# Seasonal Variations of the Earth's Gravitational Field: An Analysis of Atmospheric Pressure, Ocean Tidal, and Surface Water Excitation

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The Earth is a dynamic system—it has a fluid, mobile atmosphere and oceans, a continually changing global distribution of ice, snow, and water, a fluid core that is undergoing some type of hydromagnetic motion, a mantle both thermally convecting and rebounding from the glacial loading of the last ice age, and mobile tectonic plates. These processes affect a number of global geodynamic properties of the Earth including its geocenter location (that is, the location of the Earth's center-of-mass relative to the crust), rotation, and gravitational field. Since the Earth's global gravitational field changes only in response to net mass redistribution, observations of it allow the isolation and subsequent investigation into the Earth's changing mass distribution. Here, seasonal variations in the Earth's gravitational field are investigated through the analysis of LAGEOS I satellite laser ranging measurements spanning 1984 to 1992. Global surface pressure data from the National Meteorological Center (NMC) are analyzed to study the contribution of atmospheric mass redistributions to the observed gravitational field variations; a self-consistent equilibrium ocean tide model is used to compute the effect on the gravitational field of the annual and semiannual ocean tides; and the effect of seasonal variations in continental surface water storage [*Chao and O'Connor*, Global surface-water-induced seasonal variations in the Earth's rotation and gravitational field, *Geophys. J.*, 94, 2,63-270, 1988] is considered. Since laser ranging measurements to a single satellite arc sensitive only to certain satellite-dependent linear combinations of the gravitational field coefficients, those same linear combinations of coefficients are formed when modeling the effect on the gravitational field of seasonal variations in atmospheric pressure, continental surface water storage, and ocean tides.

Table 1. Correlation and Variance Reduction Between Observed and Predicted $C_{even}$ (1984– 1992)

| | Inverted Barometer (IB) | | Non-Inverted Barometer (NIB) | |
|---|---|---|---|---|
| | Correlation* Coefficient | Variance Explained | Correlation Coefficient | Variance Explained |
| Atmospheric pressure† | 0.83 | 65.4% | 0.75 | 39.9% |
| Atmospheric pressure plus equilibrium ocean tides | 0.89 | 78.4% | 0.81 | 48.7% |
| Atmospheric pressure plus equilibrium ocean tides plus surface water | 0.91 | 82.3% | 0.84 | 44.2% |
| Atmospheric pressure plus equilibrium ocean tides plus annual surface water | 0.93 | 86.1 % | 0.86 | 46.7% |

* From Monte Carlo tests, the 99% significance level for the correlation coefficient is 0.243.

† All series have been highpass-filtered with a cutoff period of 2 years prior to computing their correlation and variance reduction,

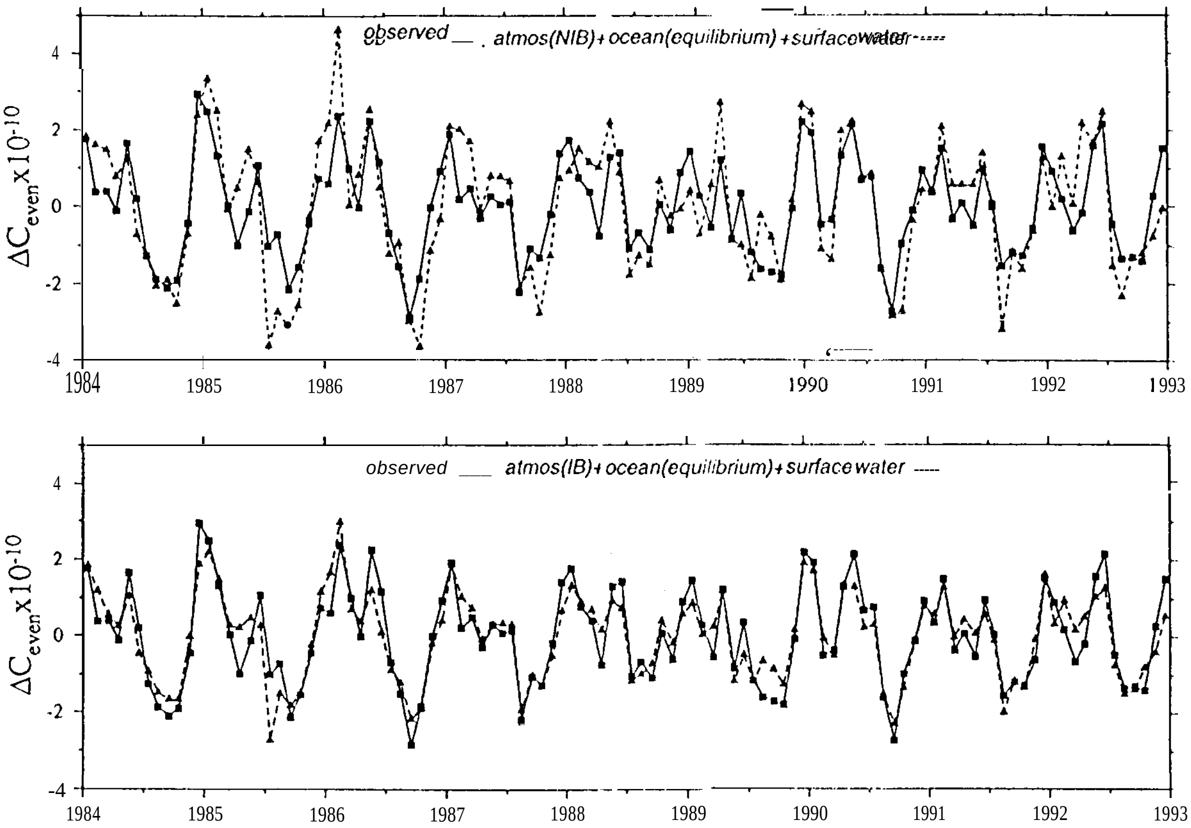

Figure 1, (a) Variations of observed (solid line) and predicted (dashed line) $C_{even}$. The predicted $C_{even}$ values are the sum of the modeled effects of (1) NMC atmospheric surface pressure computed under the non-inverted barometer (NIB) model, (2) equilibrium ocean tides, and (3) surface water. (b) Same as (a) except the predicted atmospheric effect is computed under the inverted barometer (IB) model. Variations with periods greater than two years have been removed from all series plotted by highpass filtering.

The observed $C_{even}$ gravitational field parameter analyzed here is a linear combination of primarily the low-degree, even zonal gravitational field coefficients and will therefore be most sensitive to mass changes occurring in high latitude regions of the Earth since it is in these regions that the low-degree Legendre functions, which can be viewed as weighting functions when computing the individual gravitational field coefficients, have their greatest value. This allows observed variations in the $C_{even}$ gravitational field parameter to be potentially useful in studying polar processes such as fluctuations in the mass of ice sheets. Prior to these studies, however, other sources of fluctuations in $C_{even}$, such as ocean tides and atmospheric pressure, must be accurately modeled and removed from the observations.

Comparisons (see Table 1 and Figure 1) of the monthly average.d $C_{even}$ observations to that Predicted by modeled atmospheric pressure, ocean tidal, and surface water fluctuations indicate that on intraseasonal through seasonal timescales (that is, for periods less than two years), and when the atmospheric pressure effect is computed under the inverted barometer assumption, these three mechanisms alone can account for up to 86.1 % Of the observed variance, and have a correlation as large as 0.93 with the observations. Under the NIB assumption, these three mechanisms can account for at most 48.7% of the observed variance. The strong preference for the IB assumption obtained here is consistent with numerous studies that have demonstrated the validity of the inverted barometer assumption on these timescales.