OBSERVTION OF HUNGA TONGA VOLCANIC ERUPTION USING HYPERSPECTRAL INFRARED SATELLITE SENSORS

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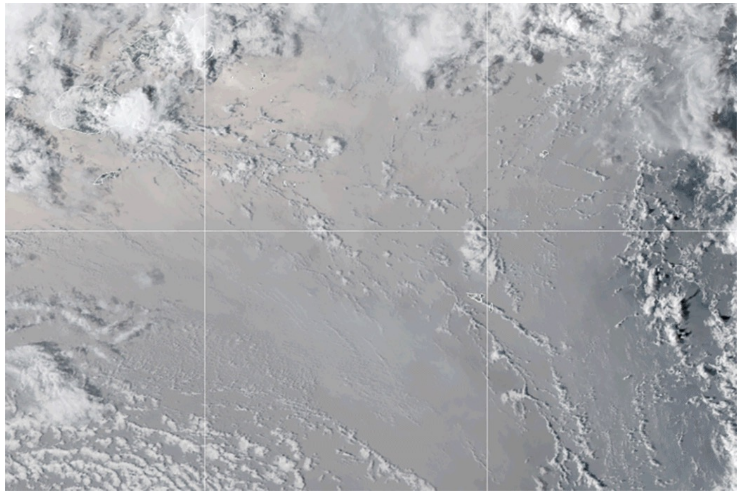
HUNGA TONGA VOLCANIC ERUPTION



This looping video shows an umbrella cloud generated by the underwater eruption of the Hunga Tonga-Hunga Ha'apai volcano on Jan. 15, 2022. The GOES-17 satellite captured the series of images that also show crescent-shaped shock waves and lightning strikes. u003cstrongu003eCredits: NASA Earth Observatory image by Joshua Stevens using GOES imagery courtesy of NOAA and NESDISu003c/strongu003e

- After experiencing two major eruptions of Hunga Tonga-Hunga Ha'apai (HTHH) volcano (175.38°W, 20.57°S) on 19 December 2021 (20:35 UTC) and 13 January 2022 (15:20 UTC), **the most highly explosive eruption of HTHH occurred on 15 January 2022 (between 04:00-04:10 UTC)**, which overshoots the tops of plume to the lower mesosphere of ~55 km.

- In addition to a large amount ejection of SO_2, an exceptional feature from this submarine volcano is the unprecedented ejection of water vapor (in both magnitude and altitudes), which may need to take several years for the H_2O plume to dissipate.

- With a pronounced and persistent sulfate aerosol layer formed near the mid-stratosphere formed and the excess water plume, this eruption may have a large impact on stratospheric temperature, O_3 and climate.

Courtesey https://www.nasa.gov/earth/tonga-eruption-blasted-unprecedented-amount-of-water-into-stratosphere/

Outline

Purpose

- To explore the use of (1) *Cross-track Infrared Sounder (CrIS)* measured hyperspectral infrared spectrum and (2) Single-Field-View (SFOV) sounding retrieval product (SiFSAP) in observing **HUNGA TONGA VOLCANIC ERUPTION** (**the most highly explosive eruption between 04:00-04:10 UTC**),
- Using S-NPP and JPSS-1 data on Jan 15, 2022 (**12:30 UTC and 13:20 UTC) – 8 hours later**

- **Introduction of CrIS, PCRTM and the SiFSAP Retrieval Products**

- **Results:**
  1. **Some Special Features of Hyperspectral Infrared Spectrum of Volcano Umbrella Clouds**
  2. **A New Method to Detect the Cloud Heights using Hyperspectral Infrared Spectrum**
  3. **Some Characteristics of Temperature, Water Vapor and Ozone from SiFSAP**
     - **Enhancement of water vapor**

- **Summary**

CrIS and SiFSAP Products

- **The *Cross-track Infrared Sounder (CrIS)* is an advanced Fourier transform spectrometer that measures the thermal infrared radiances in the long-wave IR band 1 (648.75–1096.25 cm^{-1}), the mid-wave IR band 2 (1208.75– 1751.25 cm^{-1}), and the short-wave IR band 3 (2153.75– 2551.25 cm^{-1})**

- **SiFSAP is a Single Field-of-View Sounder Atmospheric Products retrieved using CrIS and the Advance Technology Microwave Sounder ATMS, based on Principal Component (PC) Radiative Transfer Model (PCRTM)**
  - *Enable calculations of whole CrIS spectrum with very fast speed;*
  - *Able to compute cloud multiple scattering accurately;*

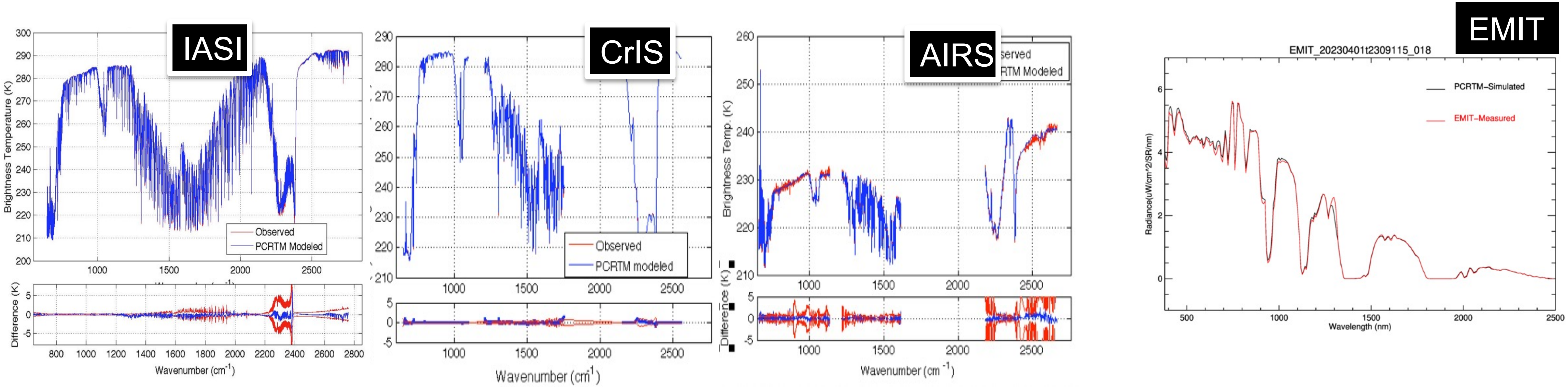
▪Include cloud scattering in forward simulation and directly fit the sounder measurements in the retrieval process under all-sky conditions

▪Avoid using cloud-clearing technique to produce single FOV rather than FOR results

  - *Cloud phase, height, temperature, size, optical depth;*
  - *Surface emissivity spectrum and skin temperature;*

PCRTM (Principal Component based Radiative Transfer Model)

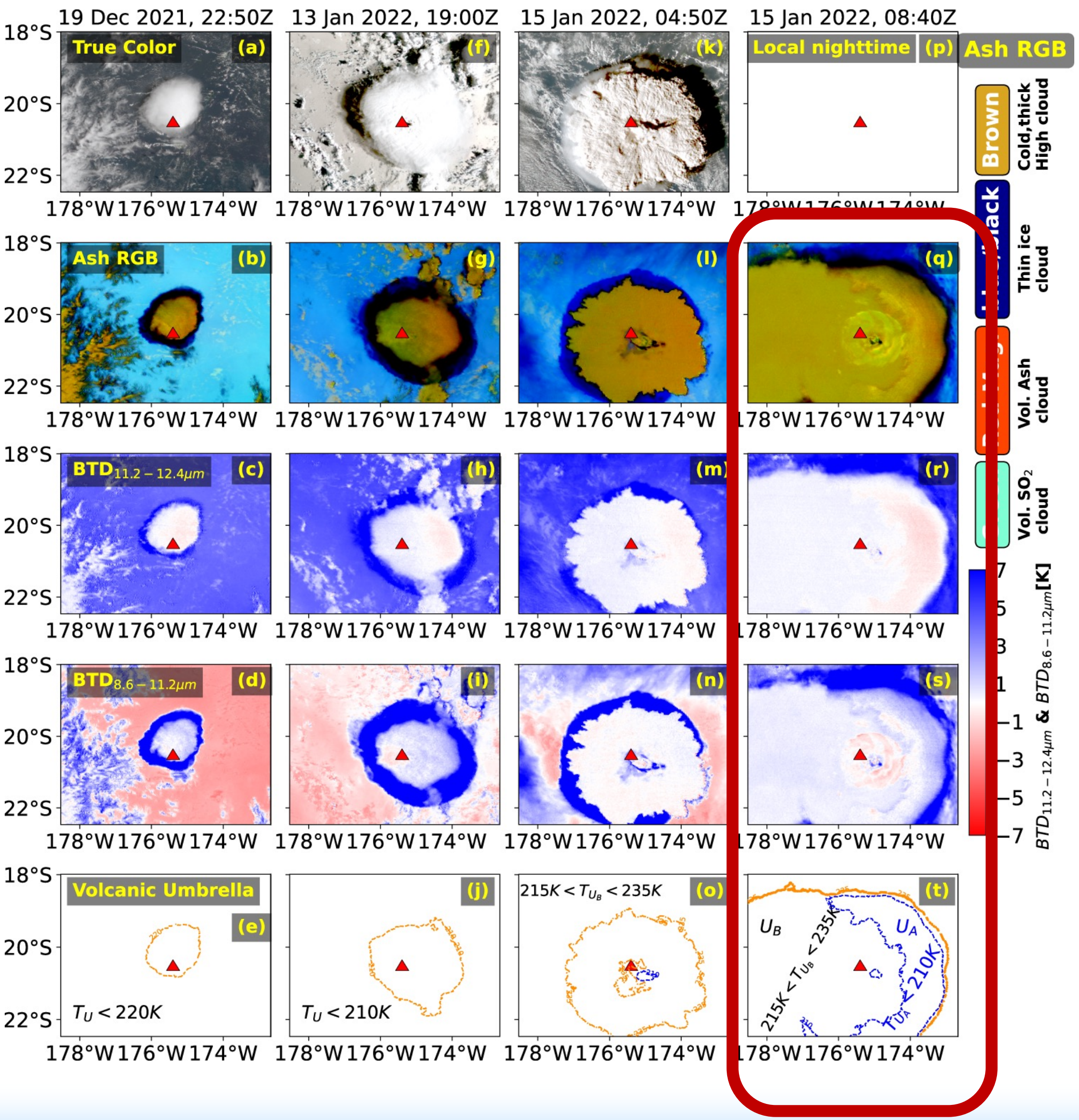
- PCRTM removes spectral redundancy by PC compression;
- PCRTM is a physics-based RTM which needs limited number of monochromatic RT calculations;
- PCRTM has been developed for many satellite remote sensors (AIRS, CrIS, IASI, NAST-I, CLARREO, CPF, SCIAMACHY, OMI, OMPS, EMIT etc.) with many many application (forward model for operational L2/L3 algorithms, look-up table generations, AI algorithm training databases, sensor spectral calibrations, inter-satellite calibrations, high-fidelity simulators, RTM for climate related products….)

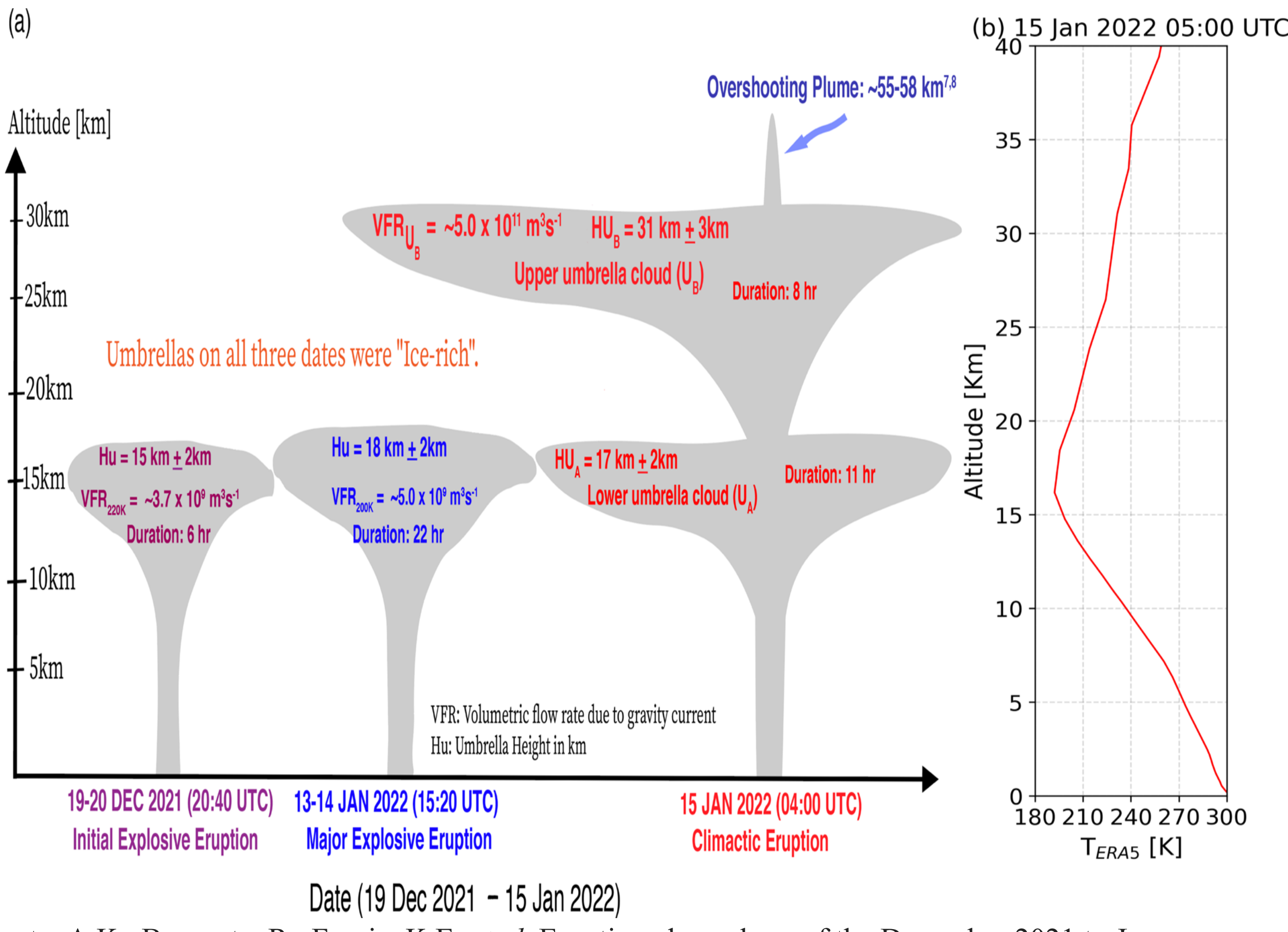


PCRTM simulated and IR sounder (AIRS, CrIS, and IASI) and UV-NIR-SWIR observed TOA radiance

Overshooting of Volcano Plume to Stratosphere

-- two obvious layers of Umbrella Clouds from Himawari-8 geostationary satellite after 5:30 UTC

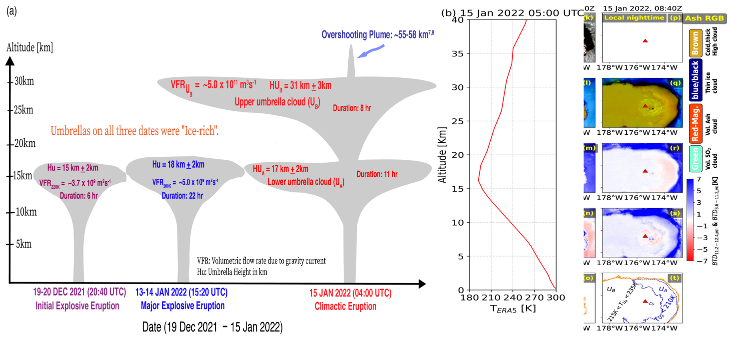




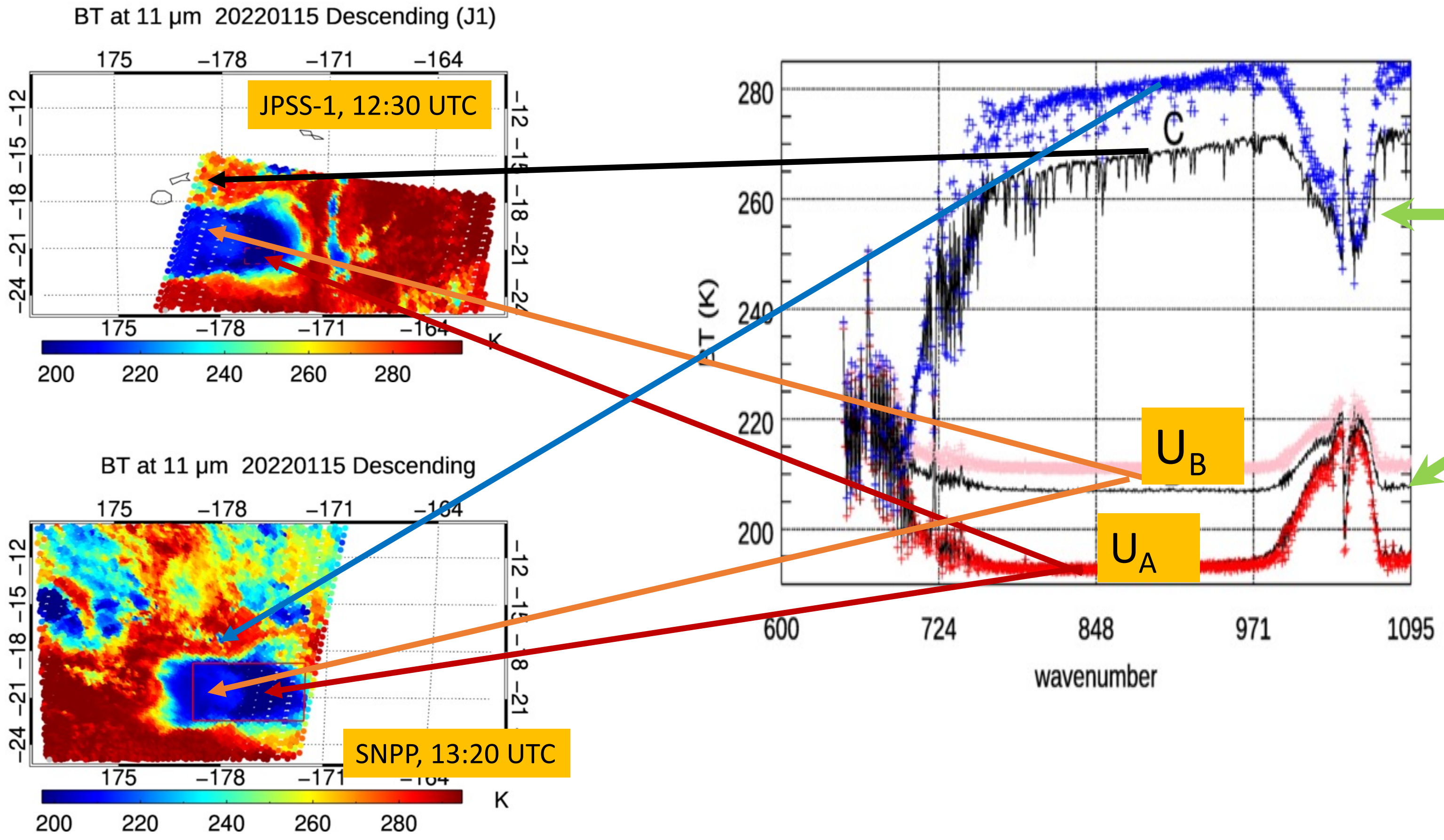
Gupta, A.K., Bennartz, R., Fauria, K.E. *et al.* Eruption chronology of the December 2021 to January 2022 Hunga Tonga-Hunga Ha'apai eruption sequence. *Commun Earth Environ* **3**, 314 (2022). https://doi.org/10.1038/s43247-022-00606-3

Special Spectral Feature of Volcano Clouds on Jan 15, 2022 from CrIS on J-1 (12:30) and S-NPP (13:20 UTC)

Gupta et al., Nature, 2022 shows the upper umbrella cloud (U_B) at 31 km ± 3 km and the lower umbrella cloud (U_A) at 17 km ± 2 km



Courtesy of Gupta et al., Nature, 2022



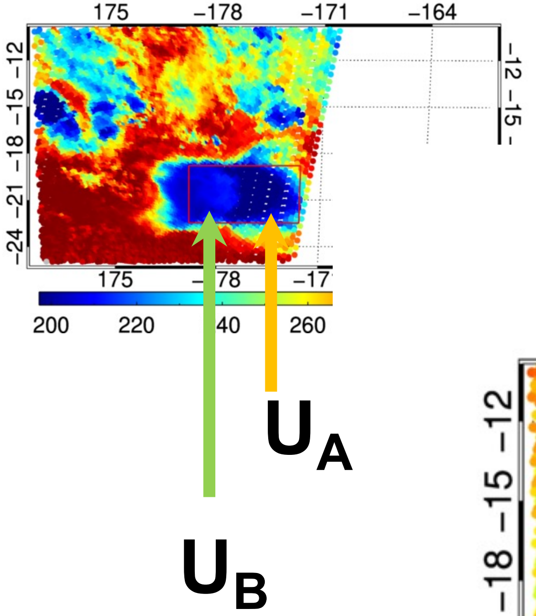
Over clear sky and low clouds

- ✓ Inverted-V shape near 9.6 μm (1042cm^{-1});
- ✓ it is shallower over upper cloud(U_B) than over U_A

In the square, left half is U_B and right half is U_A

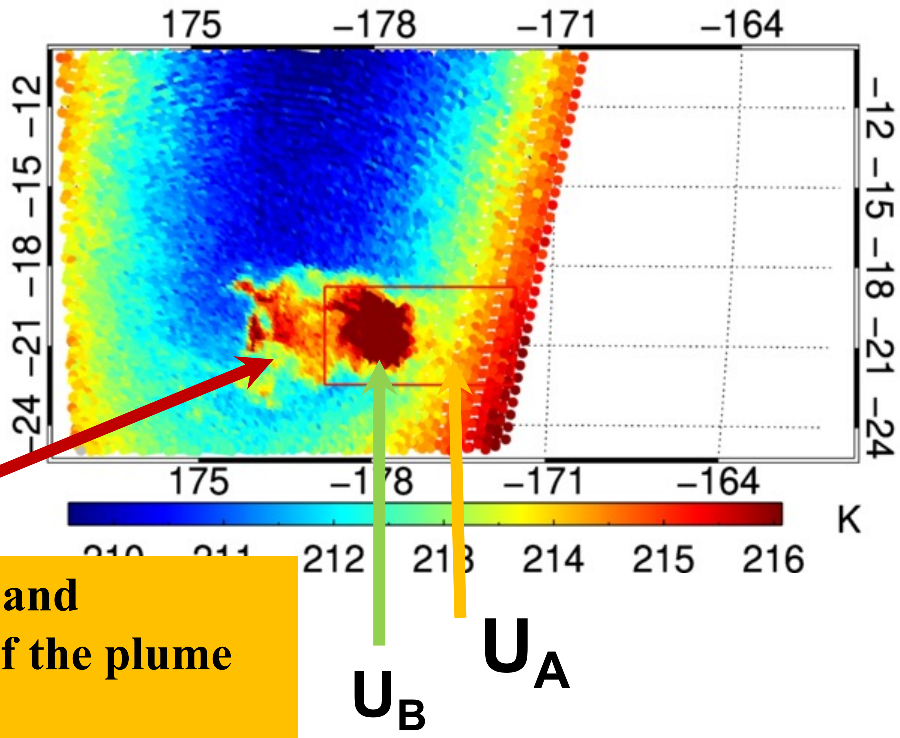
Upper Umbrella Cloud U_B is evident from Stratospheric channels of CrIS

BT at 11 μm 20220115 Descending (J1)



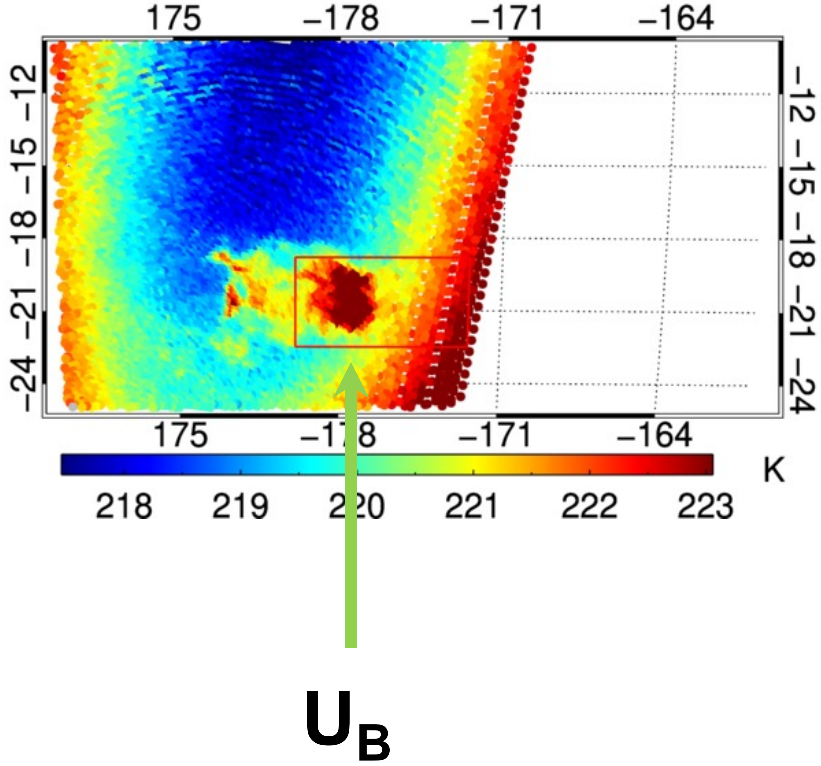
(with the most energy from ~100-5 hPa)

BT at at 678.125 cm-1 20220115 Descending



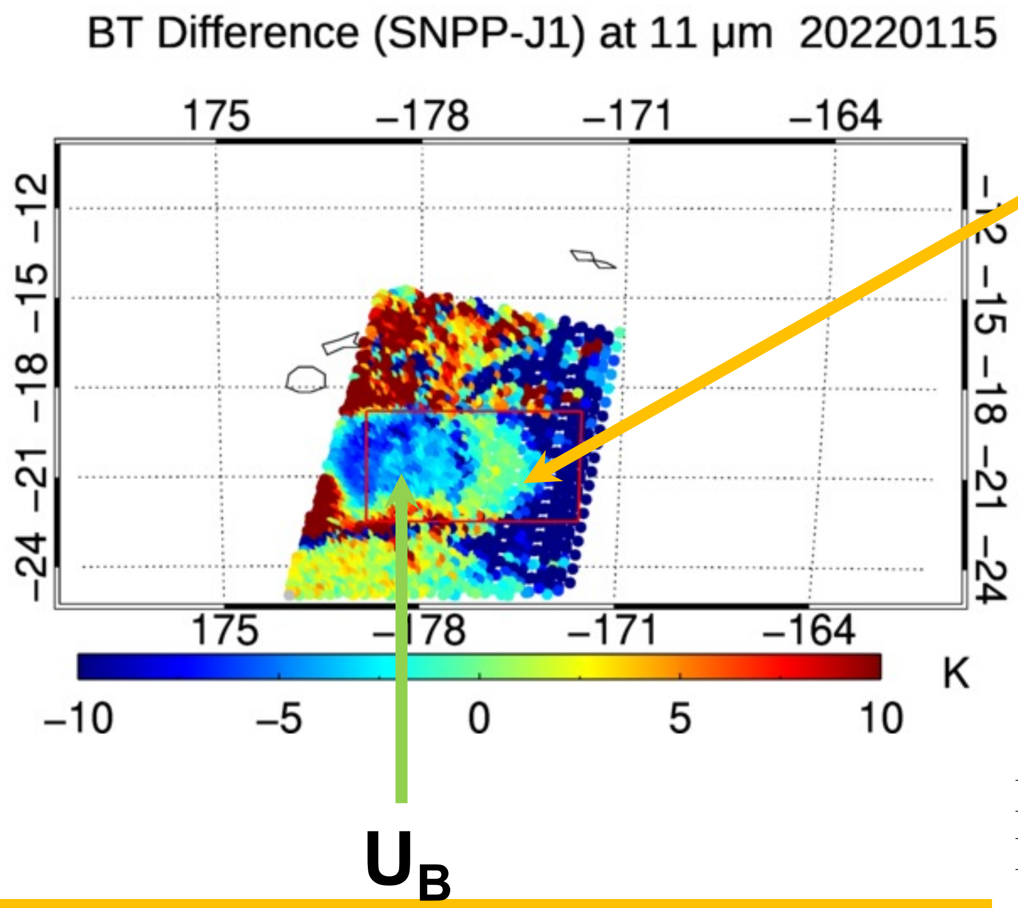
Sensitive to lower altitude than left

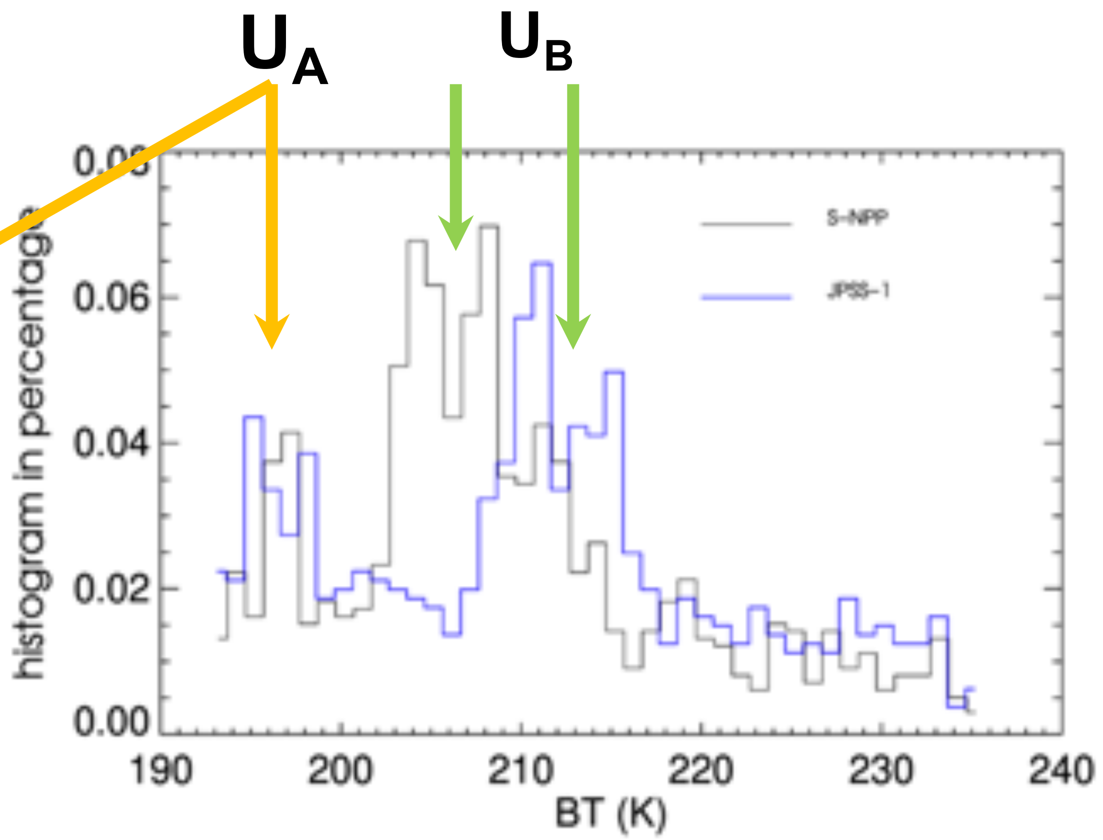
BT at at 691 cm-1 20220115 Descending



Westward propagation and downward movement of the plume in the west of U_B

Difference of BT at 11.1 μm (BT11) from CrIS on S-NPP (13:20 UTC) minus JPSS-1 (12:30 UTC)



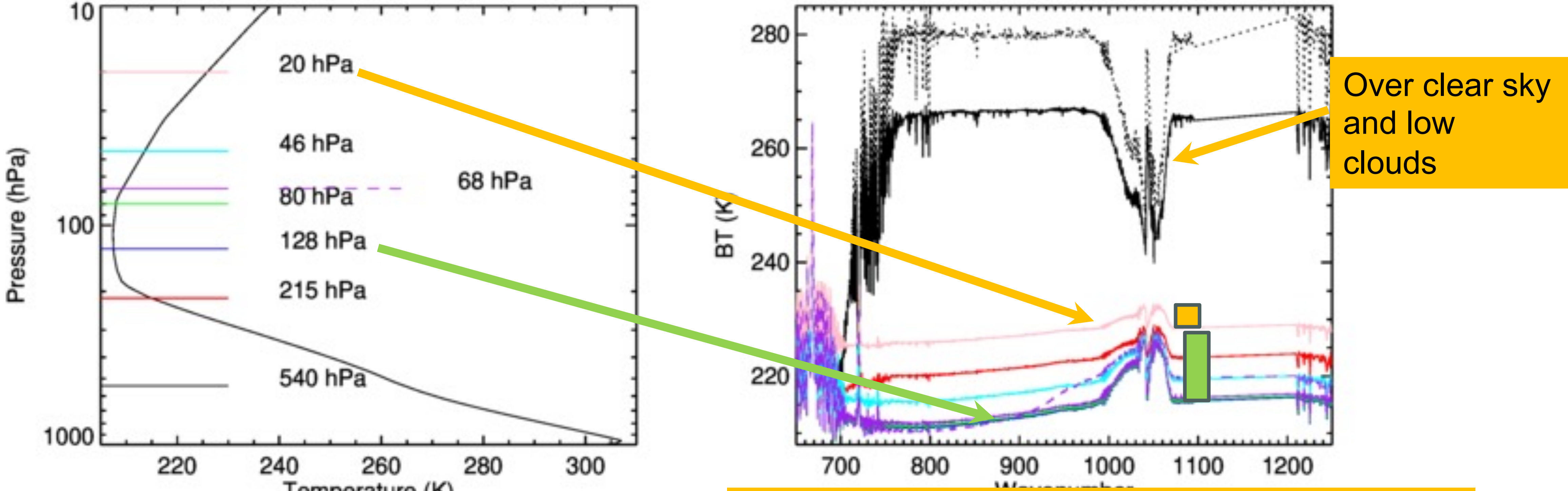


U_B is getting cooler in 50 minutes apart from 12:30 to 13:20 UTC → demonstrating the downward movement and dissipation of the plume over stratosphere

Histograms of BT11 using CrIS on S-NPP and JPSS-1 data with BT11< 235.15 K.

- The 1st peak corresponding to lower clouds (U_A) is almost the same, while the 2nd peak, corresponding to upper cloud (U_B)

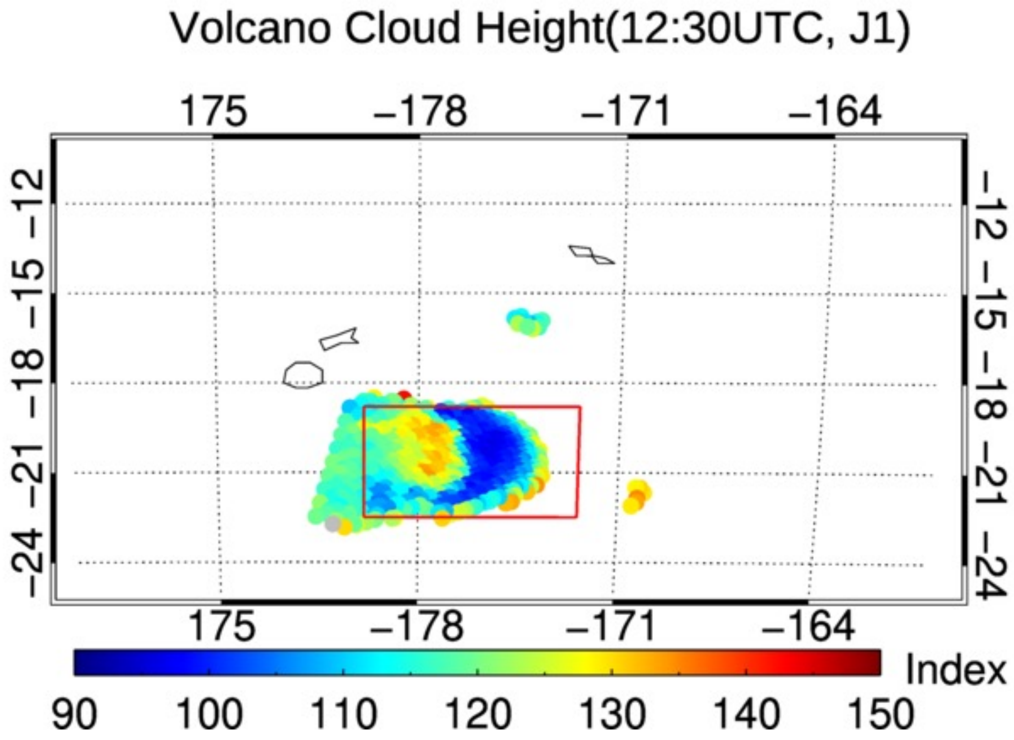
RTA Simulation Proves the Inverted V-shape of Spectrum

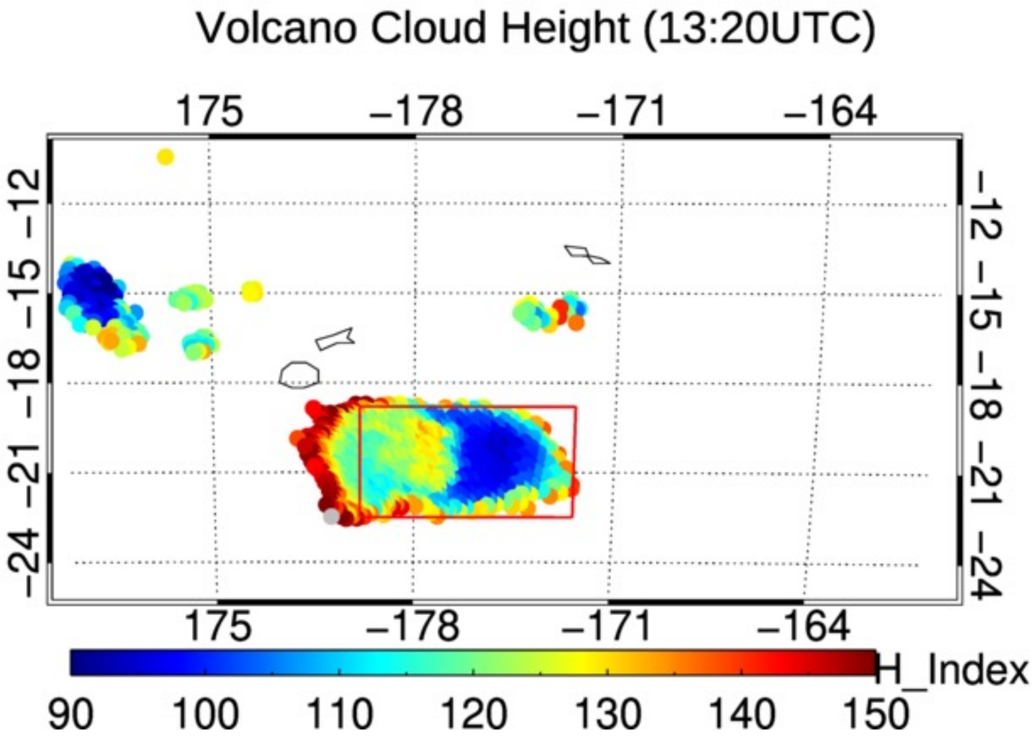


- ✓ Inverted-V shape near 9.6 μm (1042cm^{-1});
- ✓ it is shallower for upper cloud at stratosphere

Temperature profile from ERA5 (left) and the PCRTM-simulated spectra (right). Different colors for the spectra correspond to the clouds with different top heights with the same color lines in the left panel. Dash dark line in the right is for clear sky, and pink dash line is for ice cloud with De=30 μm.

Detection of Cloud Height using the Inverted-V Spectra of O3 band

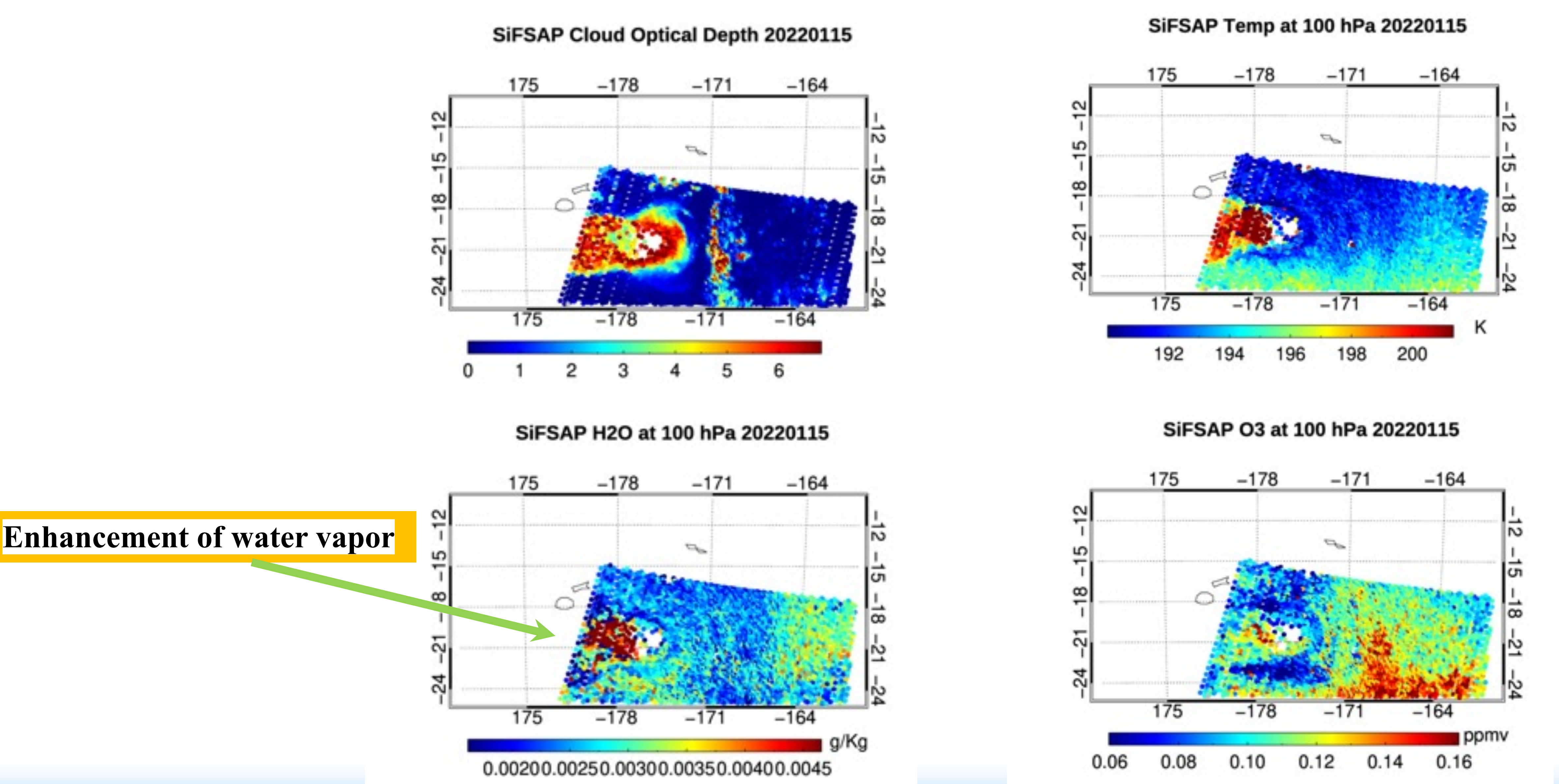




A New Method for Detection of Deep Convective Cloud Height using the Inverted-V Spectra near O3 band (a paper to be submitted to remote sensing, under preparation)

If compared to the observation in 4-5 hours earlier, however the plume height of upper cloud should be below 30 hPa, which is about 7-8 km lower than that estimated by Gupta et al. using observation data in 7-8 hours earlier.

SiFSAP retrieved cloud optical depth, temperature, water mixing ratio (H_2O) and O_3 at 100 hPa from J-1



Summary

1. The infrared hyperspectrum acquired by CrIS over the umbrella volcano clouds show a unique inverted "V" feature for the spectrum near 9.6 μm that is associated with the umbrella clouds.

2. PCRTM simulations demonstrates this inverted "V" spectral feature. This inverted "V" spectral feature can be used for detecting the high clouds with the tops near or over tropopause, particularly during the nighttime. A paper is under preparation.

3. Two layers of umbrella clouds can be identified in 8-9 hours after the most explosive eruption. It is found the upper cloud at stratosphere continues to propagate westward and dissipate with the cloud top decreasing by about 1-2 km from two consecutive observations by CrIS in 50 minutes apart;

4. The single field-of-view retrieval product, SiFSAP, shows a large enhancement of H_2O at lower stratosphere, supporting the unprecedented ejection of water vapor to the stratosphere from HTHH.

Acknowledgements

- SNPP CrIS and ATMS L1B data, OMPS L2 and MERRA-2 data were downloaded from NASA DISC: https://disc.gsfc.nasa.gov/datasets

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