An approach to obtain a tropospheric mapping function based on ECMWF models

Computation of slant tropospheric delays

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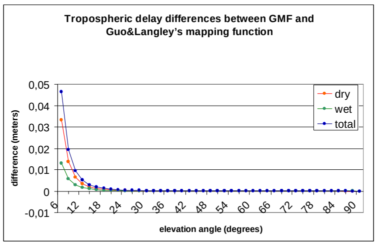
MOTIVATION

CNES/GRGS has developed a tool (GINS) for processing all geodetic techniques. Particularly in case of technique combination it is important to unify the tropospheric corrections from SLR, GPS, VLBI, DORIS measurements.

Tropospheric zenithal dry and wet delay grids (delivered by Meteo-France) from ECMWF 3D-models of pressure, temperature and humidity are now used systematically for altimetry and geodesy in CNES/GRGS.

Moreover we have developed a raytracing code from the ECMWF 3D-models to compute slant delays at any point and for any azimuth and elevation.

Our idea is to adapt the mapping function to be used in GINS from the original ECMWF multi layers meteorological products and the Meteo-France integrated vertical delays.



STATE-OF-THE-ART

Tropospheric delays remain a major limitation today for global positioning at the mm level. Differences in delays between models can reach up to several centimetres at low elevations (< 12 deg.)

Several studies have been already performed on:

- computation of zenithal tropospheric delays (ZTD) depending on the co-indice expression: Marini & Murray (1963), Essen & Froome (1963), Elden (1966), Owens (1967), Tayer (1974), Mendes & al. (2004)… but ZTDs are in general adjusted for electromagnetic tracking techniques

- computation of tropospheric mapping functions: Marini (1972), Chao (1972), Davis & al. (1985), Ifadis (1986), Herring (1992), Niell & al. (1996,2001), Guo & Langley (2004), Böhm & al. (2004, 2006)… directly applied usually

OBJECTIVE OF THE STUDY

To adjust parameters of the mapping function (Marini type) based on raytracing through model grids:

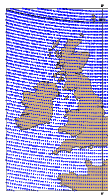
Using as input ECMWF models of P, T, H over 91 layers at a temporal resolution of 6h and at a space resolution of .225 deg (2 days of data used at 6 month interval : 15/08/2006 and 14/02/2007)

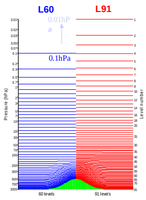
Computing (dry and wet) vertical delays integrated through all layers, similar to the products delivered by Meteo-France

Computing (dry and wet) slant delays integrated through all layers at different elevations and azimuths

Searching for adequacy between vertical and slant delays adjusting the dry and wet mapping functions

ECMWF GRIDS AND PRODUCTS





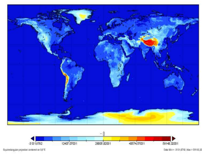
Horizontal resolution:

T_L 799 ECMWF gaussian grid of 843 490 points (1600 points in longitude at low latitudes, 19 at high latitudes) converted in regular grid at a resolution of .225 deg × .225 deg

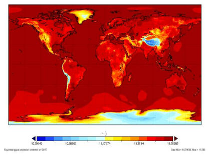
Vertical resolution:

L91 hybrid vertical levels (compared here to the previous L60 –before Feb. 2006)

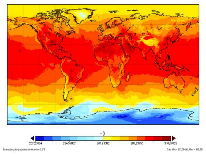
Levels are isobaric at high altitude only.



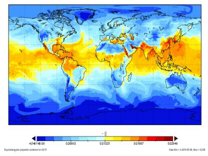
Geopotential surface [m2.s-2]*



Surface pressure (in ln scale)*



Temperature [K], level 91*

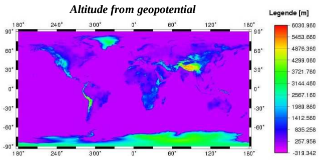


Specific humidity [kg.kg-1] level 91*

(* 15/08/2006 H00)

VERTICAL TROPOSPHERIC DELAYS

Construction of Altitude grids



Map of altitudes [m] determined from geopotential surface at 15/08/2006 H00

alt0 = Geo0 / g

g = 9.80665 m.s-2

Construction of altitude grids from the Laplace's model:

Equations of hydrostatic equilibrium (*dP=-ρ g dz*) and of ideal gas (*M P=ρ R T*)

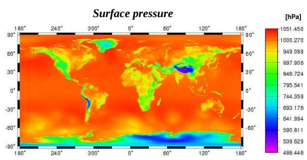
$$\Rightarrow z_1 - z_2 = \frac{R}{M_d \cdot g} \cdot T \cdot \left(1 + q \cdot \left(\frac{M_d}{M_w} - 1\right)\right) \cdot ln\left(\frac{P_2}{P_1}\right)$$

$$R = 8.31434\, J.mol^{-1}.K^{-1}$$
$$g = 9.80665\, m.s^{-2}$$
$$M_d = 28.9644\, 10^{-3}\, kg.mol^{-1}$$
$$M_w = 18.0153\, 10^{-3}\, kg.mol^{-1}$$

Construction of pressure grids

$$P_{surf} = \frac{\exp(LNSP)}{100},\ [hPa]$$

$$P(i) = a(i) + b(i) \times P_{surf},\ [hPa]$$



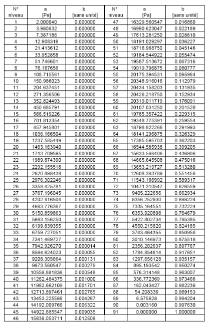
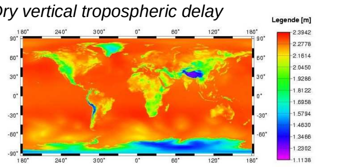


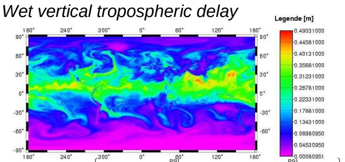
Table of a and b coefficients on the 91 vertical levels

Dry vertical tropospheric delay



$$\Delta L_d^z \approx 2.277 \cdot 10^{-3} \cdot P_{91} \cdot [1 + 0.0026 \cdot cos(2 \cdot \varphi)]$$

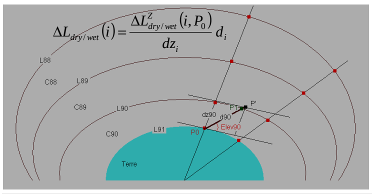
Wet vertical tropospheric delay

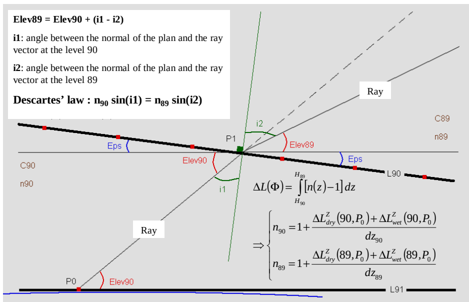


$$\Delta L_w^z \approx [1 + 0.0026 \cdot \cos(2 \cdot \varphi)] \cdot \left\{1.116454 \cdot 10^{-3} \cdot \int_{P1}^{P91} \frac{\rho_w}{\rho} \cdot dP + 17.66543928 \cdot \int_{P1}^{P91} \frac{\rho_w}{\rho T} \cdot dP\right\}$$

SLANT TROPOSPHERIC DELAYS

Methodology





<u>One knows:</u>

point P0, elevation, azimuth

<u>One determines on the ray</u>

P' at the altitude *dz90*

P1 crossing the L90 layer

<u>One computes</u>

the distance P0-P1=*dz90*

the dry and wet tropospheric delays

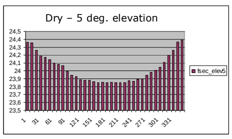
<u>One iterates</u>

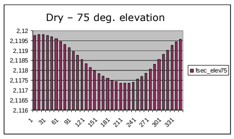
this process in the next layer taking account the change in elevation according to the Descartes' law

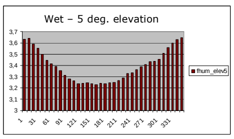
Results

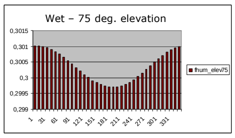
Tropospheric dry and wet delays as a function of azimuth at 5 and 75 deg. Elevation

(Middle mesh point - Lat: 27 deg. Lon: 87 deg. Alt: 1208 m)

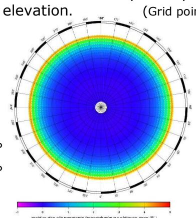








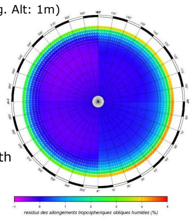
Discrepancies between slant delays and projected zenithal delays (G&L) according to azimuth and elevation. (Grid point - Lat: 15 deg. Lon: 90 deg. Alt: 1m)



Dry component

< 2% for elev. > 15°

> 5% for elev. < 10°



Wet component

< 2% for Φ > 10°

> 5% for Φ < 7°

Assimetry South-North

ADJUSTEMENT OF THE MAPPING FUNCTION (WORK IN PROGRESS)

Mapping function (Marini type):

$$f(\Phi) = \frac{1 + \dfrac{a_1 + a_2 \cdot z + a_3 \cdot \cos(\varphi)}{1 + \dfrac{b}{1 + c}}}{\sin(\Phi) + \dfrac{a_1 + a_2 \cdot z + a_3 \cdot \cos(\varphi)}{\sin(\Phi) + \dfrac{b}{\sin(\Phi) + c}}}$$

Coefficients of Guo & Langley

dry	wet
a_1=1.18972 10^{-3}	a_1=6.1120 10^{-4}
a_2=-2.6855 10^{-5}	a_2=-3.5348 10^{-5}
a_3=1.0664 10^{-4}	a_3=-1.526 10^{-5}
b=3.5716 10^{-3}	b=1.8576 10^{-3}
c=8.2456 10^{-2}	c=6.2741 10^{-2}

Dry and wet delays:

$$\Delta L(\Phi) = f_{dry}(\Phi) \times \left(\Delta L^Z_{dry} + \frac{H_{dry}}{tan(\Phi)}\left[G^E_{dry} \sin(a_z) + G^N_{dry} \cos(a_z)\right]\right) + f_{wet}(\Phi) \times \left(\Delta L^Z_{dwet} + \frac{H_{wet}}{tan(\Phi)}\left[G^E_{wet} \sin(a_z) + G^N_{wet} \cos(a_z)\right]\right)$$

Where:

Φ : *elevation angle*

a_z : *azimuth angle*

H : *gradient reference height* $(\sim 100 - 500\, m)$

$G^N = \frac{\partial \Delta L^Z}{\partial \theta}$: *North gradient of zenithal delay*

$G^E = \frac{\partial \Delta L^Z}{\cos\varphi\, \partial \lambda}$: *East gradient of zenithal delay*

Equations of partial derivatives

$$\left(\frac{\partial \Delta L}{\partial a_1}\right) \cdot \Delta a_1 + \left(\frac{\partial \Delta L}{\partial a_2}\right) \cdot \Delta a_2 + \left(\frac{\partial \Delta L}{\partial a_3}\right) \cdot \Delta a_3 + \left(\frac{\partial \Delta L}{\partial b}\right) \cdot \Delta b + \left(\frac{\partial \Delta L}{\partial c}\right) \cdot \Delta c + \left(\frac{\partial \Delta L}{\partial H}\right) \cdot \Delta H = \sum_{i=1}^{91} \Delta L_i - f(\Phi) \Delta L^z$$

Resolution of the coefficients by least squares method: too preliminary results for now

CONCLUSION AND OUTLOOK

We have gained experience in computing tropospheric delays and developed a dedicated software for slant corrections

But, the work is still on going and needs to be finalized

Next steps will be:

- correcting some remaining artefacts or approximations
- studying sensitivity (according to zones, stations…) and assessing errors
- comparing with other mapping functions
- implementing in the GINS software
- testing in tracking data processing (VLBI, GPS…)