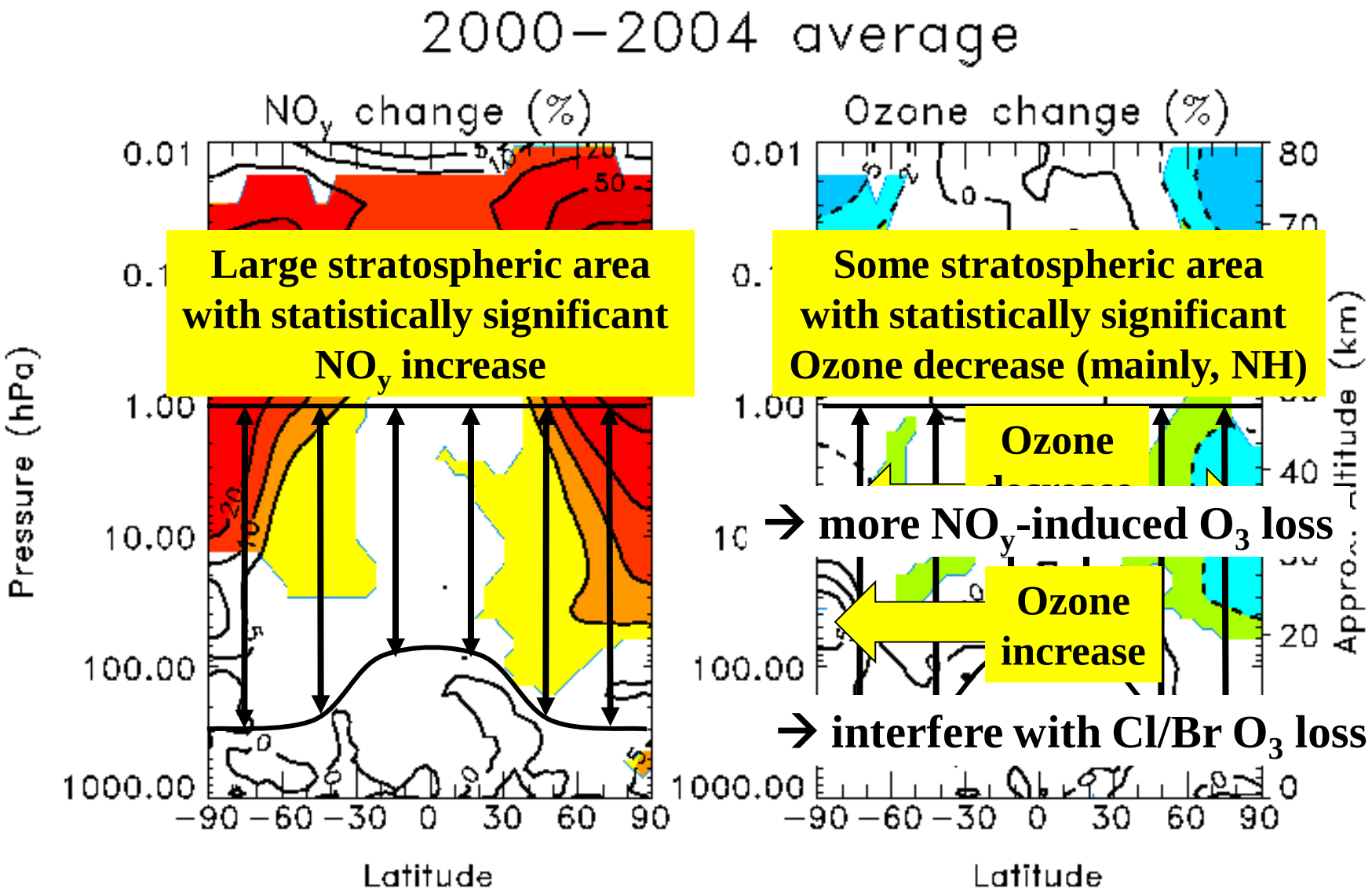

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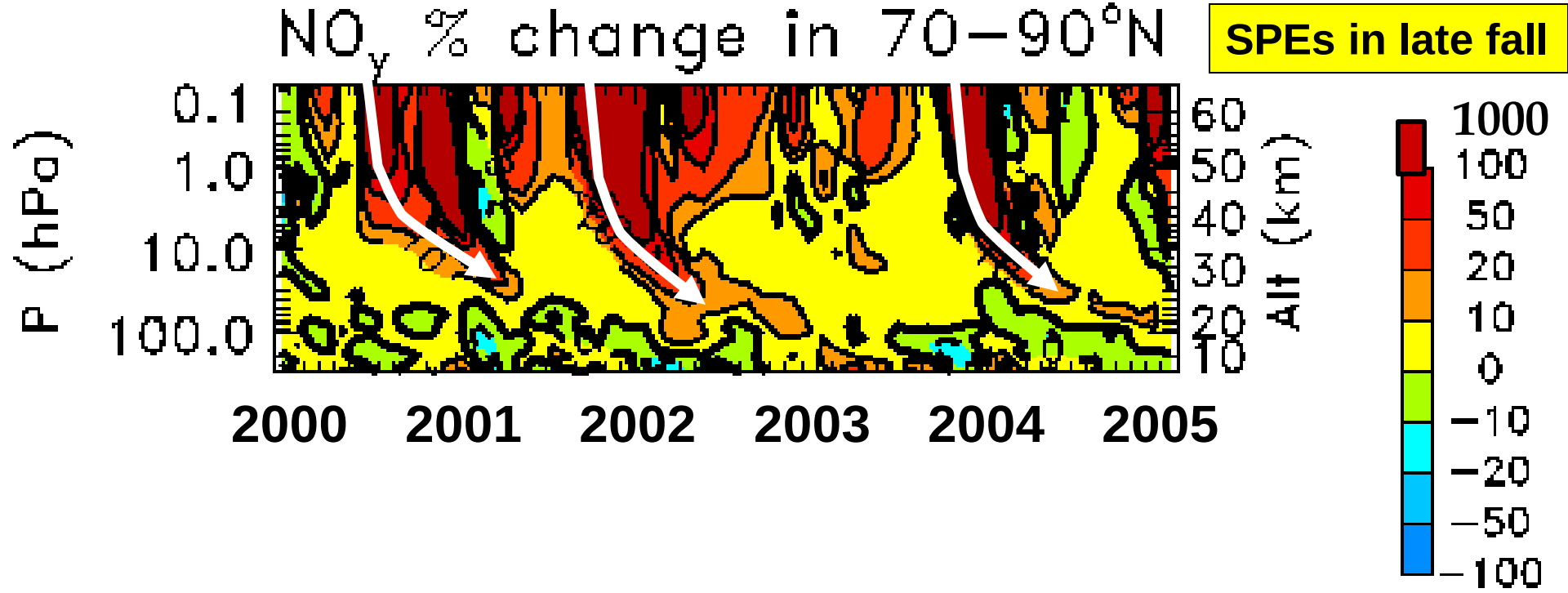
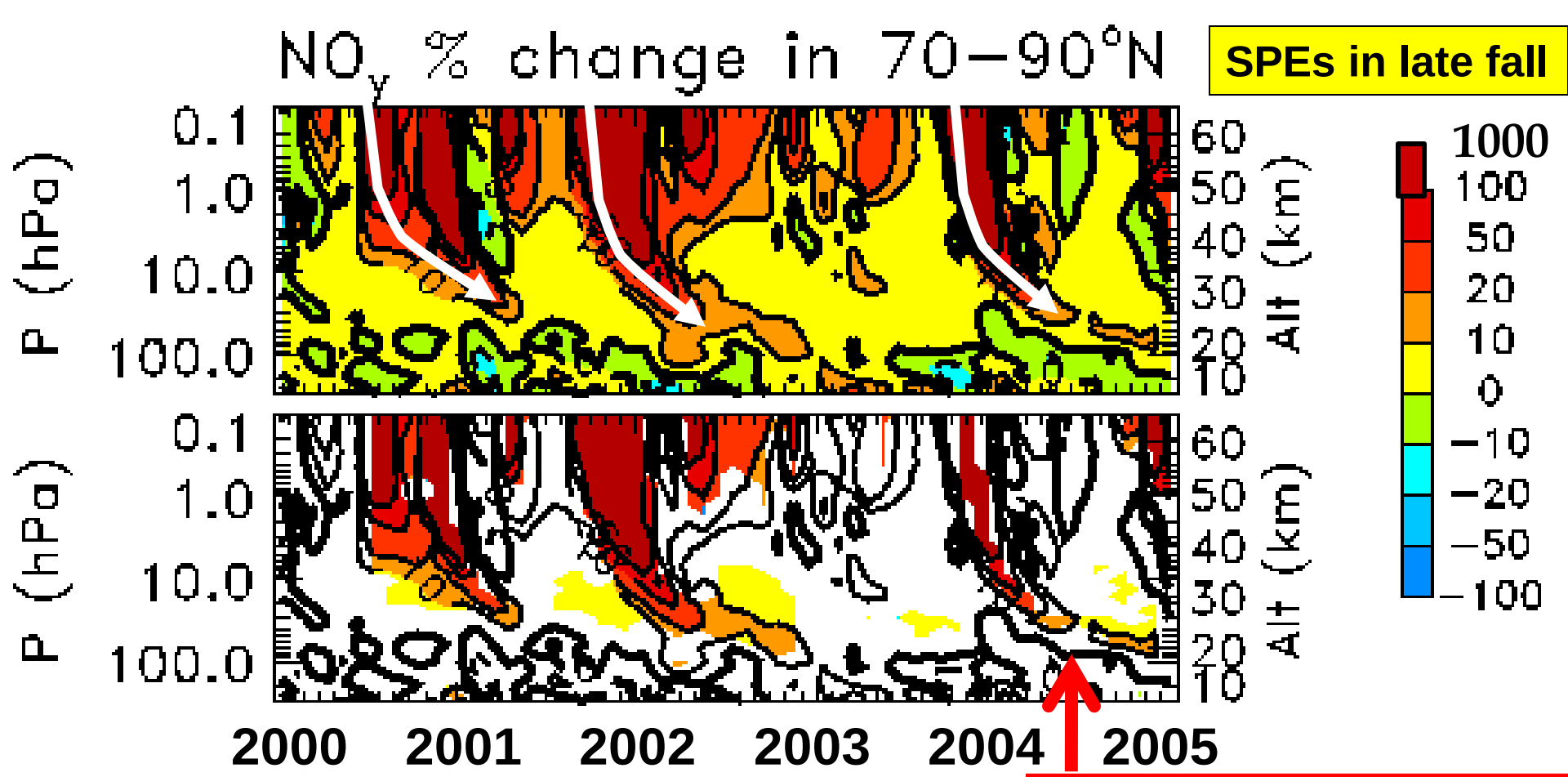
Look at Northern Hem. Polar Region for Years 2000-2004

Odd Nitrogen (NO_y)



NO_y percentage change in the Northern Hemisphere polar region (70-90ºN)



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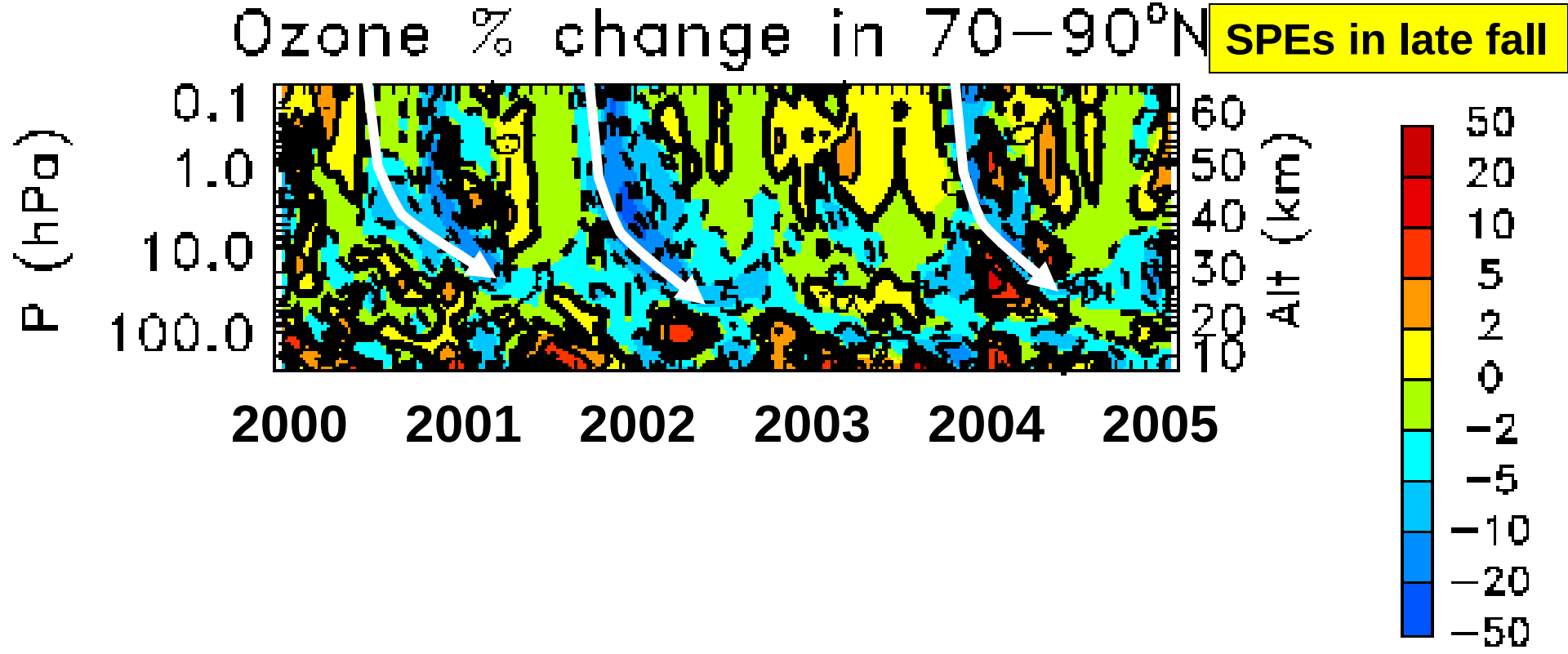
Look at Northern Hem. Polar Region for Years 2000-2004

Ozone



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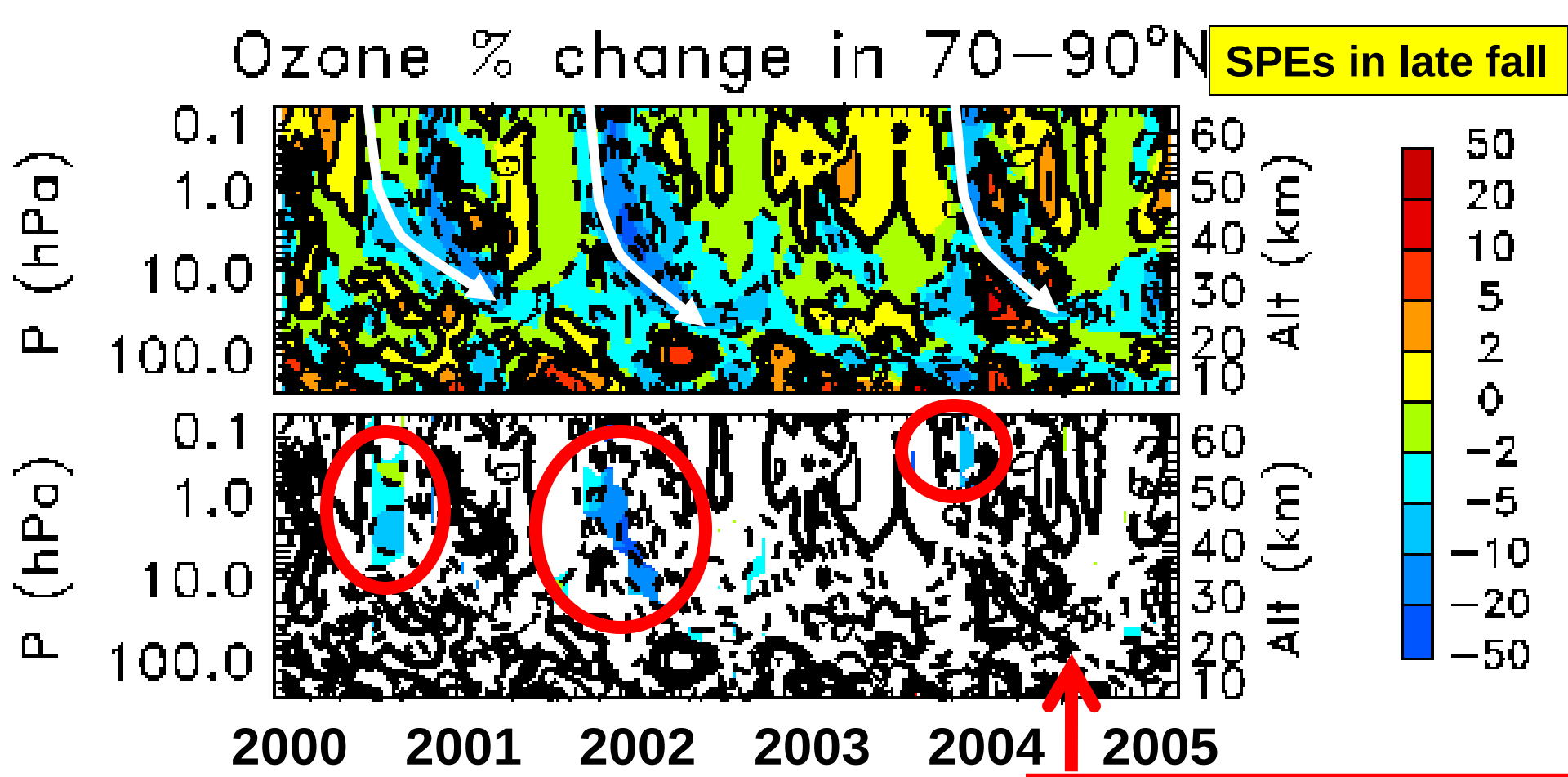
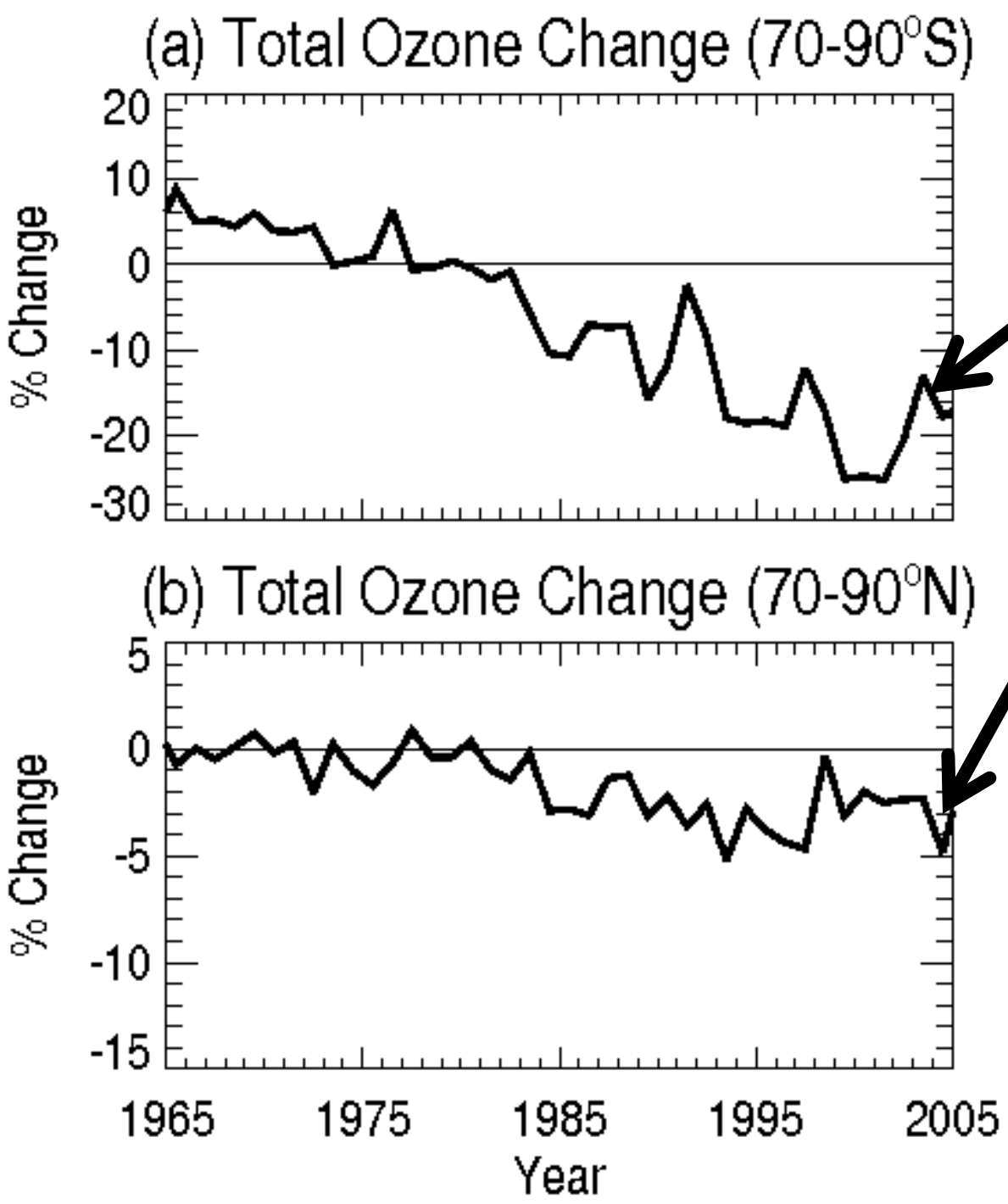
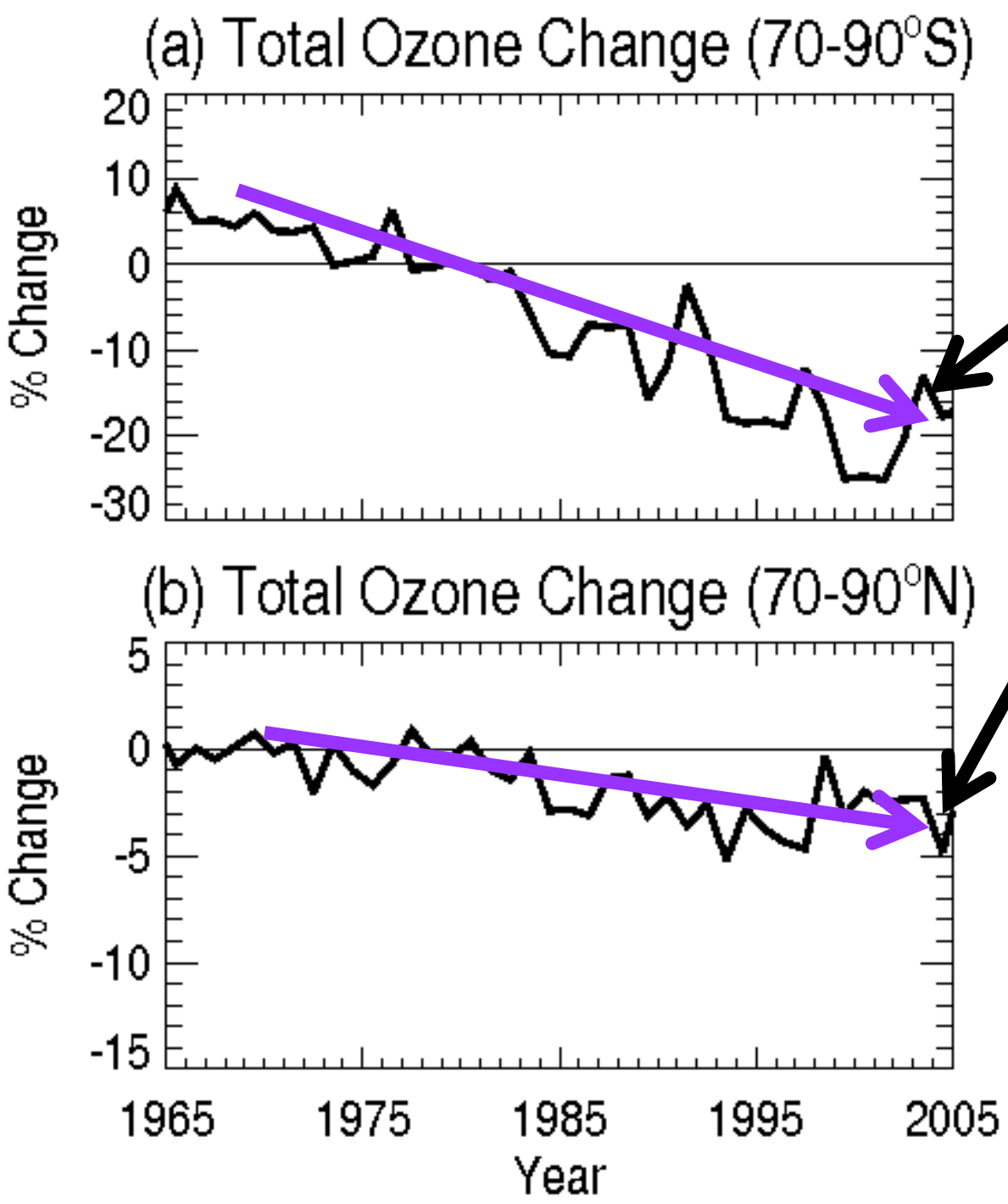


Ozone percentage change in the Northern Hemisphere polar region (70-90°N)

Polar Total Ozone Change (1965-2004)



Average of Base ('Without' SPEs) Simulations



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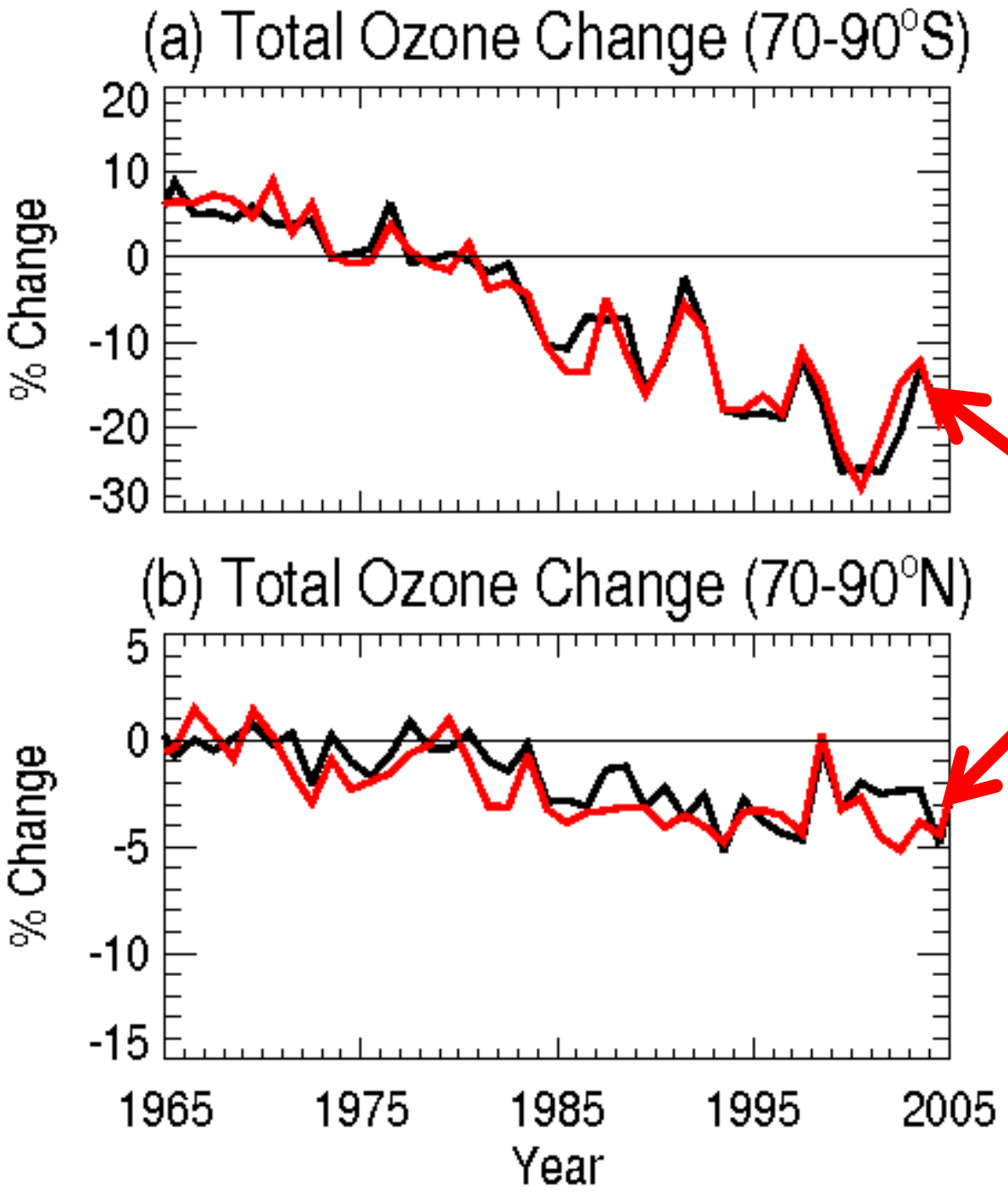
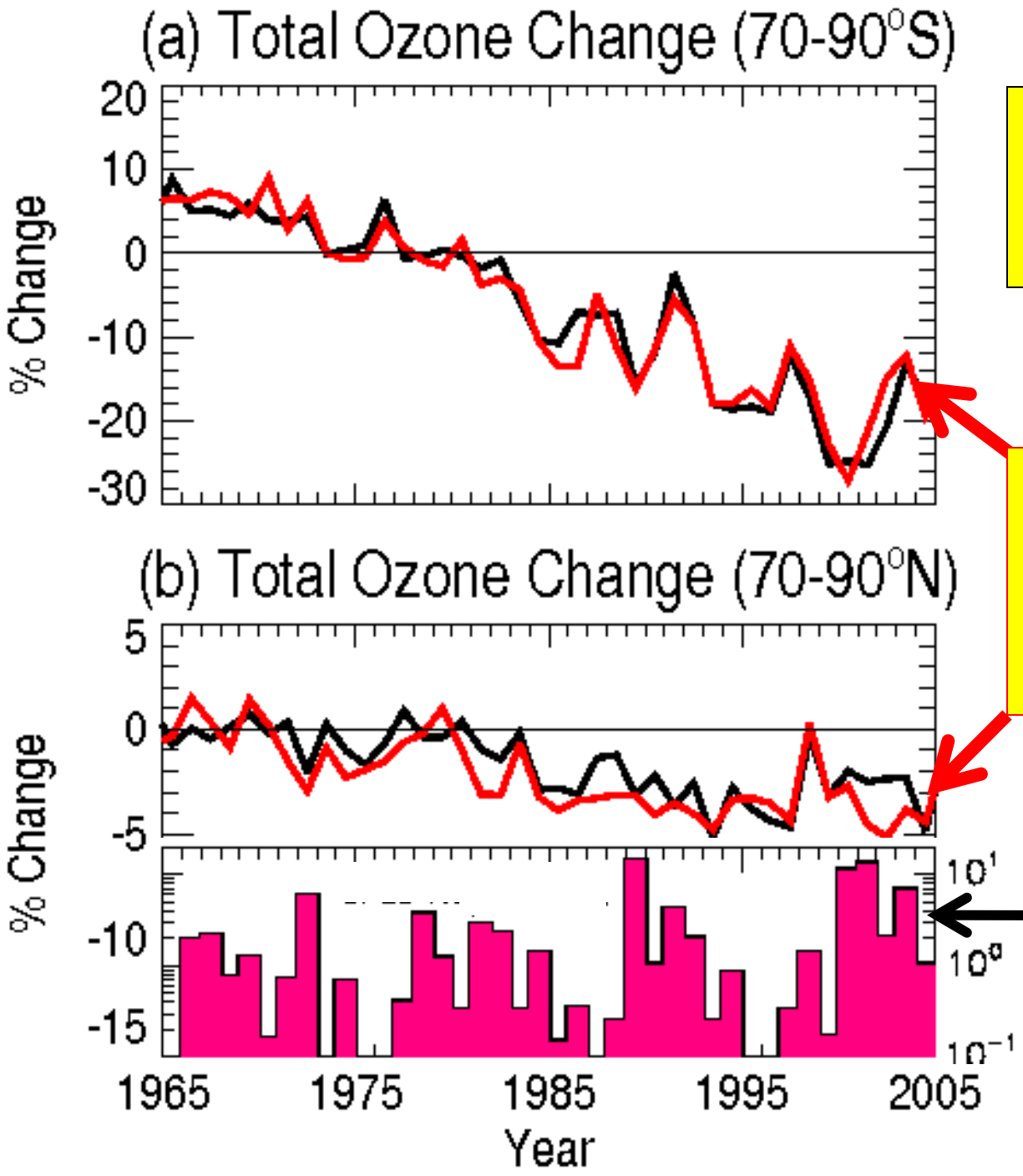


Average of Base ('Without' SPEs) Simulations

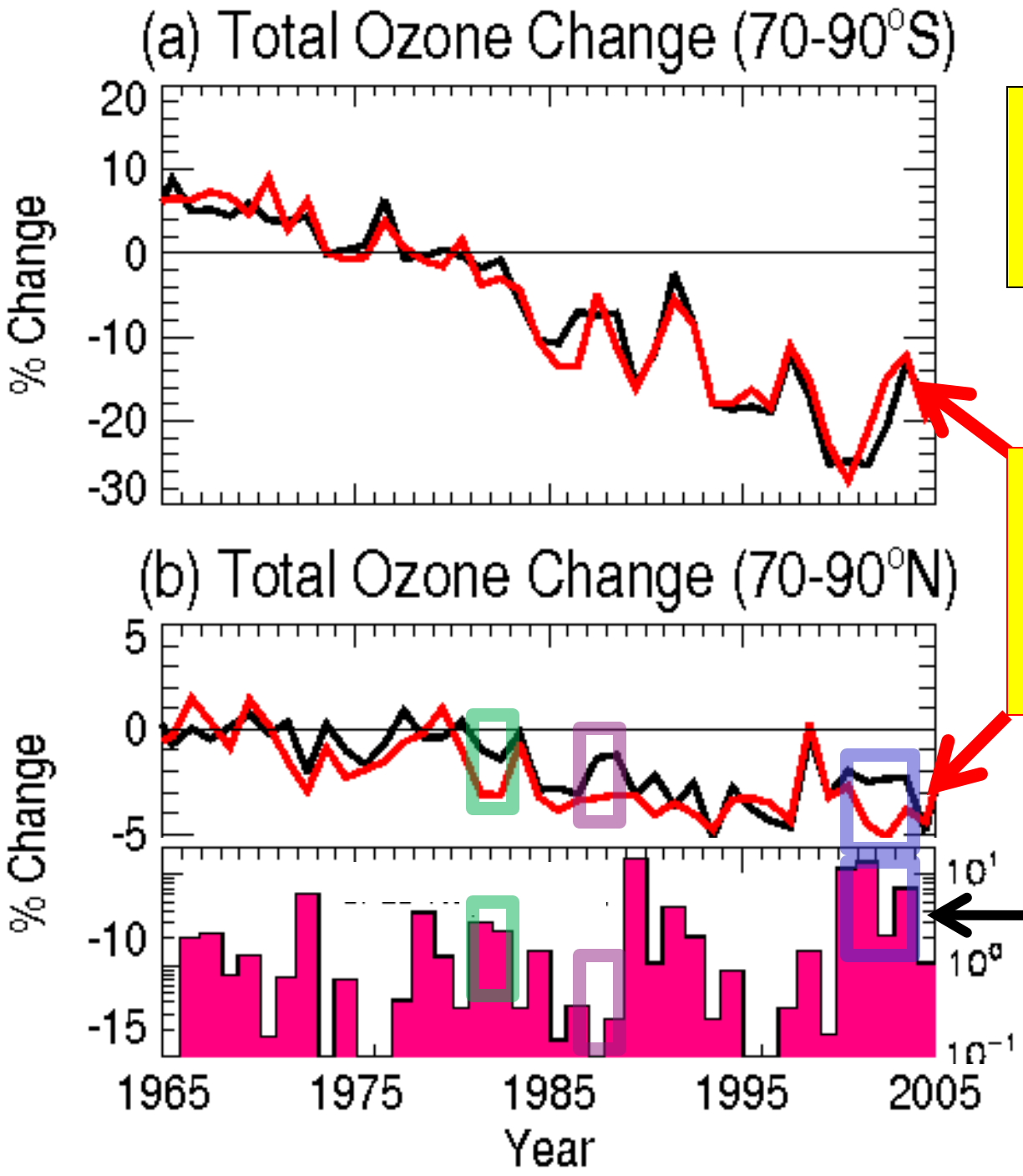
Average of Perturbed ('With' SPEs) Simulations



Average of Base ('Without' SPEs) Simulations

Average of Perturbed ('With' SPEs) Simulations

NO_y Production (GM/yr) by SPEs



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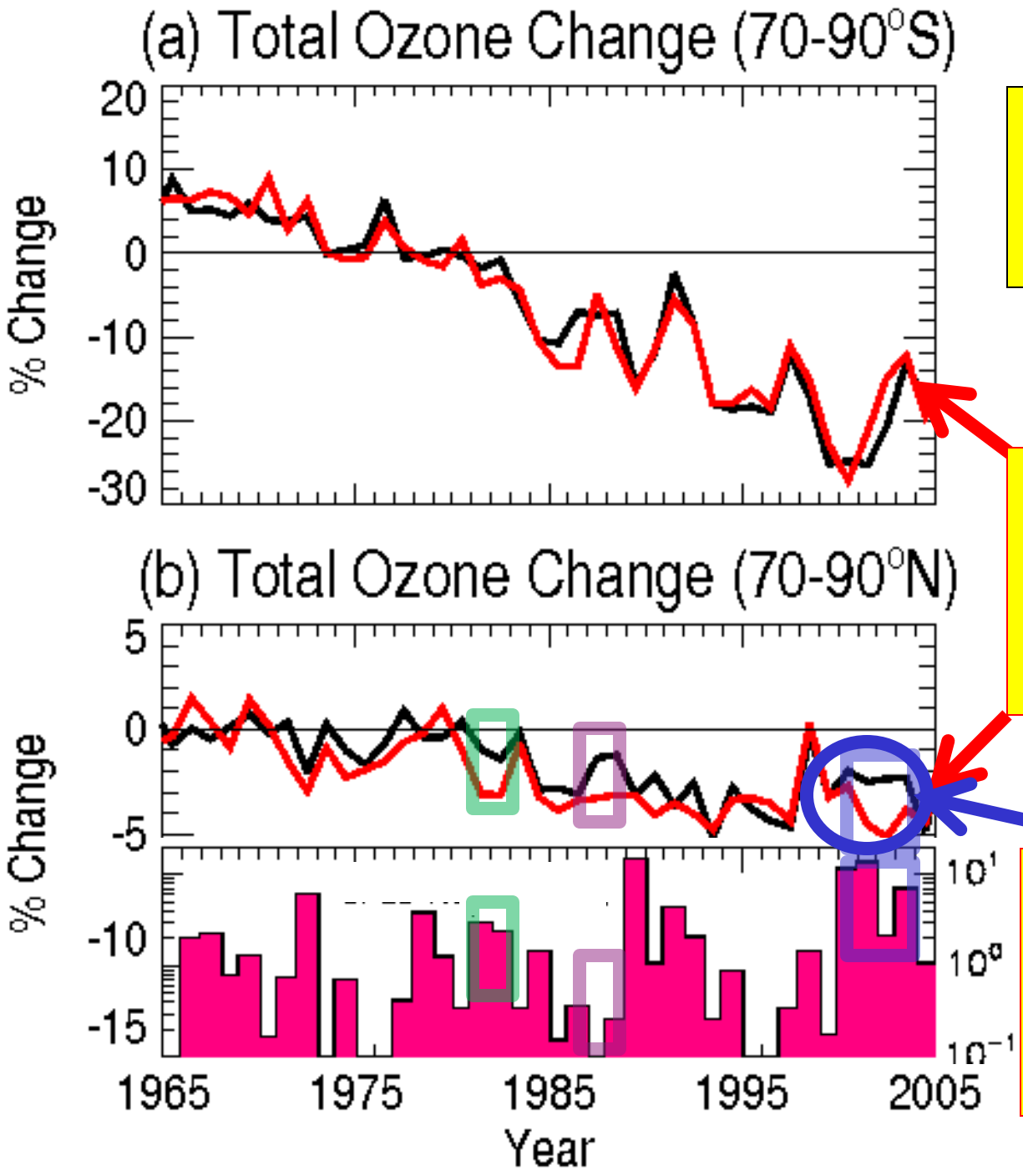
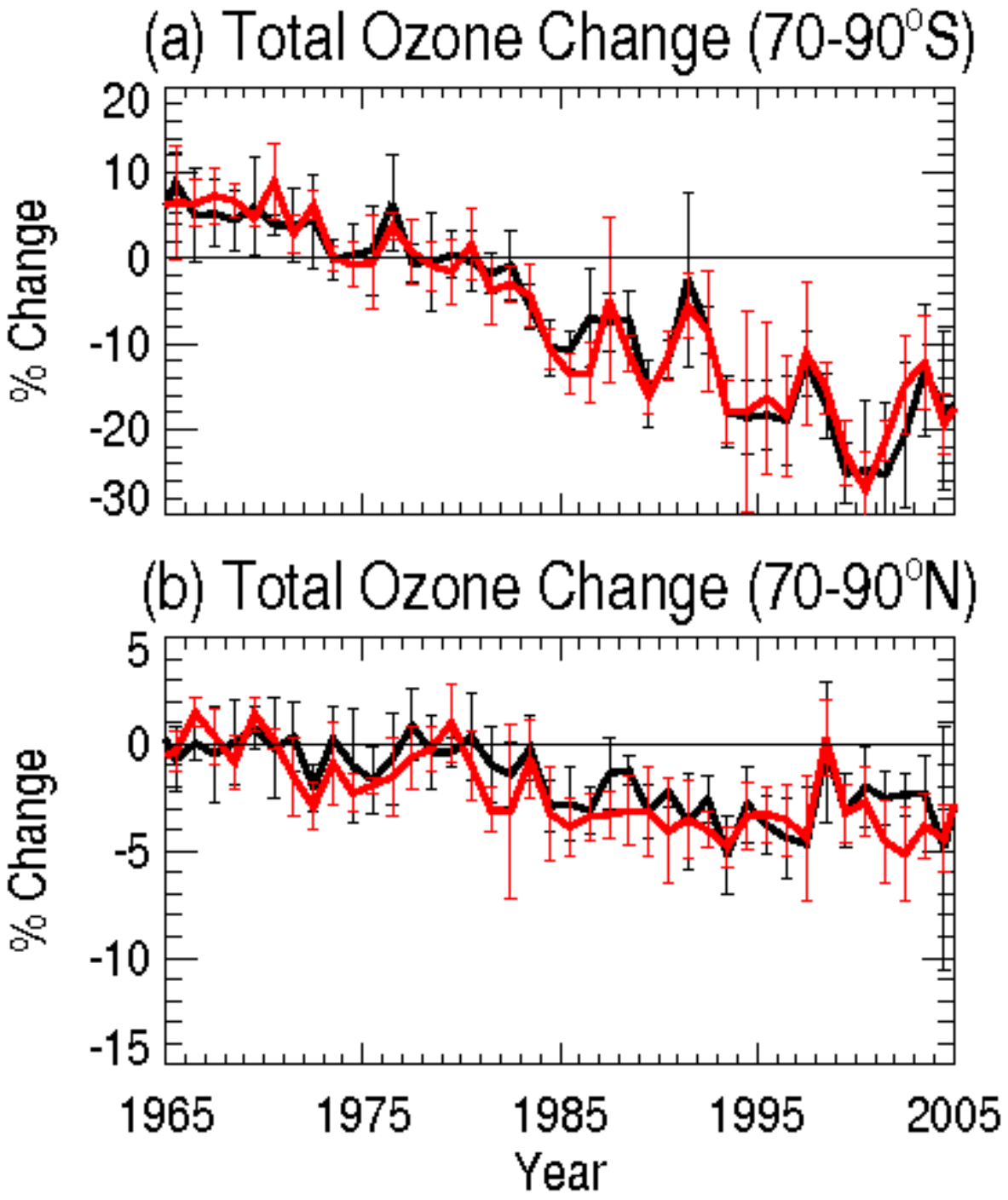


Average of Base ('Without' SPEs) Simulations

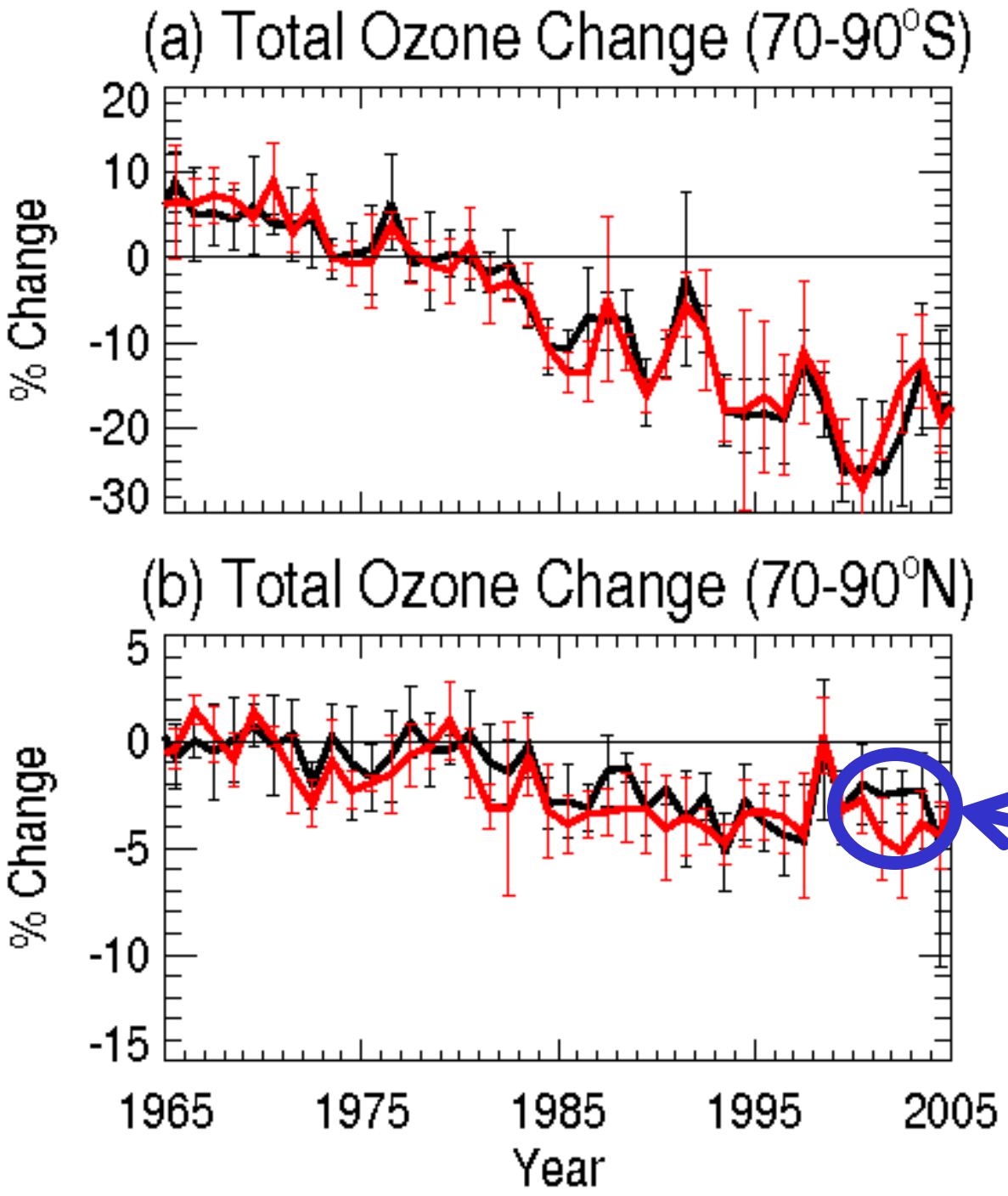
Average of Perturbed ('With' SPEs) Simulations

Could this Total Ozone Decrease have been caused by SPEs?



Base – black
Perturbed - red

Standard Deviation (one sigma '**σ**') Added



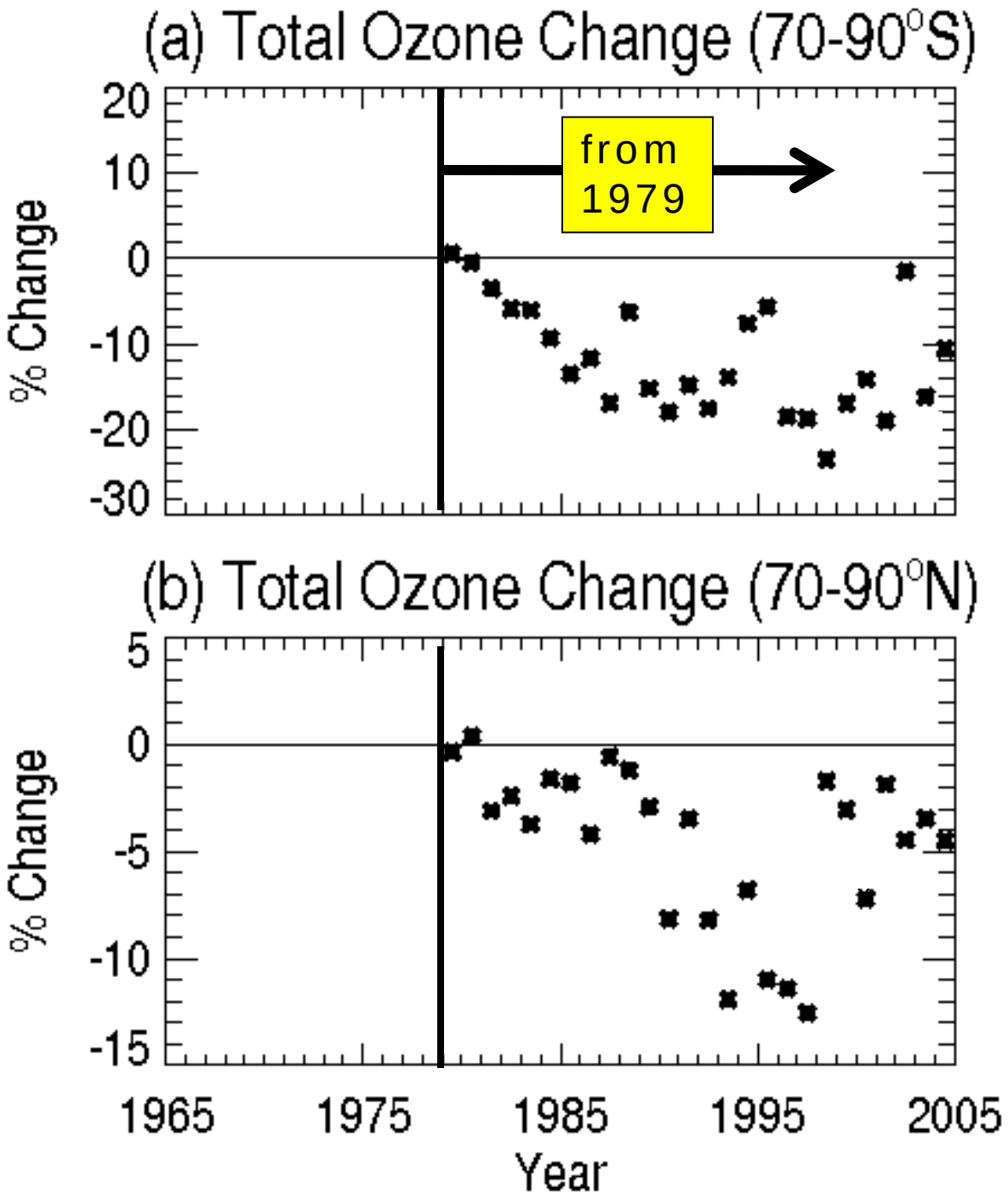
Base – black
Perturbed - red

Standard Deviation (one sigma '**σ**') Added

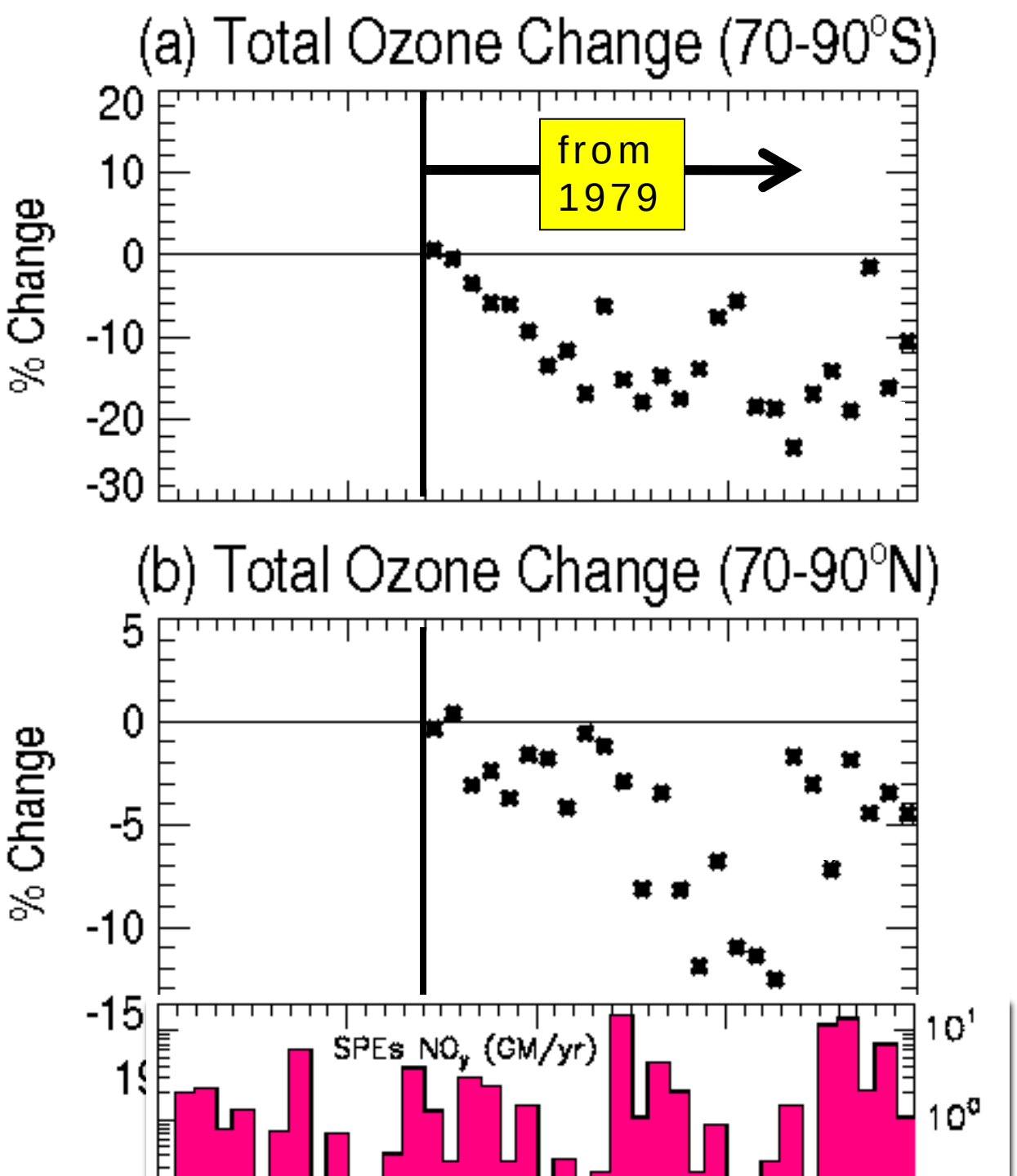
Difference is greater than 1**σ**, but less than 2**σ**. Not Stat. Sig.

What about Total Ozone data???

Do TOMS/SBUV observations show any SPE influence?



'x' symbol
TOMS/SBUV
Measurements



'x' symbol
TOMS/SBUV
Measurements

Conclusions – *(SPEs in 1963-2004)*

- **Caused some Polar Mesospheric and Stratospheric changes (especially, 2000-2004)**

- **Large amounts of *Polar* NO_y were produced**
  → Maximum impact in Fall/Winter

- ***Polar Ozone* was also changed**
  → Long-lived (~months) ozone changes
  → Both decreases & increases in the stratosphere
  → No Statistically Significant Total Ozone decreases due to SPEs

published in Jackman et al. [JGR, 2009]

Thank you for your attention!