



# **Solar Cycle influence on Stratospheric O<sub>3</sub>**

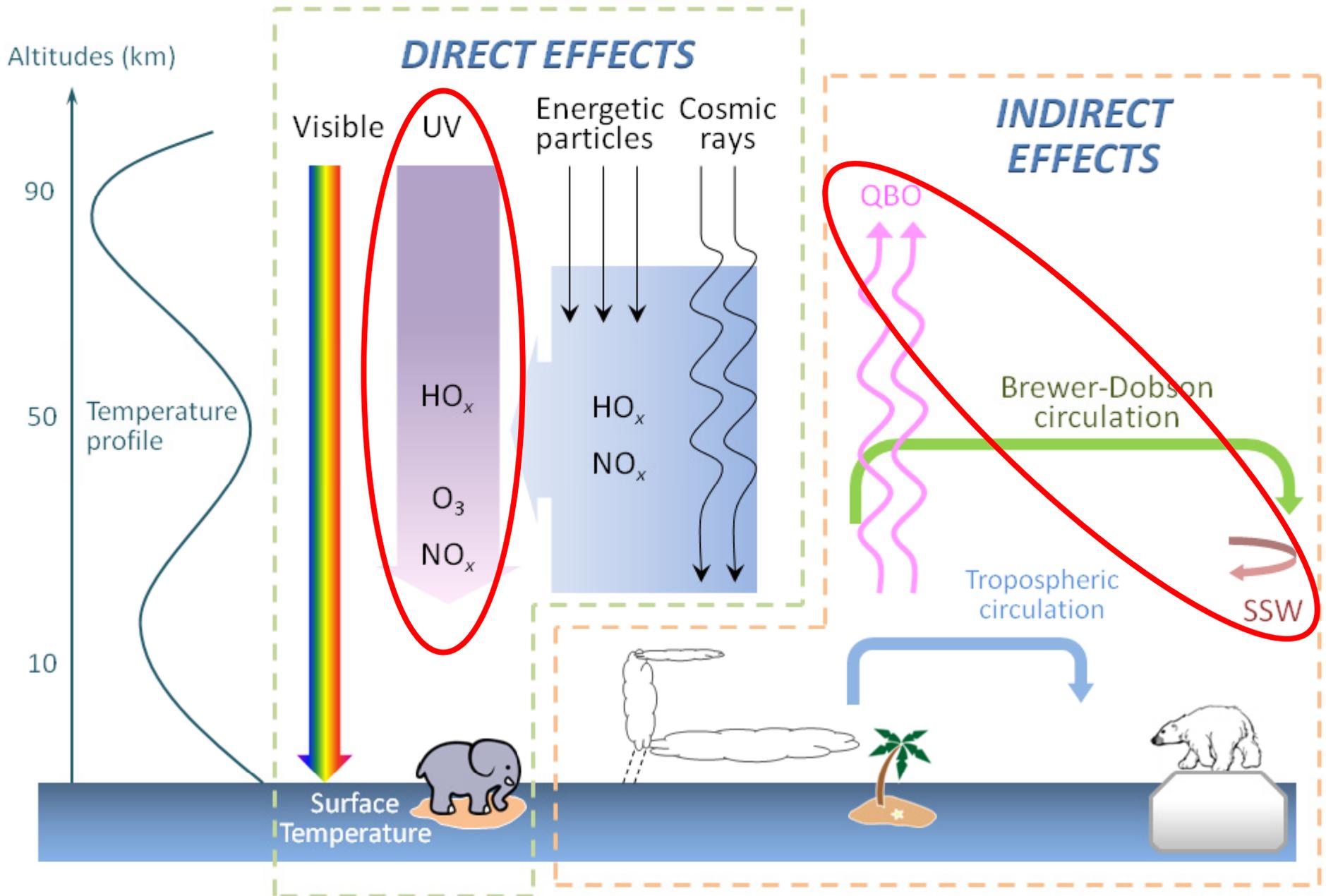
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# O<sub>3</sub> solar-cycle response

## Take-Home Messages:

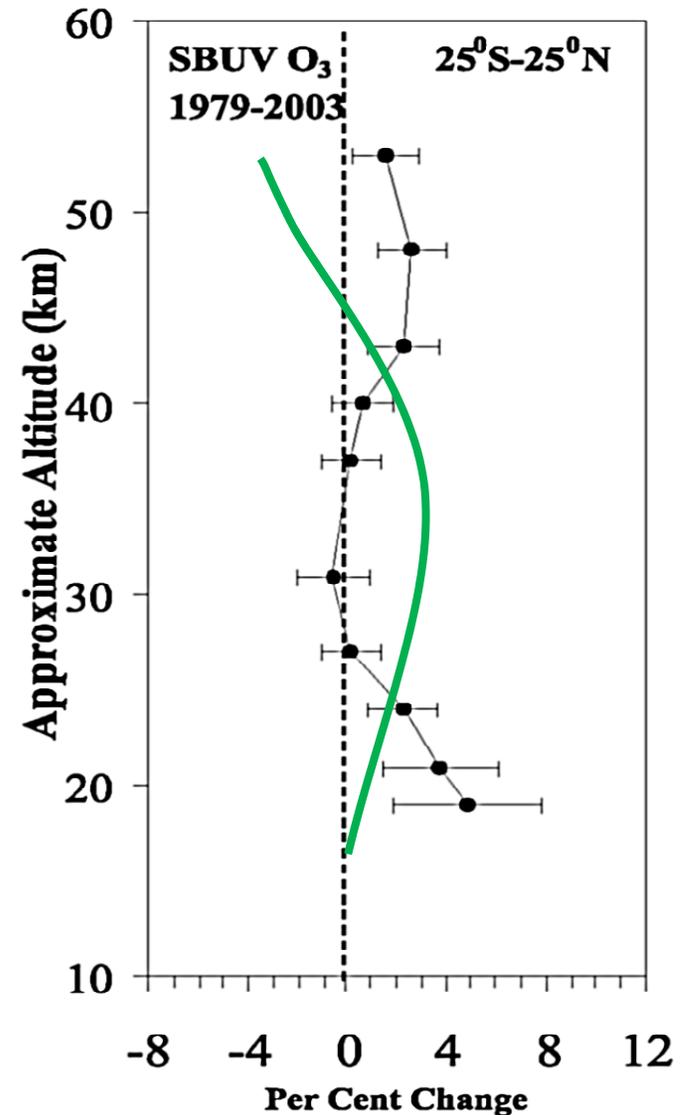
- Tropical stratospheric O<sub>3</sub>
  - ✓ Solved, (quite) completely!
  
- Polar stratospheric O<sub>3</sub>
  - Partially solved (and partially unsolved)

# VARYING SUN



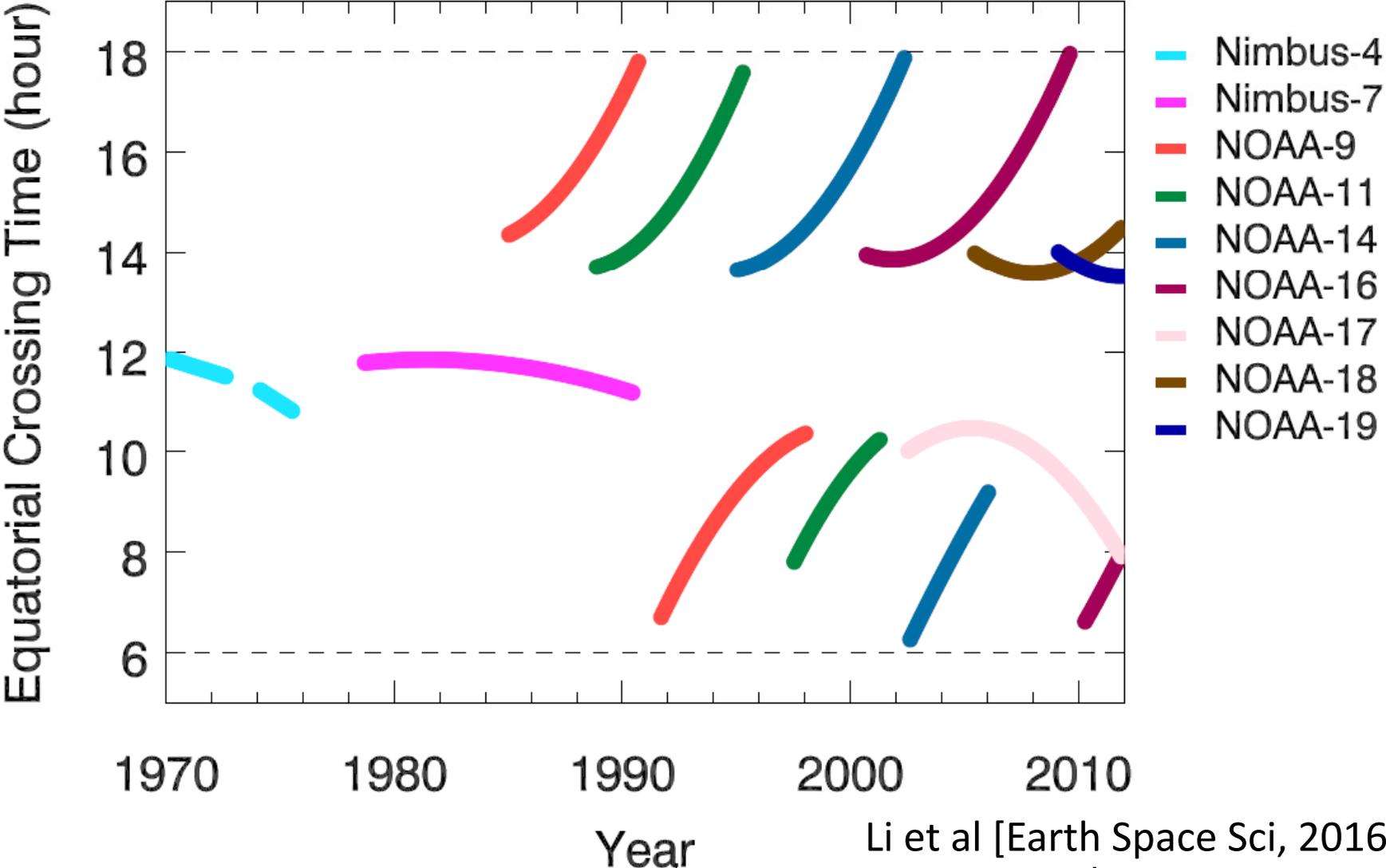
# Surprise: Tropical O<sub>3</sub>

- ❑ Observation:
  - Double peaks with practically zero response in middle stratosphere
- ❑ Photochemical Model:
  - Single peak in middle stratosphere
- ❑ Proposed Solutions:
  - Solar modulation of QBO [Chipperfield and Gray, 1992]
  - New chemistry
  - Inaccurate kinetic rates
  - Inaccurate solar UV variations [Haigh et al., Nature, 2010]



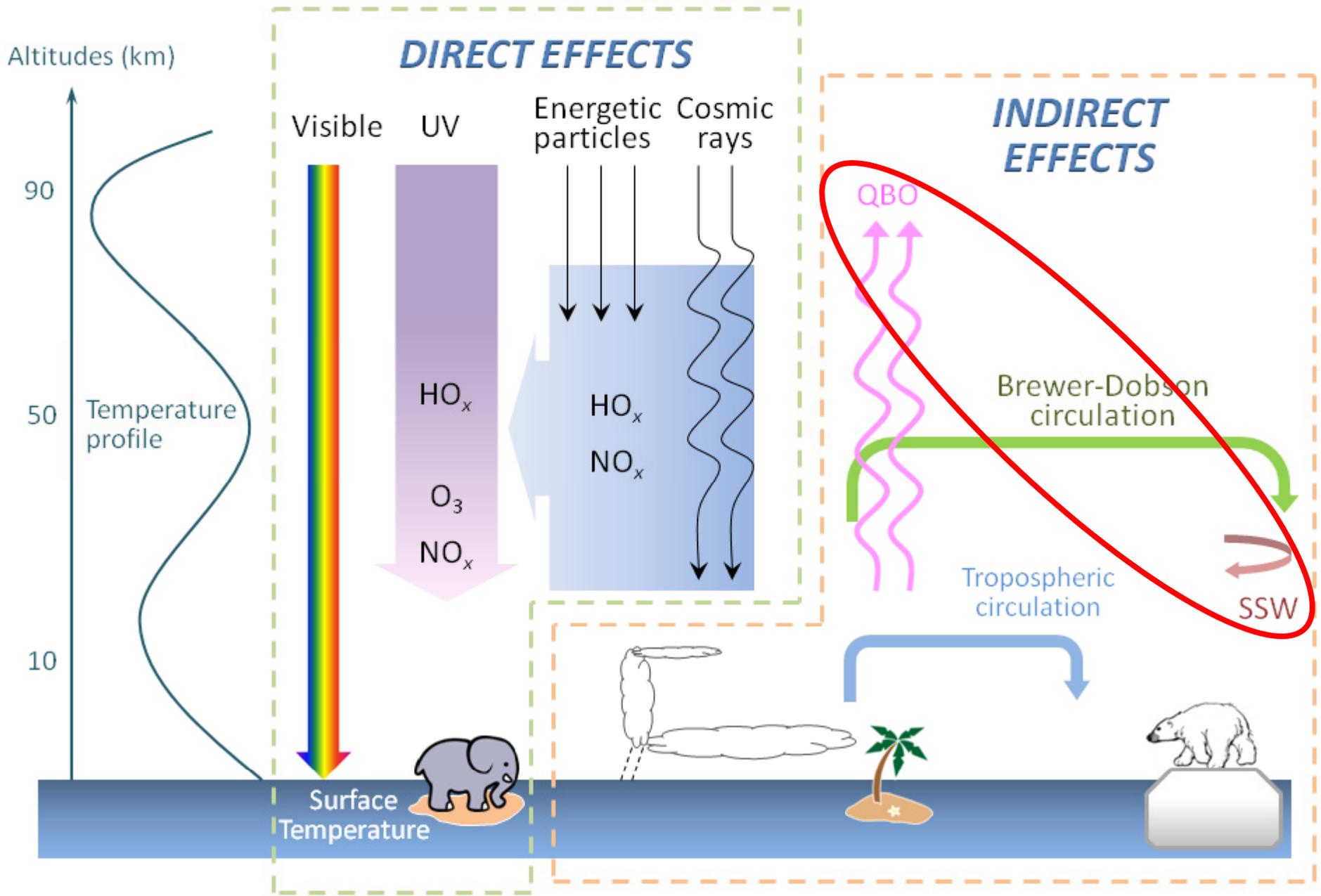
Hood [1993], Brasseur [1993]  
Soukharev and Hood [2006]

# Orbital Drifts



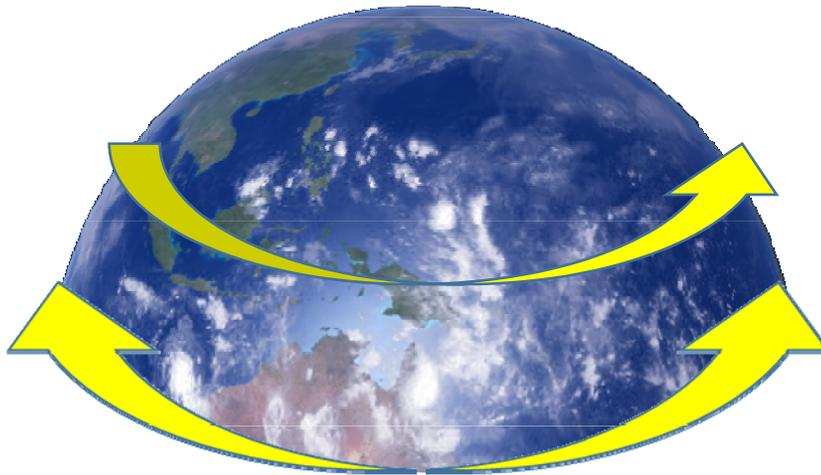
Li et al [Earth Space Sci, 2016, doi:10.1002/2016EA000199]

# VARYING SUN



# Quasi-biennial Oscillation

- ❑ One of the most remarkable phenomena in the Earth's atmosphere. Discovered in 1959 by Graystone et al. (UK)



Westerly mid-lat jets

Westerly ↔ Easterly  
every ~28 months

- ❑ Relevant for seasonal prediction
- ❑ Modulate dynamical transports
- ❑ **Affects ... how the solar cycle interacts with the atmosphere.**

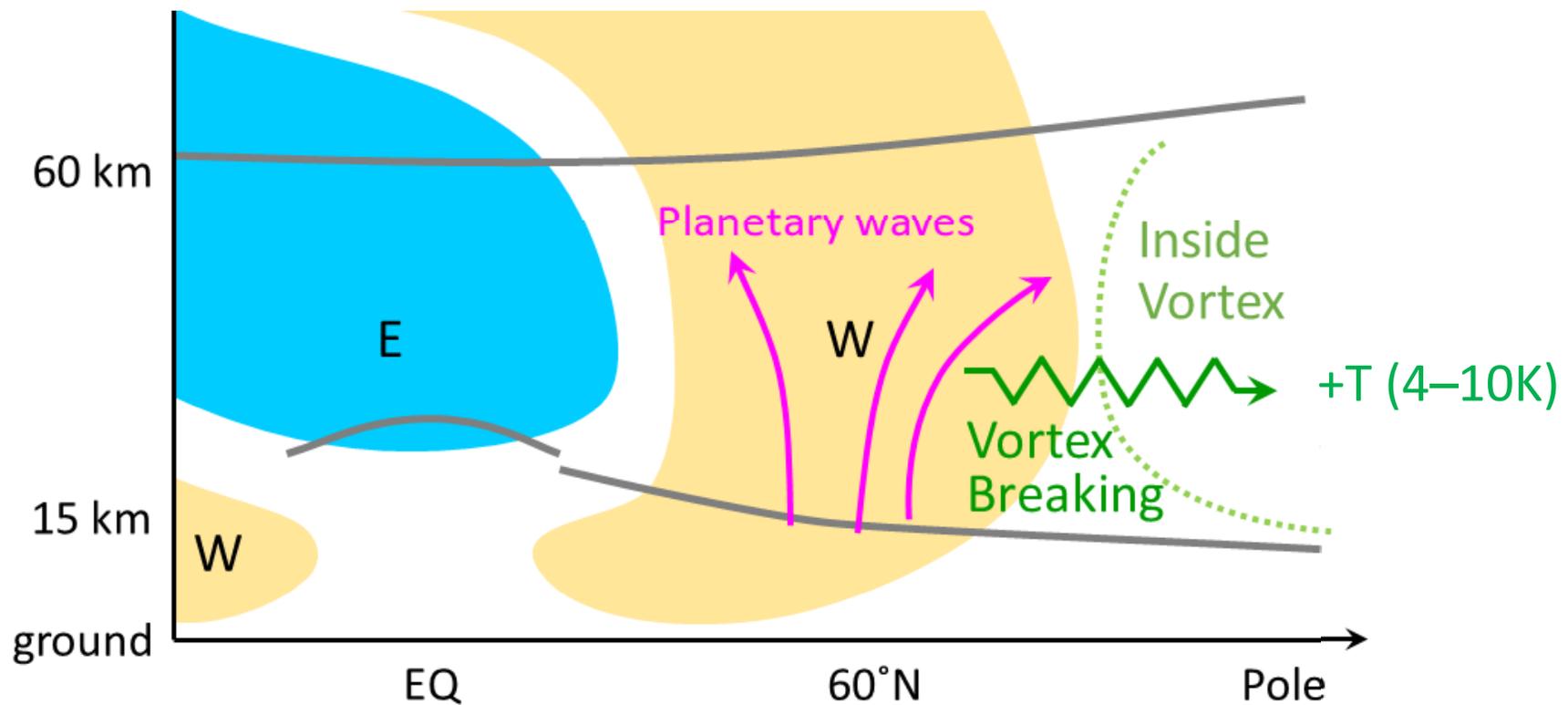
# Solar cycle on stratospheric temperature

- ❑ Tropics:
  - ~1 K increase, due to O<sub>3</sub> absorption of solar UV
  - Understood!
  
- ❑ Pole:
  - ❑ > 10 K, cannot be photochemical
  - ❑ Only occurs in late winter
  - ❑ seen “only when stratified according to the phase of QBO ” [Labitzke and von Loon, 1988].

# QBO Teleconnection

## Holton-Tan mechanism

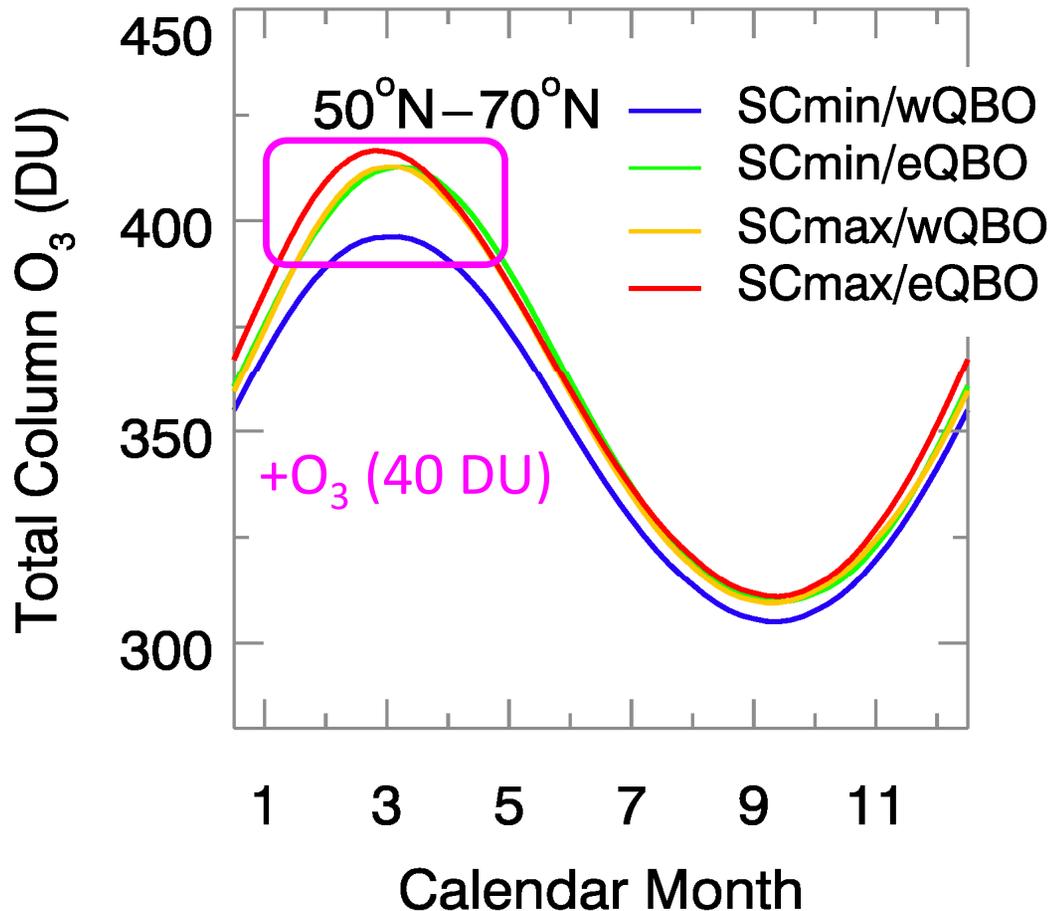
- During wQBO phase, planetary waves freely propagates
- During eQBO phase, planetary waves are squeezed poleward, transporting energy to break the vortex



- ❑ 1987: Labitzke – **Warmer pole** during **solar max/wQBO**
- ❑ 1988: Labitzke & von Loon – **Cooler pole** during **solar max/eQBO**  
→ **reversal of Holton-Tan mechanism?**
- ❑ 2005: Labitzke – No apparent solar effects during **eQBO**
- ❑ 2007: Camp & Tung – with longer records and better statistical methods: **Warmer pole** during **solar max** regardless of QBO phases  
→ **Holton-Tan mechanism is NOT reversed**
- ❑ 2015: Garfinkel et al. (JGR) wrote in their Introduction  
“North polar stratospheric temperatures are ... negatively correlated (with solar cycle during) ... eQBO.”
- ❑ 2014: Kren ... Pilewskie – Cannot find the temperature signal in WACCM4 or WACCM3.5 (w/ or w/o prescribed QBO)

# O<sub>3</sub> is better than temperature

- Temperature is complicated by radiative processes
- O<sub>3</sub> is only affected by dynamics in polar region

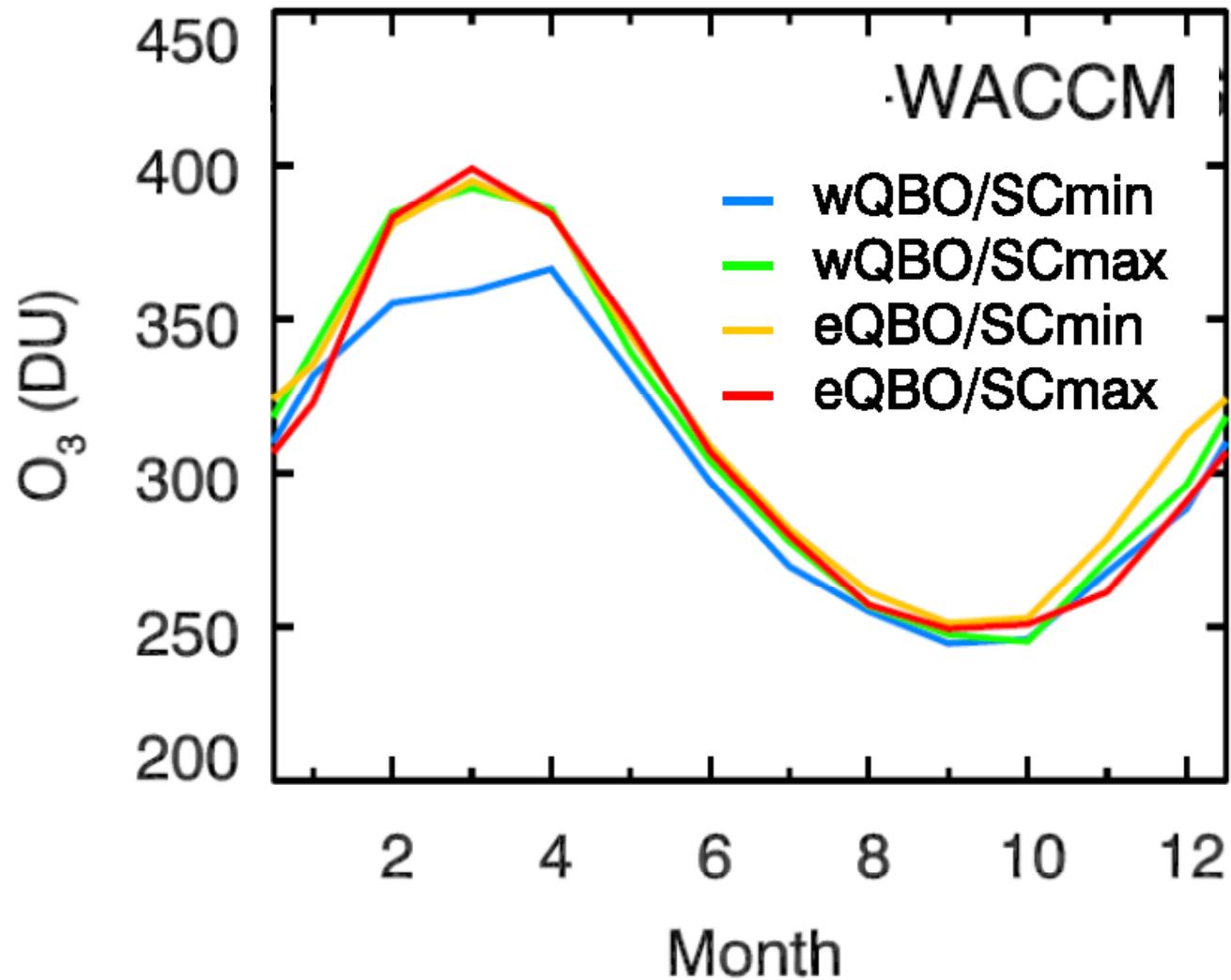


|       | SC-min   | SC-max                       |
|-------|--|------------------------------|
| w-QBO | 1985, 1986, 1993, 1995, 1997, 2007, 2009, 2011 | 1981, 1991, 1999, 2000, 2002 |
| e-QBO | 1984, 1987, 1994, 1996, 1998, 2006, 2008, 2010 | 1982, 1989, 1990, 2001       |

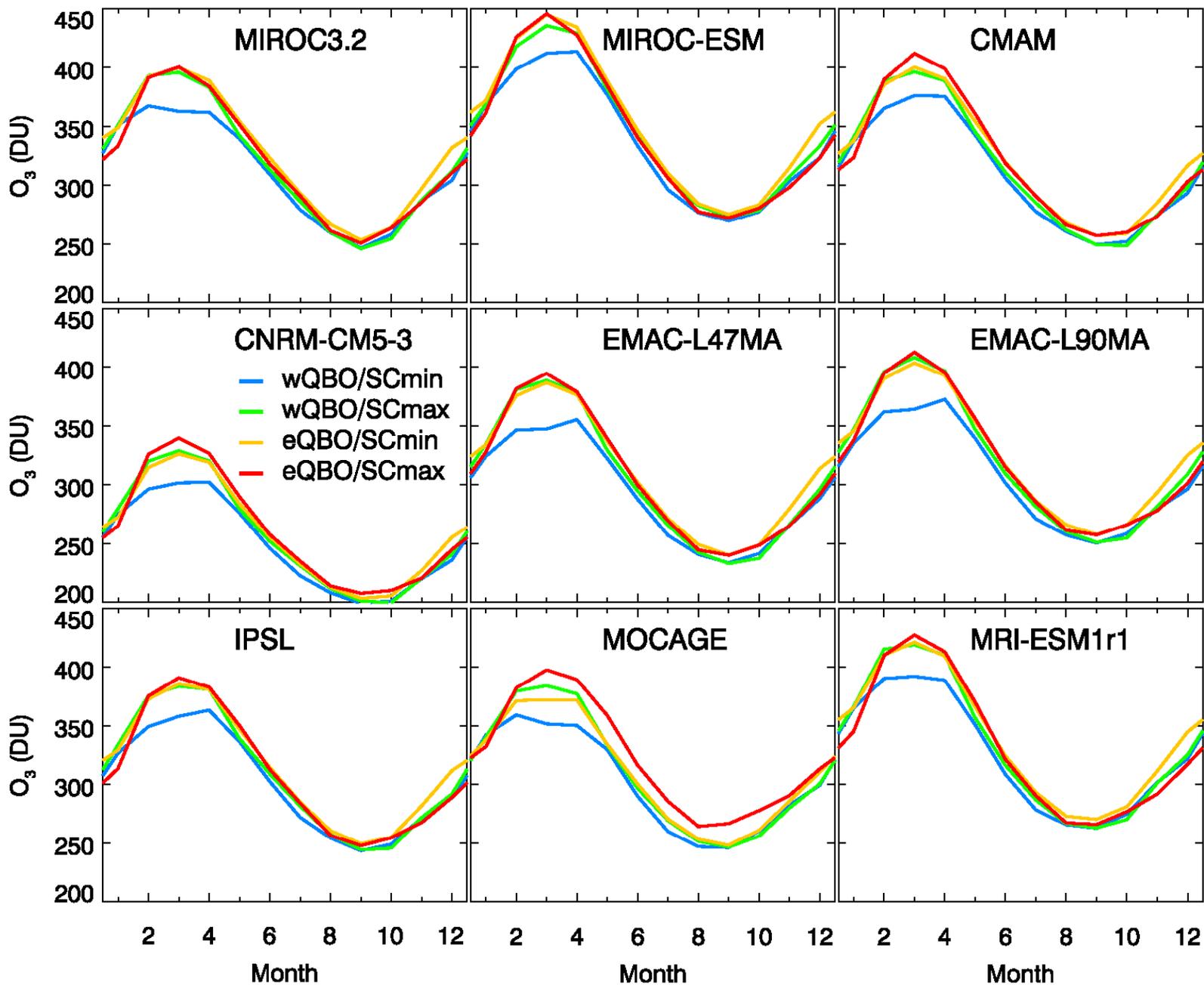
Li and Tung [2014]

# WACCM3.5 with constrained wind

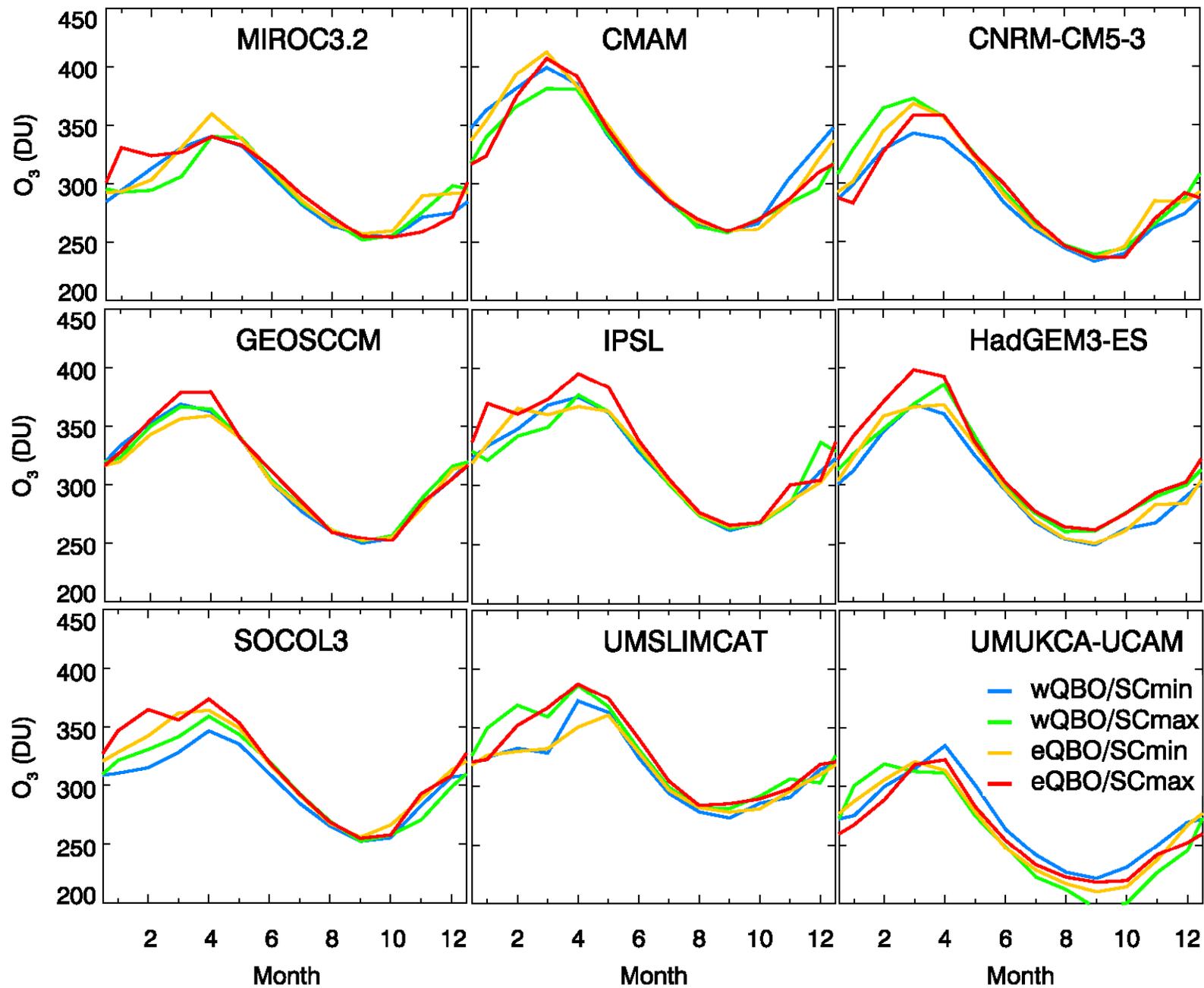
□ Same for WACCM4



## Models with constrained wind



## Models with self-calculated winds



# Conclusions

- ❑ Chemical transport in these models are well built.
- ❑ No reversal of the Holton-Tan mechanism is required!
- ❑ Unresolved problem
  - What is the Holton-Tan-like mechanism for solar cycle teleconnection?