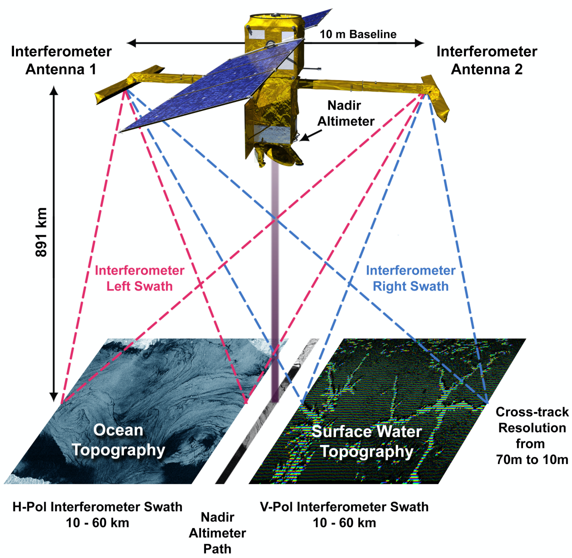
Improved processing of multitemporal SWOT SAR images with deep learning

1 Context

The SWOT mission developed by the space agencies NASA and CNES has been launched at the end of 2022 and, after a first commissioning phase, is now delivering its data. With its wide-swath Ka-band radar interferometer KaRIn, SWOT delivers unprecedented images of Earth's lakes and rivers. The combination of a high frequency band and near-nadir incidence maximizes the radar return of water areas and leads to images with very different radiometric contrasts and geometric distortions compared to more conventional synthetic aperture radar (SAR) images by satellites such as Sentinel-1.

During the preparation of the mission, research and development work supported by two Ph.D. works supervised at Telecom Paris has led to the design of processing pipelines to detect lakes and rivers and feed the water height estimation with water masks. With the delivery of images captured by the satellite and the rise of powerful deep learning techniques, advanced processing strategies can now be considered in order to (i) improve SWOT images (reduction of speckle fluctuations and of interferometric phase noise) and (ii) enhance information extraction from these images thanks to the combination of geometrical models of the acquisition, multi-temporal information, and data from different sources. The objective is to overcome current limitations that degrade the water detection (e.g. : dark water, bright mud, wet fields, built areas,...) and prevent the level 2 products from reaching the full potential of the SWOT data. The reduction of speckle and the analysis of time-series of SWOT images are expected to open up new perspectives for the study of wet areas or snow-covered lakes. In the context of a possible InSAR Sentinel-3 NG Topo mission, more robust processing pipelines will be necessary to compensate for the less reliable interferometric phase measurements (due to the use of a smaller interferometric baseline and poorer signal-to-noise ratio specifications). The deployment of deep neural networks and the tighter inclusion of complementary sources of data is a promising research direction to achieve greater robustness.



The two modes of the SWOT mission, one for the ocean observation with a coarse resolution, and the other one with a finer resolution for continental applications.

2 PhD description

In this thesis, we propose to exploit deep learning approaches to :

— improve SWOT data (speckle reduction and improvement of the interferometric phase quality),

— extract information (water mask segmentation, height estimation, change detection).

We distinguish three lines of research : the first one based on the exploitation of single-date data ; the second analyzing SWOT or multi-sensor time series ; the third focusing on height extraction by combining information.

2.1 SWOT image despeckling and single-date water segmentation

SWOT data, like all radar data, are subject to the speckle phenomenon with strong fluctuations present in amplitude or interferometric data. Reducing these fluctuations allow a better exploitation of these data.

We propose to develop speckle reduction approaches dedicated to SWOT data by adapting and extending the SAR2SAR [2] and MERLIN [3] approaches we have recently proposed. The adaptation of SAR2SAR for radiometric improvement requires the availability of independent SWOT image pairs with no displacement of scene objects. Exploiting SWOT multi-temporal acquisitions should enable dedicated training for this sensor, provided we can compensate or take into account not only radiometric changes but also any translations linked to height variations. Another possibility would be to exploit data acquired with a short revisit time of one day, between March 29 and July 10, 2023 which should present few temporal changes. The MERLIN adaptation requires the spectrum to be symmetrical with respect to the origin, but then allows the network to be trained on the basis of the complex data alone. Another avenue for further research is the simultaneous use of the interferometric pair as a replacement for the coherent power calculation currently performed by [5].

It is also possible to extend these speckle reduction frameworks, in particular SAR2SAR for complex multi-channel data, i.e. in interferometric configuration. We therefore propose to evaluate their interest for improving interferometric phase and coherence in the SWOT processing chain.

In addition to amplitude and interferometric phase denoising for the extraction of water surfaces and the calculation of the 3D point cloud on rivers, deep learning approaches could be highly effective for extracting the water mask, or other intermediate classes that are visible on SWOT data (frozen lakes, wetlands, etc.). Works on "self-supervised learning" have shown that training a network on an ancillary task enables the construction of an efficient representation space for other tasks. We propose to exploit these approaches for water surface extraction, using the ancillary task of denoising in the spirit of the "Denoiseg" method [1] and MERLIN-Seg [4]. Indeed, even with a small number of labeled data, very good results can be obtained. It would also be interesting to exploit coherence information within this framework and extend the "Denoiseg" principle to the interferometric context.

2.2 Multi-temporal, multi-sensor processing

SWOT enables acquisitions with a revisit period of 22 days in nominal mode. Exploiting multi-temporal information opens the way to very efficient strategies for speckle reduction [6]. In the context of SWOT and the incidence angles used, variations in water height can lead to significant translations in the image. It will be necessary to take this phenomenon into account in the neural architecture developed (for example, by jointly calculating a water mask or a shift mask, or by exploiting the interferometric and translation information). It will also be important to take into account the presence of auxiliary data such as water masks known a priori.

Another topic of interest is the use of other satellite data like Sentinel-1 or Sentinel-2 to help SWOT data exploitation. The preliminary registration step should be carefully handled by taking into account SWOT specificities.

2.3 Novel methods of water height estimation

Deep neural networks can be trained to estimate the water level from different types of information : geometric information provided by acquisitions in ascending and descending modes, and information provided by single-pass interferometry. Water segmentation and height estimation tasks would then be jointly performed. Beyond estimation, uncertainty characterization is crucial to pave the way for subsequent information fusion processes.

3 Supervision of the PhD

The doctoral work will be carried out in the LTCI laboratory of Télécom Paris, under the supervision of Prof. Florence Tupin (Télécom Paris) and Prof. Loïc Denis (Université Jean Monnet Saint-Etienne). Links with ongoing works on swath altimetry missions will be reached by a CNES supervision (DTN/CD/TPA : Nicolas Gasnier, DTN/TPI/TR, and DOA/OT/OH) and regular stays at the CNES. If adequate, further association with SWOT and Sentinel-3 NG Topo missions could translate into collaborations with the international partners.

Références

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