National Aeronautics and
Space Administration

Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Surface Water and Ocean Topography (SWOT) Mission

Validation Meeting

June 18-19, 2024

KaRIn CA Crossover MASS/Lidar Validation

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Outline

- MASS capabilities and technical description
- Post-launch campaign
  - Operational challenges
  - Environmental conditions
  - Flight patterns
  - Example of MASS-SWOT collocated observations
- Spectral analysis and SWOT performance validation

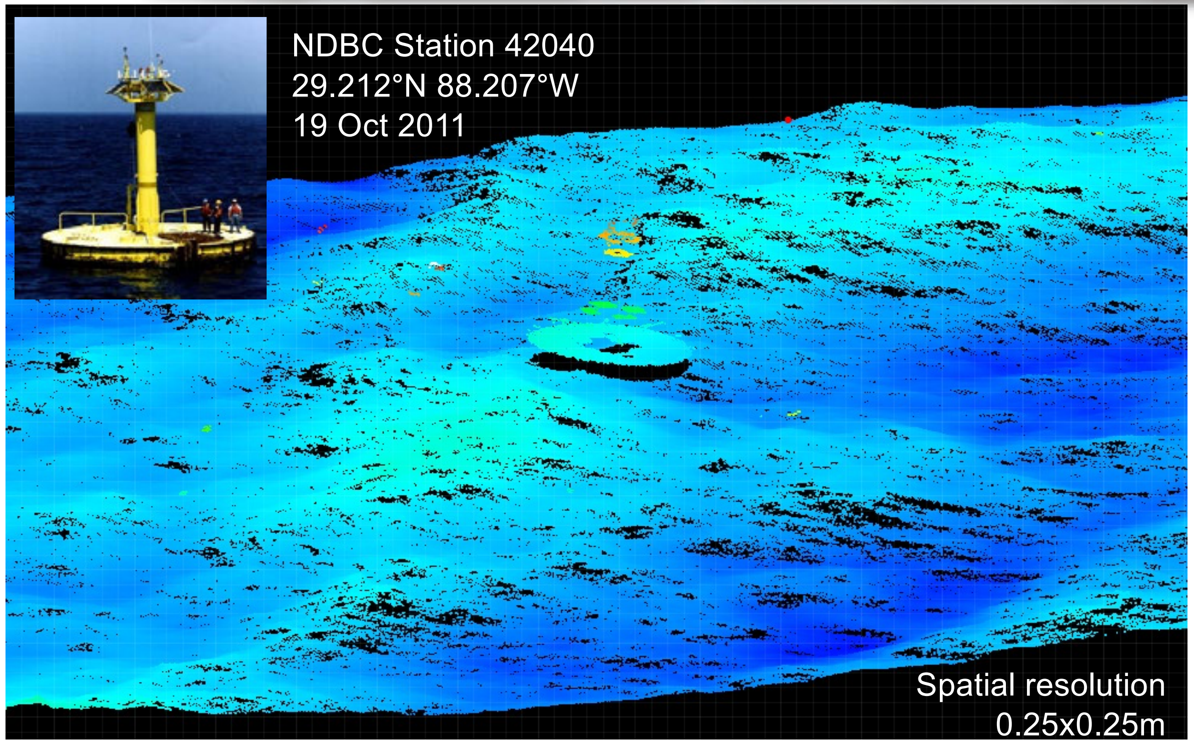
SIO Modular Aerial Sensing System (MASS)

- The MASS is a **mature and proven** portable package of high-resolution instrumentation built specifically for airborne remote sensing applications.
  - Over 800 hours of accumulated flight time over the course of more than **28 different field campaigns.**
  - Successfully operated from a broad range of aircraft (Cessna 206, Partenavia P-68, **Gulfstream-V** and DHC-6 Twin Otter) as well as from a Bell 206 helicopter.
  - ***Major component of S-MODE Earth Venture Suborbital III mission***.

- MASS collects airborne measurements of:
  - Sea surface displacement
  - Temperature
  - Surface kinematics

- MASS data are used to provide measurements of:
  - Ocean waves
  - Currents
  - Stokes drift
  - Sea surface height (SSH)
  - Ocean transport and dispersion
  - Biological activity
  - Hydrological and terrestrial applications include measurements of snow cover, coastal geomorphology, and the built environment

SIO Modular Aerial Sensing System (MASS)



Example of surface elevation as measured from the MASS during a 2011 experiment in the Gulf of Mexico, flying above NDBC buoy #42040. (wind~12m/s, Hs = 3.1m, aircraft altitude = 500m AMSL)

Instrumentation		Measurement
Scanning Waveform Lidar (x2)	Riegl Q680i	Surface wave, surface slope, directional wave spectra (vert. accuracy ~2-3cm)
Long-wave IR Camera	FLIR SC6700	Ocean surface processes, wave kinematics and breaking, frontal processes
High-Resolution Video	JaiPulnix AB-800CL	Ocean surface processes, wave kinematics and breaking, frontal processes
Hyperspectral Camera	Specim Kestrel	Ocean surface and biogeochemical processes
Redundant GNSS/IMU	Novatel SPAN-LN200	Georeferencing, trajectory

Flight operations

NASA JSC GV flight request:

- **Phase I:** Start Date 03/01/2023 End Date 03/30/2023 – **30 days.**
- **Phase II:** Start Date 05/01/2023 End Date 05/21/2023 – **20 days.**

Actual availability caused by limited JSC staff availability & Astronaut Return commitment

- **Phase I:** Start Date 03/28/2023 End Date 04/14/2023 – **17 days (including multiple down days).**
- **Phase II:** Start Date 06/05/2023 End Date 06/09/2023 – **5 days.**

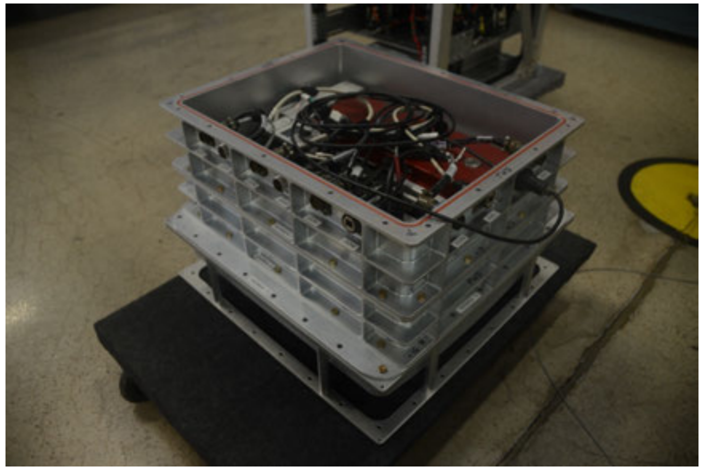
In the end, we only were able to obtain a fraction of the flight days initially requested which impacted our sampling strategies, limiting data collections to 9 flight days for phase I, and 5 flight days for phase II.

Phase I environmental conditions were ok most days, though a persistent cloud layer during all flights constrained flight operations to below the cloud base (~1000-1500ft) with contamination from few lower level clouds/ cloud bank /fog layers in part of the flight track.

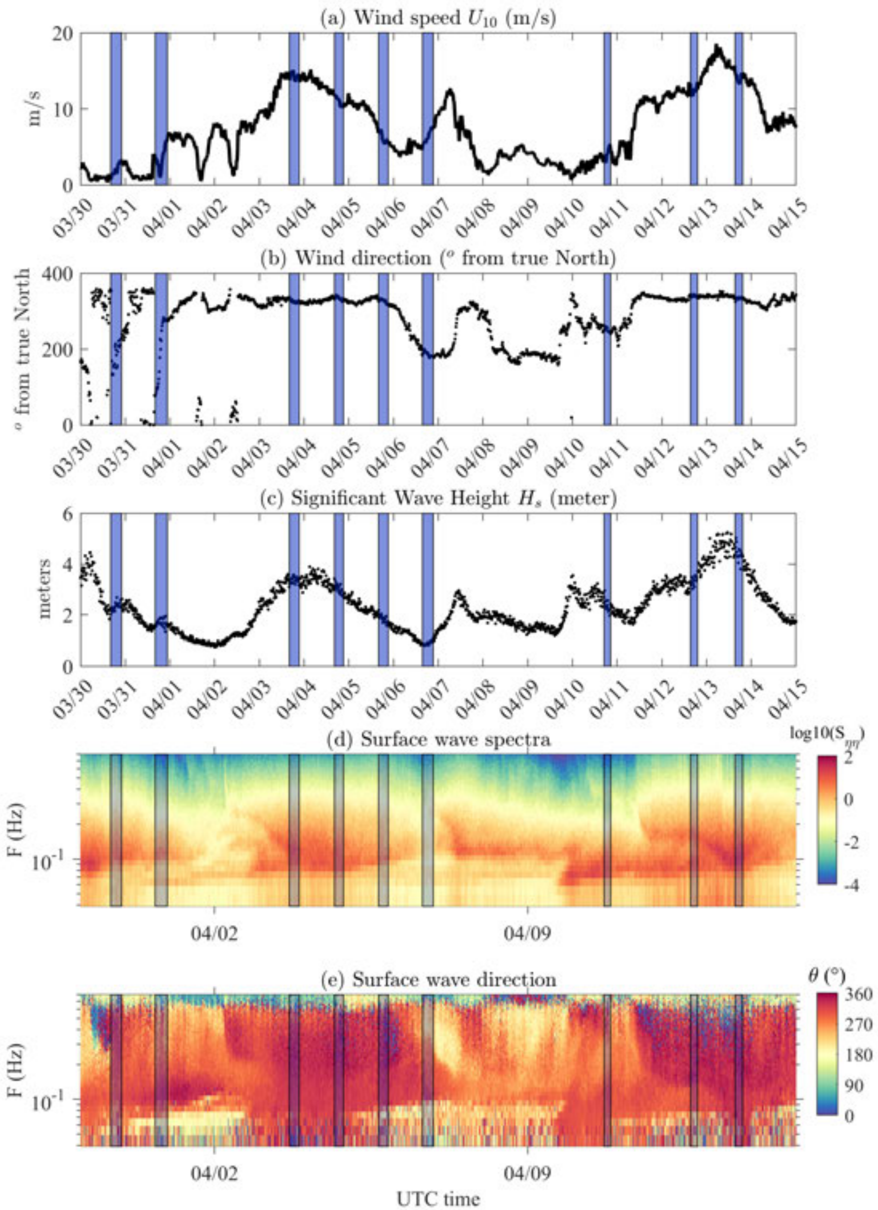
Phase II environmental conditions were poor (clouds & low winds)

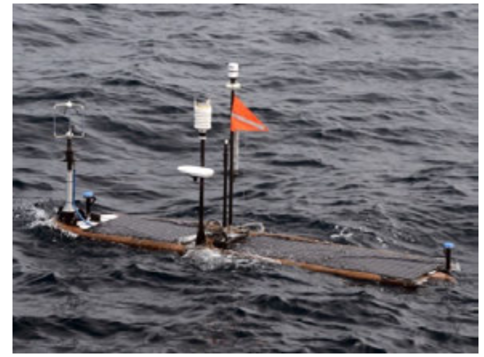
A total of 36,000km flown with the NASA GV as part of the post-launch CalVal.

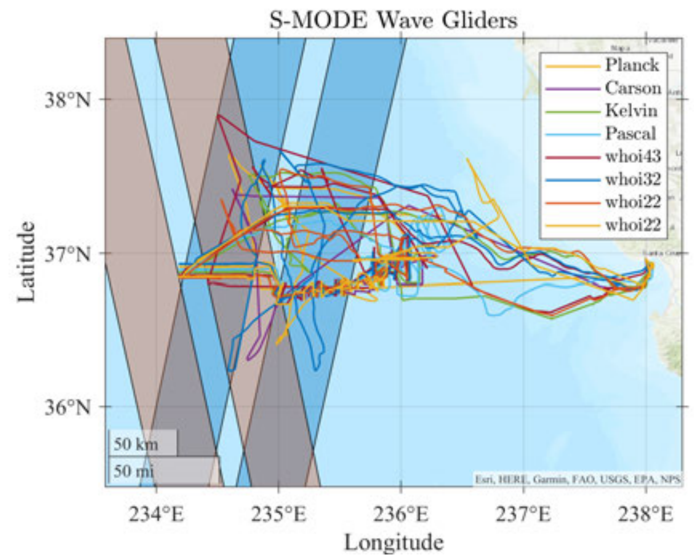
MASS-GV Installation

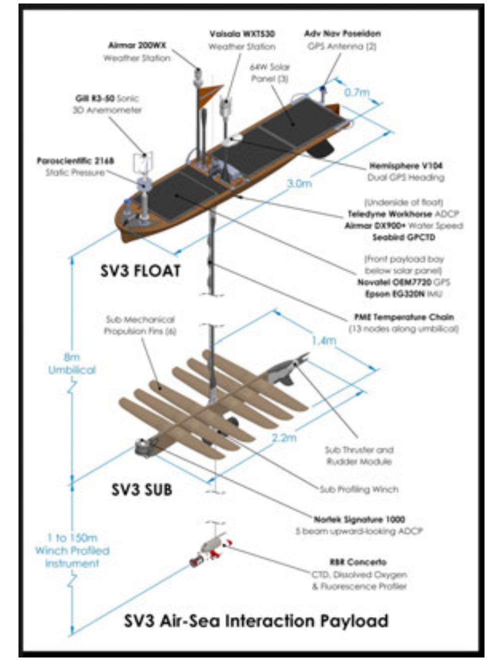


Phase I – Environmental conditions



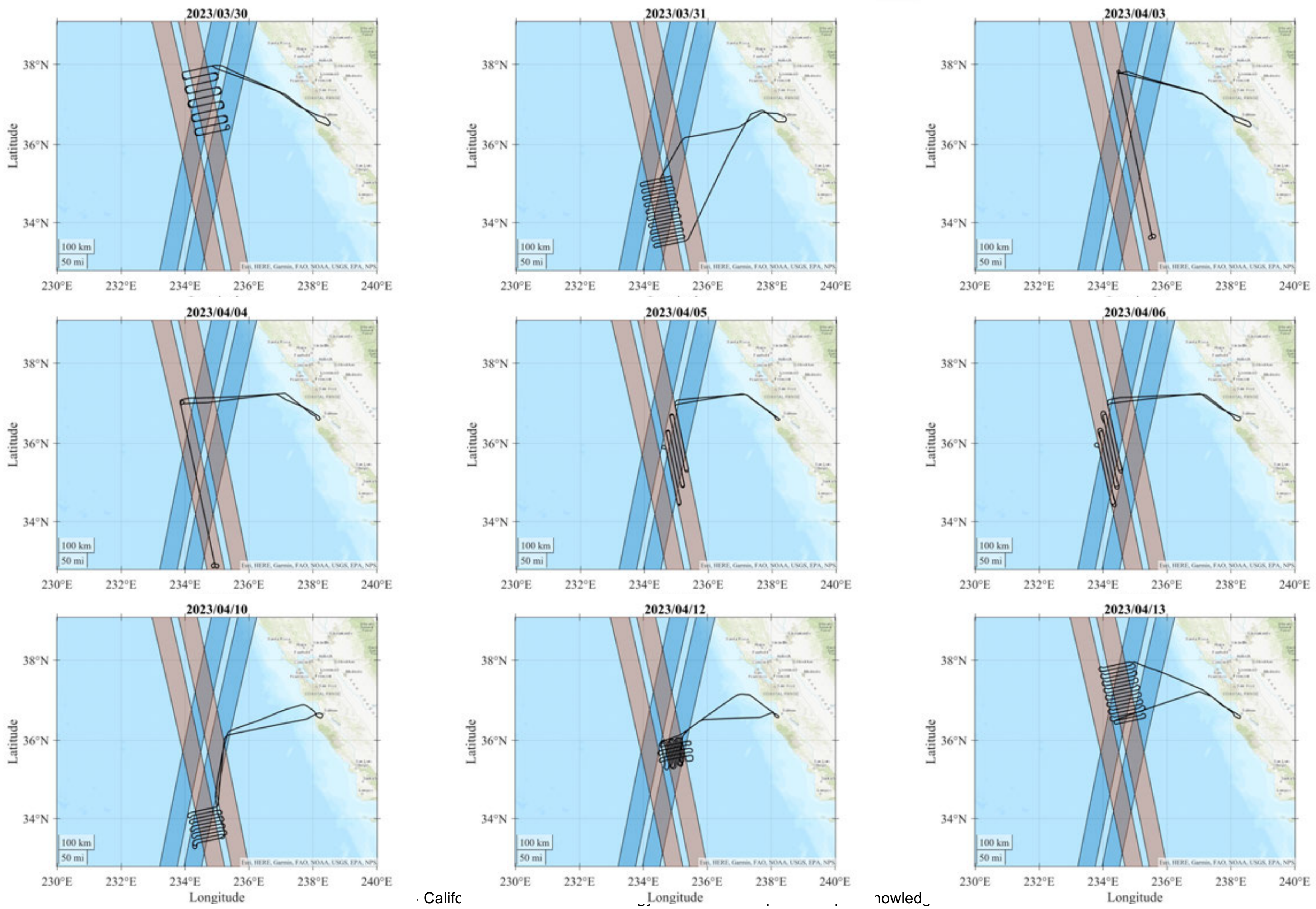




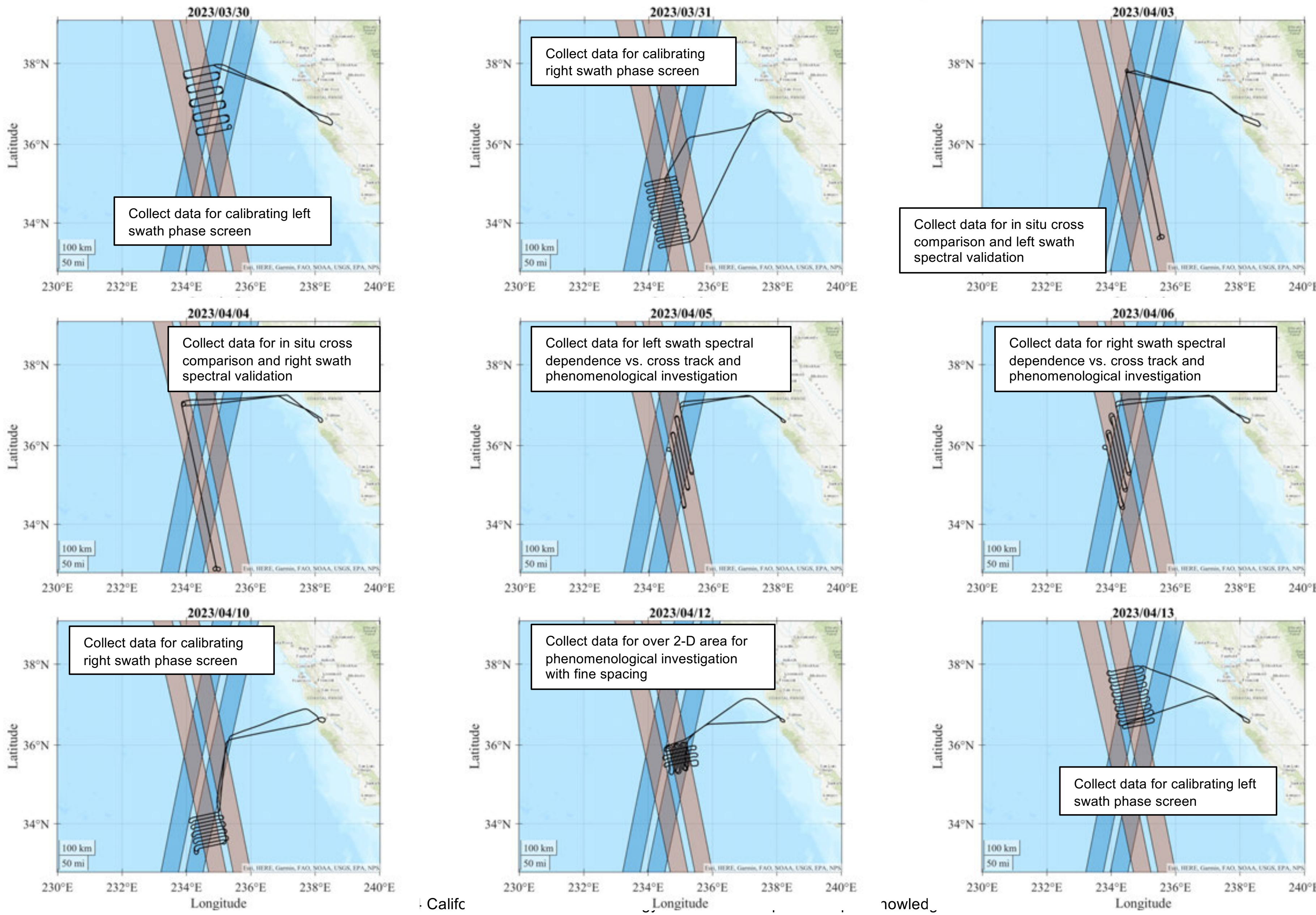


Leveraging NASA S-MODE IOP2 assets: In-situ observations from fleet of instrumented Wave Gliders

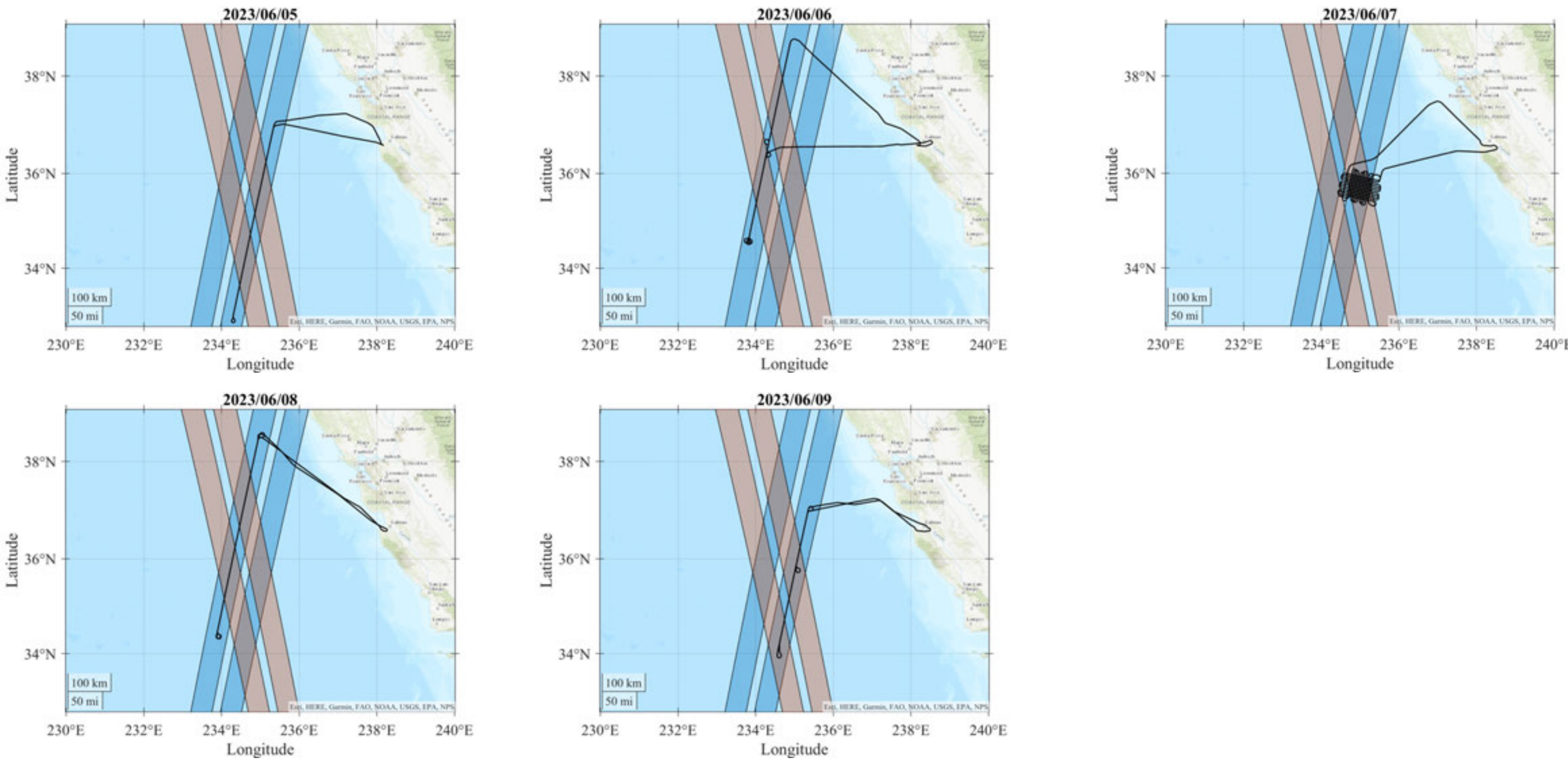
Phase I – Flight tracks



Phase I – Flight tracks

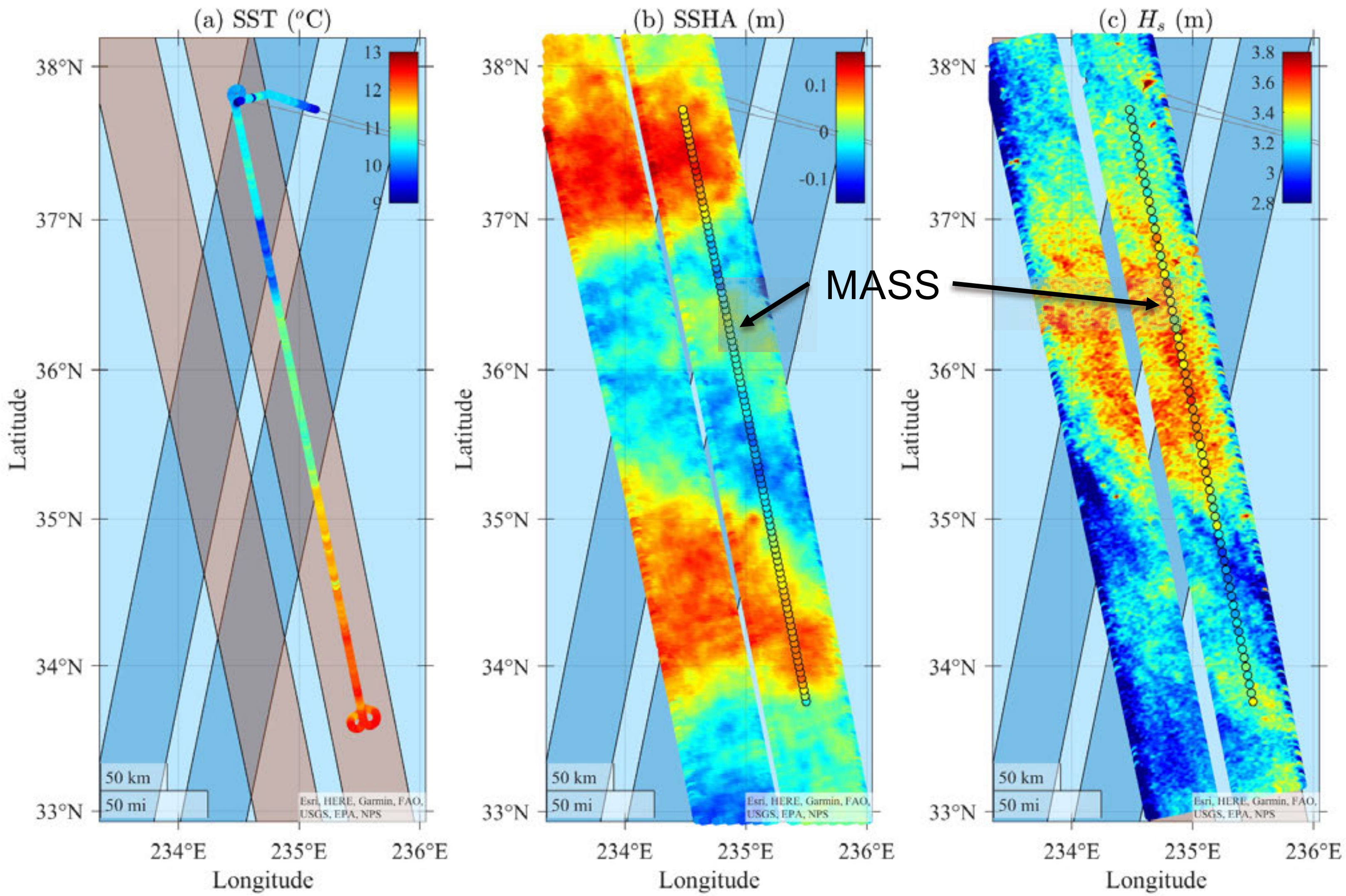


Phase II – Flight tracks



Example of SST, SSH and Hs observations

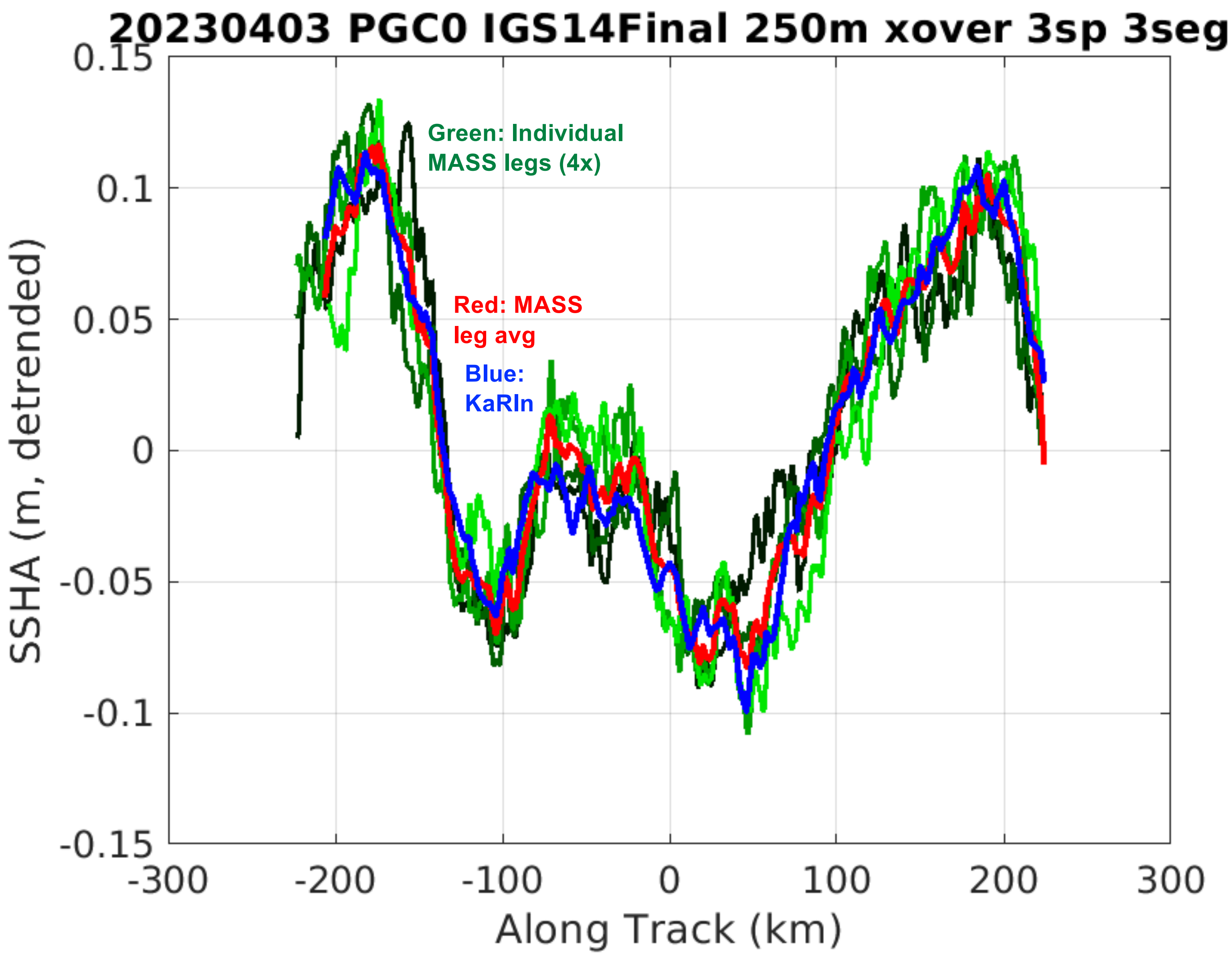
April 3rd 2023



Example SSHA Comparison

- **MASS and KaRIn agree very well in spatial domain**
  - Small bias between MASS and KaRIn is not unexpected due to residual crossover error (does not affect along-track spectrum; plot is detrended)
  - Variation between MASS legs has similar magnitude as difference between KaRIn and MASS leg average

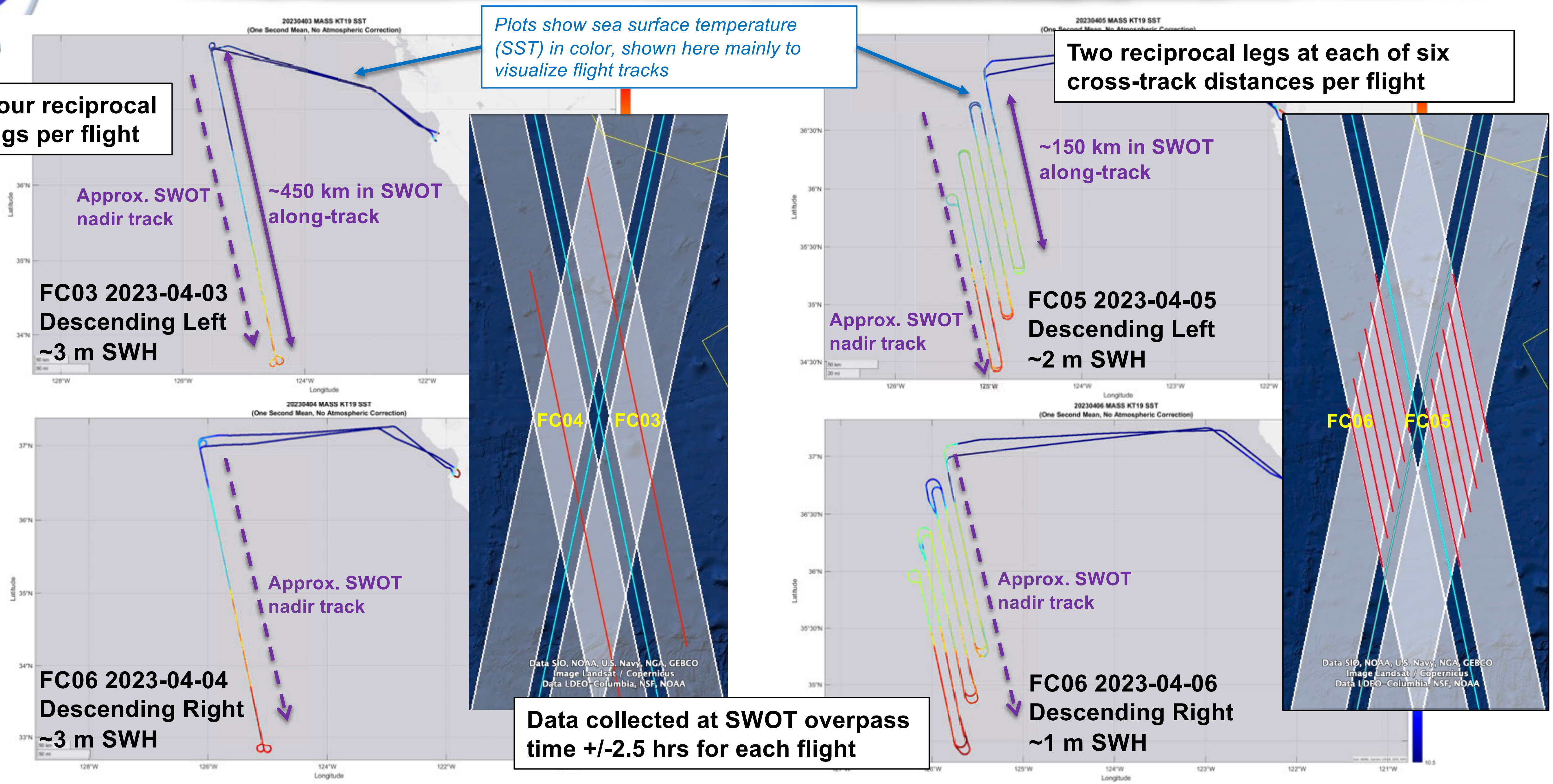
- Averaging:
  - MASS: Full lidar swath and 2.5 km in along track
  - KaRIn: Three 2 km pixels in cross track centered on MASS swath



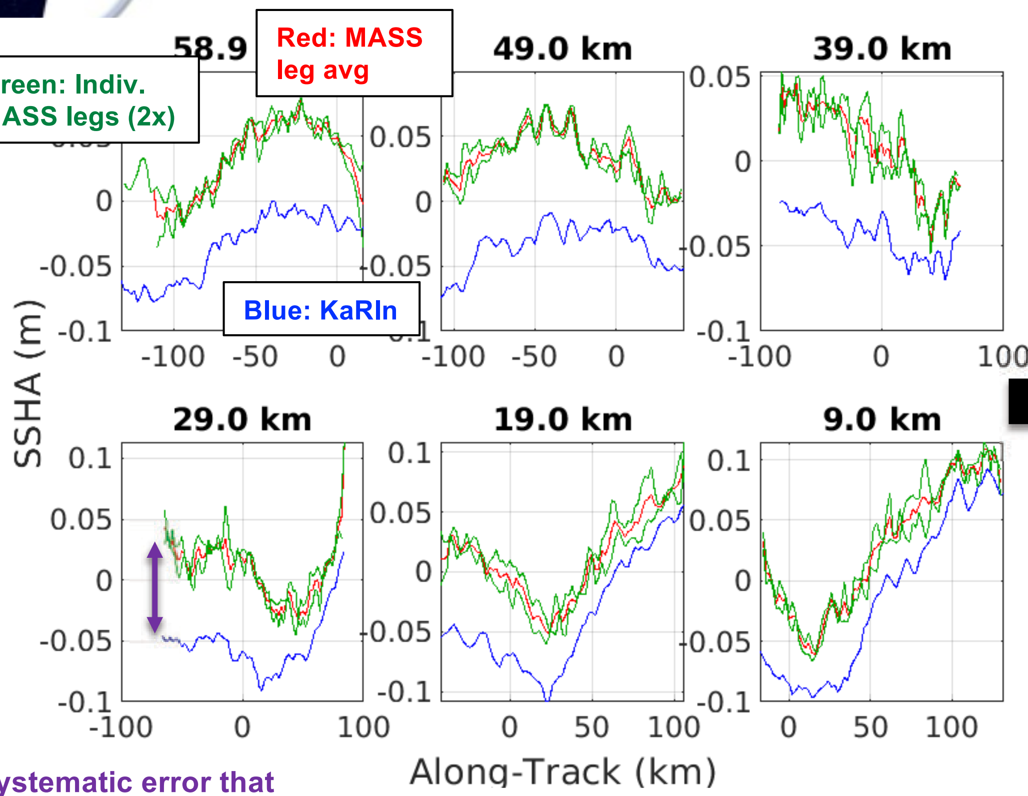
Spectral Analysis Overview

- Compare KaRIn SSHA to MASS SSHA to validate L2 spectral performance:
  - 2023-04-05, FC05
  - 2023-04-06, FC06
  - 2023-04-03, FC03
  - 2023-04-04, FC04
- FC05 and FC06 each have six 150 km along-track segments staggered every 10 km in cross track from 10 to 60 km; each segment is flown twice
  - FC05/06 have more segments over which spectral error estimate can be averaged
  - 1-2 m SWH
- FC03 and FC04 each have 450 km along-track segment at KaRIn midswath; segment is flown four times
  - FC03/04 have more MASS legs that can be averaged to estimate truth
  - ~3 m SWH
  - Data have some gaps
- Subtract MASS spectral error estimate from KaRIn vs. MASS comparison to estimate KaRIn error

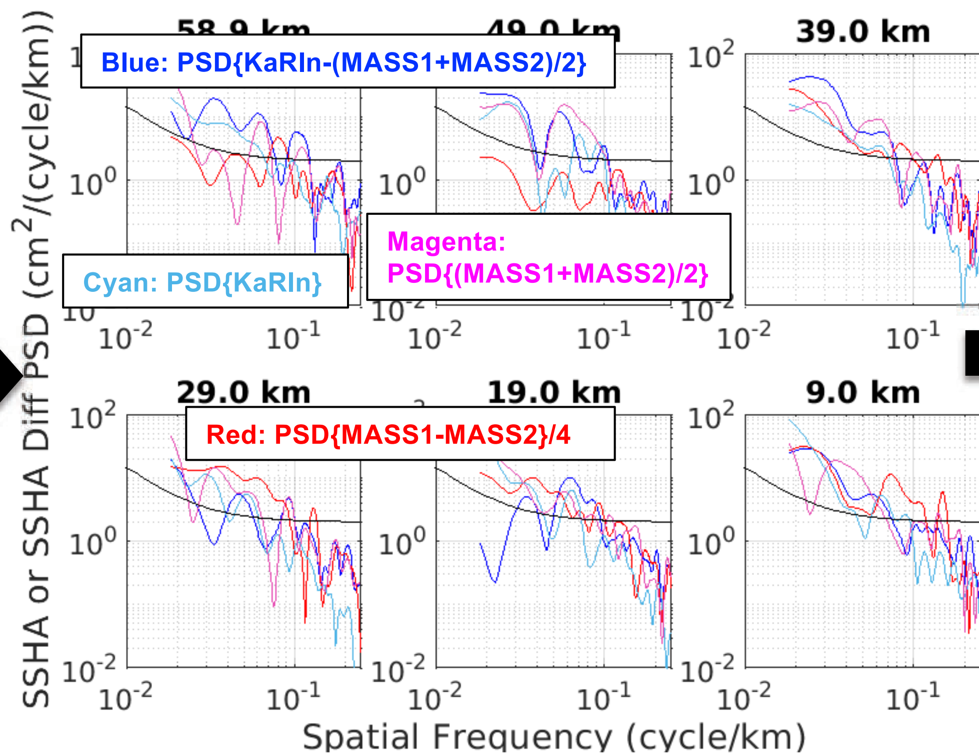
Flight Patterns Suitable for Along-Track Spectral Validation

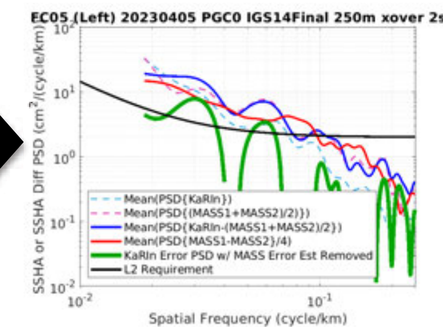


Along-Track Spectral Analysis: FC05 Example



Systematic error that depends on cross track is not unexpected because residual XOverCal errors are possible





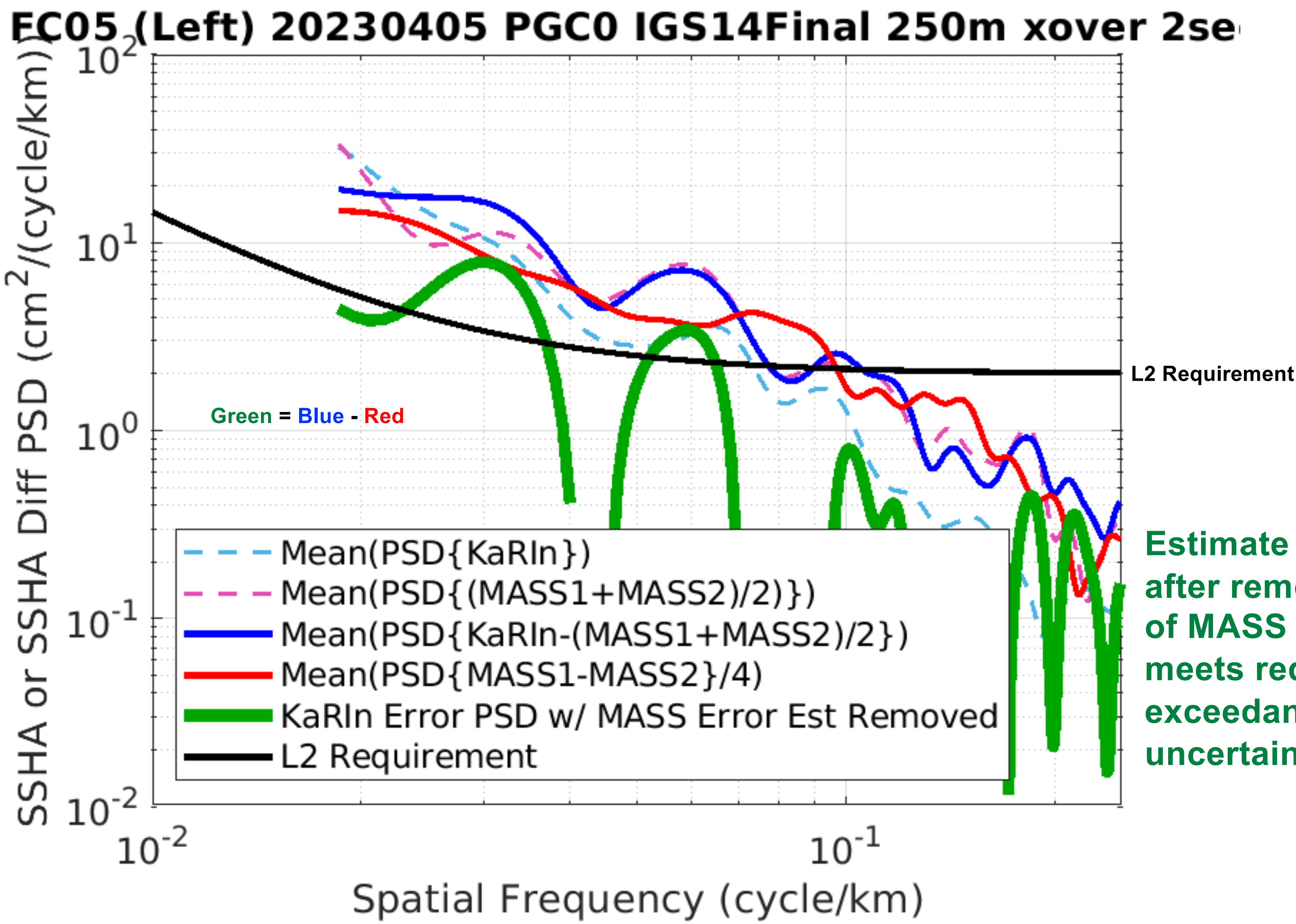
Step 1: Compute SSHA PSDs at each of six KaRIn cross-track locations of:

- KaRIn
- Mean(MASS legs)
- KaRIn minus Mean(MASS legs)
- Variance(MASS legs) [equivalent to difference if only two legs]

Step 2: Average spectra over six cross-track locations

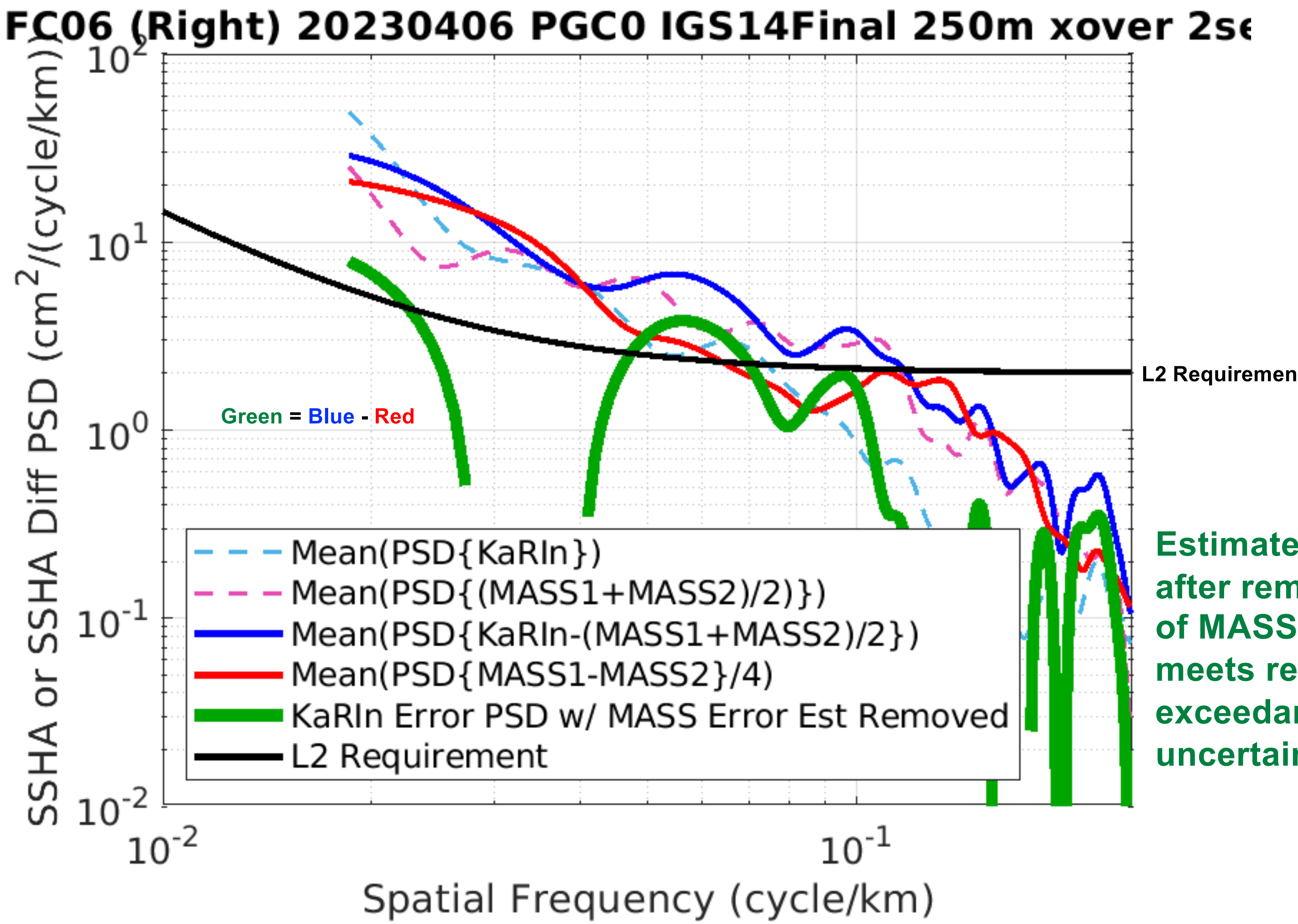
Step 3: Subtract estimate of MASS error PSD from PSD of KaRIn minus MASS to obtain estimate of KaRIn-only error PSD

FC05 Average of Spectra Over Pairs



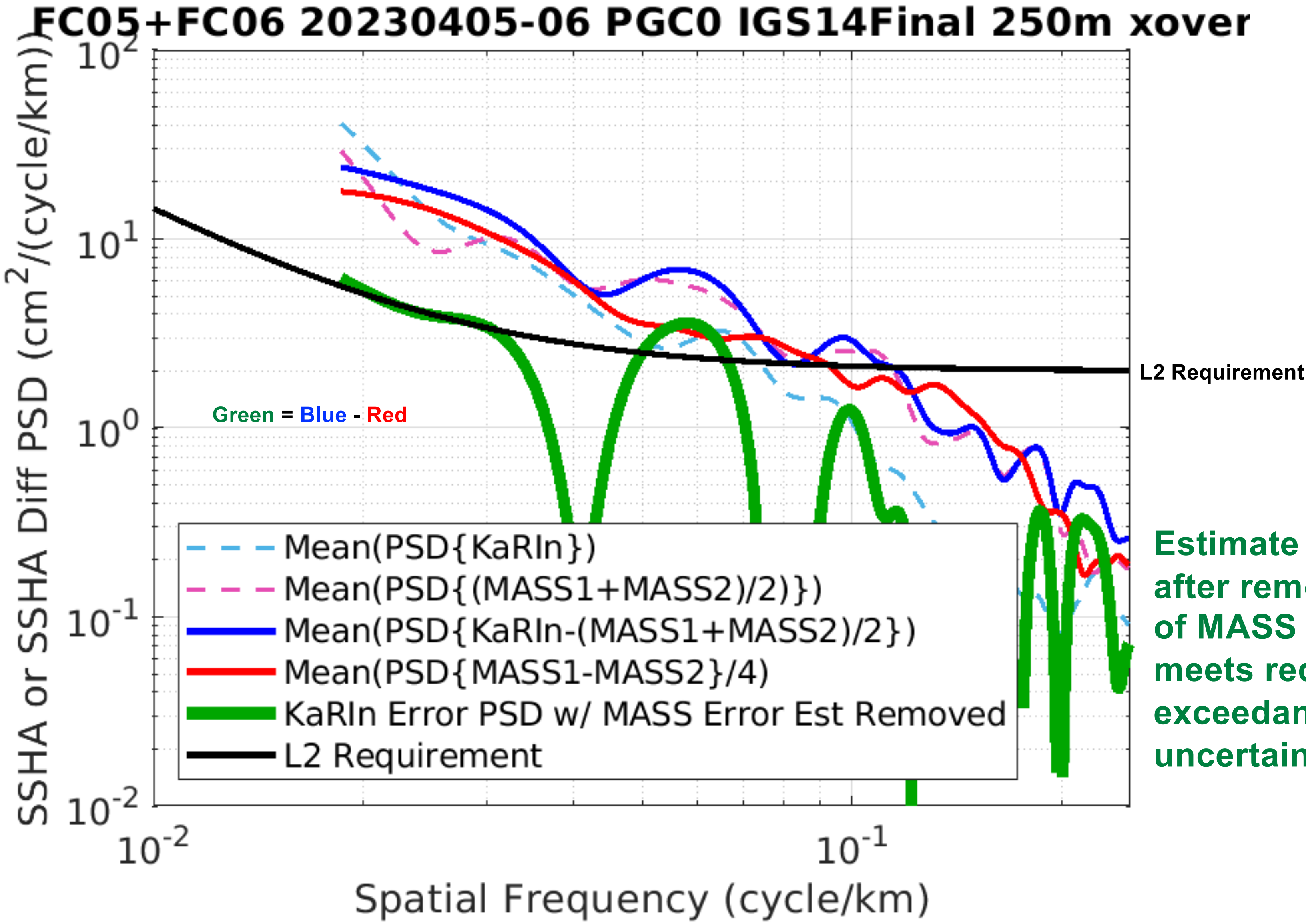
Estimate of KaRIn error after removing estimate of MASS error largely meets requirement; exceedance is within uncertainty of estimate

FC06 Average of Spectra Over Pairs



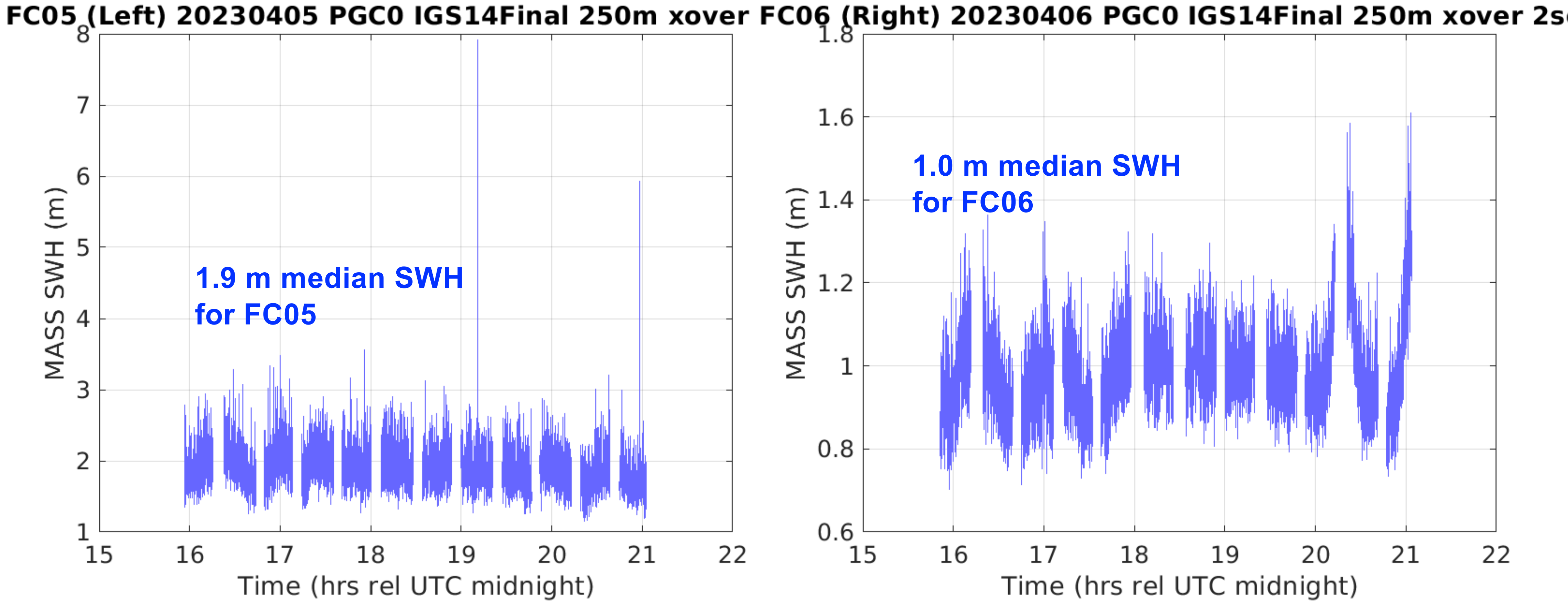
Estimate of KaRIn error after removing estimate of MASS error largely meets requirement; exceedance is within uncertainty of estimate

FC05/06 Average of Spectra Over Flights



Estimate of KaRIn error after removing estimate of MASS error largely meets requirement; exceedance is within uncertainty of estimate

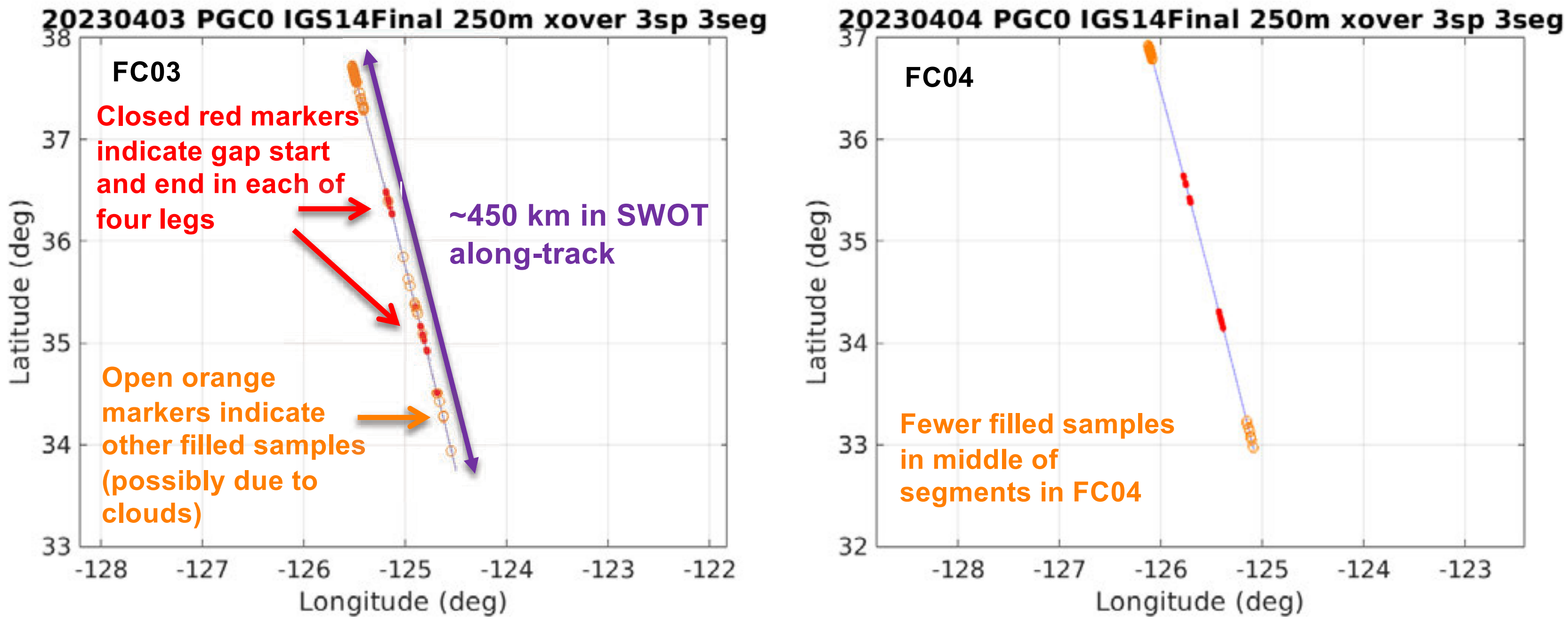
FC05 and FC06 MASS SWH



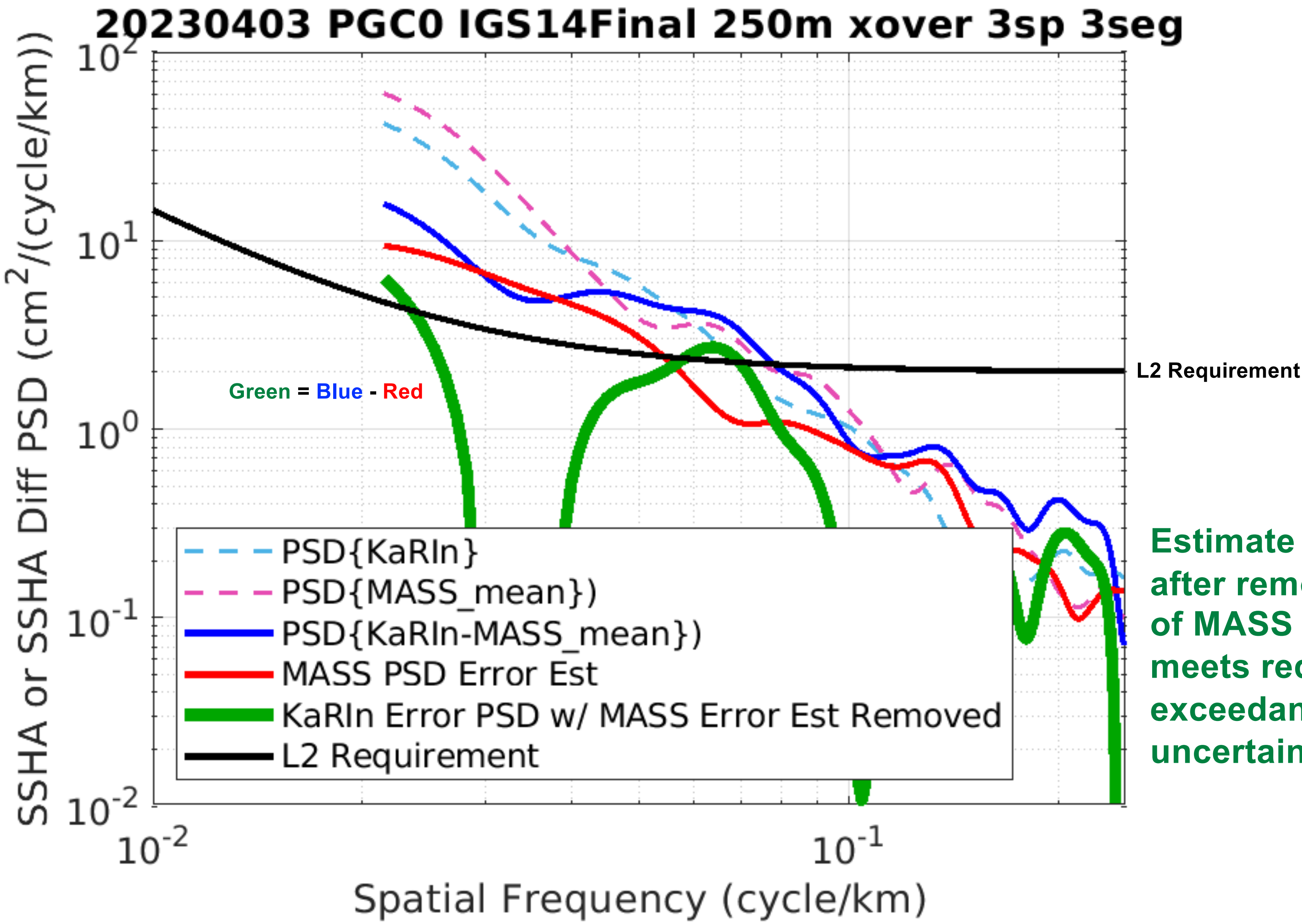
Note: 2023-04-05 and 2023-04-06 are the only days with along-track MASS flight patterns suitable for along-track spectral validation and SWH of 2 m or less

Gaps in FC03 and FC04

- MASS lidar data from 2023-04-03 and 2023-04-04 have ~20 sec gaps due to operator error that split ~450 km track into three segments of ~150 km each per leg
  - Due to procedural error in data collection when starting new files
  - Not present in later flights
  - ~20 sec corresponds to ~2 km along-track distance
  - Gaps are not exactly spaced evenly or in same place per segment
- Gaps are filled by smoothing and interpolation, but may still cause artifacts
- When estimating PSD, split ~450 km track into three ~150 km segments and use Welch's method for each ~150 km segment individually
  - Gaps may not be exactly at ends of ~150 km segments but will be weighted down significantly by Hann window used for spectral estimation

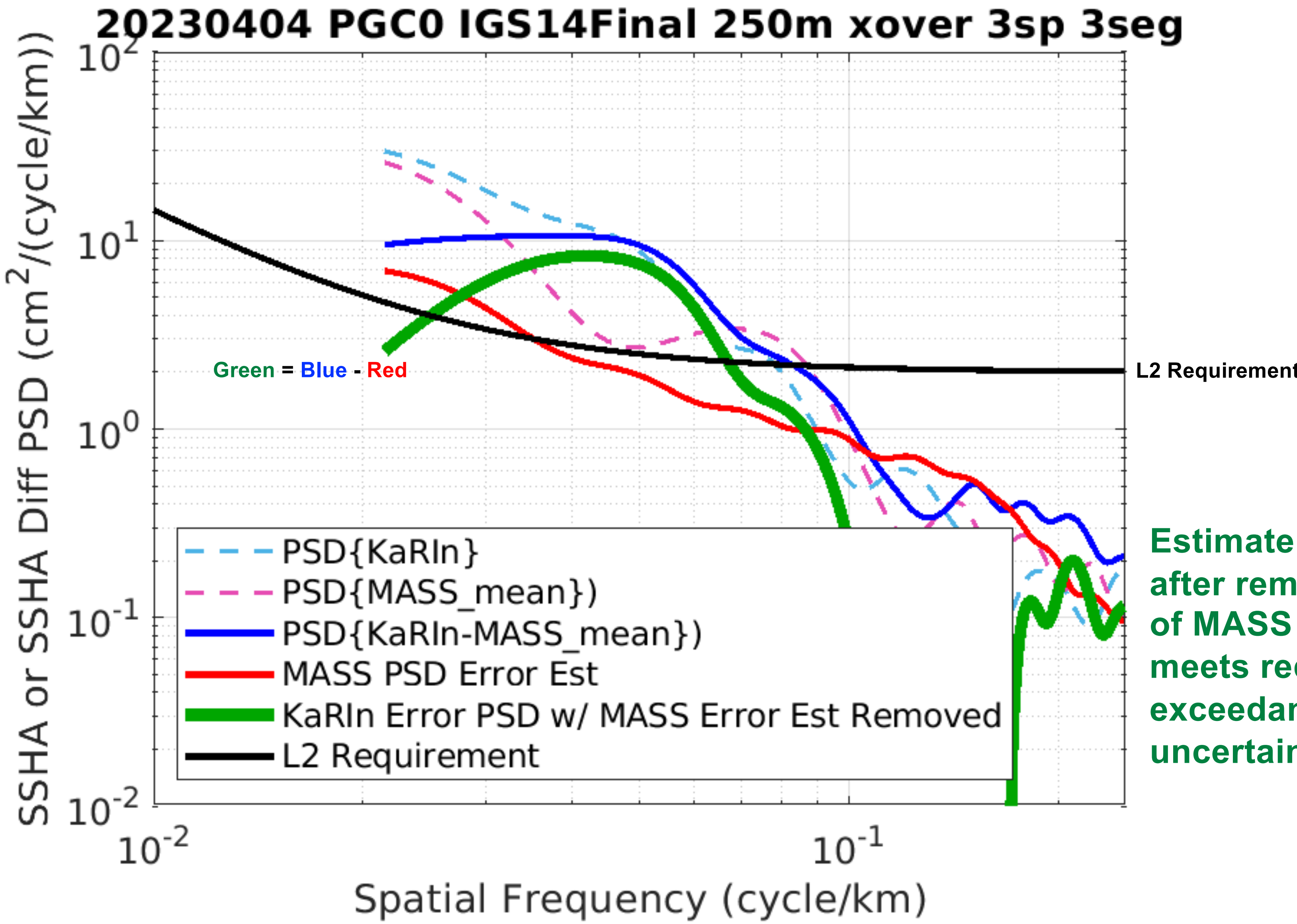


FC03 Spectra



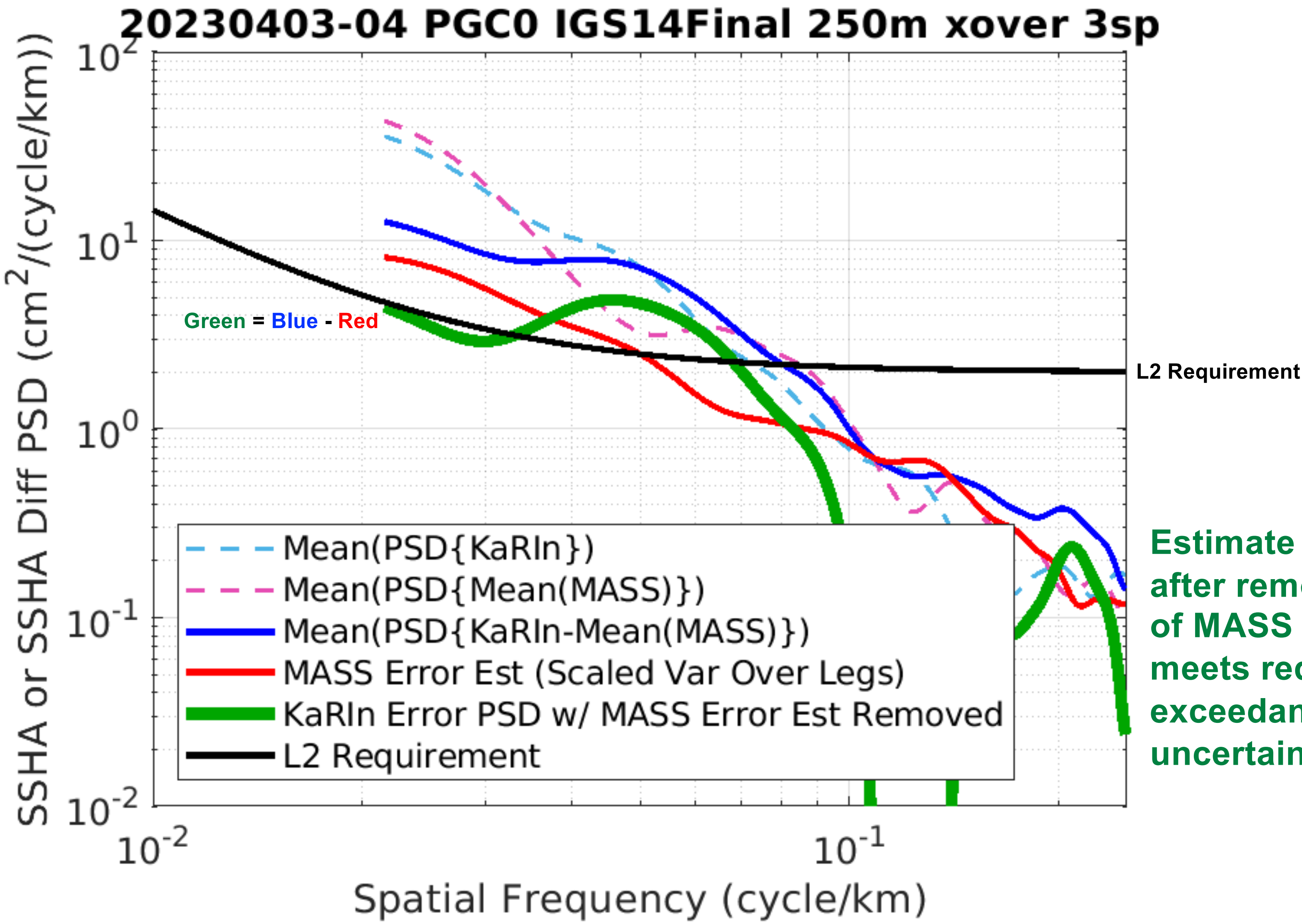
Estimate of KaRIn error after removing estimate of MASS error largely meets requirement; exceedance is within uncertainty of estimate

FC04 Spectra



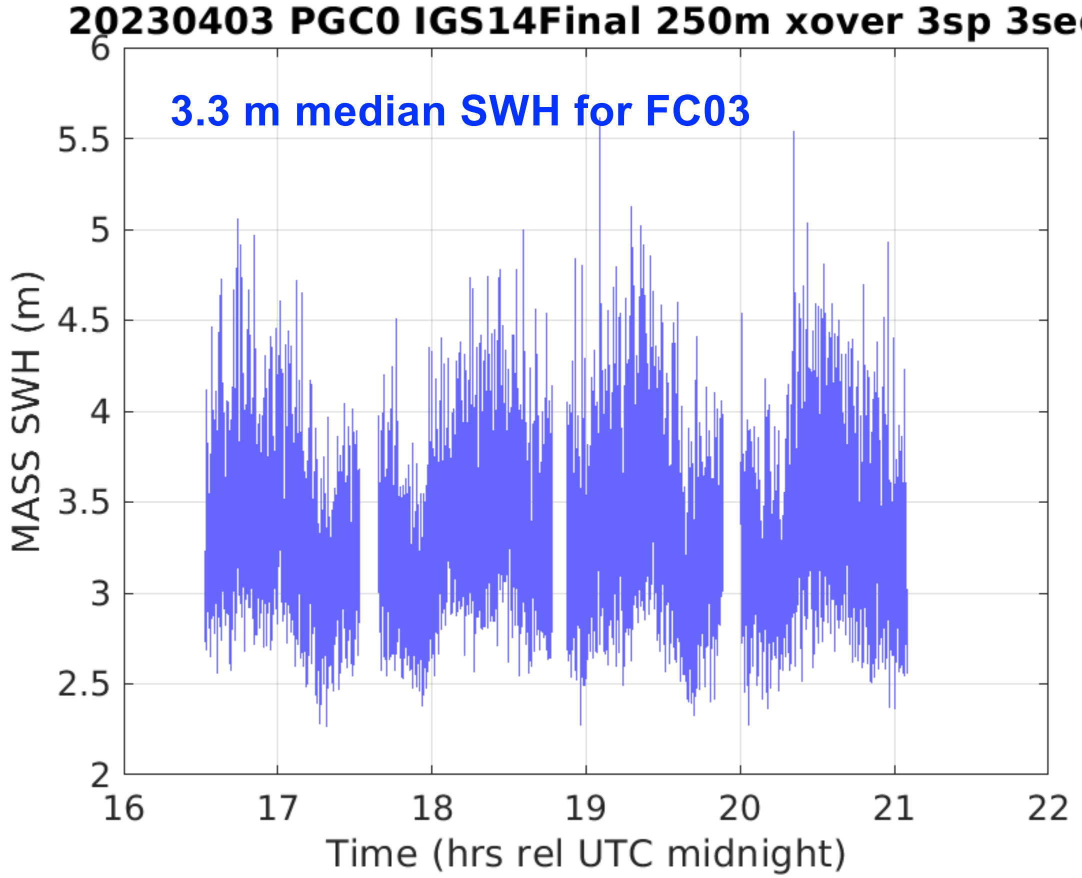
Estimate of KaRIn error after removing estimate of MASS error largely meets requirement; exceedance is within uncertainty of estimate

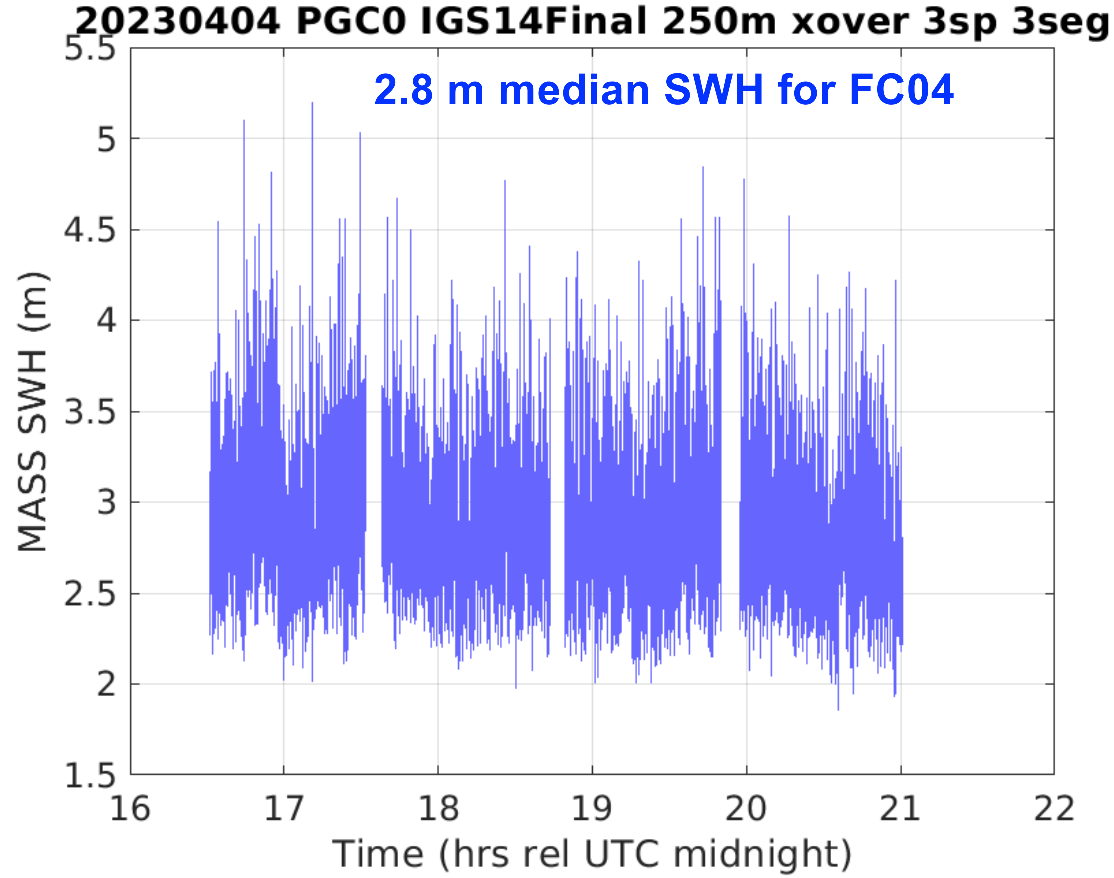
FC03/04 Average of Spectra Over Flights



Estimate of KaRIn error after removing estimate of MASS error largely meets requirement; exceedance is within uncertainty of estimate

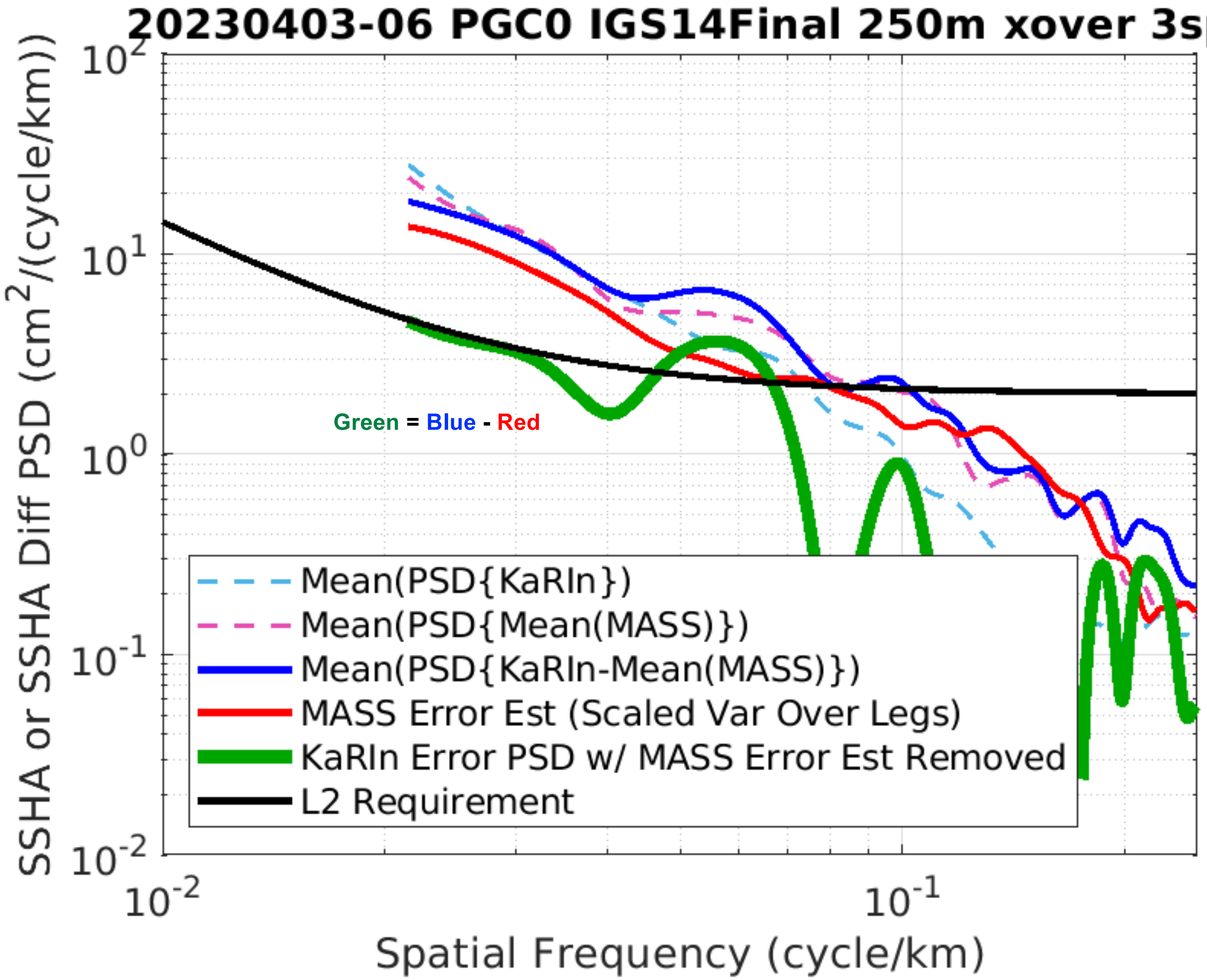
FC03 and FC04 MASS SWH





Note: Strictly, L2 requirement is applicable to SWH of 2 m or less

FC03/04/05/06 Average Over Flights



Note: Spectra are weighted by track length in average over flights because spectral estimation error should decrease with track length, so FC05 and FC06 have more weight than FC03 and FC04

L2 Requirement

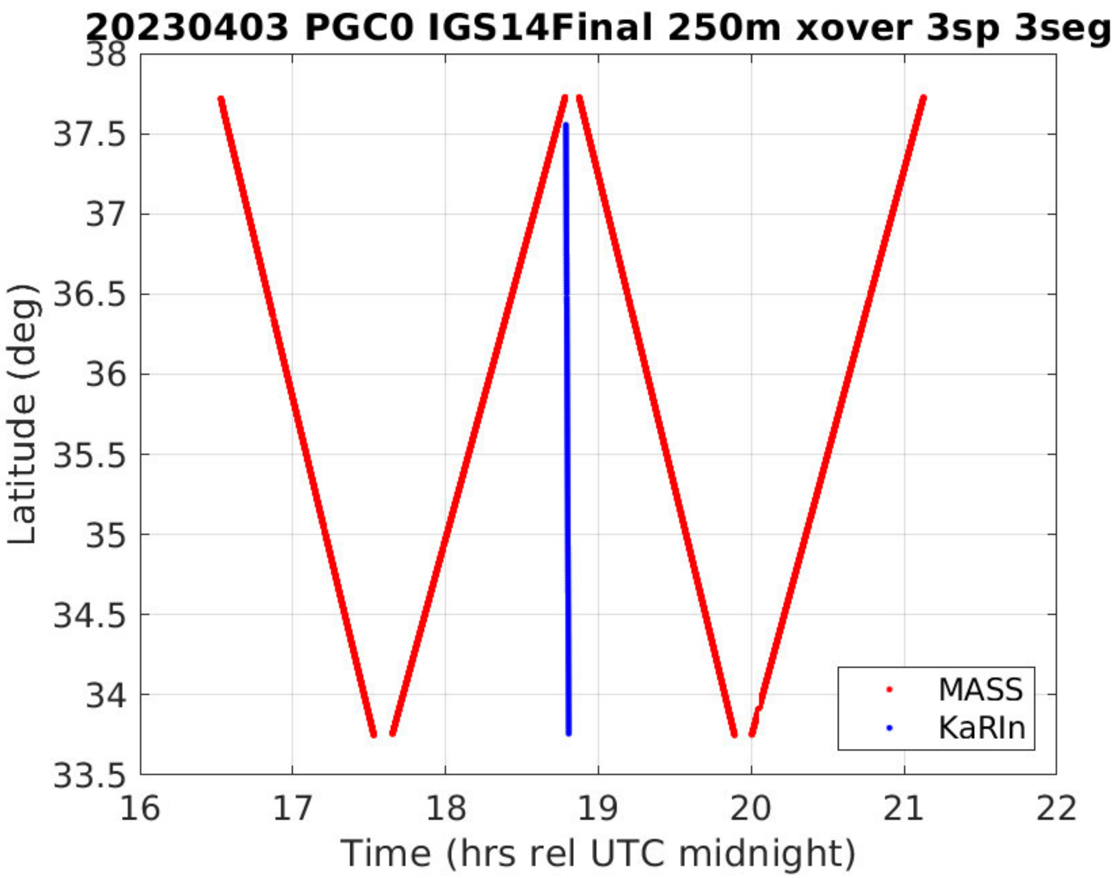
Estimate of KaRIn error after removing estimate of MASS error largely meets requirement; exceedance is within uncertainty of estimate

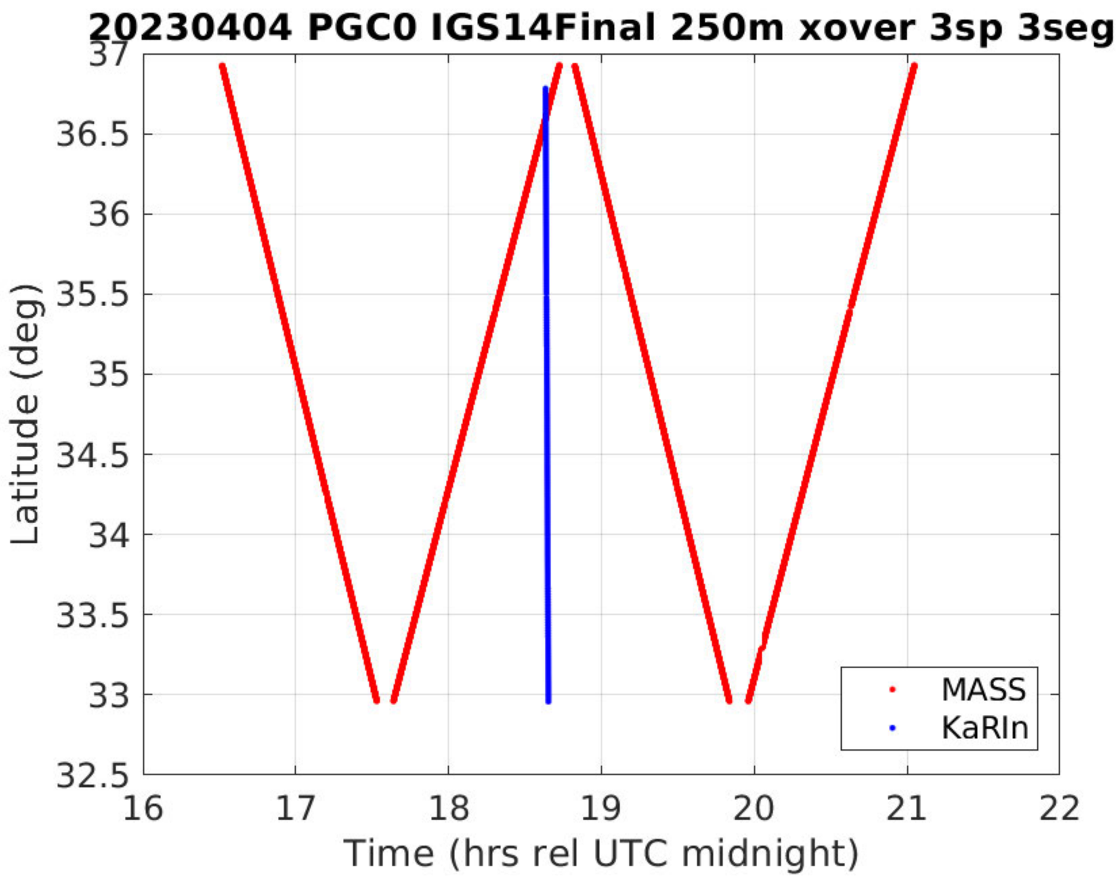
Conclusions

- MASS data suggest that KaRIn is meeting ocean along-track spectral requirements at 15-50 km wavenumbers
- MASS flights provide rich data set for KaRIn validation beyond along-track spectra (e.g., KaRIn phase screen and SWH validation)

Backup

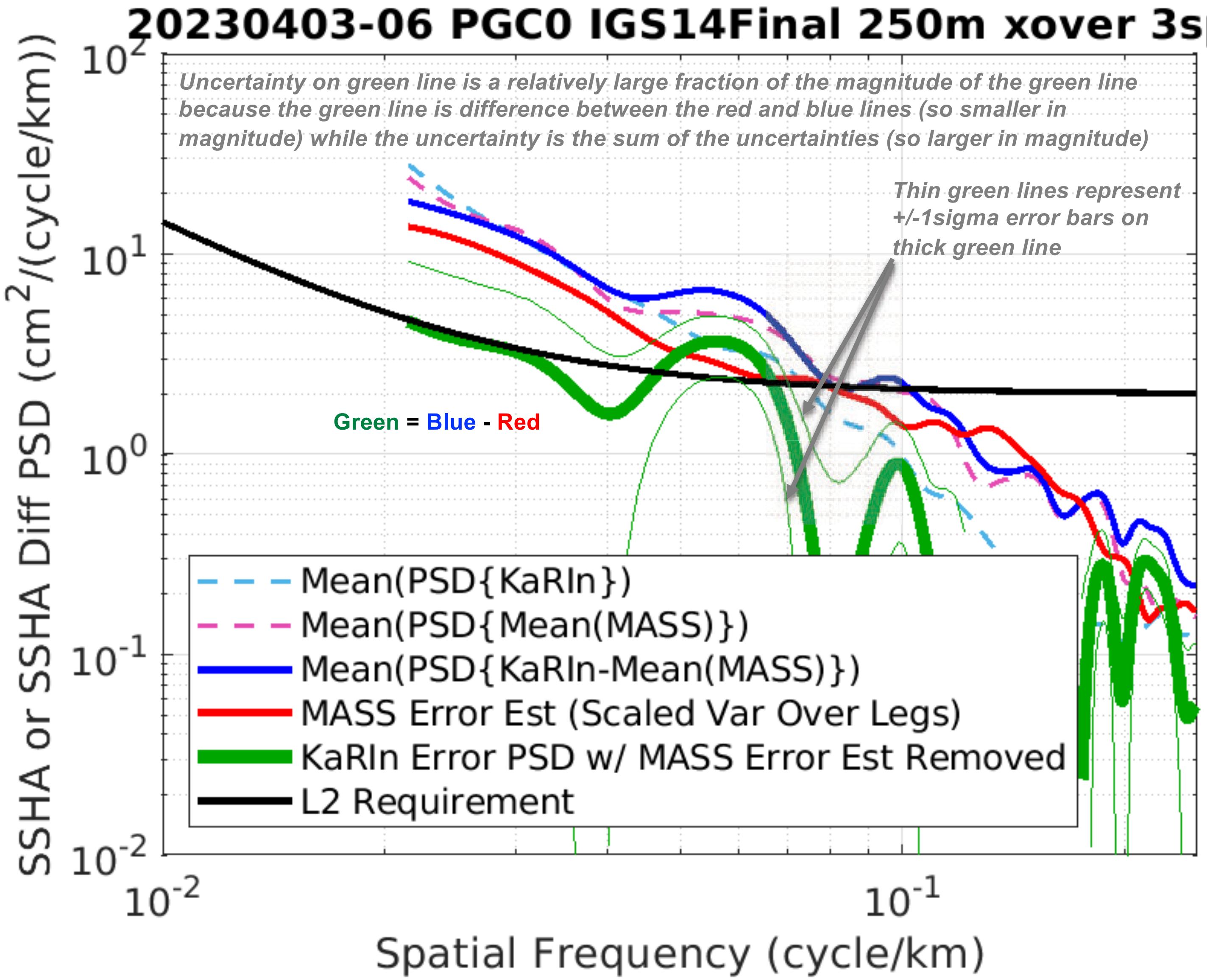
FC03/04 Latitude vs. Time





- Each 450 km MASS leg takes ~1 hr
- About 5-10 min between legs (slow in order to minimize aircraft bank angle and avoid loss of GNSS tracking)
- Aircraft flight was planned to be approximately centered on KaRIn overpass time

FC03/04/05/06 Average Over Flights



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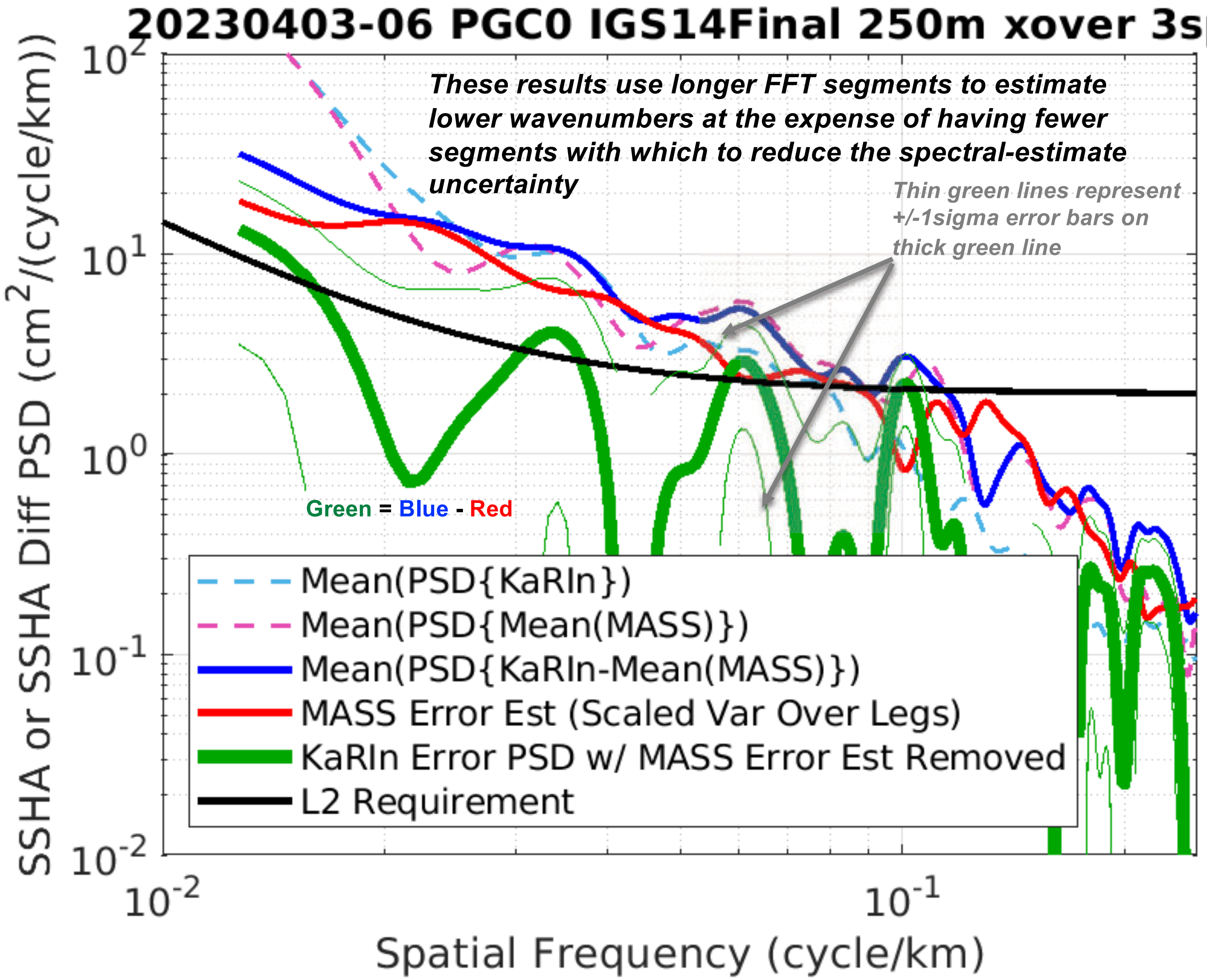
L2 Requirement

Estimate of KaRIn error after removing estimate of MASS error largely meets requirement; exceedance is within uncertainty of estimate

FC03/04/05/06 Average w/Longer FFT



Note: Spectra are weighted by track length in average over flights

L2 Requirement

Estimate of KaRIn error after removing estimate of MASS error largely meets requirement; exceedance is within uncertainty of estimate