Observation-based estimates of aerosol radiative forcing

Nicolas Bellouin, University of Reading

with contributions from Johannes Quaas, David McNamara, Ed Gryspeerdt, James Mollard, and Johannes Muelmenstaedt

Yoram Kaufman Memorial Symposium

NASA GSFC, Greenbelt MD – 22 June 2016

Back in 2005

Global estimate of aerosol direct radiative forcing from satellite measurements

Nicolas Bellouin[1], Olivier Boucher[1], Jim Haywood[1] & M. Shekar Reddy[2]

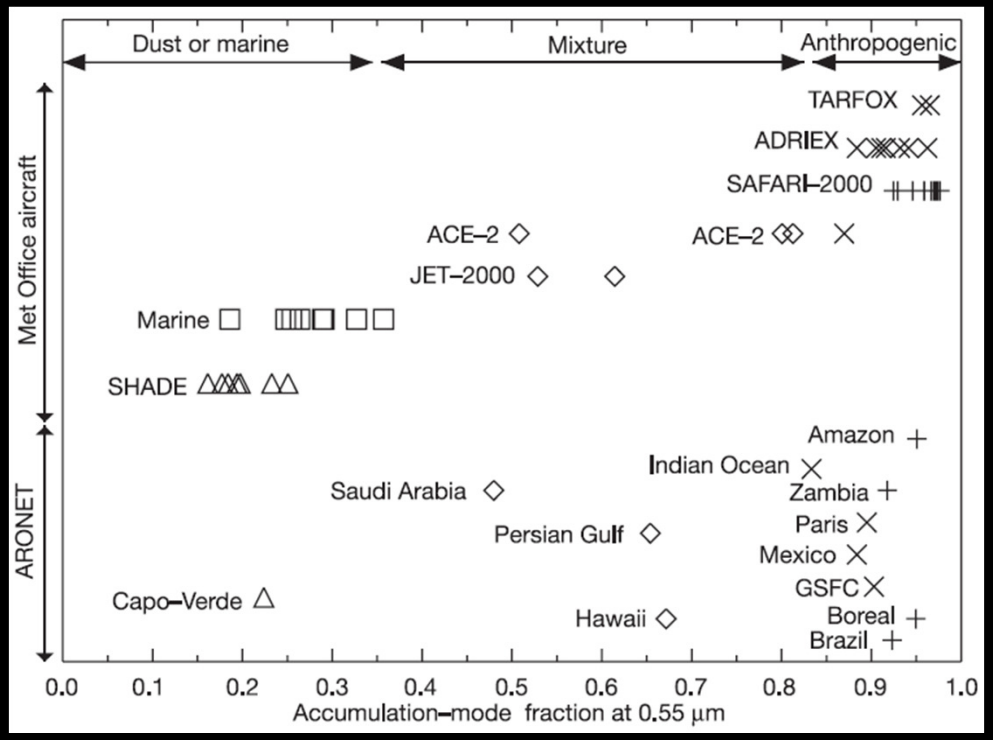
Aerosol anthropogenic component estimated from satellite data

Y. J. Kaufman,[1] O. Boucher,[2,3] D. Tanré,[4] M. Chin,[1] L. A. Remer,[1] and T. Takemura[1,5]

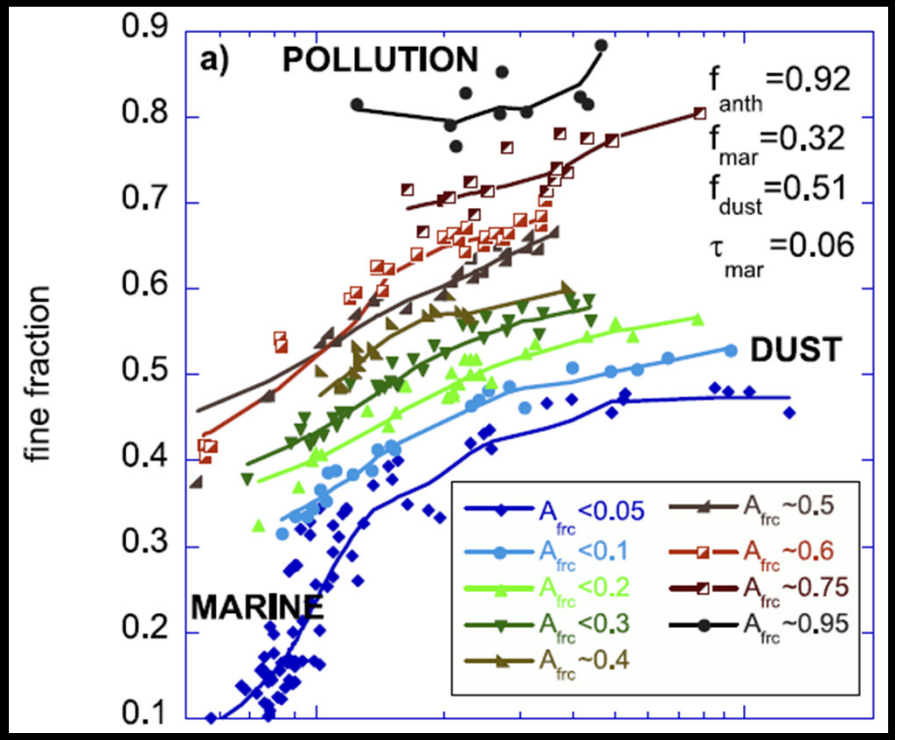
Global anthropogenic aerosol direct forcing derived from satellite and ground-based observations

Chul Eddy Chung, V. Ramanathan, Dohyeong Kim, and I. A. Podgorny

Identification of aerosol origin



Bellouin et al. (2005)



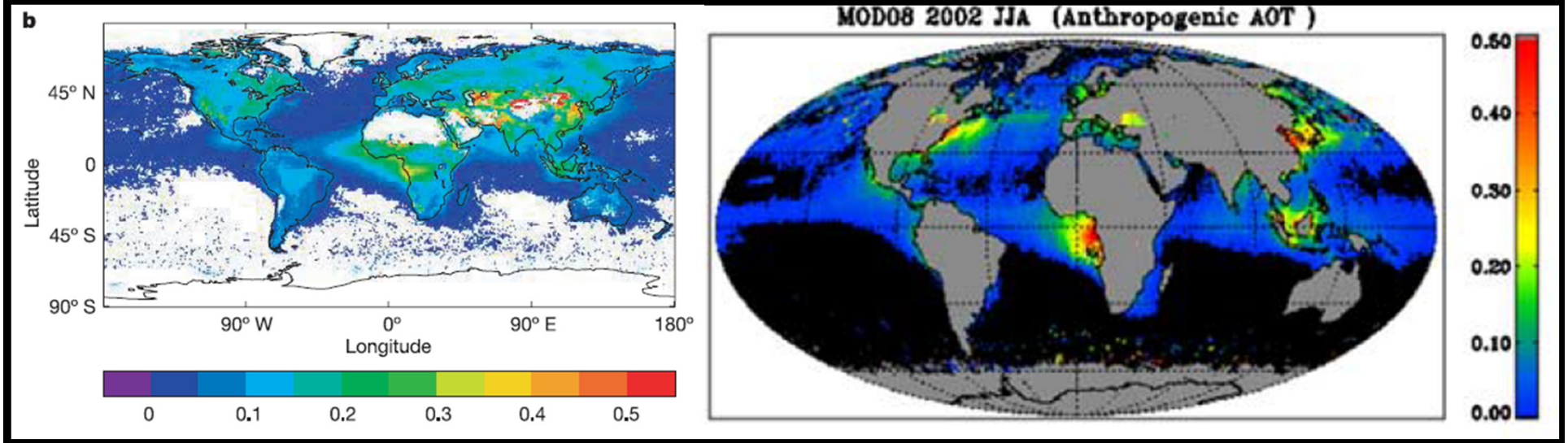
Kaufman et al. (2005)

Coverage:

Kaufman: – Cloud-free oceans

Bellouin: – Cloud-free global, but with help from global aerosol models over land

Anthropogenic aerosol optical depth



Bellouin et al. (2005)

Kaufman et al. (2005)

Direct radiative forcing (RFari)

Kaufman: Cloud-free oceans: -1.4 ± 0.4 W m^{-2}

Bellouin: Cloud-free global: -1.9 ± 0.3 W m^{-2}

All-sky global: -0.8 ± 0.1 W m^{-2}

Evolutions

1. Quantifications of indirect RF (RFaci) by regressions between CERES fluxes and MODIS aerosol and cloud retrievals (Quaas et al. 2008)

2. Move from satellite retrievals to MACC Reanalysis of Aerosol Composition (Bellouin et al. 2013)

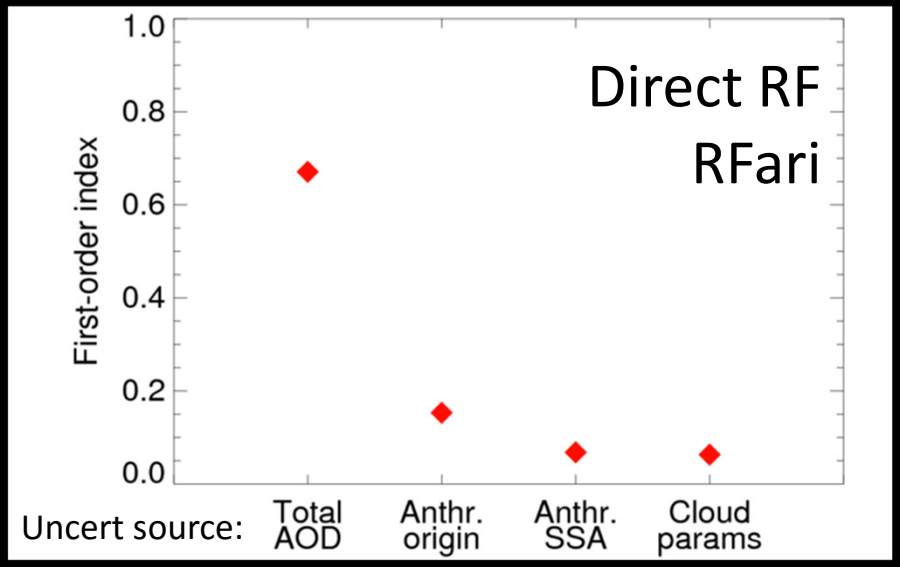
3. Quantification of direct RF (RFari) from aerosols above clouds: +0.01 W m^{-2} on a global average

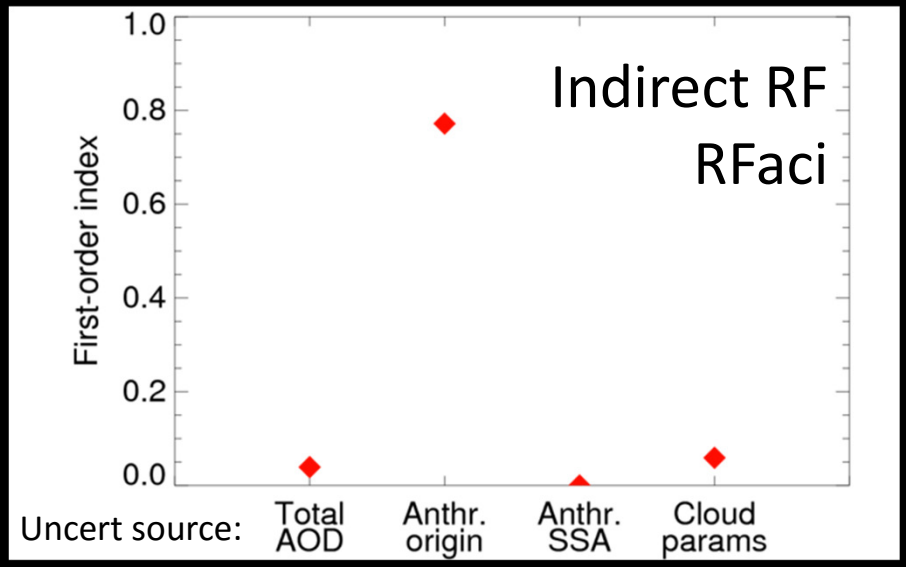
4. Variance-based uncertainty analysis

5. First attempts at 2nd indirect RF (rapid adjustments to RFaci)

Variance-based uncertainty analysis

- First-order indices quantify contribution to total variance

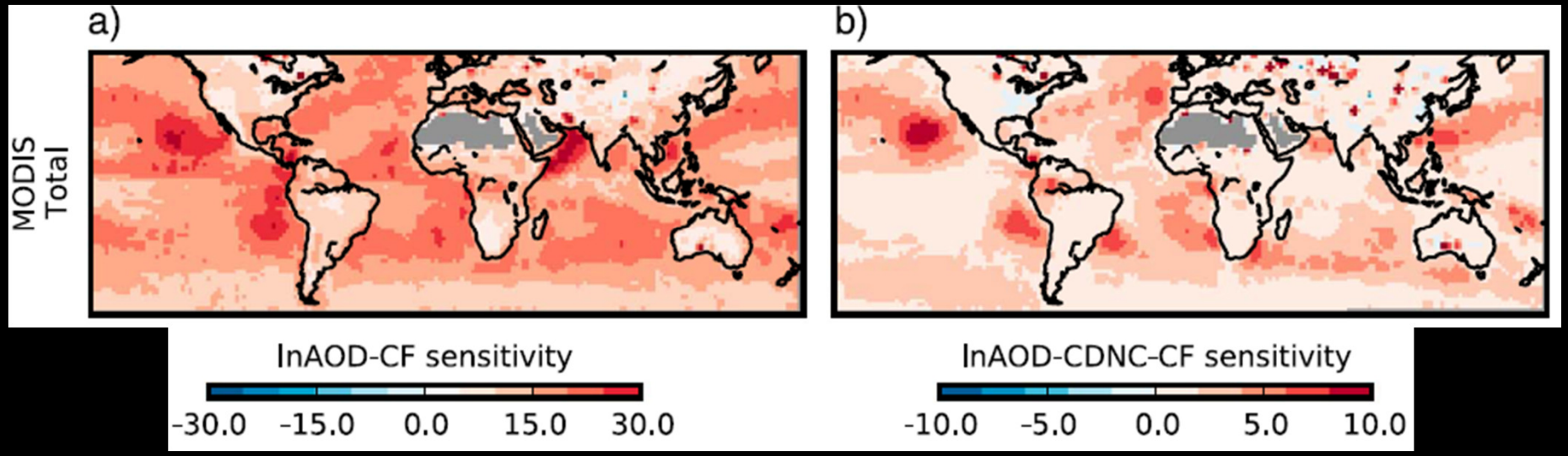




Cloud-free sky only.
Aerosol amounts dominate uncertainties on the global average.

Aerosol origin now dominates.
(Here, impact of uncertainties on cloud susceptibilities underestimated.)

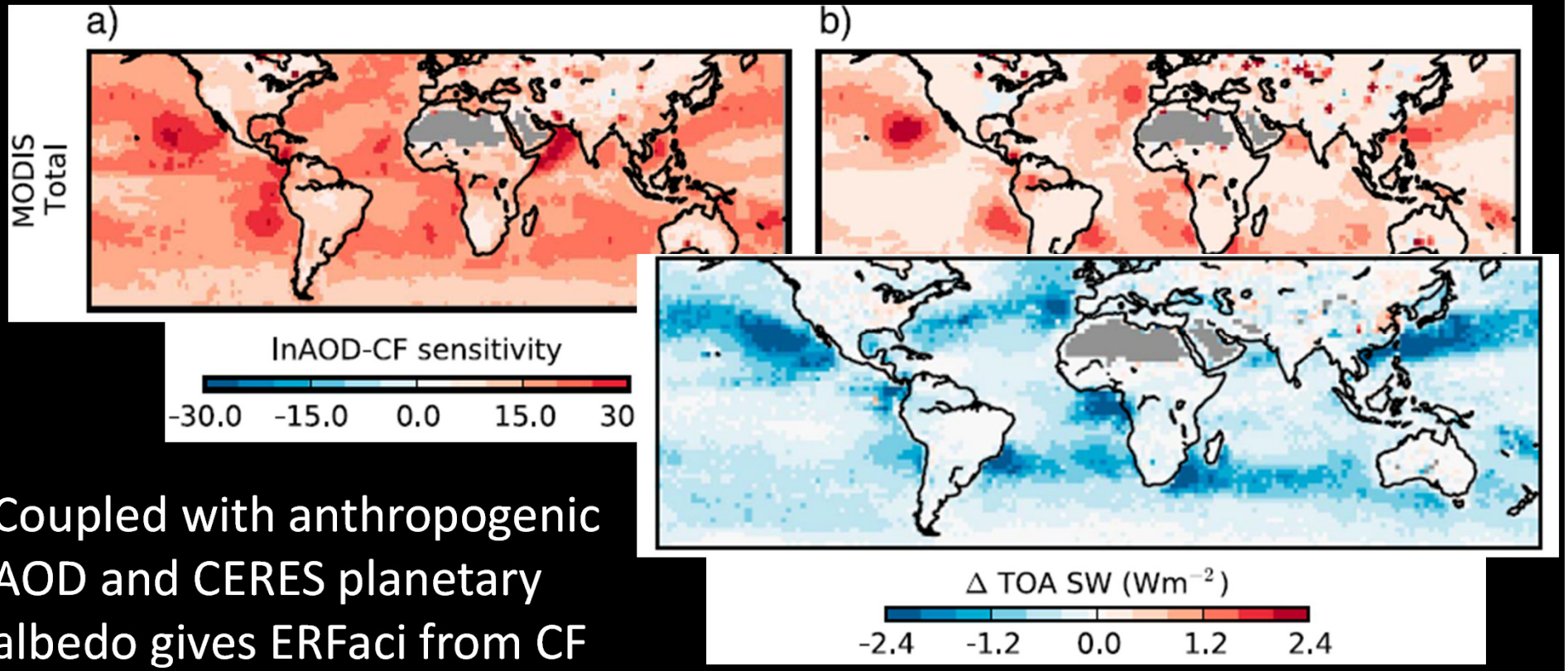
Cloud fraction effects (ERFaci)



MODIS CF-AOD correlations:
(a) full (b) conditional to mediation by a CDNC change

Gryspeerdt et al. (2016)

Cloud fraction effects (ERFaci)



Coupled with anthropogenic AOD and CERES planetary albedo gives ERFaci from CF changes only

Gryspeerdt et al. (2016)

Where we are now

Radiative forcing component (IPCC AR5 name)	Global average (W m^{-2}) 2003—2012
Direct (RFari)	−0.8 ± 0.3
Direct+1st indirect (RFari+aci)	−1.4 ± 0.5
Direct+1st+2nd indirect (ERFari+aci)	−1.9 ± 0.8

Shortwave spectrum only
Indirect forcings over 60N—60S only
All defined with respect to present-day natural aerosols

Update of Bellouin et al. (2013); Gryspeerdt et al. (2016)

Why those estimates could be wrong

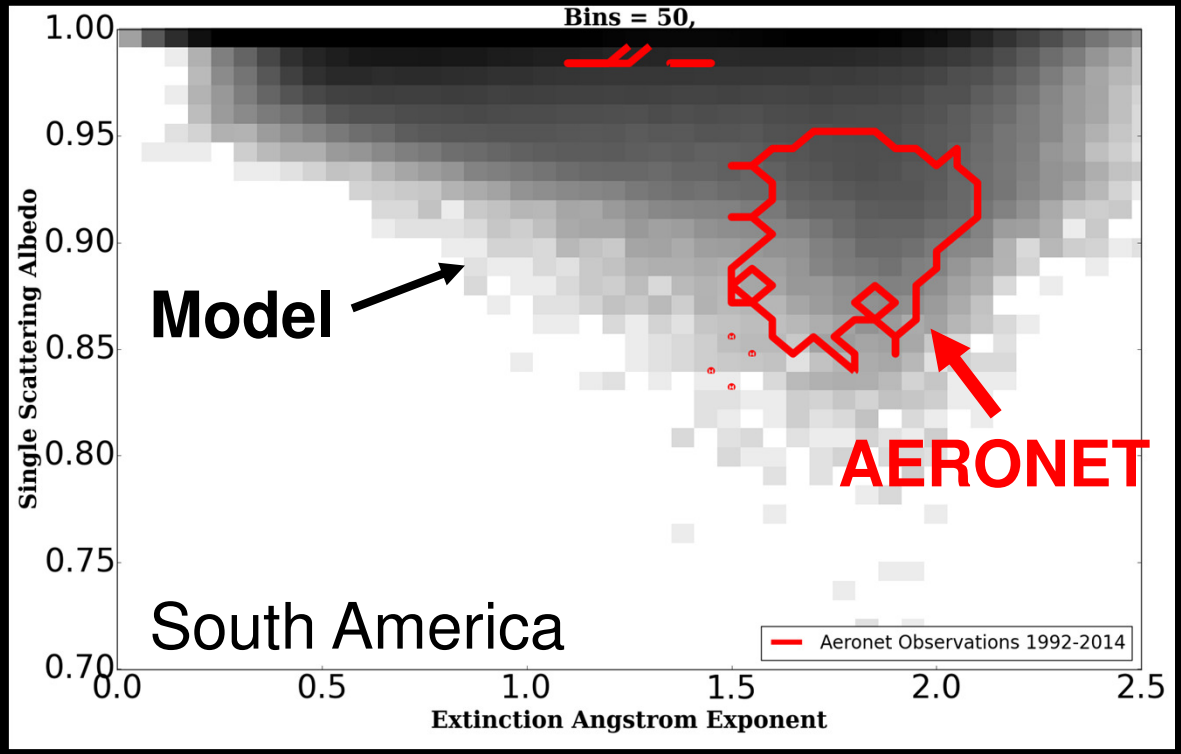
- **ERF could be weaker (less negative) if**
- Anthropogenic absorption is underestimated
- Present-day natural aerosols < pre-industrial aerosols
- Cloud albedo is strongly buffered to changes in microphysics

- **ERF could be stronger (more negative) if**
- Anthropogenic absorption is overestimated
- Anthropogenic aerosols trigger changes in cloud regimes

- **Impact unclear:**
- Aerosol reduce precipitation efficiency in convective clouds

Anthropogenic absorption

- Absorption is probably overestimated by observational constraints
- Best current dataset is AERONET, but performs best at large AODs and large SZAs
- The more optically diverse aerosol background is not observed, yet contributes more than half of the direct RF.



Alternative datasets: POLDER?

Pre-industrial state

Present-day natural aerosols are almost certainly an underestimate of pre-industrial aerosol mass and number.

Biomass-burning raises pre-industrial AOD by ~20% above present-day natural in models (Bellouin et al. 2008)
→ Weakens Direct RF (RFari) by 0.2—0.3 W m^{-2}

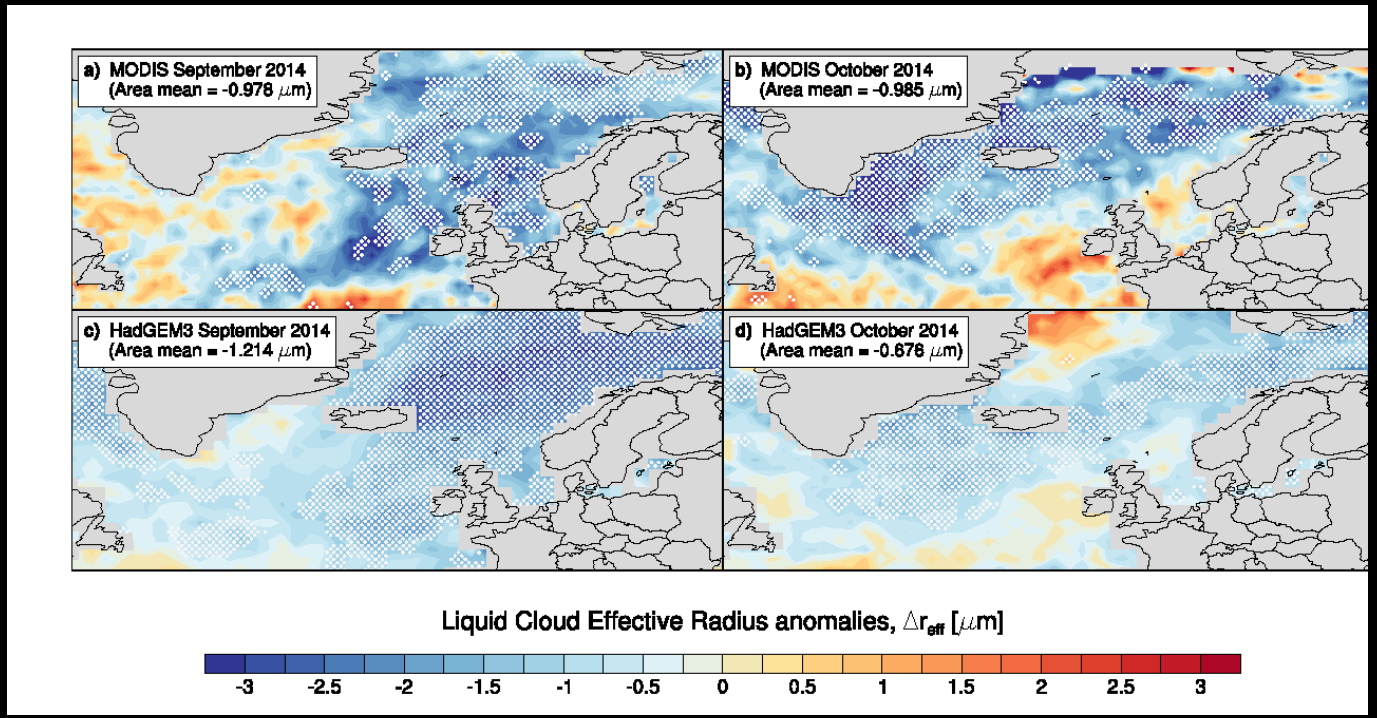
Nucleation of organics and biogenic compounds may produce large aerosol numbers in unpolluted conditions (Kirkby et al. 2016)
→ Easier to form clouds in pre-industrial? (But not only a matter of aerosol number.)

Cloud buffering: Holuhraun volcanic eruption

Fissure eruption by Icelandic volcano Sep 2014 – Feb 2015

SO2 emissions at same daily rate as entire EU

MODIS sees strong negative cloud effective radius anomalies, which are also modelled.

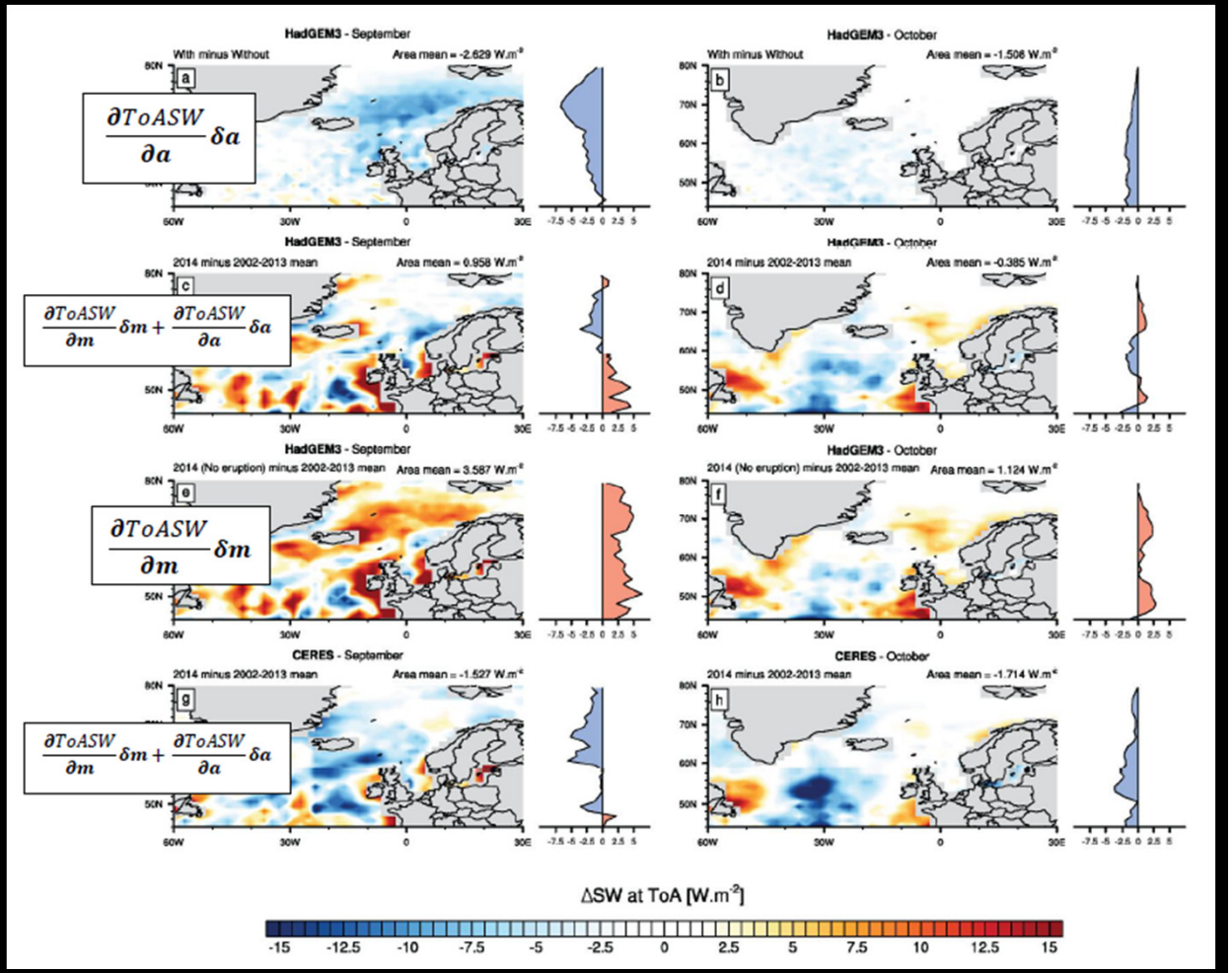


Haywood et al., submitted, 2016

Cloud buffering: Holuhraun volcanic eruption

Yet the resulting change in planetary albedo is surprisingly difficult to isolate for such a large perturbation.

The mood is the aerosol-cloud community seems to be that many cloud responses are possible, but strong responses are rare.



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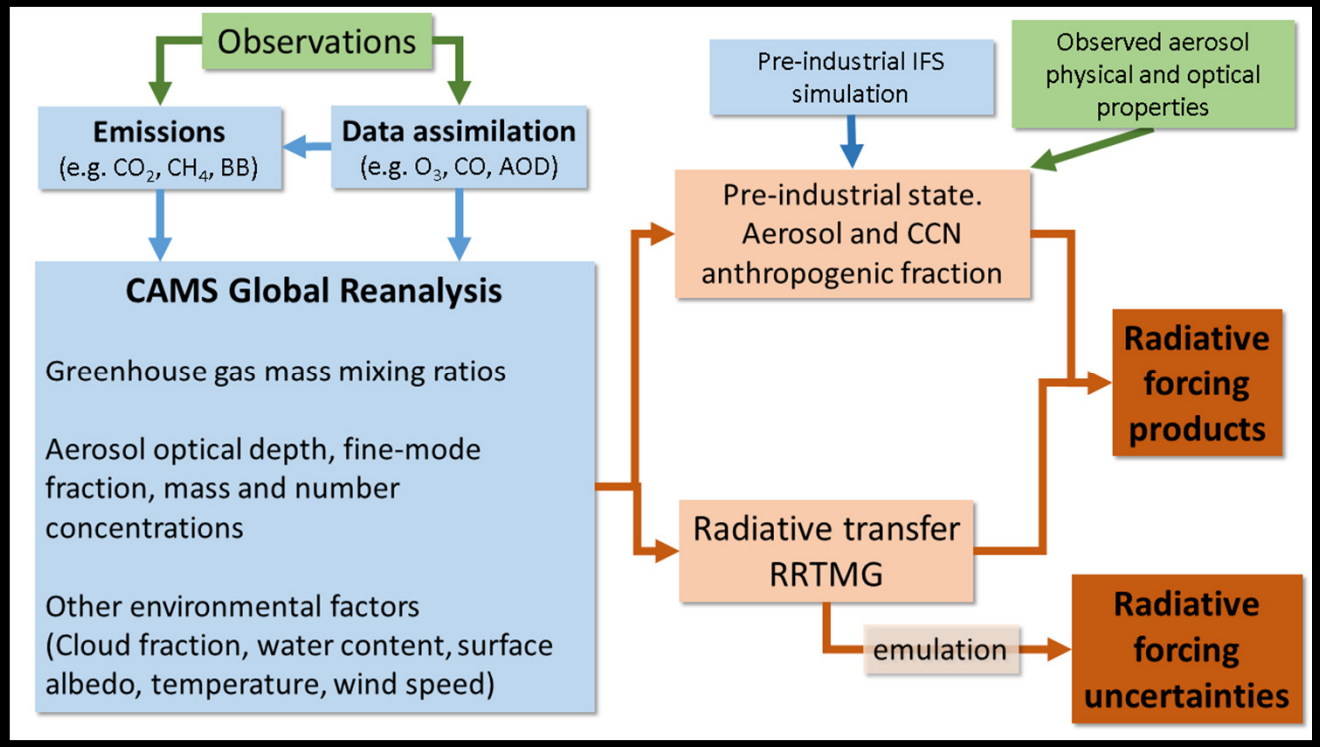
- **Anthropogenic absorption is overestimated**

Coming August 2016: Copernicus RF estimates



4 forcing agents

- CO_2, CH_4
- Trop/Strat O_3
- Aerosols (ari, aci)

- Consistent RT
- SW+LW, TOA+surface, …
- New reanalysis coming 2017

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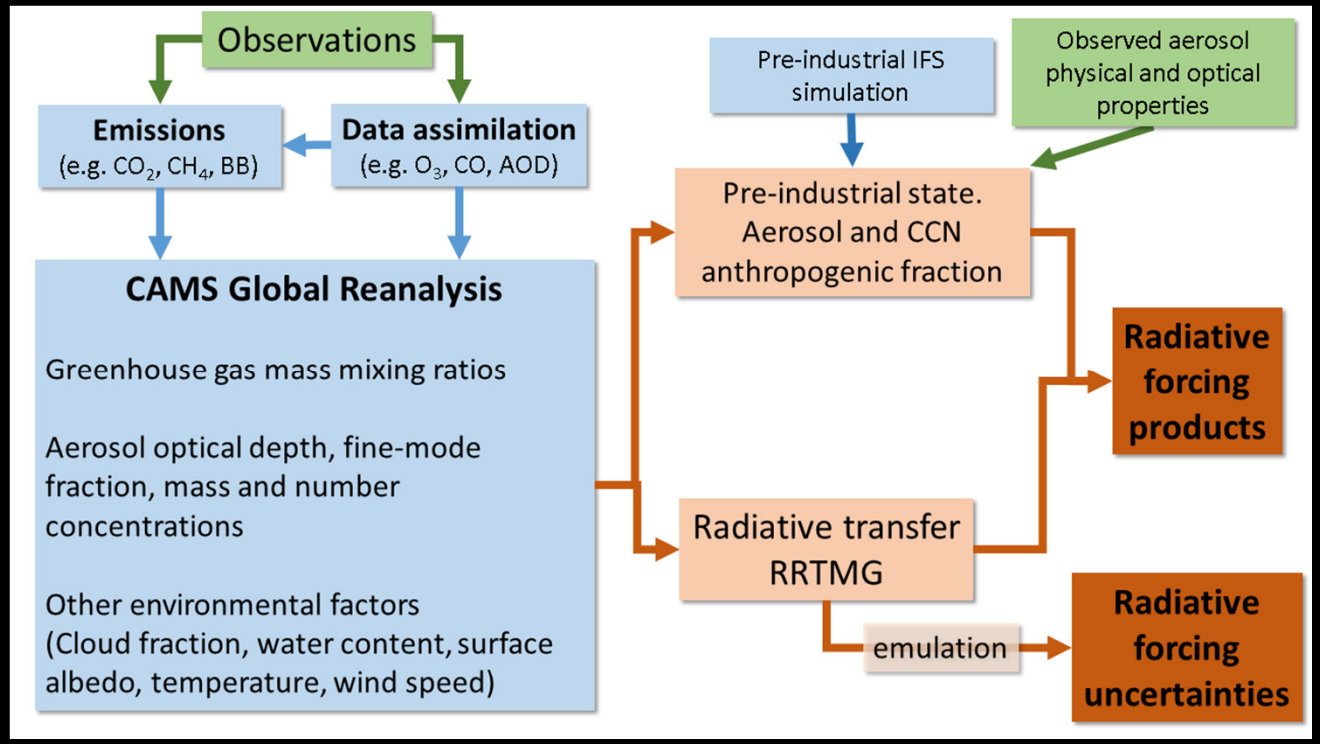


Dedicated efforts on preindustrial state and uncertainties.

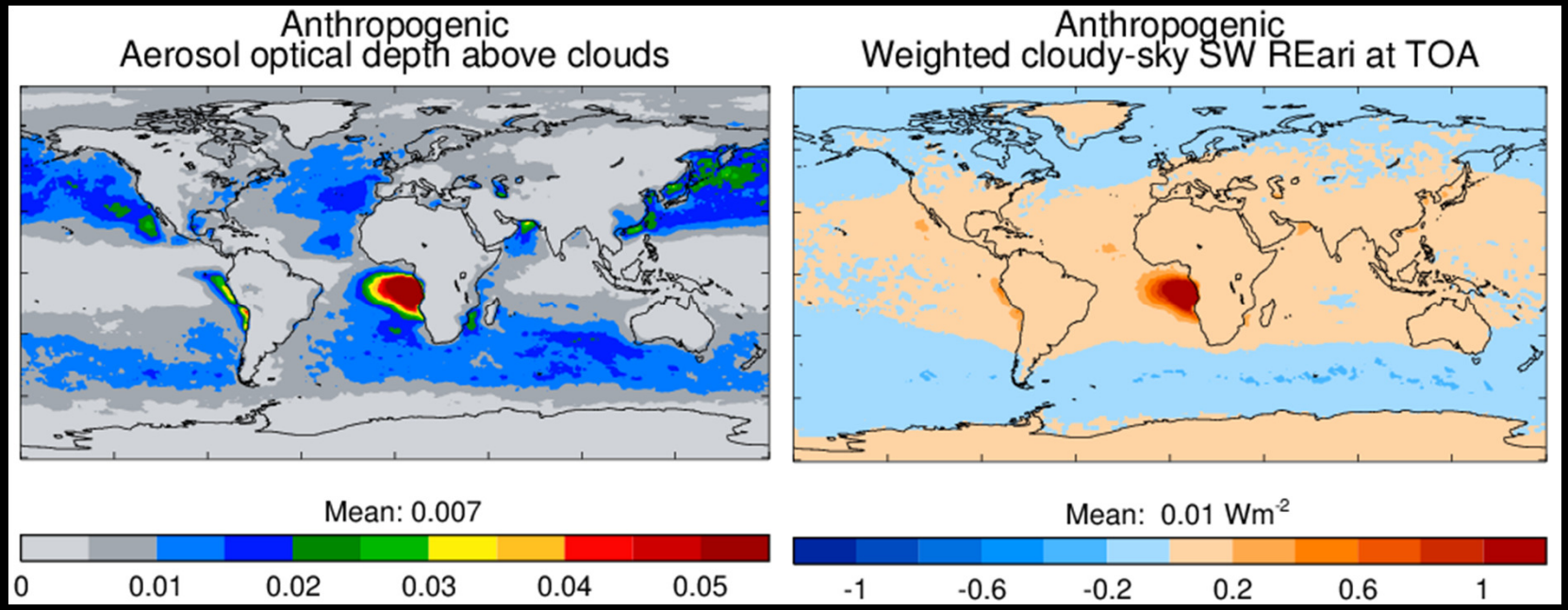
Support for aerosol anthropogenic fraction estimates from correlated CO analysis.

Thank you

atmosphere.copernicus.eu/

copernicus.eu/

Aerosols above clouds



- Need to trust modelled aerosol and cloud profiles, but comparison to CALIOP is good.
- Above-cloud AOD compares well to PARASOL (Waquet et al. 2013)