BENCHMARKING CLIMATE MODEL TOP-OF-ATMOSPHERE RADIANCE IN THE 9.6μm OZONE BAND COMPARED TO TES AND IASI OBSERVATIONS

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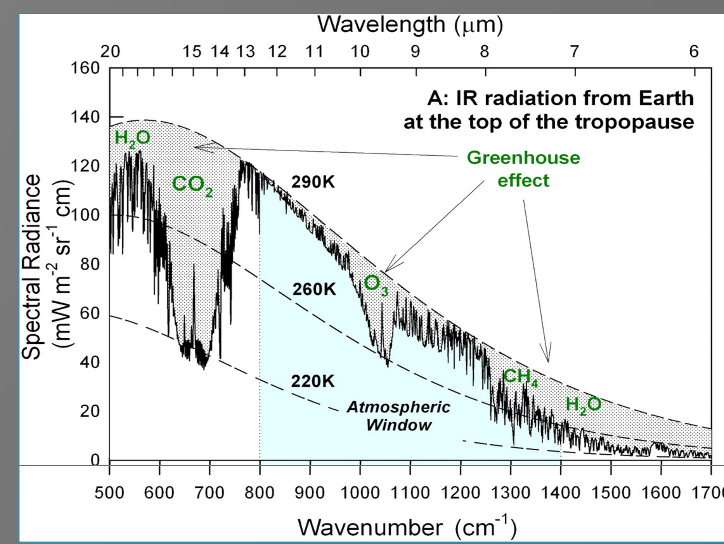
The Problem

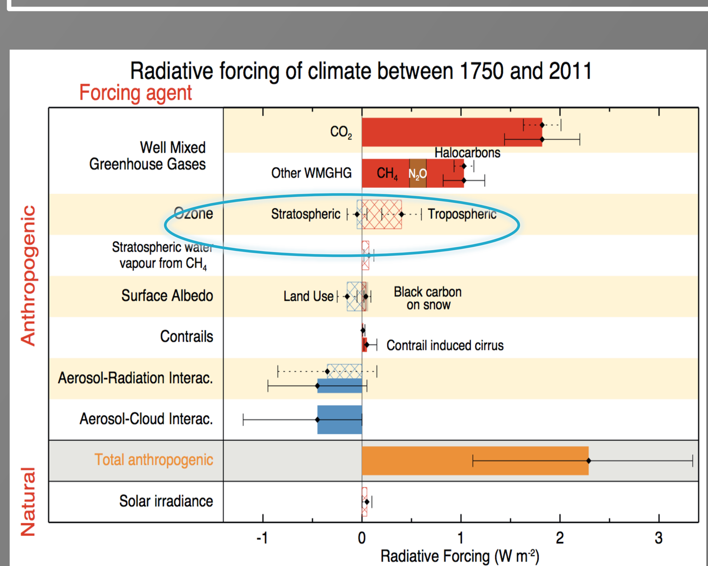
This work addresses two primary questions:

1) What is the bias in IPCC climate model predictions of present day top-of-atmosphere (TOA) flux in the 9.6μm ozone band?

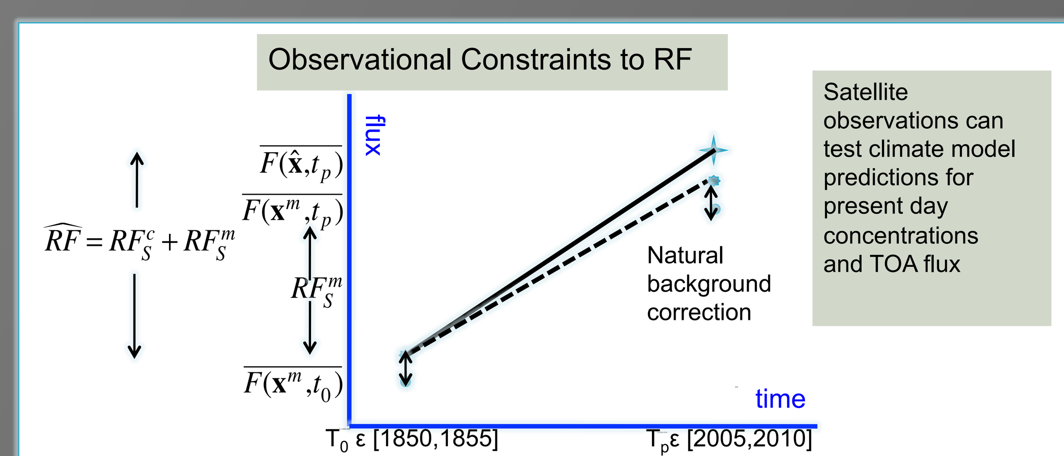
2) What is the impact of an ozone band TOA flux bias on present day tropospheric ozone flux sensitivity and pre-industrial to present day ozone radiative forcing estimates?



Wallington T J et al. PNAS 2010



IPCC AR5



Large range in model estimates for:

Direct Ozone RF

- Preindustrial-to-present day: 0.35 W/m^2 [0.25 to 0.65 W/m^2]
- through 21st century: 0.89 W/m^2

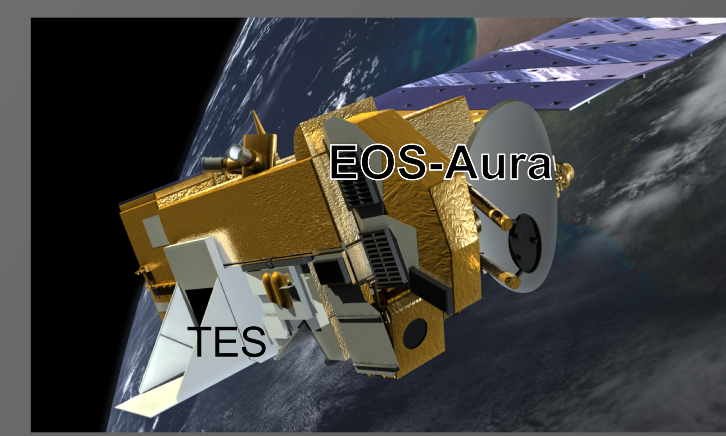
Indirect Ozone RF

Suppression of carbon uptake due to plant damage (Sitch et al., *Nature*, 2007) 0.6 to 1.1 W/m^2

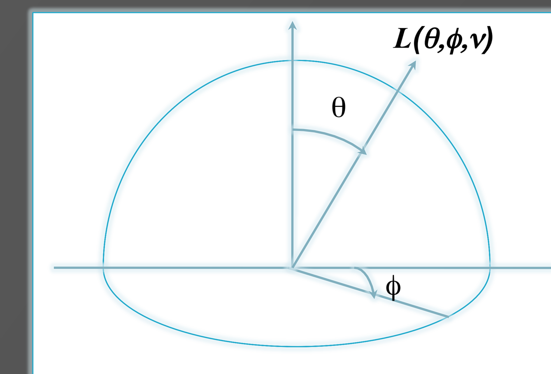
Biases in the IR ozone band TOA flux and flux sensitivity will be tested with CAM-chem, RRTMG and GISS radiative transfer (RT) models using TES and IASI TOA flux and IRKs.

Climate RT Model	Institution	Ozone bands (cm^{-1})	References
CAM-RT (band)	NCAR	1000-1120	Lamarque et al., JGR, 2008; Conley et al., GMD, 2013
CAM-RRTMG (correlated-k)	NCAR/AER	980-1080	Iacono et al., JGR, 2008
GISS-RT (band)	GISS/Duke Univ.	970-1010, 1010-1070, 1070-1210	Schmidt et al., J. Clim. 2006; Shindell et al., ACP, 2013

What TES and IASI measure



	TES	IASI
Instrument	FTS	FTS
Spectral resolution	0.1 cm^{-1}	0.5 cm^{-1}
Spectral coverage	652 to 2251 cm^{-1}	645 to 2760 cm^{-1}
NeΔT	0.30K @ 300 K	0.15K @ 280K
Footprint size	8.5 x 5.3 km^2	12km diameter
Sampling coverage	Sparse global coverage (16 days)	Daily global coverage
Orbit alt.	705 km	817 km
Eq. x-ing	13:30 LST	9:30 LST

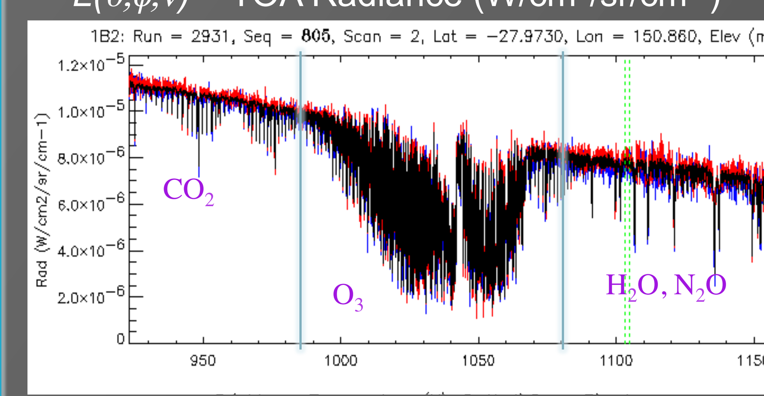


$$F_{TOA} = \int d\nu \int_0^{2\pi}\int_0^{\frac{\pi}{2}} L_\nu(\theta)\cos\theta\sin\theta\, d\theta\, d\phi$$

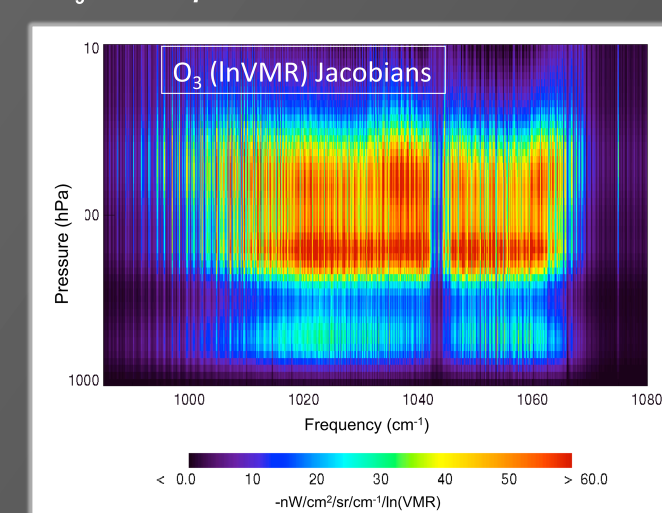
$$IRK = \frac{\partial F_{TOA}}{\partial q_l}$$

$$LWRE = \Delta F_{TOA} = \sum_{l=surface}^{tropopause}\left(\frac{\partial F_{TOA}}{\partial q_l}\right) q_l$$

$L(\theta,\phi,\nu)$ = TOA Radiance (W/cm^2/sr/cm^{-1})

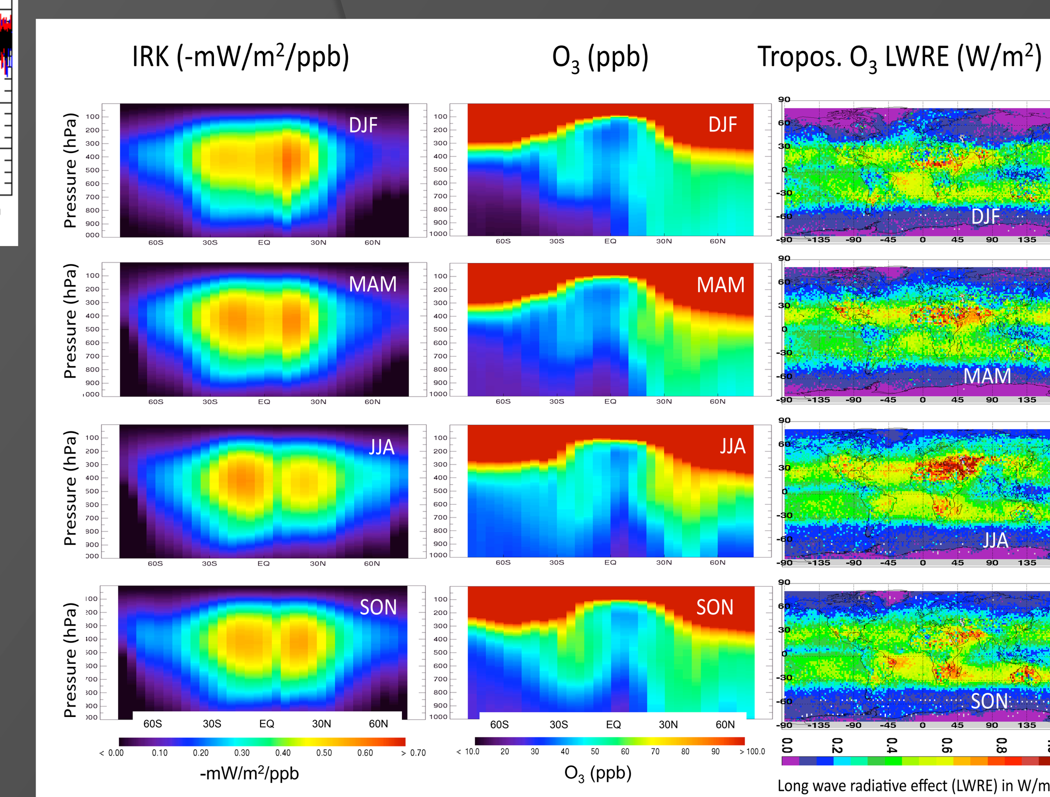


Example of TES spectral radiance used to retrieve O_3 vertical profiles.



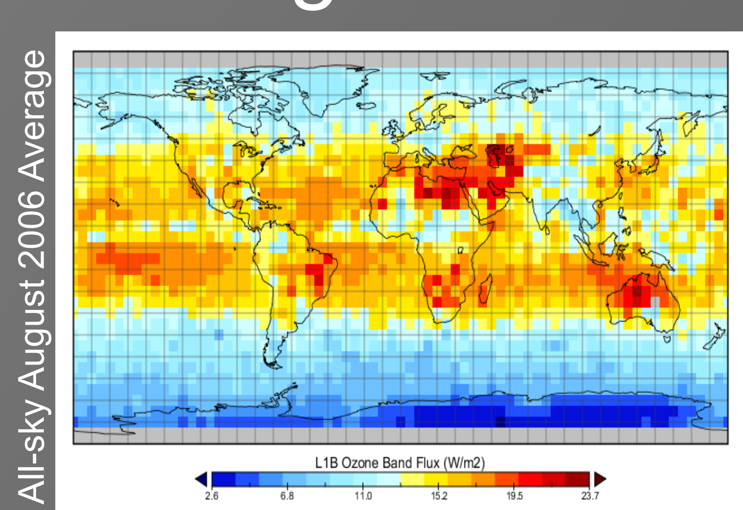
Example of TES Jacobian matrix used in O_3 retrieval and for O_3 IRKs.

$$\frac{\partial L_{TOA}(\nu)}{\partial q_l} = \frac{1}{q_l}\frac{\partial L_{TOA}(\nu)}{\partial \ln q_l}$$



TES all-sky zonal/seasonal averages 2005-2009
Bowman et al., ACP, 2013

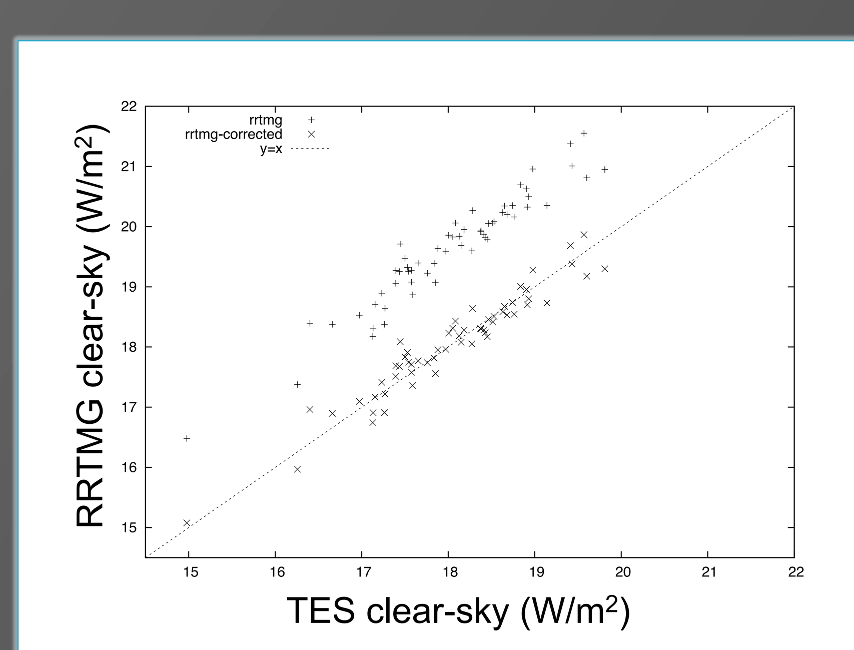
TOA long-wave ozone band flux



TES TOA flux (F_{TOA}) for August 2006

- Similar to OLR but only for the IR ozone band
- This is a fundamental quantity, predicted by climate models, but never tested against observations.

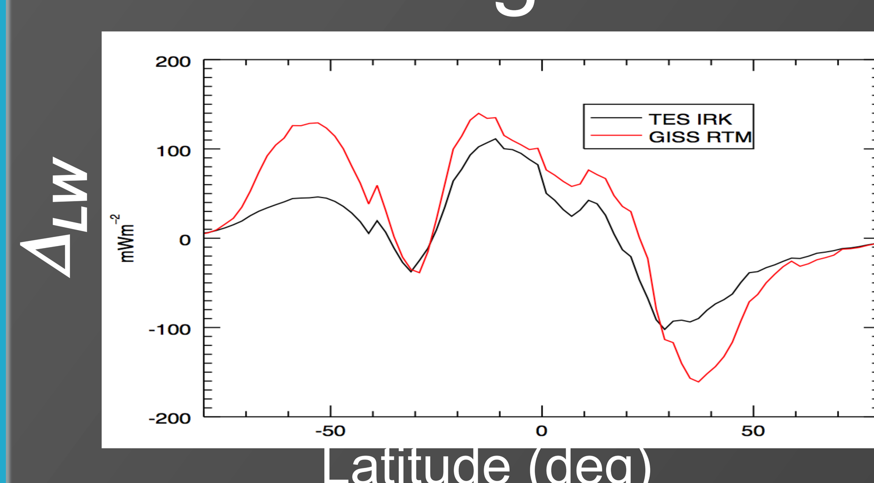
O_3 band flux comparison with RRTMG for atmospheres specified from TES retrievals.



Known issues:

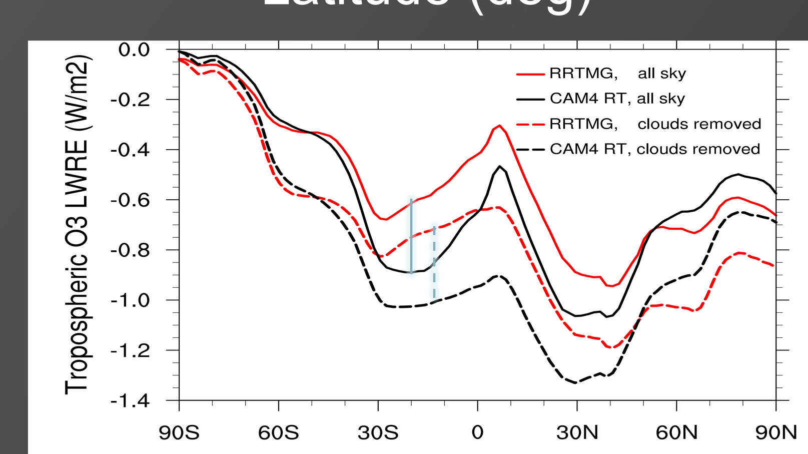
- RRTMG band is 980-1080; TES band is 985-1080 (~1.1 to 1.7 W/m^2)
- RRTMG-corrected adjusts for this difference in frequency range.
- Different estimate of anisotropy
- Assumptions for water vapor in RRTMG
- scatter not due to TES noise (0.1% for flux)

LWRE: Long-Wave Radiative Effect

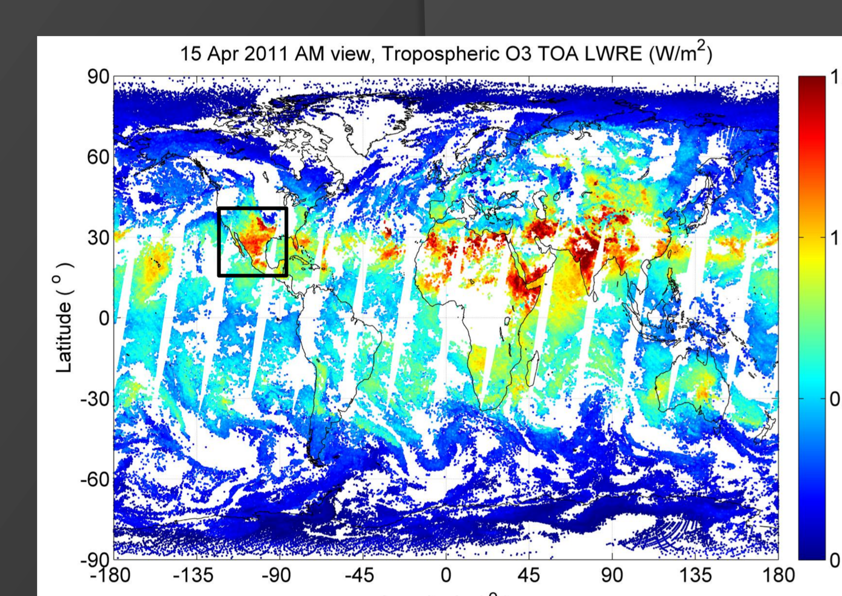


Latitudinal zonal averages of Δ_{LWRE} computed for differences (modeled – observed) in tropospheric ozone distributions using the TES IRK compared to the GISS RTM TOA flux sensitivity.

Positive values for Δ_{LWRE} in the southern hemisphere reflect negative differences in ozone, while the northern hemisphere had positive ozone differences (model higher than observations). Although the ozone difference profiles are identical for both calculations, atmospheric opacity due to clouds, water vapor and temperature could have large differences between the GISS model and TES observations. Since the GISS model has a known dry bias in the upper troposphere at mid-latitudes, [Lamarque et al., 2013, supplement], this could contribute to a higher sensitivity to changes in ozone as compared to TES.

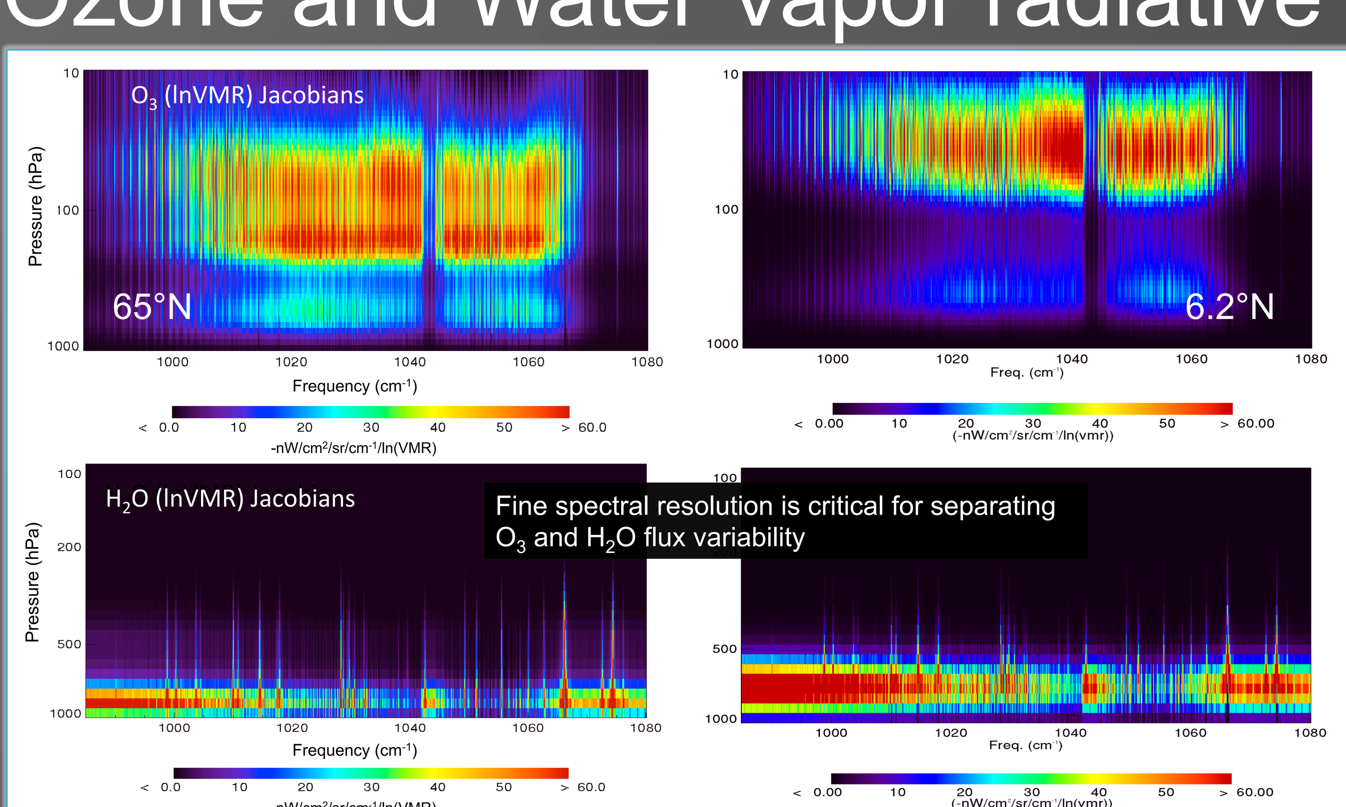


JJA zonal averages for tropospheric ozone LWRE from two RTMs applied to the same atmospheric and surface conditions. Differences are due only to the different assumptions for radiative transfer in CAM4 RT vs. RRTMG. Note the large differences even for clear-sky (clouds removed).

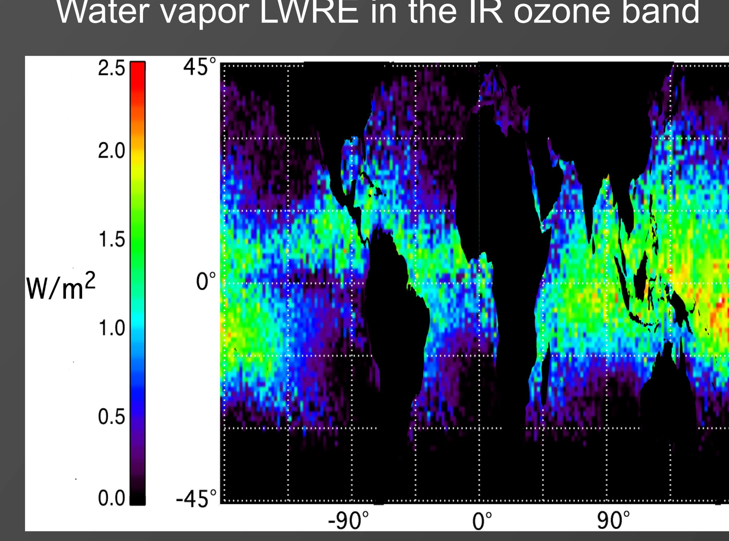


Tropospheric O3 LWRE from IASI on MetOp-A for a single day of observations. White areas indicate clouds and measurement gaps.

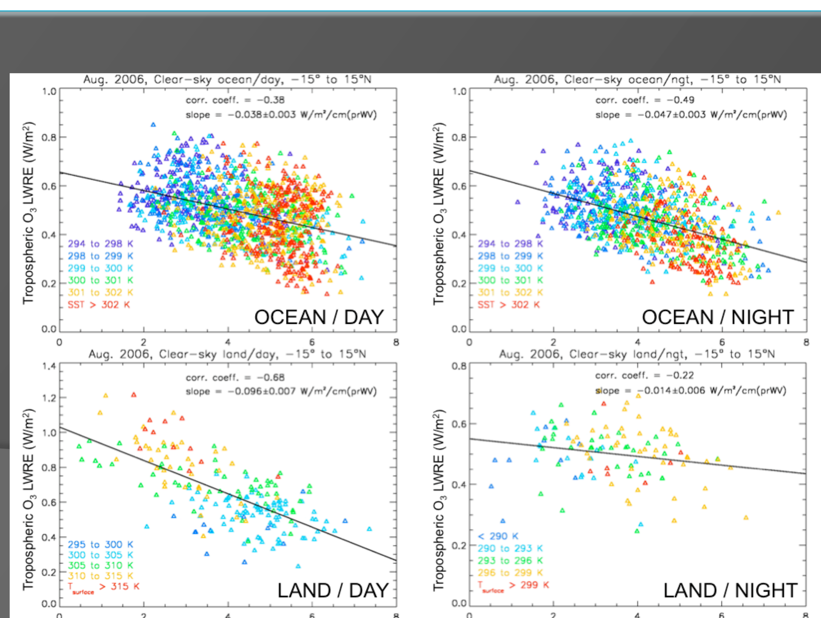
Ozone and Water Vapor radiative coupling



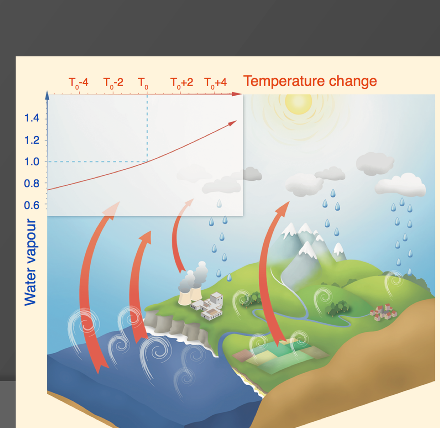
Water vapor LWRE in the IR ozone band



Worden et al., Nature GEO, 2008



Worden et al., JGR, 2011



IPCC AR5 FAQ 8.1 Fig. 1: Water cycle with water vapour feedback ~7%/°C

Attribution of bias in O_3 LWRE due to model/data differences in atmospheric state:

Fasullo and Trenberth [2012] showed that IPCC models overestimated relative humidity in the tropical subsidence regions, which was directly related to how the models predicted global mean surface temperature change from a doubling of CO2 (i.e., climate sensitivity). Therefore, we could expect that IPCC chemistry-climate models will have a biased atmospheric state in the tropical subsidence region, which will then lead to biases in the model LWRE due to atmospheric opacity and consequently ozone radiative forcing.

New TES research products to examine O_3 RF feedbacks and bias:

$$\frac{\partial F_{OzoneBand}}{\partial H_2O}, \frac{\partial F_{OzoneBand}}{\partial T_{atmos.}}, \frac{\partial F_{OzoneBand}}{\partial T_{surface}}, \frac{\partial F_{OzoneBand}}{\partial OD_{cloud}}, \frac{\partial F_{OzoneBand}}{\partial P_{cloudTop}}$$

Conclusions

- TOA flux from the IR Ozone band is a fundamental quantity in climate models that has not been compared to measurements.
- Continuing the TES record with IASI data is critical for understanding present day to future changes in O_3 radiative forcing, such as cloud coverage and water vapor feedback.
- Initial results show differences for both flux and flux sensitivity between models and data that need to be reconciled.

http://tes.jpl.nasa.gov/

http://smsc.cnes.fr/IASI/