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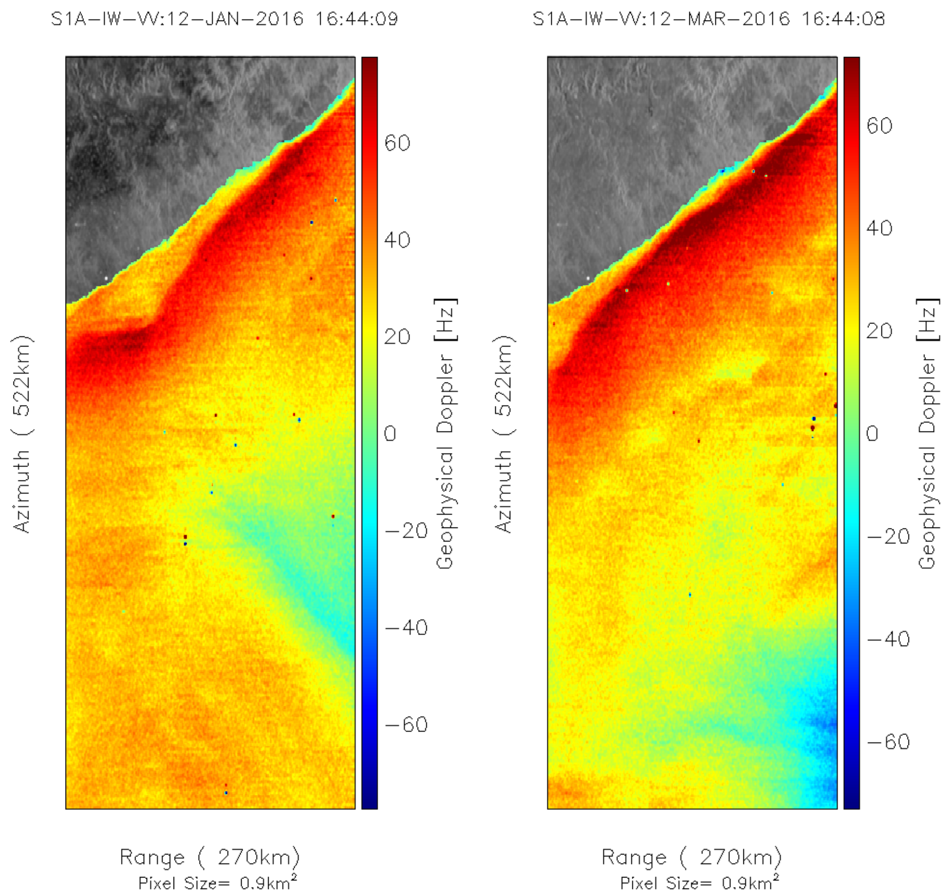
Harmony Phase 0/A

Requirement Analysis

Harald Johnsen



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Resymé / Summary:

This technical note provides some general considerations on the geophysical requirements of the Harmony L2 Ocean products and their implications to the mission requirements. Section 2 gives an overview of the geophysical requirements of the L2 ocean products. In Section 3 we outline the key system parameters and their requirements as experienced from Sentinel-1. In Section 4 specific requirements for the L2 Ocean products are tabulated for each ocean products.

Front page: Sentinel 1A IW Doppler anomaly images acquired over Agulhas current.

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1. Introduction

This technical note provides some first general considerations on the geophysical requirements of the Harmony L2 Ocean products and their implications to the mission requirements. Section 2 gives an overview of the geophysical requirements of the L2 ocean products. In Section 3 we outline the key system parameters and their requirements as experienced from Sentinel-1. In Section 4 specific requirements for the L2 Ocean products are tabulated for each ocean products.

Below is the definition of the key Harmony L2 Ocean products as defined in [10] and considered here:

- USV –ocean surface velocity vector (along and across-track components) derived from either Doppler Centroid Anomaly (DCA) frequency or ATI phase of the Harmony. It contains the mean geophysical motion of the ocean surface scatterer within the resolution cell, including the “Wave Bias” term.
- SCV – total ocean surface current velocity vector (along and across-track components) derived from the USV measurements after removing the “Wave Bias” term. It contains the total mean geophysical surface current drift of the scatterer within the resolution cell.
- SWV – ocean surface wind vector (speed and direction) derived from Harmony three LOS measurements of NRCS and image cross-spectra parameters (or use of ancillary wind direction)
- OSW – 2D ocean wave spectra derived from Harmony measurements of three LOS wave image cross-spectra.

The requirements expressed in [10] are given by accuracy and precision. With accuracy is meant offset (Bias) + random error (RMSe), and with precision is meant the random error (RMSe).

2. Geophysical Requirements

2.1. SWV: Ocean Surface Wind Vector

The horizontal resolution of SWV is driven by the resolution of the SLC image and the methodology used to derive the ocean wind vector (either short ATI or DCA Long Baseline Stereo (LBS) Mode). The SWV retrieval requires either DCA LBS or a combination between short-ATI and DCA (three LOS) measurements.

Recent studies (SATROSS) show that the use of the signed Integrated Cross-Spectra Value (ISV) [1] from S-1 and the companions together with the corresponding NRCS solves out the wind direction and wind speed better than previous approaches, and without use of any ancillary wind direction. However, this put some requirements on the companion Ocean Wave Spectra (OWS) (or more precisely on the corresponding inter-look image cross-spectra) as discussed in Section 2.3.

The main **system contributors** to the accuracy of SWV are the NESZ (especially at high incidence angles), the accuracy of NRCS, and the along track baseline. The performance will be a trade off between observation geometry (incidence angle, azimuth angle, baseline) and SNR of NRCS and Image Cross Spectra.

The main **geophysical contributors** to the accuracy of SWV are the geophysical forward models of the mono- and bistatic NRCS and image cross-spectra parameters.

The Surface Wind Vector (SWV) is used in the SCV retrieval as input to the “DC Wave Bias” forward model. This put very strong requirements on the accuracy of the wind speed and direction as discussed in Section 2.2. **However, the geophysical variability of the SWV is expected in general to be larger than of the surface current field. The ocean, as a turbulent medium, is 10 times smaller and 25 times slower than the atmosphere. Typically, a 100 km ocean mesoscale feature will have a time-correlation of 10 days, and translates to an atmosphere analogue of 1000 km lasting about 10 hours. The horizontal resolution of the SWV can thus be relaxed as compared to the required horizontal resolution of the retrieved USV/SCV. For instance, for a targeted horizontal resolution requirement of the USV/SCV of 1 km, we can relax the corresponding SWV requirement up to 10km. This will also be more consistent with using SAR cross-spectra (or ancillary model wind) as input to the wind retrieval.** Low-resolution winds will also help achieve the required precision of the SWV estimate as discussed below. These requirements on spatial resolutions are easily achievable since SWV is derived from the triplets of NRCS and cross-spectra parameters. The requirement for HARMONY SWV resolution should consider this.

To meet the HARMONY requirements for winds up to 50 m/s use of cross-pol channels are likely required for the companion, in particular for the WV mode since the S-1 WV do not operate in dual-pol receive. The Harmony should target the S1 WV and S1 IW (dual-pol) modes. Note that at high winds the bistatic cross-pol signal contains both a geometric term arising from rotation of the polarization basis, and a geophysical term arising from the scattering process. At low wind only the geometric term is expected to be above the NESZ of the companions.

2.2. SCV: Total Ocean Surface Current Vector

The horizontal resolution of SCV is driven by the resolution of the SLC image and the methodology used to derive the ocean surface radial velocity (either short ATI or DCA Long Baseline Stereo (LBS) Mode). The short-ATI mode can provide significant improved horizontal resolution (or better precision at same resolution) as compared to DCA Stereo Mode for the radial velocity component. The SCV retrieval requires either DCA LBS or a combination between short-ATI and DCA (three LOS) measurements.

Experiences with S-1, show that the DCA approach applied on the IW mode can provide SCV component with a horizontal resolution of around 4 km^2 and a precision (RMSe) of 0.25 m/s [4]. With careful calibration of the DC, the offset (bias) can be reduced to < 0.1 m/s. This is slightly above the requirements for Harmony (accuracy < 0.25 m/s). For WV mode, after calibration, we achieve an accuracy of the same order over ocean [7]. In terms of precision of DC in Hz, this corresponds to around 4Hz at 23^o incidence angle and around 5Hz at 36^o. Over land areas, the DC has a precision of around 3.7Hz in WV1 and 3.9Hz in WV2 after calibration. The SCV retrieval requires wind vector, which can be retrieved by using triplets of NRCS in combination with cross-spectra (low resolution) or ancillary model data (low resolution). In both cases the resolution is coarse (factor 10) compared to the final SCV spatial resolution. However, this can be justified as already discussed.

The main **system contributors** to the precision (RMSe) observed in S-1 radial surface current component are the lack of precise knowledge of attitude and antenna electronic mispointing. The NESZ is also important, especially at high incidence angles. These effects are discussed later. The performance of the SCV across- and along-track components will also be a trade off between observation geometry (incidence angle, azimuth angle, baseline) and SNR of the DCA.

The main **geophysical contributor** to the RMSe is the “DC Wave Bias” used to convert the Radial Surface Velocity (USV) into SCV. The HARMONY requirements on USV should therefor follow those of SCV. Simulations of “DC Wave Bias” errors show that the RMSe required for the SWV speed is <1.3 m/s, and for the SWV direction < 10 degrees to meet the HARMONY requirements for SCV precision. The RMSe of the wind field derived from S1 EW, IW and WV modes are respectively around 1.3, 1.4 to 1.6 m/s at a horizontal resolution of 1km [3]. Relaxing the spatial resolution of the wind field to 10km will improve the accuracy, since the random geophysical variability will be reduced. It should be mention that the usual model used for “DC Wave Bias” removal (CDOP) are only driven by wind vector and incidence angle, and are established by use of Scatterometer wind field and SAR observations. Ideally, the “DC Wave Bias” is driven by a moment of the underlying 2D Wave Spectra. We also note from the simulation that error in the “DC Wave Bias” is less sensitive for VV polarization and for incidence angles between 30 - 40 degrees.

Relative SCV and SWV

If we relax the requirements on absolute accuracy, the Harmony mission can provide **high-resolution relative SCV and SWV fields** with high precision. This is because some of system error contributions such as **attitude** and **antenna** are zero or at least significantly reduced when considering relative values. If we consider S-1, after careful calibration of the DC, we see that the DC RMSe over land is around 3.5Hz while over ocean it is around 4.5Hz. The larger RMSe over ocean comes from random geophysical errors (for instance errors introduced by using CDOP to remove “DC Wave Bias”). Over ocean the random geophysical errors will also be reduced. If we assume that the remaining DC RMSe of ≈3.5Hz that we achieved for S1 WV over land is due to imperfect attitude DC compensation, we are left with a relative RMSe over ocean of ≈ 1 Hz.

Such high-resolution products are valuable for studying sub-mesoscale gradients in surface wind and current fields, and of interest for comparison with the optical instrument image. The S-1 WV mode is suitable for providing such products on global scale, as exemplified in the next figure.

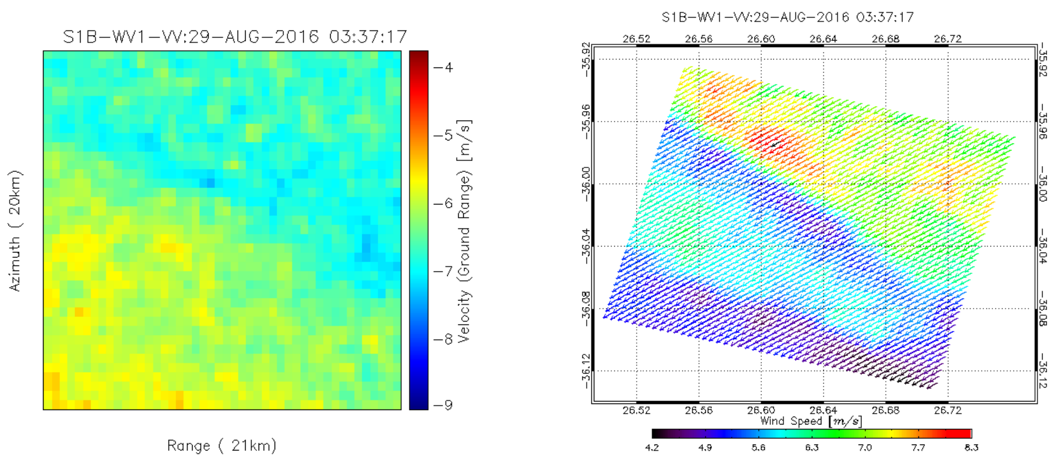

Fig. 1. High-resolution (≈2km2) level 2 radial velocity grid processed from S1a WV mode, showing the relative variability of the radial velocity and the ocean wind field over the vignette of 20x20km2.

2.3. OWS: Ocean Wave Spectra

The OWS product of S-1 is derived from the Image Cross-Spectra as part of the Level 2 processing, and both are contained in the Level 2 OCN product. This could also be foreseen for the Harmony companions. Regarding the OWS product, the main requirement is the SLC **range bandwidth**, **ground resolution**, **phase properties** and **SNR**. The OSW spectral resolution is driven by the SLC resolution. It has been demonstrated using S-1 WV mode (high bandwidth mode), that the range spectral energy of the high-frequency part of the image cross-spectra is a proxy for signed range wind speed [1], [8] i.e. very similar to the "DC Wave Bias" part of the Doppler Centroid Anomaly. Although the standard horizontal resolution for the S1 WV OSW product is 20x20km^2, a resolution down to 10x10km^2 is feasible and should be considered as a requirement for HARMONY Level 2 product. It will then also better align with the required SWV resolution, noting that use of the cross-spectra ISV parameter is foreseen in the SWV/SCV retrieval. **This requires that the companion SLC vignette and resolution are similar to S1 WV, in order to preserve the same spectral** uncertainty.

Reducing the OWS resolution from 20x20km^2 to 10x10km^2 km will increase the spectral uncertainty (less periodogram to average), but decrease the geophysical uncertainty (more homogenous area). We believe that the dominant wavelength, dominant wave direction and effective significant waveheight can be extracted from the OSW spectra within the required precision and accuracy [3], even at 10x10km^2.

However, note that these values are only valid within the 2D cut-off domain defined by the range spectral resolution and the azimuth cut-off. However, the observation diversity of the HARMONY can help achieve the requirement on the ranges of OWS dominant wavelength (30-1000m) and direction (0-360^o). Regarding the total significant waveheight, an independent empirical based algorithm is required [2] to meet the HARMONY requirement on total Hs. This total Hs algorithm will be part of the Sentinel-1 Level 2 OSW processor in near future.

In the MATER document [10] there is neither definitions nor requirements on the image cross-spectra (only on the OSW product). It should be considered as a Level1 product similar to Level1-USV, with specifications and requirements.

The OWS can also be derived from IW mode to same spatial resolution as for WV. However, the algorithm needs to combine the burst overlap areas in azimuth with the single look area to resolve a unique wave propagation direction. This algorithm has yet to be developed.

3. System Requirements

It has turned out from the S-1 Doppler analysis, that several system parameters are not known to the accuracy required for ocean current retrieval. Those are discussed in this section. As a consequence, additional data driven calibration is required for S-1.

3.1. Total zero-Doppler steering and DC oscillation

The total zero-Doppler steering of S-1 causes fast (i.e. periods below orbital scale) oscillations (with amplitude > 10Hz) in the geometric DC around the orbit. These oscillations are not picked up properly by the quaternions provided in the raw data downlink. However, the telemetry Gyro data (properly calibrated) has shown the capability to predict the observed fast oscillation in attitude DC [6]. Still some remaining variation on sub-orbit scale needs to removed using the SAR observation it self. **This should be taken into account for the companions as well**.

3.2. Electronic mispointing and DC variations

Antenna electronic mispointing introduces a bias in the estimated DC that varies over the swath. These DC biases also vary slowly with time (i.e. periods larger or equal to orbital scale). The antenna model is not able to predict precisely enough (<5Hz variation) the observed electronic mispointing DC over swaths and with slow time. This has been verified by using S-1 data acquired over rain forest data. As a consequence, systematic observation and generation of mean DC profiles from rainforest is proposed as a solution [5]. The requirement is that the antenna characteristics are stable over a few days, so that a noise free DC bias estimate can be achieved by averaging over several days. **This should be taken into account for the companions as well**.

3.3. T/R temperature compensation and DC anomaly

Temperature compensation of the S1 T/R modules during data take has shown to create anomaly in the L2 OCN RVL product. The anomaly is manifested as jumps (up to 10Hz) in the DC from one burst to another, persistent over all TOPS swaths. At the moment there is no solution to this problem. Knowledge (logging) of when the temperature compensation is triggered will help any post-processing removal of the jumps.

3.4. Base-band aliasing and DC error

A critical requirement on the antenna is related to the PRF and azimuth antenna pattern (base band). The PRF is fixed by the S-1 transmitter. The Level 2 DC must be very precise estimated and effects of aliasing from base band needs to be accounted for. This is part of the Level 2 processing. However, the closer the PRF is into the main lobe of the antenna, the stronger is the impact of base band aliasing on the DC and the more difficult is the de-aliasing process. Therefore, ideally the antenna should be designed such that the effective T/R antenna of the companions is not worse than that of S-1 relative to the PRF. However, since the bistatic antenna is much shorter than the Sentinel-1 antenna, the bistatic DC will mostly feel the Sentinel-1 antenna. So this requirement will be given by Sentinel-1.

3.5. Requirements on NESZ

The HARMONY companions offer the opportunity to use bistatic cross-polarized measurements. The bistatic cross-pol signal contains both a geometric term arising from rotation of the polarization basis, and a geophysical term arising from the scattering process (usually small over ocean for moderate winds). Due to the bistatic geometry, the cross-polarized return will be significant and must be considered in order to reconstruct the total backscattered energy (also geometry dependent). Any geophysical polarization diversity in the Doppler measurements [9] can help the retrieval and separation of various contributions to Doppler anomaly (DC Wave Bias). However, this contribution is expected to be very small.

3.6. Oscillator Errors

Oscillator errors are of concern in a bistatic radar system. The use of the DCA approach implies that uncorrected frequency offsets between the reference oscillators at the transmitter and at the receiver will be mistaken as a Doppler term. Any uncorrected deviations in the reference oscillator frequency with respect to the assumed will be interpreted as a Doppler frequency in a bi-static configuration.

3.7. Cross-Talk Errors

The current system requirements impose a very low cross-talk level, which assumes that the cross-polar return is very low. This needs to be verified in the bistatic concept. Moreover, a bistatic geometry tends to rotate the natural polarization basis, so that these very low cross-talk levels would need to be met after a corresponding transformation.

3.8. Ambiguities

The distributed total ambiguity ratio (TAR) may particularly impact the accuracy of the DC estimate. The impact is likely to be observed in coastal areas with strong gradients in backscattered intensity. The azimuth ambiguity arises from targets located ≈ 5km apart in azimuth (S1). In principle the DC estimation can account for this by modeling the impact of antenna side-band using intensity from neighboring areas.

3.9. Baseline and Observation Geometry:

In LBS mode the Harmony uses a relatively long baseline of approximately 250 km with respect to Sentinel-1. The rationale is to achieve a 45 deg ground-projected azimuth angle on receive, following the preferred geometry for Wind Scatterometer and for other monostatic TSCV mission ("WaveMill"). This translates to a monostatic equivalent angle of approximately half of it. In that sense, the 45 deg seem a rather arbitrary number, which should be traded off against, for example, the loss of sensitivity due to the increased range and increased bistatic angle of incidence. In ATI Mode the trade-off between decorrelation and InSAR phase SNR needs to be assessed. The baseline and observation geometry impact in general the precision of the measurements.

4. Specific L2 Ocean Product Requirements

4.1. USV: Ocean Surface Velocity Vector

Requirement	
USV-020 USV-021	The Mission shall observe USV globally with a horizontal resolution better than 4 km^2. The Mission shall observe USV in areas of interest and coastal areas with a horizontal resolution better than 1 km^2.
Understanding and Assumptions	
The horizontal resolution of USV is driven by the resolution of the SLC image and the methodology used to estimate the ocean surface radial velocity (either short ATI or DCA LBS Mode). The short-ATI mode can provide significant improved horizontal resolution as compared to DCA LBS Mode for the radial velocity component. The USV product resolution and the input SLC resolution are related through ENL parameter. The number of independent looks at a given resolution cell that are averaged has an impact on the standard deviation of SAR measurable such as ATI phase or accuracy of DCA estimated Doppler shift, which turns directly into a certain accuracy in derived ocean surface LOS velocity. Anyhow, the requirements on USV spatial resolution must be equal or preferably better than for SCV, since we must assume some error introduced in predicting and removing the "DC Wave Bias". The performance will be analysed for the sizing scenarios provided in GAA-020	
Design Implications and Considerations	
See USV-040	

Reformulation (if needed)
Error sources (impacting performance requirements)
Since the USV is derived directly from calibrated DC measurements (no retrieval algorithm), the random error introduced from geophysical model function and inversion can be neglected. The main error sources that impact the resolution requirements come from system parameters (see USV-040). Example of such USV product is shown in Fig. 2.

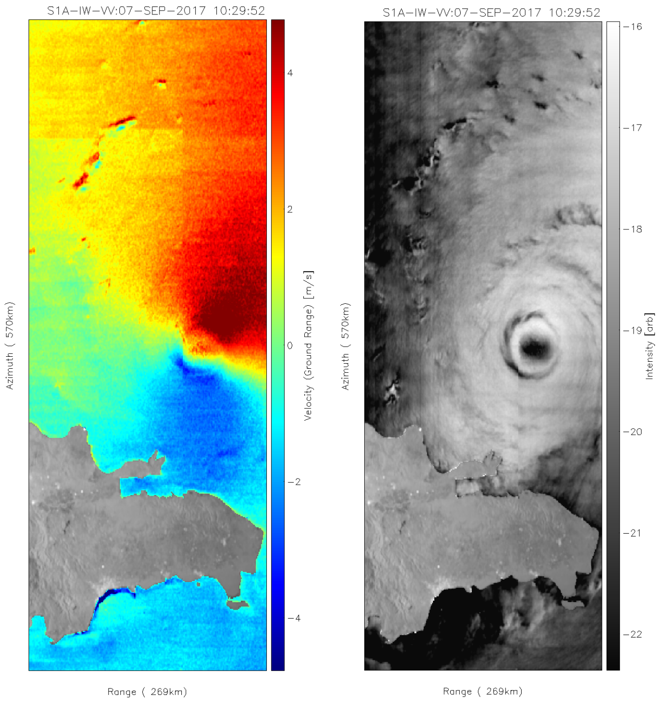

Fig. 2. Left: Costal ocean surface radial velocity of a tropical hurricane observed by S1A IW. The main velocity observed comes from the so-called "DC Wave Bias". Right: Corresponding intensity image. Resolution ≈3km^2. The radial velocity is computed directly from calibrated DCA . The geometric DC and electronic mispointing DC bias are here removed from the DC using the land areas, before computing the USV component.

Requirement	
USV-030 USV-040, USV-050	The Mission shall observe USV with a precision of <7 cm/s for both the along-track and across-track components over the range of 10 to 500 cm/s. The requirement on the accuracy is set to <20 cm/s.
Understanding and Assumptions	
Precision of the USV will be considered as the random term of the USV estimation error, which will be driven by random error terms on the non-geophysical Doppler contribution (instrument nature errors and geometry errors contribution due to fast attitude or velocity variations around the orbit). The accuracy of the USV will be considered as the sum of the bias and RMSe terms of the USV estimation error, which will be driven by errors of the non-geophysical Doppler contribution (instrument nature errors). The requirement on the accuracy imposes requirements on system	

parameters that depend on incidence angle.

Since the requirements are specified for the along and across-track components, the corresponding number for the surface velocity will depend on the direction of the velocity, with upper limit at 45 deg and lower limit at along or across track directions. The same applies for the direction.

Design Implications and Considerations

The main instrument parameter challenging the precision and accuracy of Doppler estimation (or indirectly the Radial Velocity) is the SNR, in turn driven by the limited NESZ and TAR achieved by a compact companion SAR instrument.

In addition, this requirement imposes to the system design:

- Bistatic phase error need to be minimised (USO phase noise)
- Residual frequency drift between Master and slave need to be minimised
- Stable Antenna pointing (reduce thermo-elastic and electronic high frequency pointing error)
- Antenna electronic mispointing
- Baseline and observation diversity

Reformulation (if needed)

1) The requirement on the dynamic range of USV must be much larger than that of the SCV. It scales with the range wind speed.
2) We see from figure below (Fig. 3) that to achieve a precision < 7 cm, we need to relax the requirement on spatial resolution in coastal areas from $1x1km^2$ to $3x3km^2$ for the IW mode.

Error sources (impacting performance requirements)

- SNR (see Fig. 3), DTAR and Quantization noise
- Bistatic phase/frequency error (phase noise and frequency drift)
- Bistatic geometry stability (velocities uncertainties, baseline uncertainties)
- Bistatic decorrelation due to ATI baseline (see Fig. 4)

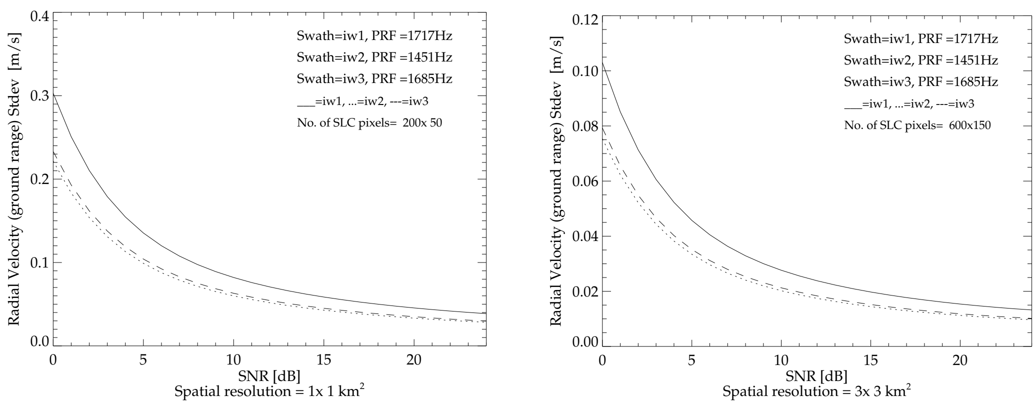

Fig. 3. Predicted Radial Velocity (ground range) standard deviation as function of SNR for S1 IW configuration processed to $1x1km^2$ (left) and $3x3km^2$ (right) resolutions.

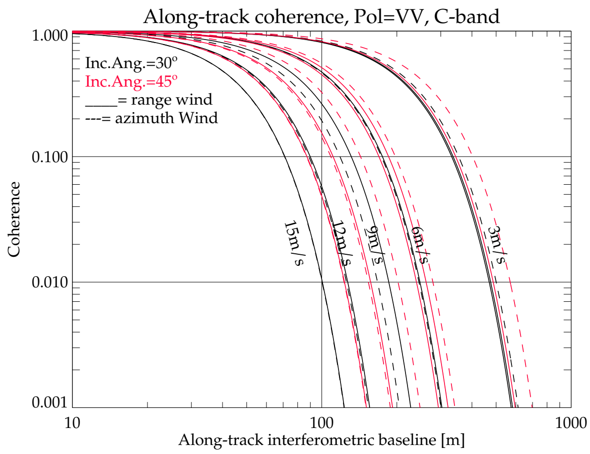

Fig. 4. ATI coherence as function of along track baseline for two different incidence angles and wind speeds.

4.2. SWV: Ocean Surface Wind Vector

Requirement	
SWV-020	The Mission shall observe SWV with a horizontal resolution of 12.5 km^2
Understanding and Assumptions	
The horizontal resolution of SWV is driven by the resolution of the SLC image and the methodology used to estimate the ocean surface wind vector. The SWV product resolution and the input SLC resolution are related through ENL parameter. The number of independent looks at a given resolution cell that are averaged has an impact on the precision of SAR measurable such as the NRCS and ISV, which turns directly into the precision in the derived ocean surface wind field. The performance will be analysed for the sizing scenarios provided in GAA-020	
Design Implications and Considerations	
See SWV-030	
Reformulation (if needed)	
The requirement on horizontal resolution can be reduced to 10 km^2.	

Error sources (impacting performance requirements)

The SWV relies on the use of triplets of NRCS and signed cross-spectra energy of short waves (ISV)[1],[8] extracted from S-1 and the companions in LBS mode. Low SNR and inter-look phase errors will decrease the precision of the ISV parameter, which again may require reducing the spatial resolution. Exemplified below (Fig. 5) is the retrieved wind direction using simulated LBS triplets of NRCS and ISV for S1 WV1 and WV2 geometry and SNR. A clear decrease in performance is observed for WV2 versus WV1, especially at low winds. This is due to the lower SNR at WV2. Recently, new EAP has been successfully tested on S1a,b WV2 to improve the SNR. This will help improve the WV2 performances.

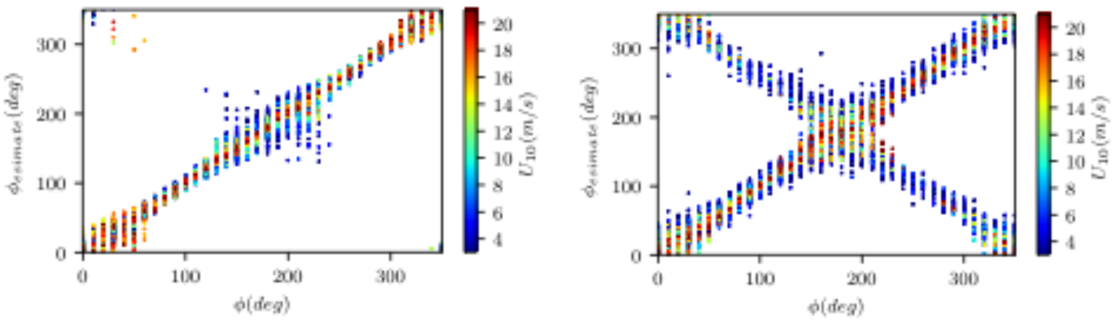

Fig. 5. Estimated ocean surface wind direction versus "observed", based on simulated triplets of NRCS and ISV in LBS mode and for S1 WV1 (left) and WV2 (right) geometry and SNR. Resolution is size of vignettes ($20x20km^2$) and along track baseline is ±250km.

Requirement

SWV-030 SWV-050->052	The Mission shall observe SWV with an accuracy of <1.5 m/s for wind speeds up to 20 m/s, and <7.7% for wind speeds between 20 – 50 m/s. The requirement on the wind direction precision is set to < 20 degree. The range of observations shall be 3-50 m/s for wind speed and 0-360^o for the wind direction.

Understanding and Assumptions

Precision of the SWV will be considered as the random term of the SWV retrieval. This will be a combination of estimation error (instrument noise) in the SAR parameters (NRCS, Image Cross Spectra, DC) plus random geophysical error of the forward/inverse models used in the retrieval of SWV. The accuracy of the SWV will be considered as the sum of the bias and RMSe of the estimation and the forward/retrieval algorithm.

The performance will be analysed for the sizing scenarios provided in GAA-020

Design Implications and Considerations

The phase properties of the inter-look Cross Spectra will be used in the SWV retrieval. This imposes requirements on the inter-look phase extracted from the L1- SLC product. Any non-geophysical inter-look phase term must be minimised to be significant lower than the expected phase shift introduced by the wind sea wave dispersion.
The SWV-030 requirement of wind speeds up to 50 m/s will likely require the use of the cross-pol return of the companions. This will impose that the cross-talk and NESZ must be minimised.
The requirement on the accuracy of SWV direction (<20 deg) imposes requirement on the along-track baseline and imaging geometry of S1+CS. It will be a trade off between NRCS and Cross-Spectra SNRs of the bistatic companions and the observation diversity spanned out by the effective bistatic scattering azimuth angles.

Reformulation (if needed)

The accuracy of SWV must reflect the accuracy in which the “Wave DC bias” needs to be predicted with.

The goal of SWV speed accuracy should be < 1.3 m/s, and direction < 10 deg in order to achieve required precision of “Wave DC bias” removal from DCA. See Fig. 8. For low incidence angles, even stronger requirement is needed.

Error sources (impacting performance requirements)

From the system, the main error sources are phase errors in cross-spectra, bias in NRCS and instrument NESZ level. The performance will be a trade off between observation geometry (incidence angle, azimuth angle, baseline) and SNR. This is shown in Fig. 6. We see that at high incidence angels and low wind speed, the NRCS will likely be below the companion NESZ.
The main geophysical error is the random geophysical error between the forward model and the corresponding observed values (NRCS, Image Cross Spectra, DC, etc.). This randomness is due to natural variations of the air/sea conditions (turbulence) around the mean (in which the forward models are based on). The geophysical error is very much driven by the required spatial resolution. By lowering the spatial resolution, we will reduce the random geophysical error.

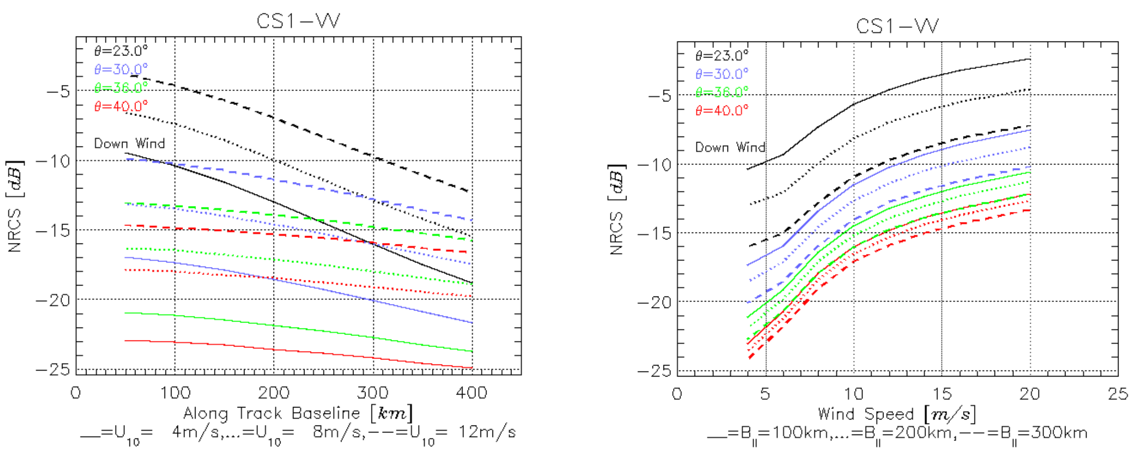

Fig. 6. Left: Predicted NRCS of companion as function of along track baseline for different incidence angles of S1 and wind speeds. Right: Predicted NRCS of companion as function of wind speed for different along track baseline and different incidence angles of S1. Wind direction is down wind.

4.3. SCV: Total Ocean Surface Current Vector

Requirement	
SCV-020	The Mission shall observe SCV globally with a horizontal resolution better than 4 km^2.
SCV-021	The Mission shall observe SCV in areas of interest and coastal areas with a horizontal resolution better than 1 km^2.

Understanding and Assumptions

The horizontal resolution of SCV is driven by the resolution of the SLC image and the methodology used to derive the ocean surface radial velocity (either short ATI or DCA Stereo Mode). The short-ATI mode can provide significant improved horizontal resolution (or better precision at same resolution) as compared to DCA Stereo Mode for the radial velocity component.

The SCV product resolution and the input SLC resolution are related through ENL parameter. The number of independent looks at a given resolution cell that are averaged has an impact on the standard deviation of SAR measurable such as ATI phase or accuracy of DCA estimated Doppler shift, which turns into a certain accuracy in derived current LOS velocity.

Experiences with Sentinel-1 show that the DCA approach applied on the IW mode can provide SCV component with a horizontal resolution of around 3-4 km^2 and an RMSe of 0.25 m/s (see figure below). With careful calibration of the DC (using land areas), the bias can be reduced to < 0.1 m/s (i.e. an accuracy of <0.35 m/s). In WV mode, the horizontal resolution can be reduced to <2 km^2 and still keep the same accuracy and precision on SCV.

The requirement of better than 1km^2 resolution in coastal areas and RMSe of <0.1 m/s will require land calibration of DC. This is feasible with acquisitions in IW mode, where both land and ocean are observed in the same scene. The WV mode is usually not operated near coast.

The performance will be analysed for the sizing scenarios provided in GAA-020

Design Implications and Considerations

See USV-040, SWV-030

Reformulation (if needed)

The most stringent requirement (Resolution≈1x1km^2 and RMSe<0.1 m/s) is most likely only achieved for relative values of SCV.

One alternative is to to relax the requirement on spatial resolution in coastal areas from 1x1km^2 to 3x3km^2 for the IW mode (see Fig. 3)

Error sources (impacting performance requirements)

For system error sources, see USV-040, and SCV-030.
If we relax the requirements on absolute accuracy, the Harmony mission can provide high-resolution relative SCV and SWV fields with high precision (see Fig. 1). This is because some of system error contributions such as attitude and antenna are zero or at least significantly reduced when considering relative values. As a consequence, higher spatial resolution can be achieved while still retaining the same precision.

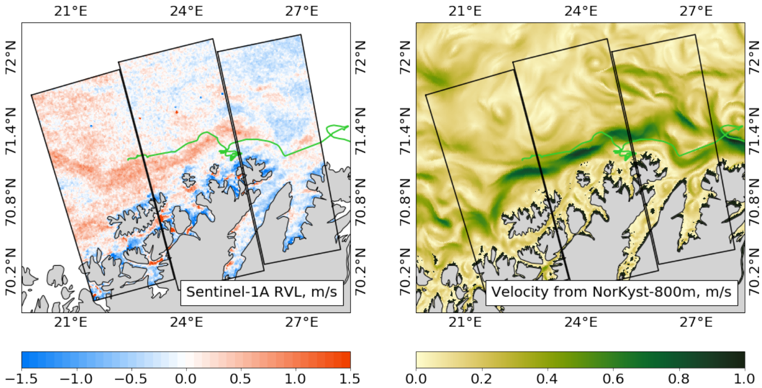

Fig. 7. Left: Costal ocean surface current radial velocity [m/s] derived from S-1 IW Doppler Centroid Anomaly at $3km^2$ resolution. The green line is surface drifter trajectory. Right: NORKYST model output at $1km^2$ resolution.

Requirement	
SCV-030 SCV-040,050	The Mission shall observe SCV with a precision of <10 cm/s for both the along-track and across-track components, within the range of 10 – 500 cm/s. The requirement on the accuracy is set to <25 cm/s
Understanding and Assumptions	
Precision of the SCV will be considered as the random term of the USV error (see Requirement USV-040) plus random geophysical error of the forward/inverse models used in the retrieval of SCV from USV. The accuracy (bias + RMSe) of the SCV will be considered as the sum of the USV estimation accuracy and the accuracy of the forward/retrieval algorithm. Both observation geometry and system noise will impact the accuracy of the SCV. Since the requirements are specified for the along and across-track components, the corresponding number for the SCV velocity will depend on the direction of the current, with upper limit at 45 deg and lower limit at along or across track directions. The same applies for the direction.	
Design Implications and Considerations	
See USV-040 The requirement on SCV along and across-track components imposes requirement on the along-track baseline of the ATI/LBS mode. It will be a trade off between DCA SNR of the bistatic companions and the observation diversity spanned out by the effective bistatic scattering azimuth angles.	

Reformulation (if needed)
1) The requirement on the accuracy is a very strong. The achieved accuracy (bias+RMSe) of S-1 radial ground range current component is of the order of <0.35 m/s. However, for relative SCV accuracy this number can be achieved even for 1x1km^2 resolution. 2) We should consider to provide the requirements on the velocity and direction, instead on the along and across-track components. This is more understandable for users.

Error sources (impacting performance requirements)

See USV-040, SWV-030 for system error sources.
The main geophysical error is the random geophysical error between the forward model and the corresponding observed values (DC, NRCS, etc.). The total geophysical uncertainty is a combination of errors in the wind field (SWV - used as input to the DC Wave Bias forward model, see figure below) and the natural variations of the air/sea conditions (turbulence) around the mean (in which the forward models are based on). The total geophysical error is very much driven by the required spatial resolution. The geophysical variability of the SWV is expected in general to be larger than of the surface current field. The ocean, as a turbulent medium, is 10 times smaller and 25 times slower than the atmosphere. For a targeted horizontal resolution of the USV/SCV at best of 1.2 km, we can thus relax the corresponding SWV to 12 km.

The requirement on the accuracy of SCV components imposes requirement on the along-track baseline of ATI/LBS mode. As for the SWV, it will be a trade off between SNR of the bistatic companions and the observation diversity spanned out by the effective bistatic scattering azimuth angles (see Fig. 6).

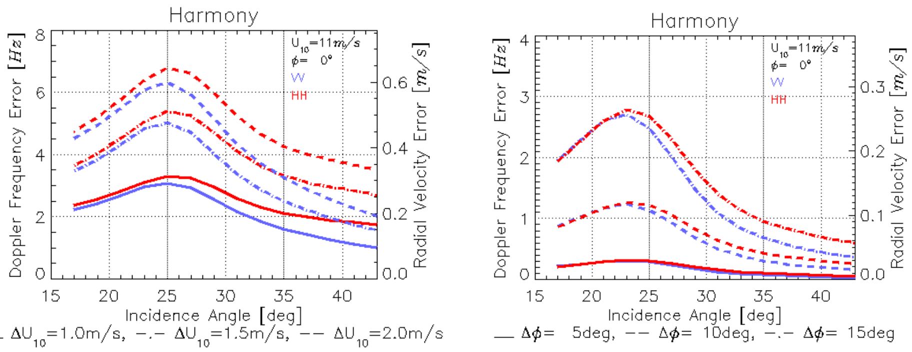

Fig. 8. Simulated VV and HH DCA and Radial Velocity (ground range) RMSe as function of incidence angle with RMSe of input wind speed of 1m/s (—) 1.5m/s (---) and 2 m/s (-.-.) (left), and with input wind direction RMSe of 5deg (___), 10deg (---) and 15 deg (-.-.) (right). Wind speed is set to 11 m/s, and wind direction is downwind.

4.4. OSW: Ocean Wave Spectra

Requirement

OSW-010 OSW-030 OSW-050->054	The Mission requirements on the observed OSW parameters are: • total Hs with precision of <0.5m and accuracy of <0.1m. • dominant wavelength with precision <50m and accuracy <10m, and in the range 30-1000m • dominant wave direction with precision $<40^{o}$ and accuracy $<10^{o}$, and in the range $0\text{-}360^{o}$ • Azimuth cut-off wavelength mean between 210-260m, and in the range 15-800m. • The OSW shall be provided at a horizontal resolution of $20x20km^2$

Understanding and Assumptions

Precision of the OSW will be considered as the random term of the OSW retrieval. This will be a combination of estimation error (+instrument noise) in the SAR parameters (NRCS, Image Cross Spectra) plus random geophysical error of the forward/inverse models used in the retrieval of OSW.

The accuracy (bias + RMSe) of the OSW will be considered as the sum of the estimation error and any errors introduced by the forward/retrieval algorithm.

The spatial resolution of OSW is the area on ground from which the 2D wave spectrum is estimated over. For WV mode, $20x20km^2$ correspond to the total vignette. It is however, feasible to process the OSW on higher resolution grid, ex $10x10km^2$ without increasing significantly the total error.

The performance will be analysed for the sizing scenarios provided in GAA-020

Design Implications and Considerations

For system error sources, see USV-040 and SWV-030
In addition to the NRCS, the amplitude and phase properties of the inter-look Cross Spectra will be used in the OSW retrieval. This imposes requirements on the inter-look phase extracted from the L1- SLC product of the bistatic measurements. Any non-geophysical inter-look phase term must be minimised to be significant lower than the expected phase shift introduced by the wave dispersion.
Recent wind vector retrievals from simulated stereo SAR observations show that use of only triplets of NRCS will provide large variance in wind direction for near azimuth winds. However, adding triplets of cross-spectral parameter will lower the variance significantly. High quality cross-spectra from the companions are thus important.

The OSW-030 requirement is challenging due to the inherent loss of coherence in SAR over the ocean causing reduced azimuth resolution. The geometric diversity of the bistatic observation can to some degree compensate this shortcoming. This again put constrain on SNR ratio versus the baseline and observation diversity.
The requirement on the dynamic range of the azimuth cut-off wavelength should be relaxed to 60 – 600m.

Reformulation (if needed)
1) We should target a horizontal resolution of ≈ 10x10km^2. 2) Relax the azimuth cut-off wavelength to 60-600m
Error sources (impacting performance requirements)
From the system size the main error sources are phase errors, SNR and NESZ impacting the quality of the image cross-spectra. The main geophysical error is the random geophysical error between the forward model and the corresponding observed values (NRCS, Image Cross Spectra). This randomness is due to natural variations of the air/sea conditions (turbulence) around the mean (in which the forward models are based on). The main contributor is here the modulation transfer functions (MTF) applied in the retrieval model. The geophysical error is very much driven by the required spatial resolution of the OSW and SWV.

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