Use of hyperspectral thermal IR measurements to constrain and attribute climate forcing.

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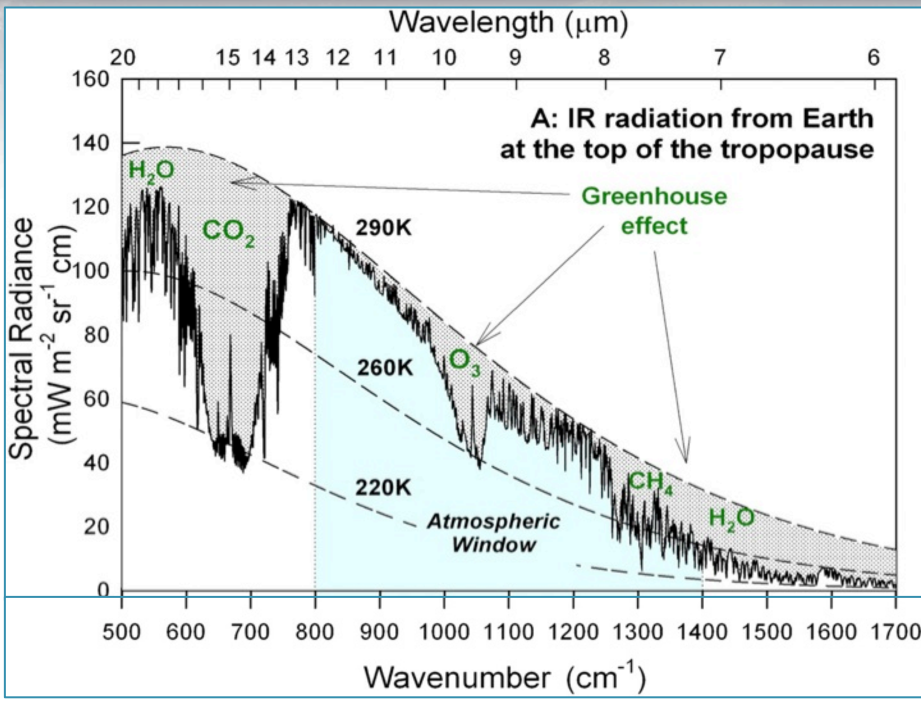
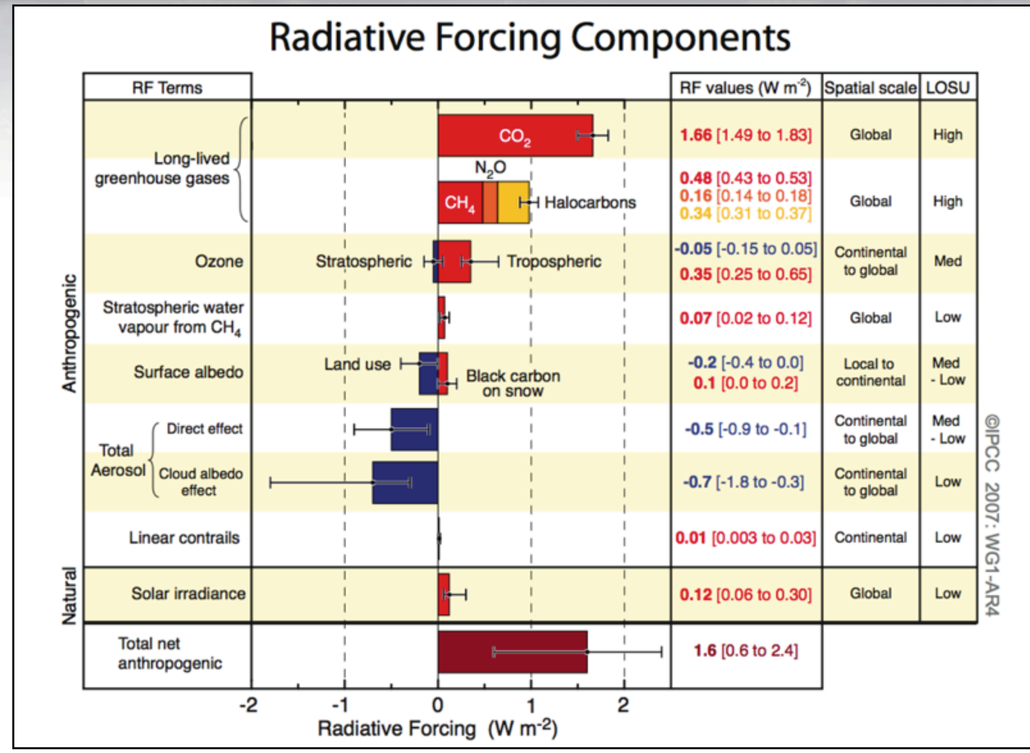
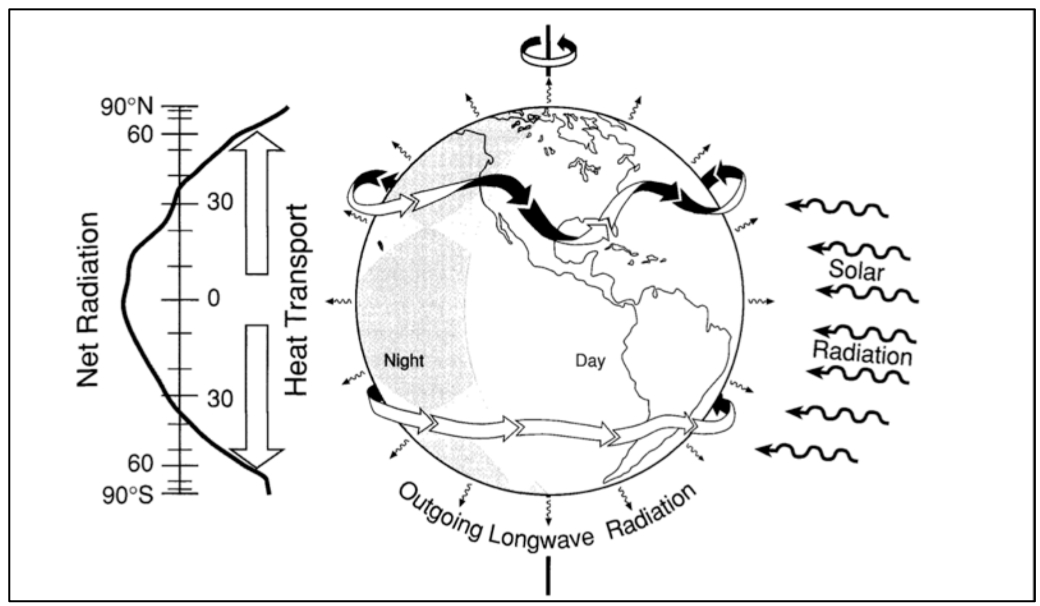
Radiative forcing from atmospheric composition



Wallington T J et al. PNAS 2010;107:E178-E179





Carbon dioxide, methane, and tropospheric ozone are the 3 most important greenhouse gases resulting from anthropogenic activities

As a consequence, the Earth is estimated to absorb 0.58 ± 0.15 watts per square meter more energy from the Sun than it is emitting to space (2005-2010) Hansen *et al*, 2011, Atm Chem. Phys.

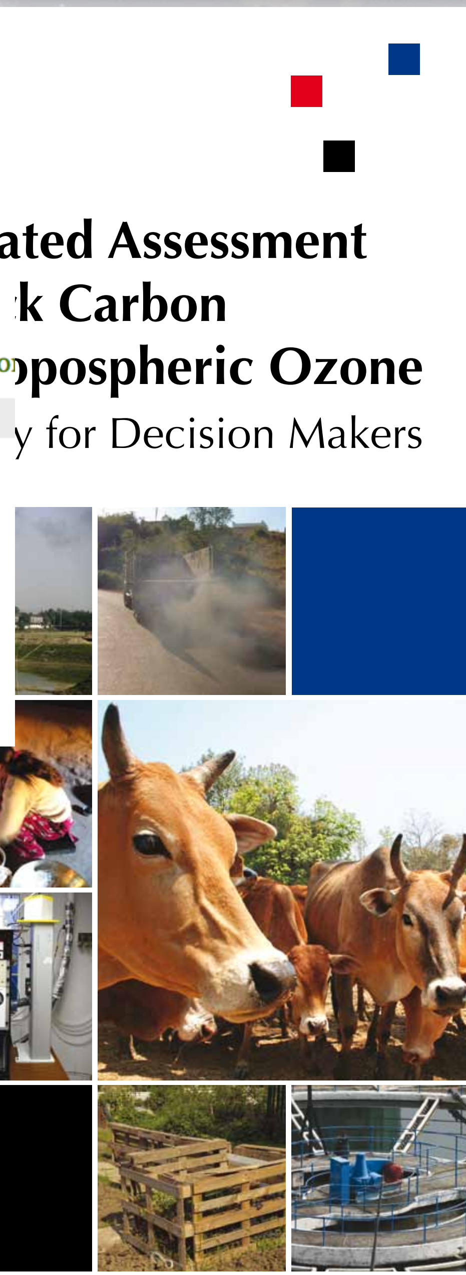
What is an air pollutant?

"Because greenhouse gases fit well within the Clean Air Act's capacious definition of "air pollutant," we hold that EPA has the statutory authority to regulate the emission of such gases from new motor vehicles."

MASSACHUSETTS *v. EPA*
Opinion of the Court, April 2nd, 2007
Justice Stevens

- Air pollutants now include Greenhouse Gases (GHG)
- Air quality constituents, e.g., ozone and black carbon, are also GHGs
- Air quality can effect both human and environmental health, with implications for carbon cycle feedbacks

Policy and Science of Short-lived Climate Forcing



The potential of short-lived climate pollutants (SLCP) for rapid climate mitigation has received considerable attention.

CCAC
CLIMATE AND CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

http://www.unep.org/ccac/

Chemistry-climate coupling: ozone

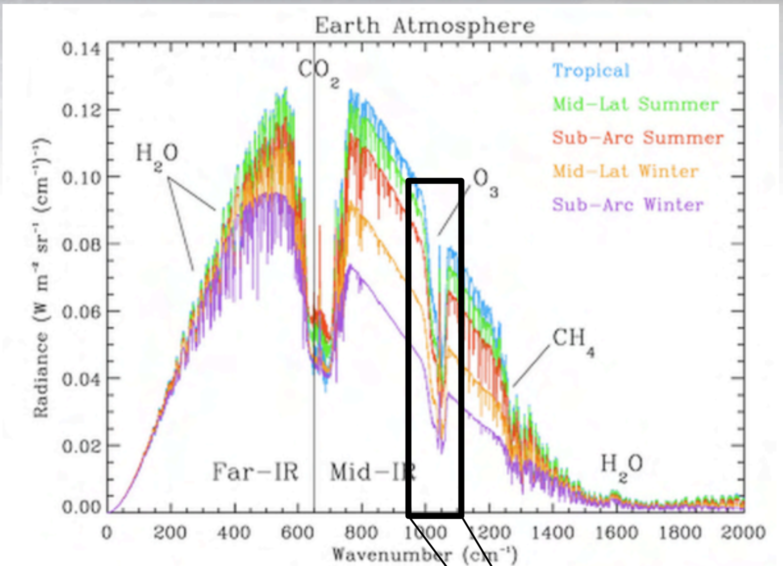
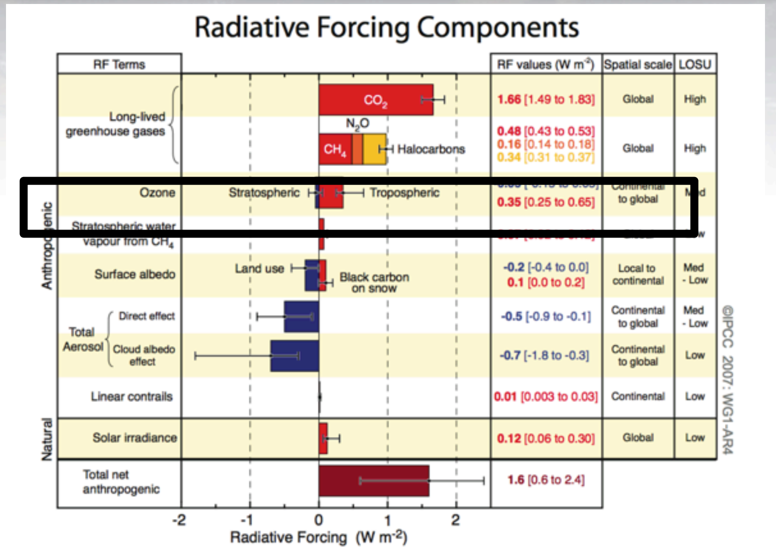
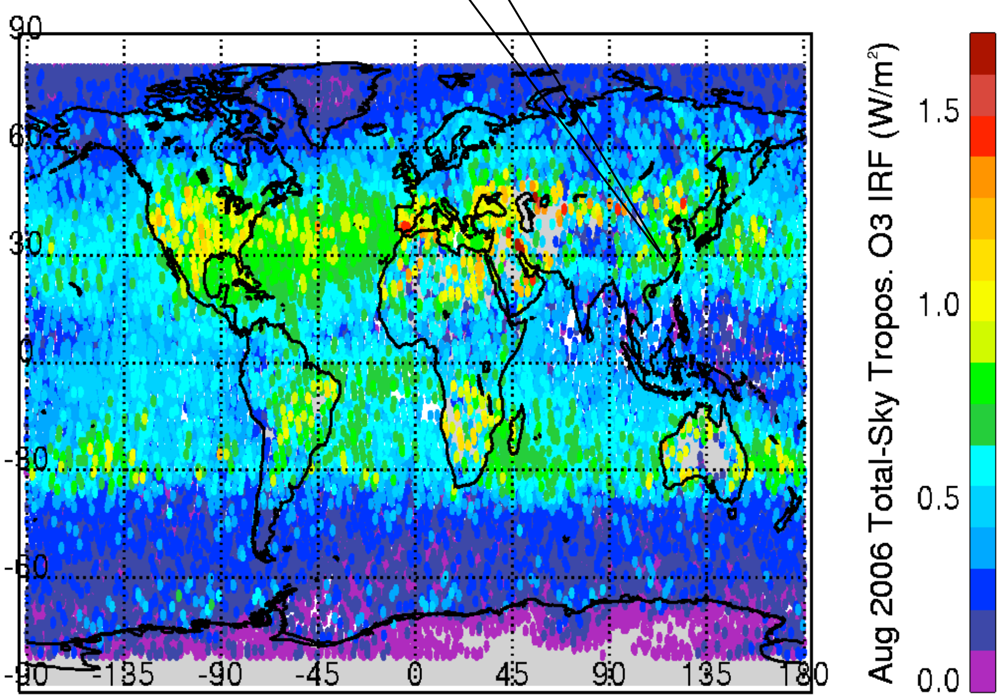


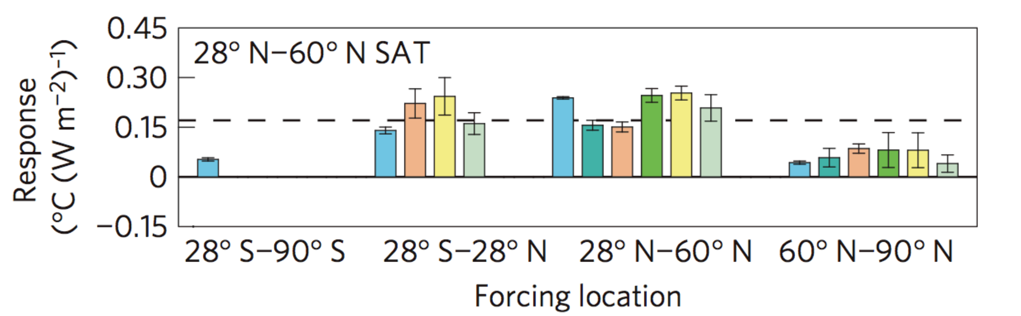
Fig. courtesy M. Mlynzcack (LaRC)

- Inter-model radiative forcing from ozone: .35 [0.25-.65] W/m² (IPCC AR4)

Radiative Forcing uncertainties:
- Pre-industrial background ozone
- Spatial distribution
- Vertical distribution

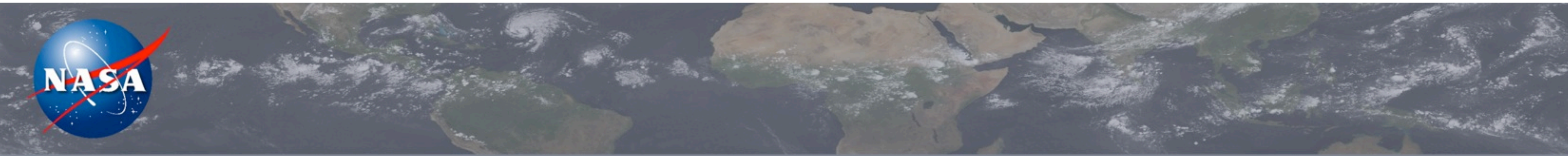




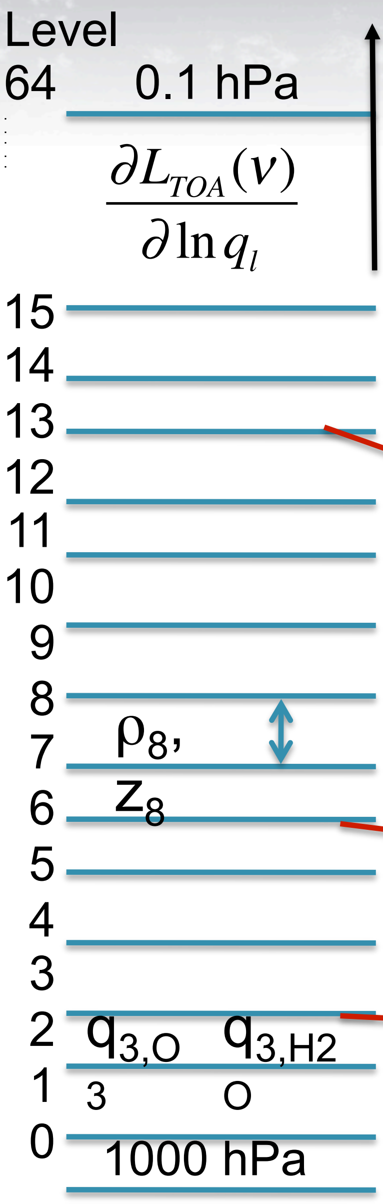


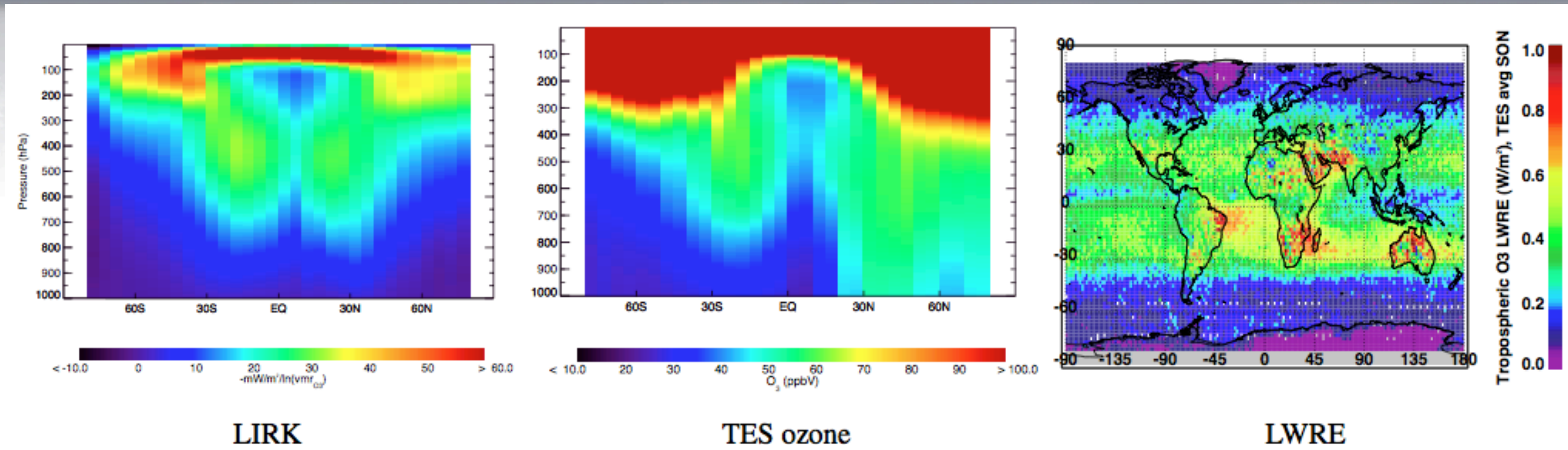
Shindell and Faluvegi, *Nature Geosciences,* 2008

The regional temperature response is a function of the forcing location

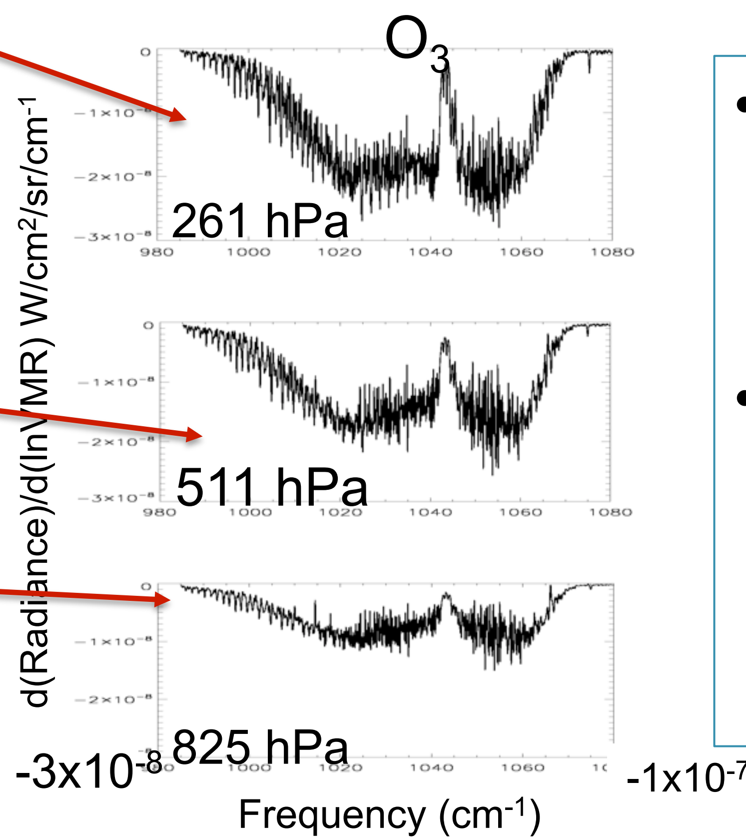


Instantaneous Radiative Kernels



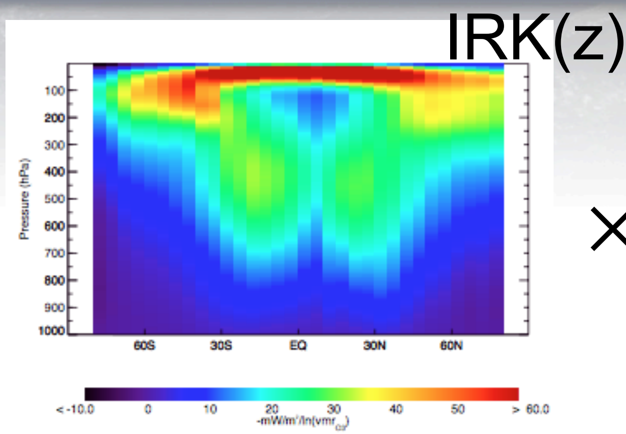


Worden *et al*, 2011 JGR



- TES Jacobians are the sensitivity of spectral radiance to the ozone profile
- Instantaneous radiative kernels are computed by integrating over frequency and conversion to flux.

OLR bias in chemistry-climate models



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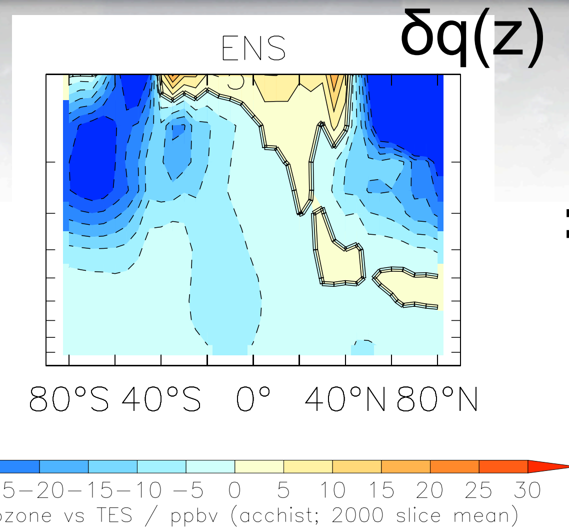

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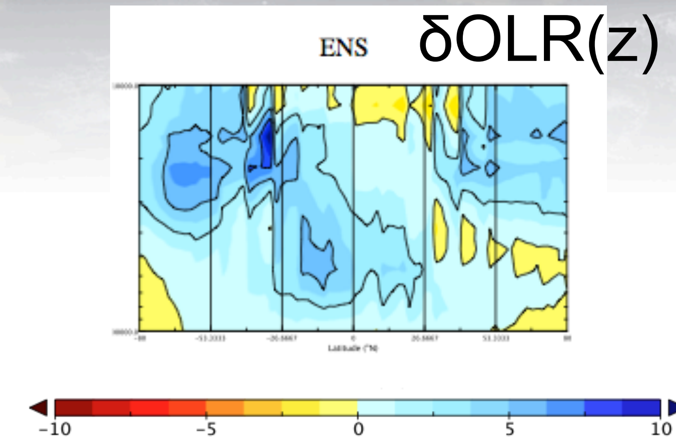
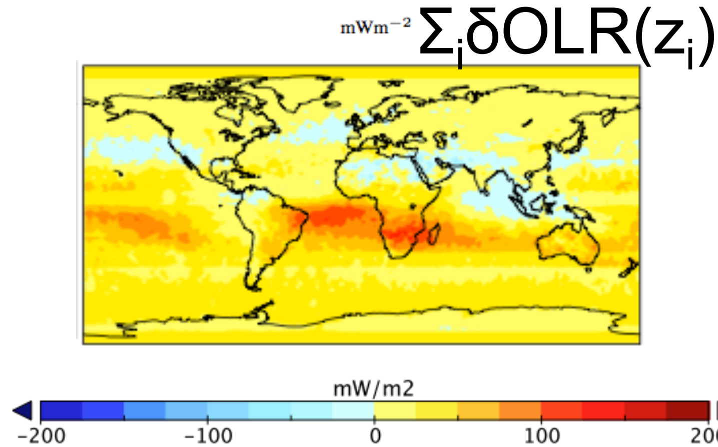
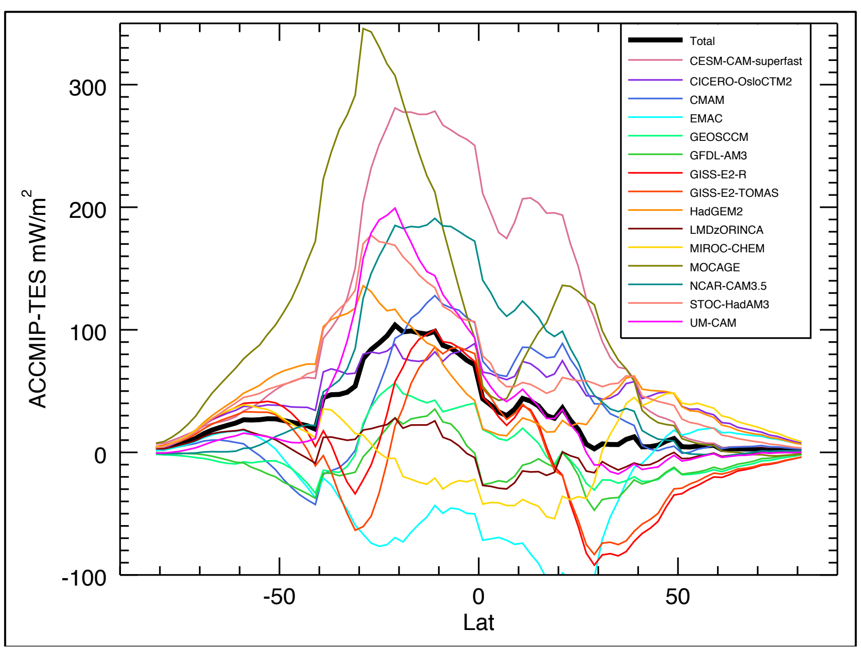




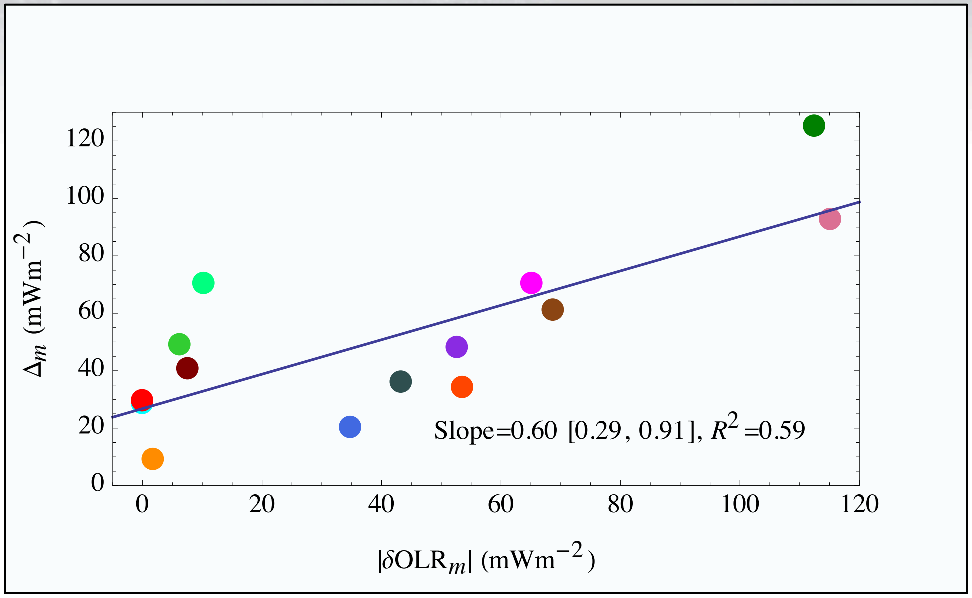
The Atmospheric Chemistry-Climate Model Intercomparison Project (**ACCMIP**) estimated historic radiative forcing (RF) and future response using consistent emissions for the IPCC 5th assessment. (Lamarque et al, 2013)



Bowman *et al*, 2013

In the tropics, discrepancies lead to over 300 mWm^{-2} for individual models and up to 100 mWm^{-2} for the ACCMIP ensemble.

Correlation of OLR bias with ozone RF



Bowman et al, 2013, ACP

IPCC AR5

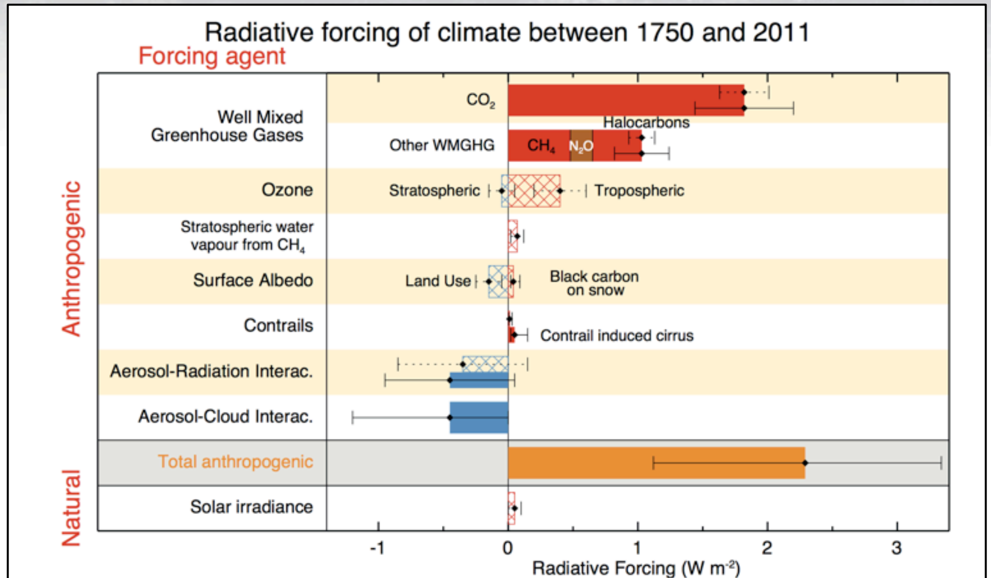


Figure 8.15 | Bar chart for RF (hatched) and ERF (solid) for the period 1750–2011, where the total ERF is derived from Figure 8.16. Uncertainties (5 to 95% confidence range) are given for RF (dotted lines) and ERF (solid lines).

y-axis: Absolute deviation of model ozone RF from ensemble mean RF

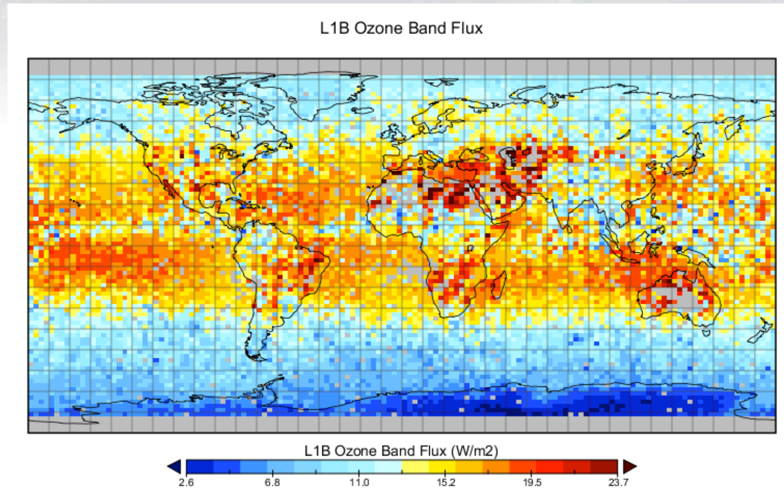
x-axis: Magnitude of TES-model OLR bias

ACCMIP/TES ozone RF incorporated into IPCC AR5

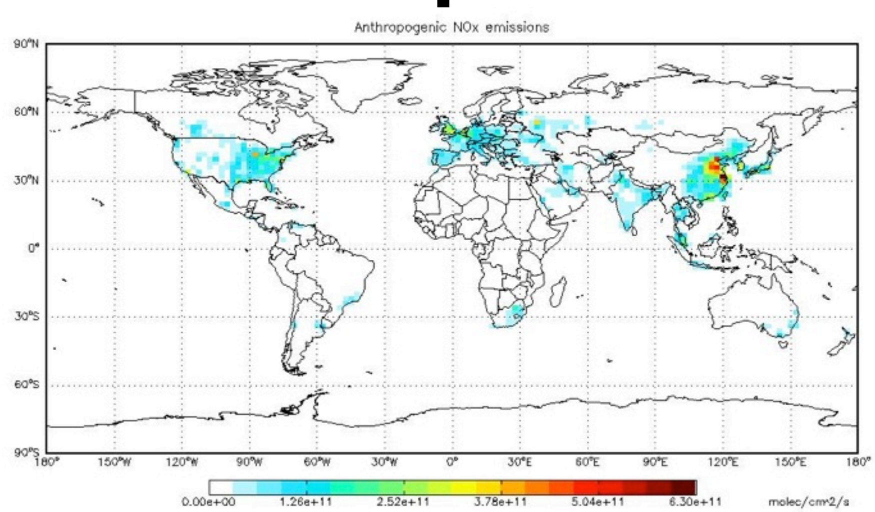
- Significant correlation for ACCMIP OLR bias and ozone RF: R^2=0.59
- Removing MOCAGE and CESM reduces correlation to R^2=0.18
- ACCMIP/TES ozone RF = 394 ± 42 mWm^{-2}
- About 28% reduction compared ACCMIP RF=389 ± 60 mWm^{-2}

What are the spatial drivers of mean OLR?

Mean



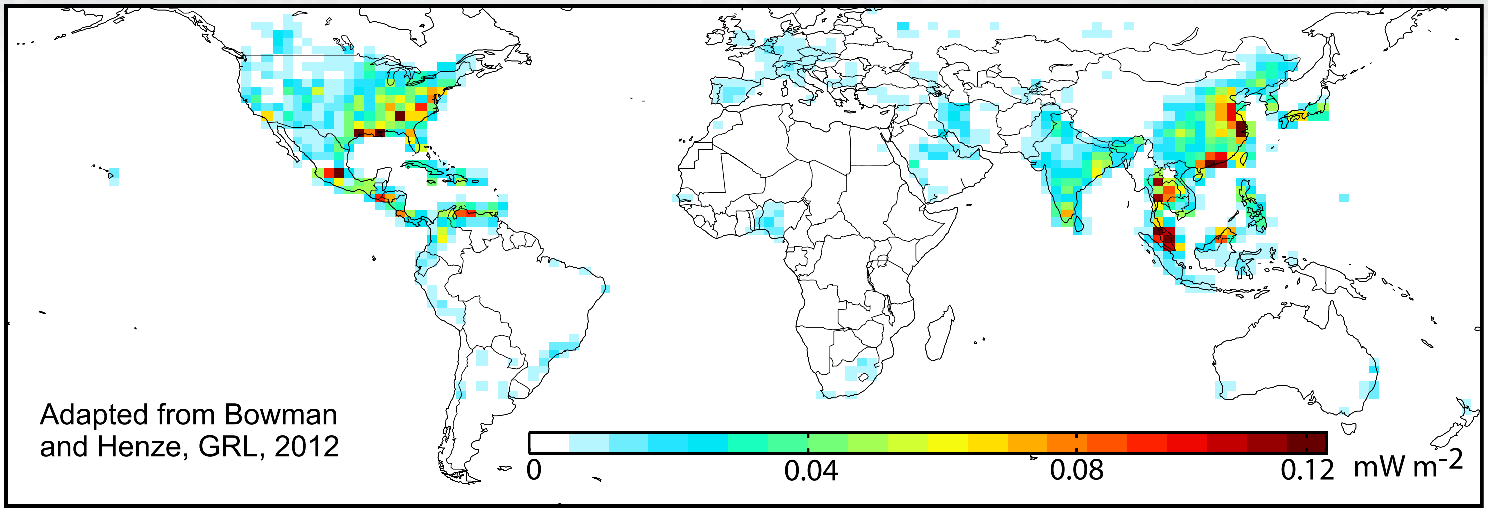
δJ(NOx)



Reducing pollution to mitigate climate change: location matters

Attribution:
The combination of TES IRK with the GEOS-Chem adjoint can attribute OLR variability to spatially-resolved precursor emissions

Contributions of NO_2 emissions – the primary source of ozone– to the global mean thermal absorption of ozone observed by the NASA TES satellite instrument in August, 2006.



Mean observed OLR

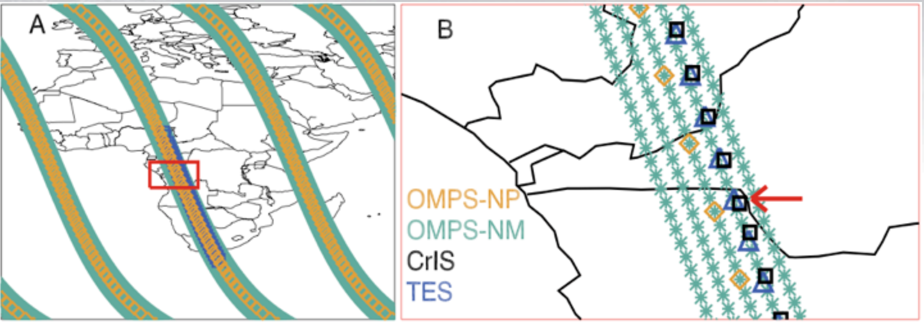
$$\mathcal{J} = \frac{1}{A} \sum_{i}^{N} a_i F_i$$

Sensitivity of OLR to emissions

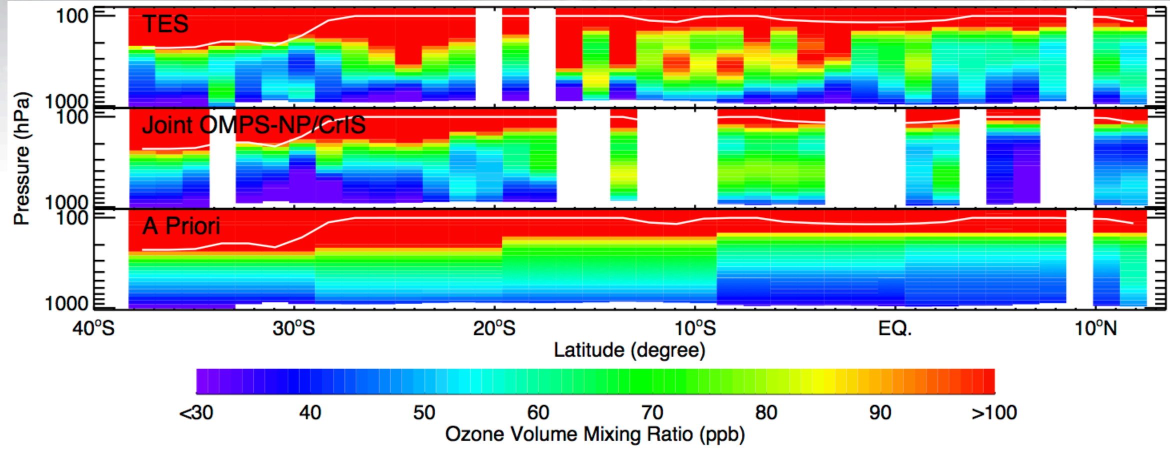
$$\lambda = \nabla_{\mathbf{E}} \mathcal{J}$$

Key Findings:
- The top 15 regional contributors to global ozone greenhouse gas levels were predominantly located in China and the United States, including regions that encompass New Orleans, Atlanta and Houston.
- There is significant regional variability –by more than a factor of 10-- in how efficiently emitted chemicals lead to heat-trapping ozone in Earth's atmosphere.
- For example, reducing ozone precursor emissions in the Atlanta region has three times the impact on climate as an equivalent reduction of emissions in Chicago.

Implications for CrIS

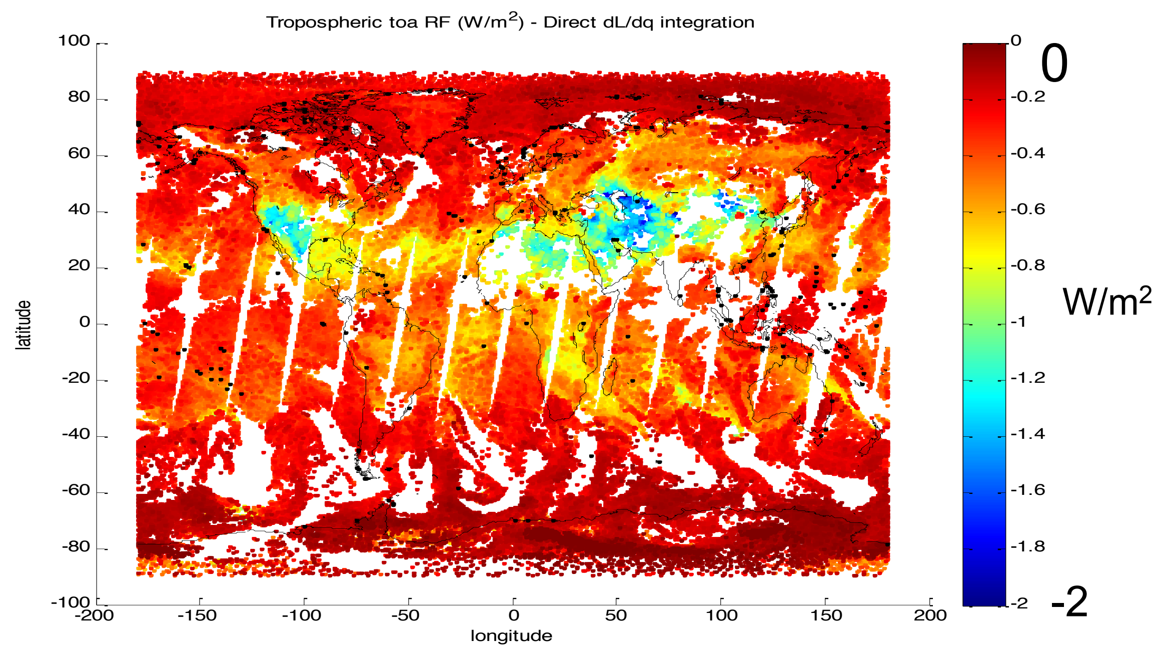


October 21, 2013



Fu et al, *in preparation*

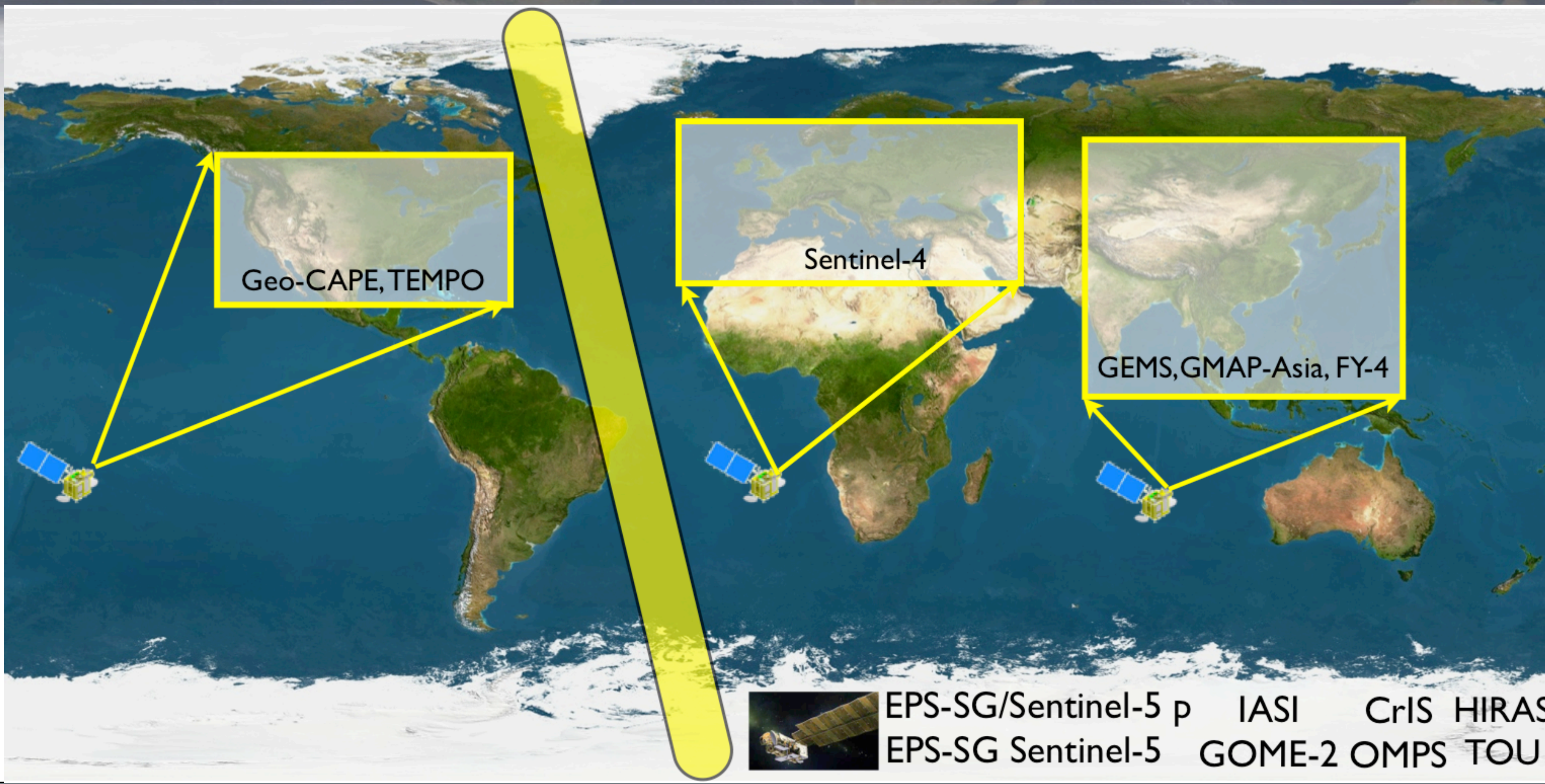
- Joint CrIS+OMPS-NP retrievals have similar information content as TES following approach in Worden et al, 2007,Hasekampf and Landgraf, 2007, Fu et al, 2013, Cuesta et al, 2013
- Preliminary IRKs produced for IASI in a joint CNRS/ULB Brussells/ NCAR/JPL collaboration



Doniki *et al*, 2014

Toward an Air Quality-Climate Constellation

Bowman et al, Atm.Env. 2013



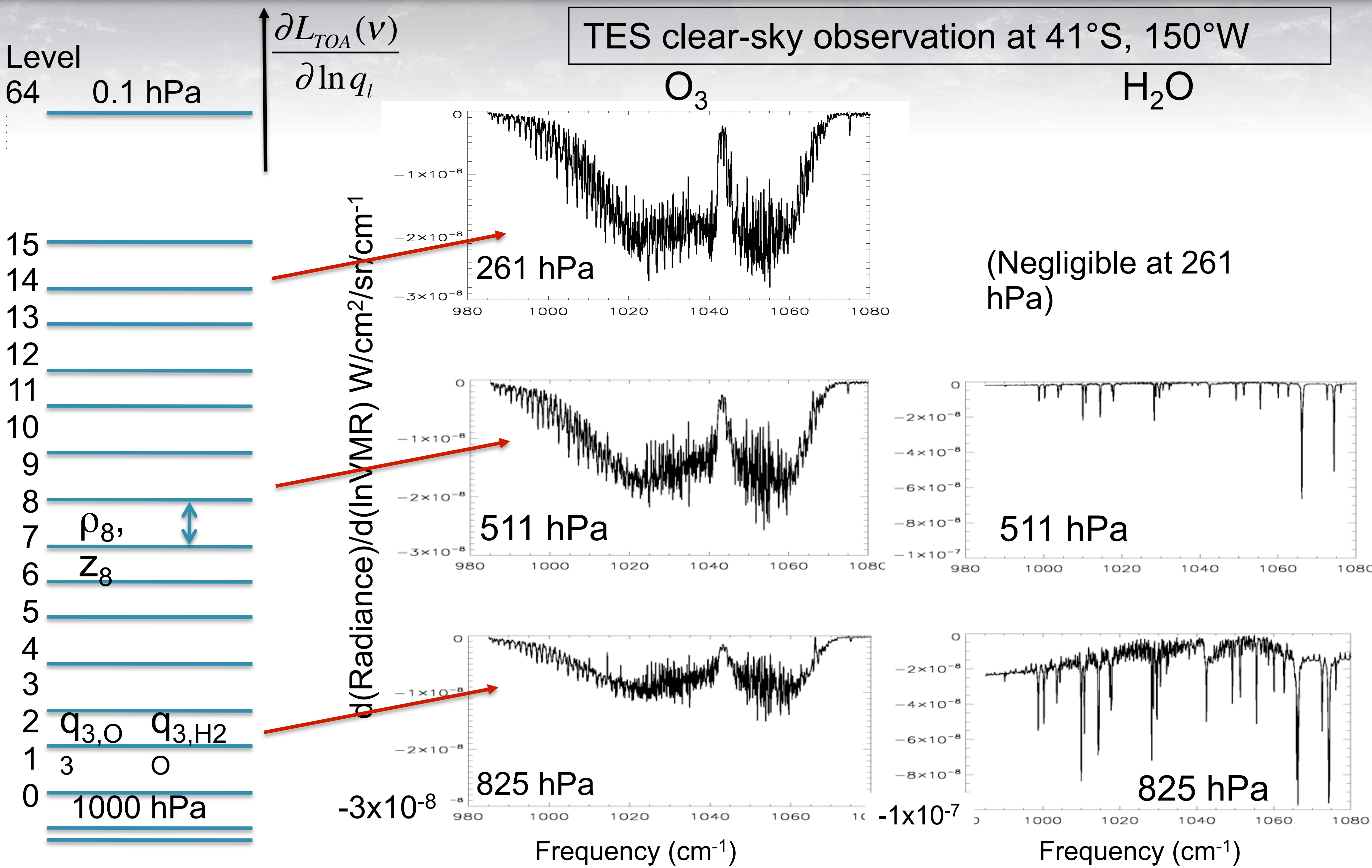
- IASI+GOME-2 will provide UV+IR ozone products for more than a decade as a part of METOP-(A,B,C).
    - Continued investments in UV+IR algorithms.
    - LEO observations to integrate GEO platforms
    - Opportunity to cross-calibrate observations
- Combined UV+IR ozone products from GEO-UVN and GEO-TIR aboard Sentinel 4 (Ingmann *et al*, 2012 Atm. Env.)
- CrIS+OMPS could provide critical afternoon ozone and OLR observations

Conclusions and Future Directions

- Monitoring of short-lived climate pollutants (SLCP), including tropospheric ozone, is a critical need for chemistry-climate science and climate mitigation strategies
- TES observations have quantified the greenhouse gas effect of ozone at unprecedented spatio-temporal scales (Worden *et al,* 2012)
- ACCMIP/TES studies have documented presented day bias of OLR and refined ozone RF estimates (Bowman *et al,* 2013)
- GISS/TES studies have quantified the balance of ODS in whole atmosphere radiative forcing (Shindell *et al,* 2013)
- GEOS-Chem/TES have attributed ozone RF to spatially-resolved precursor emissions at unprecedented scales. (Bowman and Henze, 2012)
- CrIS/OMPS shows considerable promise in continuing TES ozone and IASI has shown the potential of IRK products from other sounders.
- CrIS algorithms and products need to be developed in the context of a broader AQ-SLCP constellation and assimilation system (Bowman, 2013)

Backup

Spectral sensitivity of OLR to ozone and water vapor



Attribution of historical ozone forcing to anthropogenic emissions

Key Science Facts:

- Positive ozone changes lead to positive radiative forcing (RF) in the troposphere or negative RF in the stratosphere.
- Ozone depleting substances (ODS), e.g., CFCs, HFCs, remove ozone but are also important greenhouse gases (GHG).

Shindell *et al*, Nature Climate Change, 2013 used the the GISS chemistry-climate model *biased-corrected with TES ozone* (~30% reduction in ODS RF) to compute the "whole-atmosphere" ozone radiative forcing from ozone precursor emissions like NO_2 and ODS

The GISS/TES analysis found that

1. ozone RF from industrial precursor emissions was 0.47 W/m^2, about 35% higher than reported in the IPCC AR4 (0.35 W/m^2).
2. ozone RF from ODS by reducing *both* tropospheric and stratospheric ozone was -0.23 W/m^2, much lower than previous studies
3. Positive RF from ODS as a GHG (0.32 W/m^2) is almost compensated by the ODS as a negative ozone RF

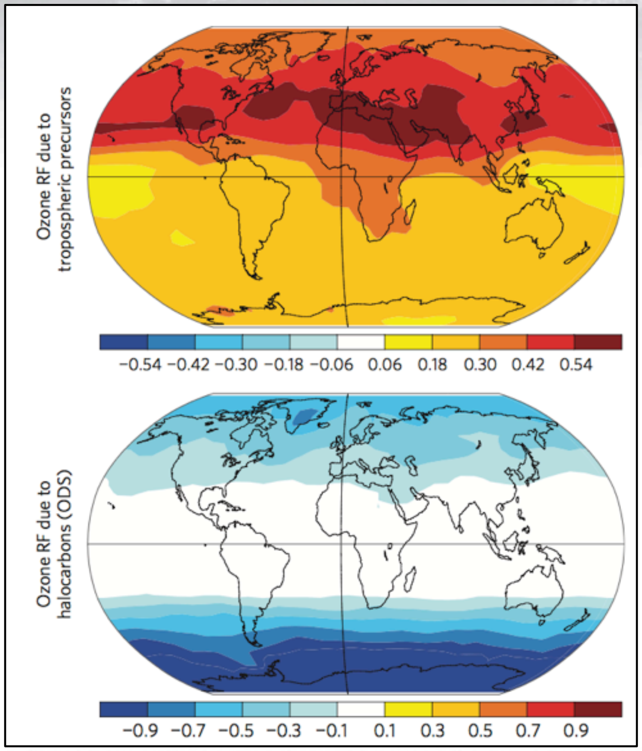


Figure 1 | Annual average whole-atmosphere ozone radiative forcing (W m^{-2}) due to the indicated drivers from GISS RTM calculations.

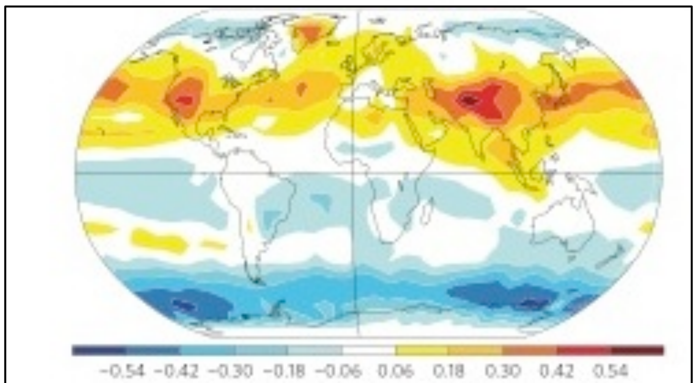


Figure 3 | Difference in annual average radiative forcing (W m^{-2}) between the GISS-E2-R model's ozone and observed TES ozone throughout the atmosphere.