New developments in data assimilation in MIKE 21/3 FM

Assimilation of along-track altimetry data with correlated measurement errors

EnKF Workshop 2016-06-20

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Agenda

- Background
- Data assimilation in MIKE 21/3 FM
- Data assimilation with correlated measurement errors
- Case study: Adriatic Sea

Personal background and DA projects

- About Jesper
  - PhD in Applied Maths 2009
  - Numerical engine development (new MIKE 3)
  - Forecast systems (The Water Forecast by DHI) e.g. Venice OFS
  - Data Assimilation (LOTUS) since 2015
- FP-7 LOTUS (2012-2015) Task 5.3
  - Marine: DA of along track altimetry data in MIKE 21/3 FM
  - DHI also in-land DA
- NordForsk EmblA (2014-2018) WP4
  - Local high-res forecast systems (Flather boundary conditions)
  - Spectral wave-monitoring data
  - DHI also in-land DA

Objective of LOTUS Task 5.3

Develop and demonstrate a new data assimilation approach in which along-track satellite altimetry are directly assimilated into a high-resolution ocean model

Data assimilation in MIKE Powered by DHI

MIKE 3

3D modelling of coast and sea

FEFLOW

Advanced groundwater modelling

MIKE SHE

Integrated hydrology

MIKE 21

2D modelling of coast and sea

MIKE HYDRO

Integrated basin management

MIKE by DHI

LITPACK

Littoral processes and coastline kinetics

MIKE 11

Unlimited river modelling

WEST

Modelling and simulation of WWTPs

MIKE URBAN

Urban water modelling

MIKE FLOOD

Urban, coastal and riverine flood modelling

Marine process overview

HYDRODYNAMICS

- Tidal flows
- Storm surges
- Wave-driven flows
- Oceanographic circulations
- Density-driven flows

ENVIRONMENT

- Advection-dispersion modelling
- Oil spill modelling
- Open water quality modelling
- Simulation of behaviour and fate of living organisms

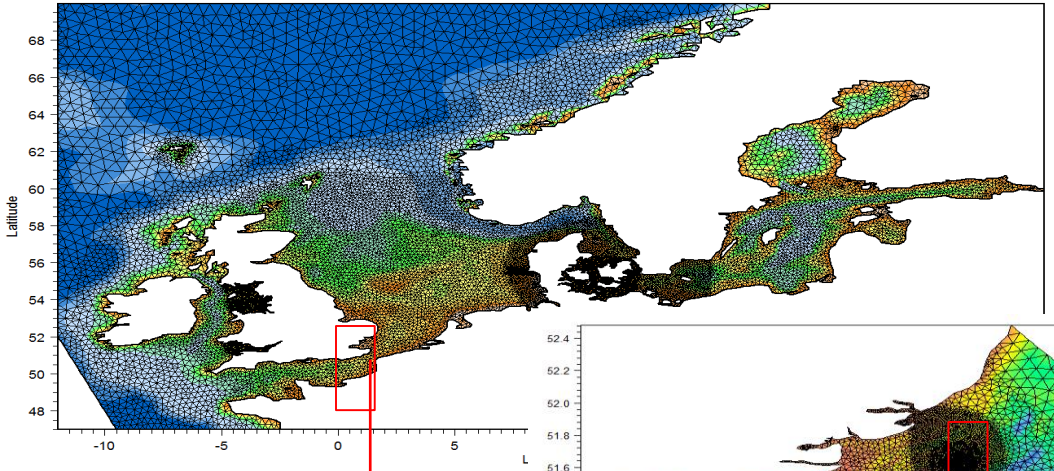
SEDIMENTS

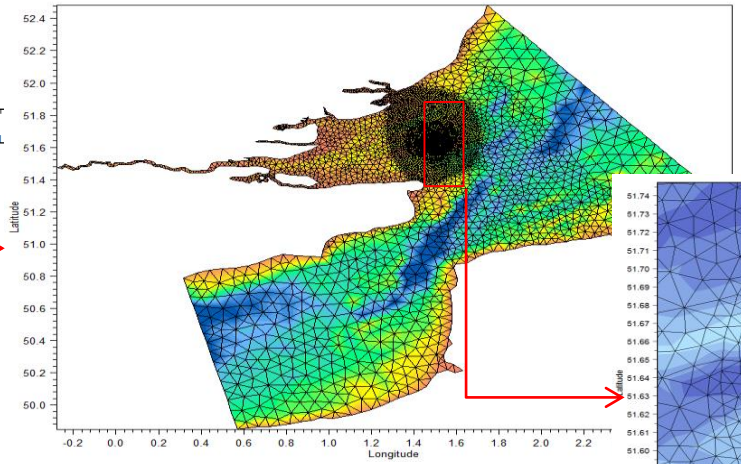
- Mud transport
- Particle tracking
- Sand transport
- Coastal morphodynamics

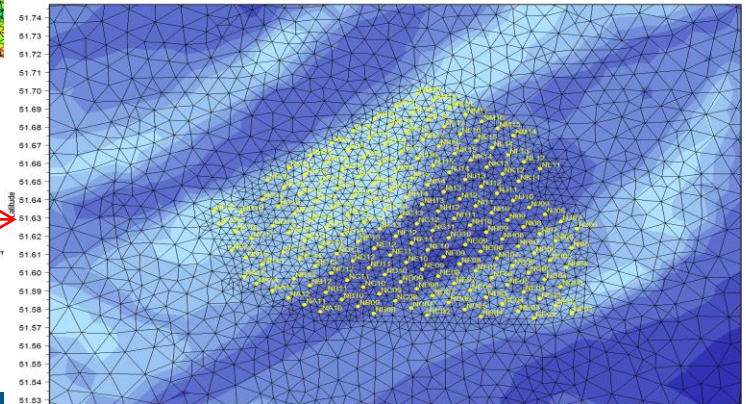
WAVES

- Offshore
- Coastal regions
- Harbours

Flexible meshes: downscaling from regional to local wave and current models







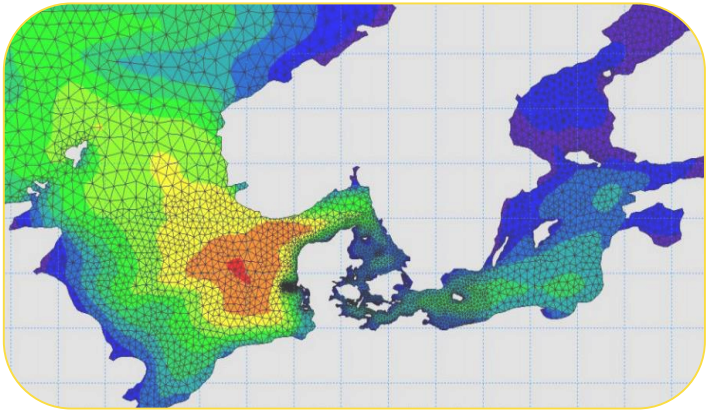
MIKE 21/3 FM system for waves and currents utilizing flexible mesh

Data assimilation in MIKE 21/3 FM

Data assimilation in MIKE 21/3

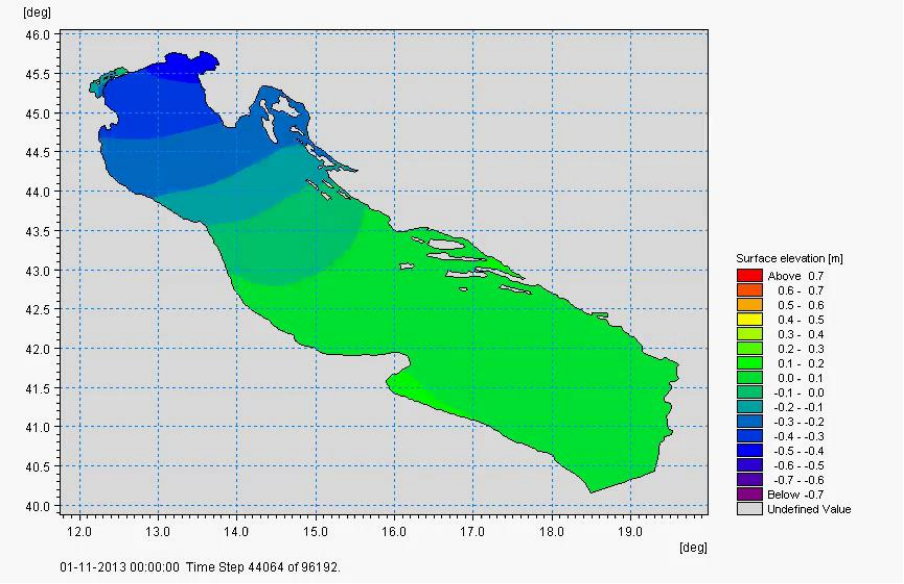
Development started in 1999 in MIKE 21/3 classic, later in MIKE 21/3 FM

- Sequential DA with Ensemble Kalman filter (EnKF)
- Mostly assimilation of tide gauge station data
- Examples of operational DA models
  - NE Atlantic Hindcast/Forecast
  - Great Lakes Forecast
  - Caspian Sea Forecast
  - Venice Forecast (2016)



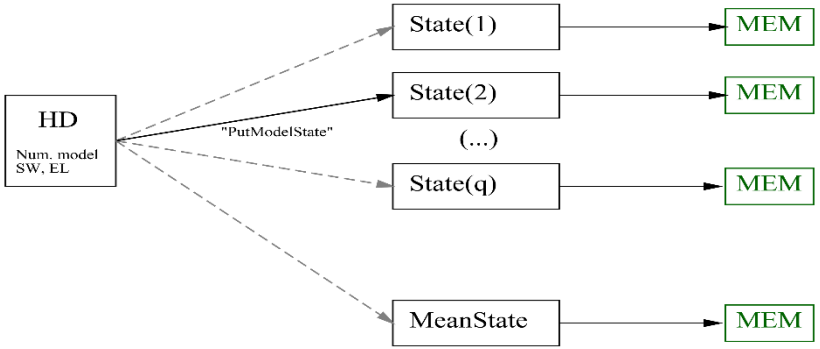
MIKE 21 Hydrodynamic model

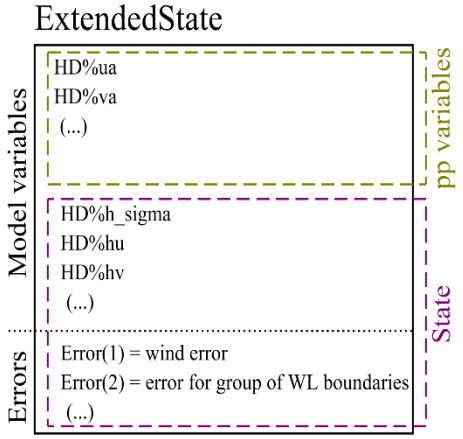
- Large models $n \approx 10^5 - 10^8$
- Forcing driven:
  - Wind
  - Water level at open boundaries

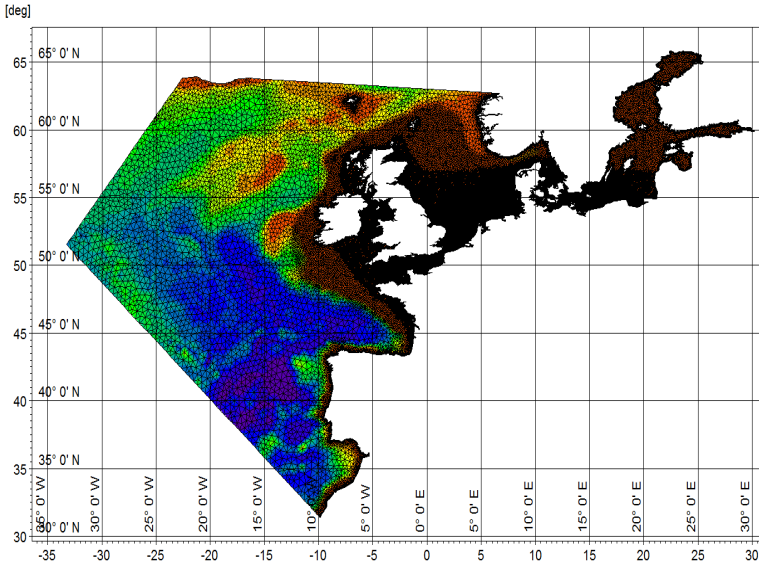


State representation in MIKE 21/3 FM

- Model variables according to selected modules
  - State variables (h, hu, …) and additional “PP” variables
- Model errors
  - Types: wlbc group, wind-u, wind-v,
  - Propagation: AR(1), temp-, spatial-corr-scale
- Pointers to model variable data







FM **DA** Module before 2015

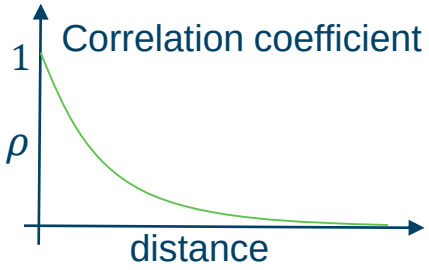
- Few fixed positioned tide gauge stations
- Sequential algorithm – one station at a time (Andersson&Andersson)
- Regularization
  - Error covariance temporal smoothing
  - Error covariance localization
- Steady run (re-using saved averaged error cov. from hindcast study)

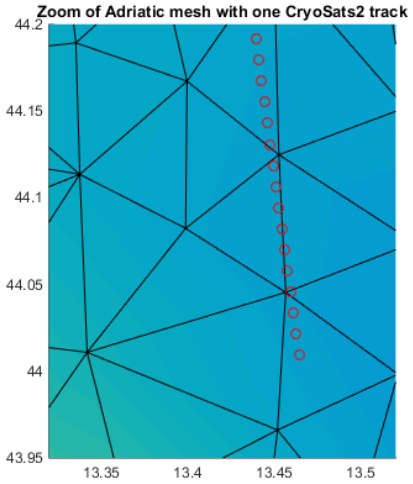
New developments in FM DA Module (2015)

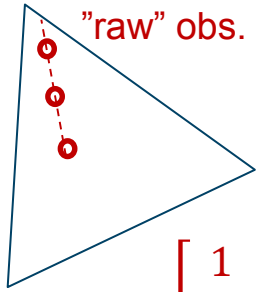
- New data structures and organization to allow changing positions and number of observations
- Implementation of ETKF and DEnKF (inspired by code by P. Sakov)
- Localization by Local Analysis
- Reading and processing track data observations (point set)
- Other: Several error formulations pr model error, improved data structures (abstraction), EnOI (in progress), improved IO, diagnostics, inflation, observation operator interpolation

Assimilating along-track satellite altimetry

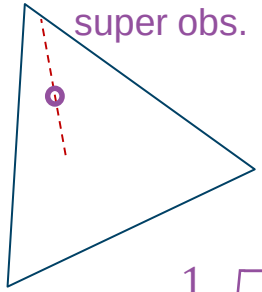
Measurement Error Covariance – correlated errors





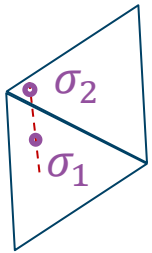


$$R_{loc} = \sigma^2 \begin{bmatrix} 1 & \rho_{12} & \rho_{13} \\ \rho_{21} & 1 & \rho_{23} \\ \rho_{31} & \rho_{32} & 1 \end{bmatrix}$$



$$\sigma_{super} = \frac{1}{n}\sqrt{\Sigma_i^n \Sigma_j^n \sigma_{ij}^2}$$

$$\sigma_{ij} = \rho_{ij}\sigma_i\sigma_j$$



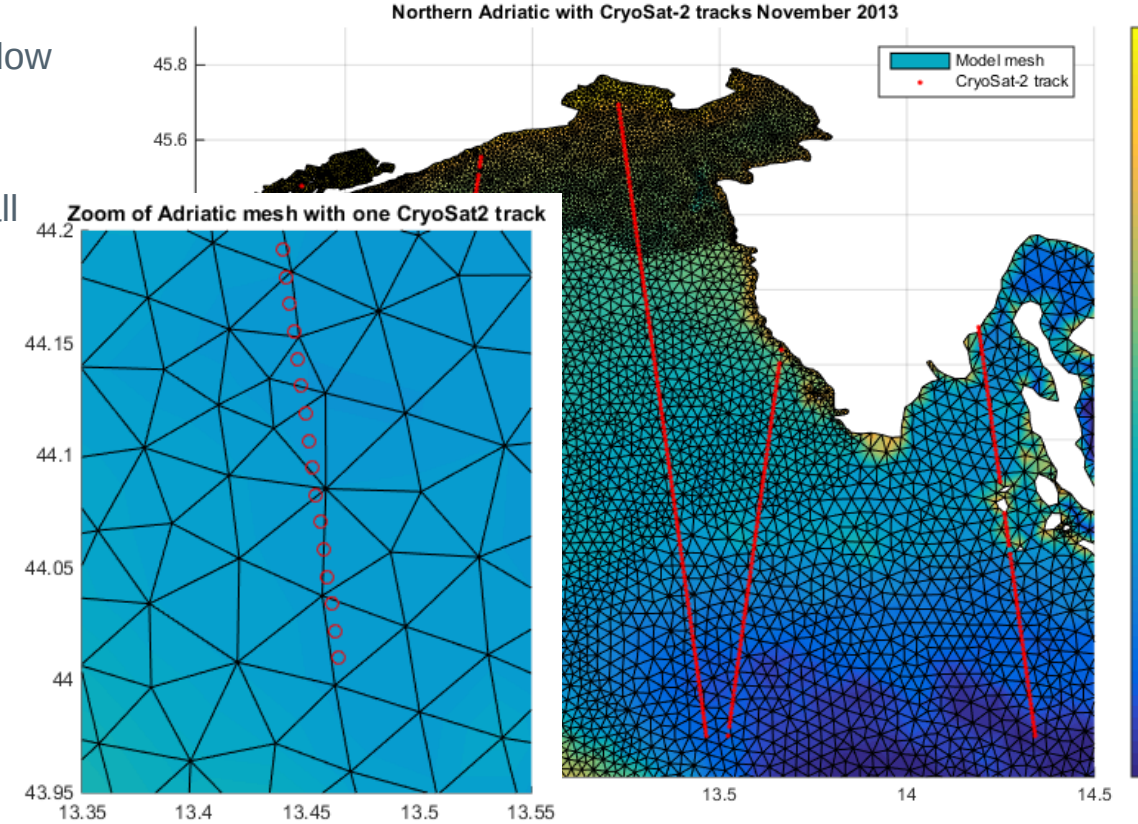
Construct R with all super obs. for this time step (here 2)

$$R = \begin{bmatrix} \sigma_1^2 & \sigma_{12} \\ \sigma_{21} & \sigma_2^2 \end{bmatrix}, \sigma_{ij} = \rho_{ij}\sigma_i\sigma_j$$

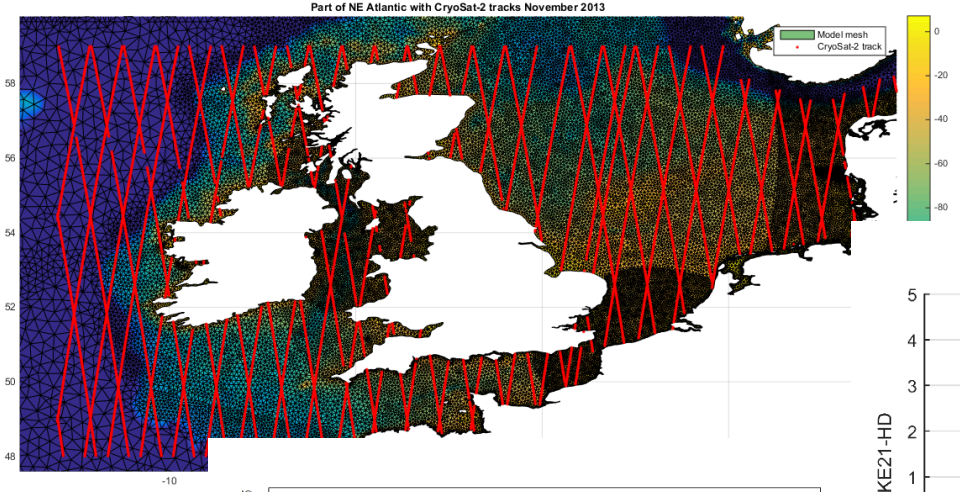
Along track altimetry observations(1)

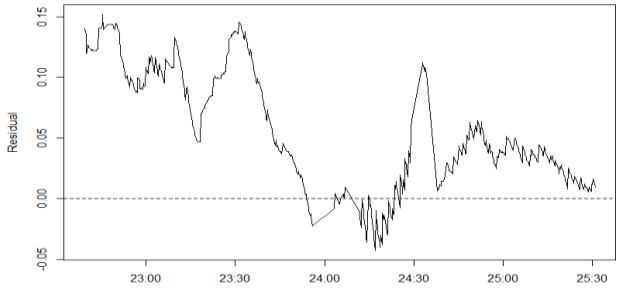
1. Collect all observations in time window
2. For each element: create super observation with adjusted st. dev.
3. Construct R for this time step with all super observations

Validation tests performed with synthetic data

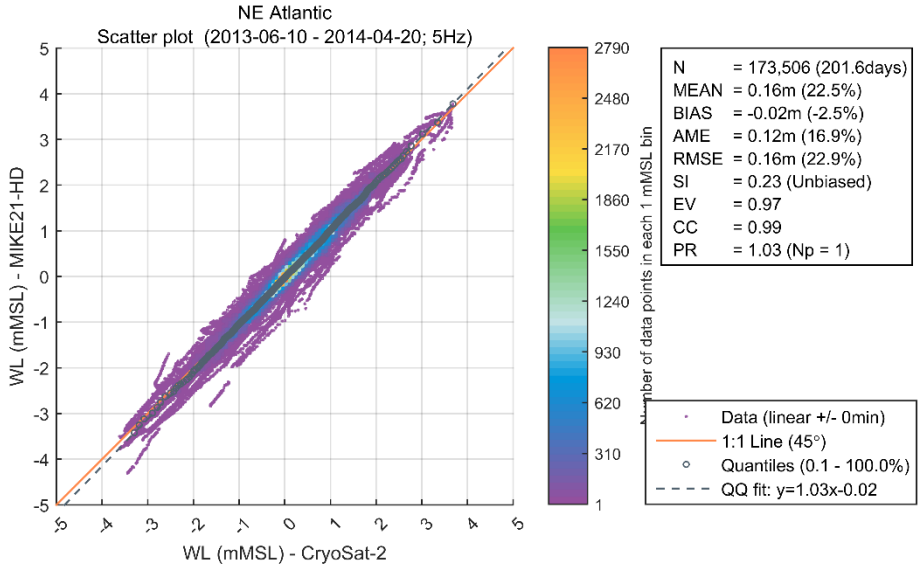


Along track altimetry observations(2) – estimating errors





- Raw data errors: st dev + correlation in time (along track)
- Estimated from difference between observations and hindcast model



Case study: Adriatic Sea

Venice Water Level Forecast

Adriatic Sea case

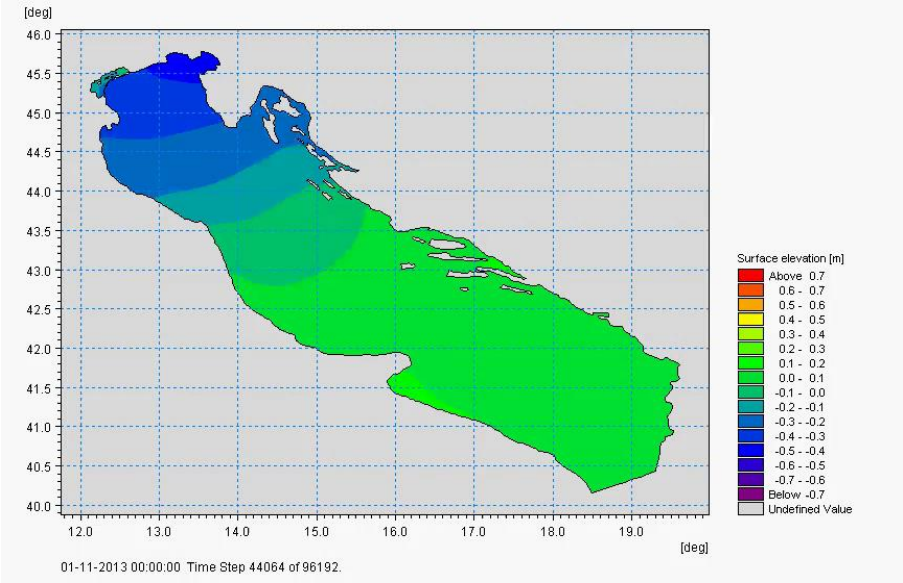
HD 2d

- Approx 5000 elements
- 11 months (June 2013 – May 2014)

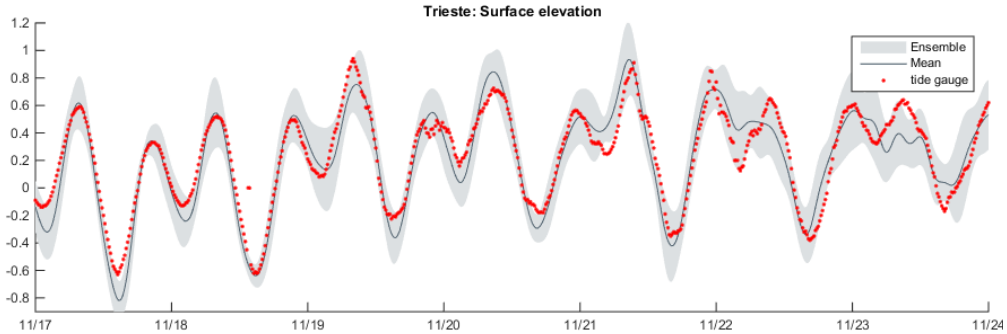
DA

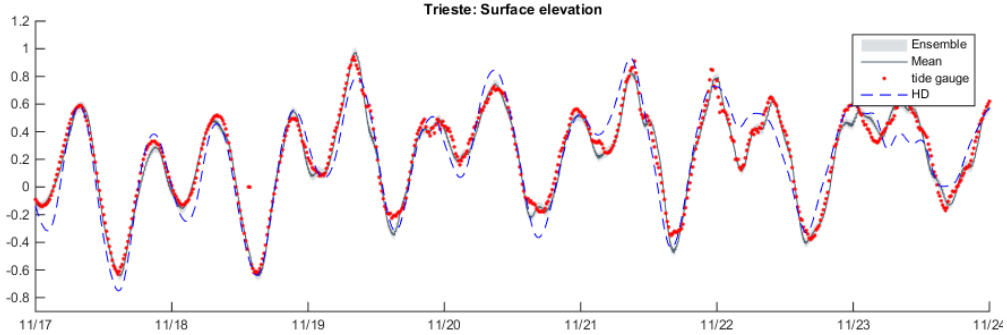
- 10 ensemble members
- Model errors
  - Wind
  - Water level on open boundary

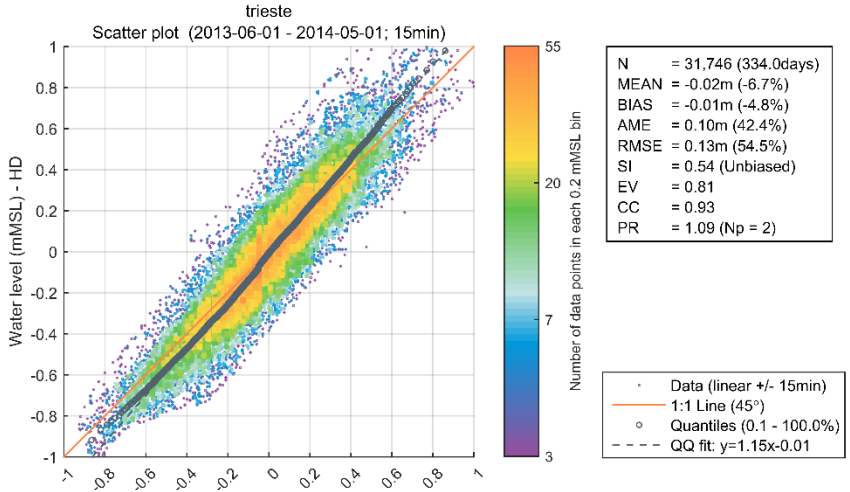
1) DA with 2 tide gauge stations
2) DA with only track data
3) DA with 2 stations and tracks

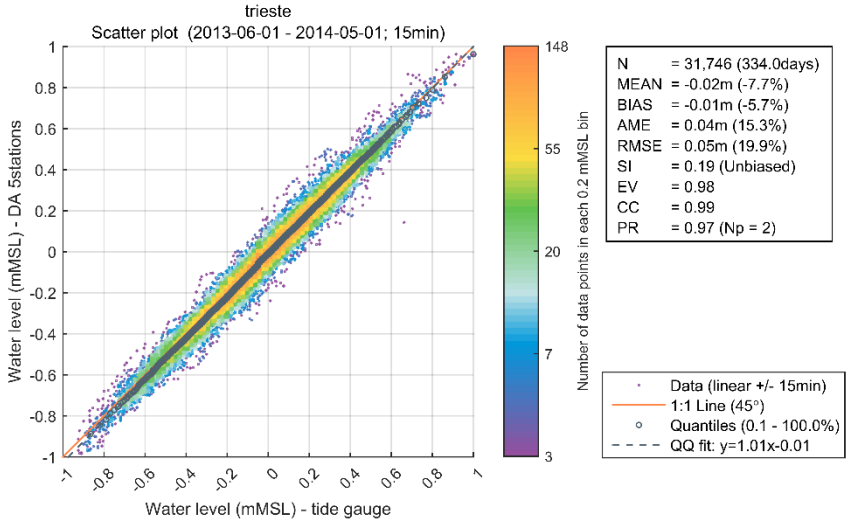


No-DA and DA with tide gauges

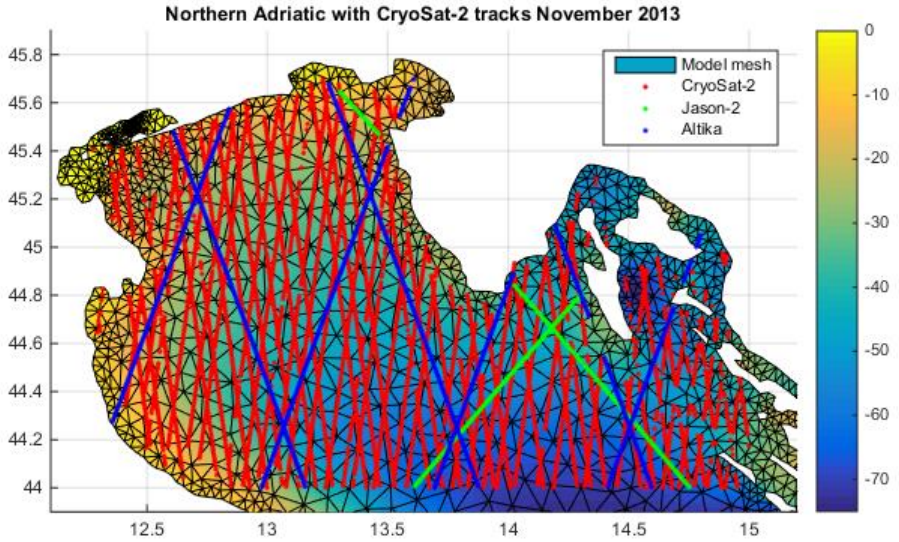








DA with along-track altimetry



Altimeter data

- Less than one minute of data a day
- Average passing frequency of 1.5 days
- Error: temporal correlation: 25 sec
- Error: st. dev. 5 cm

RMSE in cm

	HD (no DA)	DA 2stations	DA 3 tracks	DA 2st.+3trck
Trieste (DA)	12.8	2.5	14.9	2.5
Venezia	11.5	4.0	13.0	4.0
Ravenna (DA)	12.4	7.6	13.6	7.7
Ancona	9.5	3.4	10.2	3.4

Future work

- Redo study but with more (synthetic) tracks
- Redo study in North Sea (with more tracks)
- Study the effect of different correlation parameterizations

- More model error types: Flather boundary, bathymetry
- Code parallellization (MPI)
- Assimilation of other data: Spectral Wave model: Hs, Tp, MWD
- Finish EnsembleOI
- Make it more accesible to users; DA Setup assistant etc

Thank you

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