Development of a contextual (multi-waveform) retracker for estimating water levels in lakes and reservoirs

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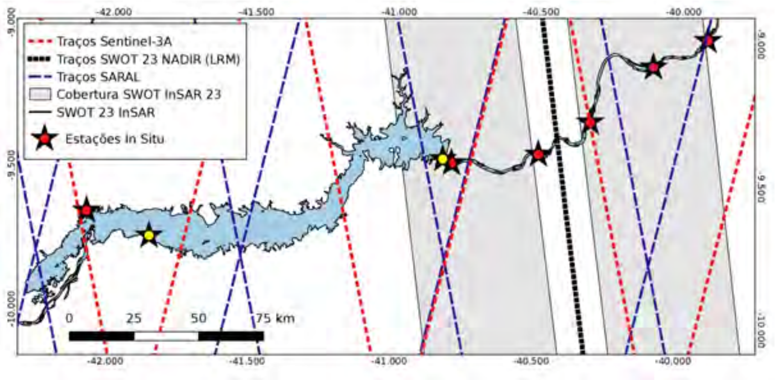
Backgroung: satellite altimetry for hydrology

- Large rivers, lakes and reservoirs are increasingly being monitored by satellite altimetry and altimeter technology is rapidly evolving and in need of **processing techniques adapted for hydrology**.
- The future of satellite altimetry for hydrological applications (scientific or management) most likely lies in **multi-mission approaches**.
- The use of satellite altimetry for hydrological applications is often limited by the absence of specific processing for river and lakes such as retracking algorithms. In this talk we are presenting a **contextual (multi-waveform) retracking algorithm**.

Study Site: Sobradinho Reservoir

The Sobradinho Reservoir is the largest in Brazil and is critical for the semiarid part of the country.



It is also a cal/val site for SWOT for both river and lake processes.

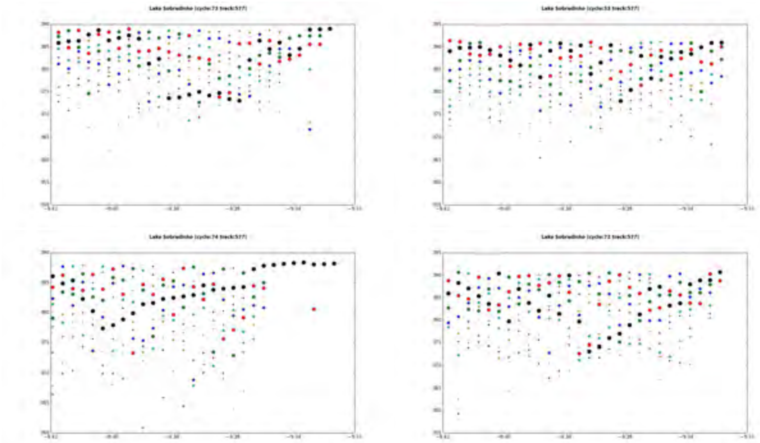
Sobradinho facts and figures

- Operator: *Companía HidroElétrica do São Francisco* (CHESF)
- Total power: 1 050 300kw
- Reservoir area: 4214km^2 at 392.5m amsl
- Reservoir volume: 34 116Hm^3
- Regular discharge: 2060m^3s^{-1}

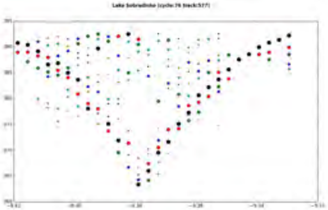
Initial concept

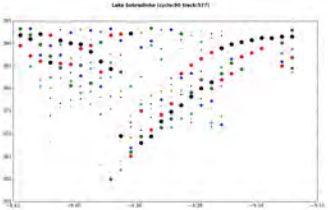
- Conventional retrackers (e.g. Ice1, Ice2, Sea-ice) often select a point within the waveform that comes from an off-nadir location;
- When this happens in a series of consecutives points, phenomenon is called "hooking";
- This can even happen in the middle of a lake or a large rive;
- We argue that this can be due to waves that can return more energy than the water at nadir;
- Still the nadir return is most probably present as an individual peak within the waveform and most probably one of the first ones (unless the point is located near the shore where the topography can produce the same effect).

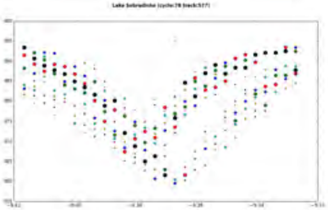
Weak hooking

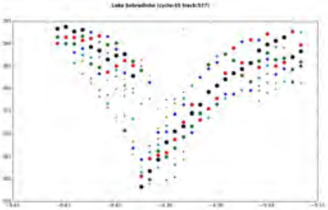


Strong Hooking

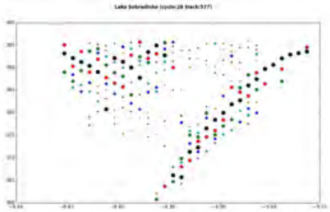


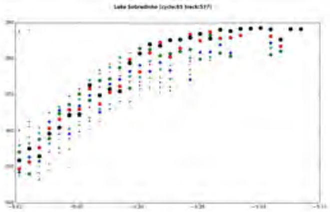






One sided Hooking





Objective

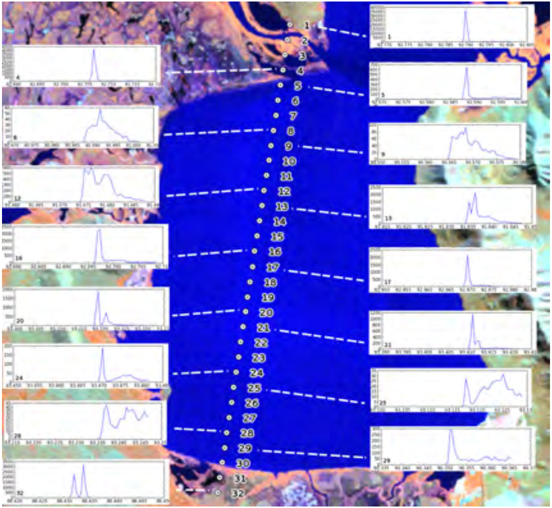
- To develop a contextual retracker algorithm that processes numerous points simultaneously
- To test the algorithm for different satellites and instruments (Envisat, Saral, jason, Sentinel-3)
- To compare the results of the algorithm with conventional retrackers
- To develop tools to eficiently and graphically process satelite altimetry data

CLR: a Contextual Lake Retracker

Basic principles and ideas:

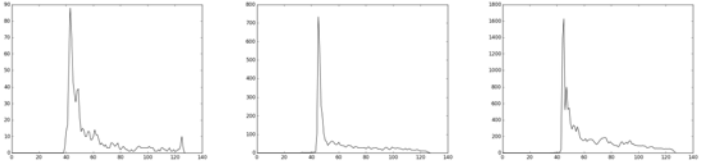
- Waveforms contains record of concentric rings of energy reflected back to the antenna
- Water, being a specular reflector usually produces strong peaks
- In calm weather (no wind), nadir reflection is usually the strongest
- First strong peak in waveform over water corresponds to shortest distance between satellite and water surface
- Windy condition can alter this relation and "fool" conventional retrackers by producing stronger returns from off-nadir
- In windy condition nadir return can be found in secondary peaks

An example with Saral in the Pantanal

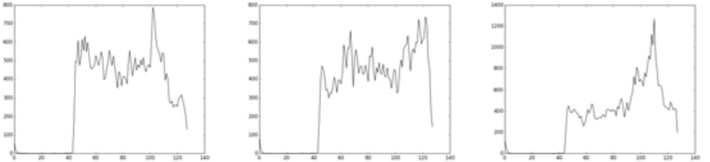


An example with Saral in the Pantanal

Simple clear response waveforms (no wind?)



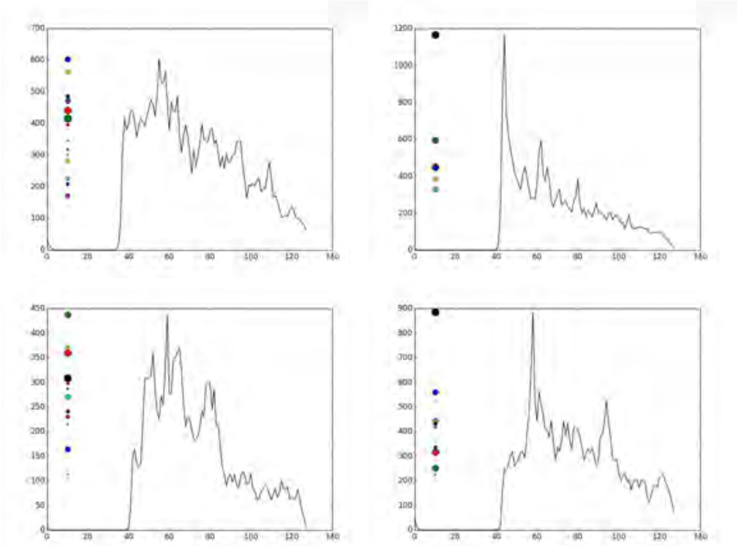
Complex unclear response waveforms (windy?)



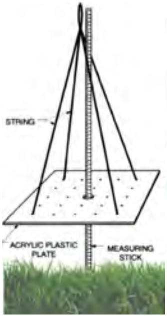
The algorithm

- It appears clear that the major peaks are related to water but can be off-nadir;
- It is also clear that within an almost flat water surface, the first peak(s) represent the water elevation even if it is not within the few strongest;
- These two facts can be combined to transform the major peaks in the waveform in a hierarchical order;
- All the ordered peaks of all the waveforms within the lake are plotted ;
- An horizontal pressure line is “dropped” on the point clouds until a maximum force threshold (based on pressure plate for measuring biomass of grasses);
- A single elevation value results.

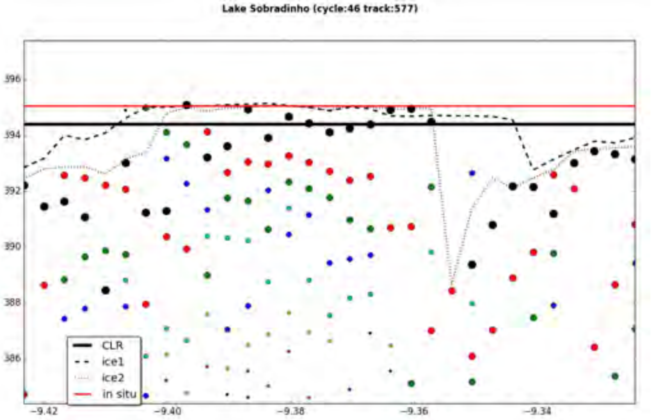
Ordering the peaks



The "pressure plate" concept



(a) the concept



(b) the application

The formulation

if $(bin_{amplitude}$ of WF is peak) and $(bin_{amplitude} \geq thershold)$:

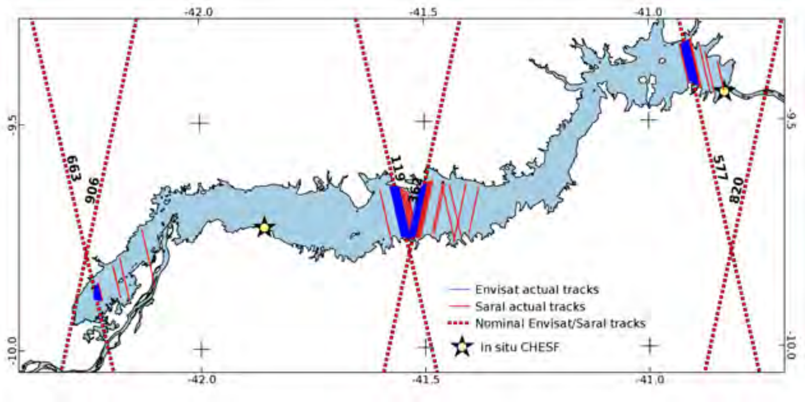
$$strength = [bin_{amplitude} \div max(amplitude)] \times [(N - bin_{number}) \div N]^4$$

Reorder bins acording to strength

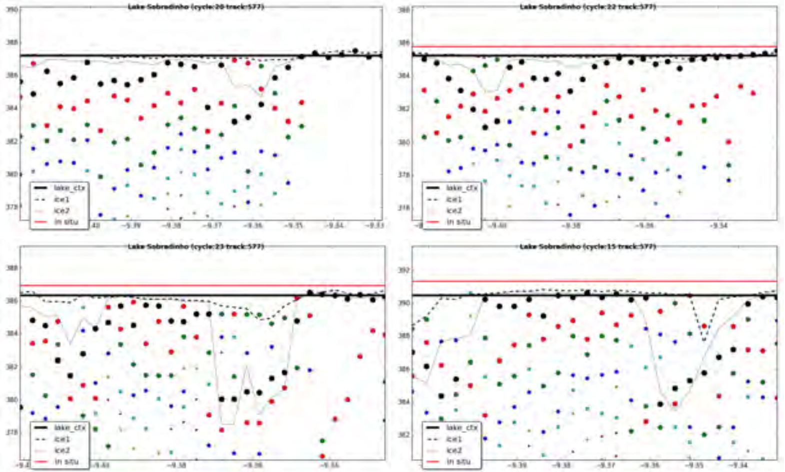
Results

Results and Discussion

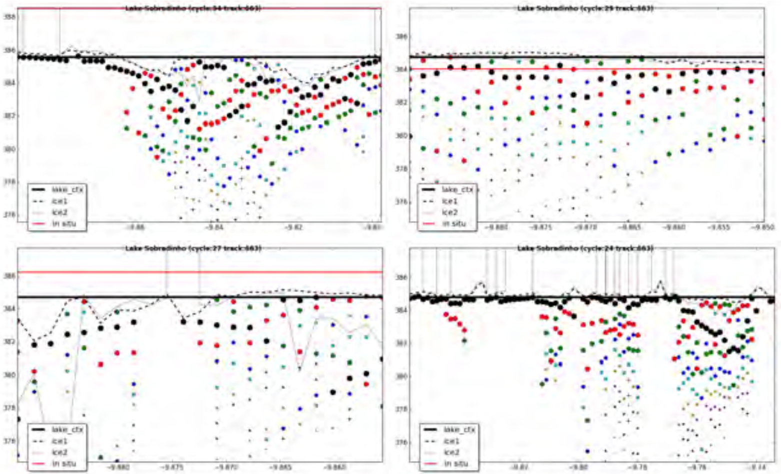
Hooking


-42.0
-41.5
-41.0
-9.5
-10.0
663
906
119
577
820
Envisat actual tracks
Saral actual tracks
Nominal Envisat/Saral tracks
In situ CHESF

Some output


Lake Sobradinho (cycle:20 track:577)
Lake Sobradinho (cycle:22 track:577)
Lake Sobradinho (cycle:23 track:577)
Lake Sobradinho (cycle:15 track:577)
lake_ctx
ice1
ice2
in situ

Some output


Lake Sobradinho (cycle:34 track:863)
lake_ctx
ice1
ice2
in situ
Lake Sobradinho (cycle:29 track:863)
lake_ctx
ice1
ice2
in situ
Lake Sobradinho (cycle:27 track:863)
lake_ctx
ice1
ice2
in situ
Lake Sobradinho (cycle:24 track:863)
lake_ctx
ice1
ice2
in situ

RMSE

	Envisat			Saral		
Track	**CLR**	**ICE1**	**ICE2**	**CLR**	**ICE1**	**ICE2**
119	0.134	0.170	0.344	0.111	0.074	0.076
362	0.138	0.054	0.061	0.143	0.105	0.109
577	0.201	0.202	0.517	0.076	0.075	0.147
663	0.531	0.564	0.855	0.449	0.476	0.731

Table: Root Mean Square Errors for the 3 retrackers, 4 tracks and for both Envisat and Saral

Ice1

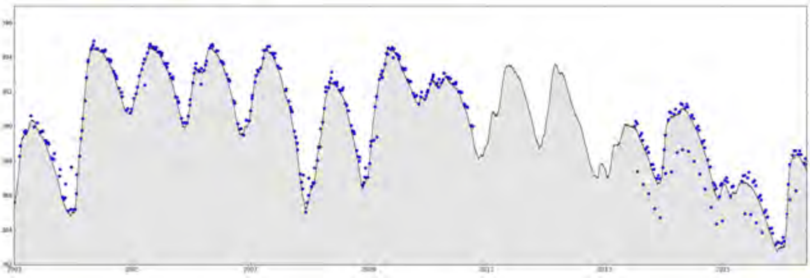


Figure: Sobradinho Water level time series with ICE1 (2003-2016)

Ice2

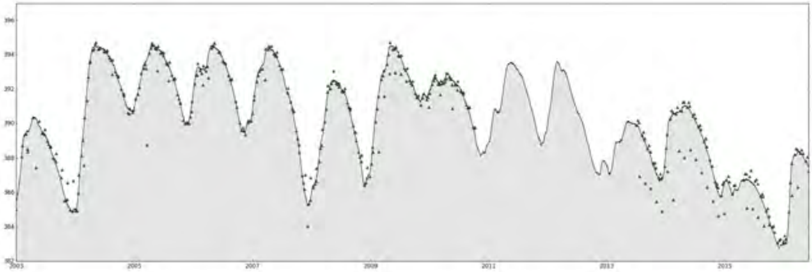


Figure: Sobradinho Water level time series with ICE2 (2003-2016)

Contextual lake retracker

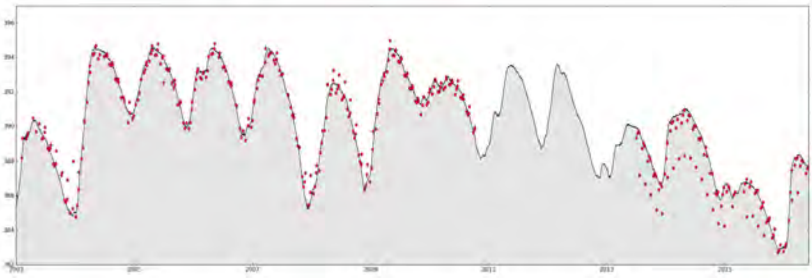


Figure: Sobradinho Water level time series with CLR (2003-2016)

Water level difference

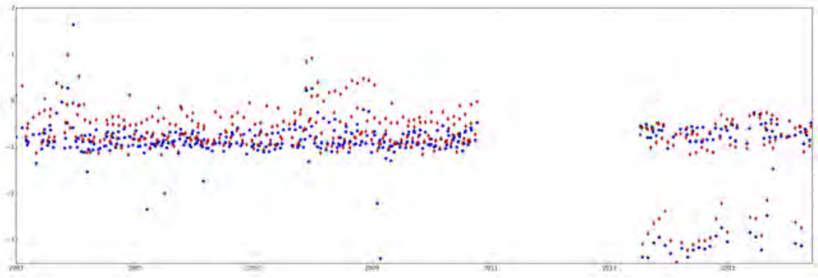


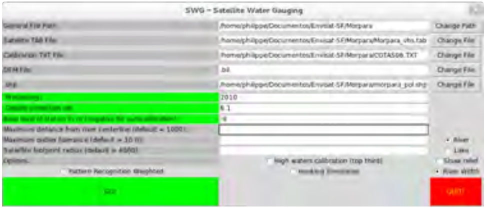
Figure: Sobradinho Water level difference CLR (red diamonds) / ICE1 (blue dots) (2003-2016)

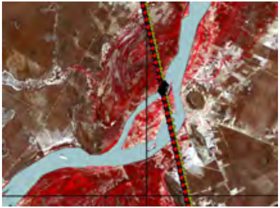
Conclusion

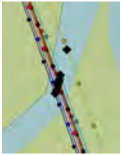
- This work is still in progress
- Although not consistently better than traditional retrackers, some success has been achieved.
- But we may be trying to reach beyond the precision the instruments can achieved.
- We are looking to use the approach on small lakes and rivers where the smaller number of points and the land contamination are more problematic.
- Some preliminary results on the Pantanal lakes seem to indicate just that

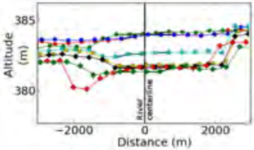
Tool Creation: SWG

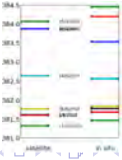
SWG (Satellite Water Gauge) is an integrated platform with a Graphical User Interface to extract, correct, process and display altimetry data as virtual altimetry stations for rivers and lakes. SWG produces a series of tabular and graphic results.











Tool Creation: SAGIS

SAGIS (Satellite Altimetry for GIS) is a program that reads, corrects and transforms satellite altimetry data into *shapefiles* to be used in a Geographic Information System (GIS) environment.

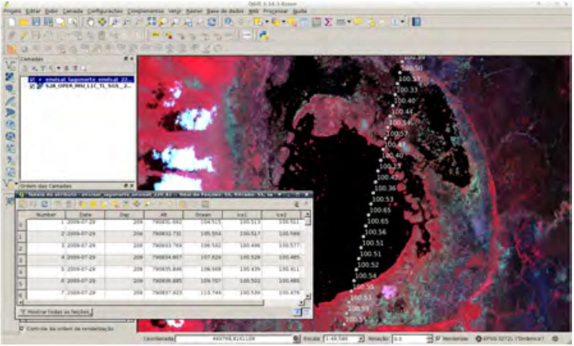


Figure: Satellite altimetry data as a *shapefile* with its attribute table in a GIS environment.

THANK YOU!

For more information:

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