Characterization of GPS EIRP and CYGNSS Ocean Calibration Update

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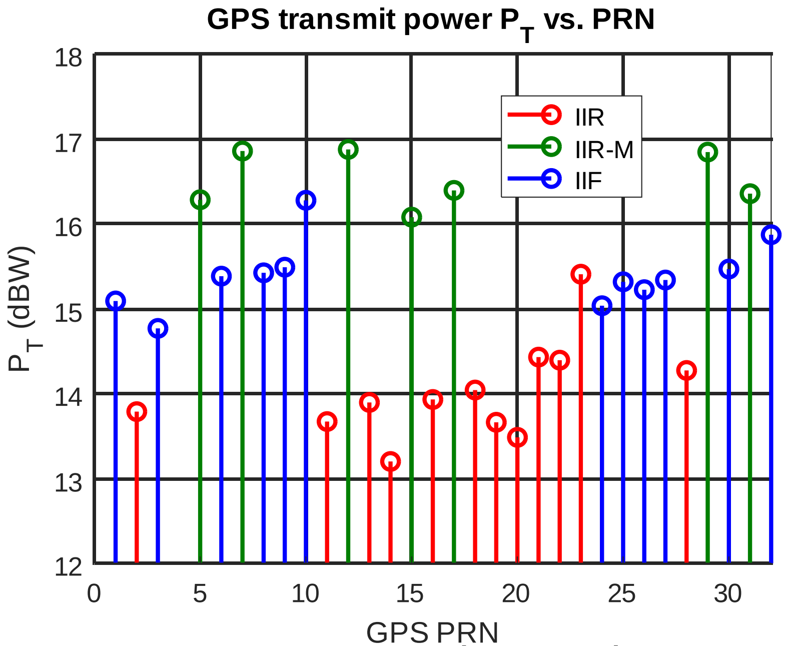
Presentation Overview

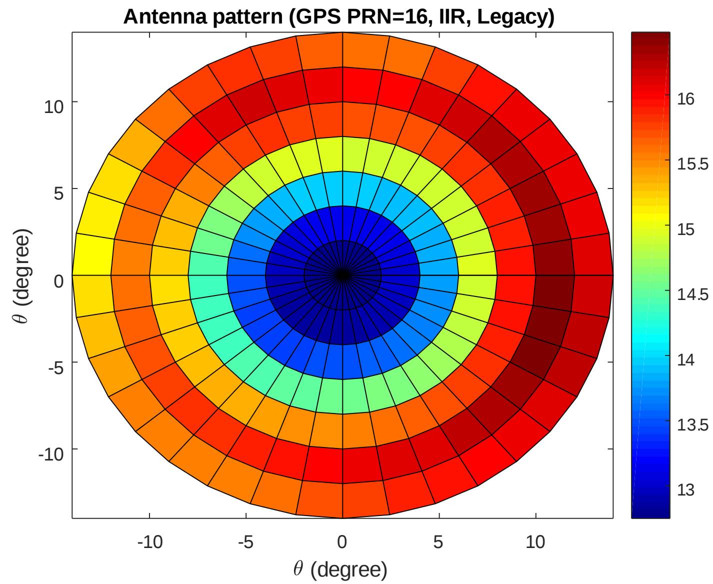
- Motivation for V3.0 Calibration
- GPS Flex Power Overview
- Summary of v3.0 Algorithm
- Receive Antenna Pattern and Specular GPS EIRP
- Example V3.0 Calibration Track
- Results from initial V3.0 Level 1 Sandbox Runs
- Next Steps

Overview of V2.1 Estimation of GPS EIRP

- The current v2.1 algorithm used a ground based GPS power monitor to estimate all of the GPS transmit powers as constant values (even the IIF transmitters). (left) are the v2.1 estimated transmit levels.
- V2.1 used pre-launch measured GPS transmit patterns for the IIR and IIR-M blocks (Lockheed-Martin). These patterns where averaged over all azimuths into a simple off-boresight gain function. No antenna pattern info for the IIF (Boeing) satellites was available.



GPS Power Monitor Estimates of GPS transmit power



Lockheed-Martin IIR Pre-Launch Pattern Courtesy Willard Marquis (L-M)

Motivation for New Level 1 Calibration Strategy

- Unpredictable transmit power fluctuations from numerous GPS transmitters.
  - Notably the Block IIF and (less often on Block IIR-M) GPS Satellites
  - The power monitor estimates do not capture the dynamic power fluctuations of the GPS satellites, thus significant errors are introduced into the calibration when they occur

- GPS antenna gain patterns are known to contain asymmetry
  - V2.1 of the calibration uses a pre-launch estimated off-boresight polynomial fit of the azimuthally averaged transmitter antenna gain, where azimuthal variations are averaged together
  - To mitigate this (in V2.1 context) would require replacement of simple off-boresight models with full GPS antenna pattern estimates and GPS satellite yaw state modeling for each transmitter. Possible but complicated.

- The above issues result in the flagging out of a large number of CYGNSS observations (including all of the IIF block transmitters)
- The V3.0 CYGNSS calibration is designed to solve and/or mitigate both of these issues

GPS Transmitter Flex Power Variations

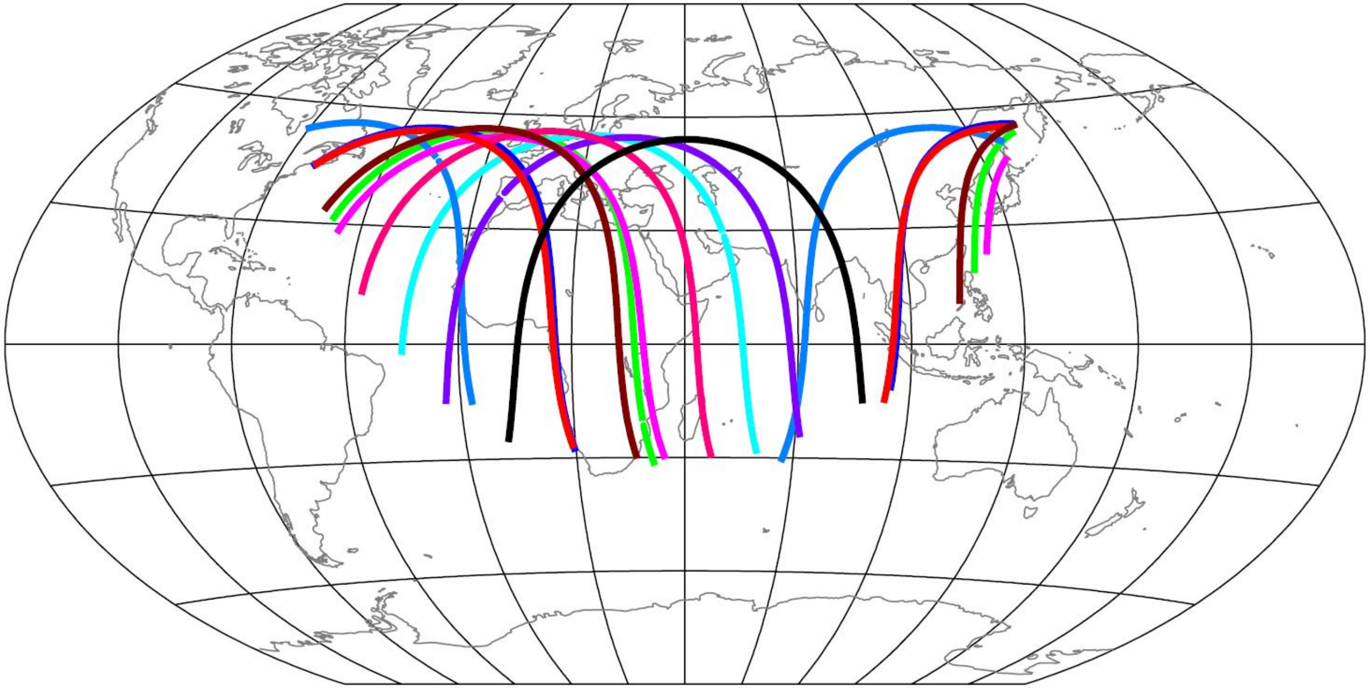
GPS Transmitter Challenges

- Background on power flex modes of Block IIF and IIR-M satellites
  - Provides capability to redistribute transmit power between individual signal components of C/A, P(Y), and M codes
  - This flex power can be used for increased protection against jamming in certain regions
  - Geographically designed flex power modes in operation since January 2017
  - Block IIF power changes every orbit. Block IIR-M also known to change, but less frequently.

- GPS antenna gain patterns are known to contain asymmetry
  - Very difficult to estimate the full pattern, and GPS pattern prediction complicated by regular yaw maneuvers
  - Published antenna patterns not optimal for CYGNSS Level 1 calibration and L-M patterns do not account for changes when mounted on the satellites

Geographic GPS Power Changes on IIF

- Ground tracks of GPS Block IIF satellites with increased C/N0 on June 2, 2018. Different colors indicate individual satellites

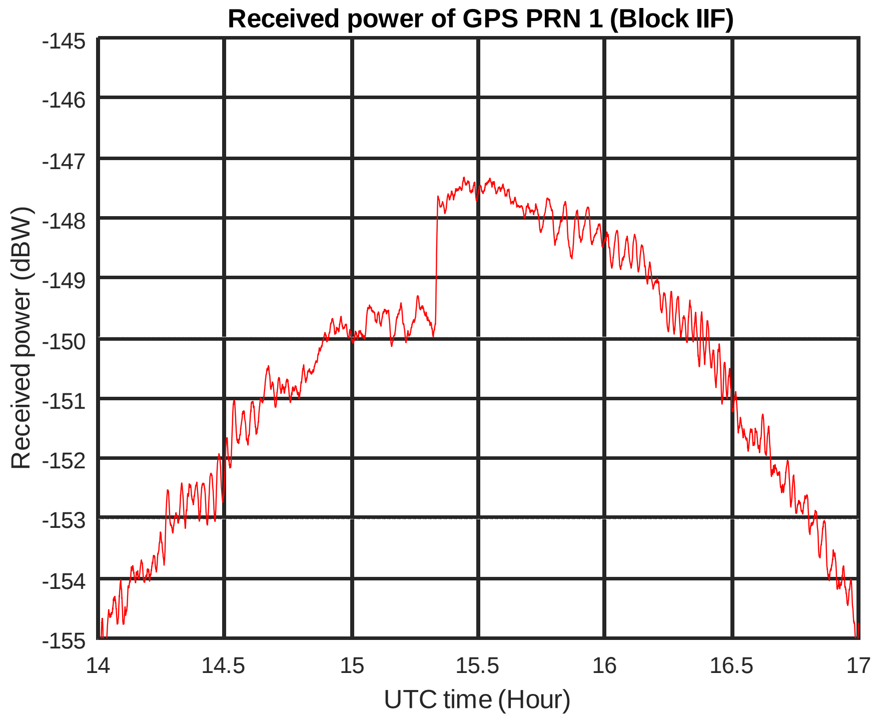


Steigenberger, P., Thölert, S. & Montenbruck, O. Flex power on GPS Block IIR-M and IIF, GPS Solutions (2019)

GPS Power Change Example

- Significant power decrease or increase over several seconds repeatedly observed with GPS Power Monitor
- Power changes were observed to be repeated at the same time over several consecutive days, which could potentially be modeled ... or

GPS transmitter power jump observed by UMichian GPS Power Monitor in Ann Arbor



Overview of CYGNSS V3.0 Level 1 Calibration

Summary CYGNSS v3.0 Calibration

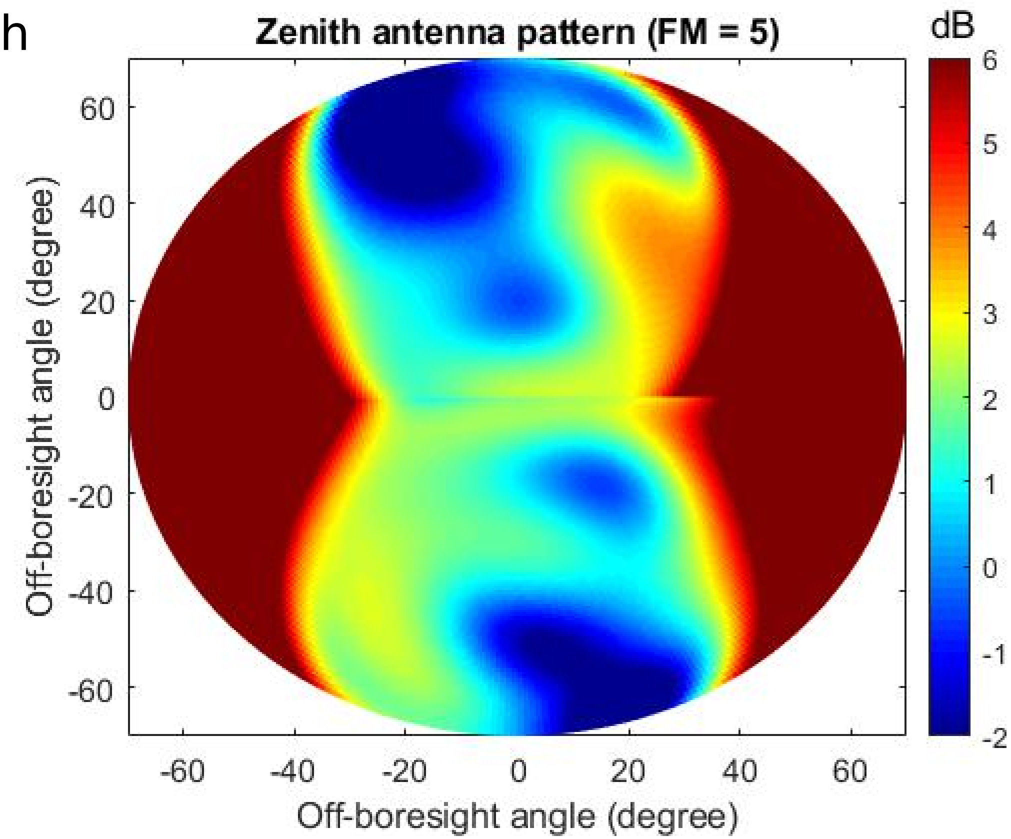
- Use measurements from the direct (zenith) antenna to estimate the specular GPS EIRP correction in the calculation of the BRCS
  - Received direct signal power can be measured using the zenith antenna and solved for zenith GPS transmitter EIRP
  - By applying corrections to the observed direct signal EIRP, it is possible to estimate the GPS EIRP in the direction of the reflected signal specular point
  - Corrections include both hardware and geometry differences between the direct and reflected channel.

- By making a direct temporally coincidence estimates of the GPS EIRP, all flex power jumps will be immediately detected
- Additionally, the geometry correction between the zenith and nadir estimates of the EIRP should be much less sensitive to GPS antenna pattern asymmetry

Estimating CYGNSS Zenith Antenna Patterns

- The accuracy of the direct observation of the GPS EIRP is dependent on accurate knowledge of the receiver zenith antenna pattern.
- The CYGNSS zenith antennas were characterized individually using a large set of direct signal measurements over several months. With zenith LNAs commanded to a constant gain level (i.e. AGC off)

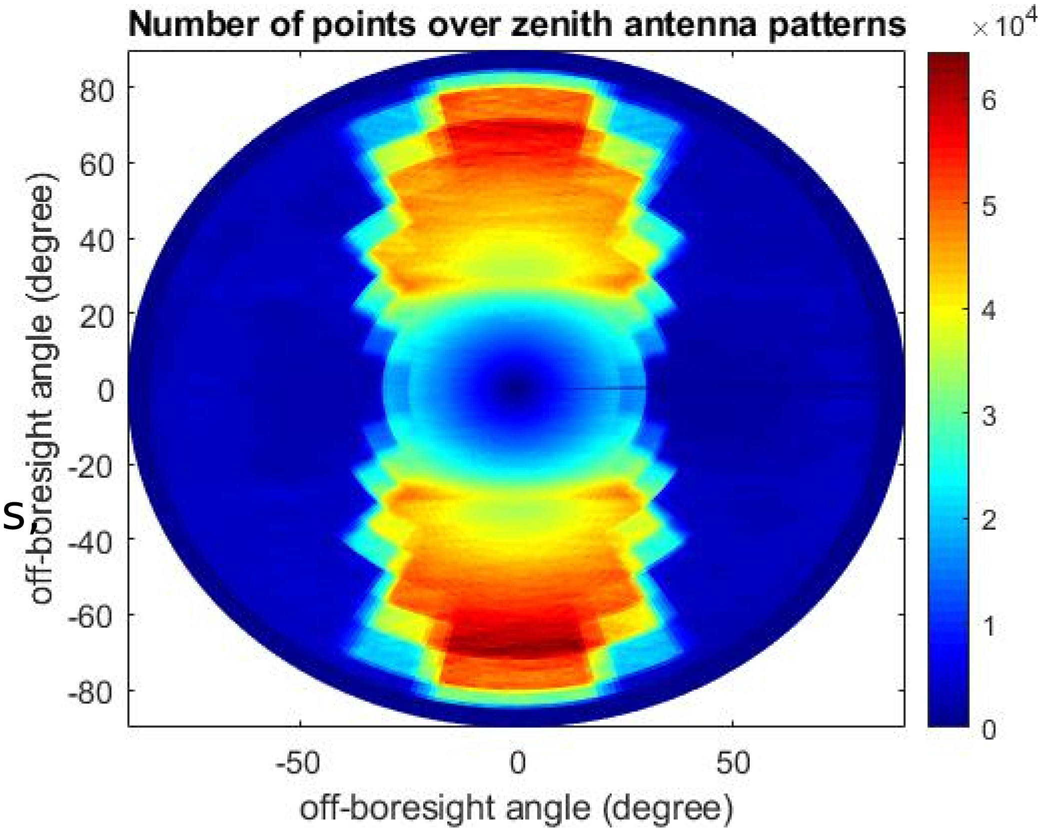
- An example CYGNSS zenith pattern is shown, generated using zenith observations and a spherical harmonic fitting algorithm



Considering Zenith Measurement Distribution

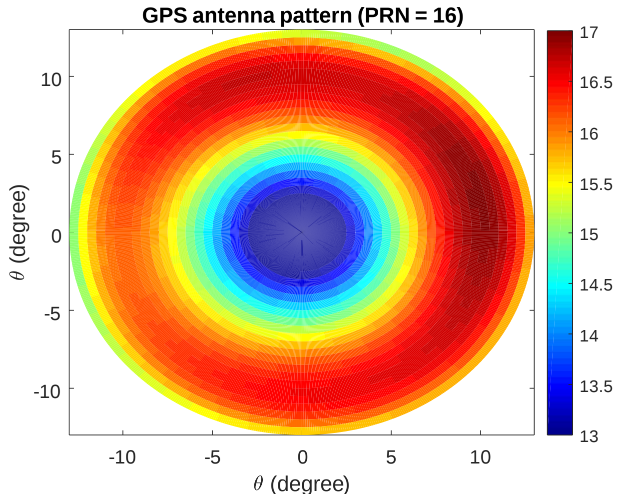
- Only direct signals linked to nadir measurements are used to estimate the GPS EIRP levels
- This results in distributions of direct measurements on the zenith antenna linked to the nadir observation selection algorithm
- Therefore, characterizing the regions of the direct antenna pattern where most measurements occur is a priority

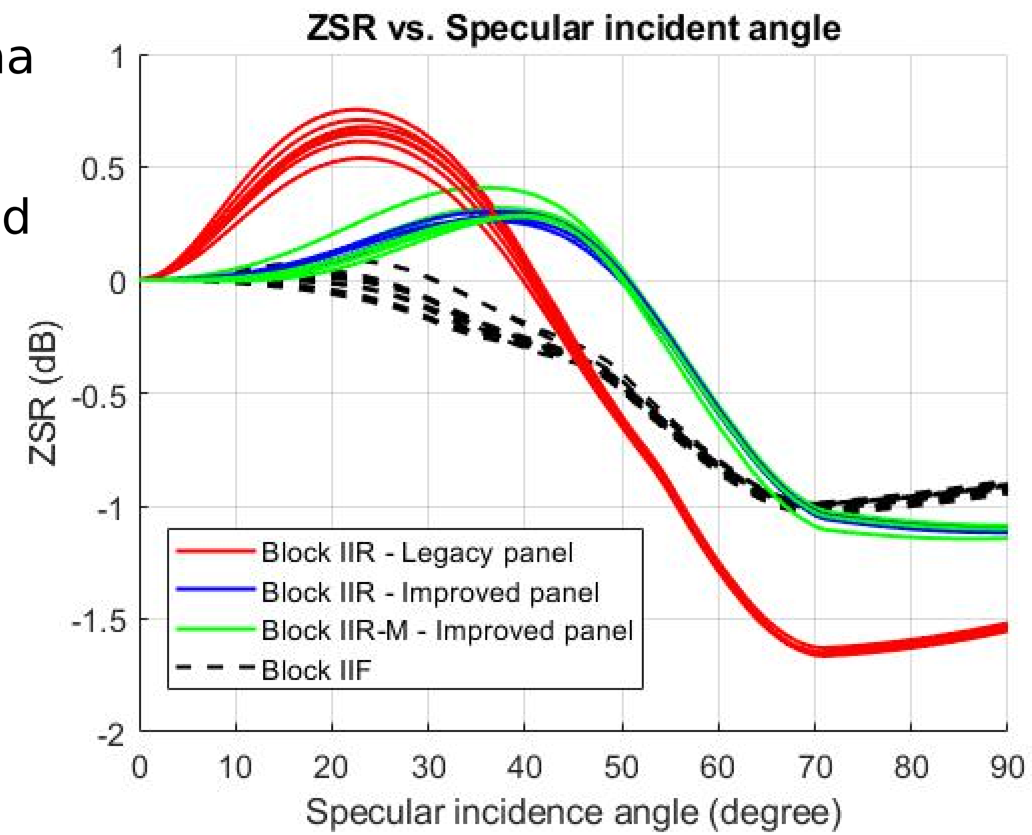
- Measurement distribution for an example zenith antenna shown to right
- Z axis color scale represents number of measurements
- A significant number of measurements occure at higher off-boresight angles which are of generally lower gain



Zenith to Specular EIRP Correction

- The line of sight angular difference between the transmitter-zenith and transmitter-nadir paths needs to be accounted for
- The difference is a function of incidence angle only, with both paths received at the same azimuth angle. This greatly reduces the effects of azimuthal variations in the pattern, and allows for a correction ratio between the zenith and nadir channels as a function of incidence angle
- (below) Derived GPS antenna pattern from zenith measurements, (right) ratio between zenith and reflected antenna gains

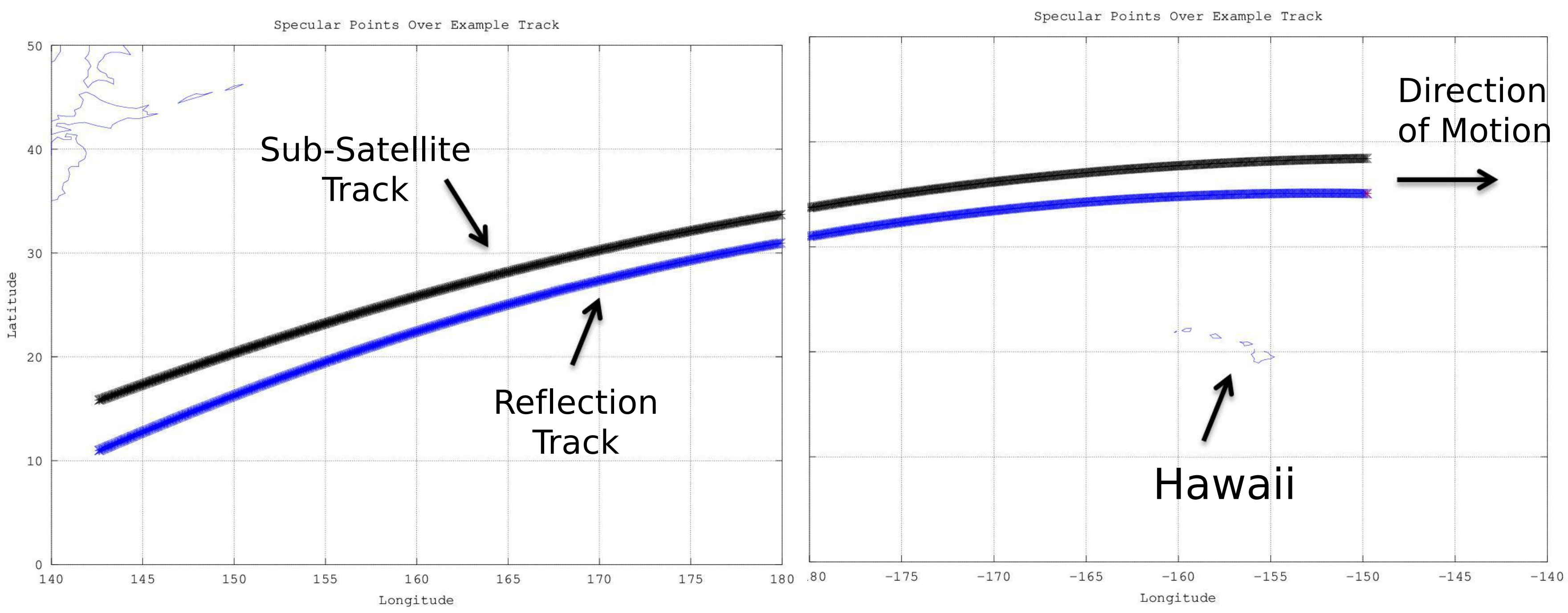




Example V3.0
Calibration Track

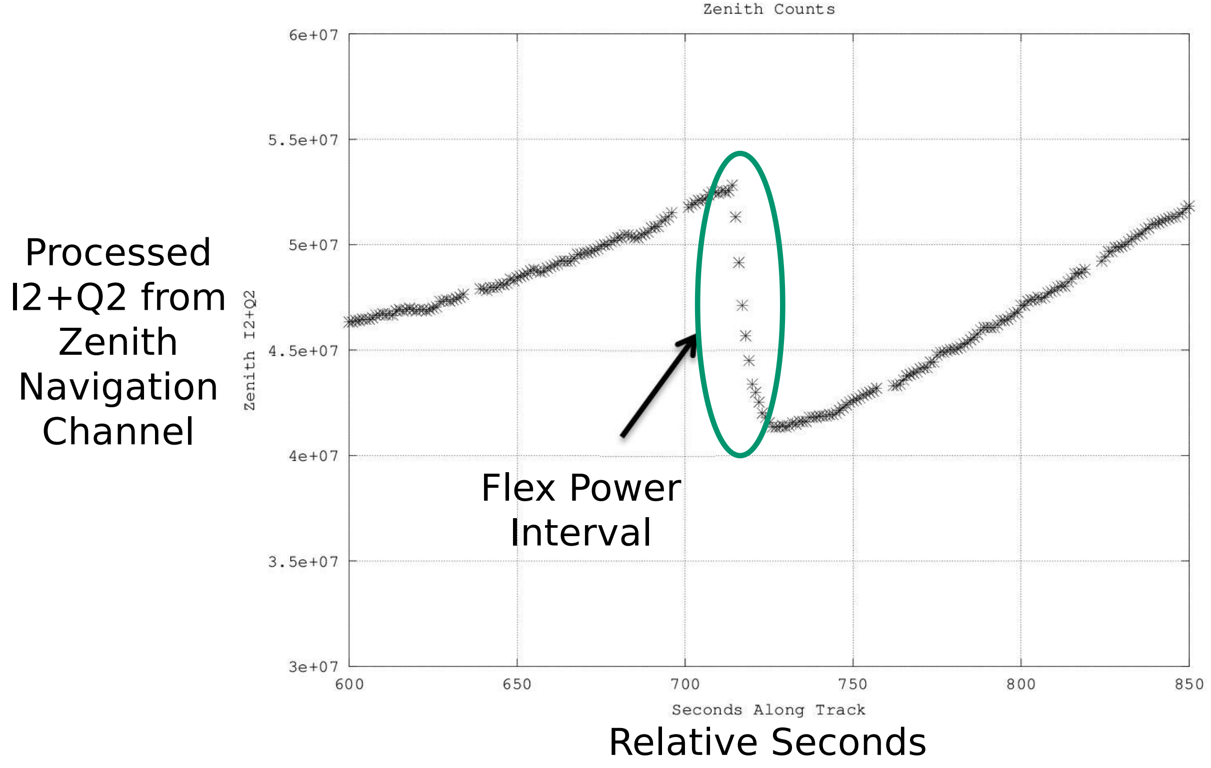
Example Track

- An example CYGNSS ocean observation track was selected, where a GPS flex power event was clearly present
- Example ocean track location shown below in the Pacific ocean.



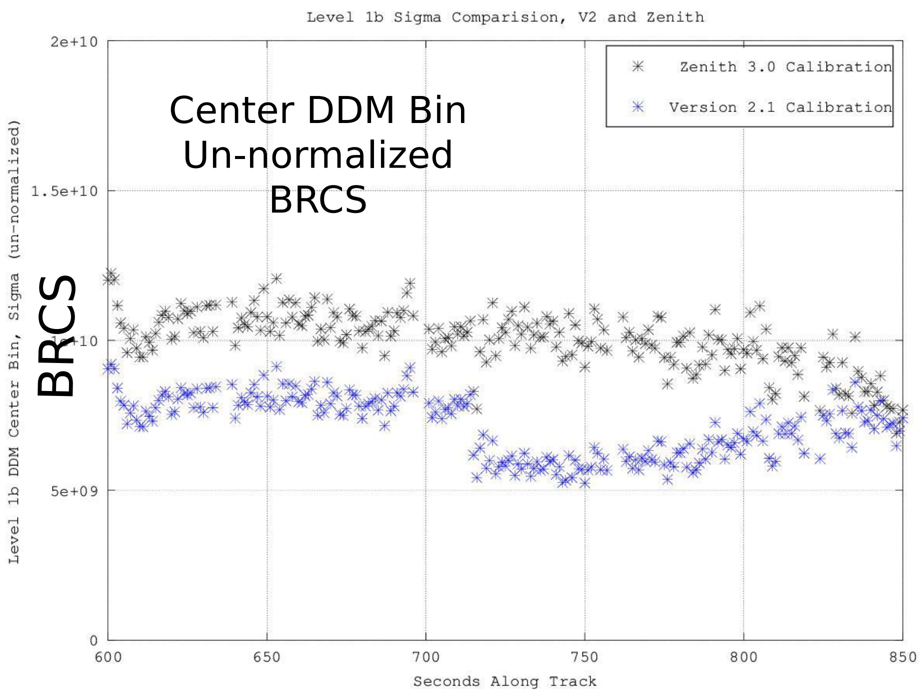
Flex Power Observed During Track

- Processed zenith raw signal counts over track clearly show a discontinuous jump, where the GPS transmit power is abruptly dropped.
- Region of track with power jump shown below. Flex power event occurs over approximately 10 seconds

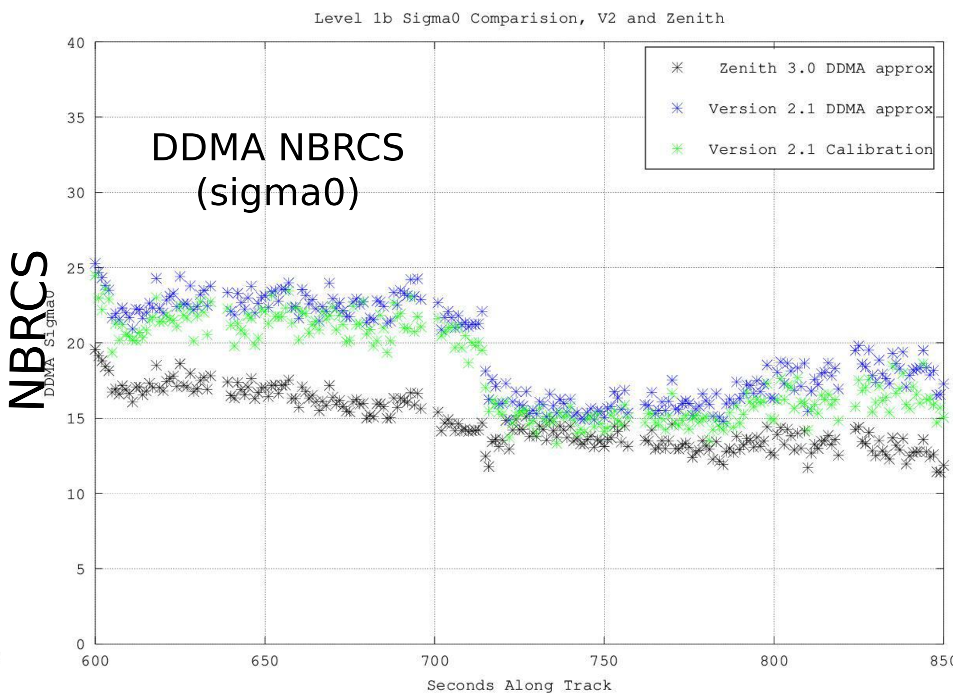


Calibration Comparison During Power Jump

- Comparison of V2.1 and V3.0 Sigma and Sigma0 estimates
- (left) Un-normalized sigma value at center DDM bin
- (right) Sigma0 estimated over 3 delay x 5 Doppler DDMA bins of the full DDM
- (black) values are V3.0 estimates, (blue/green) are V2.1 algorithm



Relative Seconds



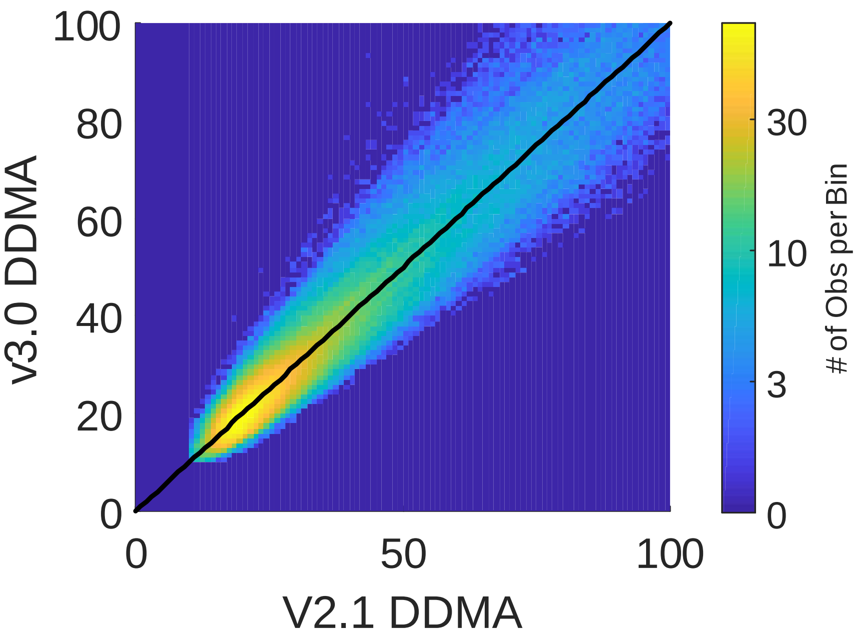
Relative Seconds

Initial Sandbox Runs of 3.0 Calibration

V3.0 Sandbox Run

- The algorithm concept was initially tested on example smaller data sets (single tracks, one day of data for single FM).
- Subsequently, a series of "sandbox runs" are generated to fine tune and validate changes on a statistically significant larger data set (months or more, all FMs) before official roll out to general users.
- A key aspect of the V3.0 algorithm tuning was determining the instrument specific digital scaling factors required to ensure realistic (physical) distributions of v3.0 sigma0 values.

- The initial v3.0 scale factors have been determined using a sub set of high confidence V2.1 observations
- The resulting scale factors result in a 1:1 scatter-plot relationship between the two observations
- One month of data shown for single CYGNSS satellite

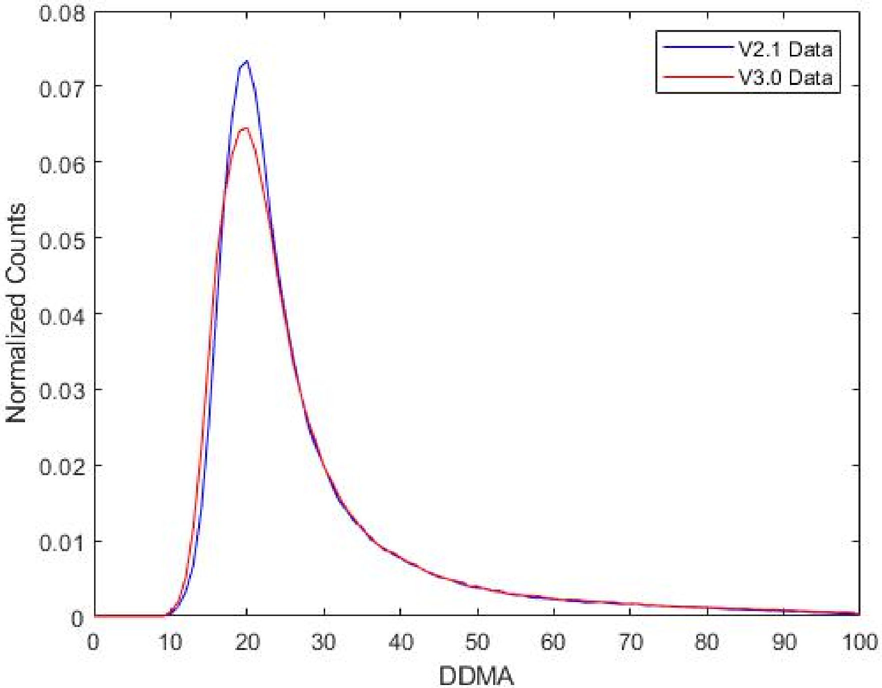


Sigma0 Distribution Comparison

- The distribution of sigma0 values for the tuned v3.0 algorithm was then compared with the equivalent V2.1 distribution
- This provides a first check that the v3.0 ocean observations are producing physically realistic observations

- (right) Normalized distribution of CYGNSS sigma0 values using one month of data for FM 7
- Distributions from other CYGNSS FMs are comparable
- This gives us reasonable confidence that the basic algorithm is working as expected

CYGNSS FM 7



DDMA Sigma0

Advantages/Challenges

- V3.0 calibration will instantaneously detect and correct power fluctuations in all GPS block transmitters.
- V3.0 calibration algorithm should significantly reduce errors due to the GPS antenna gain azimuthal asymmetry
- V3.0 data will allow observations from the GPS IIF Block satellites to be included in the standard data products. Currently observations from IIF satellites are flagged out and significantly reduce the CYGNSS measurement coverage by approximately 37%.

- The accuracy of the V3.0 algorithm is linked tightly to the uncertainty in the knowledge of the zenith antenna patterns, including many measurements in relatively low gain areas of the pattern. This will require additional refinement of the patterns and more intelligent flagging methods
- The v3.0 algorithm will reduce but not eliminate GPS transmitter gain asymmetry affects. More work is needed to refine the transmit patterns and improve the EIRP correction from zenith to specular

Next Steps

- Design improved data flagging strategy based on uncertainty in zenith antenna knowledge and other factors
- Fine tuning of geometry correction from zenith to nadir EIRP and characterization of remaining effects of GPS antenna asymmetry.
- Regenerate Level 2 ocean wind speed geophysical model functions and validate ocean wind retrieval performance
- Release V3.0 data to NASA PO-DAAC

Thank You