Feasibility Study of Sea Surface Currents measurements with Doppler Scatterometers

P. Fabry(1), A. Recchia(2), J. de Kloe(3), A. Stoffelen(3), R. Husson(1), F. Collard(1), B. Chapron(4), A. Mouche(1), V. Enjolras(5), J. Johannessen(6), C. C. Lin(7), F. Fois(7)

(1) CLS, COLLECTE LOCALISATION SATELLITES, FRANCE
(2) ARESYS, ADVANCED REMOTE SENSING SYSTEMS, ITALY
(3) KNMI, ROYAL NETHERLANDS METEOROLOGICAL INSTITUTE, NETEHRLANDS
(4) IFREMER, FRENCH RESEARCH INSTITUTE FOR EXPLOITATION OF THE SEA, FRANCE
(5) TAS-F, THALES ALENIA SPACE, FRANCE
(6) NERSC, NANSEN ENVIRONMENTAL AND REMOTE SENSING CENTER, NORWAY
(7) ESA-ESTEC, EUROPEAN SPACE RESEARCH AND TECHNOLOGY CENTRE, NETEHRLANDS

Abstract

The presented activity has been carried out in the frame of the ESA GSP study called "Feasibility Investigation of Global Ocean Surface Current Mapping using ERS, MetOp and QuikScat Wind Scatterometer" (DOPSCAT). The study assesses the potential of scatterometer instruments for sea surface current vector retrieval under the strong requirements of preserving both the swath and the surface wind vector estimation performances offered by the existing scatterometers.

The activity foresaw the exploitation of both real and simulated datasets. The first task was accomplished by analyzing ERS-2 Wind Scatterometer data, the only available scatterometer data maintaining the Doppler information on ground. The accuracy over ERS-2 was not good enough, due to the signal content and the small number of samples per echo line. Further investigations were then conducted through the design and development of a realistic Doppler Scatterometer simulator, to provide calibrated NRCS and Doppler Shifts (geometrical and geophysical) as well as aliased azimuth spectrum (low PRF) under a user defined SNR. The simulator involves the transmission of dual chirps, a mini orbit propagator that accounts for the Earth rotation, static attitude angles, CMOD5N and CDOP Geophysical Model Function, Azimuth Antenna Pattern. It provides the data for 3 of the 6 beams of a Fixed Fan Beam Scatterometer with selectable parameters (looking angles, antenna apertures, PRF, sampling frequency...). The simulated data are processed in a standard manner for what concerns wind retrieval and, based on the transmission of two chirp with opposite rates and exploiting the Doppler-Range ambiguity after matched filter compression, for the Doppler shift estimation. Results over several data sets show a standard accuracy for wind surface estimation and a good accuracy for surface current measurement. In the end, recommendations for this new instrument concept are given under realistic constraints on the onboard processing requirements.

User requirements for ocean surface current observation

Phenomenon	Approximate time scale [hr]	Approximate Length scale [km]	Approximate Velocity scale [cm/s]
Equatorial currents	240	50-100	10-150
Western boundary currents	48	10-100	10-200+
Ocean meso-scale eddies	120	10-20	10-50
Ocean fronts	120	1-5	30
Tidal currents	1	0.1-20	10-200+
Coastal currents	6	0.1-5	5-50

Tab. 1 Characteristic velocities arranged according to oceanic phenomena

Considering the values in this table as a general guide to surface current characterization [1] [2] [3] and observation requirements a number of regions can be specified as suitable for case studies to investigate the satellite retrievals of ocean surface currents using scatterometers:

1. *The Gulf Stream region*
2. *Agulhas Current*
3. *Regional sea (Western Mediterranean),*
4. *Coastal up-welling region in Spain and Portugal*
5. *Open ocean gyre.*

These regional characteristics are used to define the dynamic range of surface currents spanning from 0.05 m/s to 4 m/s with a retrieval accuracy of ~ 0.10 m/s at a spatial and temporal resolution of approximately 10 km and 12-24 hours.

Surface current estimation from ERS-2 Wind Scatterometer data

Today, the ERS2-EWIC [4] [5] data are among the very few if not the only scatterometer data offering some Doppler information. A large amount of these data (3 full cycles corresponding to about 100 days) have been processed within the study framework.

A time domain Doppler shift estimation technique, based on the Adjacent Cross-Correlation method [6] and a frequency domain technique, based on the MLS fitting of the received signal spectrum, were tested.

Both these techniques did not allow to obtain accurate enough results (an accuracy of about 50 Hz 1σ was obtained).

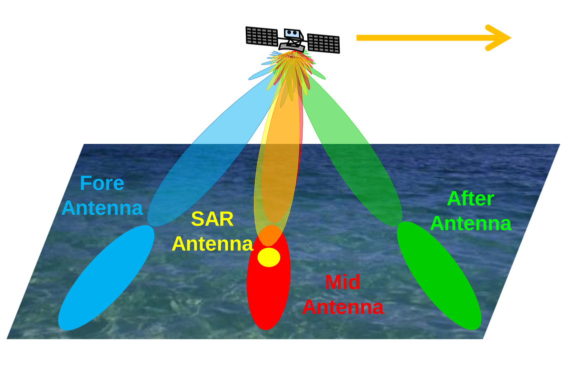

Fig. 1 ERS Wind Scatterometer acquisition geometry

ECMWF ERA40 surface winds data have been extracted from the ECMWF archives and collocated in time and location with the ERS data, but no particular correlation between the model data and the retrieved Doppler information was observed.

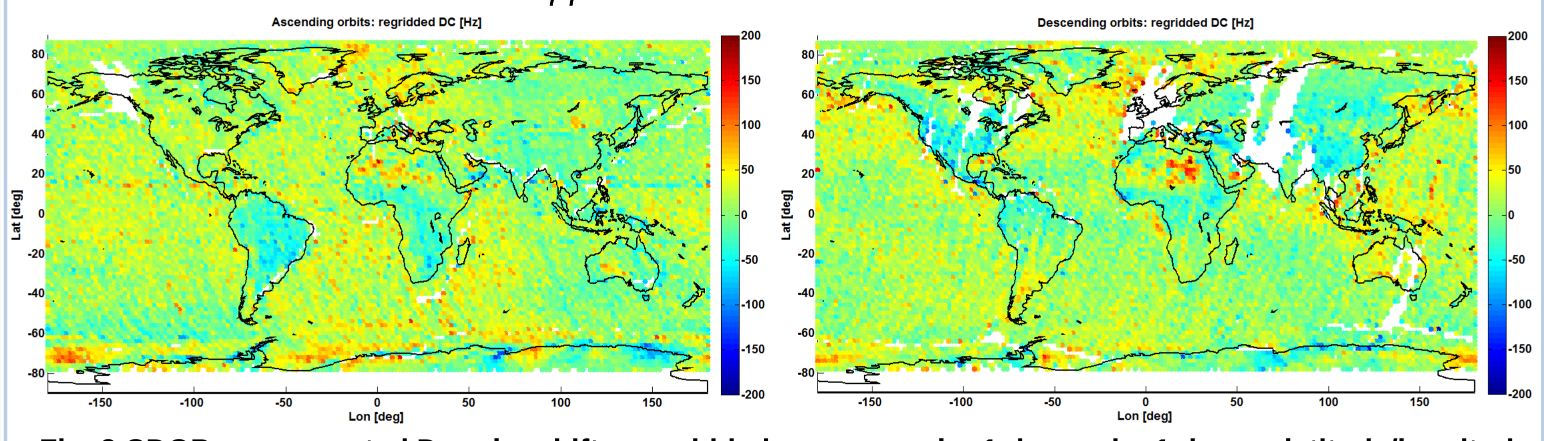

Fig. 2 CDOP compensated Doppler shifts re-gridded over a regular 1 degree by 1 degree latitude/longitude grid. The left image is for ascending orbits while the right image is for descending orbits.

Dual-chirp scatterometer concept

The Doppler shift estimation over LFM data is complicated because the Doppler shift is very reduced w.r.t. the system bandwidth and the pulse spectrum is very flat. Furthermore LFM pulses are affected by the so called range-Doppler coupling effect: after pulse compression Doppler shifts and time delays effects cannot be distinguished, making the Doppler shift estimation over standard scatterometer data more complicated.

Fortunately the range-Doppler coupling effect can be used for Doppler estimation [7], by exploiting the fact that its effects are opposite for chirps with opposite rates. For this reason we propose a system transmitting dual-chirps (i.e. two chirps with opposite rate). The Doppler estimation will be performed by measuring the relative shift between the two obtained range compressed images, through a standard cross-correlation shift estimator.

Two implementations of the dual-chirp system are possible:

1. *Transmission of the sum of the two opposite chirps*
2. *Transmission of two chirps juxtaposed in time*

The first solution is optimal from a signal correlation point of view but foresees the transmission of a non-constant amplitude pulse.

The second solution is optimal from a transmission point of view but the very quick decorrelation time of sea surface shall be considered during system design.

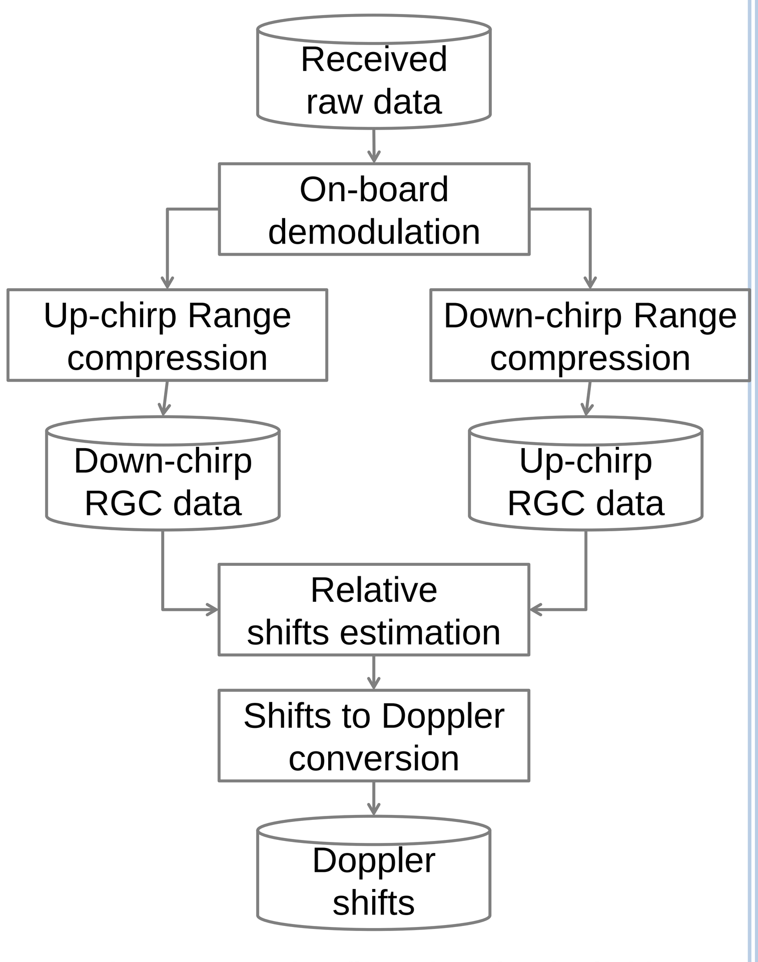

Fig. 3 Processing flow-chart for dual-chirp DOPSCAT data

DOPSCAT simulator concept

DOPSCAT simulator has been developed [8] in IDL to overcome the lack of real Scatterometer datasets, allowing Doppler shift estimation. Its main features are:

- ***Includes a mini orbit propagator***
- *Simulate 3 of 6 beams of an **ASCAT-like scatterometer** (right looking)*
- ***C band, VV polar** only (CMOD, CDOP)*
- ***Most system aspects are user-selectable***
- ***Geophysical scenario is user selectable** (average wind and current velocity vectors)*
- ***Geometric range dependent Doppler shift** computed from the orbital position, LoS, rotation rate of an ellipsoid Earth WGS84*
- ***Current Doppler shift** obtained by computation of the relative velocity vector along the LoS*
- ***Wind Doppler shift** computed from the CDOP GMF*
- ***Azimuth Bandwidth** computed & **Azimuth Spectrum aliased** according to the low PRF*
- ***NRCS calibrated with the GMF** output for the **steady wind** condition **+ some NRCS noise (variability model)***

Parameters	Value
Satellite Position	ANX
Satellite Height	817 km
Orbit inclination	98.6°
Mean Wind Velocity	6 m/s
Mean Wind Direction	90° (pure West)
Mean Surface Current Velocity	0 m/s
Pulse duration	1ms
PRF	86 Hz
Antenna az. size	0.27 m
Antenna el. size	2.95 m (squinted) 3.6 m (center)

Tab. 2 DOPSCAT simulator: study case parameters

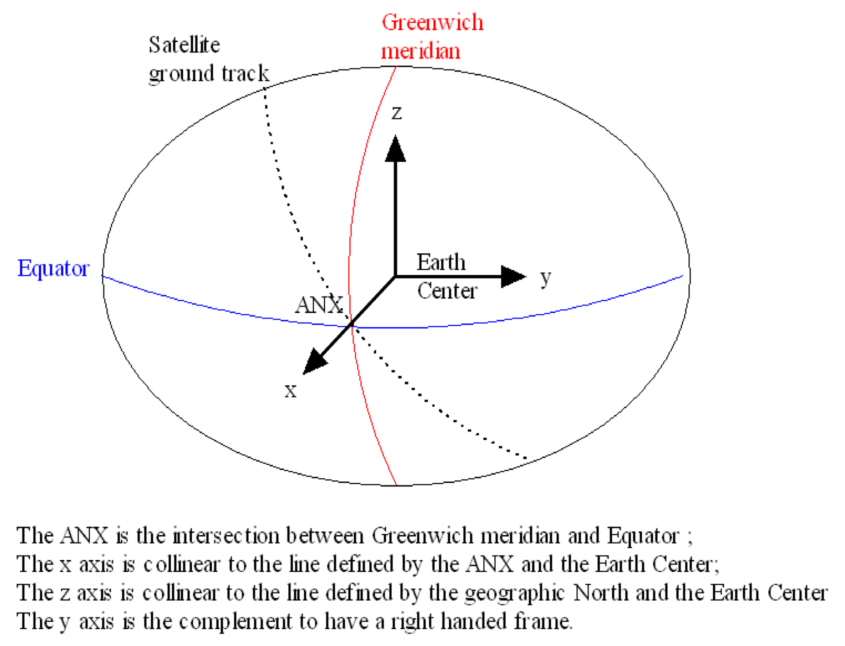

Fig. 4 DOPSCAT simulator: geometry

Estimation results over simulated data

This section presents the main results obtained applying the proposed Doppler estimation technique on Wind Scatterometer simulated datasets. Each dataset consisted in 3 right-looking beams of an ASCAT-like scatterometer. 64 datasets have been produced for the Doppler estimation technique validation. The reference scenario was always the same with different conditions of SNR and on-board Doppler demodulation errors (different colors in the figure).

Figure 5 shows two scatter plots representing the Doppler estimates bias and accuracy dependency on SNR. As expected, there is a clear correlation between the SNR and the Doppler estimation accuracy. For high SNR an estimation accuracy slightly below 40 Hz is obtained. The on-board Doppler demodulation error has also a direct impact on the quality of the Doppler shifts estimates. In particular at the increase of the error value a bias in the estimates is introduced (light blue stars in the left plot represent the highest error).

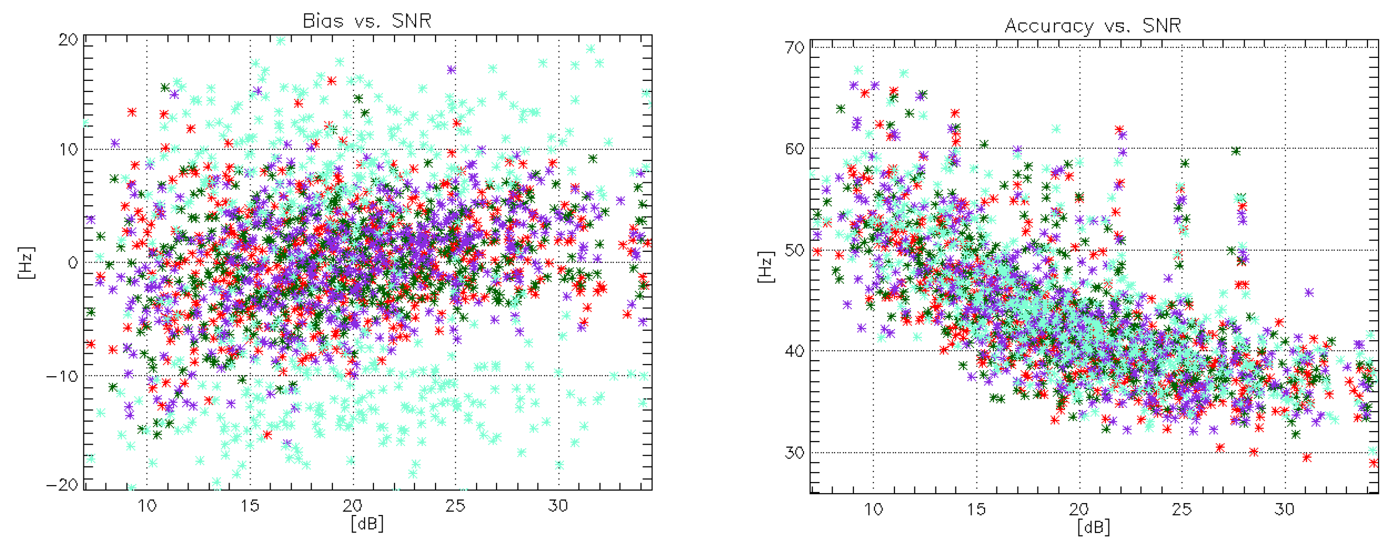

Fig. 5 Scatter plots of Doppler estimates bias and accuracy w.r.t. the SNR. The different colors represent different on-board Doppler demodulation errors..

Combined backscatter and Doppler Wind Retrievals

To further study the concept of a scatterometer that combines back-scatter and Doppler information, a separate tool was exploited to perform Monte Carlo simulations of wind retrievals. The tool scans input winds, adds scatterometer geometries and noise properties, simulates backscatter and Doppler signals and performs wind retrievals. Based on its results several Figure-of-Merit (FoM) numbers are calculated for wind vector, wind speed, wind components and wind direction differences, and a special FoM sensitive to ambiguity of results in the retrieval problem. Finally scanned wind results are combined using climatological weights for the occurrence of wind speeds.

Results are given in Figures 6 and 7. The left plot (6) scans the weight between back-scatter and Doppler signals. The right plot (7) compares QuikScat, ASCAT and several Doppler enabled ASCAT like instrument configurations.

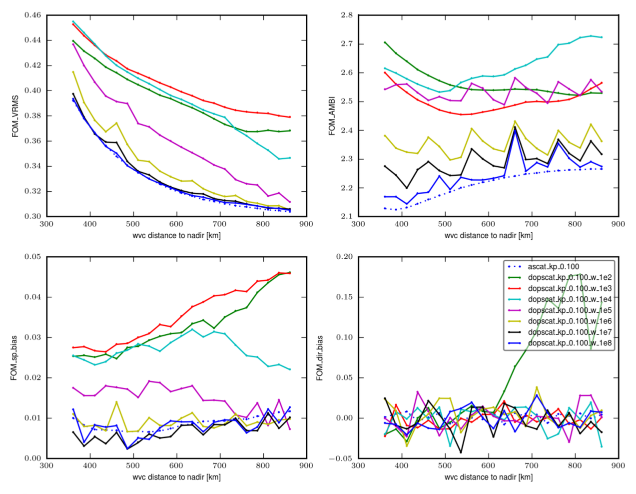

Fig. 6 FOM results for a DOPSCAT simulation based on adding Doppler capability to the ASCAT fore and aft beam for Kp=10% and a range of weight values. For reference the ASCAT result for Kp=10% has been added (blue dotted line).

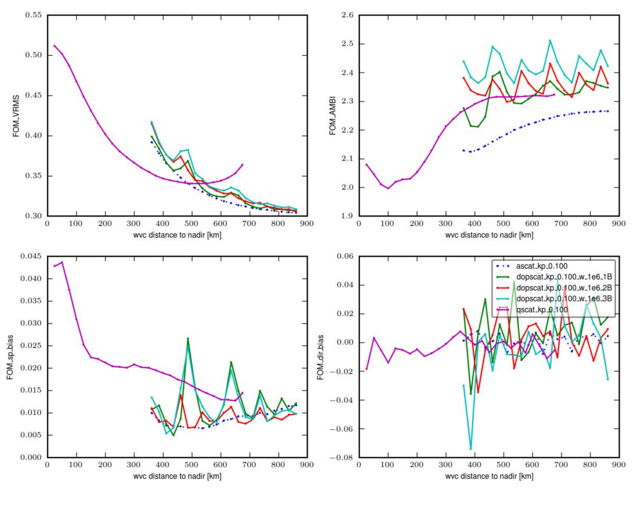

Fig. 7 FOM results for different instrument configurations all using Kp=10%. For all DOPSCAT cases a weight of 10^-6 was used.

Conclusions

The DOPSCAT study has shown that the technical implementation of Doppler shift anomaly retrievals from scatterometry is feasible, and a simulator has been developed and some preliminary results on the achievable Doppler estimation accuracy have been shown.

From the Monte-Carlo simulation results the following conclusions and recommendations can be noted:

- *Assuming a value for the relative noise (Kp) it is possible to calculate Figure-of-Merit numbers that allow comparing overall performance for different scatterometer instruments;*
- *From comparing different Doppler capable systems, adding Doppler capability to the fore and aft beam, and thus sampling two perpendicular Doppler components, gives the best performance results;*
- *No configuration was found in which extending the wind MLE with Doppler information improves upon the ASCAT instrument performance.*

In conclusion it is therefore recommended that this DOPSCAT study could be extended with further investigation and analyses, including further testing of the proposed dual-chirp concept over simulated and, preferably, real scatterometer data.

References

[1] Lin, C., A. Stoffelen, J. de Kloe, V. Wissmann, S. Bartha and H. Schulte, Wind retrieval capability of rotating, range-gated, fan-beam spaceborn scatterometer SPIE conference, 2002

[2] Lin, C.C., M. Betto, M. Belmonte-Rivas, A. Stoffelen en J. de Kloe, EPS-SG Windscatterometer Concept Tradeoffs and Wind Retrieval Performance Assessment IEEE Transactions on Geoscience and Remote Sensing, 2012, 50, 7, 2458-2472, doi:10.1109/TGRS.2011.2180393

[3] Mouche, Alexis A., Fabrice Collard, Bertrand Chapron, Knut-Frode Dagestad, Gilles Guitton, Johnny A. Johannessen, Vincent Kerbaol, and Morten Wergeland Hansen, On the Use of Doppler Shift for Sea Surface Wind Retrieval From SAR, IEEE Transactions on Geoscience and Remote Sensing, doi: 10.1109/TGRS.2011.2174998

[4] N. Miranda, B. Rosich, C. Santella, M. Grion, "Review of the Impact of ERS-2 Piloting Modes on the SAR Doppler Stability", Proc. of the 2004 Envisat & ERS Symposium, ESA SP-572, April 2005

[5] M. Sunda, R. Crapolicchio, P. Lecomte, Impact of satellite degraded attitude on ERS-2 Scatterometer data, September 2002.

[6] S. Madsen, "Estimating the Doppler Centroid of SAR Data", IEEE Transactions on Aerospace and Electronic Systems, vol. 25, no. 2, March 1989

[7] Iwashita, K.; Moriya, T.; Tagawa, N.; Yoshizawa, M., "Doppler measurement using a pair of FM-chirp signals," Ultrasonics, 2003 IEEE Symposium on , vol.2, no., pp.1219,1222 Vol.2, 5-8 Oct. 2003

[8] I. G. Dimming, « A spatially selective approach to Doppler estimation for frame-based satellite SAR processing », IEEE Transactions on Geoscience and Remote Sensing, vol. 42, no 6, p. 1135-1148, 2004