f

DOCUMENT

document title/ *titre du document*

ERS-2 MONO-GYRO PILOTING

IMPACT ON ERS-2 SAR DATA QUALITY AND ERS-2 SAR APPLICATION PERFORMANCE

prepared by/*préparé par* B. Rosich[1], D. Esteban[1], G. Emiliani[1], P. Meadows[2], B. Schattler[3], R. Viggiano[4]

reference/*réference* ES-TN-ADQ-BR02
issue/*édition* 1
revision/*révision* 1
date of issue/*date d'édition* 22 June 2000

[1] ESA/ESRIN, [2] BAE SYSTEMS,UK-PAF, [3] DLR, D-PAF, [4] Telespazio, I-PAF

a

ESRIN
Via Galileo Galilei - Casella Postale 64 - 00044 Frascati (Rome)- Italy
Tel. (39) 06 941801 - Fax (39) 06 94180 280

r

A P P R O V A L

Title *titre*	ERS-2 Mono-Gyro piloting: Impact on ERS-2 SAR data quality and applications performance	issue 1 *issue*	revision 1 *revision*

author *auteur*	B. Rosich1, D. Esteban1, G. Emiliani1, P. Meadows2, B. Schattler3, R. Viggiano4	date 22/06/00 *date*

approved by *approuvé by*		date *date*

C H A N G E L O G

reason for change / *raison du changement*	issue / *issue*	revision / *revision*	date / *date*

C H A N G E R E C O R D

ISSUE: 1 REVISION: 1

reason for change / *raison du changement*	page(s) / *page(s)*	paragraph(s) / *paragraph(s)*

r

TABLE OF CONTENTS

ACRONYMS

1GP - 1 Gyro Piloting

3GP - 3 Gyro Piloting

DES - Digital Earth sensor

IBP - Interferometric Browse product (interferometric fringes visible where coherence is higher than 0.2 and intensity visible for coherence smaller than 0.2).

ILU - Interferometric Land Use Image (RGB image generated with coherence in the red channel, mean intensity in the green and intensity difference in the blue).

InSAR - Interferometry SAR

IQL - Interferometric Quick Look

ISLR - Integrated Side Lobe Ratio

MR - Medium Resolution

QL - Quick Look

PRF - Pulse Repetition Frequency

PRI - Precise Image (SAR product type)

SLC - Single Look Complex (SAR product type)

VMP - Verification Mode Processor (Operational SAR image mode processor at ESA)

1 INTRODUCTION

ERS-1 and ERS-2 have been piloted with 3 gyros since the beginning of the ERS mission, showing an attitude extraordinary stable around the orbit.

Due to several failures and problems on the ERS-2 gyros, a software to pilot ERS-2 with one single gyro has been developed and installed on board of ERS-2. A special validation campaign to uplink and qualify the software took place from 7th to 23rd February 2000. The qualification phase was also intended to assess the impact of the new configuration on the quality of ERS-2 data and on ERS-2 applications, since it was anticipated that using a single gyro could slightly degrade the satellite attitude.

In order to characterise the response of different gyros to the new software, ERS-2 was piloted in mono-gyro mode using Gyro 6 during a first phase of the campaign (10th-16th Feb. 2000) and in mono-gyro mode using Gyro 5 during a second phase (from 16th Feb. 2000).

The activities carried out to assess the impact of the new mono-gyro piloting mode on ERS-2 SAR products and applications showed that the new piloting mode has no impact on the ERS-2 SAR product quality and it has a moderate effect on the performance of InSAR based applications. This is due to the fact that the attitude is now less stable than in nominal 3GP mode and the Doppler history around the orbit is slightly different from the one observed for ERS-2 since the beginning of the mission. In view of these conclusions and the importance of using a single gyro for piloting the satellite, ERS-2 was left in mono-gyro configuration using gyro 5 at the end of the qualification phase.

This note is intended to present the main results of the qualification phase and the evolution of the ERS-2 attitude in the form of Doppler evolution around the orbit, which is the key parameter to estimate the expected InSAR performance as a function of acquisition time and area of interest.

The information provided here covers the period from 10th to 29th of February (i.e. includes some days after the qualification phase). Updates of the Doppler evolution will be provided every 15 days afterwards.

The note is organised as follows:
Chapter 2 is focused on the analysis of the ERS-2 1GP SAR image quality using the Flevoland transponders. The impact of the mono-gyro configuration on the geophysical exploitation of SAR wave mode data is discussed in Chapter 3. Chapter 4 presents the evolution of the Doppler frequency around the orbit for ERS-1 SAR, ERS-2 3GP SAR and ERS-2 1GP SAR data. This analysis is performed mainly using SAR Wave mode data and it is verified with Image mode data when possible. Chapter 5 discusses the impact of the mono-gyro piloting for SAR processing. The impact of the mono-gyro configuration on InSAR performance is discussed in detail in Chapter 6. The main conclusions on the impact of the new mono-gyro configuration on ERS-2 SAR data

quality and on ERS SAR applications are presented in Chapter 7. References can be found in Chapter 8. The coefficients of the Doppler models for each time interval are provided in Annex A.

2 SAR IMAGE QUALITY ANALYSIS: ERS-2 1GP(6) & ERS-2 1GP(5)

The assessment of the SAR product quality is mainly based on the analysis of the Impulse Response Function (IRF) obtained over dedicated transponders. This is done on a routine basis on ERS SAR products in order to monitor the product quality and was one key activity during the mono-gyro validation phase, since any degradation of the product quality should be identified through a detailed analysis of the IRF related parameters.

2.1 Basic product quality parameters

The analysis of the basic image quality parameters has been carried out on PRI mages acquired over Flevoland by ERS-2 in 1GP(6) and ERS-2 in 1GP(5). The analysis of the IRF of Flevoland transponder's provides **nominal values for all quality parameters**.

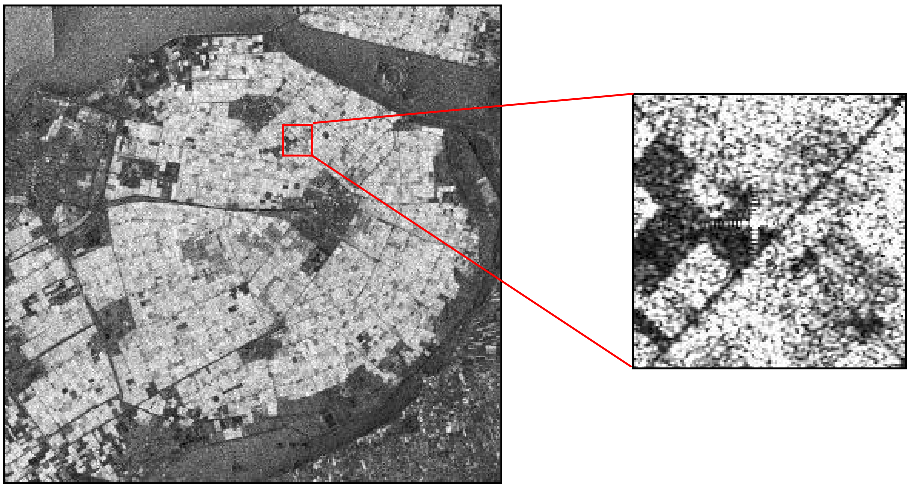


Fig. 1. *Subset of the ERS-2 1GP(6) image acquired on 11th February 2000 over Flevoland. On the right: area around transponder 3.*

The value of the main quality parameters obtained over the transponder 3 imaged by ERS-2 1GP(6) on the 11th February are provided in the table below. The values obtained for the ERS-2 3GP acquisition of the previous cycle (7th Jan. 2000) are also provided for comparison.

PARAMETER	11-02-200, ERS-2 1GP(6)	7-01-200, ERS-2 3GP
Peak value [dB]	89.93	89.6
Range resolution [m]	28.1	28.3
Azimuth resolution [m]	21.5	22.1
ISLR [dB]	-8.9	-9.5

Peak to near SLR in range [dB]	-21.8	-22.07
Peak to far SLR in range [dB]	-21.3	-21.5
Peak to right SLR in azimuth [dB]	-15.1	-16.03
Peak to left SLR in azimuth [dB]	-18.59	-16.10

As a matter of example, the range and azimuth cross sections of the impulse response of transponder 3 imaged by ERS-2 1GP(6) the 11th February, are provided in Fig. 2.

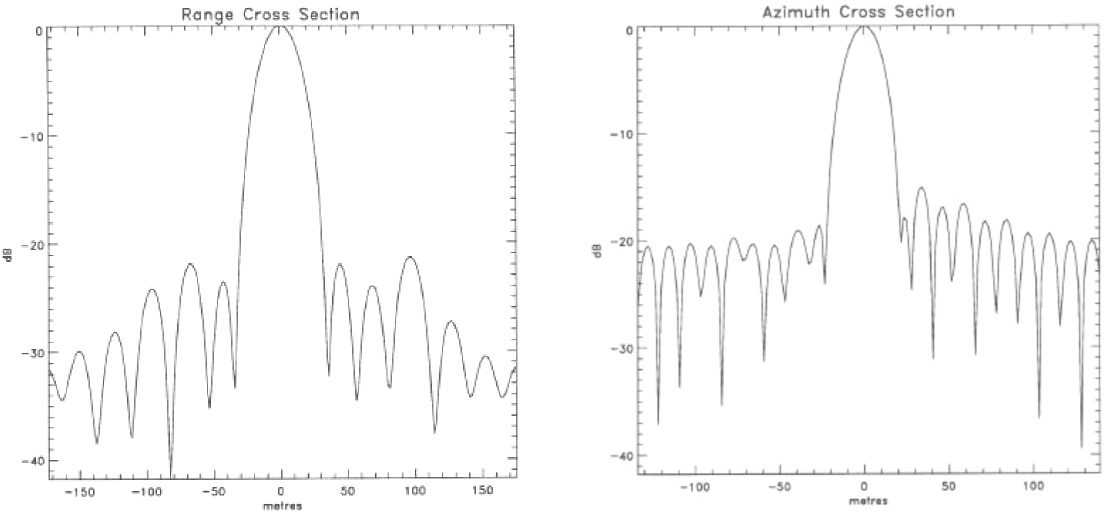


Fig. 2. *Range and azimuth cross-section of Transponder 3 (ERS-2 1GP(6), 11th Feb. 2000)*

2.2 *Localisation accuracy*

The potential impact of the mono-gyro configuration on the SAR image localisation is investigated using acquisitions over the Flevoland transponders. Results for the images acquired on 11th February 2000 and 23rd February 2000 are provided below:

- ERS-2 1GP(6) - Image acquired 11th February 2000
  - Localisation error for Transponder 2: 37.3m
  - Localisation error for Transponder 3: 38.5m
- ERS-2 1GP(5) - Image acquired 23rd February 2000
  - Localisation error for Transponder 2: 37.3m

The **localisation accuracy is therefore within the nominal range.**

2.3 Radiometric stability

The potential impact of the mono-gyro campaign on the ERS-2 radiometric stability has been also investigated through the Flevoland transponders, in particular using the following acquisitions and transponders:

- E2 Orbit 21562, 11th February - Transponder 2 & 3- Gyro 6
- E2 Orbit 25327, 23rd February 2000 - Transponder 2- Gyro 5
- E2 orbit 25434, 1st March 2000 - Transponder 2 & 3 - Gyro 5 (after the campaign but still in 1GP(5) mode)

The obtained relative radar cross-section values for these acquisitions are included in Fig.3, confirming the long term monitoring of ERS-2 radiometric stability. As it can be observed, **there is no impact of the mono-gyro configuration on the ERS-2 radiometric stability**.

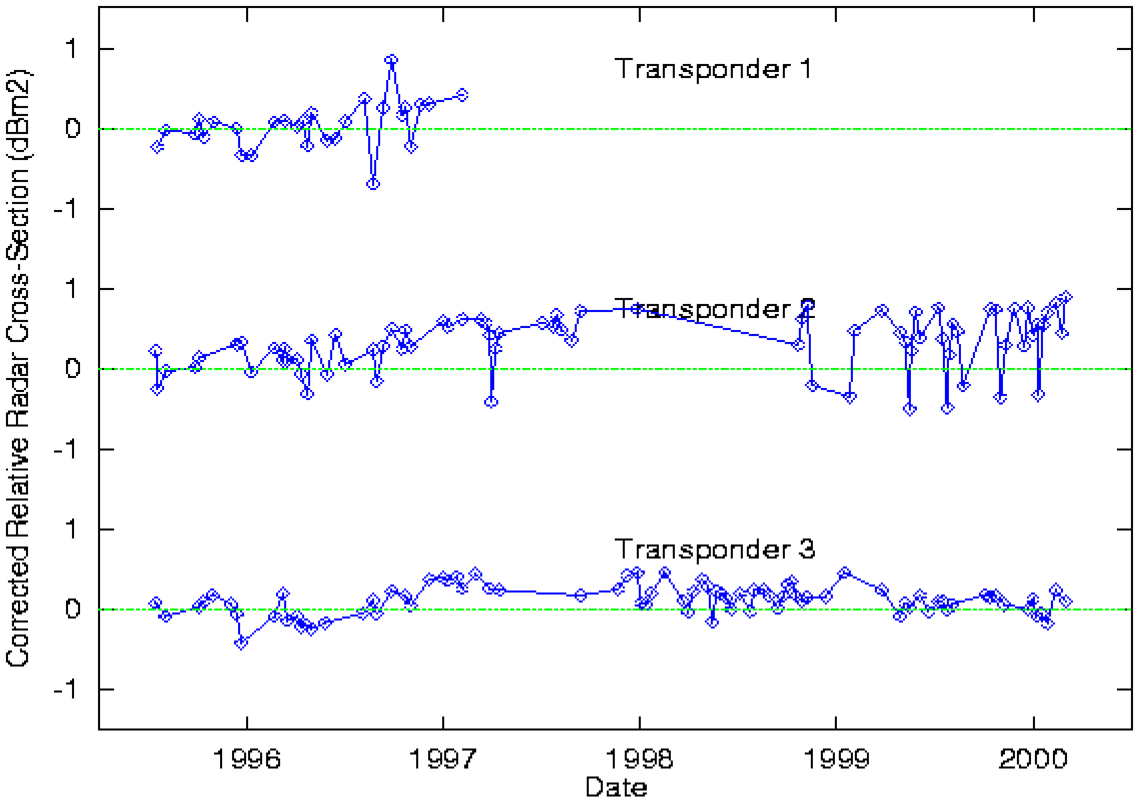


Fig. 3. *ERS-2 SAR (bottom) Corrected Relative Radar Cross-sections for the ESA transponders (including 3 values for transponder 2 and 2 values for transponder 3 in mono-gyro mode).*

3 WAVE DATA - GEOPHYSICAL ANALYSIS

From the geophysical point of view, the SAR WAVE data have not been significantly influenced by the mono-gyro piloting mode.

The comparison of the ECMWF wave height results with ERS-2 SAR wave height data for February 2000 (global) shows a bias slightly higher than in nominal 3GP configuration for the first days of the qualification period (10^{th} to 13^{th} February).

Correlation between ECMWF wave height results with ERS-2 SAR wave height data for February 2000 is provided in Fig. 4. The Time series of bias (ERS- 2 - model) and scatter index (SI) for ERS- 2 SAR wave heights in Fig. 5 shows how the larger wave height bias affects only four days during the tests and returned to normal before the end of the month.

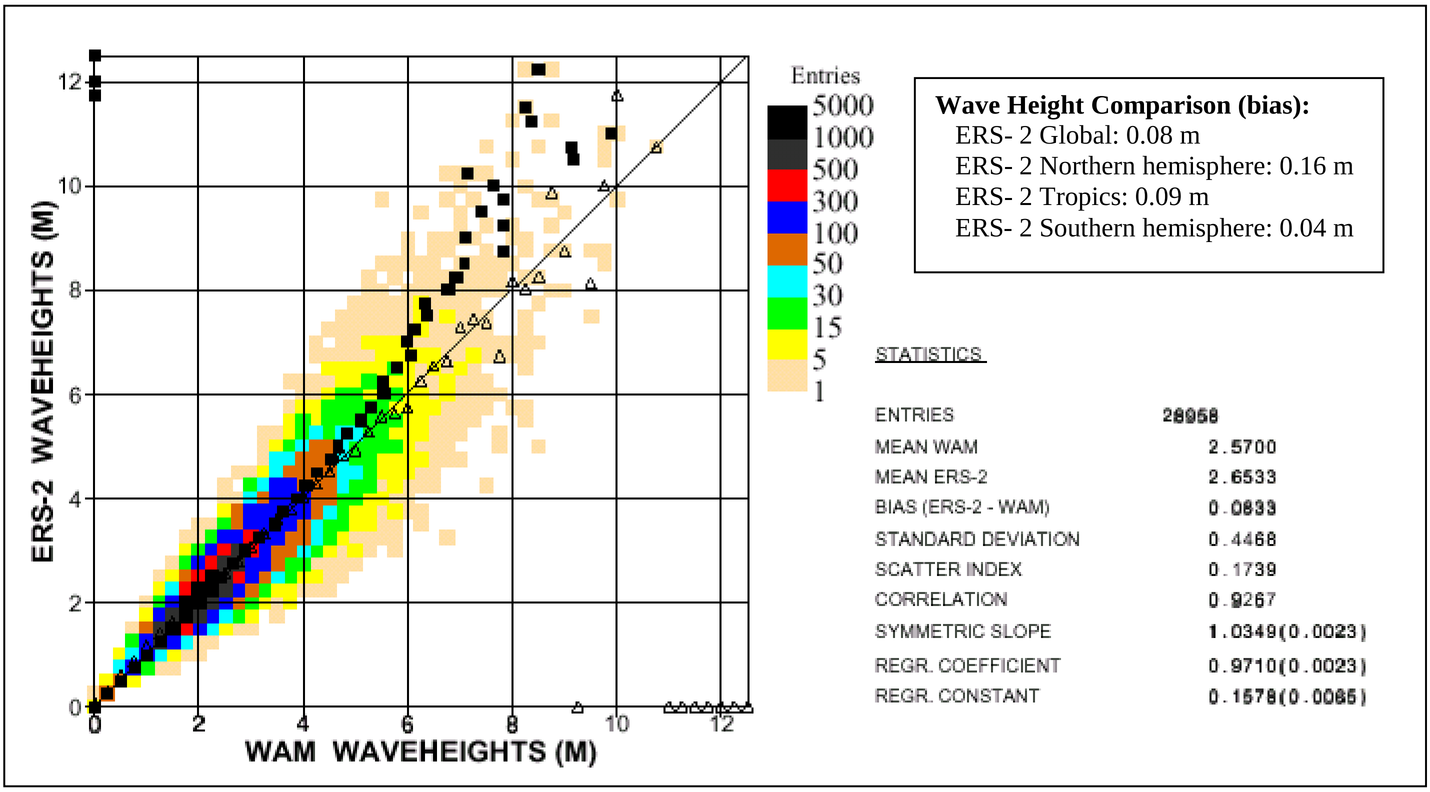


Fig. 4. *Comparison of ECMWF wave height results with ERS-2 SAR wave height data for February 2000.*

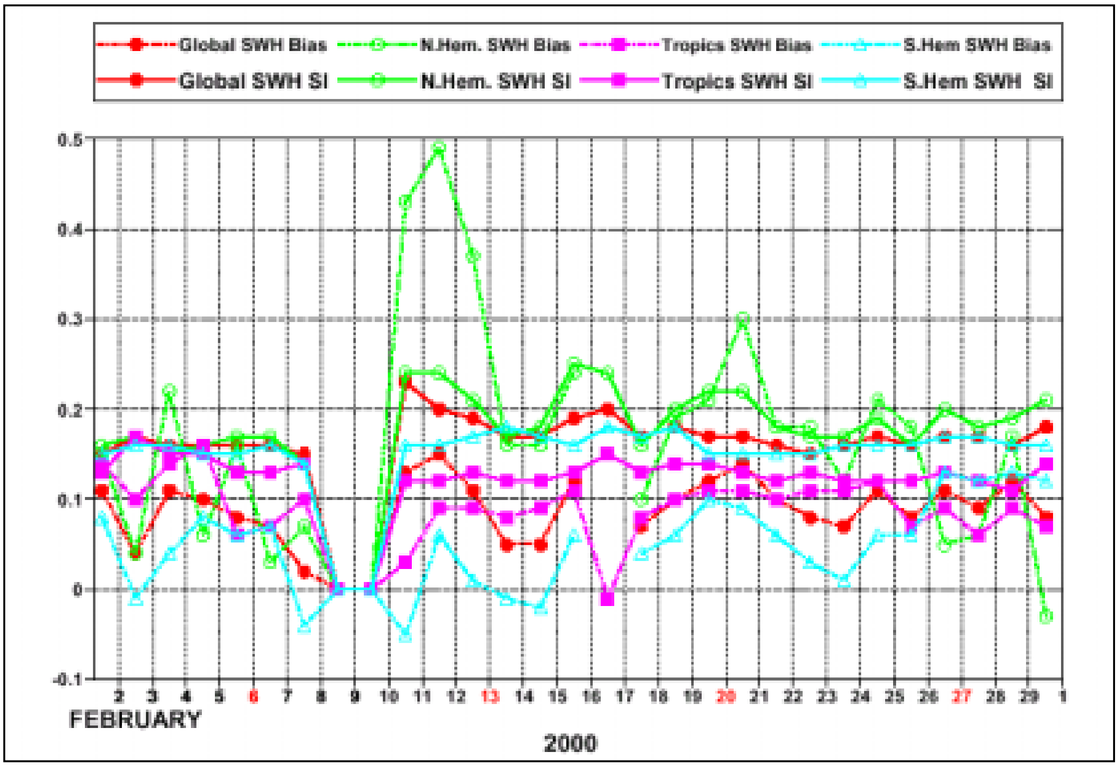


Fig. 5. *Time series of bias (ERS-2 model) and scatter index (SI) for ERS-2 SAR wave heights.*

4 ERS-2 SAR DOPPLER FREQUENCY ANALYSIS

The SAR Doppler Centroid frequency is a key parameter for correct processing of SAR images and has also implications for InSAR applications, since it establishes the location of the SAR azimuth spectra. This chapter is focused on the monitoring of the Doppler Centroid frequency as a function of time and orbit position. Implications for SAR processing are discussed in chapter 5 and for InSAR applications in chapter 6.

An average of 4 minutes of ERS-2 SAR image mode data was acquired every day during the campaign. These data provide an accurate estimation of the Doppler Centroid frequency at the time of the acquisition (i.e. for a very small portion of the orbit) but it does not allow the monitoring of the Doppler frequency all around the orbit.

Although the Doppler frequency estimated from SAR WAVE mode data is less accurate than the one from SAR image mode[1], SAR WAVE data is available for almost the complete orbit, 14 orbits per day. Therefore, the monitoring of the Doppler Centroid frequency around the orbit has been mostly based on SAR WAVE mode data.

The following sections present the Doppler around the orbit for nominal ERS-2 3GP mode (i.e. from the ERS-2 launch to 7th February 2000) and the evolution of the Doppler around the orbit with the mono-gyro configuration

4.1 ERS-2 3GP SAR Doppler Centroid frequency (nominal mode)

Since the beginning of the ERS mission, the Doppler frequency for both ERS-1 and ERS-2 has followed a very stable pattern around the orbit. The values have been stable enough to motivate developers of SAR processors to use the nominal pattern as a simple way to obtain an estimation of the Doppler ambiguity.

The nominal Doppler patterns for ERS-1 and ERS-2 SAR have been very similar for all the mission, with ERS-2 Doppler values being around 250 Hz lower than ERS-1 values.

ERS-2 SAR Wave mode Doppler frequency values around the orbit are shown in Fig. 6 together with a model of the Doppler pattern using a Fourier series. As it can be observed, dispersion of Doppler values at the same orbit position is very low and only a short orbit interval presents Doppler values in the first left ambiguity. Please notice that Doppler Centroid values outside the expected trend in the figure correspond to SAR data acquired during manoeuvres.

[1] The amount of data available to estimate the Doppler frequency in WAVE mode data is less than in Image mode data. Since the accuracy of the estimation improves with the amount of data used, the values obtained in WAVE mode can be considered to be less accurate than those obtained in Image Mode (accuracy is better than 50 Hz).

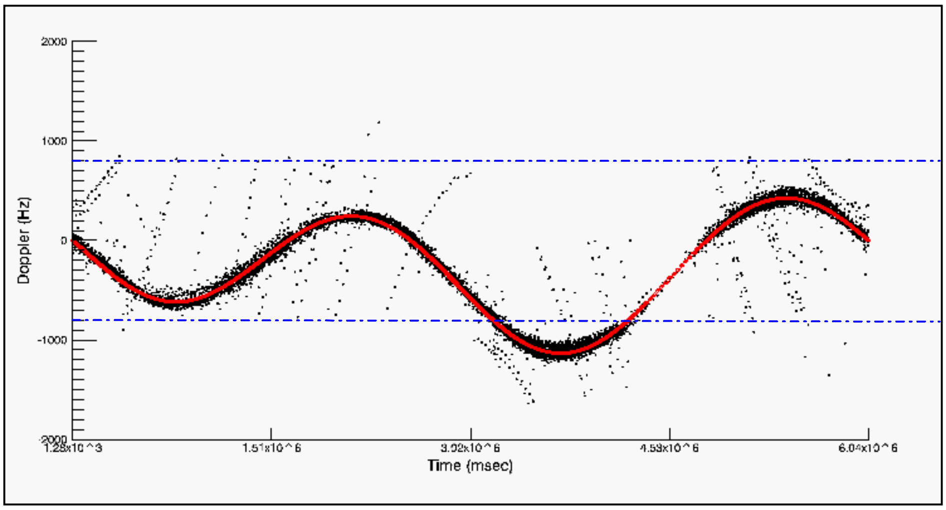


Fig. 6. *ERS-2 3GP SAR Wave mode Doppler values around the orbit (black) and polynomial fit (red). Blue lines indicated the baseband interval.*

The coefficients of the Fourier model derived for the Doppler Centroid frequency are provided in Annex A.

4.2 ERS-2 1GP(6) SAR Doppler Centroid frequency (10th-16th Feb. 2000)

With ERS-2 in mono-gyro mode with G6, the variation of the Doppler frequency for ERS-2 SAR data around the orbit differs from what has been observed since the beginning of the ERS-2 mission.

On one side, the Doppler frequency variance increases and on the other side, the Doppler frequency value decreases of about 500 Hz (with respect to the Doppler for nominal ERS-2 3GP mode) for more than half of the orbit. The Doppler frequency observed from SAR Wave mode data acquired when ERS-2 was in 1GP(6) mode is shown in Fig. 7.

The absolute Doppler values have been fitted using the Fourier coefficients in order to simplify further analysis. The Doppler fitting is shown in red on the same figure. The higher level of noise observed in the last quarter of orbit is a consequence of the DES Sun blinding effect occurring during this period of time.

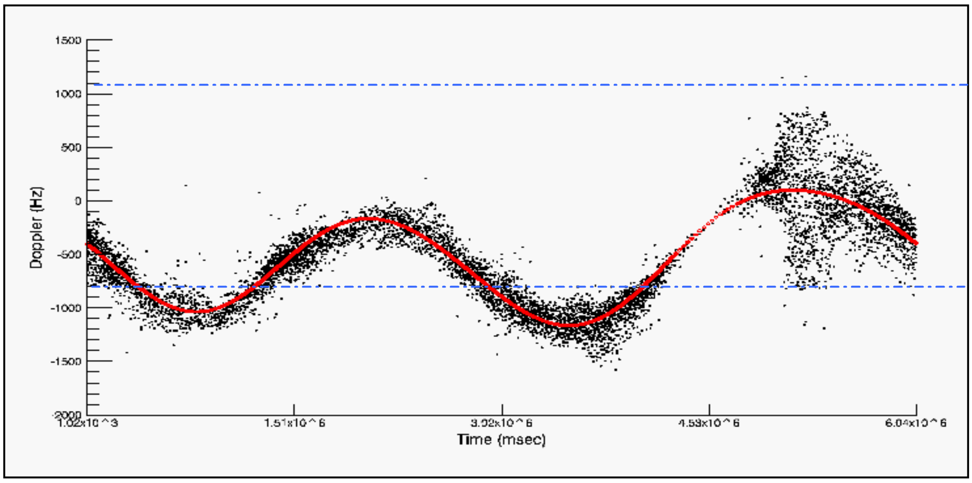


Fig. 7. ERS-2 1GP(6) SAR Wave mode Doppler values around the orbit (black) and polynomial fit (red).

Comparison between the nominal ERS-1 (black), ERS-2 (dashed) patterns with the new one (red) using derived Fourier models is provided in Fig. 8. It can be observed that although the Doppler frequency for ERS-2 1GP(6) is still in the baseband interval (dashed blue lines) for most of the orbit, it passes to the first left ambiguity at different times around the orbit. Application of the nominal ERS-2 Doppler model is therefore not possible anymore over these orbit intervals.

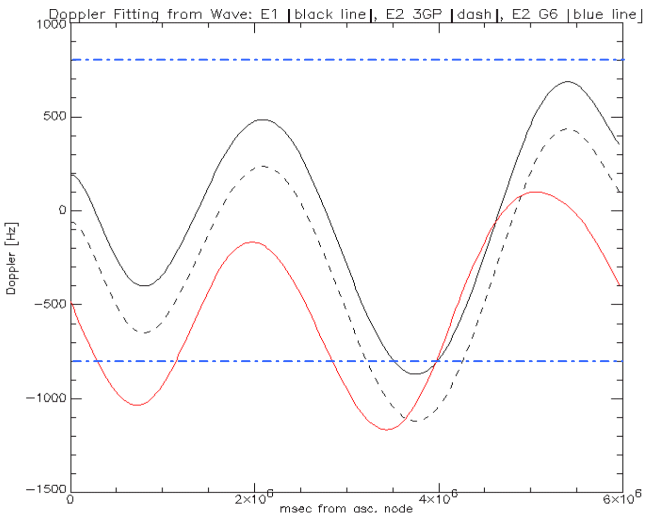


Fig. 8. *Comparison between the nominal ERS-1 (black), ERS-2 (dashed) Doppler frequency patterns with the new ERS-2 1GP(6) pattern (red) around the orbit using fitted models.*

The coefficients of the Fourier model derived for the Doppler Centroid frequency are provided in Annex A.

4.3 ERS-2 1GP(5) SAR Doppler Centroid frequency (16^{th} -29^{th} Feb. 2000)

The variation of Doppler frequency for ERS-2 in 1GP mode with G5 is different from the one observed with G6.

The Doppler frequency observed from the SAR Wave mode data acquired by ERS-2 in 1GP(5) mode during the period 16^{th}-29^{th} February is shown in Fig. 9. This period is strongly affected by the DES Sun Blinding, which is responsible of the larger attitude instability close to the South Pole.

The absolute Doppler frequency has been fitted using Fourier coefficients. The last quarter of the orbit can hardly be approximated by a model due to the large attitude variation.

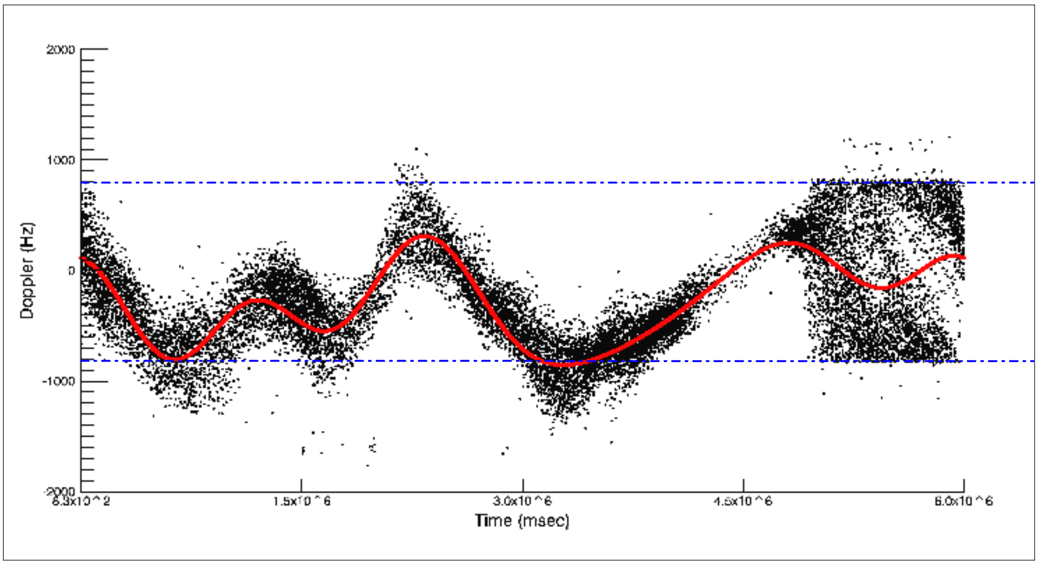


Fig. 9. *ERS-2 1GP(5) SAR Wave mode Doppler values around the orbit (black) and polynomial fit (red).*

As it can be observed, the Doppler shift between ERS-2 3GP and ERS-2 1GP(5) is changing around the orbit.

A comparison between the nominal ERS-1 (black), ERS-2 (dashed) patterns with the new one (red) using the polynomial models is provided in Fig. 10. It should be kept in mind that the standard deviation around the polynomial model is very important for this time interval. These models should be taken only as an indication of the Doppler evolution.

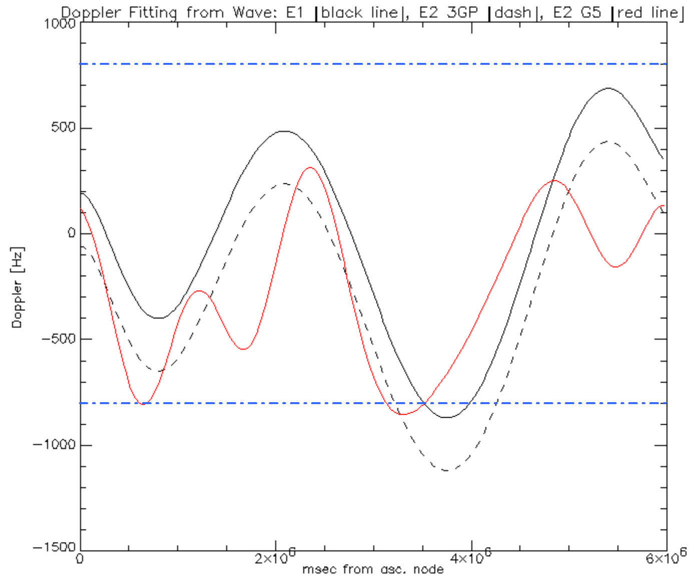


Fig. 10.*Comparison between polynomial Doppler patterns for ERS-1, ERS-2 3GP (dash) and ERS-2 1GP(5) during DES Sun Blinding (red).*

The coefficients of the Fourier model derived for the Doppler Centroid frequency are provided in Annex A.

5 IMPACT OF THE ERS-2 MONO-GYRO CONFIGURATION ON SAR PROCESSING

From the SAR data point of view, the new mono-gyro configuration has as primary effect the modification of the Doppler frequency pattern of ERS-2.

Estimation of the Doppler frequency is a key step in SAR processing and can be considered in two steps: estimation of the fine Doppler Centroid and estimation of the ambiguity number, or ambiguity resolver.

The value of the final or absolute Doppler Centroid frequency is obtained by estimating the "fine Doppler frequency" and the "Doppler ambiguity number". The first value is an accurate estimate of the Doppler frequency in the baseband, i.e. in the interval [-PRF/2, PRF/2]. However, the SAR azimuth spectra is a periodic signal with a period equal to the PRF and knowledge of the fine Dopler centroid is not enough to identify in which PRF interval it is located. The PRF cycle in which the fine Doppler frequency is located is obtained through the ambiguity resolver. Knowing both parameters, the absolute Doppler Centroid frequency for a particular image is estimated as the fine Doppler frequency plus the ambiguity number times the PRF.

Estimation of the fine Doppler ambiguity is carried out by any SAR processor but estimation of the ambiguity number is not required if the Doppler frequency remains in the baseband interval. For ERS-2 in nominal 3GP mode, the Doppler Centroid has been extremely stable and confined in the baseband for almost the 90% of the orbit interval. As a result, estimation of the correct ambiguity number has not been performed by most of the SAR processors dealing with ERS SAR data.

With the new mono-gyro configuration, the Doppler Centroid frequency fall outside the baseband over larger and different orbit intervals. The impact of no resolving the ambiguity and processing the image with an ambiguity error is an azimuth localisation error on the product of around 5 Km times the error in the Doppler ambiguity number. Therefore, estimation of the correct ambiguity number by the SAR processor becomes mandatory when processing ERS-2 1GP SAR data.

5.1 Processing of ERS-2 1GP images with SAR processors including an ambiguity resolver

Advanced SAR processors include a Doppler ambiguity estimator based on the analysis of the data to be focused. A change of the nominal Doppler Centroid behaviour will be transparent for these processors and the mono-gyro configuration will not have any no impact on the quality of the generated products.

The ESA VMP processor belongs to this kind of systems and it is able to successfully process any ERS-2 SAR product regardless its actual absolute Doppler Centroid frequency.

5.2 Processing of ERS-2 1GP images with SAR processors without ambiguity resolver

Simpler or faster SAR processors do not include an algorithm to estimate the Doppler ambiguity from the raw data and rely on the "nominal ERS SAR Doppler pattern" to derive the correct ambiguity. This is often the case for QL and Browse processors, as well as for other full resolution SAR processors.

SAR processors “without ambiguity resolver” are processors that do not include an algorithm to estimate the Doppler ambiguity from the SAR data itself. This is often the case for QL and Browse processors, as well as for some existing full resolution SAR processors.

These processors make often use of one of the following strategies to derive the absolute Doppler frequency value:

a. use a constant Doppler ambiguity value around the orbit (equal to 0 for the ERS SAR case);
b. use a "nominal" Doppler pattern around the orbit and select the ambiguity number in such a way that the absolute Doppler frequency is the closest to the expected nominal value.

The lack of ambiguity resolver can be considered as a limitation in the SAR processor since both (a) and (b) strategies can be easily subject to errors. The major impact of an error in the estimation of the ambiguity number is an azimuth location error of at least 5 Km in the SAR product[2].

The first type of processor (a) will fail the estimation of the Doppler for data acquired over areas in which the Doppler frequency is not in the baseband (i.e. it is outside the interval [-PRF/2,PRF/2]). This situation happens over a very small orbit interval for ERS-1, for a slightly larger interval in the case of ERS-2 3GP and for a more extensive and variable orbit interval in the case of ERS-2 1GP.

The second group of processors is able to generate standard quality SAR products if the nominal Doppler pattern remains constant or changes by less than PRF/2. In order to ensure a correct estimation of the ambiguity number for ERS-2 1GP, updated Doppler models should be used.

These updated models are based on Fourier series and the corresponding coefficients (time and gyro dependent) are provided in Annex A. The expression to retrieve the Doppler Centroid value as a function of time around the orbit is also provided.

---

[2] Although other quality parameters are degraded when the ambiguity is incorrectly estimated, the azimuth location error is the one more dramatically affected.

6 IMPACT OF THE ERS-2 MONO-GYRO SAR DOPPLER ON INSAR PERFORMANCE

6.1 *The role of Doppler Centroid difference on InSAR performance*

The key parameter for assessing the impact of the mono-gyro configuration on InSAR performance is the Doppler Centroid difference between pairs involving at least one image acquired in mono-gyro mode. The Doppler Centroid is the centre frequency of the image azimuth bandwidth, which is 1378 Hz for SLC images[3] (nominal azimuth processed bandwidth for the VMP processor). Since SLC images have a limited azimuth bandwidth, it is clear that when the Doppler Centroid difference between the two images of an InSAR pair becomes larger, their common azimuth bandwidth decreases and, as it will be explained below, the InSAR performance is degraded.

At this point, it is worth to introduce the concept of interferometric coherence, since it provides an indication of the expected InSAR performance, or InSAR quality, for a given pair. The interferometric coherence is a measure of the absolute value of the correlation between the two complex images of an interferometric pair[4]. It is normalized, taking values between 0 (worst coherence) and 1 (best coherence). The value of the coherence depends on multiple factors, including the surface characteristics, the time span between acquisitions, the spatial satellite baseline and the percentage of azimuth spectra overlap. The last factor has been practically constant for all ERS tandem pairs (around 250 Hz) and around 100% for ERS-2 3GP pairs. However, with the new mono-gyro configuration, this factor varies and its analysis becomes critical.

The non-common part of the azimuth spectra can be filtered out to avoid the degradation of coherence caused by the non-common frequencies. If this is not done, the "theoretical best achievable coherence" is approximately reduced by a factor equal to:

$$Decorrelation = 1 - \left| \frac{F_{DC1} - F_{DC2}}{1378} \right|$$

Where F_{DC1} and F_{DC2} are the Doppler Centroid frequencies of the two images of the pair and 1378 Hz is the original azimuth bandwidth of each one of the SLC images. Clearly, total decorrelation occurs when the difference between Doppler Centroid frequencies equals the bandwidth, i.e. when there is no common frequency between the two images. For archive ERS tandem pairs (i.e. ERS-1 / ERS-2 3GP), the decorrelation factor is around 0.82 (corresponding to a difference of Doppler Centroid around 250 Hz) and for ERS-2 3GP pairs this factor is close to 1.

---

[3] The discussion about InSAR performance is focused on SLC products since these are the most commonly used for InSAR applications (RAW can also be used but requires the use of more advanced tools and PRI cannot be used since it does not contain phase information).

[4] In this document, an "interferometric pair" stands for 2 ERS SAR images (1 ERS-2 and 1 ERS-2, or 2 ERS-1 or 2 ERS-2) acquired at different times over the same area (same track and frame).

The azimuth spectra shift caused by different Doppler Centroid between the two images of an interferometric pair is illustrated in Fig.11. The figure shows the azimuth spectra of the pair ERS-2 3GP SAR acquired on 7th Jan. 2000 (red) and ERS-2 1GP(6) SAR acquired on 11th Feb. 2000 (black). The difference of Doppler Centroid between these two images is around 500 Hz.

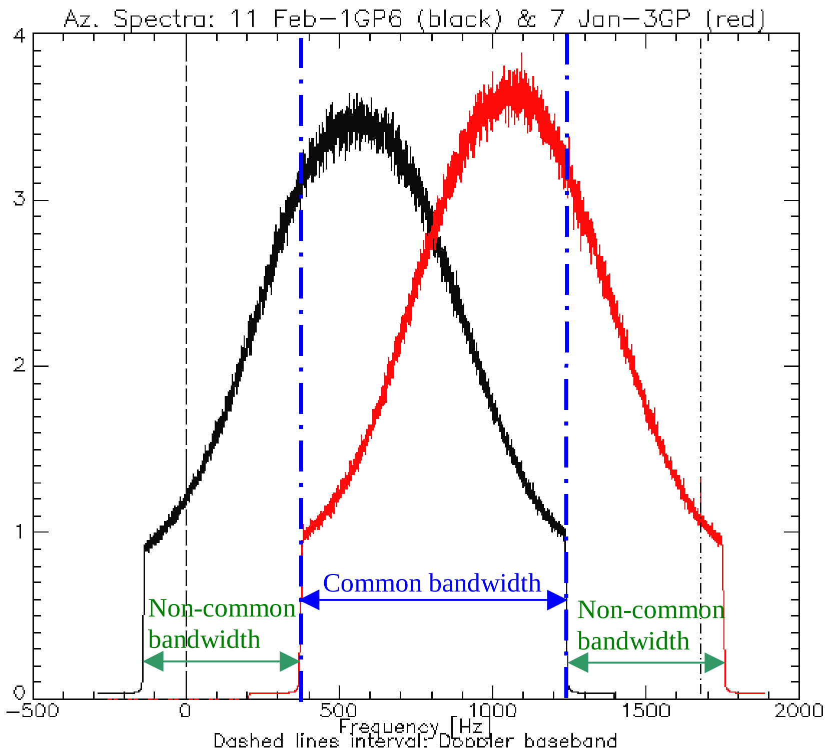


Fig. 11. *Azimuth spectra of an ERS-2 3GP/ERS-2 1GP(6) InSAR pair. Red: ERS-2 3GP image spectra, Doppler Centroid of 1047 Hz (in [0,PRF] interval). Black: ERS-2 1GP image spectra, Doppler Centroid (in ([0,PRF] interval) of 556 Hz.*

Filtering out the non-common part of the spectra avoids the decorrelation caused by the non-common frequencies. The drawback is that the available bandwidth is reduced and consequently the azimuth resolution increases since it is inversely proportional to the azimuth bandwidth.

Another method to minimise the decorrelation caused by different Doppler Centroid frequencies is to start the InSAR processing from RAW data and focus the two SLC images using their mean Doppler Centroid. Each one of the images is slightly defocused (for small differences of Doppler) but the coherence is optimised.

These techniques have not been systematically applied to ERS Tandem pairs but with the new ERS-2 mono-gyro configuration, application of these techniques will become important and not only to ERS-1/ERS-2 pairs but also to ERS-2 3GP/ERS-2 1GP pairs and possibly to ERS-2 1GP - ERS-2 1GP pairs. It is important to remark that these techniques have to be applied by the user (no preliminary improvement of SLC products for InSAR applications is currently performed by ESA).

6.2 *Doppler Centroid difference between ERS-1, ERS-2 3GP and ERS-2 1GP (G5 & G6) SAR data*

The Doppler Centroid frequency around the orbit for ERS-1, ERS-2 archive data (i.e. nominal 3GP data) and ERS-2 1GP(5,6) have been discussed in Chapter 6. In order to assess the impact of the new Doppler pattern on the InSAR performance it is important to analyse the absolute difference of Doppler Centroid around the orbit between ERS-1 and ERS-2 mono-gyro data and between ERS-2 3GP and ERS-2 mono-gyro data. These absolute differences are provided in Fig.12.

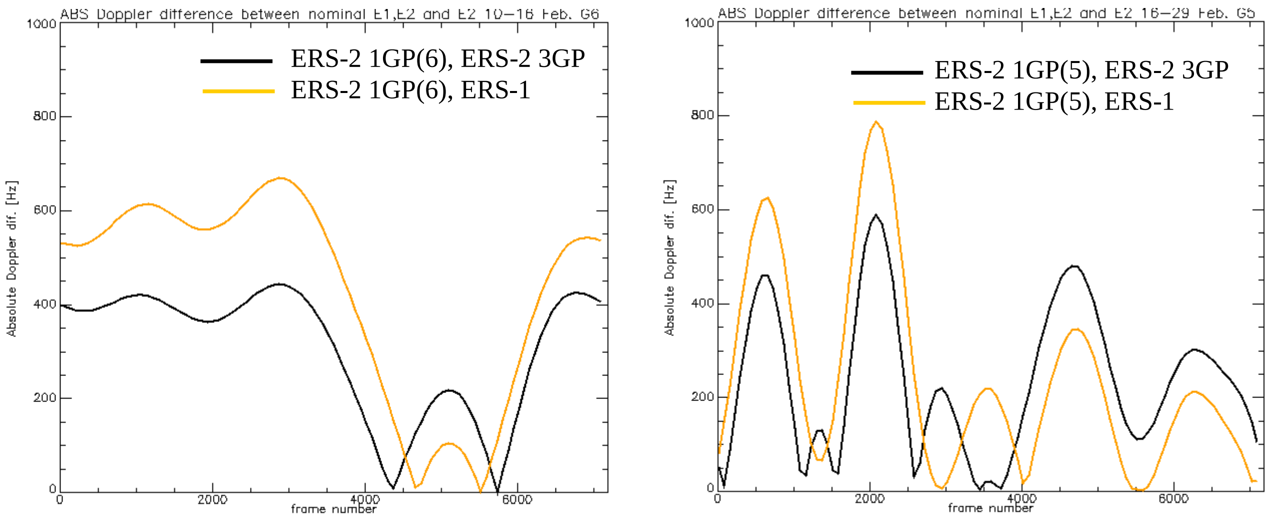


Fig. 12. *Doppler Centroid difference between ERS-1 and ERS-2 1GP pairs (black lines) and between ERS-2 3GP and ERS-2 1GP pairs (orange lines). Left: ERS-2 1GP(6), 10th -16th Feb. Right: ERS-2 1GP(5), 16th-23rd Feb.*

As expected, Doppler Centroid differences are larger for ERS-1/ERS-2 1GP pairs (black) than for ERS-2 3GP/ERS-2 1GP pairs (red). It is also important to notice that these differences are not constant around the orbit, which makes difficult their correction by the introduction of an attitude offset at the satellite level.

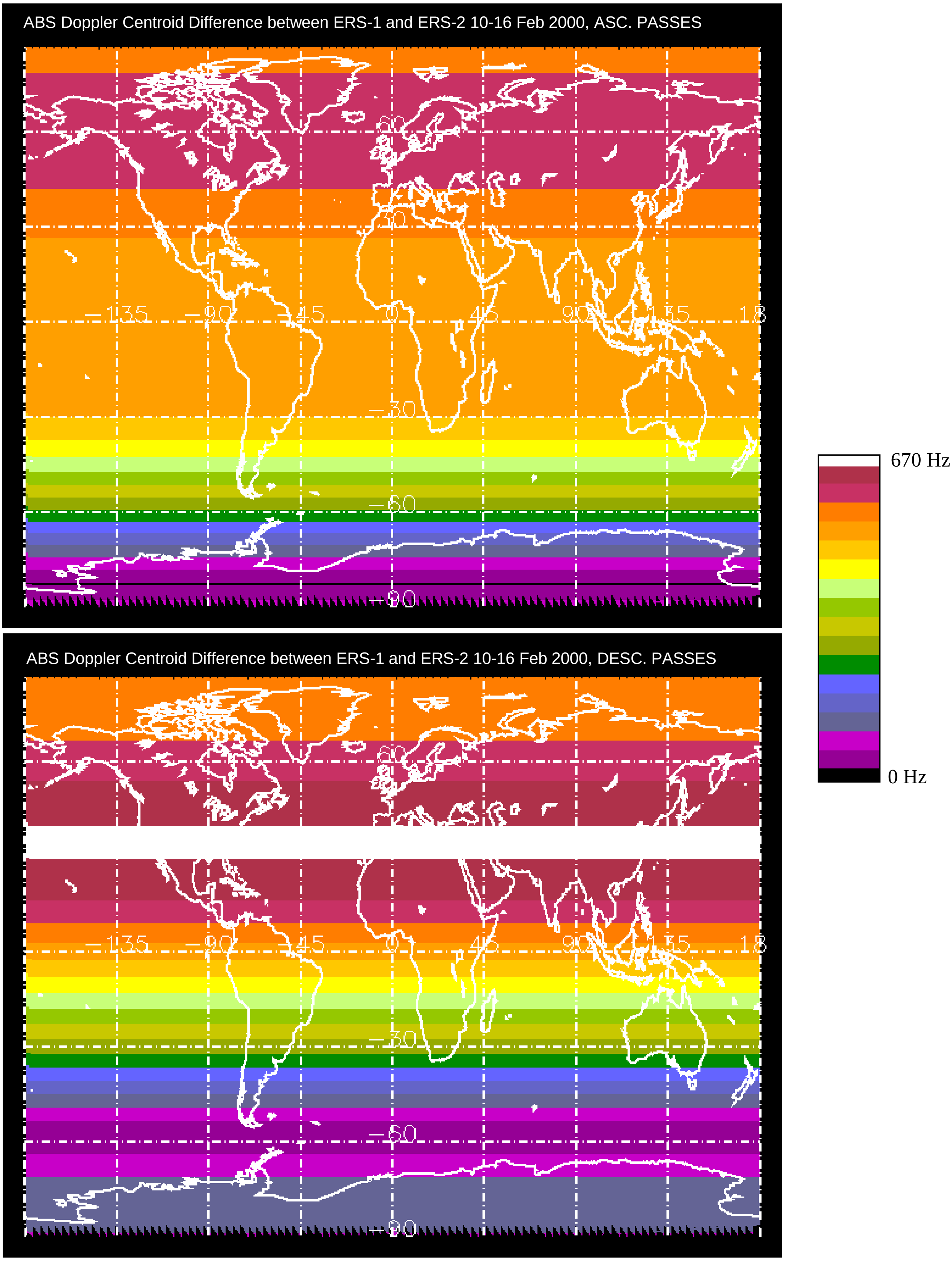
It is important to remark that these curves and the plots below are intended to provide a first estimation of the expected Doppler differences. They are based on Doppler models and the standard deviation of the real Doppler frequency values with respect to the model can be up to 200 Hz.

6.3 Doppler Difference maps

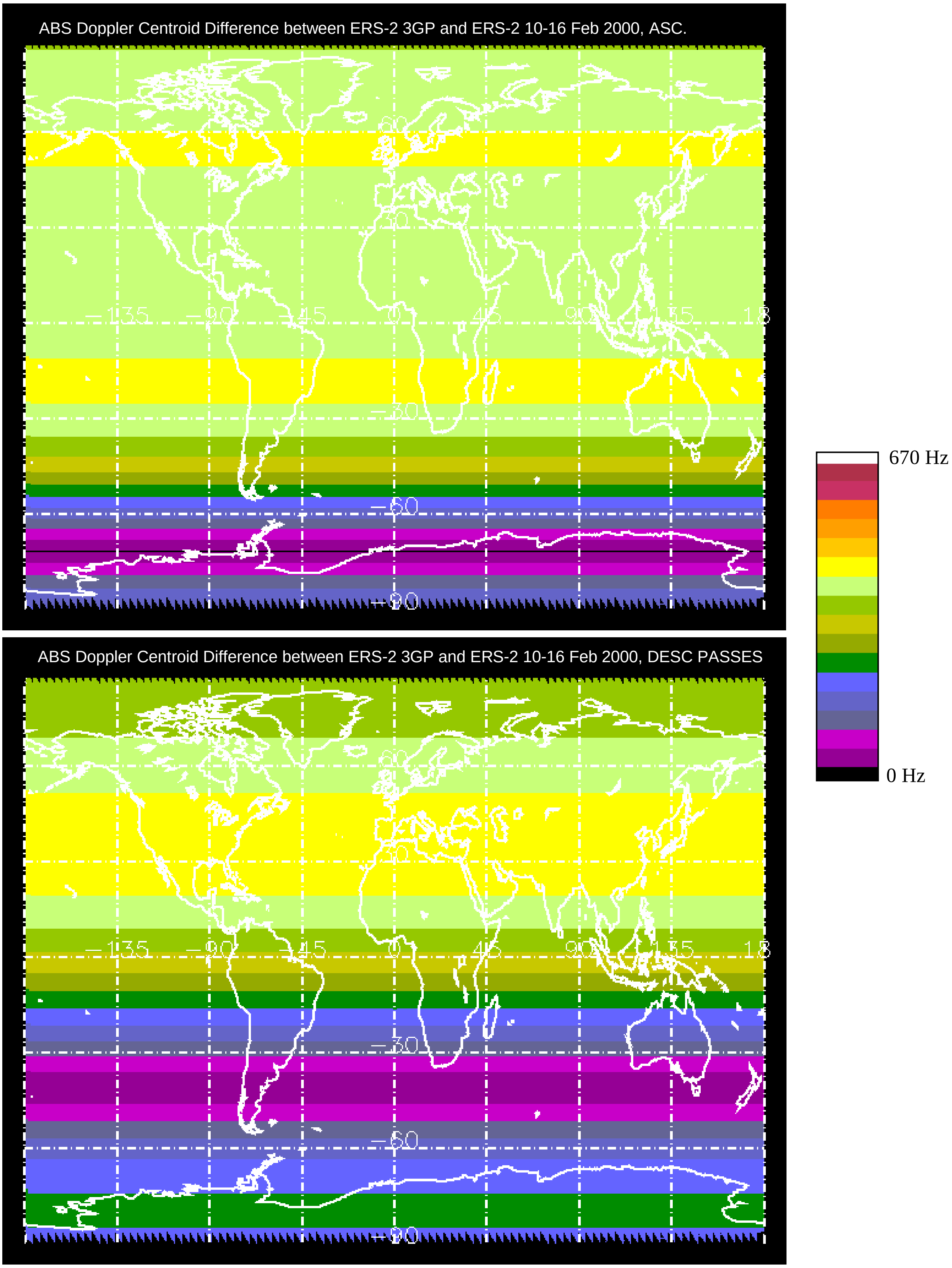
These maps intend to provide an easy way to identify the expected Doppler difference for a certain InSAR pair as a function of the acquisition time and geographical area.

The Doppler Centroid difference estimated around the orbit is overlaid on a map and colour coded. The Doppler difference for a complete orbit is split in one map for ascending and one for descending passes. The maximum error on these maps can be up to +/- 200 Hz and it is due to the fact that Doppler models are derived from SAR wave mode data and that attitude is less stable than for nominal 3GP mode.

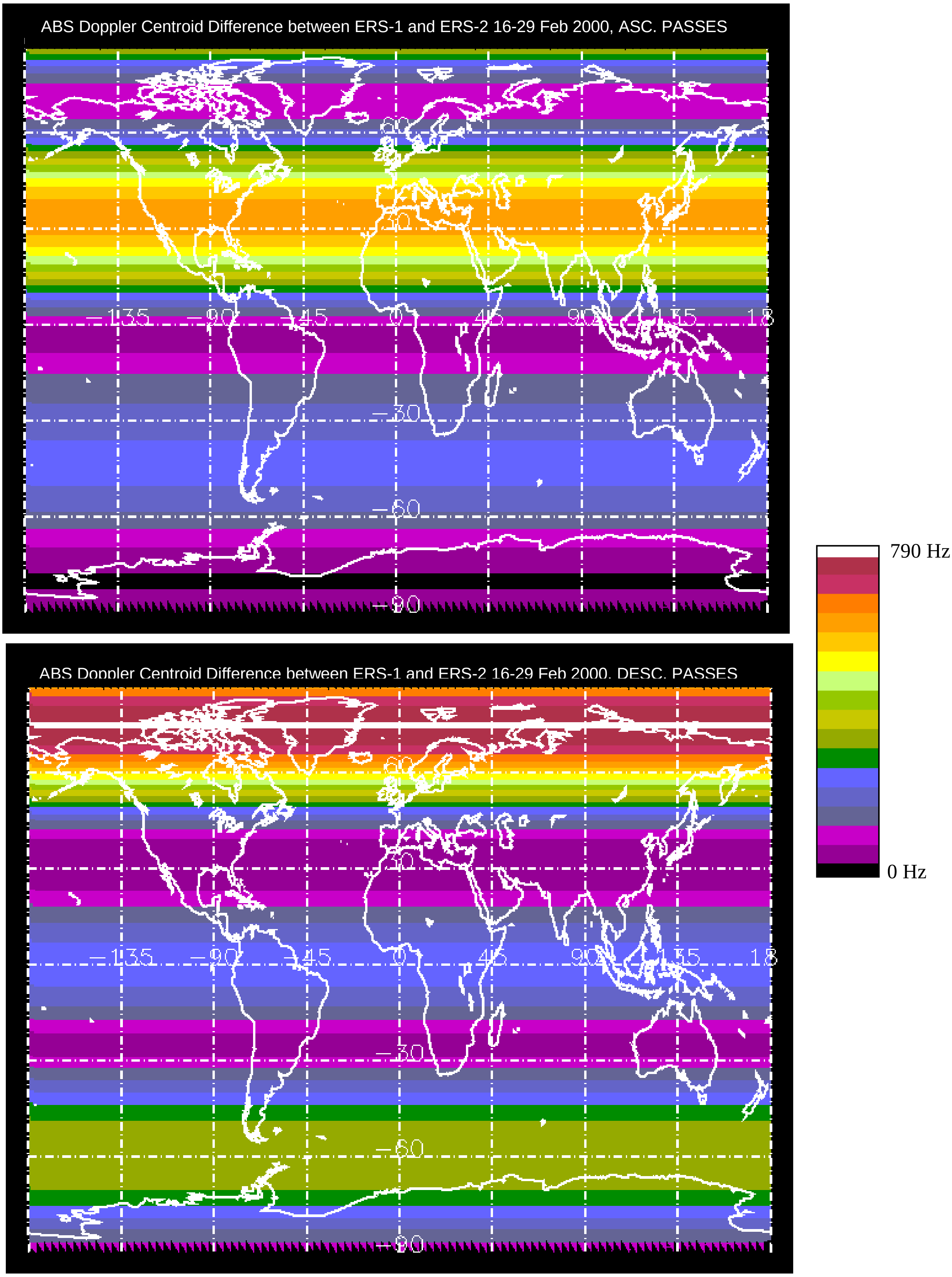
Maps of Doppler Centroid difference: ERS-1 and ERS-2 1GP(6), 10th -16th Feb. 2000



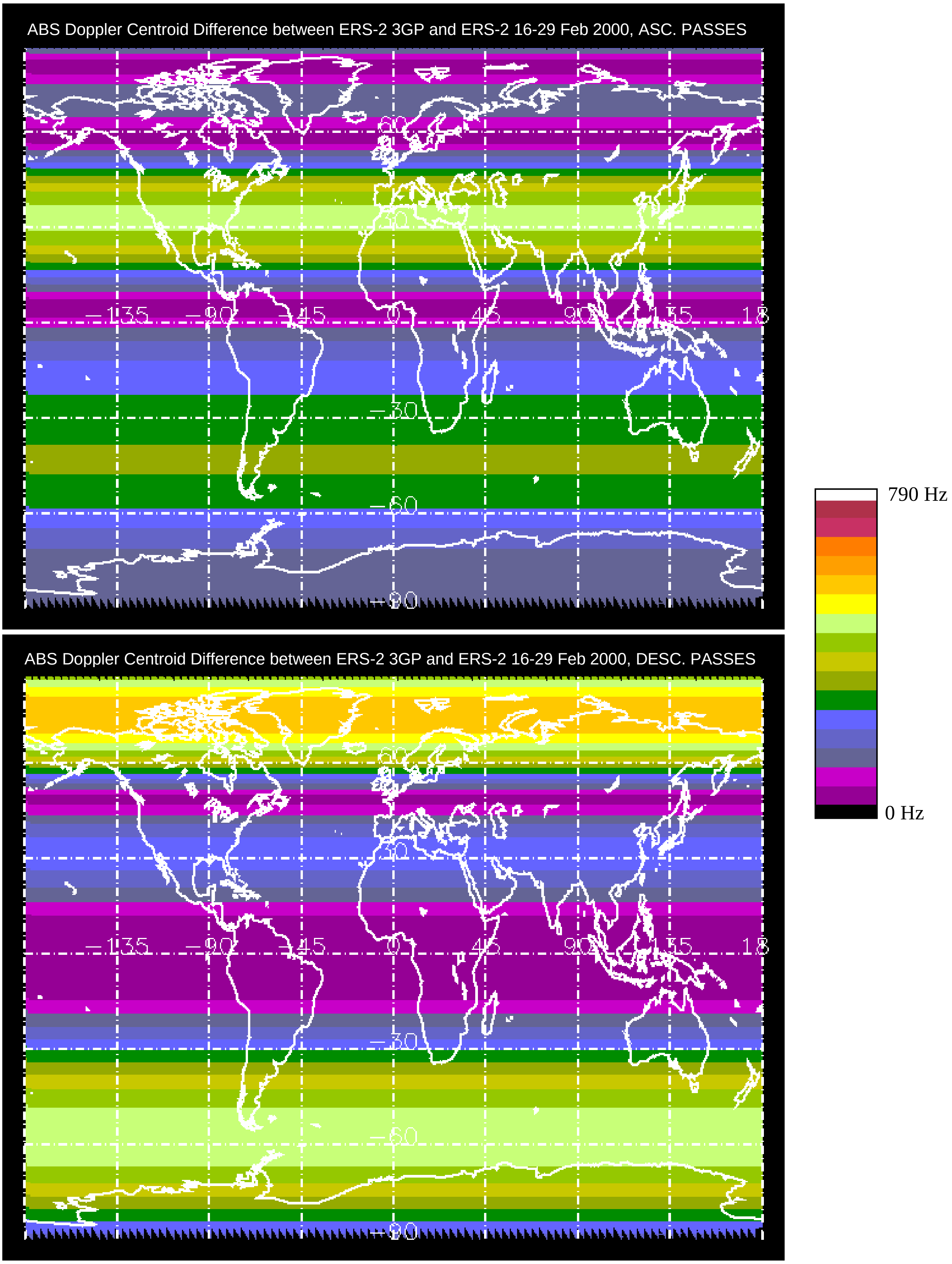
Maps of Doppler Centroid difference: ERS-2 3GP and ERS-2 1GP(6), 10th -16th Feb. 2000



Maps of Doppler Centroid difference: ERS-1 and ERS-2 1GP(5), 16th -29th Feb. 2000



Maps of Doppler Centroid difference: ERS-2 3GP and ERS-2 1GP(5), 16th -29th Feb. 2000



6.4 Some InSAR results with ERS-2 1GP

In order to illustrate the achievable INSAR performance with the new mono-gyro ERS-2 SAR data, the results for two different tandem pairs acquired during the qualification period are provided here. In one case, the Doppler Difference between the images is close to the largest observed and in the other case, the Doppler difference is close to the nominal value for ERS-2 3GP mode.

6.4.1 Example of medium quality InSAR results from an ERS-1 & ERS-2 1GP tandem pair

This is an example of the achievable InSAR quality for ERS-1/ERS-2 1GP pairs when there is an important Doppler Centroid difference between the two images (around 700 Hz in this case) and specific processing is applied to minimise the decorrelation.

This example is based on the tandem pair acquired during the AOCS campaign, on 12th/13th Feb. 2000, with ERS-2 in 1GP(6) mode, over Finland (see Fig.13). The perpendicular baseline for this pair is around 70 m and therefore, almost no decorrelation is expected due to the baseline. This data has been processed at D-PAF using the GENESIS processor, starting from standard SLC images. Results obtained over one of the frames are provided as example in Fig.13. The Doppler Centroid over this area is 427 Hz for ERS-1 and –280 Hz for ERS-2 1GP(6). Thus, there is a difference of Doppler Centroid of around 700 Hz between the two images. In order to maximise the coherence, the non-common part of the azimuth spectra has been filtered out. Visually, the quality of the results is rather good but it should be kept in mind that there is an unavoidable loss of azimuth resolution implied in the maximisation of the InSAR quality.

6.4.2 Example of high quality InSAR results from an ERS-1 & ERS-2 1GP tandem pair

This is a demonstration that over certain latitudes, the achievable ERS-1/ERS-2 1GP InSAR quality is equivalent to the one obtained with ERS-2 in nominal 3GP mode. The tandem pair acquired on 18^{th} - 19^{th} February 2000 over south of UK to Morocco (i.e. with ERS-2 in 1GP(5) mode) has been taken as example. The Doppler Centroid for ERS-2 1GP(5) data over this area is very similar to the one usually observed for nominal ERS-2 3GP SAR data. Quality of InSAR results for this tandem pair is the same as for nominal tandem pairs. Fig.14 provides a low resolution version of the ILU and IBP images generated with the IQL for this particular pair.

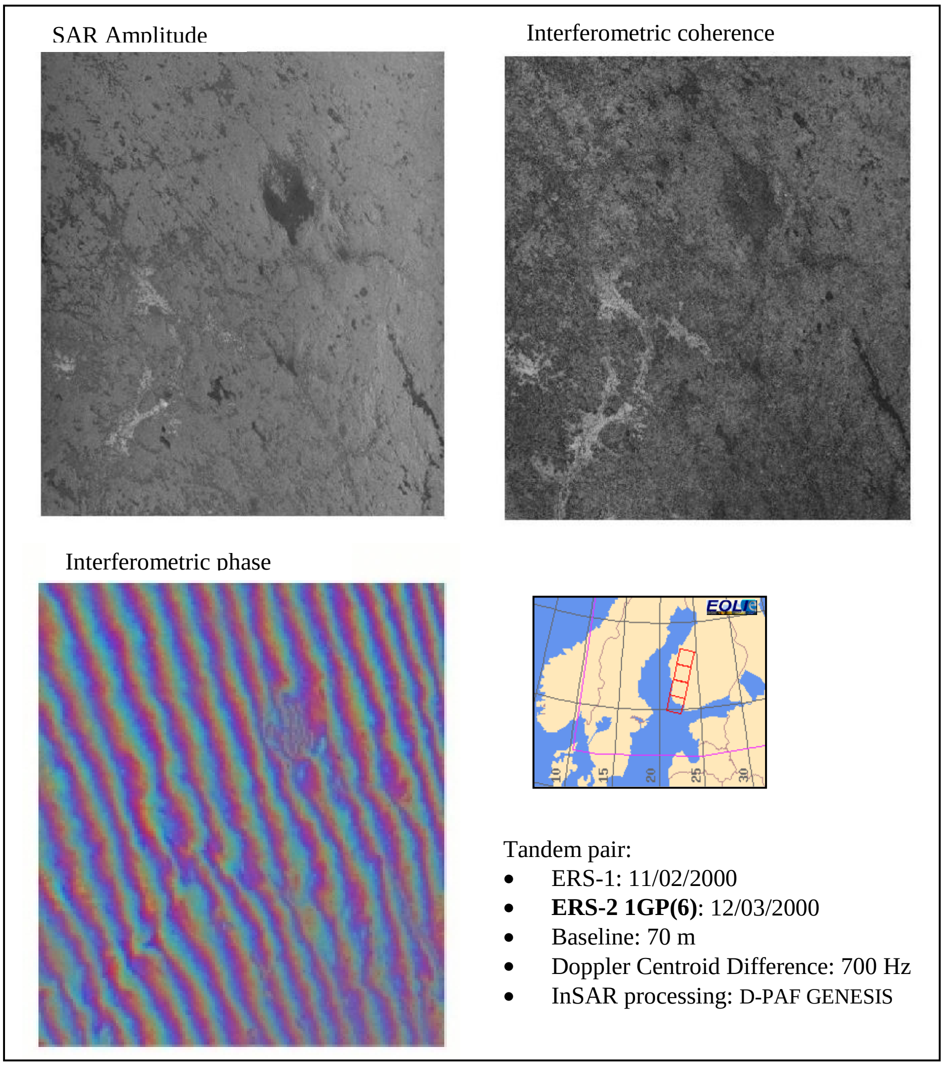


Fig. 13. *Interferometric result with a tandem pair acquired on 11/12 Feb. 2000, with ERS-2 in 1GP(6) mode and with a Doppler Centroid difference between ERS-1 and ERS-2 around 700 Hz.*

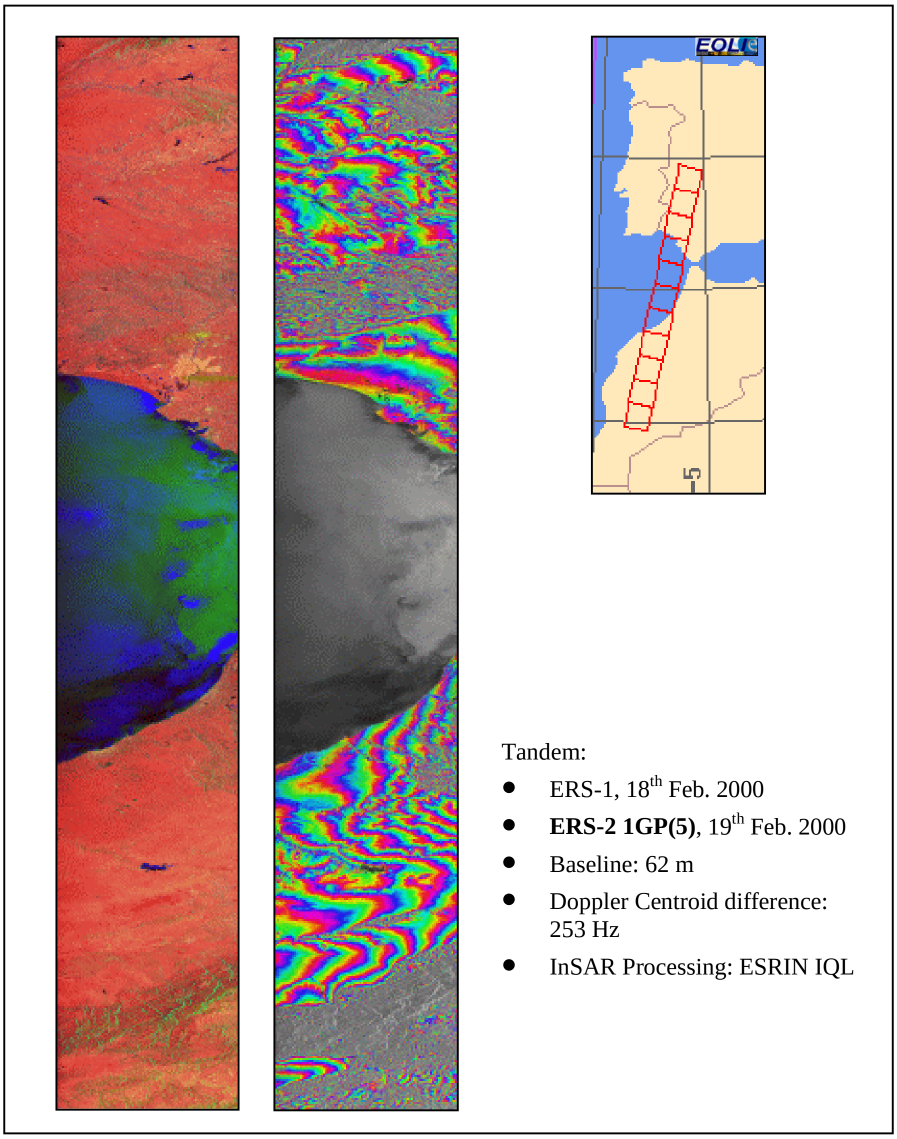


Fig. 14. *Interferometric result with a tandem pair acquired on 18/19 Feb. 2000, with ERS-2 in 1GP(5) mode and with a Doppler Centroid difference between ERS-1 and ERS-2 around 250 Hz.*

6.5 Conclusions

Some conclusions can be derived from the results presented in previous sections:

- Globally, ERS-2 3GP/ERS-2 1GP InSAR performance is expected to be better than ERS-1/ERS-2 1GP performance.
- Regarding ERS-1/ERS-2 1GP InSAR, expected performance should be better for ERS-1/ERS-2 1GP(5) than for ERS-1/ERS-2 1GP(6).
- Regarding ERS-2 3GP/ERS-2 1GP InSAR, expected performance with ERS-2 1GP(5) is more variable along the orbit than with ERS-2 1GP(6). For most of the orbit InSAR performance will be better with ERS-2 1GP(5) than with ERS-2 1GP(6), but it will be much lower for specific orbit intervals.
- InSAR performance over areas where the Doppler difference remains the same or lower than with ERS-2 3GP, will be the same or even better than with ERS-2 3GP.
- InSAR performance over areas where the Doppler difference with ERS-2 1GP is much larger than with ERS-2 3GP can be improved with specific processing techniques.

7 CONCLUSIONS

7.1 ERS-2 mono-gyro SAR product quality

No anomalies have been observed on the quality of the SAR data acquired in mono-gyro mode and standard product quality is obtained with accurate SAR processing.

The main difference between ERS-2 SAR data acquired in nominal 3GP mode and in mono-gyro mode regards the value of the Doppler frequency. A change in the Doppler frequency has no implications on the image quality (when it is correctly estimated) but may have implications on several applications.

7.2 Operational ESA ERS-2 1GP SAR Image products

All ERS-2 SAR images acquired during the mono-gyro campaign have been generated with the VMP processor.

The quality of the images does not suffer from the new configuration and remains the same as for ERS-2 in nominal 3GP mode (see Chapter 2 for details).

The VMP processor estimates the Doppler ambiguity from the SAR data to be processed and therefore, image quality should not be affected by any change in the nominal Doppler pattern.

Therefore, no product quality problems or processing failures are expected when processing ERS-2 mono-gyro data with the VMP system.

7.3 Implications for ERS-2 SAR Applications

The impact of the mono-gyro configuration on the performance of ERS-2 applications is mainly related to the Doppler frequency difference between ERS-1 and ERS-2 SAR 3GP nominal mode data and ERS-2 mono-gyro data.

Expected InSAR performance for ERS-2 3GP/ERS-2 1GP is globally better than for ERS-1/ERS-2 1GP. For those areas where the difference of Doppler (3GP and 1GP) is important, a loss in coherence (i.e. a degradation of retrieved fringe quality) is expected. This degradation of coherence can be partially avoided by means of specific processing on the user side and at the cost of azimuth resolution.

Foreseen performance as a function of the expected Doppler Centroid frequency for a certain acquisition time and over a specific geographical area is provided in this report for February 2000 and will be provided on a 15 days basis.

8 REFERENCES

[R-1] ERS1 Satellite to Ground Segment, ER-IS-ESA-GS-0001, Iss. 2C, 01/03/1991.

[R-2] AOCS Impact on ERS-2 SAR image quality. Qualification phase and routine monitoring. Issue 3, 28th Jan. 2000

[R-3] "Doppler characteristics of the ERS-1 yaw steering mode", D. Jutz, B. Schattler, Proceedings of IGARSS'92

[R-4] ECMWF report on ERS-2 SAR wave height data, February 2000

ANNEX A - DOPPLER MODEL: FOURIER COEFFICIENTS

FOURIER COEFFICIENTS, E2 3-gyro, up to 7th Feb. 2000

a_0	-275.943
a_1	134.29227
b_1	-61.401053
a_2	-9.5030992
b_2	295.47562
a_3	10.934928
b_3	4.4896503
a_4	2.1735128
b_4	2.612317

FOURIER COEFFICIENTS. ERS-2 1GP(6), 10^{th} -16^{th} FEB. 2000

a_0	-528.630
a_1	92.154663
b_1	58.386824
a_2	-74.597891
b_2	246.55058
a_3	31.627465
b_3	-11.263433
a_4	15.354427
b_4	-2.7314000

FOURIER COEFFICIENTS. ERS-2 1GP(5), 16^{th} -29^{th} FEB. 2000

a_0	-227.297
a_1	98.278977
b_1	82.036211
a_2	3.0982124
b_2	298.73199
a_3	3.1802142
b_3	28.978900
a_4	-44.864775
b_4	95.818199
a_5	62.160701
b_5	6.0984167
a_6	17.261480
b_6	-25.627431

Derivation of the Doppler Centroid frequency as a function of time around the orbit [msec from the ascending node] using a Fourier series and the coefficients provided for each time interval

Doppler centroid (time) = a_0 + 2* [a_1*cos(w_1*time) - b_1*sin(w_1*time) + a_2*cos(w_2*time) - b_2*sin(w_2*time) + a_3*cos(w_3*time) - b_3*sin(w_3*time) + a_4*cos(w_4*time) - b_4*sin(w_4*time) + a_5*cos(w_5*time) - b_5*sin(w_5*time) + a_6*cos(w_6*time) - b_6*sin(w_6*time)]

Where:

time : msec from the ascending node: [0, 6035930]

Tmax: 6035930

w_1 = 2* π / Tmax
w_2 = 4* π/ Tmax
w_3 = 6* π/ Tmax
w_4 = 8* π/ Tmax
w_5 = 10* π/ Tmax
w_6 = 12* π/ Tmax