

Evaluation of An Internally Generated Quasi-Biennial Oscillation in WACCM

Han-Li Liu

High Altitude Observatory

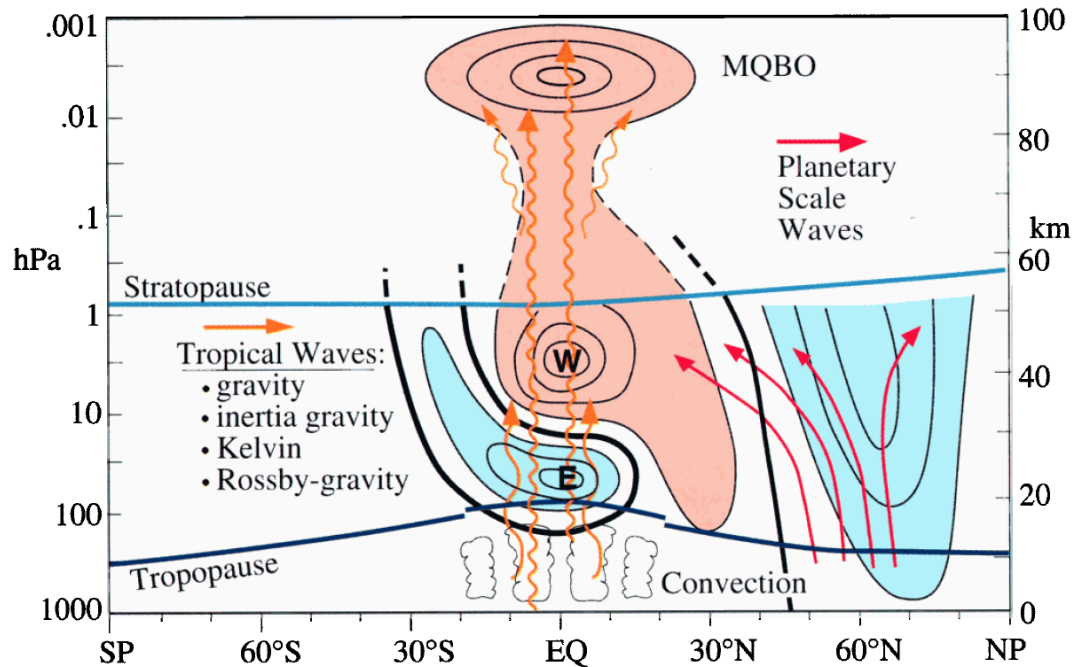
National Center for Atmospheric Research

Acknowledgement: Xianghui Xue (Univ. of Science and Technology of China), Mike Mills (Atmospheric Chemistry Division, NCAR)

Overview

- Absence of QBO in WACCM and possible causes.
- Development of an inertio-gravity wave (IGW) parameterization scheme.
- Evaluation of WACCM simulations with the IGW.
 - Zonal mean wind and forcing at the equator.
 - Extratropical effects and surface signatures.
- Processes that may affect QBO
 - Wave spectrum and duration of each phase.
 - Effects from coupling with ocean?

Possible Driving Forces of QBO



Baldwin et al, 2001

- $F(\text{GW/IGW})$ likely much larger than $F(\text{PW})$
- PW (Kelvin waves, Rossby-gravity waves) resolved by WACCM (albeit weak).
- Mesoscale GW parameterized, breaking mainly in mesosphere.
- **IGW poorly resolved, and not parameterized.**

Requirement for QBO Forcing

- QBO Acceleration rate:

- 50m/s/14months $\sim 10^{-6} \text{m/s}^2$

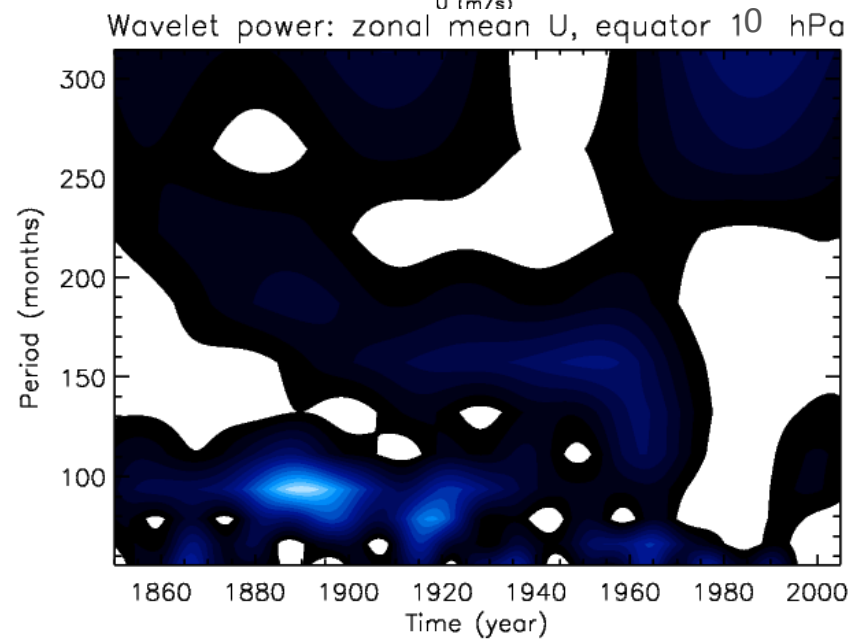
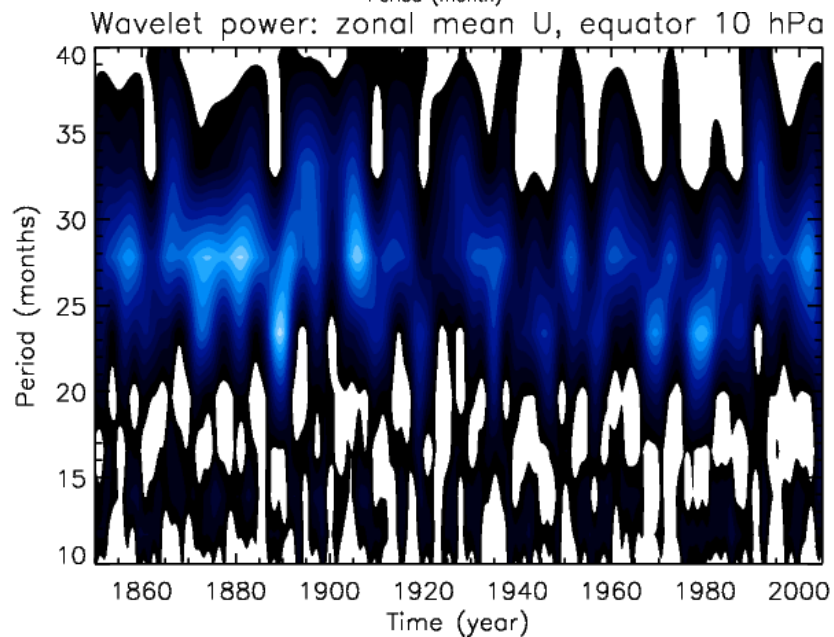
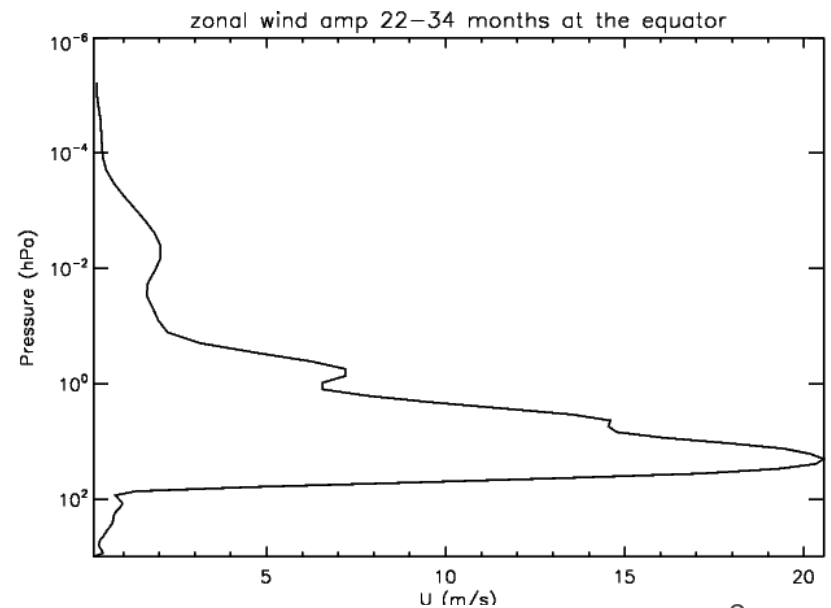
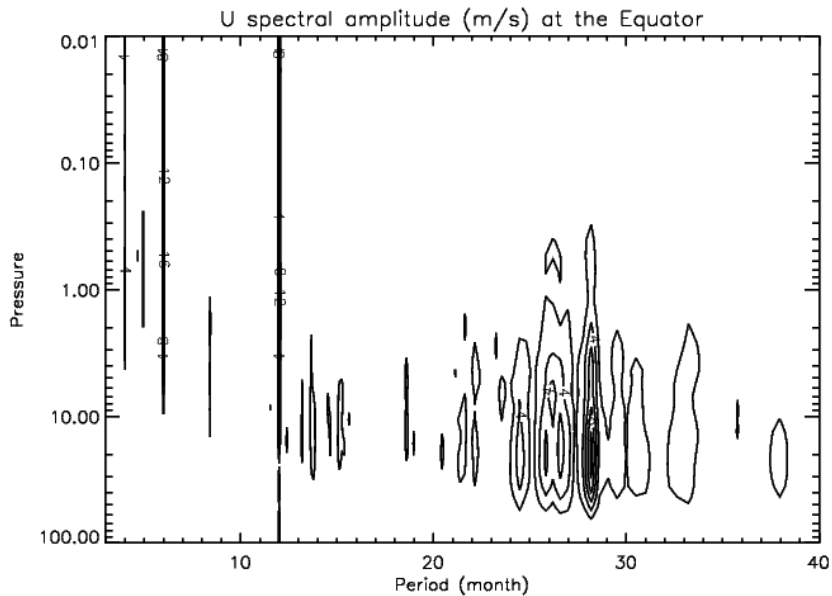
- $Q \frac{\partial u}{\partial t} = -\frac{1}{\rho} \frac{\partial \tau}{\partial z} \approx -\frac{1}{\rho} \frac{\Delta \tau}{\Delta z}$

- $\rho_{\text{strat}} \sim 0.1 \text{kg/m}^3, \Delta z \sim 10 \text{km}$

- $\rho_{\text{strat}} \Delta \tau \sim 10^{-3} \text{Pa}$

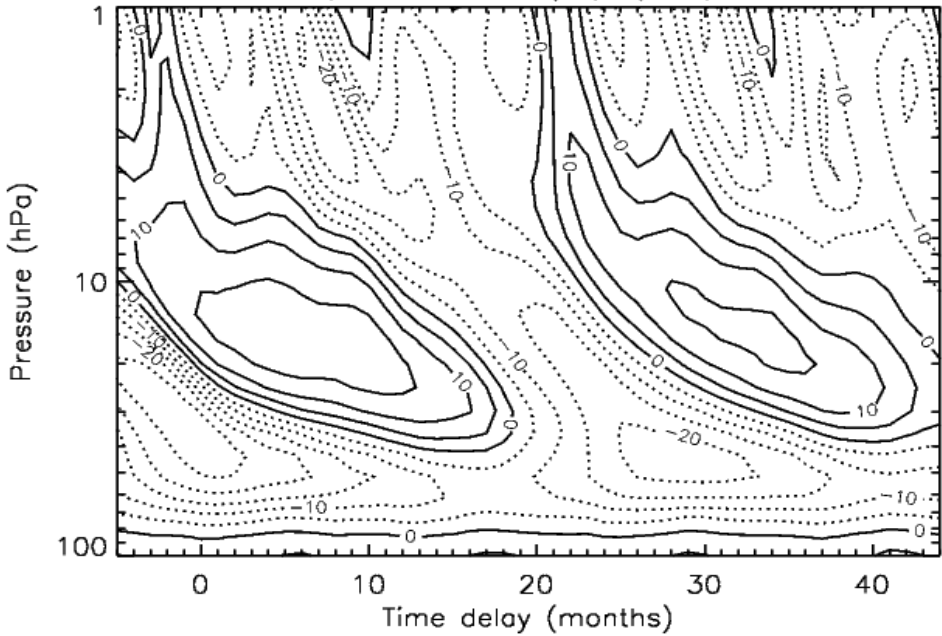
- For GW with such momentum flux to break in the stratosphere, the horizontal wavelength is $\sim 1000 \text{ km}$ according to linear saturation theory.
- IGW parameterization developed and implemented in WACCM (Xue et al., in press).

Zonal Wind Spectrum: Equator

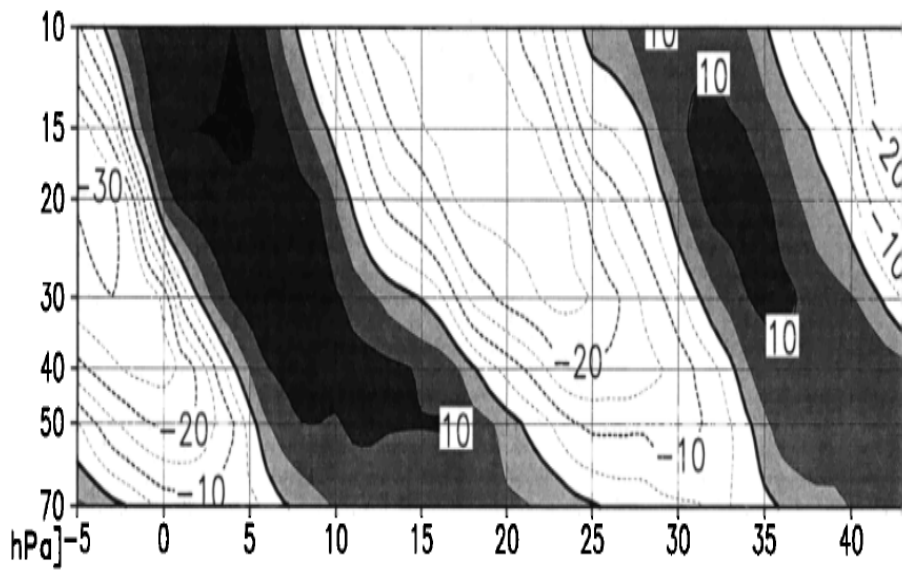


Composite Zonal Mean U: Equator

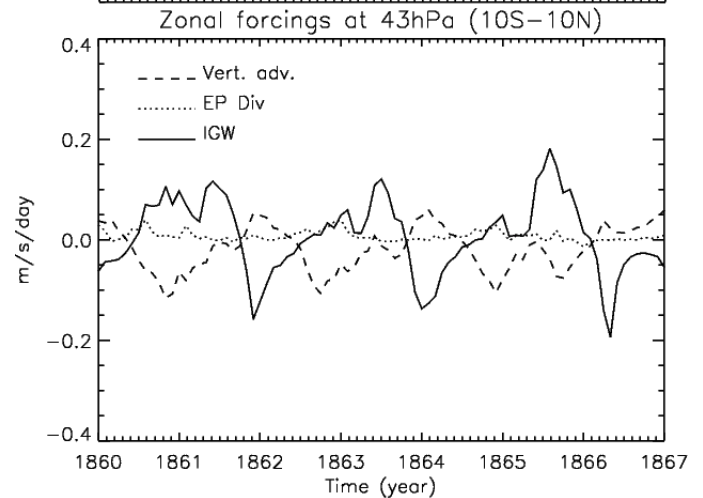
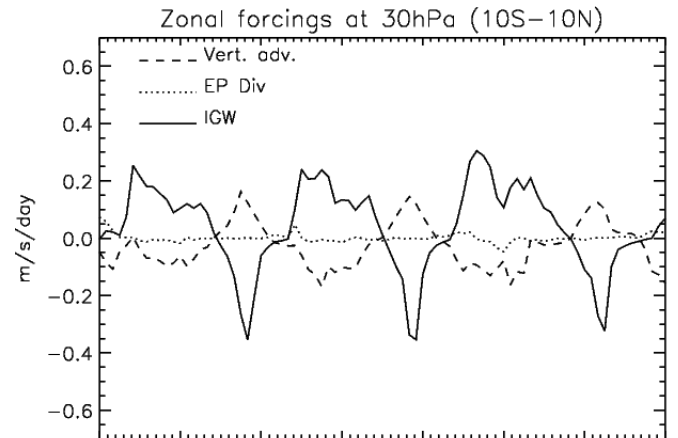
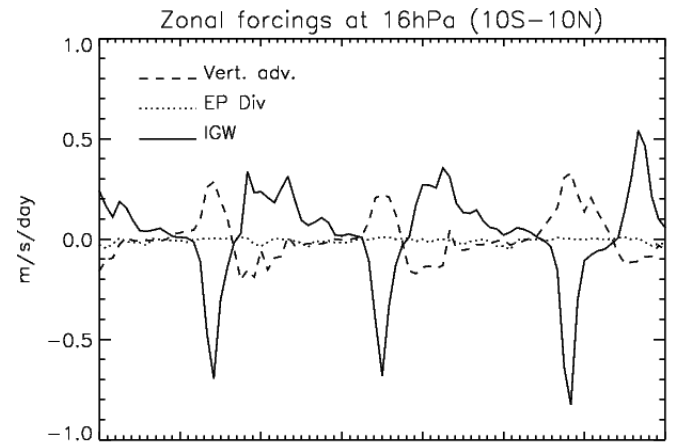
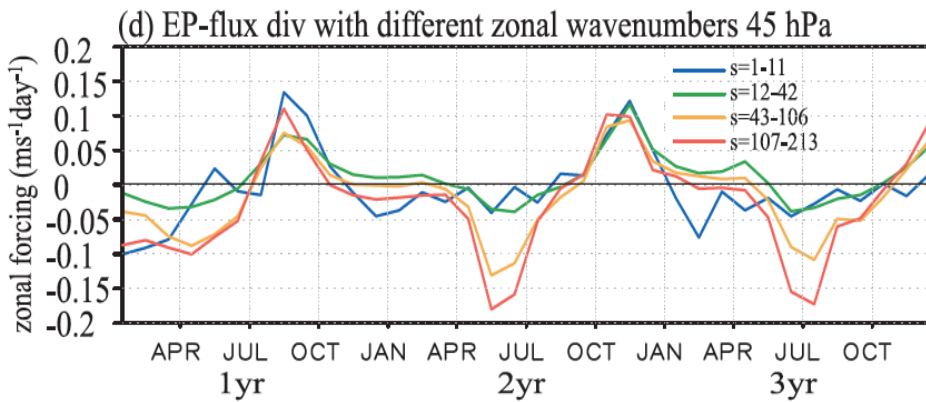
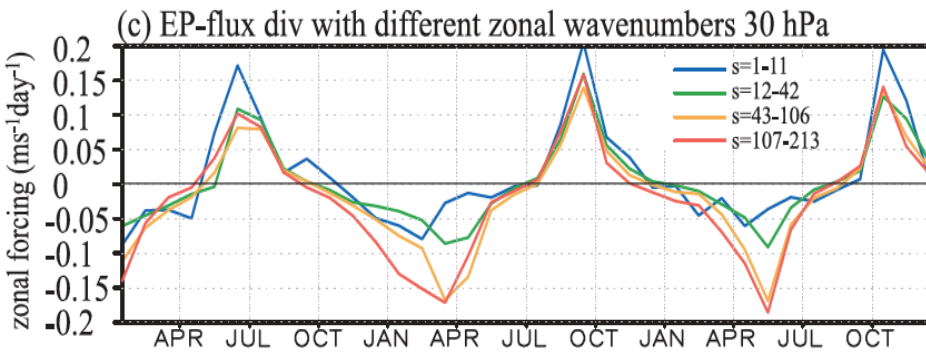
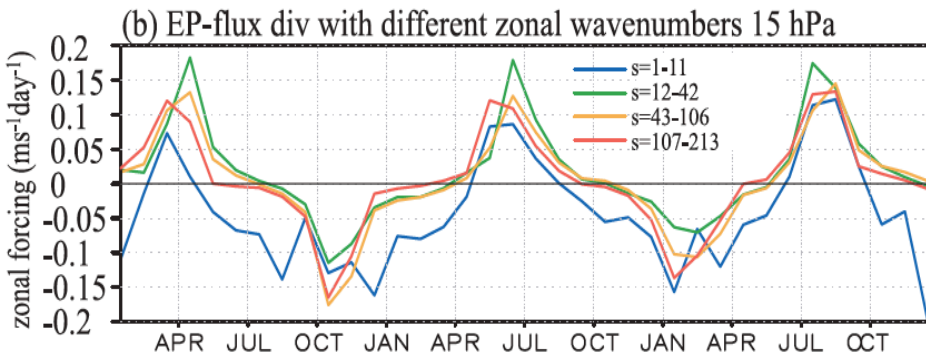
composite ubar (m/s) equator



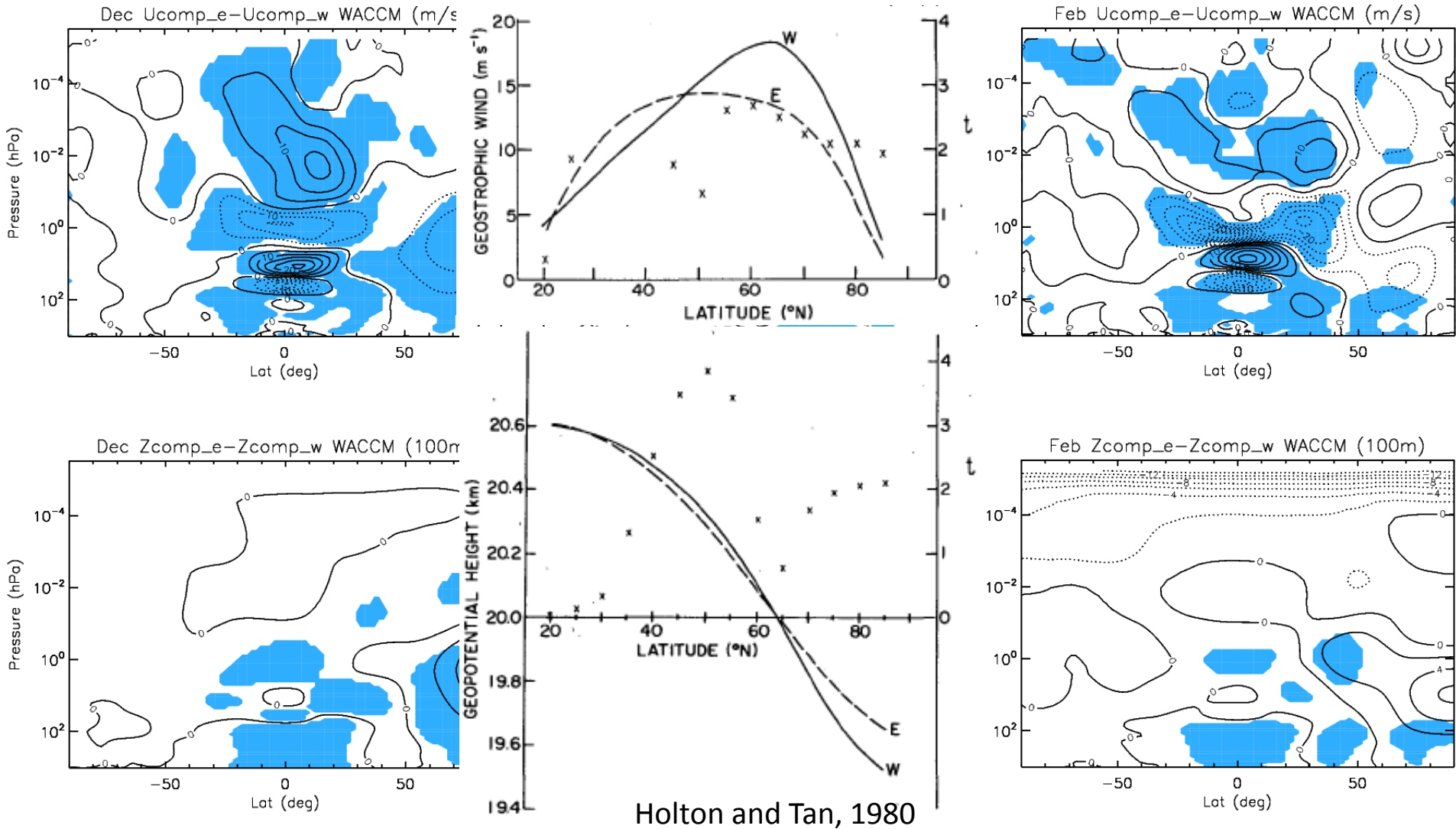
- 10 hPa: Westerly phase 18 mon. in WACCM, compared with 10 mon. in reanalysis.
- Westerly phase becomes shorter at lower altitude, opposite to the reanalysis.
- Westerly phase stops at ~ 40 hPa.



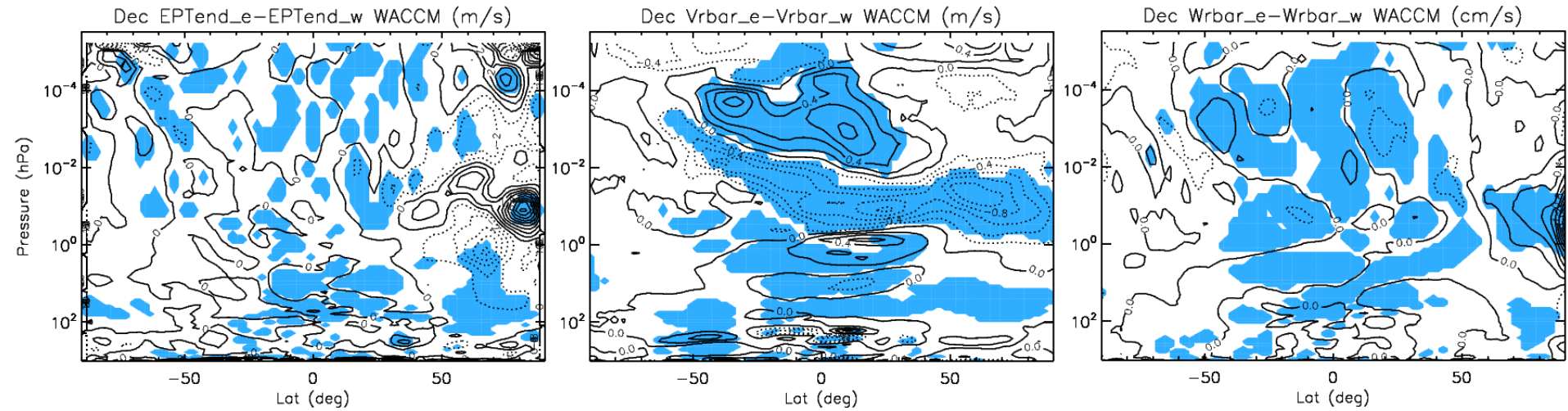
QBO Forcing



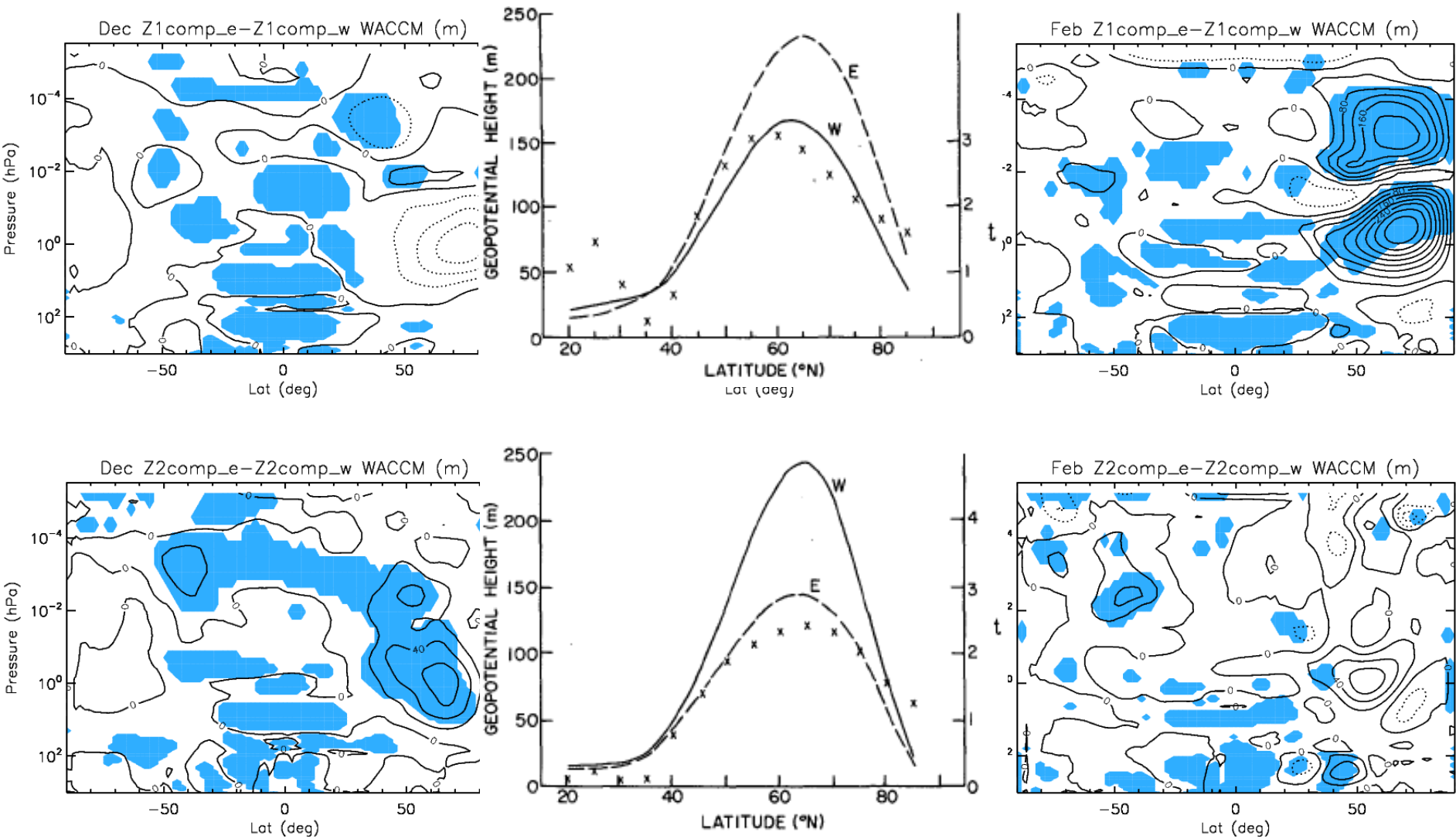
DJF Composite Diffs: E-W



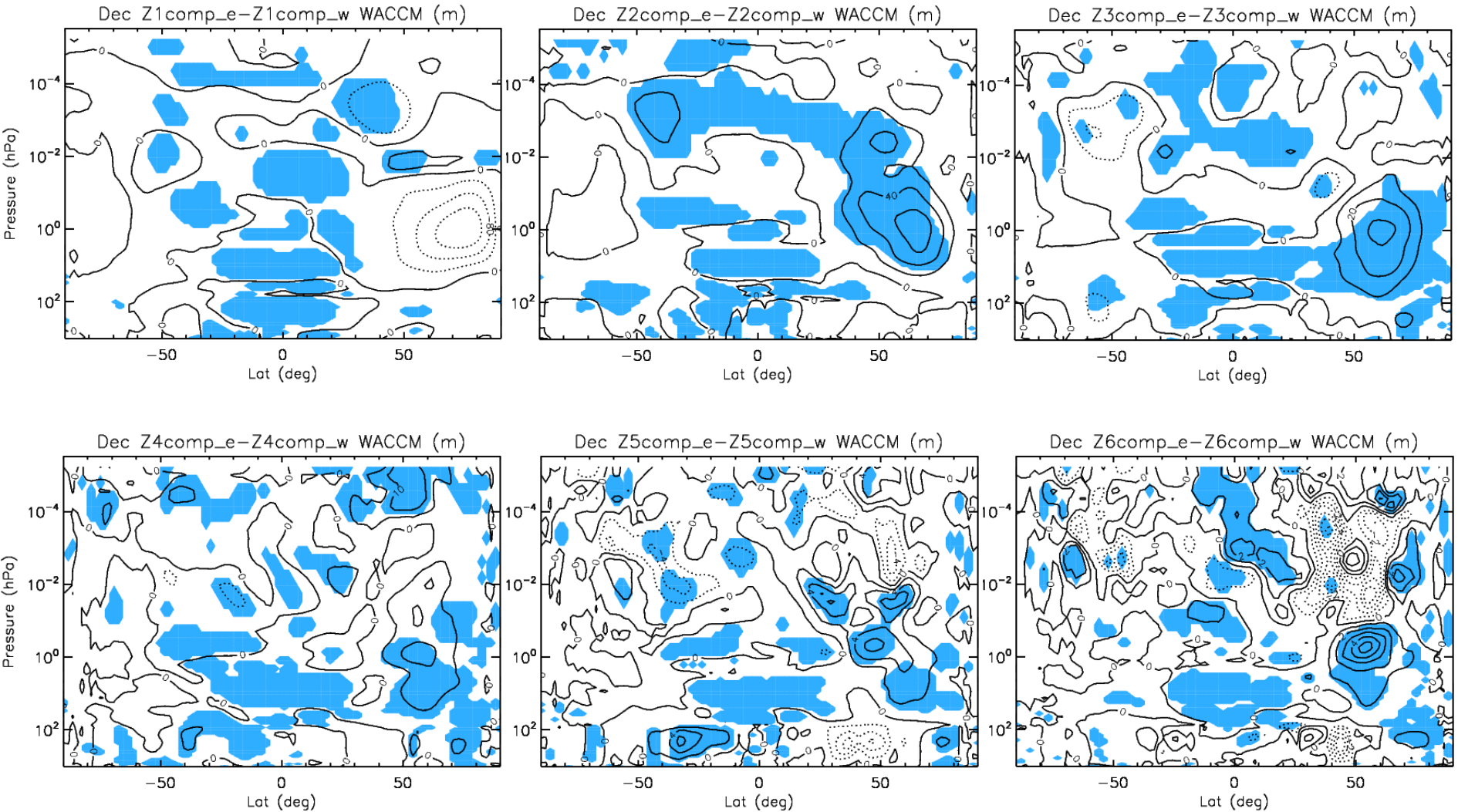
Forcing by PWs and Residual Circulation



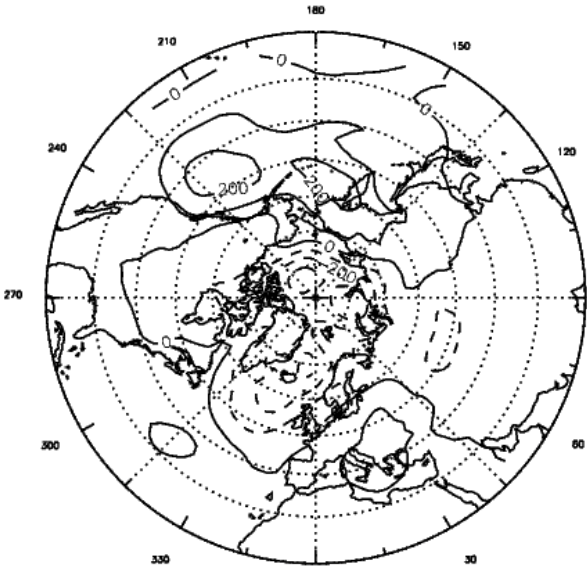
Planetary waves (1-2): E-W



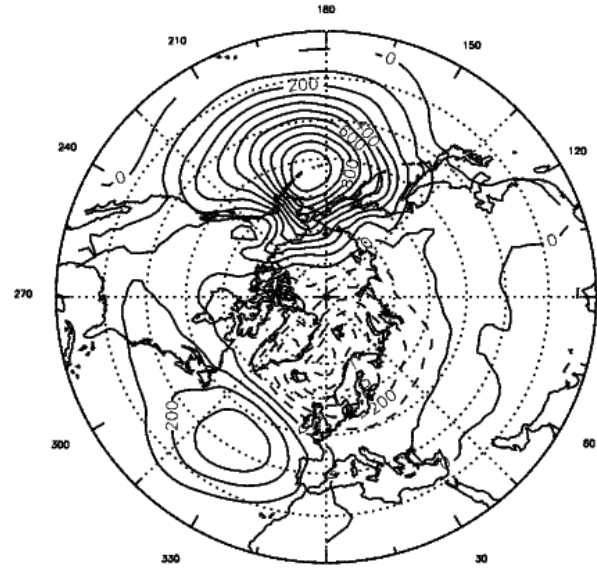
Dec Wavenumber 1-6



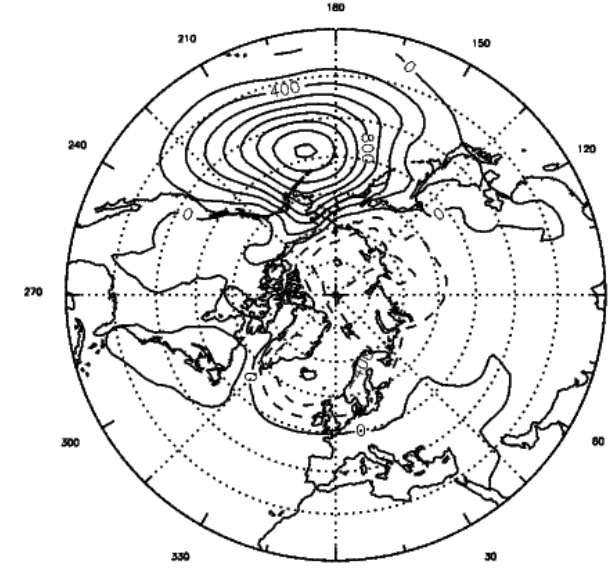
Surface Pressure: W-E



Longitude
Dec PScomp_w-PScomp_e (Pa)



Longitude
Jan PScomp_w-PScomp_e (Pa)



Longitude
Feb PScomp_w-PScomp_e (Pa)



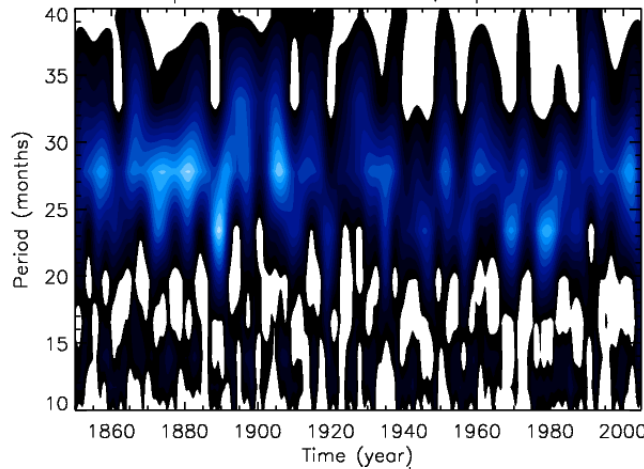
Longitude

WACCM Experiments

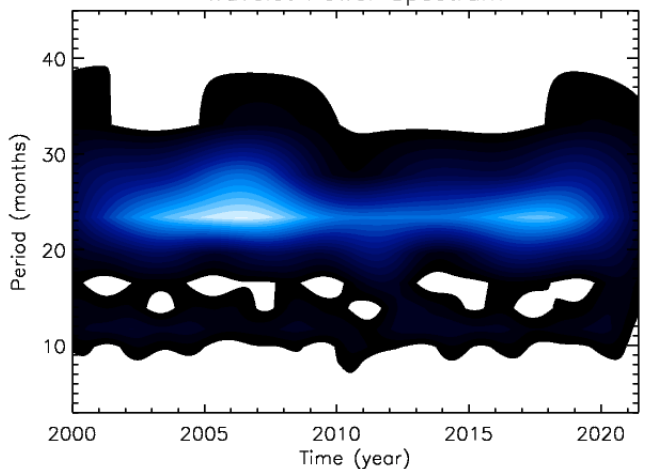
- WACCM with coupled ocean:
 - Transient run: Anisotropic IGW spectrum (shifted westward by 5m/s).
 - Transient run: Isotropic IGW spectrum.
 - Perpetual run (1850): Anisotropic IGW spectrum.
- WACCM with specified SST:
 - Transient run: Anisotropic IGW spectrum (1955-1976).
 - Perpetual run (1850): Anisotropic IGW spectrum. (21 years)
 - Perpetual run (2000): Anisotropic IGW spectrum. (21 years)

Wavelet power: zonal mean U, equator 10 hPa

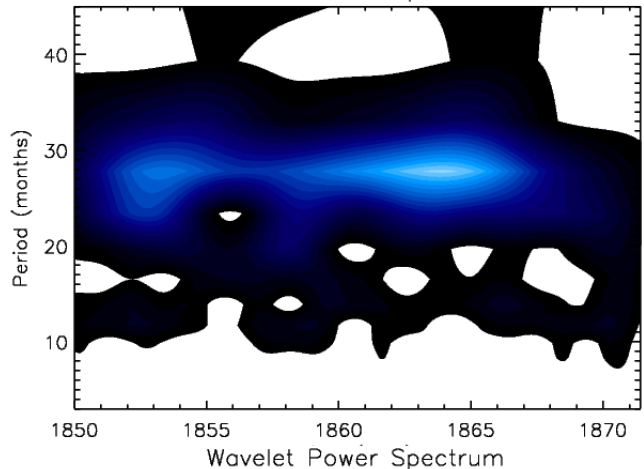
B1850-2005



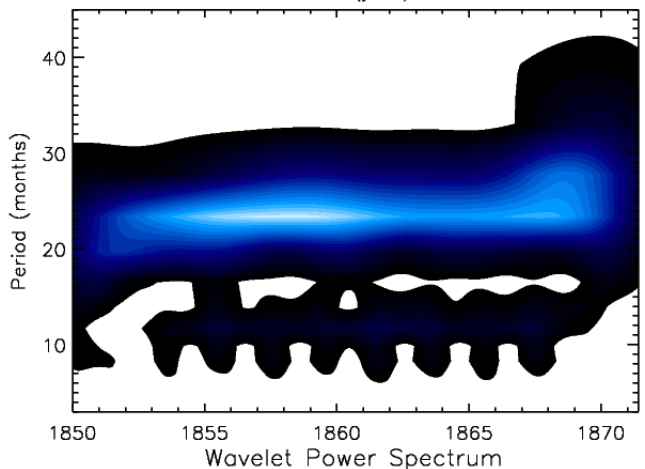
F2000



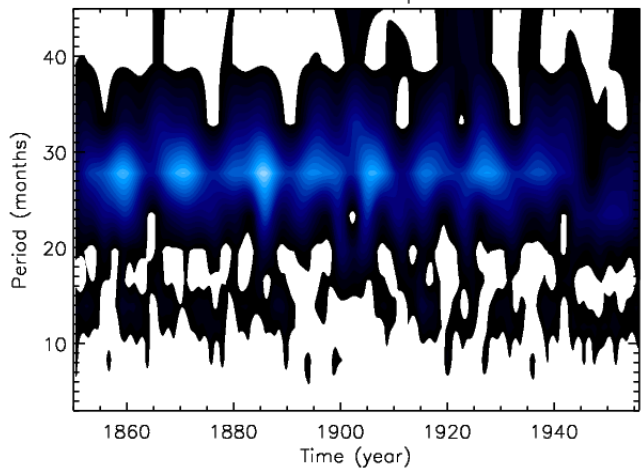
B1850



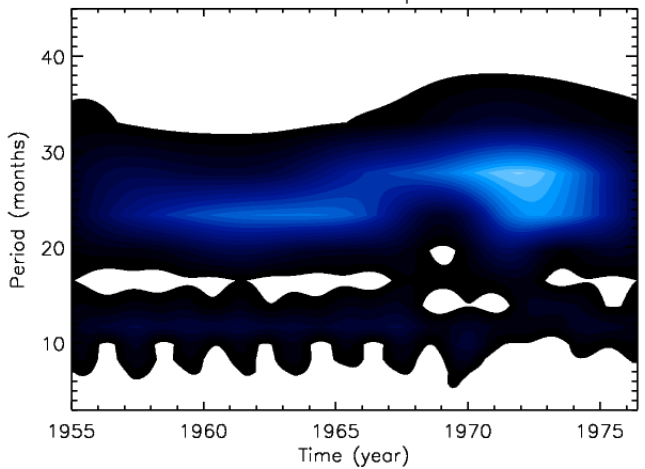
F1850



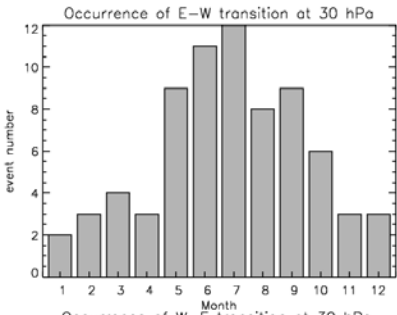
B1850-1955
"isotropic spectrum"



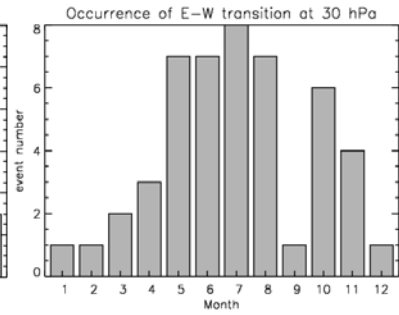
F1955-1976



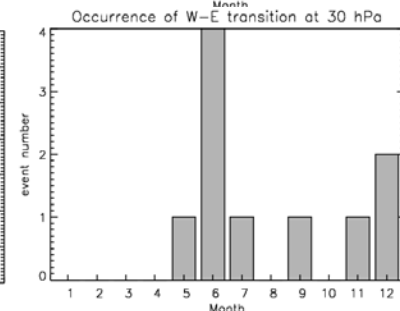
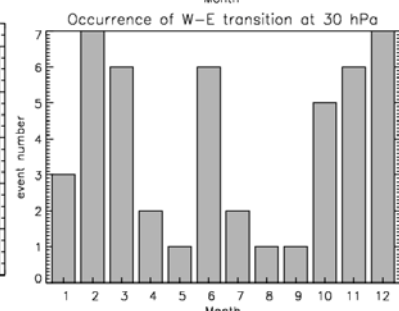
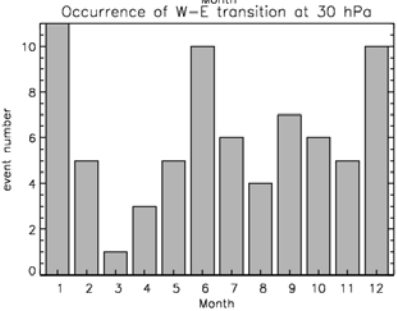
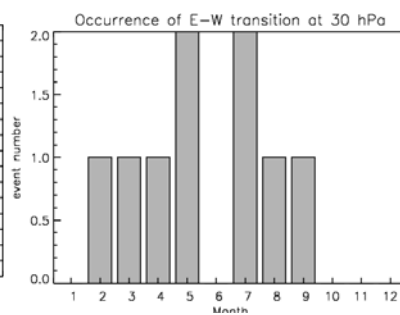
B1850-2005



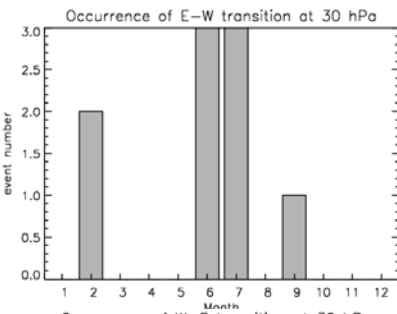
B1850-1955



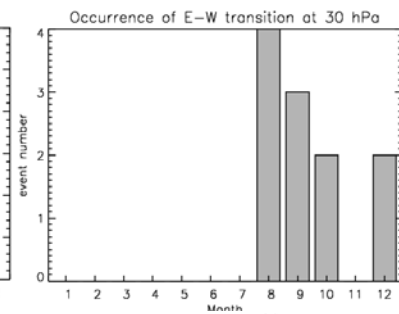
B1850



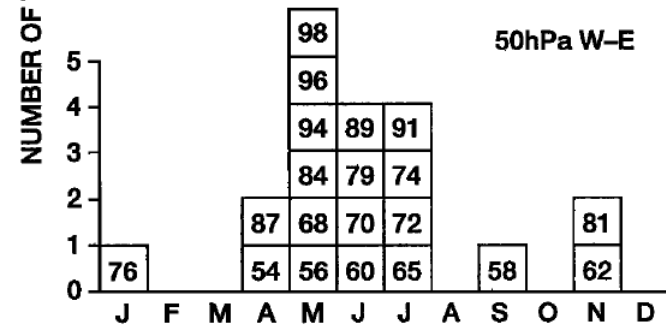
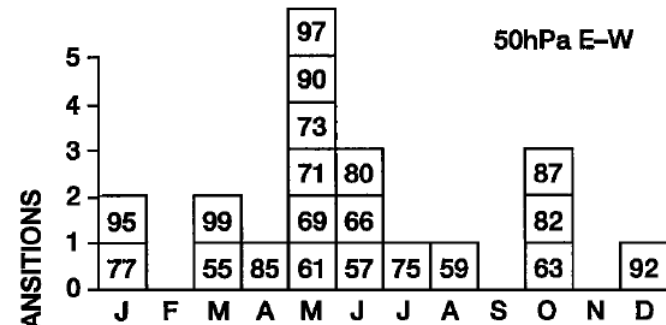
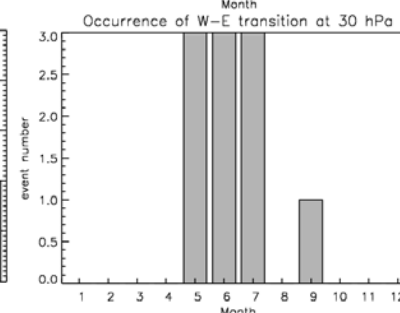
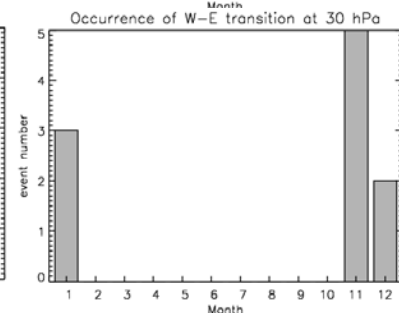
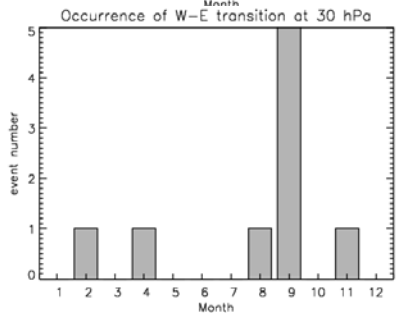
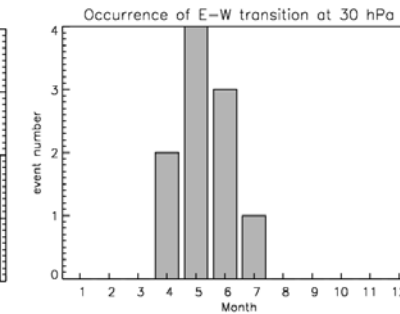
F1955-1976



F1850



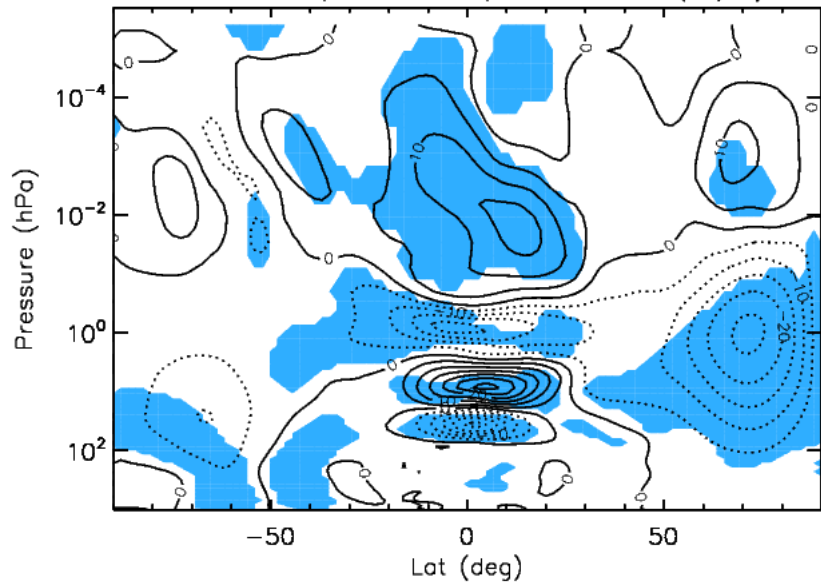
F2000



Pawson et al, 1993

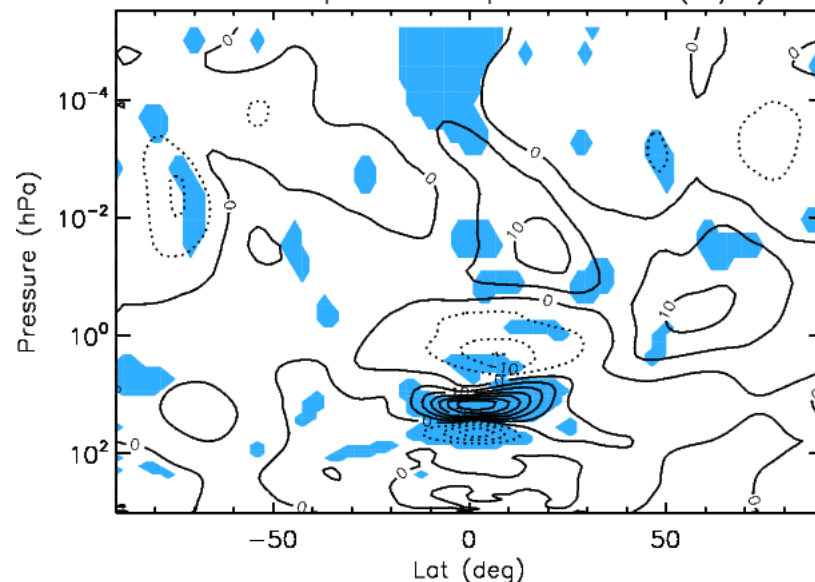
B1850

Dec Ucomp_e-Ucomp_w WACCM (m/s)



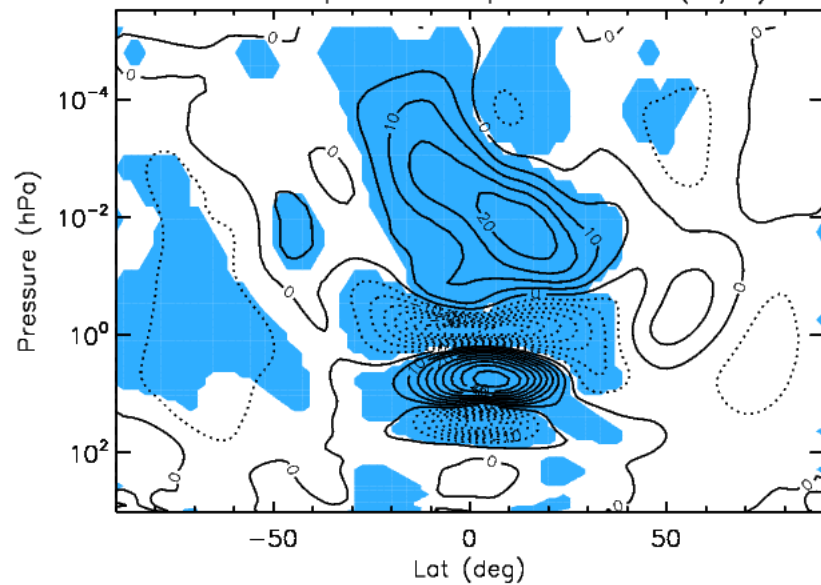
F1850

Dec Ucomp_e-Ucomp_w WACCM (m/s)



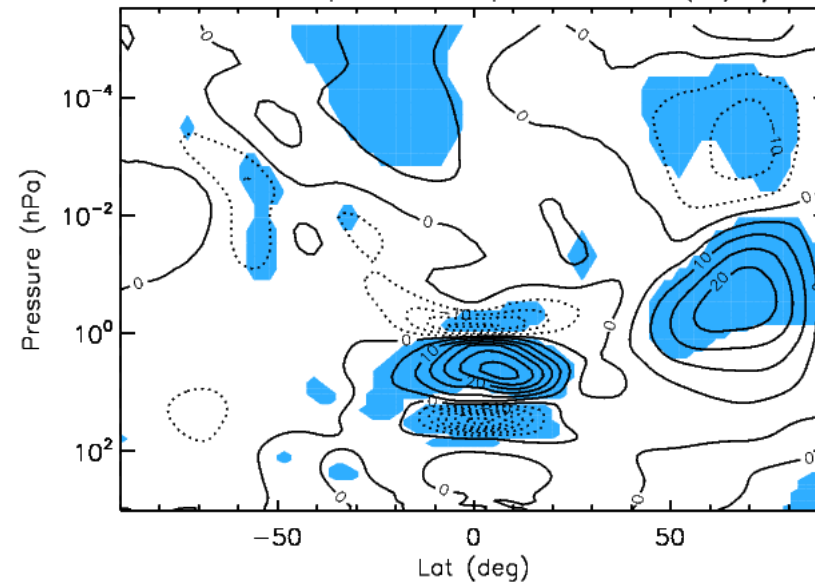
F2000

Dec Ucomp_e-Ucomp_w WACCM (m/s)

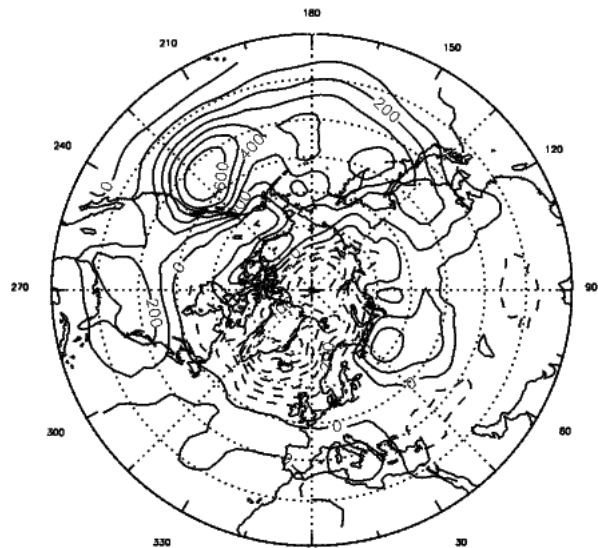


F1955-1976

Dec Ucomp_e-Ucomp_w WACCM (m/s)

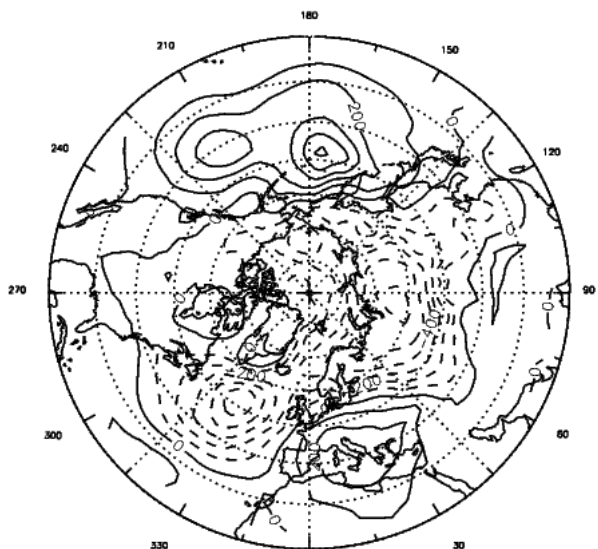


B1850



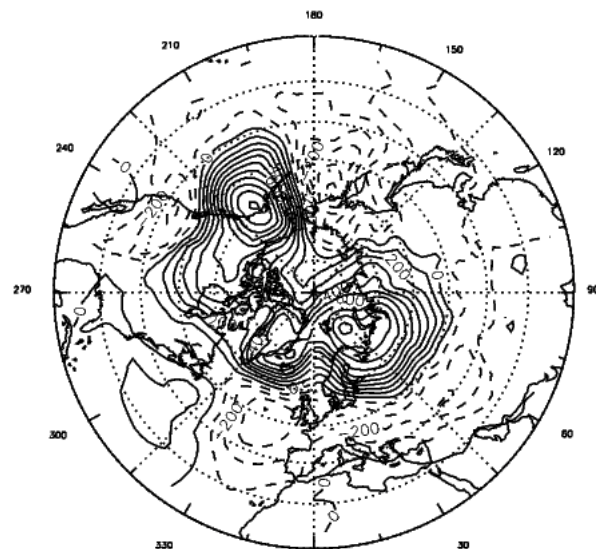
Longitude
Dec PScomp_w-PScomp_e (Pa)

F2000



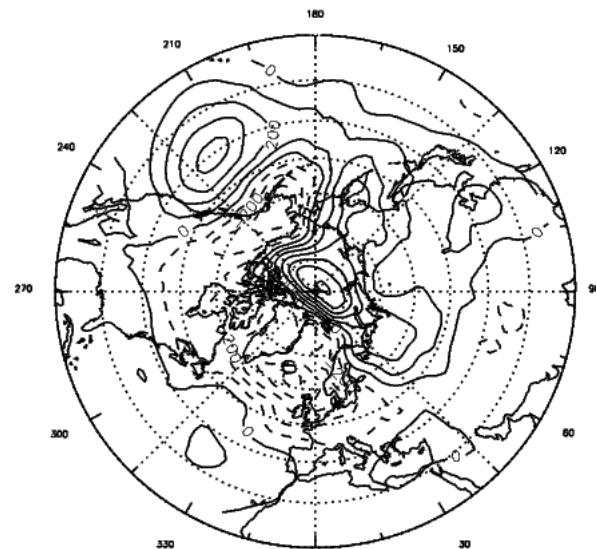
Longitude
Dec PScomp_w-PScomp_e (Pa)

F1850



Longitude
Dec PScomp_w-PScomp_e (Pa)

F1955-1976



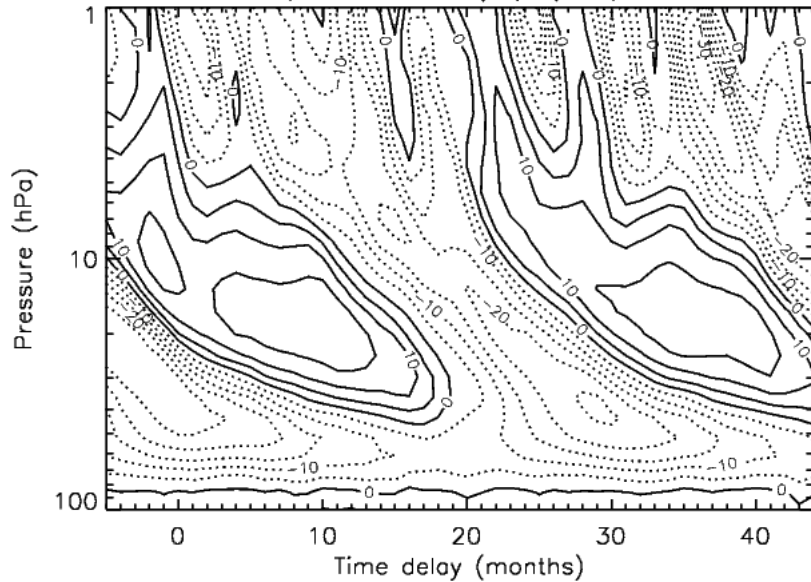
Longitude
Dec PScomp_w-PScomp_e (Pa)

Causes?

- F2000: Solar maximum. Holton-Tan doesn't hold?
 - F1850 and B1850 both under solar medium condition. Holton-Tan relation significant in latter but not in former.
 - F1955-1976 went through 2 solar cycles. Winter stratospheric wind differences opposite to Holton-Tan.
- F1850 or F2000 SST may have a somewhat artificial annual periodicity (as a pace-maker)?
 - B1850 may also have that.
 - F1955-1976 wouldn't have the problem.

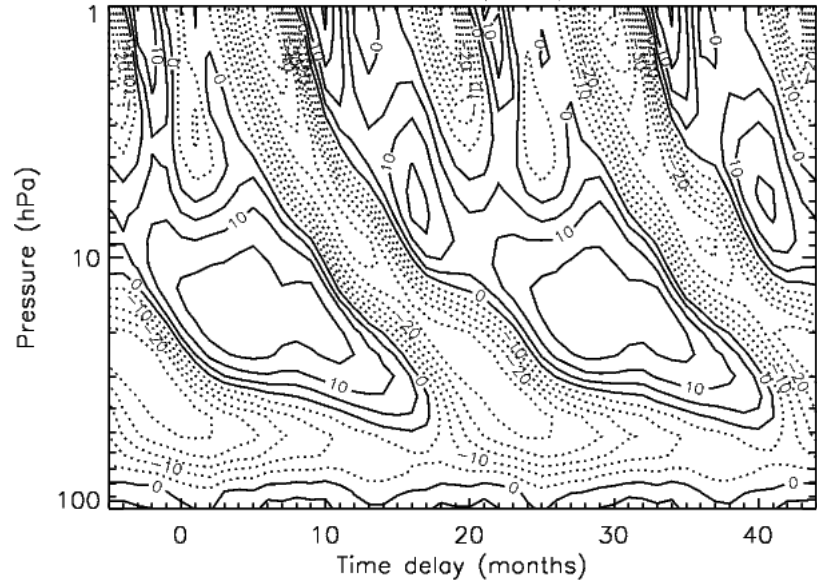
B1850

composite ubar (m/s) equator

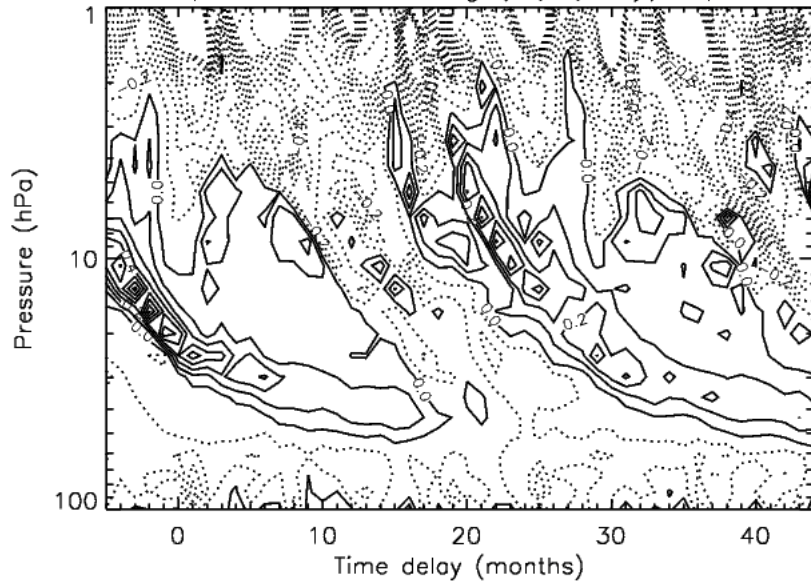


F1850

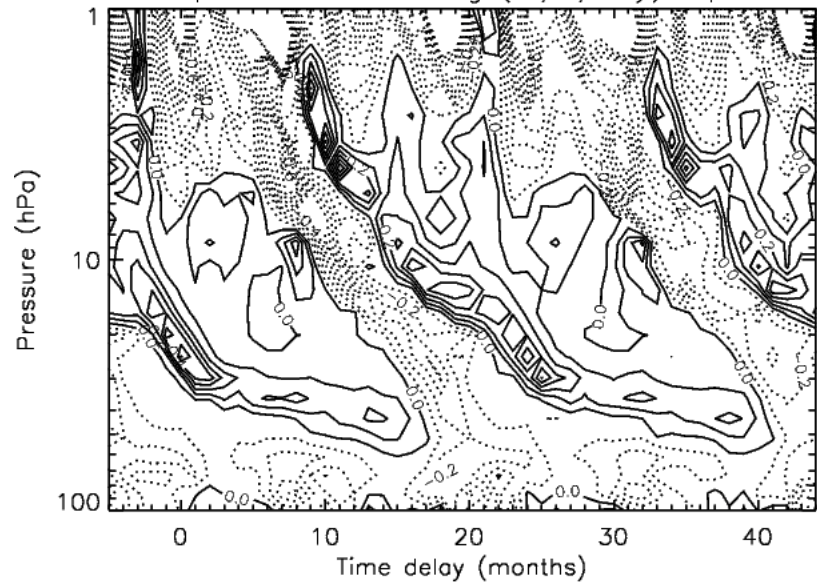
composite ubar (m/s) equator



composite total forcing (m/s/day) equator

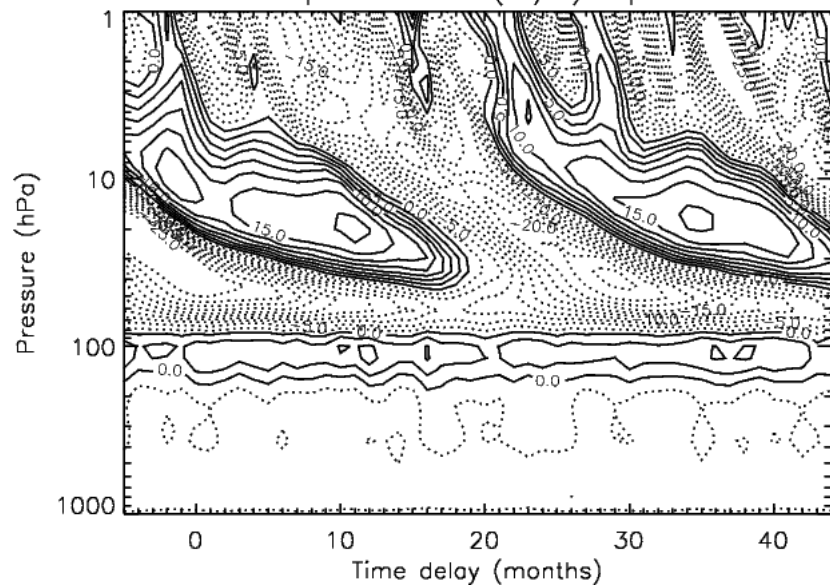


composite total forcing (m/s/day) equator

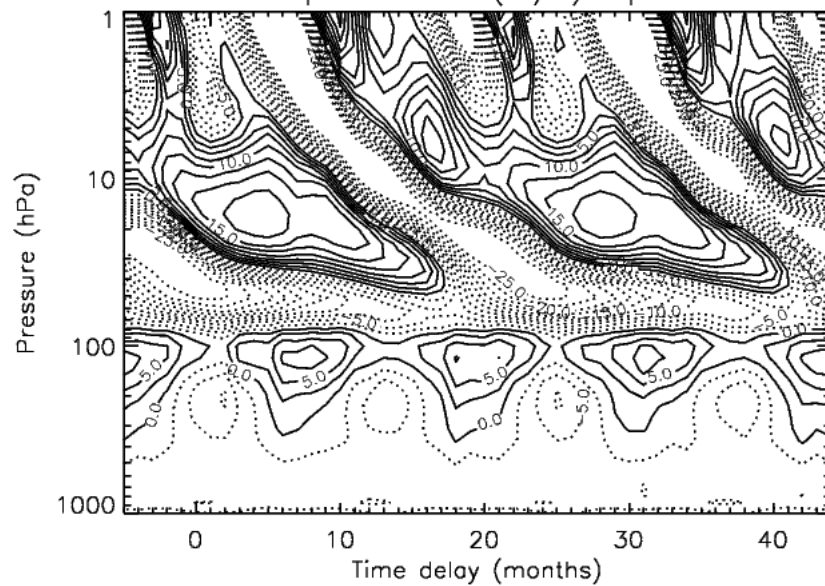


$$\text{Total Forcing} = -v \cdot \frac{dU}{dy} - w \cdot \frac{dU}{dz} + \text{div}(F_{EP}) + F_{GW}$$

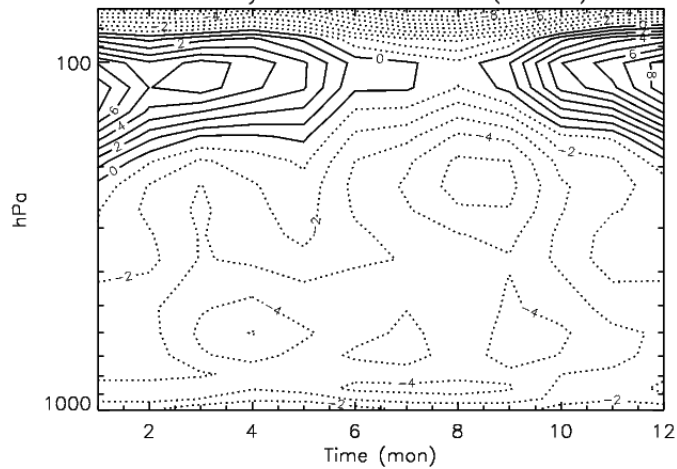
composite ubar (m/s) equator



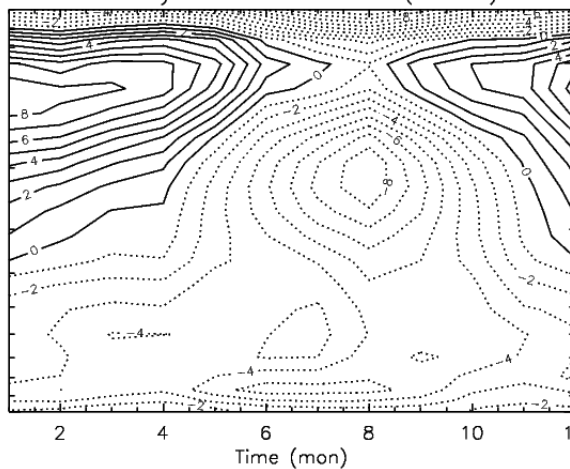
composite ubar (m/s) equator



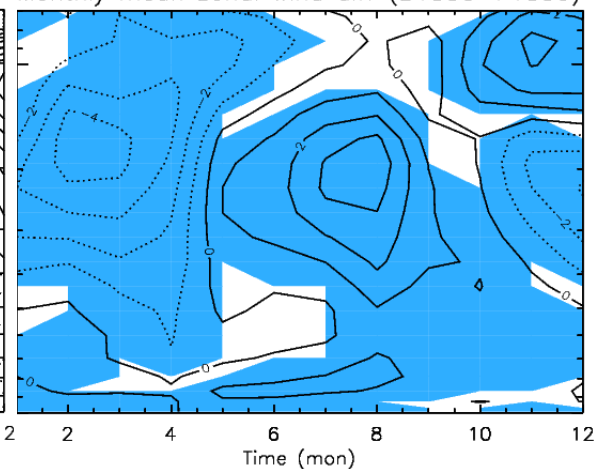
Monthly mean zonal wind (B1850)



Monthly mean zonal wind (F1850)



Monthly mean zonal wind diff (B1850-F1850)



Summary

- The new IGW parameterization scheme produce QBO-like oscillations in CESM/WACCM4 simulation.
- QBO period:
 - ~28 months with coupled ocean and perpetual 1850 condition.
 - 24-33 months with coupled ocean and 1850-2005 run.
 - 24 months with specified SST and perpetual conditions. Show some variation in transient simulation.
- QBO phase:
 - At middle stratosphere westerly phase too long, opposite lower down.
 - In simulations with ocean coupling, wind phase transition time agrees with climatology, though W-E also occurs frequently around northern winter.
 - In SST simulations, wind phase transition time nearly locked to certain months. The actual timing differs in cases.
- QBO forcing:
 - Parameterized GW forcing in general agreement with high-resolution GCM results.
 - PW forcing, particularly westward forcing, around equator very small. May explain the short easterly phase in middle stratosphere.
- Extra-tropical and surface modulation (Holton-Tan relation) significant in simulations with ocean coupling. Insignificant or significant in opposite sense in SST simulations.