GRACE Gravity Model Suite GGM05

Please note: For the satellite-only fields GGM05S and GGM05G, these solutions are not regularized, and rapidly increasing errors make the coefficients unreliable at higher degrees. GGM05S, the GRACE-only gravity solution, is available to degree/order 180 but should not be used beyond approximately degree 150 without smoothing (100 km smoothing recommended). Similarly, GGM05G, the GRACE/GOCE satellite-only combination, is available to degree/order 240 but should not be used beyond approximately beyond degree 210 without smoothing (50 km smoothing recommended). Over the polar regions, it may be possible to use slightly higher degree coefficients. If a higher resolution gravity model is required, the combination gravity model GGM05C, complete to degree/order 360, can be used; no truncation or smoothing should be necessary.

Additional Notes on the GGM05 gravity field solution and background modeling:

C20, C00, C10, C11, S11, C21, S21

C00 is defined to be exactly 1, and the degree one terms are defined to be exactly 0. These coefficients are not explicitly included in the geopotential file.

C20 is a zero-tide value, *i.e.* it includes the zero-frequency (permanent) tide contribution; in order to convert to a tide-free system, add 4.173×10^{-9}. Its epoch is 2008.0, the approximate mid-point of the ten years used (2003-2013) in the solution.

Coefficient file description:

The coefficients for GGM05 are normalized according to the so-called "fully-normalized" convention, where the squared norm of a spherical harmonic over a unit sphere is 4π (see below). The standard deviations or 'sigmas' (approximately calibrated, not the formal values) are included with the coefficients. The Earth radius (Ae) and GM to be used for scaling in the expression for the geopotential are included in the coefficient file.

'GEO' file format specification:

line 1: Format for next line
line 2: 20 character description, GM (km^3/s^2), Ae (m), Epoch (for those terms with rates)
line 3: Format for following lines
line 4+: 6-character string, degree, order, C, S, C-sigma, S-sigma, normalization flag (-1 = normalized)

Comments or Questions ? Please contact grace@csr.utexas.edu

Normalization Convention:

If φ denotes the geographical latitude of a field point (0° at equator, 90° at the North pole, and –90° at the South pole), and if $u = \sin\varphi$, then the un-normalized Legendre Polynomial of degree l is defined by

$$P_l(u) = \frac{1}{2^l \times l!} \times \frac{d^l}{du^l}\left(u^2 - 1\right)^l$$

The definition of the un-normalized Associated Legendre Polynomial is then

$$P_{lm}(u) = \left(1 - u^2\right)^{\frac{m}{2}} \frac{d^m}{du^m} P_l(u)$$

If the normalization factor is defined such that

$$N_{lm}^2 = \frac{(2 - \delta_{0m})(2l+1)(l-m)!}{(l+m)!}$$

and the Associated Legendre Polynomials are normalized by

$$\overline{P}_{lm} = N_{lm} P_{lm}$$

then, over a unit sphere S

$$\int_S \left[\overline{P}_{lm}(\sin\varphi)\begin{Bmatrix}\cos m\lambda \\ \sin m\lambda\end{Bmatrix}\right]^2 dS = 4\pi$$

In this convention, the relationship of the spherical harmonic coefficients to the mass distribution becomes

$$\begin{Bmatrix}\overline{C}_{lm} \\ \overline{S}_{lm}\end{Bmatrix} = \frac{1}{(2l+1)M_e} \times \iiint_{Global}\left(\frac{r'}{a_e}\right)^l \overline{P}_{lm}(\sin\varphi')\begin{Bmatrix}\cos m\lambda' \\ \sin m\lambda'\end{Bmatrix} dM$$

where r', φ' and λ' are the coordinates of the mass element dM in the integrand. The integration is carried out over the entire mass envelope of the Earth system, including its solid and fluid components.

This convention is consistent with the definition of fully-normalized harmonics in NRC (1997), and textbooks such as Heiskanen and Moritz (1966), Torge (1980); as well as in earlier gravity field models such as EGM96.