High Resolution Dynamics with HIRDLS

M. Joan Alexander – NWRA/CoRA

Contributions from:

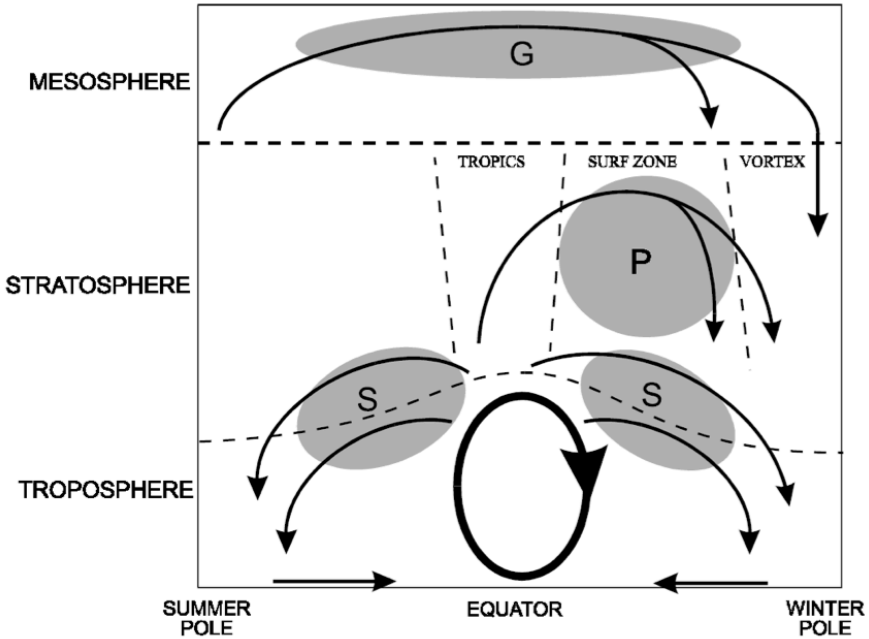
Ji-Eun Kim – Univ. of Colorado

David Ortland – NWRA

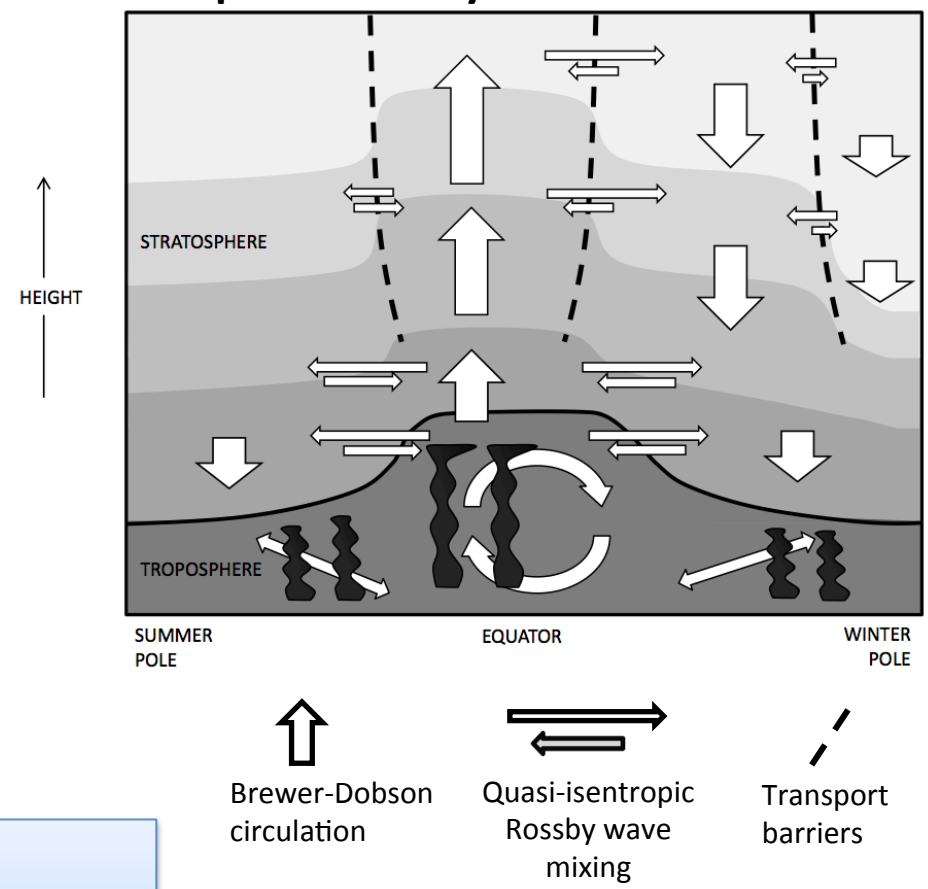
Laura Pan, John Gille – NCAR

Dynamics and Chemical Transport

Residual Mean Meridional Circulation [Plumb 2002]



Transport Pathways & Tracer Distributions

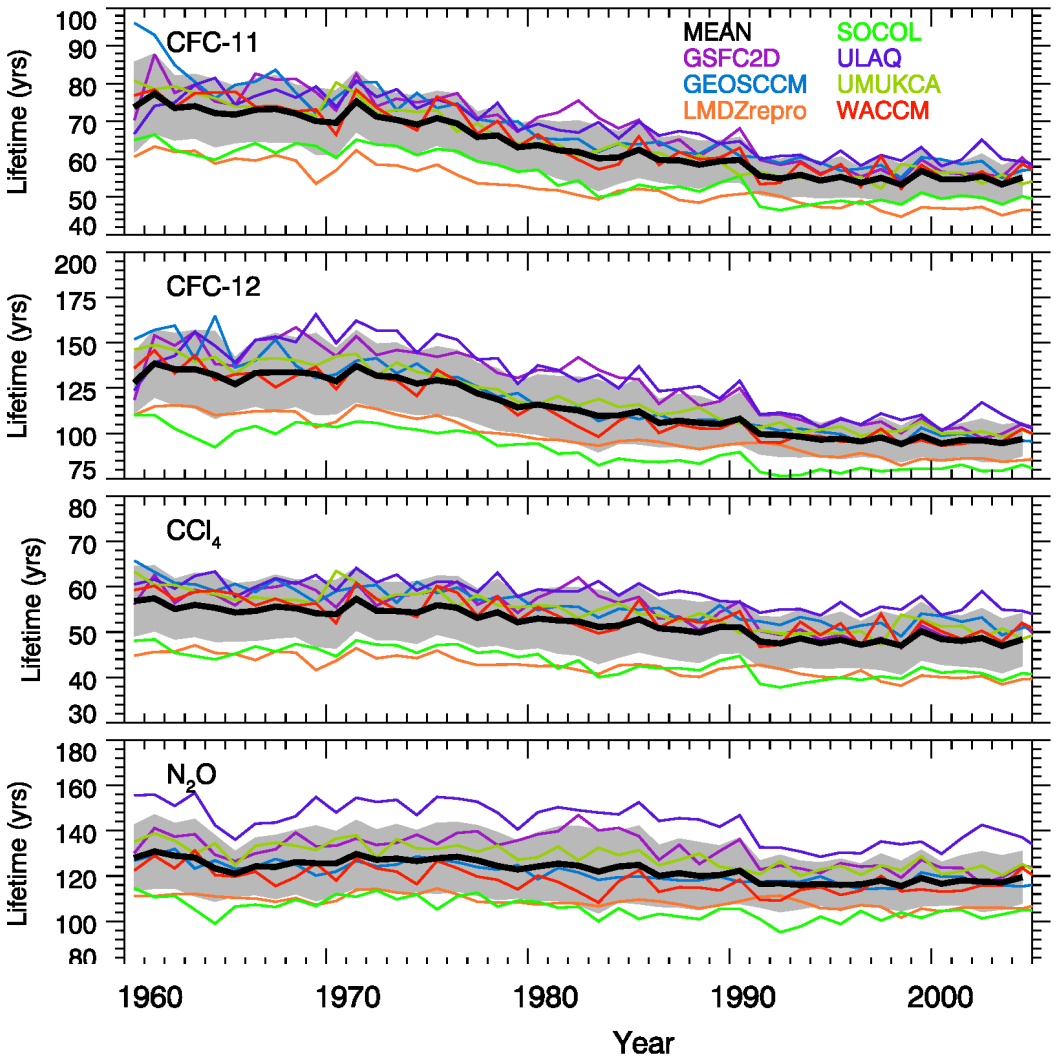


[Ko et al. 2013]

These circulations control:

- Constituent transport
- Lifetimes of many radiatively/ chemically important tracers

Dynamics and Chemical Transport



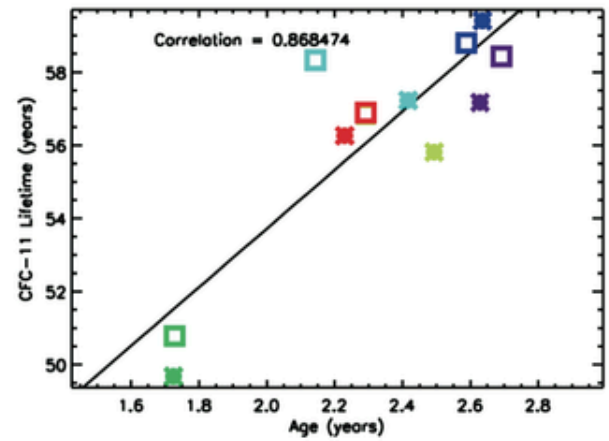
Time evolution of modeled atmospheric lifetimes
Chapter 5 by Chipperfield et al.

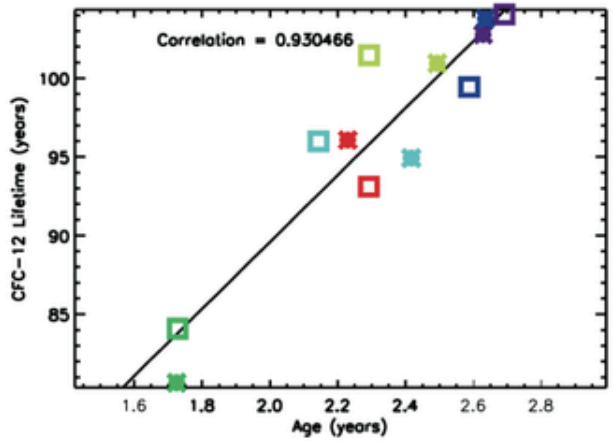
Recent SPARC Report: **"Lifetimes of Stratospheric Ozone Depleting Substances, their Replacements, and Related Species" [Ko et al., 2013]**

←Chemistry Climate Models used to estimate trace gas atmospheric lifetimes

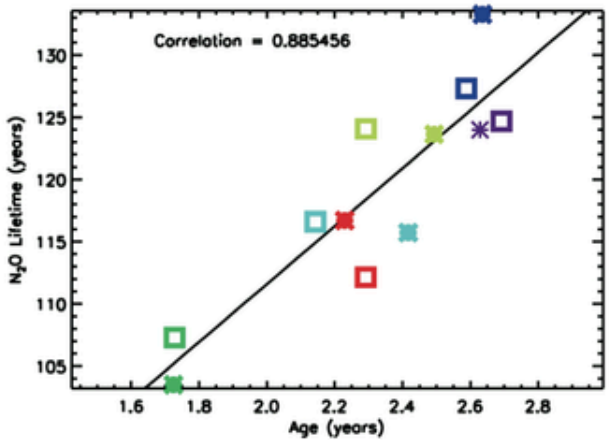
Spread among models is due to differences in speed of the Brewer-Dobson circulation

Dynamics and Chemical Transport





Lifetimes Report Chapter 5 by Chipperfield et al.



Lifetimes of tracers with removal processes in the stratosphere are controlled by the speed of the Brewer-Dobson circulation

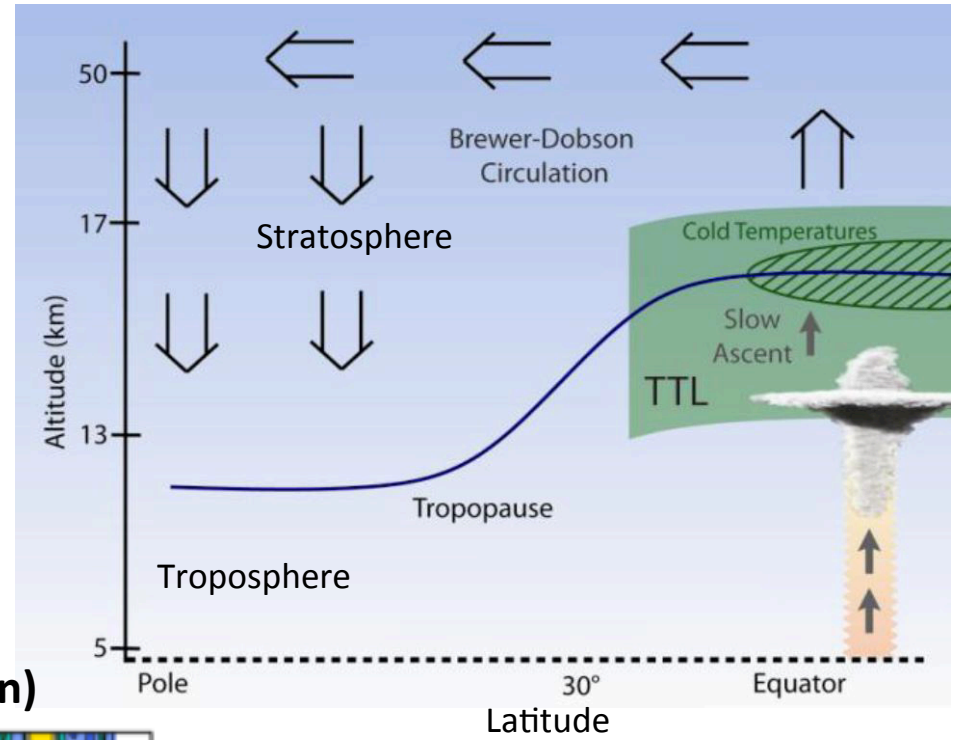
- Lifetimes are correlated with Age of Air
- Differences in the speed of the Brewer-Dobson circulation in models explain much of the spread among models in lifetimes

Dynamics and Composition

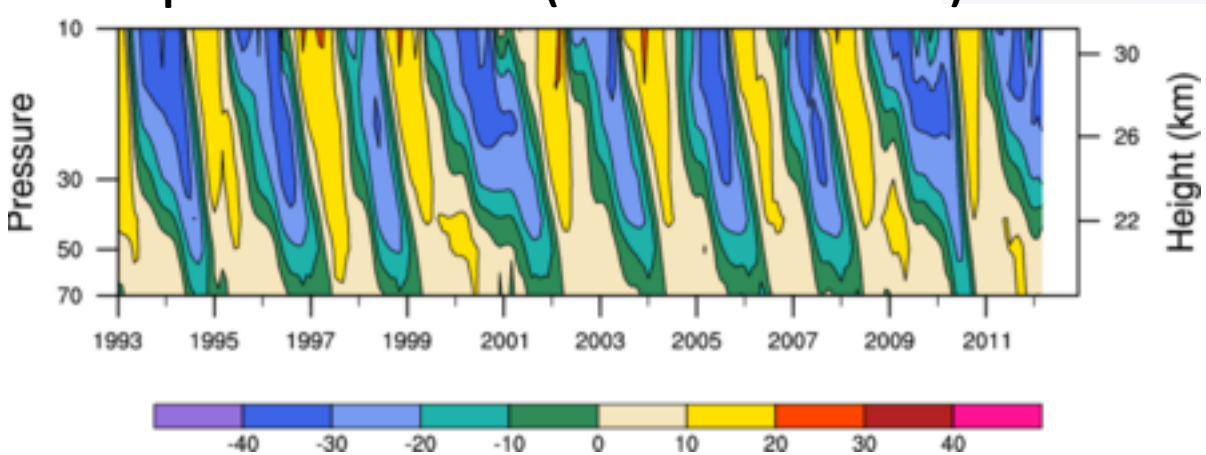
Tropical issues include:

1) Tropical tropopause layer wave temperature fluctuations and effects on stratospheric dehydration

2) Driving the Quasi-biennial Oscillation (QBO) in chemistry-climate models



Stratospheric zonal winds (data from FU Berlin)



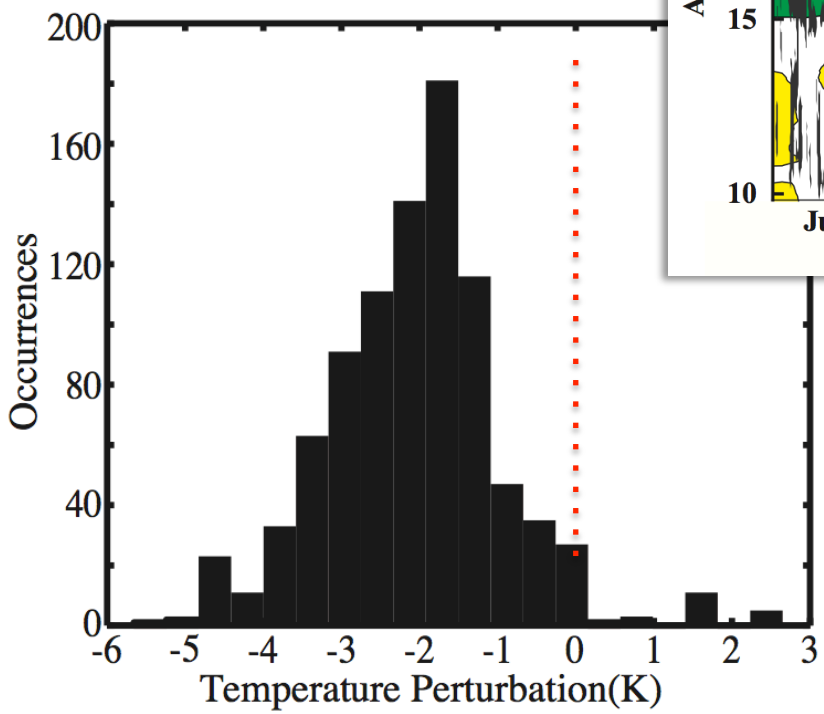
QBO drives interannual changes in lower stratospheric water vapor

Atmospheric Waves and Composition

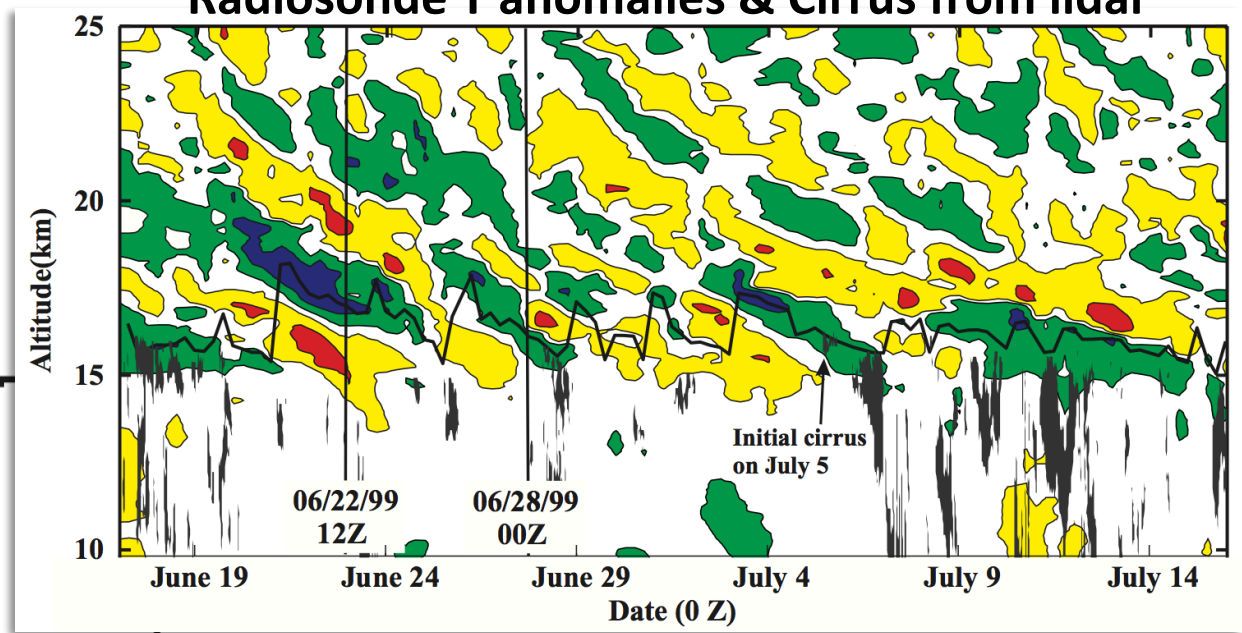
Wave effects on tropical cirrus

Boehm & Verlinde [2000]

- Observations at Nauru Is. equatorial Pacific
- Tropical cirrus modify the radiative balance



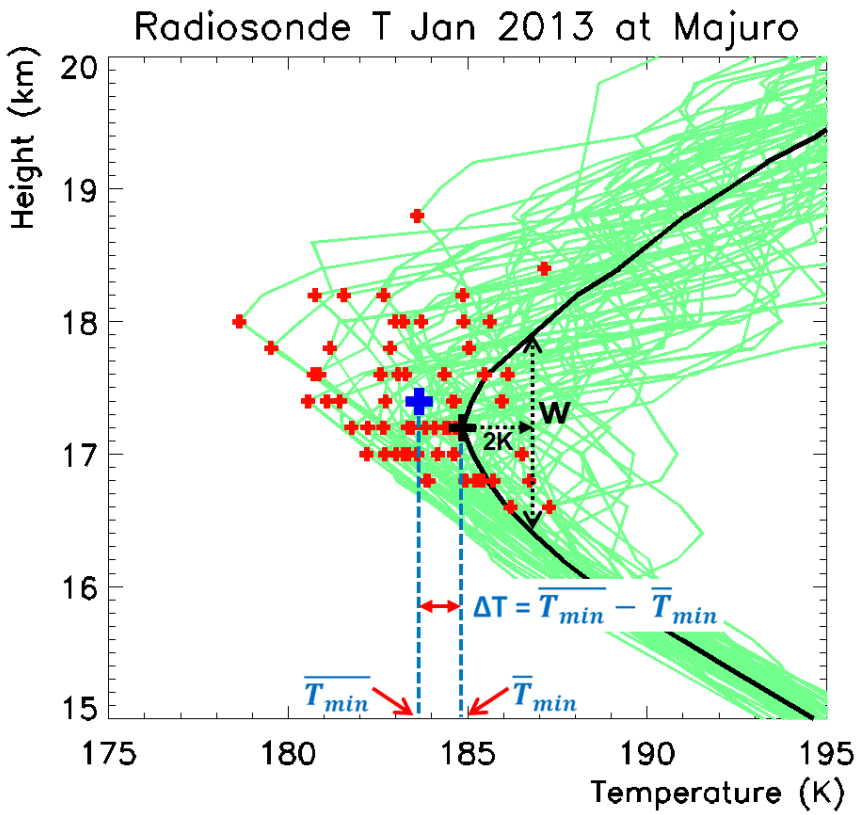
Radiosonde T anomalies & Cirrus from lidar

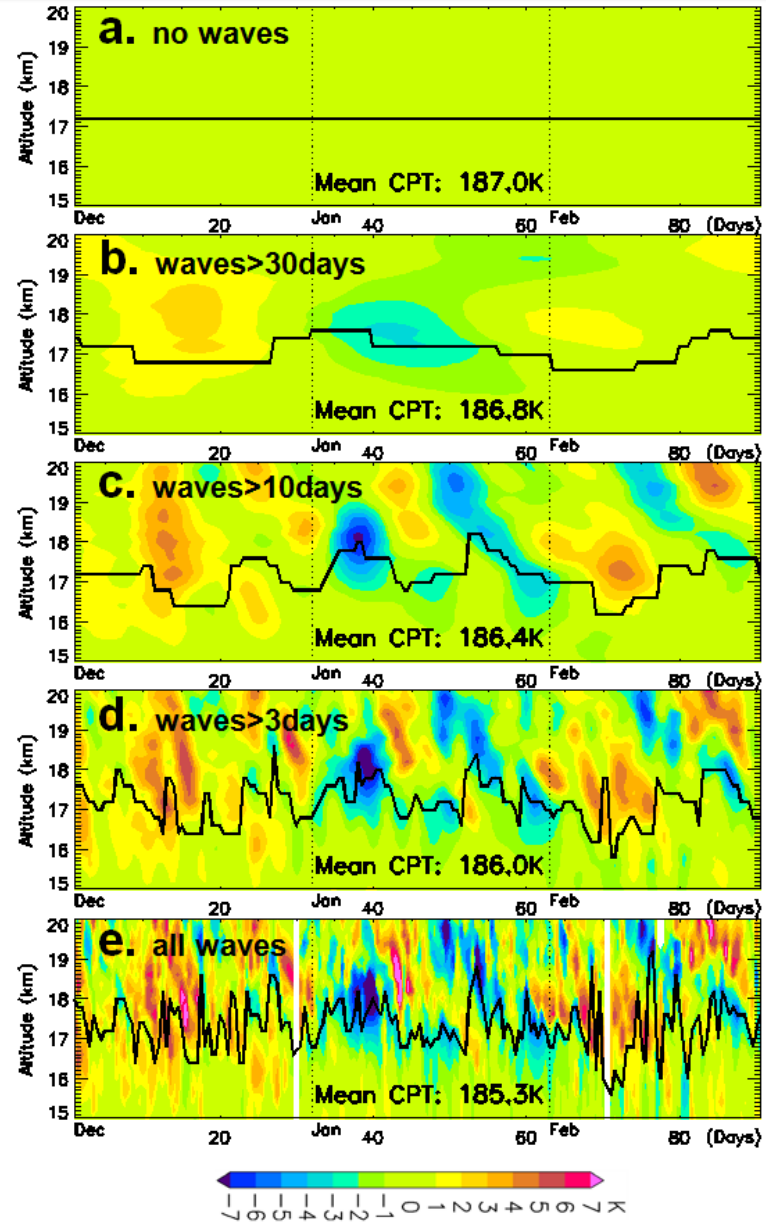


Cirrus occurrence above 15 km… almost exclusively in cold phases of tropical waves

Atmospheric Waves and Composition

Tropical waves effects on the Cold Point Tropopause [Kim & Alexander, 2014]





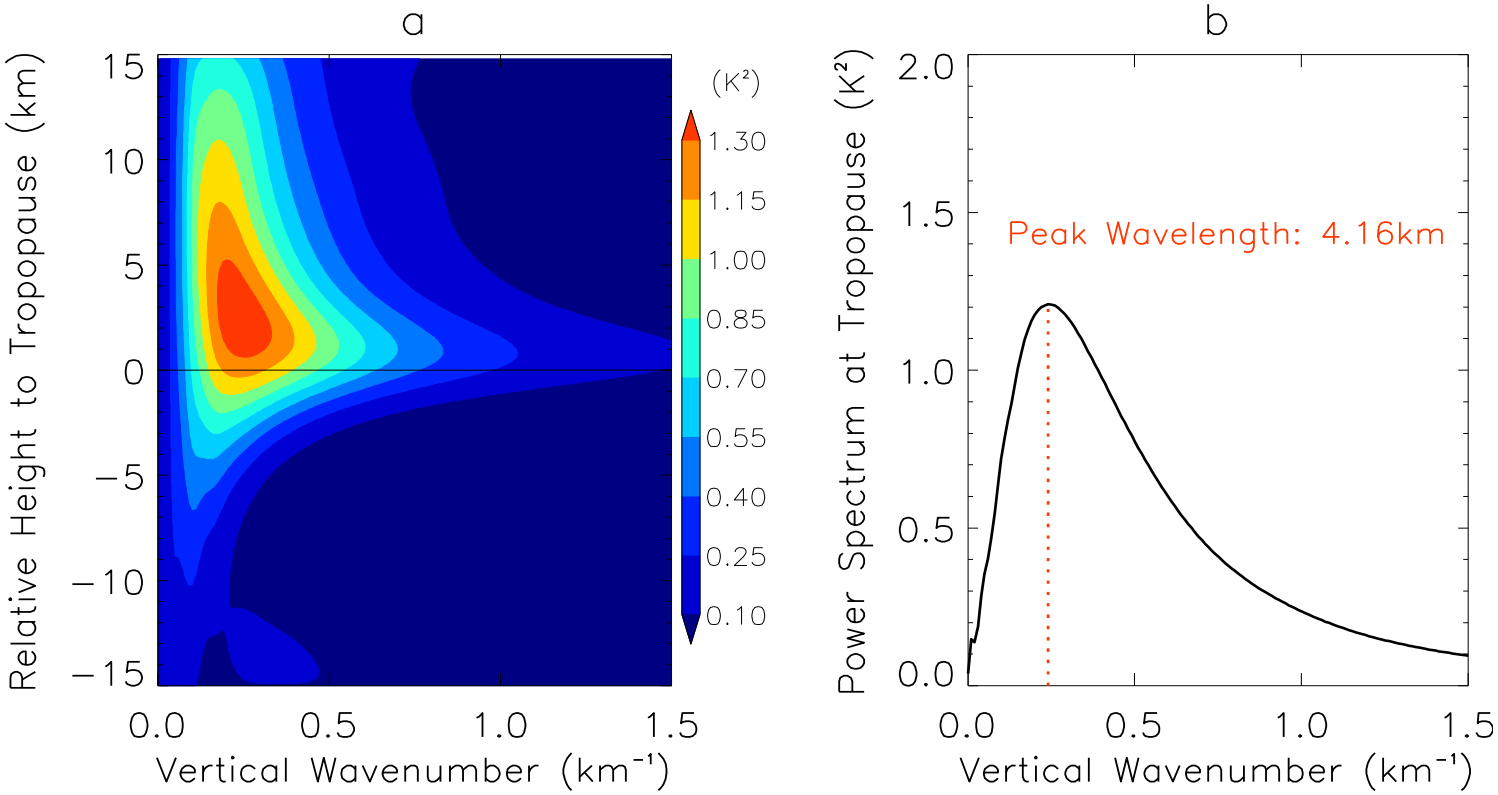
- New work submitted to *Nature-Geoscience*

Waves of all frequencies significantly influence CPT and stratospheric dehydration →

Atmospheric Waves and Composition

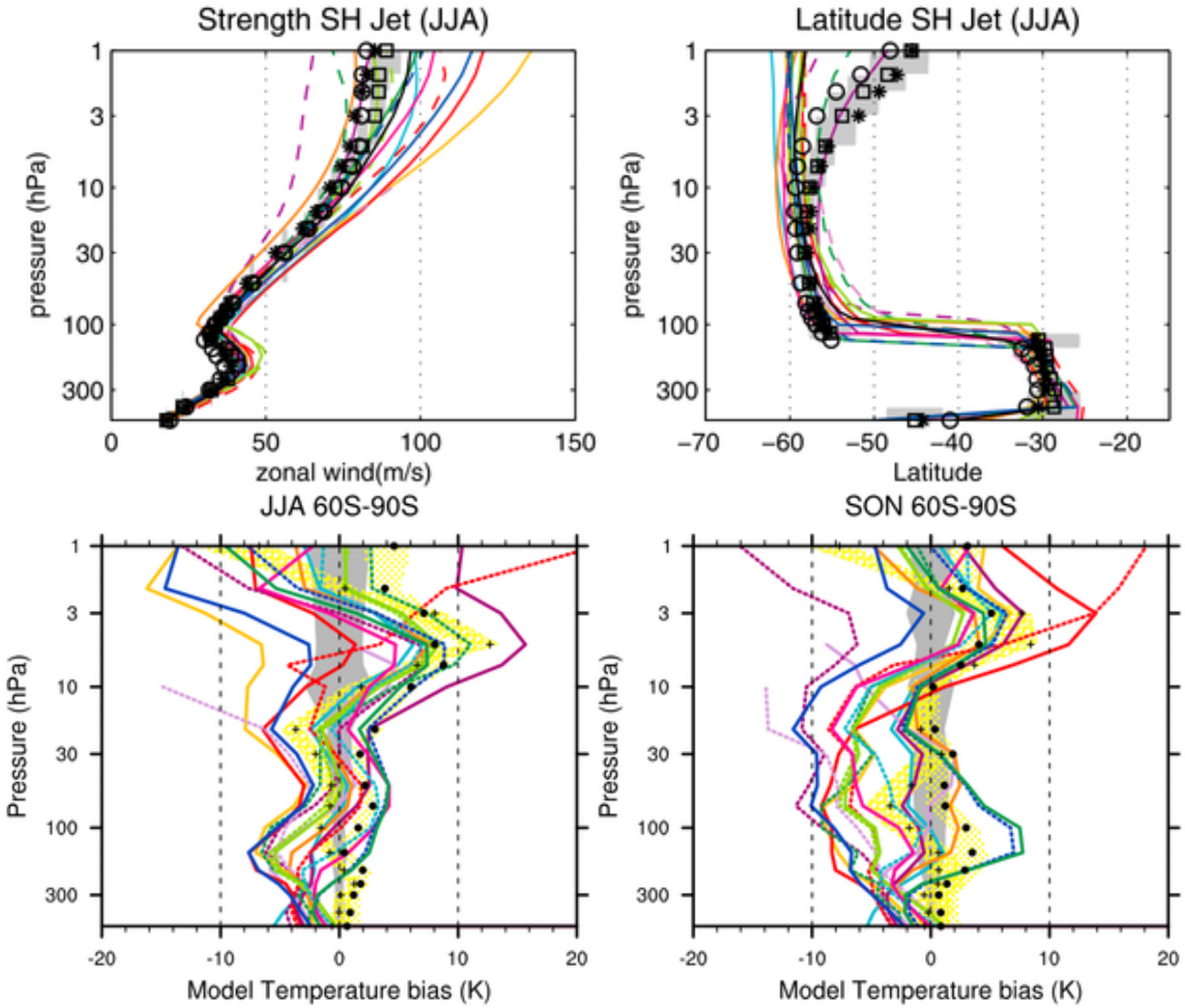
Tropical waves effects on the Cold Point Tropopause [Kim & Alexander, 2014] (submitted to *Nature-Geoscience)*

- Wavelet analysis of vertical structure of waves influencing the tropical tropopause layer reveals short vertical structure



Dynamics ⟷ Chemistry

Butchart et al. [2011]: CCM circulation and temperature biases in SH

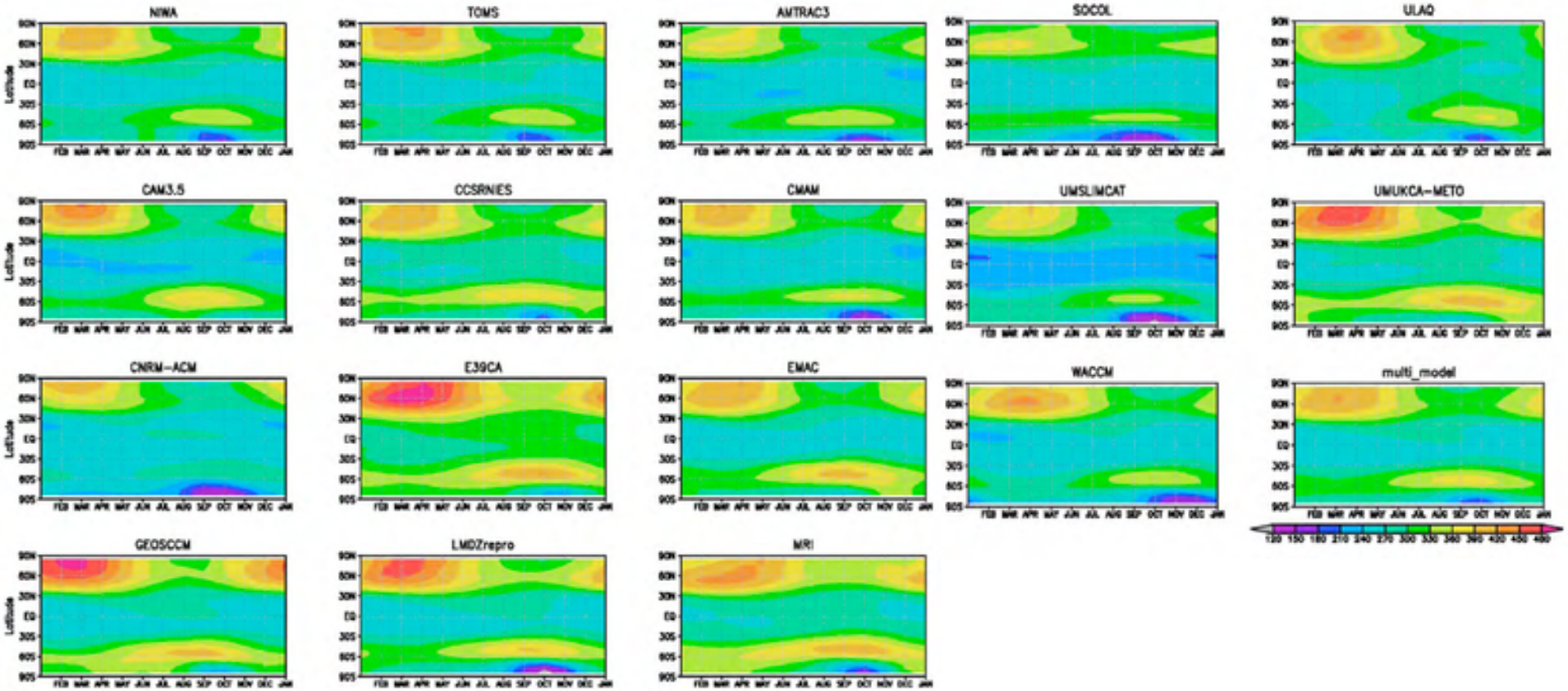


Large errors in SH circulation are common in CCMs

Large temperature biases are common in springtime

Dynamics ⟷ Chemistry

Eyring et al. [2010] Yet most models produce realistic simulations of O_3

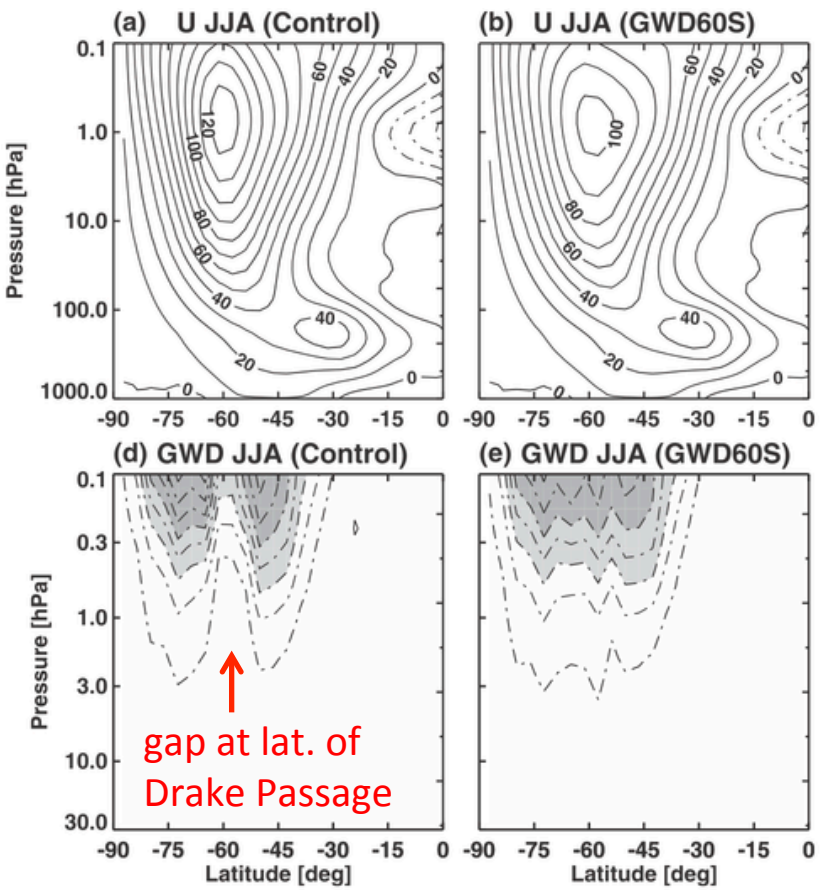


- Column ozone versus time and latitude
- Observations and models from the CCMVal-2 report

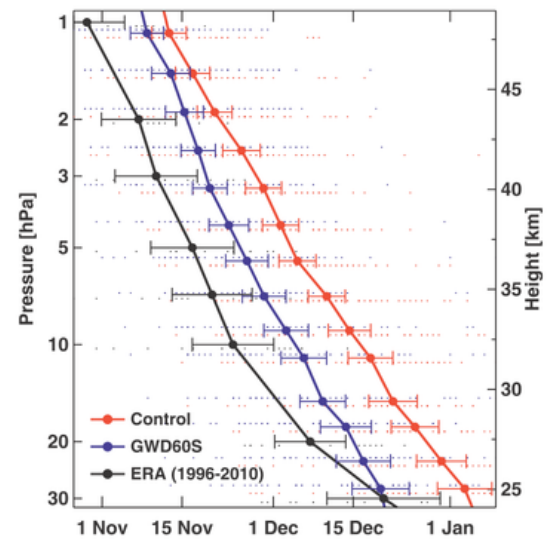
Dynamics ⟷ Chemistry

McLandress et al. [2012]– Gravity wave drag effects on SH circulation & O_3

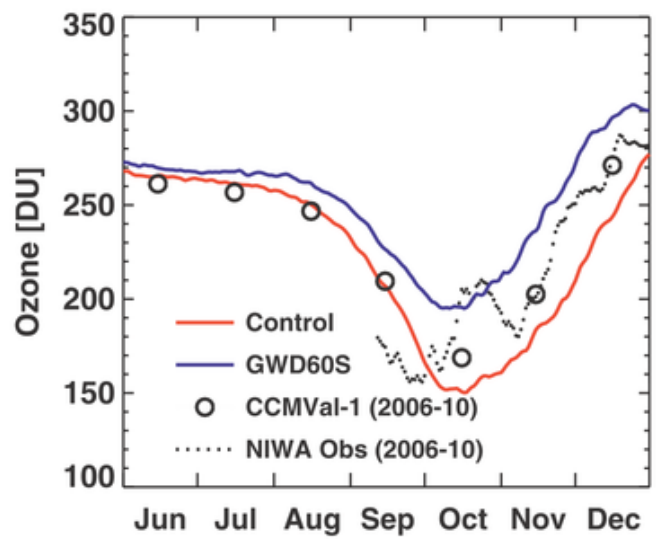
Addition of gravity wave drag in Southern Hemisphere reduces winter wind bias.



Improves the timing of the seasonal transition to easterlies →

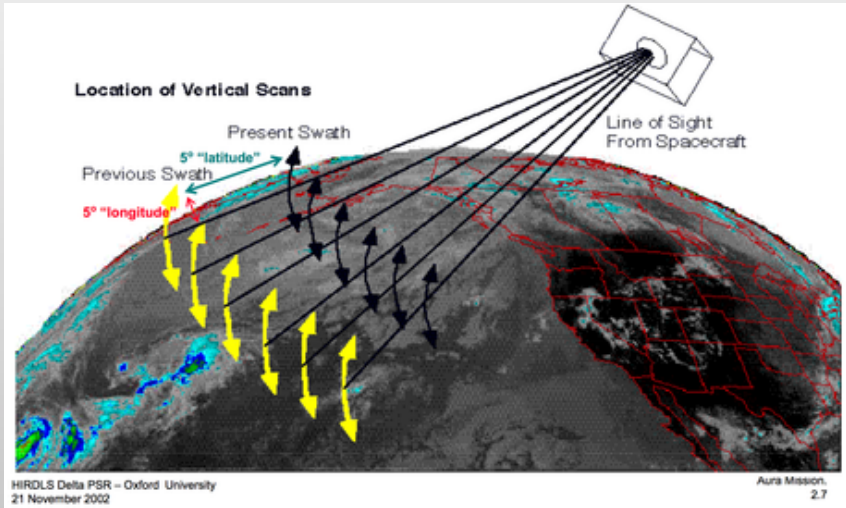


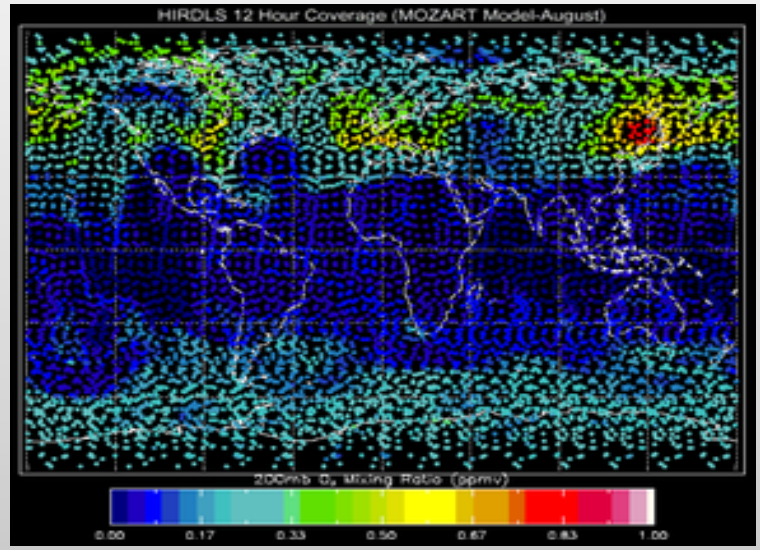
Associated changes in temperature and residual circulation weaken the ozone hole.



High Resolution *Dynamics* Limb Sounder

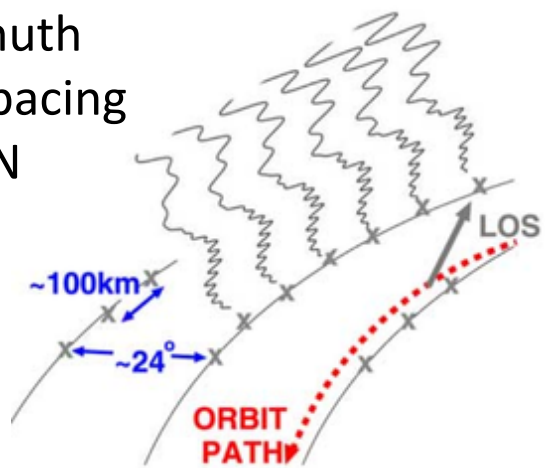
Prelaunch plan: 5°x5° profiles globally

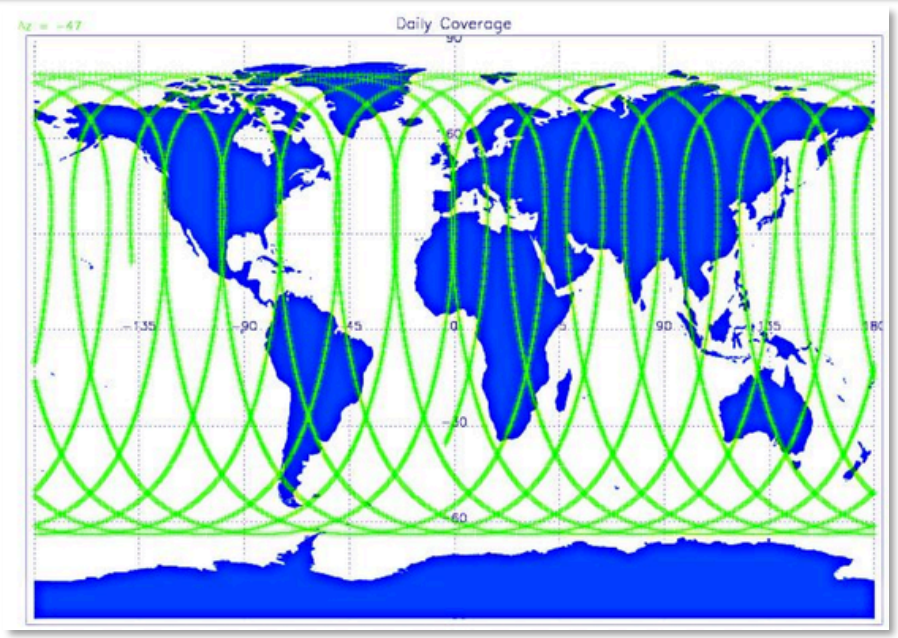




Post-launch reality:

- Single azimuth
- ~100 km spacing
- 64°S – 80°N
- ~1 km Δz

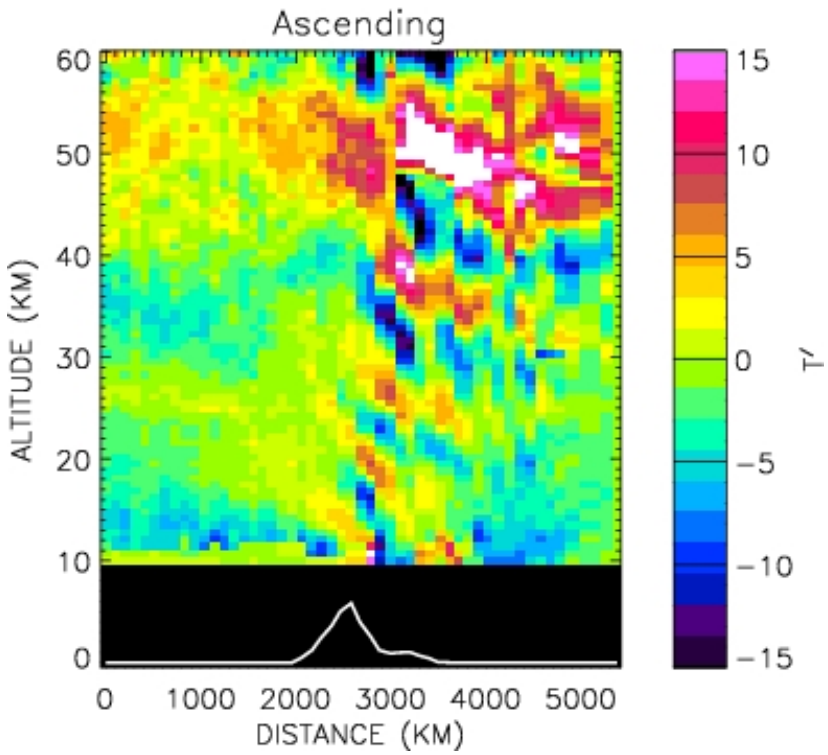




HIRDLS High Resolution Dynamics

Closely spaced profiles are advantageous for observing gravity waves

[Alexander et al. 2008]



HIRDLS remain the best global data available for estimating gravity wave momentum flux

- Wavelet analysis of temperature profiles → vertical wavelength $\lambda_Z(z)$
- Covariance in adjacent profiles → finds coherent signals
- Phase shift $\Delta\phi$ → horizontal wavenumber k_H
- Δr is separation between profiles

$$k_H = \Delta\phi_{i,i+1} / \Delta r_{i,i+1}$$

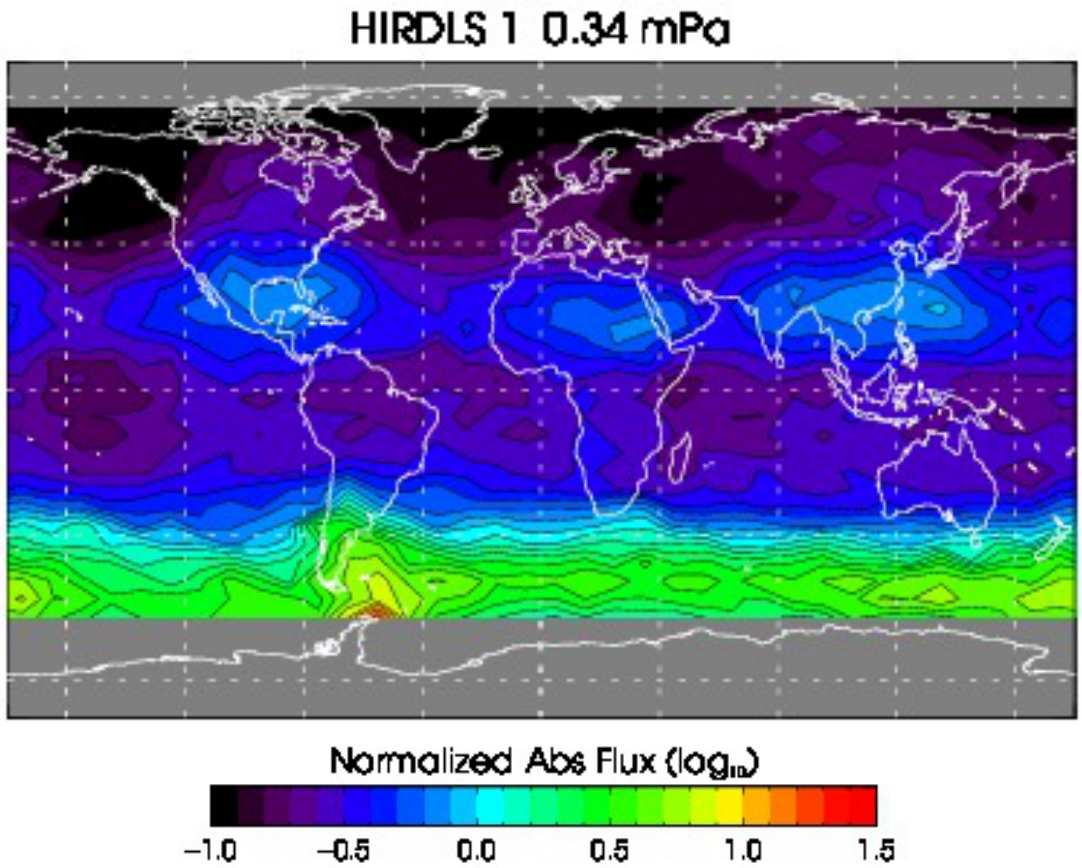
- Estimate momentum flux M:

$$M_{i,i+1} = \frac{\rho}{2} \lambda_z \frac{k_H}{2\pi} \left(\frac{g}{N}\right)^2 \left(\frac{\hat{T}_{i,i+1}}{T}\right)^2$$

- Recent update by Wright & Gille [2013] to include multiple modes

HIRDLS High Resolution Dynamics

Global distributions of gravity wave momentum fluxes [Geller et al. 2013]

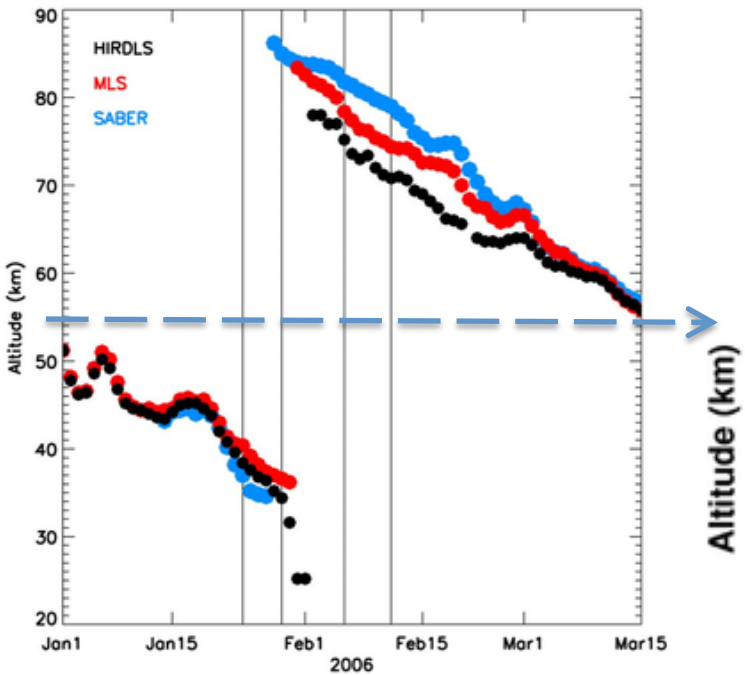


- July map at 20 km shows gravity waves in Southern Hemisphere winter
- Peak fluxes over Andes and Antarctic Peninsula
- Band of enhanced fluxes near 60°S where missing flux occurred in CMAM

Reveals important role for non-orographic gravity waves in SH circulation

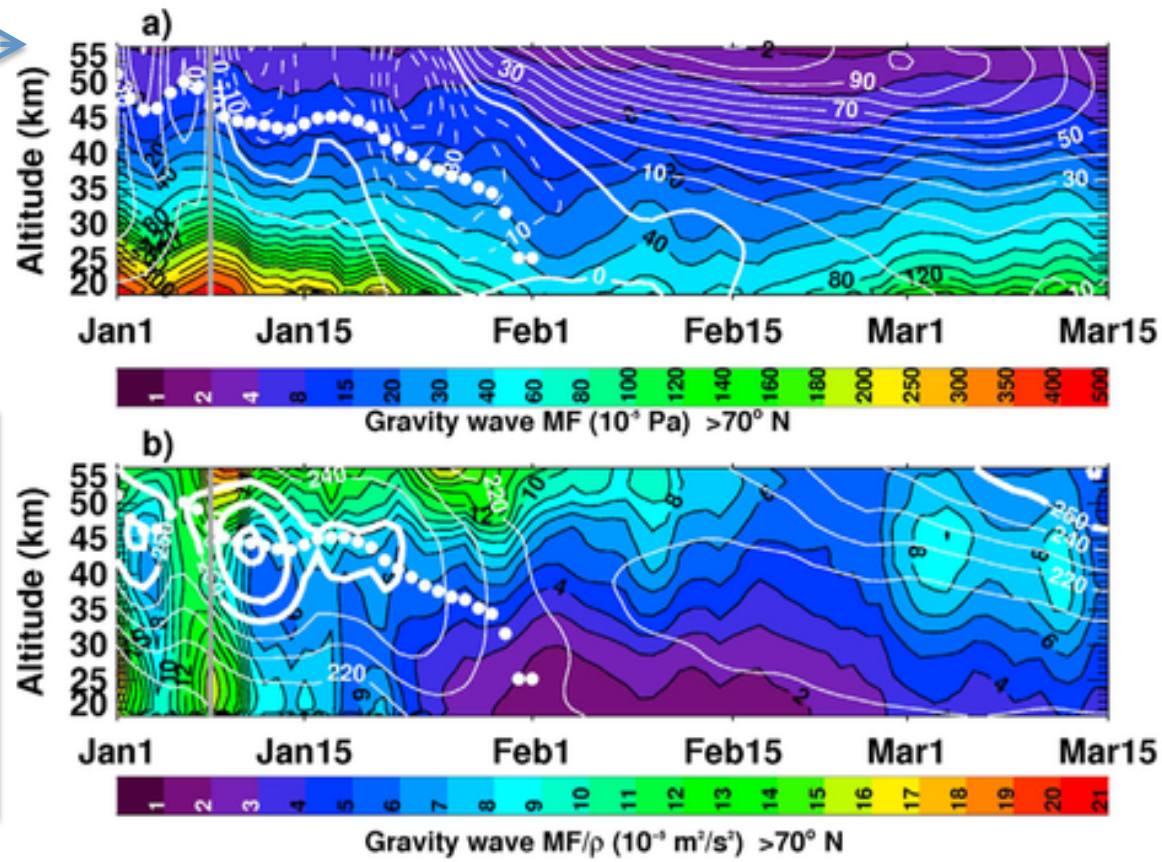
HIRDLS High Resolution Dynamics

Stratopause Height



France et al. [2012]

Role of gravity waves in the dynamics of the elevated stratopause following the 2006 major sudden warming event

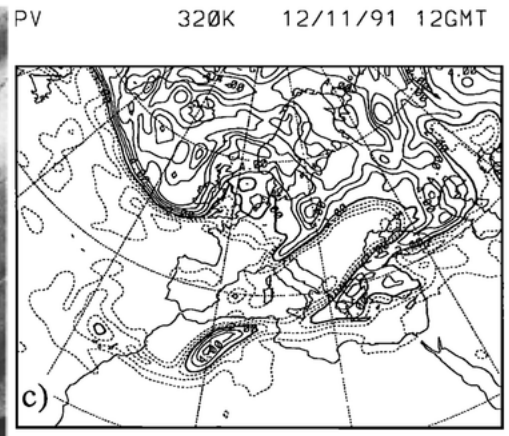


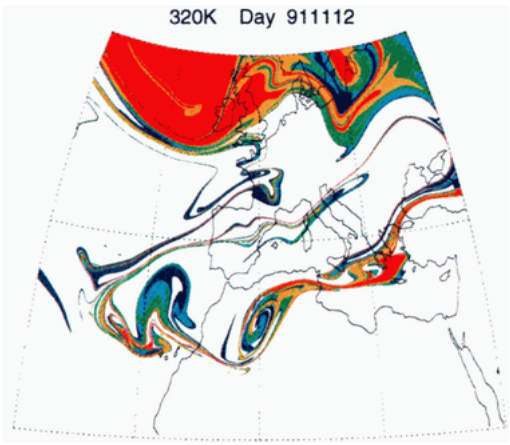
- Gravity wave fluxes are enhanced prior to onset of the Jan 24 SSW
- Enhanced fluxes at higher levels later during elevated stratopause descent

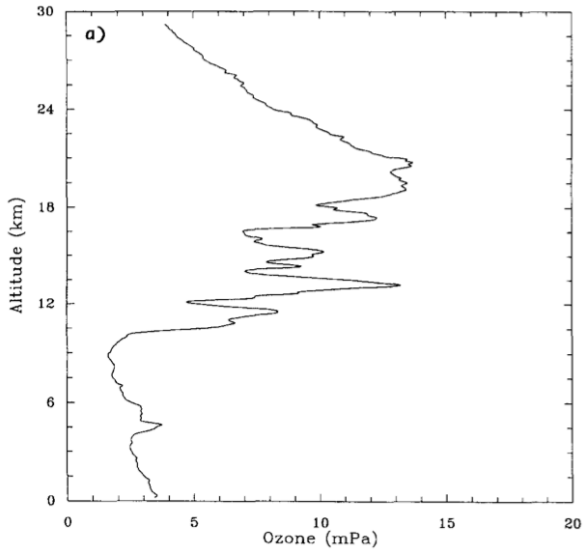
Extratropical Transport

Rossby wave breaking, laminae & intrusions

Appenzeller et al. [1996]





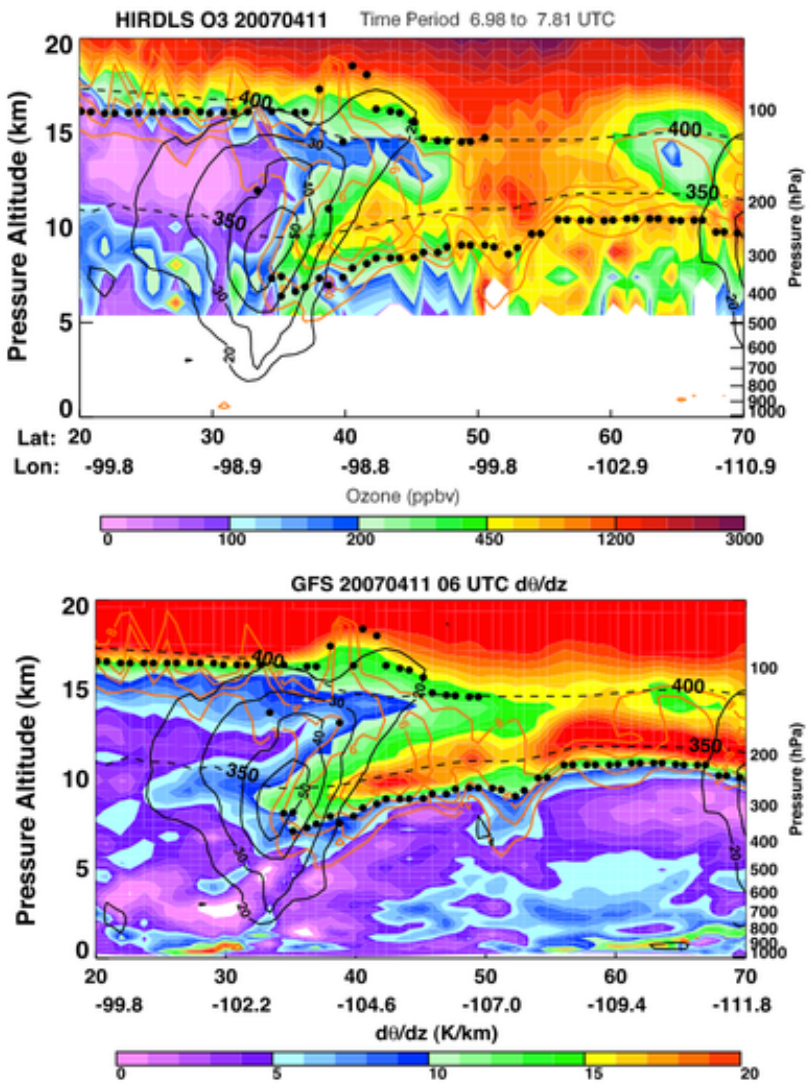


- Laminated structure in ozonesonde profiles (e.g. Teitelbaum et al. [1996])
- Structures due to a mix of inertia gravity waves and large-scale isentropic Rossby wave breaking [Holton, 1987]

HIRDLS High Resolution Dynamics

3-d view of Rossby wave breaking and attendant ozone transport

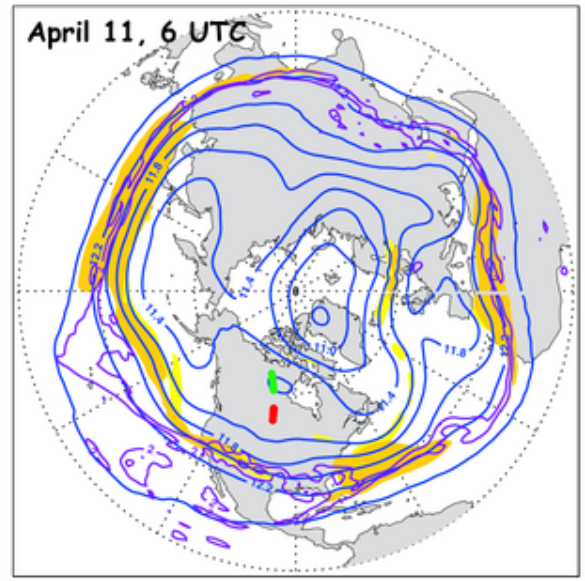
Pan et al. [2009] (also Olsen et al. [2008])

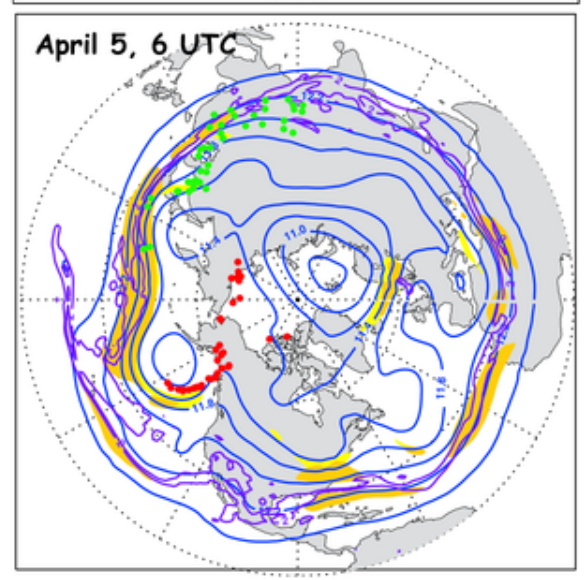


← Low O_3 intrusion to high latitudes

Associated with double tropopause structure

Back trajectory → analysis reveals low-latitude parcels transported in poleward Rossby wave breaking events



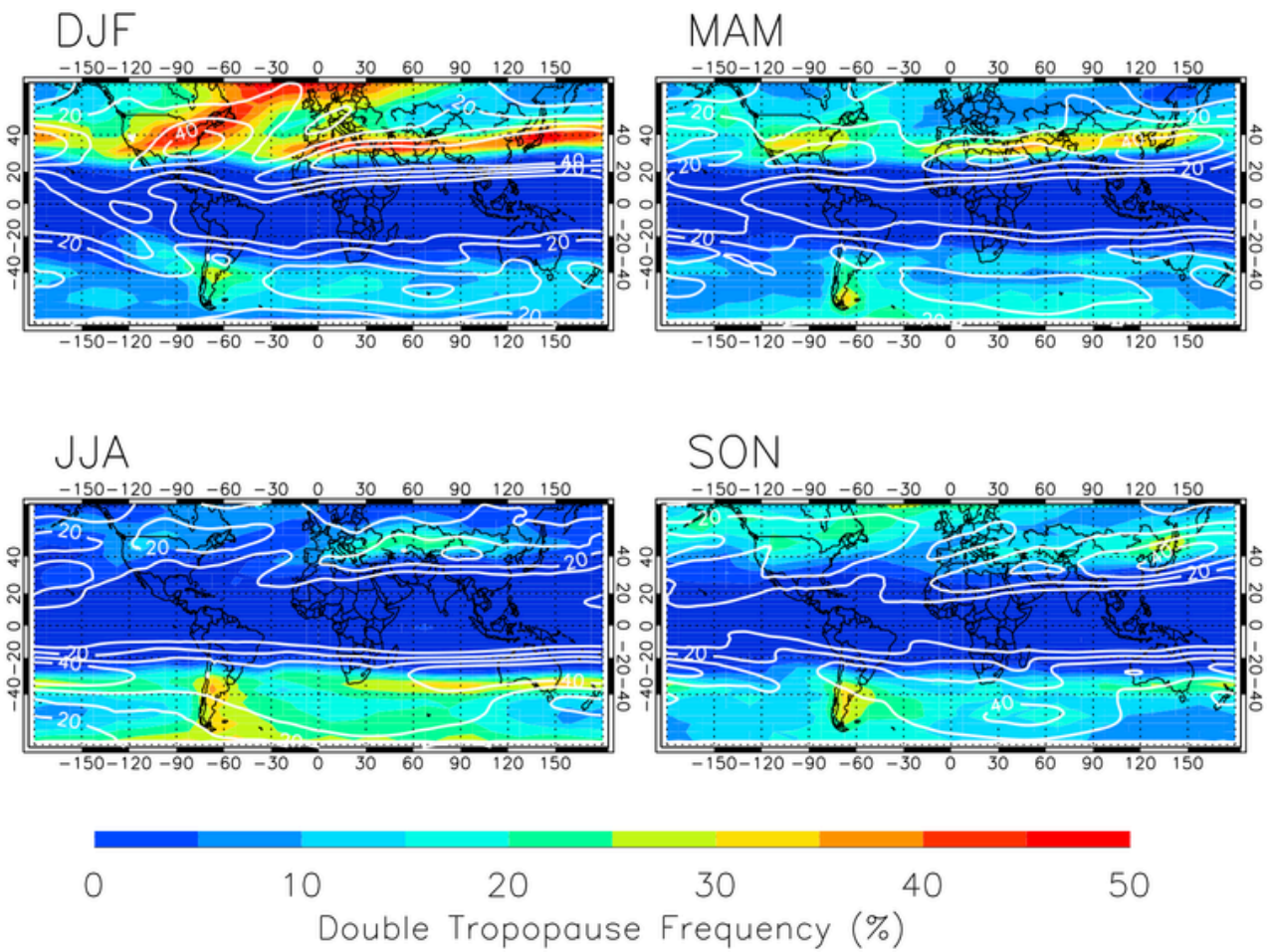


HIRDLS High Resolution Dynamics

Peevey et al. [2012]: Global distribution of Double Tropopause occurrence

High frequencies of occurrence associated with regions of Rossby wave breaking.

Year round enhancement over the high-latitude Andes related to gravity waves.

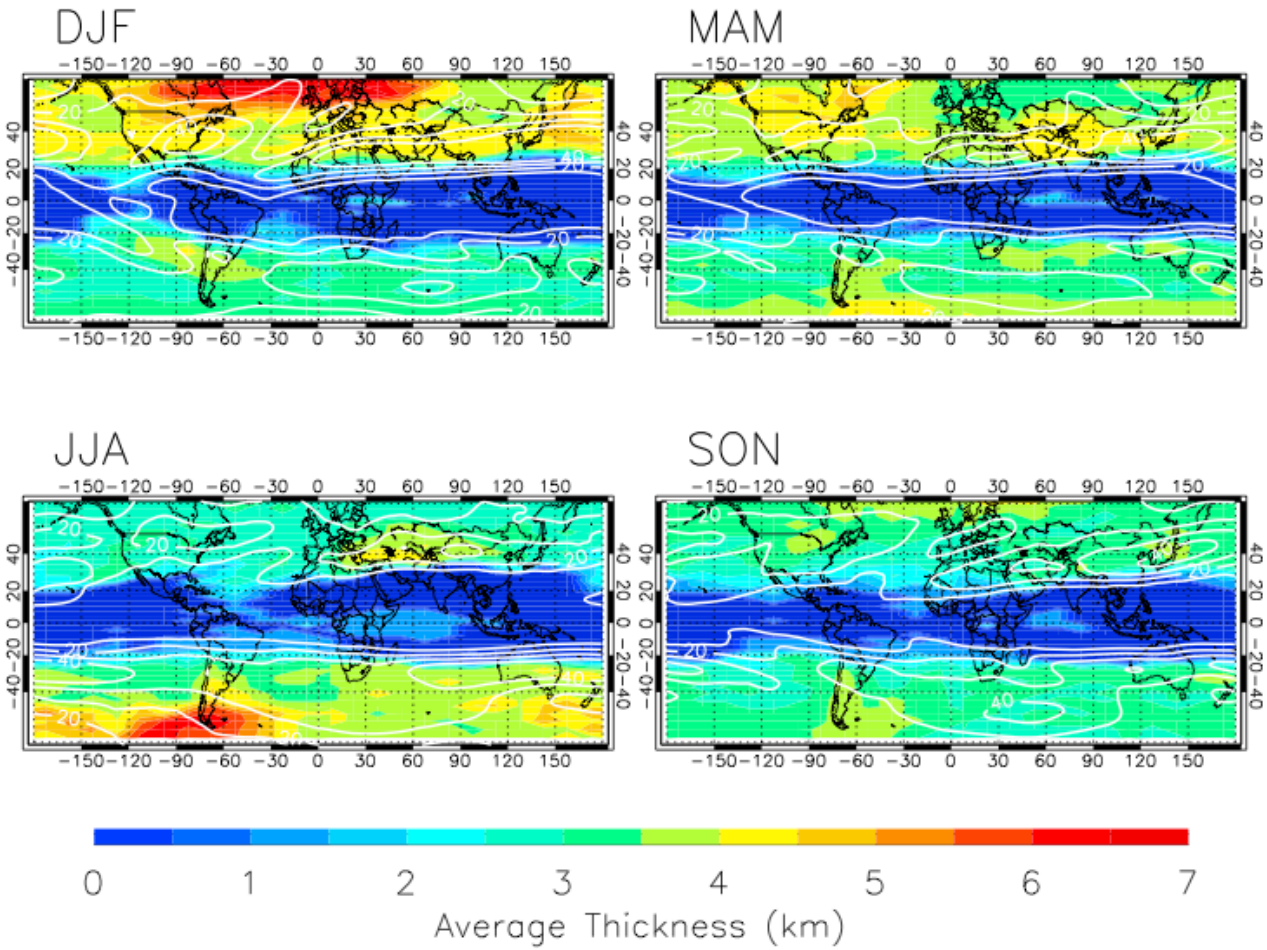


HIRDLS High Resolution Dynamics

Peevey et al. [2012]: Global distribution of Double Tropopause occurrence

Depth of the layer between double tropopauses often only 4-5km

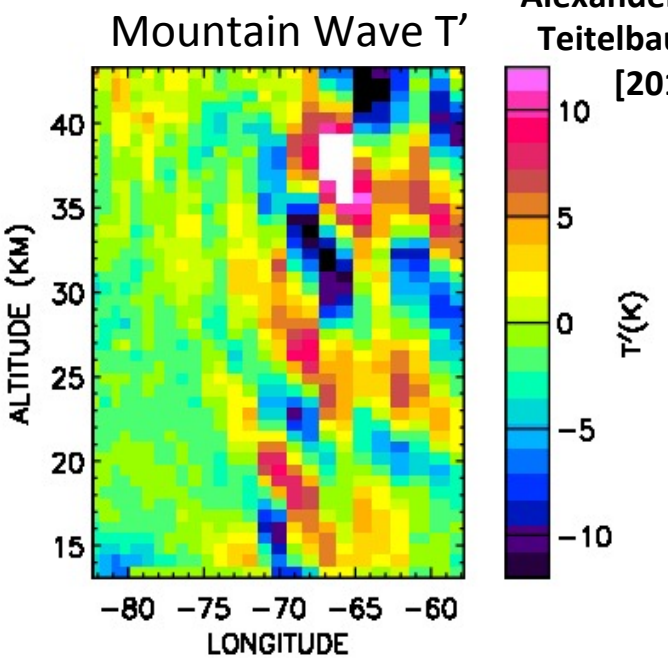
Results highlight the fine vertical scale structure of these Rossby wave breaking features



HIRDLS High Resolution Dynamics

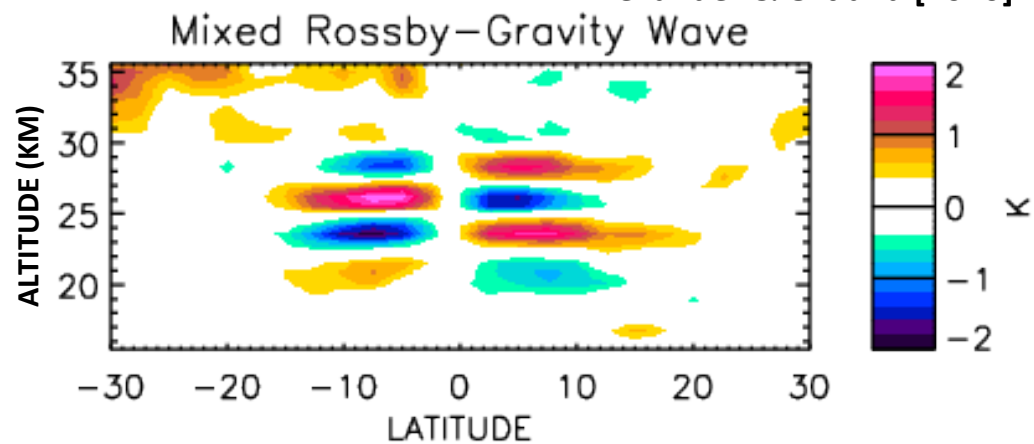
Gravity waves with long vertical wavelengths

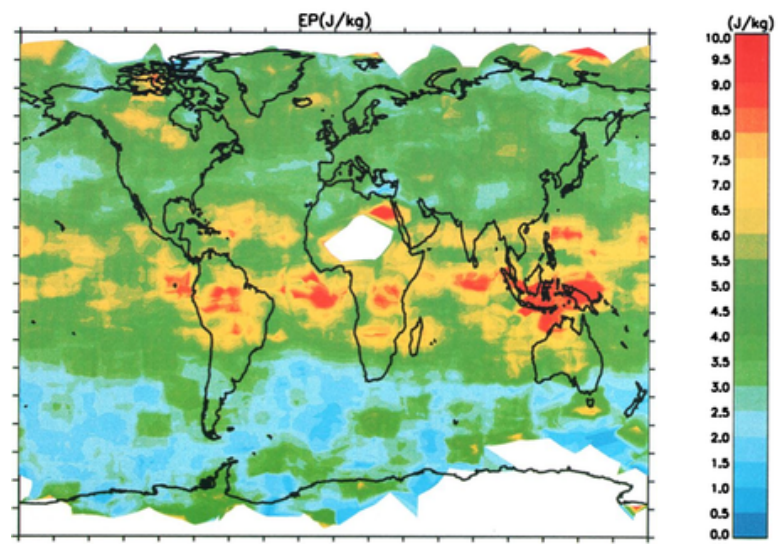
Alexander & Teitelbaum [2011]



Planetary-scale mixed-Rossby-gravity waves with fine vertical structure

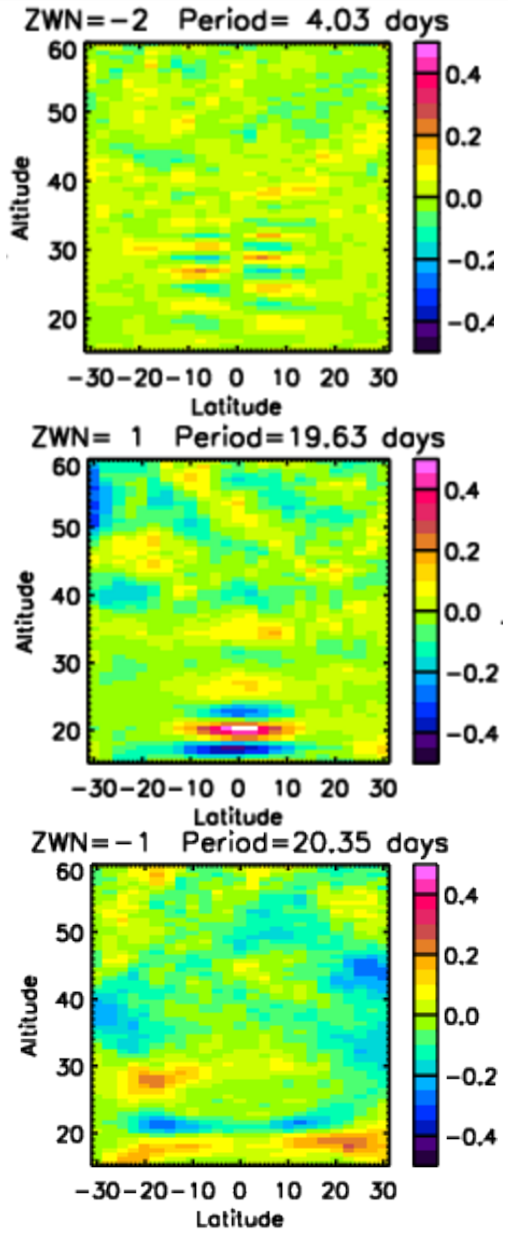
Alexander & Ortland [2010]





- Separation of gravity waves from planetary-scale waves by vertical wavelength was a myth
- Global patterns in short-vertical wavelength variance (e.g. Tsuda et al., 2000) do not isolate gravity waves

HIRDLS High Resolution Dynamics

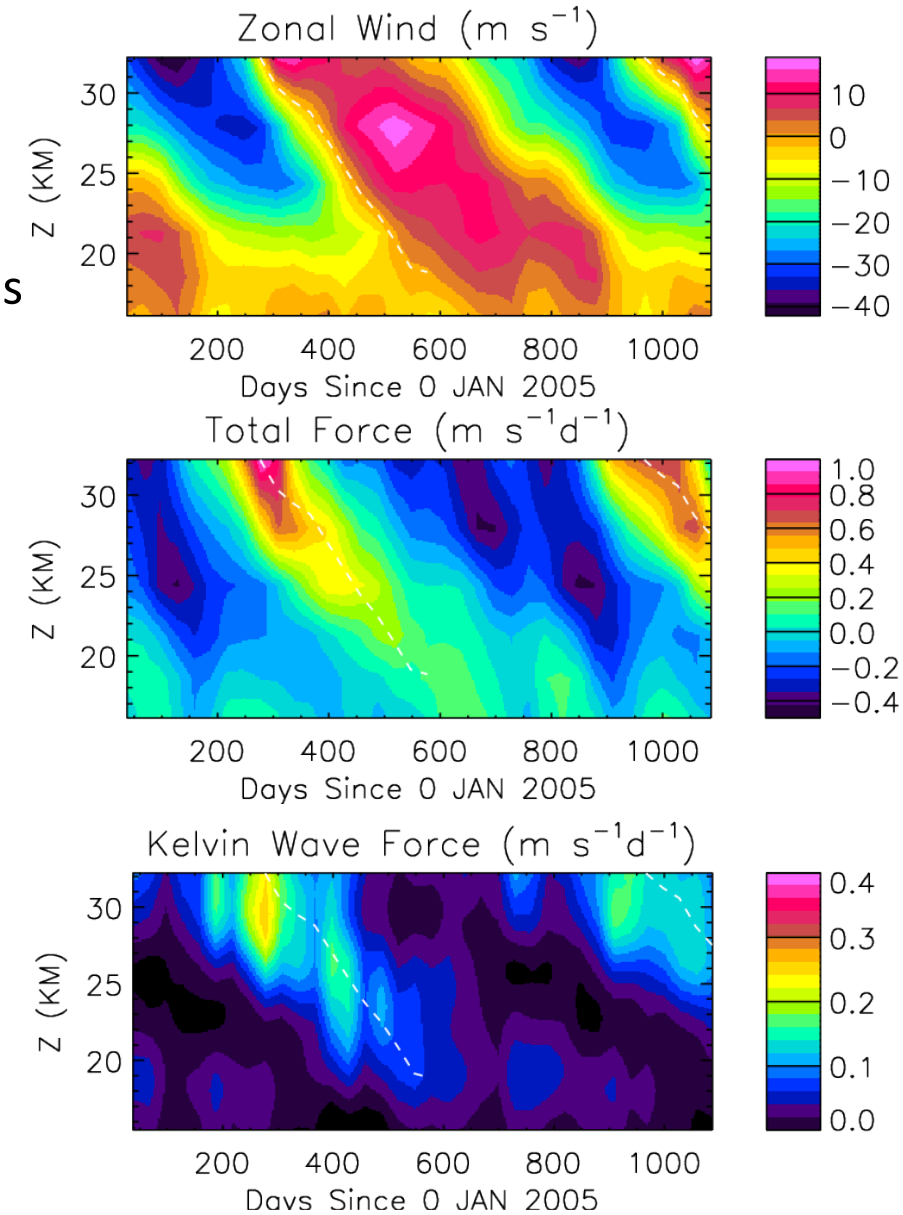


Global-scale waves approaching critical levels in QBO wind shear

- Dissipation occurs at very short vertical wavelengths

Alexander and Ortland [2010]

Kelvin wave driving of the QBO



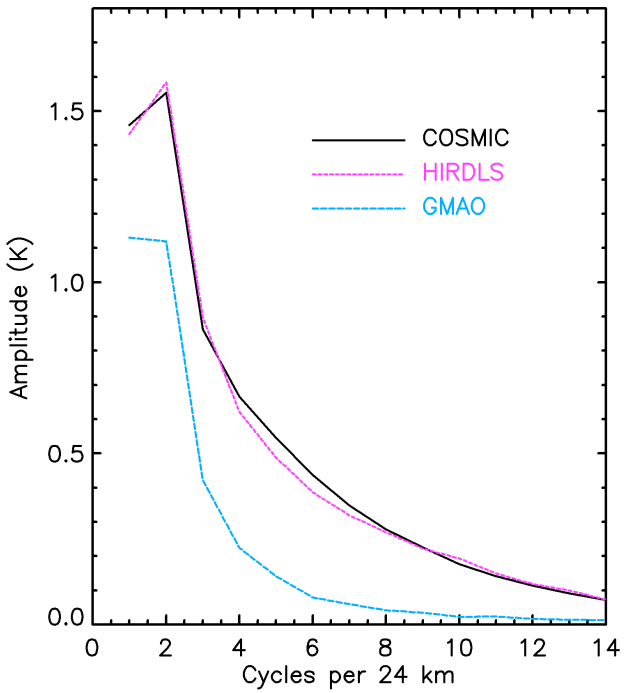
Key Points

- **High resolution temperature measurements have provided new insights into atmospheric dynamics:**
  - Gravity wave momentum fluxes and effects on general circulation
  - Rossby-wave breaking, double tropopause structure, and isentropic tracer transport
  - Tropical wave effects on stratospheric dehydration and QBO dynamics

- **Vertical structure of these phenomena challenge the limits of satellite remote sensing**

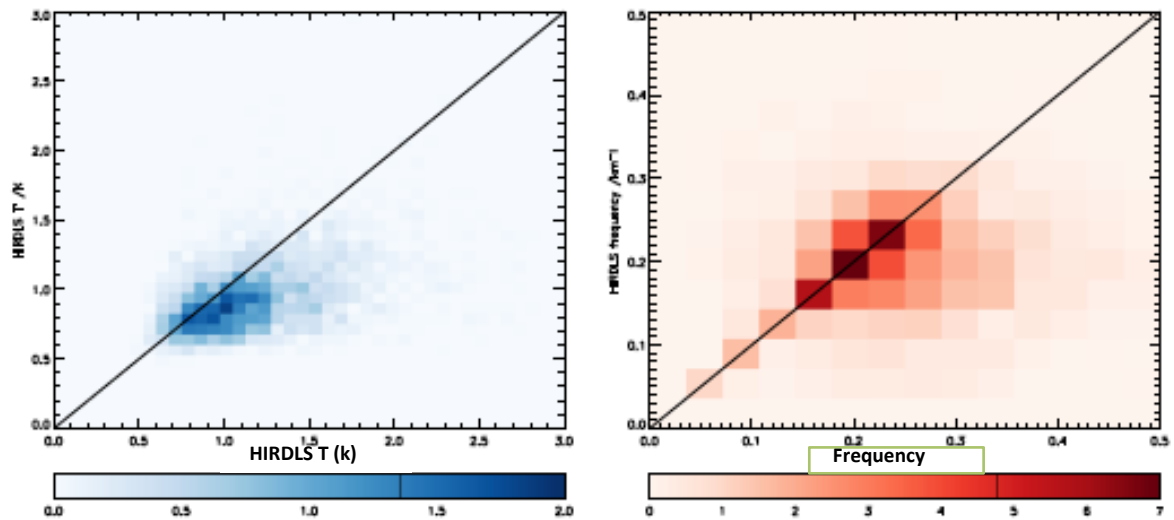
- **Dense horizontal sampling also required for gravity waves but also for many tropical wave modes**

HIRDLS Vertical Resolution Compared to COSMIC and Met Data



Gille et al., 2008 JGR
Barnett et al, 2008, SPIE

Previous analysis compared amplitudes of largest wave components of co-located profiles, suggested HIRDLS & COSMIC RO temperatures had same vertical resolution to 1km.
Wright et al. (2011) did S-Transform, looked at max amplitude wave. Conclusion that HIRDLS resolution was 1 km, COSMIC slightly higher.



Wright et al., 2011