D4.1 Algorithm Theoretical Baseline Document

(one ATBD per sub-theme or one single document, to be agreed between the Agency & team)

1. INTRODUCTION

The objective of this task is to generate an improved ionosphere correction in the North East Atlantic, over the Cryosat-2 tracks and for the whole period of the mission.

2. OVERVIEW

The SPECTRE service was developed in 2004 in the frame of ESA, CNES and French ministry funding. It is an operational ionosphere mapping service that provides TEC maps over Europe from GPS network. It was validated against Global TEC Maps (IONEX products) generated by the International GNSS Service (IGS) [Crespon et al, 2007].

3. ALGORITHM DESCRIPTION

The GPS data produced by bi-frequency receivers and used by the SPECTRE algorithm are respectively, for both frequencies f_1 (1575.42 MHz) and f_2 (1227.6 MHz), the pseudo-ranges P_1 and P_2, and the phase measurements L_1 and L_2. By combining these data one can compute the slant path delay due to the electron content of the ionosphere. The Slant Total Electron Content (STEC), expressed in TEC units, for a receiver-satellite couple at epoch t along ray i is given by the ionospheric combination:

$$d_i(t) = K\left(L_{gf}(t) - \left\langle L_{gf}(t) + P_{gf}(t) \right\rangle\right) \tag{1}$$

with,

$$L_{gf} = \lambda_1 L_1 - \lambda_2 L_2, \tag{2}$$

$$P_{gf} = P_1 - P_2, \tag{3}$$

$$K = \frac{8\pi^2 m_e \varepsilon_0}{e^2} \frac{f_1^2 f_2^2}{\left(f_1^2 - f_2^2\right)}, \tag{4}$$

where λ_1, λ_2 are the wavelengths for f_1 and f_2, e is the charge of one electron, m_e is the mass of one electron and ε_0 is the vacuum permittivity. The coefficient K is derived from the second-order approximation of the refractive index of the ionosphere (Budden, 1985). All non-dispersive effects on pseudo-range and phase measurements are avoided by the geometry-free combinations (2) and (3). The averaged sum of these combinations is subtracted to (2) in order to resolve phase ambiguity. Equation (1) is modelled by the sum of STEC and electronic biases affecting GPS satellites, Transmitter Group Delay (TGD), and GPS receivers, Inter-Frequencies Bias (IFB). These biases are assumed constant (Sardón and Zarraoa, 1999).The Slant TEC is redressed to Vertical TEC using the thin shell assumption (Mannucci et al, 1999) with maximum of ionization at 350 km.

$$d_i(t) = STEC(t) + IFB + TGD \tag{5}$$

$$d_i(t) = \frac{VTEC(t)}{f_{ob}(t)} + IFB + TGD \quad (6)$$

where f_{ob} is the obliquity factor defined by the thin shell assumption. The intersection of ray i and the thin shell at 350 km gives the position of the observation d_i that is usually called the Ionospheric Piercing Point (IPP). In order to assess the VTEC maps over GPS network, the IPP are interpolated by nearest method on a regular grid. Thus, the system of equations (7) is formed and solved by the extended Kalman algorithm (Quanrong, 1993). The solution provides conjointly an estimation of the VTEC on a regular grid and an estimation of the electronic biases IFB and TGD for each receiver and satellite by solving

$$d_{1\ldots N} = G.\begin{bmatrix} VTEC_{1\ldots P} \\ IFB_{1\ldots R} \\ TGD_{1\ldots S} \end{bmatrix} \quad (7)$$

where N is the number of GPS observations, P is the number of grid points, R is the number of GPS receivers, S is the number of GPS satellites, and G is the interpolation operator.

Finally the ionosphere correction is computed by interpolating the VTEC under the altimeter satellite track and by estimating the contribution of the VTEC below the altimeter satellite altitude. This contribution is computed by applying a scaling factor deduced from the ionosphere model IRI95. The scaling factor is the ratio between the VTEC contribution “below the satellite” and the overall VTEC modelled by IRI95.

4. ASSUMPTIONS, CONSTRAINTS, AND LIMITATIONS

a. Practical Considerations

i. *Input Data*

- Location, time tag and altitude of the Cryosat along-track data in the North-East Atlantic ocean ;
- Scaling factor from the ionosphere model IRI95 and the Cryosat altitude ;
- SPECTRE European VTEC maps database.

ii. *Output*

Ionosphere correction at the location and time tag of each Cryosat measurement in the North-East Atlantic Ocean.

b. Quality Control

The Noveltis SPECTRE software was validated by comparing its outputs with the outputs of other TEC mapping services from JPL, CODE and UPC.

5. REFERENCES

Budden, K.G., “The propagation of radio waves: The theory of radio waves of low power in the ionosphere and magnetosphere”, Cambridge and New York, Cambridge University Press, 1985.

Crespon, F., Jeansou E., Helbert J., Moreaux G., Lognonné P., Godet P.E., Garcia R., "SPECTRE (www.noveltis.fr/spectre): a web Service for Ionospheric Products", in

Proceedings of 1st Colloquium Scientific and Fundamental Aspects of the Galileo Programme, Toulouse, France, October, 2007.

Mannucci, A.J., Iijima, B., Sparks, L., Pi, X., Wilson, B. And Lindqwister, U., “Assessment of global TEC mapping using a three-dimensional electron density model”, Journal of Atmospheric and Terrestrial Physics, vol. 61, p. 1227-1236, 1999.

Quanrong, C., “Approximate Kalman filtering”, Series in approximations and decompositions, vol. 2, 1993.

Sardón E. and Zarraoa, N., “Estimation of total electron content using GPS data: How stable are the differential satellite and receiver instrumental biases?”, Radio Science, vol.32, p. 1899-1910, 1997.