Next-generation radiometer instruments, algorithms, and uncertainties due to 24 GHz 5G interference

Tanvir Islam, Shannon Brown, Sidharth Misra

Jet Propulsion Laboratory, California Institute of Technology

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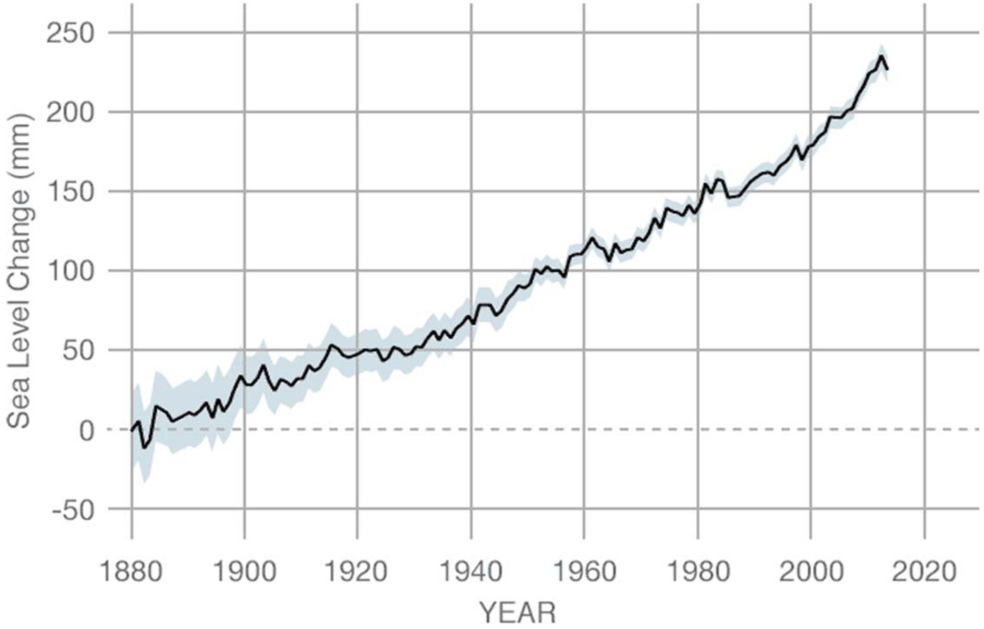
Global Sea Level Rise



- Measurement of global mean sea level rise not possible without extremely well calibrated measurement system
- Radiometer wet path delay correction generally considered largest source of uncertainty in long term GMSL trend estimate
  - Requires careful monitoring and application of periodic post-launch corrections
  - Corrections of up to 30x GMSL trend have been applied to radiometer wet PD record

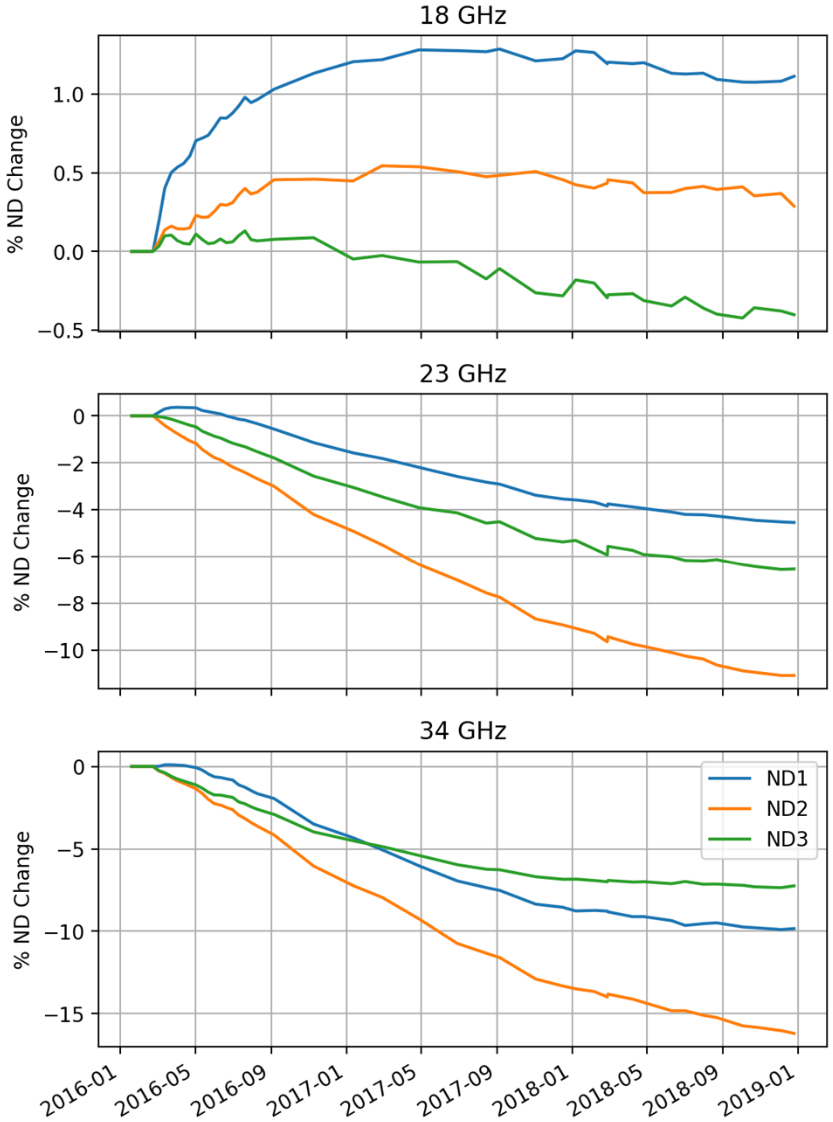
Table 2. MSL trend uncertainties from 1993 to 2008 for each correction or model impacting the MSL calculation.

Source of error for the MSL calculation		MSL trend uncertainties from 1993 to 2008	
		Minima	Maxima
Orbit:Cnes POE (GDR B) for Jason-1 and GSFC (ITRF2000) for T/P.		0.10 mm/yr	0.15 mm/yr
Radiometer Wet troposphere correction: JMR and TMR (with drift correction).		0.20 mm/yr	0.30 mm/yr
Dynamical atmospheric and dry troposphere corrections using ECMWF pressure fields.		0.05 mm/yr	0.10 mm/yr
Sigma0 drift impacting altimeter wind speed and sea state bias correction		0.05 mm/yr	0.10 mm/yr
Bias uncertainty to link TOPEX A and TOPEX B, and TOPEX and Jason-1.		0.10 mm/yr	0.25 mm/yr
Total error budget	absolute sum	0.50 mm/yr	0.90 mm/yr
	quadratic sum	0.32 mm/yr	0.44 mm/yr
	inverse formalism	0.6 mm/yr in a confidence interval of 90%	

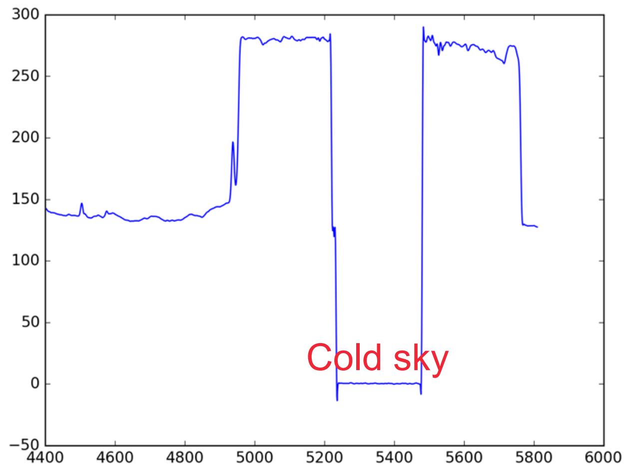
Ablain et al., 2009

Current Radiometers and Calibration Limitations

Noise diode based calibration

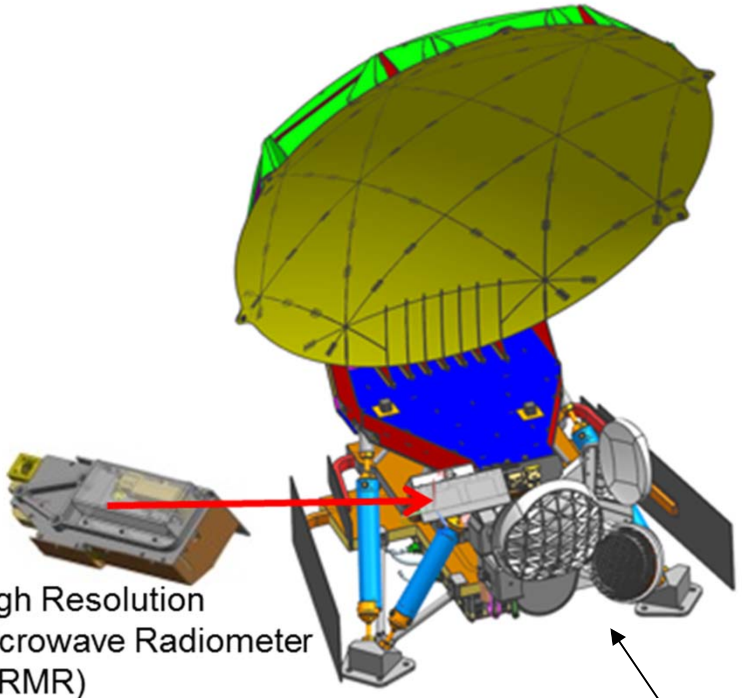


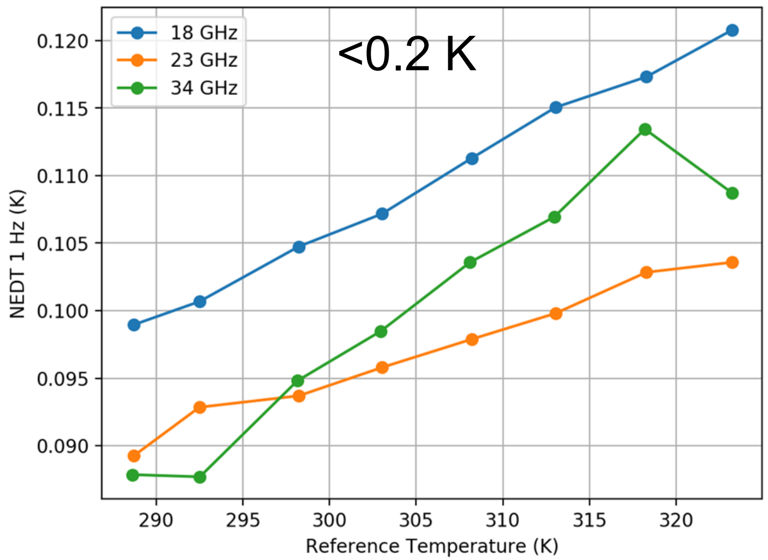
Cold Sky and Vicarious Calibration are used to characterize and remove drift in J3 AMR noise diodes



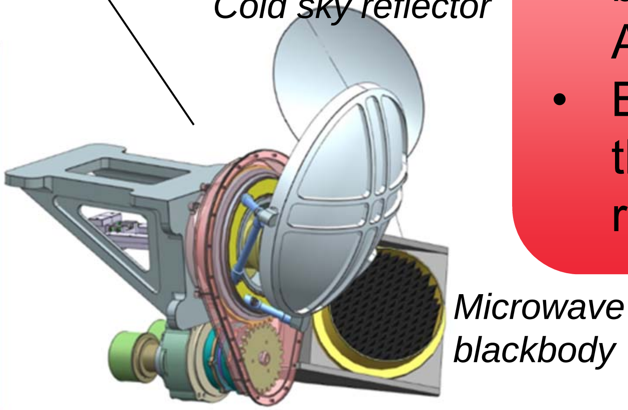
High CSM intervals, ~months

Sentinel-6 AMR-C





Sentinel-6 AMR-C includes external calibration system for long term stability based on OSTST recommendations

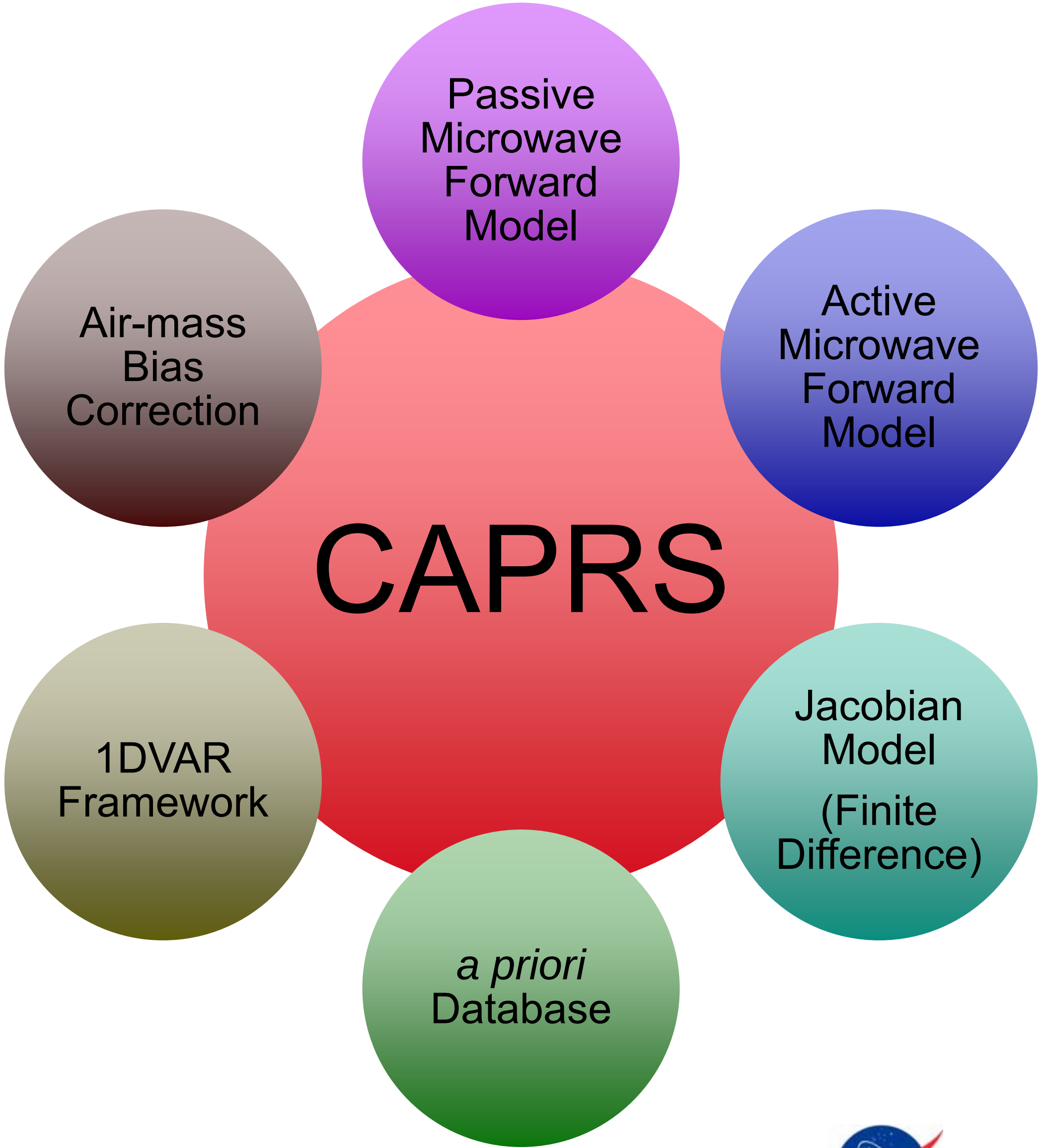


SCS (Supplemental Calibration System)

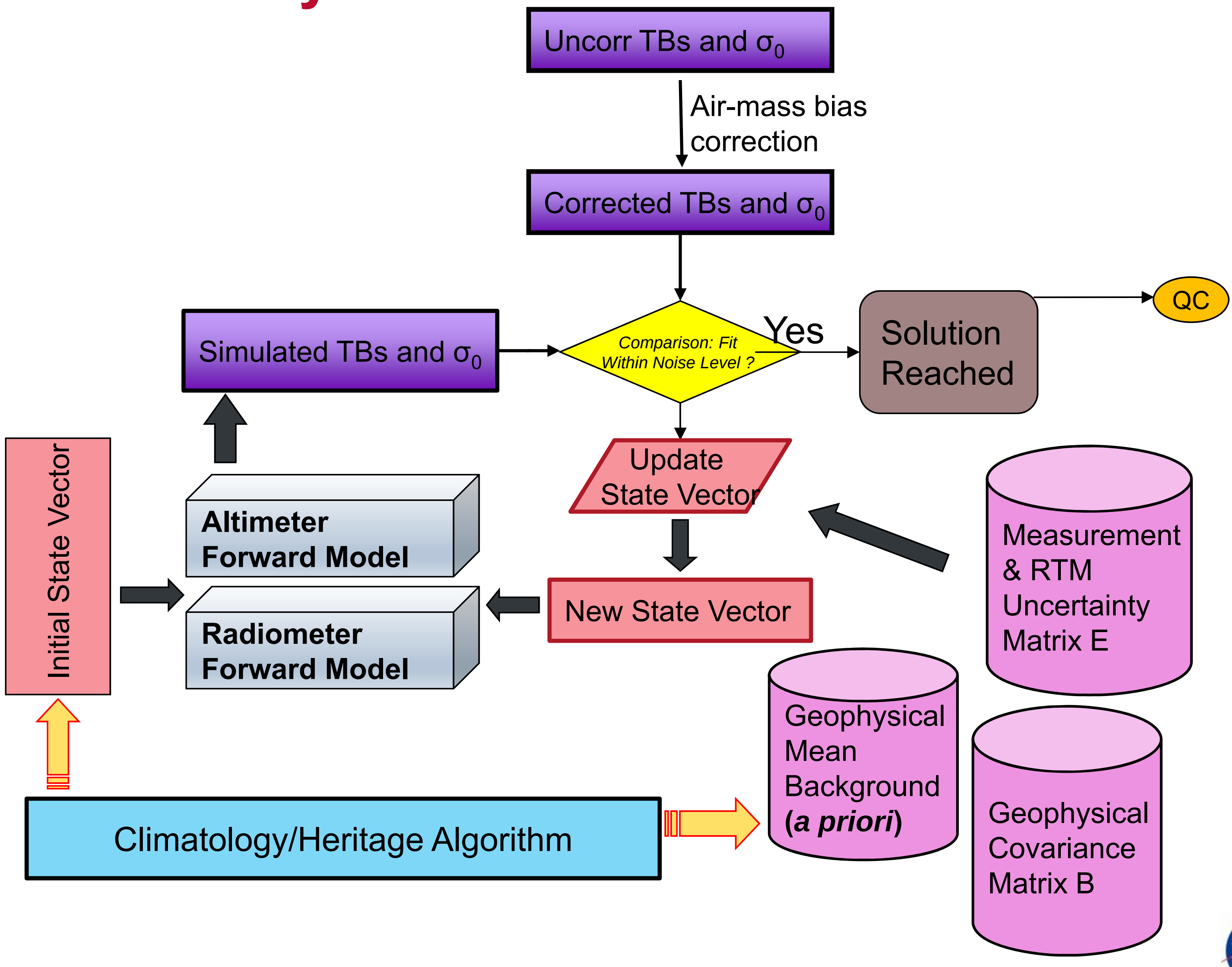
- TVAC test completed for both Sentinel-6A and B AMR radiometers
- Both radiometers meeting the noise and path delay requirements

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
- Allows parallel processing of the profiles

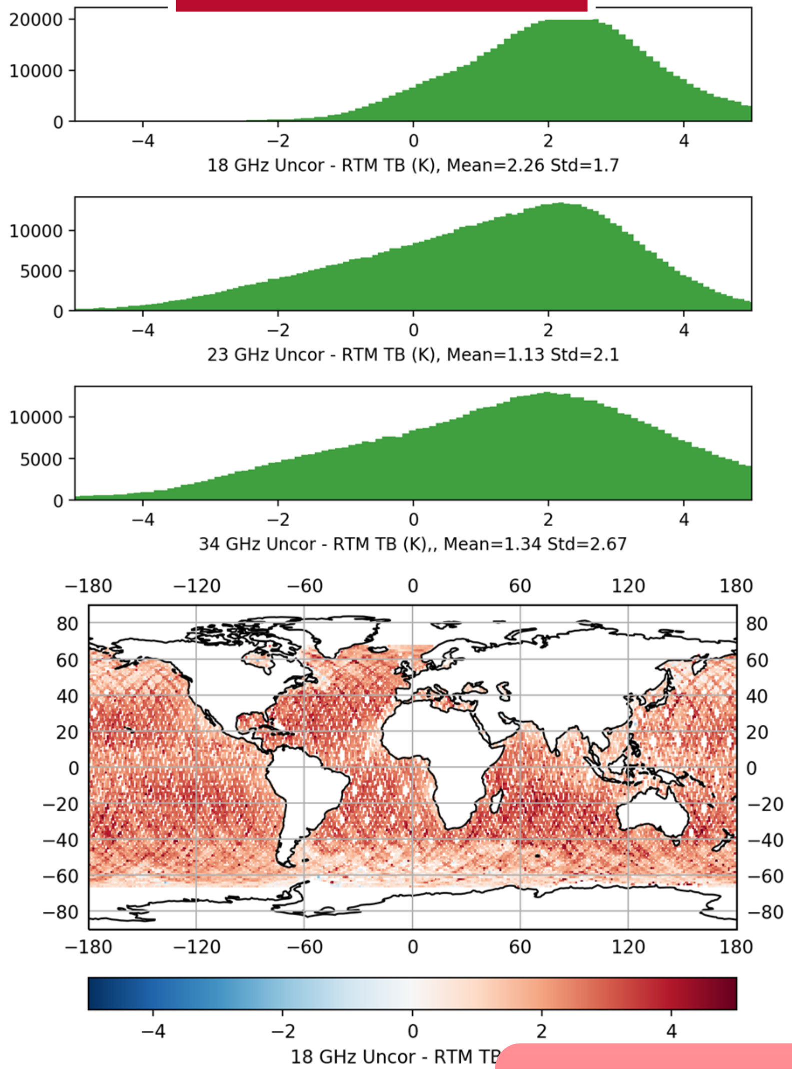


CAPRS: System Framework

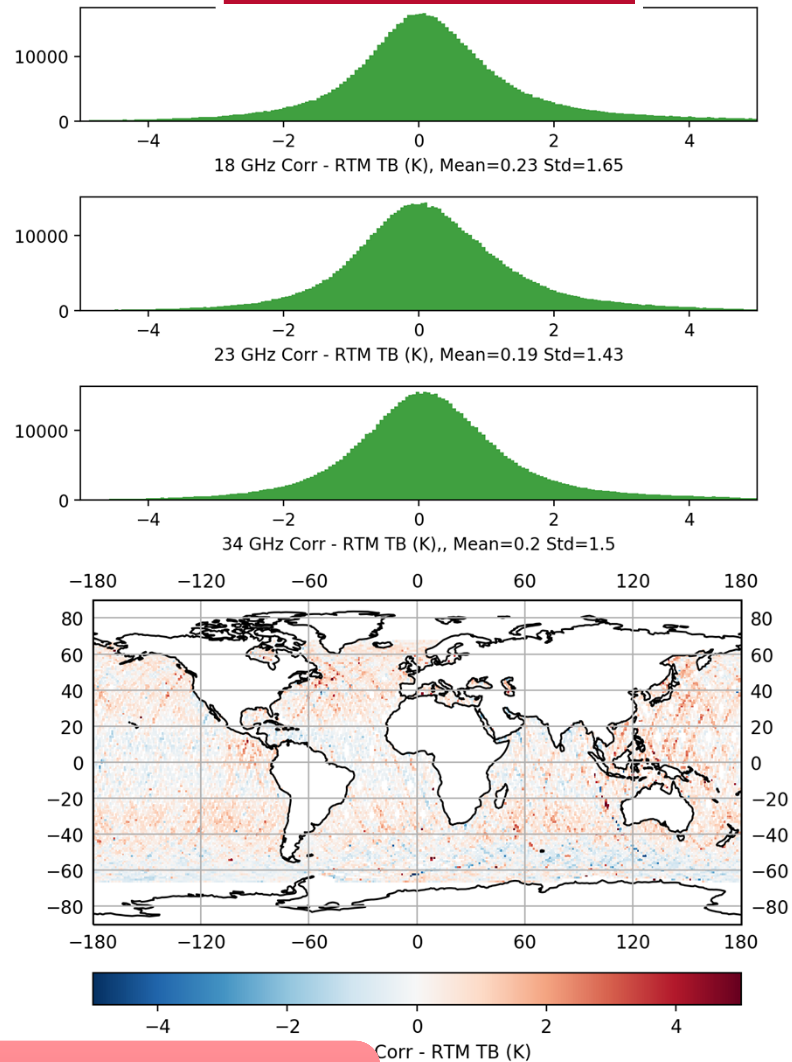


CAPRS: Air-mass Bias Correction

Uncorrected – RTM TBs



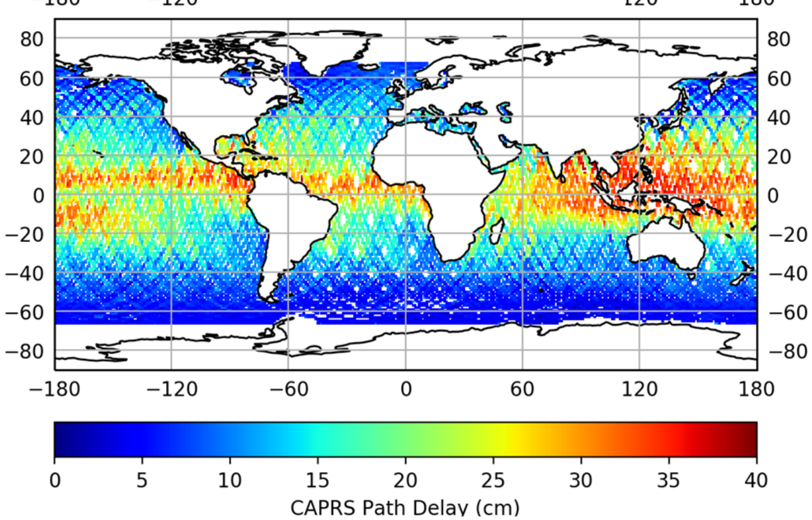
Corrected – RTM TBs



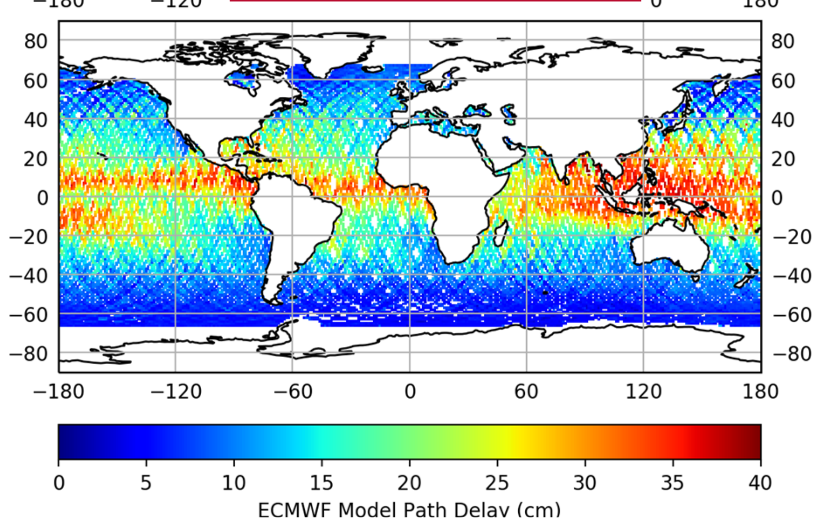
Bias Removed through Air-mass bias correction (1 Year Data)

CAPRS Performance Assessment: Path Delay

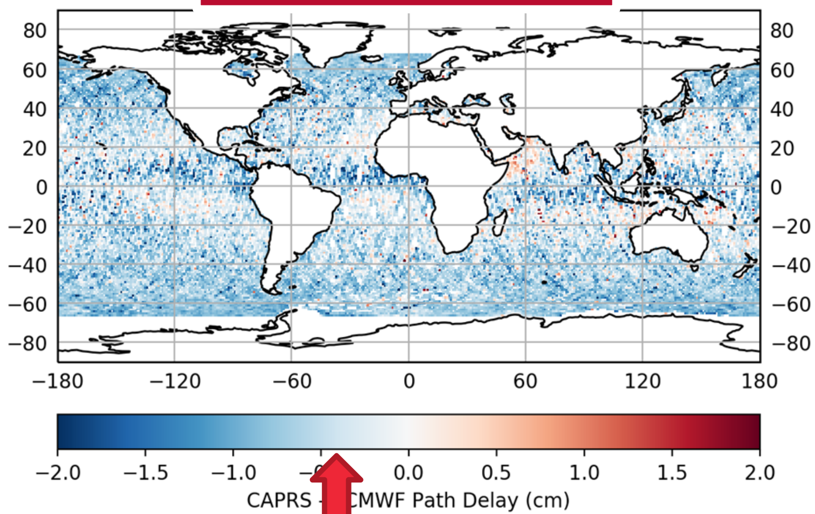
CAPRS



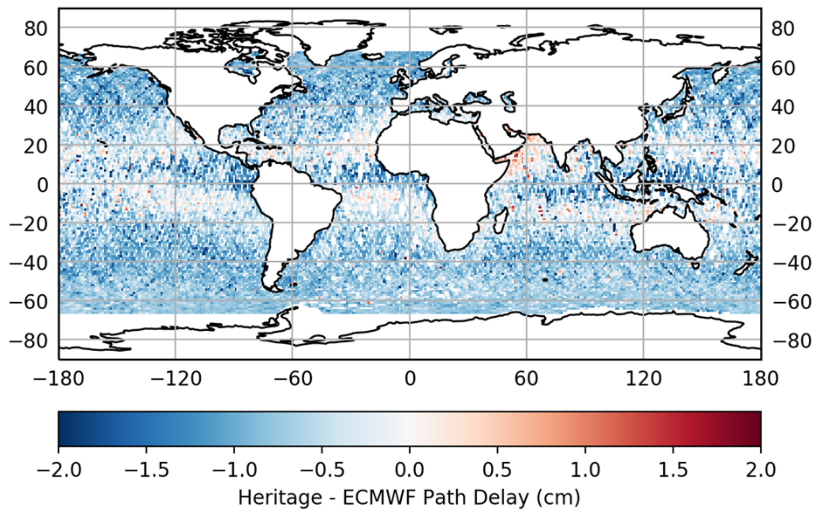
ECMWF Model



CAPRS - Model

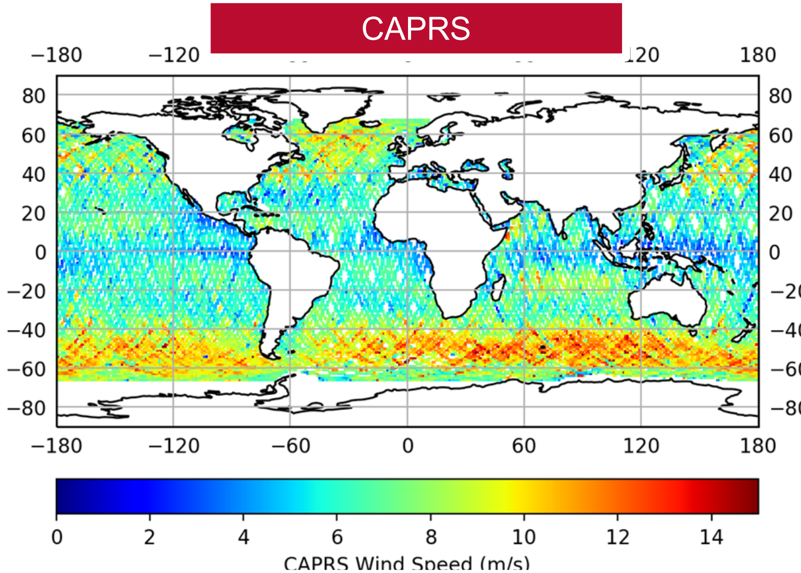


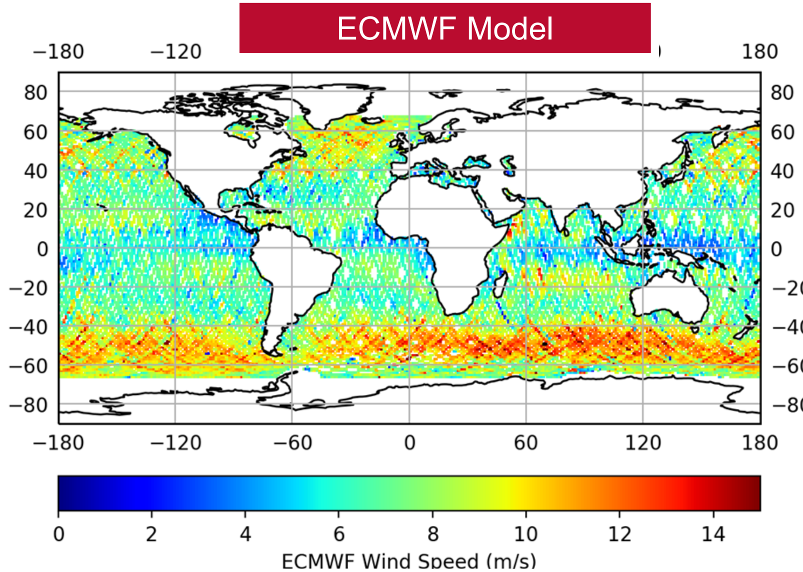
Heritage - Model

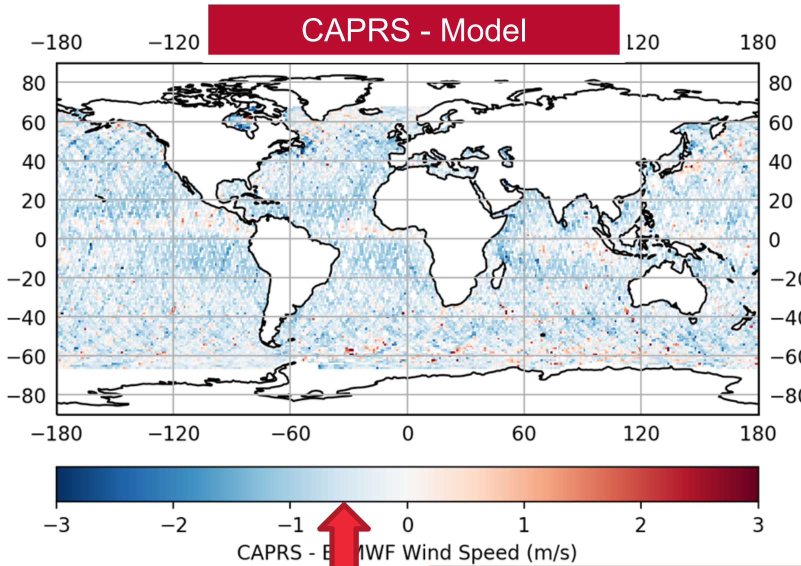


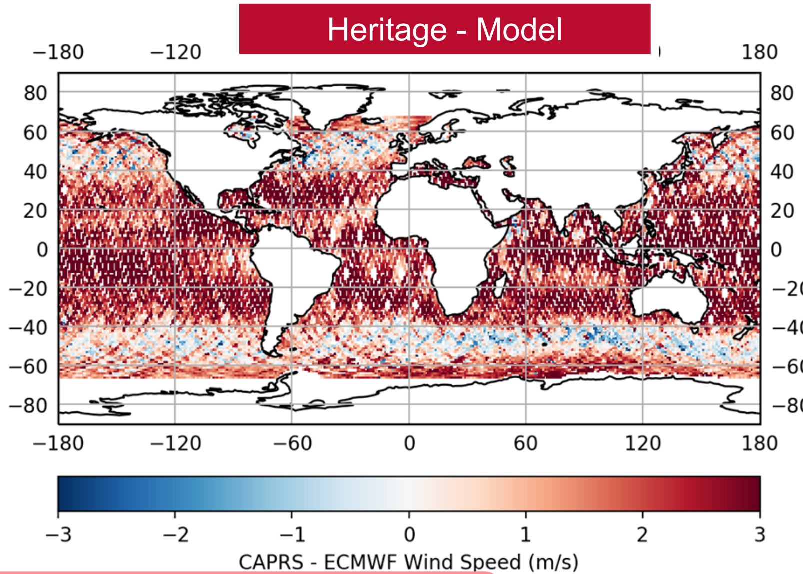
Bias reduced in the new algorithm

CAPRS Performance Assessment: Wind Speed



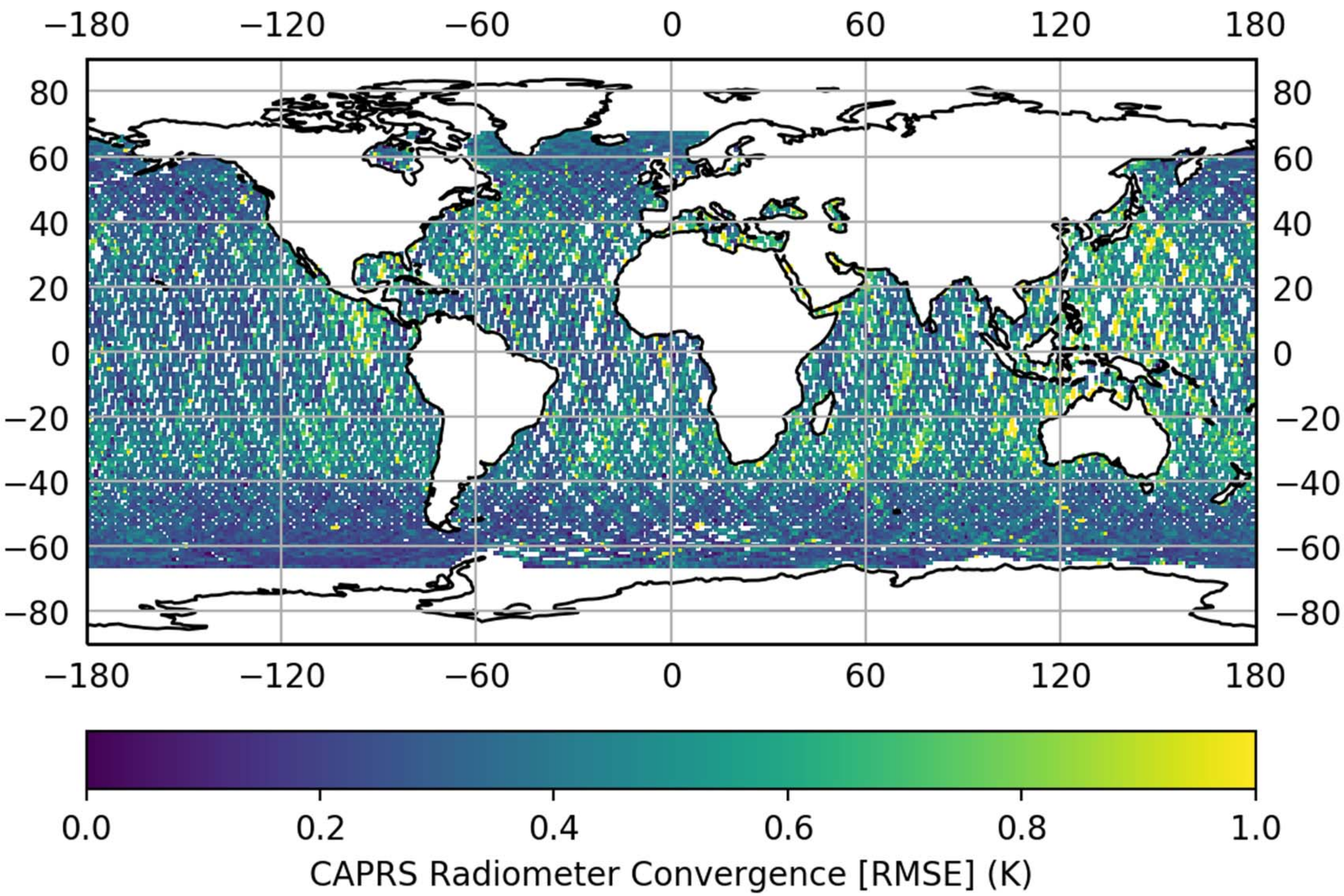






Significant improvement in Wind Speed

CAPRS: Convergence/Uncertainty Metrics



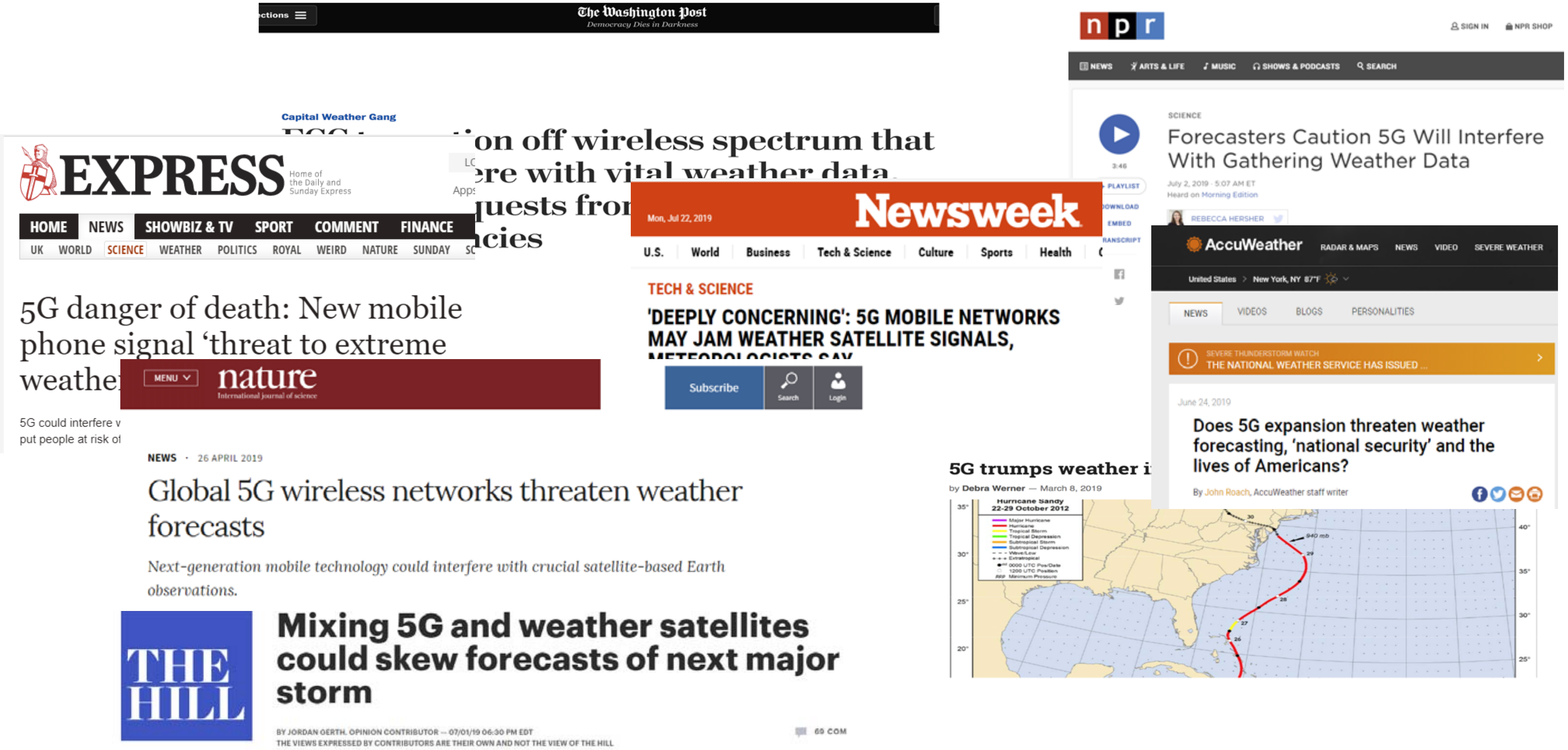
- Convergence metrics provide uncertainty estimates
- Mostly converged globally (<1 K)

- SCS will improve calibration
- CAPRS will improve retrieval

Pixabay free license

- But we have new challenge now!

Threats to Remote Sensing



5G 24 GHz Spectrum Allocation

Auction 102: Spectrum Frontiers – 24 GHz

Go to an Auction

Select an Auct...

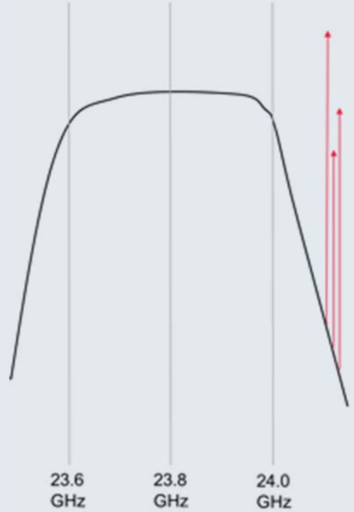
Summary | Fact Sheet | Releases | Education | Results | Application Search

- Summary
- General Releases
- Archived Auction Releases
- About Auctions
- Broadcast Incentive Auction
- CAF-II Auction (Auction 903)
- 833 Auction
- Prohibited Communications
- Conferences
- Consumer Alert
- Tribal Lands Credits
- About Form 175
- Band Plans
- Maps

Fact Sheet

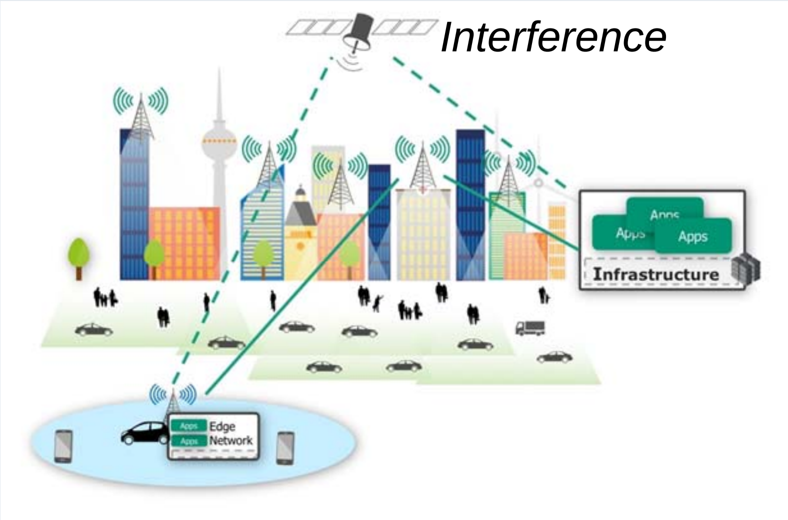
Date:	Bidding in Auction 102 began on March 14, 2019, and concluded on May 28, 2019.
Licenses:	2,909 licenses total
	Block A: 416 Partial Economic Area (PEA) licenses Block B: 416 PEA licenses Block C: 416 PEA licenses Block D: 416 PEA licenses Block E: 416 PEA licenses Block F: 416 PEA licenses Block G: 413 PEA licenses*
Spectrum	24.25 – 24.45 GHz and 24.75 – 25.25 GHz
Bandwidth:	Lower segment (24.25 – 24.45 GHz) licensed as two 100-megahertz blocks (Blocks A and B)
	Upper segment (24.75 – 25.25 GHz) licensed as five 100-megahertz blocks* (Blocks C – G)

**Note: In one PEA, the G Block license will have reduced bandwidth (75 megahertz). In three other PEAs, the G Block license is completely encumbered, and one fewer block will be available in those markets.*

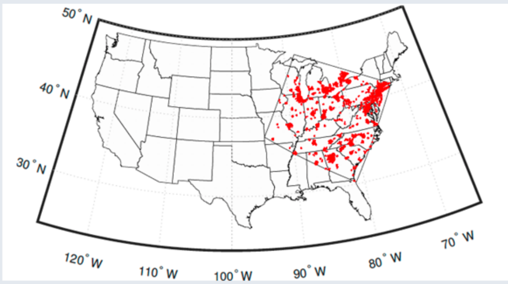


- AMR uses 23.6 – 24.0 GHz spectrum allocated for passive use
- Concern:
  - Emission becomes bright enough to pass through AMR filter and corrupt path delay measurement

Interference Simulation Studies

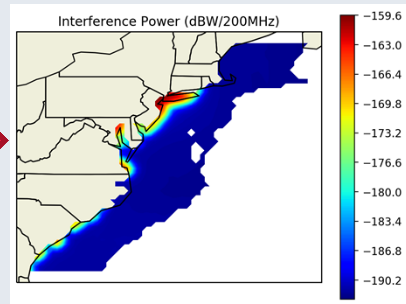


- Coordinated with NASA spectrum office
- The assumptions in the simulation study is now public document (see attachment 3 & 4 of the link).
  - https://science.house.gov/letter-to-fcc-chairman-pai-requesting-any-technical-analysis-that-the-fcc-has-conducted-or-reviewed-on-out-of-band-emissions-limits?peek=Fq%2B4XM1Po3mfjiu9tcH5x5gC042pAMMK7QoPD%2Ff5dYy60Lk%2B



5G Interference Model

Interference

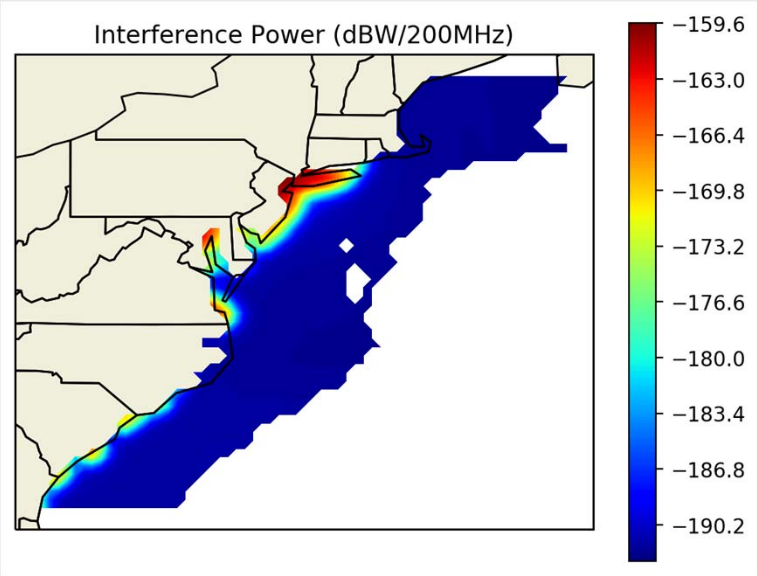


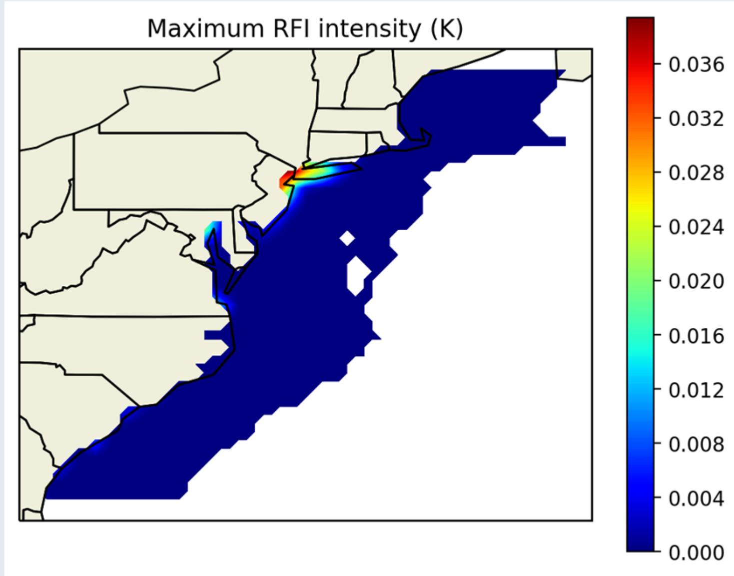
Inputs to the model:

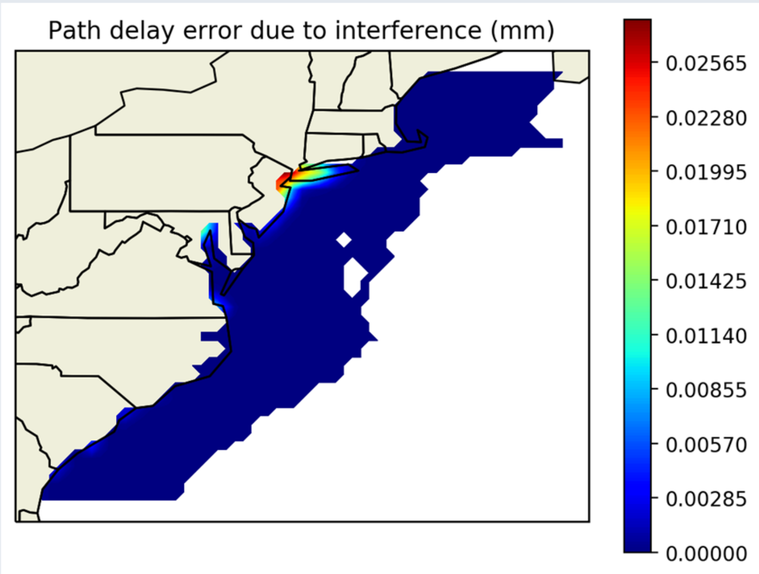
- Base stations and user equipment deployments
- Satellite AMR antenna pattern and orbital parameters
- AMR 24 GHz bandpass file
- Base station and user equipment parameters

Simulation studies conducted by:
Jacquelynne Houts & Mike Evans
NASA GRC

Base Station Interference

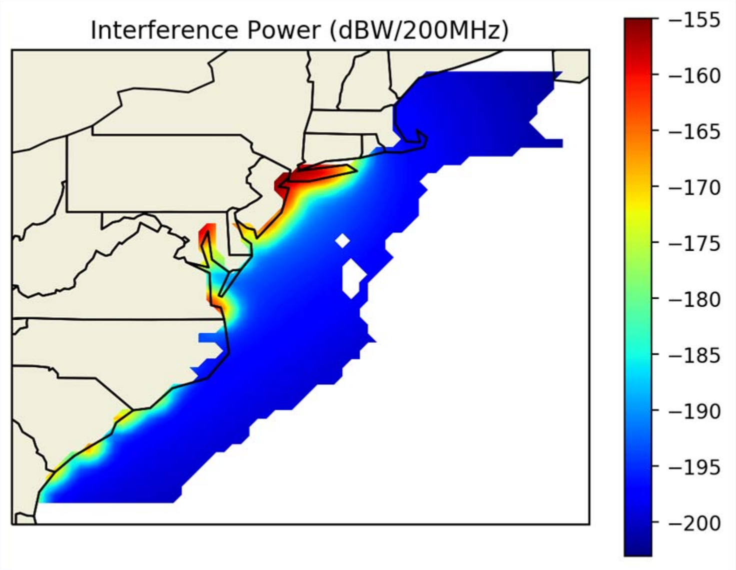


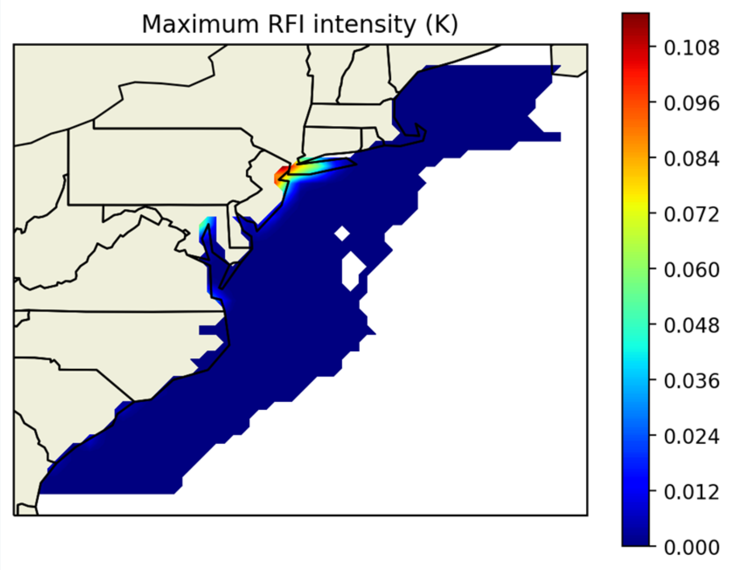


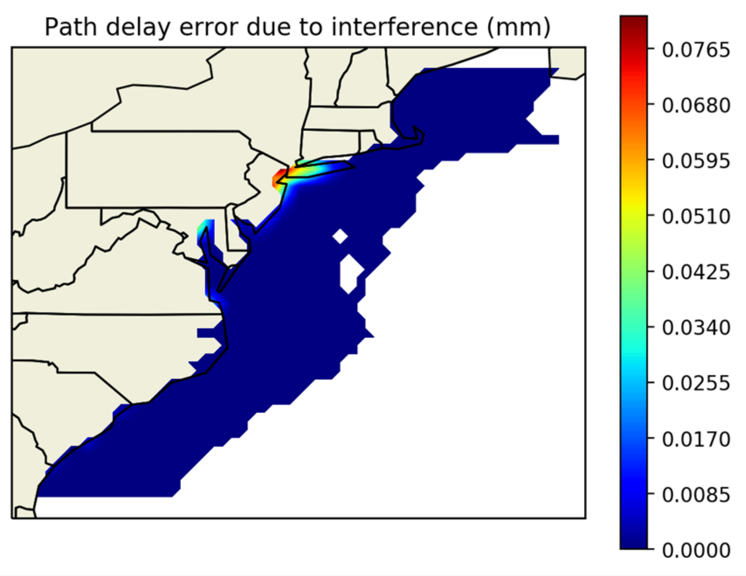


Parameters	Additional Interference error	Error Margin based on S6 CBE	Impact
Brightness Temperature	0.04 K	0.59 K	Minimal
Path Delay	0.03 mm	0.36 cm	Minimal

User Equipment Interference

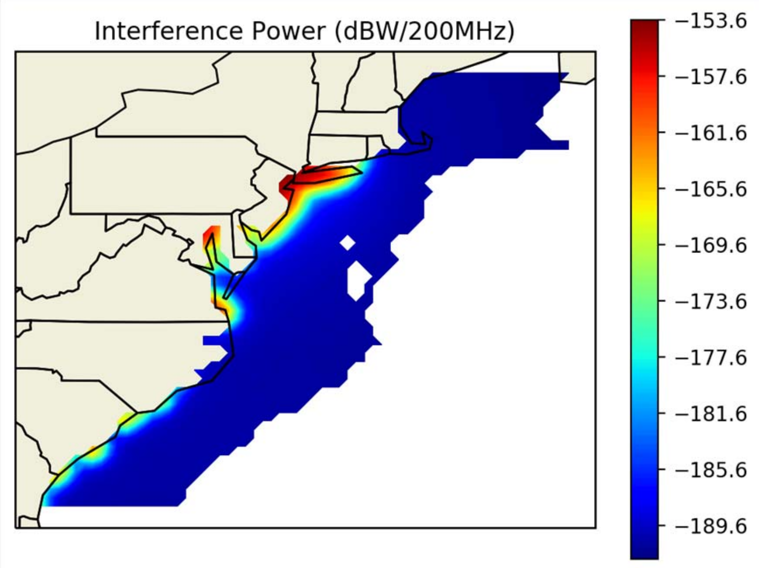


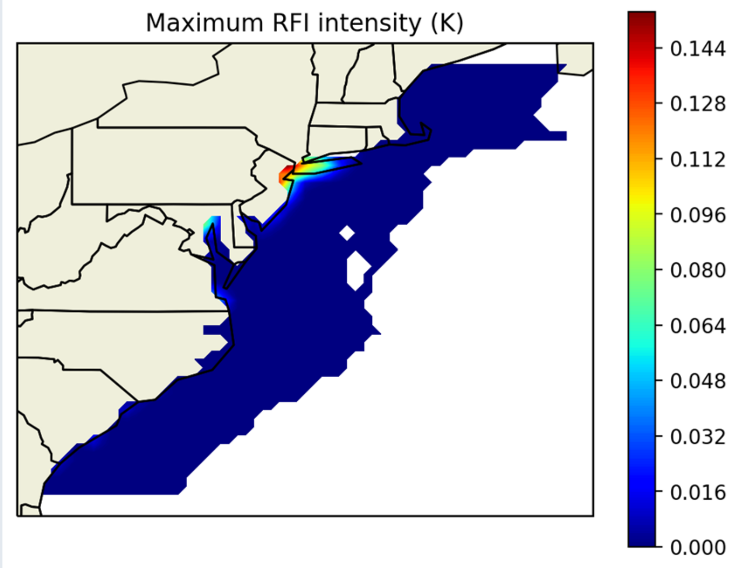


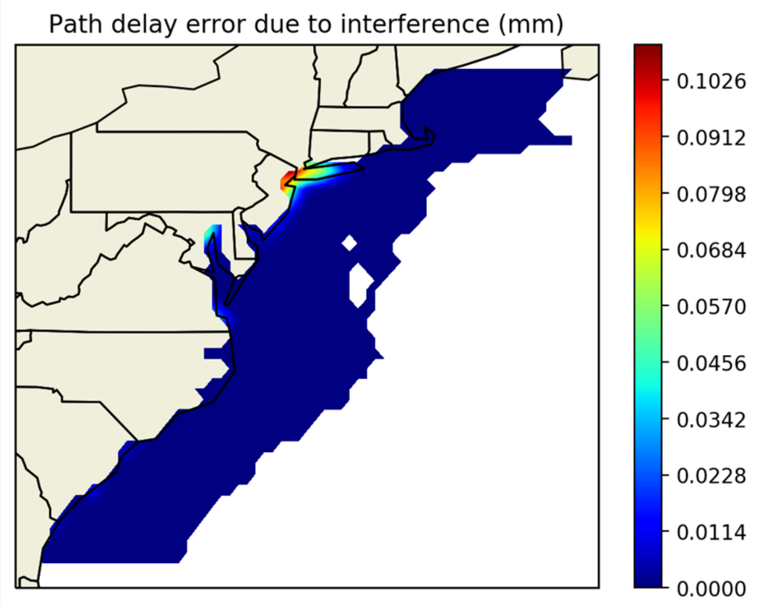


Parameters	Additional Interference error	Error Margin based on S6 CBE	Impact
Brightness Temperature	0.19 K	0.59 K	Minimal
Path Delay	0.13 mm	0.36 cm	Minimal

Total Interference (UE + Base)

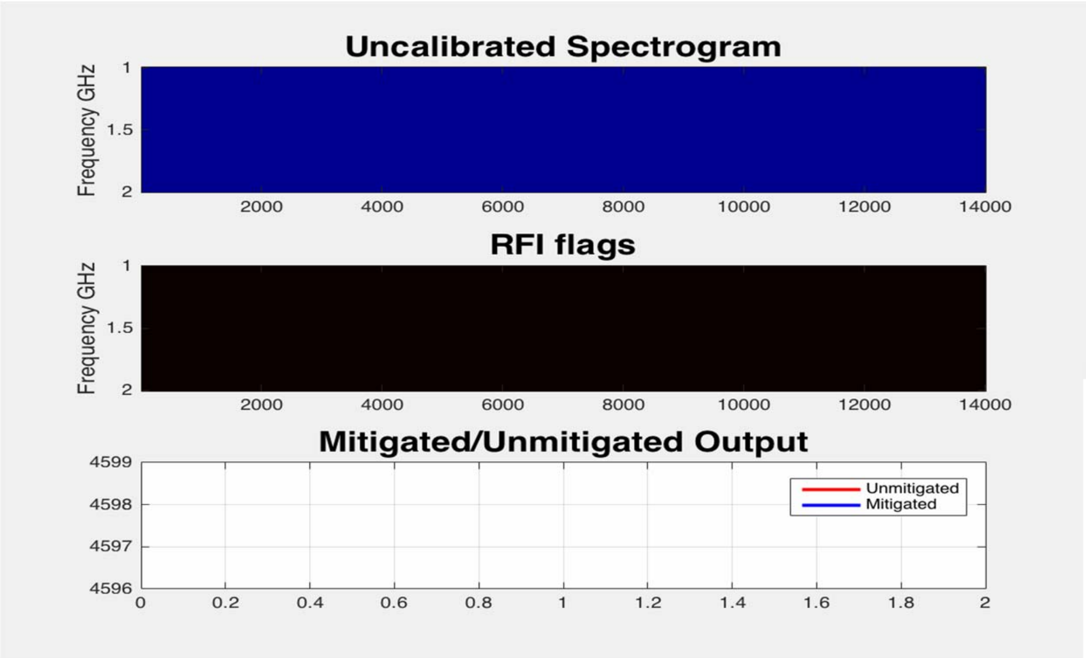






Parameters	Additional Interference error	Error Margin based on S6 CBE	Impact
Brightness Temperature	0.22 K	0.59 K	Minimal
Path Delay	0.16 mm	0.36 cm	Minimal

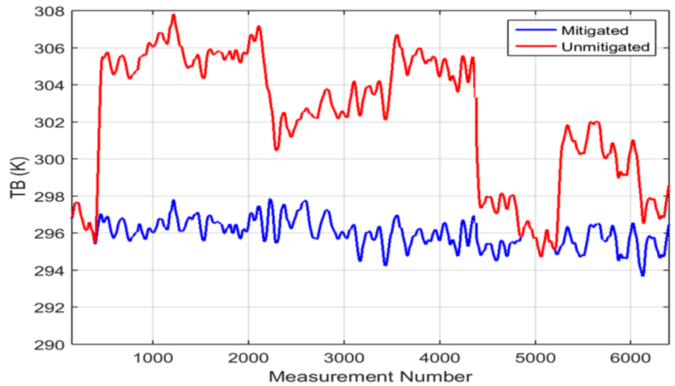
CubeRRT On-board RFI Filtering



Power: < 9W

Weight ~ 170gms

Data-Volume Reduction: > 80%

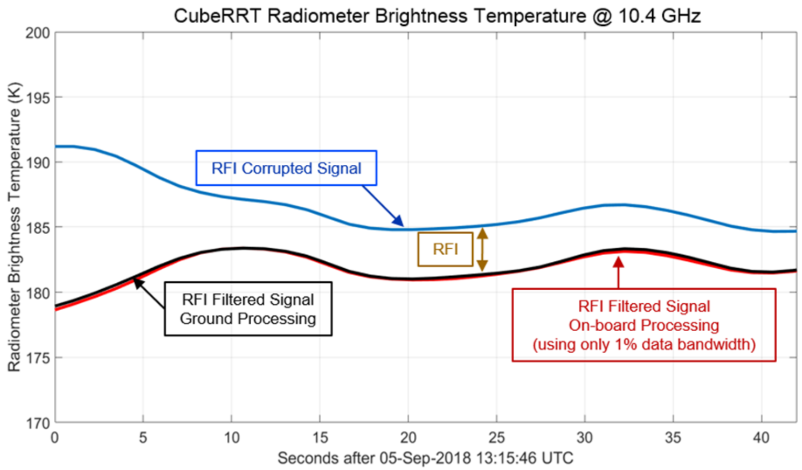


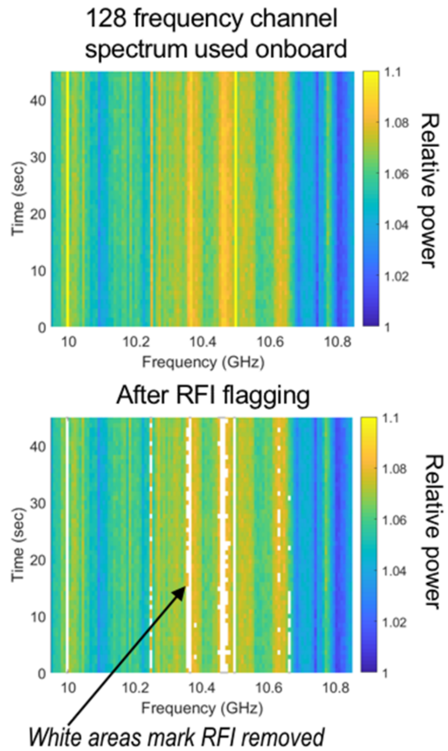
- CubeRRT mitigates RFI down to ~ 2 NEDT level

CubeRRT PI: Joel Johnson, Ohio State University

CubeRRT On-Board Detection!

10 minute data collect
over Pacific ocean
9/5/18
13:15-13:25Z





Smoothed CubeRRT radiometer brightness temperatures demonstrate on-board RFI filtering: original RFI corrupted signal (blue) corrected on-orbit to RFI filtered signal (red) that is validated with ground processed data (black). On-board filtering ***requires 99% less data to be downlinked.***

Mitigations

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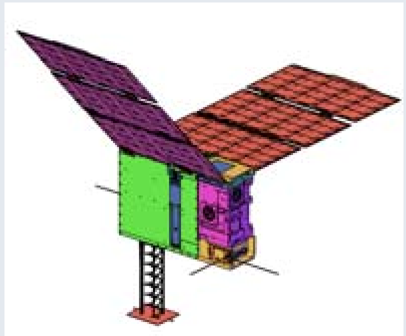
- (1) Future altimetry missions should add RFI filtering spectrometer to 24 GHz channel
    - RFI mitigation hardware technology demonstrated on NASA CubeRRT mission
    - May not be practical for S6A/SWOT
    - Studies/implementations should be an important consideration for future missions



CubeRRT RFI mitigation demonstration CubeSat (2018)

- (2) RFI detection/filtering algorithms should be developed and implemented in the ground software
    - RFI detection/flagging algorithm
    - 2-frequency PD algorithms (use 18+34 GHz & ancillary model data)
    - Evaluate use of ground assets (i.e. UPorto GPD+ algorithm)

Summary

- Sentinel-6A and B are meeting all necessary path delay requirements.
- New active/passive retrieval algorithm seamlessly integrates the altimeter and radiometer measurements to produce improved retrieval products.
- 24 GHz RFI could be an issue in future.
- Future altimetry missions should add RFI filtering spectrometer to 24 GHz channel (e.g. RFI mitigation hardware technology demonstrated on NASA CubeRRT mission).
- Robust RFI mitigation algorithm has to be implemented in the ground software system.

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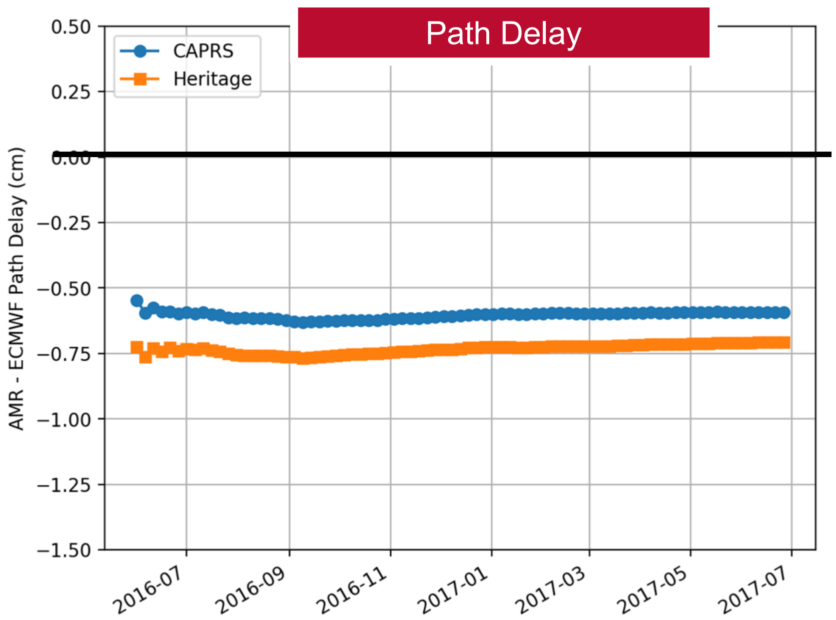
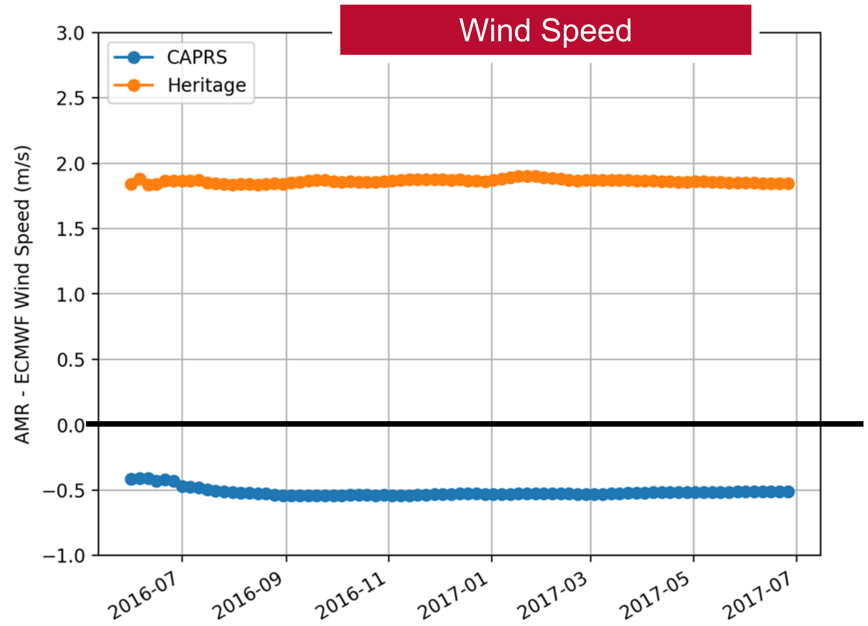
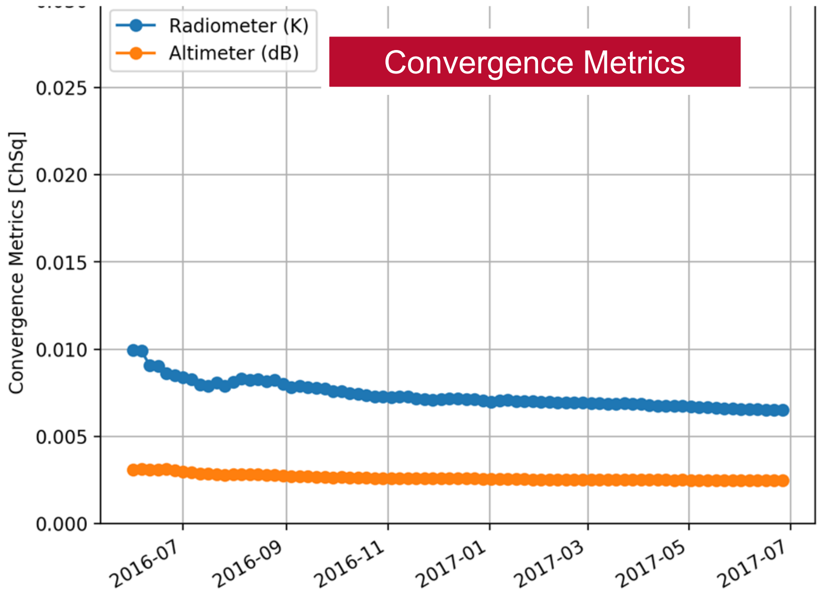
Backup slides

Performance Assessment: Time Series Trend



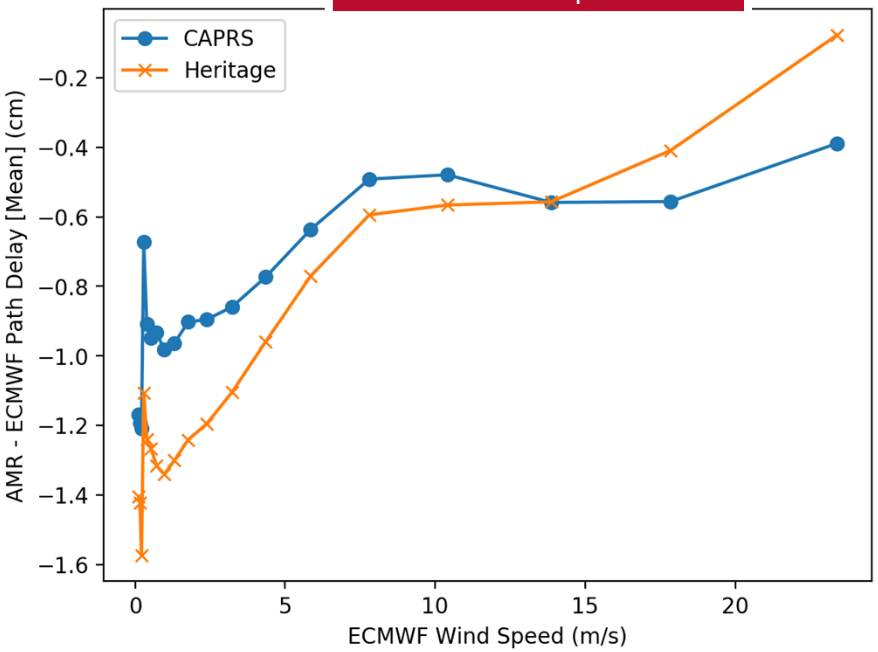




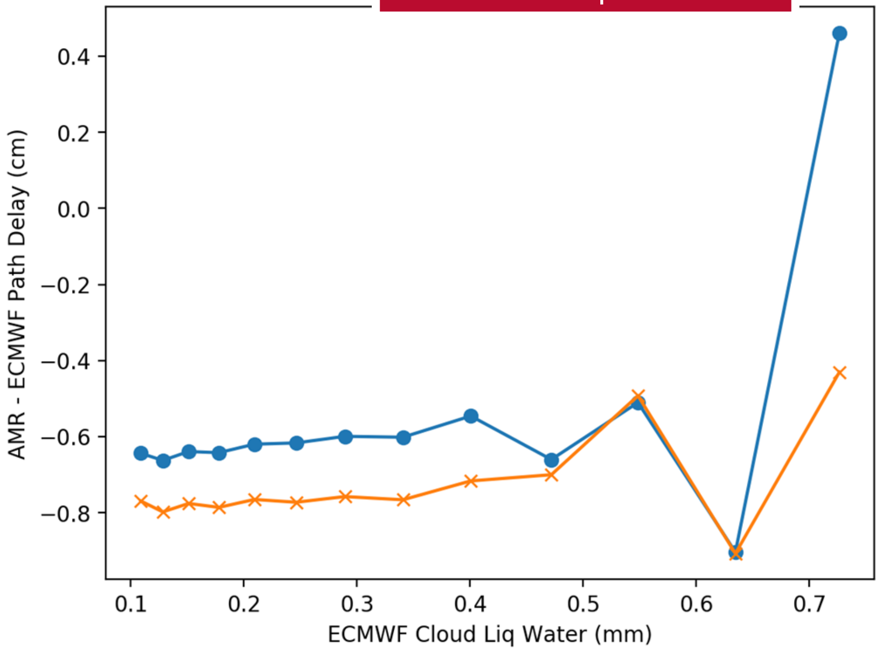
- Bias is significantly reduced in the new algorithm
- Long-term trend is not affected (no drift)
- Stable convergence metrics
- Convergence metrics can also be used for instrument status and quality monitoring

CAPRS Improvement

vs Wind Speed



vs Cloud Liquid Water



- Path delay improved as a function of wind speed (<15 m/s)
- Path delay improved as a function of cloud liquid water