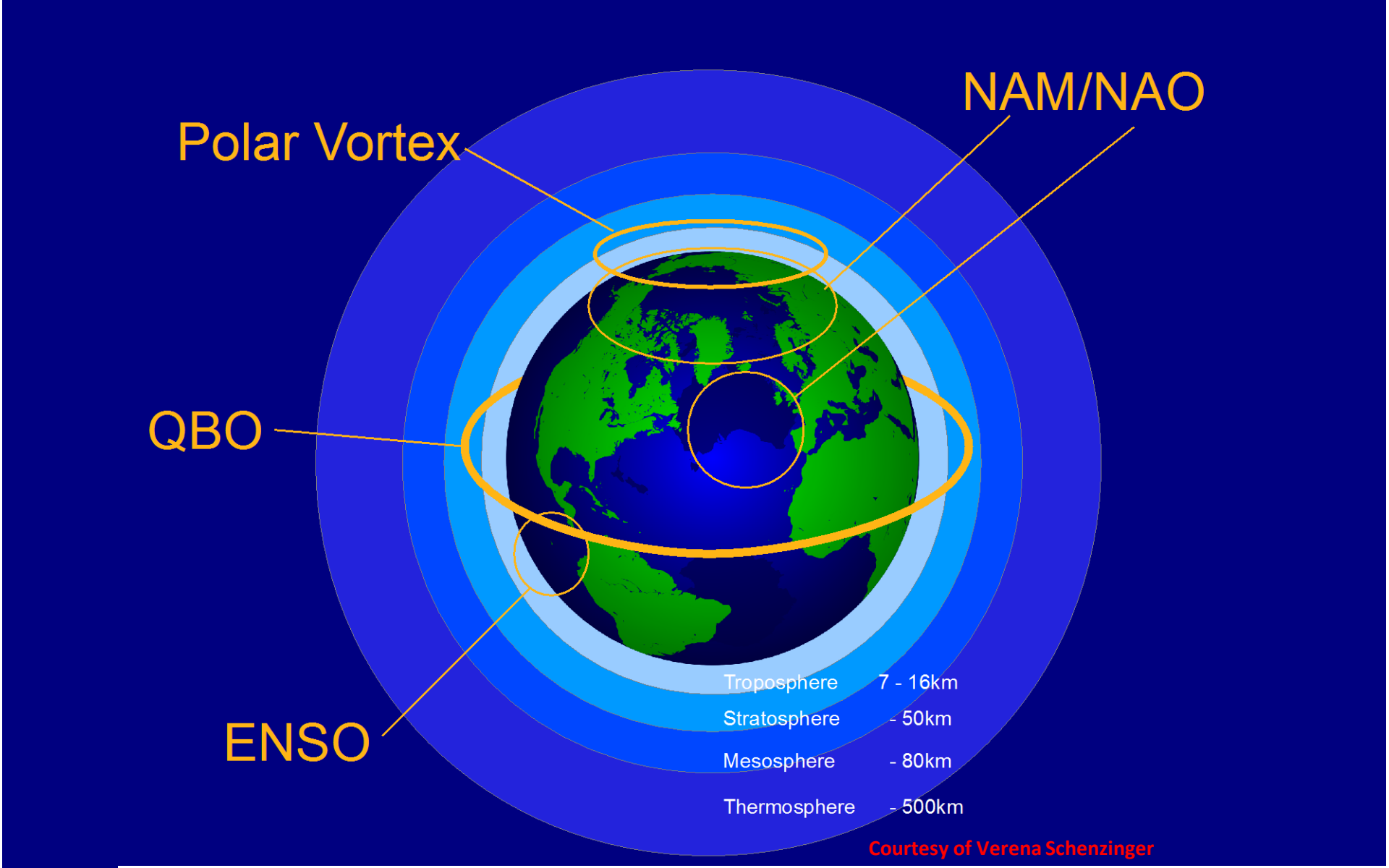
Interactions Between the Stratosphere and Troposphere

A personal perspective

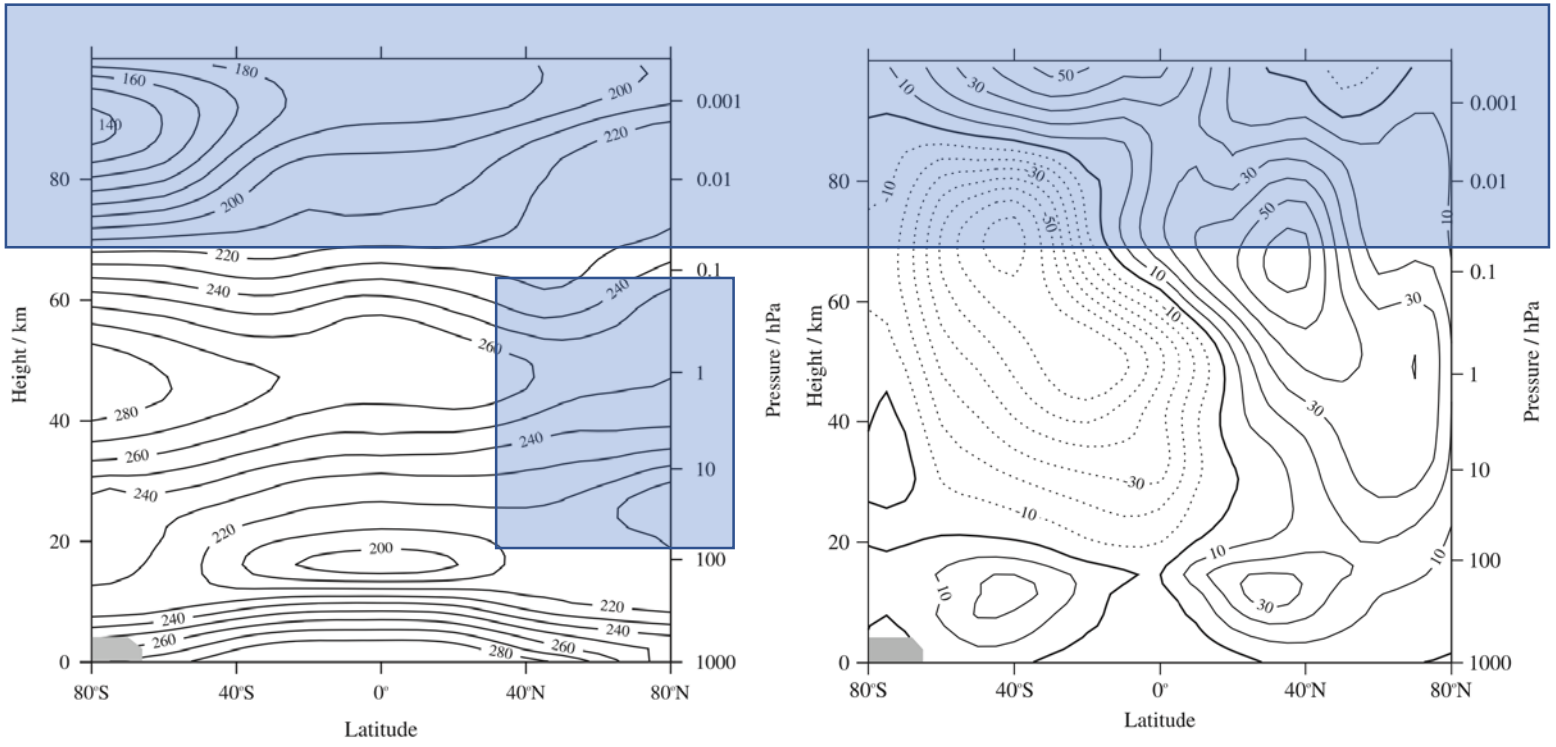
Scott Osprey


NAM/NAO
Polar Vortex
QBO
ENSO
Troposphere 7 - 16km
Stratosphere - 50km
Mesosphere - 80km
Thermosphere - 500km
Courtesy of Verena Schenzinger

The Wave-Driven Circulation

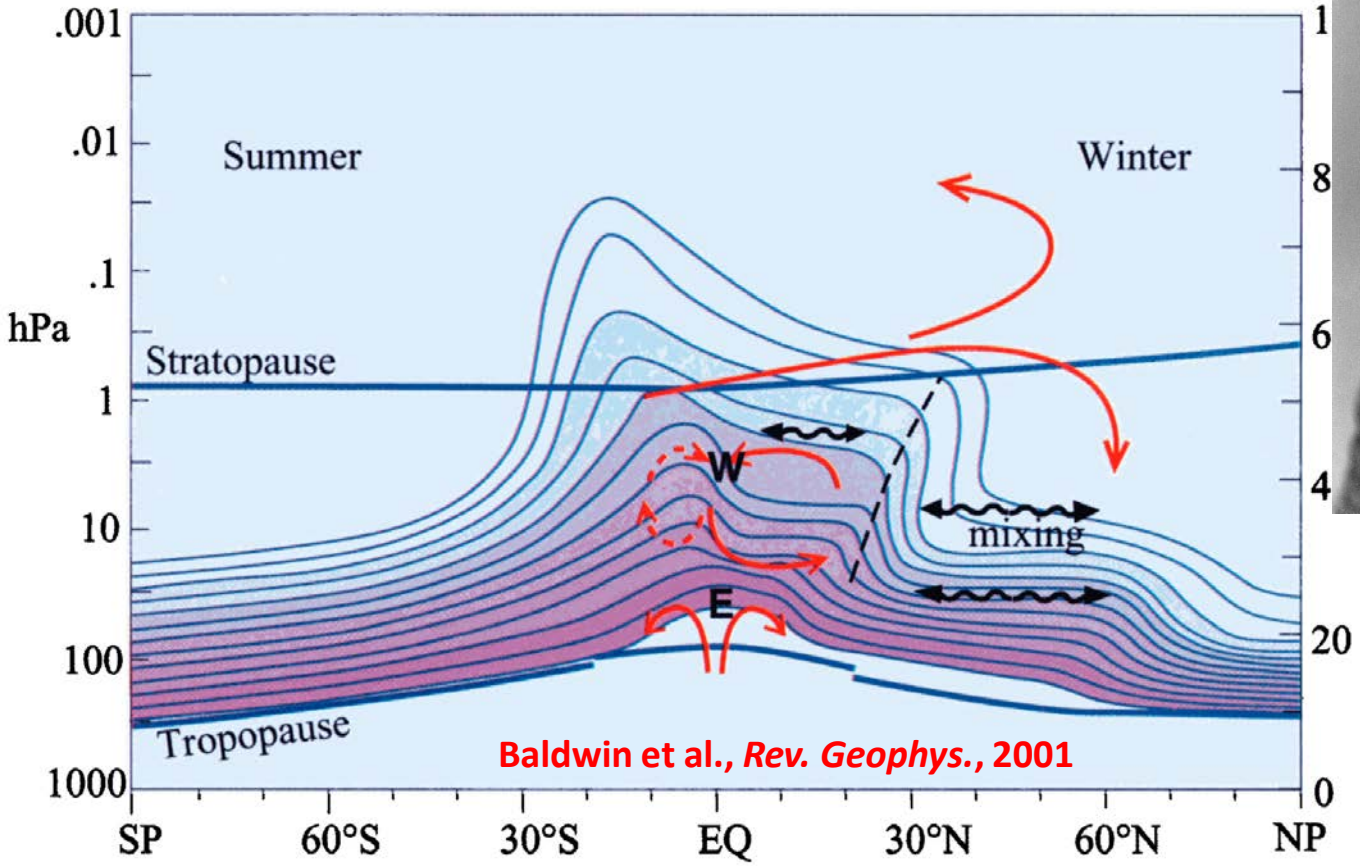
Global structure of Temperature and Wind

Temperature **Zonal Wind**

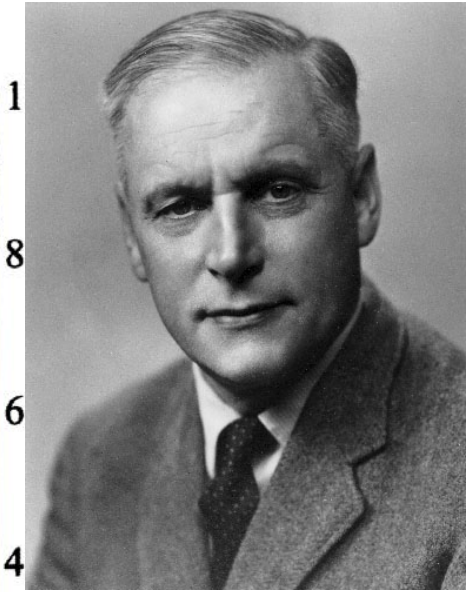


Fleming et al., *Adv. Space Res.*, 1990

Support for the Brewer Dobson Circulation: Ozone



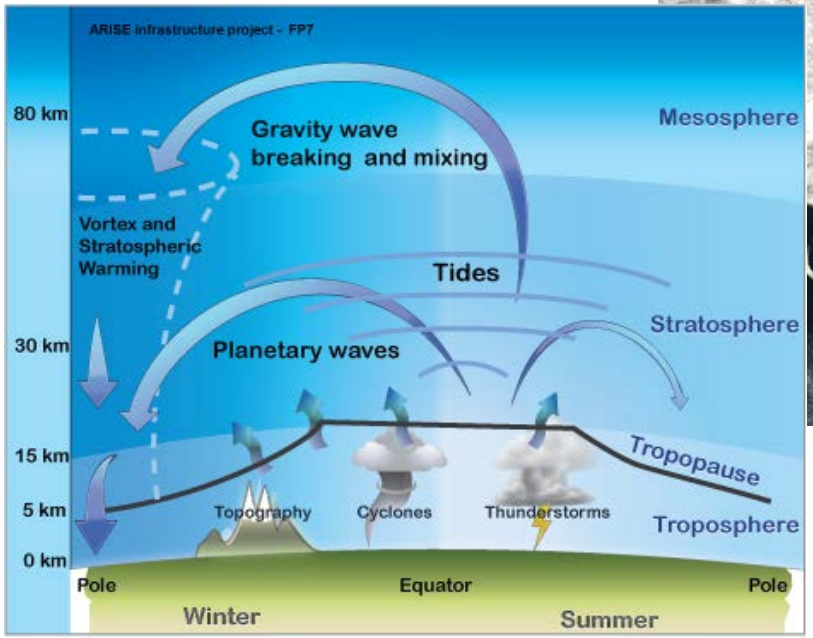
Baldwin et al., *Rev. Geophys.*, 2001

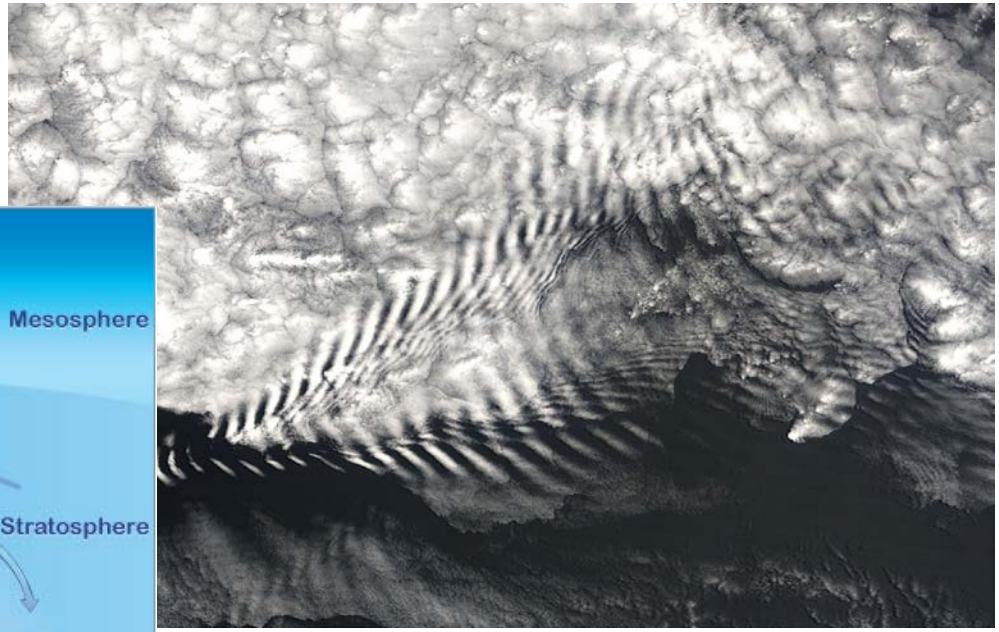


Alan Brewer

Small Waves make “Big Waves”

Both small and large scale waves set up the global Brewer-Dobson circulation in the atmosphere



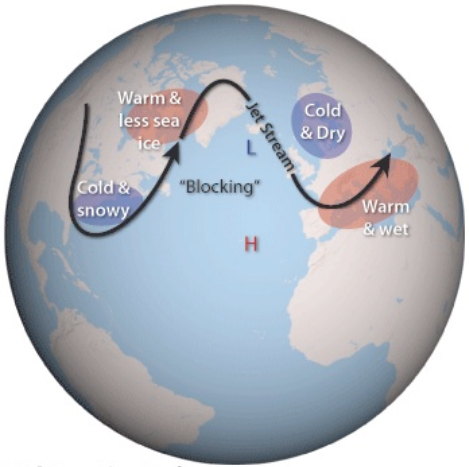


Atmospheric waves generated from air flow over an island

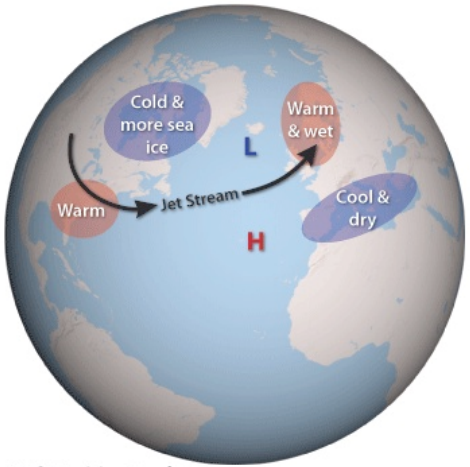
Northern Hemisphere

Wintertime Interactions

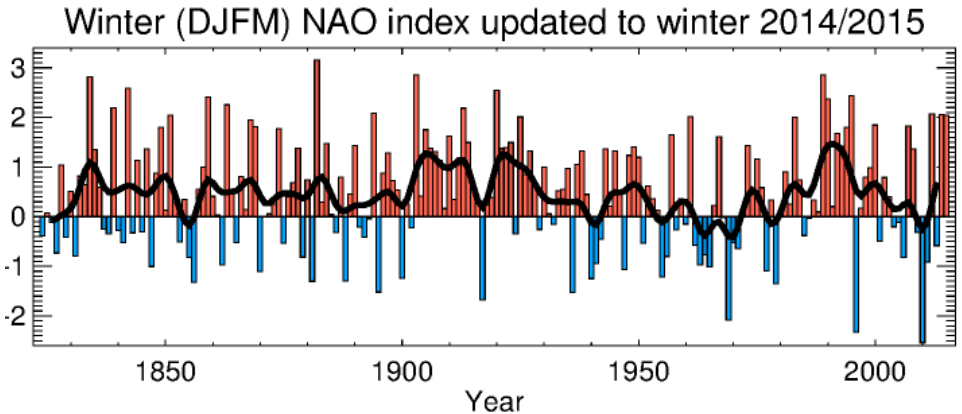
The North Atlantic Oscillation



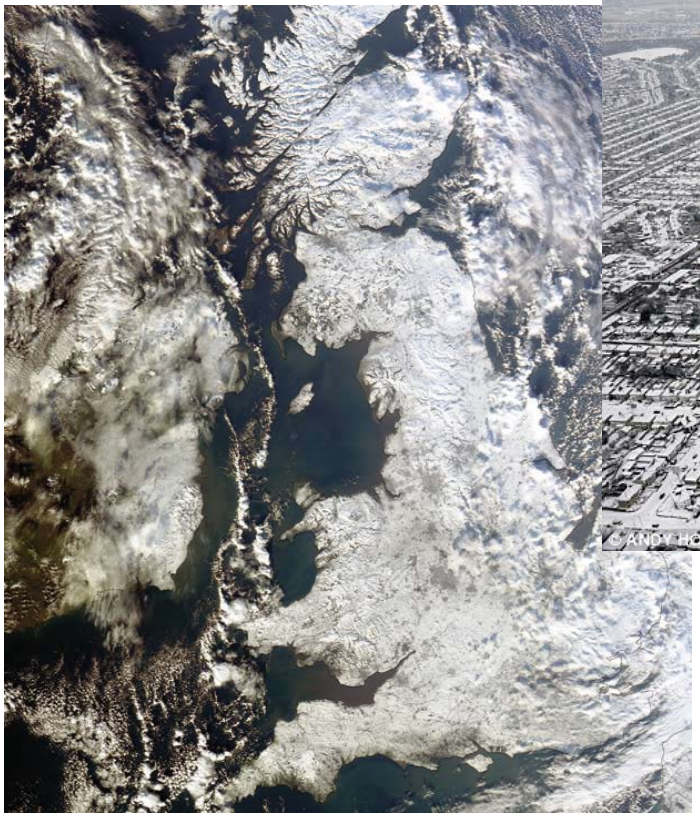
NAO Negative Mode



NAO Positive Mode



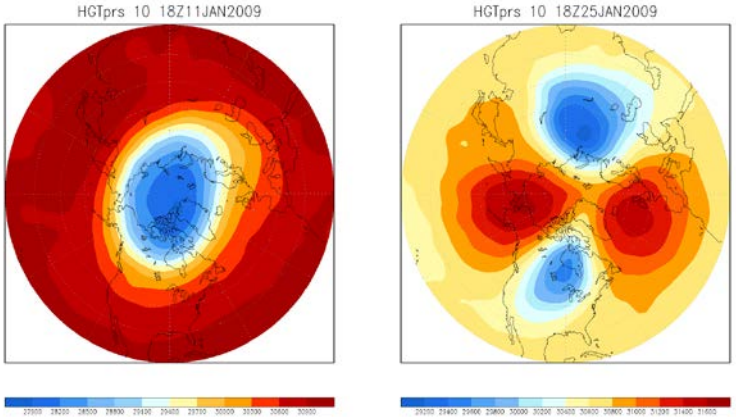
A Strongly Negative NAO!

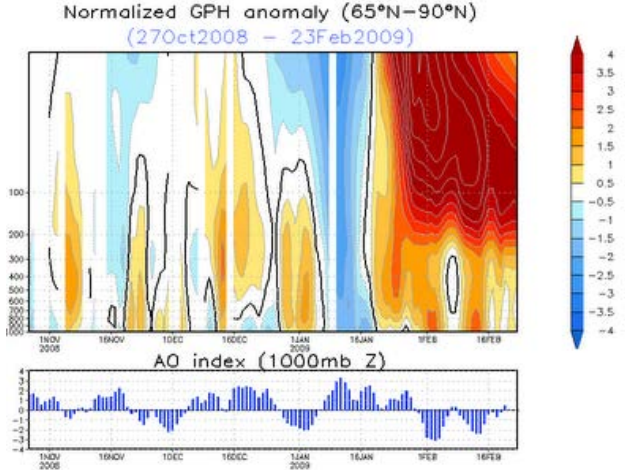


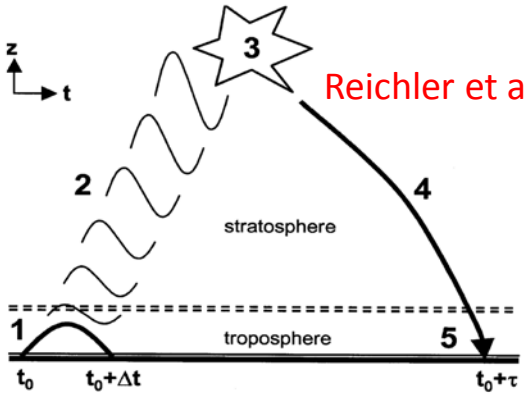
Winter 2009/2010 saw disruptions due to a stationary high pressure system

Stratospheric Sudden Warmings and impacts on the troposphere

- Wintertime stratosphere can undergo large and rapid changes known as Sudden Warmings.
- These are characterised by dramatic changes in high-latitude wind and temperature.
- In the troposphere they have been associated with a change in path of North-Atlantic weather systems.

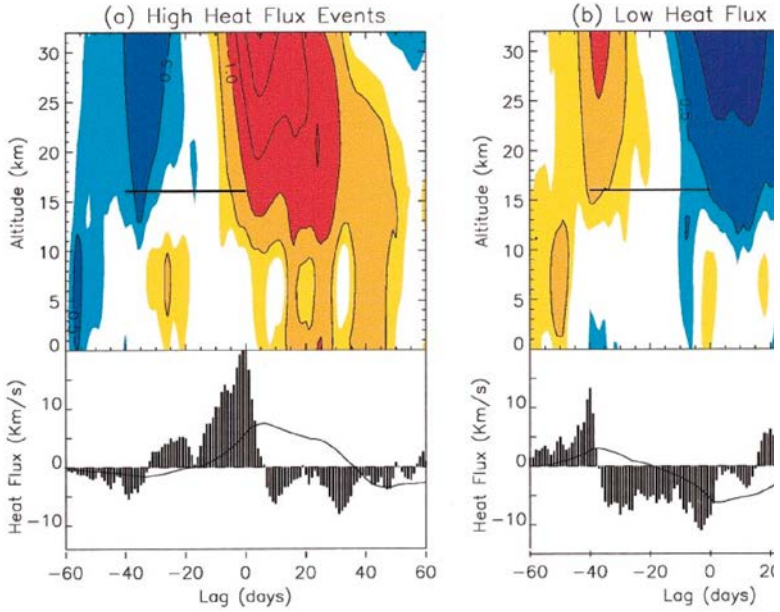




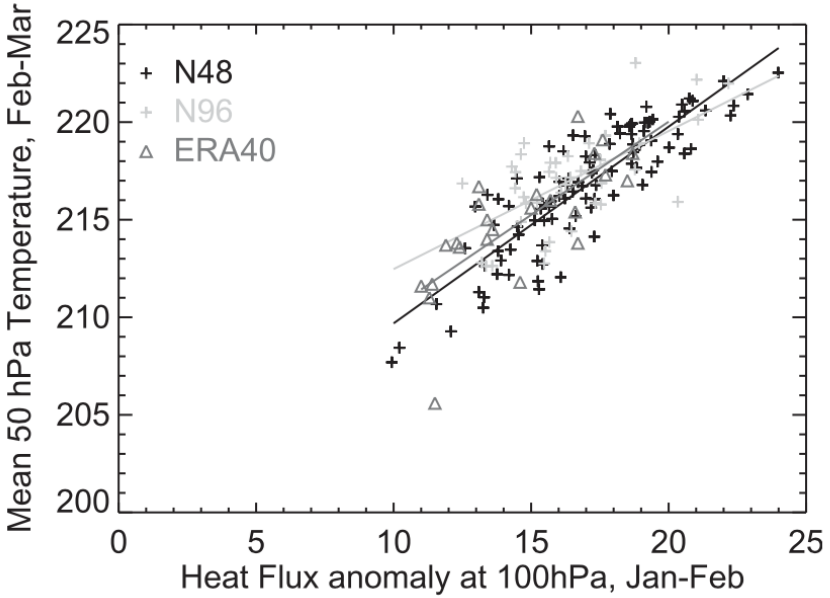


Reichler et al, *JAS*, 2005

Accumulated effects of Tropospheric waves linked with PNJ change



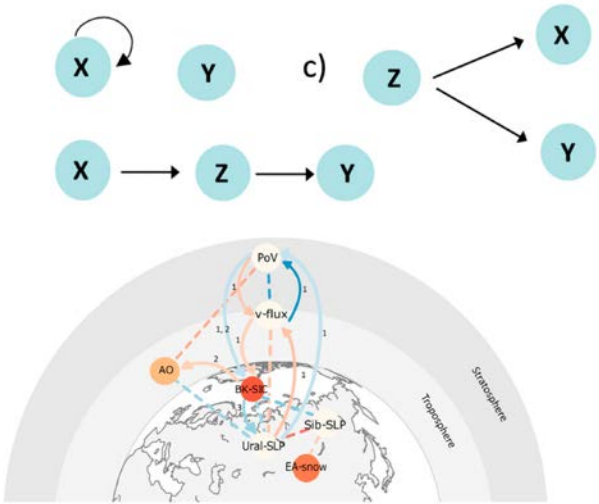
Polvani & Waugh, *J. Clim.*, 2004



Osprey et al., *JAS*, 2010

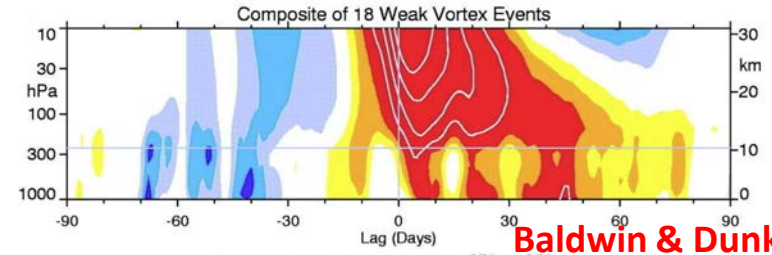
New Metrics for Diagnosing Teleconnection Sensitivity of Climate Variability

Causal Effects Networks

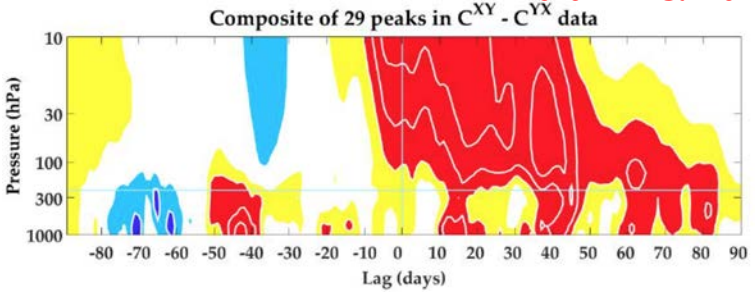


Kretschmer et al, 2016

Complex Network Metrics



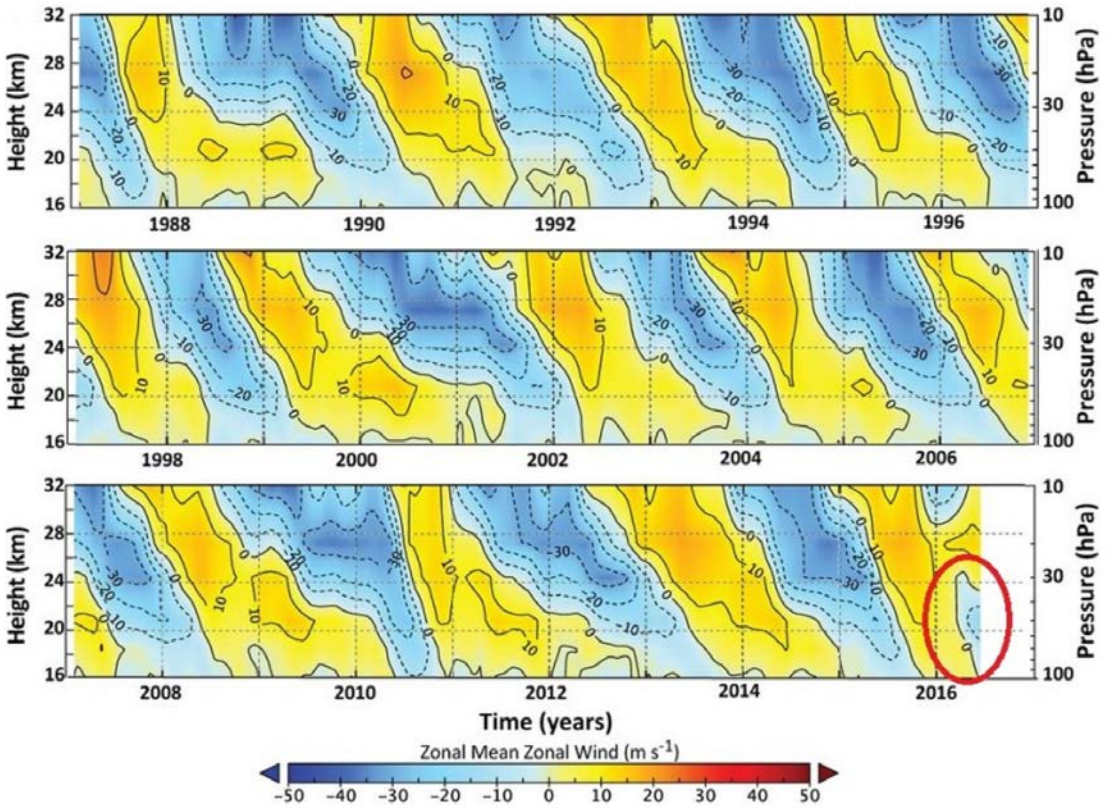
Baldwin & Dunkerton, 2001



Susheel Adamuselli

The Tropical Stratosphere

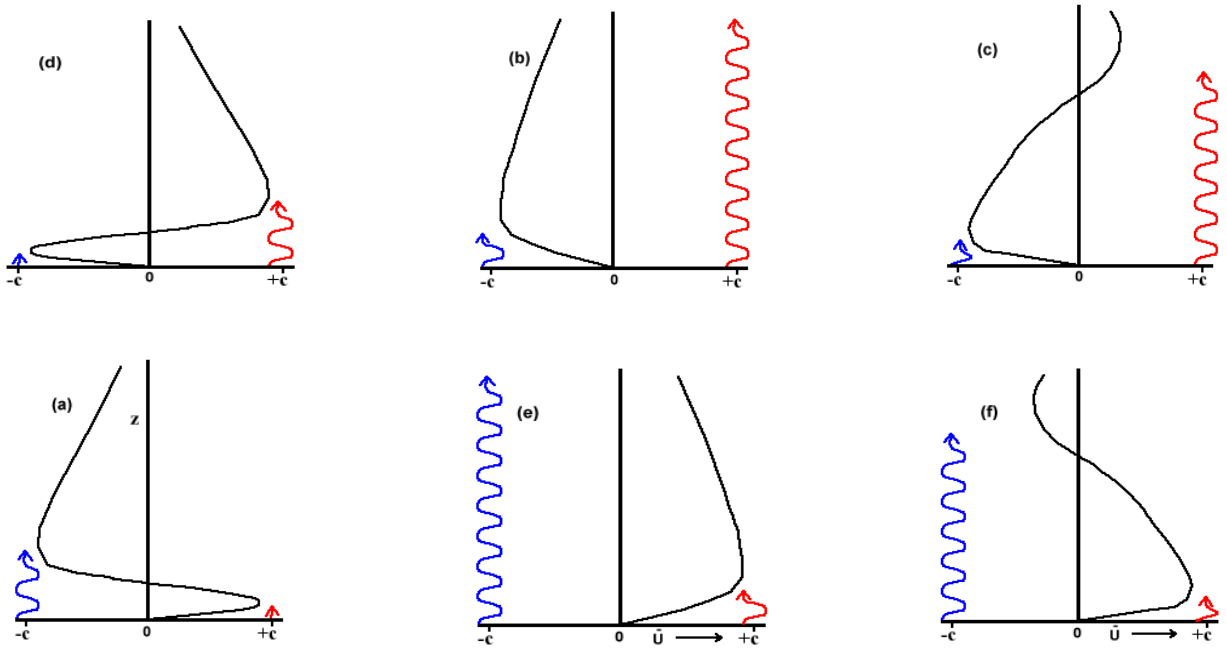
Quasi-Biennial Oscillation



How does the QBO work?

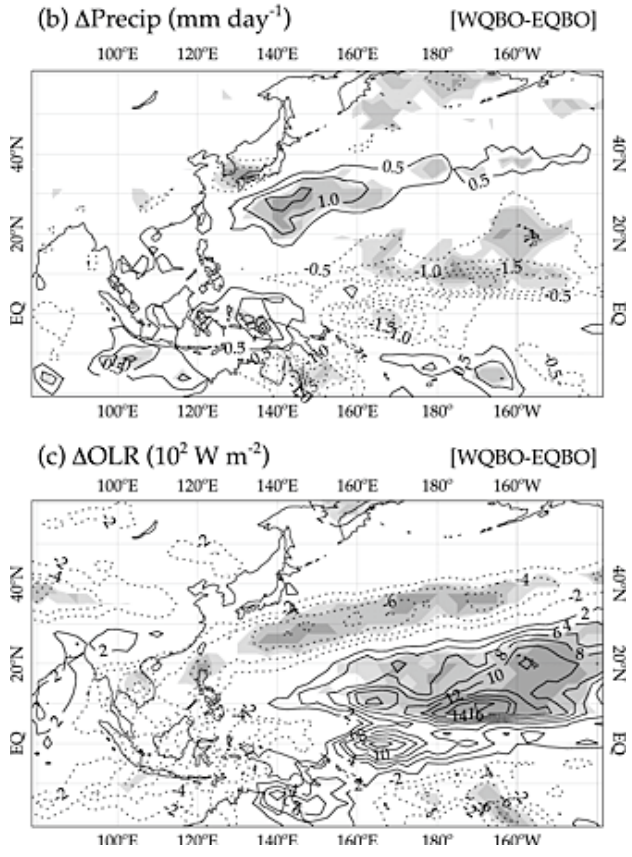
Holton and Lindzen (1972) proposed a model of the QBO based on vertically propagating waves. The mechanism was further explained by Plumb (1977).

Equatorially trapped Kelvin waves provide westerly momentum and Rossby-gravity waves provide easterly momentum to produce the QBO oscillation.



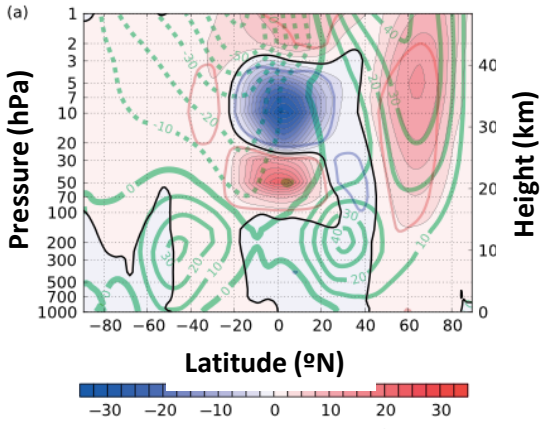
Wavy blue and red lines indicate the penetration of westward and eastward waves

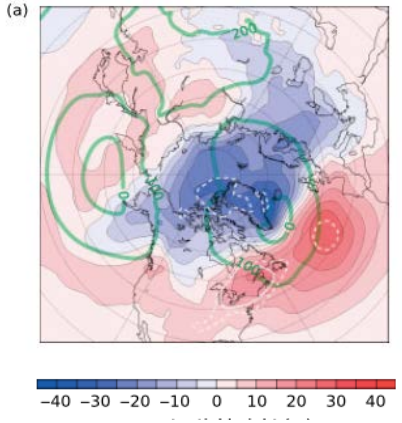
Observed QBO teleconnections to the surface



Seo et al, 2013

Anstey & Shepherd, 2014

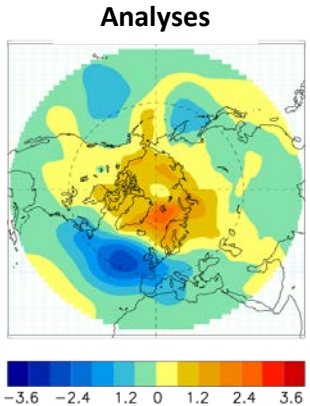




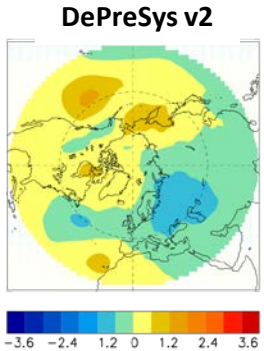
- Early studies by Ebdon and Holton & Tan showed strong links between QBO and high latitude stratosphere **AND** troposphere
- QBO winds in lower stratosphere are linked with **precipitation/convection**, especially during MAM in W-Pacific
- QBO predictable out to a couple of years at least, so scope for impacting seasonal forecast skill

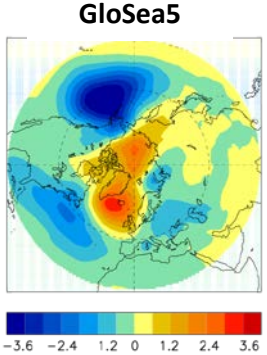
QBO - Surface & high-latitude Impact in models

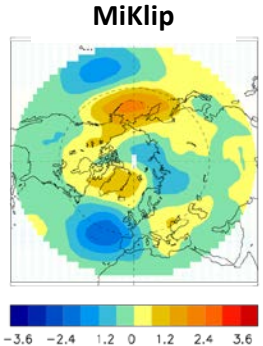
- Eastward/westward QBO linked with poleward/equatorward shift in Atlantic jet-stream in observations
- Seasonal and decadal forecast models *kind of* reproduce sign of teleconnection, but it is generally **very weak**
- Scope for **significant improvement** in seasonal-interannual forecasting.

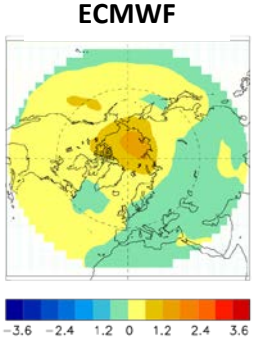


Scaife et al, 2013



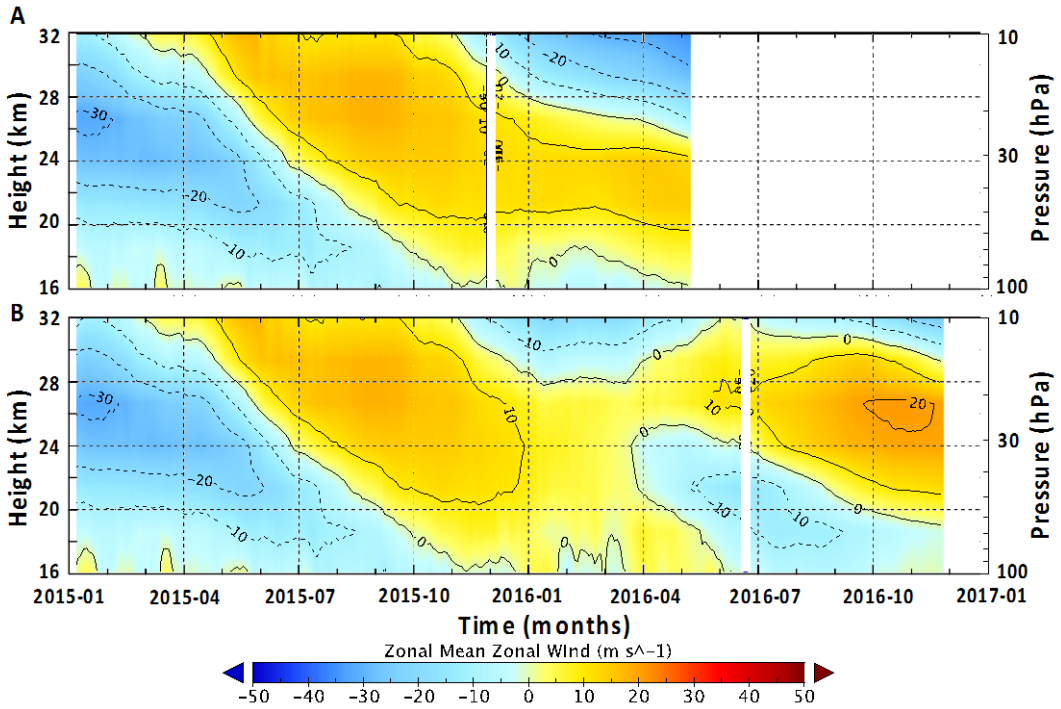






Challenges to Seasonal Forecasting: QBO disruption

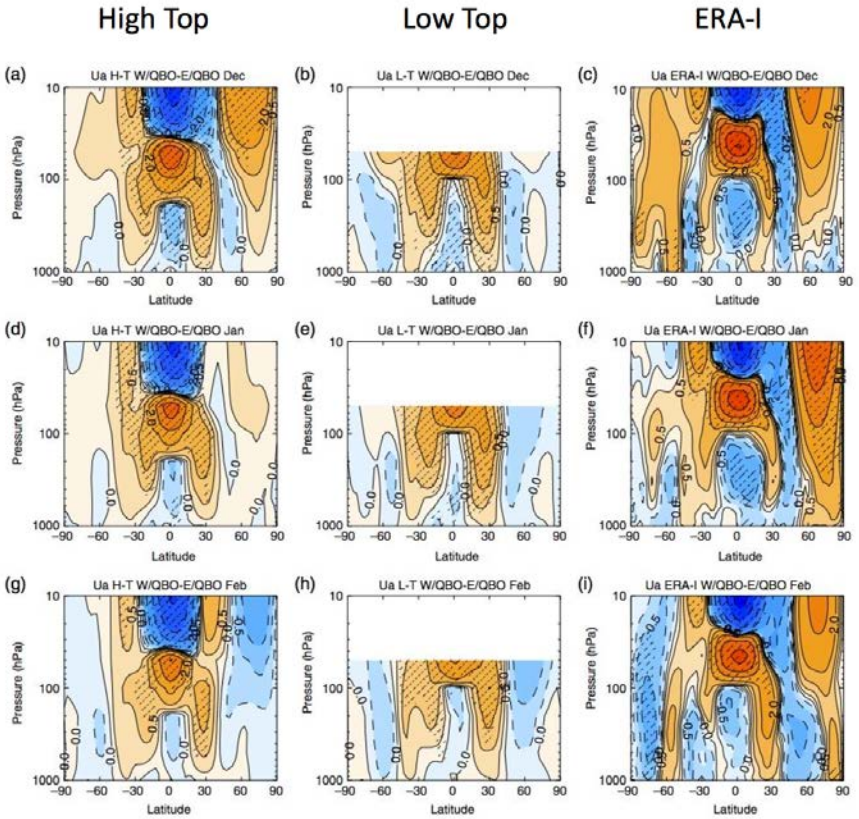
- QBO was disrupted during 2016
- Extratropical waves responsible for rapid development of westward wind jet within eastward QBO phase
- Seasonal forecasting centres apparently did not anticipate the disruption in advance
- The lack of predictability of the disruption has significant implications for the possible limits of future seasonal forecasts



Osprey et al, 2016

Better resolved stratospheres improve high latitudes in CHFP models

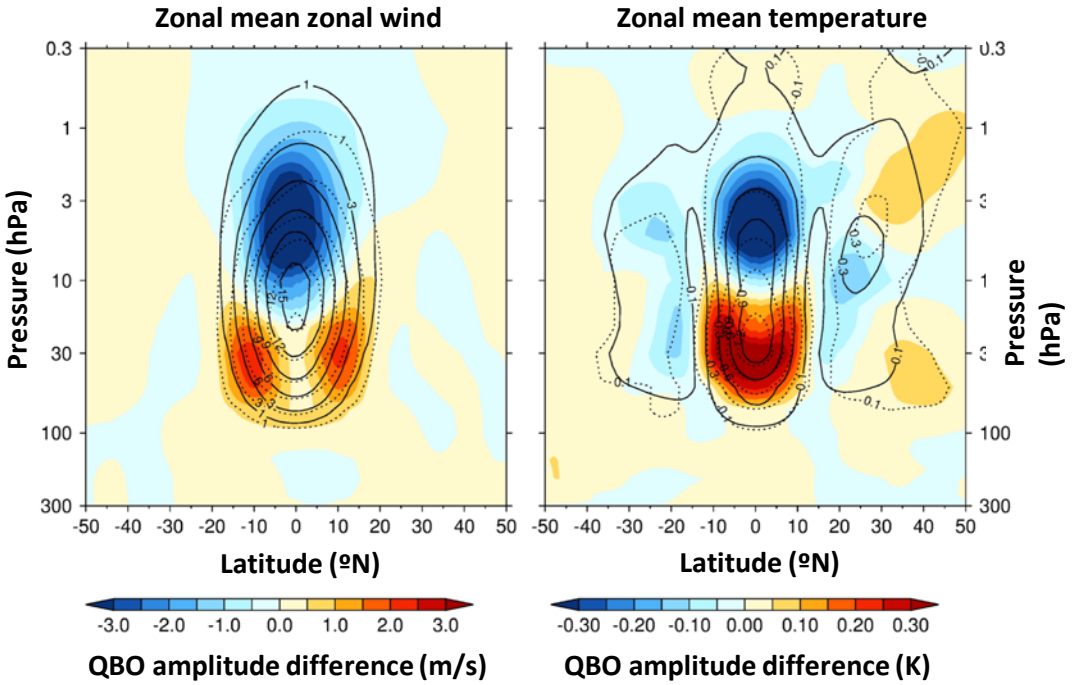
Stratosphere representation in CHFP models (incl. QBO) and ENSO pathways leads to improved responses at high latitudes



Butler et al, *QJRMS*, 2016

QBO Comparison: Models and Reanalyses

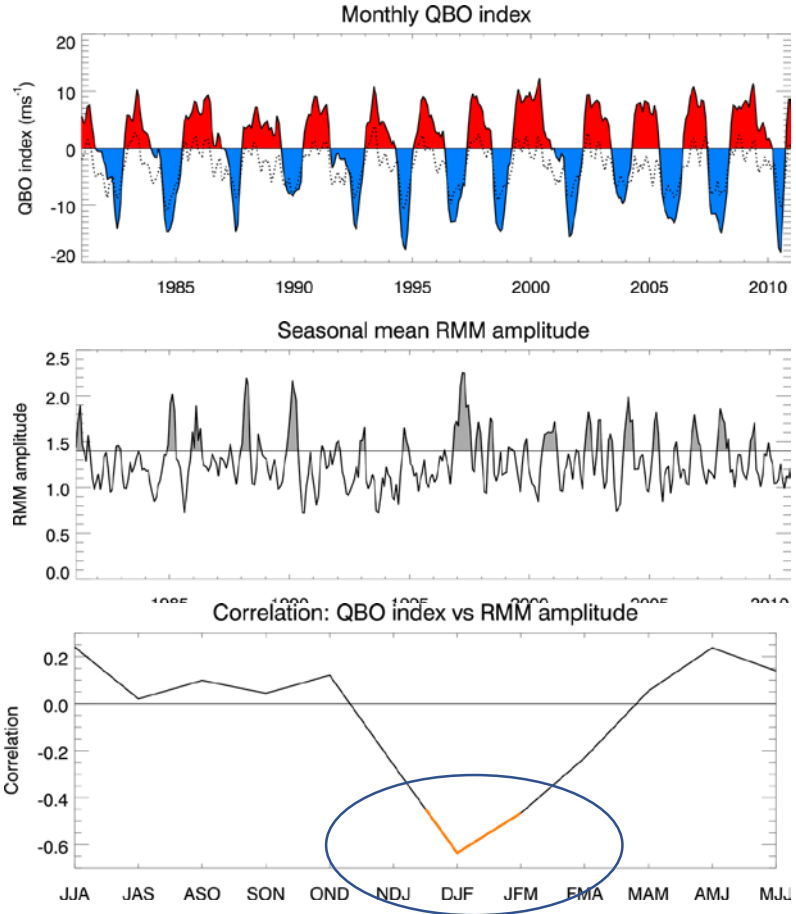
- Comparison of GCMs (CMIP5 & CCMVal-2) and reanalysis datasets.
- Peak QBO amplitude placed too high (solid lines, opposite) compared to mean reanalyses (dotted)
- Mean QBO amplitude asymmetry (east/west phases) well captured.
- Crucially GCMs do not penetrate to the **lowermost stratosphere** and are **too narrow** there
- How do these biases translate to tropospheric teleconnections and to predictability (i.e. directly relevant to the **Near-Term Climate Prediction Grand Challenge**)



Schenzinger et al, *Geosci. Model Dev.*, 2017

The Madden-Julian Oscillation

QBO and Madden-Julian Oscillation



Zonal mean zonal wind
50hPa (10N-10S)

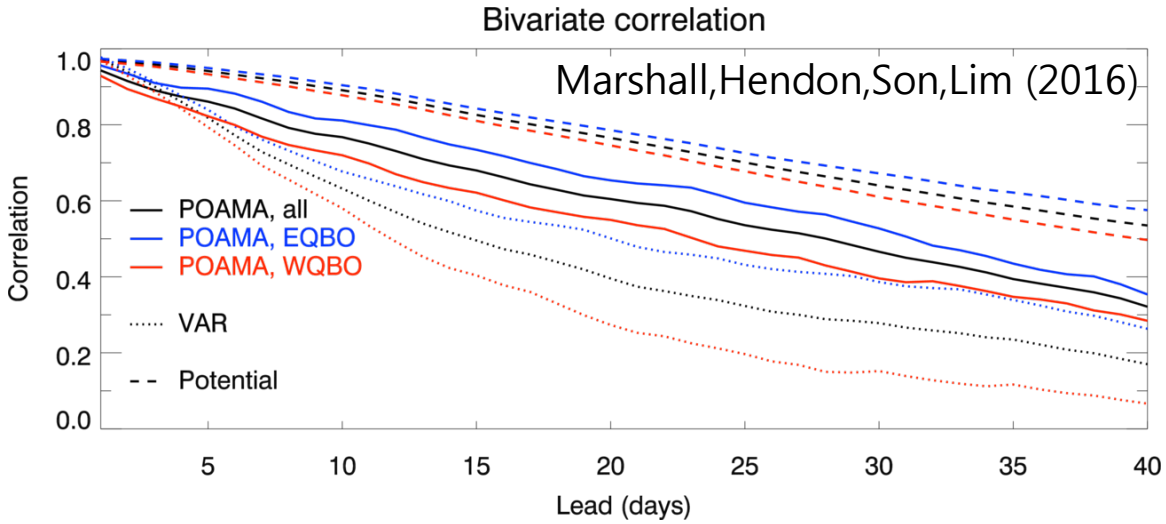
Courtesy of Harry Hendon
http://www.bom.gov.au/climate/mjo/

Amp(t)=
sqrt(rmm1^2+rmm2^2)
Filter with 90 d running mean

Strongly correlated during austral summer: (sig test takes into account auto correlation of QBO index)

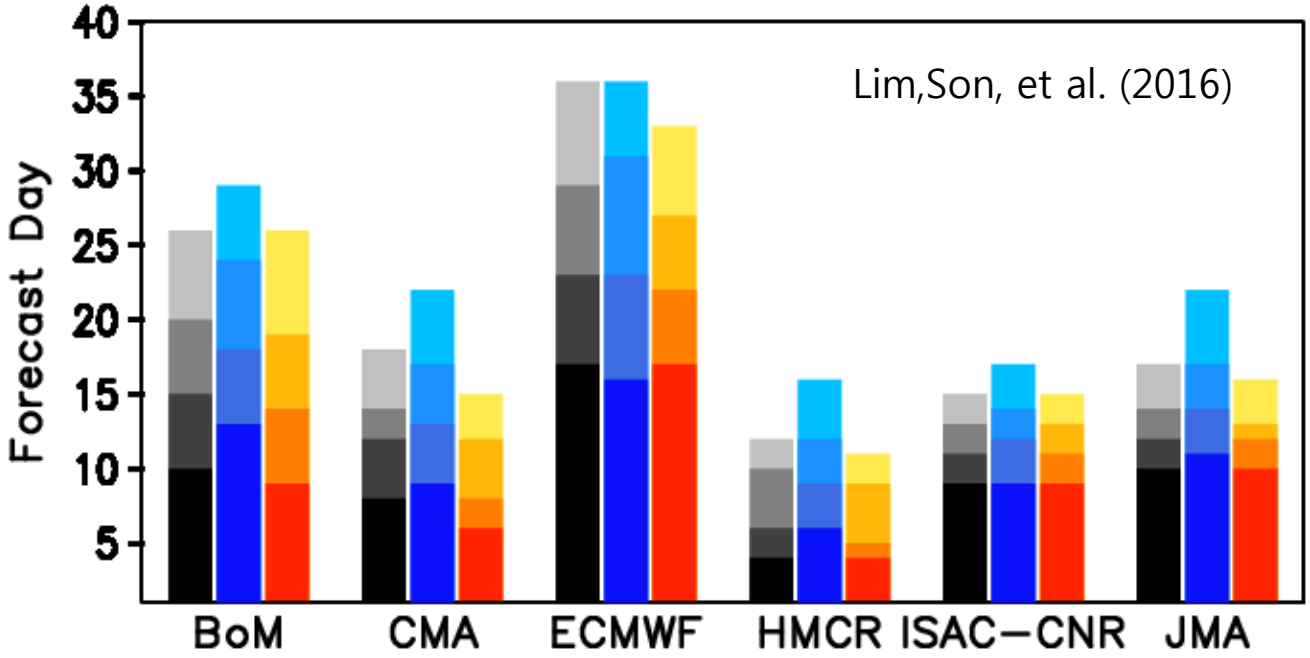
Implies predictions of MJO should be better during EQBO, based on previous studies that show predictive skill of MJO varies with MJO amplitude

MJO prediction skill: BoM model



MJO is better predicted during EQBO winter!

MJO prediction skill: 6 models

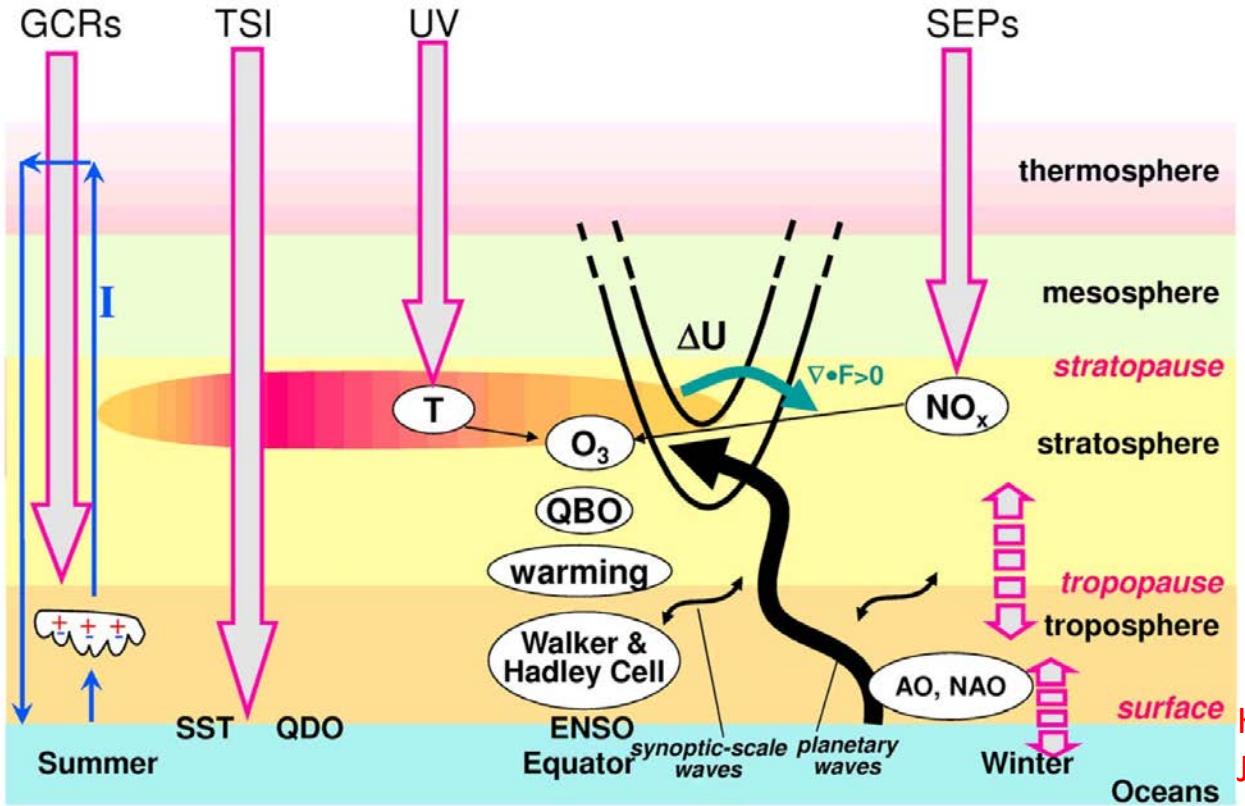


All 6 models consistently show that MJO is better predicted during EQBO winter!

Solar Cycle

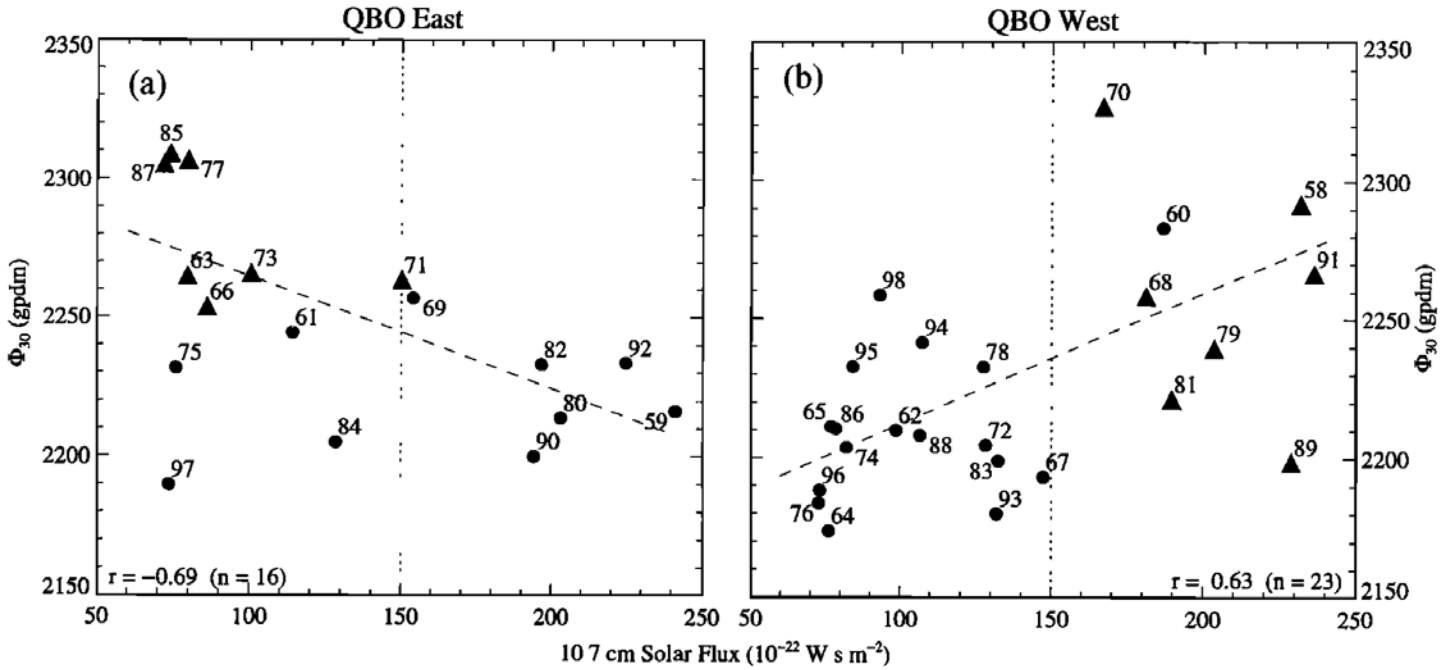
Volcanoes work too…

Solar Impact on Climate: top-down vs bottom-up mechanisms



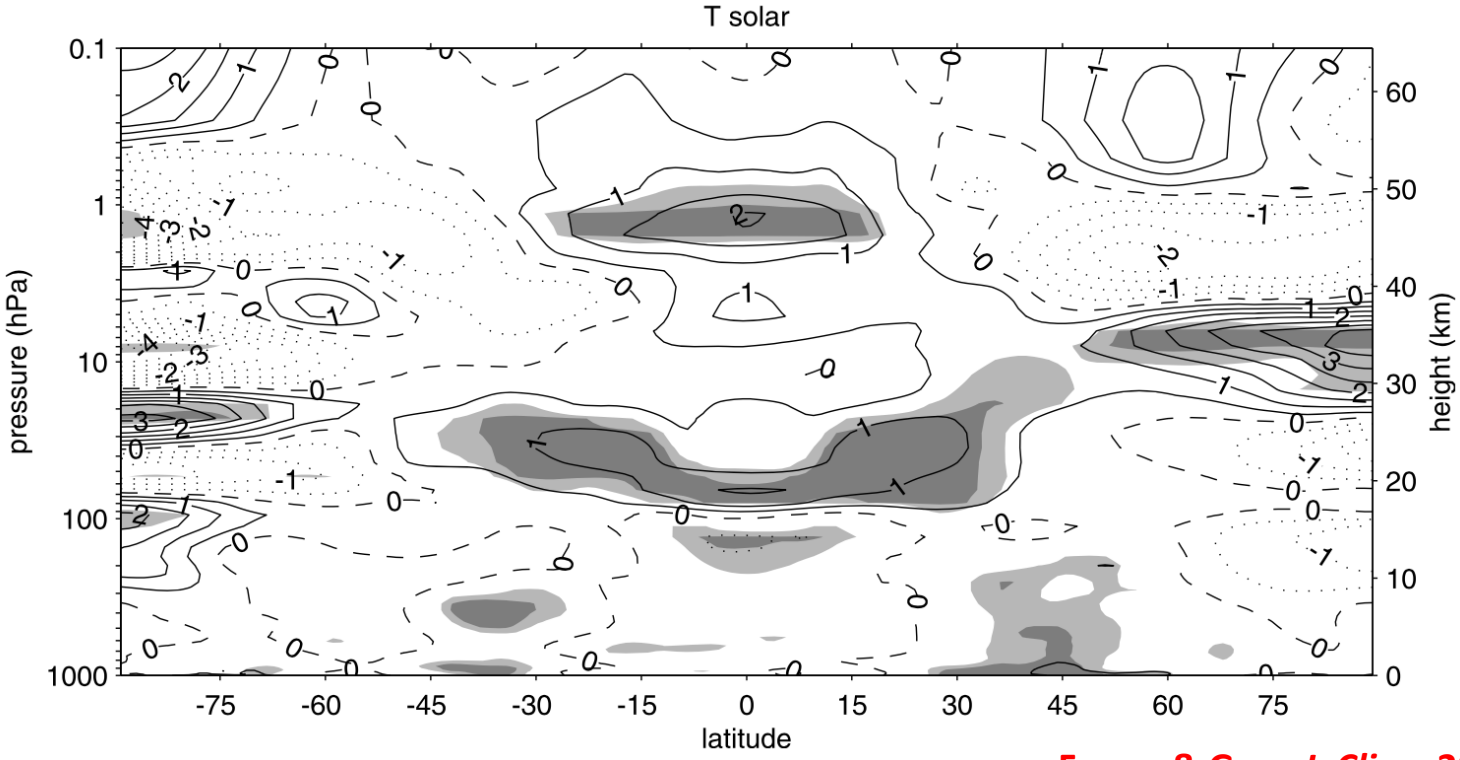
Kodera & Kuroda, JGR, 2002

Solar & QBO Impacts



After Van Loon & Labitzke, 1994

Solar Impacts on global temperature



Frame & Gray, *J. Clim.*, 2010

Other Mechanisms for Troposphere-Stratosphere Coupling

- Non-local balanced response to a given stratospheric torque
  - Downward control (Haynes et al. 1991)
  - PV inversion (Ambaum & Hoskins 2002 and others)
- Wave behavior determined by given zonal-mean flow via index of refraction (e.g. Charney & Drazin 1961, Matsuno 1970)
  - Dissipation at critical layer (e.g. McIntyre & Palmer 1983)
  - Reflection (e.g. Perlwitz & Harnik 2003, 2004, Shaw et al. 2010)
- Synoptic scale wave feedbacks and impacts from the stratosphere (Lorenz and Hartmann 2001, 2003, Simpson et al. 2009, Thompson & Birner 2012)

Wave driven circulation above the troposphere