Instrumented site for TIR CalVal

STUDY ON LA CRAU SITE

September 2023

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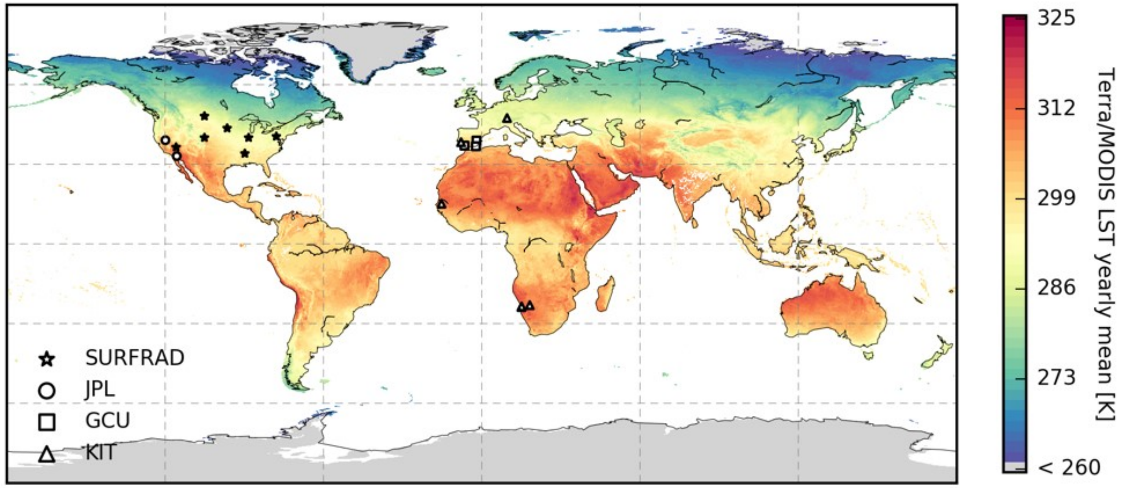
Context

- **TRISHNA, LSTM, SBG**
- **Existing network for LST**
- **Need for a denser network**
  - that provides L_{TOA}
  - with evaluated uncertainty for each site
  - with a demanding requirement on TOA radiance (0.5K)

- **Impact of uncertainty sources ?**
  - Atmosphere
  - Emissivity
  - Temperature (retrieved from radiometer measurements)

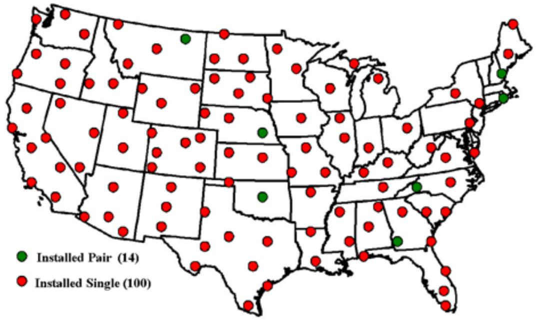
→ Study on LaCrau site

JPL TIR radiometer installed in LaCrau



SURFRAD: Surface Radiation, NOAA
JPL network
GCU: Global Change Unit, University of Valencia
KIT (Karlsruhe Institute of Technology) stations

Location of ground observational networks currently used to validate standard LST products derived from US and European spaceborne instruments.



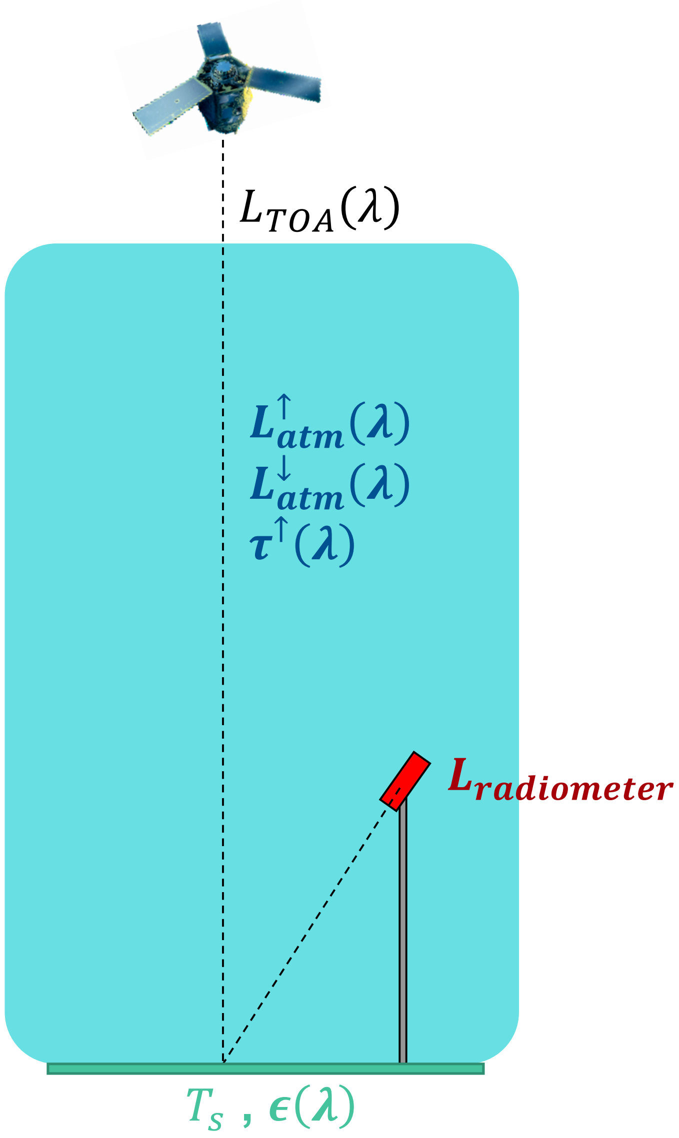
USCRN: US Climate Reference network

End-to-end simulation

- **Radiative transfer equation**

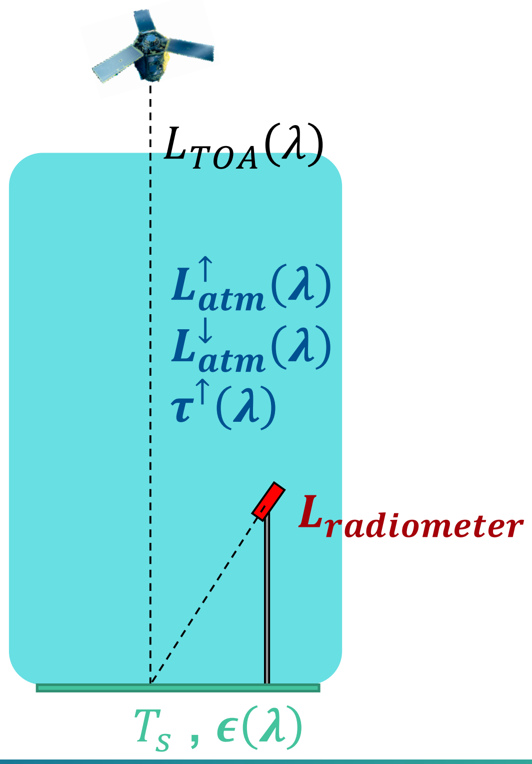
$$L_{TOA} = L_{atm}^{\uparrow} + \tau^{\uparrow} \left(\epsilon\, L_{BB}(T_S) + (1 - \epsilon)\, L_{atm}^{\downarrow} \right)$$

- **General assumptions**
  - Lambertian surface
  - Nadir satellite
- **« Known » quantities**
  - Atmospheric profiles (ECMWF)
    - + RTTOV with IASI spectral bands: $L_{atm}^{\uparrow}(\lambda)$, $L_{atm}^{\downarrow}(\lambda)$, $\tau^{\uparrow}(\lambda)$
  - Surface emissivity $\epsilon(\lambda)$ (Labed 91 for LaCrau soil)
  - Radiometer measurement $L_{radiometer}$
- **Derived quantities**
  - Estimated surface temperature $\tilde{T}_S$
- **True quantities : known quantites + uncertainty, T_s**



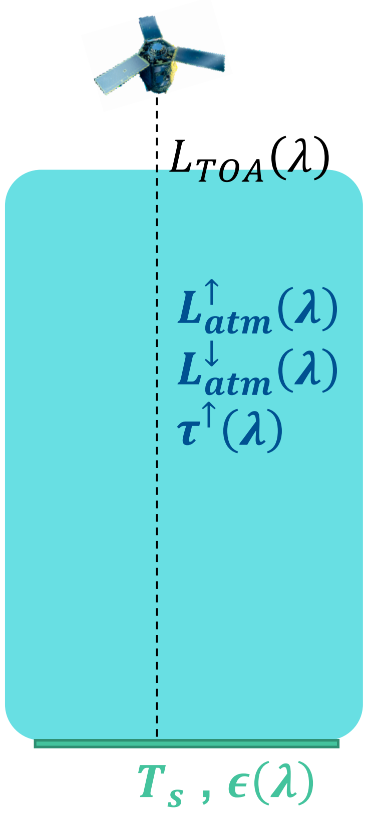
Choices for this study

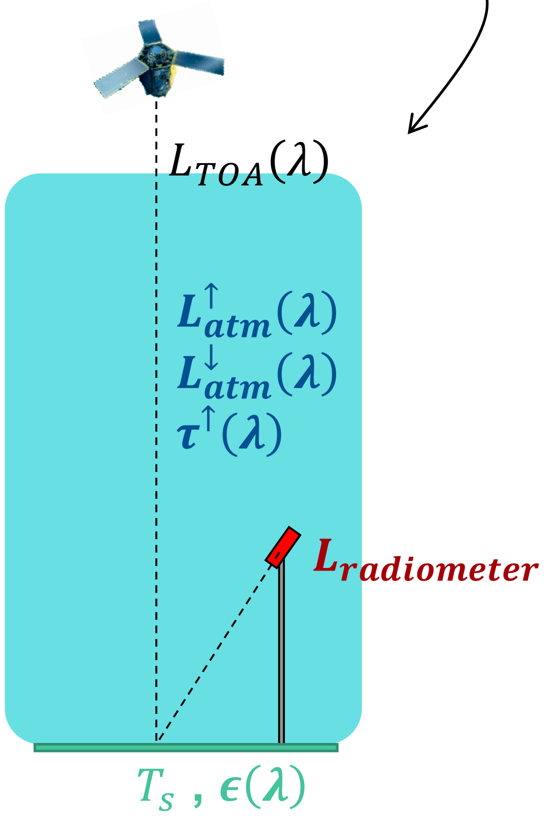
- **Atmospheric profiles**
  - LaCrau 2022 monthly average, 1 pm (ERA5 reanalysis)
    - January (driest month), July (hottest), October (wettest)
  - Uncertainty: white gaussian noise with following std
    - 10% for WV content (per pressure level)
    - 20% for ozone content (per p.l.)
    - 0.8K for temperature profile (per p.l.)
- **Emissivity**
  - LaCrau soil (Labed & Stoll 1991)
  - Uncertainty: white gaussian noise with following std
    - 0.02 (for each discretized λ)
    - 0.01 (for mean emissivity)
- **Temperature**
  - T_{skin} (ECMWF)
- **Radiometer**
  - Uncertainty: white gaussian noise with following std
    - 0.02 W/m²/sr/µm (0.1-0.2K)



Summary

- 1. Atmosphere : impact of uncertainty on atmospheric profiles alone
- 2. Emissivity : impact of uncertainty on emissivity alone
- 3. Instrumented site : impact of all considered sources of uncertainty





1

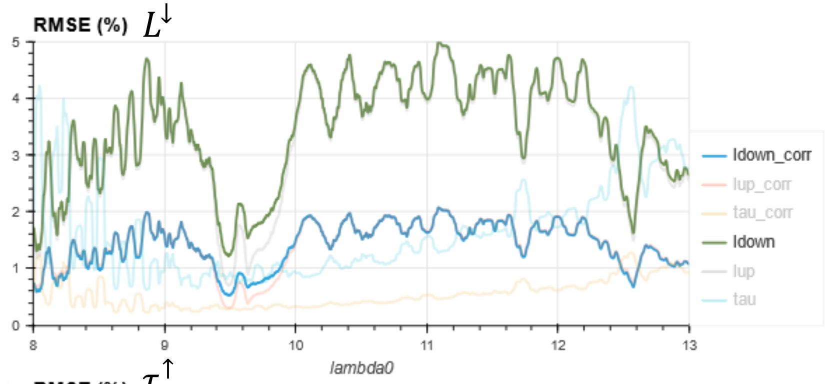
ATMOSPHERE

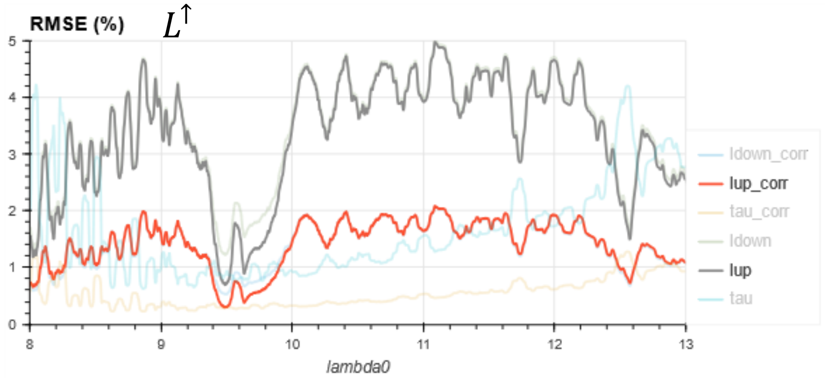
IMPACT OF UNCERTAINTY ON ATMOSPHERIC PROFILES ALONE

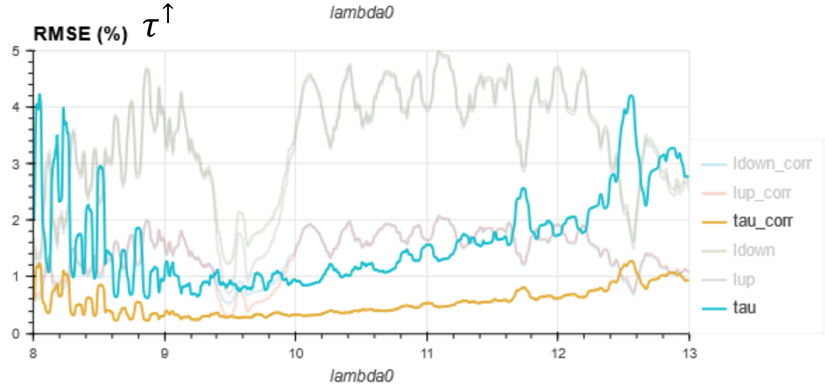
Uncertainty on WV content only (10%)

- **20 draws**
- **January and July**
- **Test with:**
  - Noised atmosphere vs reference atmosphere
  - Noised atmosphere vs corrected reference atmosphere (same integrated WV content)

July



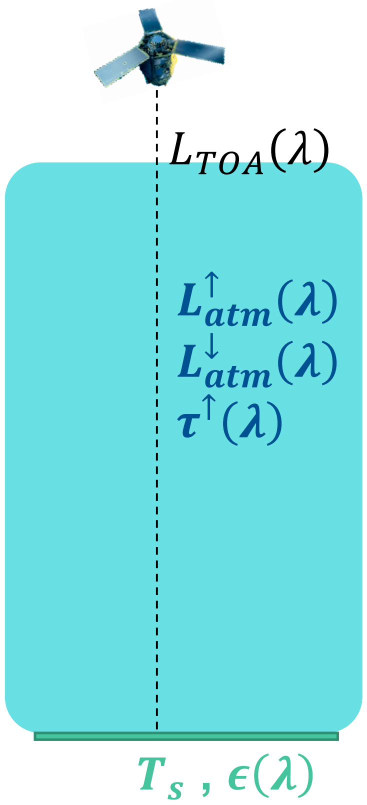




Integrated WV content

January: 0.86 g/cm²

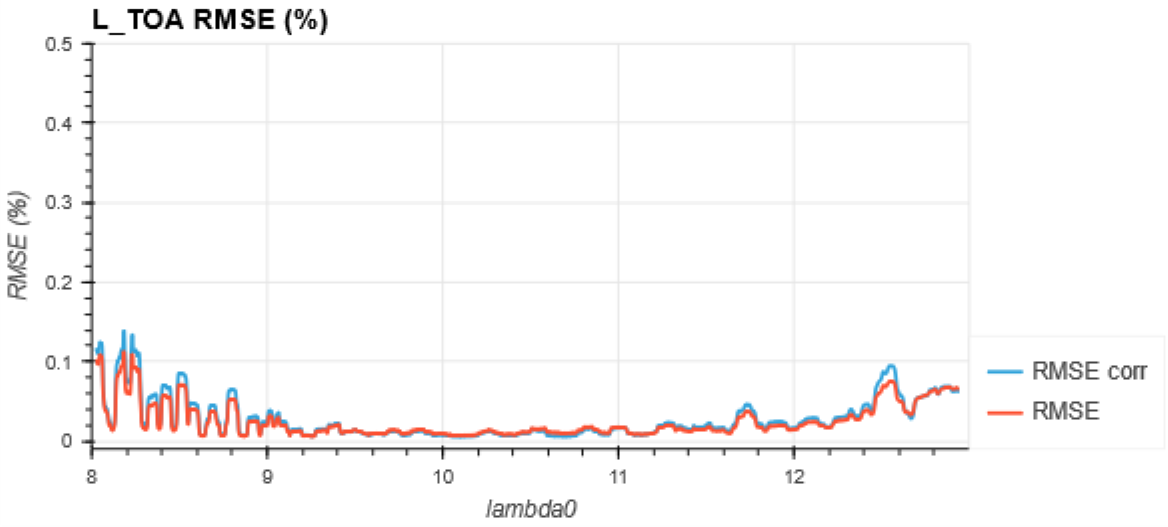
July: 2.6 g/cm²



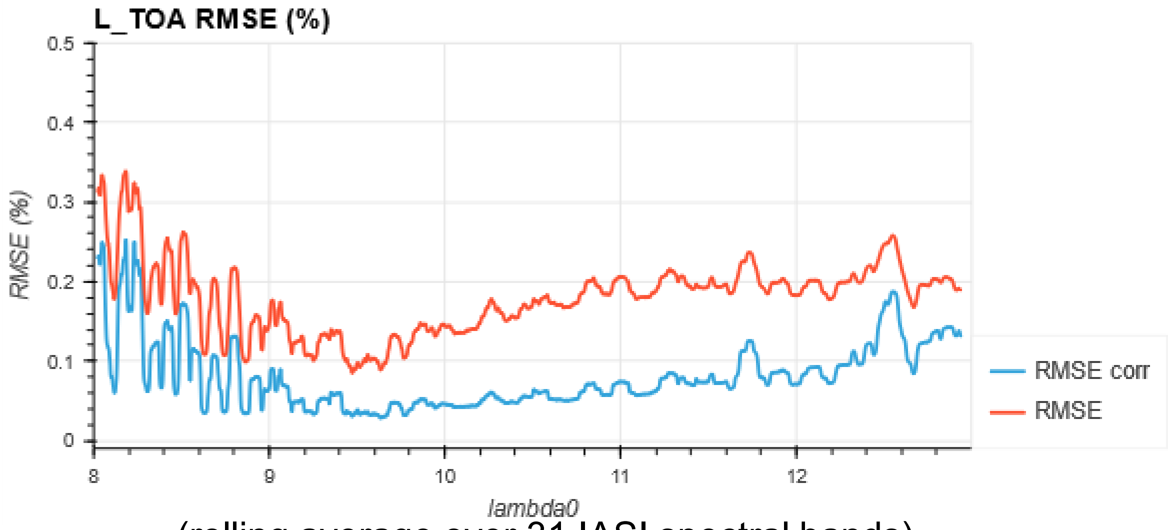
RMSE on L_{TOA} (%)

$$L_{TOA} = L_{atm}^{\uparrow} + \tau^{\uparrow} \left(\epsilon\, L_{BB}(T_S) + (1 - \epsilon)\, L_{atm}^{\downarrow} \right)$$

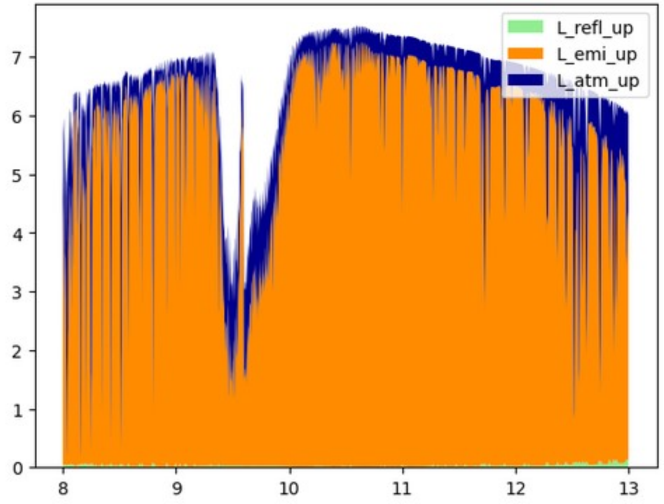
January

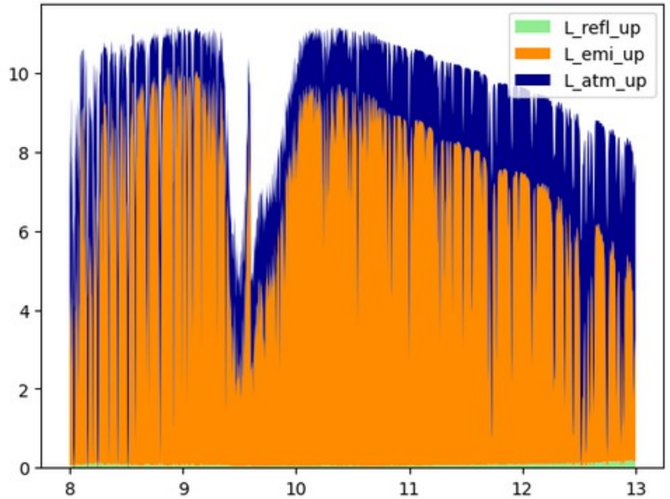


July



(rolling average over 31 IASI spectral bands)



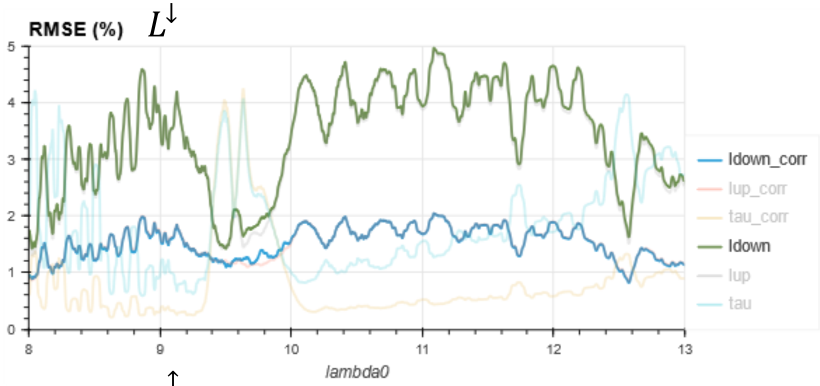


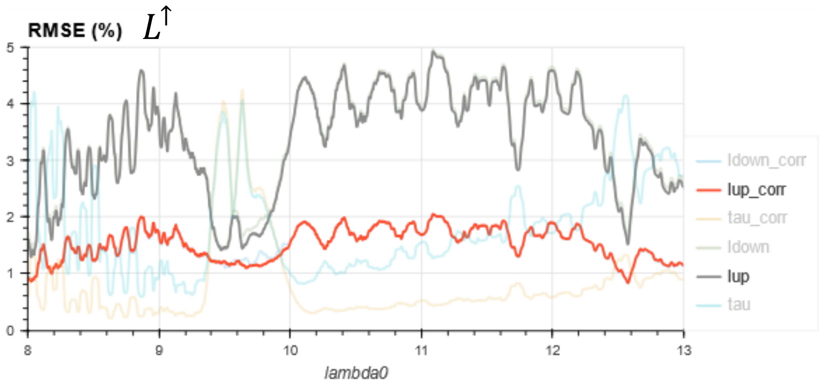
TOA signal for each wavelength, colored by contribution (emitted signal, reflected signal, atmospheric upwelling radiance)

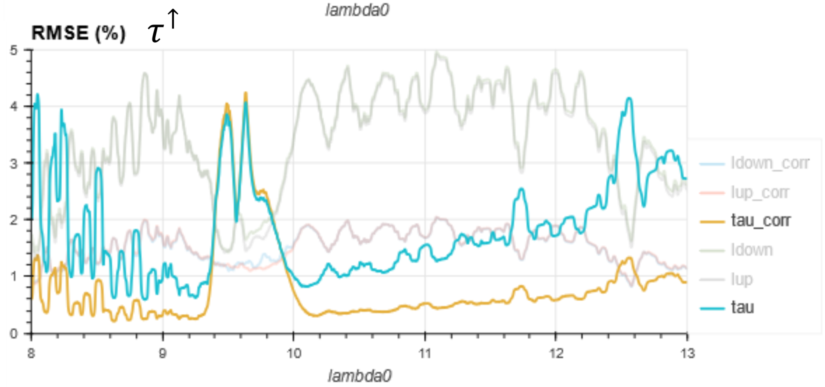
Uncertainty on WV content (10%), ozone (20%) and temperature (0.8K)

- **60 draws**
- **January, July and October**
- **Test with:**
  - Noised atmosphere vs reference atmosphere
  - Noised atmosphere vs corrected reference atmosphere (same integrated WV content)

July





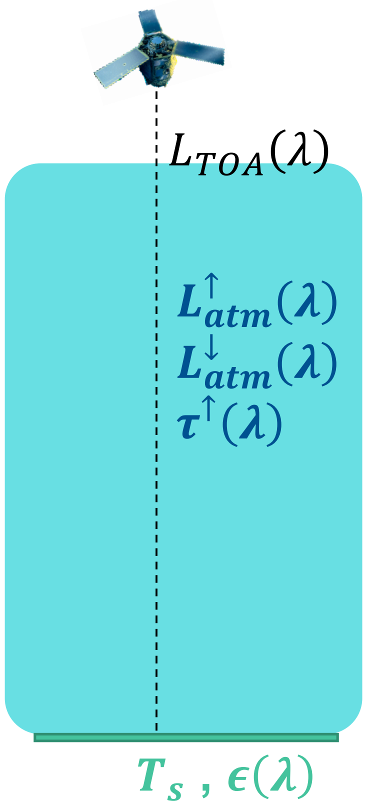


Integrated WV content

January: 0.86 g/cm²

July: 2.6 g/cm²

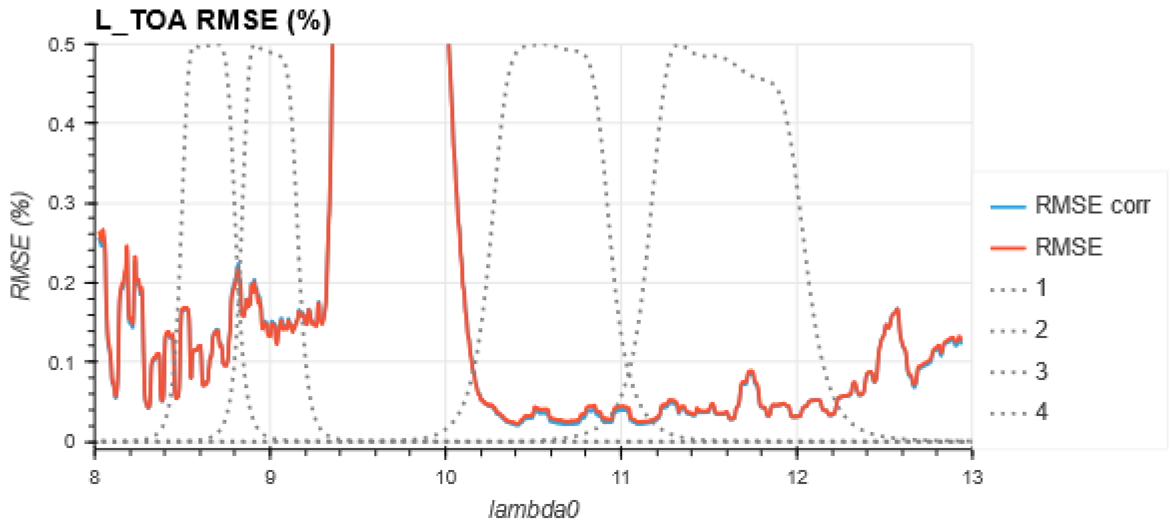
October: 2.7 g/cm²

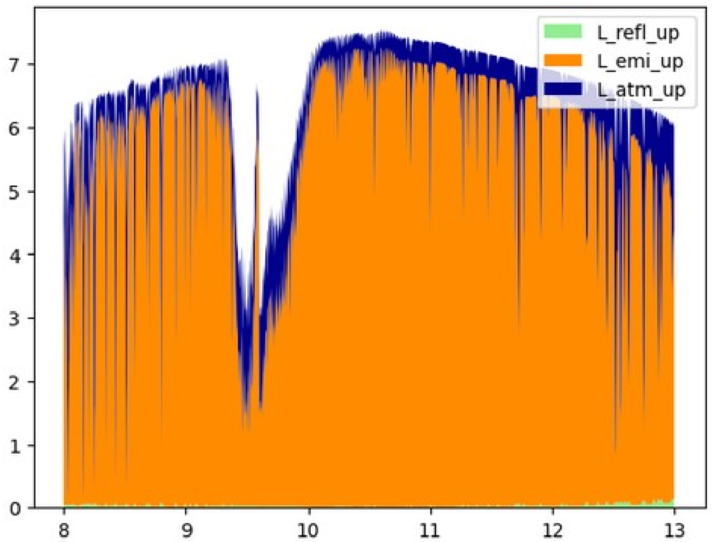


RMSE on L_{TOA} (%)

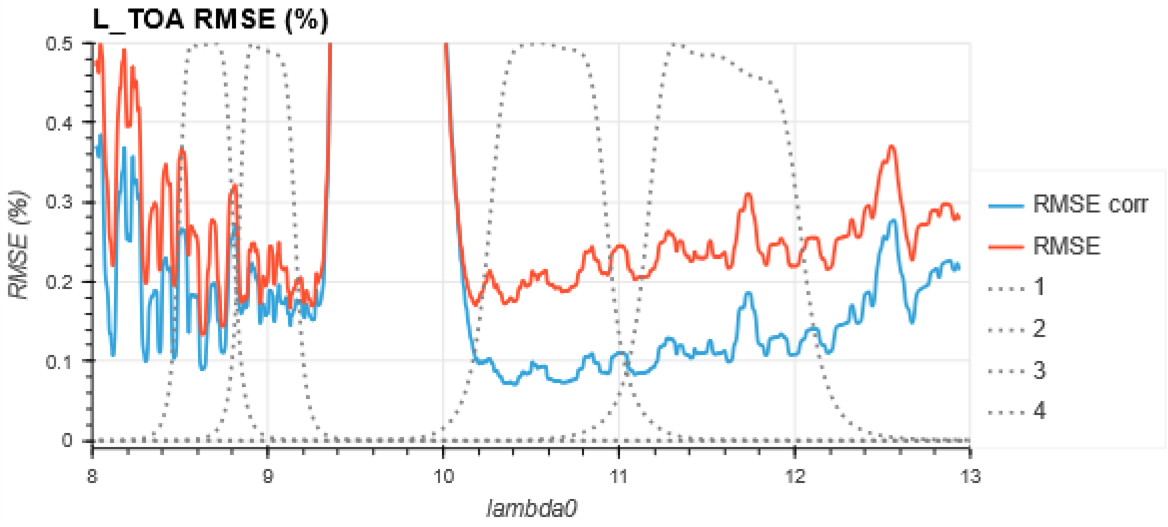
$$L_{TOA} = L_{atm}^{\uparrow} + \tau^{\uparrow} \left(\epsilon \, L_{BB}(T_S) + (1 - \epsilon) \, L_{atm}^{\downarrow} \right)$$

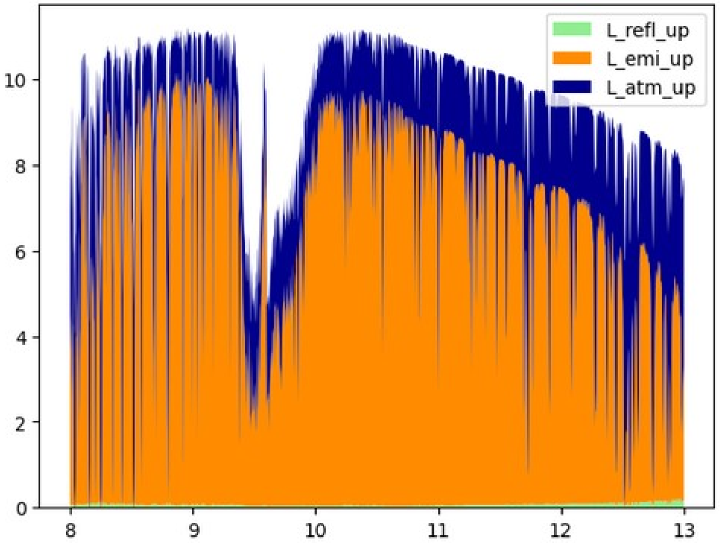
January





July

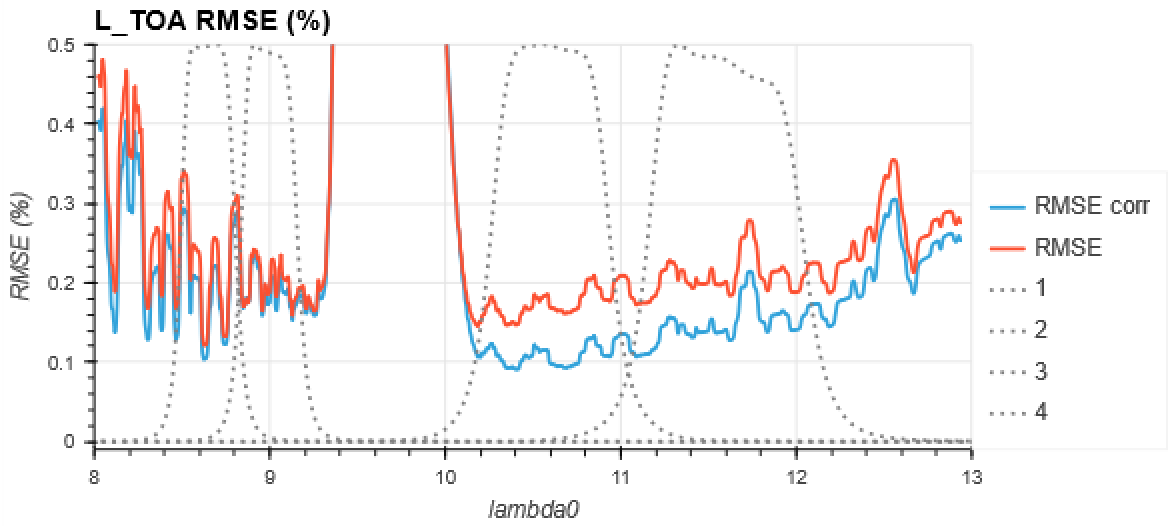




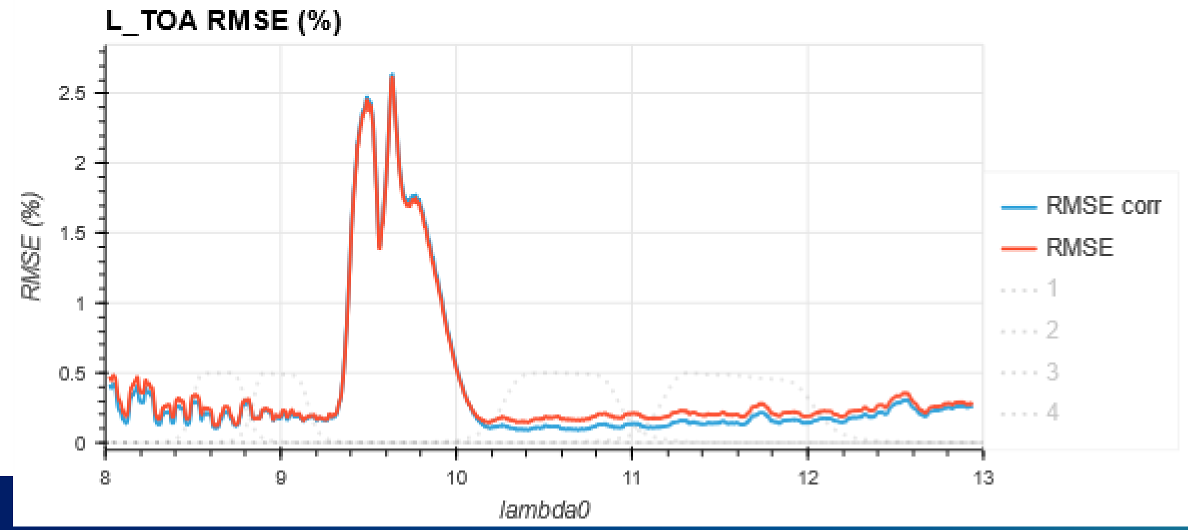
RMSE on L_{TOA} (%)

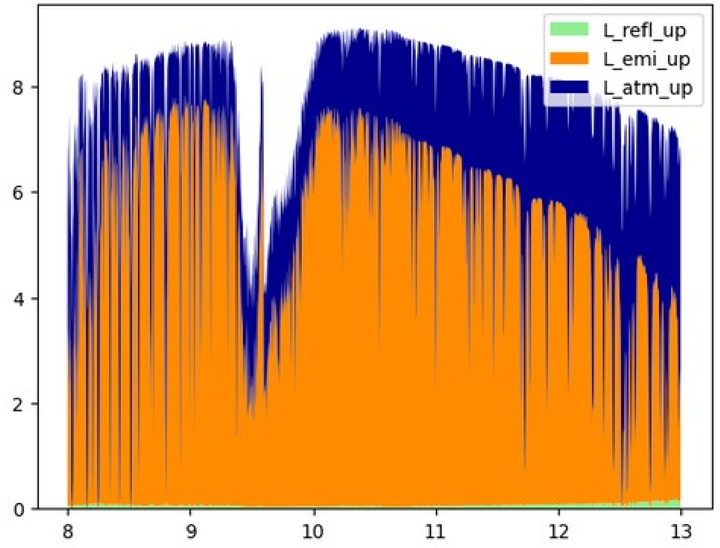
$$L_{TOA} = L_{atm}^{\uparrow} + \tau^{\uparrow}\left(\epsilon\, L_{BB}(T_S) + (1-\epsilon)\, L_{atm}^{\downarrow} \right)$$

October



Zoom out

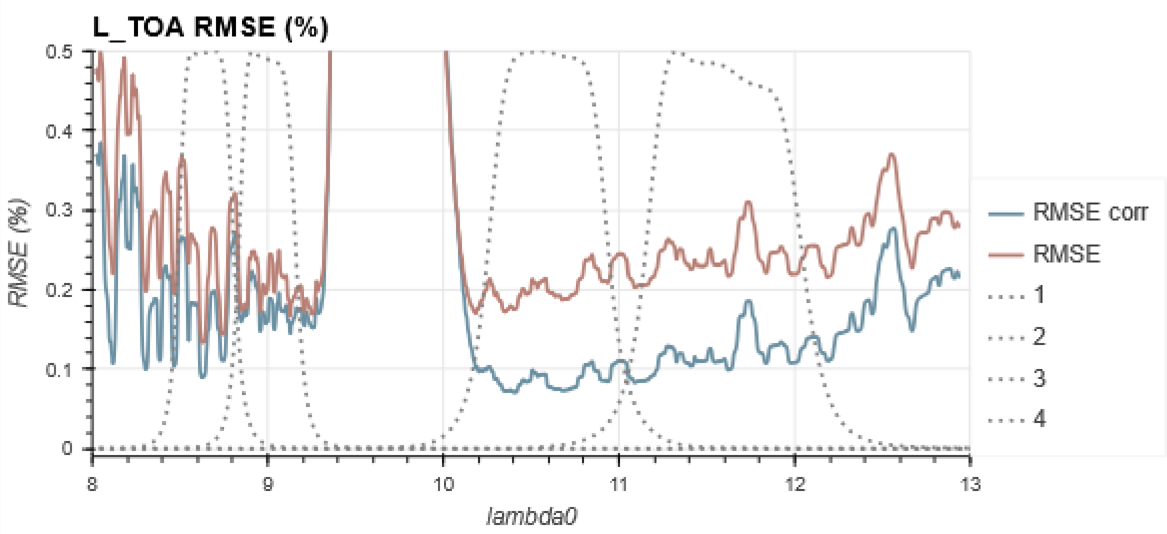




Results

- ~4% RMSE on $L^{\uparrow}$ and $L^{\downarrow}$, ~2% on $\tau^{\uparrow}$. Divided by 2 with corrected integrated WV content.
- Uncertainties compensate each other in L_{TOA} computation.
- 0.05% to 0.25% RMSE on L_{TOA} .
- Up to 0.1% improvement with corrected integrated WV content. No improvement in January.

July, atmospheric uncertainties



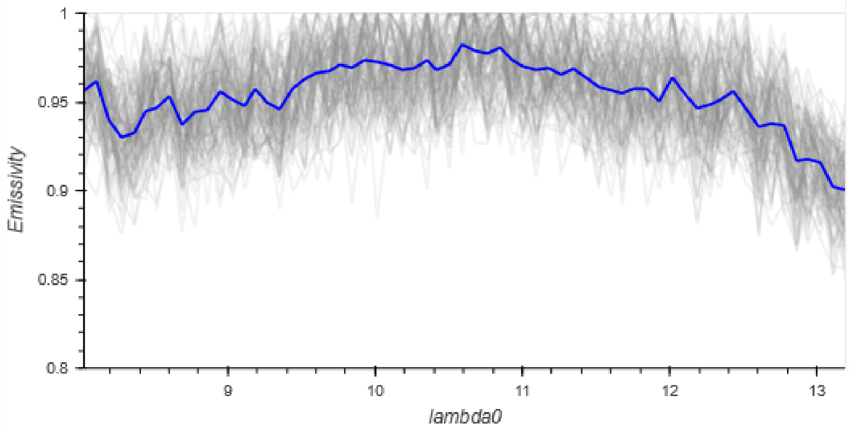
2

EMISSIVITY

IMPACT OF UNCERTAINTY ON EMISSIVITY ALONE

Uncertainty on emissivity only (0.02 on each value, 0.01 on mean ϵ)

- 100 draws
- All months



Mean emissivity distribution

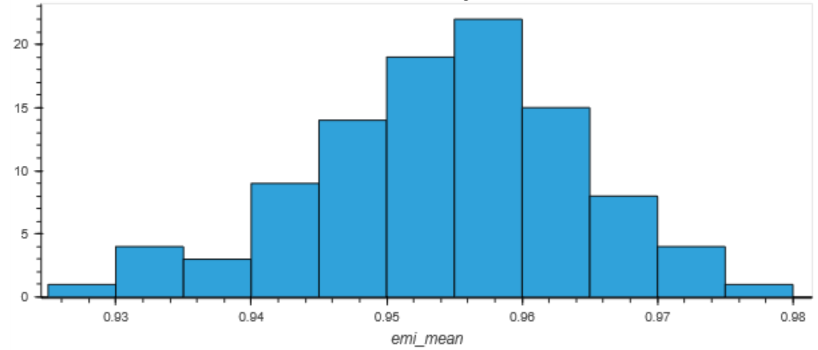
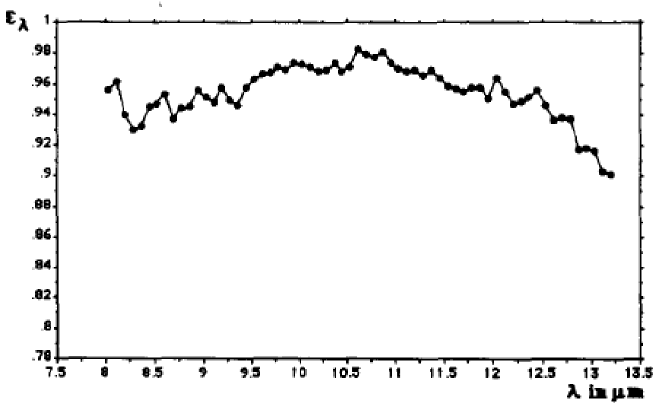


Figure 4. Absolute emissivity signature of a taken soil sample.



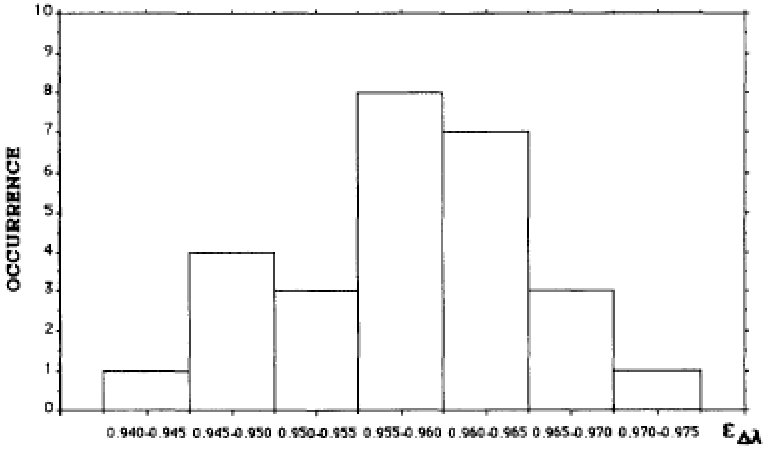
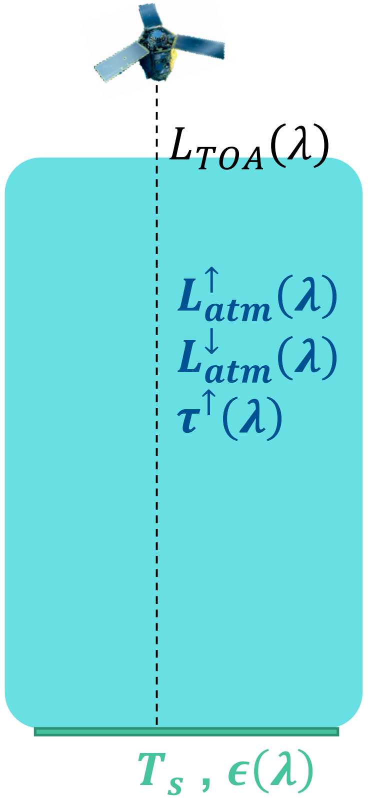


Figure 3. Spatial variability of the spectrally and spatially integrated emissivity in the stony area of "La Crau."

Labed & Stoll 91

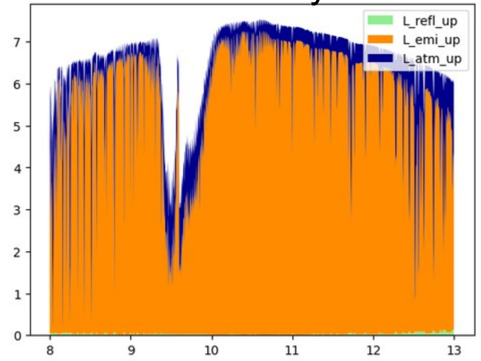


Results

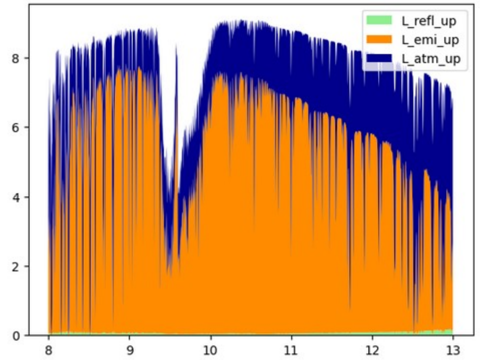
- **1-1.5% RMSE.**
- **RMSE lower if $L^{\uparrow}$ is a greater part of L_{TOA} (October)**

$$L_{TOA} = L_{atm}^{\uparrow} + \tau^{\uparrow} \left(\epsilon \, L_{BB}(T_S) + (1 - \epsilon) \, L_{atm}^{\downarrow} \right)$$

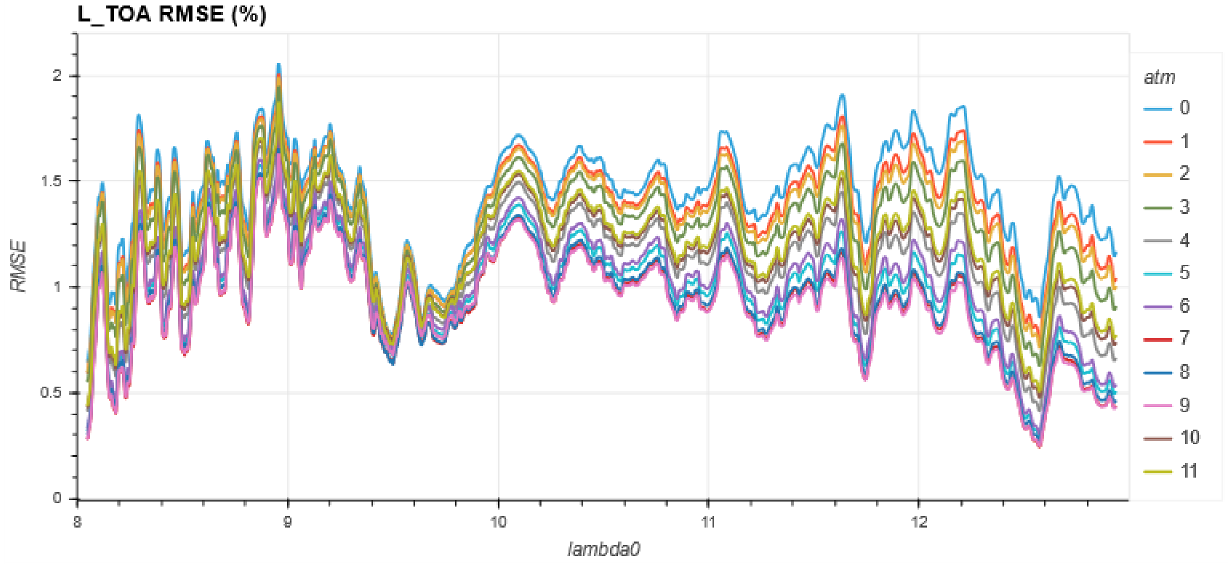
January

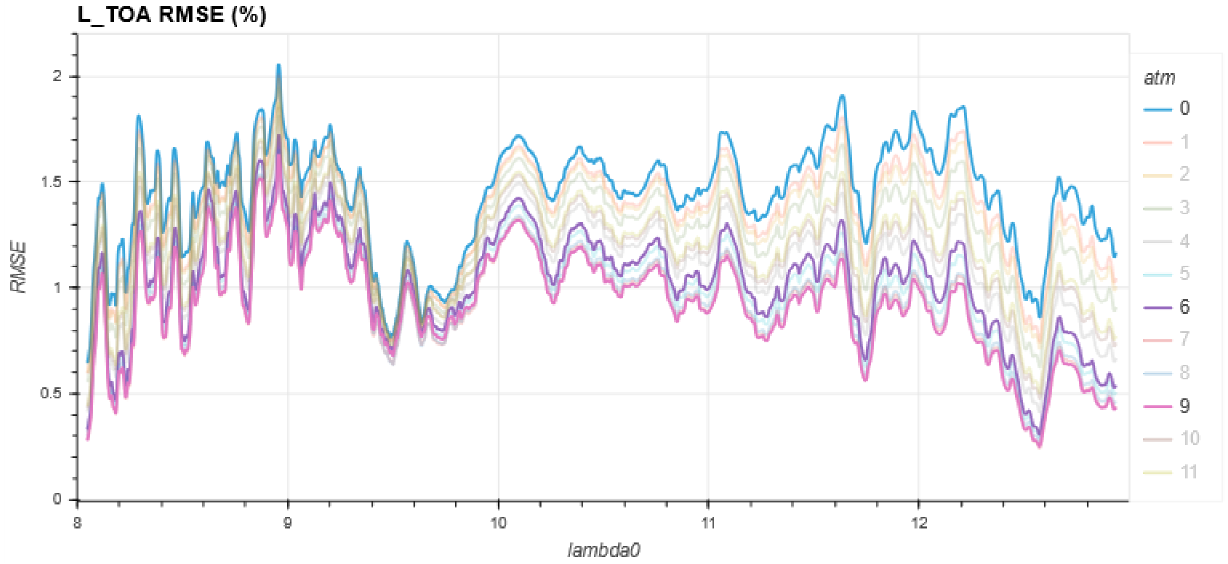


October



The 12 curves are the 12 months in 2022.





Uncertainty on emissivity and atmosphere / Results

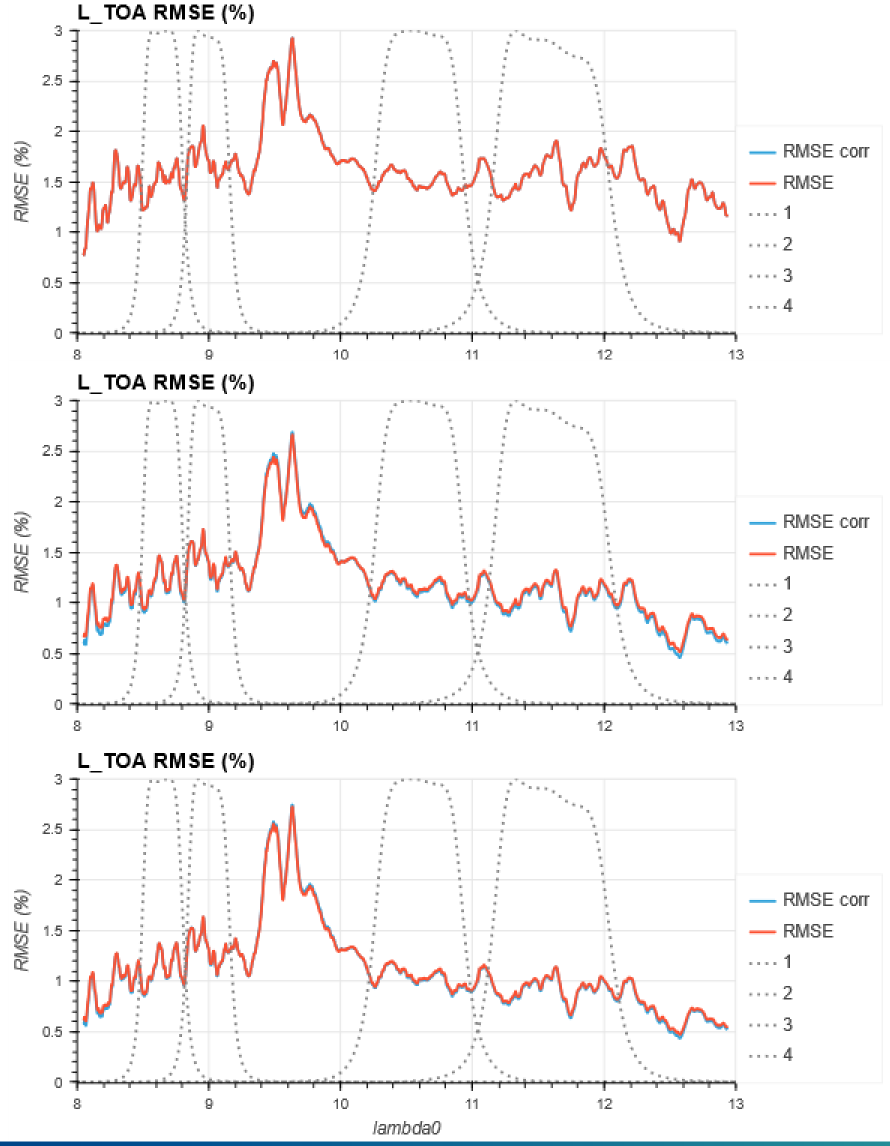
- ❖ **Emissivity : 100 draws**
- ❖ **Atmosphere : 60 draws**

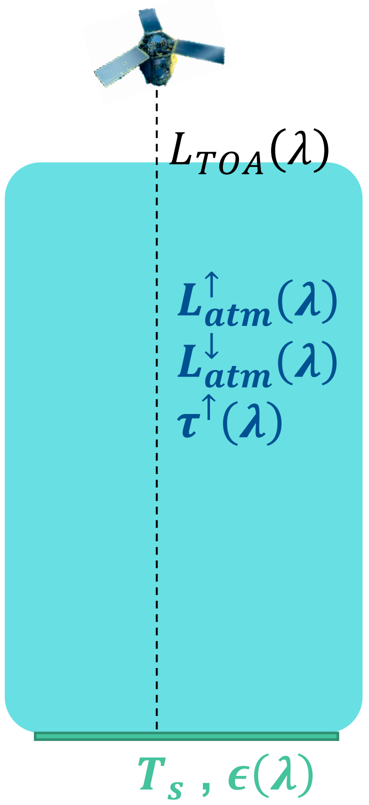
- ❖ **1-1.5% RMSE.**
- ❖ **No improvement with corrected integrated WV content.**
- ❖ **Atmospheric uncertainties impact is negligible compared to emissivity uncertainties impact.**

January

July

October





3

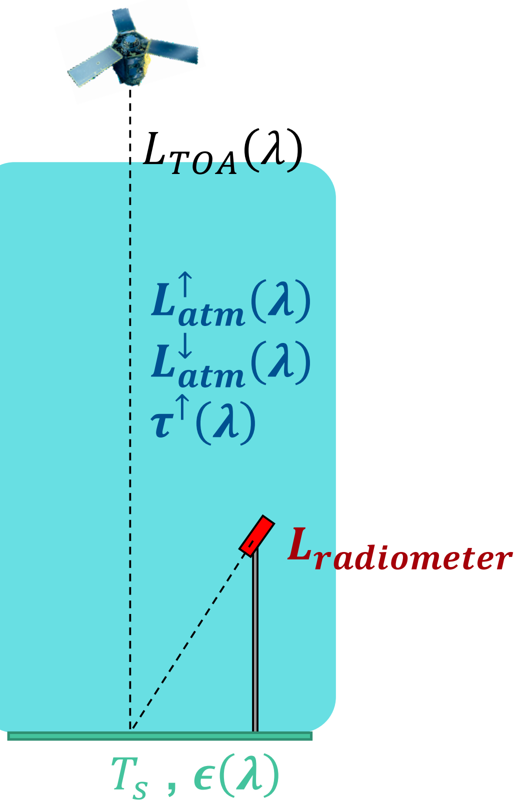
INSTRUMENTED SITE

IMPACT OF ALL CONSIDERED SOURCES OF UNCERTAINTY

Numerical set up

- **60 x 50 scenarios (atmosphere: 60 draws ; emissivity: 50 draws) for a given ECMWF atmospheric profile and a given emissivity spectrum.**
- **Single true surface temperature T_S for all scenarios (assumed to be unknown).**

- **For each scenario:**
  - → true L_{TOA} for each scenario (60x50 values)
  - $L_{radiometer}$ computation with true quantities + ISRF
  - + noise on $L_{radiometer}$ (5 draws) → known value



Noise on radiometer measurement: 0.02 W/m²/sr/µm (0.1-0.2K)

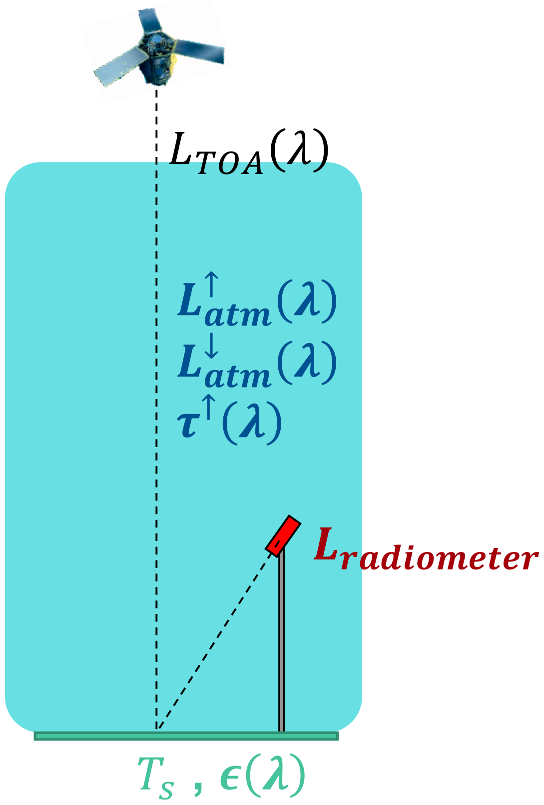
Numerical resolution

- 60 x 50 scenarios (atmosphere: 60 draws ; emissivity: 50 draws) for a given ECMWF atmospheric profile and a given emissivity spectrum.
- Single true surface temperature T_S for all scenarios (assumed to be unknown).

- For each scenario:
  - → true L_{TOA} for each scenario (60x50 values)
  - $L_{radiometer}$ computation with true quantities + ISRF
  - + noise on $L_{radiometer}$ (5 draws) → known value

  - Surface temperature estimation $\tilde{T}_S$ (60x50x5 cases)
  - TOA radiance estimation $\tilde{L}_{TOA}$

  - Comparison $\tilde{L}_{TOA}$ vs L_{TOA}



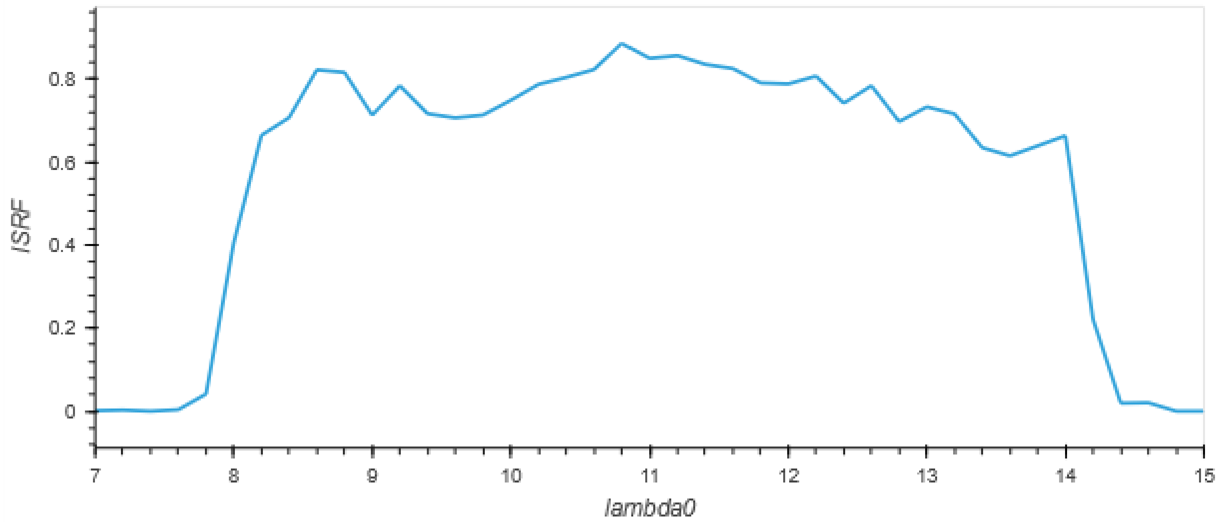
Noise on radiometer measurement: 0.02 W/m²/sr/μm (0.1-0.2K)

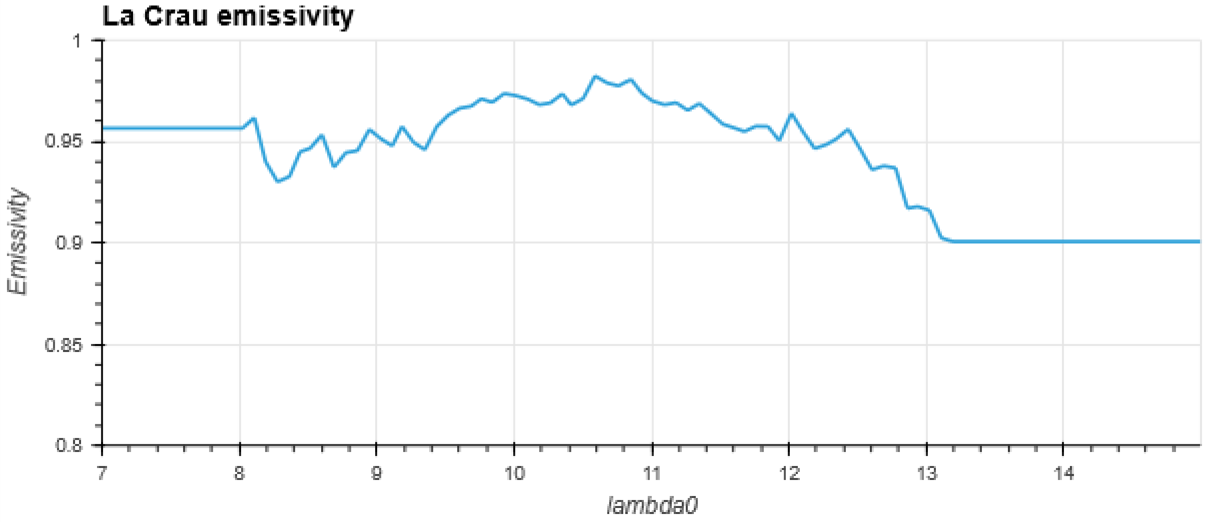
Additional assumptions

- **Emissivity extrapolation**
  - To match radiometer bandwidth

- **Ground-Radiometer radiative transfer**
  - $L^{\downarrow}$ same as ground-TOA RT
  - $L^{\uparrow} \approx 0$
  - $\tau^{\uparrow} \approx 1$

  Test with Modtran : 0,0057 K error

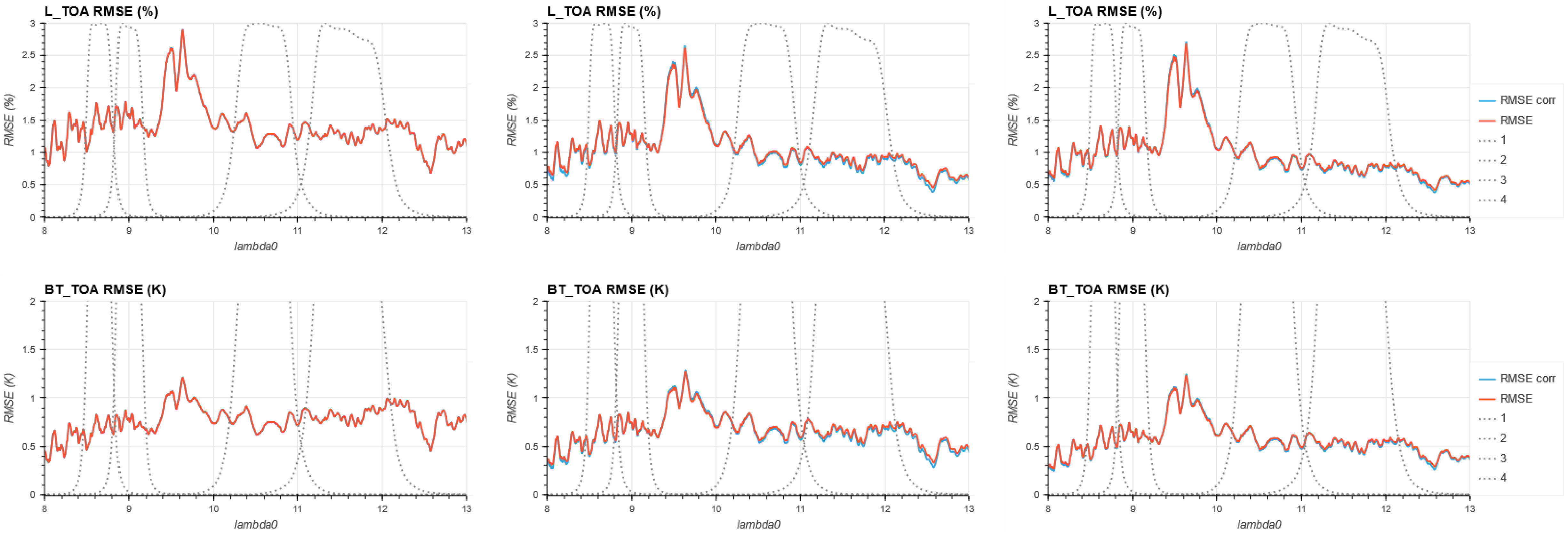




Results

- **1-1.5% RMSE (0.5-1 K)**
- **No improvement with corrected integrated WV content.**

January July October



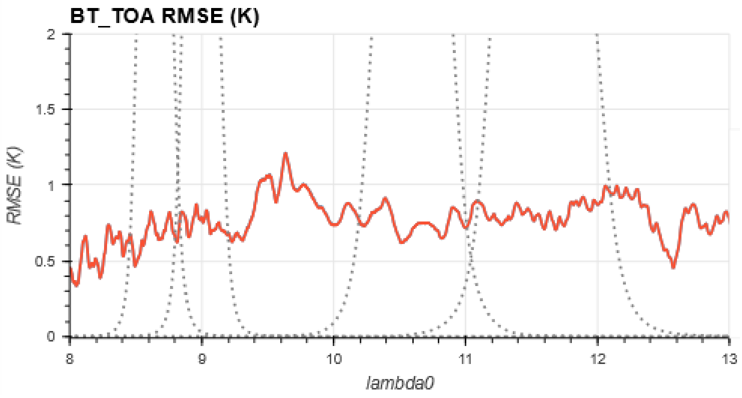
CONCLUSION

Conclusion

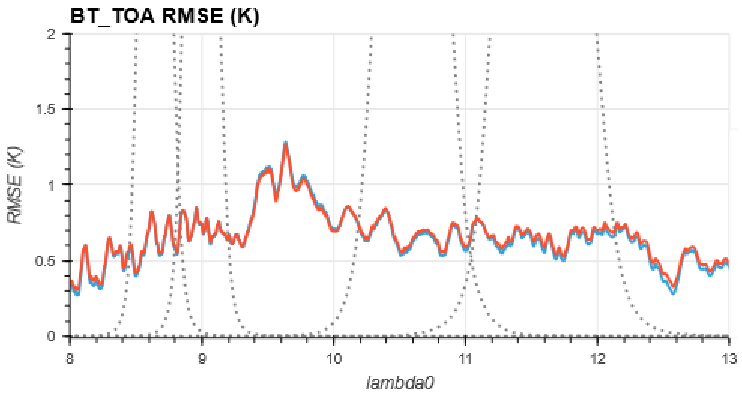
With the considered uncertainty values:

- **Atmospheric uncertainties are negligible compared to emissivity uncertainties.**
  - ➤ No need for an accurate in-situ atmosphere characterization
- **Correcting the integrated WV content is not necessary.**
- **Emissivity uncertainties drive the overall uncertainty.**
- L_{TOA} **RMSE seems lower for « wet » months**

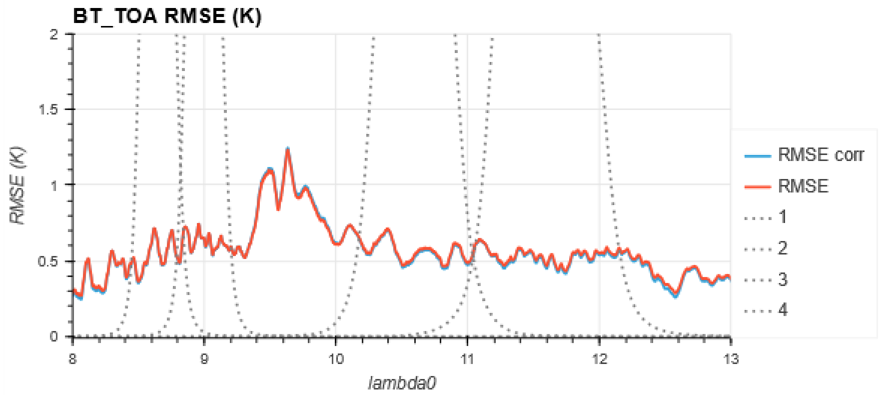
January



July



October



Future work

- **TOA RMSE values for each spectral band of a given instrument**
- **Application to other sites:**
  - Contractor support (KO 21/09/2023)
  - Data provided by KIT for Lake Constance and Gobabeb
  - Lake Tahoe and Russel Ranch information could also be used (JPL)
- **Spatial variations (emissivity and temperature) / different FoV (radiometer vs spatial instrument)**
- **Spatial variations (ECMWF atmospheric profiles)**
- **Temporal variations (emissivity evolution, turbulence)**
- **Multispectral TIR radiometer**
- **Emissivity directional effects estimation**
- **Environmental effects**

