CrIS Polarization and Radiometric Uncertainty

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THE UNIVERSITY of WISCONSIN MADISON

SSEC

Outline

- CrIS Polarization
  - Introduction
  - Theory
  - Polarization parameter derivation
  - Sample Correction Results
- CrIS RU
  - Method
  - Sample results
- Summary

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CrIS Polarization Sensitivity

- The SSM has a 45° angle of incidence for all SSM positions
  - constant polarization due to incident angle regardless of SSM rotation angle
  - **unprotected gold: extremely low degree of polarization in the IR**
- Incident radiance is partially polarized by reflection from the scene select mirror
- The orientation of the polarization of the scene select mirror changes with scene mirror rotation.
- When coupled with the polarization sensitivity of the sensor, this produces a radiometric modulation of the detected signal that is dependent on the rotation angle of the scene select mirror and creates a calibration error
- Assuming that SSM and sensor are each predominantly linear in polarization:
  - SSM and sensor act as a polarizer and analyzer pair
  - **The variation in total transmission as the SSM polarization orientation angle rotates with respect to the sensor polarization orientation angle is extremely small**
  - **However: the polarized emission from the scene mirror also needs to be accounted for and the impact on calibrated radiance can be significant for cold scenes**
- Similar to formalism described by Pagano et al for the AIRS instrument.

Partial Polarizer – Analyzer Pair

- Total signal *intensity* generated for an arbitrary, unpolarized scene or calibration radiance observed at a scene selection mirror angle δ and a sensor polarization axis at an angle α:

$$
\begin{aligned}
C_\delta = {} & \frac{L_\delta}{2} r_p \left[t_{\max} \cos^2(\delta-\alpha) + t_{\min} \sin^2(\delta-\alpha) \right] \\
& + \frac{L_\delta}{2} r_s \left[t_{\max} \sin^2(\delta-\alpha) + t_{\min} \cos^2(\delta-\alpha) \right] \\
& + \frac{B_{SSM}}{2} \varepsilon_p \left[t_{\max} \cos^2(\delta-\alpha) + t_{\min} \sin^2(\delta-\alpha) \right] \\
& + \frac{B_{SSM}}{2} \varepsilon_s \left[t_{\max} \sin^2(\delta-\alpha) + t_{\min} \cos^2(\delta-\alpha) \right] \\
& + C_{inst} .
\end{aligned}
$$

The first two terms: Scene (reflected by SSM into sensor). The third and fourth terms: Emission from SSM.

- which can be simplified to:

$$C_\delta = (L_\delta - B_{SSM})rt + B_{SSM}t + (L_\delta - B_{SSM})\underline{p_r p_t rt \cos 2(\delta-\alpha)} + C_{inst} \qquad [1]$$

r_p	*Reflectivity of the scene mirror for the parallel polarization state*
$\varepsilon_p = 1 - r_p$	*corresponding emissivity*
r_s	*Reflectivity of the scene mirror for the perpendicular polarization state*
$\varepsilon_s = 1 - r_s$	*corresponding emissivity*
t_{min}	*intensity transmission on the minor axis of the sensor polarization ellipse*
t_{max}	*intensity transmission on the major axis of the sensor polarization ellipse*
α	*major axis orientation angle (sensor)*
δ	*scene mirror angle*
L_δ	*scene radiance as attenuated by the scene mirror reflectance*
B_{SSM}	*radiance from a blackbody at the temperature of the scene selection mirror*

Polarization Induced Calibration Error

- A relationship between the correct calibrated radiance (L_S) and the calibrated radiance affected by the calibration bias due to polarization ($L_{\delta,S}$) can be defined as:

$$L_{\delta,S} = L_S + E_p \qquad [2]$$

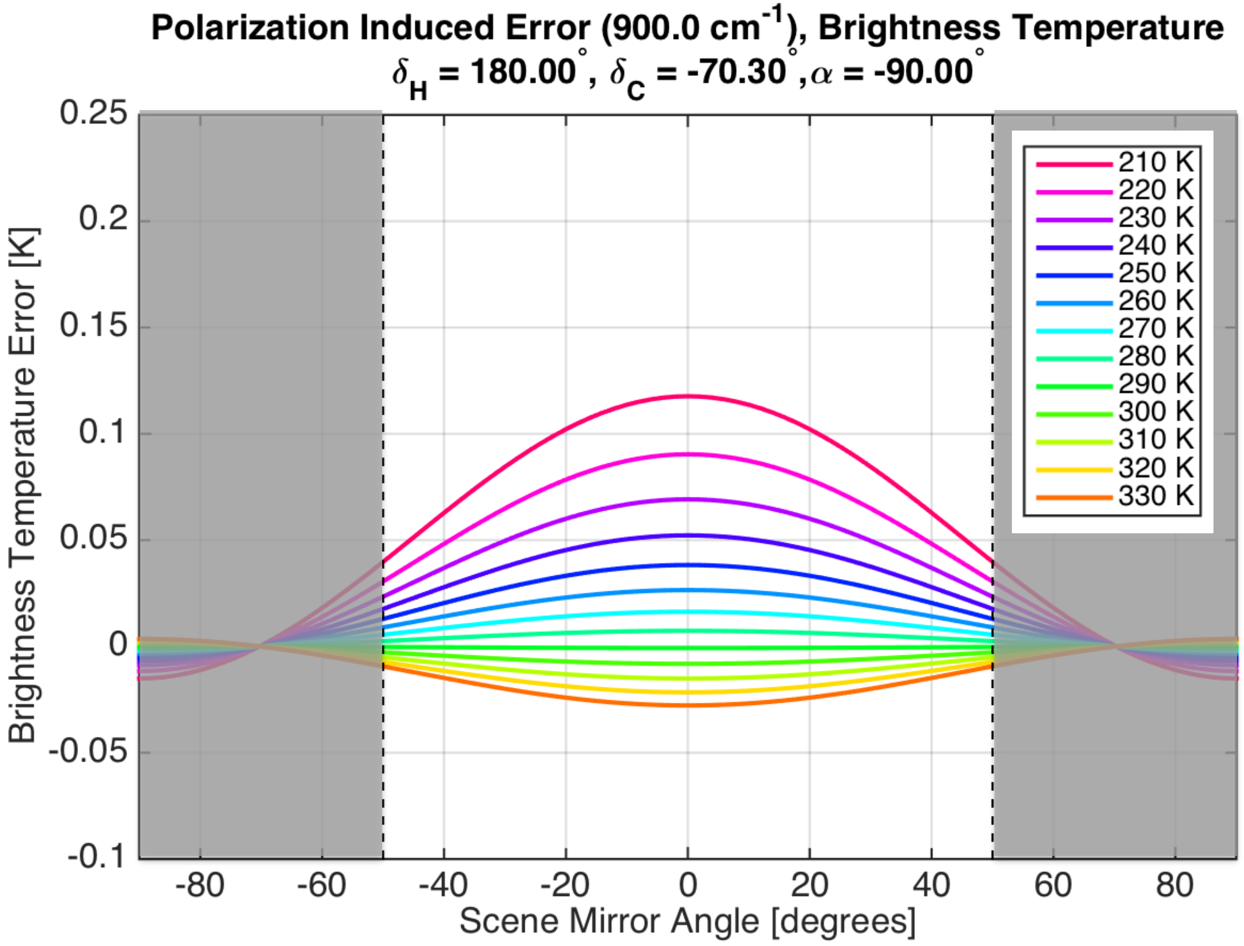
$$L_S = L_{\delta,S} - E_p$$

- where E_p is the calibration error due to polarization, and ($L_{\delta,S}$) can be determined by substituting Eq. [1] into the calibration equation (Eq. [3]):

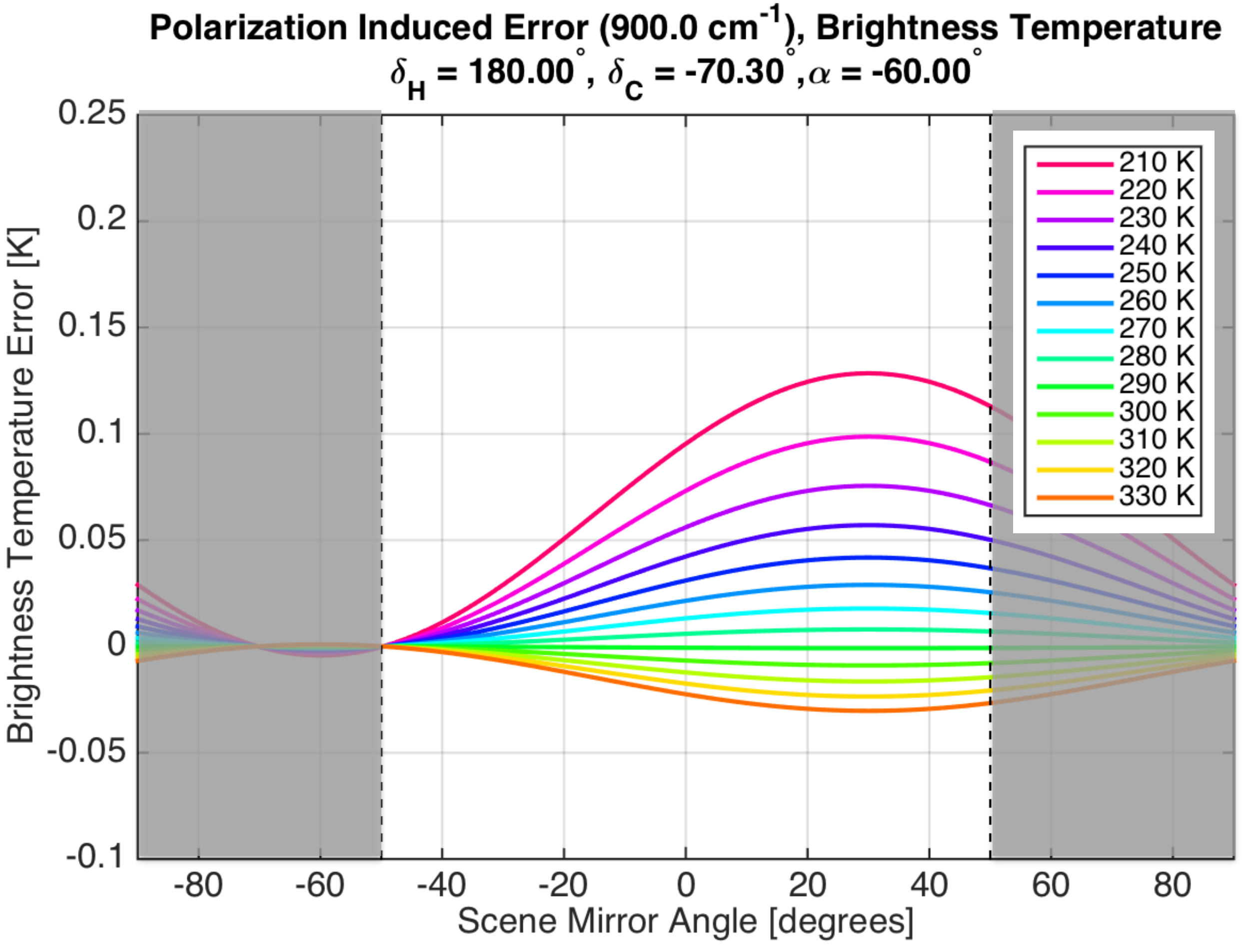
$$L_{\delta,S} = \left(L_H - L_C\right)\left[\frac{C_{\delta,S} - C_{\delta,C}}{C_{\delta,H} - C_{\delta,C}}\right] + L_C \qquad [3]$$

$$E_p \cong p_r p_t \left\{ \begin{aligned} & L_S \cos 2\left(\delta_S - \alpha\right) - L_H \frac{L_S - L_C}{L_H - L_C} \cos 2\left(\delta_H - \alpha\right) - L_C \frac{L_H - L_S}{L_H - L_C} \cos 2\left(\delta_C - \alpha\right) \\ & - B_{SSM}\left[\cos 2\left(\delta_S - \alpha\right) - \frac{L_S - L_C}{L_H - L_C} \cos 2\left(\delta_H - \alpha\right) - \frac{L_H - L_S}{L_H - L_C} \cos 2\left(\delta_C - \alpha\right)\right] \end{aligned} \right\}$$

Polarization Induced Calibration Error



α = -90°,
900 cm^{-1}



α = -60°,
900 cm^{-1}

The Pitch Maneuver

- The maneuver provides space view for all CrIS cross-track (ES) and DS FORs and FOVs
- Represents our only end-to-end polarization measurements for CrIS

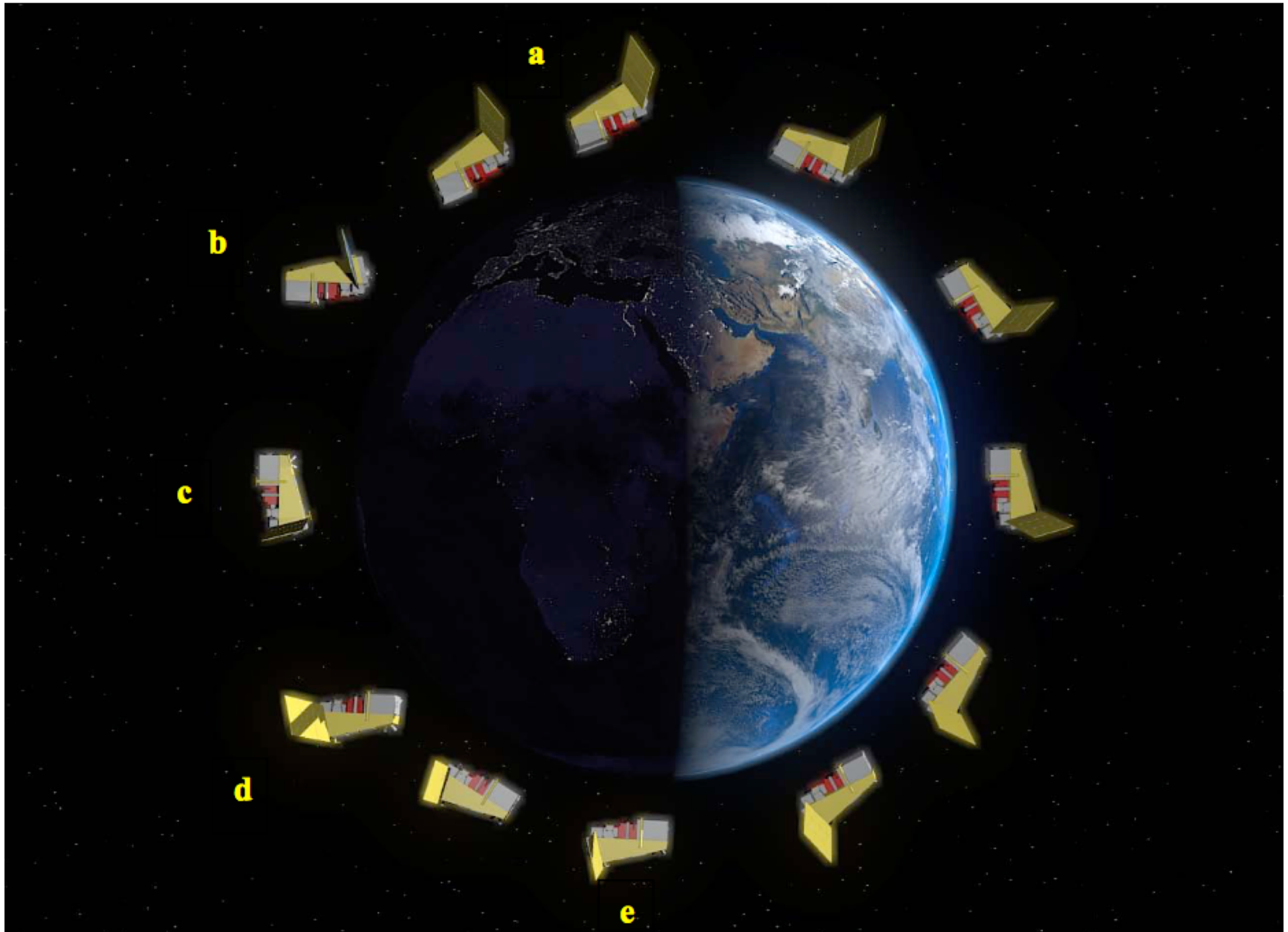
a. The maneuver begins with a slight pitch down of the nose of the spacecraft.

b. The nose of the spacecraft in the process of pitching up.

c. The spacecraft is pitched completely away from viewing the Earth on the dark side of the orbit, and the instrument is oriented to view deep space.

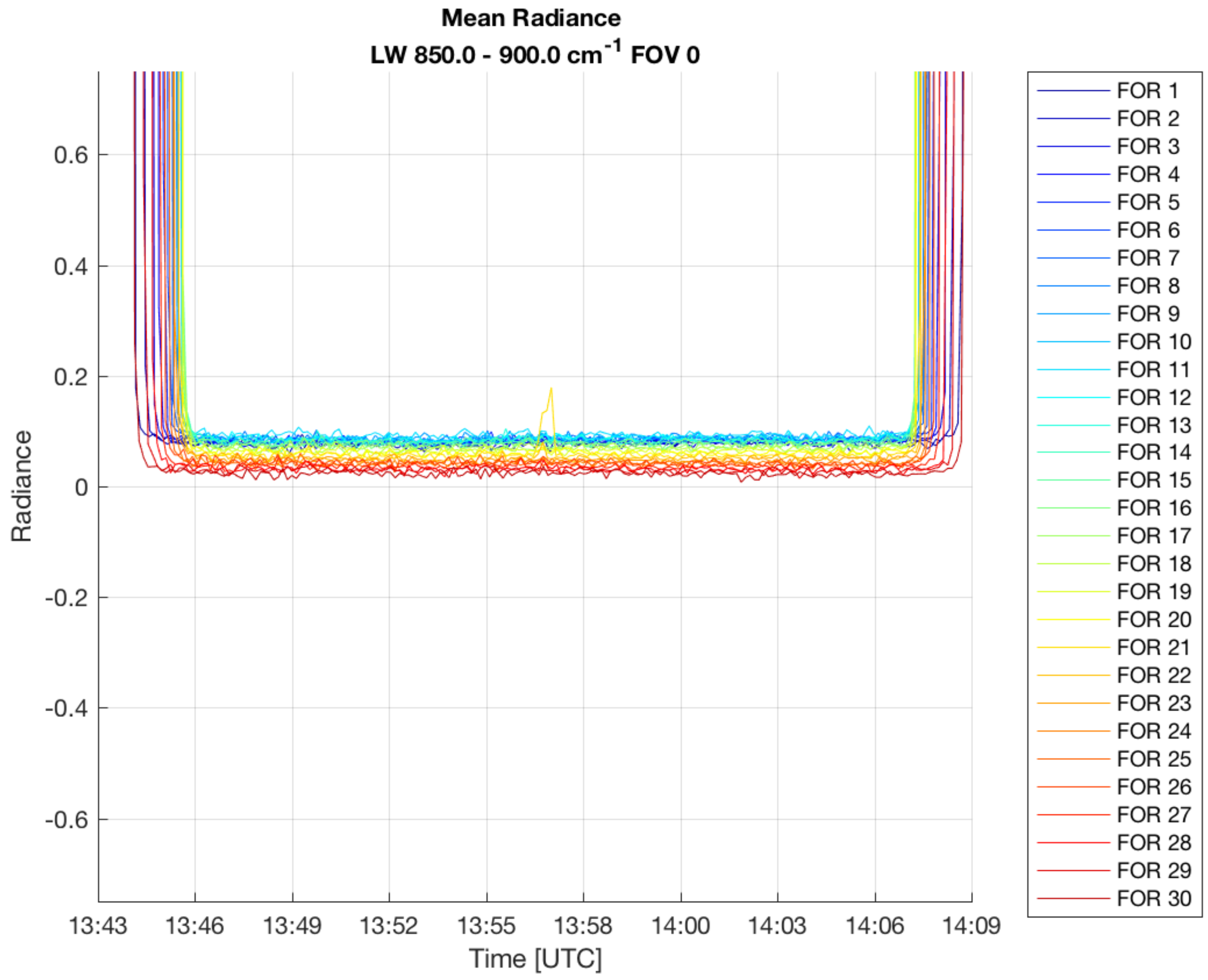
d. The pitch maneuver continues to return the spacecraft to nominal Earth viewing mode.

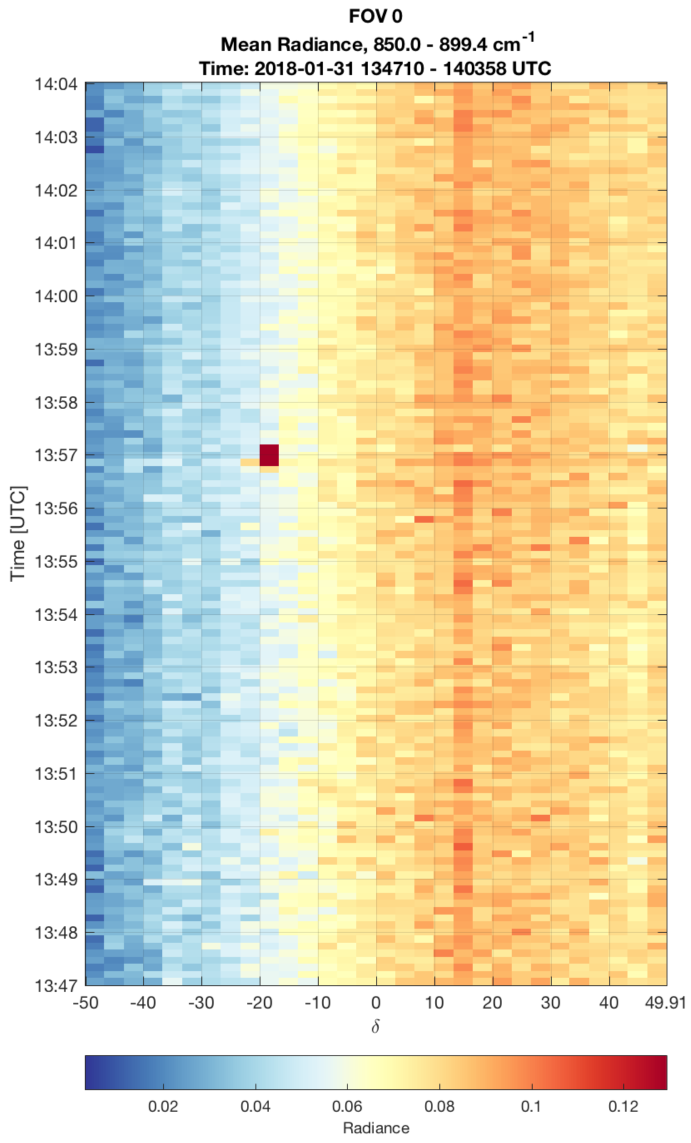
e. The spacecraft has returned to its nominal Earth viewing geometry



J. Butler et al: "An overview of Suomi NPP VIIRS calibration maneuvers" (Section 2c, Figure 8)

NOAA-20 Pitch Maneuver: Radiance Time-series 850-900 cm^{-1}, mean over all FOVs; All Cross-track FORs viewing Deep Space 1347:1406 UTC (2018-01-31)





Polarization Parameter Derivation

- Using the pitch maneuver data to assess the polarization parameters for CrIS
  - The raw and calibrated signals show clear polarization effects, and are very well represented by the theoretical model
- α, the effective polarizer angle of the sensor:
  - Initial estimate derived from raw ES and DS spectra, refined using calibrated radiances using expression for E_p
  - Detector band dependence (aft optic dichroics)
  - Small FOV dependence
- $p_r p_t$, the combined polarization of the SSM (p_r) and sensor (p_t):
  - Derived from calibrated radiances using expression for E_p
  - Spectral dependence
  - Small FOV dependence

Longwave Band

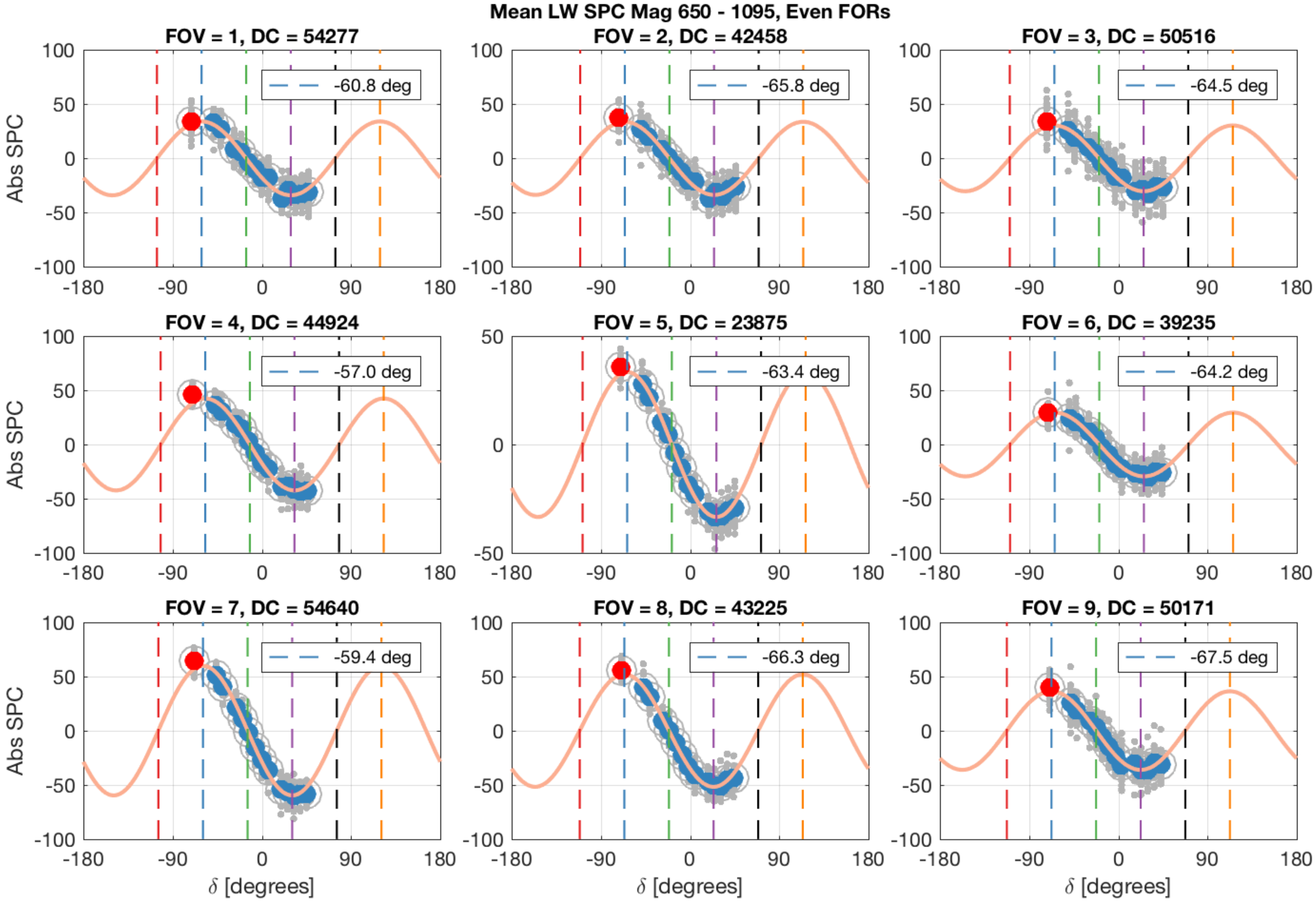
2012-02-20, 18:27 – 18:30

2018-01-31, 13:47 – 13:51

Fit Sinusoid to Band Averaged Magnitude Spectra for Even FOR 650 – 1095 cm^{-1}

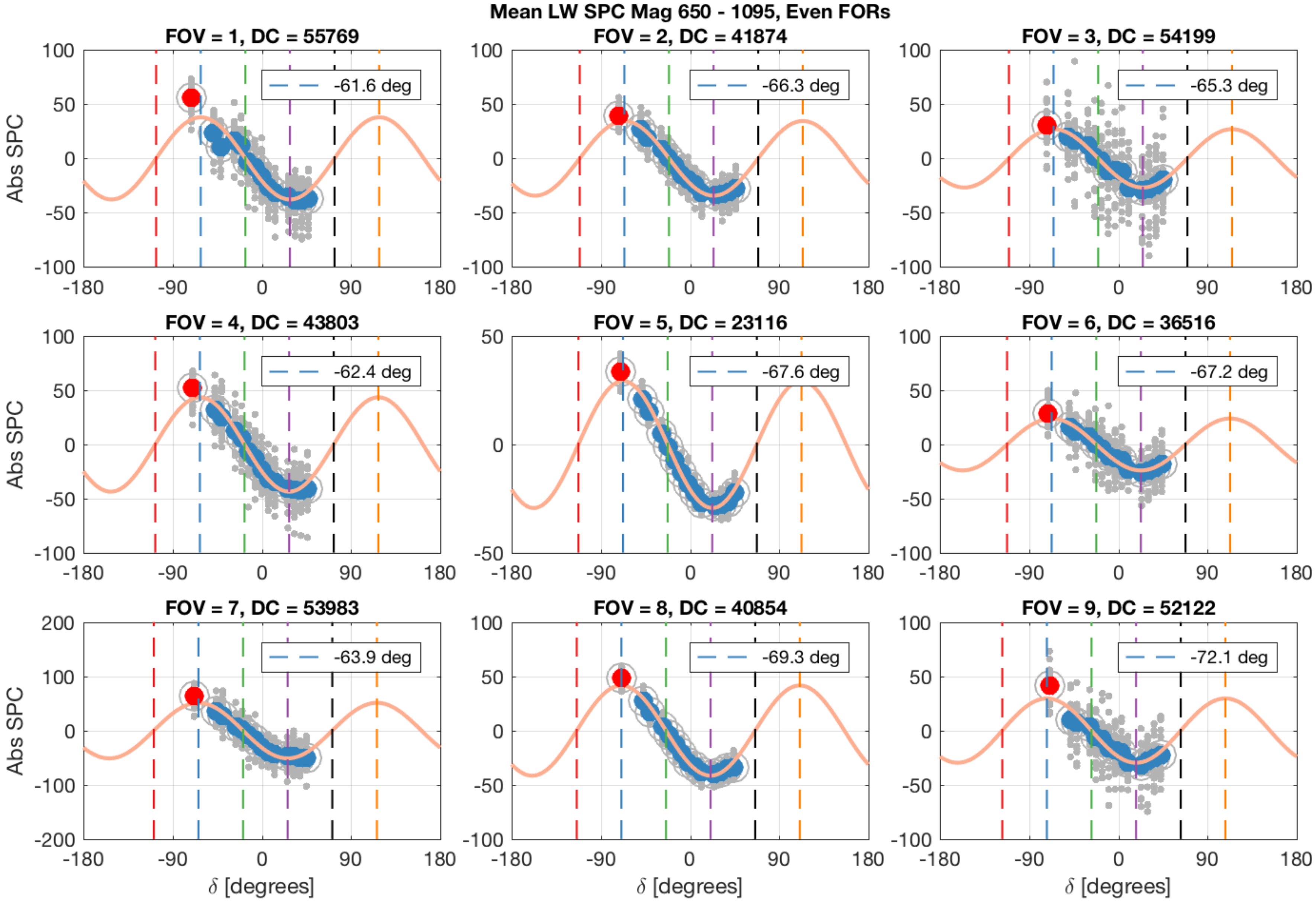
SNPP

DS view in red



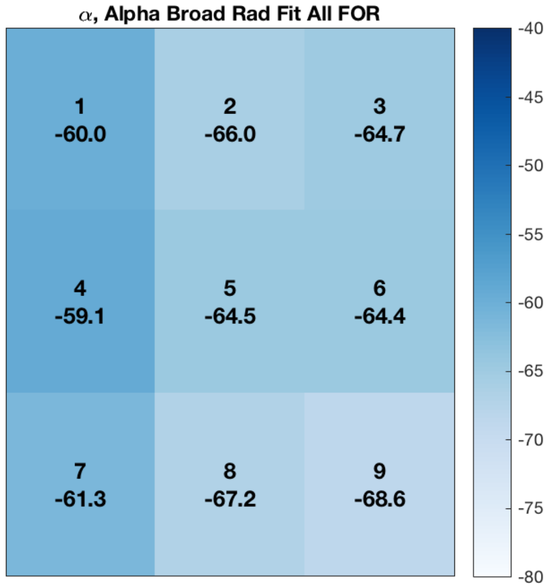
Fit Sinusoid to Band Averaged Magnitude Spectra for Even FOR 650 – 1095 cm^{-1}

DS view in red

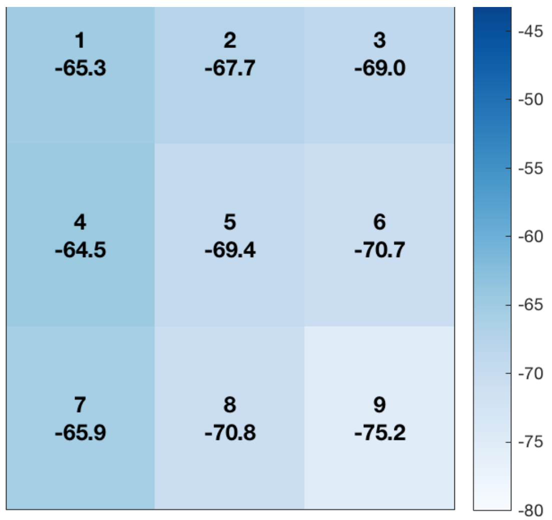


LW α and $p_r p_t$: FOVs 1-9

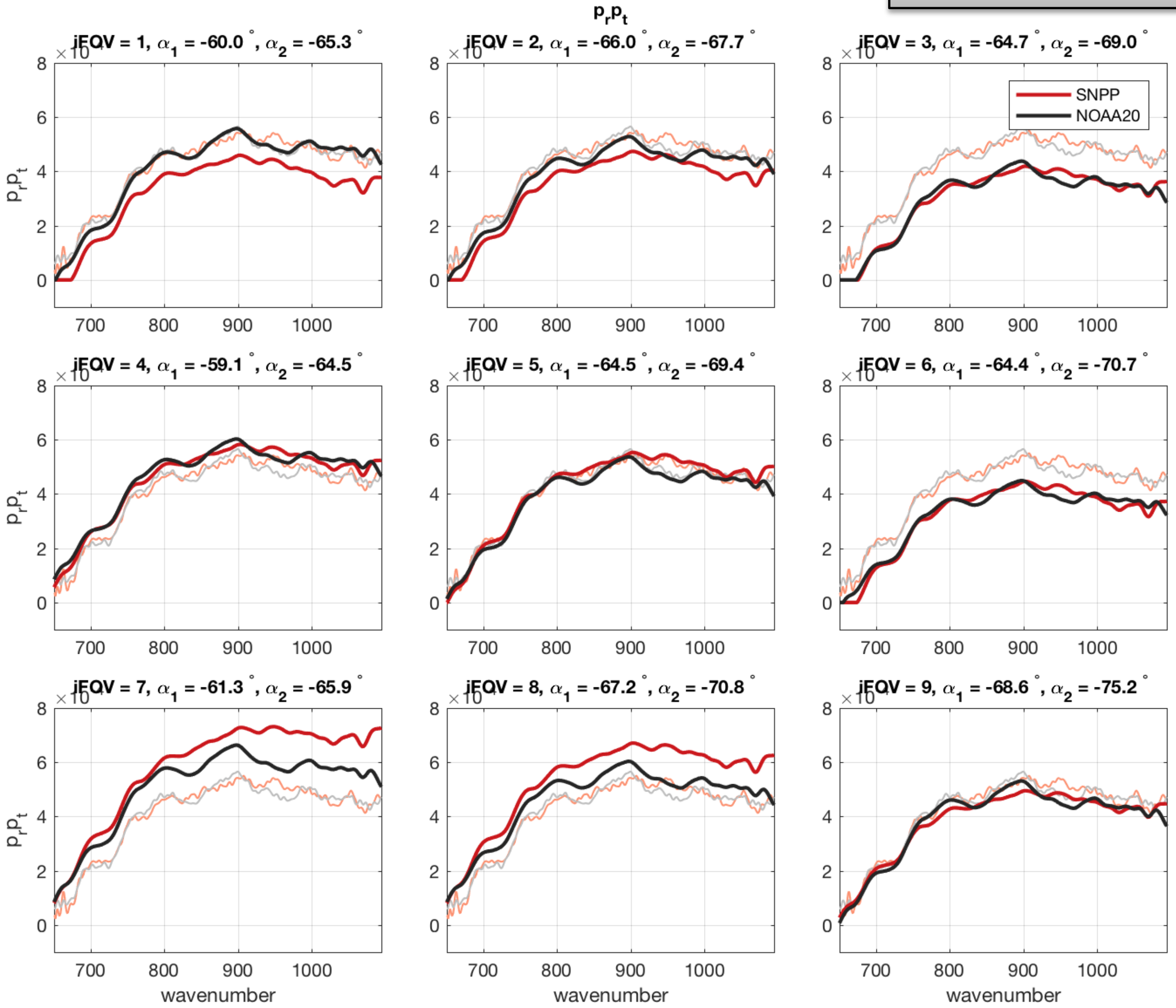
light lines: FOV0 fit with no filtering or smoothing



SNPP



NOAA20



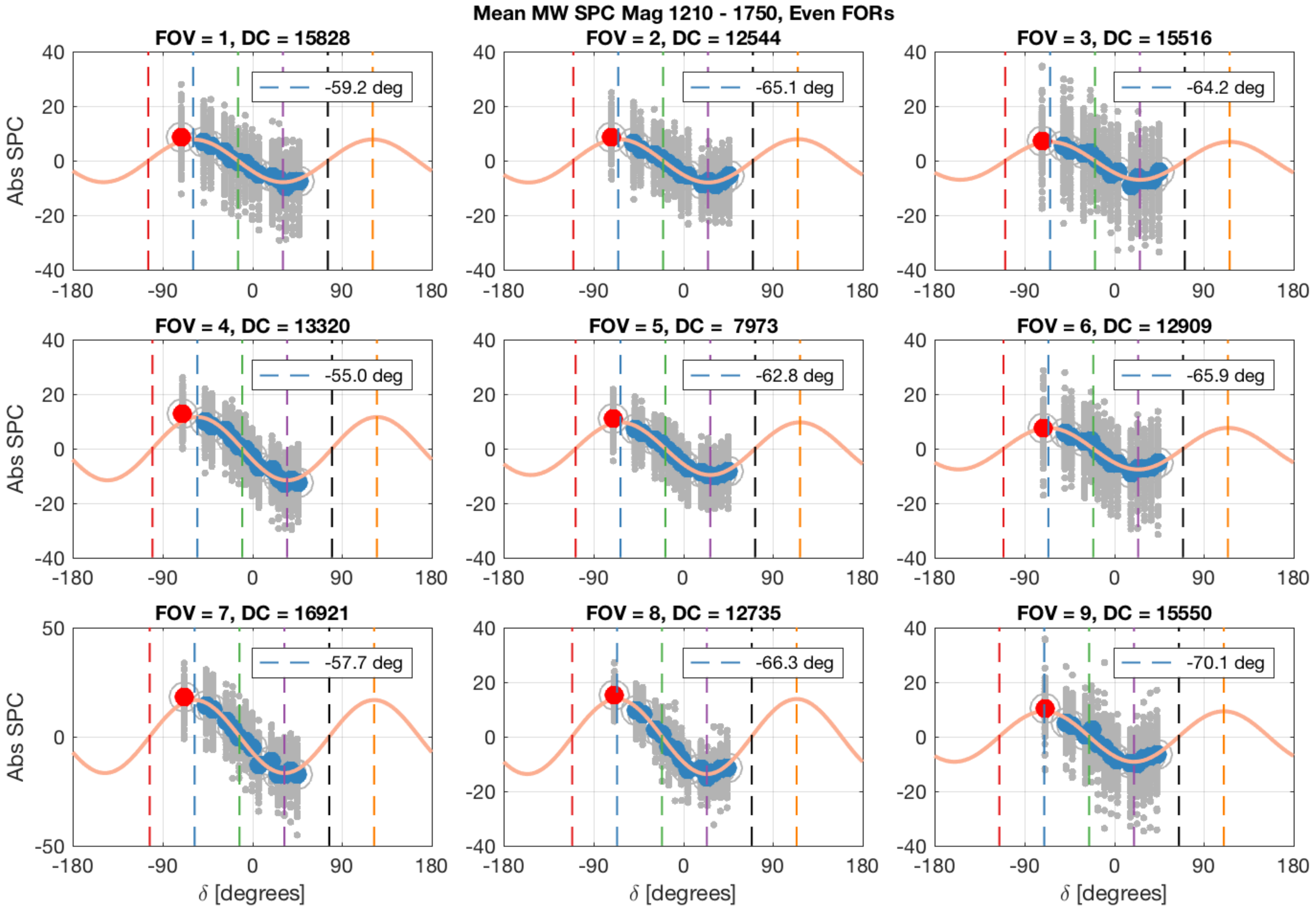
Midwave Band

2012-02-20, 18:27 to 18:41

2018-01-31, 13:47 to 14:04

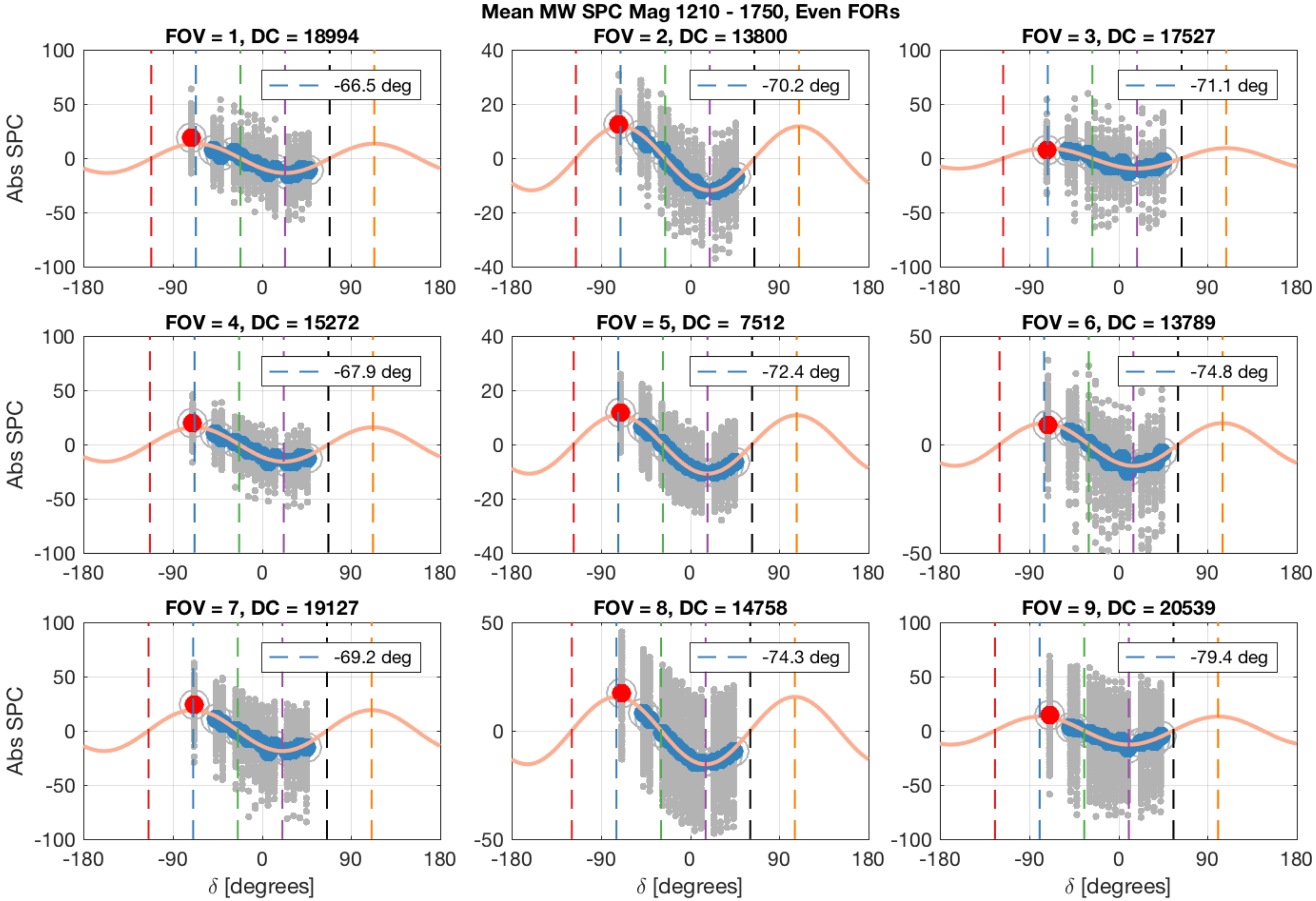
Fit Sinusoid to Band Averaged Magnitude Spectra for Even FOR 1210 – 1750 cm^{-1}

DS view in red



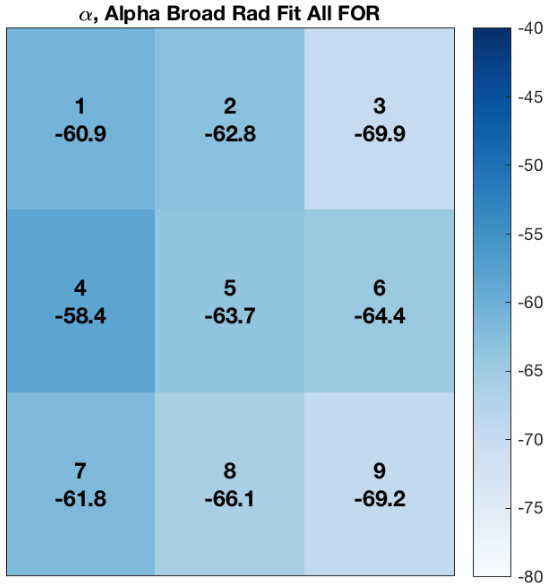
Fit Sinusoid to Band Averaged Magnitude Spectra for Even FOR 1210 – 1750 cm^{-1}

DS view in red

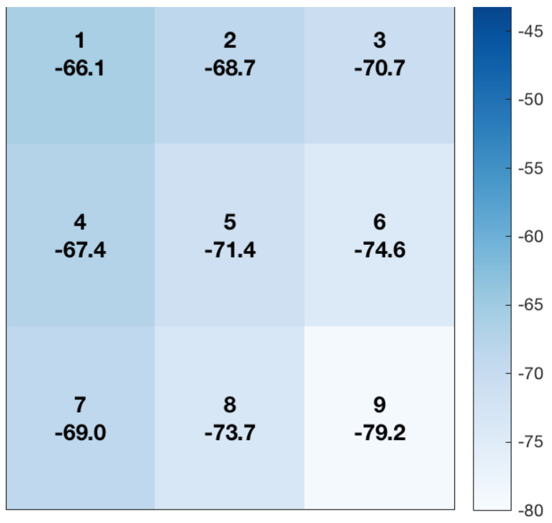


MW α and $p_r p_t$: FOVs 1-9

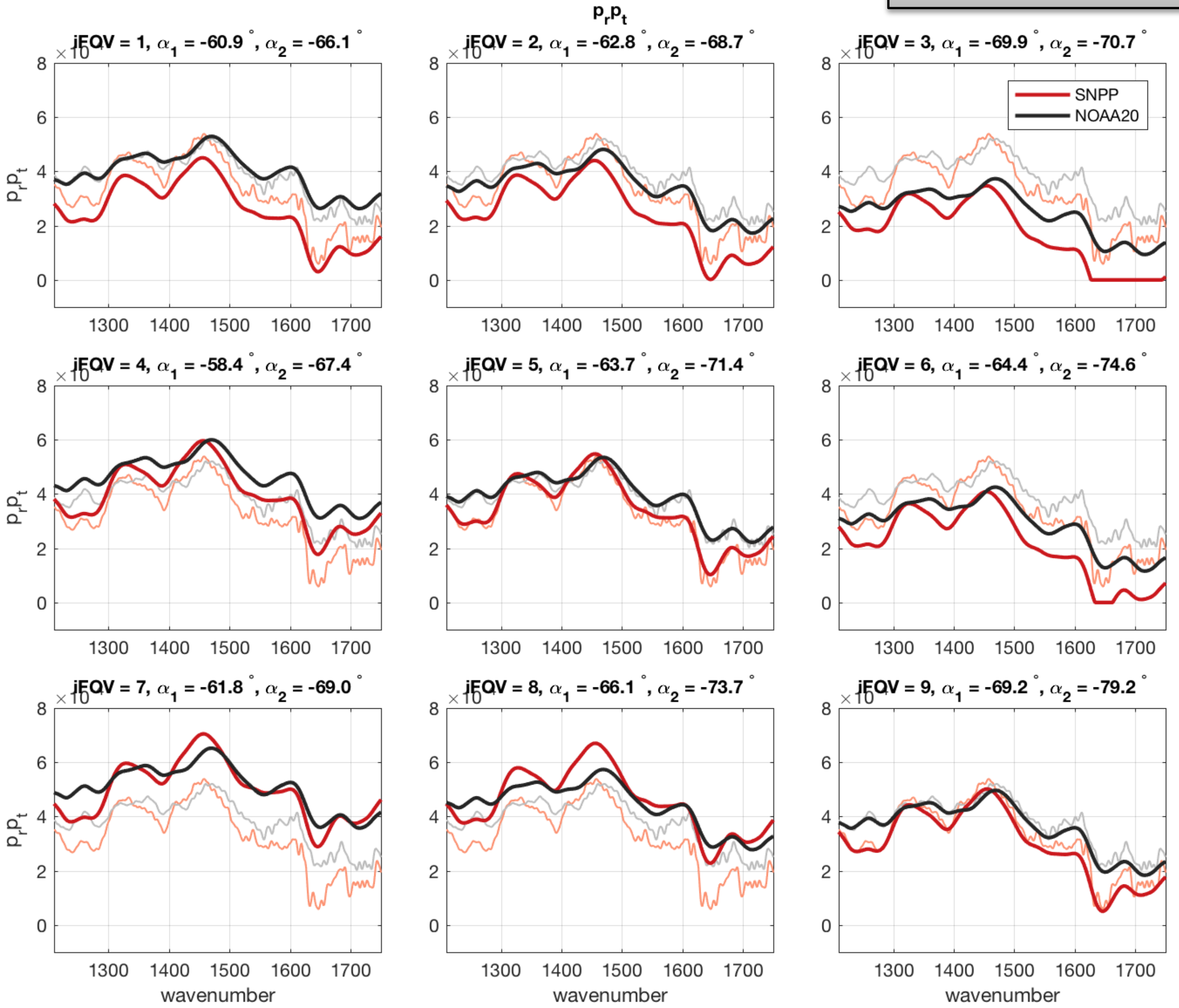
light lines: FOV0 fit with no filtering or smoothing



SNPP



NOAA20



Shortwave Band

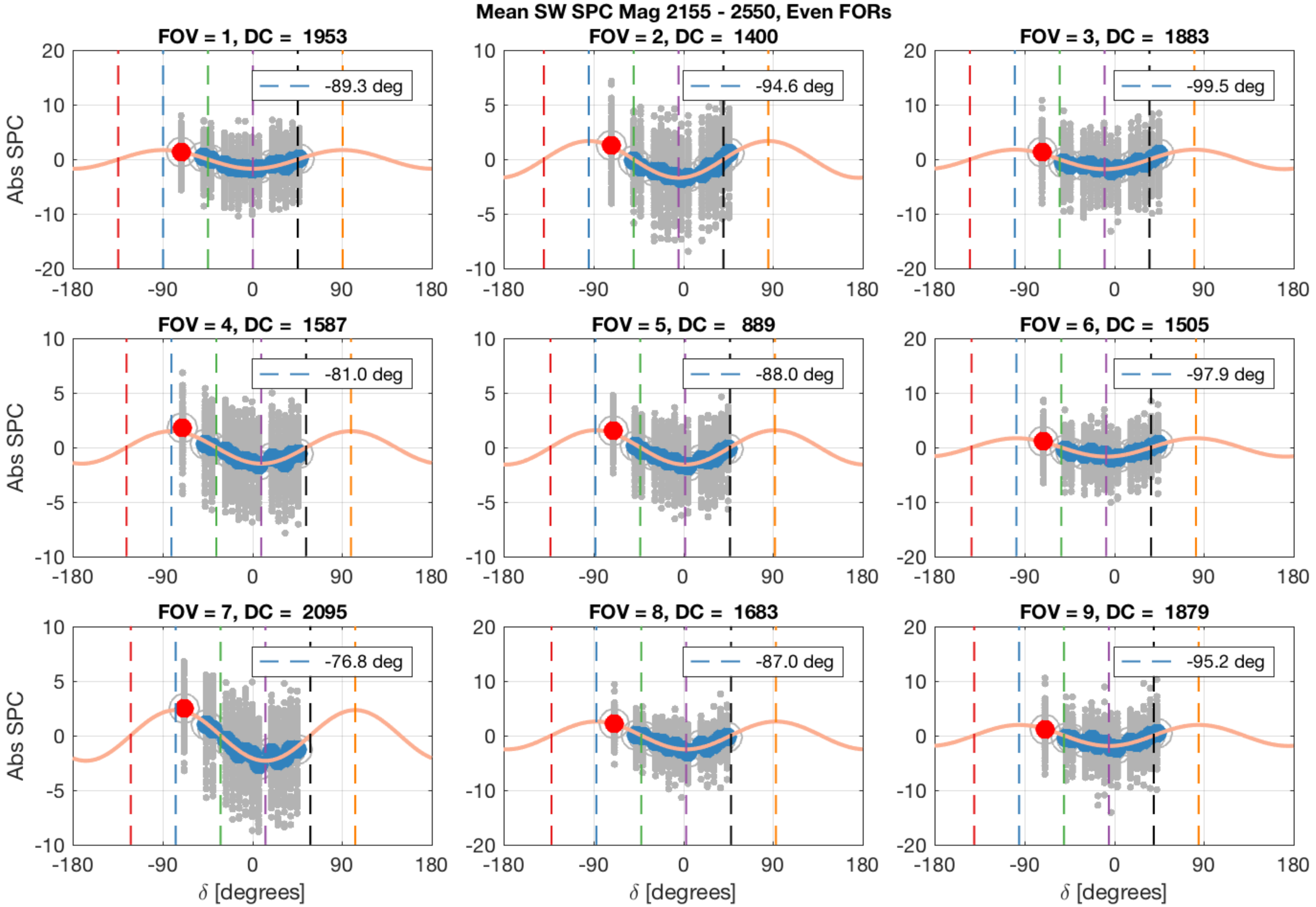
2012-02-20, 18:27 to 18:41

2018-01-31, 13:47 to 14:04

Fit Sinusoid to Band Averaged Magnitude Spectra for Even FOR 2155 – 2550 cm^{-1}

SNPP

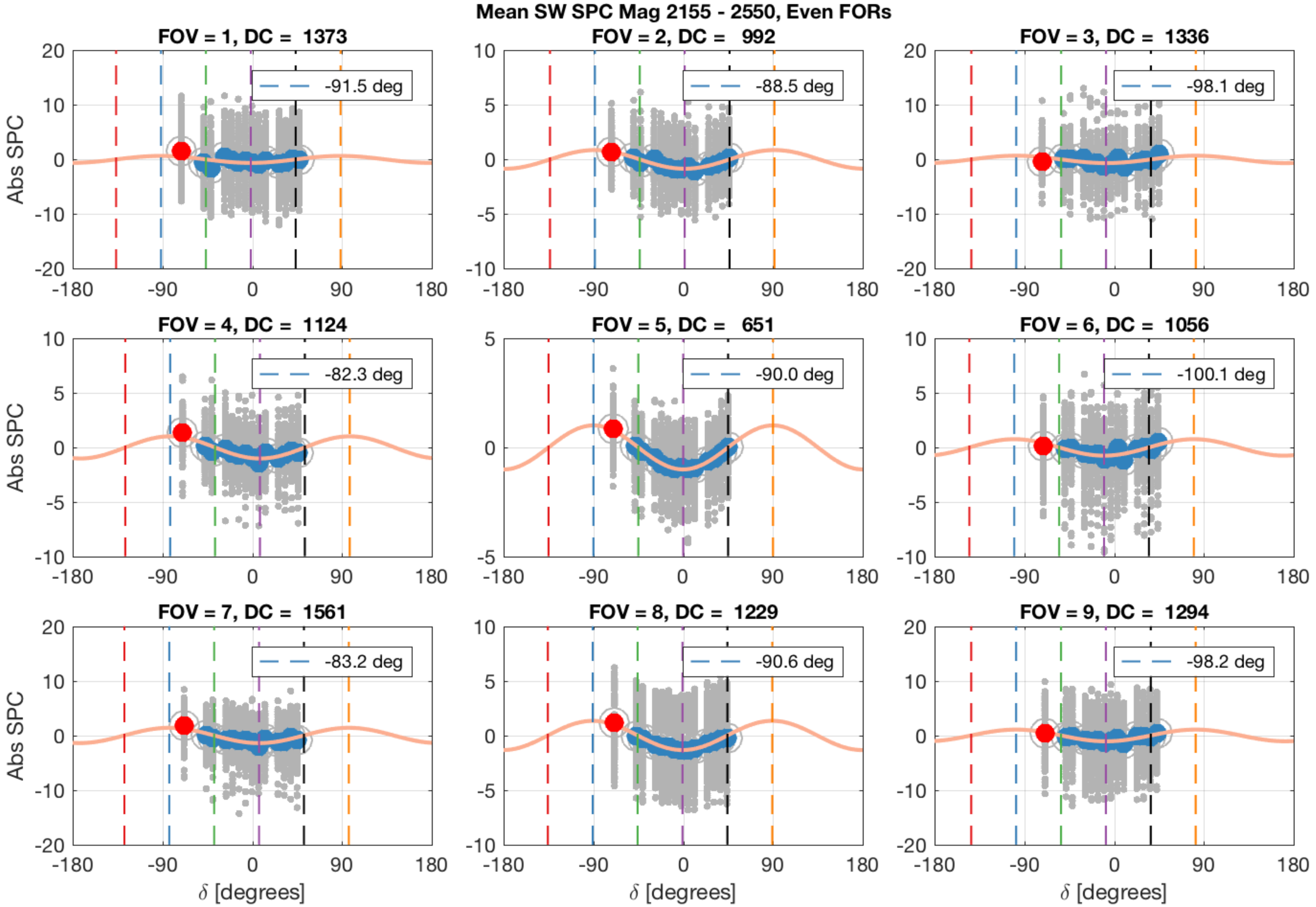
DS view in red



NOAA20

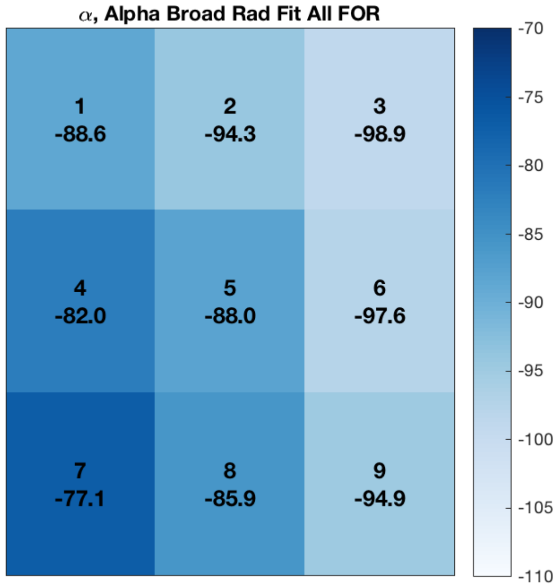
Fit Sinusoid to Band Averaged Magnitude Spectra for Even FOR 2155 – 2550 cm^{-1}

DS view in red

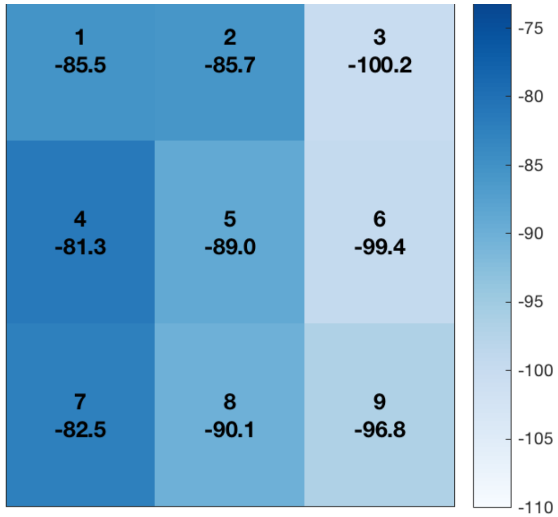


SW α and $p_r p_t$: FOVs 1-9

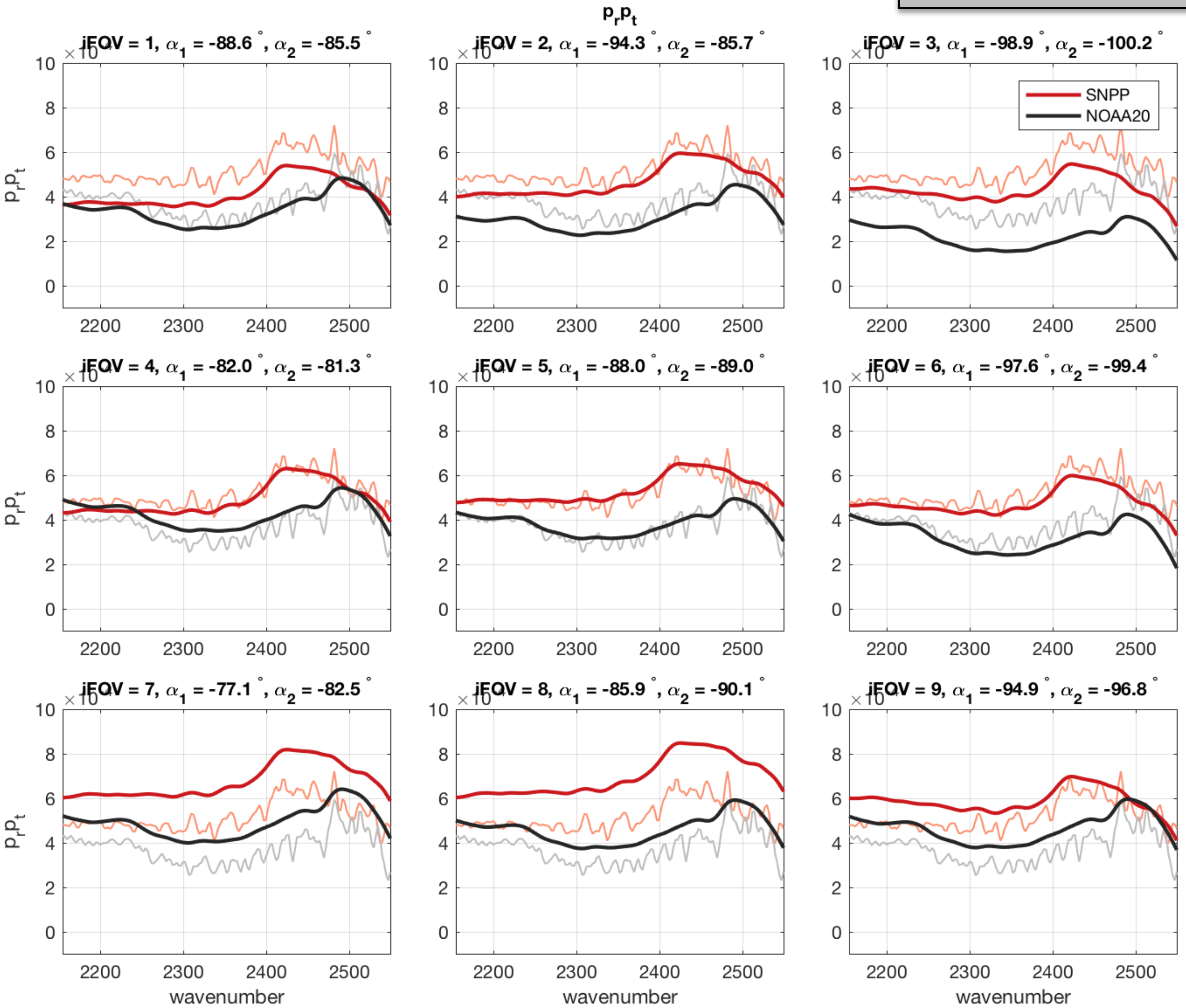
light lines: FOV0 fit with no filtering or smoothing



SNPP



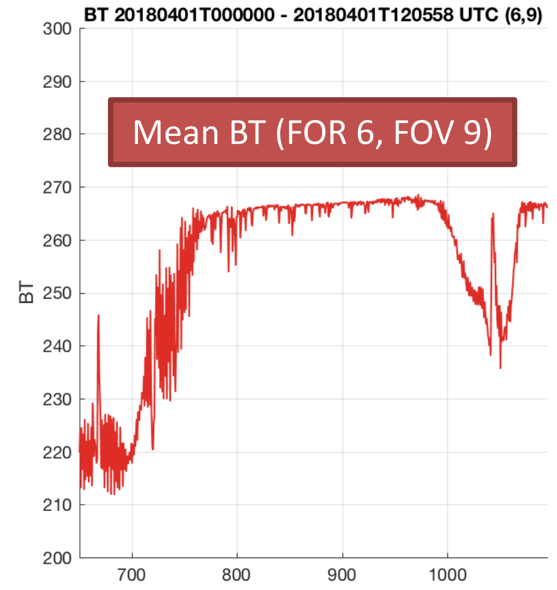
NOAA20

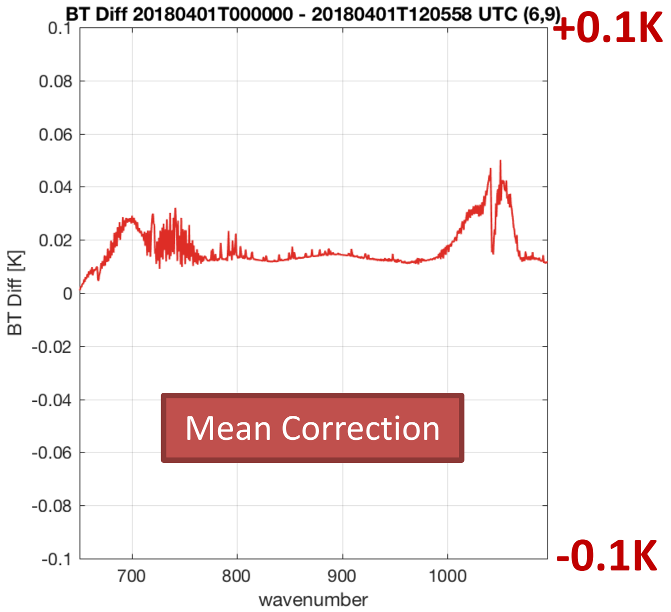


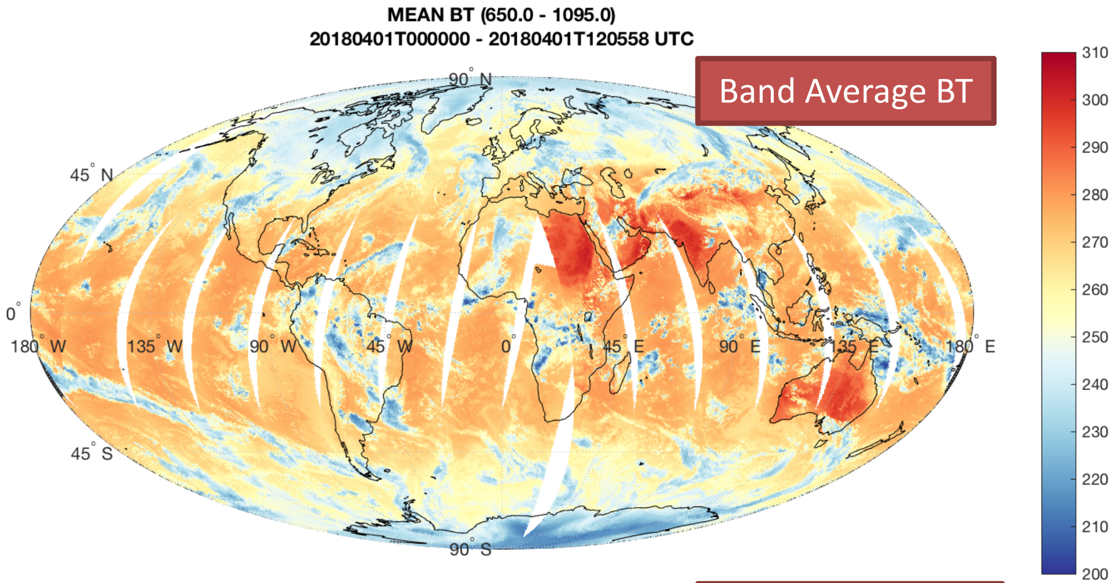
Sample Polarization Correction Results, NOAA20

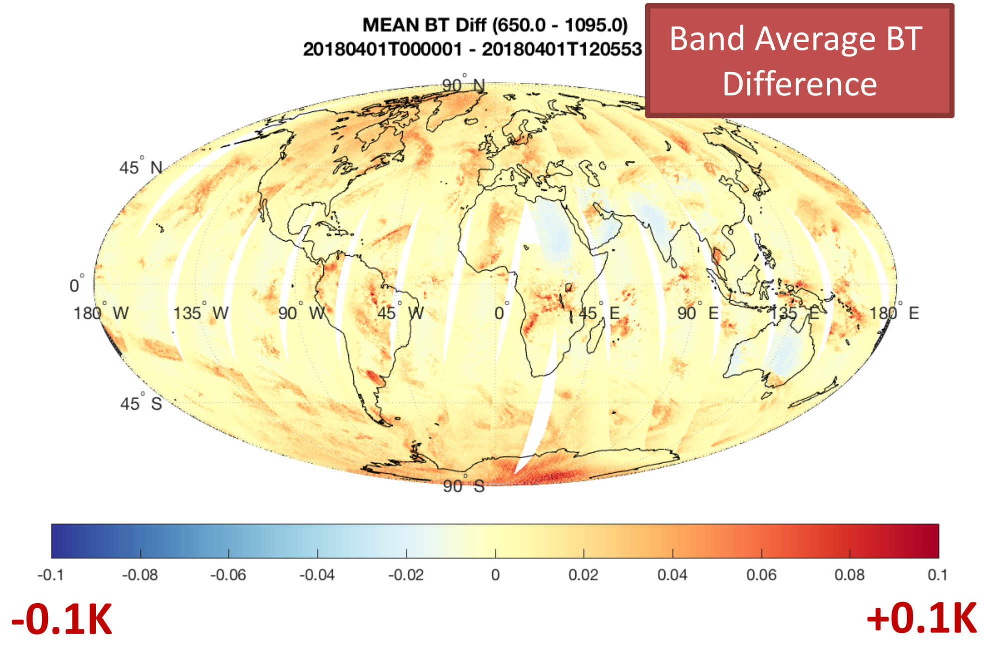
2018JD091, 00:00 – 12:00 UTC

Mean BT and Mean BT Diff (Uncorrected – Corrected), LW
2018J019: 00:00 – 12:00

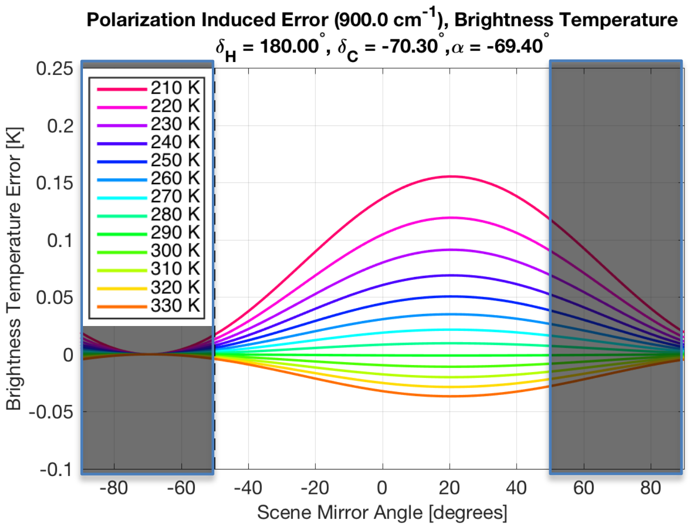






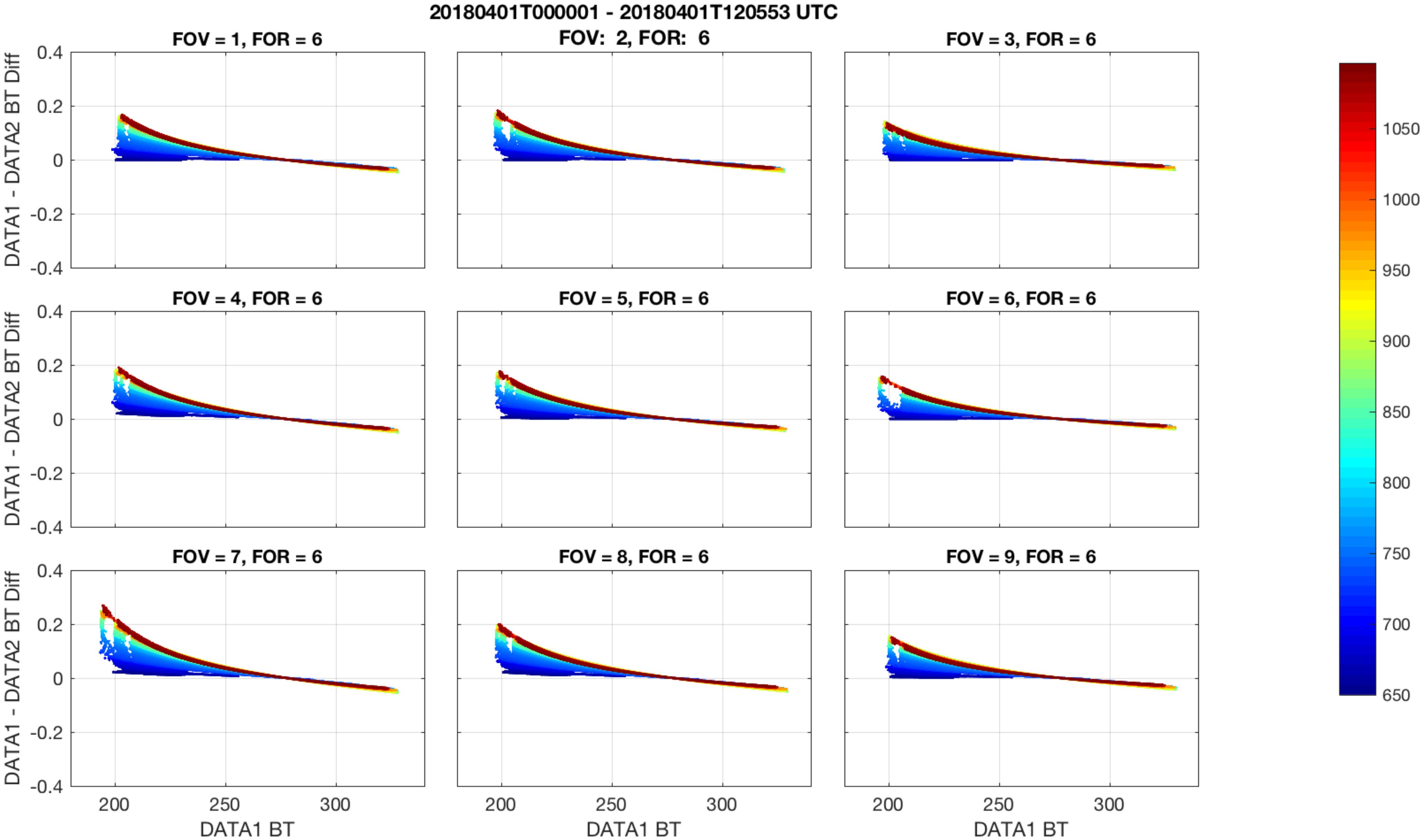


- LW: α = -69.4°
- LW correction maximum near FOR 10 (FOR 6, FOV 9 shown at far left)

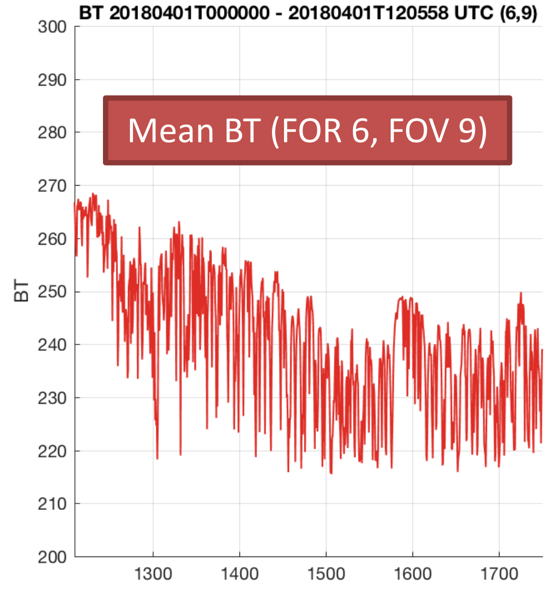


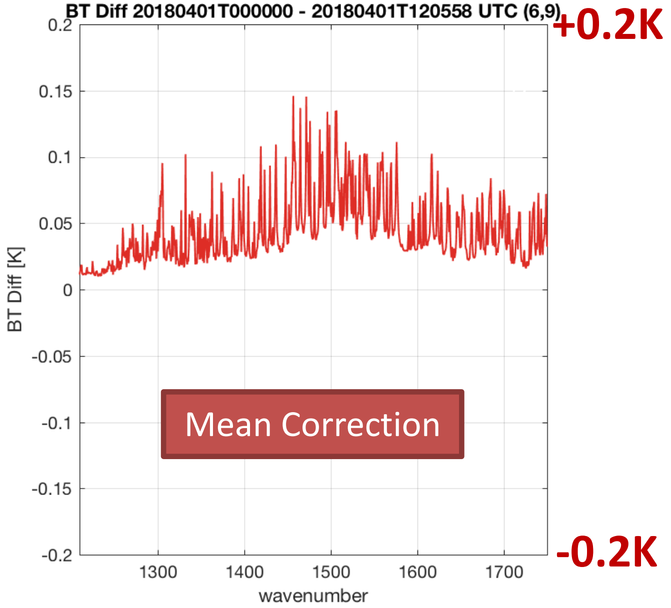
Mean BT Diff (Uncorrected – Corrected), LW
2018J019: 00:00 – 12:00

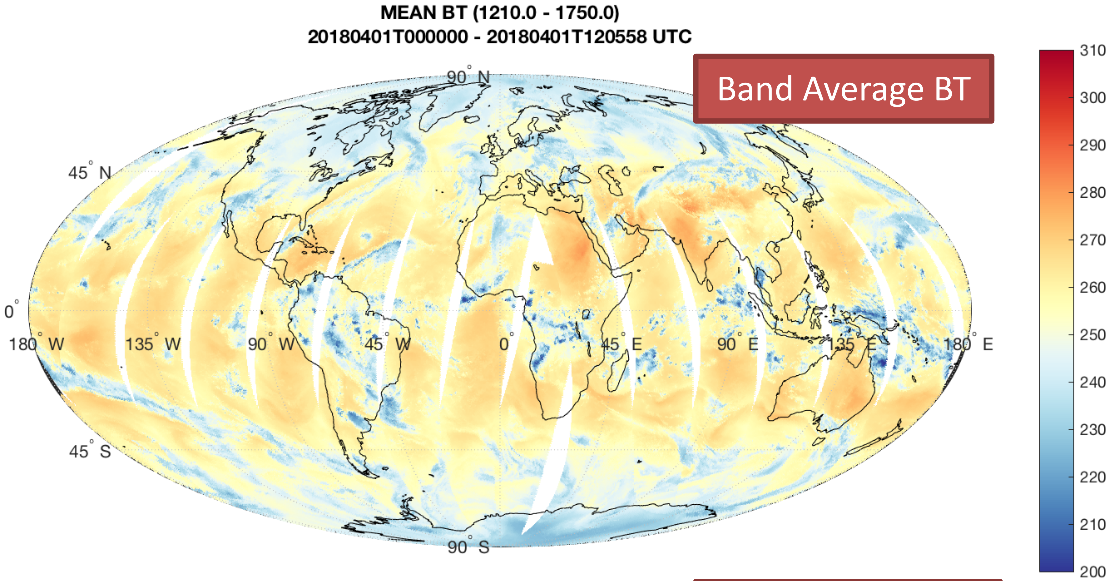
y-limits=
±0.4K

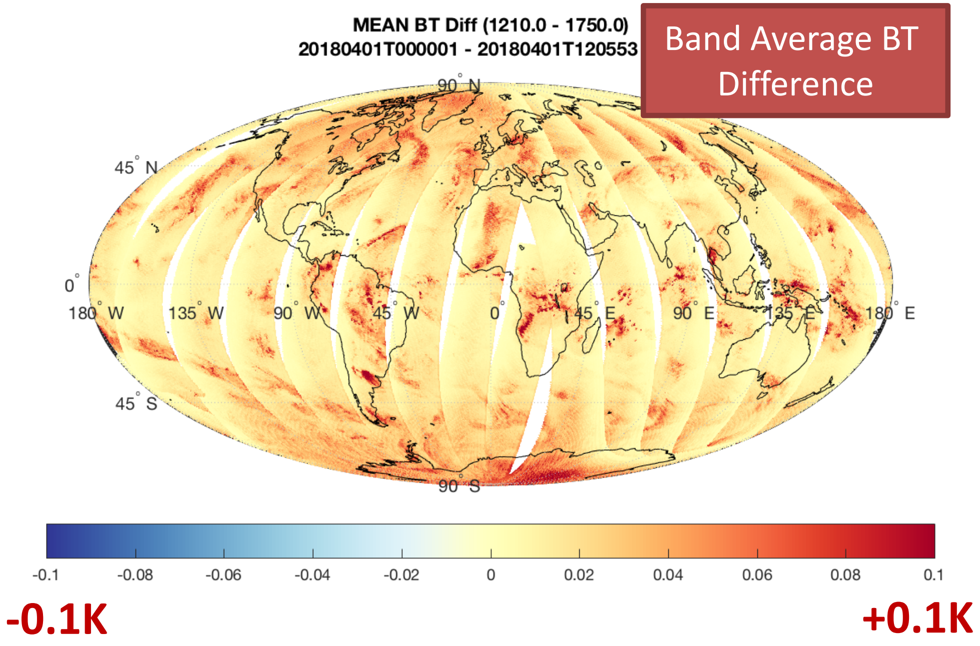


Mean BT and Mean BT Diff (Uncorrected – Corrected), MW
2018J019: 00:00 – 12:00

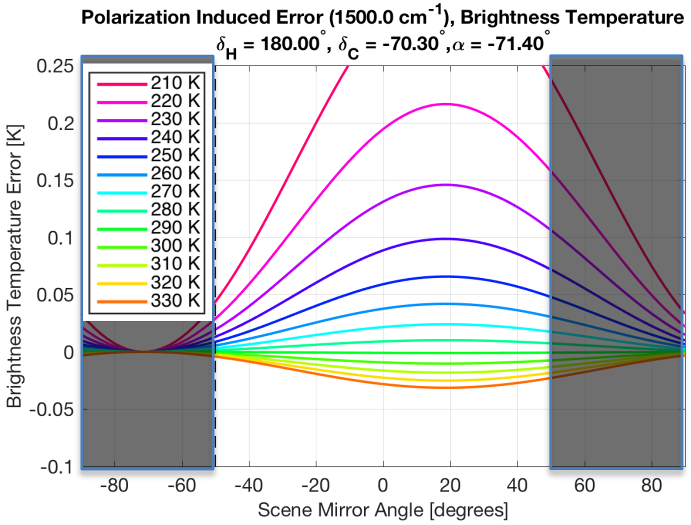






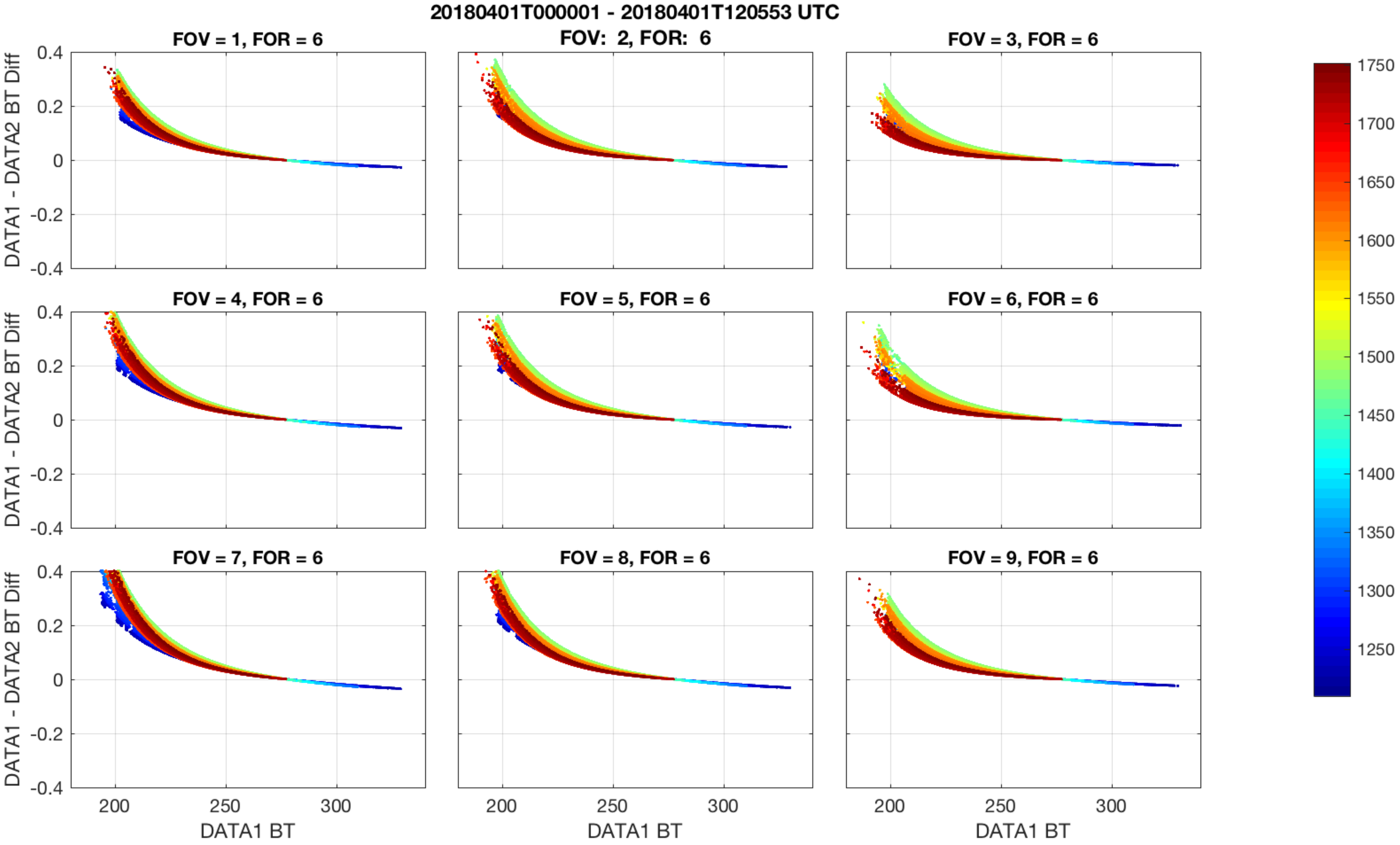


- MW: α = -71.4°
- MW correction maximum near FOR 10 (FOR 6, FOV 9 shown at far left)

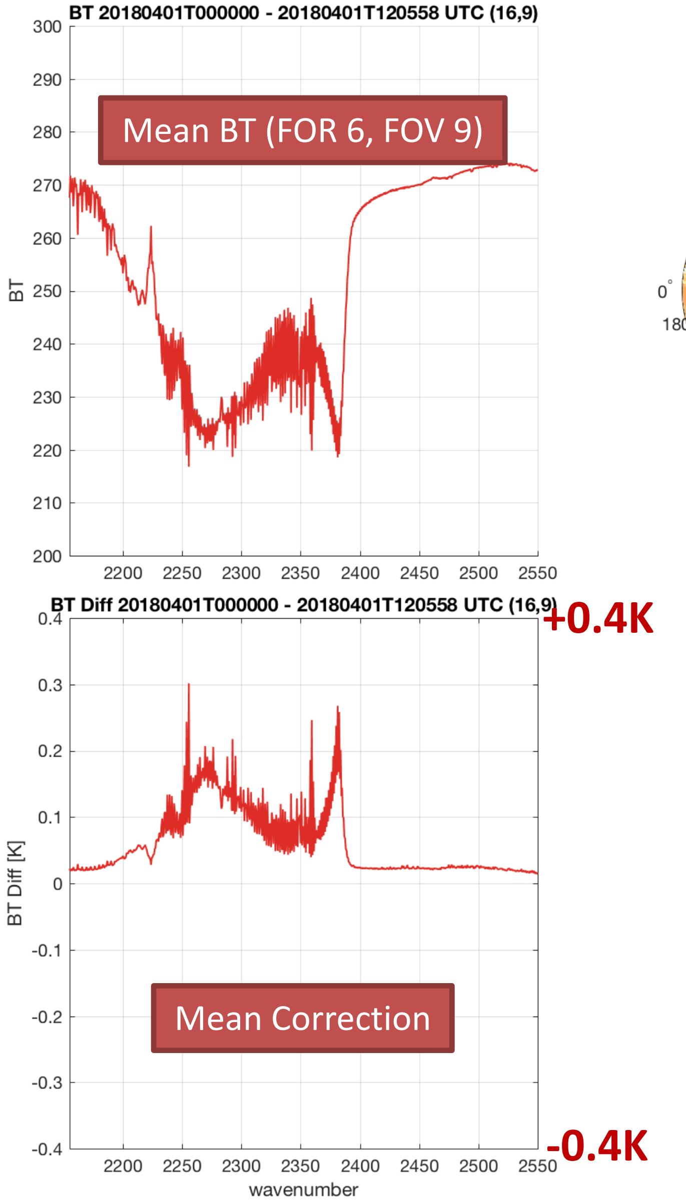


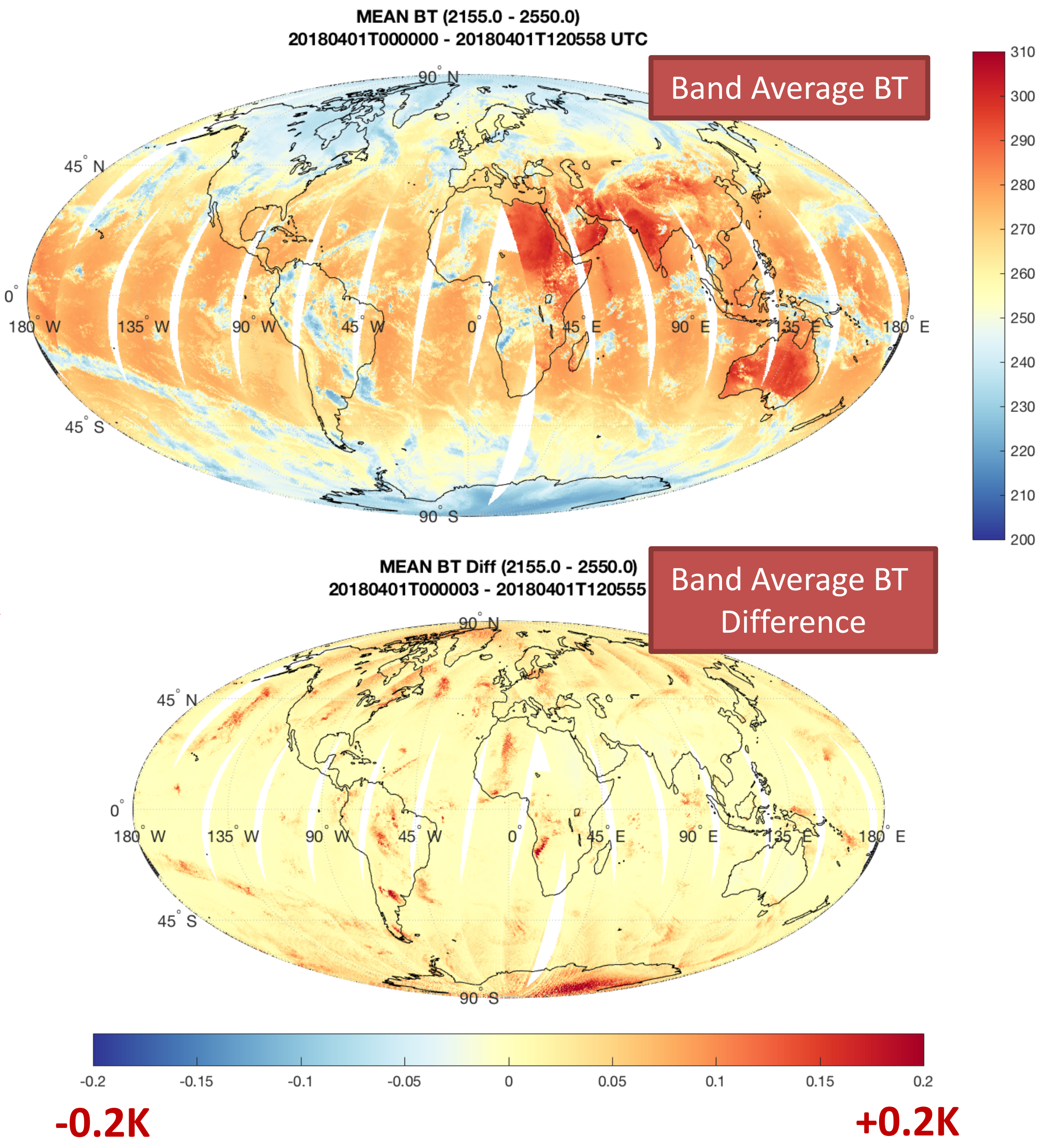
Mean BT Diff (Uncorrected – Corrected), MW
2018J019: 00:00 – 12:00

y-limits= ±0.4K

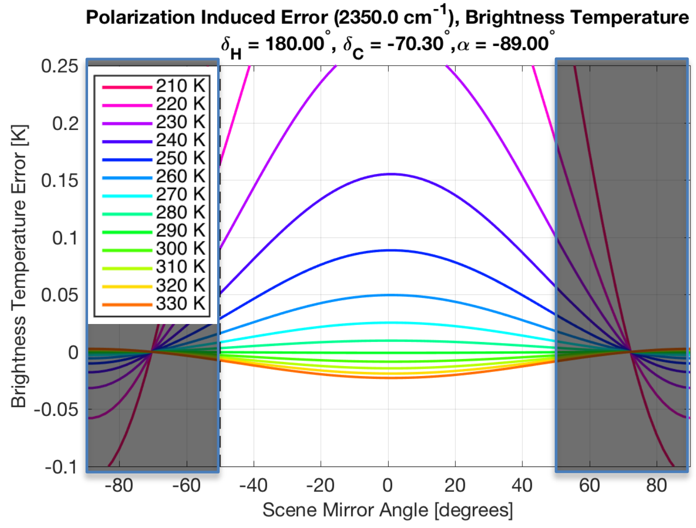


Mean BT and Mean BT Diff (Uncorrected – Corrected), SW 2018J019: 00:00 – 12:00



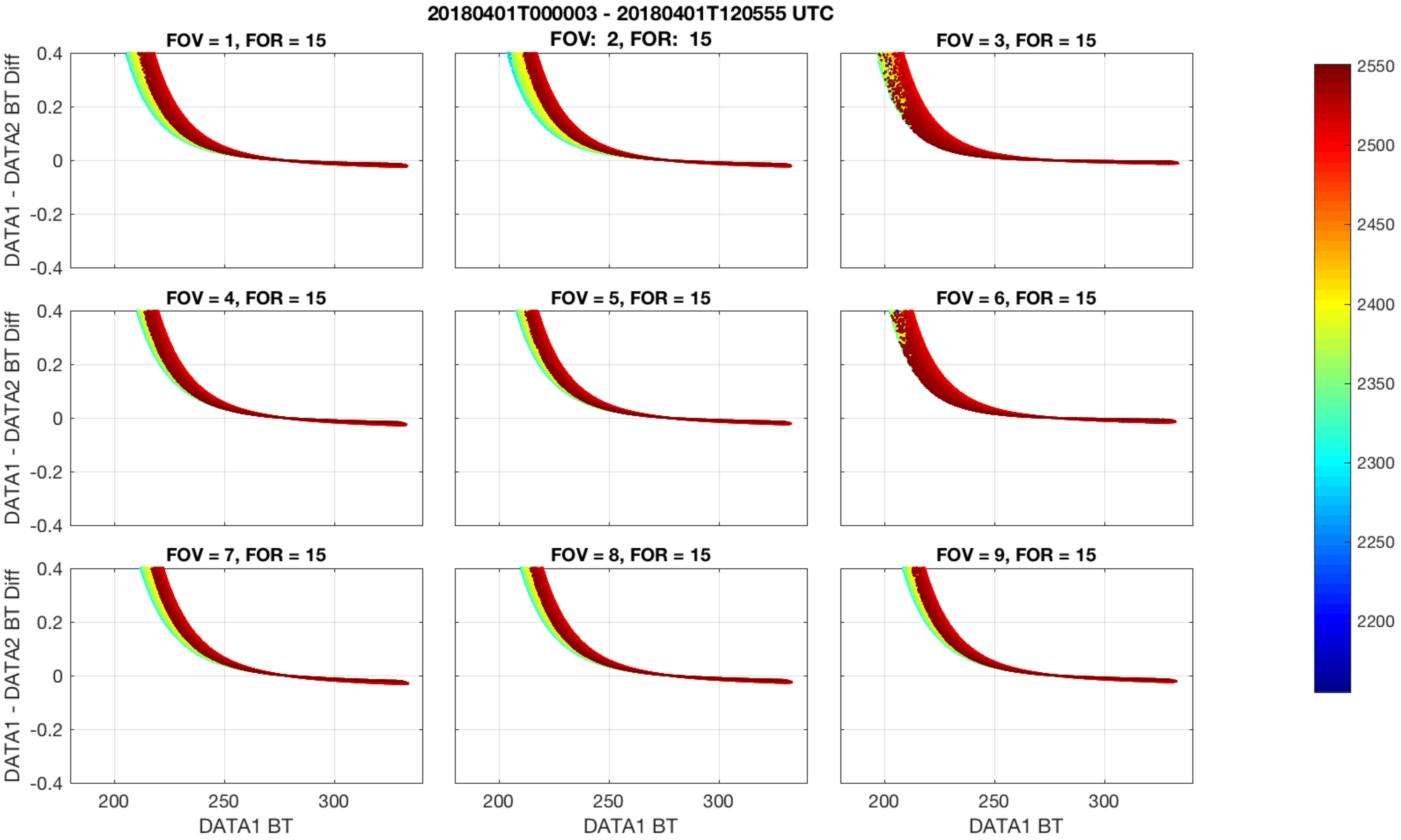


- SW: α = -89.0°
- SW correction maximum near FOR 15 – 16 (FOR 16, FOV 9 shown at far left)



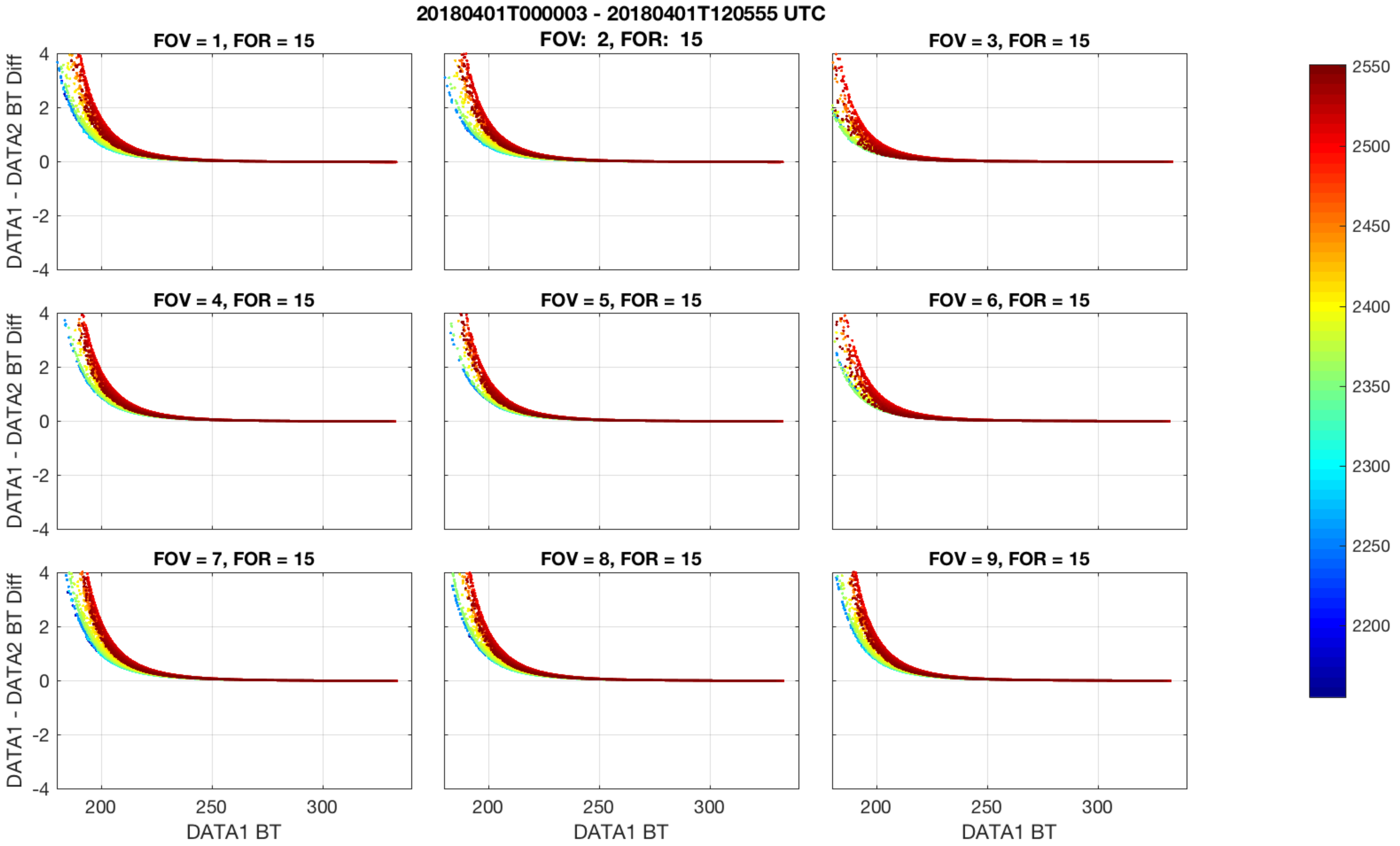
Mean BT Diff (Uncorrected – Corrected), SW
2018J019: 00:00 – 12:00

y-limits= ±0.4K



Mean BT Diff (Uncorrected – Corrected), SW
2018J019: 00:00 – 12:00

y-limits= ±4K



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  - Sample Correction Results
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  - Sample results
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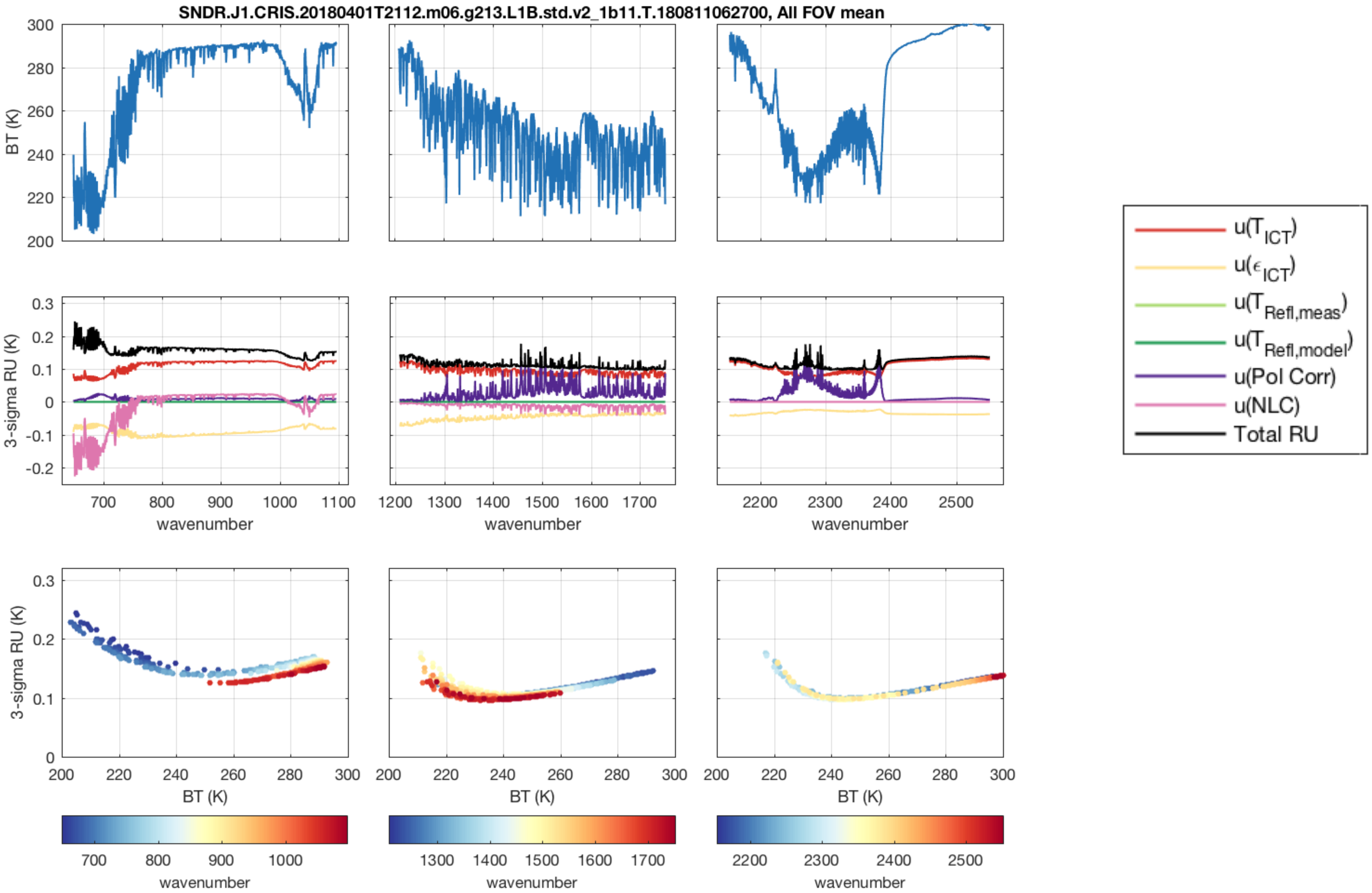
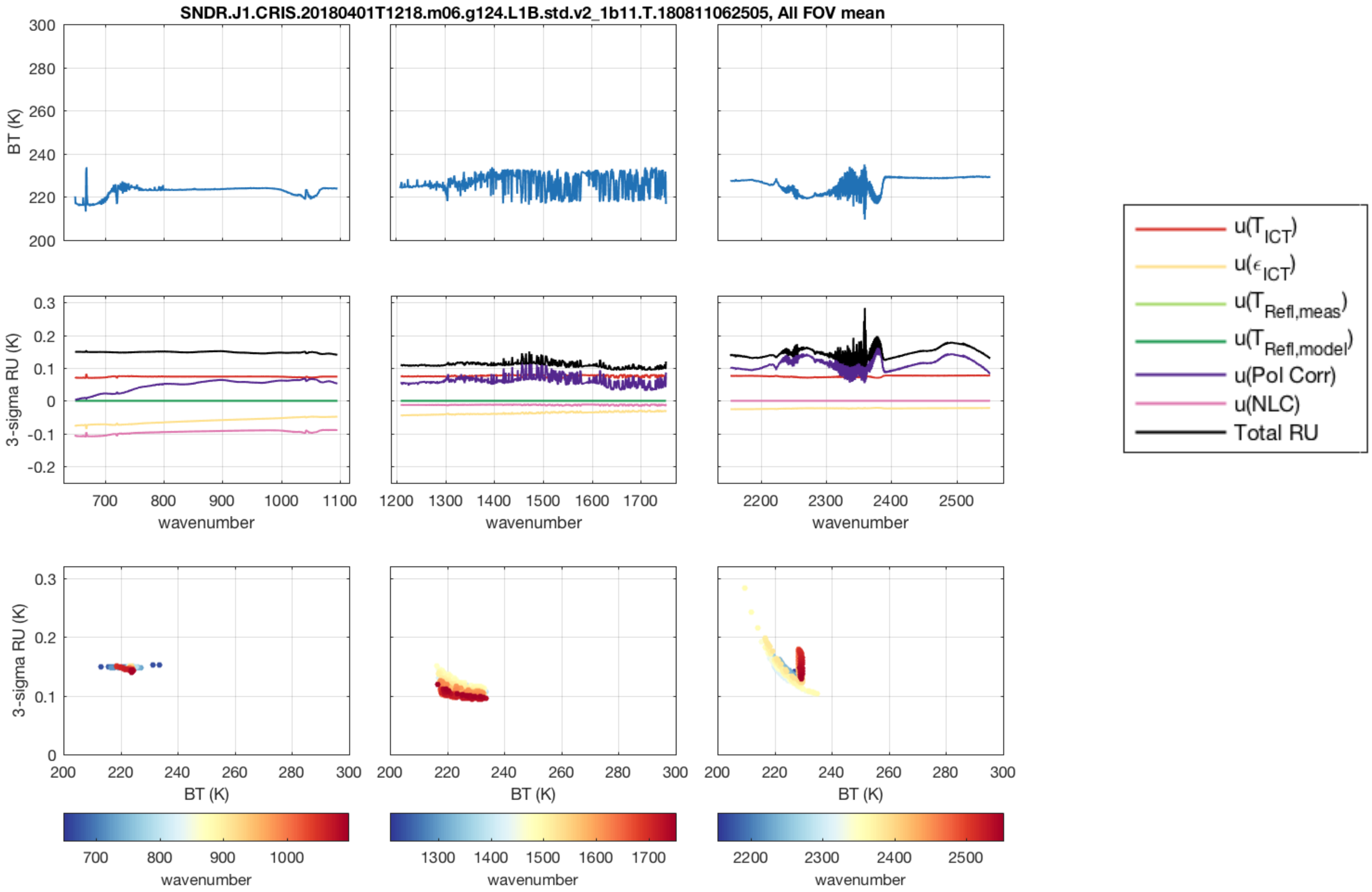
CrIS Radiometric Uncertainty (RU) Evaluation

- The radiometric uncertainty (RU) in the calibrated radiance can be determined via a perturbation analysis of the calibration equation
  - Equivalent to a differential error analysis described in the GUM (Guide to Uncertainty in Measurements)
- SNPP CrIS: Tobin, D., et al. (2013), Suomi-NPP CrIS radiometric calibration uncertainty, *J. Geophys. Res. Atmos.*, 118, 10,589–10,600, doi: 10.1002/jgrd.50809.
- The current operational processing does not include polarization correction
- Thus, the calibration bias due to polarization is uncorrected and the associated RU contributor is assumed to be 100% of the uncorrected bias due to polarization ($\delta p_r p_t$ = 100%)

2018-04-01 T2112, no polarization correction: Tropical with Scattered Cloud (mean of 6 minutes of data, All FOV mean)



2018-04-01T1218, no polarization correction: Typical Antarctic Cold Scene (mean of 6 minutes of data, All FOV mean)



Comparison of RU

- The following 2 slides show the RU estimates for (1) a tropical scene with scattered cloud over ocean and (2) a typical cold Antarctic scene
- RU is compared for
  - Total RU if bias due to polarization is uncorrected and is included in RU estimate
  - Total 3-σ RU with polarization correction uncertainties included
  - Total RU if the sensor had zero polarization sensitivity
- The comparison demonstrates the reduced radiometric uncertainty when the polarization correction is included.

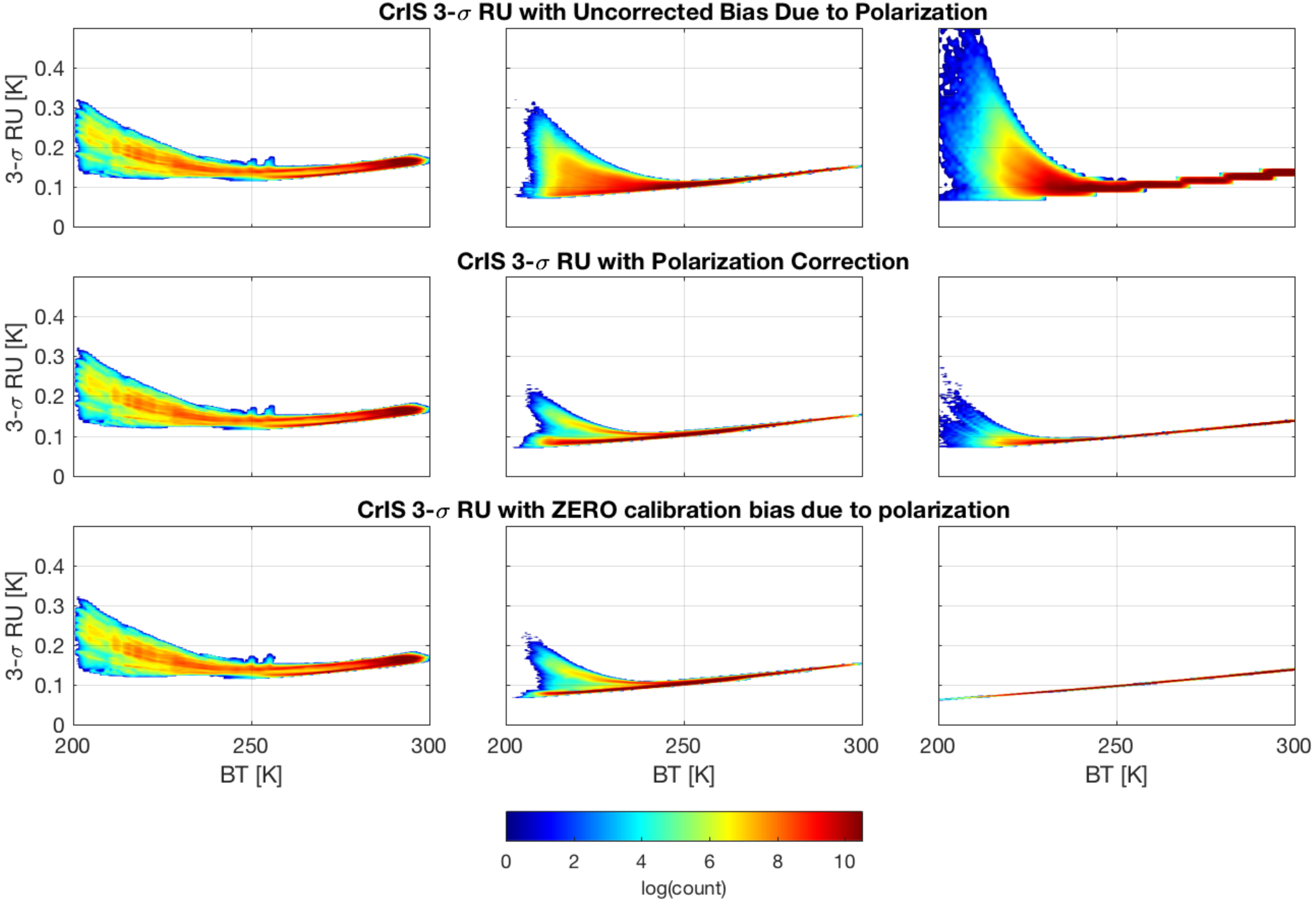
On-orbit 3-σ RU Estimate (NOAA20, 6 minutes data)
Density plots of T_b uncertainty at scene T_b (all spectral channels and FOVs)

Top row:
- Total RU if bias due to polarization is uncorrected and is included in RU estimate

Middle row:
- Total 3-σ RU with polarization correction uncertainties included
  - $\Delta p_r p_t = +20\%$, $\Delta\alpha = +10°$
  - conservative estimate of uncertainties in polarization correction parameters
  - $p_r p_t$ uncertainty is dominant term in RU for polarization correction

Bottom row:
- Total RU if the sensor had zero polarization sensitivity

2018-04-01T2112: Tropical with Scattered Cloud



On-orbit 3-σ RU Estimate (NOAA20, 6 minutes data)
Density plots of T_b uncertainty at scene T_b (all spectral channels and FOVs)

Top row:
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Middle row:
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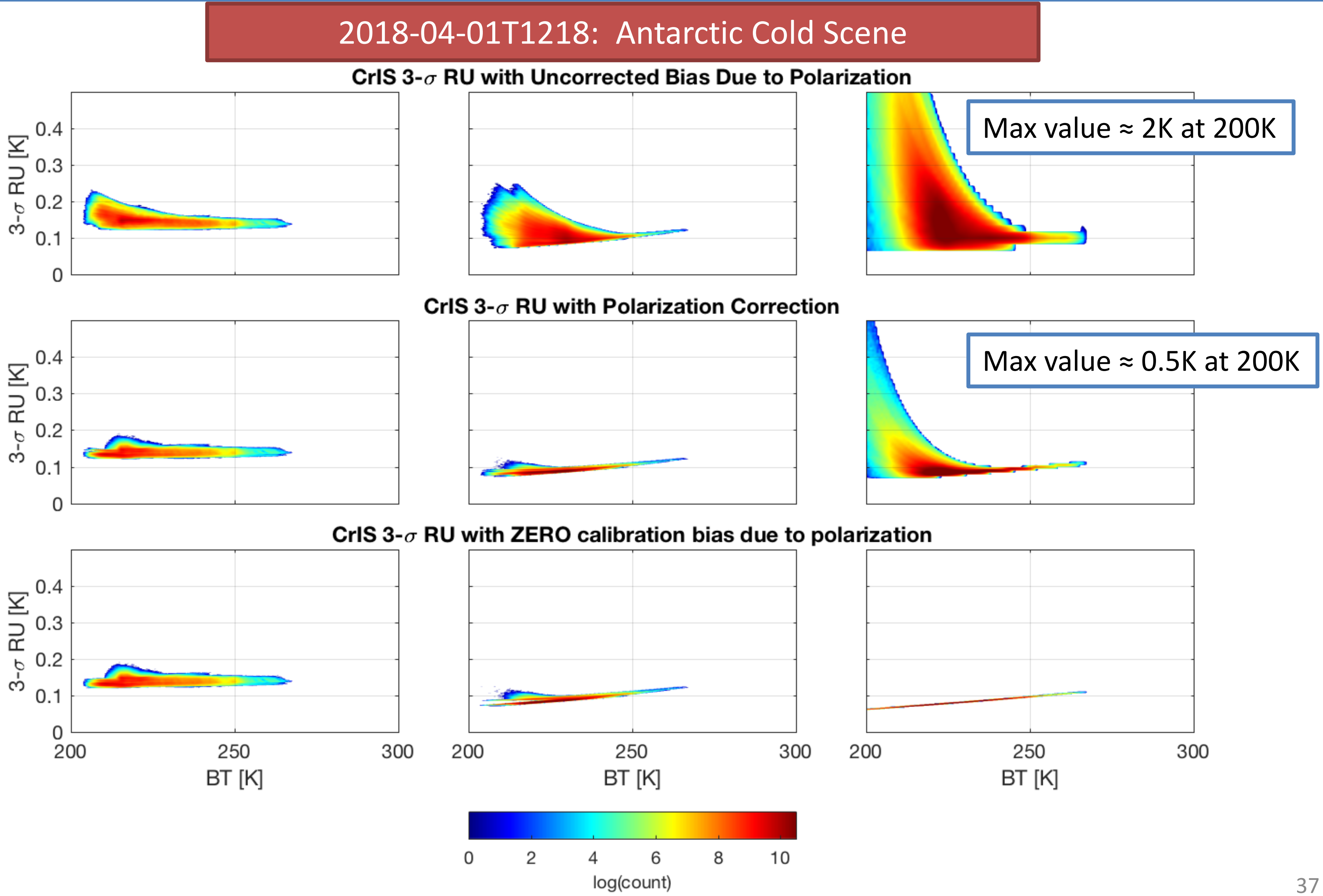
Bottom row:
- Total RU if the sensor had zero polarization sensitivity



Summary - Polarization

- Pitch maneuver derived $p_r p_t$ are reasonably consistent between NOAA-20 and SNPP
- Pitch maneuver derived α values are reasonably consistent between NOAA-20 and SNPP
- An example of the correction for 12 hours of data (2018-JD019) has been presented herein
  - Mean correction is largest in SW (when expressed as brightness temperature), and approach 0.4 – 0.5K for 220 – 230K scene temperatures.
  - Mean correction in LW and MW are relatively small, but not insignificant for cold scenes
- Currently implementing polarization correction within internal L1b beta product

Summary – Radiometric Uncertainty

- The radiometric uncertainty (RU) for CrIS has been determined via a perturbation analysis of the calibration equation
  - Equivalent to a differential error analysis described in the GUM (Guide to Uncertainty in Measurements)
  - Using current engineering best estimates for uncertainty contributors
  - Current ICT emissivity uncertainty estimate is very conservative
  - The current operational processing does not include polarization correction
  - Thus, the calibration bias due to polarization is uncorrected and the associated RU contributor is assumed to be 100% of the uncorrected bias due to polarization ($\delta p_r p_t$ = 100%)
- Capable of quickly producing RU estimate for any given L1b granule
- Planning to include radiometric uncertainty estimates in v3.0 product