Instantaneous radiative kernels for tropospheric ozone: Satellite observations and model evaluation

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ABSTRACT: Radiative kernels representing the TOA (Top of Atmosphere) flux response to a change in an atmospheric state variable are essential to understanding radiative feedbacks in climate change predictions [Soden et al., 2008]. Using infrared spectra for the 10 micron ozone band and corresponding Jacobian calculations from the Tropospheric Emission Spectrometer on EOS-Aura, we can compute instantaneous radiative kernels (IRK) for the vertical distribution of ozone. By storing TES radiance Jacobians for the final converged retrieval iteration and estimating anisotropy we derive ozone IRK profiles in (W/m2/ppb) for all observation types: ocean and land, cloudy and cloud-free conditions. Along with ozone IRKs for August 2006, we show comparisons of climate model ozone distributions to TES measurements with corresponding radiative implications of ozone differences.

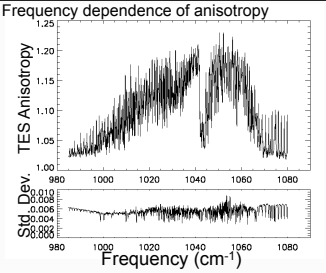
TOA Flux derivative

$$\frac{\partial F_{TOA}}{\partial q} = \int_{\nu}\int_{0}^{2\pi}\int_{0}^{\frac{\pi}{2}} \frac{\partial L_{TOA}(\nu\,\theta\,\phi)}{\partial q}\cos\theta\,\sin\theta d\theta d\phi d\nu$$

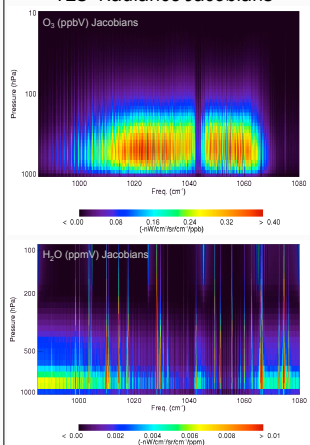
Where:
F = flux (W/m^2)
L = TOA radiance (W/m^2/cm^{-1}/sr)
q = e.g., ozone VMR (ppb)
R(θ) = anisotropy = πL(θ)/F

To obtain flux in W/m^2 from nadir radiances for different surfaces and clouds, we need an estimate of anisotropy for each scene. By computing a forward model radiance using the retrieved atmospheric state at 41.8° off-nadir, we perform a Gaussian integration to obtain the hemispherical flux and estimate the anisotropy for each TES observation. Below is an example for 31 clear-sky ocean scenes, Aug. 2006, Atlantic 16° to 30°N.

Frequency dependence of anisotropy

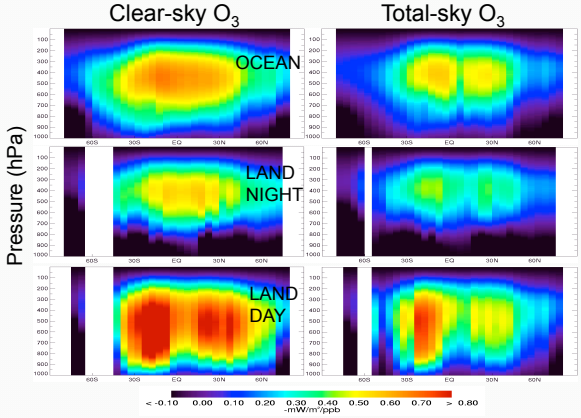


TES Radiance Jacobians



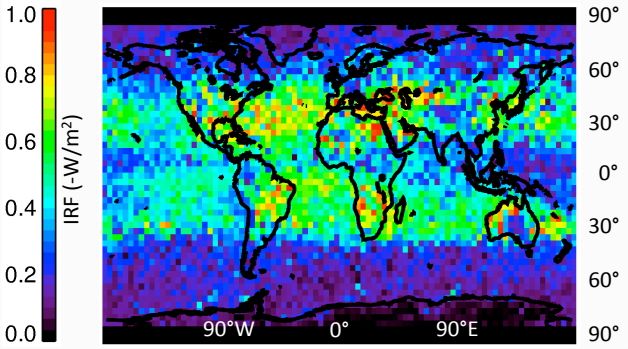
For a subset (August 2006) of TES data, we stored the Jacobian matrices in W/m^2/cm^{-1}/sr/ppb for ozone and water vapor (1585 frequencies x 64 pressure levels) for the final iteration of each retrieval. The O3 and H2O Jacobians in this figure are for a TES observation at 65°N, Aug 2006, surface T = 295 K, H2O vmr = 1.3E-2, thermal contrast = 8.7K.

Zonal Average IRKs (-mW/m^2/ppbV)



Multiplying the Jacobians and anisotropy gives a frequency dependent flux in W/m^2/cm^{-1}/ppbV. We Then integrate over frequency from 985 to 1080 cm^{-1} to obtain instantaneous radiative kernels (IRK) In W/m^2/ppbV. Zonal averages for August 2006 are shown above for ocean (top) land/night (middle) and land/day (bottom) scenes with clear-sky subsets on the left and total-sky on the right.

Tropospheric ozone as a greenhouse gas

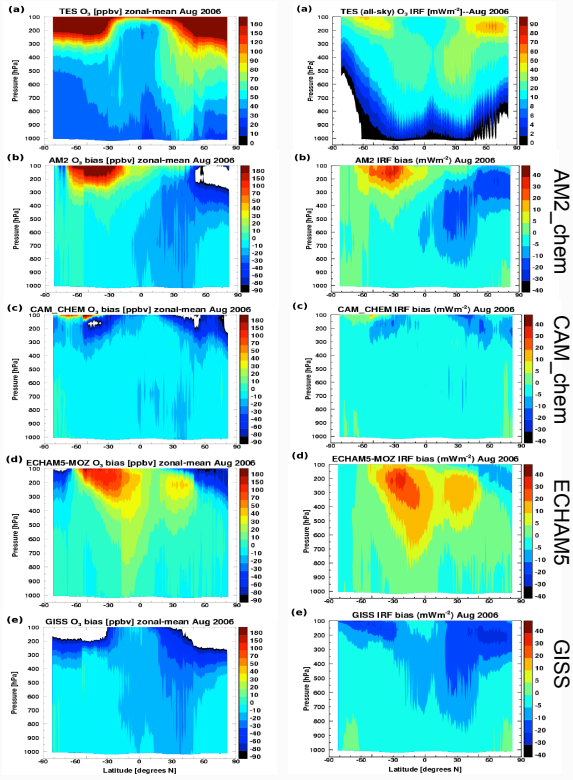


Instantaneous Radiative Forcing (IRF) for total sky tropospheric O_3, TES O_3 measurements * IRK, August 2006.

TES (ref.)

Comparison in ppbV

Comparison in mW/m^2



Model Evaluation:

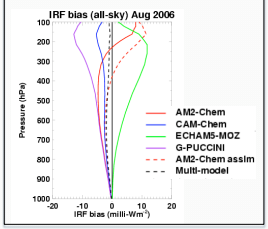
AM2_Chem (NOAA-GFDL)
- chemistry scheme of MOZART-2 (41 species, 100 reactions)
- 2 x2.5 grid, 24 vertical levels (up to 3hPa)
- Simulation constrained by NCEP reanalysis data
- Emissions derived from 1990s (Horowitz et al., 2003)

CAM_Chem (NCAR CAM v3.5)
- MOZART-2 chemistry and stratospheric chemistry (Lamarque et al., 2008)
- 1.9 x 2.5 grid, 26 vertical levels (up to 0.1hPa)
- observed SST (Rayner et al, 2003)
- POET anthropogenic emissions (REAS over Asia), GFEDv2 biomass burning emissions

ECHAM5-MOZ (Max Planck Institute for Meteorology)
- MOZART 2.4 CTM chemistry (63 transported species, 168 reactions)
- 2.8 X 2.8 grid, 31 vertical levels (up to 10hPa)
- ECMWF operational forecast data
- RETRO 2000 emissions (Shultz et al., 2007)

GISS-PUCCINI (NASA, Goddard)
- PUCCINI tropospheric and stratospheric chemistry (50 species, 156 reactions)
- 2 x 2.5 grid, 40 vertical levels (up to 0.1hPa)
- NCEP reanalysis data
- AR5 2000 anthropogenic, aircraft, and agricultural; GFED biomass burning

$$\Delta_{IRF} = \frac{\partial F_{TOA}}{\partial q}(q_{sim} - q_{ref})$$



CONCLUSIONS:

We have demonstrated how new TES IRK products can assess the instantaneous radiative forcing due to tropospheric ozone under any observing conditions, and can be used to evaluate climate model ozone differences and IRKs. Model differences in tropospheric O_3 can have an effective forcing from -0.4 to 0.7 W/m^2, which is the same magnitude as the IPCC anthropogenic RF for tropospheric O_3 (0.35 W/m^2).

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