Atmospheric & Hydrological loading provider

Jean-Paul Boy

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Atmospheric and hydrological induced loading effects can be found in the folowing directories:

- `http://loading.u-strasbg.fr/V1.0/APLO/`: 3-D displacements due to surface pressure (IB assumption) loading for SLR (102), DORIS (157), VLBI (203) and IGS (424) sites.
- `http://loading.u-strasbg.fr/V1.0/AGRA/`: time-variable gravity field due to atmospheric pressure (IB assumption).
- `http://loading.u-strasbg.fr/V1.0/HGRA/`: time-variable gravity field due to continetal water storage (soil-moisture and snow).

All products have been currently computed from ECMWF (European Centre for Medium-range Weather Forecasts) operational and reanalysis models. There are only minor differences with the AGRA (Service of the atmospheric contribution to geopotential) (`http://gemini.gsfc.nasa.gov/agra/`) and APLO (Atmospheric pressure loading service) (`http://gemini.gsfc.nasa.gov/aplo/`) products (Petrov and Boy, 2004), computed using NCEP Reanalysis (Kalnay *et al.*, 1996) pressure fields.

1 Time-variable gravity field

The Stokes coefficients ($C_n^m(t)$ and $S_n^m(t)$) are computed up to degree 72, at every 6 hourly sample:

$$\left\{ \begin{array}{c} C_n^m(t) \\ S_n^m(t) \end{array} \right\} = \frac{3}{4\pi} \frac{1+k_n^{'}}{2n+1} \frac{1}{\rho g a} \iiint p(\theta^{'},\lambda^{'},t) P_n^m(\cos\theta^{'}) \left\{ \begin{array}{c} \cos m\lambda \\ \sin m\lambda \end{array} \right\} \sin\theta^{'} d\theta^{'} d\lambda^{'} \quad (1)$$

where θ, λ and P_n^m are respectively the co-latitude, the longitude and the fully-normalized (Heiskanen and Moritz, 1967) Legendre functions of degree n and order m. $k_n^{'}$, ρ, g and a are respectively the load Love number of degree n, the mean Earth density, surface gravity and radius.
As the ocean response to atmospheric pressure is modeled as an *Inverted Barometer* process, the acting pressure $p(\theta,\lambda,t)$ on the Earth surface is equal to the atmospheric pressure over continents and equal to the mean pressure over the oceans (total ocean mass conservation).
For the continental hydrology, the acting pressure is the sum of the soil-moisture (4 layers up to a depth of 2.55 m) and snow (Viterbo and Beljaars, 1995). The total water content is conserved by adding (or removing) a uniform thin-layer in the oceans.
In addition to the time-variable gravity field, the geocenter motion, due to atmospheric and hydrological loading are also provided (see Figure 1).

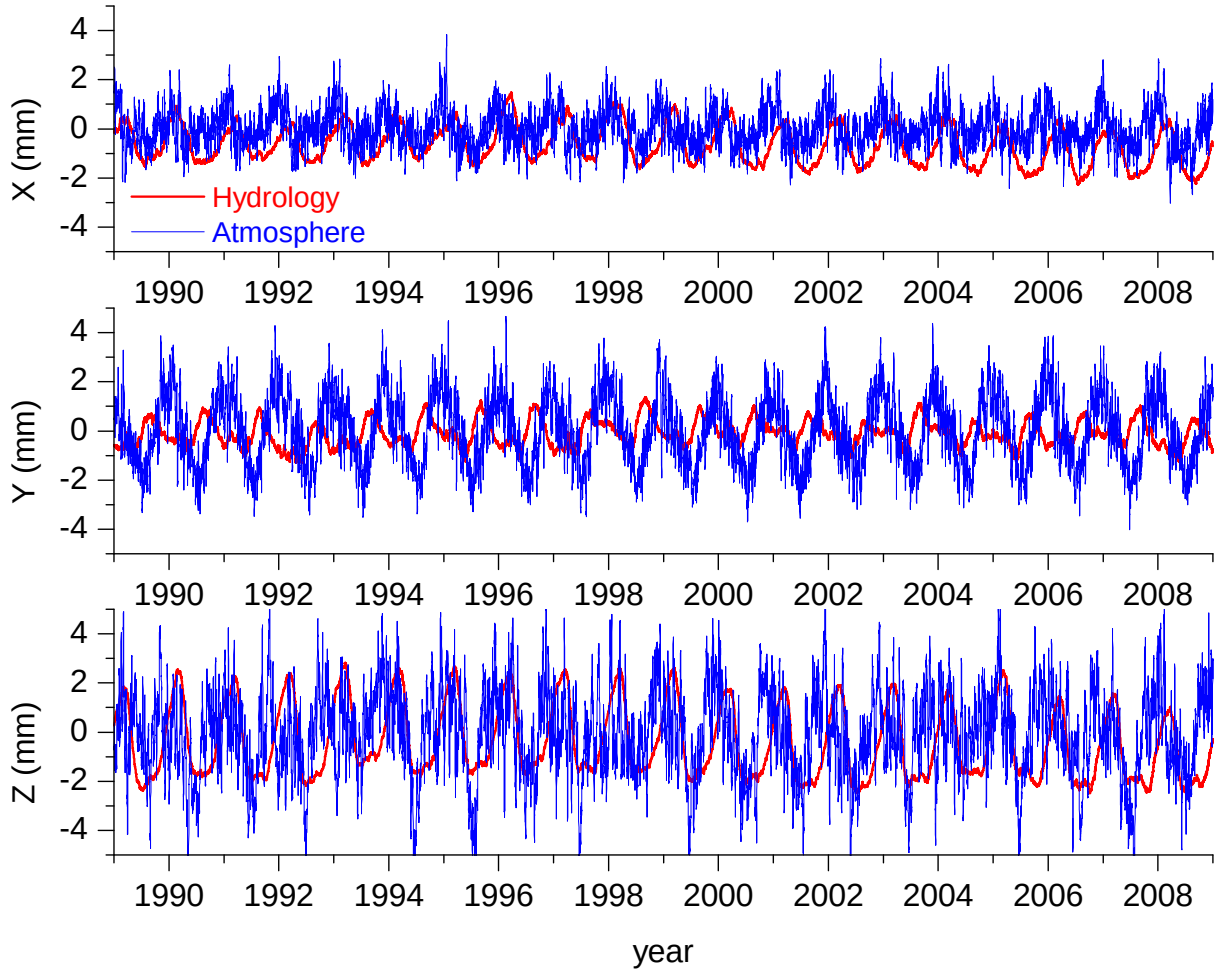

Figure 1: Geocenter motions due to hydrology (red) and atmosphere (blue), modelled with ERA-interim.

2 3-D displacements

The 3-D surface displacements are modeled using the Green's function formalism (Farrell, 1972; Petrov and Boy, 2004):

$$u_r(\theta,\lambda,t) = \iint p(\theta',\lambda',t) G_r(\psi) \sin\theta' d\theta' d\lambda' \tag{2}$$

$$\vec{u}_h(\theta,\lambda,t) = \iint \vec{q}(\theta,\lambda,\theta',\lambda') p(\theta',\lambda',t) G_h(\psi) \sin\theta' d\theta' d\lambda' \tag{3}$$

where G_r and G_h are repectively the vertical and horizontal Green's functions:

$$G_r(\psi) = \frac{Ga}{g^2} \sum_{n=0}^{+\infty} h_n' P_n(\cos\psi) \tag{4}$$

$$G_h(\psi) = -\frac{Ga}{g^2} \sum_{n=0}^{+\infty} l_n' \frac{\partial P_n(\cos\psi)}{\partial\psi} \tag{5}$$

where G, $h_n^{'}$ and $l_n^{'}$ are the universal constant of gravitation, and the load Love numbers of degree n.
3-D displacements due to atmospheric loading are currently computed for SLR, DORIS, VLBI and IGS (GPS) stations (see Figure 2).

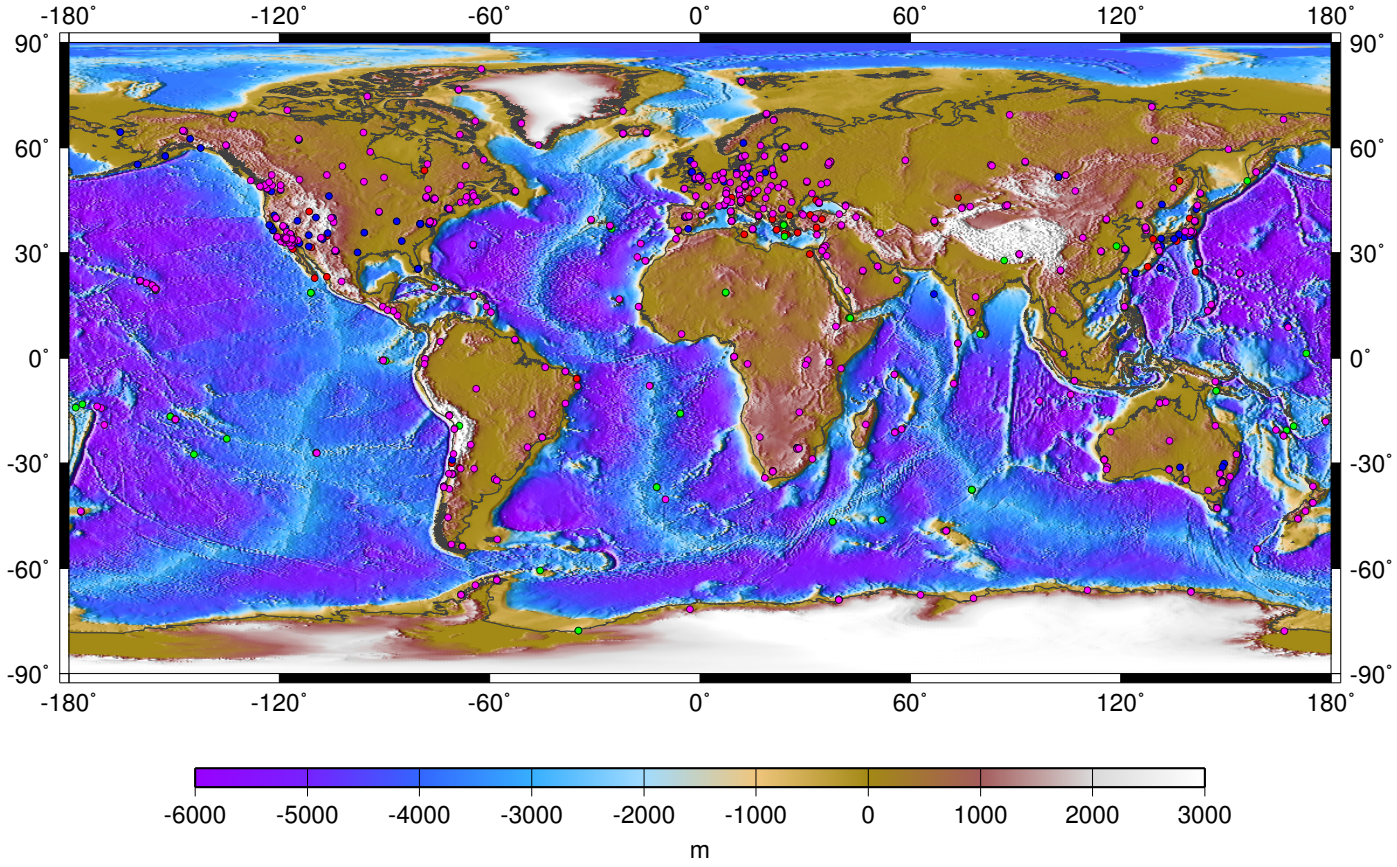

Figure 2: Distribution of the SLR (red), DORIS (green), VLBI (blue) and IGS (purple) stations.

3 Land-sea masks

Two different land-sea masks are used in the atmospheric loading computations:

- a high resolution (0.05^o) in the vicinity of the station (angular distances smaller than 10^o) for the 3-D displacement computations,
- a low resolution (0.25^o) far from the station for 3-D displacement computations and the gravity field variations.

Both are derived from the Generic Mapping Tools (`http://gmt.soest.hawaii.edu/`).

4 Atmospheric models

Atmospheric (3-D displacements and time-variable gravity) and hydrological (time-variable gravity) loading are computed from both ECMWF operational and reanalysis models. Unlike NCEP Reanalysis project (Kalnay *et al.*, 1996), there are no ECMWF reanalysis (ERA) covering entirely the 1970-now period. However, loading contributions are computed using:

- ERA40 for the 1970/01 - 2002/08 period, with a spatial resolution of 1.125^o (Uppala *et al.*, 2005).
- ERA-interim for the 1979/01 to now (with about a 2 month delay) period, with a spatial resolution of 0.7^o (compared to the 2.5^o, respectively 1.125^o for the current NCEP and JRA reanalysis projects).

The operational model regularly changes with time at ECMWF, and especially its spatial resolution. We compute atmospheric and hydrological loading contributions only since 2000/12. The spatial resolution has been improved in February 2006, as well as in January 2010.

- 2000/12 - 2006/01: ECMWF Operational, with a spatial resolution of about 0.35^o.
- 2005/10 - 2009/12: ECMWF Operational, with a spatial resolution of about 0.25^o.
- 2009/10 - now: ECMWF Operational, with a spatial resolution of about 0.15^o.

In addition to the improvement of the spatial resolution, the land-surface model has significantly changed in November 2007. Therefore 4 different time series are given for time-variable gravity field variations due to continental hydrology variations: 2000/12-2006/01, 2005/10-2007/10, 2007/06-2009/12 and 2009/10-now.

5 Air Tides

To be consistent with Petrov and Boy (2004) computations, the diurnal S1 and semi-diurnal S2 tides are removed from the 6-hourly surface pressure fields.
We currently advice to use Ponte and Ray (2002) S1 and S2 air tides derived from 6-hourly surface pressure from ECMWF. Thanks to the availability of 3-hourly surface pressure data from 4D-variational analysis, we will provide later S1 and S2 air tides, as well as their effects on gravity field variations and surface displacements.

6 Future improvements

Here are the possible improvements of our loading estimates.

6.1 Hydrology loading

In addition to the different hydrology (operational and reanalysis) models from ECMWF, the GLDAS (Global Land Data Assimilation System) (Rodell *et al.*, 2004) provides soil-moisture, snow equivalent height and canopy water for the 1979/01-now period for different land-surface models (CLM, MOSAIC, NOAH and VIC) with 3-hourly and 1 degree samples. Although the quality of the forcing is not uniform (as opposed to reanalysis products), they can be used to model time-variable gravity field variations. The resolution is clearly an issue for computation 3-D displacements.
A higher spatial resolution for GLDAS/NOAH is provided for the 2000/03-now can be used for both time-variable gravity field and 3-D displacement computations.
3-D displacements due to hydrological loading, using ERA40 and ERA-interim products, for SLR, DORIS and VLBI sites (see Figure 2) can also be computed.

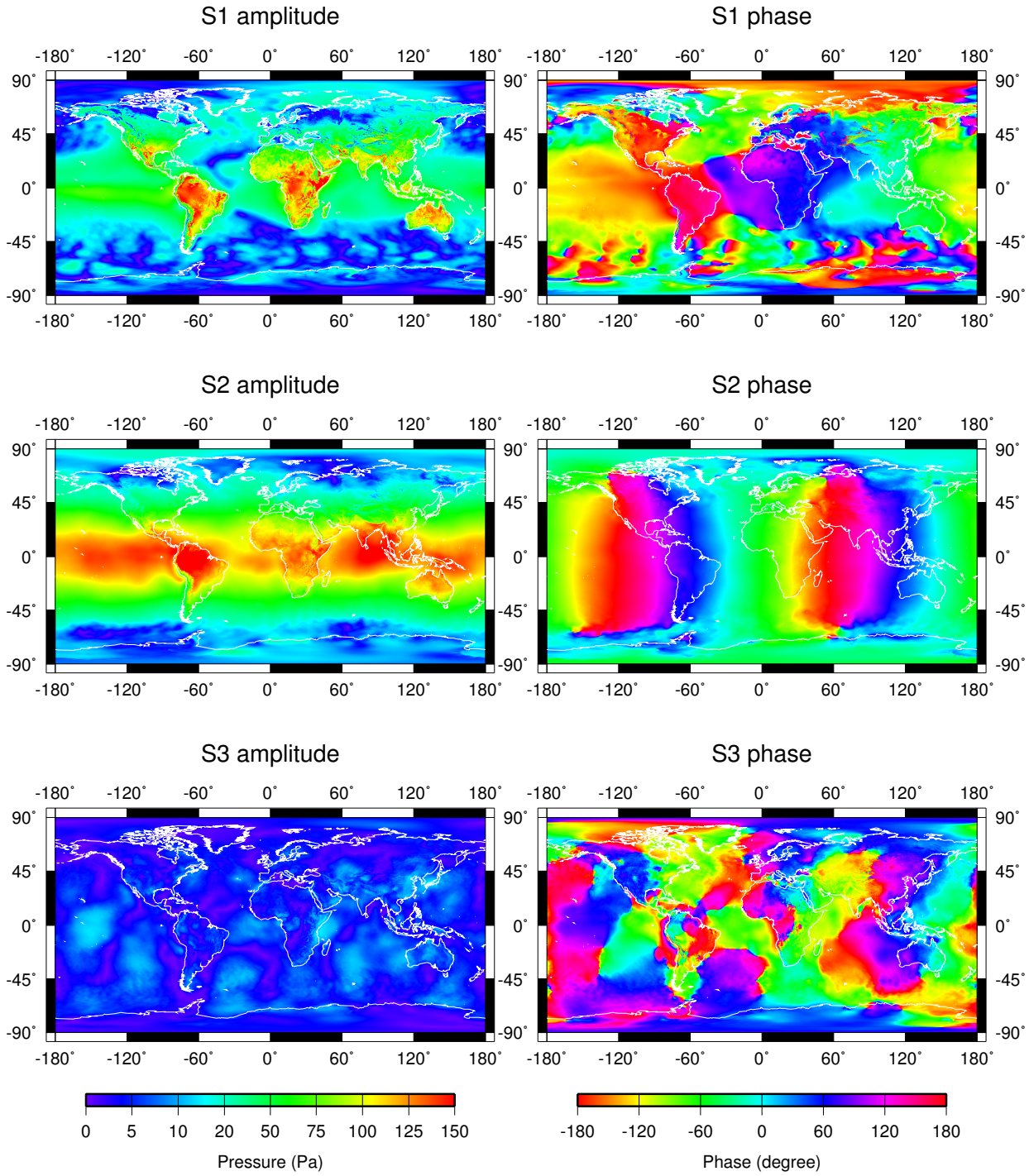

Figure 3: Amplitude (left) and phase (right) of S1 (top), S2 (middle) and S3 (bottom) air perssure waves estimated from 3 hourly ECMWF surface pressure for the 2006-2009 period.

6.2 Atmospheric loading and dynamic ocean model

The inverted barometer hypothesis is showed to be valid only for period exceeding typically a month. High frequency barotropic ocean models, such as MOG2D (Carrère and Lyard, 2002) can be used instead, as for the current processing of the GRACE mission or superconducting gravimeters (Boy and Lyard, 2008). However, almost real-time cannot be achieved currently. In addition the ocean response can be only as good

as the atmospheric forcing, and it seems not reasonnable to go back in time up to 1970.

6.3 Air tides

Air tides (S1 and S2) extracted from 3-hourly ECMWF surface pressure, as well as the induced gravity changes and 3-D displacements will be provided after validation. Currently, the best available model is from Ponte and Ray (2002).

7 Summary of the available datasets

APLO, AGRA and HGRA directories in `http://loading.u-strasbg.fr/V1.0/` are subdivided into 3 directories:

- ERA40 where loading computations from ERA40 ECWMF reanalysis model are provided (1970/01 to 2002/08),
- ERAin where loading computations from ERA-interim ECWMF reanalysis model are provided (1979/01 to now),
- OPERA where loading computations from ECWMF operational models are provided (2000/12 to now). Sub-divisions indicate changes in the operational models (spatial resolution or land-surface model for hydrology).

When using the products, please cite Petrov and Boy (2004) and contact `jpboy@eost.u-strasbg.fr` for any questions.

References

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