→ 8th COASTAL ALTIMETRY WORKSHOP

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Cyclone Xaver seen by Geodetic Observations

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Outline

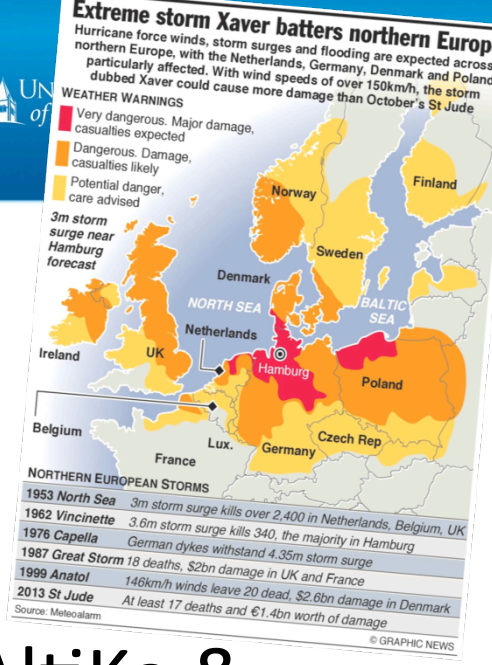
- Motivation: Extreme events & Sea Level Change
- Approach: Event 5-6 Dec. 2013
- Data: In-situ, altimetry, storm forecast, forcing
- Results: Geodetic observations wrt model predictions
- Conclusion

Motivation

- Long history of extra-tropical cyclones as substantial hazard for low coasts in North Sea
- Extreme sea levels (a. tides + waves + storms surges (NW winds + external waves lp NA))
- The dynamic response of coastal and shelf area is complex (deep & shallow water).
- Monitoring by a geodetic observing system

- **Approach: Event 5-6 Dec. 2013**

Approach



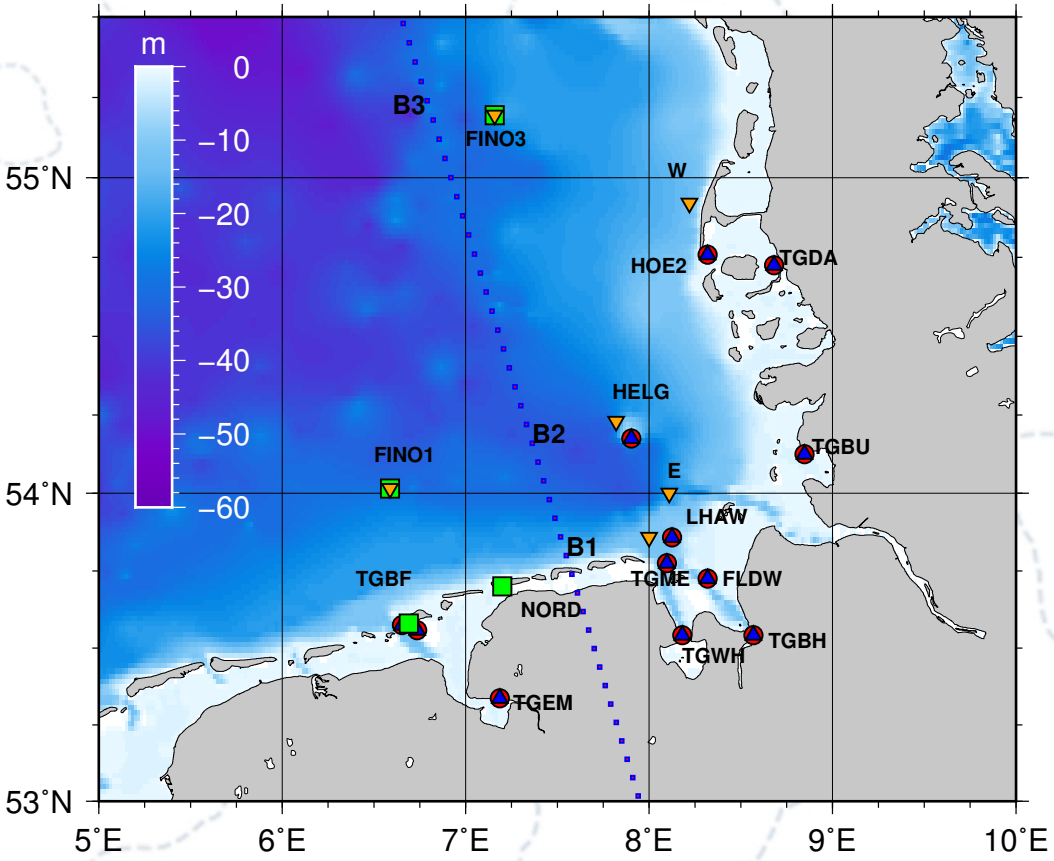
- Xaver Storm 06.12.2013
- SL, SWH, U10 derived from SARAL/AltiKa &
- Validated against in-situ geodetic data
- & two models and forcing fields
- Vertical displacement caused by loading of surge compared against GPS

Approach cont.

- **STORM SURGE** = Large scale rise of the SS caused by high winds and low atm pressure
- TWLE=orbit - range – DTU10 – corr_app
- corr_app = all corrections except ocean tide and dac (consistency with TG)
- **SS** = TWLE – GOT4.8 ocean tide @ altimetry
- **SS** = OBS – ocean tide from 10y @ TG

- **Data: In-situ, altimetry, storm forecast, forcing**

Data: In-situ geodetic network



Data: In-situ geodetic network (cont.)

- German national water information system (WSV)
  - Tide gauges (water level) (1 min) NRT
  - Anemometers (wind speed, U10)
  - Wave buoys (significant wave height, SWH) NRT
  - GNSS: Bernese GPS estimates kinematic solution for 12 sites with 1-min sampling (28 Nov-15 Dec), makes SL observations comparable in absolute sense (ITRF2008), correction for ocean loading applied (FES2004), data cleaned for outliers, siderial filter, down-sampled to 15 min

Data: In-situ geodetic network (cont.)

Off-shore platforms FINO1 and FINO3

- Wind speed and multiple elevations
  - Will show @33 m elevation here
- Wave height
  - Acoustic Wave and Current Profiler (AWAC) every 30 minutes
  - Acoustic Doppler Current Profiler (ADCP) every 60 minutes

Courtesy of Bundesumweltministerium (BMU) and Projektträger Jülich (PTJ)

Models: Storm surge & Forcing

- Bundesamt für Schifffahrt und Hydrologie (BSH)
  - BSHcmod is forced by Deutscher Wetterdienst (DWD) meteorological model (COSMO-EU)
  - Daily 3-day forecasts of wind speed, wave height and water level (including tide)
  - Includes tides (not only surge)
  - Here GOT4.8 astronomical tide removed to obtain surge
- Joint Research Centre
  - Hyflux2 is forced by ECMWF meteorological model fields with 3-day lead time
  - Forecasts storm surge due to tropical cyclones (excluding tide)
- Evaluate Earth's response to the loading of the models

Meteorological and tide models

- ECMWF
  - Operational meteorological model (wind shown here)
- ERA-Interim
  - ECMWF Interim Reanalysis model
- NOAA/GFS
  - Global Forecasting System
- GOT4.8
  - Goddard (astronomical) Ocean Tide version 4.8
  - Used to reduce tide gauge measurements, satellite altimetry, and BSH model to surge height (sea level anomaly)

- **Results: Geodetic observations wrt model predictions**

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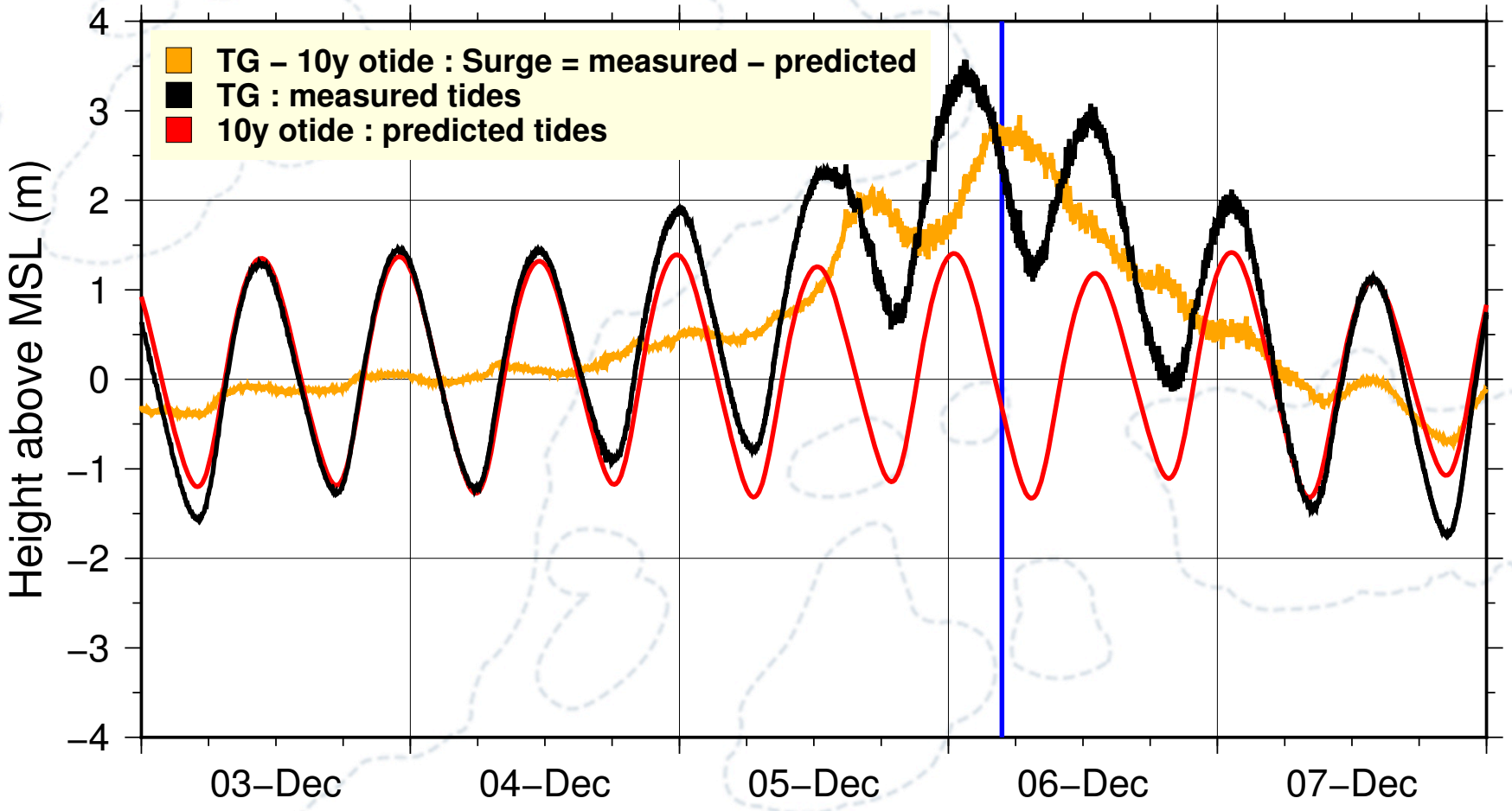
Storm Surge Height in Helgoland



In-situ observations

- Wind speed
  - off-shore

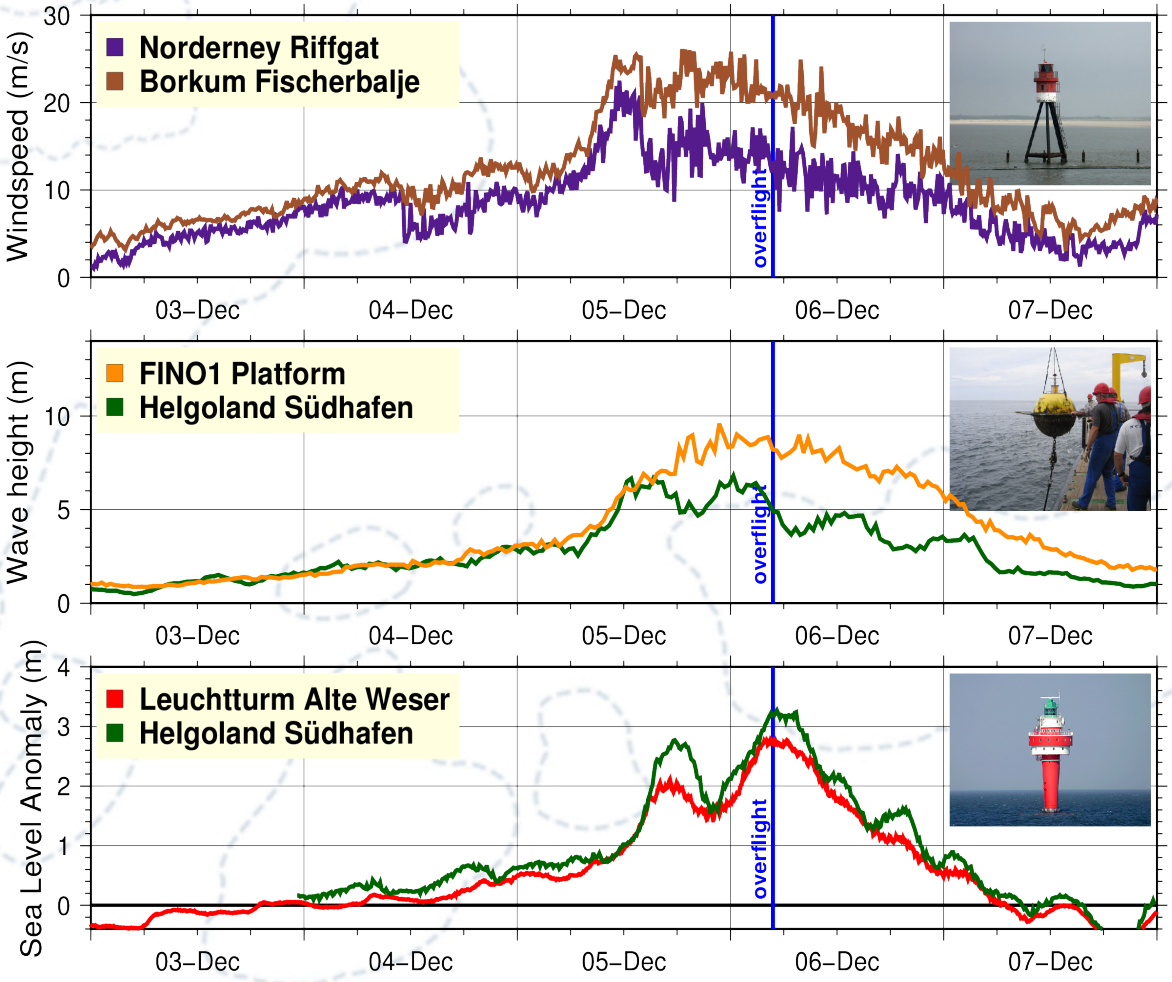
- Significant wave height

- Storm surge

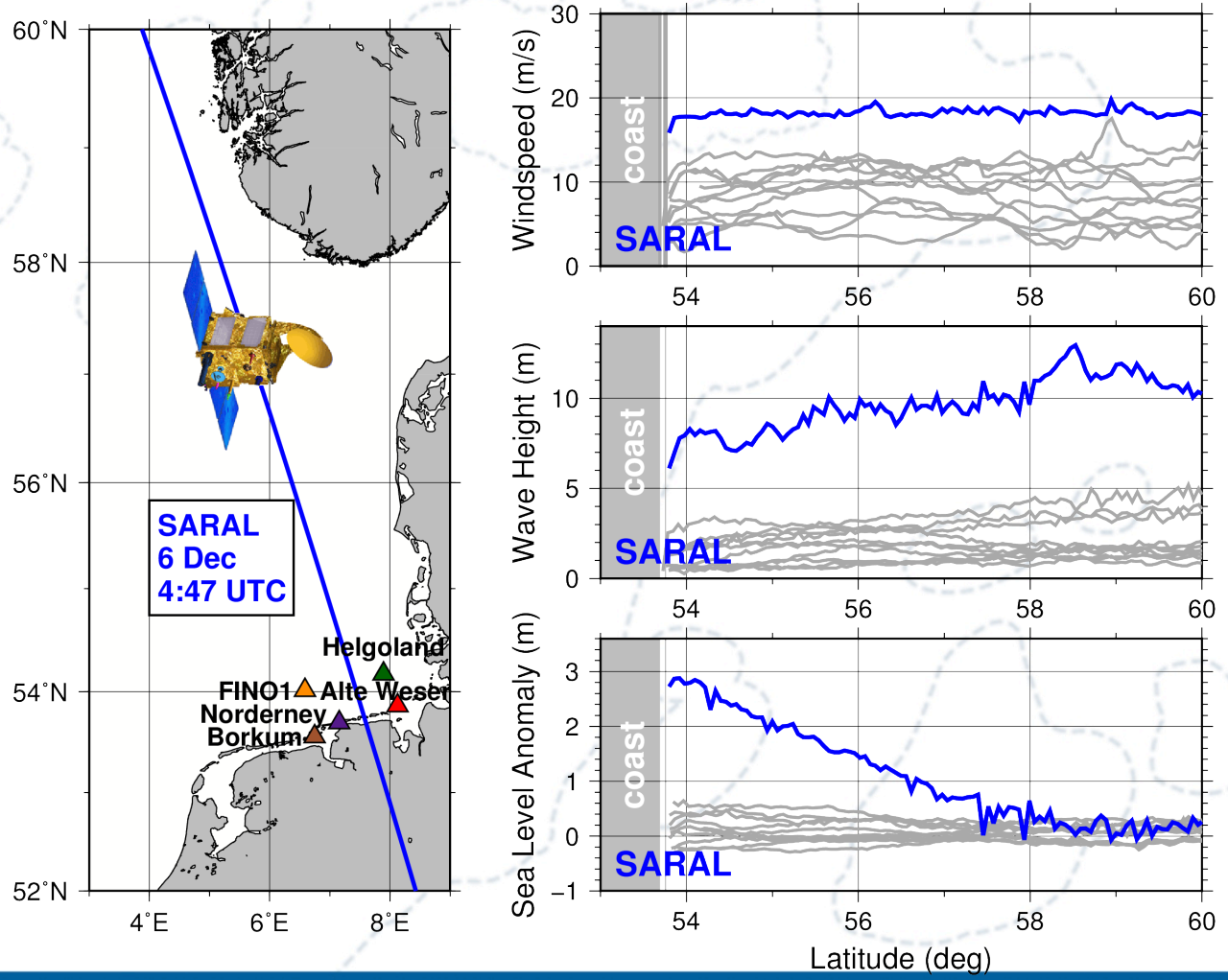
  = water level

  – astronom tide

  – reference



Data: Satellite Altimeter SARAL/AltiKa



Close to height of storm

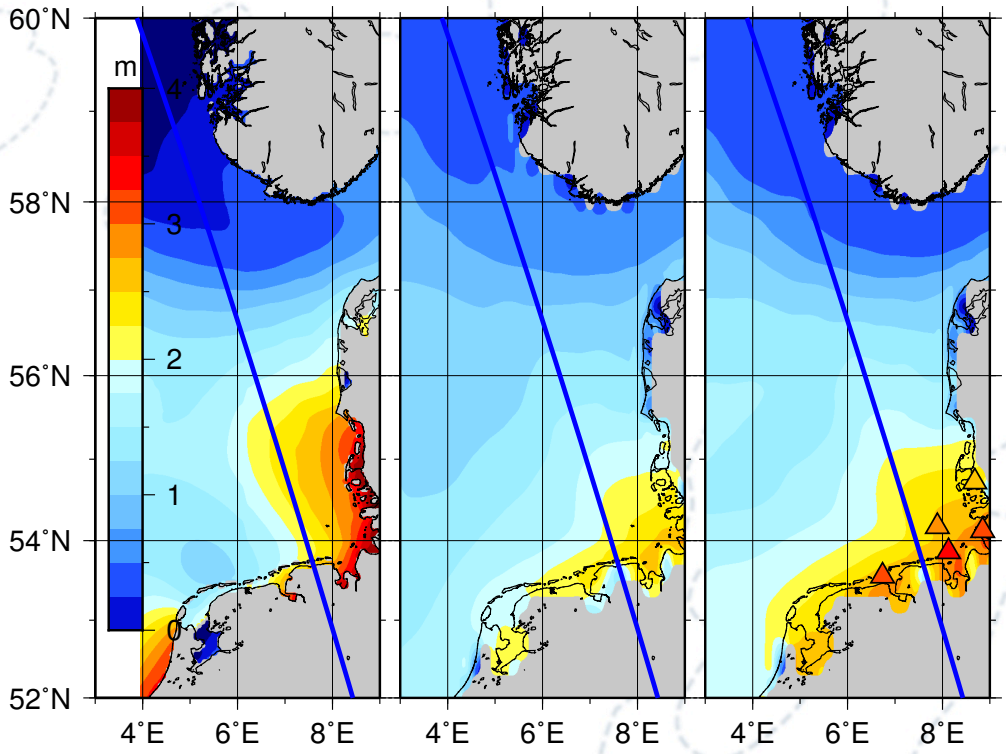
Heavily instrumented region

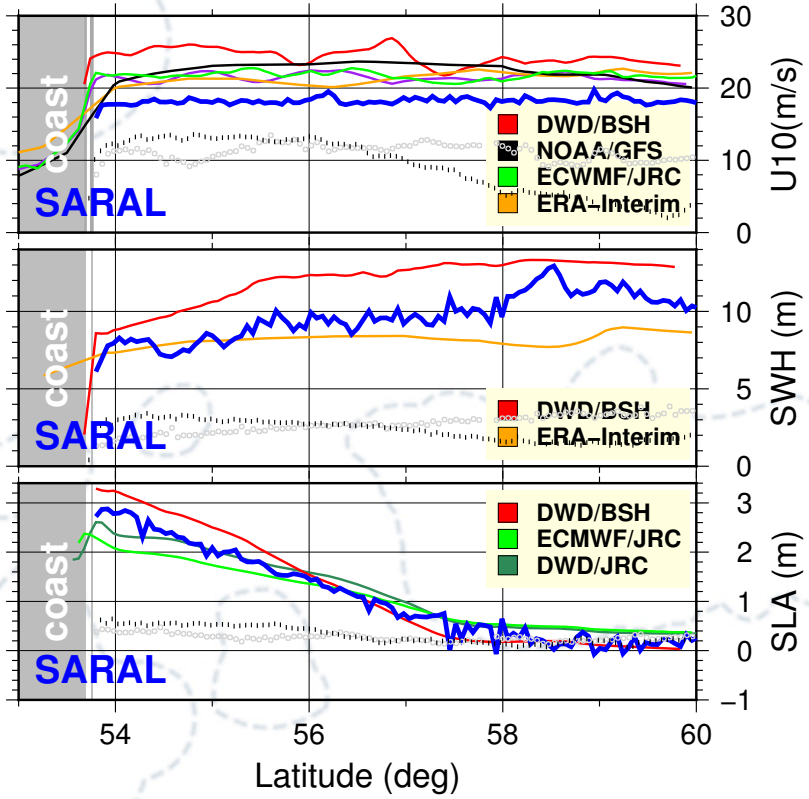
Unique conditions

Compared to 7 months before and 3 months after

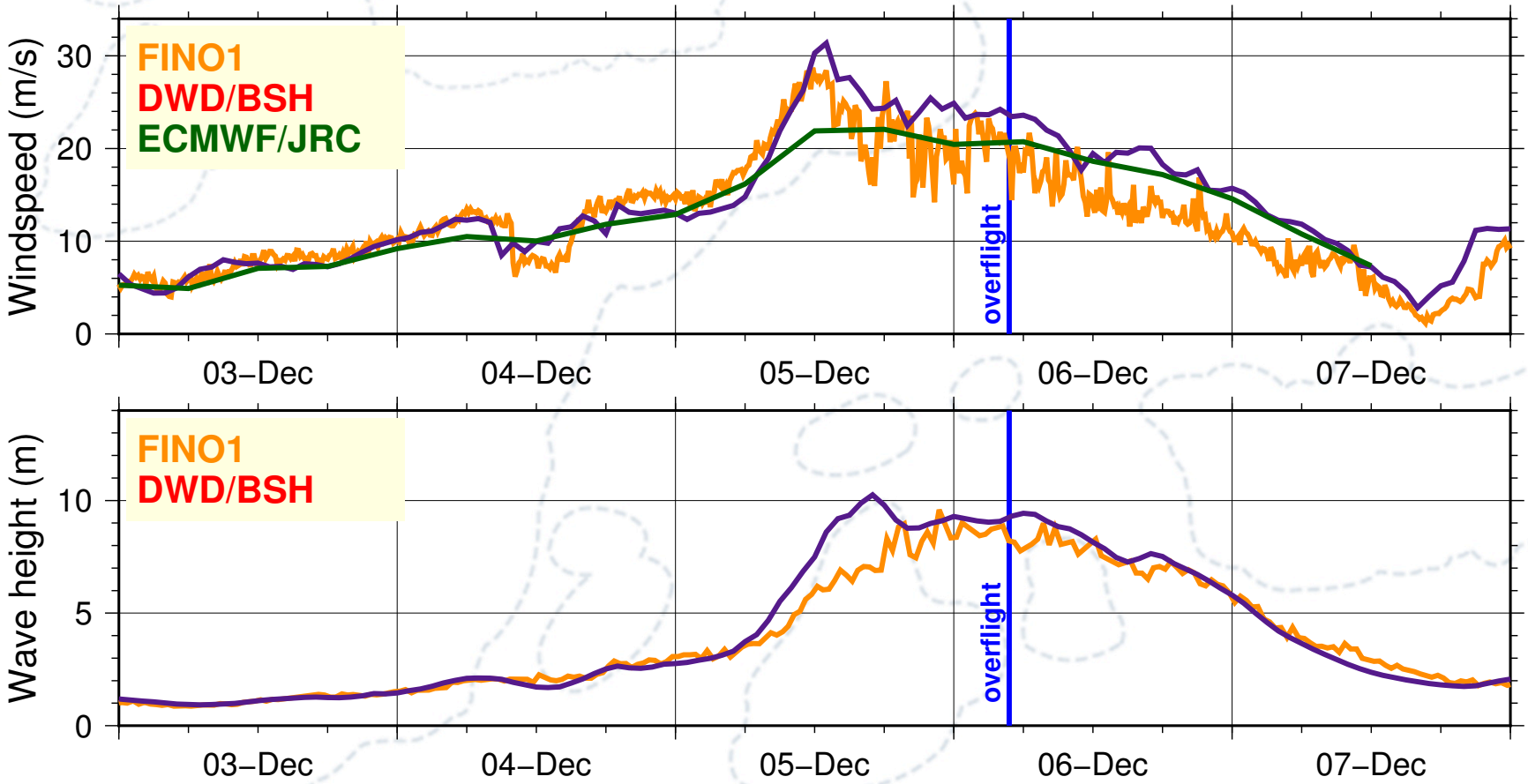
	Field 1	Field 2	corr	mean	std	rms	slope	si
SS				(m)	(m)	(m)		
a	SARAL	DWD/BSH	0.95	-0.05	0.31	0.31	1.04	0.28
a	SARAL	ECMWF/JRC	0.98	0.03	0.29	0.29	0.69	0.13
a	SARAL	DWD/JRC	0.98	0.12	0.21	0.24	0.82	0.16
a	ECMWF/JRC	DWD/BSH	0.96	-0.04	0.39	0.39	1.47	0.27
a	DWD/JRC	DWD/BSH	0.97	-0.13	0.28	0.30	1.23	0.21
Htg	HELG	DWD/BSH	0.98	0.15	0.19	0.24	1.08	0.27
Htg	HELG	ECMWF/JRC	0.96	0.08	0.21	0.22	0.81	0.53
Htg	HELG	DWD/JRC	0.90	0.16	0.18	0.24	0.90	0.52
SWH				(m)	(m)	(m)		
a	SARAL	DWD/BSH	0.84	2.36	0.82	2.50	0.82	0.08
a	SARAL	ERA-INTERIM	0.45	-1.42	1.26	1.90	0.13	0.03
a	ERA-INTERIM	DWD/BSH	0.85	3.42	1.54	3.75	3.75	0.12
F1tg	FINO1	DWD/BSH	0.98	0.24	0.73	0.77	1.14	0.16
U10				(m/s)	(m/s)	(m/s)		
a	SARAL	DWD/BSH	0.60	4.30	0.61	4.34	1.02	0.03
a	SARAL	ECMWF/JRC	0.10	3.24	0.64	3.30	0.14	0.03
a	ECMWF/JRC	DWD/BSH	0.34	2.77	1.07	2.97	0.50	0.05
F1tg	FINO1	DWD/BSH	0.94	0.85	2.20	2.36	0.99	0.18
F1tg	FINO1	ECMWF/JRC	0.92	0.32	2.33	2.36	0.90	0.19
F1tg	ECMWF	DWD/BSH	0.92	0.32	2.33	1.71	0.90	0.19

Observations and model comparison

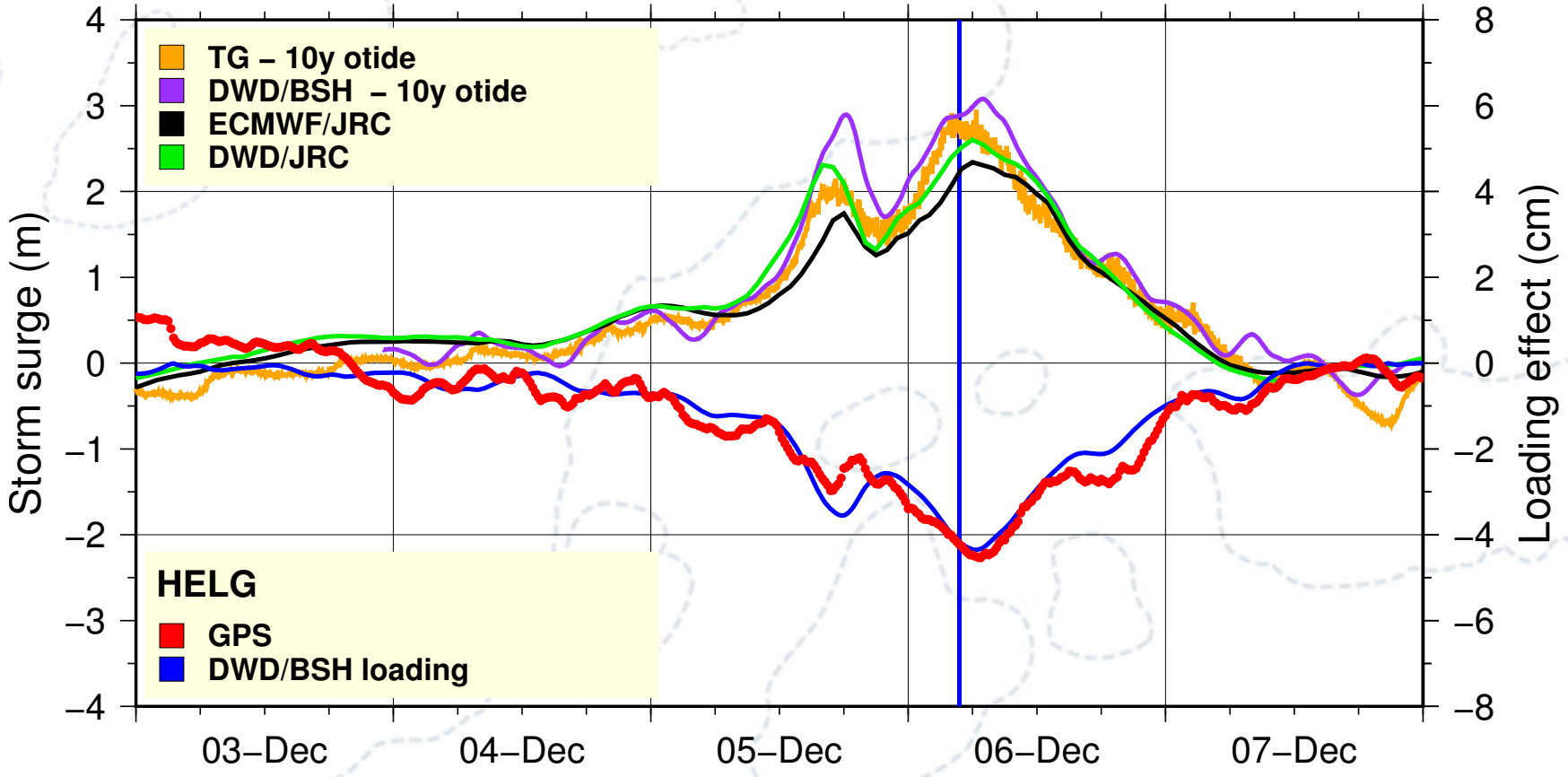




SWH and U10 at FINO1 Platform



In-situ geodetic network in GBight



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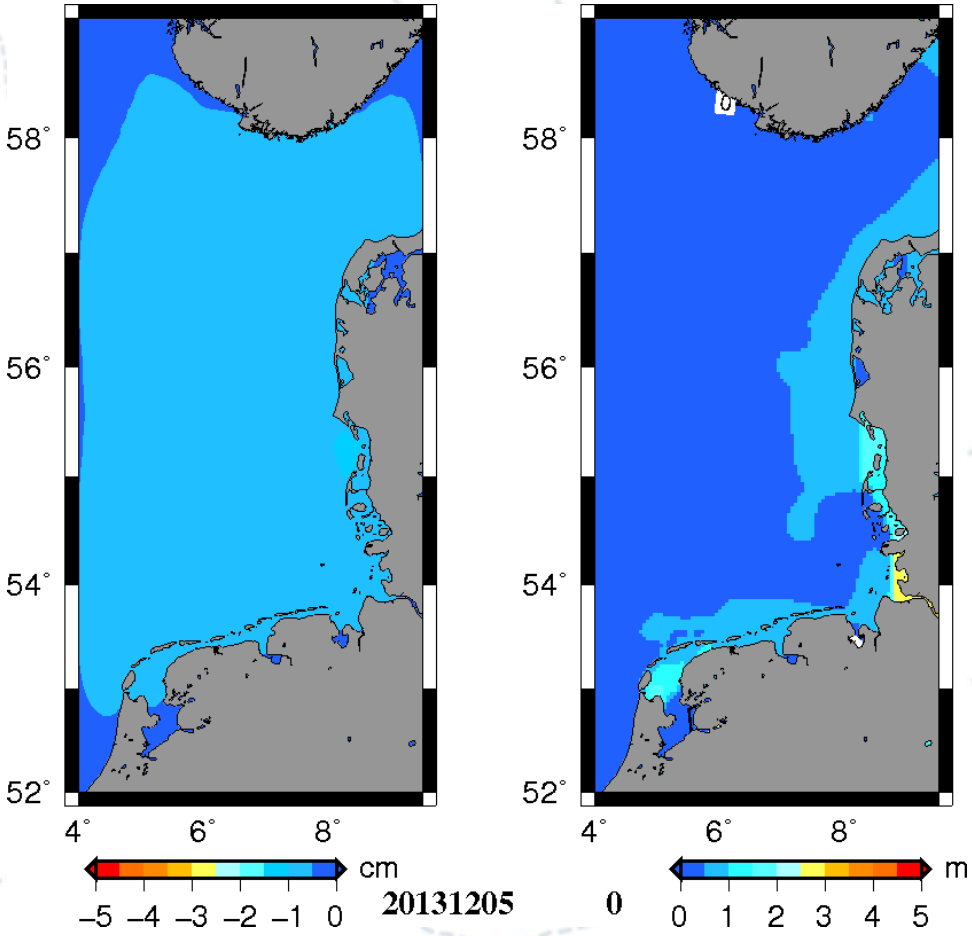
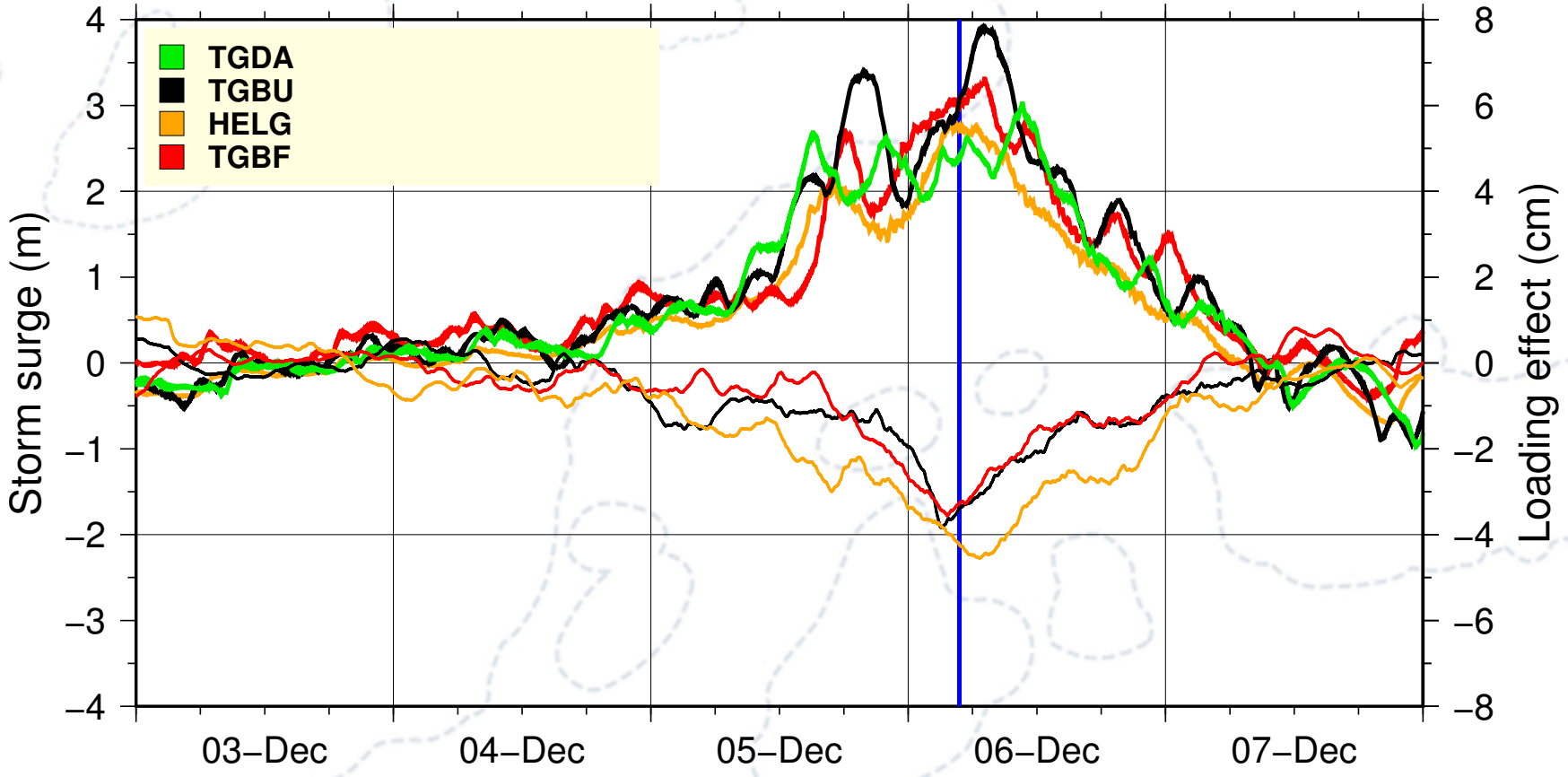
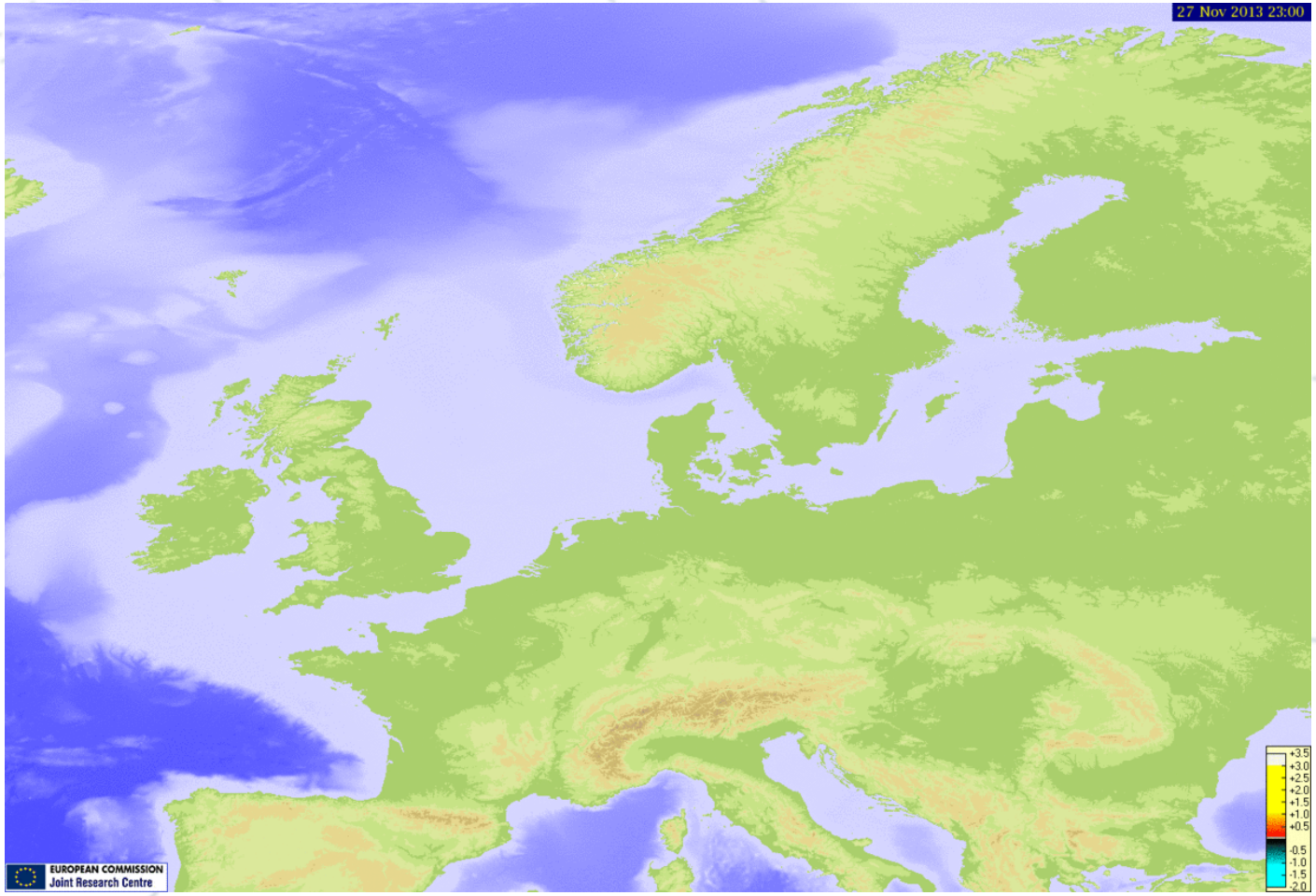


In-situ geodetic network in GBight



JRC Storm surge Forecast



Conclusions

- **SARAL/AltiKa**
  - Unique snapshot pass of sea level, wind and wave height
  - Correctly reproduces the SS amplitude
  - Appears to underestimate high wave height (~2 m) and high wind speed (~4 m/s): *improvement in algorithm is needed*
- **Models**
  - Largely agree on wind speed (±1 m/s), difference between models due to wind forcing
  - Agree reasonably with altimeter on surge (±50 cm)
  - Differ with altimetry on wave height (±2 m)
- **In-situ data**
  - Largely agree with models, but differ on peak events
  - Non-tidal LVM of 3-4 cm at maximum well detected by **GPS; POTENTIAL**
- Altimetry provides valuable information on the spatial structure, *assimilation promising to reduce uncertainties : how to best integrate in validation of model forecast?*
- Present satellite constellation inadequate for operational storm surge monitoring, *place for improvement?*

alti – TG SL corrected for ocean model

Table 6 Statistics of the difference between the sea surface heights in Table 5 corrected by using an ocean-tide model.

Sat.	Dist. to TG [km]	FES2004 Corr.	FES2004 Mean [m]	FES2004 Std. [m]	GOT4.7 Corr.	GOT4.7 Mean [m]	GOT4.7 Std. [m]	DTU2010 Corr.	DTU2010 Mean [m]	DTU2010 Std. [m]	EOT11a Corr.	EOT11a Mean [m]	EOT11a Std. [m]	Nr. obs. [%]
						Helgoland								
N/C	24	0.967	-0.195	0.092	0.959	-0.194	0.105	0.967	-0.190	0.093	0.963	-0.195	0.097	88.8
N/C	10	0.977	-0.004	0.085	0.976	0.001	0.088	0.984	0.000	0.069	0.971	-0.004	0.094	95.1
N/C	30	0.870	-0.159	0.220	0.867	-0.157	0.226	0.898	-0.156	0.181	0.863	-0.160	0.222	90.2
ESA	29	0.914	-0.165	0.110	0.859	-0.119	0.145	0.935	-0.152	0.096	0.904	-0.161	0.122	91.6
ESA	9	0.970	-0.040	0.073	0.983	-0.029	0.057	0.982	-0.031	0.059	0.958	-0.036	0.093	95.3
ESA	33	0.933	-0.354	0.119	0.934	-0.381	0.128	0.943	-0.348	0.116	0.930	-0.352	0.128	94.4
						LT Alte Weser								
N/C	27	0.946	0.169	0.140	0.933	0.174	0.146	0.962	0.172	0.109	0.948	0.168	0.132	89.8
N/C	35	0.974	0.353	0.097	0.931	0.358	0.151	0.974	0.357	0.090	0.979	0.353	0.099	96.3
N/C	53	0.952	0.199	0.132	0.879	0.202	0.210	0.951	0.203	0.124	0.946	0.199	0.139	92.8
ESA	59	0.935	0.241	0.106	0.874	0.303	0.154	0.922	0.242	0.115	0.927	0.238	0.112	93.5
ESA	31	0.965	0.359	0.093	0.928	0.393	0.138	0.971	0.359	0.086	0.959	0.359	0.097	96.3
ESA	16	0.915	0.050	0.139	0.944	0.043	0.122	0.952	0.046	0.109	0.921	0.046	0.136	96.3

Model	Spatial (km)	Temporal (h)	Parameters
ECMWF	15	6	u,v,u10
ERA_interim	78	6	u,v,u10,swh
GFS	50	6	u,v,u10
JRC/ECMWF	3.7	1	u,v,u10
ECMWF	15	1	u,v,u10
BSHcmod	7	0.25	TWLE
COSMO-EU	7	1	u,v,u10