Detecting sub-waveforms using spatio-temporal waveform information in combination with sparse representation and conditional random fields for coastal applications

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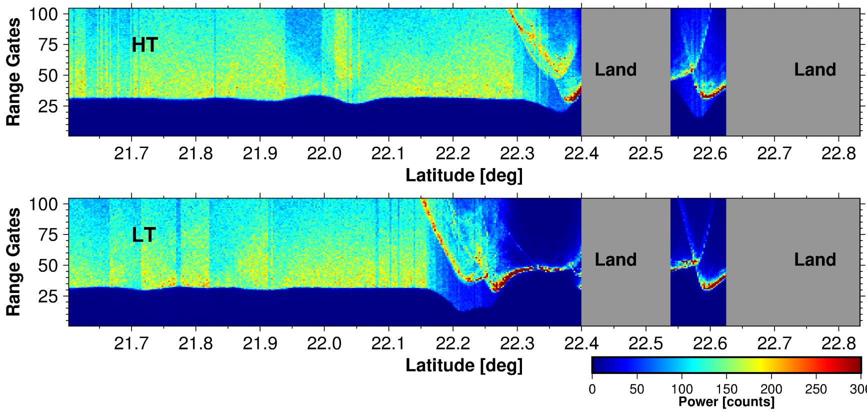
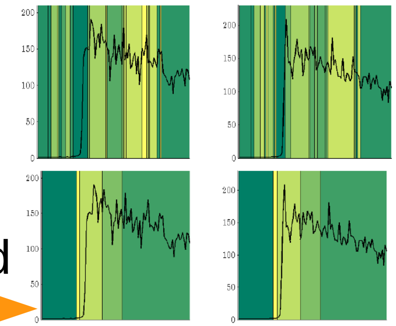
Motivation and Scope



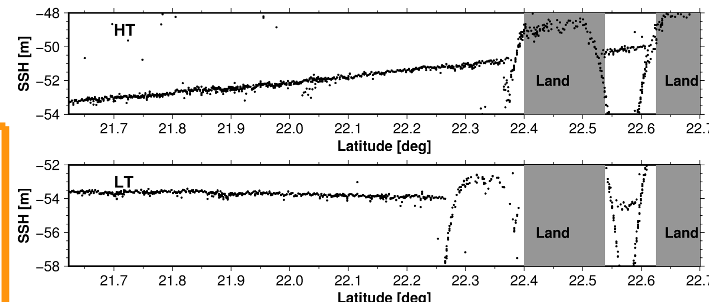
Sub-waveform Detection
→ Sparse Representation
→ Conditional Random Field

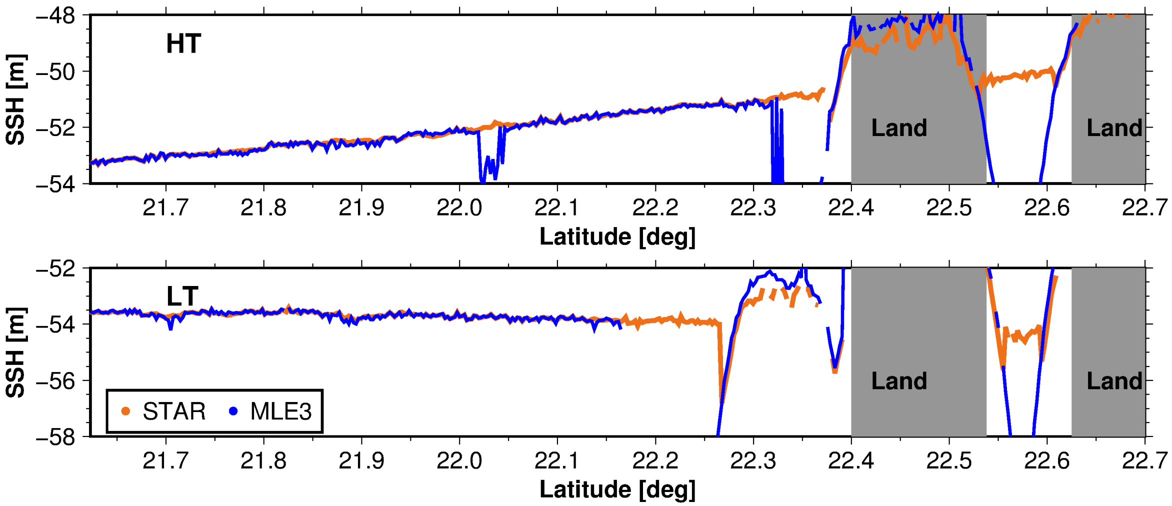


MLE3
(swf)

STAR: Spatio-Temporal Altimetry Retracker

MLE3

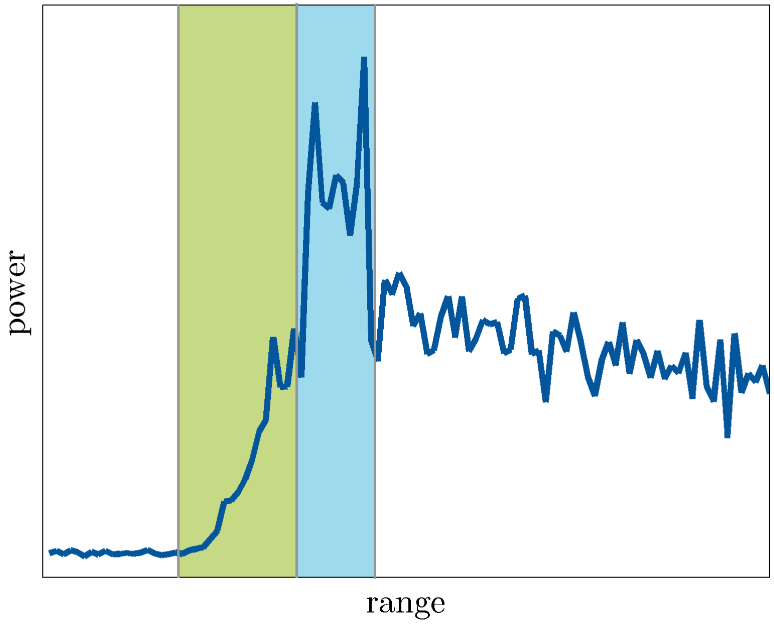




Dijkstra-Algorithm

Overview

- Sub-waveform Detection
- Retracking Model and Selection of final Estimates
- Spatio-Temporal Altimetry Retracker (STAR)
- Results and Validation
- Summary and Conclusion

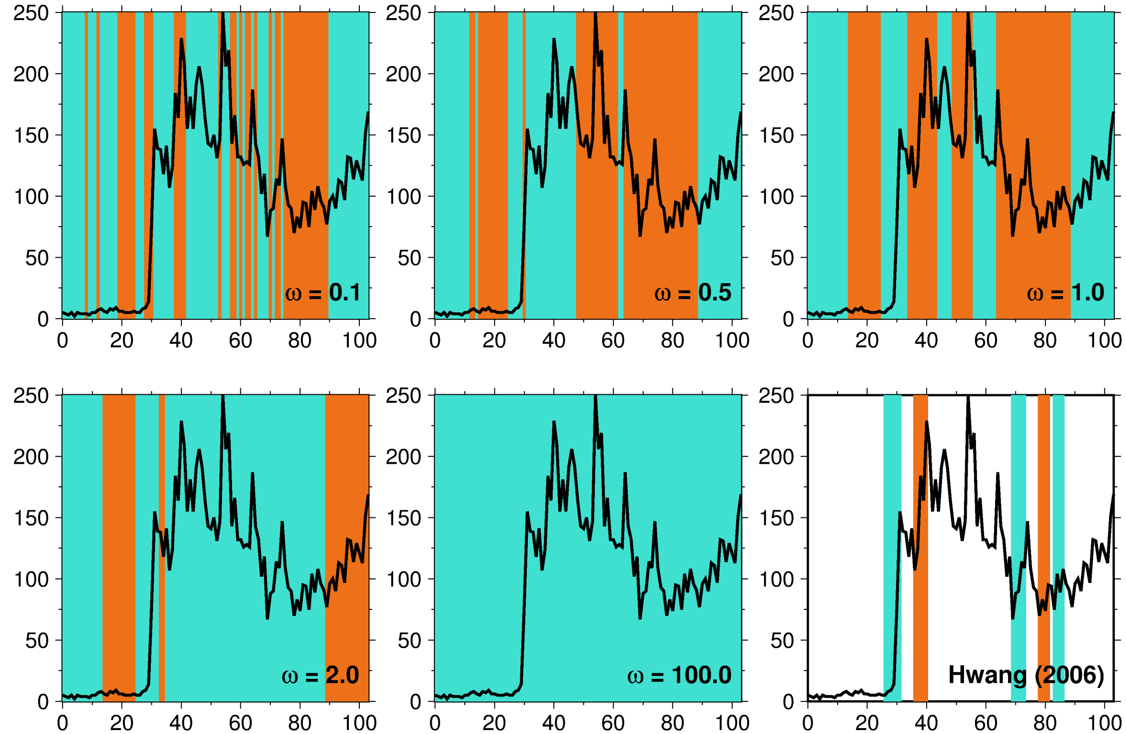


Sub-waveform Detection

Definition

- Incorporate spatial (within one waveform) and temporal (successive waveforms along the satellite groundtrack) information on neighboring range gates to derive a comprehensive partitioning of the total waveform into individual sub-waveforms
  - Hwang et al. (2006): leading edges only
- <u>Assumption:</u>
  All successive range gates that are approximated by the same combination of model waveforms form a sub-waveform

→ **Conditional Random Field**



Sub-waveform Detection

Conditional Random Field

- Minimize energy function

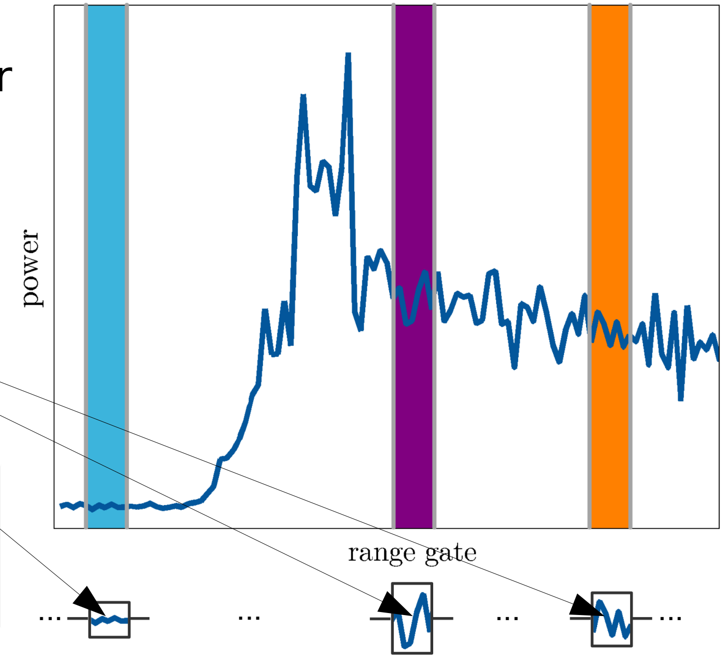
$$\mathcal{E}(\boldsymbol{y}) = \sum_{l,g} \left(\boldsymbol{r}'_{l,g} + \boldsymbol{\beta}'_{l,g} \right) - w \sum_{l,g,q \in \mathcal{Q}} \mathcal{B}(\boldsymbol{\xi}_{l,g}, \boldsymbol{\xi}_{l,q}, \boldsymbol{y}_{l,g}, \boldsymbol{y}_{l,q})$$

- L waveforms
- G range gates

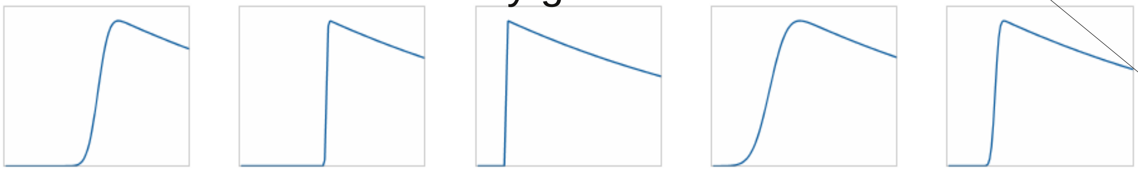
  – Unary terms
    - **r'**$_{l,g}$ … normalized reconstruction error
    - **β'**$_{l,g}$ … normalized difference to 1

  – Windowed waveforms **ξ**

  – Identified basis elements **y**



Basis elements: randomly generated



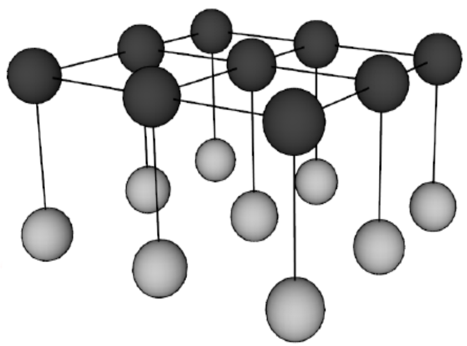
Sub-waveform Detection

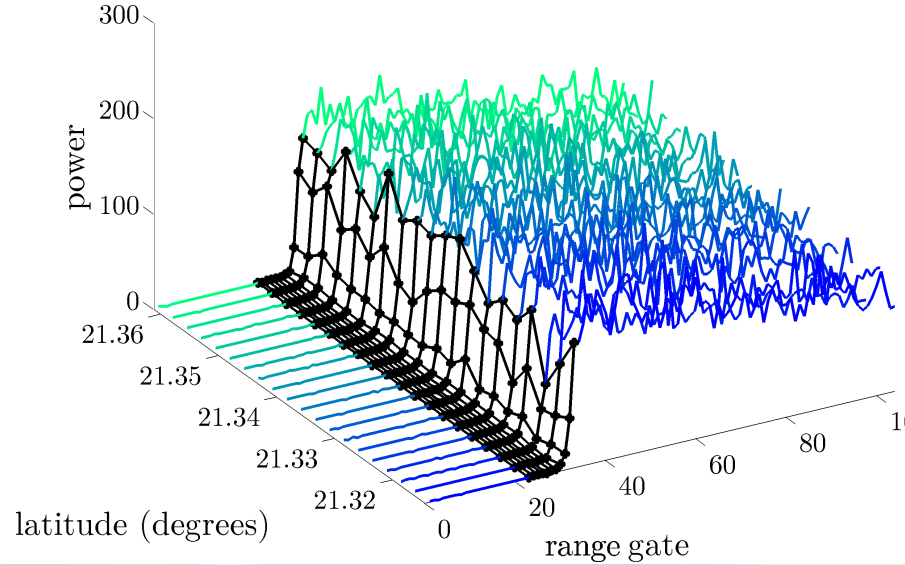
Conditional Random Field

- Energy function $$\mathcal{E}(\boldsymbol{y}) = \sum_{l,g} \left(\boldsymbol{r}'_{l,g} + \boldsymbol{\beta}'_{l,g}\right) - w \sum_{l,g,q\in\mathcal{Q}} \mathcal{B}(\boldsymbol{\xi}_{l,g}, \boldsymbol{\xi}_{l,q}, \boldsymbol{y}_{l,g}, \boldsymbol{y}_{l,q})$$
  - Binary term

$$\mathcal{B}(\boldsymbol{\xi}_{l,g}, \boldsymbol{\xi}_{l,q}, \boldsymbol{y}_{l,g}, \boldsymbol{y}_{l,q}) = \begin{cases} \cos\left(\boldsymbol{\xi}_{l,g}\ ,\ \boldsymbol{\xi}_{l,q}\right), & \text{if} \quad \boldsymbol{y}_{l,g} = \boldsymbol{y}_{l,q} \\ 0, & \text{if} \quad \boldsymbol{y}_{l,g} \neq \boldsymbol{y}_{l,q} \end{cases}$$

  - Hyperparameter ω acts as a weight to enforce homogeneity, i.e. the size and number of sub-waveforms
  - Range gates are represented as a graphical model

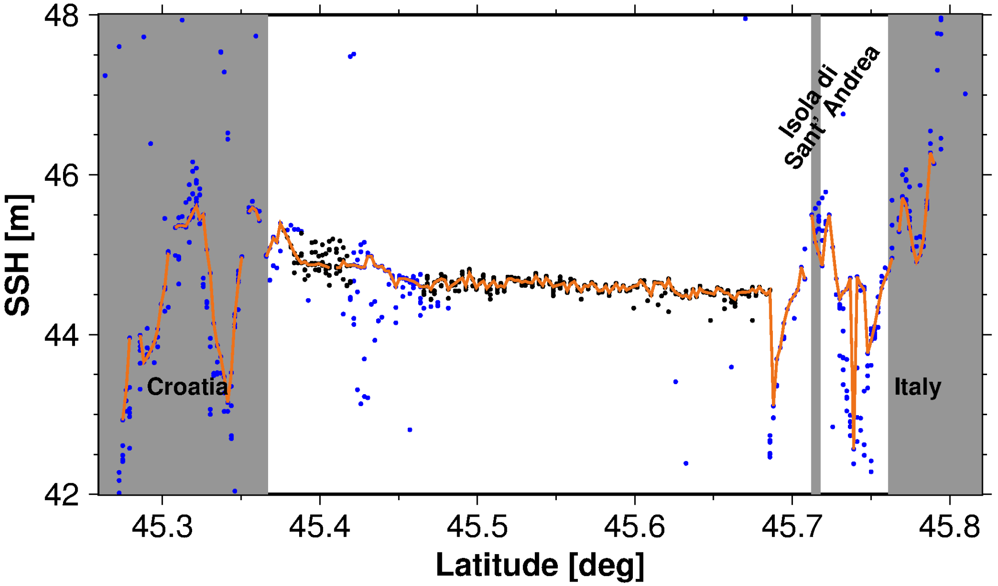


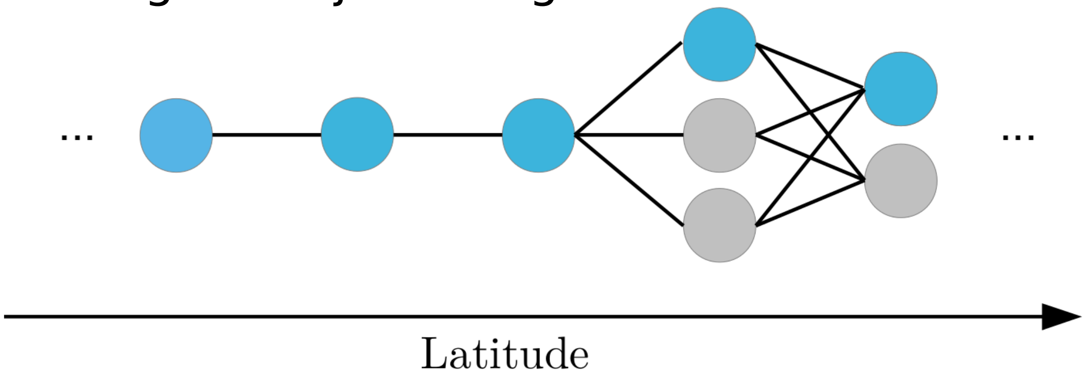


Retracking Model and Selection of final Estimates

Point Cloud and Dijkstra-Algorithm

- Sub-waveform detection partitions the entire waveform
- The sub-waveforms can be combined with an any retracking model
- Result: SSH point-cloud
- Final estimates from finding the 'best path' through the point cloud using the Dijkstra-algorithm

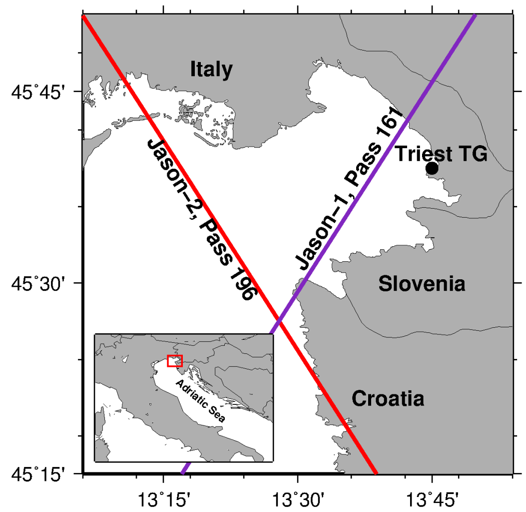


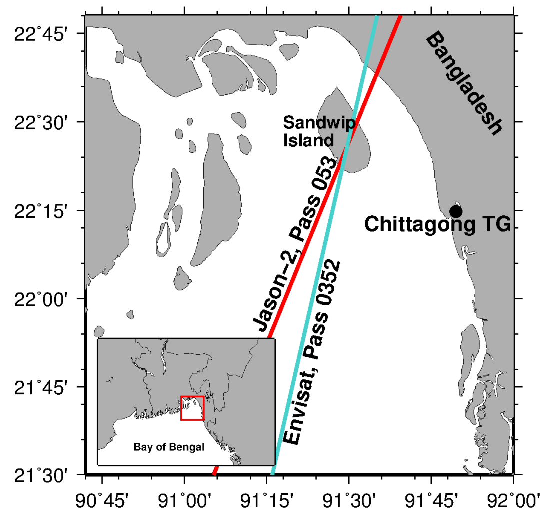


Spatio-Temporal Altimetry Retracker (STAR)

Specifications and Study Sites

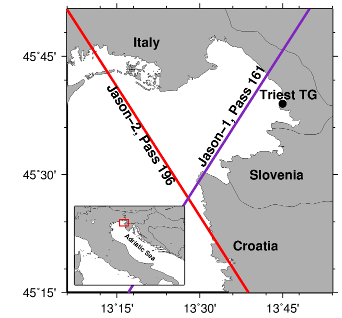
- **STAR**: Spatio-Temporal Altimetry Retracker
  - Weight ω = {0.1, 0.5, 1.0, 2.0, 100.0}
    - 5 partitionings of the entire waveform (location-independent)
  - 3-parameter ocean model (Halimi et al., 2013)
    - Applied to each sub-waveform
- Study Sites



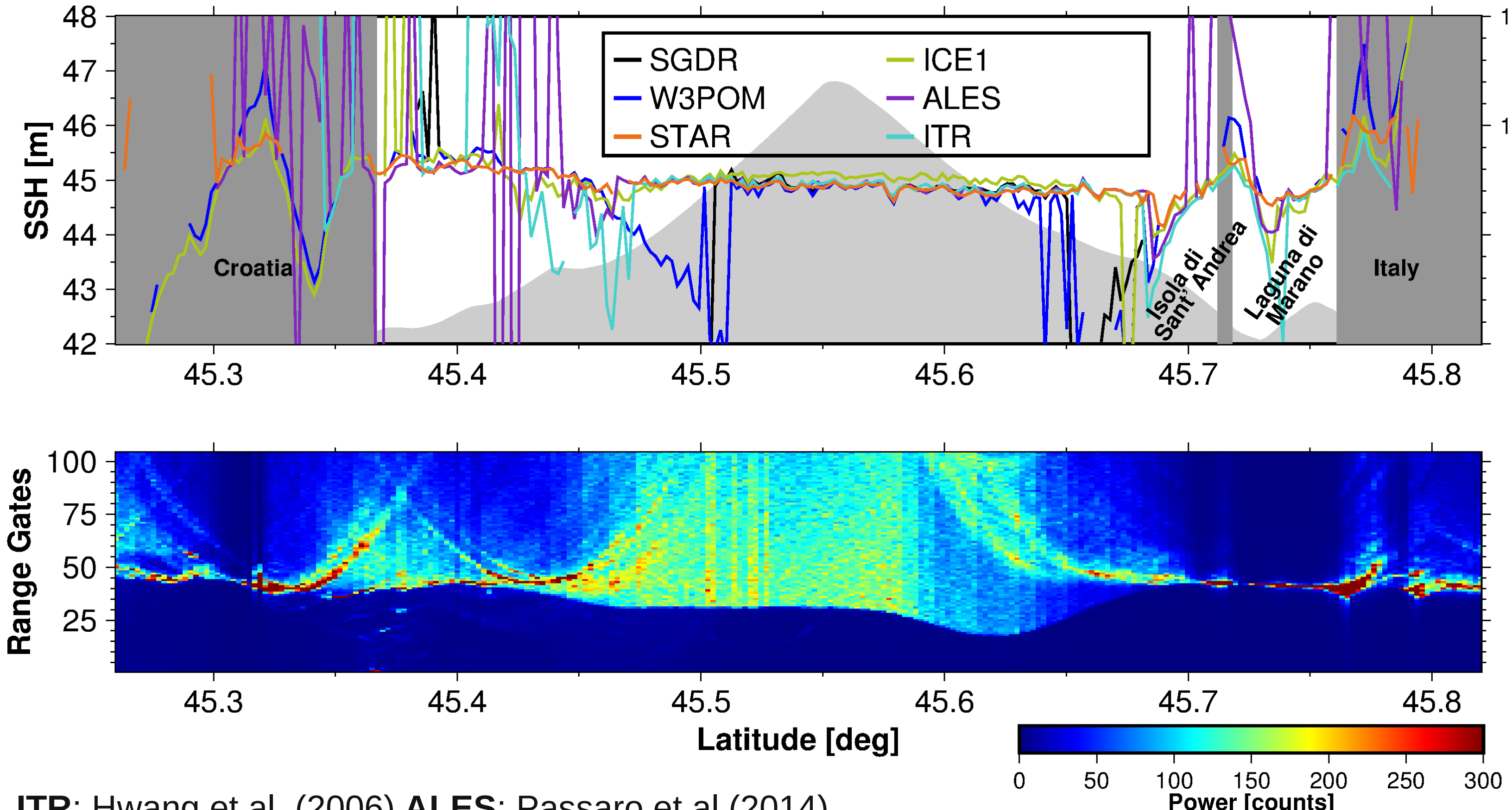


Results and Validation

Comparison of SSH

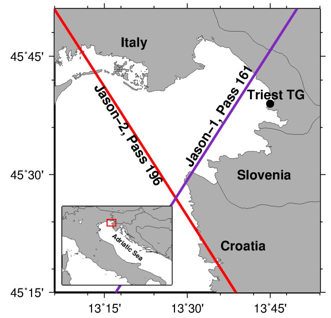


- SSH from Jason-2, Pass 196, Cycle 165



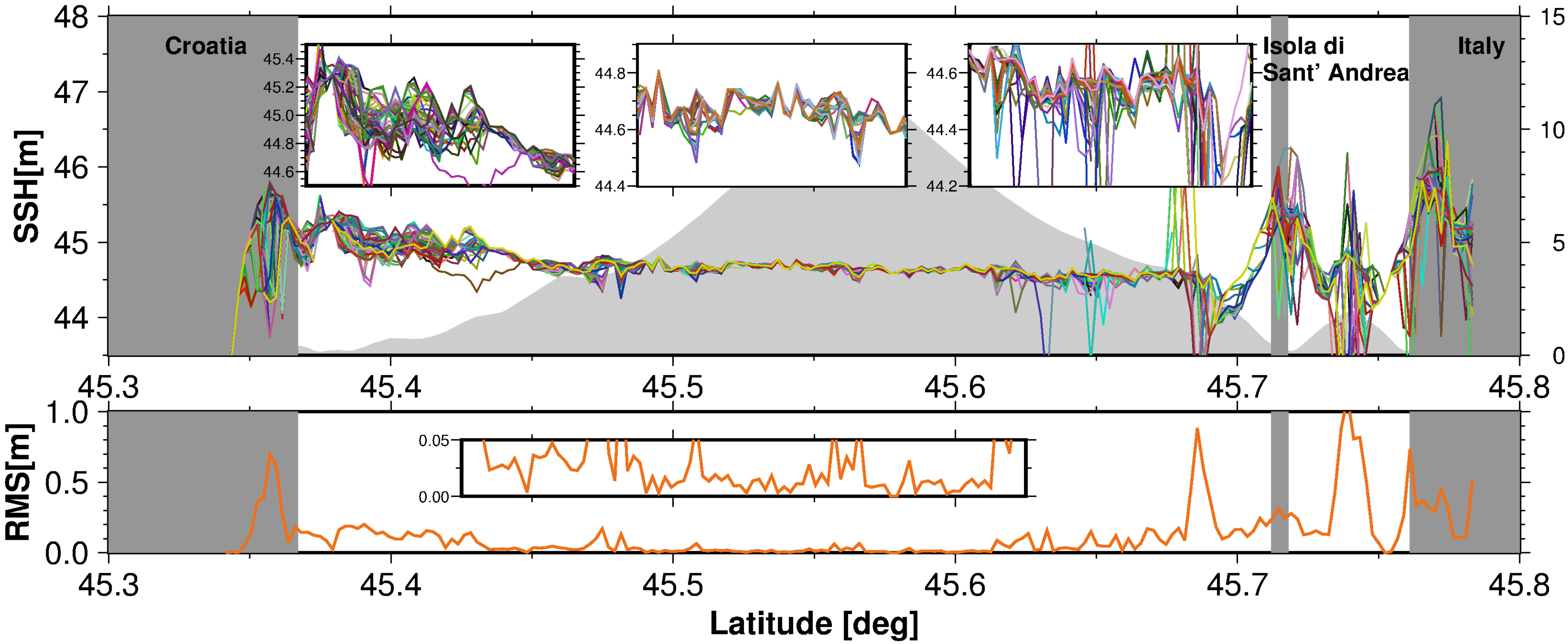
ITR: Hwang et al. (2006) **ALES**: Passaro et al (2014)

Results and Validation

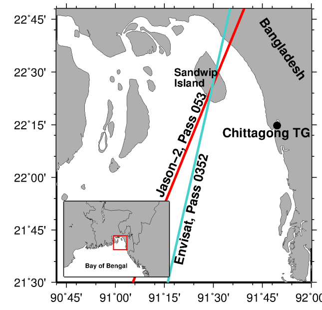


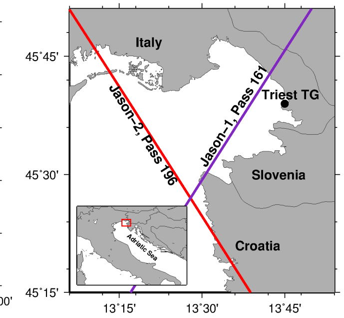
Repeatability of STAR

- Random generation of base functions results in varying SSH for multiple runs of the same pass and cylce.
- 1000 runs of Jason-2, Pass 196, Cycle 165



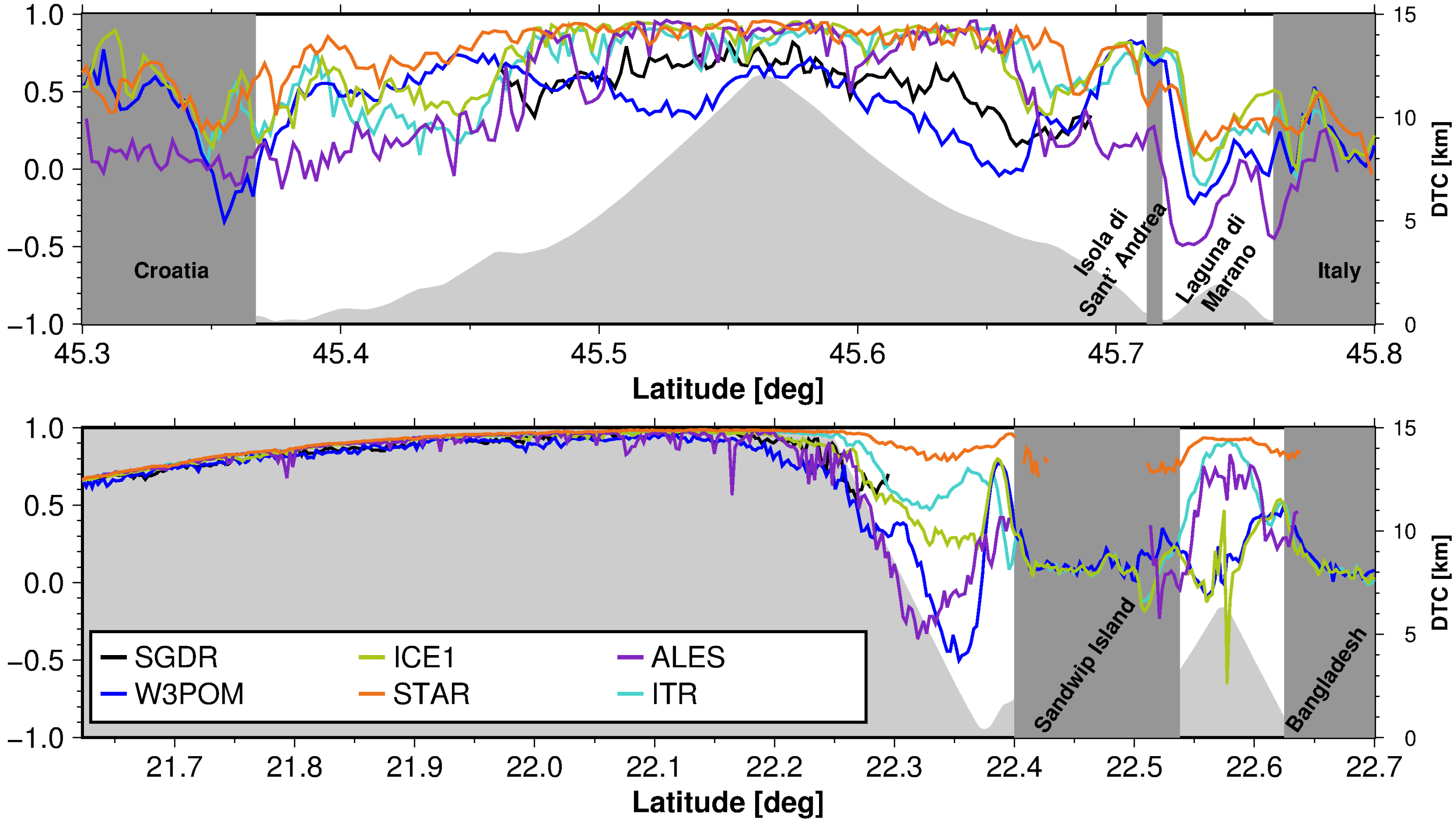
Results and Validation





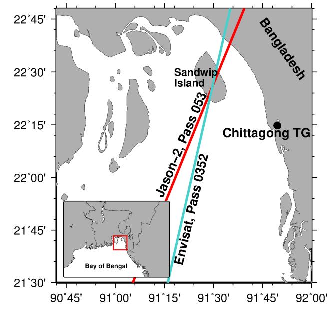
Overall Correlation

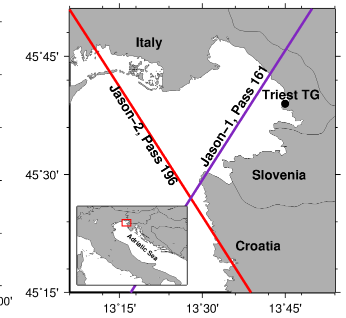
- Hourly tide gauge data and altimetry (2009/07-2014/12)
  - No ocean tide/atmosph. pressure correction applied; outliers removed



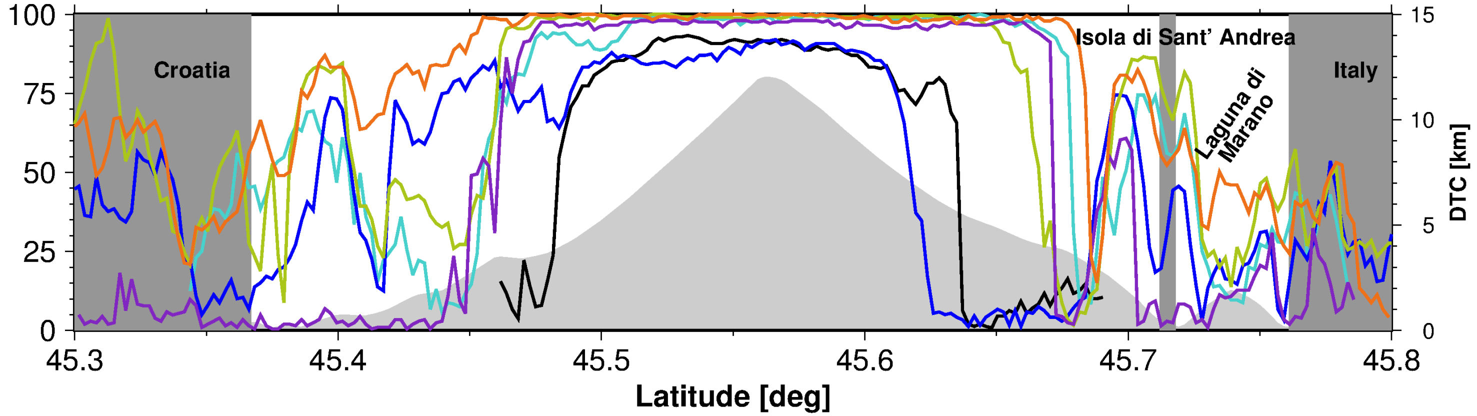
Results and Validation

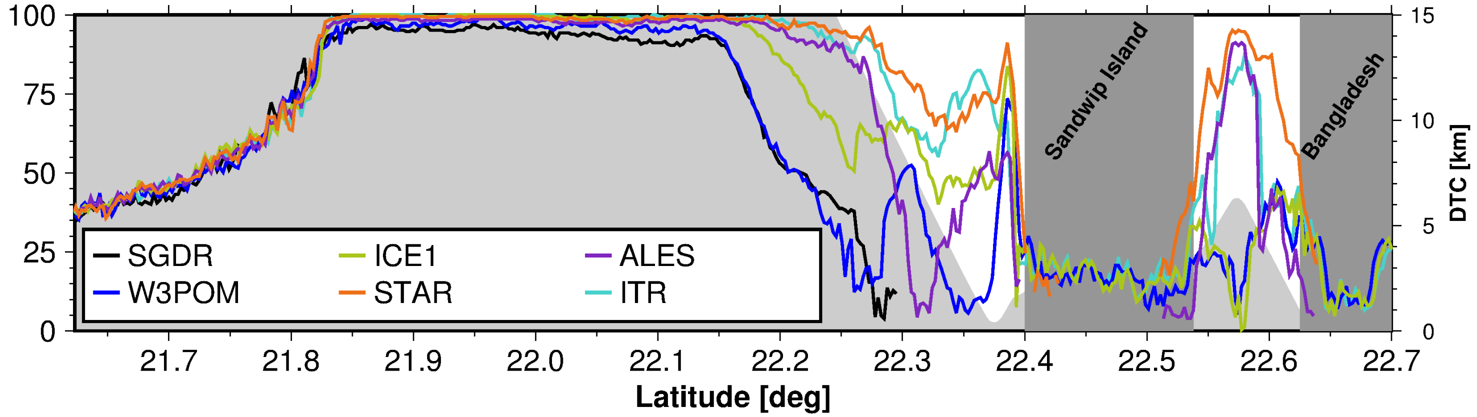
Retained Cycles





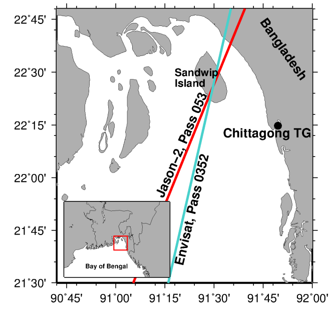
- Percentage of retained cycles (2009/07-2014/12)
  - Iteratively remove largest difference until correlation >0.9

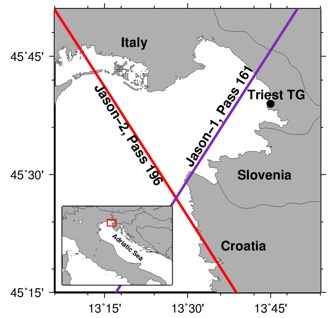




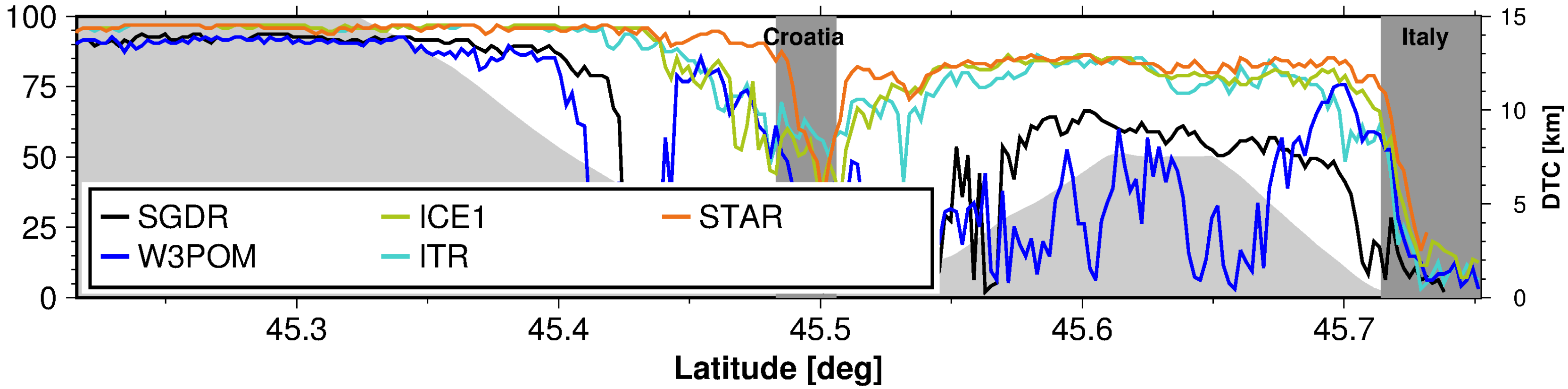
Results and Validation

Application to Jason-1 and Envisat Data

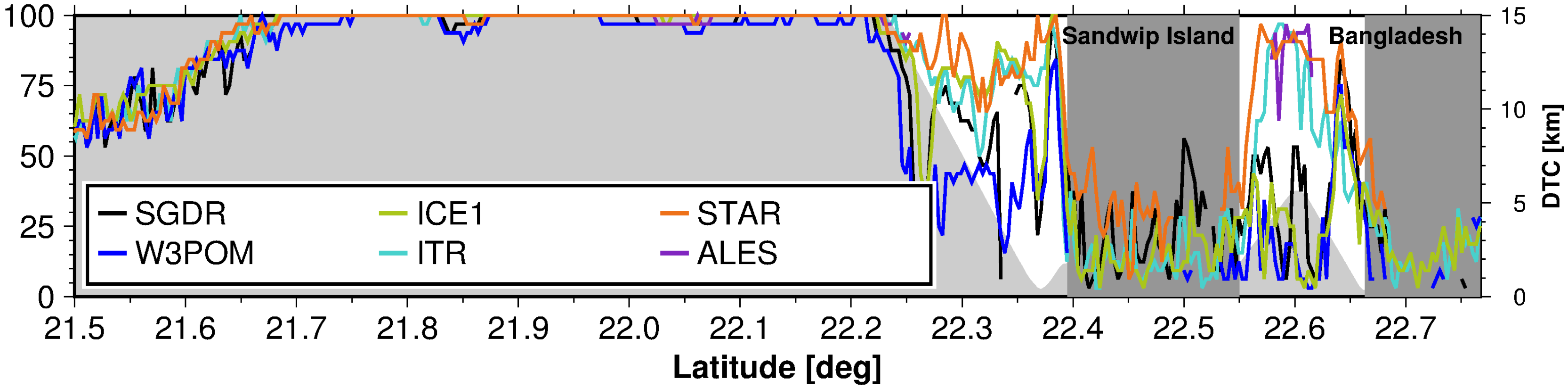




- Jason-1, Pass 161: Percentage of retained cycles (Gulf of Trieste)



- Envisat, Pass 0352: Percentage of retained cycles (Bay of Bengal)



Summary and Conclusions

- Novel approach for deriving sub-waveforms
  - Incorporating neighboring information using conditional random field
  - Partitioning of the entire waveform
  - Combination with any retracking model possible
  - Point cloud of possible SSH (same for SWH and Sigma-naught)
- STAR method generally provides coastal SSHs of at least the same quality or better for a larger number of retained cycles (>20% in some regions) compared to other methods
  - Variation introduced by the random component is in range with other modifications (e.g. weighting scheme, MLE/WLS …)
  - Quality of Cryosat-2 PLRM-STAR SSHs is comparable to SAR mode data (see pres. by Fenoglio-Marc et al. at SAR altimetry workshop)
  - Next steps: further investigate SWH and Sigma-naught

Roscher, R., Uebbing, B. and Kusche, J. (2016/17). STAR: Spatio-Temporal Altimeter Waveform Retracking using Sparse Representation and Conditional Random Fields. *Remote Sensing of Environment* (submitted)