The effects of using inconsistent OTL correction models for PPP users with IGS products

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ORIGINAL ARTICLE

The effect of using inconsistent ocean tidal loading models on GPS coordinate solutions

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Motivation

- Ocean Tidal Loading (OTL) displacements can reach several cm in magnitude in the vertical component for some specific areas.
- The Green's functions for OTL calculations are different when choosing different reference frames (e.g. CE, CM).
- The current IERS Conventions state that OTL corrections should be computed in CM. Older conventions and products might be in a different reference frame.
- So what is the effect of using a "WRONG" reference frame to model OTL?

Reference Frames

- CE: center of mass of the solid Earth.
- CM: center of mass of the whole Earth system.
- CF: center of figure of the solid Earth surface; nearly equivalent to CE.

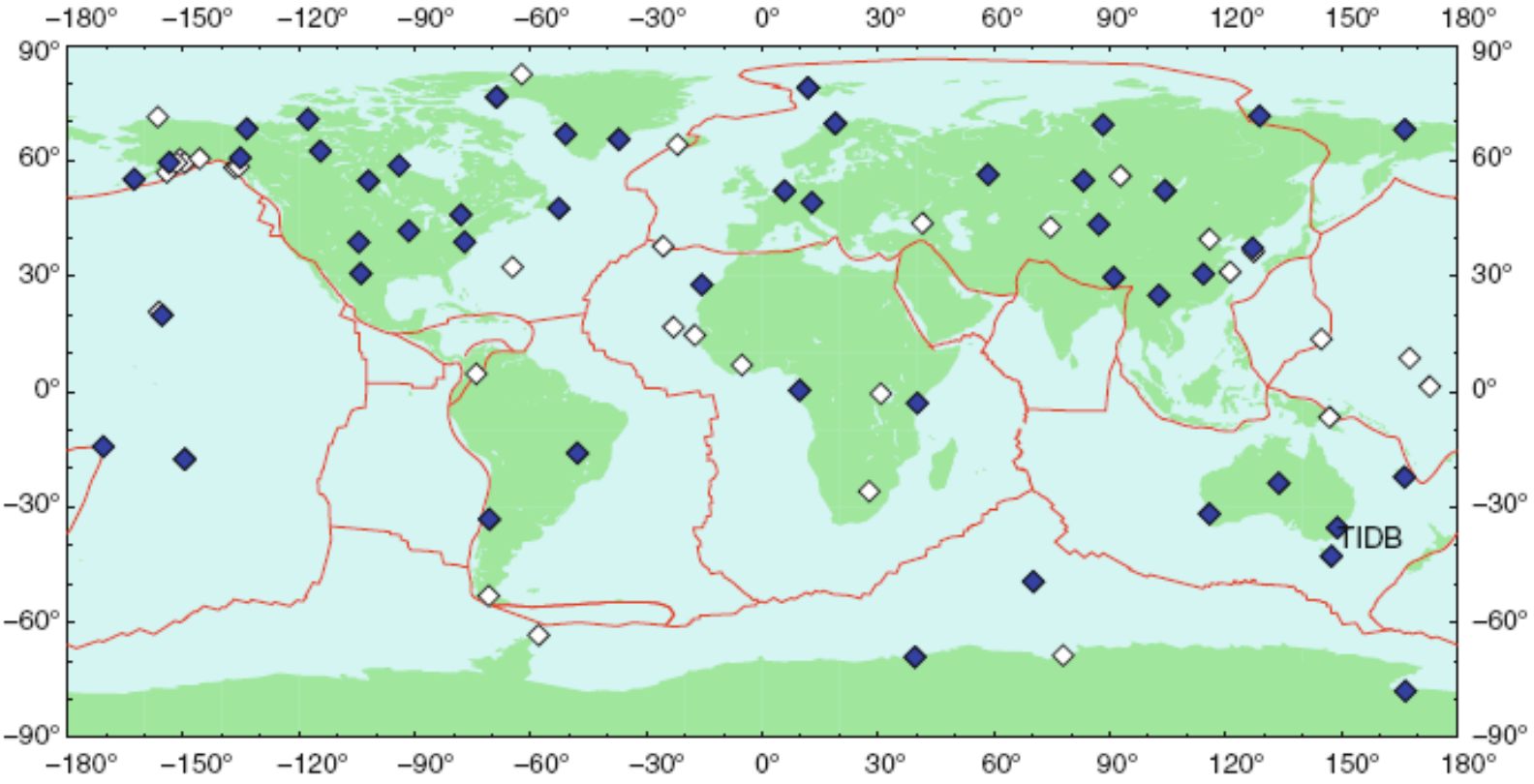
There are two places in GPS data analysis that require the reference frame to be specified for the ocean tides:

1. Analysis Center: frame used for orbit/clock products.
   JPL's **legacy** products: CE; JPL's **reanalysis** products: CM

2. User: the frame to be used when computing the OTL corrections for the site motion model.

3. What happens if the two are inconsistent?

GPS Data Used

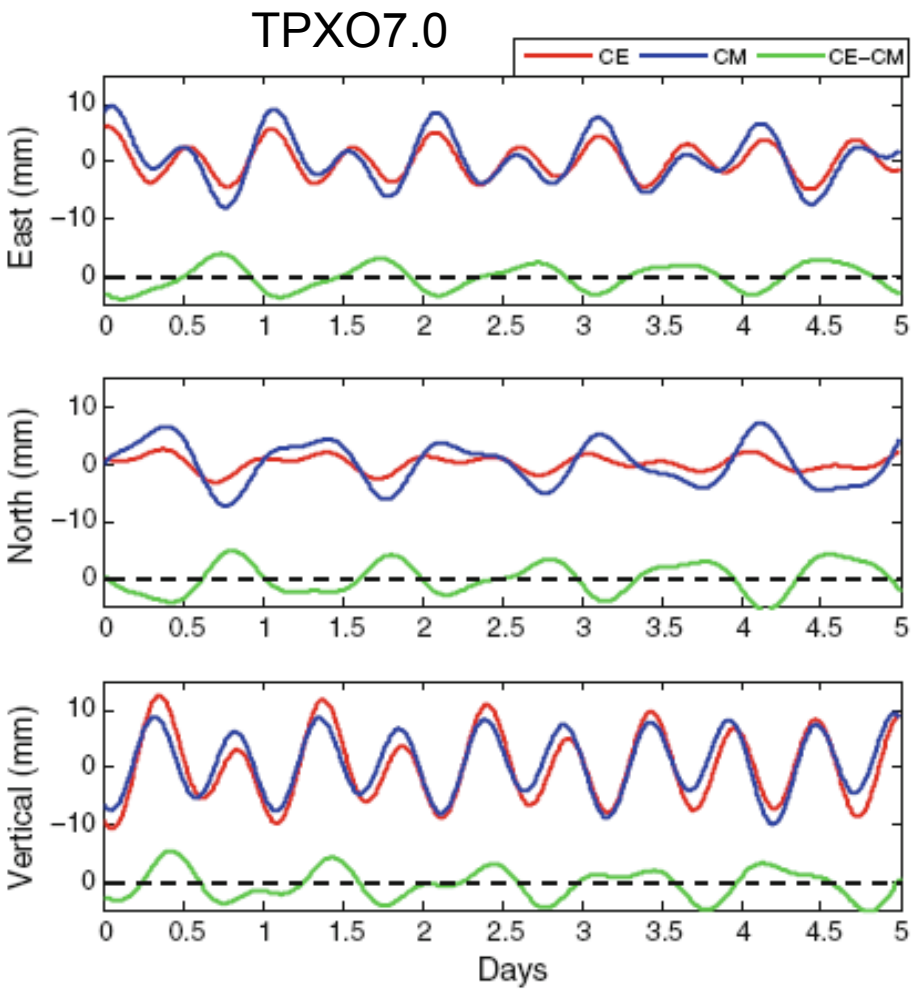


85 globally distributed continuous GPS stations. *Solid diamonds* denote sites used in the stacked power spectral analysis (~48 sites).

OTL Calculation Methods

- In this analysis, we use the tidal model computed from two different sources:
  1. FES2004 tide model (including the tidal components M2, S2, N2, K2, K1, O1, P1, Q1, MF, MM and SSA) were computed using Hans–Georg Scherneck's web tool:
     a. http://www.oso.chalmers.se/~loading/
     b. Users can choose the reference frame.
  2. TPXO7.0 tide model (components M2, S2, N2, K2, K1, O1, P1, Q1, MF, MM) were computed using the SPOTL software (Agnew, 2012). Green's Functions in CE and CM are provided.

Modeled OTL displacement example



Modeled OTL displacement of station TIDB for the first 5 days of 2005

Constituent	Period (hours)	Aliased Period (days) 24 hr Processing	Repeat Orbit
M2	12.42	14.76	13.66
S2	12.00	∝	182.63
N2	12.66	9.61	9.13
K2	11.97	182.63	∝
O1	25.82	14.19	13.66
K1	23.93	365.26	∝
P1	24.07	365.24	182.63
Q1	26.87	9.37	9.13

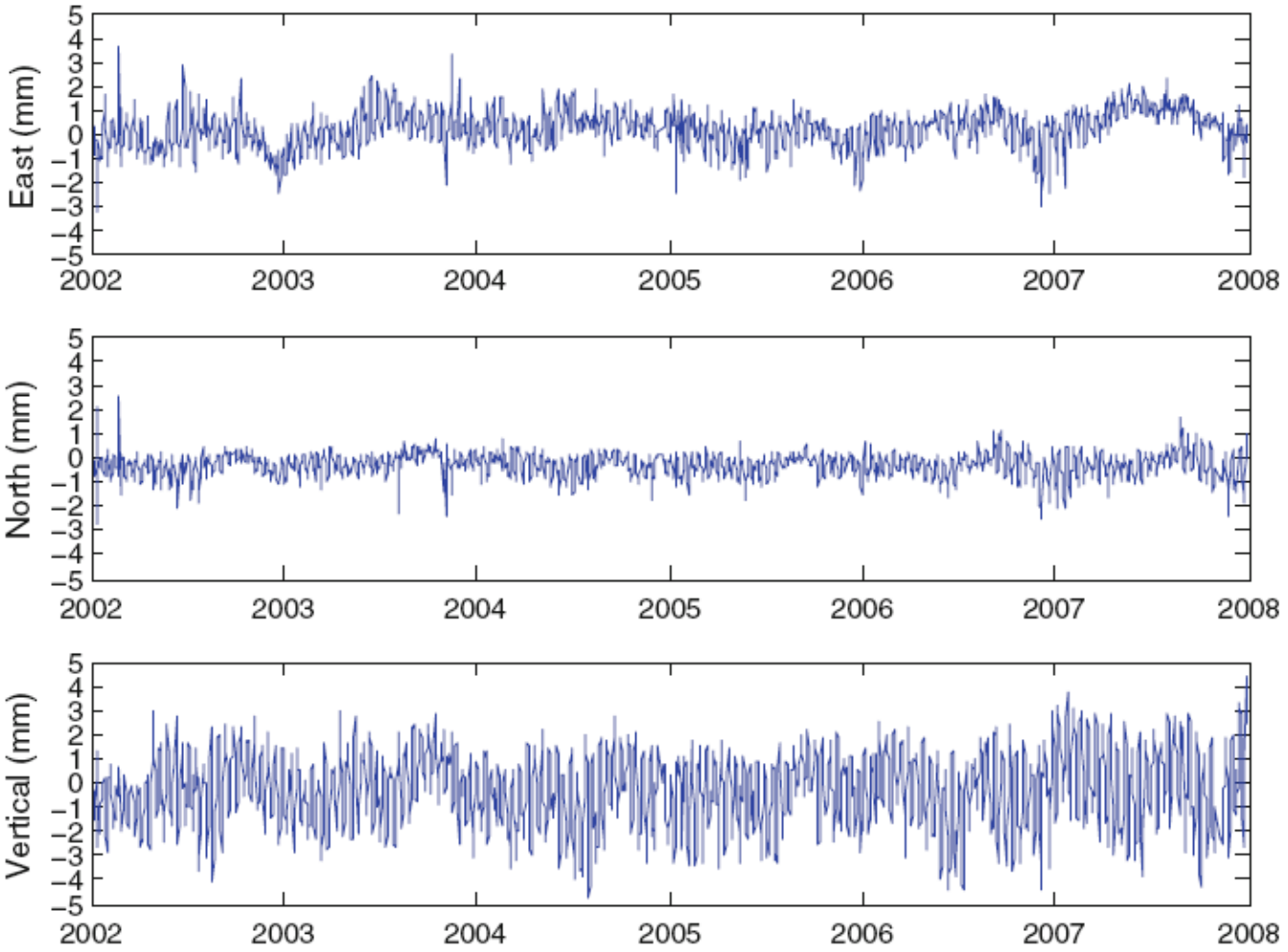
(Penna and Stewart 2003)

- Any mis-modeling of diurnal and semidiurnal tidal constituents can be aliased to longer period signals in the GPS coordinate time series.

Comparison between solutions using different frame for PPP

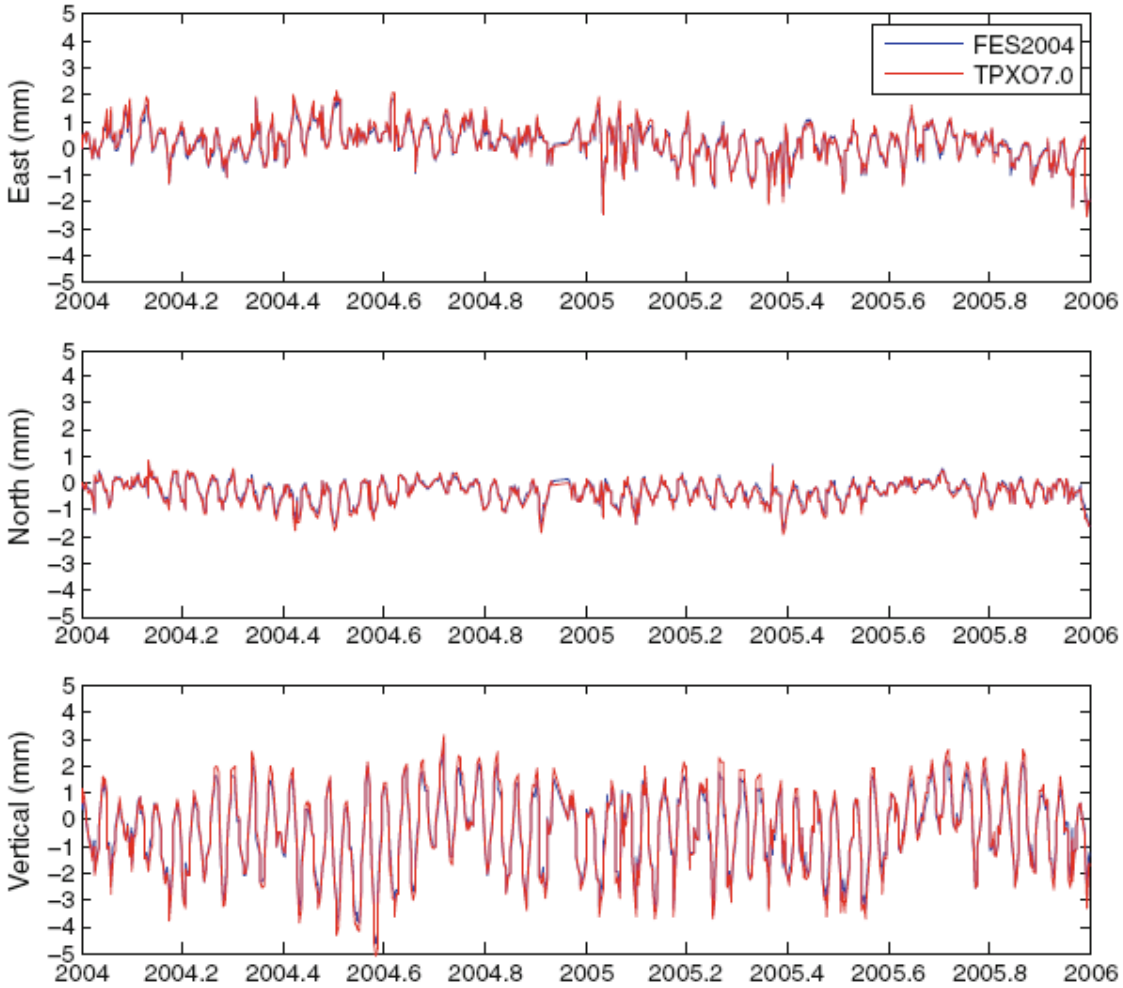
- Use JPL's **reanalysis** orbit/clock product (OTL-CM)
- Compute station motion using CM and CE frame
- Compare the difference
- No particular tide model

, AustrTIDB (Canberraalia)



Comparison between solutions using different frame for PPP

- Differences for a single year using different tidal model

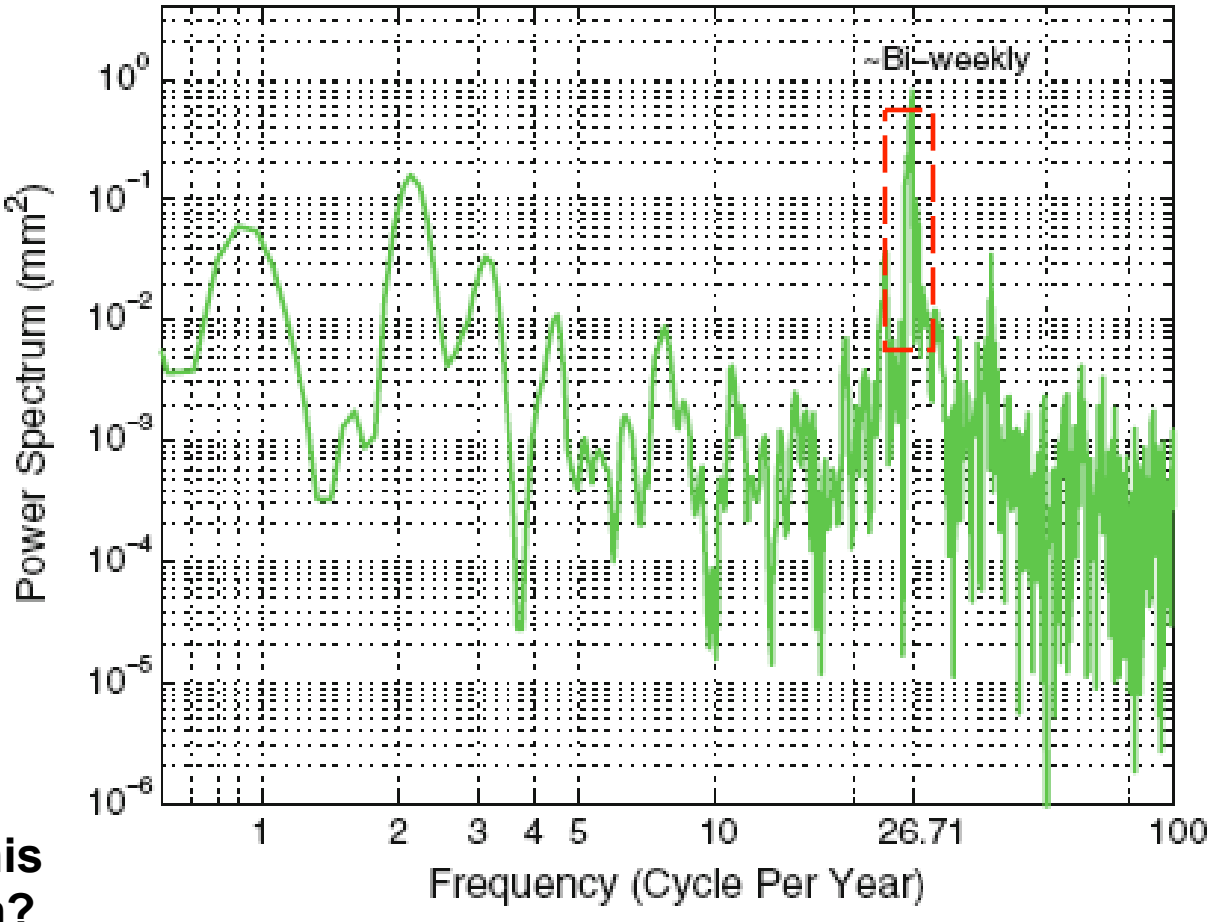


Differences driven by the different reference frame are larger than the differences between the tidal models

Spectrum of the Differences

- Use JPL's **reanalysis** orbit/clock product (OTL-CM)
- Compute station motion using CM and CE frame
- Compare the difference
- No particular tide model
- Power spectrum of the vertical coordinate differences from the 6 year time series

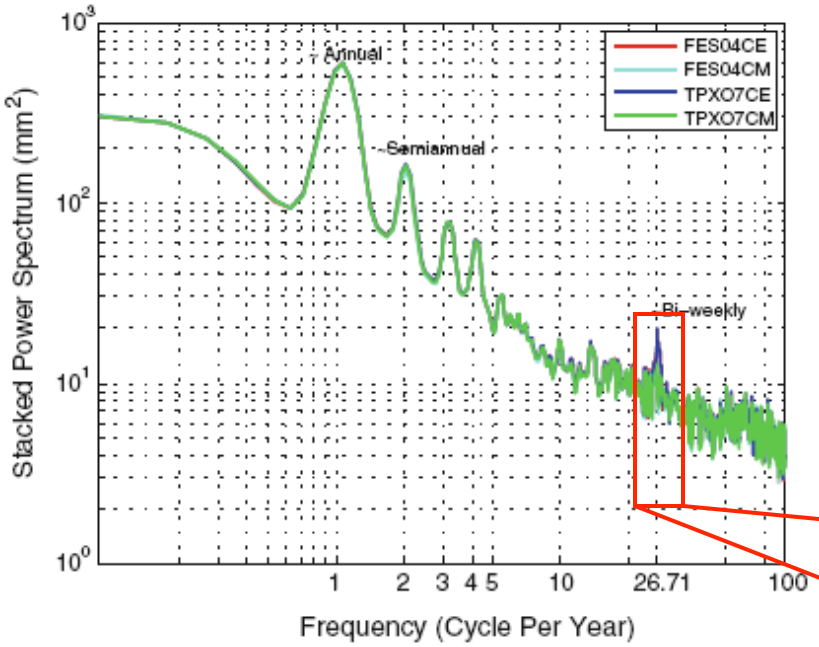
TIDB (Canberra, Australia)



Which solution contains this spurious periodic variation?

Which reference frame is driving the fortnightly power?

- Stacked Power spectrum from the 48 sites for 4 cases of station motion model
  - FES2004 CM
  - FES2004 CE
  - TPXO7.0 CM
  - TPXO7.0 CE
- In all cases, we use the reanalysis product (OLT CM)

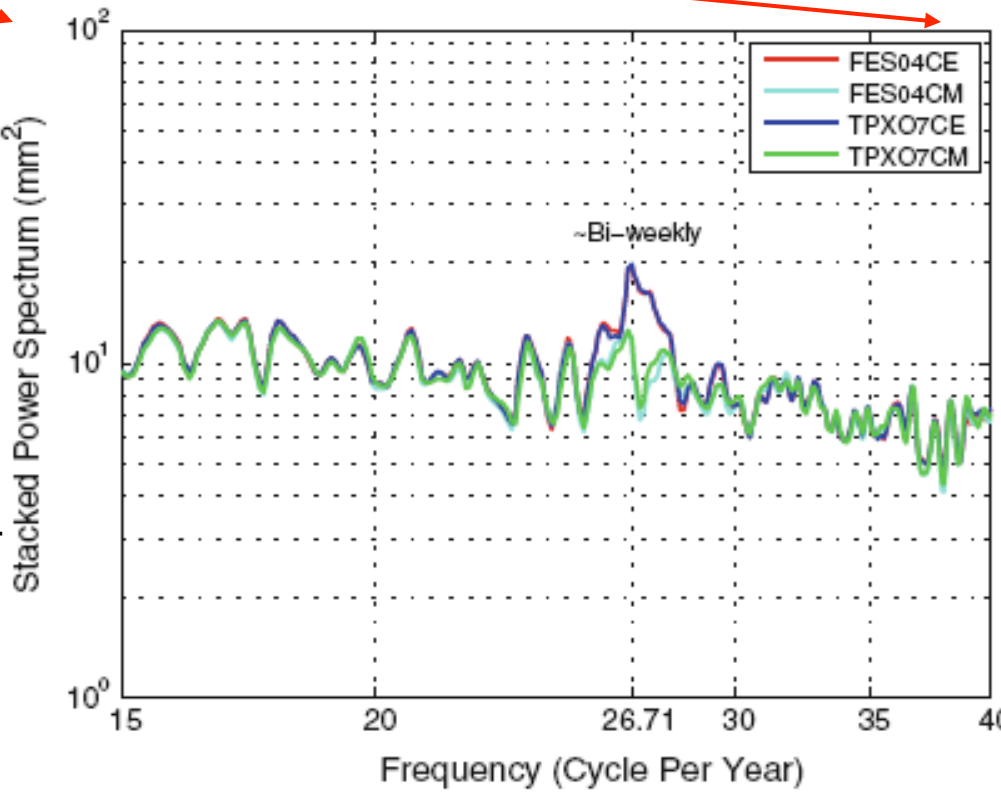


Stacked power spectrum for the vertical coordinate timeseries of 48 GPS stations.

A detail of the top panel highlighting the ~14-day period.

~14-day peak is only present in solution using OTL-CE frame.

- JPL's **reanalysis** orbit/clock products: OTL-CM.
- JPL's **legacy** orbit/clock products: OTL-CE.
- Let's see what happens when the site motion model is inconsistent with the legacy products



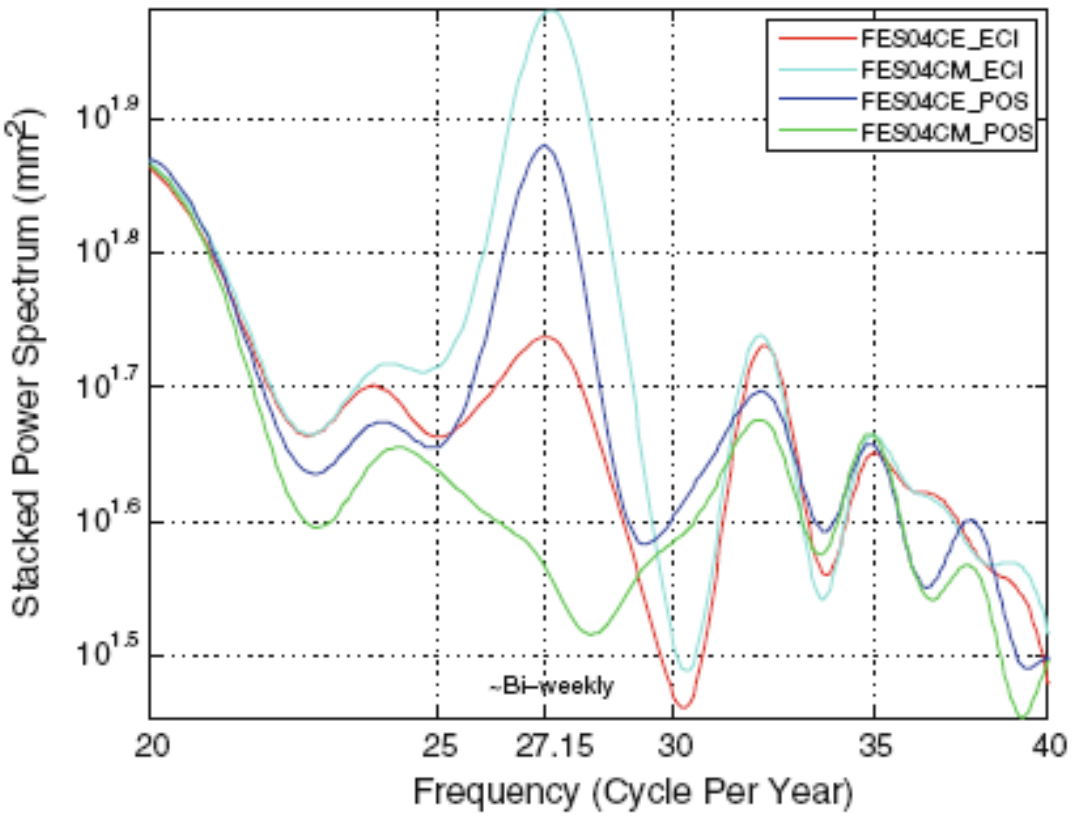
Testing the importance of consistency in OTL coefficients

JPL's **reanalysis** orbit/clock products: OTL-CM.
JPL's **legacy** orbit/clock products: OTL-CE.

Methods:
We want to test four combinations of OTL coefficients used for PPP users and orbit/clock products:

Solution Name	Orbit Product	Frame of product	Frame for user	consistency
FES04CE_ECI	Legacy (eci)	**CE**	**CE**	**Yes**
FES04CM_ECI	Legacy (eci)	**CE**	**CM**	*No*
FES04CE_POS	Reanalysis (pos)	**CM**	**CE**	*No*
FES04CM_POS	Reanalysis (pos)	**CM**	**CM**	**Yes**

- Stacked power spectrum showing the ~14-day period component of 1-year (2002) detrended vertical coordinate timeseries for GPS solutions.
- The same tidal model is used in all cases



- The power at the fortnightly period is smaller for solutions with consistent OTL coefficients used for products and the site motion model: **FES04CM_POS** and **FES04CE_ECI.**
- Using a reference frame for the site motion that is inconsistent with the products can introduce systematic errors.
- At this point, we can not conclude that using consistent CM is better than consistent CE, because there are many differences between the legacy and the reanalysis orbits

Is consistent CM significantly better than consistent CE?

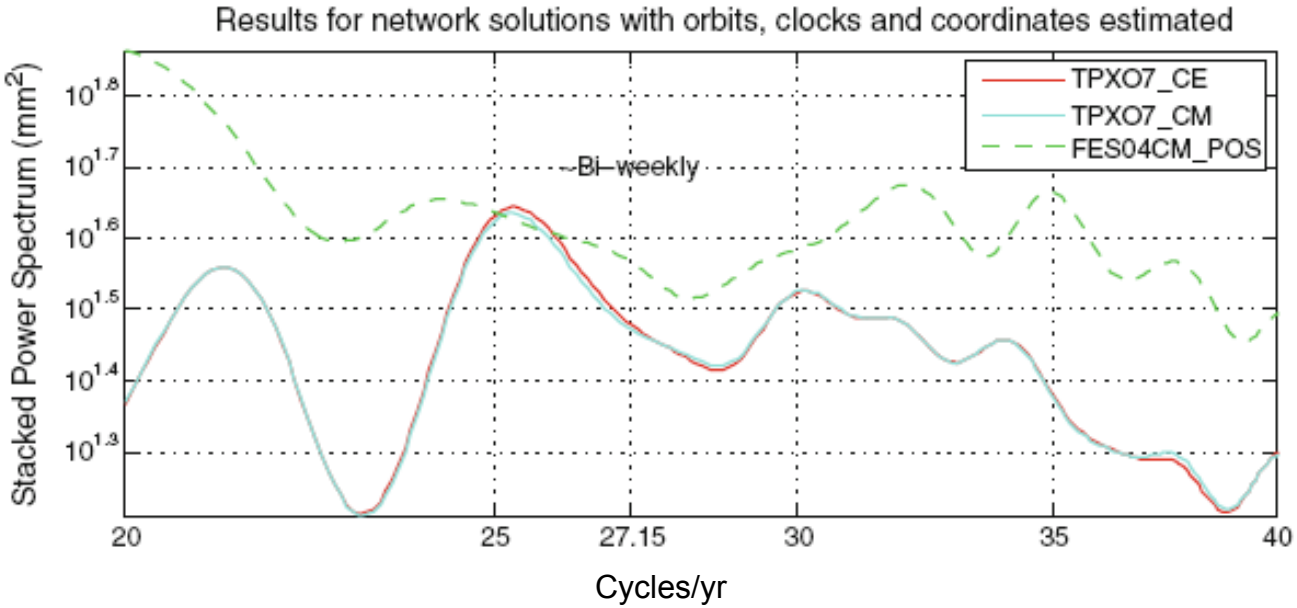
Testing Method:

- We generated a 1-year (2006) set of solutions with orbits, clocks and positions estimated.

- In a single-step global solution, it is not possible to generate an inconsistency in OTL coefficients as all parameters are estimated simultaneously in the solutions.

Is consistent CM significantly better than consistent CE?

NO



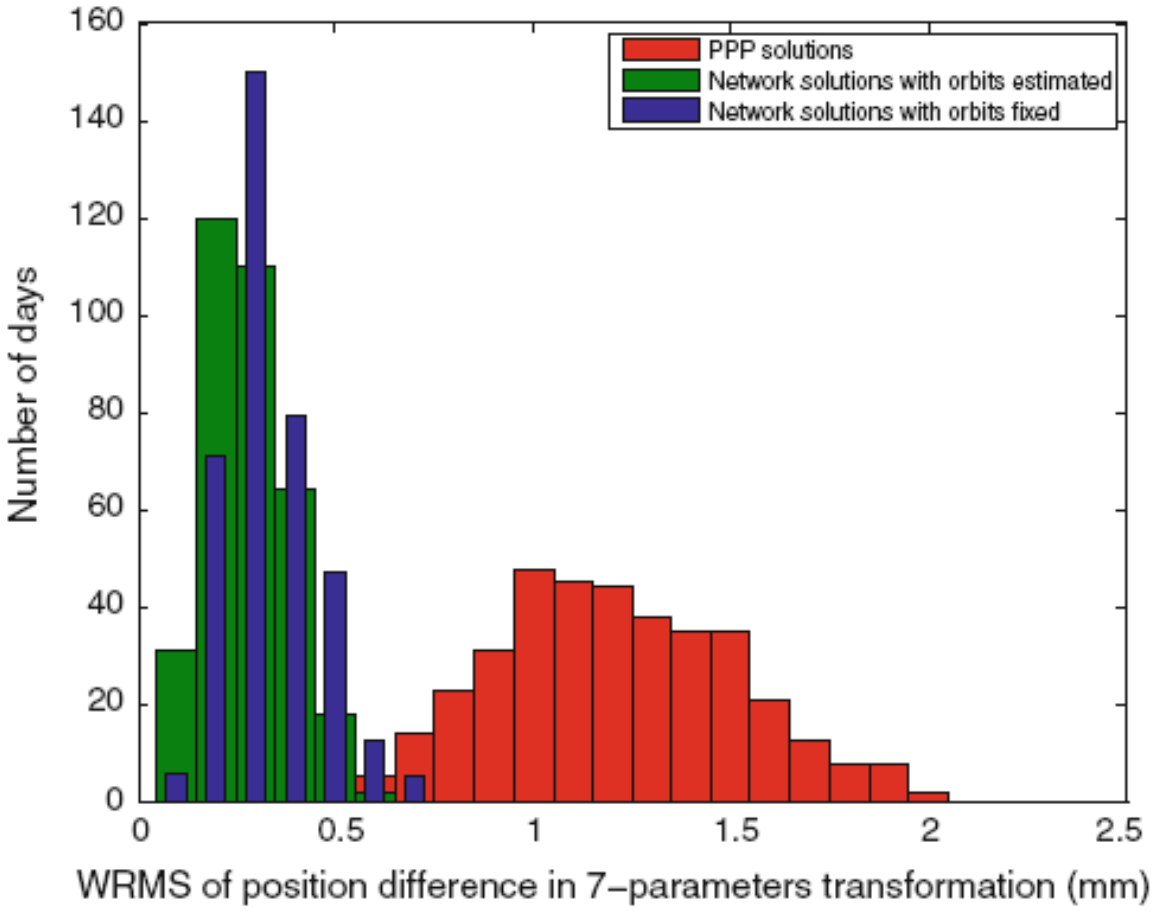
(Stacked power spectra showing the ~14-day period component from 1-year detrended vertical coordinate time series for global solutions with orbits, clocks and coordinates estimated)

- The biases at ~14-day period disappear.
- The magnitudes difference between TPXO7_CE and TPXO7_CM are indistinguishable.
- **The use of consistent OTL coefficients is more important than using one particular frame or the other!**

Network Solutions

- Many users who want network solutions do not employ ppp but fix orbits (external products) and estimate clocks.
- If the reference frame inconsistency only affects the orbits, then then this solution will look just like a ppp solution.
- If it affects the clocks, then the impact of the inconsistency will be much smaller.
- We compare 3 sets of solutions:
  - PPP peak at 1.3 mm
  - Network with orbits, clocks, and positions estimated,
  - Network with only the clocks and positions estimated, 0.3 mm
- Yuning and Jeff used a 7 parameter transformation to compare the coordinate differences of the 2 different solutions.

Where do the biases go: orbit or clock?



Histograms of WRMS (mm) of vertical coordinate differences after application of a 7-parameter transformation between solutions with OTL modeled in two different frames.

The differences between solutions using OTL-CM and OTL-CE:

WRMS [Global solution (orbit, clock estimated] is approximately equal to the WRMS [Network solution with the orbit fixed]
BOTH are much less than the WRMS [PPP]

Indicates: Biases mainly remain in clock.

Summary

- Significant biases can be introduced into GPS solutions when a user solution uses OTL coefficients computed in a different reference frame to those used by the analysis center in their product generation solution.

- The most distinguishable biases occur at a period of ~14 days.

- In any solution that uses fixed orbits or fixed orbits and satellite clocks, it is the analyst's responsibility to maintain consistency with the analysis center that generated the products.