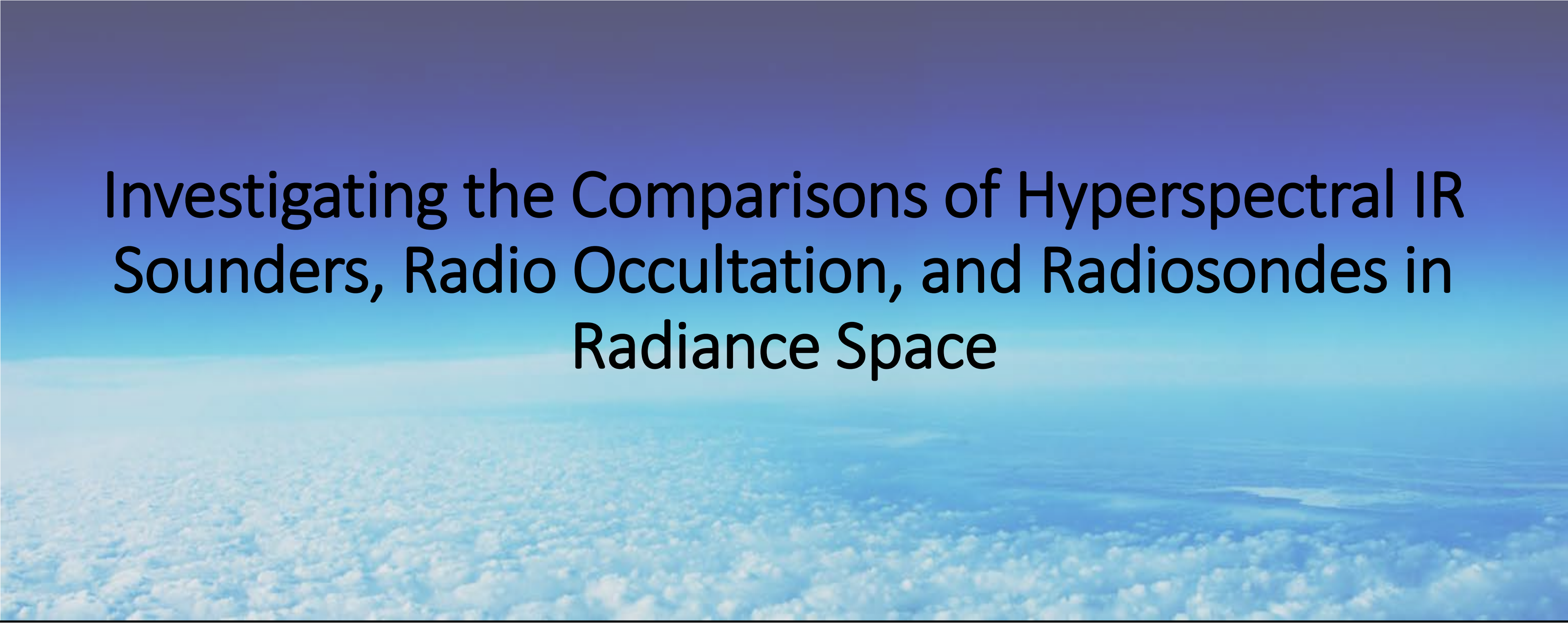

Investigating the Comparisons of Hyperspectral IR Sounders, Radio Occultation, and Radiosondes in Radiance Space

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EUMETSAT ROMSAF – IROWG 2019

Outline

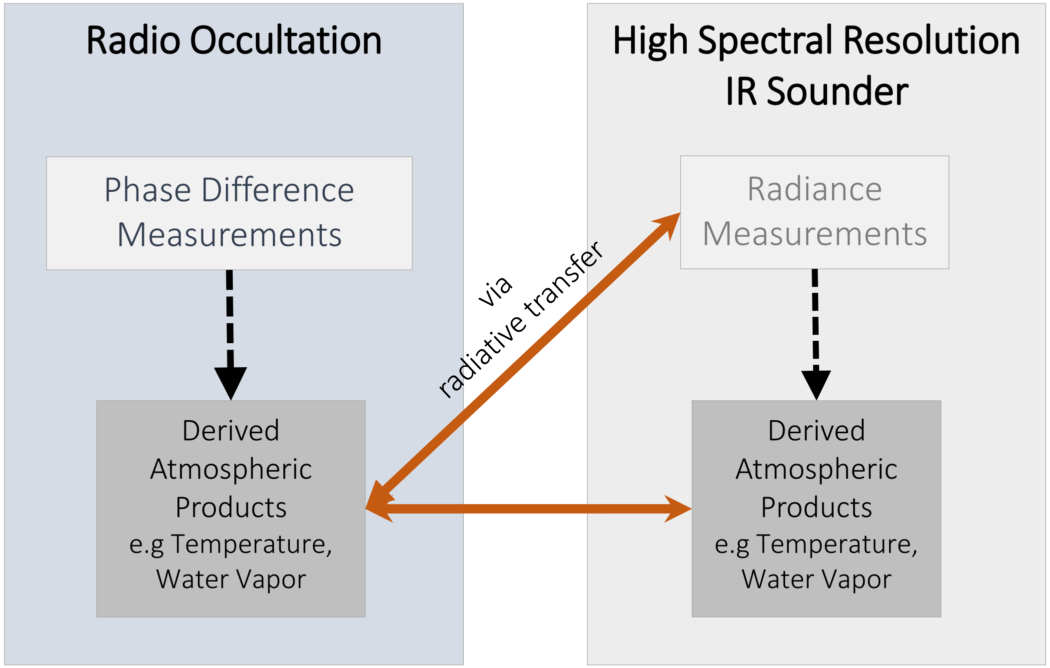
- Background
- Methods
- Uncertainties
- Case Study Results
- Concluding Remarks

Background

Background

Assessment of infrared (IR) temperature retrievals in upper-troposphere, lower-stratosphere using RO as a reference:

- *Divakarla, et al. (2014), The CrIMSS EDR algorithm: Characterization, optimization and validation, JGR Atmos., doi: 10.1002/2013JD020438.*
- *Feltz, et al. (2014), Application of GPS radio occultation to the assessment of temperature profile retrievals from microwave and infrared sounders, AMT, doi: 10.5194/amt-7-3751-2014.*
- *Feltz, et al. (2017), Assessment of NOAA NUCAPS upper air temperature profiles using COSMIC GPS radio occultation and ARM radiosondes, JGR Atmos., 122, doi: 10.1002/2017JD026504.*



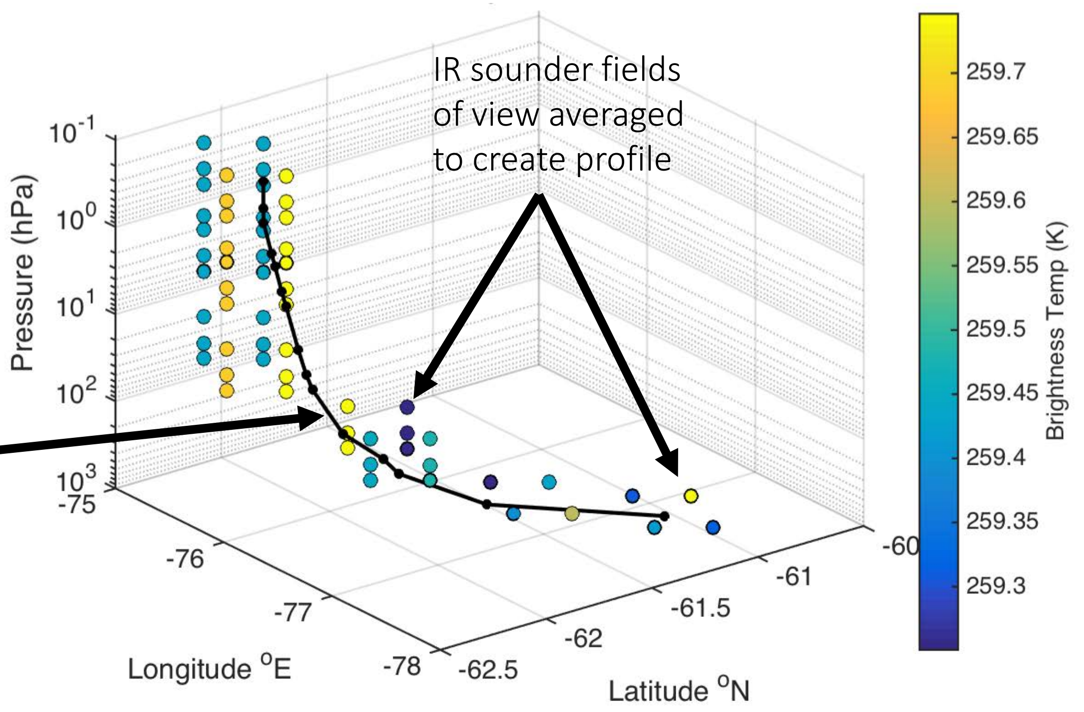
Assessment of RO temperature via radiative transfer using IR radiances as a reference:

- *Feltz M., R. Knuteson, and H. Revercomb (2017), Assessment of COSMIC radio occultation and AIRS hyperspectral IR sounder temperature products in the stratosphere using observed radiances, JGR Atmos., 122, doi: 10.1002/2017JD026704.*
- *ROMSAF Visiting Scientist Project Report: Assessment of Differences Between ROM SAF GRAS Derived Brightness Temperatures and Hyperspectral Infrared Brightness Temperature Observations, SAF/ROM/DMI/REP/VS/33, CDOP-2 VS No. 33. (http://www.romsaf.org/Publications/reports/romsaf_vs33_rep_v10.pdf)*

Methods

Methods: Matchup Scheme

Individual Matchup Case



IR sounder fields of view averaged to create profile

GRAS RO profile location

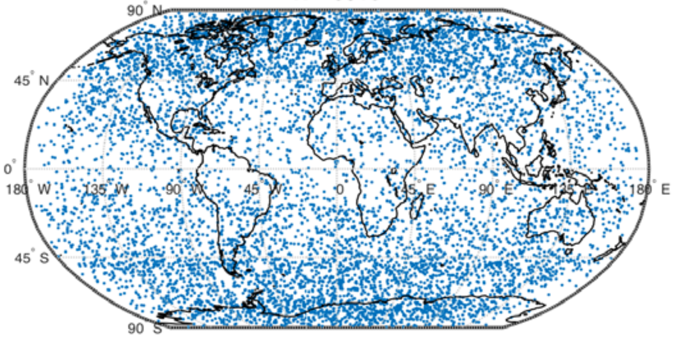
- Use a profile-to-profile matchup method
  - Accounts for the unique RO profile geometry and horizontal resolution
  - <1 hr time criterion

FOR MORE DETAILS: Feltz, M. et al. (2014), A methodology for the validation of temperature profiles from hyperspectral infrared sounders using GPS radio occultation: Experience with AIRS and COSMIC, JGR, doi:10.1002/ 2013JD020853.

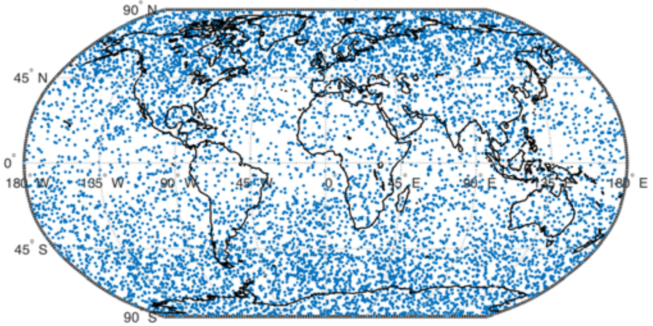
Methods: Matchup Scheme

Example Matchup
Distributions:
JULY 2011

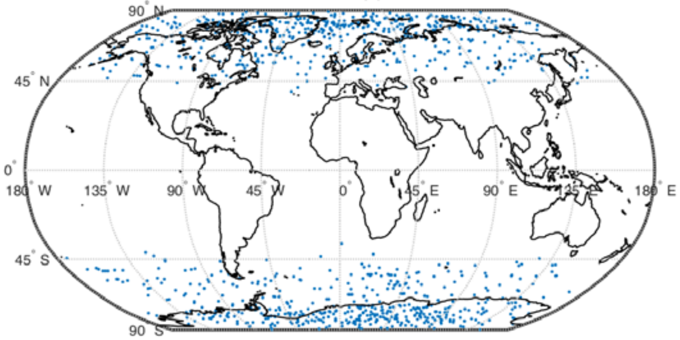
COSMIC & AIRS
July 2011
N = 8913



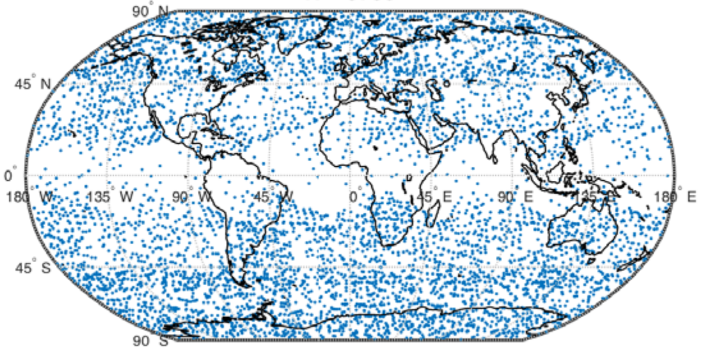
COSMIC & METOP-A IASI
July 2011
N = 10264



METOP-A GRAS & AIRS
July 2011
N = 1153



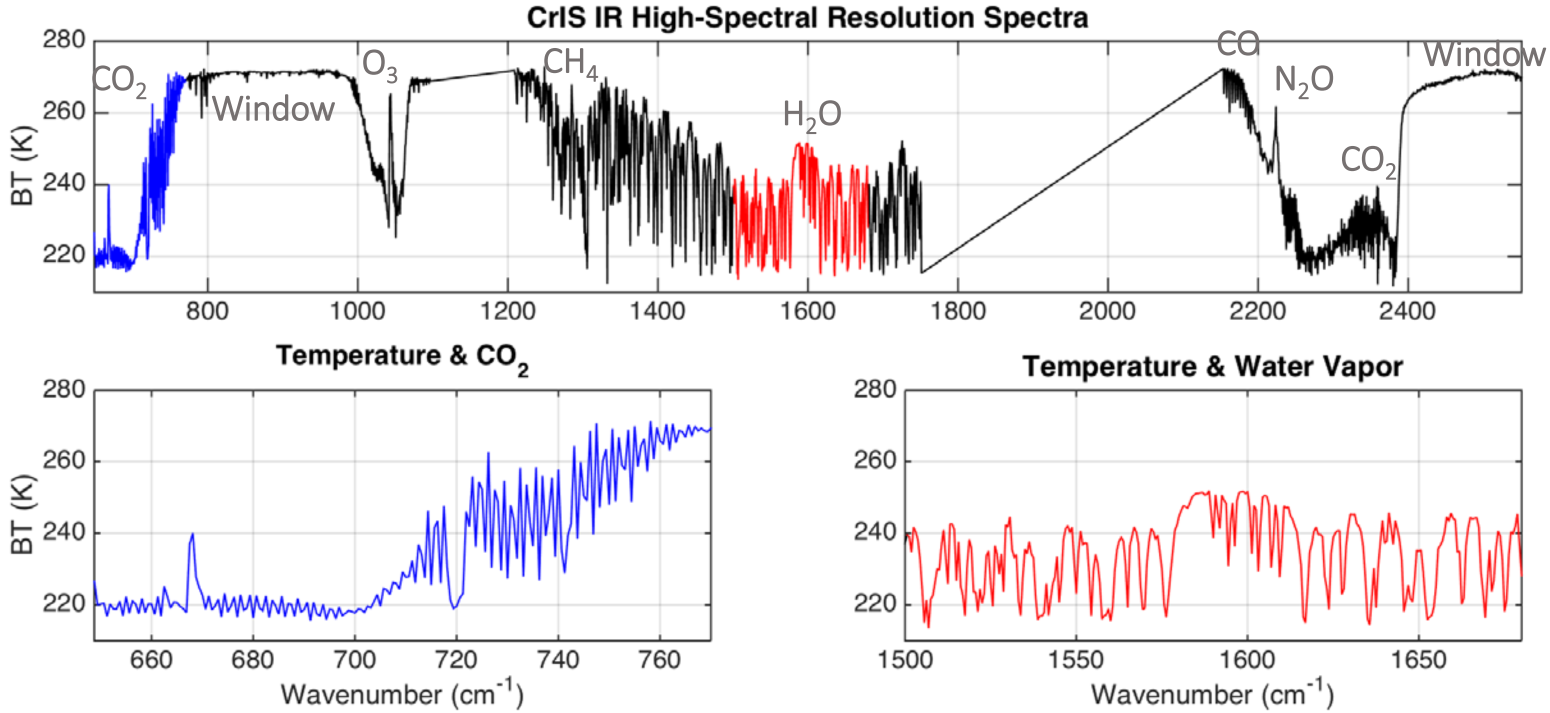
METOP-A GRAS & METOP-A IASI
July 2011
N = 6755



- Distribution and number of matchups depends on orbital mechanics
- Method applicable to data from different platforms/processing centers

Methods: Radiative Transfer

- Optimal Spectral Sampling Radiative Transfer Model (RTM)
  - Based off reference model, Line-by-Line RTM (Atmospheric and Environmental Research) which uses HITRAN database of molecular absorption lines
  - *LBLRTM Ref: Clough, et al., Line-by-line calculation of atmospheric fluxes and cooling rates: Application to water vapor. JGR, 97, 1992.*
  - *HITRAN Ref: Rothman, et al., The HITRAN2012 molecular spectroscopic database. J. of Quantitative Spec. & Radiative Transfer, 130, 4-50, 2013.*
  - Model Input: ECMWF Reanalysis, NOAA CarbonTracker, NASA CAMEL Land or Nalli Ocean Emissivity



Methods: Radiative Transfer

- Jacobians of temperature and atmospheric constituents are computed
  - Linearization of RTM about a specific state, e.g. a temperature Jacobian, K, is defined as:

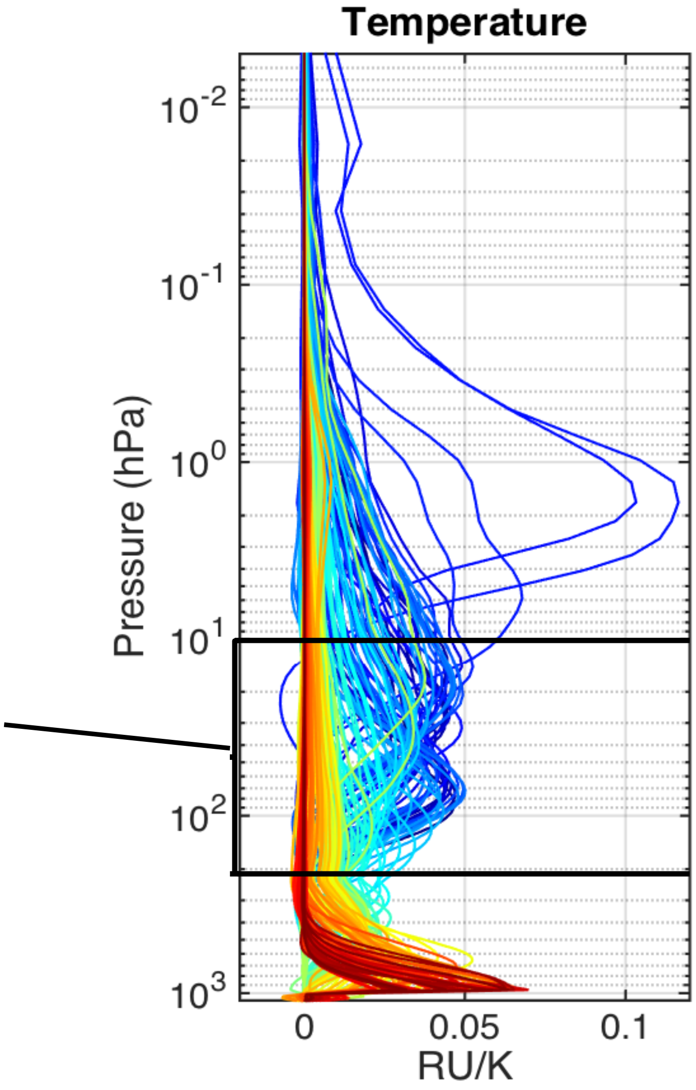
$$K = (R-R_o)/(T-T_o) = dR/dT$$

  where R_o and T_o are perturbations of the radiance and temperature from a given state

  - Jacobians show where the radiance information is coming from

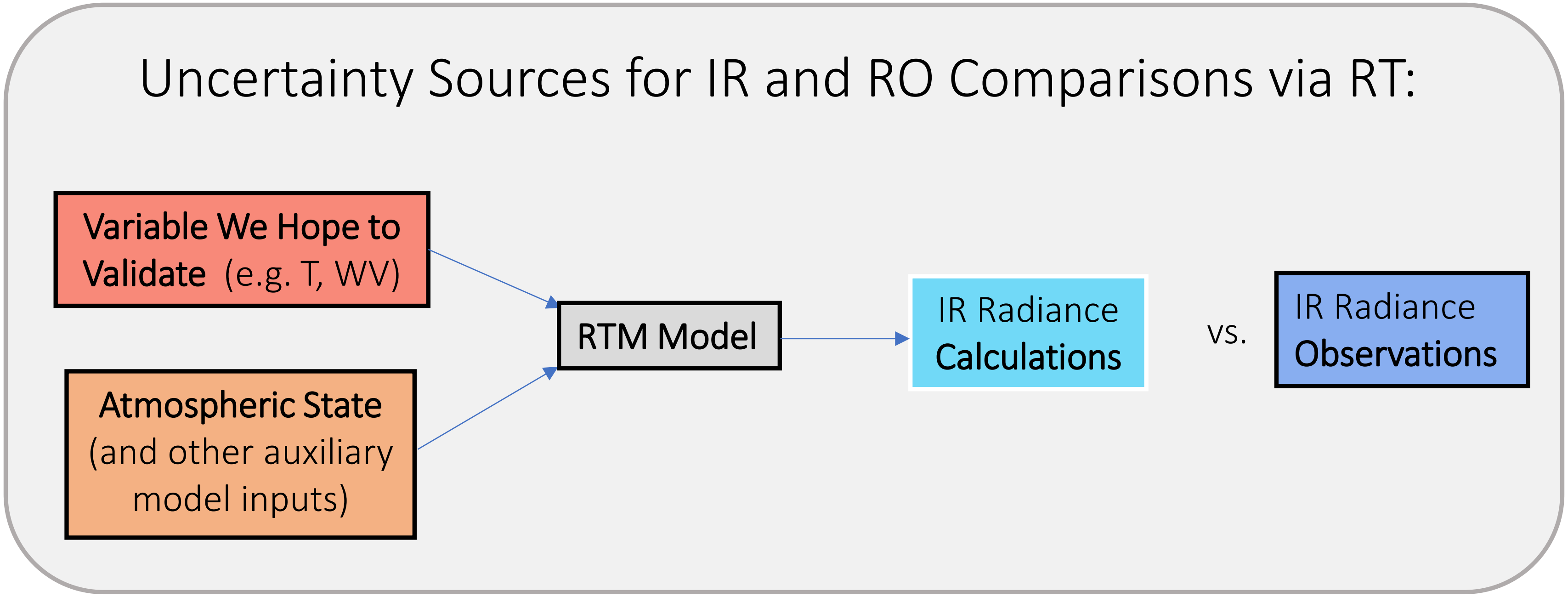
- For temperature profile assessments, we focus on channels with Jacobian maxima (or with most weight) between ~200-10 hPa

- Need to be aware that the radiative transfer inherently smooths out high vertical resolution features of the profiles



Uncertainties

Uncertainties



Uncertainty Sources for IR and RO Comparisons via RT:

Variable We Hope to Validate (e.g. T, WV)

Atmospheric State (and other auxiliary model inputs)

RTM Model

IR Radiance **Calculations**

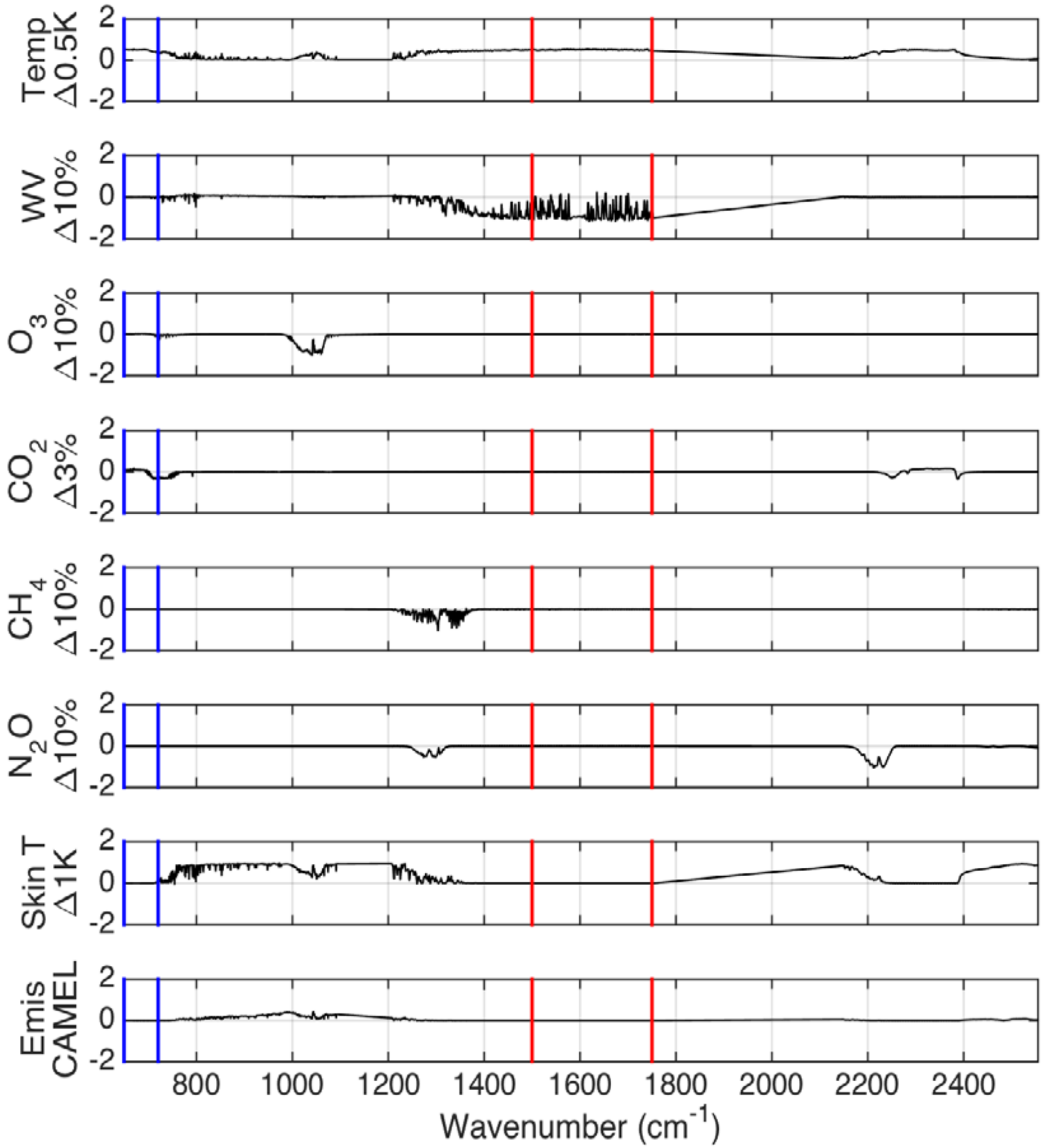
vs.

IR Radiance **Observations**

- Following section provides details on:
  - Atmospheric state uncertainty
  - Observation uncertainty

Uncertainties: Atmospheric State

- Atmospheric state uncertainty estimation method:
  - Calculate sensitivities of RTM output to model inputs
  - Scale sensitivities to input error estimates
  - Combine scaled sensitivities via root sum squared (RSS)
- Sensitivities to right computed at CrIS spectral resolution
- 650-720 cm^{-1} → CO_2, temperature (T)
- 1500-1750 cm^{-1} → water vapor (WV), T

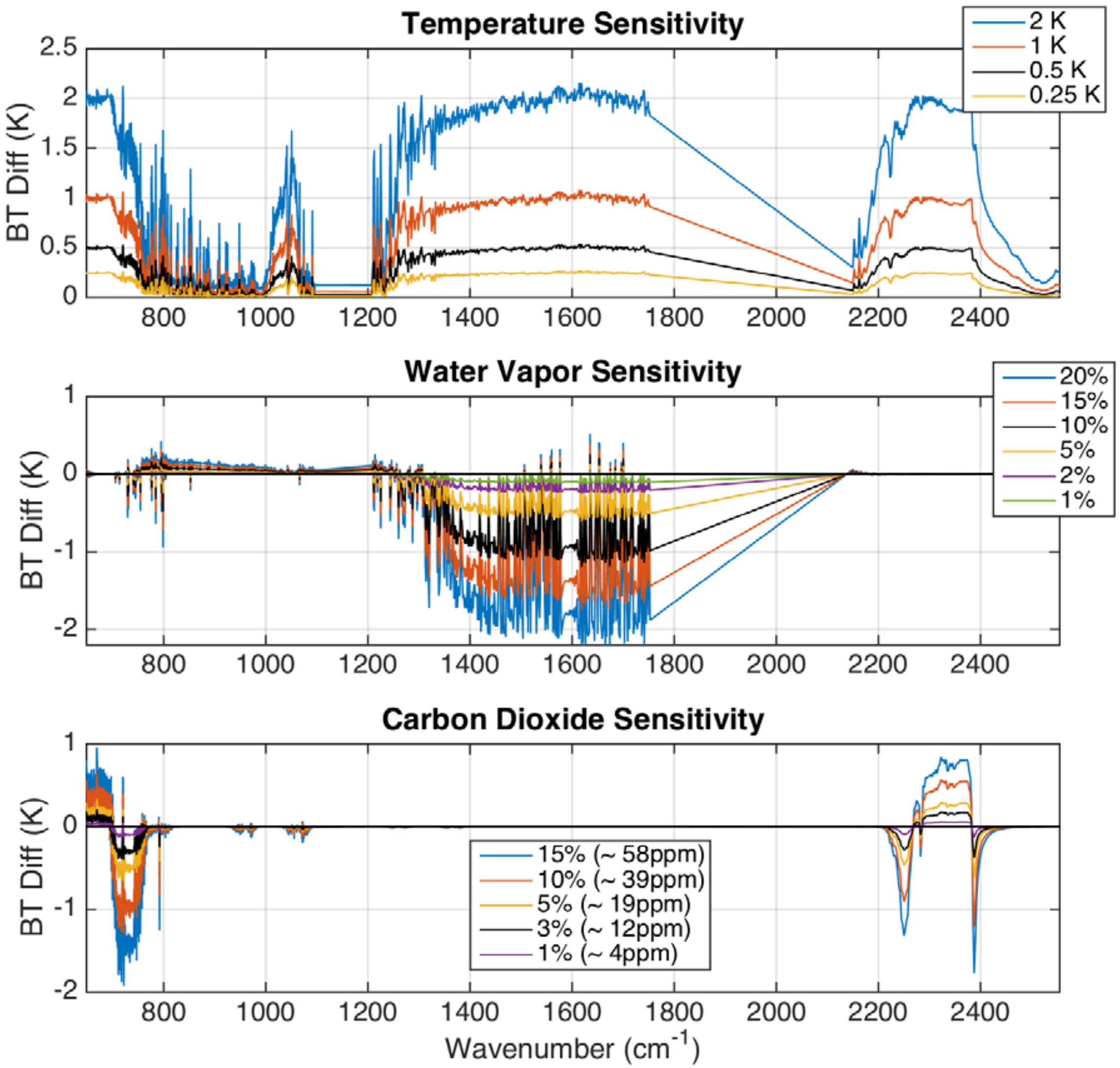


Uncertainties: Atmospheric State

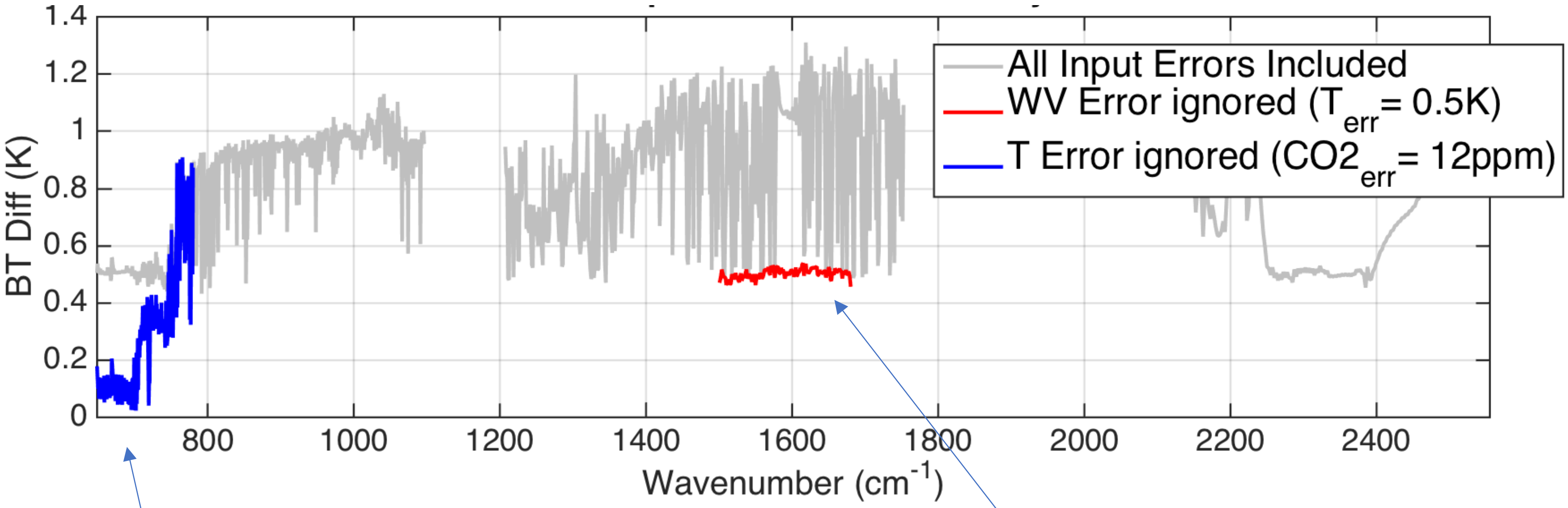
- Assumed error (uncertainty):
  - T: 0.5 K
  - WV: 10 %
  - CO_2: 12 ppm

- ~1:1 map from T_{unc}:BT_{unc} in WV channels

- ~10:1 map from WV_{unc}:BT_{unc} in WV channels (when ΔWV expressed as %)



Uncertainties: Atmospheric State

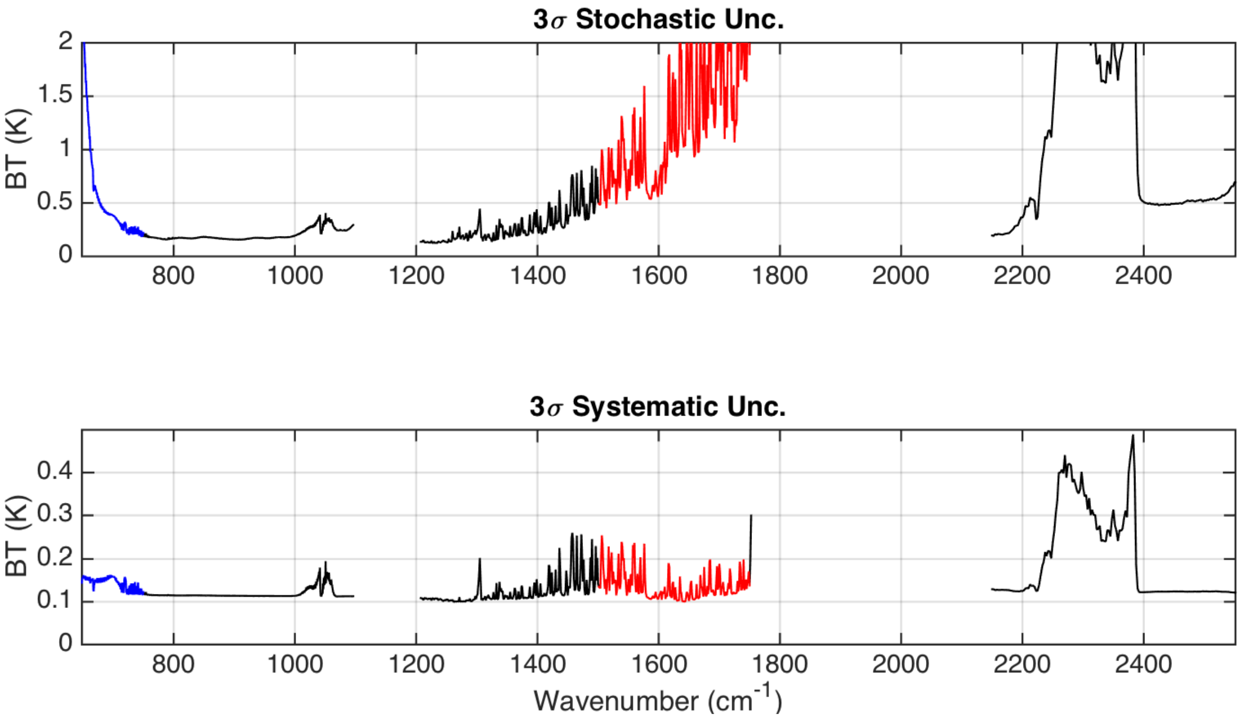


- Uncertainty due to CO_2 is **~0.1 K** for channels with wavenumbers less than 700 cm^{-1}

- Uncertainty of WV channels (primarily due to T) is **~0.5K**
- Ambiguity between T and WV implies we can only validate the WV to the degree we know our input T

Uncertainties: CrIS Radiance Observations

- CrIS is a Michaelson interferometer with onboard calibration techniques
- Much work has gone into estimating its calibration uncertainty and is detailed for SNPP in Tobin (2013)
- Stochastic unc under 0.25 K for regions of CO_2 sounding channels and decently under 1 K for parts of WV region
- Systematic unc is between 0.1 and 0.2 K for CO_2 & WV region



*Provided by Joe Taylor of UW–Madison, SSEC

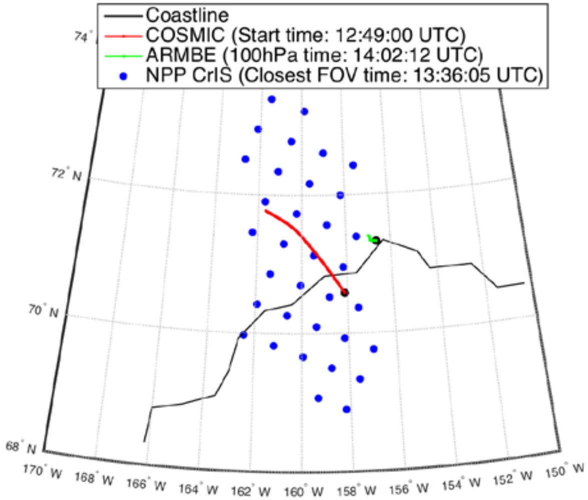
For more details:
Tobin D. et. al., Suomi-NPP CrIS radiometric calibration uncertainty, JGR: Atmos., 2013

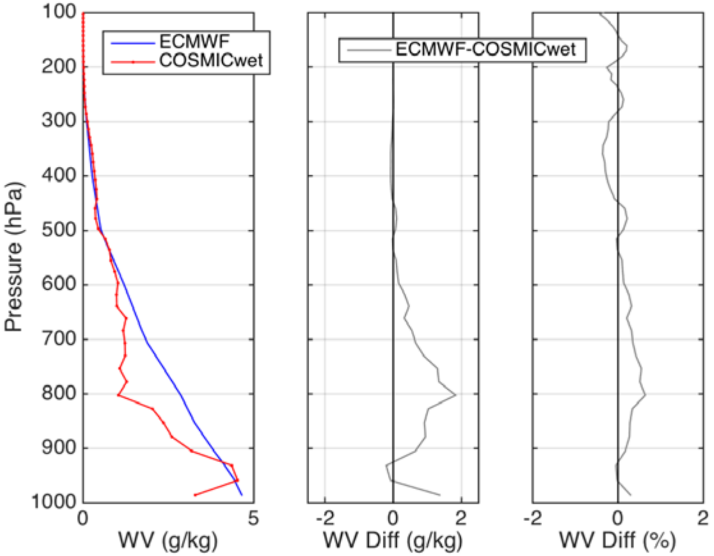
Case Study: Water Vapor Assessment

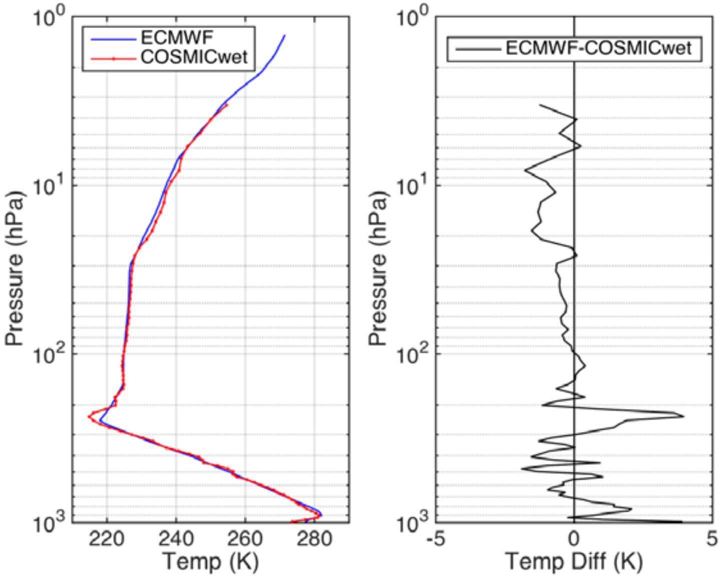
Case Study: Water Vapor Assessment

North Slope of Alaska (NSA) ARM Site
August 14th, 2014

- RO in comparison to coincident ECMWF forecast is:
  - dryer in lower troposphere
  - colder at the tropopause
  - warmer in stratosphere



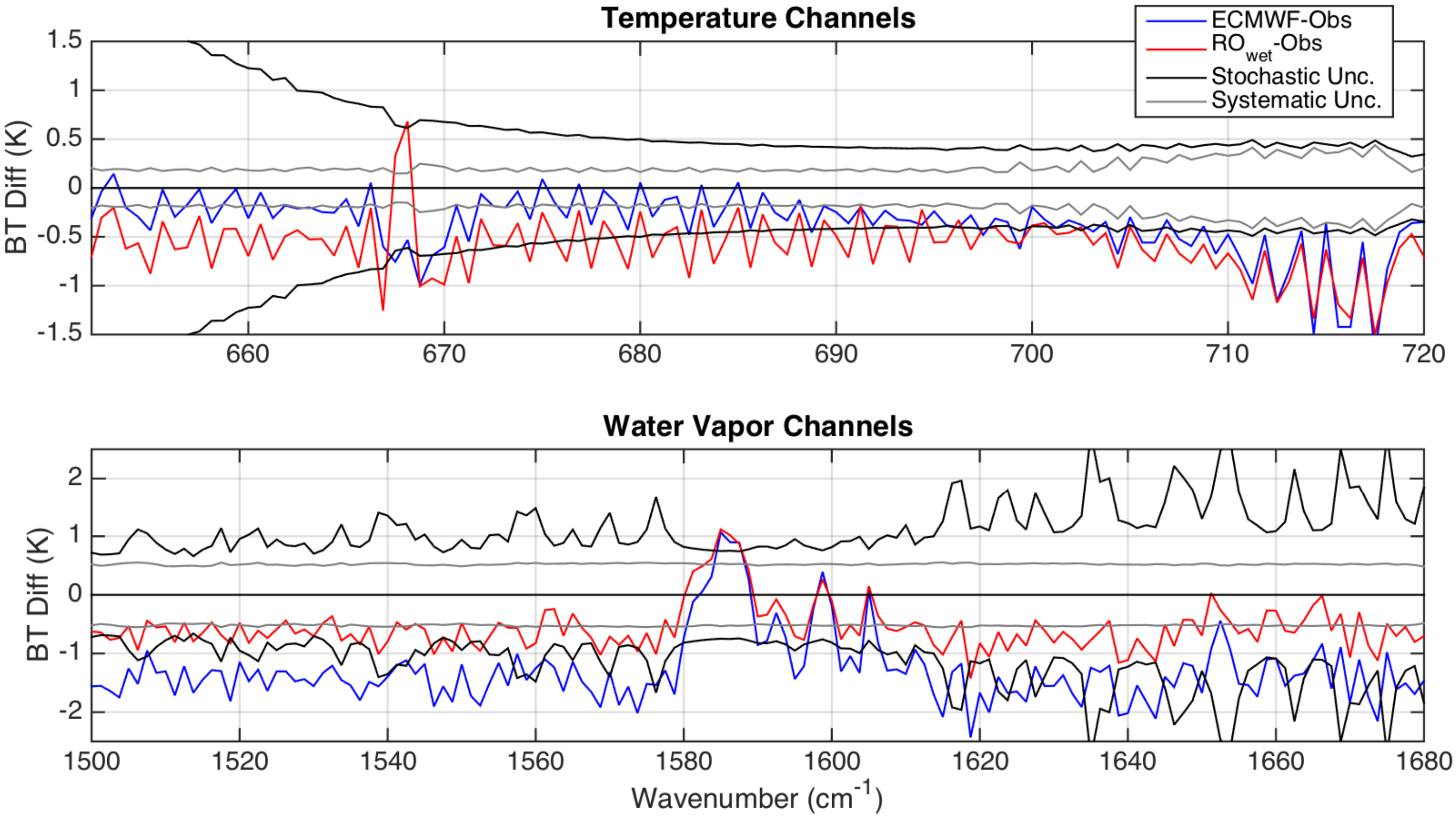




UCAR COSMIC data obtained from the COSMIC Data Analysis and Archive Center

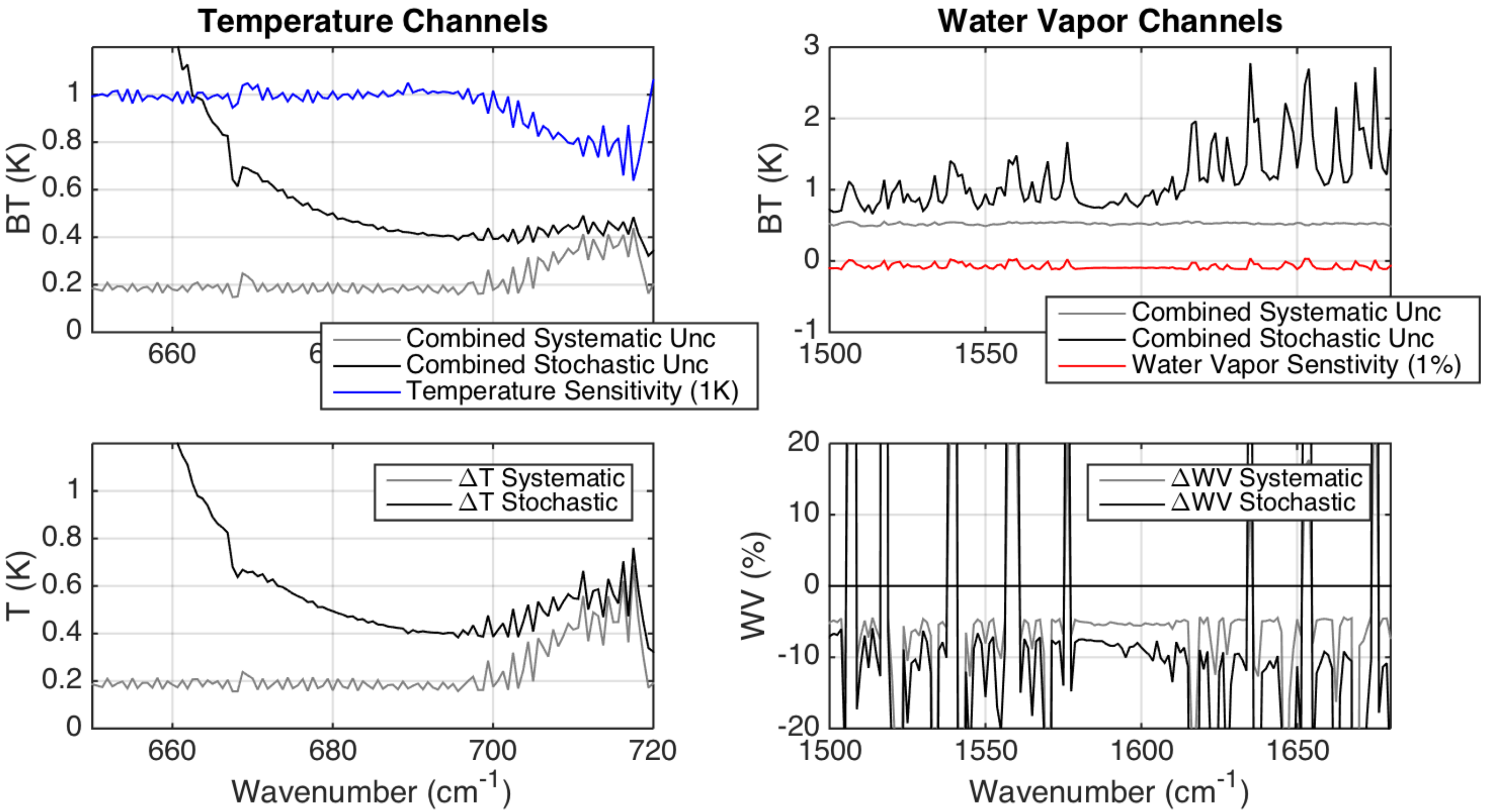
Case Study: Water Vapor Assessment

*Uncertainties are 3σ



**Does not include uncertainty of RO/ECMWF temperature or water vapor profile

Case Study: Water Vapor Assessment



- Minimum detectable upper-trop/lower-strat T
  - bias is ~0.2 K
  - single sample error is ~0.6 K

(Based off 12ppm CO_2 error + CrIS obs unc)

- Minimum detectable tropospheric WV
  - bias is ~6%
  - single sample error is ~10%

(Based off 0.5 K T error & CrIS obs unc)

Concluding Remarks

Concluding Remarks

- Previous work used the IR radiance observations as a reference for assessing RO temperature profile products

- A more detailed, case study investigation into the uncertainties associated with the IR sounder and RO comparison via radiative transfer was conducted using CrIS and showed:
    - The **single sample** minimum detectable stratospheric T error to be ~0.6 K, and the minimum detectable tropospheric WV error to be ~10%
    - The **ensemble mean** minimum detectable stratospheric T error to be ~0.2 K, and the minimum detectable tropospheric WV error to be ~6%

- Future work includes applying this method to assess the accuracy of the upper tropospheric water vapor derived from COSMIC-2 operational wet profiles using coincident observations from the operational NOAA-20 CrIS

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Methods: Radiative Transfer

- At infrared wavelengths in the absence of clouds, it can be assumed the atmosphere is non-scattering. With the additional assumption of LTE, the upwelling radiance is given by:

$$R_v = \epsilon_v B_v(T_s)\tau_v(p_s \to 0, \theta_{sat}) + \int_{p_s}^{0} B_v(T(p))\frac{d\tau_v(p \to 0, \theta_{sat})}{dp}dp + \mathrm{F}_\mathrm{v}^\mathrm{d}\rho_\mathrm{v}^\mathrm{t}\tau_\mathrm{v}(\mathrm{p_s} \to 0, \theta_\mathrm{sat})$$

SFC. BLACKBODY EMISSION + ATM. EMISSION + DOWN-WELLING ATM. EMISSION REFLECTED BY SFC.

- ϵ_v is surface emissivity,
- $B_v(T_s)$ the Planck function,
- τ_v the transmittance,
- θ_{sat} the satellite zenith angle,
- $\mathrm{F}_\mathrm{v}^\mathrm{d}$ the down-welling thermal flux,
- $\rho_\mathrm{v}^\mathrm{t}$ the $\mathrm{F}_\mathrm{v}^\mathrm{d}$surface reflectance
- T is temperature