Observational constraints on the vertical distribution of instantaneous ozone radiative forcing in chemistry climate models

K.W. Bowman, Jet Propulsion Laboratory (JPL), California Institute of Technology, JIFRESSE University of California Los Angeles

H.M. Worden, J.F. Lamarque , National Center for Atmospheric Research (NCAR)

A.M. Aghedo, S.S. Kulawik, A. Eldering, JPL, California Institute of Technology

M. Parrington, D.B.A. Jones, University of Toronto

L. Horowitz, NOAA / Geophysical Fluid Dynamics Laboratory (GFDL)

D. Shindell, NASA / Goddard Inst. For Space Studies (GISS)

Radiative forcing from ozone

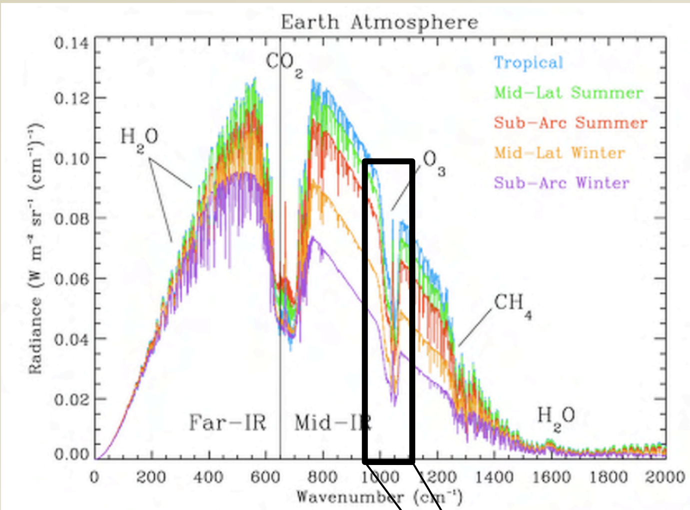
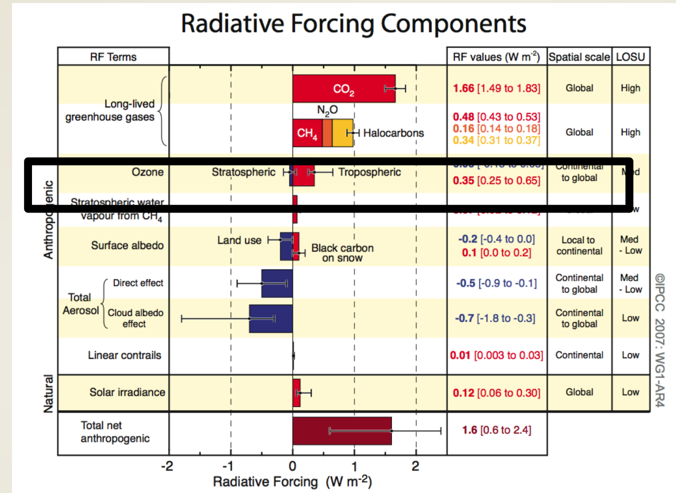


Fig. courtesy M. Mlynzcack (LaRC)

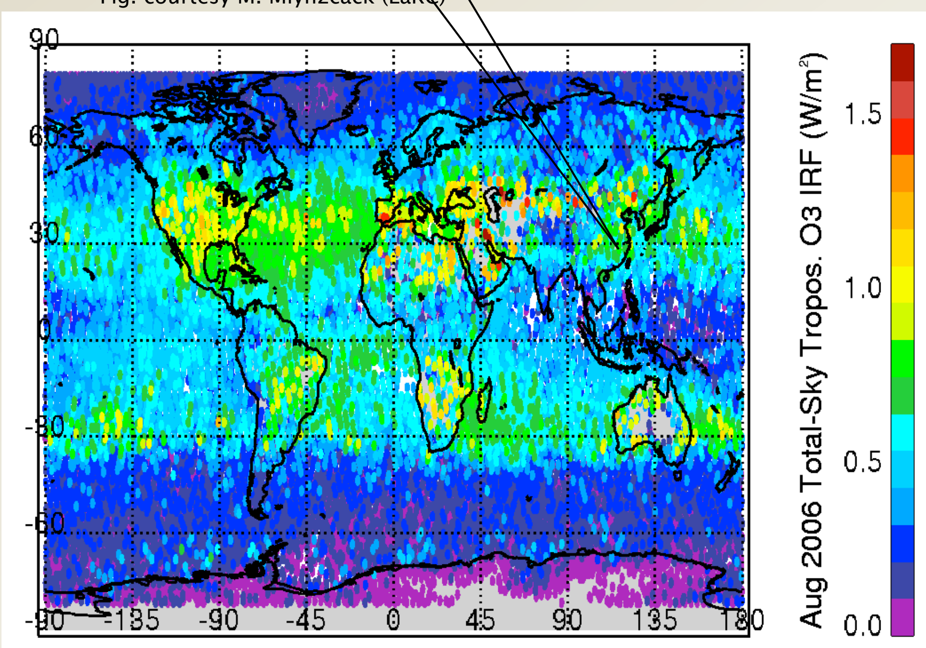
- Inter-model radiative forcing from ozone: .35 [0.25-.65] W/m^2 (IPCC AR4)

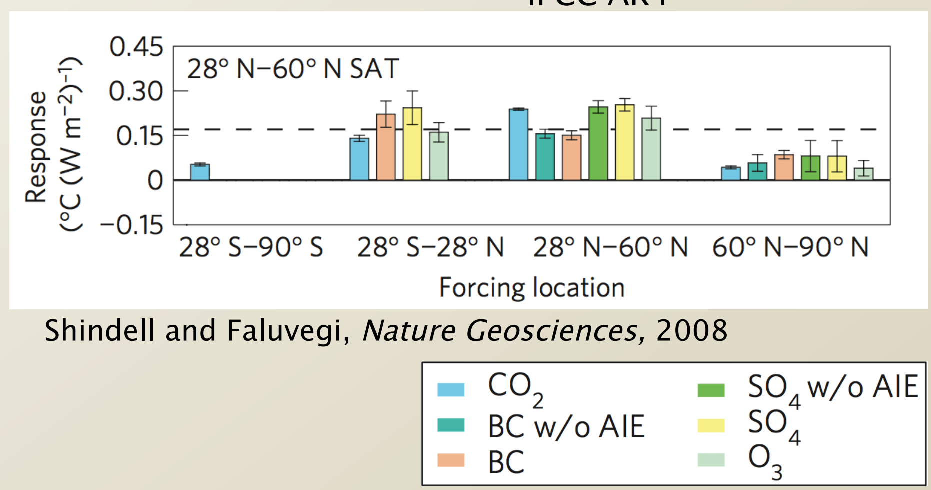
Radiative Forcing uncertainties:

- Pre-industrial background ozone
- Spatial distribution
- Vertical distribution



IPCC AR4





Shindell and Faluvegi, *Nature Geosciences*, 2008

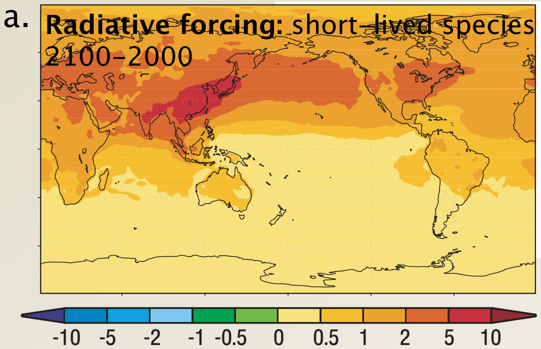
The regional temperature response is a function of the forcing location

Impact on short-lived gases and aerosols on climate

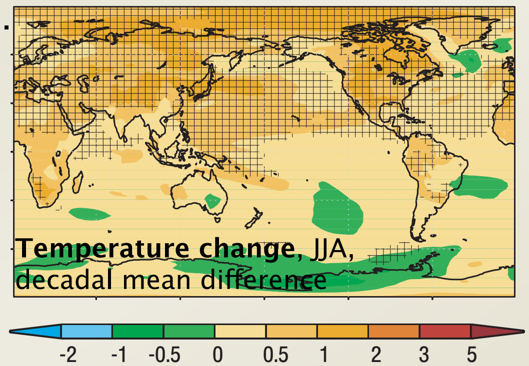
"By 2050, projected changes in short-lived pollutant concentrations….are responsible for approximately 20 percent of the simulated global-mean annual average warming"

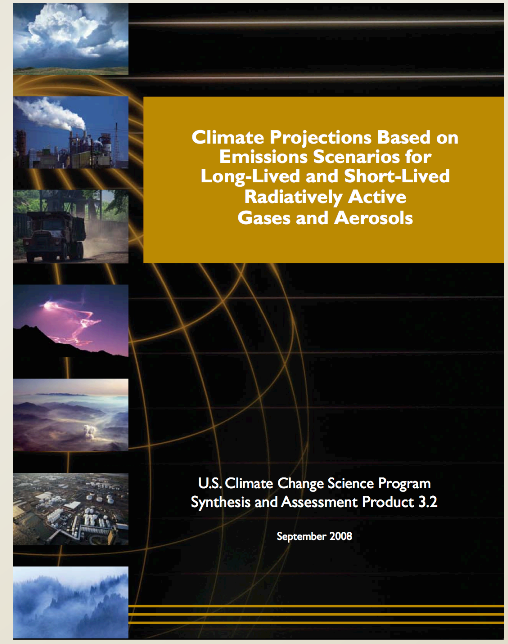
Projected changes...can contribute by up to 40 percent of the total projected summertime warming in the central United States from 2050-2100

a.

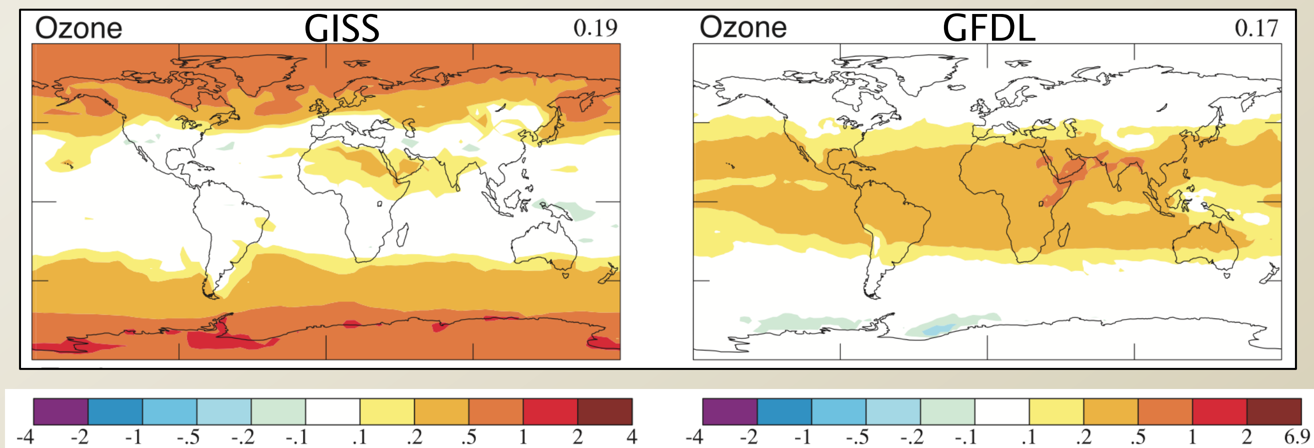


b.



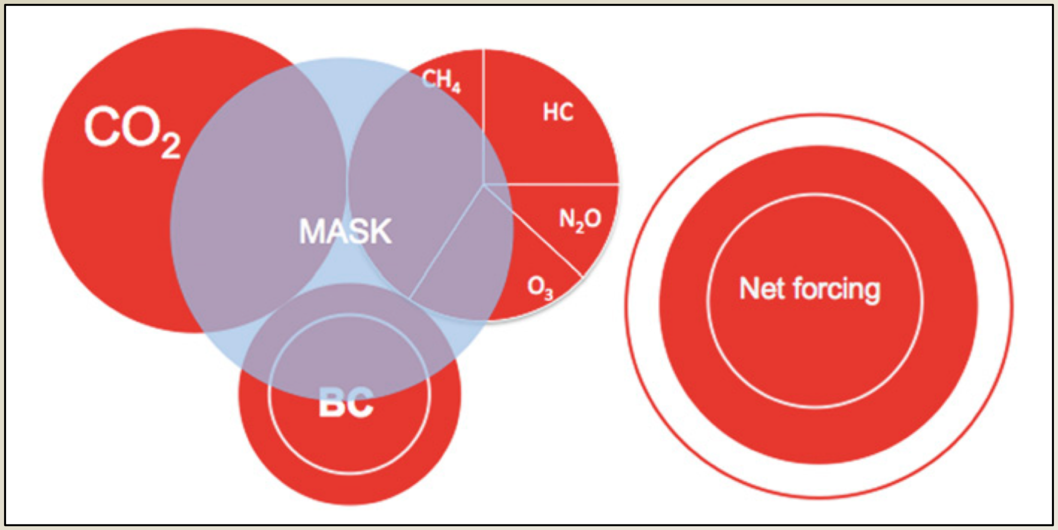


Annual average instantaneous radiative forcing (W/m2) at the tropopause near 2050 relative to 2000



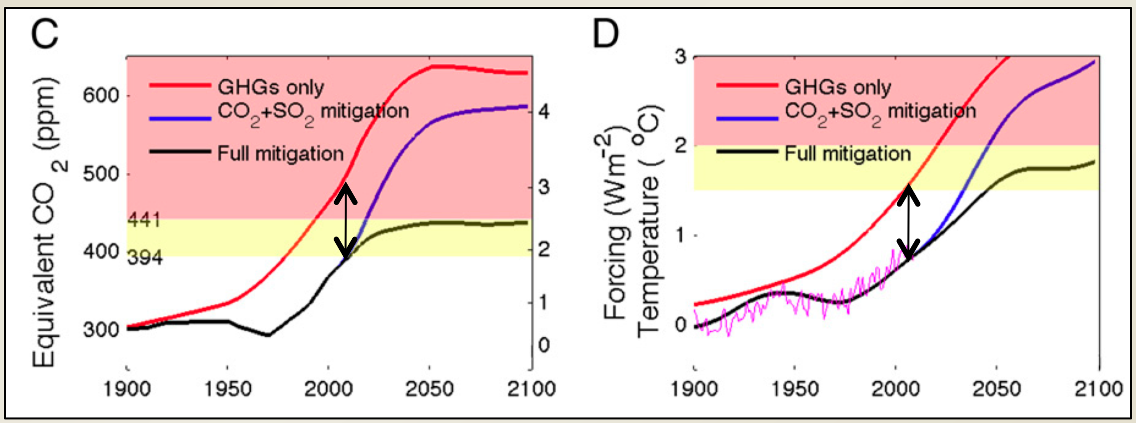
Shindell *et al*, JGR 2008

Ozone and climate mitigation



GHG radiative forcing budget:
(1.65 W/m²) CO_2
(1.35 W/m²) non-CO_2 GHGs

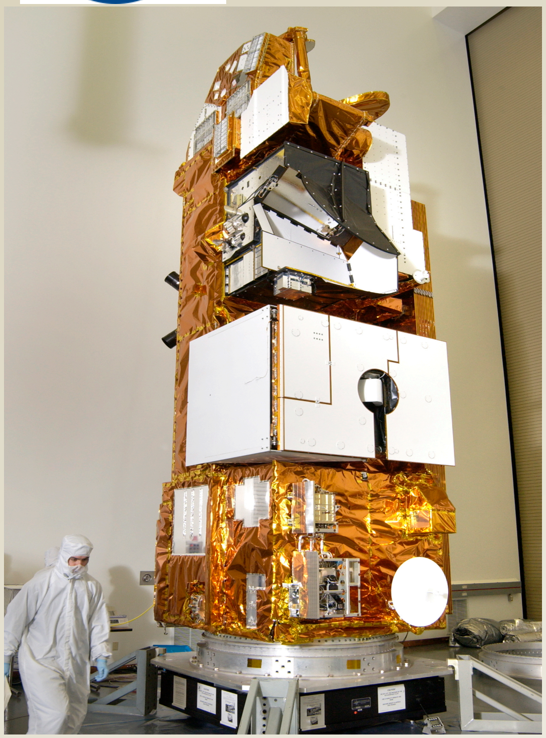
Copenhagen Accord
"reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius"

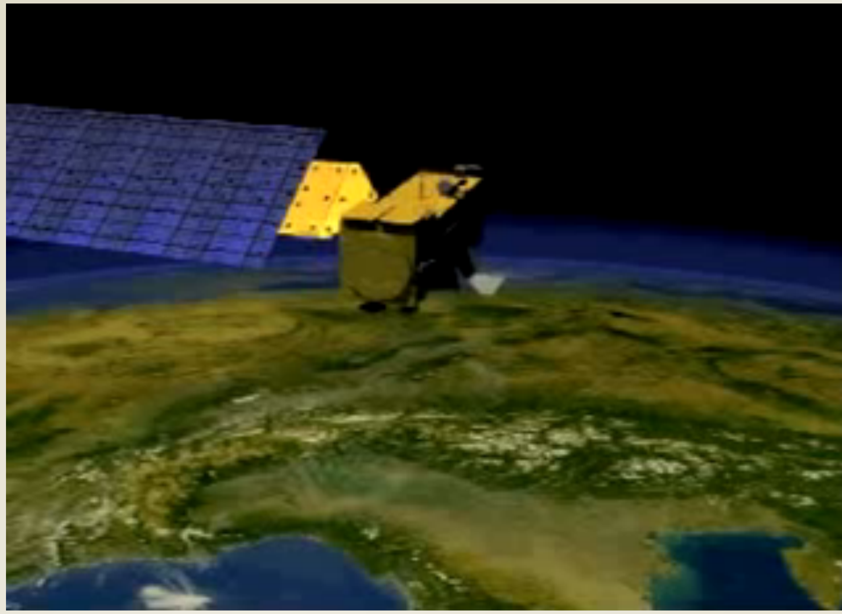


- Actual temperature increase is offset by sulfate, nitrate, and organic aerosols
- Improvements in air quality (particularly in Asia) can lead to enhanced warming
- Air pollution regulations that reduce the masking effect of cooling aerosols must also include reductions in emissions of BC and ozone-producing gases to remain watt-neutral.

The Copenhagen Accord for limiting global warming: Criteria, constraints, and available avenues
Veerabhadran Ramanathan and Yangyang Xu, PNAS, 2010

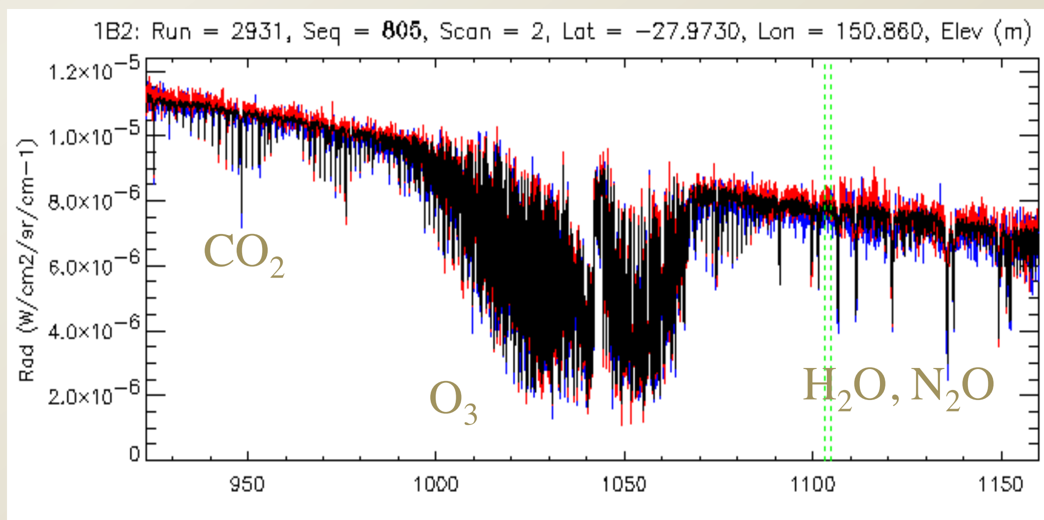
Tropospheric Emission Spectrometer





TES, launched aboard the Aura spacecraft in 2004, is a Fourier Transform Spectrometer measures infrared spectral radiances from 3.2 to 15.4 microns.

Spectral Resolution (unapodized)	0.06 cm^{-1} (nadir) 0.015 cm^{-1} (hi-res)
Spectral Coverage	650 to 3050 cm^{-1} (3.2 to 15.4 microns)
Global survey coverage	72 observations/orbit 16 orbits/day
Spatial Resolution	0.5 x 5 km (nadir) 2.3 x 23 km (limb)
Nadir NEDT @290K (Noise Equivalent Delta Temperature)	2B1: 1.08 K 1B2: 0.36 K 2A1: 0.36 K 1A1: 2.07 K



Chemistry Climate Models

All simulations for August 2006 only

AM2_Chem (NOAA-GFDL)

- MOZART-2 chemistry
- 2 x2.5 Gaussian grid, 24 vertical levels (up to ~3hPa)
- NCEP reanalysis data
- Emissions derived from 1990s (Horowitz et al., 2003.)

CAM_Chem (NCAR CAM v3.5)

- MOZART-2 chemistry
- 1.9 x2.5 Gaussian grid, 26 vertical levels (up to 40 km)
- observed SST
- POET anthropogenic emissions (REAS over Asia), GFEDv2 biomass burning emisions.

ECHAM5-MOZ (Max Planck)

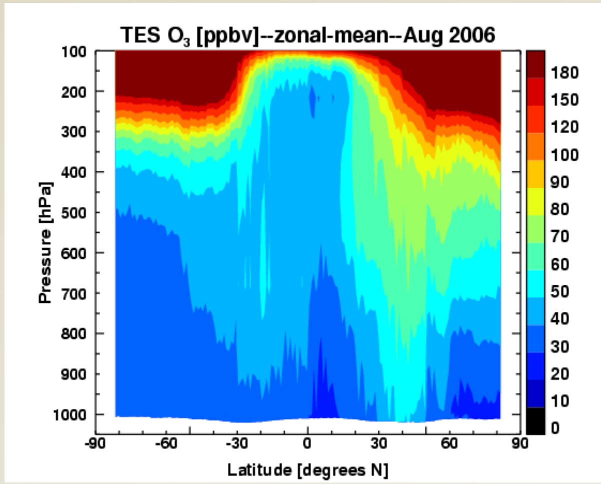
- MOZART 2.4 chemistry
- 2.8X2.8 Gaussian grid, 31 vertical levels (up to 10hPa)
- nudging to ECMWF
- RETRO 2000 emissions

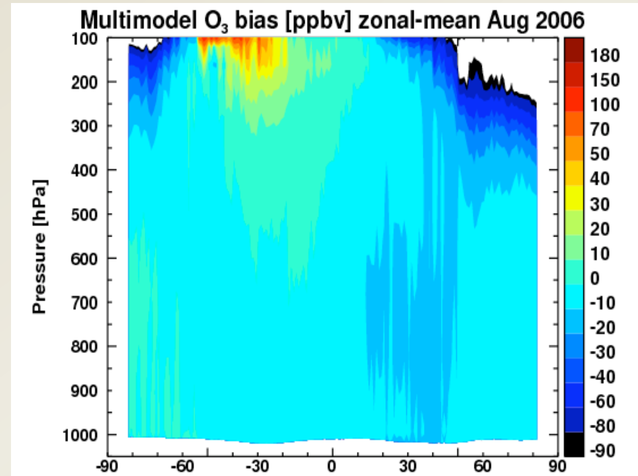
GISS-PUCCINI (NASA)

- PUCCINI tropospheric and stratospheric chemistry
- 2 x 2.5 grid, 40 vertical levels (up to 0.1hPa)
- NCEP reanalysis data
- AR5 anthropogenic, aircraft, and agricultural; GFED biomass burning

Models tropospheric ozone evaluation with TES

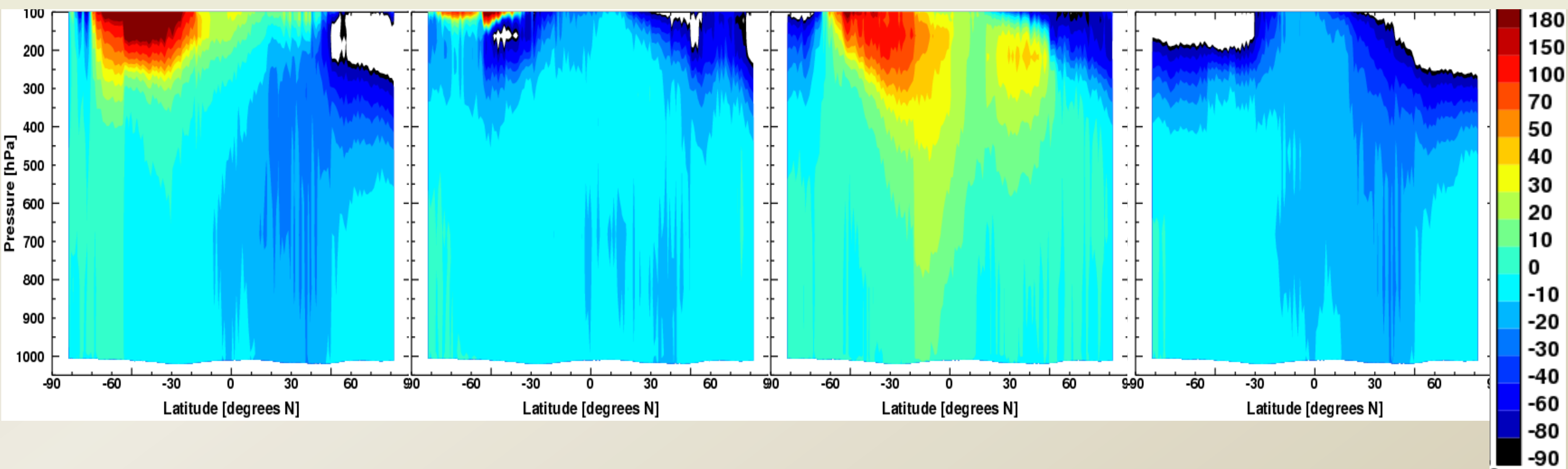
TES ozone (ppbv)



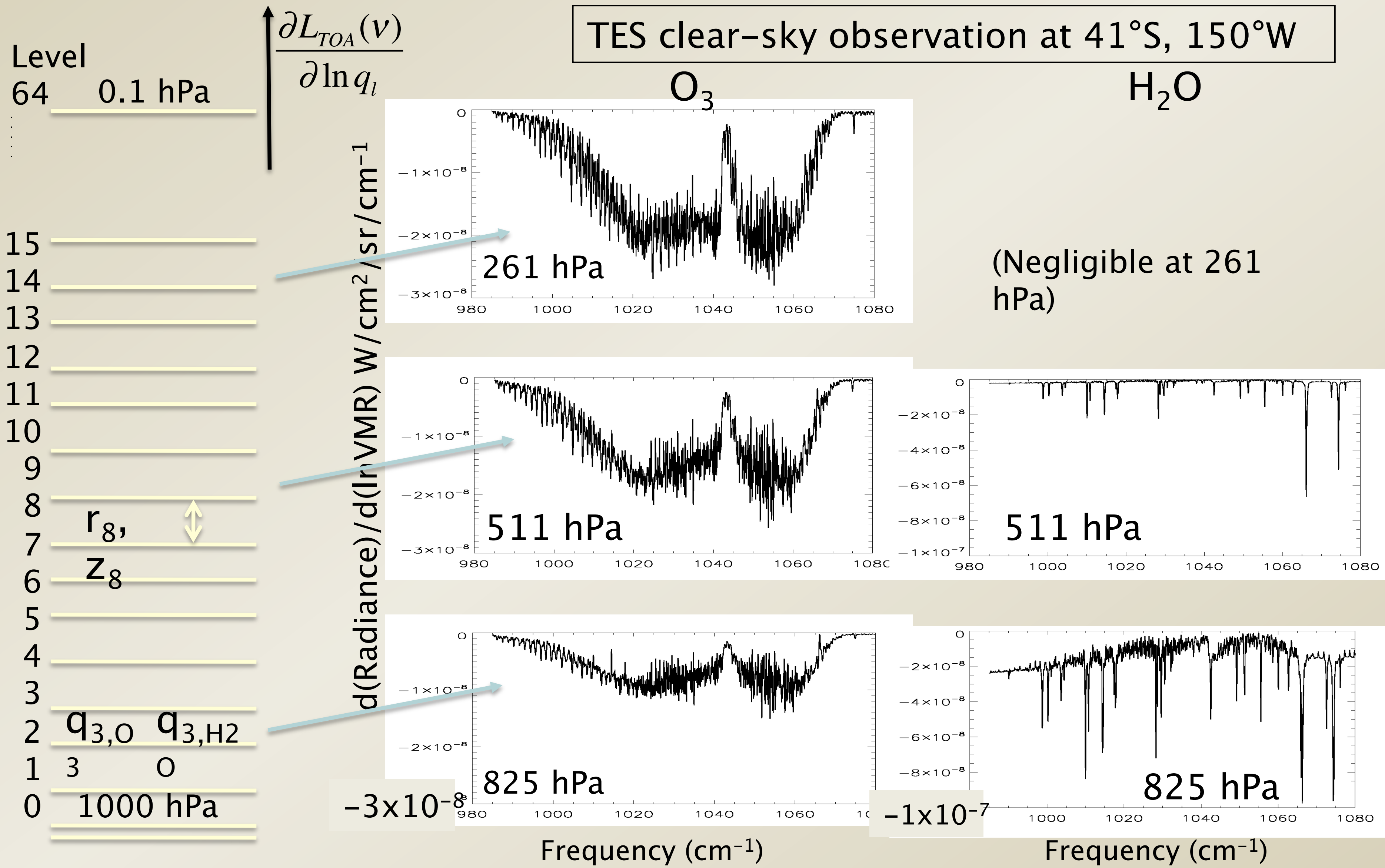


Zonal-mean model bias (ppbv) – Aug 2006

AM2-Chem CAM-CHEM ECHAM5-MOZ GISS-PUCCINI



Spectral sensitivity of OLR to ozone and water vapor



Instantaneous Radiative Forcing Kernel (IRFK)

Spectral radiance radiative forcing kernel in **W/m²/cm⁻¹/str/ppb**

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

Flux spectral radiative forcing kernel is calculated including anisotropy in **W/m²/cm⁻¹/ppb**

$$\frac{\partial F_{TOA}(\nu)}{\partial q_l} = \sum_{\nu}\frac{\pi\Delta\nu}{R(\nu)}\frac{\partial L_{TOA}(\nu)}{\partial q_l}10^4\,(cm^2/m^2)$$

(Flux) instantaneous radiative forcing kernel in **W/m²/ppb**

$$\partial_q F_{TOA}(z_l) = \int_{O_3\ \text{band}}\frac{\partial F_{TOA}(\nu)}{\partial q_l}d\nu$$

Instantaneous radiative forcing discrepancy in **W/m²**

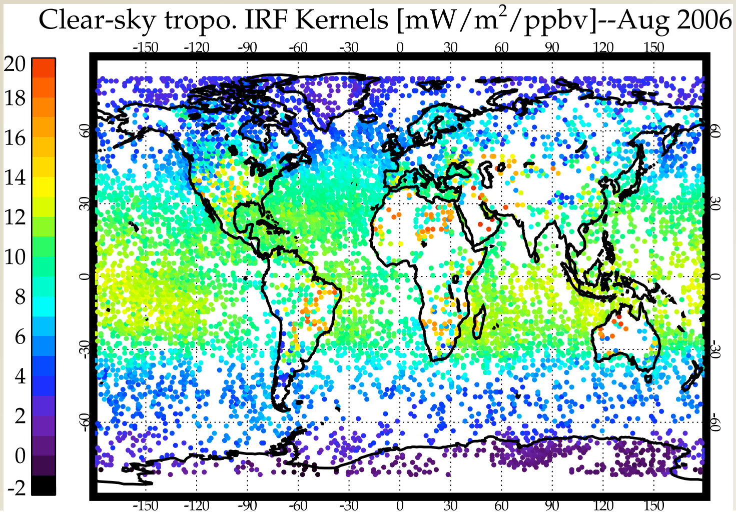
$$\delta\mathrm{IRF} = \mathbf{h}^{\top}(\partial_q\mathbf{F})(\hat{\mathbf{x}} - \hat{\mathbf{x}}_m)$$

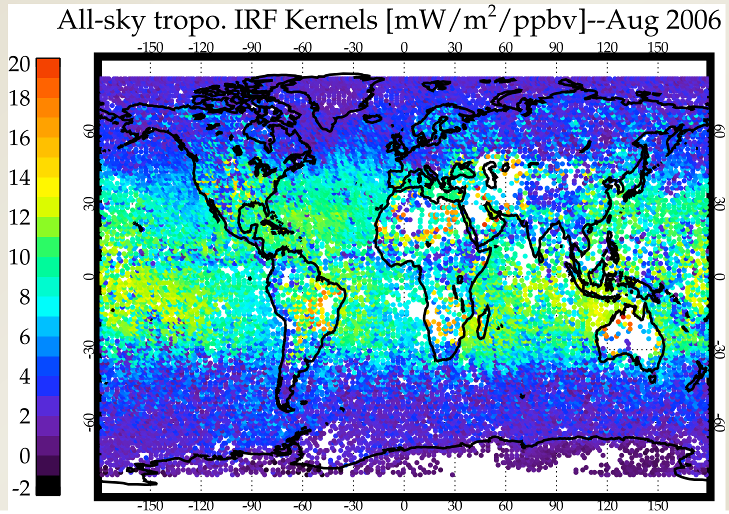
Forward model based on LBLRTM, Clough et al, IEEE Trans. Geosci. Remote Sens. 2006

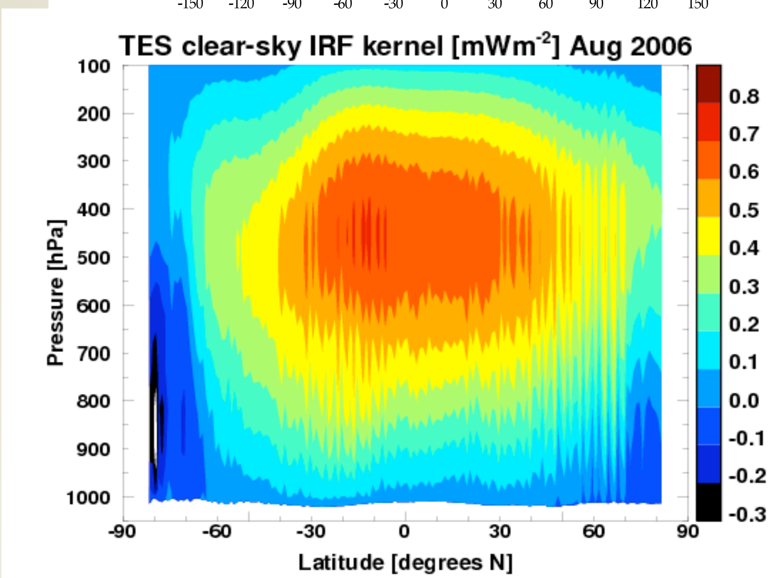
TES instantaneous radiative forcing kernels

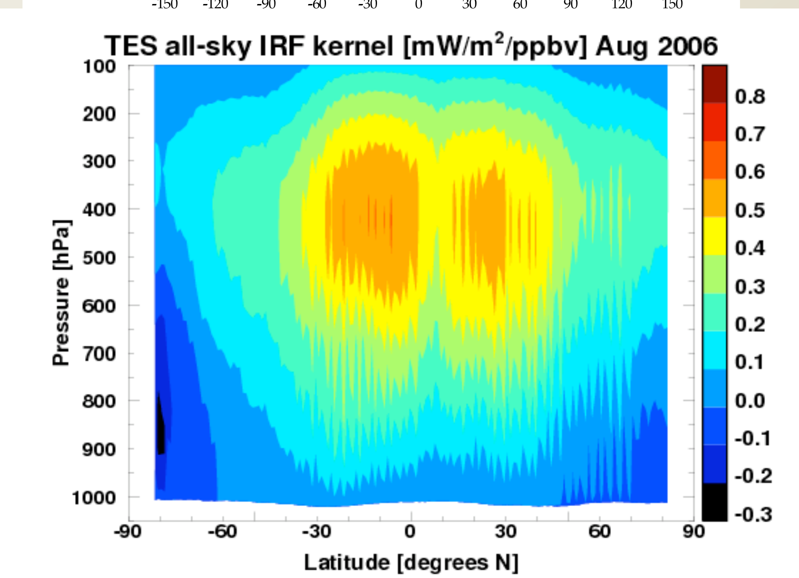
Clear sky

Total sky



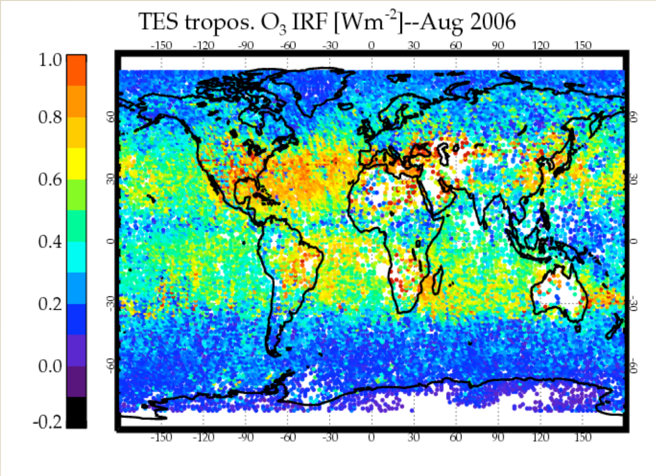


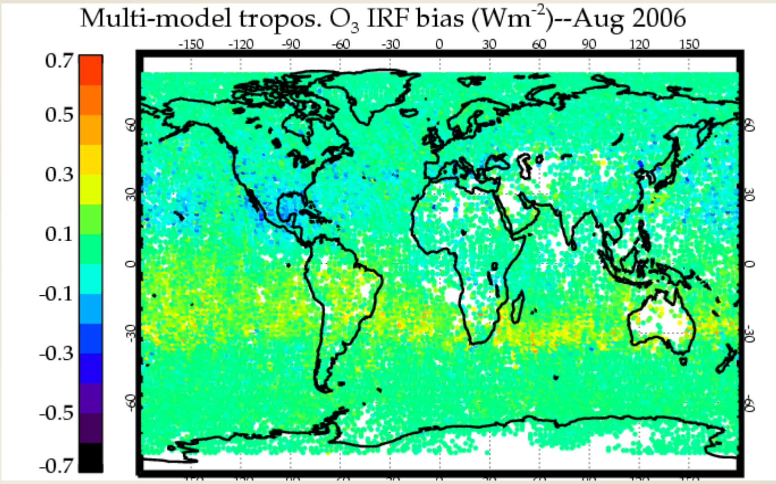




Tropospheric ozone IRF (all-sky) Aug 2006

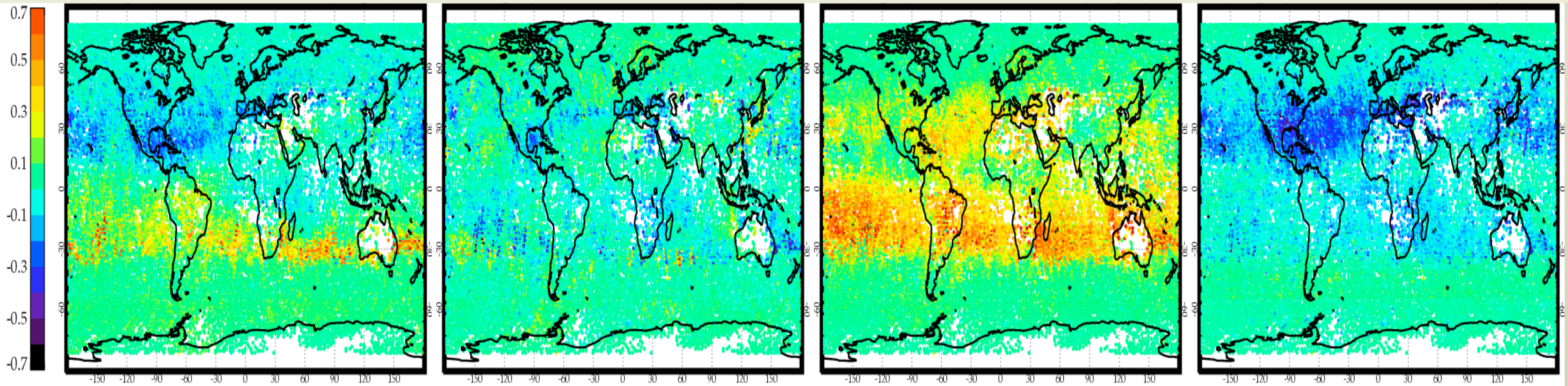
TES IRF (W/m^2)





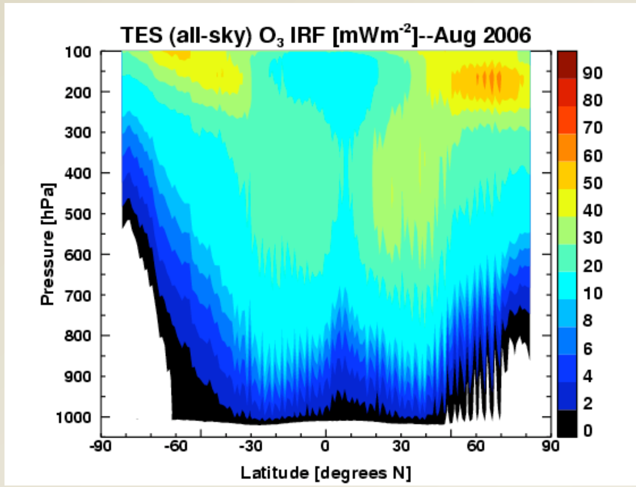
model IRF bias (W/m^2) – Aug 2006

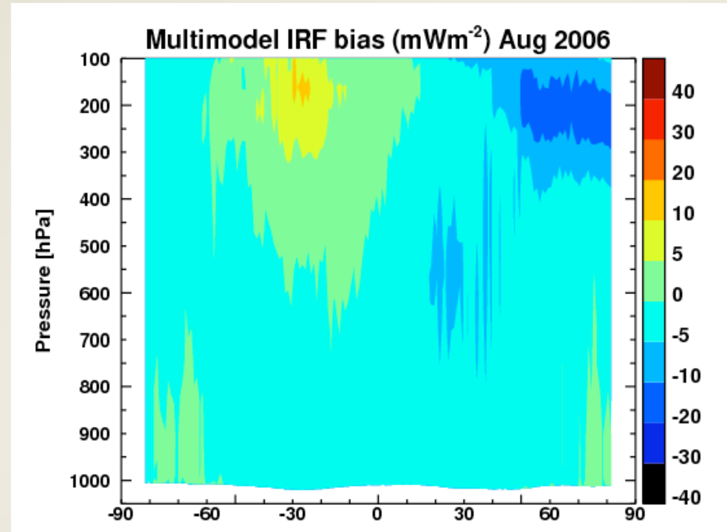
AM2-Chem CAM-CHEM ECHAM5-MOZ GISS-PUCCINI



Zonal-mean tropospheric ozone IRF

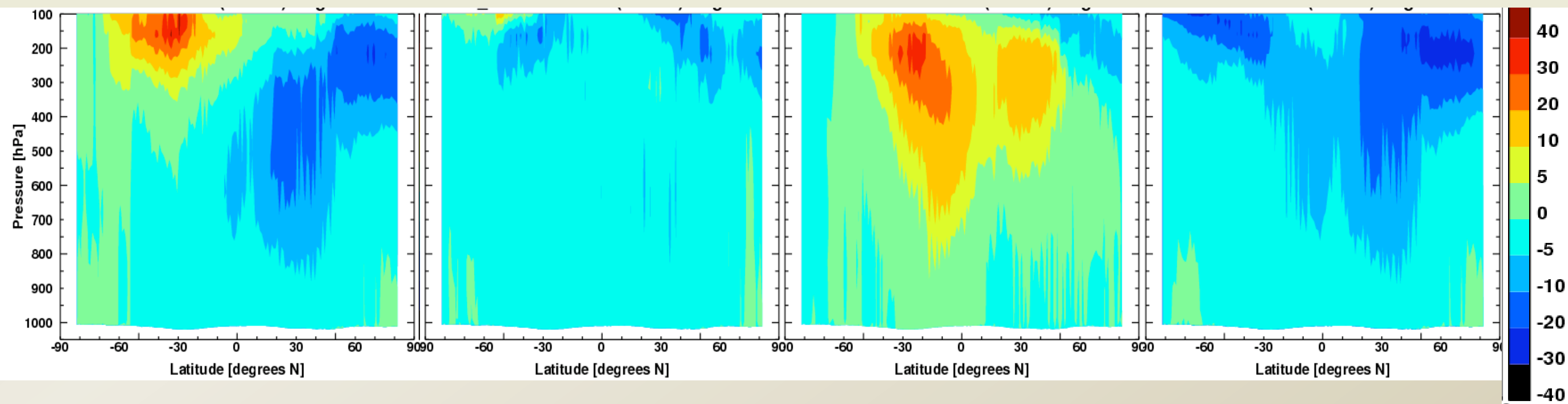
TES IRF (W/m²)



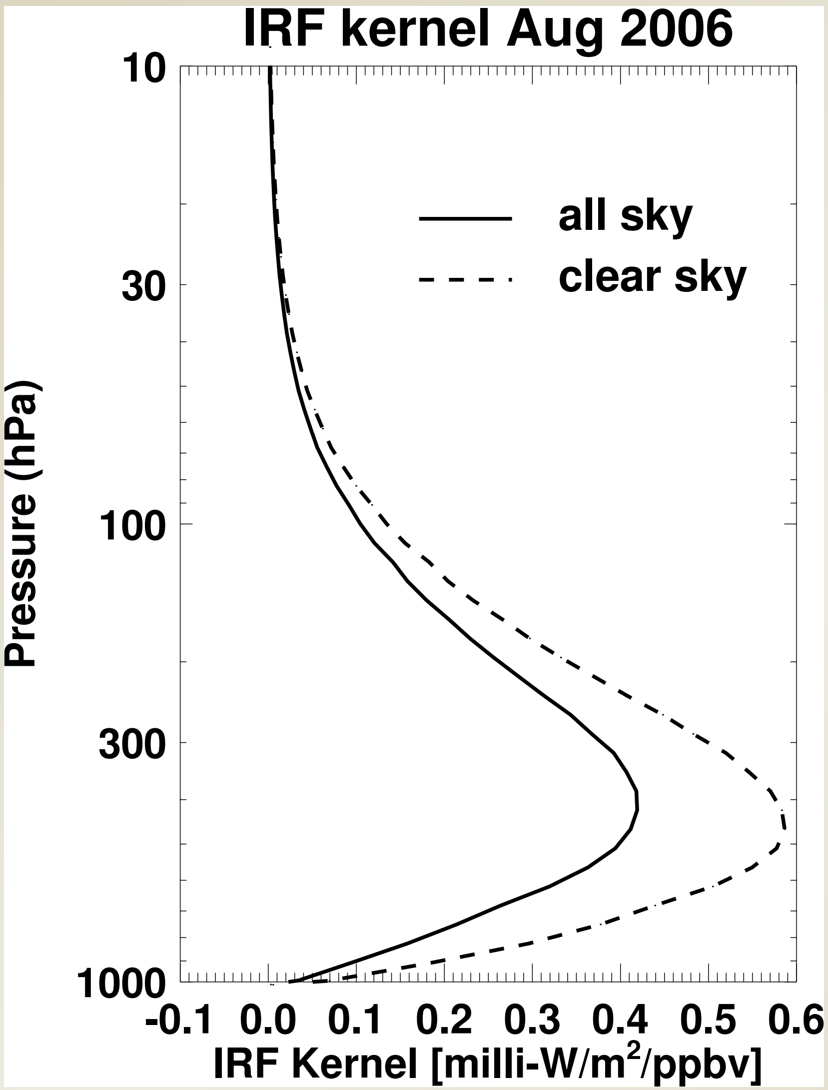


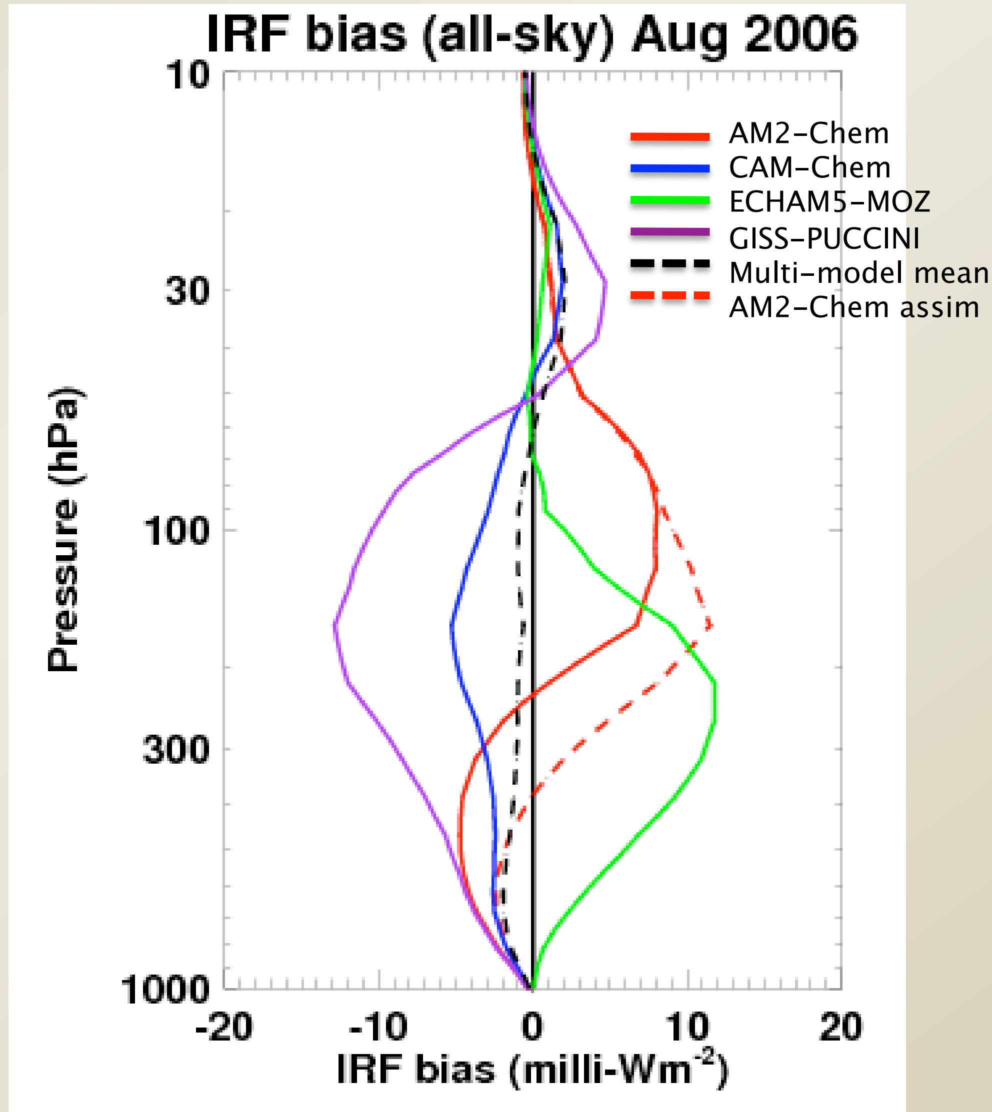
Zonal-mean model IRF bias (mW/m²) – Aug 2006

AM2-Chem CAM-CHEM ECHAM5-MOZ GISS-PUCCINI



Vertical profile of models tropospheric ozone IRF





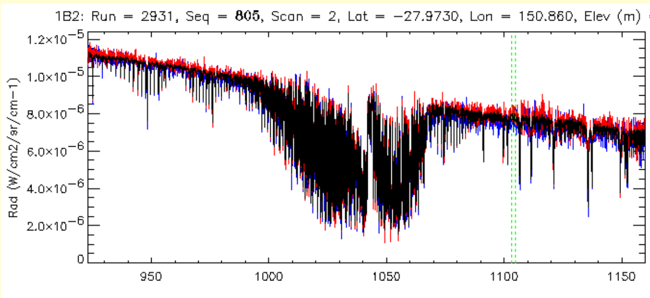
Conclusions and future directions

- Instantaneous radiative forcing kernels (IRFK)
  - strong latitude distribution
  - strong vertical distribution with maxima in the tropics
  - function of cloudiness and water vapor, which also contribute to climate sensitivity, along with dynamics, e.g., Hadley Cell.
- Relative to TES radiative forcing bias is
  - high ECHAM5-MOZ
  - low GISS
  - low lower trop, high upper trop AM2
- These biases can result in regionally specific differences between -.6 to .7 W/m^2 for August 2006.
- Multi-model mean is low biased in the troposphere by less than .2 W/m^2
- Preliminary analysis suggests that upper tropopsheric anomalies in the southern hemisphere are associated with “nudging”
- Approach can be used to support the next IPCC for radiative forcing
- Techniques are being extended to the attribution of ozone radiative forcing to support mitigation policies

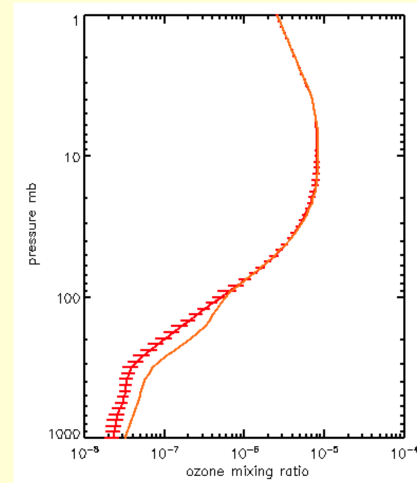
BACKUP

TES observation operator:

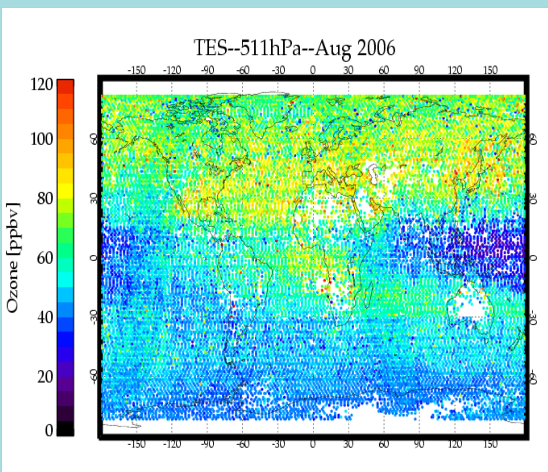
connecting measurements to models



$$\|\mathbf{y}-\mathbf{F}(\mathbf{x}_a)\|^2_{\mathbf{S}_n^{-1}}+\|\mathbf{x}-\mathbf{x}_a\|^2_{\mathbf{S}_a^{-1}}$$



$$\hat{\mathbf{x}}=\mathbf{x}_a+\mathbf{A}(\mathbf{x}-\mathbf{x}_a)+\mathbf{G}\mathbf{n}$$



$$\mathbf{H}_i(\bullet)=\mathbf{x}_a+\mathbf{A}_i(\bullet-\mathbf{x}_a)$$

$$\hat{\mathbf{x}}_{GISS}=\mathbf{H}_i(\mathbf{x}_{GISS})$$