Centre of Space Techniques

Department of Space Geodesy

Investigation of atmospheric and hydrological loading signals in the annual signal of GPS station positions

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Problematic

- Space geodesy is the science which uses the satellite measurements to determine the shape of the Earth and its dimensions, as well as its gravity field.

- In space geodesy, the different measurements are collected, pre-processed and assigned a measurement date. We thus form time series.

- These time series contain a considerable amount of information of physical origin, but they are also affected by noise and systematic errors (trend and seasonal terms) ?

- The assessment of these residual errors in geodetic time series is essential to:
  - provide a better understanding of the physical phenomena , global or local, governing the variation of the studied variable.
  - improve continually the accuracy of the estimated variable.

Objective

- Many studies have demonstrated the presence of atmospheric and hydrological pressure loading in station position time series (VLBI, SLR, GPS and DORIS).

- The purpose of this study is to investigate the potential origin of the annual signal in GPS station position time series by studying its correlation with the three-dimensional (North, East and Up) displacements of stations caused by atmospheric and hydrological loading.

Time series

Time Series : Sequence of numerical observations X_t measured at successive times t (t = 1…, N; N : length of the series)

$$X_t = m_t + s_t + \varepsilon_t$$

m_t : *Trend* *(long-term evolution of the time series)*

s_t : *Cyclical component* *(seasonal components)*

ε_t : *Residual component* *(noise affecting the time series)*

Wavelet Multiresolution Analysis

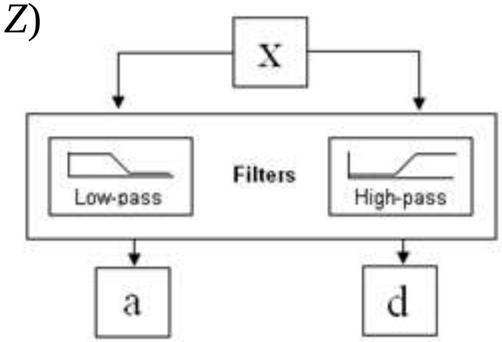
❑ The *Continuous Wavelet Transform (CWT)* can *be defined as the projection of the signal X on the basis of wavelet function $\psi_{u,s}$:*

$$CWT_{u,s}(t) = \int_{-\infty}^{+\infty} X(t)\, \psi_{u,s}(t)\, dt \;, \qquad \psi_{u,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-u}{s}\right) \qquad \text{with } s \in \Re_{+}^{*} \text{ and } u \in \Re$$

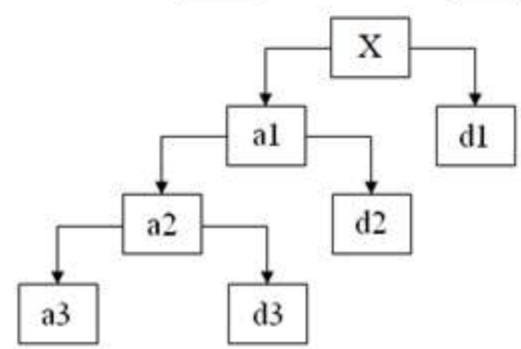
Where: *u, s* translation and scale factor, respectively.

❑ The *Discrete Wavelet Transform (DWT)* is formalized as:

$$DWT_{m,n}(t) = 2^{-\frac{m}{2}} \int_{-\infty}^{+\infty} X(t)\, \psi(2^{-m} t - n)\, dt \qquad \text{with } s = 2^m \text{ and } u = n\, 2^m\ (n, m \in Z)$$



❑ The *MultiResolution Analysis* allows the computation of the wavelet coefficients $DWT_{m,n}$. It allows to *decompose the signal X* on several scales and to reconstruct it from the elements of this decomposition. At each scale, the signal X is decomposed in two signals: (*i*) the detail signal d (representing its high frequencies), allows to assess the seasonal variability of the data, and *(ii)* the approximation signal a (representing its low frequencies), allows to identify the trend.



Data used

GPS time series

Time series of daily position residuals of 11 GPS stations, referred to ITRF2014, expressed in the local geodetic reference frame (North, East and Up), available on the JPL Web site (http://sideshow.jpl.nasa.gov).

Acronym	Site	Country	Lat (deg)	Long (deg)	Data span
GODE	Greenblet	U.S.A.	38.90	-76.80	2013.0–2017.7
KOKB	Kauai	U.S.A. (Hawaii)	22.01	-159.67	2002.8–2017.7
METS	Metsahovi	Finland	60.20	24.70	1994.0–2017.7
NKLG	Libreville	Gabon	0.30	9.70	2011.4–2017.7
NYA1	Ny-Alesund	Norway	78.93	11.87	1998.2–2017.7
REYK	Reykjavik	Island	64.15	-21.98	1996.1–2017.7
STJO	St John's	Canada	47.60	-52.70	1994.0–2017.7
SYOG	Syowa	Antarctica	-69.00	39.58	1999.1–2017.7
THTI	Papeete	France	-17.58	-149.62	1999.5–2017.7
TLSE	Toulouse	France	43.55	1.48	2001.0–2010.2
USNO	Goldstone	U.S.A.	35.30	-116.80	2002.8–2017.7

Data used

Atmospheric and hydrology loading displacements time series

- The used atmospheric and hydrological loading time series are the three-dimensional (North, East and Up) displacements in millimetres for ITRF2014 sites, available at http://loading.u-strasbg.fr/ITRF/CF/.

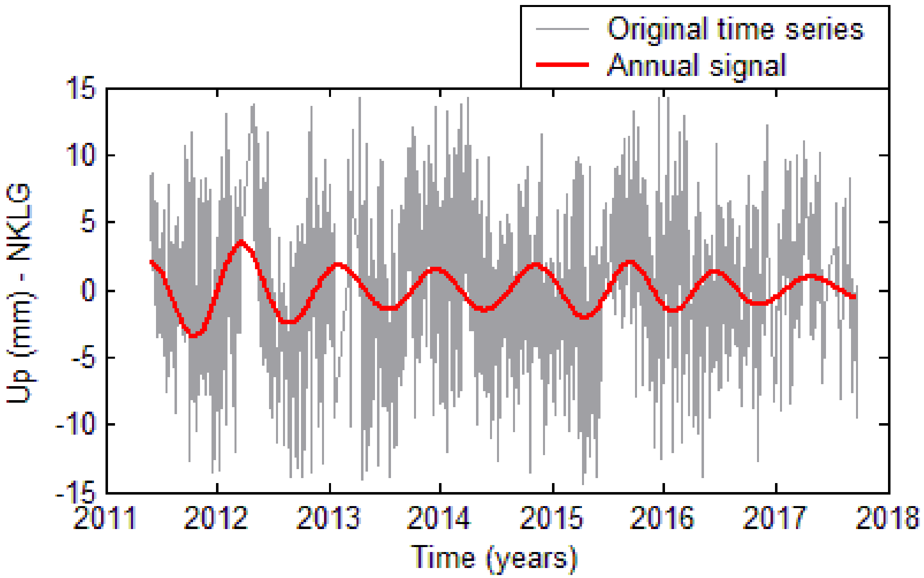
- For atmospheric loading estimates, we used the ECMWF-IB, ECMWF-TUGO-m barotropic and ERA interim models. The atmospheric loading estimated from ECMWF-IB and TUGO-m barotropic models are computed from surface pressure from ECMWF (European Centre for Medium-Range Weather Forecasts) operational model, assuming respectively an inverted barometer ocean response to pressure forcing and a dynamic ocean response to pressure and winds, with temporal resolution of 3 hours. While those estimated from ERA interim are computed from surface pressure from ECMWF reanalysis model, assuming an inverted barometer ocean response to pressure forcing, with temporal resolution of 6 hours.

- For hydrological loading, we used the GLDAS/Noah, ERA interim and MERRA2 models. The GLDAS/Noah hydrological loading estimates (soil moisture, snow and canopy water) are computed from the global GLDAS/Noah model, with temporal resolution of 3 hours. For ERA interim model, the hydrology loading (soil-moisture and snow) is estimated from ERA interim (ECMWF Reanalysis) model. For MERRA2 model, the hydrology loading (soil moisture and snow) is estimated from MERRA2 model with temporal resolution of 1 hour.

Results and discussion

Stations	North (mm)	East (mm)	Up (mm)
GODE	0.50	0.46	1.39
KOKB	0.60	0.48	1.32
METS	0.66	0.47	1.28
NKLG	0.68	0.78	1.95
NYA1	0.48	0.45	1.50
REYK	0.37	0.70	1.53
STJO	0.54	0.38	1.62
SYOG	0.68	0.62	2.57
THTI	0.63	0.80	2.69
TLSE	0.42	0.35	1.35
USNO	0.45	0.46	1.50
Average	0.55	0.54	1.70

Amplitudes of the annual signals in the components North, East and Up.



Overlay of the Up component of the NKLG station with its annual signal (detail 8) using discrete Meyer wavelet.

Results and discussion

Stations	ECMWF-IB			ECMWF-TUGO-m			ERA interim		
	North	East	Up	North	East	Up	North	East	Up
GODE	-0.10	-0.01	-0.04	-0.12	-0.03	-0.11	-0.09	0	-0.08
KOKB	-0.16	0.09	0.13	-0.13	0.11	0.10	-0.15	0.07	0.13
METS	0.09	0.07	0.06	0.11	0.09	0.09	0.17	0.09	0.04
NKLG	-0.63	-0.07	0.11	-0.59	-0.02	0.11	-0.66	-0.09	0.15
NYA1	0	-0.09	0.03	0.03	-0.06	0.04	-0.01	-0.04	0
REYK	0.02	0	0.15	0.05	0.05	0.16	-0.07	-0.02	0.03
STJO	-0.01	-0.01	-0.04	-0.03	-0.02	-0.01	-0.05	0	-0.05
SYOG	0.13	0.16	0.15	0.15	0.21	0.23	0.14	0.06	0.13
THTI	0.03	0	-0.01	0.02	-0.01	-0.04	-0.02	-0.09	0.01
TLSE	-0.01	0.08	0.08	0.06	0	0.08	-0.01	0.08	0.08
USNO	-0.01	-0.08	-0.03	0.02	-0.06	-0.05	0.02	-0.05	-0.02

Correlation between the GPS annual signal and the atmospheric loading displacements estimated from ECMWF–IB, ECMWF–TUGO–m barotropic and ERA interim models, in the components North, East and Up.

Results and discussion

Stations	GLDAS/Noah			ERA interim			MERRA2		
	North	East	Up	North	East	Up	North	East	Up
GODE	0.36	0.39	0.16	0.20	0.31	-0.30	0.32	0.42	0.06
KOKB	-0.10	-0.46	0.03	-0.16	-0.51	0.12	-0.11	-0.43	0.05
METS	-0.04	-0.05	0.15	0.07	-0.01	-0.09	0.01	-0.02	0.10
NKLG	-0.13	0.34	0.03	0.04	0.41	0.04	-0.24	0.36	0
NYA1	0.01	-0.11	0.06	0.07	-0.04	0	0.08	-0.02	0.03
REYK	0	-0.05	0.05	0.08	-0.05	0.01	-0.01	-0.03	-0.04
STJO	-0.24	0.01	0.03	-0.04	0.14	0.02	-0.02	0.11	0.03
SYOG	-0.09	-0.03	-0.10	0	0.05	-0.07	-0.04	-0.02	0.02
THTI	0.01	0.08	-0.13	-0.01	0.10	-0.11	0.06	0.06	-0.19
TLSE	0.02	-0.58	0.32	-0.03	-0.52	0.33	0	-0.56	0.28
USNO	-0.24	-0.06	-0.20	-0.16	-0.05	0.10	-0.14	-0.09	0.11

Correlation between the GPS annual signal and the hydrological loading displacements, estimated from GLDAS/Noah, ERA interim and MERRA2 models, in the components North, East and Up.

Conclusion

- The main purpose of this paper was to study the correlation between the annual signal observed in GPS station position time series and the atmospheric and hydrological pressure loading signals.

- After having extracted the annual signal from the analyzed position time series, the correlations between the annual signal and the atmospheric loading estimated from ECMWF-IB, ECMWF-TUGO-m barotropic and ERA interim models, and the hydrological loading estimated from GLDAS/Noah, ERA interim and MERRA2 models, are small (or negative) in the three components (North, East and Up) for all analyzed stations.

Thank you for your attention

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