Volcanic Aerosol Emission Impacts on Orographic Precipitation in Hawaii

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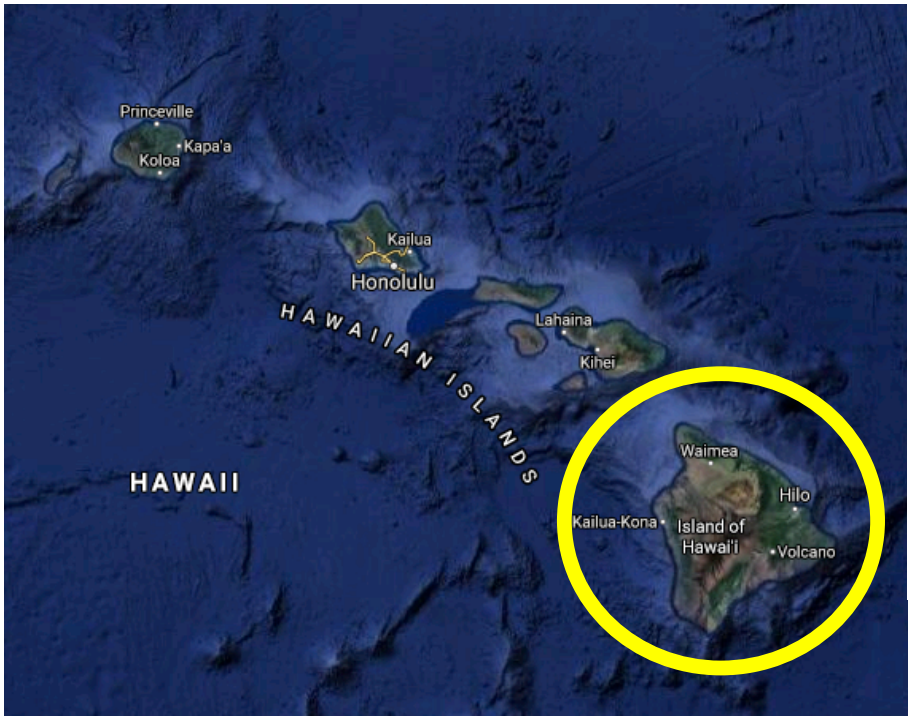
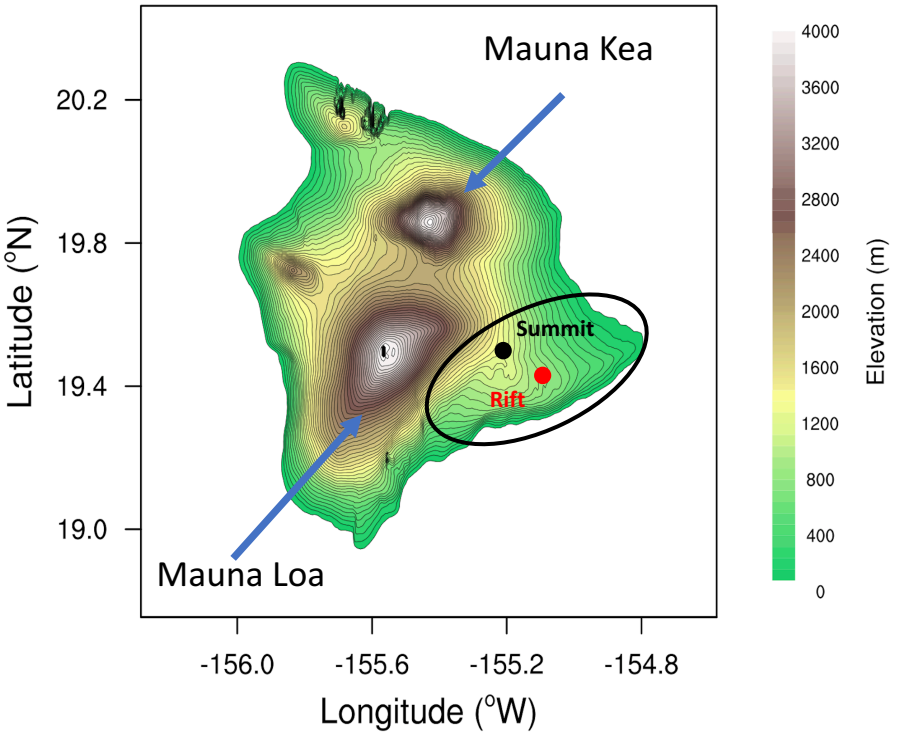
Introduction - Kilauea and Vog





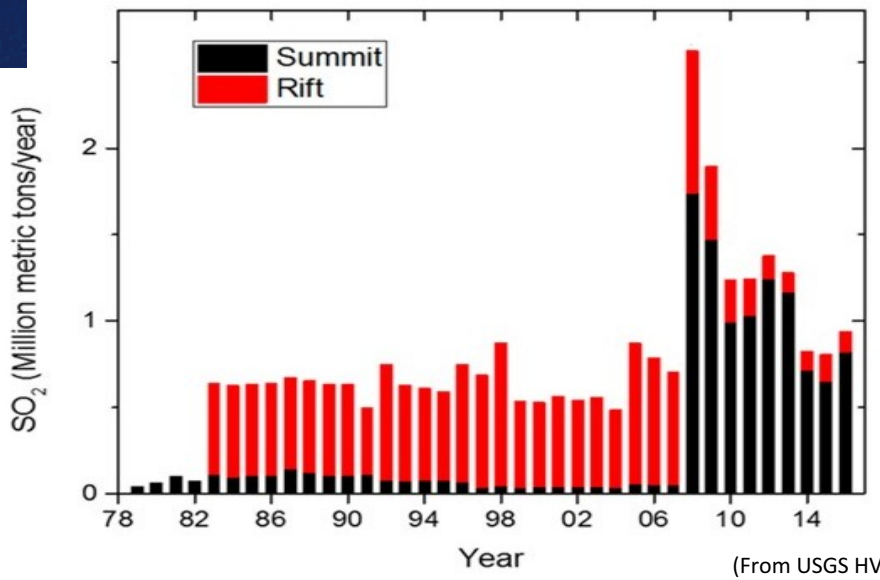
Kilauea Volcano

- *Located along the southeastern shore of Hawaii island*
- *Two distinct degassing hotspots:*
  - *(1) Pu'u 'Ō'ō vent within east rift zone (ERZ)*
  - *(2) Halema'uma'u vent within Summit*

Volcanic Smog (Vog)

- *Composed of both gas phase sulfur dioxide (SO_2) and sulfate aerosols (SO_4^-)*

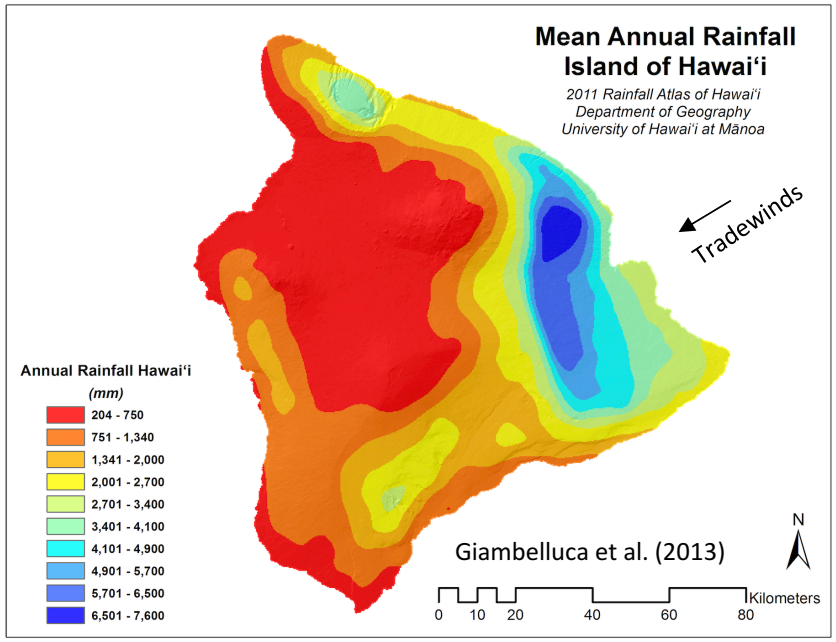
Annual SO_2 emissions from the Kīlauea Volcano, 1979-2016



(From USGS HVO)

Introduction - Rainfall on Hawaii Island

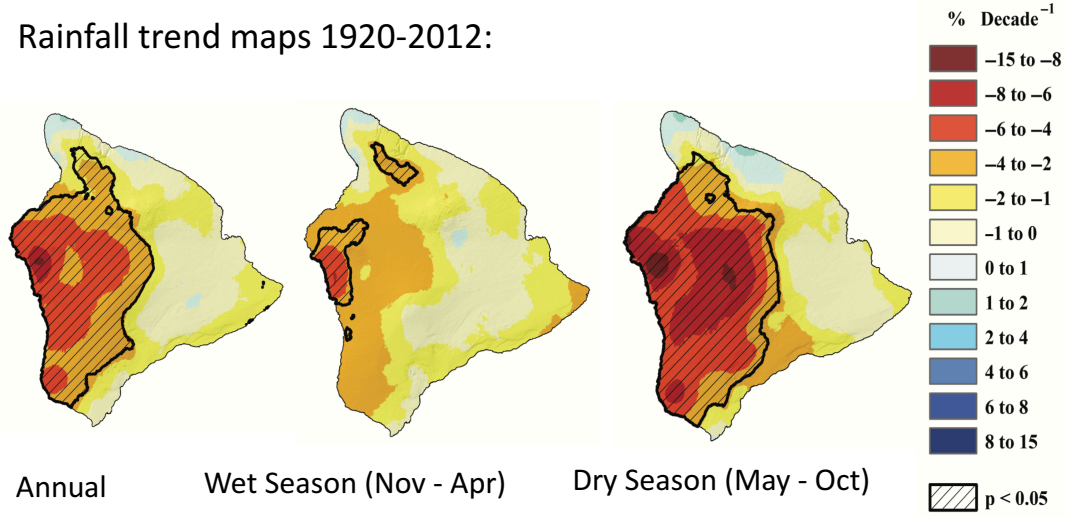
Mean annual rainfall pattern:



Wet windward slopes
Dry leeward areas
Dry high elevations

Leeside drying, especially during the dry season

Rainfall trend maps 1920-2012:



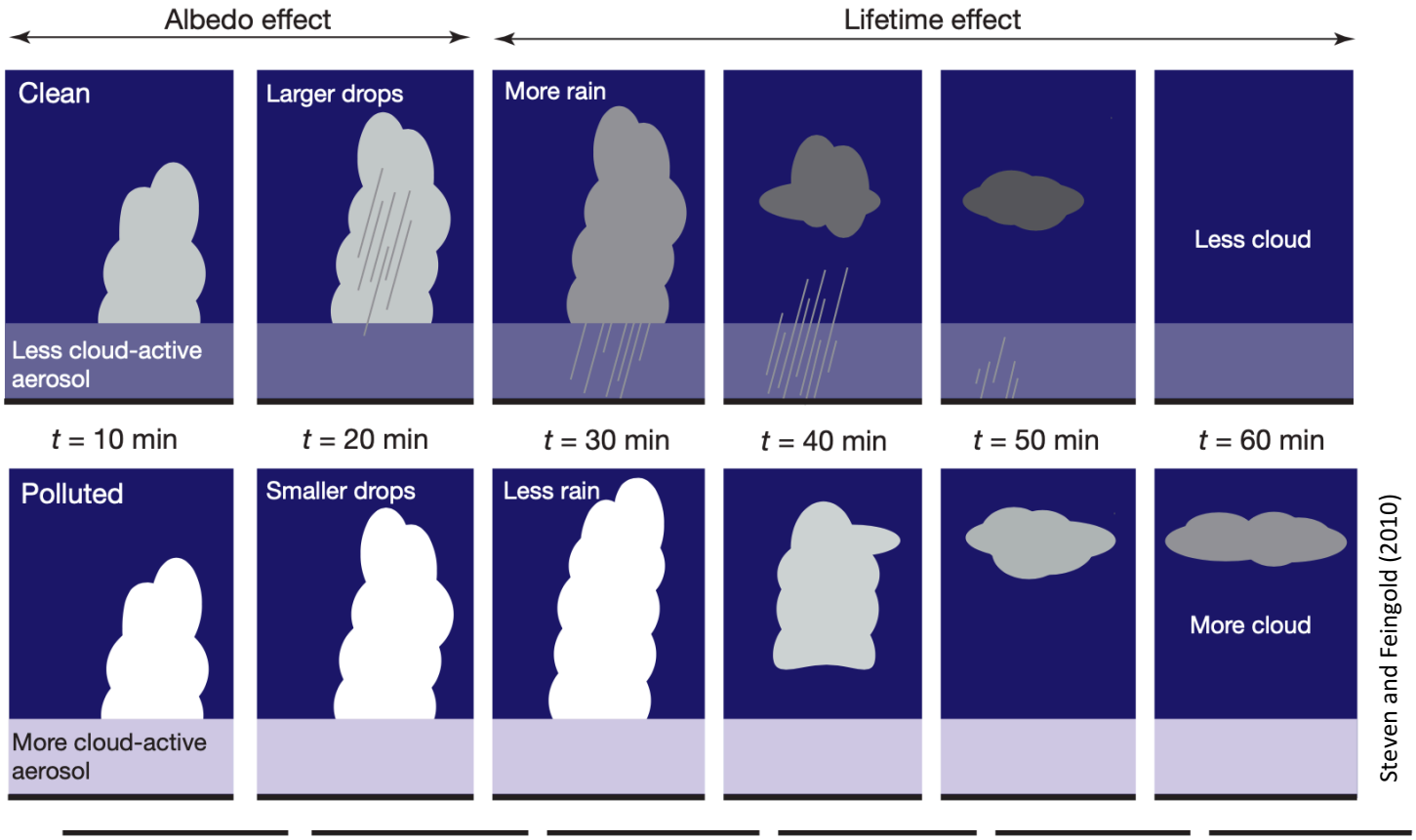
Frazier and Giambelluca (2017)

Previous studies have shown a drying trend in Hawai'i:

- *Frazier and Giambelluca (2017) showed that for the period 1920 to 2012, over 90% of the state experienced drying*
- *Chu et al. 1993 and Chu and Chen 2005 found that the drying trend is associated with large-scale modes of climate variability (ENSO, PDO & PNA)*

Research Question: Can vog also affect rainfall & contribute to this drying trend?

Introduction - Aerosol-Cloud Interactions (ACI)



In addition to delaying the warm rain production, Muhlbauer and Lohmann (2008) also suggests the aerosol effects will lead to a downwind shift in precipitation location, which affects the hydrological cycle on the local scale.

Kilauea provides a natural source of aerosols to study how varying aerosol concentrations influence warm rain clouds.

Remote sensing studies have looked at how Kilauea's volcanic aerosols influence clouds downstream of Hawai'i (Yuan et al. 2011, and Malavelle et al. 2017), but have come to contradictory conclusions that are either consistent with the ACI theories, or are inconclusive. No studies have looked at ACI for rainfall ON Hawai'i Island.

Motivation

- Locals hypothesize that vog reduces rainfall on Hawai'i Island, however, no scientific studies have been conducted

- Address previous contradictory studies on volcanic aerosols in Hawai'i, and focus on rainfall over Hawaii Island rather than the ocean downstream.

- Rainfall is a vital natural resource and essential to the replenishment of freshwater aquifers in Hawai'i, raising concerns over the decrease in rainfall and increase in droughts over the past century

Questions

1. Is there a connection between rainfall and vog emissions in Hawai'i?

    - Observations of rainfall and vog emissions
    - Numerical Model

2. How does vog affect cloud properties?

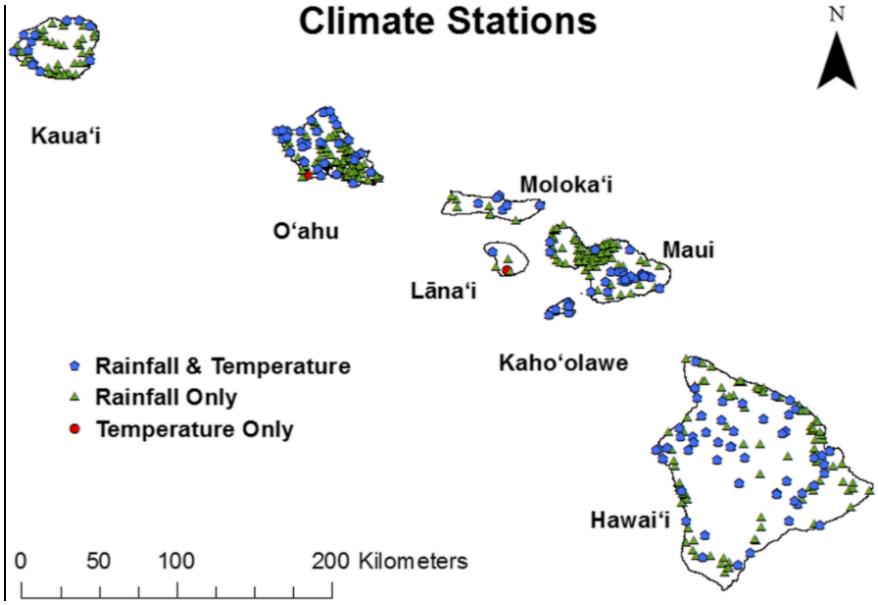
3. How does vog affect rainfall amount and location?

Observational Datasets

1. Daily Rainfall Gridded Maps of the Hawaii Island

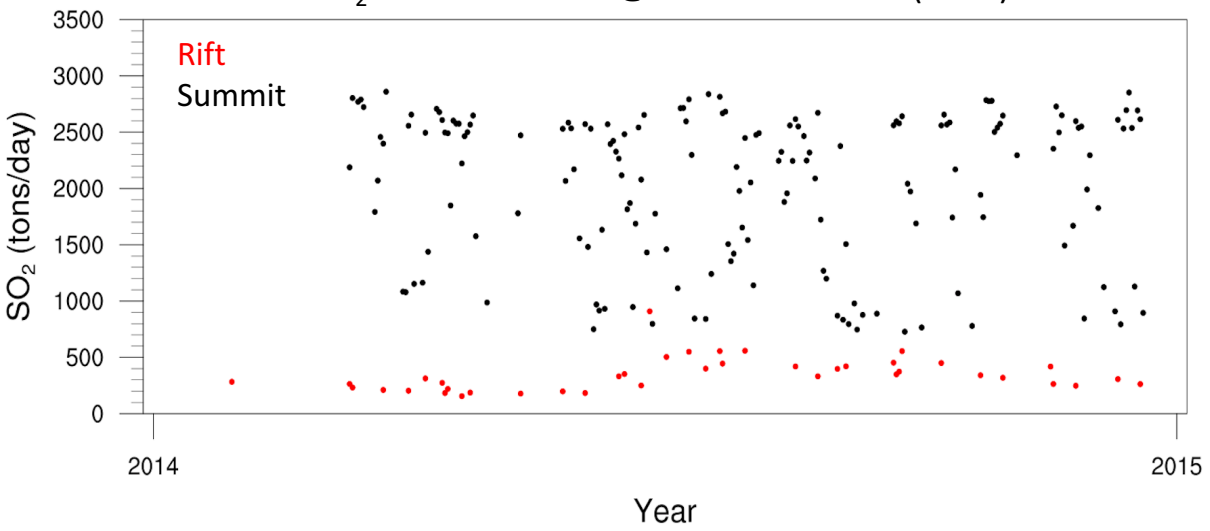
- *Compiled available daily rain gauge observations from heterogeneous networks (at right)*
- *Generated using climatologically aided interpolation (CAI)*
- *Resolution: 250 m*

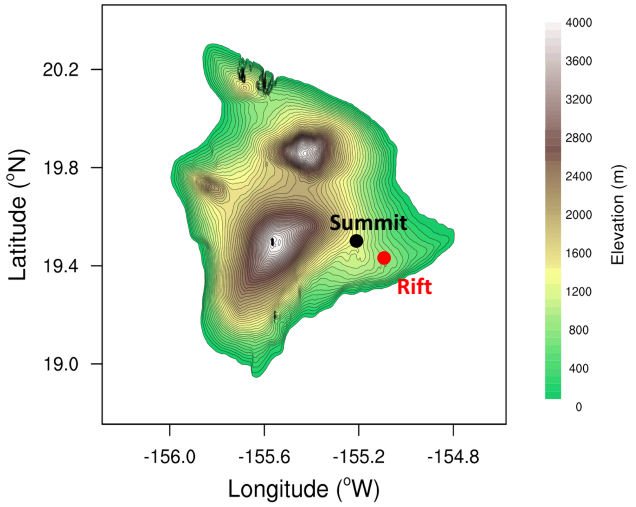
2. Kilauea SO_2 Emissions rates @ Summit and Rift (below) measured by the USGS, when available in 2014
(Elias et al. 2018)



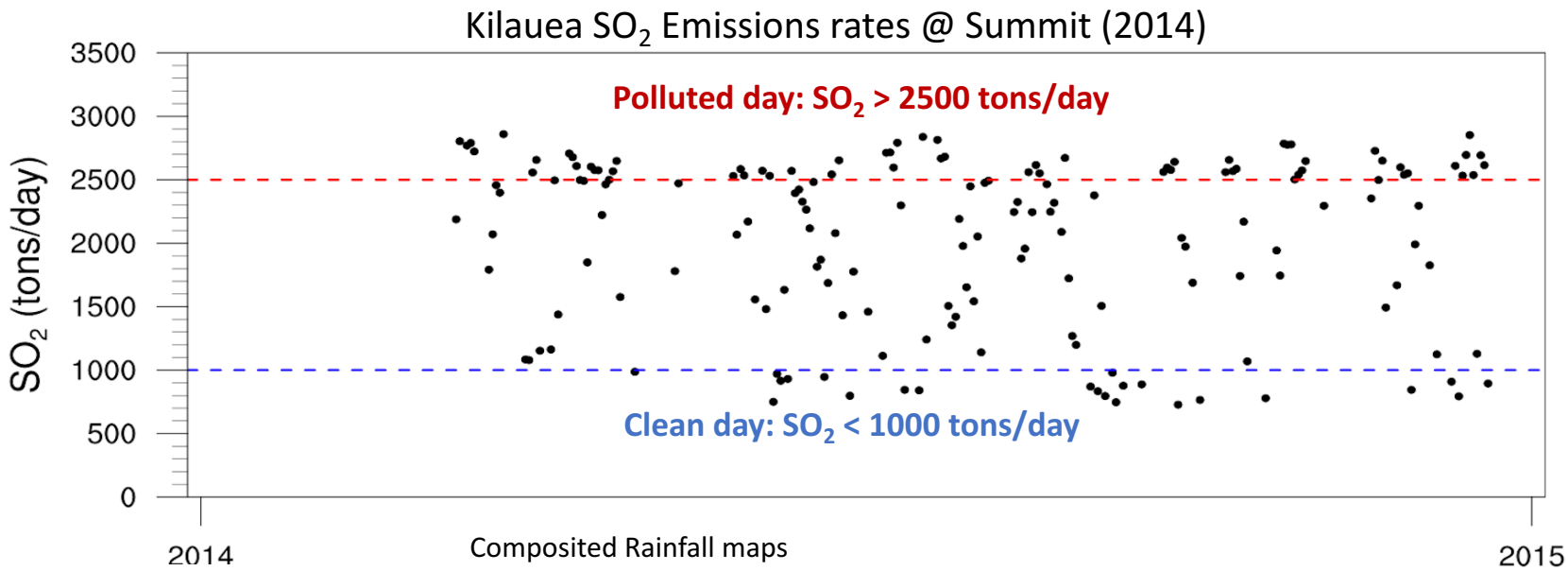
(Longman et al. 2019)

Kilauea SO_2 Emissions rates @ Summit and Rift (2014)

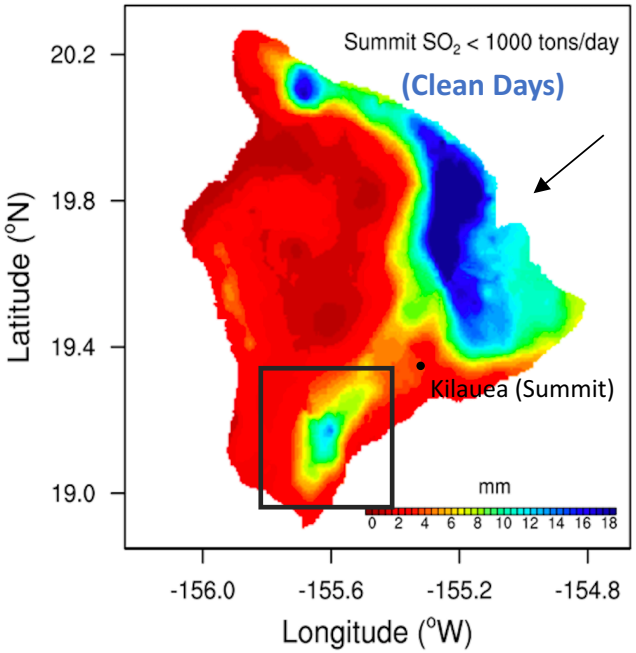


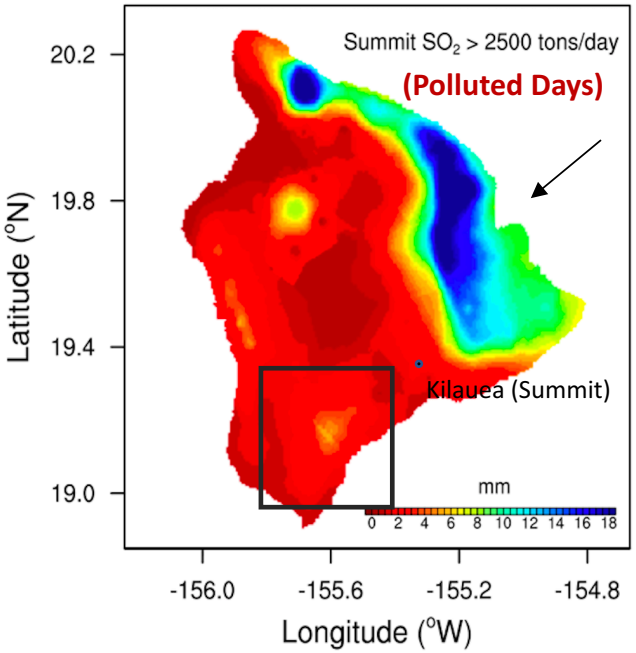


Statistical results - Rainfall Comparison between clean & polluted days



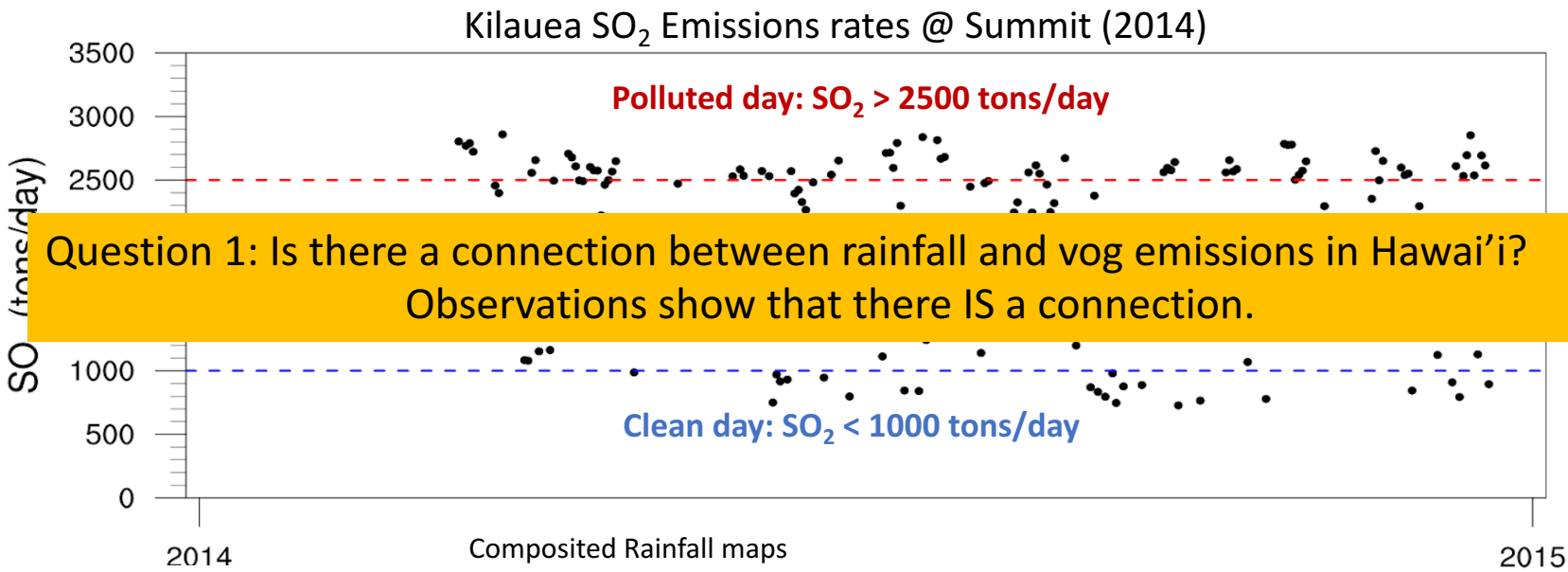
Composited Rainfall maps





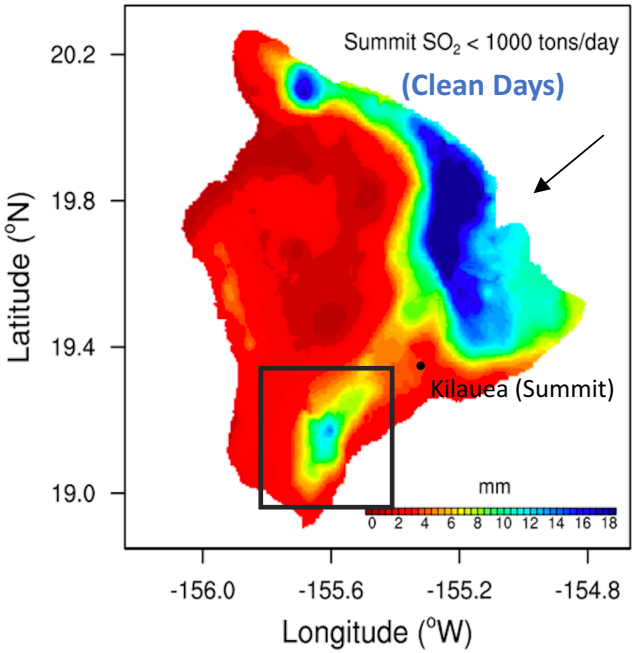
- The region downwind of Kilauea (black box) receives much less rainfall when emissions are high
- The rainfall differences for the rest of the island are small

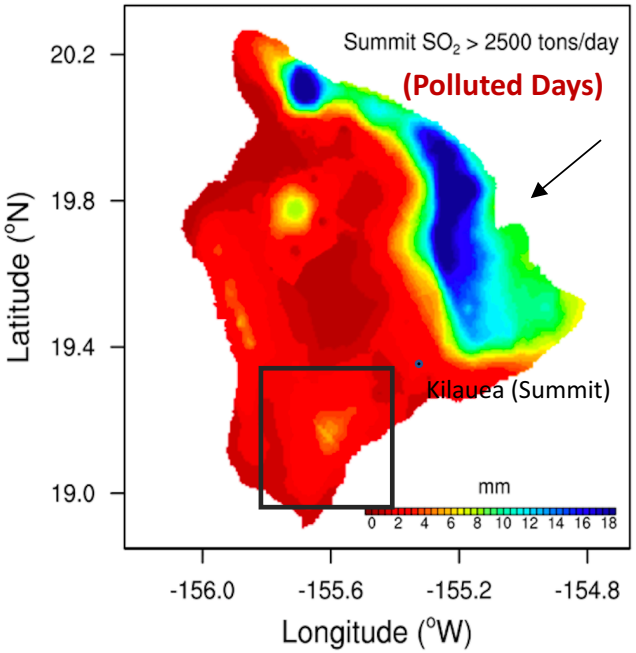
Statistical results - Rainfall Comparison between clean & polluted days



Question 1: Is there a connection between rainfall and vog emissions in Hawai'i? Observations show that there IS a connection.

Composited Rainfall maps





- The region downwind of Kilauea (black box) receives much less rainfall when emissions are high
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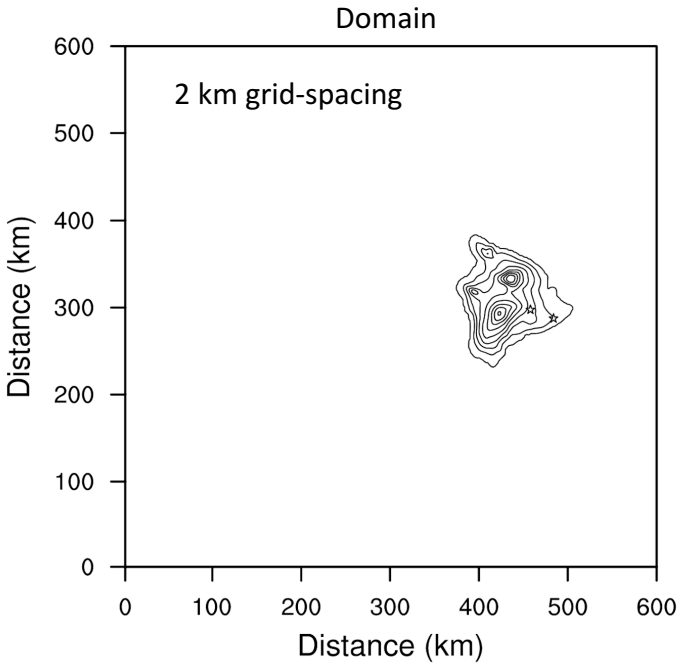
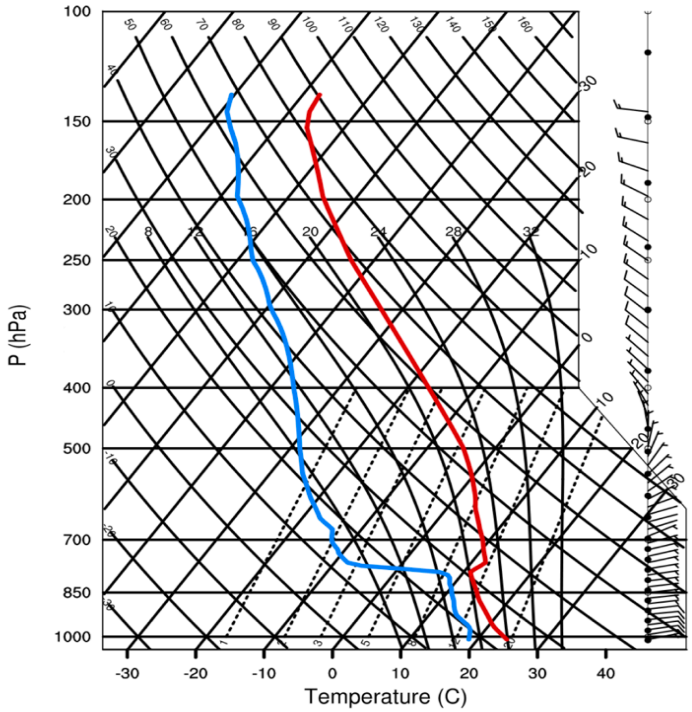
Numerical Model Setup

Weather Research and Forecasting (WRF) model V3.9.1

- Idealized simulation
- 2-km grid spacing
- Smoothed realistic terrain
- Trade-wind sounding from HaRP
- 24 hrs duration（one diurnal cycle from midnight to midnight)
- Diurnal heating
- 15-sec time step & hourly output
- RRTMG cloud-radiation scheme
- 5-layer thermal diffusion scheme
- Thompson aerosol-aware bulk microphysics scheme
- Clean oceanic background aerosol profile
- Two point sources of sulfate-like aerosol from the Kilauea vent locations

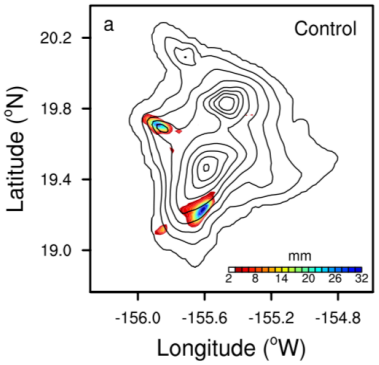
4 Separate Experiments	Emission rate (aerosol cm^{-3} s^{-1})
1. Control	0
2. Na100	100
3. Na1000	1000
4. Na5000	5000



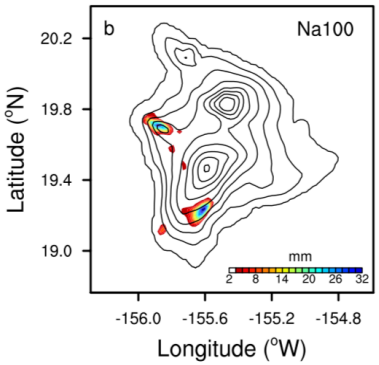


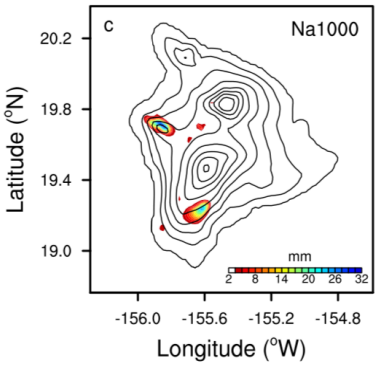
Model results - 24-hour rainfall accumulation

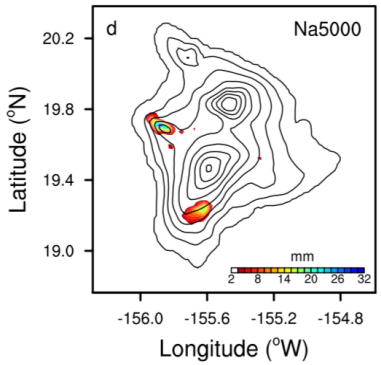
Control



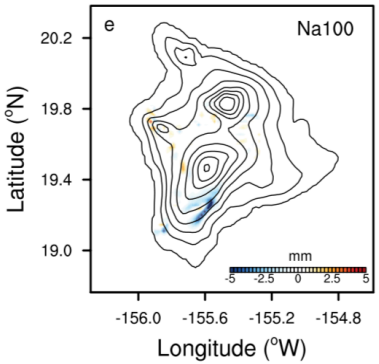
24-hr Rainfall

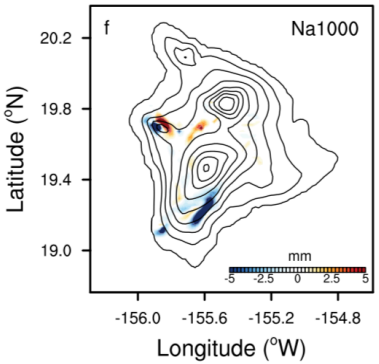


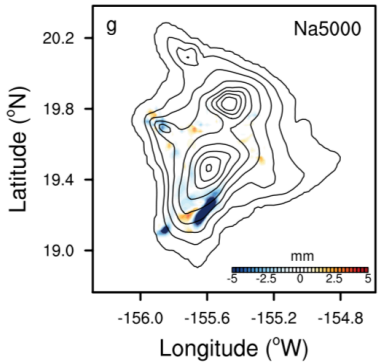




Rainfall Difference from Control



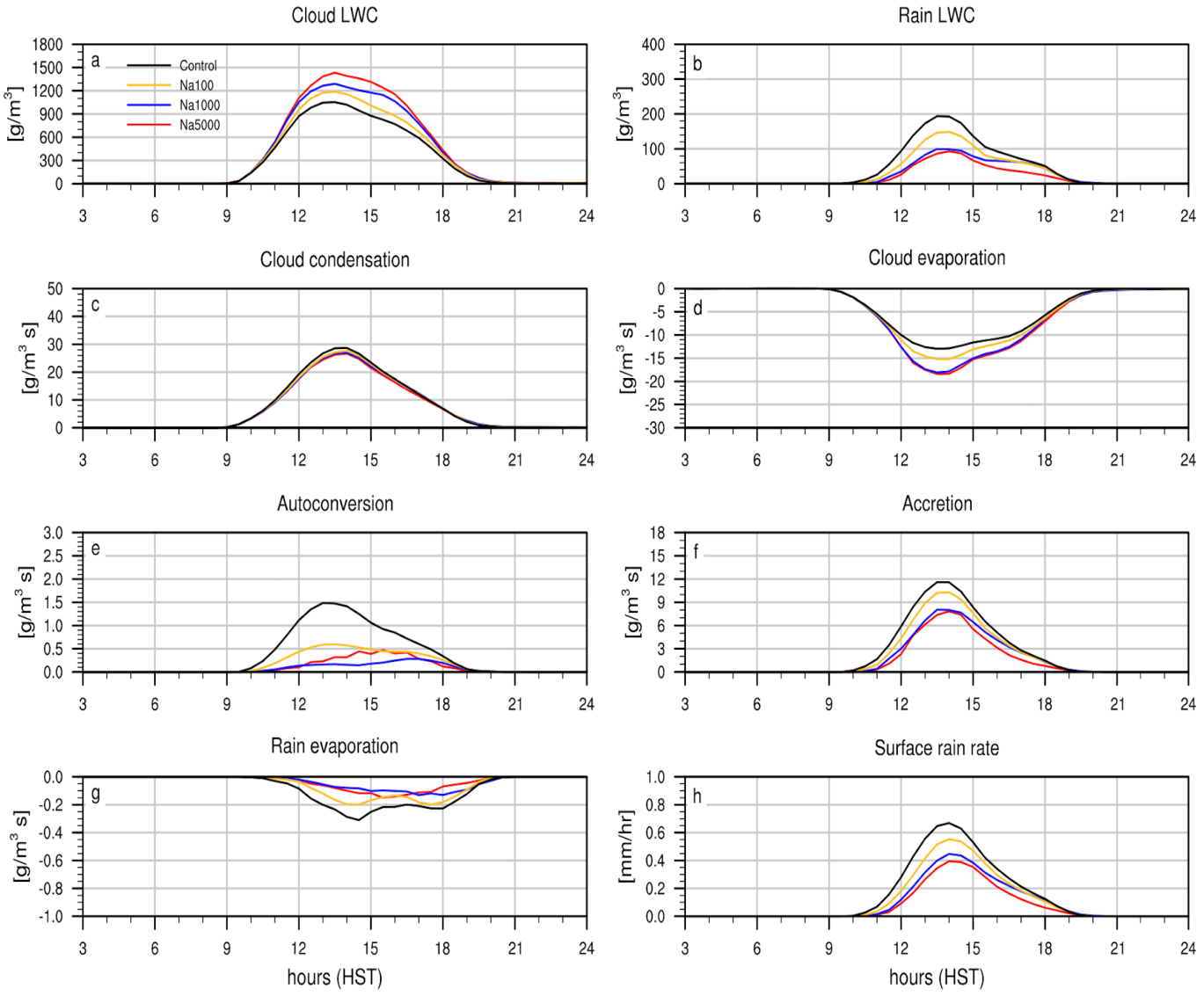


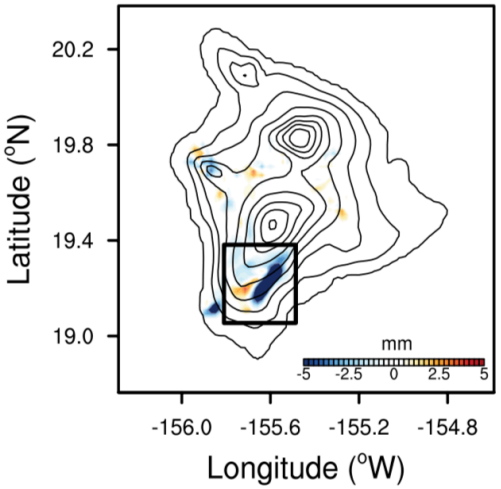


Increasing Aerosol Emissions →

- Most of the rainfall is downwind of Kilauea and in the lee (no upwind convection)
- Reduced rainfall downwind of Kilauea with increasing emissions
- Plotting the rainfall difference shows that the rainfall location has also shifted downstream

Model results - temporal evolution of key cloud & rain processes





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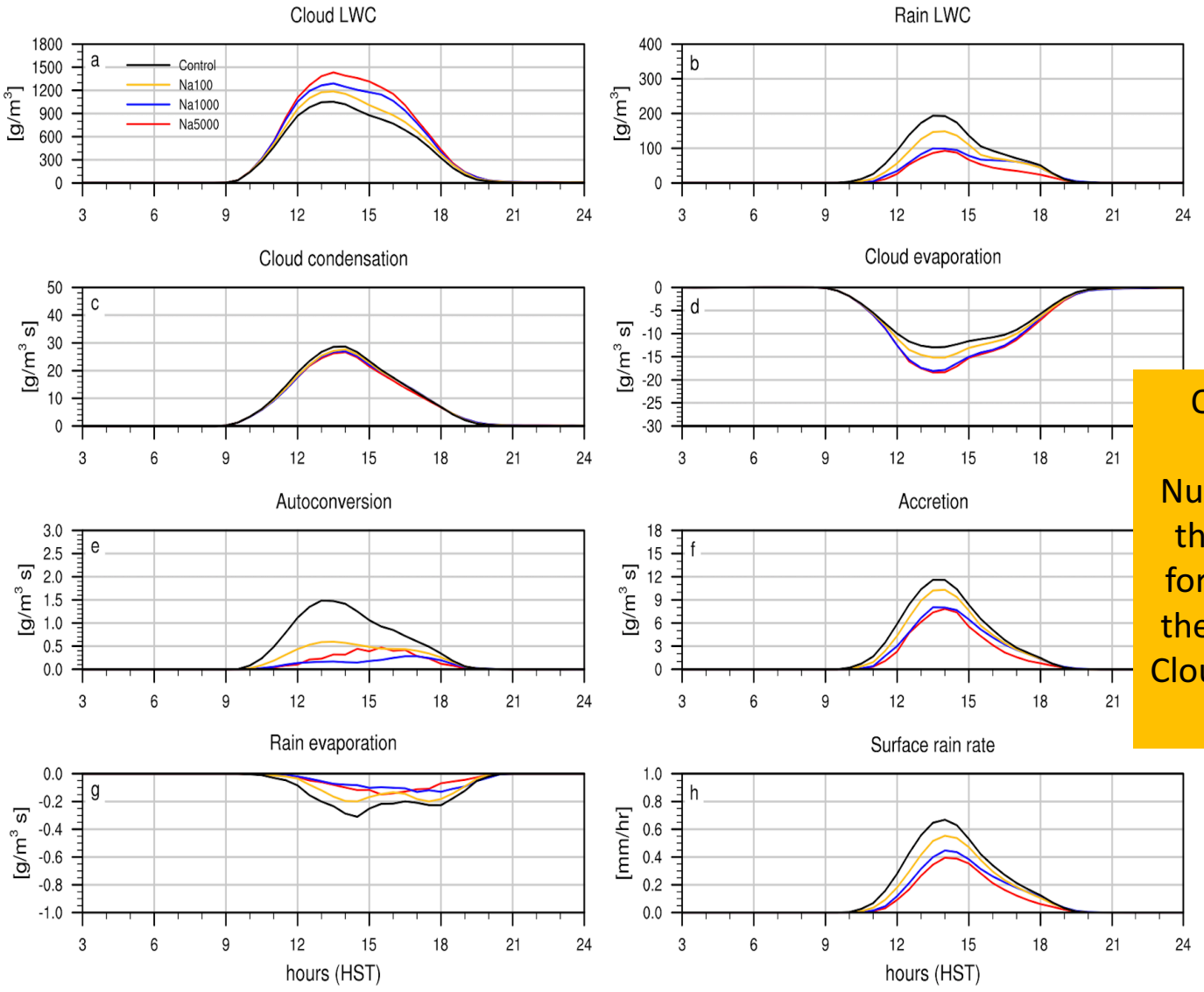
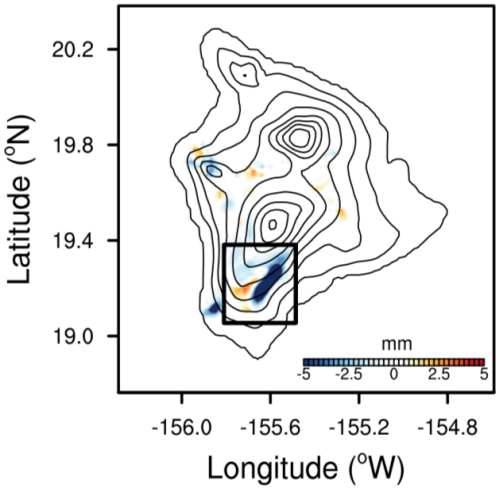
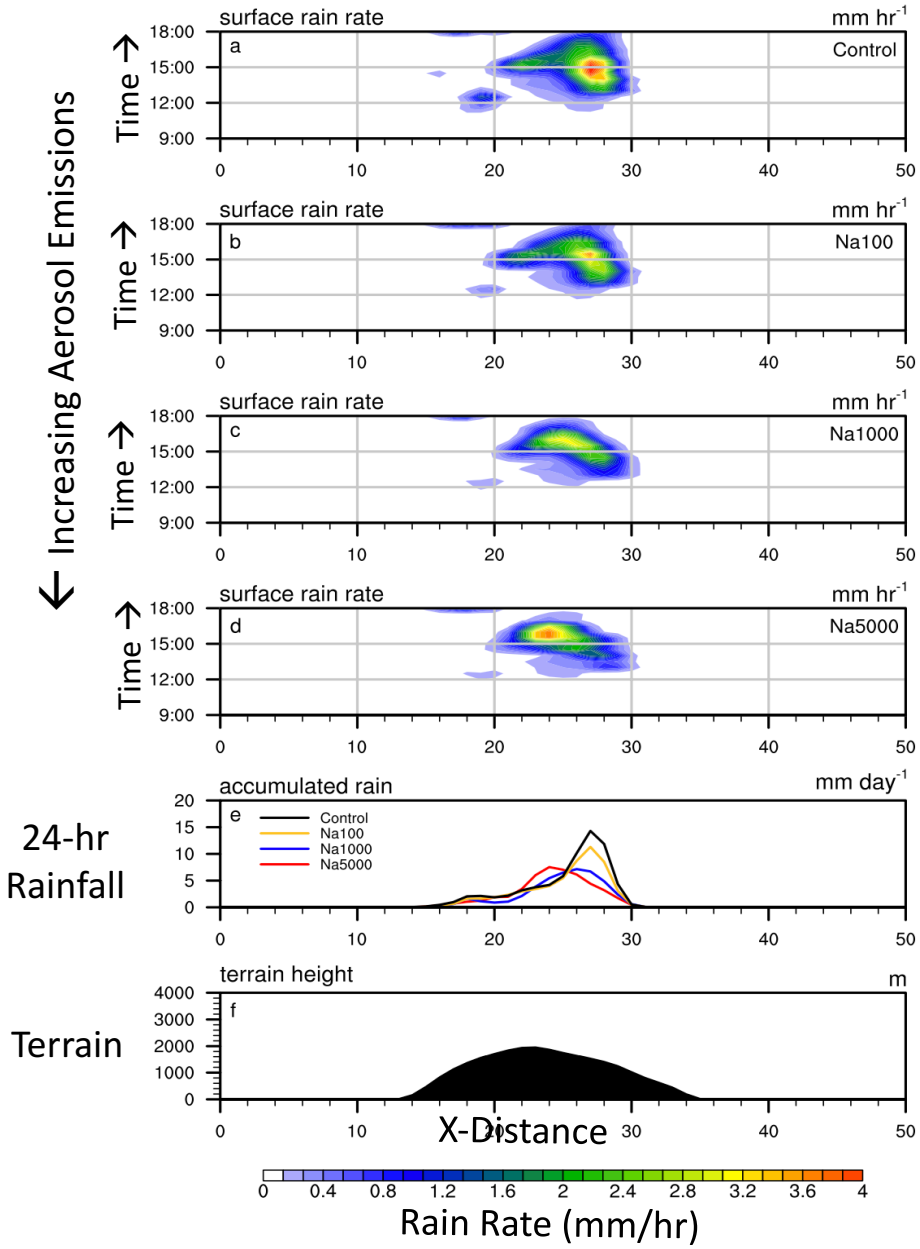


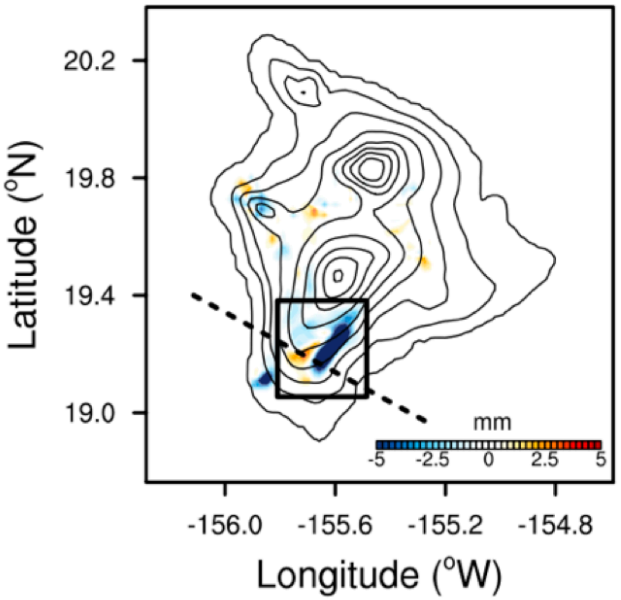


Question 2: How does vog affect cloud properties? Numerical model results show that vog delays precipitation formation, thereby increasing the Cloud LWC, and increasing Cloud Nc which enhances cloud droplet evaporation

Model results - Hovmöller diagrams

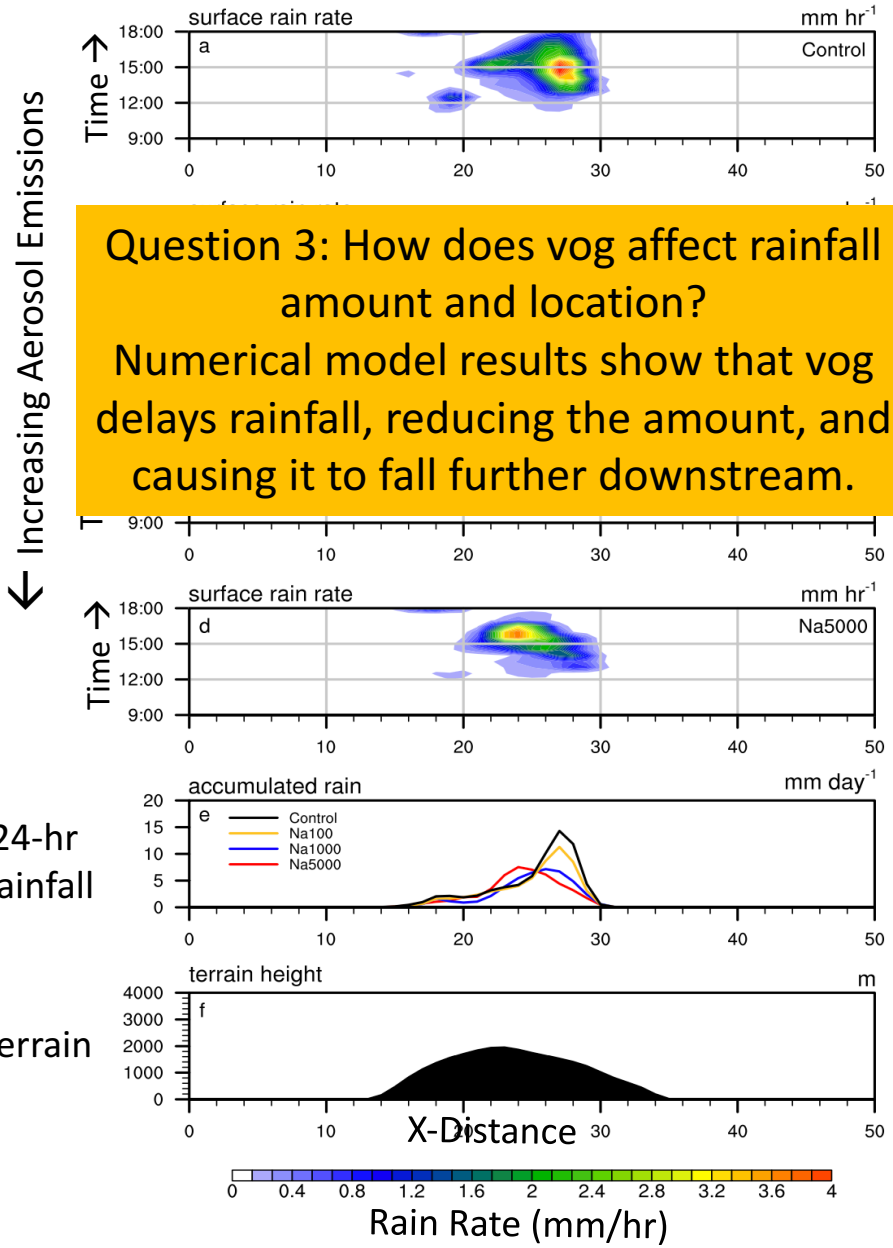


Wind Direction



- The timing and location of peak rainfall intensity and accumulated 24-hr rainfall amounts vary due to the microphysical feedbacks from differing aerosol loading
- In polluted cases (Na1000 and Na5000), the rainfall maximum location shifts downstream toward the terrain peak, and occurs later

Model results - Hovmöller diagrams



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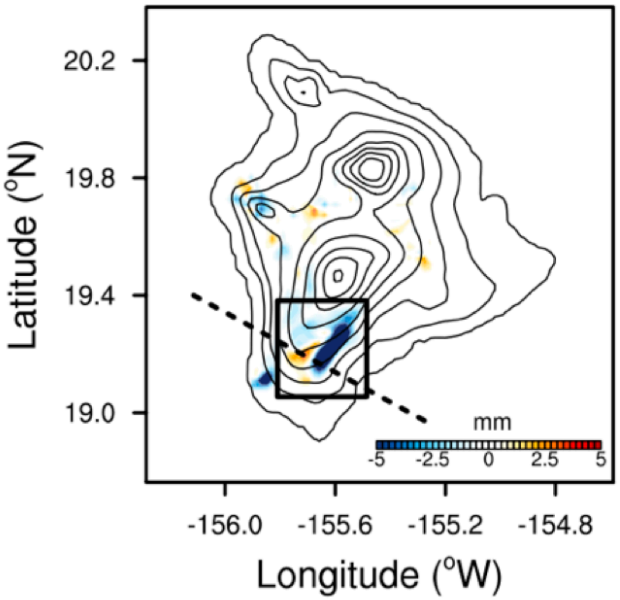

Question 3: How does vog affect rainfall amount and location?
Numerical model results show that vog delays rainfall, reducing the amount, and causing it to fall further downstream.

- The timing and location of peak rainfall intensity and accumulated 24-hr rainfall amounts vary due to the microphysical feedbacks from differing aerosol loading
- In polluted cases (Na1000 and Na5000), the rainfall maximum location shifts downstream toward the terrain peak, and occurs later

Conclusion

- Both observational and numerical model analyses show that rainfall over Hawai'I island is strongly modulated by SO_2 emissions, especially downwind of the Kilauea Volcano
- The observed daily rainfall difference between high and low emission days is shown to be 10 mm downwind of Kilauea, while the rest of the island does not show a change with emissions, emphasizing that the rainfall variations are attributable to localized vog only
- Sensitivity simulations with varied volcanic aerosol emissions shows that the added volcanic aerosols tend to increase cloud water content, enhance cloud evaporation, and suppress rain production
- In addition to delaying and reducing the rainfall, model results also show that vog modifies the spatial distribution of rainfall on the windward slopes of the mountainside downwind of Kilauea

References

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