Ozone Instantaneous Longwave Radiative Effect from IASI and TES observations

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Introduction

Ozone plays an important role in the radiative budget of the atmosphere. Tropospheric ozone is the third most important greenhouse gas in terms of radiative forcing (RF), with estimated values around +0.40 ± 0.20 Wm^{-2} (*IPCC AR5*, 2013). Stratospheric ozone RF is unchanged throughout the latest years at -0.05 ± 0.10 Wm^{-2}. Confidence intervals tend to be large due to difficulties mostly in the calculation of pre-industrial ozone concentrations. Different climate models report different values of RF, confirming the complexity of such calculations and the accurate representation of ozone global and vertical distributions.

In this study we use the IASI/MetOp-A measurements to compute the Instantaneous Radiative Kernels (IRKs) and the Longwave Radiative Effect (LWRE) of tropospheric and total ozone at the top of the atmosphere (TOA) in the full 9.6μm band. IASI is sensitive in the range from ground to 40 km, and especially at the UTLS, making possible the discrimination between tropospheric and stratospheric subcolumns (Clerbaux et al., 2009). The calculations of the IRKs are performed with two methods, with the Direct Integration of TOA radiance Jacobians (Doniki et al., 2015) and by using an anisotropy estimation. The latter was introduced and applied on TES/Aura data by *Worden et al.* (2011). We compare these methods and point out the angular issues of the anisotropy estimation. We then present global results of LWRE from IASI/FORLI, we compare with TES/Aura data and perform a primary assessment of three Chemistry-Climate models used in ACCMIP (Bowman et al., 2013) and IPCC.

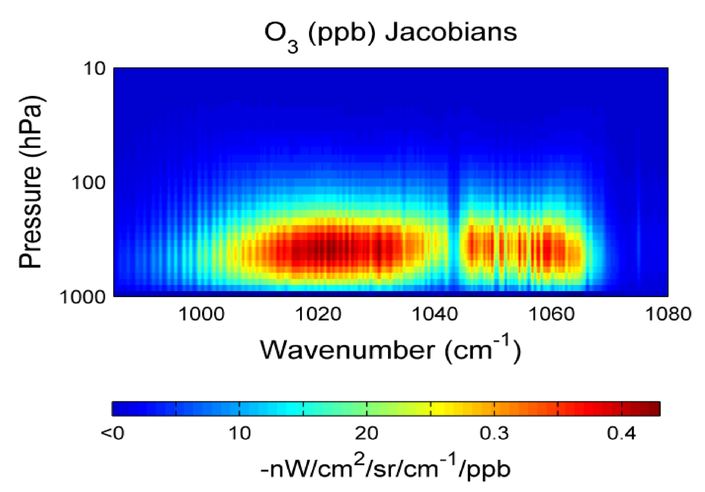
IRK Formulation

Direct Integration

$$\frac{\partial F_{TOA}}{\partial q_{zl}} = 2\pi \frac{\partial}{\partial q_{zl}}\Bigg|_i \int_0^{\pi/2}\int_v L_{TOA}\cos\theta_i \sin\theta_i \, d\theta dv$$

Anisotropy

$$\frac{\partial F_{TOA}}{\partial q_{zl}} = \int_v \frac{\partial L_{TOA}}{\partial q_{zl}} \frac{\pi dv}{R(v)}$$



- → F_{TOA} = TOA Flux
- → L_{TOA} = TOA radiance
- → q_{zl} = O_3 concentration in ppb in mean altitude *z* of layer *l*
- → θ = Nadir viewing angle
- → v = Wavenumber

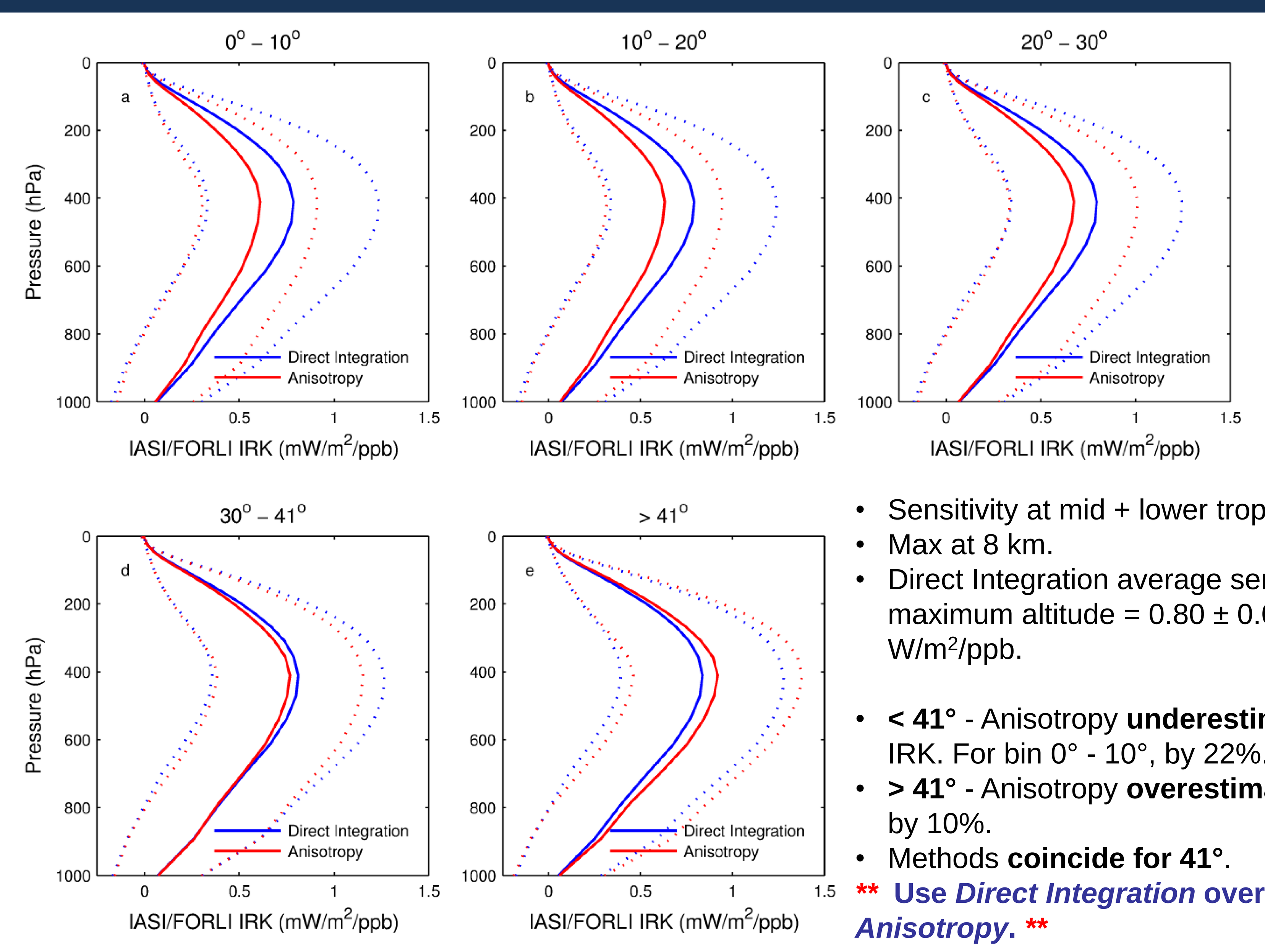
- Calculation of Jacobians $\partial L_{TOA}/\partial q_{zl}$ for different angles.
- Calculation only of L_{TOA} radiances.
- $\partial L_{TOA}/\partial q_{zl}$ = Constant
- *R(v)* = Constant

- Azimuthal symmetry assumed.
- Integration over wavenumber, v and –weighted – over nadir angles, θ_i, (Li, 2000).
- Breaking down the "Direct Integration" method, via "Anisotropy":

$$2\pi \frac{\partial}{\partial q_{zl}} \int_0^{\pi/2}\int_v L_{TOA}(\theta,v,q)\cos\theta_i \sin\theta_i \, d\theta dv = \int_v \frac{\partial L_{TOA}(\theta,v,q)}{\partial q_{zl}} \frac{\pi dv}{R(v)} - \int_v F_v(\theta,v,q) \frac{\partial}{\partial q_{zl}} \ln\big(R(\theta,v,q)\big)$$

Direct Integration — **Anisotropy** — **ΔRF**

IRK Distribution



- Sensitivity at mid + lower troposhere.
- Max at 8 km.
- Direct Integration average sensitivity at maximum altitude = 0.80 ± 0.02 W/m^2/ppb.

- **< 41°** - Anisotropy **underestimates** IRK. For bin 0° - 10°, by 22%.
- **> 41°** - Anisotropy **overestimates** IRK, by 10%.
- Methods **coincide for 41°**.

** *Use Direct Integration over Anisotropy.* **

Conclusions & Perspectives

→ We have presented two methods to calculate the longwave radiative impact (LWRE) of ozone from satellites, the Direct Integration and the Anisotropy method. Of the two, the Direct Integration is the most reliable, as shown in the IRK formulation and distribution sections.

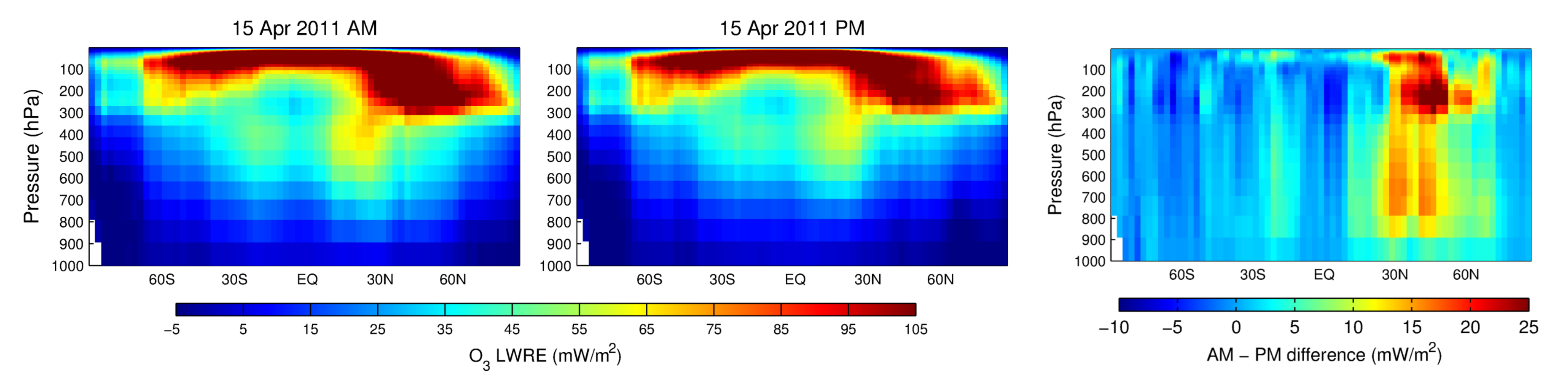
→ The Direct Integration method was applied on IASI data and we were able to derive - layer by layer - the vertical distribution, total and tropospheric columns of the O_3 LWRE.

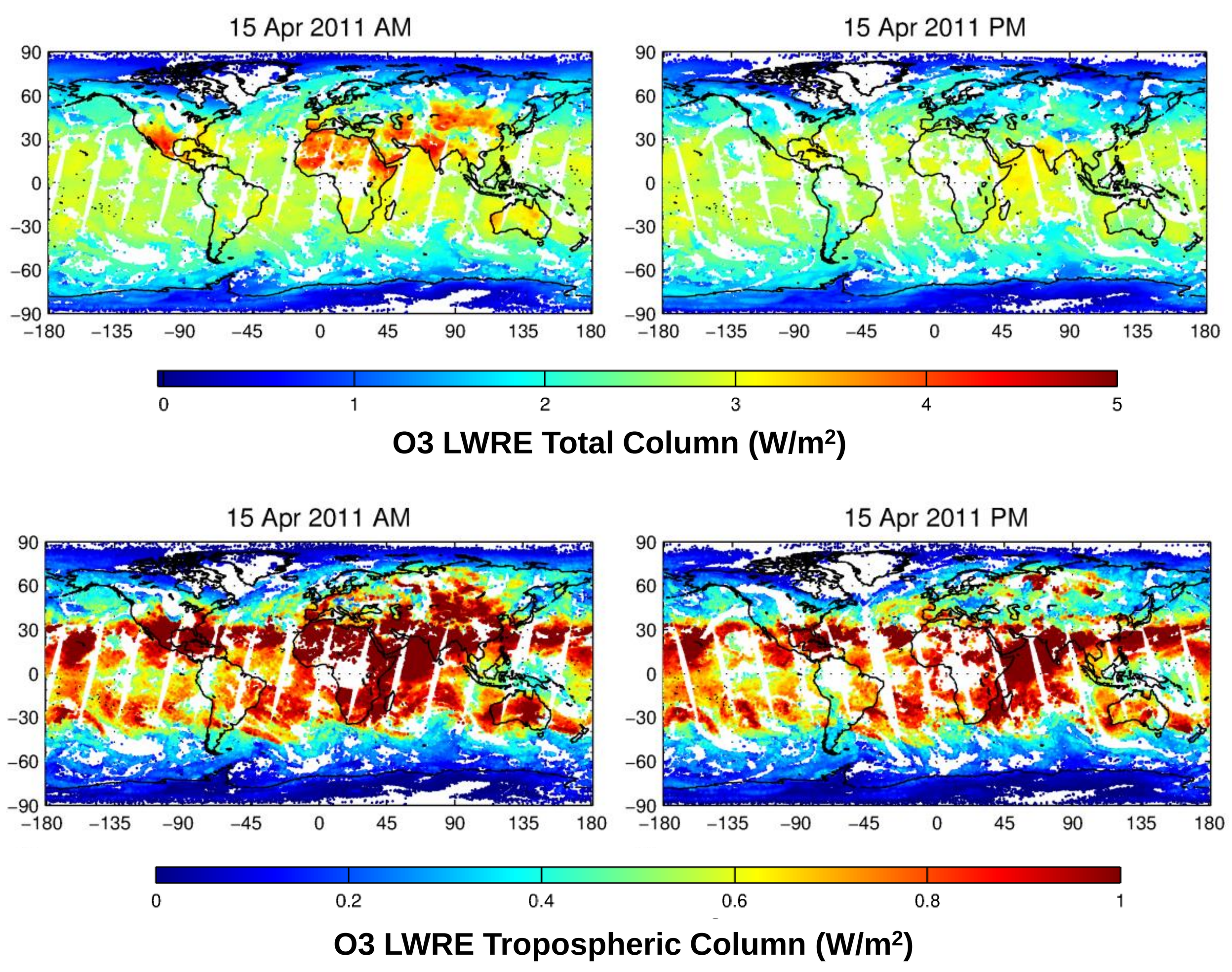
→ The results of the studies show a strong connection between the LWRE and the surface temperature.

→ IASI LWRE was compared against TES and Chemistry-Climate Models (used in CCMI and IPCC), as a result:

- IASI and TES agree well, but exhibit differences, which are mainly described by instrumental & a-priori differences.
- Chemistry-Climate models show biases ranging from acceptable to really important.
- A thorough and overall assessment of more Chemistry-Climate models is necessary and foreseen.

LWRE Distribution





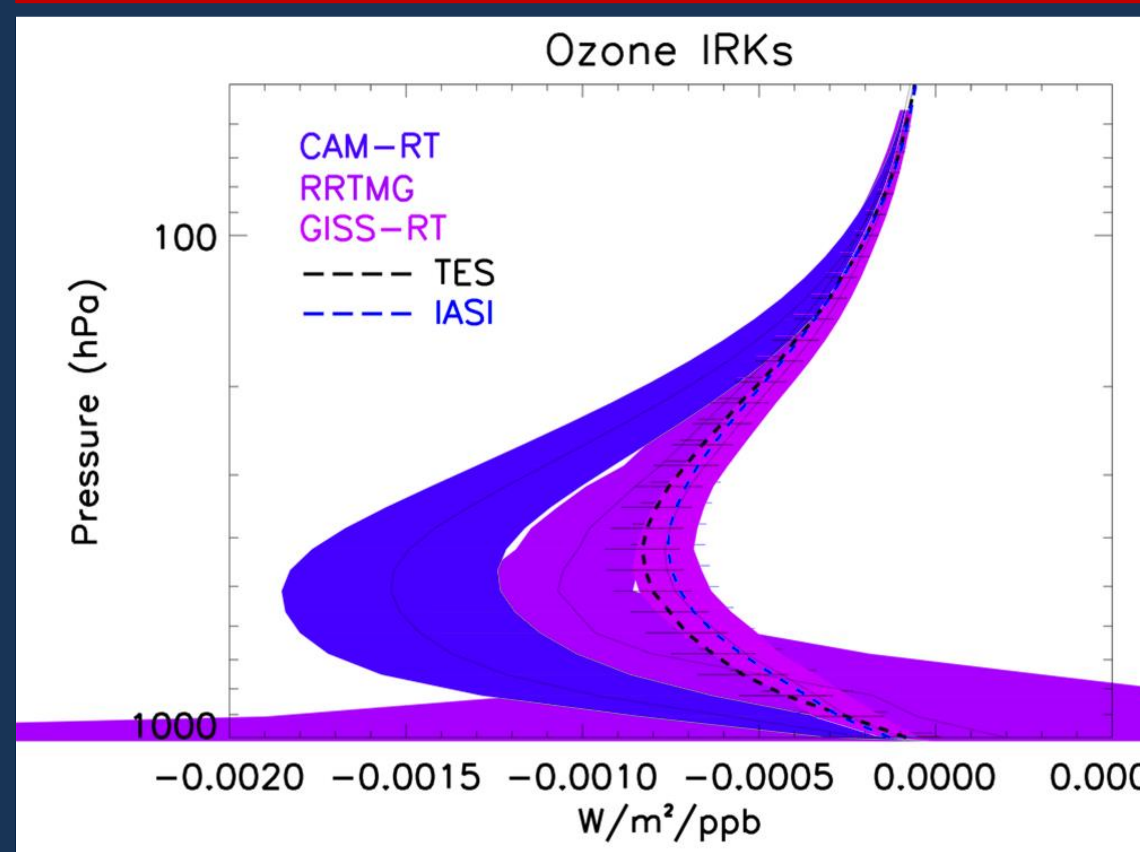
$LWRE_l = IRK_l \times O_3(ppb)_l$

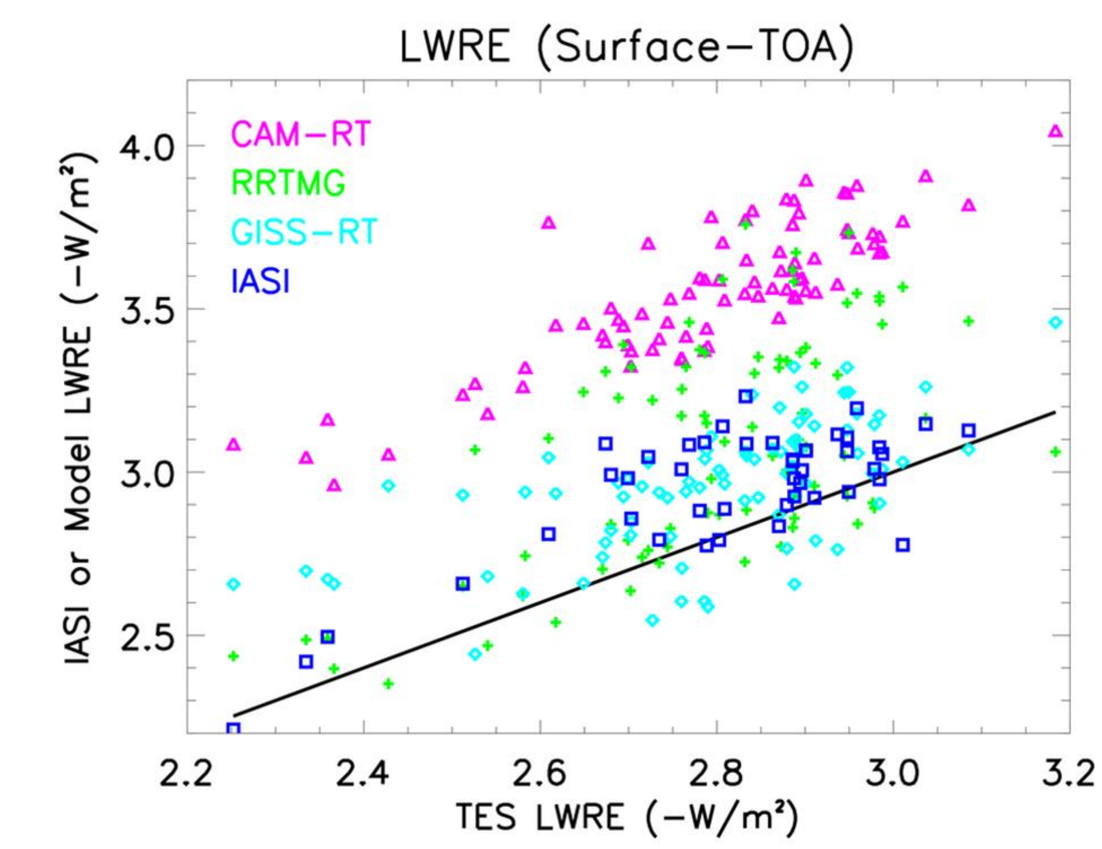
- High LWRE at high altitudes – O_3 layer.
- NH midlatitudes (AM-PM) :
  - Up to 25 mWm^{-2} @ 250 hPa.
  - Up to 15 mWm^{-2} @ mid + lower troposphere.

- O_3 Total Column LWRE Global Average = 2.30 ± 0.49 Wm^{-2}.
- O_3 Tropospheric LWRE Column Global Average = 0.54 ± 0.09 Wm^{-2}.

- **SH**: cool clean ocean – near stable conditions.
- **NH**: land domination + high pollution.
- **Tropics**:
  - → Low O_3 content.
  - → High $T_{surface}$.

IASI vs TES vs Climate Models





15 July 2011 – 81 cases, clear-sky ocean scenes

Collocation:
- Lat/Lon: IASI = TES ± 100 km
- Time: 0 ≤ TES – IASI ≤ 6h

→ Models fed with same TES profiles to produce collocated IRKs and LWRE.

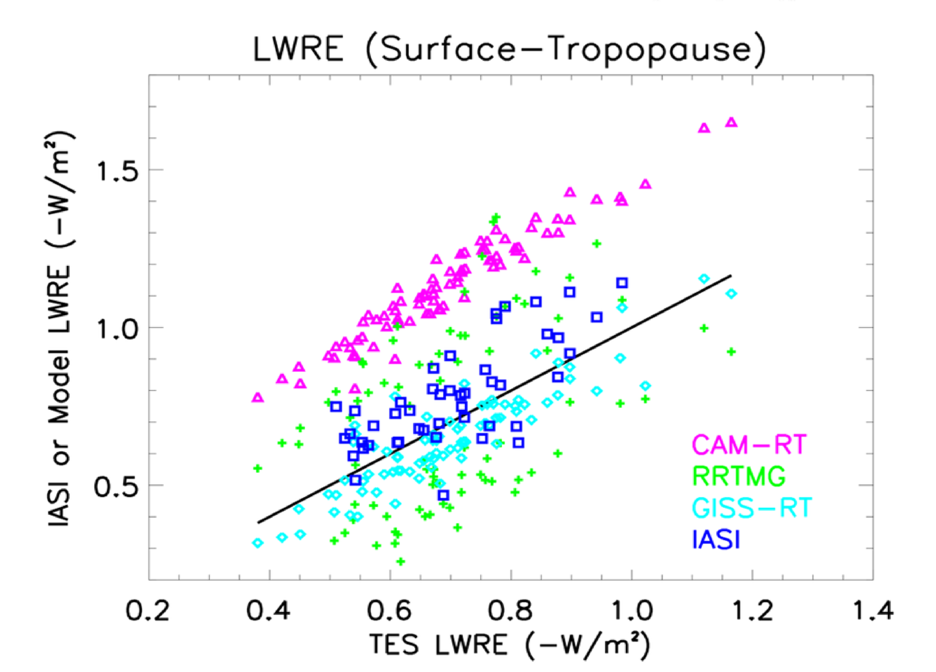
→ IASI and TES agree well, with differences mostly attributable to instruments and corresponding retrieval algorithms; requires technical investigation.

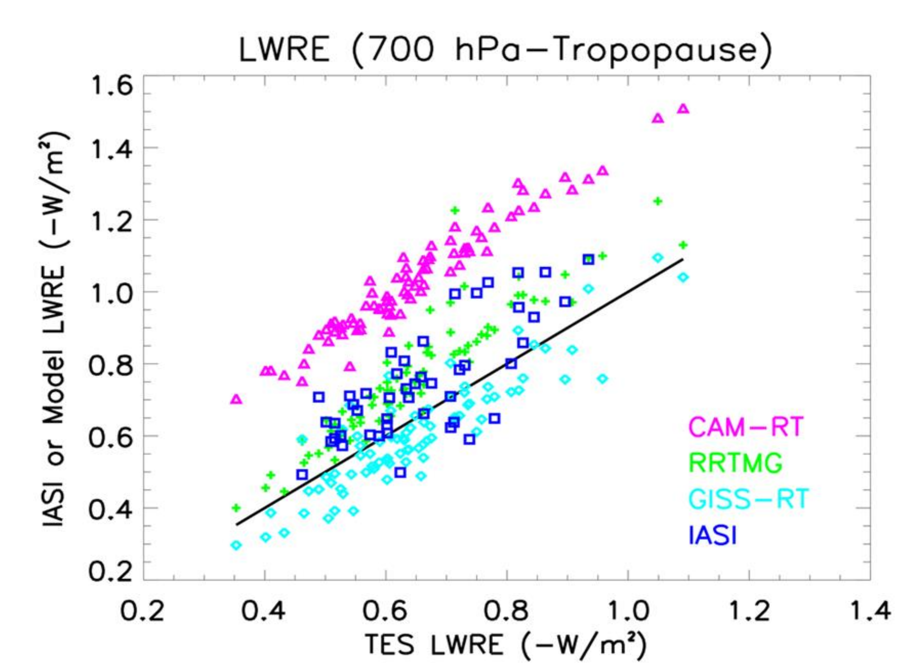
→ IASI has limited sensitivity in the first km above ground, overestimating results compared to TES in total.

→ RRTMG shows weak sensitivity to H_2O near the ground, producing fault results; surpassed when considered above 700 hPa.

→ CAM-RT shows large differences compared to the observations overall.

**** These Chemistry-Climate models are used in the *ACCMIP* and *IPCC* studies. The ability of comparing IASI & TES IRKs and LWRE directly with the models, is a big step towards the accurate representation of the true atmospheric state in models, its radiative impact and limiting the uncertainties in RF calculations. ****





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