European Commission

JRC TECHNICAL REPORTS

JRC Sea Level Database: *Coastal hazards*

The importance of the tides in the JRC storm surge alert systems (GDACS & SSCS)

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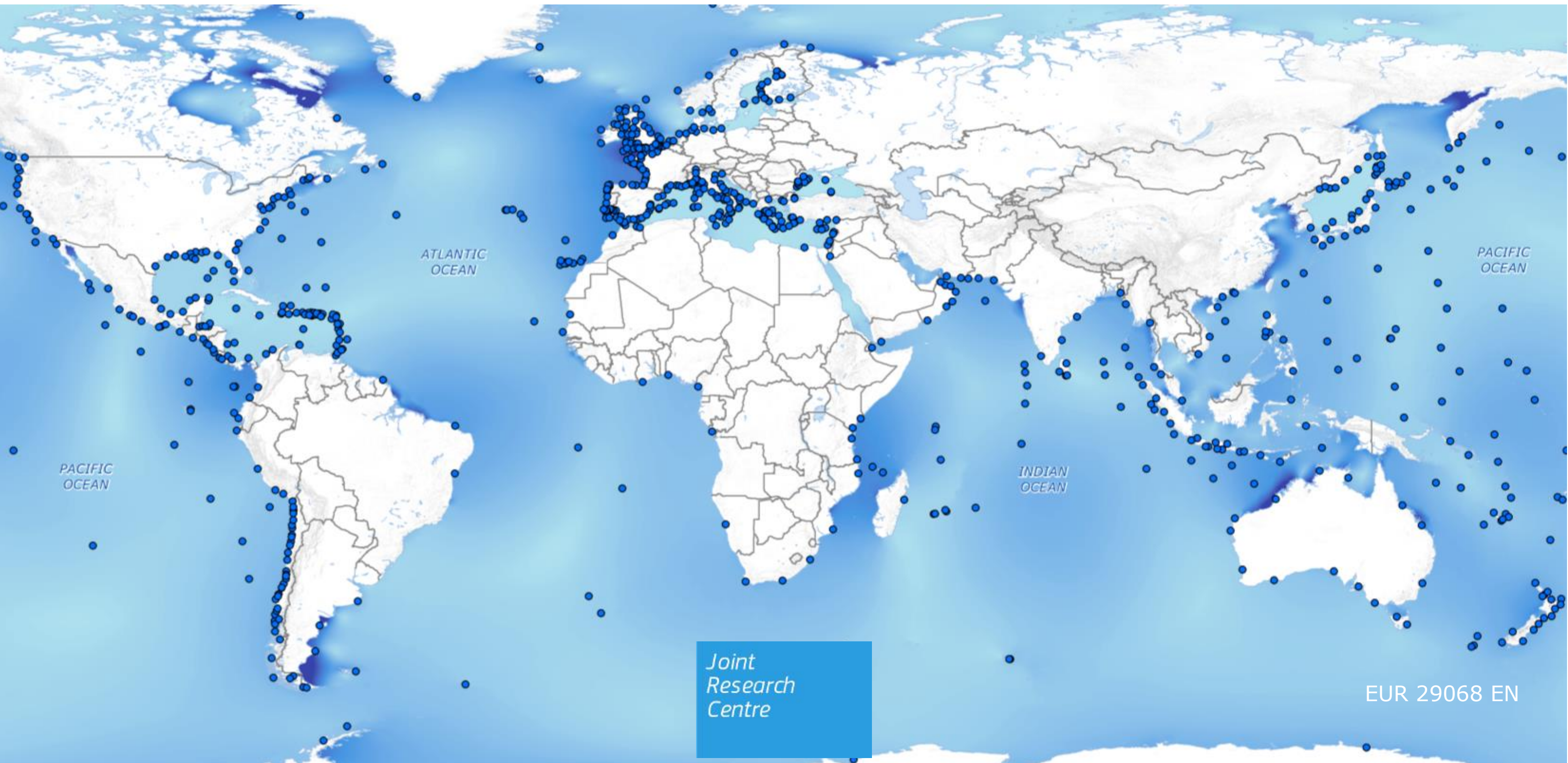
2017



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Abstract

The Joint Research Centre (JRC) of the European Commission has developed a storm surge system for the Tropical Cyclones included in the Global Disasters Alert and Coordination System (GDACS) and the Storm Surge Calculation System (SSCS) for the storm surge events in Europe. Every day the results of these calculation systems are compared with the measurements included in the JRC Sea Level Database. This database includes the sea level measurements, theoretical sea levels tides and storm surge for more than 1000 stations around the world and is wildly used in storm surge and tsunami activities.

Currently, the alert levels in the JRC storm surge systems are based only on the maximum storm surge heights and don't include the effect of the tides. This effect is very important, because the increase of the water level is extremely damaging when the storm surge coincides with a period of high tide.

In this analysis, the JRC Sea Level Database is used to show the importance of the tides in the JRC storm surge alert systems (GDACS and SSCS).

1 INTRODUCTION

The Joint Research Centre (JRC) of the European Commission has developed the Global Disasters Alert and Coordination System (GDACS, www.gdacs.org), an early warning system created to alert the humanitarian community about the potential disasters which are under development (e.g: tropical cyclones, tsunamis, earthquakes and floods).

One of the dangerous effects of the Tropical Cyclones (TCs) that causes damage and deaths is the **storm surge**, that is an abnormal rise of water above the astronomical tides, generated by strong winds and a drop in the atmospheric pressure. It is important to note that also the intense low pressure systems that affect Europe can generate a storm surge.

The JRC has developed the storm surge system for the TCs in GDACS in 2011, while the one for the storm surge events in Europe in 2013 (JRC Storm Surge Calculation System-SSCS). Recently it has developed a new storm surge system used in GDACS and in the SSCS. A complete description of these systems can be found in Probst and Franchello (2012) and in Annunziato and Probst (2016, 2017). Every day the results of these calculation systems are compared with the measurements included in the JRC Sea Level Database. This database developed by the JRC includes the sea level measurements, theoretical sea levels tides and storm surge for more than 1000 stations around the world and is wildly used in tsunami and storm surge activities.

For the alert level of the storm surge systems, the effect of the tides is very important, because the increase of the water level is extremely damaging when the storm surge coincides with a period of high tide. The impact of a large storm surge during a period of low tide could be less intense than a lower storm surge during a period of high tide. The maximum water level reached during an intense storm could be lower than the one reached during a less intense storm. The damage due to an increase of the sea level is therefore related to the storm surge and tides levels (see Figure 1).

Storm Tide (ST) = Storm Surge (SS) + Tide (TD)

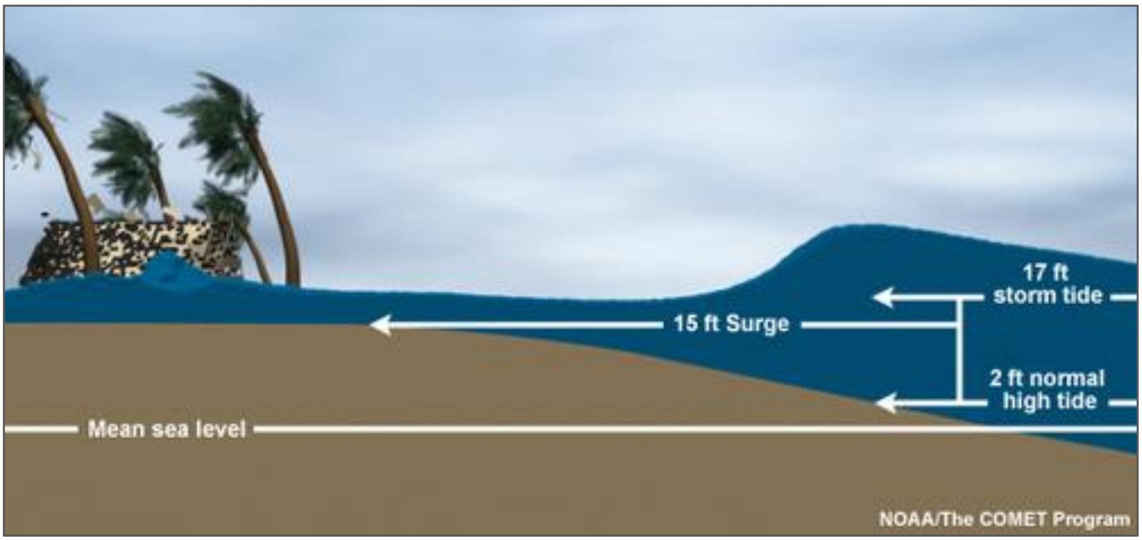


Figure 1 – Characteristics of the Storm Surge in respect to the Storm Tide
(Source: NOAA, http://www.nhc.noaa.gov/surge/#TIDE)

Currently, the JRC storm surge systems don't include the effect of the tides and therefore the storm surge alerts are based only on the maximum storm surge height. The current alert level used in GDACS for the Tropical Cyclones is shown in Table 1, while the one of the SSCS is shown in Table 2.

GDACS Storm Surge Alert Level For Tropical Cyclones	
Alert Level	**Storm Surge Height**
Green	**< 1.0 m**
Orange	**1.0 – 3.0 m**
Red	**> 3.0 m**

Table 1 - GDACS Storm Surge Alert Level for Tropical Cyclones

Colour scheme used for in the SSCS system for the European storms[1] *(*)*	
Alert Level	**Storm Surge Height**
Green	**0.05 - 0.5 m**
Yellow	**0.5 – 1.0 m**
Orange	**1.0 – 2.0 m**
Red	**2.0 – 3.0 m**
Violet	**> 3.0 m**

Table 2 - SSCS Storm Surge Alert level for the Storms in Europe

In order to have a more realistic alert system the tide levels have to be included in the system:

- including directly the tides in the model or
- adding the tide level to the storm surge calculations.

One of the aims of this report is to show the importance of including the tides in the alert system, analysing the differences of the alert levels including or not including this effect. The sea level measurements will be compared with the values of max tides simulated by a specific model, in order to identify when a storm surge event occurs during a period of low or normal tide or when it occurs during a period of high tide with the risk of becoming an extremely damaging event.

A number of tide models are available to simulate the tide level worldwide; in this analysis, the DTU10 global ocean tide model created at the DTU Space (National Space Institute, Technical University of Denmark) is used. The output of this model is compared with the sea level measurements included in the JRC sea level database for a number of global stations (Jan 2014) and for several stations of the United Kingdom (from Dec 2013 to Mar 2014). The UK was particularly affected by several storms during the winter 2013/14.

An overview of the DTU10 model and sea level measurements are presented in Section 2, while the comparisons between the two and the alerts obtained considering the tide levels are in Section 3. Concluding remarks and future steps are in Section 4.

[1] The JRC is creating a specific scale for different areas of Europe (e.g. one scale for the Mediterranean Sea, another one for the North Sea). More information in Annunziato and Probst (2016).

2 DATA SOURCES

A description of the JRC sea level database is presented in Section 2.1, while the one of the model used to simulate the tides is in Section 2.2. The comparisons between the sea level measurements and the tides simulated are shown in Section 3.

2.1 Sea Level Measurements

2.1.1 JRC Sea Level Measurements

JRC is collecting the sea level data from several sources, mostly from the Global Sea Level Observing System (GLOSS), but also from other organizations (i.e. the UK the data of UK National Oceanography Centre-NOC are also included in the JRC database). The JRC is maintaining a database with more than 1000 measures located in all place in the world (see Figure 2 and Annex 1). This database includes also the data of new "JRC inexpensive device" developed by the JRC in 2015. This new mareograph device has been established in order to improve the sea level network in use for the Tsunami Hazard monitoring in the Mediterranean Sea and in the North Atlantic area (NEAMTWS area of UNESCO). More information can be found in Annunziato (2015). The sea level data can be found in:

- *JRC Sea Level Database (see Section 2.1.1.1)*
- *JRC Tsunami Analysis Tools (TAT) Web System (see Section 2.1.1.2)*

In addition to the sea level measurements, this database includes also the tides, obtained using a method developed by the JRC described in Section 2.1.1.3.

2.1.1.1 JRC Sea Level Database

The JRC Sea Level Database website is a web interfaces that shows the sea level measurements (ML), the theoretical Sea Levels Tides (TD) calculated by an algorithm (see Section 2.1.1.3), and the storm surge (SS) values obtained removing the TD from the ML for each buoy included in the Database. The website includes:

- Measurements Station Map and List (see Figure 2).
  - ➔ The user can search and select a specific station (name, ID, …)
- Tide Gauge details (see Figure 3).
- Data and charts (see Figure 4) of the following parameters:
  - Sea level measurements (ML)
  - Tide estimated (TD) by the JRC (see Section 2.1.1.3.)
  - Storm surge (SS)

Sea Level Measurements (ML) = Storm Surge (SS) + Tide (TD)

  - ➔ The user can select a specific period to be displayed in the chart and download the specific data in text format
- Description of the tide harmonics and properties (see Figure 8)

This system has been used to download and display the data of this report.

The JRC Sea Level Database can be found at:
http://webcritech.jrc.ec.europa.eu/SeaLevelsDb/Home/BuoyLocations

NOTE: JRC is preparing a ***new website*** *for this database that will be launched at the beginning of 2018. The main page of this new website is shown in Figure 5.*

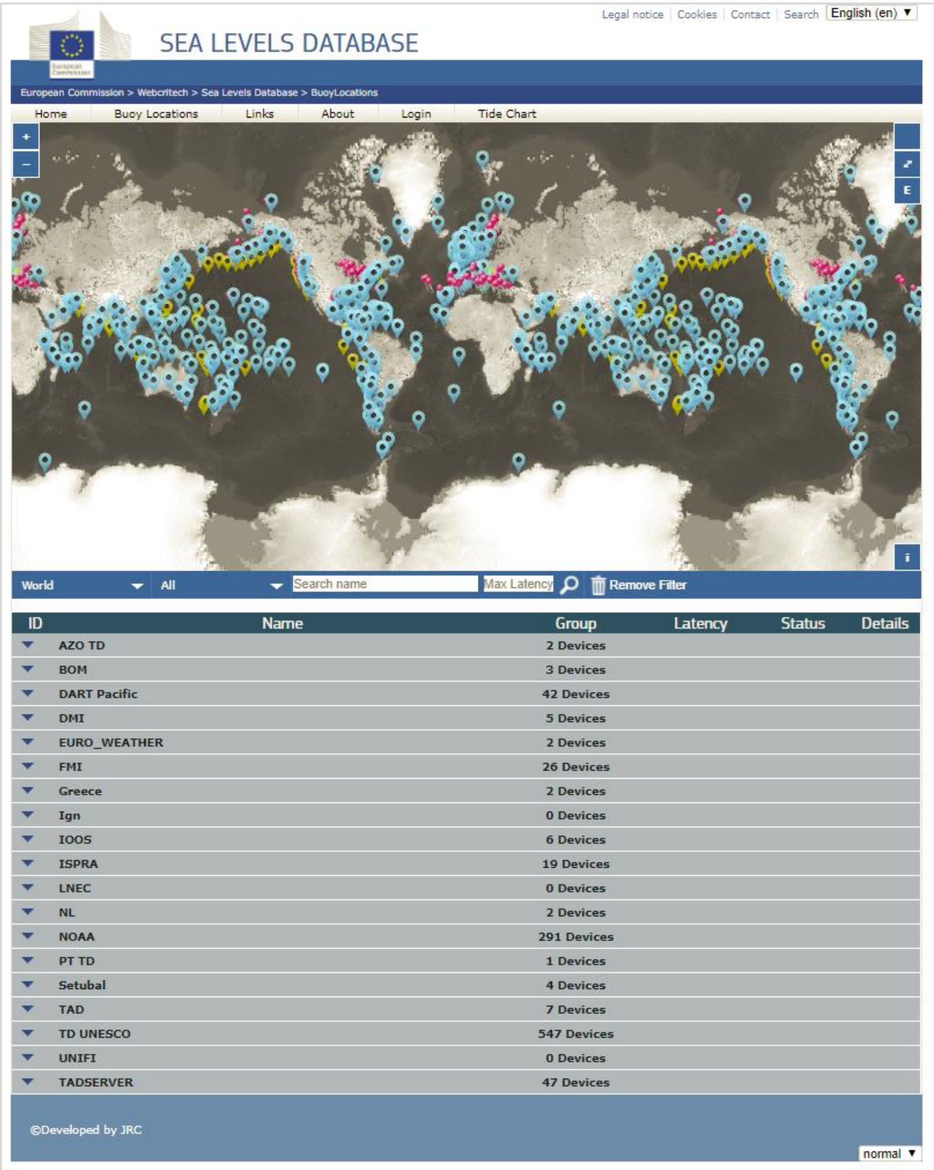
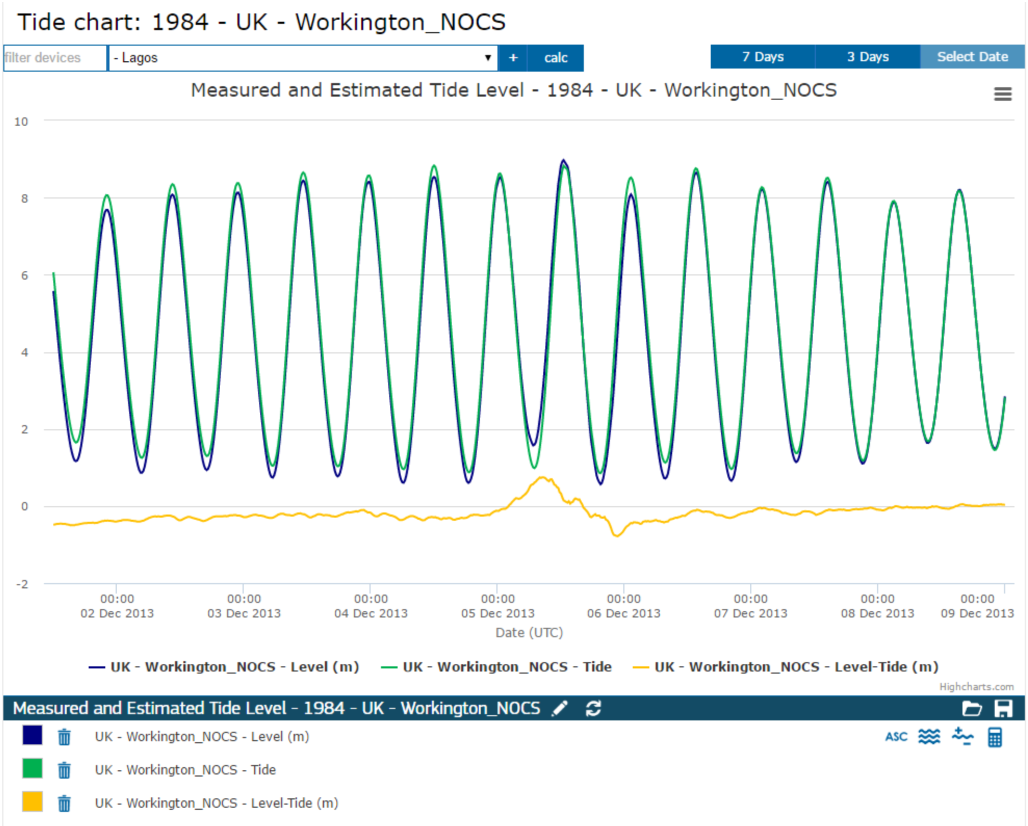


Figure 2 – JRC Sea Level Database
(Source: http://webcritech.jrc.ec.europa.eu/SeaLevelsDb/Home/BuoyLocations)

Figure 3 - Example of Tide gauge details for UK-Workington



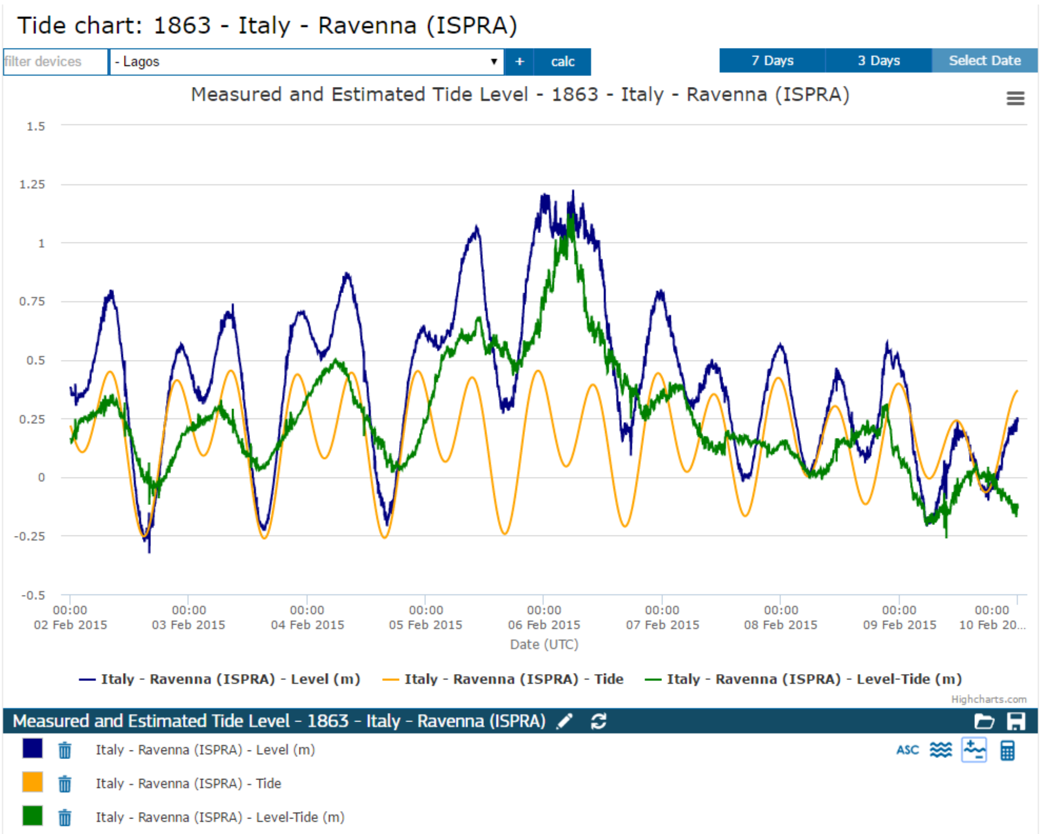


Figure 4 - Example of Tide chart for Workington-UK (above) and for Ravenna-IT (below) obtained using the JRC Sea Level Database. Blue line represents the total water measured (ML), the green line the tide estimated (TD) and the yellow line the storm surge (SS) obtained as: ML-TD.

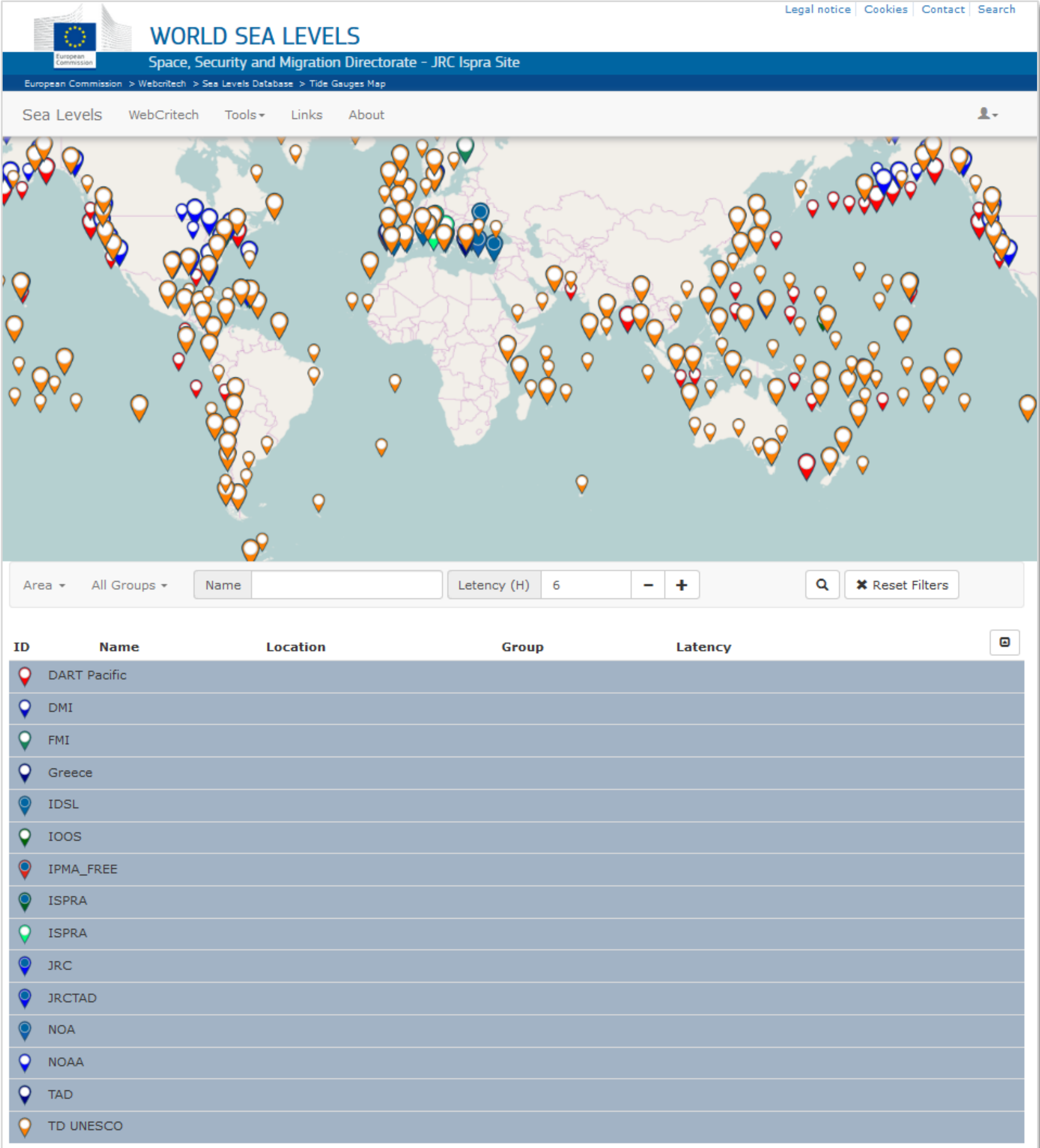


Figure 5 - Example of the new JRC Sea Level Database

2.1.1.2 JRC Tsunami Analysis Tool (TAT)

The TAT website is similar to the JRC Sea Level Database, but it includes also the JRC Tsunami calculations in case of a Tsunami. This system has been set-up by the JRC in order to use it in Early Warning System when a new earthquake event is occurring which may lead to a potential Tsunami (magnitude > 6.5 and epicenter located under water). The system is currently integrated into GDACS to give an estimation of the wave propagation height and travel time within few minutes from the earthquake detection on the seismological networks.
The TAT website is: http://webcritech.jrc.ec.europa.eu/TATWeb/Home/SeaLevelsMap

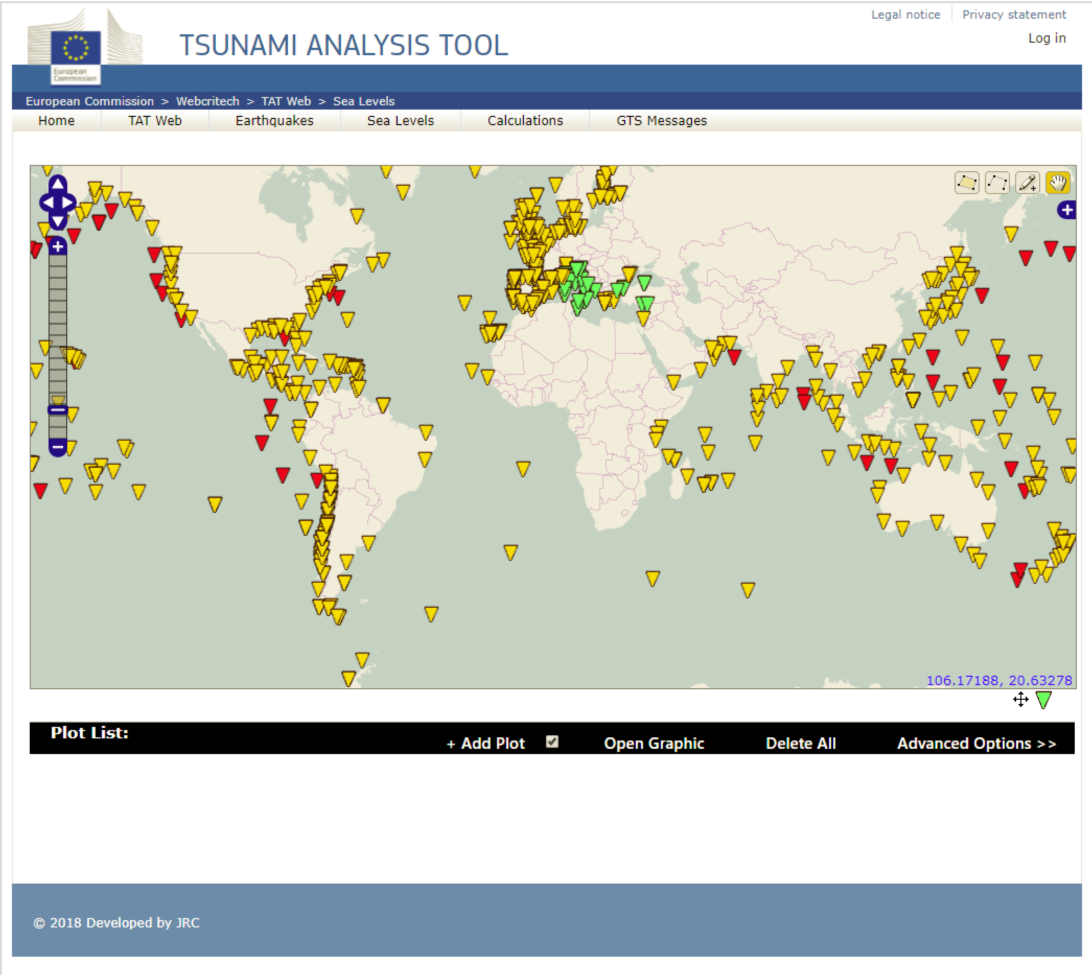


Figure 6 - JRC Tsunami Analysis Tools (TAT) Web System

2.1.1.3 JRC Harmonics calculations

Removing the tidal component from sea level measurement in the case of Tropical Cyclones or Tsunami is very important to distinguish the tide contribution from the one of the Natural events. Therefore the JRC has developed a new methodology that is used for thousands of sea level measurement signals collected in the JRC Sea Level Database.

The harmonics are calculated using the following formula:

$$H(t) = A_0 + \sum_{i=1}^{n} A_i \cos\sigma_i t + \sum_{i=1}^{n} B_i \sin\sigma_i t$$

and the following codes:

Visual Basic Syntax

```
Function EstimateTideValues() As [Function]
    Dim Pi As [Double] = Math.PI
    Dim sum As [Double] = harmonics(0, 1)
    For k As Int16 = 1 To harmonics.GetUpperBound(0)
        Dim period As [Double] = 2 * Pi / harmonics(k, 0)
        Dim coefCos As [Double] = harmonics(k, 1)
        Dim coefSin As [Double] = harmonics(k, 2)
        sum = sum + coefCos * Math.Cos(time * period)
        sum = sum + coefSin * Math.Sin(time * period)
    Next
    Return sum
End Function
```

C# Syntax

```
Function EstimateTideValues()
{
    Double Pi = Math.PI;
    Double sum = harmonics[0, 1];
    for (Int16 k=1; k <= harmonics.GetUpperBound(0); k++)
    {
        Double period = 2 * Pi / harmonics[k, 0];
        Double coefCos = harmonics[k, 1];
        Double coefSin = harmonics[k, 2];
        sum += coefCos * Math.Cos(time * period);
        sum += coefSin * Math.Sin(time * period);
    }
    return sum;
}
```

Figure 7 - Visual basic and C# codes for the calculation of the Harmonics

The determination of the harmonics coefficients from the measured data is a known method, based on least square approximation of the first order in the coefficients. However the computational requirements when several years of data are considered may be a limiting factor for a routine and frequent update of the coefficients; several centres determine the constants once a year or less frequent.

The JRC is currently using a new method, named Continuous Harmonics Determination (CHD), in order to continuously compute the harmonics with a rather limited computing time; this allows to repeat the harmonics identification procedure once per hour for thousands of different sensors worldwide. All 69 harmonics components and all the available data are used in this system. The estimation of the harmonics is performed every hour and requires, for some 1000 signals, about 30-40 min in total. The estimated values considered are related to the whole amount of data available. It is important to note that this method is valid if the data are valid and if the reference point of the measurement is kept constant over the years, which sometimes is not the case. It is therefore necessary from time to time, to check the consistency of the collected data.

A complete description of this method can be found in Annunziato and Probst (2016), while the values of the harmonics calculated by the JRC are available on the JRC Sea Level Database. An example of the harmonics calculated for the station located in Workington (1984, source: NOCS) is shown below.

Harmonics

Points Num.	130207
Min. Time	23 Oct 2012 17:00
Max. Time	18 Nov 2016 09:45

Harmonics Constants

Comp #	Period (day)	Cos factor (m)	Sin factor (m)
0	0.00000	4.53843E+0	0E+0
1	0.12877	-6.31481E-5	2.04207E-4
2	0.12886	4.16492E-4	-2.25994E-3
3	0.12938	1.49263E-3	-2.50419E-3
4	0.14707	-2.30008E-4	-1.98468E-4
5	0.16841	-1.67411E-4	1.98947E-3
6	0.16857	1.53343E-3	-4.21612E-3
7	0.17036	3.57681E-3	1.40357E-3
8	0.17052	-1.50837E-2	-9.79925E-3
9	0.17251	-6.06905E-3	1.39792E-2
10	0.17470	-7.94779E-4	-2.20716E-3
11	0.19989	-5.005E-4	1.0006E-3
12	0.20545	-1.24933E-3	-1.07631E-3
13	0.24966	-1.26223E-3	3.31171E-3
14	0.25000	7.09664E-3	-2.67267E-3
15	0.25395	1.2094E-2	9.59382E-3
16	0.25431	-3.13066E-2	-6.4513E-2
17	0.25631	4.46387E-4	-1.03487E-3
18	0.25667	-3.7808E-3	4.90949E-3
19	0.25876	-1.07746E-1	9.77058E-2
20	0.26122	5.10333E-2	2.23313E-2
21	0.33303	-1.49219E-3	8.18505E-3
22	0.34071	8.46645E-3	-3.58977E-4
23	0.34135	3.82289E-3	-3.59431E-3
24	0.34502	5.5212E-3	1.70743E-2
25	0.34943	-4.09377E-3	-5.84958E-3
26	0.48977	-2.63316E-3	-4.46537E-3
27	0.49109	8.85664E-3	-2.13348E-2
28	0.49863	-1.88522E-1	2.0698E-2
29	0.49932	-1.03516E-2	-9.26055E-4
30	0.50000	8.29451E-1	2.4888E-1
31	0.50798	-1.16463E-1	-4.80379E-2
32	0.50924	7.89684E-3	5.28722E-2
33	0.51606	-5.94599E-3	3.49942E-3
34	0.51679	7.95293E-3	6.12573E-3
35	0.51753	2.81722E-1	-2.80146E+0
36	0.51826	-1.54998E-2	1.28068E-2
37	0.52608	2.08325E-2	-1.19105E-1
38	0.52743	-5.3132E-1	9.68725E-2
39	0.53632	1.31624E-2	-1.38177E-2
40	0.53772	2.92032E-2	6.29171E-2

Figure 8 - Harmonics calculated for the station in Workington (1984, NOCS) (only the first 40 values are shown in the figure)

2.1.2 Global Sea Level Observing System (GLOSS)

The Global Sea Level Observing System (GLOSS) description is presented below:

> *"The Global Sea Level Observing System (GLOSS) is an international programme conducted under the auspices of the Joint Technical Commission for Oceanography and Marine Meteorology (JCOMM) of the World Meteorological Organisation (WMO) and the Intergovernmental Oceanographic Commission (IOC). GLOSS aims at the establishment of high quality global and regional sea level networks for application to climate, oceanographic and coastal sea level research. The programme became known as GLOSS as it provides data for deriving the 'Global Level of the Sea Surface'. The main component of GLOSS is the 'Global Core Network' (GCN) of 290 sea level stations around the world for long term climate change and oceanographic sea level monitoring. The present definition of the GCN (the definition is modified every few years) is called GLOSS10."* (Source: GLOSS website)

The Sea Level Station Monitoring Facility is shown in Figure 9.

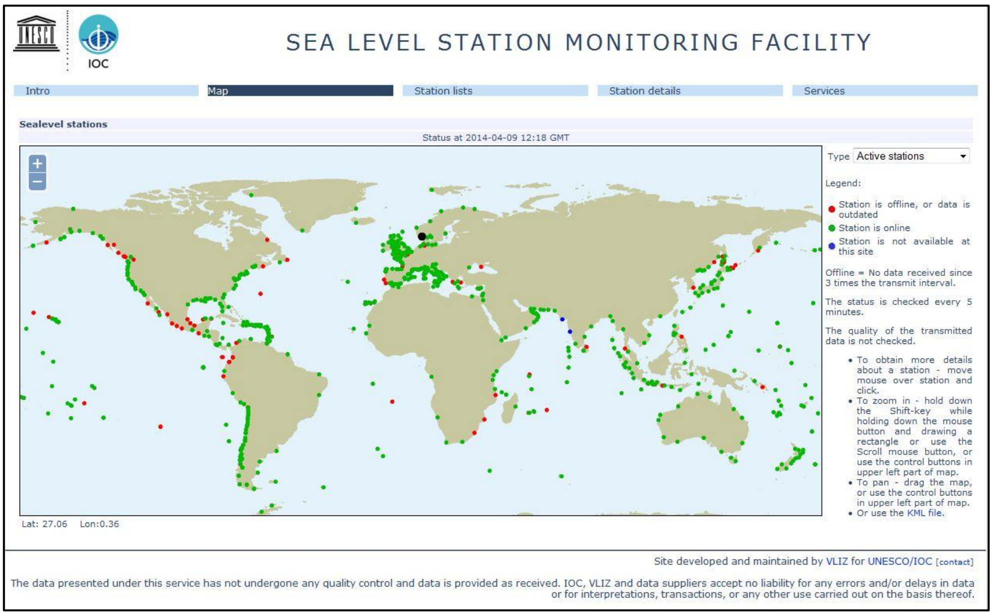


Figure 9 - Sea Level Station Monitoring Facility (UNESCO/IOC)
(Source: http://www.ioc-sealevelmonitoring.org/map.php?code=treg)

2.1.3 UK National Oceanography Centre (NOC) - National Tidal and Sea Level Facility (NTSLF)

The National Tidal and Sea Level Facility (NTSLF) comprises the UK National Tide Gauge Network, as well as gauges data in South Atlantic, Antarctica, Gibraltar and British Overseas Territories. The UK National Tide Gauge Network records tidal elevations at 44 locations around the UK coast, as it is shown in Figure 10. More information is available at the National Oceanography Center – NTSLF website (http://www.ntslf.org/).

Figure 10 - UK National Tide Gauge Network
(Source: http://www.ntslf.org/data/uk-network-real-time)

2.2 Tide Simulations (DTU10 global ocean tide model)

The DTU10 global ocean tide model created at the DTU Space (National Space Institute, Technical University of Denmark / *Danmarks Tekniske Universiet* - DTU) is used in this analysis to simulate the tides. This code is written in FORTRAN 77. JRC has created and tested a new version of this code in Visual Basic. The outputs of this new code has been compared with the sea level measurements (see Section 3).

2.2.1 DTU10 global ocean tide model

The description of DTU10 is presented below:

> *"The DTU10 stands for global ocean tide model derived at DTU Space in 2010 using response method for residual analysis of multi-missions altimeter data. The extended global tidal model FES2004 (Finite Element Solutions) was used as a reference model. The model is an empirical ocean tide model which means that it does not include tidal currents. Both phase A and four years of phase B data from multi-mission altimetry measurements (TOPEX/POSEIDON and Jason-1/2) are applied for the development of the new global tide model. The combined altimeter datasets from ERS-2, Geosat Follow On (GFO) and Envisat is used below and above 66°S and 66°N to extend the coverage at high latitudes. Outside the coverage of altimetry the model relaxes to FES2004. The Ocean tide model is extended onto land in order to enable proper interpolation close to the coast. In case a mask is used we suggest that you use a detailed mask like DTU10BAT or use the mask provided in the BATHYMETRY_MASK directory."* (Source: DTU website)

This model can be downloaded from the ftp DTU website at:
ftp://ftp.space.dtu.dk/pub/DTU10/DTU10_TIDEMODEL/
while more information are available at DTU10 website and in Cheng and Andersen (2010).

2.2.2 Subroutine ("PERTH")

DTU10 model includes a subroutine called PERTH (PREdict Tidal Heights) available at the DTU ftp website (ftp://ftp.space.dtu.dk/pub/DTU10/DTU10_TIDEMODEL/SOFTWARE/). This subroutine is able to compute the ocean tidal height at a given time and location from grids of harmonic constants. As reported in the DTU website:

> *"The version available uses the 8 largest constituents in the semidiurnal and diurnal bands, with other tides inferred, plus the one radiational tide S1, plus optionally the one compound tide M4. The long period tides are not computed by this routine".*

The programming language used for this subroutine is Fortran 77. More information on this routine could be found in Doodson (1941) and at DTU Space Institute website (ftp://ftp.space.dtu.dk/pub/DTU10/DTU10_TIDEMODEL/DTU10_TideModel_readme.txt). The INPUTS and OUTPUTS of the Subroutine PERTH3 are listed in Table 3. The JRC has created a Visual Basic (VB) version of this code, that has been used for this analysis.

SUBROUTINE PERTH3 *(DLAT, DLON, TIME, TIDE, ISDATA)*	
INPUT	
DLAT	North latitude (in degrees) for desired location
DLON	East longitude (in degrees)
TIME	Desired UTC time, in (decimal) Modified Julian Date
OUTPUT	
TIDE	Computed tidal height (cm)
ISDATA	Logical denoting whether tide data exist at desired location. If FALSE, then TIDE is not modified

Table 3 - INPUT / OUTPUT of Subroutine PERTH

2.2.3 World Tide Map using the DTU10 model

The maximum and minimum tides obtained using the DTU10 model for all world for 2014 with a resolution of ≈14 km are shown in Figure 11 and Figure 12 respectively.
The maximum tide and the time of the maximum tides are also shown in the table that includes the characteristics of the locations analysed, as well as in the figures of the comparisons (see Section 3).

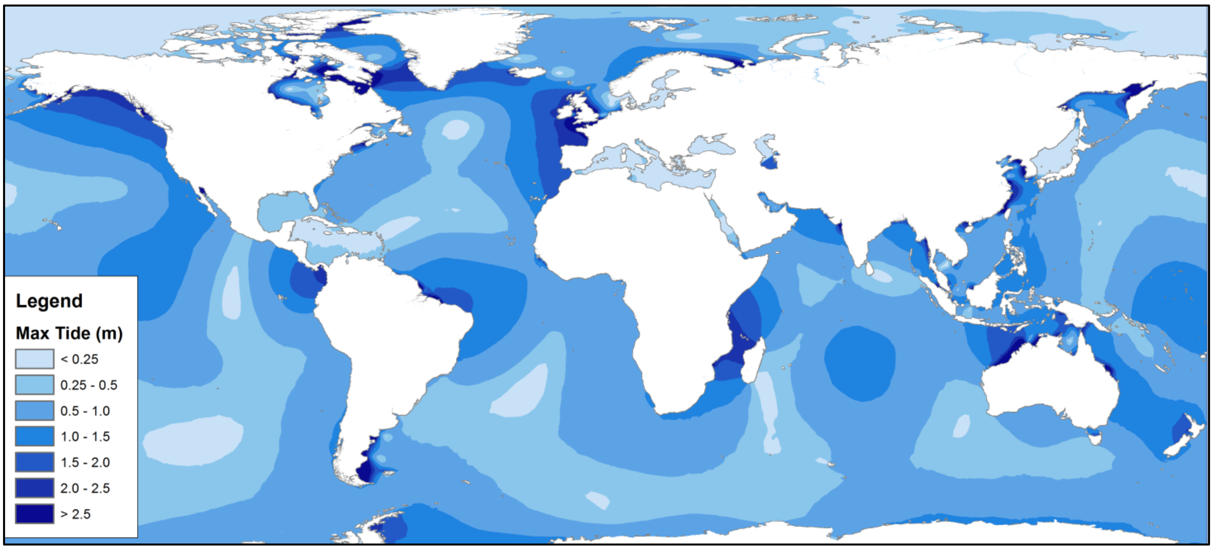


Figure 11 – Max tide level simulated by DTU10 model

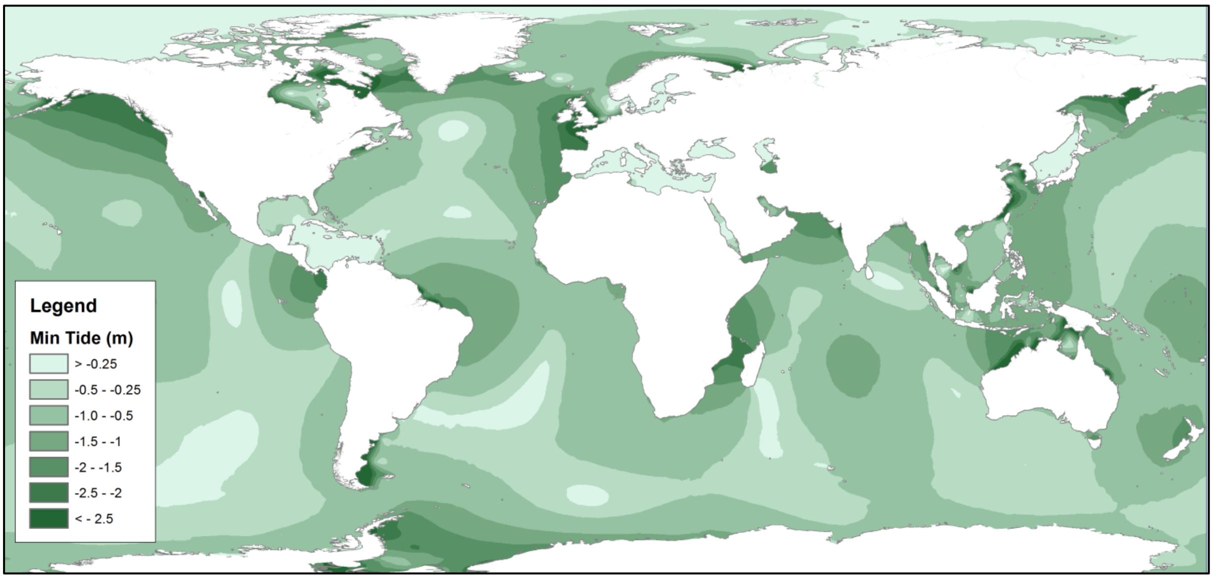


Figure 12 – Min tide level simulated by DTU10 model

3 ANALYSIS AND COMPARISONS

3.1 Initial Considerations

The analyses and comparisons between the sea level measurements and the tide level simulations of DTU10 model[2] are presented in this Section, while an overview of these analyses is shown in Table 4.

Analysis	Description
GLOBAL (Section 3.2)	the sea level measurements of six global stations are compared with the tide level calculations for one month (January 2014).
UK (Section 3.3)	the sea level measurements of four stations in the UK are compared with the tide level calculations for three months, from December 2013 to February 2014, analysing also each month singularly

Table 4 - Description of the analysis and comparison presented in this repot

The following steps have been conducted by the JRC before comparing the tides with the sea level measurements:

1. Download of the following data for the analysis, using the JRC Sea level database
   - Sea level measurements (ML)
   - JRC estimated tides (TD_{JRC})
   - Storm surge (SS)
2. Run the JRC VB version of DTU10 model to obtain the estimated tides (DTU_{10}Tides)
3. Add a specific offset to the DTU_{10} Tides (TD_{10})
4. Determinate the maximum tide level (MTD_{10})
5. Calculation of the alert level considering the maximum tide (TAL)
6. Classification of the alert level

All these steps are described below.

3.1.1 Data from JRC Sea Level Database

The JRC Sea Level Database includes the total water level measured (ML), the estimated tides (TD_{JRC}) and the Storm Surge values (SS), obtained as follow:

Storm Surge (SS) = Sea Level Measurements (ML) - Tide (TD_{JRC})

Where:

- **SS** = Storm Surge (SS)
- **ML** = Sea level measurements of the JRC database (see Section 2.1.1.1)
- **TD_{JRC}** = Tide levels estimated by JRC (see Section 2.1.1.3)

The JRC has created a specific script to download these data from the JRC Sea Level Database and another one to remove the outliers.

[2] Only the results obtained using the VB code are shown in the figures (see Section 2.2)

3.1.2 VB version of DTU model

The original DTU10 global ocean tide code is written in FORTRAN 77 (see Section 2.2). The JRC has created and tested a Visual Basic (VB) version of this code. The comparisons between the two codes are not shown in this report. Since the results of the two codes were the same, the JRC has decided to use the VB version in this analysis.

3.1.3 Offset for DTU10 tides

In order to take into account the shift of the sea level measured in respect to the tide level simulated by DTU10, an offset has been added to the values calculated by the model:

- Sea level measurements → Absolute levels = signal as received (without outliers)
- Tides → Relative levels = DTU10 Tides (see Section 2.2.1) + offset

Two different offsets have been used:

- For the **GLOBAL Analysis**: the average of the sea level data over the selected period (outliers previously removed from the original signal)
- For the **UK Analysis**: the first term of the Harmonics calculated by JRC using the sea level measurements over the whole period (see Section 2.1.1.3).

The tides calculated by DTU10 model used in this analysis are obtained as follow:

$$\mathbf{TD_{10} = DTU_{10}\ Tides + offset}$$

where

- DTU_{10} Tides = tide level obtained using JRC VB version of the DTU10 model
- Offset = Offset obtained (average or first term of the harmonics, see above)
- TD_{10} = tide level obtained using the JRC VB version of the DTU10 model + offset

3.1.4 Maximum Tide Level

For this analysis the JRC has calculated:

- maximum tide level (**MTD_{10}**) using DTU10
- maximum tide level (**MTD_{JRC}**) using JRC estimations

Note:

- The highest astronomical tide level (HAT) is determined over a period of 19 years, but in this analysis only a period of one year has been used. For a complete alert system DTU10 has to be run for a period of 19 years and not only for one year.
- The same offset previously calculated (see Section 3.1.2) has been added to the MTD10 value

3.1.5 Alert Level Calculation

The alert level considering the maximum tide level (MTD_{10}) has been calculated as follow:

$$TAL = ML - MTD_{10}$$

where

- ML = Sea level measurements of the JRC database
- MTD_{10} = maximum tide level obtained using DTU10 + offset

Hereafter this alert level system will be indicated as "TAL" system.

3.1.6 Alert Level Classification

The values of TAL obtained have been classified using the following colour scheme:

FOR TC *(TAL = ML – MTD10)*	
White	< 0.05 m
Green	0 – 1.0 m
Orange	1.0 – 3.0 m
Red	> 3.0 m

FOR SSCS *(TAL = ML – MTD10)*	
White	< 0.05 m
Green	0.05 - 0.5 m
Yellow	0.5 – 1.0 m
Orange	1.0 – 2.0 m
Red	2.0 – 3.0 m
Violet	> 3.0 m

Table 5 - Colour scheme used for the classification alert level considering the tides. LEFT: for TCs in GDACS, RIGHT: for storms in Europe.

A corresponding graph using this alert is also presented in this report (see Figure 14), where blue bars represent the TAL values.

3.1.7 Description of the sea level analysis and comparisons

Each comparison includes the following table/map/chart.

1) Table: includes the characteristics of the Stations analysed

- **ID** of the station.
- Position of the station (**Latitude**; **Longitude**).
- **Time:** Selected Period of the analysis.
- **Offset:** offset used to take into account the shift of the sea level measured in respect to the tide level simulated by the model (see Section 3.1.3).
- **1° Harmonics:** first term of the Harmonics calculated by JRC using the sea level measurements over the whole period (see Section 3.1.3).
- **Max Tide DTU10 (MTD_{10})**: maximum tide level simulated + offset calculated
- **Max Tide JRC (MTD_{JRC})**: maximum tide level obtained by JRC system
- **Time Max Tide DTU10:** time of the max. tide level simulated by the DTU10 model.

2) Map: the location of the station analysed is inside the red circle.

3) First Chart (Comparisons):

- **Blue line (ML)**: sea level measurements, removing outliers (ML), using the JRC Sea Level Database
- **Yellow line (TD_{10})**: sea level simulated by the DTU10 tide level model (VB CODE) + offset selected for that analysis
- **Red line (MTD_{10})**: Max Tide calculated by DTU10 model + offset
- **Vertical grey dotted line**: Time of the maximum MTD_{10} (not always visible in the figures, only if the maximum of the tide occurs during the period selected).

4) Second Chart (storm surge):

The blue line represents the storm surge. The signal is obtained by removing the tides (using the JRC harmonics) from the original sea level (see Section 2.1.1.3). The graph has been created using the JRC Sea Level Database Tools (see Section 2.1.1).

The lower alert level thresholds of GDACS (Table 1) or SSCS (Table 2) are also included as a horizontal dotted line in this figure.

5) Third Chart (TAL):

The results of TAL are shown in this figure, where the blue bars represent TAL = ML - MTD10. The thresholds used for the alert levels (see Table 5) are shown in this figure.

Note: this graph has been created for the cases that have at least a "Green Alert" (not for "White Alert") and only the most significant events have been reported in the report.

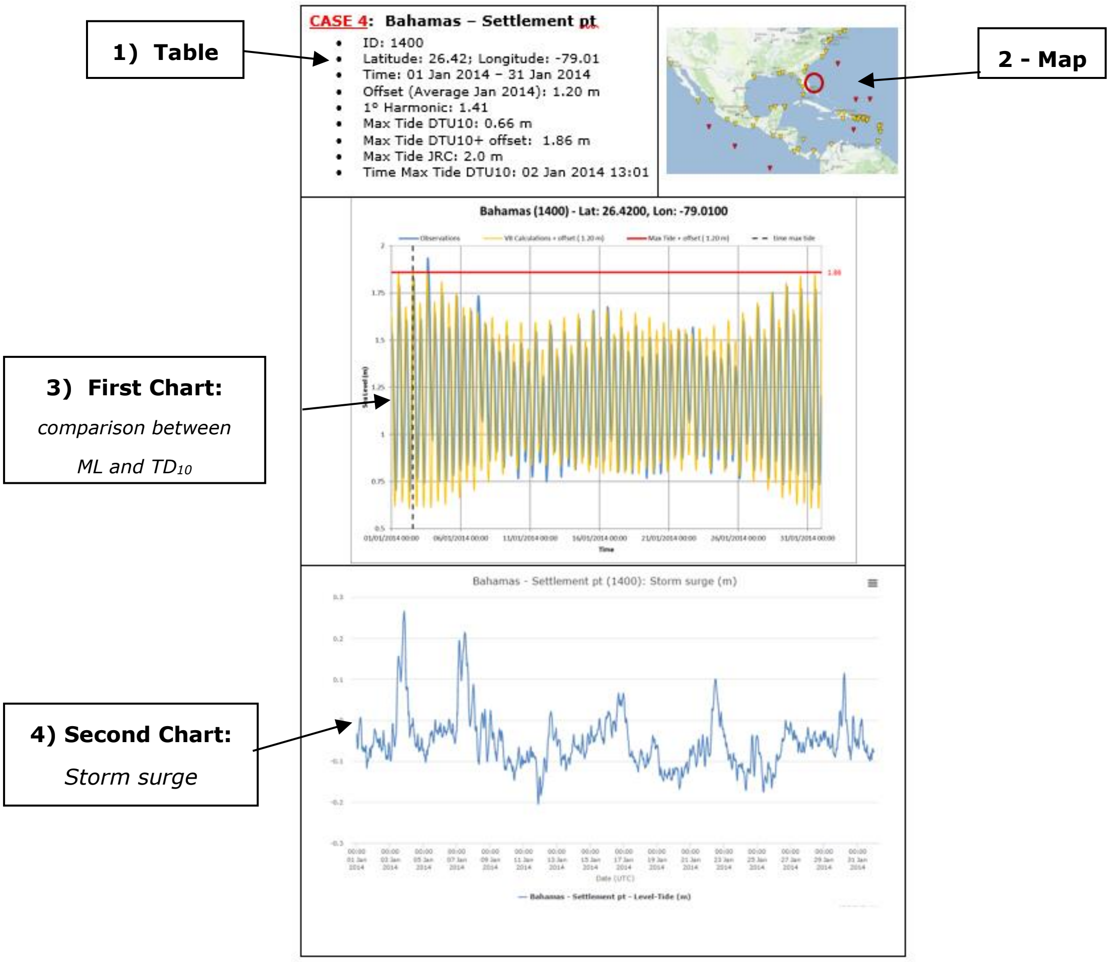


Figure 13 - Example of the analysis

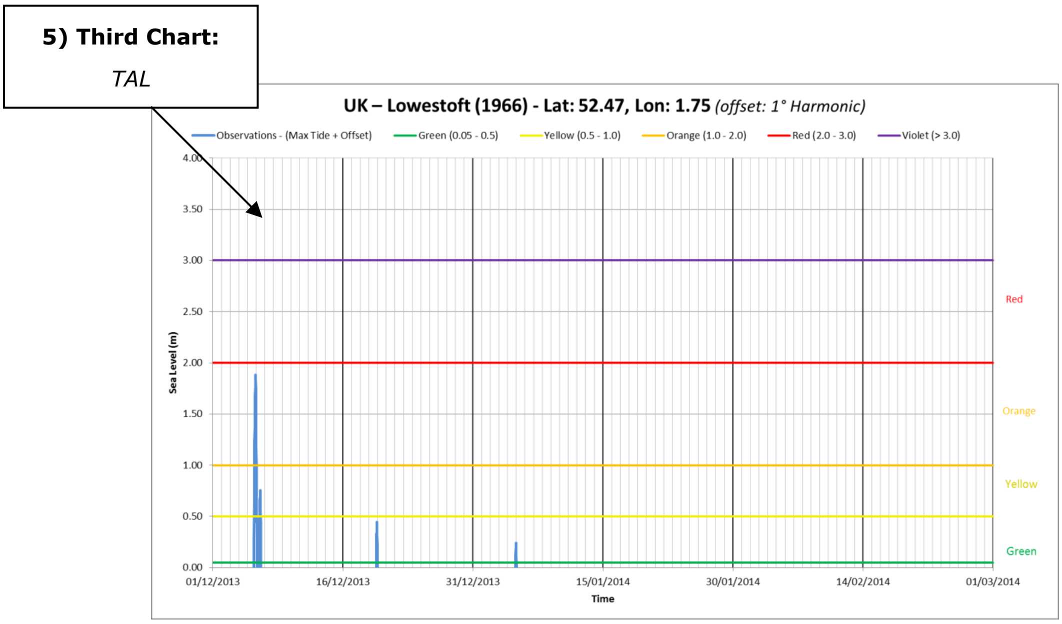


Figure 14 - Example of the TAL system. Blue bars represent TAL = ML - MTD_{10}

3.2 World Stations

The sea level measurements of six stations located around the world (see Table 6) are compared with the tide simulations obtained using the VB-DTU10 program over the period: 1 – 31 January 2014. The offset used in this analysis is the average of the sea level values measured in January 2014 in the station analysed (outliers not included in the average).

Note: this in only a short example of one of the possible application of the JRC Sea Level database. The only significant results are for the stations of Cape Ferguson and Workington, therefore the TAL figures included in this section are only for these stations. The TAL will be analysed more in detail in the next Section.

Data:

- Sea Level Measurements (JRC database, data source: GLOSS + UK NOC)
- Tide simulations (VB program)

Time Period:

01 January 2014 00:00 UTC – 31 January 2014 23:59 UTC

Offset:

Average of the observed sea level data for January 2014

List of locations:

CASE	ID	Name	Latitude	Longitude	Source
1	874	**Australia** - Cape Ferguson	-19.28	147.06	GLOSS
2	944	**Japan** - Naha	26.22	127.67	GLOSS
3	1338	**Marshall Islands** - Majuro	7.11	171.37	GLOSS
4	1400	**Bahamas** - Settlement	26.42	-79.01	GLOSS
5	1680	**South Africa** – Port Elizabeth	-33.97	25.63	GLOSS
6	1984	**UK** - Workington	54.65	-3.57	UK/NOC

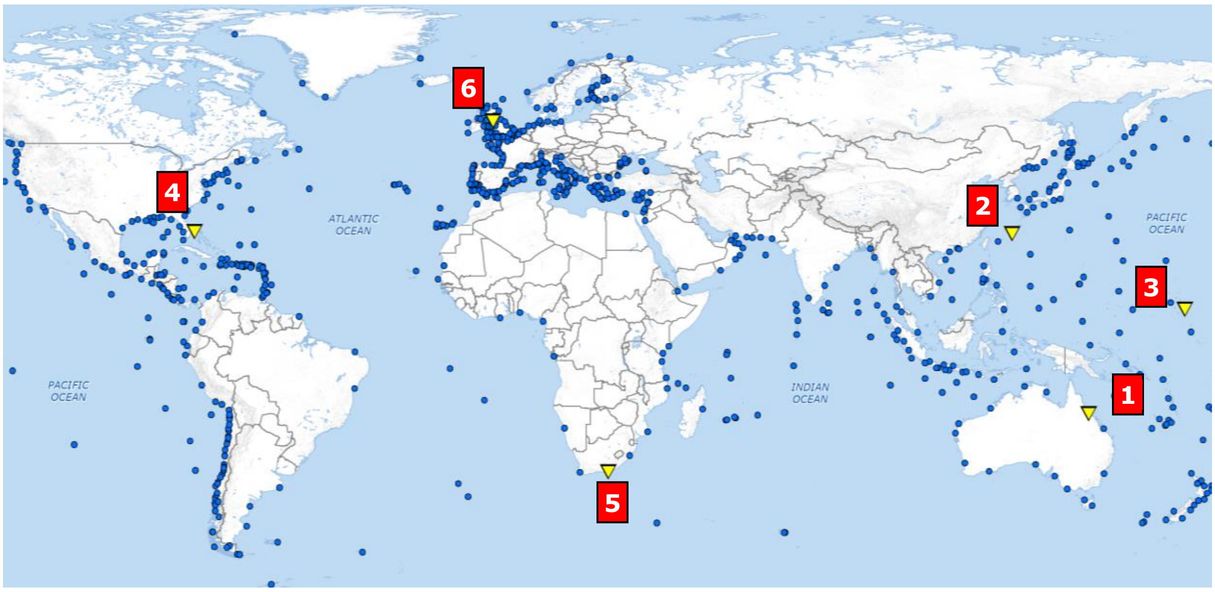
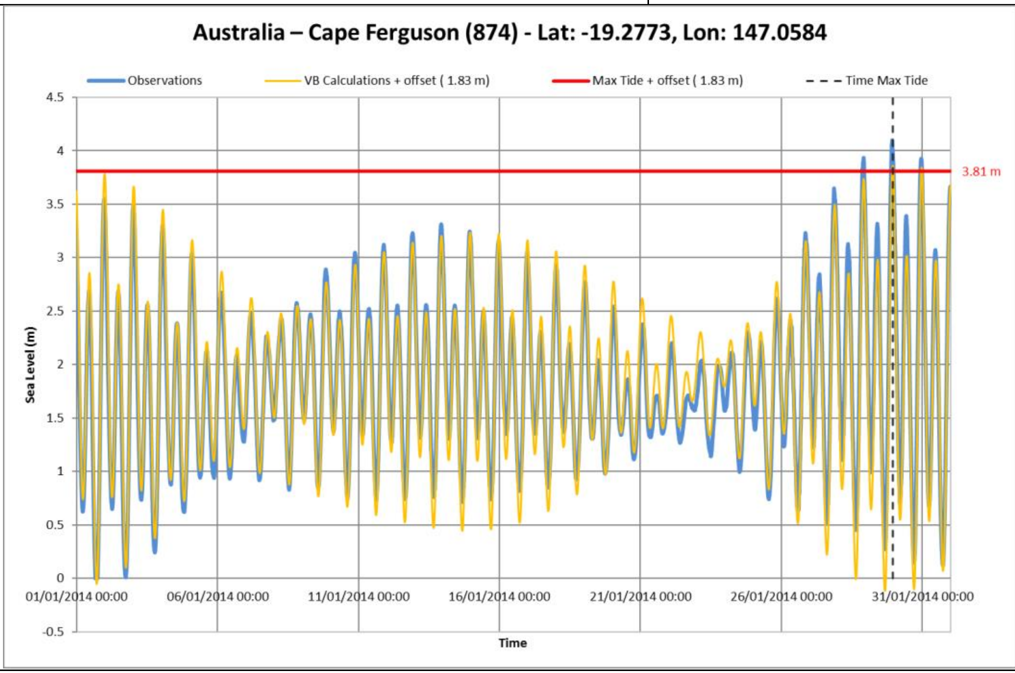
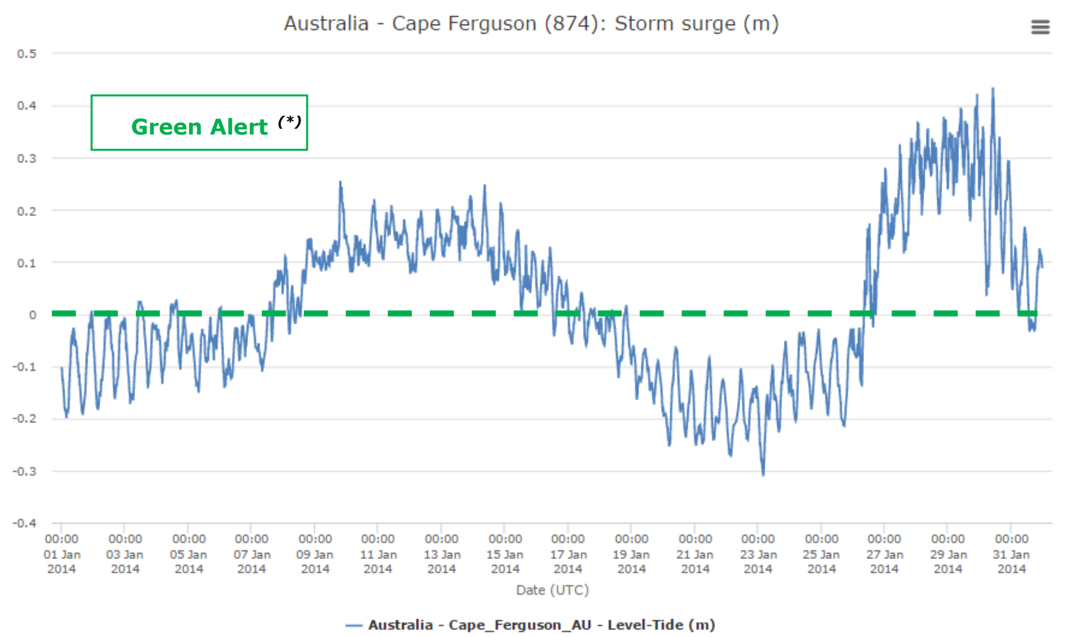


Table 6 – List, Characteristics, Map of the stations selected for this analysis

CASE 1: Australia – Cape Ferguson

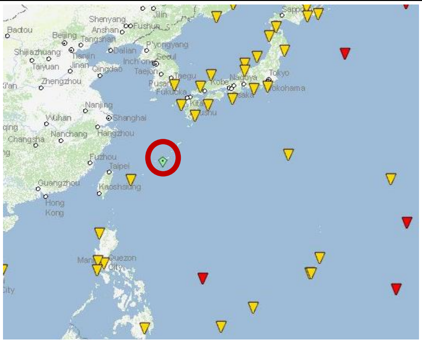
- ID: 874
- Latitude: -19.28; Longitude: 147.06
- Time: 01 Jan 2014 – 31 Jan 2014
- Offset (Average Jan 2014): 1.83 m
- 1° Harmonic: 1.75
- Max Tide DTU10: 1.98 m
- Max Tide DTU10 + offset: 3.81 m
- Time Max Tide DTU10: 29 Jan 2014 22:58 UTC

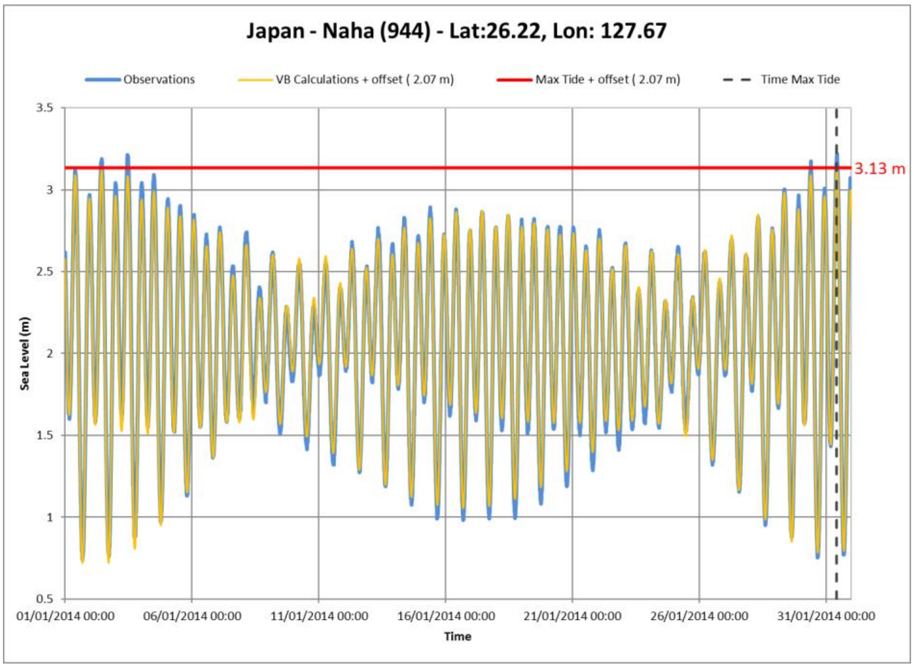


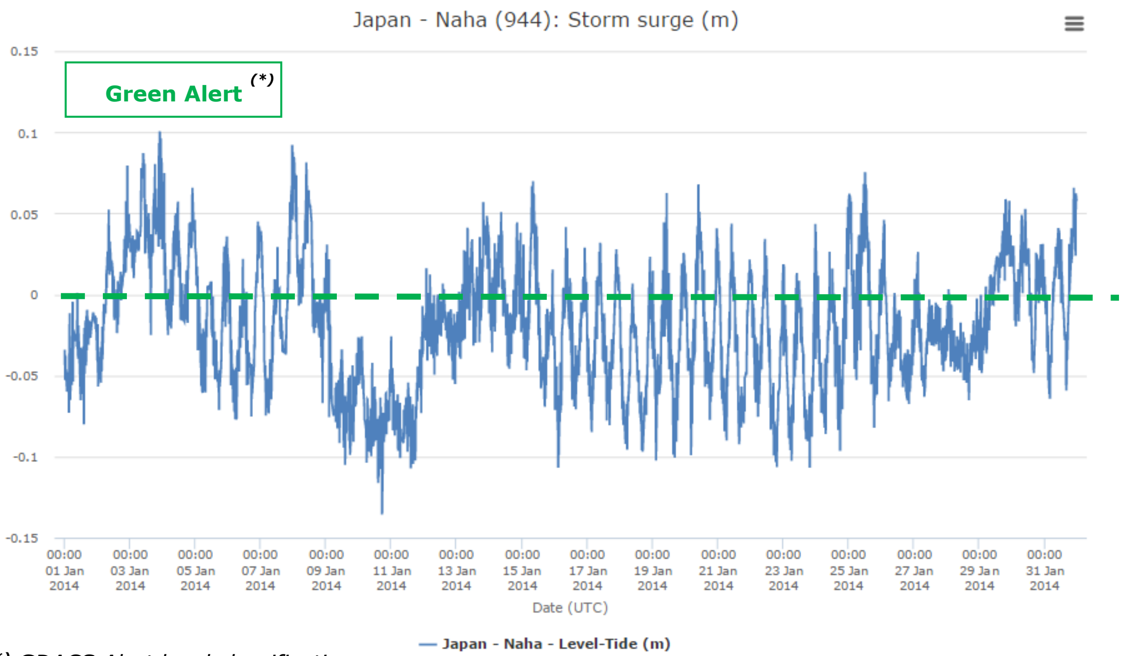


(*) GDACS Alert level classification

Figure 15 - Analysis and comparisons for "CASE 1 - Australia - Cape Ferguson (874)" (see figure description in Section 3.1)

CASE 2: Japan – Naha	
• ID: 944 • Latitude: 26.22; Longitude: 127.67 • Time: 01 Jan 2014 – 31 Jan 2014 • Offset (Average Jan 2014): 2.07 m • 1° Harmonic: 2.23 • Max Tide DTU10: 1.06 m • Max Tide DTU10 + offset: 3.13 m • Time Max Tide DTU10: 31 Jan 2014 10:01 UTC	



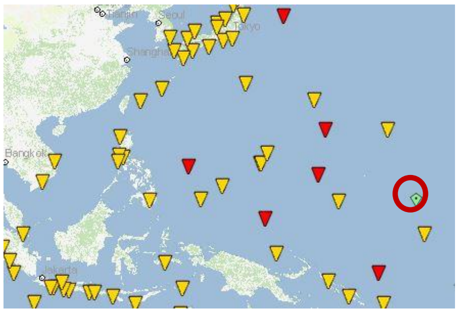


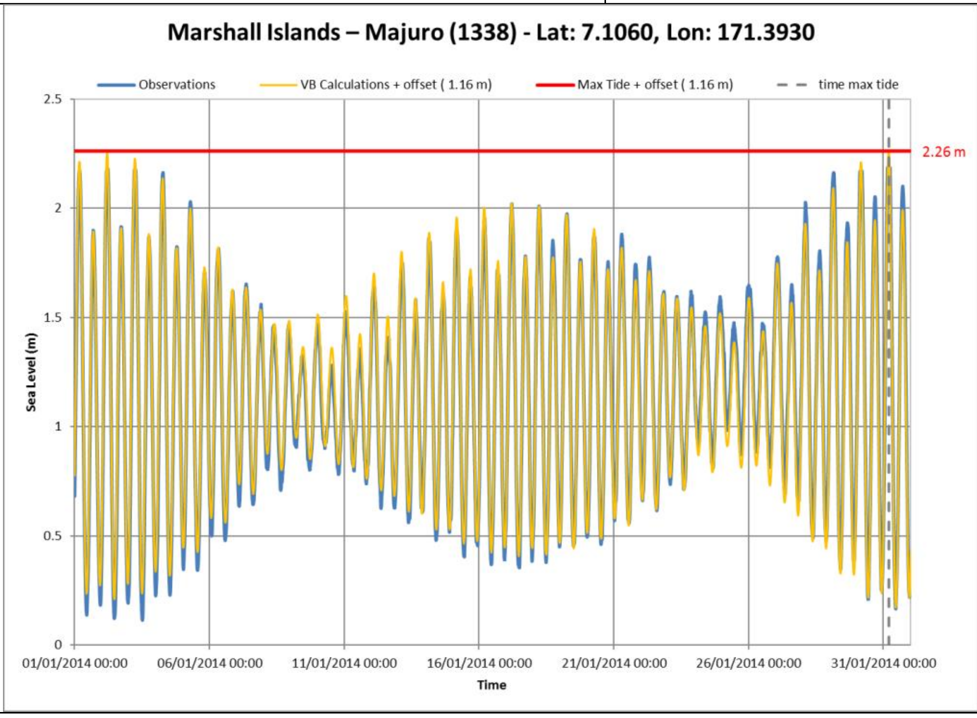
(*) *GDACS Alert level classification*

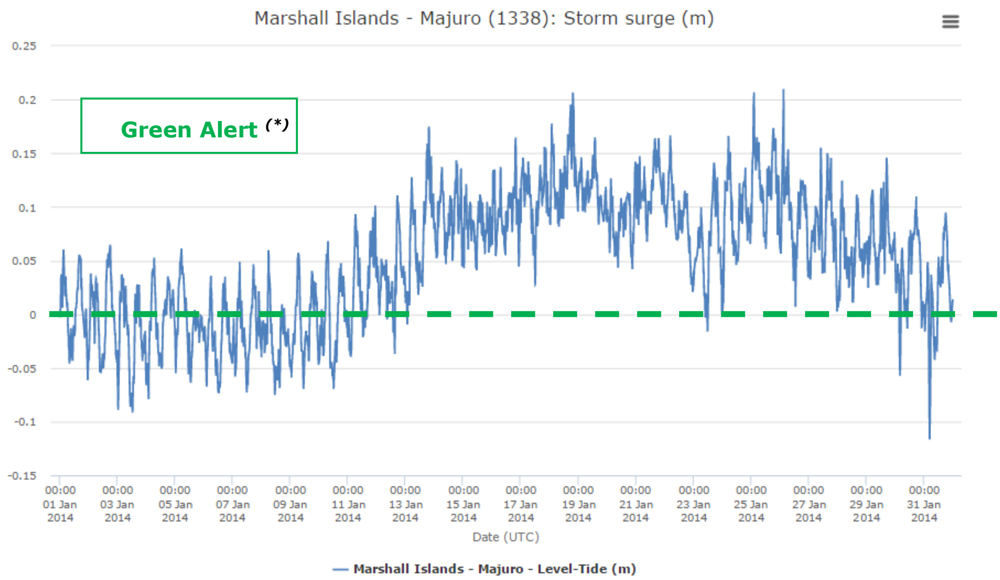
Figure 16 - As in Figure 15, for CASE 2: Japan – Naha.

CASE 3: Marshall Islands – Majuro

- ID: 1338
- Latitude: 7.11; Longitude: 171.37
- Time: 01 Jan 2014 – 31 Jan 2014
- Offset (Average Jan 2014): 1.16 m
- 1° Harmonic: 1.04
- Max Tide DTU10: 1.10 m
- Max Tide DTU10 + offset: 2.26 m
- Time Max Tide DTU10: 31 Jan 2014 04:58 UTC





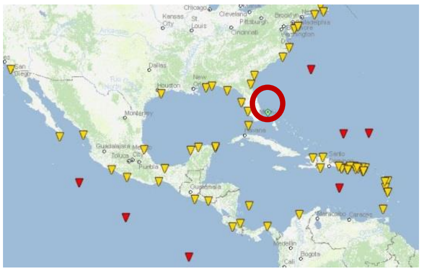


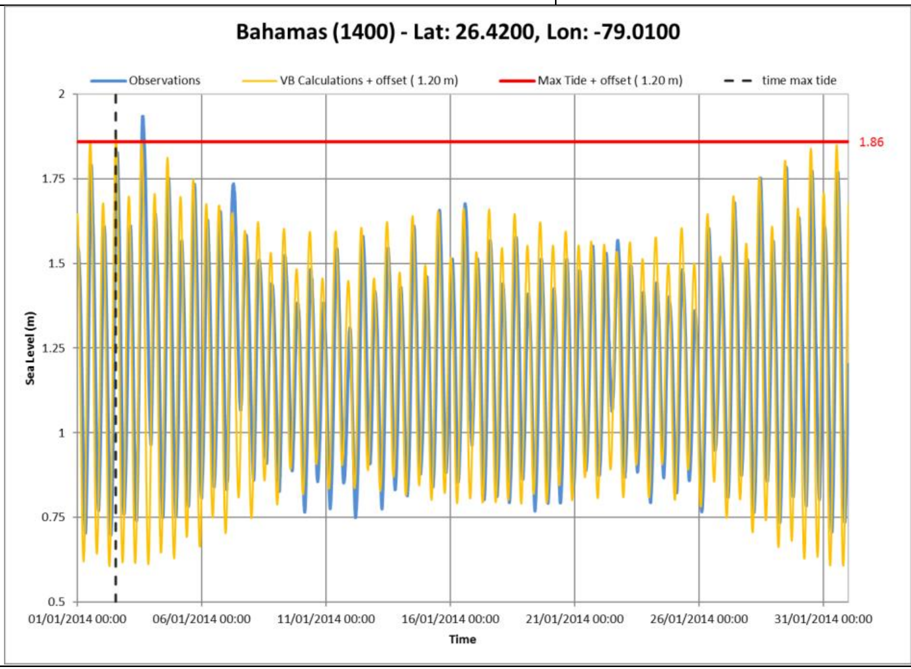
(*) *GDACS Alert level classification*

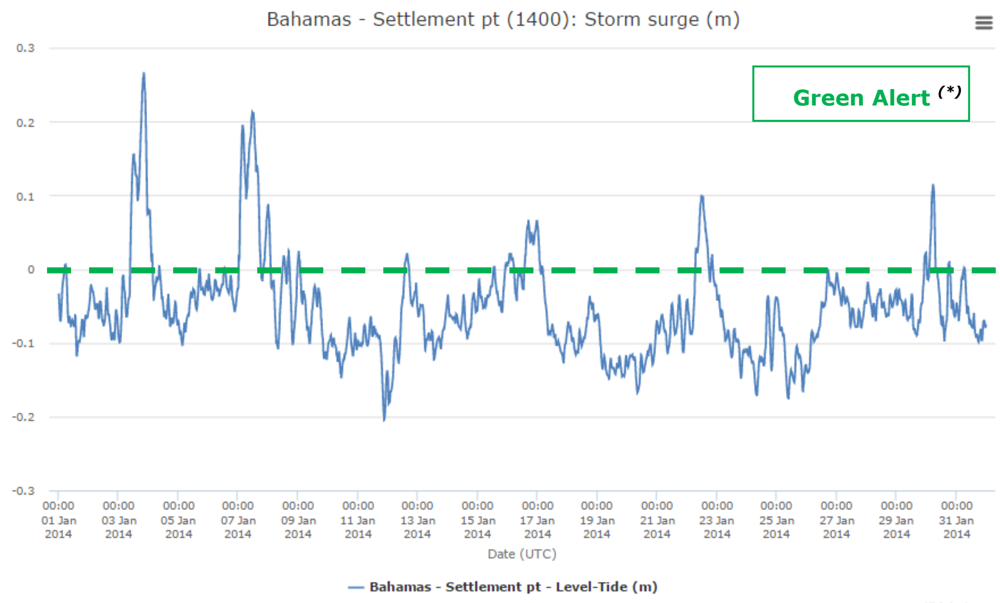
Figure 17 - As in Figure 15, for CASE 4: Marshall Islands – Majuro.

<u>CASE 4</u>: Bahamas – Settlement pt

- ID: 1400
- Latitude: 26.42; Longitude: -79.01
- Time: 01 Jan 2014 – 31 Jan 2014
- Offset (Average Jan 2014): 1.20 m
- 1° Harmonic: 1.41
- Max Tide DTU10: 0.66 m
- Max Tide DTU10+ offset: 1.86 m
- Time Max Tide DTU10: 02 Jan 2014 13:01





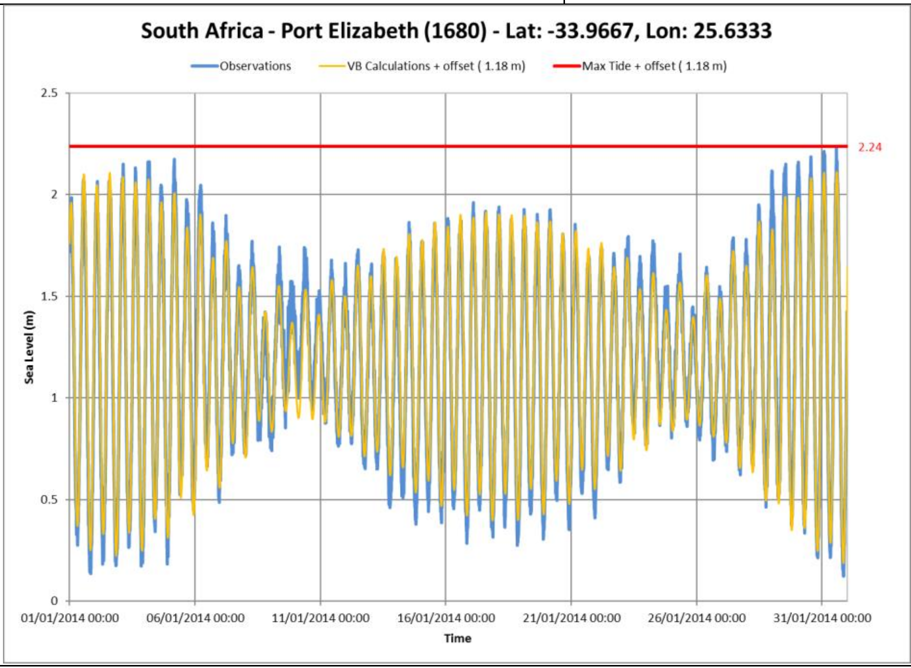


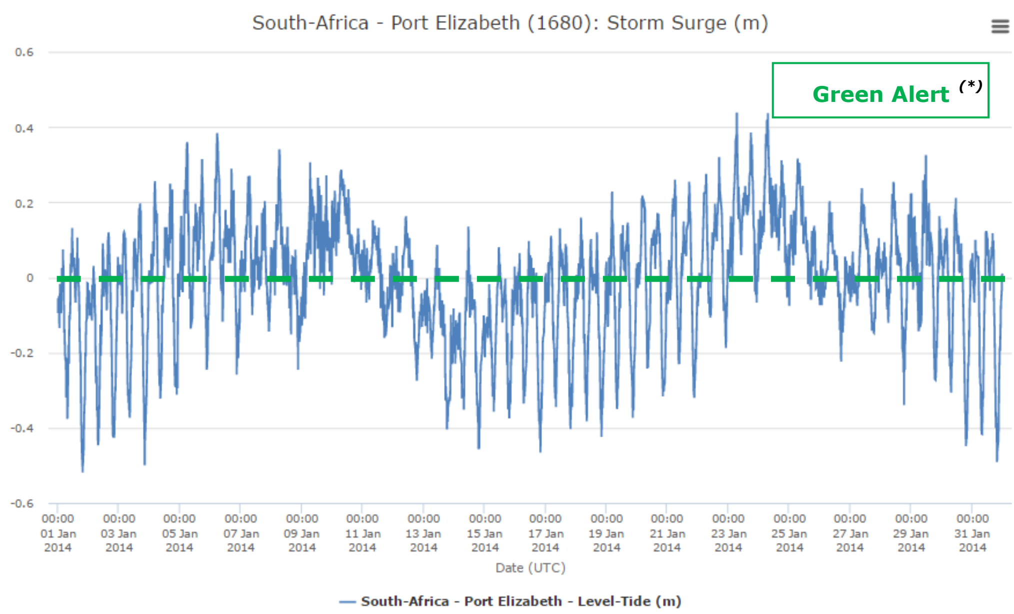
(*) *GDACS Alert level classification*

Figure 18 - As in Figure 15, for CASE 5: BAHAMAS.

<u>CASE 5</u>: South Africa – Port Elizabeth

- ID: 1680
- Latitude: -33.97; Longitude: 25.63
- Time: 01 Jan 2014 – 31 Jan 2014
- Offset (Average Jan 2014): 1.18 m
- 1° Harmonic: 1.20
- Max Tide DTU10: 1.06 m
- Max Tide + offset: 2.24 m
- Time Max Tide DTU10: 9 Sep 2014 13:58



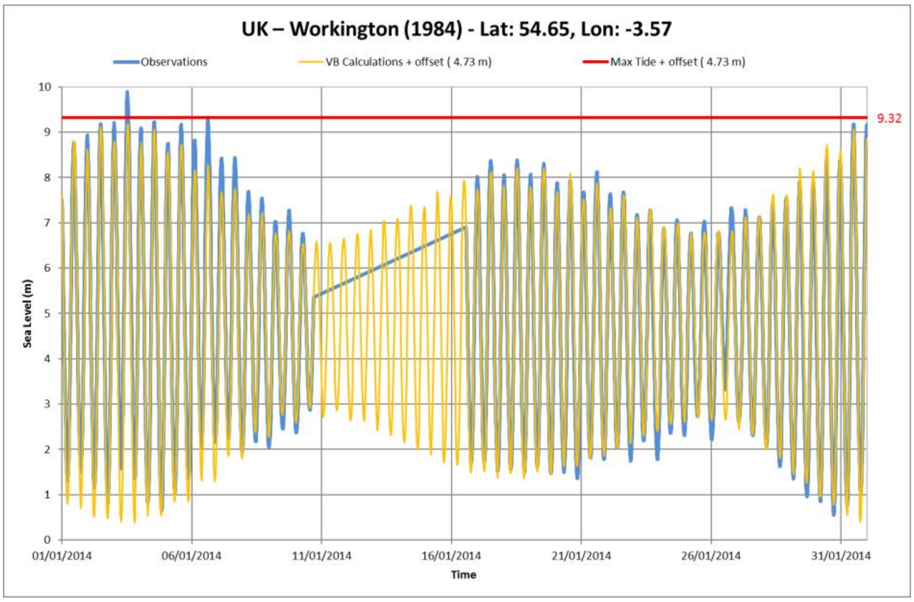


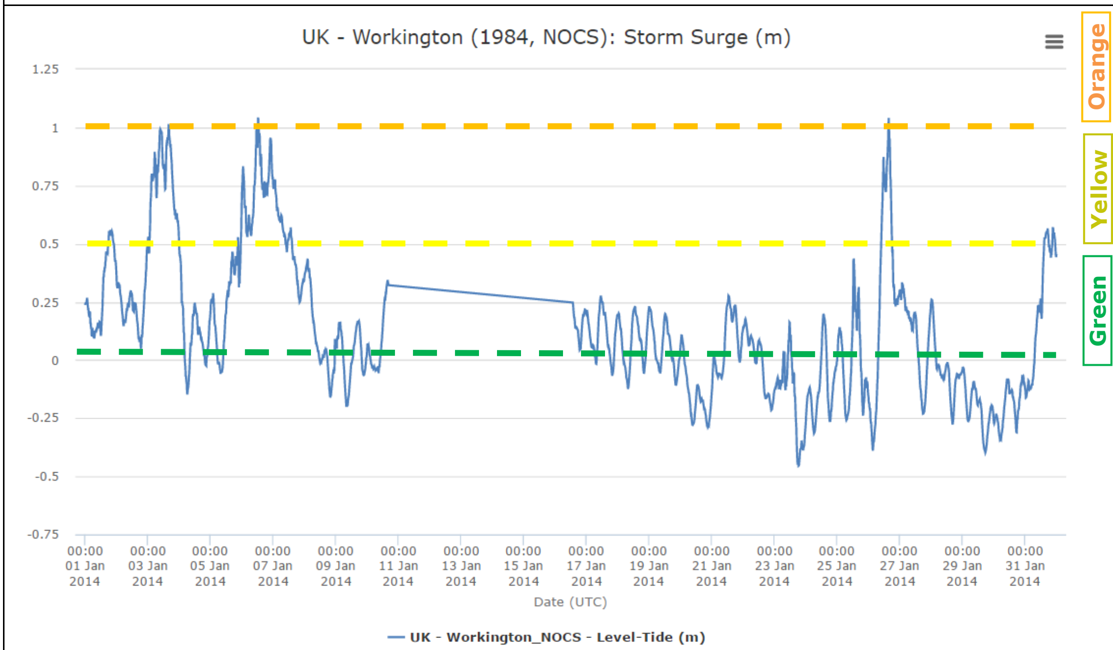
(*) *GDACS Alert level classification*

Figure 19 - As in Figure 15, for CASE 7: South Africa - Port Elizabeth.

CASE 6: UK – Workington

- ID: 1984
- Latitude: 54.65; Longitude: -3.57
- Time: 01 Jan 2014 – 31 Jan 2014
- Offset (Average Jan 2014): 4.73 m
- 1° Harmonic: 4.52
- Max Tide DTU10: 4.59 m
- Max Tide DTU10+ offset: 9.32 m
- Time Max Tide DTU10: 13 Aug 2014 01:01



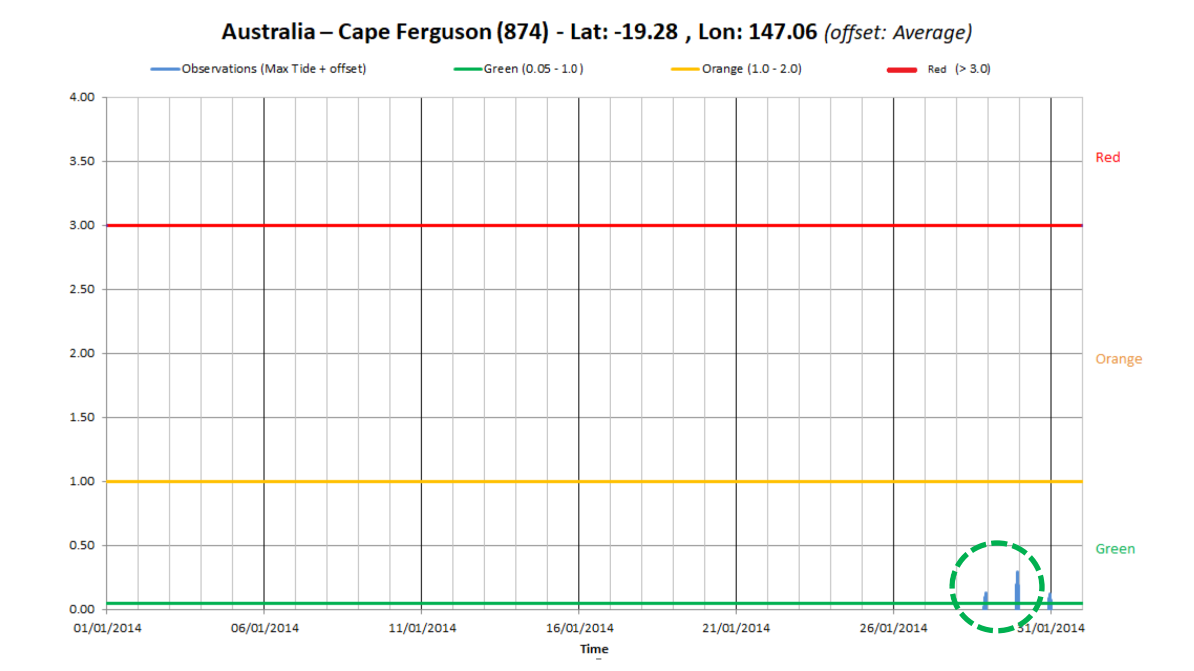


(*)

(*) *SSCS Alert level classification*

Figure 20 - As in Figure 15, for CASE 8: UK – Workington.

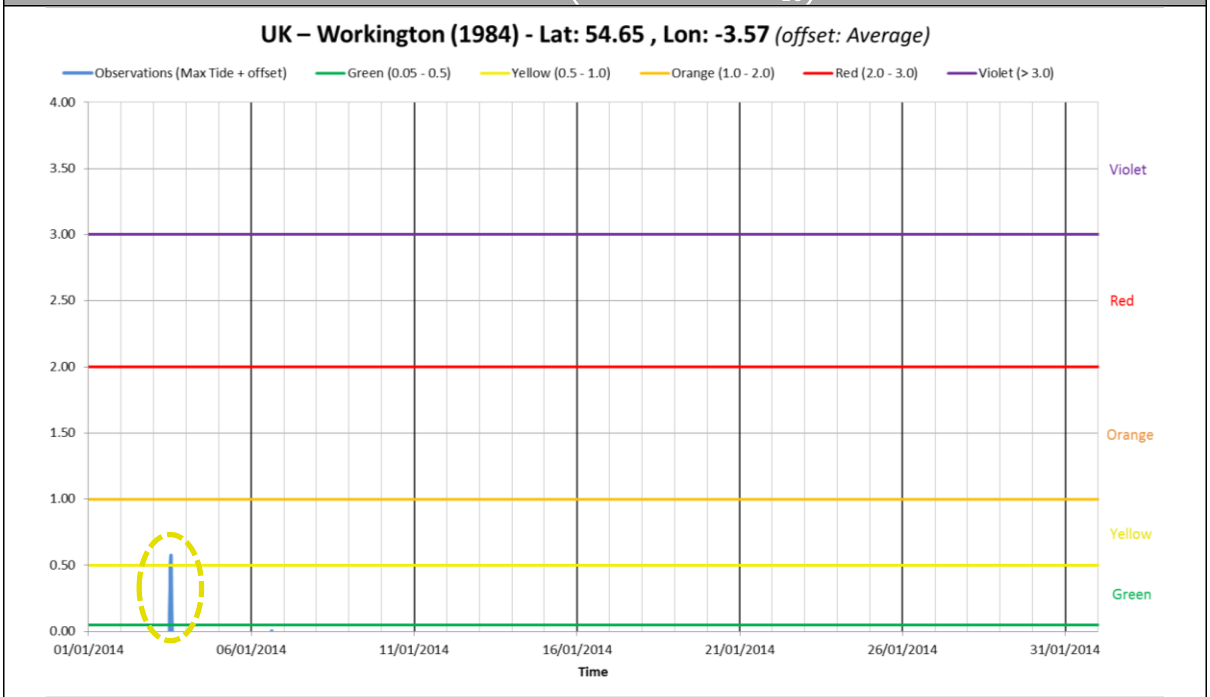
ALERT LEVEL (TAL=ML-MTD_{10})



GREEN ALERT: 0.05 – 0.5 m

Figure 21 - Station: Australia-Cape Ferguson. Blue bars represent "TAL=ML-MTD_{10}". The lower limit of the GDACS alert level (see Table 5) is also shown in this figure (green / yellow / orange / red / violet lines). The maximum alert level for January 2014 is shown below the figure.

ALERT LEVEL (TAL=ML-MTD_{10})



YELLOW ALERT: 0.5 – 1.0 m

Figure 22 - As in **Figure 21**, but for the station: UK-Workington and using the European storms alert colour code (see SSCS Table 5).

Considerations

The comparisons conducted in this Section show that:

- According to the storm surge figures (second charts in the Figure 15-20) several storm surge events occurred during the period of the analysis, but not all these events happened during a period of high tides as it can be seen from the first charts. The alerts levels TAL for these analysed cases are mostly WHITE (< 0.05 m) or GREEN (0.05 – 0.5 m), except for **UK – Workington** (see Figure 22).

  UK – Workington: for this station there is a YELLOW (0.5 – 1.0 m) TAL alert on 3 January 2014. UK was particularly affected by storms over the winter 2013/14, therefore the JRC has decide to focus its analysis on the UK stations. This station will be analysed in detail in the next Section.

- One of the Green alert, **Australia-Cape Ferguson** over the period **28-31 January** is particularly interesting, because tropical cyclone DYLAN affected north-eastern Australia, including Cape Ferguson area, on 29-31 January, exactly during the period of the maximum of the high tide, HAT (29 Jan 2014 22:58 UTC). DYLAN made landfall near Hideaway Bay in Whitsunday region (northern Queensland) in the afternoon (UTC) of 30 January, as a tropical storm. According to the sea level measurements (see Figure 15), DYLAN generated a storm surge of 0.40 m in Cape Ferguson (Green Alert in GDACS). For this case the TAL value is 0.26 m, that corresponds also to a Green Alert. According to media, storm surges combined with high tides caused isolated flooding in Mackay, Townsville and Airlie Beach (Queensland); only minor damage was reported.

3.3 UK Stations: "Winter Storms 2013/14"

Several winter storms affected the UK throughout December, January and February 2013/14, causing deaths and serious damage. Several areas of the UK were affected by strong winds, heavy rains, as well as storm surge. In particular, during the passage of the storm named "Xaver", a considerable storm surge (approx. 2 m in Lowestoft) affected eastern coast of the UK (see Figure 33). A detailed analysis for this event is presented in Annunziato and Probst (2016). The complete list of the storms that affected the UK during last winter (December 2013 – February 2014), the areas affected and the type of the events (winds, rains, storm surge) are shown in Table 7.

The sea level measurements of 4 stations located in the UK are compared with the tide simulated by DTU10 model over the period: 1 December 2013 – 28 February 2014 (see Table 6). A comparison for each single month is also presented. A detailed comparison for one station located on the eastern coast of the UK during the passage of Xaver is also shown in this section.

The offset used in this analysis is the value of the first harmonic calculated by JRC.

Data:

- Sea Level Measurements (JRC Sea Level Database, data source: UK NOC)
- Tide simulations (DTU10 VB program)

Time Period:

- 01 December 2013 00:00 UTC – 28 February 2014 23:59 UTC

Offset:

- First harmonic calculated by JRC

List of locations:

CASE	ID	Name	Lat	Lon	Source
1	1984	**UK** - Workington	54.65	-3.57	UK/NOC
2	1966	**UK** - Lowestoft	52.47	1.75	UK/NOC
3	1986	**UK** - Newlyn	50.10	-5.54	UK/NOC
4	1985	**UK** - Lerwick	60.15	-1.15	UK/NOC

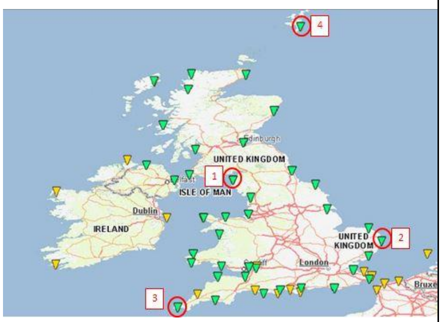


Table 7 - List, Characteristics, Map of the stations selected for this analysis

List of the storms:

The list of the major storms that affected the UK during the winter 2013-2014 is shown in the Table below. The areas most affected by winds/rains/storm surge are indicated in the 2° column, while the type of the hazard (winds/rains/storm surge) that affected these areas is indicated as "●" respectively in the 3°, 4°, 5° columns. A more detailed analysis of the impact caused by storm surge for the locations analysed is shown in the table below.

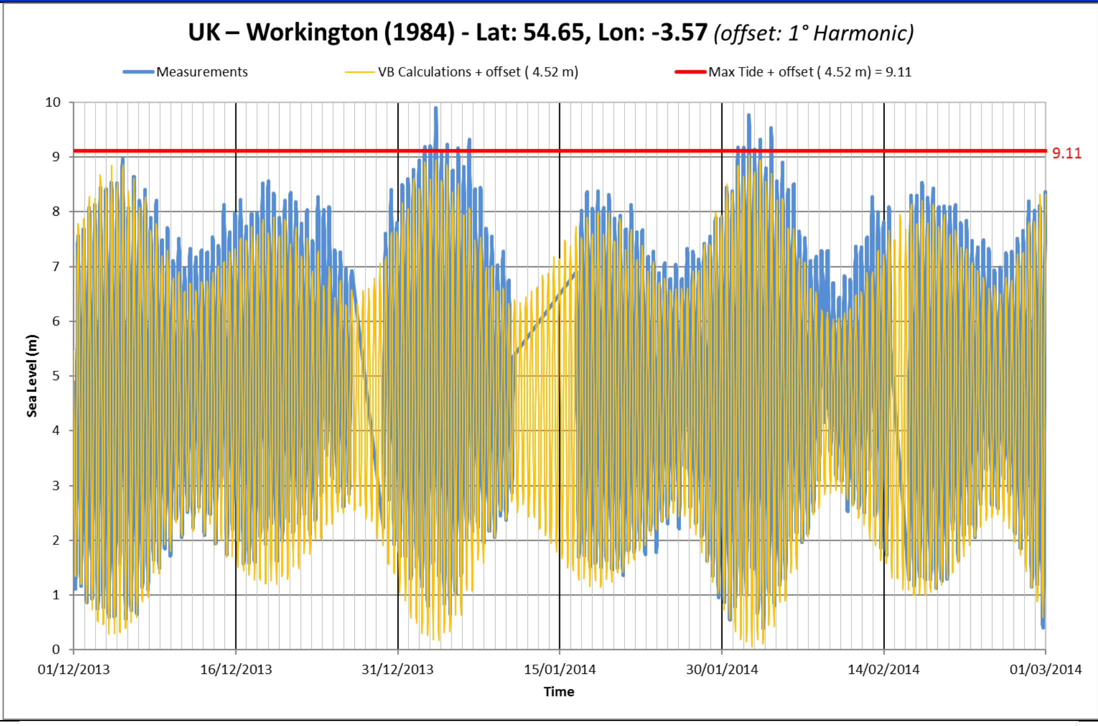
TIME	Areas most affected	Hazard		
		Winds	Rains	Storm surge
4 - 6 Dec 2013	Scotland, E and N England, N Wales	●	●	●
18 – 19 Dec 2013	Western Scotland, Northern Ireland	●		
23 – 24 Dec 2013	Southern England, Wales	●	●	
26 – 27 Dec 2013	Wales	●		
30 – 31 Dec 2013	Wales, SW England	●	●	
3-4 Jan 2014	S England, Wales, Scotland	●	●	●
5-6 Jan 2014	SW England, S Wales	●	●	●
25 - 26 Jan 2014	W and N UK	●		
31 Jan - 1 Feb 2014	N and W UK	●		●
4 – 5 Feb 2014	S Wales, SW England	●	●	●
8 – 9 Feb 2014	S Wales, SW England	●		
12 Feb 2014	Wales, NW England	●		
14 – 15 Feb 2014	S Wales, S England	●		

Table 8 - List of the storms that affected UK throughout December 2013, January and February 2014

CASE 1: UK – Workington

- ID: 1984
- Latitude: 54.65; Longitude: -3.57
- Time: 01 Dec 2013 – 28 Feb 2014
- Offset (1° Harmonic): 4.52 m
- Average (Dec 2013 - Feb 2014): 4.79 m
- Max Tide simulated: 4.59 m
- Max Tide + offset: 9.11 m
- Time Max Tide: 13/08/2014 01:01 UTC

DECEMBER 2013 – FEBRUARY 2014: UK – WORKINGTON (1984)



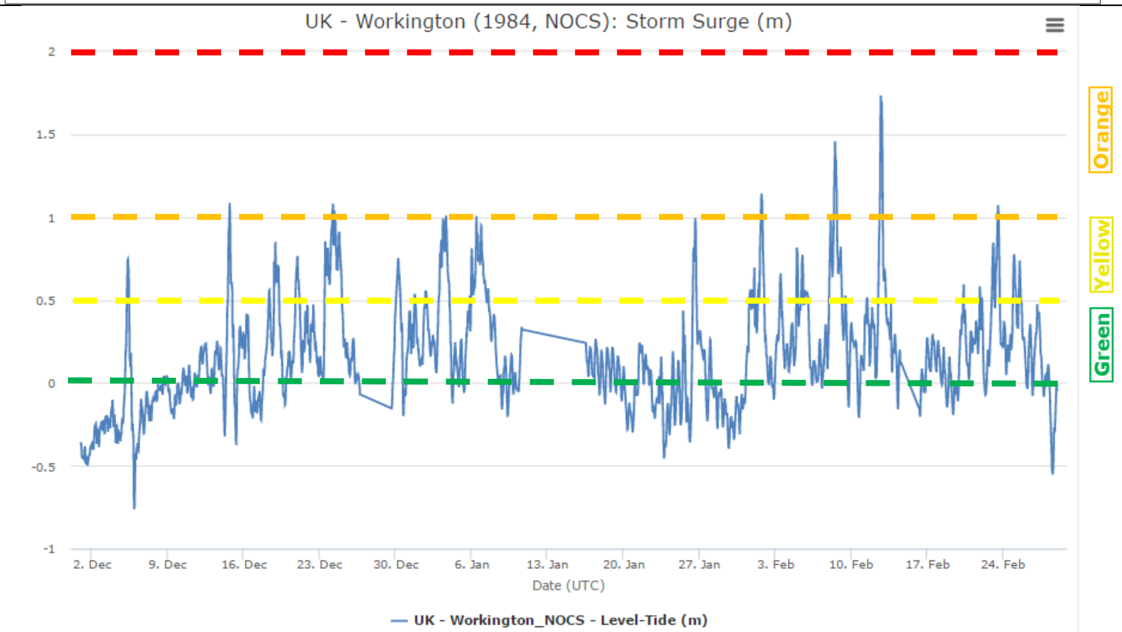


Figure 23 - As in Figure 15, but for UK - Workington for the period Dec 2013 - Feb 2014

DECEMBER 2013: UK – WORKINGTON (1984)

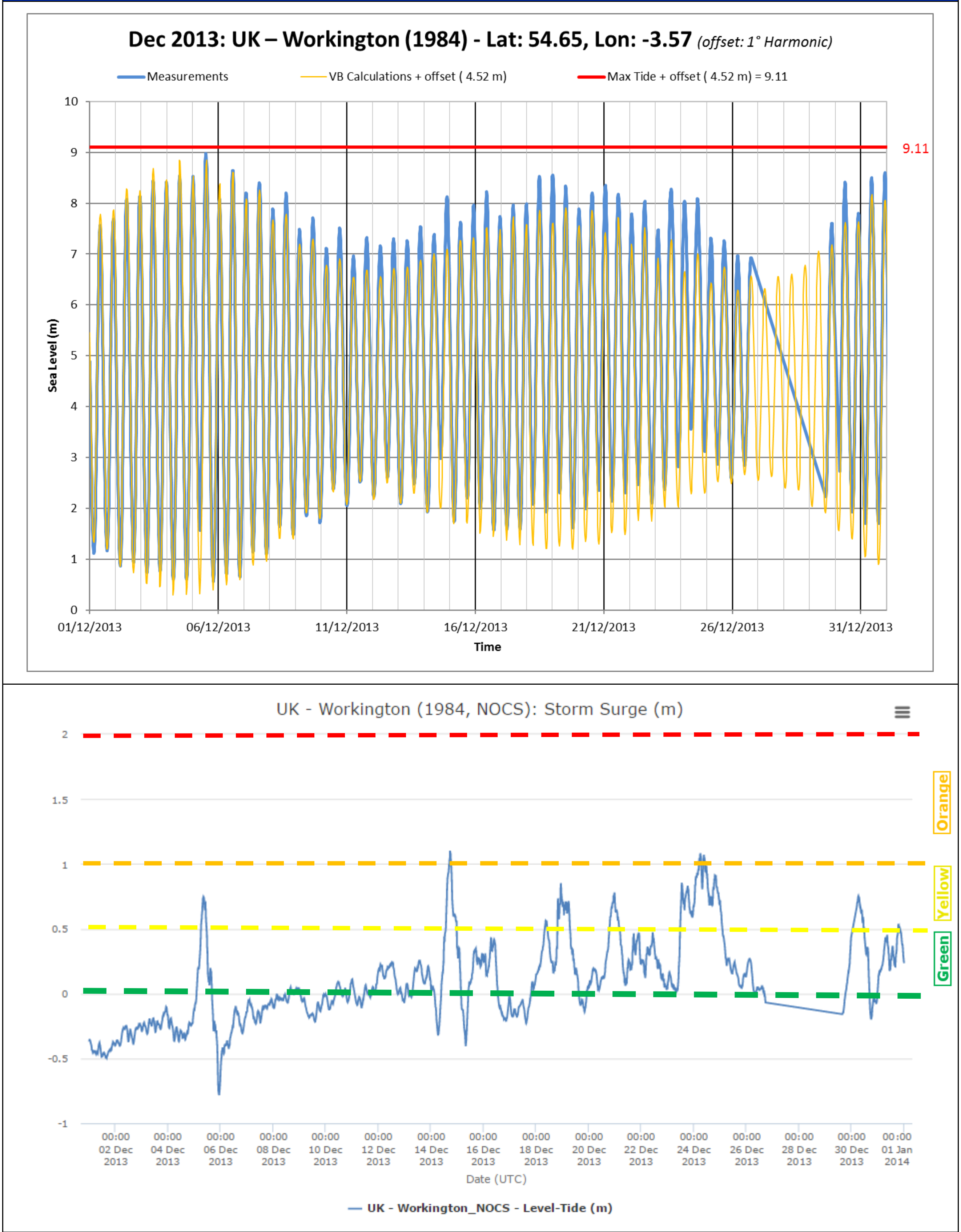
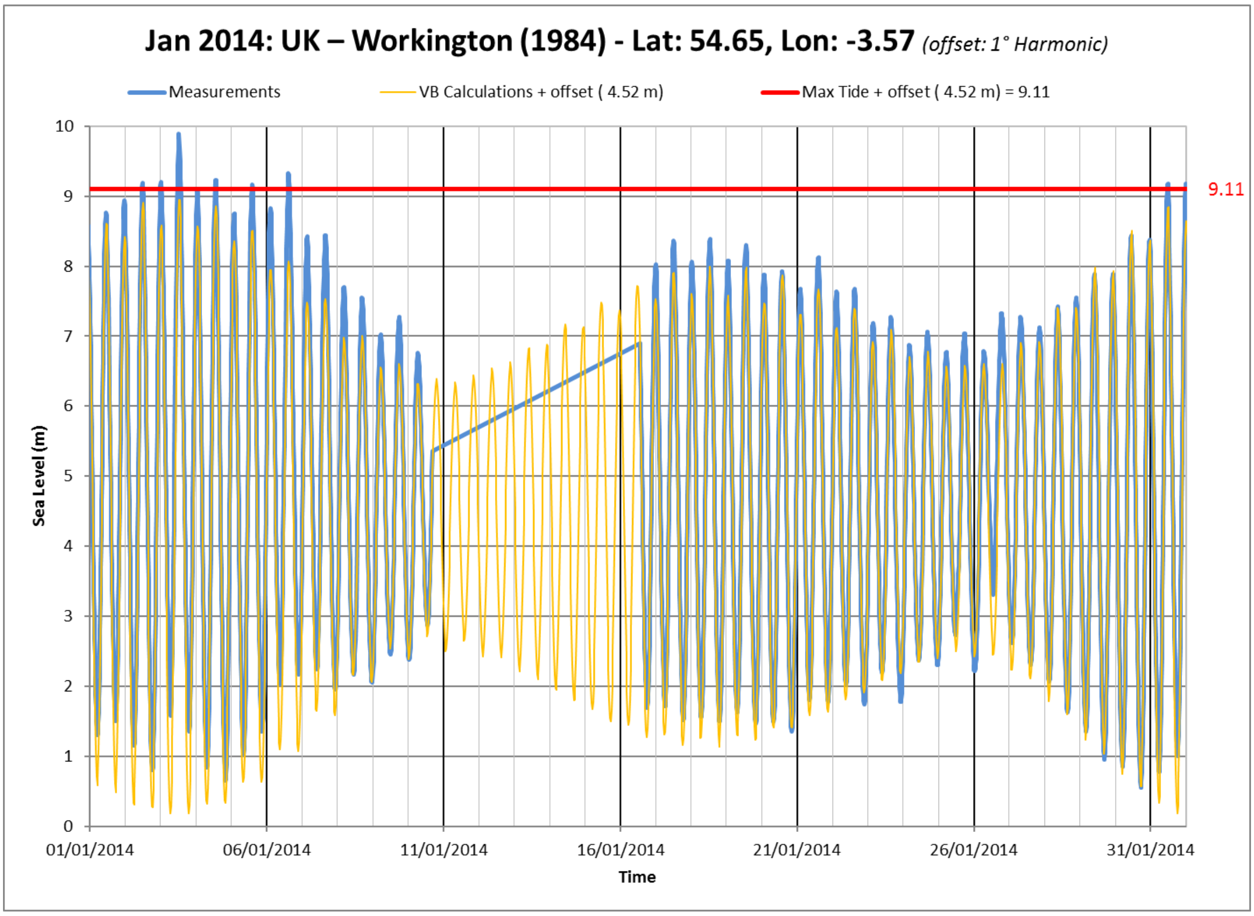


Figure 24 - As in Figure 23, but only for December 2013

January 2014: UK – Workington (1984)



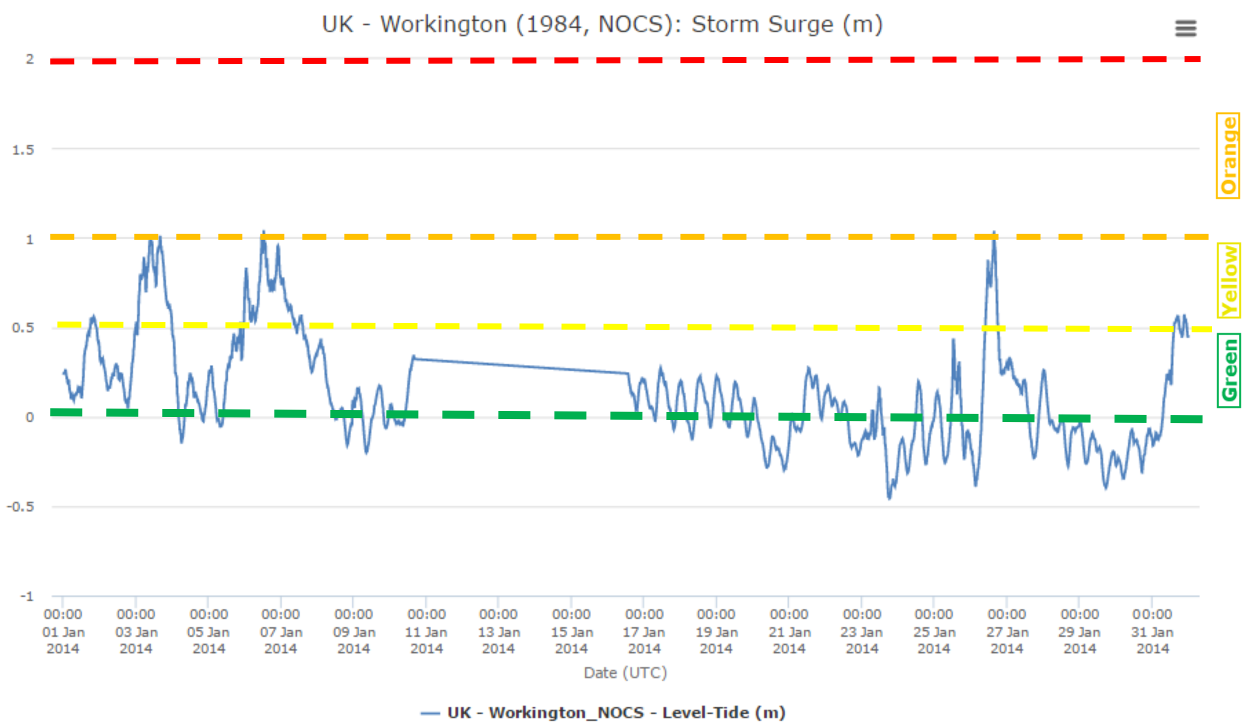
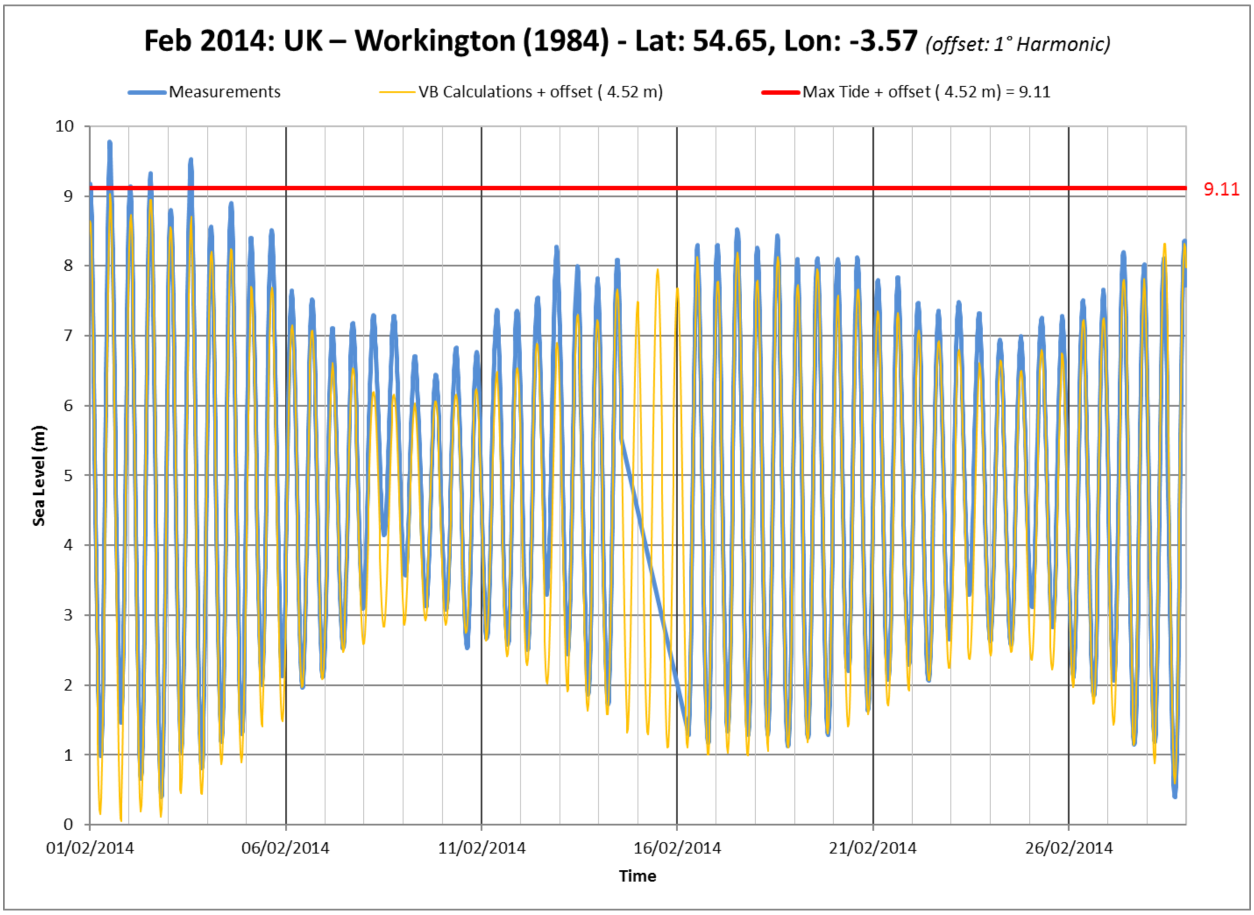


Figure 25 - As in Figure 23, but only for January 2014

FEBRUARY 2014: UK – WORKINGTON (1984)



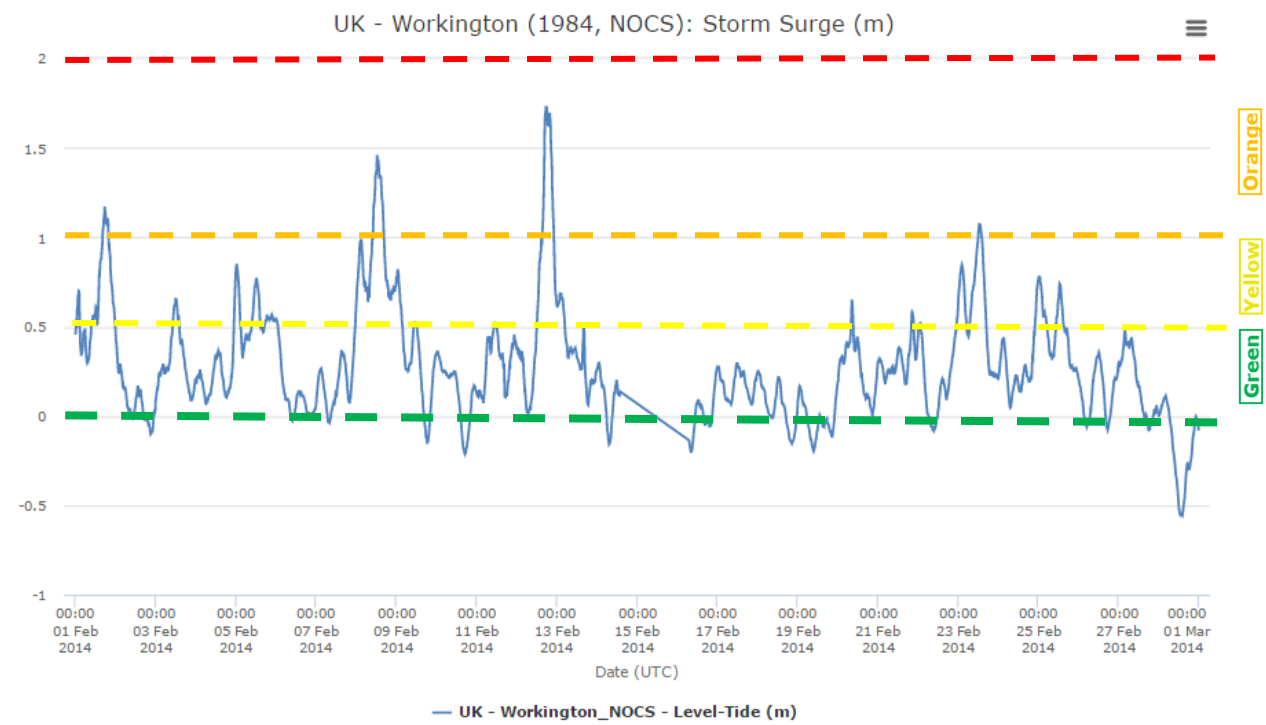
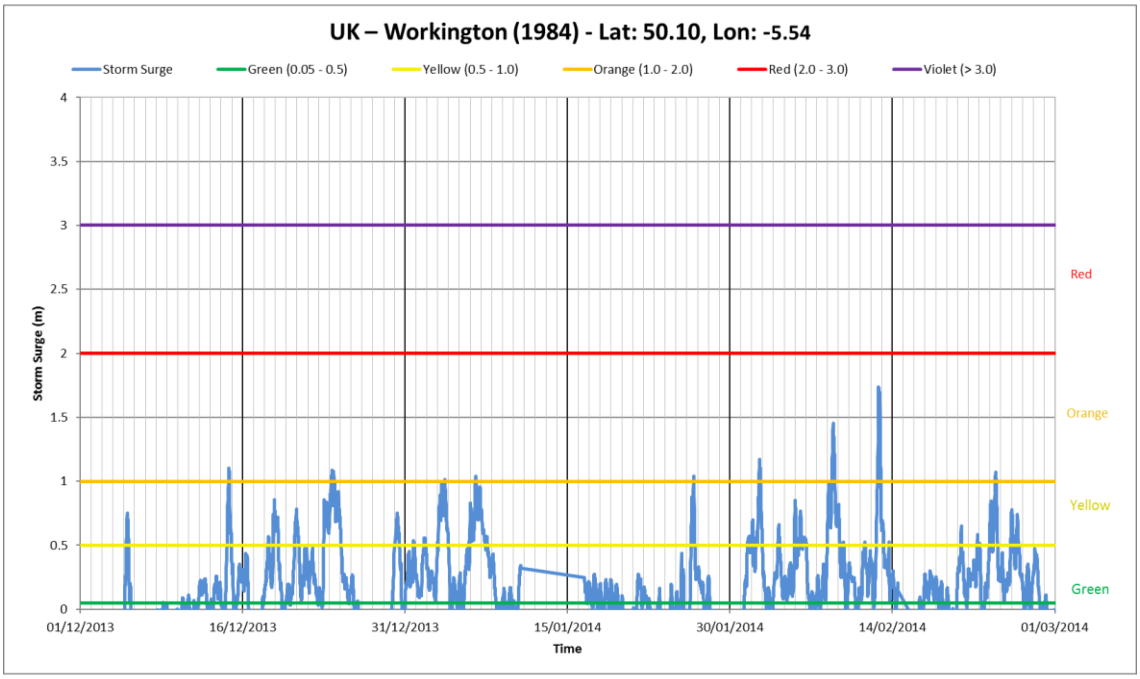
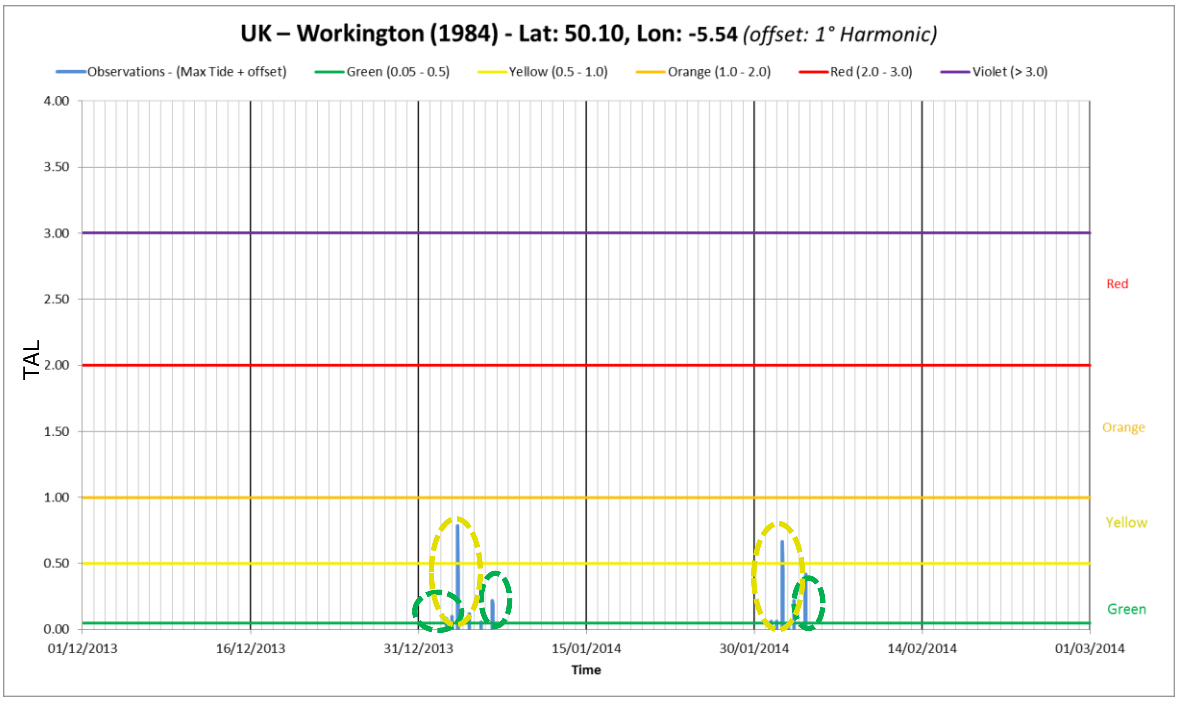


Figure 26 - As in Figure 23, but only for February 2014

ALERT LEVEL: UK – WORKINGTON (1984)



SSCS Max Alert: ORANGE ALERT (1.0 – 2.0 m)



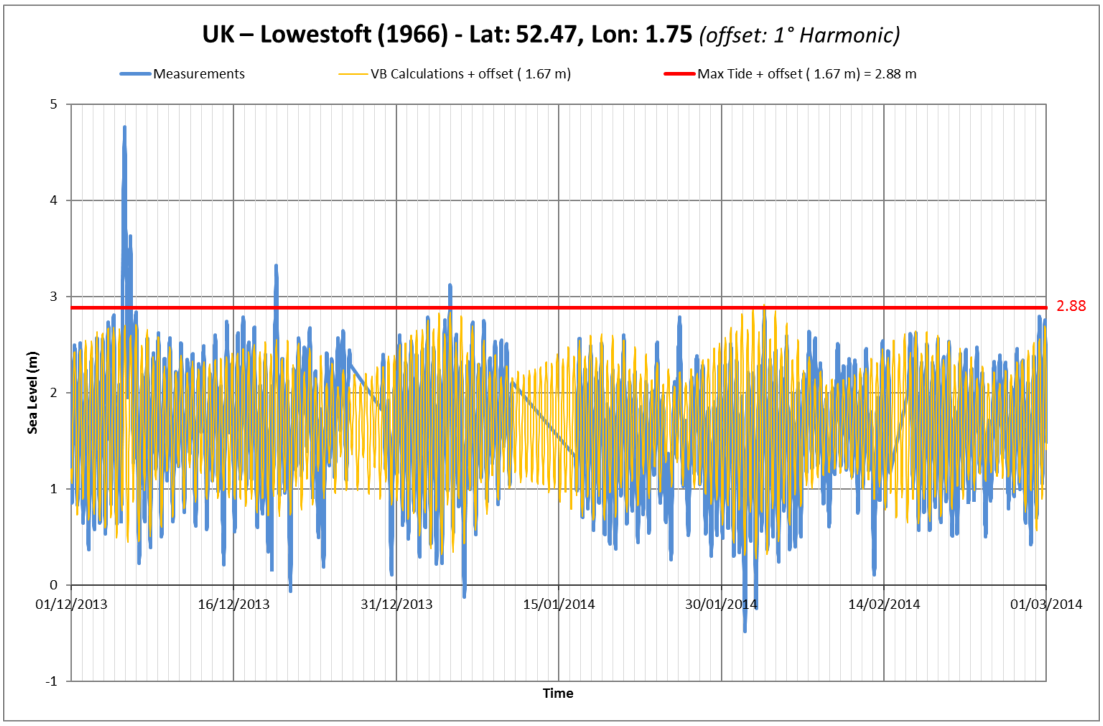
TAL Max Alert: YELLOW ALERT (0.5 – 1.0 m)

Figure 27 - The alert level using the SSCS alert level (above) and using the "TAL system" (below) for UK - Workington (CASE 1) over the period Dec 2013 - Feb 2014

CASE 2: UK – Lowestoft

- ID: 1966
- Latitude: 52.47; Longitude: 1.75
- Time: 01 Dec 2014 – 28 Feb 2014
- Offset (1° Harmonic): 1.67 m
- Average (Dec 2013 - Feb 2014): 1.63 m
- Max Tide simulated: 1.21 m
- Max Tide + offset: 2.88 m
- Time Max Tide: 13 Aug 2014 10:58 UTC

DECEMBER 2013 – FEBRUARY 2014: UK – LOWESTOFT (1966)



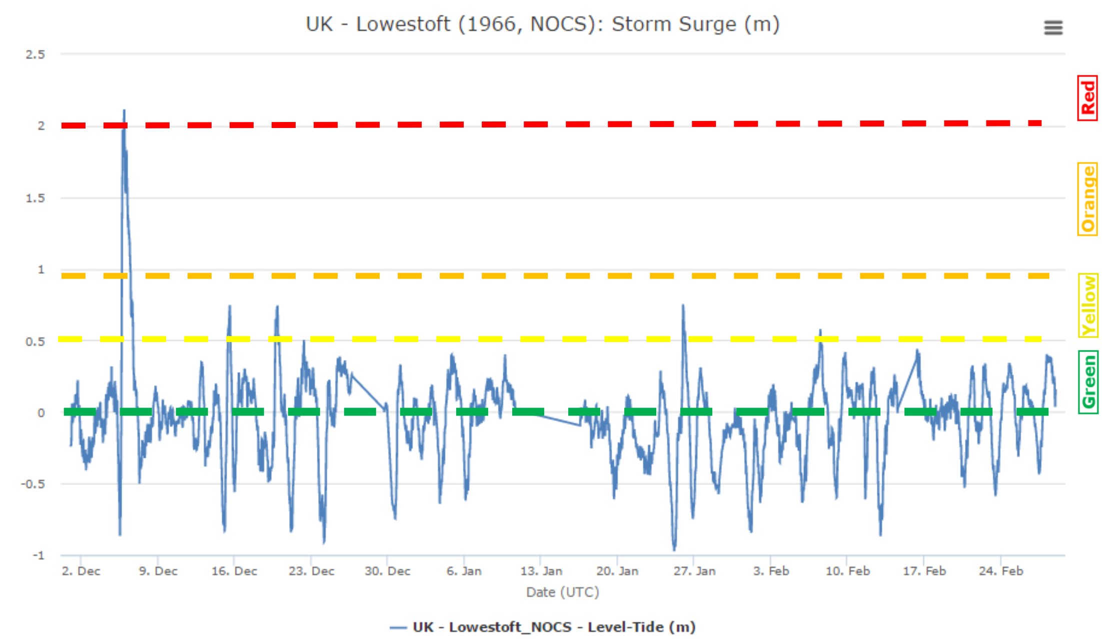
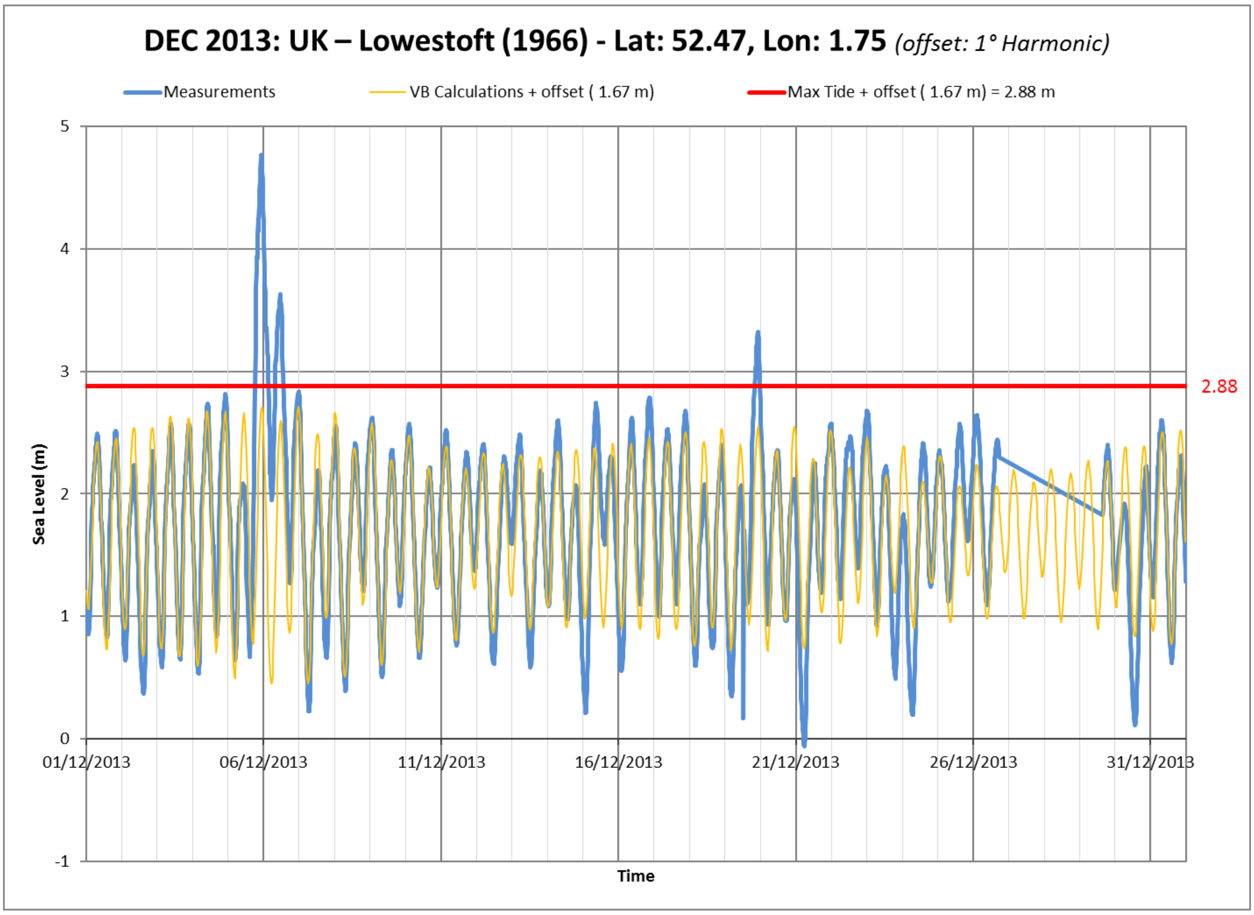


Figure 28- As in Figure 23, but for UK - Lowestoft

DECEMBER 2013: UK – LOWESTOFT (1966)



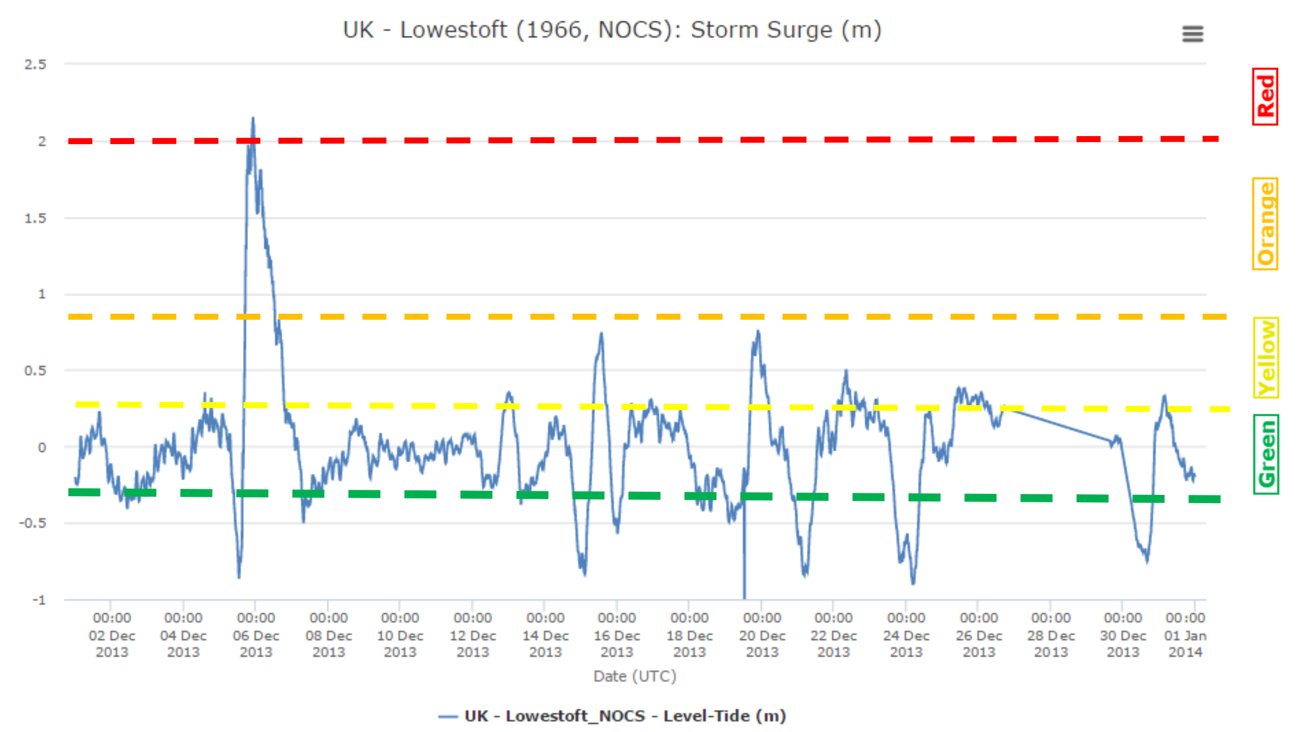
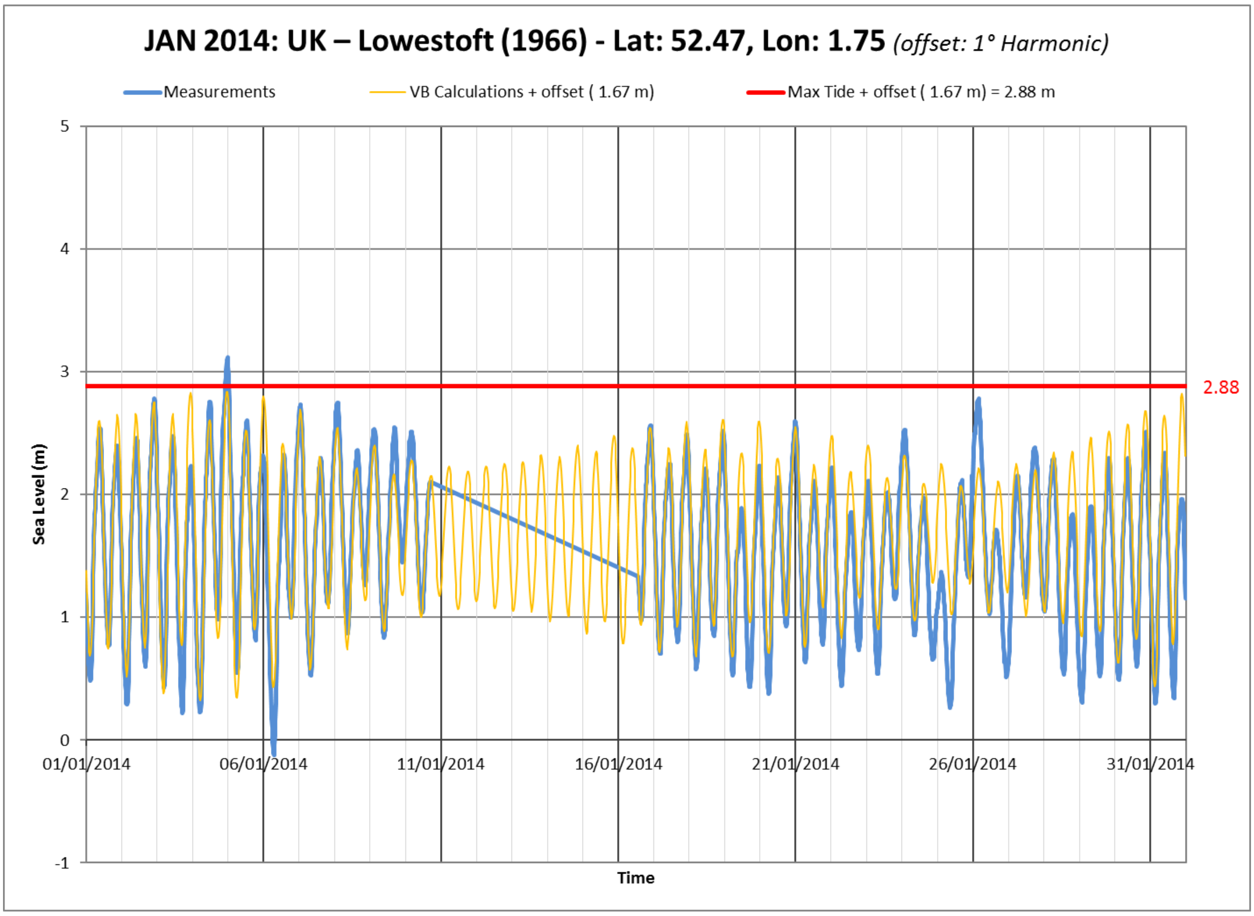


Figure 29 - As in Figure 28, but only for December 2013

JANUARY 2014: UK – LOWESTOFT (1966)



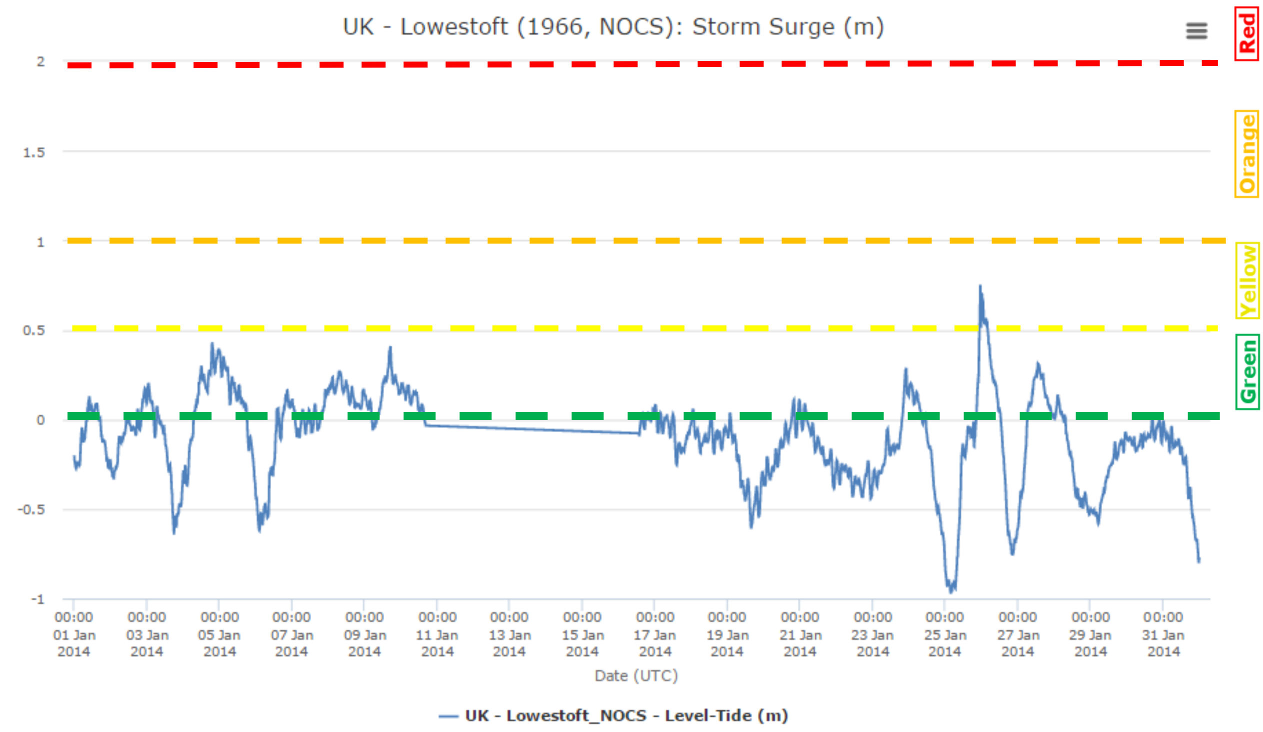
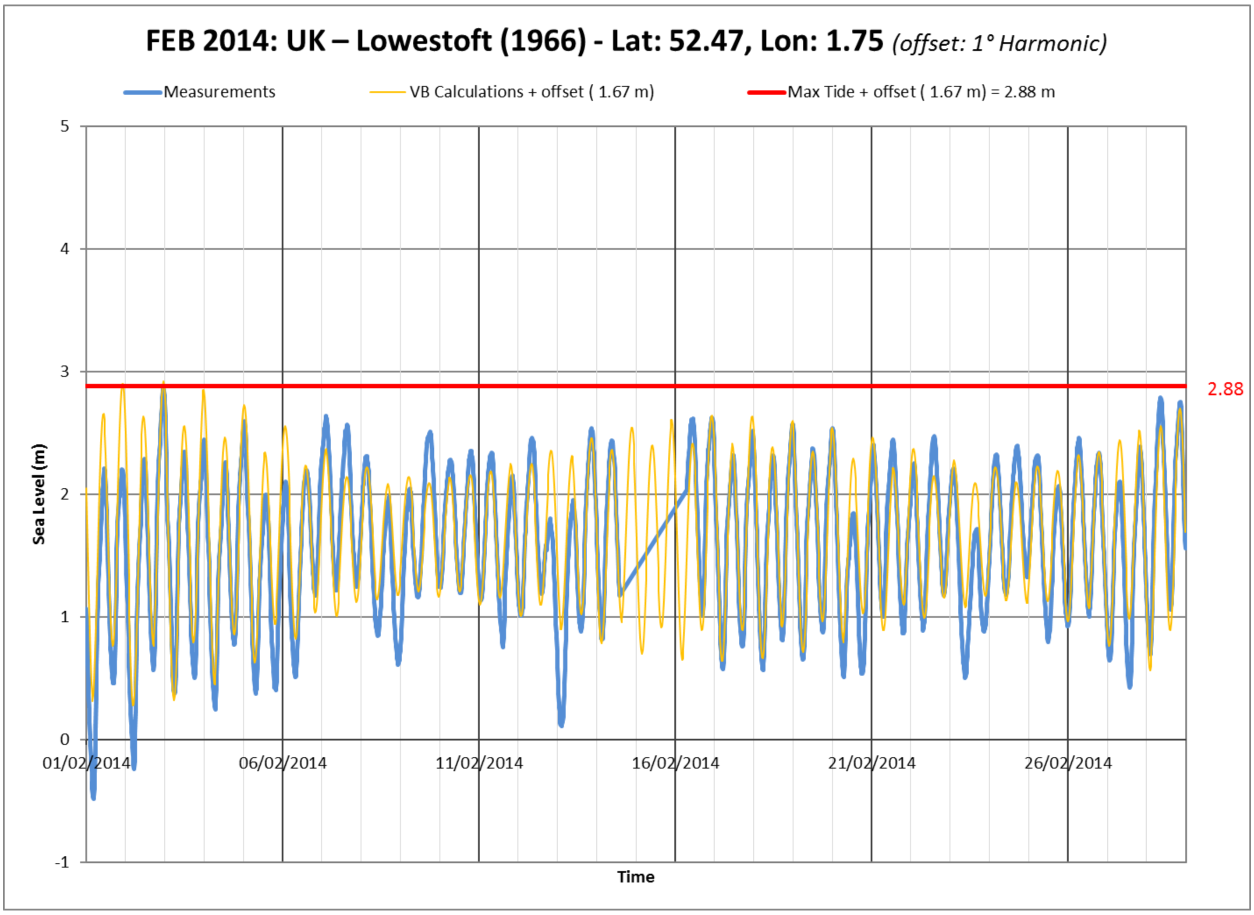


Figure 30 - As in Figure 28, but only for January 2014

FEBRUARY 2014: UK – LOWESTOFT (1966)



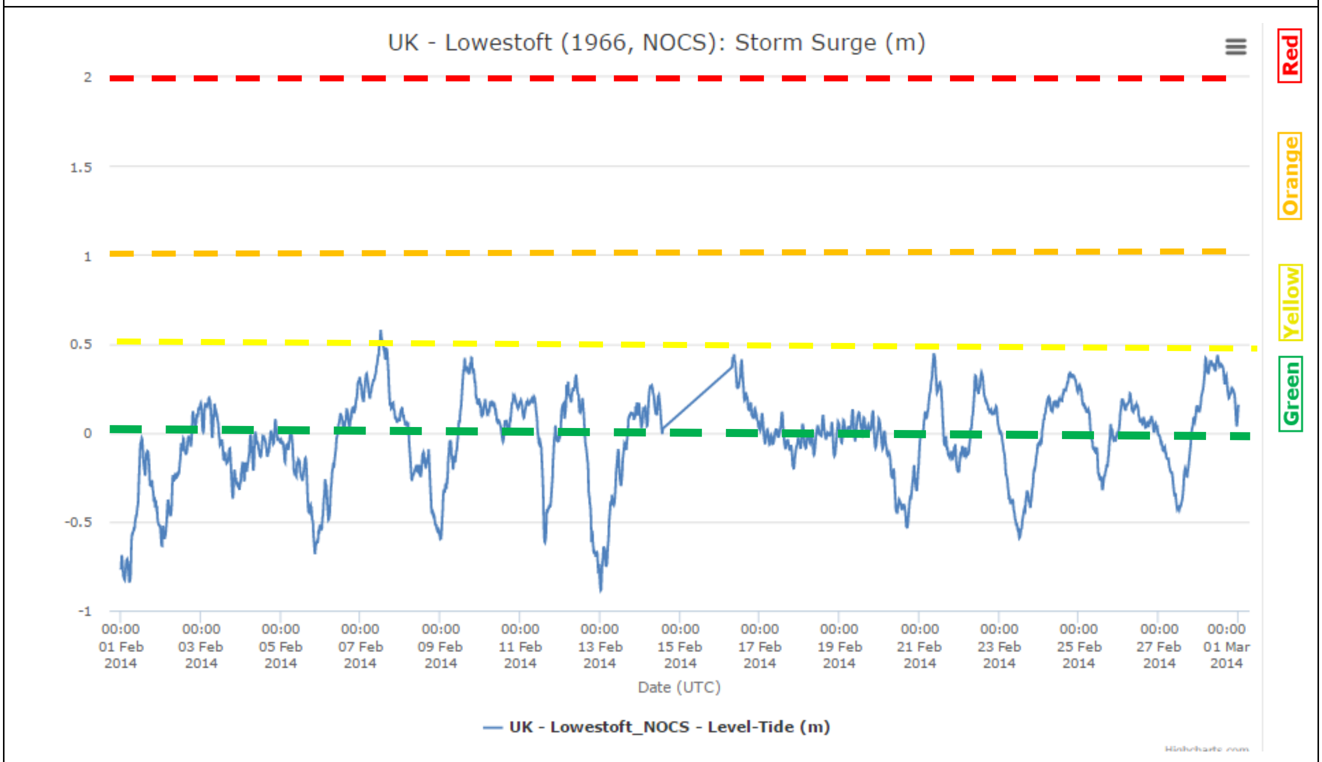
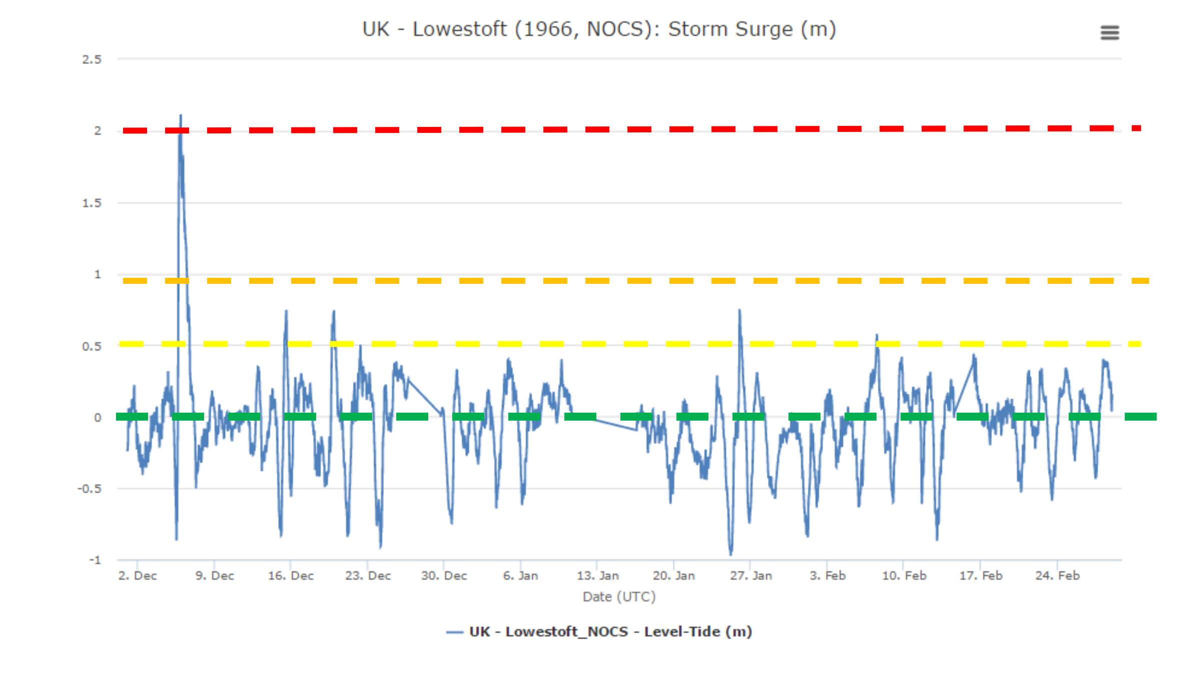
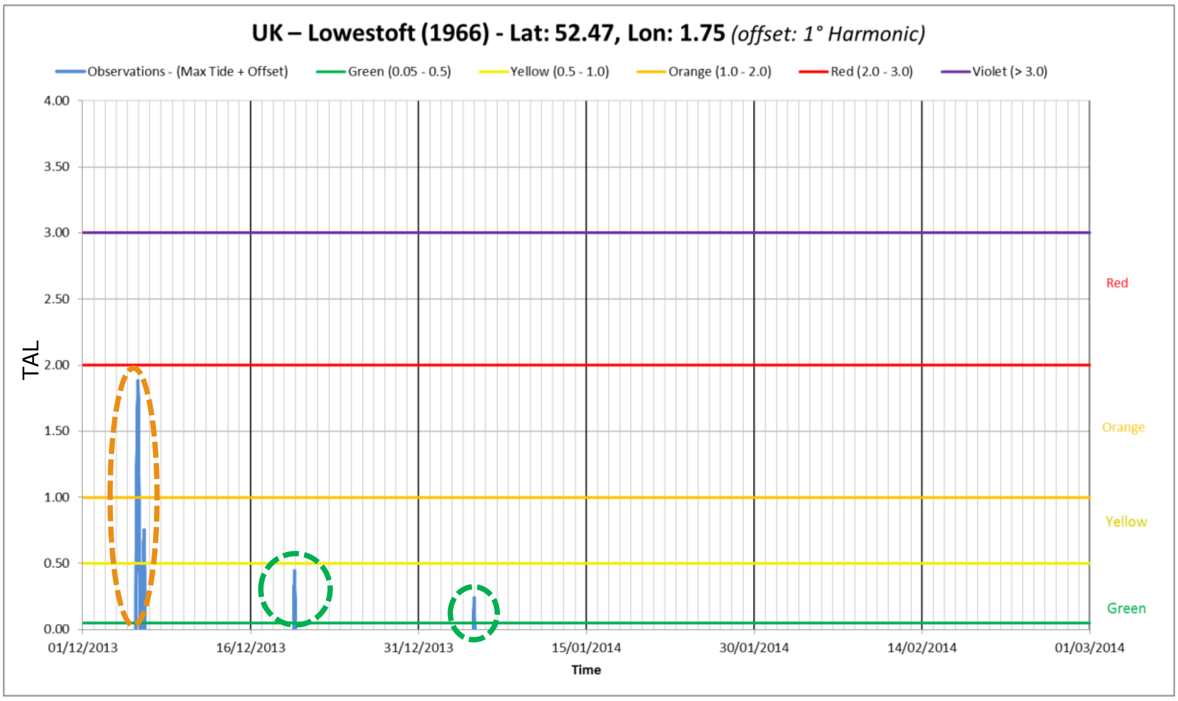


Figure 31 - As in Figure 28, but only for February 2014

ALERT LEVEL: UK – LOWESTOFT (1966)



SSCS Max Alert: RED ALERT (> 2.0 m)



TAL Max Alert: ORANGE ALERT (1.0 – 2.0 m)

Figure 32 – As in Figure 27, but for UK - Lowestoft (CASE 2) over the period Dec 2013 - Feb 2014

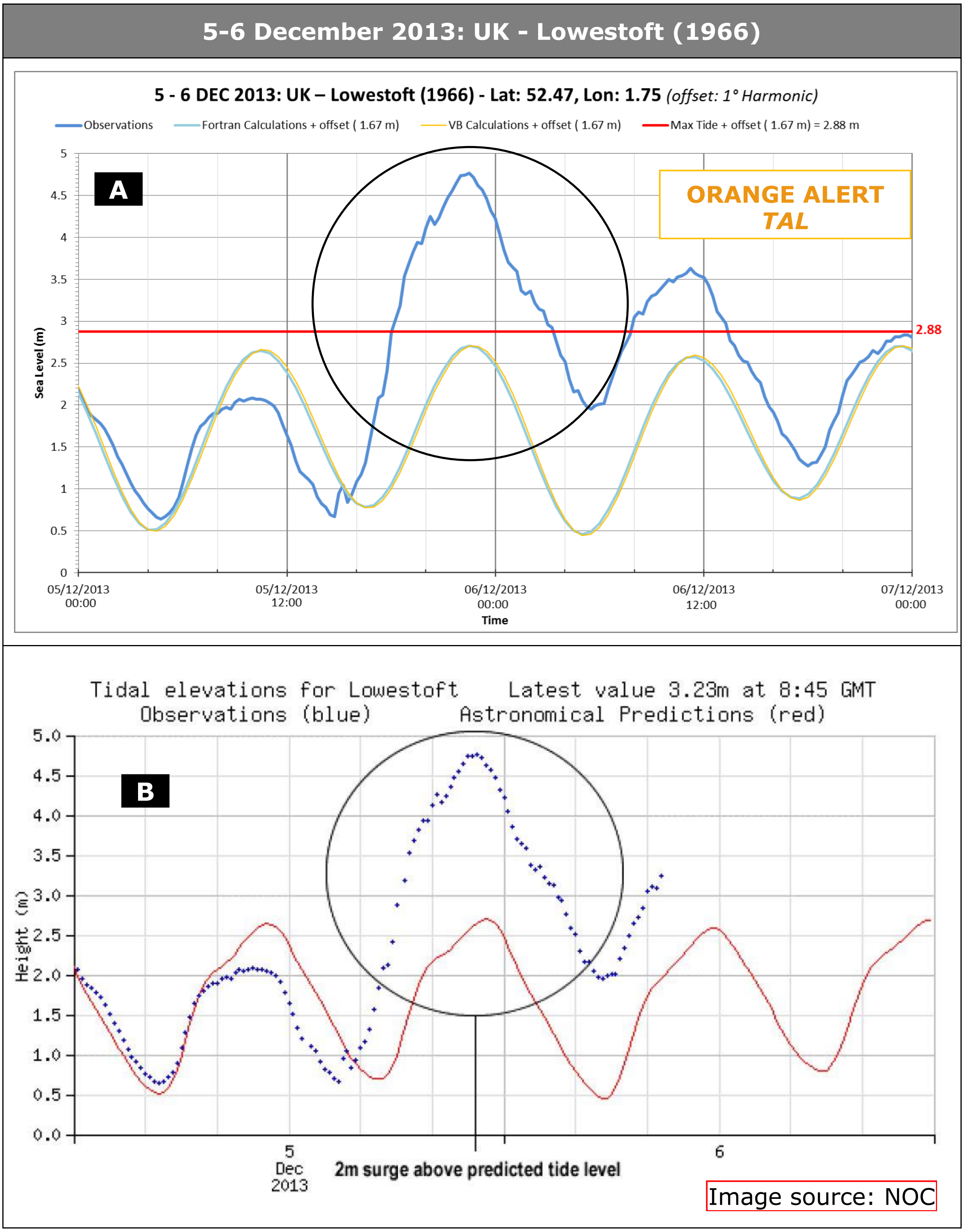
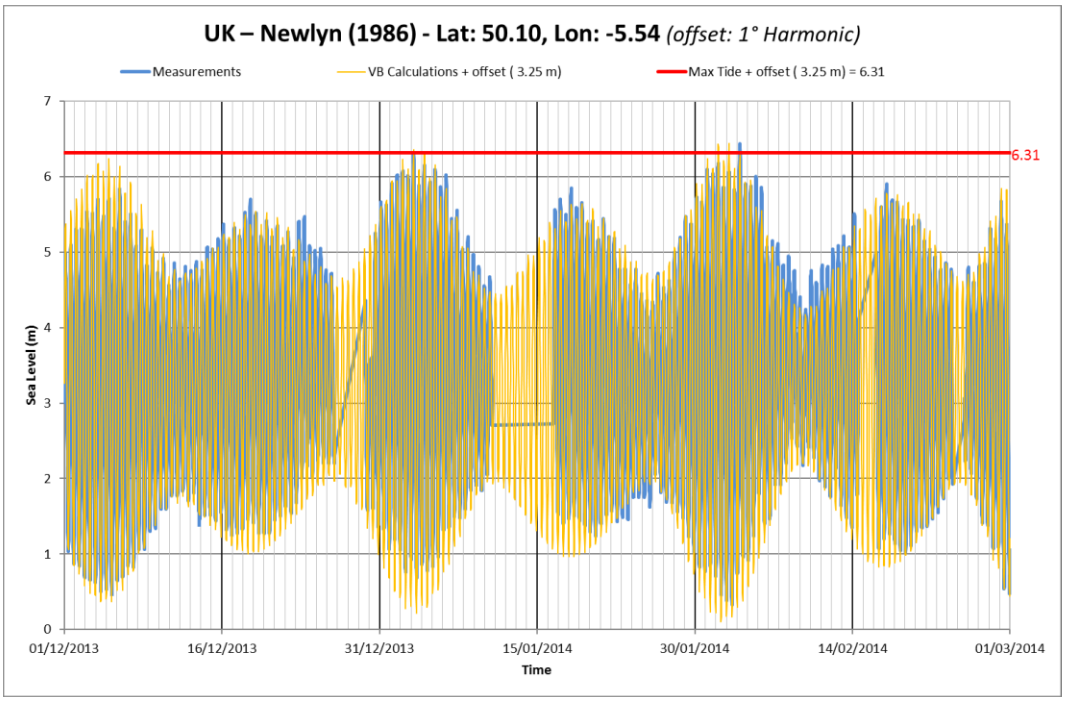


Figure 33 - Comparisons during the passage of "Xaver". A) JRC B) NOC

CASE 3: UK – Newlyn

- ID: 1986
- Latitude: 50.1; Longitude: -5.54
- Time: 01 Dec 2014 – 28 Feb 2014
- Offset (1° Harmonic): 3.25 m
- Average (Dec 2013 - Feb 2014): 3.36 m
- Max tide simulated: 3.06 m
- Max Tide + offset: 6.31 m
- Time Max Tide: 12 Aug 2014 00:00 UTC

DECEMBER 2013 – FEBRUARY 2014: UK – NEWLYN (1986)



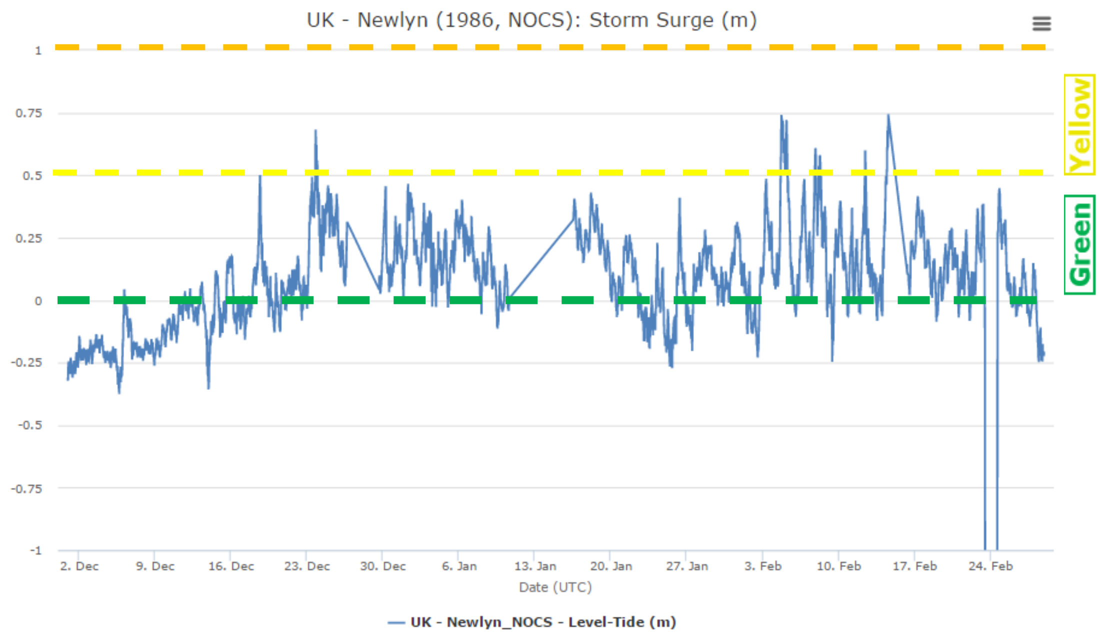
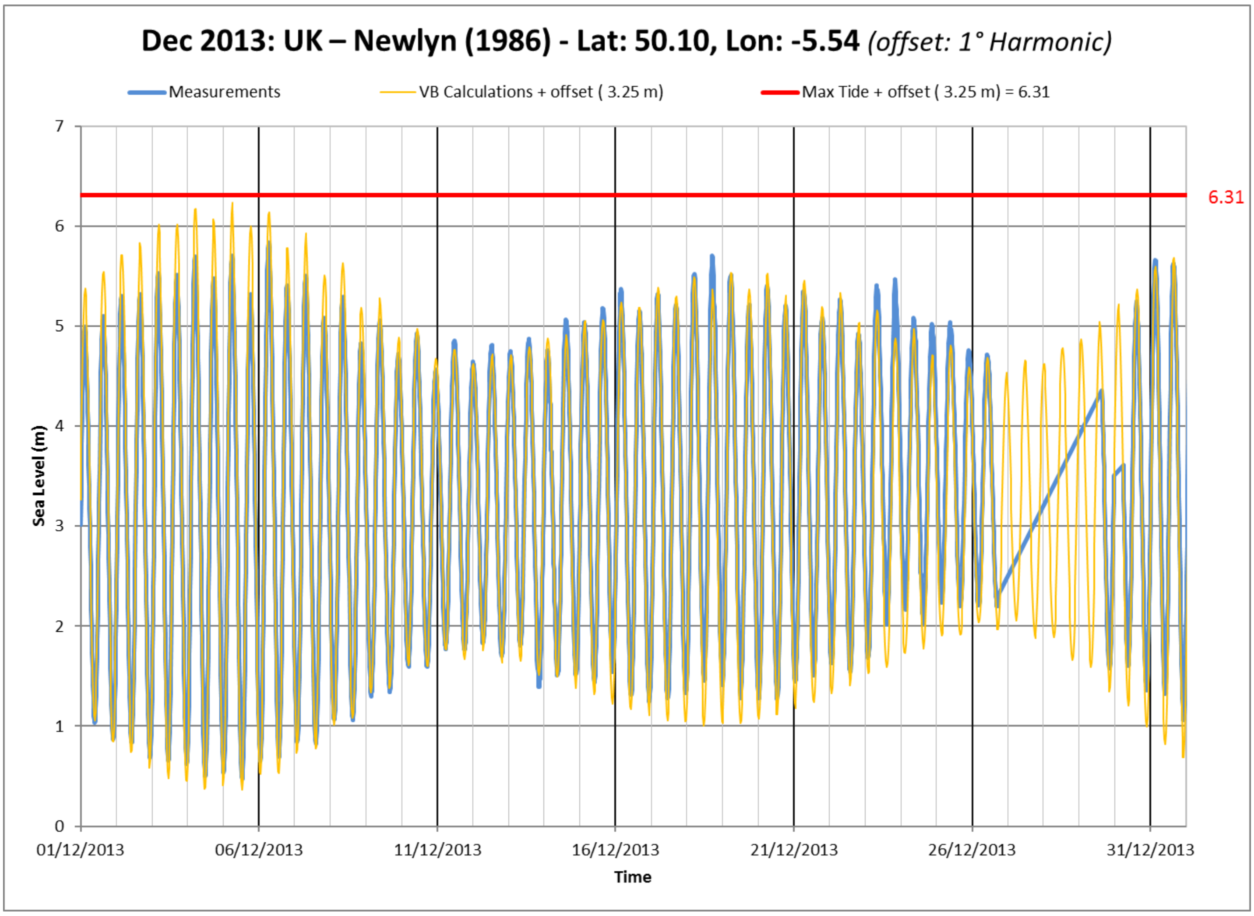


Figure 34 - As in Figure 23, but for UK – Newlyn (1986)

DECEMBER 2013: UK – NEWLYN (1986)



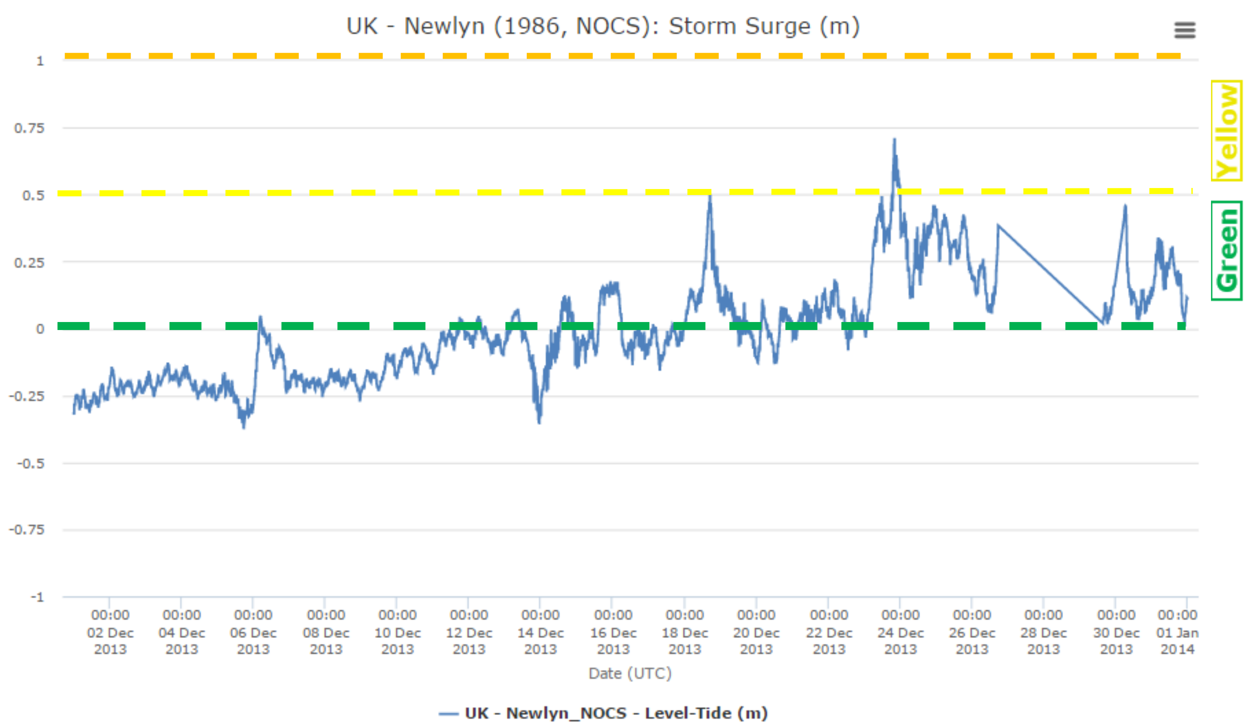
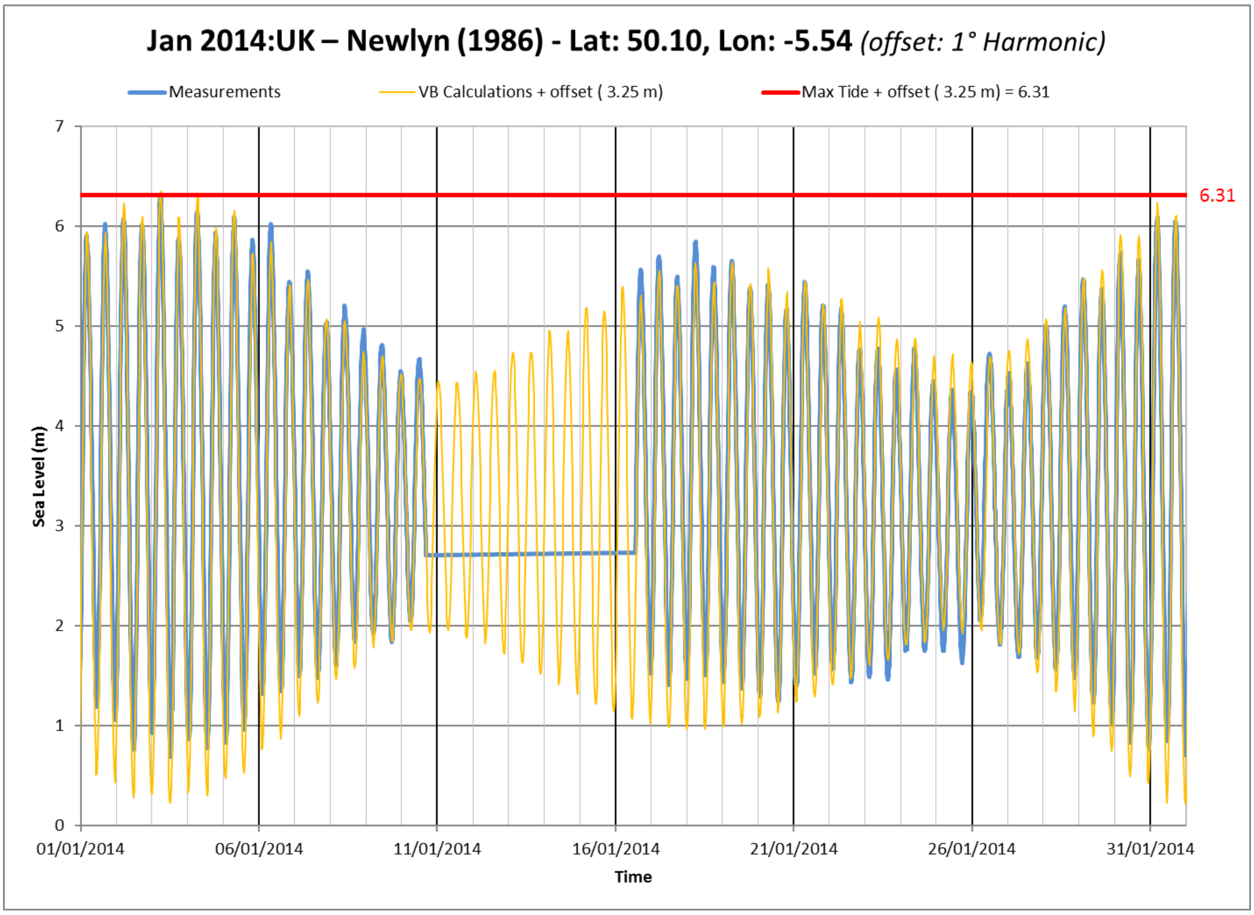


Figure 35 – As in Figure 34, but only for December 2013

JANUARY 2014: UK – NEWLYN (1986)



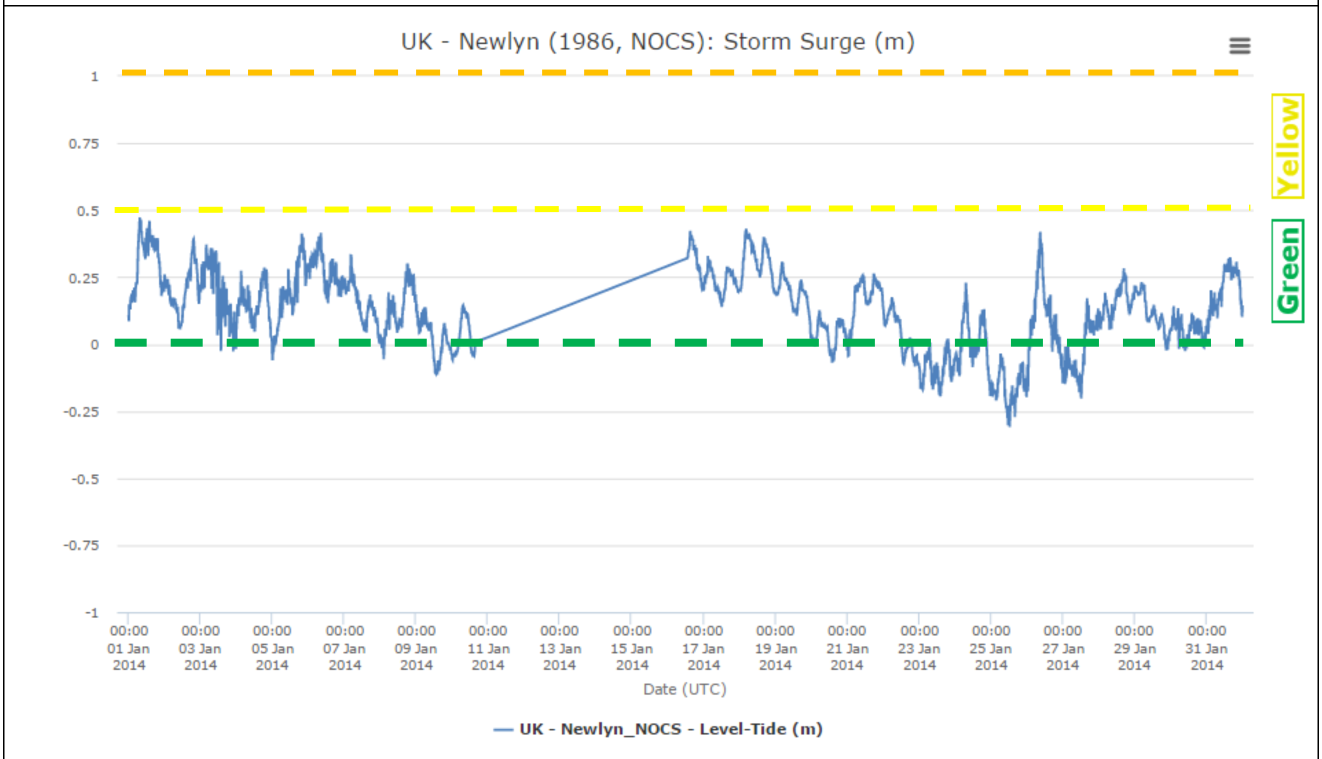
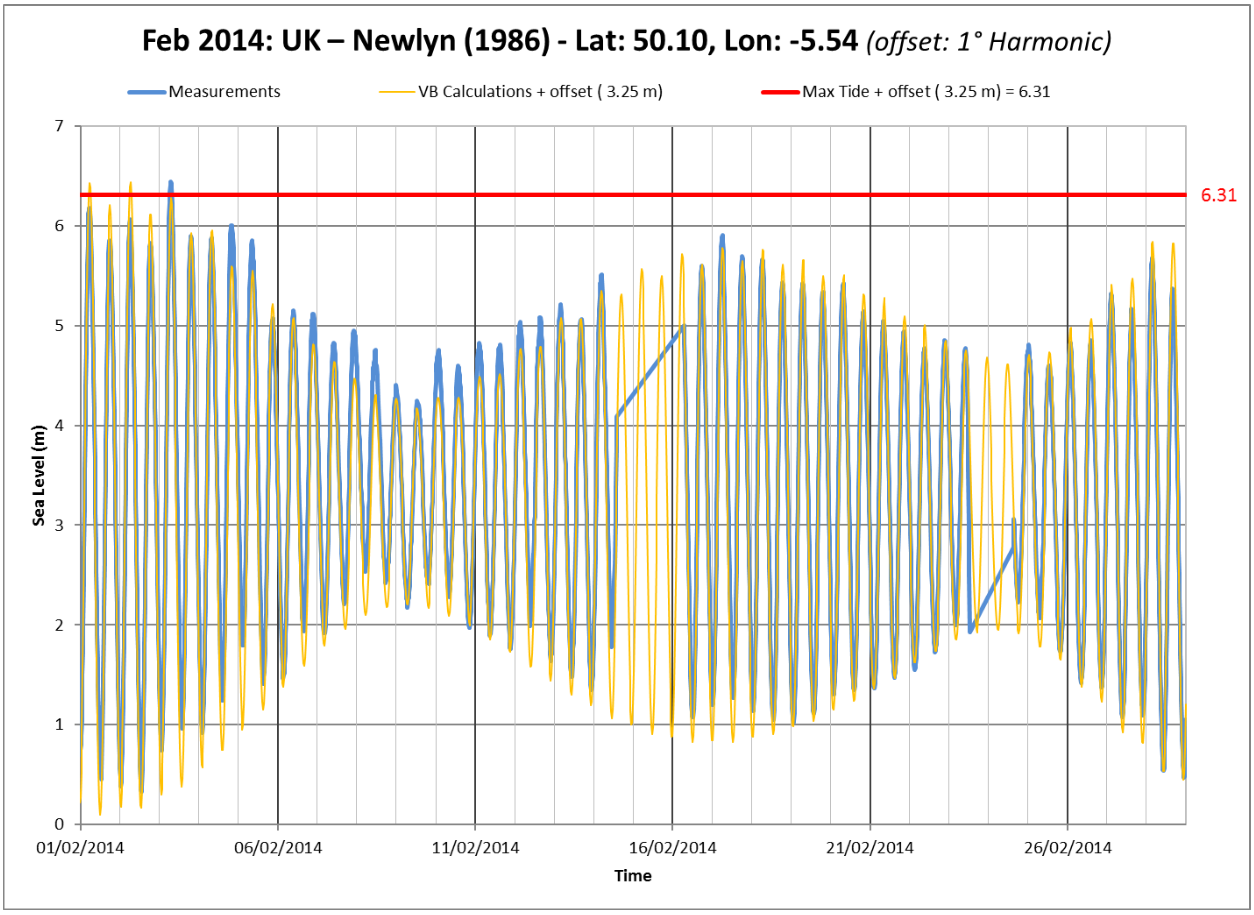


Figure 36 - As in Figure 34, but only for January 2014

February 2014: UK – Newlyn (1986)



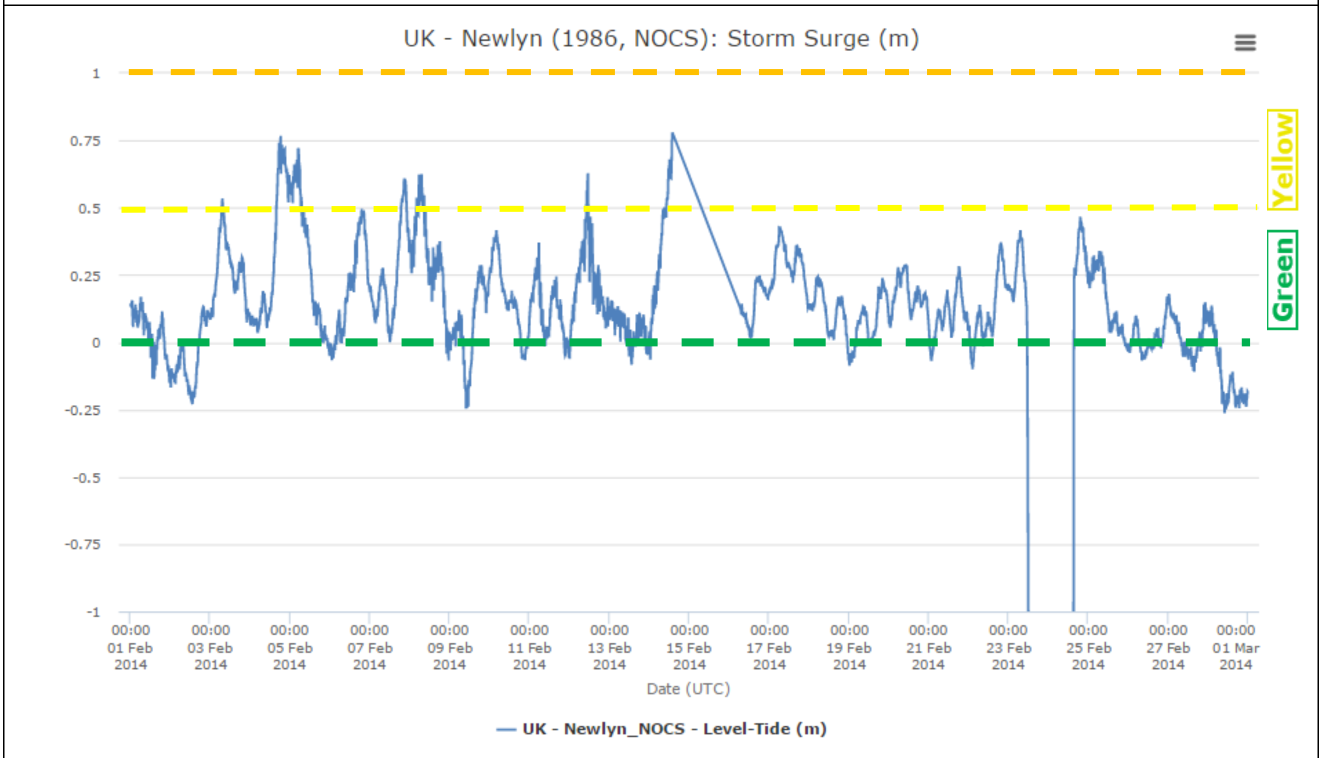
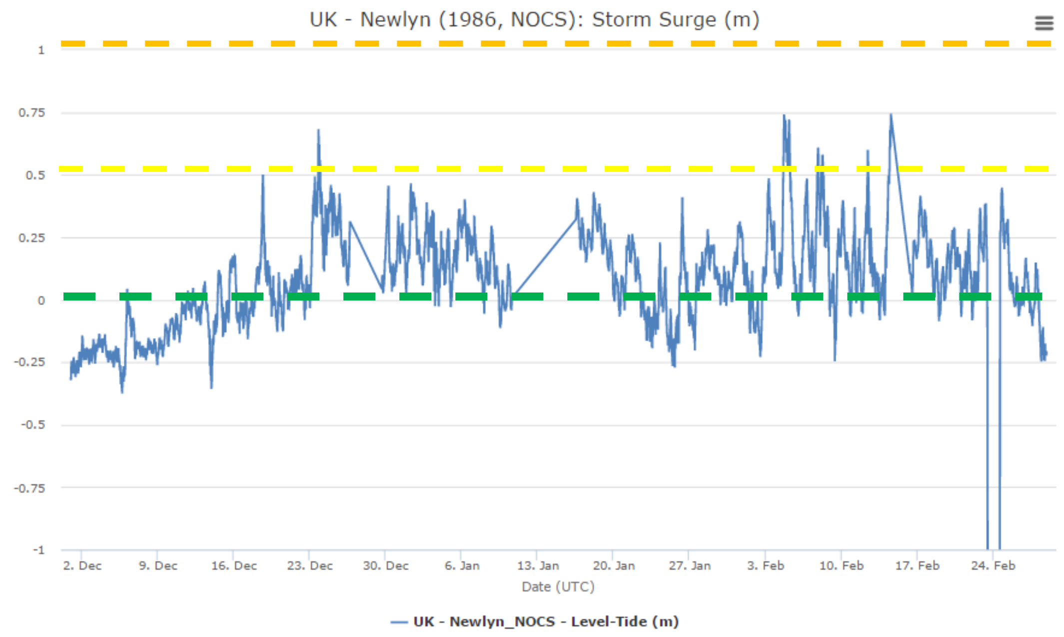
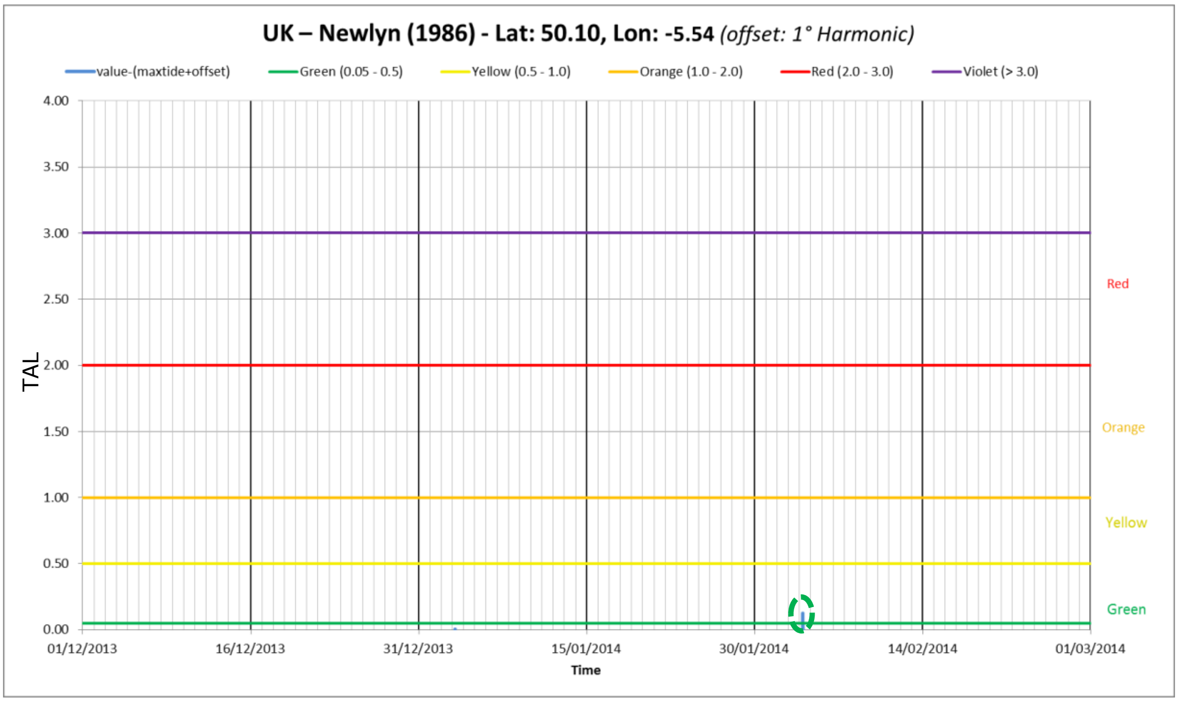


Figure 37 - As in Figure 34, but only for February 2014

ALERT LEVEL: UK – NEWLYN (1986)



SSCS Max Alert: YELLOW ALERT (0.5 – 1.0 m)

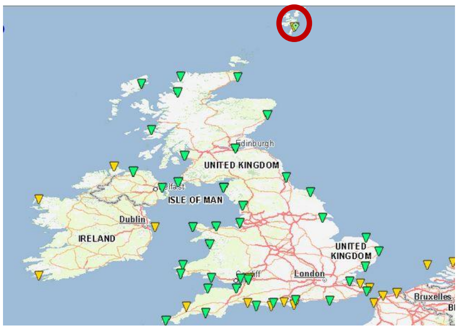


TAL Max Alert: GREEN ALERT (<1.0 m)

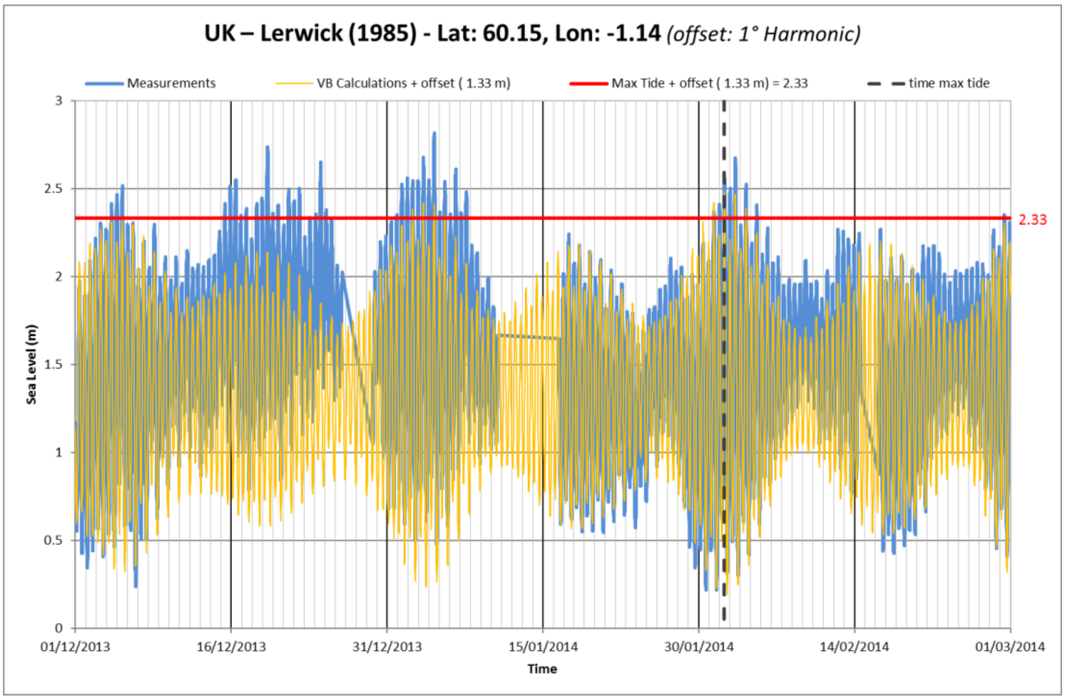
Figure 38 - As in Figure 27, but for UK - Newlyn (CASE 3) over the period Dec 2013 - Feb 2014

CASE 4: UK – Lerwick

- ID: 1985
- Latitude: 60.15; Longitude: -1.14
- Time: 01 Dec 2014 – 28 Feb 2014
- Offset (1° Harmonic): 1.33 m
- Average (Dec 2013, Feb 2014): 1.50 m
- Max tide simulated: 1.00 m
- Max Tide + offset: 2.33 m
- Time Max Tide: 1 Feb 2014 10:58 UTC



DECEMBER 2013 – FEBRUARY 2014: UK – LERWICK (1985)



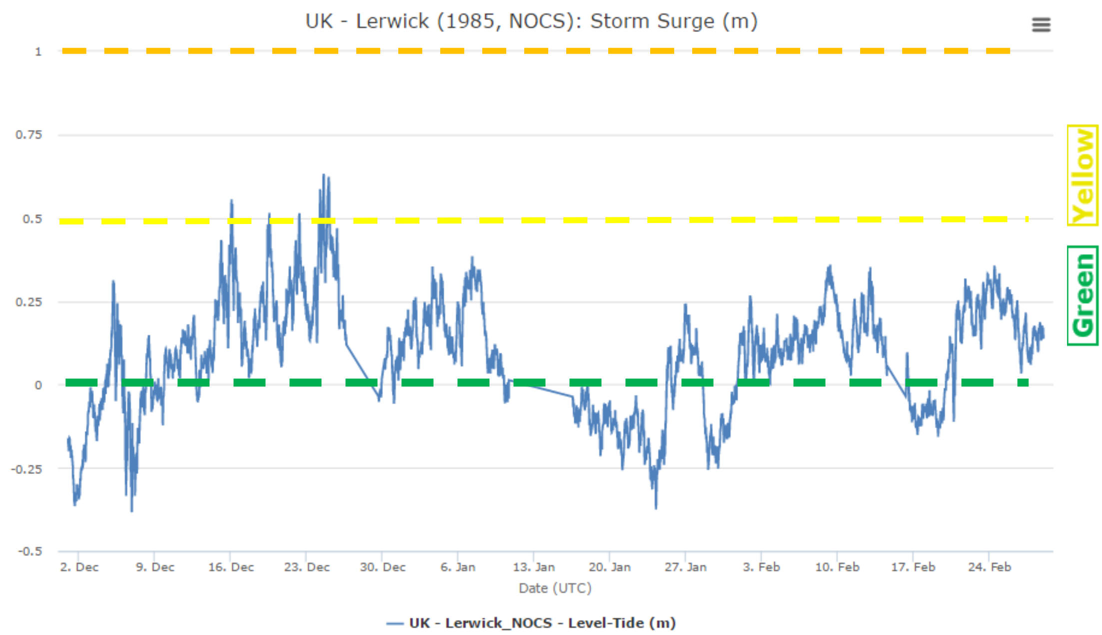
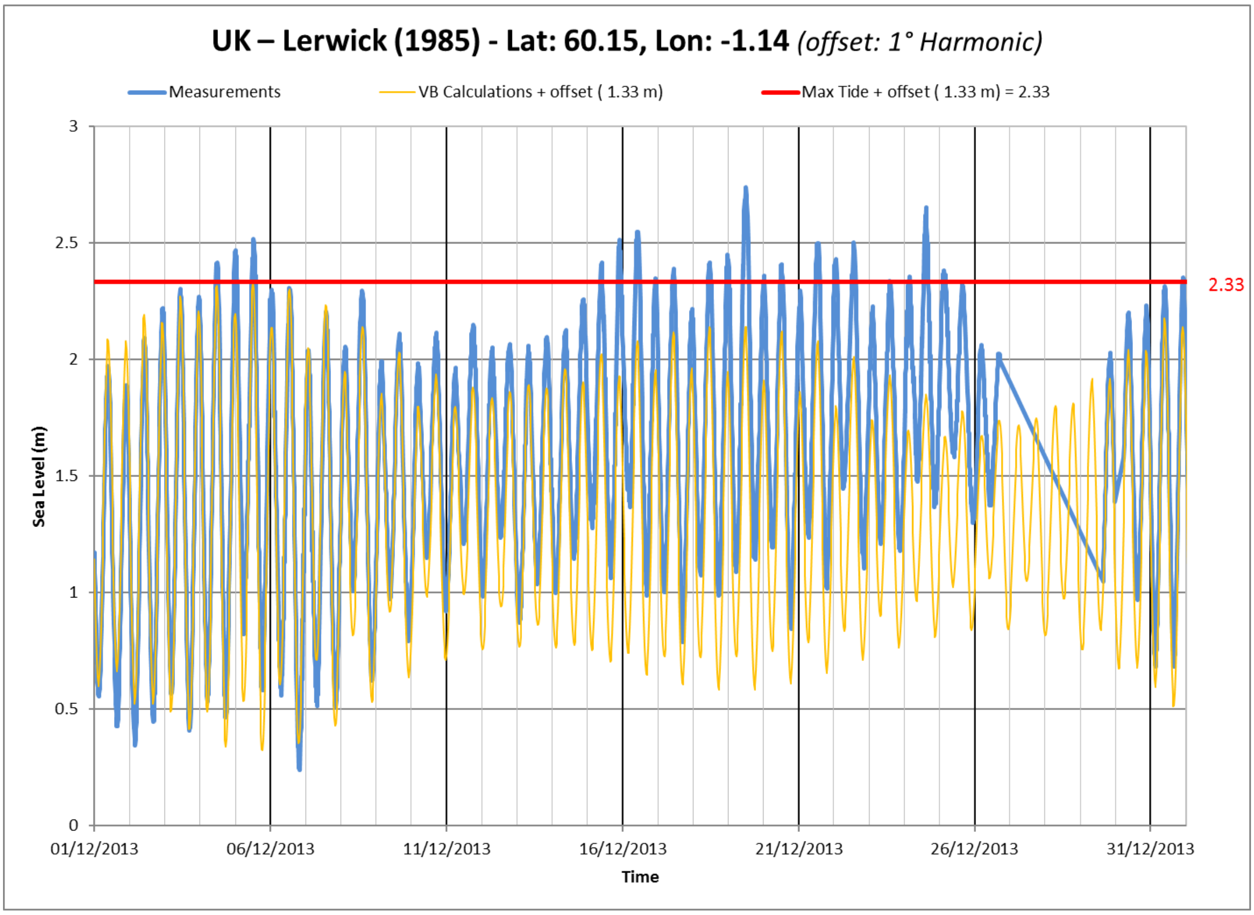


Figure 39 - As in Figure 23, but for UK – Lerwick (1985)

DECEMBER 2013: UK – LERWICK (1985)



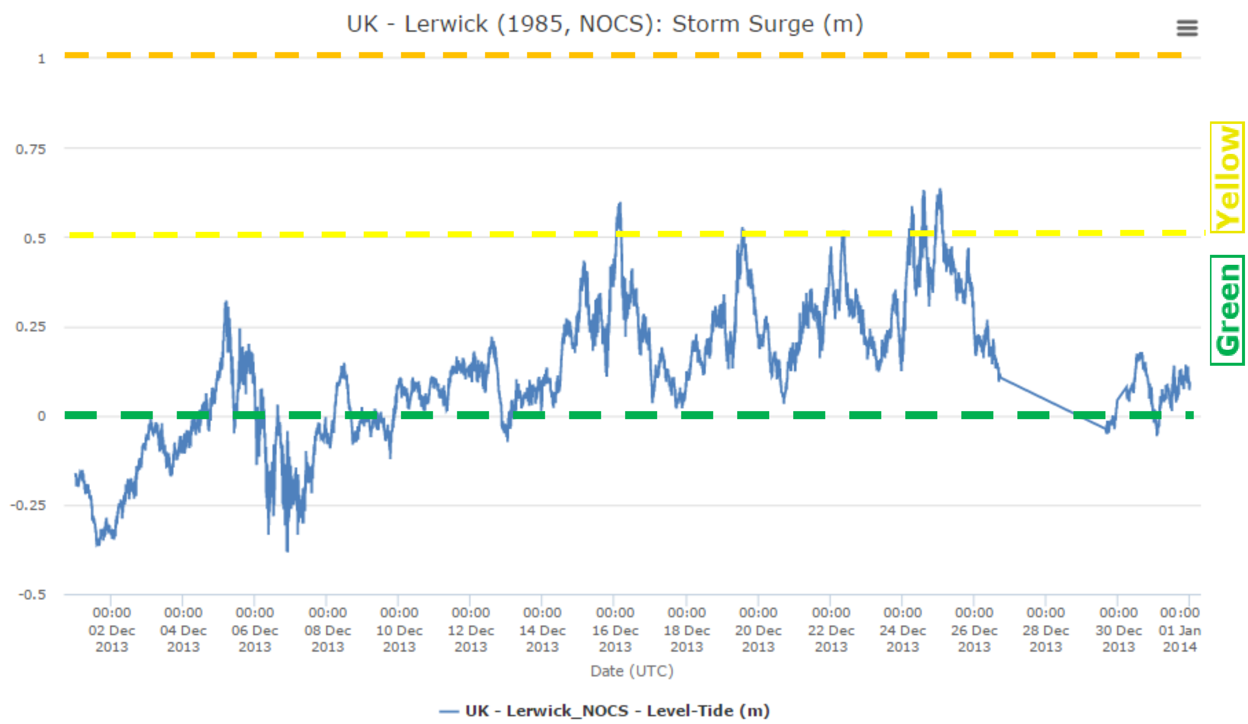
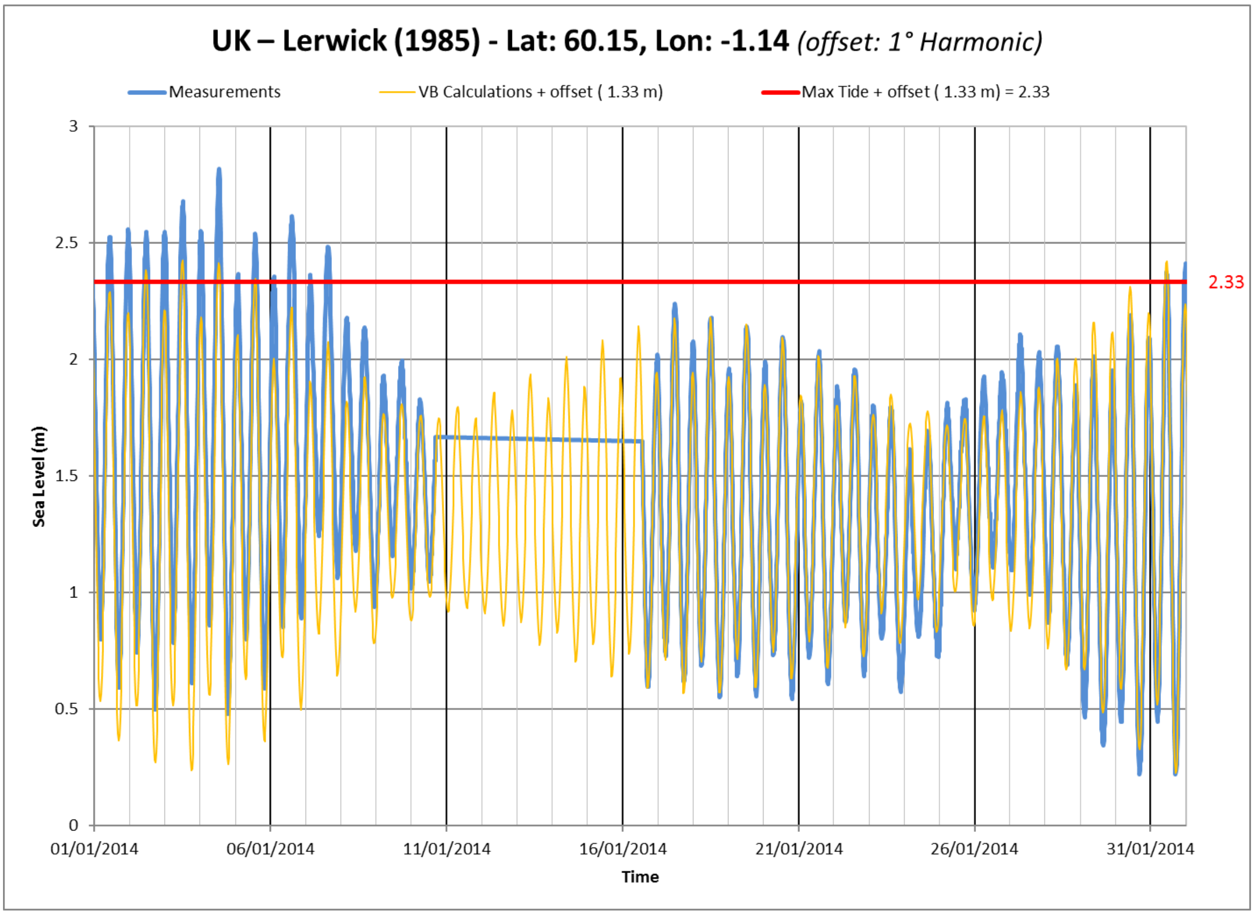


Figure 40 - As in Figure 39, but only for December 2013

JANUARY 2014: UK – LERWICK (1985)



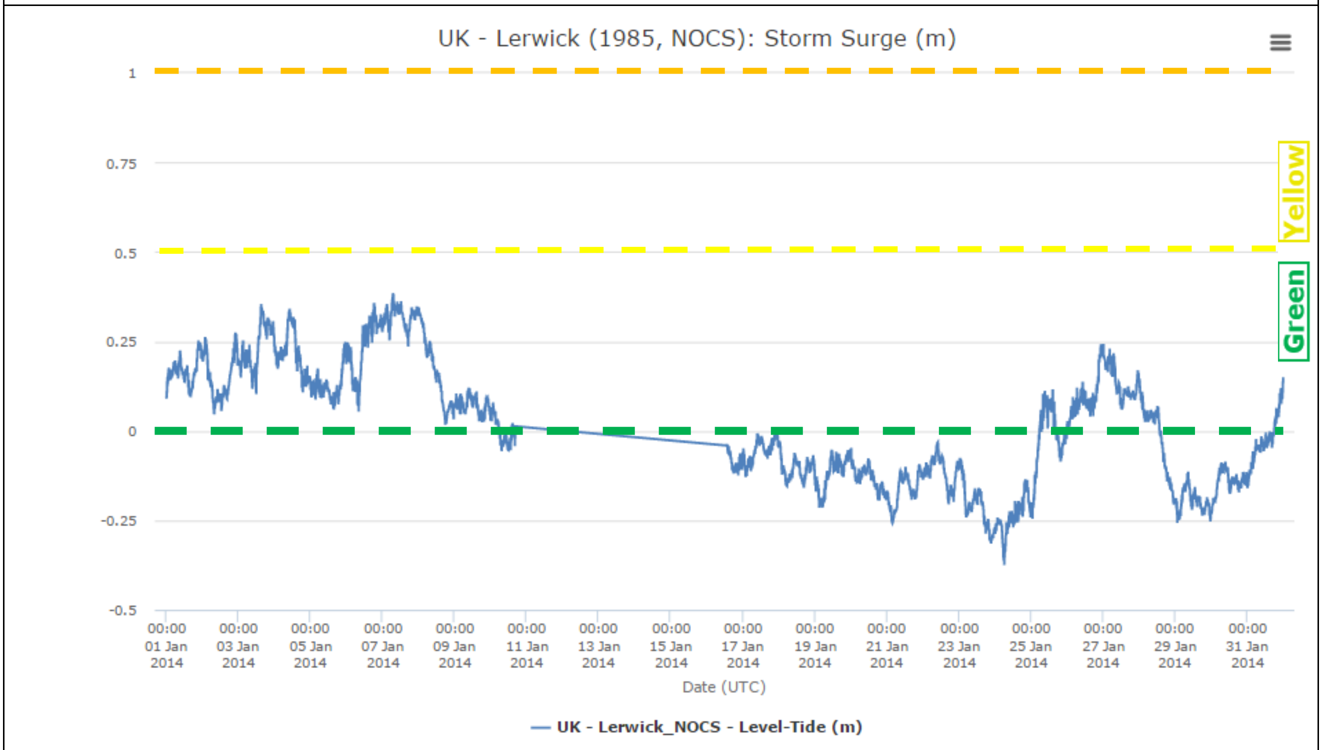
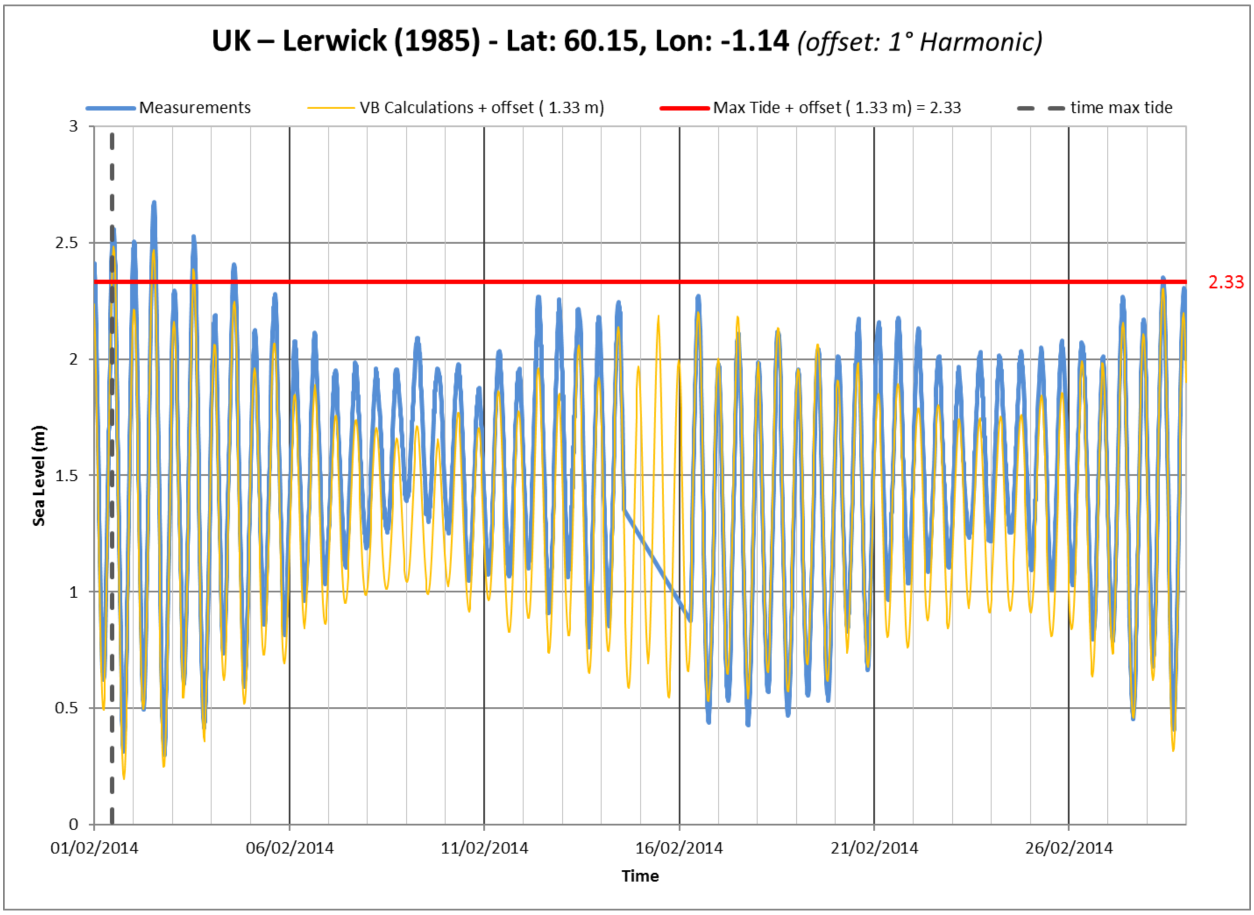


Figure 41 - As in Figure 39, but only for January 2014

FEBRUARY 2014: UK – LERWICK (1985)



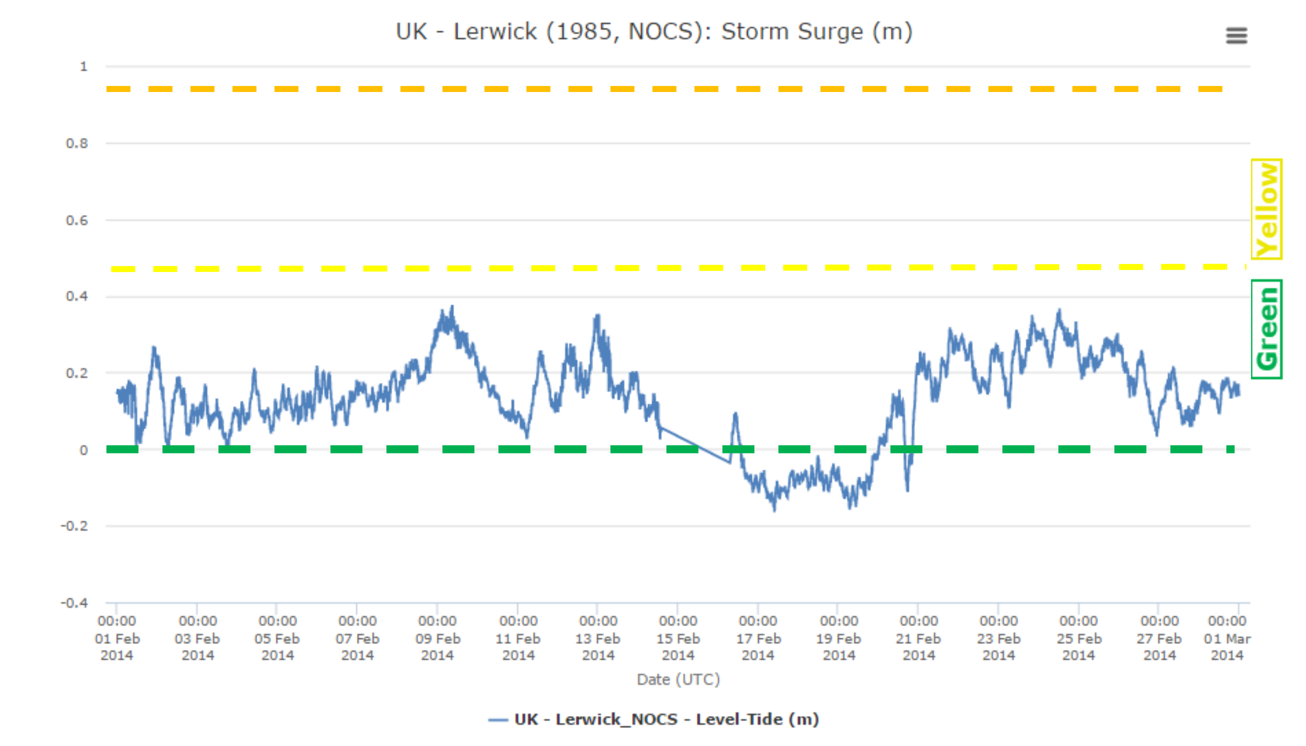
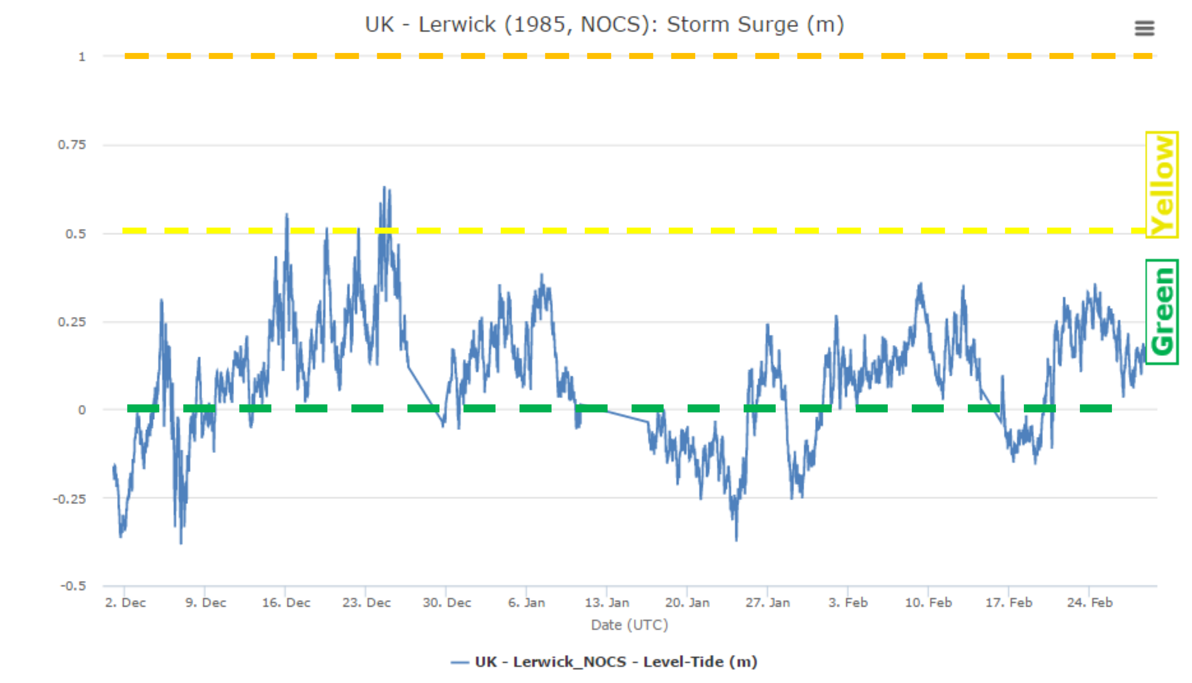
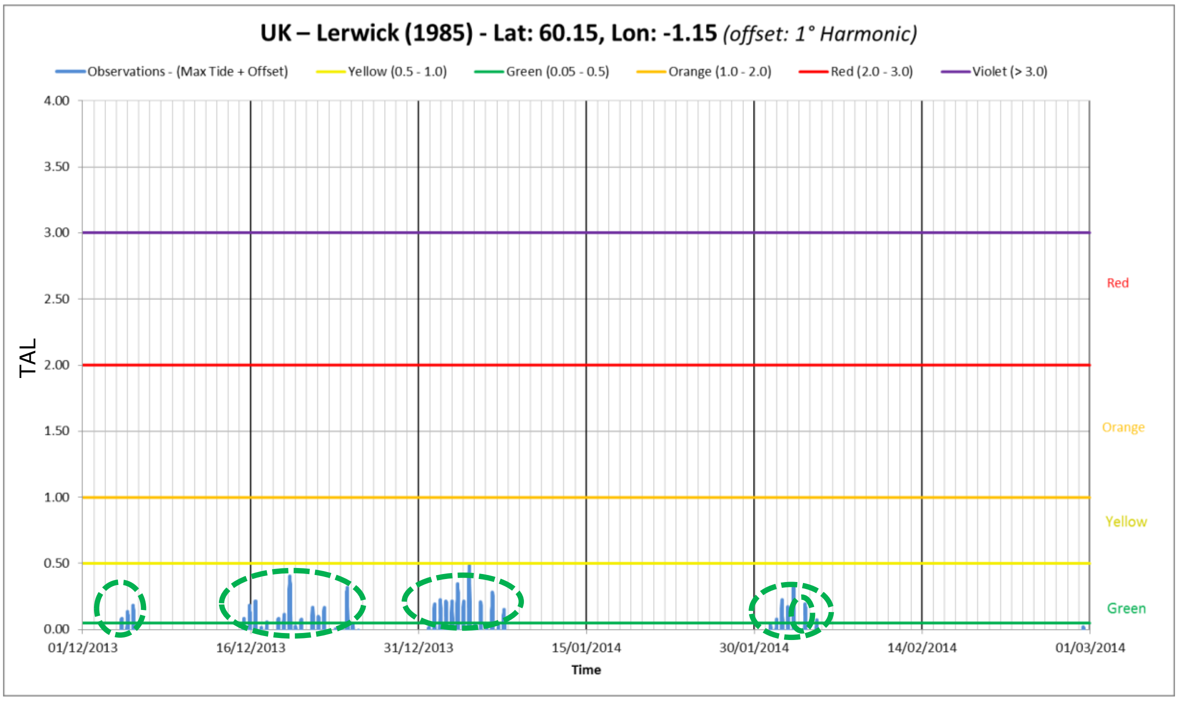


Figure 42 - As in Figure 39, but only for February 2014

ALERT LEVEL: UK – LERWICK (1985)



AL$_{SSCS}$ Max Alert: YELLOW ALERT (0.5 – 1.0 m)



TAL Max Alert: GREEN ALERT (0.05-0.5 m)

Figure 43 - As in Figure 26, but for UK - Lerwick (CASE 4) over the period Dec 2013 - Feb 2014

Considerations:

The analysis and comparisons conducted in this Section show that:

- The storm surge figures (second graph in the Figure 23 -Figure 42) show several storm surge events. Instead, analysing the first graph in the Figure 23 -Figure 42 , the ML (blue line) is higher than the MTD10 (red line) only in a number of cases:
  - CASE 1 Workington: 3-6 Jan 2014, 31 Jan – 5 Feb 2014
  - CASE 2 Lowestoft: 4-6 Dec 2013, 18-19 Dec 2013, 5 Jan 2014
  - CASE 3 Newlyn: 4-5 Feb 2014
  - CASE 4 Lerwick: 4-6 Dec, 18-19 Dec, 23-24 Dec 2013, 3-5 Jan, 31 Jan-5 Feb 2014

The alert colours for the storm surge of the cases analysed (using the colours of Table 6) are shown in Table 9, where the "●" indicates that damage due to storm surge[3] was observed (according to media) in these locations.

- The alert level used in the SSCS (AL_{SSCS}) and the one considering the max. tides (TAL) for the UK analysis are shown in Table 9. Most of the alerts levels are WHITE (< 0.05 m) or GREEN (0.05 – 0.5 m), however there are two YELLOW (0.5 – 1.0 m) alerts for Workington, one in Jan 2014 and one in Feb 2014, and an ORANGE (1.0 – 2.0 m) alert for Lowesoft on 5-6 Dec 2013.
  - The ORANGE alert in Lowesoft (eastern UK) occurred during the passage of the Storm "Xaver" (see Annunziato and Probst, 2016). The maximum TAL value is 1.88m, which is an orange alert (according to Table 6). The storm surge measured using the JRC Sea Level Database (see Figure 29) is 2.10 m, that is an orange alert using the GDACS colour code and Red using the SSCS colour code. The sea level observed and the tide simulated for this case are analysed in detail in Figure 33. Sea level data of the JRC database and tide level calculations (see Section 2.1 and 2.2) are in Figure 33A, while those from NOC are shown in Figure 33B. In both figures, the sea level observed is significantly higher than the normal tide levels. According to media, damage and floods were observed along the south-eastern coast of the UK during the passage of the storm "Xaver".
  - The two YELLOW alerts for Workington in the "TAL" system are consistent with the "ALsscs" systems. Note: In these two cases, the storm surge occurred during a period of high tides.
  - In other cases the alert level is not the same using the "ALsscs" alert system or the "TAL" system. In particular, there are a number of interesting cases observed in Workington, when the storm surge didn't occur during a period of high tide:

    A storm surge of approx. 1-1.2 m was observed on 14 Dec 2013, 24 Dec 2013, 26 Jan 2014 and of approx. 1.7 m on 12 Feb 2014. A storm surge of 1.7 m corresponds to an "ORANGE" alert in the "current" method. Instead, in the "TAL system", the value considering the tide is lower than the maximum of the high tides, which is a "WHITE" alert. For this event, no serious damage caused by storm surge has been reported in the media. In this case the new alert system seems to be more consistent with the damage observed, but this is only a preliminary analysis and the JRC is analysing a longer period and more locations, using the tides values included in the JRC Sea Level Database.

[3] The damages due to strong winds and heavy rains reported in the media are not included in the table

STORM SURGE *Storm surge alerts and damages*				
	Workington	**Lowestoft**	**Newlyn**	**Lerwick**
4 – 6 Dec 2013		Orange ●		Green
18 – 19 Dec 2013		Green		Green
23 – 24 Dec 2013				Green
26 – 27 Dec 2013				
30 – 31 Dec 2013				
3 – 4 Jan 2014	Yellow ●		Green ●	Green
5 – 6 Jan 2014	Green ●	Green		Green
25 – 26 Jan 2014				
31 Jan – 1 Feb 2014	Yellow ●			Green
4 – 5 Feb 2014	Green ●		Green ●	Green
8 – 9 Feb 2014				
12 Feb 2014				
14 – 15 Feb 2014				

Table 9 – Storm surge alerts using the AL colour scheme, see Table 6, and the • indicates that damages due to storm surge were reported in the media in the area near the location analysed.

4 CONCLUSIONS

The Joint Research Centre (JRC) of the European Commission has developed a storm surge system for the Tropical Cyclones included in the Global Disasters Alert and Coordination System (GDACS) and the Storm Surge Calculation System (SSCS) for the storm surge events in Europe. Every day the results of these calculation systems are compared with the measurements included in the JRC Sea Level Database. This databased includes the sea level measurements, theoretical sea levels tides and storm surge for more than 1000 stations around the world and is wildly used storm surge and tsunami activities.

Currently, the alert levels in the JRC storm surge systems are based only on the maximum storm surge heights and don't include the effect of the tides. This effect is very important, because the increase of the water level is extremely damaging when the storm surge coincides with a period of high tide.

In this report, the JRC Sea Level Database and DTU Tide Model have been used to show the importance of the tides and the variation of the alert level, including or not this effect. This is just only a preliminary analysis and only a limited number of global and UK stations over a selected period have been analysed, in particular for the period of the passage of the storm Xaver in December 2013. JRC is analysing a longer period and more locations, using the tides values included in the JRC Sea Level Database.

For each station analysed a specific Alert Level considering the maximum tide (TAL) has been calculated as follow: **TAL = ML – MTD_{10}**
where

- ML = Sea level measurements of the JRC database (total water level)
- MTD_{10} = maximum tide level obtained using DTU_{10} model + offset

This analysis shows that:

- Most of the alerts are WHITE or GREEN, except two YELLOW alerts and one ORANGE alert. The ORANGE alert occurred in Lowestoft (south-eastern UK) during the passage of the storm XAVER in Dec 2013. Damages due to storm surge have been observed (media). The level of this alert is consistent with the damage observed.
- The TAL alert levels are different from the one of GDACS and SSCS in several cases. For example in Workington on 12 February 2014, a storm surge of 1.7 m has been observed (see Figure 26). Considering only the storm surge (SSCS system), it is an ORANGE alert, while considering also the tide level (TAL system) it is a WHITE alert; this is due to the fact that this event occurred during a period of low tide. According to media, no serious damage has been observed. The TAL alert system seems to be more correct in this case, as in other cases (see Section 3.3).

Considering only the storm surge, the system could generate "false" alerts:

- **Alert level too high**: a storm could generate a large storm surge, but if it occurs during a period of low tide, the damage could be limited if the storm surge level is lower than the maximum of the tides at that moment. Therefore the "GDACS and SSCS" alert method could generate a "false alert". Note: in this case the damage due to the storm surge could be limited, but the strong winds and heavy rains generated by the intense storm could cause several damages.
- **Alert level too low**: it is also possible that a "minor" storm surge caused by a weaker storm occurs during the period of maximum tide, exceeding the maximum value of the high tides. This could cause floods and damage along the coastal areas.

Concluding this preliminary analysis shows that in order to have a more realistic storm surge alert system the tides have to be included in the system including directly the tides in the model or adding the tide level to the storm surge calculations.
The next step of this work will be include the tides also in the alert level of the JRC storm surge systems (TCs and SSCS).

Acknowledgements

The authors would like to thank **Daniele Brusa** and **Lorenzo Mancon** for their work in the development of the JRC Sea Level Database.

Authors

Pamela Probst and Alessandro Annunziato

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DTU Tide Model ftp website: ftp://ftp.space.dtu.dk/pub/DTU10/DTU10_TIDEMODEL/

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European Commission, Joint Research Centre (JRC), Tsunami Analysis Tools (TAT) Web System: http://webcritech.jrc.ec.europa.eu/TATWeb/Home/SeaLevelsMap

Global Disasters Alert and Coordination System (GDACS): www.gdacs.org

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- Winter storms, December 2013 to January 2014: http://www.metoffice.gov.uk/climate/uk/interesting/2013-decwind
- Winter storms, January to February 2014: http://www.metoffice.gov.uk/climate/uk/interesting/2014-janwind
- The Recent Storms and Floods in the UK, February 2014: http://www.metoffice.gov.uk/media/pdf/n/i/Recent_Storms_Briefing_Final_07023.pdf
- Winter 2013/14, June 2014: http://www.metoffice.gov.uk/climate/uk/summaries/2014/winter

UK National Tidal and Sea Level Facility (NTSL), National Tide Gauge Network: http://www.ntslf.org/data/uk-network-real-time

List of abbreviations and definitions

DTU	*Danmarks Tekniske Universiet* - Technical University of Denmark
EC	European Commission
ECHO	European Civil Protection and Humanitarian Aid Operations
ERCC	Emergency Response Coordination Centre of DG ECHO
GDACS	Global Disasters Alerts and Coordination System
GLOSS	Global Sea Level Observing System
JRC	Joint Research Centre
ML	Sea level measurements
MTD	Maximum Tide
NOC	UK National Oceanography Centre
NTSLF	National Tidal and Sea Level Facility
SSCS	Storm Surge Calculation System
SS	Storm Surge
TAL	Maximum Tide Alert Level (ML-MTD)
TC	Tropical Cyclone
TD	Tide

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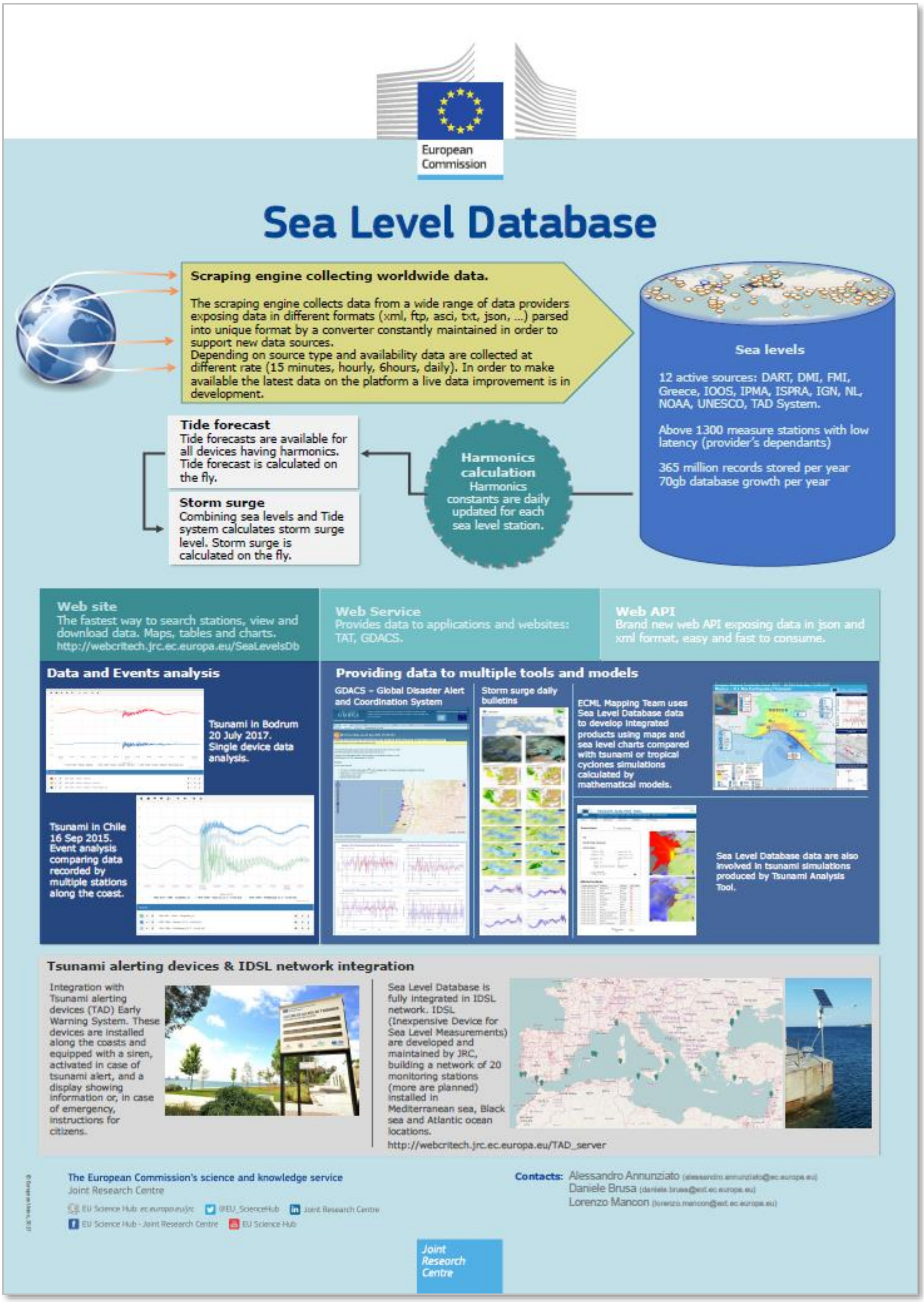
Annex – JRC Sea Level Database



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