Strong constraints on aerosol-cloud interactions from volcanic eruptions


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-Veitivötn fissure eruption in Iceland
(GRL, 2015)

Daniel McCoy and Dennis Hartmann

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

ii) Today – Using the 2014-15 volcanic eruption at Holuhraun to investigate Aerosol-Cloud Interactions
Some real world examples of Aerosol-Cloud Interactions (ACI)

Ship Tracks – The poster boy of ACI

Schmidt et al., 2012 (ACP)

Small scale emissions are of limited value

Typical GCM grid box

- aerosol modified clouds

Zavodovski Island –
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).
What observations from Holuhraun suggest about aerosol-cloud interaction climate impacts.

Scattering & absorption of radiation

Unperturbed cloud

Increased CDNC (constant LWC) (Twomey, 1974)

Drizzle suppression. Increased LWC

Increased cloud height (Pincus & Baker, 1994)

Increased cloud lifetime (Albrecht, 1989)

Direct effects

Cloud albedo effect/ 1st indirect effect/ Twomey effect

Cloud lifetime effect/ 2nd indirect effect/ Albrecht effect

Observed

Non-Observed
Is it useful for constraining ACI?

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

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S. Ghan et al., PNAS 2016
Some GCMs response to Holuhraun emission ...

- HadGEM3-UKCA
  - Area mean $= -0.67 \, \mu m$

- HadGEM3-CLASSIC
  - Area mean $= -2.37 \, \mu m$

- NCAR-CAM5.3
  - Area mean $= -1.35 \, \mu m$

- CAM5-Oslo
  - Area mean $= -0.82 \, \mu m$

- MODIS
  - Area mean $= -0.98 \, \mu m$

Liquid cloud effective radius anomalies, $\Delta r_{eff} (\mu m)$

Liquid water path anomalies, $\Delta LWP \, (g \, m^{-2})$
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 $\text{SO}_2$ 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
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.* Auxiliary simulation Intercomparison of the Kilauea impact on liquid clouds.

4. **Hol-AE1:** *This experiment is optional.* Set-up soil forcing for Pre-Industrial conditions.

5. **Hol-AE2:** *This experiment is optional.* Set-up soil forcing for a different location.

6. **Hol-AE3:** *This experiment is optional.* Set-up soil forcing for a different timing (summer in 2014).

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
To summarise

1. We know that GCMs provide a wide range of ACI estimates (e.g. Lohmann et al., 2010 Ghan et al., 2016)

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

3. Let's 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
\[
\frac{d \ln \overline{R}}{d \ln \overline{E}} = \left[ \frac{d \ln \overline{C}}{d \ln \overline{N}_d} + \frac{d \ln \overline{R}_c}{d \ln \overline{\tau}} \left( \frac{d \ln \overline{L}}{d \ln \overline{N}_d} - \frac{d \ln \overline{r}_e}{d \ln \overline{N}_d} \right) \right] \frac{d \ln \overline{N}_d}{d \ln \overline{CCN}} \frac{d \ln \overline{CCN}}{d \ln \overline{E}}
\]
Some thoughts:
Could we improve the representation of ACI in GCMs?

- Is the story complete?
- Do we need 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\(^{-2}\)
(b) Global: -0.61 Wm\(^{-2}\)  Regional: -8.80 Wm\(^{-2}\)
(c) Global: -0.49 Wm\(^{-2}\)  Regional: -7.93 Wm\(^{-2}\)
(d) Global: -0.32 Wm\(^{-2}\)  Regional: -2.26 Wm\(^{-2}\)
'ERF'
SEP-OCT

ERF - Full Sky

Hol - NoHol Global mean = -0.207 W.m\(^{-2}\)

\[ \Delta \text{Radiation changes at ToA for Sep/Oct 2014 [W.m}^{-2}\] \]
Meridional average between [45N, 75N]

- ERF
  - SEP-OCT

**Graph:**
- Clear Sky
- All Sky

**Axes:**
- ERF [W/m²]
- Longitude [°]

**Legend:**
- Blue line: Clear Sky
- Red line: All Sky
‘ERF’
Jun-Jul

ERF - Full Sky

Hol - NoHol Global mean = -0.609 W.m$^{-2}$

$\Delta$Radiation changes at ToA for Sep/Oct 2014 [W.m$^{-2}$]
‘ERF’
Jun-Jul

Meridional average between [45N,75N]
Turning off dependence on CDNC in Autoconversion
Grey in zonal mean = 1 standard deviation.
Similar results for September (except there is some contribution from continental pollution to south of the region)
Cloud
Grey = 1 stdev. Similar results for September (except there is some contribution from continental pollution to south of the region)

HadGEM3-MODE (Model) – October 2014

a
Area mean = -0.676 μm

b
Proportion (%)

2014 (excl.volcano)
2014 (incl.volcano)
2002–2013

Cloud Effective radius

Co
Area mean = -0.745 g m⁻²

Cloud LWP

Grey = 1 stdev. Similar results for September (except there is some contribution from continental pollution to south of the region)
IASI (OBS) – SO$_2$ time series

(2014-09-01 AM)
Assessment of emission rates

(a) Graph showing emission rates over time.

(b) Graph showing SO$_2$ total mass over time.

(c) Graph showing SO$_2$ columnar density over time.

(d) Graph showing SO$_2$ columnar density by day.
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.
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