CENTRE NATIONAL D'ÉTUDES SPATIALES

Analysis of Jason-2 doris phase residuals and related POD results

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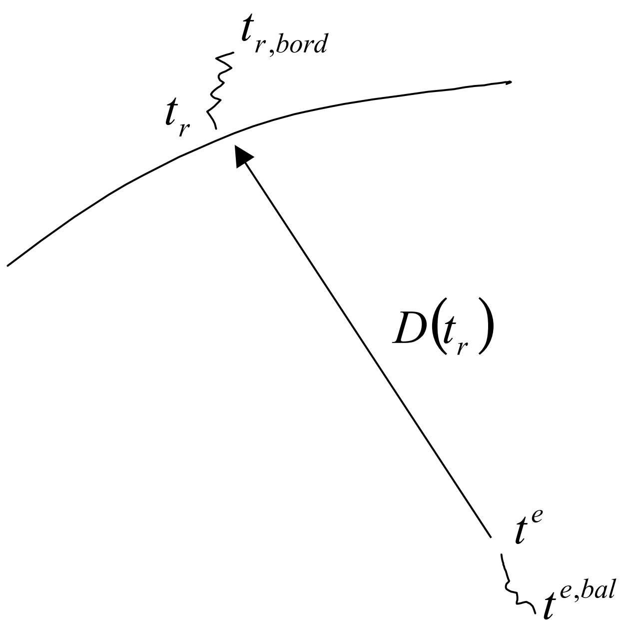
Jason-2 new measurements types

Double-frequency synchronous phase and pseudo-range measurements (L1,C1 : 2 GHz L2,C2 : 400 MHz)

- 10 sec. sampling
- 10 sec. + 3 sec. sample (not used here)

Pseudo-range measurements , for time-tagging



propagation, including tropospheric effects

$$t_{r,bord} = t_r + h_r$$

$$t^{e,bal} = t_r - \frac{D(t_r)}{c} + h^e$$

$$C = c\left(t_{r,bord} - t^{e,bal}\right) = D(t_r) + c\left(h_r - h_e\right)$$

pseudo-range

Time-tagging method used by CNES POD Team :

- preliminary orbit
- h^e is known on reference beacons
- $t_{r,bord}$ is also known (on board time on Rinex files)
- h_r is solved-for as polynomial (implicit form)

$$D\left(t_{r,bord} - h_r\right) + c\left(h_r - h^e\right) = C$$

Measurement : either C1 or C2, or iono-free combination

Pseudo-range residual example

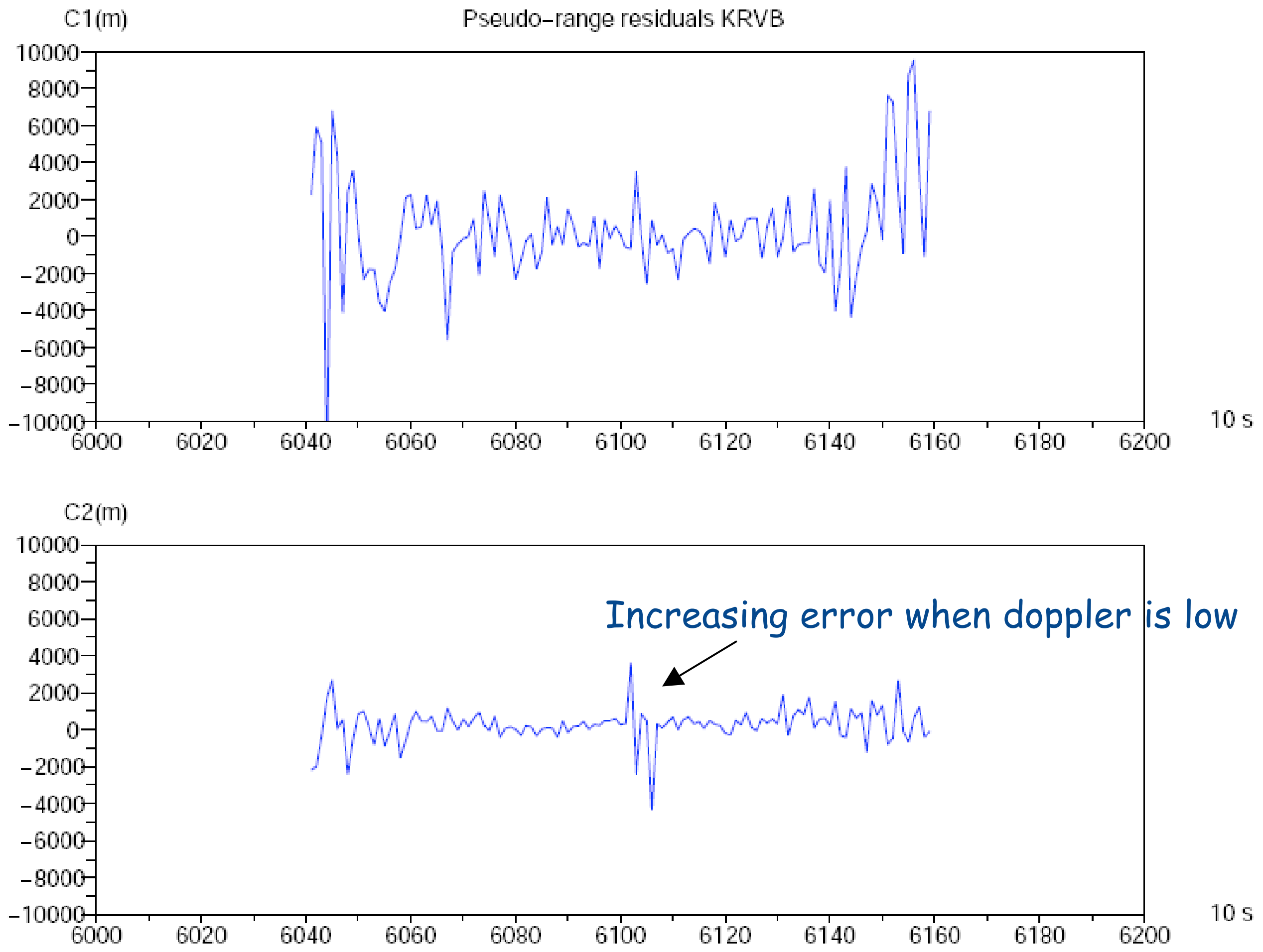


Figure 1: Pseudo-range residuals, sampling 10 seconds

Phase measurements

Phase measurements, synchronous at the satellite phase centre

$$\lambda_1 L_1 = D_{1,w}(t_r) - e + c\left(h_r - h^{e1}\right) - \lambda_1 N_1$$
$$\lambda_2 L_2 = D_{2,w}(t_r) - \gamma e + c\left(h_r - h^{e2}\right) - \lambda_2 N_2$$

propagation, including troposphere, and windup

Beacon and receiver clocks

- Useful equations to detect cycle slips (integer variations of N1 and N2 within the same pass)

- Use the receiving time $t_r = t_{r,bord} - h_r$ to model the distance and time-tagging polynom for the term ch_r (long term clock behaviour of receiver)

- In practice for orbit determination and station positioning, we process the iono-free observable, including a polynomial per pass to account for additional clock errors and ambiguities:

$$\frac{\gamma\lambda_1 L_1 - \lambda_2 L_2}{\gamma - 1} = D_{c,w}(t_r) + ch_r + a_0 + a_1 t + \ldots + c\left(\delta h_r - \delta h^e\right)$$

Residual clock errors

Geometric model and troposphere

Long term on board clock model

Beacon/On-boards clocks at the pass time-scale and N1,N2 ambiguities (degree 1 is minimum degree for the polynomial)

Phase measurements interruption, Doppler collisions

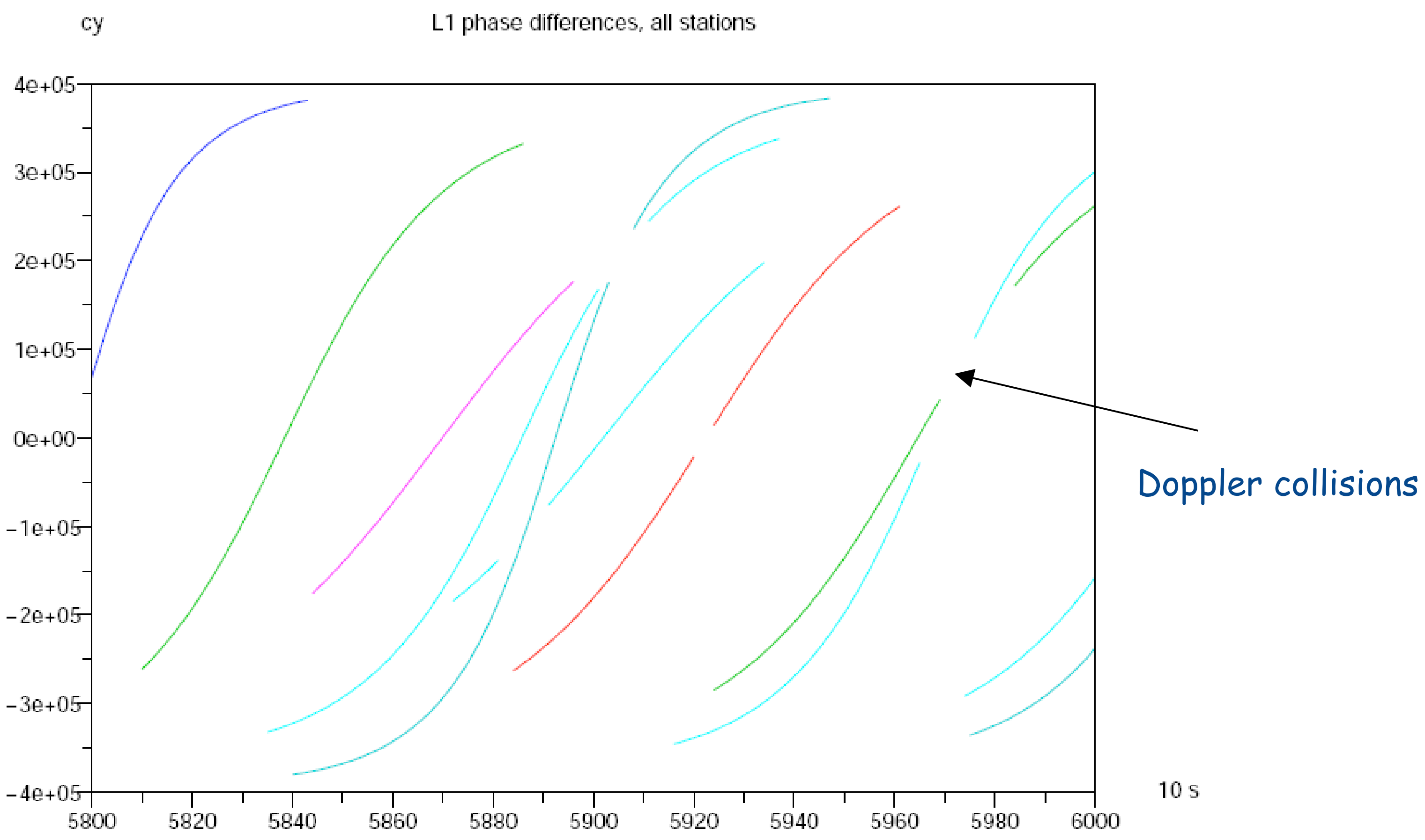


Figure 3: L_1 time variations, sampling 10 seconds

Up to six simultaneous channels

Phase continuity within a pass is often interrupted

Phase measurements example, near-zero doppler measurements

Presence of cycle slips (mainly on L1)

At low elevation and near-zero doppler

Can be detected and fixed (see backups slides)

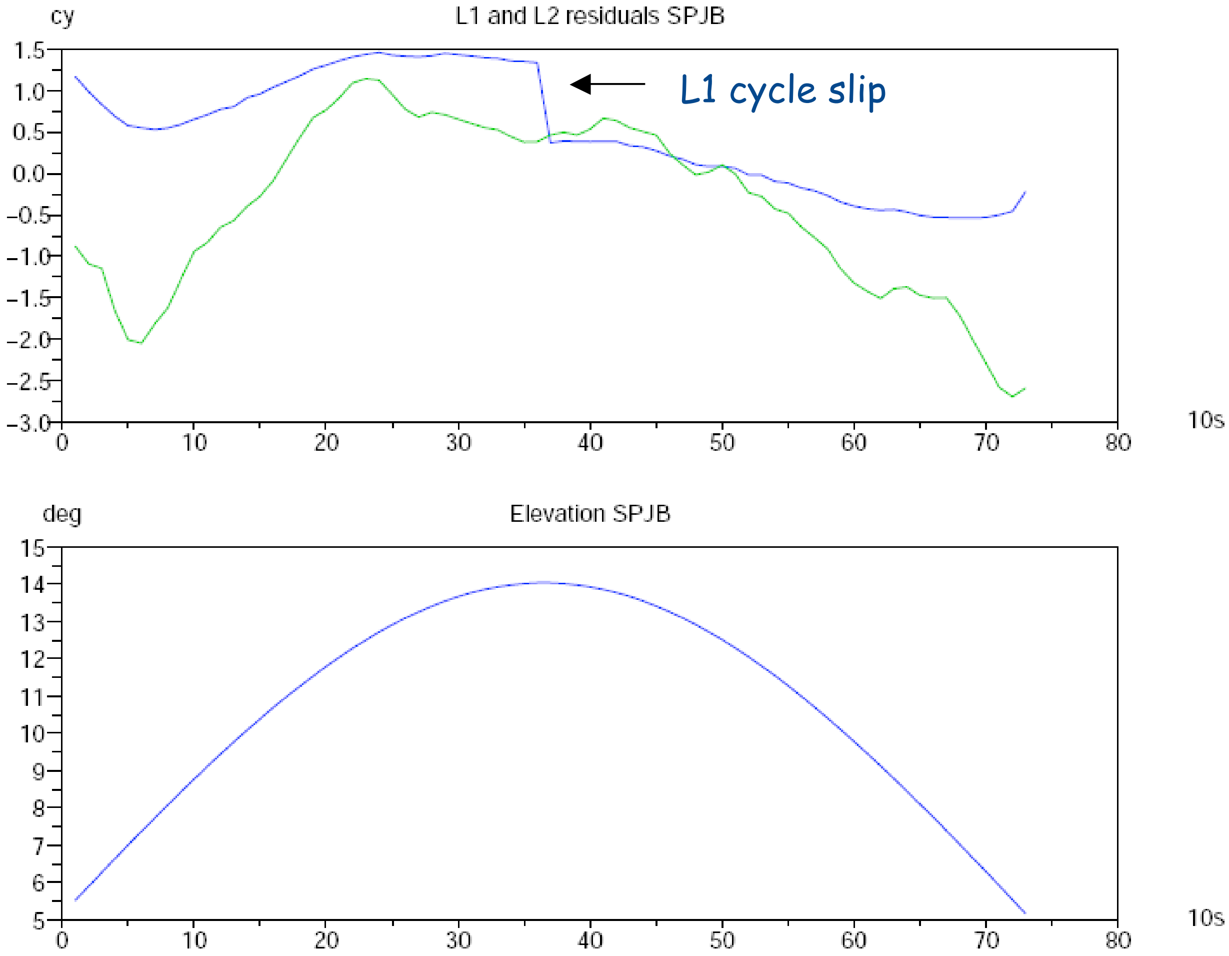
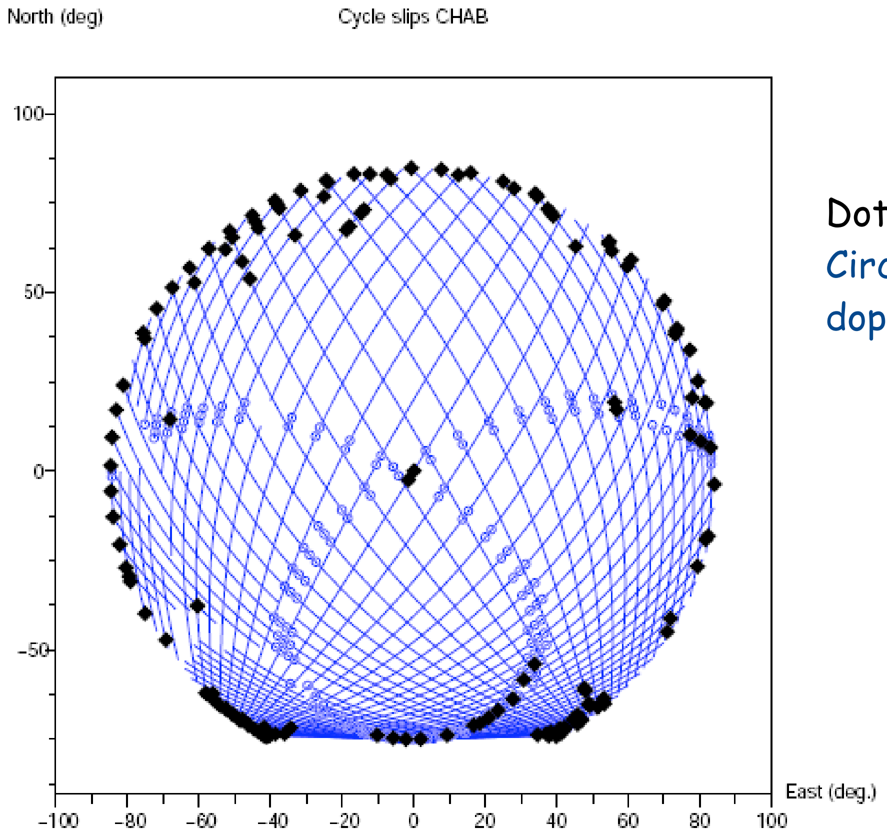


Figure 4: L1 residuals : one pass Jason2 station SPJB

Cycle-slip reconstruction (CHAB)



Dots: cycle slip
Circles: near-zero doppler (<310 m/s)

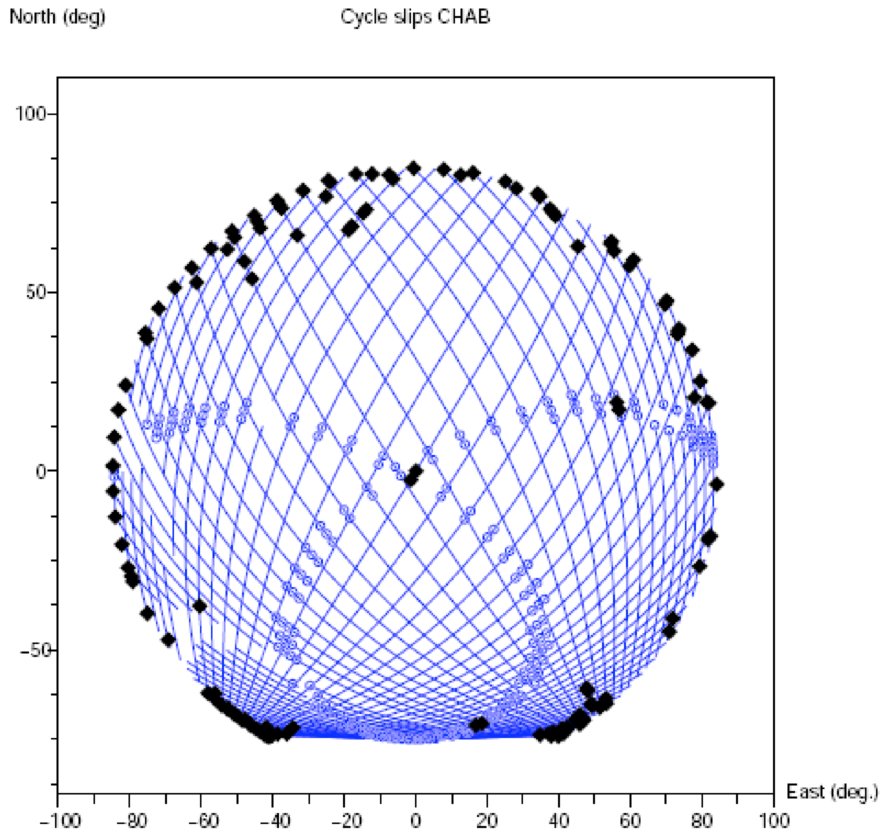


Figure 5: Cycle slips station CHAB, without and with reconstruction

Phase residuals analysis and antenna phase maps

Method :

Eliminate the contribution of clock error : possible if many repeat cycles are processed

Cycle slip reconstruction to minimise pass brakes

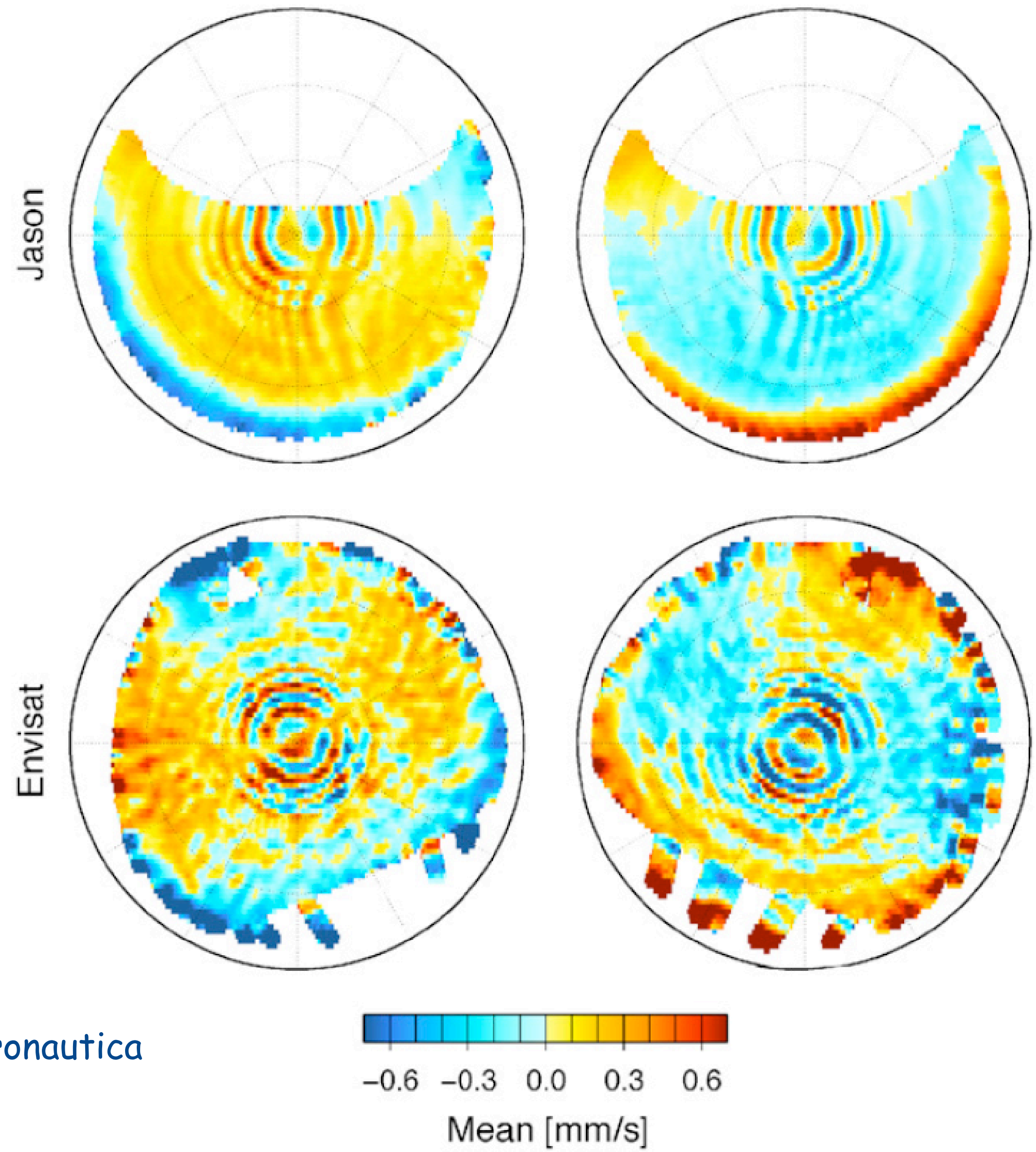
Phase processing allows direct comparison of residuals and building of real phase maps.

In the case of Doppler, one has only access to the derivative along the ground track. Residuals are usually separated between ascending and descending tracks to avoid the handling of ground-tracks intersections.

→ Phase residuals maps have been built for almosto all the network

Known doppler results on Fairbanks

Need to distinguish ascending from descending tracks, to avoid pass intersection. Difficult to handle high latitude stations on Jason orbit

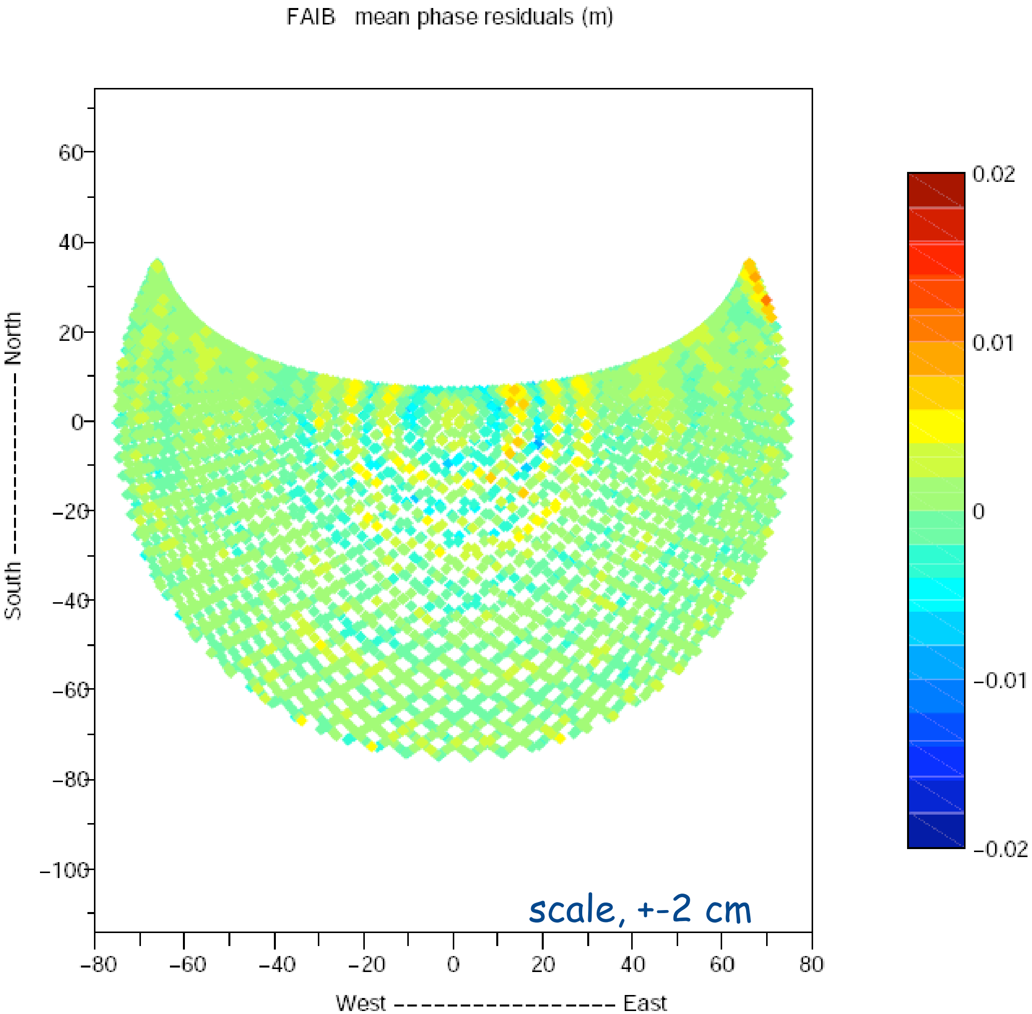


publication : E. Doornbos, P. Willis, Acta Astronautica

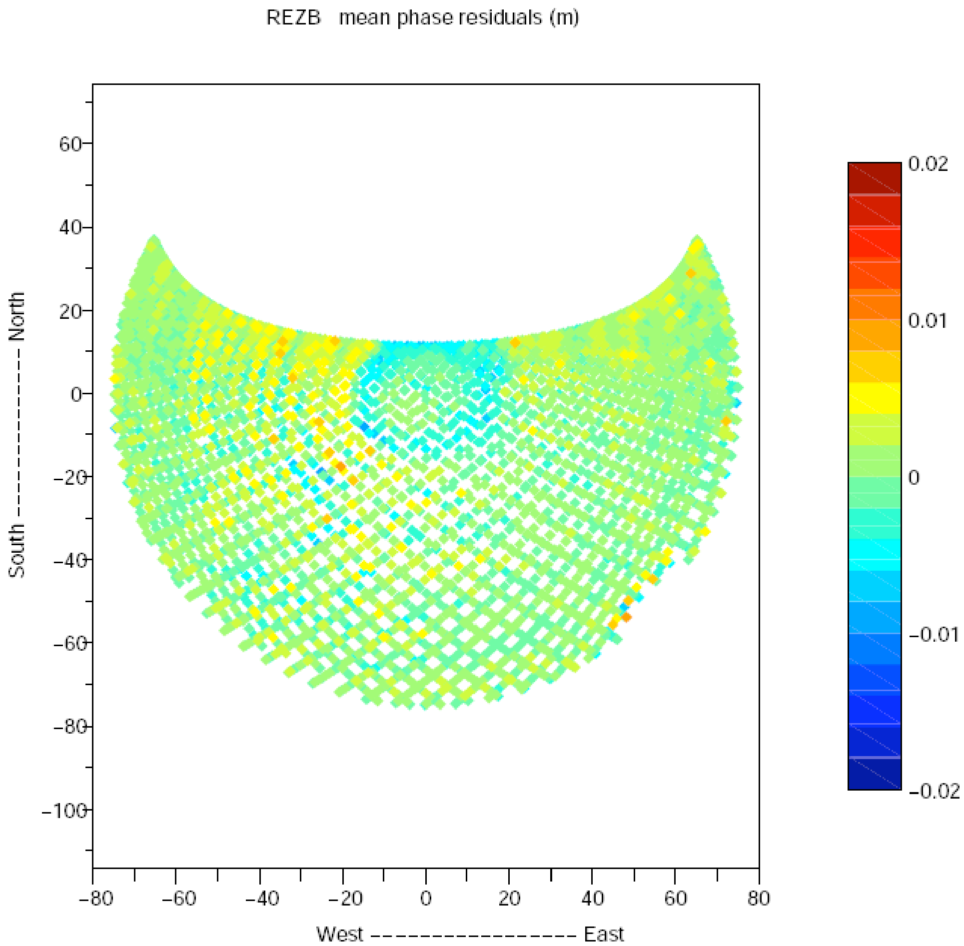
Fairbanks phase map

Plot of the Jason-2 phase residuals over each mean pass. The mean was established over cycles 1-17
Interference ring pattern is clearly visible and very regular

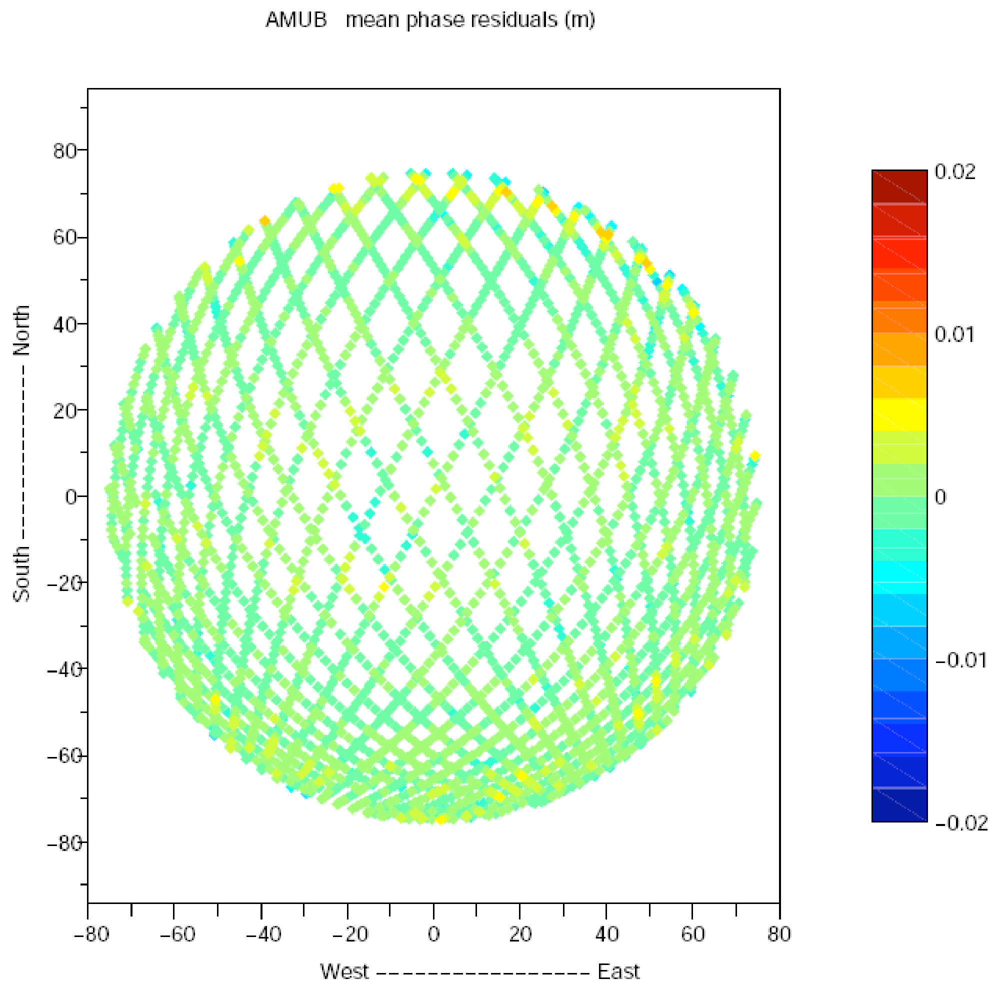
Site IDS : http://ids.cls.fr/html/doris/stations/station.php3?code=FAIB



Reykjavijk


REZB mean phase residuals (m)
North
South
West
East
0.02
0.01
0
−0.01
−0.02

AMUB


AMUB mean phase residuals (m)
South ---------------- North
West ---------------- East
80
60
40
20
0
−20
−40
−60
−80
0.02
0.01
0
−0.01
−0.02

More details on the processing of residuals used to obtain phase maps

Adjusted parameters per each visibility:

- 1 ambiguity per continuous phase measurement subset
- 1 wet tropospheric zenith delay
- 1 degree 3 polynomial

Measurements are synchronized with respect to the beginning of the cycle and the mean is performed over the corresponding passes of each cycle

Residuals per pass

Residuals after adjustment of :

- troposphere bias
- degree 1 polynomial
- ambiguities

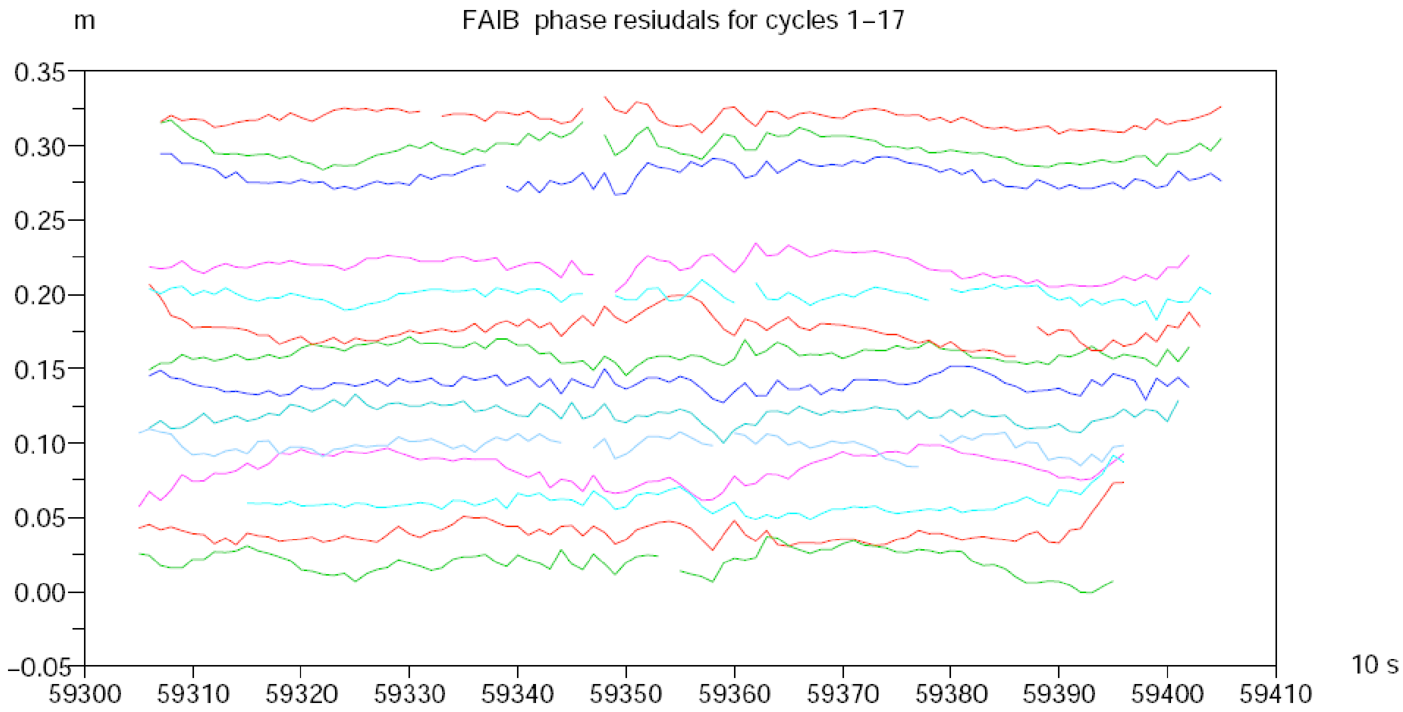
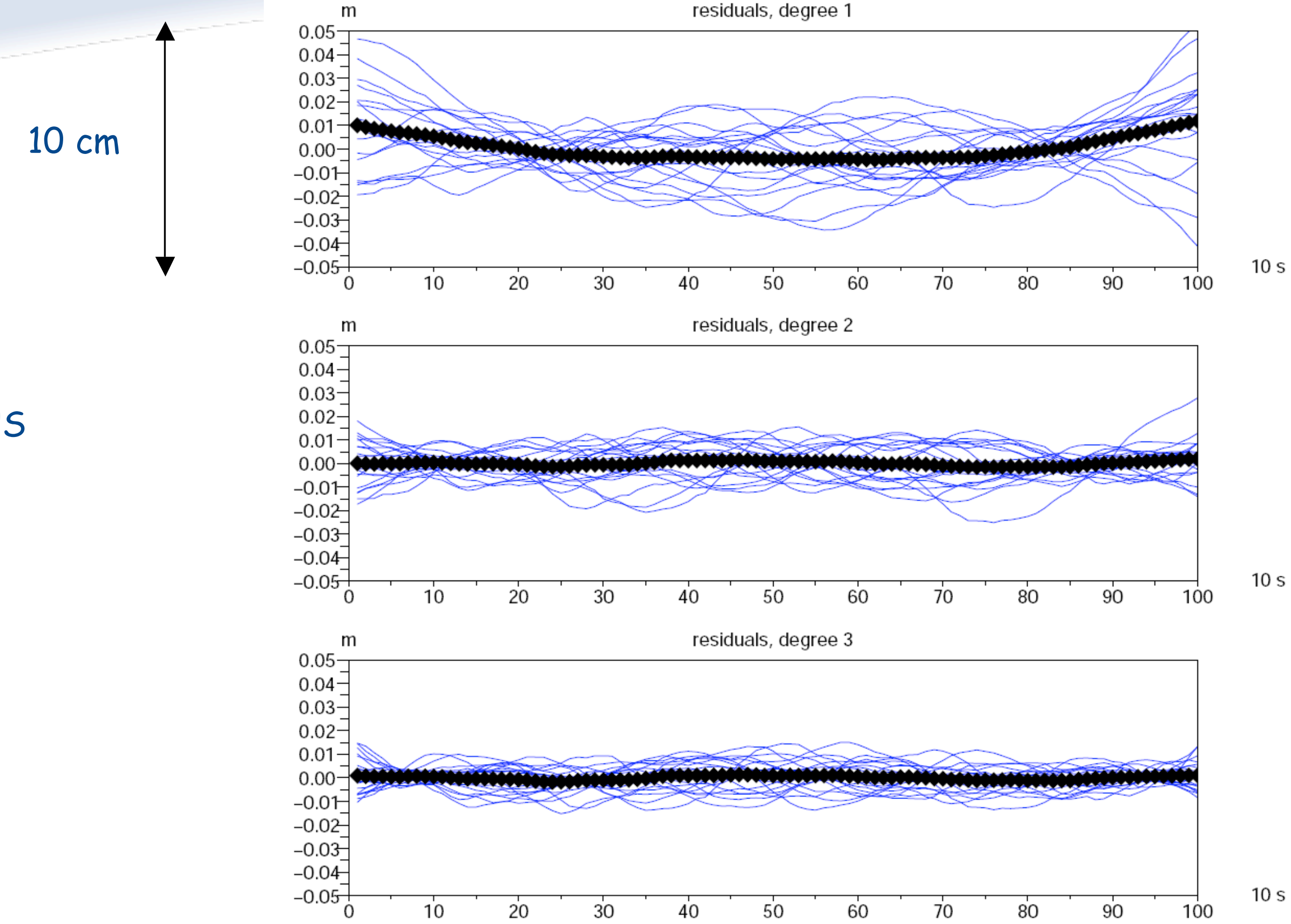


Figure 7: FAIB phase residuals for cycles 1-17, 2 cm offset added for each cycle

Short term oscillation are repeatable from one cycle to the other (phase maps)
Low frequency fluctuations (clock ?) --> need higher degree for polynomial (3)
Phase processing : loss of observability due to interruptions

→ impossible to observe correctly low frequency evolutions

Impact of clocks at 1000 sec time-scale



Example: ground test of OUS
- polynomial fit over 1000 s
- impact of degree (1,2 or 3)
- mean over 20 cases

To eliminate the impact of clocks :
- need to have many cycles
- use degree 3 polynomial

POD results using phase measurements

Phase processing without cycle-slip reconstruction

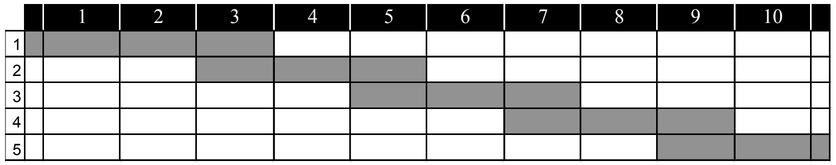
- Pass-break introduced whenever a phase discontinuity(*) occurs
- Phase discontinuities caused by near zero-doppler measurements are not considered
- Subsets left with < 10 valid measurements are rejected

Processing type	Doppler	Phase
Bias	-	1/set
Clock Drift	1/pass	1/set
Wet Zenith Delay	1/pass	1/set
Mean number of measurement per pass or set	68	49

(*) Phase discontinuity: when the time interval between two valid measurements is greater than 10 sec.

POD results using phase measurements

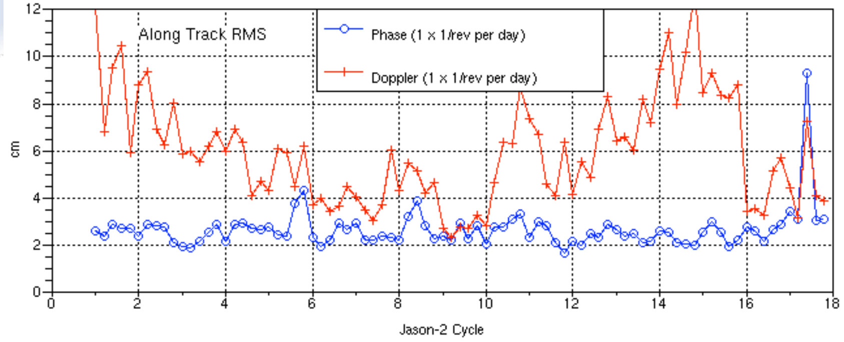
- Each 10-day cycle split into 5 arcs of about 3 days each with 1 day overlap
- Abut 35% of edited measurements
  - 20 % for cut-off angle = 10 deg.
  - 15 % usual editing of outliers (polynomial fit on doppler residuals)



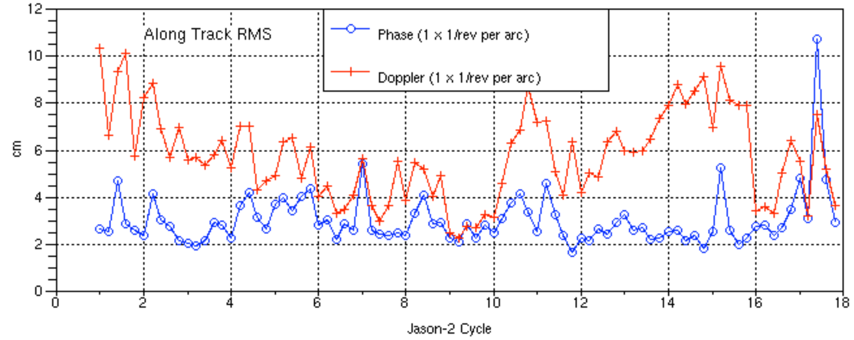
Arc number	Available measure-ments	Edited measurements		Valid passes	
		Doppler	Phase	Doppler	Phase
1	88612	30169	30556	861	1190
2	79033	27312	27738	762	1048
3	78554	26867	27442	768	1064
4	77806	26520	27090	761	1056
5	47467	16309	16631	461	626

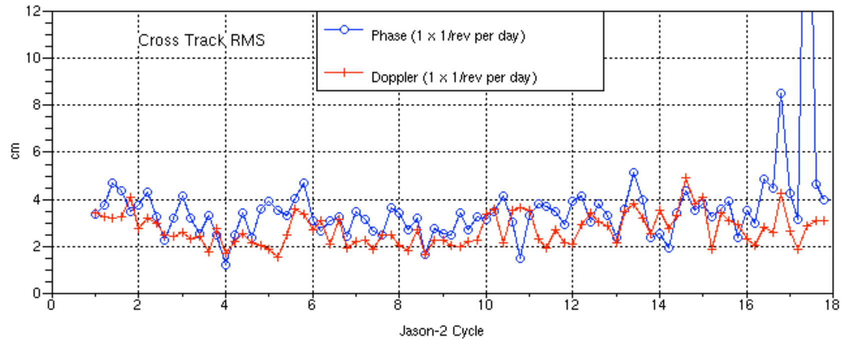
POD results using phase measurements

Comparison to CNES D/L/G POE

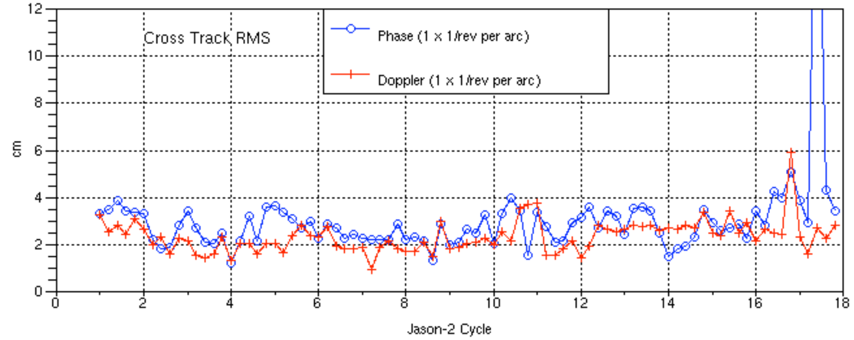


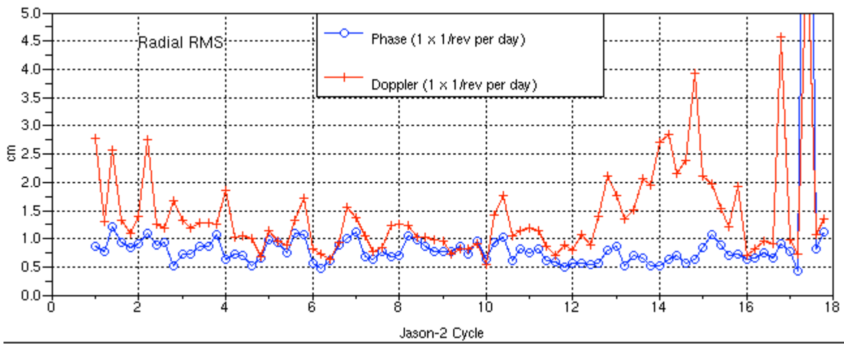
1 along-track 1/rev per day

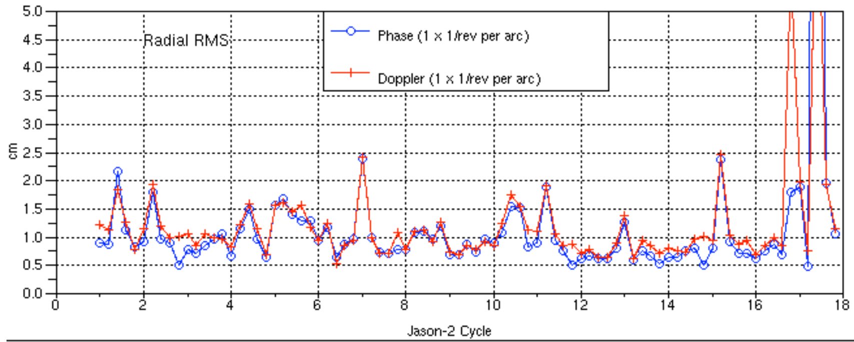




1 along-track 1/rev per arc

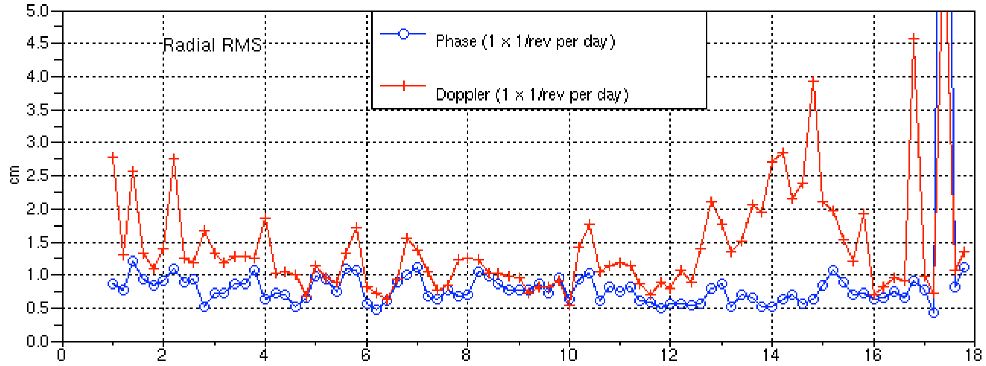




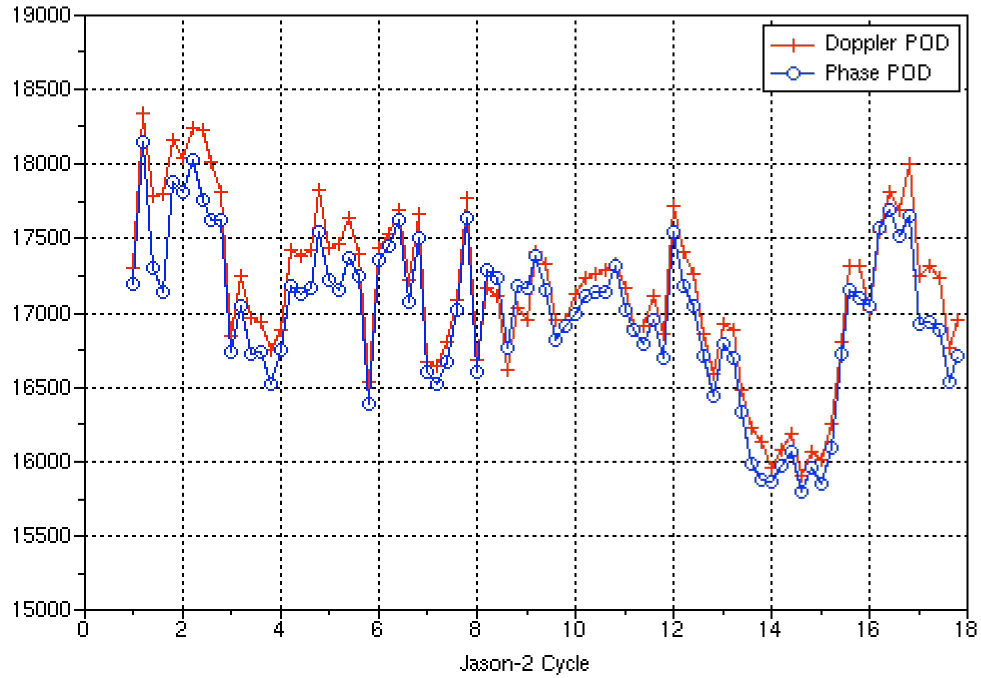


POD results using phase measurements

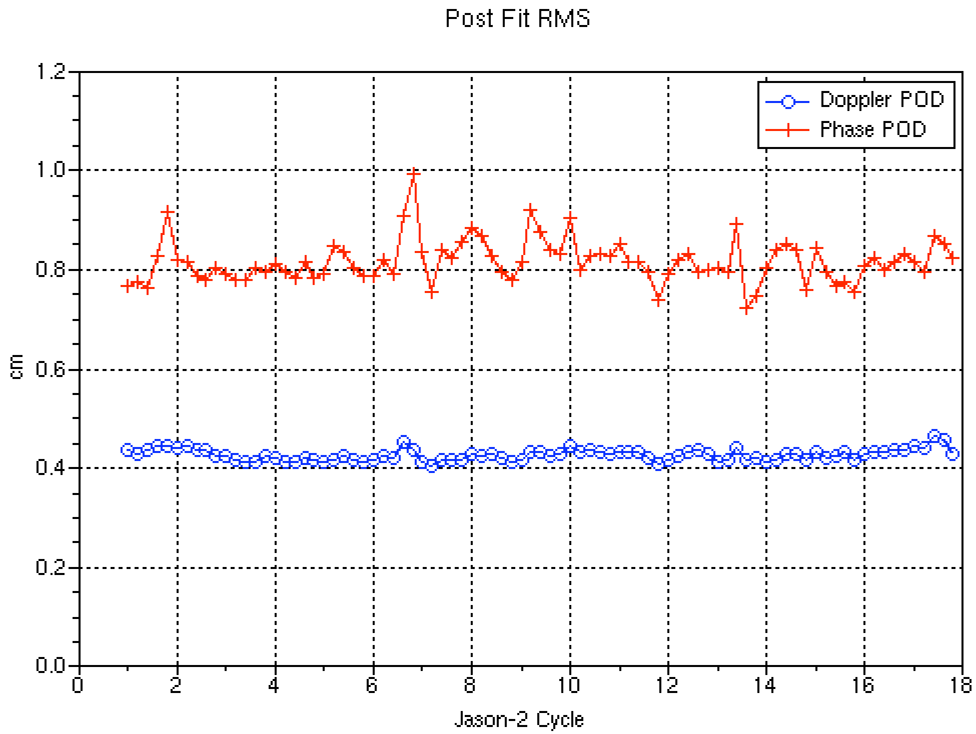
- 1/rev-per-day Doppler arcs much more affected by small variations of the measurements density
- Very stable performance of phase arcs, without needing any particular intervention

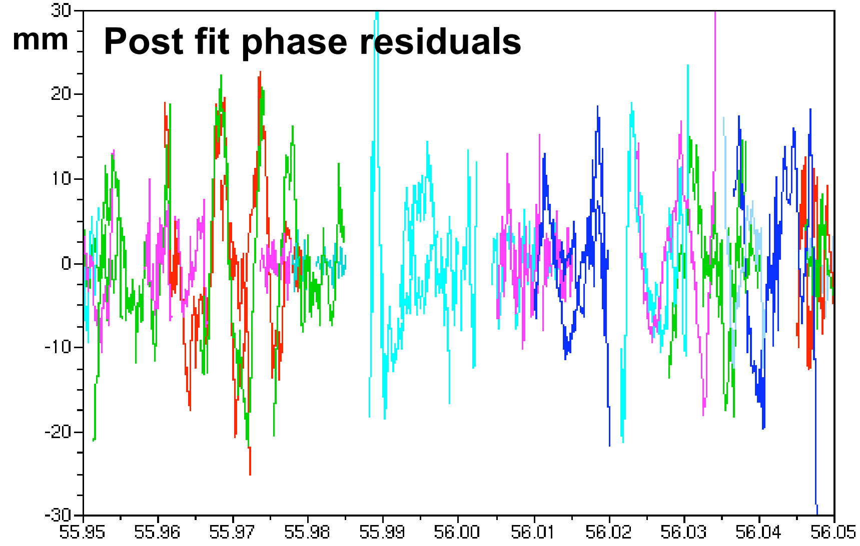


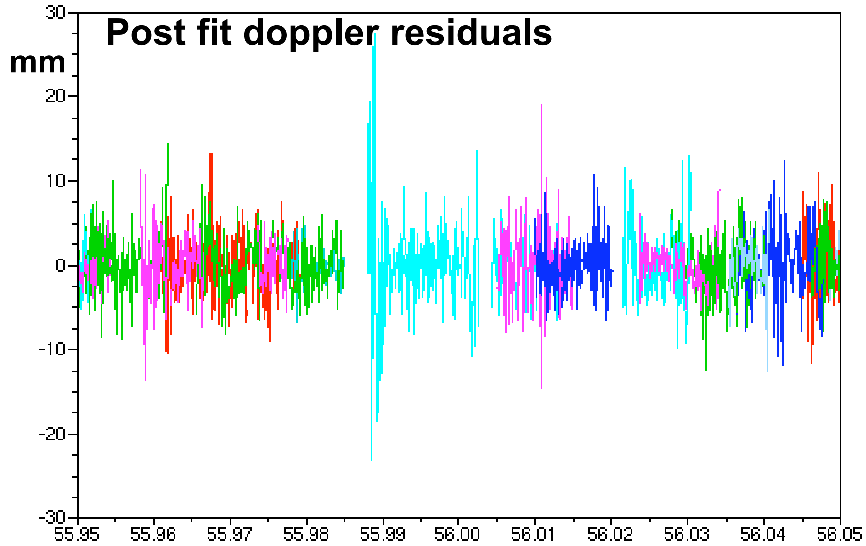
Number of valid measurements per day



Post-fit residuals







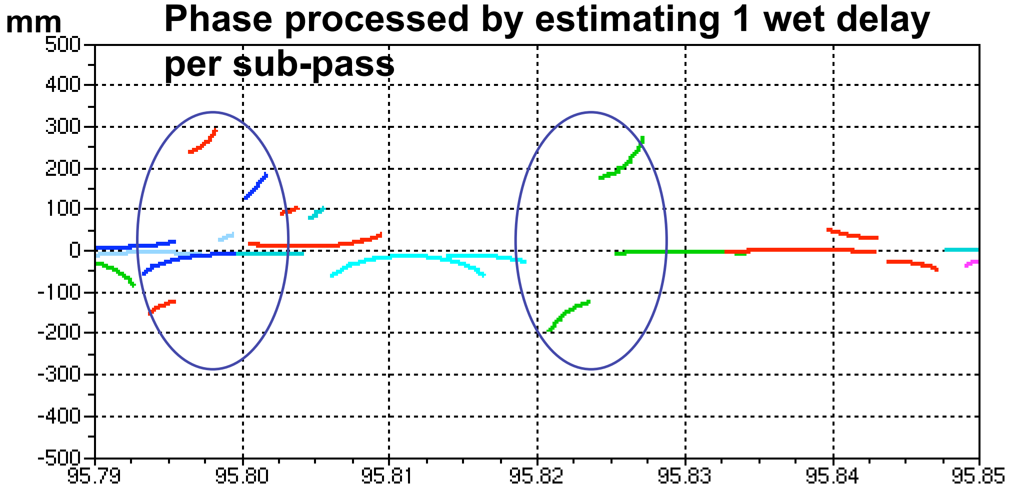
Days since 11/7/2008

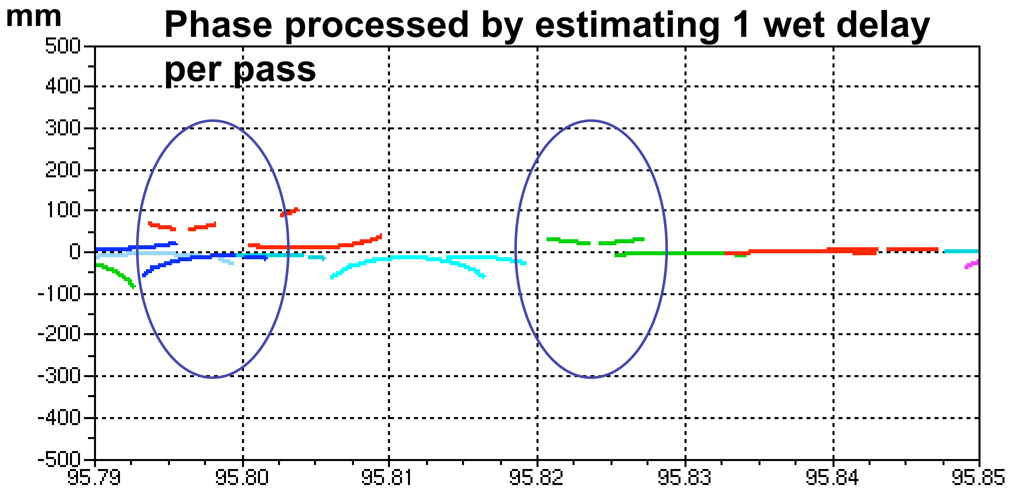
Doppler measurements residuals are less dependent on clock behaviour at the pass time-scale

Tropospheric zenith delay

Comparison of doppler and phase troposheric corrections after estimation of wet zenith delay

- The difference usually below 10 cm; can be much higher when the tropospheric bias gets correlated with clock offset
- This happens for short sub-passes
- Test performed by adjusting the phase troposphere over one full pass, like for doppler
- Resulting tropospheric delay is more consistent between doppler and phase
- No impact on the orbit (see backup slide)
- But what about positioning ?





CONCLUSIONS

- Analisys of phase residuals allows to clearly observe interference patterns and build phase maps for all the stations of the network
- It would not be realistic to correct these effects using maps obtained by phase residuals.
  - only visible effect would probably be to reduce RMS
  - but with the risk to introduce undesired biases in the solution
- Clocks' behaviour at 1000 sec. time scale is responsible for a large part of the post-fit phase residuals
- Orbits obtained by directly processing phase instead of doppler measurements can benefit from a significant gain in observability, without any observed impact of the aforementioned clock error
- Station positioning using phase measurements needs to be performed and investigated

Backups

Reconstruction/Elimination des sauts de phase

Résidus de la combinaison $5L_1 - L_2$ (contribution iono très faible, mais 5 fois le bruit L1)

-saut proche d'un multiple de 5 (typiquement k*5+[-0.25,0.25] avec k>1)
correction de L1
permet de traiter simplement les sauts fréquence centrale

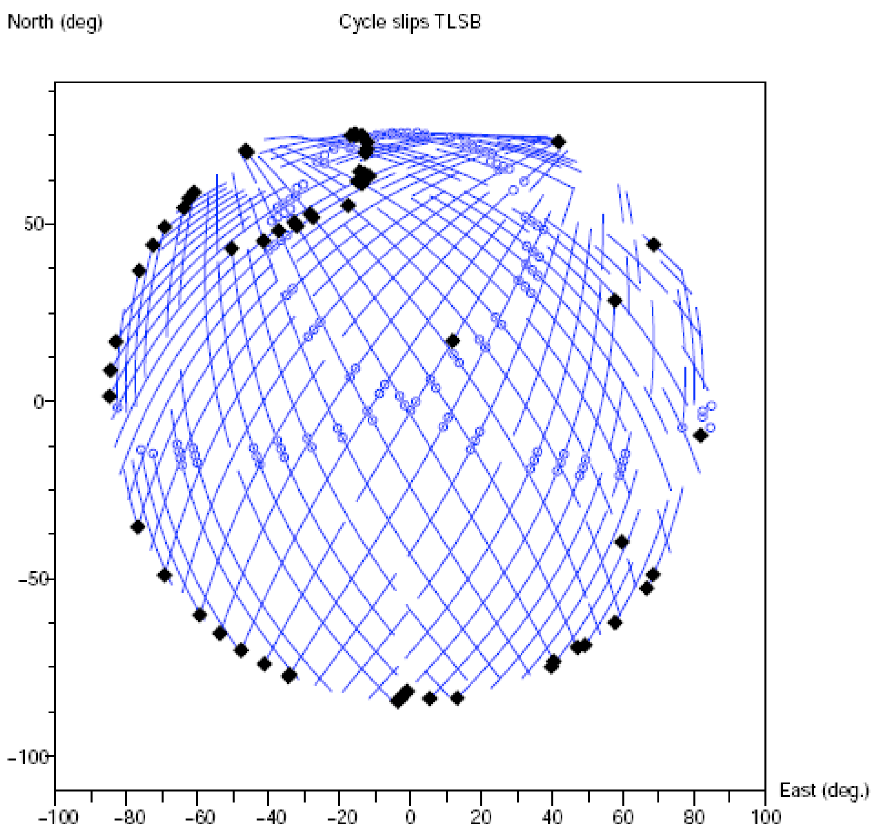
-les sauts restants sont tels que :
k cycles L1 et 5k cycles L2 simultanés
donc détection sur L1 (1 cycle) ou L2 (5 cycles)
(performances similaires, moins de bruit sur L2)

Remarque :
si trop d'effet ionosphérique, remonter les seuils, il peut rester k=1

fait un saut de 2.2 mm sur la combinaison iono-free : $\frac{\gamma\lambda_1 - 5\lambda_2}{\gamma - 1}$

effet acceptable :
probabilité de beaucoup de cycles L2 vers le milieu du passage faible
biais de 2.2 mm en extrémité de passage non important devant les autres effets (horloges..)

Sauts de phase et interruptions



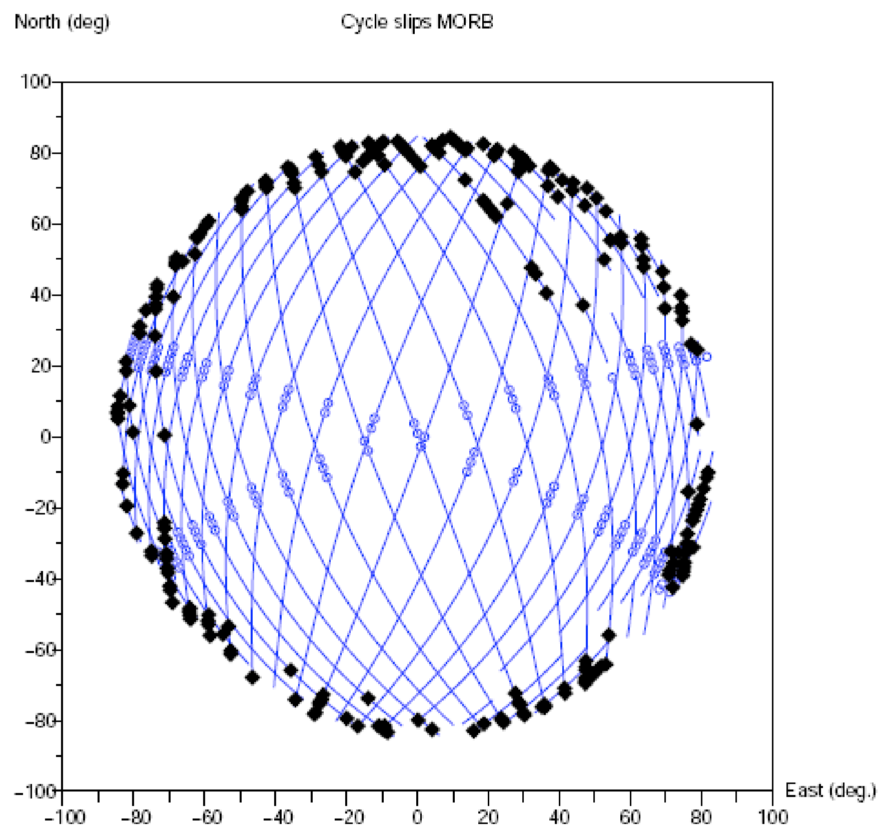


Figure 6: Cycle slips stations TLSB and MORB, with reconstruction

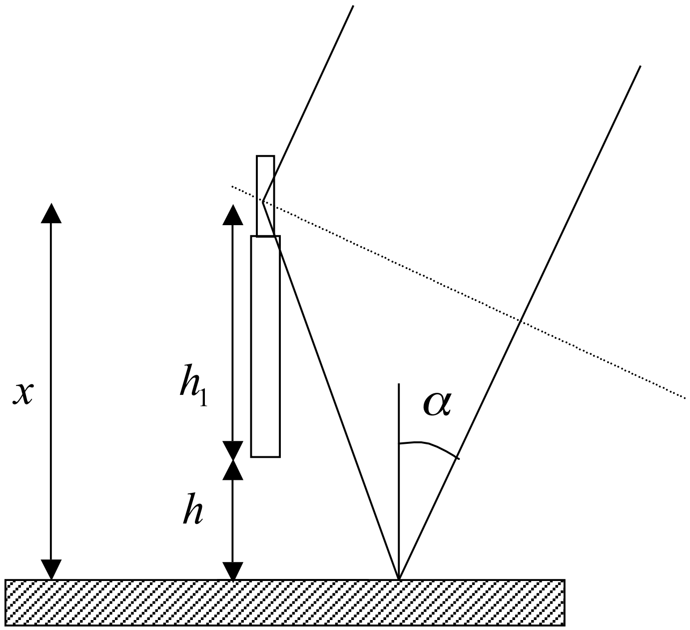
Nombreuses interruptions non reconstructibles sur TLSB

Estimation qualitative des interférences (1)

Objectif : comprendre les diamètres des cercles observés
400 MHz ou 2 GHz (plutôt du 2 GHz à cause de la combinaison iono-free ?)

Différence de marche entre direct et réfléchi :

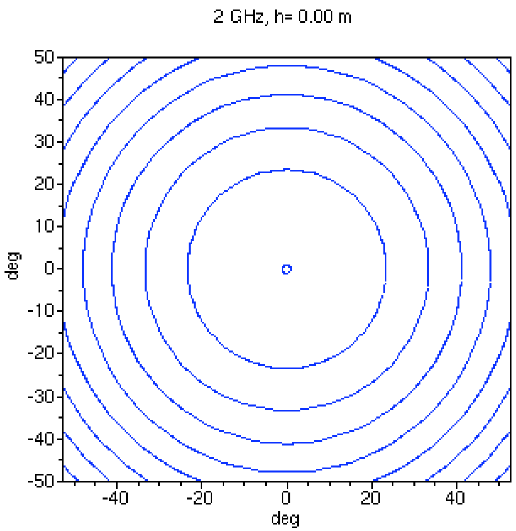
$$\frac{x}{\cos(\alpha)} + \frac{x}{\cos(\alpha)}\cos(2\alpha) = 2x\cos(\alpha)$$

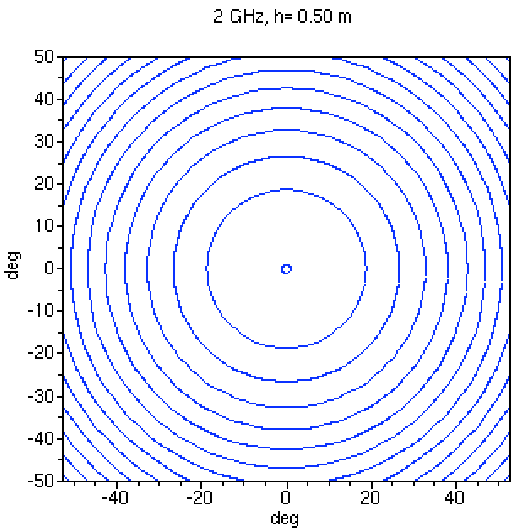


Variations par rapport au signal dans l'axe (2 GHz) :

$$k = \frac{2(h+h_1)(\cos(\alpha)-1)}{\lambda_1}$$

h : hauteur de la base





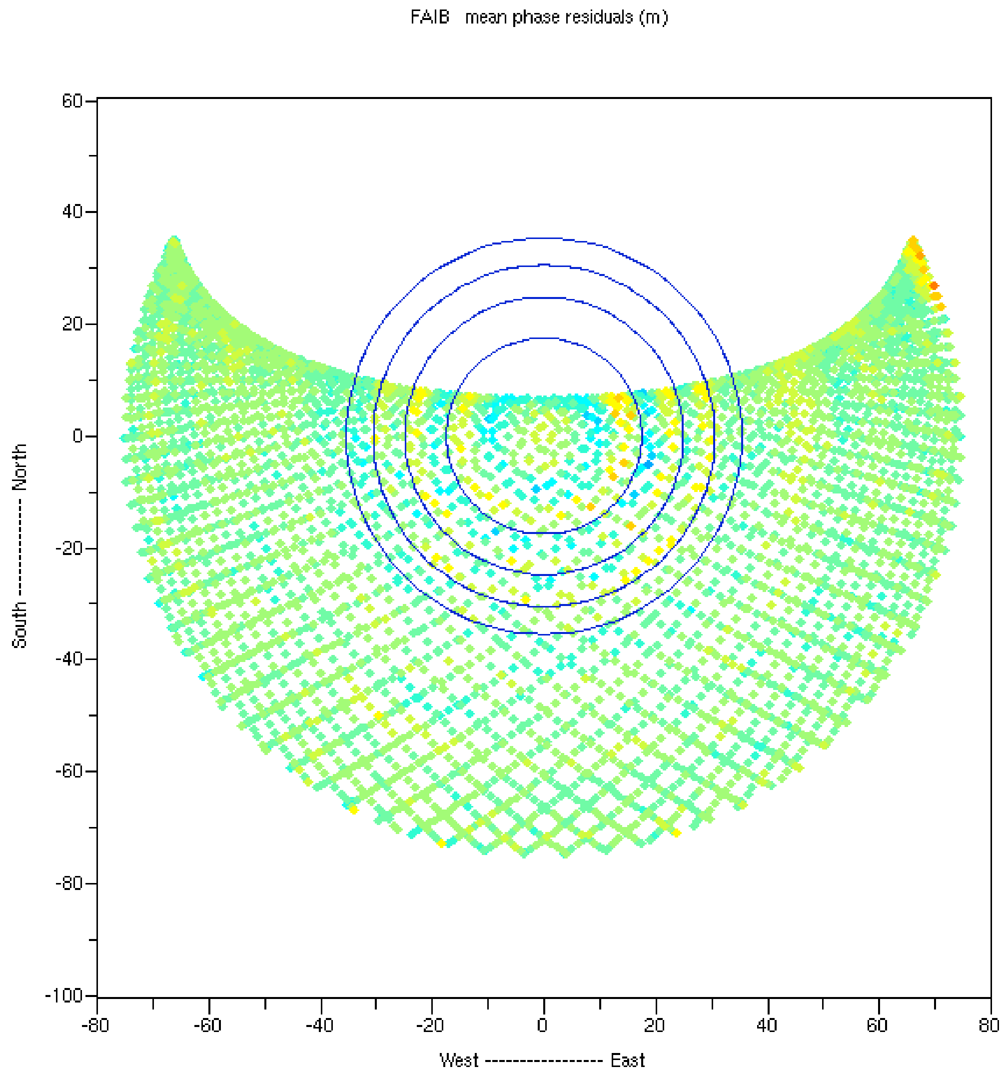
une analyse RF plus fine serait très intéressante
(effet du montage de l'antenne ?)

Estimation qualitative des interférences (2)

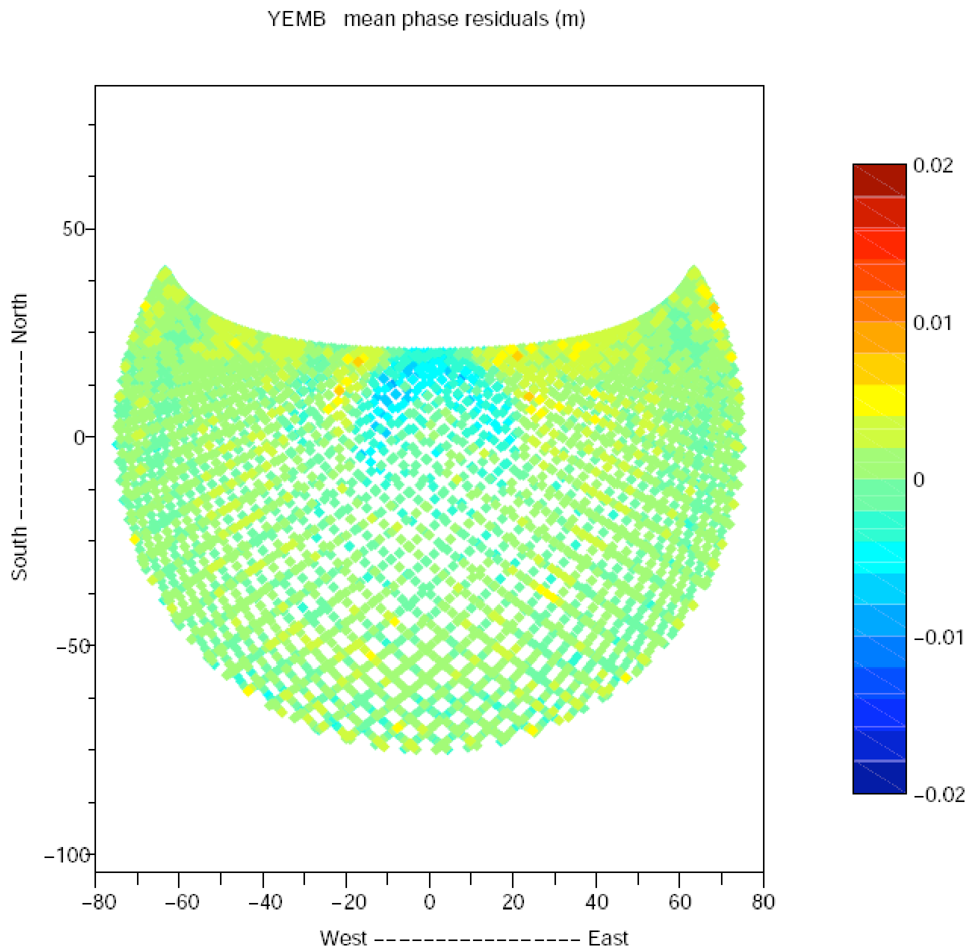
Fairbanks

Calcul sur Fairbanks : h=0.7 m

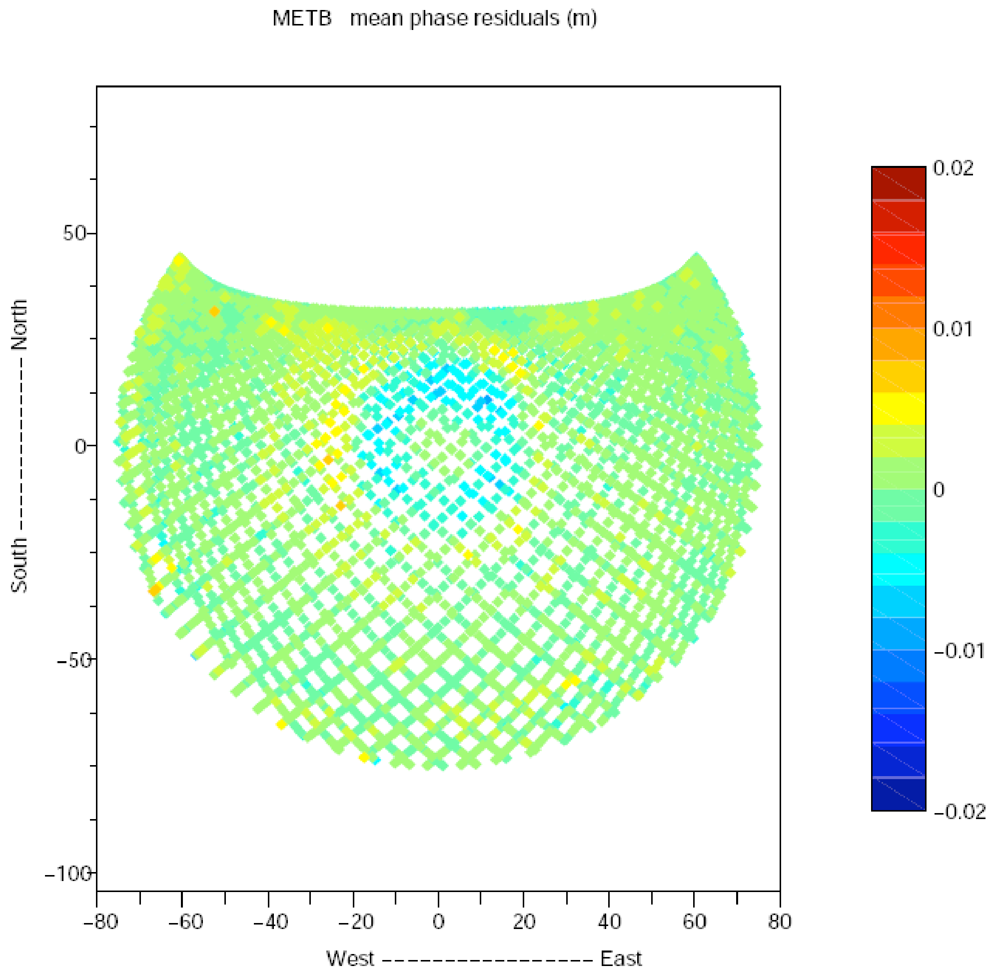
- cercles principaux dus au 2 GHz
- grands cercles (vers 45 degrés) 400 MHz ?



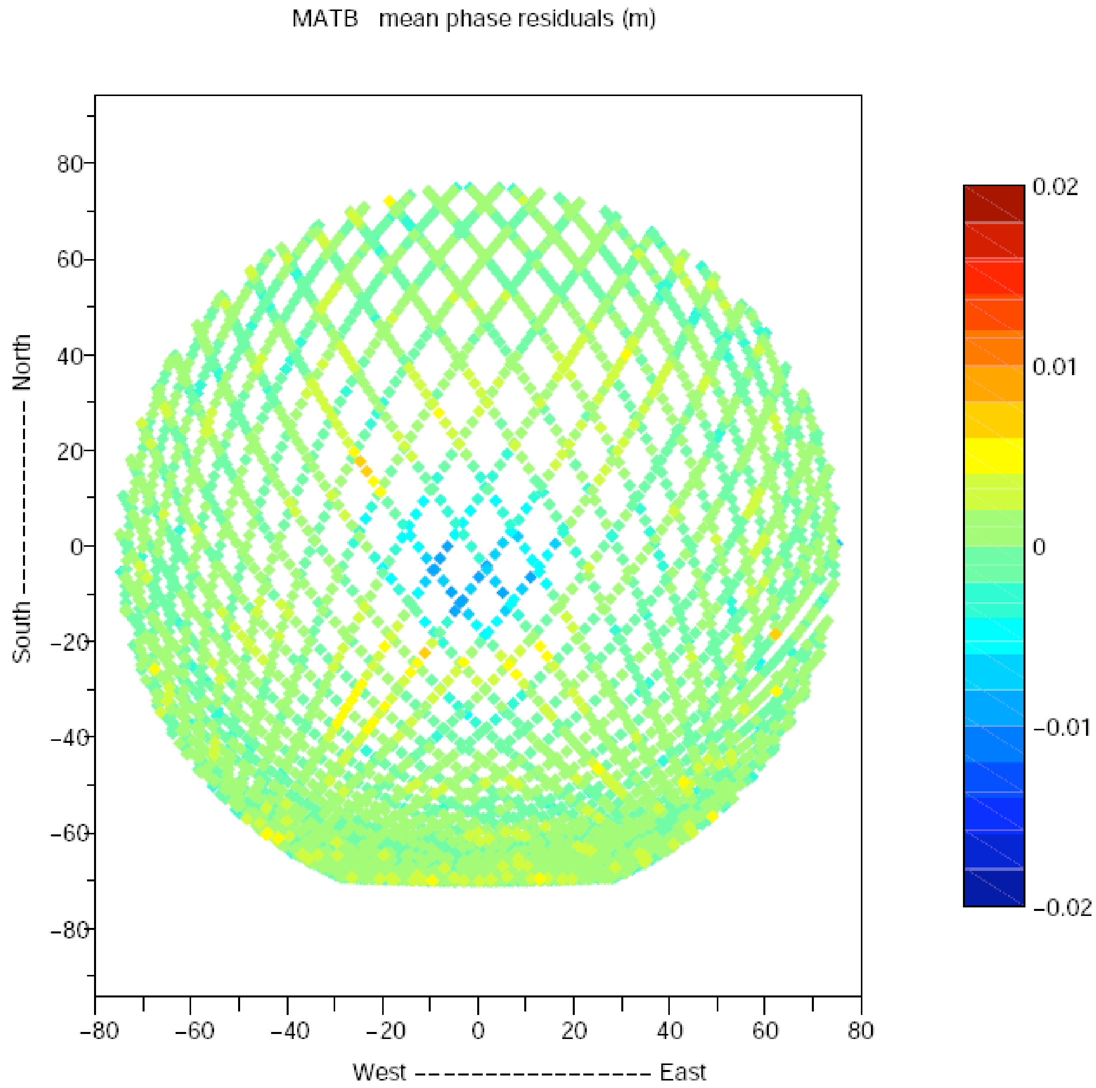
Autres cartes, Yellowknife



Autres cartes, METB



Autres cartes, MATB



Synthèse, résidus de phase (1)

La mesure de phase permet de construire des cartes de résidus de phase

- observation des interférences dans l'axe des antennes

- pas de limitation sur la géométrie des passages

- les effets d'horloge sont gênants

Synthèse, résidus de phase (2)

Observation de multitrajets dans l'axe des antennes sur beaucoup de stations

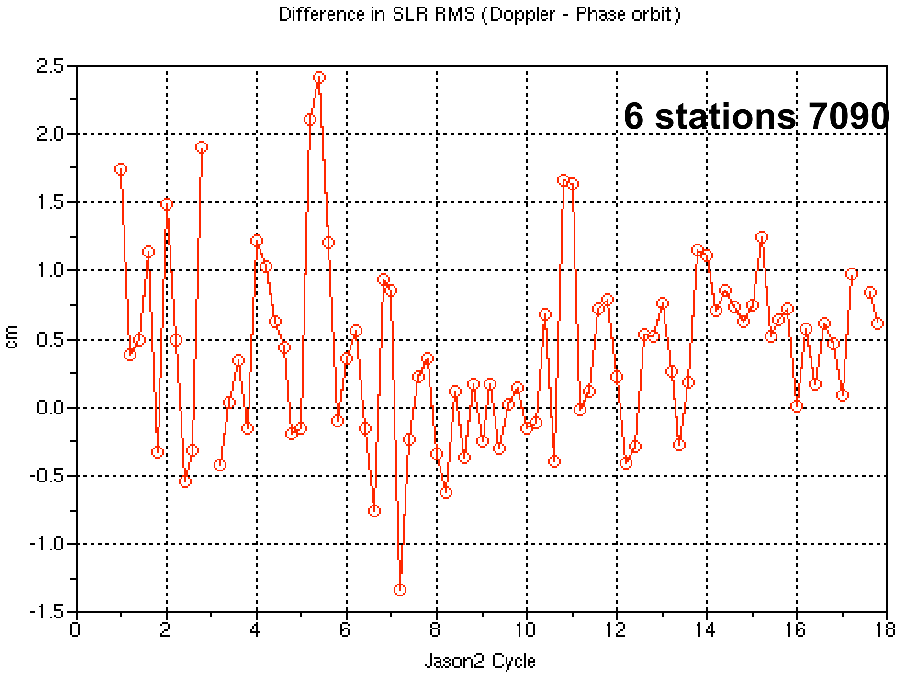
- termes de bas degré inobservables (en particulier termes paraboliques)
- comportement axisymétrique marqué
- anneaux concentriques sur certaines stations, erreurs max +-2 cm
  plus faciles à observer aux latitudes élevées (densité des mesures)
  ADFB, FAIB, METB, RESB, YEMB
- résultats excellents sur certaines stations (AMUB)
  donc probablement peu d'effets dus à Jason 2
- sur beaucoup de balises tendance à avoir un 'creux' au milieu (entre 0 et 20 degrés)
  configuration balise ? influence du paramétrage (tropo, degré polynôme…) ?
- il ne serait pas réaliste de corriger ces effets par des cartes identifiées sur ces résidus
  seul effet significatif : diminuer les rms
  risque d'introduire des biais indésirables
- les cartes Jason2 sur l'ensemble du réseau, cycles 1-17, ont été calculées,
  document disponible
- en attendant Cryosat …

Pour orbitographie/positionnement : paramétrage plus complexe pour la phase par rapport au Doppler

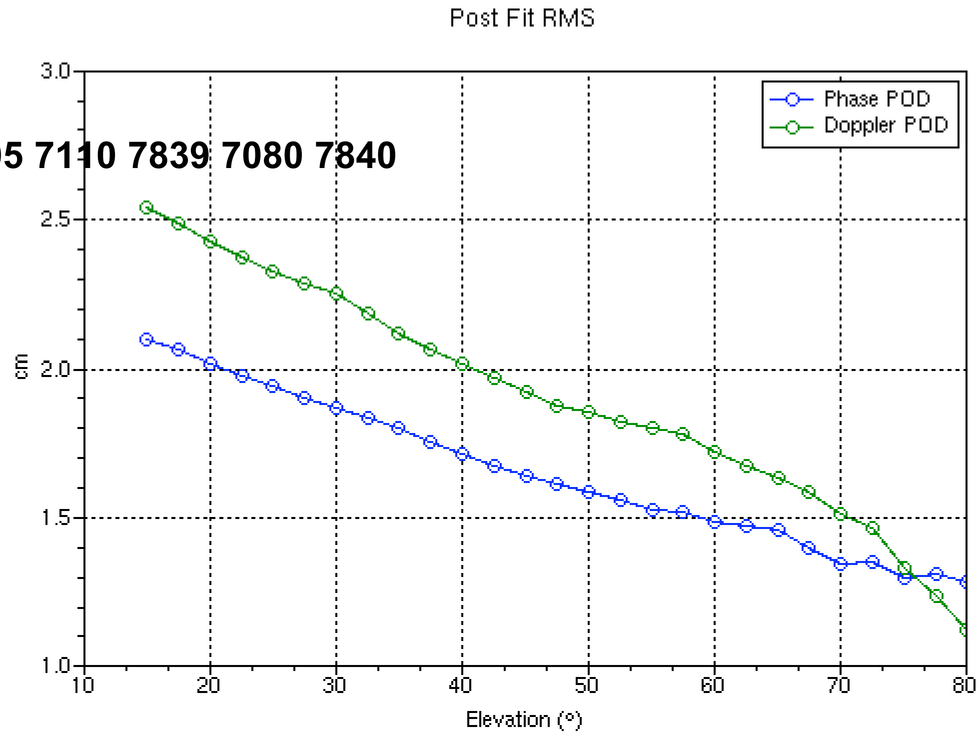
- ambiguité par paquet de phase continue
- troposphère par passage en visibilité
- effets de l'horloge : ajuster uniquement le biais de fréquence laisse des signatures paraboliques pouvant atteindre quelques centimètres
- impacts sur le positionnement des stations ?

Résidus laser sur orbites DORIS (Doppler / Phase)

- Dégradation des orbites doppler le long de la trace visible dans le résidus laser
  - Analyse sur la meilleur série Doppler (1 période de Hill / arc) et la meilleur série Phase (1 période de Hill / jour)



6 stations 7090 7105 7110 7839 7080 7840



Troposphere adjustement

❑ **Augmenter le nombre d'allongements tropo (découpage des visibilités) ne**

Comparaison entre la solution de phase avec estimation d'un allongement tropo par sous-passage et une avec un allongement tropo par passage