Path attenuation estimates for the DPR

Robert Meneghini[1], Hyokyung Kim[2] and Liang Liao[2]

1. NASA/GSFC, Greenbelt, MD
2. Morgan State University, Goddard Earth Science Technology and Research, Greenbelt, MD

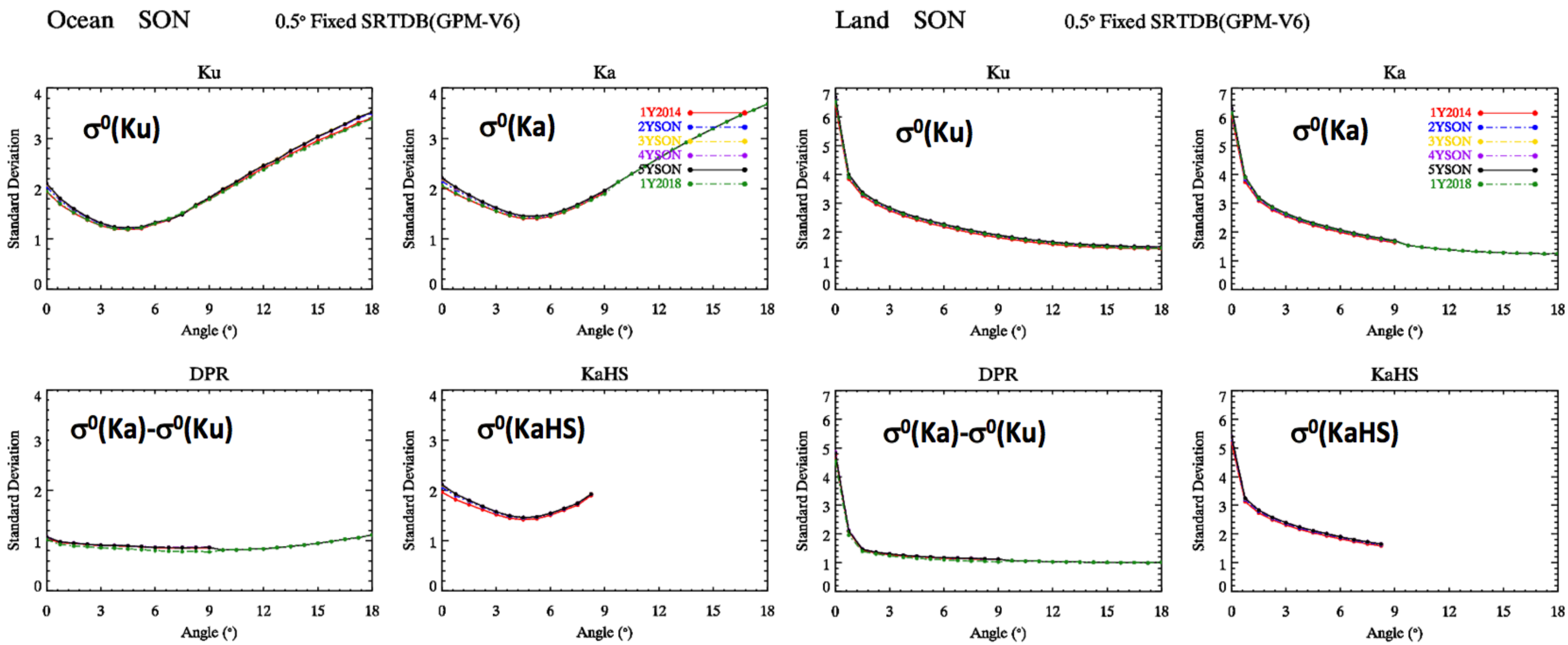
Outline

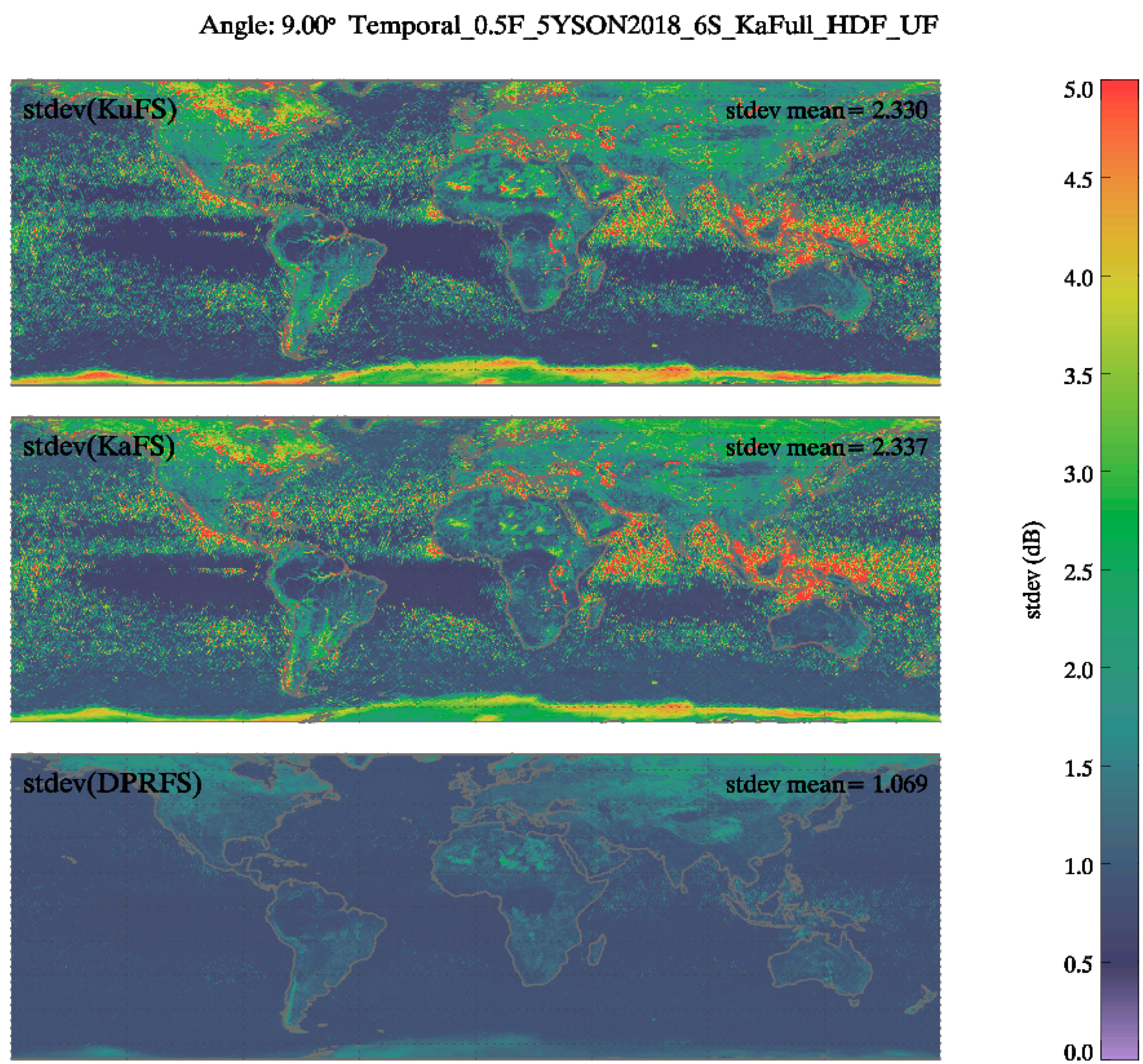
- Developments in path attenuation algorithm(s)
- Basic Ideas and Equations
- Some V6A/V6X comparisons
- Statistical Comparisons
- Progress in temporal look-up tables
- Issues, Questions
- Developments in L3-DPR algorithm

Developments in path attenuation algorithm

- With dual-freq radar data, we're able to extend SRT to 2 frequencies
  - Variance of $\delta\sigma^0$ (σ^0(Ka)- σ^0(Ku)) is smaller than σ^0(Ku)/σ^0(Ka) [rain-free]
  - $\delta\sigma^0$ shows less angle-dependence than σ^0(Ku)/σ^0(Ka) [rain-free]

- Despite this, SRT/DSRT is still limited at low & high rain rates
  - At high R, loss of σ^0(Ka) signal $\Rightarrow$ revert to single-freq (Ku-band) method
  - At low R, std dev of σ^0, $\delta\sigma^0$ limits accuracy $\Rightarrow$ use other method(s)
  - At low R, often the case that Ku detects rain but Ka does not $\Rightarrow$ revert to single-freq (Ku-band) SRT or, better yet, single-freq hybrid
    - (differential sensitivity between Ku/Ka –band especially in inner swath)


Ocean SON
0.5° Fixed SRTDB(GPM-V6)
Land SON
0.5° Fixed SRTDB(GPM-V6)
Ku
Ka
σ0(Ku)
σ0(Ka)
σ0(Ka)-σ0(Ku)
σ0(KaHS)
DPR
KaHS
1Y2014
2YSON
3YSON
4YSON
5YSON
1Y2018
Standard Deviation
Angle (°)



Angle: 9.00° Temporal_0.5F_5YSON2018_6S_KaFull_HDF_UF
stdev(KuFS)
stdev mean= 2.330
stdev(KaFS)
stdev mean= 2.337
stdev(DPRFS)
stdev mean= 1.069
stdev (dB)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0

Developments in path attenuation algorithm

- Improve PIA estimate by considering other methods
  - Hitschfeld-Bordan (HB)
  - Standard dual-wavelength (DW)
  - (Other methods: Dr. Iguchi's method; PIA derived from radar T_B (Dr. Kanemaru))
  - Combine results into a 'hybrid' estimate of PIA (HY)
  - Multiple estimates of PIA give insight into strengths/weaknesses of each method

- Revise algorithms to accommodate new Ka-band scan pattern (V6X)
  - Dual-freq SRT and Hybrid estimates are now applicable to the full swath
  - Issue with definitions of 'reliabFactor' for SRT & Hybrid estimates
  - Issue with 'standard dual-wavelength' method
  - Issue with how the PIA's are affecting rain rates (in outer swath)

- Continue work on updating temporal look-up rain-free σ^0 tables

Basic Equations

•

$$SRT:$$

$$A(r_s) = 2\int_0^{r_s} k(s)ds$$

$$k(s) = c\int_{D_{\min}}^{D_{\max}} \sigma_{ext}(D)N(D;s)dD$$

$$\hat{A}_{SRT}(r_s) = \sigma^0(no-rain) - \sigma^0(rain)$$

$$DSRT:$$

$$\delta A(r_s) = A(Ka, r_s) - A(Ku, r_s)$$

$$\delta\hat{A}_{SRT}(r_s) = \delta\sigma^0(no-rain) - \delta\sigma^0(rain)$$

$$\delta\sigma^0 = \sigma^0(Ka) - \sigma^0(Ku)$$

Basic Equations

SRT

$$A_{SRT}(f_i) = \sum_{j=1}^{5} w_j A_j(f_i); \quad (f_1 = 13.6\,GHz, \quad f_2 = 35.5\,GHz)$$

$$\delta A_{SRT} = \sum_{j=1}^{5} \tilde{w}_j \,(\delta A_i)$$

$$A_1 = A_{FA},\; A_2 = A_{BA}, A_3 = A_{FX}, A_4 = A_{BX}, A_5 = A_T$$

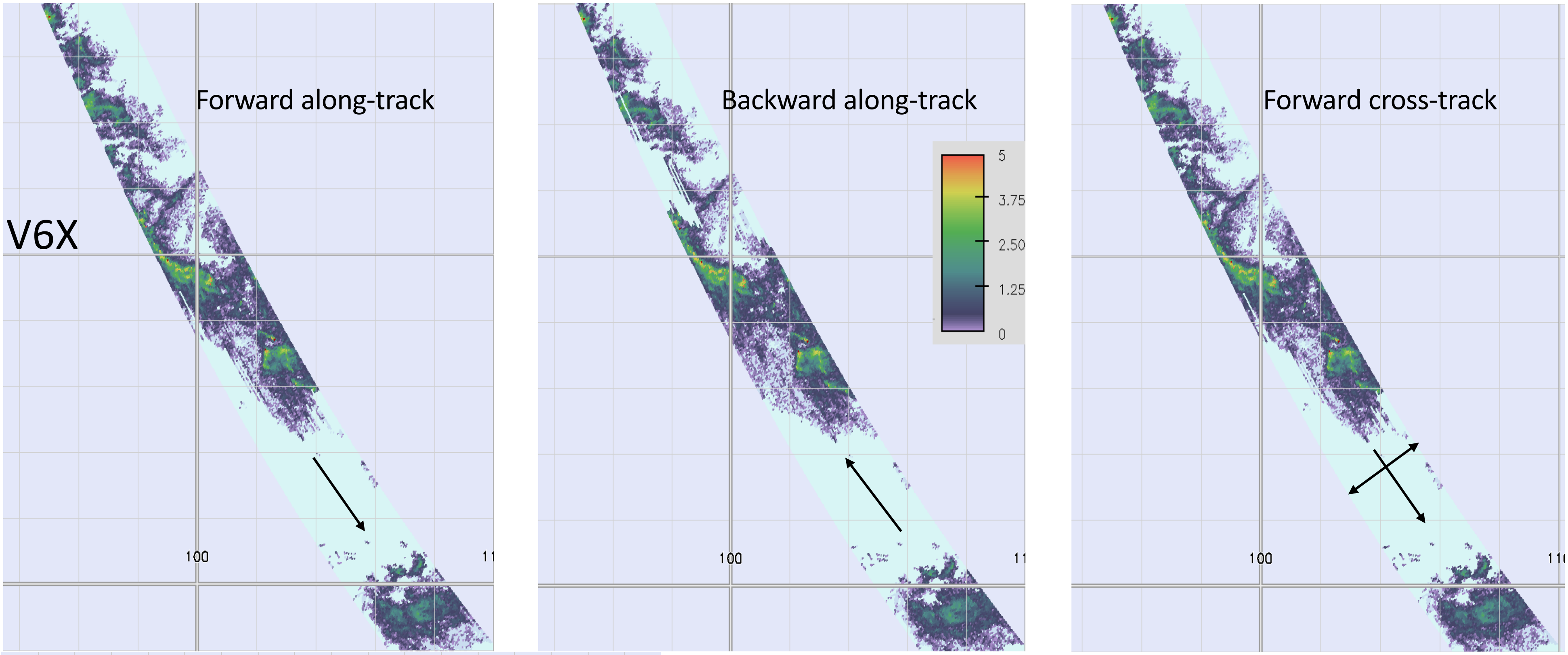
$$\delta A_1 = \delta A_{FA},\; \delta A_2 = \delta A_{BA}, \delta A_3 = \delta A_{FX},\; \delta A_4 = \delta A_{BX},\; \delta A_5 = \delta A_T$$

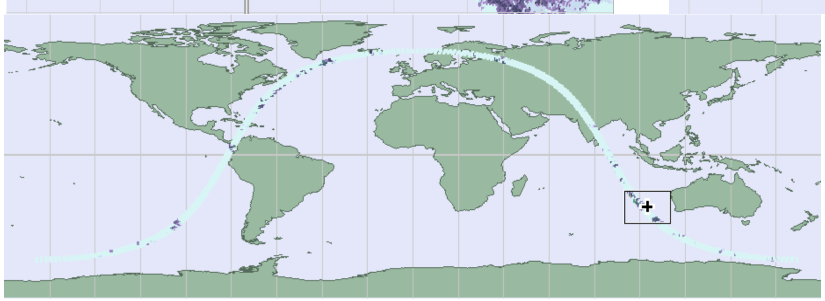
$$w_j \propto 1/\,\mathrm{var}(A_j)$$

$$\tilde{w}_j \propto 1/\,\mathrm{var}(\delta A_j)$$

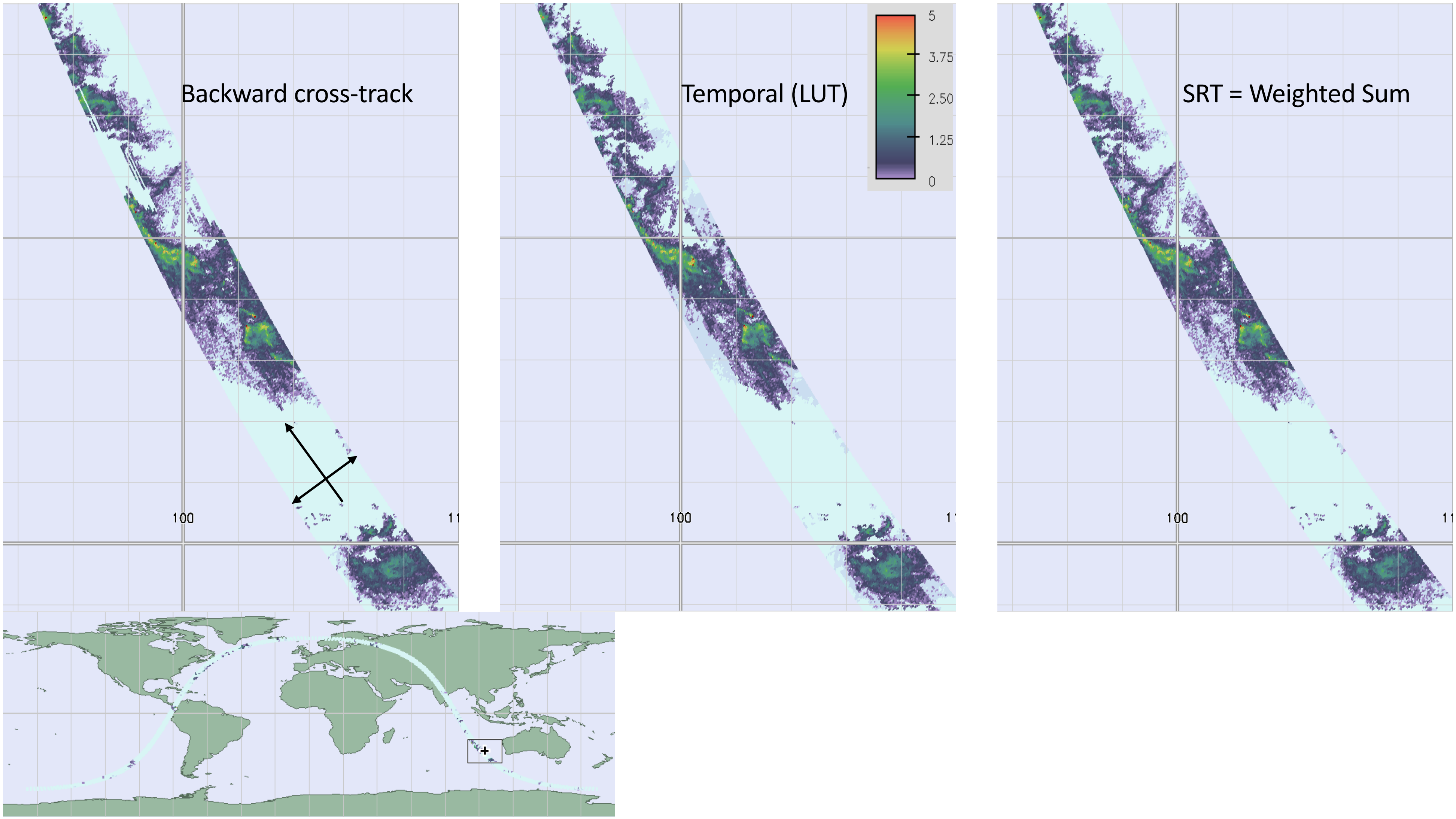
$$A_{FA} = \left\langle \sigma^0_{FA}(no-rain) \right\rangle - \sigma^0(rain)$$

$$\delta A_{FA} = \left\langle \delta\sigma^0_{FA}(no-rain) \right\rangle - \delta\sigma^0(rain)$$





- Orbit 24642, 30 Sep 2018
- DSRT(Ku-band) estimates
- West of Australia
- Version V6X


Backward cross-track
100
Temporal (LUT)
5
3.75
2.50
1.25
0
100
SRT = Weighted Sum
100

Basic Equations

- For Hybrid

$$A_{HY}(f_i) = \sum_{j=1}^{2} w_j A_j(f_i)$$

$$\delta A_{HY} = \sum_{j=1}^{3} \tilde{w}_j\,(\delta A_i)$$

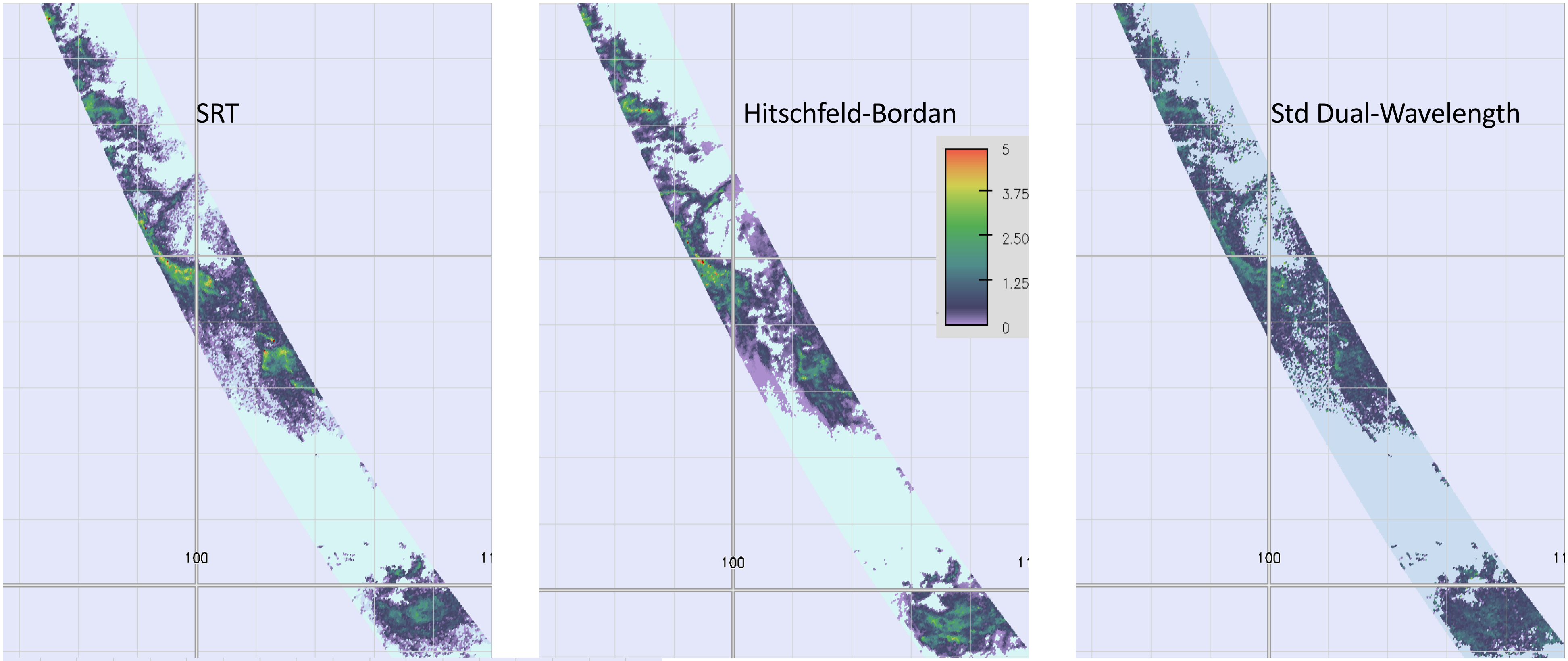
$$\delta A = A(Ka) - A(Ku)$$

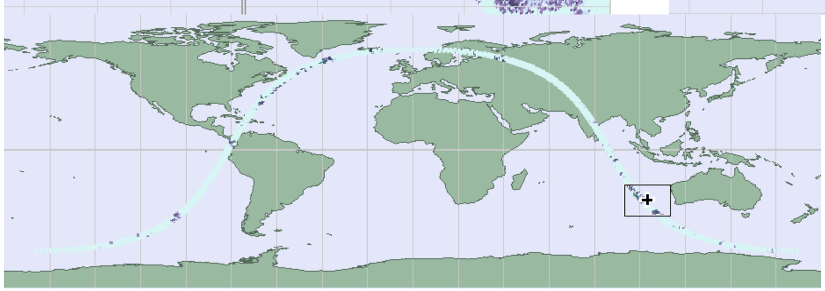
$$A_1 = A_{SRT},\ A_2 = A_{HB}$$

$$\delta A_1 = \delta A_{SRT},\ \delta A_2 = \delta A_{HB}, \delta A_3 = \delta A_{DW}$$

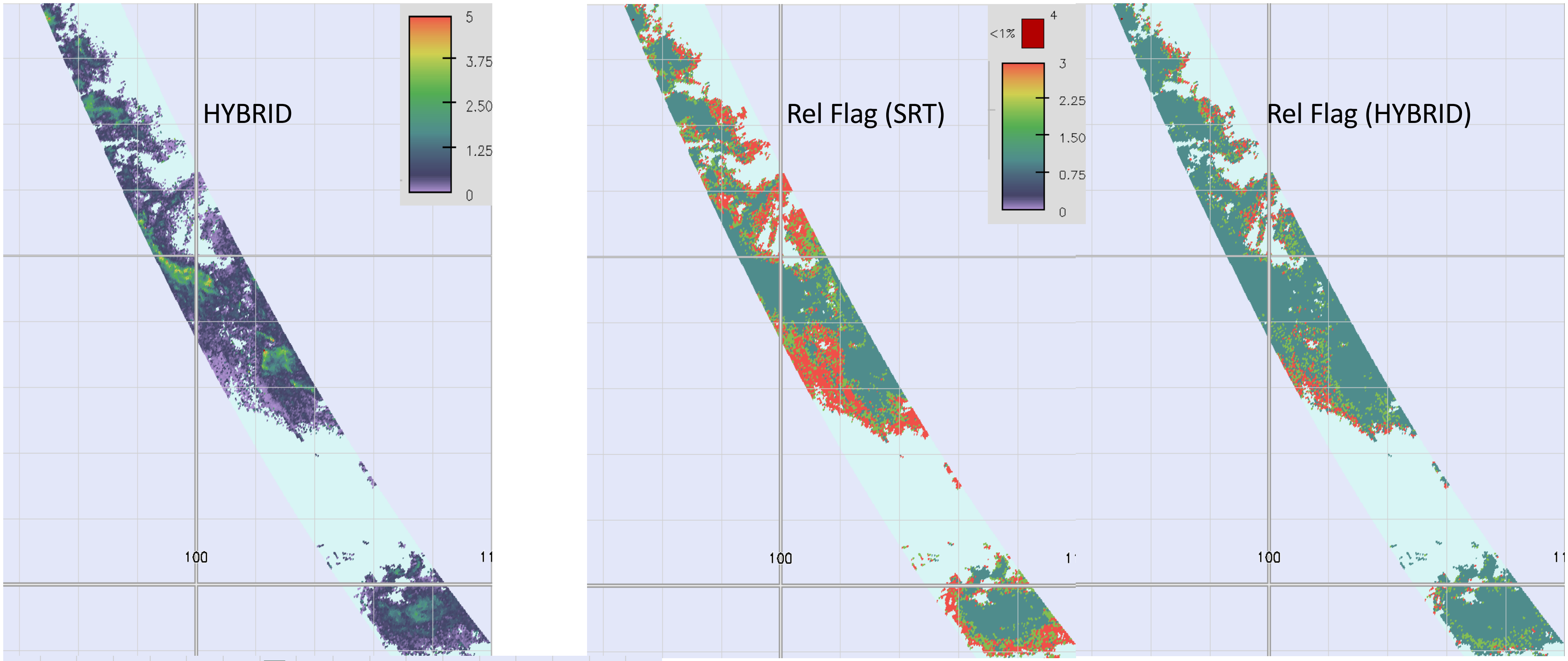
$$w_j \propto 1/\mathrm{var}(A_j)$$

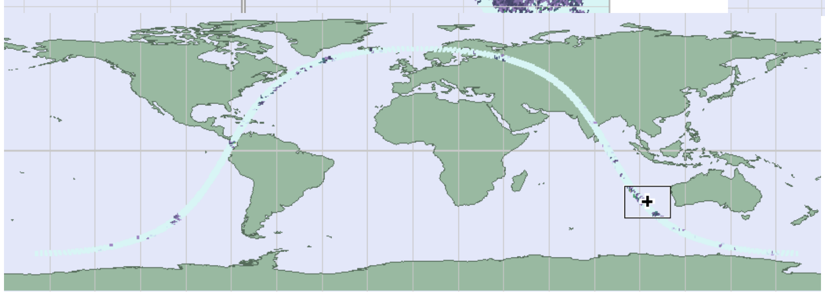
$$\tilde{w}_j \propto 1/\mathrm{var}(\delta A_j)$$





- Orbit 24642, 30 Sep 2018
- DHybrid(Ku-band) estimate
- West of Australia
- Version V6X





RelFactor = E(A)/σ(A)

Rel Flag = 1 (reliable) if RelFactor > 3

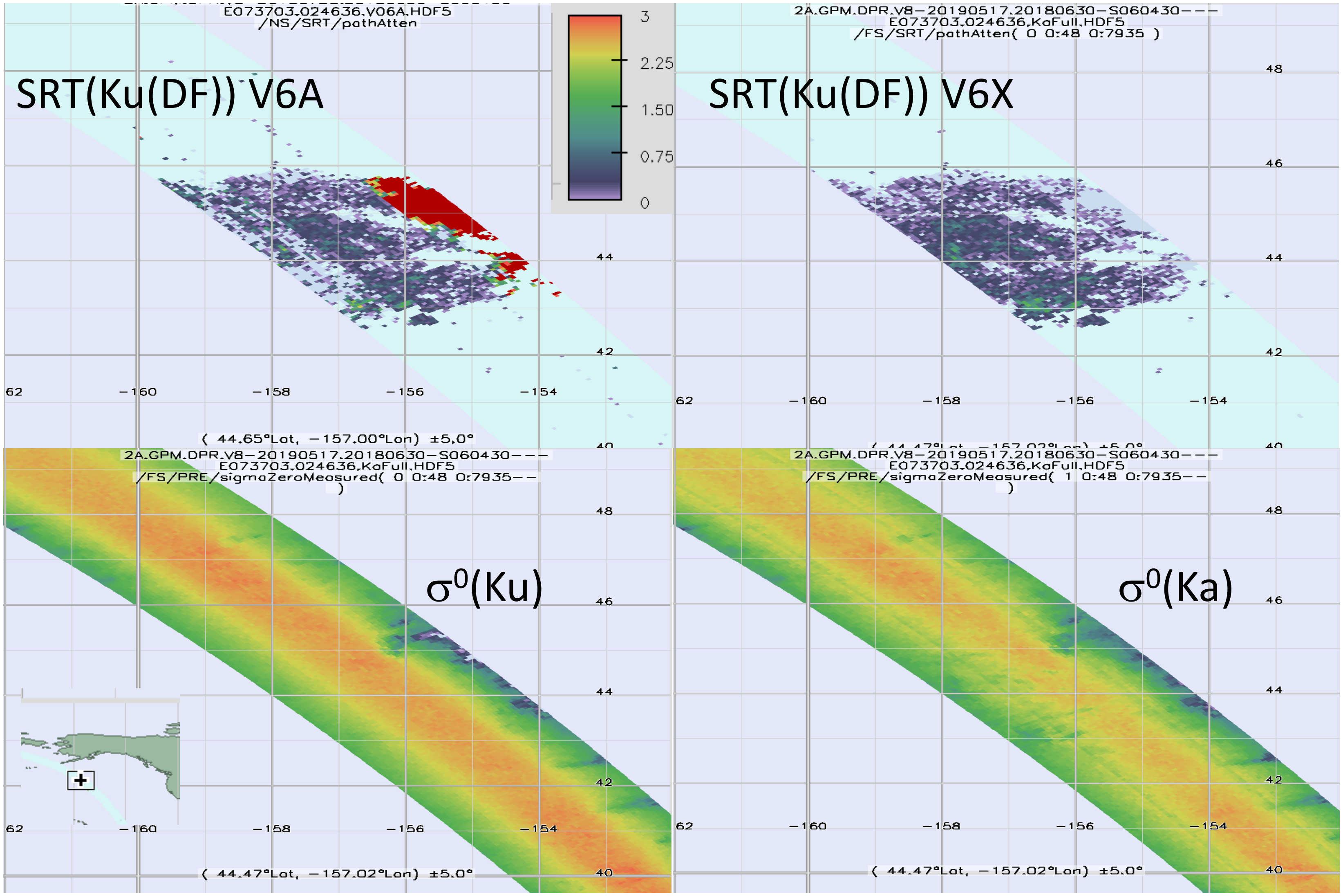
Rel Flag = 2 (marginally reliable) if 1 <RelFactor < 3

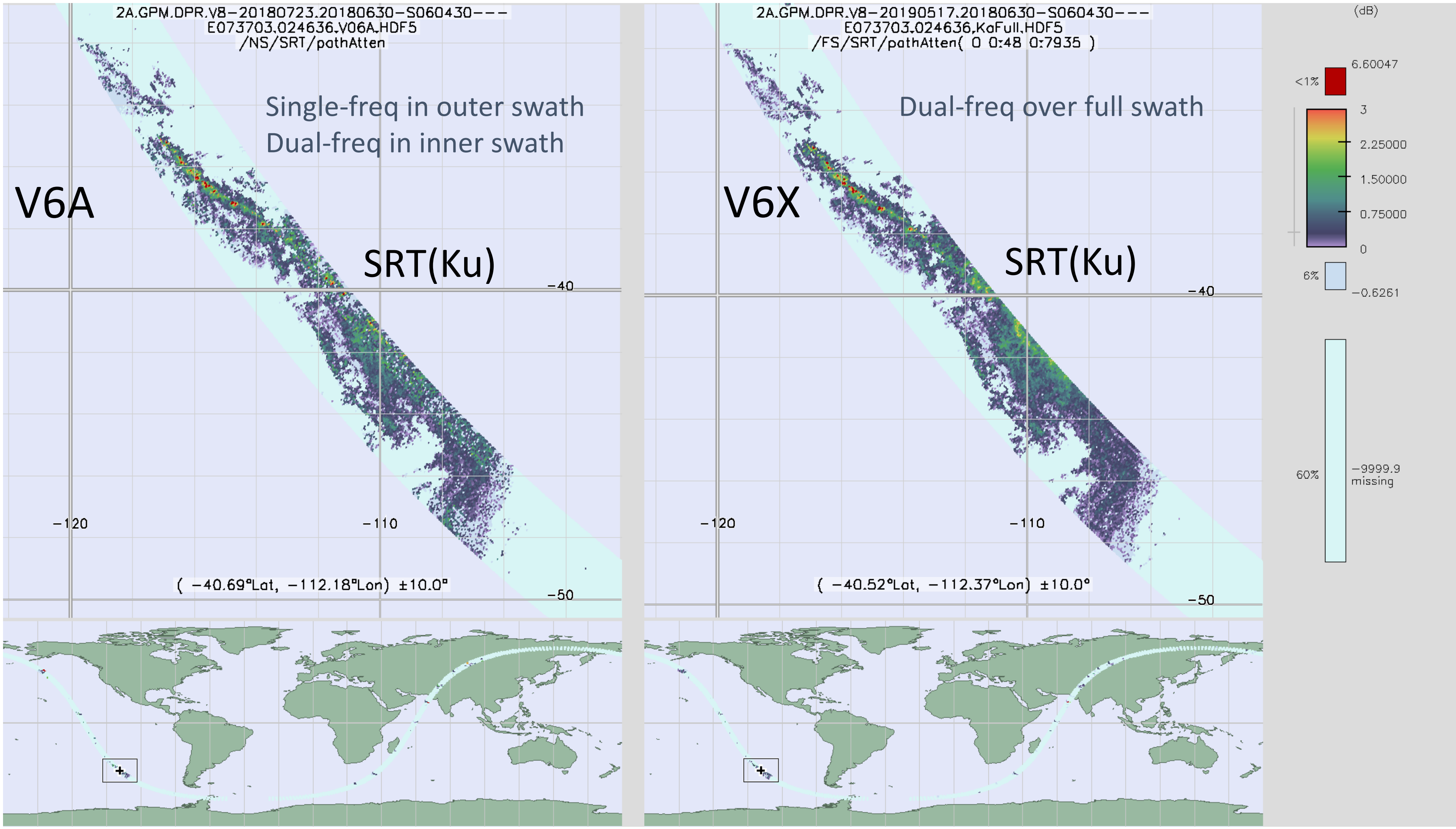
Rel Flag = 3 (unreliable) if RelFactor < 1

Rel Flag = 4 (lower bound) if surface at Ka not detected

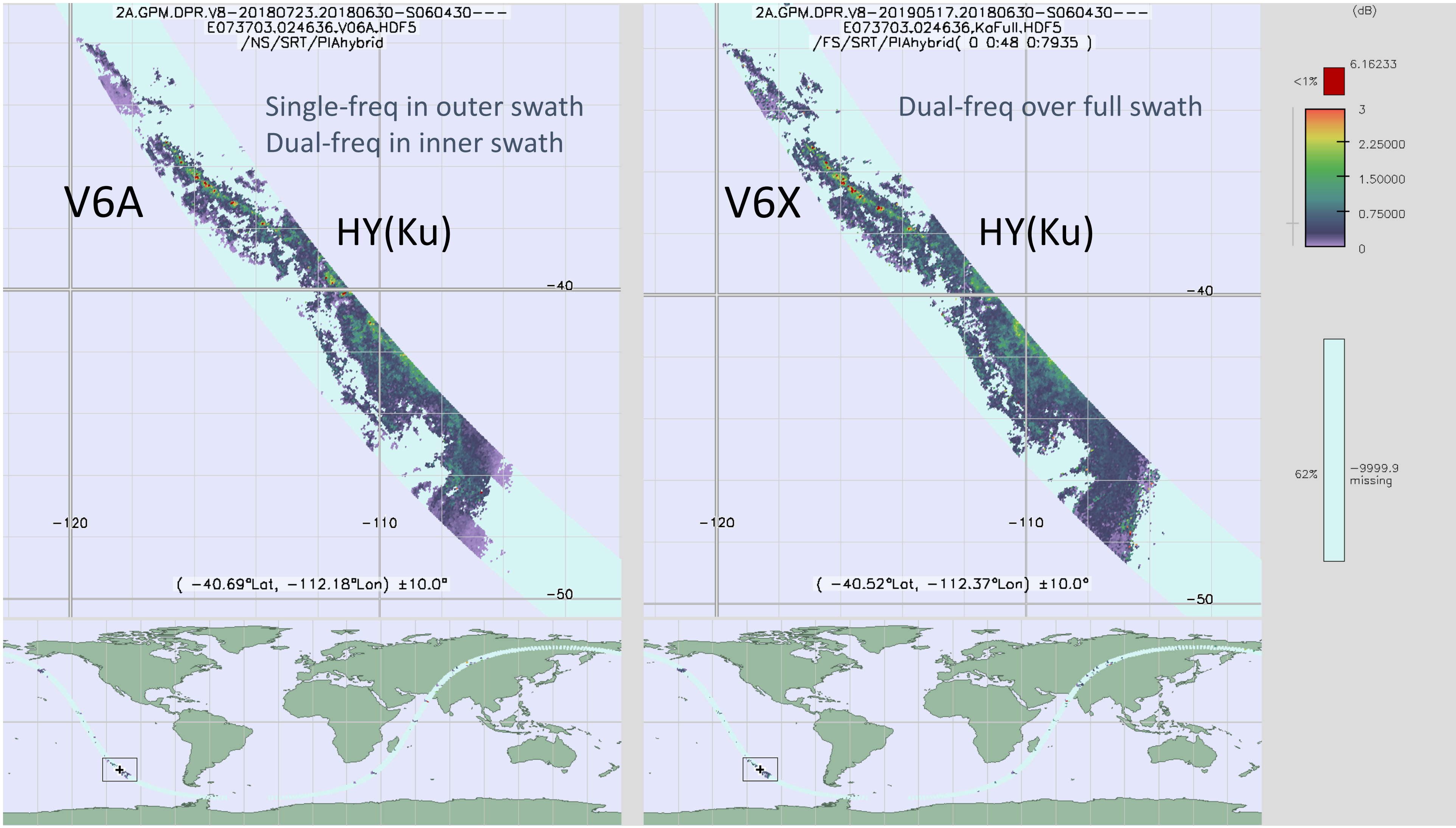
V6A (narrow swath Ka) vs V6X (full swath Ka)

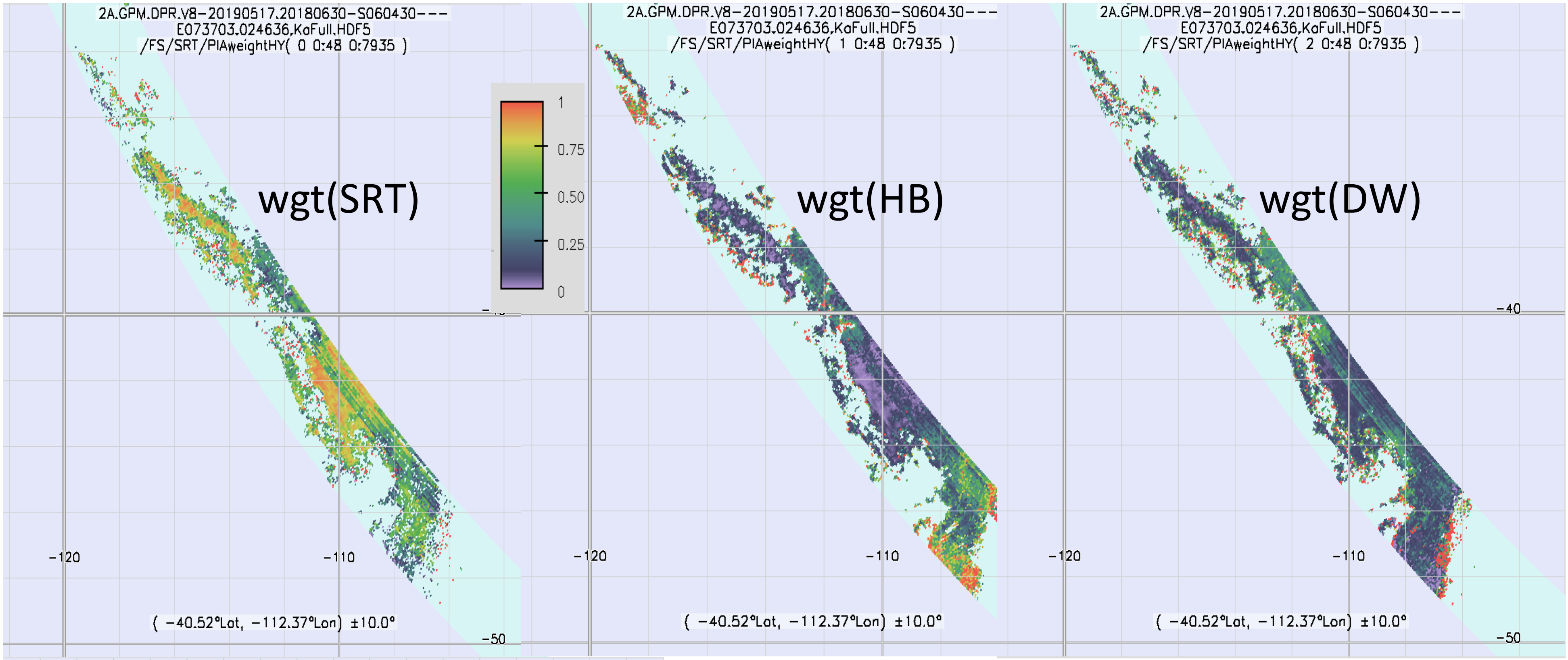
- Fairly extensive code changes made for new Ka-band scan
- Code needs to work both before & after scan change (V7)
- Comparisons between V6A and V6X
  - We see a reduction in number of large SRT overestimates in Outer Swath
  - For single-freq operation, at angles > 10 deg over ocean
    - Low wind speed reduces σ^0
    - When this occurs in the presence of rain, PIA is overestimated
    - However, $\delta\sigma^0$ is relatively independent of wind speed so bias is reduced
    - Opposite effect at high wind speeds
    - Inhomogeneities over land can have similar effects

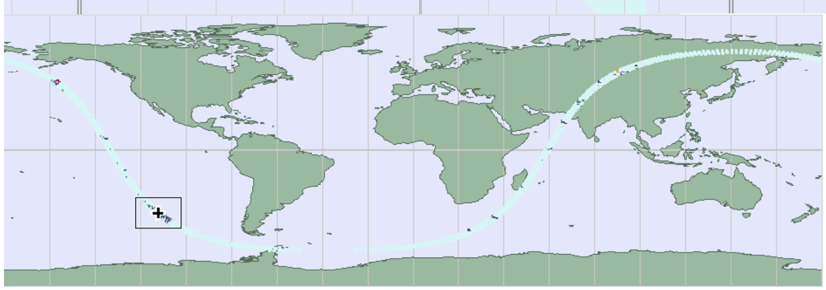

E073703.024636.V06A.HDF5
/NS/SRT/pathAtten
SRT(Ku(DF)) V6A
3
2.25
1.50
0.75
0
(44.65°Lat, −157.00°Lon) ±5.0°
2A.GPM.DPR.V8−20190517.20180630−S060430−−−
E073703.024636.KaFull.HDF5
/FS/SRT/pathAtten(0 0:48 0:7935)
SRT(Ku(DF)) V6X
2A.GPM.DPR.V8−20190517.20180630−S060430−−−
E073703.024636.KaFull.HDF5
/FS/PRE/sigmaZeroMeasured(0 0:48 0:7935−−
)
σ0(Ku)
(44.47°Lat, −157.02°Lon) ±5.0°
2A.GPM.DPR.V8−20190517.20180630−S060430−−−
E073703.024636.KaFull.HDF5
/FS/PRE/sigmaZeroMeasured(1 0:48 0:7935−−
)
σ0(Ka)
(44.47°Lat, −157.02°Lon) ±5.0°



2A.GPM.DPR.V8-20180723.20180630-S060430---
E073703.024636.V06A.HDF5
/NS/SRT/pathAtten
Single-freq in outer swath
Dual-freq in inner swath
V6A
SRT(Ku)
-40
-120
-110
-50
(-40.69°Lat, -112.18°Lon) ±10.0°
2A.GPM.DPR.V8-20190517.20180630-S060430---
E073703.024636.KaFull.HDF5
/FS/SRT/pathAtten(0 0:48 0:7935)
Dual-freq over full swath
V6X
SRT(Ku)
-40
-120
-110
-50
(-40.52°Lat, -112.37°Lon) ±10.0°
(dB)
<1%
6.60047
3
2.25000
1.50000
0.75000
0
6%
-0.6261
60%
-9999.9
missing


2A.GPM.DPR.V8-20180723.20180630-S060430---
E073703.024636.V06A.HDF5
/NS/SRT/PIAhybrid
Single-freq in outer swath
Dual-freq in inner swath
V6A
HY(Ku)
-40
-120
-110
(-40.69°Lat, -112.18°Lon) ±10.0°
-50
2A.GPM.DPR.V8-20190517.20180630-S060430---
E073703.024636.KaFull.HDF5
/FS/SRT/PIAhybrid(0 0:48 0:7935)
Dual-freq over full swath
V6X
HY(Ku)
-40
-120
-110
(-40.52°Lat, -112.37°Lon) ±10.0°
-50
(dB)
6.16233
<1%
3
2.25000
1.50000
0.75000
0
62%
-9999.9
missing

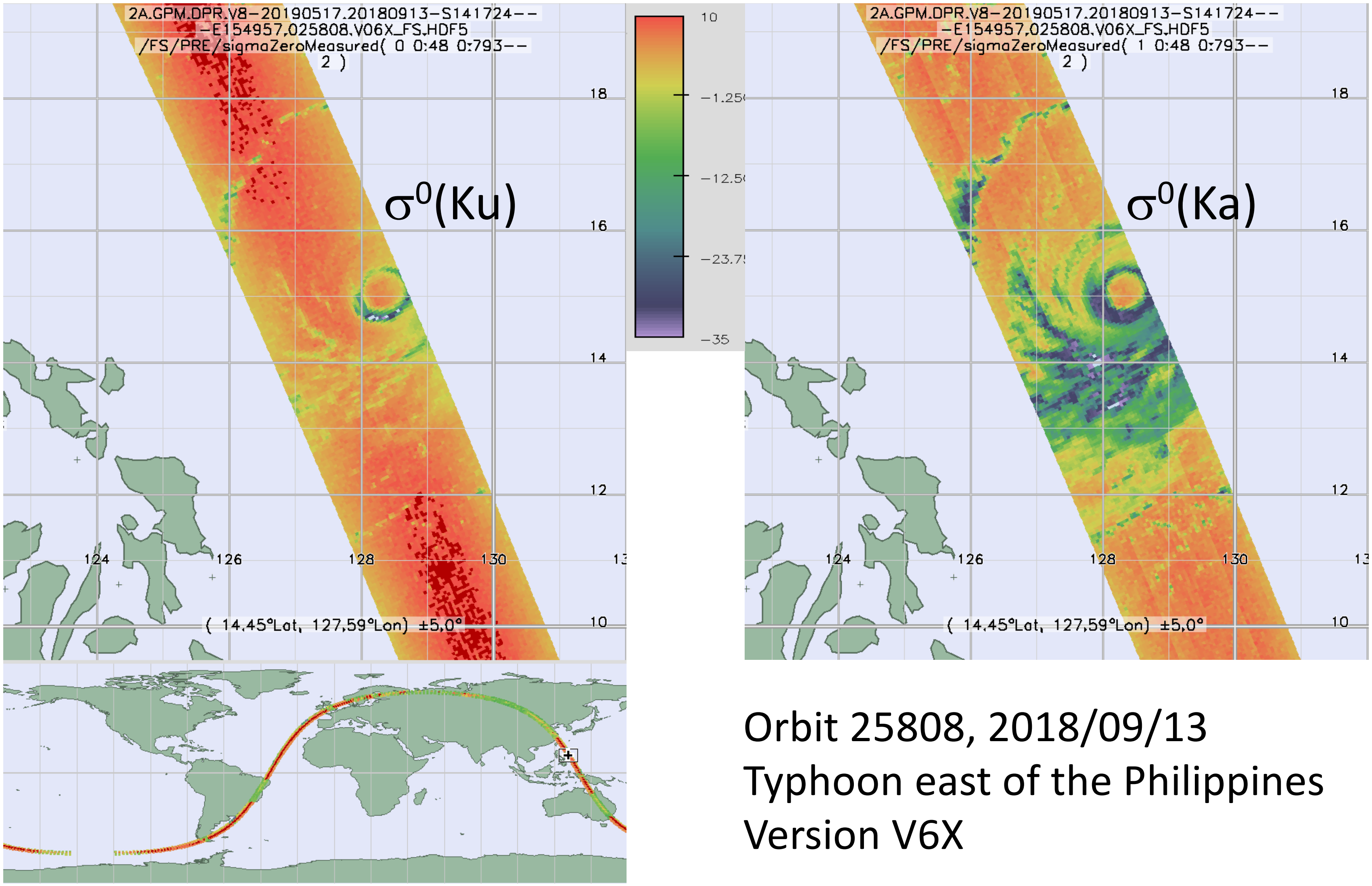




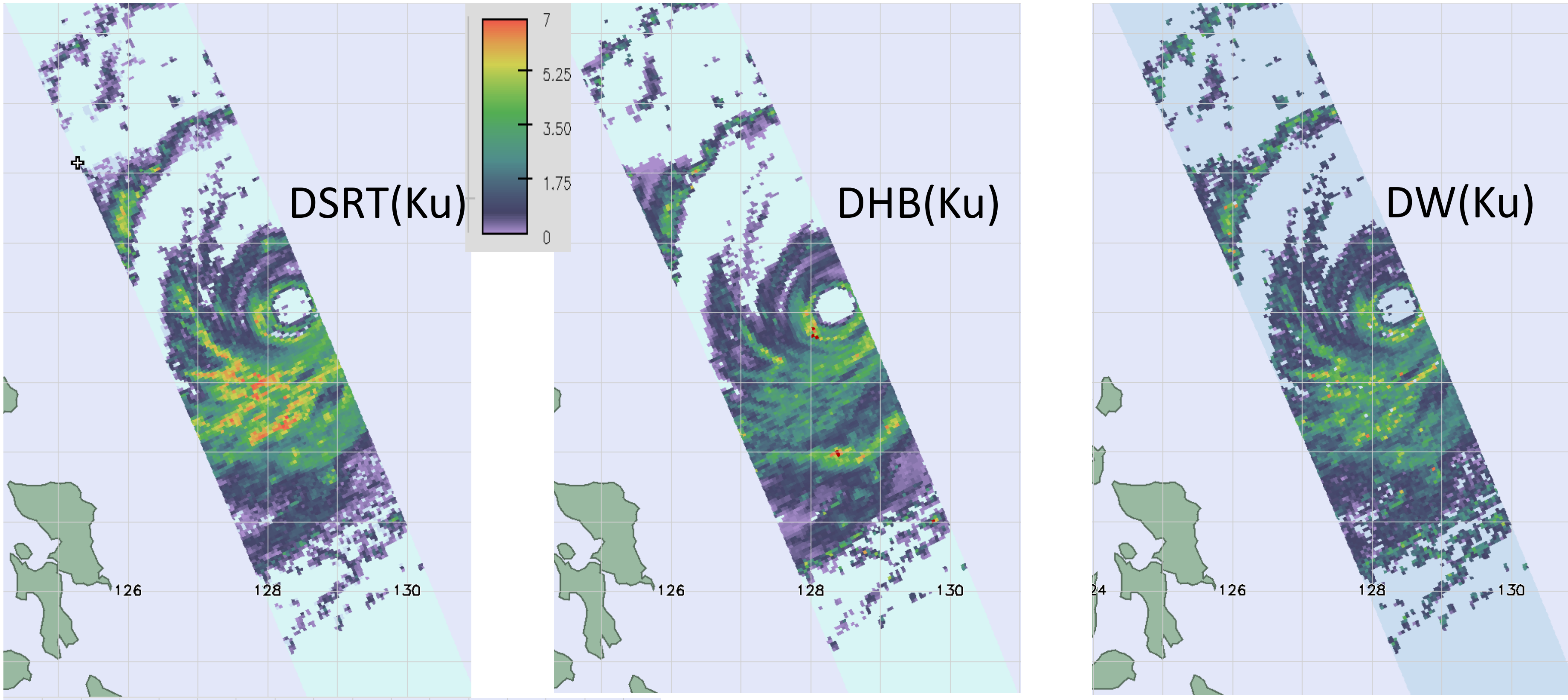
For dual-frequency results:

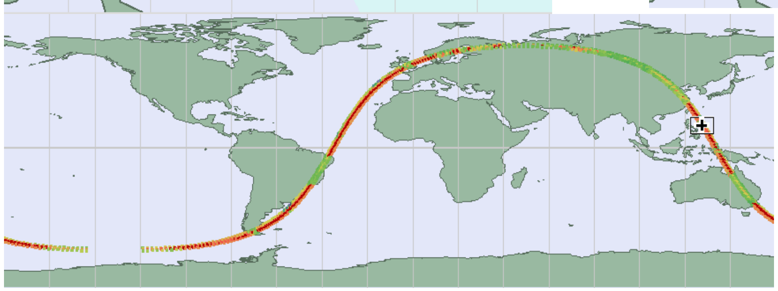
- SRT(Ku) weighted fairly strongly in moderate/high rain areas
- HB/DW weighted strongly in light rain areas

V6X

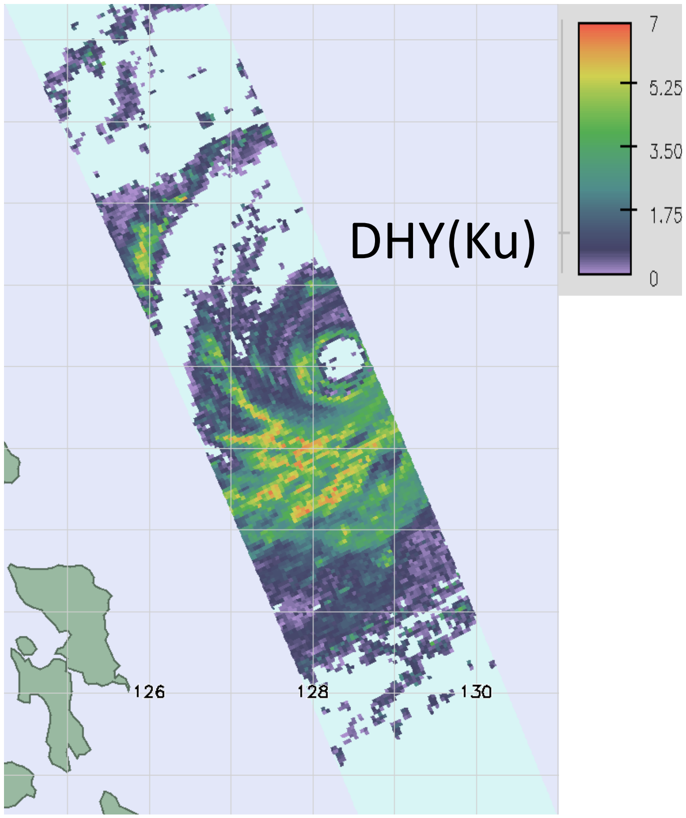


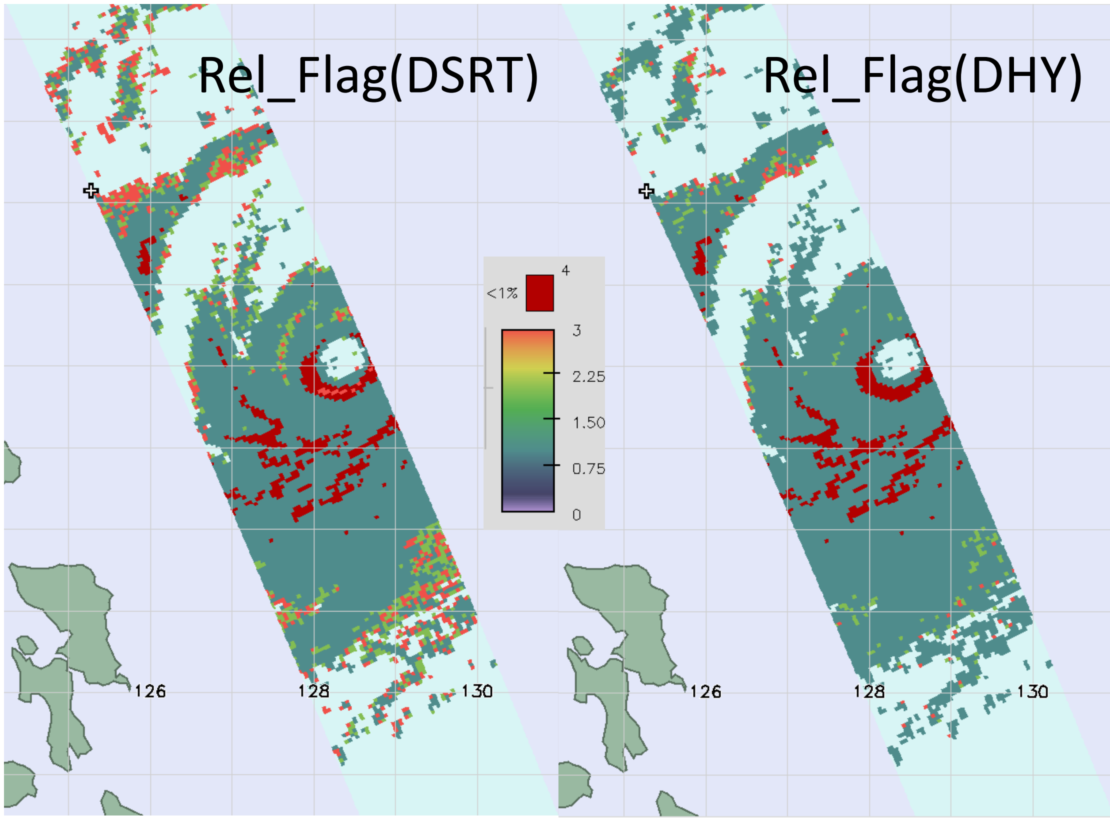
Orbit 25808, 2018/09/13
Typhoon east of the Philippines
Version V6X



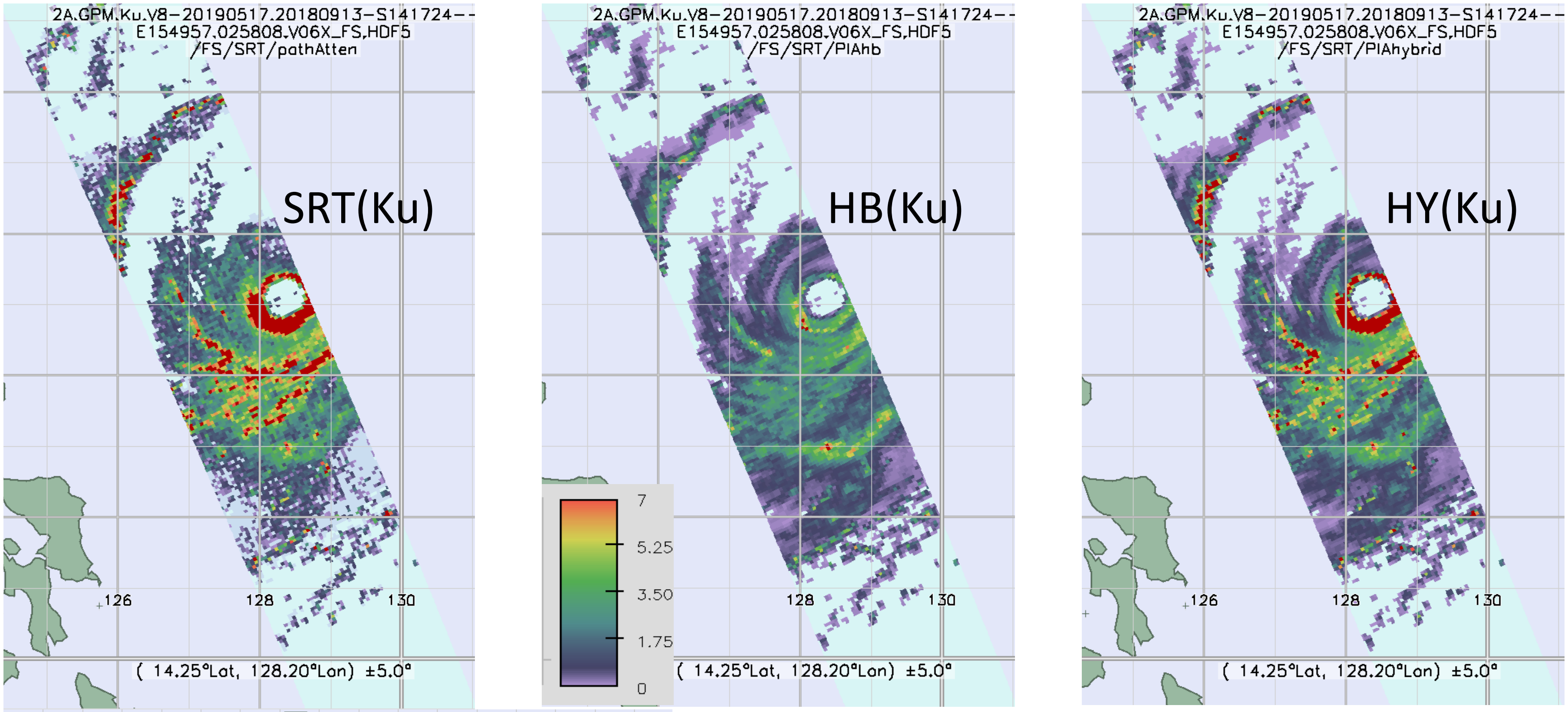


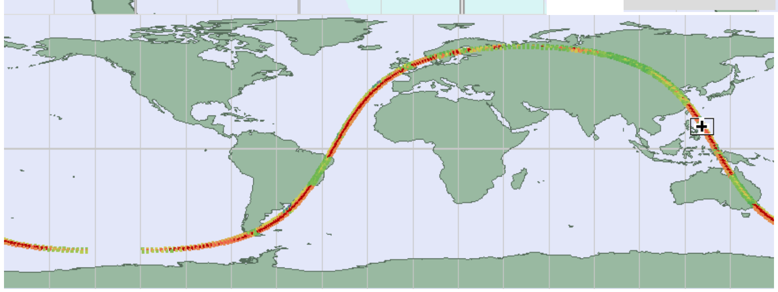
Dual-freq estimates of Ku-band attenuation
SRT, HB and DW
Max PIA less than 8 dB





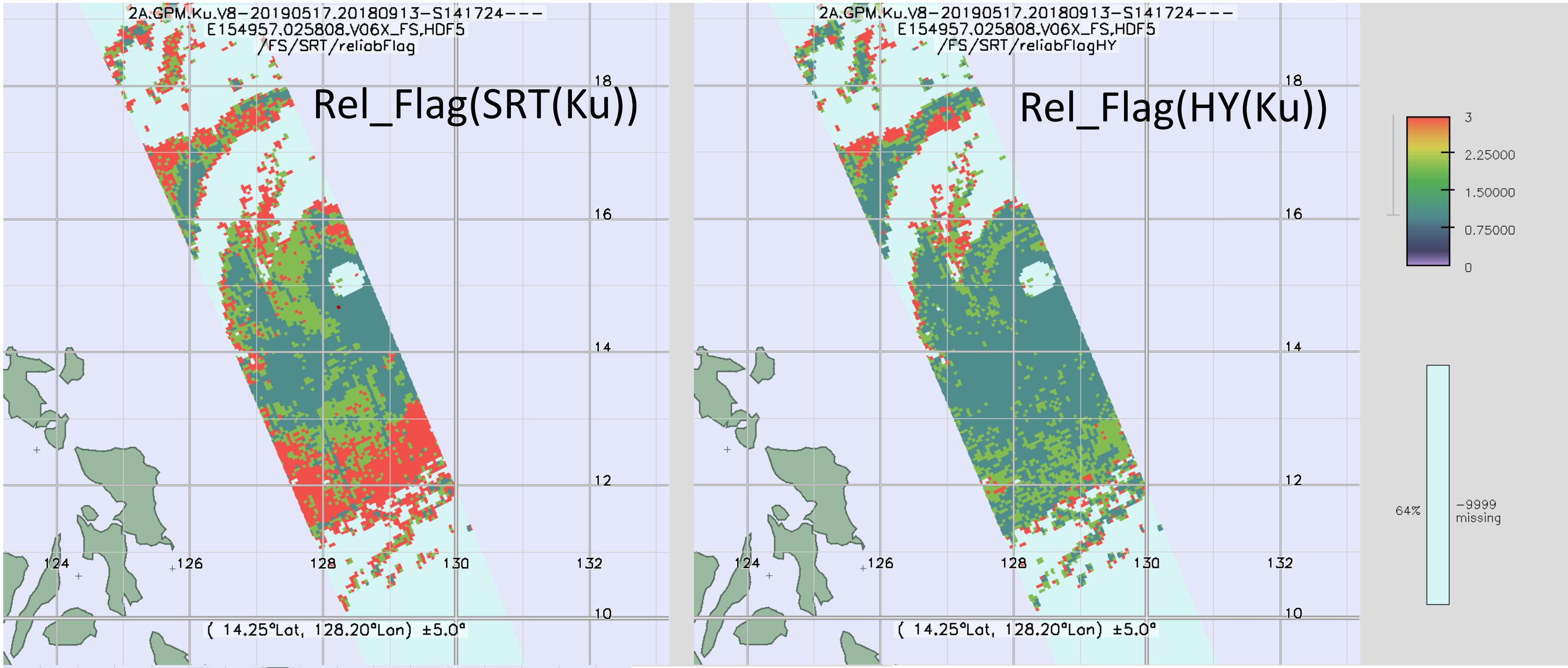
- Red Areas shown above indicate regions where the Ka-band surface/rain returns are lost
- Implies that PIA estimates are lower bounds on actual attenuation

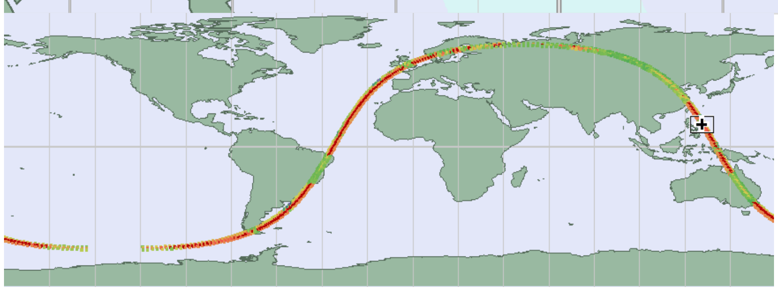




Single-frequency estimates of PIA

SRT(Ku) has significantly larger maximum PIA than that for DSRT(Ku)

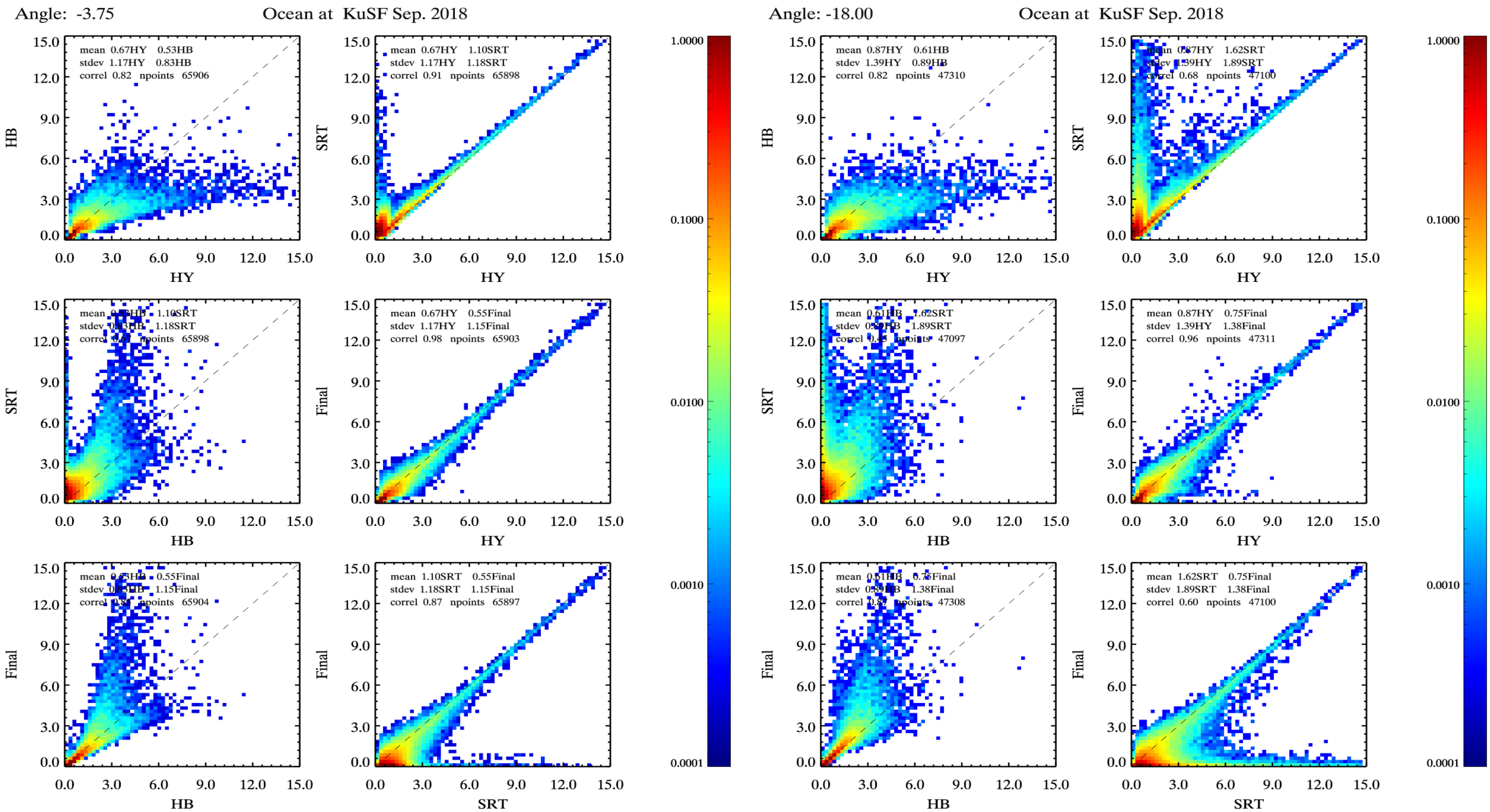




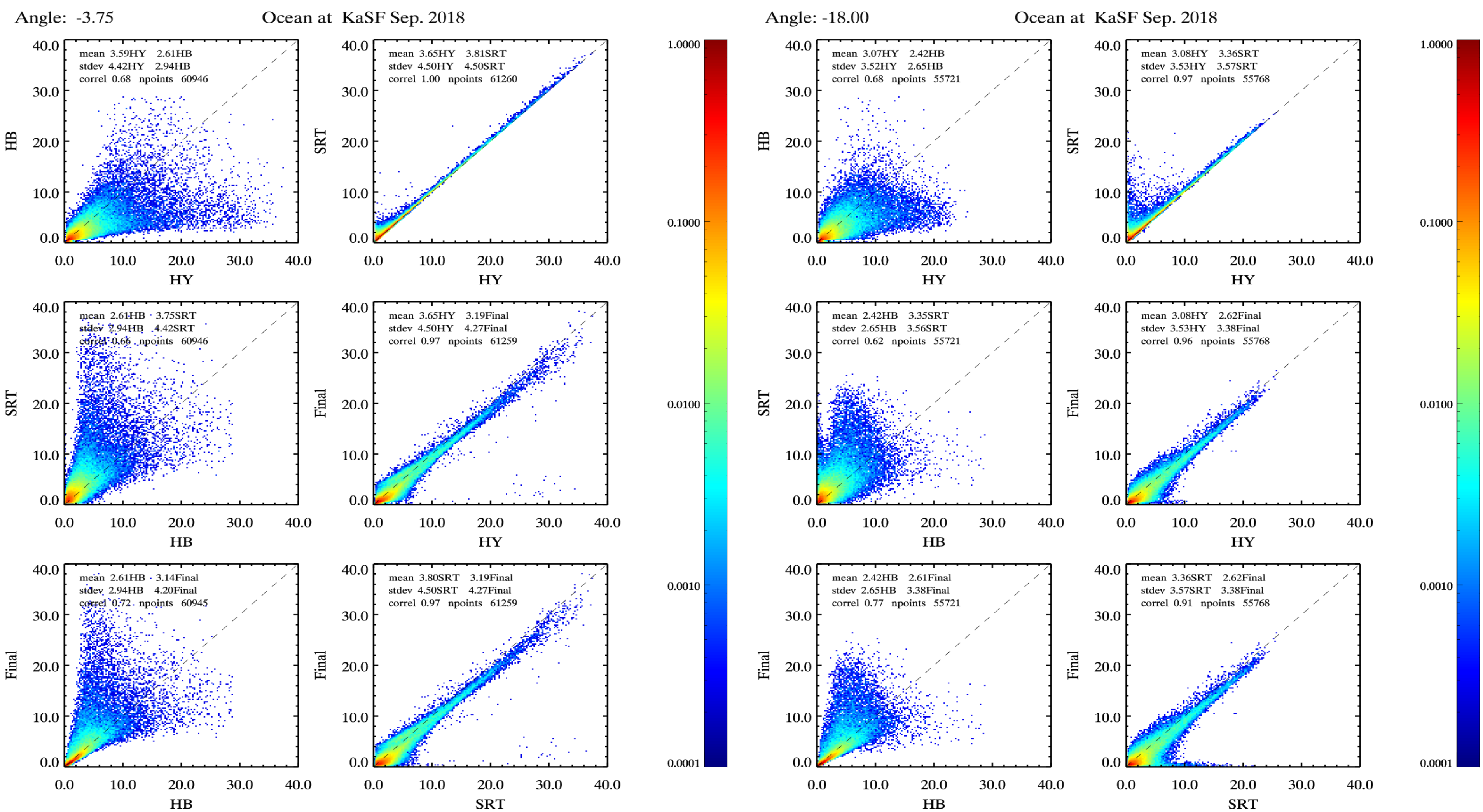
- Single freq Ku: Hybrid is much more accurate than SRT(Ku) and exists in areas of heavy rain
- Dual freq Ku: Hybrid is more accurate than single-freq Hybrid except in areas of high rain

Statistics of PIA's

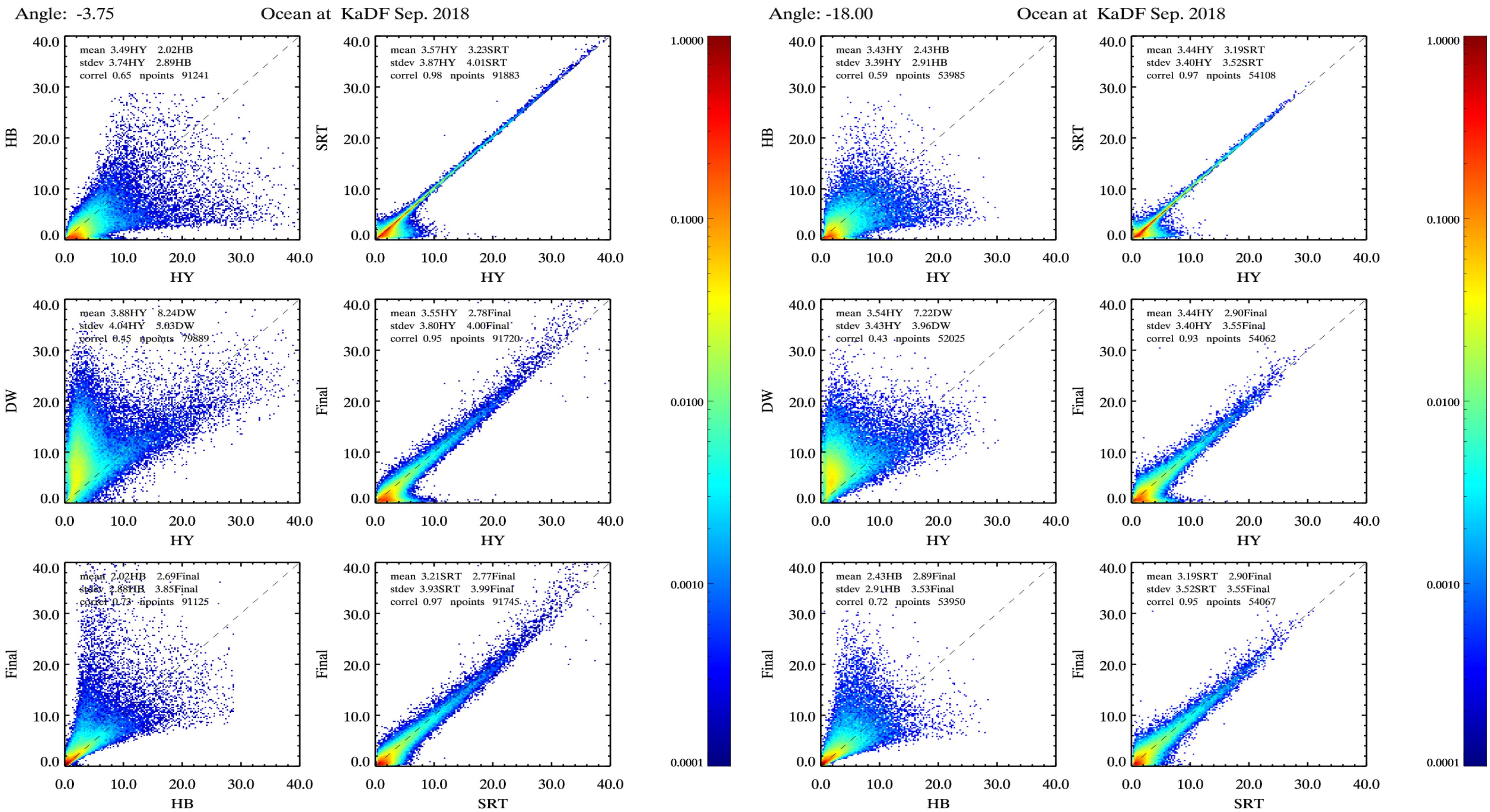
- General Features
  - Hybrid reduces large overestimates by single-freq SRT
  - These overestimates are also eliminated by dual-freq SRT
  - Hitschfeld-Bordan (HB) is effective in supplementing SRT, esp at Ku-band SF
  - HB is less effective for Ka or DPR since variance is larger
  - Final value (from solver module) is well correlated with hybrid for SF
  - Final value (from solver module) is well correlated with SRT for DF

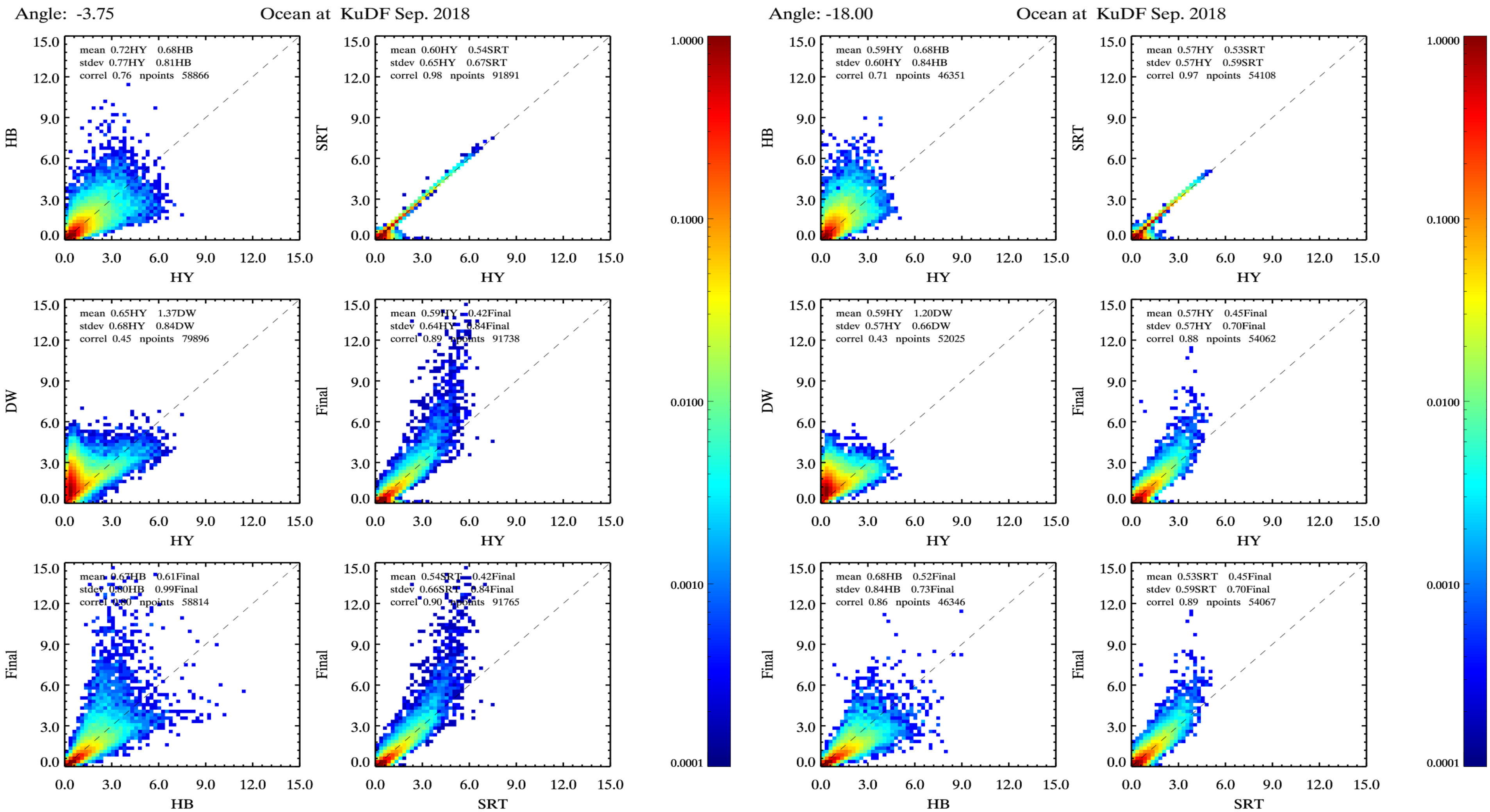


Angle: -3.75
Ocean at KuSF Sep. 2018
mean 0.67HY 0.53HB
stdev 1.17HY 0.83HB
correl 0.82 npoints 65906
mean 0.67HY 1.10SRT
stdev 1.17HY 1.18SRT
correl 0.91 npoints 65898
mean 0.67HY 0.55Final
stdev 1.17HY 1.15Final
correl 0.98 npoints 65903
mean 1.10SRT 0.55Final
stdev 1.18SRT 1.15Final
correl 0.87 npoints 65897
HB
SRT
Final
HY
1.0000
0.1000
0.0100
0.0010
0.0001
Angle: -18.00
Ocean at KuSF Sep. 2018
mean 0.87HY 0.61HB
stdev 1.39HY 0.89HB
correl 0.82 npoints 47310
mean 0.87HY 0.75Final
stdev 1.39HY 1.38Final
correl 0.96 npoints 47311
mean 1.62SRT 0.75Final
stdev 1.89SRT 1.38Final
correl 0.60 npoints 47100
0.0
3.0
6.0
9.0
12.0
15.0



Angle: -3.75
Ocean at KaSF Sep. 2018
mean 3.59HY 2.61HB
stdev 4.42HY 2.94HB
correl 0.68 npoints 60946
mean 3.65HY 3.81SRT
stdev 4.50HY 4.50SRT
correl 1.00 npoints 61260
mean 2.61HB 3.75SRT
stdev 2.94HB 4.42SRT
correl 0.66 npoints 60946
mean 3.65HY 3.19Final
stdev 4.50HY 4.27Final
correl 0.97 npoints 61259
mean 2.61HB 3.14Final
stdev 2.94HB 4.20Final
correl 0.72 npoints 60945
mean 3.80SRT 3.19Final
stdev 4.50SRT 4.27Final
correl 0.97 npoints 61259
Angle: -18.00
Ocean at KaSF Sep. 2018
mean 3.07HY 2.42HB
stdev 3.52HY 2.65HB
correl 0.68 npoints 55721
mean 3.08HY 3.36SRT
stdev 3.53HY 3.57SRT
correl 0.97 npoints 55768
mean 2.42HB 3.35SRT
stdev 2.65HB 3.56SRT
correl 0.62 npoints 55721
mean 3.08HY 2.62Final
stdev 3.53HY 3.38Final
correl 0.96 npoints 55768
mean 2.42HB 2.61Final
stdev 2.65HB 3.38Final
correl 0.77 npoints 55721
mean 3.36SRT 2.62Final
stdev 3.57SRT 3.38Final
correl 0.91 npoints 55768
HY
HB
SRT
Final
0.0
10.0
20.0
30.0
40.0
1.0000
0.1000
0.0100
0.0010
0.0001


Angle: -3.75
Ocean at KaDF Sep. 2018
mean 3.49HY 2.02HB
stdev 3.74HY 2.89HB
correl 0.65 npoints 91241
mean 3.57HY 3.23SRT
stdev 3.87HY 4.01SRT
correl 0.98 npoints 91883
mean 3.88HY 8.24DW
stdev 4.04HY 5.03DW
correl 0.45 npoints 79889
mean 3.55HY 2.78Final
stdev 3.80HY 4.00Final
correl 0.95 npoints 91720
mean 2.02HB 2.69Final
stdev 2.88HB 3.85Final
correl 0.73 npoints 91125
mean 3.21SRT 2.77Final
stdev 3.93SRT 3.99Final
correl 0.97 npoints 91745
HY
HB
SRT
DW
Final
Angle: -18.00
Ocean at KaDF Sep. 2018
mean 3.43HY 2.43HB
stdev 3.39HY 2.91HB
correl 0.59 npoints 53985
mean 3.44HY 3.19SRT
stdev 3.40HY 3.52SRT
correl 0.97 npoints 54108
mean 3.54HY 7.22DW
stdev 3.43HY 3.96DW
correl 0.43 npoints 52025
mean 3.44HY 2.90Final
stdev 3.40HY 3.55Final
correl 0.93 npoints 54062
mean 2.43HB 2.89Final
stdev 2.91HB 3.53Final
correl 0.72 npoints 53950
mean 3.19SRT 2.90Final
stdev 3.52SRT 3.55Final
correl 0.95 npoints 54067
1.0000
0.1000
0.0100
0.0010
0.0001



Angle: -3.75
Ocean at KuDF Sep. 2018
mean 0.72HY 0.68HB
stdev 0.77HY 0.81HB
correl 0.76 npoints 58866
mean 0.60HY 0.54SRT
stdev 0.65HY 0.67SRT
correl 0.98 npoints 91891
mean 0.65HY 1.37DW
stdev 0.68HY 0.84DW
correl 0.45 npoints 79896
mean 0.59HY 0.42Final
stdev 0.64HY 0.84Final
correl 0.89 npoints 91738
mean 0.67HB 0.61Final
stdev 0.80HB 0.99Final
correl 0.80 npoints 58814
mean 0.54SRT 0.42Final
stdev 0.66SRT 0.84Final
correl 0.90 npoints 91765
HB
SRT
DW
Final
HY
HB
SRT
Angle: -18.00
Ocean at KuDF Sep. 2018
mean 0.59HY 0.68HB
stdev 0.60HY 0.84HB
correl 0.71 npoints 46351
mean 0.57HY 0.53SRT
stdev 0.57HY 0.59SRT
correl 0.97 npoints 54108
mean 0.59HY 1.20DW
stdev 0.57HY 0.66DW
correl 0.43 npoints 52025
mean 0.57HY 0.45Final
stdev 0.57HY 0.70Final
correl 0.88 npoints 54062
mean 0.68HB 0.52Final
stdev 0.84HB 0.73Final
correl 0.86 npoints 46346
mean 0.53SRT 0.45Final
stdev 0.59SRT 0.70Final
correl 0.89 npoints 54067
1.0000
0.1000
0.0100
0.0010
0.0001

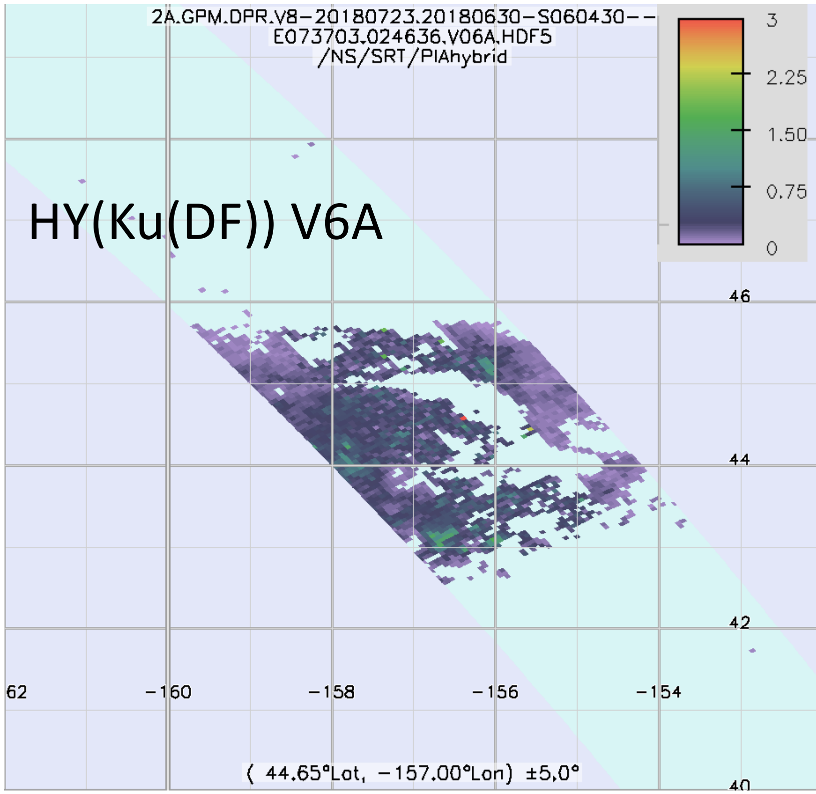
Questions & Issues

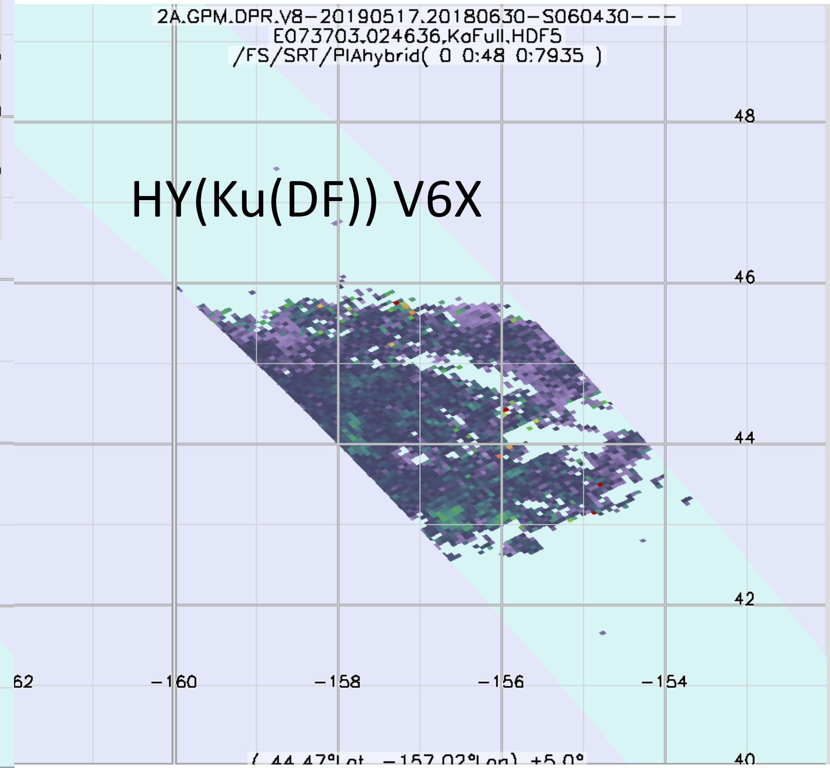
- Need to understand the role of PIA in underestimation of rain in outer swath
  - Might be related to how dual-freq methods treat cases where Ku detects rain, Ka does not

- Can the formalism be used to incorporate other atten estimates
  - Biggest hurdle is in approximating the variance of the estimate
  - Even with present methods, this issue needs to be revisited

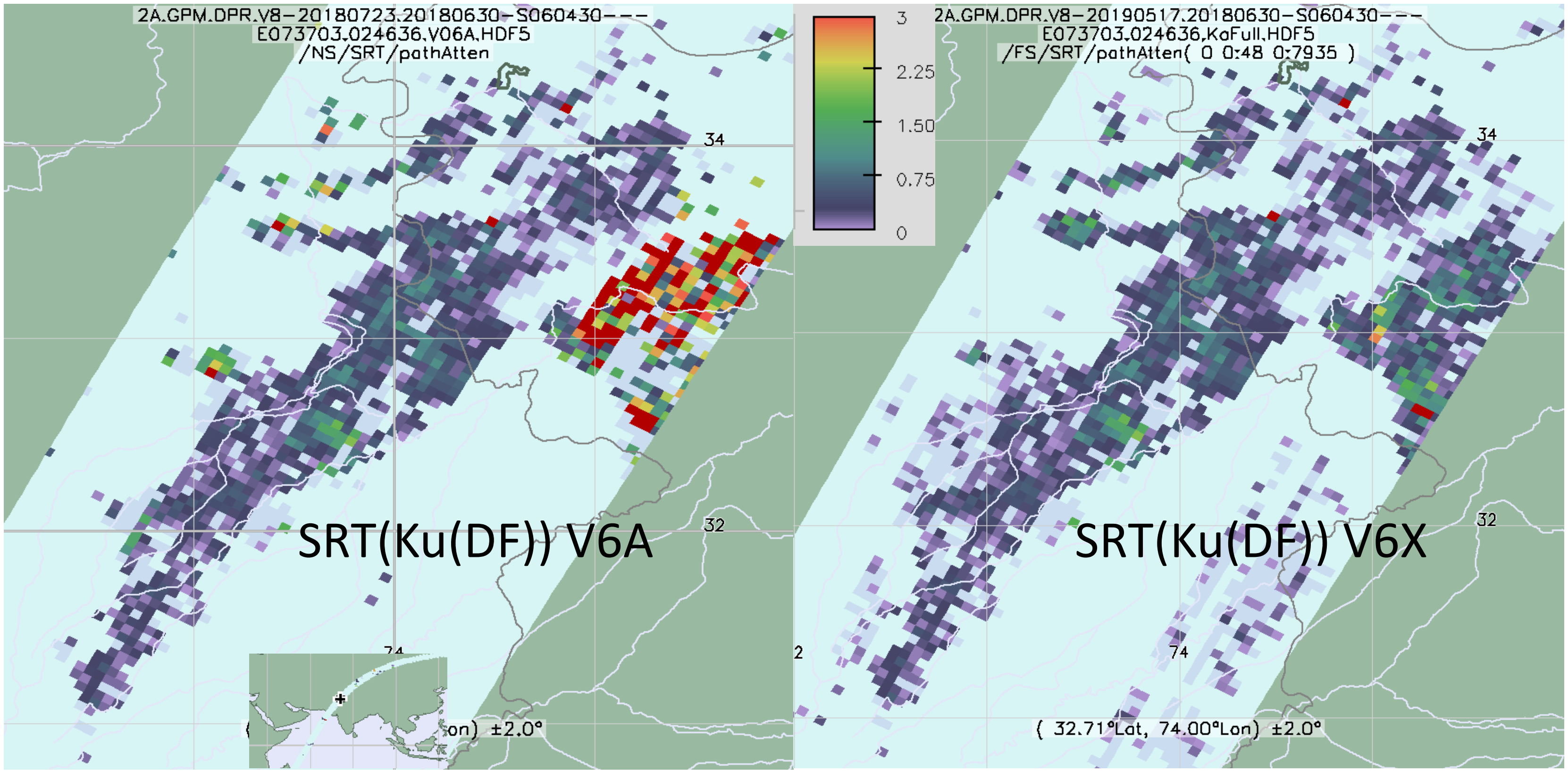
- Hybrid estimates are done separately for single/dual-freq data
  - Dual-freq estimate is more accurate at low-moderate rain rates (if both detect rain)
  - Single-freq estimate (Ku-band) is needed at high rain rates (after loss of Ka-band signal)
  - A more accurate hybrid would combine single- and dual-freq estimates

- Issues remain wrt definition of 'reliability factor' and standard DW method

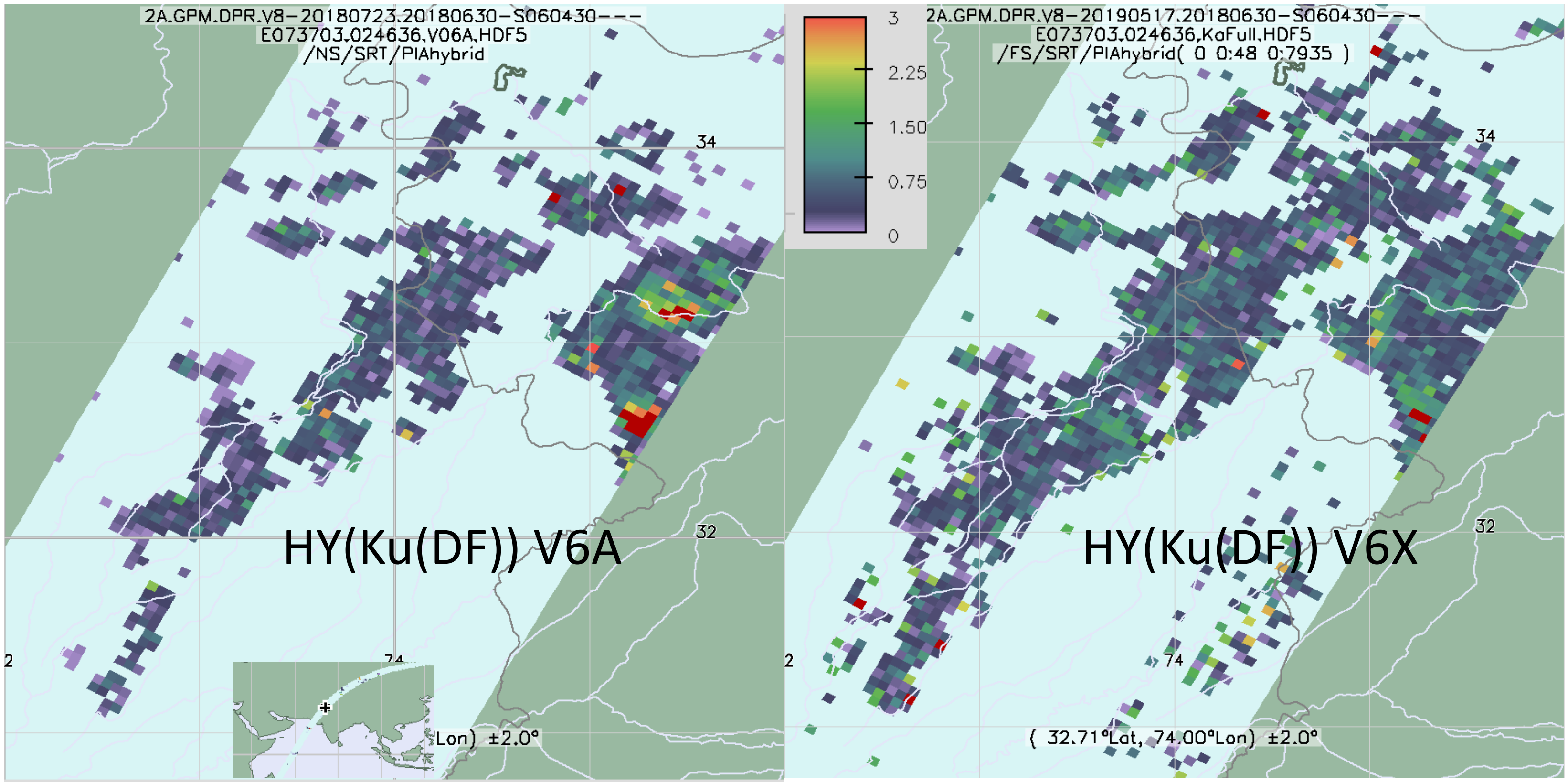




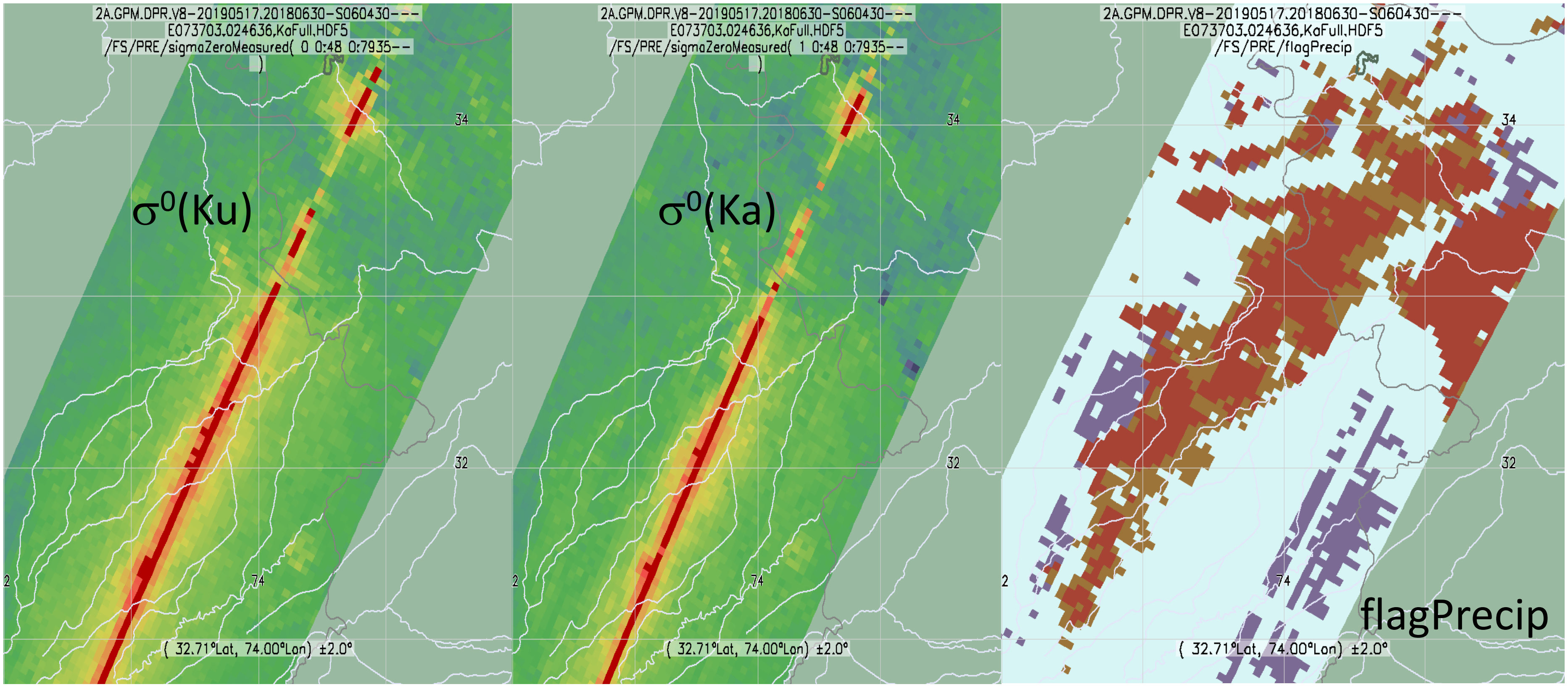
- Orbit 24636, 30 Sep 2018
- DHybrid(Ku-band) estimates
- South of Alaska
- Version V6X



- Large overestimate on right-hand of swath (V6A, left) is eliminated in V6X, (right), by use of dual-freq data
- Some Ka-band surface clutter evident over mountainous region (lower right)



- For Hybrid PIA estimates, both V6A and V6X give reasonable estimates
- For V6X, outer swath is influenced by SRT


2A.GPM.DPR.V8-20190517.20180630-S060430---
E073703.024636.KaFull.HDF5
/FS/PRE/sigmaZeroMeasured(0 0:48 0:7935--
)
σ0(Ku)
34
32
74
(32.71°Lat, 74.00°Lon) ±2.0°
2A.GPM.DPR.V8-20190517.20180630-S060430---
E073703.024636.KaFull.HDF5
/FS/PRE/sigmaZeroMeasured(1 0:48 0:7935--
)
σ0(Ka)
34
32
74
(32.71°Lat, 74.00°Lon) ±2.0°
2A.GPM.DPR.V8-20190517.20180630-S060430---
E073703.024636.KaFull.HDF5
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