Polarization deconvolution and geophysical retrieval from a dual-pol, cross-track scanning microwave radiometer (AMPR) during OLYMPEX/RADEX

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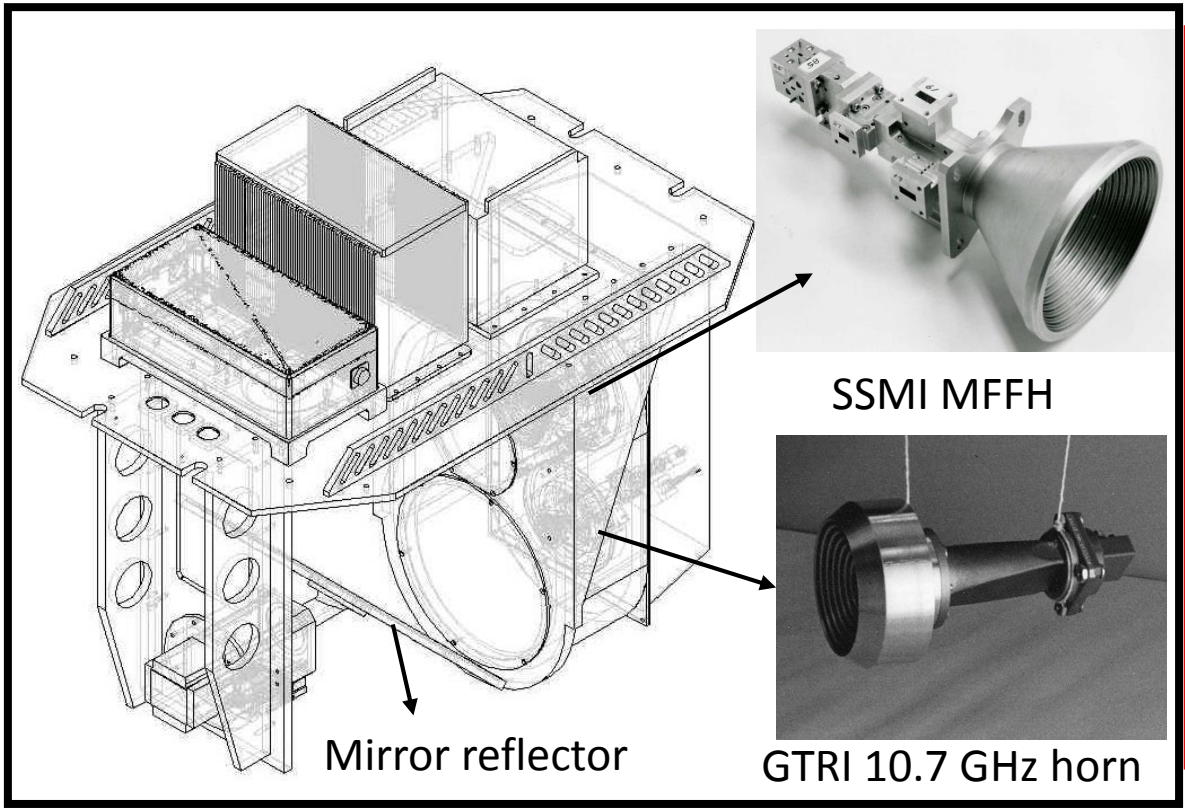
Outline

- Advance Microwave Precipitation Radiometer (AMPR) Instrument
- Polarization Mixing & Deconvolution
- Biases & Correction
- Retrieval
- Results

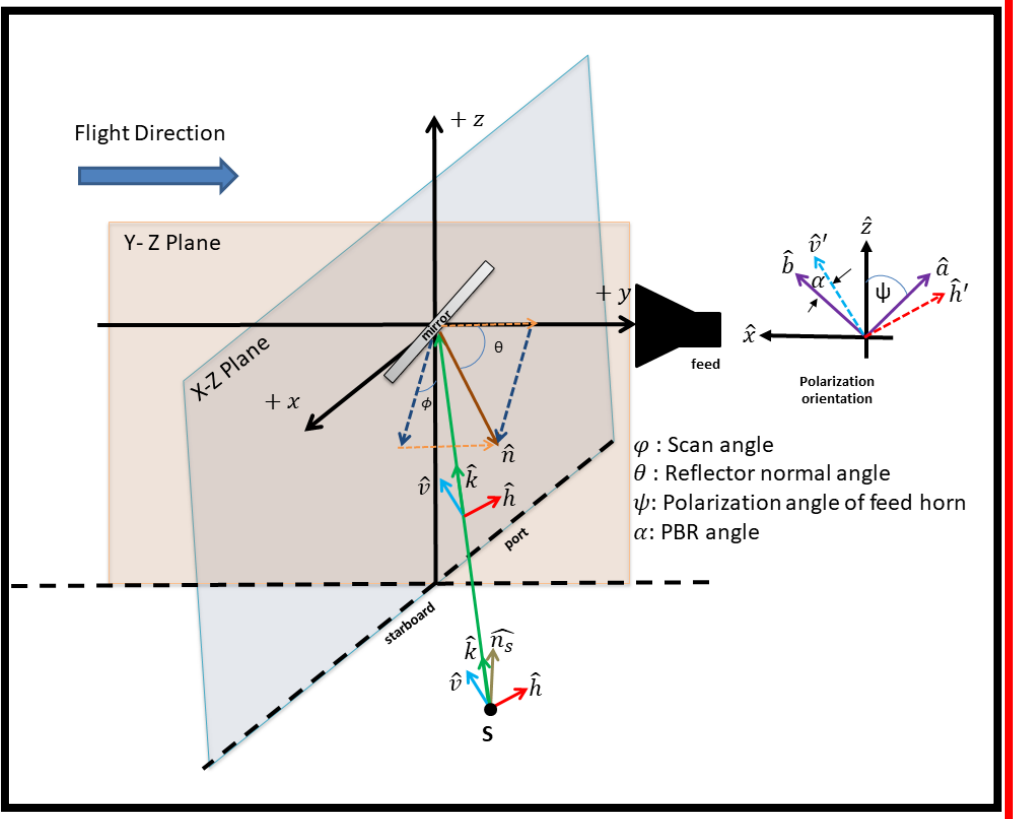
AMPR Instrument



Channel Center Frequency	85.5GHz	37.1GHz	19.35GHz	10.7GHz
Polarization	A/B	A/B	A/B	A/B
Pre Detection Bandwidth (MHz)	1400	900	240	100
Integration Time (ms)	50	50	50	50
Horn Type	SSM/I	SSM/I	SSM/I	GTRI
Lens Diameter (inches)	5.3	5.3	5.3	9.7
Beam width (degrees)	1.8	4.2	8.0	8.0
Footprint (km) [@20 km ER-2 alt. 500kts]	0.64	1.48	2.78	2.78

- Cross-track scanning microwave radiometer
- Feed horn polarization basis (A/B) rotates with respect to the scene polarization basis (V/H) as a function of scan angle.

Geometry of Polarization Basis Rotation



$$\begin{bmatrix} T_{F,B} \\ T_{F,A} \\ T_{F,U} \\ T_{F,V} \end{bmatrix} = \begin{bmatrix} \cos^2\alpha & \sin^2\alpha & \frac{1}{2}\sin 2\alpha & 0 \\ \sin^2\alpha & \cos^2\alpha & -\frac{1}{2}\sin 2\alpha & 0 \\ -\sin 2\alpha & \sin 2\alpha & \cos 2\alpha & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} T_{E,v} \\ T_{E,h} \\ T_{E,U} \\ T_{E,V} \end{bmatrix}$$

$$\alpha = \tan^{-1}\left[\frac{\{\cos 2\theta \sin\psi + 2\sin^2\theta \sin\phi \sin(\phi-\psi)\}}{\{\cos 2\theta \sin\psi + 2\sin^2\theta \sin\phi \cos(\phi-\psi)\}}\right]$$

In AMPR, $\boldsymbol{\theta = 45^0}$.

Therefore, $\boldsymbol{\alpha = \phi - \psi}$

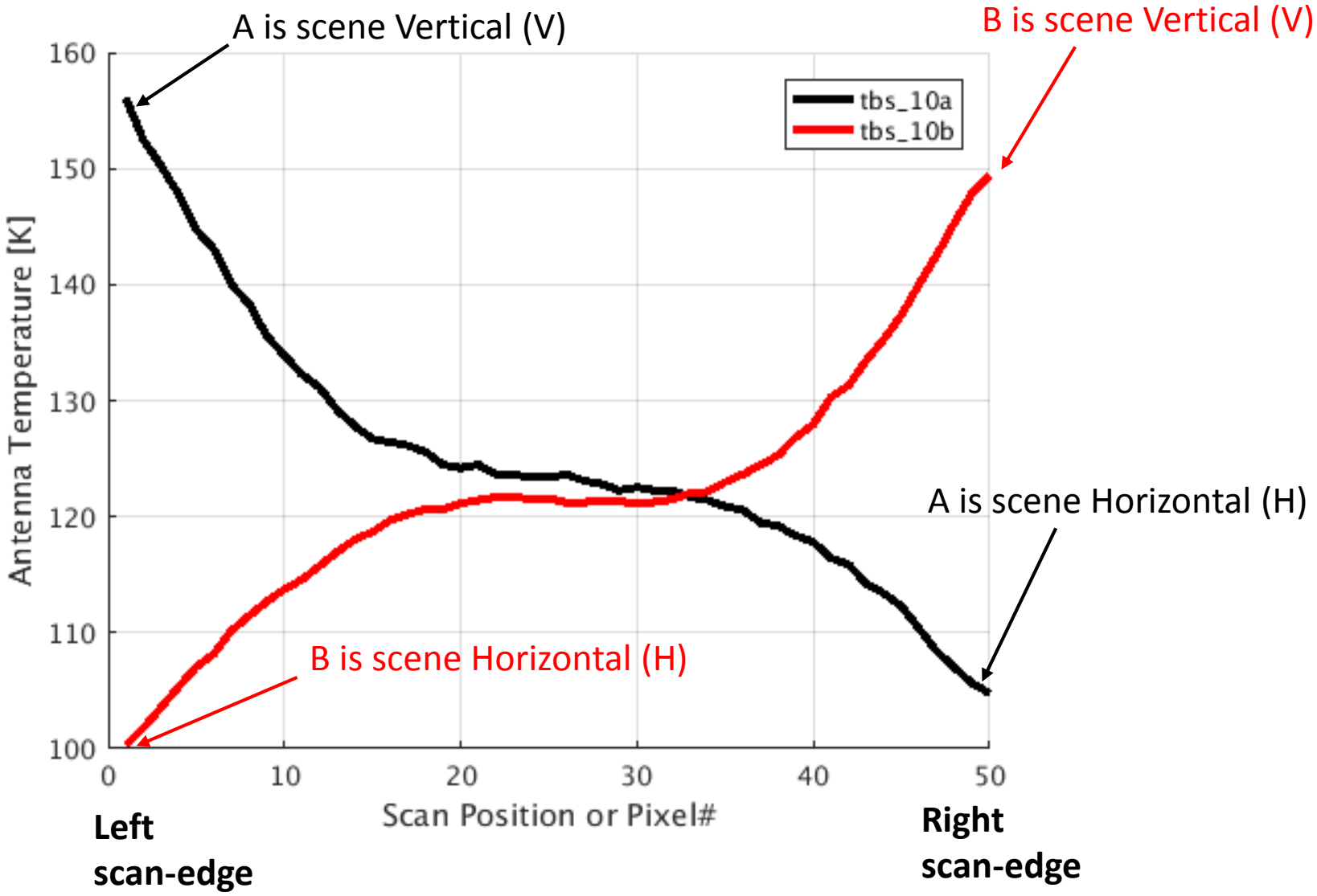
Since, the modified 3rd (T_U) and 4th (T_V) stokes brightness temperatures are not measured, the simplified transform is:

$$\begin{bmatrix} T_{F,B} \\ T_{F,A} \end{bmatrix} = \begin{bmatrix} \cos^2\alpha & \sin^2\alpha \\ \sin^2\alpha & \cos^2\alpha \end{bmatrix} \begin{bmatrix} T_{E,v} \\ T_{E,h} \end{bmatrix}$$

Where,

$$\alpha = \phi - 45^0$$

Geometry of Polarization Basis Rotation



Observed Bias in recovered V & H –pol Brightness Temperature (Tb)

- The relationship between Tb measured in instrument polarization basis (A,B) and the scene polarization basis (V,H) is given by,

$$\begin{bmatrix} T_V \\ T_H \end{bmatrix} = \begin{bmatrix} \sin^2(45-\phi) & \cos^2(45-\phi) \\ \cos^2(45-\phi) & \sin^2(45-\phi) \end{bmatrix} \begin{bmatrix} T_A \\ T_B \end{bmatrix} \quad (1)$$

- Equation (1) is used to created observed V,H –pol Tb data from AMPR measurements.
- Tb Bias = Tb (Observed) – Tb (Simulated)
- GDAS profiles and SST information was used to simulate V,H –pol TB for several OLYMPEX flights with data over ocean.

Bias sources

- The Tb bias for any AMPR polarization channel (A or B) is defined as,

$$\Delta Tb = Tb^{OBSERVED} - Tb^{SIMULATED}$$

where,

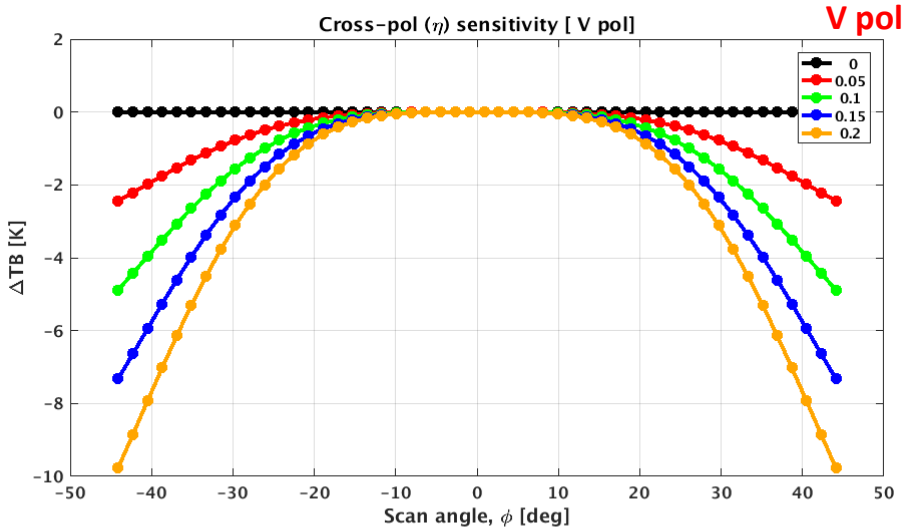
$$Tb^{SIMULATED} = (1-\eta)*[A(\theta,\psi,\phi)*Tb^{V} + B(\theta,\psi,\phi)*Tb^{H}] + \eta*[B(\theta,\psi,\phi)*Tb^{V} + A(\theta,\psi,\phi)*Tb^{H}] \quad (2)$$

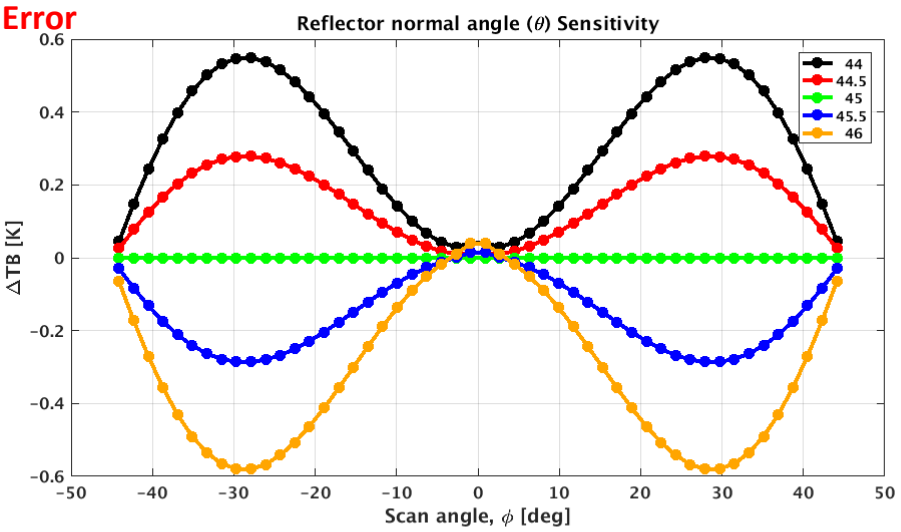
η = cross polarization fraction
A,B = polarization mixing weights (function of geometry)
θ,ψ,ϕ = reflector normal angle, polarization alignment angle, sensor scan angle

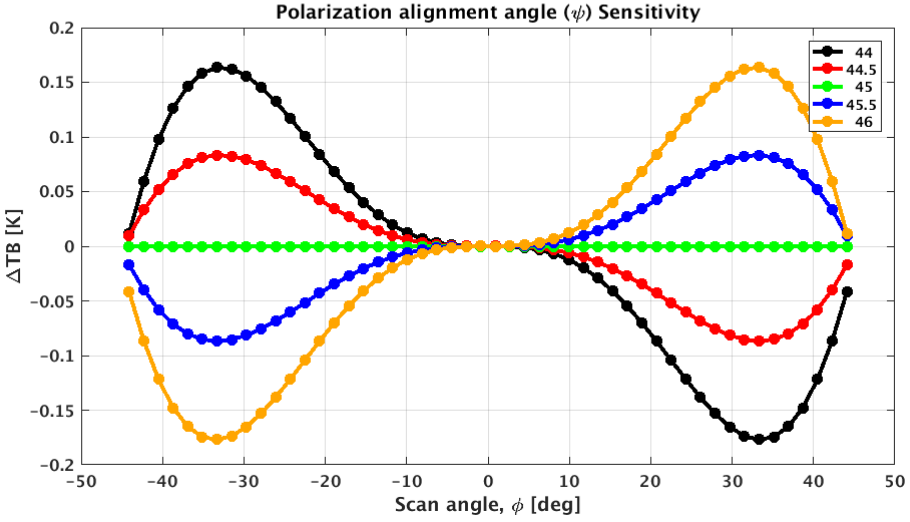
- Any deviation of the following parameters from the nominal values will result in a bias:
  η, θ,ψ,ϕ

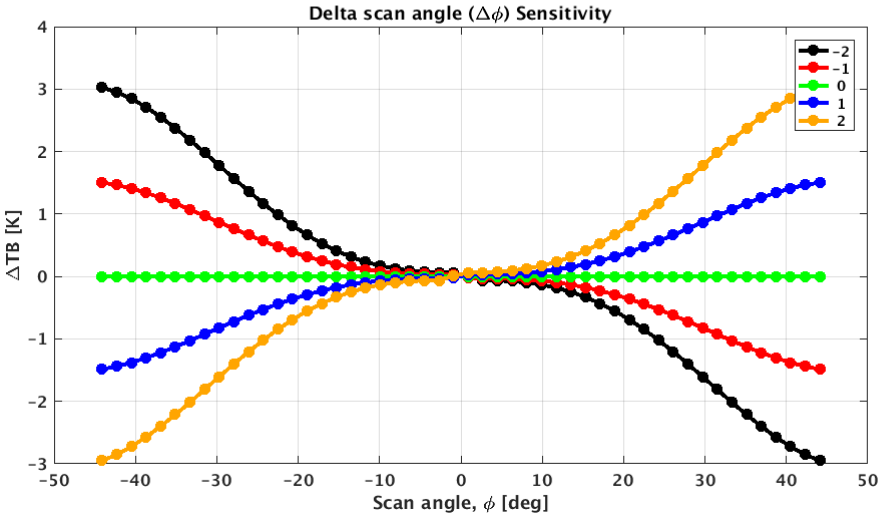
- A simulator is developed to analyze the bias sensitivity to any of the above parameters

V –pol Bias Due to Angle Error

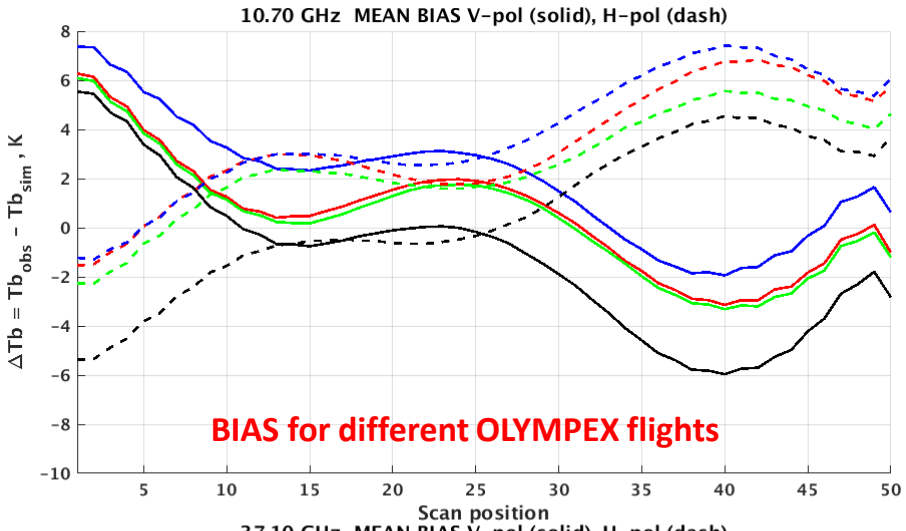


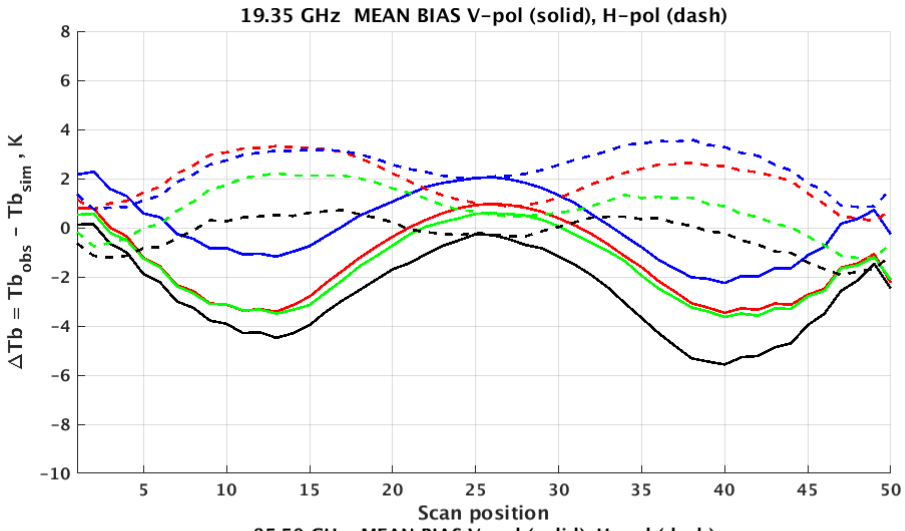


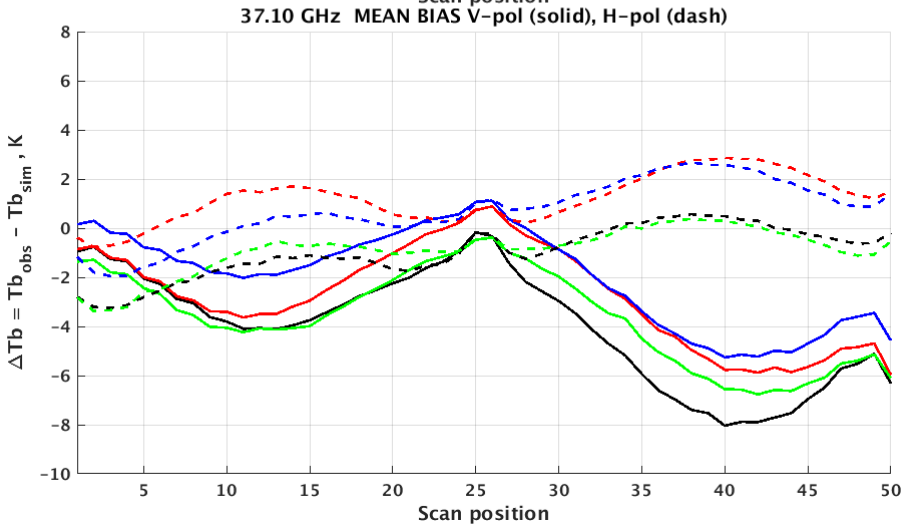


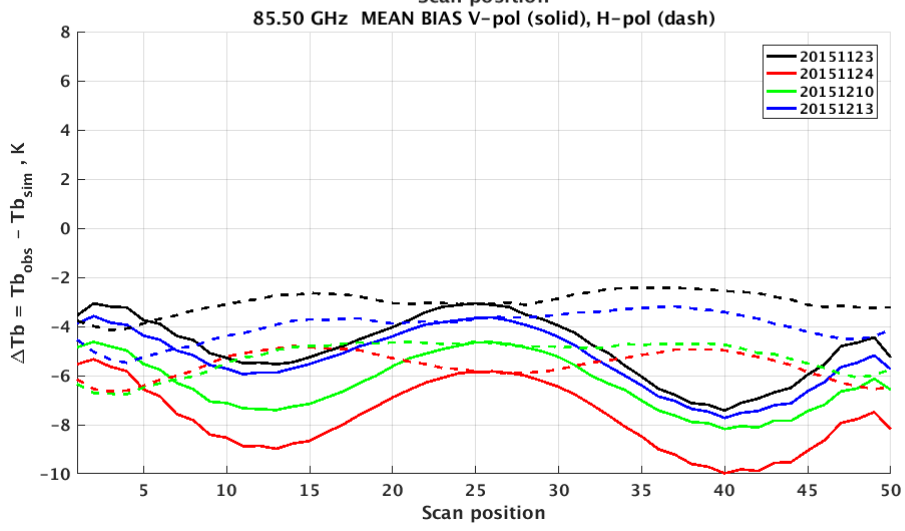


V & H –pol Tb Bias

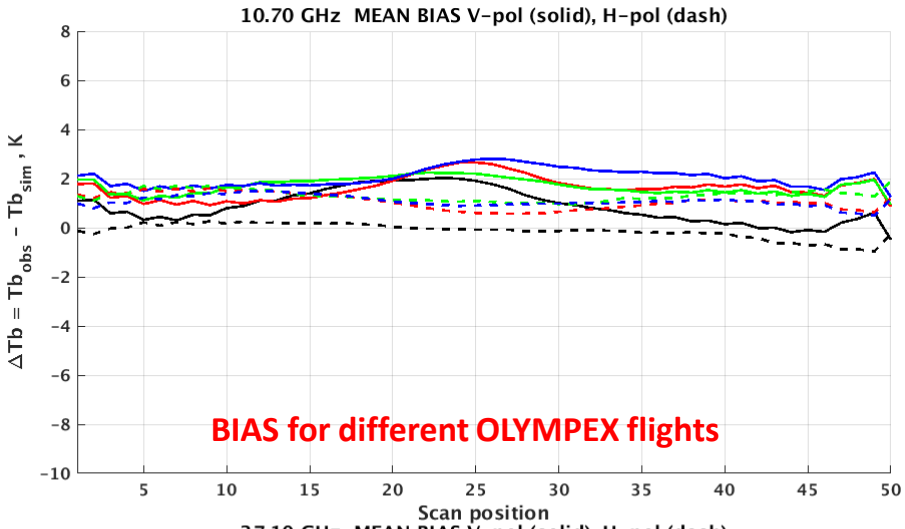


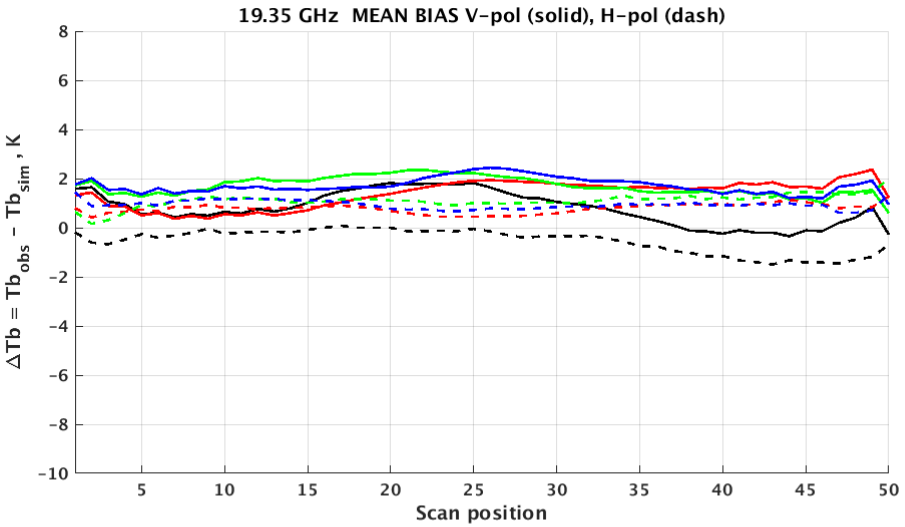


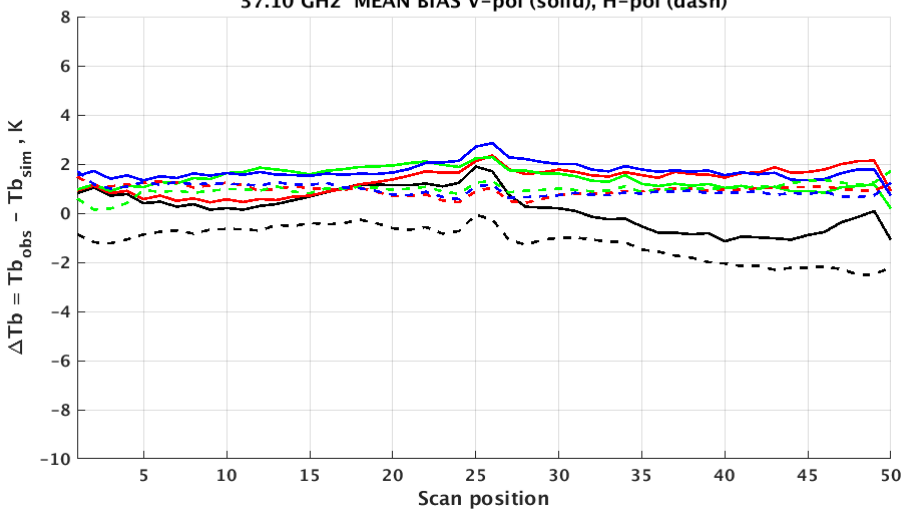


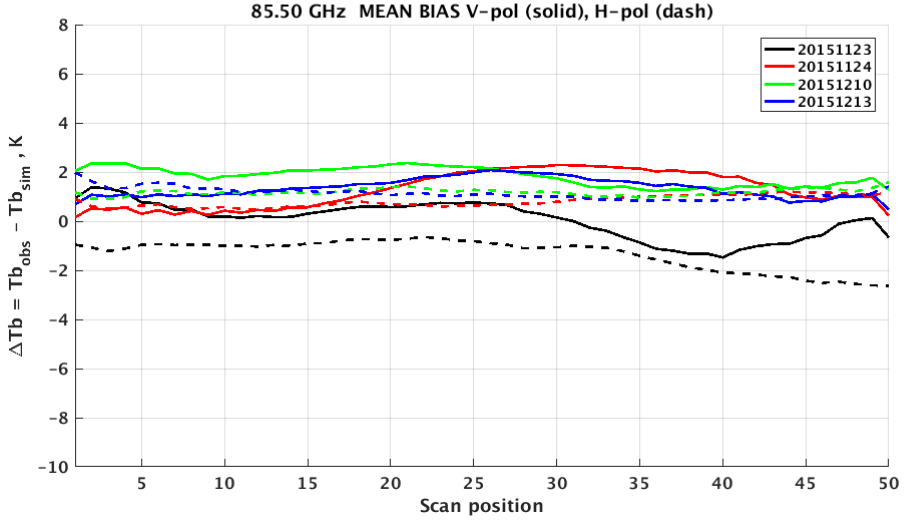


V & H –pol Tb Bias – AFTER CORRECTION









Multi-Linear Regression Model(s)

- Model for Columnar Water Vapor (V in mm):

$$V\ (mm) = a_0 + a_1*T_{B10v} + a_2*T_{B10h} + a_3*\ln(290-T_{B19v}) + a_4*\ln(290-T_{B19h}) + a_5*\ln(290-T_{B37v}) + a_6*\ln(290-T_{B37h})$$

- Model for Columnar Cloud Liquid Water (L in mm):

$$L\ (mm) = a_0 + a_1*\ln(290-T_{B19v}) + a_2*\ln(290-T_{B19h}) + a_3*\ln(295-T_{B85v}) + a_4*\ln(295-T_{B85h})$$

- Model for Surface Wind Speed (WS in m/s):

$$WS\ (m/s) = a_0 + a_1*T_{B10v} + a_2*T_{B10h} + a_3*\ln(290-T_{B19v}) + a_4*\ln(290-T_{B19h}) + a_5*T^2_{B10v} + a_6*T^2_{B10h} + a_7*T_{B10v}*T_{B10h} + a_8*SST$$

Where, $T_{Bnv,h}$ = Measured T_B for n GHz v,h-polarization channels

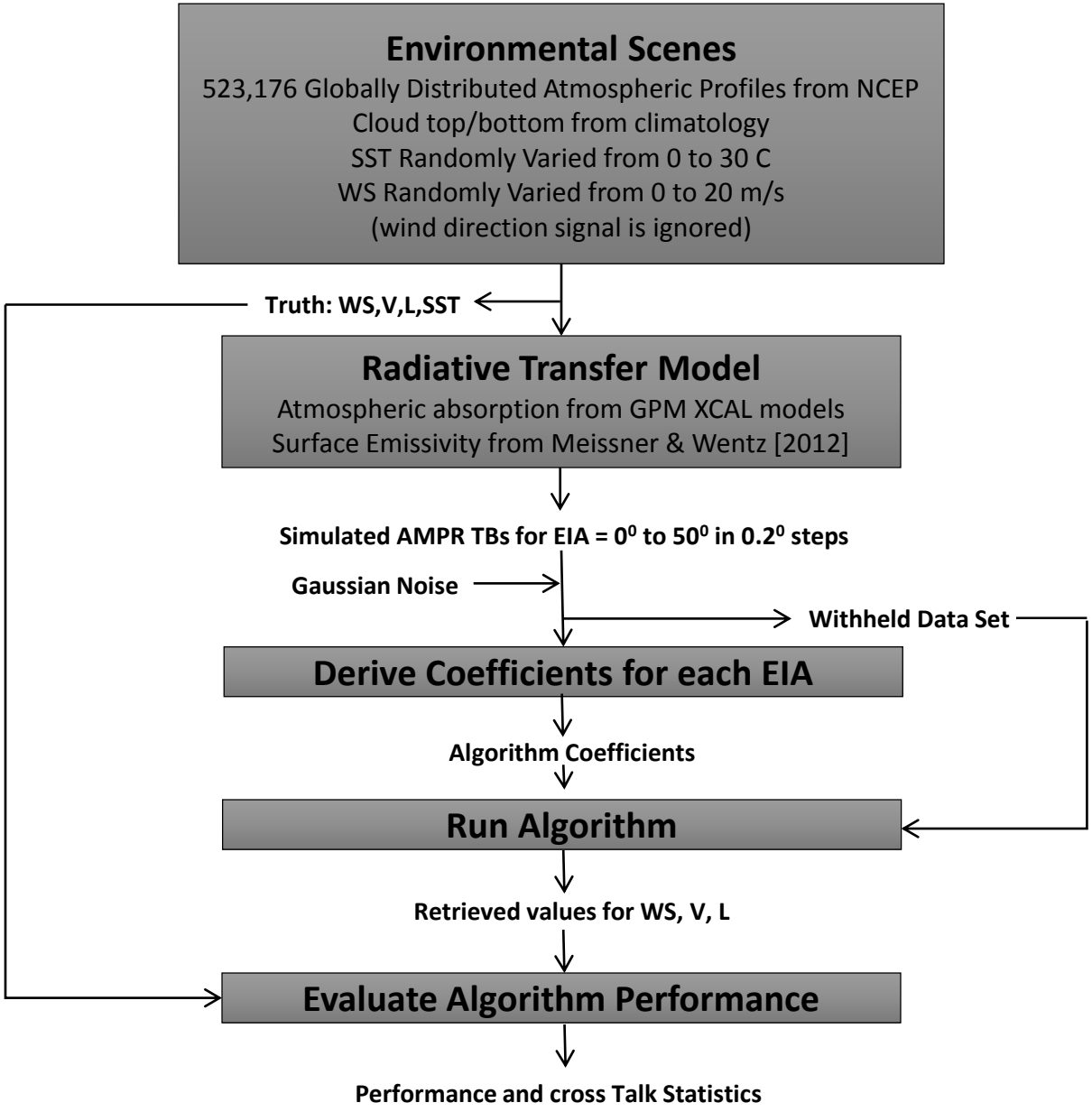
SST = Sea Surface Temperature in kelvin (a priori value needed)

a_n coefficients are polynomial functions of the incidence angle*

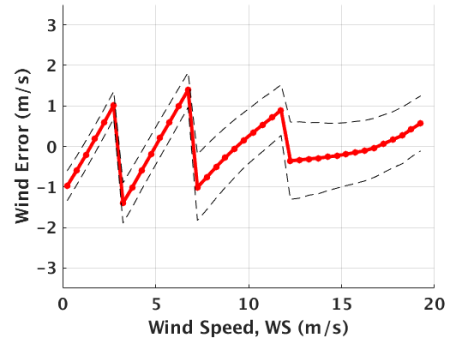
The WS retrieval is further improved by generating 'a' coefficients for different range of wind speeds, e.g. WS<=3, 3<WS<=7, 7< WS<=12 & WS>12 .

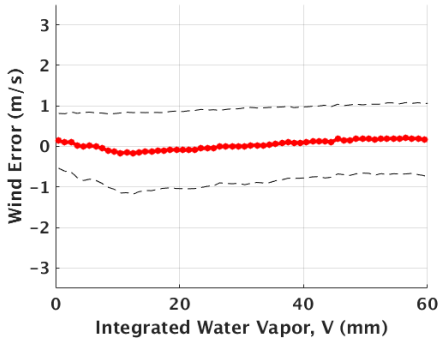
(*AMPR is a cross-track scanner and the observation incidence angle varies between 0^0 to 45^0)

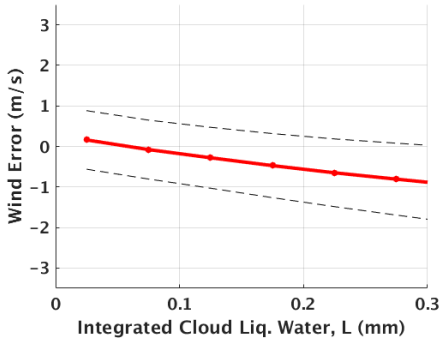
Coefficient Derivation & Testing

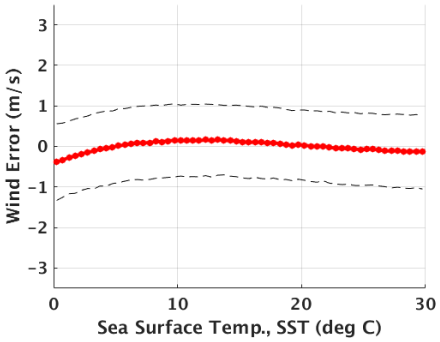


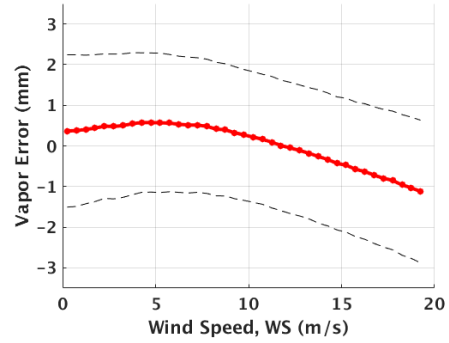
Retrieval and Cross-Talk Error

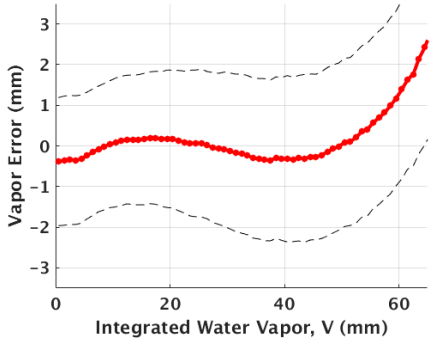


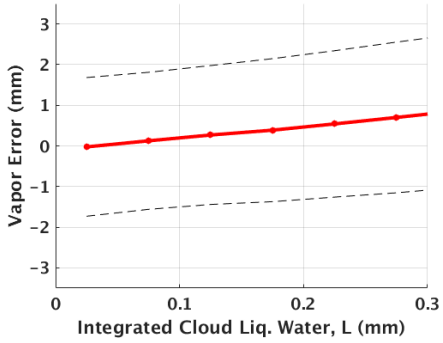


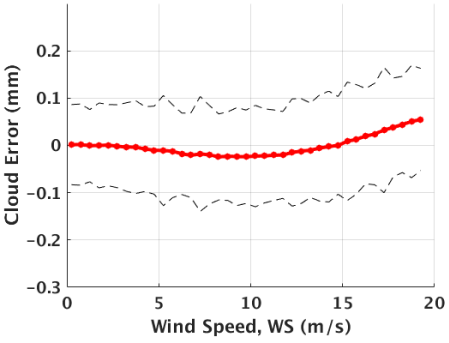


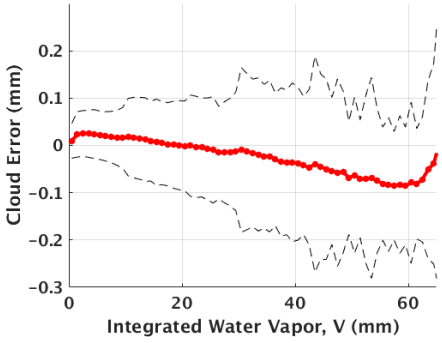


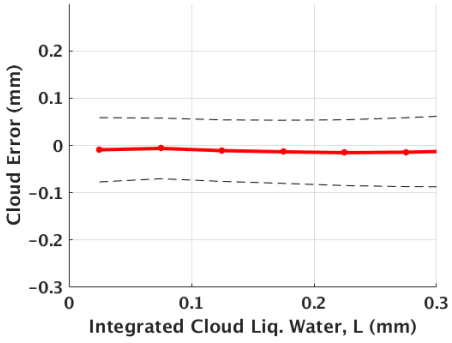








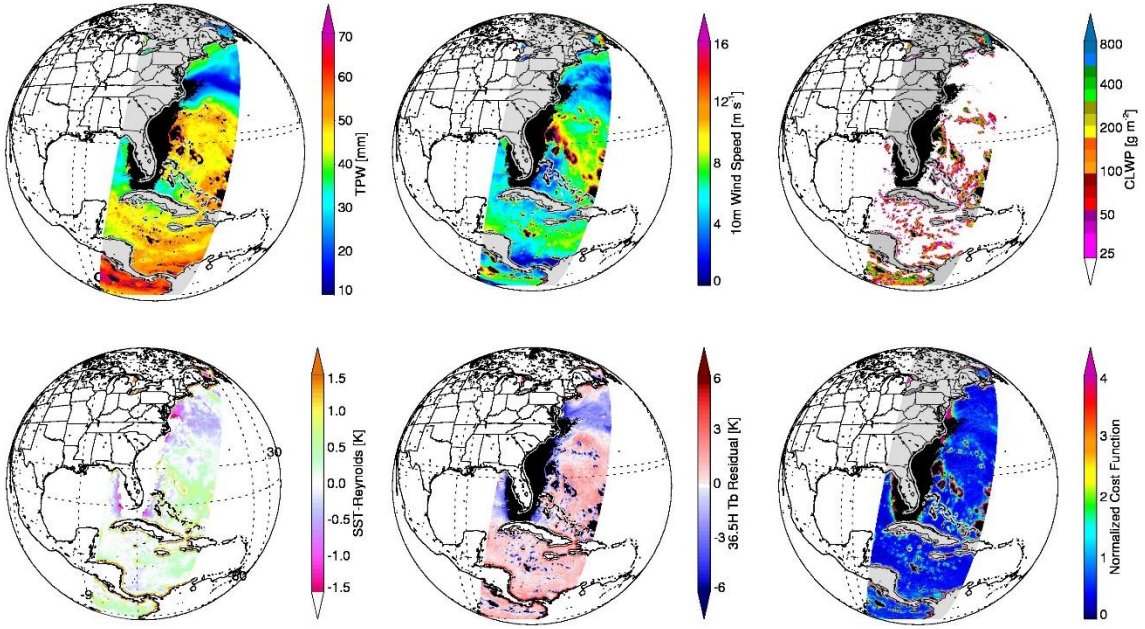


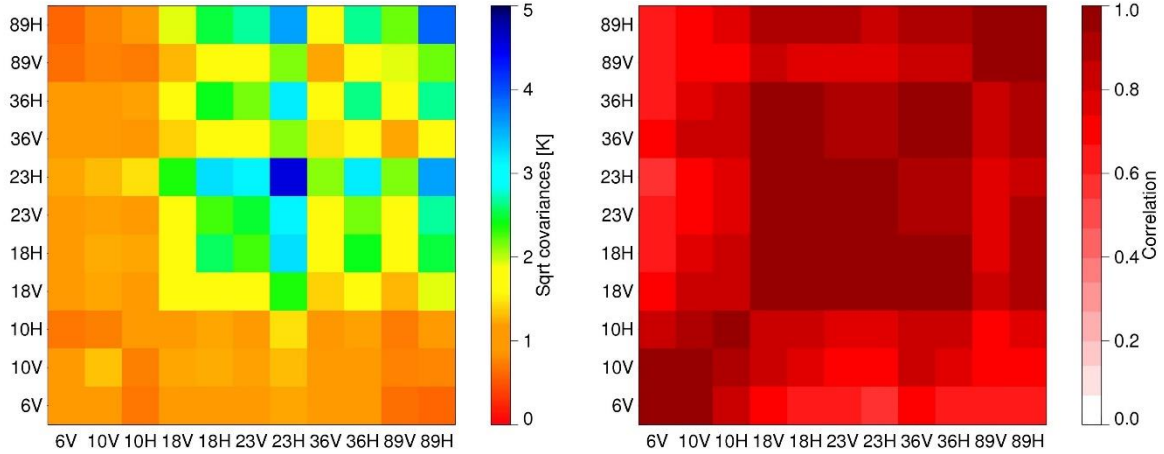


EIA average RMS Retrieval Error	
WS (m/s)	0.9
V (mm)	1.85
L (mm)	0.11

Errors are averaged over all EIA between 0 to 50 deg

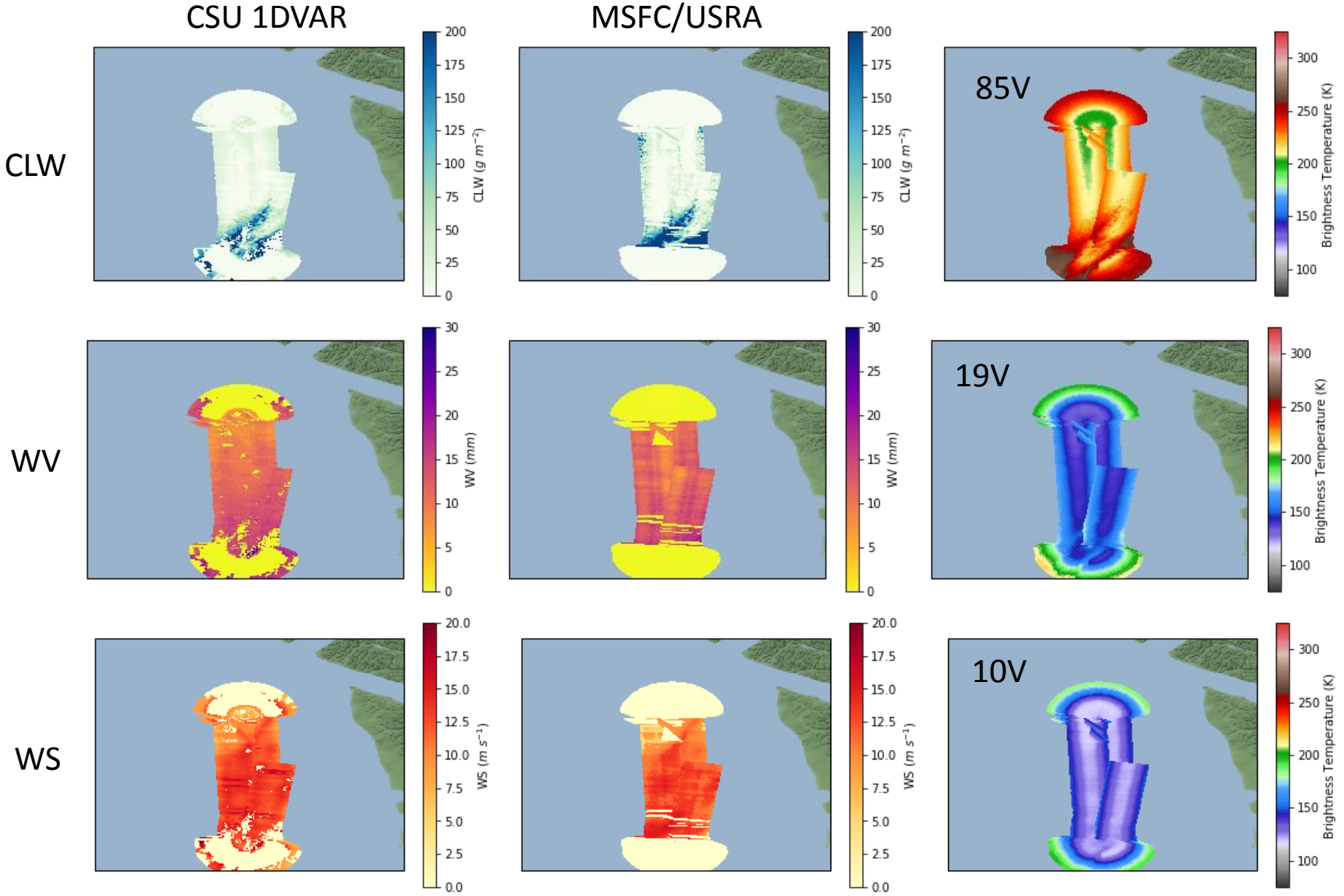
CSU 1DVAR





- Optimal estimation retrieval for microwave imagers over ocean
- Simultaneously solve for wind speed, SST, liquid water path, and water vapor profile
- CRTM with FASTEM6 in forward model
- Water vapor profile decomposed into principal components
- Novel observation error covariance matrix accounts for co-varying forward model errors
- Applicable to any imager platform due to physical forward model
- See Duncan and Kummerow (2016) for additional details

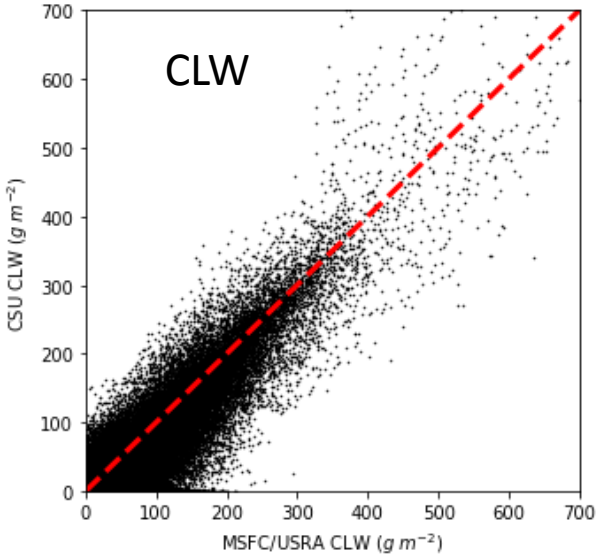
11/24/15 2000-2038 UTC

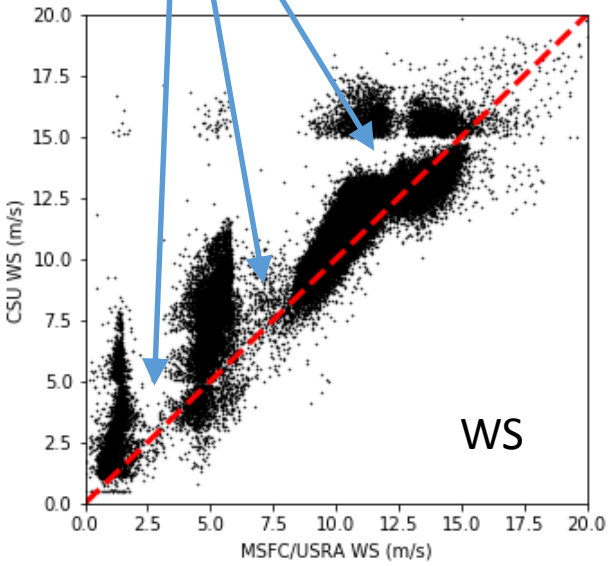


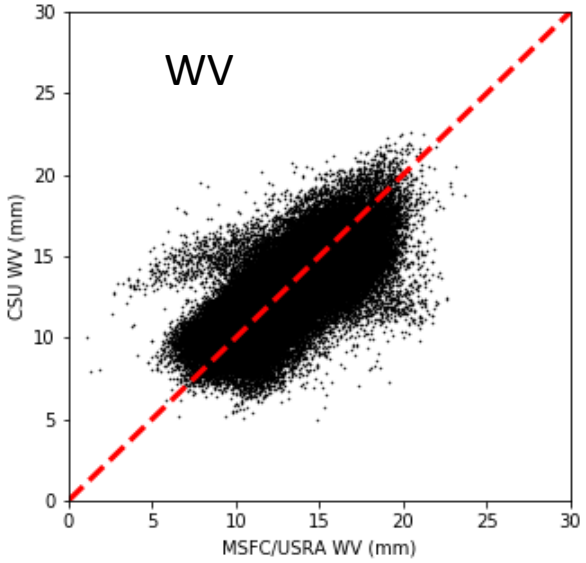
Comparison between CSU 1DVAR Algorithm and MSFC/USRA Algorithm for 11/24/2015

- CLW good agreement overall
- WV and WS impacted by artifacts resulting from MSFC algorithm
- MSFC retrieves even in possibly raining scenarios
- CSU masks potential precip-impacted regions, but sometimes mask fails leading to highly erroneous retrievals

Artifacts from MSFC wind speed retrieval break points



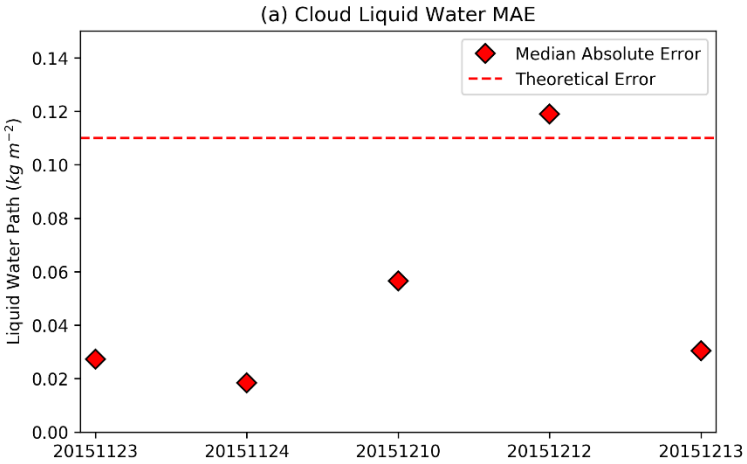


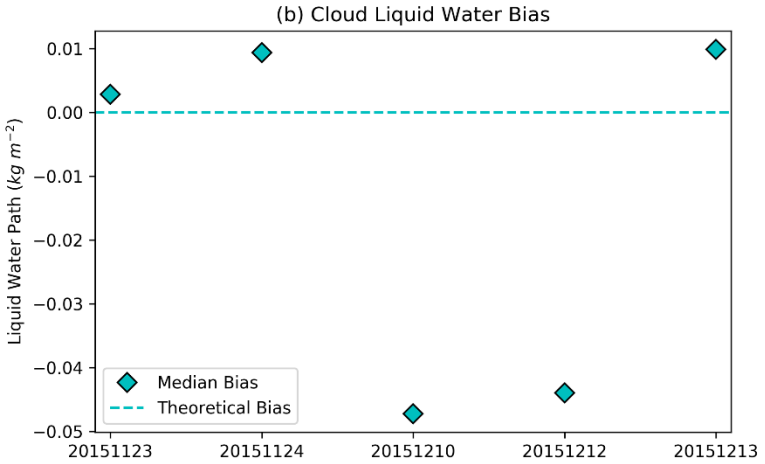


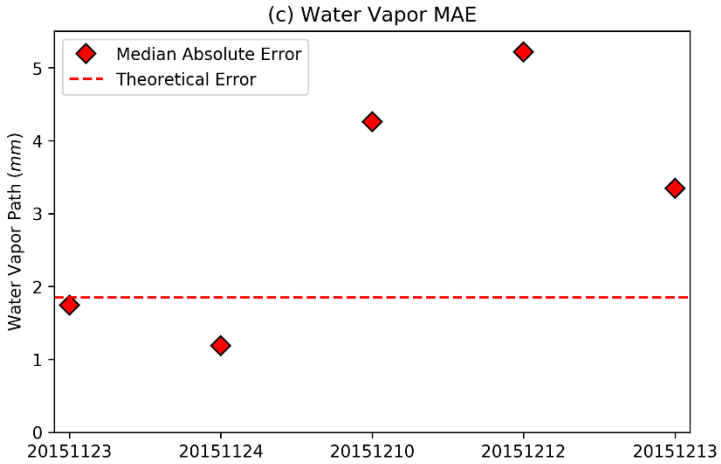
MSFC vs. CSU Algorithms

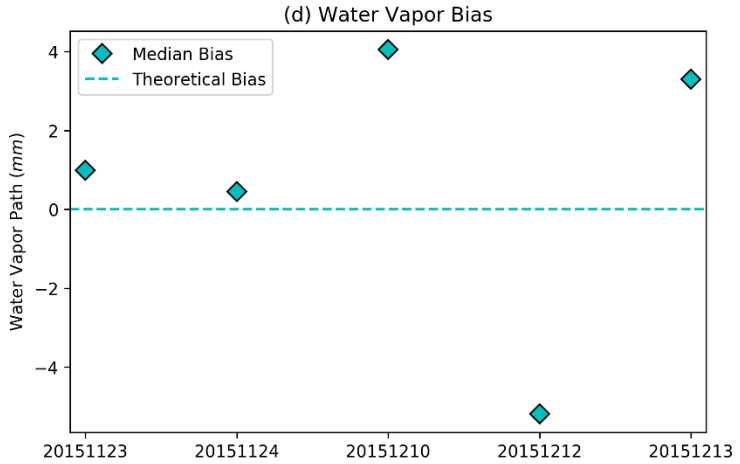
Five different case days

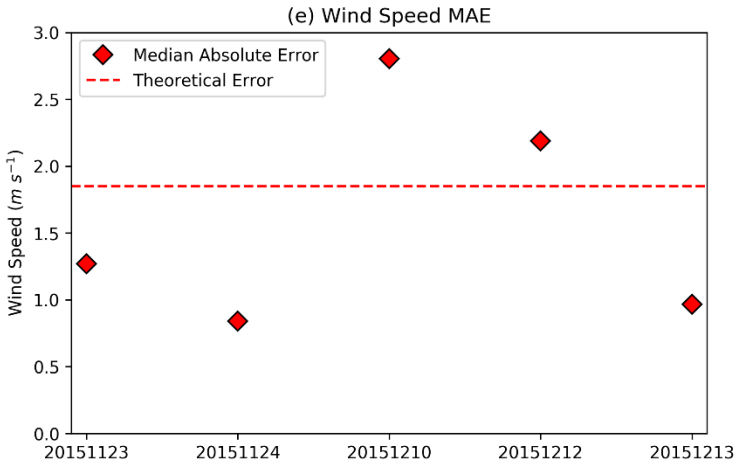
11/23, 24
12/10, 12, 13

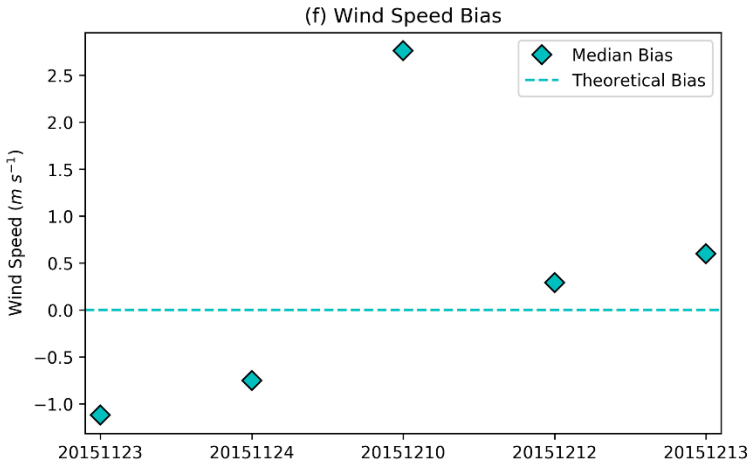






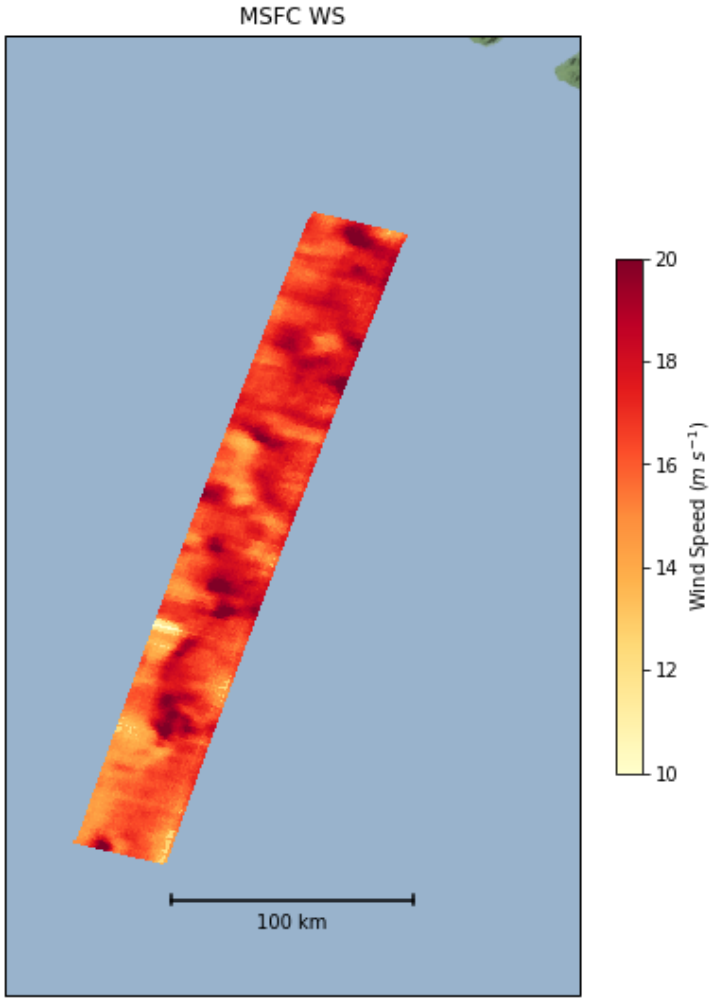


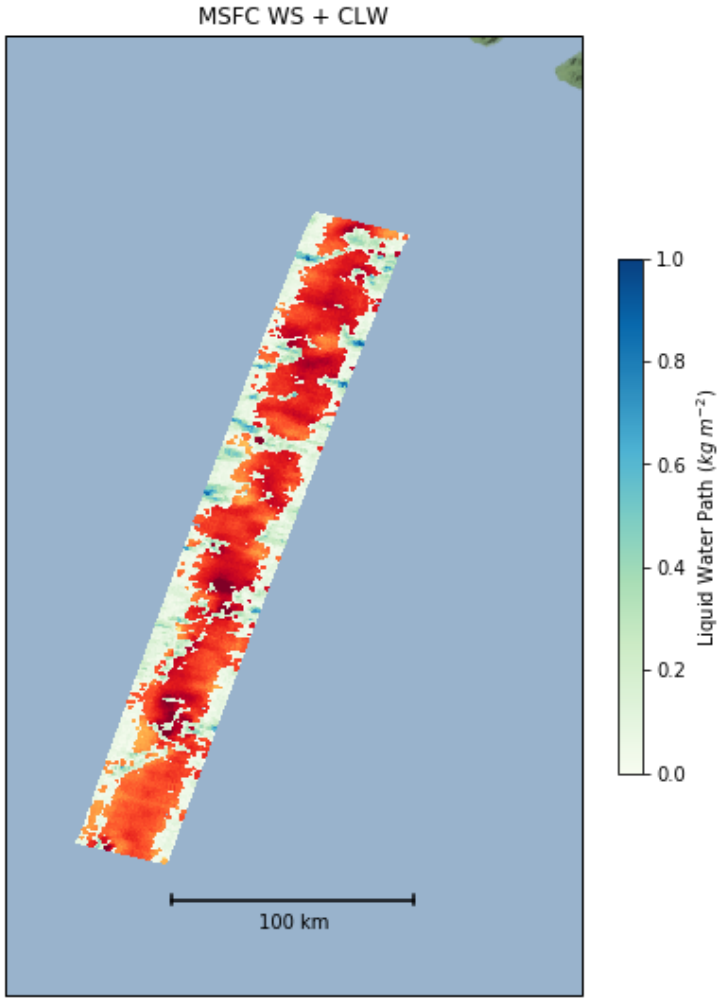




12/13, 1916-1947 UTC

Small-scale variability in WS suggests post-frontal convection influencing surface winds





"Lumpiness"

Wind speed masked for CLW > 0.01 kg m^{-2}

Conclusions

- Significant improvements have been made to AMPR brightness temperature measurements, enabling deconvolution to V and H polarizations and the retrieval of physically realistic values for CLW, WV, and WS.

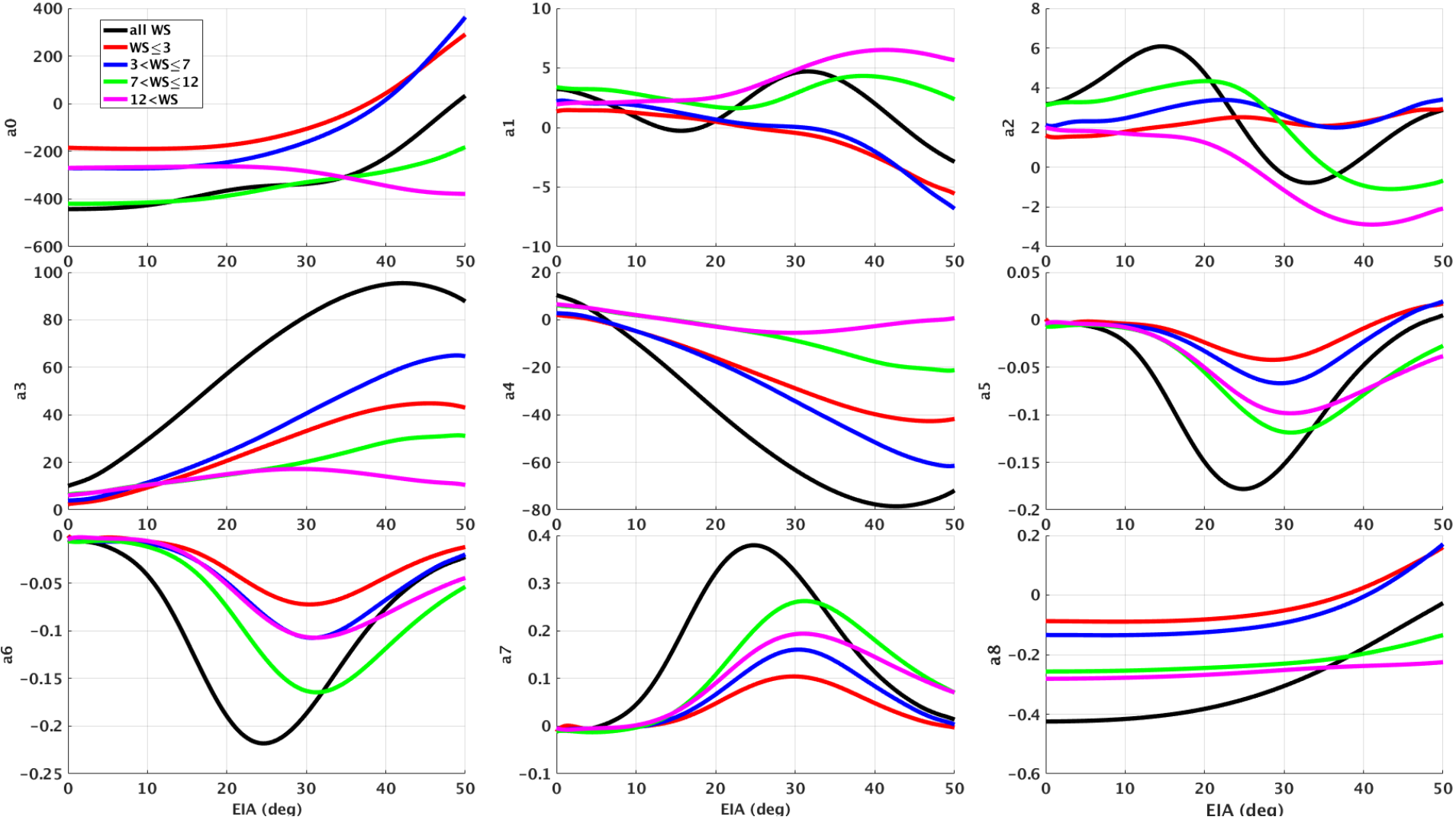
- Some artifacts still remain, due to instrument uncertainties as well as algorithm limitations – Improvement efforts continue

- MSFC algorithm capable of detecting apparent small-scale variability in convectively driven winds outside post-frontal cells on 12/13

Ackknowledgement:

BACKUP

WS regression coefficients

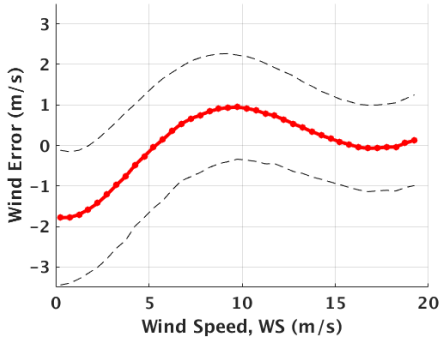


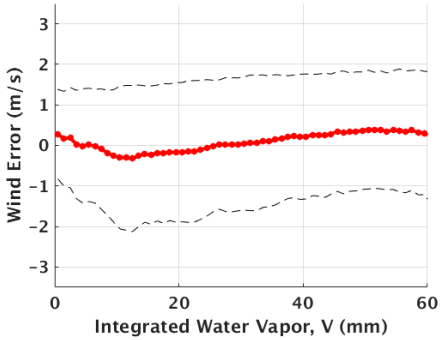
Two step retrieval:

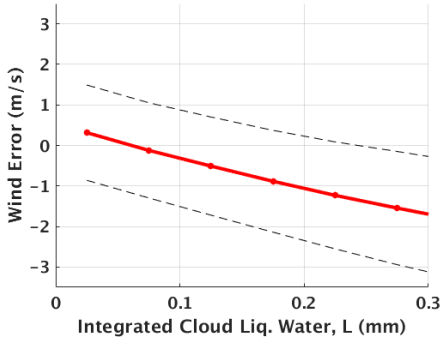
1. **"all WS" coefficients are used for the first retrieval.**
2. **Depending on the retrieved WS value of "all WS" algorithm, corresponding set of coefficients are chosen for a second and final retrieval.**

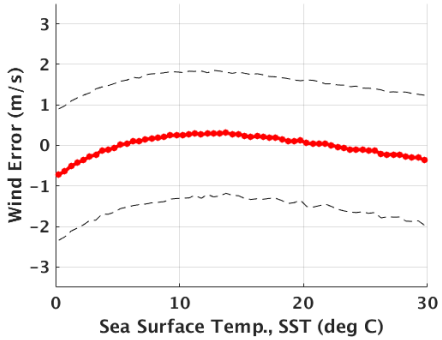
Performance Comparison of Two step WS algorithm and One step algorithm

One Step Algorithm Error & Error correlation

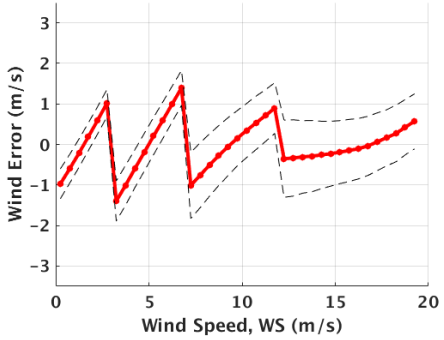


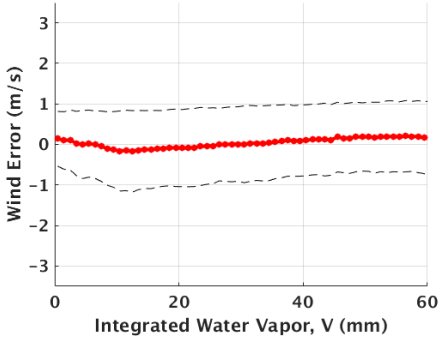


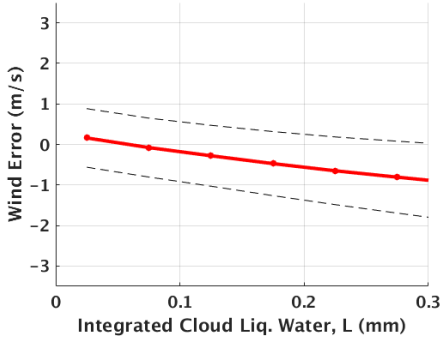


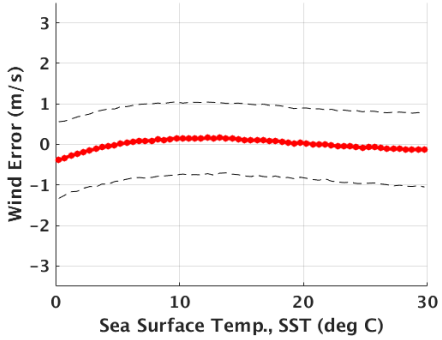


Two Step Algorithm Error & Error correlation

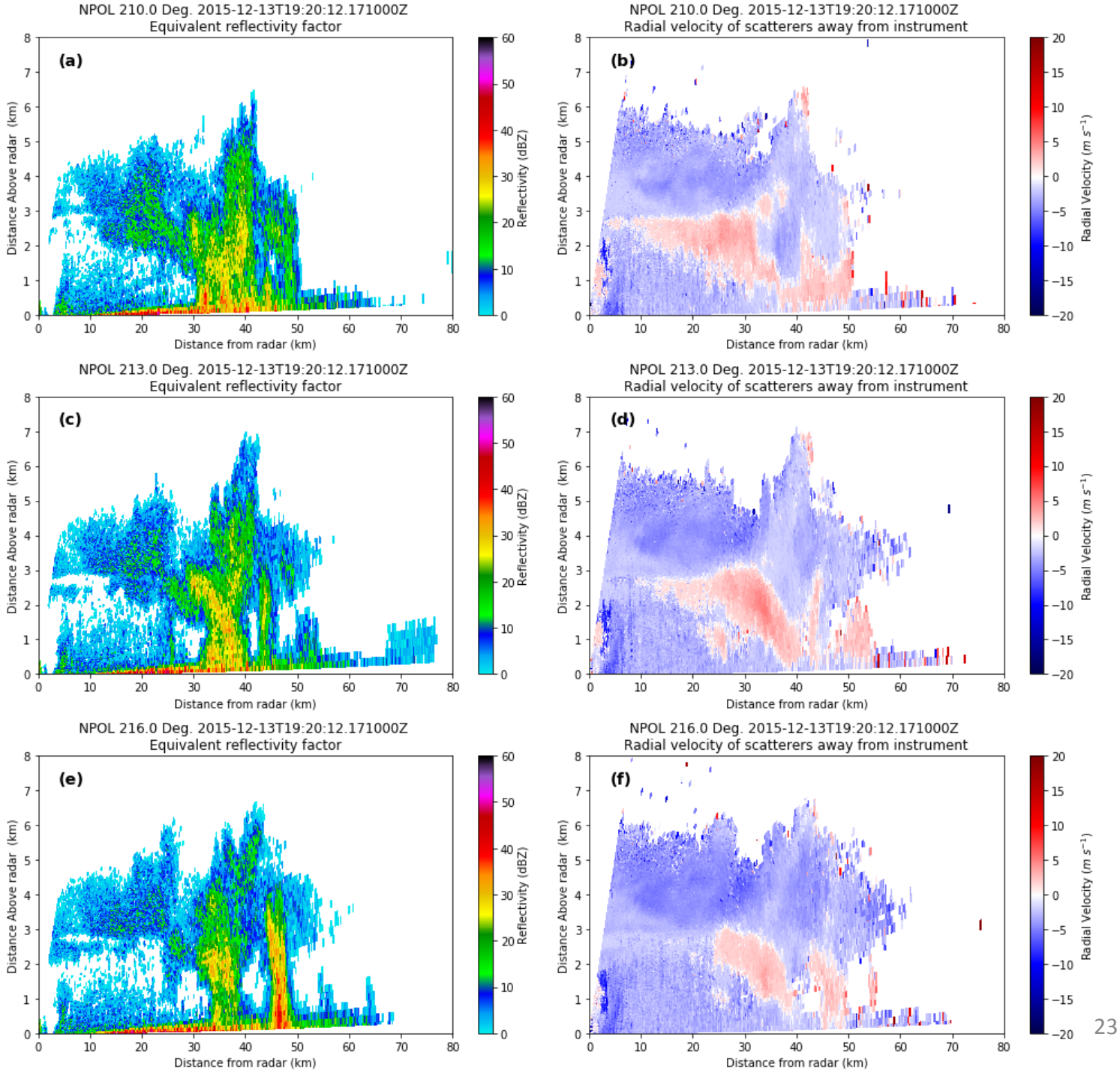


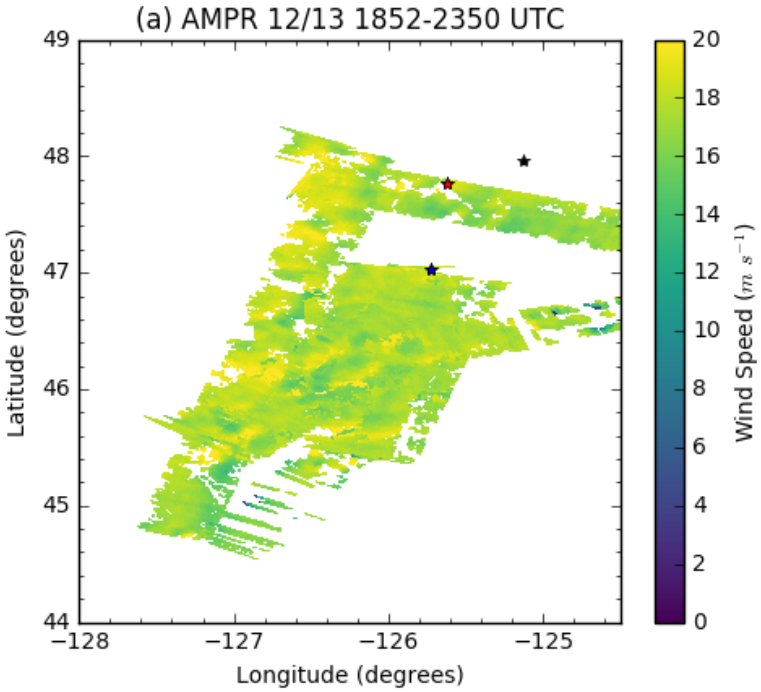


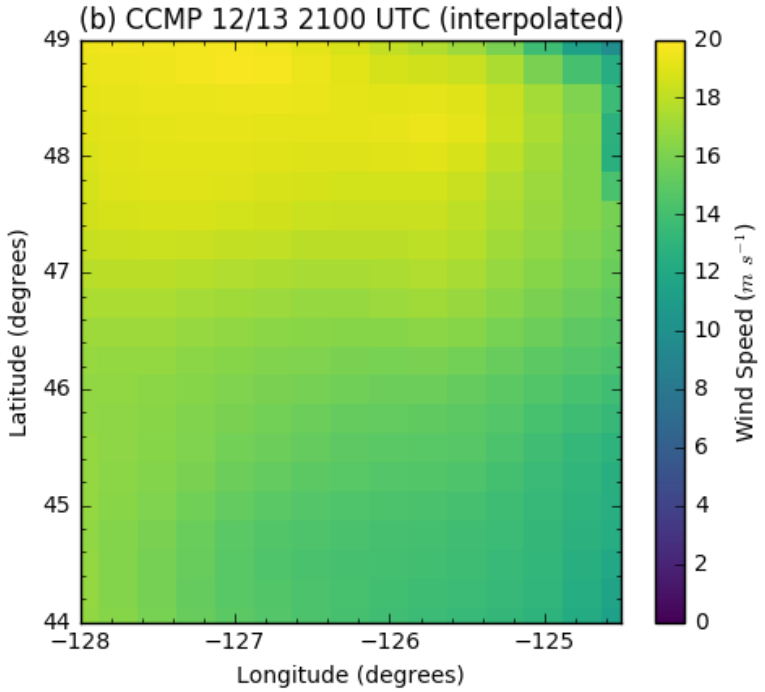




‘red’ solid line is the mean error (averaged over all incidence angles).
Dashed line show the +/- one std. deviation of the error about the mean value
Two step algorithm performs better as expected.


NPOL 210.0 Deg. 2015-12-13T19:20:12.171000Z
Equivalent reflectivity factor
(a)
Distance Above radar (km)
Distance from radar (km)
Reflectivity (dBZ)
NPOL 210.0 Deg. 2015-12-13T19:20:12.171000Z
Radial velocity of scatterers away from instrument
(b)
Distance Above radar (km)
Distance from radar (km)
Radial Velocity ($m\ s^{-1}$)
NPOL 213.0 Deg. 2015-12-13T19:20:12.171000Z
Equivalent reflectivity factor
(c)
Distance Above radar (km)
Distance from radar (km)
Reflectivity (dBZ)
NPOL 213.0 Deg. 2015-12-13T19:20:12.171000Z
Radial velocity of scatterers away from instrument
(d)
Distance Above radar (km)
Distance from radar (km)
Radial Velocity ($m\ s^{-1}$)
NPOL 216.0 Deg. 2015-12-13T19:20:12.171000Z
Equivalent reflectivity factor
(e)
Distance Above radar (km)
Distance from radar (km)
Reflectivity (dBZ)
NPOL 216.0 Deg. 2015-12-13T19:20:12.171000Z
Radial velocity of scatterers away from instrument
(f)
Distance Above radar (km)
Distance from radar (km)
Radial Velocity ($m\ s^{-1}$)





12/13 dropsonde comparison

Dropsondes > 1 h from AMPR; however, closest one (red star) within 1.2 m s^{-1}