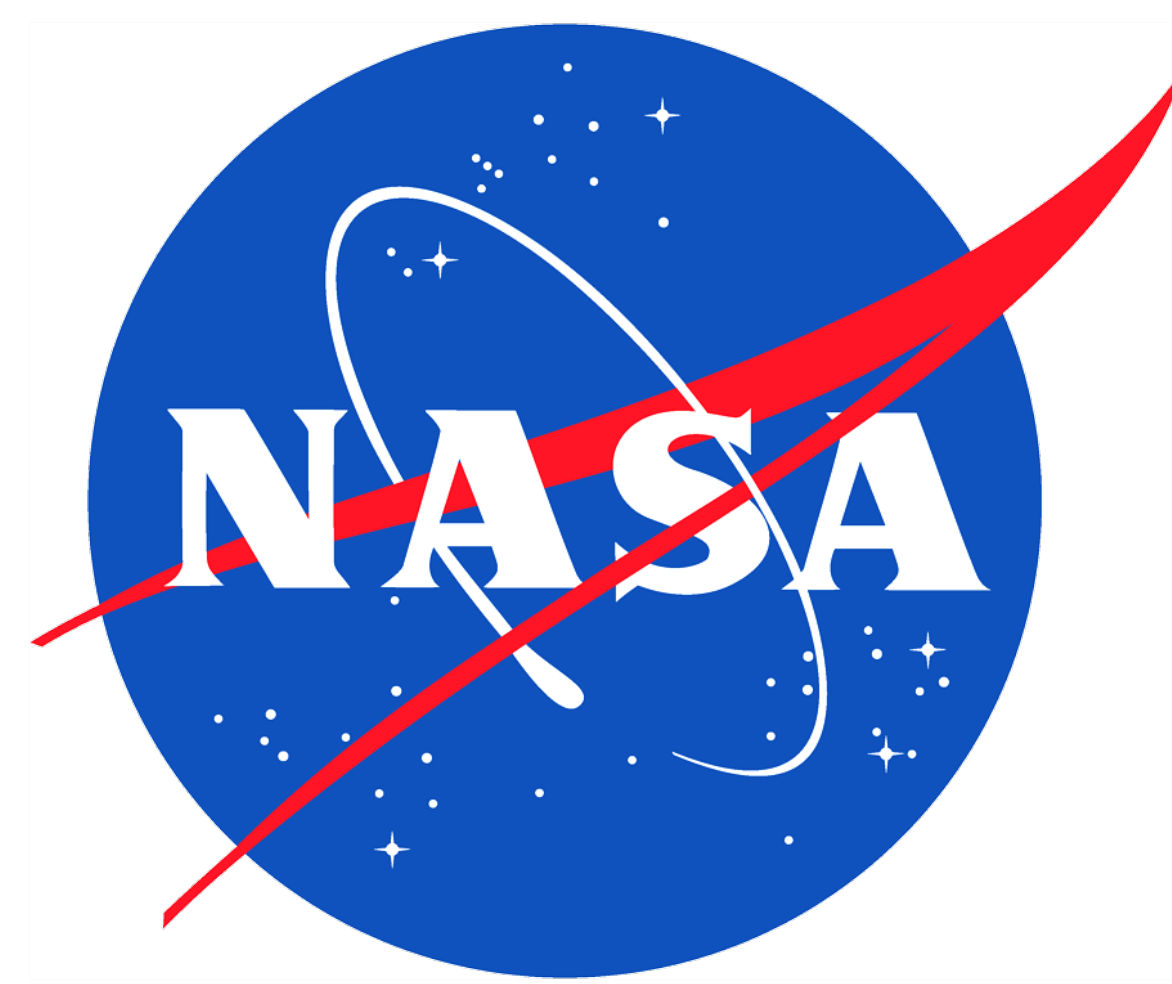# PyroCbs from Australia Fires and its Impact Using Satellite Observations from CrIS and TROPOMI and Reanalysis Data (*Poster #A210*)

Xiaozhen (Shawn) Xiong[1], Xu Liu[1], Wan Wu[1], Liqiao Lei[1,2], Qiguang Yang[1,2], Daniel K. Zhou[1,] Allen M. Larar[1]

[1] NASA Langley Research Center, Hampton, VA
[2] Science Systems and Applications, Inc., Hampton, VA

E-mail: Xiaozhen.Xiong@nasa.gov

Abstract

Australia's unprecedented fire disasters at the end of 2019 to early 2020 emitted huge amounts of carbon monoxide (CO) and fire aerosol particles to the atmosphere, particularly during the Pyrocumulonimbus (pyroCb) outbreak that occurred in southeast Australia between 29 December 2019 and 4 January 2020. It was estimated that at least 18 pyroCbs were generated during this episode, and some of them injected ice, smoke, and biomass burning gases above the local tropopause. An unprecedented abundance of H_2O and CO in the stratosphere, and the displacement of background ozone (O_3) from rapid ascent of air from the troposphere and lower stratosphere were found from satellite observations. Some other studies also found that the fire emissions and their long-range transport altered the Antarctic ozone and vortex, posing great impact to local air quality and climate change.

This study will focus on the thermodynamic state of atmosphere associated with these pyroCbs, and its impact on the change of the cloud properties and trace gases during this unprecedented Australia fires, mainly based on a new single Field of View (SFOV) Sounder Atmospheric Products (SiFSAP). SiFSAP was developed by NASA using the Cross-track Infrared Sounder (CrIS) and Advanced Technology Microwave Sounder (ATMS) onboard SNPP and JPSS-1, and will soon be available to the public at NASA DAAC. Since this product has a spatial resolution of 15 km at nadir, which is better than most global weather and climate models and other current operational sounding products, a process-oriented analysis of the dynamic transport of CO and fire plumes during this unprecedented fire disasters will be made in this study. SiFSAP is based on a Principal Component Radiative Transfer Model (PCRTM) and an optimized estimation retrieval algorithm, and a simultaneously retrieval using the whole spectral information measured by CrIS was made to derive temperature, water vapor, trace gases (such as O_3, CO_2, CO, CH_4 and N_2O), cloud properties and surface properties. Use of ATMS together with CrIS allows SiFSAP to get accurate retrieval products under thick pyroCb conditions.

It is found that the PyroCb can be detected using the hyperspectral spectral information. The change of CO, H_2O, O_3, and cloud properties between the largest PyroCb on December 29-30, 2019 and the next outbreak on Jan 4, 2020, as well as some comparison with the products of TROPOMI and model data from the NASA's Modern-Era Retrospective Analysis for Research and Applications Version-2 (MERRA-2) will be presented.

SiFSAP Algorithm and Data Use
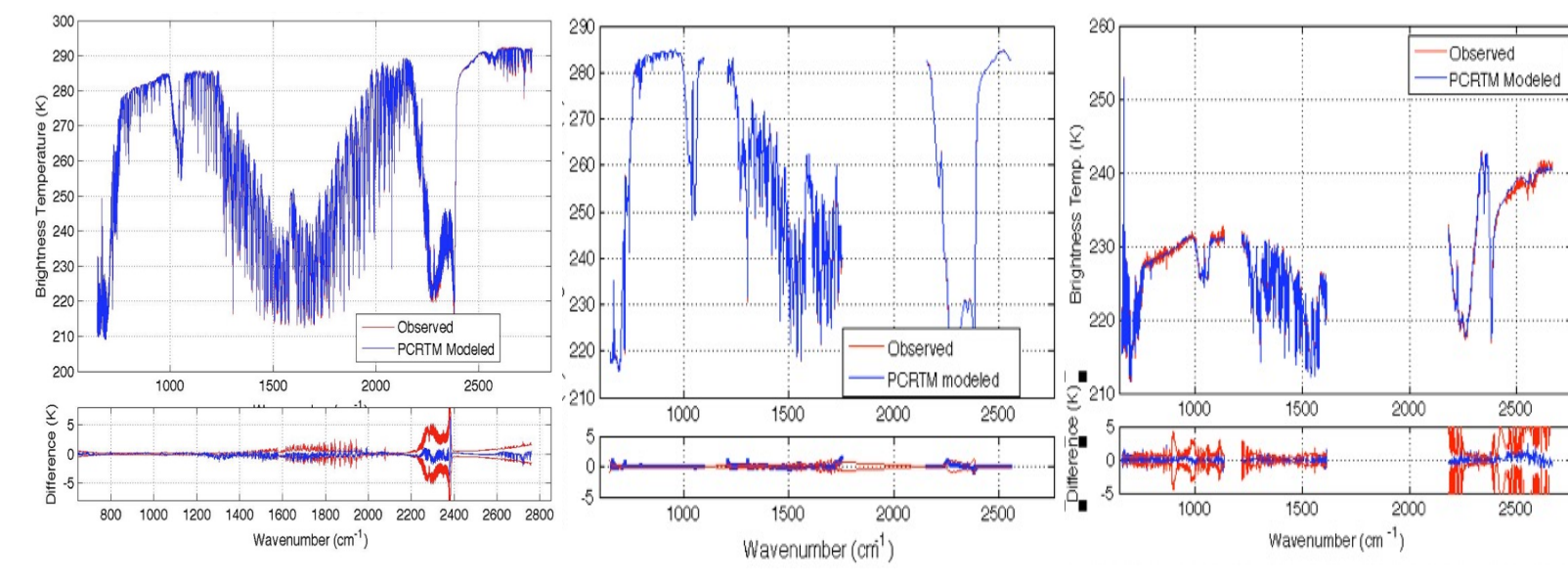
PCRTM Simulations for IR Sounders

Figure 1a Comparison between observed and PCRTM modeled spectra of three major hyperspectral sounders (Left column: IASI; Middle column: CrIS; Right column: AIRS), and the spectral difference (in blue curves) with the sounder instrument noise level (in red curves) being plotted as the reference.

Figure 1b Comparison of CLIMCAPS, NUCAPS, AIRS V7 with SiFSAP, and some characteristics of PCRTM-RA algorithm.

CLIMCAPS, NUCAPS, AIRS V7 | SiFSAP
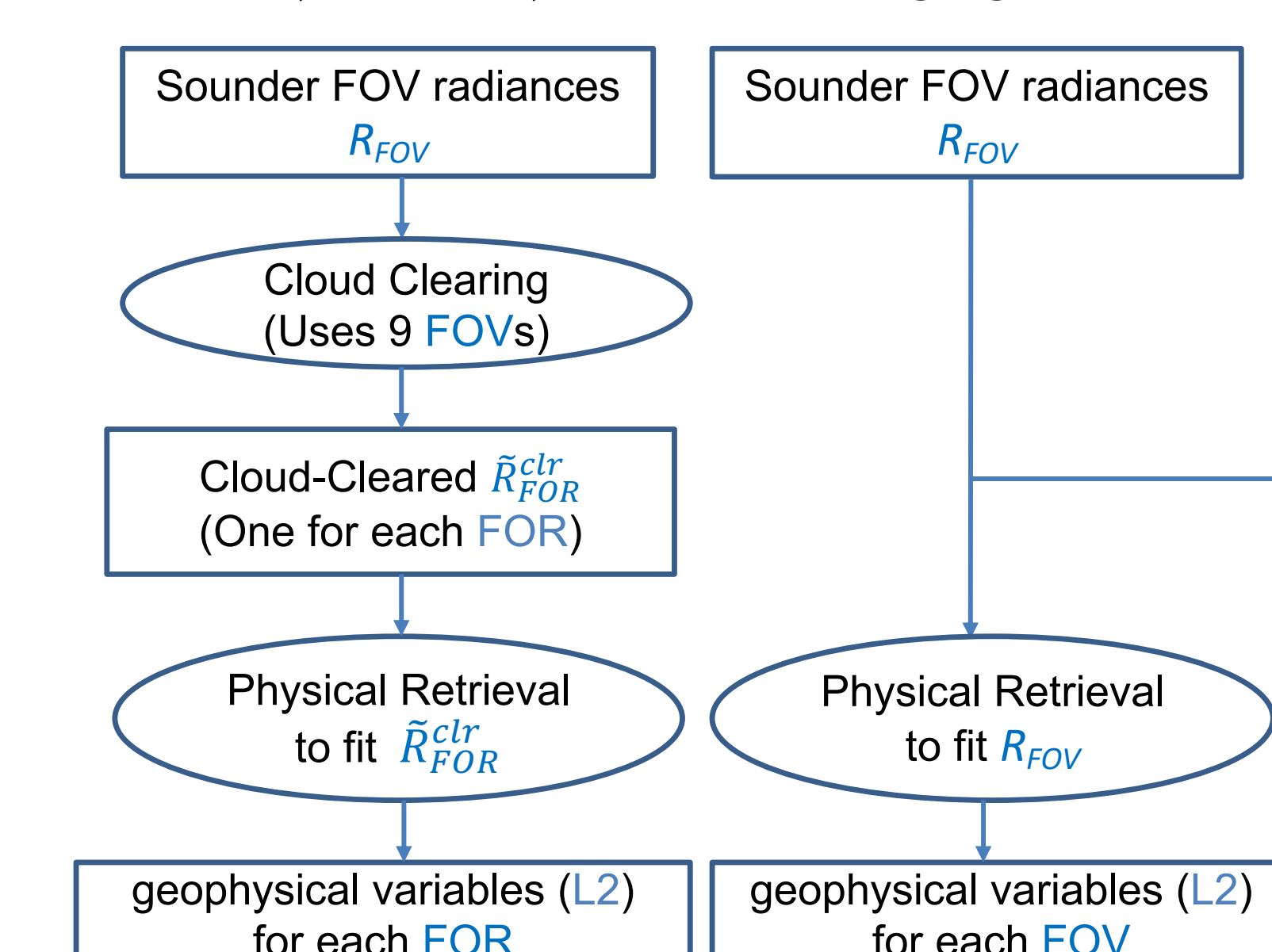
PCRTM-RA Algorithm
- Optimal estimation method (OEM) based physical retrieval algorithm
- Synergistic IR+MW retrieval
- Cloud scattering included in the forward model
- Principal Component Analysis to utilize all measurement channels
- Simultaneous retrieval of Temp., water vapor, O_3, CO_2, CO, CH_4, N_2O, cloud properties and surface properties.
- Spectral radiances fitting based quality control
- Radiative kernel (Jacobian)
- Averaging kernel and error estimation under the OEM scheme

- Satellite Data used:
  - CrIS L1B data and SiFSAP from CrIS on SNPP from 29 Dec 2019 – 2 Jan 2020
  - *Ozone* Mapping and Profiler Suite (OMPS) on SNPP
  - TROPOMI (5.5km X 3.5km)

- Model Data used: MERRA-2

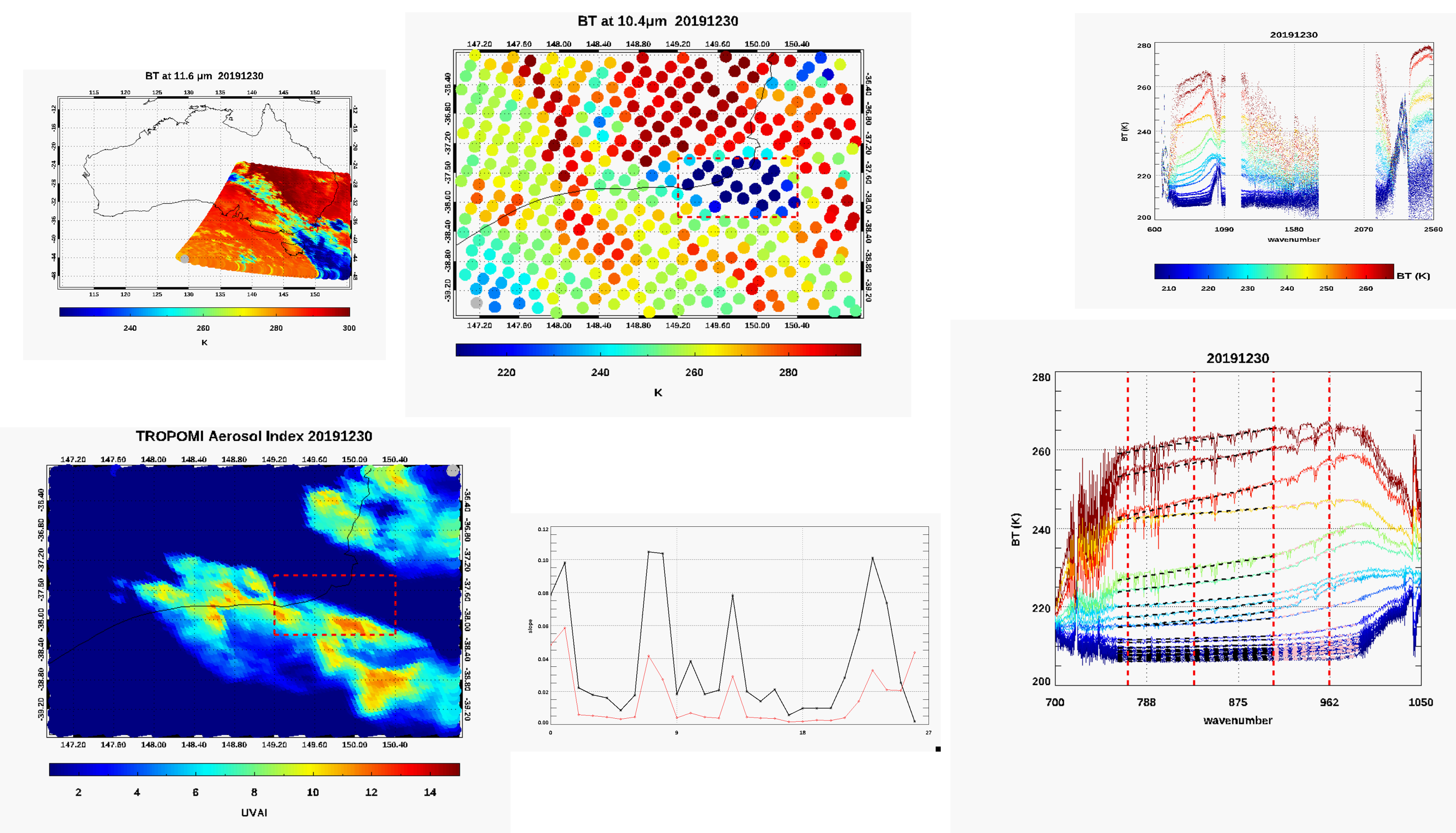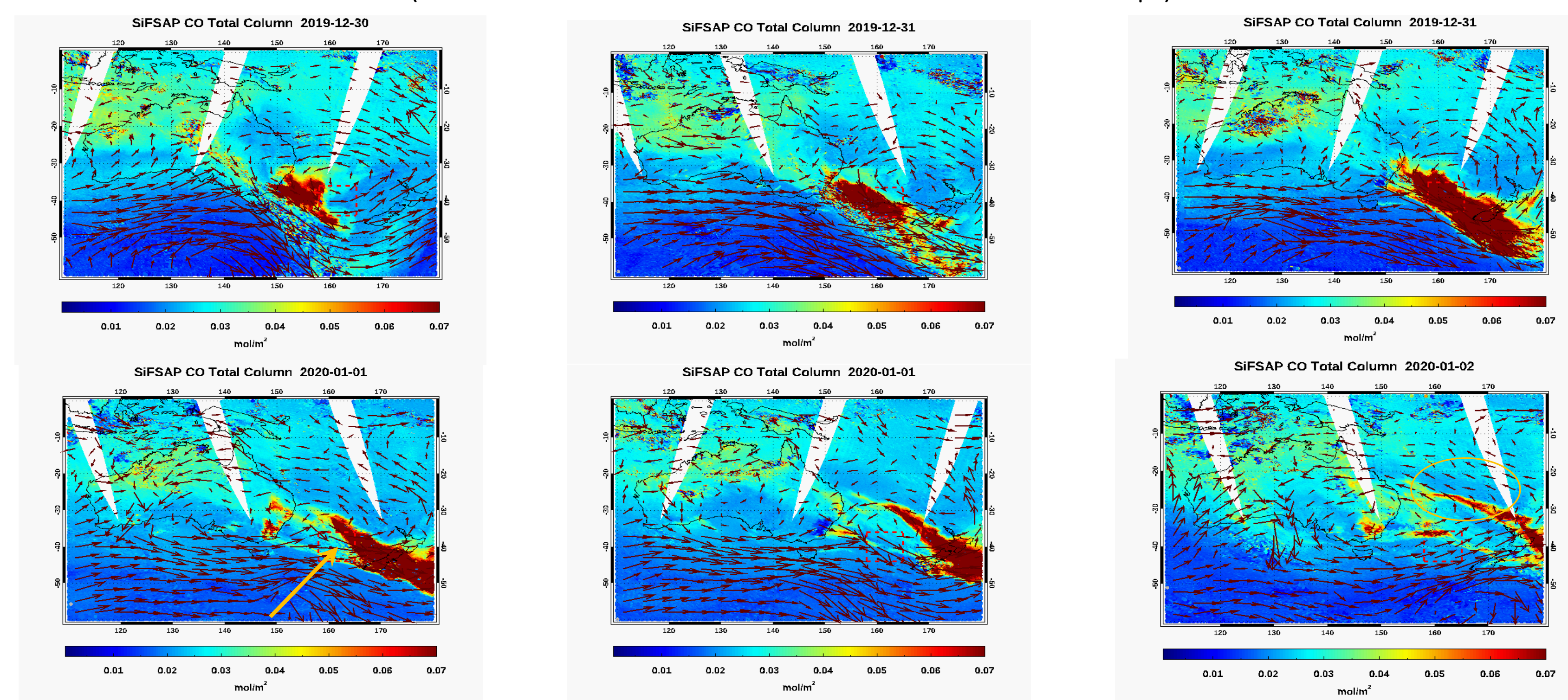## PyroCb from Australia Fires and Its Spectral Features

Fig 2. PyroCb and CrIS measured spectral; Dash box marks the location of PyroCb, where the BT from CrIS window channel is < - 40 K; Also shown Aerosol Index from TROPMI.

Transport of CO Plume from Australia Fires

(SiFSAP total column CO overlaid with MERRA-2 wind fields at 850 hpa)

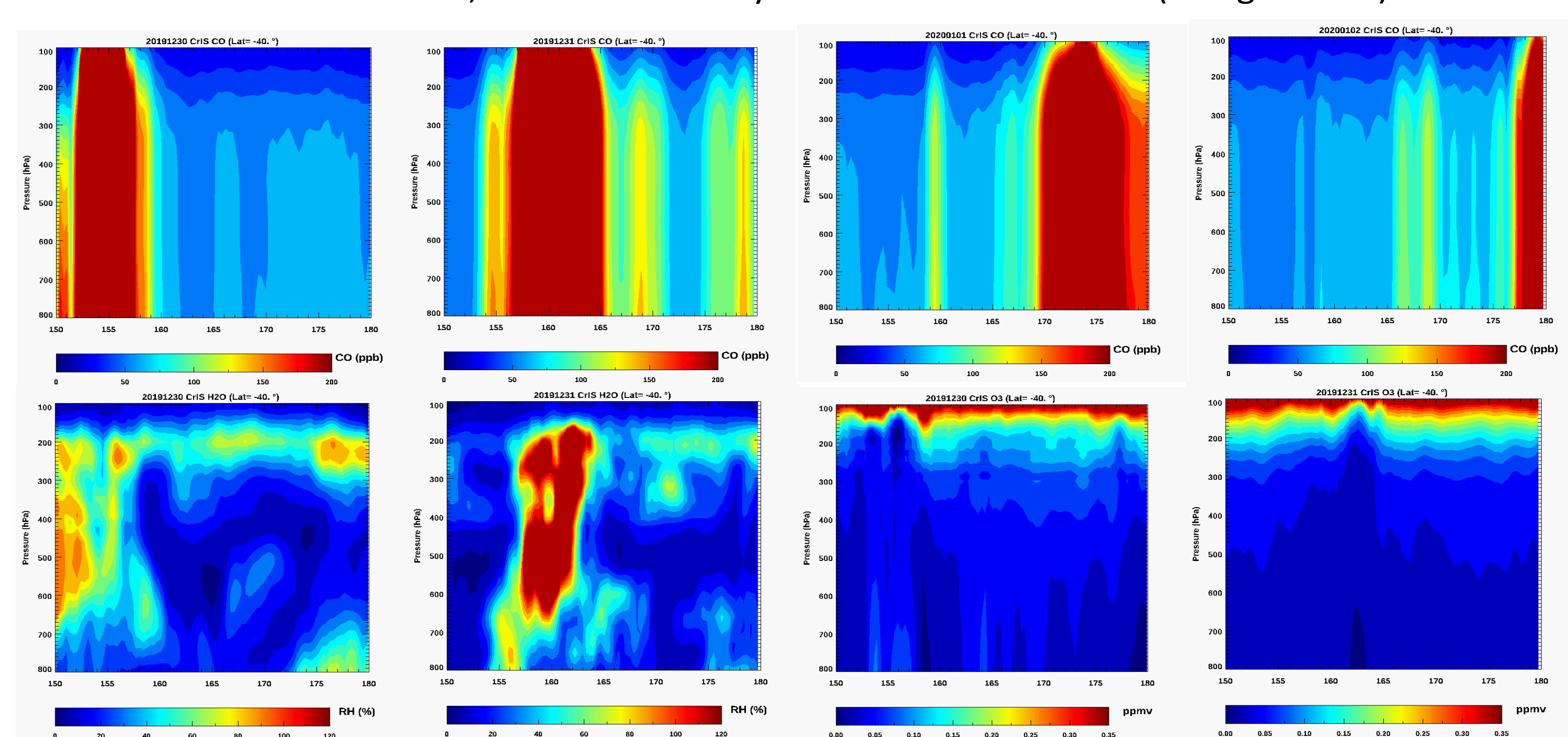### Cross-Section of CO, Relative Humidity and Ozone from SiFSAP (along lat=40°)

Fig 3. Transport of CO after the largest PyroCb on December 29-30, 2019, and the vertical distribution of CO, H_2O and O_3.

PyroCb and its Impact to T, H_2O, O_3 and Clouds

Matchup of SiFSAP, TROPOMI and MERRA-2 CO on 02 Jan 2020

Large difference between satellite observation and MERRA-2
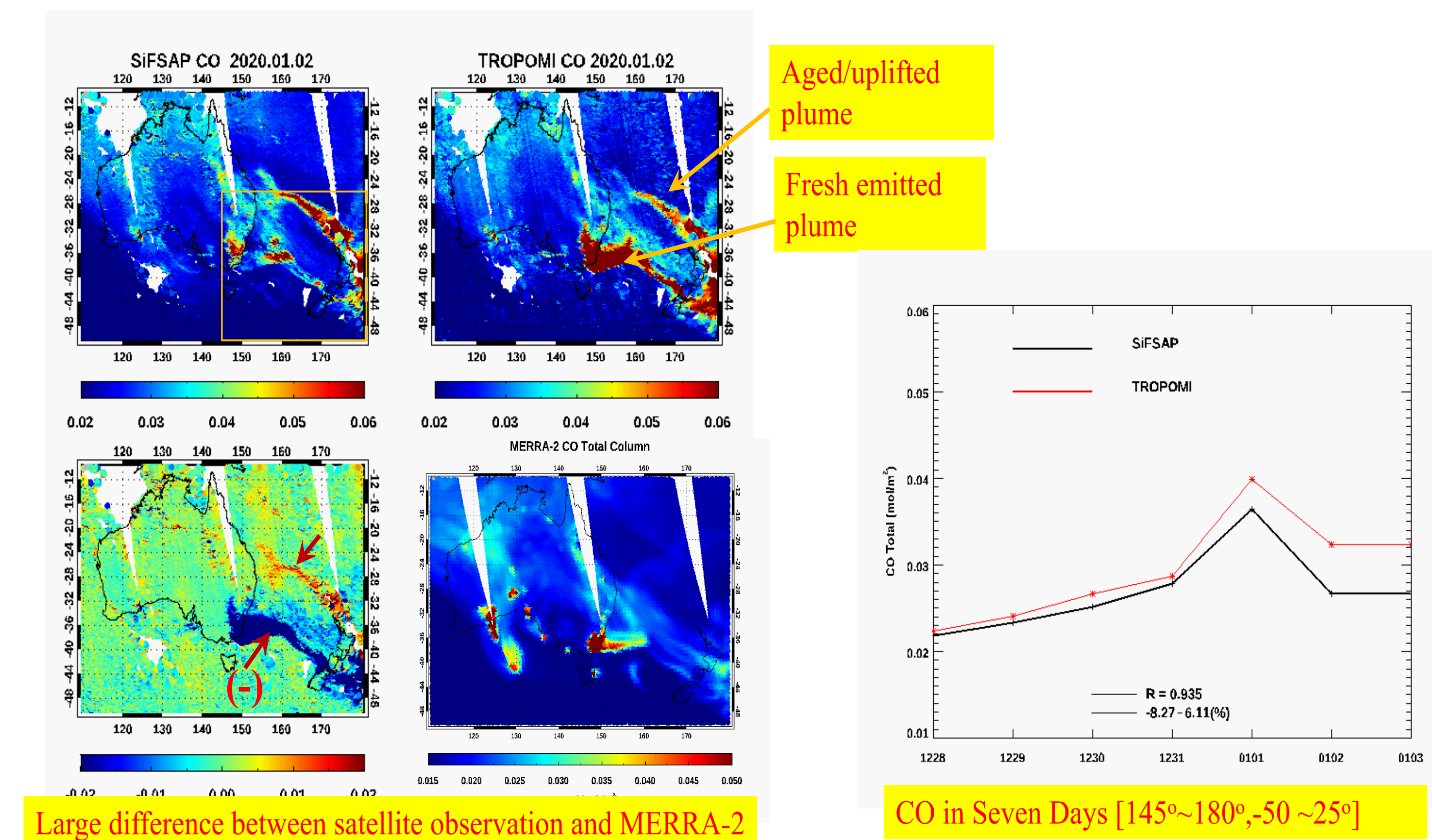
CO in Seven Days [145~180°,-50 ~25°]

Fig 4. TROPOMI and CrIS SiFSAP agree well (~2%, R=0.94) in the observed CO transport from Australia to New Zealand, but the CO from MERRA-2 reanalysis data is much smaller; TROPOMI has higher resolution but more missing pixels due to the impacts by fire emitted particles and cloud; For aged/uplifted plume, SiFSAP CO is larger than TROPOMI and vice versa for the fresh emitted plume.
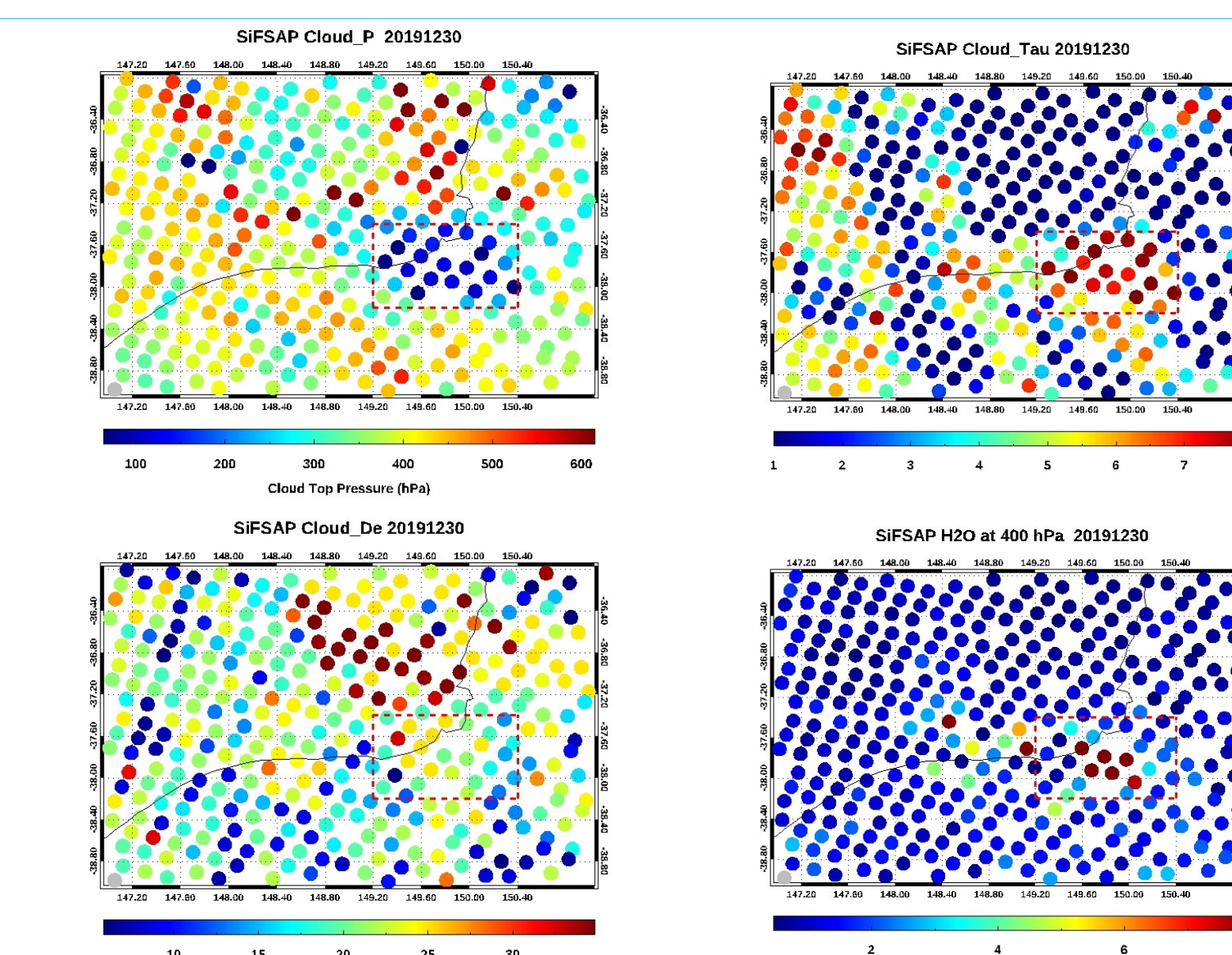

Fig 5. PyroCb top pressure is up to 100-200 hPa, with the optical depth about 7-9 and effective radius of 20-25 micron. Enhancement of H_2O at upper troposphere is also evident from H_2O at 400 hPa and from the cross-section of H_2O along latitude 40°S (Figure 4).

Summary and Conclusions

1. Large emissions of CO and its transport following the largest PyroCb outbreak on December 29-30, 2019 during the 2019-2020 Australia wildfires were well captured using SiFSAP products from CrIS on SNPP and J1; For aged/uplifted plume SiFSAP CO > TROPOMI CO, and vice versa for fresh emitted fire plume, which is expected as TROPOMI is more sensitive to CO in the lower troposphere while CrIS is more sensitive to mid-troposphere;
2. Compared with SiFSAP and TROPOMI, MERRA-2 CO is lower biased;
3. From SiFSAP, the pyroCb cloud top is up to 100-150 hPa, with cloud optical depth 7-9 and large ice particles.
4. Some interesting features of temperature, O_3 (decrease) and H_2O (enhanced) within the pyroCb were first detected from CrIS SFOV products.

References

1. Kablick, G. P. III, Allen, D. R., Fromm, M. D., & Nedoluha, G. E. (2020). Australian pyroCb smoke generates synoptic-scale stratospheric anticyclones. Geophysical Research Letters, 47, e2020GL088101. https://doi. org/10.1029/2020GL088101.
2. Rieger, L. A., Randel, W. J., Bourassa, A. E., & Solomon, S. (2021). Stratospheric temperature and ozone anomalies associated with the 2020 Australian New Year fires. Geophysical Research Letters, 48, e2021GL095898. https://doi.org/10.1029/2021GL095898.
3. Wu et al., "The Application of PCRTM Physical Retrieval Methodology for IASI Cloudy Scene Analysis," in IEEE Transactions on Geoscience and Remote Sensing, vol. 55, no. 9, pp. 5042-5056, Sept. 2017, doi: 10.1109/TGRS.2017.2702006.
4. Xu Liu, William L. Smith, Daniel K. Zhou, and Allen Larar, 2006, "Principal component-based radiative transfer model for hyperspectral sensors: theoretical concept," Appl. Opt. 45, 201-209 (2006).
5. Xiong, X., X. Liu, W. Wu, K. E. Knowland, Q. Yang, J. Welsh, D. K. Zhou, 2022: Satellite observation of stratospheric intrusions and ozone transport using CrIS on SNPP, Atmospheric Environment, Volume 273, 2022, 118956, ISSN 1352-2310, https://doi.org/10.1016/j.atmosenv.2022.118956.
6. Xiong, X., X. Liu, W. Wu, K. E. Knowland, F. Yang, Q. Yang, and D. K. Zhou. 2022: "Impact of Stratosphere on Cold Air Outbreak: Observed Evidence by CrIS on SNPP and Its Comparison with Models", Atmosphere, 13, no. 6: 876. https://doi.org/10.3390/atmos13060876.
7. Zhou, D.K., A. M. Larar, X. Liu, and X. Xiong, 2022: Estimation of Fire-induced CO Plume Age from NAST-I During the FIREX-AQ Field Campaign, JARS. 16,3, 034522, doi: 10.1117/1.jrs.16.034522.