MWR Rain Rate Retrieval Algorithm

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MSEE Thesis defense

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Outline

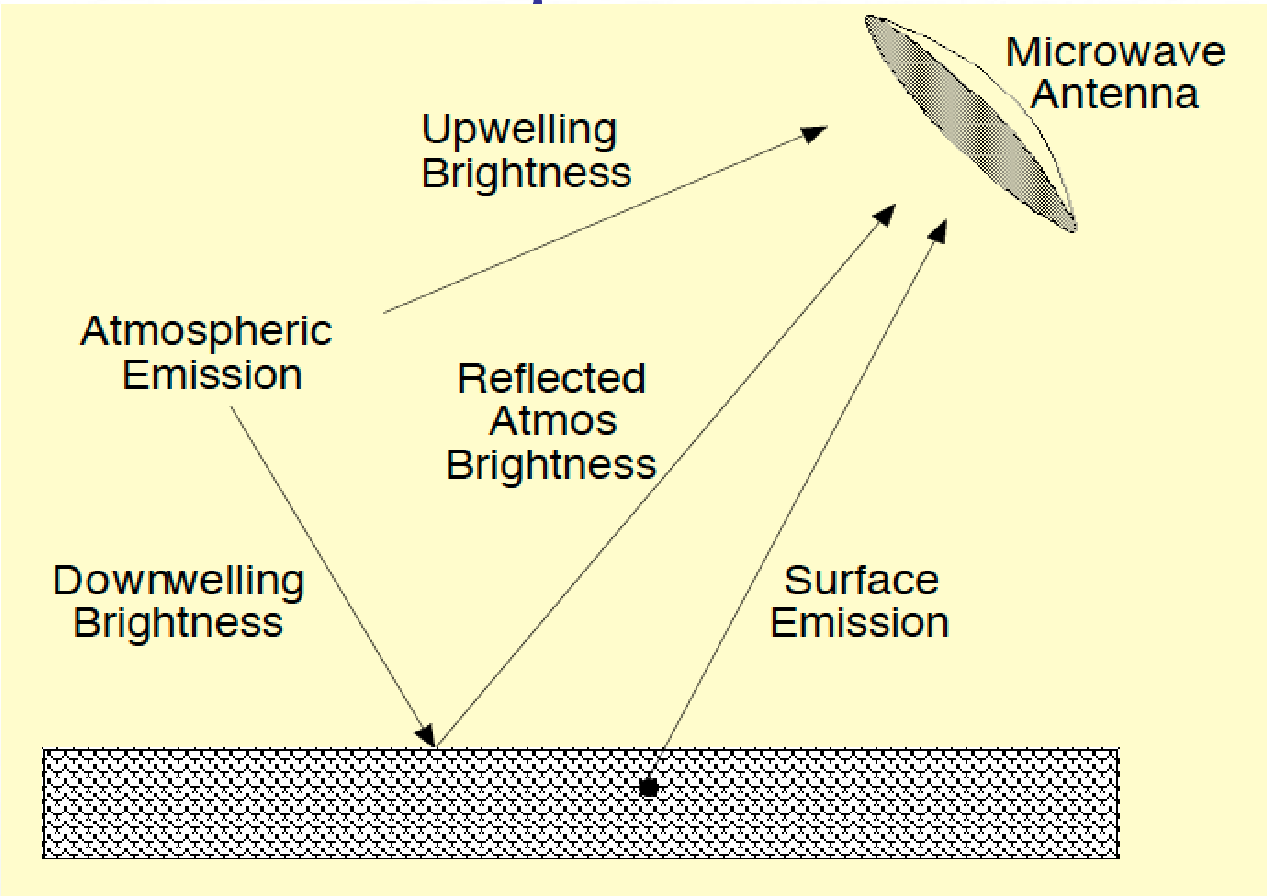
- Objective
- Theoretical Basis
- Algorithm Approach
- Geophysical Retrieval Results
- Conclusion
- Future Work

Thesis Objective

- To develop a rain retrieval algorithm for the Aquarius/SAC-D Microwave Radiometer (MWR)
  - Algorithm approach
    - Based upon both radiative transfer theory and statistical regression
    - Tuned using empirical data from WindSat
  - Algorithm validation using WindSat Environmental Data Record (EDR)
- To deliver an Algorithm Theoretical Basis Document (ATBD) to CONAE in December 2010

Algorithm Theoretical Basis

Microwave Brightness is the sum of three components



Radiometric Emissions are Non-coherent and their Powers Add

Microwave Ocean Apparent Temp (Tap) (single layer atmosphere approx)

$$T_{ap} = T_{BU} + \tau_{atmos} * (T_b + T_{scat})$$

$$T_{scat} = (1-\varepsilon) * (T_{BD} + \tau_{atmos} * T_{BC})$$

$$T_{BU} = (1-\tau_{atmos}) * T_U$$

$$T_{BD} = (1-\tau_{atmos}) * T_D$$

T_b = ocean surface emission = ε * SST
τ_{atmos} = Atmospheric loss (transmission coefficient)
T_{BC} = cosmic brightness = 2.7 K
(1 - τ_{atmos}) = Atmospheric absorption
(1 - ε) = ocean Fresnel power reflection coeff
T_U & T_D = effective atmos phys temp (up/down)

Atmospheric Transmissivity

Atmos optical depth (nepers)

$$A_{atmos} = \int_0^{TOA} K \; dZ$$

$$A_{atmos} = A_O + A_V + A_L$$

Atmos transmissivity

$$\tau_{atmos} = \exp[-\sec\theta * (A_O + A_V + A_L)]$$

$$\tau_{atmos} = \tau_O * \tau_V * \tau_L$$

K = Atmospheric absorption coefficient (nepers/km)
Z = Atmos height (zenith direction)
A_{atmos} = atmospheric absorption (Optical depth)
τ_O = Transmissivity due to oxygen
τ_V = Transmissivity due to water vapor
τ_L = Transmissivity due to liquid water (cloud liquid water and rain)

WindSat Rain Rate Algorithm

Rational for using WindSat

- WindSat radiometer has **measured brightness temperatures** (T_b) to develop this algorithm
- MWR has three channels, which are a subset of WindSat
  - MWR: 24 GHz H-pol & 37 GHz H- & V-pol
  - Corresponding WindSat: 24 GHz & 37 GHz, H-pol & V-pol
- Similar incident angles
  - WindSat: 53°
  - MWR: 52°& 58°
- Also WindSat environmental data records (EDR) are available for algorithm tuning and validation

Rain Retrieval Algorithm Theoretical Basis

- The following journal papers were used:
  - Wentz, F. J. and T. Meissner. "Algorithm Theoretical Basis Document (ATBD), version 2: AMSR Ocean Algorithm." *RSS Tech. Proposal 121599A-1. Remote Sensing Systems, Santa Rosa, CA*. (2000): 66 pp.
  - Spencer, W. Roy and Wentz, Frank J. "SSM/I Rain Retrievals within a Unified All-Weather Ocean Algorithm." *Journal of the Atmospheric Sciences* 55:9 (1998): 1613-1627.
- The MWR 24 GHz H-pol & 37 GHz (V- & H-pol) are a subset of the AMSR radiometers channels

AMSR Tb Forward Model

- Wentz AMSR algorithm is based on the fundamental principles of radiative transfer and explicitly shows:
  - The forward geophysical model function (GMF) defines relationships between radiometer measurements
    - Tb_{24h}, Tb_{24v}, Tb_{37h}, Tb_{37v}
  - and environmental inputs
    - Surface wind speed, W
    - Columnar water vapor, V
    - Cloud liquid water, CLW
    - Columnar rain rate, R
    - Atmos phys temp, T_{atmos}
    - Sea surface temp, SST

Liquid Water Transmissivity Algorithm

- The retrieval algorithm is the inversion of the forward model
  - Four equations (Tb_{24v}, Tb_{24h}, Tb_{37v}, Tb_{37h})

$$Tb_{24V} = F_{24V}(W, V, \tau_{L24}, SST)$$

$$Tb_{24H} = F_{24H}(W, V, \tau_{L24}, SST)$$

$$Tb_{37V} = F_{37V}(W, V, \tau_{L37}, SST)$$

$$Tb_{37H} = F_{37H}(W, V, \tau_{L37}, SST)$$

    - where SST is known a priori and τ_L is atmos transmissivity due to liquid water
- The simultaneous solution yields the four unknown parameters: $(W, V, \tau_{L24}, \tau_{L37})$

Liquid Water Transmissivity Algorithm cont.

- Unfortunately, these four non-linear equations have coefficients that are themselves f(V, SST)
  - Therefore, the complexity of the equations made the simultaneous solutions impractical using MatLab

$$F = T_U - (\tau_V \times \tau_O \times T_U) \times \tau_L + (\tau_V \times \tau_O \times \mathrm{E} \times SST) \times \tau_L +$$

$$(\tau_V \times \tau_O \times (1-\mathrm{E}) \times T_D) \times \tau_L - (\tau_V^2 \times \tau_O^2 \times (1-\mathrm{E}) \times T_D) \times \tau_L^2 +$$

$$2.7(\tau_V^2 \times \tau_O^2 \times (1-\mathrm{E}) \times T_D) \times \tau_L^2$$

$$T_U = function(V, f)$$

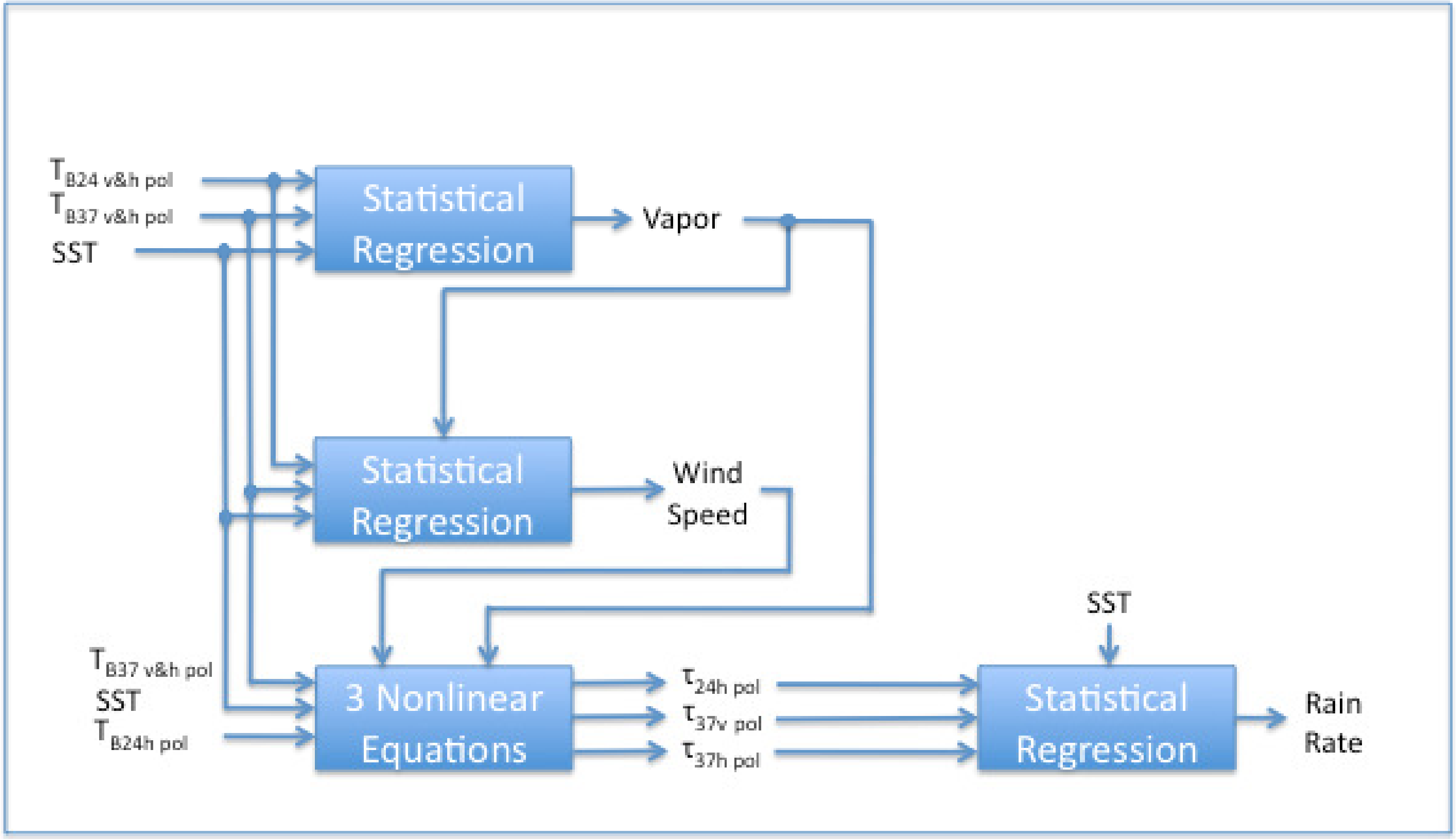
$$T_D = function(V, f)$$

$$\tau_V = function(V, f)$$

$$\tau_O = function(V, f)$$

$$\mathrm{E} = function(W, f, \theta_i)$$

Selected Rain Retrieval Approach



Water Vapor and Wind Speed Retrieval

- Statistical Regression to calculate Water Vapor
  - Dependent Variables: T_{B24h}, T_{B24v} ,T_{B37h} ,T_{B37v} , SST

$$V = function(T_{B24v}, T_{B24h}, T_{B37v}, T_{B37h}, SST)$$

- Statistical Regression to calculate Wind Speed
  - Dependent Variables: T_{B24h}, T_{B24v} ,T_{B37h} ,T_{B37v} , SST, V

$$W = function(T_{B24v}, T_{B24h}, T_{B37v}, T_{B37h}, SST, V)$$

  - When rain is present, wind speed regression produces negative values which are replaced by a priori estimate of wind speed = 6.5 m/s

Liquid Water Transmissivity Retrieval

- After solving for V & W sequentially, this yields three 2nd-order equations of a single variable:

$$T_{B24h} = a_1 + b_1 \times \tau_{L24h} + c_1 \times \tau_{L24h}^2$$

$$T_{B37v} = a_2 + b_2 \times \tau_{L37v} + c_2 \times \tau_{L37v}^2$$

$$T_{B37h} = a_3 + b_3 \times \tau_{L37h} + c_3 \times \tau_{L37h}^2$$

where the coefficients based on AMSR Tbs are

$$a_{coeff} = function(T_U, f)$$

$$b_{coeff} = function(\tau_O, \tau_V, T_D, T_U, SST, \mathrm{E}, f)$$

$$c_{coeff} = function(\tau_O, \tau_V, T_D, T_{ex}, \mathrm{E}, f)$$

Rain Rate Retrieval

- Statistical regression used to estimate columnar rain rate (R) as a function of
  - τ_{L24} & τ_{L37} (atmos transmissivity due to liquid water)
  - Height and temperature of rain (Wentz 1998)

$$H = function(SST)$$

$$T_L = (SST + 273)/2 \quad (Kelvin)$$

- Rain statistical regression – 3rd order

$$R = function(H, T_L, \tau_{L24h}, \tau_{L37v}, \tau_{L37h})$$

Tuning WindSat Brightness Temperature

- Coefficients for liquid water transmissivity equations are based on AMSR Tb's
- Tuning is necessary to match WindSat and AMSR Tb's

Geophysical Model Function: $F_{freq}(W,V,\tau_L)$

- GMF = Model TBs from radiative transfer theory
- Using GMF's from Wentz (1997) :

$$F_{freq}(W,V,\tau_L) = T_{BU} + \tau_{atmos} \times [E \times SST + (1-E) \times (T_{BD} + \tau_{atmos} \times T_{BC})]$$

Where

F(W,V,t) = modeled AMSR Tb's

T_{BU} = Upwelling Brightness Temperature (freq dependent)

τ_{atmos} = Atmospheric transmittance (freq dependent)

E = Sea-surface emissivity (freq dependent)

SST = Sea Surface Temperature

T_{BD} = Downwelling Brightness Temperature (freq dependent)

T_{BC} = Cosmic Background Radiometric Temperature (2.7 K)

Empirical Relationships (based on AMSR)

- Atmospheric components (τ_{atm}, T_{BU}, T_{BD}, T_U, T_D)

$$\tau_{atm} = function(V, SST, \tau_L, f)$$

$$T_U \approx T_D = function(V, SST, f)$$

$$T_{BU} = (1 - \tau_{atm}) * T_U = function(V, SST, f, \tau_L)$$

$$T_{BD} = (1 - \tau_{atm}) * T_D = function(V, SST, f, \tau_L)$$

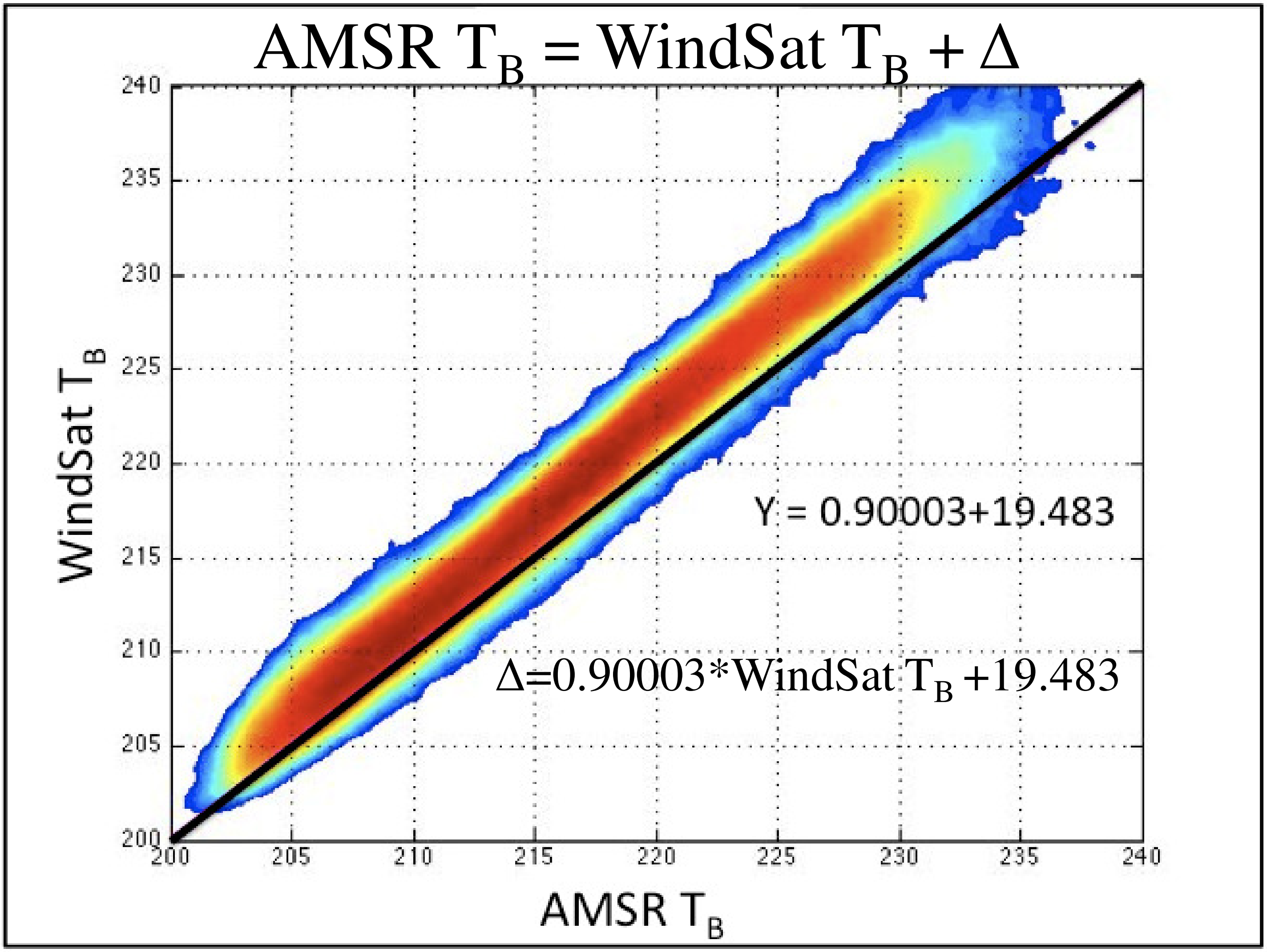
- Sea Surface components – Emissivity

$$\varepsilon = \varepsilon_0 + \Delta\varepsilon_W$$

$$\varepsilon_0 = function(SST,\ salinity,\ \theta_i,\ f)$$

$$\Delta\varepsilon_W = function(W, f)$$

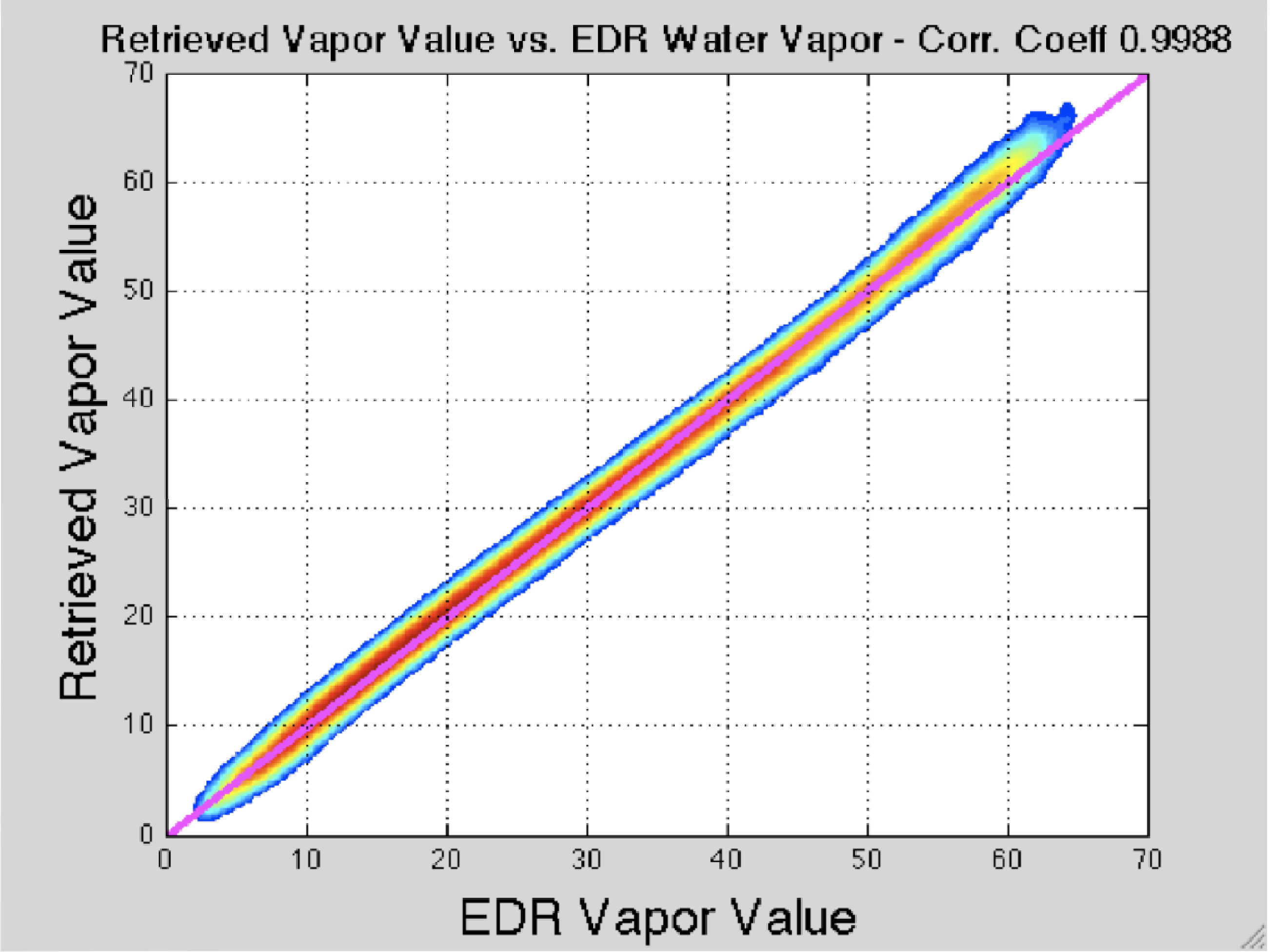
AMSR and WindSat Tb Tuning



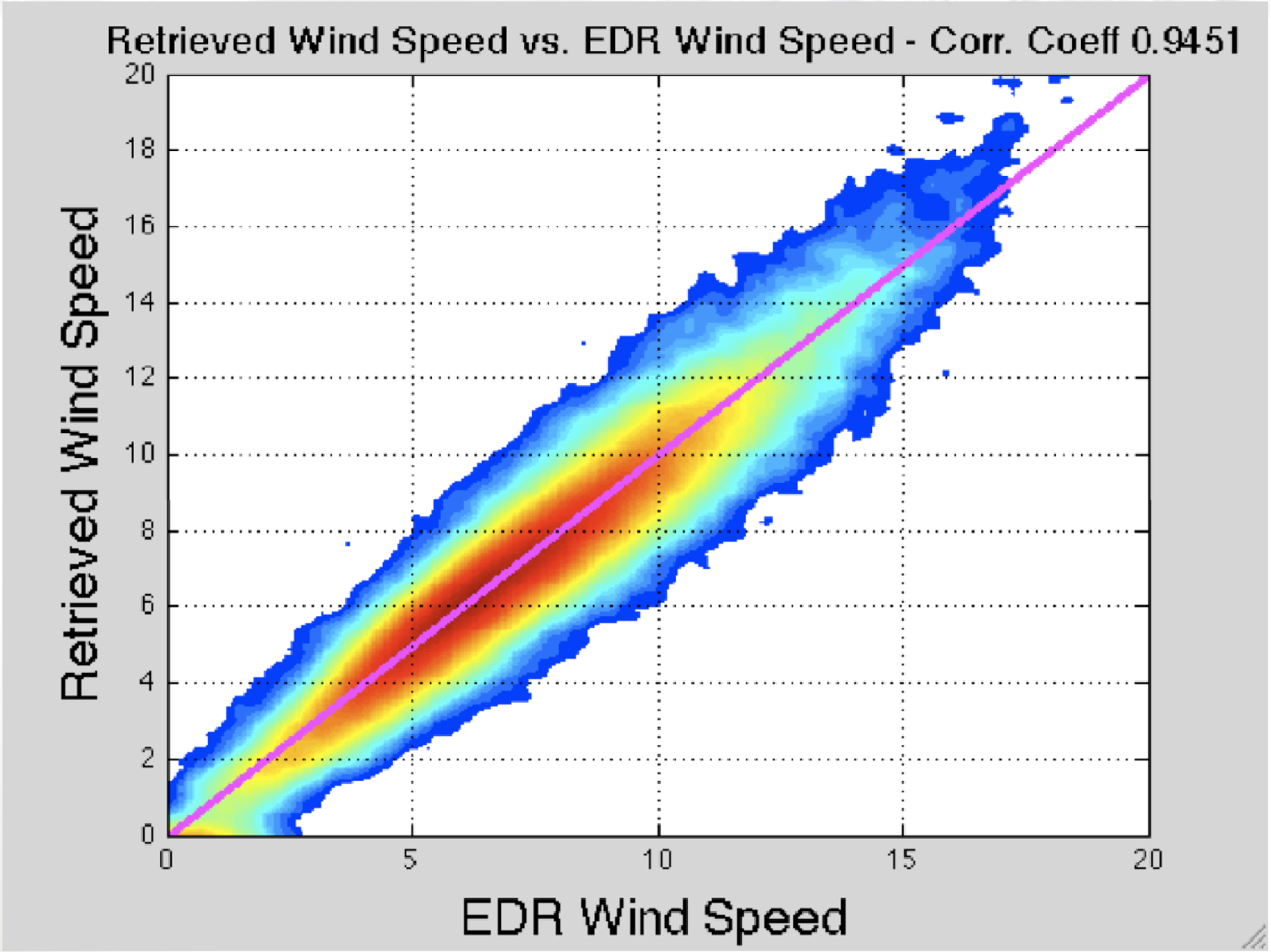
WindSat Retrieval results

- EDR = WindSat Environmental data record retrievals
  - Water Vapor
  - Wind Speed
  - Rain Rate

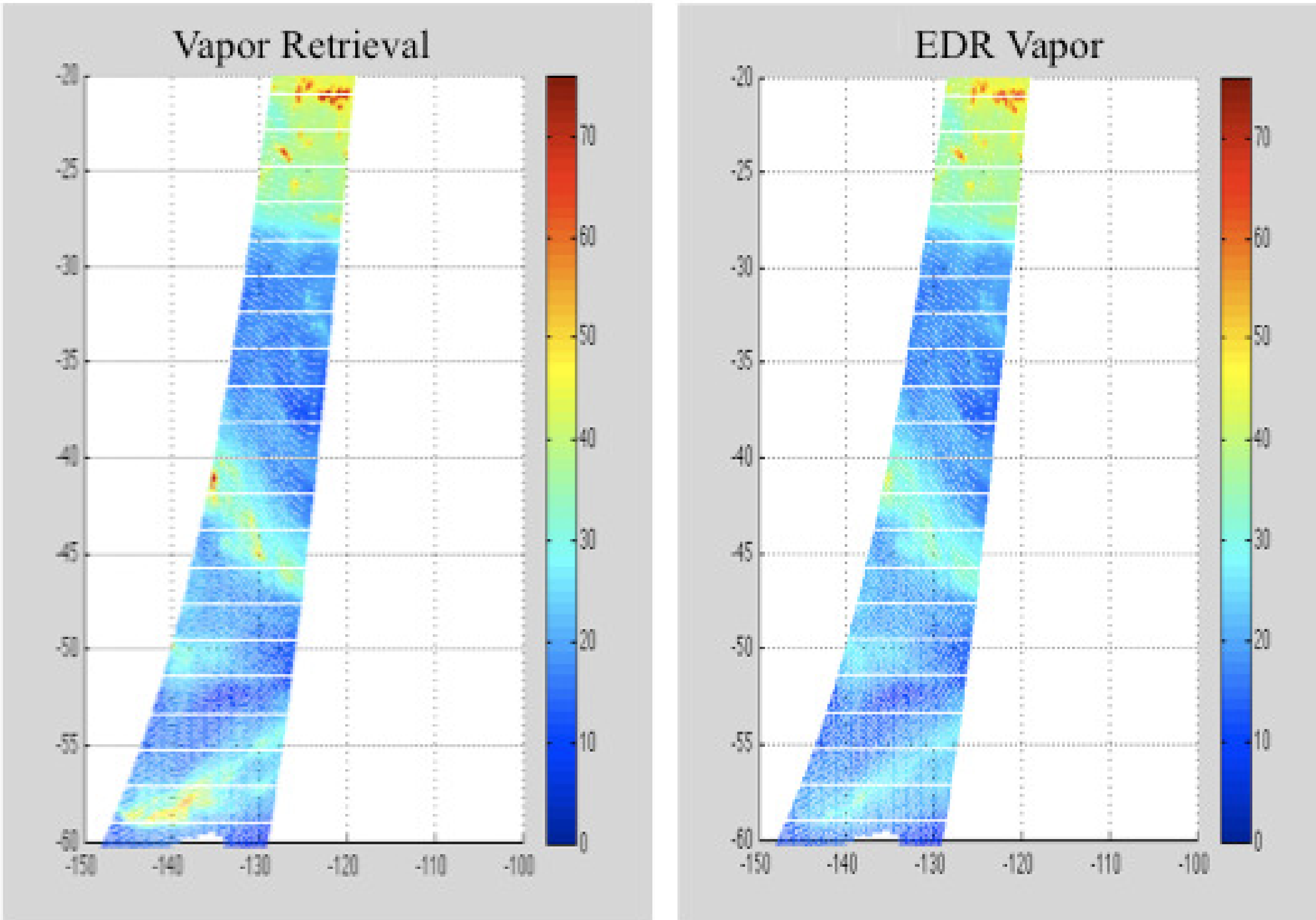
Water Vapor Retrieval (Rain-Free)



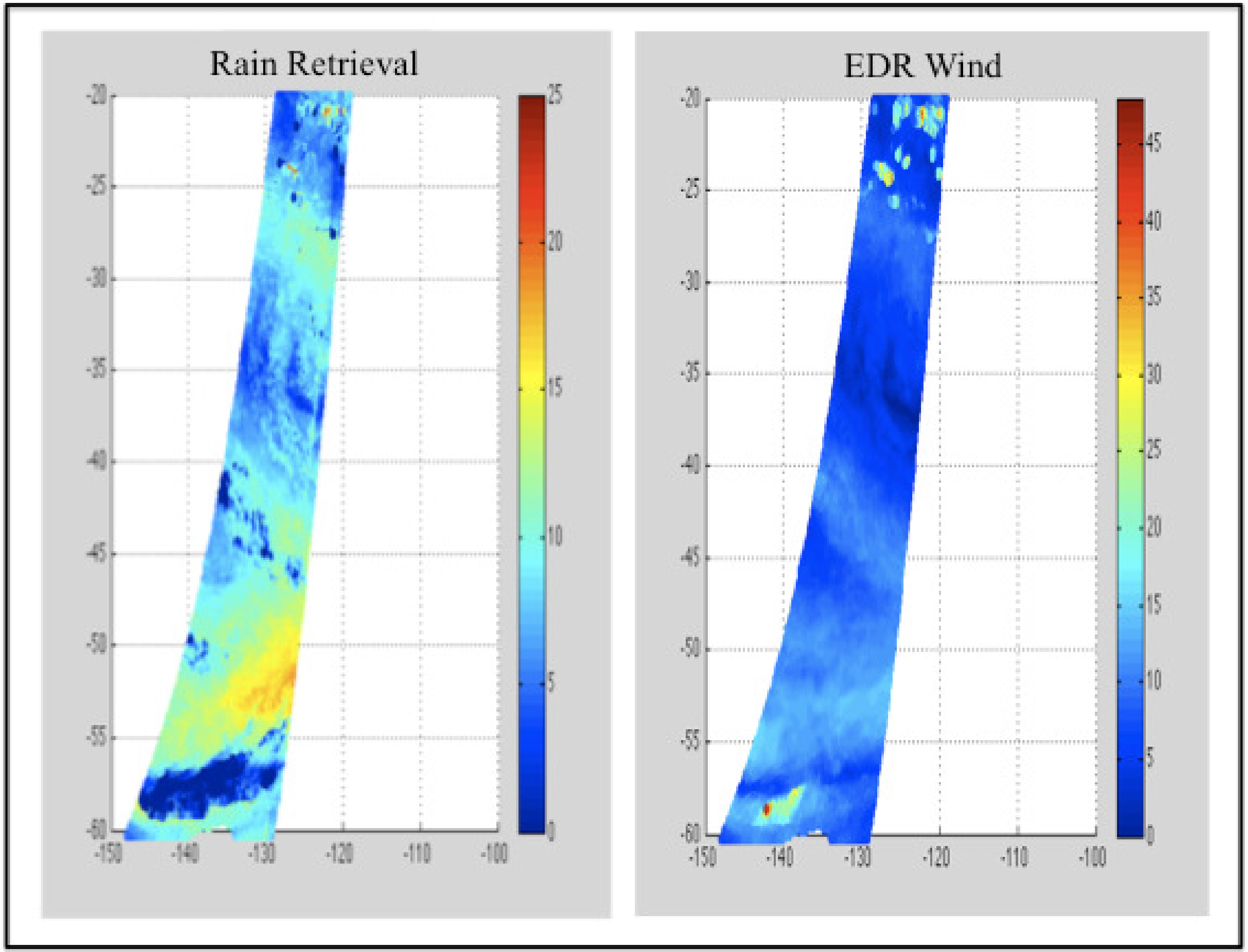
Wind Speed Regression (Rain-free)



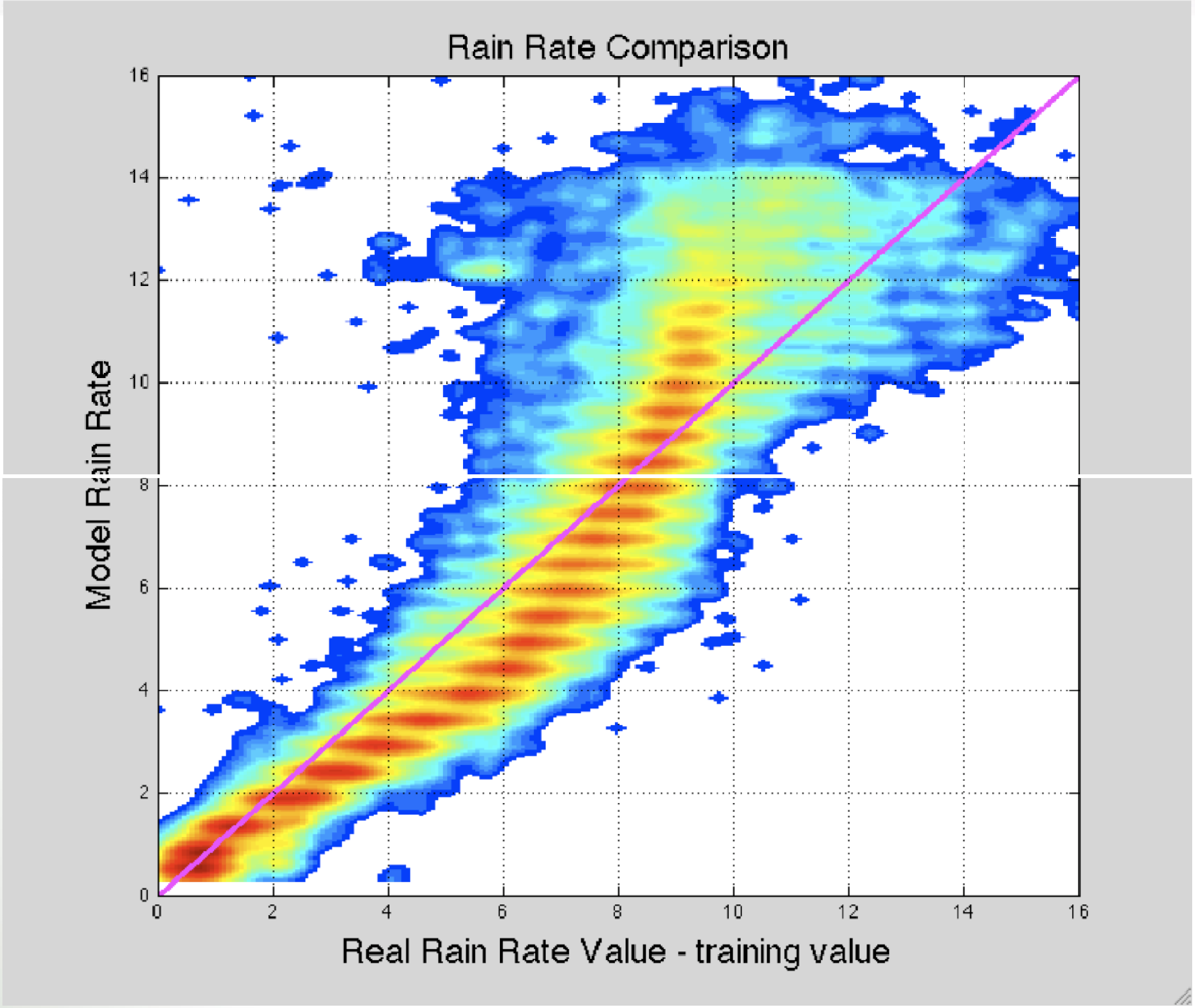
Water Vapor Comparison



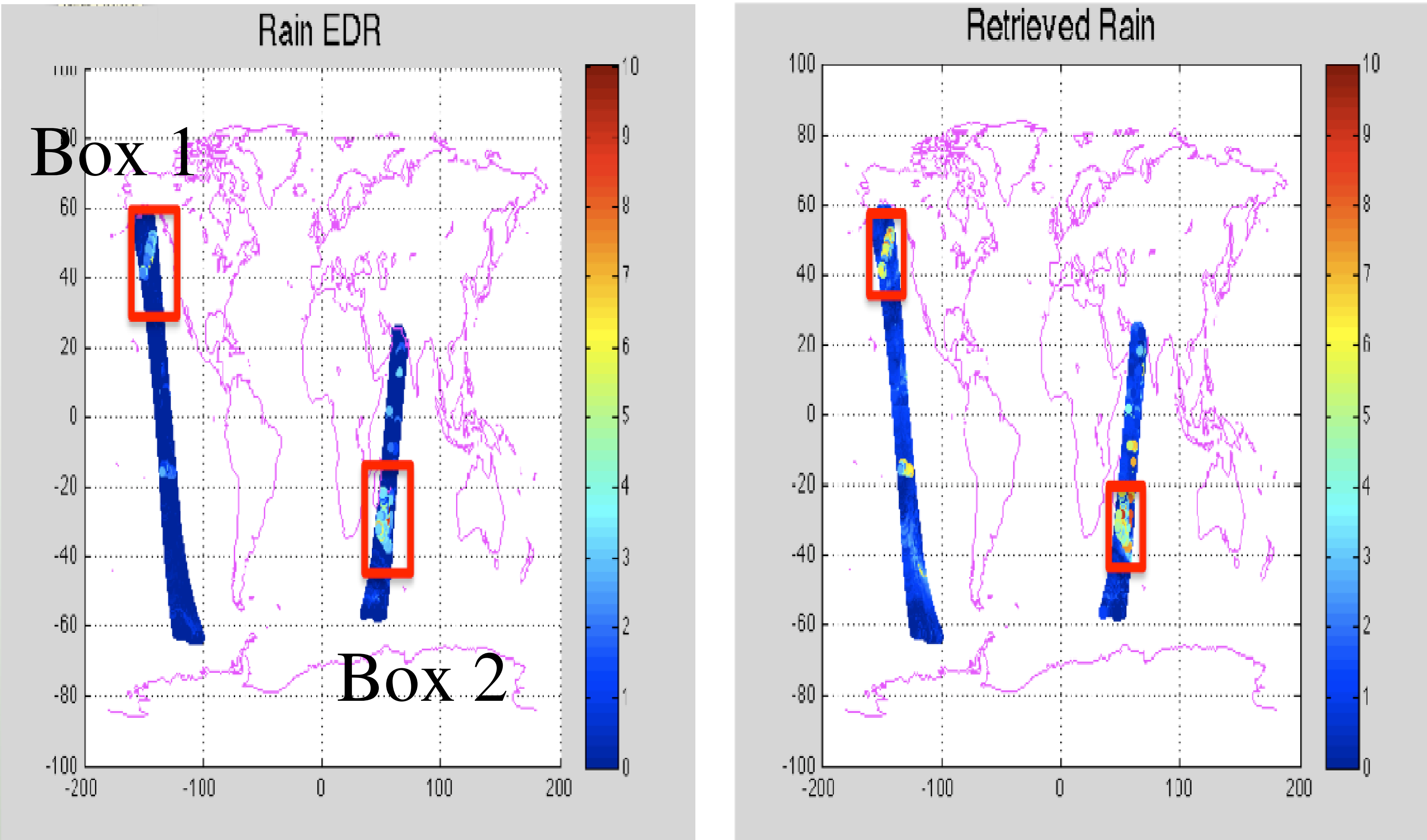
Wind Speed Comparison



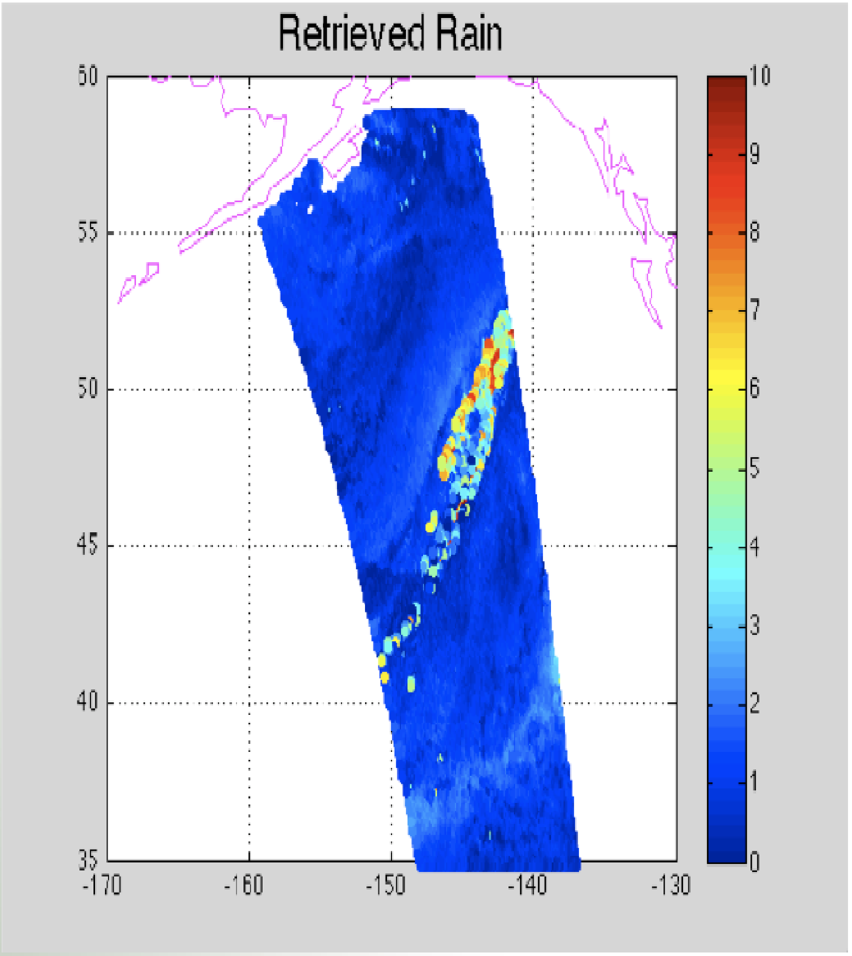
Rain Rate Comparison

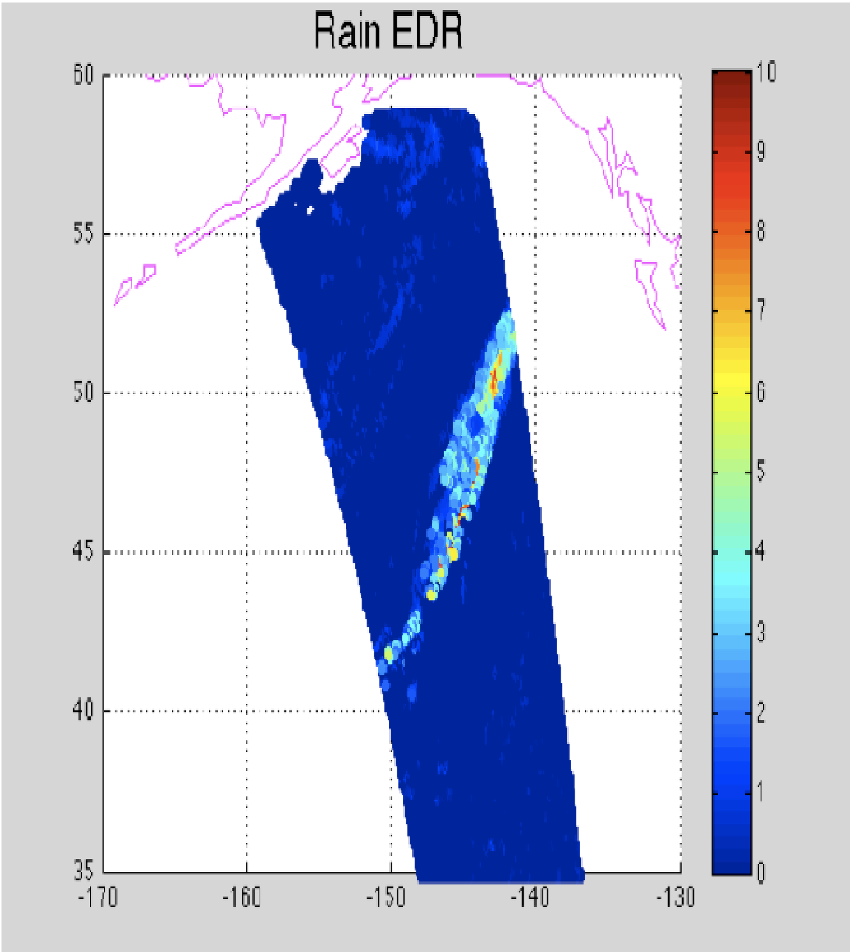


Rain Rate Image

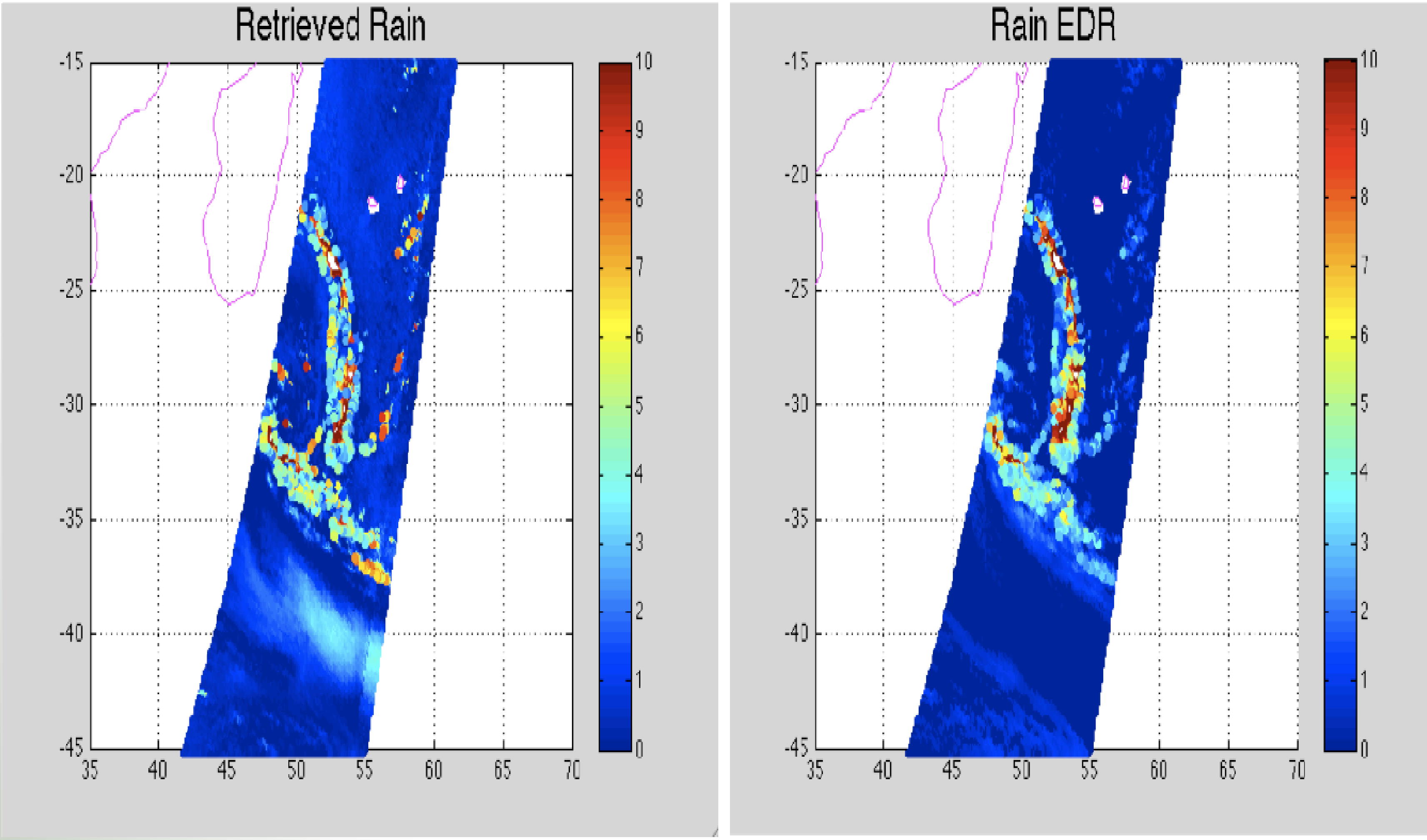


Rain Rate Comparison - Box 1





Rain Rate Comparison - Box 2



Conclusion

- A semi-empirical rain rate retrieval algorithm has been developed for the WindSat satellite radiometer
  - Algorithm implemented in MatLab
  - Capable of processing satellite data (faster than real time)
- Geophysical Retrievals
  - Water Vapor, Wind Speed, Atmos Transmissivity due to Liquid Water (24 GHz & 37 GHz), and Rain Rate
  - Performed rain rate validation using independent WindSat data set (~ 2 million pixels)

Future Work

- Investigate using GDAS water vapor and wind speed to retrieve atmos transmissivity (due to liquid water)
- Simulate MWR Tb measurements at spatial resolution: IFOV = 40 x 60 km
  - Retrieve atmos transmissivity @ 24 GHz & 37 GHz
  - Perform rain rate statistical regression
  - Validate rain rate retrieval error using WindSat EDR's
- Develop MWR Rain Retrieval Algorithm Theoretical Basis Document (ATBD)
  - Deliver to CONAE early Dec. 2010