CENTRE NATIONAL D'ÉTUDES SPATIALES

Doris phase and ionosphere effects

F. Mercier CNES DCT/SB/OR

Introduction

New Doris instruments (Jason2, Cryosat, ...)

- dual frequency synchronous phase measurement
- pseudo range measurement
- new data format (Rinex)
- 6+1 channels

Formulation for the ionosphere effects

- properties of the geometry free combination (~ iono)
  - frequencies are very different (400 MHz, 2 GHz)
- geometrical effects
  - antenna phase centre
  - antenna patterns
- windup
- effect of cycle slips
- second order iono terms

Measurements

Pseudo-range : too noisy to be used (~ 1000 m noise)

Phase :

L1 : 2036.25 MHz L2 : 401.25 MHz ratio close to 5

λ_1 : 14.7 cm λ_2 : 74.7 cm measurement noise ~ 1/100 cy

clock biases

$$\lambda_1 L_1 = D_1 + \lambda_1 d_w - e_1 + h_{rec} - h_{emi} + A_1$$

ambiguity

$$\lambda_2 L_2 = D_2 + \lambda_2 d_w - e_2 + h_{rec} - h_{emi} + A_2$$

geometry (including tropo)

phase windup

iono delay

Difference of the measurements, clock term cancels, elimination of main propagation effect, estimation of the iono effects

unknown bias for each pass

$$(e_2 - e_1) = (\lambda_1 L_1 - \lambda_2 L_2) - (D_1 - D_2) - (\lambda_1 - \lambda_2) d_w + A$$

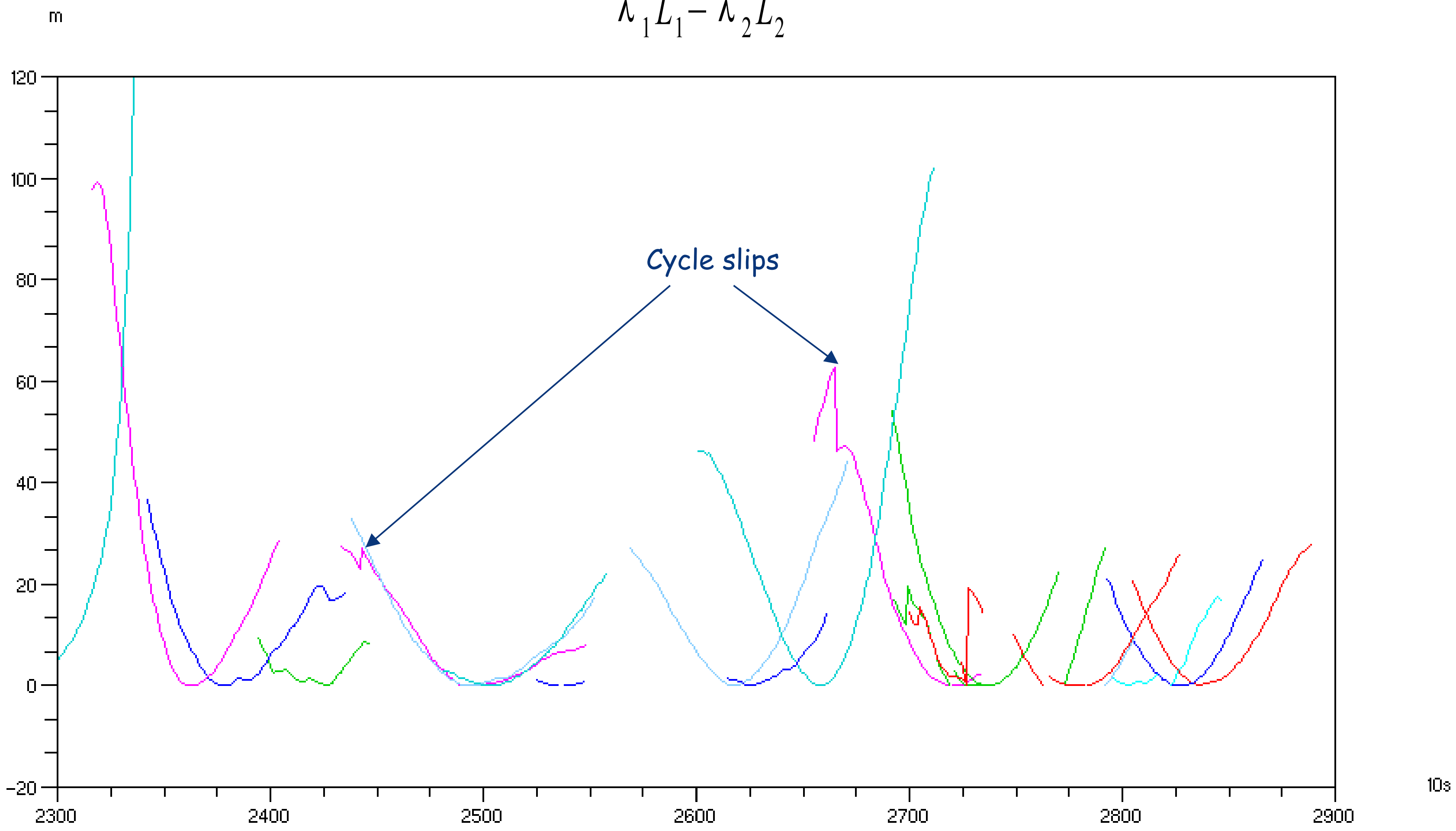
phase measurements

geometry correction

phase windup

Example

$\lambda_1 L_1 - \lambda_2 L_2$

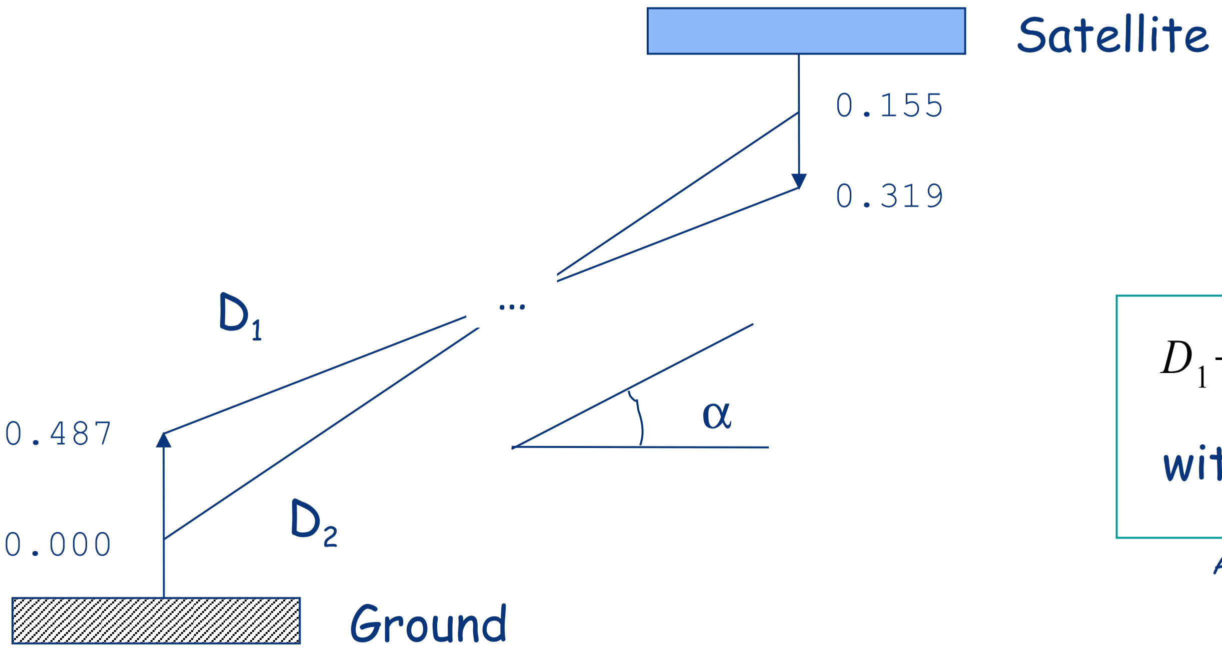


Cycle slips

Biases have been aligned to have zero minimum value of each pass
(passes are defined here as consecutive measurements, without interruption)

Geometry correction

Expression : $D_1 - D_2$



$$D_1 - D_2 \simeq -d \sin(\alpha)$$

with d = 0.651 m (Jason 2)

Approximate formula, due to orbit curvature

This term can be reconstructed using the geometry solution used for the iono modelisation.

Windup effect

Expression : $\left(\lambda_1 - \lambda_2\right) d_w$

The term d_w is usually very small

~0.5 cy maximal variation for each antenna along a pass
(case of fixed yaw)
the effects of the receiver and ground antennas almost cancel

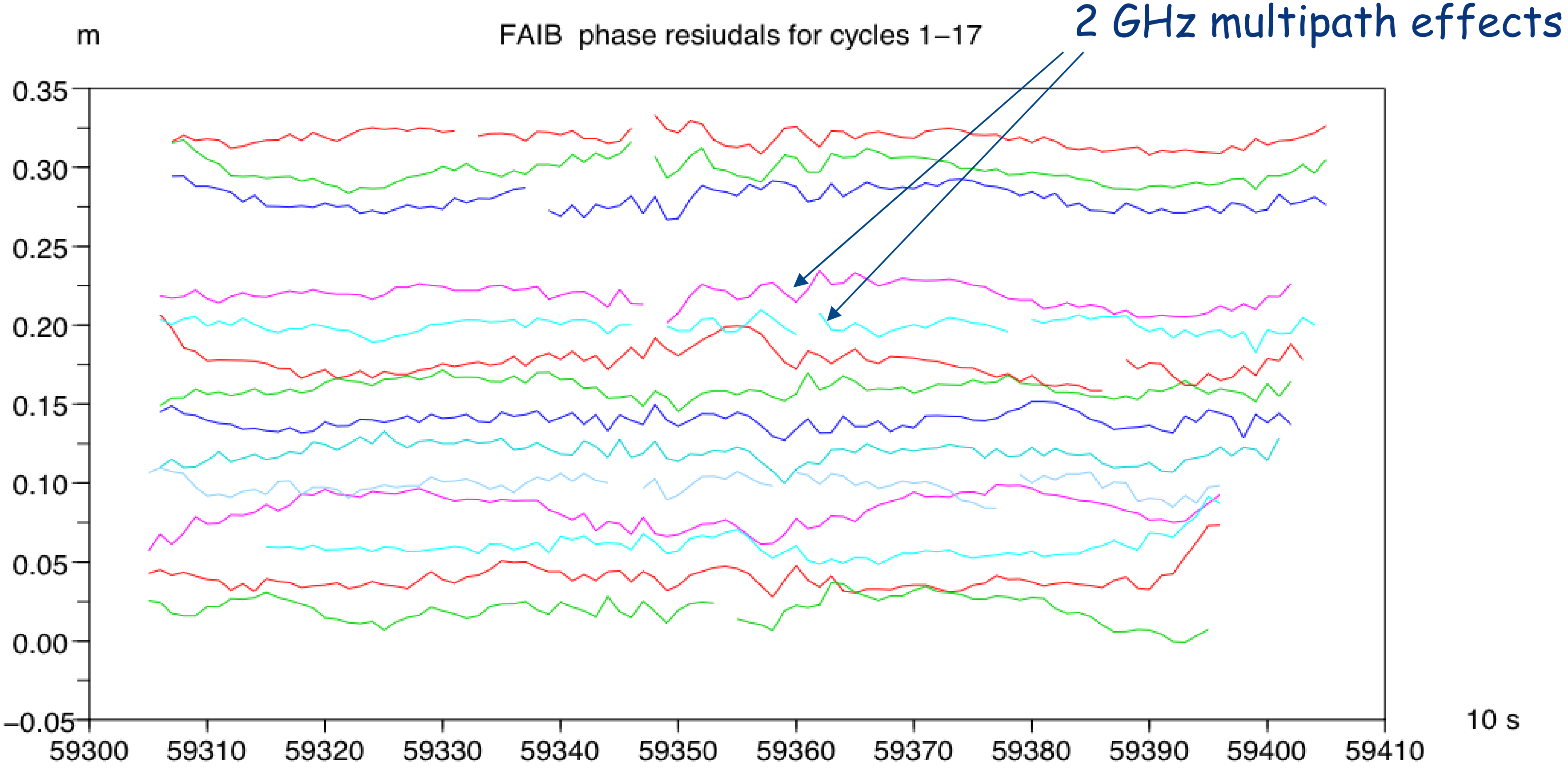
Effect of yaw steering, variation proportional to the satellite angle in orbital local frame
example : 0.5 cy for a flip

$\lambda_1 - \lambda_2 = -0.60$ m

Max value ~ 0.30 m, but much smaller for almost all passes
Not simple to compute for Jason 2 because satellite attitude must be known
Negligible for Cryosat

Multipath

Multipath effects have been observed on Doris iono-free residuals



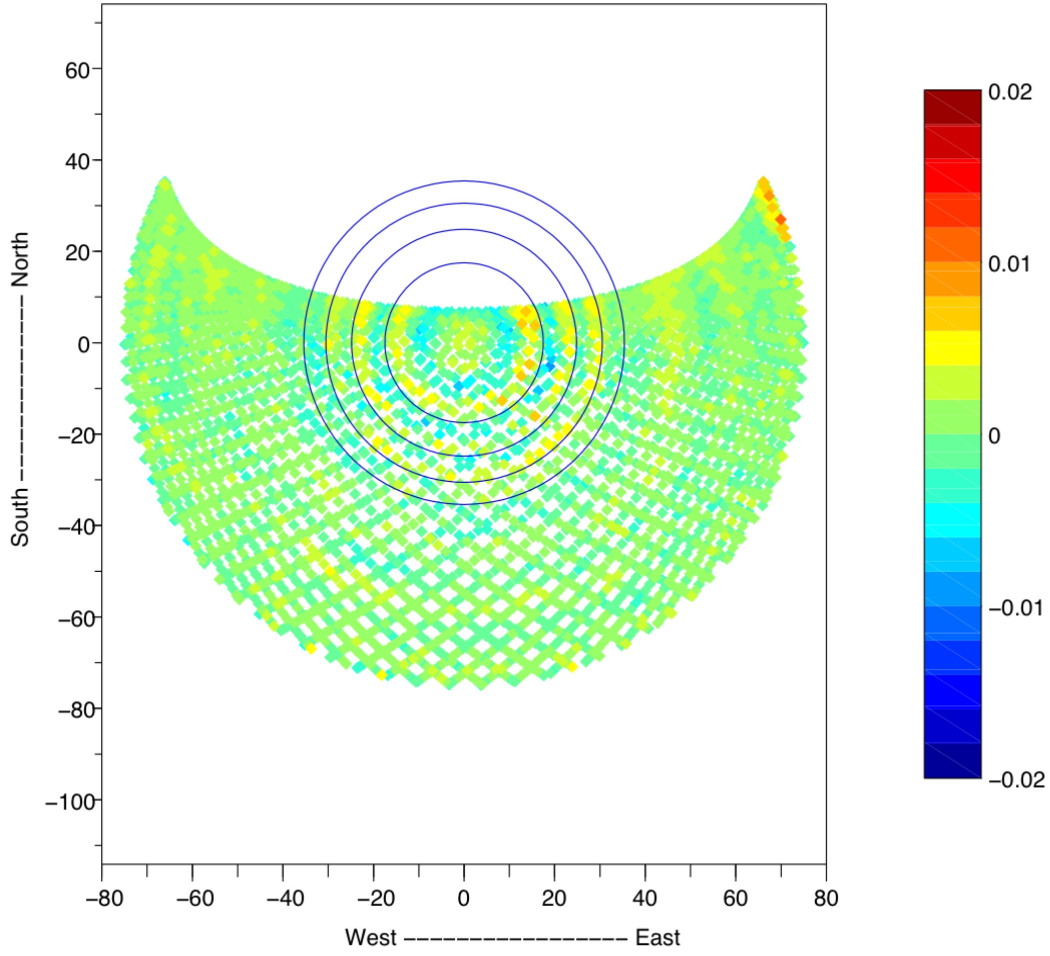
2 GHz multipath effects

Iono-free residuals on Fairbanks, Jason2 cycles 1-17 (offset applied for each cycle)
This is a worst case, multipath effects are usually smaller.
No information for 400 MHz

Multipath Fairbanks

Fairbanks, average residuals over cycles 1-17

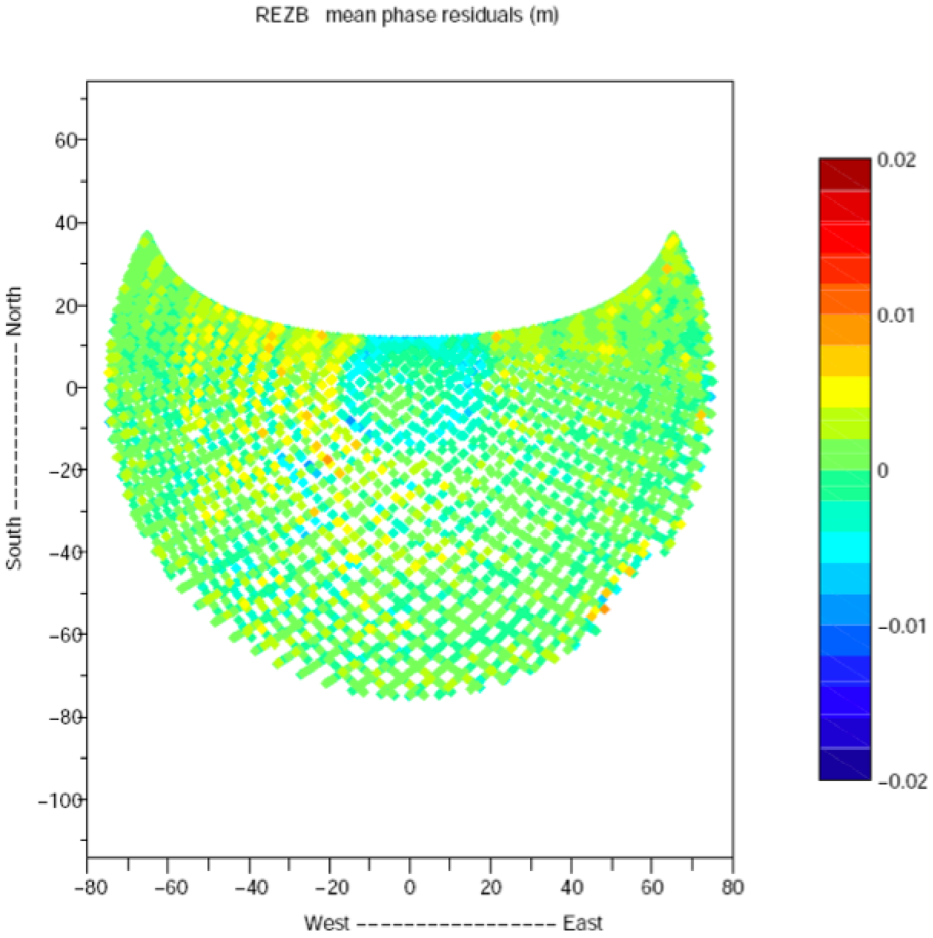
2 GHz : ~1 cm
400 MHz : ?



Multipath Reikjavijk

Reikjavijk, average residuals over cycles 1-17

2 GHz : ~1 cm
400 MHz : ?



Cycle slips

Specific behaviour of the instrument

- L1 cycle slips may occur at the highest elevation for low elevation passes
  - difficult to reconstruct without a precise model of the propagation
  - usually 1 cycle only (14.7 cm)
- L2 and L1 cycle slips at very low elevation
  - difficult to detect without a precise model of the propagation, and only for smooth iono effects
  - can be detected if they are important (threshold on possible iono variations)
  - any amplitude possible

One L1 cycle slip may remain in the middle of low elevation passes
(below ~ 30 degrees for Jason 2), effect 0.15 m
not observed on Cryosat

Higher order iono effects

Dependency in frequency $e=\frac{s_1}{f^2}+\frac{s_2}{f^3}+\frac{s_3}{f^4}$

$$e_2-e_1=\frac{s_1}{f_2^2}\left(1-\frac{f_2^2}{f_1^2}\right)+\frac{s_2}{f_2^3}\left(1-\frac{f_2^3}{f_1^3}\right)+\frac{s_3}{f_2^4}\left(1-\frac{f_2^4}{f_1^4}\right)$$

$$=0.96\frac{s_1}{f_2^2}+0.99\frac{s_2}{f_2^3}+1.00\frac{s_3}{f_2^4}$$

Order of magnitude : worst case from IERS (models for propagation delays)
0.61 m for the higher order terms

The complete 400 MHz iono (e_2, including the higher order terms)
is directly observed with an error much smaller than 2 cm

$$e_2\simeq 1.04\left(e_2-e_1\right)$$

Conclusion

Error sources : iono effect at 400 MHz

meas. noise	a few centimeters	correction
geometry term	65 cm	easy
windup	30 cm max (jason) generally much smaller	not easy (attitude)
cycle slips	15 cm bias on the half of a low elevation pass	not easy (complete prop. model)
higher order	60 cm pessimistic (?)	(?)

Conclusion :

400 MHz ionosphere propagation is observed in the phase geometry free combination

Typical geometry corrections and possible errors have been presented

For the estimation of the TEC, a bias must be identified for each pass using a model