Arctic Ocean Tides from GRACE Satellite Accelerations

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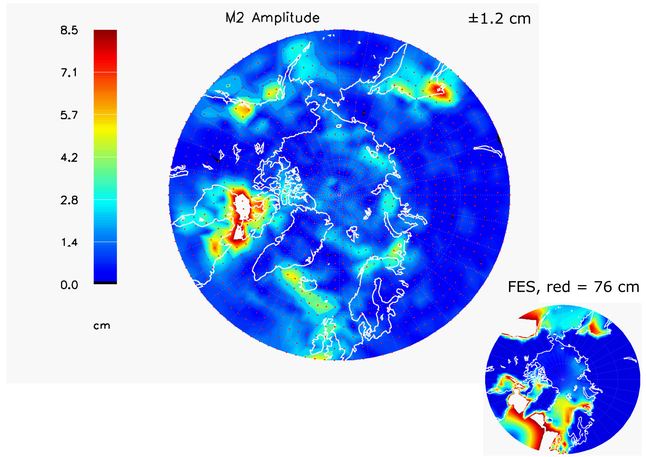
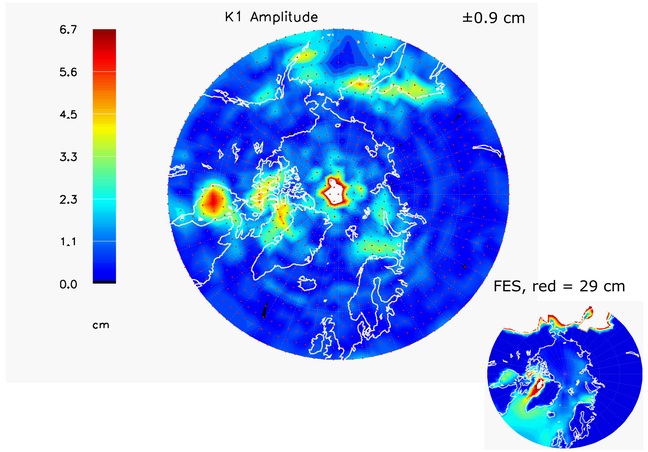
Residual Tide Amplitudes, Relative to FES 2004

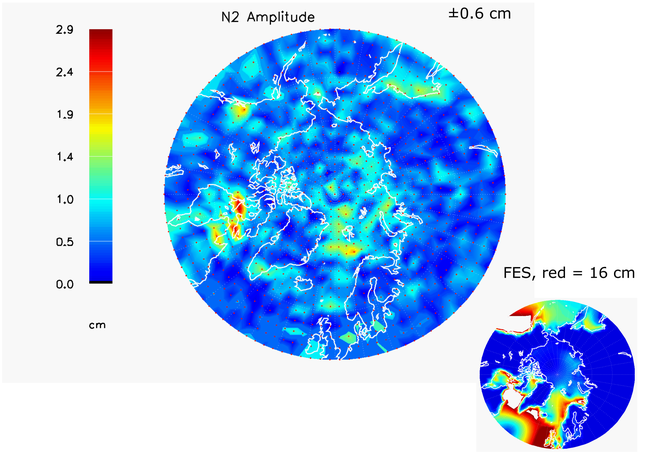
GRACE measures gravity fluctuations using two satellites in the same low-earth orbit. One satellite is ~220km ahead of the other, and the two satellites are connected by a microwave ranging system that continuously measures their relative separation distance. Because the first satellite is ahead of the second, it's affected by differences in local gravity before the second satellite. This delay can be used to deduce the underlying gravity variations. Many GRACE projects describe these gravity variations using spherical harmonics, but we chose to use mass concentrations (or "mascons") to parameterize variations in local gravity.

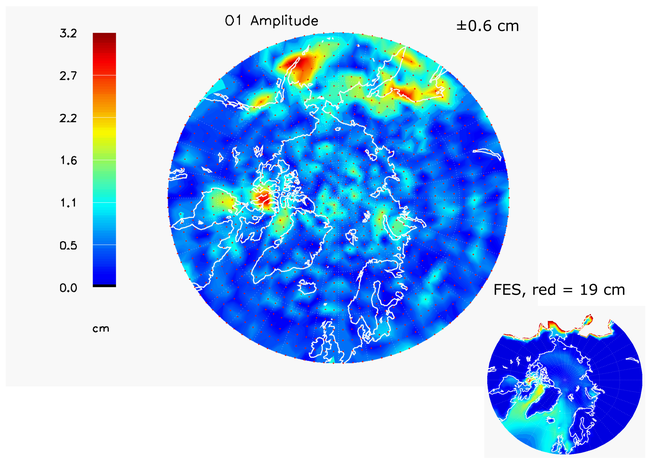
5 years of GRACE inter-satellite accelerations were inverted to solve for the following tide amplitude maps. The inversion used point mass mascons separated by 230 km. (7 year results are ongoing.) These accelerations have had FES 2004 and various dealiasing products subtracted, and have been smoothed by a 50 second CRN filter. Tikhonov damping was applied by adding an identity matrix (multiplied by 20) to the covariance matrix before solving for the tide amplitudes. Amplitudes and phases for all tides were solved simultaneously over the entire region shown in figures 1-5, along with a constant, linear trend, semi-annual and annual periods (not shown). Each figure is accompanied by a small version of the matching FES tide and its (saturated) color scale which is much larger than the main figure's color scale.

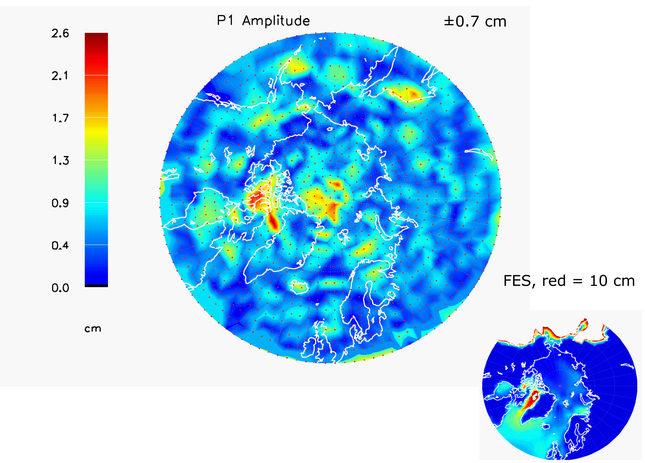
Figures 1-5 - Tide Amplitudes











Verification of Residuals

The mascon fields have much larger tide amplitudes in the ocean than on land, and generally have higher amplitudes where FES 2004 is also highest. Land tides are assumed to be due to instrumentation noise, aliasing and leakage from the oceans. The 1 sigma error bars quoted in figures 1-5 are derived from the signal over land.

These mascon fields should reduce the RMS of residual GRACE accelerations. 5 years of residual accelerations recorded every 5 seconds when the satellites were north of 50N were available. The first 80% of these accelerations were used to solve for the tides in figures 1-5, as well as a nontidal part (not shown) consisting of a constant, linear trend, semi-annual and annual amplitudes. The last 20% of the data were reserved to verify that the inverted mascons reduce the RMS of acceleration values not used in the solution.

The accelerations due to the nontidal part of the solution were subtracted from the original accelerations, then the additional reduction in RMS due to the tides was calculated. The reduction due to tides was calculated separately for ocean tides (defined as tides at mascons with at least some ocean) and land tides (tides at mascons with no ocean.) Each of these reductions were calculated separately for those accelerations used in the inversion and those reserved for verifications.

- Ocean tide RMS reduction for inverted accelerations : 0.95%
- Ocean tide RMS reduction for verification accelerations: 0.71%
- Land tide RMS reduction for inverted accelerations : 0.19%
- Land tide RMS reduction for verification accelerations : 0.07%

The ocean tides reduce the RMS of the inversion and verification accelerations by roughly the same amount. The land tides, however, don't reduce the RMS of the verification accelerations as much as those used in the inversion. This supports the idea that land tides are significantly noisier than ocean tides, but also shows that this noise isn't random (otherwise the land tides wouldn't reduce the RMS at all.)

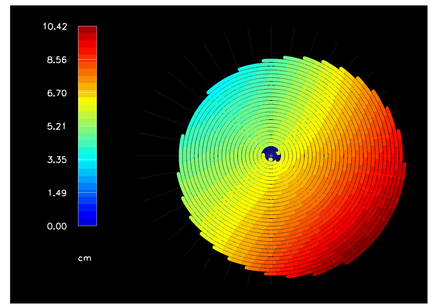
North Pole Anomaly

An irregularly shaped region ~40km in diameter centered on the north pole is being treated as land by FES 2004, in the sense that tides aren't modeled there. Upon conversion to the spherical harmonic basis, the sharp discontinuity in every constituent likely results in a Gibb's phenomenon that increases both the amplitude of the discontinuity and its geographical extent.

The possibility of a connection between the FES hole and the K1 north pole anomaly is intriguing. The anomaly might appear in the inverted mascon field for K1 most strongly because of its long (~7.5 year) alias period with the GRACE sampling. At latitudes south of the turning latitude (89 N) GRACE samples the K1 tide twice during each period on the ascending/descending passes. At the turning latitude, however, the tide is only measured once during each period because GRACE's sensitivity is stronger directly underneath the GRACE midpoint and because the K1 forcing potential is stationary in inertial space. As a result, each time GRACE is at the turning latitude it's sensing almost exactly the same phase of the K1 tide because the GRACE orbit precesses very slowly and is thus almost stationary in inertial space too.

Thanks to Richard Ray for his insights regarding this matter.

Figure 6 - Hole in FES 2004 M2 amplitude



Conclusions

- The mascon fields have much larger tide amplitudes in the ocean than on land, and are mostly larger where FES 2004 is also larger. This reinforces the assumption that the ocean solutions do reflect the true tidal signal.
- Ocean tides reduce the RMS of accelerations not used by the inversion nearly as well as they reduce the RMS of accelerations used in the inversion. Land tides don't, so they're used as noise estimates.
- Mascon solutions based on 7 years of accelerations will be posted soon at http://emmykillett.com
- FES 2004 requires interpolation to fill in the hole at the north pole.
- The K1 north pole anomaly is most prominent of all constituents due to the long alias period of K1 at the turning latitude.

References

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