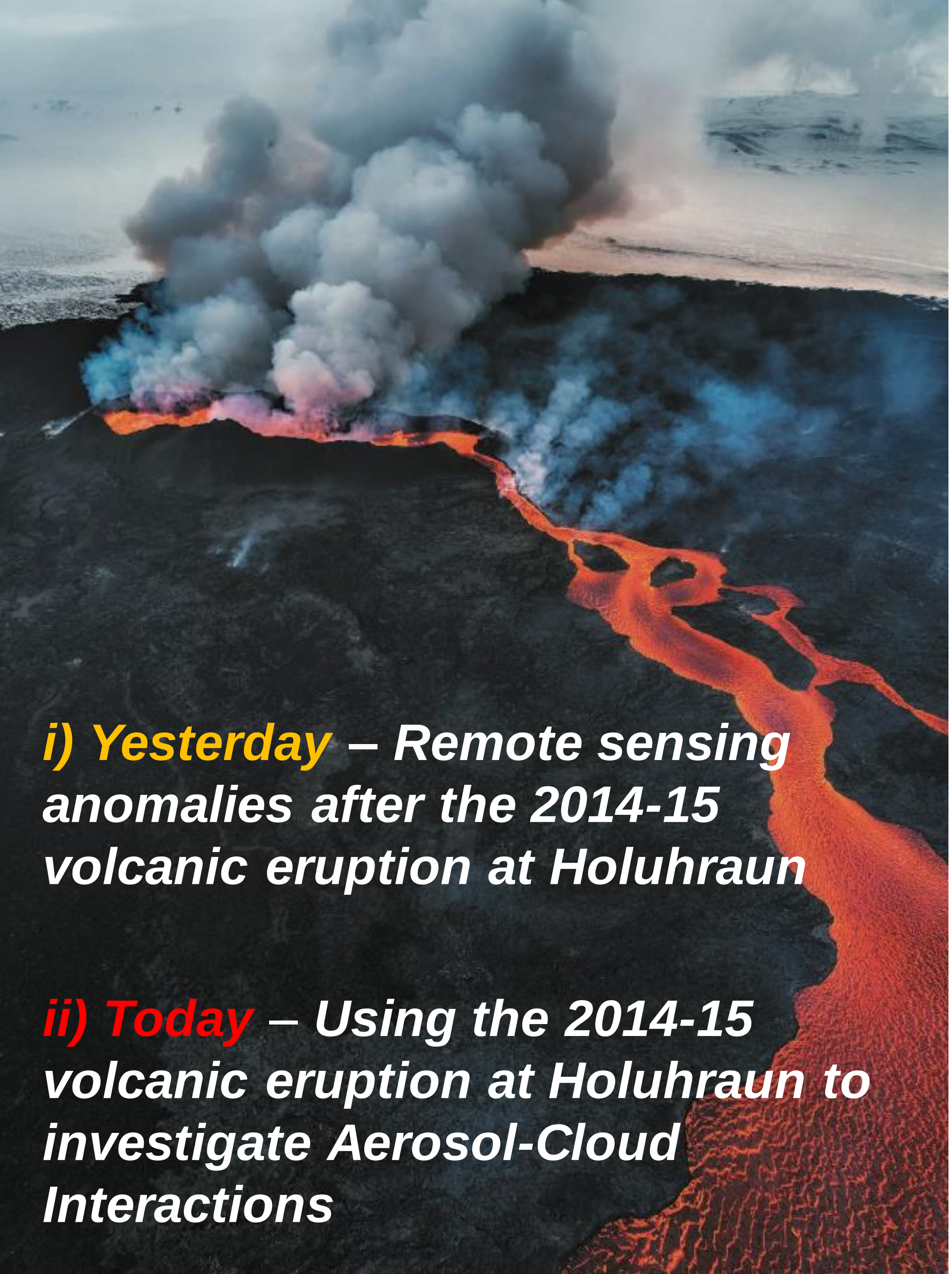


Strong constraints on aerosol-cloud interactions from volcanic eruptions

(Nature, 2017)

Florent F. Malavelle, Jim M. Haywood, Andy Jones, Andrew Gettelman, Lieven Clarisse, Sophie Bauduin, Richard P. Allan, Inger Helene H. Karset, Jón Egill Kristjánsson, Lazaros Oreopoulos, Nayeong Cho, Dongmin Lee, Nicolas Bellouin, Olivier Boucher, Daniel P. Grosvenor, Ken S. Carslaw, Sandip Dhomse, Graham W. Mann, Anja Schmidt, Hugh Coe, Margaret E. Hartley, Mohit Dalvi, Adrian A. Hill, Ben T. Johnson, Colin E. Johnson, Jeff R. Knight, Fiona M. O'Connor, Daniel G. Partridge, Philip Stier, Gunnar Myhre, Steven Platnick, Graeme L. Stephens, Hanii Takahashi & Thorvaldur Thordarson.

Icelandic volcanic emissions and climate

(Nature Geoscience, 2015)

Andrew Gettelman, Anja Schmidt & Jón Egill Kristjánsson

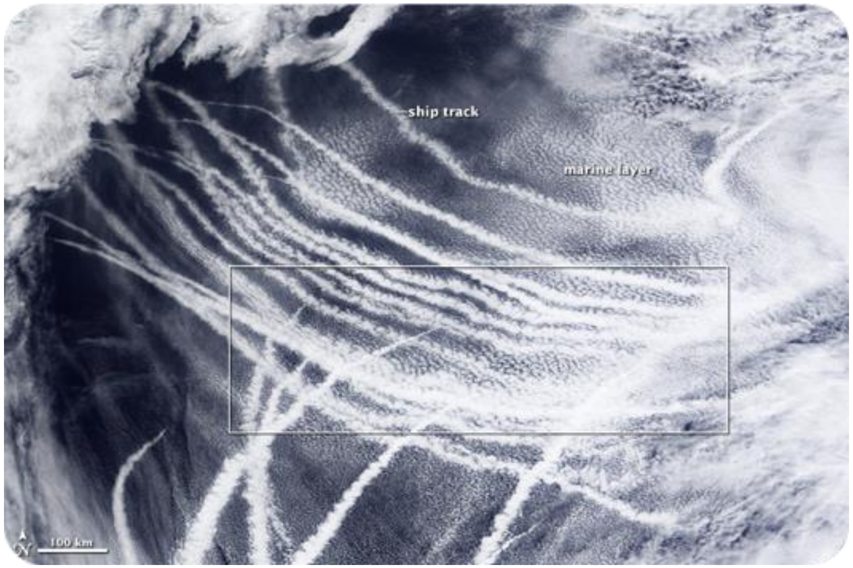
Observations of a substantial cloud-aerosol indirect effect during the 2014–2015 Bárðarbunga-Veiðivötn fissure eruption in Iceland

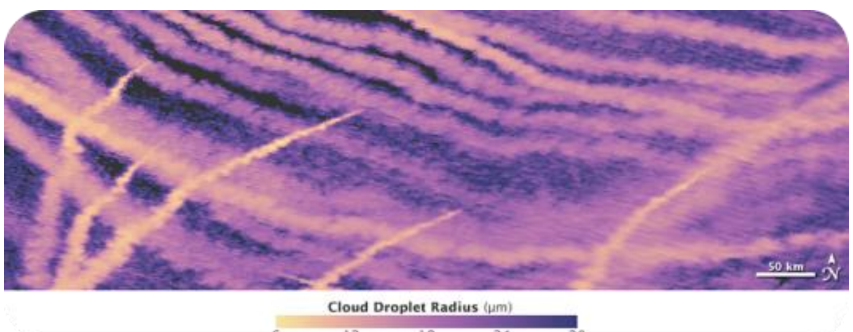
(GRL, 2015)

Daniel McCoy and Dennis Hartmann

Some real world examples of Aerosol-Cloud Interactions (ACI)

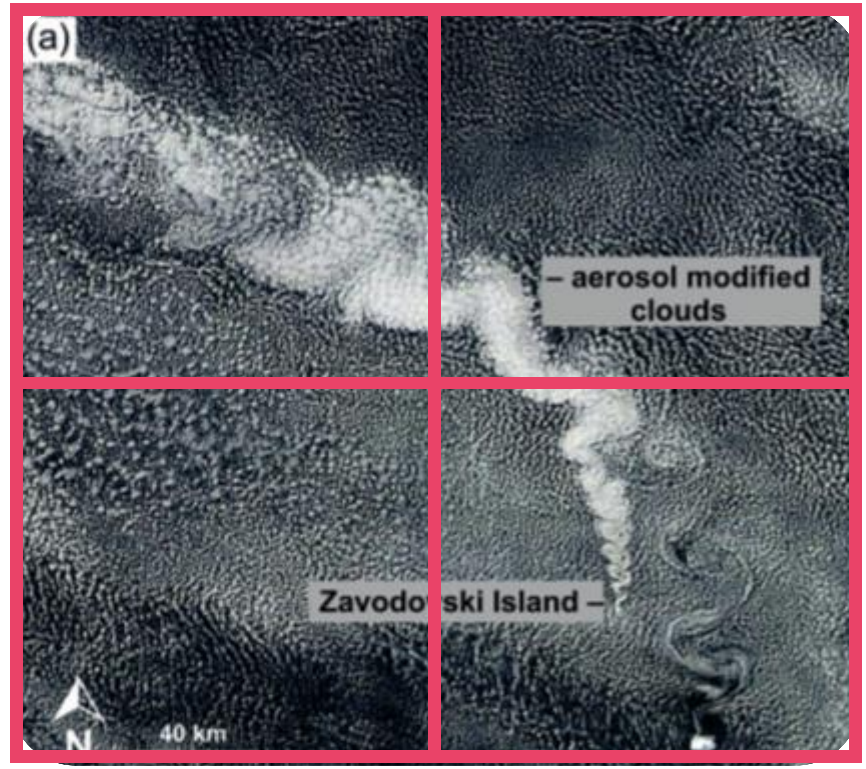
Ship Tracks – The poster boy of ACI





http://earthobservatory.nasa.gov/Features/Aerosols

Typical GCM grid box

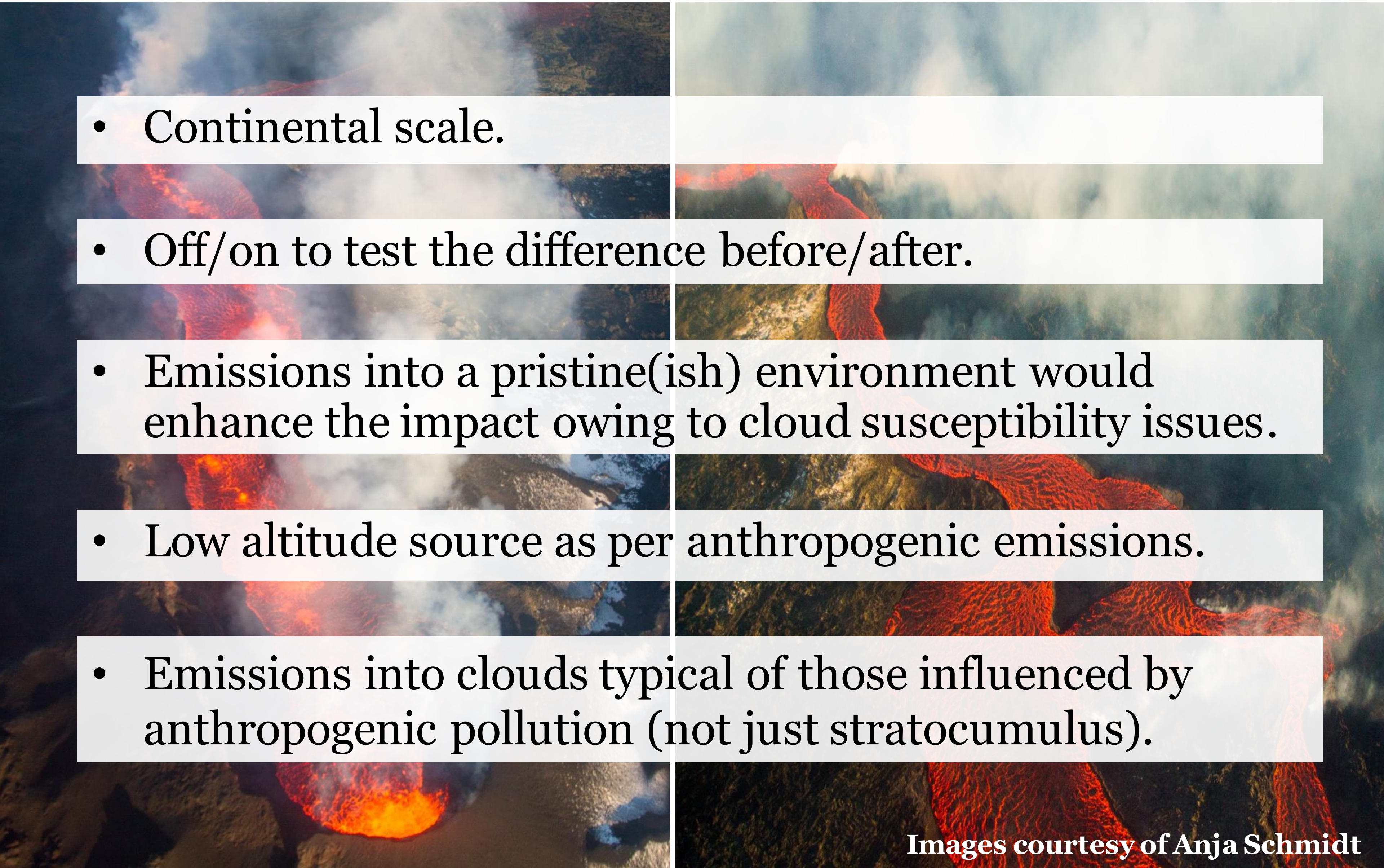


Schmidt et al., 2012 (ACP)

Small scale emissions are of limited value

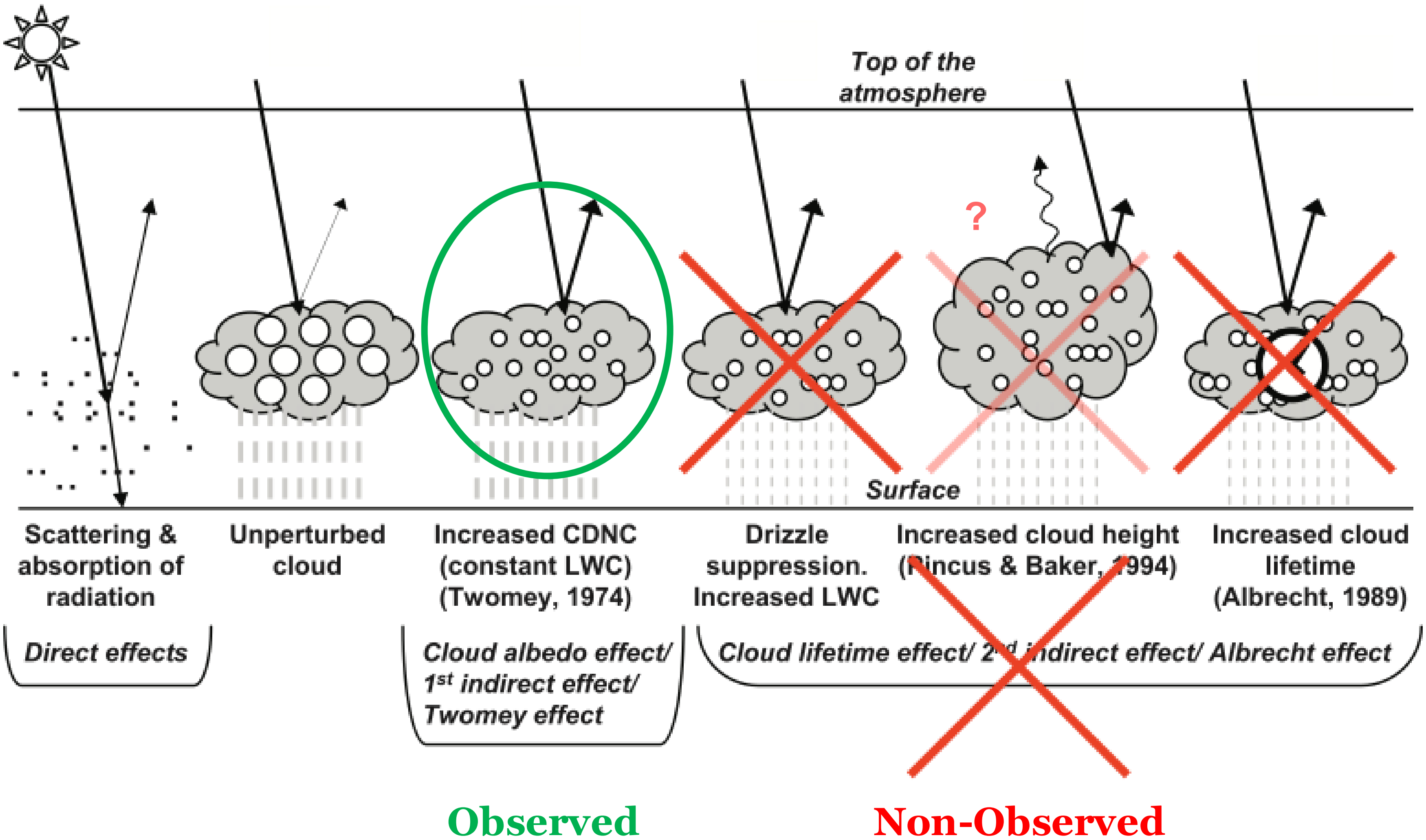
Holuhraun fissure eruption
an ideal framework to test ACI in GCMs.

- Continental scale.
- Off/on to test the difference before/after.
- Emissions into a pristine(ish) environment would enhance the impact owing to cloud susceptibility issues.
- Low altitude source as per anthropogenic emissions.
- Emissions into clouds typical of those influenced by anthropogenic pollution (not just stratocumulus).

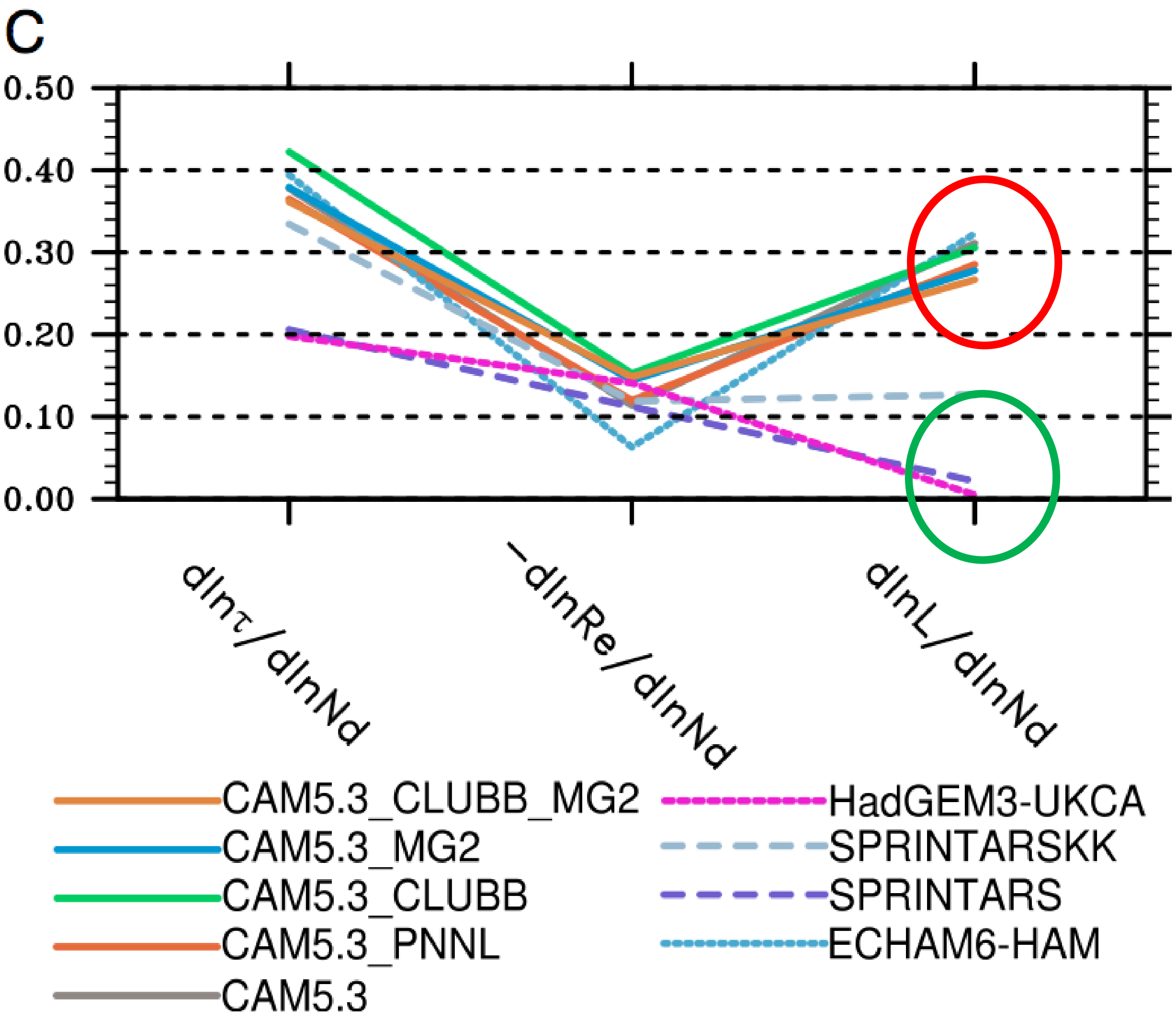


Images courtesy of Anja Schmidt

What observations from Holuhraun suggest about aerosol-cloud interaction climate impacts



Is it useful for constraining ACI ?



- **What most GCMs tend to do**
- **What is suggested by observations from Holuhraun**

S. Ghan et al., PNAS 2016

Some GCMs response to Holuhraun emission …

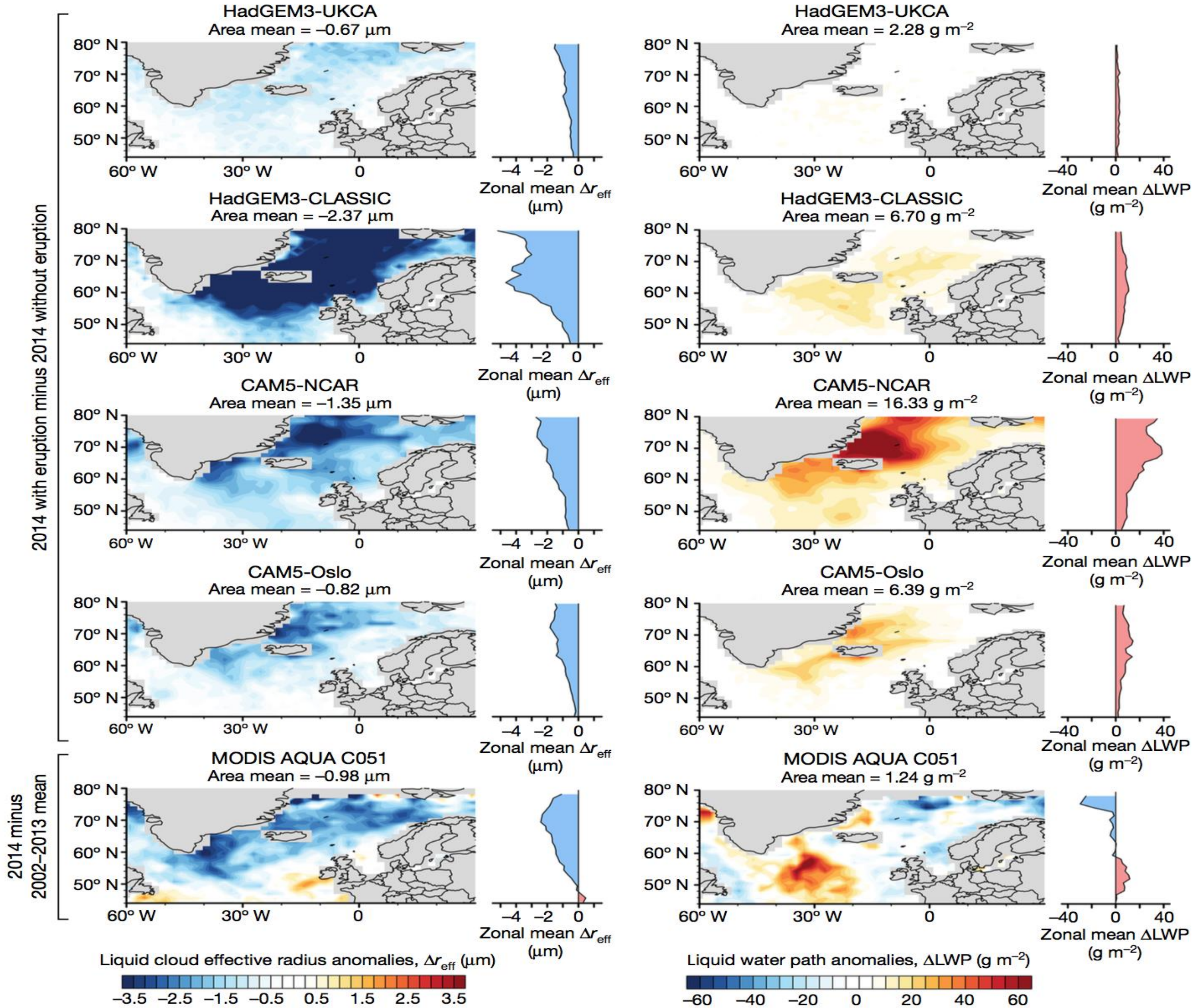
HadGEM3-UKCA

HadGEM3-CLASSIC

NCAR-CAM5.3

CAM5-Oslo

MODIS



Florent Malavelle
F.Malavelle@exeter.ac.uk

AeroCom Volcano-ACI experiment

- This document describes the AeroCom Holuhraun experiment and the data we hope to obtain from modelling groups. The experiment aims to evaluate current global climate model simulation of aerosol-cloud interactions in response to the SO_2 emissions from the 2014-15 Holuhraun and the 2008 Kilauea eruptions against remote sensing observations.

- The experiment only requests standard model outputs and should require no further model development.

- Results will be published in peer-reviewed journals and all modellers that submitted data will be offered co-authorship. For questions, please contact Florent Malavelle.

Rationale

We know that aerosols potentially have a large effect on climate, particularly through their interactions with clouds. However, the magnitude of this effect is highly uncertain and there is little agreement in the estimates derived from state of the art Global Climate Models (GCM).

Effusive eruptions (i.e. non-explosive) release important quantities of gases in the lower atmosphere which can provide a natural analogue to anthropogenic aerosol

Simulation design 1/2

1. ***CTRL:*** This simulation is compulsory. Control simulation without Holuhraun/Kilauea emissions.
2. ***Hol-CE:*** This experiment is compulsory. Main experiment – GCM simulation Intercomparison of the Holuhraun impact on liquid clouds.
3. ***Kil-CE:*** This experiment is optional. Aux
simulation Intercomparison of the Kilaue
4. ***Hol-AE1:*** This experiment is optional. Se
forcing for Pre-Industrial conditions.
5. ***Hol-AE2:*** This experiment is optional. Se
forcing for a different location.
6. ***Hol-AE3:*** This experiment is optional. Se
forcing for a different timing (summer in

7. ***Hol-AE4 (+CTRL_SSTclim):*** This experiment is optional. Sensitivity experiment – role of SST variability. *Note that this experiment requires a new baseline simulation (CTRL_SSTclim).*
8. ***Hol-AE5:*** This experiment is optional. Sensitivity experiment – prolonging the Holuhraun simulations longer to look for opportunity to further constrain the volcanic plume.

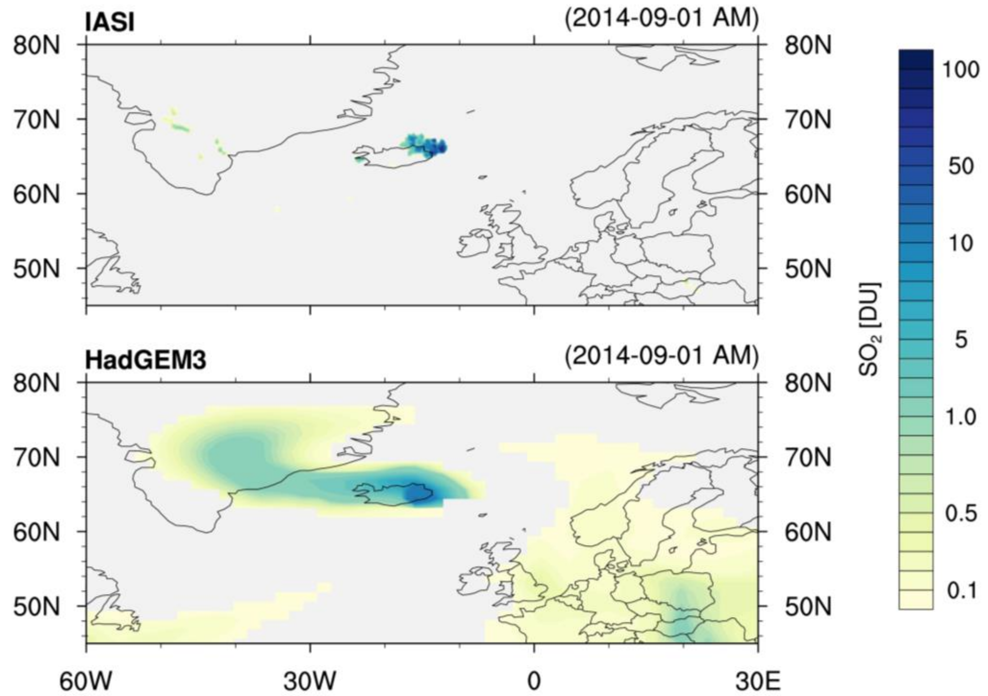
Simulation design 2/2

- **Model to be Nudged to** meteorology: *Allows to Untangle the impacts of meteorology from the aerosol impacts* (*Stevens and Brenguier, 2009*).

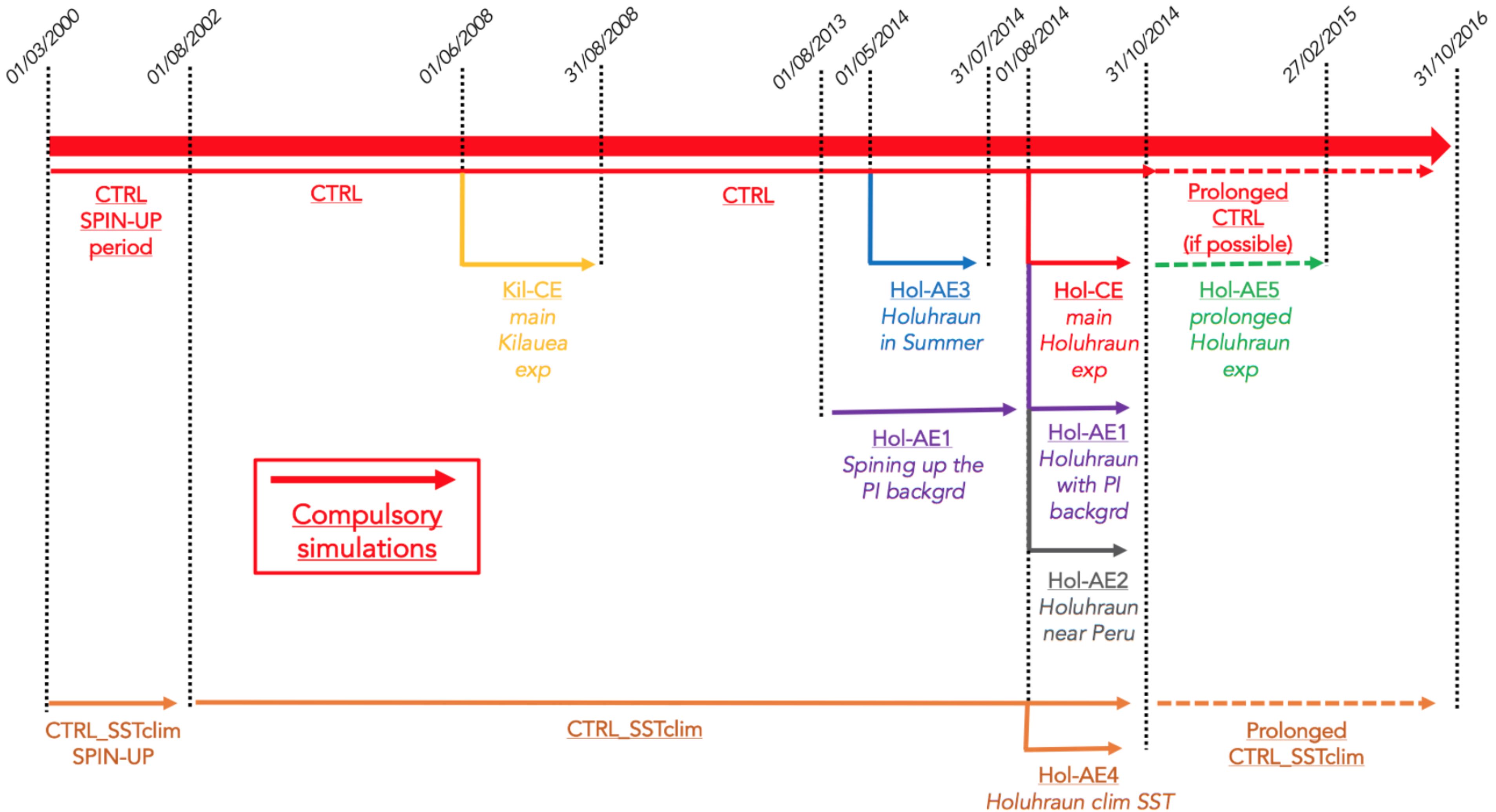
- **Time varying SO_2 Emissions** *from Empirical relationship between degassed sulphur and TiO_2/FeO ratios and lava production.*

- About 180-200 months of model simulation (i.e.15-17 years)

- Required outputs about 50-70 Go of disk space



Simulation design 2/2



To summarise

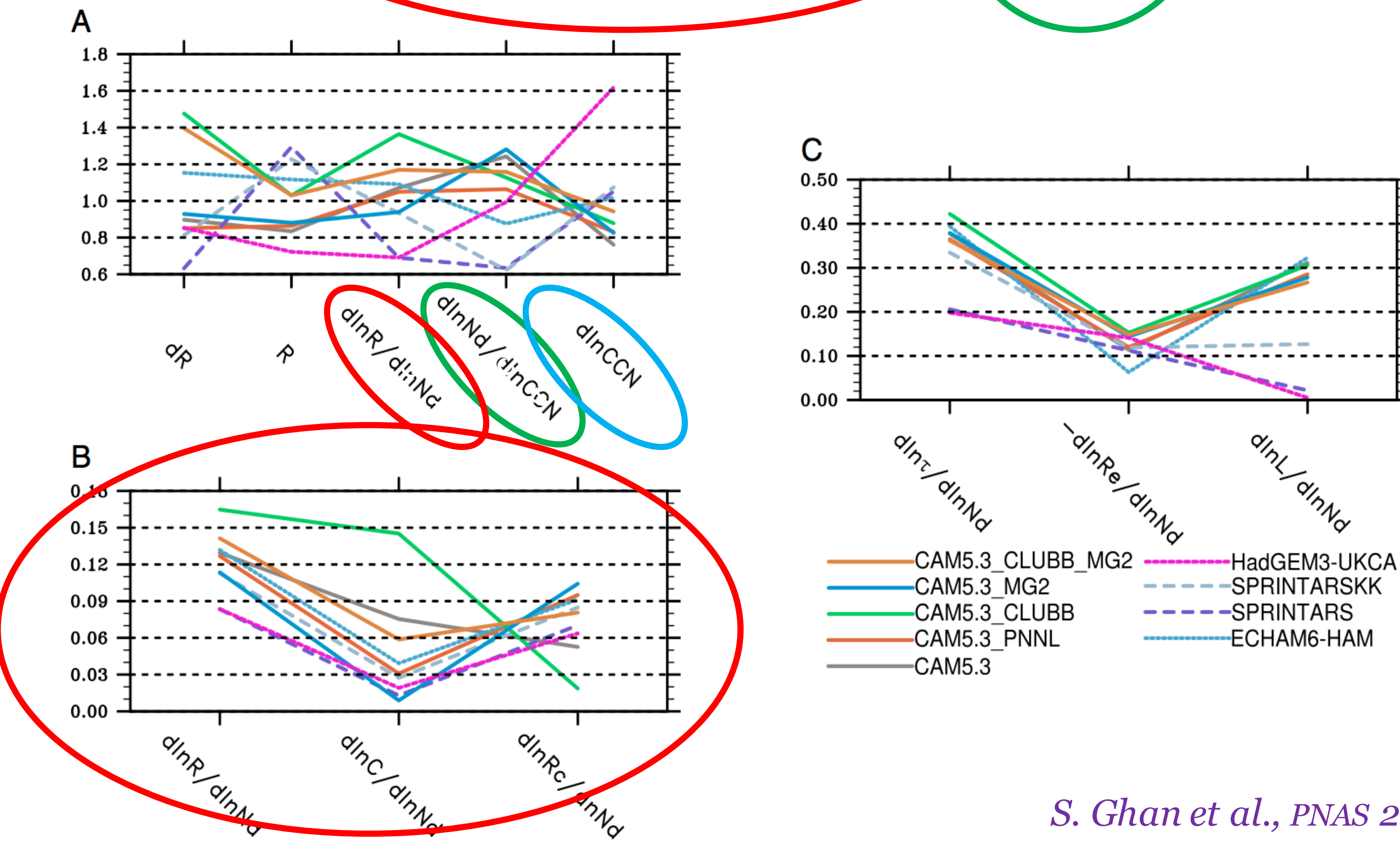
1. **We know that GCMs provide a wide range of ACI estimates** (*e.g. Lohmann et al., 2010 Ghan et al., 201*6)

2. **Holuhraun suggests that strong LWP response to aerosol emissions is less likely**

3. **Lets bring several GCMs together on a Holuhraun inter-comparison:**
    - *Rule out excessive LWP responses.*
    - *Can trust model with low LWP sensitivity too (e.g. HadGEM3) … Are they right for the right reason?*
    - *Identify where differences in models behaviour occur.*

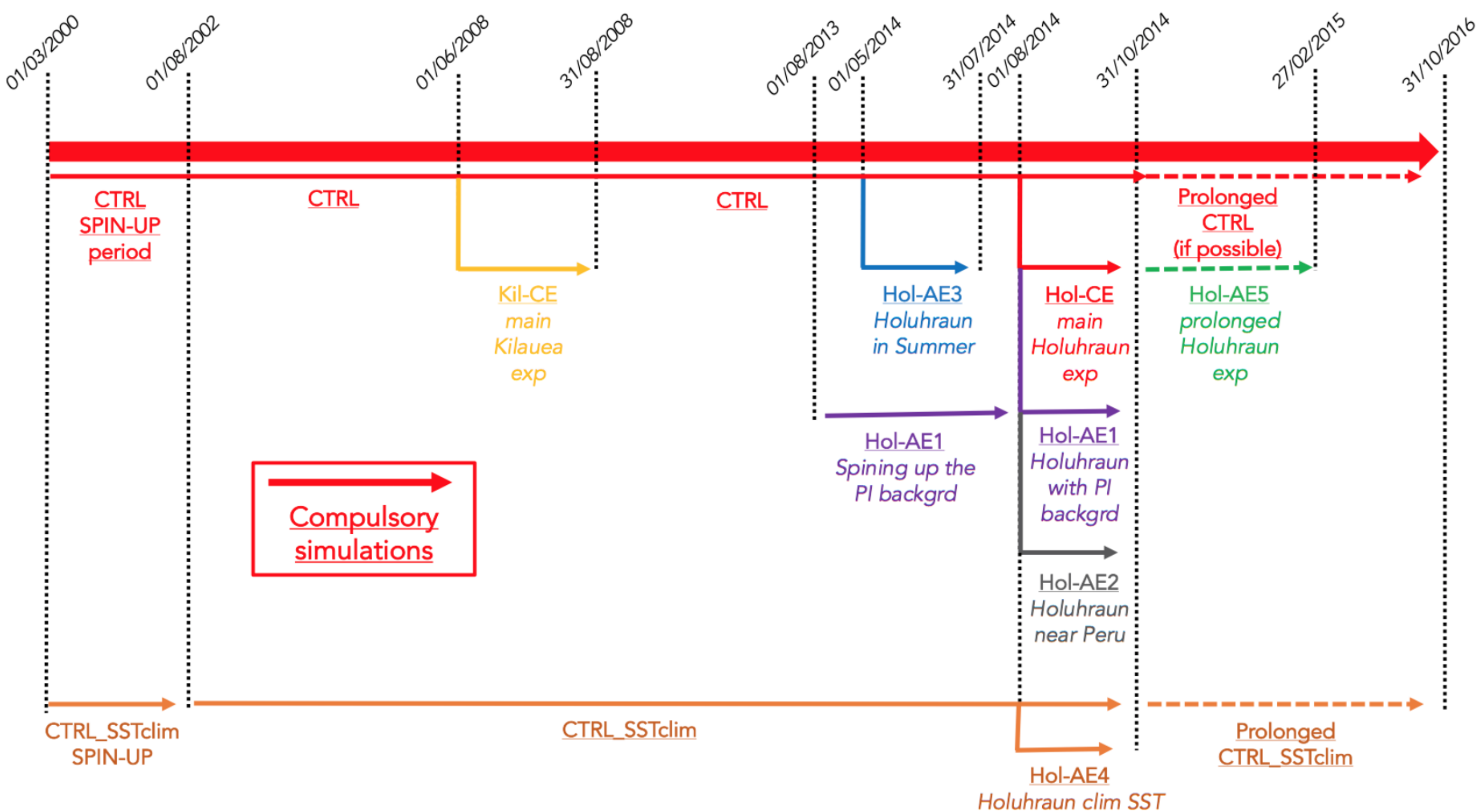
Additional Material

$$\frac{d\ln \overline{R}}{d\ln \overline{E}} = \left[\frac{d\ln \overline{C}}{d\ln \overline{N}_d} + \frac{d\ln \overline{R}_c}{d\ln \overline{\tau}}\left(\frac{d\ln \overline{L}}{d\ln \overline{N}_d} - \frac{d\ln \overline{r}_e}{d\ln \overline{N}_d}\right)\right]\frac{d\ln \overline{N}_d}{d\ln \overline{CCN}}\frac{d\ln \overline{CCN}}{d\ln \overline{E}}$$



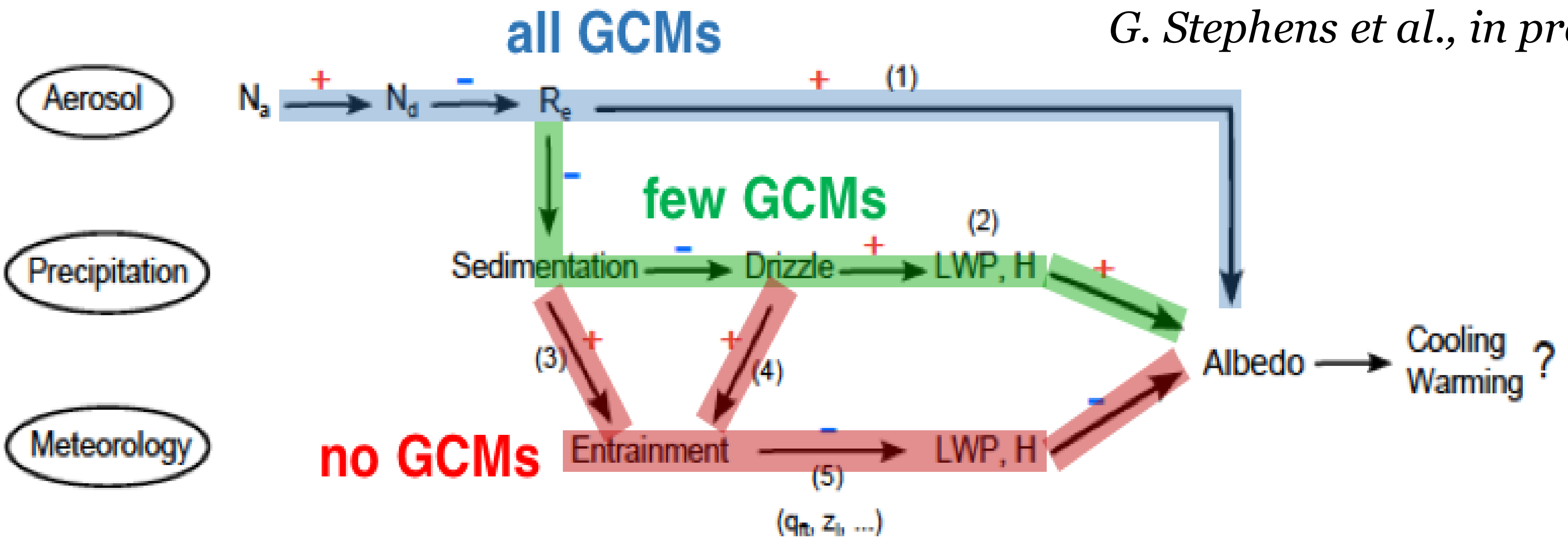
S. Ghan et al., PNAS 2016

Simulation design 2/2



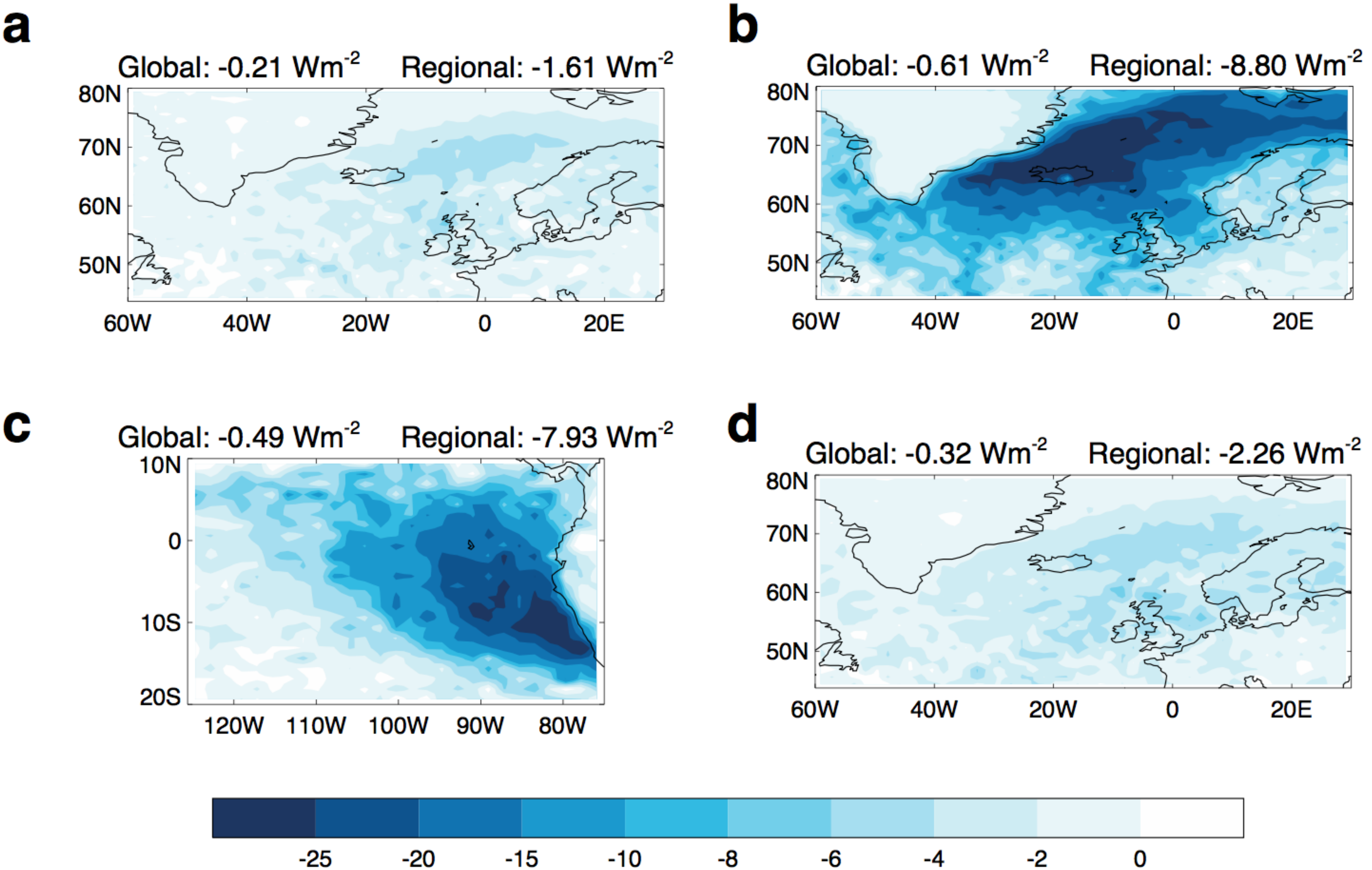
Some thoughts:
Could we improve the representation of ACI in GCMs ?

G. Stephens et al., in prep



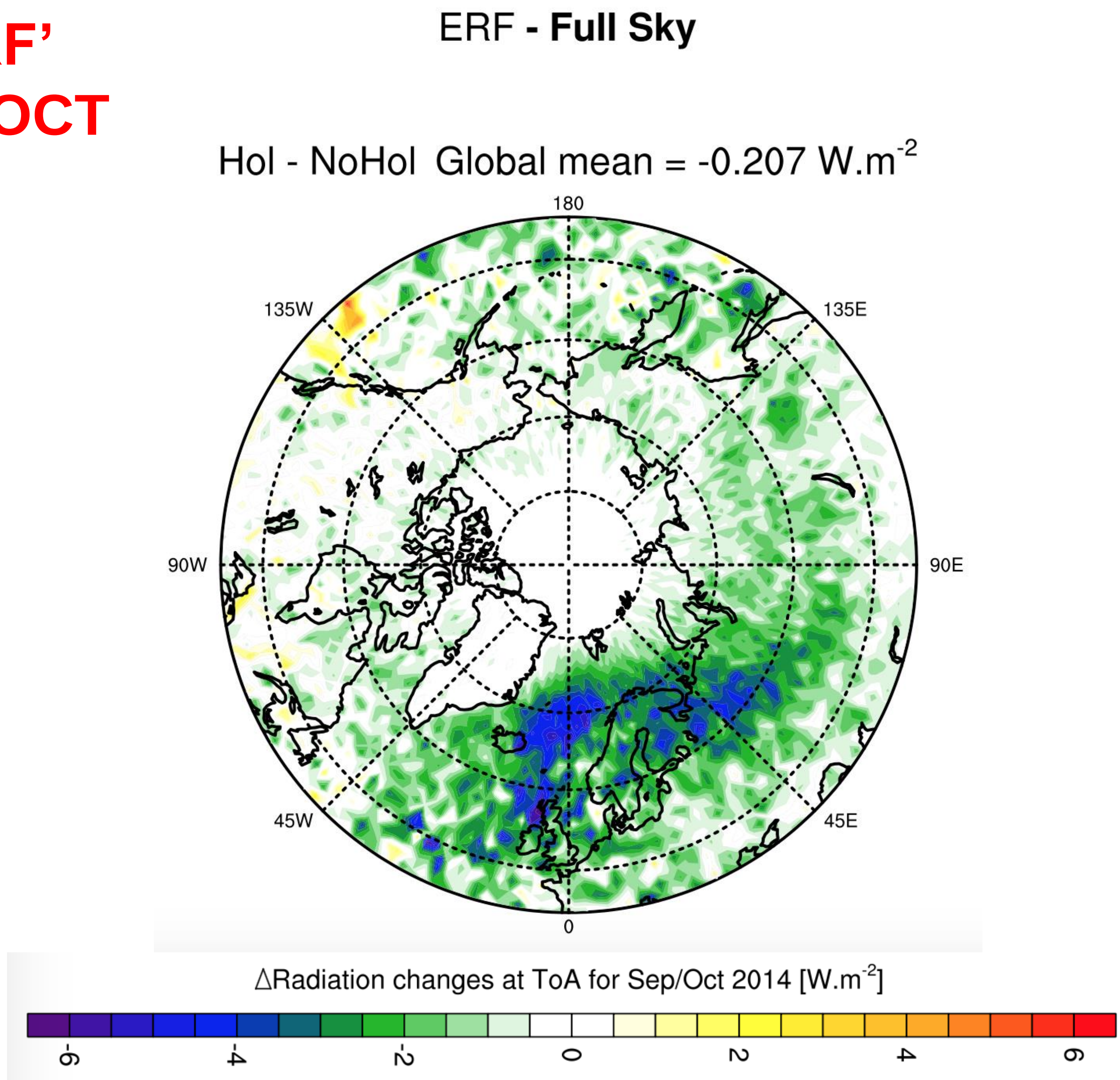
- Is the story complete ?
- Do we need at all all that complexity ?
- Could we reframe the problem in simpler terms ? – *e.g. Feingold et al., PNAS 2016*

‘ERF’ SEP-OCT



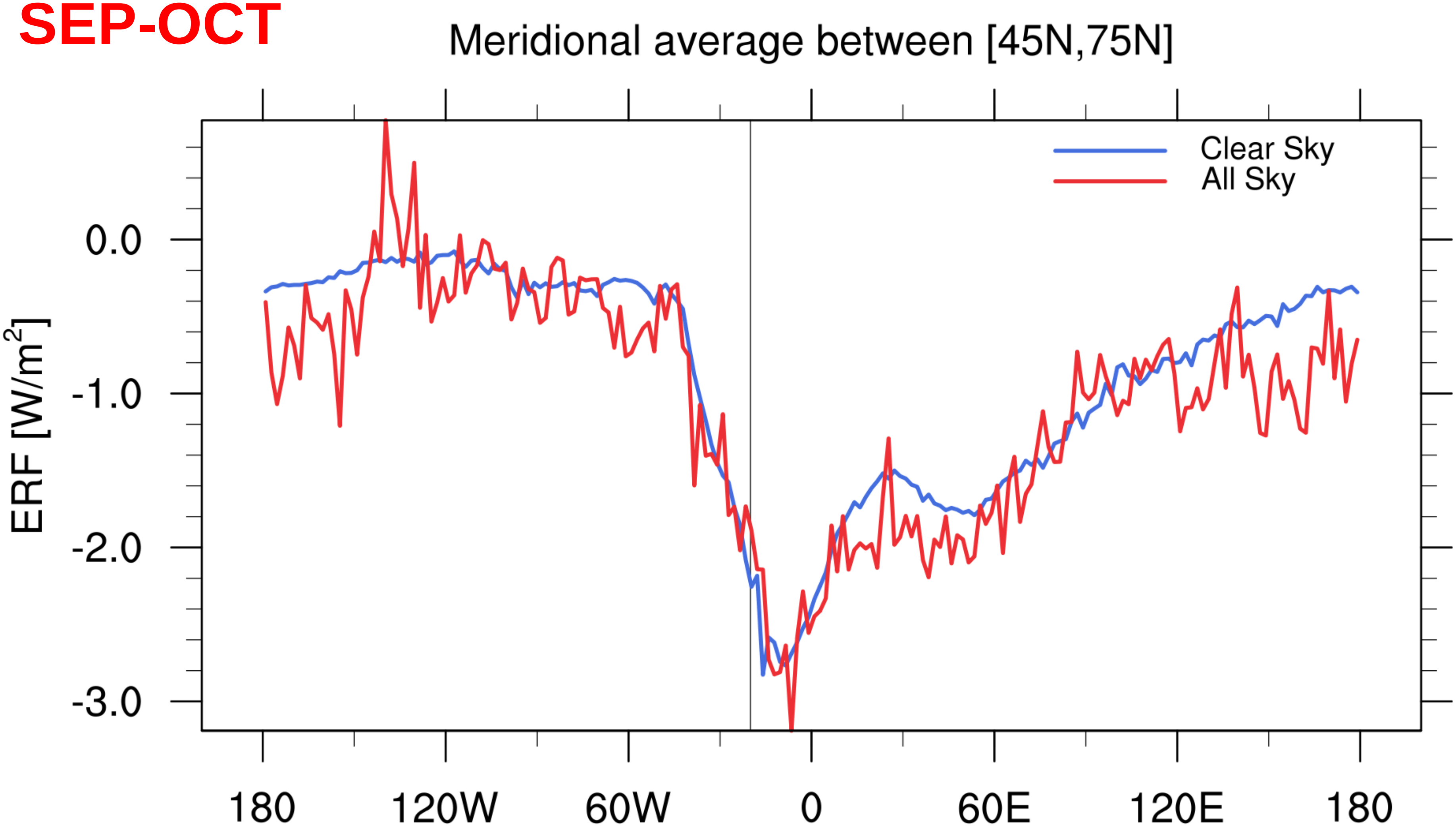
a
Global: -0.21 Wm-2
Regional: -1.61 Wm-2
80N
70N
60N
50N
60W
40W
20W
0
20E
b
Global: -0.61 Wm-2
Regional: -8.80 Wm-2
c
Global: -0.49 Wm-2
Regional: -7.93 Wm-2
10N
0
10S
20S
120W
110W
100W
90W
80W
d
Global: -0.32 Wm-2
Regional: -2.26 Wm-2
-25
-20
-15
-10
-8
-6
-4
-2
0

'ERF'
SEP-OCT

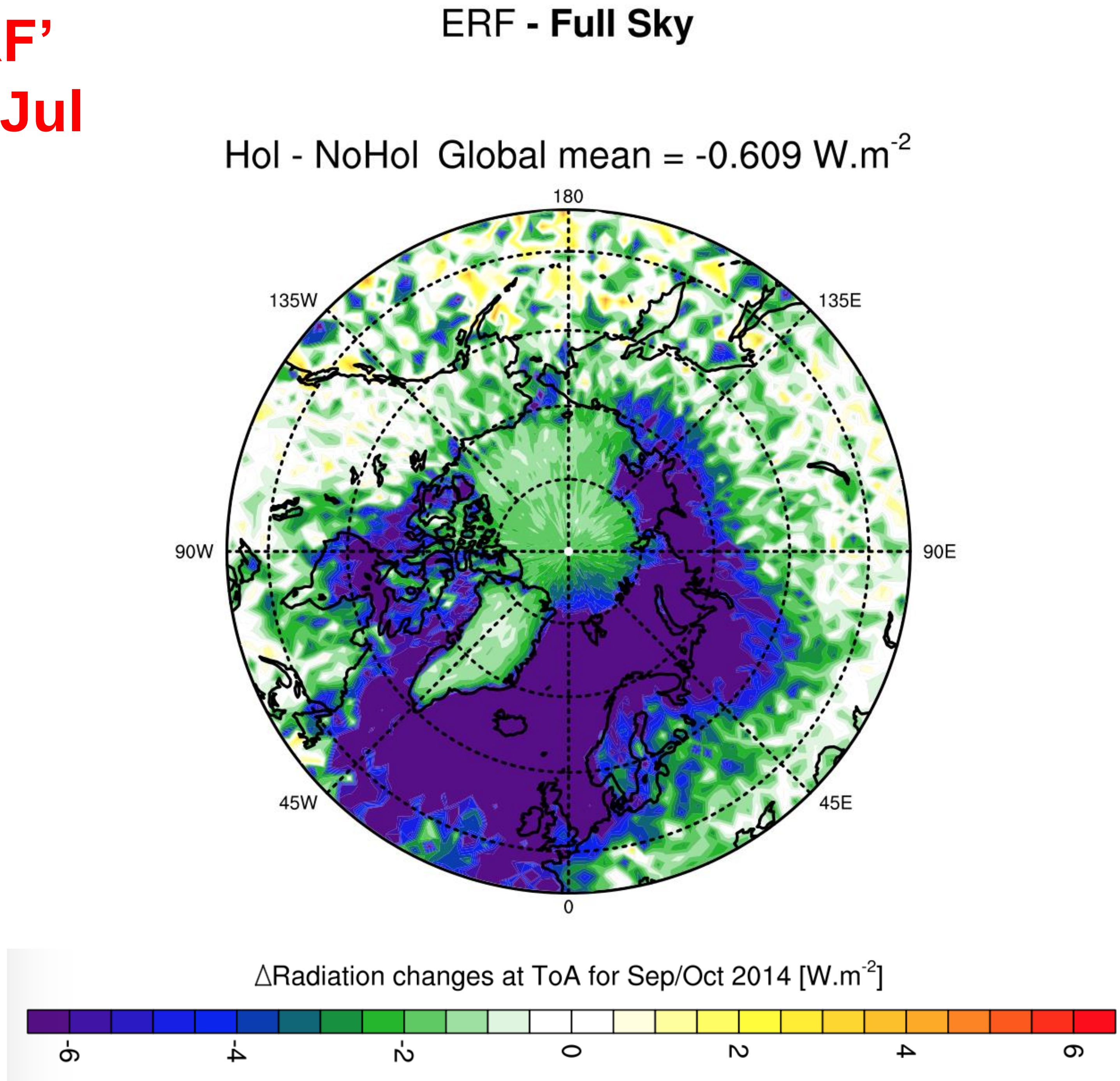


ERF - Full Sky
Hol - NoHol Global mean = -0.207 W.m-2
180
135W
135E
90W
90E
45W
45E
0
ΔRadiation changes at ToA for Sep/Oct 2014 [W.m-2]
-6
-4
-2
0
2
4
6

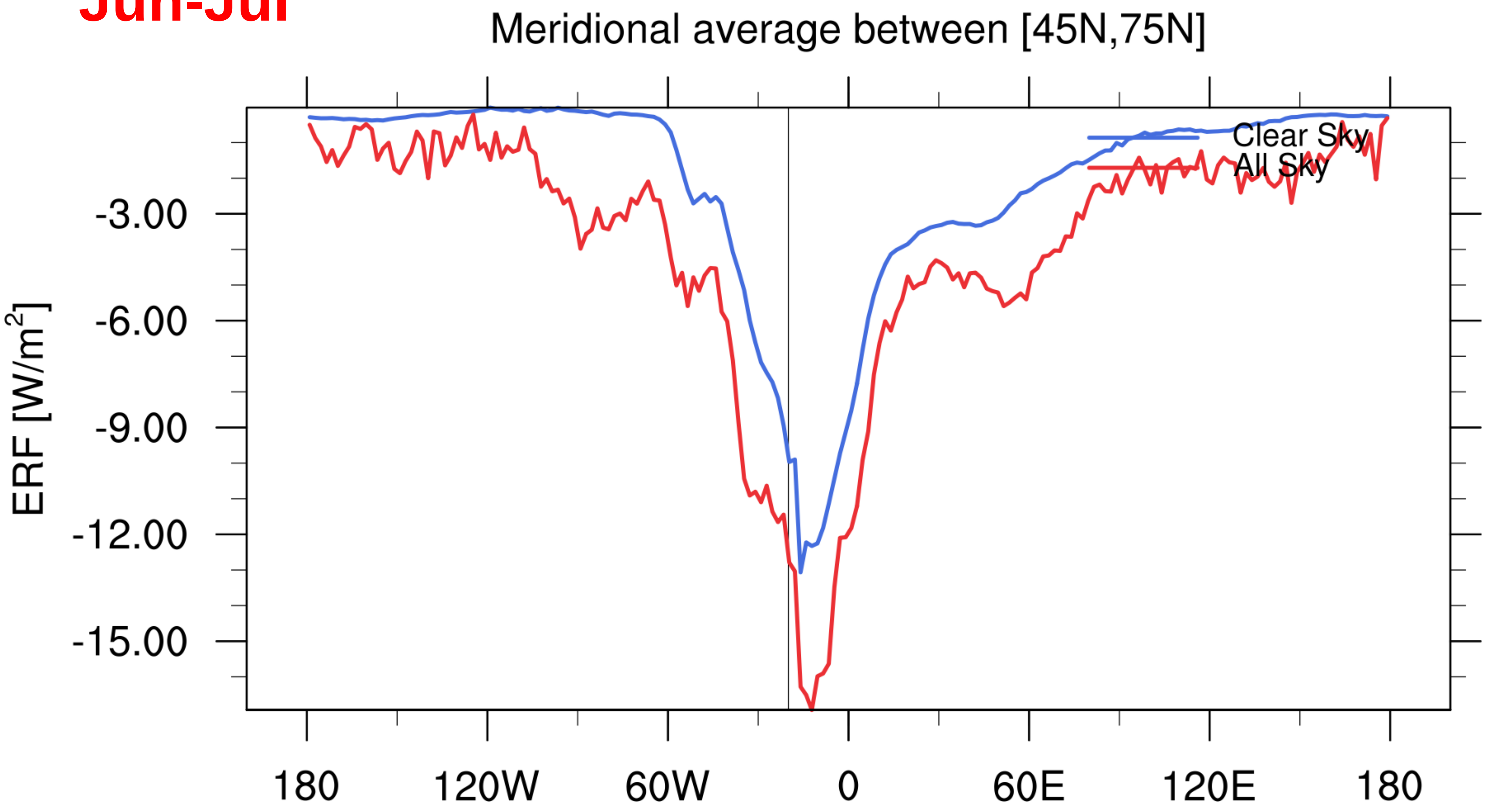
‘ERF’
SEP-OCT


Meridional average between [45N,75N]
Clear Sky
All Sky
0.0
-1.0
-2.0
-3.0
ERF [W/m2]
180
120W
60W
0
60E
120E
180

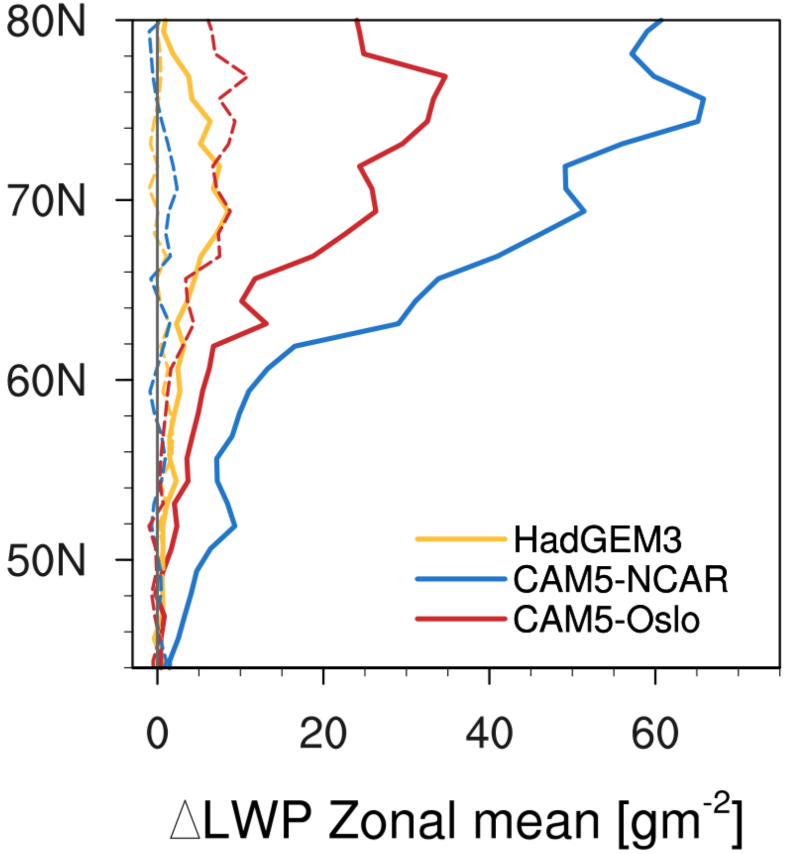
‘ERF’ Jun-Jul

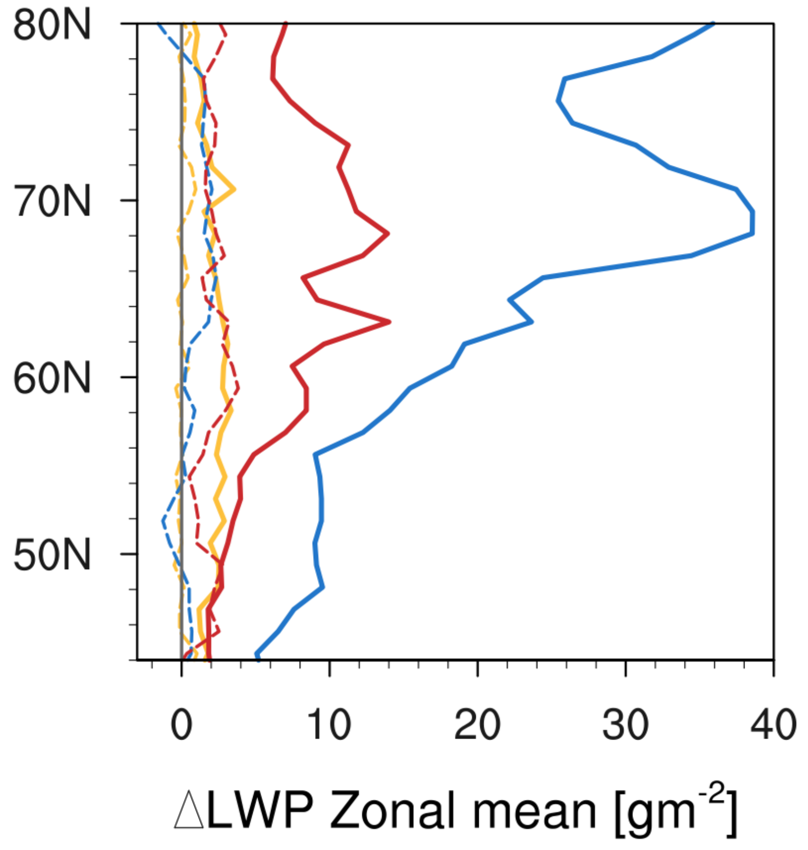

ERF - Full Sky
Hol - NoHol Global mean = -0.609 W.m-2
180
135W
135E
90W
90E
45W
45E
0
ΔRadiation changes at ToA for Sep/Oct 2014 [W.m-2]
-6
-4
-2
0
2
4
6

‘ERF’
Jun-Jul

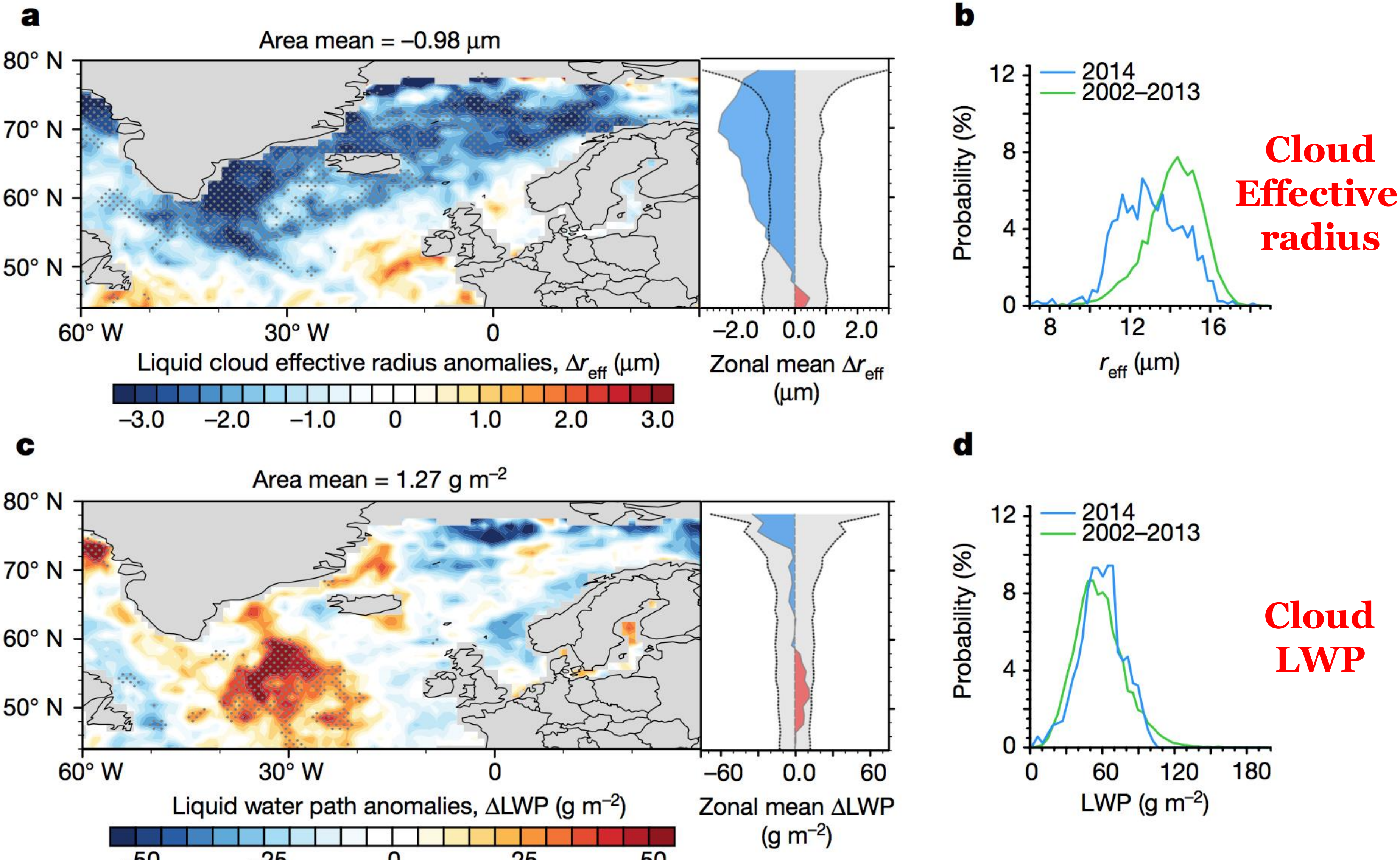

Meridional average between [45N,75N]
ERF [W/m^2]
-3.00
-6.00
-9.00
-12.00
-15.00
180
120W
60W
0
60E
120E
180
Clear Sky
All Sky

Turning off dependence on CDNC in Autoconversion



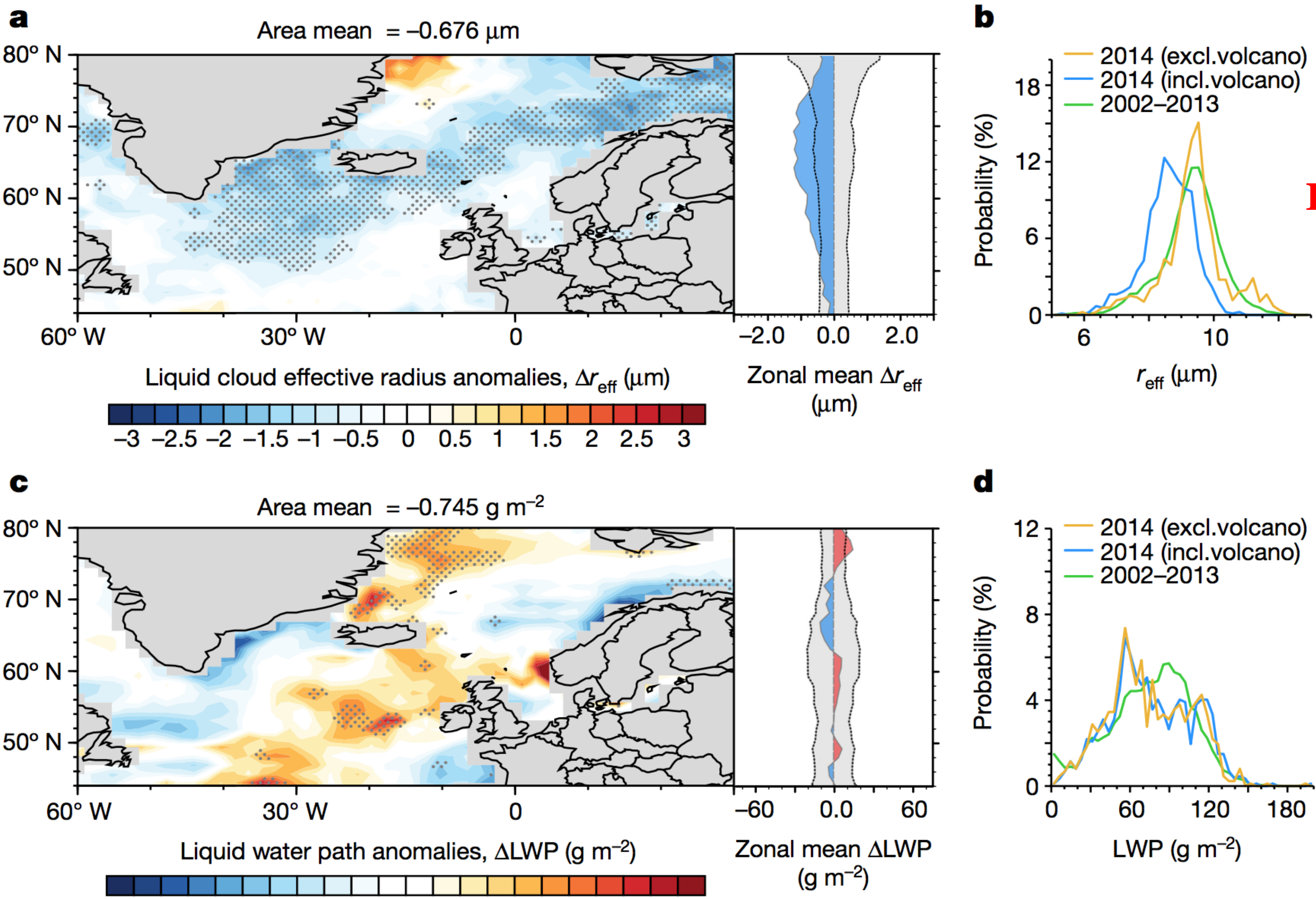


AQUA MODIS (OBS) – October 2014



Grey in zonal mean = 1 standard deviation.
Similar results for September (except there is some contribution from continental pollution to south of the region)

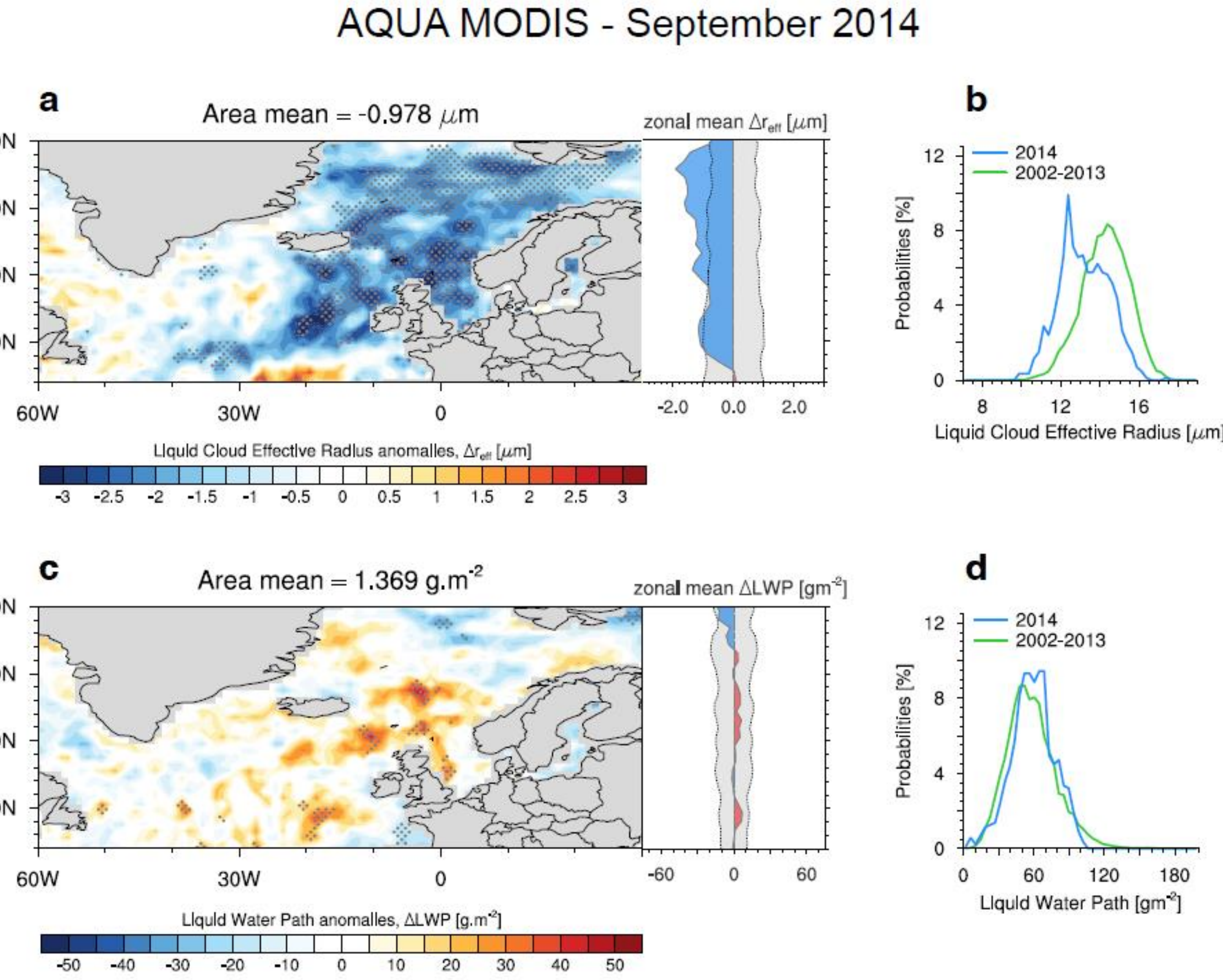
HadGEM3-MODE (Model) – October 2014



Cloud Effective radius

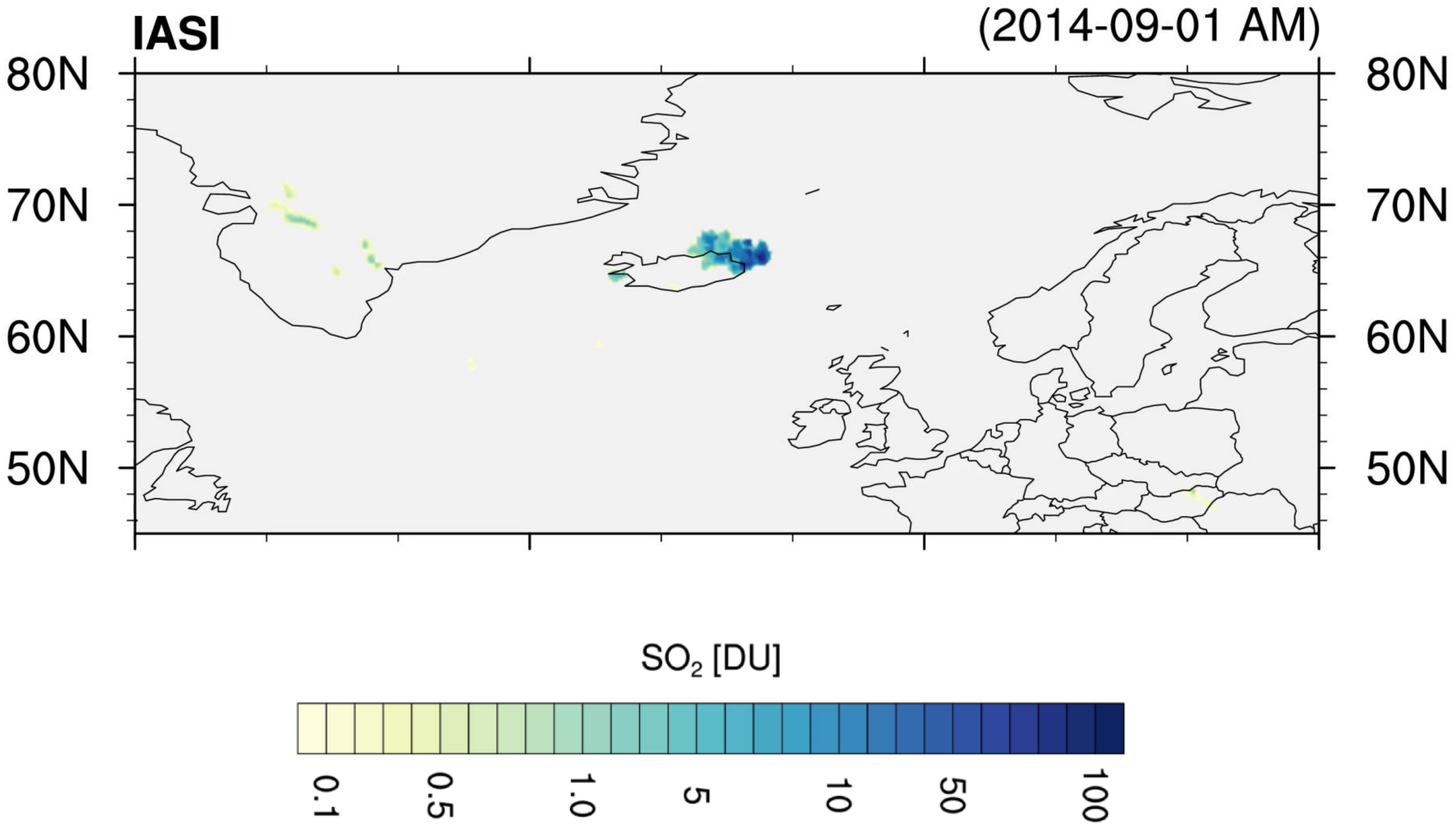
Cloud LWP

Grey = 1 stdev. Similar results for September (except there is some contribution from continental pollution to south of the region)

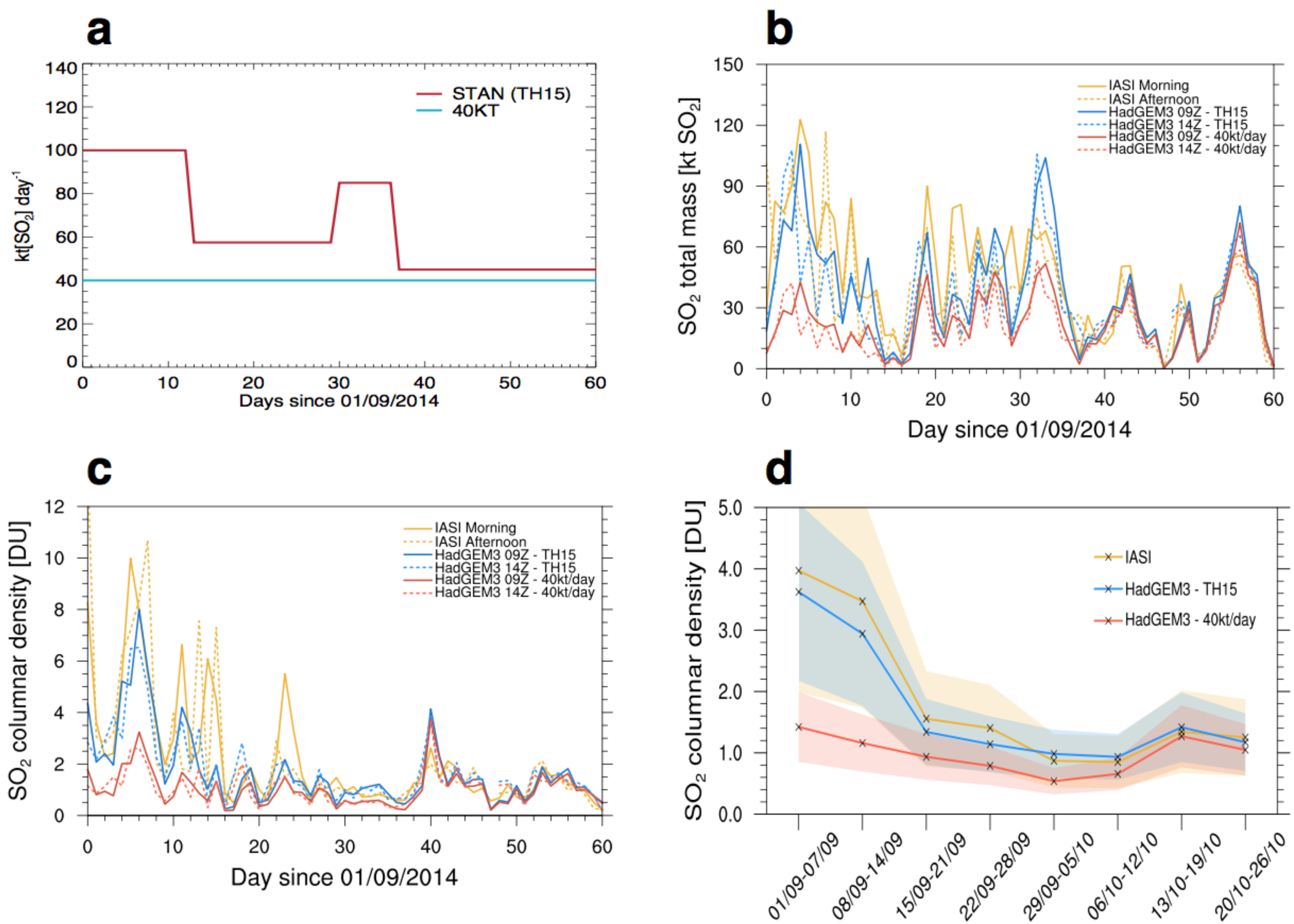


AQUA MODIS - September 2014
a
Area mean = -0.978 μm
zonal mean Δr_eff [μm]
80N
70N
60N
50N
60W
30W
0
-2.0
0.0
2.0
Liquid Cloud Effective Radius anomalies, Δr_eff [μm]
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
b
2014
2002-2013
Probabilities [%]
Liquid Cloud Effective Radius [μm]
c
Area mean = 1.369 g.m⁻²
zonal mean ΔLWP [gm⁻²]
-60
0
60
Liquid Water Path anomalies, ΔLWP [g.m⁻²]
-50
-40
-30
-20
-10
10
20
30
40
50
d
Liquid Water Path [gm⁻²]
120
180

IASI (OBS) – SO_2 time series



Assessment of emission rates



More detail on precipitation

Impacts on precipitation over during September/ October are very unremarkable ...

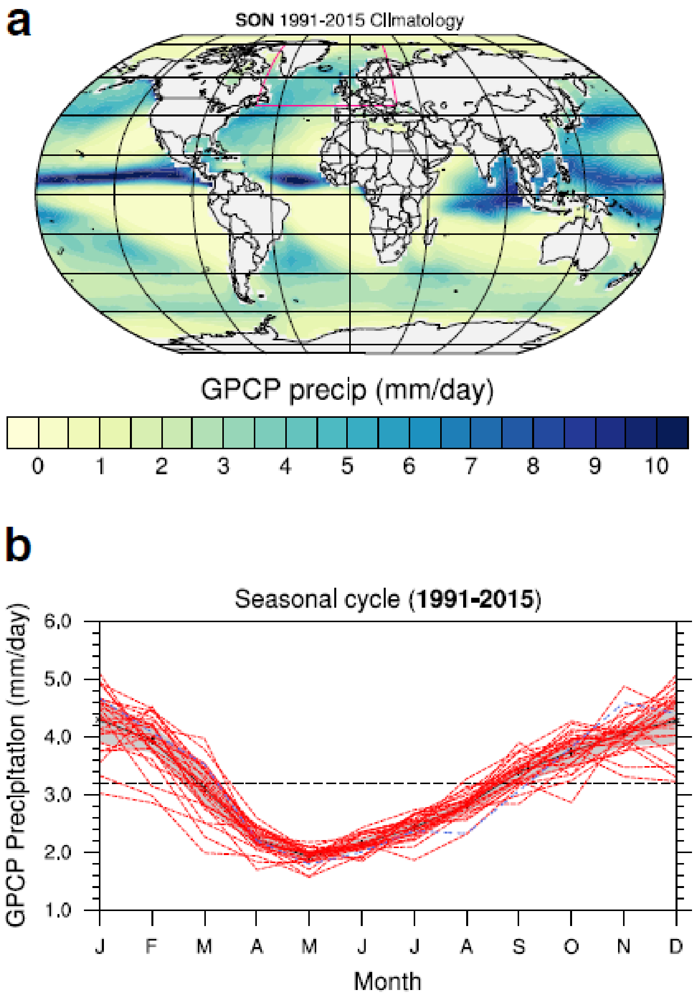
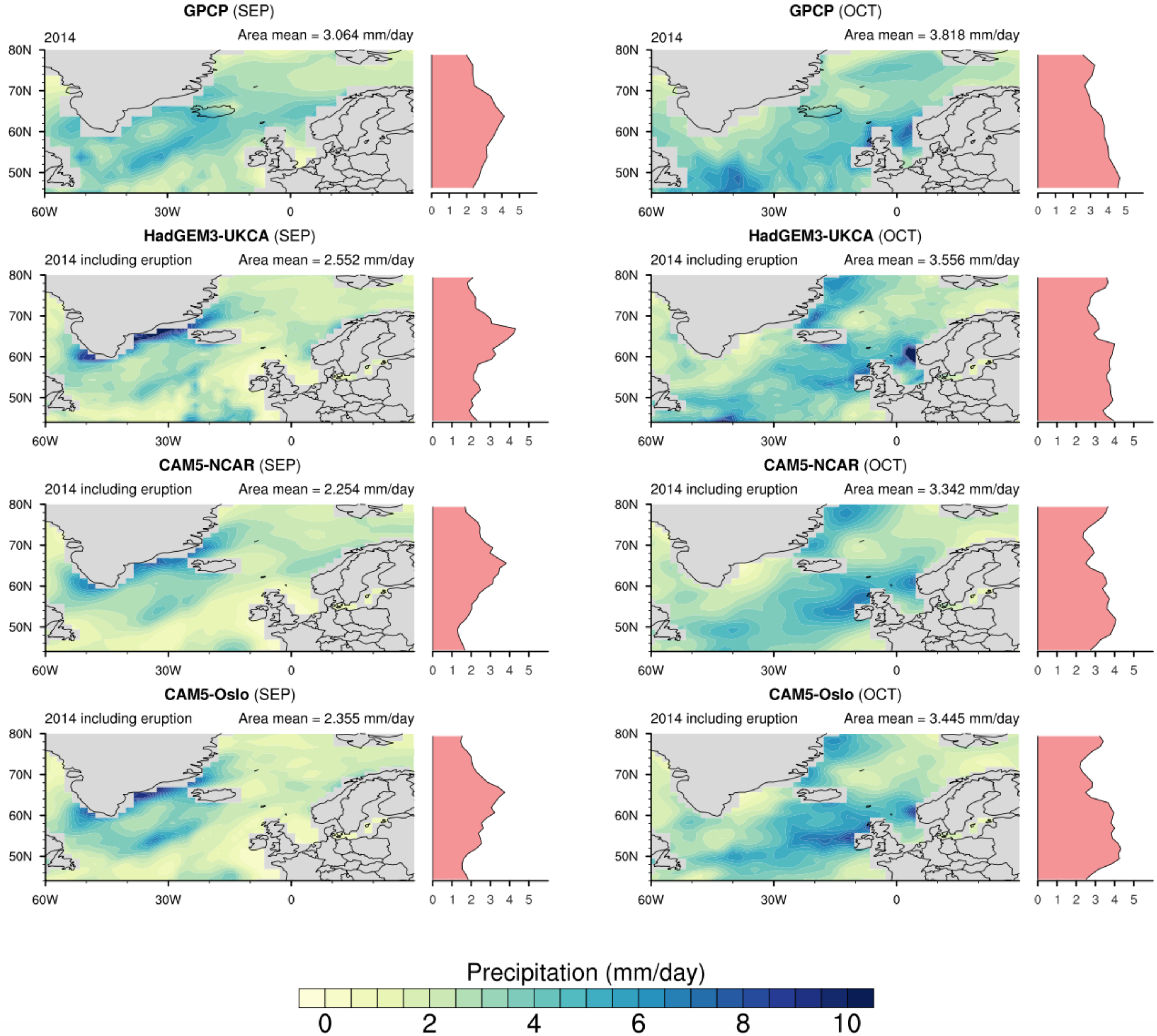


Figure S10.1. The climatology of surface precipitation from GPCP. The precipitation rate (in mm/day) shown as a) September-October-November (SON) seasonal average for the 1991-2015 period, and b) the corresponding seasonal cycle derived for the region in the vicinity of Holuhraun (45°N-80°N; 60°E-30°W). The long term (1991-2015) mean seasonal cycle is represented by the black line. The red dashed lines represent the seasonal cycle for each individual year. 2014 is highlighted in blue.



GPCP (SEP)
2014
Area mean = 3.064 mm/day
GPCP (OCT)
2014
Area mean = 3.818 mm/day
HadGEM3-UKCA (SEP)
2014 including eruption
Area mean = 2.552 mm/day
HadGEM3-UKCA (OCT)
2014 including eruption
Area mean = 3.556 mm/day
CAM5-NCAR (SEP)
2014 including eruption
Area mean = 2.254 mm/day
CAM5-NCAR (OCT)
2014 including eruption
Area mean = 3.342 mm/day
CAM5-Oslo (SEP)
2014 including eruption
Area mean = 2.355 mm/day
CAM5-Oslo (OCT)
2014 including eruption
Area mean = 3.445 mm/day
80N
70N
60N
50N
60W
30W
0
0 1 2 3 4 5
Precipitation (mm/day)
0
2
4
6
8
10

The precipitation is actually the most average October in the satellite record……..

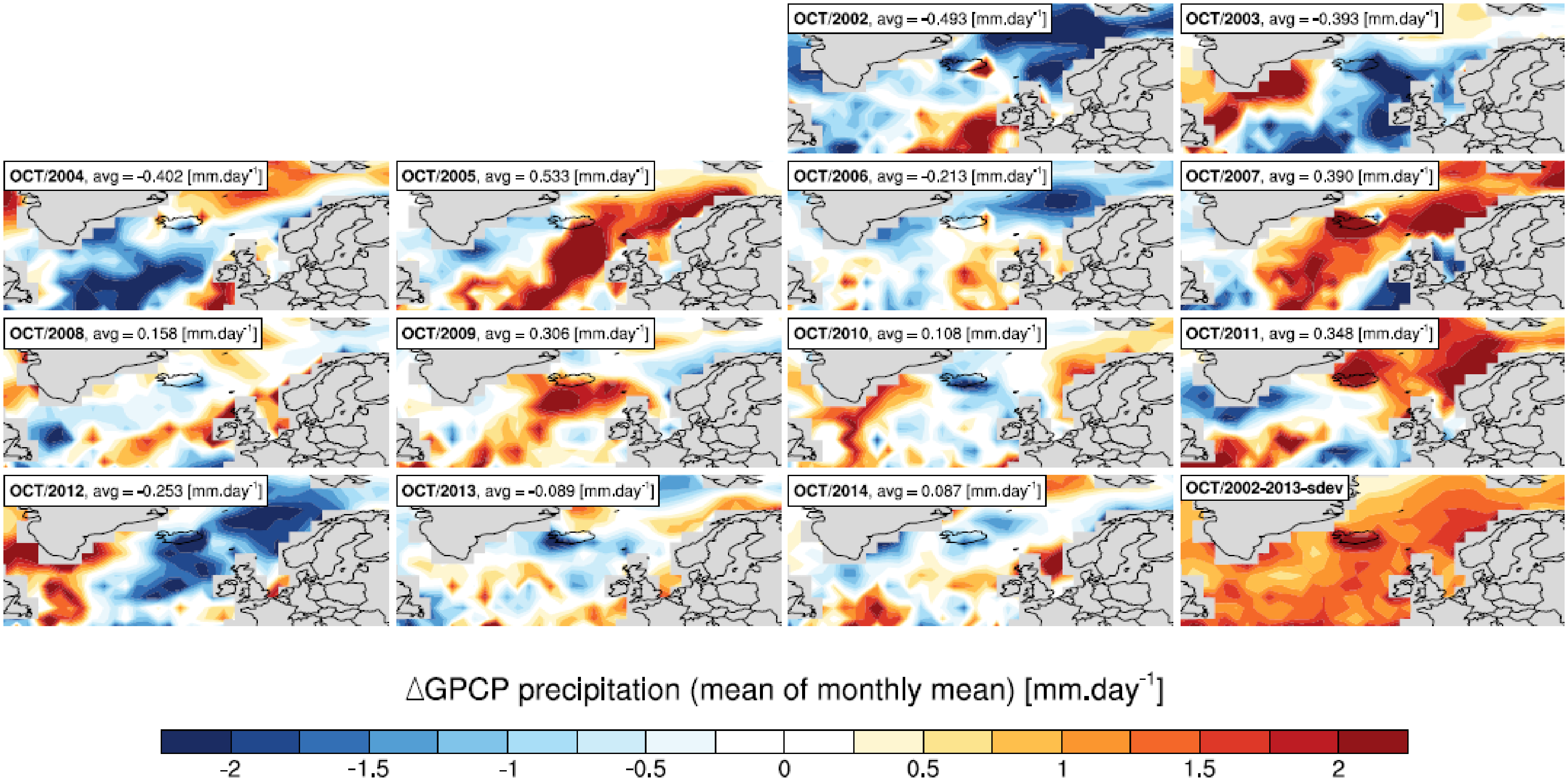
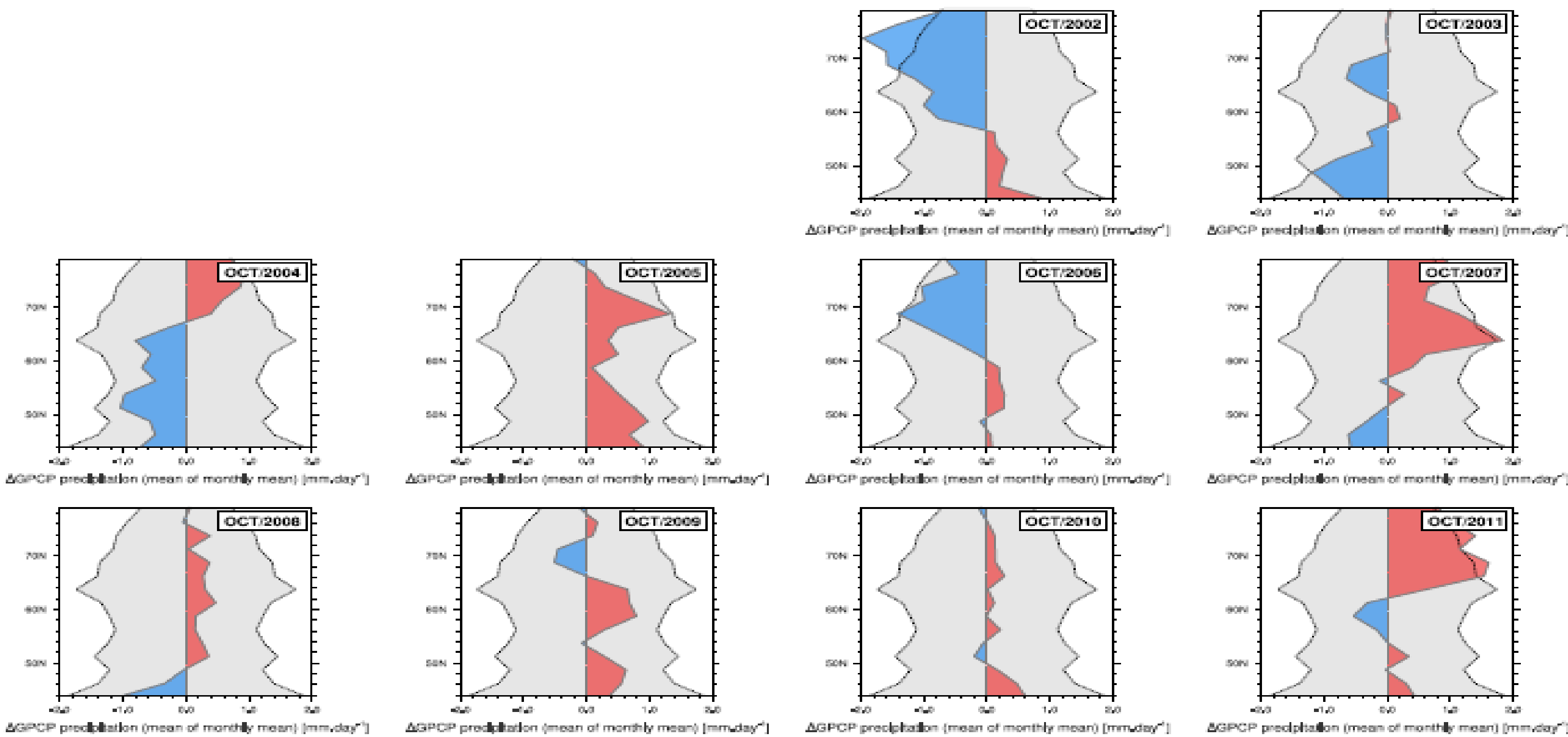
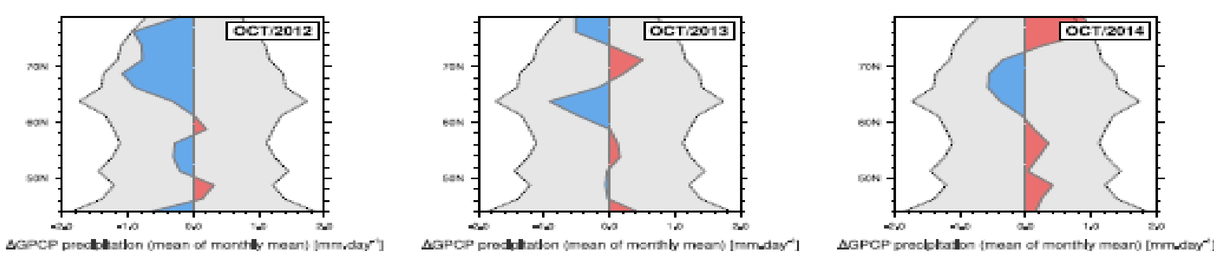


***Figure S10.3. The precipitation rate anomalies during October months from GPCP.** The precipitation rate anomalies are shown from 2002 to 2014 period (in mm/day) with their associated zonal mean (continued). The anomalies are calculated with regard to the 2002-2013 climatology. The grey shading represents the standard deviation from the 2002-2013 period. The last panel shows the precipitation rate standard deviation (sdev) calculated for the 2002-2013 period. In the first 13 panels, 'avg' represents the average anomalies.*

The precipitation is actually closest to the average ....





.... and the zonal mean anomaly does not stand out.

HadGEM3-UKCA

HadGEM3-CLASSIC

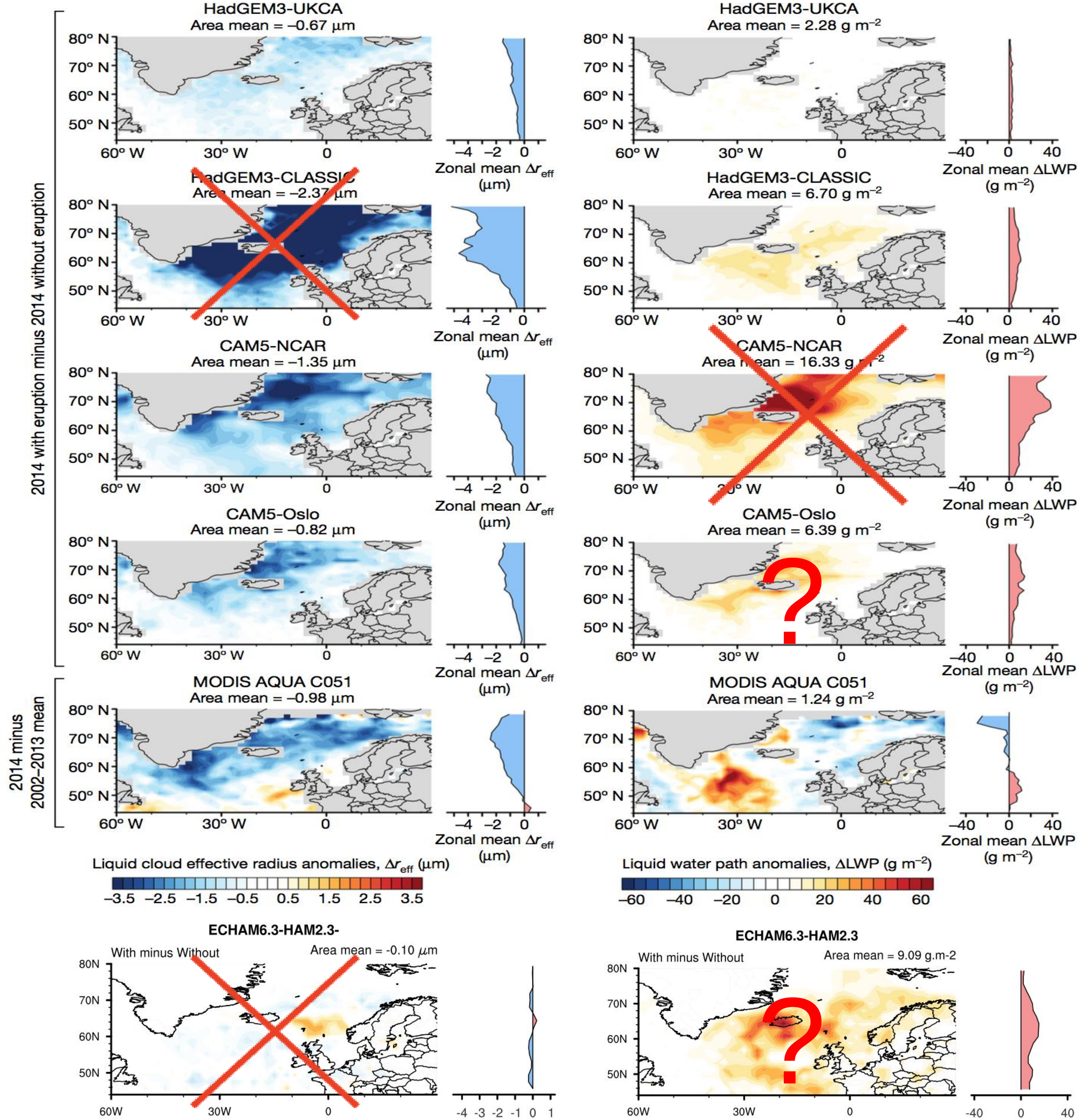
NCAR-CAM5.3

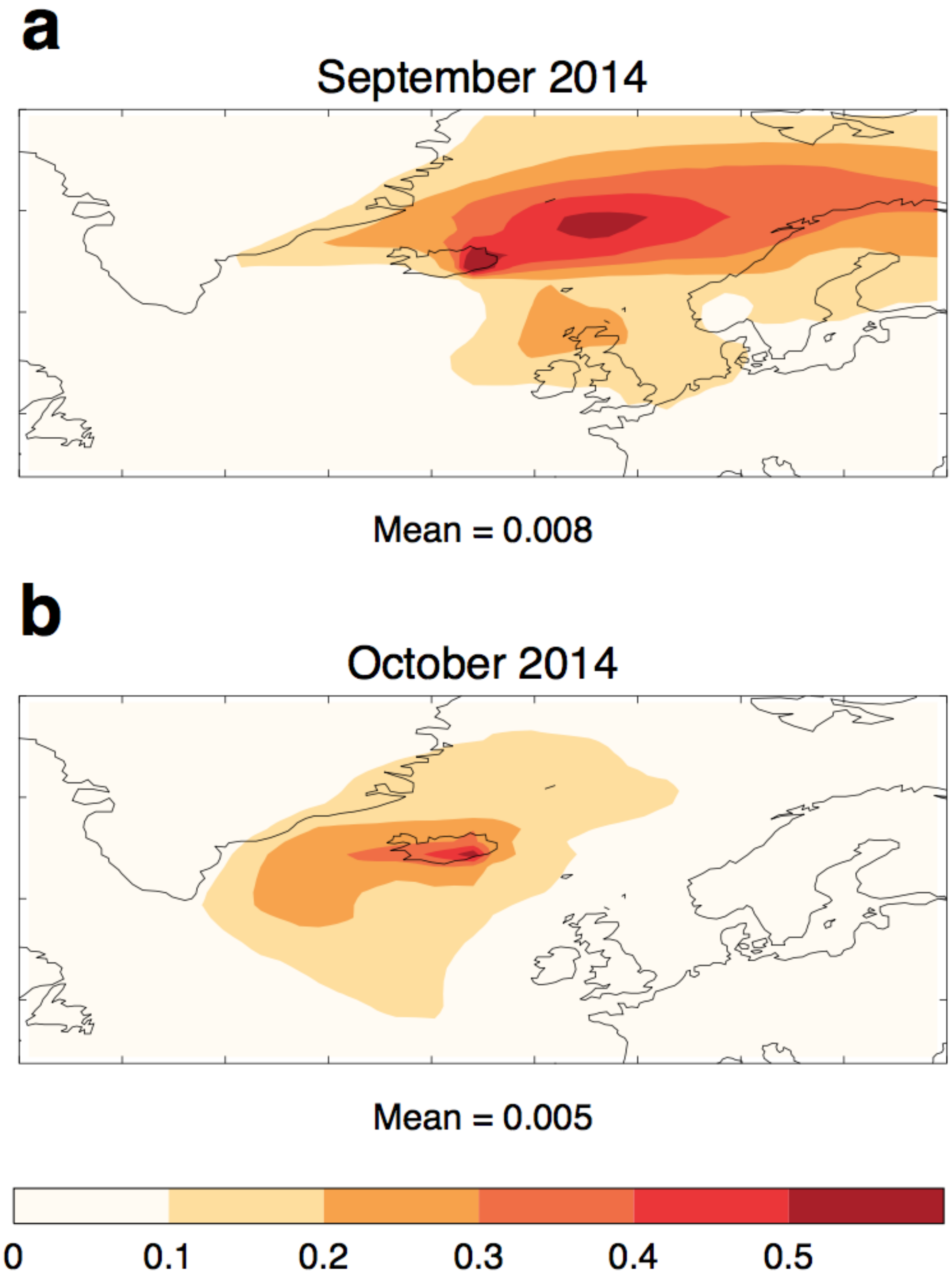
CAM5-Oslo

MODIS

ECHAM6.3-HAM2.3

Very Very preliminary result !




a
September 2014
Mean = 0.008
b
October 2014
Mean = 0.005
0
0.1
0.2
0.3
0.4
0.5