The ESA/ESOC Analysis Centre progress and improvements

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Content

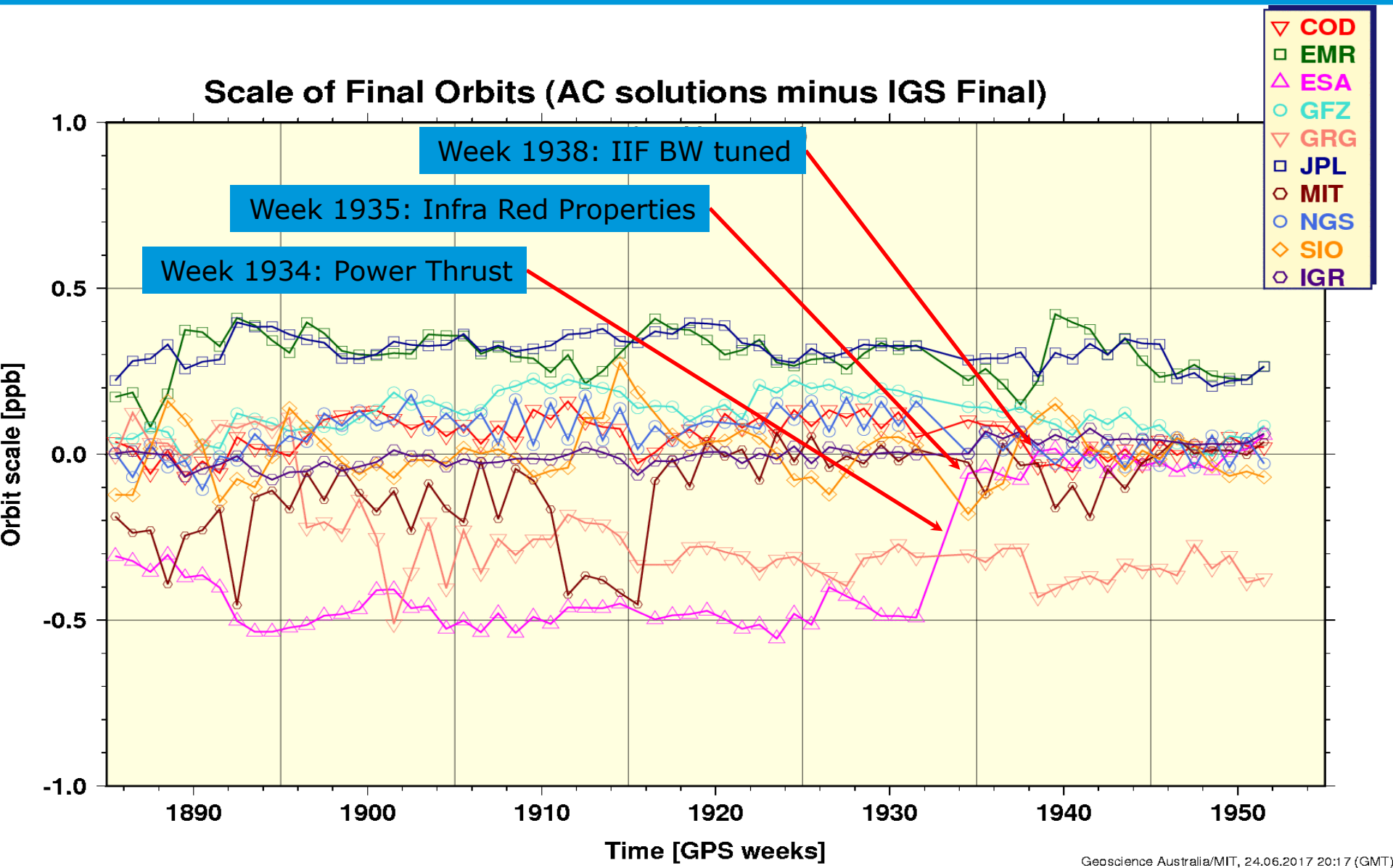
1. ESA/ESOC Changes with introduction of ITRF2014
    a. ITRF2014 and IGS14.atx
    b. Power Thrust for GPS and GLONASS
    c. Updated Infra-Red Properties for GPS IIR and GLONASS satellites
    d. Tuned GPS IIF box-wing satellite properties
2. Sub-daily ERP model investigations
    a. Long standing issue with 14 day periods in GNSS time-series
    b. Revisit of work done in 2011, which was revived in 2014
3. Preparing for the inclusion of Galileo in ESA/ESOC routine IGS products
    a. IOV (GAL-1) metadata available!
    b. FOC (GAL-2) metadata to follow
    c. Galileo results are very good

ITRF2014 and Related Changes

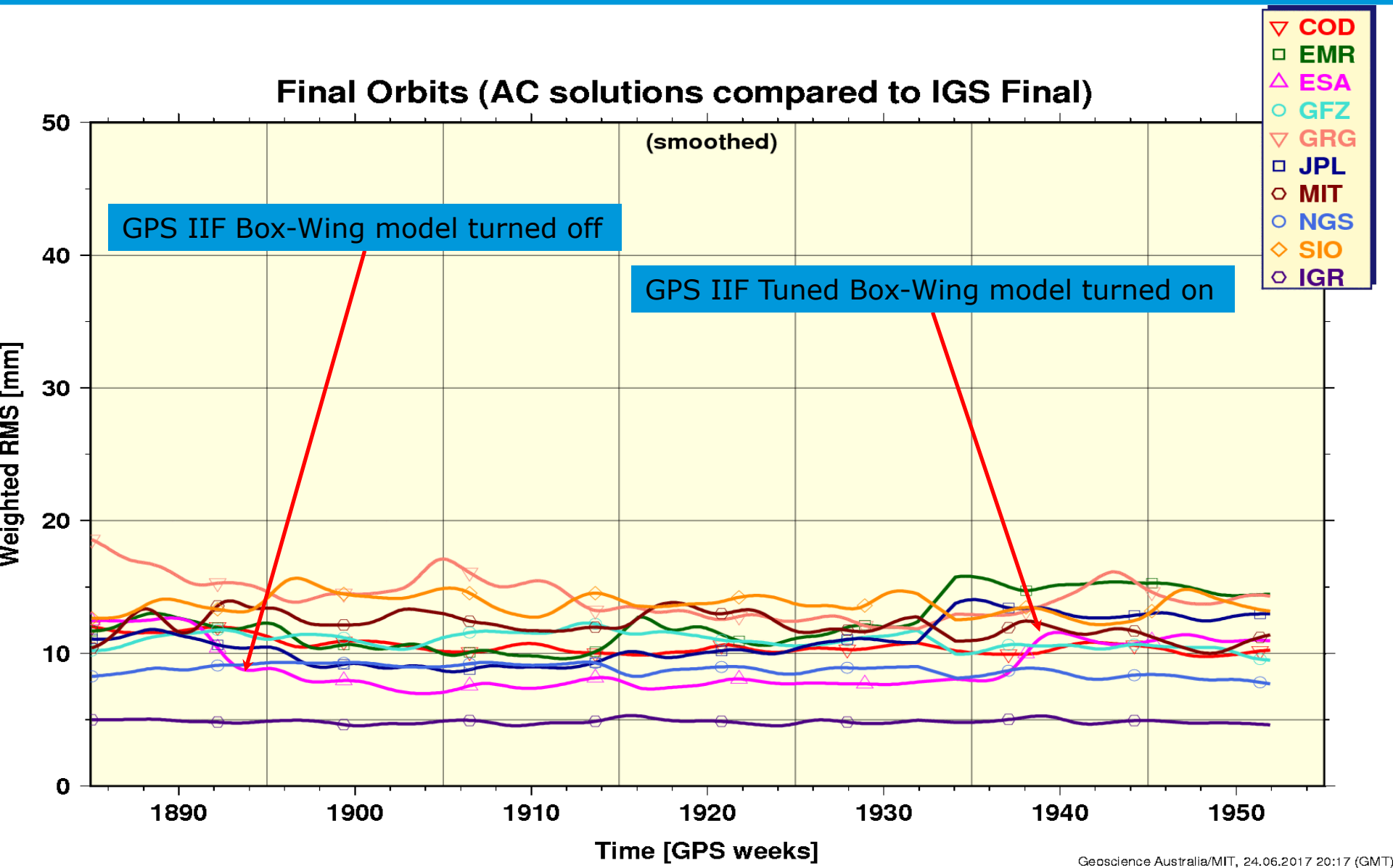
- ESA/ESOC IGS Analysis changes
  - ITRF2014 and IGS14.atx
    - Significant changes, also Z-PCO's of GPS and GLONASS
  - Introduced (finally) Power Thrust for GPS and GLONASS
  - Updated Infra-Red (IR) Properties for GPS IIR and GLONASS satellites

- Box-wing for IIF was turned of in 2016 due to giving poor results
  - Need to turn it on for scale induced by Earth radiation
  - Standard IGS values do not work very well!
    - Tuned the values, but still sub-optimal
    - Looking into "reradiation" effect

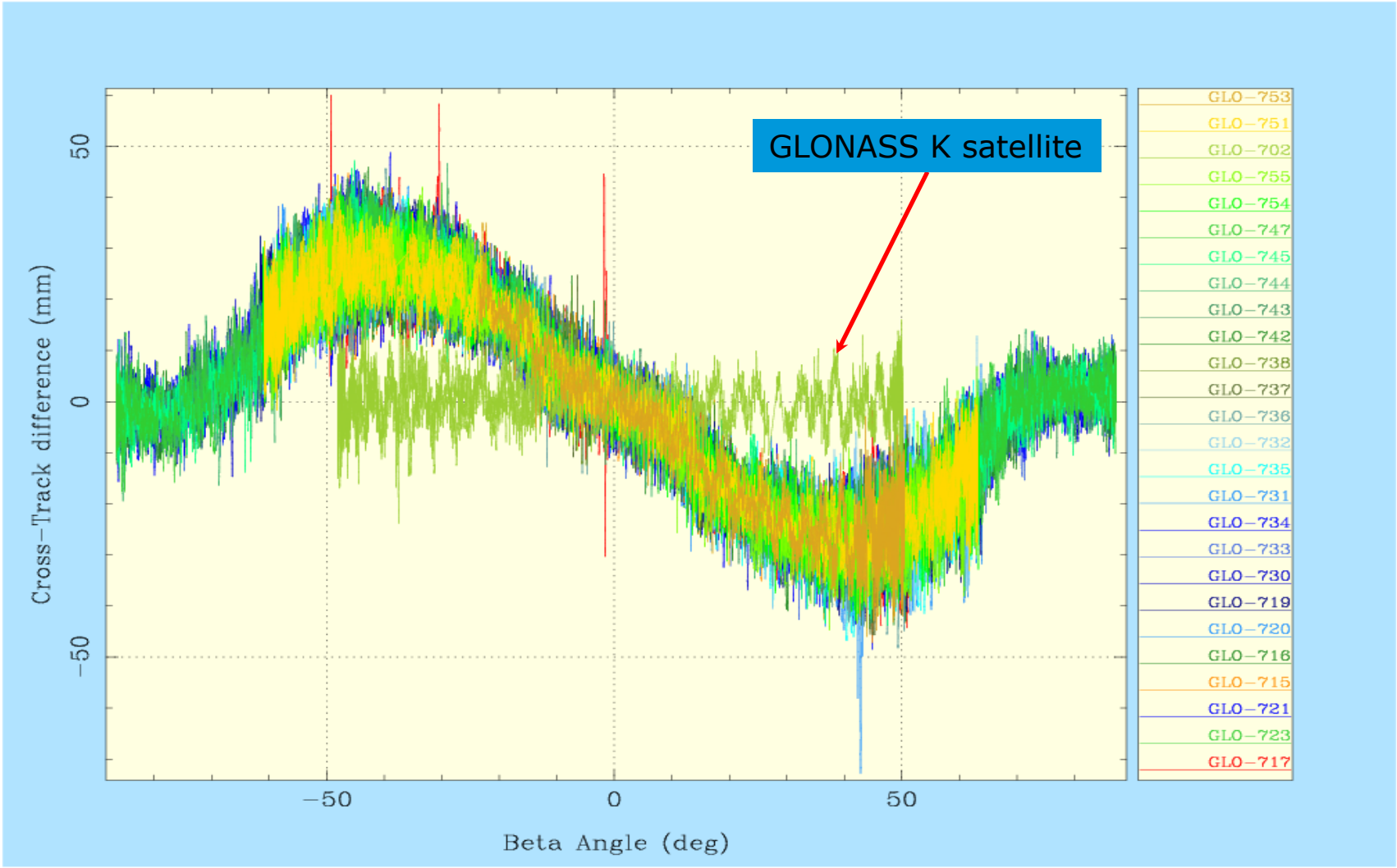
ESOC IGS Changes: Effect on Orbit Scale



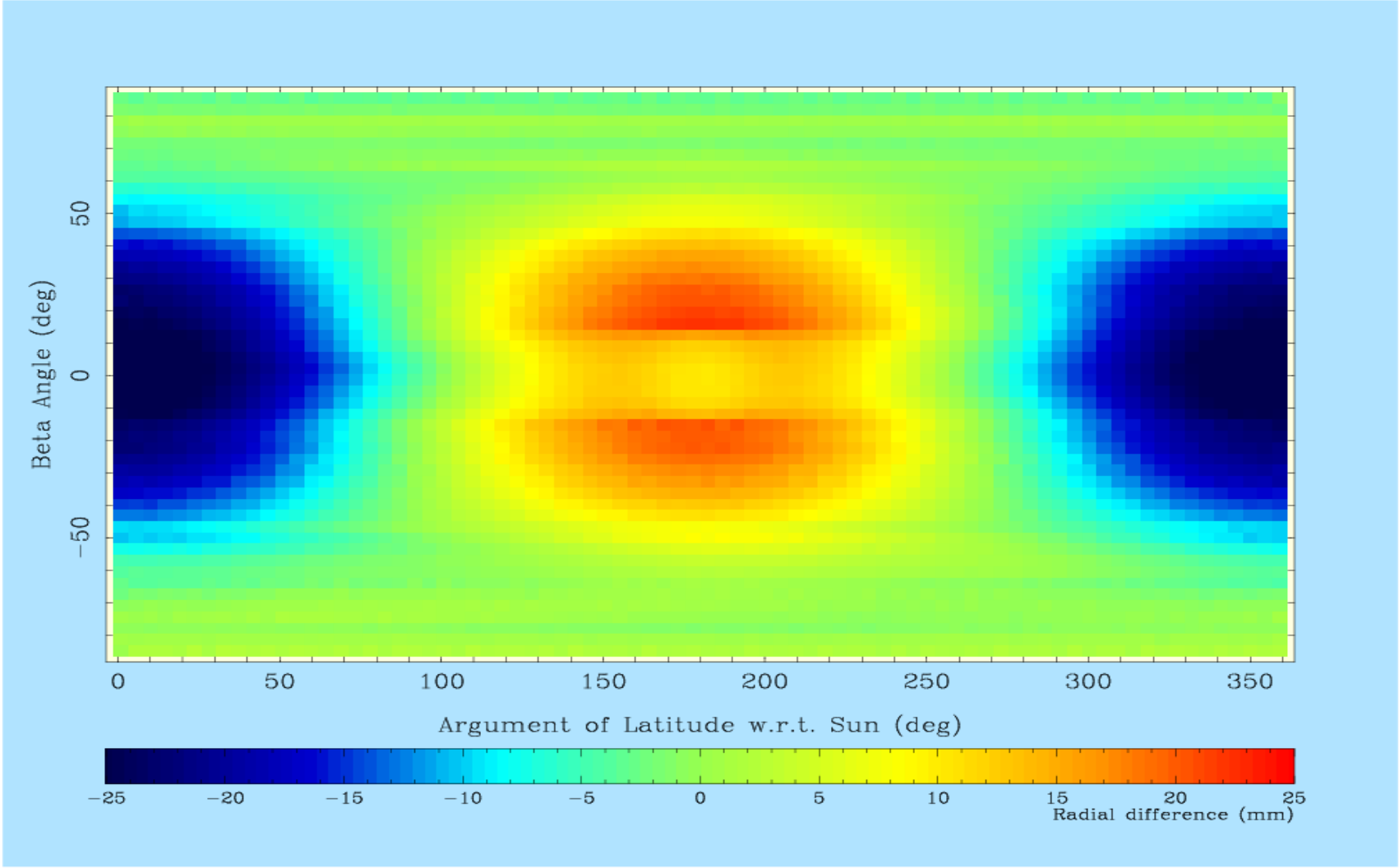
ESOC IGS Changes:
Effect on Orbit Comparison



GLONASS Re-radiaton: Cross-Track Effect



GLONASS Re-radiaton: Radial Effect



Re-radiation Effect

- Rather surprising results when using re-radiation
  - Largest differences found for GLONASS!
  - GPS <4mm, GLONASS 20mm for cross-track RMS differences
- Initially reason unclear but then found:
  - For GLONASS IGS Box-wing values for +Z and –Z different
    - GPS values are identical for +Z and –Z
  - Solar Radiation only shines on +X, +Z and –Z
    - Difference between Z-sides causes a significant force!
- Very unlikely that the Z-sides are the same
  - +Z-side has the GNSS antenna pointing towards the Earth
  - -Z-side is certainly very different!

We are probably making significant errors in GPS!

Sub-daily ERP model investigations
A bit of history…..

- Sub-daily ERP model investigations initially done in 2011
  - Used different models: IERS, GOT4.7, TPXO7.1, and Gipson (2010a.hfeop_v3_cor6_bakcon)
- Renewed interest after hearing Gipson presentation in 2014 at UAW (after IGS workshop in Pasadena)
  - Despite adding 4 more years of data model is not changing anymore. This is what VLBI gives us
  - Agreed with Gipson to (re)test his model
  - Took until 2016 to re-establish contact, testing in 2017
  - Model: orthow_2016b_withlibra
- Other models also considered
  - Bonn models (Artz) VLBI, and VLBI&GPS model
  - Vienna model planned, but so far no source code obtained

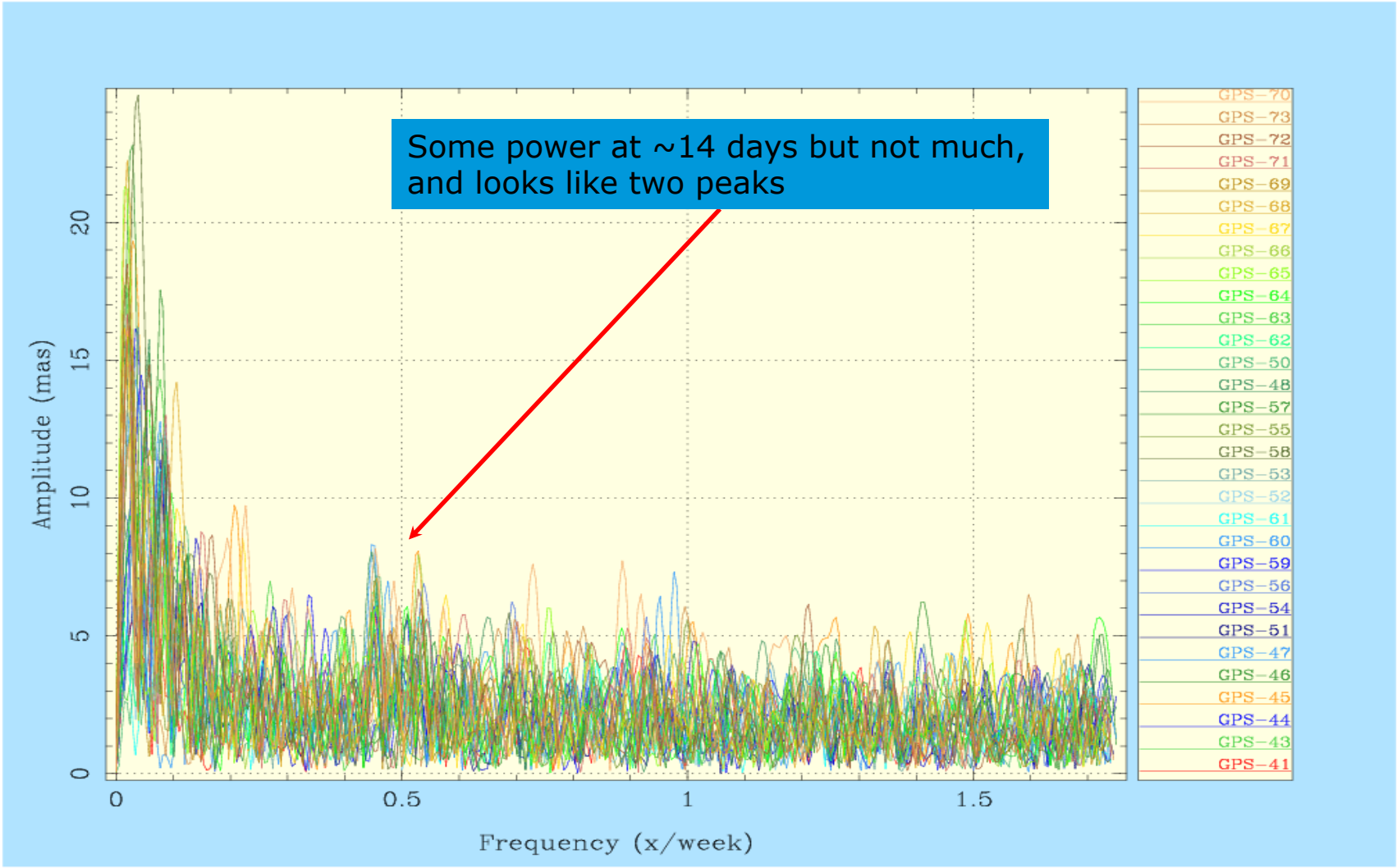
Sub-daily ERP model investigations
Test set-up

- Boundary conditions:
  - To see the effect clearly at least 1 year of data needed
  - For station coordinates probably even longer period is needed
  - Testing should be quick in order to keep it interesting and stay motivated, ideally "overnight"
- Selected setup:
  - Use ESA/ESOC IGS Final processing set-up
  - But limit tracking station network to 60 stations
  - Do the preprocessing only once so that all test solutions use exactly the same data
  - Use GPS, GLONASS ***and Galileo*** as the near 12 hour periods of GPS may be an issue. The different orbit constellations should also help to separate real model effects from artificial GNSS effects

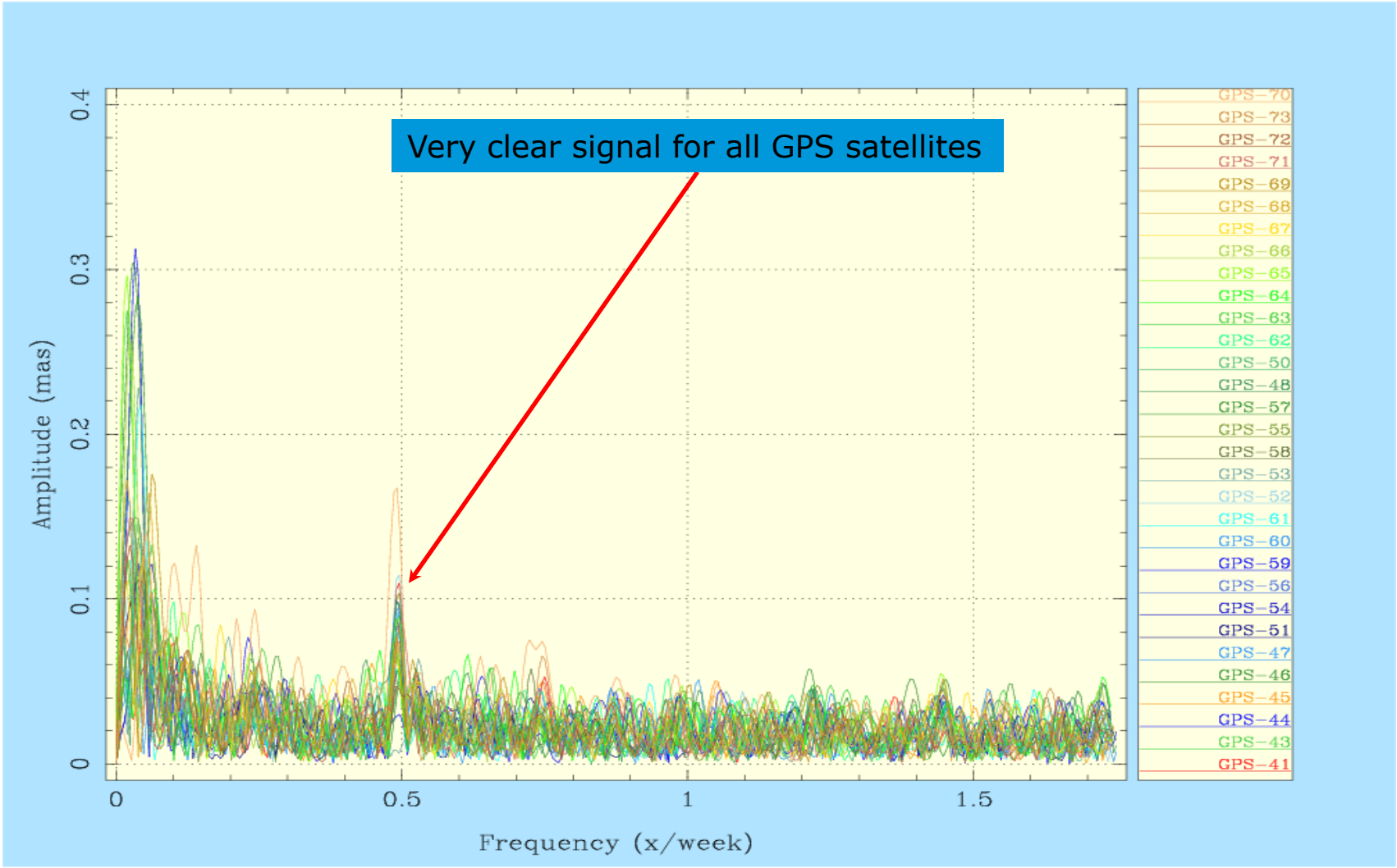
Sub-daily ERP model evaluations

- Look at orbit overlaps:
  - Radial, along-, and cross-track
    - Some signals cross-track but not very clear
  - Look at overlap of the Kepler elements
    - Very clear signal in right ascension of the ascending node (RAAN)
- Look at ERP differences to IERS pole series
  - Some signals in the pole rates and LOD
- Look at repeatability of the station coordinates
  - Seems 60 stations may be too limited
  - And/or one year timeframe to little to separate signal from other station related effects

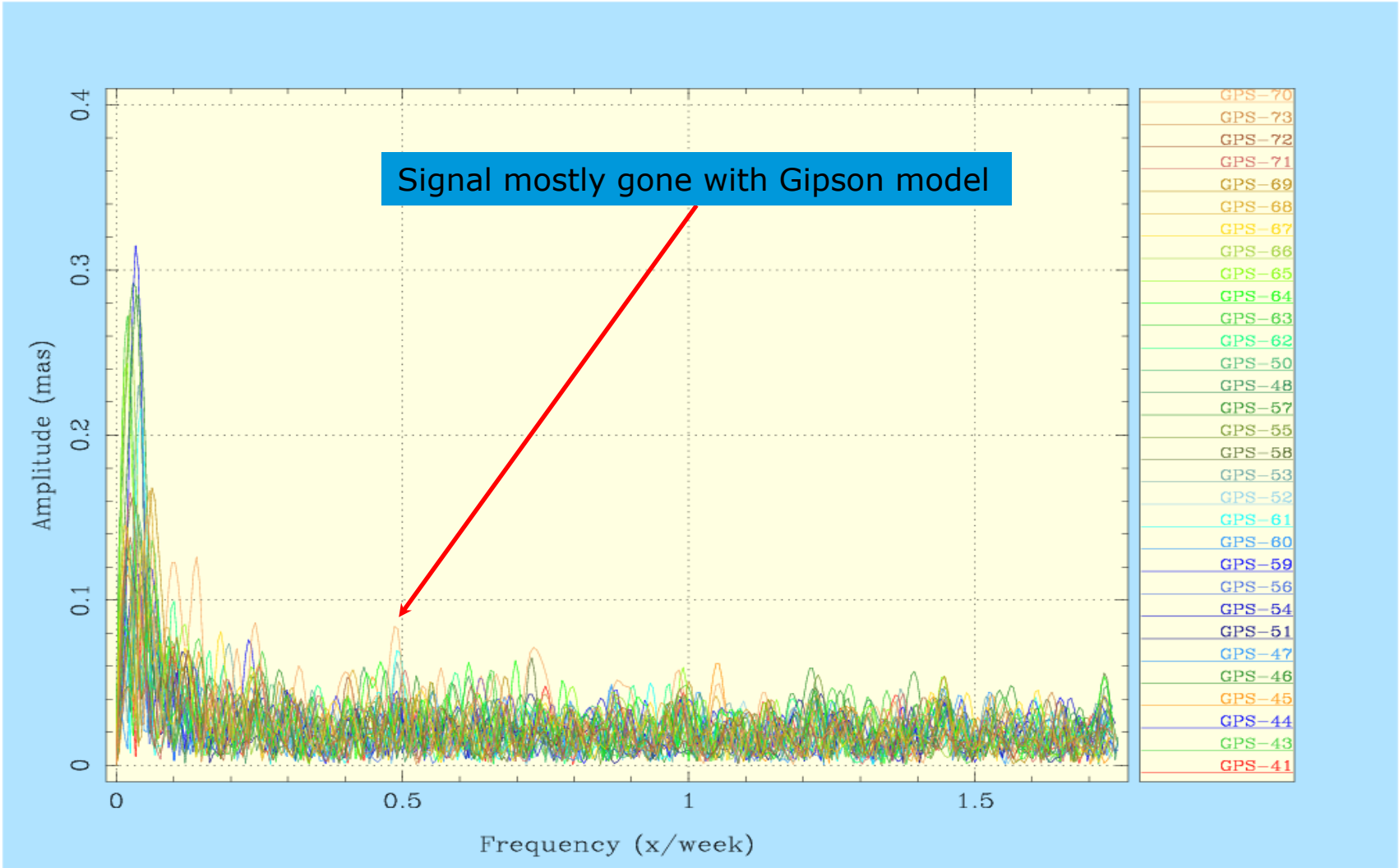
GPS Amplitude Spectrum IERS Model: Cross-track orbit overlaps



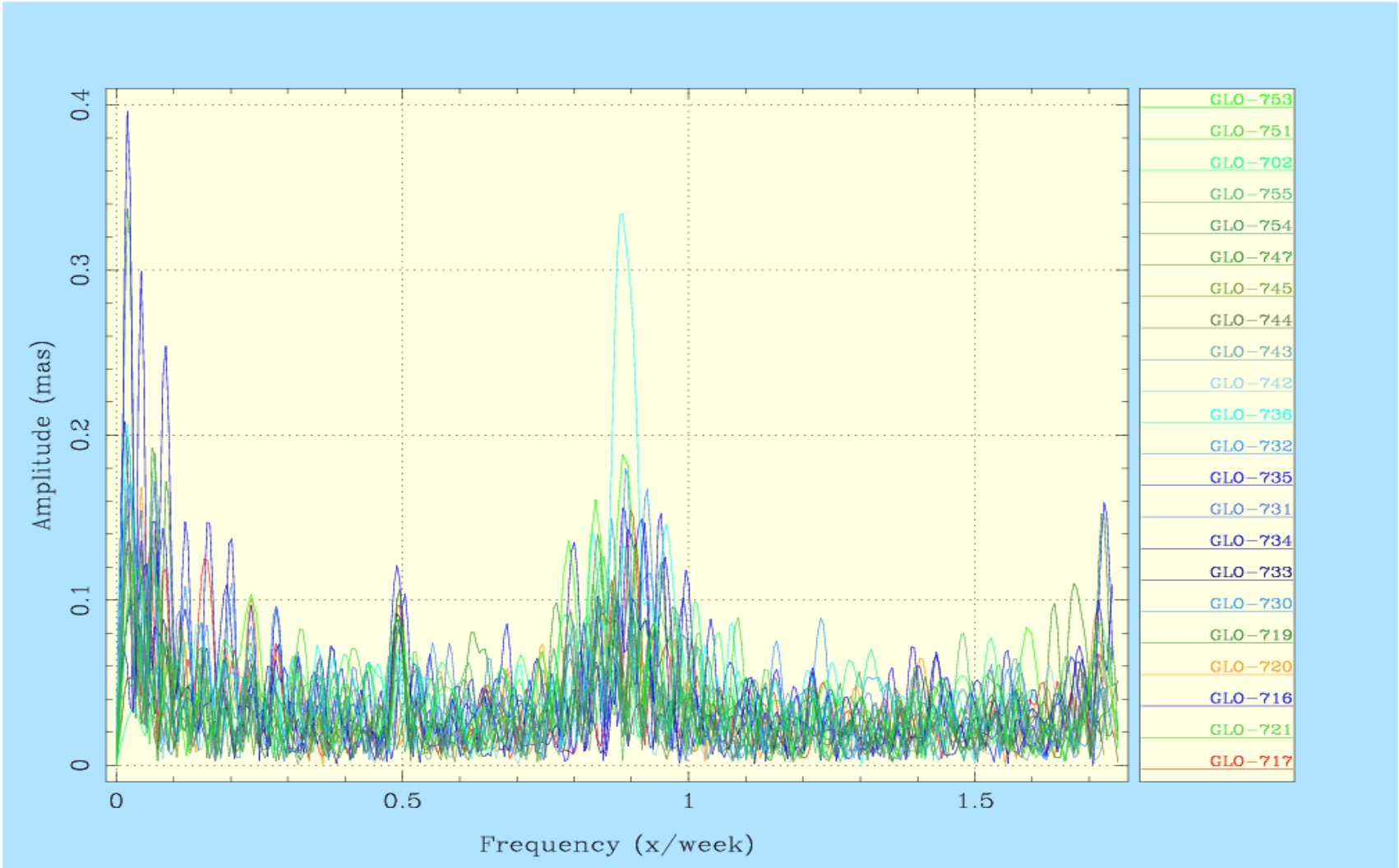
GPS Amplitude Spectrum IERS Model: Right Ascension of the Ascending Node



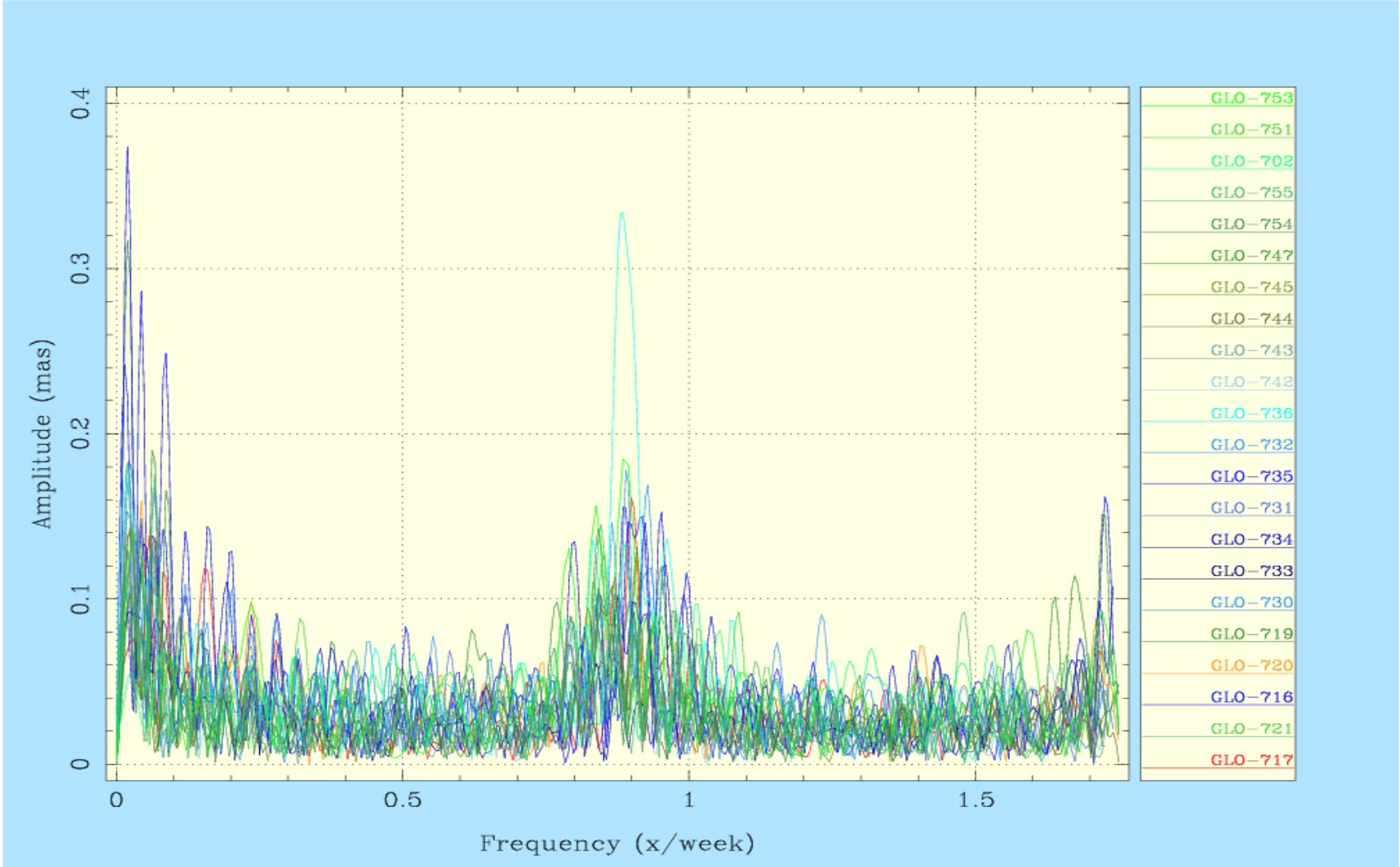
RAAN Amplitude Spectrum for GPS: Gipson model



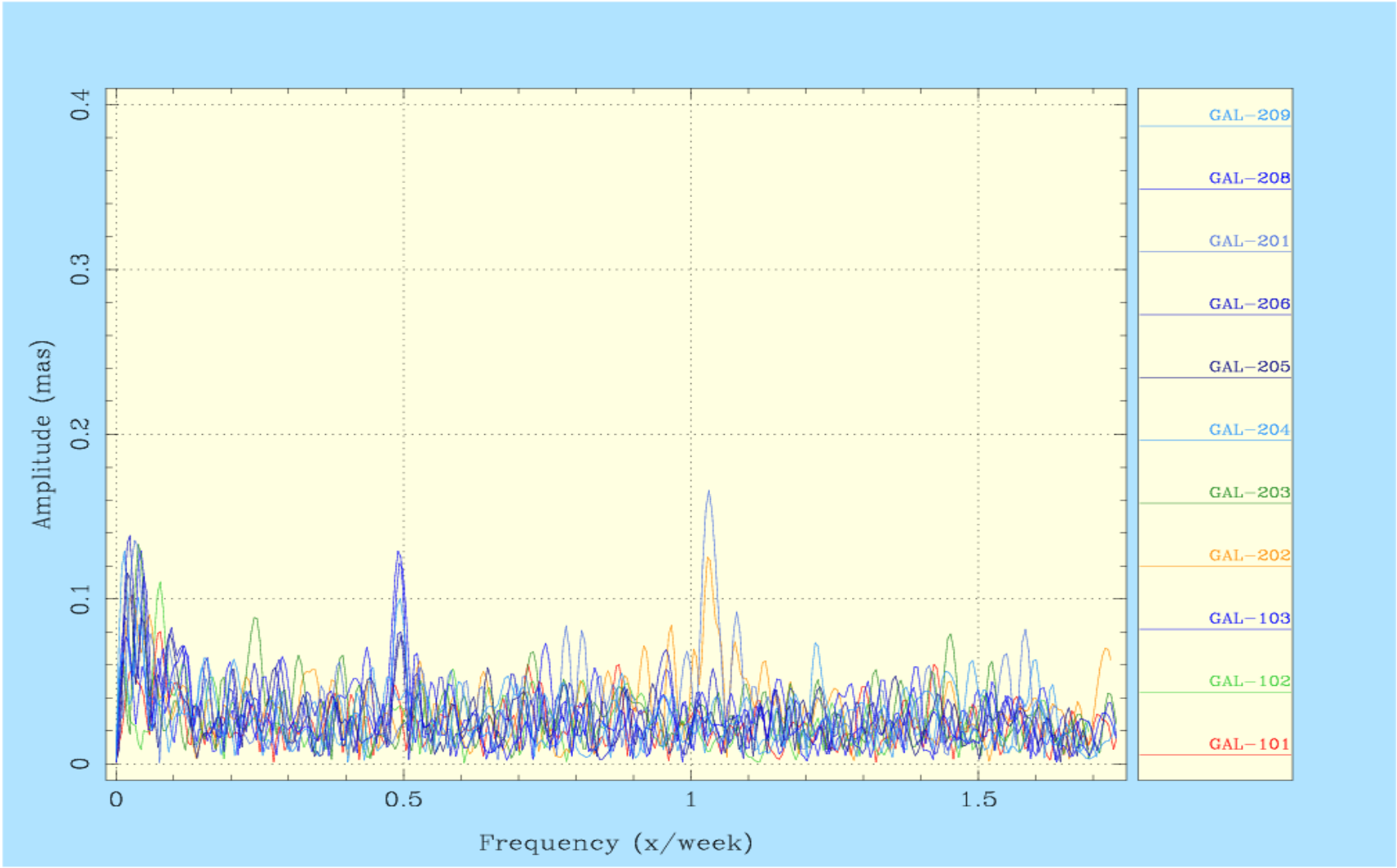
RAAN Amplitude Spectrum for GLONASS: IERS model



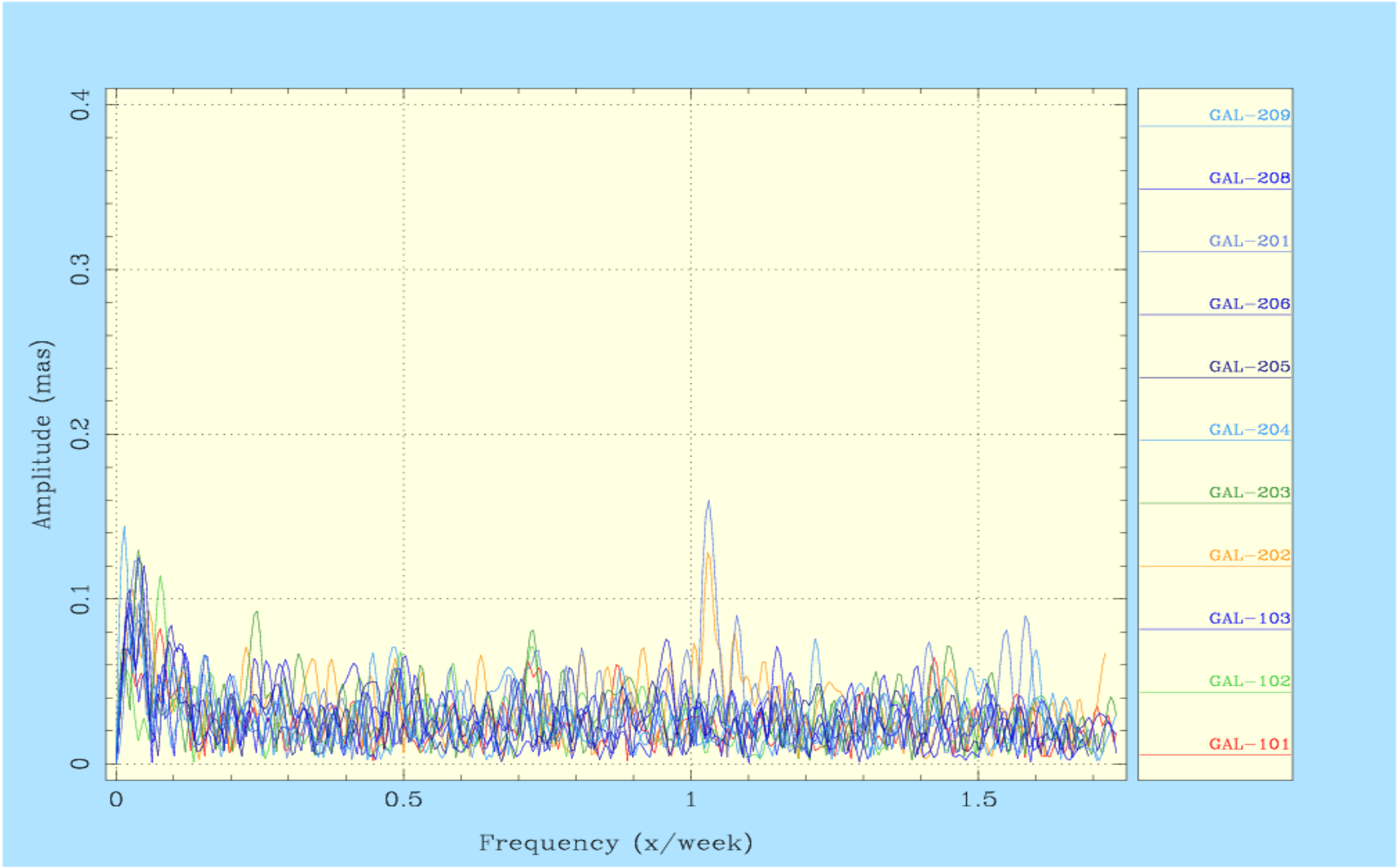
RAAN Amplitude Spectrum for GLONASS: Gipson model



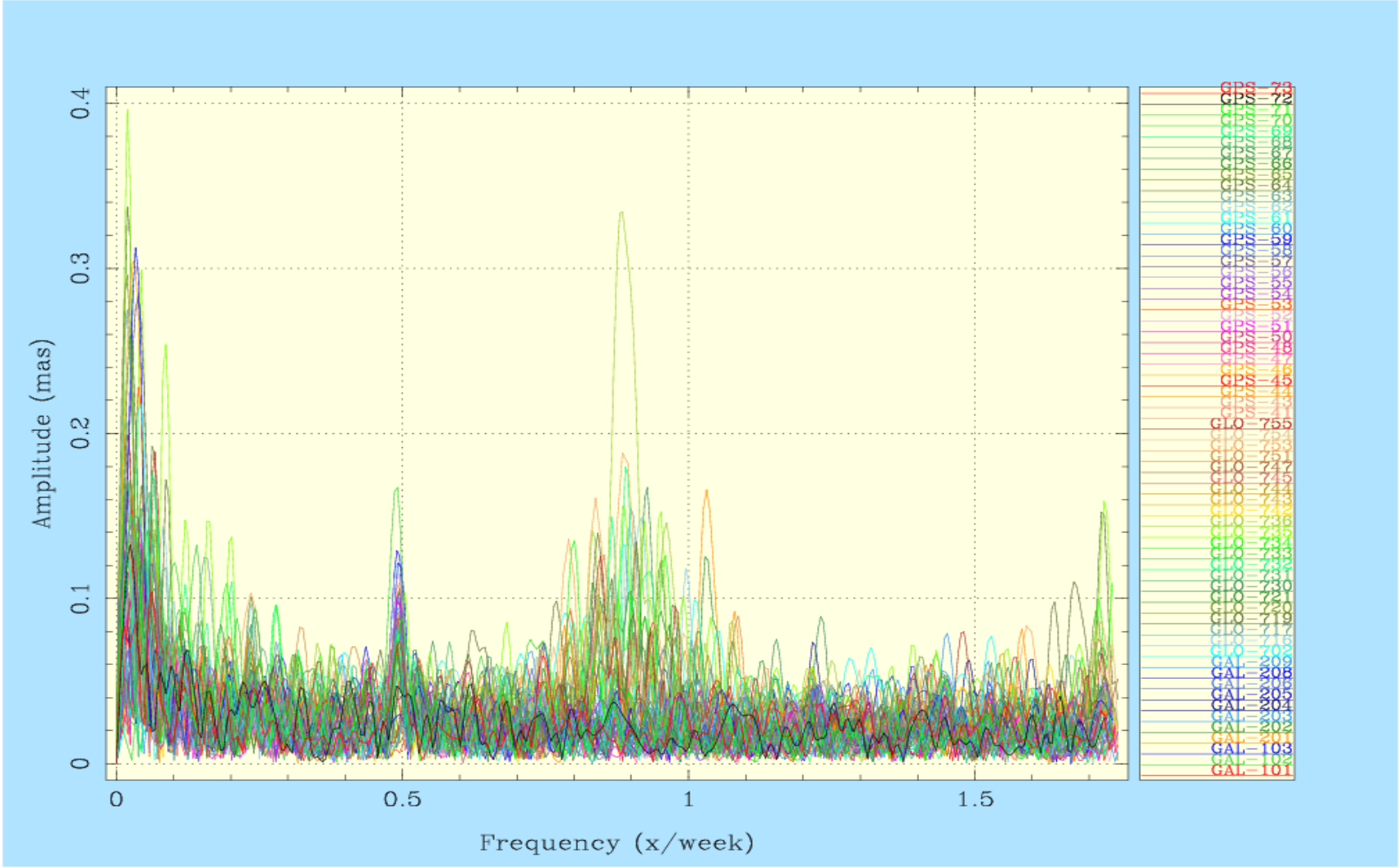
RAAN Amplitude Spectrum for Galileo: IERS model



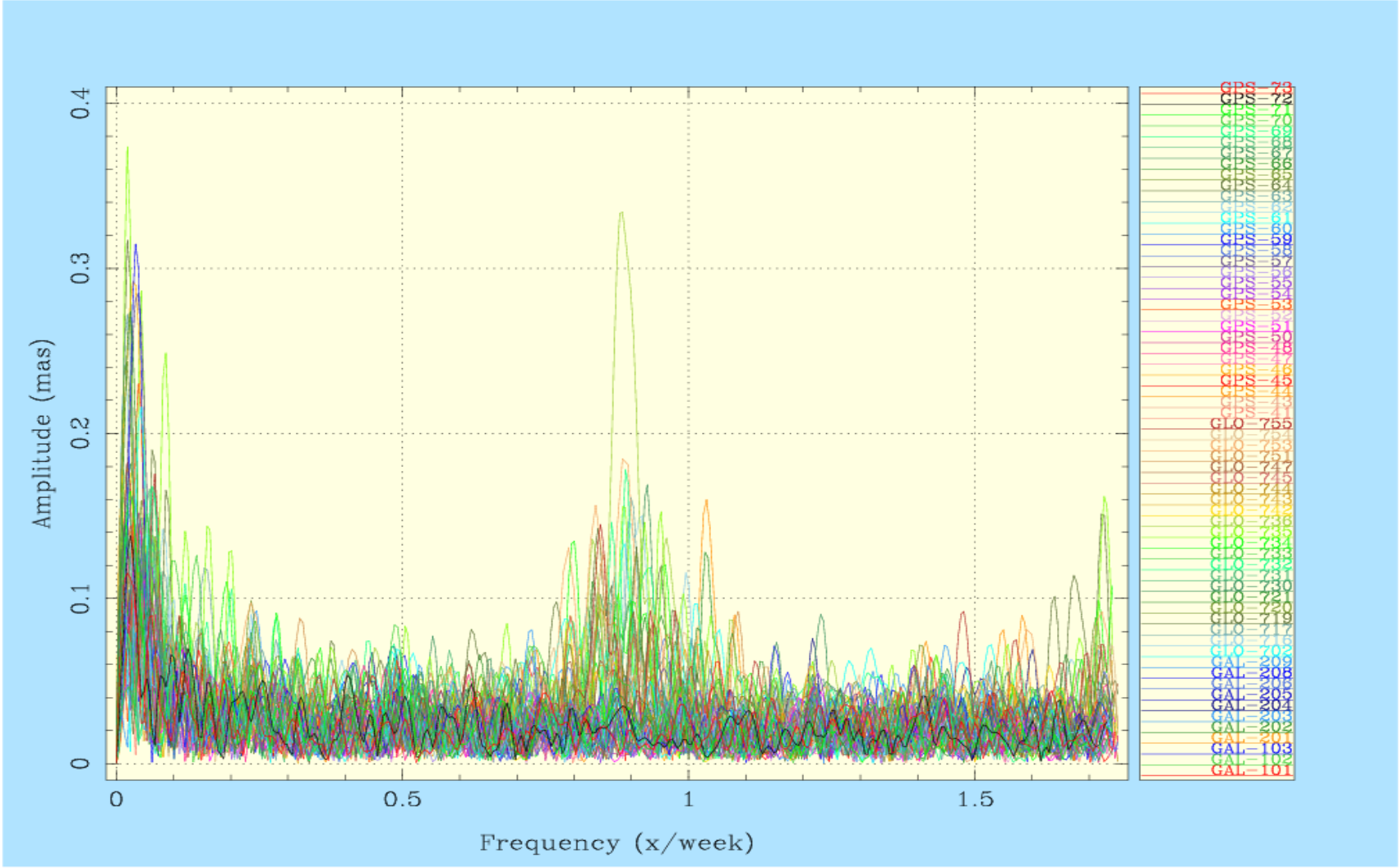
RAAN Amplitude Spectrum for Galileo: Gipson model



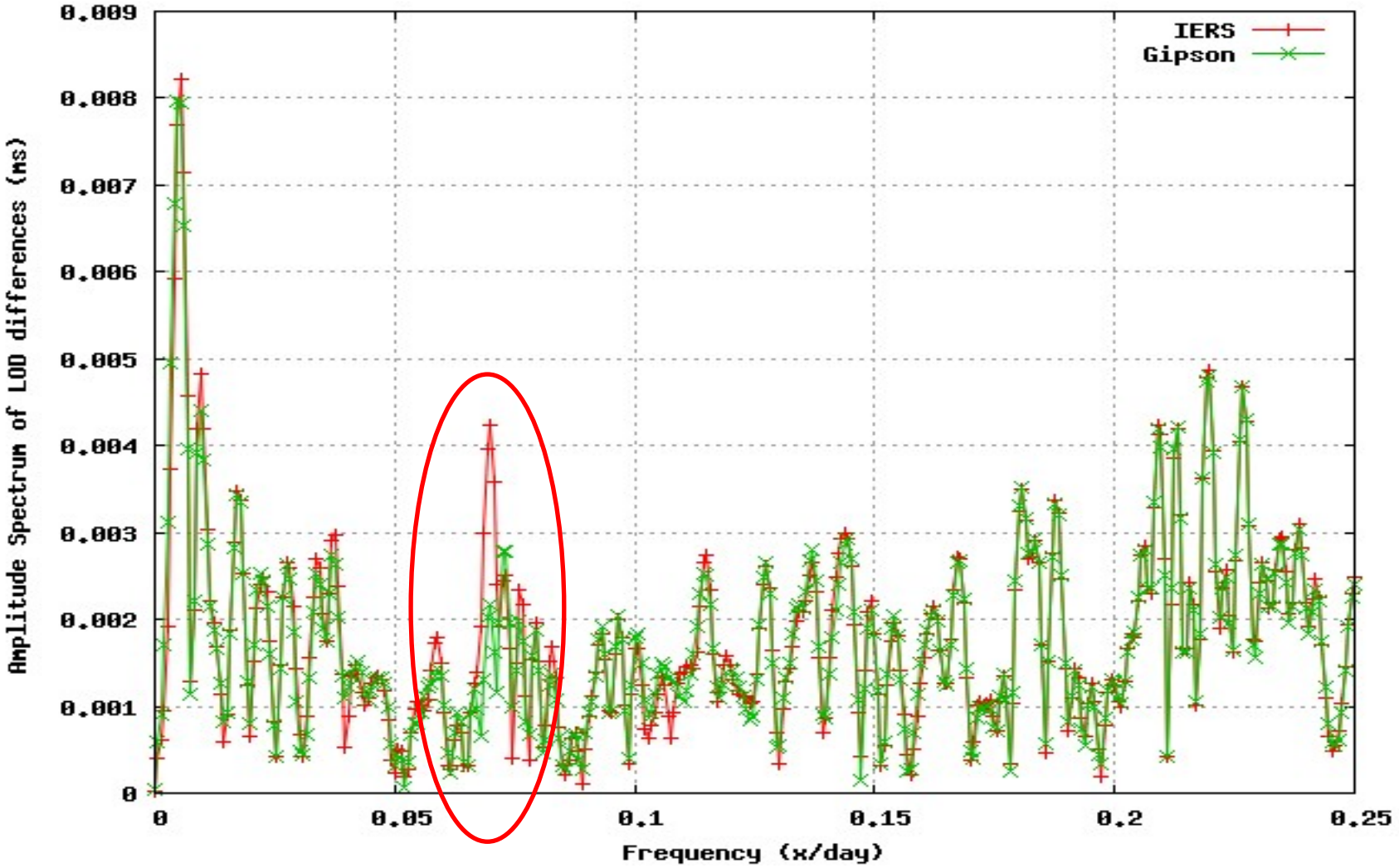
RAAN Amplitude Spectrum for ALL: IERS model



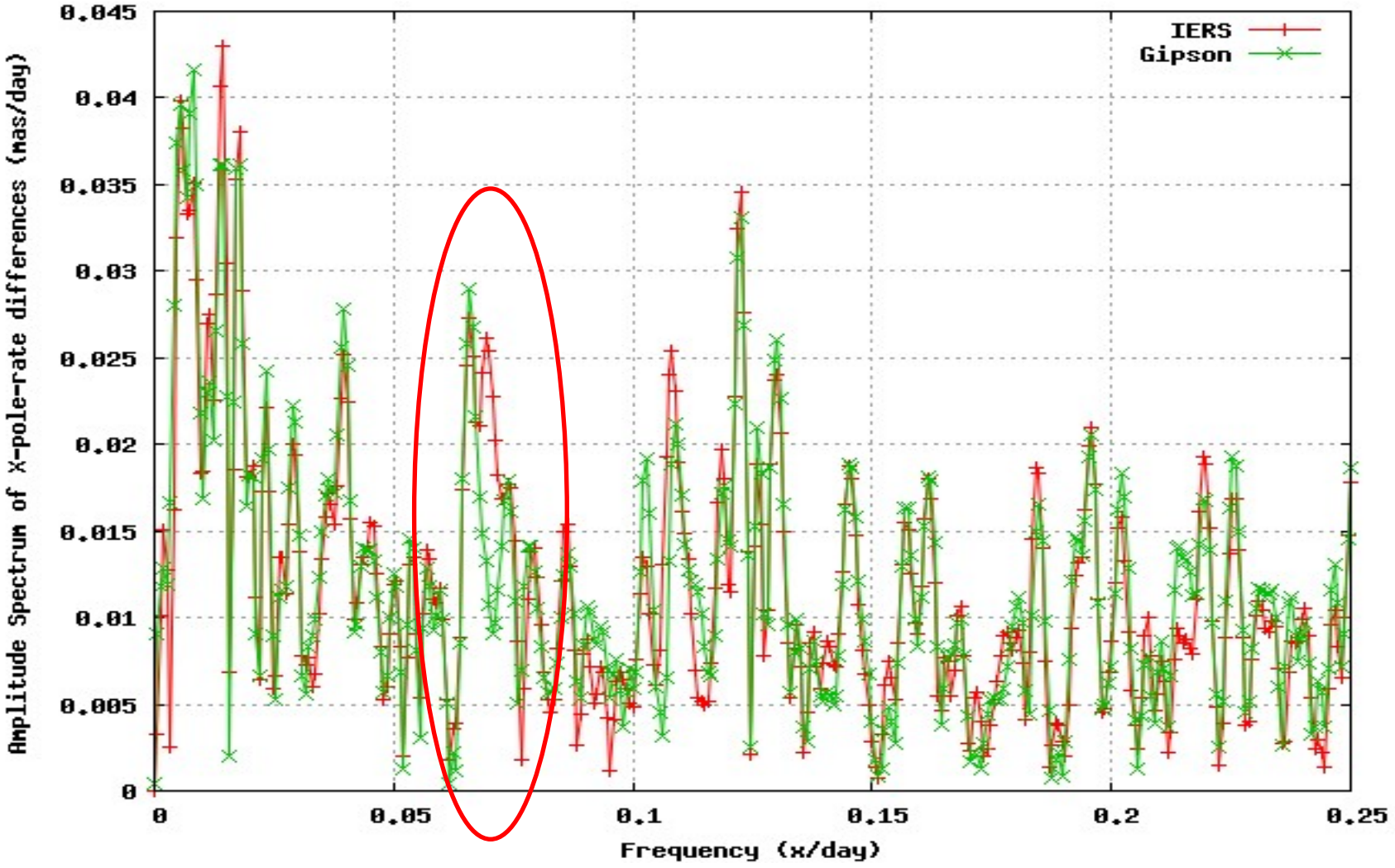
RAAN Amplitude Spectrum for ALL: Gipson model



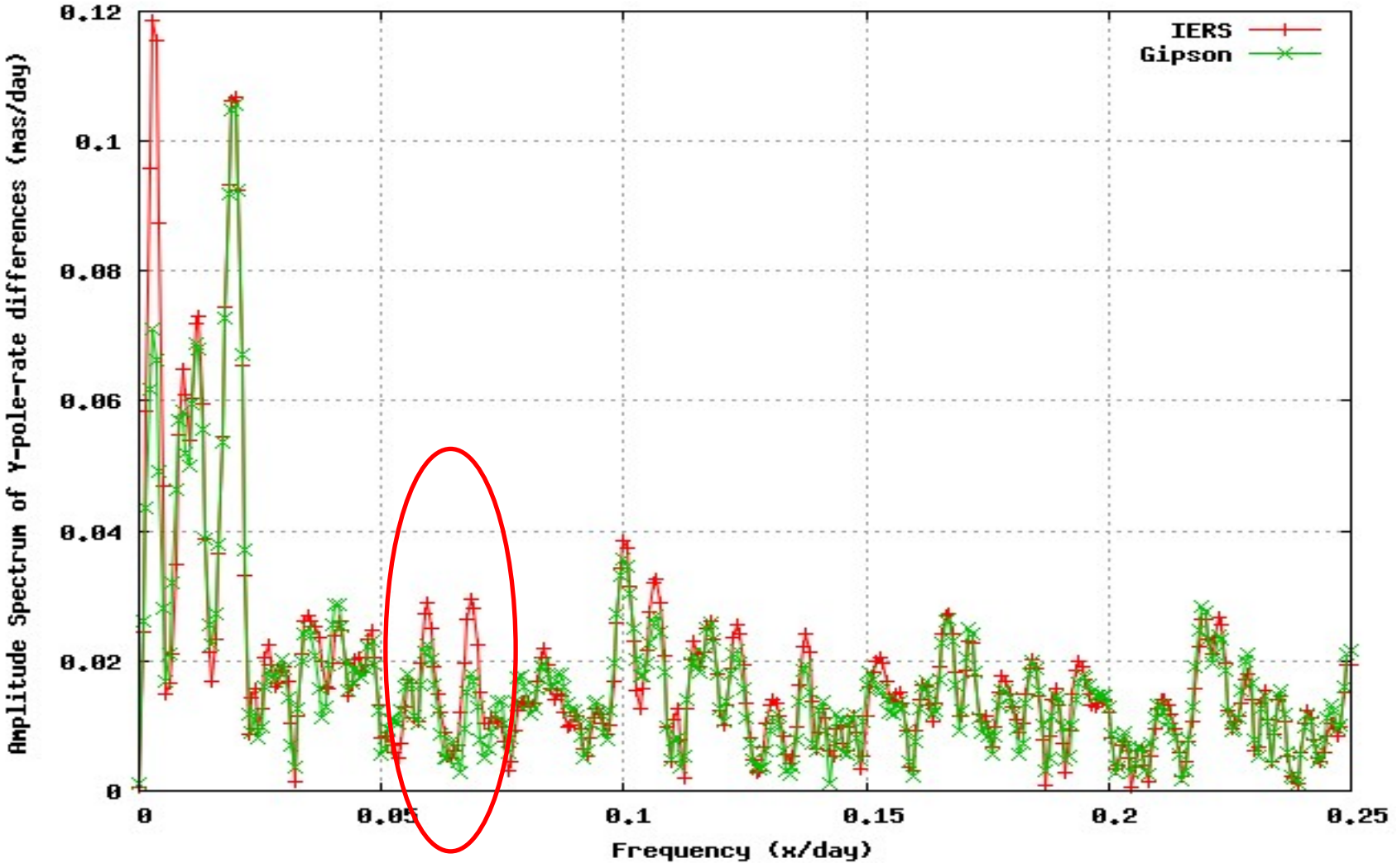
Amplitude Spectra: LOD



Amplitude Spectra: X-pole rate



Amplitude Spectra: Y-pole rate



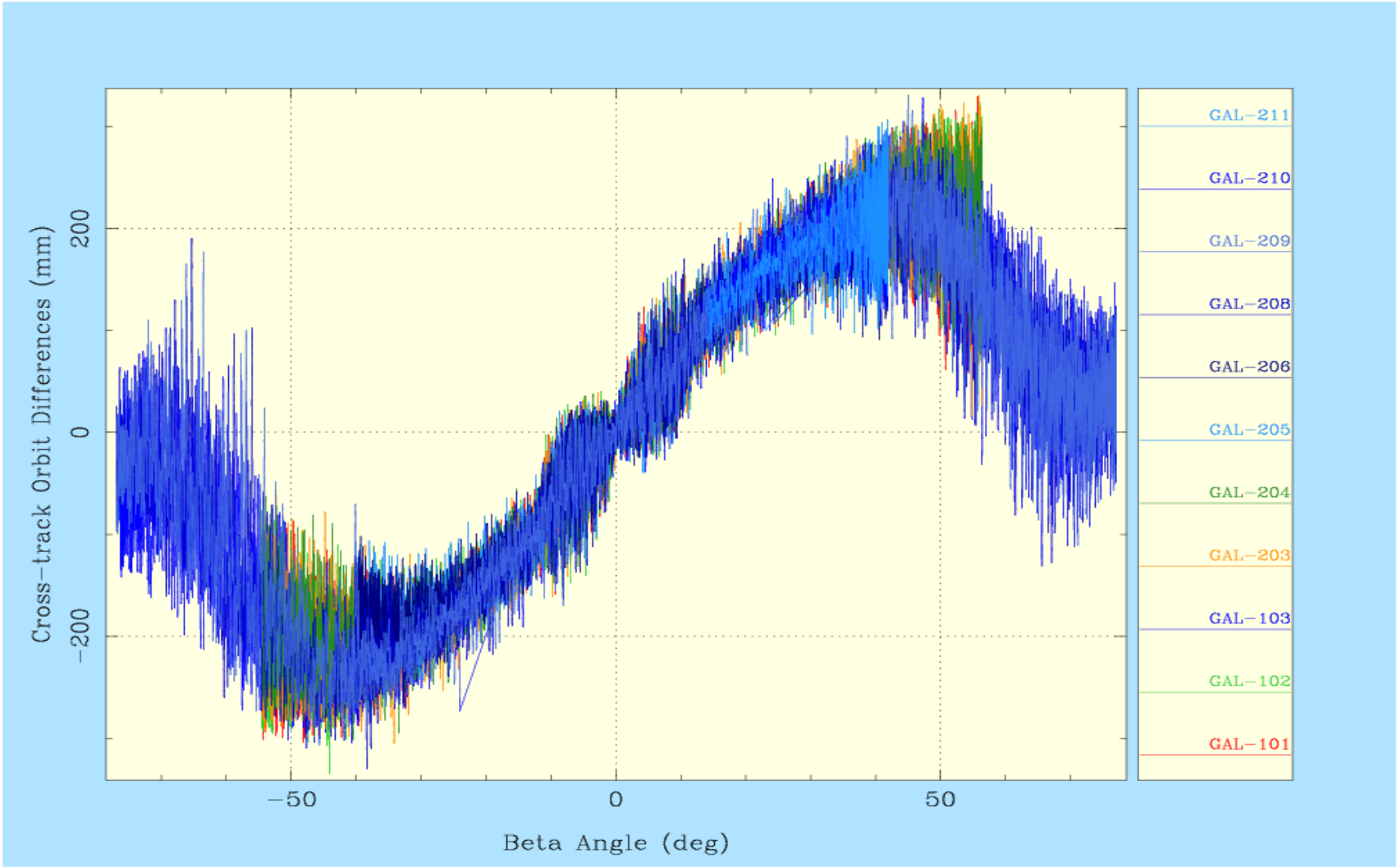
Sub-daily ERP model conclusions

- The results confirm what we saw in 2011 with the 2010 Gipson model
- But in 2011 it was based only on using GPS, now we also included GLONASS and Galileo which gives more confidence in these results
- 14 day period most clearly seen in RAAN
    - Indicates largest model errors to be in UT/LOD?
    - 14 day period practically gone with the tested models
    - The models also reduce the 14-day peak in LOD
    - Gipson also reduces the 14-day peaks in X- and Y-pole rates
- Gipson model holds the promise to significantly reduce the 14-day periods observed in several of the IGS products
    - Model change has been proposed to the IERS conventions!
    - A ocean tides based model may be preferred but given the lack of such a VLBI based model is fully acceptable for the IGS

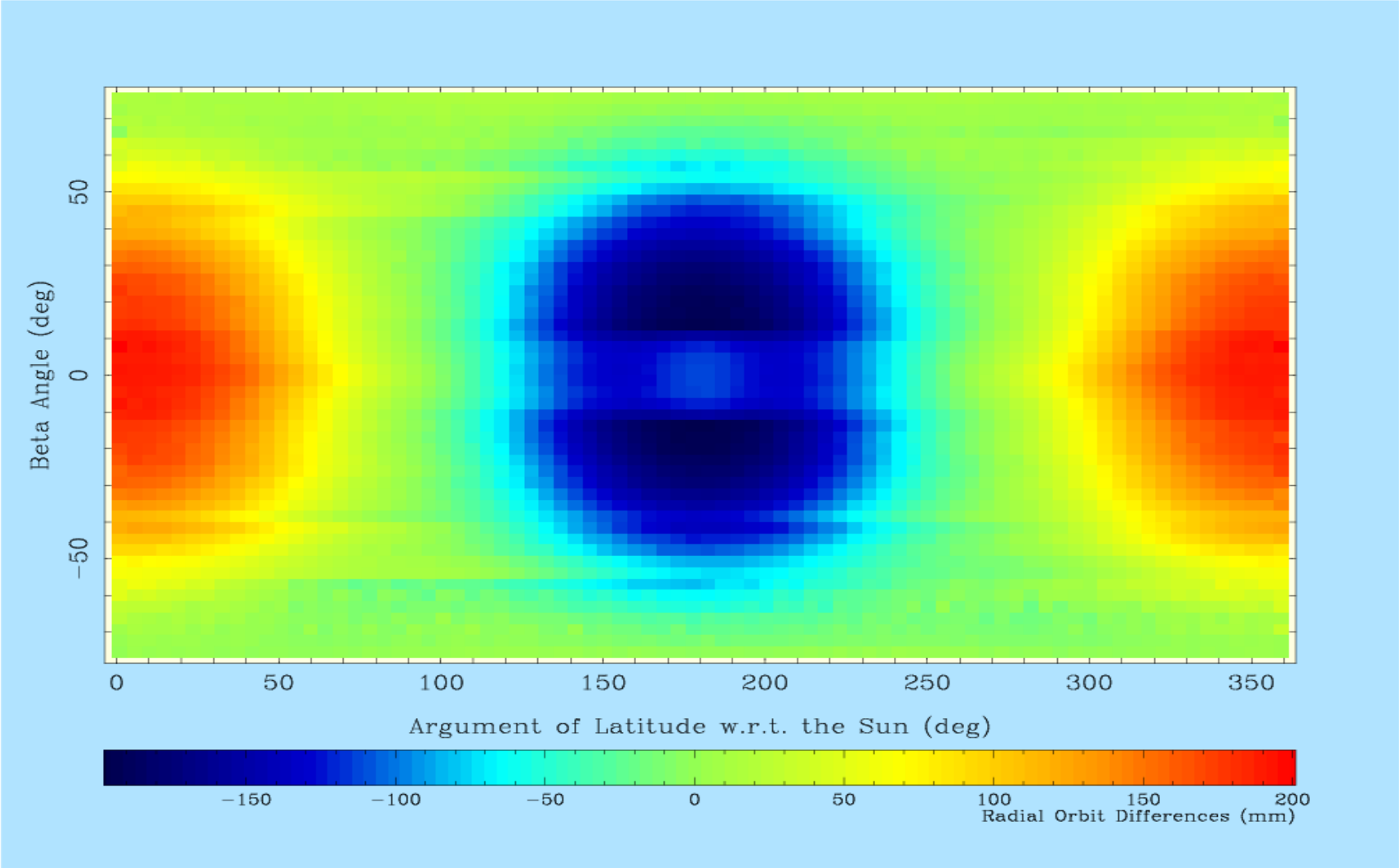
Towards Galileo in ESOC products
Starting with IGS Final products

- Galileo well understood
  - Very good cooperation with Galileo Project!
  - Very good precision of Galileo Orbit
  - Ambiguity resolution no problem
- Metadata for IOV (GAL-1) available. FOC (GAL-2) will follow
  - Metadata needed from ALL GNSS would be very good
    - PCO/PCV values for the different frequencies
    - Satellite weight, sizes, and optical and IR material properties
- Radiation Pressure Model for Galileo very important
  - Very low weight
  - Different sizes of X- and Z-surface areas

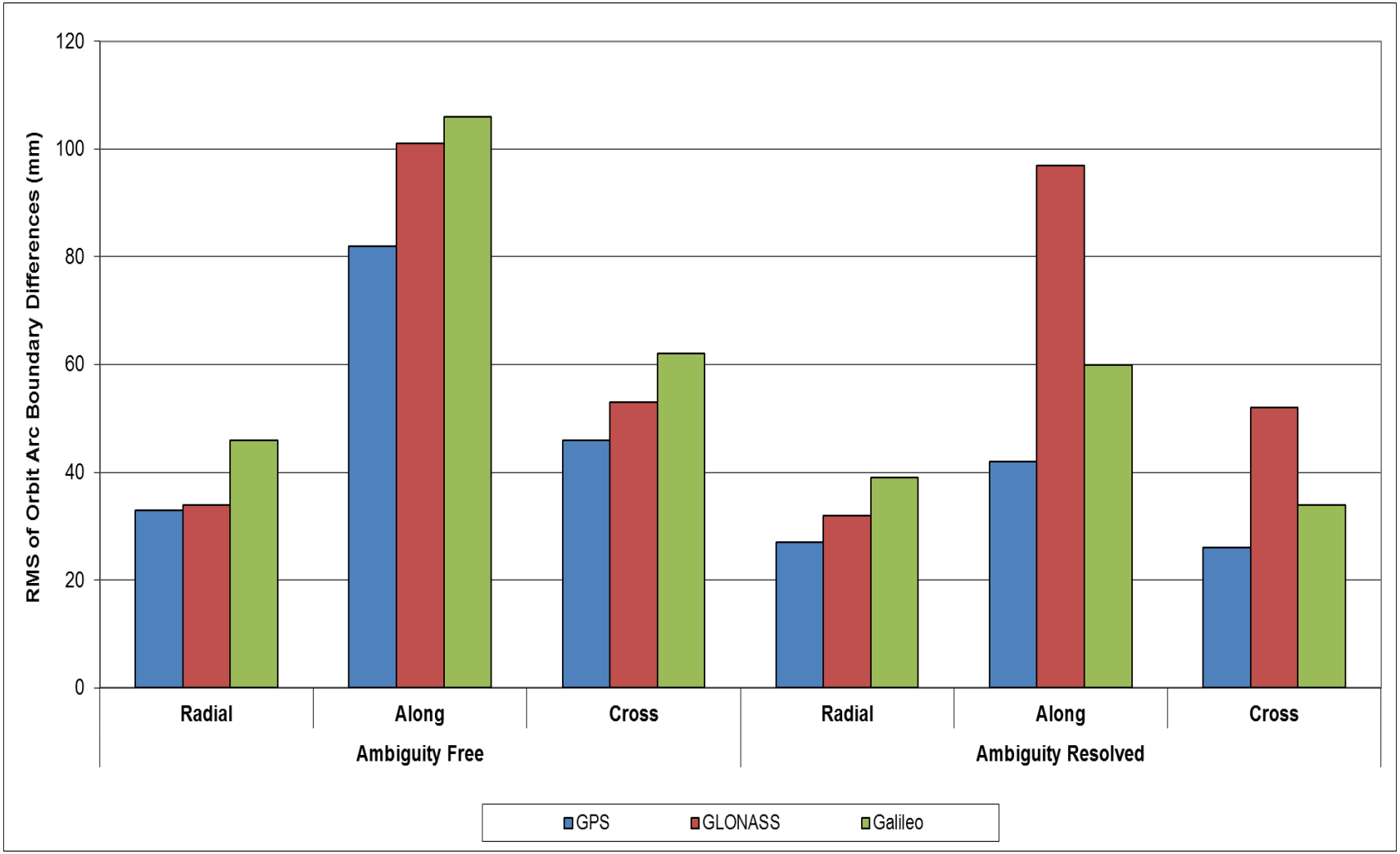
Galileo Radiation Pressure: Cross-track Effect



Galileo Radiation Pressure: Radial Effect



Performance of ESOC 3-GNSS Using full year of 2016



Galileo were only 11 Satellites (+2 for last 90 days of 2016)

Conclusions

- Our knowledge about the satellites impacts the achievable accuracy
  - Minor changes in the box-wing models significantly affect the radial and cross-track of the orbit estimates
  - Also temperature household of the satellite, i.e. re-radiation, very important to model correctly
- Sub-daily ERP model investigations
  - A clearly better model was identified (Gipson)
    - Update of sub-daily ERP model proposed to IERS
- ESOC IGS Final products may be based on GPS + GLONASS **+ *Galileo***
  - Galileo orbit overlap amplitude spectrum very good!
  - Galileo metadata good example, all other GNSS should follow!
  - Galileo may enable IGS to contribute to terrestrial scale!?

THANK YOU

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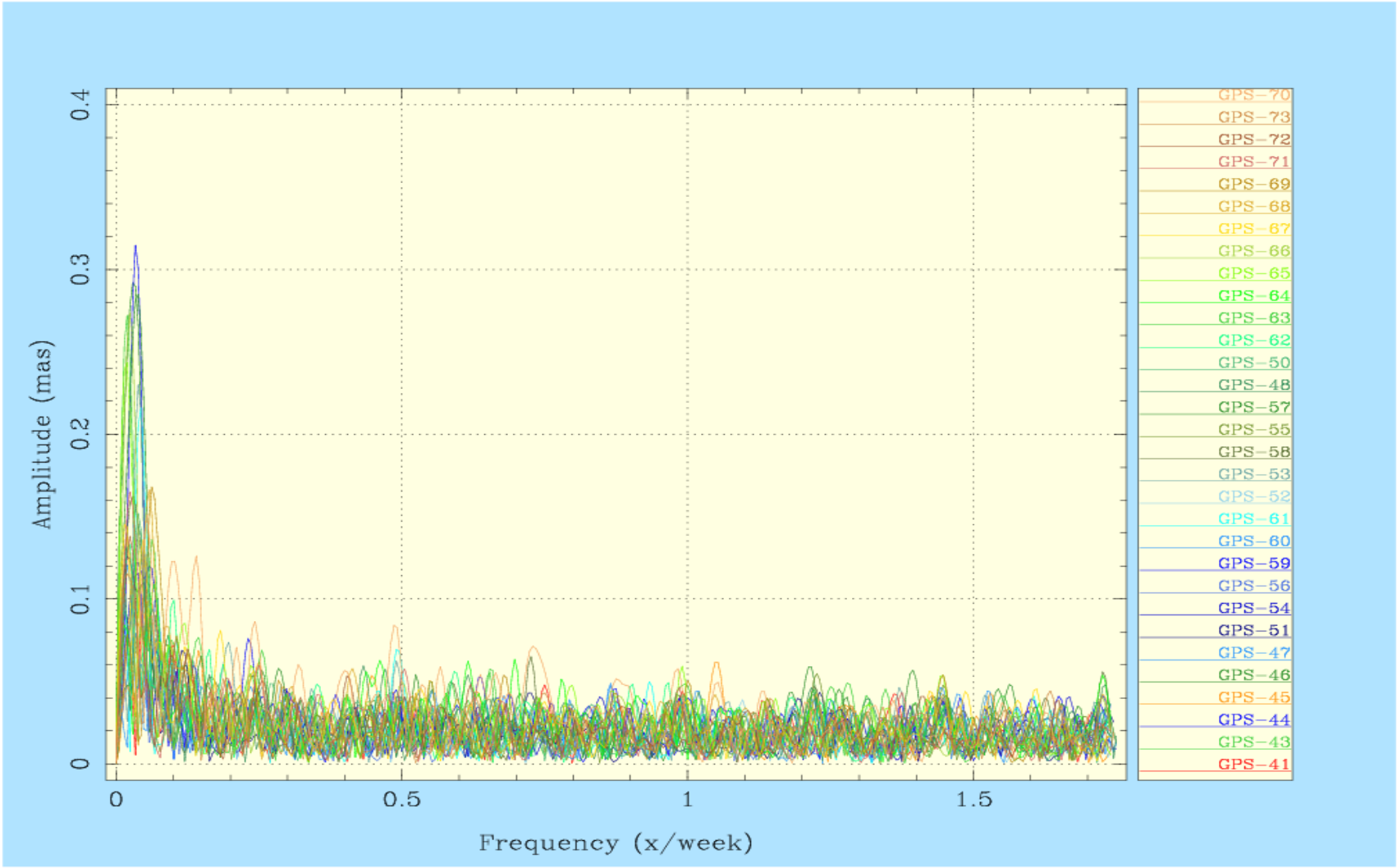
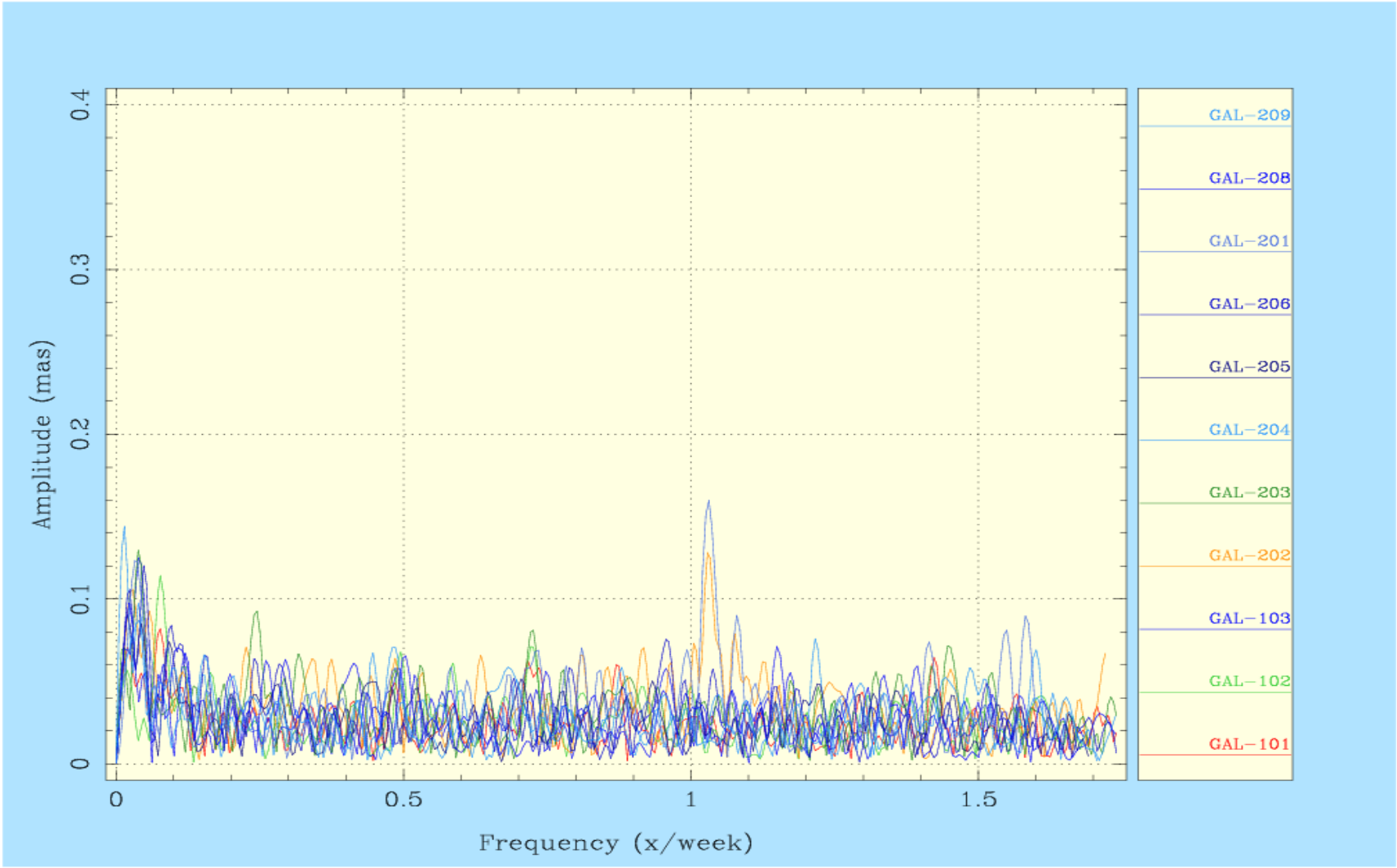
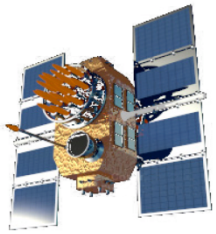


RAAN Amplitude Spectrum for Galileo: Gipson model



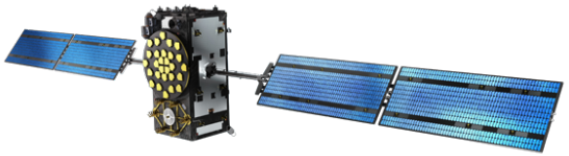
Multi-GNSS data processing 2014-2015

ESA and MGEX sites

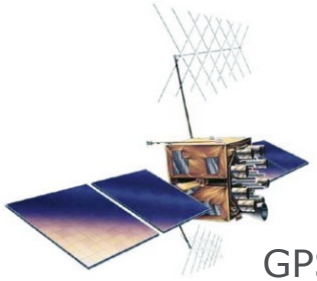


GPS-IIA

GLONASS-M



Galileo

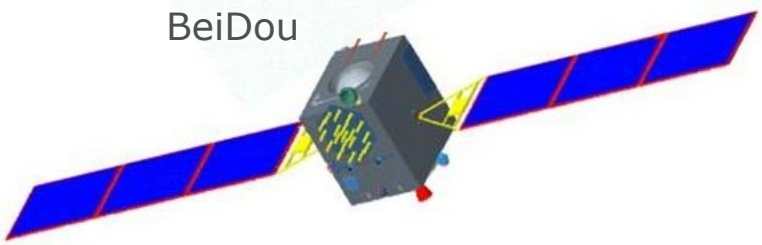


GPS-IIR/RM

~68-75 satellites

QZSS

GPS-IIF



BeiDou