

Towards a high-resolution ASCAT scatterometer wind product

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Abstract— In scatterometry, the wind vector retrieval problem is ambiguous, i.e., the inversion procedure does not result in a unique wind solution. To remove such ambiguity, a spatial filter is applied over the ambiguous wind field. Such filtering methods succeed in most of the cases. However, as the resolution increases both the noise and the direction ambiguity in retrieved winds increases, leading to arbitrary local minima wind solutions. Exploiting the full wind vector probability density function of the wind inversion, and adopting spatial meteorological balance constraints in a 2D-Var ambiguity removal (AR) alleviates the problem of arbitrary minima and noise, and provides a spatially consistent scatterometer wind field at high resolution. In other words, the method has the advanced filtering properties needed for maintaining small-scale meteorological information in scatterometers, while reducing noise. The method can be adopted in the context of 3D- or 4D-Var data assimilation systems. Moreover, these findings will be used to develop a high resolution (12.5-km sampled) coastal wind product from the new ASCAT scatterometer.

Keywords: scatterometer, wind inversion, ambiguity removal, high resolution, random error estimation.

I. INTRODUCTION

Scatterometer measurements contain relevant information on mesoscale phenomena and have proven important for the forecasting of dynamical weather systems, such as tropical cyclones. Current research is focused on the development of high resolution scatterometer wind products. A good assessment of the information content of scatterometer winds is particularly important in order to assimilate them in weather analysis.

Figure 1 shows the wind solutions derived from the scatterometer inversion (the ambiguity is most relevant in the wind direction domain). The purple curve's local minima represent wind solutions with (local) maximum probability of being the true wind. The standard procedure (SP) uses such minima as the “candidate” (ambiguous) solutions before ambiguity removal (AR). This is a valid procedure when the local minima are well defined. However, when the minima become broad, the standard procedure may not be appropriate since many wind solutions with comparable probability are not taken into account for AR.

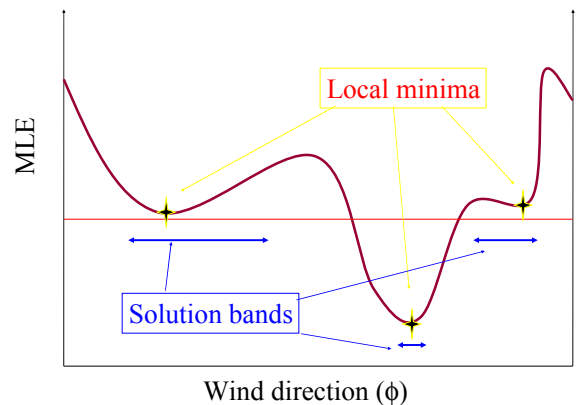


Figure 1. Schematic representation of the scatterometer inversion output in terms of solution probability.

Reference [1] shows that the poor azimuth diversity of the SeaWinds scatterometer beams in the nadir swath region produce broad minima in the cost function and proposes the multiple solution scheme (MSS), which, in contrast with SP, uses all wind solutions with significant probability as ambiguities. Both procedures use a variational analysis scheme, i.e., 2D-Var, for AR. Such scheme combines a background field (e.g., the National Centers for Environmental Prediction or NCEP winds) with the observations (ambiguous solutions), assuming that both sources contain errors and these are well characterized, to get an analysis field, which is spatially consistent and meteorologically balanced. The closest-to-analysis ambiguous solution is then selected. In 2D-Var, the solution probability is explicitly used, such that solutions with higher probability will have a greater chance of being selected.

The MSS+2D-Var has been successfully tested at 100 km resolution. It shows a more consistent wind field when using MSS, as compared to SP, especially at nadir. Moreover, by assigning more weight to the observation term, 2D-Var is successfully exploiting the observations rather than the background. As such, although the quality of the background is taken into account, it does not significantly affect the quality of the retrieval.

The SeaWinds DIRTH product distributed by the National Oceanographic and Atmospheric Administration (NOAA) uses the concept of multiple solutions together with a median filter AR [2]. In contrast with MSS+2D-Var, DIRTH does not use the solution probability information explicitly nor meteorological (but rather direction continuity) constraints. Reference [3] shows that, unlike MSS+2D-Var, DIRTH often depicts the wrong selected wind flow in cases such as the vicinity of cold fronts or rain.

In this paper, the ability of the different wind retrieval schemes (i.e., SP+2D-Var, MSS+2D-Var, and DIRTH) to reduce random noise, while keeping the geophysical information contained in the scatterometer measurements, is tested as resolution increases. The goal is to investigate the validity of the mentioned schemes for higher resolution systems, such as the new ASCAT scatterometer onboard the European MetOp satellite, which will provide winds at 12.5 km sampling.

II. RANDOM NOISE ESTIMATION

Figure 2 shows the autocorrelation (near the origin) for the zonal wind component, u , of the 25-km SeaWinds wind product. The curves are based on all available data from December 2004 and are averaged over all satellite across-track locations or wind vector cells (WVCs). The SeaWinds winds, either with SP or with MSS, show slightly less correlation than the NCEP model winds. This indicates that the SeaWinds winds have more variability at short distances.

The autocorrelations of the model wind and the SeaWinds wind obtained with MSS approach smoothly the value 1, at zero distance. The SeaWinds wind derived with SP, however, shows a clear discontinuity (note that the autocorrelation is given every 25 km and that the curves are drawn to guide the eye). Reference [4] shows that the discontinuity in the origin is a measure for the random noise in the scatterometer wind field, since the latter is completely uncorrelated except for zero

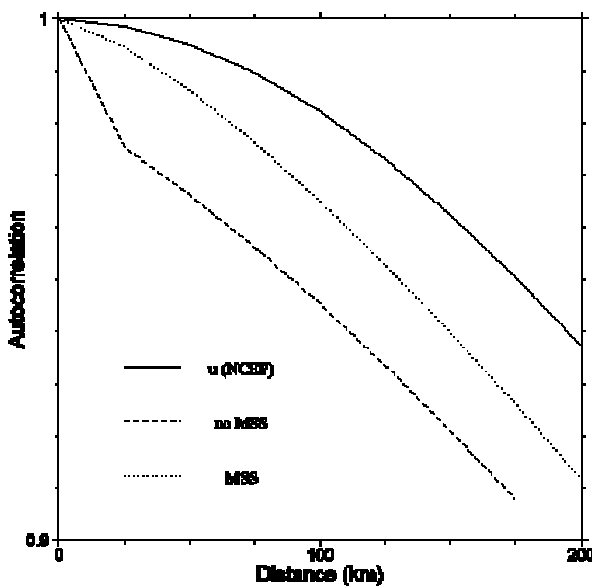


Figure 2. Autocorrelation (at short distances) of the zonal wind component u obtained from the NCEP model (solid curve) and from the SeaWinds measurements using SP+2D-Var (dashed) and MSS+2D-Var (dotted).

distance. It is shown that the height of the discontinuity in the autocorrelation, a , is directly proportional to the noise variance σ_n^2 . The constant of proportionality equals the total variance of the wind field, σ_s^2 . In terms of standard deviations the relation reads:

$$\sigma_n = \sigma_s \sqrt{a} \quad (1)$$

A. Noise for different retrieval schemes

By computing the total wind variance and the discontinuity of the autocorrelation (see Figure 2), the noise variance can be easily derived from (1). Figure 3 shows that noise variance of the SeaWinds 25-km resolution retrieved wind components (u and v) as a function of WVC number, for the three wind retrieval schemes: SP+2D-Var, DIRTH, and MSS+2D-Var.

The SP+2DVAR scheme generates high noise levels as shown by the black curves in Figure 3. The noise level is highest in the nadir part (centre) of the swath (up to $2 \text{ m}^2/\text{s}^2$ variance or 1.4 m/s standard deviation), where the poor azimuth diversity of the SeaWinds beams leads to larger errors in the wind retrieval process. The DIRTH scheme (red curves) performs quite well: it causes a small white noise component with a standard deviation of 0.47 m/s at most. Again, the noise level is highest in the nadir swath, although less pronounced as for the SP+2DVAR. [Note that the standard level 2 SeaWinds product also gives some results for the outer swaths (WVC 1-8 and 69-76). These WVC's are rejected by our processor]. Even though DIRTH performs quite well, it still contains some noise. Only application of the MSS+2DVAR scheme (green curves) removes the noise below its detection level.

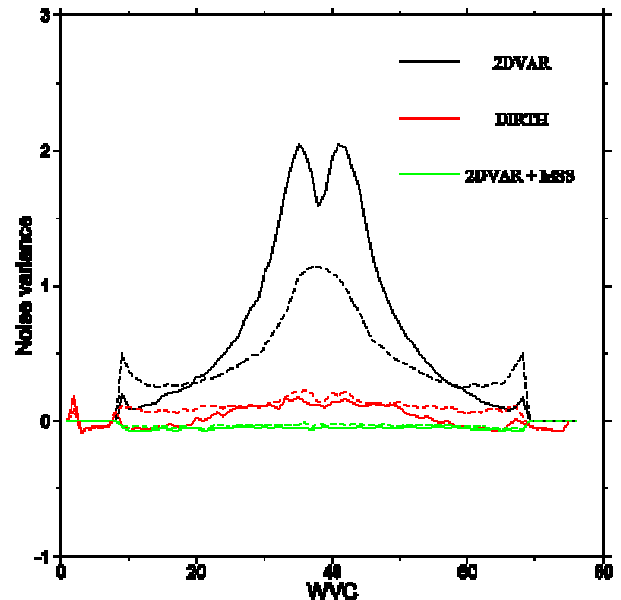


Figure 3. Variance of the noise against WVC number, for SeaWinds derived zonal (solid curves) and meridional (dashed curves) wind components, using SP+2DVAR (black curves), DIRTH (red curves), and MSS+2DVAR (green curves).

B. Effects of resolution

The effects of resolution in the random noise generation are tested for the SP+2D-Var scheme. Figure 4 shows the variance of the noise level in the scatterometer wind speed components u and v as a function of WVC number for various resolutions.

The noise level roughly decreases with a factor of two when the resolution cell doubles in size. It should be noted here that the systematic error may vary with resolution, because the separation between the support points for extrapolation of the autocorrelation at the origin increases with resolution. At 100 km resolution little noise is detected: estimation of the noise peak height with quadratic extrapolation yields a negative value in most cases. This indicates that the noise level at 100 km resolution is hardly statistically significant, except for extreme nadir viewing.

It is clear from this plot that high for resolution scatterometer systems, the level of noise in the retrieved wind fields is substantial when using SP. A method such as MSS+2D-Var is effective in reducing the noise and producing meteorologically balanced winds.

III. METEOROLOGICAL DETAIL AT 25 KM

It is important to check whether MSS+2D-Var is able to keep the meteorological detail at 25-km resolution while effectively removing the noise.

Figure 5 shows the wind variance versus spectral wave number for a climatological spectrum (k^{-2}), for the MSS+2D-Var SeaWinds 25-km SeaWinds wind product, and the for collocated ECMWF 10-m winds in log-log scale. It is clear from Figure 5 that SeaWinds winds contain substantially larger variability than ECMWF at smaller scales.

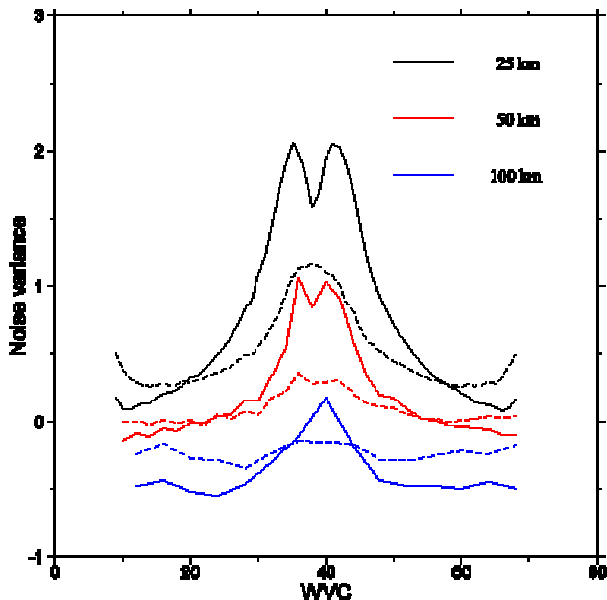


Figure 4. Variance of the noise for both wind speed components u (solid curves) and v (dashed curves) using SP+2D-Var at various resolutions.

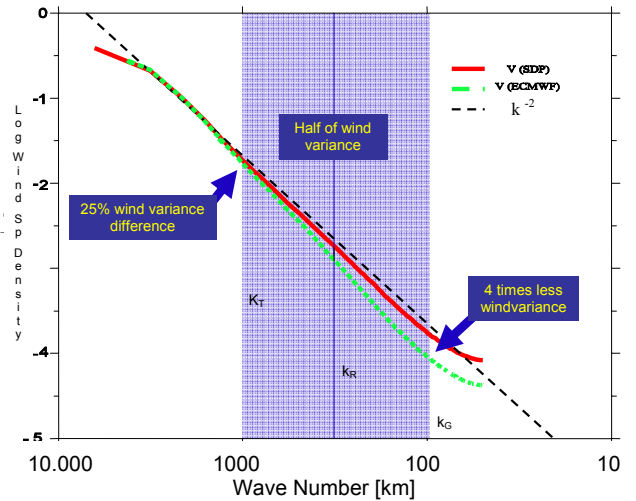


Figure 5. Wind variance versus spectral wave number for a climatological spectrum (k^{-2}), for the MSS+2D-Var SeaWinds 25-km wind product, and the for collocated ECMWF 10-m winds in log-log scale. With respect to the SeaWinds curve, the NWP spectral curve drops faster in variance over the blue shaded spectral range of corresponding wavelengths from 1000 km to 100 km.

The difference in wind variance at such scales between SeaWinds and the ECMWF NWP model illustrates the general deficiency of NWP models. Marked sharper features in the scatterometer winds often appear near islands and in the coastal region. The smaller scales in the scatterometer winds suggest that ocean eddies which are of typical 10-km size are forced much more effectively by a scatterometer wind field than by NWP fields. High resolution scatterometer winds derived with MSS+2D-Var could therefore be very useful as input (instead of the smooth NWP analysis winds) for applications such as storm surge and wave prediction, marine warnings, ocean forcing, etc.

The improvements in MSS+2D-Var are mainly due to the reduction of occasional erratic noise; while coherent mesoscale structures remain present and become more visible due to the noise reduction. Figure 6 shows a MSS+2D-Var SeaWinds wind field at 100-km (top) and 25-km (bottom) resolution. It is clear that important mesoscale details, potentially useful for marine and weather nowcasting and forecasting, are added at 25 km.

IV. OUTLOOK

With the launch of ASCAT the series of C-band scatterometers is continued with currently useful coverage of the ocean surface wind and ice. The European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT) already started providing timely user services in collaboration with the Royal Netherlands Meteorological Institute (KNMI), while these are now being further set up and freely available at <http://ww.knmi.nl/scatterometer> for the SeaWinds, ERS-2 and ASCAT scatterometers. Research and development at KNMI

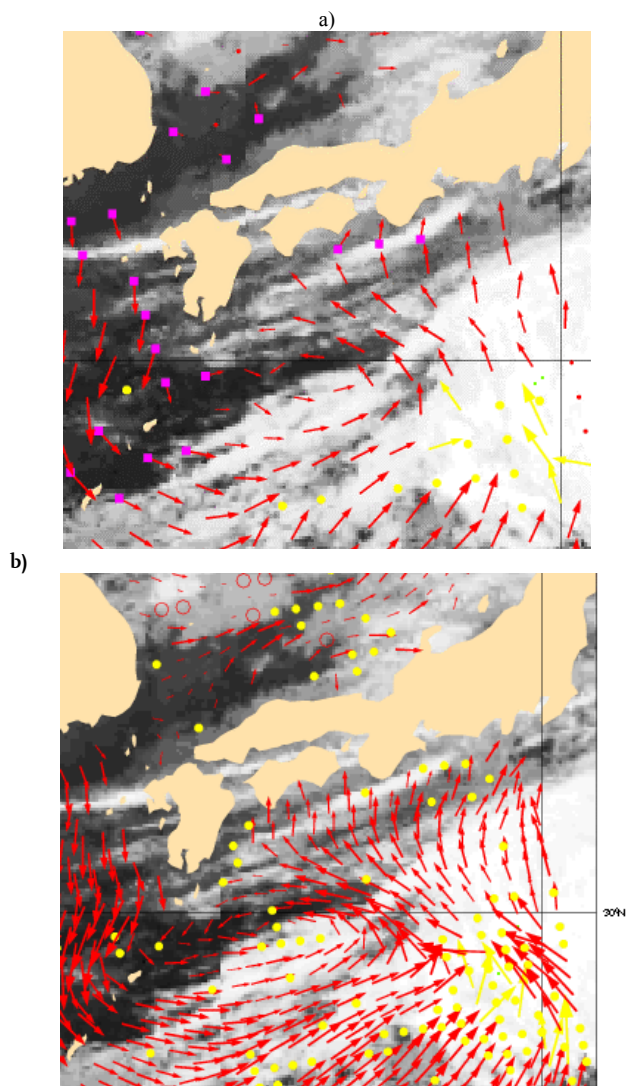


Figure 6. MSS+2D-Var SeaWinds wind field at 100-km (top) and 25-km (bottom) resolution, acquired on 26 April 2006 around 20UTC near the coast of Japan. Yellow dots denote WVC quality control, while yellow arrows indicate failure in the 2D-VAR spatial consistency check. GMS infra-red cloud imagery is provided underneath for reference.

will continue within the EUMETSAT Satellite Application Facilities, SAFs, to enhance the wind processor capability towards a 12.5-km sampled product, nearer to the coast, and with improved geophysical interpretation.

Timely, highly accurate, spatially consistent and broad swath scatterometer winds provide mesoscale structures over water surfaces. Since the transient atmospheric mesoscale structures are relatively short-lived, sampling twice a day from one polar satellite is rather limited. Although concrete plans exist in China and India to launch a scatterometer, no guarantee yet exists for improved temporal sampling on the longer term after SeaWinds has ceased. Reinforced international collaboration between space agencies is needed to build an effective ocean surface wind mission.

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