High Resolution Microwave Radiometer (HRMR) on Sentinel-6

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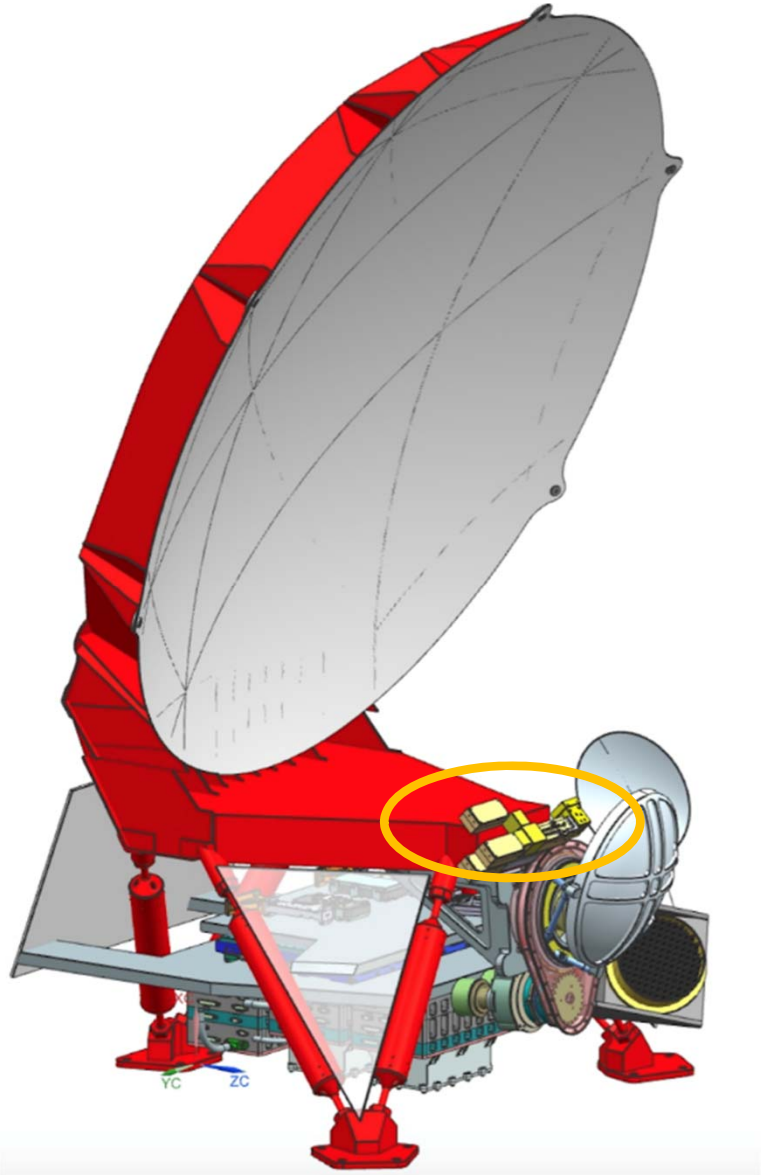
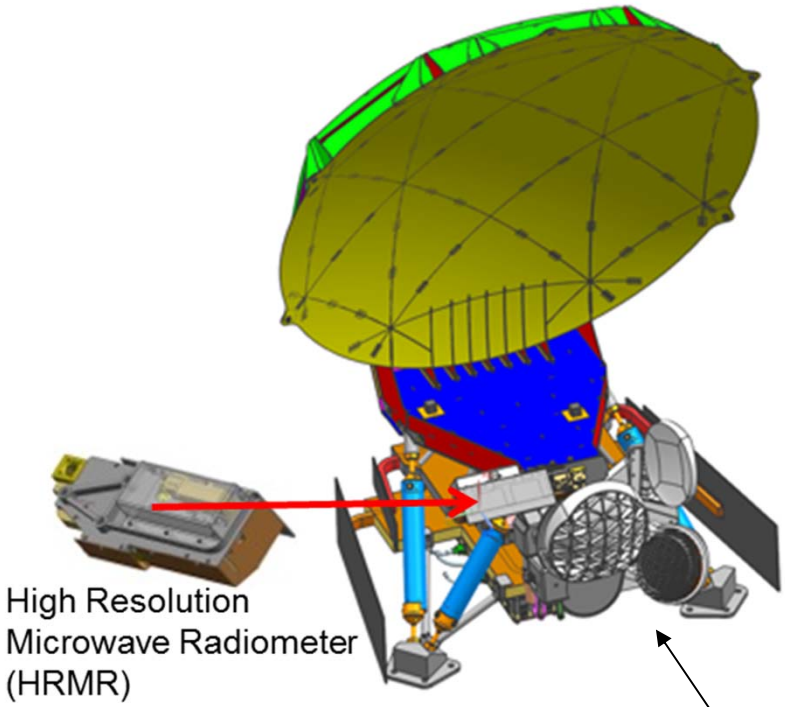
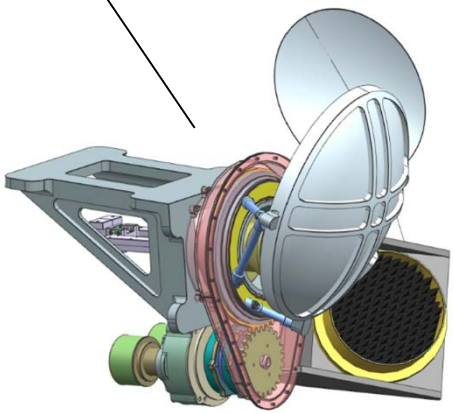


Sentinel-6 AMR-C

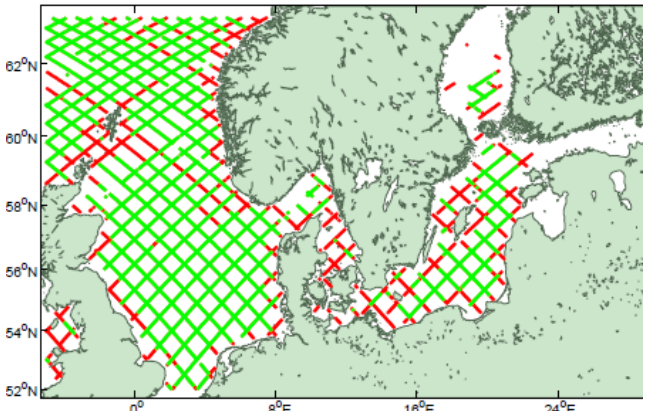


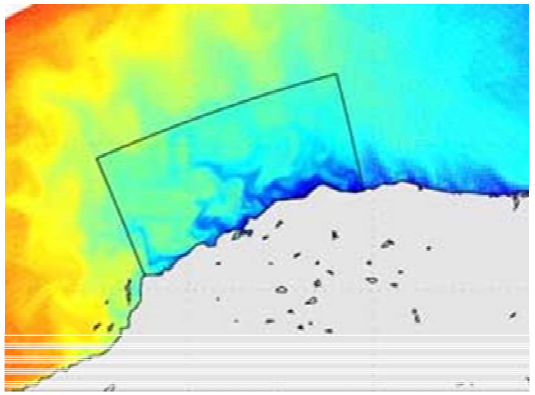
- **Sentinel-6 AMR-C includes two new design features based on OSTST recommendations**
  - External calibration system for long term stability
  - High Resolution Microwave Radiometer for coastal PD – *experimental*



Introduction

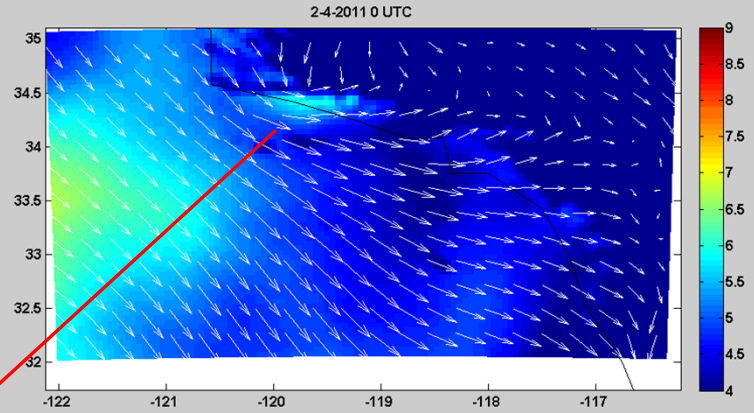
- The next generation of altimeter measurement systems, such as Sentinel-6, feature high resolution along-track altimetric observations from Synthetic Aperture Radar (SAR) mode
- This enables new science applications in the coastal region, including estuaries and over inland water bodies such as lakes and rivers
  - e.g. coastal currents
- Heritage low-frequency radiometer systems are not able to provide valid wet tropospheric path delay correction do not provide valid retrievals close to the coast or over land
- High-frequency radiometers offer the potential to fill this measurement gap and improve altimetric observations in the coastal and inland regions
- HRMR is an experimental payload to demonstrate this new capability

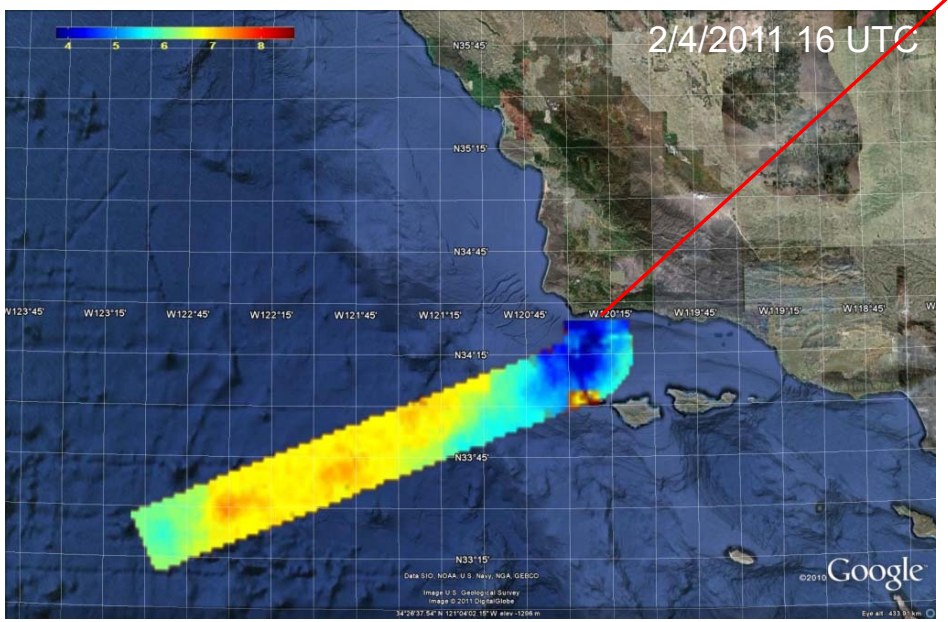


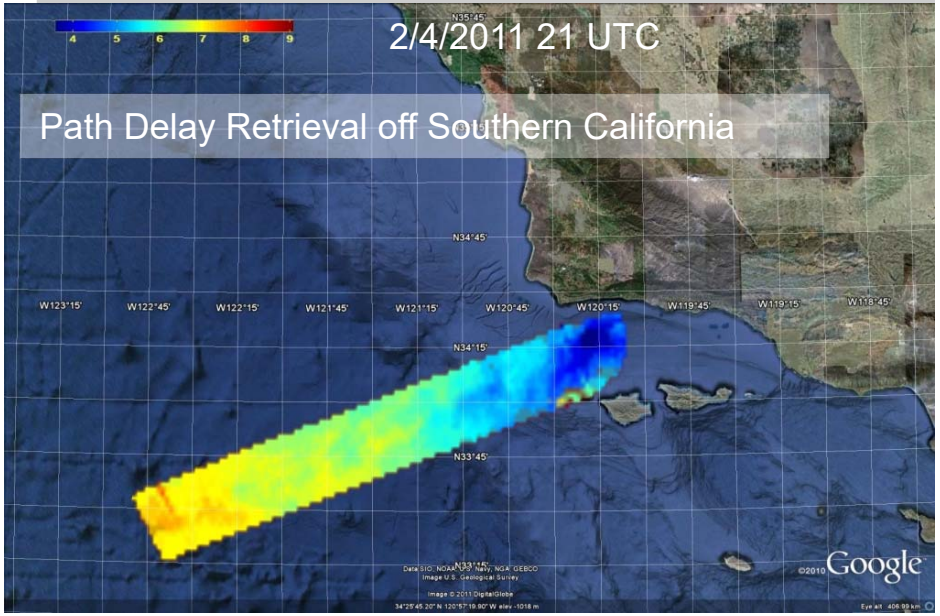


Example: Off-shore Winds

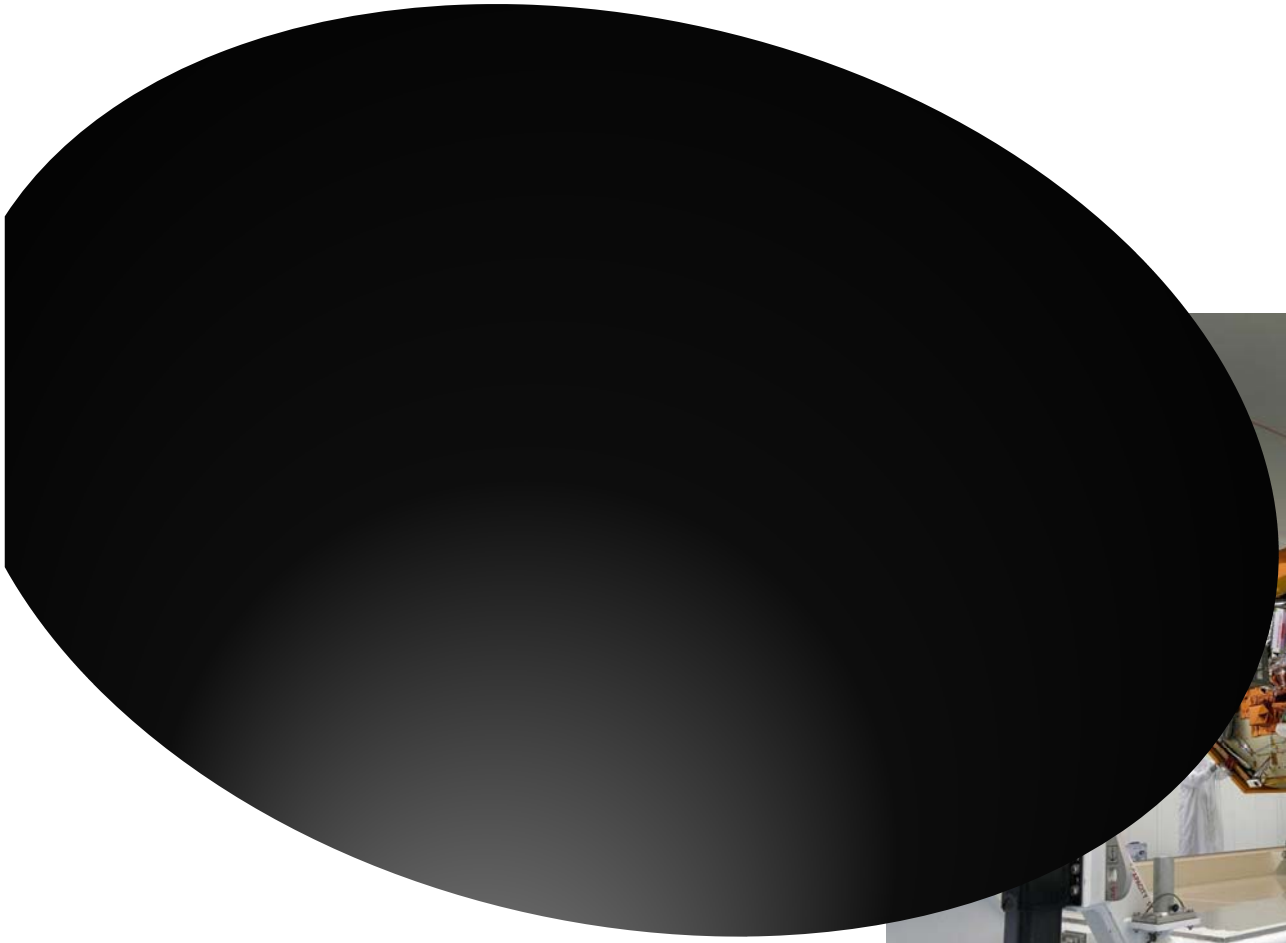
- **Certain areas can result in large systematic biases**
- **Example of Santa Ana winds off California coast**
  - **~3-4 cm bias at the coast**

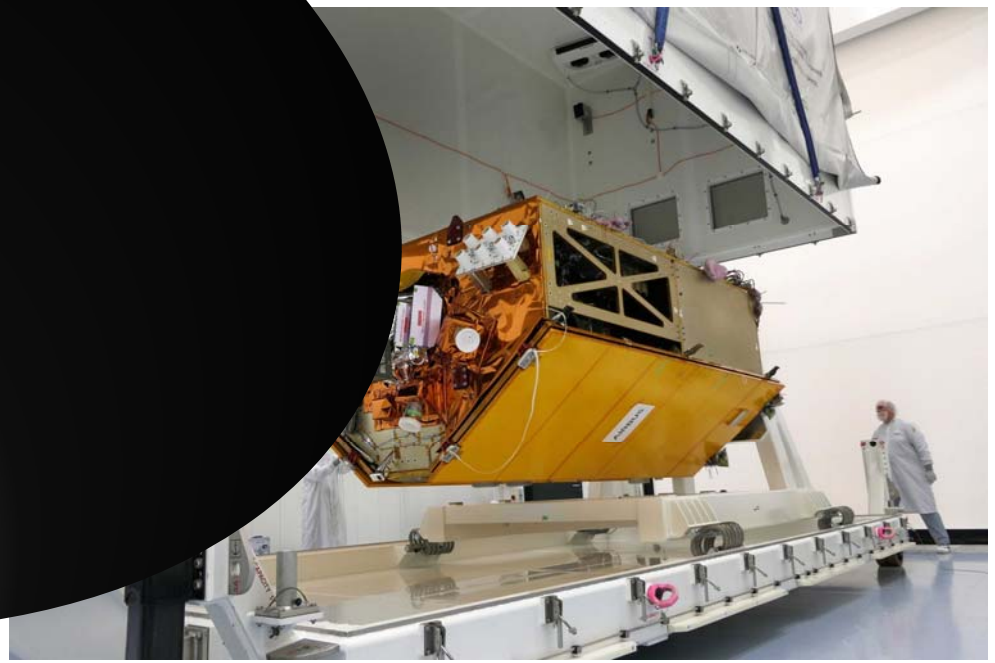






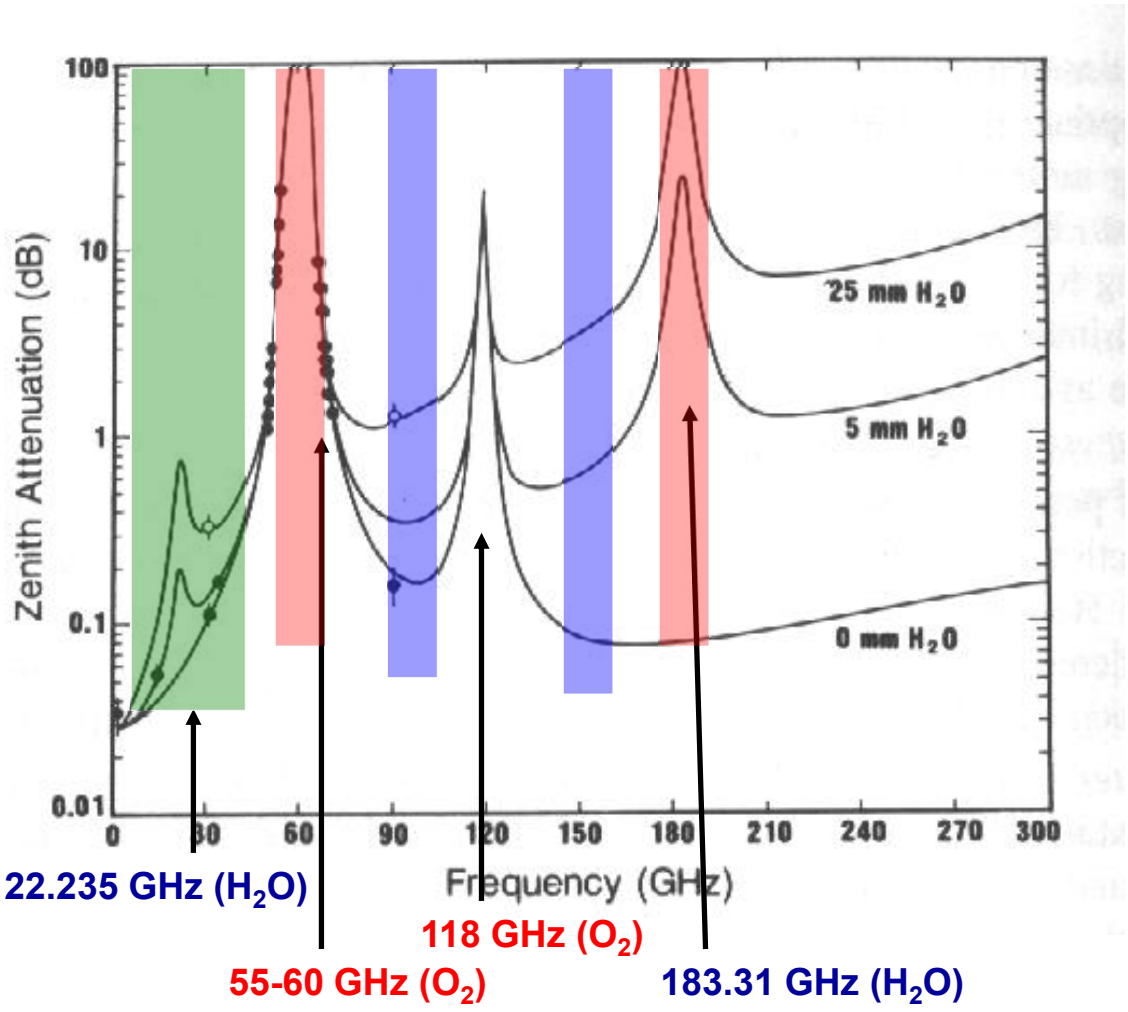
Achieving 5km resolution (?)





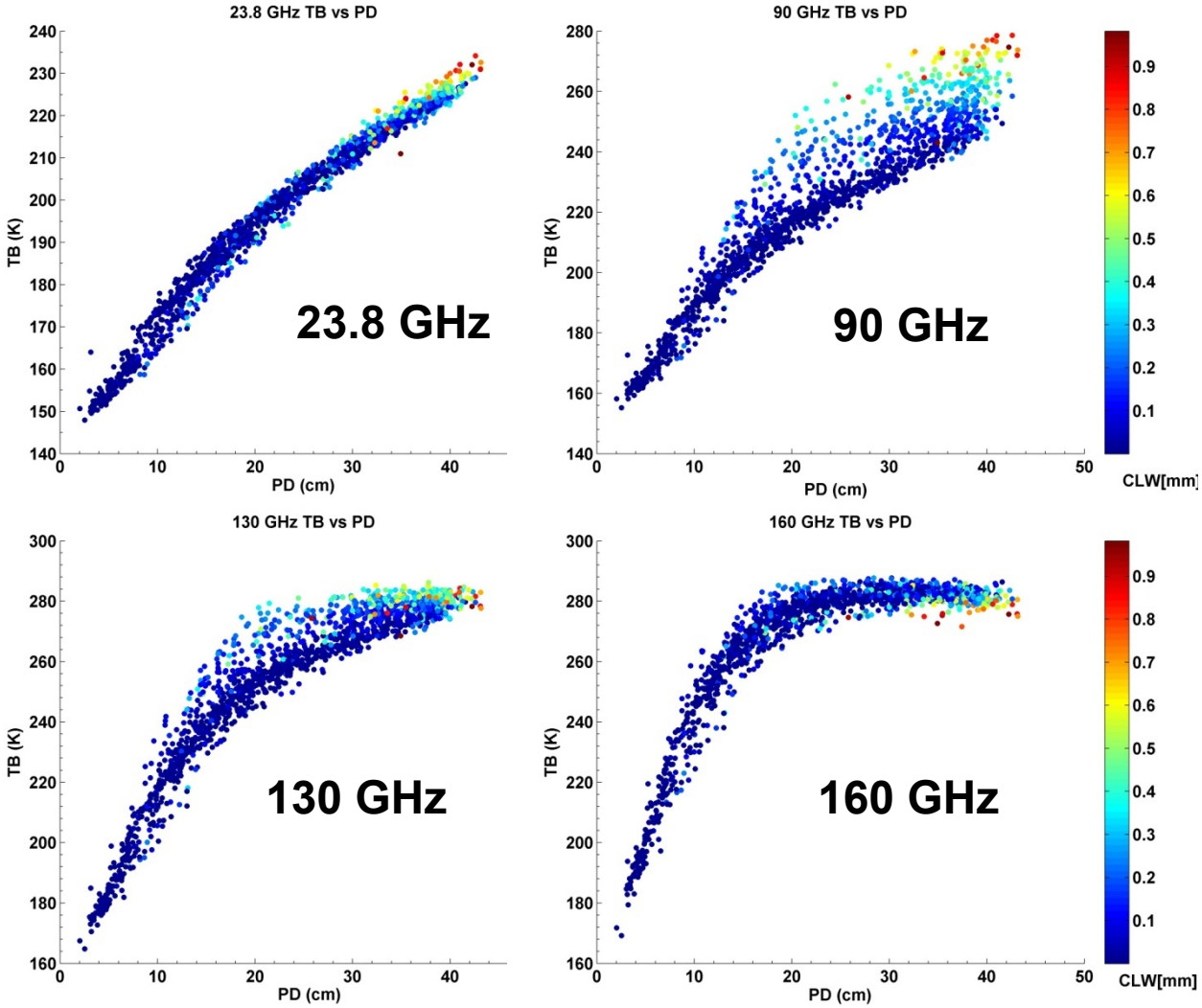
Move to Higher Frequency

- For a given antenna aperture, the spatial resolution scales with frequency
- High-frequency window channels sensitive to water vapor continuum

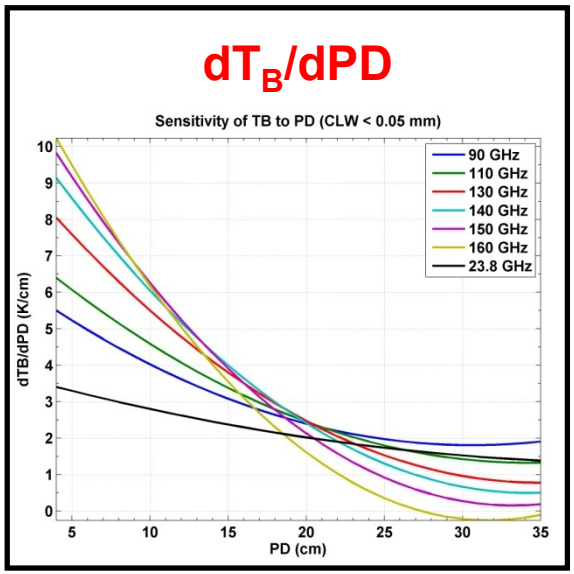


Window Channel Sensitivity to PD

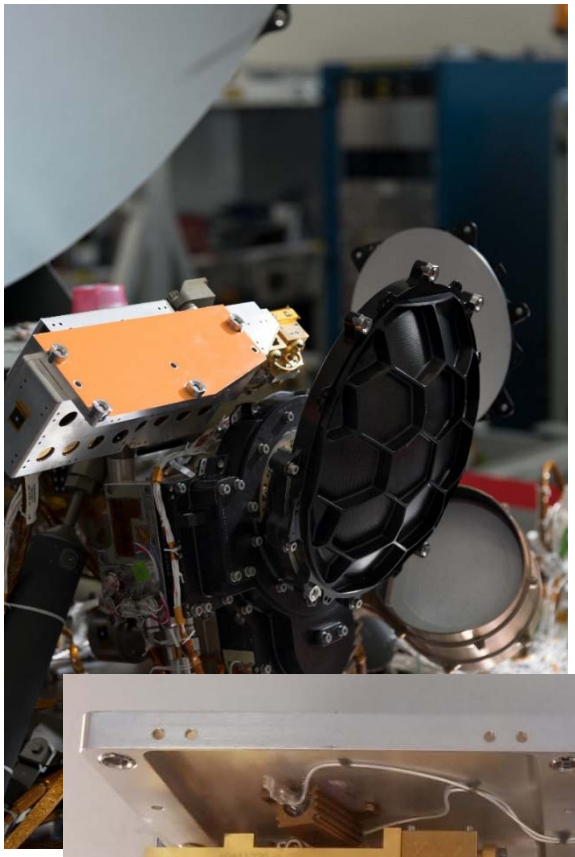
Modeled Brightness Temperature to PD and CLW



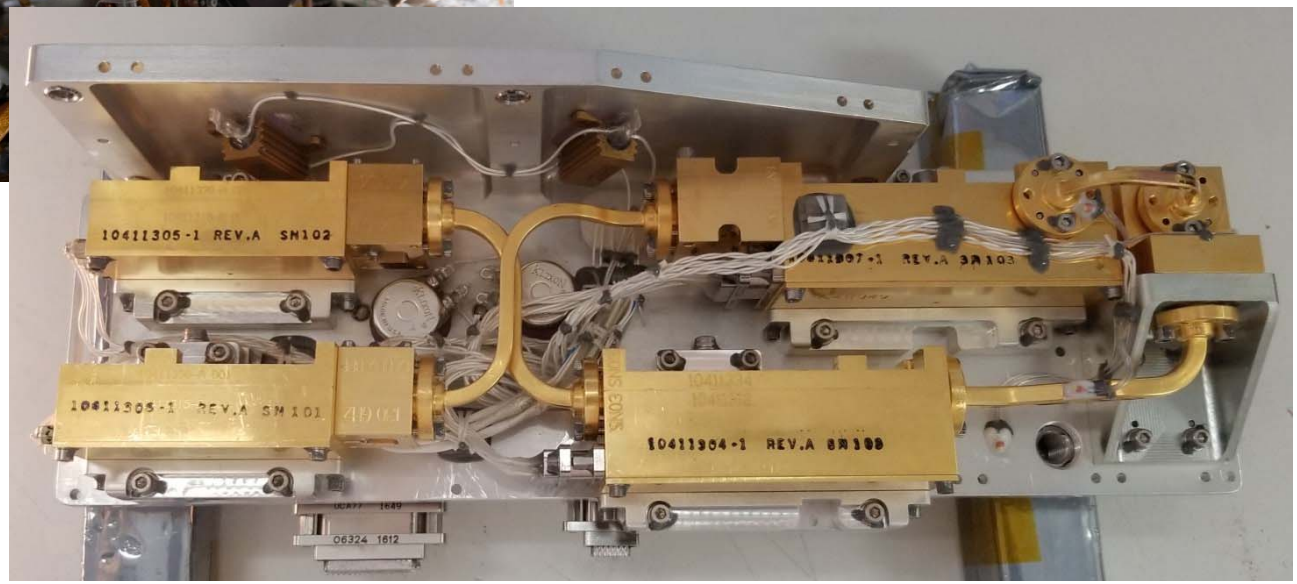
- 90 GHz T_B ~8x more sensitive to CLW than 23.8 GHz T_B
- Sensitivity to high PD decreases with frequency



High Resolution Microwave Radiometer

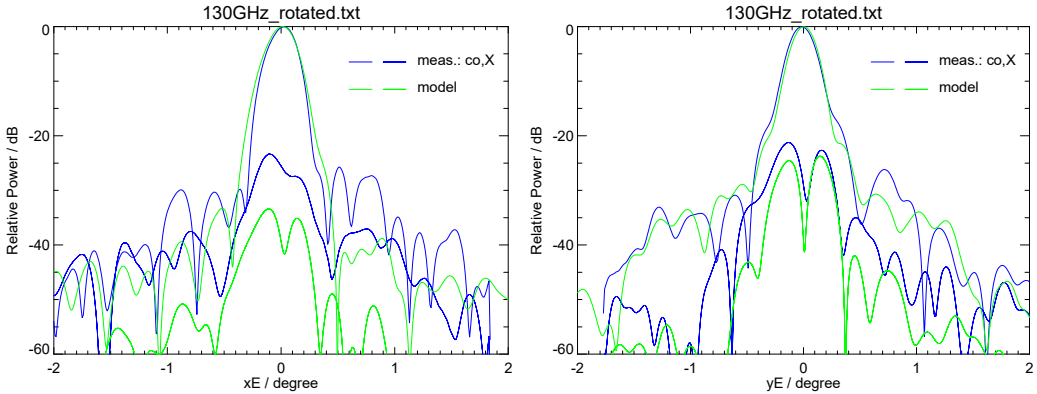


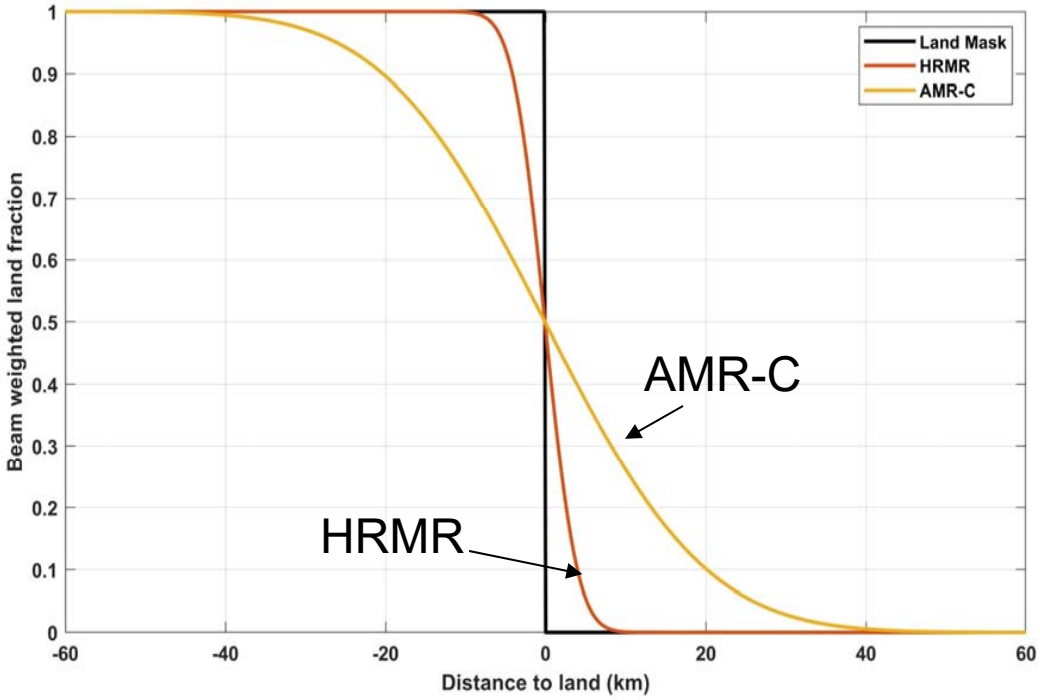
- 3-frequencies at 90, 130 and 166 GHz
- Co-located footprints with a spatial resolution of 4-7km
- Noise diode and switch to reference load for calibration
  - 0.2K TB uncertainty

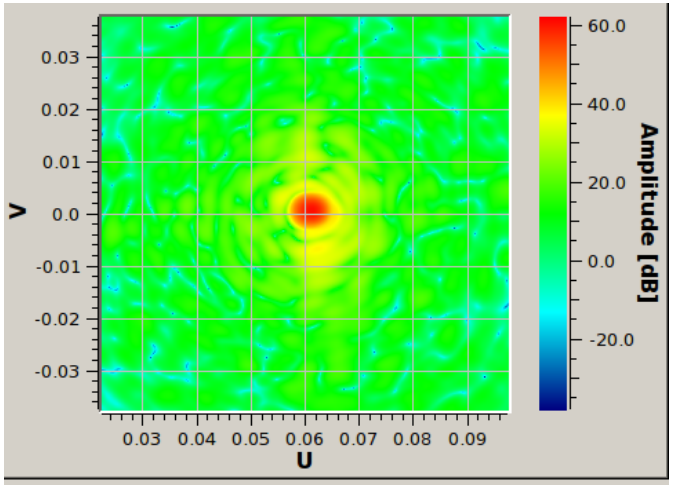


Pre-launch Antenna Pattern Measurements

Frequency	BW (degrees)	Footprint (km)
90	0.32	7.2
130	0.22	5.3
168	0.18	4.3



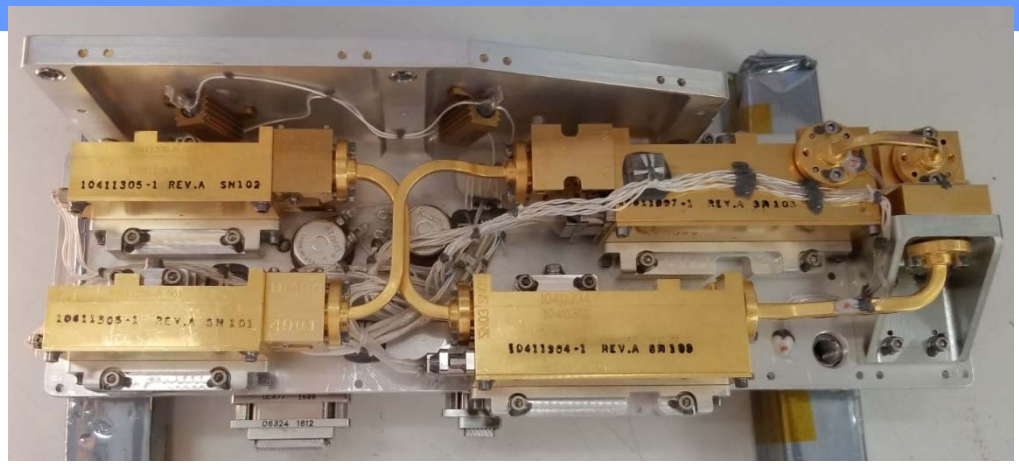




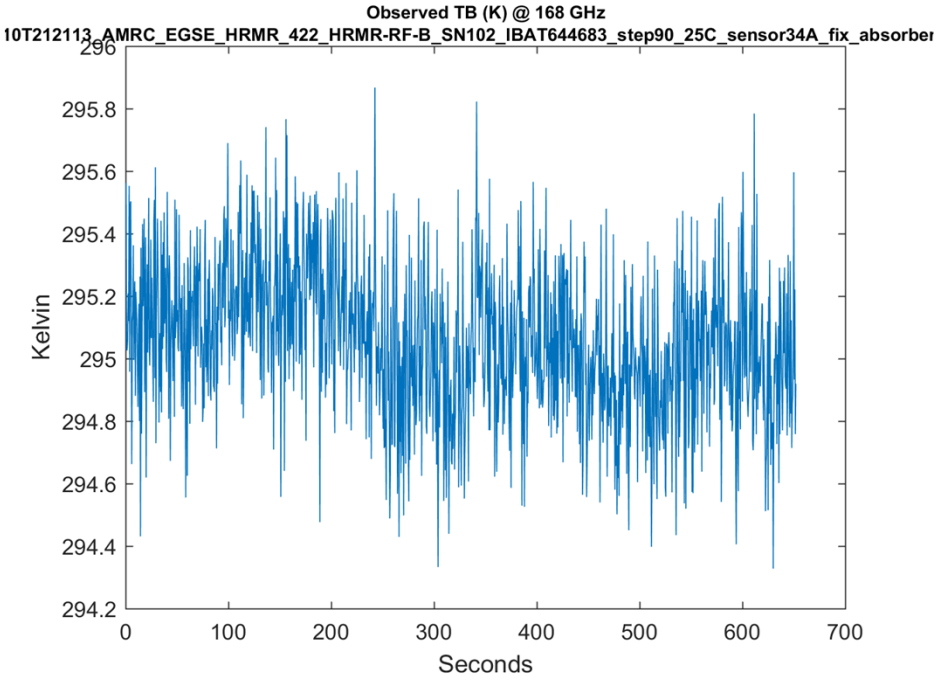
Pre-launch Receiver Testing

- To meet 1cm path delay target, radiometer sensitivity need to be 0.2K

- Pre-launch testing verified sensitivity over thermal conditions

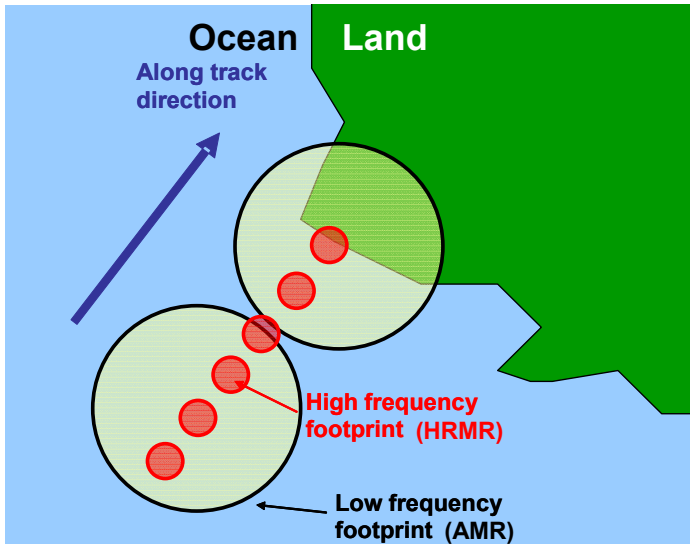


Frequency	Goal	HRMR Sensitivity
90	0.2 K	0.05 K
130		0.12 K
168		0.17 K



HRMR Day 1 Algorithm

- Channels between 90-160 GHz sensitive to water vapor continuum
- Also more sensitive to cloud liquid water and water vapor scale height
- Hybrid concept developed to use high-frequency channels near land with a dynamically trained retrieval algorithm – referenced to AMR low frequency channels



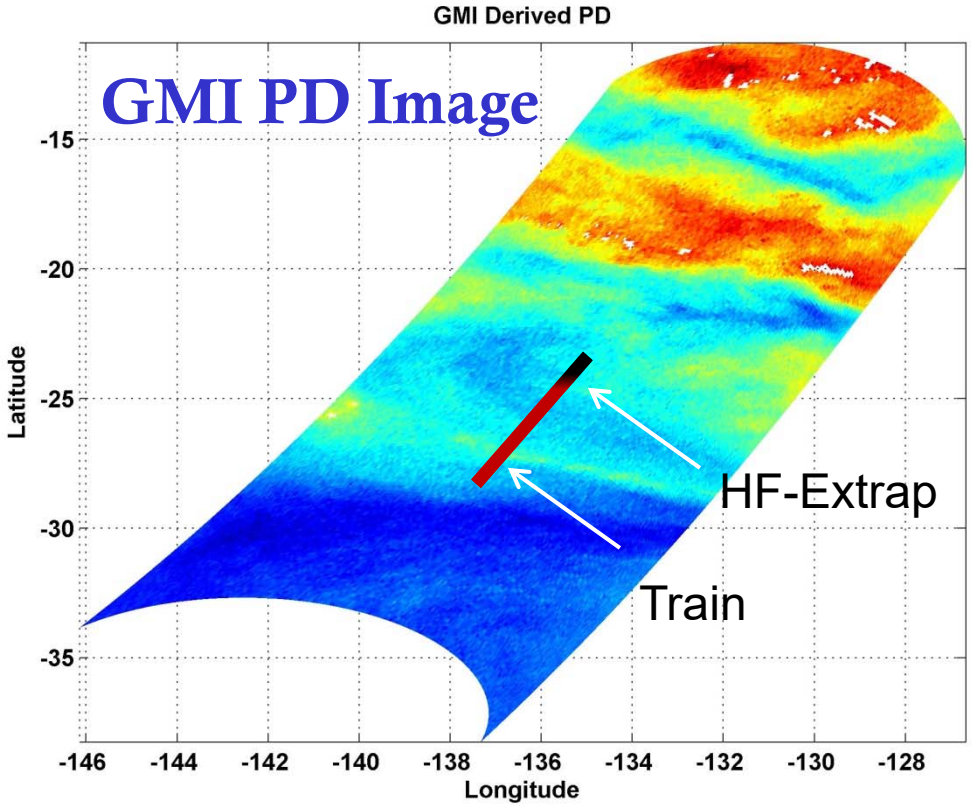
- Standard low-frequency channels (18-34 GHz) used for PD retrieval in open ocean (> 30 km from land)
- High-frequency window channels, 90, 130 and 166 GHz used to continue PD measurement to ~5km from land using a prior information from nearest LF PD

$$PD_{HF} = c_o + \sum_{i=1}^{N_f} c_i T_{Bi}$$

Testing Algorithm with Satellite Data

- The Global Precipitation Measurement Microwave Imager (GMI) has 18.7-37 GHz channels and also a high resolution 90 GHz channel
- GMI data used to evaluate algorithm performance in real atmospheres
- Path delay computed from GMI low-frequency (18-37 GHz) channels
- High-frequency (HF) coastal extrapolation algorithm applied to 90 GHz channel

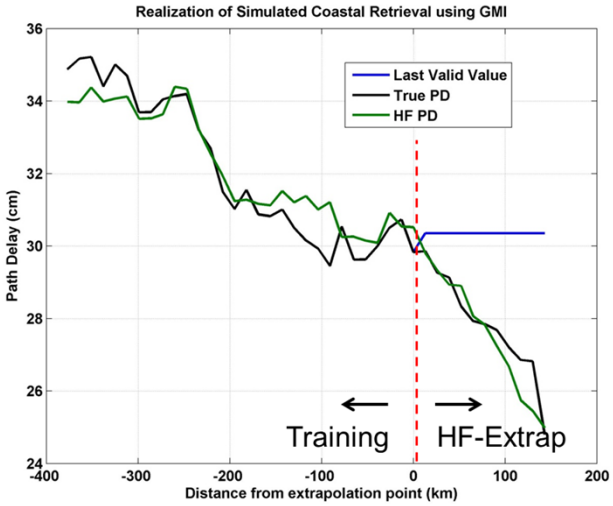
- 500 km segments extracted and used to evaluate algorithm
  - 400 km used to dynamically train HF algorithm
  - HF algorithm then applied to last 100 km and compared to low-frequency PD
  - Data filtered for highly variable clouds since only a single high frequency channel was used

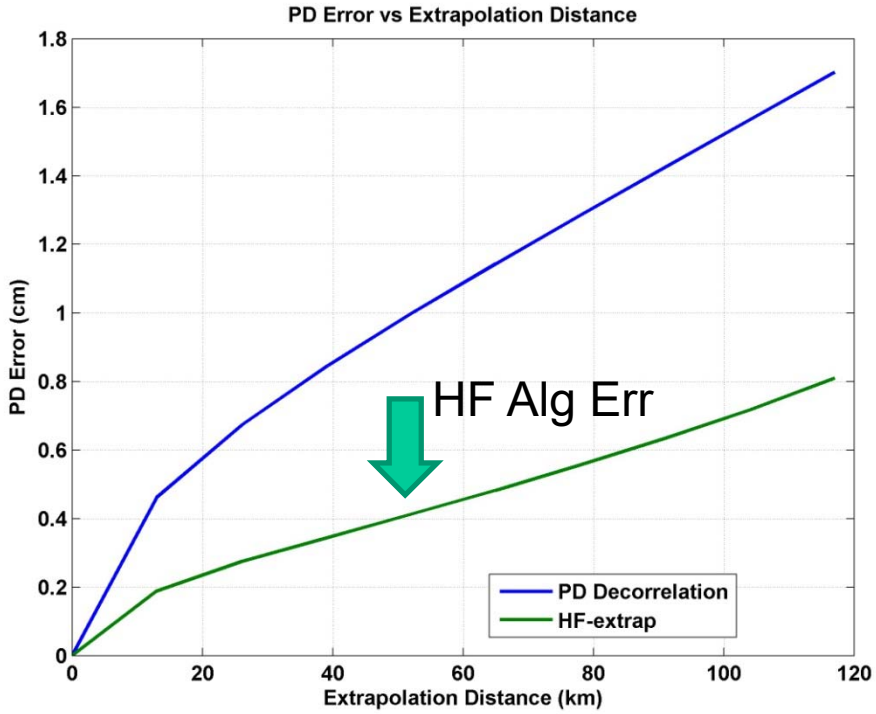


HF Algorithm Performance using GMI

- **Computed statistics for a large number of realizations, encompassing various atmospheric conditions**
- **HF algorithm shows significant reduction in PD variance (e.g. assuming constant PD value to the coast)**
- **Assuming a low-frequency radiometer that is contaminated at 50km from the coast, the HF algorithm reduces show 4mm uncertainty**

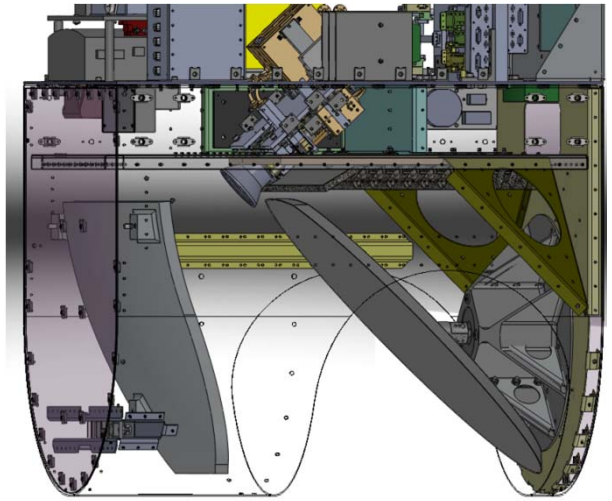
One Example Retrieval



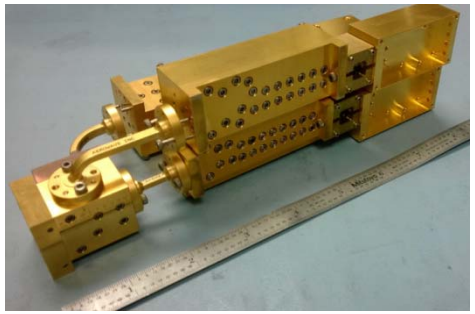


HAMMR Airborne Radiometer

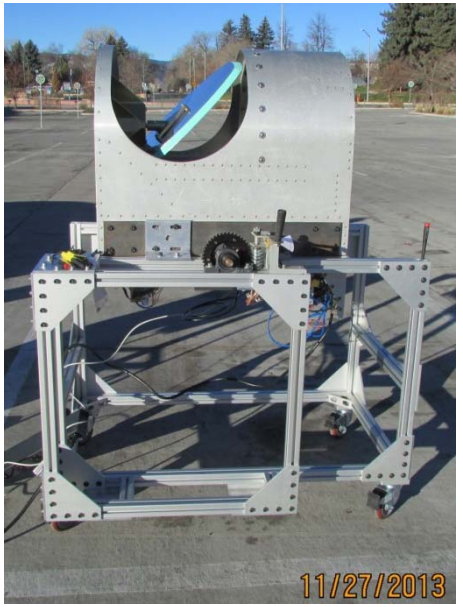
- **Multi-channel high resolution imaging radiometer for measuring PD over ocean, land and in coastal regions (PI – Steve Reising, CSU)**
  - Low-frequency microwave channels - *Identical to Jason AMR*
    - 18.7, 23.8 and 34.0 GHz (H and V)
  - **High-frequency mm-wave window channels *(coastal)***
    - **90, 130 and 166 GHz**
  - High-frequency mm-wave sounding channels *(over-land)*
    - ASIC analog spectrometer with 8 bands near 118 and 183 GHz
  - Cross track imaging, < 150m spatial resolution

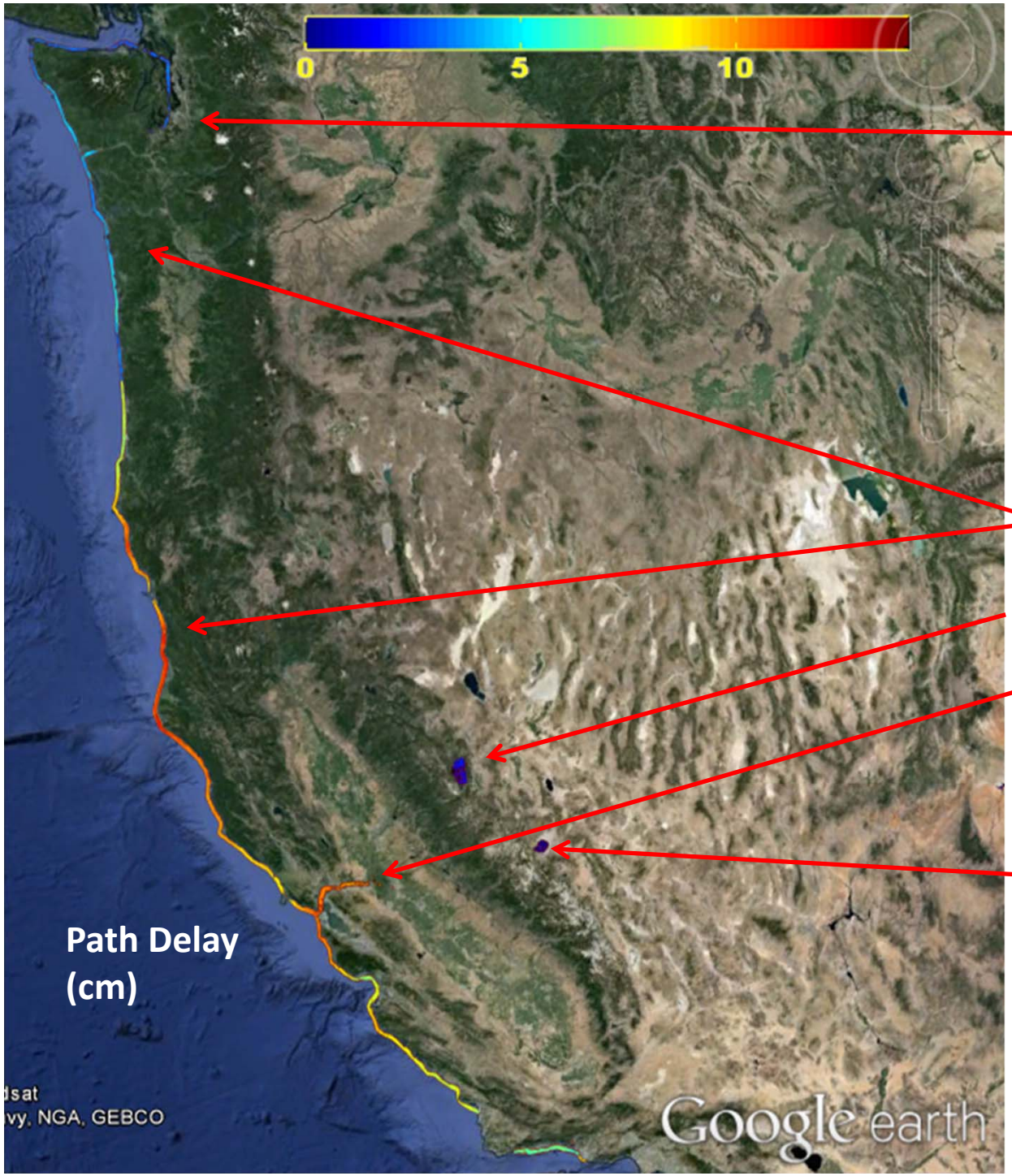


- **Science flights took place in November 2014**
  - Over open ocean and coastal regions to test **coastal wet path delay retrievals** and **evaluate PD spectrum**
  - Over large inland water bodies to test over-land wet path delay retrievals



HRMR prototype





Puget Sound

West Coast Field Campaign November 2014

Coastal Ocean

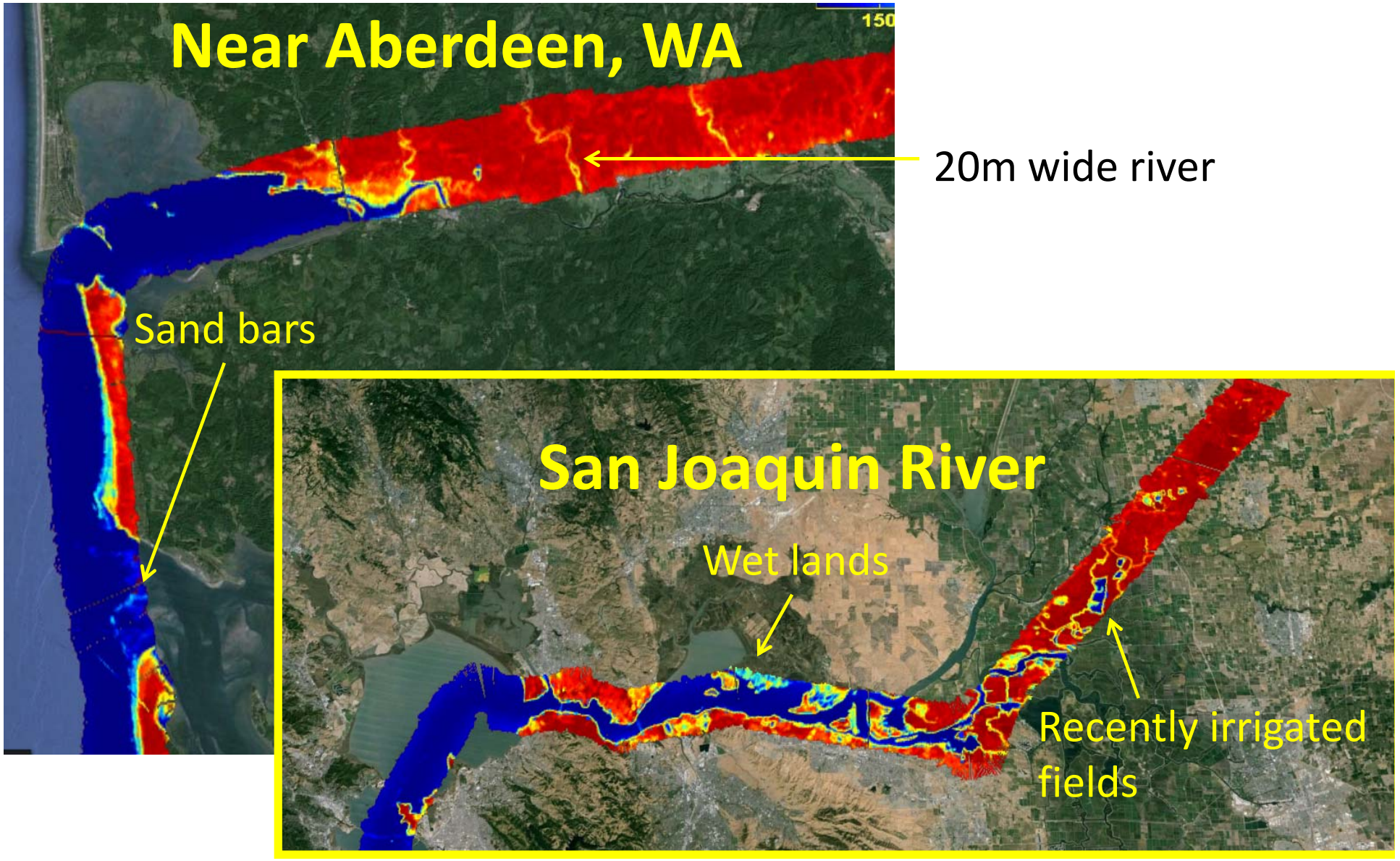
Lake Tahoe

San Joaquin River

Mono Lake

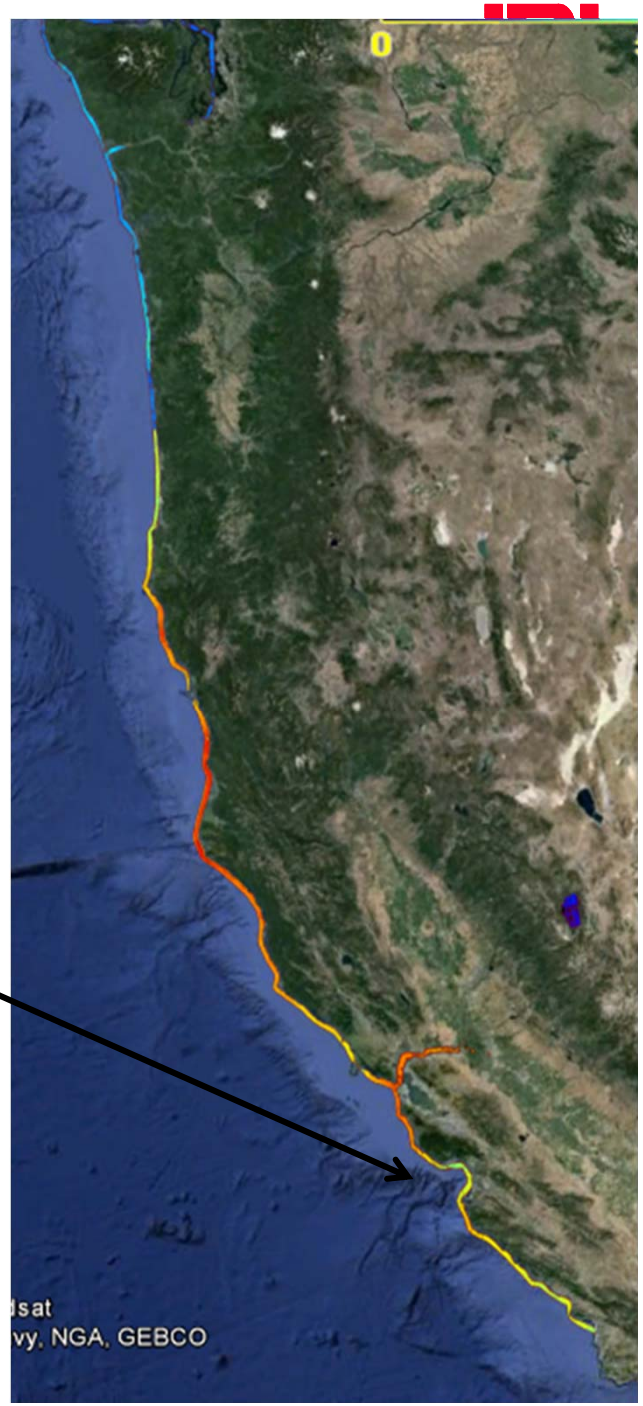
Observations at 150m spatial resolution

150m Spatial Resolution Images



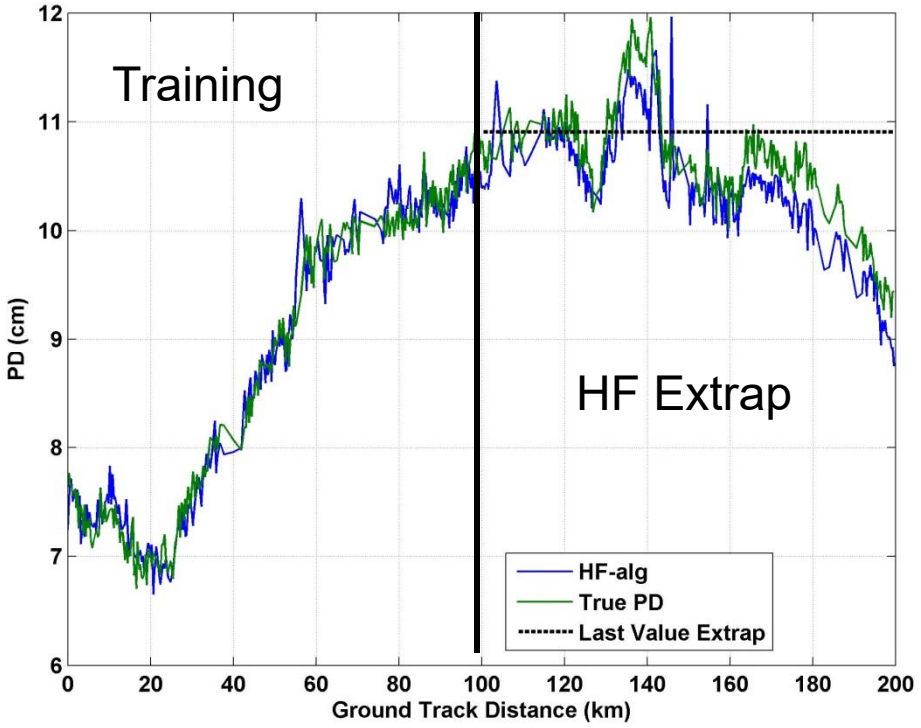
Coastal Data

- Data collected along entire US west coast over several days
- Flight rules dictated that the plane had to fly within 1 mile of shore
- Therefore, all data have land in part of the swath



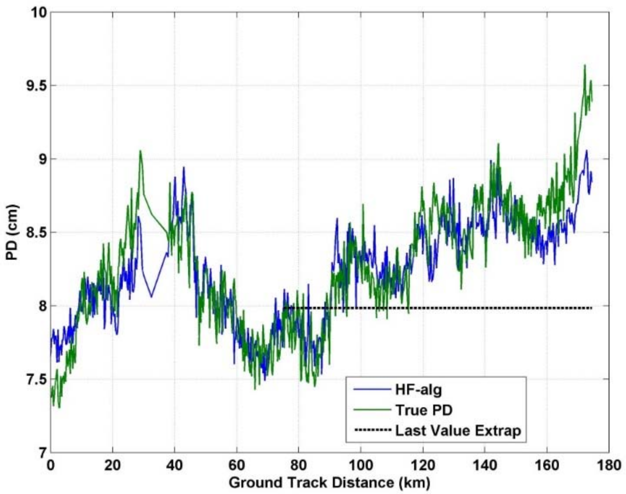
High Frequency Algorithm Testing with HAMMR

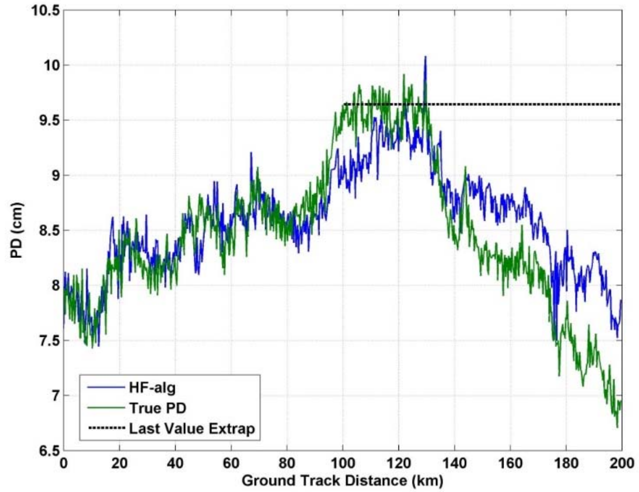
- First retrieved PD over the ocean using low-frequency 18-34 GHz channels
- Then, dynamically trained HF algorithm along track using 100km of along track data and evaluated performance over next 100km
- Evaluated performance by comparing to low-frequency "true" PD over next 100km

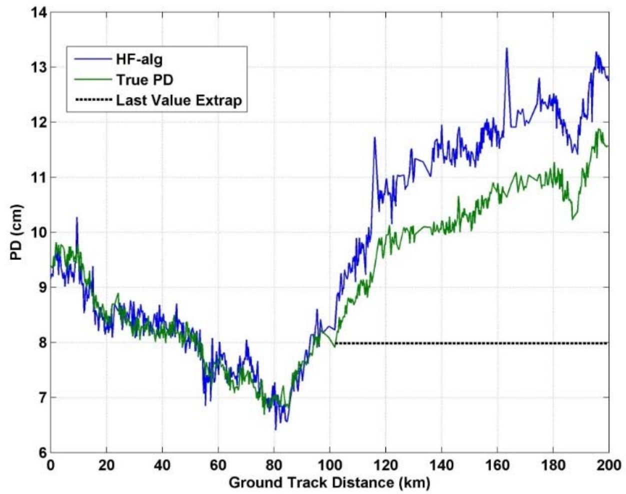


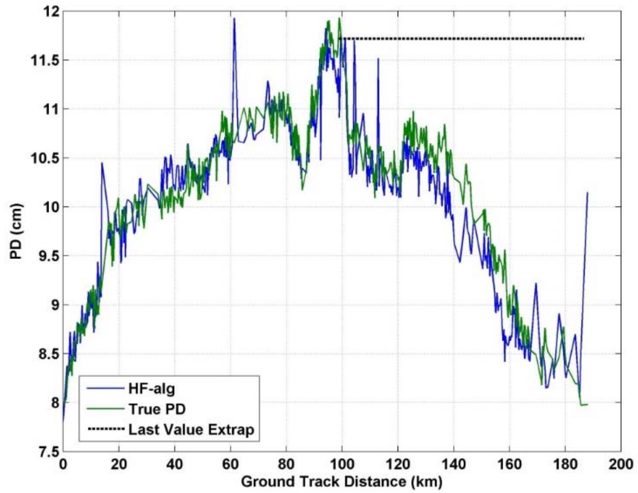
Last valid PD extrapolation

Testing with HAMMR Dataset





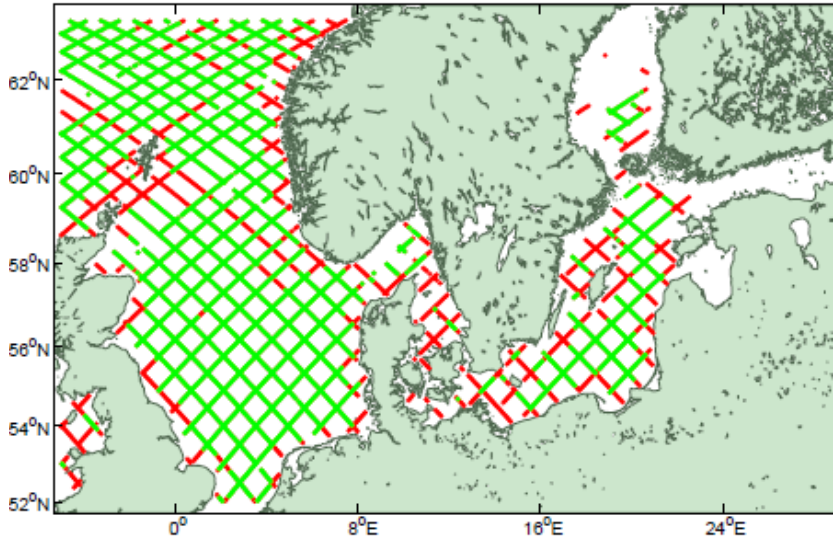




- **PD error as a function of extrapolation distance computed for both HF algorithm and for using last valid PD value**
- **Error for all cases estimated to be 0.6cm up to ~5km from land**

Post-Launch Plans

- HRMR is classified as an experimental radiometer
- Data are not included in radiometer Level 2 product at launch
- During cal/val phase, radiometer will be calibrated and algorithms tested
- Evaluation product will be produced after cal/val period
- Eventually, HRMR data will be integrated into normal radiometer L2 product



Summary and Conclusions

- Sentinel-6 will include an exciting new high resolution microwave radiometer for coastal wet path delay estimation

- Simulations, validated by satellite and airborne data shown open-ocean like performance possible (PD error <0.8 cm)

- HRMR data will be first available as experimental evaluation product and later integrated into processing system after validation