European Commission

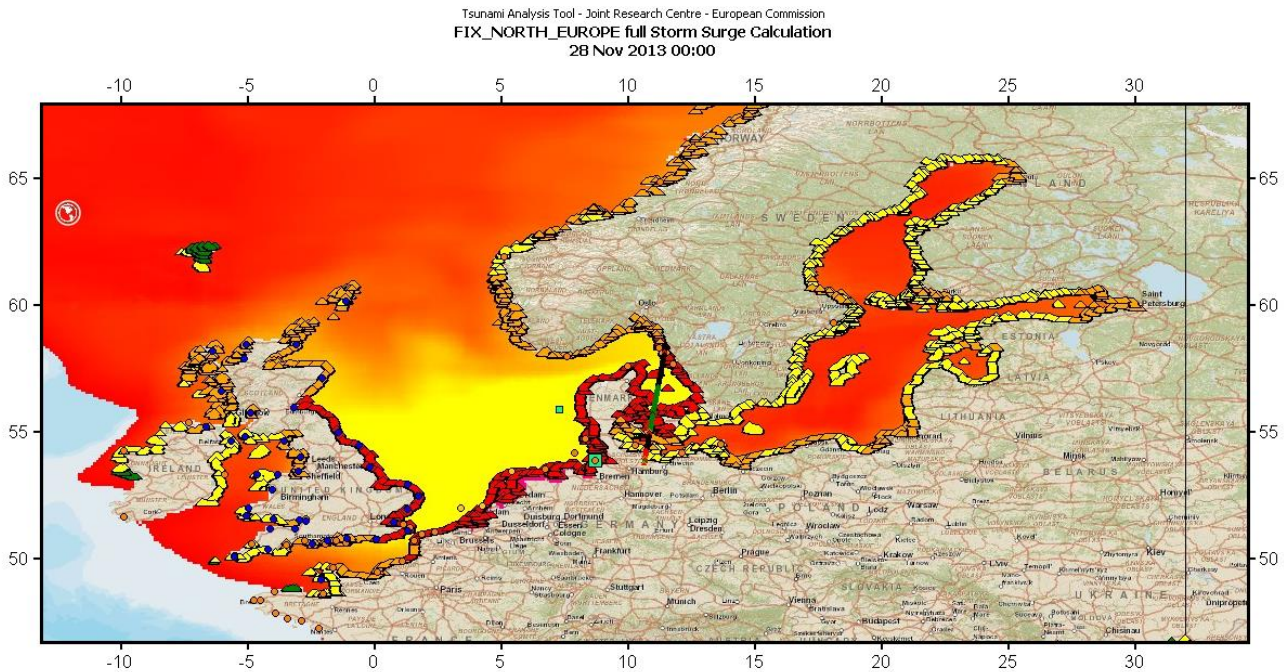
JRC TECHNICAL REPORTS

The JRC Storm Surge Calculation System

Application to the Xaver Extra Tropical Cyclone Event

A. Annunziato, P. Probst

2015



EUR 27637 EN

Joint Research Centre

JRC Science Hub
https://ec.europa.eu/jrc

JRC 99136

EUR 27637

PDF ISBN: 978-92-79-54139-1 ISSN: 1831-9424 doi:10.2788/522394

Print ISBN: 978-92-79-54140-7 ISSN: 1018-5593 doi:10.2788/080290

How to cite: A. Annunziato, P. Probst; The JRC Storm Surge Calculation System; EUR27637; doi:10.2788/522394

Table of contents

Abstract

The **Xaver** storm affected in the first days of December 2013 (4th -7th) several Nordic countries, causing inundation and damages along its path. Severe storm alerts have been issued some days in advance by various European Meteorological Institutes indicating the possibility of large inundation of coastal areas.

This report describes the calculations that have been performed online during the passage of the **Xaver** storm. These calculations are part of a new development performed at JRC in order to be able to estimate tropical cyclones and extra tropical cyclones adopting worldwide pressure and wind speed estimations obtained by the European Center for Medium Weather Forecasts (ECMWF) as boundary conditions to the hydraulic calculations.

The JRC Storm Surge Calculation System, application to the Analysis of North Atlantic Storm Surge of Xavier Extra Tropical Cyclone Event

A. Annunziato, P. Probst

1 Introduction

The **Xaver** storm affected in the first days of December 2013 (4th -7th) several Nordic countries, causing inundation and damages along its path. Severe storm alerts have been issued some days in advance by various European Meteorological Institutes indicating the possibility of large inundation of coastal areas.

This report describes the calculations that have been performed online during the passage of the **Xaver** storm. These calculations are part of a new development performed at JRC in order to be able to estimate tropical cyclones and extra tropical cyclones adopting worldwide pressure and wind speed estimations obtained by the European Center for Medium Weather Forecasts (ECMWF) as boundary conditions to the hydraulic calculations.

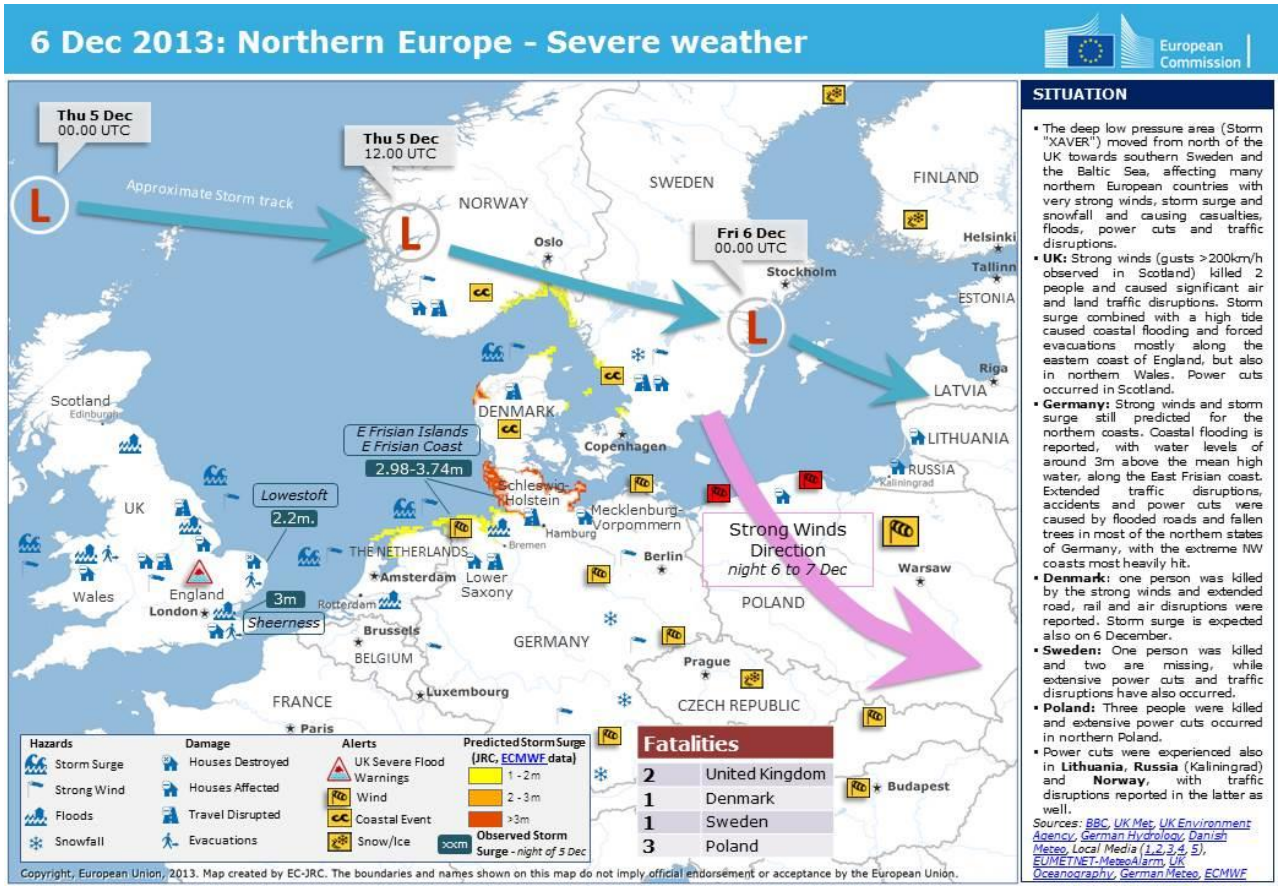


Figure 1 - ECHO Daily Map of 6 Dec 2013 (source: JRC - ERCC Portal, [3])

2 Meteorological conditions

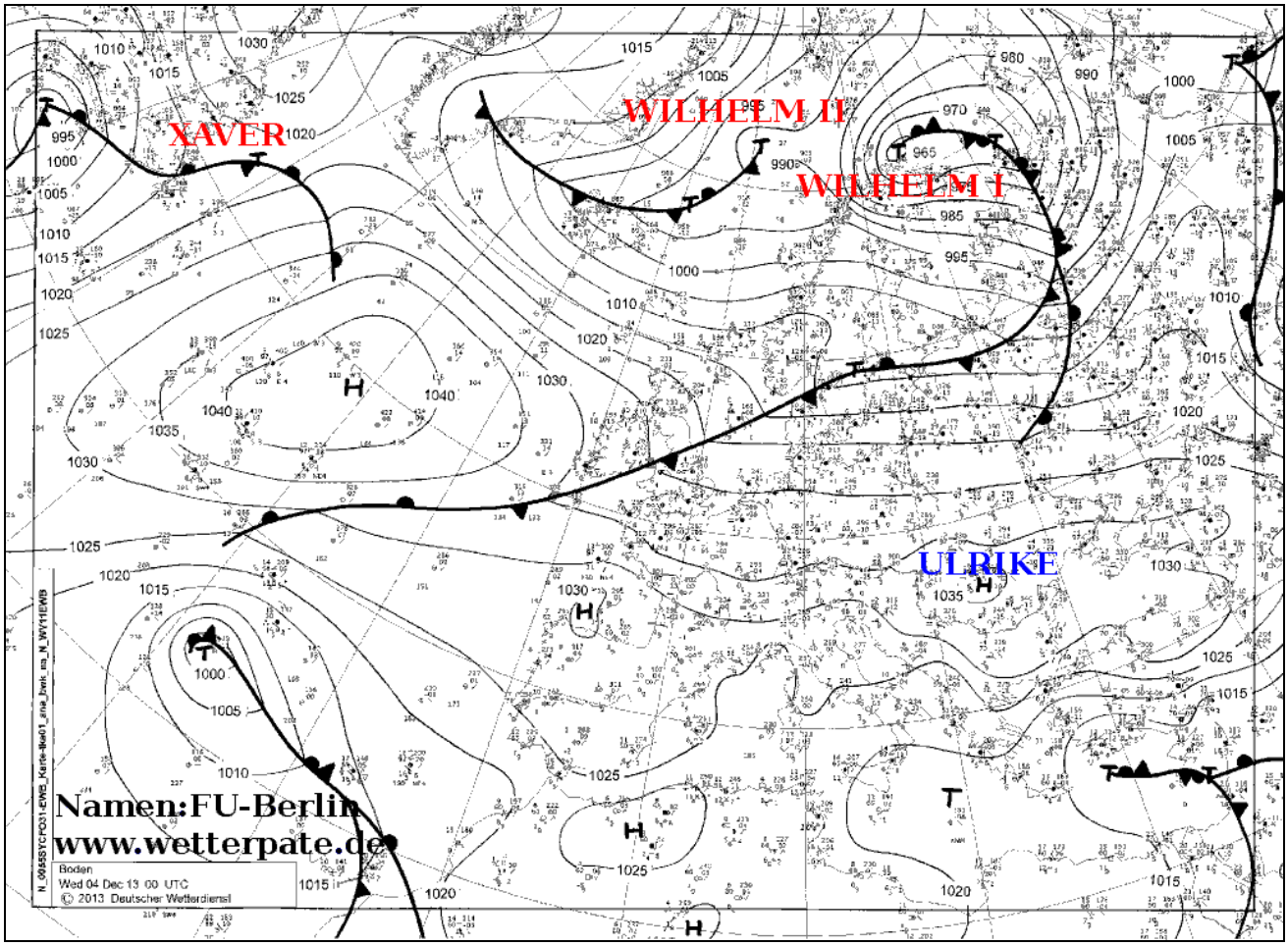


Figure 2 - "Xaver" - Free University of Berlin [1]

A low pressure system (named "Xaver" by the "Free University of Berlin", see Figure 2) formed over the North Atlantic Ocean off the west coast of Iceland on 4 December and moved towards northern Europe, intensifying. Its center passed off the coast of northern UK in the morning of 5 December, over southern Norway and southern Sweden in the following hours and reached the Baltic Sea on 6 December (see time evolution in Figure 3). Warning/Alerts for winds, storm surge, floods have been issued by the national weather services (see Figure 4 and Figure 1). During its passage it affected several northern European countries with very strong winds and storm surge, causing floods, power cuts and traffic disruptions (see Figure 1).

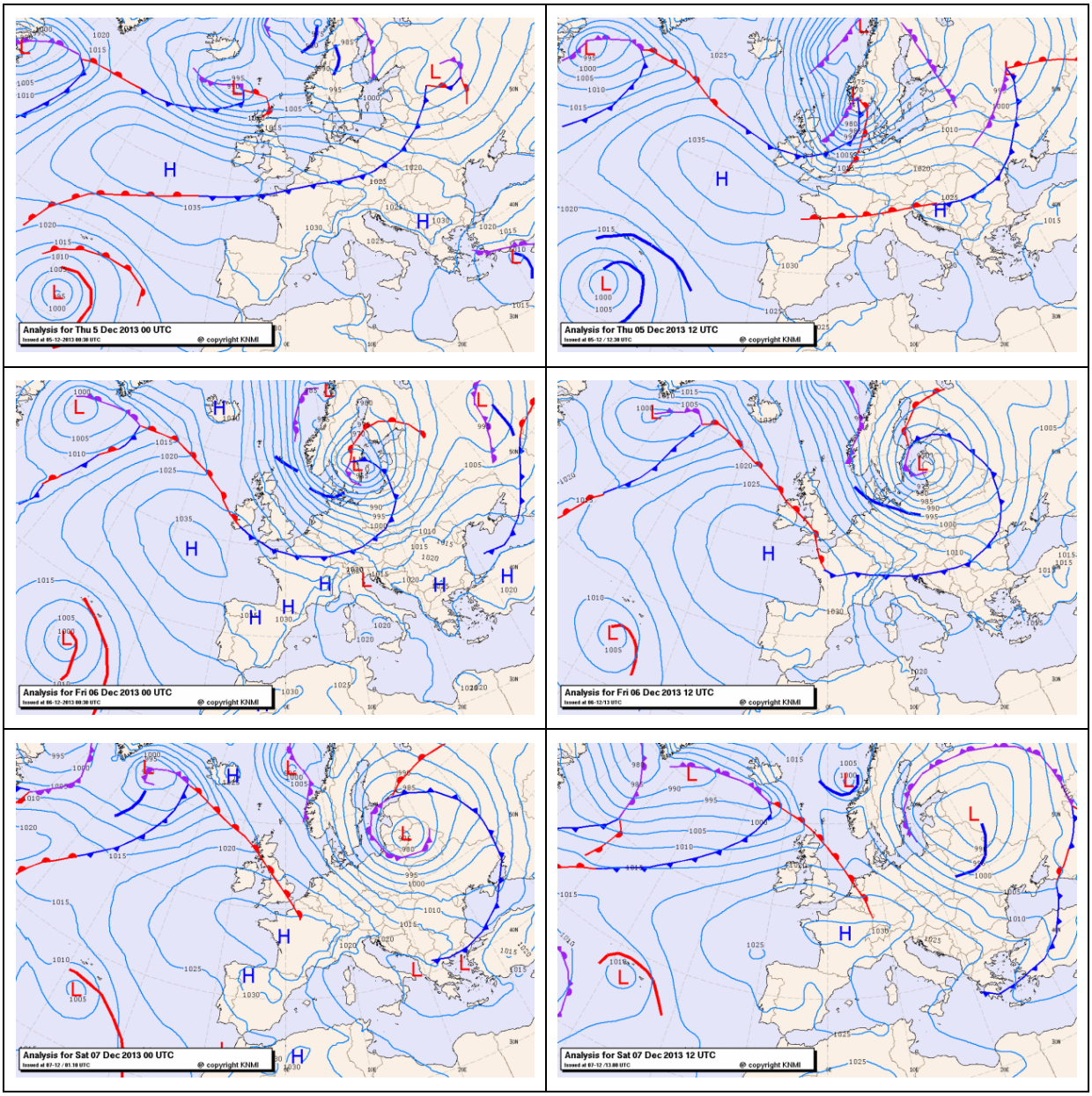


Figure 3 - Weather Map from 05 Dec 00:00 UTC to 07 Dec 12:00 UTC (source: KNMI, [2])

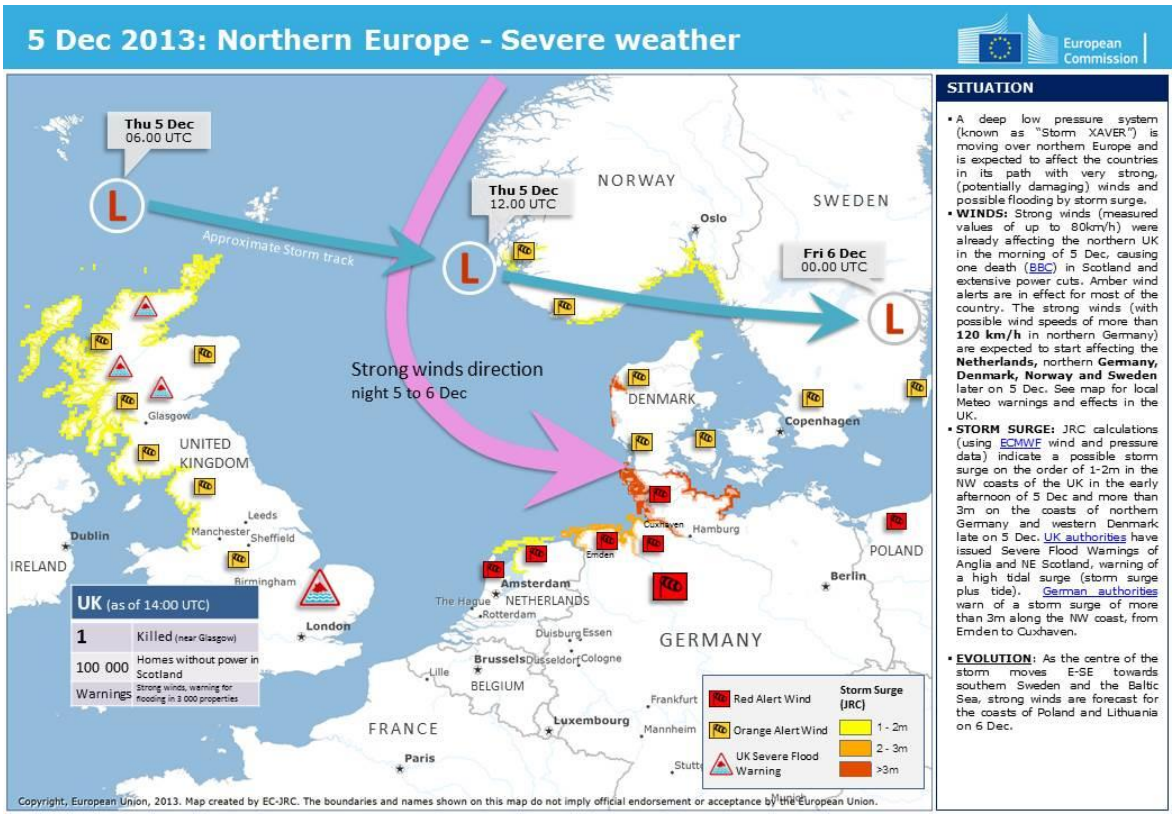


Figure 4 - ECHO Daily Map of 5 Dec 2013 (source: JRC – ERCC Portal, [2])

Sources:

[1] Free University of Berlin: http://www.met.fu-berlin.de/de/wetter/maps/Analyse_20131204.gif

[2] Koninklijk Nederlands Meteorologisch Instituut (KNMI): http://www.knmi.nl/klimatologie/daggegevens/weerkaarten/index.cgi

[3] ECHO Daily Map of 5 Dec 2013 : http://ercportal.jrc.ec.europa.eu/ERCMaps/ECDM_20131205_NorthernEurope_SevereWeather.pdf

[4] ECHO Daily Map of 5 Dec 2013 : http://ercportal.jrc.ec.europa.eu/ERCMaps/ECDM_20131206_NorthernEurope_SevereWeather.pdf

3 The JRC Storm Surge Calculation System

The JRC Storm Surge Calculation System is a new development that has been established at the Joint Research Centre in the frame of the Global Disasters Alerts and Coordination System (GDACS). The system is intended as a series of procedures that use meteorological forecasts produced by ECMWF in order to estimate the storm surge as a result of Tropical Cyclone or in general Storm events.

ECMWF produces every 12 hours a worldwide 10-day 'Deterministic' forecasts of Mean Sea Level Pressure, of Wind Speed and Temperature at low levels, and of the Height of the 500-hPa isobaric surface. The forecast file contains time intervals of 1 h and is in form of grib file.

An automatic procedure has been develop that performs the following actions:

- Download the ECMWF grib file 2 time per day, as soon as the file becomes available (typically at 9:30 AM and 9:30 PM for the 00 and 12 h respectively)
- Extract a portion of the grib file and convert in netcdf for a number of windows of interest
- Prepares the input file needed by the storm surge calculations (geoTif raster maps for each time interval for pressure and wind speed components)
- Launches the calculations using the HyFlux2 code
- Post process the results
    - Creates the files needed to analyse with TAT (tsunami Analysis Tool)
    - Creates bulletins for fixed windows
    - Publishing in internet the results

Two type of calculations are launched

- Fixed calculations
    - A number of interest windows have been defined for which two calculations per day are performed using the previous forecast at -6 h and the forecasted values for the 72 h after the time 0 of the forecast
    - At the moment we have defined 4 windows
        - Whole European Window plus half of the Atlantic Ocean with a resolution of 10 min
        - 3 dedicated windows with resolution of 4 min
            - Mediterranean Sea
            - North Sea
            - Atlantic Ocean
- Cyclone calculations
    - When in GDACS a new cyclone is identified with its official name a window is defined using the expected track provided by ECMWF and considering ample margin in the border to contain the cyclone
    - The calculation is performed until the exhausting of the cyclone

At the moment the calculation of the fixed windows is performed using 6 cores. We use a 24 cores Linux workstation and this allows to compute the 4 windows without disturbing each other. The presence of Cyclones calculation slows down the calculations because they are in addition to the fixed window ones. A new server with 80 cores has been ordered and should support the existing one and share the computational needs.

The current computing time is in the order of 2h.

4 ECMWF Weather Deterministic Forecast

To infer pressure and wind fields we are utilising numerical weather forecasts provided on global scale by the European Centre for Medium-Range Forecasts (ECMWF) model. This comprehensive earth-system model developed at ECMWF in co-operation with Météo-France forms the basis for all data assimilation and forecasting activities.

All main applications required are available through one computer software system called the Integrated Forecasting System (IFS). The IFS runs both in "deterministic forecast" mode and as an ensemble. The IFS operational high-resolution (HIRES) with its deterministic single-model configuration runs every 12 hours and forecasts out to 10 days on a global scale.

HIRES horizontal resolution corresponds to a grid of 0.125° x 0.125° lat / long (~16 km) or any multiple thereof (global or sub-area) while its vertical resolution is equal to 137 levels with the model top at 0.01 hPa. Such so called "sigma-levels" follow the earth's surface in the lower- and mid-troposphere being used as vertical coordinates to become surfaces of constant pressure in the upper stratosphere and mesosphere. A smooth transition between these types of levels is ensured (Untch et al, 1999).

The spectral resolution is equal to T1279 based on a spherical harmonic expansion, truncated at total wave number 1279, for the representation of upper air fields and the computation of the horizontal derivatives resulting in a better representation of features such as tropical storms, fronts, heavy rainfall and land / sea transitions. Furthermore, the location and intensity of synoptic (extra-tropical) features have been improved in many cases.

In addition to the spectral representation, there is the grid point representation used for computing dynamic tendencies and the physical (diabatic) parametrization. This so–called Gaussian grid, is regular in longitude and almost regular in latitude (Hortal and Simmons, 1991). Due to the convergence of the longitudes toward the poles, the east–west distance between the grid points decreases poleward. To avoid some numerical problems
around the poles, but most importantly to save computing time, a reduced Gaussian grid was introduced in 1991 by reducing the number of grid points along the shorter latitude lines near the poles, so as to keep the east–west separation between points on different latitudes almost constant. With the current resolution the grid is identical to a regular Gaussian grid between 24N and 24S.

On a tactical basis the following fields are retrieved by JRC twice a day and then incorporated in our Storm Surge Calculation System

- U component of wind (10U) at 10 meters in m/s
- V component of wind (10V) at 10 meters in m/s
- Mean Sea Level Pressure (MSLP) in Pa

These components (10U / 10V / MSLP) are based on 00 and 12 UTC analysis fields and have a maximum forecast horizon of 10 days; we only use the first 3 days of data. They are in GRIB / WMO (World Meteorological Organization) format having a forecast step of 1 hour till the first 96 hours (day 4).

Untch, A., A. Simmons et al., 1999: Increased stratospheric resolution in the ECMWF forecasting system, ECMWF Newsletter Number 82, reprinted in ECMWF Data Services pp. 98-105.

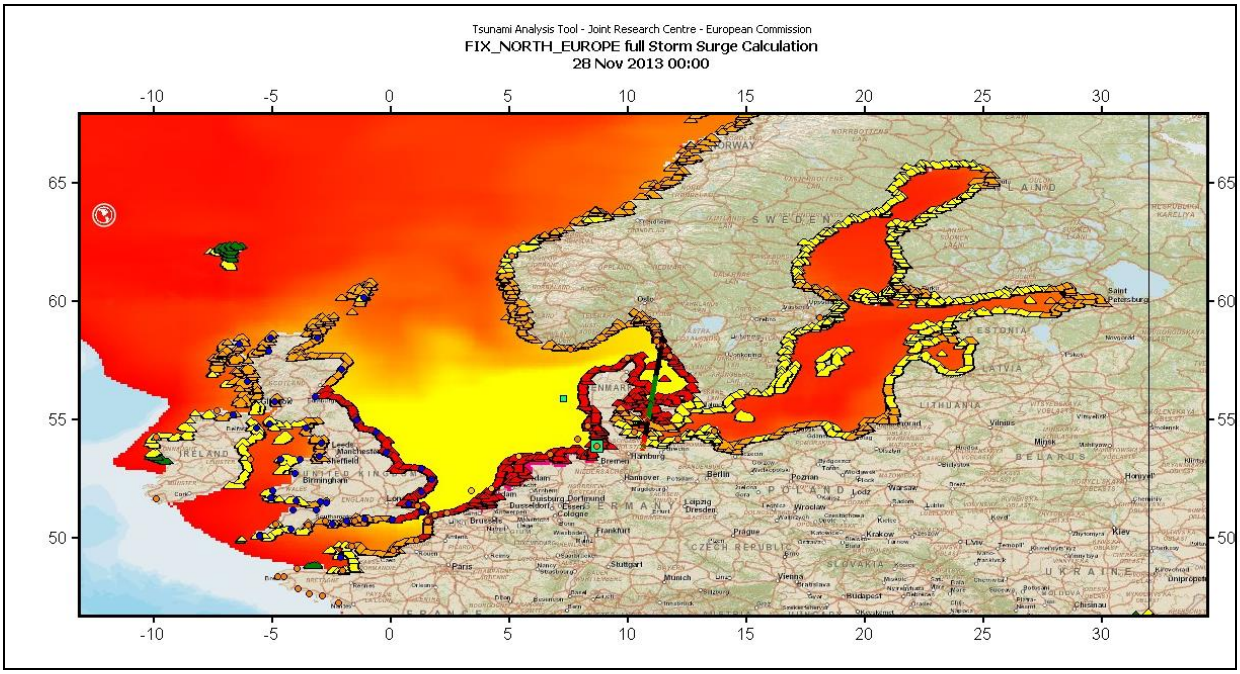
Hortal, M., and A.J. Simmons, 1991: Use of reduced Gaussian grids in spectral models. Mon.Wea.Rev., 119, 1057-1074.

5 Results of Xaver Event calculations

The Xaver storm estimations have been performed using a number of different nodalization skemes in order to assess which would be the best and more efficient calculation. The basic calculation was done with a 6 min bathymetry cell size which is rather coarse (about 12 km) but is the closest to the original meteorological cell size (15 km). Then 2 min (4 km) and for the specific area of Germany and Denmark a 0.5 min (1 km) resolution. The calculations have been conducted in the period 28 November to 8 December in order to cover the build up phase and the impact phases (5-6 December).

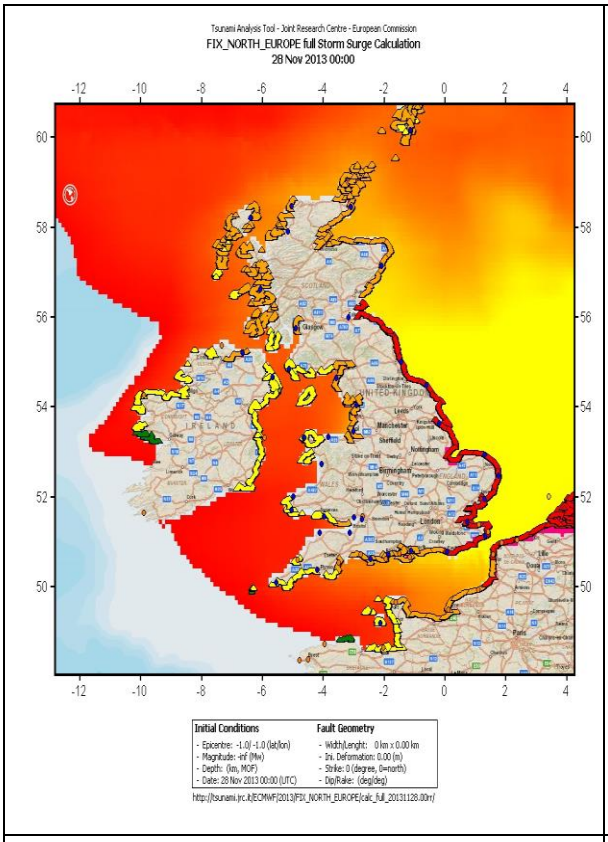
The result of the 6 min calculation is shown below and represents the maximum sea level height over the whole period. It is possible to recognize that the highest sea level (greater than 1m as net increase above the normal astronomical tide) is occurring the in west part of UK, in Netherland, Germany, Denmark and Sweden.

Detailed analysis and comparison with measured sea levels are presented below.

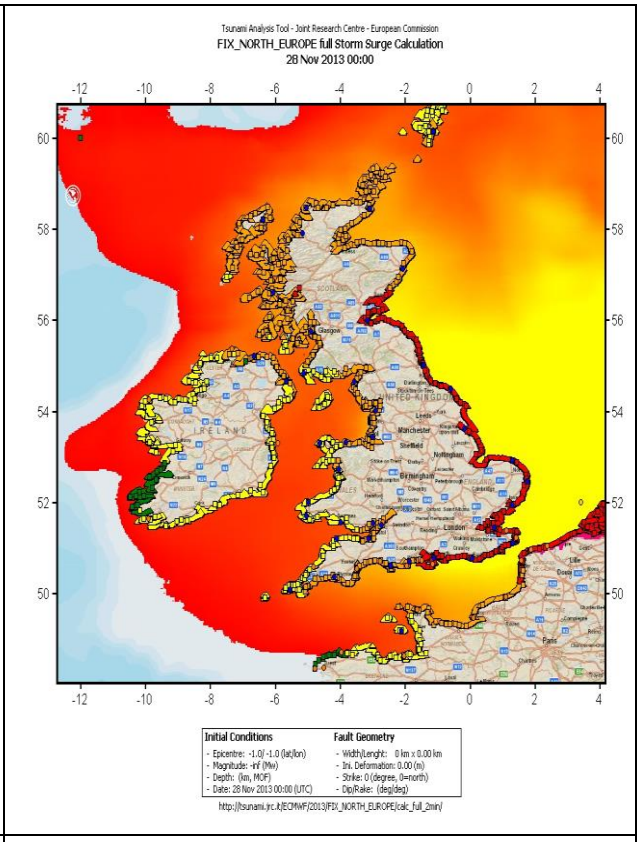


5.1 United Kingdom

The comparison of the estimated maximum height in United Kingdom is presented in the figure below that shows the 6 min vs the 2 min comparison. There are some differences in the west part of Ireland which shows a higher sea level increase with the 2 min resolution. Similar difference is also present in the south west part.



6 min

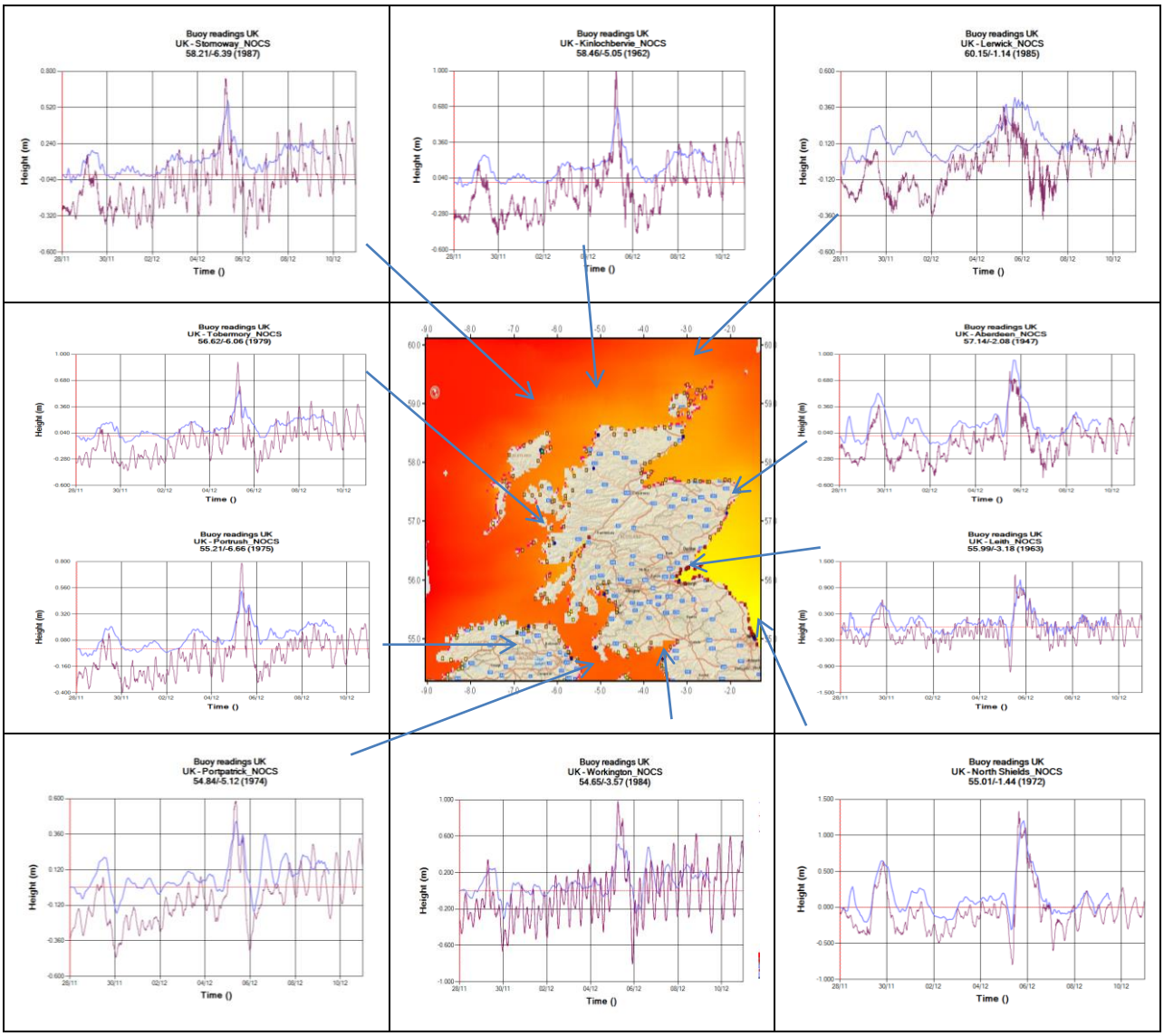


2 min

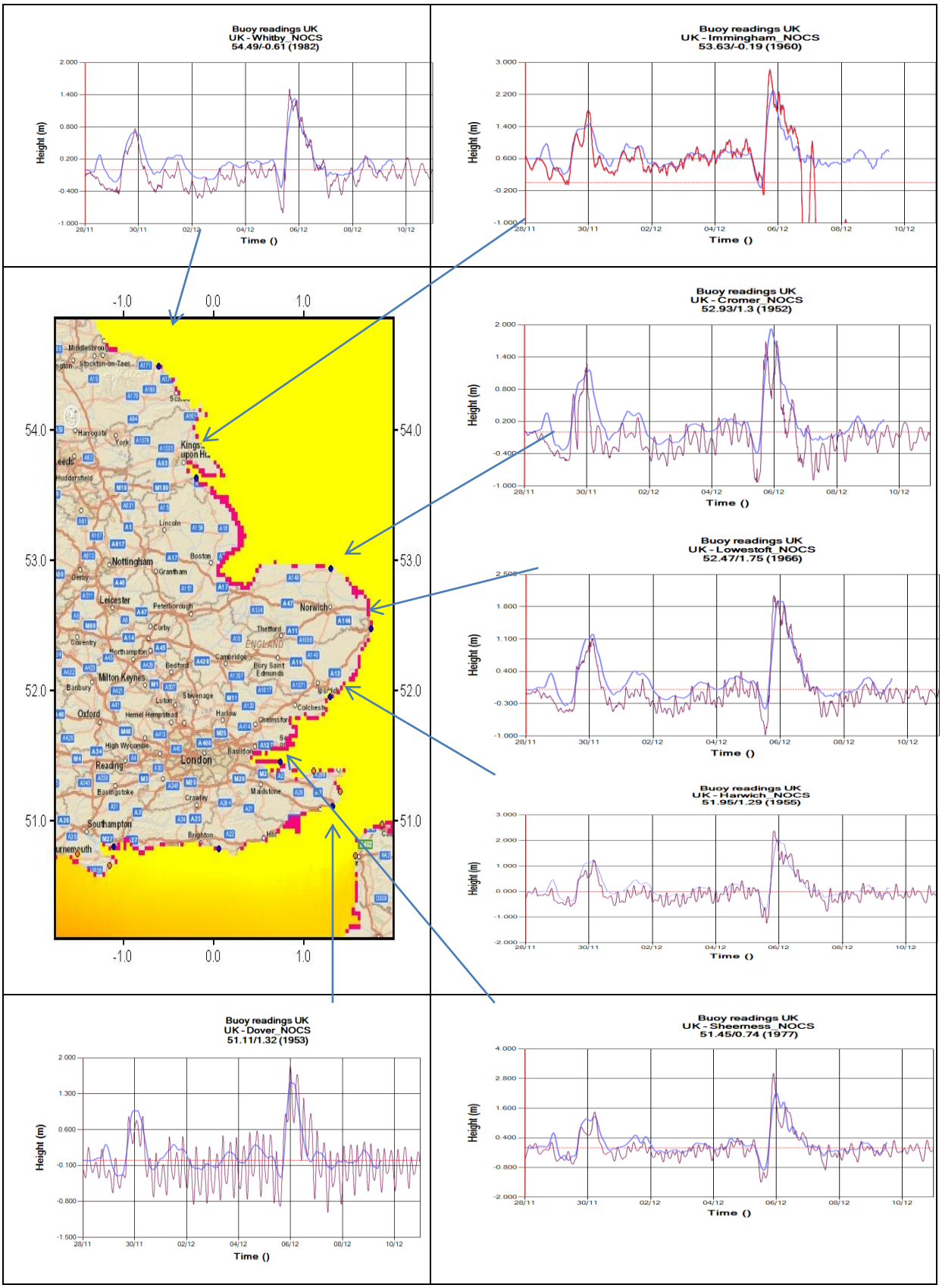
5.1.1 SCOTLAND

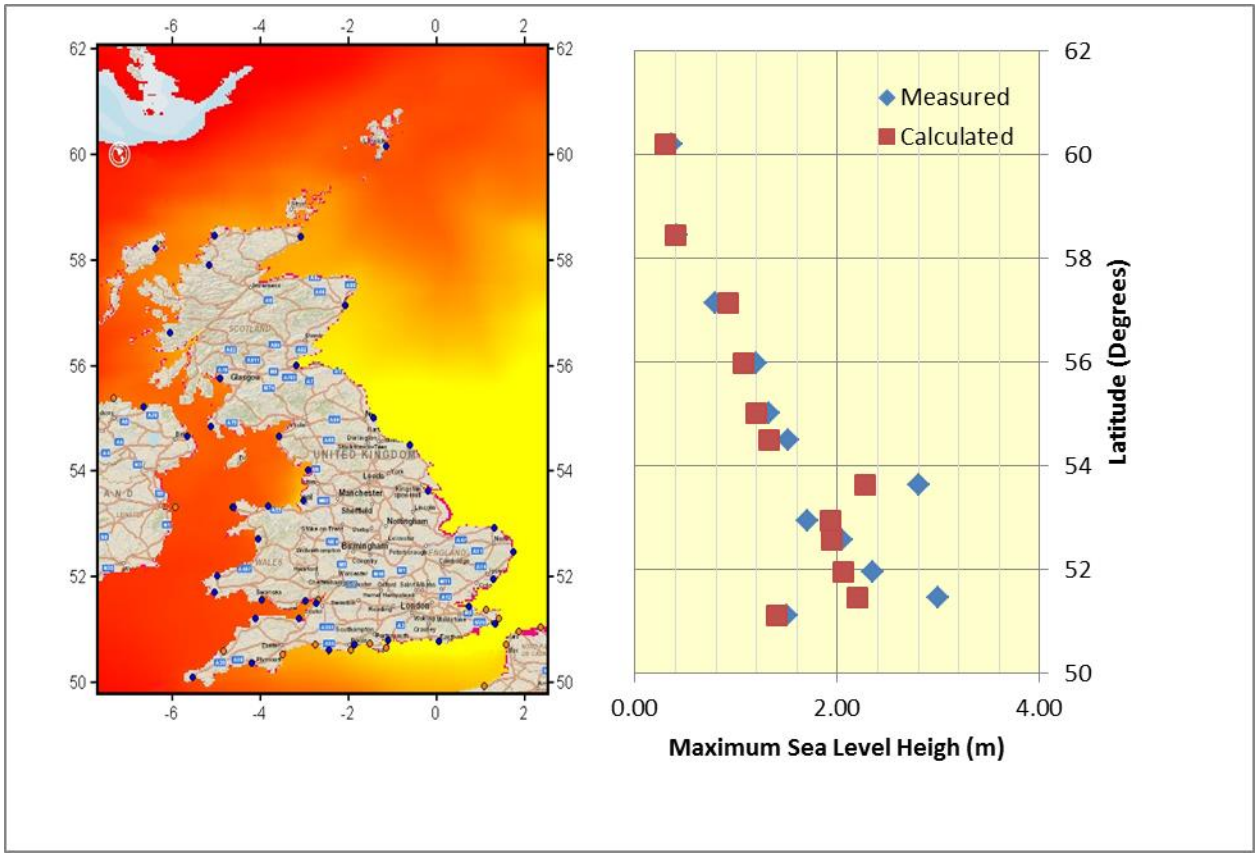
Scotland has been subject to important storm surge between 5th and 6th December with measured height up to 1 m above the astronomical tide. The east coast of Scotland appears more affected with sudden sea level surge mostly occurring in the morning of 5th.

The comparison of the measured and calculated sea level is rather interesting and shows very good coincidence of the time of rise over the progression of the storm from north to south.



5.1.2 East UK Coast



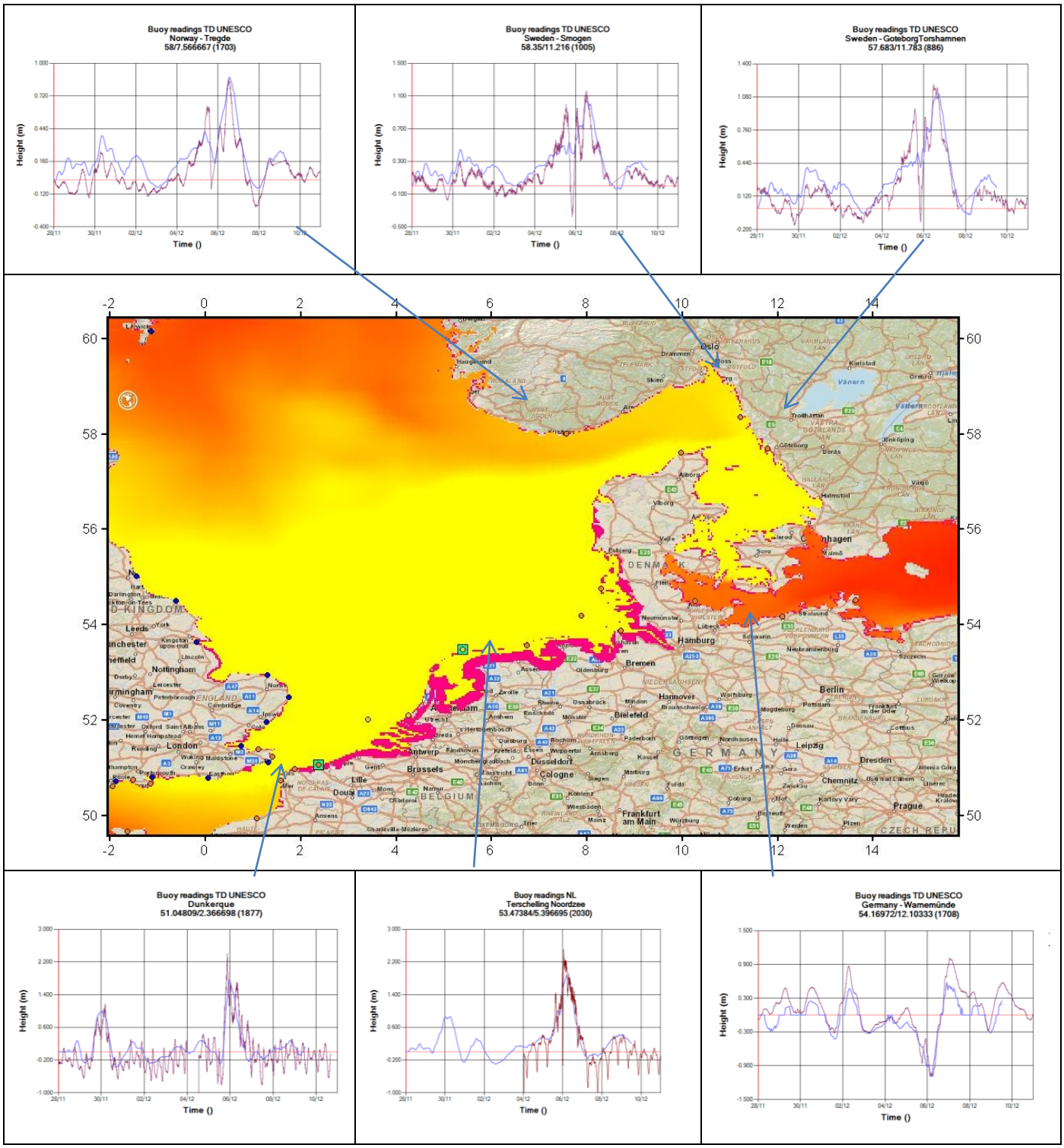


The estimation of the sea level in the east coast shows an increase of maximum sea level height going from north to south. In specific locations (Sherness) the estimated height is too low even if the overall trend is well reproduced in relation to the data.

	Latitude	Longitude	Measured (m)	Calculated (m)	Applied shift
Lerwich	60.21	-1.14	0.36	0.30	0.15
Wic	58.44	-3.09	0.41	0.40	0.35
Aberdeen	57.14	-2.08	0.79	0.92	
Leith	55.99	-3.18	1.20	1.07	
North Shields	55.01	-1.44	1.32	1.20	
Whitby	54.49	-0.61	1.51	1.32	
Immingham	53.63	-0.19	2.80	2.28	
Cromer	52.93	1.3	1.70	1.93	
Lowestoft	52.57	1.75	2.04	1.95	
Harwick	51.95	1.29	2.35	2.06	
Sherness	51.45	0.74	3.00	2.20	
Dover	51.11	1.32	1.50	1.40	

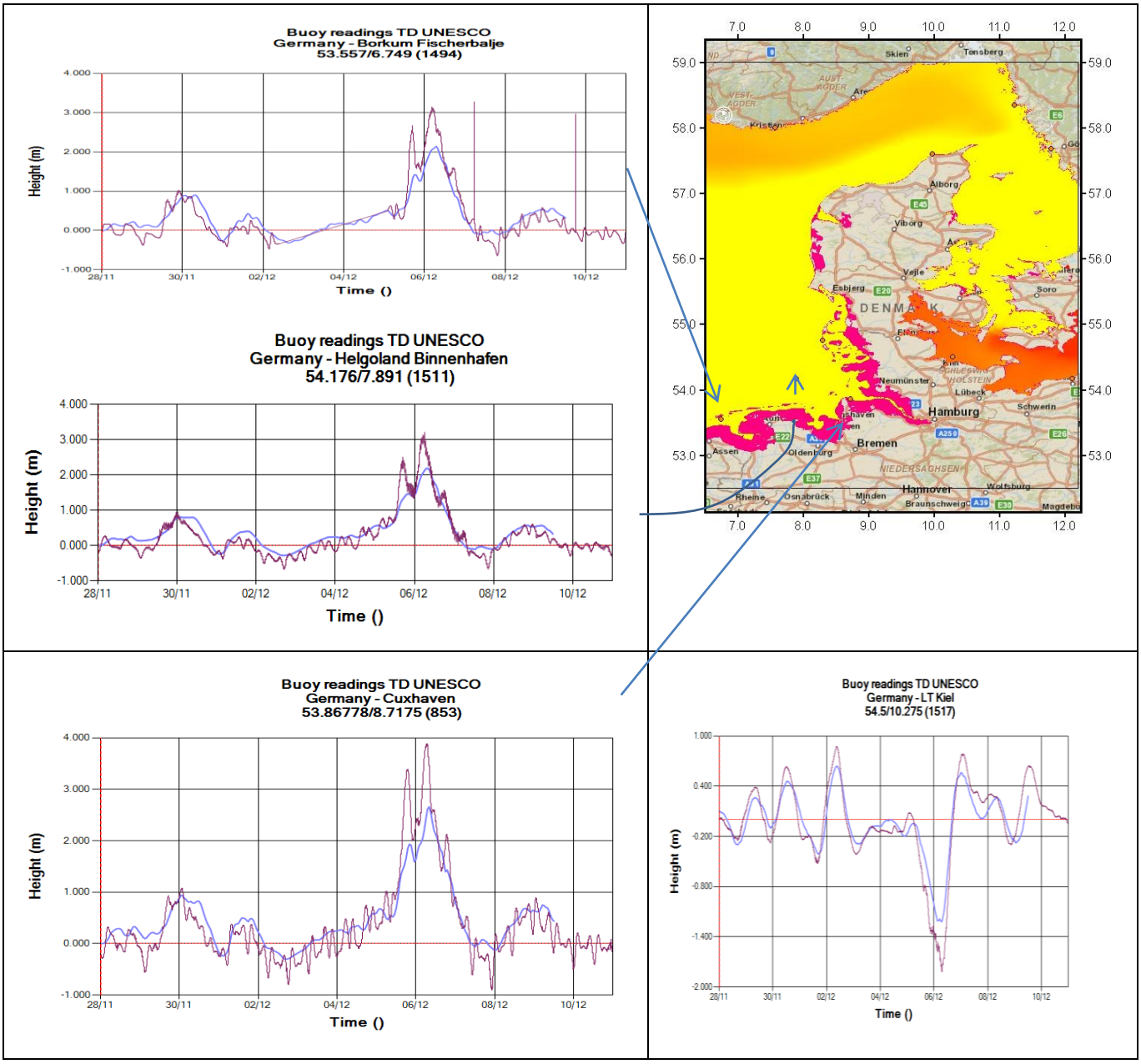
5.2 North Sea Countries

The northern countries are the ones where the storm surge was the highest one with peaks of up to 4 m in Germany. Large inundation areas are also present (pink areas in the map below) even if the inundation extent estimation suffer from the poor topography present in the GEBCO bathymetry used for the calculations.



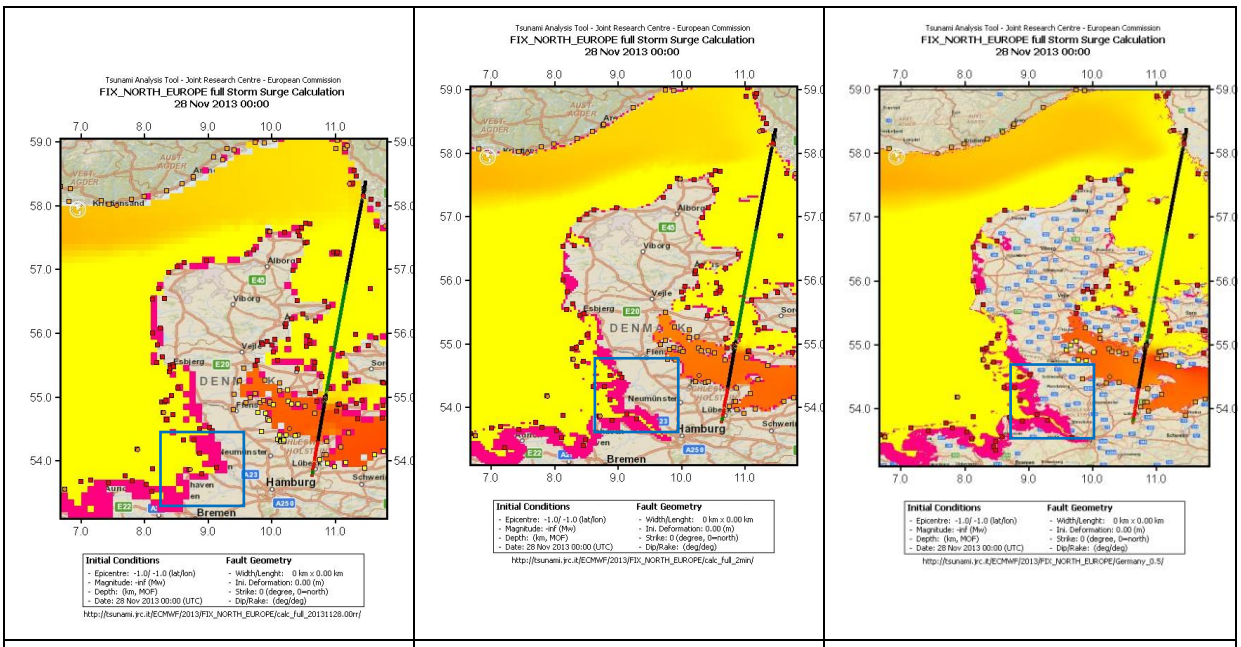
5.2.1 Germany and Denmark

In Germany (Helgoland and Cuxhaven) the sea level behavior is very consistent but the peak is underestimated because the wind speed peak is also underestimated with a maximum of 80 km/h vs a measured value of 130 km/h in the area.

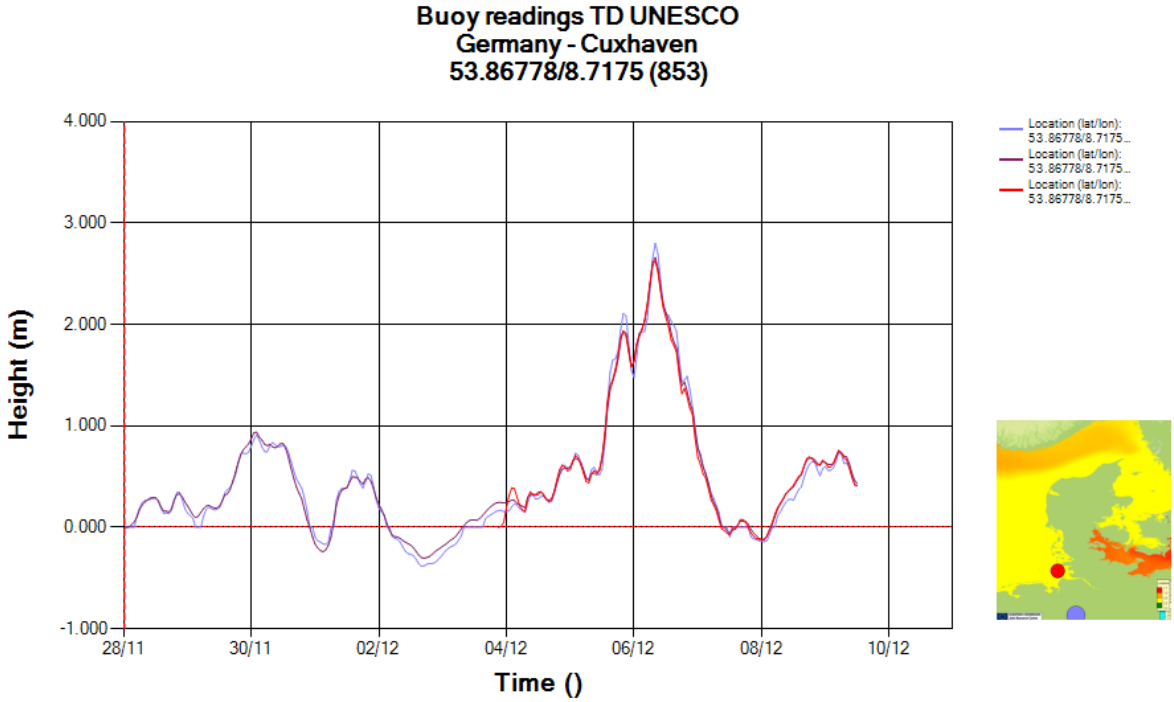


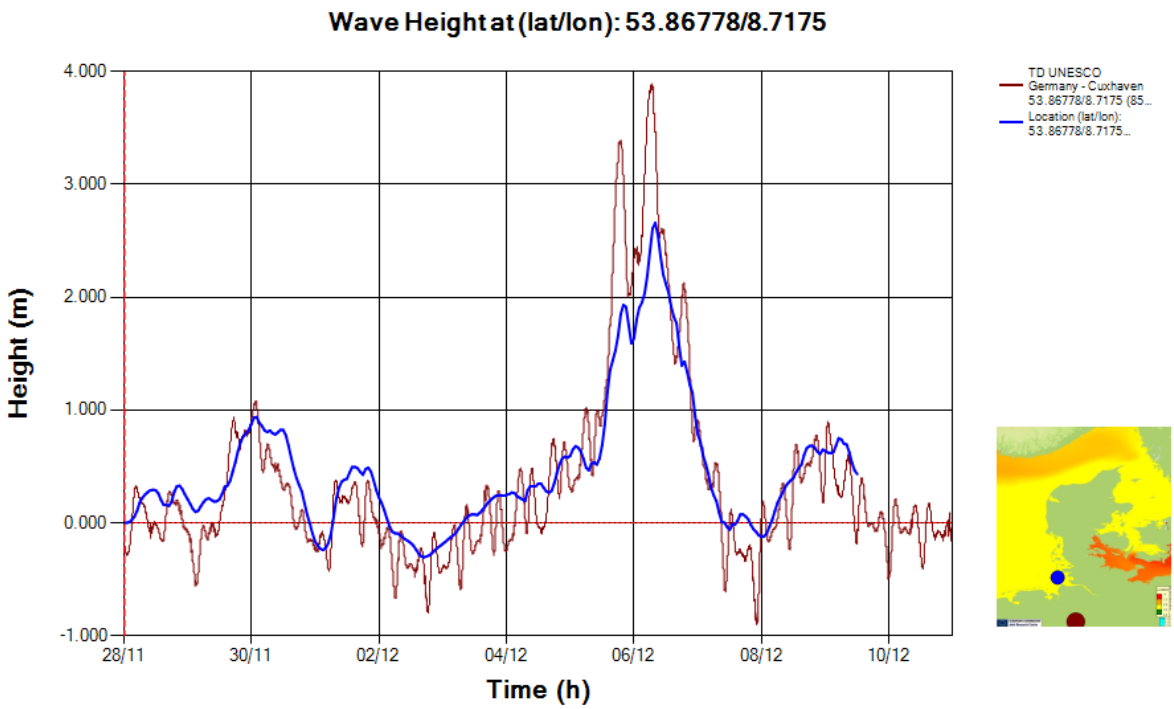
The effect of the use of various nodalization resolutions can be clarified in the images below. Although the sea level height does not change dramatically the detail of the Hamburg channel can be resolved only using a more detailed nodalization skeme. Infact the plot below shows the sea level in Cuxhaven where the 3 curves (6 min, 2 min and 0.5 min) are overlapping each other. The use of the more refined curve is however unable to solve the maximum peak that remains underpredicted.

It should be noted that this is different from Tsunami calculations in which instead the use of finer nodding is necessary in order to resolve the wave propagation because the wave size may be smaller than the nodalization cell size close to the coast. In the case of Tropical cyclones or storm in general the rise is rather constant over a very large portion of the sea and the height increases close to the coast due to the greater effect of the wind but there is not a reduction of the size of the disturbance therefore there is no need (a part the better geographical resolution) of performing a very high resolution calculation.



6 min | 2 min | 0.5 min

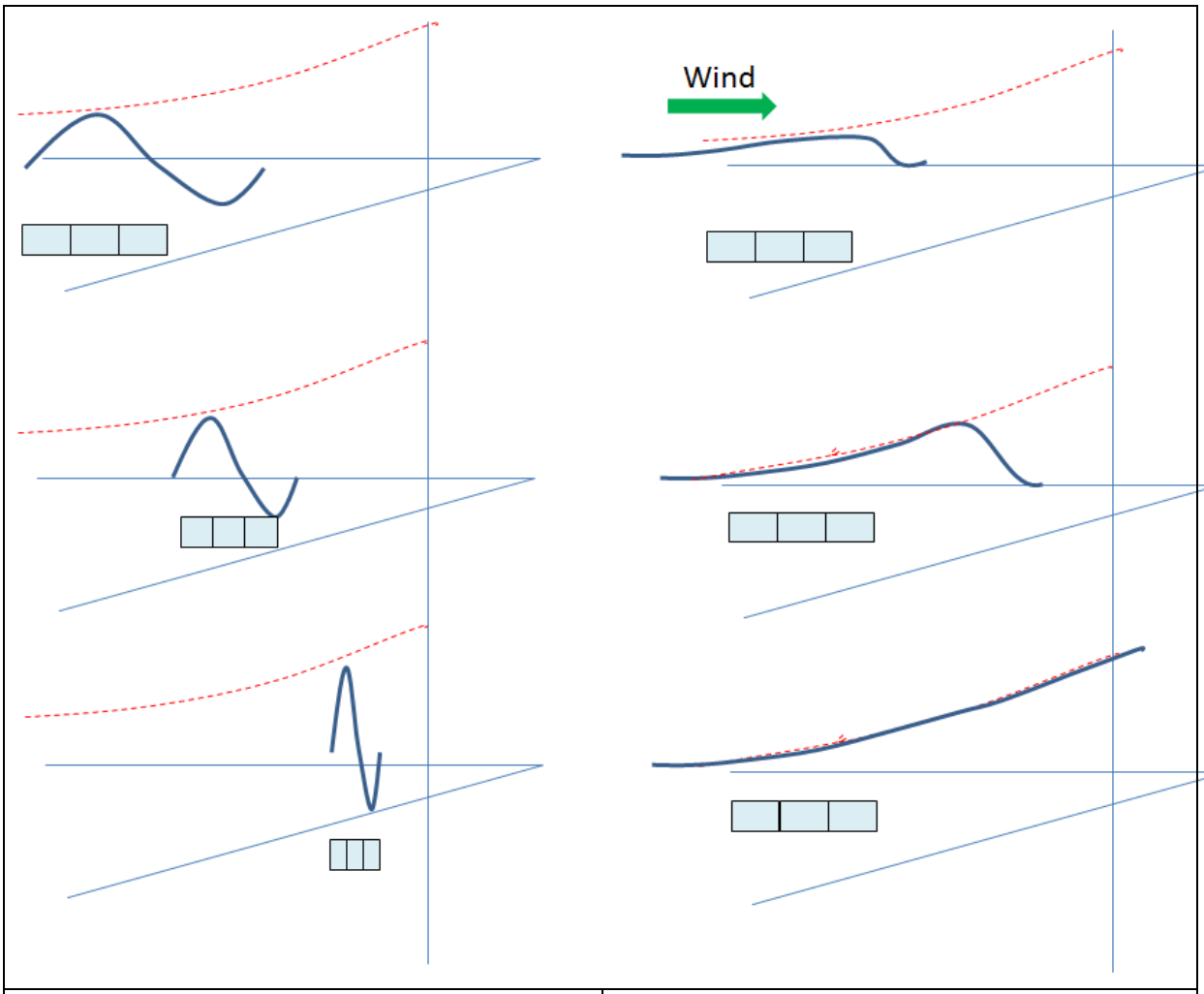




In order to even better clarify this concept the sketch below has been developed. In the case of Tsunami (left) the wave reduces its wave length and increase in height as it approaches the coastline. The resolution needed to resolve the wave increases close to

the coast. Keeping the same resolution as offshore tends to smooth and average the maximum height.

In the case of wind storm (right), the height increases due to a larger wind effect but the size of the disturbance is large and therefore the cell size of the calculation can remain the same as offshore. It is clear that very small and intense perturbations cannot be solved with very large cell sizes. In any case the small perturbations are not resolved by the meteo boundary conditions. The conclusion is that if not for geographical representation purposes the cell size of the hydraulic calculation can follow the meteorological boundary conditions cell size. Much finer nodding than the meteo conditions is not necessary.

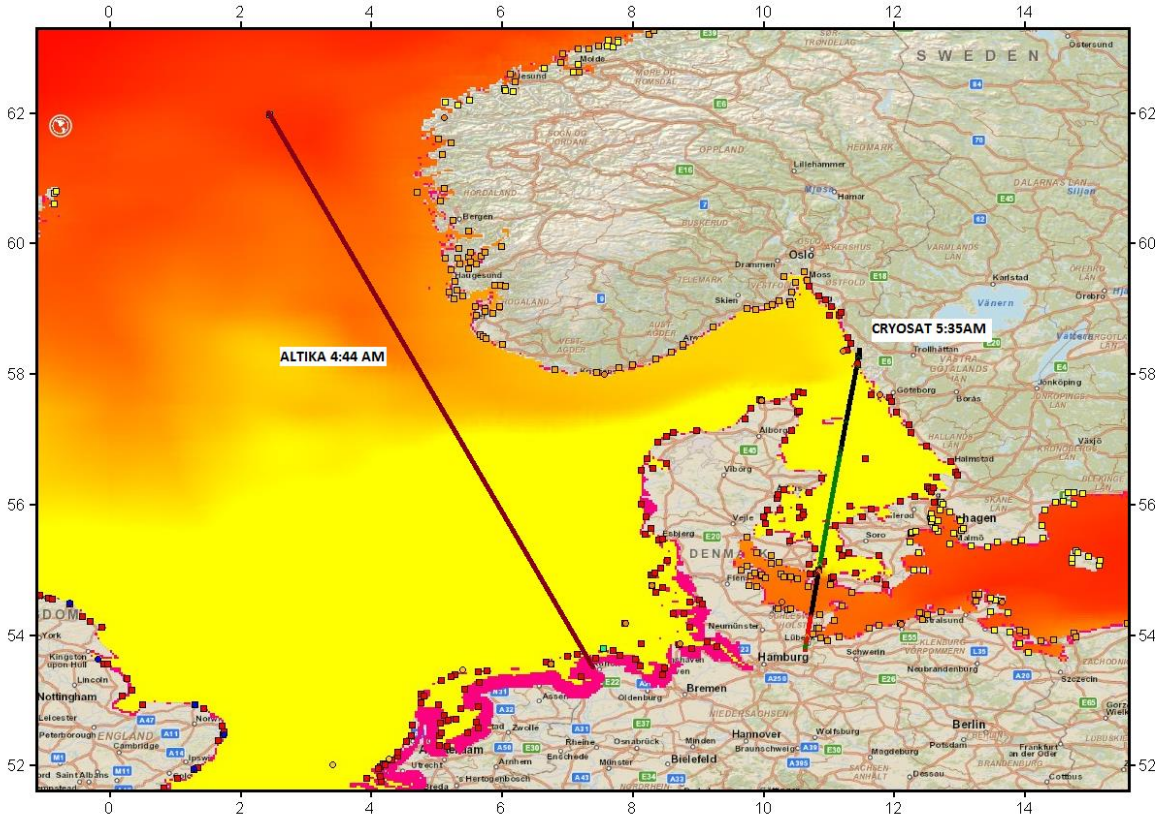


Tsunami case	Wind Storm case

The comparison of the measured wind in the North Sea confirms this discussion. Infact comparing the wind measured in a number of locations in the North Sea shows that the ECWMF wind forecast is missing the two large peaks between 5 and 6 December and as a consequence also the sea level shows an underestimation in Cuxhaven for example.

6 Comparison with altimetry data

Satellite Altimetry data are quite important because they can give an overview of the sea level over a long section and not influenced by local conditions, like in the case of a tidal gauge in a port. However not always is ensured the availability of tracks useful for comparing them with measurements. In the case of Xaver event there are at least 2 tracks, one from Cryosat 6th December at 5:35 AM and another one from Altika satellite, passed at 6th December at 23:05 AM .



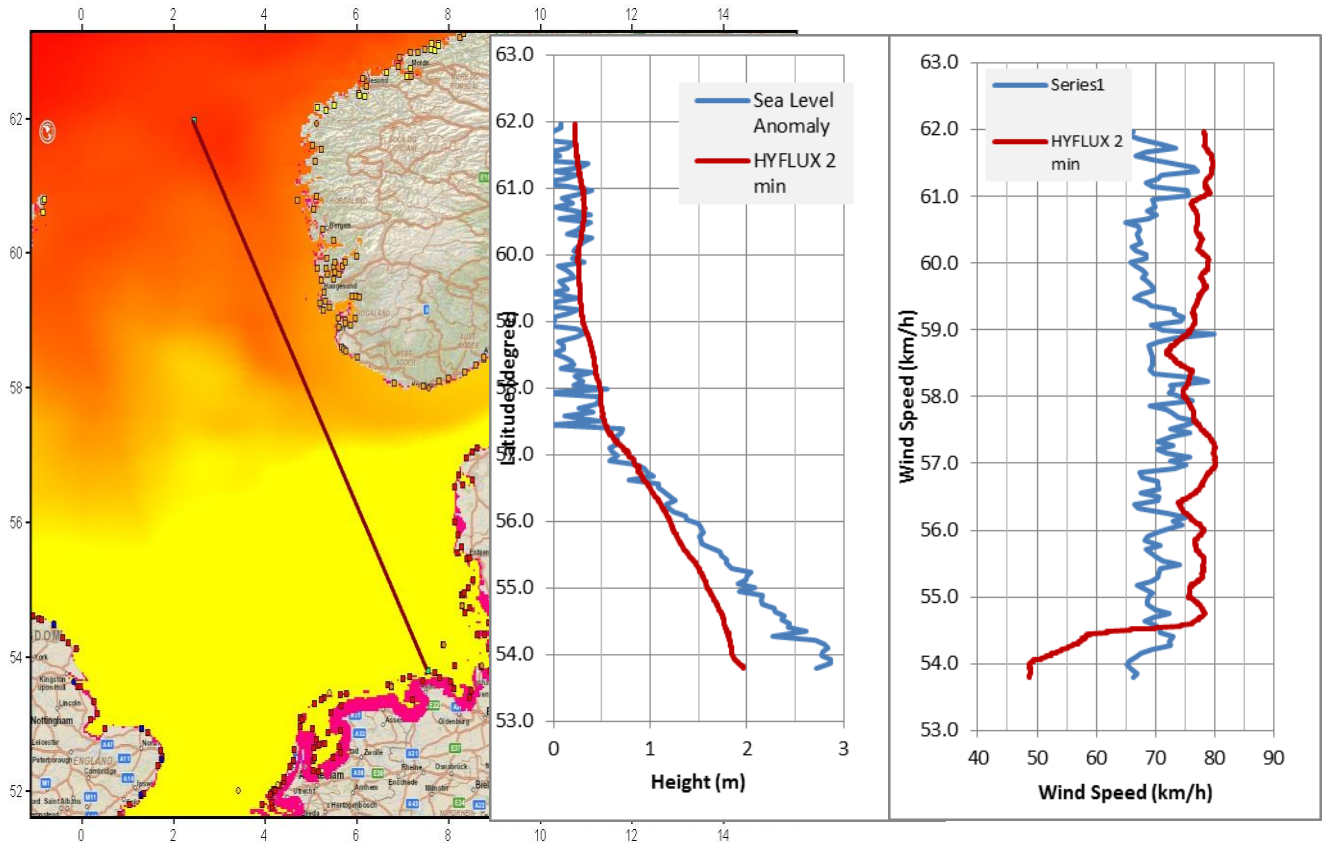
Altika altimetry data

A short report comparing the storm surge measured by the satellite altimeter AltiKa on-board the SARAL satellite and by in-situ stations from a network of tide gauges, buoys and offshore platforms in the German Bight was prepared at the University of Darmstadt and at EUMETSAT/Darmstadt and published online a few days after the event (http://www.eumetsat.int/website/home/News/DAT_2087062.html .)

SARAL is a French-Indian satellite mission launched on 25 February 2013. Among other instruments, it carriers a Ka-band satellite radar altimeter named AltiKa. EUMETSAT, in cooperation with the French space agency CNES, is processing and distributing in near-realtime AltiKa's measurements of significant wave height, wind speed and sea level height. The data was available to the users by EUMETSAT within 3 hours of reception.

The tide gauge data were made available in real time by the Wasser- und Schifffahrtsverwaltung des Bundes (WSV). These stations are part of a network of tide gauges and offshore platforms in the German Bight equipped with continuously operation Global Navigation Satellite System (GNSS) receivers. Since the coordinates of the zero point of the tide gauge are computed in the International Terrestrial Reference Frame (ITRF) the absolute comparison between sea level from tide gauge and altimetry is possible.

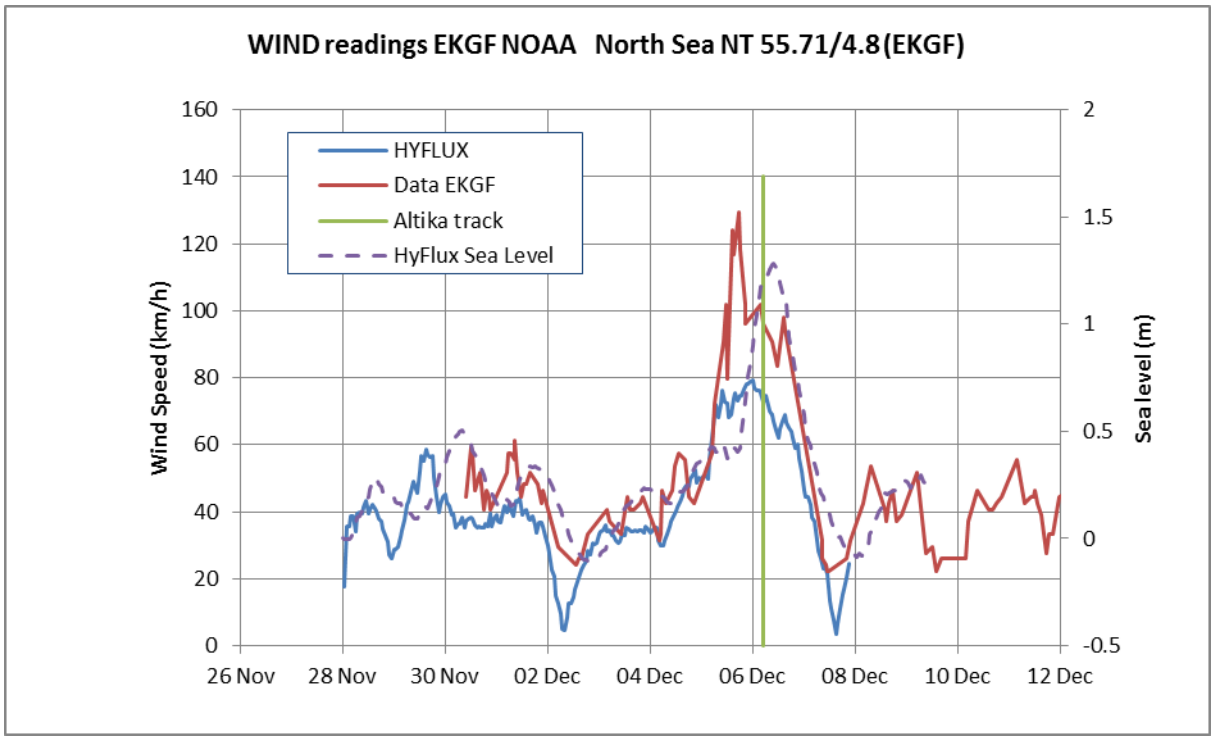
Sea Level Anomaly (SLA) is compared with the HyFlux calculation as this quantity is obtained by removing the tidal component from the measured value. The comparison is quite good in the lower range of height, from Latitude 62 up to 56. Then the calculated value correctly identifies the start of the larger surge but the maximum estimated height is too low compared with the measured height.



Although the wind speed over the altimetry line agrees well or is even a bit higher than the measured value, the sea level is the result of previous events, i.e. in the same location of the altimetry line, few hours before the track time (4:44 am) the wind speed was much higher than the value imposed by the ECMWF wind forecast.

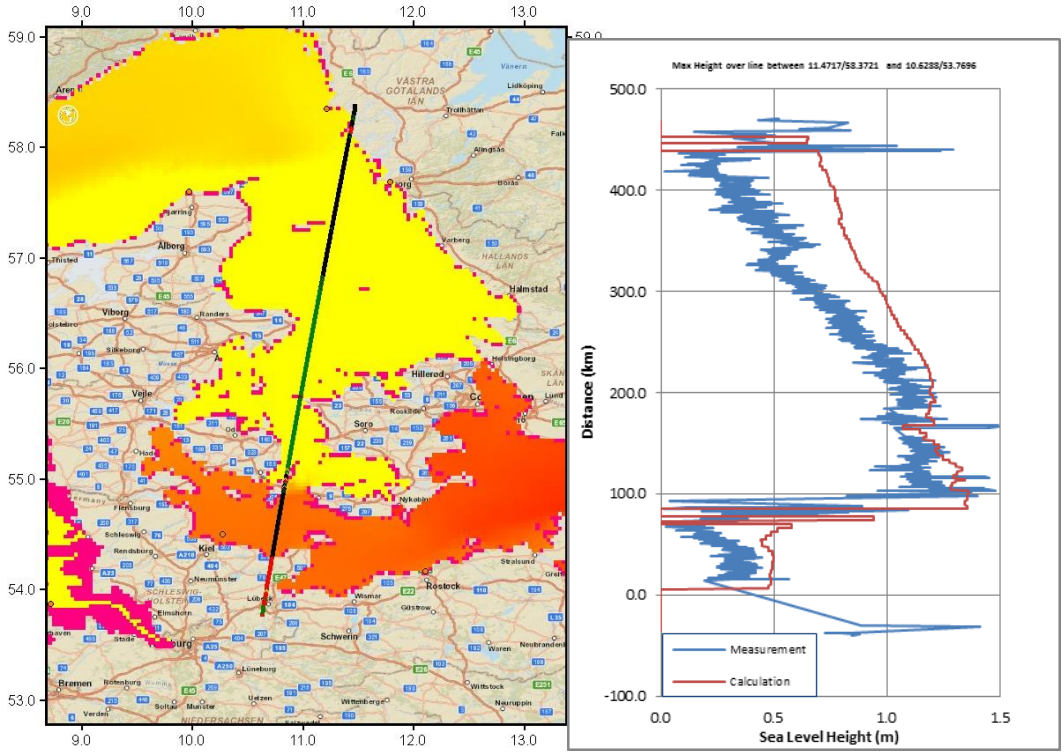
The following figure shows a comparison of the measurements done in the EKGW station in the North Sea (identified by the blue dot in the previous figure). The maximum wind speed measured at this station is in the order of 130 km/h and is much higher than the 80 km/h present in the ECMWF boundary conditions. This explains why the storm surge estimated on the coast does not show the large peaks at 4PM on the 5th and at 5 AM on the 6th (see comparison of Cuxhaven for example.

It would be interesting to perform storm sure calculations by artificially increasing the wind speed by 60% in order to see if respecting the wind speed peak also the storm surge is more realistic.



Cryosat

One of the tracks of Cryosat is useful for the comparison with the sea levels and is the pass at 23:05 on 6th December. The comparison shows that the calculation correctly predicts the form of the height with a drop in the southern section of the track. The maximum sea level is well represented with a maximum of about 1.3 m. In the northern section however the sea level is overestimated by 0.3 m.



7 Conclusions

The Storm Surge calculation system is currently running since 1 year. This report demonstrates the good quality of the forecasts taking as example the Xaver storm of 2013 and showing that the system is able to capture the main features of this extra tropical storm.

Operational calculations have been setup for the Mediterranean Sea, North Europe and North Atlantic and every day 2 bulletins are produced as soon as the ECMWF data are available

A more systematic analysis of the performance is necessary and will be performed next year by comparing the detection of all the major events occurred in the Mediterranean Sea and in the North Sea.

LB-NA-27637-EN-N

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

Publications Office

doi:10.2788/522394

ISBN: 978-92-79-54139-1