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Decadal Variability in the Sun and Climate
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The Effect of Decadal Solar UV Variability on the Middle Atmosphere: A 2-D Modeling Perspective

John McCormack
Upper Atmospheric Physics Branch
US Naval Research Laboratory, Washington DC
john.mccormack@nrl.navy.mil

Outline

1. Review working theory of sun/climate link

2. Solar cycle in stratospheric O_3 and T: observations vs. models

3. 2D model simulations of solar/QBO interaction

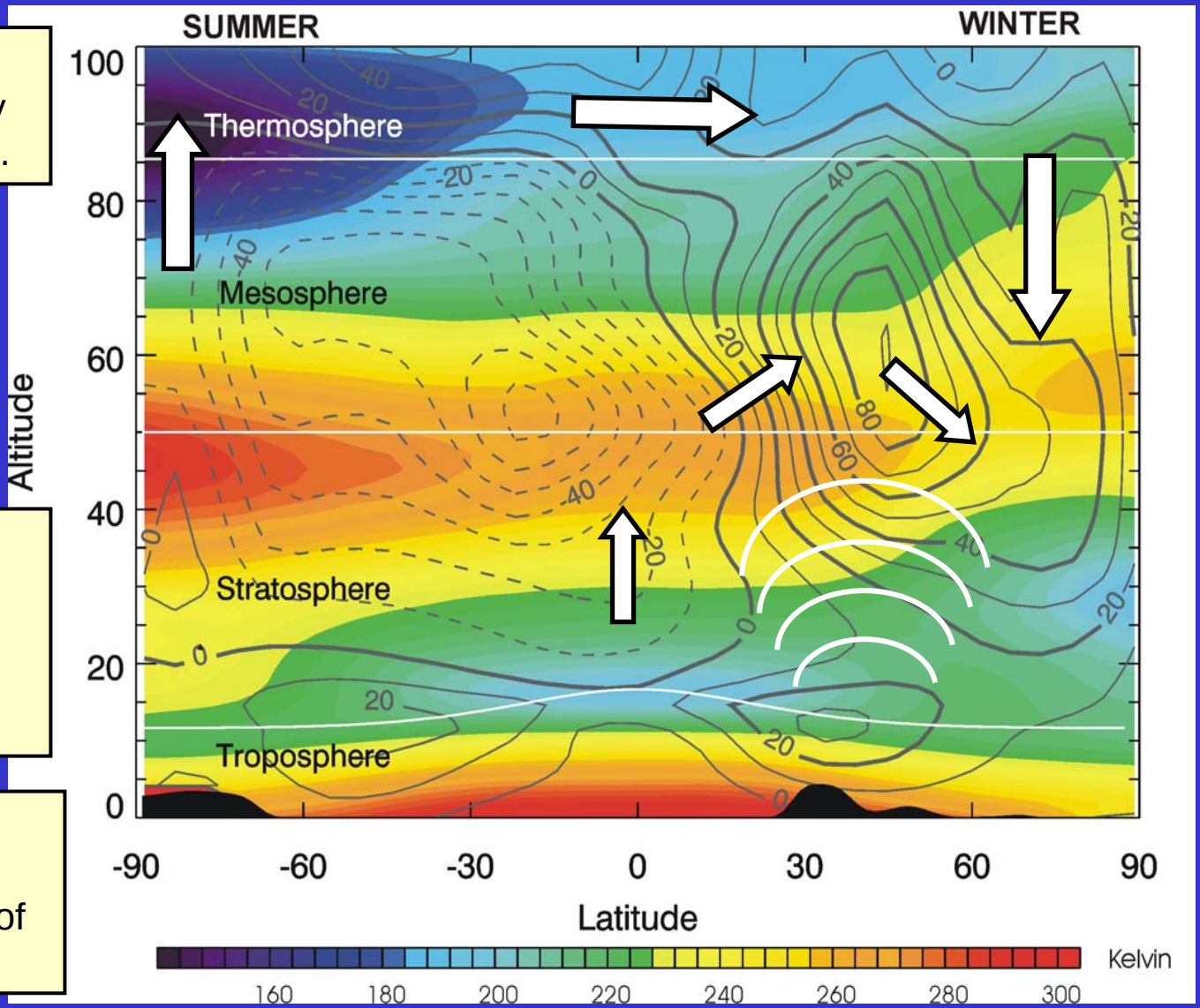
Zonally averaged (2D) zonal wind, temperature for December

Meridional temperature gradient sets up westerly jet in winter stratosphere.

Planetary-scale waves (PW) propagate upward under westerly flow in winter hemisphere.

PW's grow and "break", decelerating westerlies, driving poleward & downward meridional circulation (arrows).

PW propagation is sensitive to strength of westerlies and location of zero wind line.



(CIRA climatology, *Fleming et al.*, 1990)

The Quasi-Biennial Oscillation (QBO)

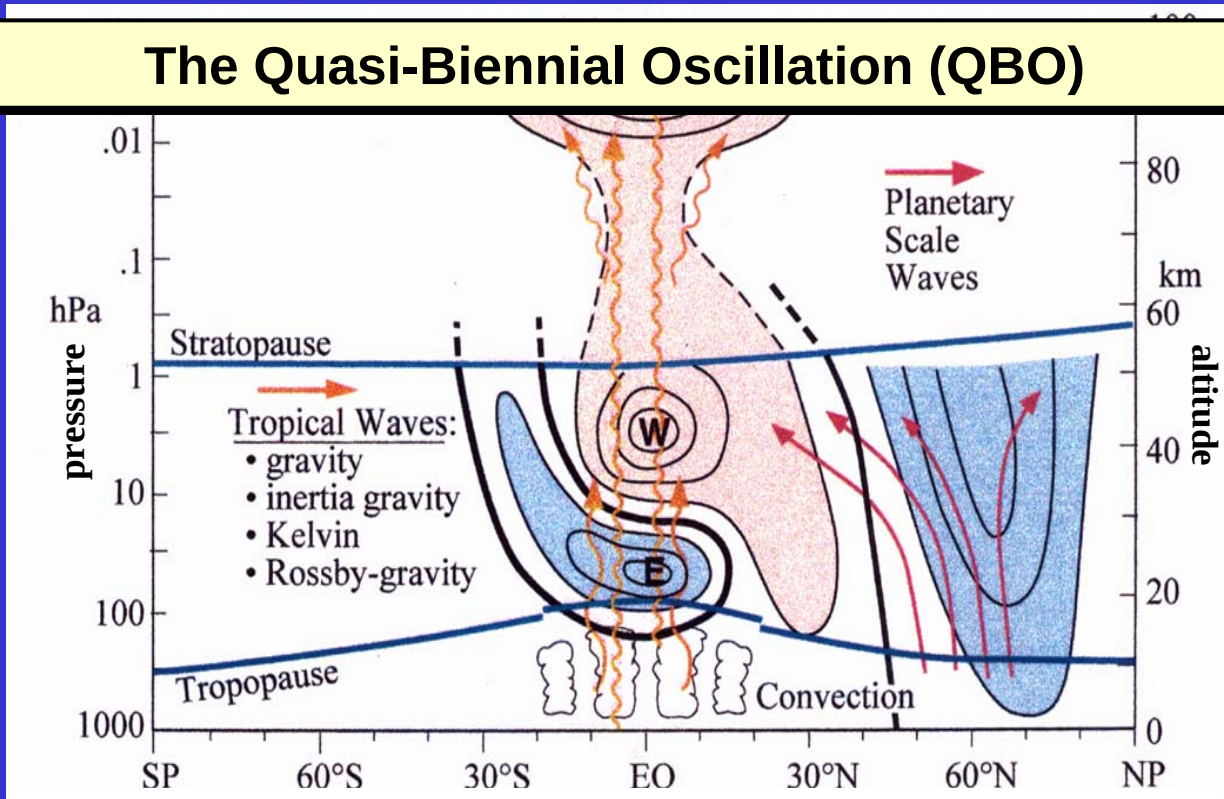
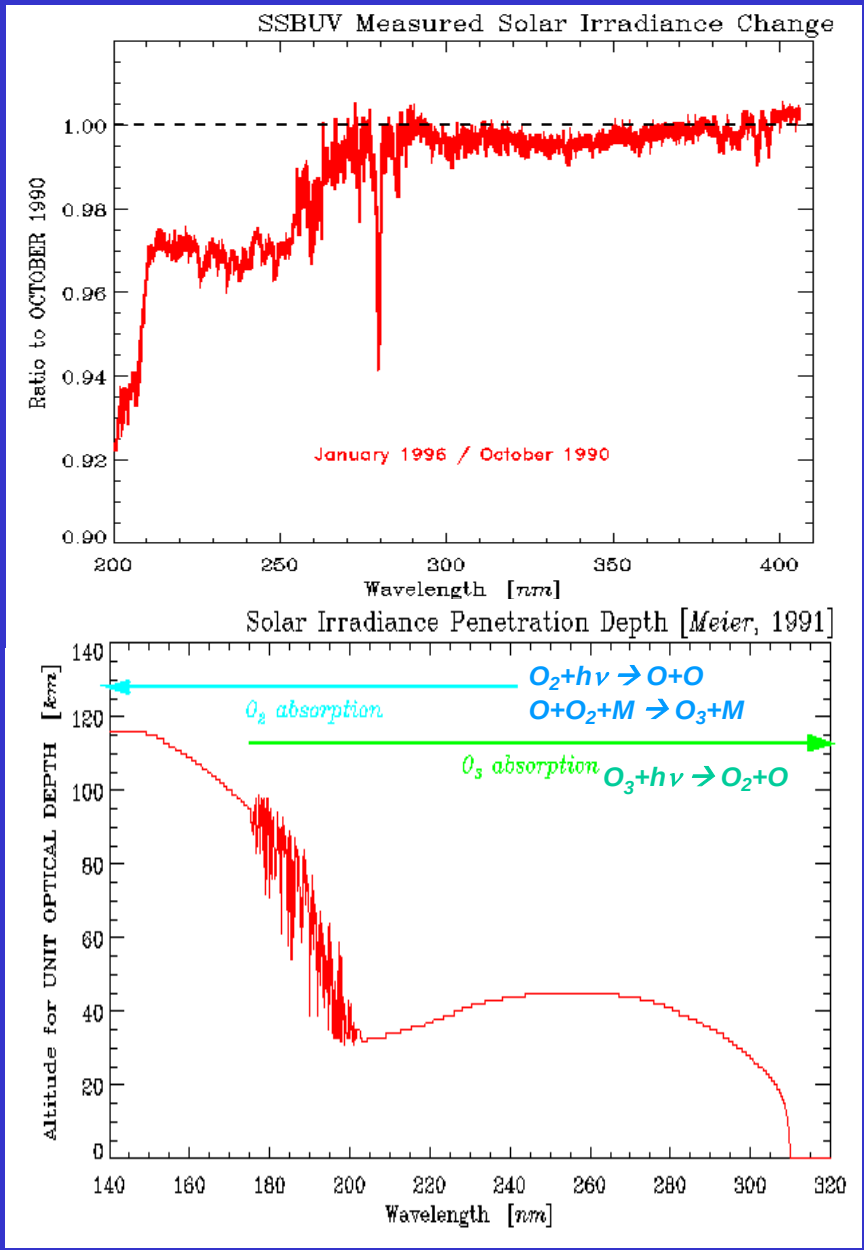


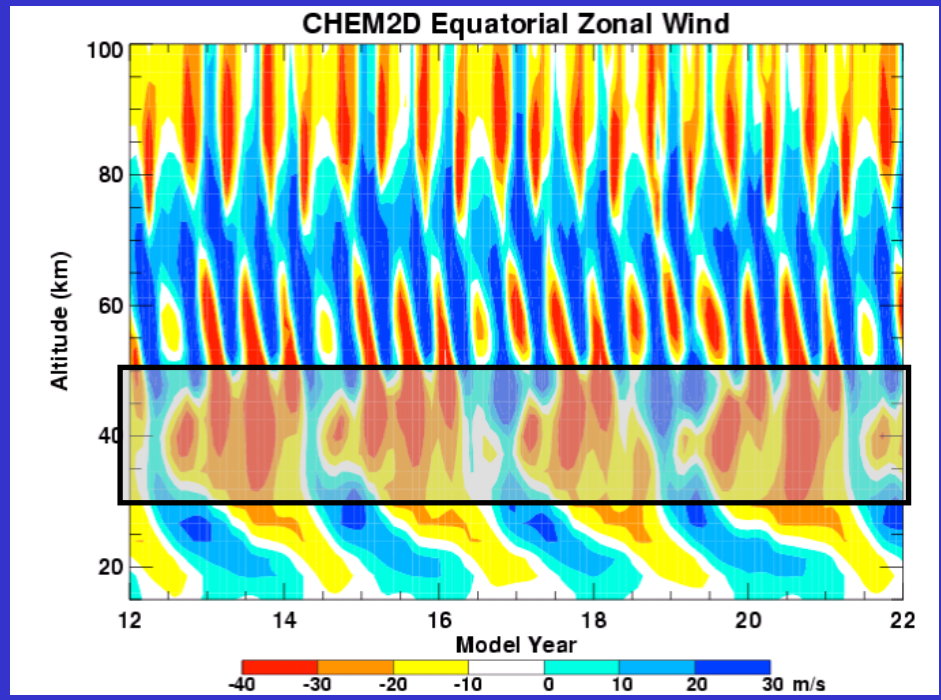
Fig 5 of Baldwin et al., Rev. Geophys., 2001.

- **Alternating easterly/westerly winds in equatorial stratosphere (20- 40 km); average period of 28 months**

- **QBO phase affects PW propagation (red arrows): Easterly phase → weaker westerlies at high latitudes in NH winter**

- **Influence of QBO on NH polar temperatures linked to 11-year solar cycle (e.g., *Labitzke and van Loon, 1988*).**



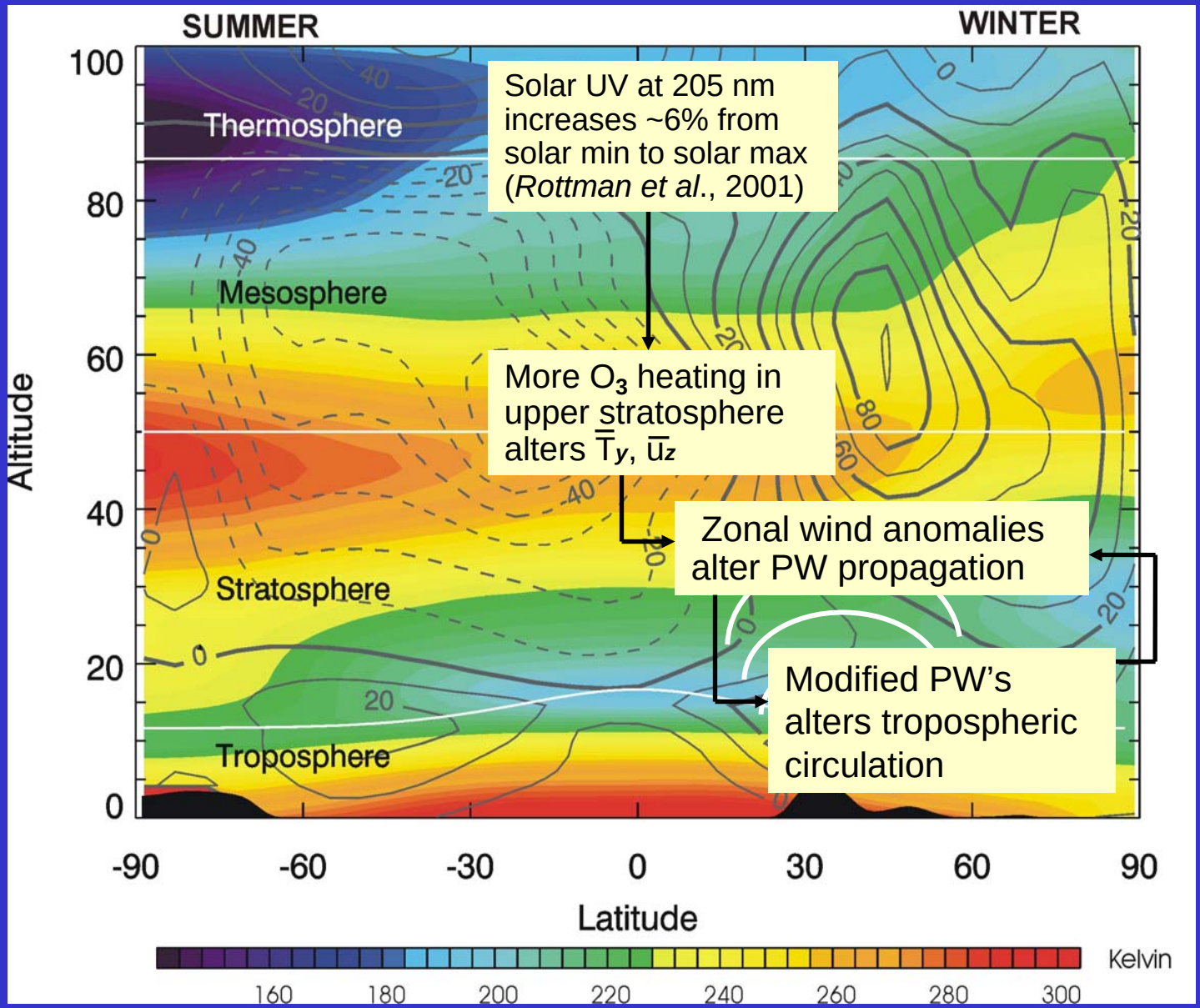


- Equatorial QBO and semi-annual oscillation (SAO) dominate where O_3 heating is greatest (35-50 km)
- *Gray* (2003): equatorial upper stratospheric winds also impact high latitude NH winter circulation

→ accurate representation of both SAO & QBO winds is needed!

http://ssbuv.gsfc.nasa.gov/solar.html

Solar-Climate Connection: A Working Theory



Key Questions

1. Do we understand the response of upper stratospheric O_3 and T to changes in solar UV over the 11-year cycle?
   - Compare observations with NRL CHEM2D model calculations

2. Can this response in O_3 & T produce a change in circulation capable of influencing global climate?
   - Use CHEM2D model with realistic solar UV changes & QBO to identify possible mechanisms
   - Then carry out more detailed 3D model simulations to fully test these mechanisms

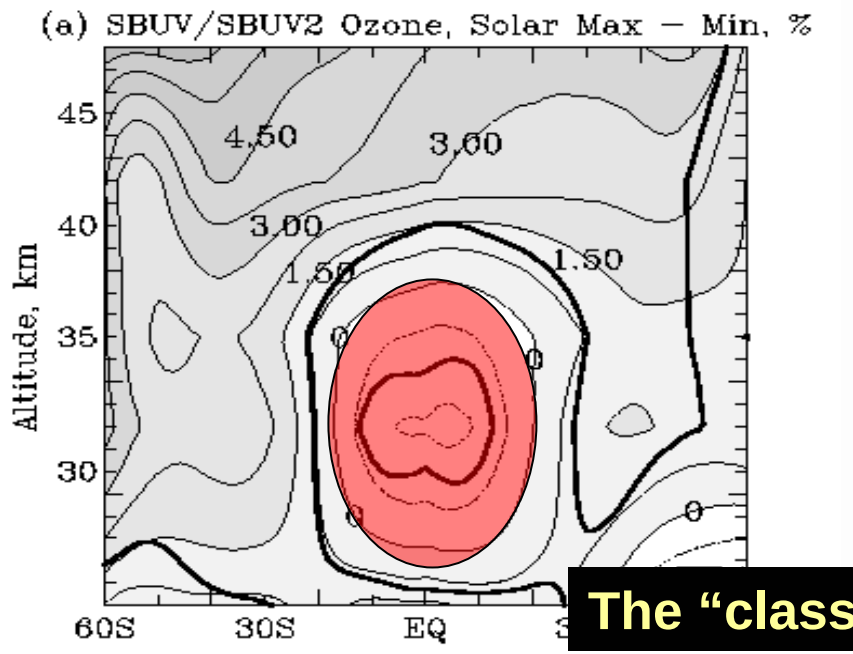
NRL-CHEM2D Model

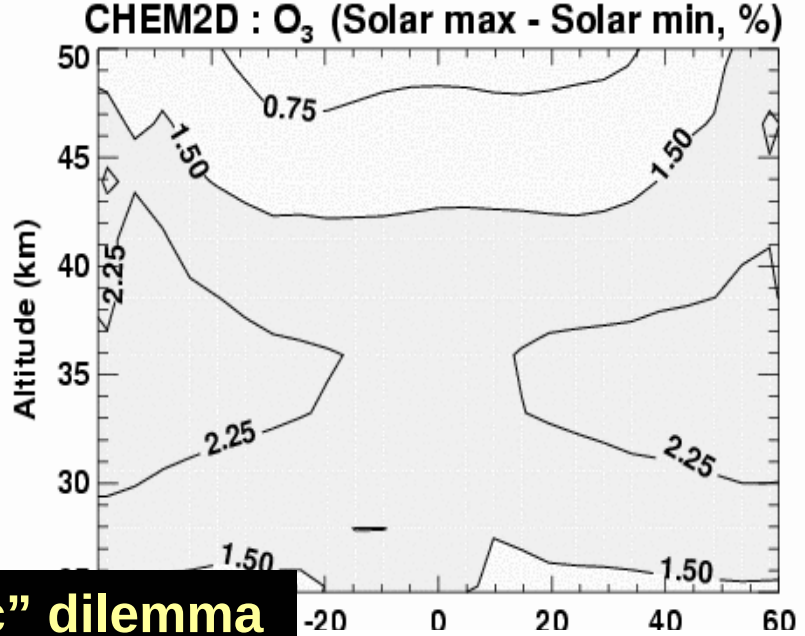
- Extends from pole to pole, 0 to ~120 km; 47 chemical species; 280 reactions; fully coupled photochemistry, radiative heating, and dynamics (*Siskind et al.*, 2003; *McCormack*, 2003)
- **Advantages**
  - Solar UV variations based on *Lean et al.* (1997)
  - GWD scheme produces realistic zonal wind SAO
  - Interactive zonal wind QBO scheme (*Holton and Lindzen*, 1972; *Gray et al.*, 1989)
- **Drawbacks:**
  - 2D model framework can't fully capture wave-mean flow interactions
  - fixed PW amplitudes for *wavenumber 1 only* imposed at model lower boundary.

Model/Data Comparisons

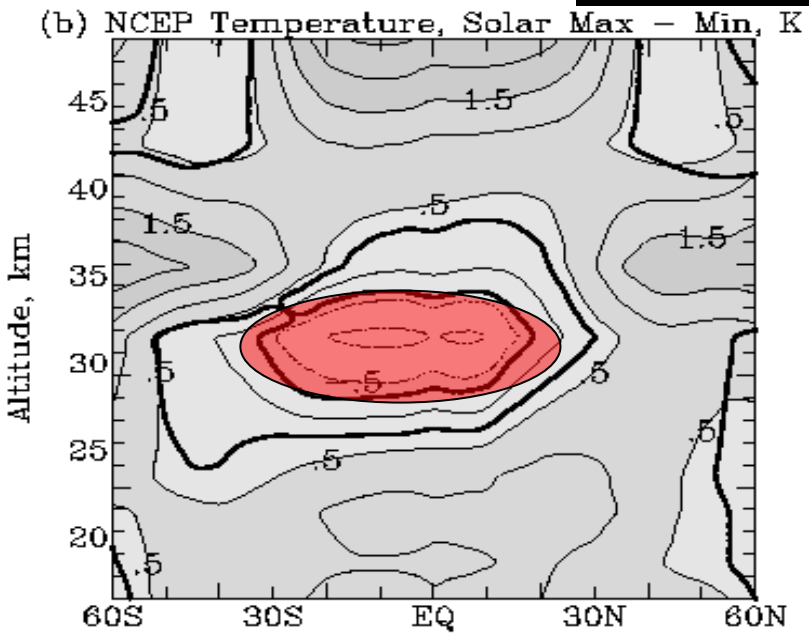
- **"classic" dilemma: observations of solar cycle in stratospheric O_3, T don't agree with modeled response.**

- **"new" dilemma: more recent observations of solar cycle in stratospheric O_3, T don't agree with earlier observational estimates.**

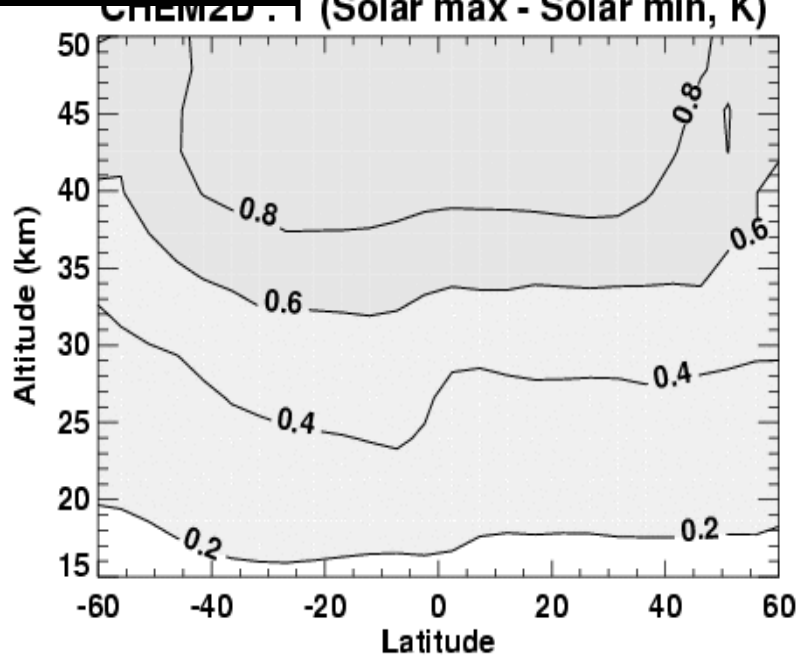




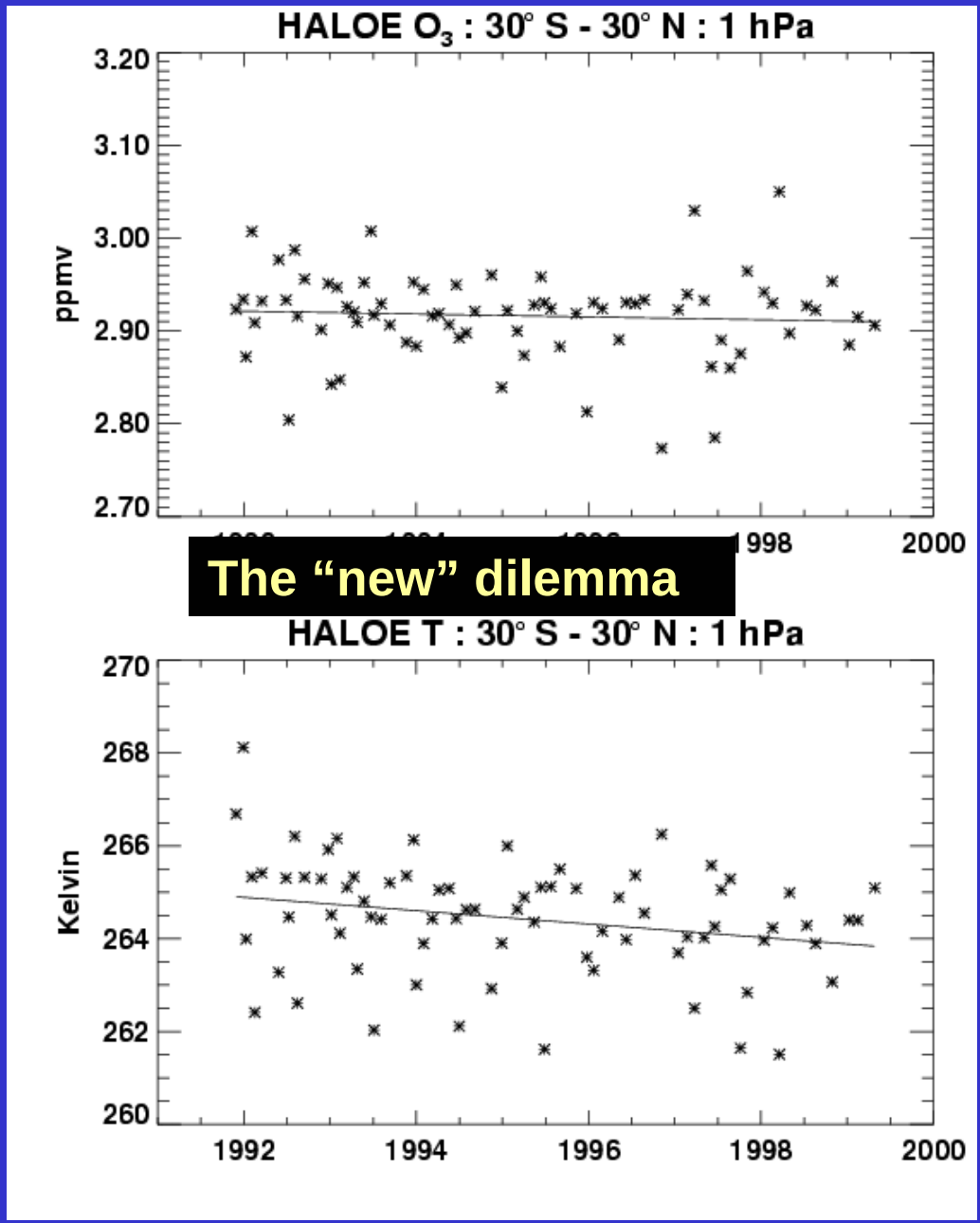
The "classic" dilemma



From Hood [2003]



- HALOE O_3 & T at 1 hPa in tropics shows no apparent 11-year variation from solar cycle 22 to solar cycle 23 (*Remsberg et al.*, 2002).
- Both SBUV/2 and SAGE I/II O_3 records indicate a 3 - 5% change in the tropical upper stratosphere over solar cycles 21-22.
- Estimates of solar cycle in upper stratospheric T vary from zero to ~1K (satellite, rocketsonde, lidar)

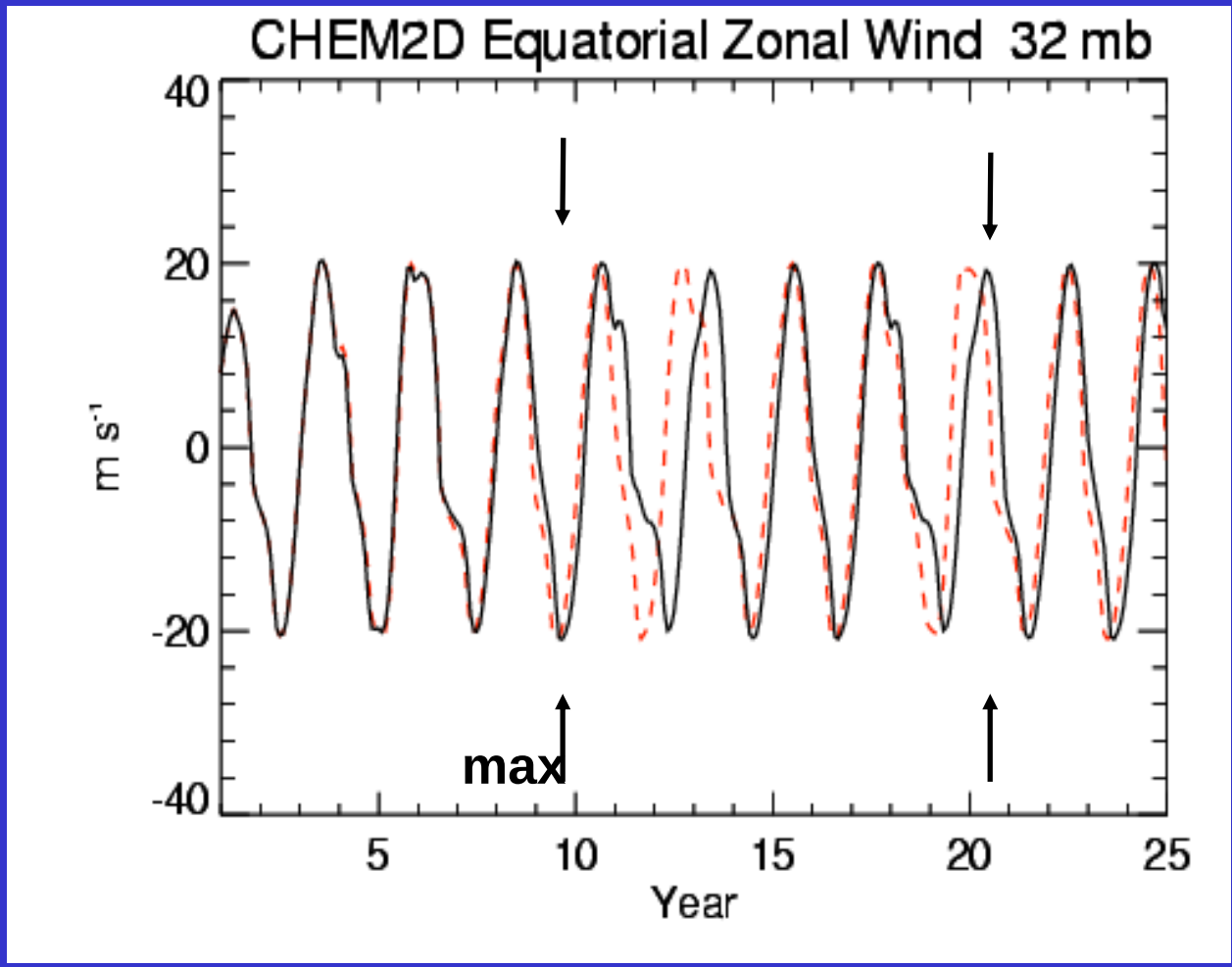


Key Question No. 2

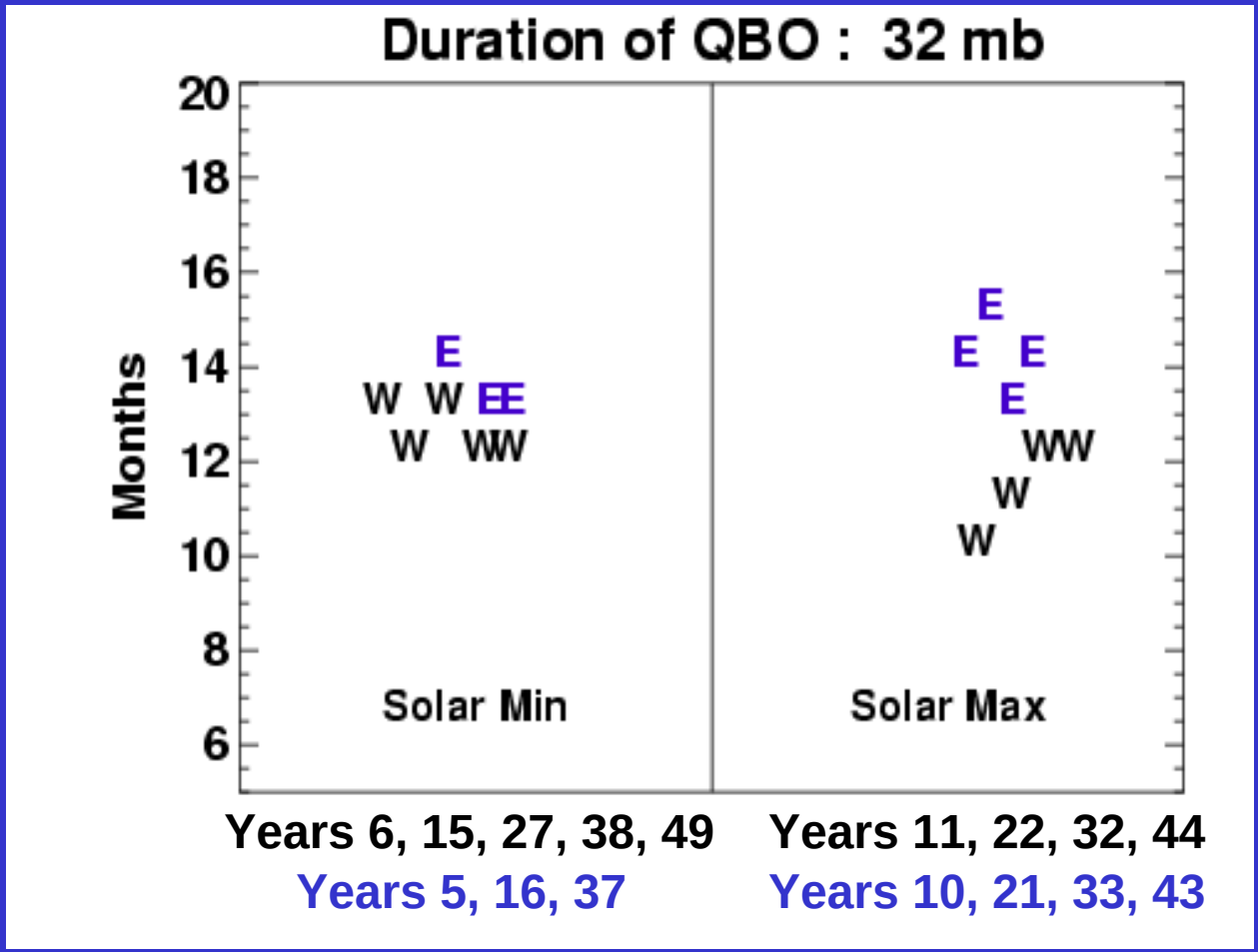
Can the observed 11-year cycle in solar UV produce large-scale circulation changes ?

- **shorter westerly QBO phase observed at solar max** (*Salby and Callaghan*, 2000)
- **stronger stratopause westerlies in winter near 35^{o} N at solar max** (*Kodera & Kuroda*, 2002)
- **solar cycle modifies QBO's influence on NH winter polar vortex** (*Labitzke and van Loon*, 1988)

$\rightarrow$ run 50-year CHEM2D model with observed solar UV changes, equatorial zonal wind QBO & SAO



When solar UV variations are included (red curve), westerly QBO phase tends to be shorter near solar maximum (arrows). This effect is only present when zonal wind SAO is also included.



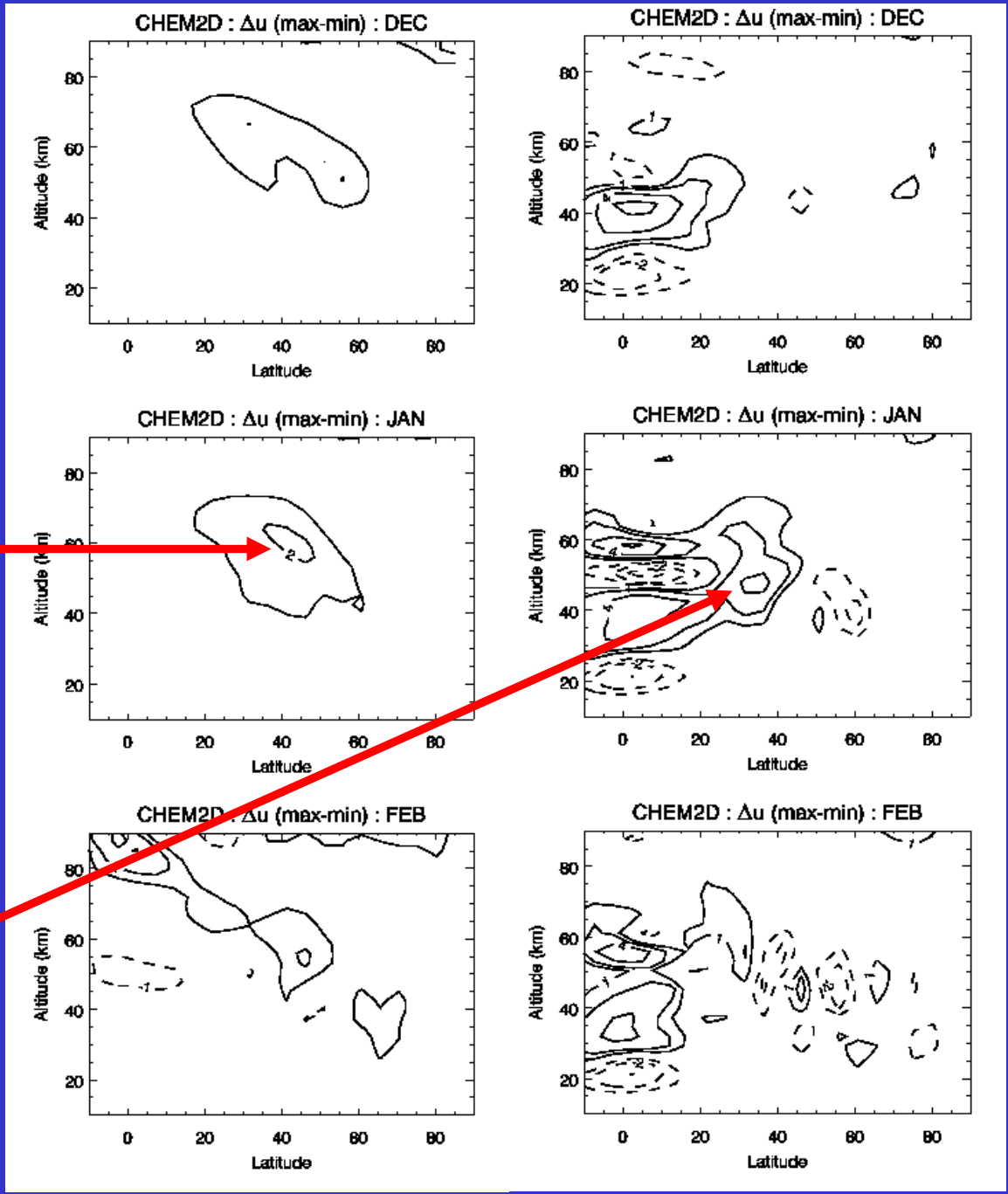
Duration of westerly (W) and easterly (E) phases of the QBO in CHEM2D equatorial zonal wind, sorted according to phase of solar cycle.

Effect is similar to, but smaller than, observed solar-cycle modulation of QBO (*Salby and Callaghan*, 2000).

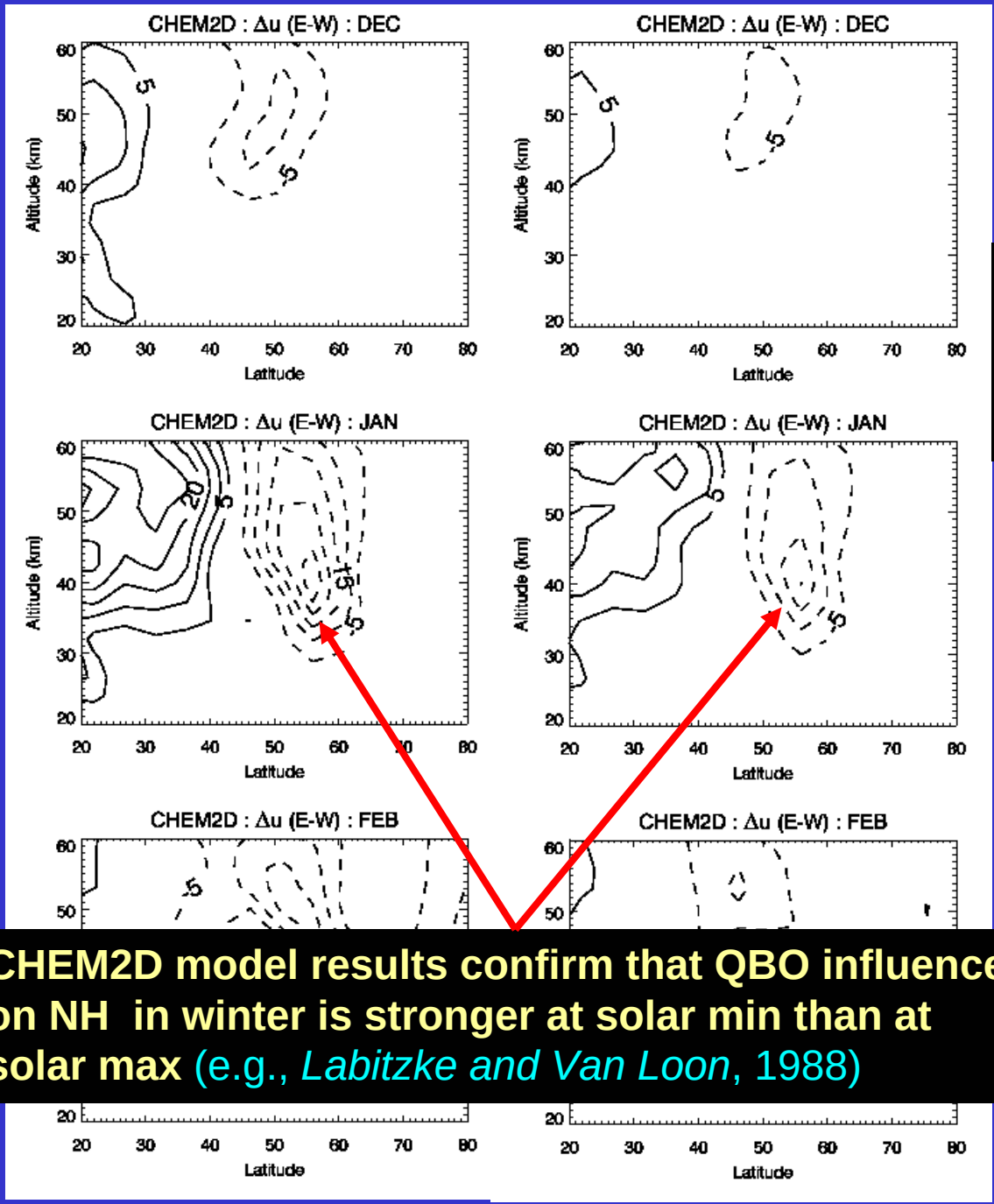
CHEM2D composite zonal wind anomalies (solar max – solar min) in NH winter.

With no QBO, location and timing of zonal wind anomalies are similar to observations (*Kodera & Kuroda*, 2002), but amplitude is MUCH less.

When QBO is included, anomalies increase by factor of 2.



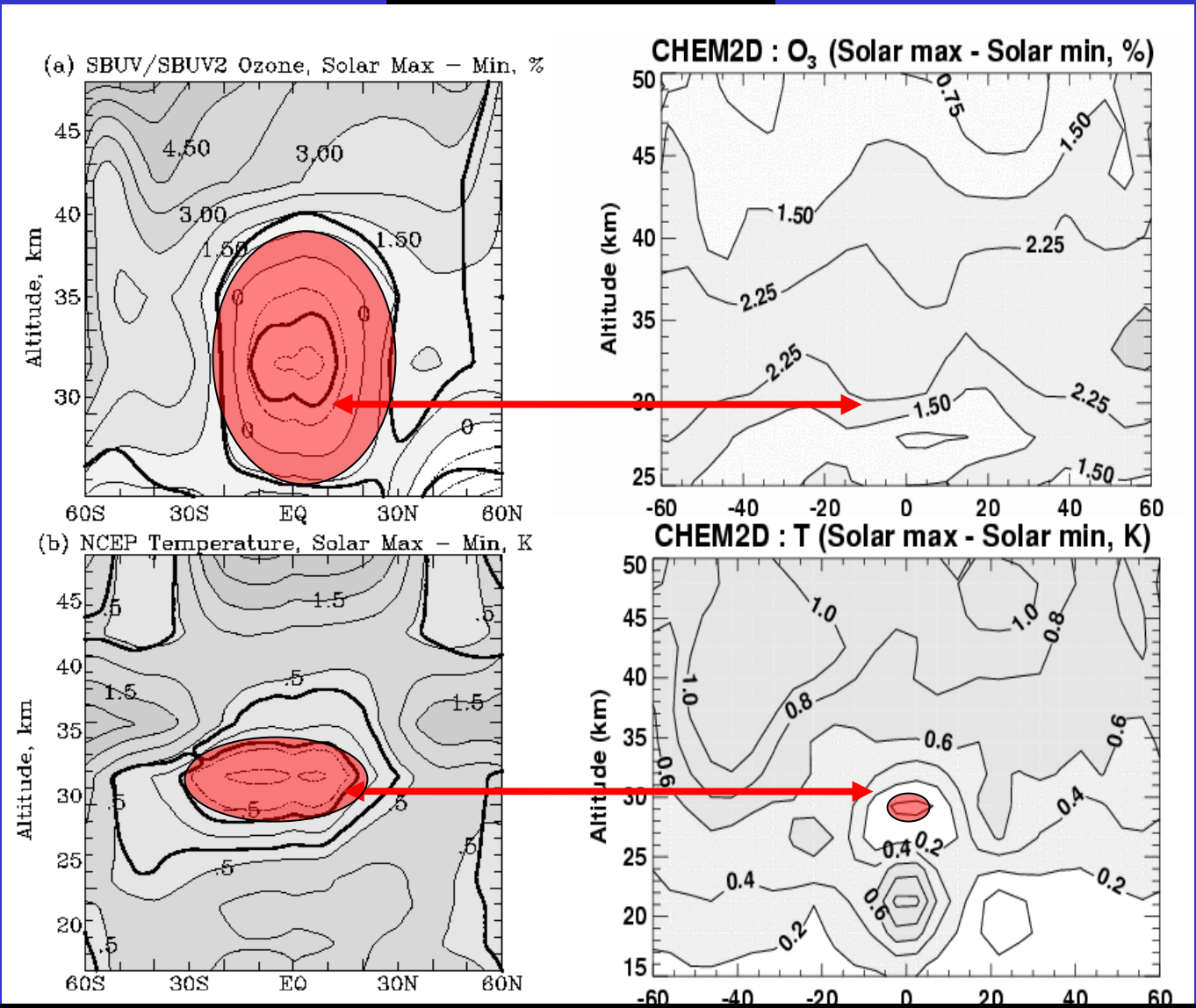
Zonal wind anomalies (East - West) at solar min



Zonal wind anomalies (East - West) at solar max

CHEM2D model results confirm that QBO influence on NH in winter is stronger at solar min than at solar max (e.g., *Labitzke and Van Loon*, 1988)

Solar + QBO



Including QBO/SAO in CHEM2D model produces better agreement with previously observed 11-year variations in stratospheric O_3, T

Key Question No. 1

- **Do we understand the response of stratospheric O_3 and T to changes in solar UV over the 11-year cycle?**
  - **Yes and No.**
  - **Observed decadal variability in stratospheric O_3, T might be explained by solar/QBO interaction** (see also *Lee and Smith*, 2003)
  - **There is significant disagreement in estimates of solar variability among different O_3 & T records**
  - **Is the atmospheric response to solar cycle the same from one cycle to the next? Recent HALOE obs. suggest not. ?**

Key Question No. 2

- **Can the observed 11-year cycle in solar UV produce large-scale circulation changes?**
  - **Yes. Initial O_3 heating perturbation modulates phase of zonal wind QBO, alters strength of winter westerlies at higher latitudes**
  - **2-D model results show effects that are consistent with observations but smaller**
  - **3-D models are needed to fully capture possible wave-mean flow feedback mechanism in NH winter and asses its impact on climate**

THE END

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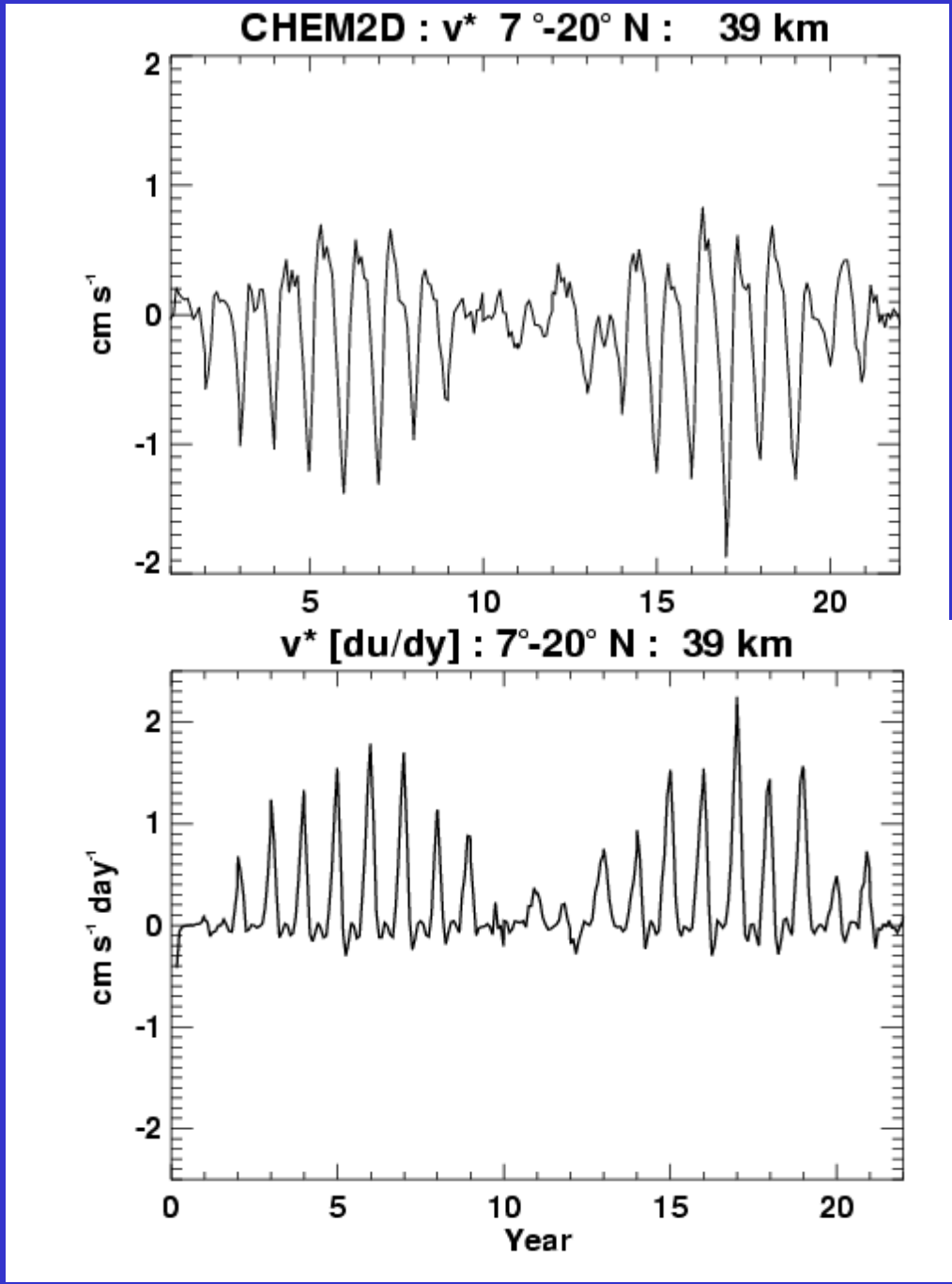
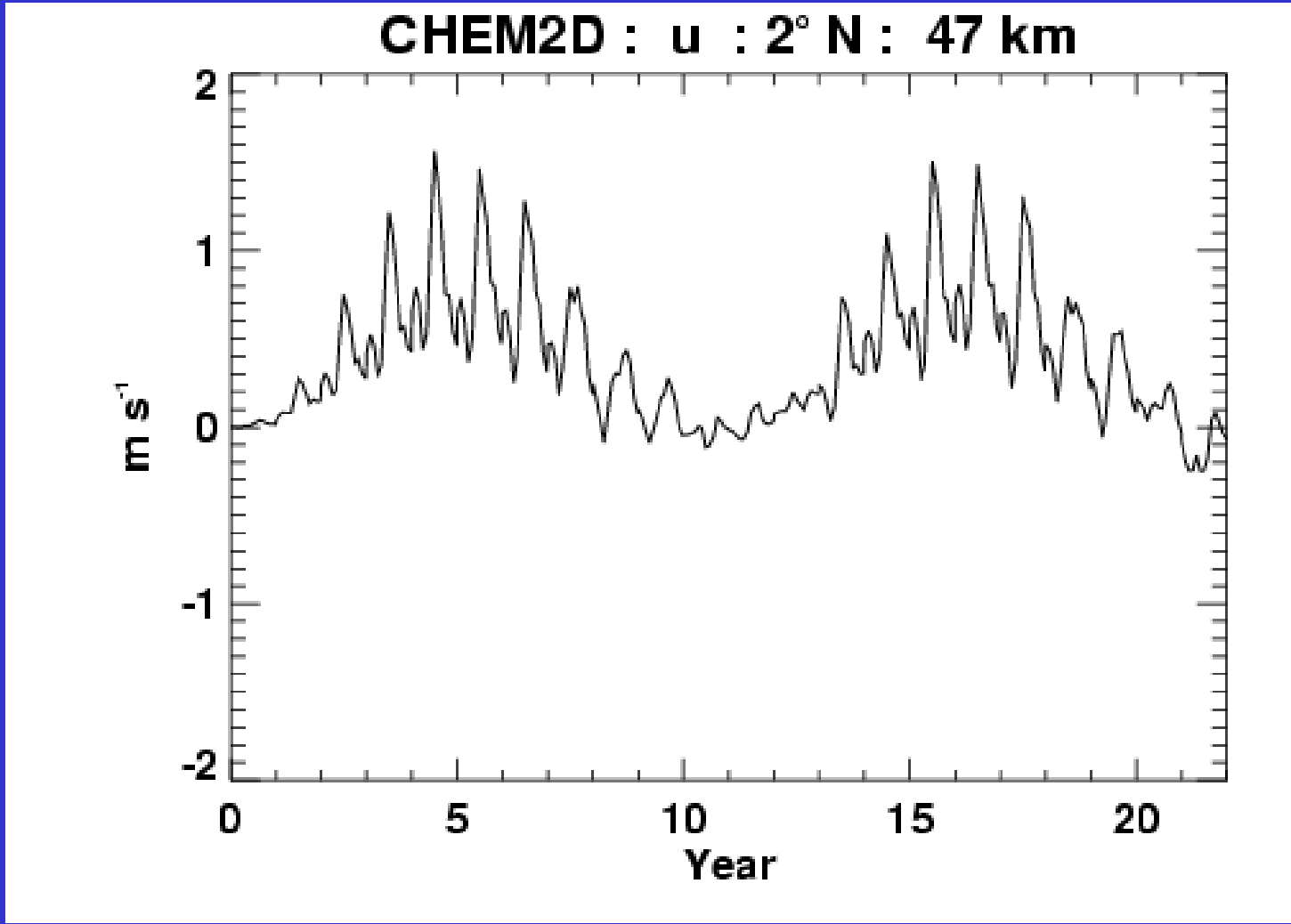
Dynamical response to solar UV changes, no QBO present

Negative v* *anomaly* at solar minimum, especially during NH winter…

…producing anomalous horizontal momentum advection throughout tropical upper stratosphere





Imposed solar cycle variation induces decadal modulation in strength of westerly zonal wind SAO

Solar Cycle Temperature Changes at Stratopause

Source	Period	ΔT	Remarks
Rocketsonde *Dunkerton et al.* [1998]	1962-1991	~1.1 K*	8^{o} S-37^{o} N lat., *30-60 km
Rocketsonde *Keckhut* [2003]	1969-1991	~1 K	~2 K at 40 km
NCEP/CPC *Hood* [2003]	1979-1997	1.5 - 2 K	inter-calibration errors (?)
UKMO TOVS *Scaife et al.* [2000]	1979-1997	~0.3 K	adjusted SSU radiances
UARS HALOE *Remsberg et al.* [2002]	1991-2001	0 - 0.4 K	only detected at 20^{o} N