Development of an operational flood forecasting model for the Firth of Clyde, Scotland

Firmijn Zijl (Deltares)
Amy Tavendale (SEPA), Daniel Twigt (Deltares)

JONDMOD, May 2010

Development of a flood forecasting model for the Firth of Clyde, Scotland

• Critical in providing flood warnings for at-risk communities on the shores of the Firth of Clyde (more than 50 Flood Warning Locations)

• Model to provide water level forecasts with 36-hour lead time (forecast every 6 hours)

• Provide downstream boundary conditions for fluvial flood forecasting models

• Hydrodynamic model setup for real-time flood forecasting in FEWS Scotland, maintained by Scottish Environment Protection Agency (SEPA)

• Hydrodynamics module of Delft3D framework

Focus of this presentation:

model setup, calibration and validation

ares
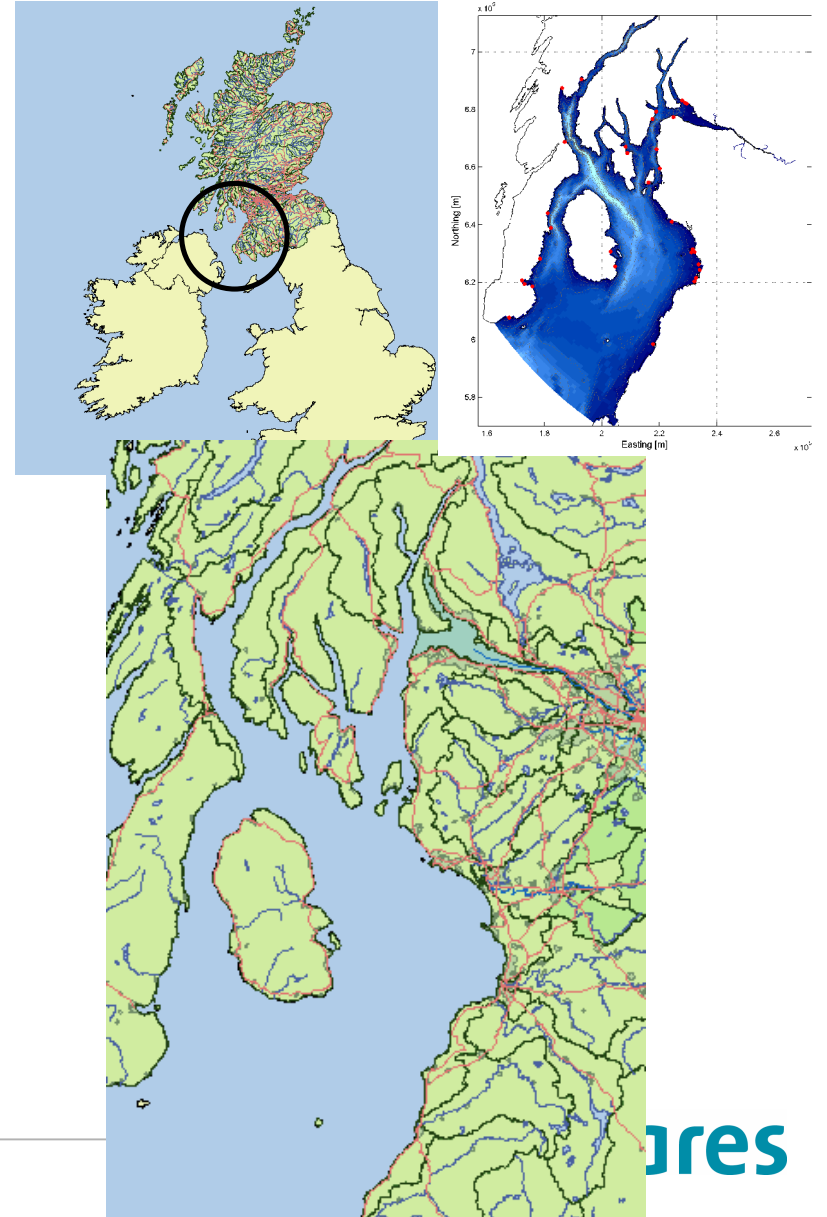
The Firth of Clyde is a water body connected to the North Channel and Clyde Estuary and River (northeast)

• The dynamics of the system are dominated by the tide as well as meteorologically induced surges

• Tide is mainly semi-diurnal with an amplitude of about 1.5 m (spring tide) to 1.0 m (neap tide)

• Under extreme conditions, the surge can reach a height of 1.5 m or more

• Surge is mostly externally generated (i.e., it enters the Firth of Clyde through the North Channel)

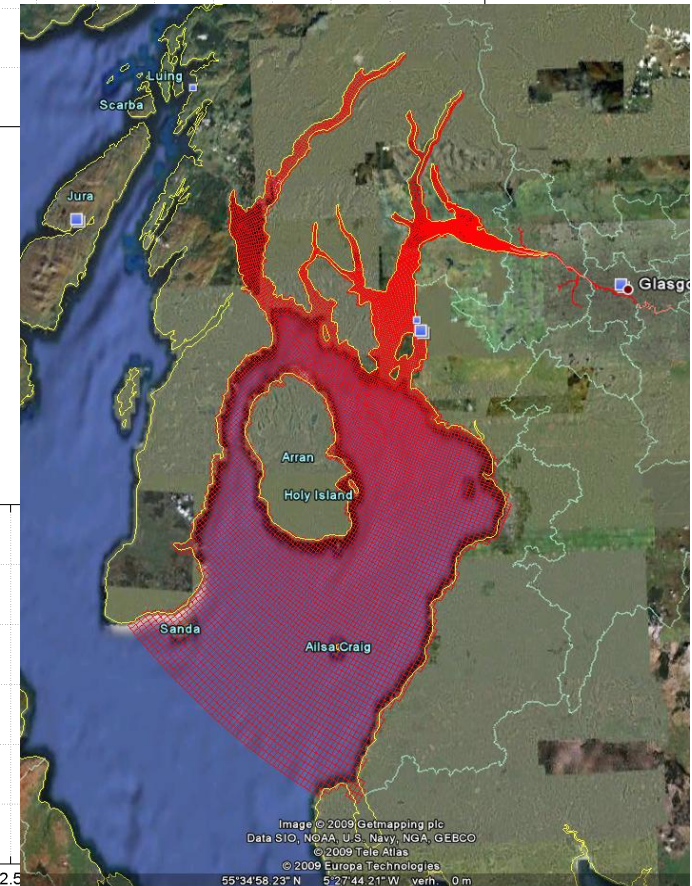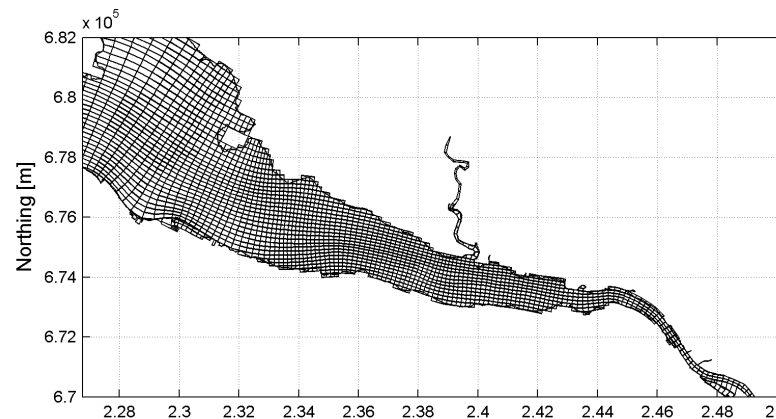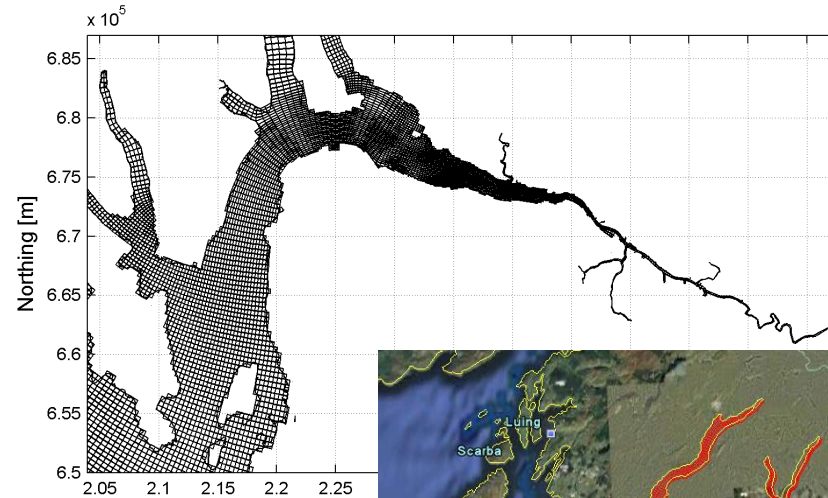• In the Clyde Estuary and River local wind setup can increase the surge by over 0.5 m

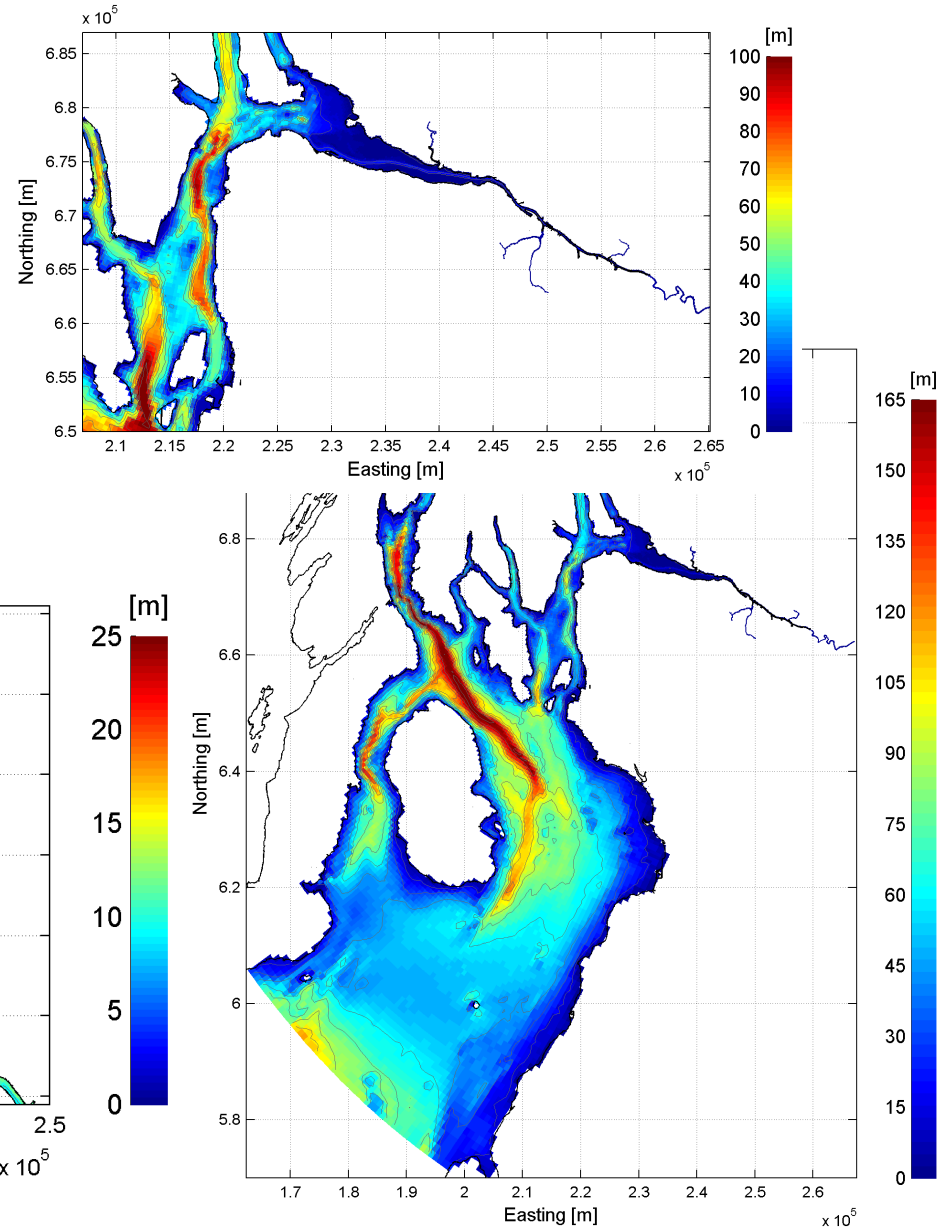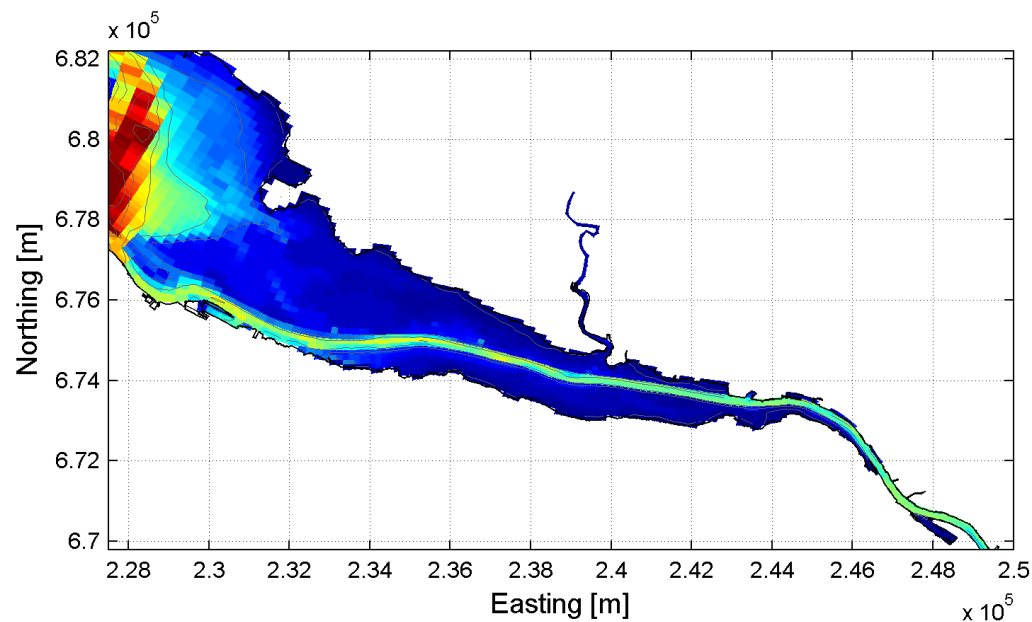# Model setup

Deltares

Model setup - computational grid

• Orthogonal curvilinear grid, aligned with local geometric features (e.g. along the channel through the Port Glasgow mud flats)

• Spatially varying resolution (1 km – 100 m) - saves computational time – cells smaller than 100 m avoided

• Run in 2D, 3D effects are secondary for water level predictions

• Based on a computational time step of 1 minute, a 1 day simulation takes approximately 6 minutes

Model setup – bathymetry

• Compiled from various data sources (Digital Survey Bathymetry from SeaZone, survey, LIDAR, ...)

   •LIDAR data covers inter-tidal flats near Port Glasgow

   •Special focus on channel through inter-tidal flats

Model setup - boundary forcing

• Open boundary with 5 sections defined at southern side of model domain; at each end of a section water levels are prescribed; in between water levels are interpolated linearly

• Distinction made between 2 components of the water level elevation:

    • Tide (variation caused by astronomical phenomena):

       Amplitudes and phases of 50 tidal constituents

    • Surge (meteorological processes):

       Time-varying surge data used:

       •Calibration: 'measured' surge from Campbeltown

       •Operational: CS3 surge predictions

Deltares
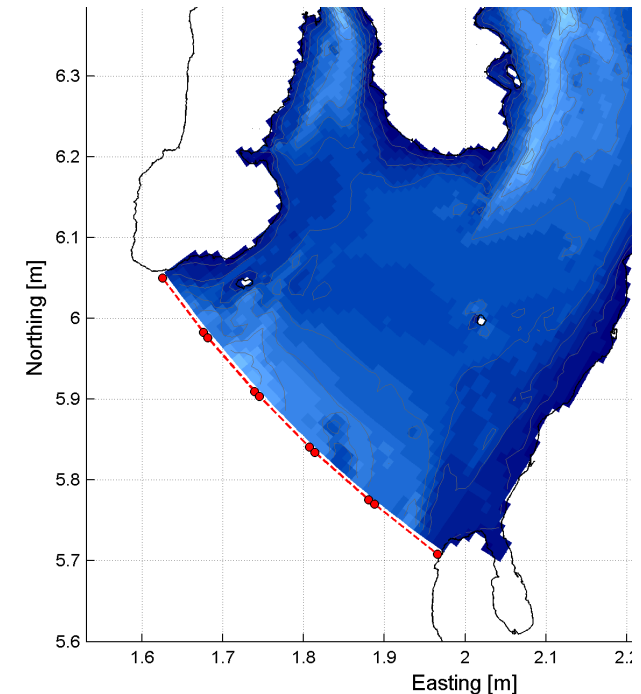
Firth of Clyde model setup (meteo forcing)

Model setup - meteo forcing
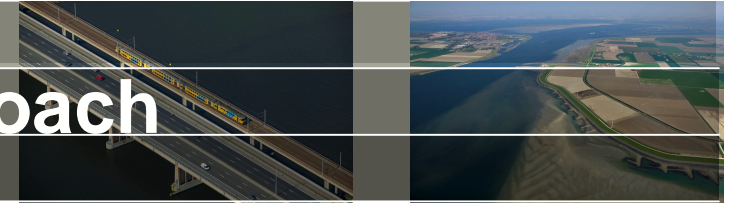
- Meteorological forcing by time-varying, spatially uniform wind speed and direction

    - Calibration: Prestwick meteorological station

    - Operational: Wind from CS3 model forecasts, available through FEWS Scotland

Deltares

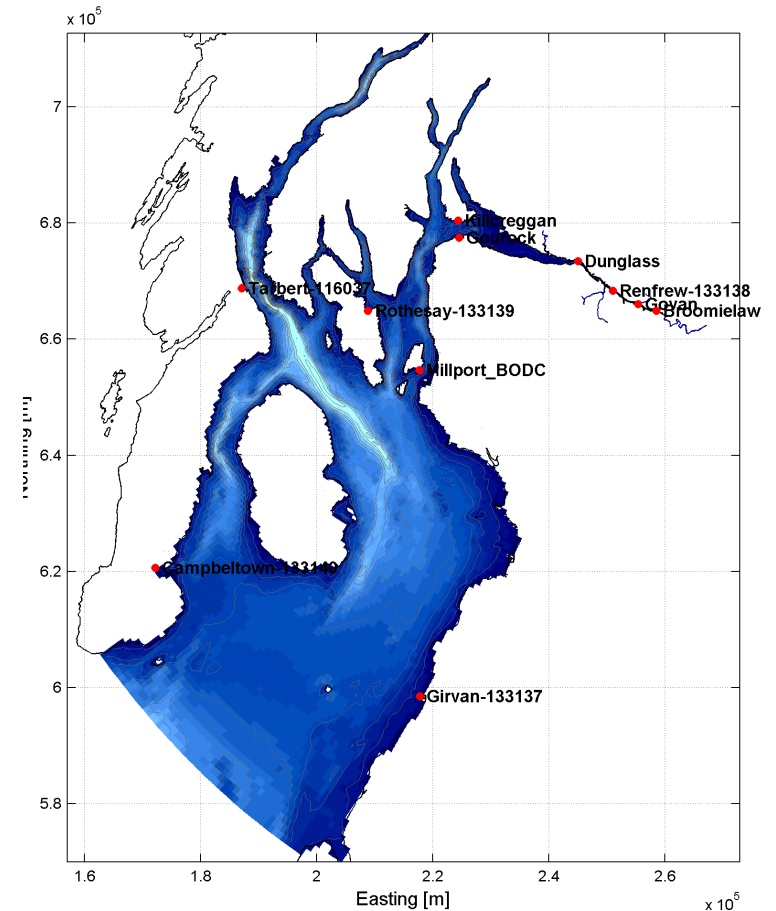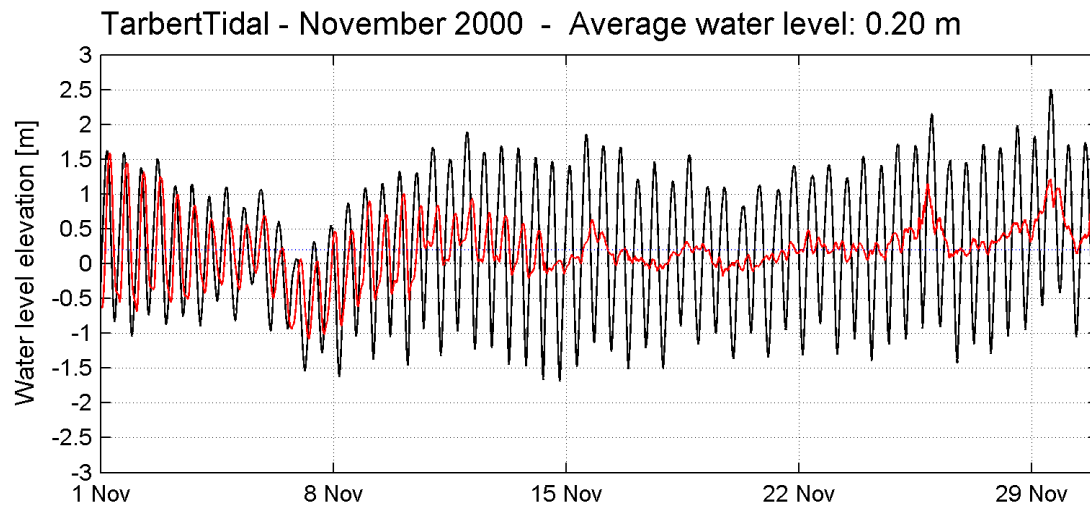**Modeling approach**

Deltares

Modeling stage	Description
Calibration	One year period (2005)
Validation (1)	One year period (2007 – 2008), historical in-situ data for forcing
Validation (2)	One year period (2007 – 2008), operational data for forcing
Validation (3)	Modeling of historical events
Validation (4)	One year period (2007 – 2008), assessment of forecast accuracy (4 runs / day with a 48 hr lead-time)

| Data	Description
Historical in-situ data	Local in-situ wind and storm surge measurements → non real-time and historical only
Operational data	Modeled wind and storm surge (CS3) → real-time and forecast (historical record compiled from forecast data)

Deltares

Calibration and validation using tide gauge data at 11 locations

- Quality checking of data: harmonic analysis → plotting all data → visual inspection of residual → suspicious data removed → procedure repeated

- Available data varies per modeling period

TarbertTidal - November 2000 - Average water level: 0.20 m

Firth of Clyde modelling approach
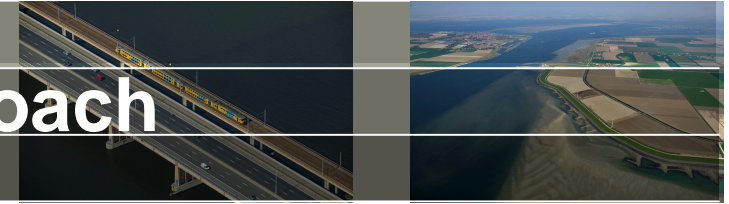
Goodness-of-Fit criteria *frequency domain*

$$GoF_{freq} = RMS_{stations}RSS_{constituents}VD$$

Where   VD is the Vector Difference for each tidal constituent,

         $RSS_{constituents}$ is the Root-Summed-Square over all VD's and

         $RMS_{stations}$ is the Root-Mean-Square of the RSS values for all stations

Goodness-of-Fit criteria *time domain*

$$GoF_{time} = RMS_{stations}RMSE_t$$

Where $RMSE_t$ is the Root-Mean-Square-Error at each station

Goodness-of-Fit criteria time domain – *high water only*

$$GoF_{time} = RMS_{stations}RMSE_{HW}$$

Where $RMSE_{HW}$ is the Root-Mean-Square Error of all high waters (approximately one every 12 hours, ignoring small differences in timing)

Deltares

Model calibration

Deltares

Firth of Clyde model calibration
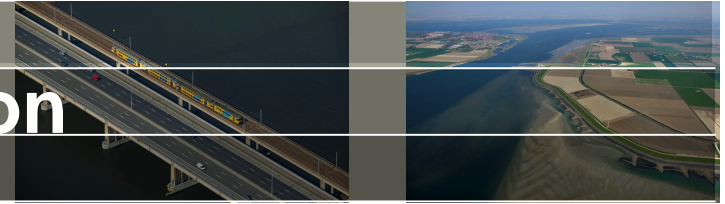
Key model adjustments during calibration
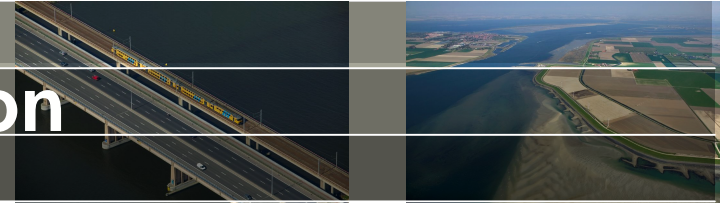
(1) Adjustment of tidal amplitudes and phases at open boundaries

(2) Local adjustments to model bathymetry and bed roughness to optimize tidal propagation in Clyde Estuary and River Clyde (initially too slow)

(3) Adjustment of wind drag coefficient to improve representation of internally generated surge
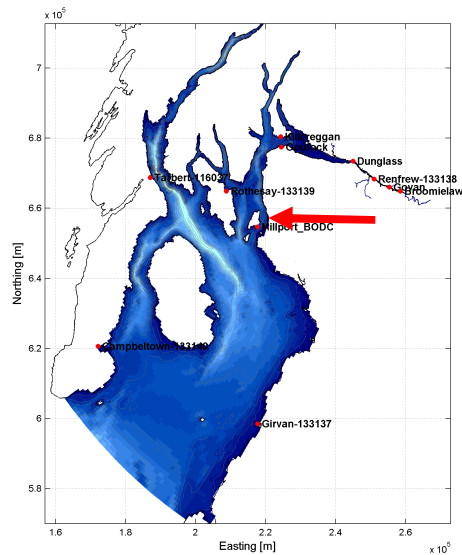
Goodness-of-Fit criteria (in cm) for final calibration results

	GoF_{freq} (cm)	GoF_{time} (cm)	GoF_{HW} (cm)
Firth of Clyde and Clyde Estuary	4.1	6.1	6.0
River Clyde	8.6	15.6	14.0
All stations	6.0	10.3	9.5

- GoF_{freq} is smaller than GoF_{time}

- GoFs in Firth of Clyde and Clyde Estuary are smaller than in River Clyde

Deltares

Firth of Clyde model calibration
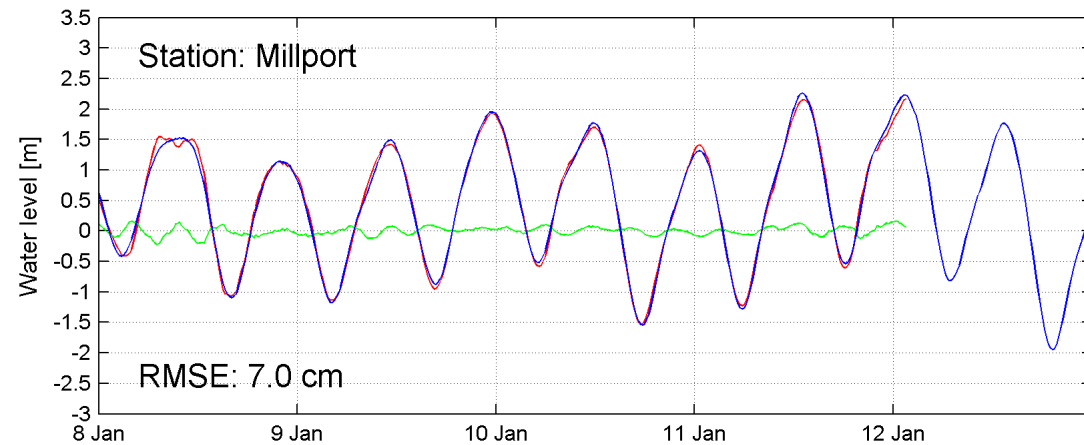
Calibration results in time domain

Without significant surge event

Station: Millport

RMSE: 3.7 cm
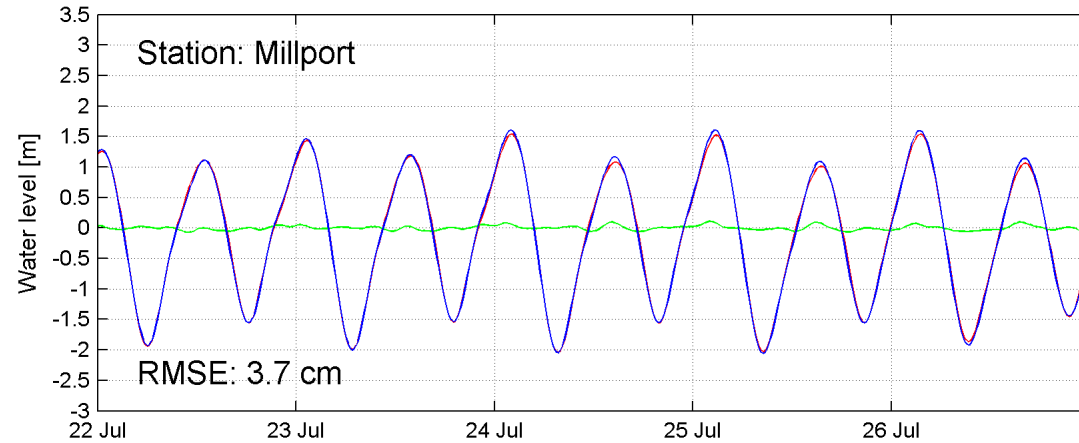
With significant surge event (~1.5 m at Millport)

Station: Millport
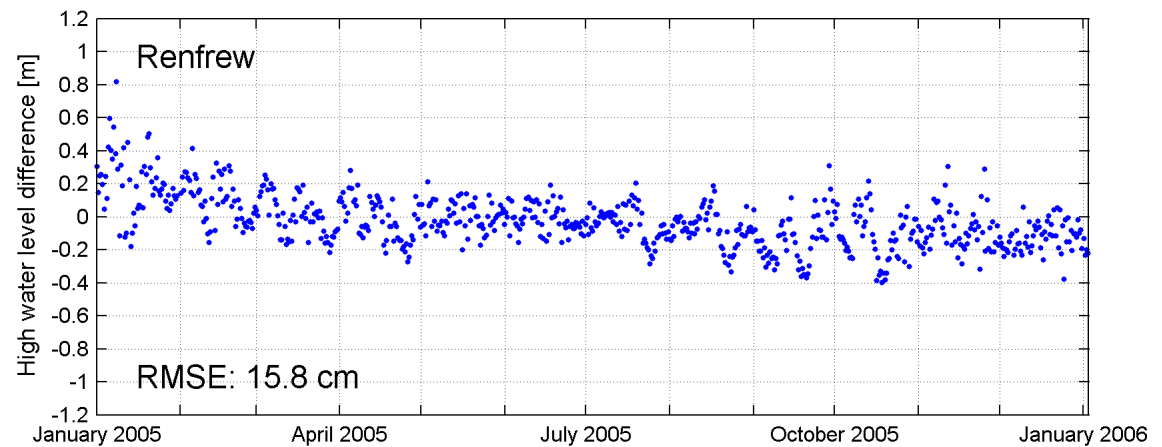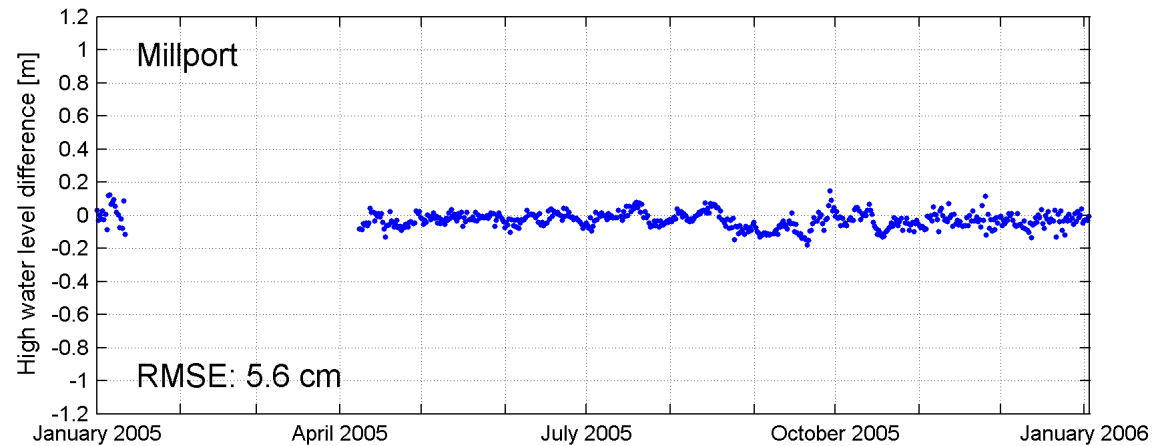
RMSE: 7.0 cm

Red: Measurement

Blue: Computation

Green: Residual
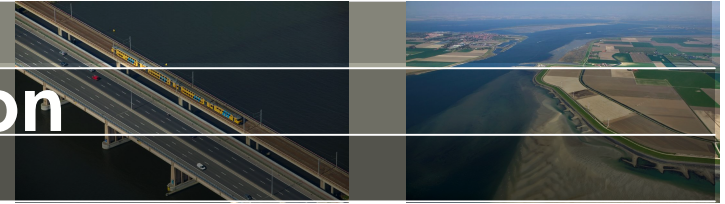
Calibration results in time domain (high waters only)
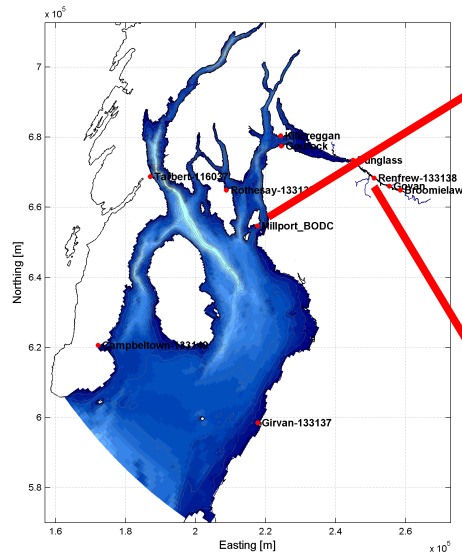
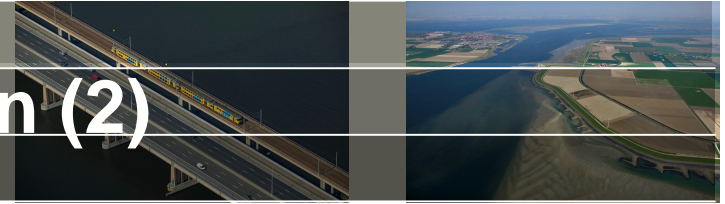Errors in high waters do not exceed 20 cm in Firth of Clyde and Clyde Estuary

Deltares

Model validation (1) & (2)

Deltares

Operational data vs. Historical data

Goodness-of-Fit criteria (in cm) for validation results

	GoF_{freq}		GoF_{time}		GoF_{HW}	
Firth of Clyde and Clyde Estuary	4.4	4.0	8.9	4.5	9.2	4.6
River Clyde	9.2	8.3	20.1	13.7	18.5	11.9
All stations	6.4	5.8	13.7	8.8	13.0	7.8

- Similar (or even better) GoF for historical validation compared to calibration

- Quality of tidal representation hardly affected (as expected)

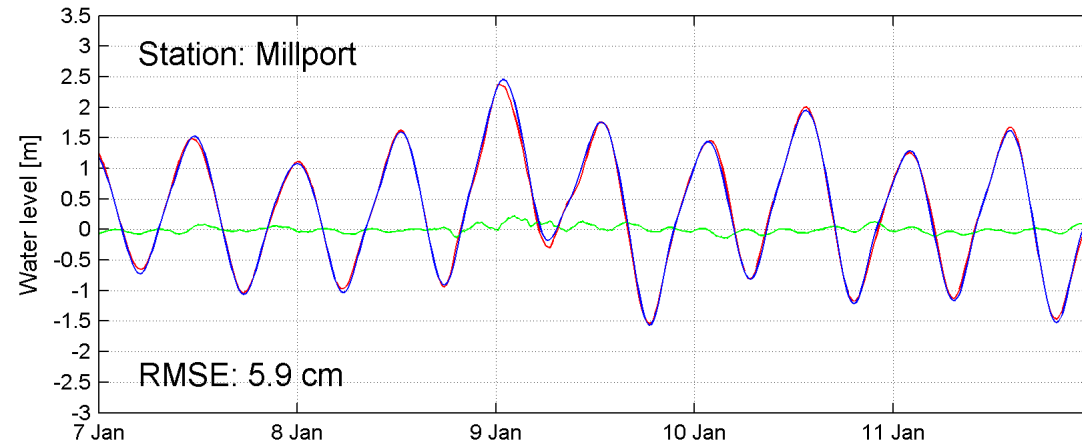- GoF_{time} and GoF_{HW} double, due to external factors

Deltares
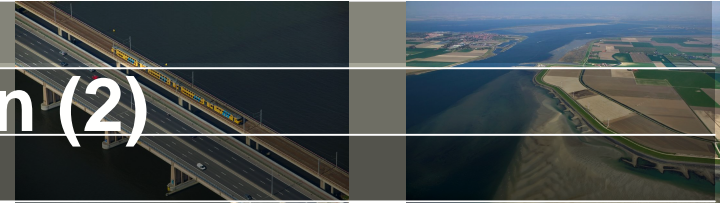
Validation results in
time domain
(operational data)
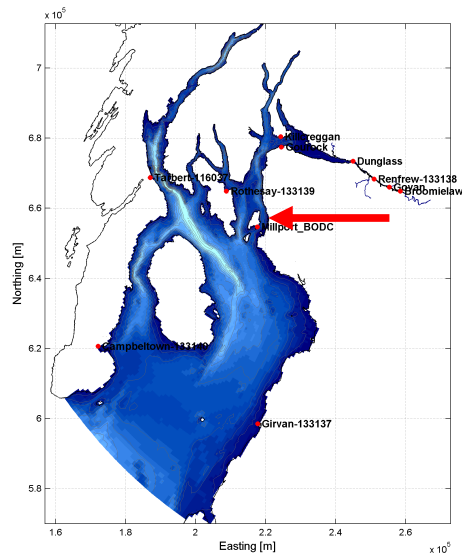
Surge ~1.3 m at Millport

In-situ data

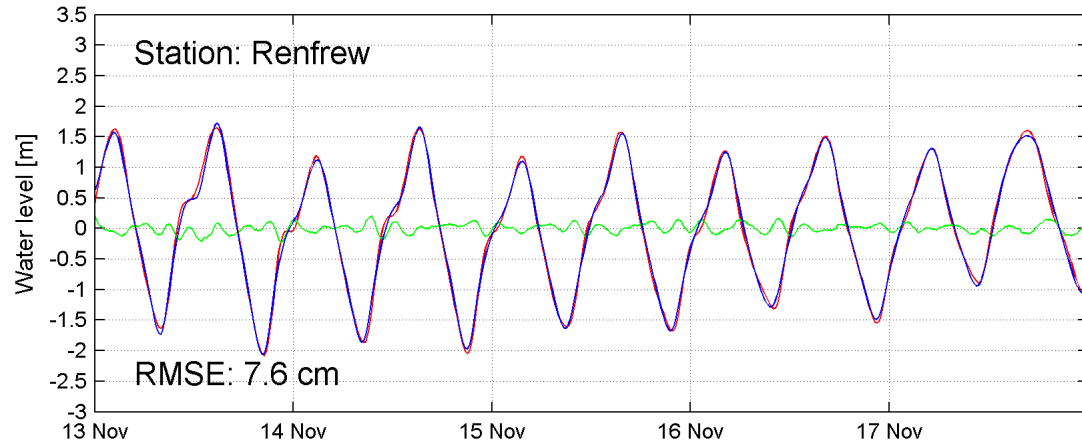### Operational data
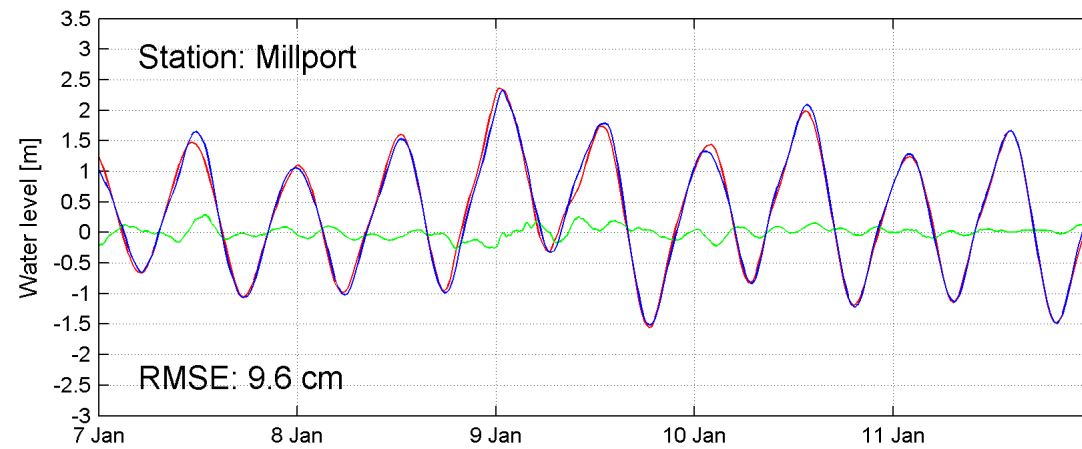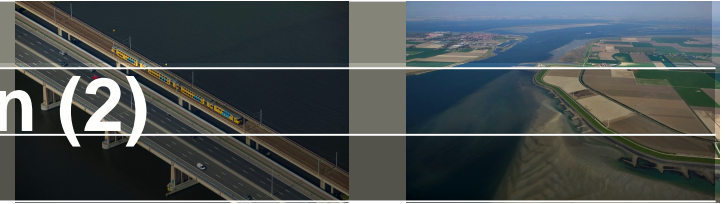
Validation results in time domain (operational data)
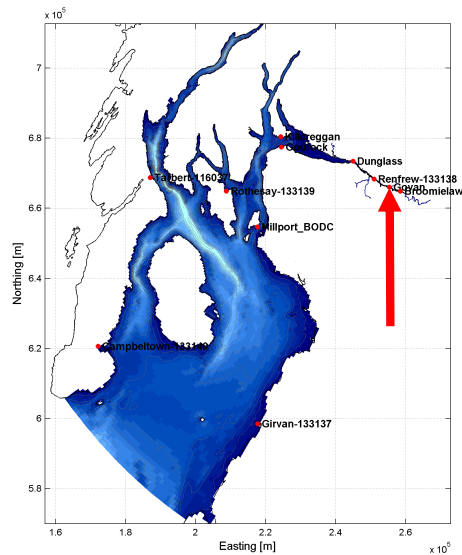
No significant surge

In-situ data

Station: Renfrew

RMSE: 7.6 cm
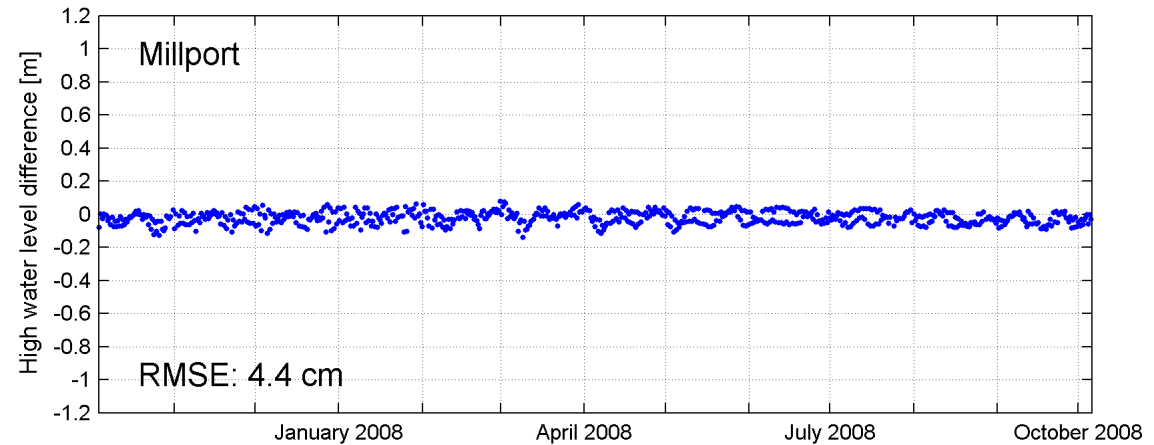
Operational data

Station: Renfrew

RMSE: 11.9 cm
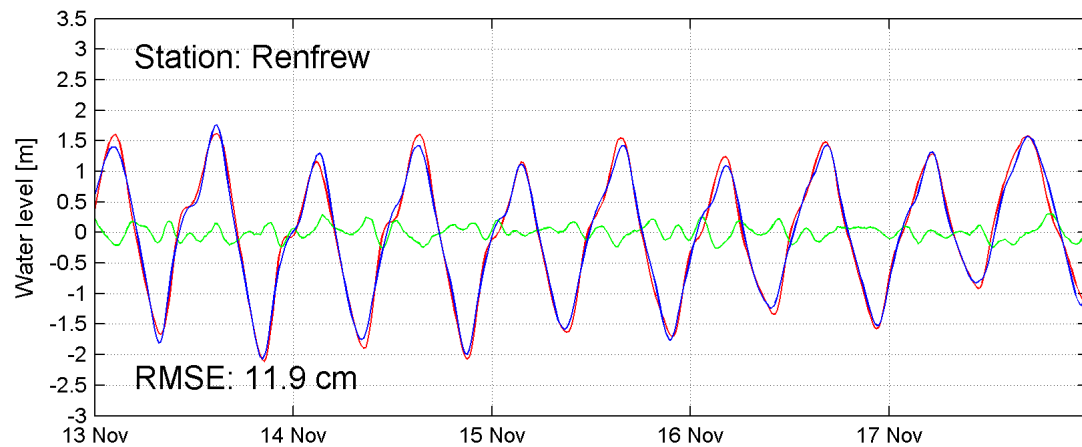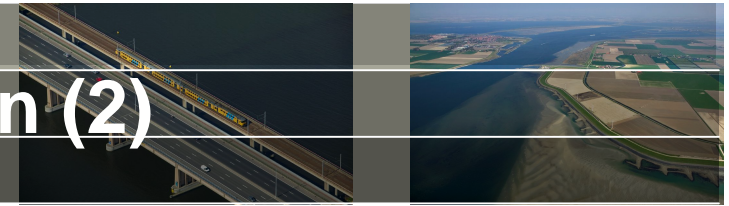
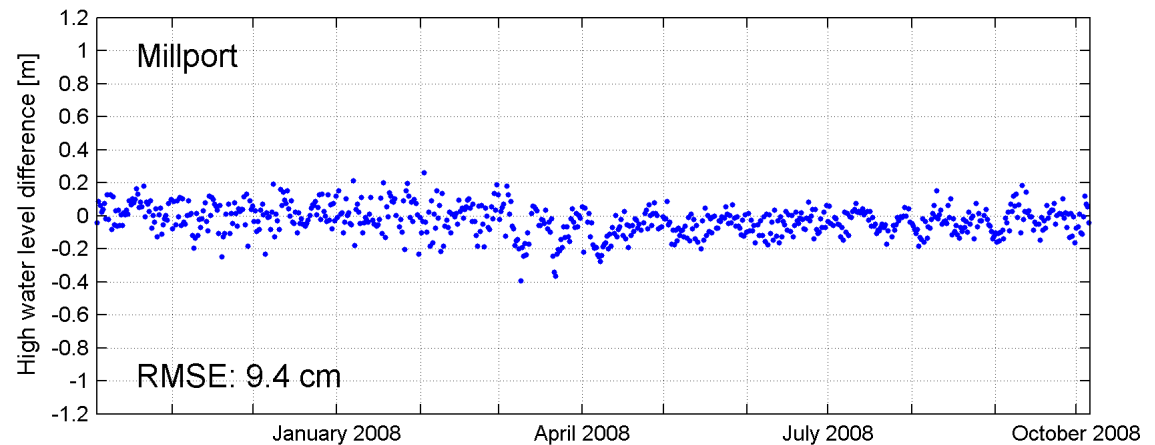**Validation results in time domain (operational data, high waters only)**
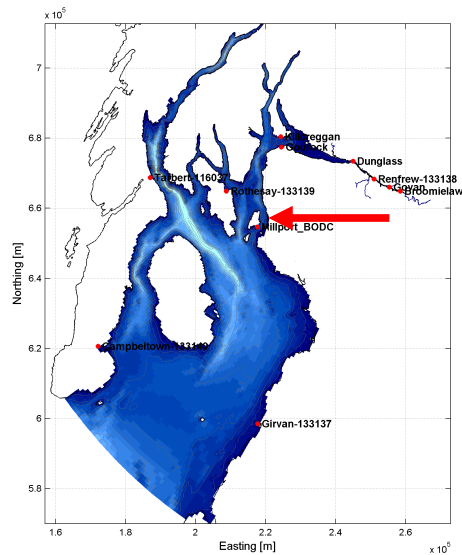
Underpredictions of high waters do not exceed 30 cm in Firth of Clyde and Clyde Estuary

In-situ data

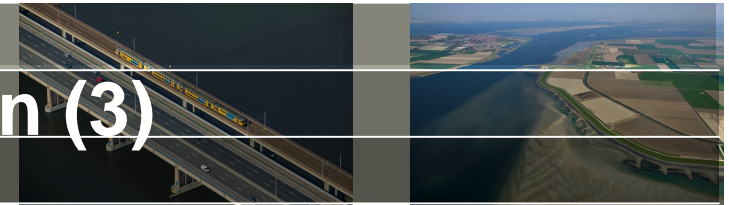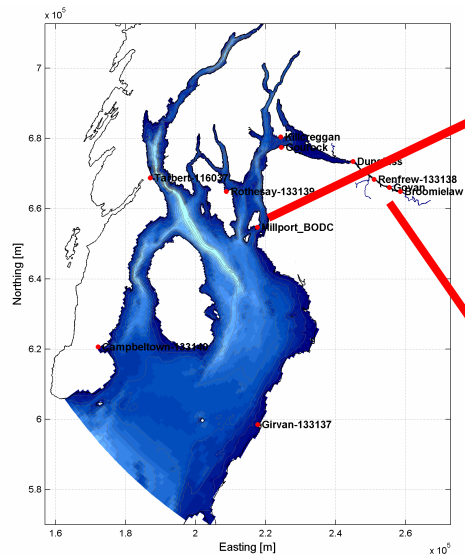### Operational data

Deltares

Model validation (3): historical surges

Deltares

Validation results for major historical surge events

December 1998

Surge at Millport 1.9 m;

Maximum surge coincides with low tide

Deltares
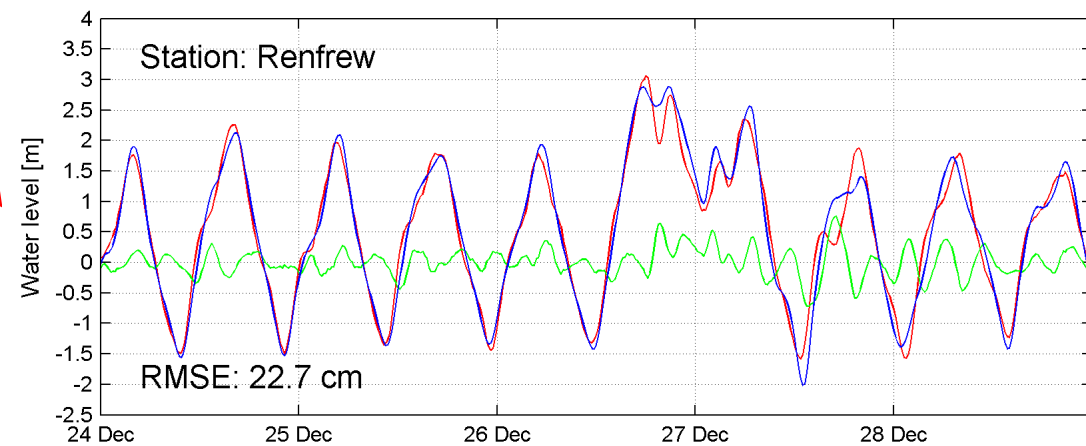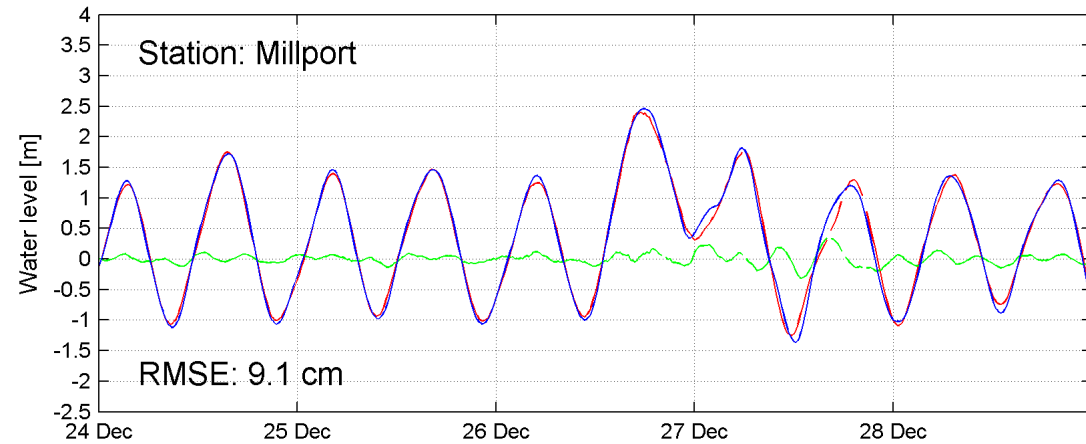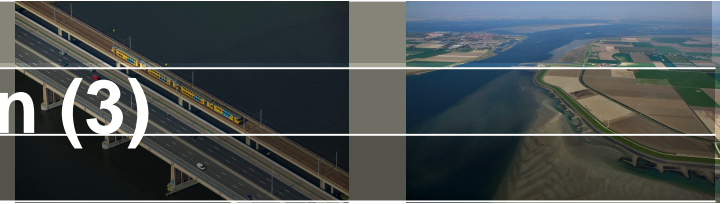
Validation results for major historical surge events (1)

Date	Source of surge forcing	Station	Max. measured surge (m)	Max. measured water level (m)	Max. simulated water level (m)	Difference (m)
Jan 17, 1995	Portpatrick	Millport	1.48	2.53	2.30	**-0.23**
Dec 26, 1998	Millport	Millport	1.86	2.40	2.46	**0.06**
		Tarbert	1.87	2.47	2.44	**-0.03**
		Renfrew	3.04	3.06	2.88	**-0.18**
Jan 4, 1999	Portpatrick	Millport	1.12	2.59	2.60	**0.01**
		Tarbert	1.20	2.58	2.53	**-0.05**
		Renfrew	1.81	3.52	3.60	**0.08**
Dec 23-25, 1999	Campbelt.	Campbelt.	0.90	2.20	2.04	**-0.15**
		Tarbert	1.20	2.44	2.31	**-0.13**
		Rothesay	1.14	2.59	2.36	**-0.23**
		Millport	1.07	2.49	2.31	**-0.19**
		Renfrew	2.15	3.76	3.16	**-0.60**

Deltares
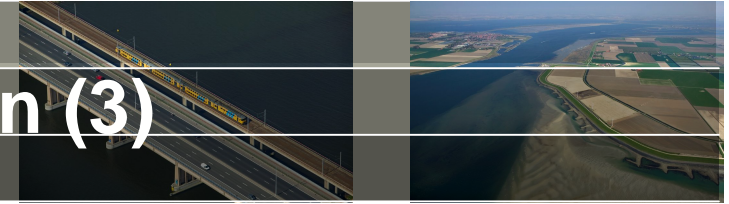
Validation results for major historical surge events (2)

Date	Source of surge forcing	Station	Max. measured surge (m)	Max. measured water level (m)	Max. simulated water level (m)	Difference (m)
Jan 28, 2002	Campbelt.	Campbelt.	1.06	2.26	2.20	**-0.06**
		Tarbert	1.14	2.57	2.41	**-0.16**
		Rothesay	1.19	2.59	2.45	**-0.14**
		Millport	1.09	2.51	2.43	**-0.08**
		Renfrew	1.76	3.35	2.96	**-0.39**
Feb 1, 2002	Campbelt.	Campbelt.	1.32	2.65	2.57	**-0.08**
		Tarbert	1.35	2.76	2.78	**0.01**
		Rothesay	1.41	2.80	2.81	**0.01**
		Millport	1.27	2.72	2.77	**0.05**
		Renfrew	1.59	3.42	3.21	**-0.21**
Dec 31, 2006	Portpatrick	Rothesay	1.66	2.58	2.25	**-0.33**
		Millport	1.66	2.49	2.25	**-0.24**
		Renfrew	2.54	3.58	3.16	**-0.42**

Errors are generally below 20 cm in Firth of Clyde and Clyde Estuary

Deltares

Model validation (4): forecast accuracy

Deltares
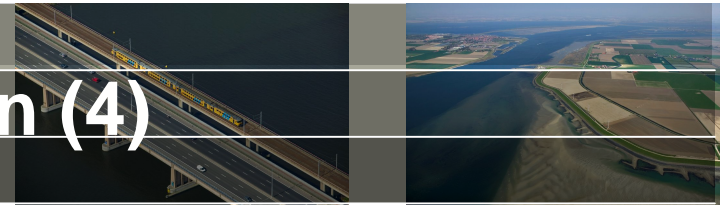
Forecast accuracy for various lead times
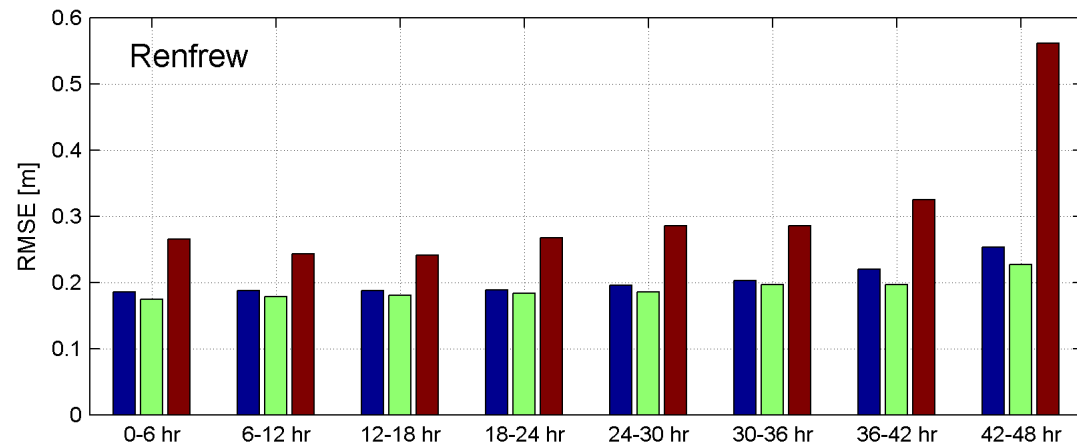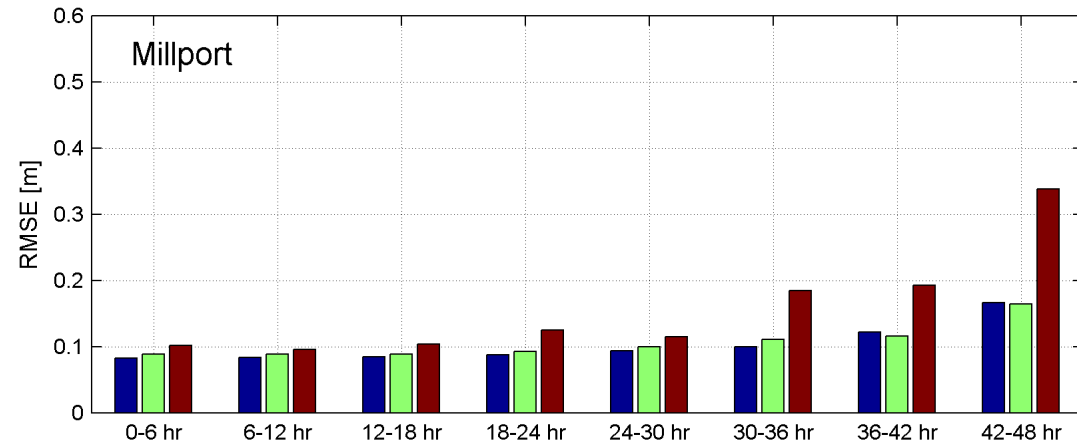
(based on collection of ~1500 historical runs in operational setting)
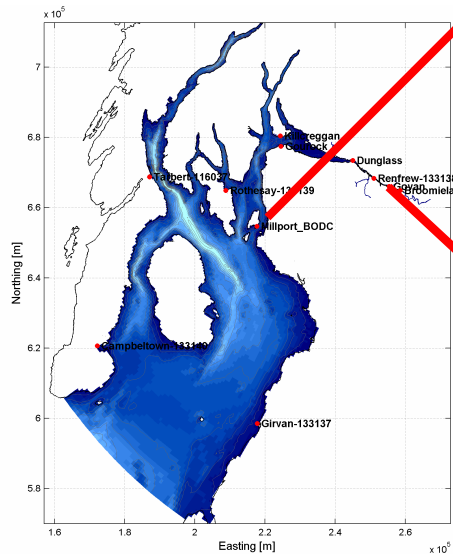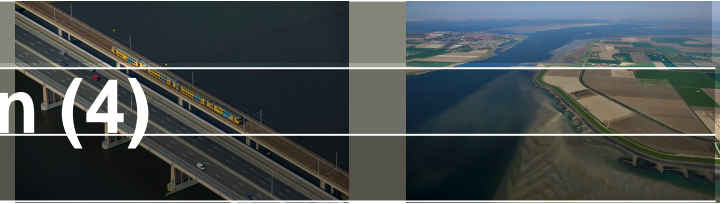

Blue: $RMSE_t$

Green: $RMSE_{HW}$

Red: $RMSE_{HW > 97\%}$

- Forecast accuracy (0-6 hr) compares well with accuracy of hindcast with operational data

- Hardly decrease of accuracy up to lead-time of 30 hr

Deltares

Skill Scores

Based on number of observed and predicted threshold crossings

False Alarm Rate $\qquad FAR = \dfrac{b}{a+b}$
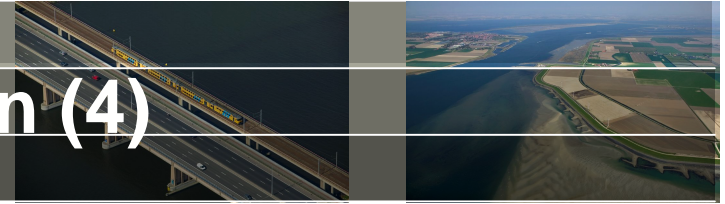
Probability of Detection $\quad POD = \dfrac{a}{a+c}$

Critical Success Index $\quad CSI = \dfrac{a}{a+b+c}$

		Threshold Observed	
Threshold Forecast		Yes	No
Yes		**a**	**b**
No		**c**	**d**

Deltares

Forecast accuracy as Skill Scores (as a function of lead-time)

Conclusions

Deltares

Overall conclusions

• The tidal representation of the model is accurate, with average GoF values of 4 cm (Firth of Clyde and Clyde Estuary) to 6 cm (all stations together).

• The representation of the full water level signal (i.e. tide and surge) is accurate, with GoF values of about 5 cm for the Firth of Clyde and the Clyde Estuary and 10 cm for all stations together. Looking at high waters only, similar values are found.

• The model performs well under a large range of extreme surge events, with errors in maximum water level generally below 20 cm. In the River Clyde values can be higher.

• Using predicted CS3 surge boundary forcing increases the model errors. The source of these additional errors is external and cannot be resolved in the model.

•A hindcast validation using operational data gives a good estimate of the forecast accuracy for a 0-6 hr lead-time.

• Up to a lead-time of about 24-30 hr, the forecast accuracy remains stable.

Deltares

Firth of Clyde model development

Thank you!

Deltares