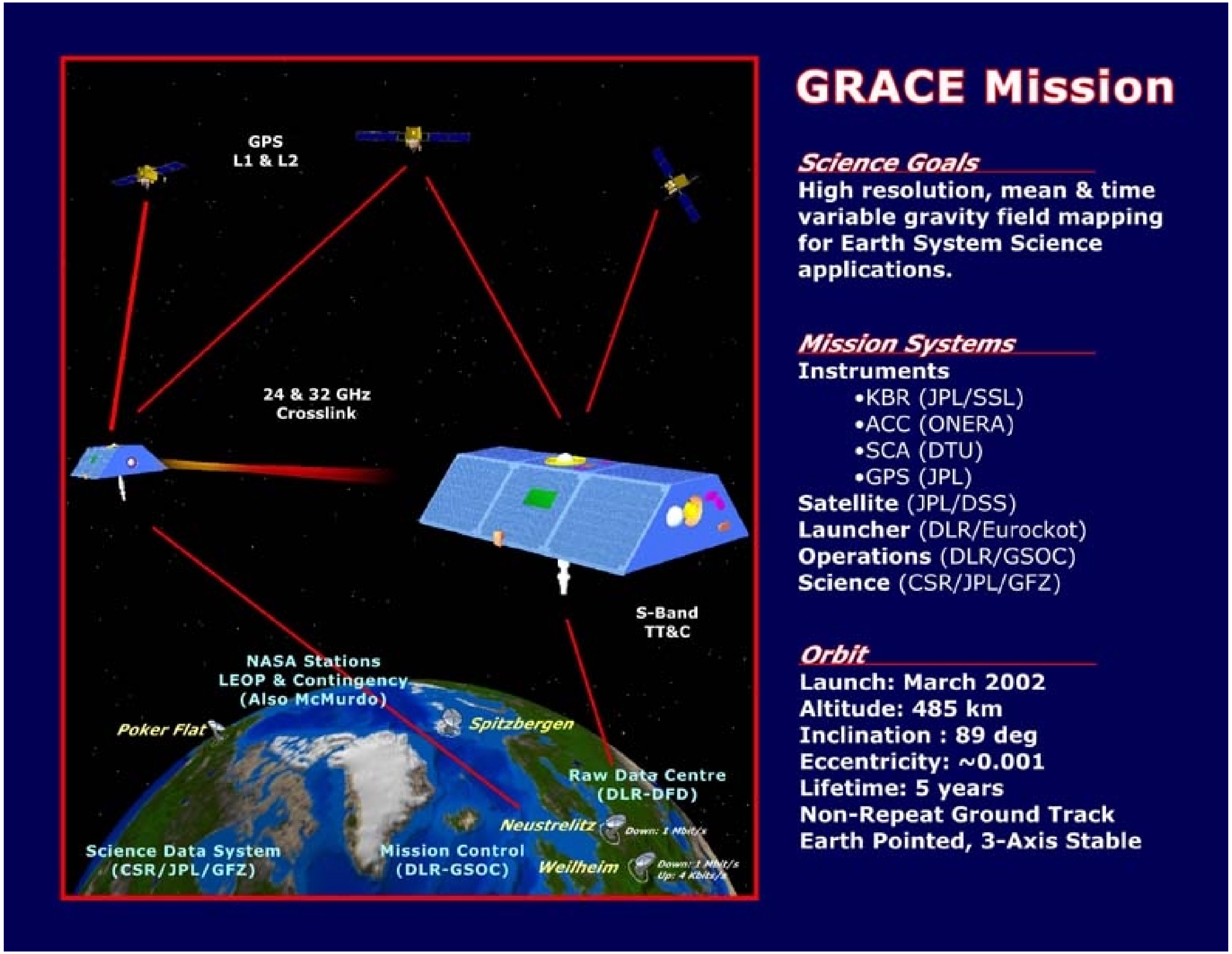
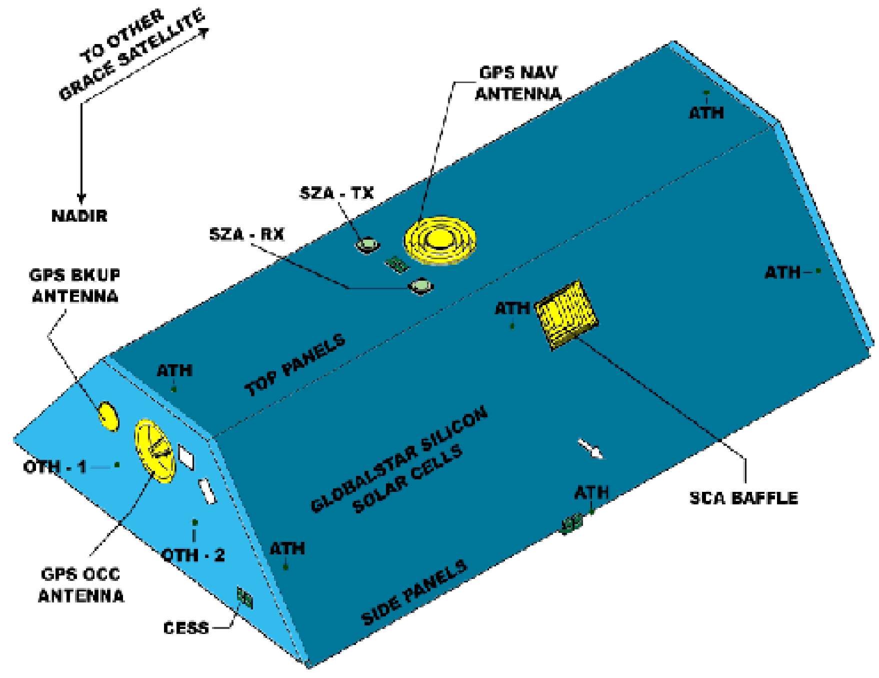
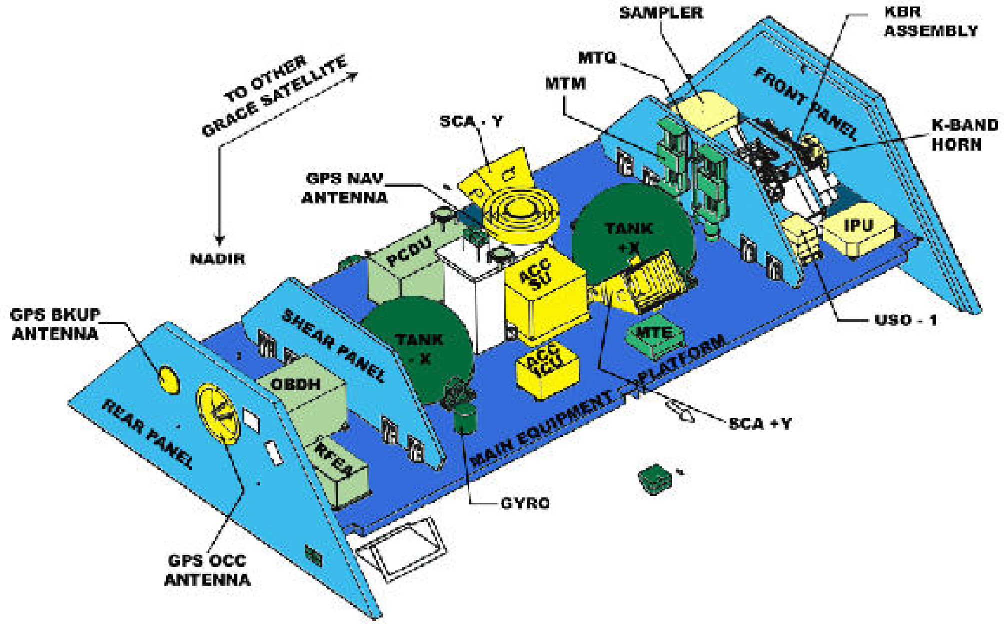
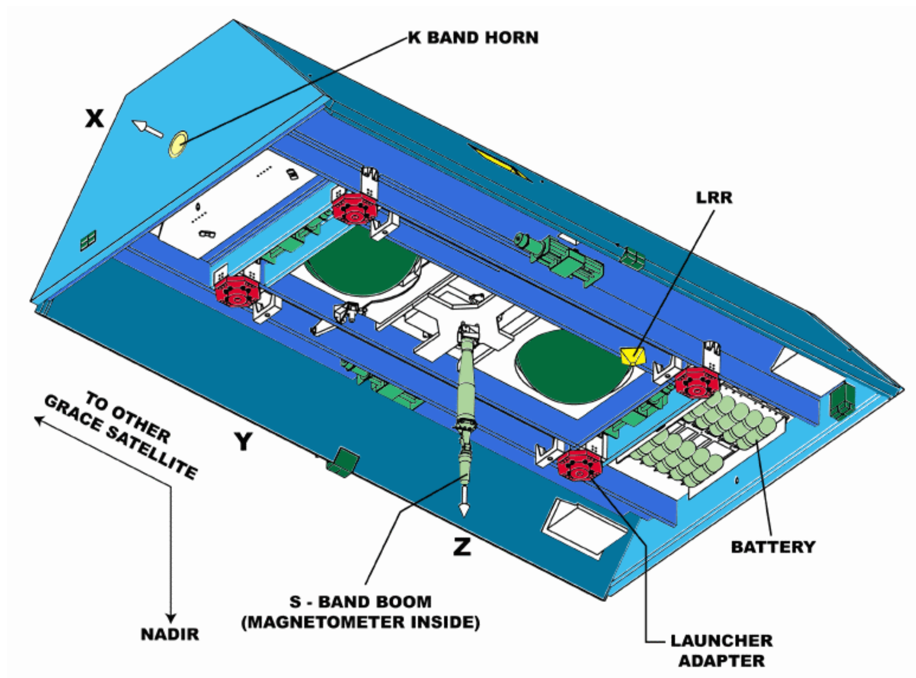


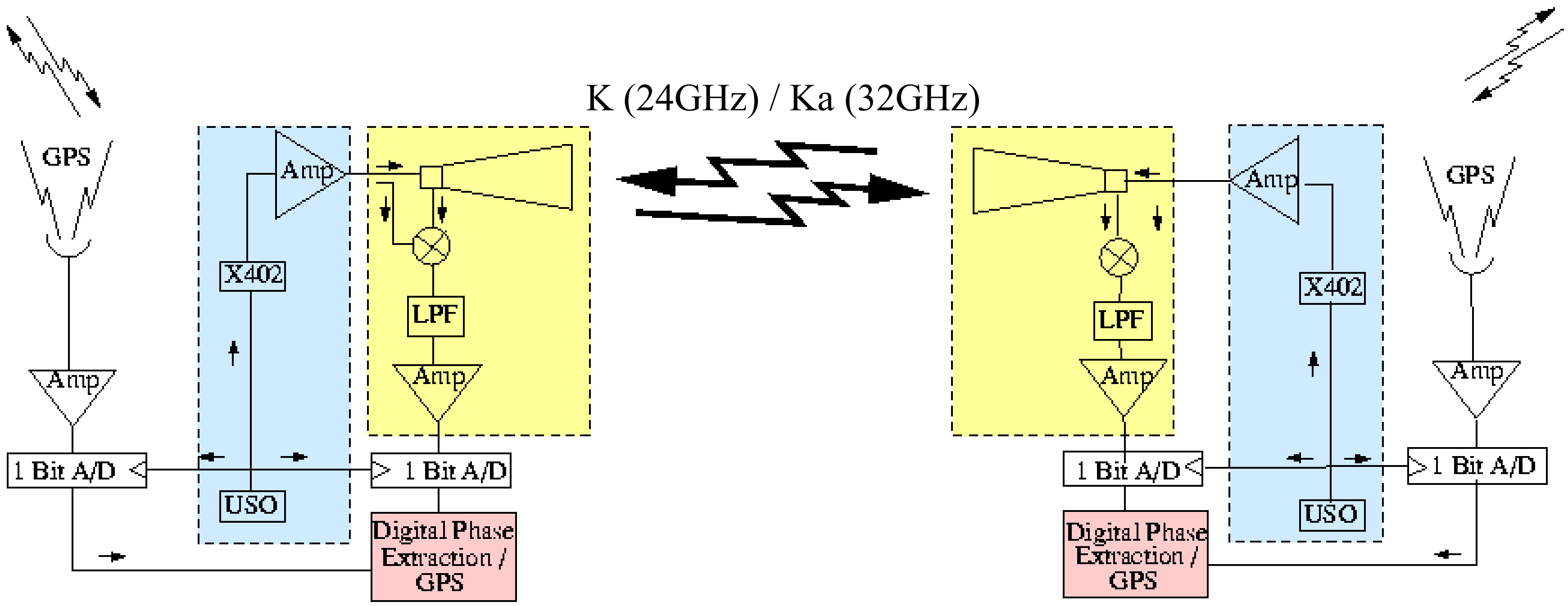
News: lancé le 17 mars 2002 à 9h21mn TUC depuis Plesetsk sur une orbite à 500 km d'altitude


TO OTHER GRACE SATELLITE
NADIR
GPS NAV ANTENNA
SZA - TX
SZA - RX
GPS BKUP ANTENNA
ATH
TOP PANELS
GLOBALSTAR SILICON SOLAR CELLS
SIDE PANELS
SCA BAFFLE
OTH - 1
OTH - 2
GPS OCC ANTENNA
CESS


TO OTHER GRACE SATELLITE
NADIR
SAMPLER
KBR ASSEMBLY
MTQ
MTM
SCA - Y
FRONT PANEL
K-BAND HORN
GPS NAV ANTENNA
PCDU
TANK +X
IPU
ACC SU
GPS BKUP ANTENNA
SHEAR PANEL
TANK - X
ACC ICU
MTE
USO - 1
OBDH
PLATFORM
MAIN EQUIPMENT
SCA +Y
REAR PANEL
RFEA
GYRO
GPS OCC ANTENNA

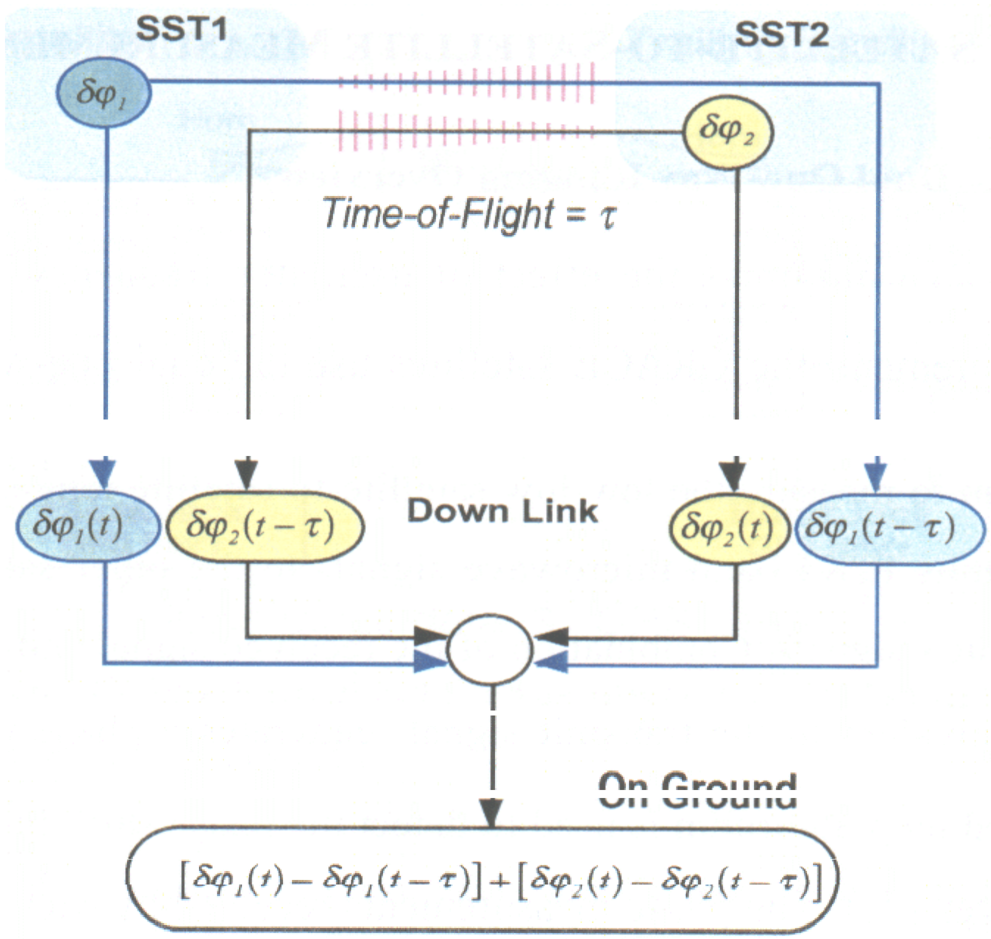

K BAND HORN
X
LRR
TO OTHER GRACE SATELLITE
Y
Z
NADIR
S - BAND BOOM (MAGNETOMETER INSIDE)
BATTERY
LAUNCHER ADAPTER

Microwave ranging system



Dual one-way ranging principle

Illustration of the oscillator noise reduction



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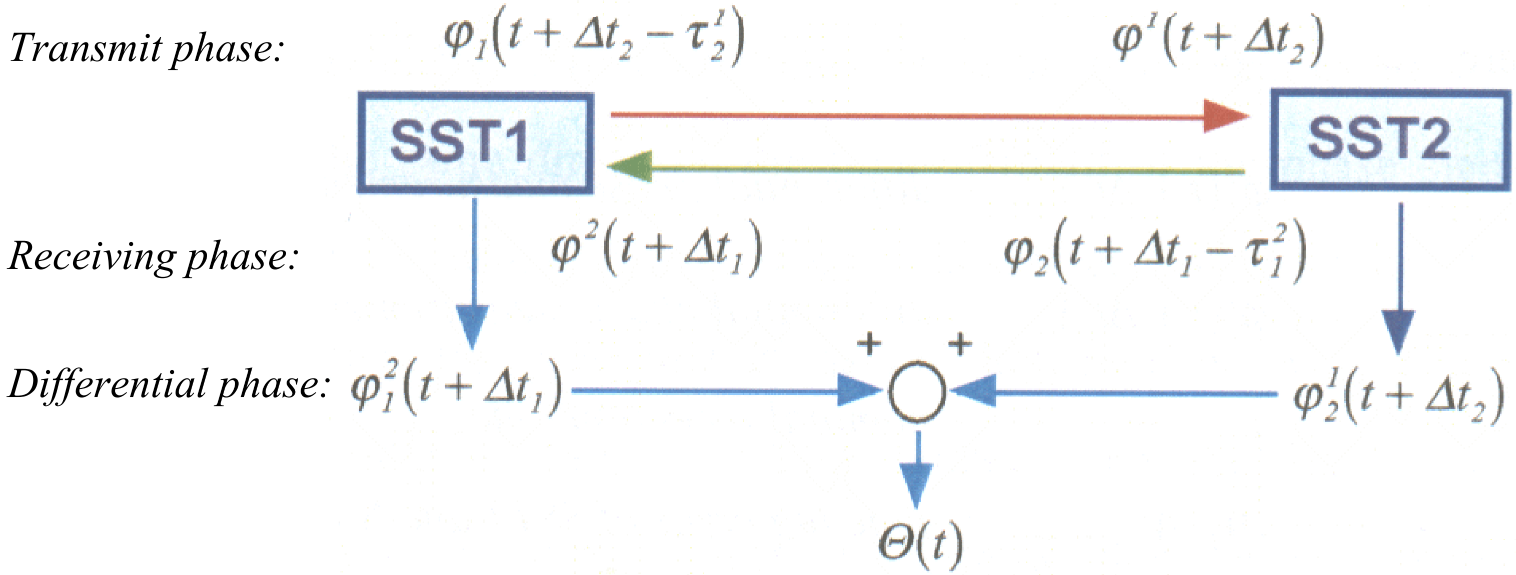
Dual one-way ranging formulation



Dual one-way ranging phase measurement:

$$
\begin{aligned}
\Theta(t) &= \varphi_1^2(t+\Delta t_1) + \varphi_2^1(t+\Delta t_2) \quad \textit{t : nominal reception time, } \Delta t \textit{ : time tag error} \\
&= \overline{\varphi}_1(t+\Delta t_1) - \overline{\varphi}_2(t+\Delta t_1-\tau_1^2) + \overline{\varphi}_2(t+\Delta t_2) - \overline{\varphi}_1(t+\Delta t_2-\tau_2^1) \quad \textit{reference frequency} \\
&+ \delta\varphi_1(t+\Delta t_1) - \delta\varphi_2(t+\Delta t_1-\tau_1^2) + \delta\varphi_2(t+\Delta t_2) - \delta\varphi_1(t+\Delta t_2-\tau_2^1) \quad \textit{phase error} \\
&+ (N_1^2+N_2^1) + (I_1^2+I_2^1) + (d_1^2+d_2^1) + (\varepsilon_1^2+\varepsilon_2^1) \quad \textit{integer ambiguities, iono phase shift,} \\
&\qquad \textit{instrument offset, multipath, noise}
\end{aligned}
$$

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Phases and phase errors can be linearized as follows:

$$\overline{\varphi}_i\left(t+\Delta t_i\right) \approx \overline{\varphi}_i(t) + \dot{\overline{\varphi}}_i(t)\,\Delta t_i = \overline{\varphi}_i(t) + f_i\ \Delta t_i$$

$$\overline{\varphi}_i\left(t+\Delta t_j - \tau_j^i\right) \approx \overline{\varphi}_i(t) + \dot{\overline{\varphi}}_i(t)\,\Delta t_j - \dot{\overline{\varphi}}_i(t)\,\tau_j^i = \overline{\varphi}_i(t) + f_i\ \Delta t_j - f_i\ \tau_j^i$$

$$\delta\varphi_i\left(t+\Delta t_i\right) \approx \delta\varphi_i(t) + \delta f_i\ \Delta t_i$$

$$\delta\varphi_i\left(t+\Delta t_j - \tau_j^i\right) \approx \delta\varphi_i(t) + \delta f_i\ \Delta t_j - \delta f_i\ \tau_j^i$$

They cancel after combining the two phase signals and the dual one-way ranging phase measurement becomes a function of the time-of-flight and other error terms:

$$\begin{aligned}\Theta(t) &= \left(f_1\tau_2^1 + f_2\tau_1^2\right) + \left(\delta f_1\tau_2^1 + \delta f_2\tau_1^2\right) \\ &\quad + \left(f_1 - f_2\right)\left(\Delta t_1 - \Delta t_2\right) + \left(\delta f_1 - \delta f_2\right)\left(\Delta t_1 - \Delta t_2\right) \\ &\quad + (N_1^2 + N_2^1) + (I_1^2 + I_2^1) + (d_1^2 + d_2^1) + (\varepsilon_1^2 + \varepsilon_2^1)\end{aligned}$$

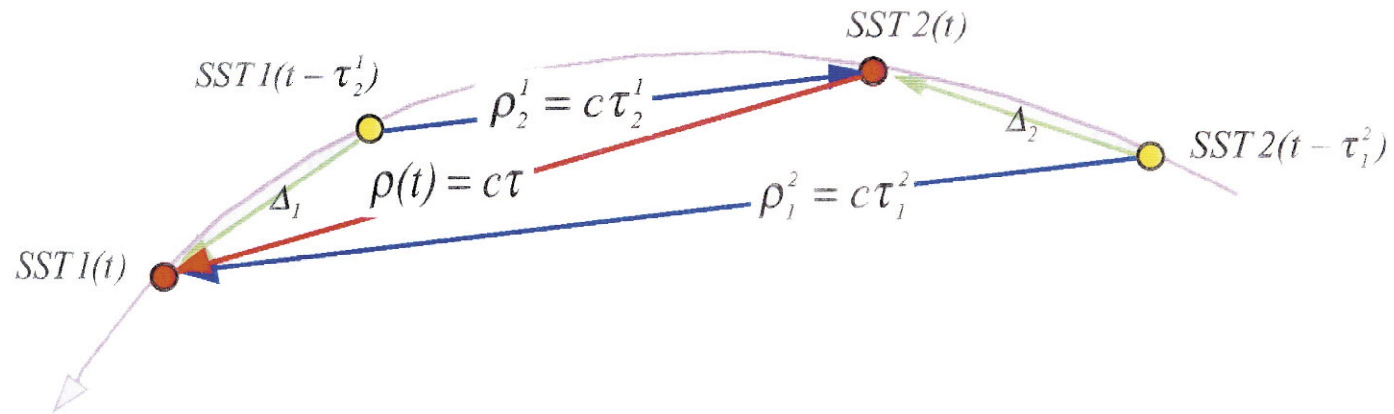
The time-of-flight τ (<1ms) corresponding to the instantaneous inter-satellite range at nominal time t is then computed by algorithm introducing an instantaneous range correction :

$$\left(f_1\tau_2^1 + f_2\tau_1^2\right) = \left(f_1 + f_2\right)\tau - \Delta\Theta_{TOF}(t)$$

The inter-satellite biased range is the computed from the dual one-way phase by multiplying the speed of light and by dividing the sum of the two carrier frequencies:

$$\begin{aligned}R(t) &= \frac{c\,\Theta(t)}{f_1+f_2} = \rho(t) - \Delta\rho_{TOF}(t) + c\,\frac{\delta f_1 + \delta f_2}{f_1+f_2}\,\tau \\ &\quad + c\,\frac{N_1^2 + N_2^1}{f_1+f_2} + c\,\frac{I_1^2 + I_2^1}{f_1+f_2} + c\,\frac{d_1^2 + d_2^1}{f_1+f_2} + c\,\frac{\varepsilon_1^2 + \varepsilon_2^1}{f_1+f_2}\end{aligned}$$

Instantaneous range correction



Since the estimation equations utilize the instantaneous range, it is necessary to convert the phase-derived range ρ_1^2 and ρ_2^1 into the instantaneous range:

$$\left(f_1\tau_2^1 + f_2\tau_1^2\right) = \left(f_1 + f_2\right)\tau - \Delta\Theta_{TOF}\left(t\right)$$

$$\Delta\rho_{TOF}\left(t\right) = c\frac{\delta f_1}{f_1 + f_2}\left(\Delta_1 - \Delta_2\right)^T.\hat{e}_{12} - \frac{f_1 - f_2}{f_1 + f_2}\left(\Delta_2^T.\hat{e}_{12}\right)$$

$$with: \quad r_1 - r_2 = \rho.\hat{e}_{12} \quad , \quad \rho_2^1 = \rho - \Delta_1^T.\hat{e}_{12} \quad , \quad \rho_1^2 = \rho - \Delta_2^T.\hat{e}_{12}$$

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Measurement errors

Oscillator noise :

it depends on the oscillator characteristics (quartz crystal oscillator with an Allan variance close to 10^{-13}) and on the dual one-way filter (function of frequency offset, carrier frequency and separation distance).

System noise :

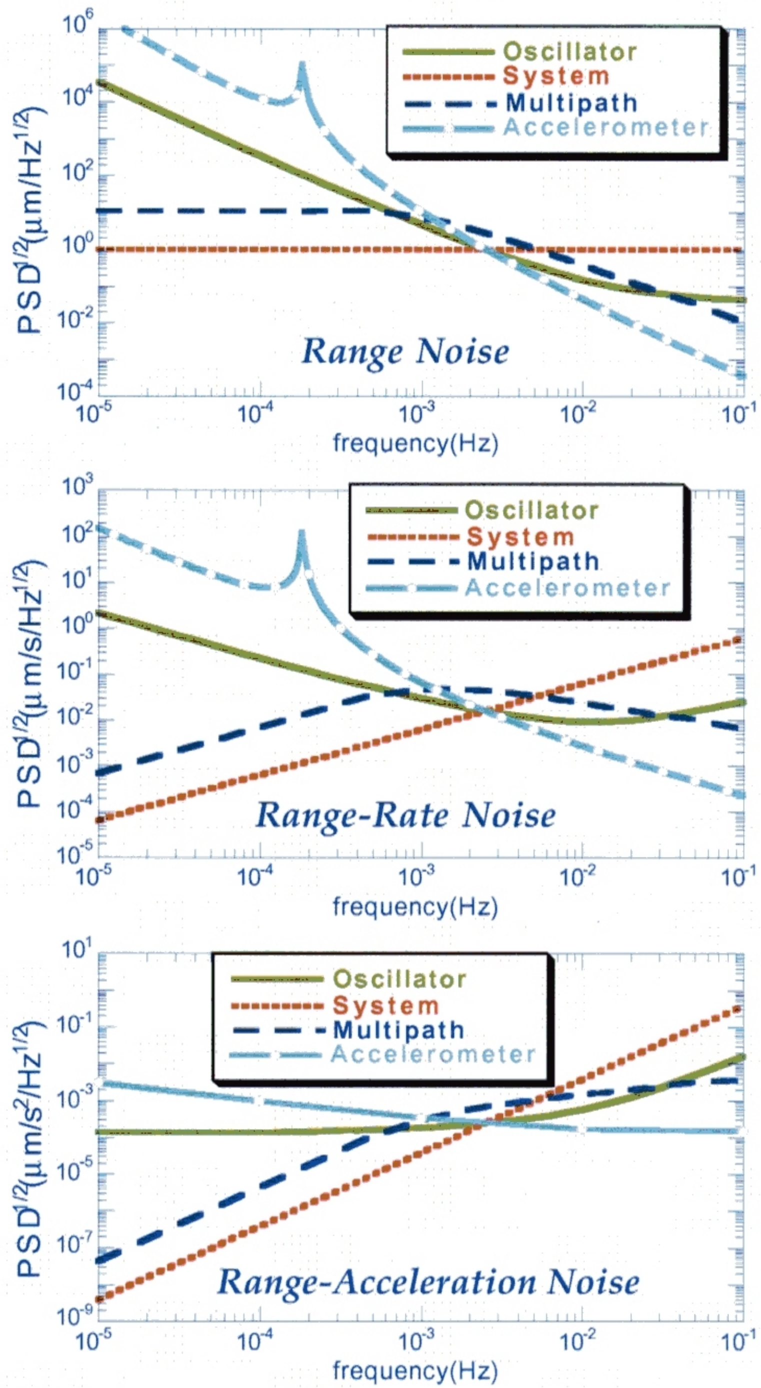
it comes from the receiver subsystem (white noise for the range constant to 1 µm) and from the time-tag error (less than 70 ps when using GPS time-tag corrections).

Multipath noise :

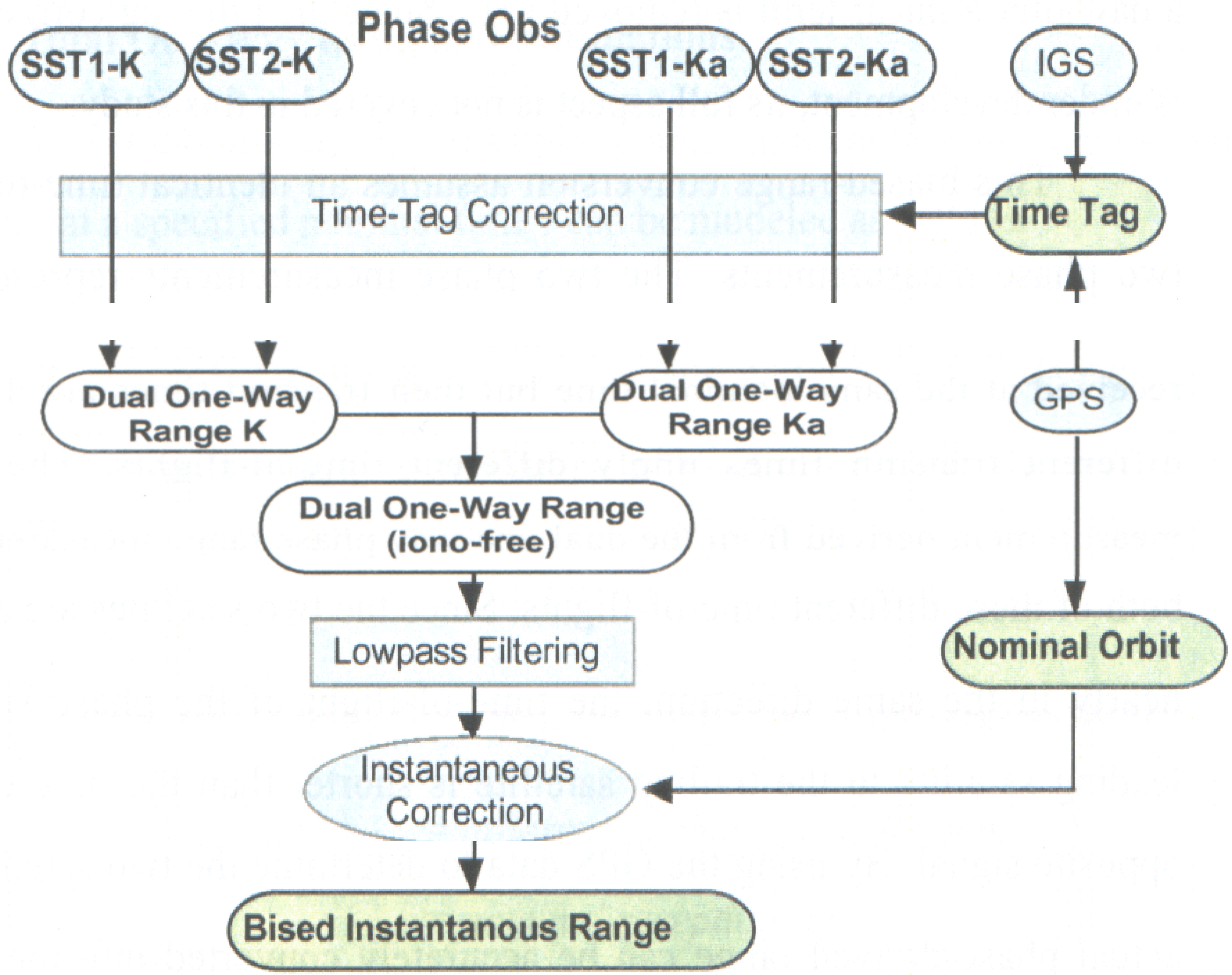
it is due to the indirect microwave signals which are reflected around the antenna horn. It depends on the reflectivity of the front surface and of the satellite attitude (< 0.3 mrad).

Accelerometer noise :

the SuperSTAR accelerometer (Onera) has a specification noise of 10^{-10} $m/s^2/Hz^{1/2}$ along R and T and of 10^{-9} $m/s^2/Hz^{1/2}$ along N. Attitude and misalignment errors may be as much as 0.3 mrad.



Pre-processing procedure (JPL)



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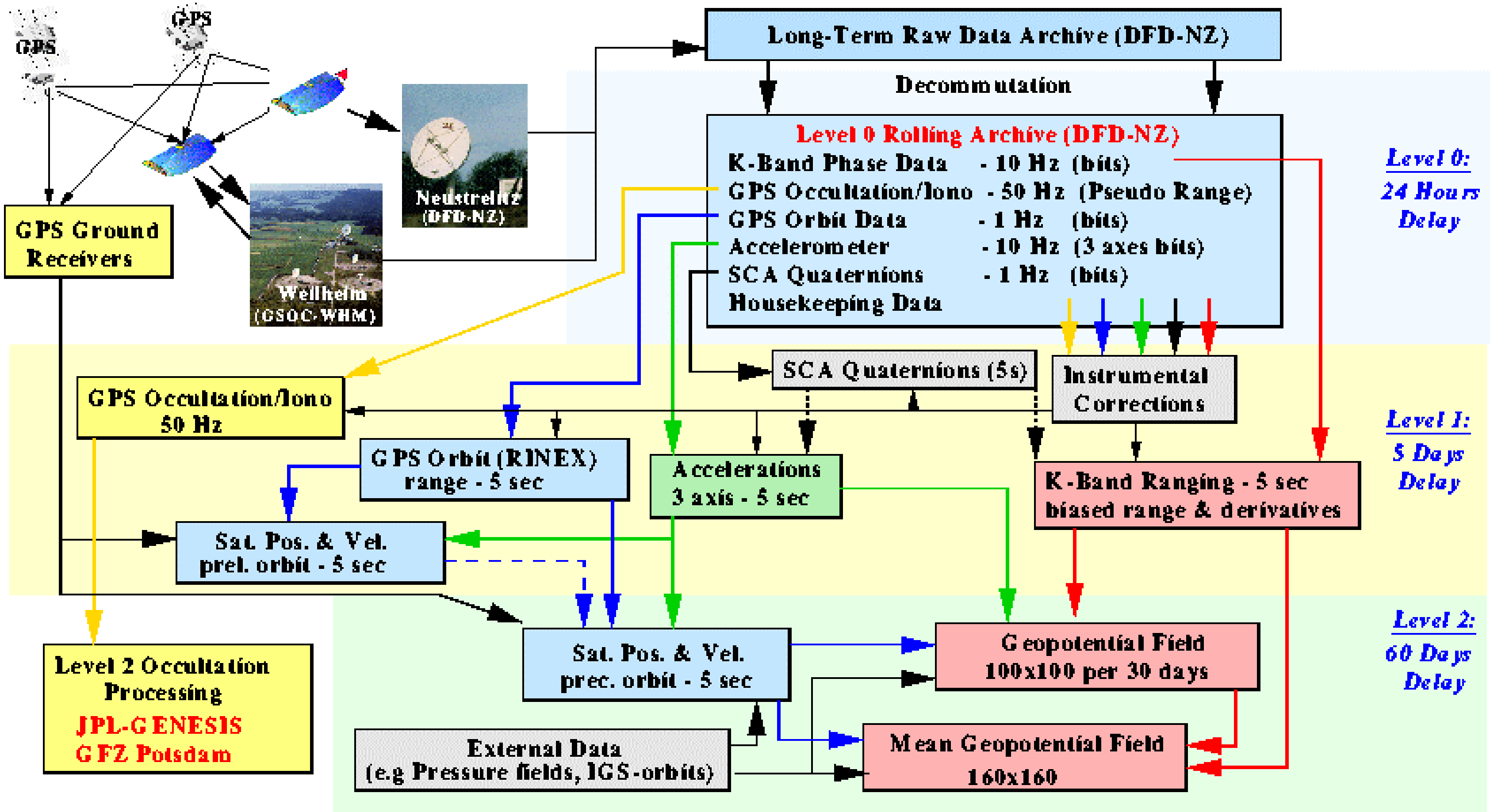
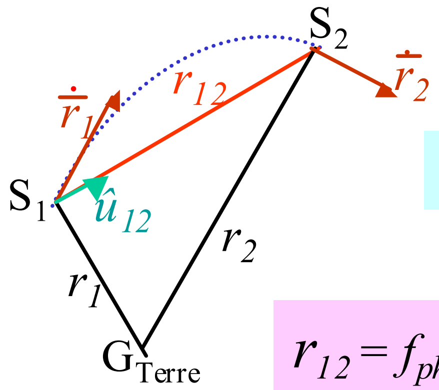
GRACE products and data flow



Exemple d 'équations d'observation pour GRACE



observables

$$\begin{cases} r_{12} = \| \bar{r}_2 - \bar{r}_1 \| \\ \dot{r}_{12} = (\dot{\bar{r}}_2 - \dot{\bar{r}}_1).\hat{u}_{12} \;,\; (\hat{u}_{12} = \bar{r}_{12} / r_{12}) \end{cases}$$

$r_{12} = f_{phase}.(phase\ mes.) + ambiguité\ (par\ ensemble\ de\ mes.\ cont.)$

Distance

$$r_{12}^{obs} - r_{12}^{calc} \approx dr_{12} = \hat{u}_{12}.(d\bar{r}_2 - d\bar{r}_1)$$

Vitesse

$$\dot{r}_{12}^{obs} - \dot{r}_{12}^{calc} \approx d\dot{r}_{12} = \hat{u}_{12}.(d\dot{\bar{r}}_2 - d\dot{\bar{r}}_1) + \frac{(\dot{\bar{r}}_2 - \dot{\bar{r}}_1) - \dot{r}_{12}\hat{u}_{12}}{r_{12}}.(d\bar{r}_2 - d\bar{r}_1)$$

mesurées (r_{12}^{obs}, $\dot{r}_{12}^{obs}$) — *de l 'intég. num.* (r_{12}^{calc}, $\dot{r}_{12}^{calc}$)

avec $$d\{\bar{r}_i, \dot{\bar{r}}_i\} = \sum_j \frac{\partial\{\bar{r}_i, \dot{\bar{r}}_i\}}{\partial(PInt_i^j)}.\Delta(PInt_i^j) + \sum_k \frac{\partial\{\bar{r}_i, \dot{\bar{r}}_i\}}{\partial(PExt^k)}.\Delta(PExt^k)$$

pour l'arc { i }

Eq. aux variations

(intég. num.)

Expected cumulative geoid error