A new synergistic radiometer/altimeter instrument processing algorithm

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Outline

- AMR heritage algorithms
- Active/passive complementary measurements
- Combined Active Passive Retrieval System (CAPRS)
  - CAPRS: Mathematical basis
  - CAPRS: System framework
  - CAPRS: Covariance/correlation matrix
  - CAPRS: Passive microwave forward model
  - CAPRS: Active microwave forward model
  - CAPRS: Jacobian model and sensitivity
- CAPRS retrieval performance
- Summary and future work

AMR Heritage Algorithms

Calibrated TBs

18, 23, 34 GHz

Regression →

AMR L2 Products
Wet tropospheric correction
Wind speed
Cloud liquid water
Radiometer water vapor content
Atmospheric attenuation correction on C band backscatter coefficient
Atmospheric attenuation correction on Ku band backscatter coefficient
Rain/No rain flag
Sea ice flag

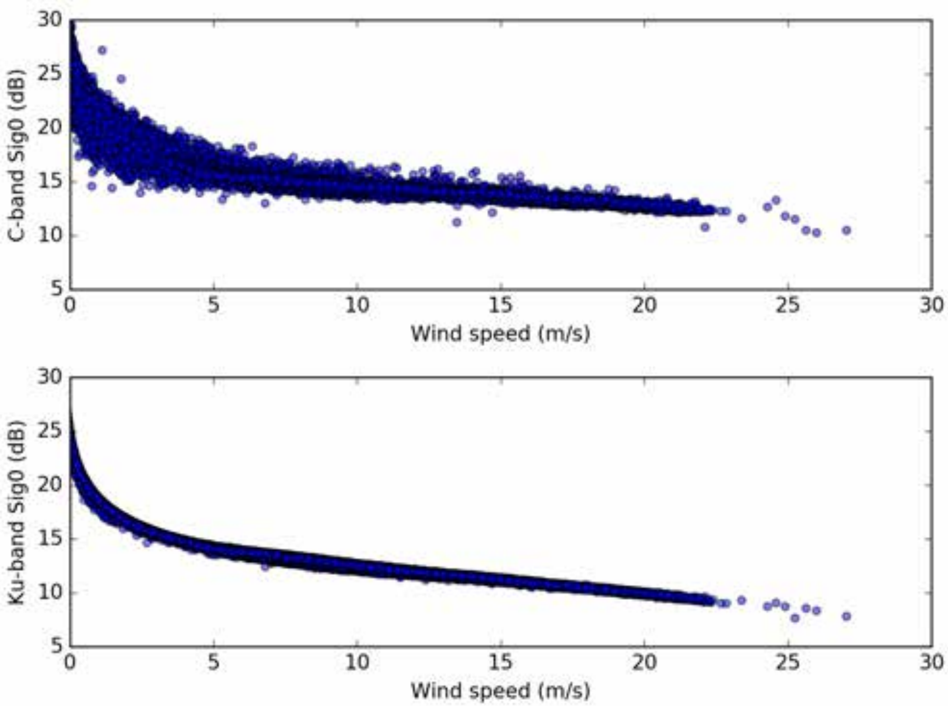
- **Limitations:**
- Altimeter and radiometer algorithms are decoupled
- No use of altimeter backscatter signatures in the retrieval
- Multi-linear regression based, not "physically" based
- Regression algorithms are frequency dependent, thus, three frequency AMR algorithms cannot be applied to two frequency radiometers (e.g. SARAL/AltiKa, Sentinel 3)

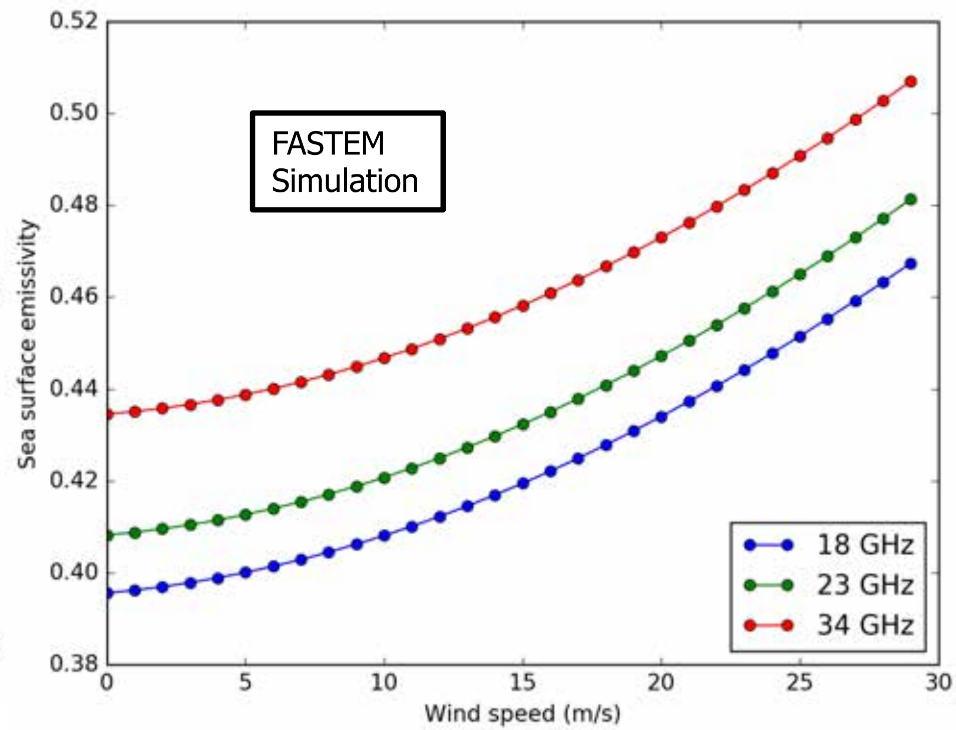
$$W = w_0(j) + \sum_{i=1}^{3} w(f_i, j).T_b(f_i) \qquad \text{(in m/s)}$$

$$L_Z = L_0(j) + \sum_{i=1}^{3} L(f_i, j).T_b(f_i) + L_{sq}(j).[T_b(f_3)]^2$$

$$PD^{(g)} = B_0^{(g)}(j) + \sum_{i=1}^{3} B^{(g)}(f_i, j)\ln[280 - T_b(f_i)] \qquad \text{(in cm)}$$

Active/Passive Complementary Measurements

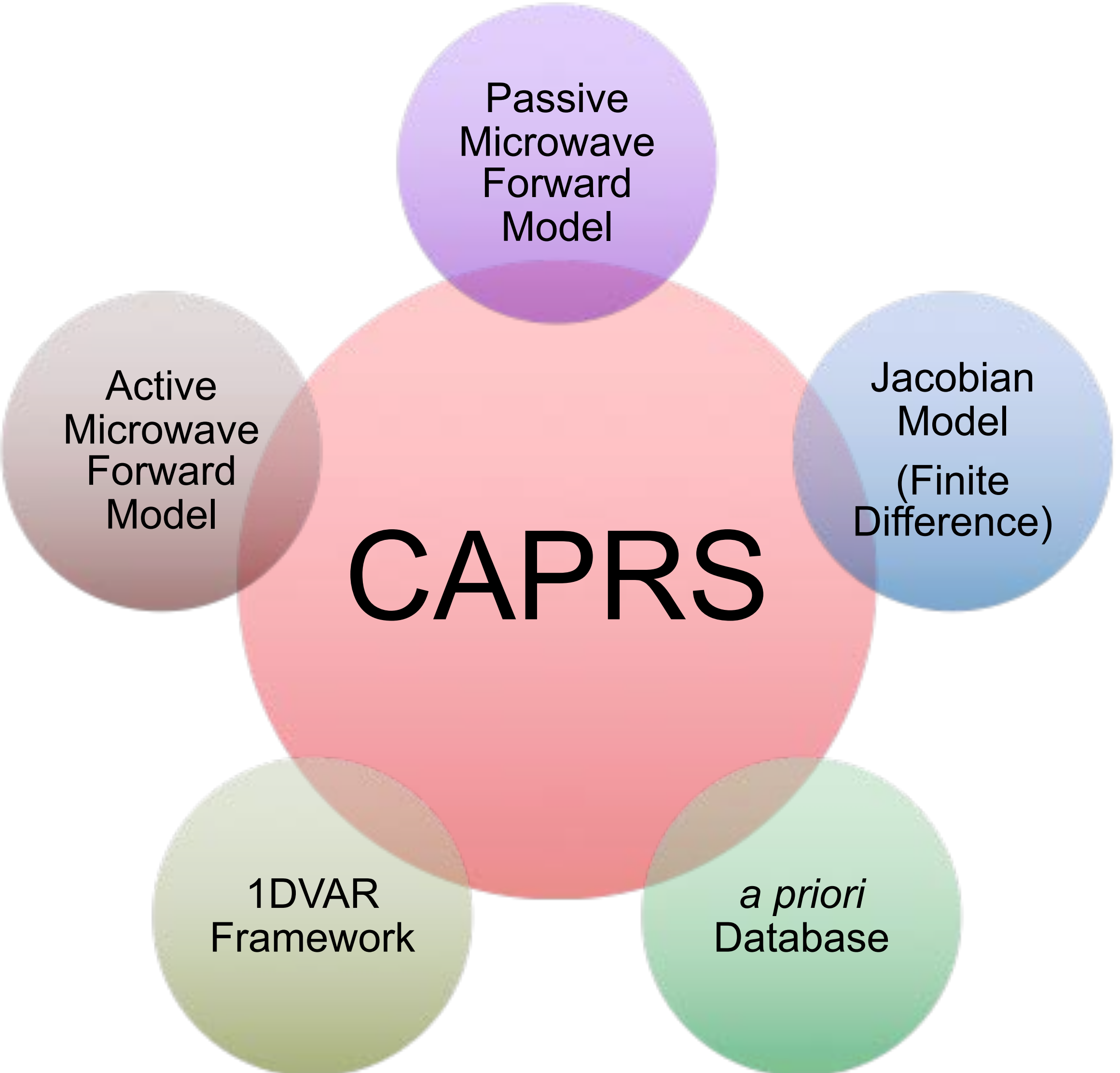




- Altimeter and radiometer measurements contain complementary information
- Therefore, a combined active/passive retrieval system should help in retrieving geophysical parameters simultaneously

Combined Active Passive Retrieval System (CAPRS)

- Physically based algorithm
- Combines radiometer and altimeter information content for simultaneous retrieval of geophysical parameters
- Modular framework, can be easily extended to *any* number of radiometer and altimeter frequencies
- Open source framework in Python

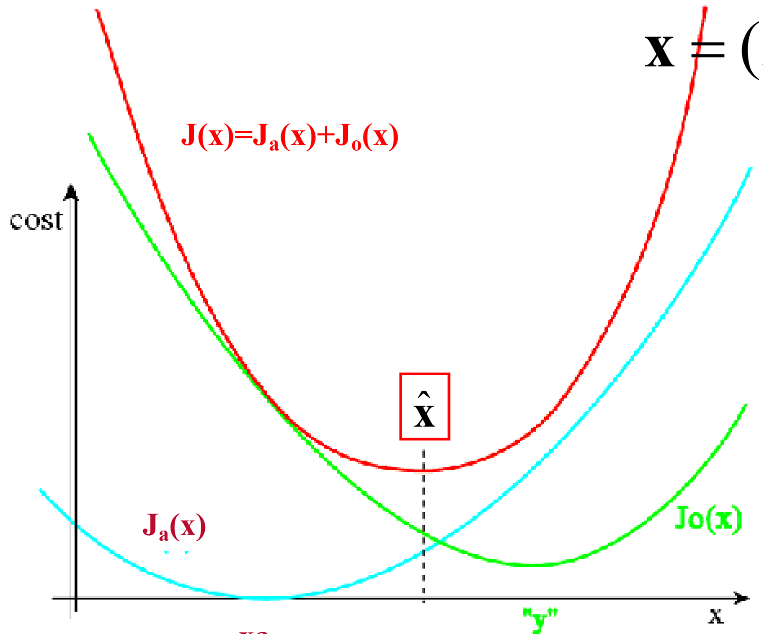


CAPRS: Mathematical Basis (1DVAR)

$$J(\mathbf{x}) = \underbrace{(\mathbf{x}-\mathbf{x_a})^T \mathbf{S_a}^{-1}(\mathbf{x}-\mathbf{x_a})}_{\text{a priori term } J_a} + \underbrace{(\mathbf{y}-\mathbf{Kx})^T \mathbf{S_y}^{-1}(\mathbf{y}-\mathbf{Kx})}_{\text{Observation term } J_O}$$

a priori term J_a *Observation term* J_O

S_a = covariance matrix of the background error
S_ε = covariance matrix of the observation error
+ covariance matrix of representativeness error (interpolation, discretization)
K = linearized forward model

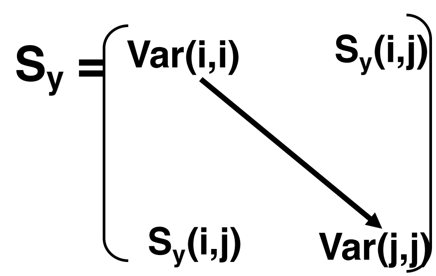


Bouttier and Courtier, 1999

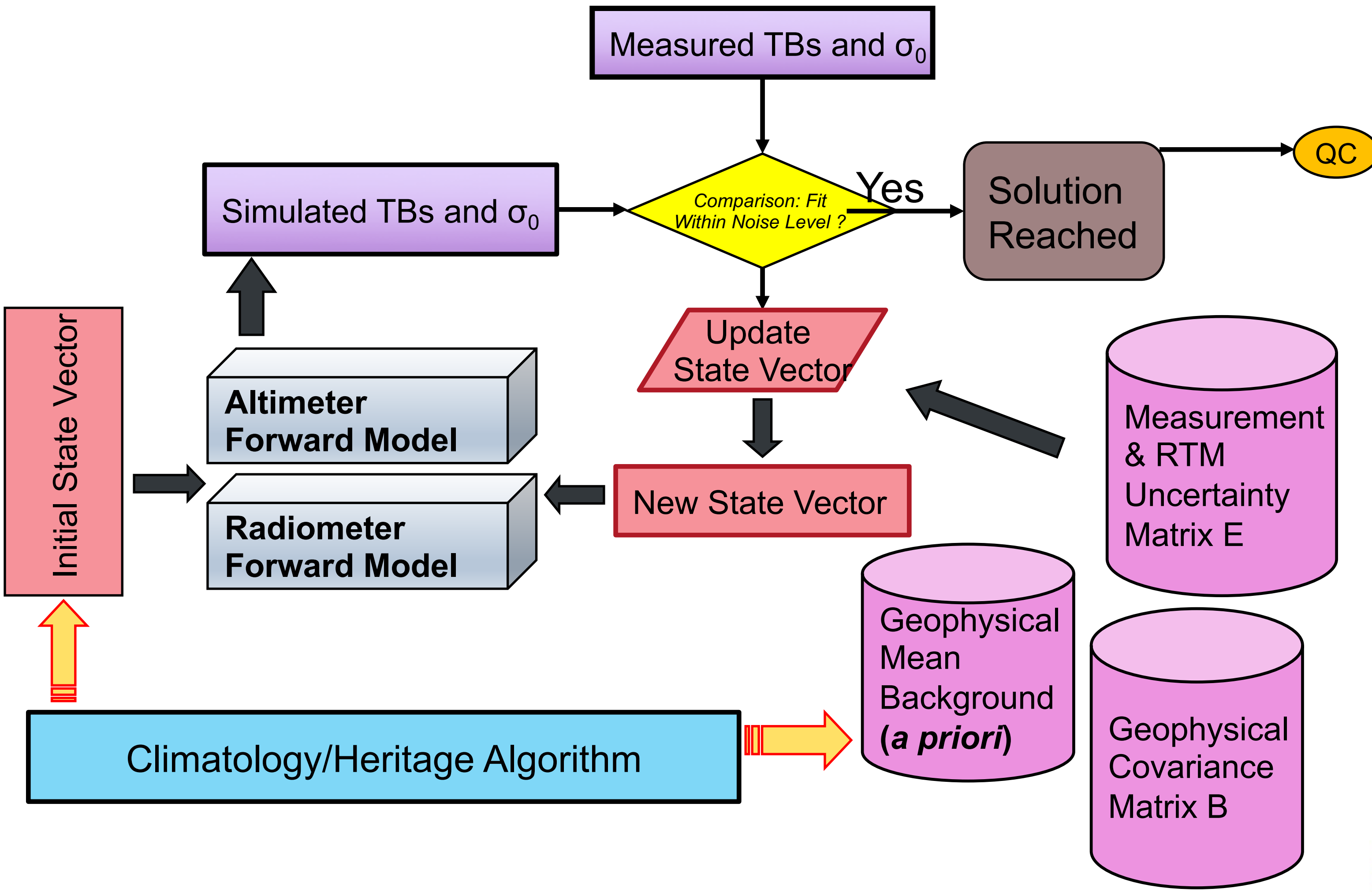
$$\mathbf{x} = (x_1, \ldots x_n)^T \qquad \mathbf{y} = (y_1, \ldots y_m)^T \qquad \mathbf{y} = \mathbf{Kx} + \boldsymbol{\varepsilon}$$

Minimization of the cost function:

$$\nabla_{\mathbf{x}} J(\mathbf{x}) = 2\mathbf{S_a}^{-1}(\mathbf{x}-\mathbf{x_a}) + 2\mathbf{K}^T\mathbf{S}_y^{-1}(\mathbf{Kx}-\mathbf{y}) = \mathbf{0}$$

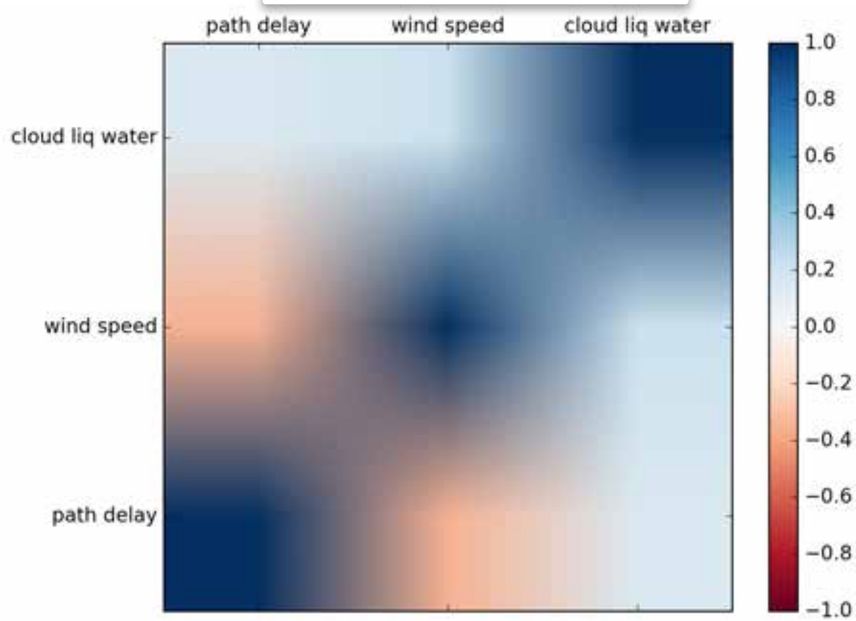


CAPRS: System Framework

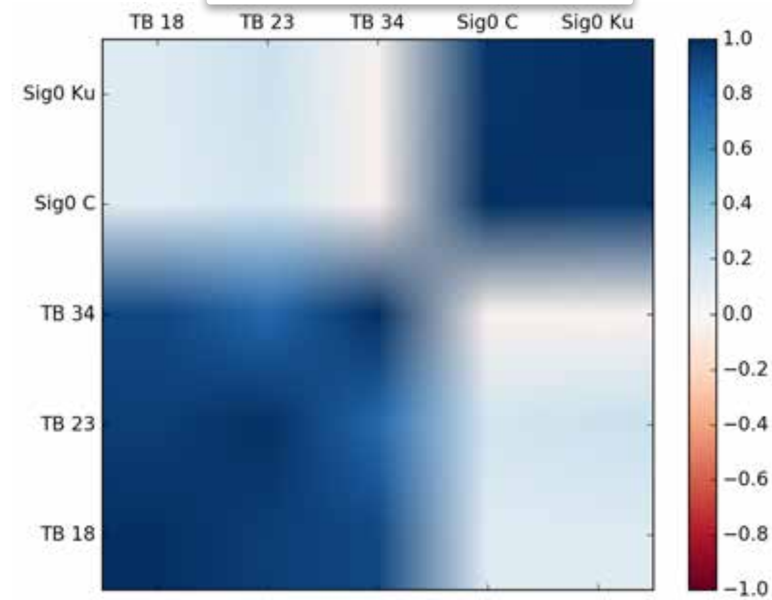


CAPRS: Covariance/Correlation Matrix

State Vector Corr Matrix



Obs Corr Matrix



$$\mathbf{x} = (x_1, \ldots x_n)^T$$

$$\mathbf{y} = (y_1, \ldots y_m)^T$$

$$\mathbf{y} = \mathbf{Kx} + \boldsymbol{\varepsilon} \text{ , where } \mathbf{K} = \frac{\partial \mathbf{y}}{\partial \mathbf{x}}$$

Jacobian Model (Finite Difference)

5 x 3

3 x 1

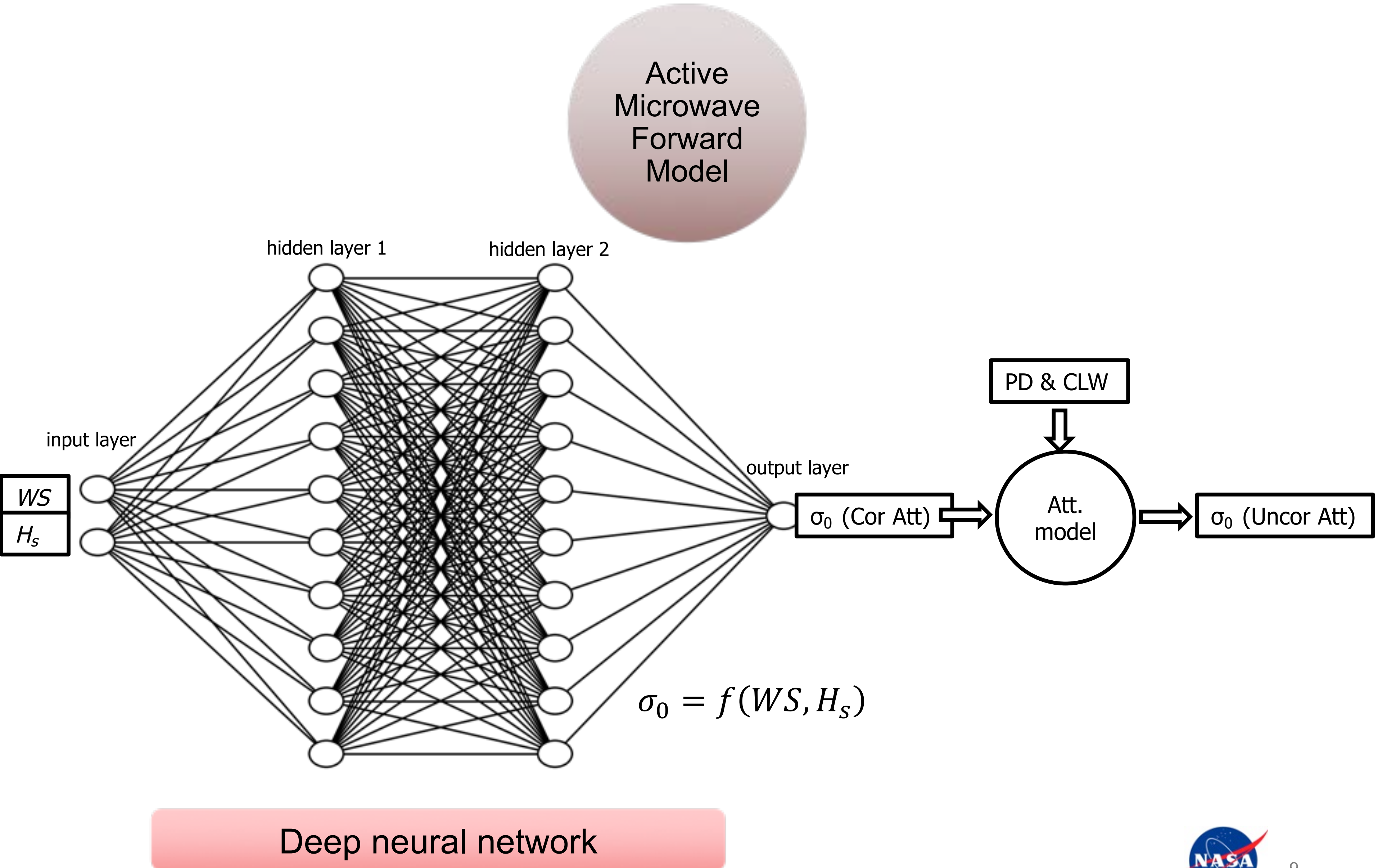
$$\mathbf{x} = \begin{bmatrix} PD \\ WS \\ CLW \end{bmatrix}$$

5 x 1

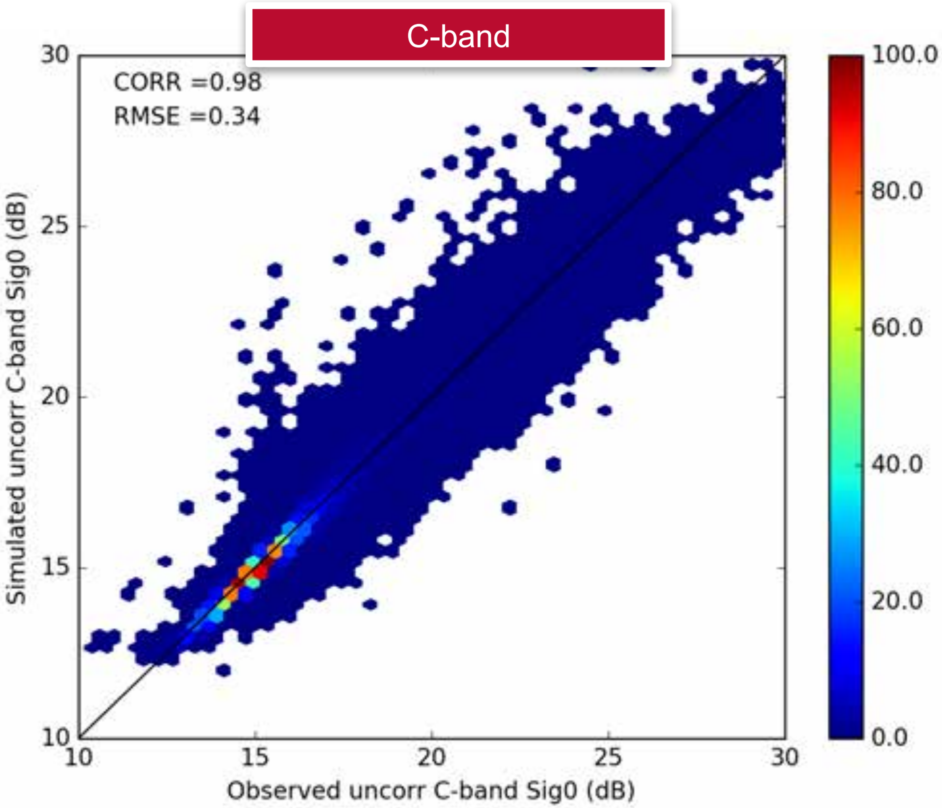
$$y = \begin{bmatrix} TB18 \\ TB23 \\ TB34 \\ \sigma_0 C \\ \sigma_0 Ku \end{bmatrix}$$

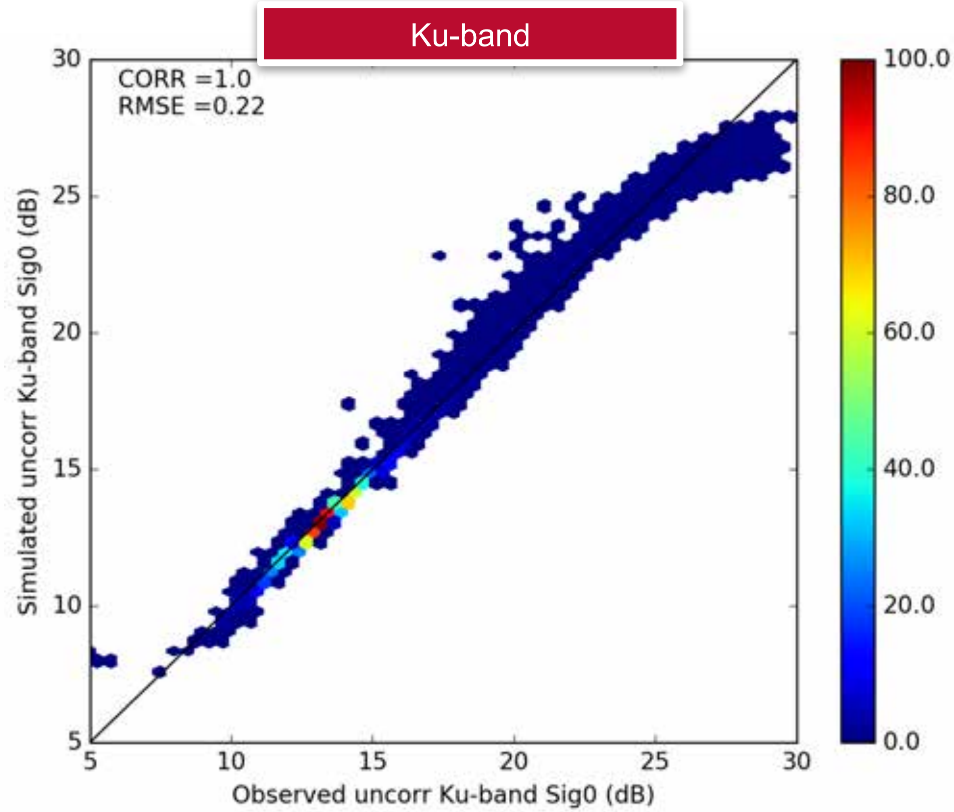
A priori database is generated by combining the ECMWF model with the heritage algorithm and calibrated TBs

CAPRS: Active Microwave Forward Model



CAPRS: Active Microwave Forward Model





Independently assessed using one month Jason-3 data (June 2017)

CAPRS: Passive Microwave Forward Model

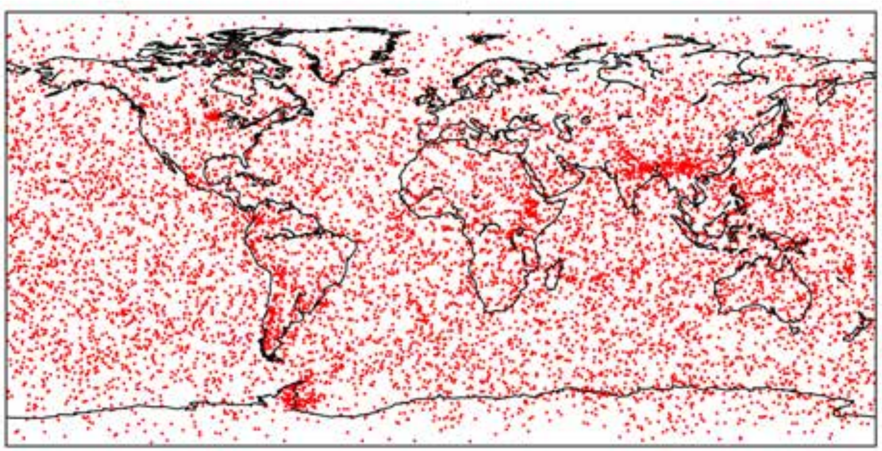
- Parameterized single layer fast radiative transfer model

$$T_B = \varepsilon T_{sfc} e^{-\tau} + \left(1 - e^{-\tau}\right) T_{Eff}^{UP} + (1-\varepsilon)\left(\left(1 - e^{-\tau}\right) T_{Eff}^{DOWN} + T_{cosmic} e^{-\tau}\right) e^{-\tau}$$

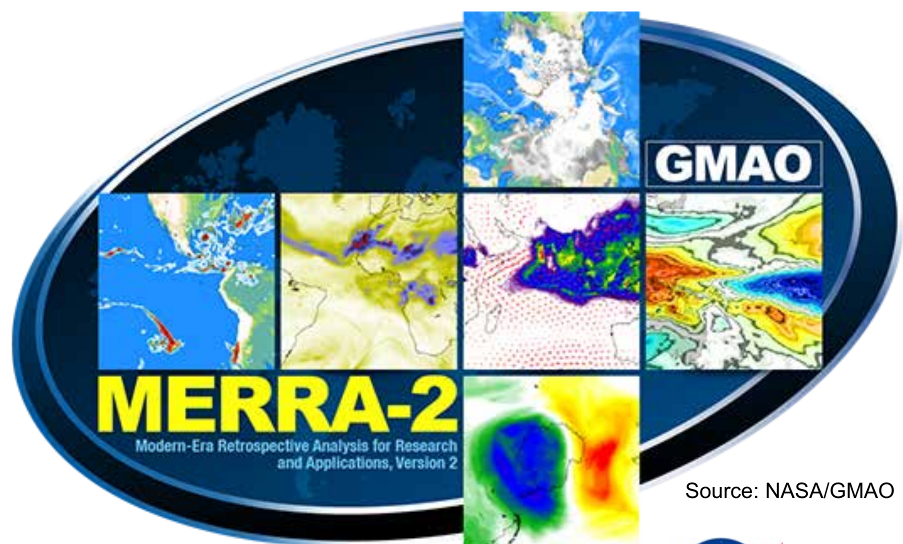
$$emissivity = f(wind\ speed, sst)[FASTEM]$$

$$tau = f(temp\ 2m, tpw, liquid\ water\ path)$$

- Used ~25,000 profiles to derive "fast" radiative transfer coefficients



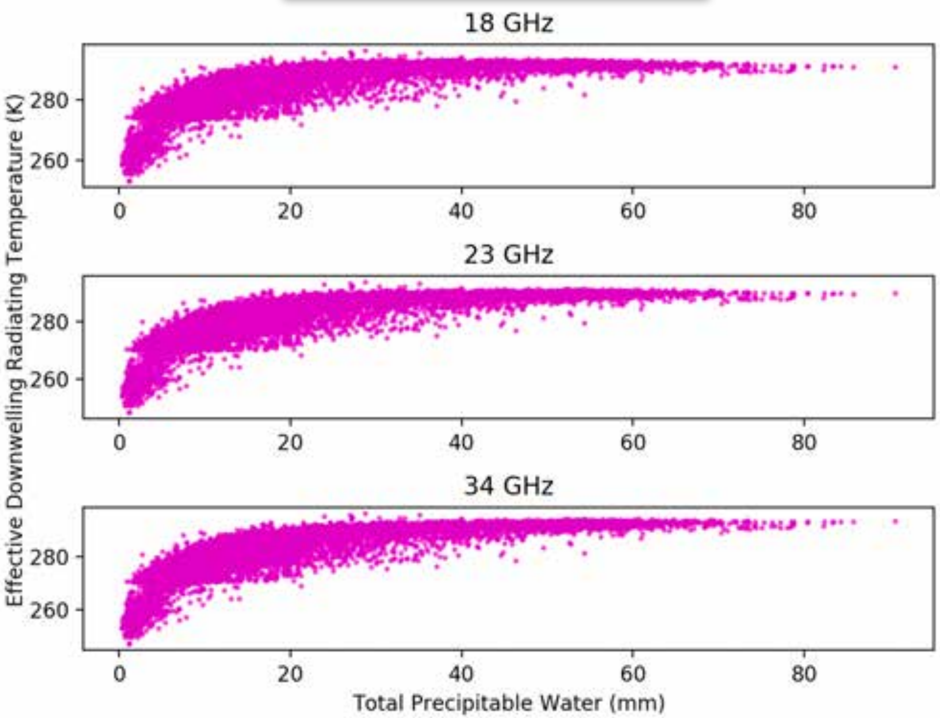
Auxiliary data: Sea surface temperature and 2m Air temperature from MERRA-2



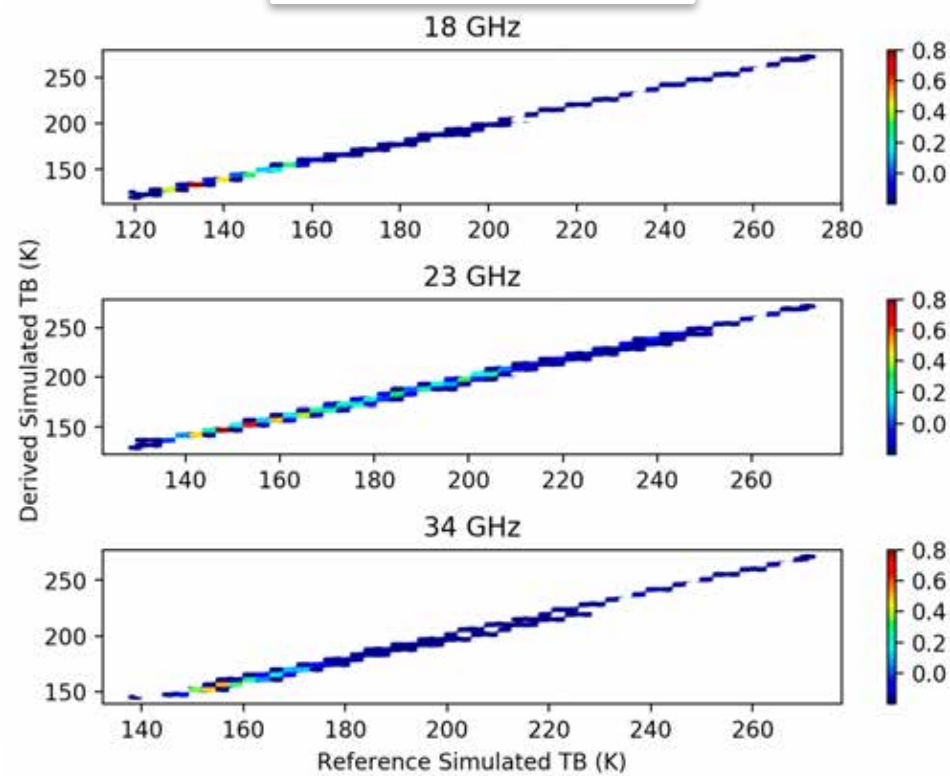
Source: NASA/GMAO

CAPRS: Passive Microwave Forward Model

Eff. Downwelling Temperature vs TPW



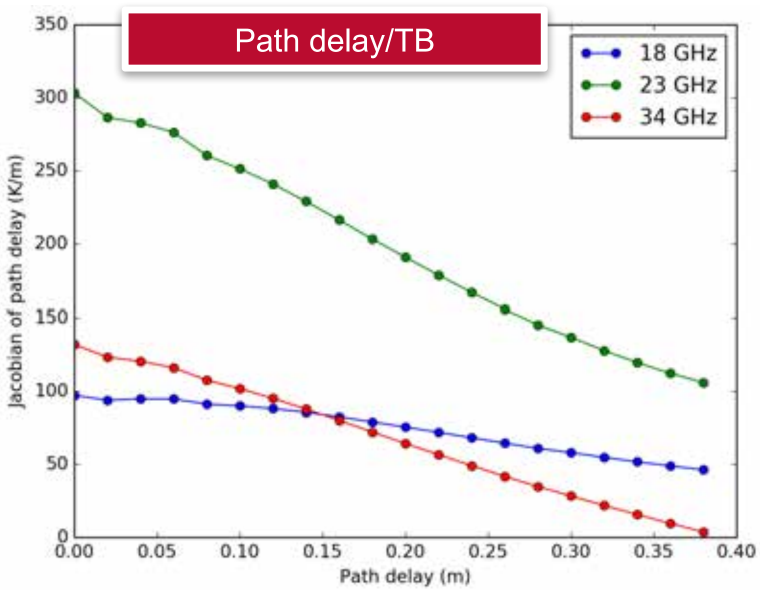
TBs

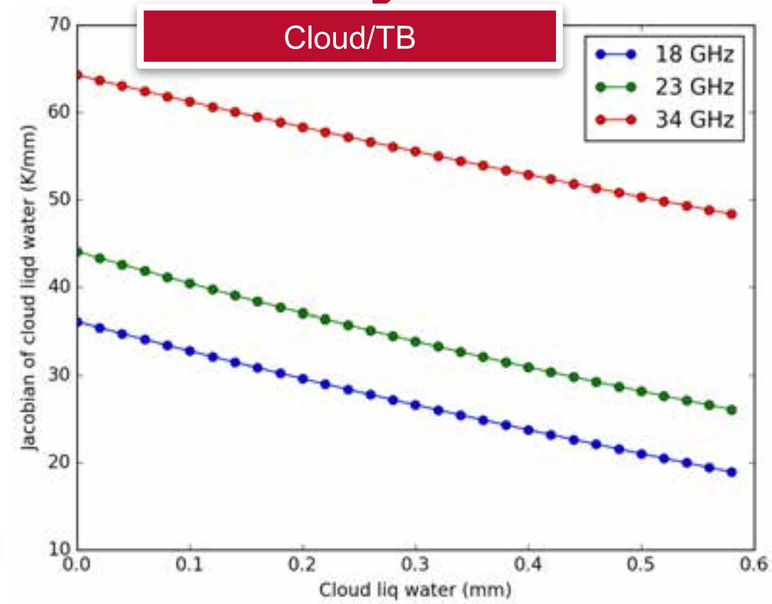


- Effective upwelling, downwelling radiating temperatures as well as optical depths are computed within the radiative transfer model

Simulation TB accuracy<0.1 K

CAPRS: Jacobian Model and Sensitivity

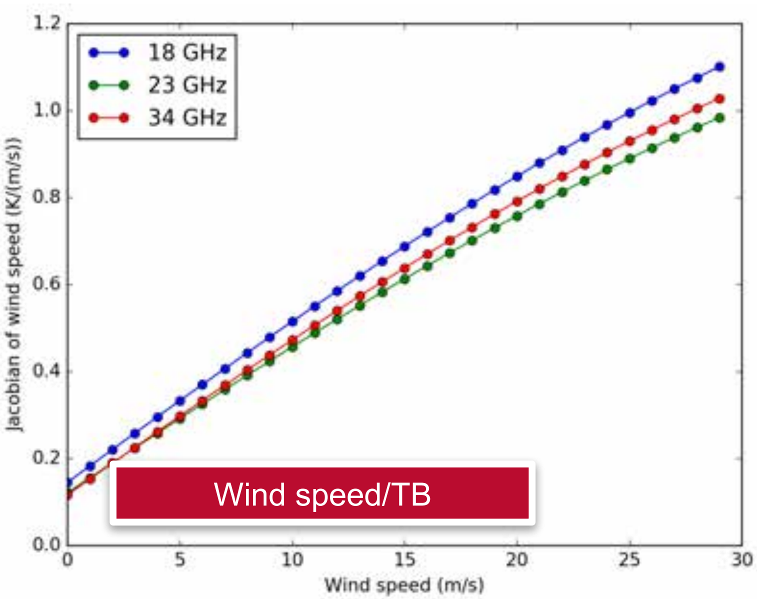


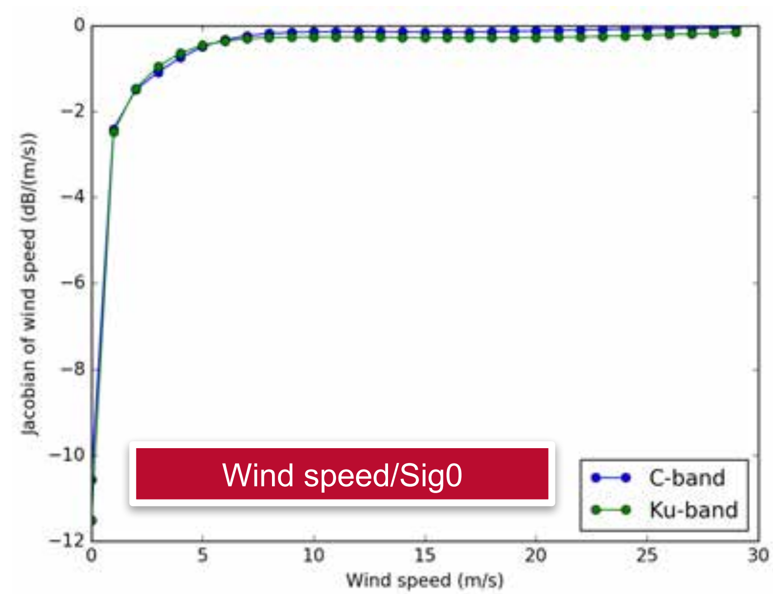


Jacobian Model

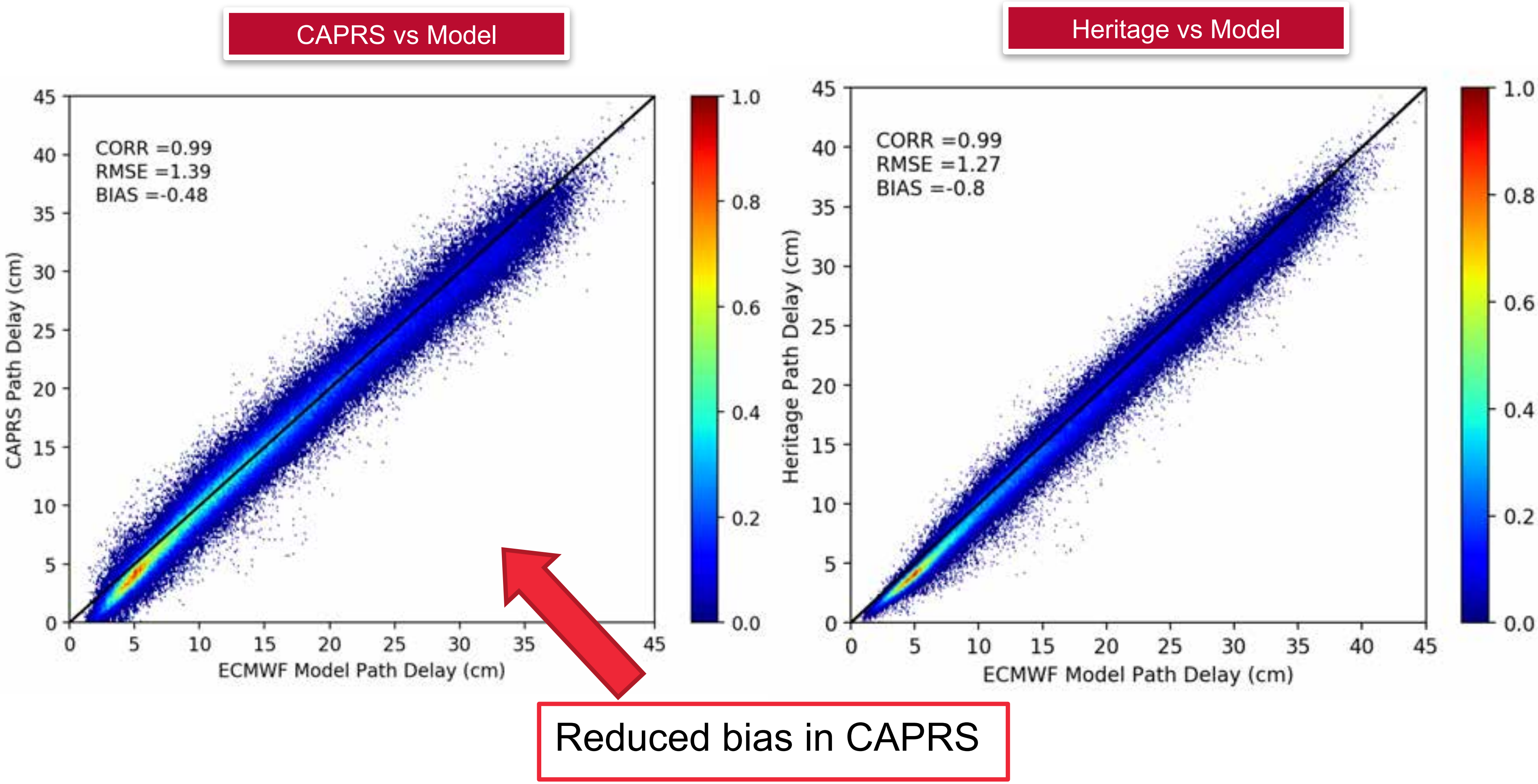
(Finite Difference)

$$K = \frac{\delta y}{\delta x}$$





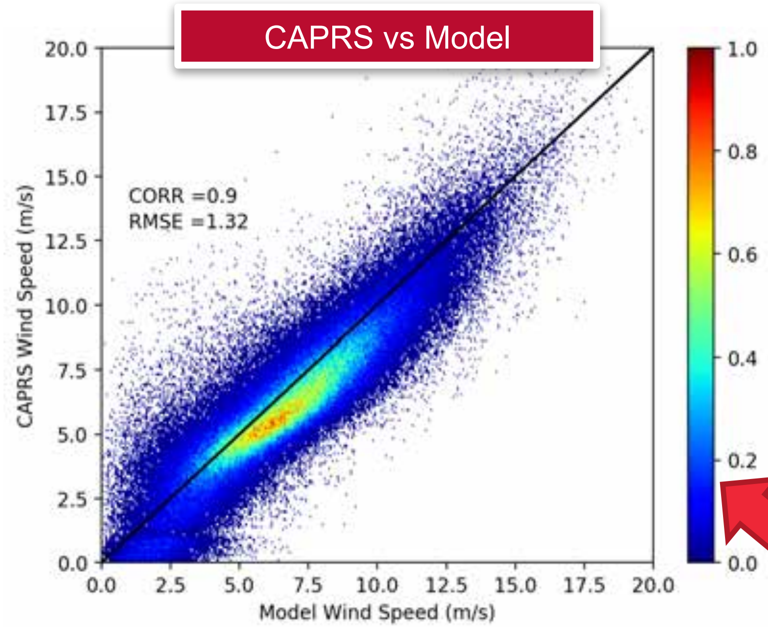
Performance Assessment: Path Delay

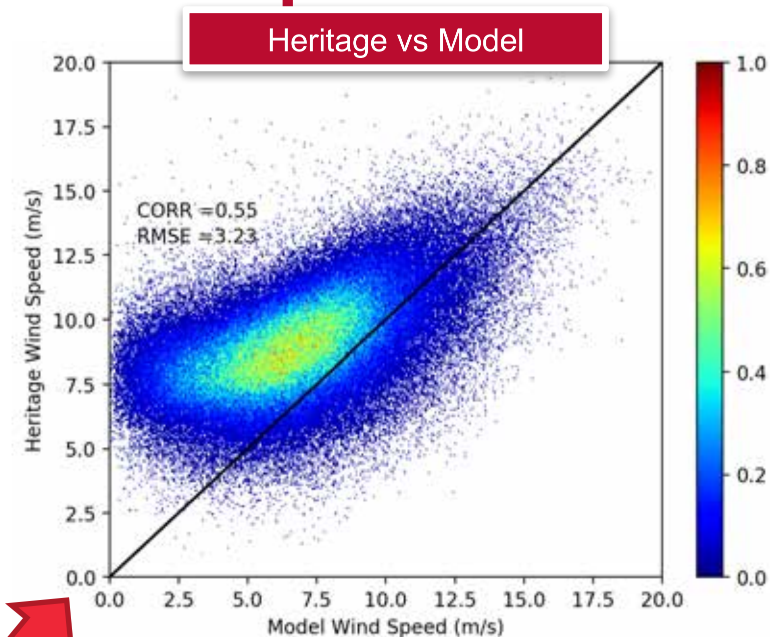


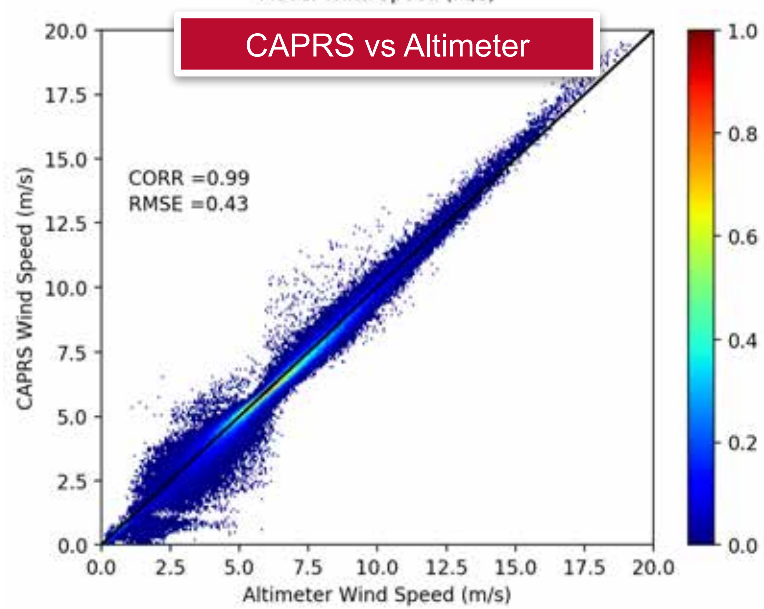
CAPRS Uncertainty: ~1.39 cm

~ 1 year assessment period on Jason-3:
July 2016 –Aug 2017

Performance Assessment: Wind speed



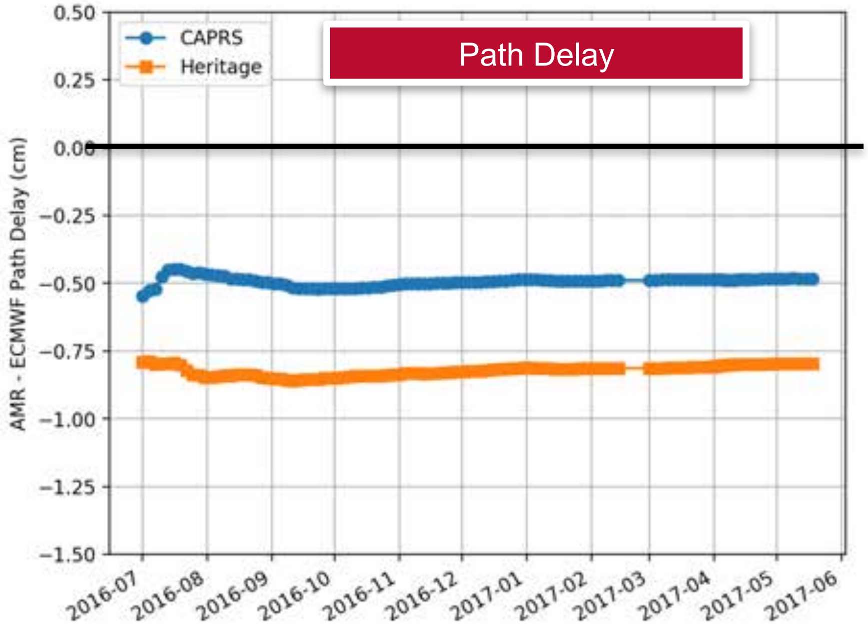


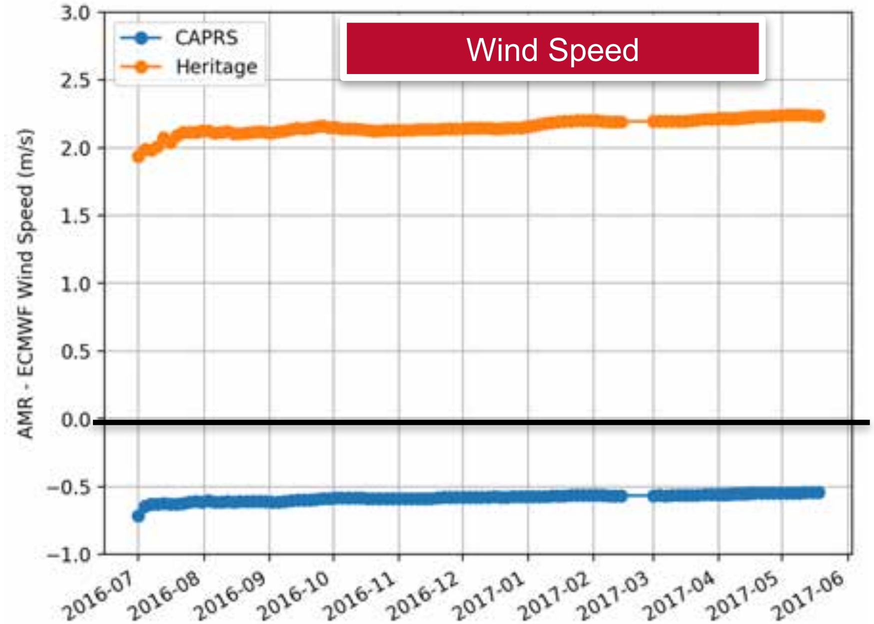


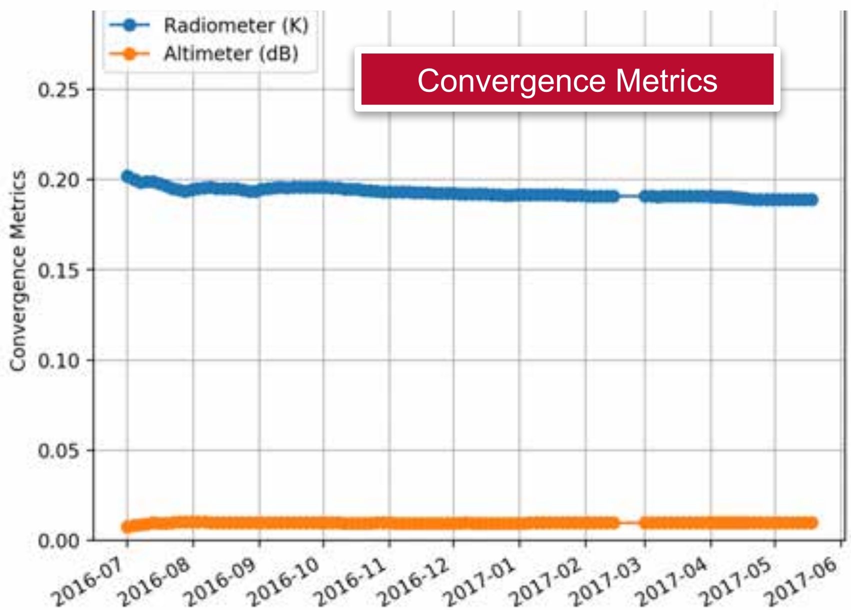
Wind speed retrieval significantly improved in CAPRS!

CAPRS Uncertainty: ~1.32 m/s

Performance Assessment: Time Series Trend

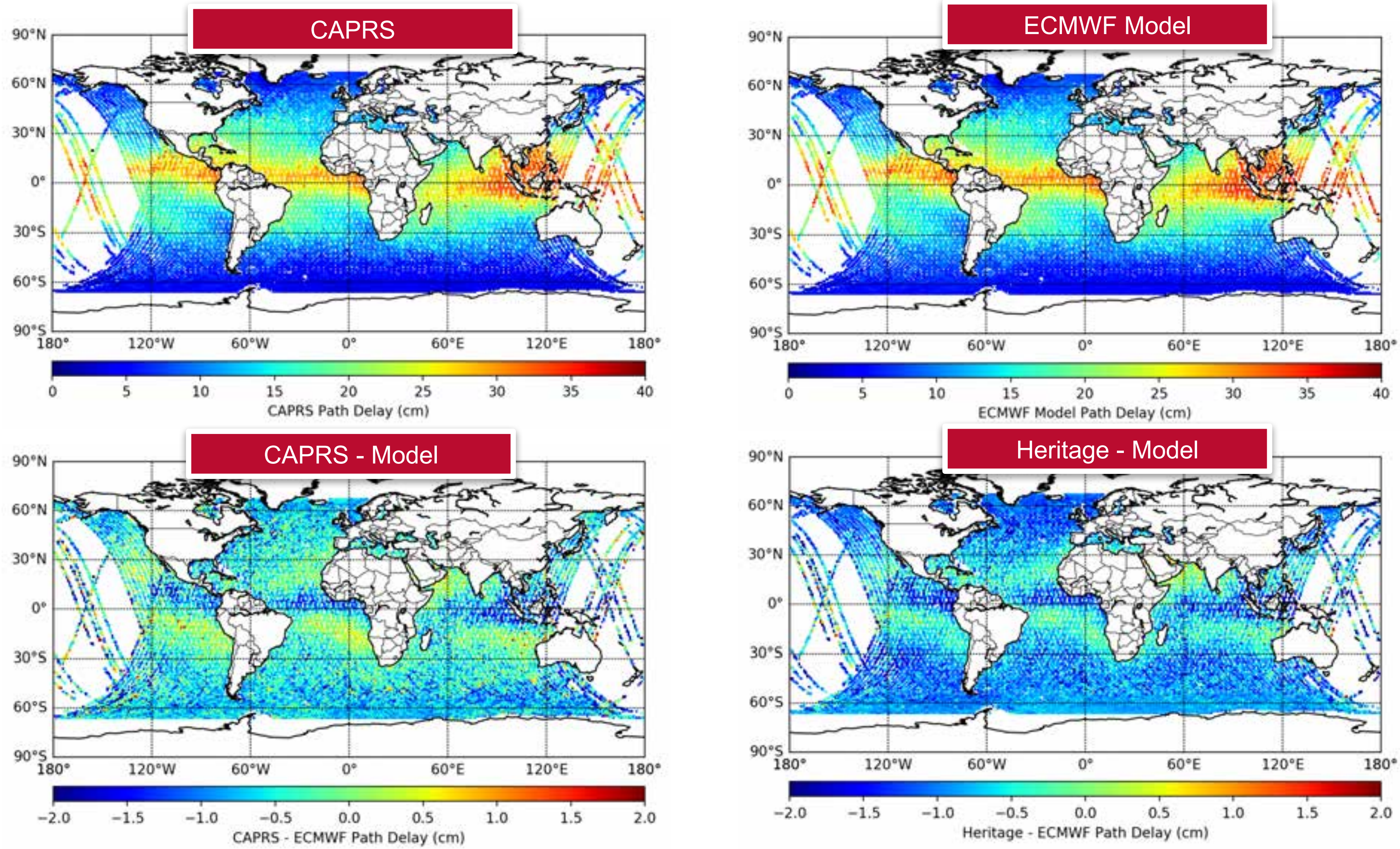






- Bias is significantly reduced in the new algorithm
- Long-term trend is not affected (no drift)
- Stable convergence metrics
- Convergence metrics can also be used for instrument status and quality monitoring

Performance Assessment: Global Distribution



- Bias is significantly reduced in the new algorithm

Summary and Future Work

- Developed an active/passive retrieval algorithm that seamlessly integrates the altimeter and radiometer measurements to produce retrieval products of wet path delay, ocean wind speed and cloud liquid water path.
- Wet path delay biases are noticeably reduced.
- Wind speed retrieval is significantly improved.
- Long-term trend is not affected in the new synergistic radiometer/altimeter instrument processing algorithm.
- Future work:
  - Development of value added products such as precipitation
  - Extensive validation

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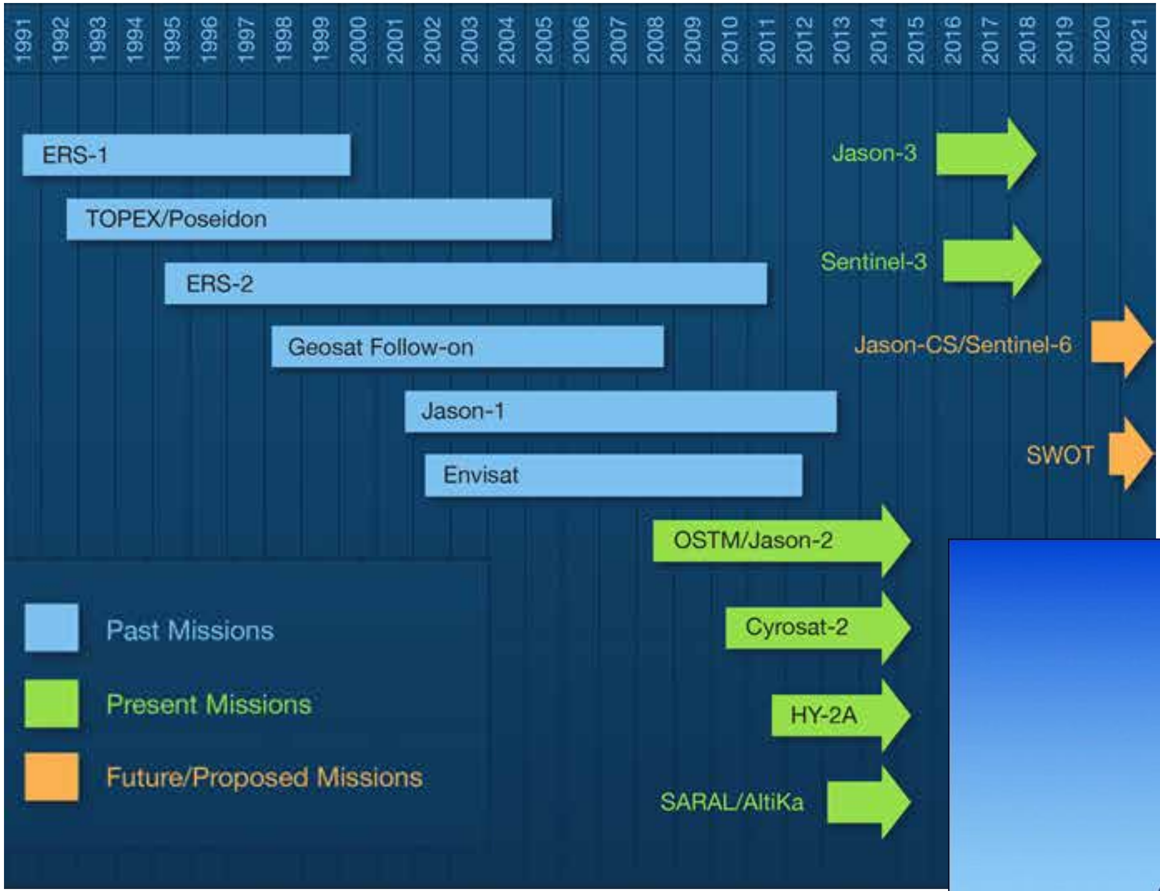
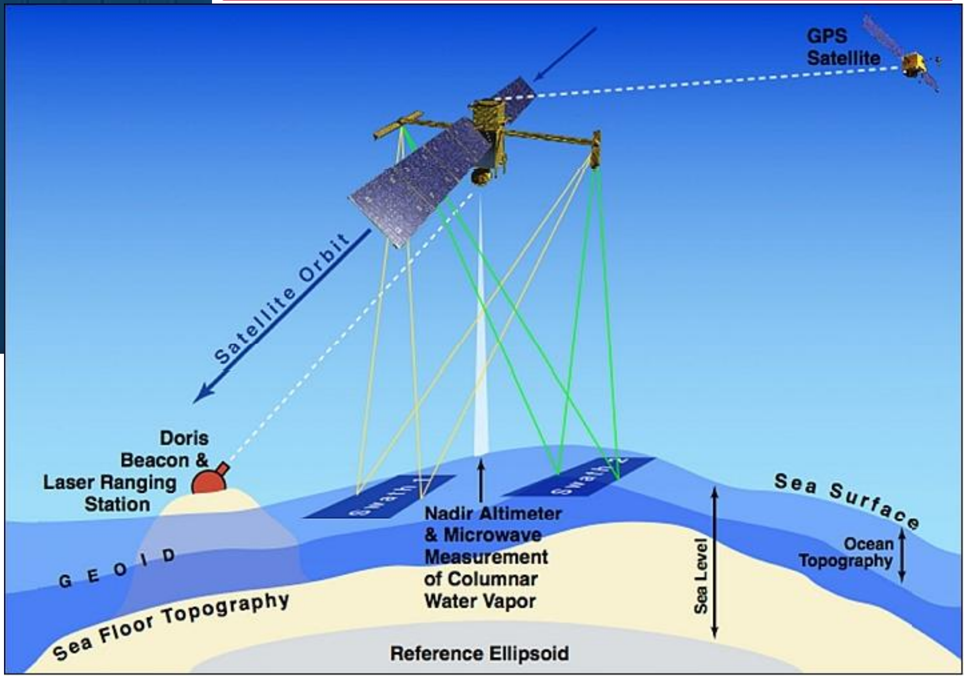
Backup slides

Altimetry Measurement Basis



Source: JPL

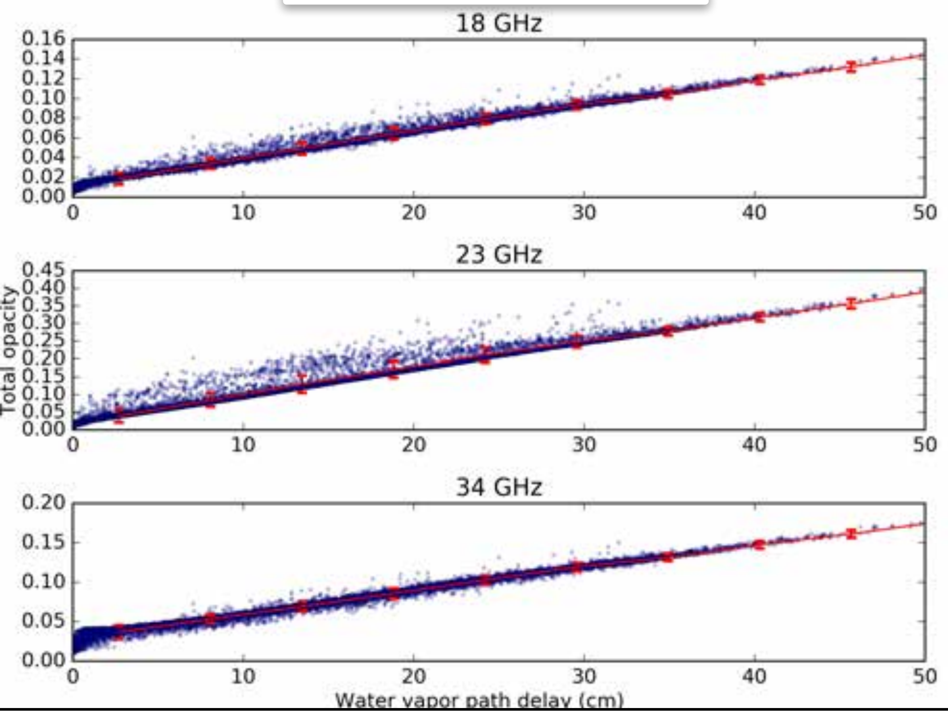
- The atmosphere reduces the speed of the radar pulse, bending its trajectory and, therefore, causing a “path delay” of the altimeter signal
- For wet tropospheric correction, passive microwave radiometers are added to the altimetry missions, e.g. AMR on Jason series.



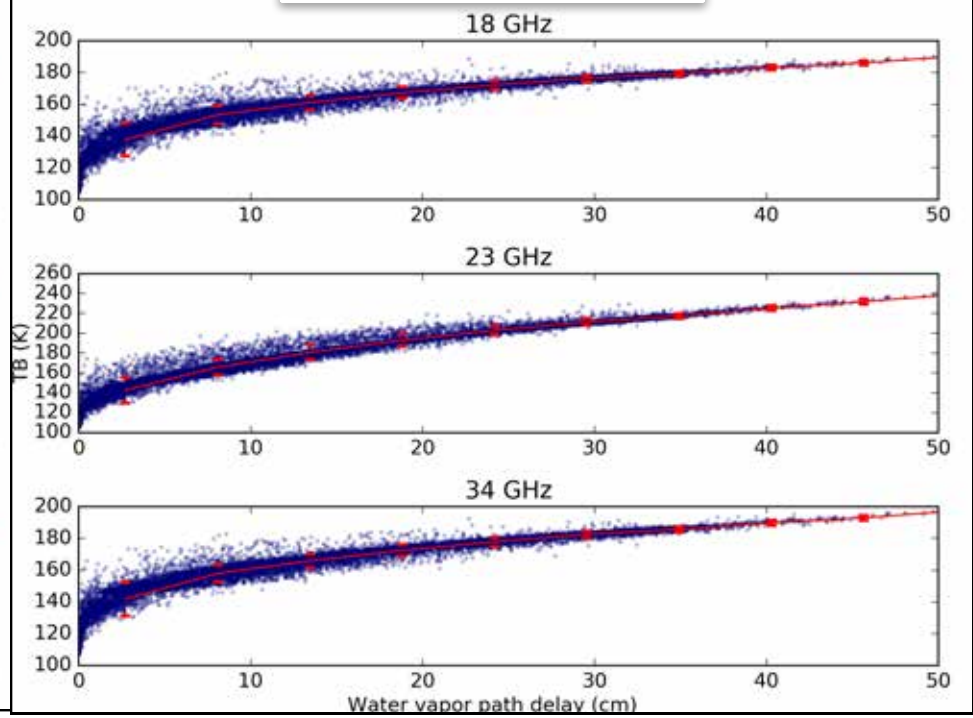
Source: NOAA

AMR Instrument Frequencies

Opacity vs Path Delay

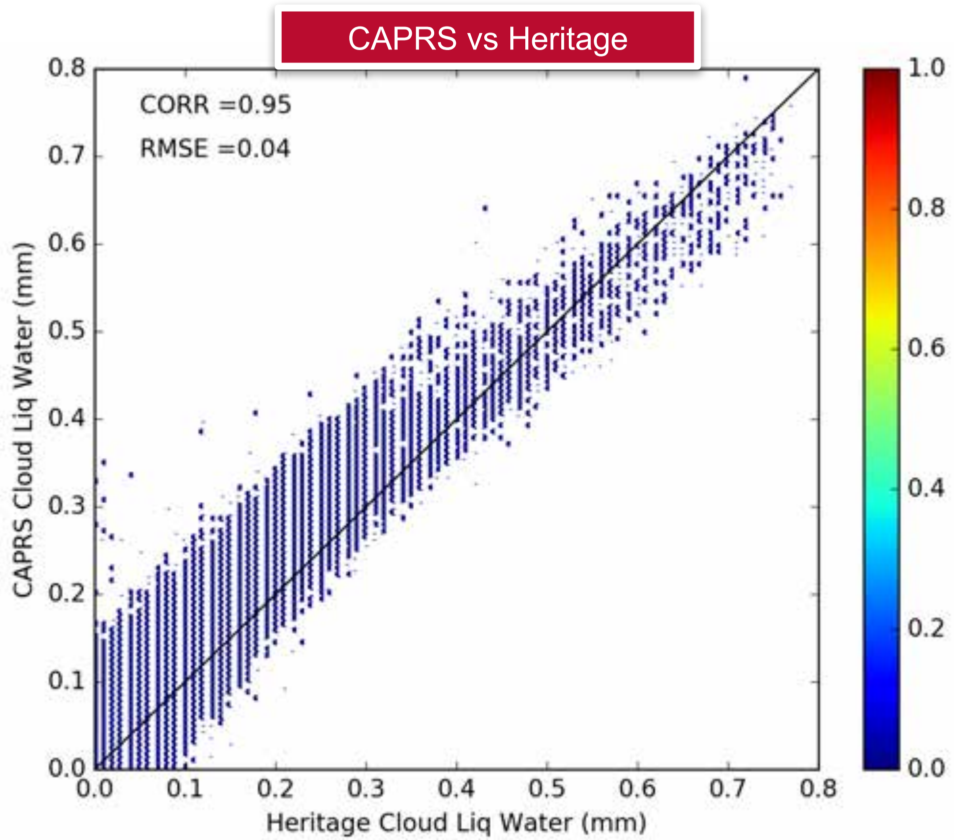


TBs vs Path Delay



- AMR is operated at three frequencies
- Figure shows strong linear relationship between total opacity and water vapor path delay in the three AMR channels (18.7, 23.8, and 34.0 GHz). Rosenkranz absorption model is employed in this simulation.

Performance Assessment: Cloud Liquid Water



CAPRS Uncertainty: ~0.04 mm