Aerosol radiative effects from satellites

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Overview

- Motivation:
  - why calculate aerosol radiative effect
  - connection to radiative forcing
- Methodology:
  - aggregation of satellite data into regional, monthly estimates
  - uncertainty and error analysis
  - radiative calculations
- Radiative forcing?
- What next

See: G.E. Thomas et al., Atmos. Chem. Phys., 13:393-410, 2013

Nomenclature

Aerosol radiative effect

Difference between the net downwelling broadband flux with and without aerosol at some atmospheric level:

$$\Delta R = (F^{\downarrow} - F^{\uparrow})_{aerosol} - (F^{\downarrow} - F^{\uparrow})_{\text{"clean"}}$$

Aerosol radiative forcing

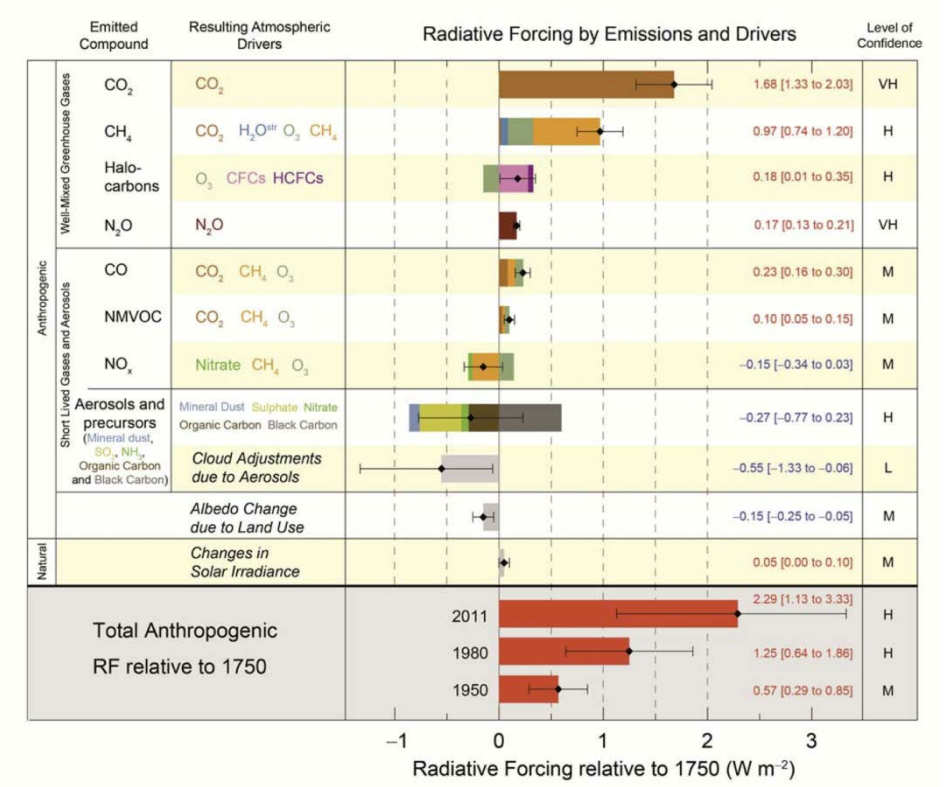
Follow the IPCC definition: change in radiative effect at top-of-atmosphere since 1750:

$$R_f = (F^{\downarrow} - F^{\uparrow})_{present} - (F^{\downarrow} - F^{\uparrow})_{1750}$$

Note: aerosol radiative forcing is only takes account of changes in aerosol itself

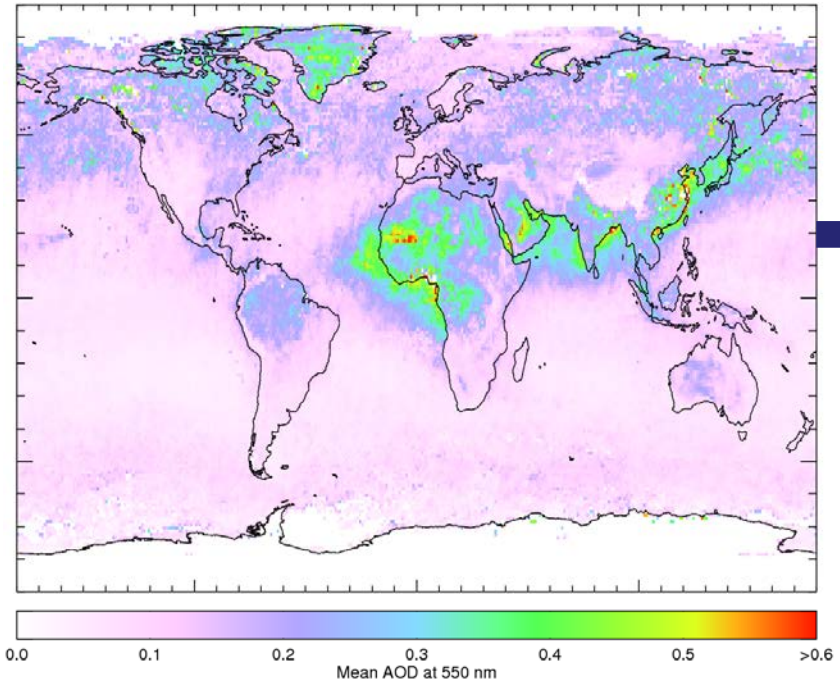
Why calculate aerosol radiative effect

- Climatically speaking aerosol is important for two reasons:
  1. Scattering and absorption of solar radiation
  2. Their influence on cloud properties
- Aerosol can result in either a significant cooling or warming at the surface
- Calculating the radiative effect is *relatively* straight forward (compared to forcing)



IPCC AR5: Radiative forcing breakdown

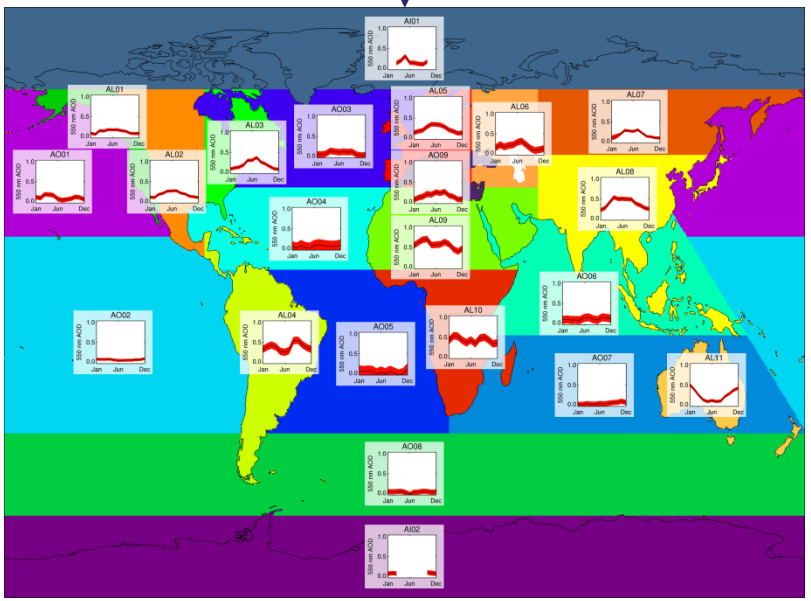
Aggregation of satellite data



Level-2 satellite data:

- 10 km spatial resolution along satellite tracks

1. Regional evaluation versus AERONET – bias and scatter
2. Bias correction
3. Temporal/spatial averaging



GlobAEROSOL AATSR AOD: 2006

Regional-monthly mean AOD fields:

- Averaged values for each region
- Bias corrected, with uncertainties

Uncertainties and error propagation

A range of error terms need to be taken into account:

- Uncertainty in input data
- Error from spatially averaging AOD
- Error from temporally averaging AOD
- Uncertainty in aerosol radiative properties
- Uncertainty in assumed aerosol height distribution
- Error from spatially/temporally averaging surface albedo
- Error due to low spectral resolution

Options for propagating uncertainty:

1. Brute force mapping of parameter uncertainty into radiative flux space – Monte Carlo simulation for instance.
2. Bayesian mapping of uncertainty into radiative flux – use gradient of radiative transfer model wrt to parameters.
3. Approximate by running radiative transfer at $\pm\sigma$ for each parameter.

Uncertainties and error propagation

Random or systematic?

- Random errors add in quadrature
- Systematic errors add linearly

→ *In this case assuming all errors are random gives more conservative uncertainty*

Relative or absolute?

- Are uncertainties best described as some fraction of the parameter of interest?

Optical depth

$$(\delta_{\mathcal{R}}\Delta R)^2 = (\delta_\tau \Delta R)^2 + \left(\Delta R \frac{\delta_{\mathrm{A}}\Delta R}{\Delta R_{\mathrm{April}}}\right)^2 \text{ Spatial averaging}$$

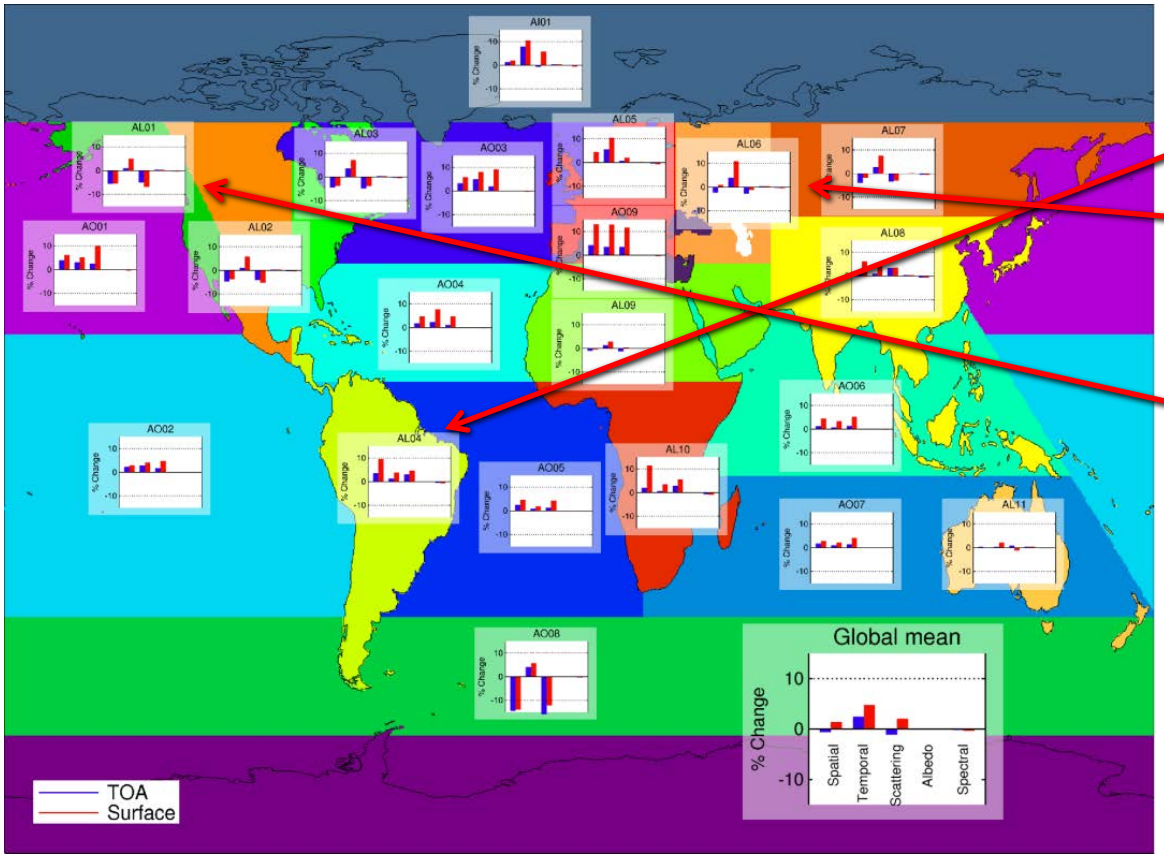
$$+ \left(\Delta R \frac{\delta_{\mathrm{t}}\Delta R}{\Delta R_{\mathrm{April}}}\right)^2 \text{ Temporal averaging}$$

$$+ \left(\Delta R \frac{\delta_{\mathrm{s}}\Delta R}{\Delta R_{\mathrm{April}}}\right)^2 \text{ Radiative properties}$$

$$+ (\delta_\rho \Delta R)^2 \quad \text{Albedo}$$

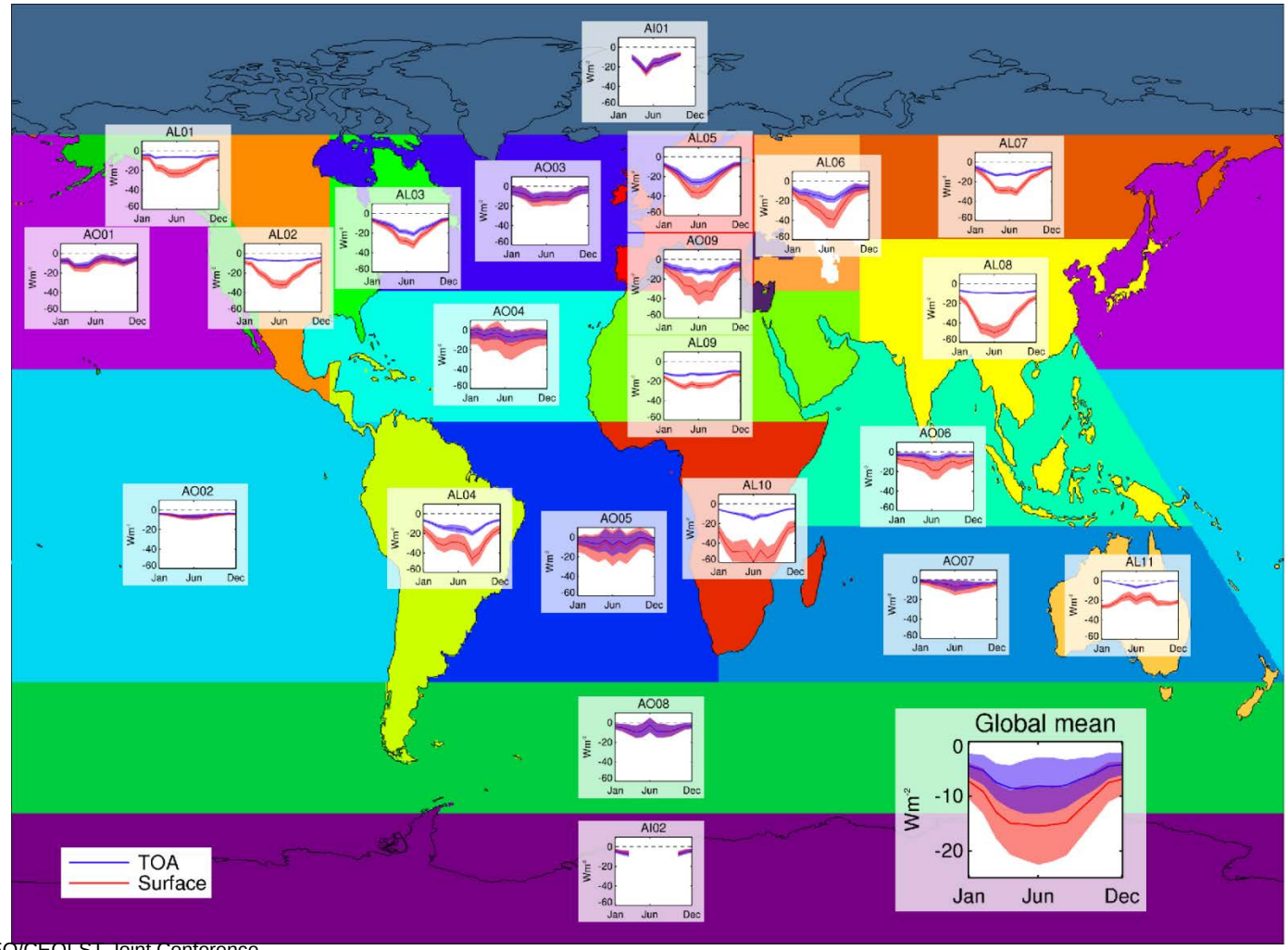
$$+ \left(\Delta R \frac{\delta_{\mathrm{v}}\Delta R}{\Delta R_{\mathrm{April}}}\right)^2 \text{ Spectral variability}$$

Uncertainties and error propagation



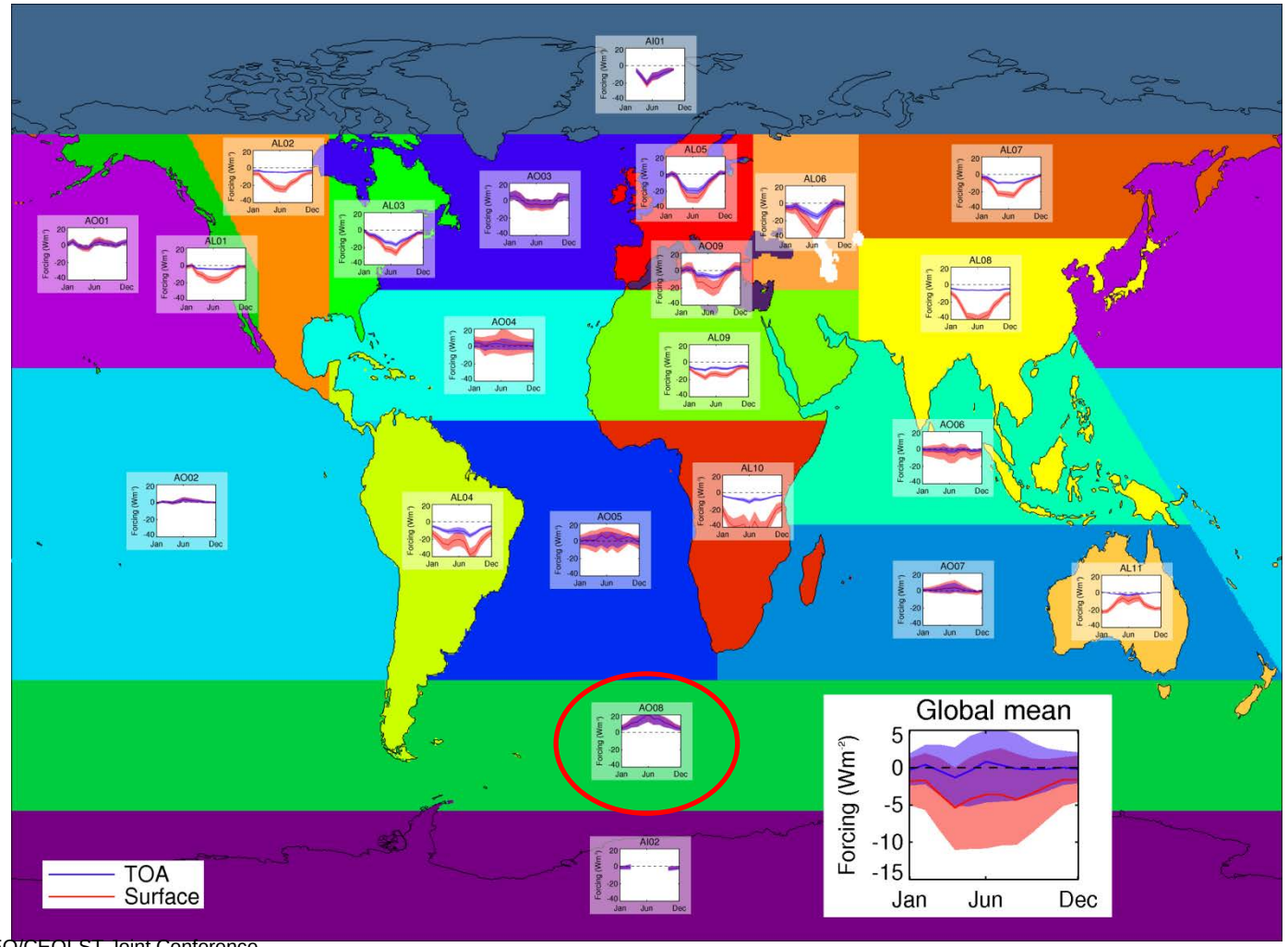
Spatial and/or temporal averaging, and aerosol radiative properties dominate uncertainty

Radiative effect



GlobAEROSOL AATSR radiative effect: 2006

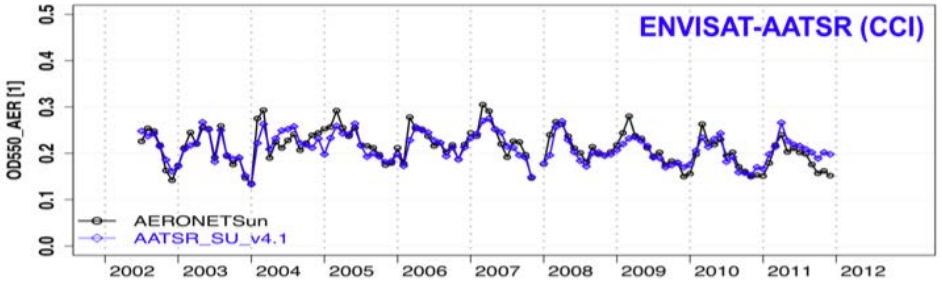
Radiative forcing?



GlobAEROSOL AATSR radiative forcing: 2006

Next steps

- ESA Aerosol_cci project will provide 17 years (A)ATSR data
  - Much improved quality
  - Consistent calibration
  - 3 independent algorithms
- Uncertainty propagation can be further improved
- Improvements to Radiative transfer



Full AATSR record – global average AOD at AERONET sites
(Plot: Peter North)

17 year record of global/region radiative effect with comprehensive uncertainties

Open issues

- Radiative forcing calculation remains problematic
  - Model/observation biases need to be solved
  - Deriving “anthropogenic fraction” from satellite observations is not straight forward either
- Uncertainty in, and variability of, aerosol properties will remain a limiting factor in error budget
- Coverage is not global
  - “Clear-sky” radiative effect only
  - The so called “twilight-zone” where observations are classified as neither cloud or aerosol