Doris measurement processing

Non synchroneous phase measurements, ionospheric correction

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1 Introduction

For Doris instruments, the process of eliminating the first order ionospheric effect is also performed by a combination of the phase measurements on the two frequencies. Then the differences between the expressions at each end of the Doppler intervals are constructed in order to have the phase variations equations.

However the phase measurements on the two frequencies are not exactly synchronized, and it is necessary to correct for this offset. This offset can be separated into two contributions : a term common to all measurements, and a variable term. The common term corresponds to instrumental delays, and can reach 20 microseconds depending on the satellite. For the new instruments including Jason2, this term is lower than 2 microseconds.

For instruments before Jason2 the measurements epochs on the two frequencies correspond to the first integer cycle count after a reference epoch. This means that this fluctuating term is limited by one cycle at 400 MHz (equivalent to 2.5 ns).

2 Phase measurement definitions

We have, for the phase measurements on the two frequencies, using only the first order term for the ionospheric effect :

$$\begin{array}{ll} \rho_p^{(a)} = D(t) + d_a(t) - \frac{s_1(t)}{f_a^2} & \text{frequency } f_a \text{ (2 GHz, epoch } t\text{)} \\ \rho_p^{(b)} = D(t+h) + d_b(t+h) - \frac{s_1(t+h)}{f_b^2} & \text{frequency } f_b \text{ (400 Mhz, epoch } t+h\text{)} \end{array} \tag{1}$$

$D(t)$ is the in vacuo propagation term between the receiver and emitter reference points, including the clock offsets and the phase ambiguities. h is the difference between the two acquisition epochs (from 2.10^{-6} to 20.10^{-6} s). $d_a(t)$ and $d_b(t+h)$ are the geometrical corrections for each frequency. They have very slow evolutions with time (effect of windup terms, satellite attitude and centre of phase offsets).

3 Estimation of the ionospheric term at one epoch

The standard Doris conventions are related to the 2 GHz frequency band, and the Doppler measurement files contain the variations of the raw measurement $\rho_p^{(a)}$ and the corresponding variations of the estimated ionospheric correction $\delta\rho_{I,p}$. This correction is estimated neglegting the higher order terms and assuming that $s_1(t)$ is very close to $s_1(t+h)$:

$$\delta\rho_{I,p} = \frac{\rho_p^{(b)} - \rho_p^{(a)}}{\gamma - 1} - \frac{D(t+h) - D(t)}{\gamma - 1} - \frac{d_b(t+h) - d_a(t)}{\gamma - 1} \tag{2}$$

In this expression, the first term is the standard expression depending only on the mesurements, the third term is a geometrical term, which can be approximated by $\frac{d_b(t)-d_a(t)}{\gamma-1}$ due to the very slow variations of the geometrical corrections, so doesn't anymore depend on h. These two terms are the ones to be used for a synchronized acquisition on the two frequencies. The desynchronisation term is $\frac{D(t+h)-D(t)}{\gamma-1}$. The order of magnitude is $\frac{h}{\gamma-1}\frac{dD}{dt}$ and can reach 7 mm at low elevation for the highest values of h.

4 Property of the first-order-ionospheric-free combination

For the recent instruments, the raw phase measurements are available on the two frequencies. The first-order-ionospheric-free combination $\rho_p^{(1)}$ eliminates the first order ionosphere term, but some corrections due to non null h remain (and also higher order ionospheric effects) ($\gamma = \frac{f_a^2}{f_b^2}$) :

$$\begin{aligned} \rho_p^{(1)} &= \tfrac{\gamma\rho_p^{(a)} - \rho_p^{(b)}}{\gamma-1} \\ &= \tfrac{\gamma D(t) - D(t+h)}{\gamma-1} + \tfrac{\gamma d_a(t) - d_b(t+h)}{\gamma-1} - \tfrac{s_1(t) - s_1(t+h)}{f_a^2 - f_b^2} \end{aligned} \tag{3}$$

$s_1(t)$ is very close to $s_1(t+h)$, so the direct ionosphere contribution due to h vanishes. $d_b(t+h)$ is very close to $d_b(t)$, so the second term is equivalent to the geometrical correction on the ionosphere free combination $d(t)$.

$$d(t) = \frac{\gamma d_a(t) - d_b(t)}{\gamma - 1} \tag{4}$$

The term $D(t+h)$ can be expanded to first order in h, and the first-order-ionospheric-free measurement equation can be expressed as:

$$\rho_p^{(1)} = D(t - \frac{h}{\gamma - 1}) + d(t - \frac{h}{\gamma - 1}) \tag{5}$$

We see that the effect of the first-order-ionospheric-free measurement combination is to change the measurement epoch of the 2GHz frequency band by $-\frac{h}{\gamma-1}$. This means an effect of 0.8 microsecond for $h = 20$ microseconds, which produces a constant time bias in the measurement epochs. This time bias corresponds to an along track error of 7 mm. For the recent satellites (after Jason2), the corresponding error is below 1 mm. The variable term corresponding to the integer cycle acquisition for the instruments before Jason2 has a negligible effect (effect on h much below 1 microsecond).