GHRSST
GROUP FOR HIGH RESOLUTION SEA SURFACE TEMPERATURE

Effects of the Hunga Tonga-Hunga Ha'apai Eruption on MODIS-retrieved Sea Surface Temperatures

International SST User Symposium and GHRSST International Science Team Meeting (GHRSST24)

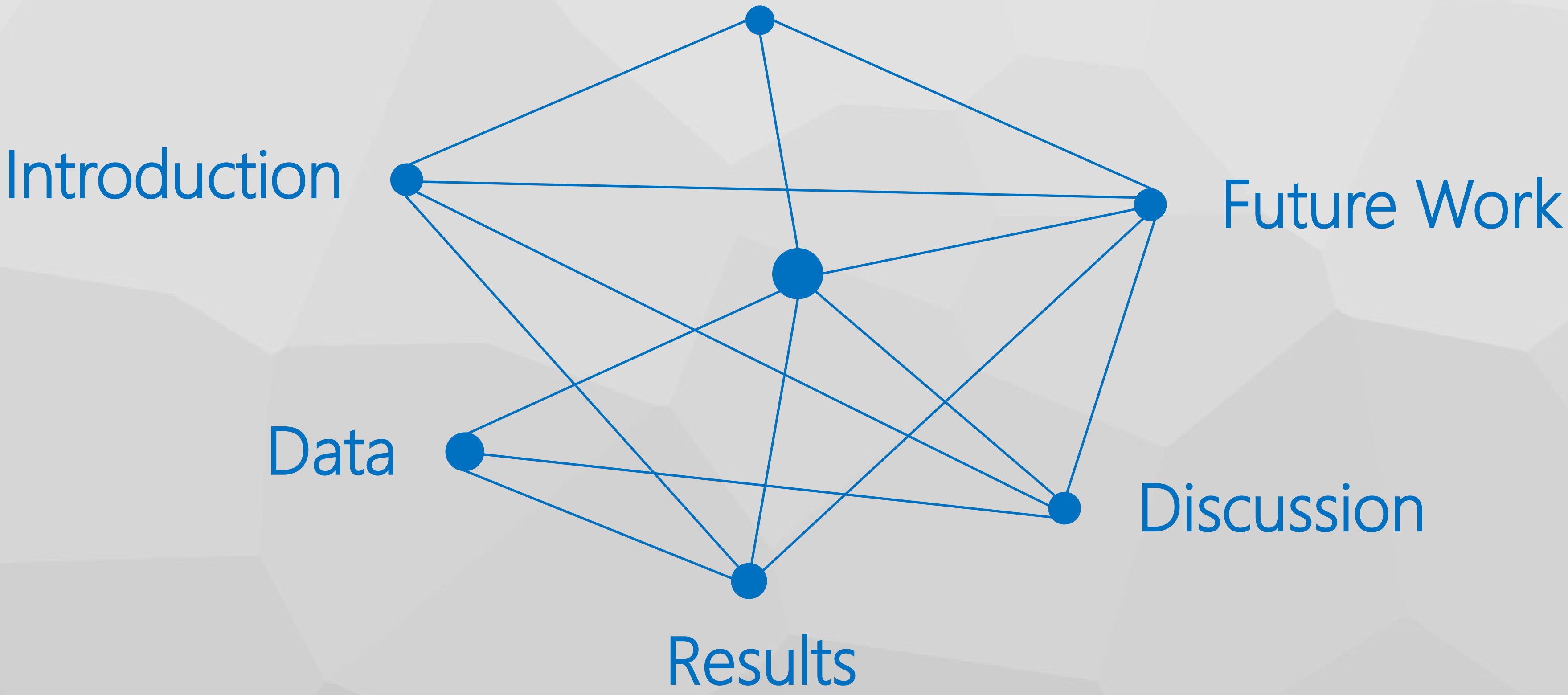
Rosenstiel School of Marine, Atmospheric, and Earth Science, University of Miami

Presenter： Chong Jia

Co-author： Peter Minnett

GHRSST
GROUP FOR HIGH RESOLUTION SEA SURFACE TEMPERATURE

CONTENT



Find further details from:

Jia, C., & Minnett, P. J. (2023). Effects of the Hunga Tonga-Hunga Ha'apai eruption on MODIS-retrieved sea surface temperatures. *Geophysical Research Letters*, 50, e2023GL104297. https://doi.org/10.1029/2023GL104297

1 Introduction

Research Background

GHRSST
GROUP FOR HIGH RESOLUTION SEA SURFACE TEMPERATURE

MODIS Nonlinear SST (NLSST) Retrieval Algorithm

$$SST_{sat} = a_0 + a_1 BT_{11} + a_2(BT_{11} - BT_{12})T_{sfc} + a_3(\sec\theta - 1)(BT_{11} - BT_{12})$$
$$+ a_4(mirror) + a_5(\theta) + a_6(\theta^2)$$

- BT_{11}: Brightness temperature (BT) in the 11 μm channel
- BT_{12}: BT in the 12 μm channel
- T_{sfc}: Reference SST
- θ: Sensor zenith angle
- $mirror$: Different sides of the MODIS scan mirror
- a_0-a_6: Algorithm coefficient set for month of year and latitude zone

GHRSST
GROUP FOR HIGH RESOLUTION SEA SURFACE TEMPERATURE

Aerosol Effect on SST from Infrared Satellite

- Satellite retrievals are highly degraded in aerosol-contaminated regions, for example, caused by tropospheric dust from the Saudi Arabian and Sahara deserts.
- Luo et al. (**2019**) demonstrated the aerosol effect on MODIS retrieved SST and introduced an improved algorithm for nighttime data in the Saharan dust outflow area.
- Beyond dust aerosols, dramatic volcanic explosions inject large amounts of aerosol into the stratosphere, such as Mt. Pinatubo (Philippines, 1991) and El Chichón (Mexico, 1982).
- Reynolds et al. (**1989**) showed a mean bias of −0.3 K for the Advanced Very High Resolution Radiometer (AVHRR) multichannel SST from 1982 to 1984 associated with the stratospheric aerosol due to El Chichón.
- Reynolds (**1993**) further studied the impact of Mt. Pinatubo aerosols on AVHRR SST, where nighttime data had average negative biases with magnitudes > 1 K between 20° N and 20° S in August and September 1991.

Hunga Tonga-Hunga Ha'apai Volcanic Eruption

Image credit: Maxar Technologies via Getty Images

- The submarine eruption of volcano Hunga Tonga-Hunga Ha'apai (HTHH) (20.54° S, 175.38° W) on 15 January 2022 was the most explosive eruption since Mt. Pinatubo in 1991.
- HTHH injected an unprecedented mass of H_2O into the stratosphere, up to 146 Tg (Millán et al., 2022), ~10% of the total stratospheric burden.

- In contrast, the sulfur dioxide (SO_2) injection was surprisingly low, estimated ~0.4 Tg from several satellite instruments (Carn et al., 2022; Millán et al., 2022), whereas Mt. Pinatubo lofted ~20 Tg SO_2 into the stratosphere (Guo et al., 2004; Read et al., 1993).
- However, it was the greatest perturbation of stratospheric aerosols since the Mt. Pinatubo eruption with 1–3 Tg of sulfate aerosol injected (Sellitto et al., 2022).

2

Data

Research Methodology

MODIS Matchup Database (MUDB)

- A matchup database (MUDB) has been established by collocating MODIS retrieved SST, BTs derived from radiance measurements, in situ drifting buoy SST (SST_{buoy}) and other ancillary information (e.g., time, location, quality level (QL) flag and viewing geometry).
- The time window between satellite and field measurements is < 30 min, and the distance is < 10 km.
- The good quality data with QL = 0 (best) and QL = 1 (degraded, generally by longer atmospheric path lengths resulting from larger scan angles) are used.
- The SST bias error, ΔSST, is defined as: $\Delta SST = SST_{sat} - SST_{buoy}$

Auxiliary Datasets

- MODIS on Aqua aerosol optical depth (AOD) at 550 nm is taken from the MYD04_L2 files, applying the Dark Target algorithm over the ocean.
- The Rutherford Appleton Laboratory Infrared/Microwave Sounder (IMS) retrieval core scheme retrieves sulfate-specific optical depth (SOD) at 1,170 cm^{-1}.
- The Ozone Mapping and Profiler Suite Limb Profiler (OMPS-LP) onboard the Suomi-NPP satellite provides the aerosol to molecular extinction ratio (AMER), analogous to aerosol mixing ratio, and integrated stratospheric AOD (sAOD) in six visible bands.
- The Microwave Limb Sounder (MLS) on board NASA's Aura satellite provides H_2O mixing ratio derived from radiances measured primarily by the 190 GHz radiometer.
- Surface and vertical profiles of meteorological data are taken from MERRA-2 reanalysis, including temperature, specific humidity and wind speed.

3

Results

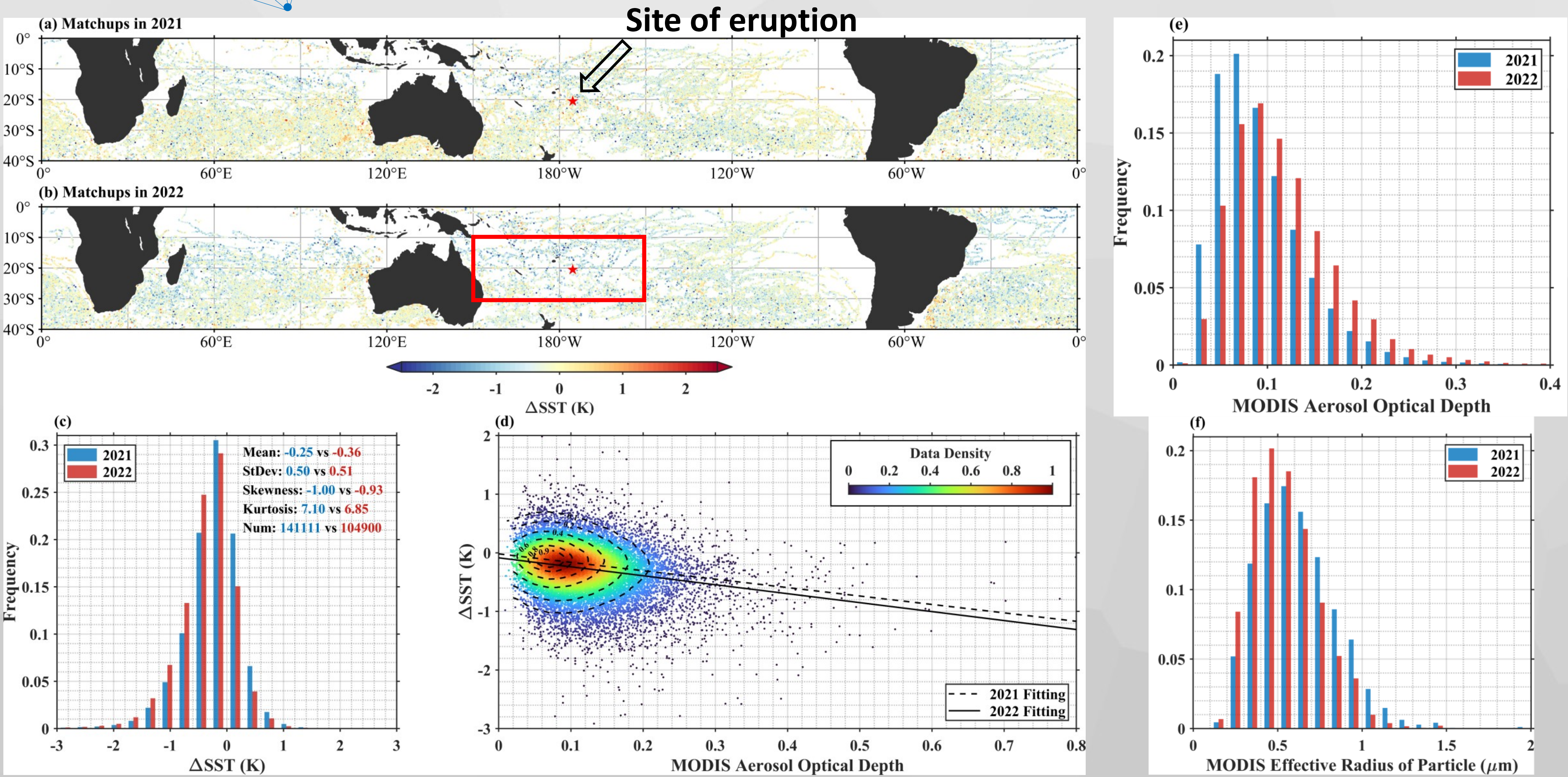
Research Procedure

General Effect of the HTHH Eruption on MODIS SST

Table 1
Statistics of Moderate Resolution Imaging Spectroradiometer Aqua ΔSST (K) Between 40°S–0° and 180°W–180°E, Including the Mean, Median, Standard Deviation, Robust Standard Deviation and Number of Data, Are Presented in Terms of (a) Day and Night Flags and (b) Quality Flags

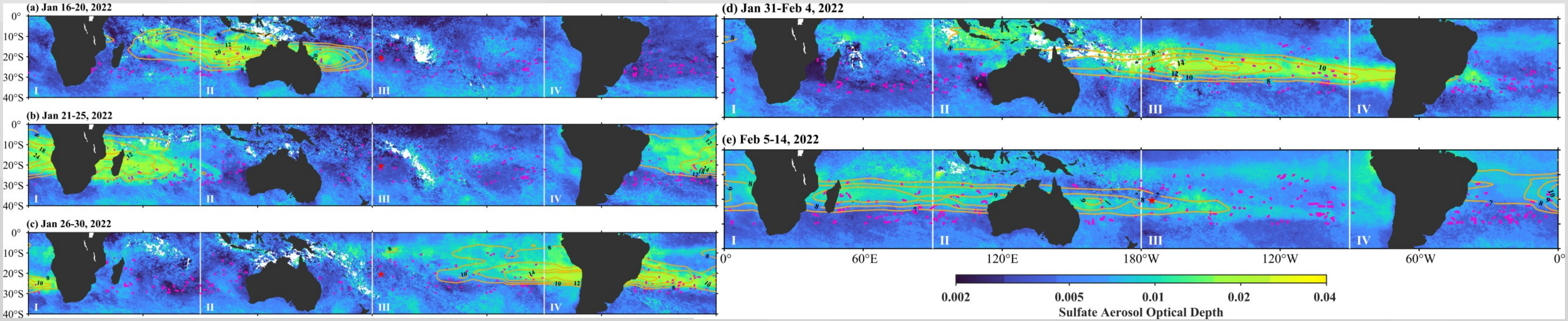
	Day		Night		Total	
(a)	2021	2022	2021	2022	2021	2022
Mean	–0.231	–0.342	–0.272	–0.388	–0.250	–0.363
Median	–0.175	–0.285	–0.210	–0.320	–0.195	–0.300
StDev	0.492	0.494	0.509	0.508	0.500	0.501
Robust StDev	0.419	0.426	0.381	0.393	0.400	0.411
Number	76,056	56,262	65,055	48,638	141,111	104,900
	QL = 0		QL = 1		Total	
(b)	2021	2022	2021	2022	2021	2022
Mean	–0.204	–0.305	–0.340	–0.474	–0.250	–0.363
Median	–0.160	–0.260	–0.290	–0.420	–0.195	–0.300
StDev	0.431	0.433	0.603	0.595	0.500	0.501
Robust StDev	0.344	0.344	0.533	0.541	0.400	0.411
Number	93,533	68,648	47,578	36,252	141,111	104,900

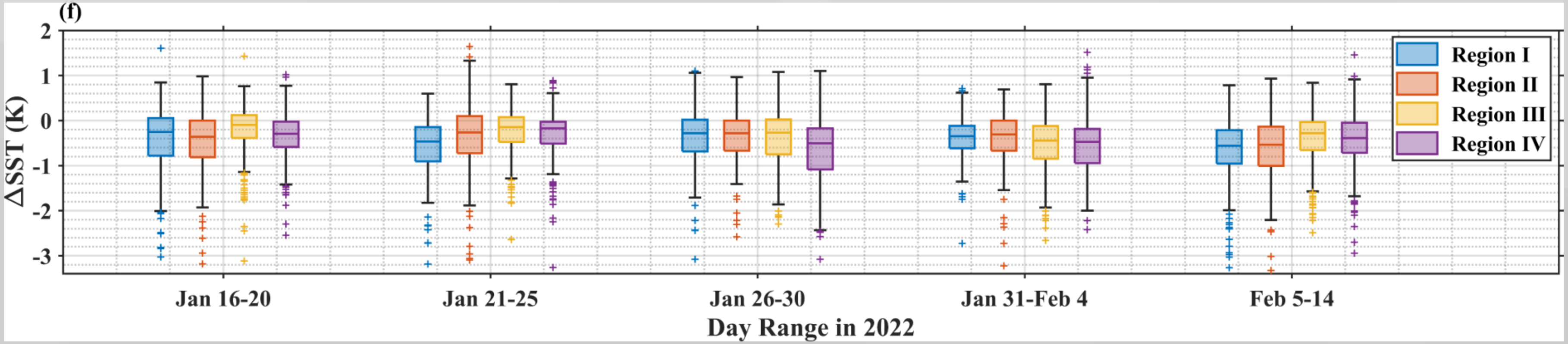
General Effect of the HTHH Eruption on MODIS SST



Initial Evolution of HTHH Plume and Its Effect on MODIS SST

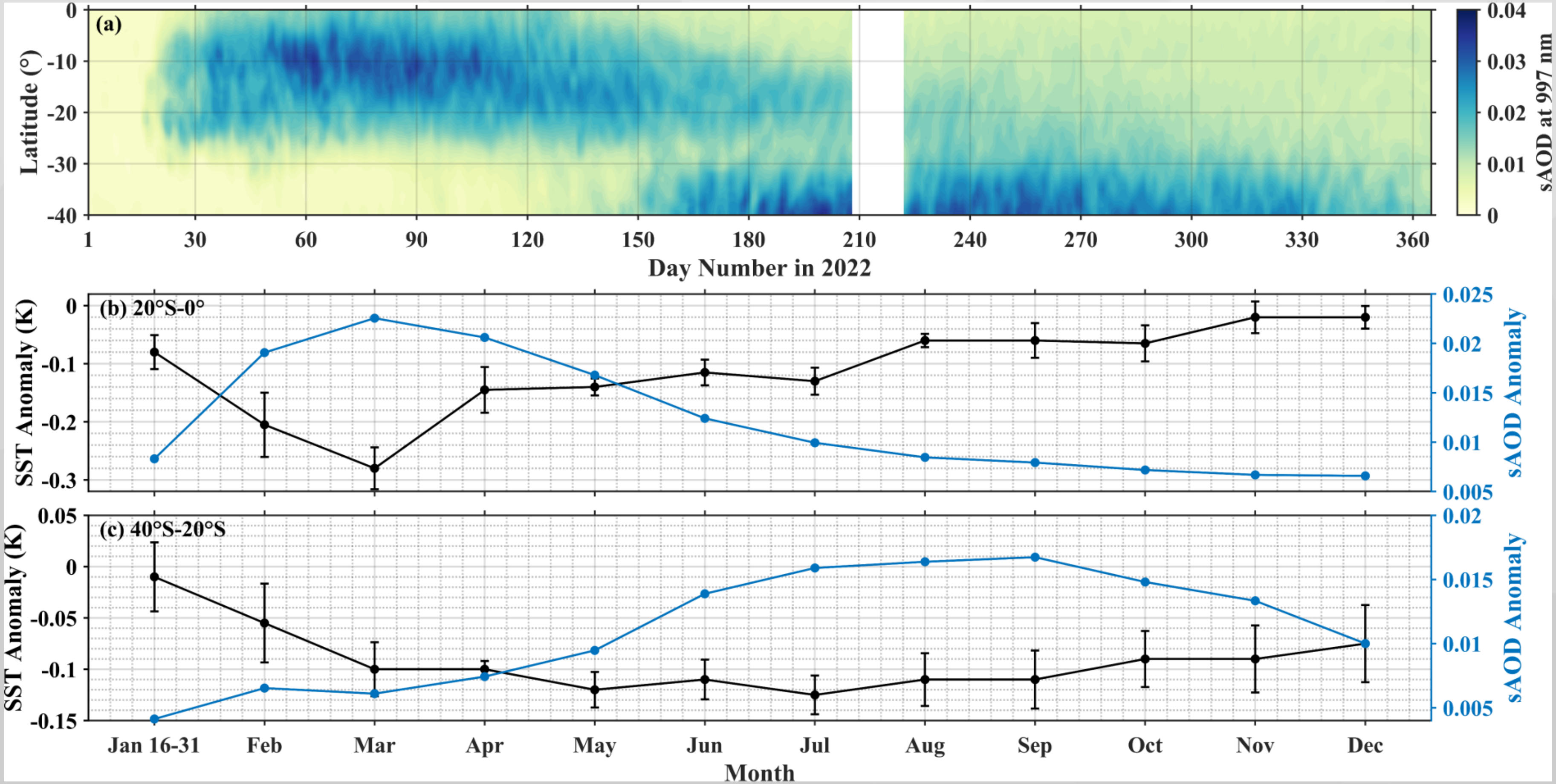
Rapid conversion of SO_2 to sulfate aerosols due to the presence of abundant H_2O in the plume injected into the stratosphere leading to the accelerated oxidation of SO_2 to H_2SO_4.





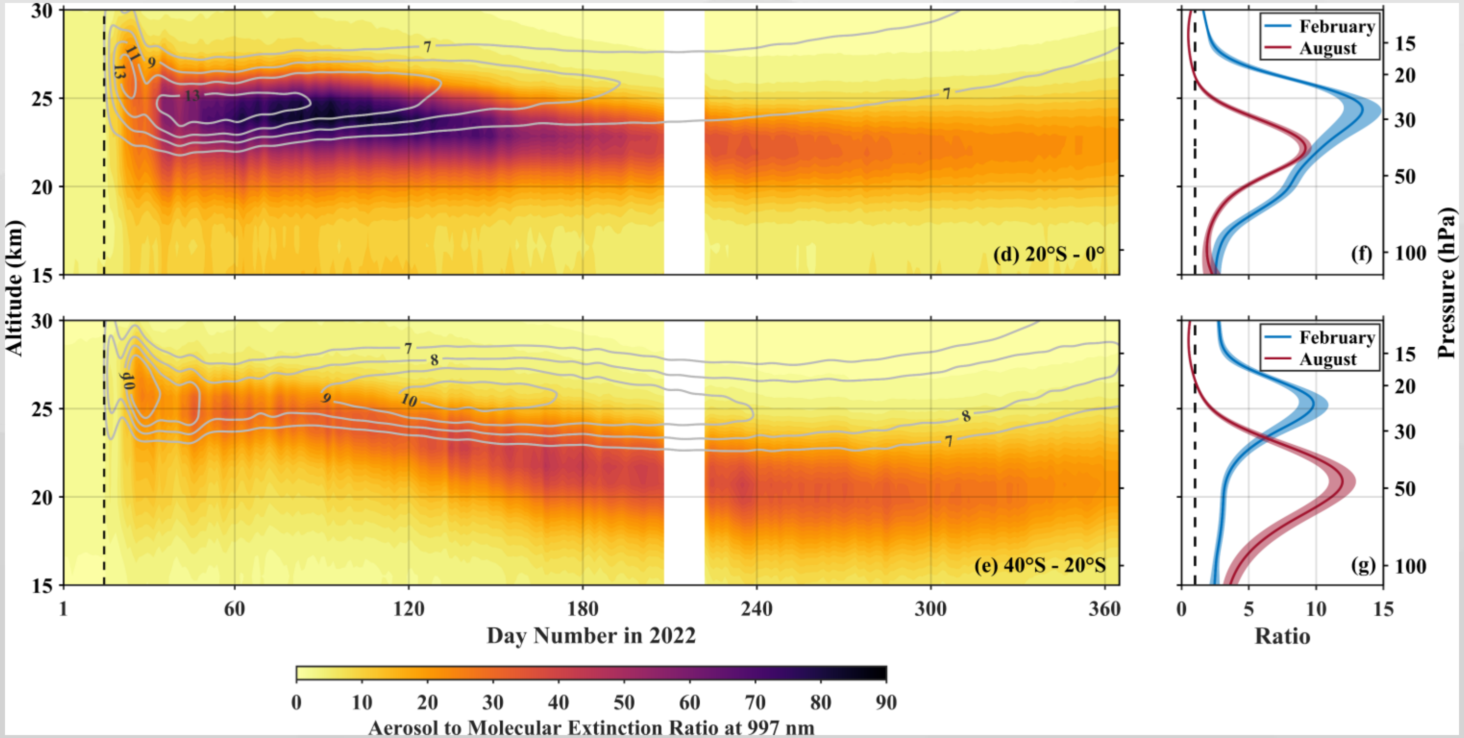
Long-Term Variation of Volcanic Aerosol Effect on MODIS SST

With time, the volcanic aerosol plume continued to elongate and disperse over the whole Southern Hemisphere (SH) tropics, and was subsequently transported poleward by the Brewer–Dobson circulation (BDC) in weeks to months.



GHRSST
GROUP FOR HIGH RESOLUTION SEA SURFACE TEMPERATURE

Long-Term Variation of Volcanic Aerosol Effect on MODIS SST



- **To quantify the aerosol-induced error in MODIS SST, RTTOV v13.1 atmospheric radiative transfer model is used.**
- **The Optical Properties of Aerosols and Clouds (OPAC) pre-defined sulfated droplets type (SUSO) is used in the simulations.**
- **The climatological aerosol profiles generated by the OPAC model are considered as the background aerosol, while the perturbations due to HTHH eruption are evaluated by the monthly mean ratio of 2022/2021 Aerosol to Molecular Extinction Ratio.**

Table 2
Radiative Transfer for TOVS (RTTOV) Simulations of (a) the Mean Negative Biases (K) of Moderate Resolution Imaging Spectroradiometer-Retrieved Sea Surface Temperature Caused by Hunga Tonga-Hunga Ha'apai Volcanic Sulfate Aerosol Compared With the Results From Matchup Data and (b) the Mean Brightness Temperature (BT) Deficits (K) in 11 and 12 µm Channels With the Corresponding BT Difference Induced by Aerosol and H_2O

	February			August		
(a)	MUDB	RTTOV	Number	MUDB	RTTOV	Number
20°S–0°	–0.205	–0.242	2,596	–0.060	–0.089	2,722
40°S–20°S	–0.055	–0.091	9,956	–0.110	–0.144	8,699

GHRSST
GROUP FOR HIGH RESOLUTION SEA SURFACE TEMPERATURE

4 Discussion

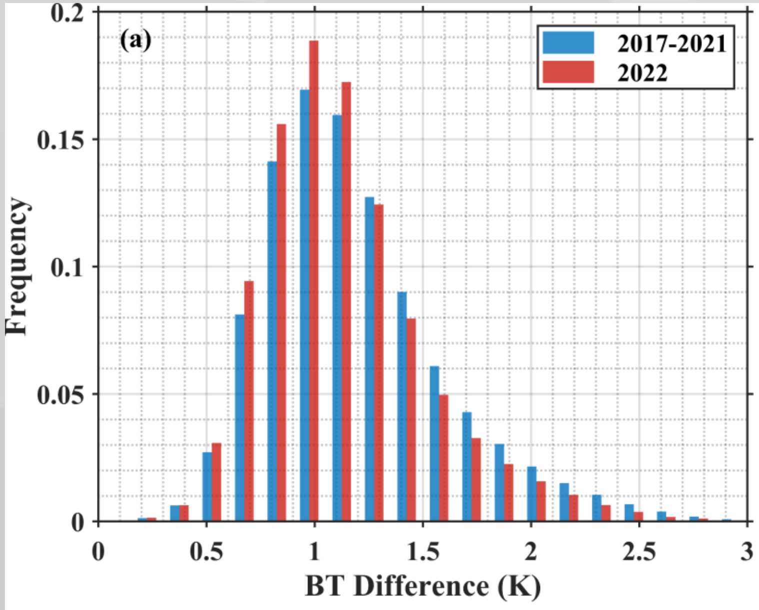
Problem Exploration

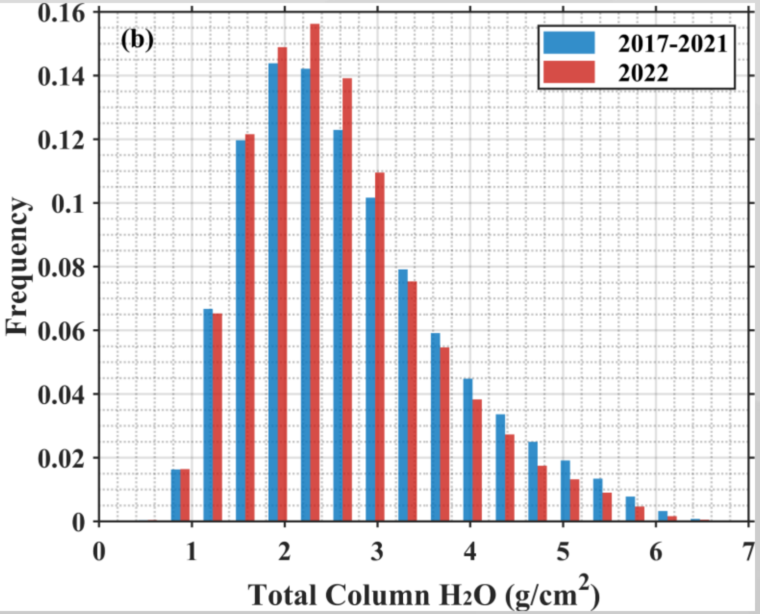
BT Deficits due to H_2O vs Aerosol

Table 2

Radiative Transfer for TOVS (RTTOV) Simulations of (a) the Mean Negative Biases (K) of Moderate Resolution Imaging Spectroradiometer-Retrieved Sea Surface Temperature Caused by Hunga Tonga-Hunga Ha'apai Volcanic Sulfate Aerosol Compared With the Results From Matchup Data and (b) the Mean Brightness Temperature (BT) Deficits (K) in 11 and 12 μm Channels With the Corresponding BT Difference Induced by Aerosol and H_2O

		February			August		
(b)		BT_{11} deficit	BT_{12} deficit	BT_{11}–BT_{12}	BT_{11} deficit	BT_{12} deficit	BT_{11}–BT_{12}
20°S–0°S	Aerosol	−0.228	−0.174	−0.054	−0.097	−0.079	−0.018
	H_2O	−6.970	−8.330	1.361	−5.870	−6.947	1.077
40°S–20°S	Aerosol	−0.085	−0.065	−0.020	−0.105	−0.064	−0.041
	H_2O	−5.423	−6.490	1.067	−3.761	−4.558	0.797





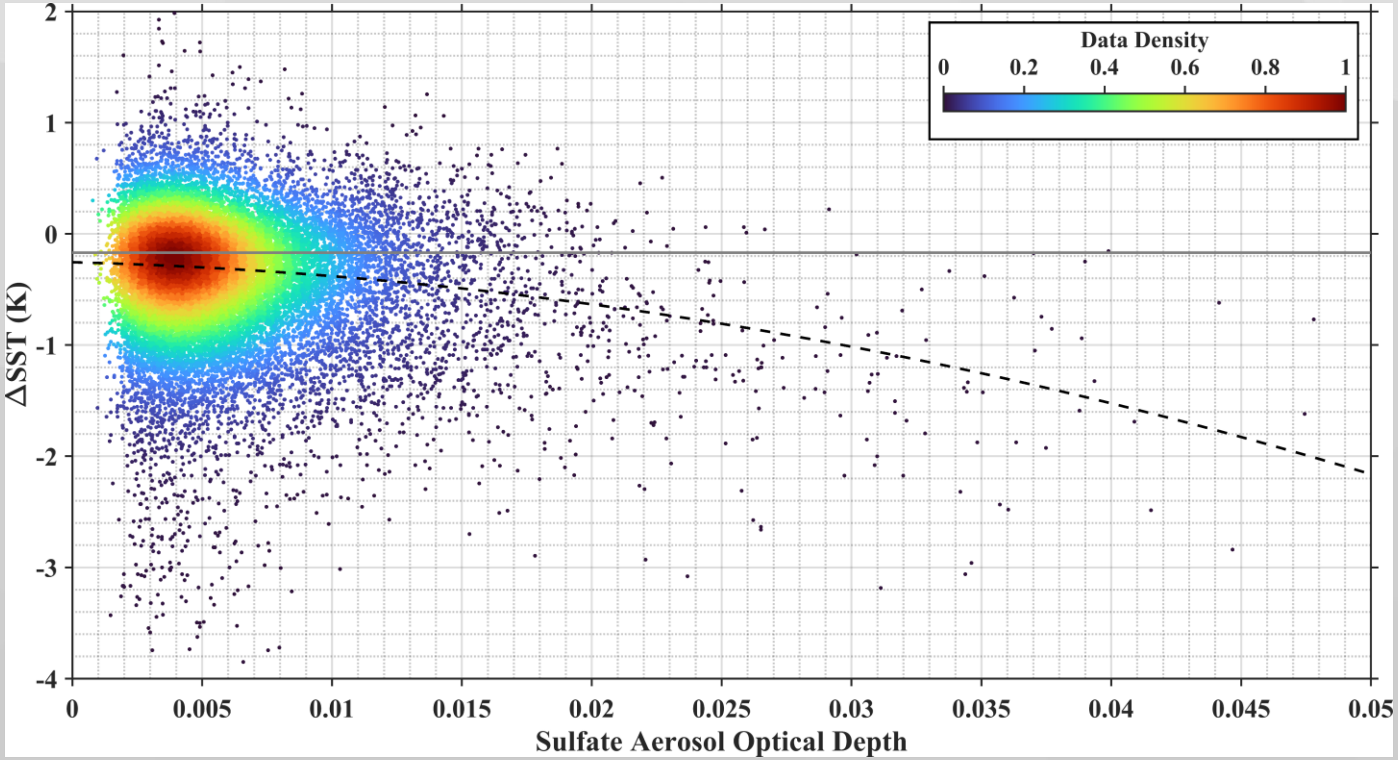
- **The BT deficit due to H_2O absorption at 12 μm is greater than that at 11 μm, whereas the aerosol-induced attenuation is opposite.**
- **The negative offsets of BT difference, −0.06 K on average, are observed in the MUDB.**
- **The total column H_2O in the atmosphere was reduced.**

5 Future Work

Further Research

Possible Further Studies

- To check the HTHH eruption effect on SST from other infrared satellite remote sensing sensors, such as AVHRR, VIIRS, SLSTR.
- To develop a strategy or an improved algorithm to correct for these aerosol effects, considering the long duration and wide coverage with some parts of the plume crossing the equator.



References

- Luo, B., Minnett, P. J., Gentemann, C., & Szczodrak, G. (2019). Improving satellite retrieved night-time infrared sea surface temperatures in aerosol contaminated regions. *Remote Sensing of Environment*, 223, 8–20. https://doi.org/10.1016/j.rse.2019.01.009
- Reynolds, R. W., Folland, C. K., & Parker, D. E. (1989). Biases in satellite-derived sea-surface-temperature data. *Nature*, 341(6244), 728–731. https://doi.org/10.1038/341728a0
- Reynolds, R. W. (1993). Impact of Mount Pinatubo aerosols on satellite-derived sea surface temperatures. *Journal of Climate*, 6(4), 768–774. https://doi.org/10.1175/1520-0442(1993)006<0768:iompao>2.0.co;2
- Millán, L., Santee, M. L., Lambert, A., Livesey, N. J., Werner, F., Schwartz, M. J., et al. (2022). The Hunga Tonga-Hunga Ha'apai hydration of the stratosphere. *Geophysical Research Letters*, 49(13), e2022GL099381. https://doi.org/10.1029/2022gl099381
- Carn, S. A., Krotkov, N. A., Fisher, B. L., & Li, C. (2022). Out of the blue: Volcanic SO2 emissions during the 2021–2022 eruptions of Hunga Tonga—Hunga Ha'apai (Tonga). *Frontiers in Earth Science*, 10, 976962. https://doi.org/10.3389/feart.2022.976962
- Guo, S., Bluth, G. J. S., Rose, W. I., Watson, I. M., & Prata, A. J. (2004). Re-evaluation of SO2 release of the 15 June 1991 Pinatubo eruption using ultraviolet and infrared satellite sensors. *Geochemistry, Geophysics, Geosystems*, 5(4), 1525–2027. https://doi.org/10.1029/2003gc000654
- Read, W. G., Froidevaux, L., & Waters, J. W. (1993). Microwave limb sounder measurement of stratospheric SO2 from the Mt. Pinatubo Volcano. *Geophysical Research Letters*, 20(12), 1299–1302. https://doi.org/10.1029/93gl00831
- Sellitto, P., Podglajen, A., Belhadji, R., Boichu, M., Carboni, E., Cuesta, J., et al. (2022). The unexpected radiative impact of the Hunga Tonga eruption of 15th January 2022. *Communications Earth & Environment*, 3(1), 288. https://doi.org/10.1038/s43247-022-00618-z

GHRSST
GROUP FOR HIGH RESOLUTION SEA SURFACE TEMPERATURE

THANKS