4DVAR assimilation of surface currents and water level measurements into a 3D barotropic model of the German Bight

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German Bight Circulation

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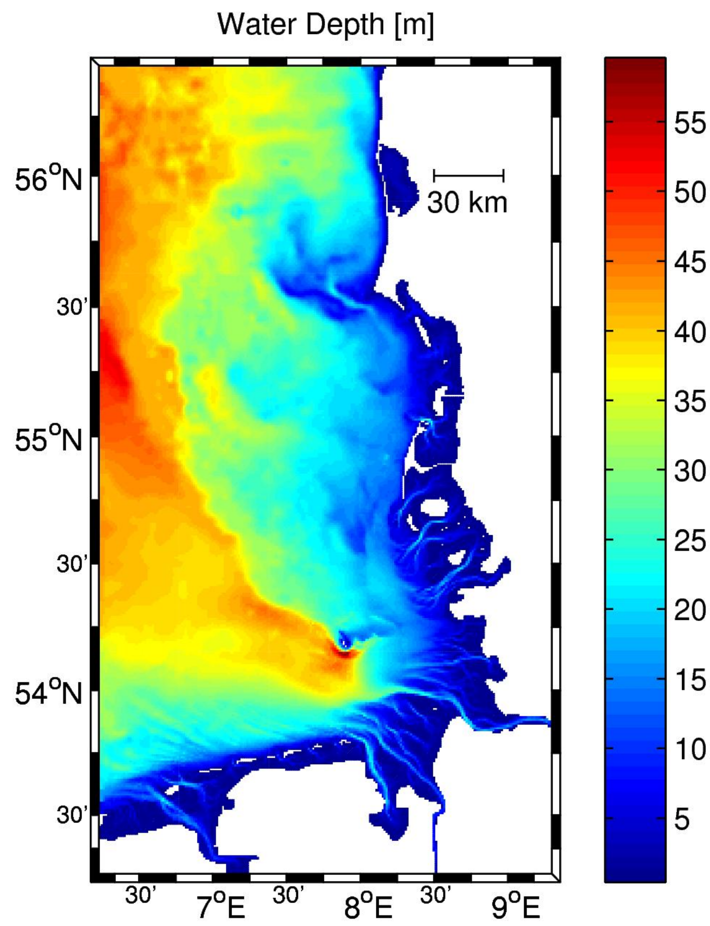
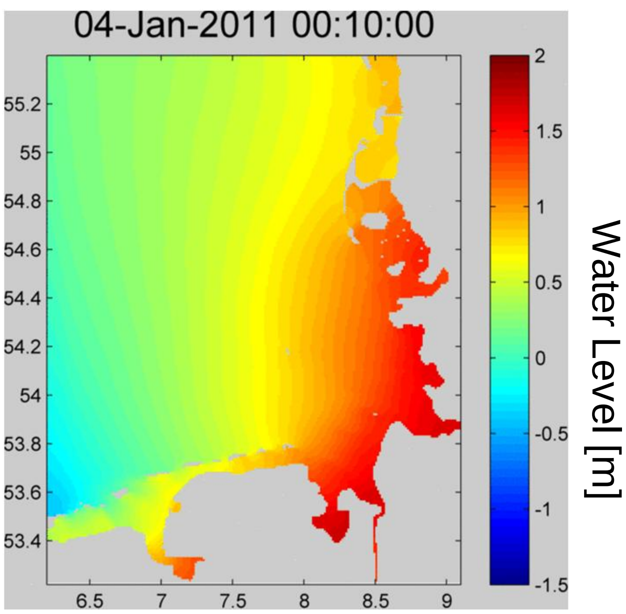
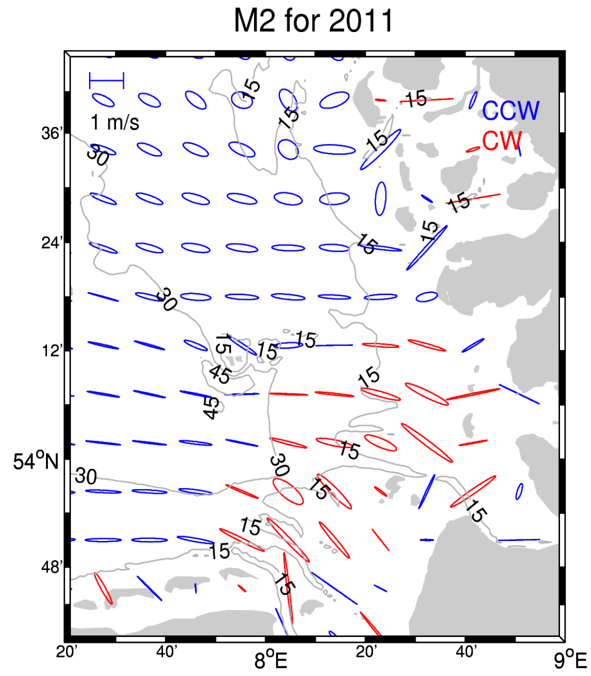
- →Very shallow (< 50m)
- →Complicated bathymetry
- →Tidal dominated (+/-1.5 m, 0.5-1 m/s)
- →Drying and flooding
- →Bottom friction important
- →OB forcing important







Objectives

- *Develop tools to reduce both systematic and stochastics errors in German Bight circulation models using HF radar data in combination with other measurements such as ADCP and tide gauges*

  - *improve transports not only surface currents*
  - *keep tidal signal*

- *Improve understanding of sensitivity of the system with respect to various parameters*

- *Take into account requirements of the operational systems run at the Hydrographic Agency (BSH)*

How to combine HFR and Model ?

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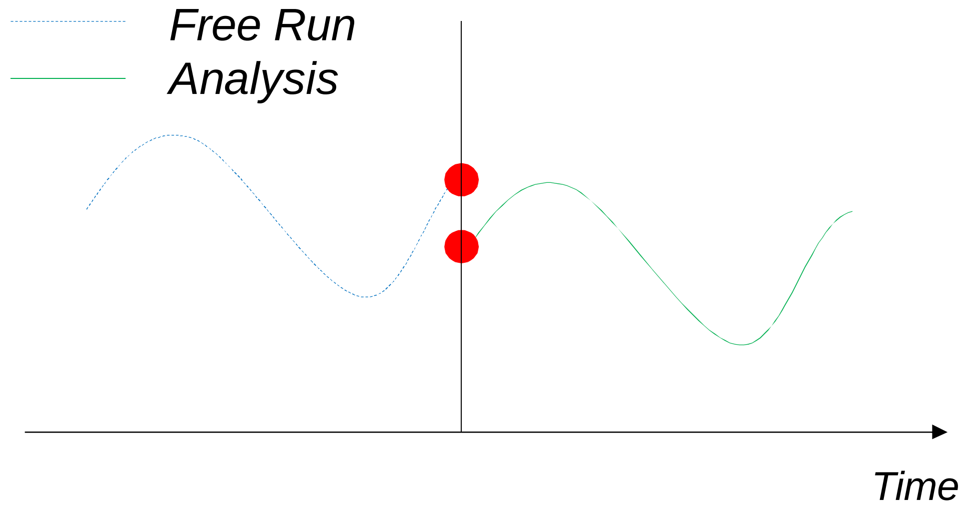
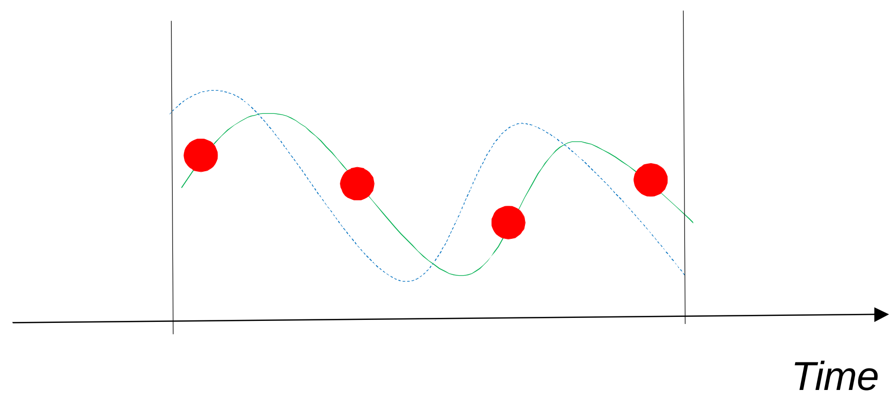
Filter ?

Combination at individual time steps



Smoother ?

Combination over longer analysis windows



Smoother approach has advantage for tidal dominated dynamics, because the correction of tidal phase and amplitude errors is more straightforward if the analysis window contains at least one tidal cycle

4DVAR Technique

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Minimize Cost Function

$$J(\alpha) = 0.5\,||y - Hx(t_i)||^2 + \ldots.$$

Requires Gradient – how to estimate ?

x: *model state*
y: *observations*
H: *obs. operator*
α*:* control vector

Forward Model

$$x(t_i) = M_i M_{i-1} \ldots M_1 x_0$$

Adjoint Model

$$\nabla J_{x_0} = M_1^T \ldots \tilde{M}_{i-1}^T \tilde{M}_i^T H^T (y - Hx(t_i))$$

3D barotropic Model for German Bight and adjoint Model

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- *Primitive equation model*
  Momentum advection, Momentum Diffusion, Bottom friction, Internal Friction, wind forcing, Coriolis Force
- *1 km spatial resolution (C-grid, BSH bathymetry)*
- *5 sigma layers*
- *One Equation turbulence model*
- *Clamped OB conditions using data from the Hydrographic Agency (BSH)*
- *Wind forcing from DWD*
- *Constant Bottom friction coefficient*

Control Vector for systematic error treatment

- *Atmospheric Drag coefficient (assumed constant)*
- *Bottom Drag coefficient or z0*
- *Internal Friction parameters*

$$A = \alpha\sqrt{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2 + S}$$

- *Different vertical profiles of α*
- *Amplitude and phase at OB*

Sensitivity on vertical diffusivity near surface

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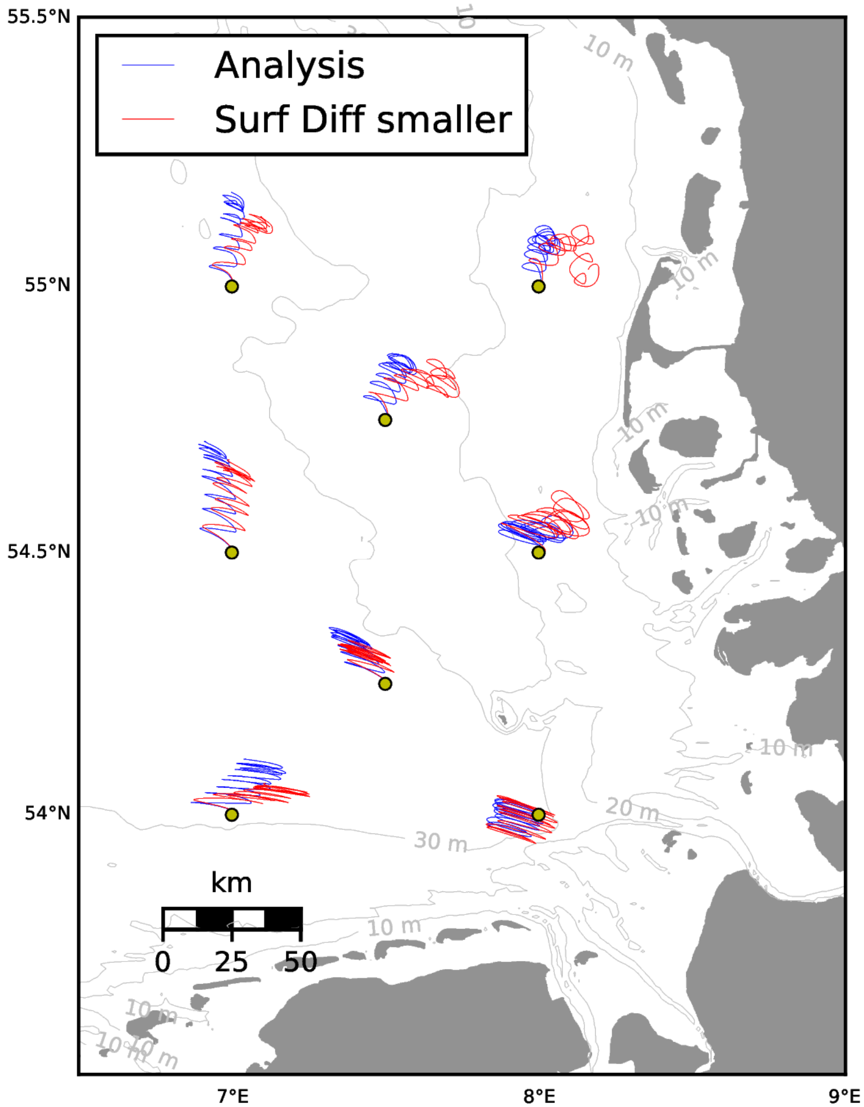
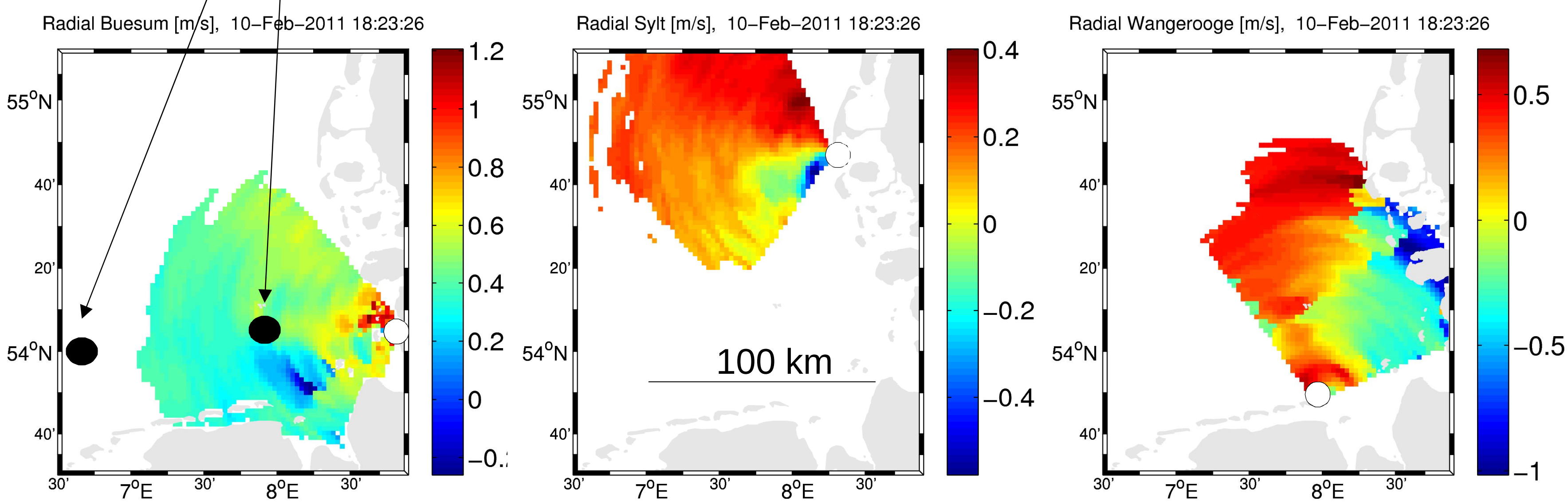


Observations Used for first Inversions

- *Radial Components from three WERA stations*
- *Tide Gauge Helgoland*
- *Lower levels of ADCP measurements from FINO-1 ADCP*



Results Compared to operational BSH model

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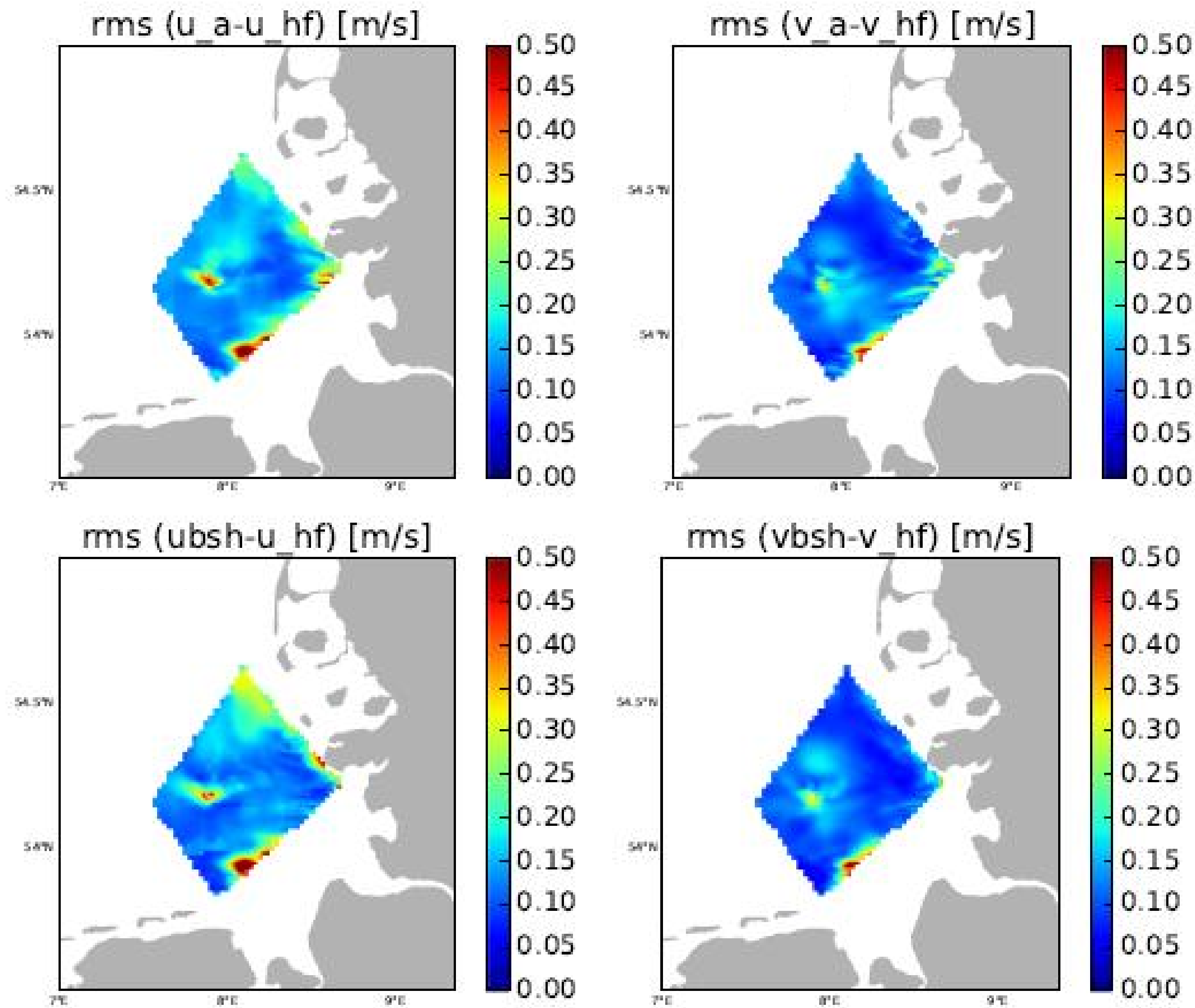


Model with first round of tuning

BSH Model

Helgoland Water Level

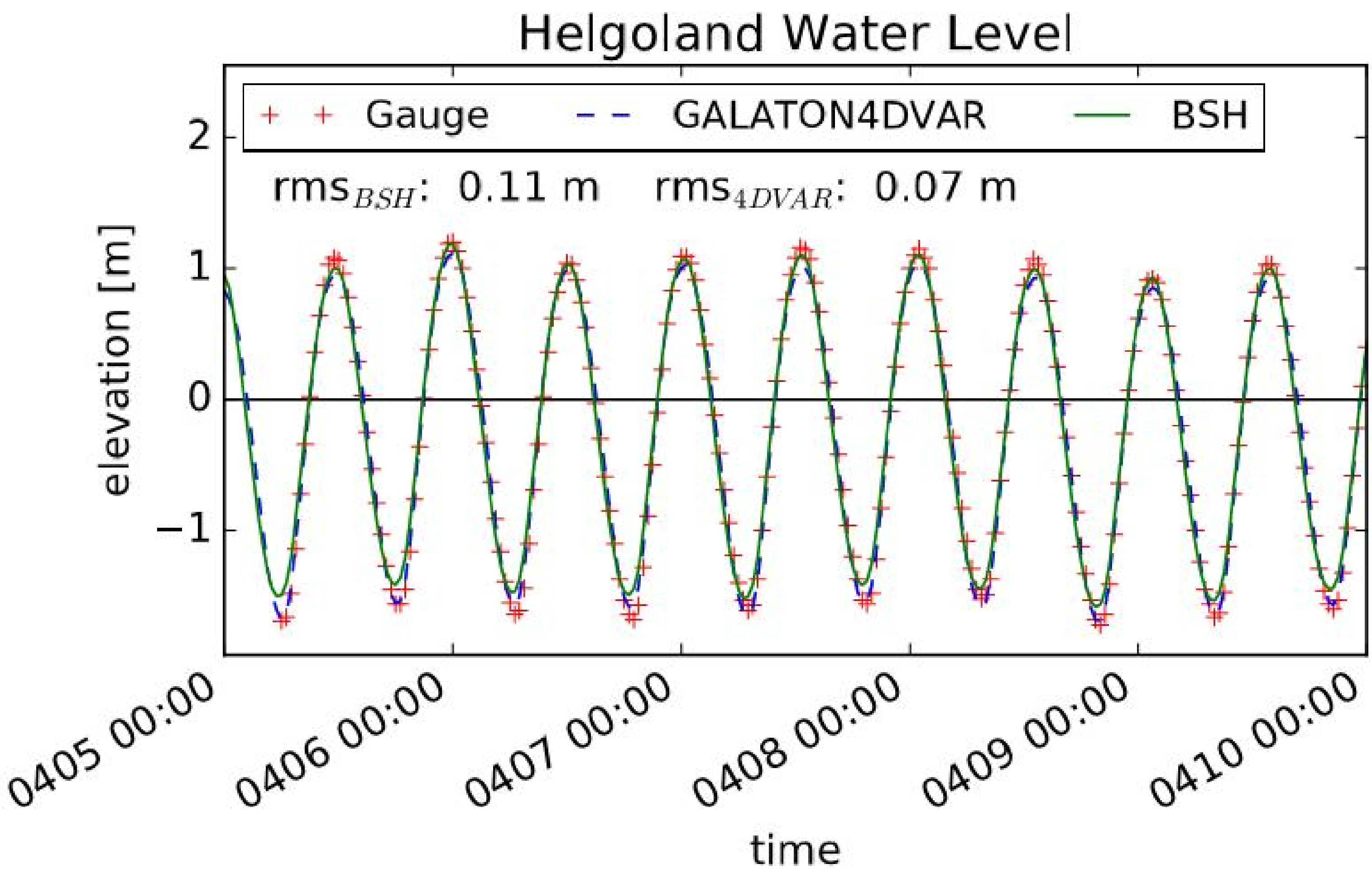
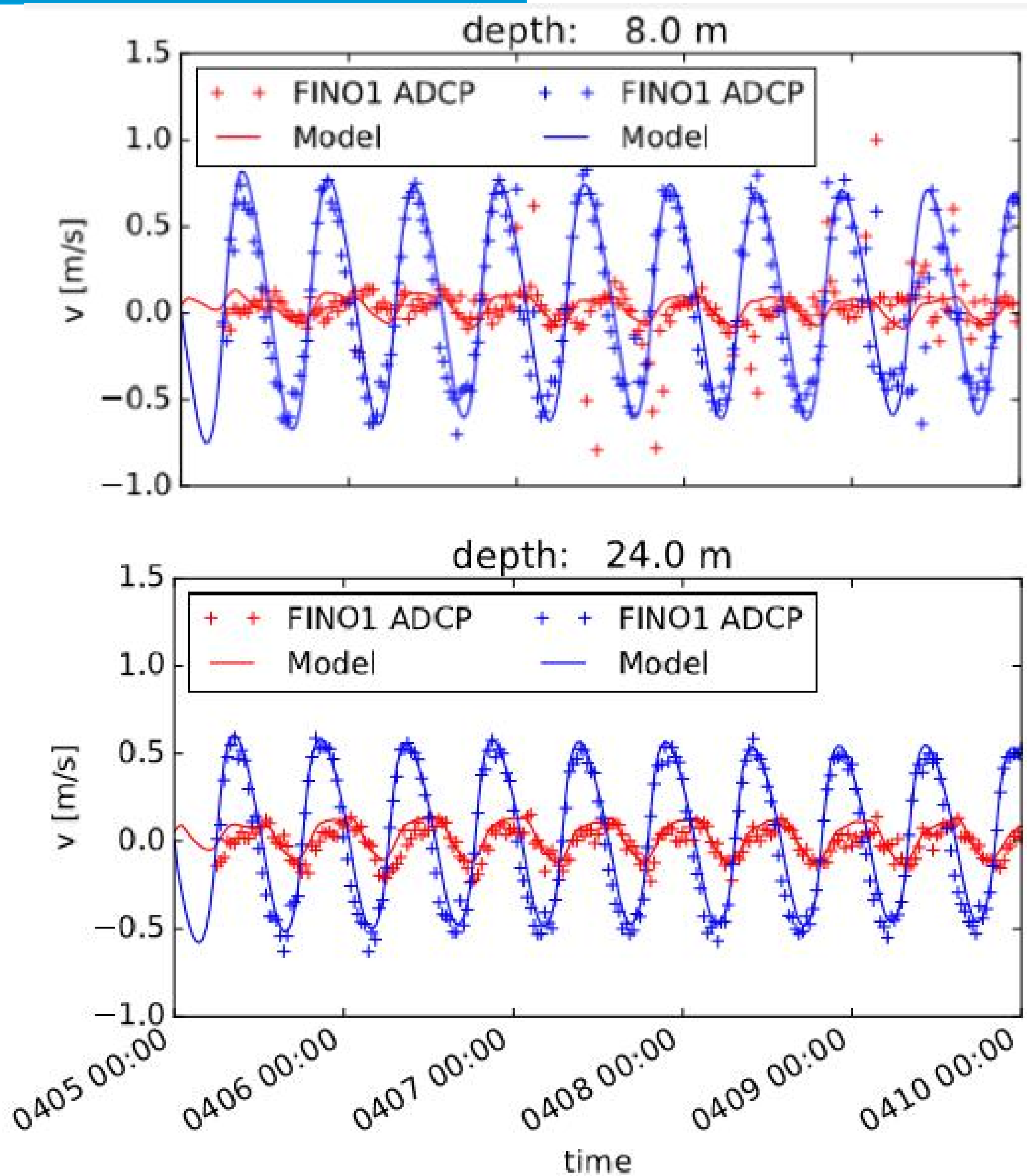


Figure 9. Water level at tide gauge Helgoland

FINO-1 ADCP Comparisons



Relative Improvement

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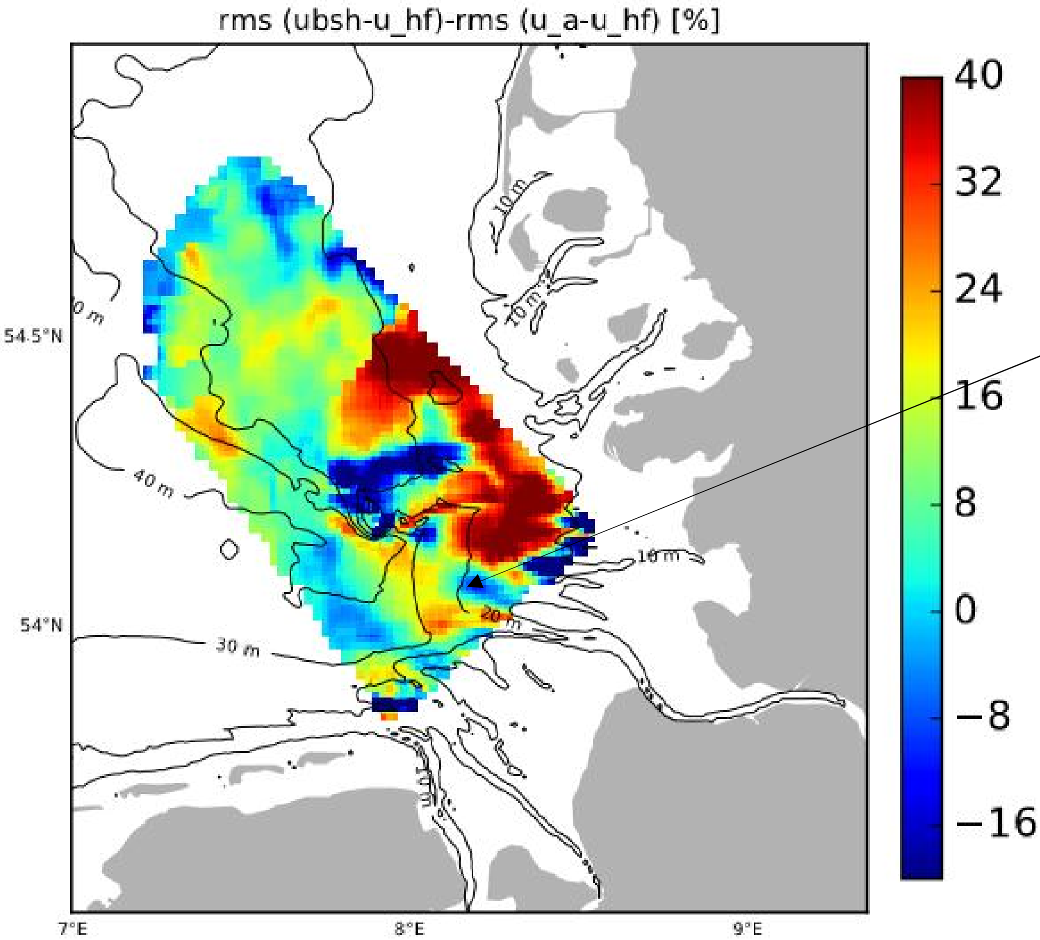
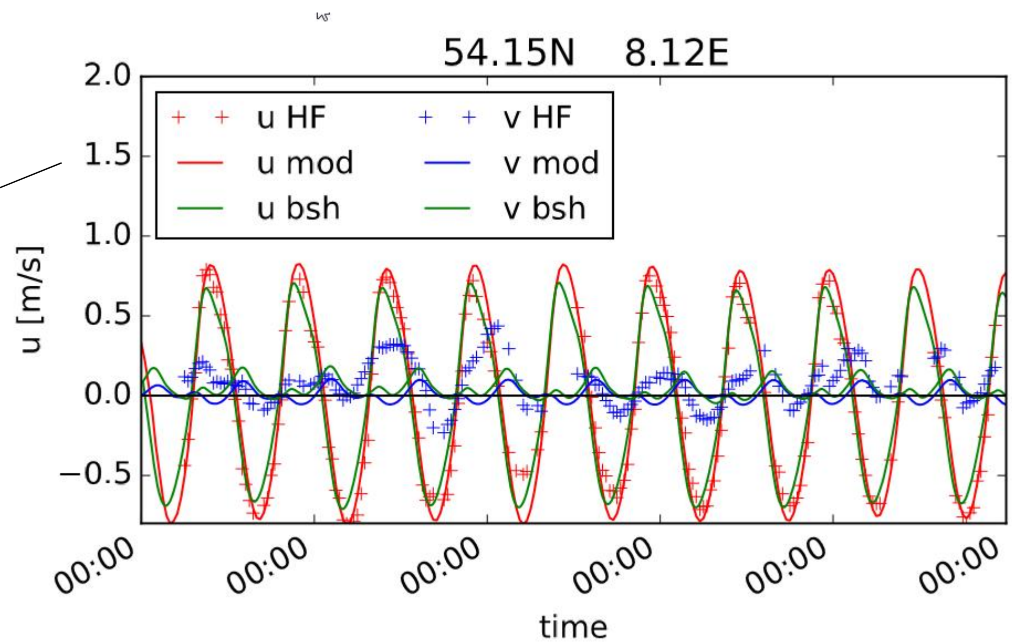
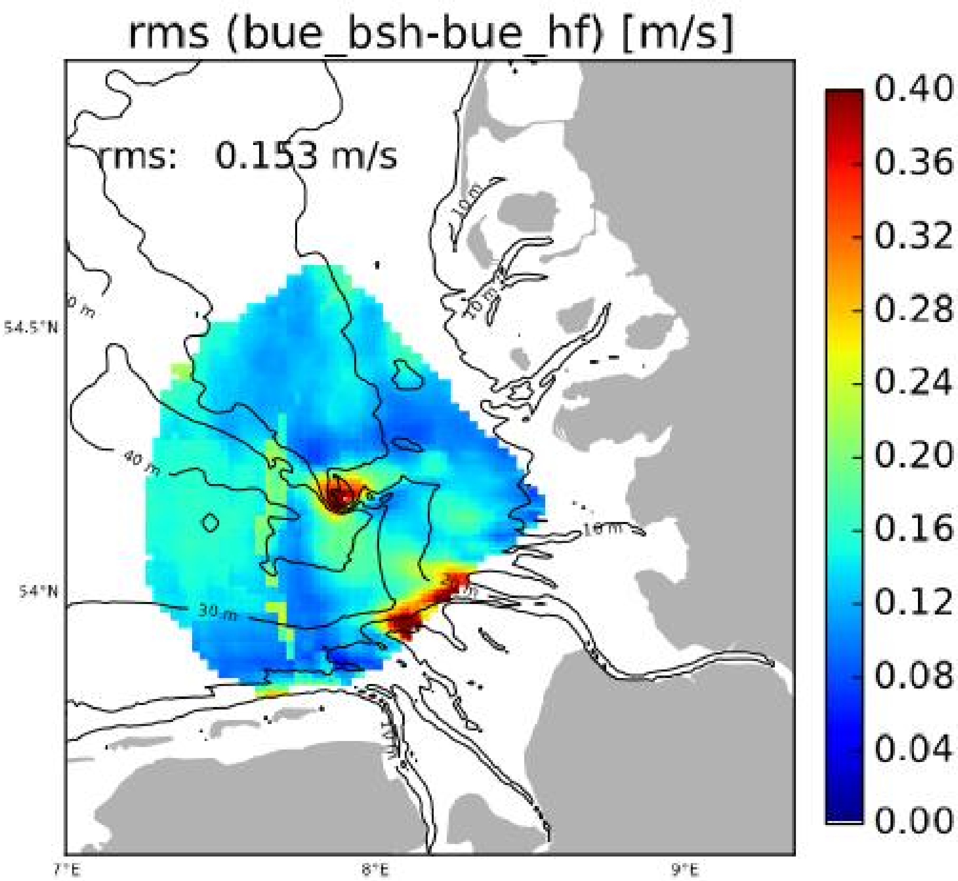
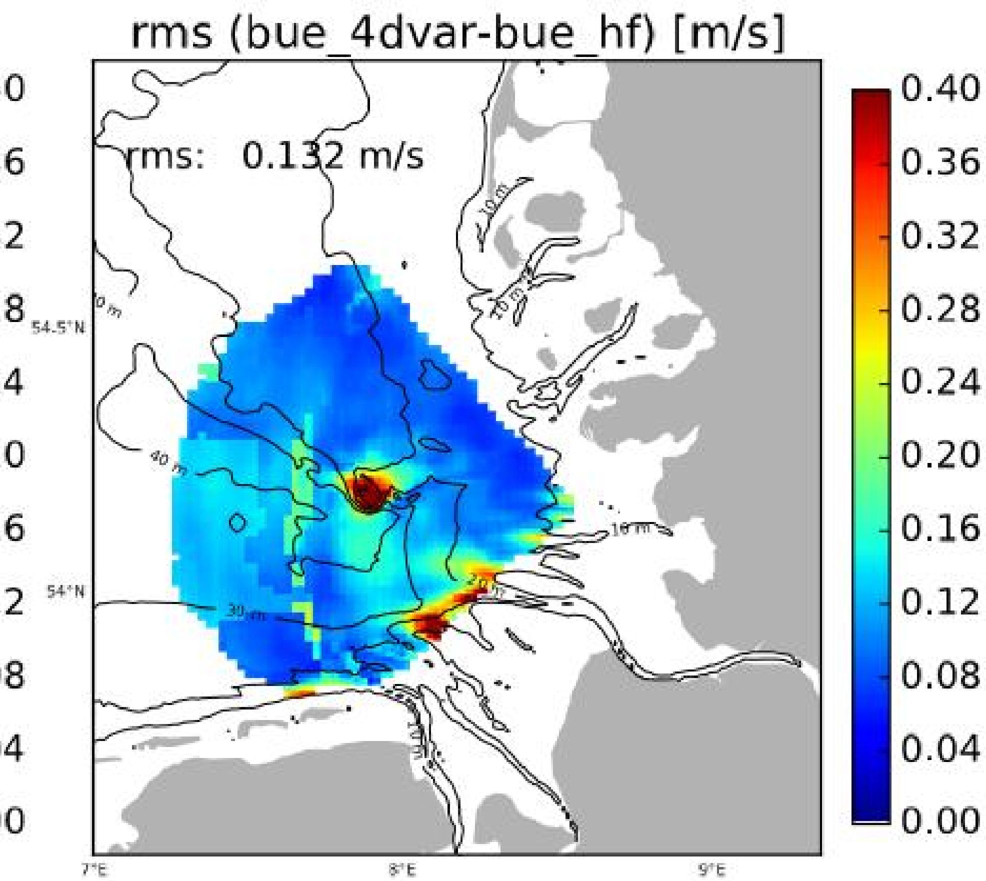


V component more stochastic



Buesum


rms (bue_bsh-bue_hf) [m/s]
rms: 0.153 m/s
0.40
0.36
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
54.5°N
54°N
7°E
8°E
9°E
40 m
30 m
10 m


rms (bue_4dvar-bue_hf) [m/s]
rms: 0.132 m/s
0.40
0.36
0.32
0.28
0.24
0.20
0.16
0.12
0.08
0.04
0.00
54.5°N
54°N
7°E
8°E
9°E
40 m
30 m
10 m

Summary/Outlook

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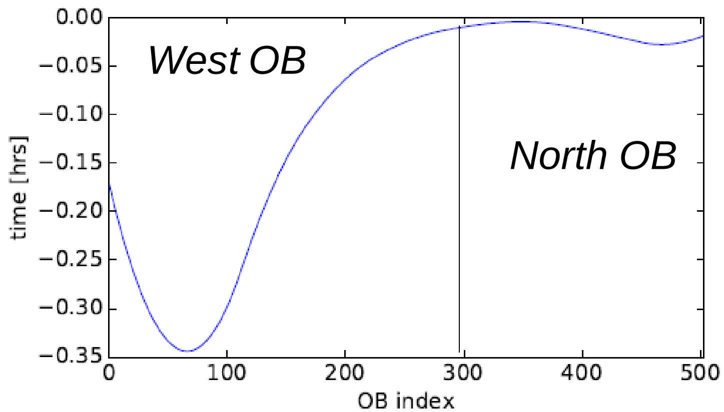
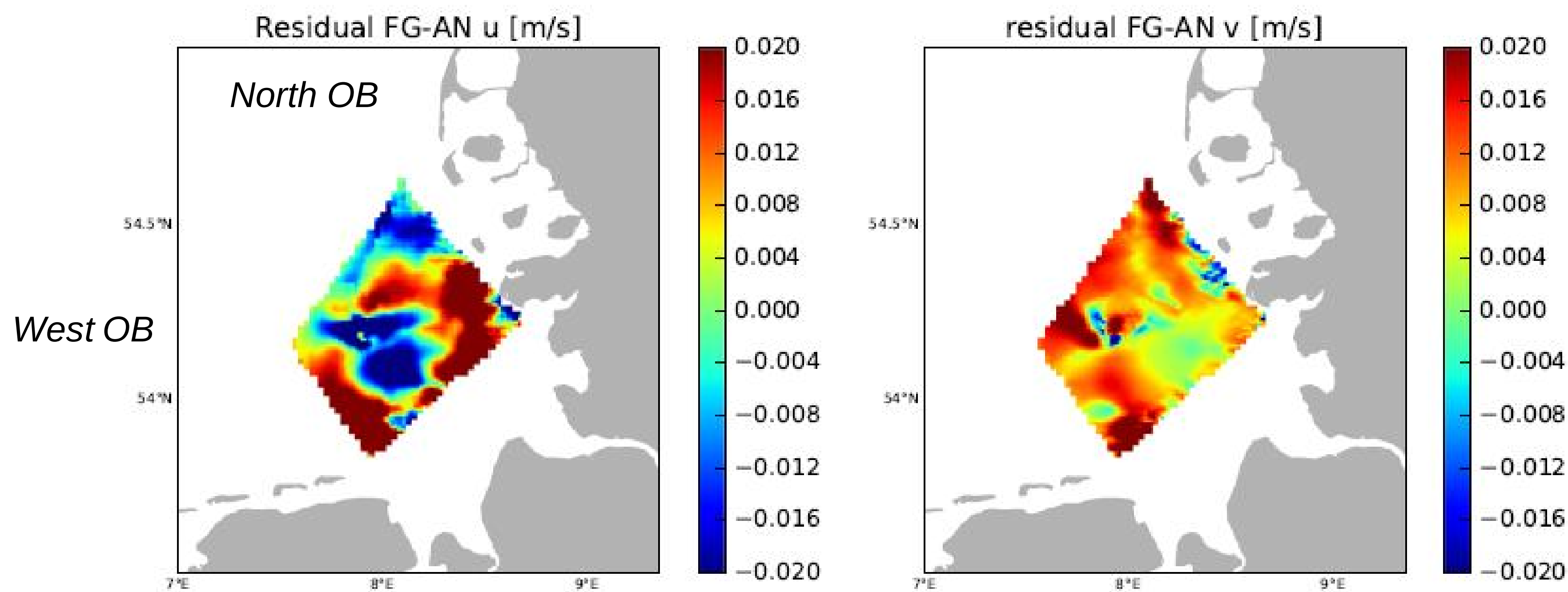
- *A 3D barotropic model and the respective adjoint were implemented and shown to give results very consistent with Hydrographic Agency model*
- *First Steps towards reduction of systematic and stochastic errors in German Bight models based on 4DVAR technique are promising*
- *Statistics over longer period*
- *Allow bottom roughness to vary in space as a next step*

Impact of stochastic component optimisation



Time lag of western and northern OB estimated with adjoint model

Improved agreement with HFR data (for the most part)



Control Vector for stochastic error treatment

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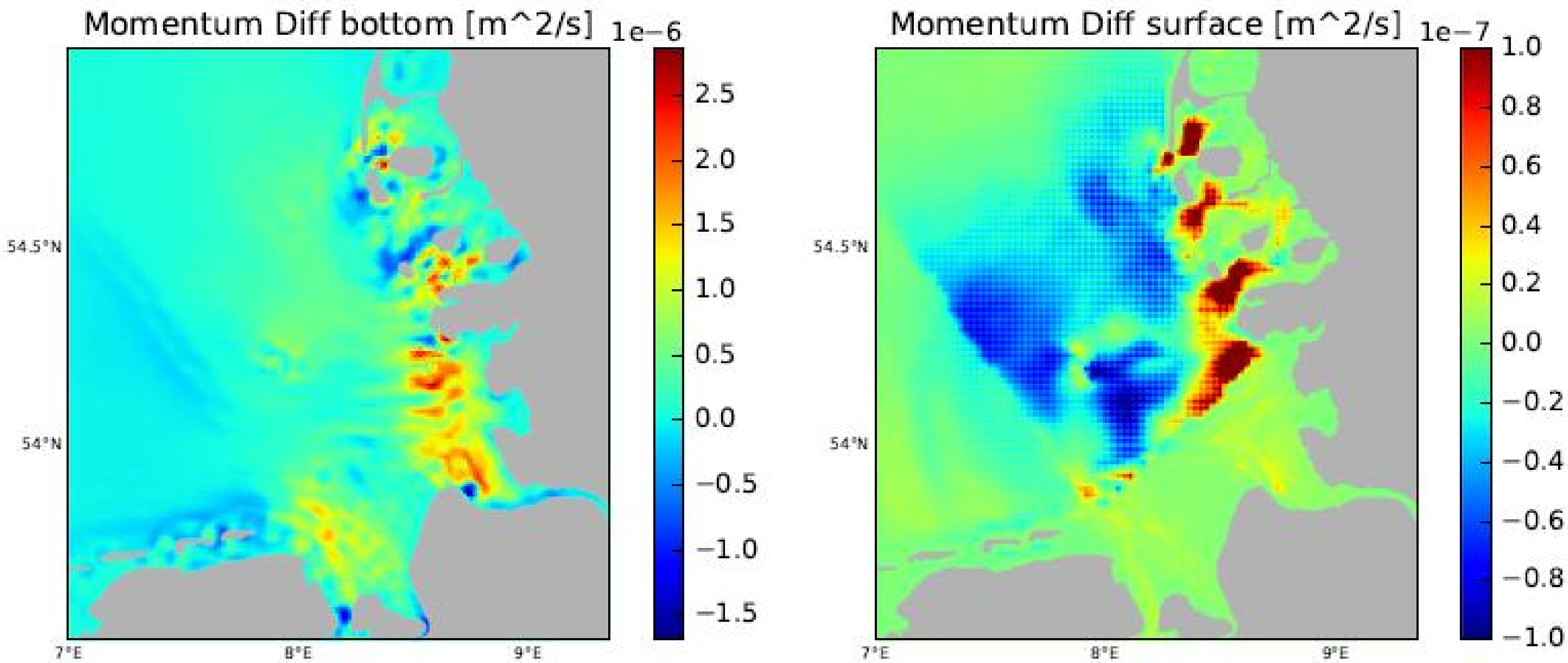
- *OB forcing (time lags, amplitude errors)*
  - *ensuren smoothness through use of B-splines*

- *Internal friction due to turbulence*
  - *Allow surface and bottom momentum diffusion to vary in space*

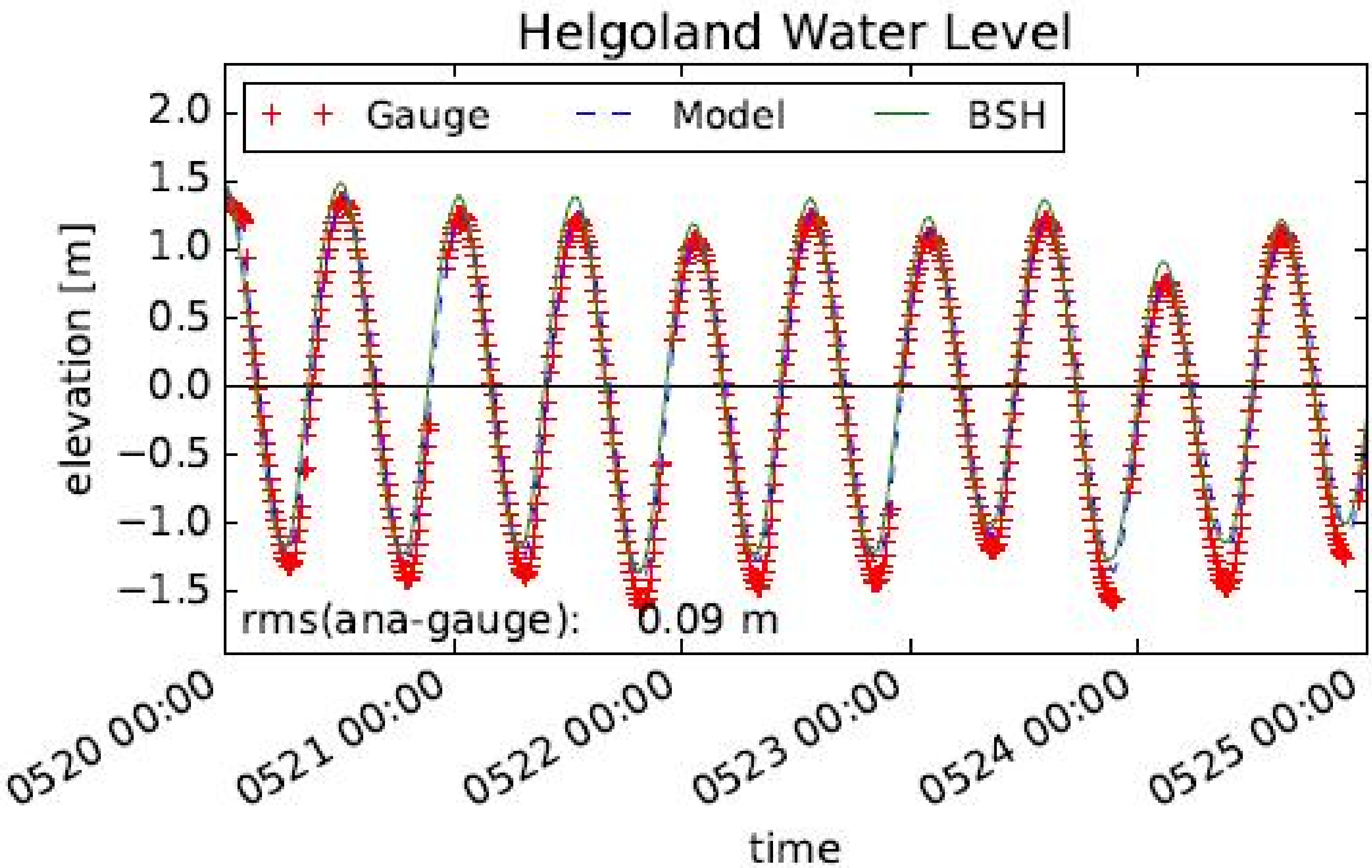
  - *Ensure smoothness through Tikhonov regularisation*

- *Meteo forcing (time lag and amplitude errors in U_{10}, V_{10}*
  - *Assumed constant over space and time*

Bottom/Surface Momentum Diffusion



Helgoland Tide Gauge



FINO-1 Bottom Layer

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