Consortium Members

Lake Ice Thickness

D3: System Development

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1. Summary

This document provides a description of the two systems implemented for the retrieval of lake ice thickness (LIT) using data from altimetry missions, including their main functionalities, architecture, input data to the retrieval algorithms (described in D2), output products generated and how verification tests on the LIT products are performed.

2. Introduction

This document contains a detailed description of two systems implemented for the retrieval of LIT using data from altimetry missions. The first system, developed at LEGOS, uses both backscatter (radar altimeter) and brightness temperature (passive microwave radiometer) measurements for the estimation of LIT while the second system, developed at CLS, is based on the exploitation of radar waveforms (Low Resolution Mode). Details regarding the retrieval algorithms implemented in both systems can be found in D2 (Technical Note: Algorithm Theoretical Basis Document (ATBD)).

3. System Implemented at LEGOS

The system implemented at LEGOS uses radar backscatter and brightness temperature data, simultaneously measured at nadir on the same satellite platform, for LIT product generation.

3.1. General Description

The LIT product generated from the empirically-based algorithm approach provides two values of the ice thickness: one from passive microwave radiometer measurements of brightness temperature and one from radar altimeter measurements of backscatter at Ku-band. Simultaneous measurements of backscatter and brightness temperature in two frequencies (see section 3.4) are used in the LIT processing chain for determination of the ice season (i.e. detection of open water and ice). The main processing chain based on radiometric measurements is presented in Figure 1. The radar-based LIT production is similar and runs within the same system.

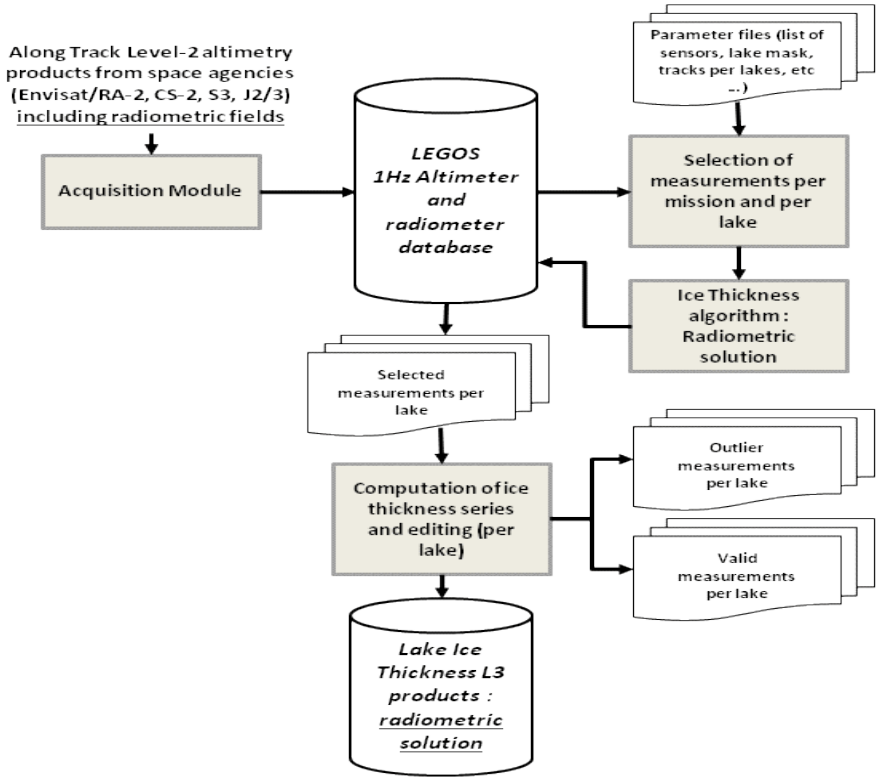

Figure 1: Main processing chain implemented. The diagram shows the processing for radiometric measurements but is also applicable to the case of backscatter measurements.

3.2. Main functionalities

The system consists of four modules:

1. Acquisition module
2. Satellite measurements extraction module
3. Computation of LIT module
4. LIT editing module

Parameters used in the LIT retrieval module (thresholds for ice detection and calibrated coefficients) depend on mission (mainly on frequencies of radiometer and on retracker parameterisation) and are stored in a look-up table. The look-up table can be updated as data from a new altimeter mission is included in the workflow. Two versions of the extraction module exist. A general module needs only a specification of the lake. In this case, the LIT is retrieved for all predefined tracks within limits setup in the look-up table. An interactive version uses the altimetry measurements overlaid on a MODIS image (GeoTiff) and permits the user to define graphically the part of the lake for which the LIT processing is to be performed.

3.3. Architecture

The LIT processing architecture is based on in-house processing modules implemented in Matlab and in Python. The processor supports historical (Jason-2, ENVISAT) and current (Jason-3, Sentinel-3) missions. The Acquisition module is compatible with the GDR products downloadable from AVISO+ (https://www.aviso.altimetry.fr) portal and CTOH (http://ctoh.legos.obs-mip.fr/data) for Jason-2,-3 and ENVISAT missions, respectively.

3.4. Input

The Lakes_cci Data Access Requirement Document (**Erreur ! Source du renvoi introuvable.**) contains the characteristics of the Jason-2, Jason-3 and ENVISAT satellites input data used to estimate LIT and the ancillary data (MODIS reflectance) that can be used in the satellite measurement extraction module (interactive version).

Input data consist of:

- Brightness temperature obtained at 24 GHz and 18 GHz (for Jason series satellites) and 34 GHz and 24 GHz (for ENVISAT).
- Ku-band backscatter retrieved from the ICE1 retracker.

3.5. Output

The structure of LIT output product from the empirically-based approach is presented in Table 1. Data is provided in csv format.

Table 1: List of LIT product variables.

Variable name	Description	Units	Type	Dims
time	Time of measurement	decimal year	do	time
year	year of measurement		do	time
month	month of measurement		do	time
day	day of measurement		do	time
lon	Lake center longitude [-180;+180]	degrees	do	time
lat	Lake center latitude	degrees	do	time

Variable name	Description	Units	Type	Dims
	[-90;+90]			
LIT_sigKu	Ice thickness retrieved from Ku backscatter by empirical method [0; 3]	m	do	time
LIT_tb18	Ice thickness retrieved from brightness temperature measurements in 18GHz frequencies by empirical method [0; 3]	m	do	time
LIT_avr	Ice thickness obtained by averaging of LIT_sigKu and LIT_tb18, [0; 3]. Allows for compensation of LIT_sigKu and LIT_tb18 outliers in pre-melting period.	m	do	time
LIT_sigKu_std	Standard deviation of Ice thickness retrieved from Ku backscatter by empirical method for a given date [0; 3]	m	do	time
LIT_tb18_std	Standard deviation of Ice thickness retrieved from brightness temperature measurements in 18GHz frequencies by empirical method for a given date [0; 3]	m	do	time
Lit_avr_std	Standard deviation of Ice thickness obtained by averaging of LIT_sigKu and LIT_tb18, [0; 3].	m	do	time
mission	Satellite mission name used for LIT retrievals		char	time
Flag	LIT retrieval quality flag [0,1,2,3]		int	time

3.6. Verification tests

Several verification steps are integrated in the system in order to ensure the quality of the product:

1. Statistical verification: The retrieved LIT values are plotted on the LIT seasonal cycle plot with max/min limits obtained from the Canadian Lake Ice Model (CLIMo; Duguay et al., 2003) for corresponding lake. An alert is produced if the value exceeds the max/min for the corresponding date by more than 10 cm for LIT <= 1 m and for more that 10 % for LIT> 1 m.

2. Visual inspection: Visual verification of the monotonic increase in LIT during winter can be accomplished using a plot of the LIT time series constructed one step before the saving of the output file.

4. System Implemented at CLS

This section describes the system implemented at CLS based on the exploitation of radar altimeter waveforms (Low Resolution Mode, LRM) that contain information correlated with the seasonal evolution of ice thickness over freshwater lakes.

4.1. General Description

The LIT product is generated by the ice thickness retrieval algorithm, that is, the LRM_LIT retracker, a novel physically-based analytical retracker developed specifically to optimize the estimation of LIT from LRM radar altimetry data (Mangilli et al., in review).

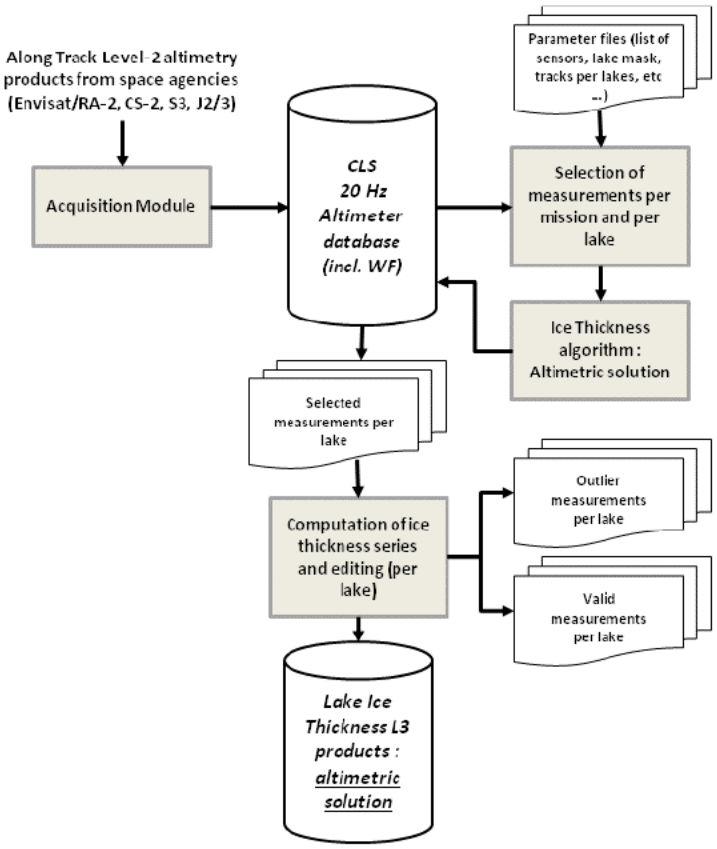

Figure 2. *Main processing chain implemented for the retrieval of LIT based on the physically-based analytical LRM_LIT retracker.*

4.2. Main functionalities

The LRM_LIT retracker analysis consists of three main steps:

1. Data selection (target lake and region of interest (ROI))
2. Optimization step (waveform weighted fit; this module includes goodness-of-fit statistics)
3. LIT estimation with the associated uncertainty (the module includes data editing to exclude possible outliers).

The advantage of a physically-based analytical retracker for the estimation of LIT is that it allows to simplify the set-up of the analysis as there are no empirical settings required that depend on the

satellite mission or target. In the actual implementation, the ROI is defined by hand, but it can be generalized by imposing specific criteria for data selection, as for example choosing the center of the ROI around the maximum distance from the lake shoreline to avoid land contamination.

4.3. Architecture

The LIT processing architecture is based on in-house processing modules implemented in Python. The processor supports historical (ENVISAT, Jason-1, Jason-2) and current (Jason-3, Sentinel-3, Sentinel-6) missions. The Acquisition module is compatible with the GDR products downloadable from the AVISO+ (https://www.aviso.altimetry.fr) portal.

4.4. Input Data

The input data are HR waveform data at 20 Hz from conventional altimetry missions.

4.5. Output

The structure of LIT output product from the LRM_LIT retracking algorithm is presented in Table 2.

Table 2: List of LIT product variables.

Variable name	Description	Units	Type	Dims
time	Time of measurement	decimal year	do	time
year	year of measurement		do	time
month	month of measurement		do	time
day	day of measurement		do	time
lon	longitude (center of the ROI) [-180;+180]	degrees	do	time
lat	latitude [-90;+90]	degrees	do	time
LIT_LRM	Ice thickness	m	do	time
LIT_LRM_STD	Standard deviation of Ice thickness	m	do	time
mission	Satellite mission name used for LIT retrievals		char	time

Complementary output that could be included: the best fit LIT estimations from the fit of each radar waveforms in the LIT analysis window (ROI) over the target lake with the corresponding coordinates. This typically consists of ~one hundred LIT estimates for each cycle. It is useful to have this output to check the spatial evolution of the LIT in the analysis window and to eventually extract LIT estimates from smaller regions in the analysis window.

4.6. Verification tests

Goodness-of-fit tests are performed (reduced chi2 metrics) to monitor the fit and for data editing. Comparison with thermodynamic LIT simulations from the lake ice model CLIMo (Duguay et al., 2003) is done on target lakes for which these simulations are available. For a quantitative comparison between different LIT estimates (simulations or different data sets), the Mean Bias Error (MBE) and the Root Mean Square Error (RMSE) are computed.

5. References

Duguay, C.R., G.M. Flato, M.O. Jeffries, P. Ménard, K. Morris, and W.R. Rouse, 2003. Ice cover variability on shallow lakes at high latitudes: Model simulations and observations. Hydrological Processes, 17(17): 3465-3483.

Mangilli, A., P. Thibaut, C.R. Duguay, and J. Murfitt, in review. A new approach for the estimation of lake ice thickness from conventional radar altimetry. *IEEE Transactions on Geoscience and Remote Sensing*.