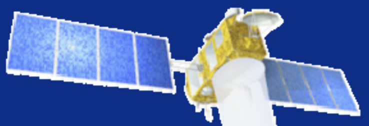
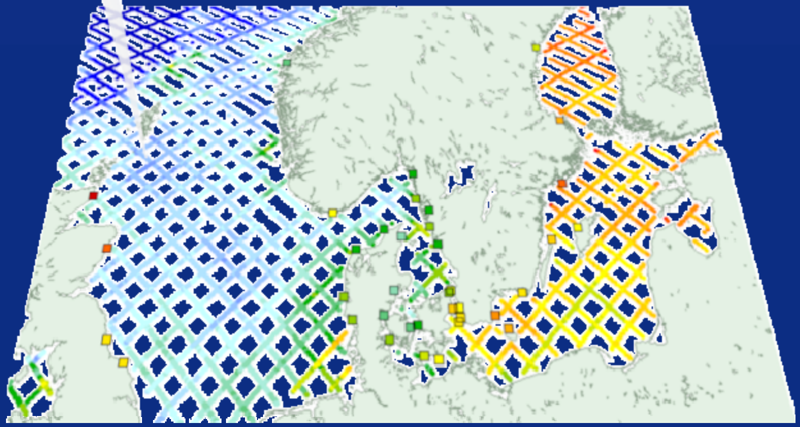
DMI
Center for Ocean and Ice



Real time sea level from satellite altimetry in coastal regions



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Danish Meteorological Institute and University of Copenhagen
With contributions from John Wilkin

Agenda

- Challenges in operational coastal altimetry
- A statistical storm surge model for the North Sea – Baltic Sea area
- Data assimilation with ROMS on the American east coast

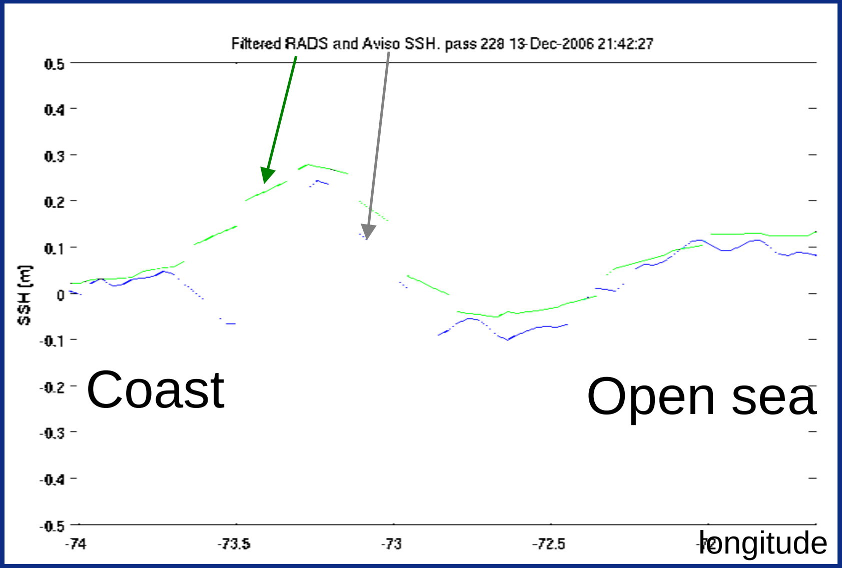
Challenges in operational coastal altimetry
A) Getting data close to the coast

Gridded products like the AVISO Ssalto/Duacs 1/3° sea level anomaly are most often made for the open ocean

- Corrections may not be valid in coastal areas
- Assumed temporal and spatial scales too long

and may be delayed (AVISO NRT 7 days delay)

Therefore: use along-track data



Challenges in operational coastal altimetry
A) Getting data close to the coast

Retracking?

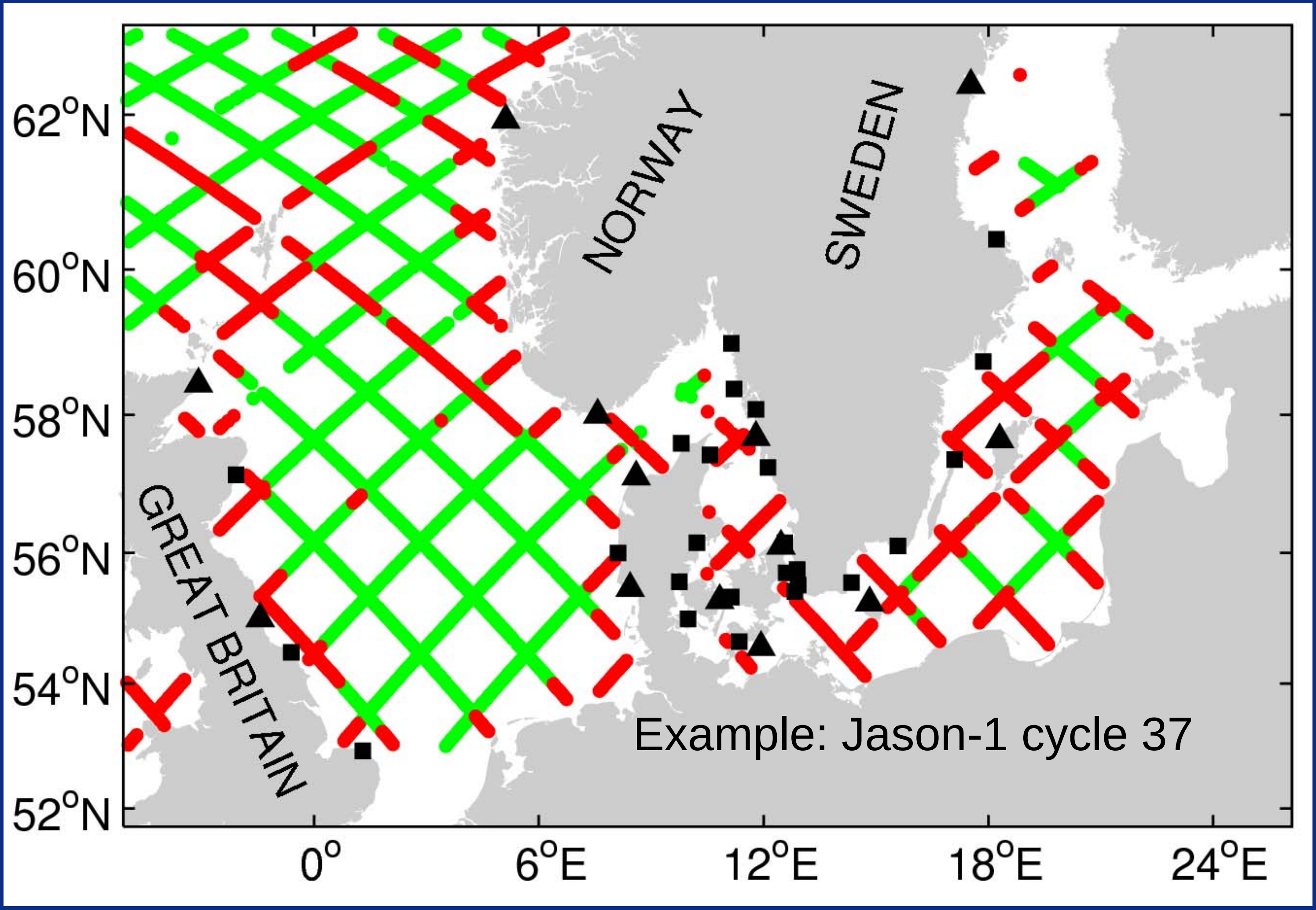
The altimeter measurement has standard Brown-like waveform until 10 – 20 km from the coast

Corrections

Tides: a local tide model is often needed

Wet tropospheric correction: the radiometer measurement has larger footprint (50 km). Therefore use model correction or set up local post processing system. Ongoing research!

Challenges in operational coastal altimetry
A) Getting data close to the coast



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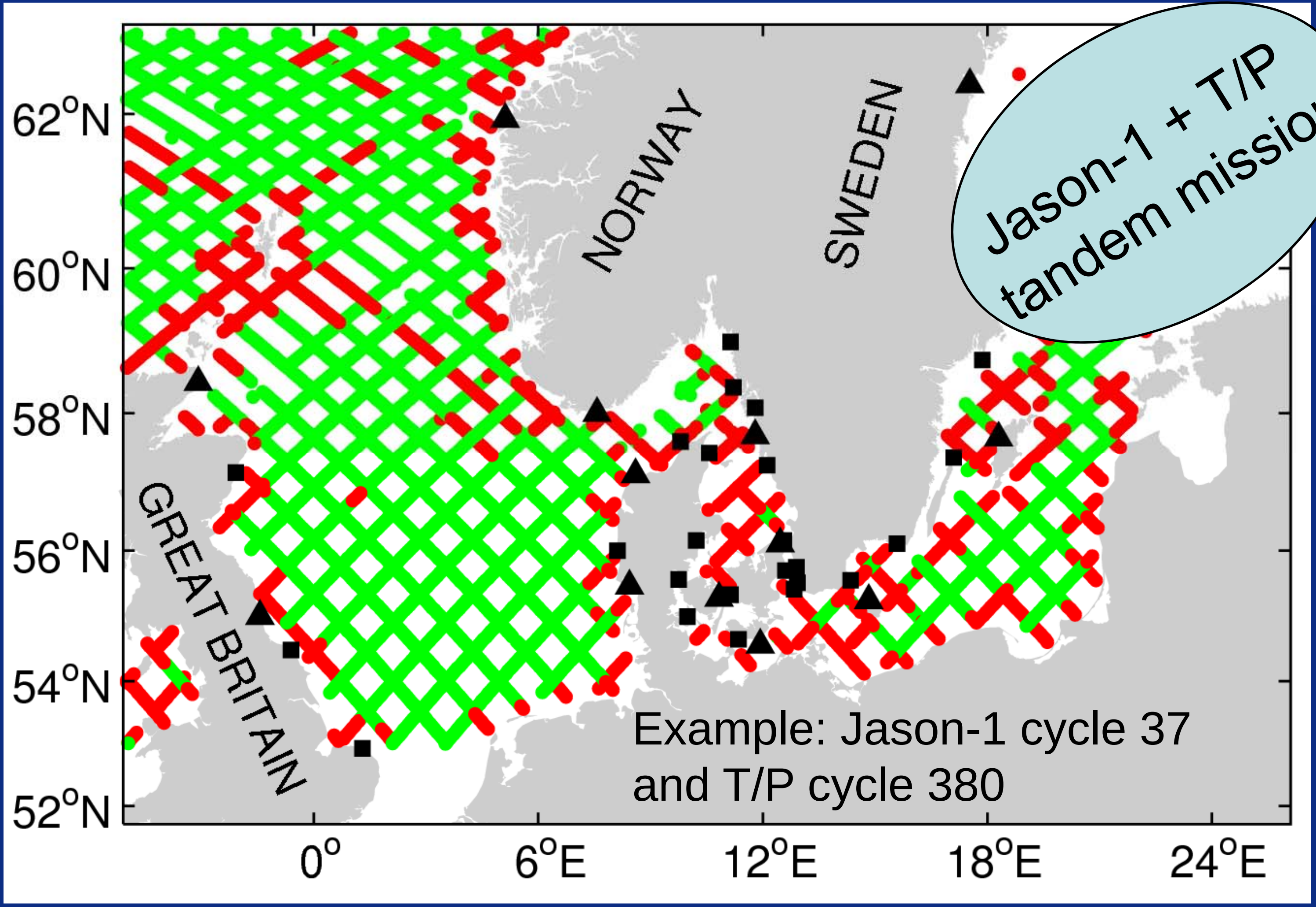
Challenges in operational coastal altimetry
A) Getting data close to the coast

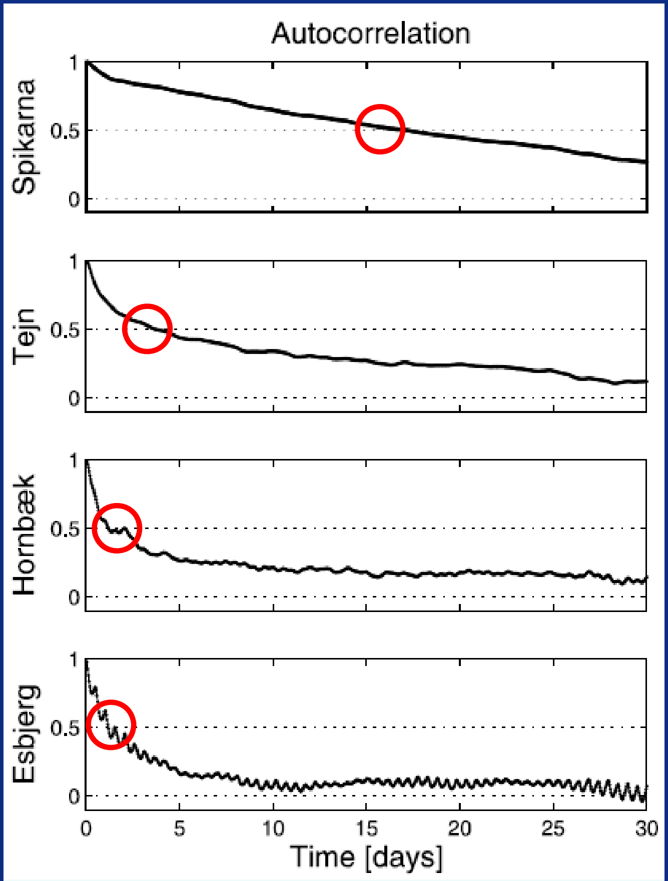


Challenges in operational coastal altimetry
B) The temporal resolution

The *time scales* in coastal systems are often much shorter than the 10 day repeat cycle

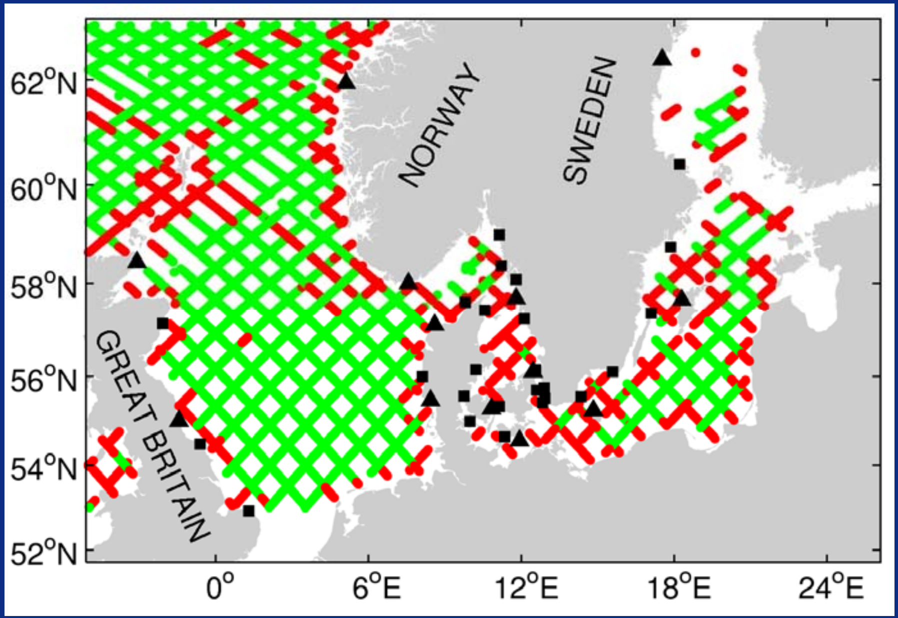
Suggested solutions

- Linking tide gauge data and altimetry through a statistical model based on variational regression analysis
- Assimilating altimetry into a 3D ocean model



Statistical model
Data used

- RADS database – along track data
- Topex/Poseidon and Jason-1 tandem mission
- ECMWF model wet tropospheric correction
- Inverse barometer effects included (no corrections)
- No global tide model corrections applied – empirical harmonic correction in North Sea
- Also: 39 tide gauges from UK, Sweden, Norway and Denmark
- Common reference system for all data – regional geoid



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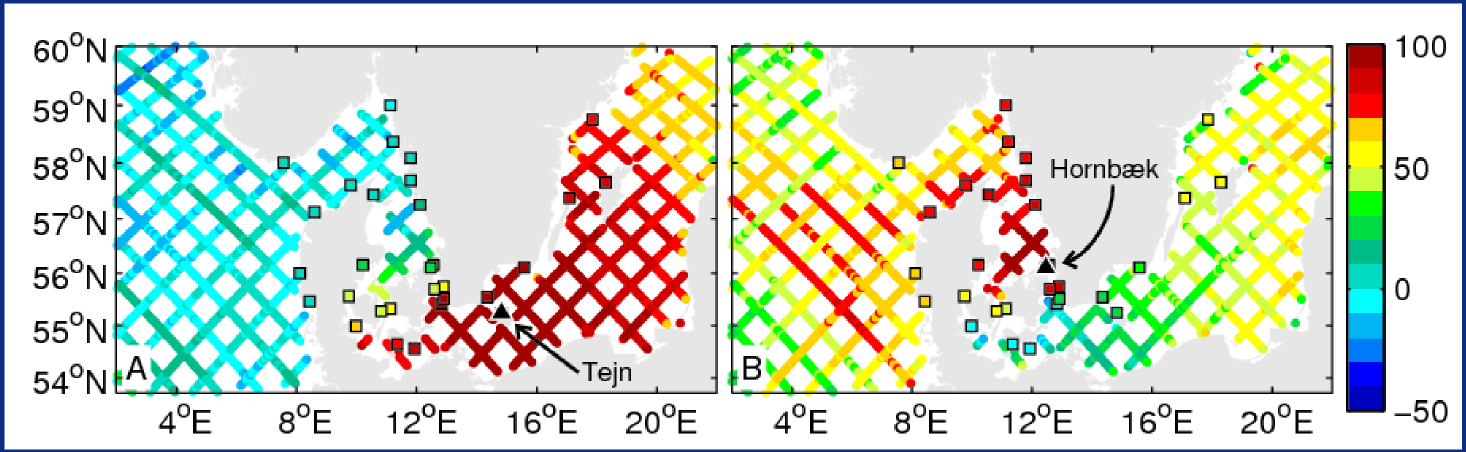
Statistical model
Method

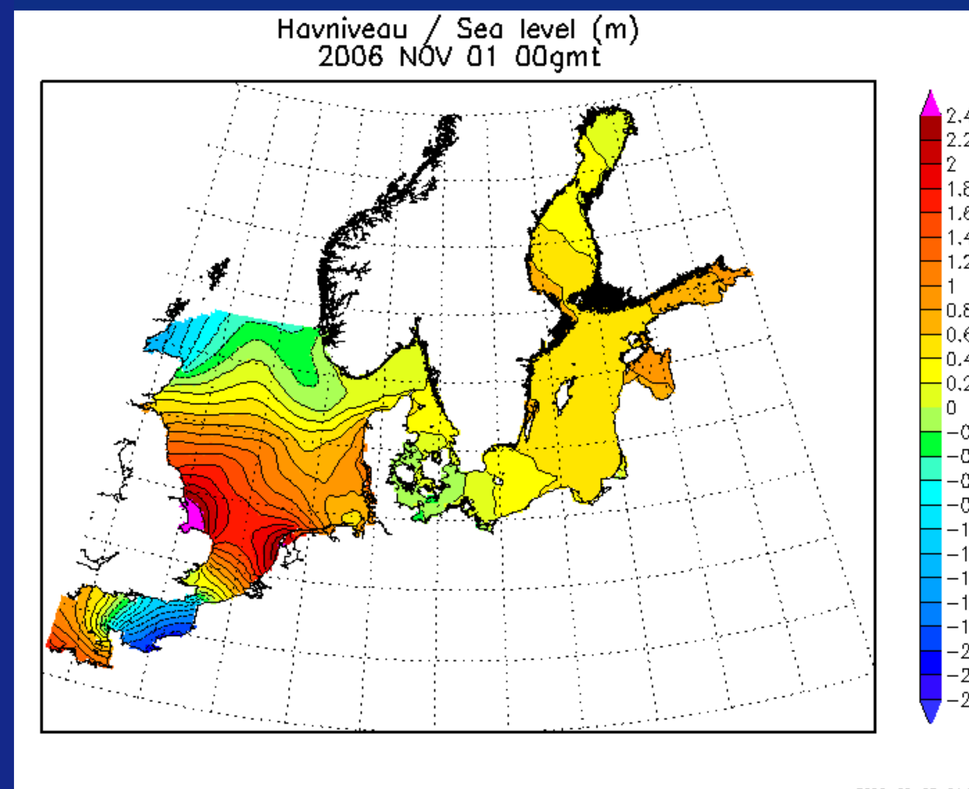
- Multivariate regression where data from 14 tide gauge stations are regressed onto the satellite altimetry observations
- Tide gauges selected based on the correlation with satellite observations
- Allows real-time sea level estimation in points where satellite data are available
- Assumes stationarity



Test case

Storm surge, November 1 2006

- 100 year event in the Danish Straits
- Caused by an unusual wind pattern with northerly winds both in Kattegat and the Baltic Sea, the resulting high waters meeting in the Danish Straits.
- Forecasted by 3D model DMI-BSHcmod (figure)



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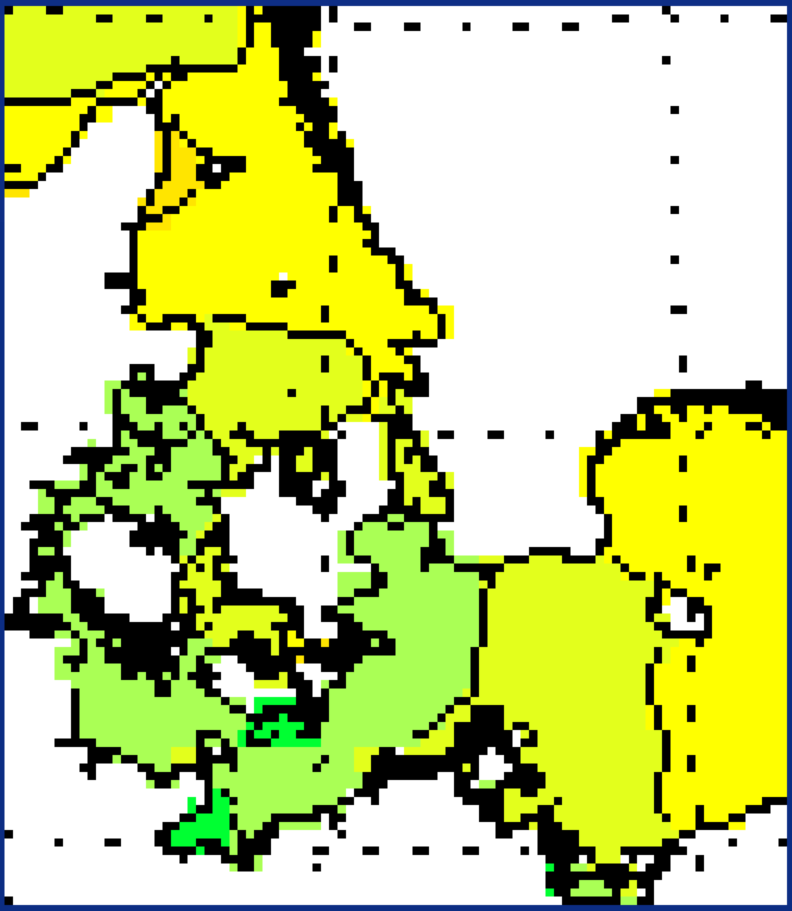
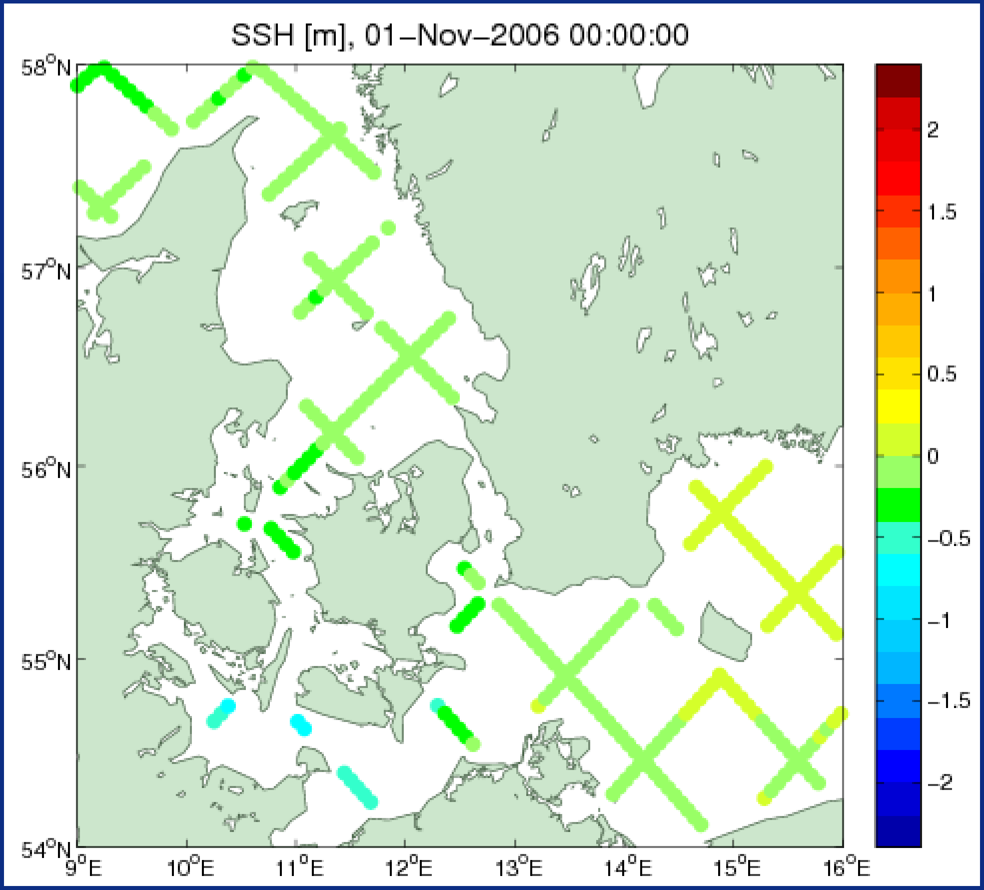
Test case – comparison of 3D model and statistical model

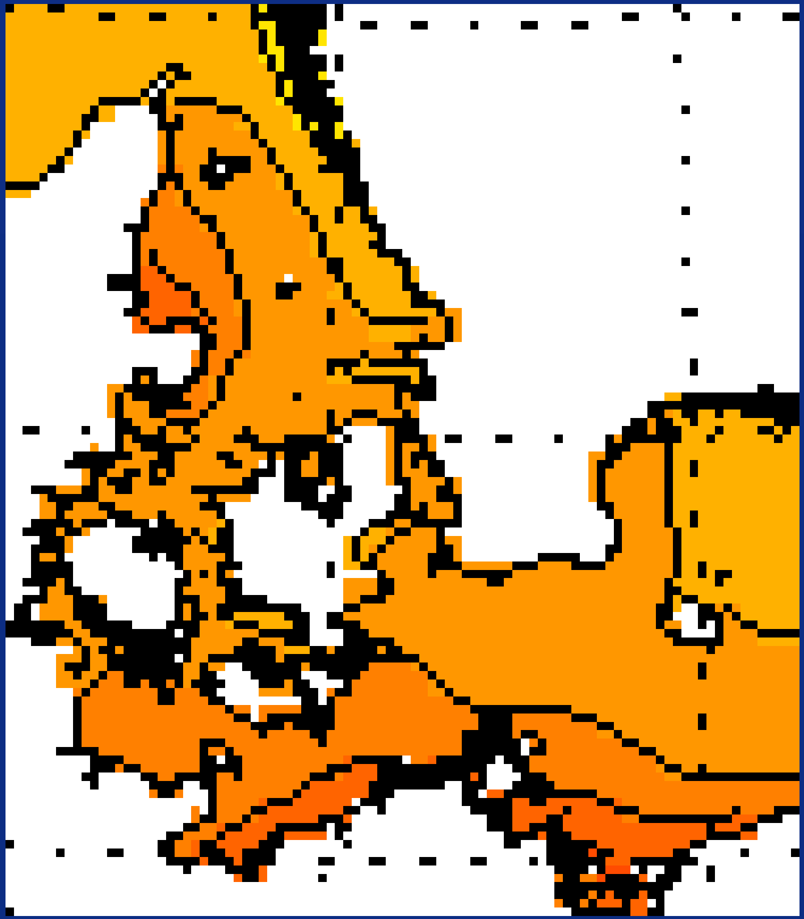
November 1 2006, 00:00

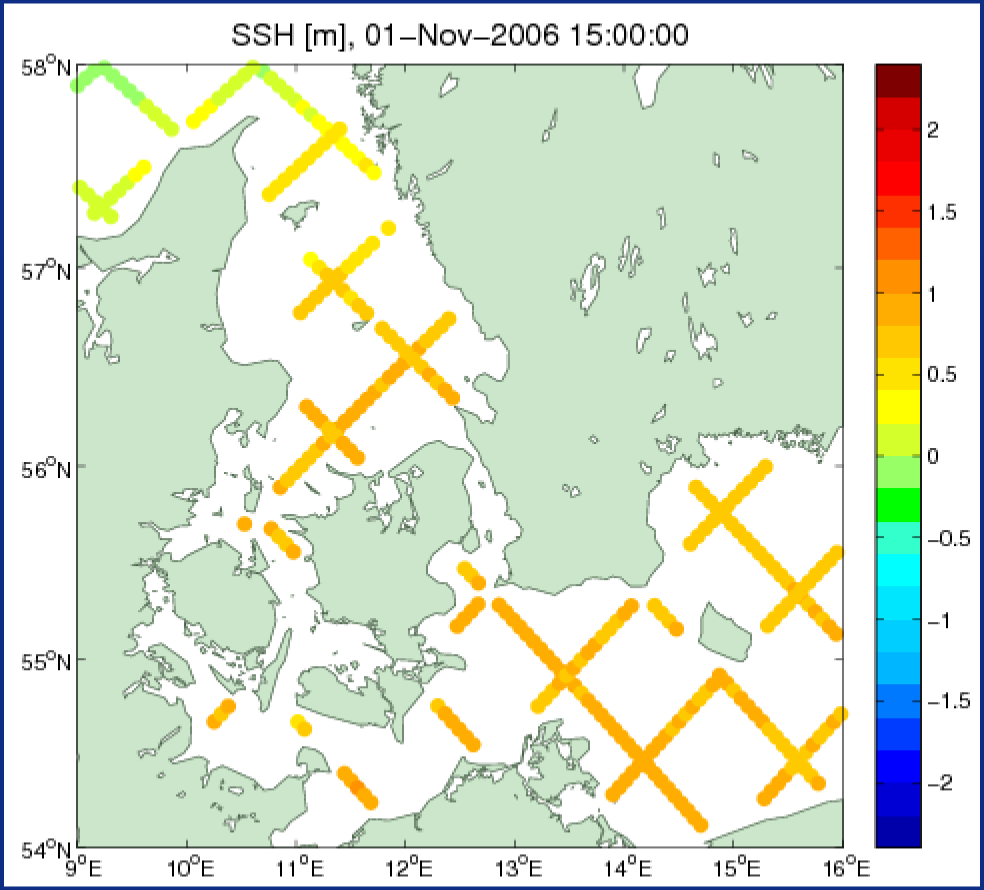




Test case – comparison of 3D model and statistical model

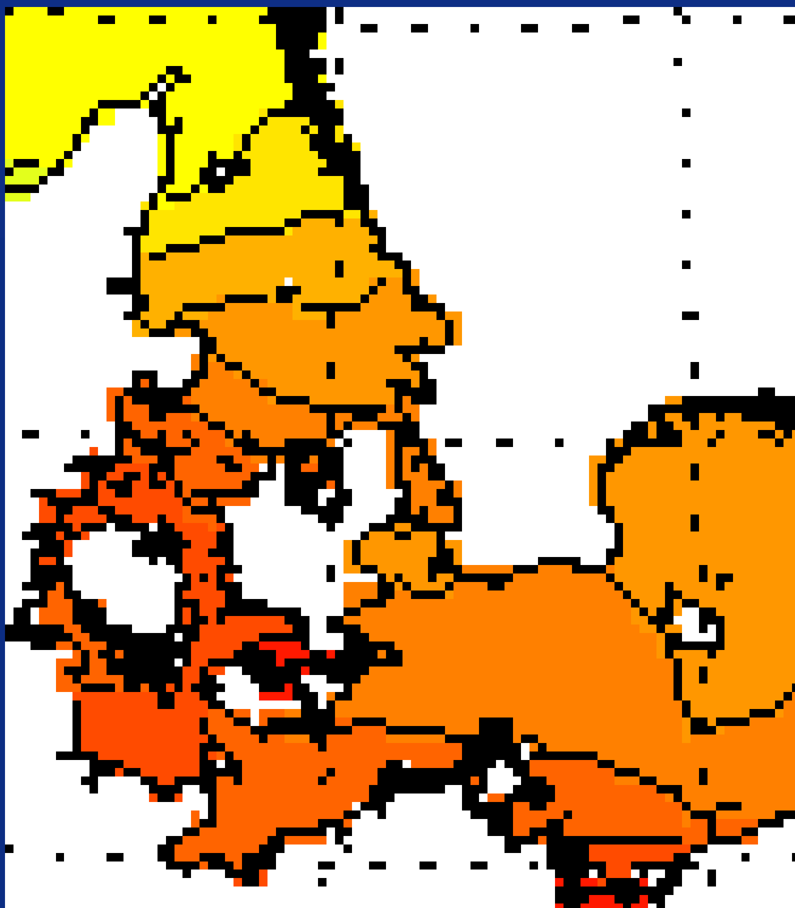
November 1 2006, 15:00

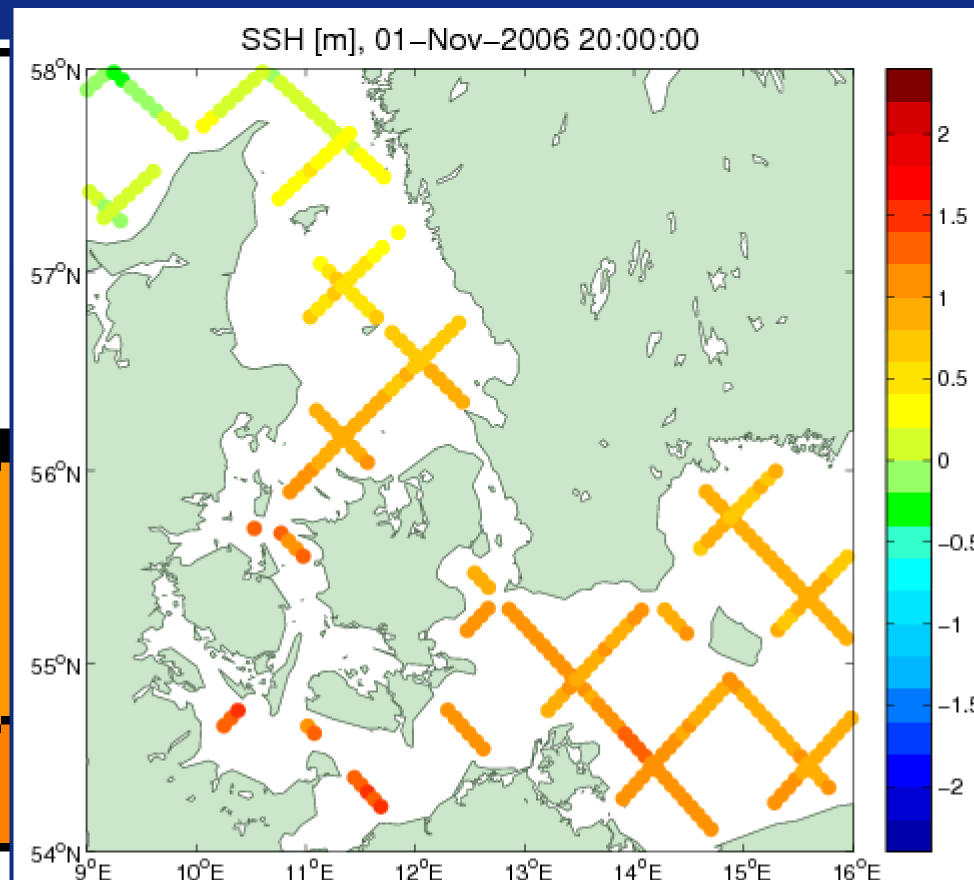




Test case – comparison of 3D model and statistical model

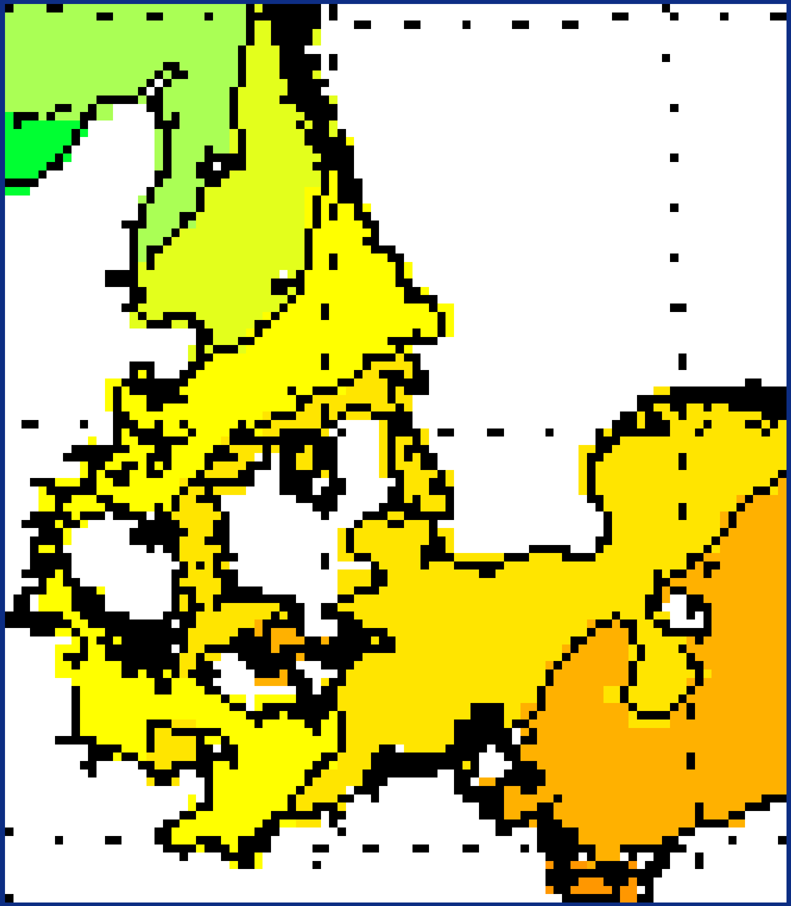
November 1 2006, 20:00

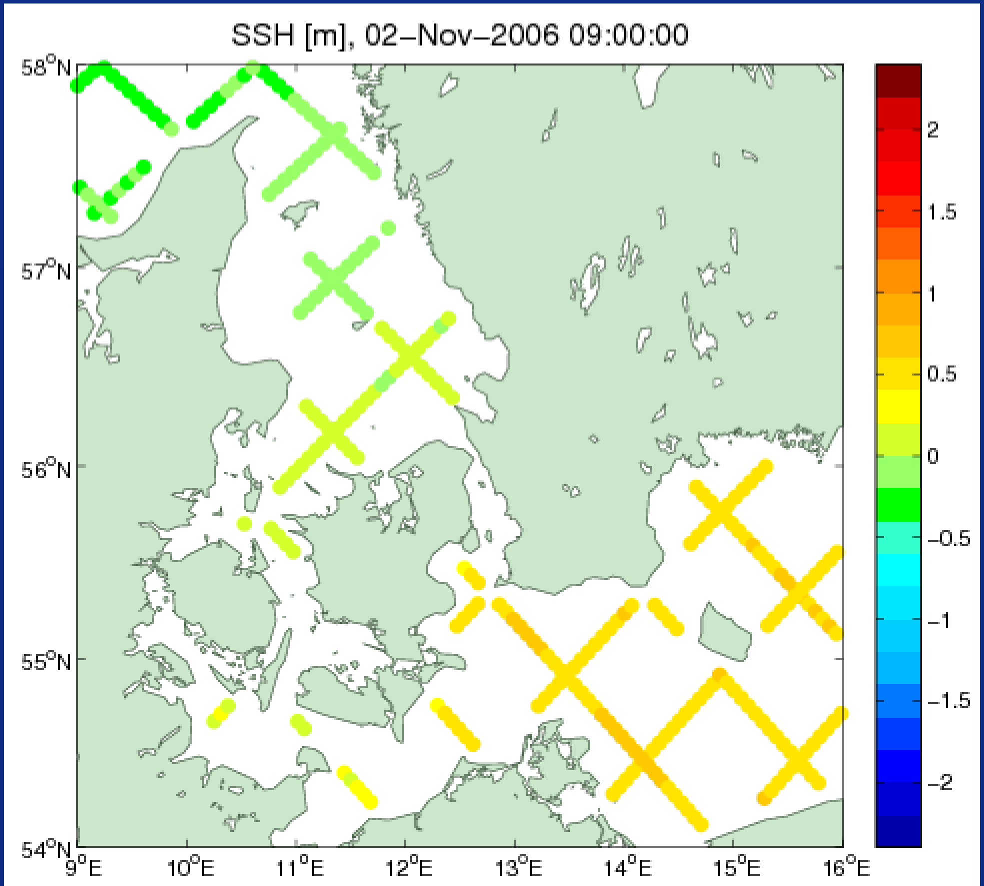




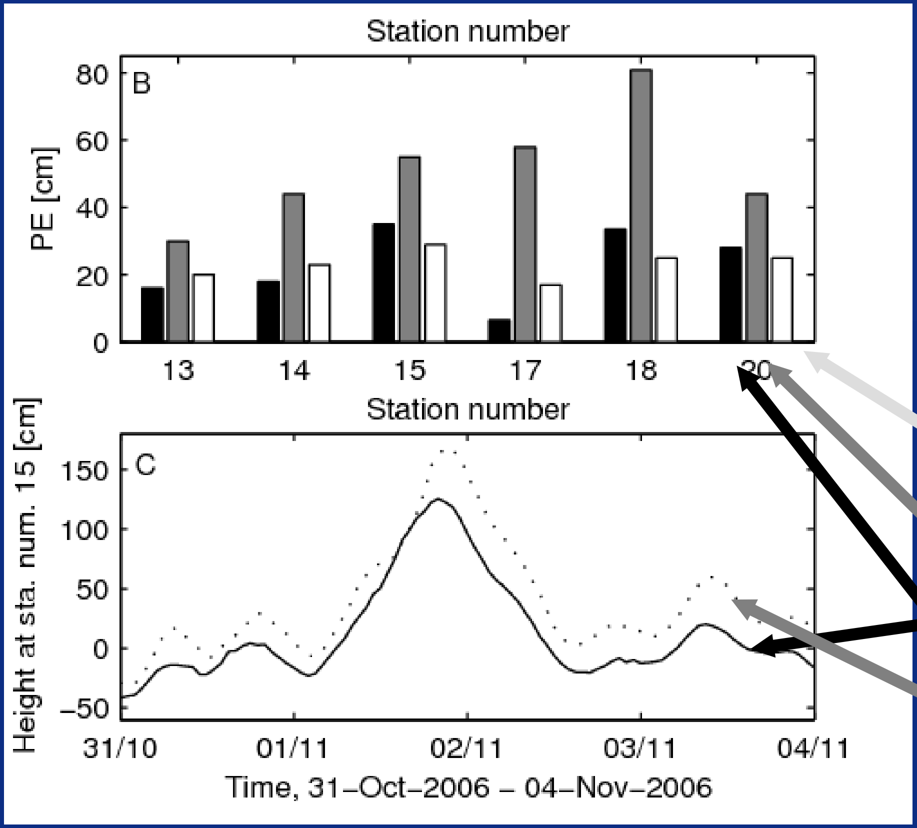
Test case – comparison of 3D model and statistical model

November 2 2006, 09:00





Test case – comparison of 3D model and statistical model



The statistical model performs better than our 2D storm surge model and similar to our 3D model

3D storm surge model

2D storm surge model

Statistical model

Observations

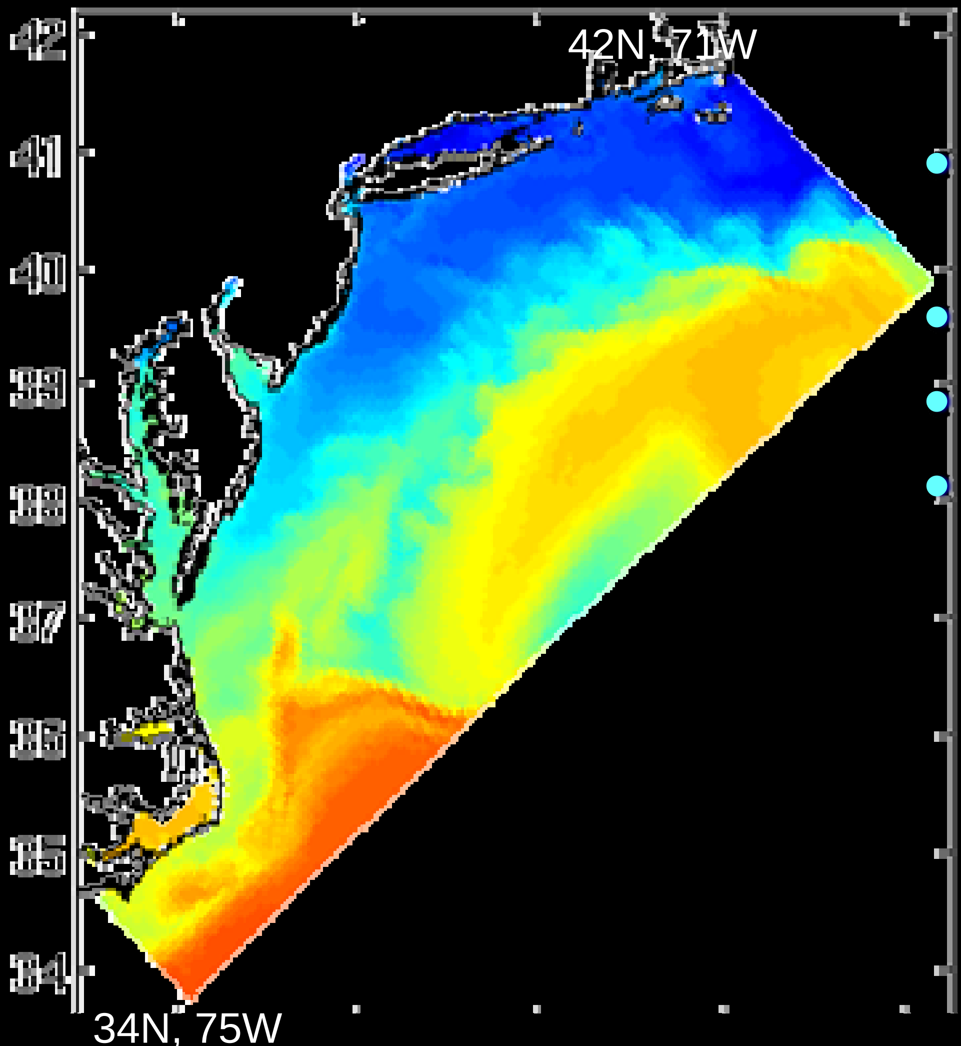
Ref: Madsen et. al., GRL, 2007

Statistical model Operationalization

We will set up this model for operational use, using:

- Real time tide gauge data
- Time varying statistics based on weekly or monthly Jason-2 OGDR and IGDR observations
- If available, also data from Jason-1 in tandem mission

Mid-Atlantic Bight ROMS model for data assimilation

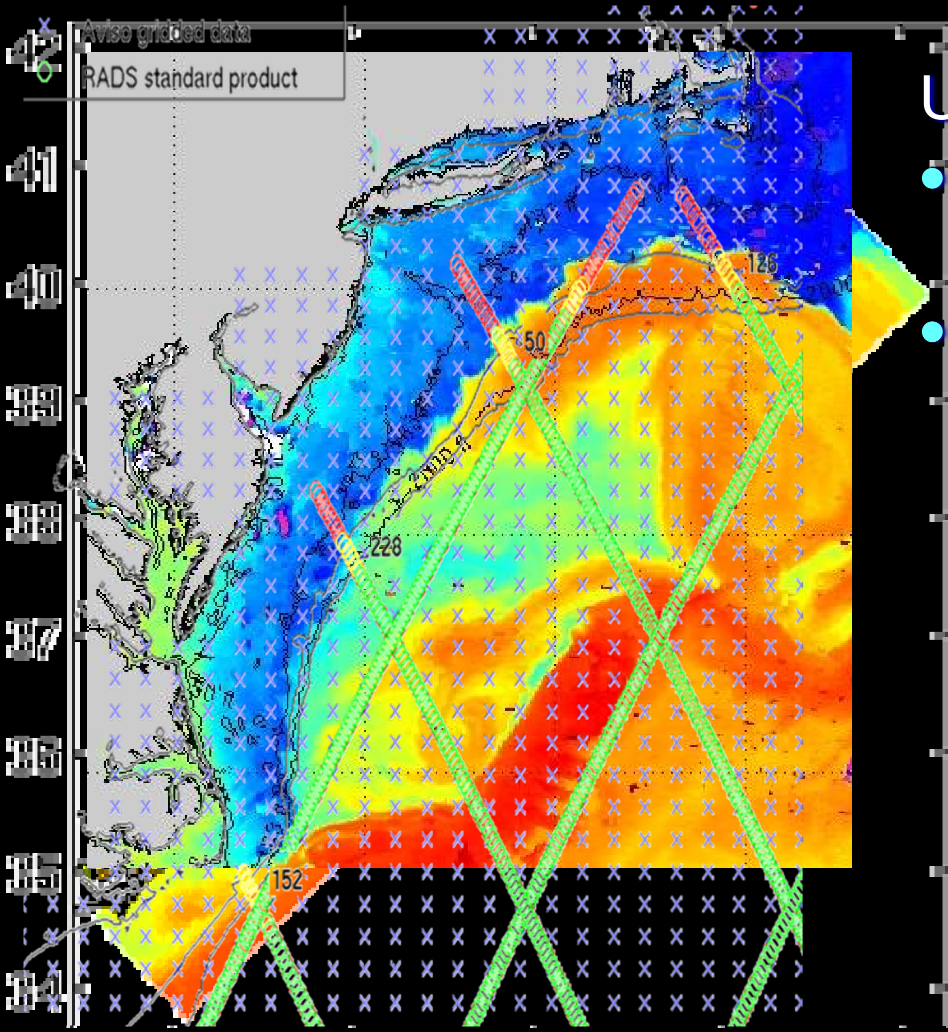


5 km resolution for IS4DVAR

1 km downscale forecast

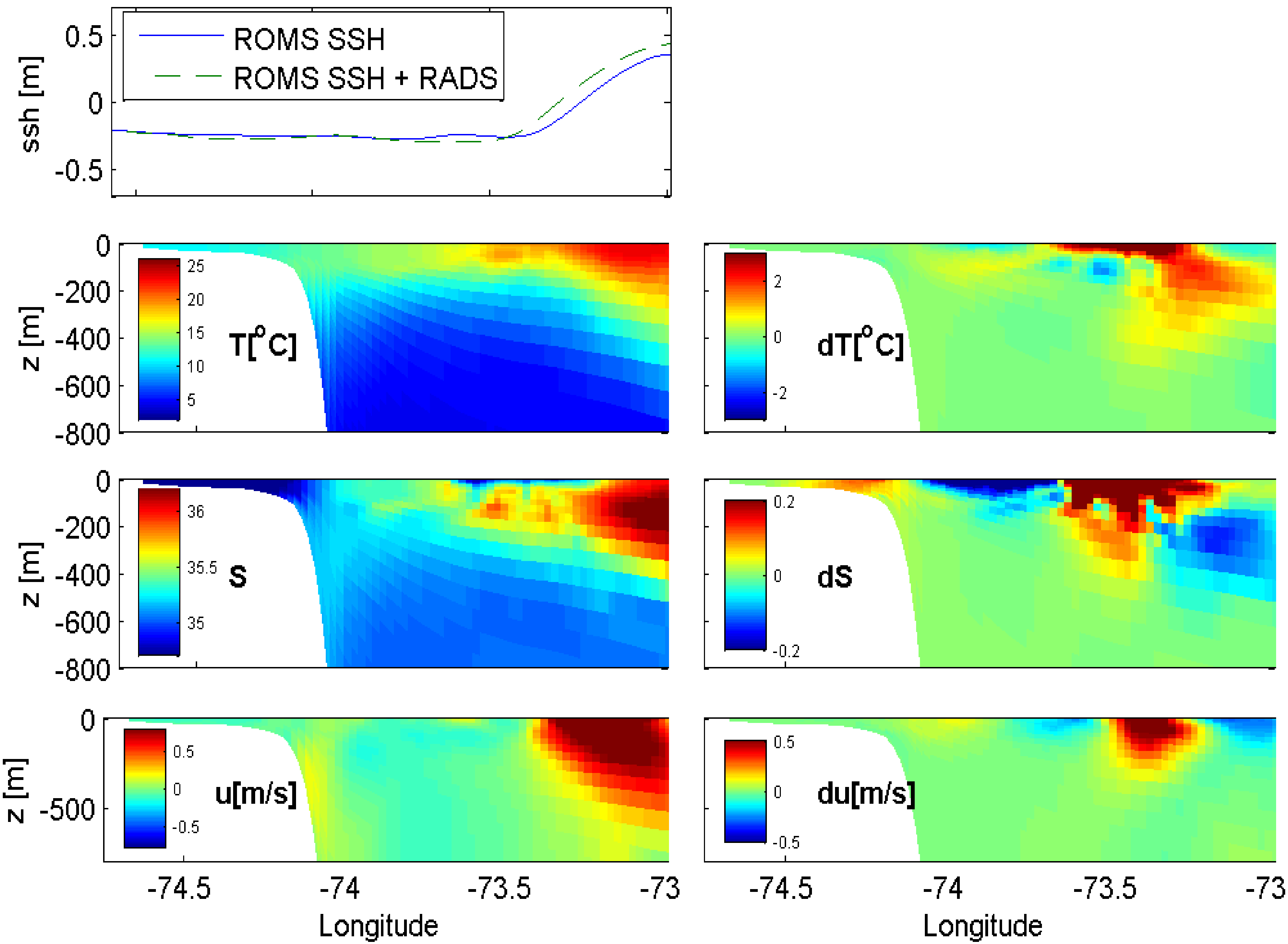
- 3-hour forecast meteorology NCEP/NAM
- daily river flow (USGS)
- boundary tides (TPX0.7)
- nested in ROMS MAB-GoM (which is nested in Global-HyCOM*) (*which assimilates altimetry)
  - nudging in a 30 km boundary zone
  - radiation barotropic mode

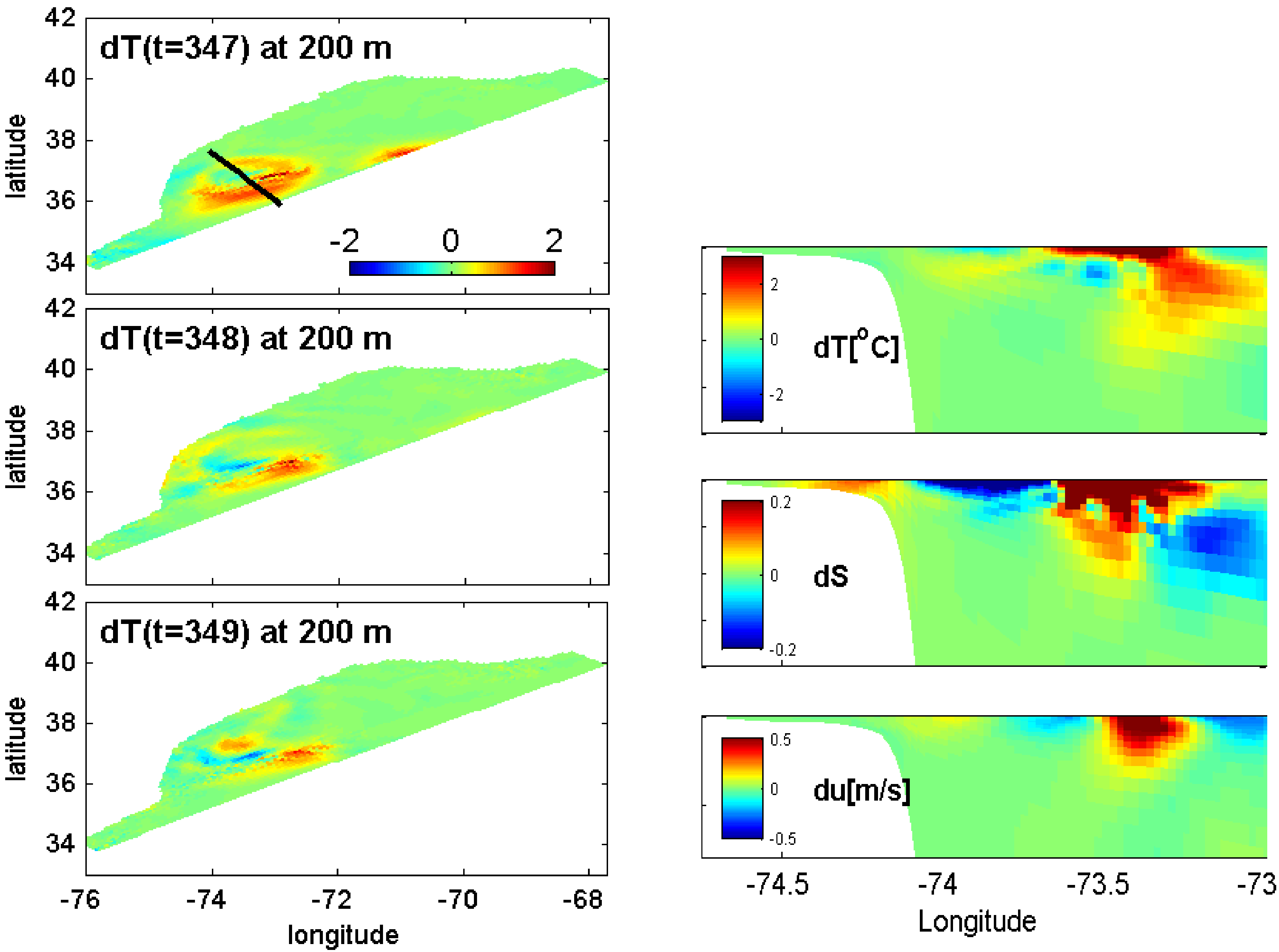
Mid-Atlantic Bight ROMS Model for IS4DVAR



Use along-track altimetry:

- 4DVar uses the data at time of satellite pass
- model “grids” along-track data by simultaneously matching observations and dynamical and kinematic constraints


ROMS SSH
ROMS SSH + RADS
ssh [m]
0.5
0
-0.5
z [m]
0
-200
-400
-600
-800
T[°C]
25
20
15
10
5
dT[°C]
2
0
-2
S
36
35.5
35
dS
0.2
0
-0.2
u[m/s]
0.5
0
-0.5
-500
du[m/s]
0.5
0
-0.5
-74.5
-74
-73.5
-73
Longitude



dT(t=347) at 200 m
dT(t=348) at 200 m
dT(t=349) at 200 m
latitude
longitude
-2
0
2
42
40
38
36
34
-76
-74
-72
-70
-68
dT[°C]
dS
du[m/s]
2
0
-2
0.2
0
-0.2
0.5
0
-0.5
-74.5
-74
-73.5
-73
Longitude

Summary - 1

- We can obtain high quality SSH satellite observations in the coastal seas.
- The use of a model wet tropospheric correction is important for data return in coastal regions. Still data loss close to the coast (~10-20 km).
- Gridded AVISO product is not appropriate because of length/time scales of variability and need for specialized corrections.

Summary - 2

- Combination of satellite and tide gauge observations through a statistical model performs well for real time estimation of sea level in the Danish Straits, even in extreme cases.
- An operational version will be set up at DMI to complement our storm surge models. Jason-2 data will hopefully give better data return closer to the coast.

- Assimilation of along-track SSH successful but requires consideration of …
  - tidal signal in data-model
  - time filtering IS4DVAR increment to reduce inertial oscillations
  - forcing time correlation of SLA obs to suppress gravity wave in adjoint solution

… so still work to do before becoming operational.

Thank you!