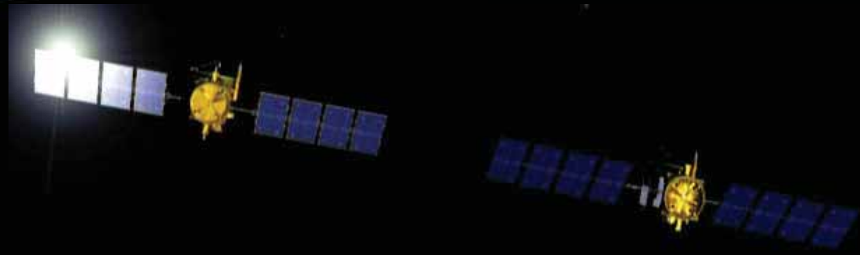
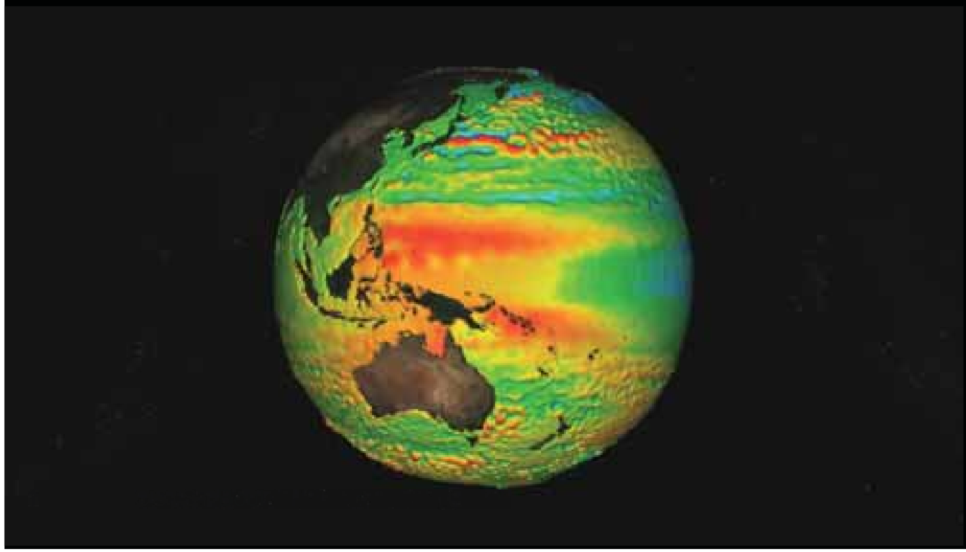


Splinter I – Precision Orbit Determination

Towards the *1 mm/y* Stability of the Radial Orbit Error at Regional Scales

A. Couhert, L. Cerri, F. Mercier, S. Houry

October 8, 2013



Ocean Surface Topography Science Team Meeting
Boulder, Colorado

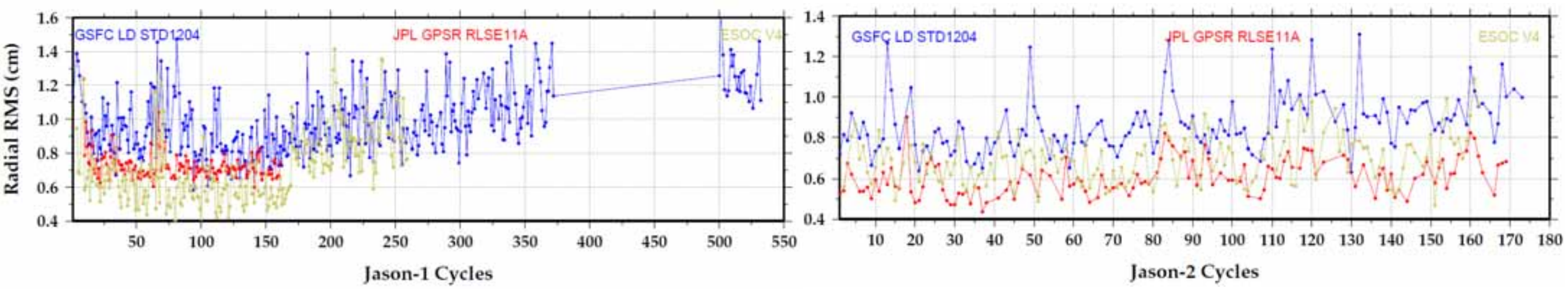
Outline

- POD Radial Accuracy Achieved
- Tracking Measurement System Errors
- Terrestrial Reference Frame Effects on Orbit and MSL
- Time-Varying Gravity Field Modelling Errors
- Prospects for Orbit Accuracy Improvement

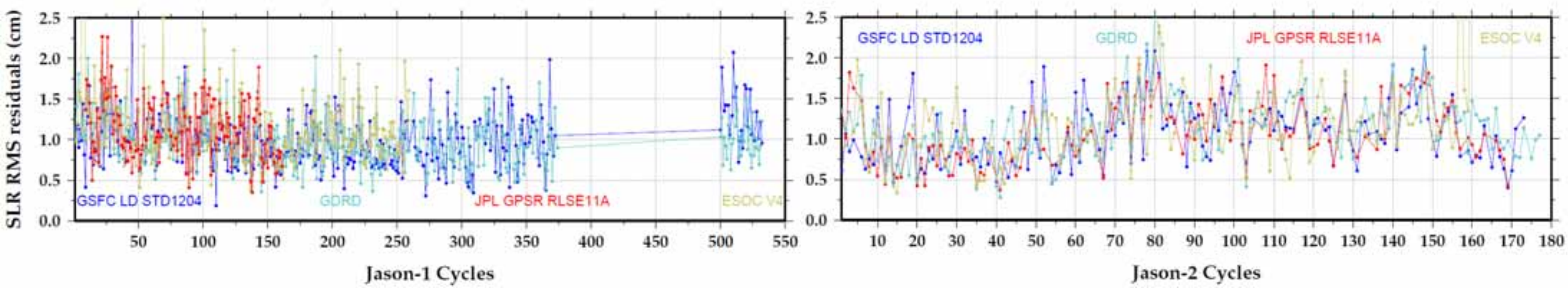
POD Radial Accuracy Achieved

The *1-cm* RMS Orbit

- Comparison of GSFC (DORIS+SLR), JPL (GPS, reduced dynamic) and ESOC (GPS+DORIS+SLR) with CNES GDRD orbits



- High elevation (> 70 deg) SLR reference stations (7090Yarr, 7105Wash,7839Graz) residuals on the previous solutions

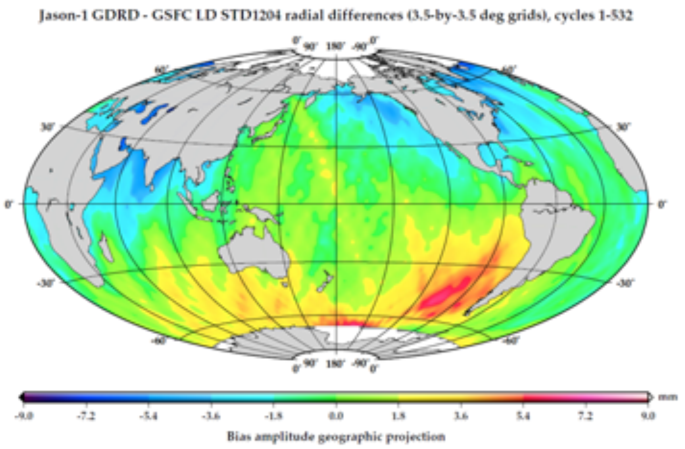


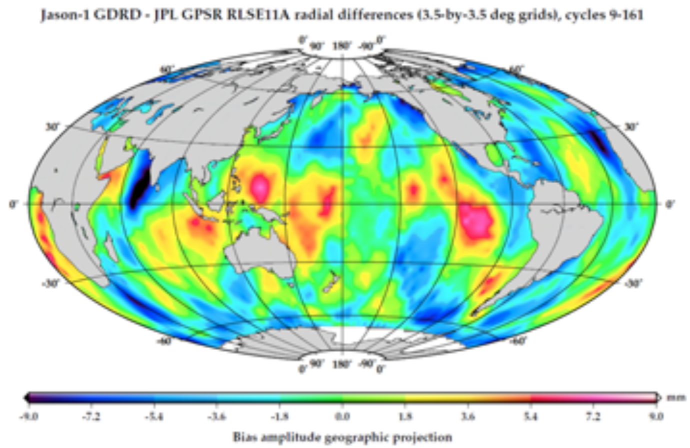
 OSTST Boulder 2013, Couhert et al.

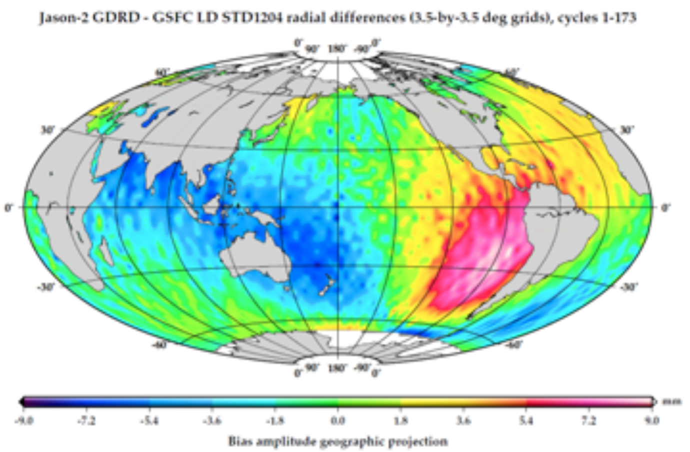
POD Radial Accuracy Achieved

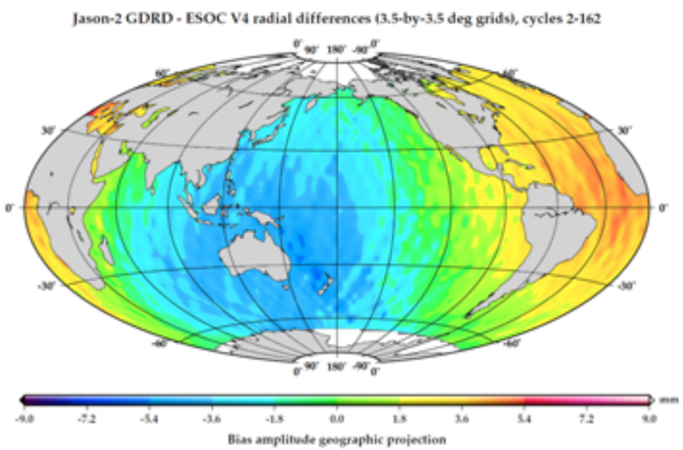
Current POD Limitations

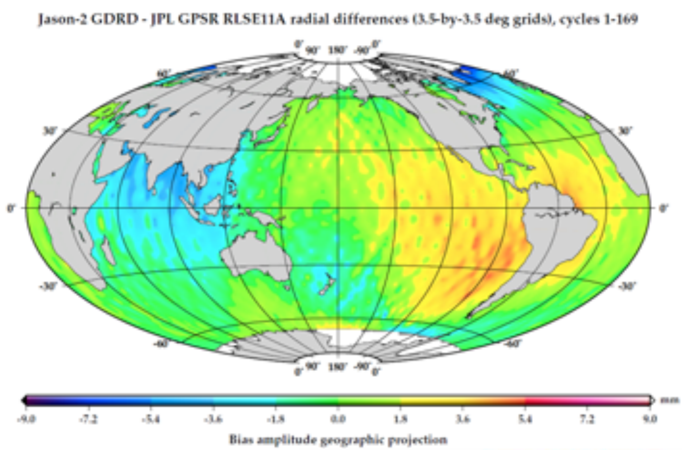
- Up to *9 mm* regional biases observed on Jason-1 and Jason-2 orbits between independent POD groups









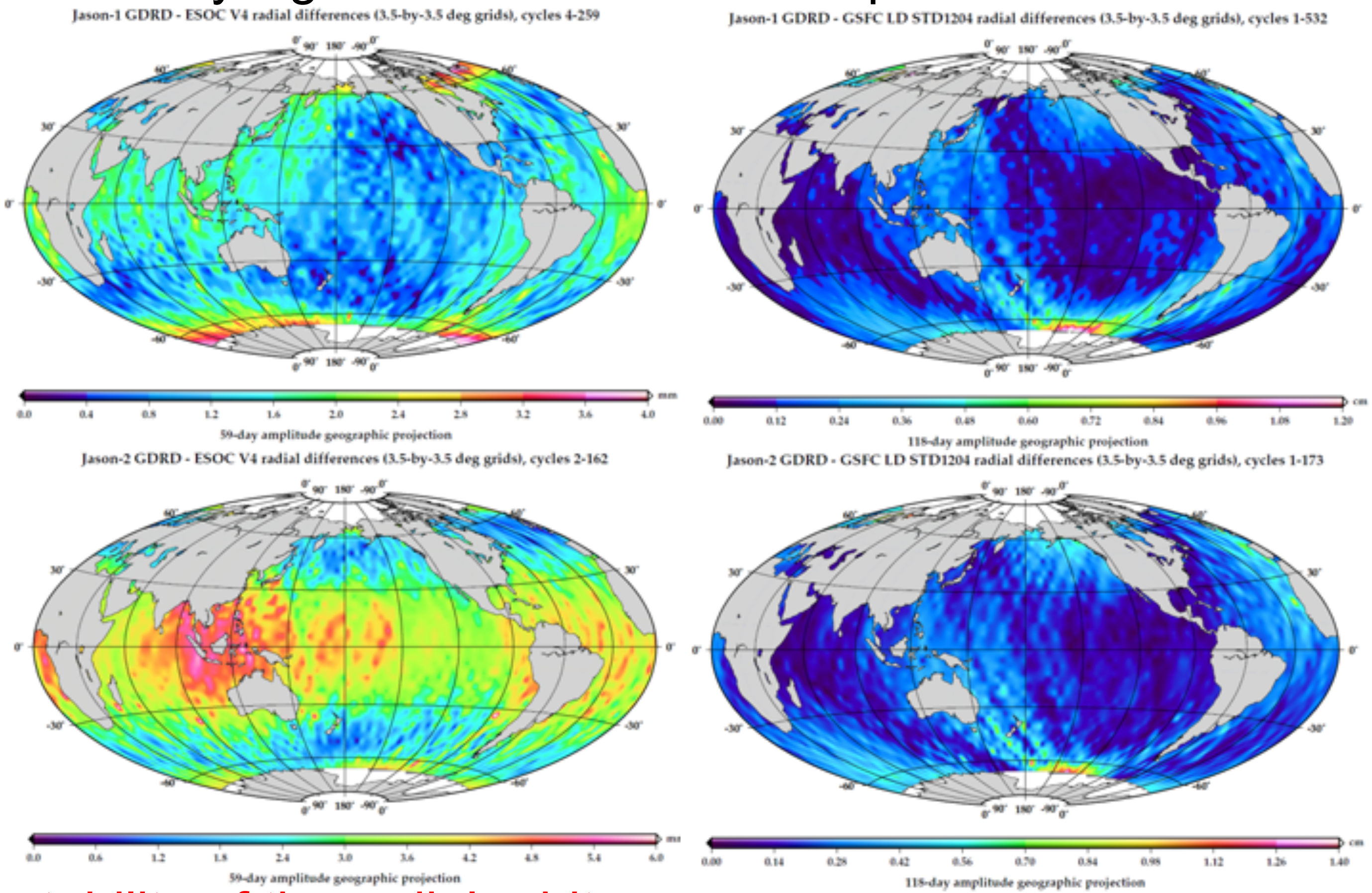


POD Radial Accuracy Achieved

Current POD Limitations

- *5 mm* 59-day and *1 cm* 118-day signatures in the orbit comparisons

How the radial orbit differences evolve over time?

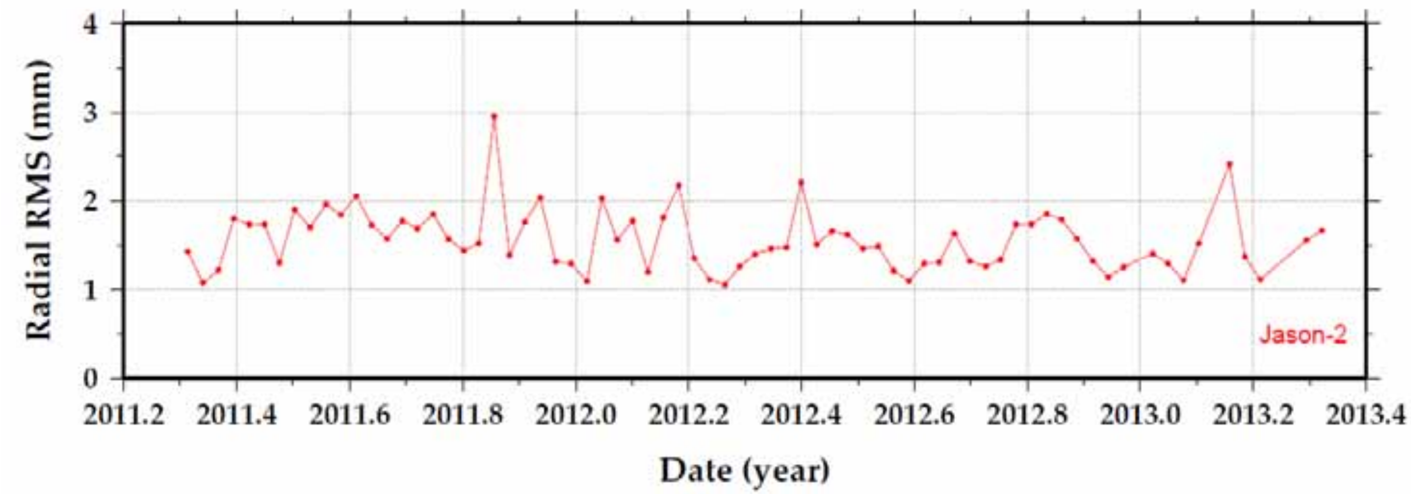


=> Need of long-term stability of the radial orbit error at regional scales at the 1 mm/y level for MSL estimates

Errors in the GPS Measurement System

Impact of the GPS Constellation

- RMS of radial differences between two Jason-2 GPS-based orbits using different GPS orbits and clock solutions, JPL and IGS



✦ Stable radial differences well below *2 mm* RMS

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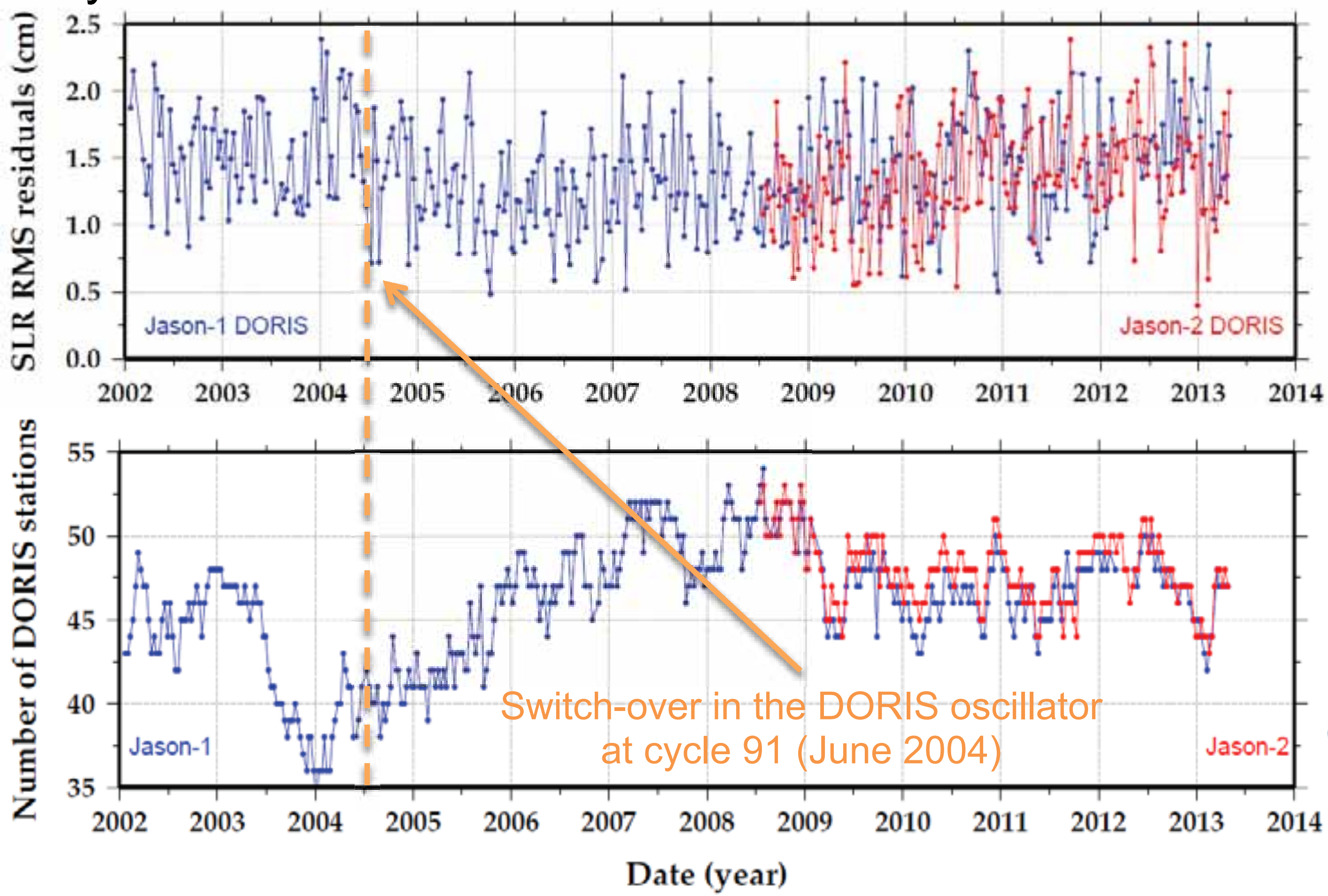
Errors in the DORIS Measurement System

DORIS Ground Network and Receiver Stability

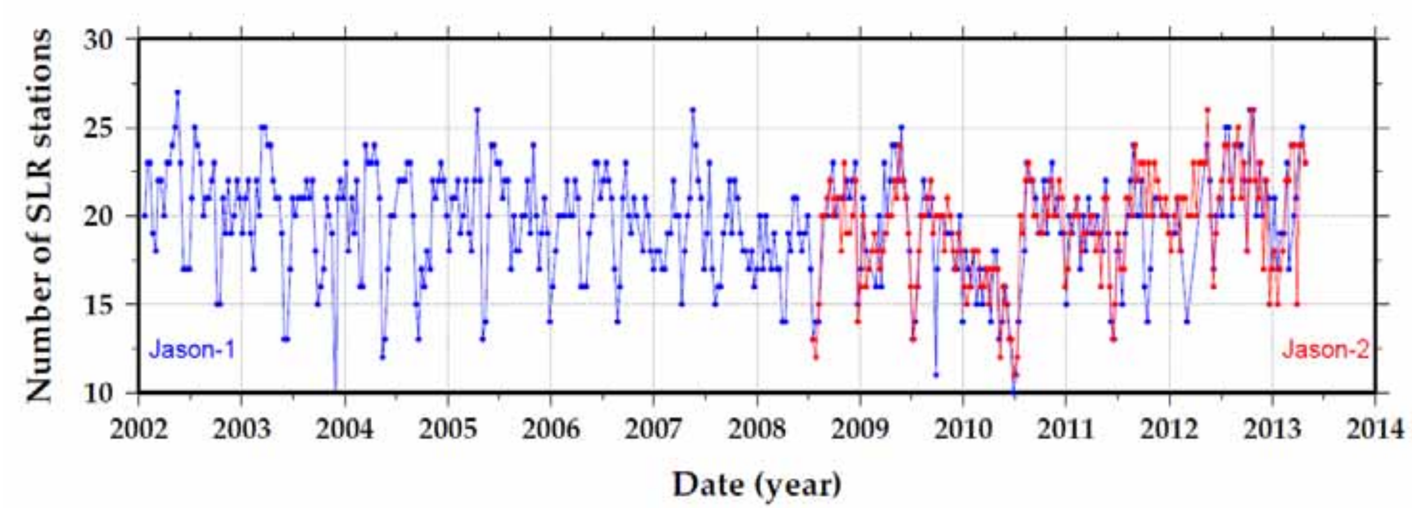
- High elevation SLR core network residuals on Jason-1 and Jason-2 independent DORIS-only solutions
  - » The change from the primary to backup DORIS oscillator on Jason-1 removed *~5 mm* of radial orbit error
  - » No conclusive correlation between the radial orbit accuracy and the size of the DORIS ground network



Errors in the SLR Measurement System

SLR Ground-Based Tracking Stability

- ~20 SLR stations routinely track the Jason-1 and Jason-2 satellites

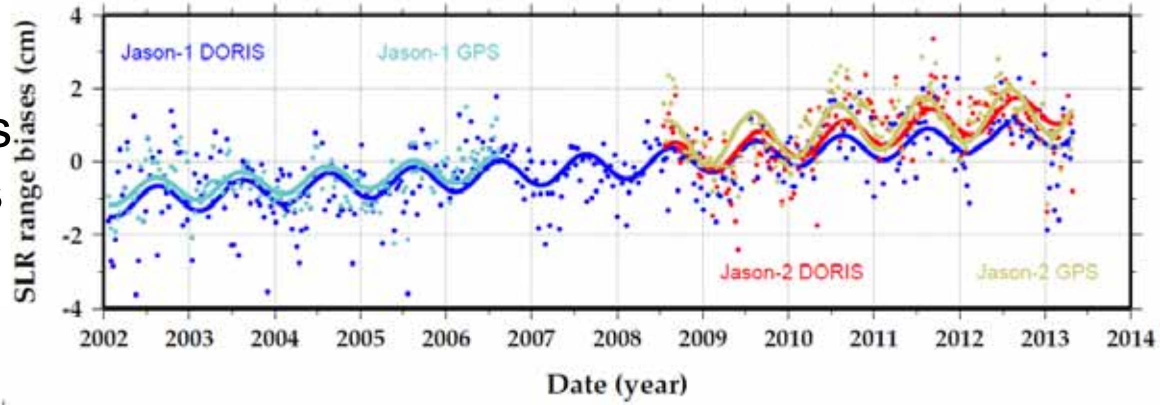


Errors in the SLR Measurement System

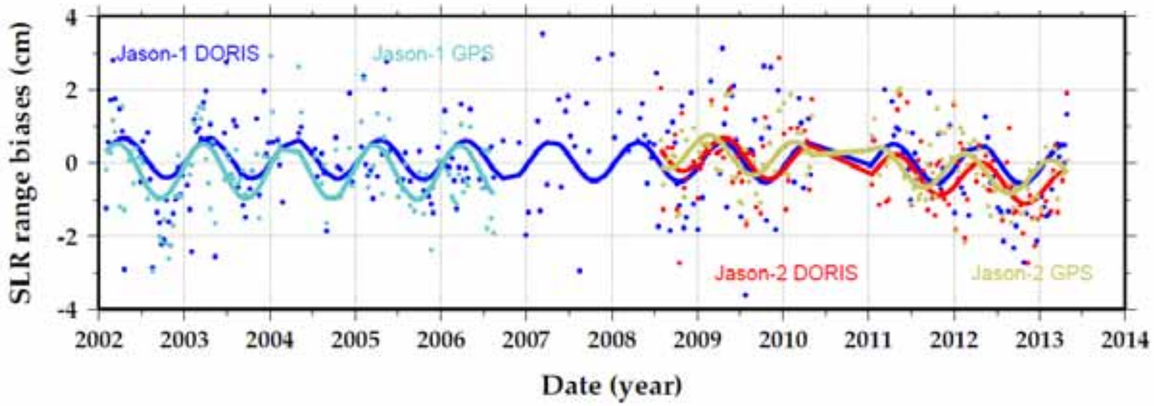
SLR Reference Stations Range Biases

- Bias, drift and annual estimates of high elevation SLR residuals on independent DORIS and GPS orbits

L7090



L7105

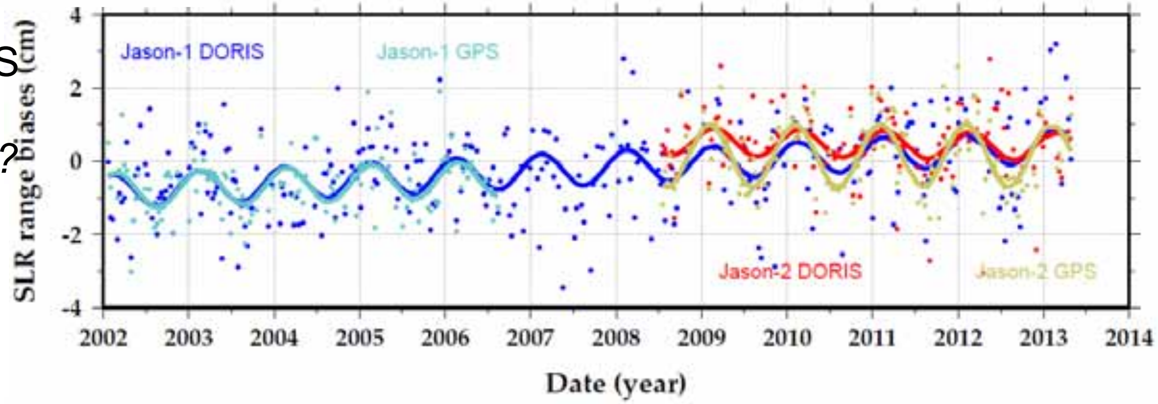


2 mm/y drift on both satellites DORIS and GPS orbits as seen by Yarragadee

-2 mm/y drift on Jason-2 DORIS and GPS orbits as seen by Washington

=> *Any range biases on these two SLR stations?*

L7839



Annual terms (*3 to 9 mm*), stronger on GPS than DORIS orbits, of opposite phases in the two hemispheres => *geocenter motion?*

=> Limitations in the use of the SLR tracking as an absolute calibration of the orbit error

Terrestrial Reference Frame Effects on Orbit and MSL

Global Scale

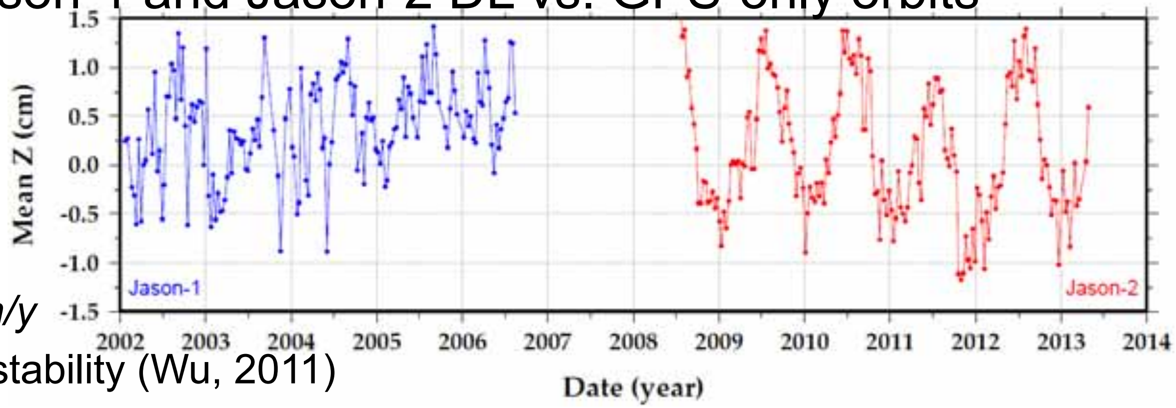
- North/South consistency of Jason-1 and Jason-2 DL vs. GPS-only orbits
  - Well known annual term

    J1: *2.8 ± 0.8 mm*, J2: *7.9 ± 1.0 mm*
  - Z-drift:

    J1+J2: *-0.3 ± 0.1 mm/y*

    J1: *1.2 ± 0.3 mm/y*, J2: *-0.6 ± 0.4 mm/y*

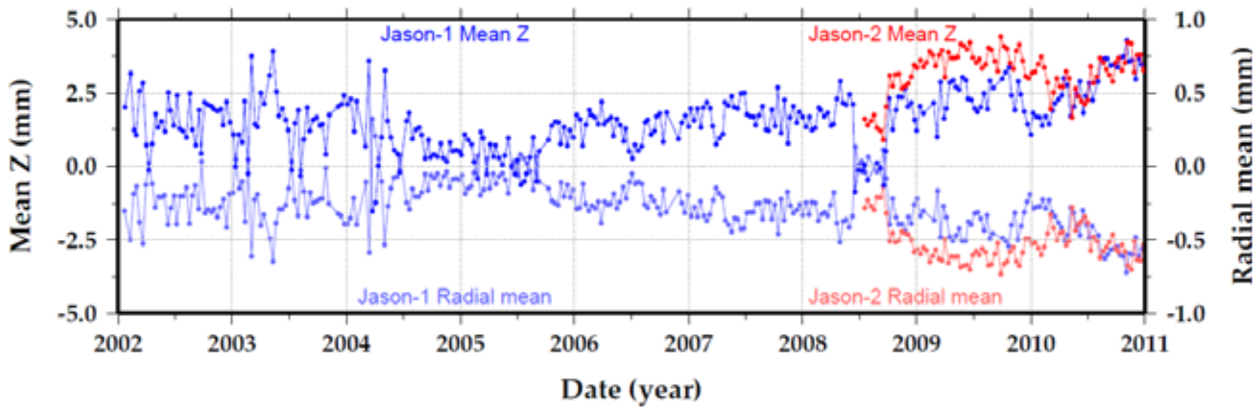
    Consistent with *0.5 mm/y* ITRF2008 stability (Wu, 2011)



- Jason-1 and Jason-2 DL ITRF2008-ITRF2005 mean orbit differences (Z + radial over oceans) – *most sensitive orbits to ITRF errors (Cerri, 2010)*
  - » Z-drift: J1: *0.15 ± 0.02 mm/y*, J2: *0.26 ± 0.11 mm/y*
  - » GMSL rate error: J1: *-0.027 ± 0.004* mm/an, J2: *-0.042 ± 0.018 mm/y*
  - » Tracking system independent

  GMSL rate error = -0.16 x Z-drift

  (Morel and Willis, 2005)

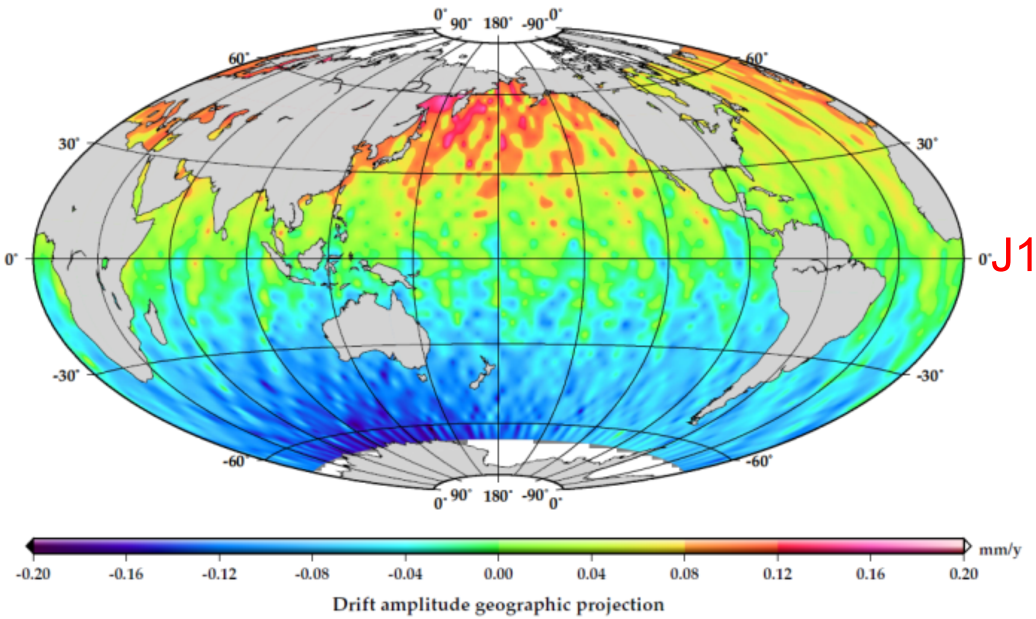


Terrestrial Reference Frame Effects on Orbit and MSL

Extreme Latitudes Regional Variability

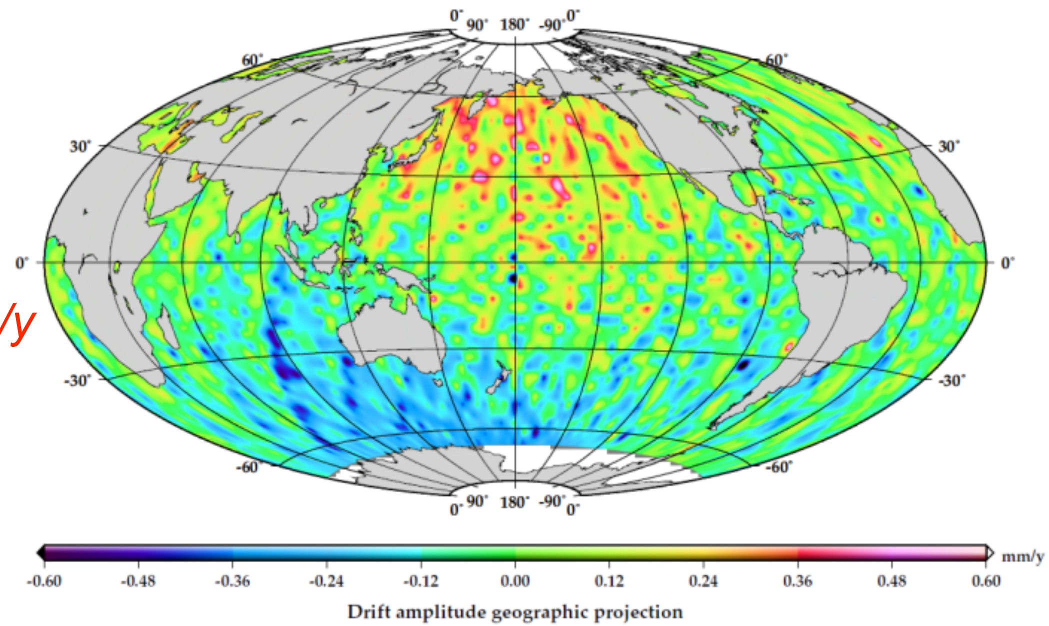
- Jason-1 and Jason-2 DL ITRF2008-ITRF2005 radial orbit drift

Jason-1 DL ITRF2008 - ITRF2005 radial differences (3.5-by-3.5 deg grids), cycles 1-330



J1 geographically correlated drifts < *0.2 mm/y*

Jason-2 DL ITRF2008 - ITRF2005 radial differences (along-track), cycles 1-91



J2 geographically correlated drifts < *0.6 mm/y*

Time-Varying Gravity Field Modelling Errors

Overview

- Focus is on providing a long-term error budget of the 10-year Jason-1 and ENVISAT orbit time series at two time scales: interannual (2-5 years) and decadal (> 10 years)
  - 10-day series of GRACE-derived gravity field are taken as a reference
  - Only DORIS-derived orbits are considered:
    - To derive an upper-bound estimate of TVG errors
    - To ease the interpretation of the results

- Jason-1 and Jason-2 GDRD orbits are then further evaluated through comparisons with external orbits, using different TVG modelling options

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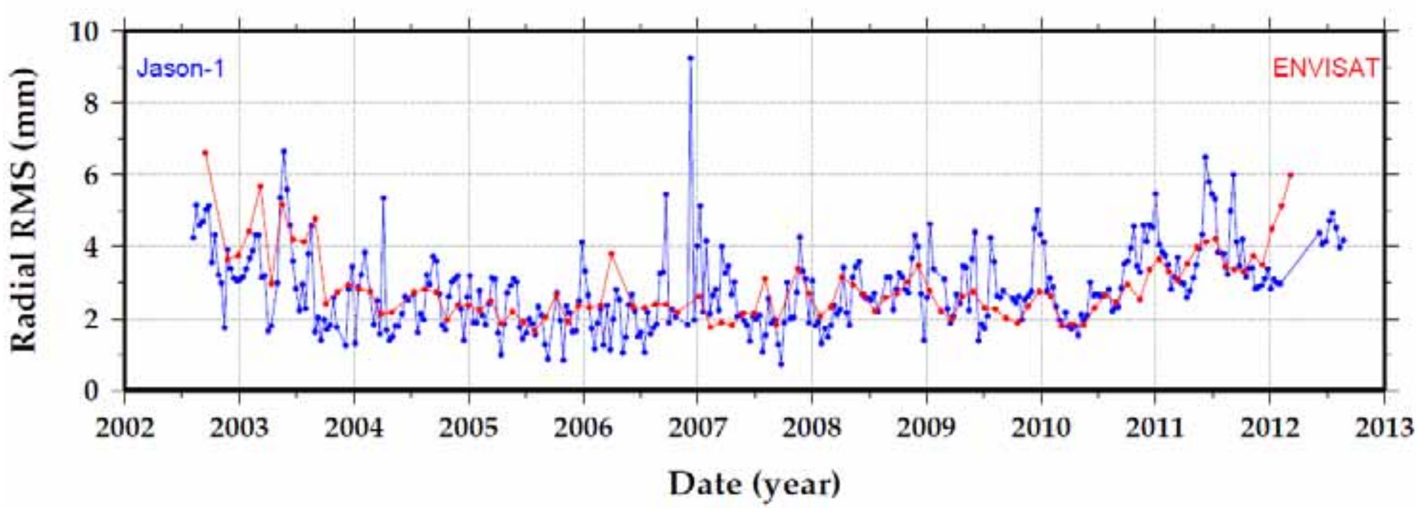
Time-Varying Gravity Field Modelling Errors

Global Impact on the Radial Orbit Accuracy < *5 mm* RMS

- "U-shape" of radial differences between the GDRD solution (mean model) and GDRD orbits using the GRACE's 10-day solutions



Slightly different behaviour out of the adjustment period (2003-2010) of the gravity mean model

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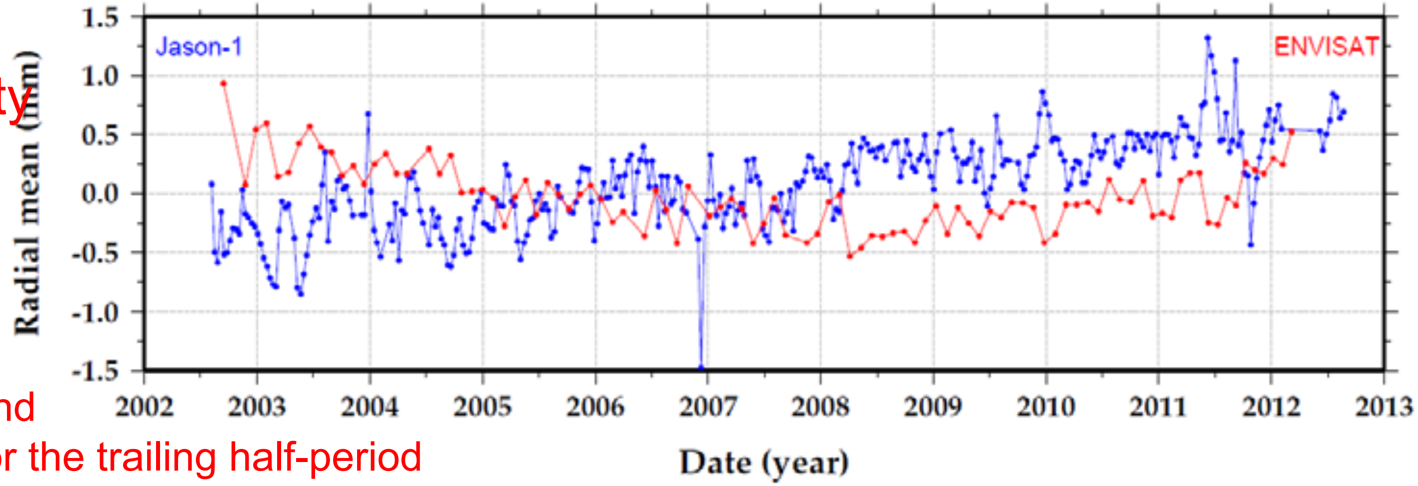
Time-Varying Gravity Field Modelling Errors

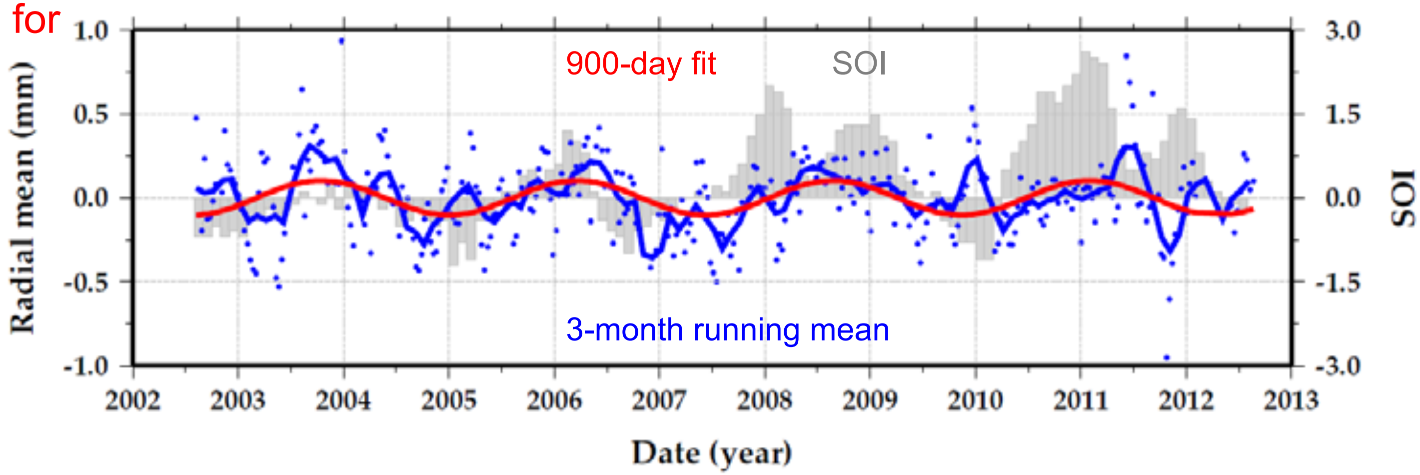
Impact on the Global Mean Sea Level

- Long-term evolution
  - » *0.10 ± 0.01 mm/y* for Jason-1, parabolic shape for ENVISAT (*-0.03 ± 0.01 mm/y*)



- Interannual variability
  - » Although taken over 10 years ENVISAT has a near-zero linear trend, the drift of the leading half-period is *-0.14* and *+0.14 ± 0.03 mm/y* for the trailing half-period
  - » ~900-day oscillations for Jason-1 of amplitude *0.10 ± 0.04 mm* phased with the SOI

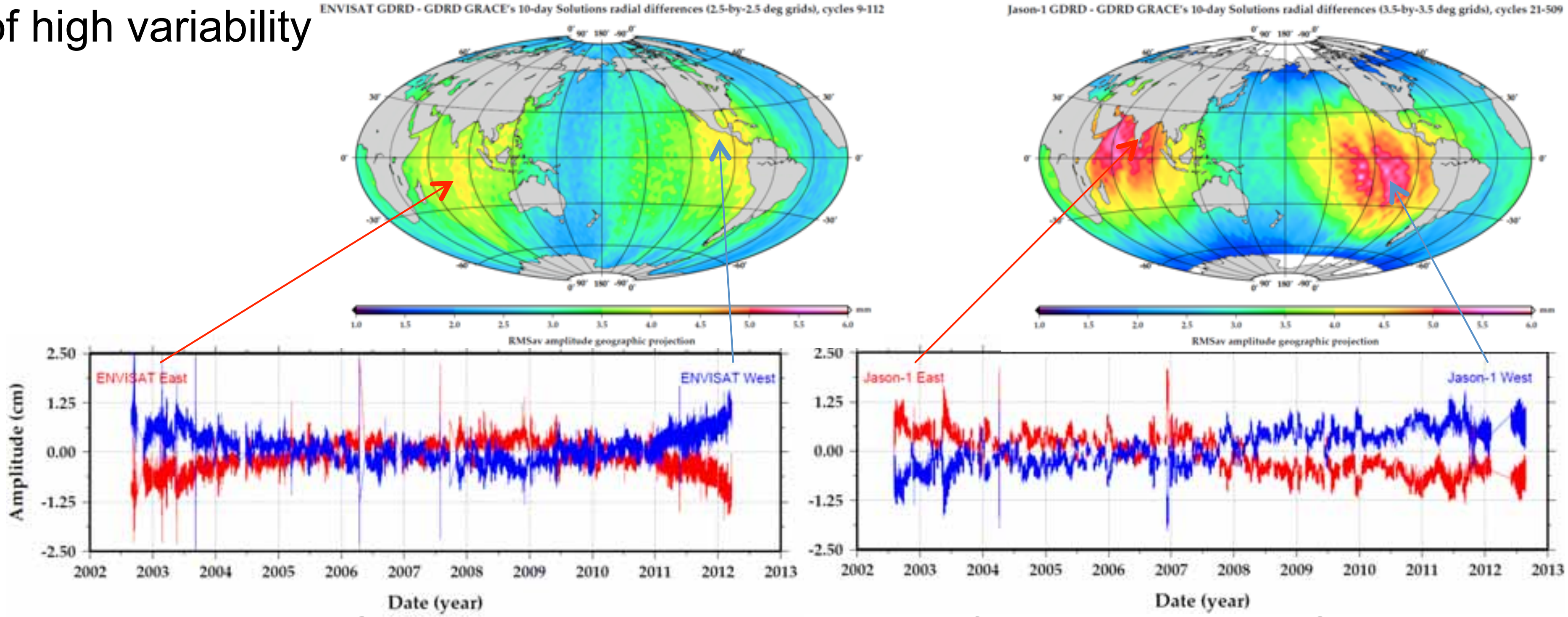
=> ENSO-related TVG?



Time-Varying Gravity Field Modelling Errors

Impact at Regional Scales

- The RMS maps of geographically correlated orbit errors gives the regions of high variability



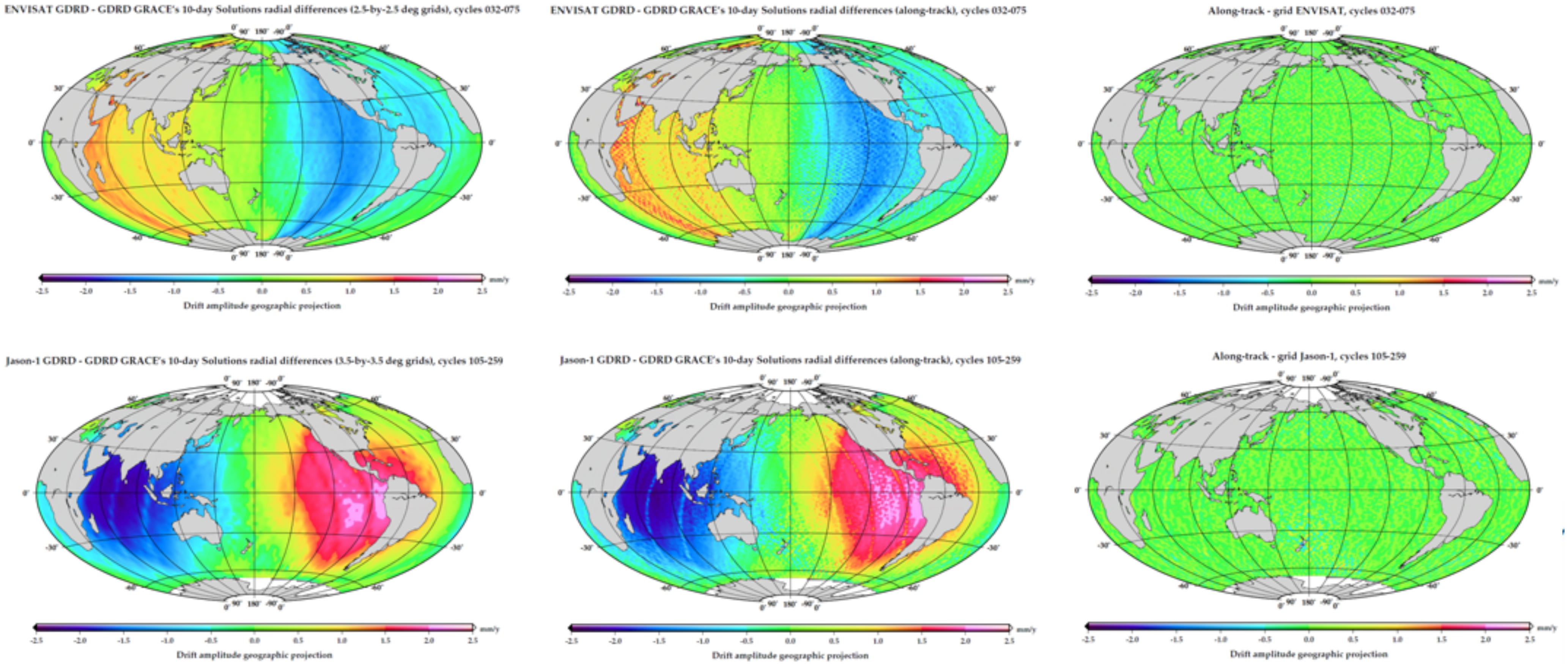
  » With respect to the GDRD mean model, regional residual drifts are visible on ENVISAT and Jason-1 orbits when comparing to the Grace's 10-day solution

=> Fitting a polynomial of degree 2 for ENVISAT and degree 1 for Jason-1 is enough to retrieve their long-term and interannual evolutions

Time-Varying Gravity Field Modelling Errors

Impact of Method on the Inference of Long-Term Geographically Correlated Errors

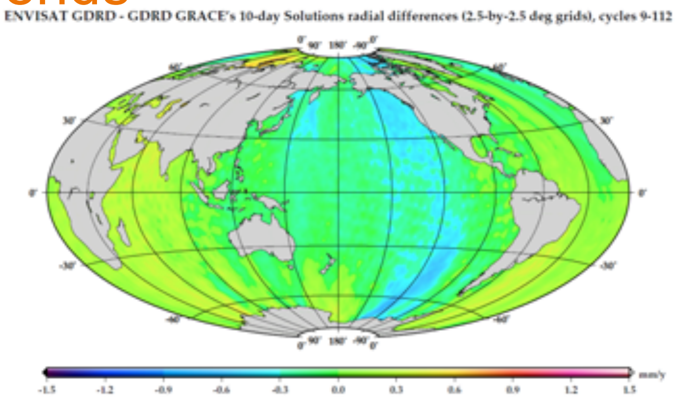
- “along-track” (data sampled along-track for each orbital cycle) vs. “grid” (data binned in grid cells) drift estimates give comparable results

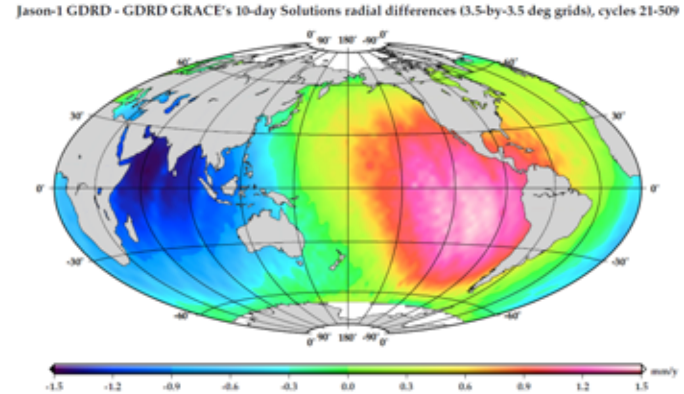


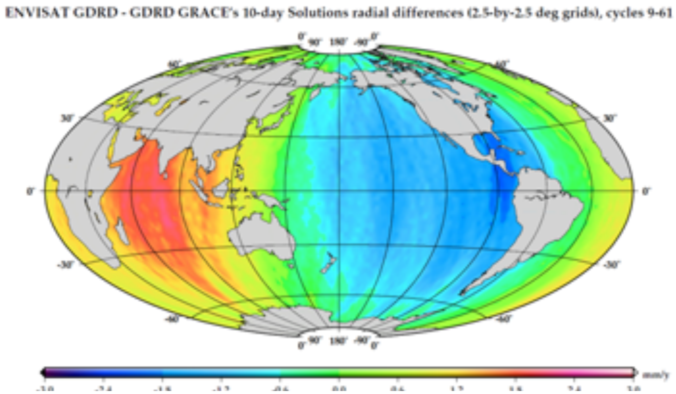
Time-Varying Gravity Field Modelling Errors

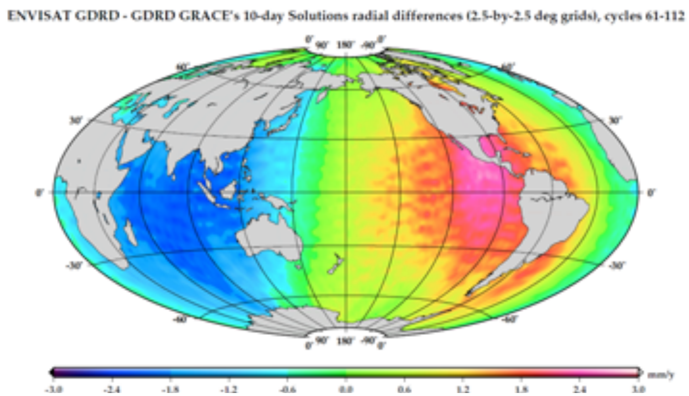
Analysis of Regional Trends

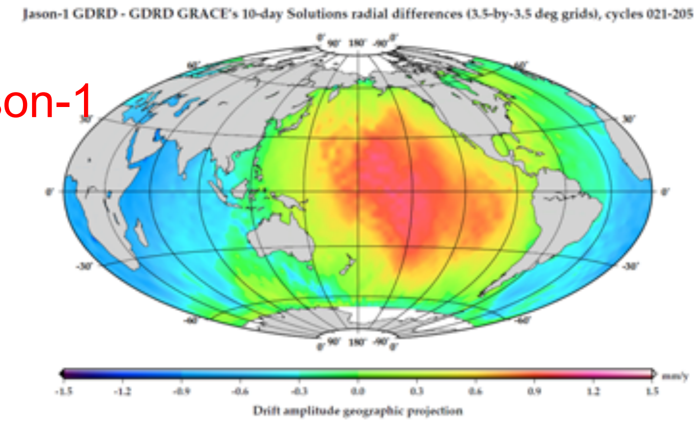
- <u>Long-term evolution:</u>
  - < *1.5 mm/y* for Jason-1
  - < *1 mm/y* for ENVISAT
- <u>Interannual variations:</u>
  - ~5 years for ENVISAT and < *3 mm/y*
  - Little variability for Jason-1

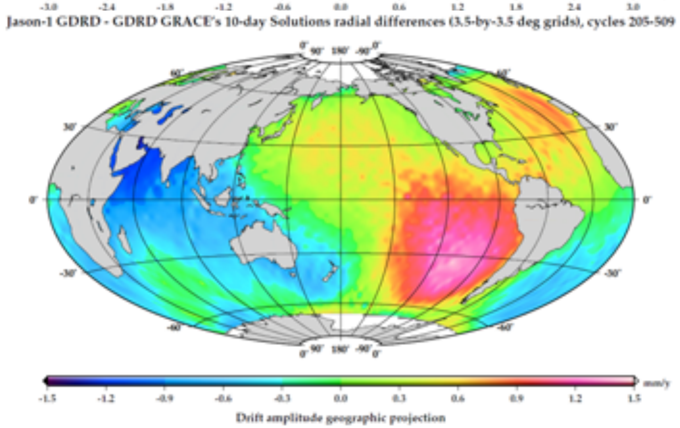








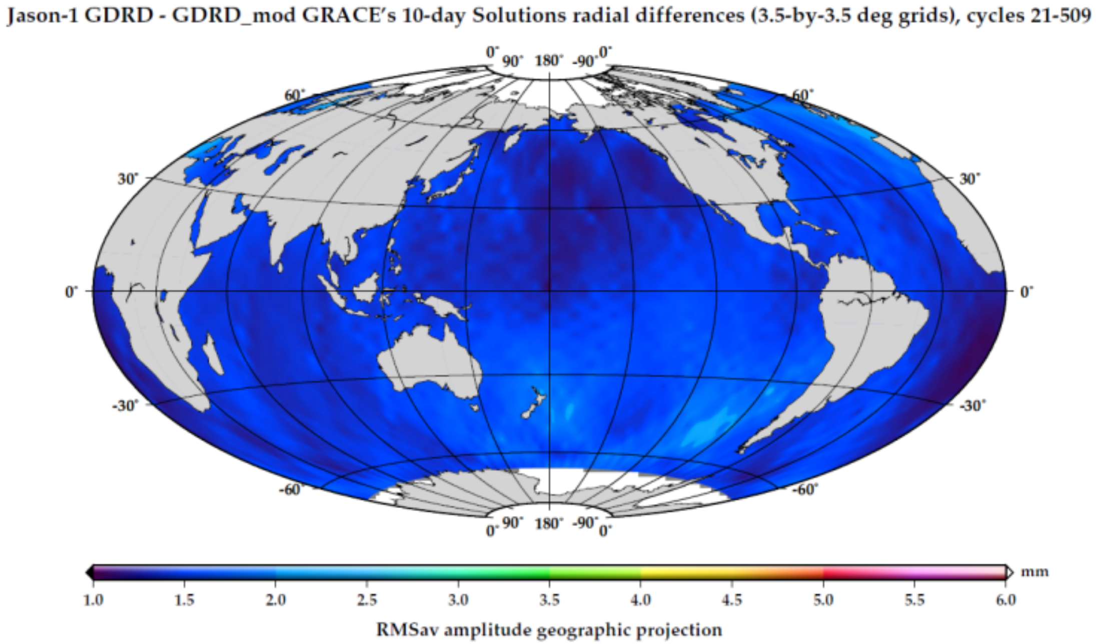




Time-Varying Gravity Field Modelling Errors

Jason Orbit Sensitivity to C_{31} and S_{31} Gravity Coefficients

- Jason-1 RMS of radial differences between the GDRD solution (mean model) and GDRD orbits using the GRACE's 10-day solutions making C_{31}/ S_{31} identical



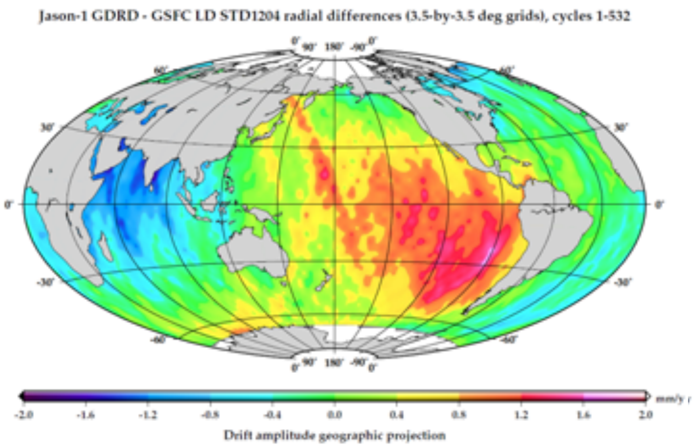
✦ The East-West patterns of high variability are just the effect of C_{31}/S_{31} differences

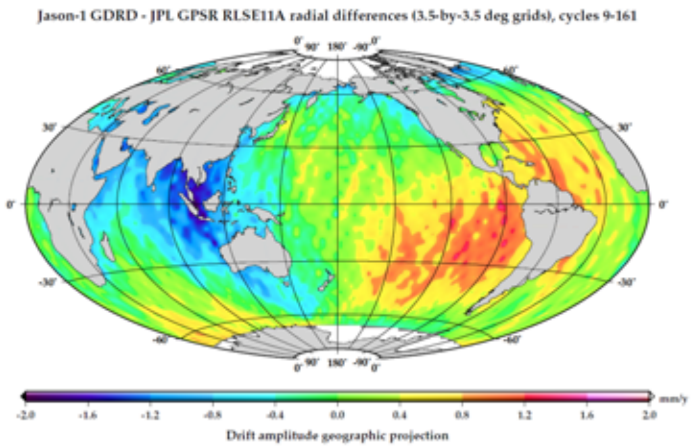
=> TVG effects on Jason orbit could be accommodated with the estimation of C_{31}/S_{31} coefficients in the orbit determination process?

Prospects for Orbit Accuracy Improvement

Geographical Distribution of Radial Drifts Between Orbits Using Different TVG Modelling Options

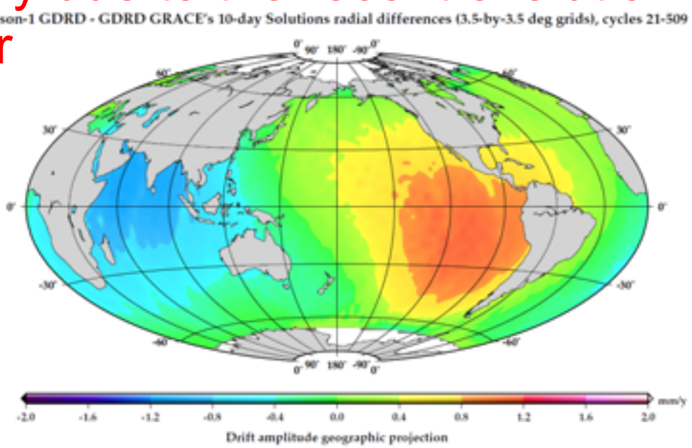
- Estimated drifts for Jason-1: East-West order-1 patterns < *2 mm/y*

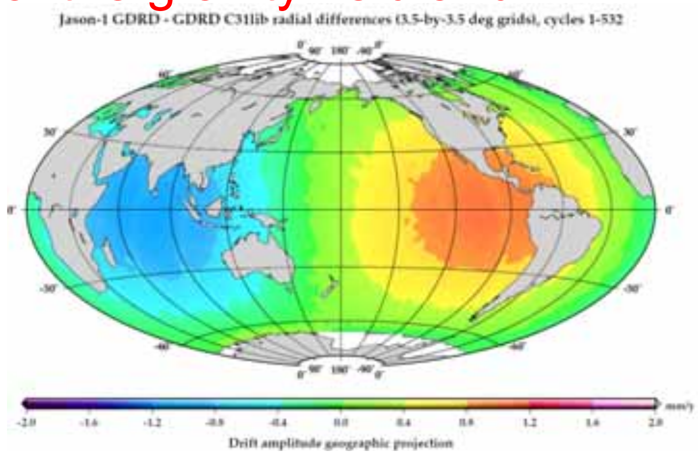




- These drifts are mainly due to the recent evolution of the gravity field and may be accounted for by estimation of C_{31}/S_{31} coefficients

=> Reducing drift to sub-mm/y level

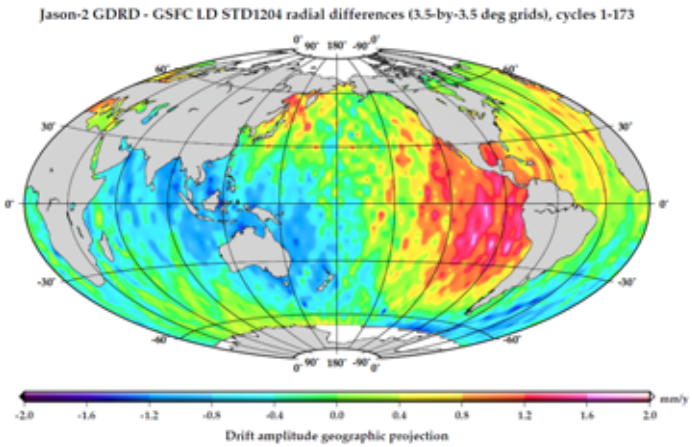


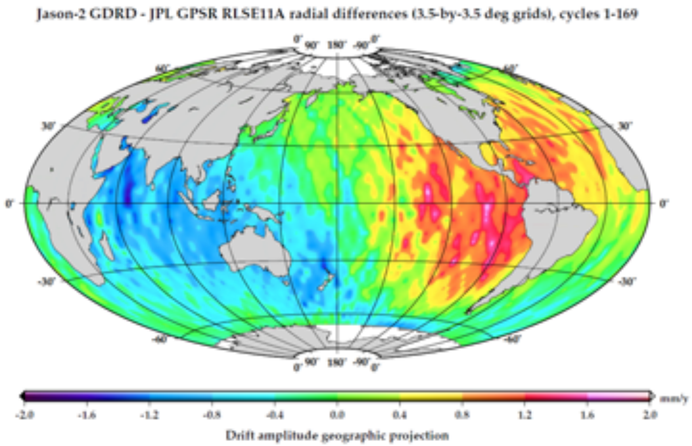


Prospects for Orbit Accuracy Improvement

Geographical Distribution of Radial Drifts Between Orbits Using Different TVG Modelling Options

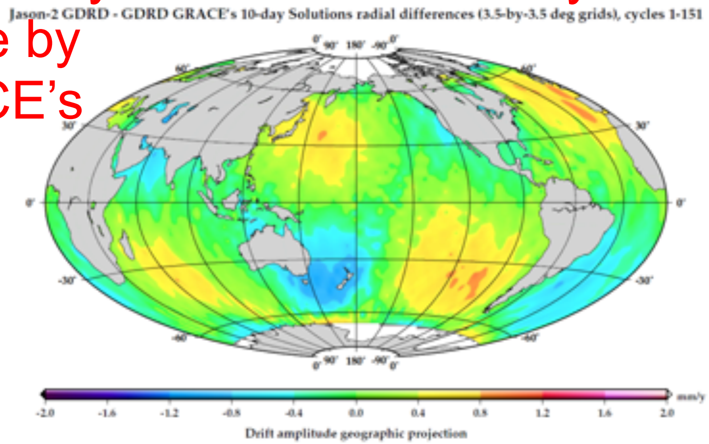
- Estimated drifts for Jason-2: East-West order-1 patterns < *2 mm/y*

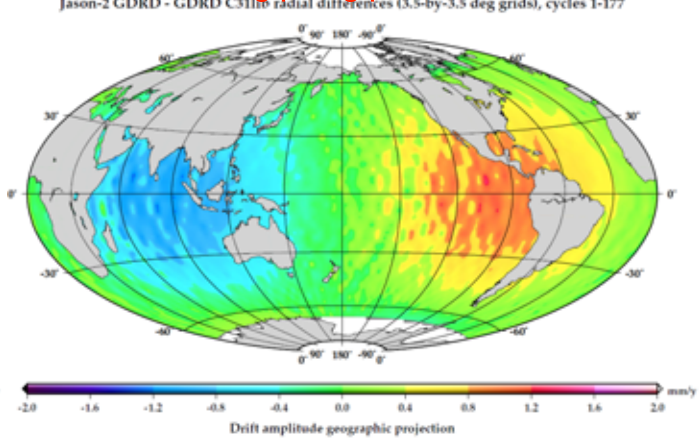




- These drifts seem to only be accounted for by estimation of C_{31}/S_{31} coefficients, no more by the use of the GRACE's 10-day solutions

=> Reducing drift to sub-mm/y level

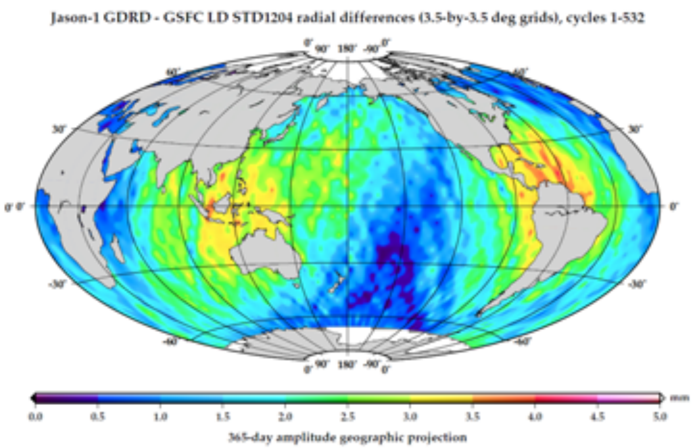


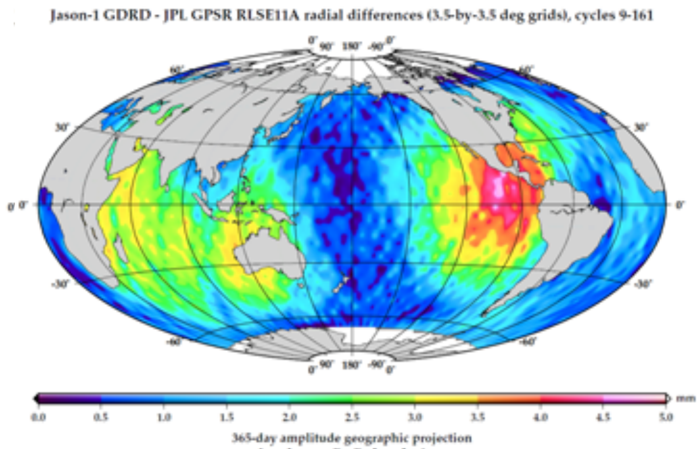


Prospects for Orbit Accuracy Improvement

Geographical Distribution of Annual Terms Between Orbits Using Different TVG Modelling Options

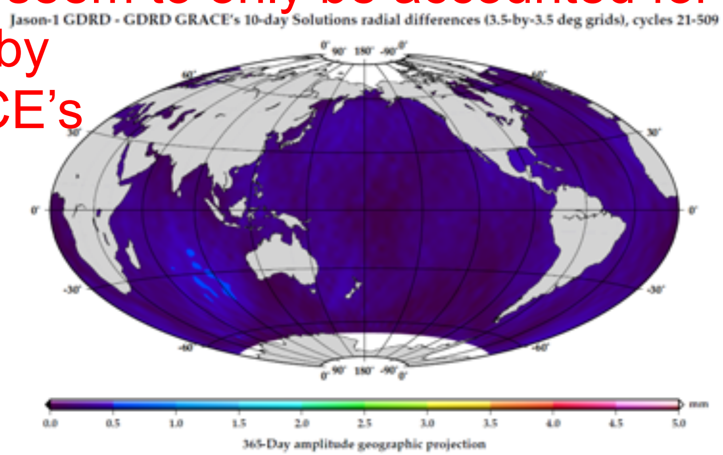
- Estimated amplitudes for Jason-1: East-West order-1 patterns < *4 mm*

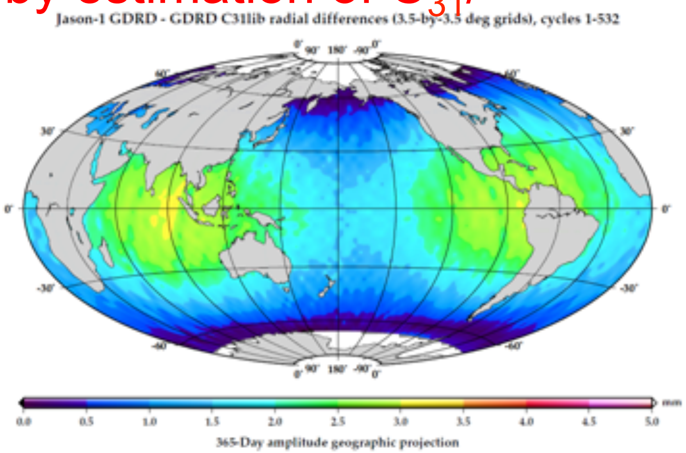




- These annual terms seem to only be accounted for by estimation of C_{31}/ S_{31} coefficients, not by the use of the GRACE's 10-day solutions

=> Reducing annual terms to < *2 mm*

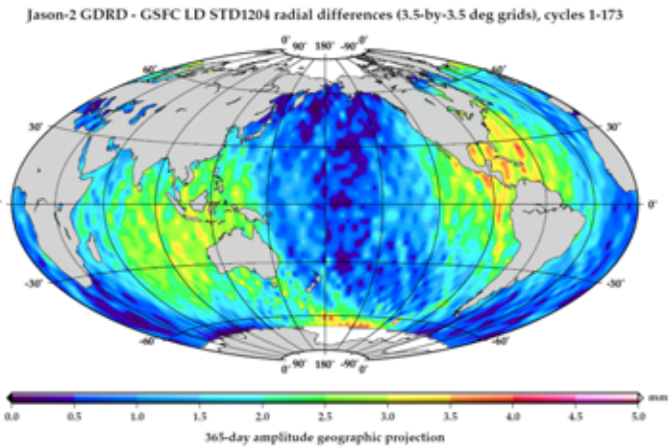


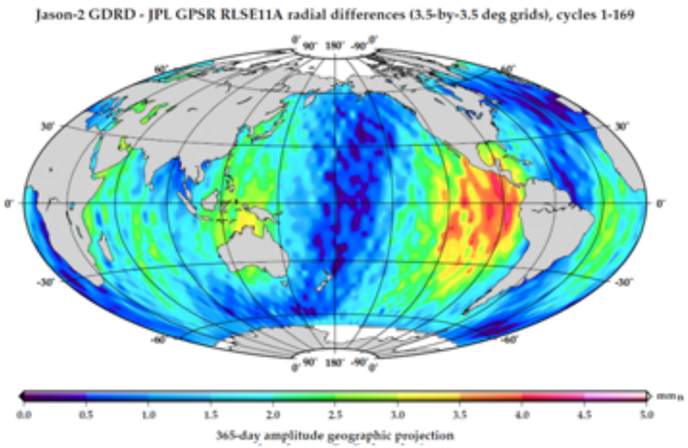


Prospects for Orbit Accuracy Improvement

Geographical Distribution of Annual Terms Between Orbits Using Different TVG Modelling Options

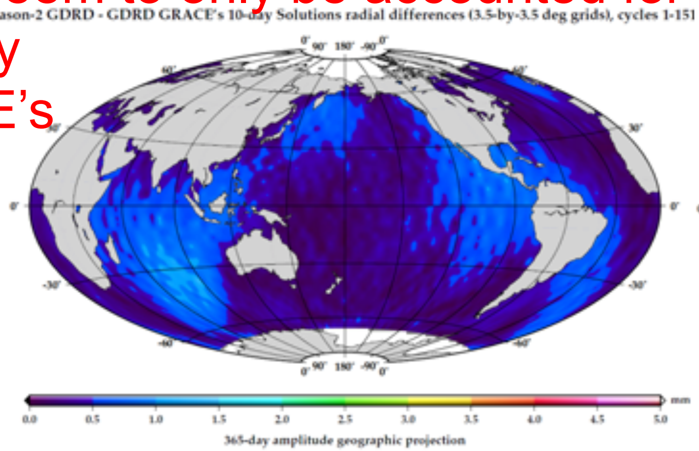
- Estimated amplitudes for Jason-2: East-West order-1 patterns < *4 mm*

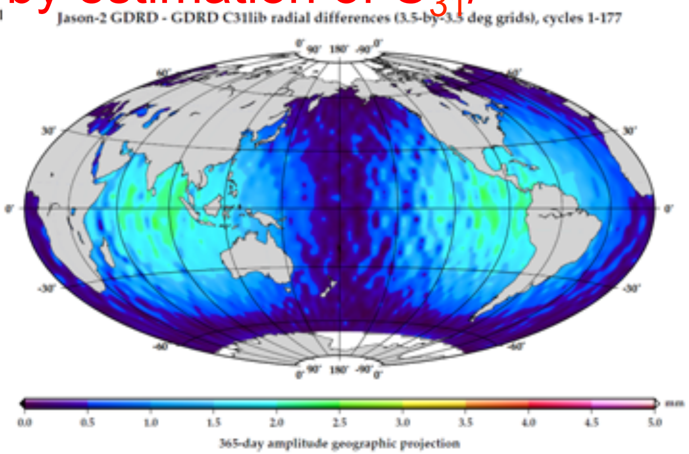




- These annual terms seem to only be accounted for by estimation of C_{31}/ S_{31} coefficients, not by the use of the GRACE's 10-day solutions

=> Reducing annual terms to < *2 mm*

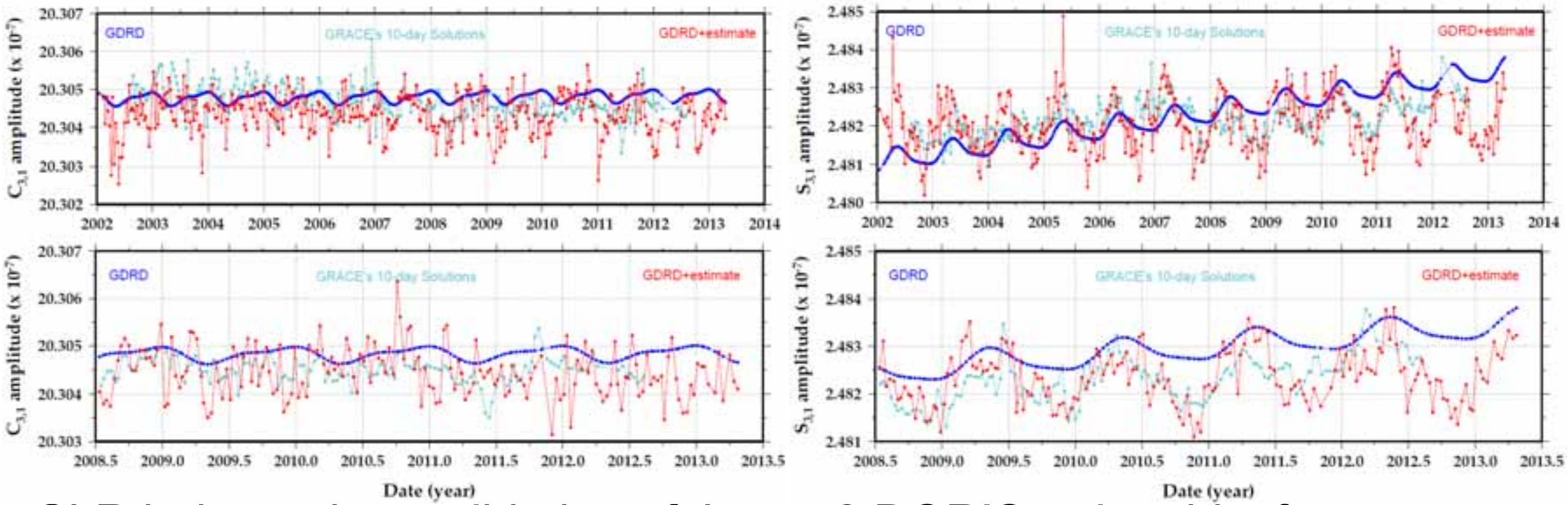




Prospects for Orbit Accuracy Improvement

Does an Estimation of C_{31}/S_{31} Coefficients Improve the GDRD Orbit Accuracy?

- Plots of the C_{31}/S_{31} coefficients estimated on Jason-1 and Jason-2



- SLR independent validation of Jason-2 DORIS-only orbits from two reference stations located in the East-West order-1 patterns

L7090 :

w/o C_{31}/S_{31} estim. : drift *3.3 ± 0.5 mm/y*, annual term *4.3 ± 1.4 mm*
w C_{31}/S_{31} estim. : drift *2.8 ± 0.5 mm/y*, annual term *3.3 ± 1.4 mm*
Drift reduction of *0.5 mm/y*, amplitude reduction of *1.0 mm*

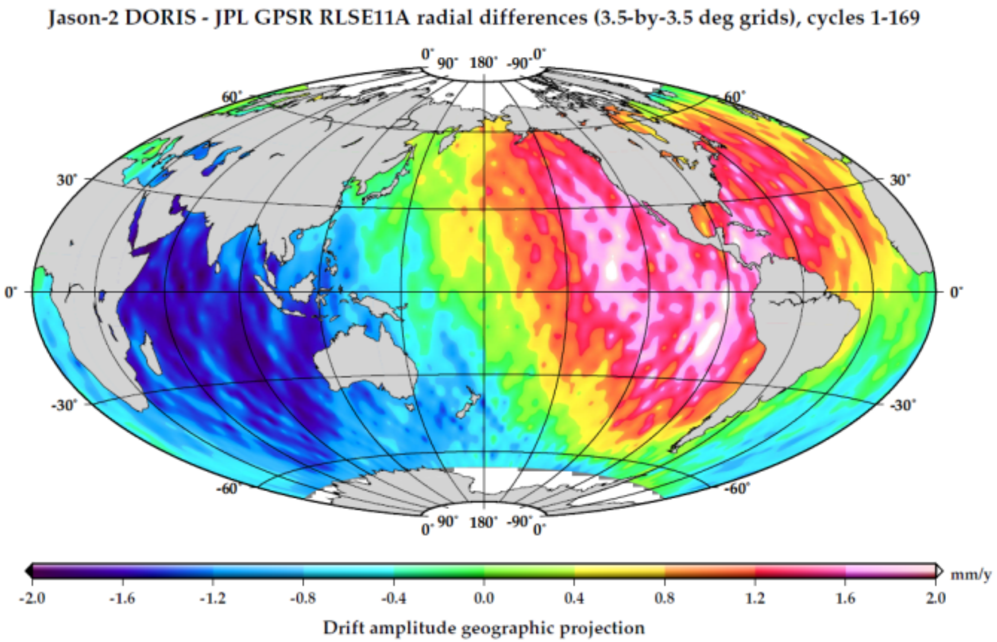
L7105 :

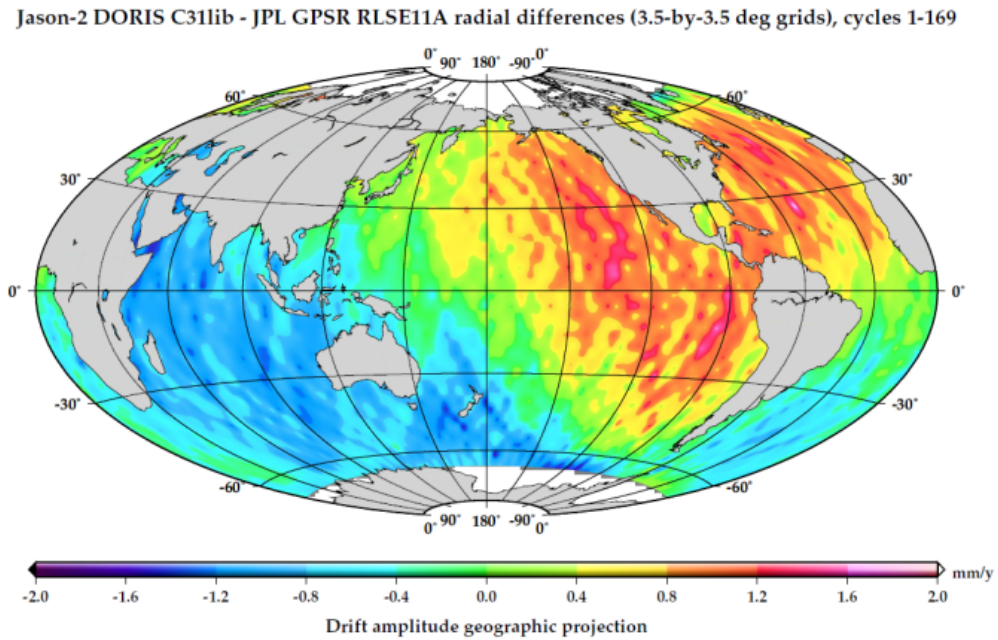
w/o C_{31}/S_{31} estim. : drift *-2.4 ± 0.7 mm/y*, annual term *5.1 ± 2.0 mm*
w C_{31}/S_{31} estim. : drfit *-2.0 ± 0.6 mm/y*, annual term *3.8 ± 1.9 mm*
Drift reduction of *0.4 mm/y*, amplitude reduction of *1.3 mm*

Prospects for Orbit Accuracy Improvement

C_{31}/S_{31} coefficients differ slightly when estimated from DORIS or GPS measurements

- A sub-mm/y level of drift between different orbit solutions can not be guaranteed when using DORIS measurements only





Summary

- Short-term orbit errors are relatively stable over time and do not prevent radial orbit accuracy from reaching the 1-cm RMS goal

- The estimation of C_{31}/S_{31} coefficients in the orbit determination process enables the reduction of radial drifts between the GDRD solution and external orbit series to sub-mm/y level, over the span of the Jason-1 and Jason-2 missions…

  … however, some unexplained discrepancies can be noted between these estimates and their 10-day Grace's solutions counterparts, and between the DORIS and GPS estimates if taken over a shortened period of time

- Estimates of GDRD orbits error budget (> 365-day) are summarized on the following slide

Estimates of GDRD Orbits Error Budget (> 365-day)

Error Source	Global	Regional
Tracking Systems (GPS, DORIS, SLR)	/	<u>Annual term:</u> SLR range biases oscillations from *3* to *9 mm* <u>Long-term evolution:</u> SLR range biases drift (5-10 years) < *2 mm/y*
Reference Frame	<u>Annual term:</u> North/South oscillations < *8 mm* <u>Long-term evolution:</u> Z-drift (10 years) < *0.3 mm/y* <u>GMSL long-term evolution:</u> Drifts (10 years) < *0.05 mm/y*	<u>Long-term evolution:</u> - Jason2 (5 years) < *0.6 mm/y* at extreme latitudes - Jason1 (10 years) < *0.3 mm/y* at extreme latitudes
Time Variable Gravity (TVG)	<u>GMSL long-term evolution:</u> Jason-1 (10 years) < *0.10 mm/y* <u>GMSL interannual variation:</u> - ENVISAT (5 years) < *0.15 mm/y* - Jason-1 ~900-day variability < *0.10 mm*	<u>Annual term:</u> East/West patterns < *4 mm* <u>Long-term evolution:</u> East/West patterns < *2 mm/y* <u>Interannual variations:</u> ENVISAT (5 years) < *3 mm/y*