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Preliminary CYGNSS Intercalibration

Darren McKague, Chris Ruf,
Rajeswari Balasubramaniam, Maria-Paola Clarizia
University of Michigan

SPACE PHYSICS RESEARCH LABORATORY

Intercalibration Overview

- CYGNSS will produce wind speed and mean squared slope (MSS) estimates from multiple satellites
  - Want estimates to be consistent from receiver to receiver
- Intercalibration is the process of ensuring that receiver to receiver biases are identified and addressed
  - Preference is to addressed at L1/observable level
  - Best case scenario: from analysis of biases, root cause is determined and fixed at lowest possible level
  - Fall-back: if root cause cannot be found and corrected on a "do no harm" basis, develop empirical corrections to provide consistent retrievals
- This presentation will show preliminary results of CYGNSS intercalibration efforts …

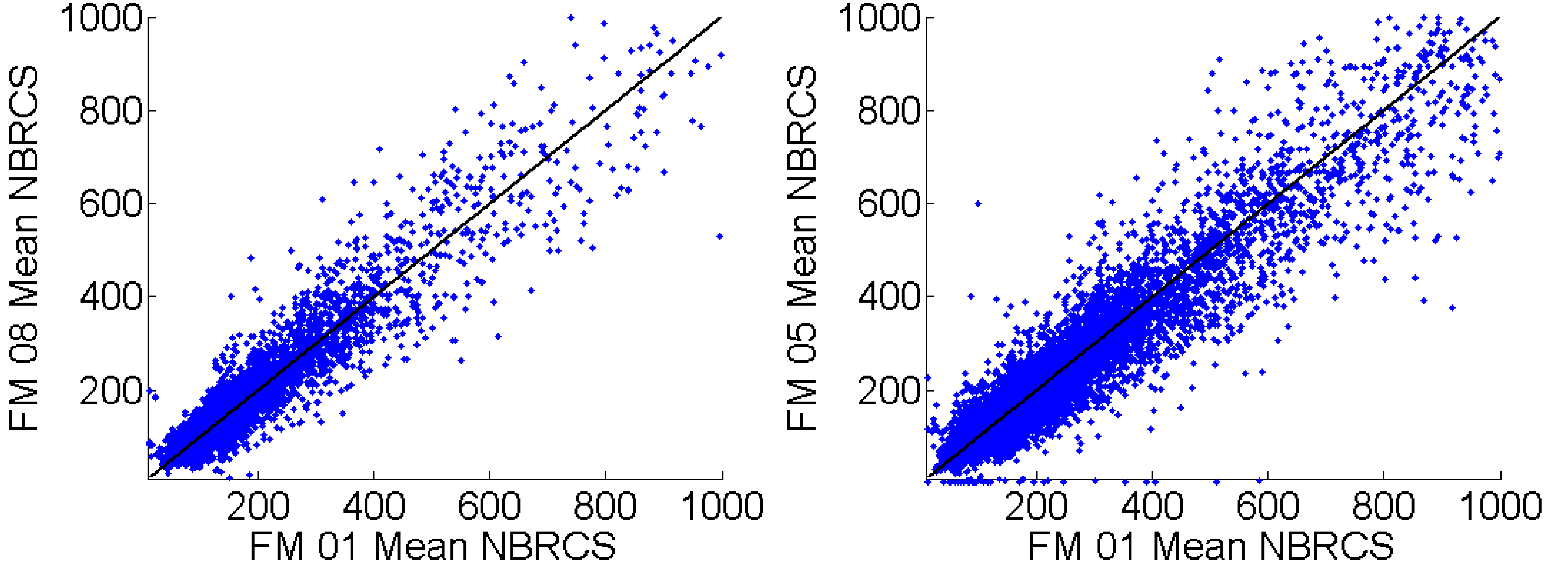
Scope of CYGNSS Intercal

- Multiple receivers and transmitters to characterize
  - Receivers: 8 CYGNSS satellites each with two antennas (port, starboard)
    - Within control of CYGNSS mission with relatively well understood status (e.g., antenna patterns, attitude, receiver gains)
  - Transmitters: 31 GPS satellites
    - Out of CYGNSS mission control with limited available characterization (e.g., antenna patterns, attitude, transmit power)
  - Several possible combinations with several unknowns
- Must break problem down into components
  - Start with GPS Transmitter/CYGNSS Receiver split …

CYGNSS Intercalibration

- First look CYGNSS satellite to satellite variability in terms of main observable: NBRCS
- Keeping SVN fixed, look for simultaneous observations between pairs of CYGNSS Satellites
  - Criteria for simultaneity:
    - Same PRN
    - Within 30 minutes
    - Within .25 degrees of latitutude and longitude
  - Data set: first 60 days of NBRCS
    - All available PRN, incidence angles, RCG > 10
    - Don't pick up all possible pairs – need more data

Example NBRCS Matchup FM 01 with FM 05, FM 08



R^2 .95
Bias 1.2

R^2 .93
Bias 4.4

GPS Intercalibration

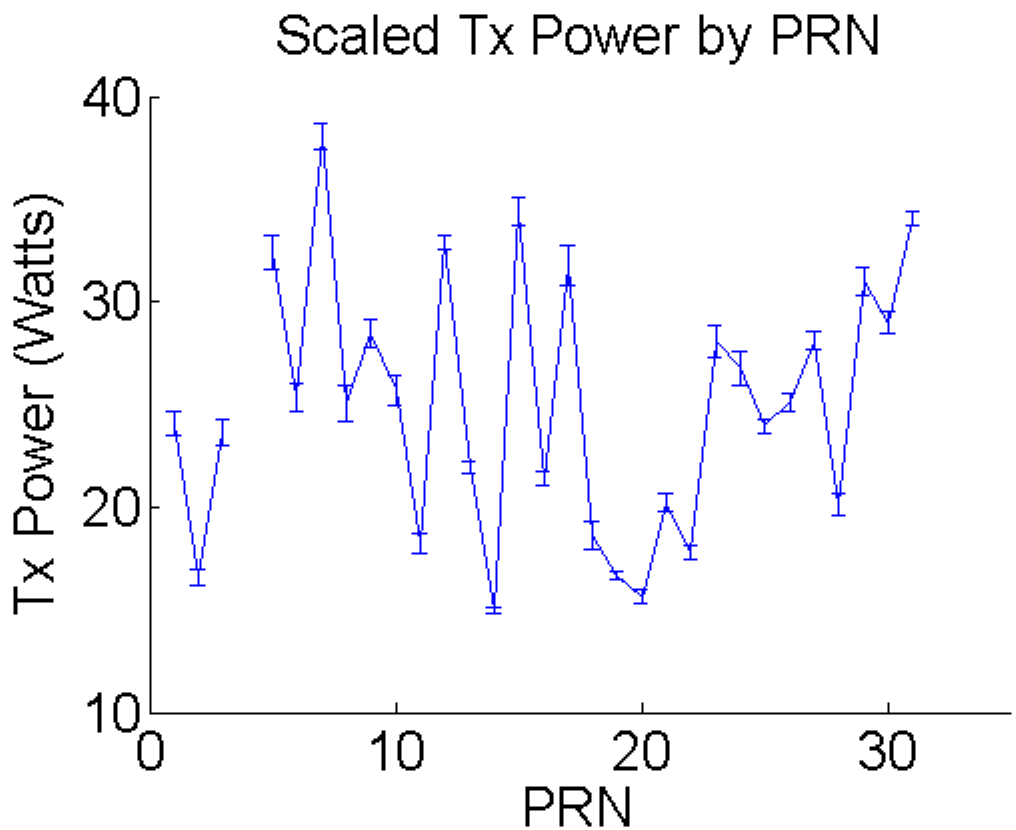
- Now look at GPS constellation with respect to NBRCS
  - Keeping CYGNSS FM fixed, look at NBRCS as a function of GPS SVN/PRN
    - Break down into ranges of conditions where NBRCS should be same from PRN to PRN: narrow range of sea states (wind speed), viewing geometry (incidence angle)

Normalization of GPS Tx Power

- To compute NBRCS, need to know Tx power by SVN
  - Not reported in the public domain (averaged power ~25 W)
  - Compute a relative power:
- For given CYGNSS satellite, look at NBRCS in narrow range of wind speeds, incidence angles
  - Based on first 40 days of data, assuming constant Tx power over period
  - Compute mean NBRCS for each PRN and normalize from mean across all PRNs in multiple wind speed, incidence angle ranges
  - Compute overall PRN specific relative power and uncertainty from the mean and stand deviation over these multiple bins

  - Wind speed bins: 5-7, 7-9, 9-11 m/s
  - Incidence angle bins: 20-25, 25-30, 30-35 degrees

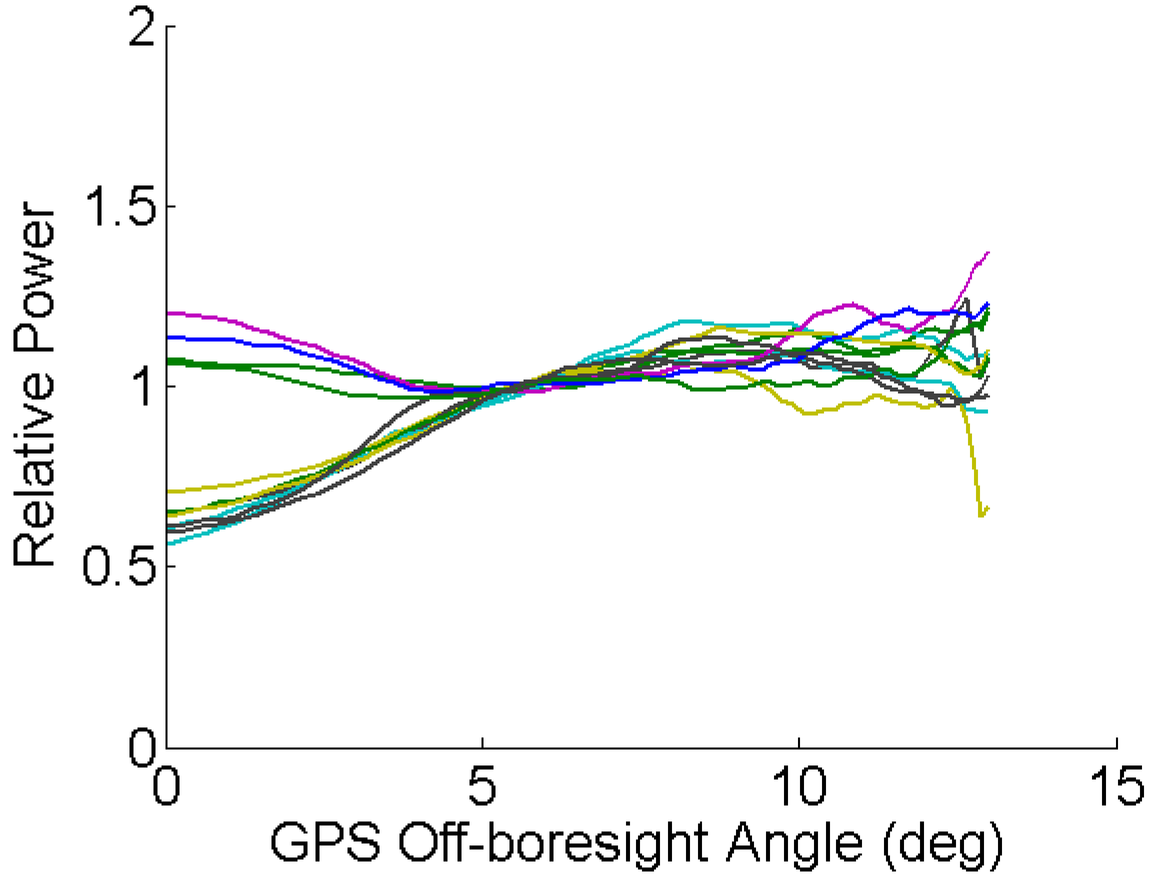
Relative Power vs. PRN Assuming Average of 25 W



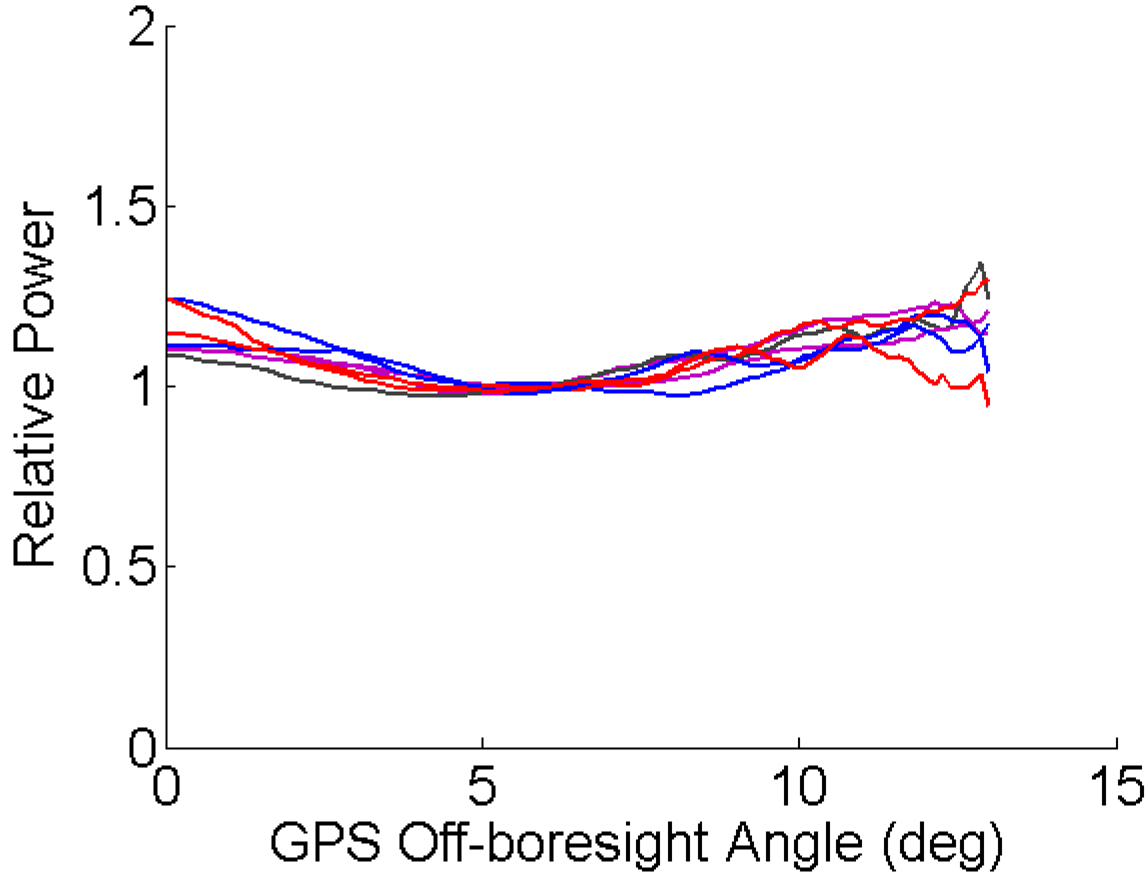
GPS Antenna Patterns

- There are published antenna patterns for two of the third GPS block, but expect variability within block and need patterns for third block
  - Address variability in same manner as Tx power: compute relative gains from CYGNSS NBRCS as function of off-boresight angle (azimuth not considered)
- Start with published GPS antenna patterns and:
  - Compute mean NBRCS for each PRN over range of off-boresight angles and wind speed bins (1 degree angle bins, same wind speed bins as above)
    - Smooth results in off-boresight angle
  - Normalize these by mean across all PRNs for each bin
  - Compute PRN specific gain scale factor as function of off-boresight angle from mean across wind speed bins
  - Scale these by Tx power scale factor from above to normalize by total power
    - This gives relative power as function of off-boresight angle with respect to power at incidence angle of 20-35 degrees = off-boresight angle of 4-6 degrees

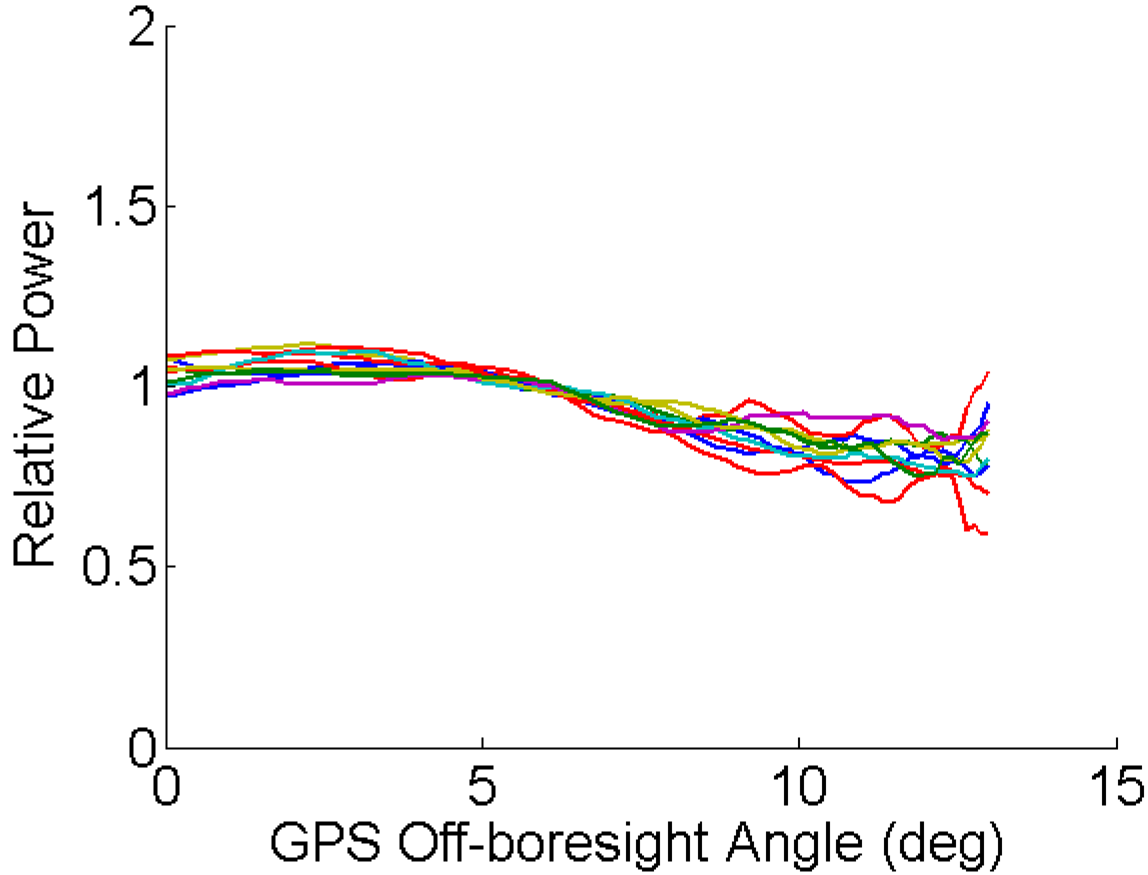
Block IIR Relative NBRCS
No Antenna Pattern Scaling



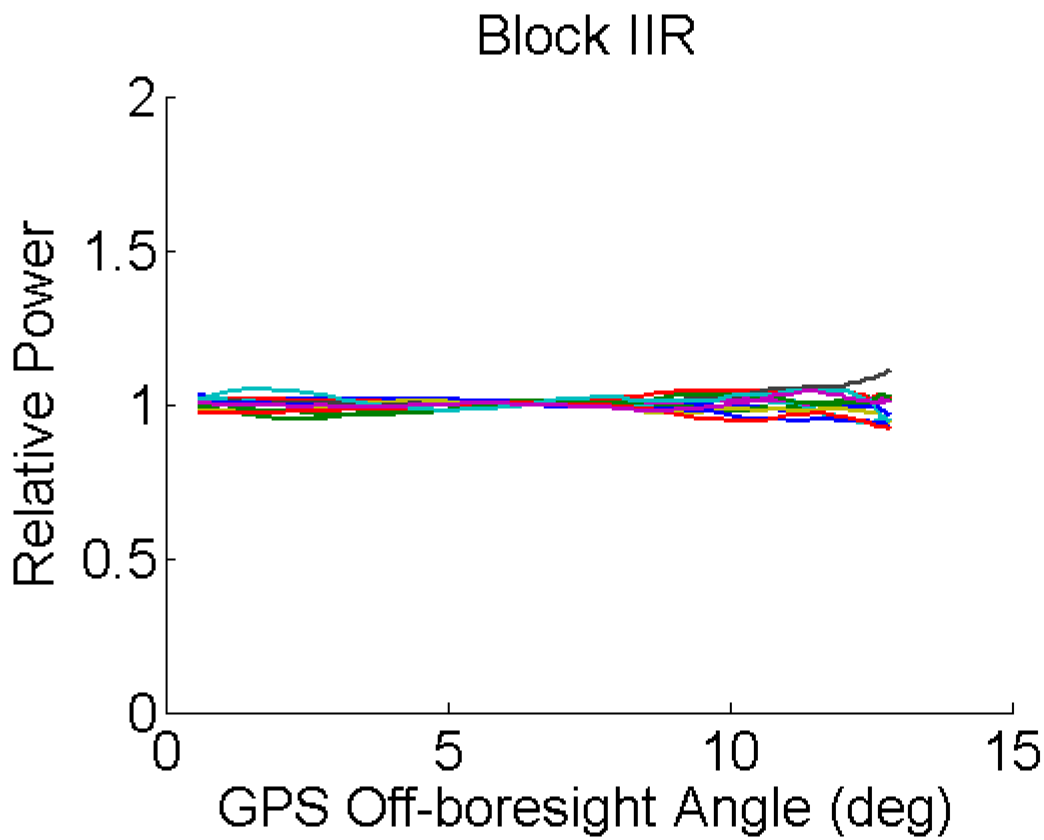
Block IIR-M Relative NBRCS No Antenna Pattern Scaling



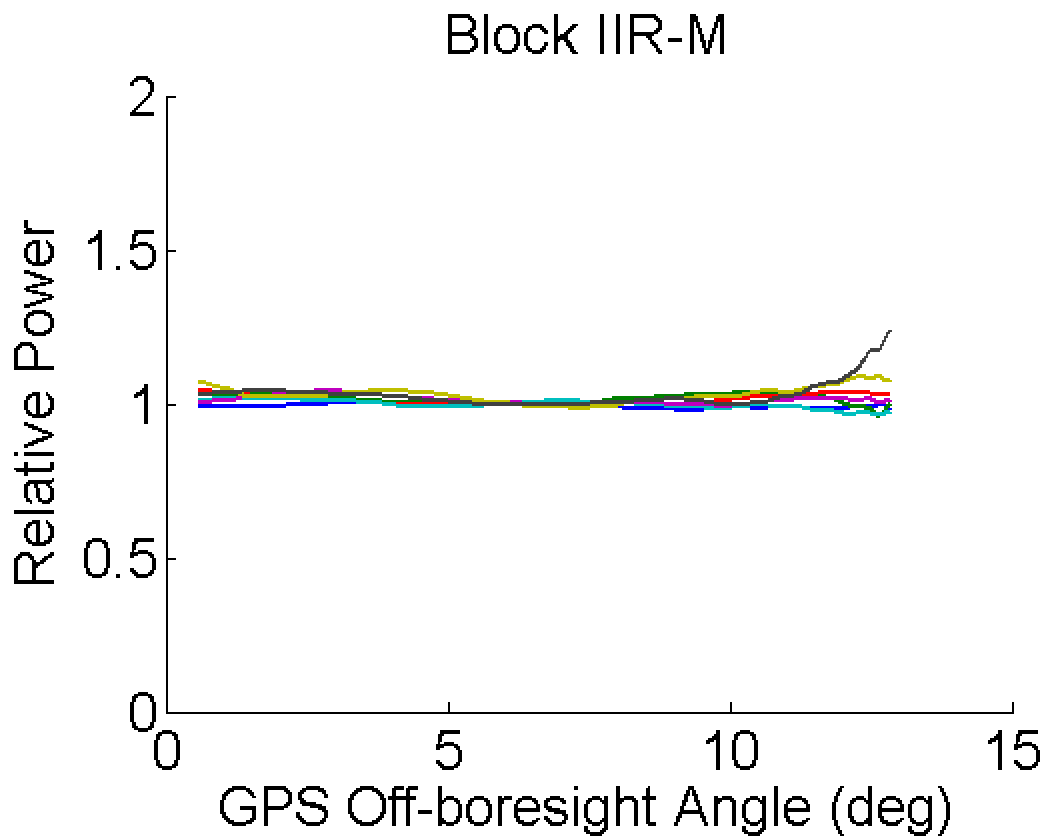
Block IIF Relative NBRCS No Antenna Pattern Scaling



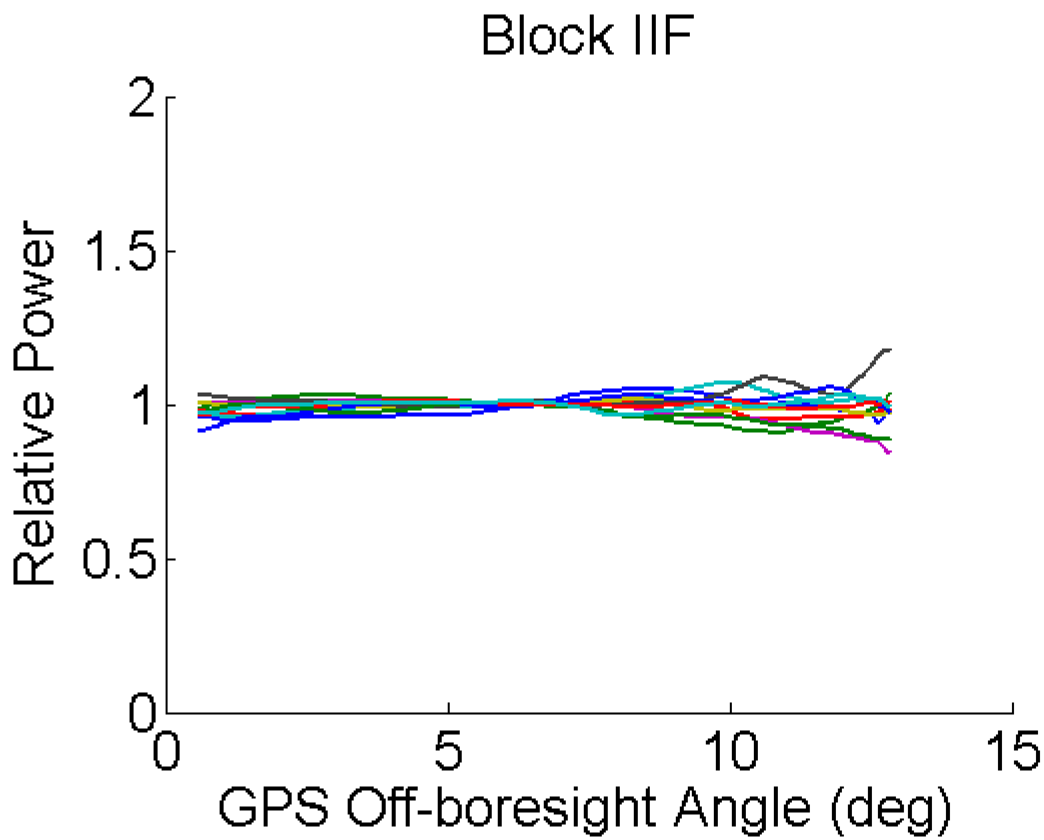
Block IIR Relative NBRCS With Antenna Pattern Scaling



Block IIR-M Relative NBRCS With Antenna Pattern Scaling



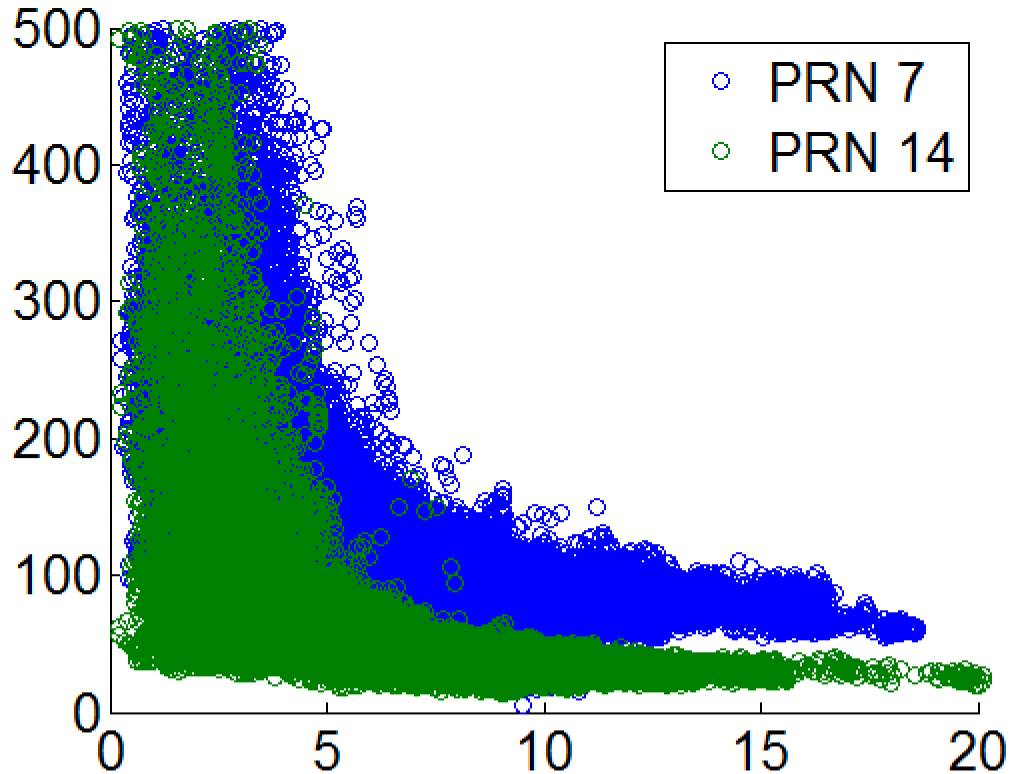
Block IIF Relative NBRCS With Antenna Pattern Scaling



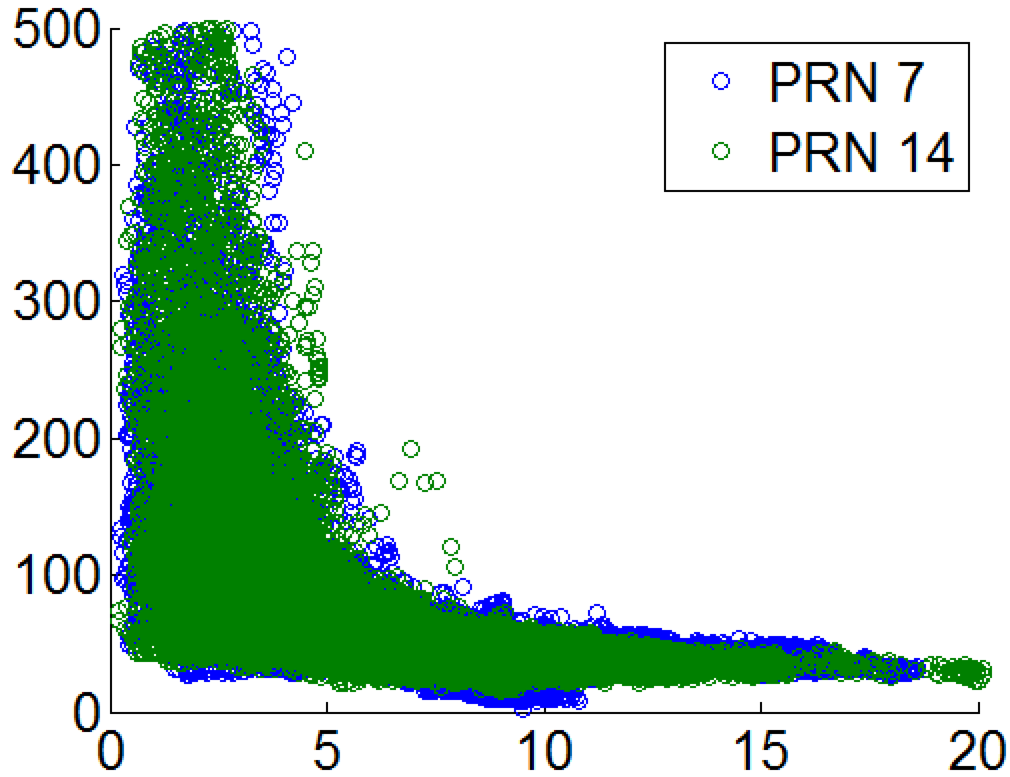
Impact of Scaling

- After scaling Tx power and antenna patterns, should have consistency from PRN to PRN in NBRCS as a function of wind speed and incidence angle
  - Example: two widest spread PRNs – 7 and 14 …

NBRCS vs. Wind Speed, No scaling Incidence Angle 25-30 degrees



NBRCS vs. Wind Speed with Scaling Incidence Angles 25-30 degrees



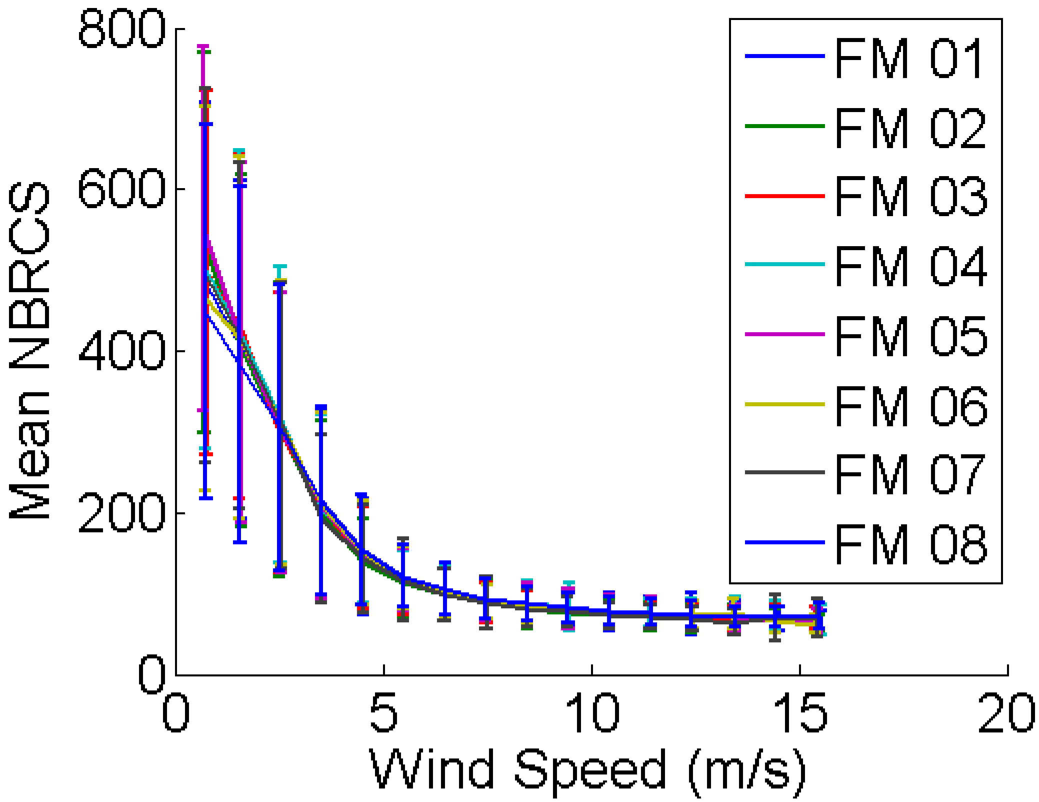
Preliminary CYGNSS Intercal Summary

- Initial CYGNSS intercalibration has:
  - Addressed to first order GPS satellite to satellite variability
    - Made assumption that Tx power did not vary during analysis and ignored azimuthal variability, yaw maneuvers
    - Adjustments were indirect (through CYGNSS reflectometer measurements) and not absolute (only relative assuming 25 W average power)
  - Assessed CYGNSS satellite to satellite variability
    - Uncertainties are large, and some biases present, but variability between CYGNSS satellites relatively minor compared to uncertainties and no outliers satellites seen
- Next steps:
  - GPS side:
    - Absolute measurements of GPS Tx power and more direct antenna pattern measurements: UM GPS power monitoring ground station (see poster from Tianlin Wang)
    - GPS yaw state "monitoring" from JPL GIPSY-OASIS software
  - CYGNSS side: find more satellite pair matchups and analyze
    - Track down and resolve sources of outliers
    - Quantify and characterize biases between all satellites in pairwise fashion

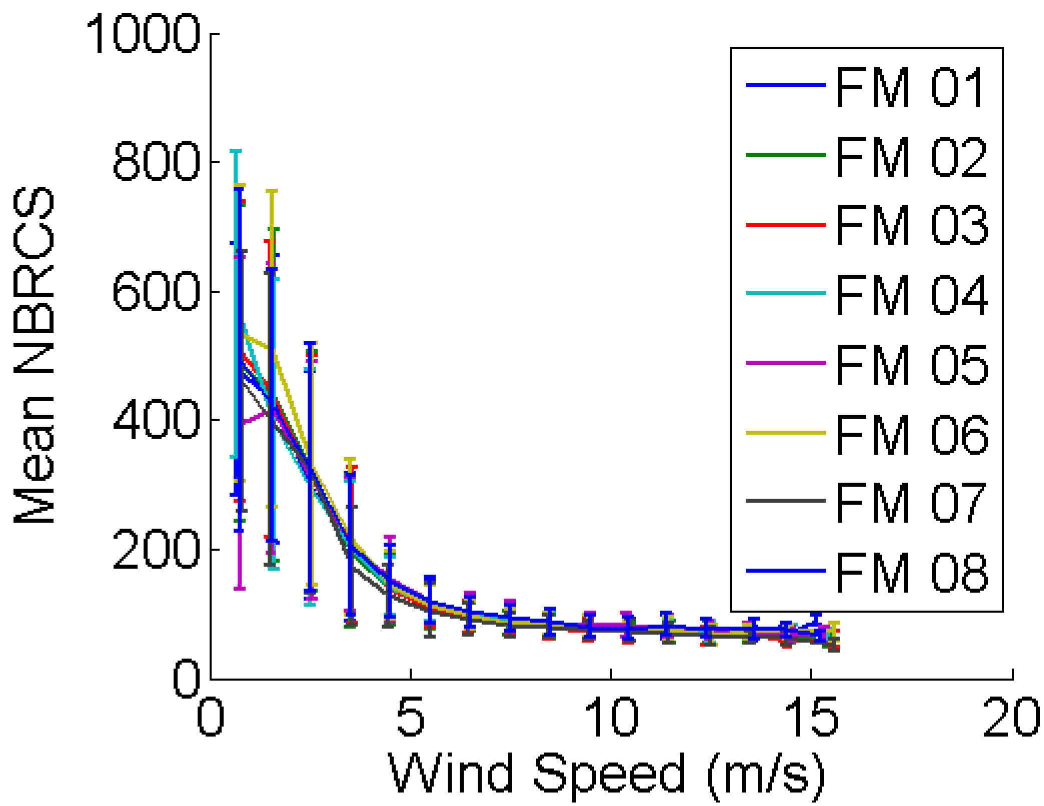
CYGNSS Intercalibration

- With GPS intercalibration addressed in a relative sense, now use updated NBRCS to assess CYGNSS satellite to satellite biases
  - As with above, keep PRN fixed and assess NBRCS as a function of wind speed and incidence angle

Mean NBRCS, Incidence Angle 28-30 degrees



Mean NBRCS, Incidence Angle 4-6 degrees



Mean NBRCS, Incidence Angle 60-52 degrees