Effects of volcanic emissions on clouds during Kilauea degassing events

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Abstract

Aerosols influence Earth's radiative balance directly by scattering and absorbing solar radiation, and indirectly by modifying cloud properties. Current scientific consensus indicates that these effects may offset as much as 50% of the warming due to greenhouse gas emissions. Over the last two decades dramatic volcanic events in Hawaii have produced localized aerosol emissions in otherwise clean environments. These are "natural experiments" where the aerosol effects on clouds and climate can be partitioned from other effects like meteorology and industrial emissions. Therefore, these events provide a unique opportunity to learn about possible effects of aerosol pollution on climate through cloud modification. In this work we use the version 5 of the NASA Goddard Earth Observing System (GEOS-5) and satellite retrievals to analyze and evaluate the strength of the aerosol indirect effect on liquid and ice clouds during the 2008 and 2018 Kilauea degassing events using different emissions scenarios (0×, 1×, and 5× actual emissions). Our results suggested that the 2018 event was stronger and more regionally significant with respect to cloud formation process for both liquid and ice clouds, while the 2008 affected local liquid clouds only. GEOS-5 predictions reproduced spatial patterns for all parameters, however better precision could be gained by using more accurate plume parameters for height and ash concentration.

Background and Objective

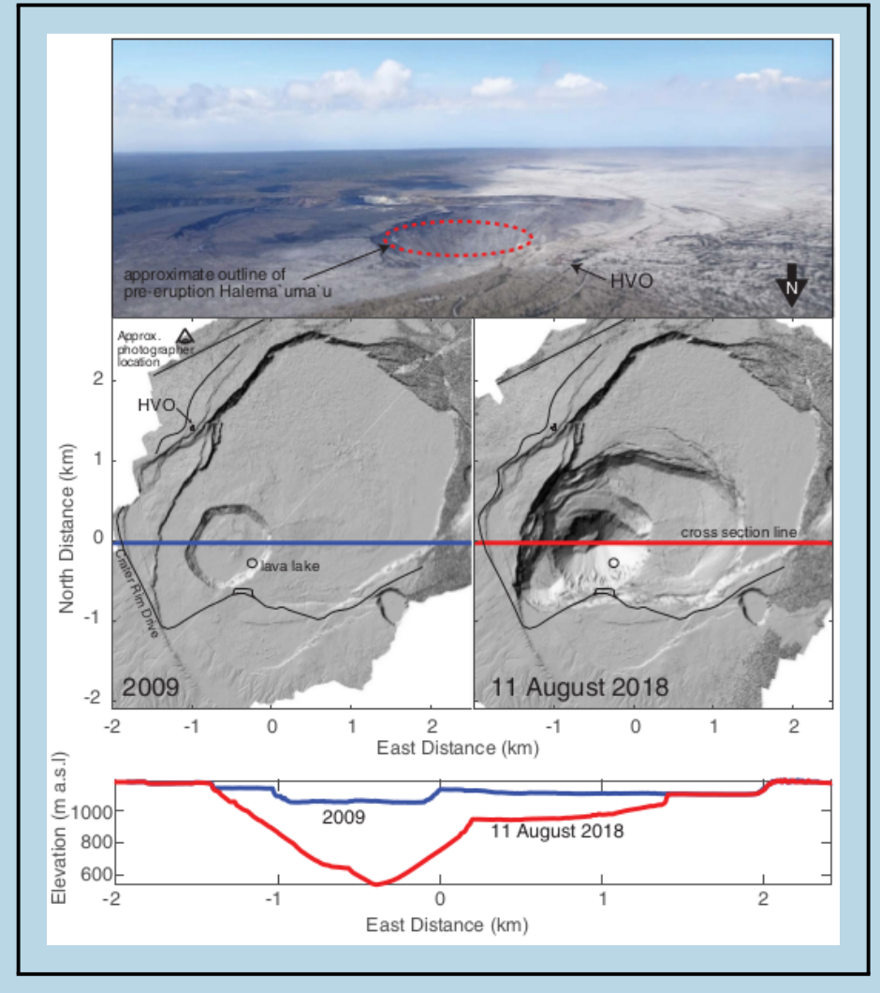
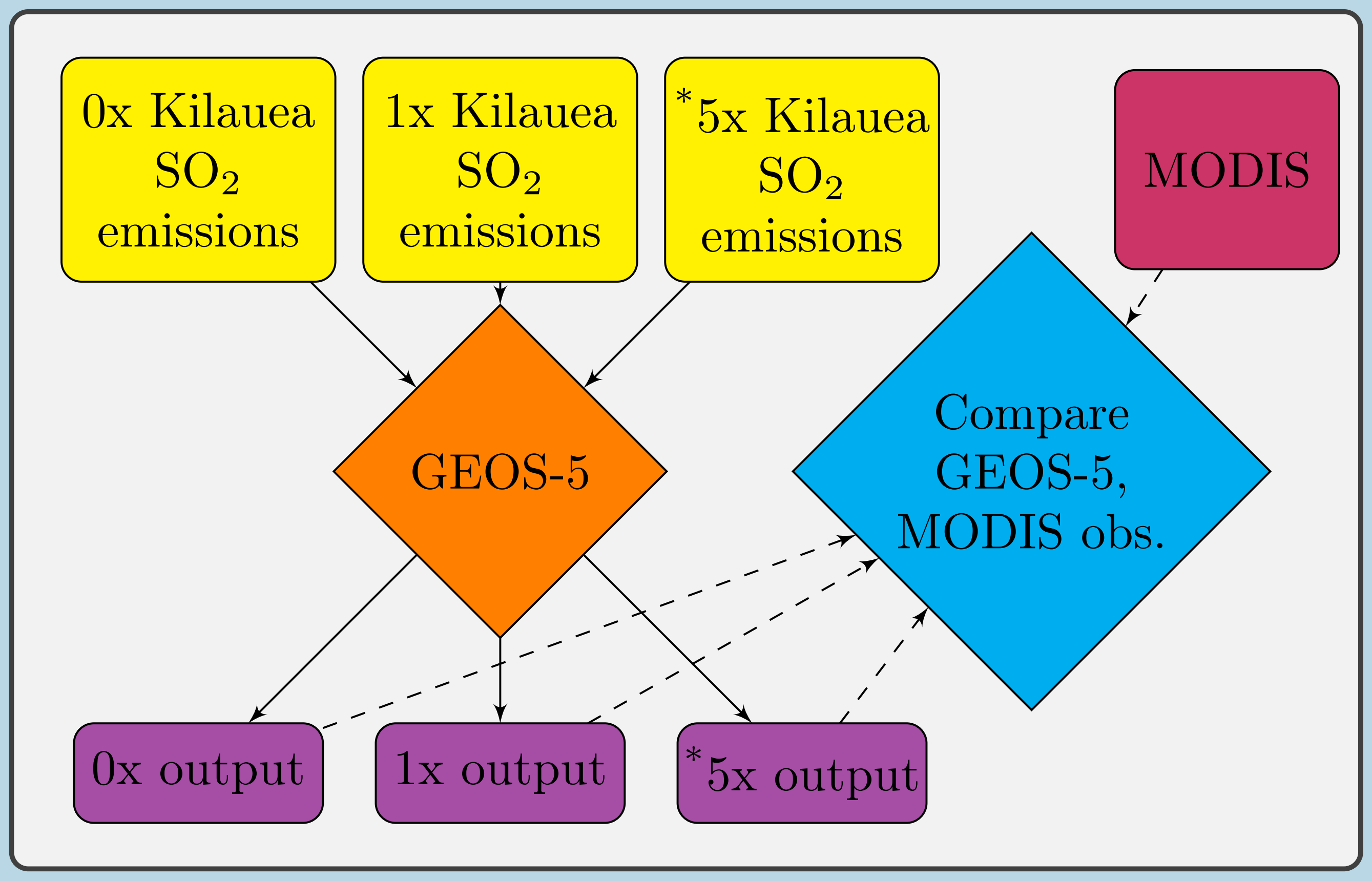


Figure (1) LiDAR digital elevation models of the Kilauea summit crater after the 2008 (left) and 2018 (right) degassing events [9].

The objective of this work is to assess the effects of sulfate aerosols on cloud formation using two volcanic eruptions in the Hawaiian islands (Kilauea volcano; 2008, 2018) as natural experiments [12, 6]. Kilauea is an active volcano located on the island of Hawaii characterized by weak eruptive (explosive) and effusive (lava flow) events. Degassing associated with summit eruptions in summer 2008 formed an aerosol plume to the W-SW of Kilauea. In late May/early June 2018, Kilauea experienced its largest volcanic events in 200 years - a coincident effusive event in the East Rift Zone (ERZ) and violent summit eruptions causing the collapse of the caldera (Figure 1).

Summit degassing was likely caused by rockfalls related to vent widening and/or seismic activity which then released gas trapped below the lava lake surface [10]. Degassing events produced variable volumes of tephra (ash), with maximum plume heights of ≈ 2500 m (2008) and ≈ 8100 m (2018) [5, 9]. Both events were accompanied by effusive lava flows in the ERZ. Elevated SO_2 levels were observed in 2008; however, levels in 2018 were 2–3× greater than mean values [12, 9]. Cloud macro/microphysical changes are evident in the plume to the W of Hawaii following the 2088 and 2018 events.

Methods



0x Kilauea SO_2 emissions

1x Kilauea SO_2 emissions

*5x Kilauea SO_2 emissions

MODIS

GEOS-5

Compare GEOS-5, MODIS obs.

0x output

1x output

*5x output

*5x emissions for 2008 only

Datasets

The Aqua/MODIS Aerosol Cloud Monthly L3 Global 1° datasets were acquired from the Level-1 and Atmosphere Archive & Distribution System (LAADS) Distributed Active Archive Center (DAAC), located in the Goddard Space Flight Center in Greenbelt, Maryland (https://ladsweb.nascom.nasa.gov/).

The MODIS Cloud Droplet Number Concentration (CDNC) Climatology (2003 – 2015) was provided by [4]. The data can be downloaded at https://doi.org/10.15695/vudata.ees.

GEOS Model

The current generation of the Global Earth Observing System (GEOS-5; http://gmao.gsfc.nasa.gov/research/) is described in [11, 7, 2]. The formation and evolution of clouds is calculated with a two-moment cloud microphysics scheme [2], which allows the linkage of aerosol emissions to cloud properties and predicts the mixing ratio, cloud droplet number concentration, and effective radius of ice and liquid clouds [8, 2]. Ice crystal nucleation and cloud droplet activation are treated using approaches of [3] and [1], respectively.

Results

2008 Liquid Clouds

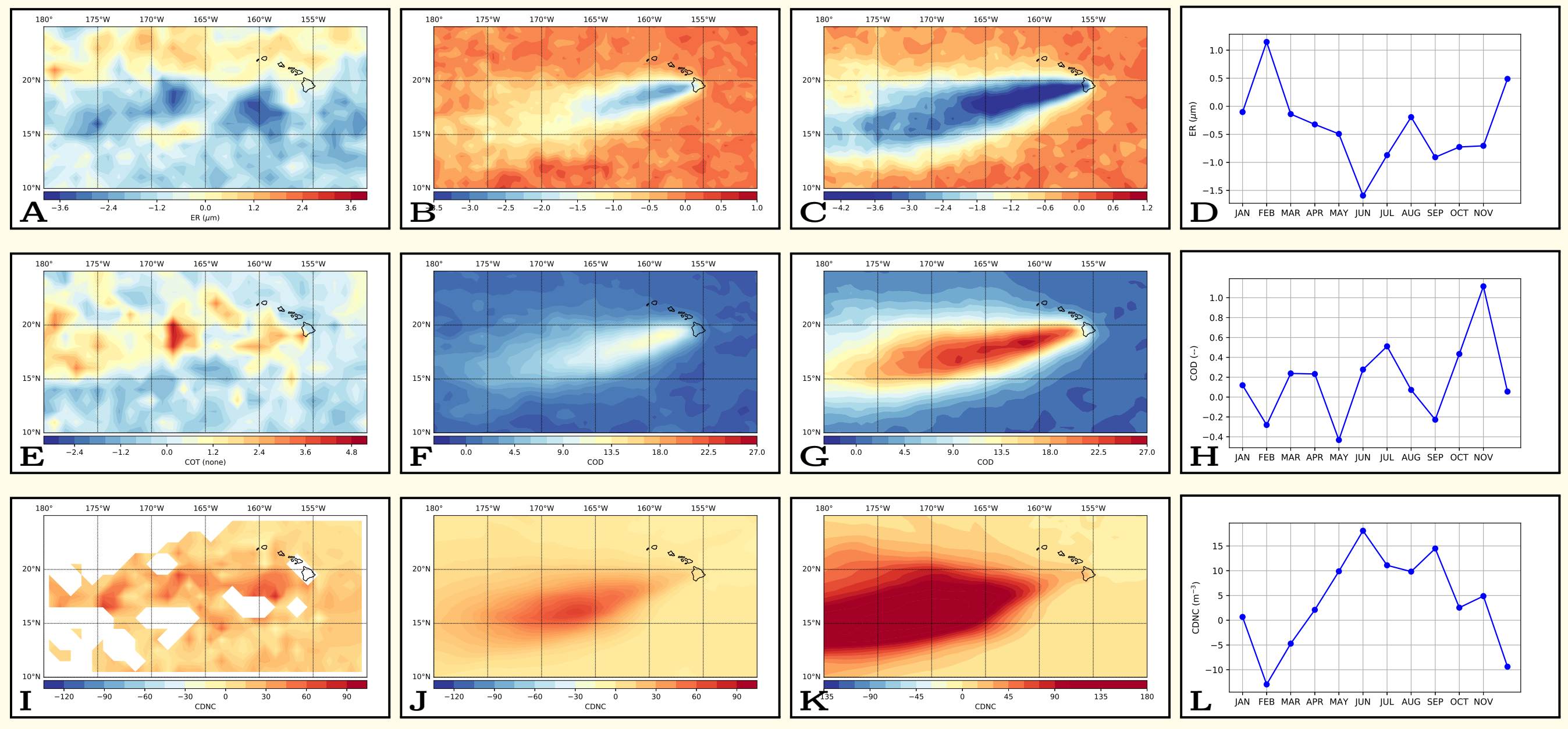


Figure (2) MODIS observations and GEOS-5 predictions for liquid clouds following 2008 Kilauea degassing event. From left: MODIS JJA anomaly wrt seasonal climatology (2003 – 2015), GEOS-5 prediction difference for 1 × −0× emissions, GEOS-5 model prediction difference for 5 × −0× emissions, MODIS monthly mean anomaly for 2008 with seasonal means removed. A-D: effective radius (microns), E-H: Cloud optical depth (COD; –), I-L: cloud droplet number concentration (CDNC; m^{-3}).

2018 Liquid Clouds

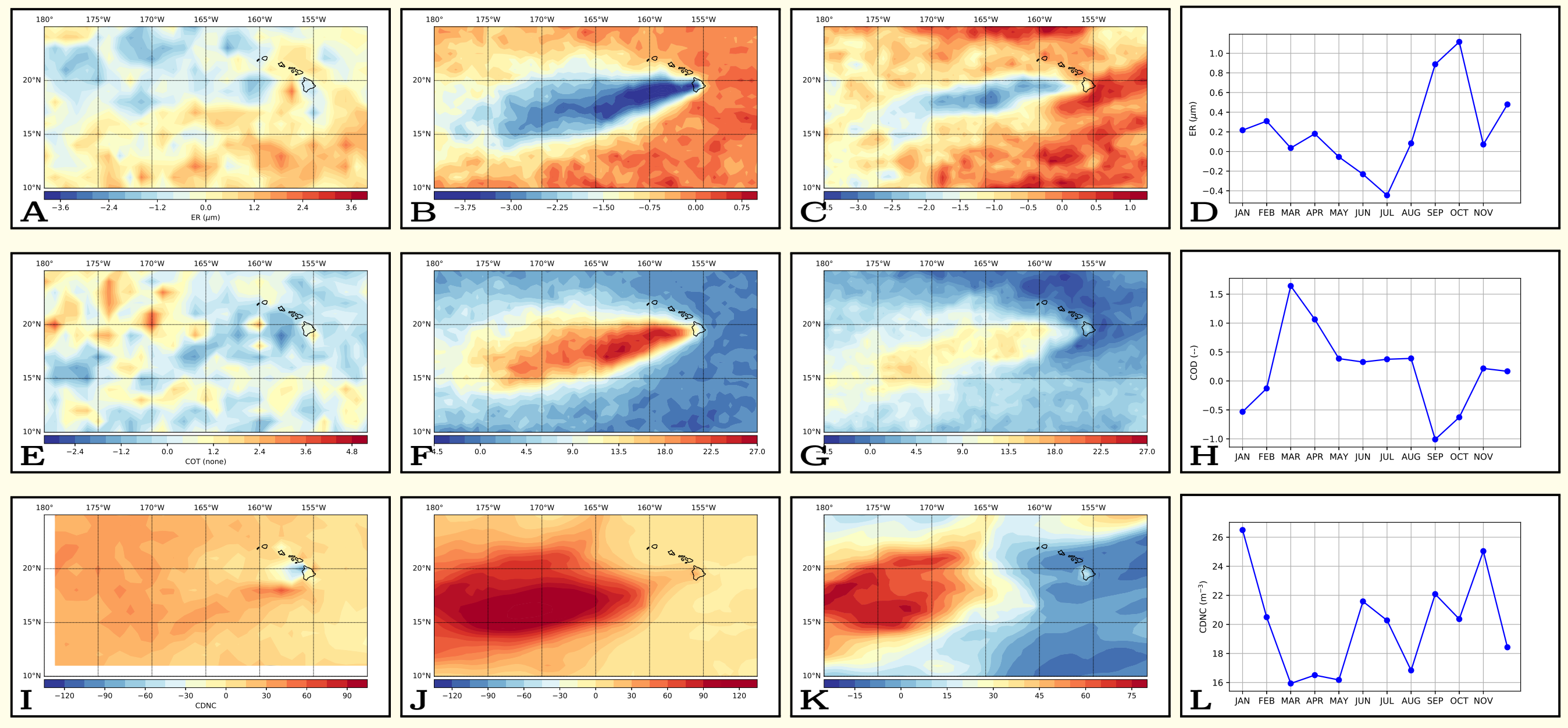


Figure (4) MODIS observations and GEOS-5 predictions for liquid clouds following 2018 Kilauea degassing event. From left: MODIS JJA anomaly wrt seasonal climatology (2003 – 2015), GEOS-5 prediction difference for 1 × −0× emissions, GEOS-5 model prediction difference for 1× 2018 −1× 2008 emissions, MODIS monthly mean anomaly for 2018 with seasonal means removed. A-D: effective radius (microns), E-H: Cloud optical depth (COD; –), I-L: cloud droplet number concentration (CDNC; m^{-3}).

2008 Ice Clouds

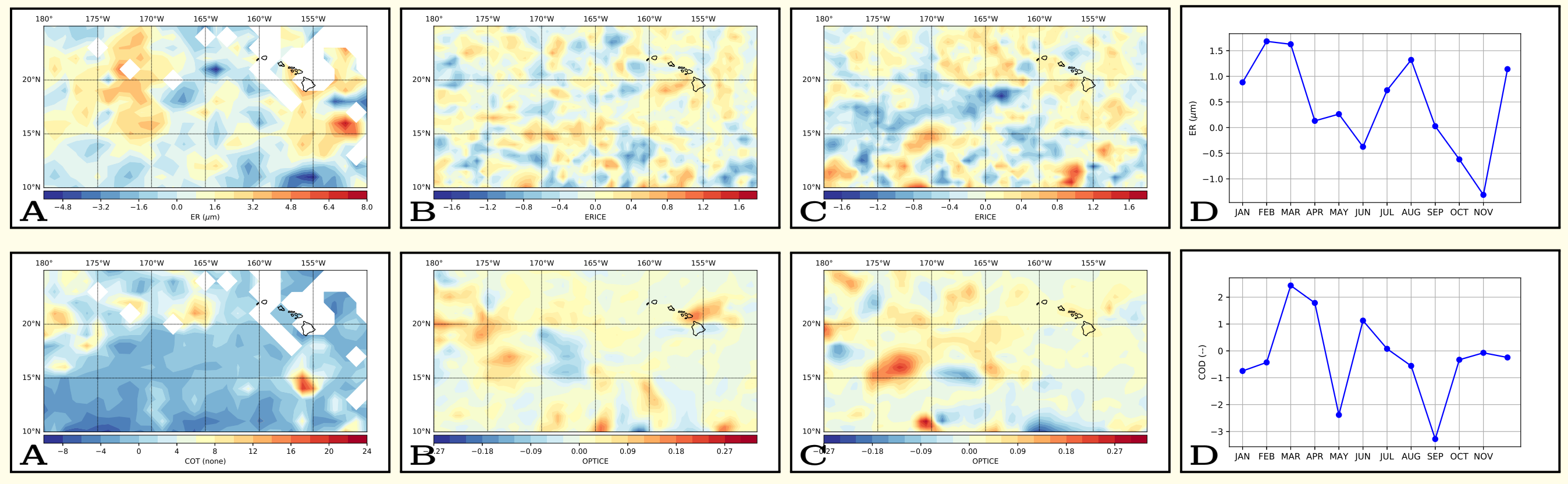


Figure (3) MODIS observations and GEOS-5 predictions for ice clouds following the 2008 Kilauea degassing event. From left: MODIS JJA anomaly wrt seasonal climatology (2003 – 2015), GEOS-5 prediction difference for 1 × −0× emissions, GEOS-5 model prediction difference for 5 × −0× emissions, MODIS monthly mean anomaly for 2008 with seasonal means removed. A-D: effective radius (microns), E-H: Cloud optical depth (COD; –).

2018 Ice Clouds

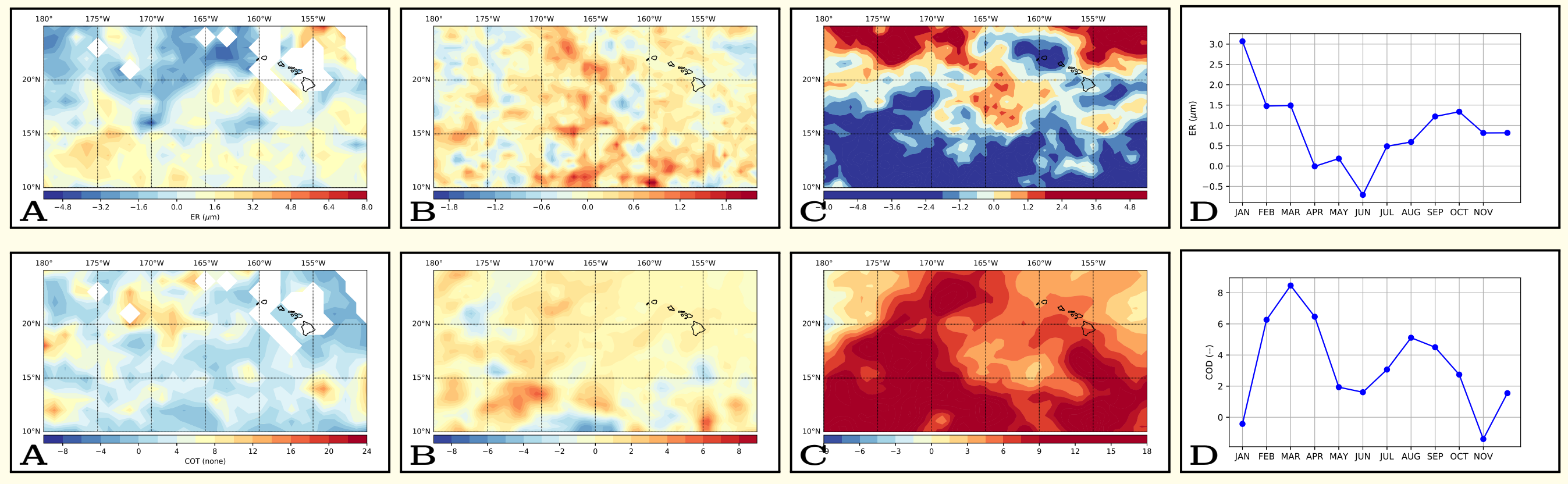


Figure (5) MODIS observations and GEOS-5 predictions for ice clouds following 2018 Kilauea degassing event. From left: MODIS JJA anomaly wrt seasonal climatology (2003 – 2015), GEOS-5 prediction difference for 1 × −0× emissions, GEOS-5 model prediction difference for 1× 2018 −1× 2008 emissions, MODIS monthly mean anomaly for 2018 with seasonal means removed. A-D: effective radius (microns), E-H: Cloud optical depth (COD; –).

Conclusions

The 2018 Kilauea degassing event was stronger and more regionally significant with respect to cloud formation process for both liquid and ice clouds, while the 2008 affected local liquid clouds only.

For liquid clouds, The 2008 5× emissions scenario resembles modeled and observed conditions for the 1× event in 2018. This indicates that effects on liquid clouds were dominated by elevated SO_2 concentrations.

For ice clouds, changes in cloud microphysics were significant following the 2018 event while few, if any, effects are apparent wrt the 2008 event. This suggests that plume height was a significant factor in ice droplet nucleation.

Acknowledgements

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