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1.0	30/09/2014	First version	Víctor Navarro
1.1	10/10/14	Section 3. Added clarification: Surface backscatter will be generally lower for water bodies protected from wind, complicating surface height retrieval. Section 4.1. Added 10% accuracy goal value for discharge requirement. Section 4.2. Updated surface extent and height accuracy requirements for lakes/reservoirs according, which now depend on nominal size. Section 5.1.2. Added clarification: baseline calibration over in-land areas might be good enough to allow for accurate surface height retrieval in hybrid AT/XT configuration. Section 5.1.3. - Clarified that WM dual-beam configuration makes it sensitive to currents directions other than line-of-sight, though retrieval accuracy may differ depending on current direction. - Added NESZ plot to show relationship with velocity estimation accuracy. Section 6. Added comment concerning low backscatter from calm waters. References: Updated reference [10] (SWOT mission science requirements) with new version of the document	Víctor Navarro

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Acronyms and Abbreviations

ATI	Along Track Interferometry/Interferometer
CCN	Contract Change Notification
DEM	Digital Elevation Model
DRA	Dual Receive Antenna
GCM	Global Climate Model
InSAR	Synthetic Aperture Radar Interferometry
LOS	Line-of-sight
NESZ	Noise Equivalent Sigma Zero
OSCMS	Ocean Surface Current Mission Study
OSTM	Ocean Surface Topography Mission
SAR	Synthetic Aperture Radar
SLC	Single Look Complex
SWOT	Surface Water and Ocean Topography mission
TOPEX	Ocean Topography Experiment
WM	WaveMill
WPCC	Wavemill Proof of Concept Campaign
XTI	Across Track Interferometry/Interferometer

Abstract

This document evaluates the capabilities of Wavemill to provide secondary terrestrial hydrology products, while meeting the scientific requirements for ocean currents monitoring.

Keywords

Wavemill, Product Assessment, Interferometry, SAR, terrestrial hydrology

1 Introduction

The goal of this study is to evaluate the capability of Wavemill (WM) to retrieve secondary terrestrial hydrology products, taking into account that the application driving the system configuration is ocean current monitoring.

Observation of continental water systems has demanding requirements, given the environment heterogeneity and the complexity of inflow and outflow processes. WM achievable resolution will determine the scale of the water bodies that the system will be able to analyse, ranging from narrow rivers and tributaries to large lakes and reservoirs.

The analysis will focus on the main processes governing terrestrial hydrology, which are *discharge* (volume flow rate, generally associated with rivers) and *storage* (water mass stored, in lakes or reservoirs). These parameters are ingested, for instance, by Global Climate Models (GCM), widely applied for climate analysis and weather forecasting. They are also of great interest for flood monitoring and prevention.

Discharge and storage cannot be measured directly, but instead they are obtained from models implying measurable hydrological variables, such as the water surface elevation (or *stage*), the water surface slope, water flow velocity, etc.

In the following sections we discuss how WM may contribute to the remote measurement of the hydrological variables associated with river discharge and water storage.

2 River discharge

Discharge is defined as the volume rate of water flow, in other words, the volume of water that traverses a given cross-sectional area of the river per unit of time. Its general expression is [1]:

$$Q = A\bar{v}\ [\mathrm{m}^3/\mathrm{s}]\,, \qquad \text{Eq. 2.1}$$

where

A	Area of the cross-section [m²]
$\bar{v}$	Average velocity [m/s]

Assuming a nearly rectangular river channel, Q can be approximated in many cases as $Q = W\,Y\,\bar{v}$, where W is the width of the section and Y is the river depth, both in metres. Note that it is likely that not all the elements of this expression can be measured simultaneously with enough confidence. Therefore, a number of models have been developed to estimate discharge from different sets of hydrological variables (with as few as 1 variable in some cases), which rely on statistically based relationships derived for different river morphologies and characteristics. An excellent review on this topic can be found in [1].

Models can be found in the literature that relate discharge to the following variables:

- Channel width, W [m]
- Stage (*H*, [m]) and depth (Y, [m]).
- Water-surface slope ($S = \mathrm{d}h/\mathrm{d}x$, [m/m])
- Water-surface velocity (*V*, [m/s]). Note that the average velocity $\bar{v}$ will be, in general, slightly different, since the water layers closer to the river bed will flow generally slower than the uppermost layers.
- Channel morphology parameters: sinuosity, channel slope, meander length, radius of curvature...

Estimation of hydrological variables from space has already been addressed in several studies. Altimetric data from TOPEX/Poseidon nadir-looking radar have been used to derive water level (stage) measurements, with accuracies in the range of decimetres [2]. In [5], river currents velocities were estimated from TerraSAR-X data, acquired using an experimental along-track interferometer (ATI) operation mode. The potentials of proposed SWOT mission, across-track swath interferometer (XTI), for the obtainment of river stage, slope and width have been also evaluated [7]. However, few studies have attempted to estimate river discharge entirely from remote information, since currently there is no existing system that can measure all of the required variables simultaneously.

Wavemill instrument was originally conceived as a hybrid, along-track and across-track swath interferometer (ATI and XTI), which might outperform the aforementioned systems given its potential to estimate all of the parameters required for discharge estimation in a single satellite pass. However, the capability of current WM concept designs to retrieve accurate surface height measurements is still an open issue, as discussed in [17]. Nevertheless, 2D currents velocity, obtained from the combined analysis of fore and aft squinted SAR along-track interferograms, is a very useful measurement on its own, as far as discharge rate estimation is concerned, for it allows to study water flows not oriented in LOS direction.

3 Storage in lakes and reservoirs

Storage is defined as the volume [m^3] of water accumulated in a lake, reservoir or other similar water bodies. Storage fluctuations reflect changes in the rainfall and evaporation processes. In turn, they can be perceived as water level or surface extent variations.

The main inputs to storage are direct rainfall, surface runoff (discharge) of the tributaries, and underground inputs. On the other hand, main outputs are evaporation, ground seepage and surface outflow. Note that these inputs and outputs are modulated by human (anthropogenic) activities, such as irrigation.

A general expression for storage fluctuations is given by [8]:

$$\mathrm{d}V/\mathrm{d}t = Q - A(E-P), \quad \text{Eq. 3.1}$$

where

V	Lake or reservoir volume [m^3]
Q	Discharge (runoff) from the catchment basin [m^3/s]
E	Evaporation rate over the lake per unit of area [m^3/m^2·s]
P	Precipitation rate over the lake per unit of area [m^3/m^2·s]

Storage cannot be measured directly, but it can be estimated from the water level (stage) and the inundated area variations. In this sense, SAR systems are specially useful for shoreline detection, and XTI can provide measurements of water level (H) and water level fluctuations ($\mathrm{d}H/\mathrm{d}t$). Some studies in this line can be found in [8][9]. Notice that the phase of AT/XT hybrid interferograms, such as those provided by the original Wavemill concept, is sensitive to both topography and movement, and separation of the different phase terms has proven to not be straightforward [17]. For calm waters, however, as it is to be expected from inland water bodies protected from wind, motion-related phase component might be negligible in comparison with topographic phase, so surface height might be retrieved with sufficient accuracy. Backscattering related to wind-induced surface roughness will also be lower, though, so a large amount of looks (averaging) will be needed to reduce interferometric phase error. This will have a negative impact on the product resolution, and hence the applicability of the approach will be limited to large water bodies.

4 Scientific requirements

In this section we review the scientific demands associated with discharge and storage measurements. Requirements are defined to permit monitoring rivers exceeding 100 m width, and terrestrial surface water bodies (lakes, reservoirs, wetlands) with area larger than 250 m^2 [10].

4.1 Discharge

Wavemill original concept consists of a hybrid across-track/along-track dual-beam interferometer. Given its hybrid acquisition mode XTI (useful for water level measurements) and ATI (useful for current velocity estimation), there is a chance of measuring all the variables required for discharge estimation from Wavemill, in a single satellite pass. This concept is currently being disregarded in favour of a pure ATI configuration (Javelin) given the difficulty of separating XTI and ATI contributions to the interferometric phase. Nevertheless, we will consider the opportunities provided by both configurations regarding terrestrial hydrology products.

Minimum accuracy required for discharge is set to 30% (10% goal) of its true value, with an observation cycle of 3 days [11]. Following, we analyse the requirements for each hydrological variable related to river discharge, summarised in Table 4.1.

4.1.1 Estimation of channel width

Width can be obtained directly from SAR imagery. The generally lower resolution with respect to panchromatic systems, and the geometric distortions associated with SAR squinted acquisition scheme, are compensated by the fact it is (nearly) immune to weather and light conditions. The combined use of both sources of information is desirable, whenever possible.

Current available satellite high resolution SAR systems are able to provide resolutions up to 1 m in spot-light mode, and up to 3 m using the classical strip-map mode. Comparably, Wavemill system is conceived as a wide swath interferometer, with a baseline SLC resolution in the order of 50 m in interleaved burst operation mode (to switch between beams while still providing a continuous swath).

Note that the possibility of measuring river width from any remote sensing system (be it optical or radar) does not depend entirely on the resolution. In the case of SAR, possible sources of error include wet ground, vegetation, wind roughening, rocks and, in general, everything that can obscure the edge of water and the bank.

Moller and Rodríguez [12] estimated errors in width resulting from water coherence time effects (due to wind and turbulence of the water surface). For their worst-case (temporal decorrelation time of 20 ms), width errors (1σ) were roughly 5% over a 1 km long reach, and the mean width bias was between 75 and 10 m for coherence times from 4 to 30 ms, respectively. 10 m was the minimum bias due to pixel size. Similarly, we establish the accuracy requirements to 5% error over a 1 km reach.

The accuracy goal for areal extent estimation (for rivers wider than 100 m) is set to 20% [10].

4.1.2 Estimation of channel stage and depth

Stage variations have been estimated from space using radar altimetry (Geosat, TOPEX/Poseidon, Jason-1, all decommissioned) with accuracy ranging from 11 to 60 cm for water bodies between 0.2 and 2 km wide [4]. New generation radar altimeters such as Poseidon-3 on the satellite OSTM/Jason-2 offer a theoretical accuracy of 2.5 cm for large water bodies (in the order of 2 km), since they are optimized for oceans. On the other hand, XTI techniques can provide stage accuracies on the order of 1 cm, provided that a reference height is available, and they can be applied to a wider range of water body sizes.

Backscatter from a water body depends mainly on the surface roughness and the observation's geometry. Generally, in-land water bodies are more protected from the wind than open waters, so the roughness tends to be smaller. Therefore, a larger number of looks has to be considered to obtain accurate estimates of the signal phase. In this sense, accuracy is directly linked to river width, since it limits the number of looks available for averaging and RMSE reduction. For narrow rivers, when not enough looks can be obtained for a given cross-section, it may be necessary to average along a long reach of the river to met the accuracy requirements. With this in mind, the water surface height accuracy requirement is established to 10 cm, averaged over an area of 1 km^2 within river mask [10]. River height profile at target resolution is assumed to be obtained through proper polynomial fitting from irregularly sampled elevation data (where river width and areal extent allows for accurate estimates of stage).

Depth cannot be measured directly from remote data, and has to be estimated from measurements of stage coupled with other characteristics of the channel. Durand et al. proposed in [7] an algorithm to extract an “initial” water depth based on the kinematic and continuity assumptions applied to Manning’s equation. For a test case on the Cumberland River in Ohio, the relative error in depth had a mean of 4.2% and a standard deviation of 11.2%.

In order to comply with discharge accuracy requirements, the maximum relative error is set to 5% and the observation cycle to 3 days.

4.1.3 Estimation of water-surface velocity

River speed varies from close to 0 m/s to 3.1 m/s. Hence, its range is comparable to ocean currents, with speeds varying from nearly 0 m/s to 2.5 m/s. As said, rivers are more protected from wind, so their surface is generally smoother than the ocean one, specially in the middle and lower stages of the river. Smooth river surfaces require averaging over a large number of independent samples, which means averaging over very long river sections in the case of narrow rivers (not always possible).

In [5], TerraSAR-X experimental ATI mode was used to derive line-of-sight current fields in the Elbe river (Germany), which are consistent with the UnTRIM model [13]. However, this kind of data has limited availability.

WM squinted ATI geometry allows estimation of 2D currents velocity and direction. Still, accuracy is better for currents flowing in the direction perpendicular to the across-track axis. Note that there is no guarantee that the river reach is oriented in this direction along part or the totality of the area of interest.

In a SAR system, the maximum effective resolution in azimuth direction depends on the decorrelation time of the moving target, which decreases with wind speed and surface roughness (it decorrelates faster). This makes the signatures of rivers to be broadened. Distortions are more pronounced in the uppermost river sections, because of their higher roughness, as well as in estuaries or coasts. Consequently, areas near the banks of the river have to be disregarded in these sections.

Moreover, it is known that an object (or surface) moving towards or away of the radar appears displaced in the azimuth direction a distance proportional to its velocity. This can make narrow rivers to be totally mapped over land.

The required accuracy for current velocity estimation is 10 cm/s, for an averaged area of 1 km^2 within river mask.

4.1.4 Estimation of water-surface slope

Meaningful water-surface gradients can be on the order of 1 cm/km. Available altimetric data are not accurate enough to provide hydrologically meaningful measurements of slope. Assuming an altimetric error ranging between 10 cm and 20 cm, a reach of 5-10 km could result in slopes estimates ranging from negative to 8 times the actual slope values [4].

Single-pass SAR XTI can provide accurate estimates of surface elevation changes (1 cm in large rivers and flooded areas), and through combining this information with high resolution DEM, it may be possible to estimate meaningful water-surface slopes.

The accuracy requirement established for slope estimation is 1 cm/km, from slope measurements averaged over 10 km downstream distance inside river mask [10].

4.1.5 Observation of morphological features

River channels morphology is generally stable over time, so high resolution is preferred over frequency of observations. Spotlight SAR or panchromatic imagery (when weather conditions permit) are the best performing options for this purpose.

Requirements will be, in general, the same as for the observation of width, though they can be relaxed depending on the application.

Table 4.1: Requirements for streamflow/river discharge estimation.

Variable	Product	Accuracy	Horizontal resolution	Observation cycle
Width	Georeferenced SLC	5,00%	100 m	3 d
Water-surface velocity	ATI	10 cm/s	100 m	3 d
Stage	XTI	10 cm	100 m	3 d
Depth	XTI + additional data	5,00%	100 m	3 d
Slope	XTI	1 cm / km	100 m	3 d
Discharge	ATI + XTI	30,00% (10% goal)	100 m	3 d

4.2 Storage

As explained in Section 3, storage in lakes, reservoirs and other surface water bodies can be estimated from measurements of stage and surface extent. Requirements will be similar to those described for these measurements in rivers. However, it is important to bear in mind that wind increases the surface roughness, specially in the case of large lakes where wind-induced waves can appear. This increases the backscatter, as well as the noise level. Effects of the wind on oceans are well known, but effects on continental waters are more complicated and difficult to remove, since they are affected by local topography. Averaging can alleviate these issues, but also limits the applicability of the method to wide area bodies.

As for the temporal sampling, according to [10], 90% of fresh-water stored in reservoirs is contained in the largest 1000 reservoirs, whose large size guarantees that monthly observations are enough for their monitoring. We set the minimum observation cycle to 30 days for water bodies larger than 1 km^2.

4.2.1 Estimation of stage

Typically, altimetric stage measurements can range in accuracy from a few centimetres (e.g., Great Lakes, USA) to tens of centimetres (e.g., Lake Chad, Africa), depending on size and wind conditions. In the case of the Aral Sea, contributing E-P (1.5 km3 yr−1), river runoff (3.0 km3 yr−1) and altimetry (1.5 km3 yr−1) errors combine to give a ~3.5 km^3 yr^{-1} water mass balance error [8].

As in [10], we establish the requirements of height accuracy, relative to the surrounding topography, to be 10 cm (1σ) or better, for water bodies whose surface area exceeds 1 km^2 and 25 cm or better for water bodies whose surface is between 250 m^2 and 1 km^2

4.2.2 Estimation of surface extent

As in the case of rivers width, estimation of surface extent by SAR sensors is subject to errors related to vegetation, wet ground, wind roughening, and other factors that might obscure the shoreline.

The surface water areas estimated using the water mask shall have a relative error smaller than 25% (1 σ) of the total water body area for water bodies between 250 km^2 and 1 km^2, and smaller than 10% for water bodies over 1 km^2 [10].

Table 4.2: Requirements for storage estimation.

Variable	**Product**	**Accuracy**	**Horizontal resolution**	**Observation cycle**
Surface extent	Georeferenced SLC	25,00% (250 m^2 – 1 km^2) 15,00% (> 1 km^2)	250 m	30 d
Stage	XTI	25 cm (250 m^2 – 1 km^2) 10 cm (> 1 km^2)	250 m	30 d

5 Wavemill performance

In this section we discuss the expected performance of Wavemill in retrieving the required hydrological variables. It should be pointed out that, up to date, mainly two possible configurations of WM have been proposed: **Hybrid** baseline configuration, in which antenna phase centres are separated along- and across-track, and **Javelin** configuration, in which antenna phase centres are only separated along-track. Each configuration has potential benefits and disadvantages, as detailed for example in [14][15][16].

However, during the realization of the project WPCC-CCN [17], devoted to the evaluation of WM capabilities for SSH retrieval, it was found that none of these configurations is satisfactory for across-track interferograms generation.

On the one hand, the hybrid configuration requires a phase separation method to provide separate estimates of sea surface currents and elevation. However, the combination of fore and aft observations results in a system of 2 equations (fore, aft) with 3 unknowns (radial velocity fore, radial velocity aft, and sea elevation) and thus, a priori, unsolvable.

On the other hand, in the Javelin configuration the phase centres are only separated along-track. Different approaches were proposed as a mean to retrieve height from such a configuration with no XT baseline, but none of them was found capable of providing direct observations of the surface height or, at least, not with enough accuracy [17].

Nevertheless, the hybrid configuration might be suitable for measuring topography/water surface height when movement can be disregarded, which may be the case for inland bodies of water protected from wind.

5.1 Discharge

In this section, the capability of estimating discharge from WM data is evaluated. It should be pointed out that, according to [11], the minimum observation cycle required for discharge monitoring is 3 days. Preliminary orbit parameters considered for WM mission predict partial or complete swath overlap each 3-5 days, so this requirement might be partially fulfilled. All in all, note that WM products are not intended to replace stream gauges (that can supply daily or real-time measurements), but to complement their information, or to provide coverage for non-gauged streams.

The estimation of height-related variables, such as stage or slope, does not seem to be feasible for Hybrid and Javelin configurations, as discussed in [17]. However, discharge rate might still be estimated using statistical models which ingest some “a priori” knowledge of the channel characteristics and expected behaviour of water flow, and combine them with the measured current velocities [4].

Following, expected performance is discussed for each hydrological variable related to discharge estimation.

5.1.1 Channel width

With a baseline horizontal resolution of 50 m (single-look), Wavemill may meet the requirements for channel width estimation (100 m resolution, 5% accuracy). However, at this resolution 100 m width channels will be sampled with only two points on average. In order to improve accuracy for narrow channels, a high resolution stripmap operation mode (rather than standard interleaved burst mode) may be taken into consideration for in-land areas. This will allow differentiating better the morphology of the river embankment and the width of the stream.

5.1.2 Stage and depth

As said before, estimation of stage from hybrid interferograms requires precise separation of movement and height contributions to the phase. Moreover, for a stage estimation accuracy < 10 cm, WM across-track baseline calibration requirements can be very demanding, depending on the system configuration (up to 0.1 µrad in pitch, 1 µrad in yaw and 0.01 mm in baseline length). If calibration requirements are met, and movement contribution is correctly compensated, accuracy can be in line with available altimeters, with the extra benefits associated with a large swath. However, as extracted from [17], it seems unlikely that these conditions can be met at this point with the proposed WM configurations. Although, as extracted from [17], it is unlikely that these conditions are met in an open ocean scenario, in-land areas offer better calibration possibilities.

5.1.3 Water-surface velocity

Required horizontal resolution for surface velocity estimation has been set to 100 m, to include all rivers exceeding 100 m width. For moving targets, as shown in [5] and elsewhere, the effective single-pixel resolution in the azimuth direction cannot be better than:

$$\rho_a = \frac{R}{V}\frac{\lambda}{2\tau_c}\,[m]\,, \qquad \textit{Eq. 5.1}$$

where

R	Distance between the radar platform and the target [m]
V	Platform velocity [m/s]
λ	Radar wavelength [m]
τ_c	Decorrelation time of the backscattered signal [s]

Wavemill most recent design parameters (OSCMS) are: orbit altitude of 450 km, 7644 m/s platform velocity, incidence angle ranging from 29º to 36º, and 0.022 m wavelength (Ku-band). Assuming that the decorrelation time will be greater than 10 ms for wind-speeds below 7 m/s and approximately 10 ms for wind speeds above 7 m/s [18], we obtain that WM effective azimuth resolution will range from 50 m (nominal resolution) to 100 m (for highest wind speeds).

In addition, an azimuthal displacement is to be expected, related to the current velocity in the line-of-sight direction, v_r , by:

$$\delta_a = \frac{-R}{V}v_r \approx \frac{-R}{V}v_h \sin\theta\,[m]\,, \qquad \textit{Eq. 5.2}$$

where v_h is the target velocity in the horizontal plane (water surface) and LOS direction. Thus, a current velocity of 1 m/s (slow river) corresponds to a displacement of approximately 35 m (for 30º incidence angle), and a velocity of 2.5 m/s (fast river) leads to a displacement of nearly 90 m in the azimuth direction. Note that this displacement will be smaller for currents not aligned with the LOS.

These two factors (target broadening due to decorrelation and azimuth displacement) may make more difficult the retrieval of current velocities for narrow river sections. For wider sections, areas near the river bank should be disregarded (50 – 100 m, depending on current velocity and surface roughness).

Note that, in order to reach the required velocity accuracy of 10 cm/s, a high number of looks will be required to reduce phase noise, which limits the application of the approach to wide rivers and long reaches. This requirement is accentuated by the fact that, generally, rivers will be more protected from wind than open waters and thus, the backscatter for WM reference look angle (around 30º) is expected to be low. Excessive wind, on the other hand, can introduce wave and other surface motions that need to be compensated to obtain currents that are representative of the true water column velocity.

The dual-beam architecture of Wavemill makes it sensitive to current velocity whatever the flow direction, whereas other radar systems are only sensitive to motion in the LOS direction. All in all, as shown in [14][16], surface velocity accuracy depends on the direction of the current with respect to the across-track axis. For Javelin observation geometry, the accuracy will generally be somewhat lower for currents oriented across-track.

Despite these limitations, some spaceborne ATI experiments have been carried out using suboptimal systems with promising results. Figure 5.1 shows derived line-of-sight velocities of both currents and ships, using TerraSAR-X experimental ATI mode (DRA, dual receive antenna), with increased noise level, high azimuth ambiguities, reduced swath width, and suboptimal (too short) along-track baseline [5][6].

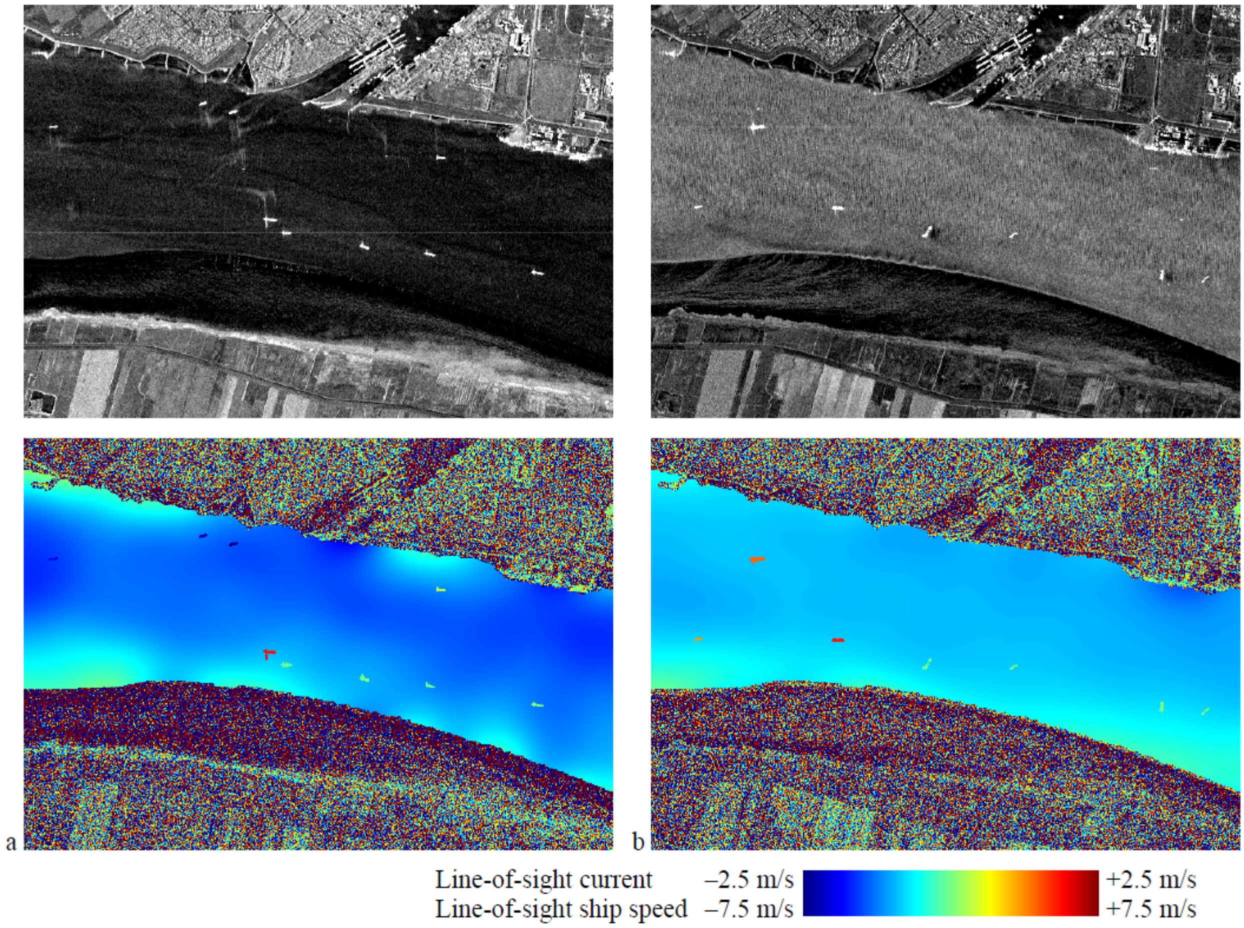

Figure 5.1: TerraSAR-X DRA-mode high resolution data acquired over the Elbe river on (a) April 24 and (b) May 5, 2009. Top row: intensity images, black to white = 15 dB. Bottom row: derived LOS currents and ship speeds [6].

For WM interleaved burst mode (baseline operating mode), an area of 0.02 km^2 (100 m width x 200 m reach) will render an equivalent number of looks (ENL) of approximately 450. Note that burst mode acts as a pseudo-scanSAR mode, alternating TX/RX between 4 beams (fore-right, aft-right, fore-left, aft-left). This reduces the available Doppler bandwidth for processing, and therefore the number of available looks, but allows a dual-sided continuous swath acquisition. Note, however, that large-swath dual-sided acquisitions may not be necessary for terrestrial hydrology products, and therefore a high resolution strip-map mode might be envisioned for in-land waters which would increase significantly the available number of looks for the same area extension.

In Figure 5.2(left) the expected surface motion accuracy is presented, considering a worst case scenario: low wind, streamflow oriented across-track and interleaved burst mode acquisition. Surface motion can be obtained with an accuracy better than 10 cm/s for any river patch with an area of 0.02 km^2 or larger, within a swath of approximately 30 km (about 2° of incidence angle variation). Possible residual across-track baseline effects (unrelated to motion) are considered calibrated to required accuracy using nearby static targets (terrain areas). In this case, the accuracy will be mostly determined by the SNR, and thus by the antenna pattern. Figure 5.2(right) shows the NESZ curve (noise equivalent sigma zero) considered in the simulation. NESZ is a measure of the sensitivity of the SAR system (the lower the NESZ, the better the sensitivity to low radar backscatter areas). It is observed that river velocity accuracy curve pretty much follows the shape of the instrument NESZ.

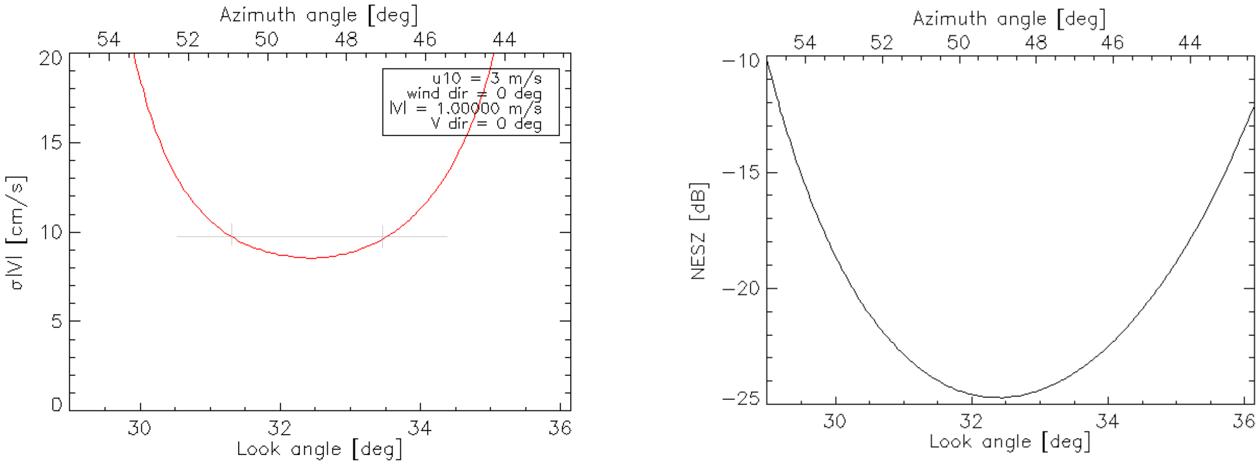

Figure 5.2: Left) Estimated river surface velocity accuracy for a worst case scenario (low wind, burst mode, streamflow oriented across-track). Right) NESZ of the instrument. In the absence of baseline errors, final accuracy is mostly determined by the instrument performance.

Modelling river backscattering is not straightforward, since it depends on many features of the channel, affecting factors such as the river turbulence. In this simulation, we used a model for open ocean backscattering, considering a low wind speed (3 m/s). Simulated NRCS at relevant angles have proven similar to that obtained empirically at Ku-band for Corwlitz River study case in [19] (See Figure 5.3).

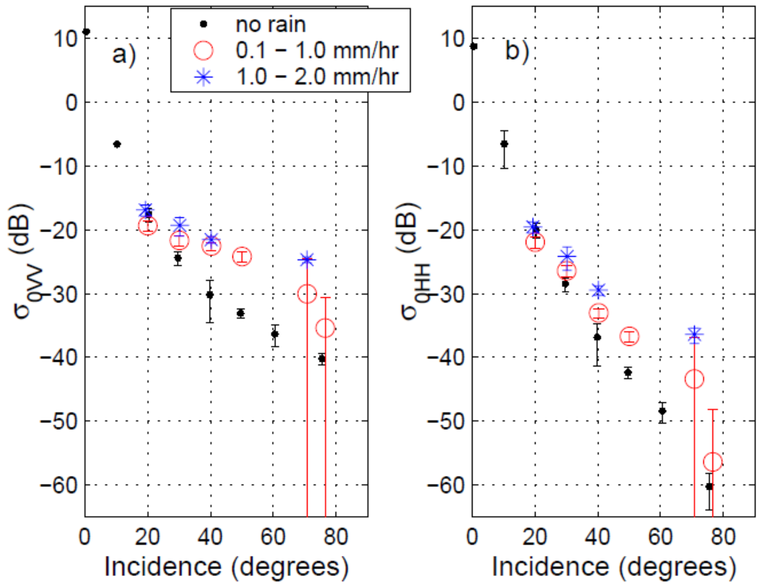

Figure 5.3: Cross section as a function of incidence angle for wind speeds between 1 and 3 m/s within 45º of the downwind direction [19]

Note that surface motion has to be converted to average river velocity before computing discharge. Moreover, wind wave effects (although low in comparison to open ocean scenarios, according to [5]) and other wind-induced Doppler may need to be compensated. This will certainly introduce further errors in the discharge retrieval. Nevertheless, if necessary, the accuracy might be increased by considering stripmap mode on land.

5.1.4 Water-surface slope

As with stage estimation, the difficulty of obtaining pure XT interferograms from Hybrid or Javelin configuration precludes the capability of measuring slope. Note that discharge can still be derived from river velocity using statistic models, which can be supported by slope estimates from available high resolution DEMs [4].

5.2 Storage

Storage can be estimated from surface extent and stage, as described in Section 4.2. With baseline single-look resolution of about 50 m, WM will easily meet the accuracy requirement for surface extent estimation of large water bodies (25% accuracy for 1 km^2 surface), as well as the observation cycle requirement (3-5 days revisit time versus 30 days requirement). In fact, frequent revisit time offers opportunities for monitoring flood events.

However, stage measurements would only be possible with XT interferometry. Note that a pure AT configuration will not be sensitive to stage variations. Still, there exists the possibility of steering the baseline so that an effective XT baseline is introduced to monitor these areas, as in the hybrid XT-AT design concept.

In hybrid XT-AT configuration, stage estimates could be achieved only for calm water surfaces, protected from wind and other disturbances, and large enough to provide a sufficient number of independent looks, which limits severely the applicability of the method. Notice that, in general, the larger the surface extent, the most likely is the existence of wind-induced currents whose contribution to the interferometric phase will be difficult to separate from the height contribution.

6 Conclusions

In this work we have evaluated the capability of Wavemill to obtain secondary terrestrial hydrology products, keeping in mind that the primary product is sea currents velocity and direction. In particular, we have focused in the main processes governing terrestrial water cycle, namely discharge (volume flow rate, generally associated with rivers) and storage (water mass stored, in lakes or reservoirs).

Discharge estimation can be obtained by direct measuring of the implicated hydrological variables (cross-section area, average velocity) or it can be derived from a reduced subset, using statistical models which rely on a priori knowledge. Wavemill capability of retrieving water surface height is still an open issue, so estimation of cross-section area entirely from WM data might not be possible. On the other hand, for wide rivers (over 200 m width), velocity and width may be estimated with enough accuracy as to derive discharge from statistical models, coupling this information with other known features of channel (such as slope or roughness).

Storage in lakes or reservoirs can be obtained from surface extent and water height. In absence of surface currents (calm waters) WM hybrid configuration might be able to obtain water height from XT interferometry, provided that AT component associated with movement is negligible. However, backscatter from calm waters is also expected to be low, which implies that a large number of looks will be required to reduce interferometric phase error. This might limit the applicability of the approach to large water bodies (> 1 km^2).

Considering the (proposed) 3-5 days revisit time of Wavemill, the 3 days observation cycle requirement for discharge can be partially met. The required observation cycle for storage monitoring is less demanding (30 days), so WM orbital cycle would be sufficient in this case.

Finally, for enhanced accuracy in the estimation of most hydrological variables, a high resolution strip-map mode should be considered for in-land areas, where optimising the resolution and the available number of looks might be preferred over dual-sided observations.

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