GRUAN-ICM15
March 11-15, 2024
Bern, Switzerland

Assessment of the Consistency between GRUAN RAOBs and Satellite Hyperspectral Infrared Sounder Measurements: Case Studies

Bomin Sun[1,2], Yong Chen[1], Denis Tremblay[1,3], and Tony Reale[1]

1 NOAA/NESDIS/Center for Applications and Research (STAR), College Park, Maryland, USA
2 IMSG, Rockville, Maryland, USA
3 GST, Greenbelt, Maryland, USA

- **Motivation**
  - Assessment of the consistency of GRUAN-satellite may tell
    - GRUAN is qualified to be the reference for satellite sensor data calibration/validation (GSICS)

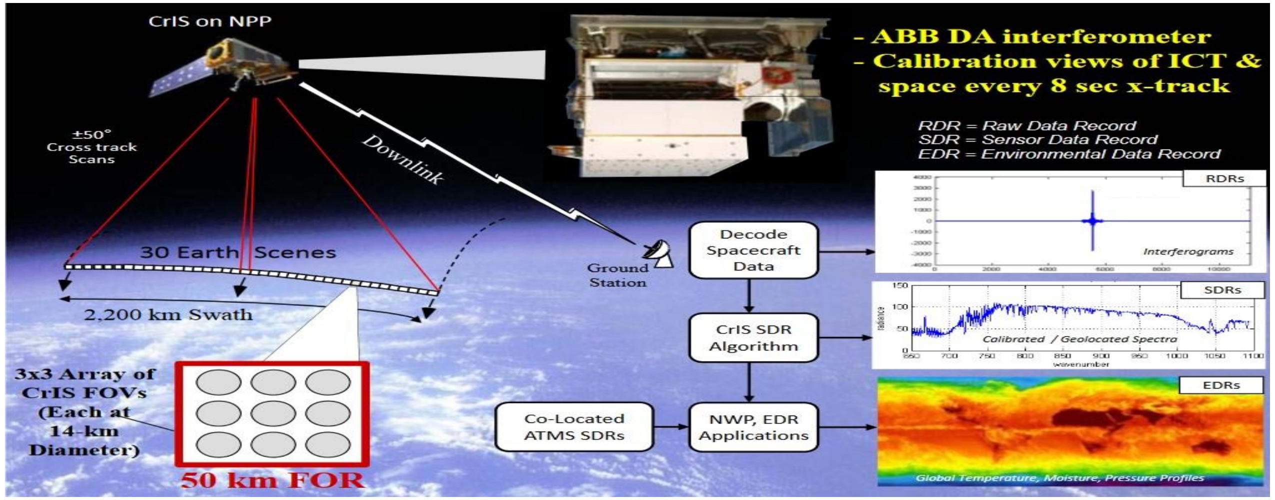
- **Past Studies**
  - Calbet et al. (2017), "Consistency between GRUAN sondes, LBLRTM and IASI", *Atmos. Meas. Tech*.
    - RS92 GDP and RS92 EDT, UT water vapor, IASI MetOp-A, LBLRTM
  - Sun et al. (2021), "Accuracy of Vaisala RS41 and RS92 upper tropospheric humidity compared to satellite hyperspectral infrared measurements", *Remote Sens*.
    - RS41EDT, RS92 GDP and RS92 EDT, UT water vapor, IASI MetOp-B, LBLRTM

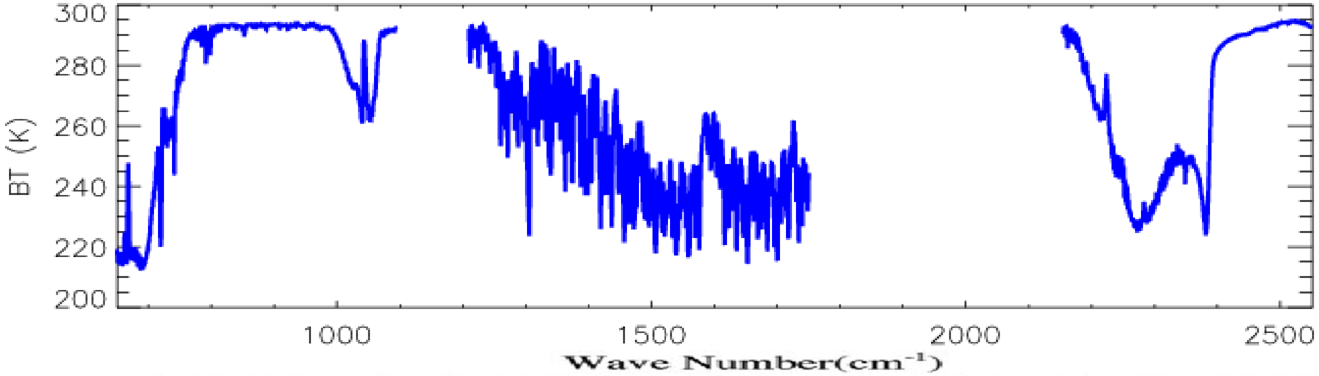
RS41 GDP *vs* CrIS *via* CRTM

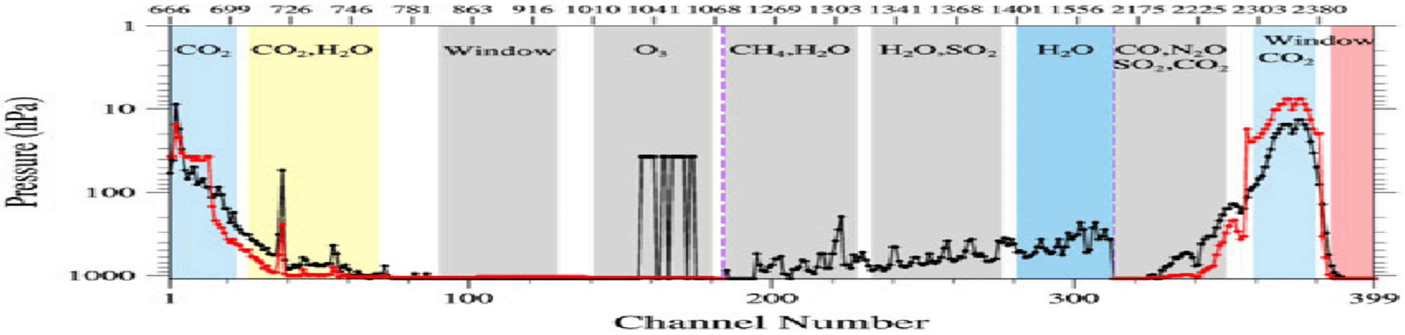
- Assessment of **lower stratospheric temperature** and **upper tropospheric water vapor**
- **RS41 GDP**, RS41 EDT, and RS92 GDP
- Cross-track Infrared Sounder (CrIS) on operational NOAA polar orbiting satellites
  - SNPP (10/28/2011)
  - NOAA-20 (11/18/2017)
  - NOAA-21 (11/10/2022)
- Community Radiative Transfer Model (CRTM, v2.4.0)

CrIS Measurement Characteristics

- Fourier transform spectrometer
- 2211 channels covering 3 spectral bands (SWIR, MWIR, and LWIR), 650-2550 cm^{-1}(3.9 to 15.4 um), 0.625 cm^{-1} spectral resolution
- Each scanline consists of 30 FORs, each FOR has 9 FOVs with 14.5 km at nadir
- Global atmospheric temperature, water vapor, O_3 and other trace gases (CO_2, CO, CH_4, N_2O)
- Play a critical role in NWP forecasting and global weather & climate monitoring
- High radiometric calibration accuracy, stable spectral calibration, excellent noise performance
- **Need post-launch absolute radiometric cal/val**

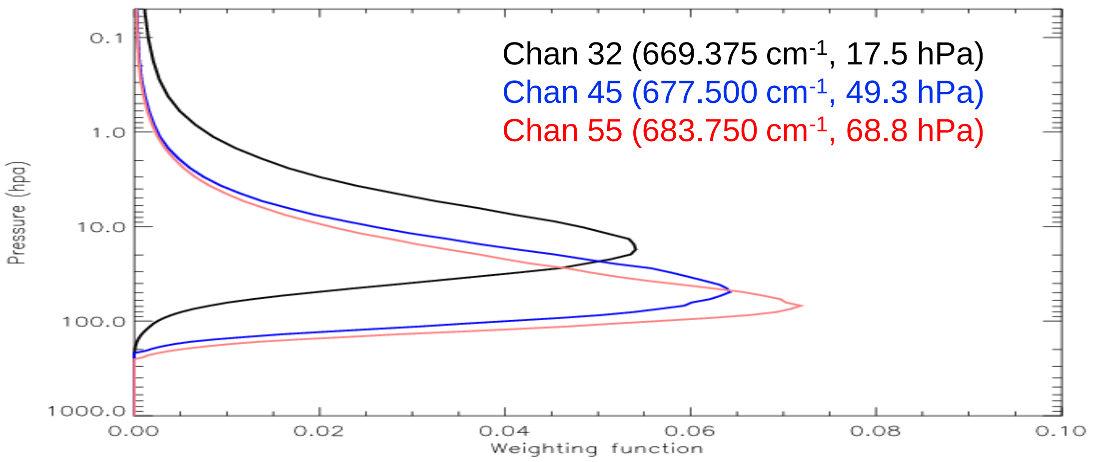


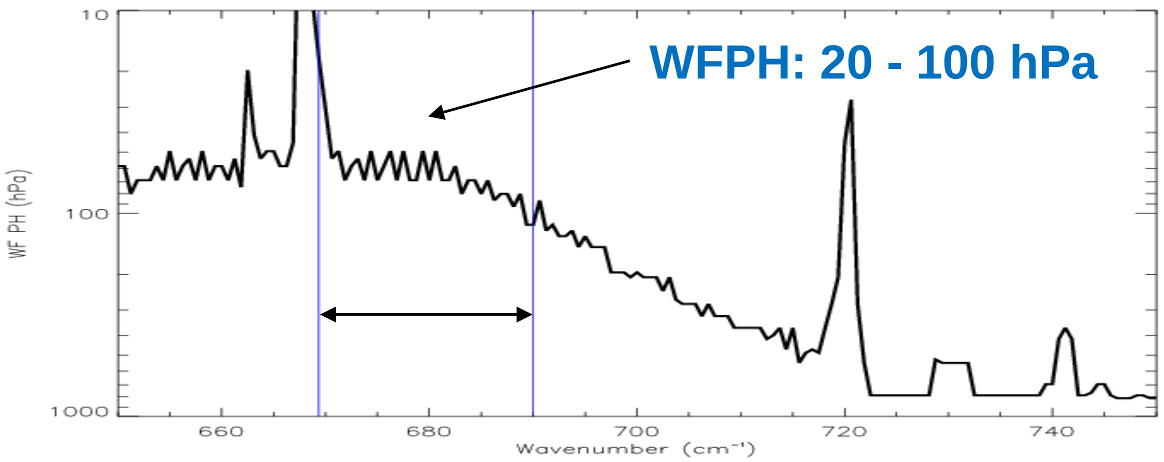




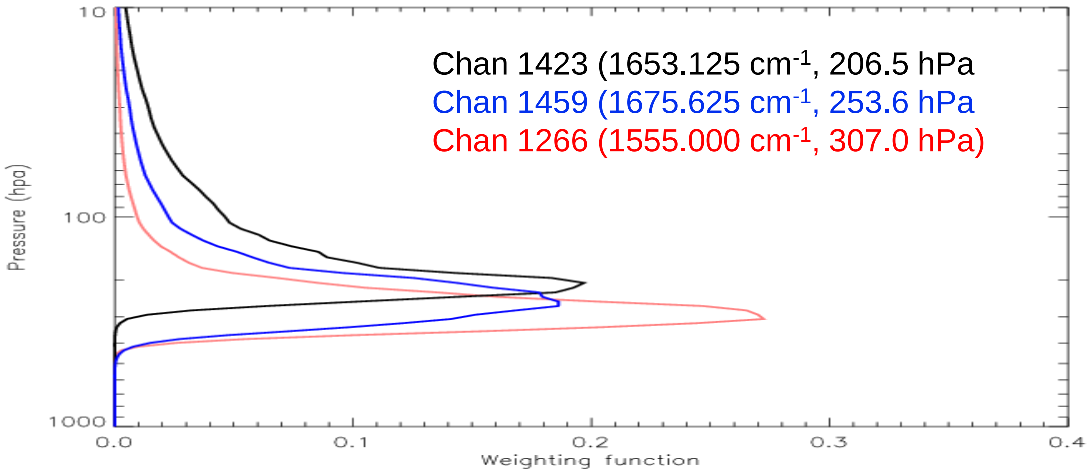
CrIS Channels Used in the Assessment

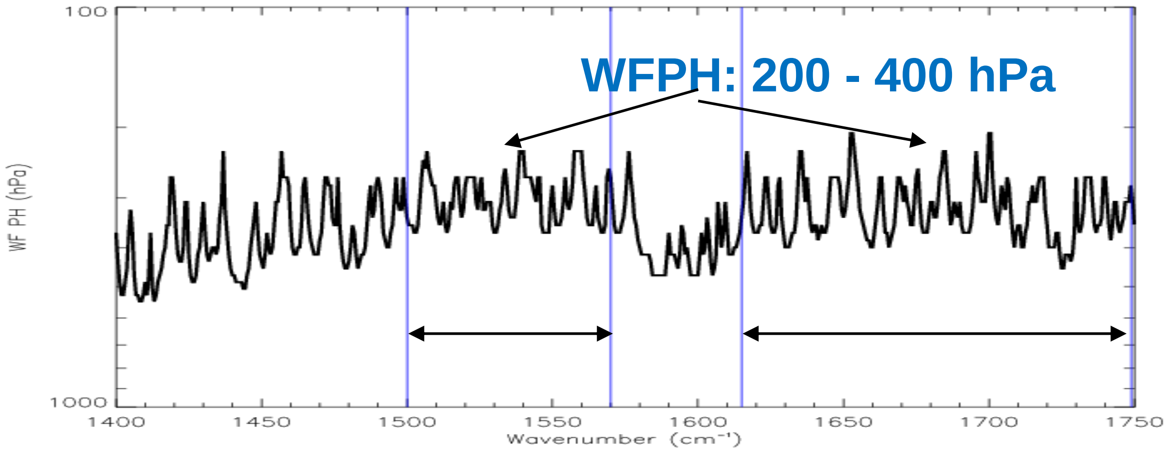
Longwave Infrared (LWIR) for LS T





Midwave Infrared (MWIR) for UT WV





Assessment Methods

- Compute radiances using CRTM with the input of radiosonde temperature and water vapor profile ("CAL").

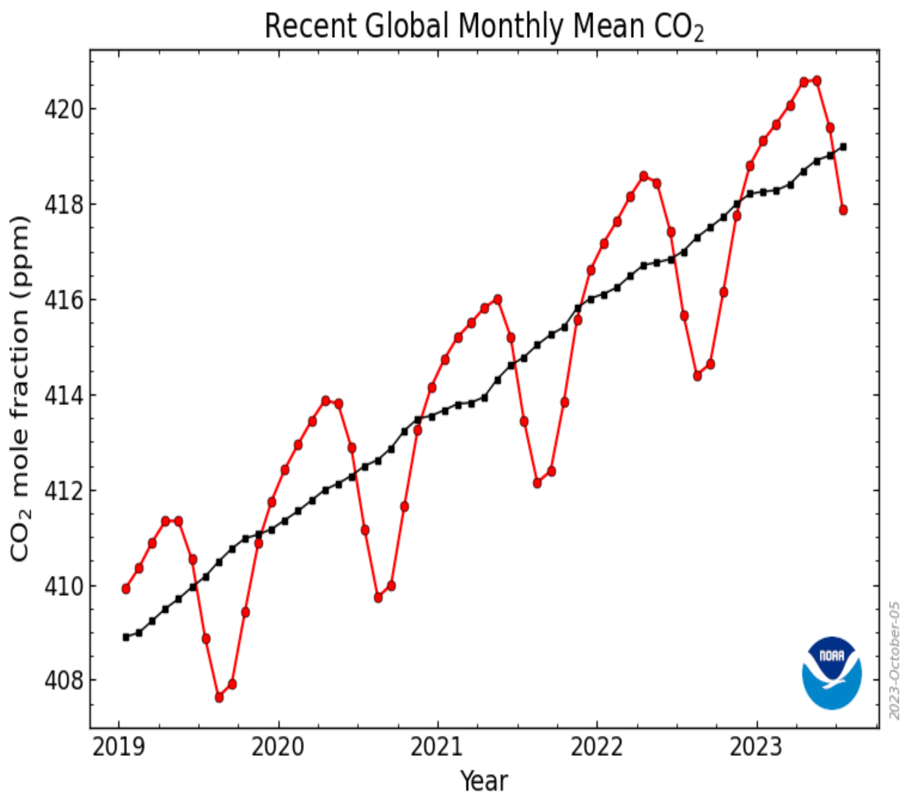
- Compare "CAL" with CrIS measurements ("OBS") …OBS-CAL
  - LS temperature (LWIR CO_2 channels with WFPH 20-100 hPa). GNSS RO profiles are also used as another reference to verify OBS-CAL ("GRUAN-GSICS-GNSS")
  - UT water vapor (MWIR channels with WFPH 200-400 hPa); **clear scenes**

- Measurement uncertainty and collocation uncertainty (including balloon drift).

CO_2 Adjustment on the Radiances Computed for Radiosondes Using CRTM

- An increase in CO_2 amount increases the radiances sensed by the CO_2 sensitive lower stratospheric temperature channels.
- **Default CO_2 in CRTM is 384 ppmv, which is far less than the amount in the real atmosphere**, for example, 411 ppmv for Mar. 2021.
- **Radiances computed for radiosondes using CRTM are adjusted for those CO_2 sensitive temperature channels.**

Chen et al. (2022), "Assessment of the consistency and stability of CrIS infrared observations using COSMIC-2 radio occultation data over ocean", Remote Sens.

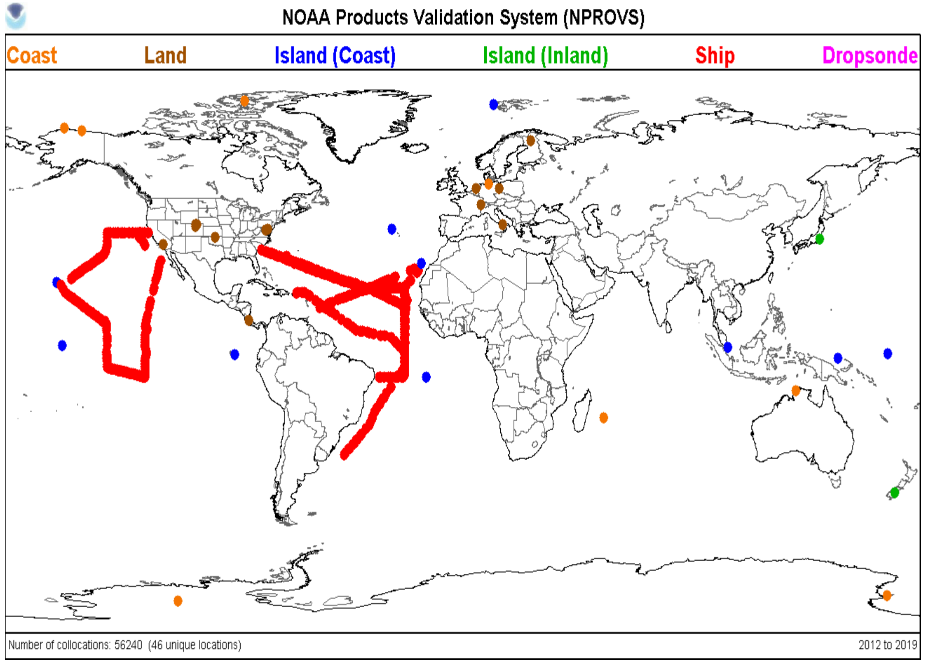


Courtesy NOAA GML

Cases for the Study

- Lamont, Oklahoma (SGP)
  - 20191008 19:23UTC, day, dedicated dual RS41&RS92 (NOAA-20)
- Payerne
  - 20190627 11:00 UTC, day, synoptic RS41 (NOAA-20)
- Radiosondes were launched under clear sky conditions

NPROVS dedicated/GRUAN collocations with satellite EDRs

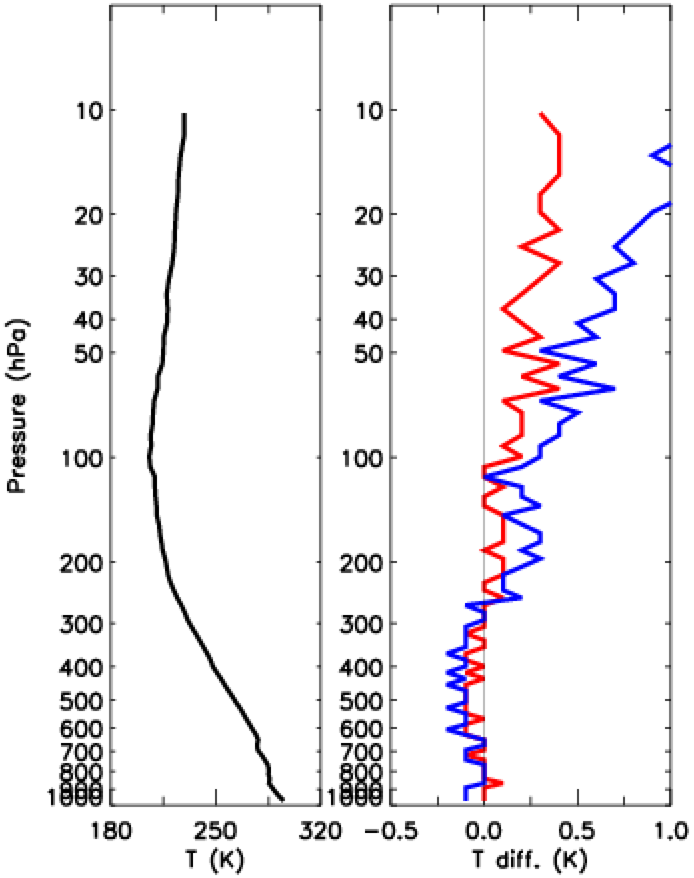


NOAA JPSS satellite synchronized dedicated radiosonde sites including ship campaigns and GRUAN. There are ~ 74,000 radiosondes (January 2013 through July 2022), of which, 26,500 are synchronized (7700 via JPSS/ARM) with satellite overpasses. Half of the radiosondes from oceanic campaigns are synchronized with MetOp overpasses.

Case: SGP, Oct. 8, 2019, Day, Dedicated for NOAA-20

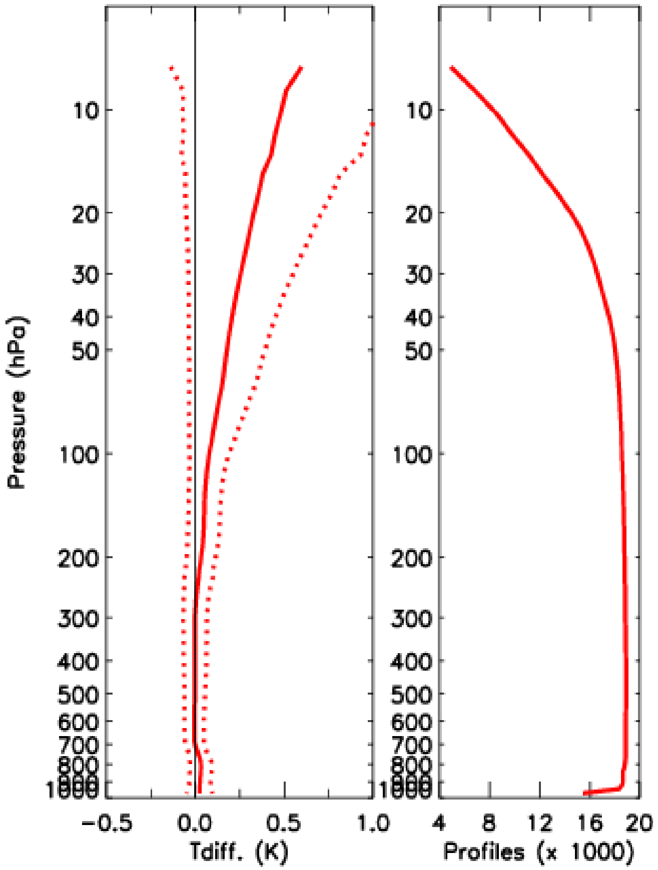
RS41 GDP vs. RS41 EDT vs. RS92 GDP

RS92 GDP - RS41 EDT
RS41 GDP - RS41 EDT

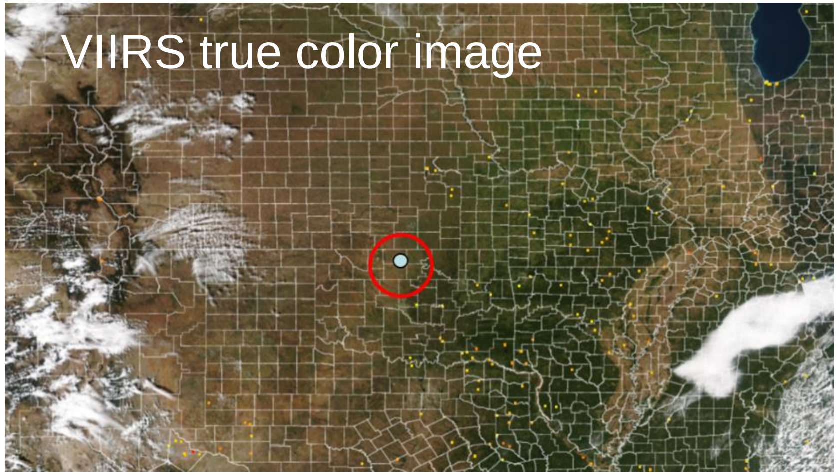


Averaged for 20-100 hPa
RS41 GDP – RS41 EDT = 0.23 K

All GRUAN sites, 5-yr, Day
RS41 GDP - RS41 EDT

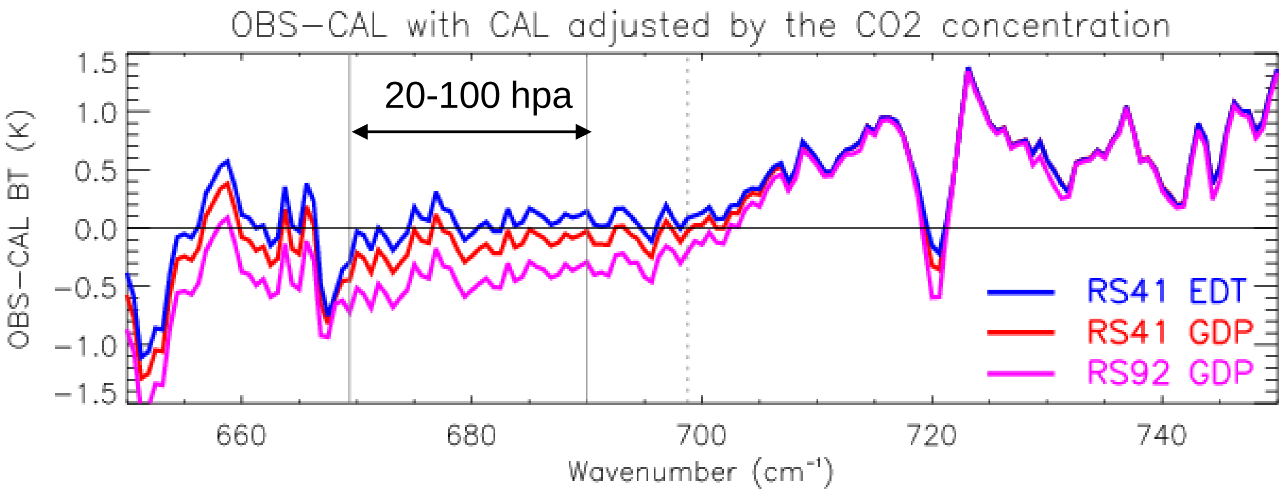


Averaged for 20-100 hPa
RS41 GDP – RS41 EDT = 0.19 ±0.23 K



Daytime RS41 GDP is warmer than RS41 EDT by around 0.2 K in the lower stratosphere (20-100 hPa)

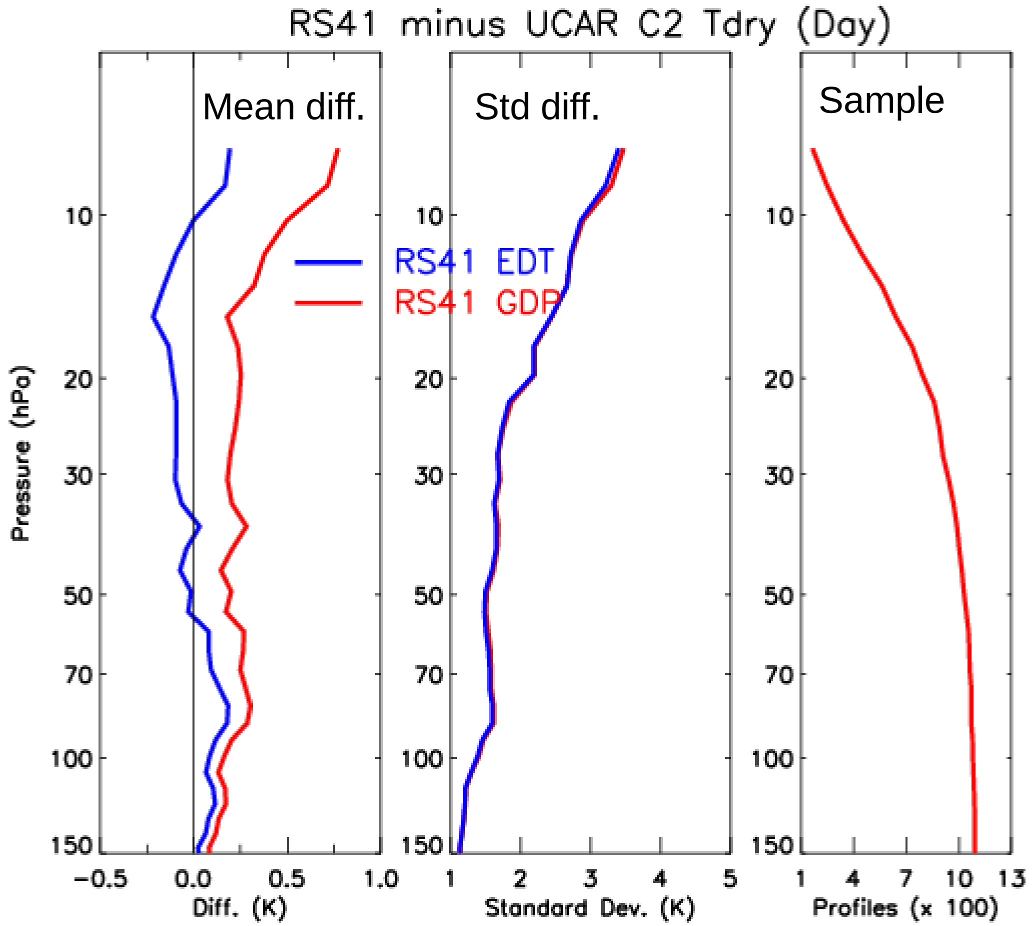
Lower Stratospheric Temperature Assessment: SGP case (day)



Relative to OBS (CrIS):
If OBS – CAL(raob) < 0, then raob is warm-biased
If OBS – CAL(raob) > 0, then raob is cold-biased

Relative to CrIS:
RS41 EDT is cold-biased by 0.03 K
RS41 GDP is warm-biased by 0.16 K
RS92 GDP is warm-biased by 0.45 K

RS41 EDT matches better with CrIS than RS41 GDP does.
RS41 GDP appears to be overcorrected?

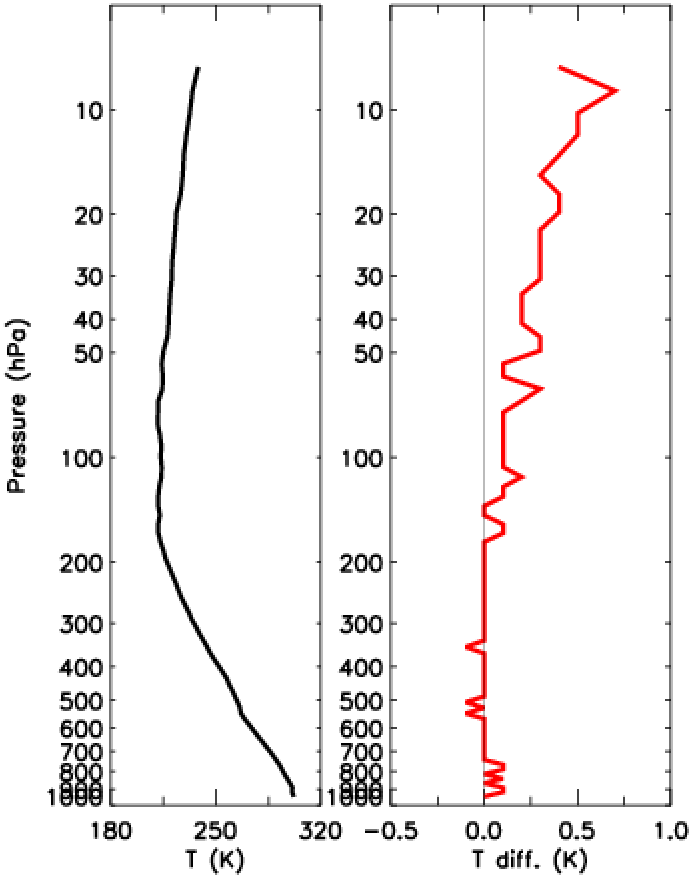


All GRUAN sites, 4-yr, Day
Averaged for 20-100 hPa,
RS41 EDT – TdryC2 = 0.01 ± 1.62 K
RS41 GDP – TdryC2 = 0.23 ±1.64 K

Case: Payerne, Jun. 27, 2019, Day, Synoptic, NOAA-20

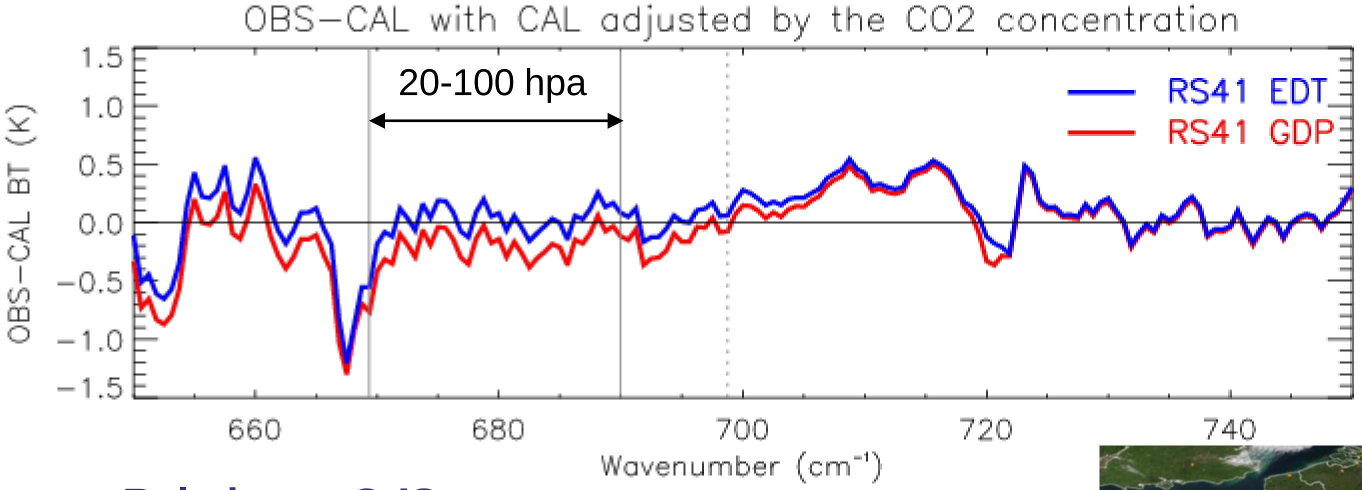
RS41 GDP vs. RS41 EDT

RS41 GDP - RS41 EDT



Averaged for 20-100 hPa

RS41 GDP – RS41 EDT = 0.21 K

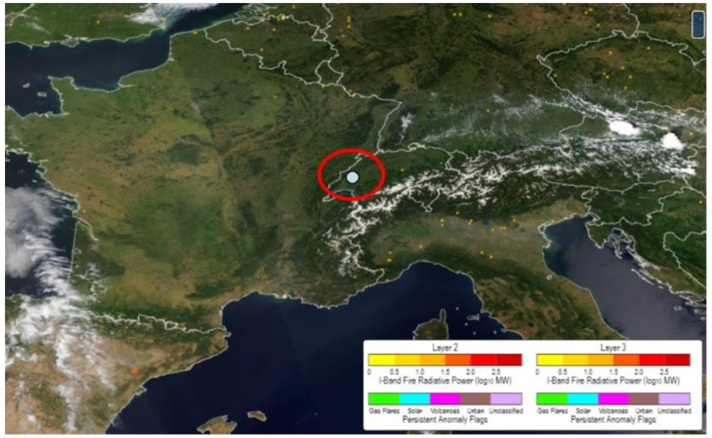


Relative to CrIS:

RS41 EDT is cold-biased by 0.01 K

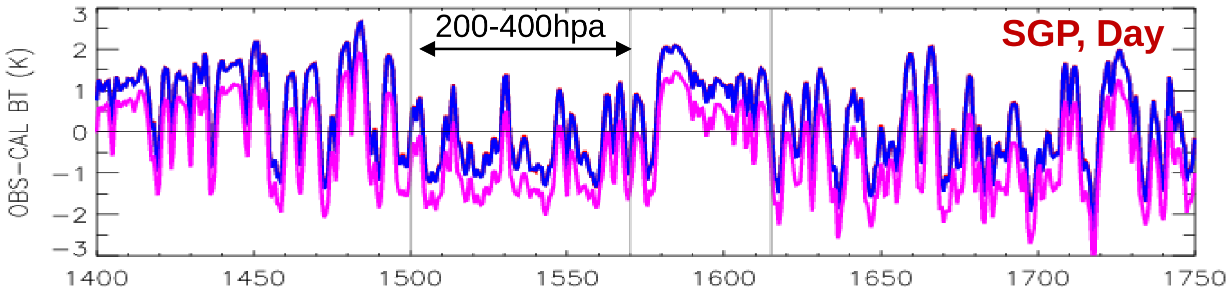
RS41 GDP is warm-biased by 0.21 K

RS41 EDT matches better with CrIS than RS41 GDP does.



Upper Tropospheric Water Vapor Assessment

MWIR OBS-CAL

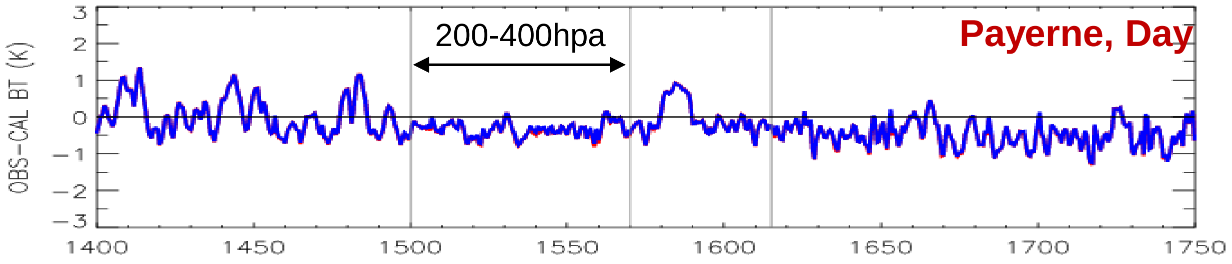


Relative to CrIS:

RS41 EDT is dry-biased by -0.022 mW m^{-2} sr cm^{-1}

RS41 GDP is dry-biased by -0.018 mW m^{-2} sr cm^{-1}

RS92 GDP is dry-biased by -0.146 mW m^{-2} sr cm^{-1}



RS41 EDT is dry-biased by -0.043 mW m^{-2} sr cm^{-1}

RS41 GDP is dry-biased by -0.045 mW m^{-2} sr cm^{-1}

Relative to OBS (CrIS):

If OBS – CAL(raob) < 0, then raob is dry-biased

If OBS – CAL(raob) > 0, then raob is wet-biased

- **RS41 GDP is < 1% RH from CrIS**
- **RS41 GDP and RS41 EDT are close to each other**

Calbet et al. (2017): 1500-1570 cm^{1}

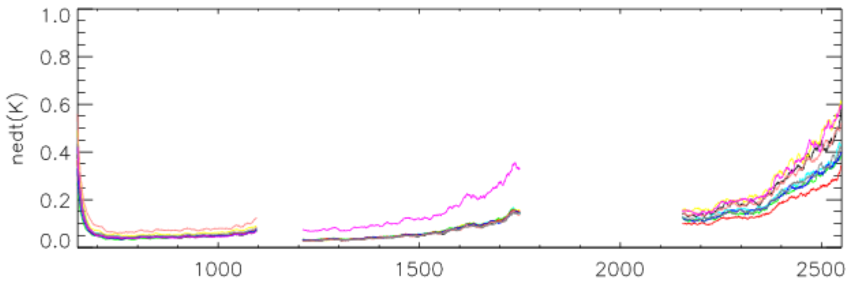
OBS-CAL: -0.1127 mW m^{-2} sr cm^{-1} = RH dry bias: 2.5%

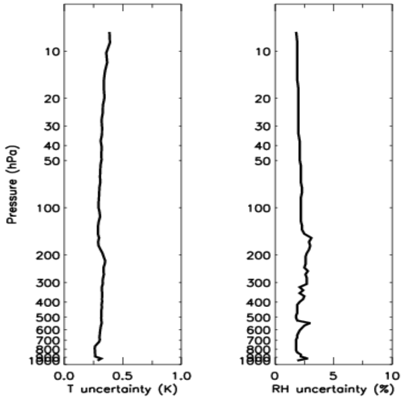
Uncertainties in the Analysis

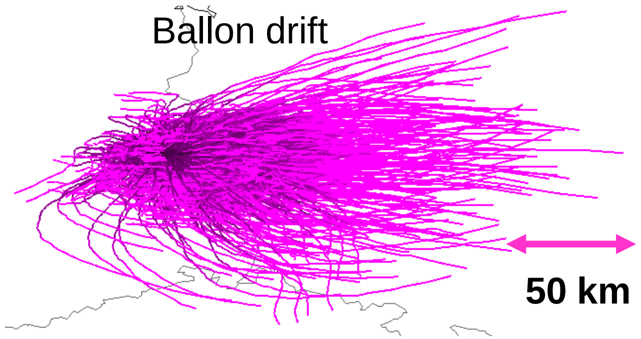
- Measurement noise
  - CrIS (LWIR and MWIR): <0.1- 0.2 K
  - GRUAN: 0.1 - 0.2 K
- Collocation mismatch
  - CrIS: different channels sense different layers of the atmosphere
  - GRUAN: balloon drift

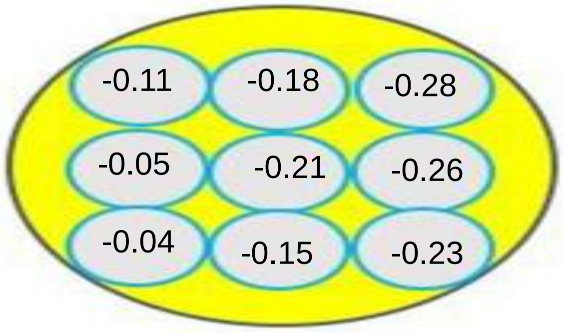
$$\left|m_1 - m_2\right| < k\sqrt{\sigma^2 + u_1^2 + u_2^2}$$

where “m_1” and “m_2” are OBS and CAL radiances to be compared, “u_1” and “u_2” the associated uncertainties, “σ” the uncertainty due to mismatch and “k” the agreement parameter.

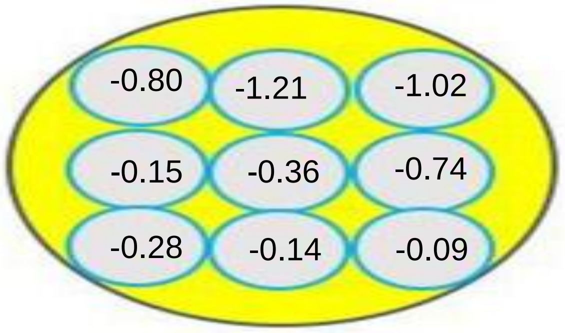








OBS-CAL for LS T



OBS-CAL for UP WV

Summary

- The consistency of GRUAN RAOBs and satellite infrared radiance measurements (ie, CrIS) is assessed based on case studies (by analyzing OBS-CAL)
  - For the UT water vapor, RS41 GDP matches well with CrIS for both day and night. RS41 GDP and RS41 EDT are close to each other. *CFH, Lidar for future evaluation?*
  - For the LS temperature:
    - Day: RS41 EDT matches better with CrIS than RS41 GDP does (ie, RS41 GDP appears to be over-corrected?).
    - The radiosonde biases identified using CrIS as the reference appear to be verified by using RO Tdry as the reference.

- *Analysis using a big ensemble is in progress.*
- *Bring uncertainties (data noise, collocation mismatch etc) into the radiance space*
- *High-ascent radiosondes are beneficial to satellite sensor cal/val in the stratosphere.*
- *Radiosonde launches under clear sky conditions are needed for MWIR WV cal/val.*