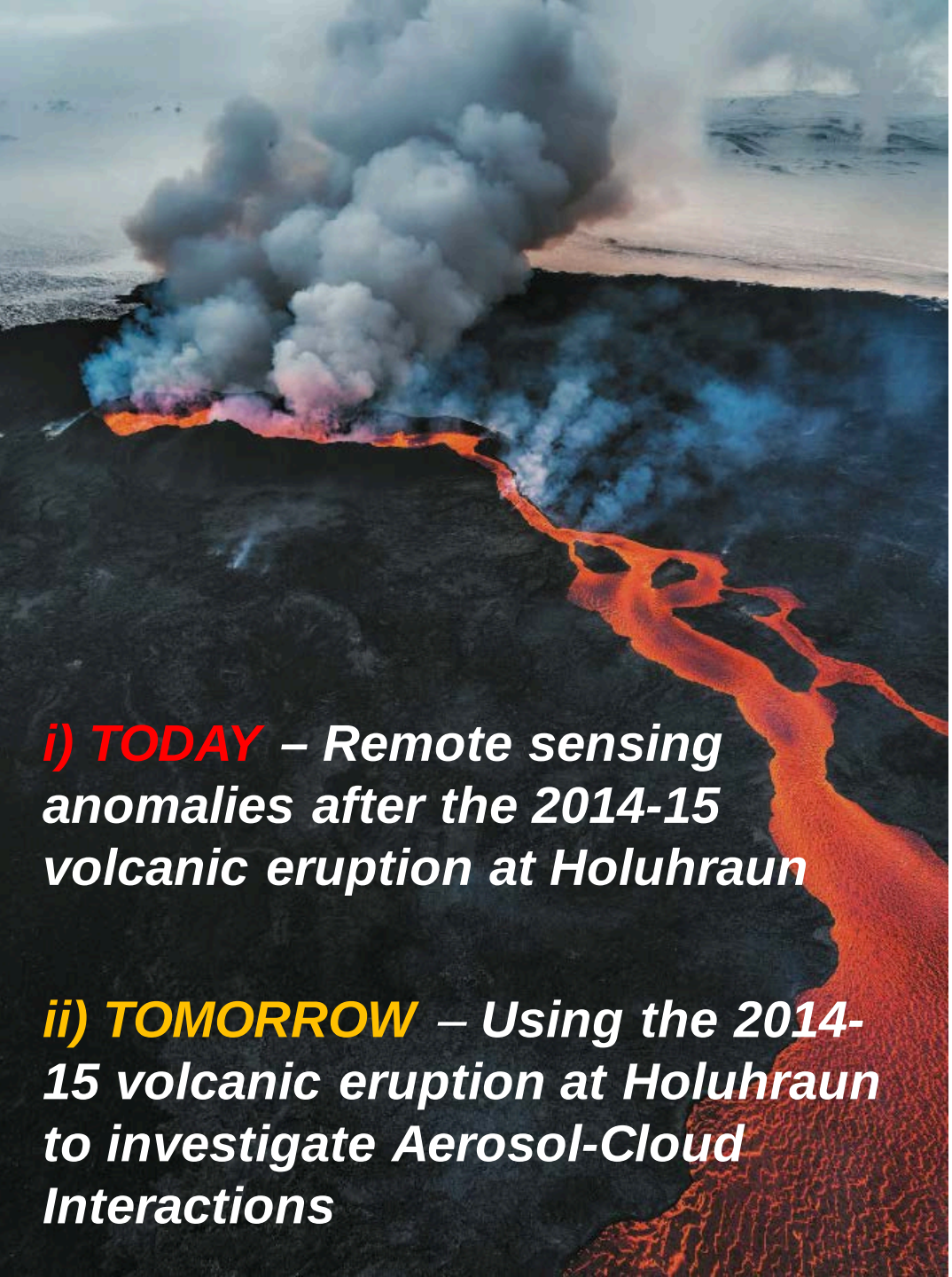


***i) TODAY** – Remote sensing anomalies after the 2014-15 volcanic eruption at Holuhraun*

***ii) TOMORROW** – Using the 2014-15 volcanic eruption at Holuhraun to investigate Aerosol-Cloud Interactions*

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

A massive **fissure eruption** at Holuhraun (Iceland) started on the 31st of AUG 2014.

- Sustained for ~ 6 months
- Up to 100 kt SO2/day
- Up to x10 emission rate from all of 28 European countries put together !!

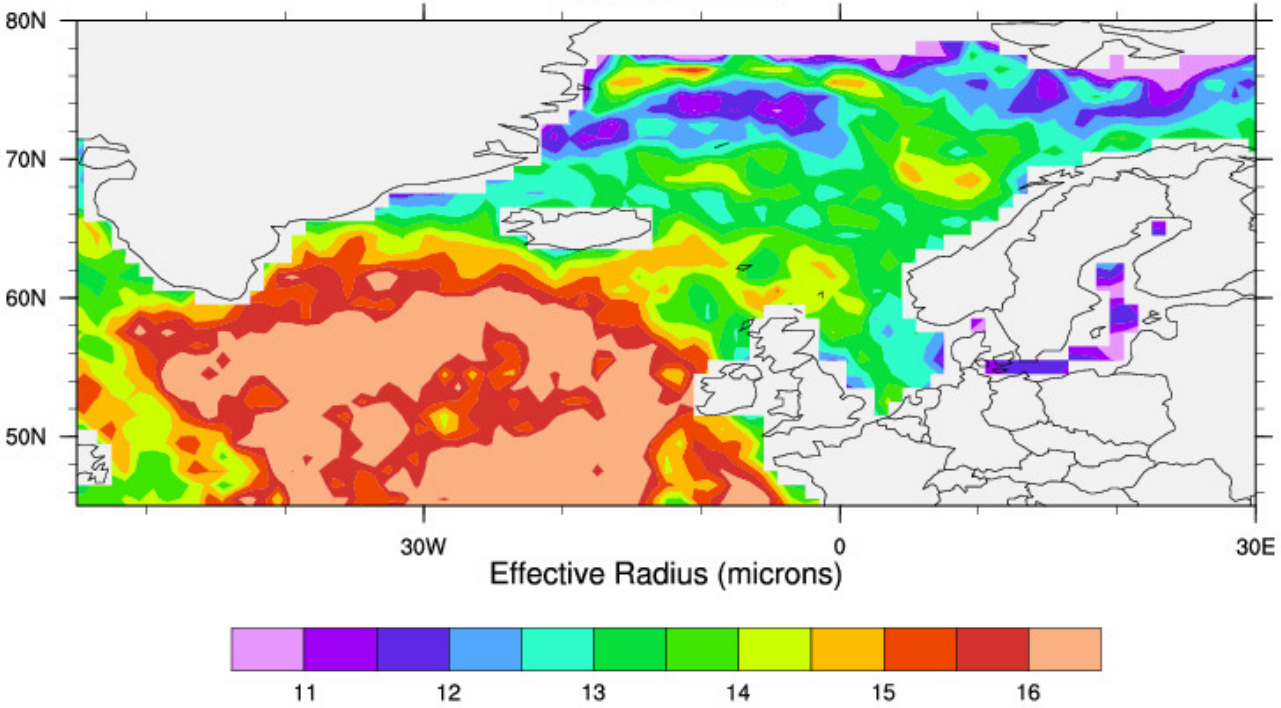
Images courtesy of Anja Schmidt

If we can't detect/model the impact on clouds then the impact is probably not important …

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2002

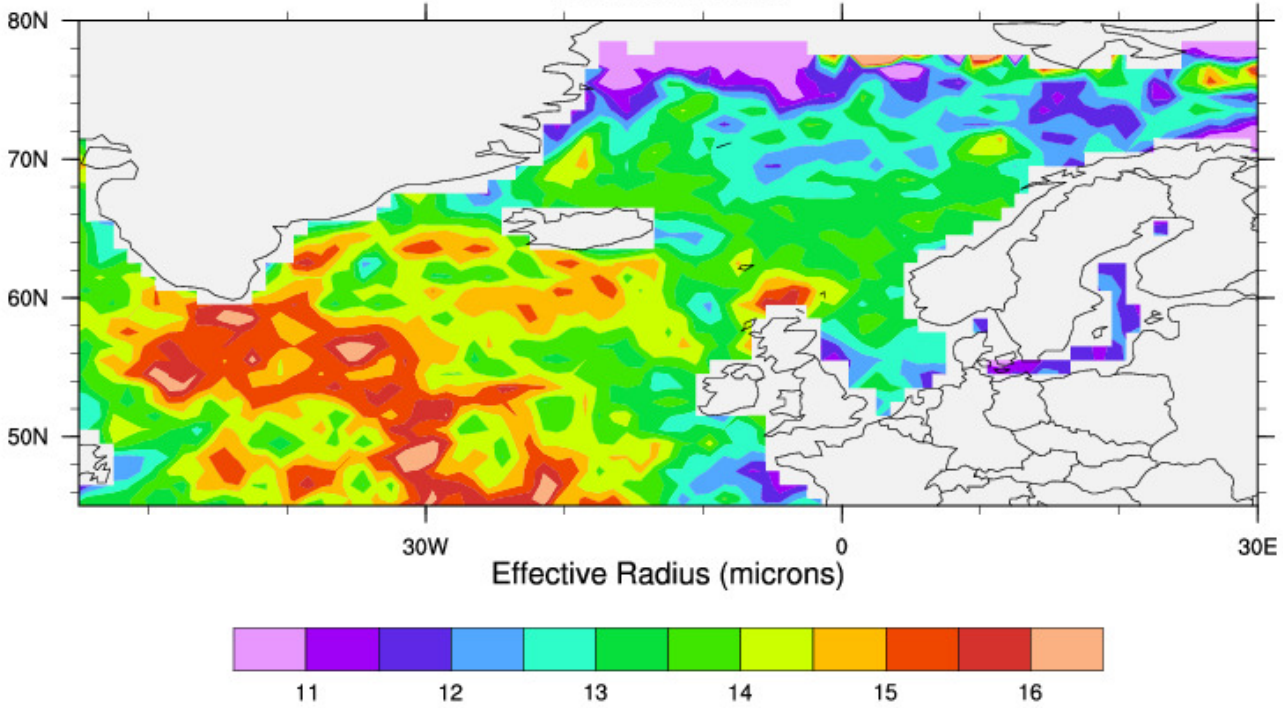


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2003

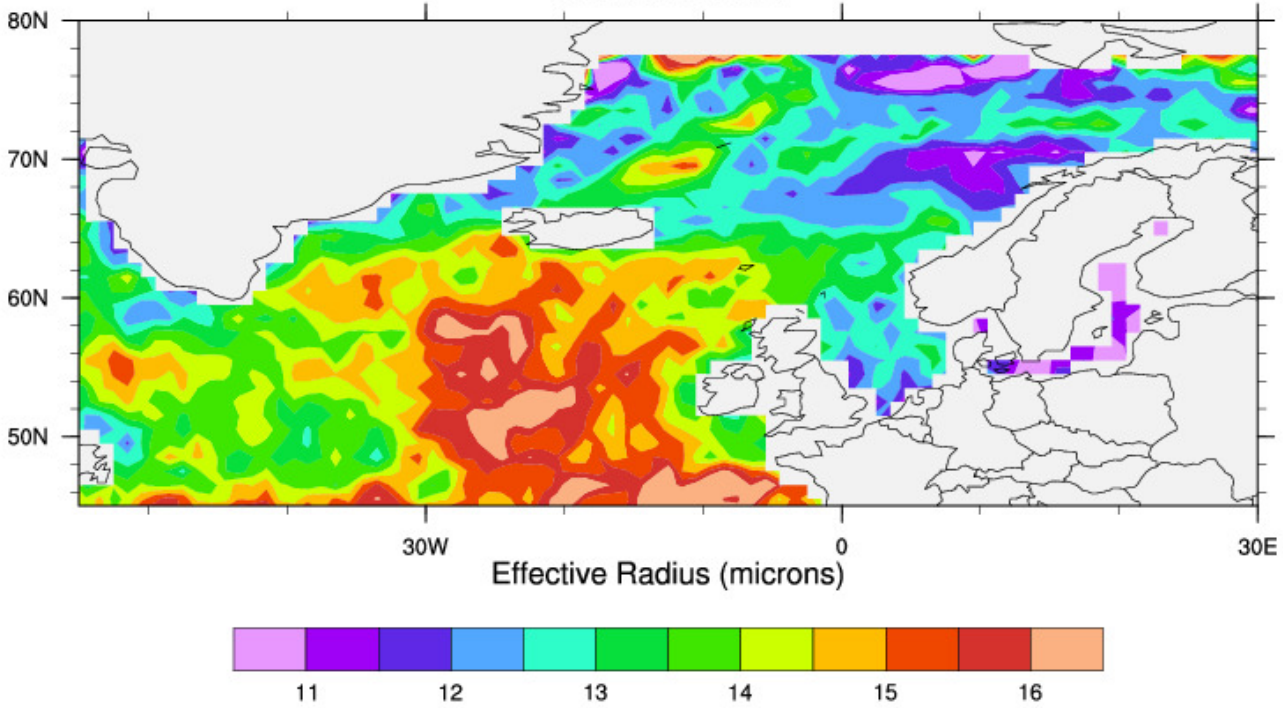


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2004

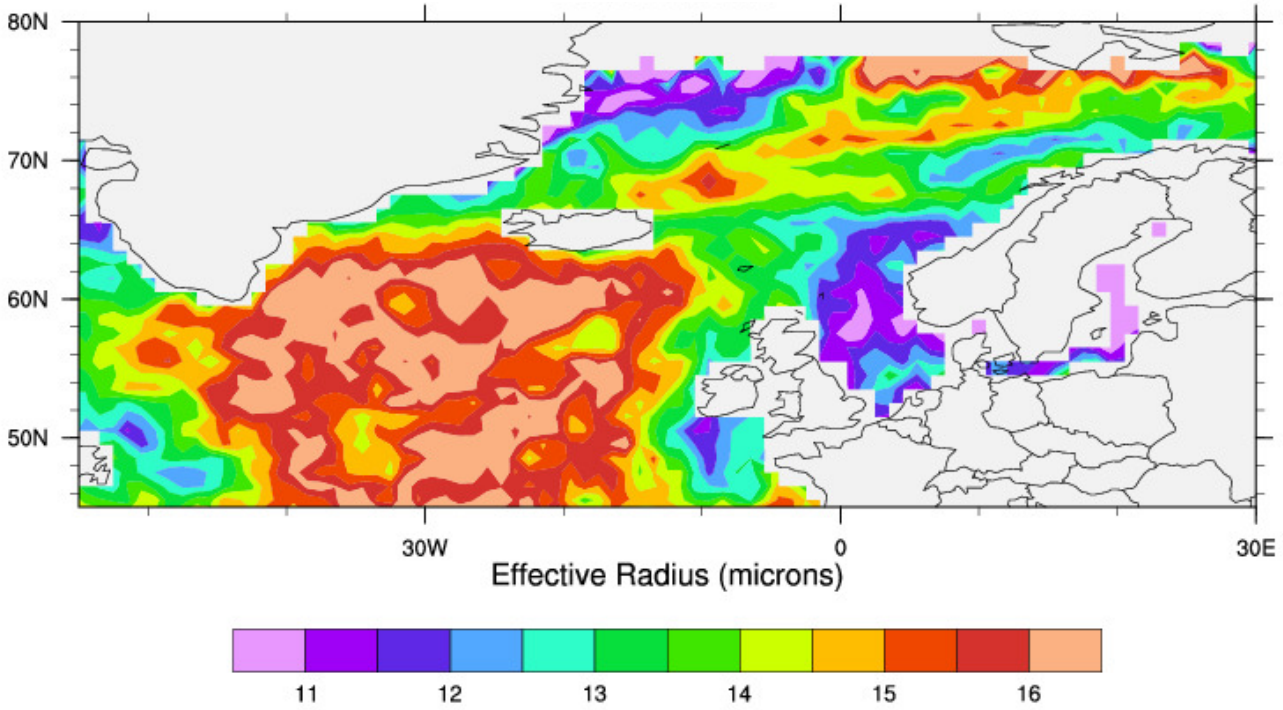


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2005

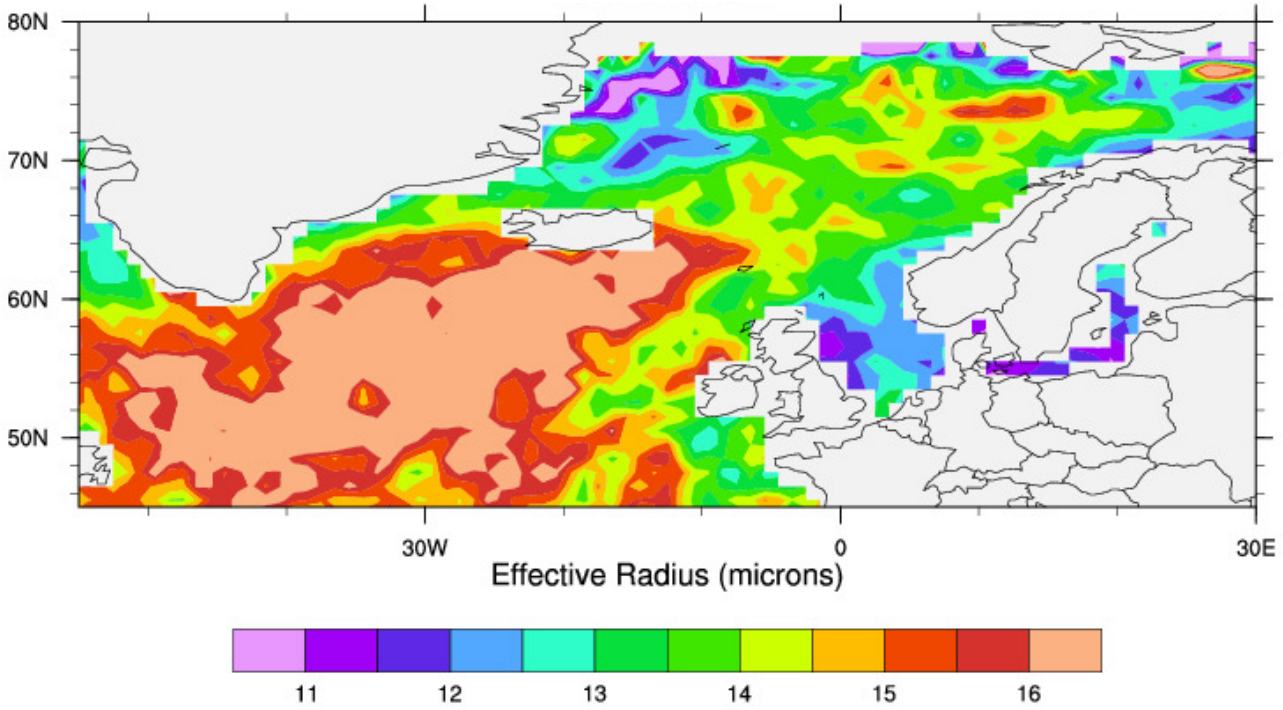


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2006

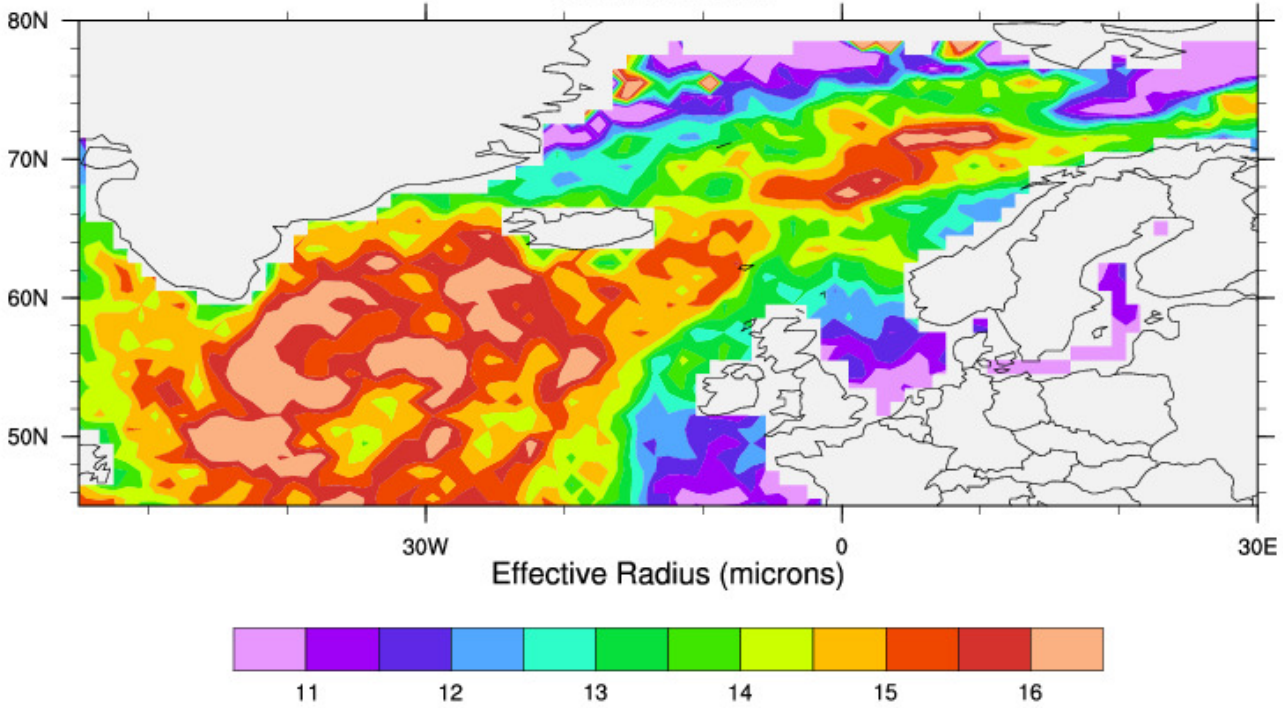


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2007

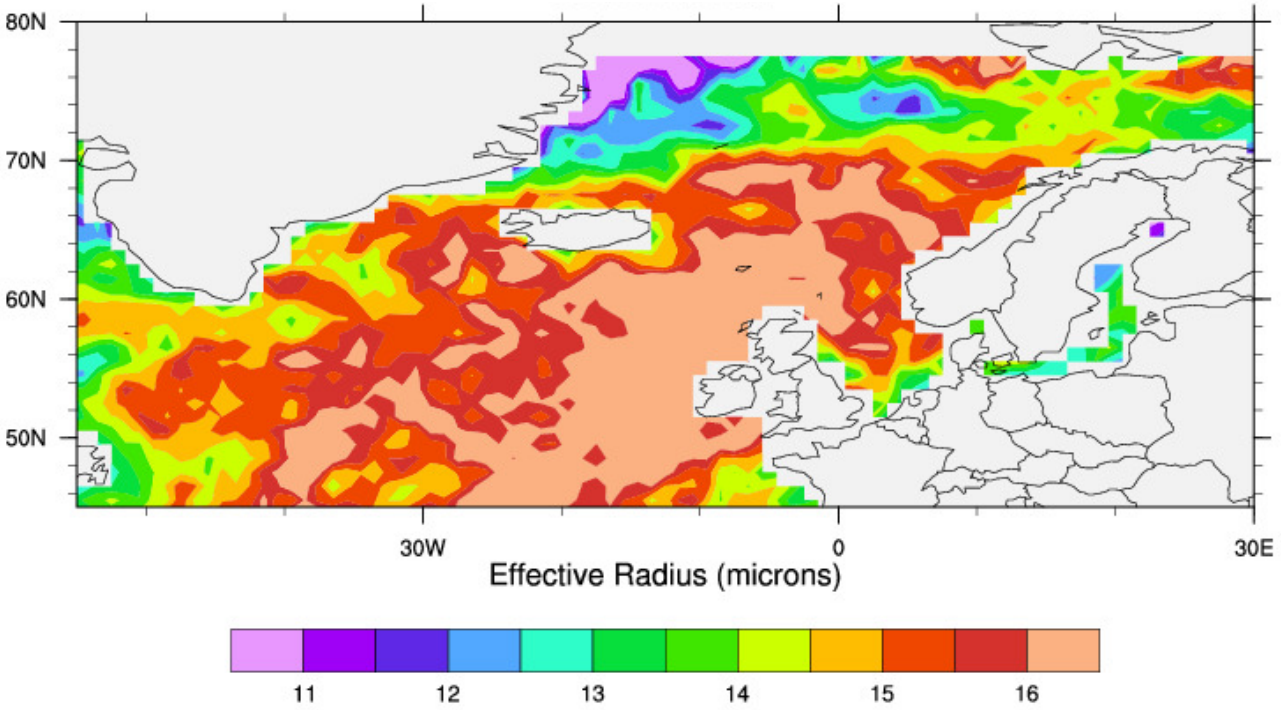


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2008

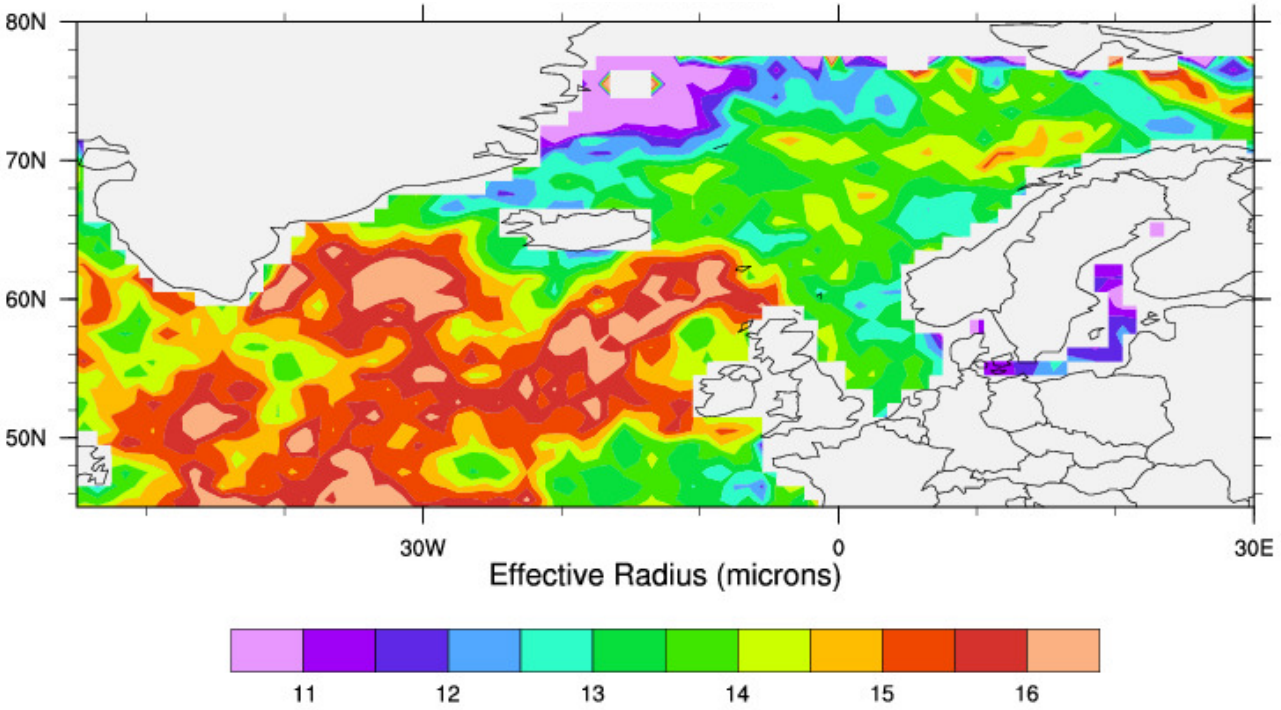


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2009

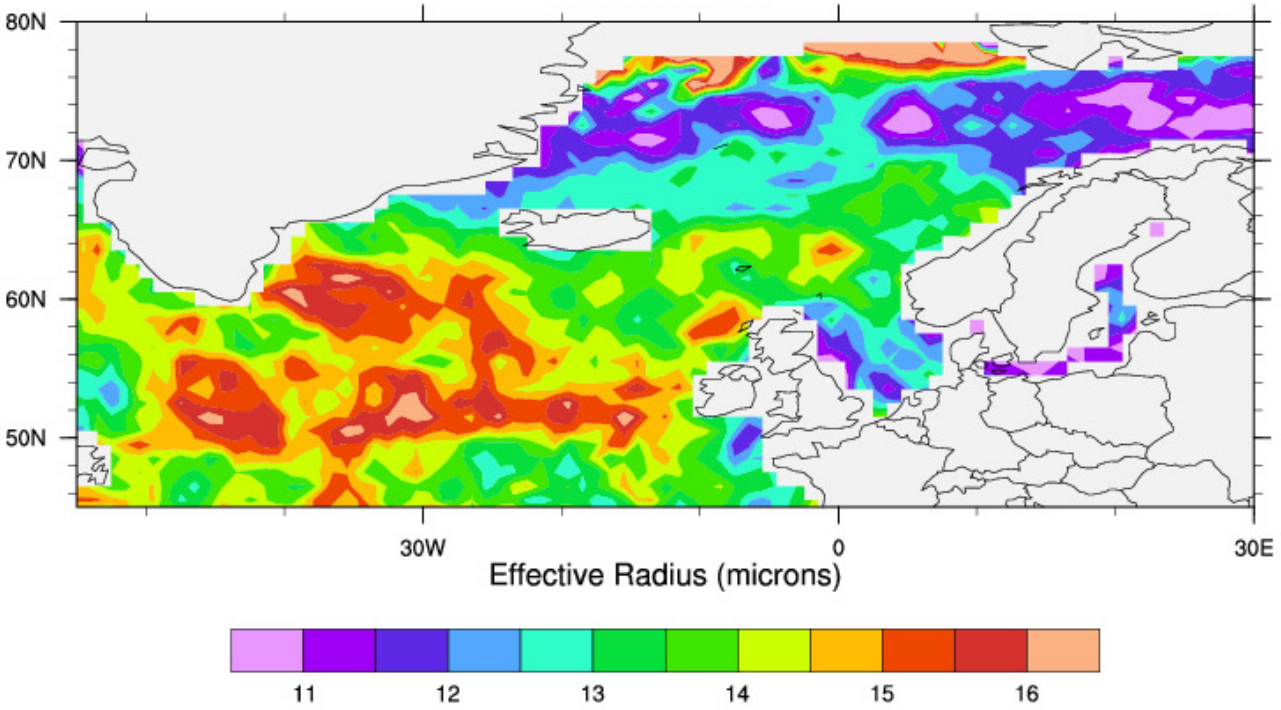


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2010

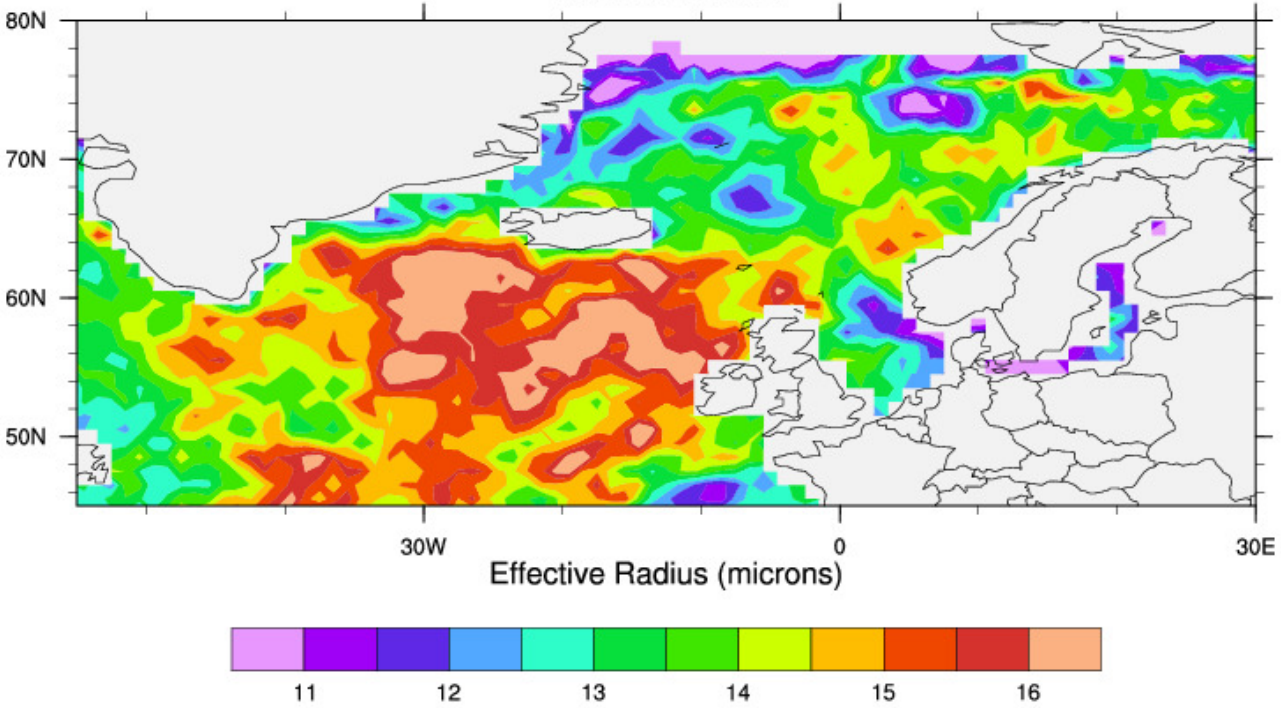


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2011

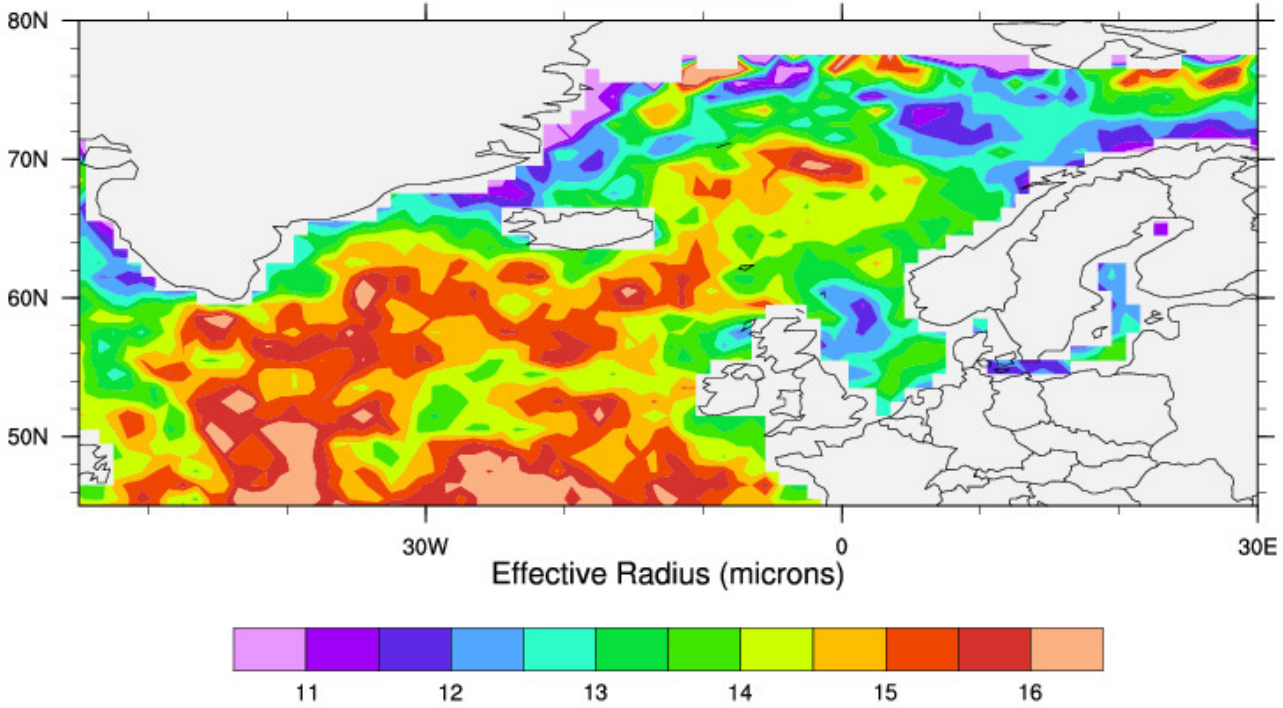


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2012

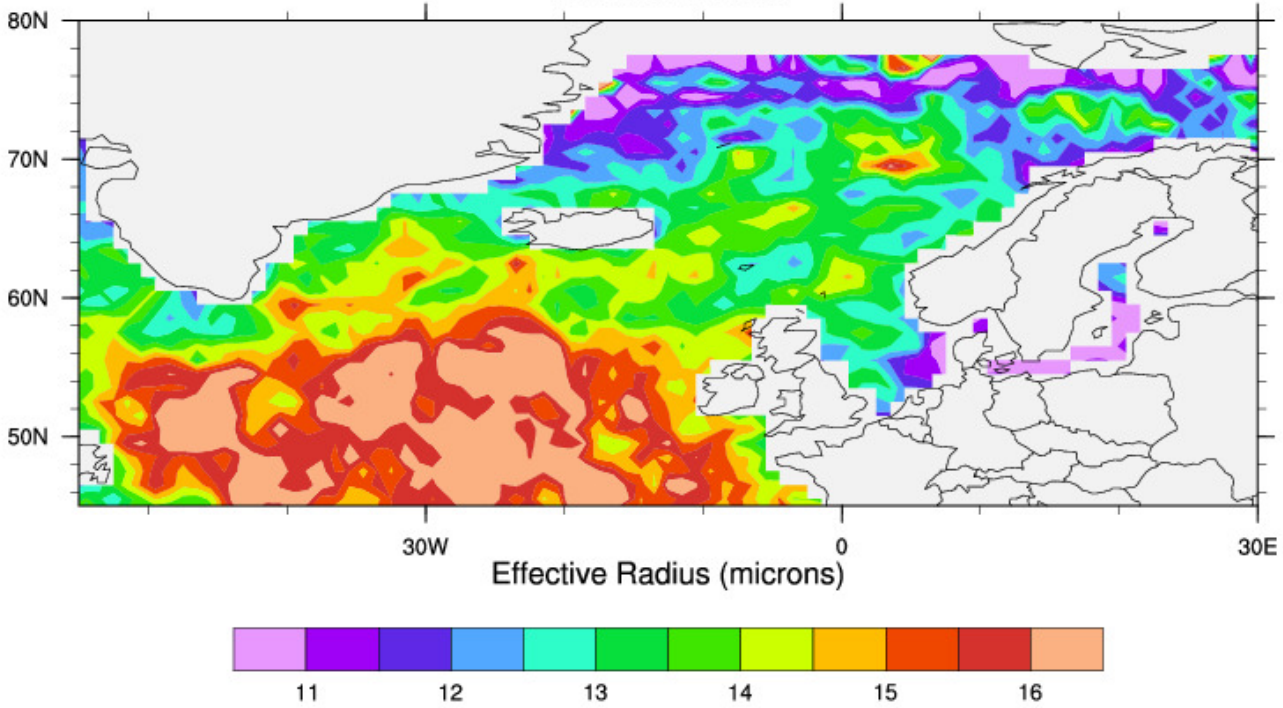


Cloud effective radius

MODIS / AQUA Collection 5.1

see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2013

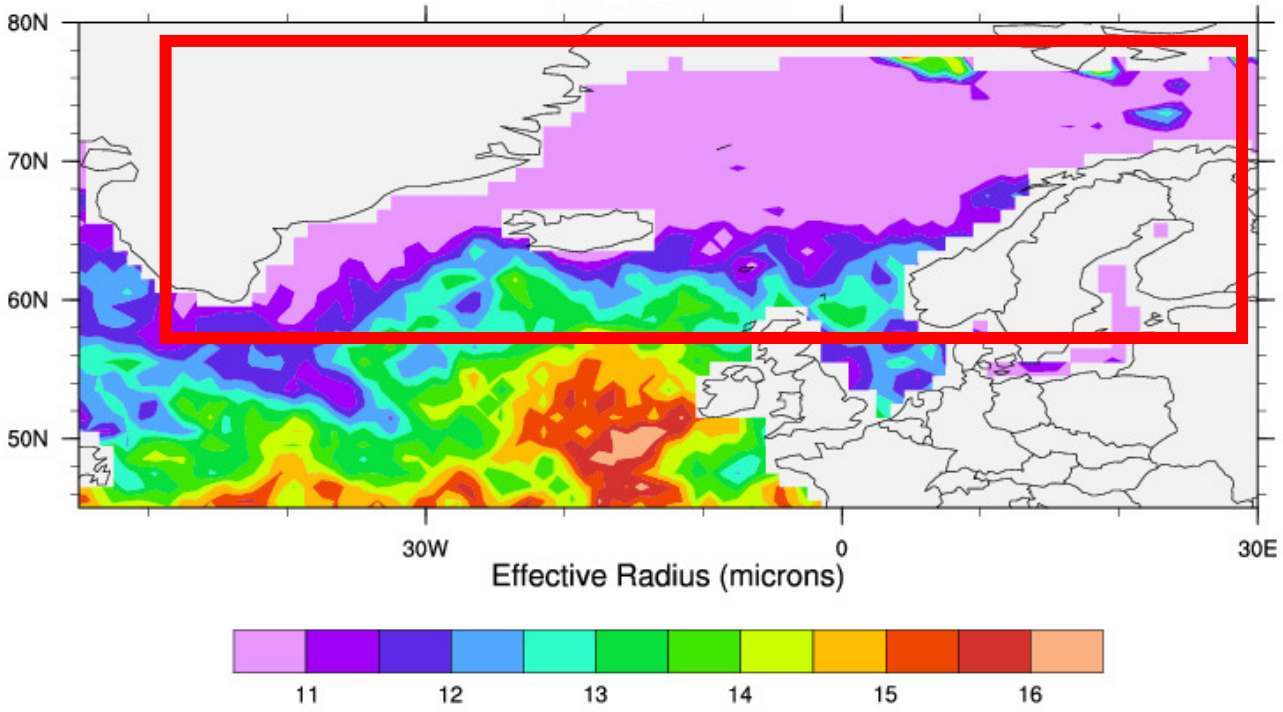


Cloud effective radius

MODIS / AQUA Collection 5.1

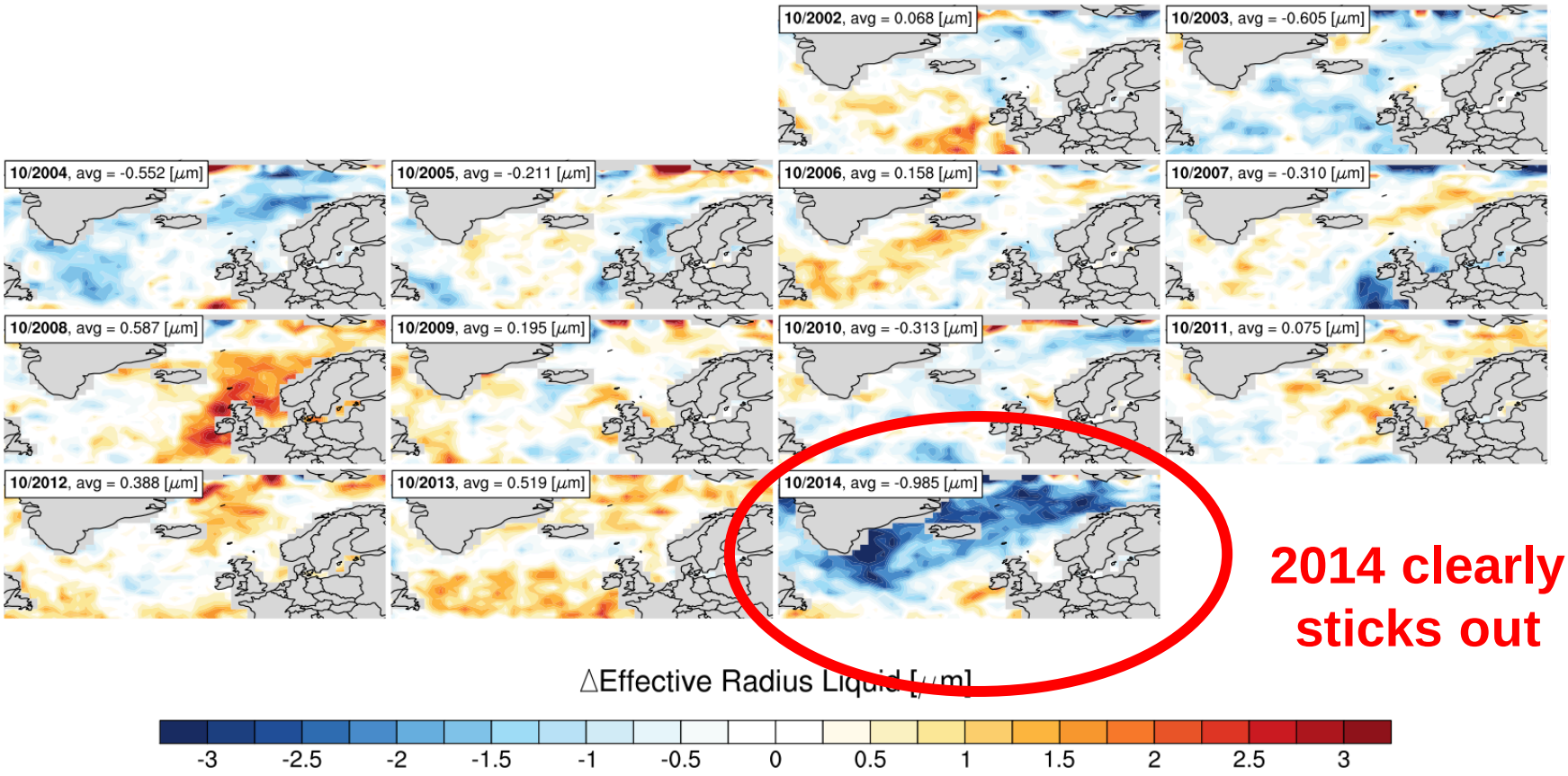
see *McCoy and Hartmann, GRL (2015)* for analysis with C6 (same results)

OCTOBER 2014



Something happened !

AQUA MODIS (OBS) – October anomalies r_{eff}

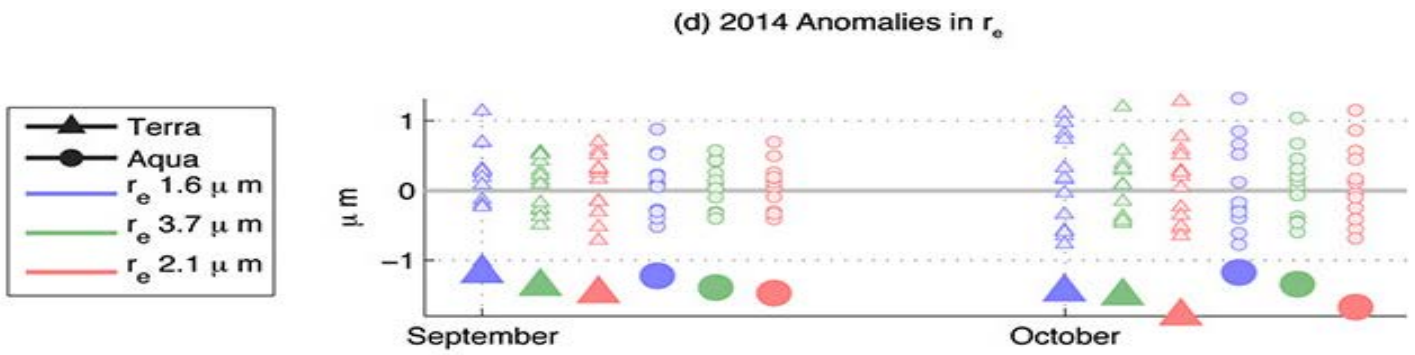


2014 clearly sticks out

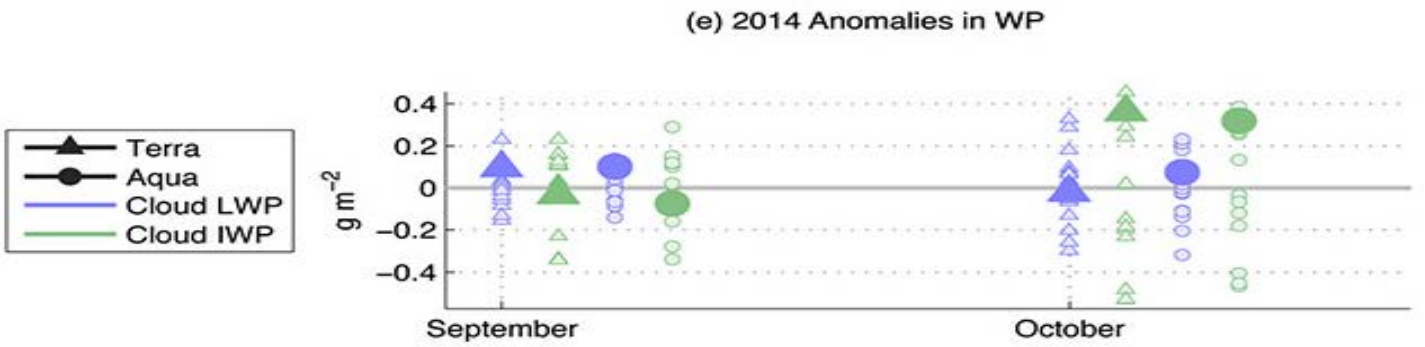
Similar results for September
(except there is some contribution from continental pollution to south of the region)

Summary of Cloud properties changes

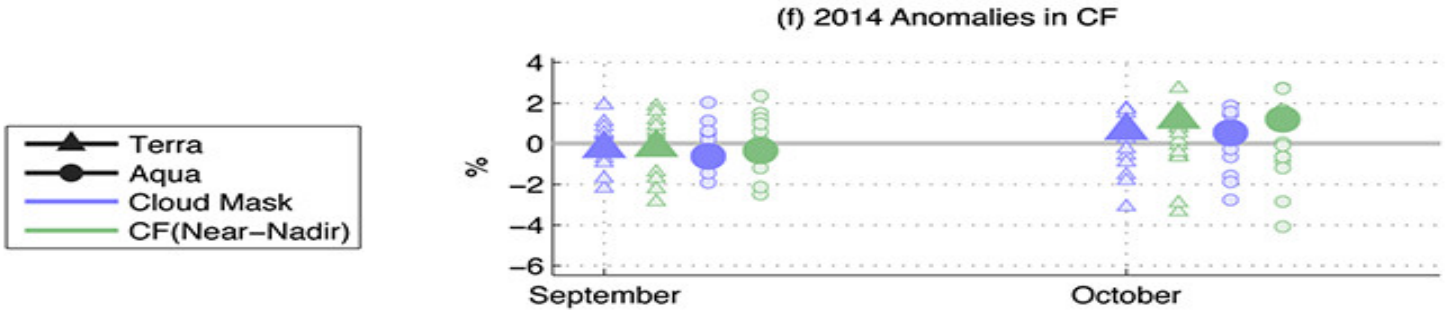
From McCoy and Hartmann, GRL (2015) using C6



Cloud effective radius

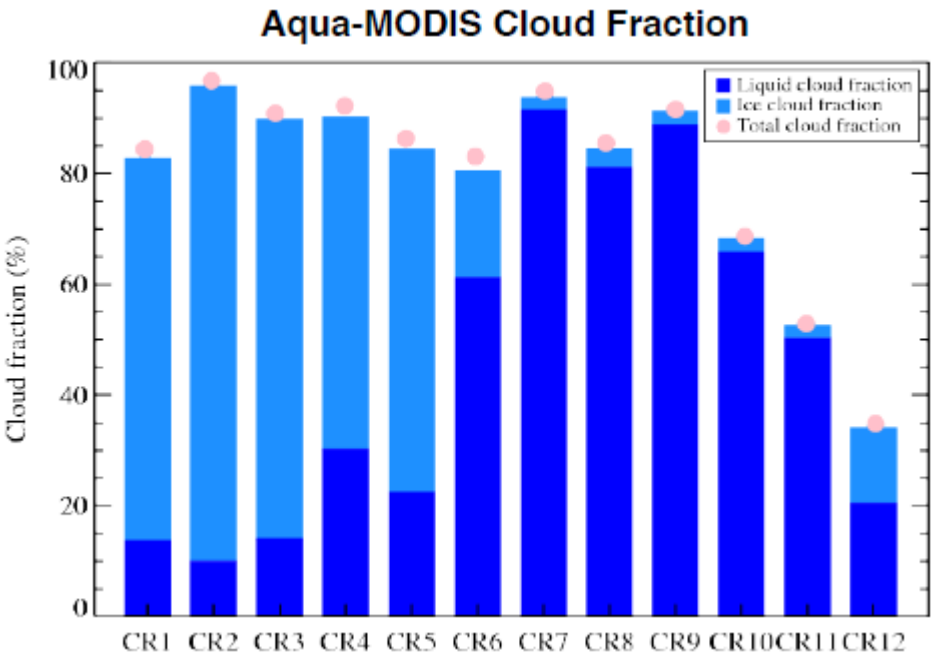


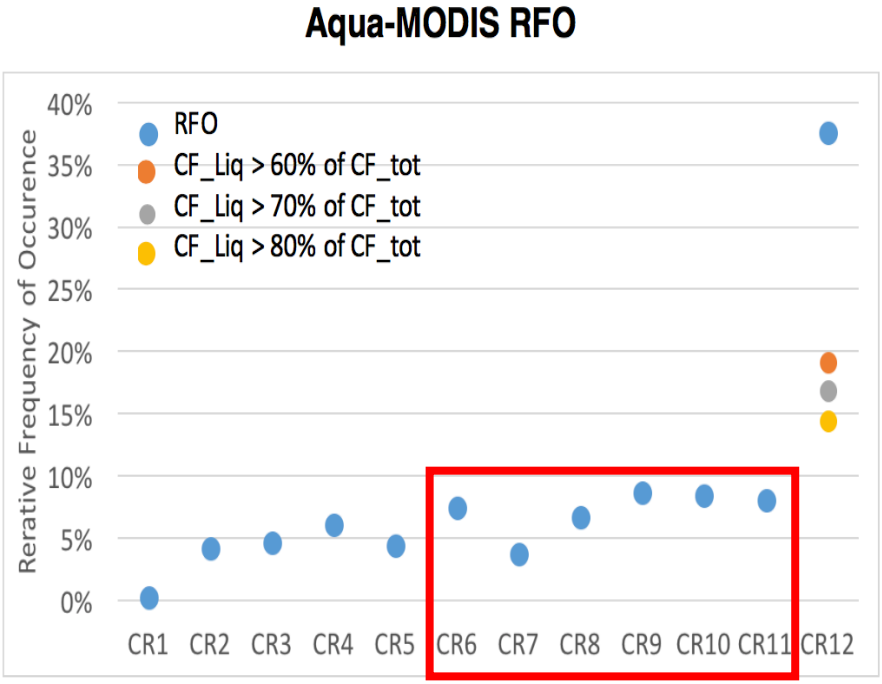
Water Path



Cloud Fraction

We are far from examining a meteorological special case – the area consists of a mix of all cloud types





Cloud Regime (CR) clustering analysis

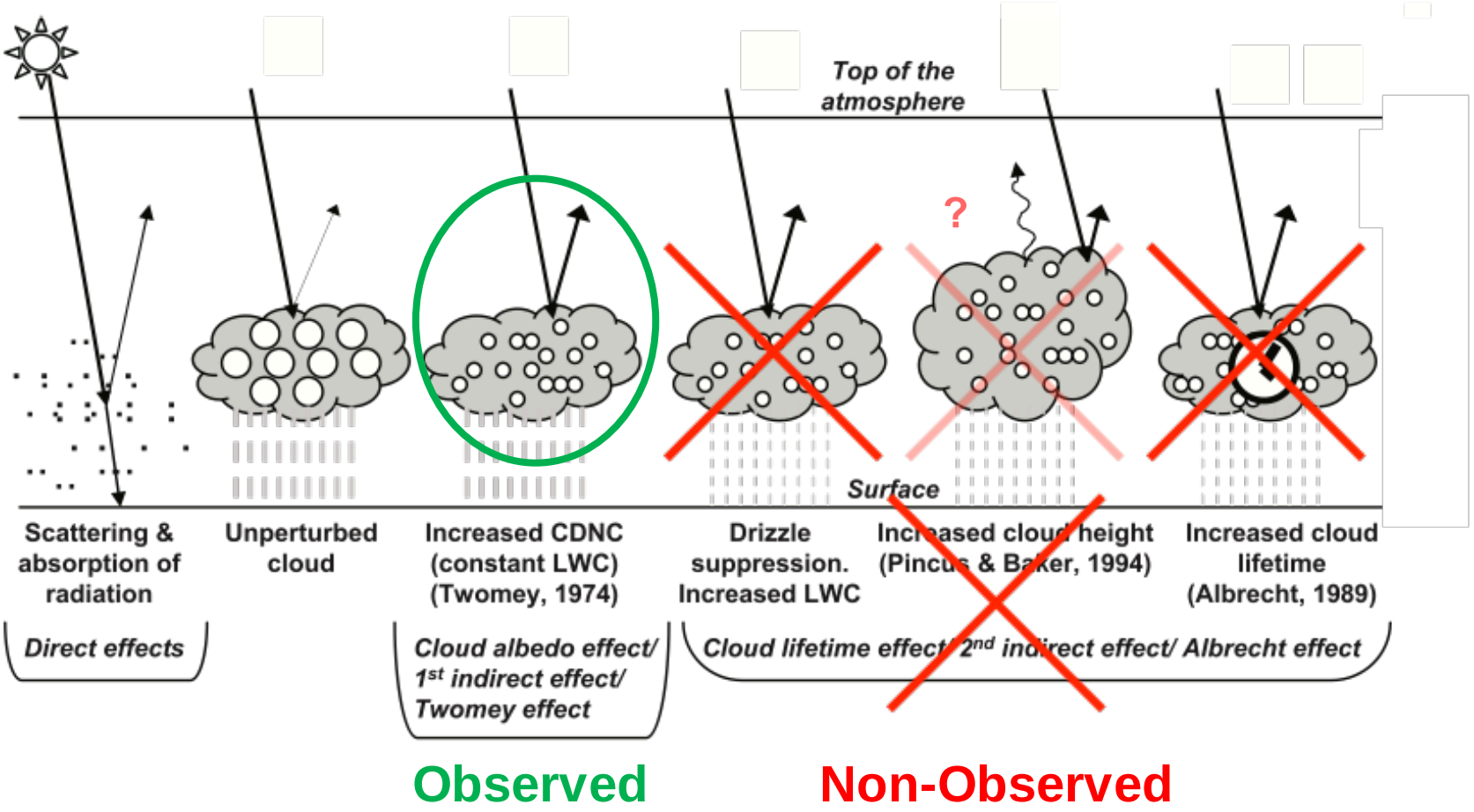
CR - Relative frequency of Occurrence (RFO)

In Summary

Emissions sustained for ~ 6 months

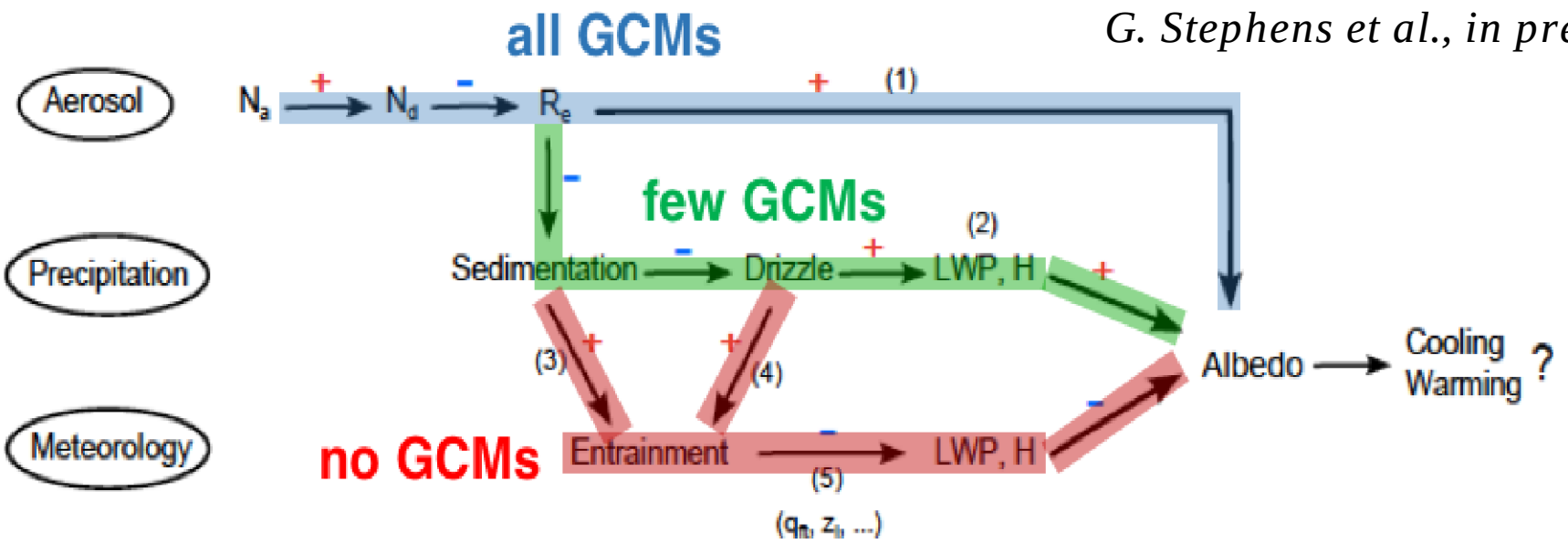
Up to 100 kt SO_2/day

Holuhraun and Aerosol-cloud interaction ?



Additional Material

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



- 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*

Cloud regime analysis – update to ISCCP: Lazarus Oreopolis et al. (2016)

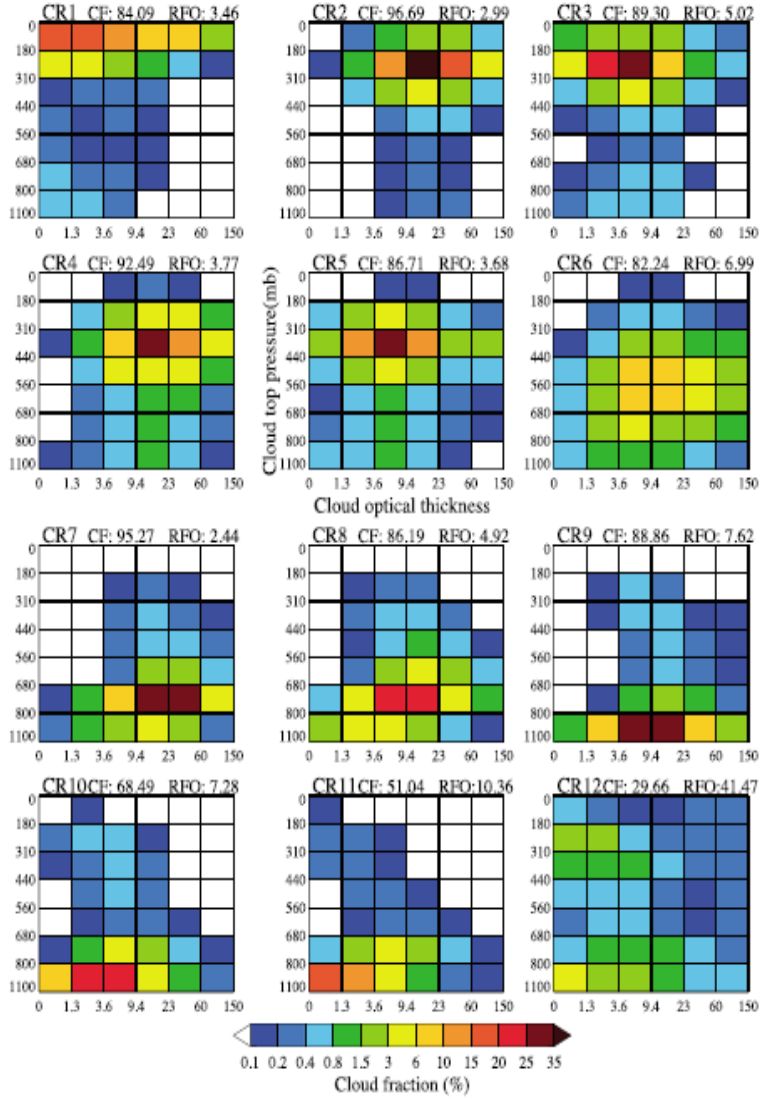


Figure 1. Centroids (mean histograms) of the 12 cloud regimes (CRs) derived from clustering analysis on 12 years of MODIS C6 Aqua-Terra p_c-τ joint daily histograms at a resolution of 1°. Additional information included in each panel is the mean global cloud fraction CF and relative frequency of occurrence (RFO) of each CR.

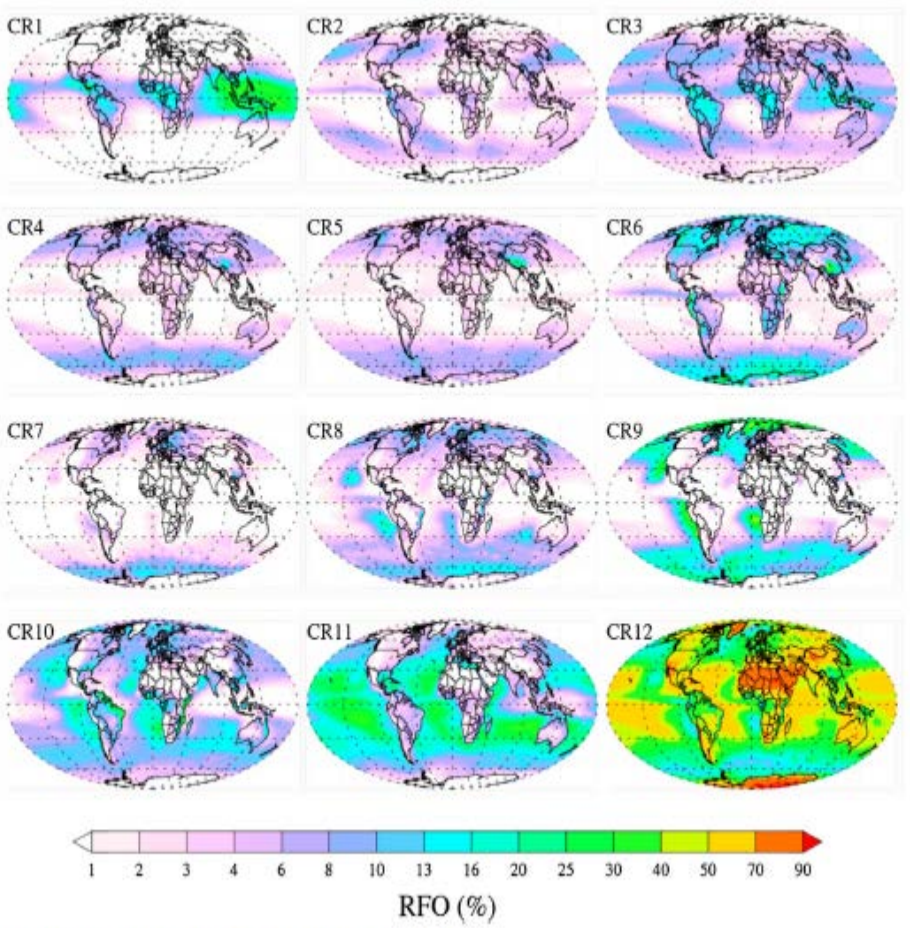


Figure 2. The geographical multiannual mean RFO of each of the 12 MODIS C6 CRs.

We are far from examining a meteorological special case – the area consists of a mix of all cloud types

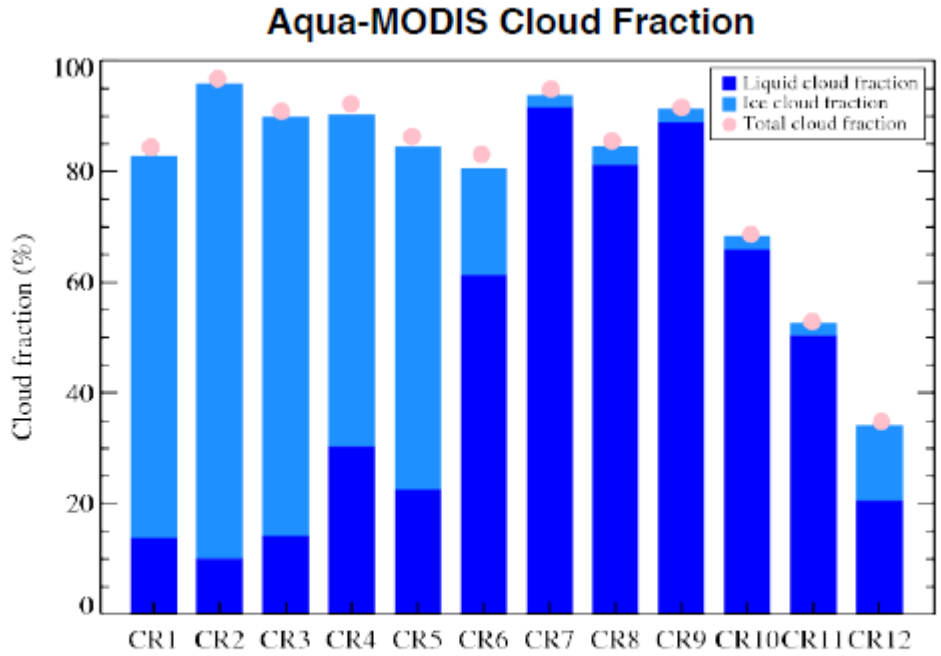


Figure S13.1. The cloud fraction from the different cloud regimes. *The Cloud Regime analysis is derived in the region 44°N-80°N, 60°W-30°E using MODIS AQUA data from 2002-2014 for the September-October months.*

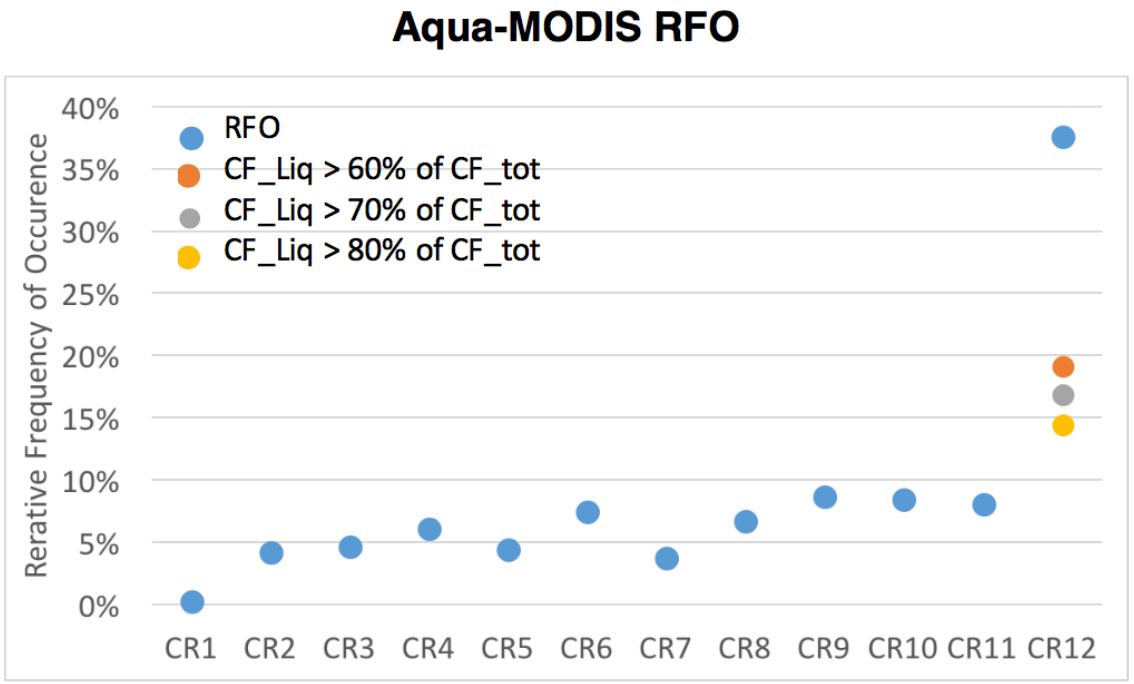
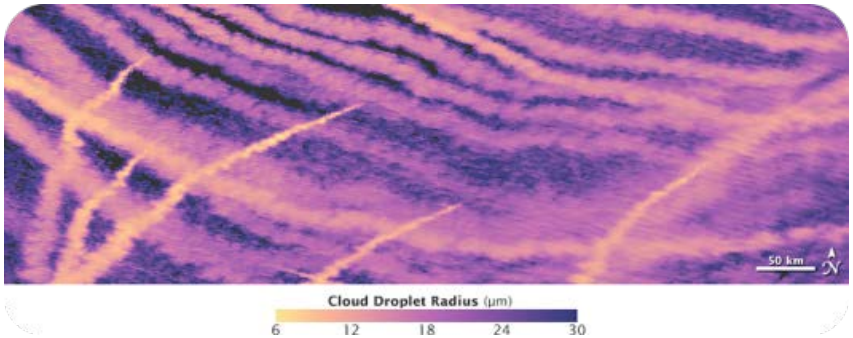


Figure S13.2. The relative frequency of occurrence of the different cloud regimes. *The relative frequency of occurrence (RFO) of the cloud regimes is derived in the region 44°N-80°N, 60°W-30°E using MODIS AQUA data from 2002-2014 for the September-October months.*

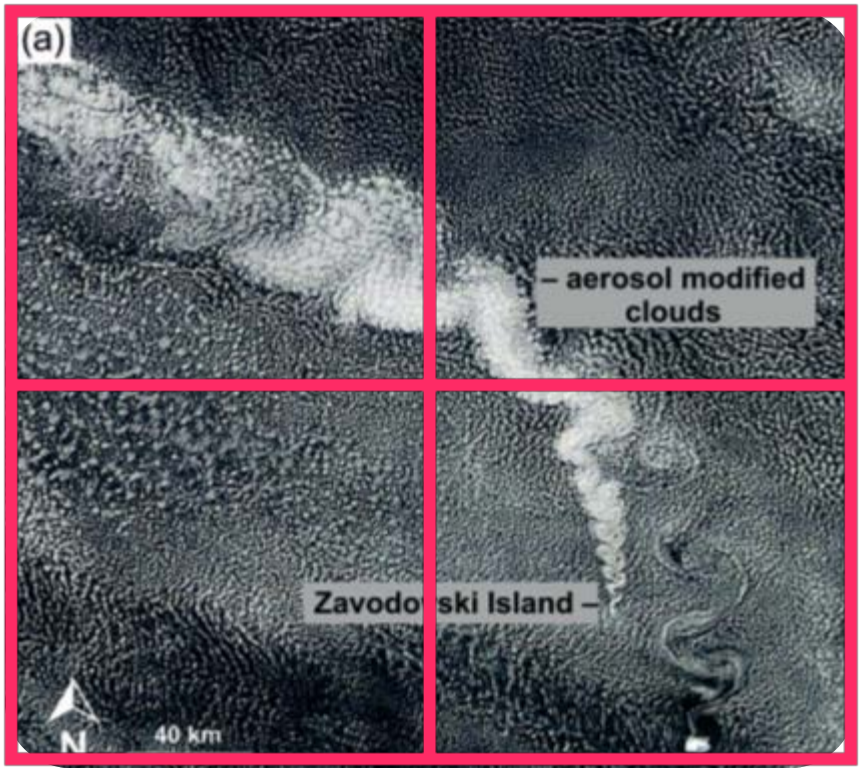
Some real world examples of Aerosol-Cloud Interactions (ACI)

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

What would be more useful for challenging 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).

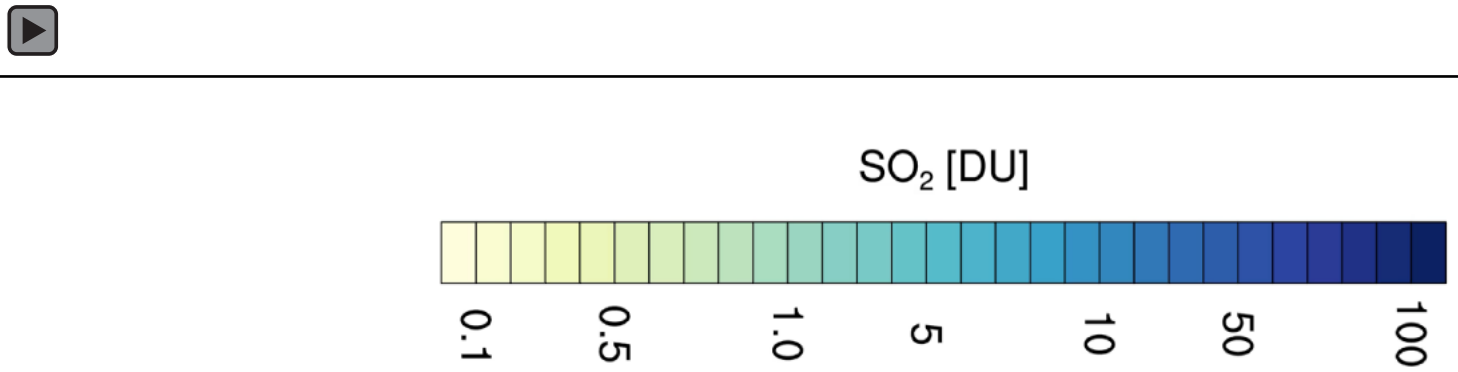
A massive **fissure** eruption at Holuhraun (Iceland) during 2014-15 .

- Up to 100 kt SO2/day
- Up to x10 emission rate from all of 28 European countries put together !!
- Sustained for ~ 6 months

If we can't detect/model the impact on clouds then the impact is probably not important …

Images courtesy of Anja Schmidt

IASI (OBS) – SO_2 time series



AQUA MODIS (OBS) – September anomalies r_{eff}

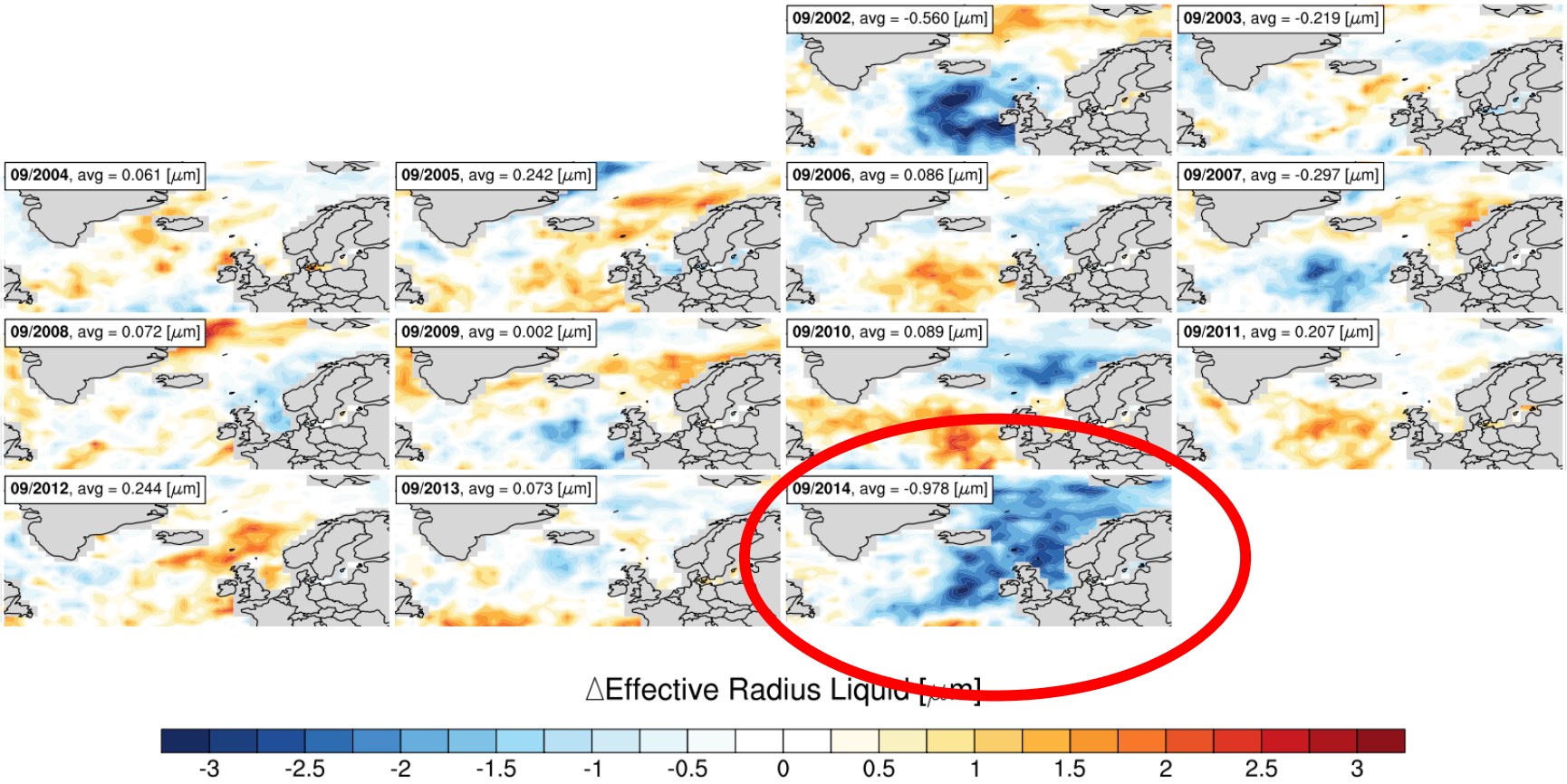
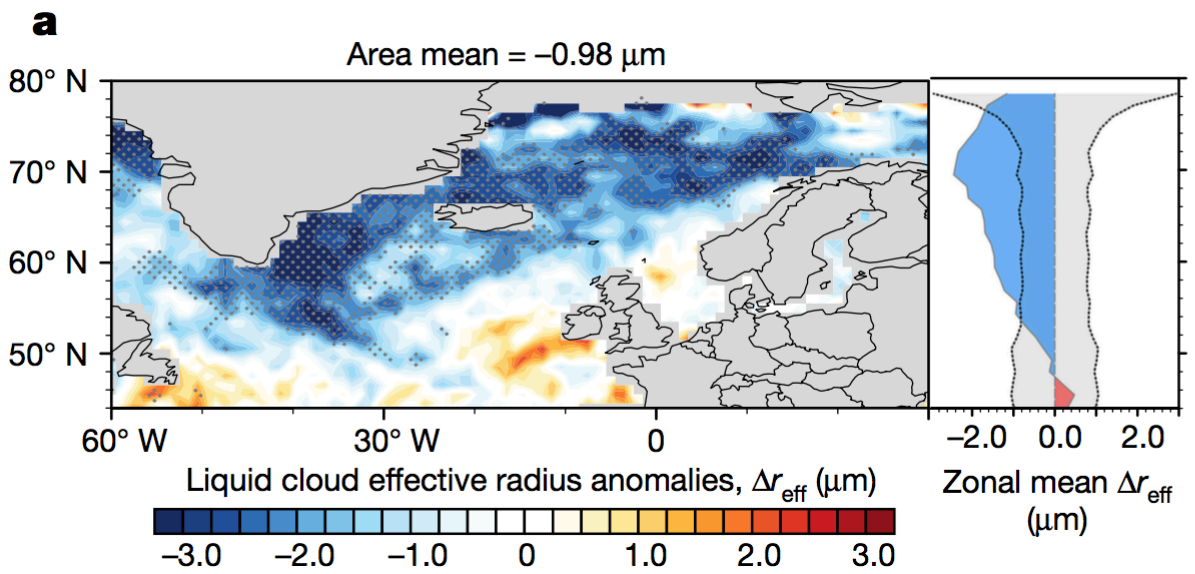
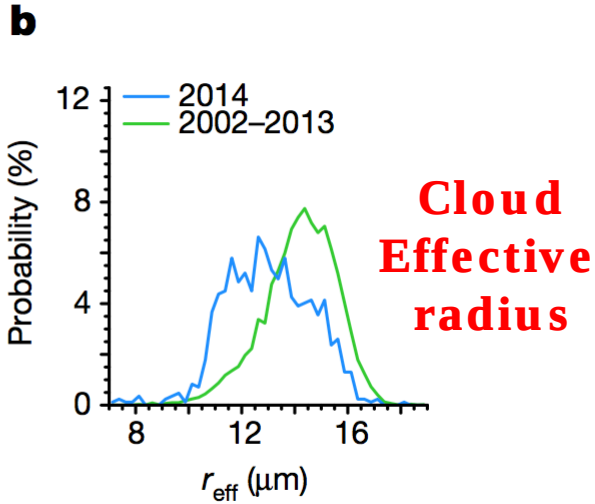


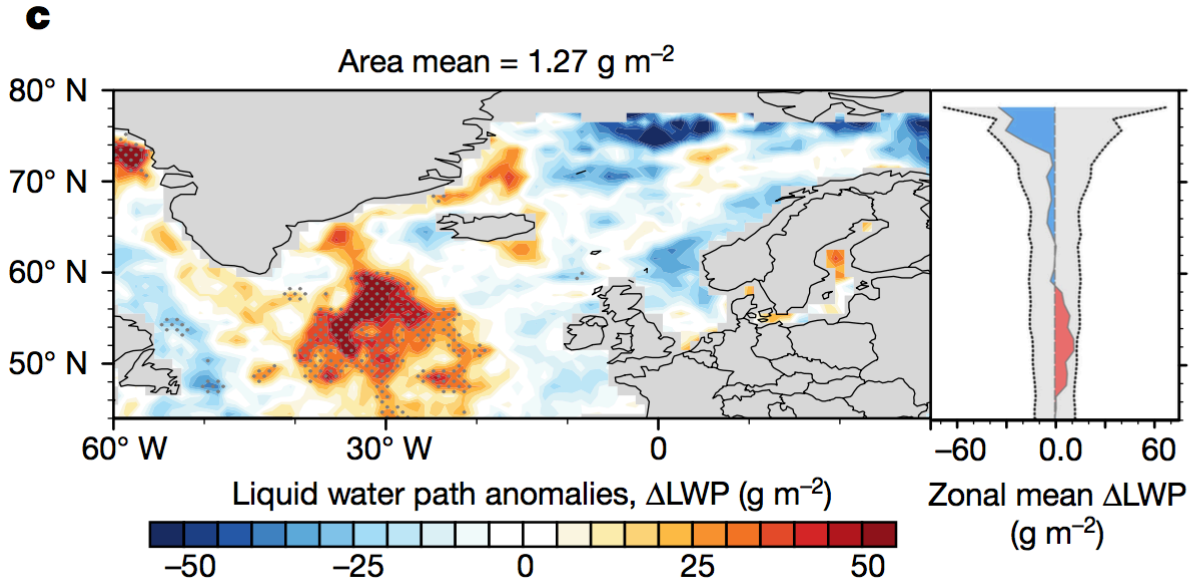
Figure S4.1. The effective radius anomalies during September months from MODIS. *Showing Δr_{eff} for each individual September month derived as the difference in annual monthly mean from the multi-year (2002-2013) September mean. In each case 'avg' represents the average anomalies.*

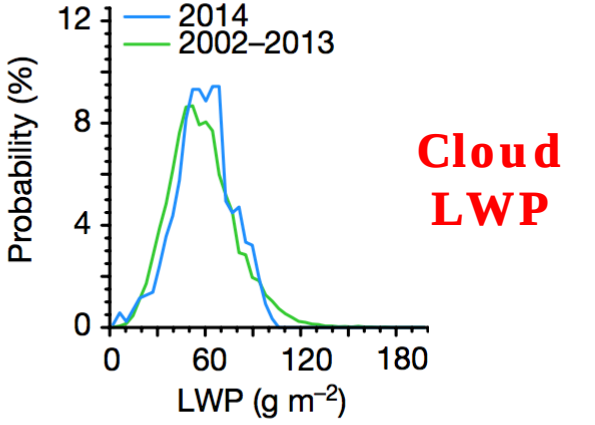
AQUA MODIS (OBS) – October 2014





Cloud Effective radius





Cloud LWP

Grey in zonal mean = 1 standard deviation.

Similar results for September (except there is some contribution from continental pollution to south of the region)

More detail on precipitation

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

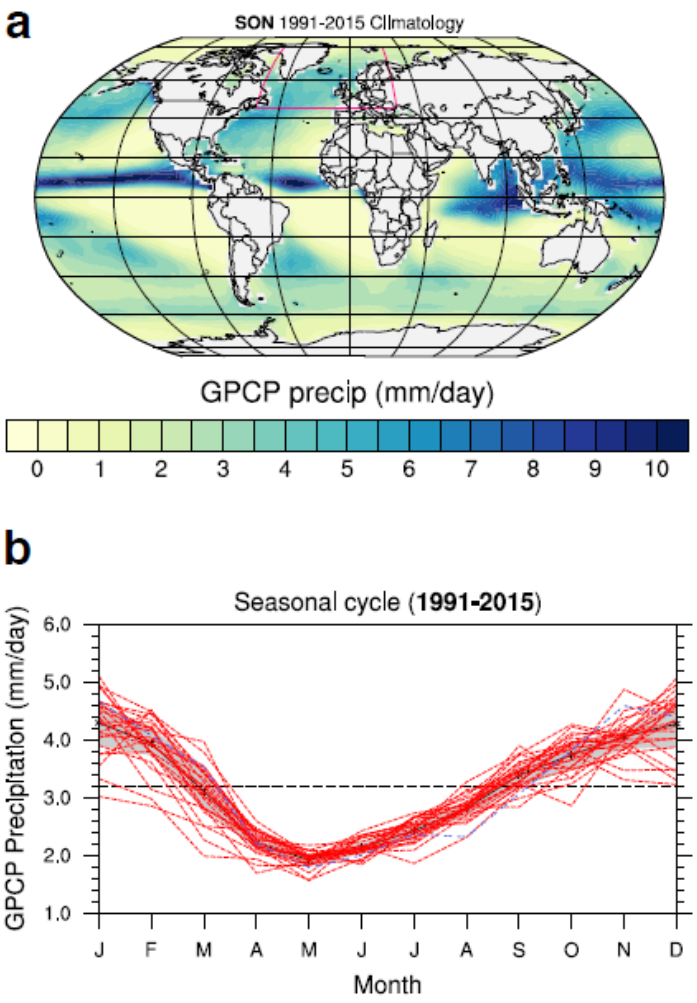
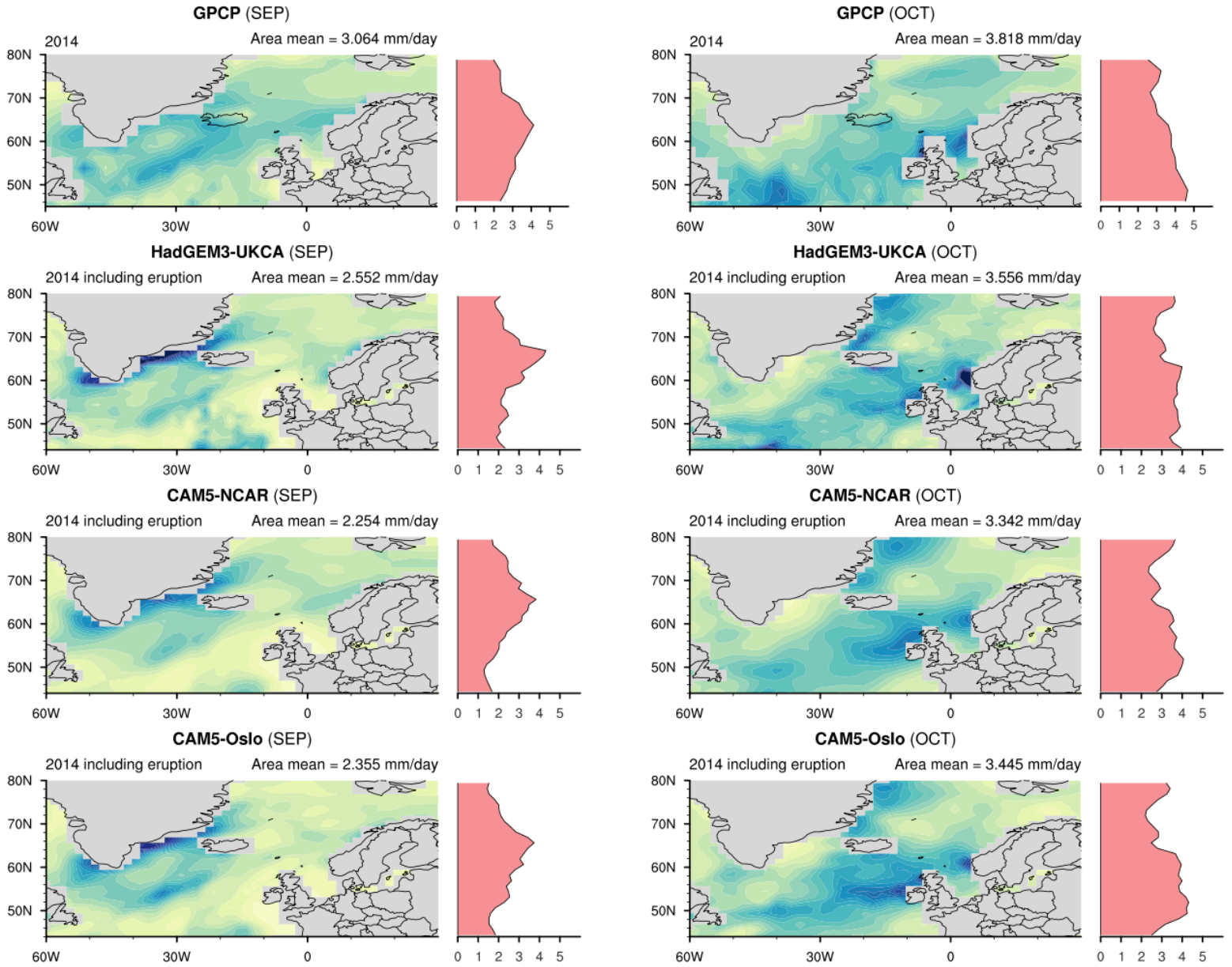


Figure S10.1. The climatology of surface precipitation from GPCP. *The precipitation rate (in mm/day) shown as a) September-October-November (SON) seasonal average for the 1991-2015 period, and b) the corresponding seasonal cycle derived for the region in the vicinity of Holuhraun (45°N-80°N; 60°E-30°W). 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