Distribution and Time Evolution of the Ozone Instantaneous Longwave Radiative Effect from IASI and TES observations

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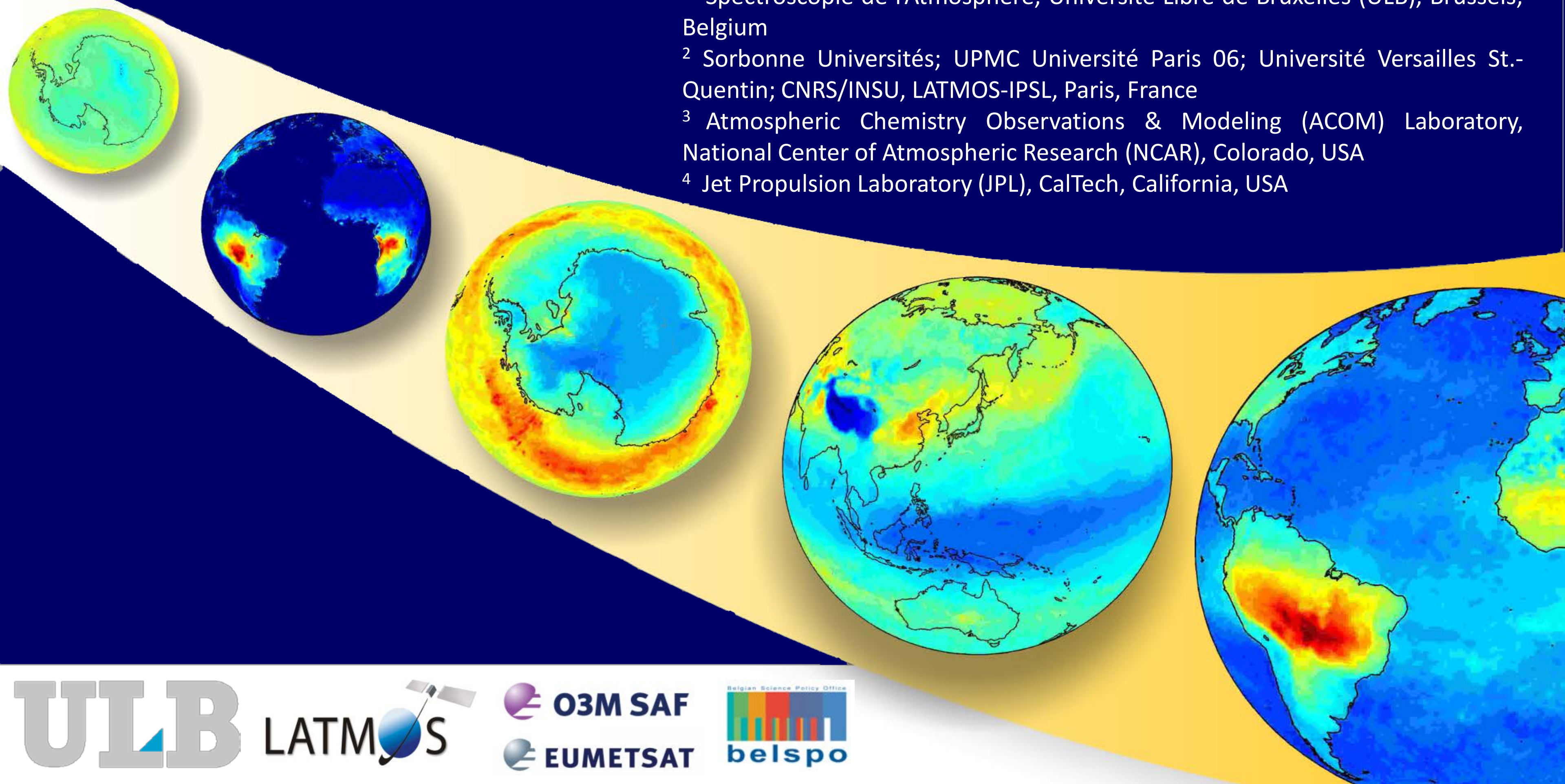
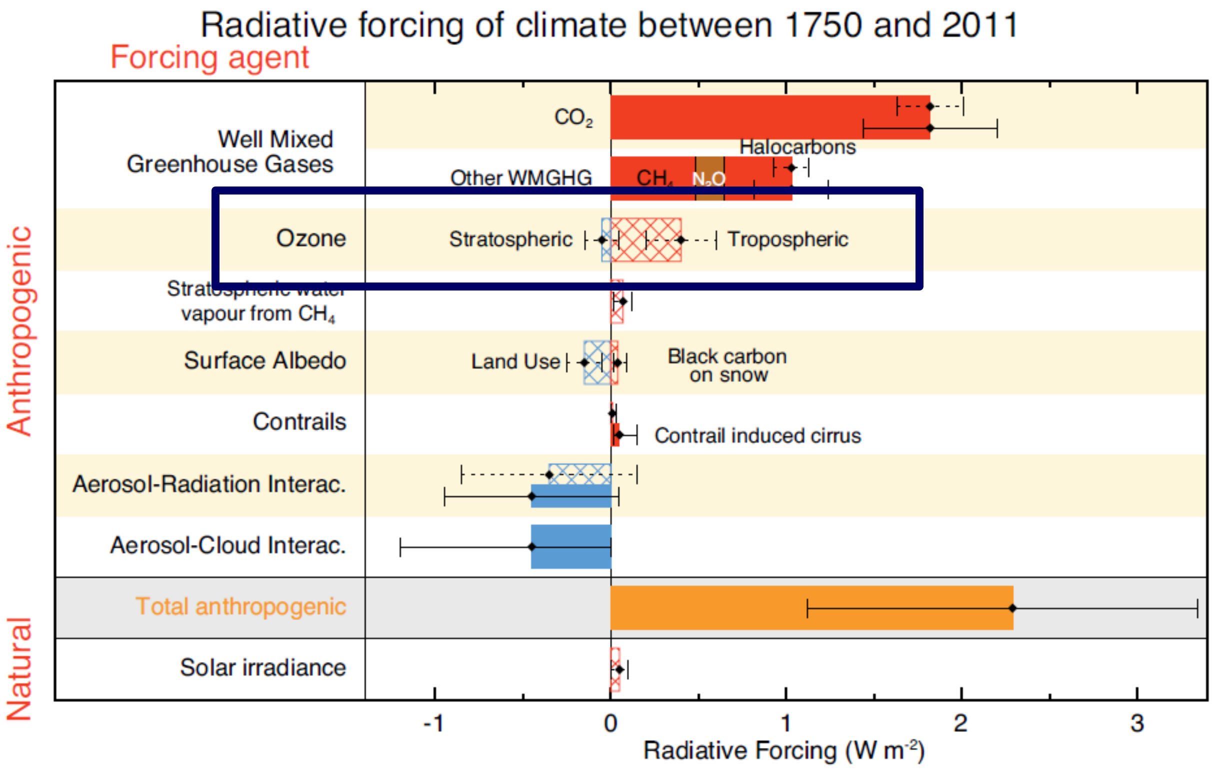


ULB LATMOS O3M SAF EUMETSAT belspo

O_3 Radiative Forcing – IPCC AR5



IPCC AR5 (2013)

- Most important GHG after WMGHGs

Certain:
→ Observed trends of O_3 and model results

Uncertain:
→ Differences between model RF estimates

Tropospheric O_3:

- Short lifetime
- Great spatial and temporal variability
- RF = + 0.40 (± 0.20) W/m^2

Stratospheric O_3:

- Lifetime ~ few weeks
- Ozone layer – UV absorption
- RF = - 0.05 (± 0.1) W/m^2

O_3 Radiative Forcing – IPCC AR5

Table 8.3 | Contributions of tropospheric and stratospheric ozone changes to radiative forcing (W m^{-2}) from 1750 to 2011. *(IPCC AR5, 2013)*

	Troposphere				Stratosphere		
	Longwave	**Shortwave**	**Total**	**Normalized Radiative Forcing m W m^{-2} DU^{-1}**	**Longwave**	**Shortwave**	**Total**
AR4 (Forster et al. (2007)			0.35 (0.25 to 0.65)				–0.05 (–0.15 to 0.05)
Shindell et al. (2013a)[f]			0.33 (0.31 to 0.35)				–0.08 (–0.10 to –0.06)
WMO (Forster et al., 2011b)							–0.03[a] (–0.23 to +0.17) +0.03[b]
Søvde et al. (2011)			0.45[c] 0.38[d]	40 39			–0.12 –0.12
Skeie et al. (2011a)			0.41 (0.21 to 0.61)	38			
ACCMIP[e]	0.33 (0.24 to 0.42)	0.08 (0.06 to 0.10)	0.41 (0.21 to 0.61)	42 (37 to 47)	–0.13 (–0.26 to 0)	0.11 (0.03 to 0.19)	–0.02 (–0.09 to 0.05)
AR5			0.40 (0.20 to 0.60)	42 (37 to 47)			–0.05 (-0.15 to 0.05)

- Different models → Different results
- Stratospheric O_3 RF value more stable: **-0.05 ± 0.10 W/m²**

No model-to-data comparisons!

- Tropospheric O_3 RF:
  → Increased **0.40 ± 0.20 W/m²**
  → Difficulties in representation of distribution due to spatial & temporal variability

O_3 Radiative Impact

How can we check what the climate models calculate for RF?

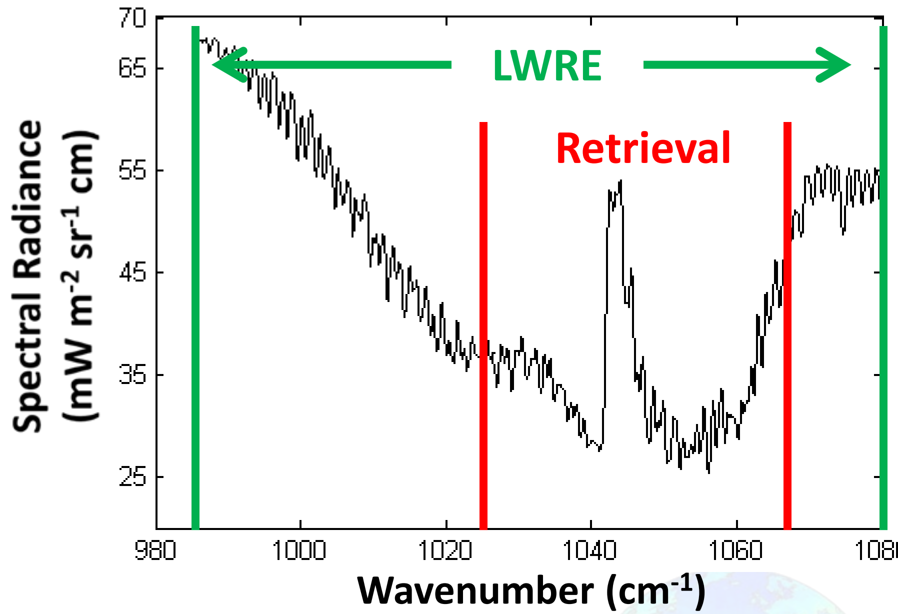
How can we involve satellites?

Why are the satellites important?

O_3 Radiative Impact + Satellites

- **Satellites provide**: Global coverage,
  Large amount of data,
  Vertical distribution of species

- For our work in the **LW band**:
  → Need of a Thermal IR instrument onboard a satellite:
  - Sufficient vertical sensitivity
  - Good spatial/temporal coverage
  - High spectral sampling



15 Jan 2011, 51.13°N, 42.23°S, UTC 04:57

- Calculations in 3 steps:
  1. **Retrieval**: O_3 profiles, Tsurface, Jacobians of last iteration etc.
  2. **Instantaneous Radiative Kernel** (IRK): Sensitivity of the OLR flux with respect to the observed O_3 profile.
  3. **Longwave Radiative Effect** (LWRE): Radiative impact of O_3 due to absorption in the LW band (full 9.6 μm).

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LWRE ≠ RF / ERF of IPCC

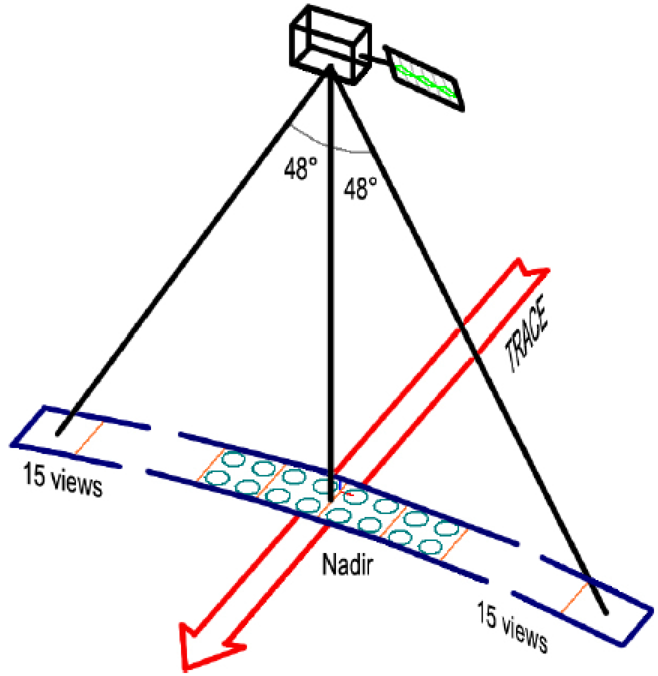
- Instantaneous / Direct, linked to each specific observation.
- No tropospheric – stratospheric adaptation to changes.
- Defined with respect to TOA.
- Not calculated as the difference between pre-industrial to present conditions.

Instrument

Infrared Atmospheric Sounding Interferometer (IASI)

- Nadir Thermal Infrared Radiation sounder
- Spectral range: 645 – 2760 cm^{-1}
- Spectral resolution: 0.5 cm^{-1} apodized
- Radiometric noise: ~ 0.1 – 0.2 K

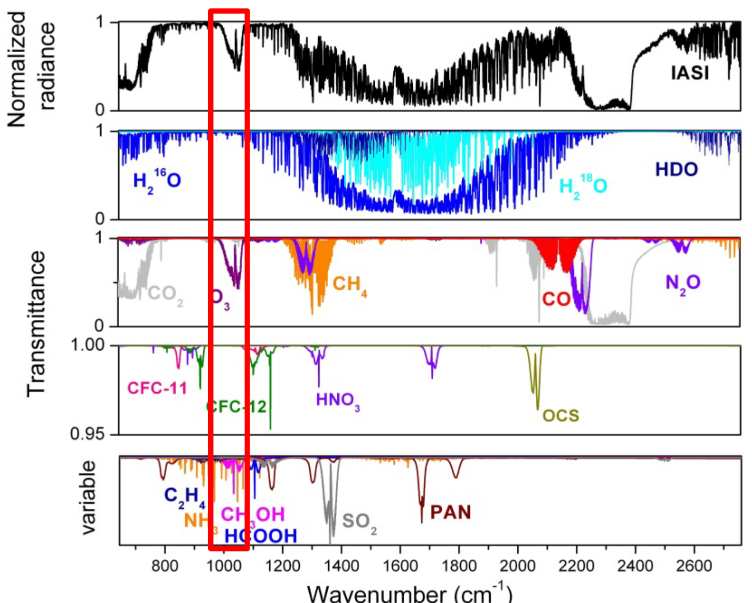
- **Spatial coverage:**
  Global 2 x daily (9:30 & 21:30 LT Equator)
- **Field of view:**
  4 simultaneous pixels – 12 km diameter at nadir each
- **Full swath width:**
  ± 48° = ~ 2200km / 120 spectra per scan



Retrieval + Calculations with FORLI-O_3 at ULB.
→ **Only Clear Sky scenes** (Cl. Coverage < 13%)

FORLI-O_3 product used:

- ESA – O3-CCI
- To be implemented in the near real-time processing @ EUMETSAT



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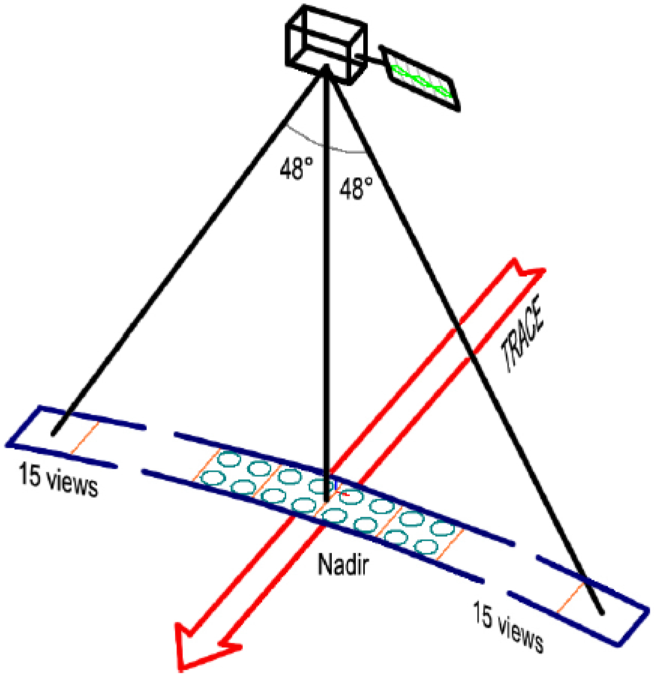
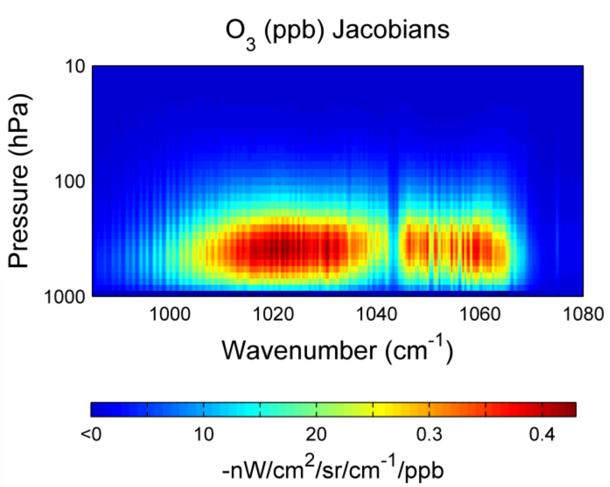
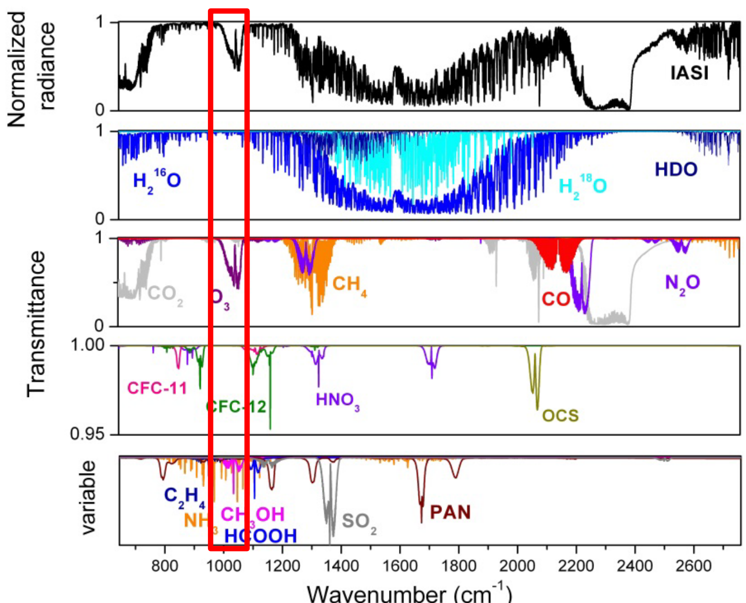




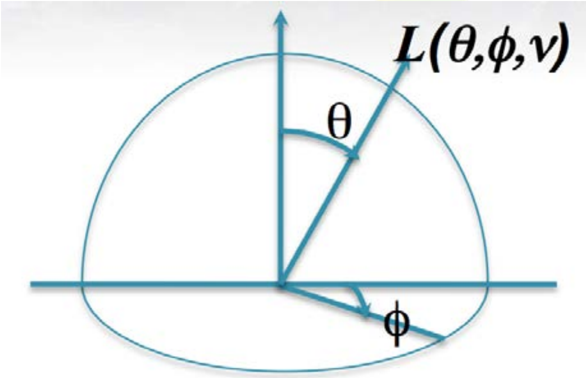
$$\frac{\partial L_{TOA}}{\partial q(z_l)}$$

Jacobians =
Sensitivity of TOA radiance to O_3 at mean altitude *z* of layer *l*



IRK Formulation

TOA Flux: $$F_{TOA} = 2\pi \int_{v} \int_{0}^{\pi} L_{TOA}(v,\theta) \cos\theta \sin\theta d\theta dv$$



IRK

→ Sensitivity of OLR flux at TOA to *$O_3(z_l)$*
(in $W/m^2/ppb$)

OR:

Change of TOA flux due to change of O_3 abundance.

Instantaneous:

Refers to **specific amount** of O_3 observed at **specific moment**.

TOA Flux

$$\frac{\partial F_{TOA}}{\partial q(z_l)} = 2\pi \int_{v} \int_{0}^{\pi/2} \frac{\partial L_{TOA}(v,\theta,)}{\partial q(z_l)} \cos\theta \sin\theta \, d\theta \, dv$$

O_3 (ppb) at altitude *z_l*

TOA radiance

IRK Formulation

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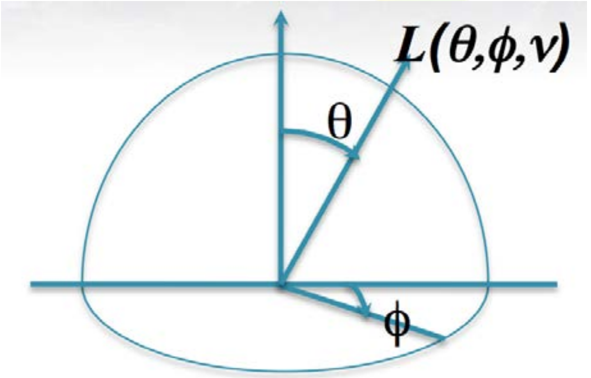

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Instantaneous:

Refers to **specific amount** of O_3 observed at **specific moment**.

2 methods for IRKs

Anisotropy →

$$\frac{\partial F_{TOA}}{\partial q(z_l)} = \int_{v} \frac{\partial L_{TOA}(v,\theta)}{\partial q(z_l)} \frac{\pi dv}{R(v,\theta)}$$

Worden et al., JGR, 2011
Doniki et al., submitted manuscript

Direct Integration →

$$\frac{\partial F_{TOA}}{\partial q(z_l)} = 2\pi \sum_{i=1}^{5} w_i \int_{v} \frac{\partial L_{TOA}(v,\theta_i)}{\partial q(z_l)} dv$$

Doniki et al., submitted manuscript

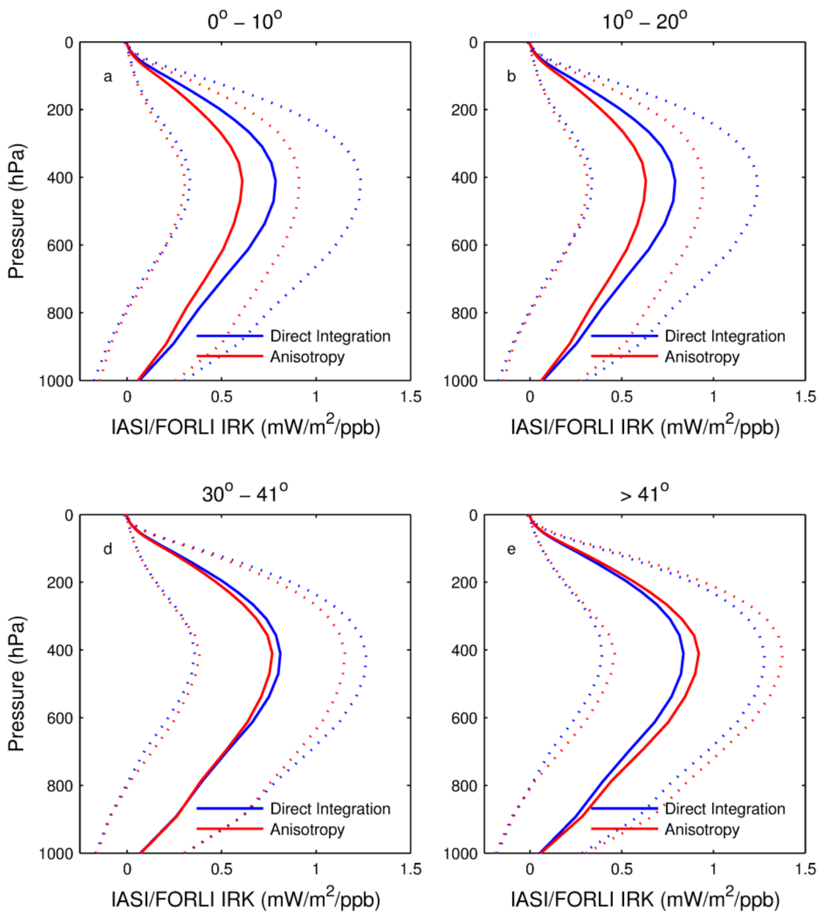
- Simulation of Jacobians for 5 angles
- $w_i + \theta_i$ from 5-node Gaussian Quadrature

Question

What are the IRKs?

What is the difference between the 2 methods?

IRK comparison



15 April 2011
Global average
Clear-sky IRKs.

Bins of 10° of IASI viewing angle from nadir.
Max angle ≈ ± 48°.

Anisotropy

Direct Integration

- Sensitivity at mid + lower troposphere.
- 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°.**

**** Anisotropy has angular issues**

✓ **Direct Integration**

Longwave Radiative Effect

What is the actual radiative impact of O_3?

Longwave Radiative Effect

What is the actual radiative impact of O_3?

LWRE = Radiative impact of O_3 due to absorption in the LW band (full 9.6 μm)

For specific location and time *i*:

$$LWRE_i = \left. \frac{\partial F_{TOA}}{\partial q(z_l)} \right|_i \cdot q(z_l)_i$$

in W/m^2

The absolute radiative impact of O_3 (compared to a reference of zero).

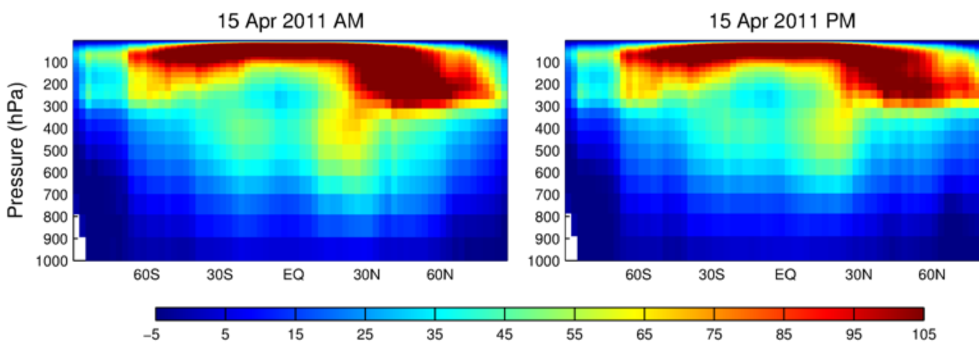
- Simple integration of vertical layers, to obtain desired column, e.g. Tropospheric LWRE

O_3 LWRE – Vertical Distribution

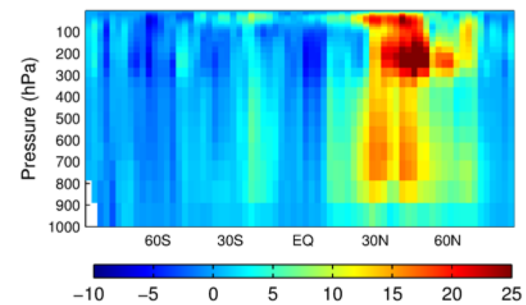
15 April 2011
Zonal average

Direct Integration

AM **PM** **AM – PM**



-5 **O_3 LWRE (mW/m²)** **105**



-10 **mW/m²** **25**

- High LWRE at high altitudes – O_3 layer

- SH: cool clean ocean – near stable conditions
- NH: land domination + pollution higher than SH
- NH midlatitudes:
  - Difference up to 25 mW/m² @ 250 hPa
  - 15 mW/m² @ mid + lower troposphere

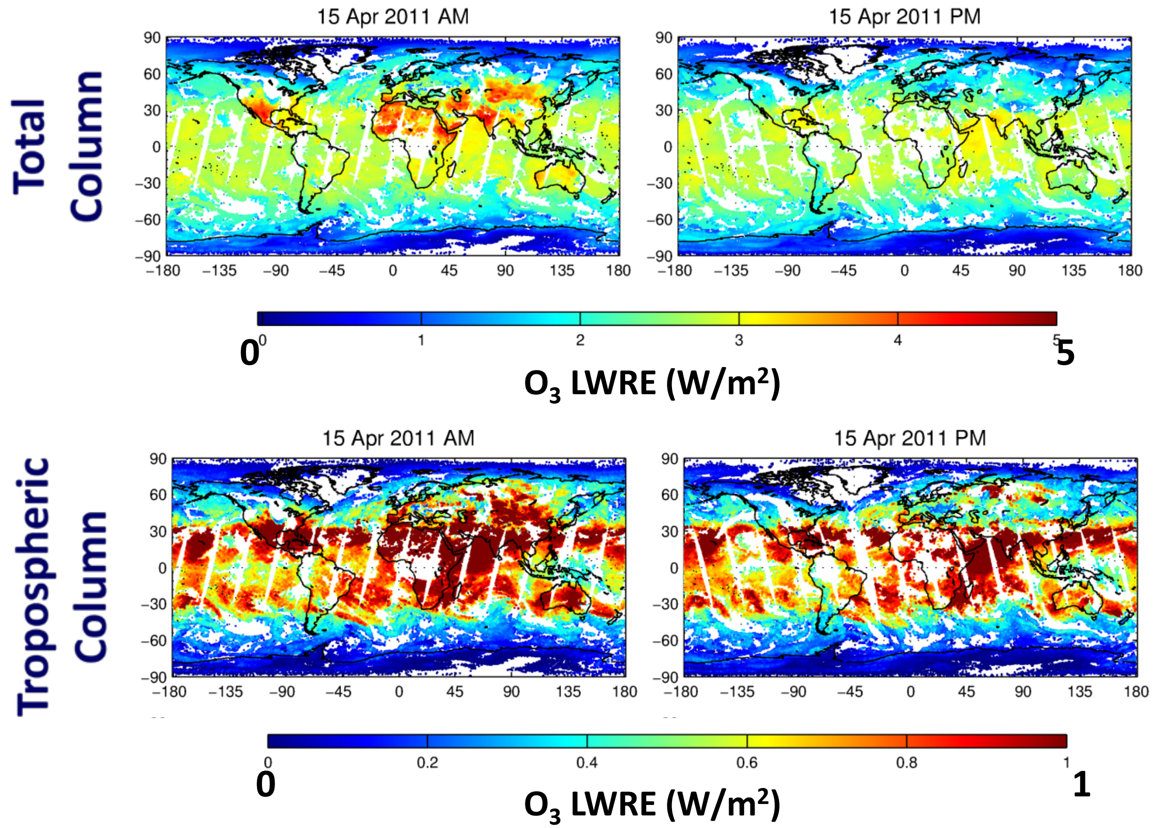
→ ΔO_3 T.C. between AM/PM = 4.2 DU
→ **ΔTsurface = 7 K**

** Tsurface affects LWRE also at high altitudes.

O_3 LWRE – Spatial Distribution

15 April 2011
Global raw data

Direct Integration



- High LWRE in Tropics:
  → Low O_3 content region
  → High Tsurface

- High LWRE in NH midlatitudes during day:
  → Tsurface

- **O_3 Total C. LWRE Global Average:**
  2.30 ± 0.49 W/m²

- **O_3 Tropospheric C. LWRE Global Average:**
  0.54 ± 0.09 W/m²

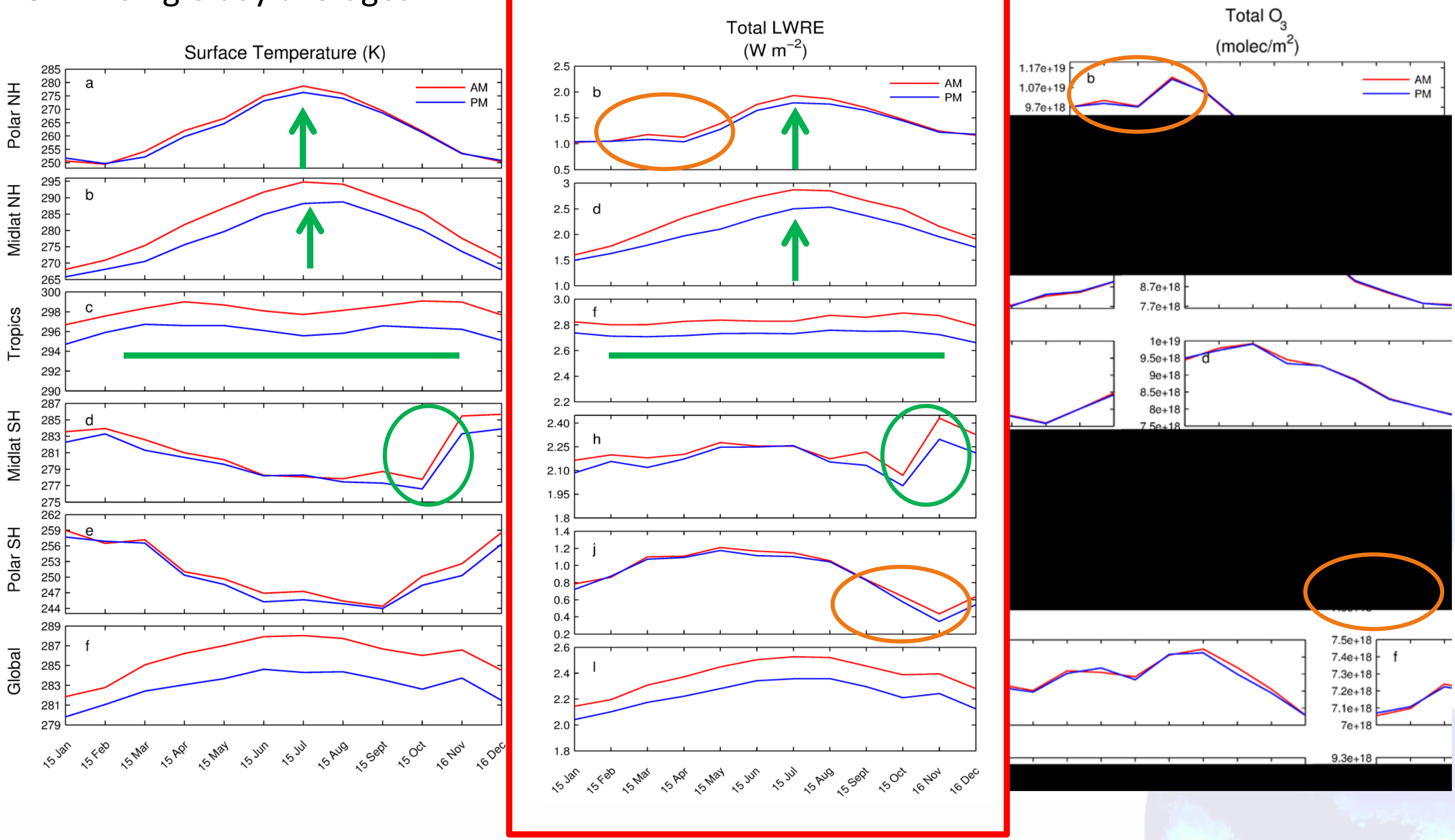
Tropospheric LWRE

- 2 to 5 times lower than Total locally.
- 4 to 5 times lower than Total globally.

O_3 LWRE Temporal Variation – Total Column

2011 – Single day averages

Direct Integration



Green: Tsurface effects

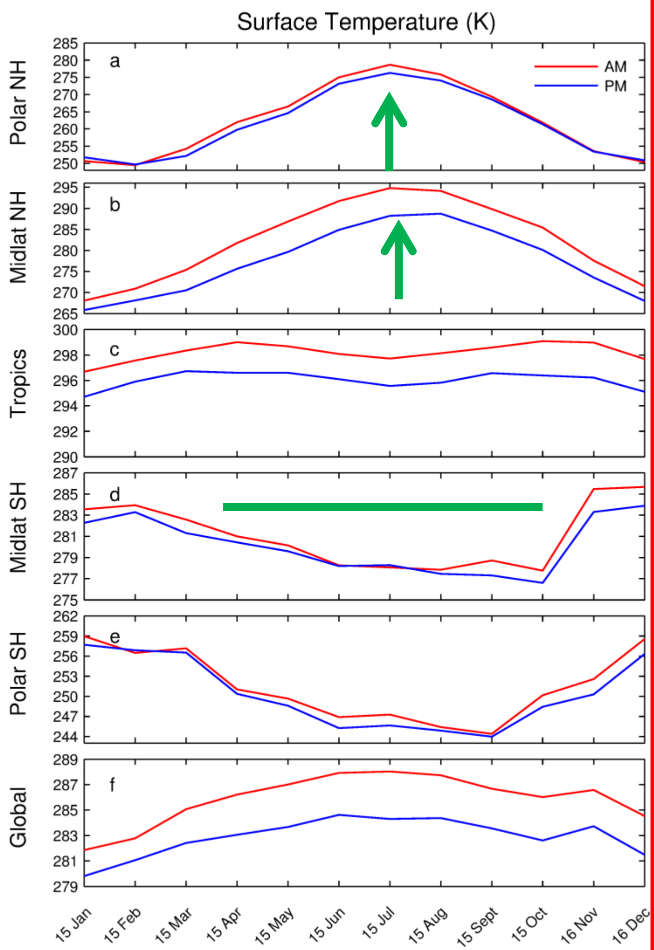
Orange: O_3 column effects

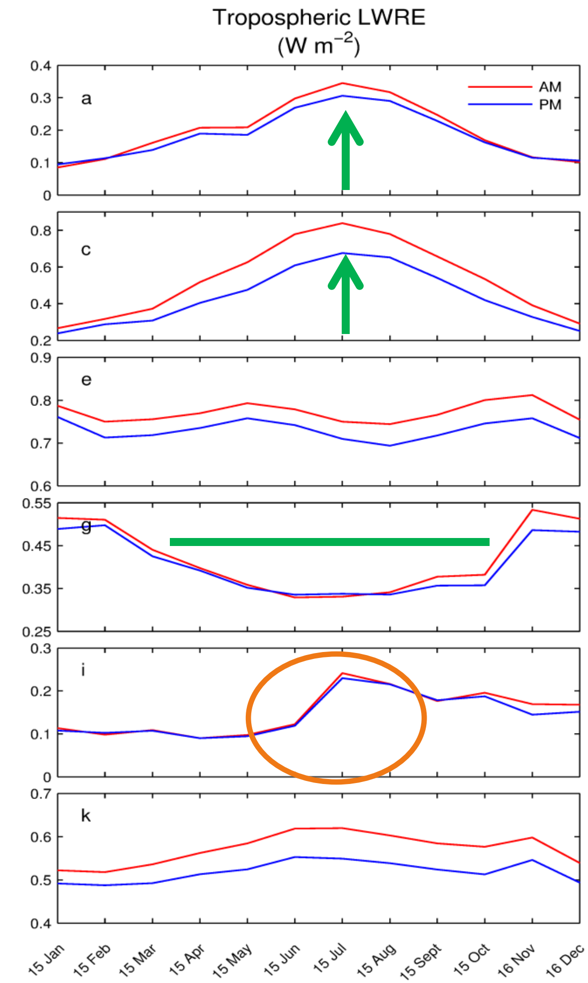
**** Global Average mostly follows Tsurface variability**

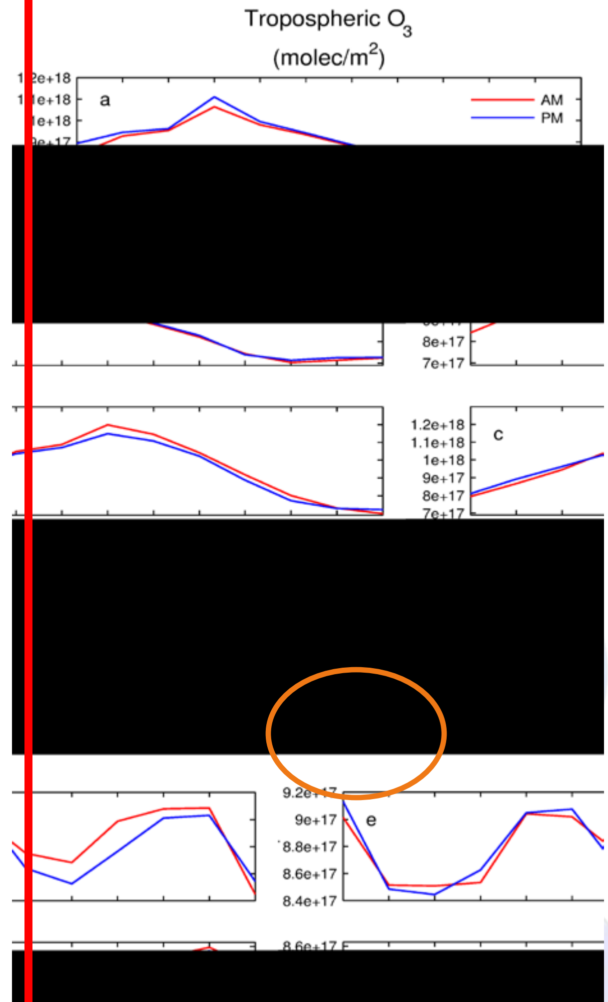
O_3 LWRE Temporal Variation – Tropospheric Column

2011 – Single day averages

Direct Integration







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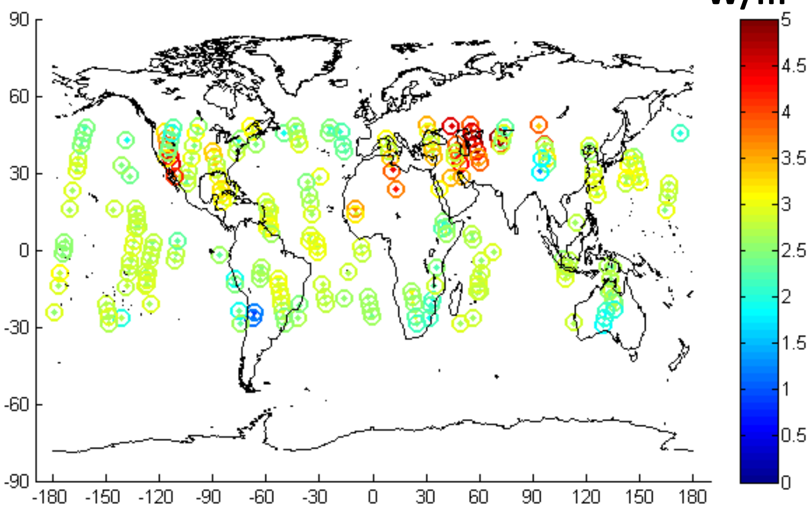
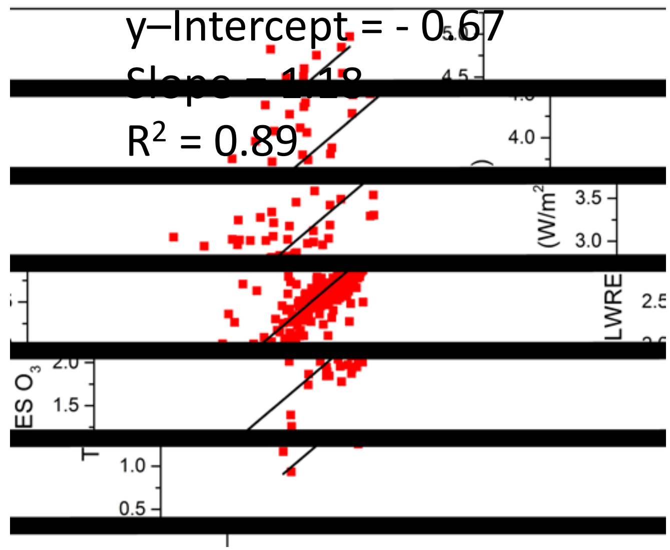
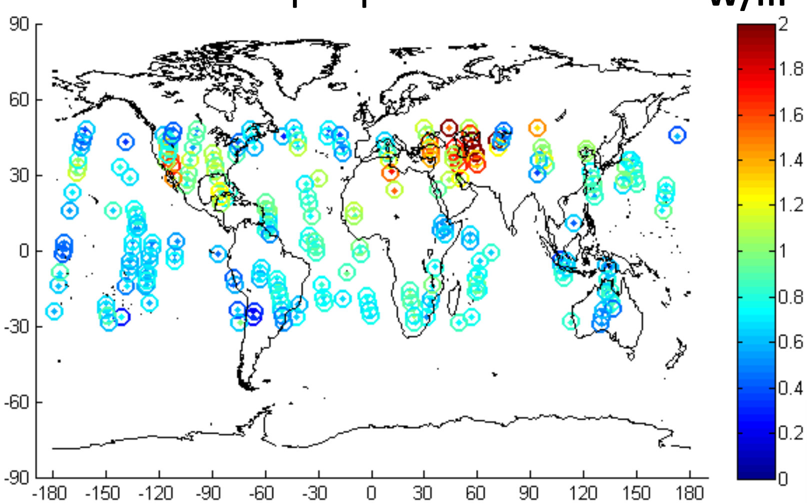
O_3 LWRE – IASI and TES/Aura

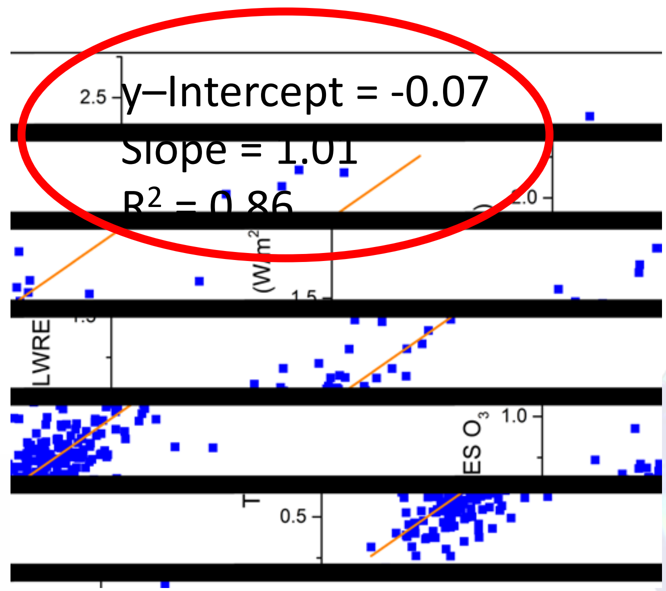
LWRE Total Column





LWRE Tropospheric Column





Direct Integration

15 July 2011

- **TES obs.**
- o **IASI obs.**

IASI=TES±0.5° lat

IASI=TES±0.5° lon

0 < TES–IASI < 6h

Conclusions

- Two new parameters:
  - → **IRK**: Sensitivity of OLR flux to O_3 profile
  - → **LWRE**: Radiative impact of O_3 due to absorption
- New method: **Direct Integration**
  - → **Accurate** for the angular integration
  - → Computationally expensive
- Strong correlation of LWRE and Temperature
- LWRE tracks O_3 changes
- Good agreement between IASI and TES
- IRK + LWRE can be used to assess Chemistry-Climate models

Interested?

Application of IRKs and LWRE on climate models

Benchmarking climate model top-of-atmosphere radiance in the 9.6μm ozone band compared to TES and IASI observations

By
H. M. Worden
(NCAR)

Friday 12/6, 11.25am

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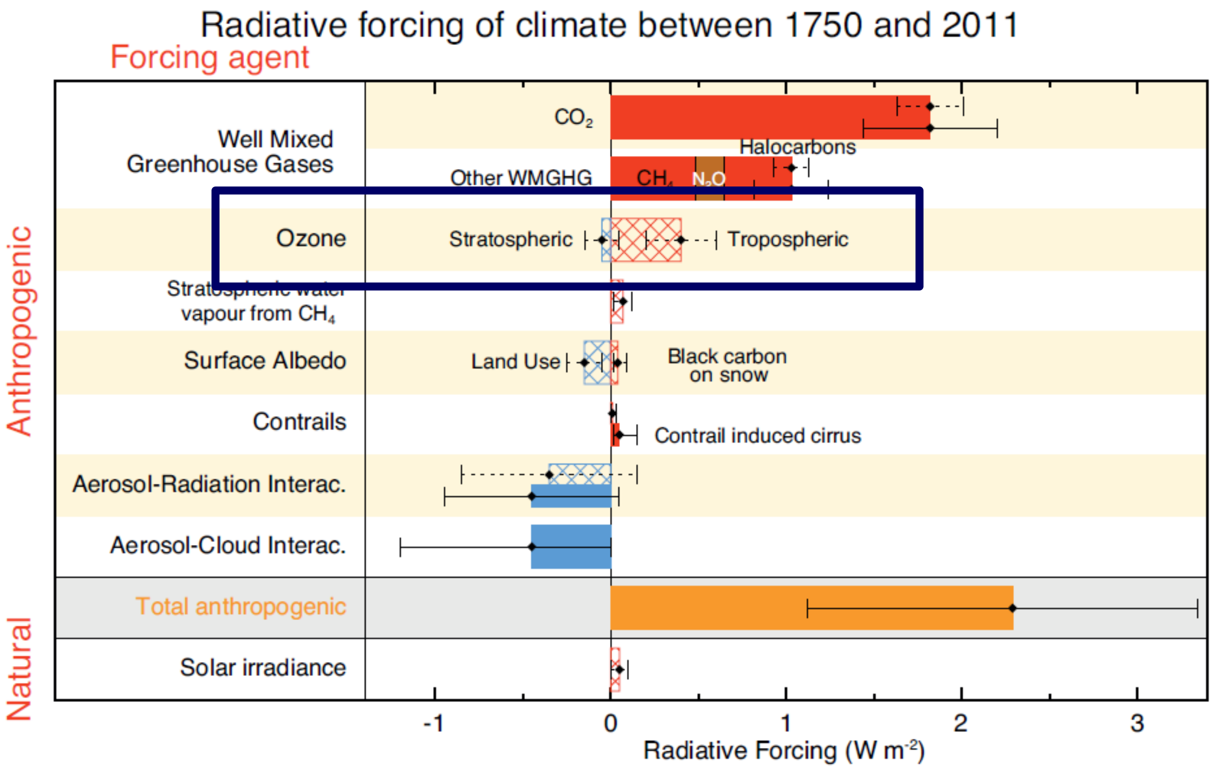
O_3 Radiative Forcing – IPCC AR5



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For specific location and time *i*:

$$LWRE_i = \left.\frac{\partial F_{TOA}}{\partial q(z_l)}\right|_i \cdot q(z_l)_i$$

in W/m^2

The radiative impact of a 100% change in O_3.

- Simple integration of vertical layers, to obtain desired column, e.g. Tropospheric LWRE

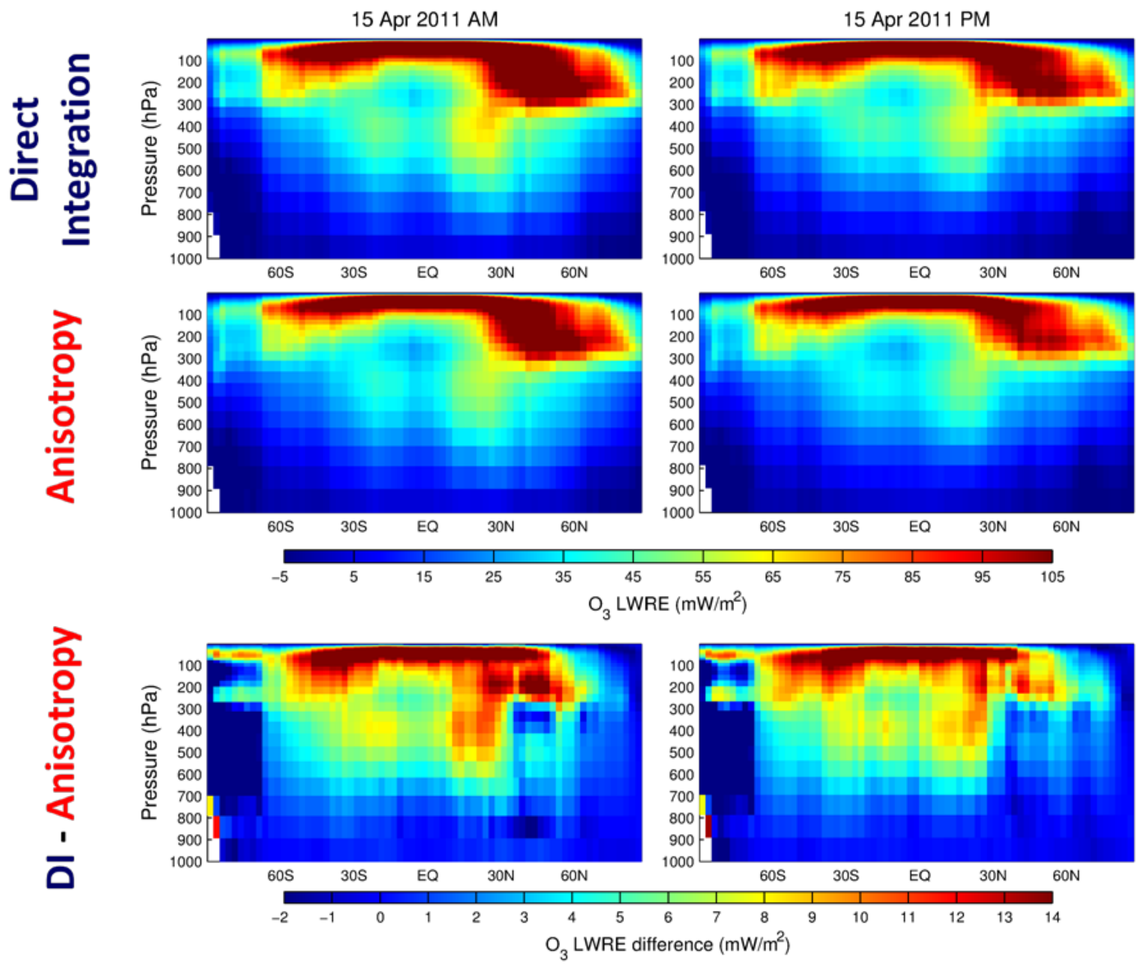
Or:

ΔLWRE: the difference between 2 observations at the same spatiotemporal spot.

$$\Delta LWRE_i = \left.\frac{\partial F_{TOA}}{\partial q(z_l)}\right|_i \cdot \left[q^{obs}(z_l) - q^{ref}(z_l)\right]_i$$

O_3 LWRE Vertical Distribution

15 April 2011
Zonal average
Vertical LWRE



IASI viewing angles: 0 to ± 48°
→ Most angles <41°

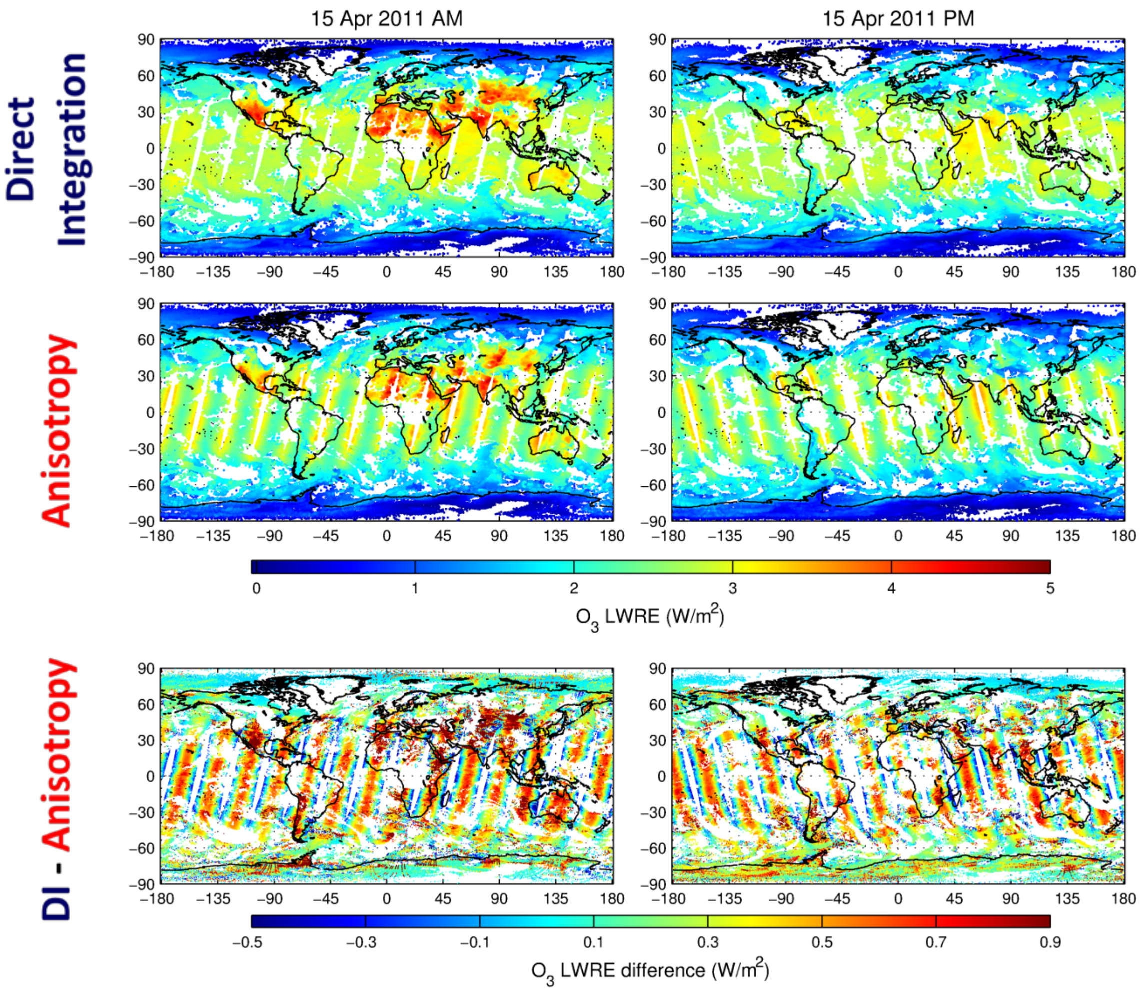
- Both methods show same patterns.
- Higher values at NH, land domination.
- Higher values at AM overpass
  → Tsurface effect
- **Anisotropy consistently underestimates LWRE.**

- The **higher the LWRE** values, the **larger the difference**.

→ Stratosphere
→ Inter-tropical mid-troposphere

O_3 LWRE Comparison– Total Columns

15 April 2011
Global raw data
LWRE total column



- Same broad patterns for both methods.
- Higher values at inter-tropical and NH, land domination.
- Higher values at AM overpass → Tsurface effect

Anisotropy:

- **Underestimates** at **near nadir** (middle of overpass - red)
- **Overestimates** at **high angles** (edges of overpass - blue)

- **Matches Direct Integration** at around **41°** (light blue)

** Polar regions: Compensation of positive/negative biases of overlapping orbits