

Using Volcanic Emissions to Estimate Aerosol-Cloud Interactions



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Thanks Jón Egill

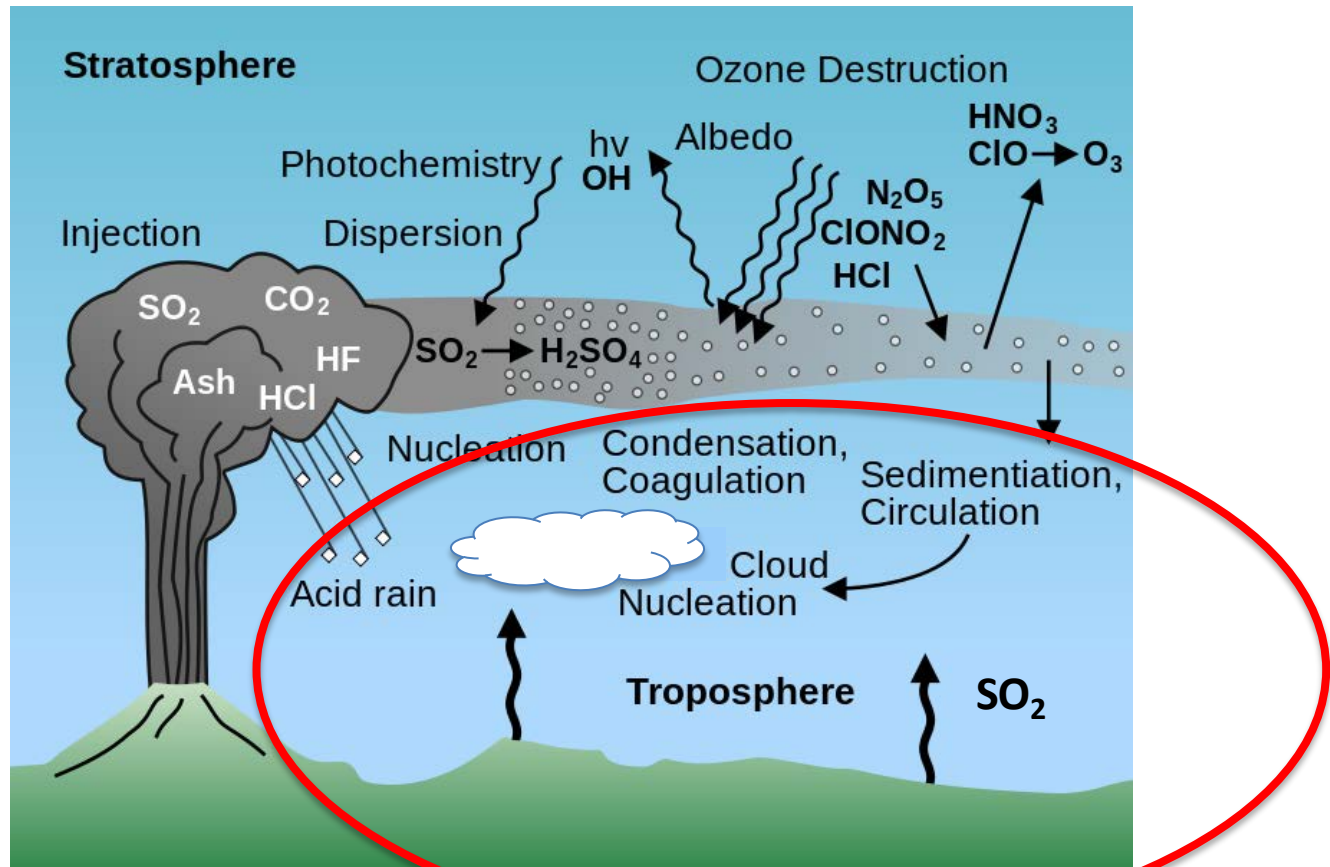


Outline

- What do volcanoes do to climate/air quality?
- Examples
 - Bárðarbunga (Holurahun, Iceland) 2014
 - Kilauea (Hawaii)
- Aerosol-Cloud Interactions in volcanic plumes
 - Natural laboratory for anthropogenic ACI
 - Observations and simulations
- Initial Model Intercomparisons
- Proposed field project



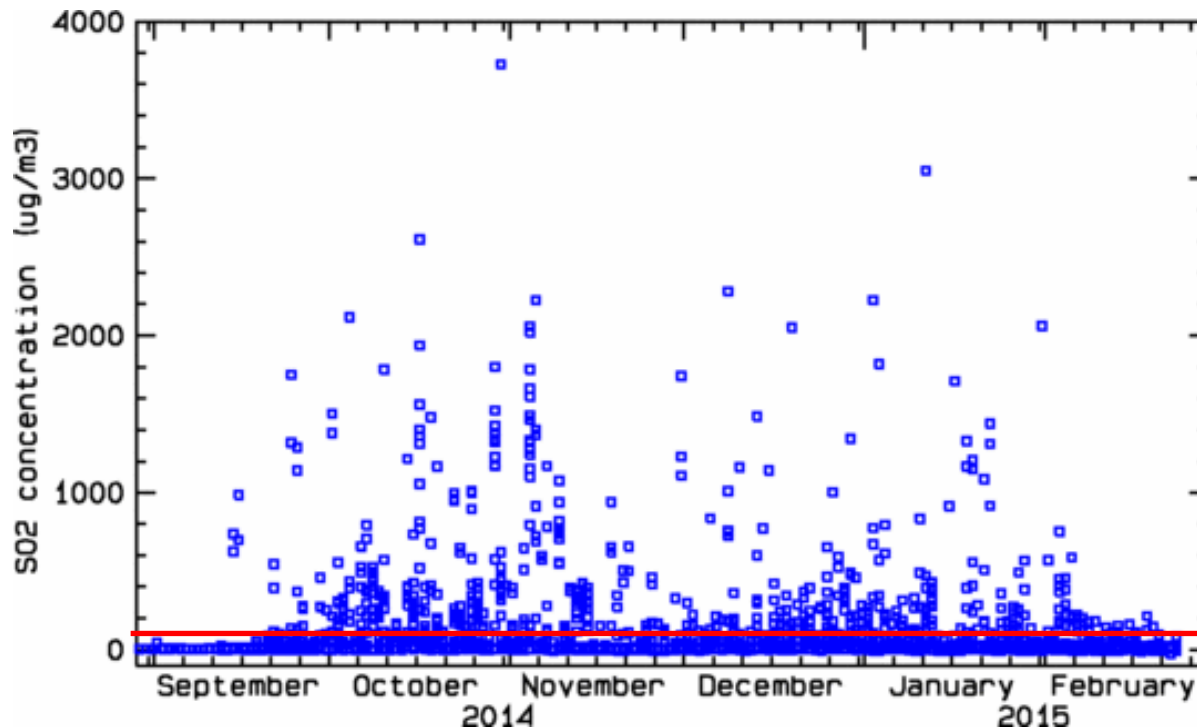
Volcanoes and Climate



- H₂O, CO₂, SO₂, ash, HCl, HF, ...
- Surface cooling; stratospheric heating; dynamical responses
- Direct forcing and dynamical responses well studied
- Effects on clouds not well studied (emerging)

Local SO₂ effects: Bárðarbunga 2014

- Remote Region of Iceland
- 6 months (Aug 2014-Feb 2015)
- Lots of SO₂ (>European emissions)
- Laki (1783-4) was even bigger....

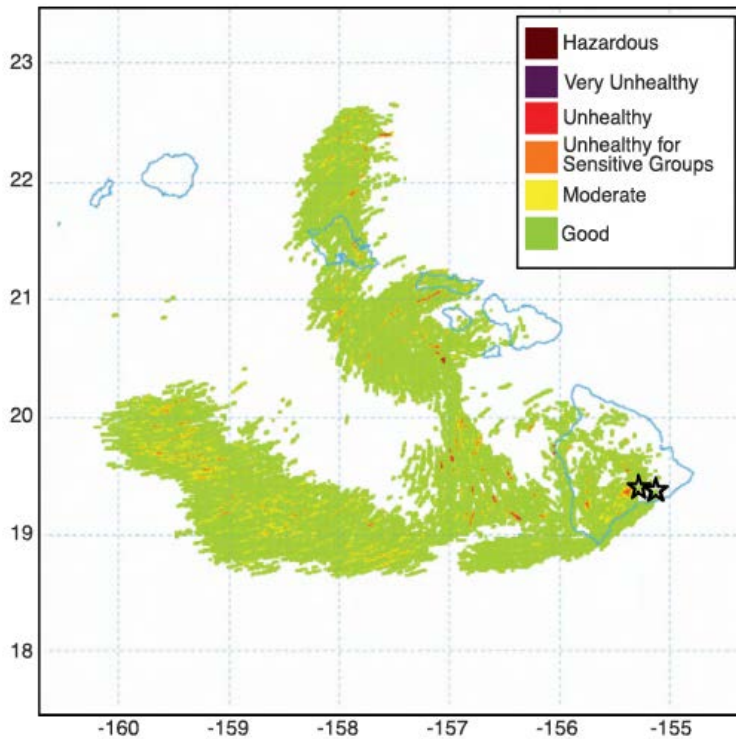


SO₂
measurements
near (several
miles from) the
eruption

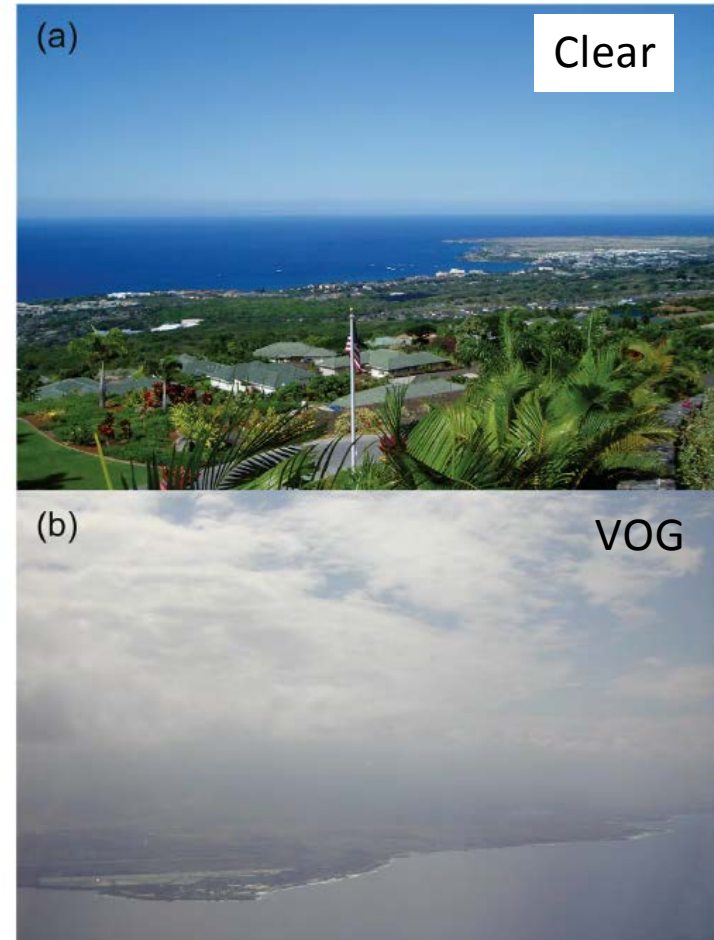
EPA 1-hr SO₂ standard
= 75 µg m⁻³

Local Air Quality Effects: Volcanic Acid 'Fog' (VOG)

Forecast Sulfate Aerosol (VOG Model)

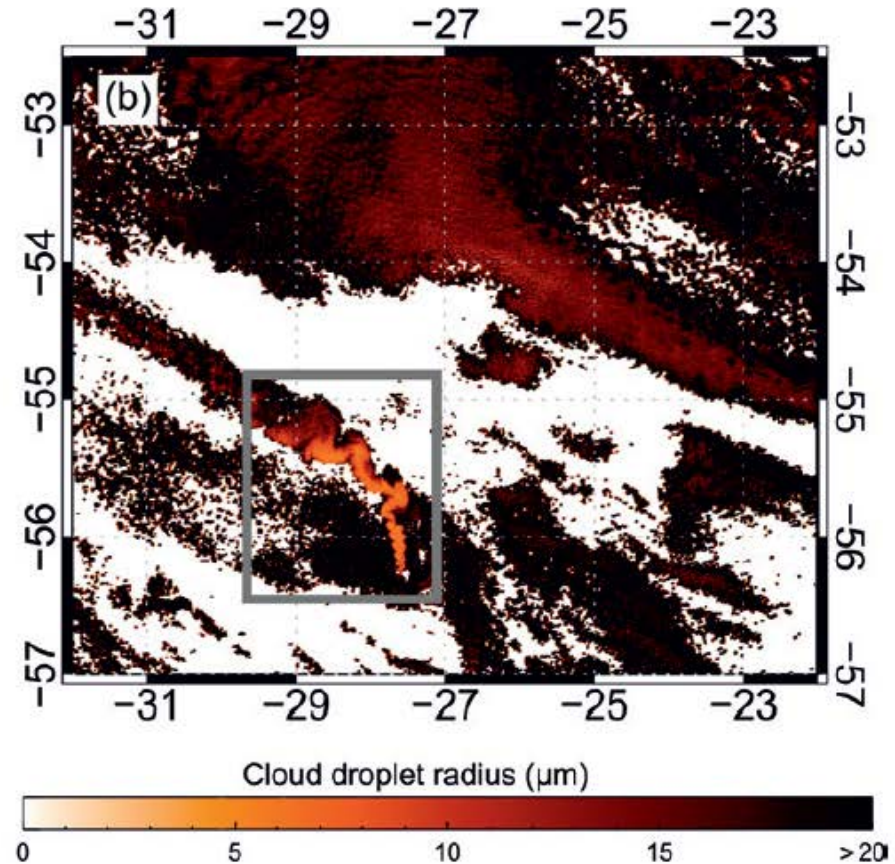
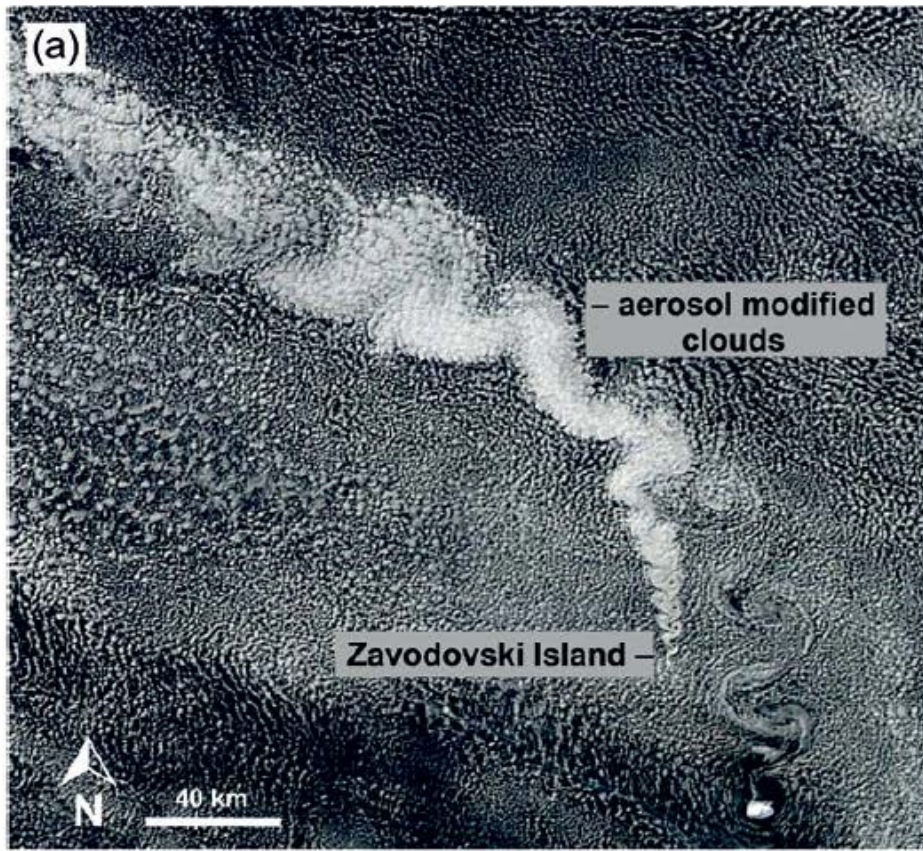


Businger et al, 2015, BAMS



Aerosol-Cloud Interactions

‘Volcano Tracks’: Emissions into a stratus deck



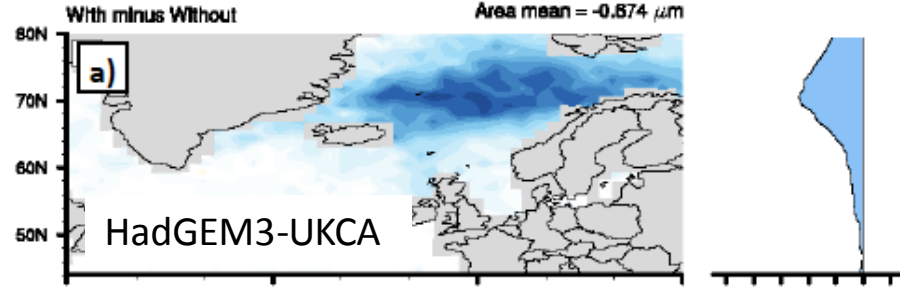
S. Sandwich Islands (Between S. America & Antarctica)

Schmidt et al 2012

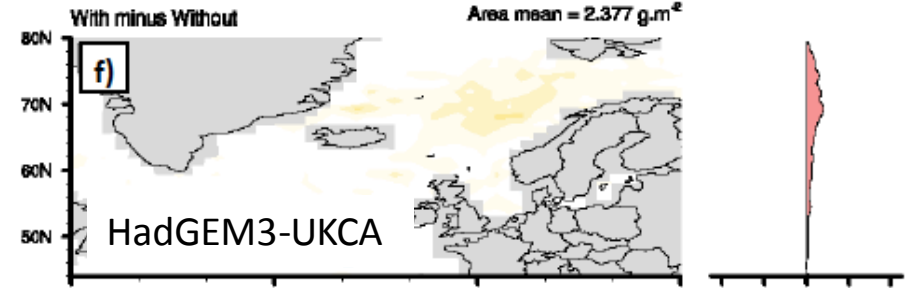
Simulated Bárðarbunga Effects on Clouds

Haywood (Pers. Comm. 2016)

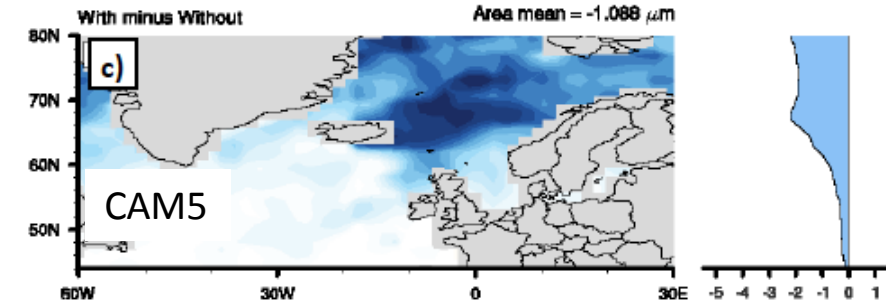
HadGEM3-UKCA - September



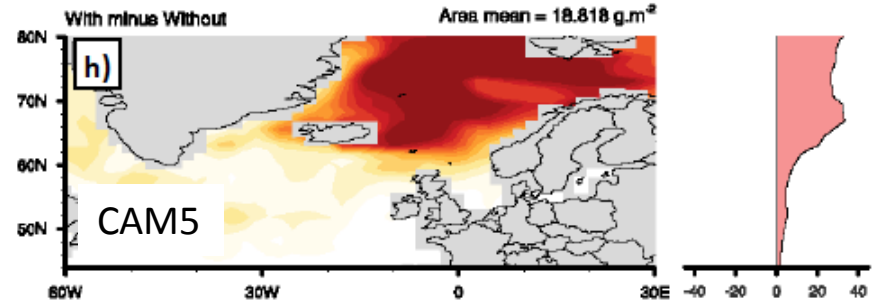
HadGEM3-UKCA - September



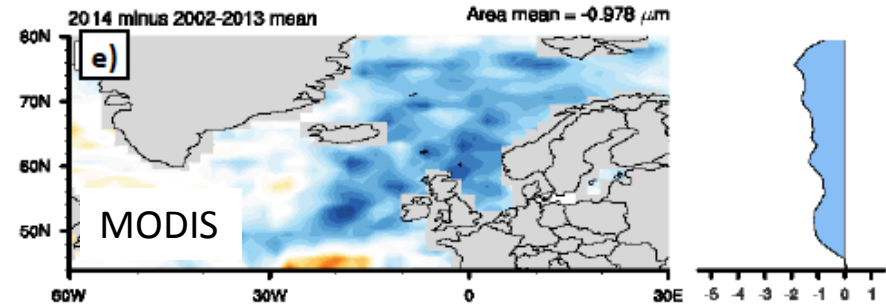
CAM5.4 - September



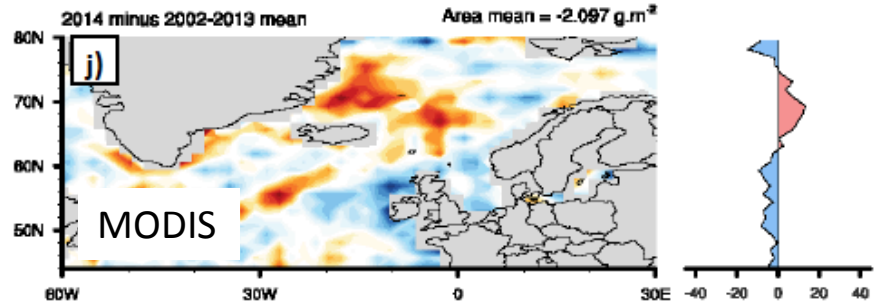
CAM5.4 - September



MODIS AQUA 5.1 - September



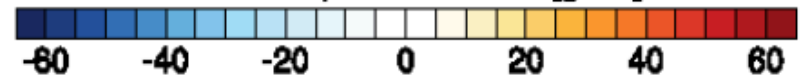
MODIS AQUA 5.1 - September



Δ Cloud Effective Radius (Liquid) [μm]



Δ Cloud Liquid Water Path [g.m^{-2}]

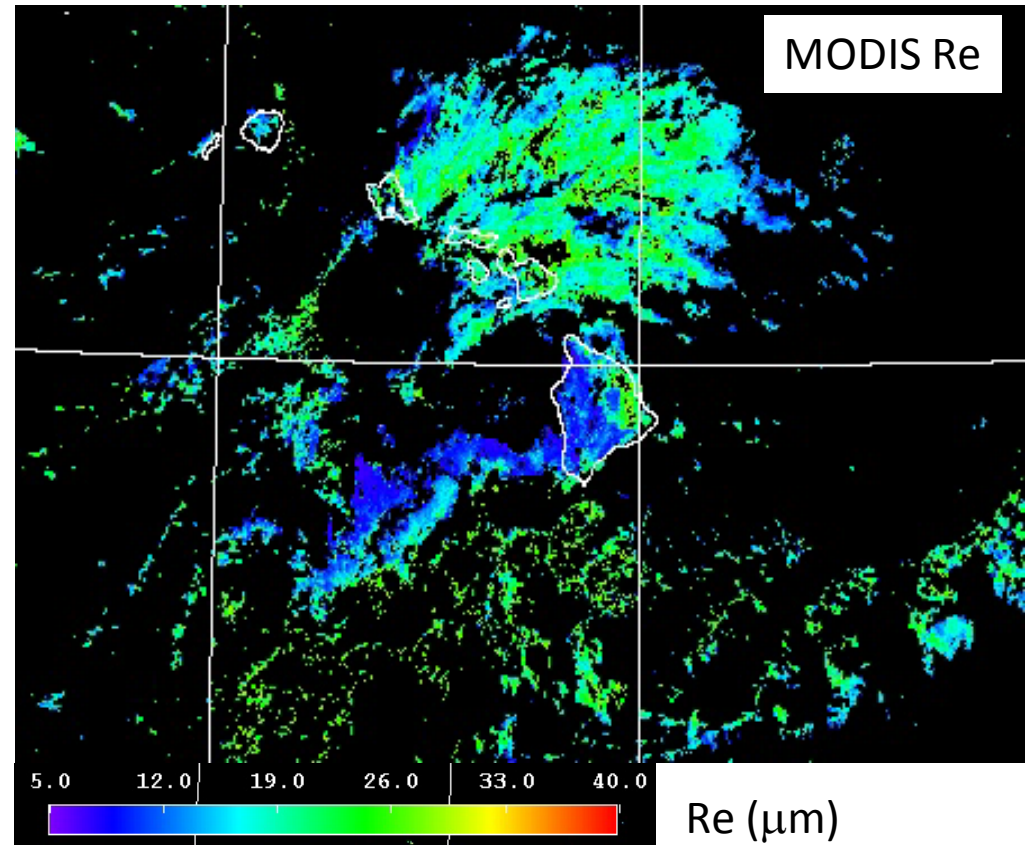
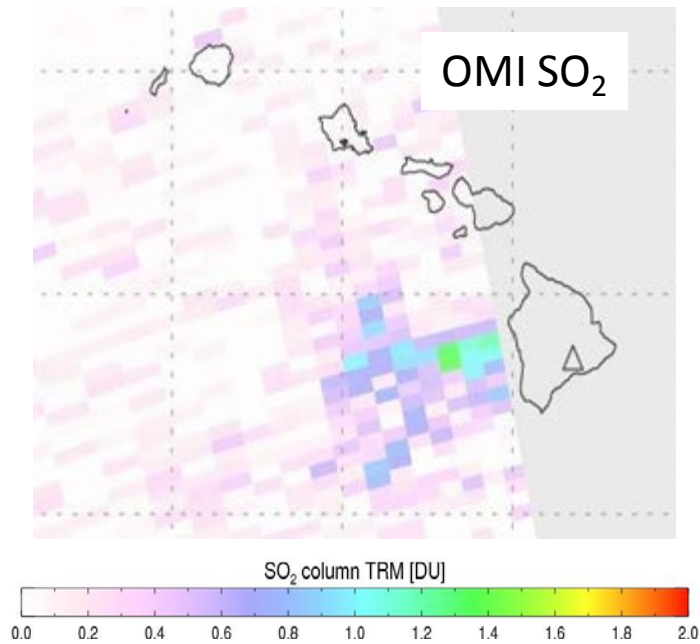


Observing Aerosol Effects on Clouds

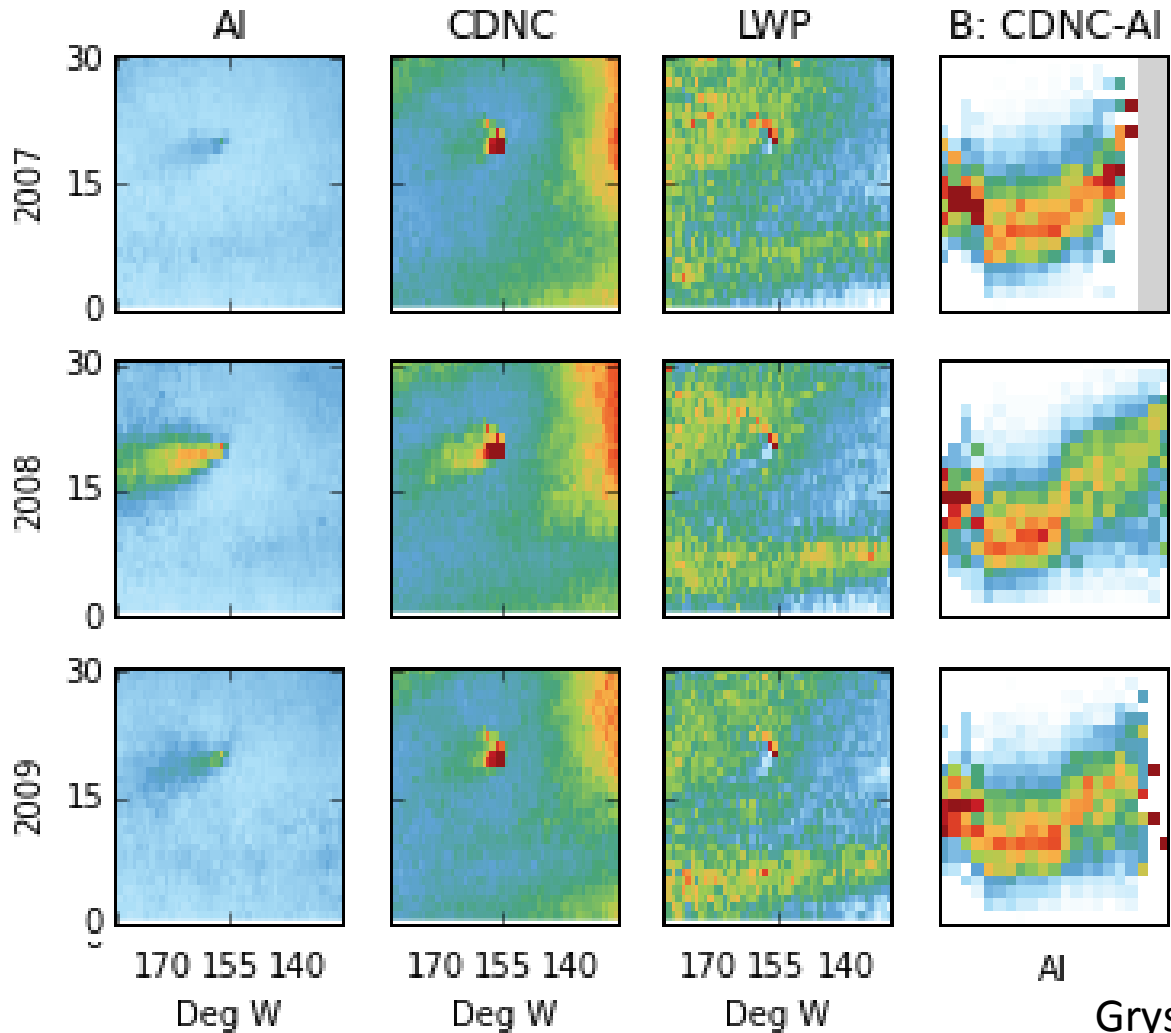
Emissions into trade cumulus clouds

Try to quantify dR_e/dA But: data not co-located

Satellite SO_2 and Cloud Top Effective Radius: June 15, 2015



Observed Relationships: MODIS



3 different years, 2008 was a 'larger' emission year (e.g. Yuan et al 2011, Mace et al 2016)

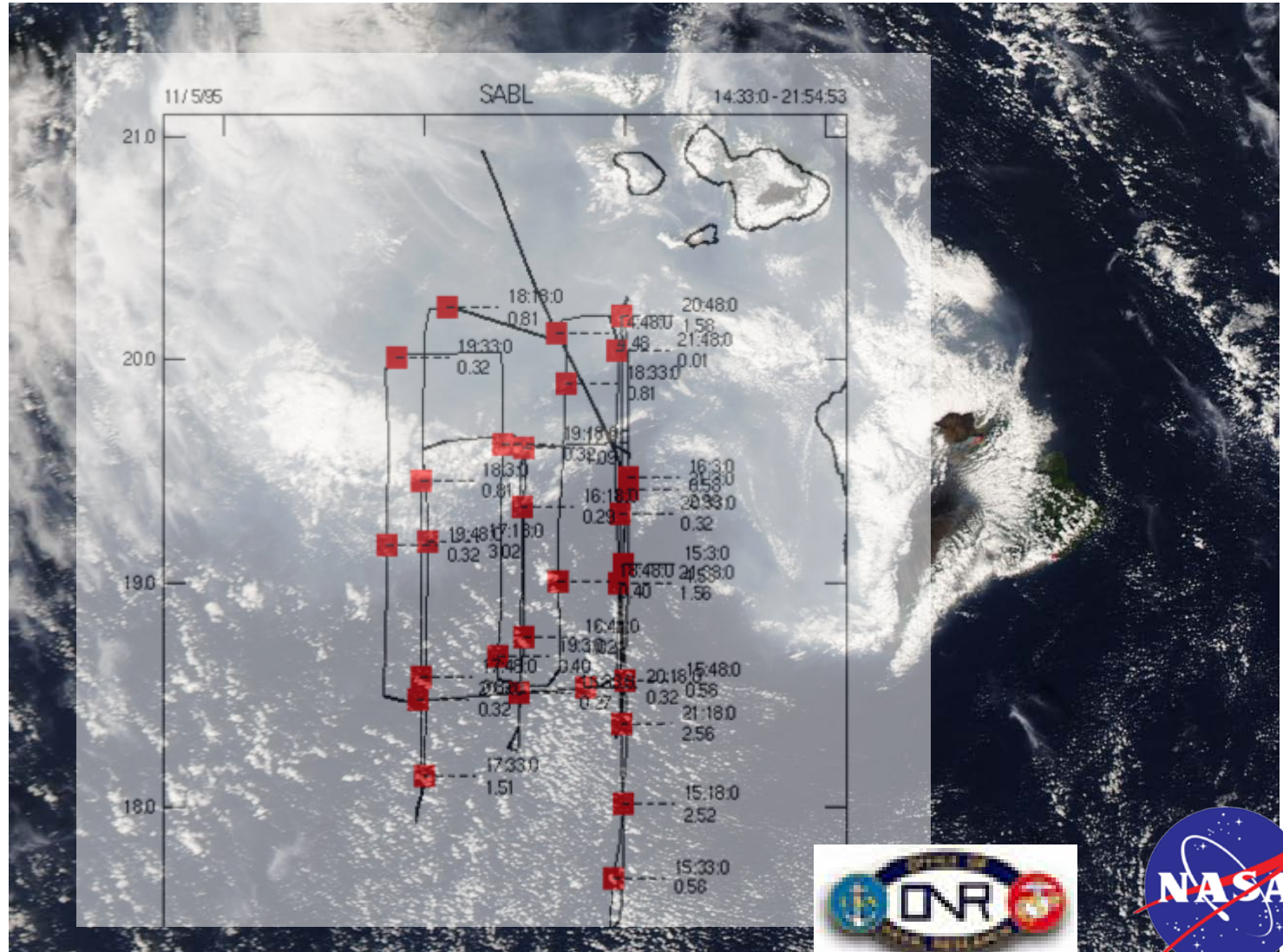
Clear signature in AI and CDNC
LWP not as clear

Difficult to make this quantitative, need to validate satellite data (e.g. broken clouds)

Example: Plume Sampling Flight

Tony Clarke, U. Hawaii, pers. Comm

ACE-1: 11/5/1995



Observing aerosol forcing

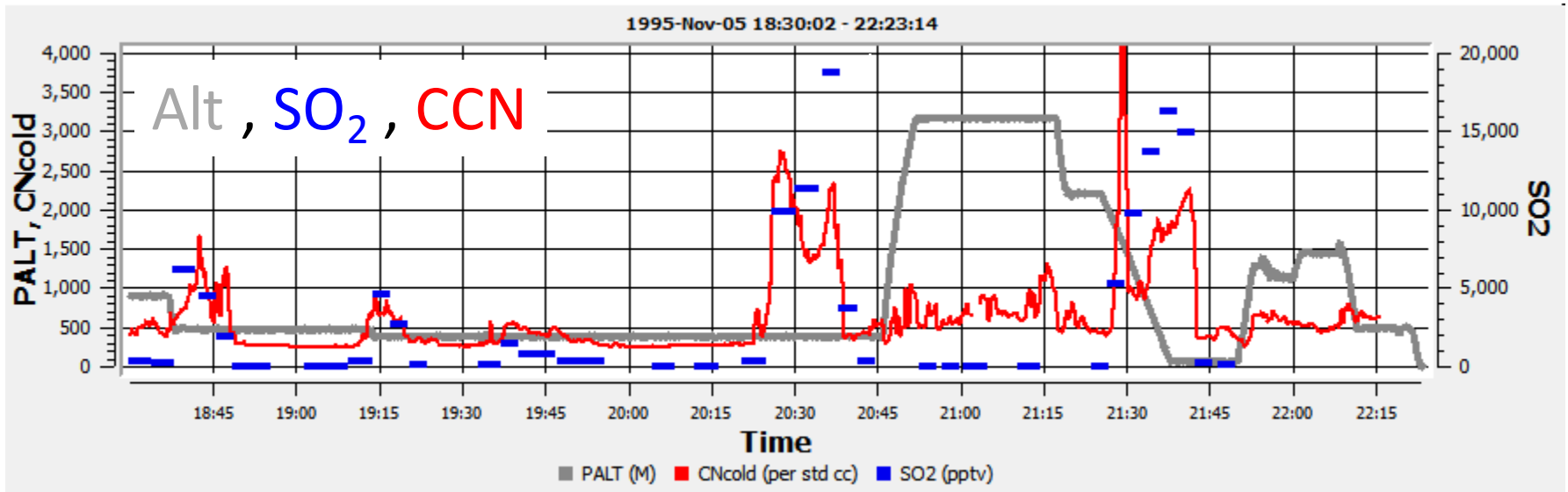
$$\frac{dR}{dA} = \frac{dCCN}{dA} * \frac{dN_c}{dCCN} * \frac{d\tau}{dN_c} * \frac{dR}{d\tau}$$

Nucleation

Activation

Microphysics

Radiation



Add Instruments:

ACE-1, Tony Clarke, U. Hawaii, pers. Comm

N_c

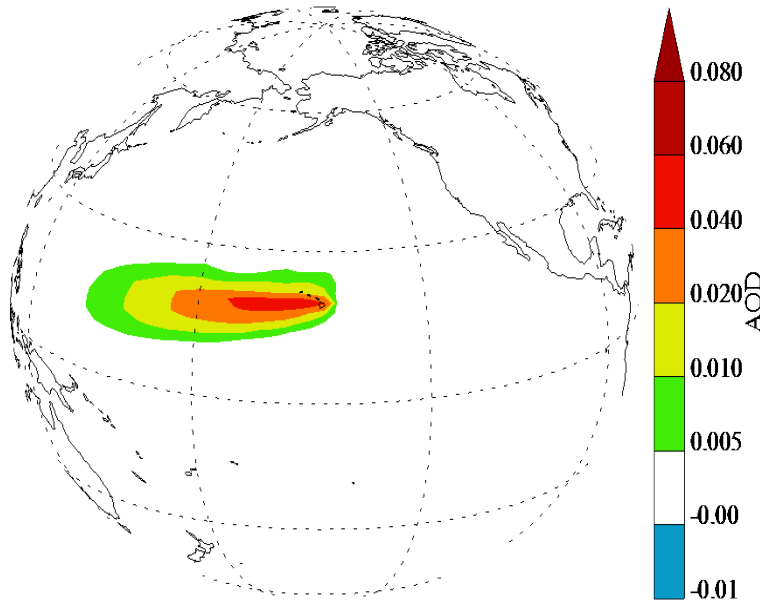
Rad Fluxes (R, τ)

Reflectance, flux divergence (τ)

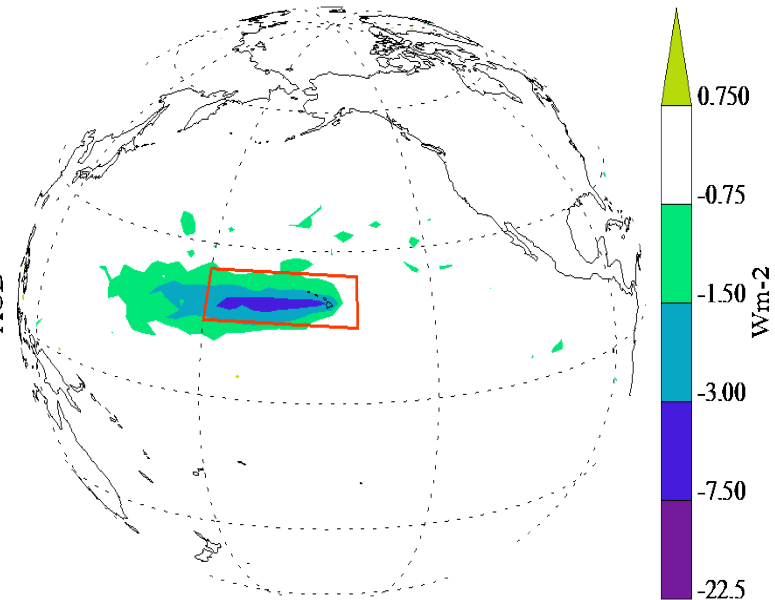
Simulating Effects of Kilauea

Specified Dynamics Simulations:
CESM1 (1°, CAM5, Kilauea SO₂ = 3kt/d & 7kt/d)

A) ANN Kilauea7+SO4 ΔAEROD



B) ANN Kilauea7+SO4 ΔTOA



Detectable effects on AOD and TOA radiation.

Does this match observations?

Can simulate particular days, sample flight tracks

Gridded Model Output

$$dR/dA = dCCN/dA * dR_e/dCCN * d\tau/dR_e * dR/d\tau$$

Nucleation

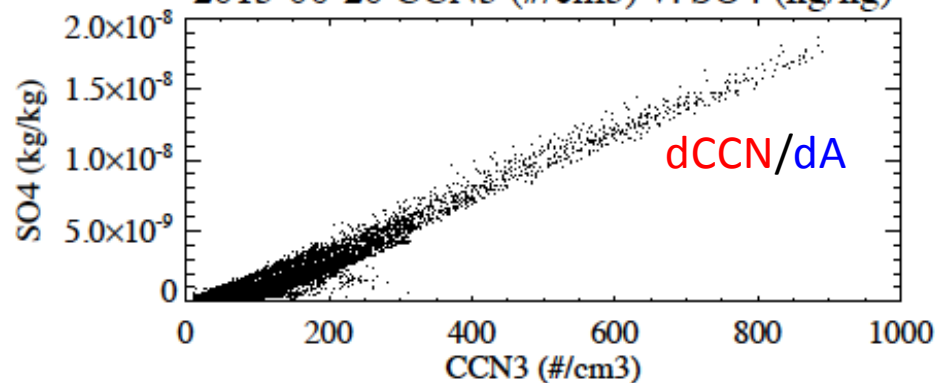
Activation

Microphysics

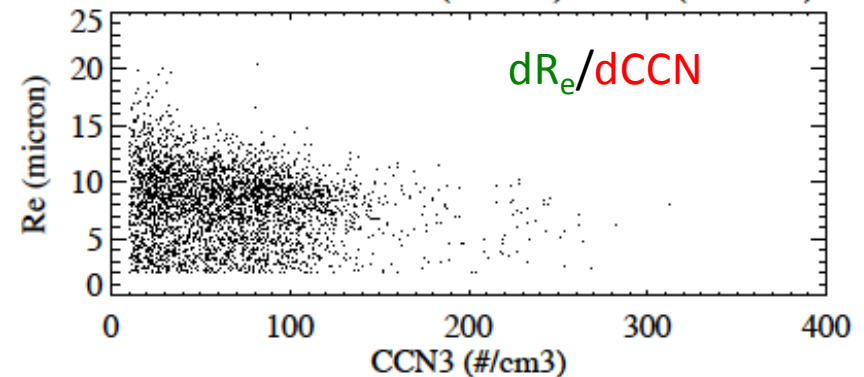
Radiation

Specified Dynamics Simulations: CESM1 (1°, CAM5, Kilauea SO₂ = 3kt/d)

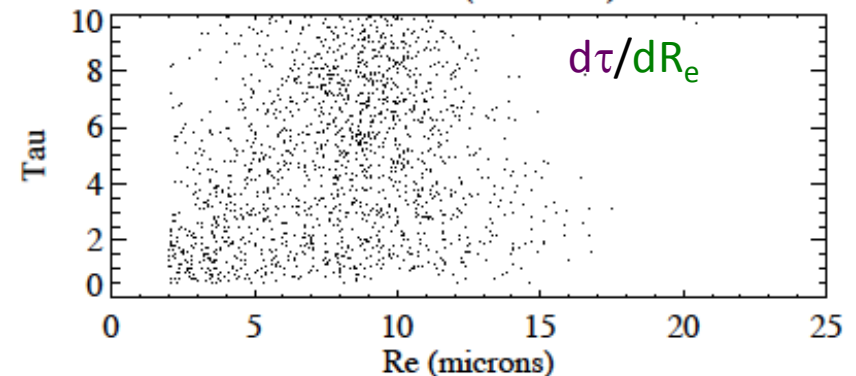
2015-06-20 CCN3 (#/cm³) v. SO4 (kg/kg)



2015-06-20 CCN3 (#/cm³) v. Re (micron)



2015-06-20 Re (microns) v. Tau



Microphysical relationships still not clear
Still working to refine
different pieces

Kilauea Aerosol Microphysics Project (KAMP)

Proposed Field Project to study sulfate effects on tropospheric Clouds

A. Gettelman (NCAR-ACOM), J. Small-Griswold (U-Hawaii),
S. Businger (U-Hawaii), J. Stith (NCAR-EOL)



Motivation:

(A) Local Air Pollution, (B) Global Climate Forcing

Science Questions to answer with NSF G-V:

1. Can we describe conversion from $\text{SO}_2 \rightarrow \text{H}_2\text{SO}_4 \rightarrow \text{CCN}$?

Basic Plume Evolution [Measure Aerosols]

Quantify evolution of $\text{SO}_2 \rightarrow \text{aerosol}$ (gas)

2. How does $\text{CCN H}_2\text{SO}_4$ affect cloud microphysics and cloud radiative effects ?

Interaction with clouds [Measure Clouds]

Effect on cloud microphysics

3. Can we simulate H_2SO_4 (vog) and ACI?

Model Evaluation



Summary

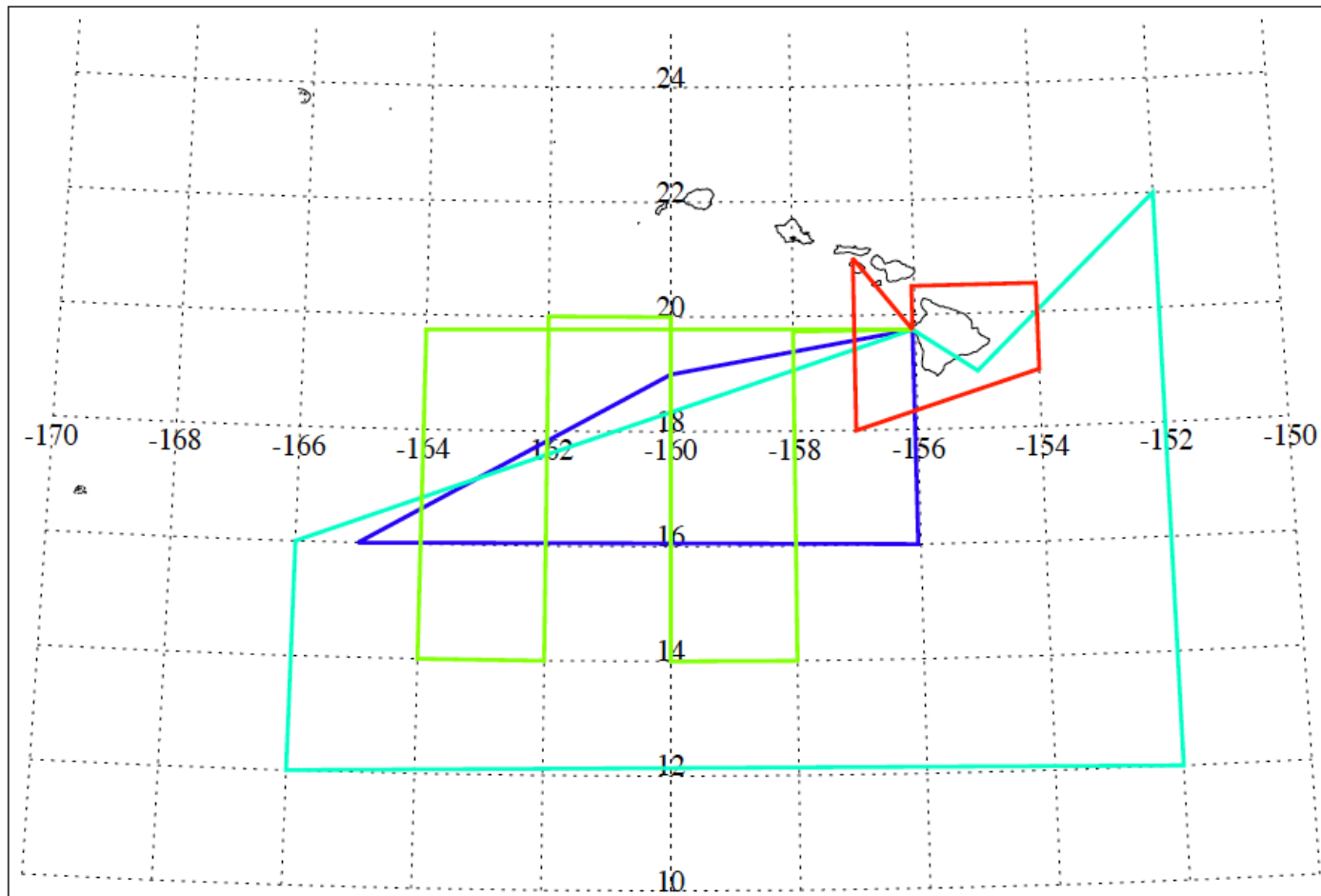
- Effusive volcanoes have regional air quality & cloud radiative impacts
- Observations show clear signals on particle size (CDNC, R_e)
 - Hard to find effects beyond this (e.g. LWP)
- Continuously erupting volcanoes (Kilauea) are a good laboratory and test case for larger events (e.g. Laki)
 - Air Quality, Climate (ACI)
 - Kilauea: Steady, affects trade-cu clouds
- Test cases for models
 - Bárðarbunga (Iceland, 2014): Haywood leading model comparisons
 - Kilauea: lots of data analysis, proposed field project (KAMP). Will use data for evaluating different scales of models
- Contact us for more info....

Extra Slides

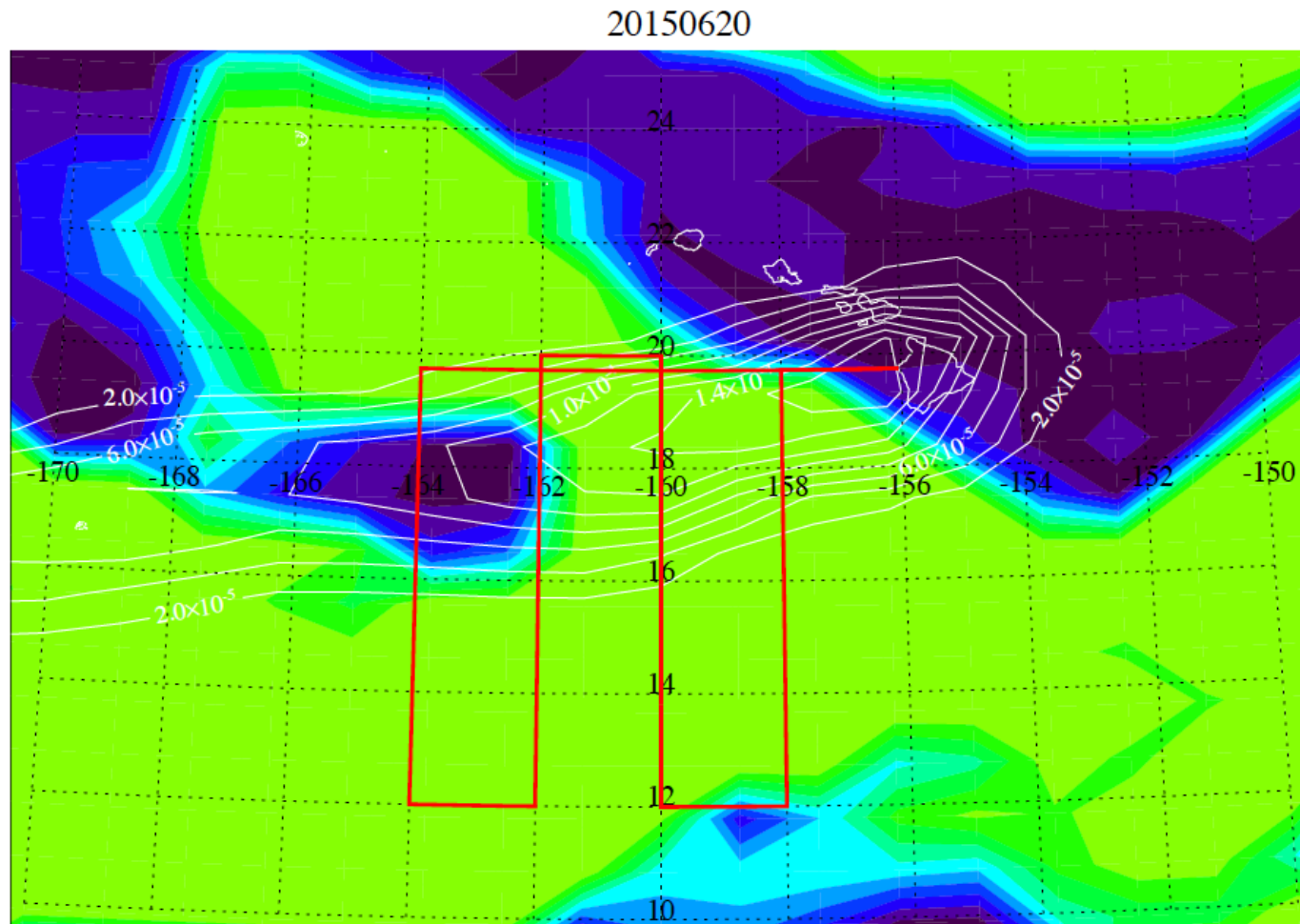
Sample Modeling

- Nudged Meteorology, Summer 2014, 2015 (June-July)
- CAM5 GCM
- 1° resolution,
- Add Kilauea SO₂ + Δ CO₂ (stochastic)
- Sample Flight Tracks

Sample Flight Tracks



Pick a Flight: Cloud Fraction & ΔCO_2



Model Along Flight Track

