This material is based in part upon work supported by the Office of Weather and Air Quality Research Program within the NOAA/OAR Weather Program Office under Award NO.NA23OAR4590412-01

Aircraft Scatterometer and Radiometer Measurements within Tropical Cyclone Extreme Rain Bands

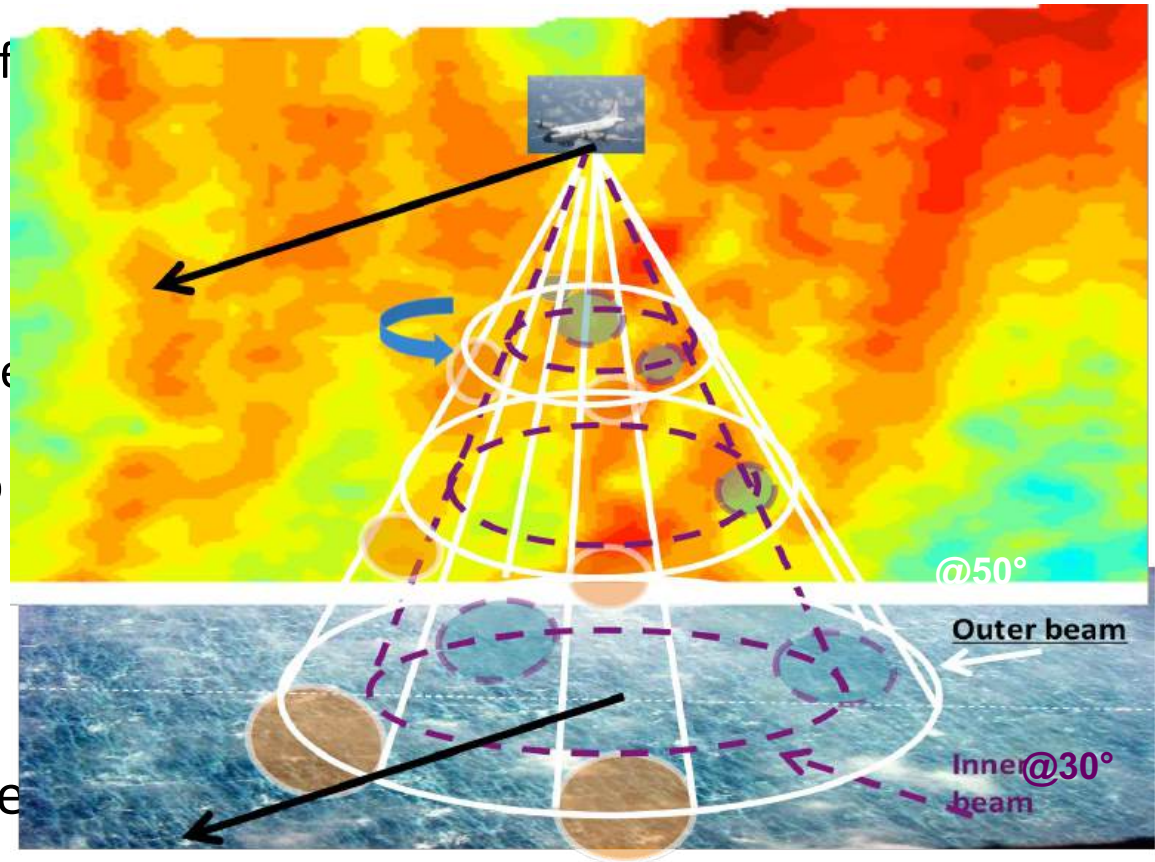
Ocean Winds Team:
[1,3]Zorana Jelenak, [1,2]Joe Sapp, [1,2]Clayton Bjorland,
[1]Paul Chang and [1,2]Casey Shoup

[1]NOAA/NESDIS/STAR
[2]Global Science & Technology, Inc.
[3]UCAR
[4]Tomorrow.io

National Environmental Satellite, Data, and Information Service

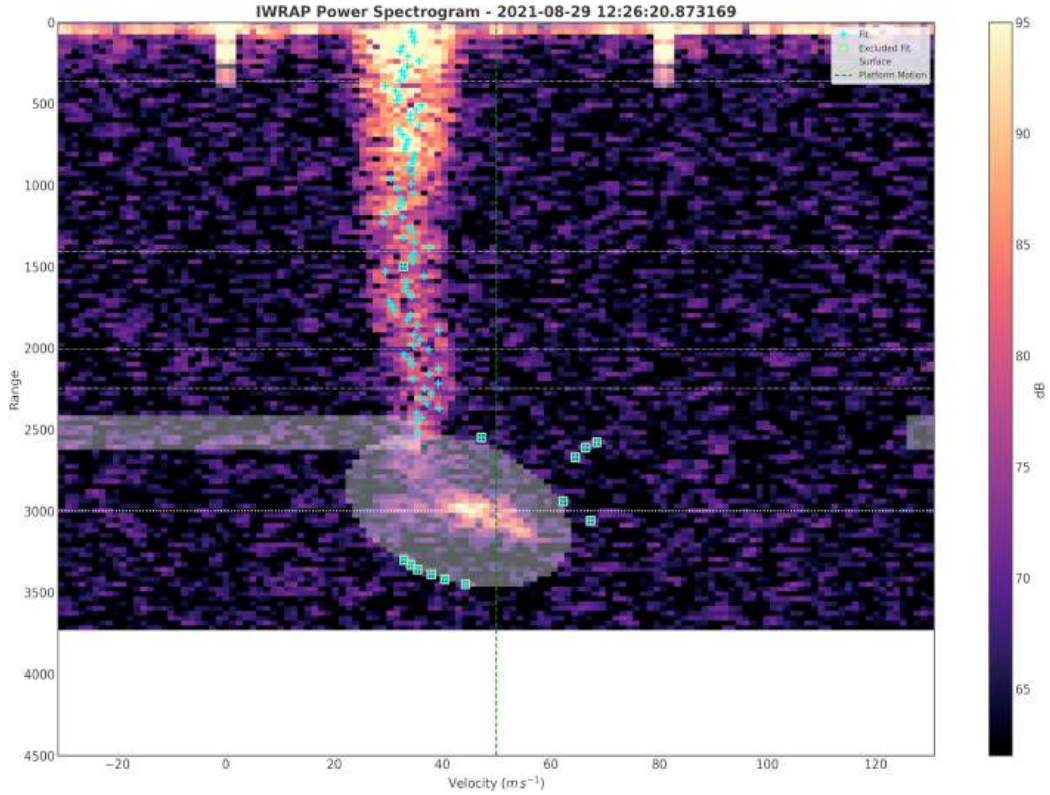
Imaging Wind and Rain Airborne Profiler – IWRAP 2021 Season Configuration

- The IWRAP is a downward-pointing, conically scanning, dual-frequency, dual-polarization Doppler radar capable of measuring surface backscatter and intervening volume reflectivity and Doppler velocity at 30 m range resolution.
- 2021 configuration:
  - Conically scanning Ku and C-band radars
  - V-pol measurements acquired at 30° and 50° incidence angles
  - Outer beam profiles from 1.5km below the aircraft up to 30m from the surface
  - Inner beam profiles from 120m below the aircraft up to 30m from the surface
- 3D wind and reflectivity profiles retrieved along the nadir at 30m vertical and 150m along track resolution
- Maximum possible swath width of ~2–3 km at typical flying altitudes



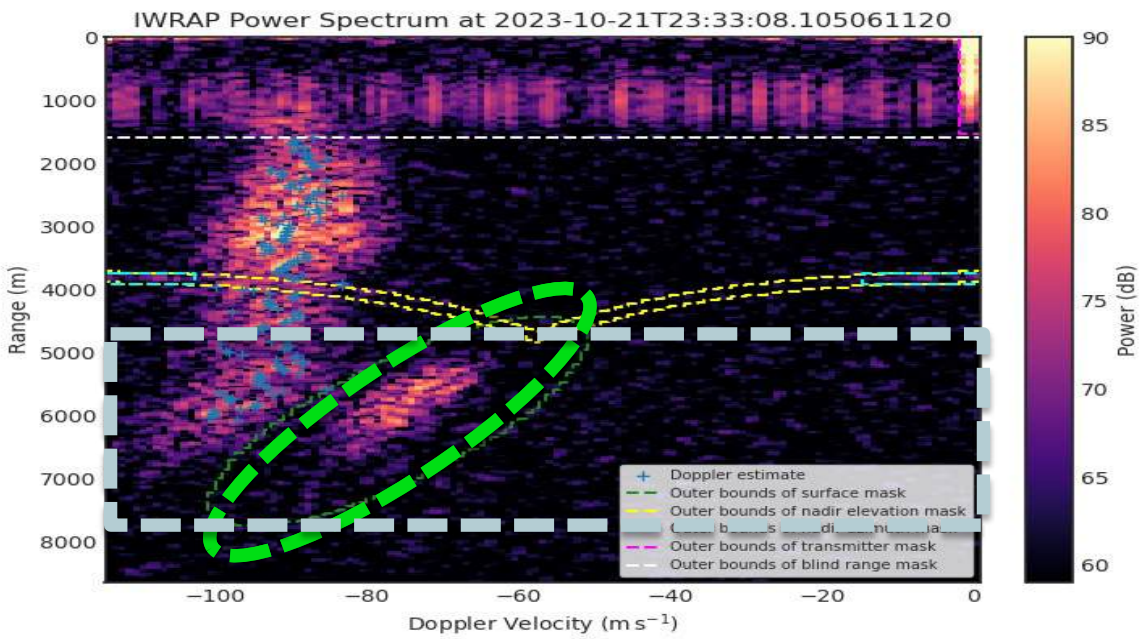
Unique Characteristics of IWRAP

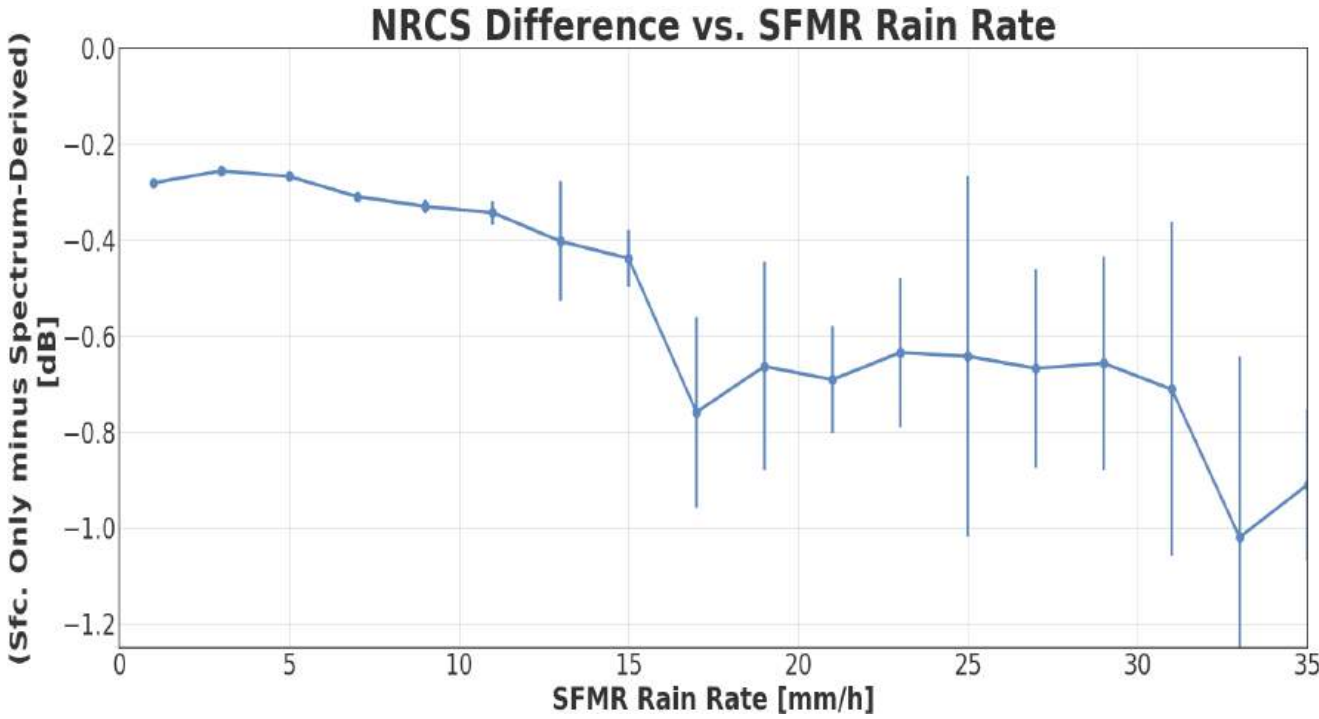
- Traditionally IWRAP wind and reflectivity profiles have been obtained by utilizing the pulse-pair processing algorithm and covariance method widely used in Doppler weather radars
  - This allows for accurate retrievals down to 300-500m above the surface
  - At lower altitudes precipitation volume backscatter is contaminated by the 1) nadir reflection from the surface backscatter and the 2) surface backscatter at the range gates closer to the ocean.
- Most unique aspect of IWRAP radar is in its advanced radar control and data acquisition system
  - This allows for spectral processing technique to be employed
- 2021 NRT processing utilized traditional pulse pair approach
  - Post season spectral processor applied on all data collected during 2021 season



Pulse Pair vs Spectrum Sigma0's

Ku @50°





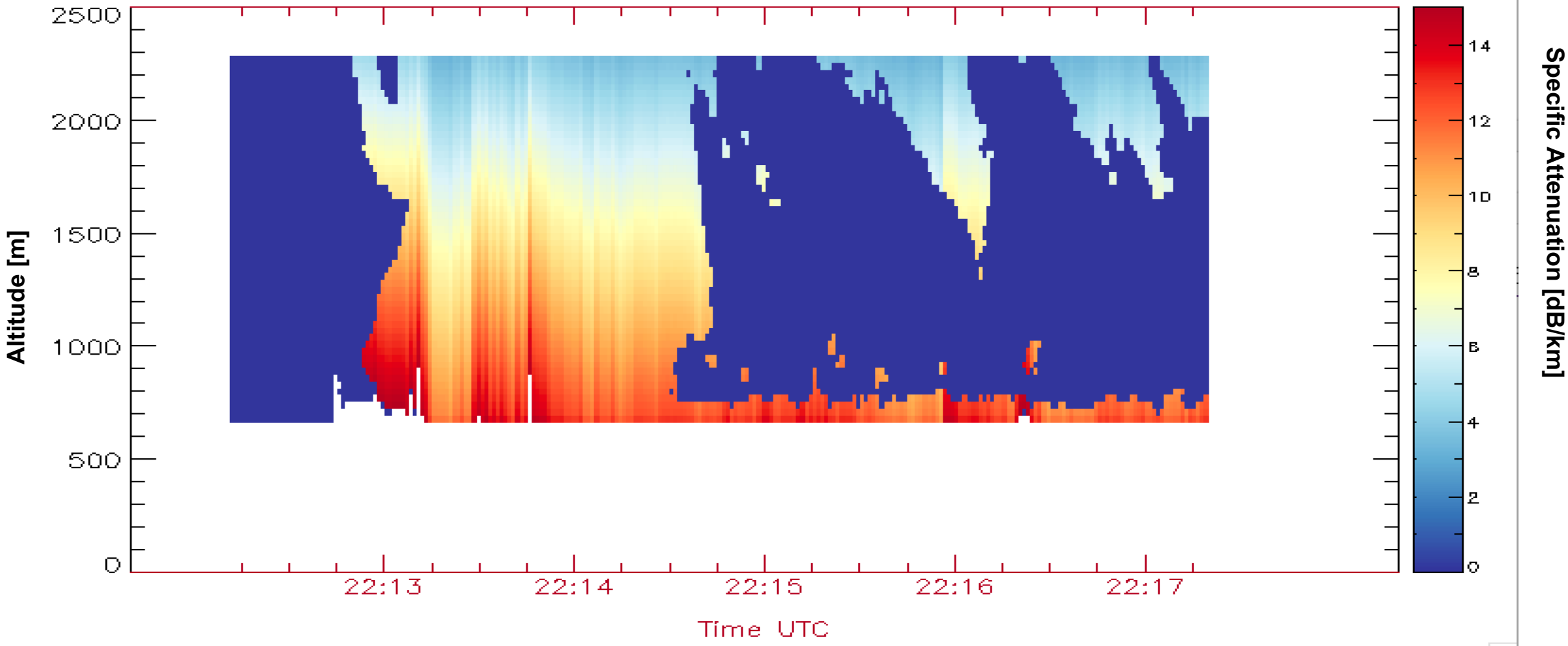
Sigma0 from pulse pair processing:

$$\sigma^0_{pp} = (\sigma^0_{cmod5h} + \Delta\sigma^0_{surf\_rr} + \sigma^0_{Vol}) * K_a$$

Sigma0 from spectral processing

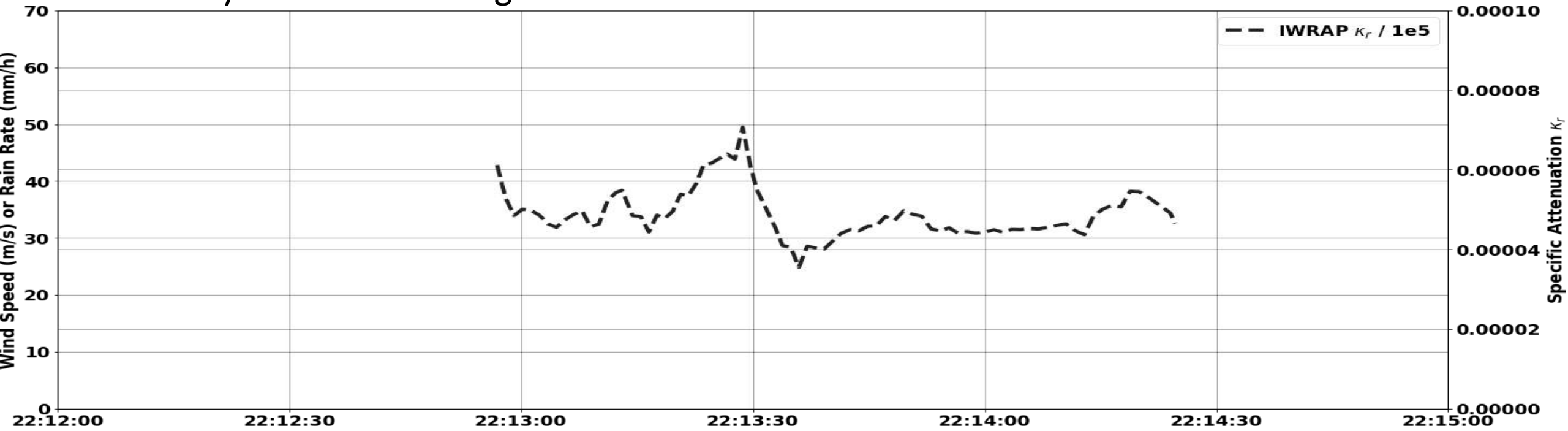
$$\sigma^0_{Spec} = (\sigma^0_{cmod5h} + \Delta\sigma^0_{surf\_rr}) * K_a$$

Specific Attenuation from IWRAP C and Ku band Reflectivities



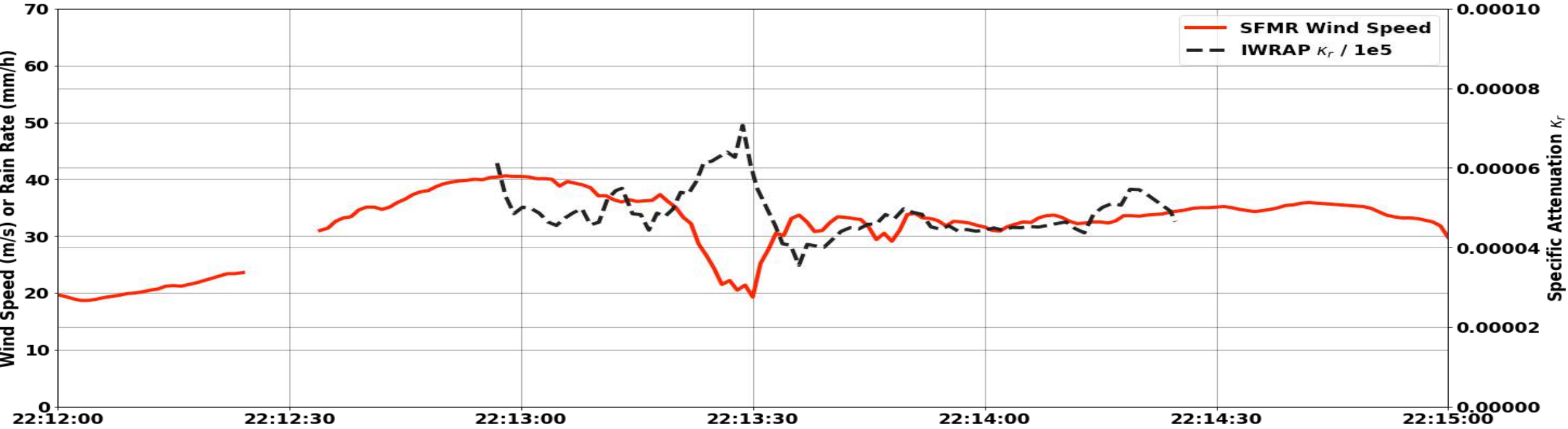
Ku-band Specific Attenuation at 30m Within Rain Band of Interest

Tammy 10212023H1 Flight



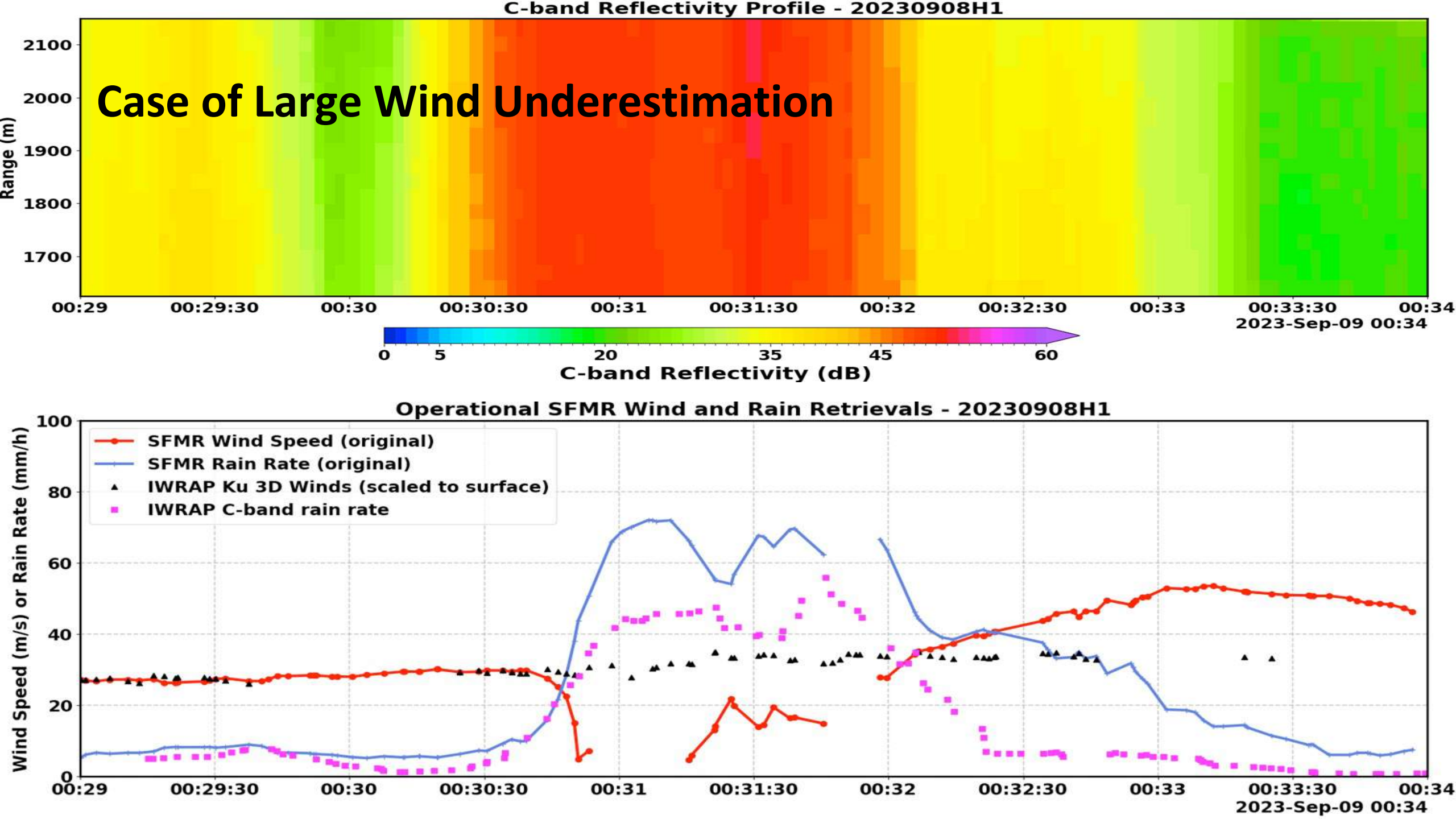
Ku-band Specific Attenuation and SFMR Wind Speed Within Rain Band of Interest

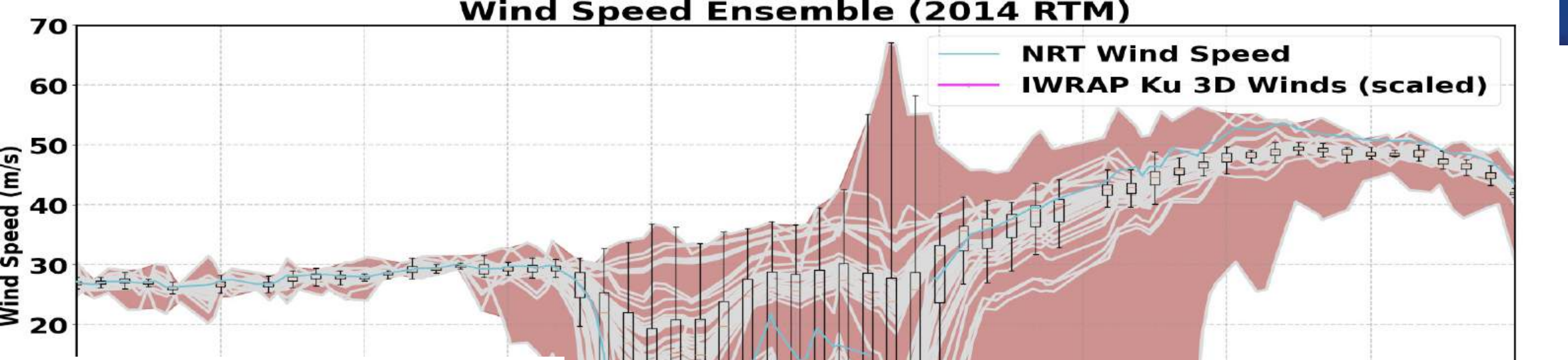
Tammy 10212023H1 Flight



Hypothesis: Error due to Retrieval Procedure Insufficiencies

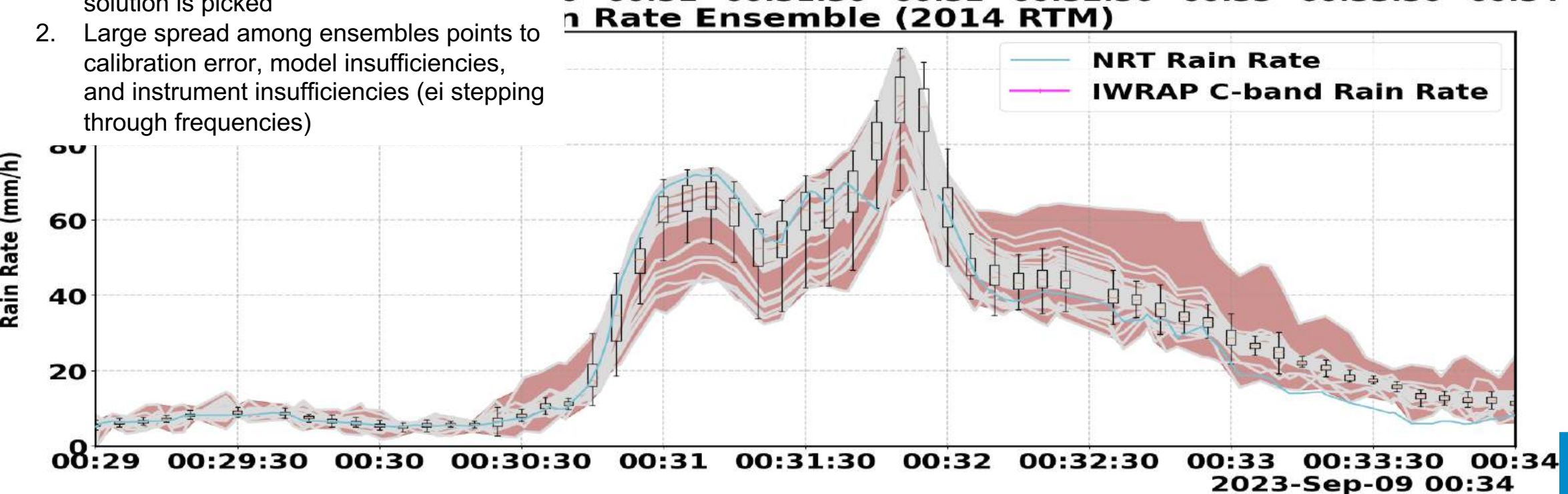
- SFMR acquires measurements at 6 different channels. How is each channel impacting retrieval
- Experiment: Produce ensemble runs utilizing different channel weightings
  - Original rain/wind forward model as utilized in the operational algorithm
  - Run 57 different combinations

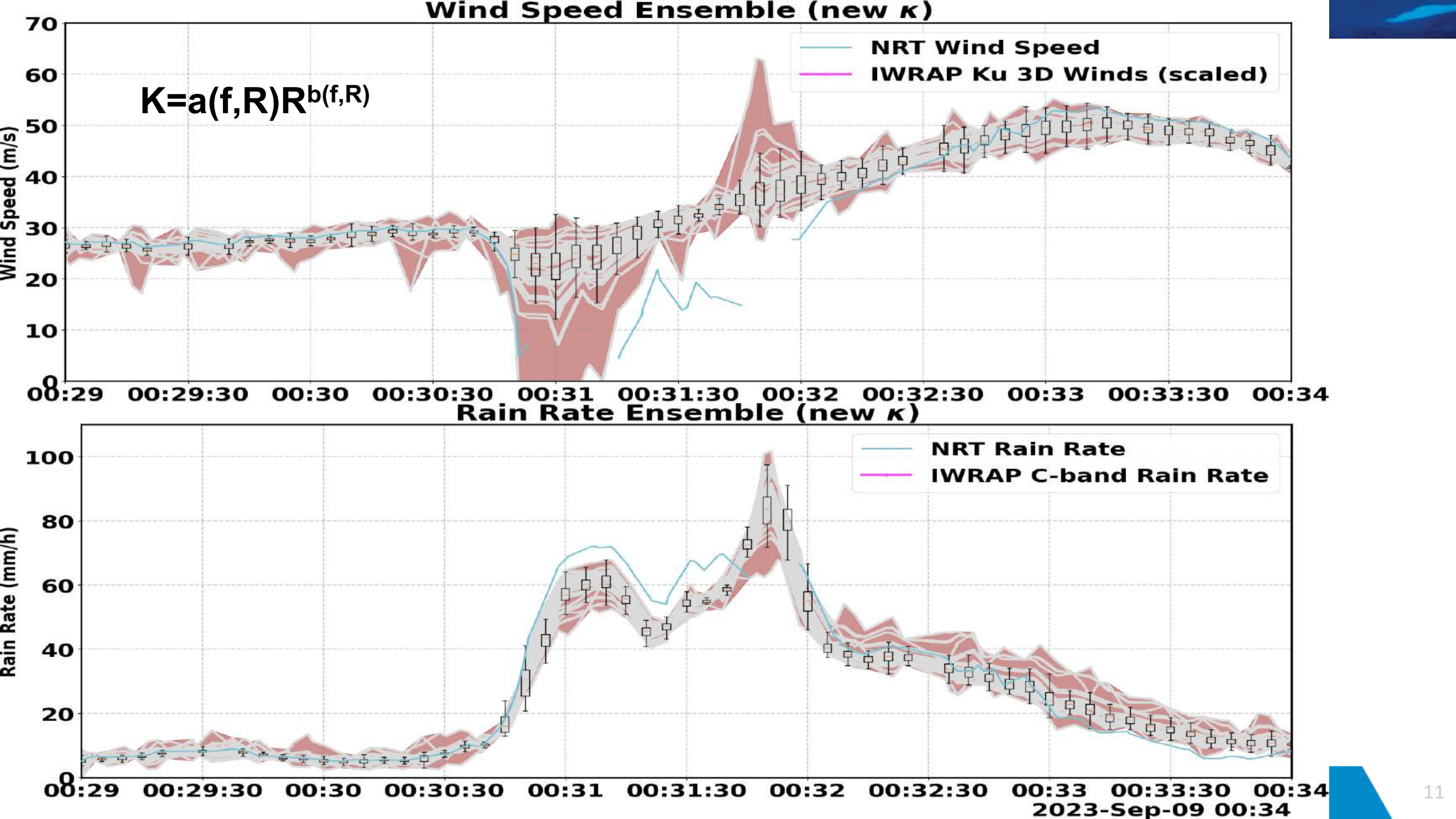

C-band Reflectivity Profile - 20230908H1
Range (m)
2100
2000
1900
1800
1700
00:29
00:29:30
00:30
00:30:30
00:31
00:31:30
00:32
00:32:30
00:33
00:33:30
00:34
2023-Sep-09 00:34
0
5
20
35
45
60
C-band Reflectivity (dB)
Case of Large Wind Underestimation
Operational SFMR Wind and Rain Retrievals - 20230908H1
SFMR Wind Speed (original)
SFMR Rain Rate (original)
IWRAP Ku 3D Winds (scaled to surface)
IWRAP C-band rain rate
Wind Speed (m/s) or Rain Rate (mm/h)
100
80
60
40
20
0
00:29
00:29:30
00:30
00:30:30
00:31
00:31:30
00:32
00:32:30
00:33
00:33:30
00:34
2023-Sep-09 00:34

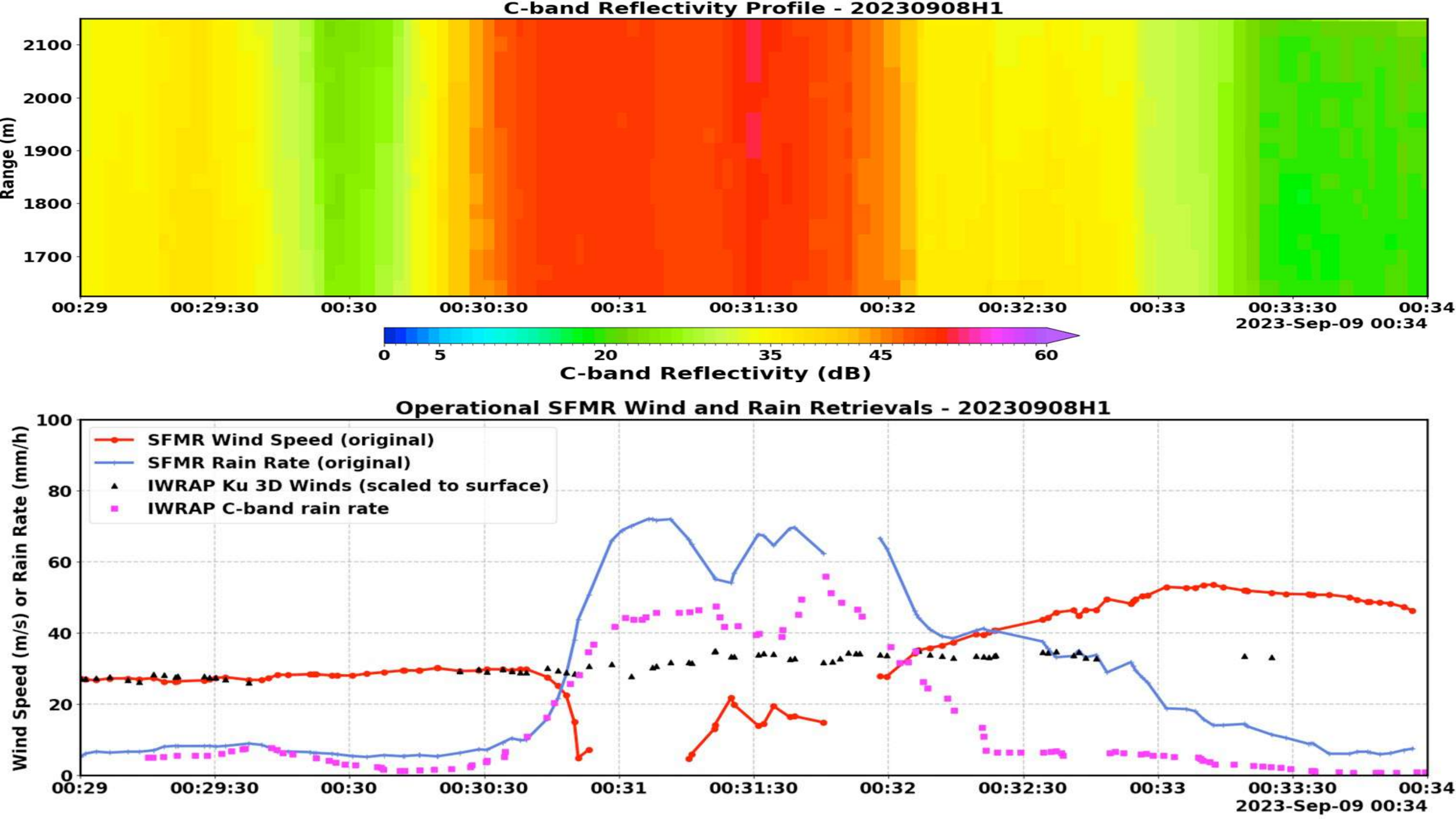


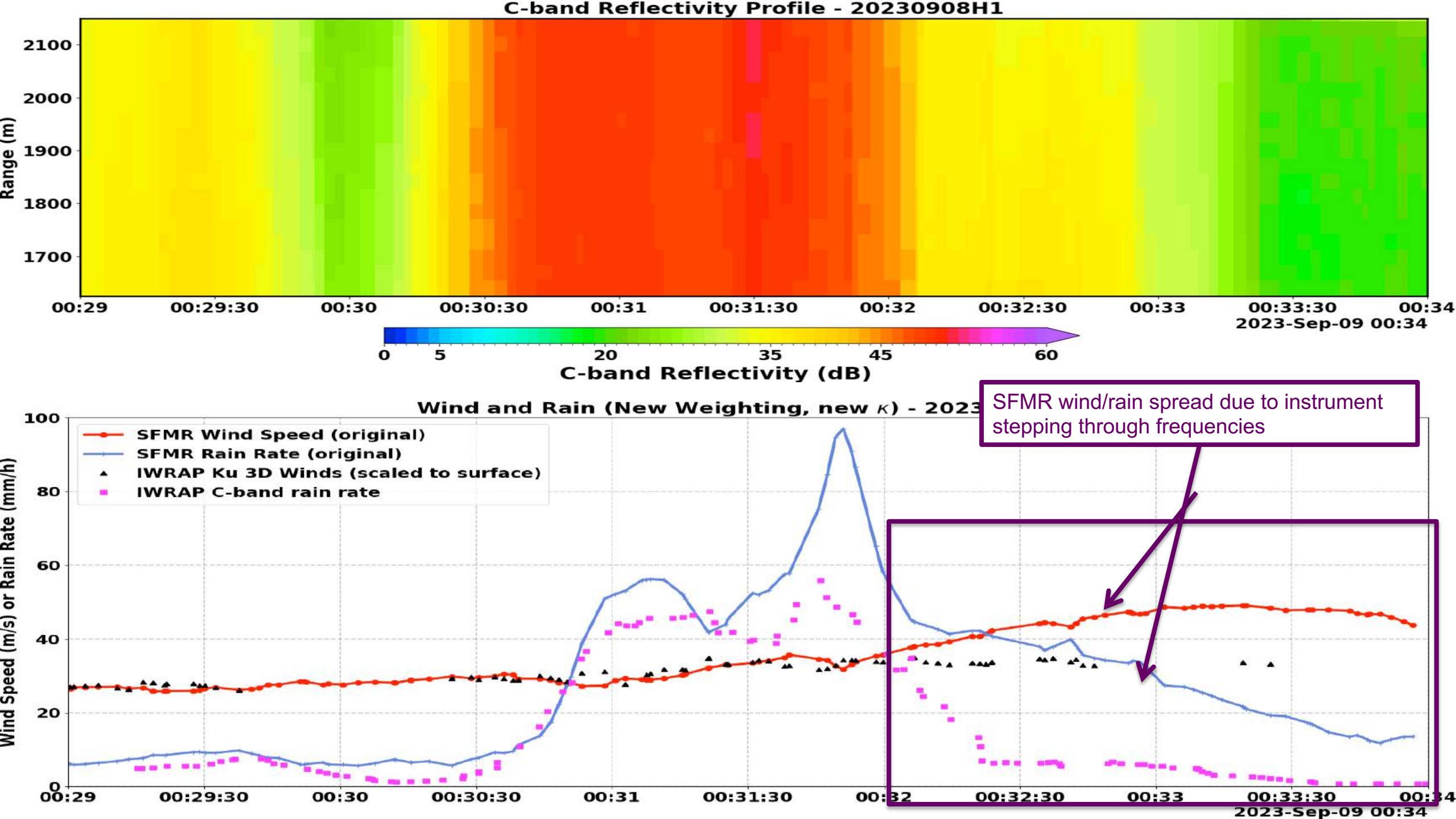
What are these results saying?

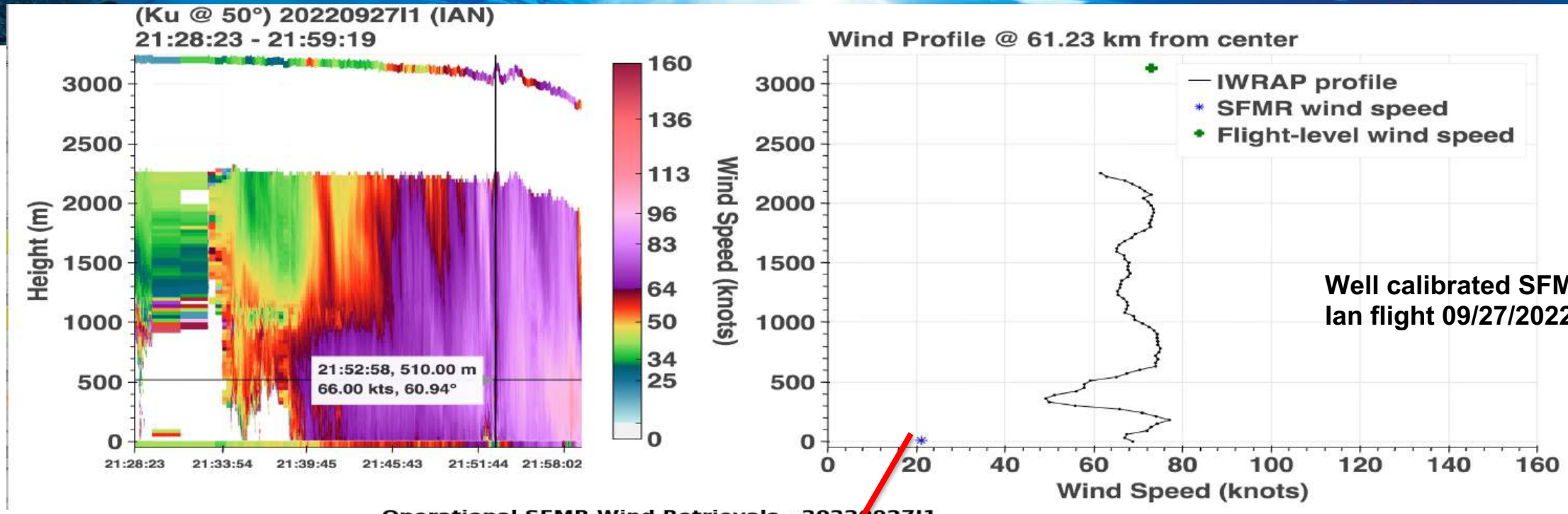
1. NRT algorithm is giving same weight to all channels – worst possible retrieval solution is picked
2. Large spread among ensembles points to calibration error, model insufficiencies, and instrument insufficiencies (ei stepping through frequencies)



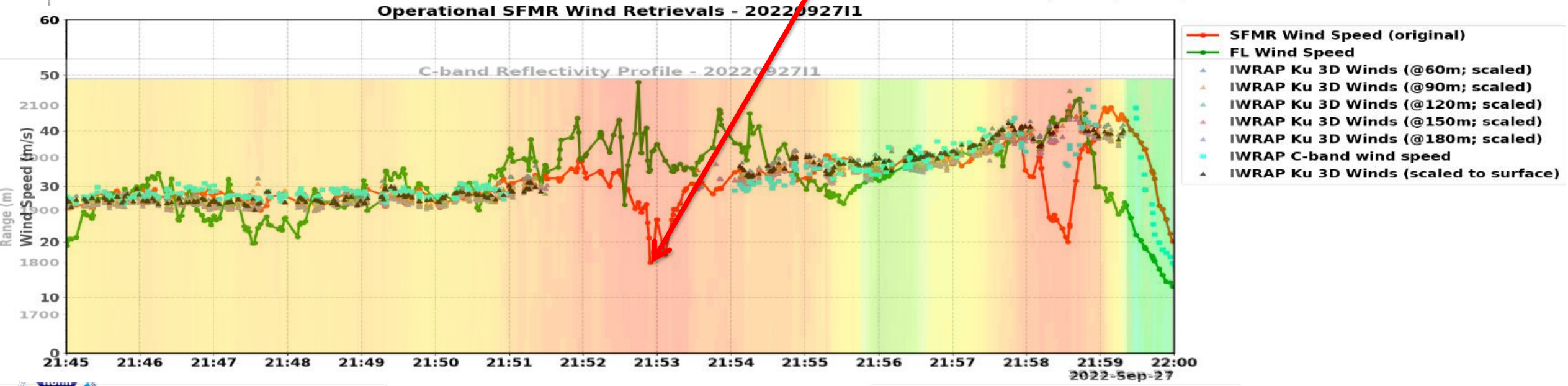

Wind Speed Ensemble (new κ)
K=a(f,R)R^b(f,R)
NRT Wind Speed
IWRAP Ku 3D Winds (scaled)
Wind Speed (m/s)
70
60
50
40
30
20
10
0
00:29
00:29:30
00:30
00:30:30
00:31
00:31:30
00:32
00:32:30
00:33
00:33:30
00:34
Rain Rate Ensemble (new κ)
NRT Rain Rate
IWRAP C-band Rain Rate
Rain Rate (mm/h)
100
80
60
40
20
0
00:29
00:29:30
00:30
00:30:30
00:31
00:31:30
00:32
00:32:30
00:33
00:33:30
00:34
2023-Sep-09 00:34

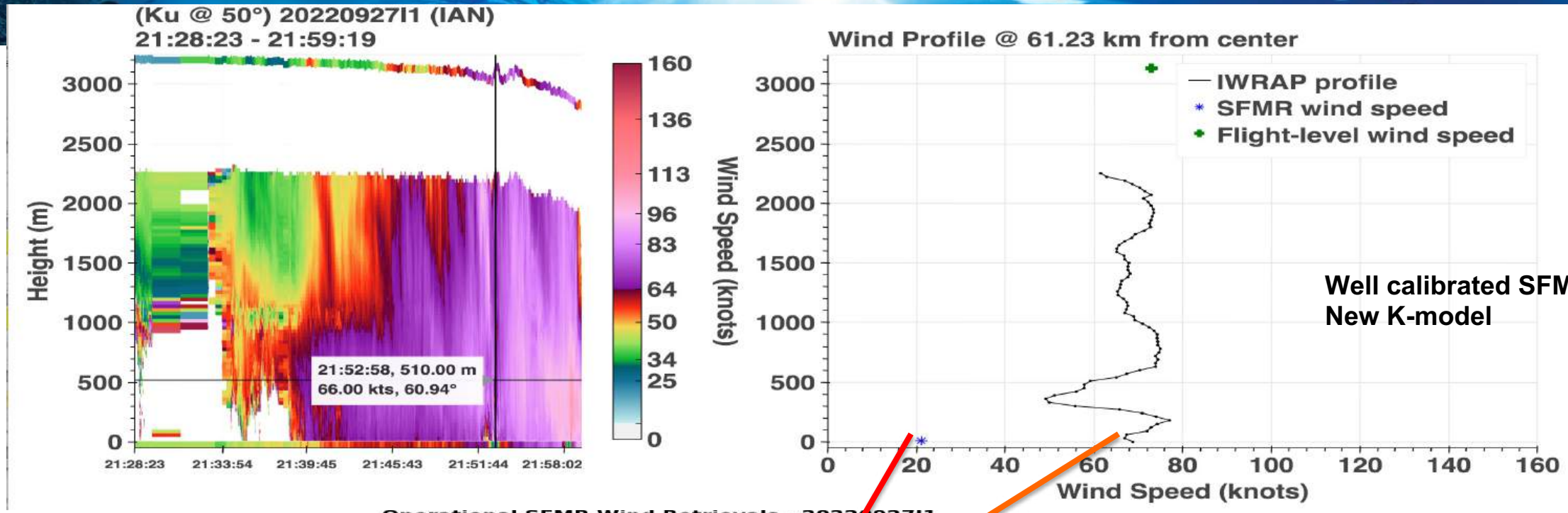

C-band Reflectivity Profile - 20230908H1
Range (m)
2100
2000
1900
1800
1700
00:29
00:29:30
00:30
00:30:30
00:31
00:31:30
00:32
00:32:30
00:33
00:33:30
00:34
2023-Sep-09 00:34
0
5
20
35
45
60
C-band Reflectivity (dB)
Operational SFMR Wind and Rain Retrievals - 20230908H1
SFMR Wind Speed (original)
SFMR Rain Rate (original)
IWRAP Ku 3D Winds (scaled to surface)
IWRAP C-band rain rate
Wind Speed (m/s) or Rain Rate (mm/h)
100
80
60
40
20
0
00:29
00:29:30
00:30
00:30:30
00:31
00:31:30
00:32
00:32:30
00:33
00:33:30
00:34
2023-Sep-09 00:34


C-band Reflectivity Profile - 20230908H1
Range (m)
2100
2000
1900
1800
1700
00:29
00:29:30
00:30
00:30:30
00:31
00:31:30
00:32
00:32:30
00:33
00:33:30
00:34
2023-Sep-09 00:34
0
5
20
35
45
60
C-band Reflectivity (dB)
Wind and Rain (New Weighting, new κ) - 2023
SFMR Wind Speed (original)
SFMR Rain Rate (original)
IWRAP Ku 3D Winds (scaled to surface)
IWRAP C-band rain rate
Wind Speed (m/s) or Rain Rate (mm/h)
100
80
60
40
20
0
SFMR wind/rain spread due to instrument stepping through frequencies

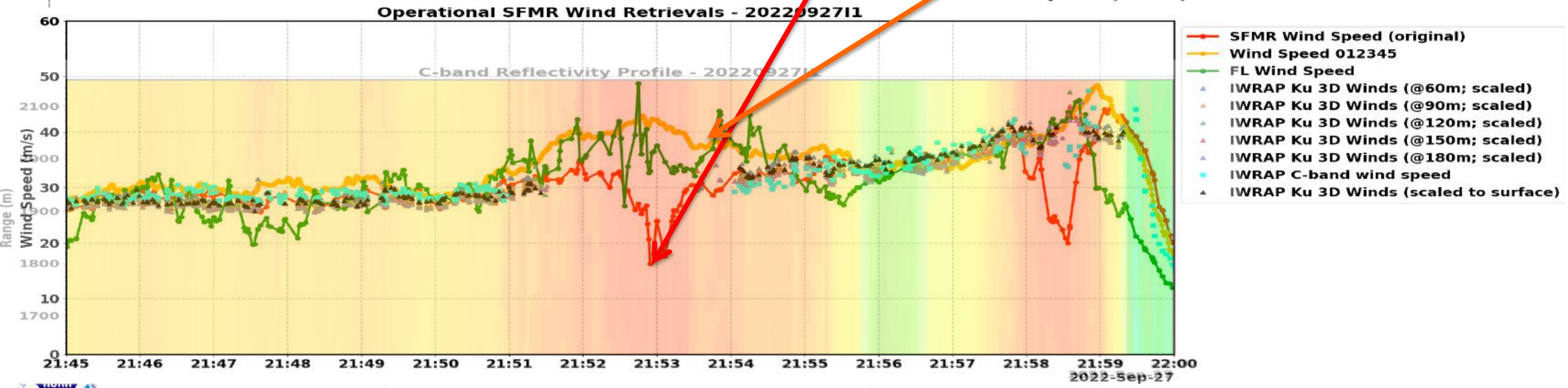


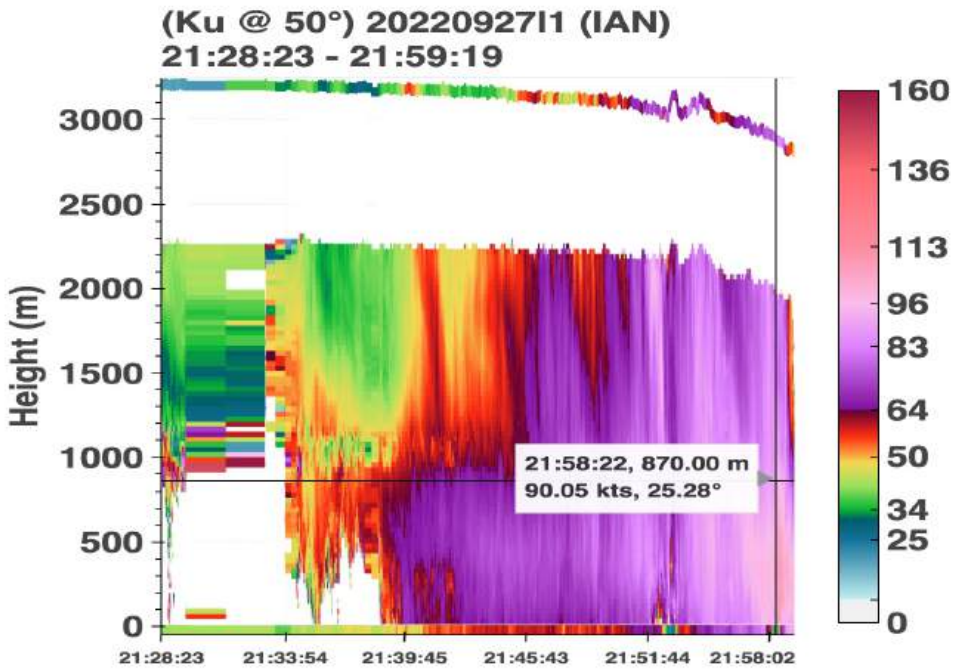
Well calibrated SFMR Ian flight 09/27/2022

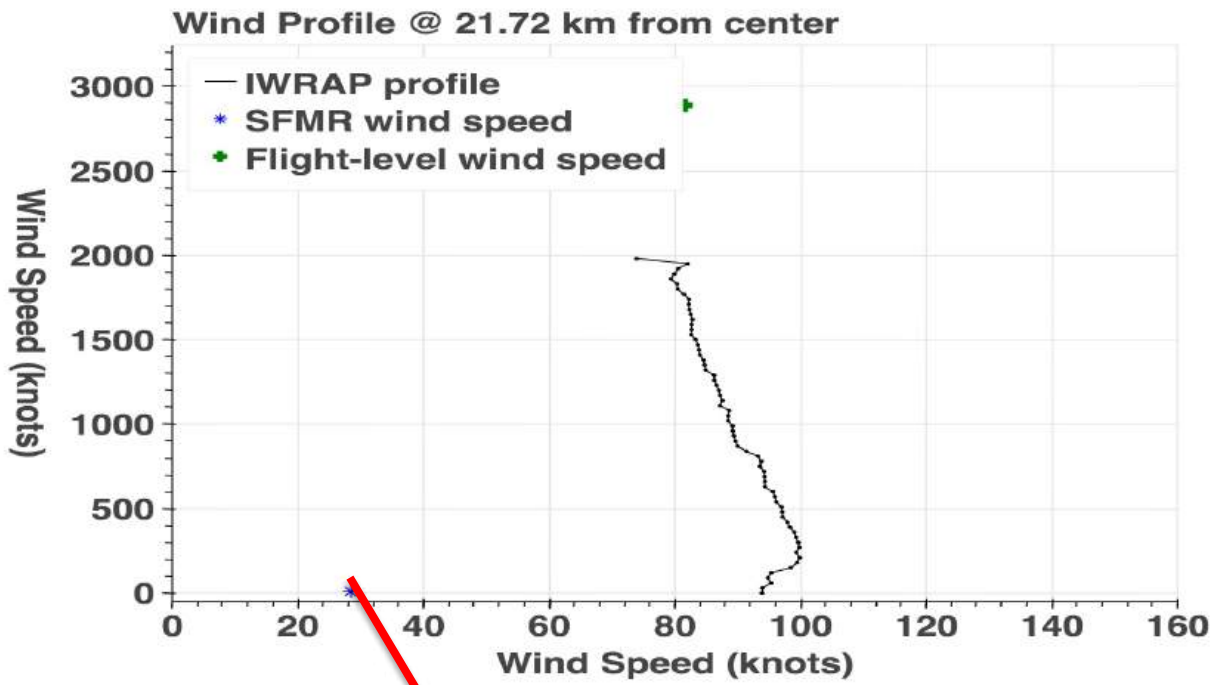


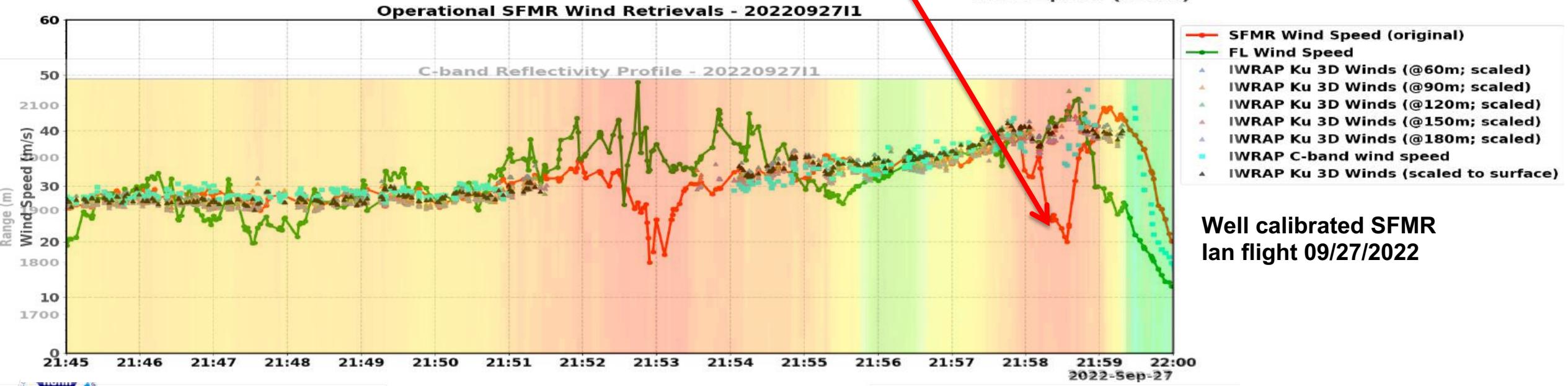


Well calibrated SFMR
New K-model

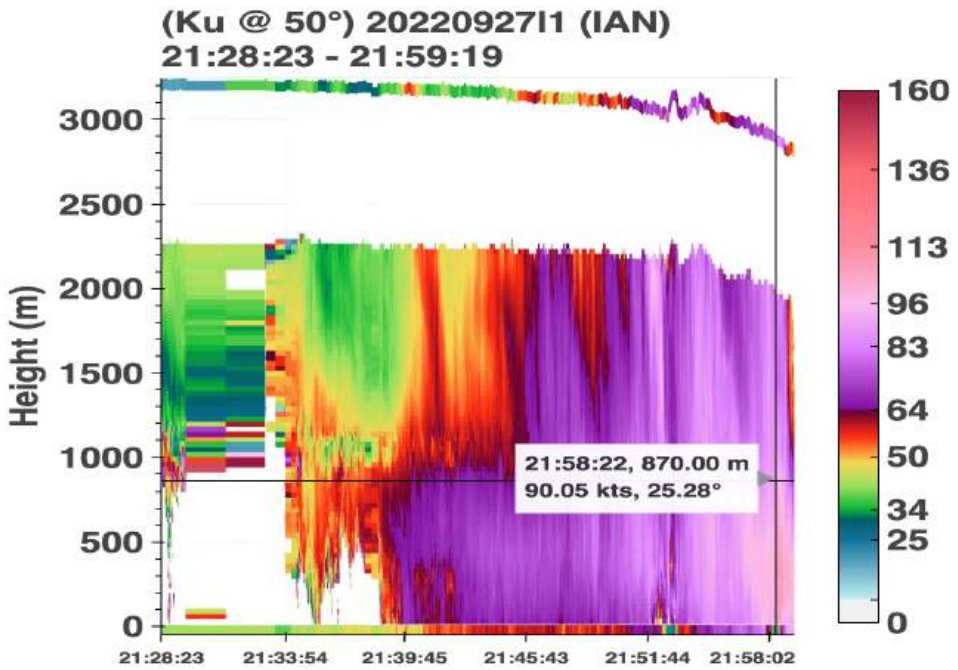


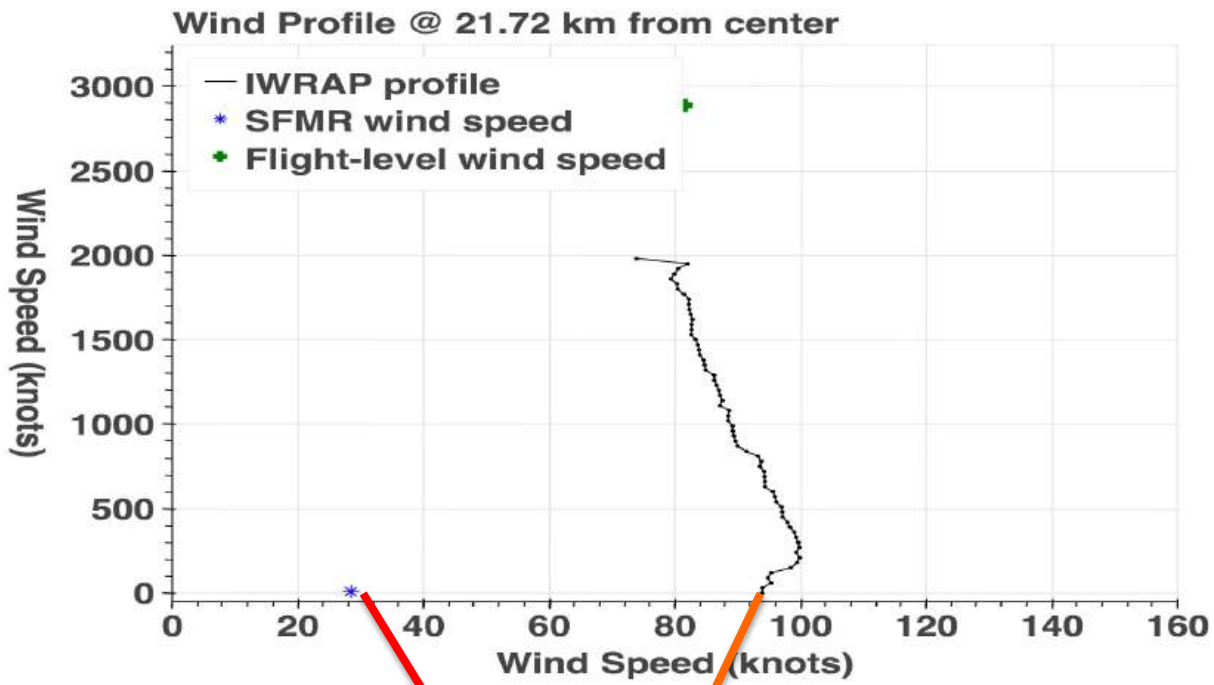


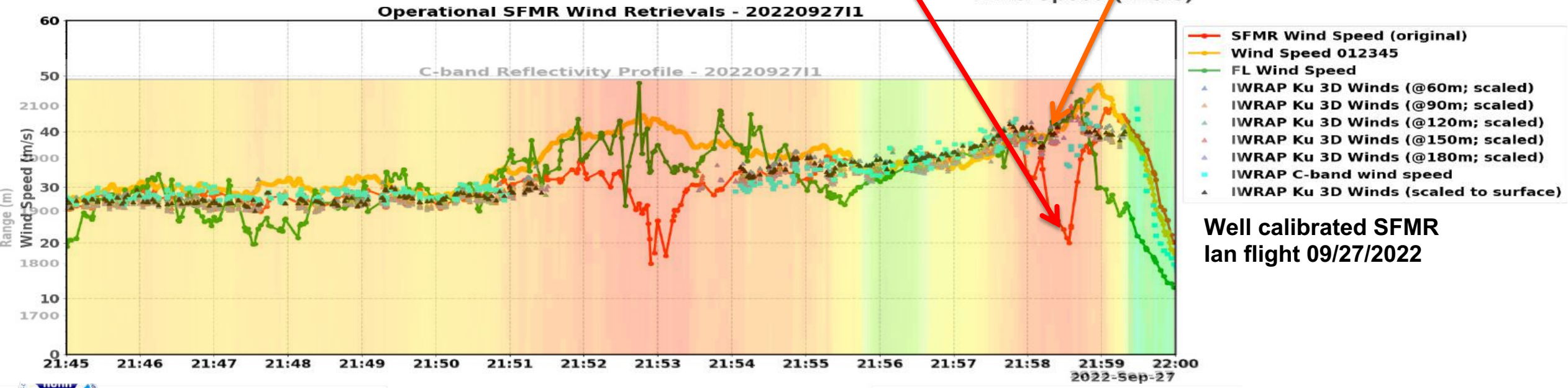




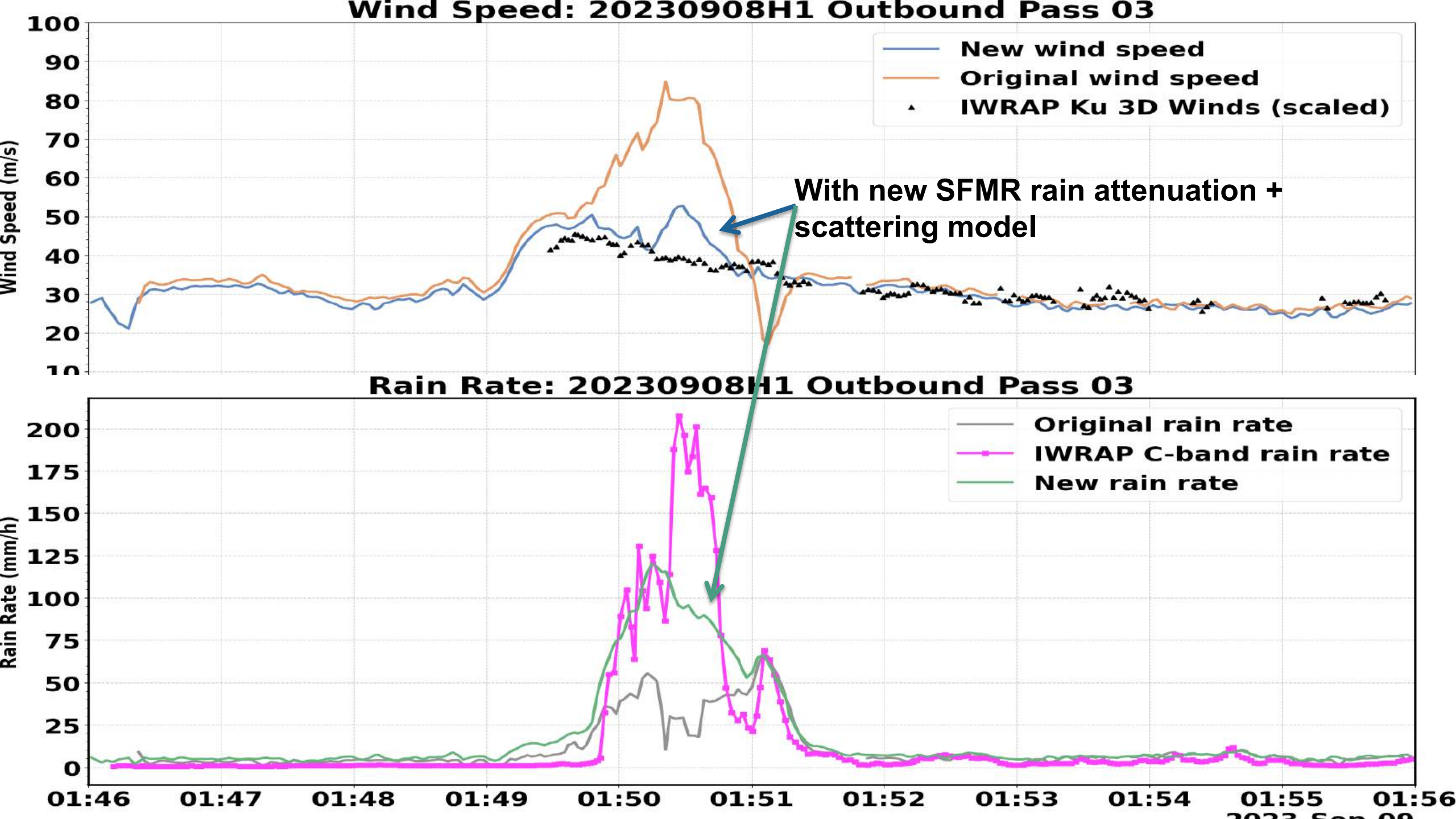
Well calibrated SFMR
Ian flight 09/27/2022



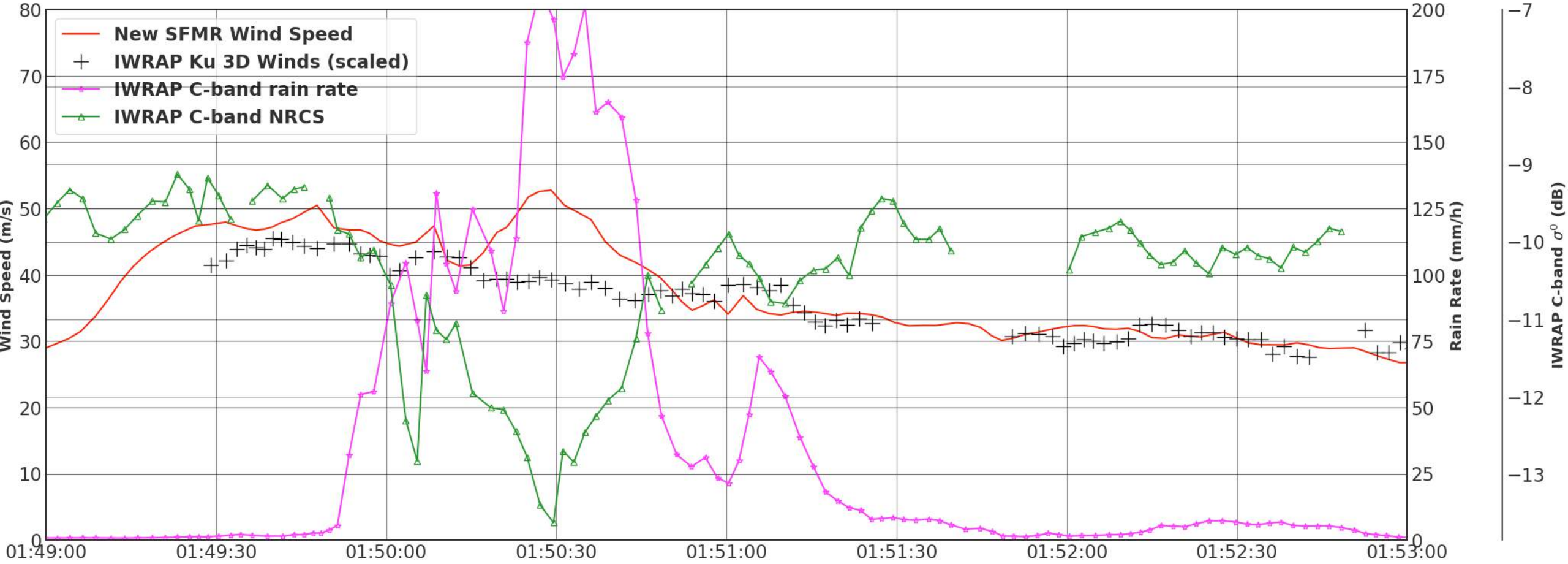


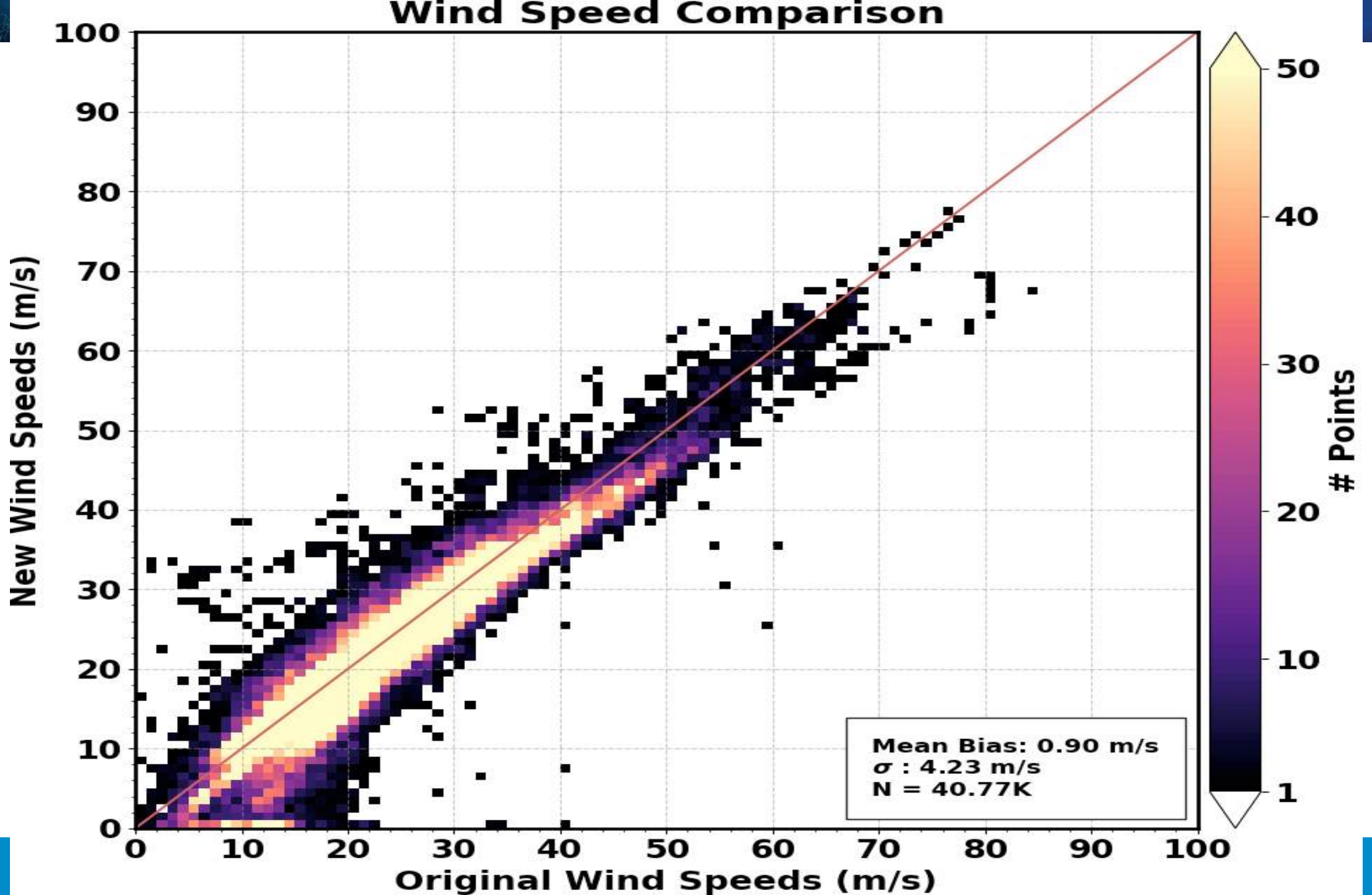


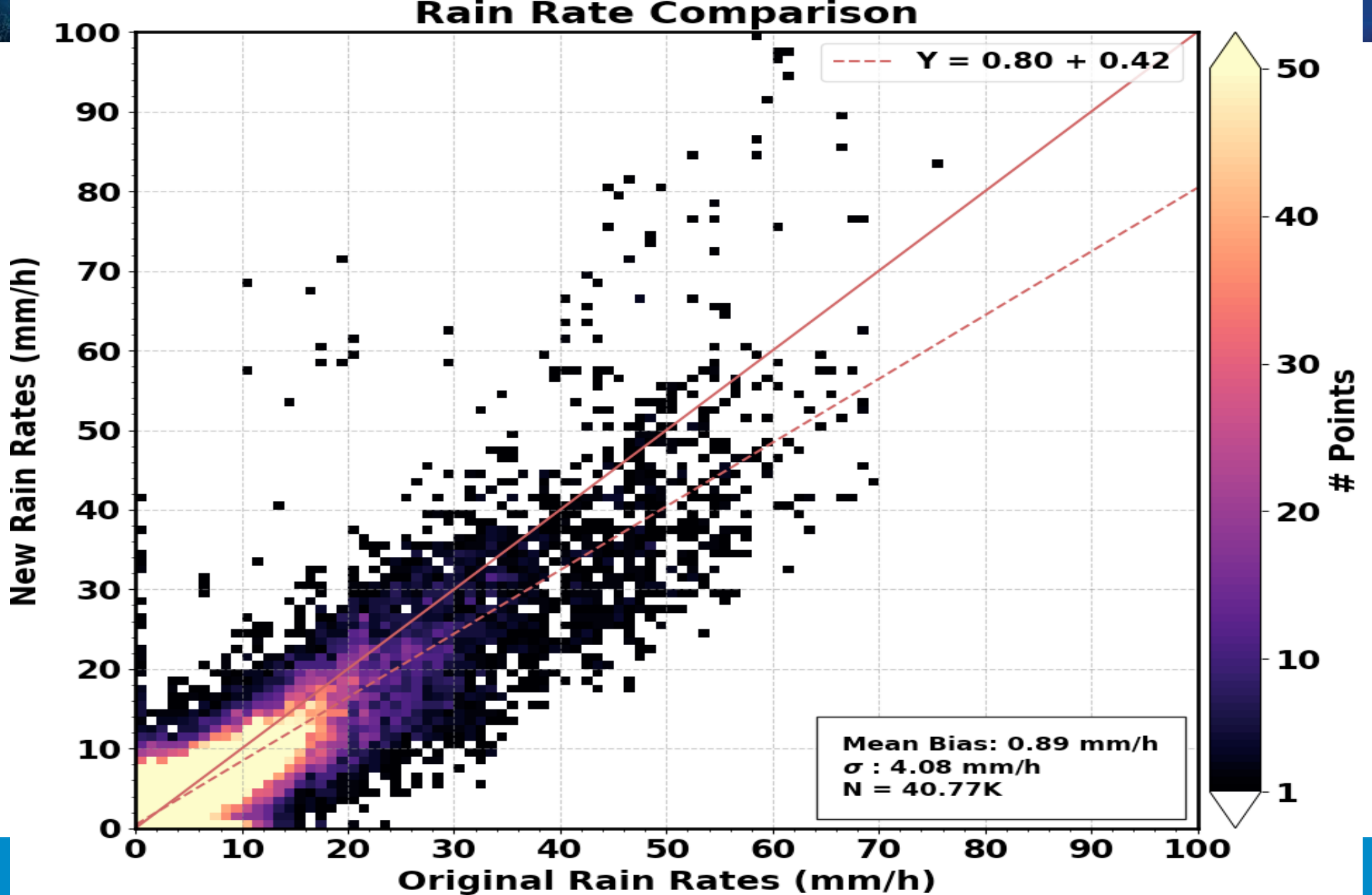
Well calibrated SFMR
Ian flight 09/27/2022


Wind Speed: 20230908H1 Outbound Pass 03
Wind Speed (m/s)
New wind speed
Original wind speed
IWRAP Ku 3D Winds (scaled)
With new SFMR rain attenuation + scattering model
Rain Rate: 20230908H1 Outbound Pass 03
Rain Rate (mm/h)
Original rain rate
IWRAP C-band rain rate
New rain rate
01:46
01:47
01:48
01:49
01:50
01:51
01:52
01:53
01:54
01:55
01:56
2023-Sep-09

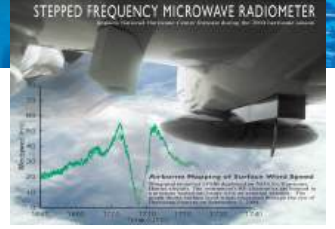
C-band is Impacted by Rain

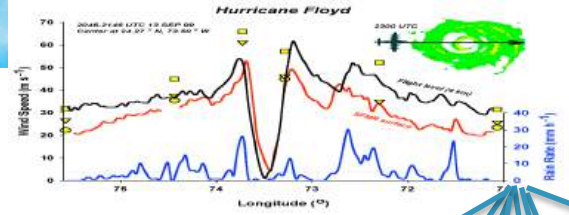



Wind Speed Comparison
New Wind Speeds (m/s)
Original Wind Speeds (m/s)
Points
Mean Bias: 0.90 m/s
σ : 4.23 m/s
N = 40.77K
0
10
20
30
40
50
60
70
80
90
100
1

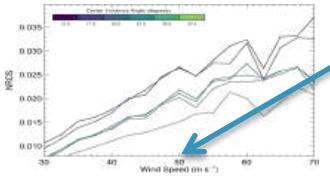

Rain Rate Comparison
Y = 0.80 + 0.42
Mean Bias: 0.89 mm/h
σ : 4.08 mm/h
N = 40.77K
New Rain Rates (mm/h)
Original Rain Rates (mm/h)
Points
0
10
20
30
40
50
60
70
80
90
100
1

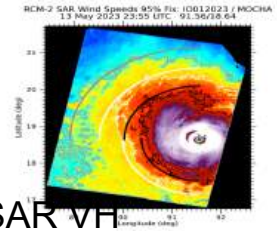
CrossPolination





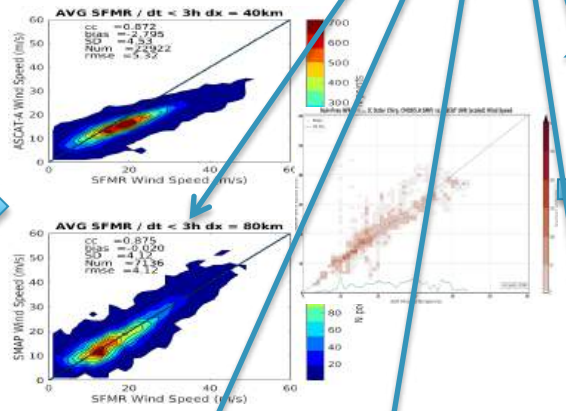
X-pol Antenna



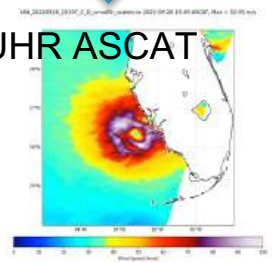


SAR VH

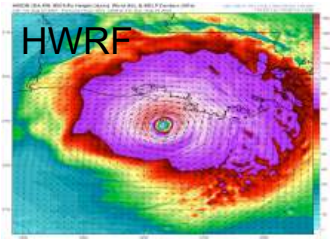
IWRAP C-band

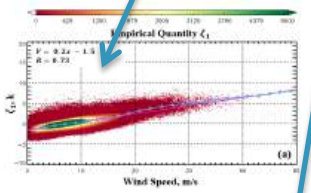


UHR ASCAT

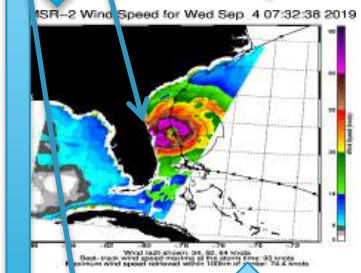


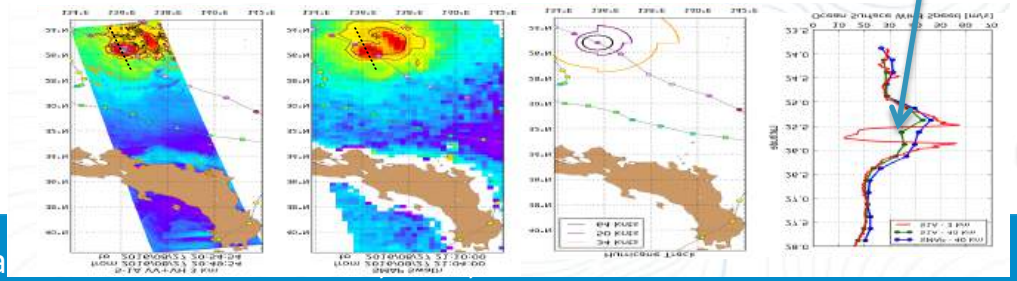
HWRF



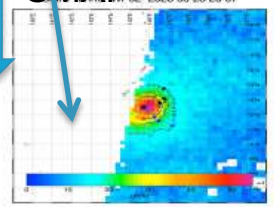


AMSR2





SMAP



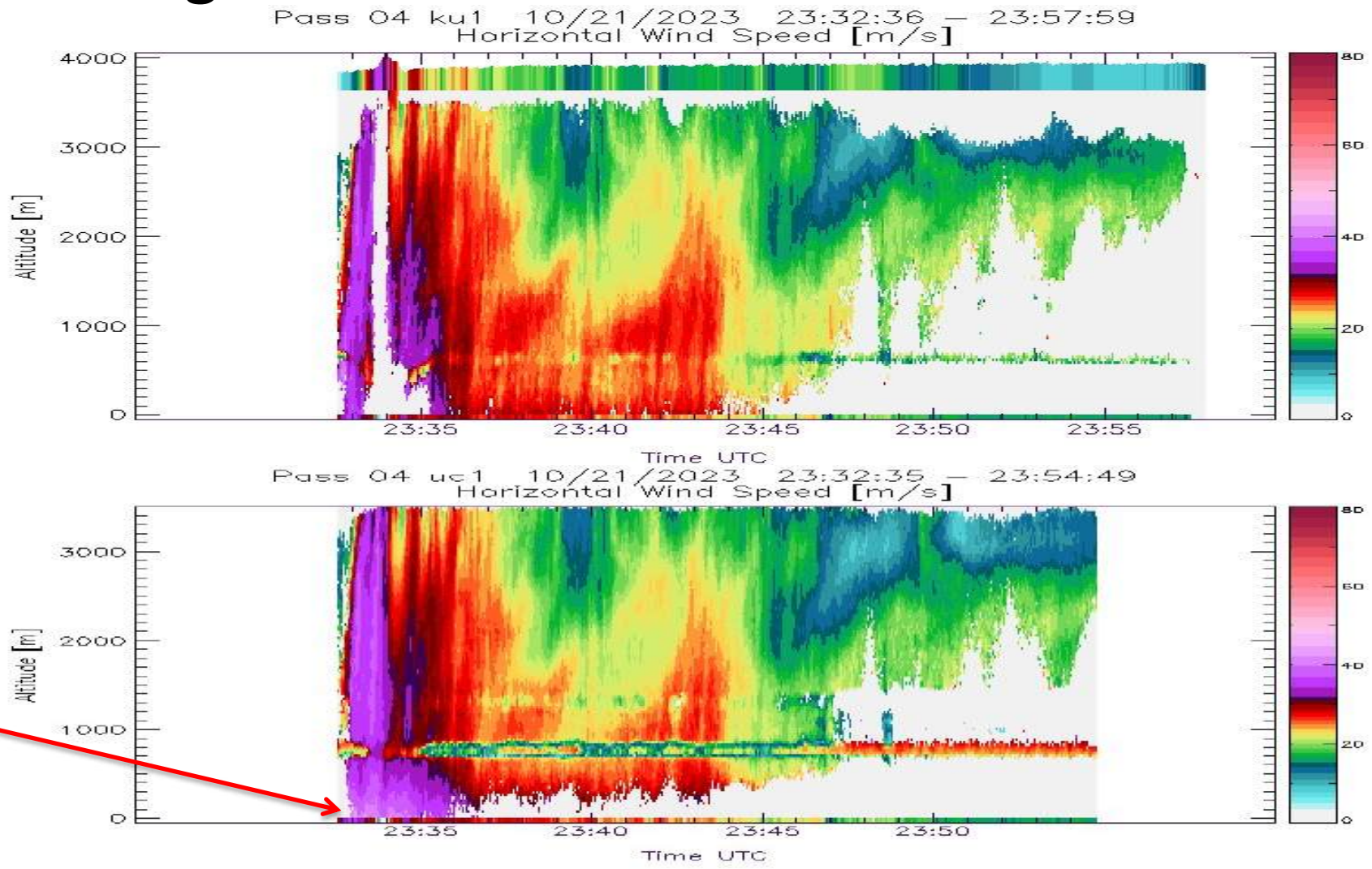
Summary

- Due to inadequate minimization scheme and rain attenuation and scattering model SFMR wind estimates both overestimate and underestimate winds within tropical cyclones
- Utilizing IWRAP measurements new attenuation/scattering model has been developed
- Considering SFMR is utilized for calibration and validation of all satellite high wind retrievals as well as for model parametarization and data assimilation we propose modification of the operational algorithm
- SFMR rain rate is also utilized for calibration of other aircraft instruments
- IWRAP NRCS and rain measurements are providing new insight of precipitation impact on scatterometry c and ku observations

Backup

Expanding our Understanding of C and Ku band Observations in Rain

- Acquired raw measurements at all 8 channels
- Better understanding of Ku and C band sensitivities
- C band seems to be more sensitive in rain column in which Ku attenuates
- These are the same rain bands within which SFMR wind speed retrievals have large errors



Typical SFMR Wind Speed Drop off within Rain Bands and Coincident IWRAP lowest 3D Horizontal Wind Retrievals