TROPICS Neural Network Atmospheric Vertical Profile Retrieval Algorithm

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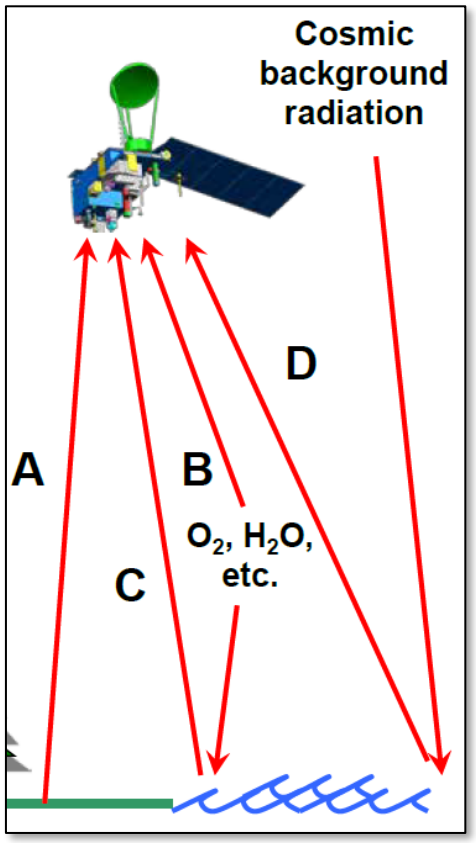
Outline

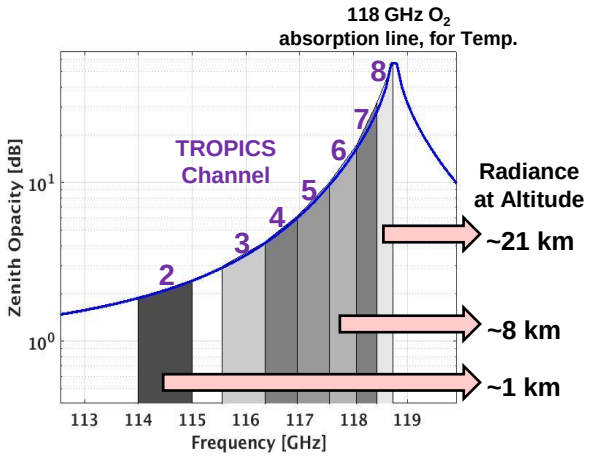
- **Atmospheric Sounding Overview**
- **Neural Network (NN) Atmospheric Retrieval**
- **TROPICS NN Retrieval Results**

Microwave Sounding

Microwave Sources

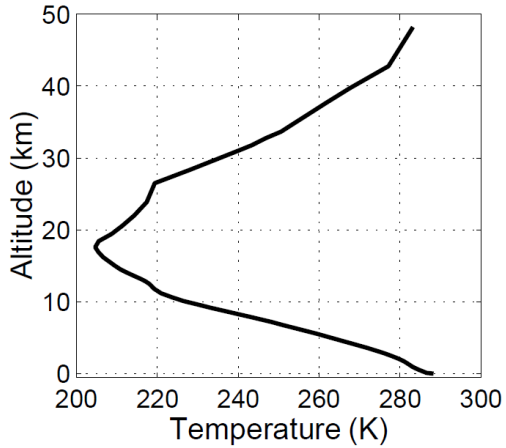


Retrieval algorithm

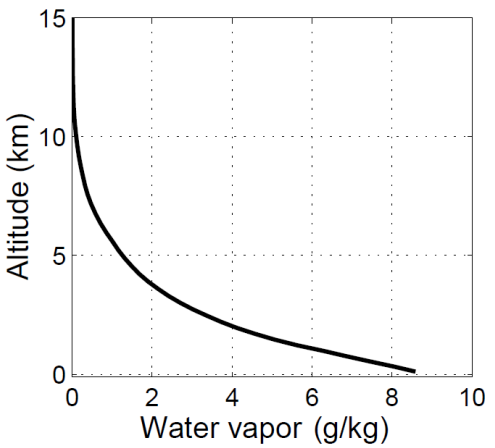


Output: Vertical Profiles *x*

Temperature Profile *T*



Water Vapor Profile *q*

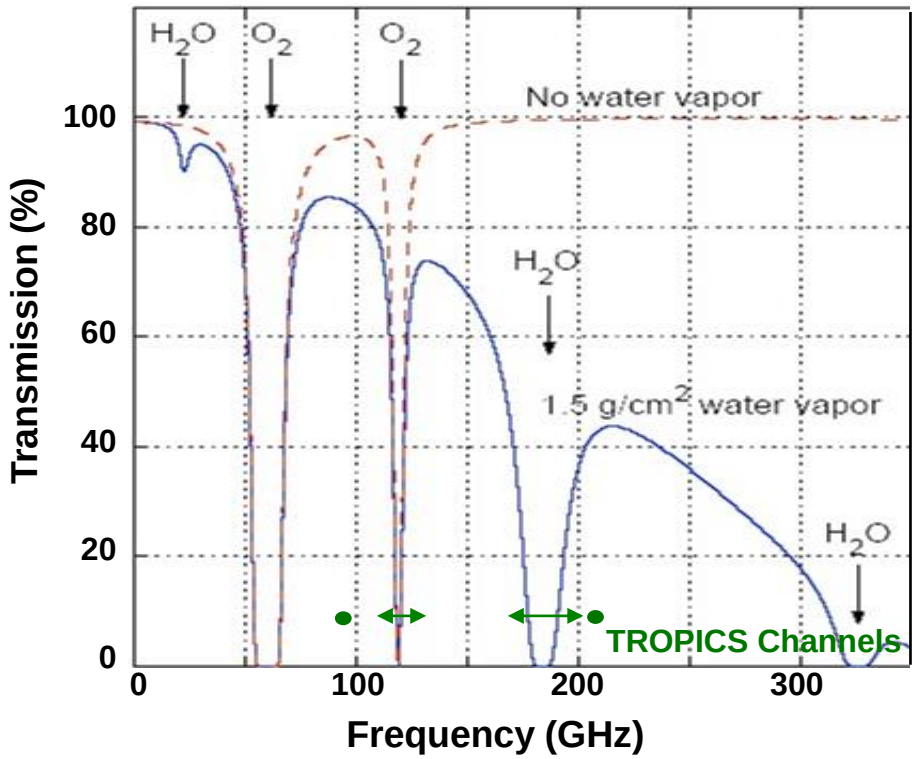


- **Microwave radiation emitted and absorbed by atmosphere on path to satellite**
- **Microwave can penetrate clouds**

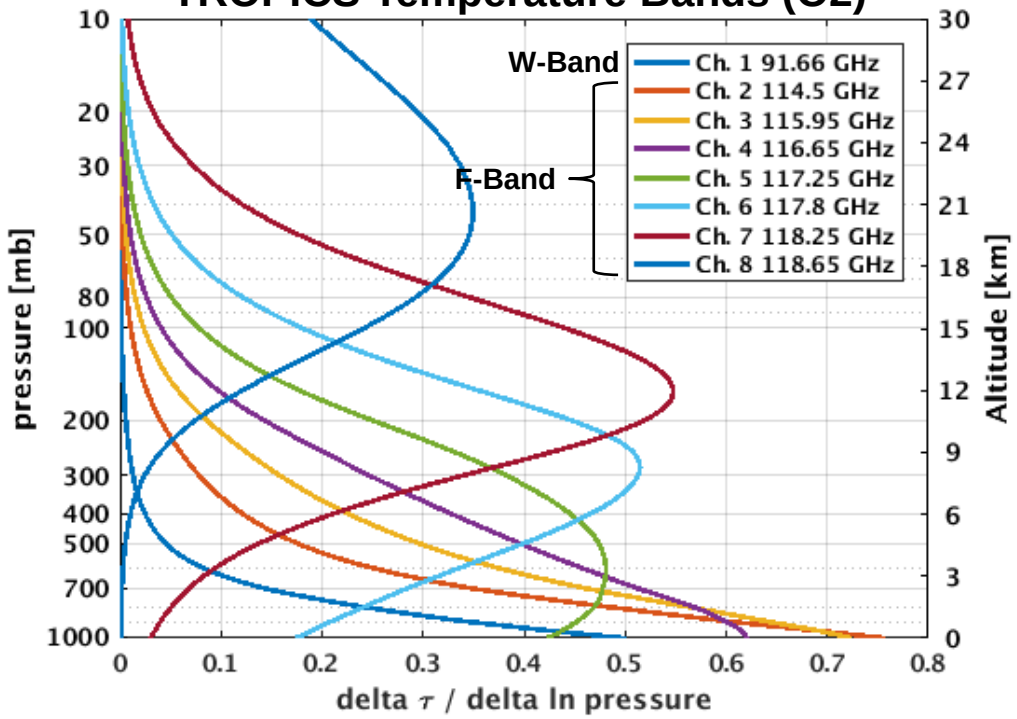
- **Temperature profile *T*, and water vapor profile *q* are estimated from each spot's spectrum**

TROPICS Microwave Atmospheric Sensing Channels

Gas Absorption Features



TROPICS Temperature Bands (O2)



TROPICS Water Bands

TROPICS Ch.	G-band Ch.	Center Freq. (GHz)
9	1	183.31 ± 1.0
10	2	183.31 ± 3.0
11	3	183.31 ± 7.0
12	4	204.8

The frequency dependence of atmospheric absorption allows different altitudes to be sensed by spacing channels along absorption lines

Atmospheric Profile Retrieval Techniques

- **Physics based estimator uses profiles based on a prior distribution to simulate measurements with a Radiative Transfer Model (RTM). Atmospheric profiles that provide minimum error with measurement is determined iteratively. Accuracy requires RTM that includes all phenomenology which is inherently slow.**
- **Neural Network estimator learns an estimator between measurements and an external training retrieval model that includes complex phenomenology and is less time constrained. Estimator can be applied quickly with similar performance to slower external retrieval algorithm.**

Neural Network Estimator

$\hat{\boldsymbol{x}} = \mathbf{g}(\boldsymbol{y})$, where $\boldsymbol{g}(\cdot)$ is a neural network, trained using:

$$\text{argmin}_{\boldsymbol{g}(\cdot)}\{\|\boldsymbol{x}_{\text{ensemble}} - \boldsymbol{g}(\boldsymbol{y}_{\text{ensemble}})\|^2\}$$

- **Learns estimator as empirical relationship**
- **Advantage: Fast, and robustness to clouds**

Physics-Based Estimator

$$\hat{\boldsymbol{x}} = \text{argmin}_{\boldsymbol{x}}\left\{\|\boldsymbol{y} - \boldsymbol{f}(\boldsymbol{x})\|^2_{\boldsymbol{\Lambda}} + \alpha\left\|\boldsymbol{x} - \boldsymbol{x}_{\text{prior}}\right\|^2_{\boldsymbol{B}}\right\}$$

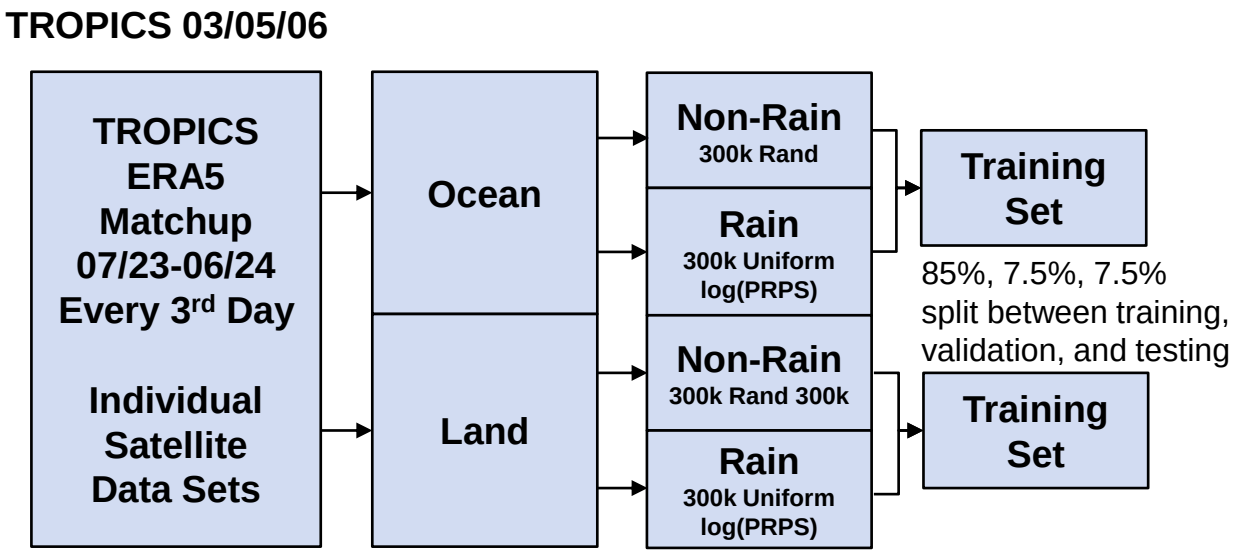
$\boldsymbol{x}$	Unknown *T(p)* or *q(p)* profile
$\boldsymbol{y}$	Spectrum measurements
$\boldsymbol{f}(\cdot)$	Forward model
$\boldsymbol{\Lambda}, \boldsymbol{B}$	Meas. and prior inverse covariances
$\boldsymbol{x}_{\text{prior}}$	First guess of *T(p)* or *q(p)*
α	Regularization parameter

- **Adjust a guess until predicted observations match measurements**
- **Advantage: Explainability**

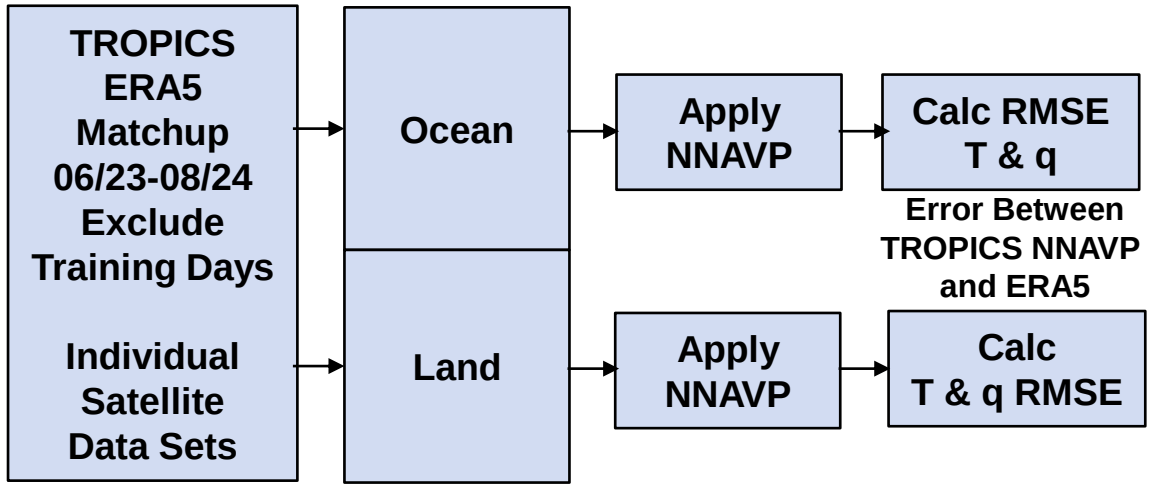
Training and Evaluation

- **A training model requires accurate atmospheric products that are spatially and temporally proximate to sensor measurements.**
- **The European Center for Medium-Range Weather Forecasts Reanalysis 5 (ERA5) was used as an external training model. It reprocesses satellite and in-situ data from several international sources to create hourly atmospheric estimates on a 0.25 degree global grid. Typically released on a 7 day lag.**
- **UW-DPC runs a matchup algorithm that spatially and temporally matches ERA5 to TROPICS measurements using nearest neighbor for each satellite. Extensive data set that can be used for training and evaluation.**

Neural Network Training Set Creation

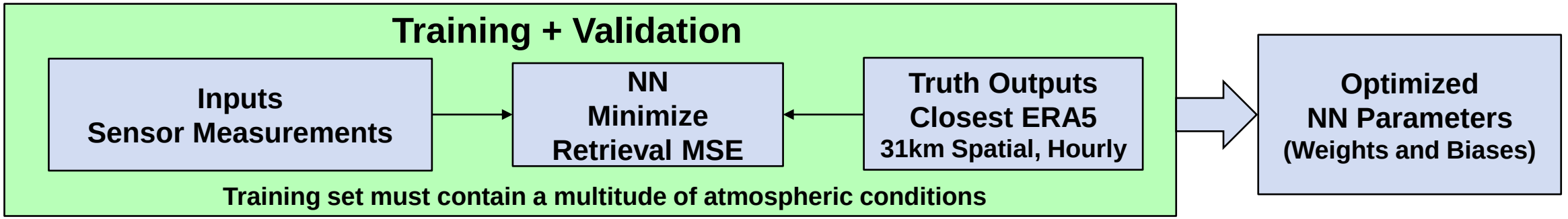


Neural Network Evaluation Set



Neural Network Retrieval Methodology

- **Neural Networks (NN) learn the relationship between the sensor measurements and the atmospheric space.**
- **A NN is a nonlinear regression between physical quantities**

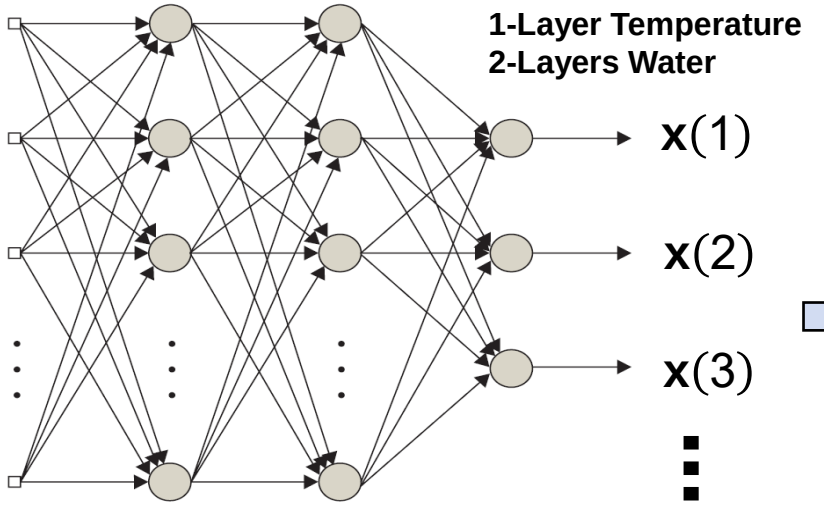


Inputs: Sensor Measurements

Brightness temps. Microwave, p_{surf}, Zen Ang, Lat, SolDec

y

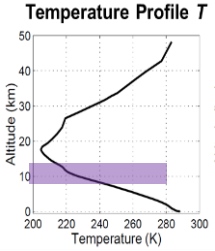
p_{surf} comes from GEOS5 forecast and used to make 91 ECMWF variable profile pressure levels. 91 Levels split into layers to train separate NN



Outputs: Atmospheric Profiles *T* or *q*

$\hat{x}=g(y)$

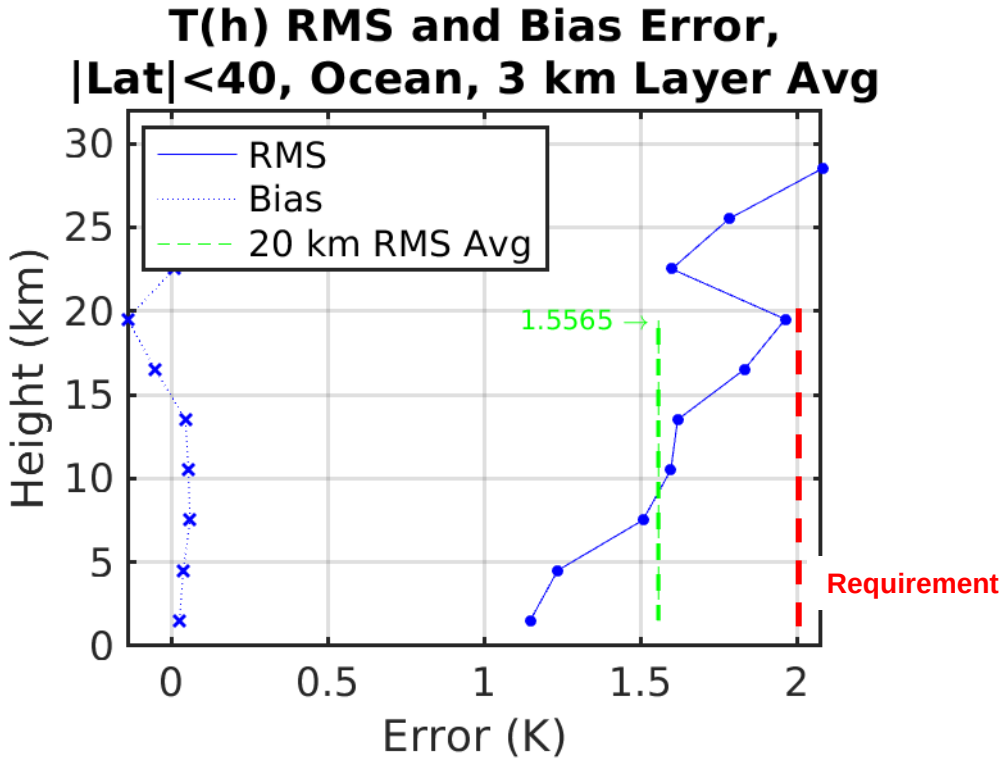
(a profile layer)
10 Layers Temperature
15 Layers Water

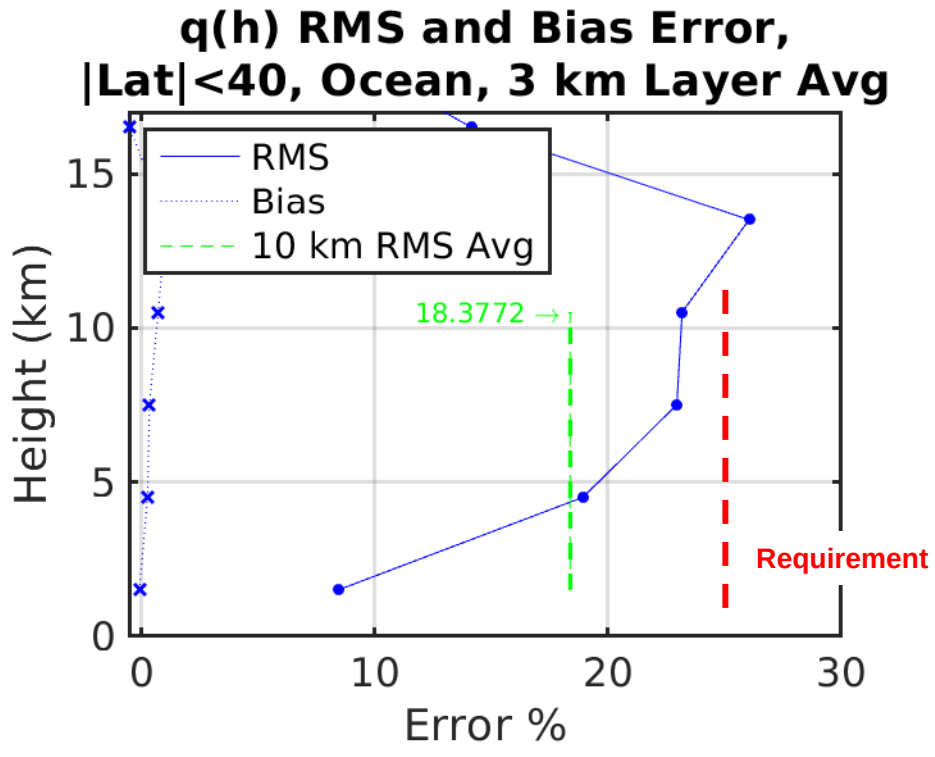


[2] From European Centre for Medium-Range Weather Forecasts (ECMWF)

TROPICS 0X Ocean Error (Exclude Training)

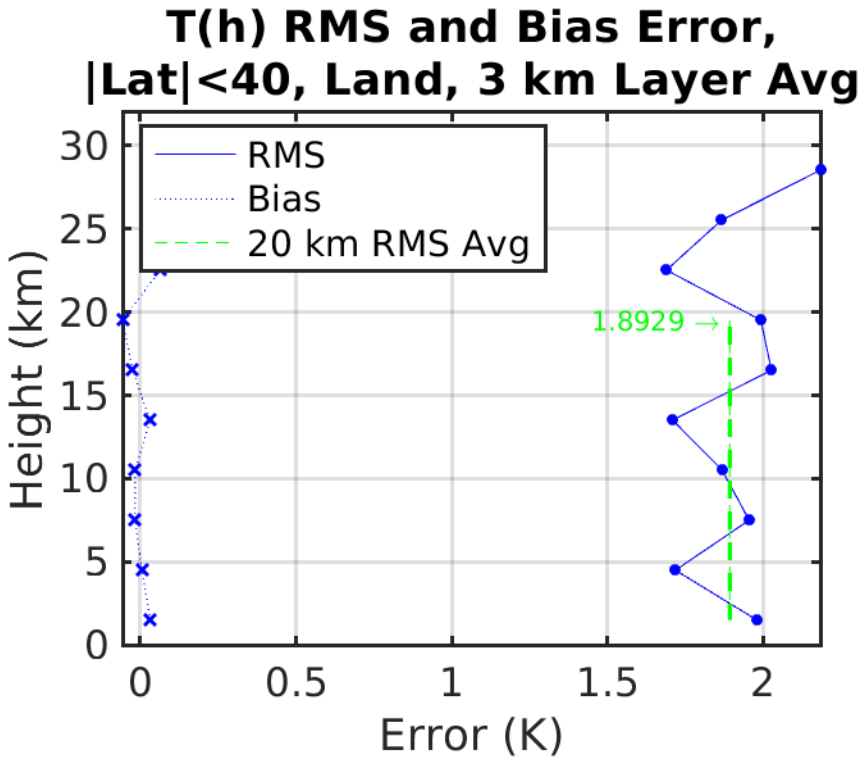
- **Global Ocean Errors relative to ERA5 for constellation, 3km layer averaged excluding training days from 06/23 to 08/24. Includes all conditions such as precipitation.**

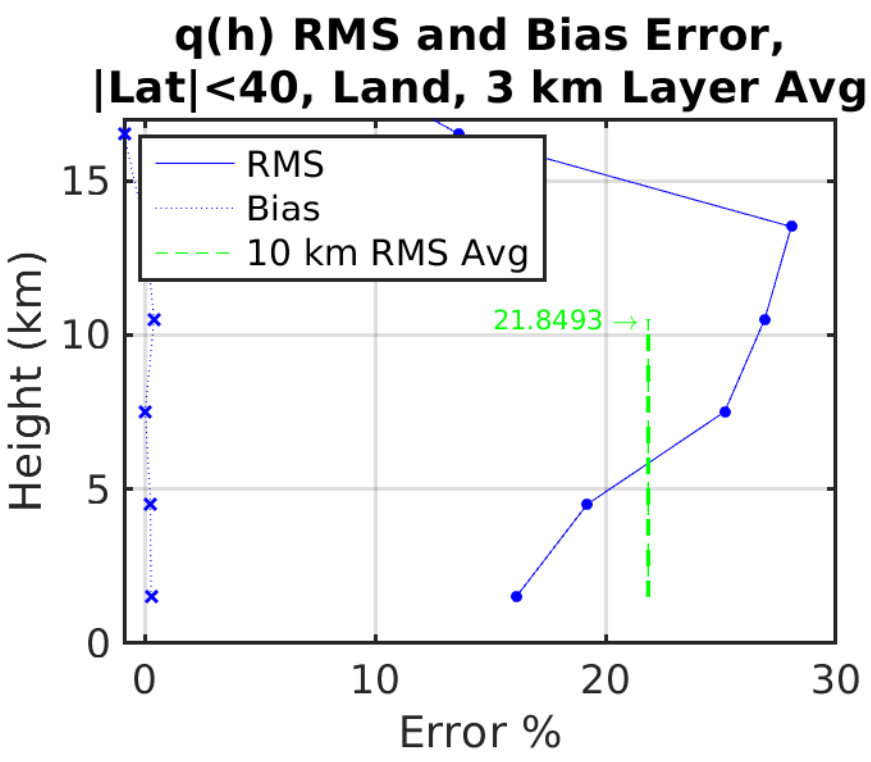




TROPICS 0X Land Error (Exclude Training)

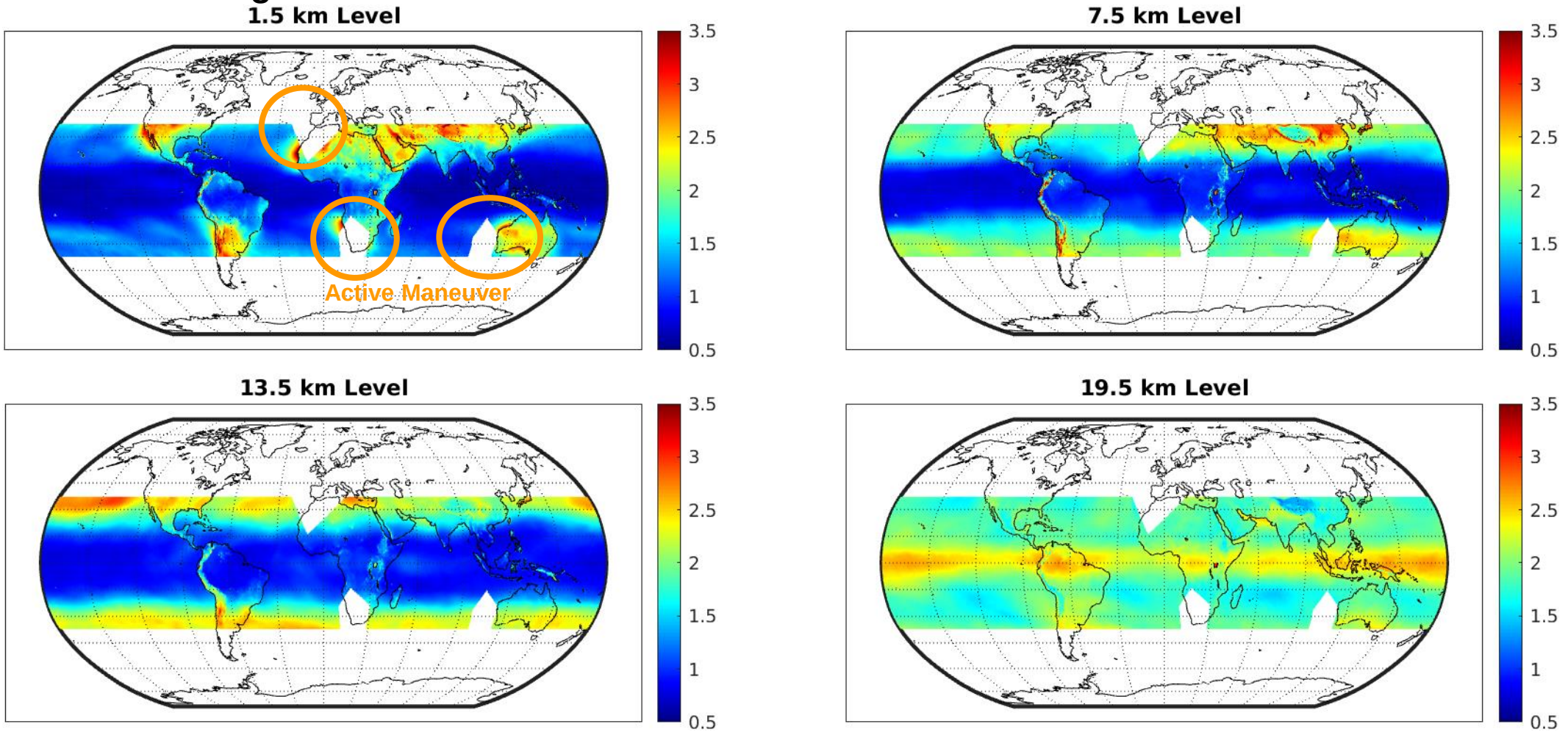
- **Global Land Errors relative to ERA5 for constellation, 3km layer averaged excluding training days from 06/23 to 08/24. Includes all conditions such as precipitation.**





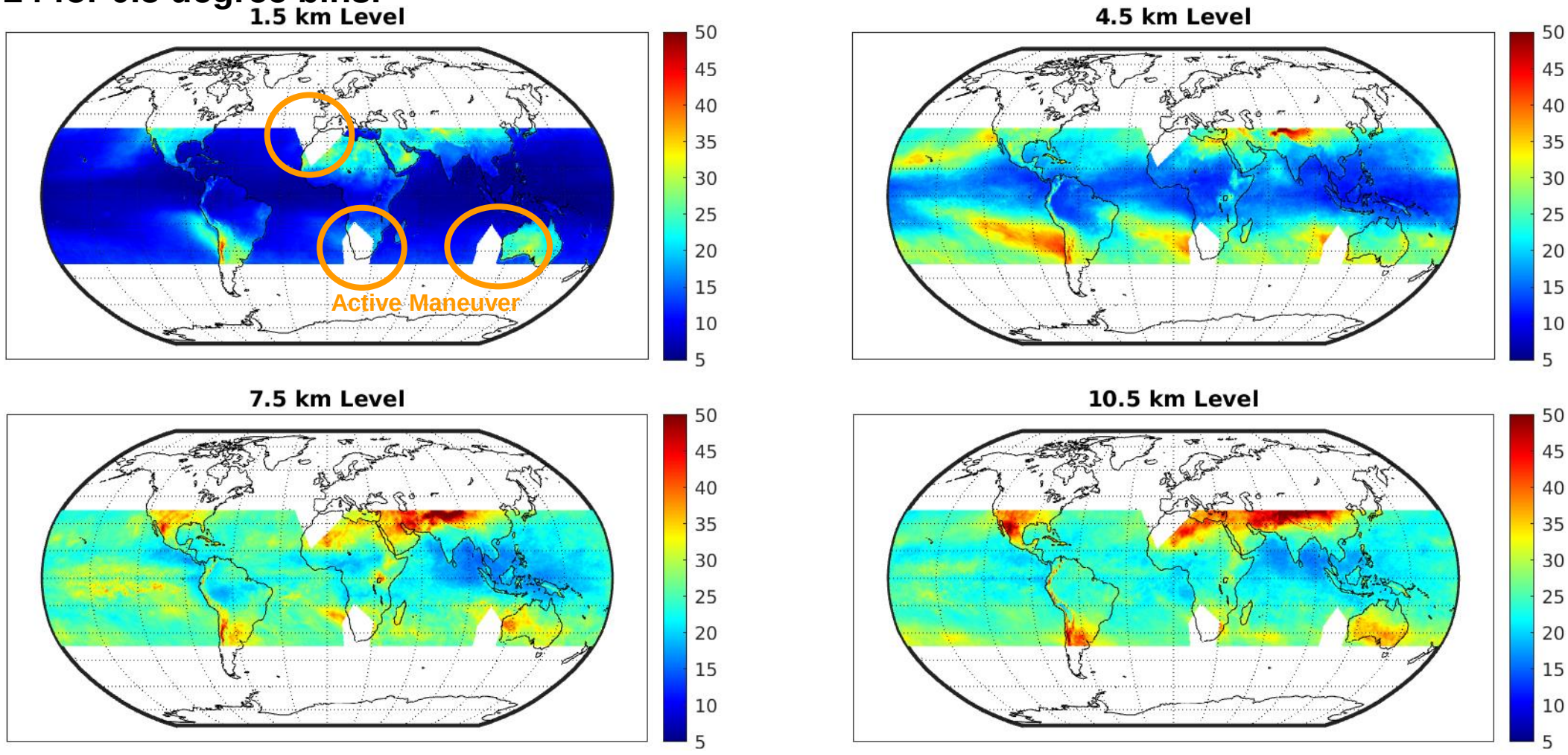
TROPICS 0X Global Temperature Error (Exclude Training Days)

- **Global Temperature 3km layer averaged RMSE for constellation excluding training days from 06/23 to 08/24 for 0.5 degree bins.**



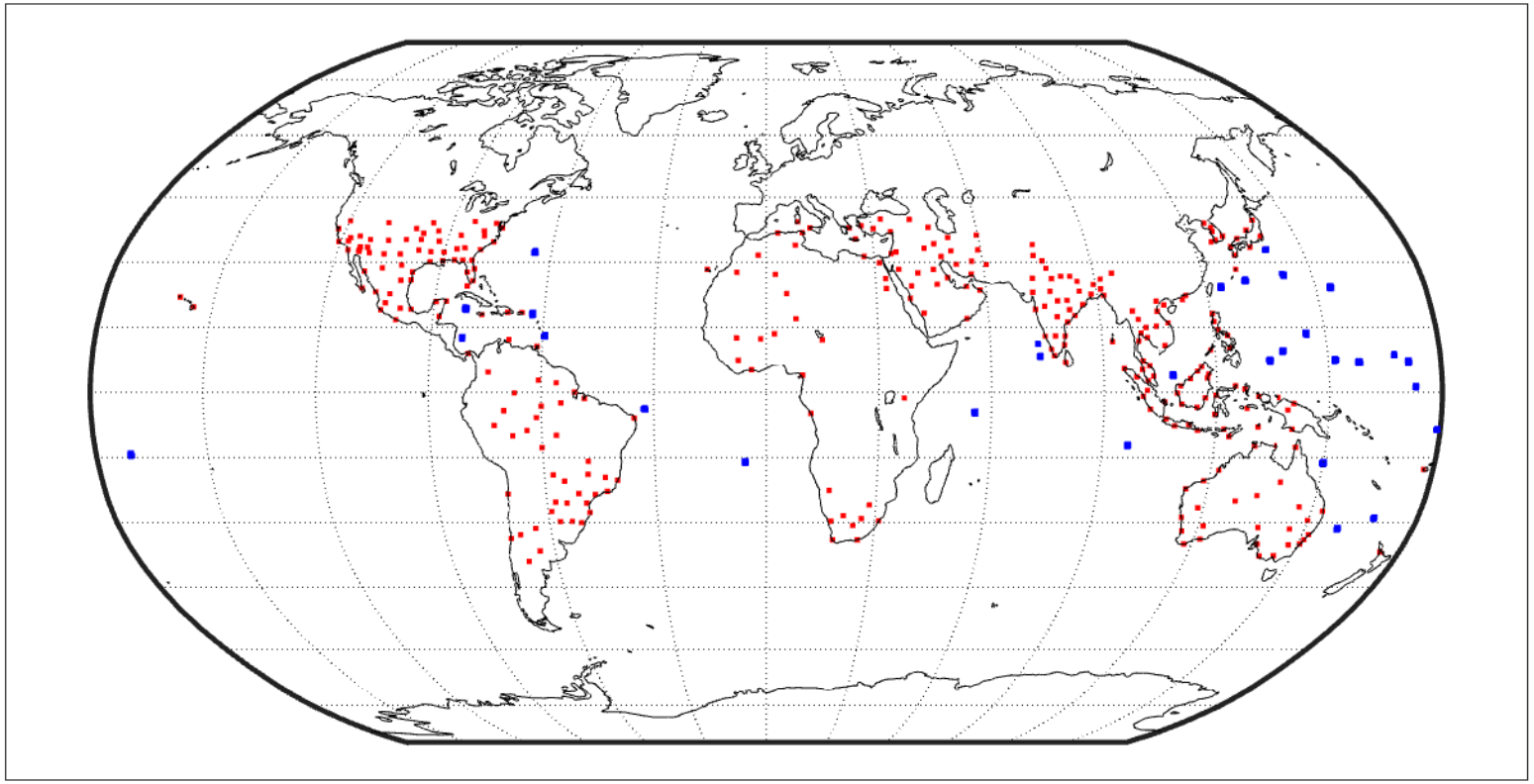
TROPICS 0X Global Water Error (Exclude Training)

- **Global Water 3km layer averaged PRMSE for constellation excluding training days from 06/23 to 08/24 for 0.5 degree bins.**



Sonde Island Locations

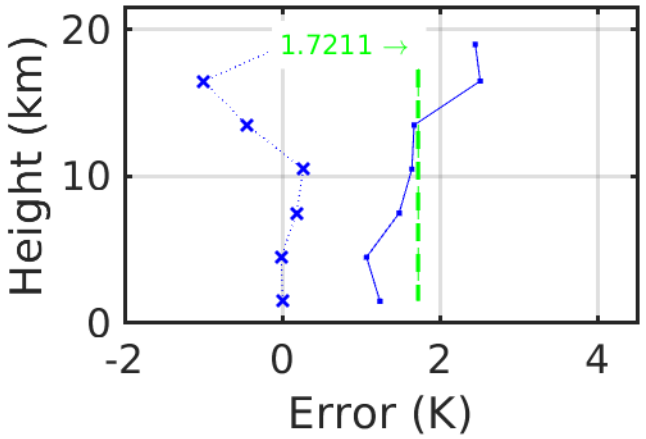
- **30 Island Stations were used to validate ocean retrievals.**
- **Used 12346 Sondes from 06/23 to mid-08/24 with 50km and 1 hour of TROPICS measurement.**



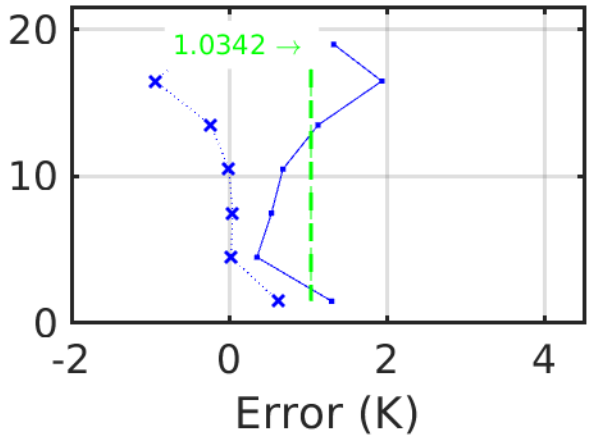
TROPICS 0X Station Sonde Ocean Errors

Temperature 3km Avg Errors

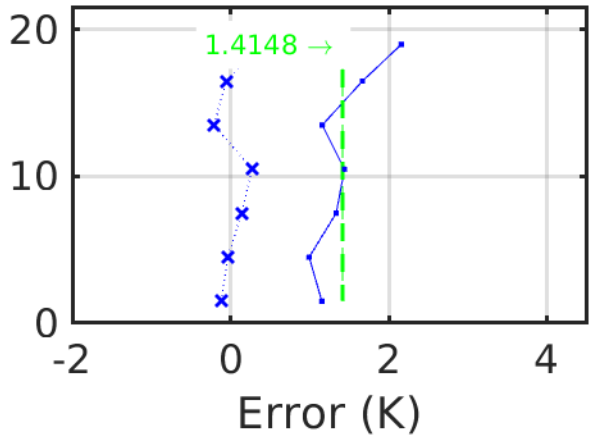
NN vs Sonde



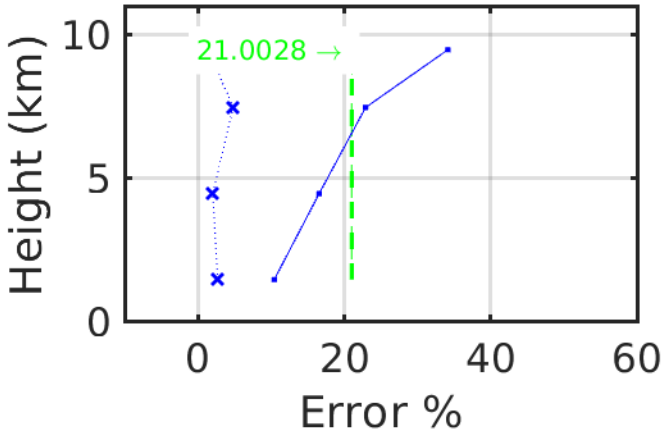
ERA vs Sonde

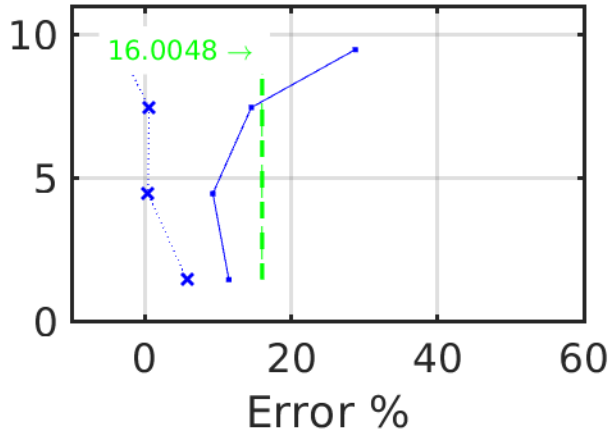


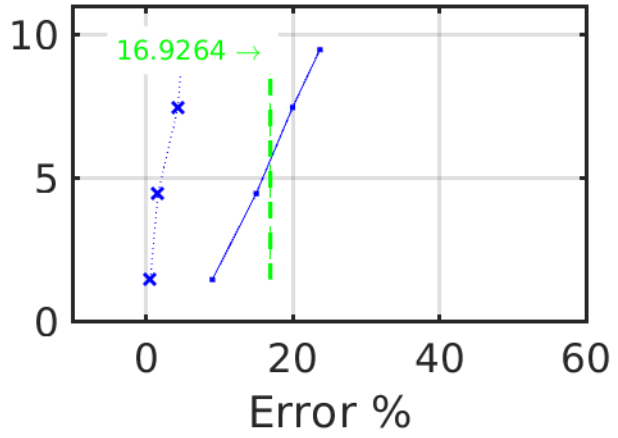
NN vs ERA



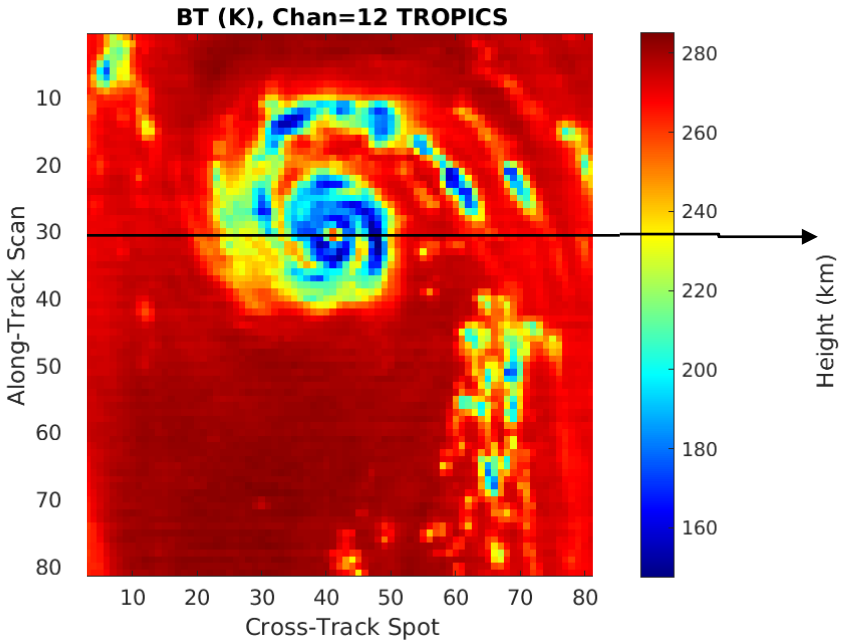
Water 3km Avg Errors



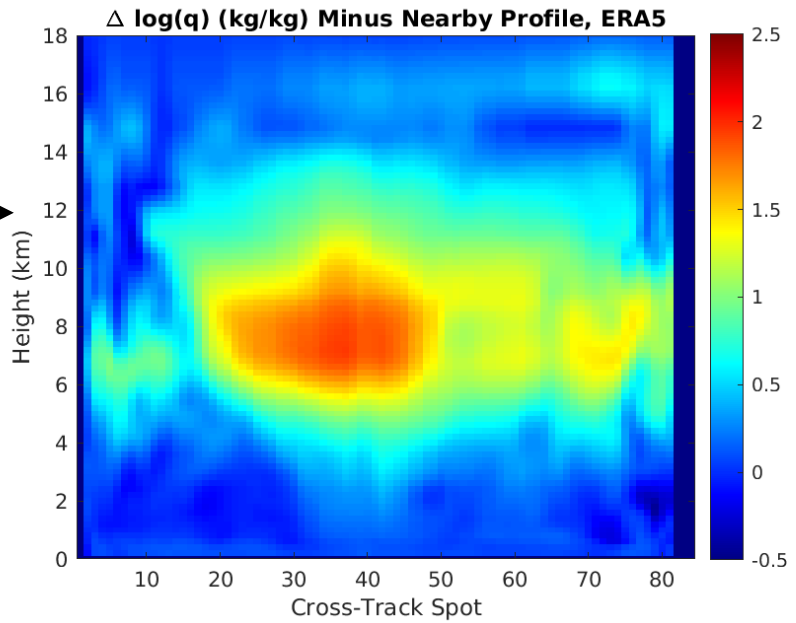




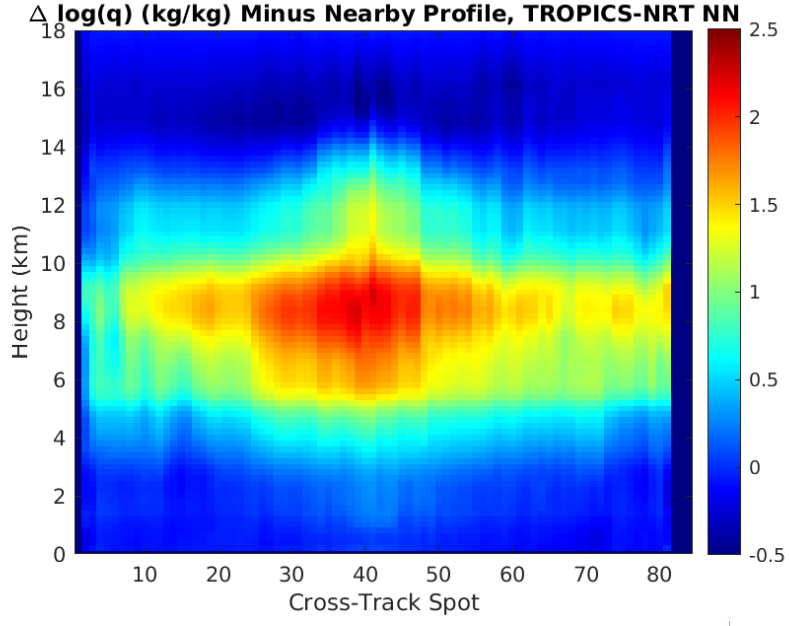
TROPICS Pathfinder and Hurricane Ida (8/28/21) Anomaly for Moisture, log(q)



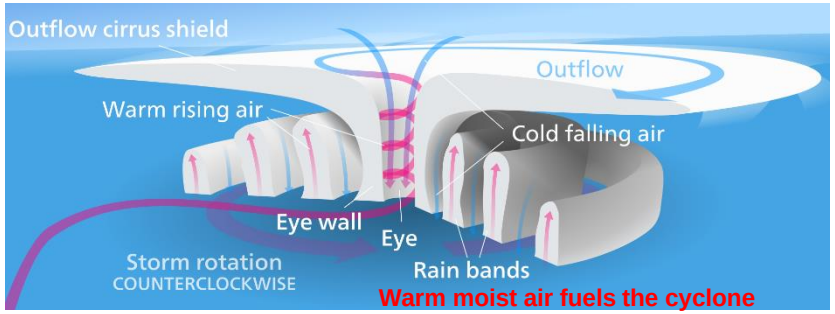
Reference Image: ERA5 Reanalysis Model

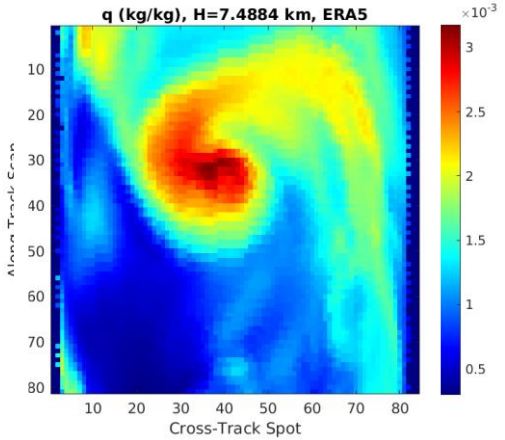


NN Retrievals

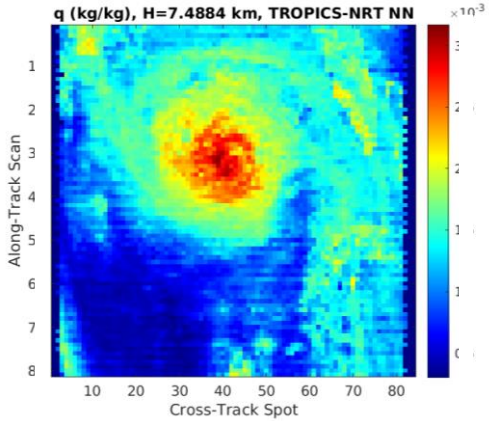


Tropical Cyclone Dynamics





Similar features near storm center



Conclusions

- **NNAVP is able to quickly and accurately retrieve temperature and water vapor profiles using TROPICS microwave measurements.**
- **Trained with extensive ERA5 data set under a multitude of conditions.**
- **Evaluation of retrievals excluding training days with ERA5 showed retrievals with the 2 K Avg 20km temperature requirement and 25% Avg. 10km water vapor requirement.**
- **Evaluation with small island radiosondes were within requirements.**