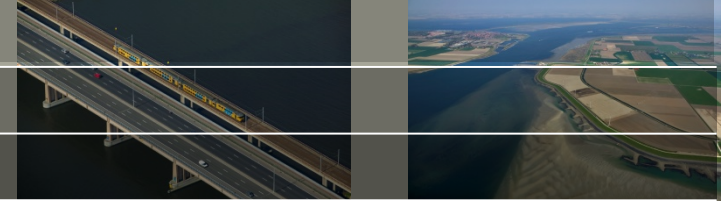




Development of a global tide and surge model

2nd JCOMM Scientific and Technical Symposium on Storm Surges,
8-13 Nov. 2015, Key West, USA; Martin.verlaan@deltares.nl

Outline



- Introduction
- Development of GTSM version 1
- Reanalysis of extreme sea levels
- GLOSSIS operational forecasting
- Tropical cyclones
- Model improvements – towards GTSM version 2

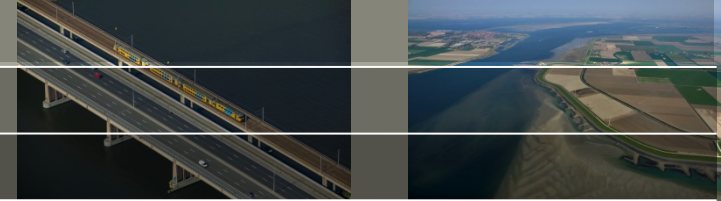
An aerial photograph of a coastal region. In the foreground, a large body of water (likely a bay or estuary) is visible, with a dike or levee system separating it from the land. The land is divided into various agricultural plots, some green and some brown. In the background, a town or village is visible, surrounded by more fields and a larger body of water. The sky is clear and blue.

Introduction & Development of GTSM v1.0

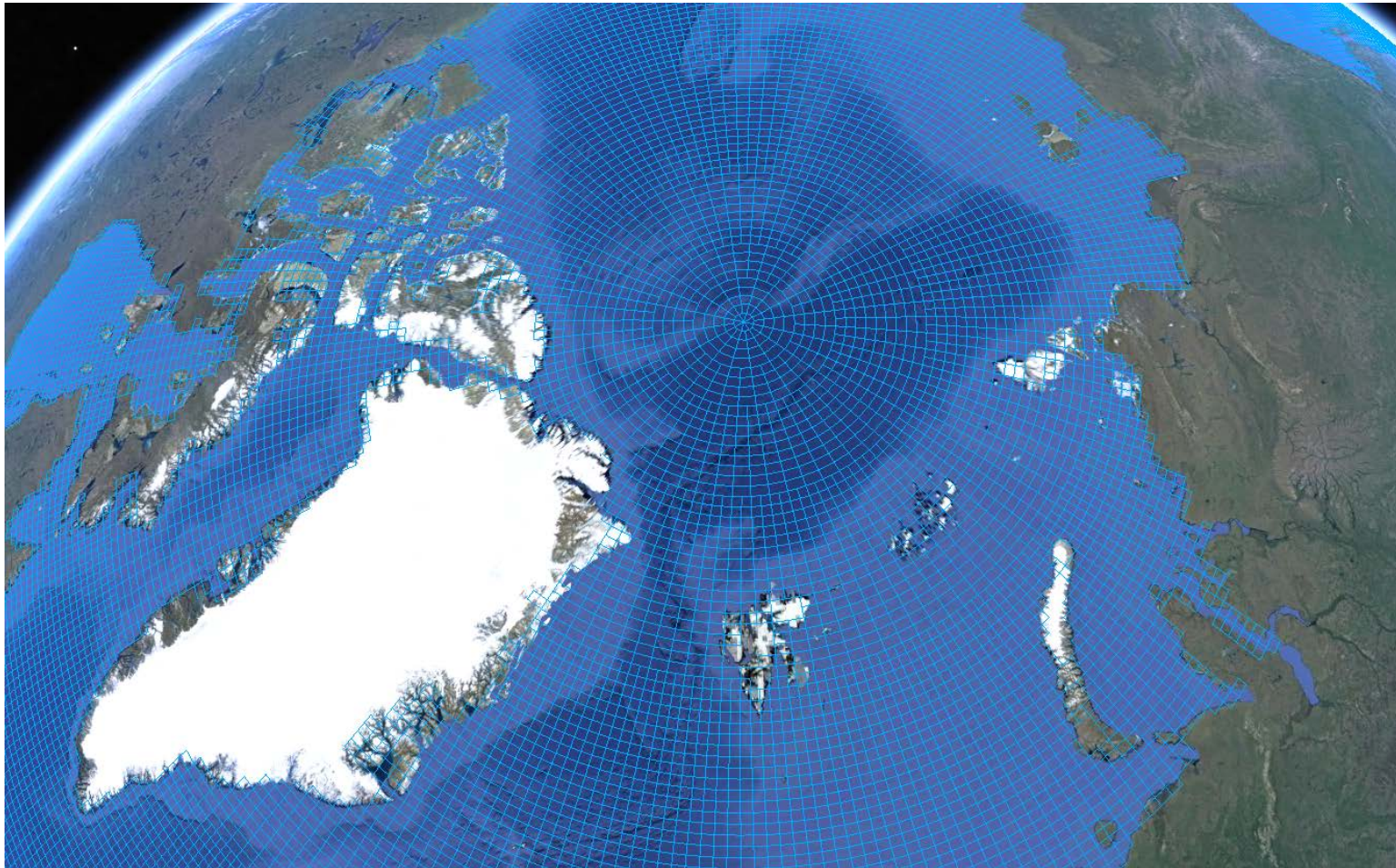
for:

Computing water levels dynamically (surge, tide etc. combined)
during any significant events but also to for statistic analysis
Study the effect of MSL on tide and water level globally

Grid in Dflow-FM



Unstructured approach - step 1: grid thinning at high latitudes



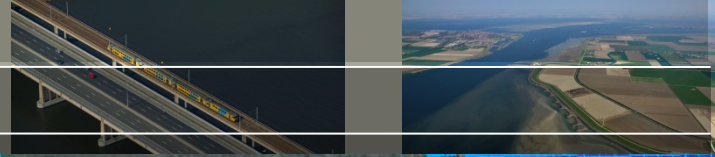
Grid in Dflow-FM

Unstructured approach - step 2: grid refinement in shallow areas

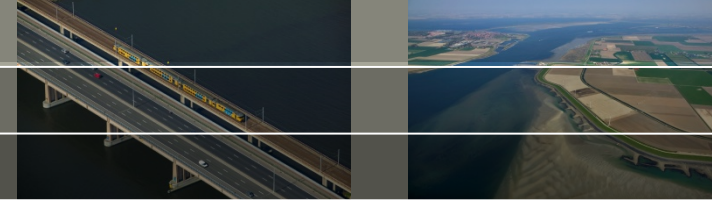


This Dflow-FM grid uses triangles and rectangles for local grid refinement. Resolution is based on Courant number.

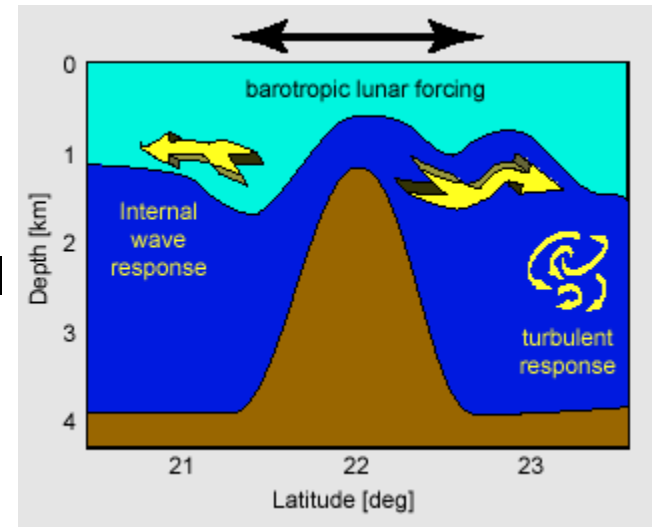
Grid North America



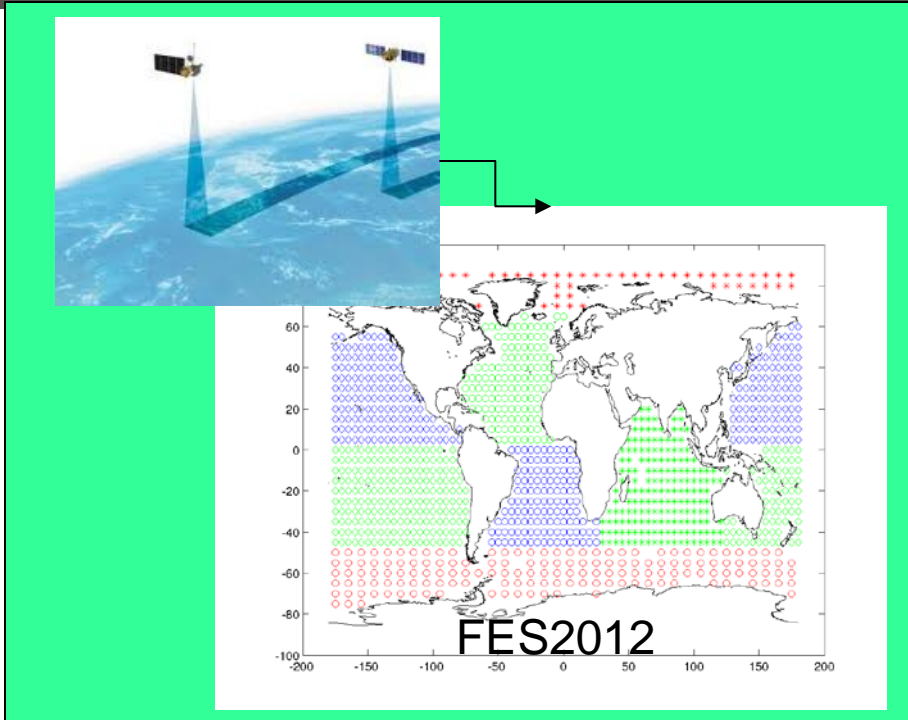
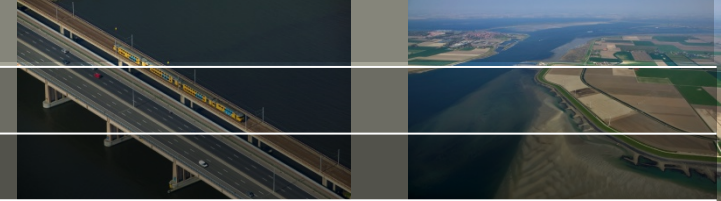
Necessary terms:



1. Self attraction and loading
 - Tides modify the gravity potential
 - Computationally expensive so we use simple approximation
2. Internal tides
 - Tides create internal tide where there is stratification and steep bathymetry
 - introduce dissipation (roughly $\frac{1}{4}$ of total tidal dissipation on global scale)

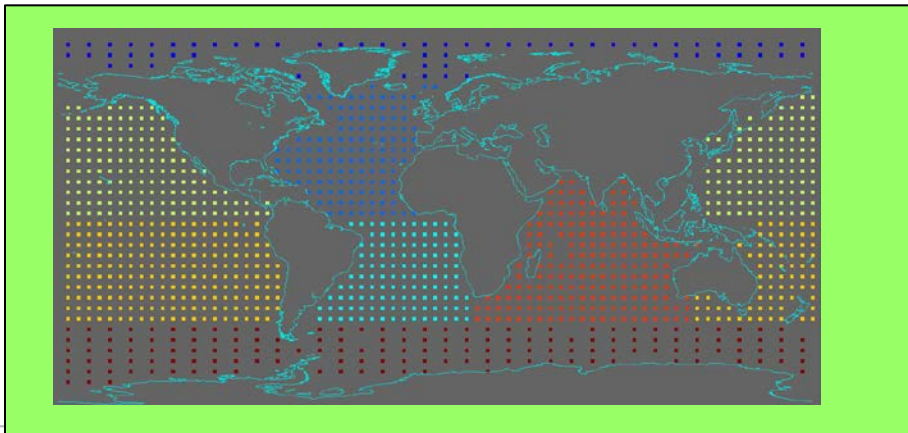


Calibration of the Model



Altimeter observations:
- assimilated FES2012 gridded data
- very accurate on deep water

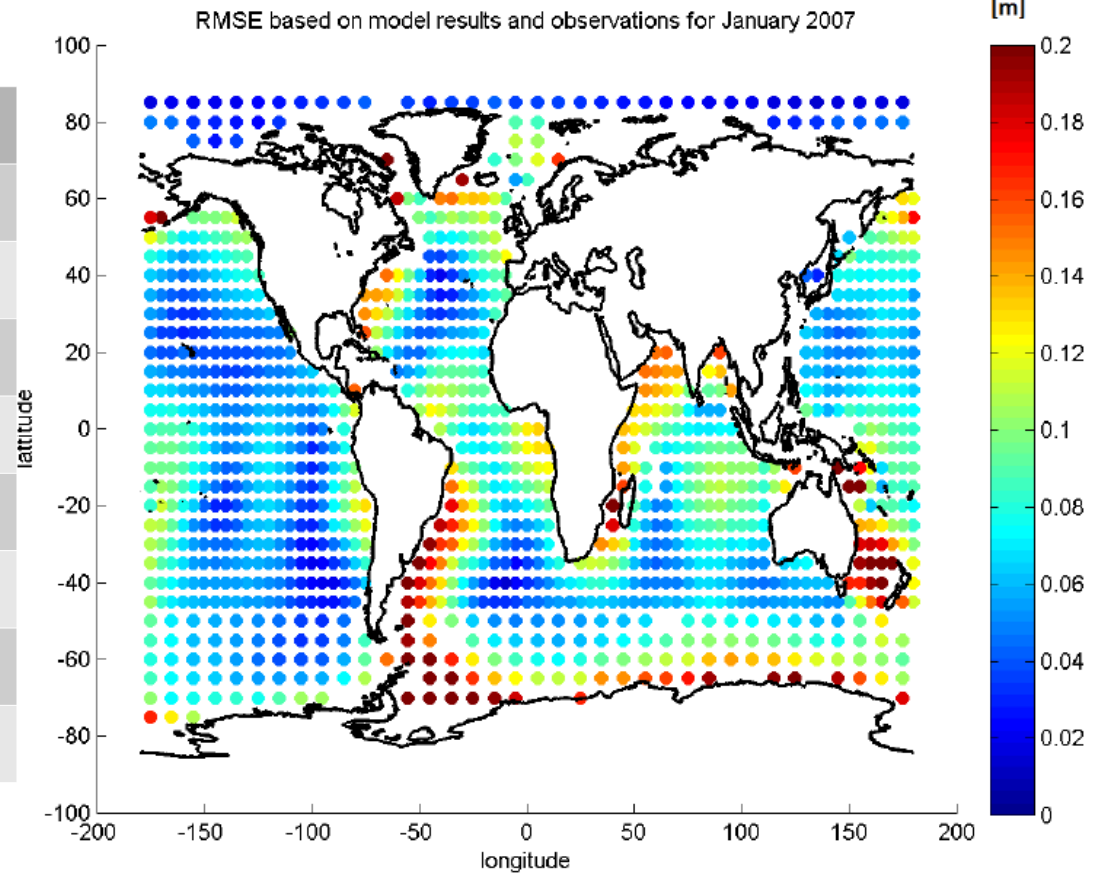
Automated calibration:
- 21 parameters
- deep water series Jan2007 **OpenDA**



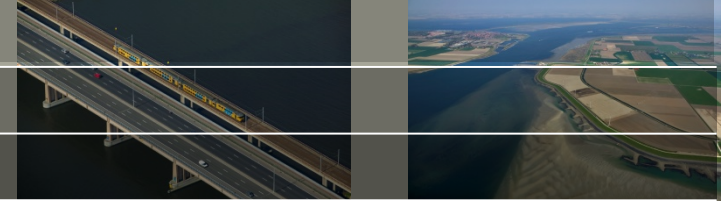
Calibration parameters:
- Depth & Friction
- 7 regions

Calibration results for deep water

Region	Before	After
Arctic	5.1 cm	3.2 cm
N. Atlantic	9.4	7.4
S. Atlantic	12.1	8.4
N. Pacific	8.1	6.2
S. Pacific	11.2	7.3
Indian Ocean	11.7	8.2
S. Ocean	12.4	10.2
Total	10.2	7.4

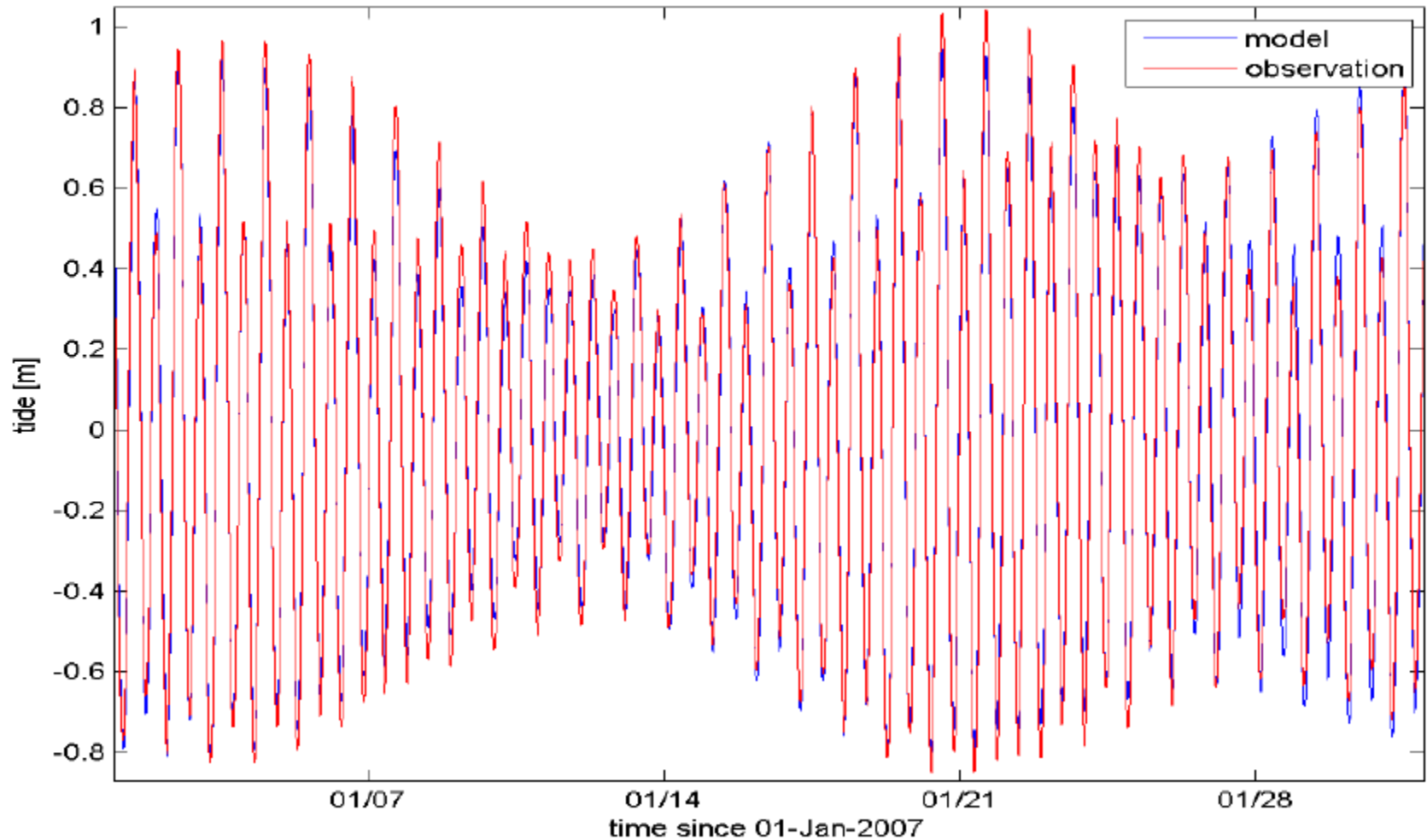


Sample deep water station

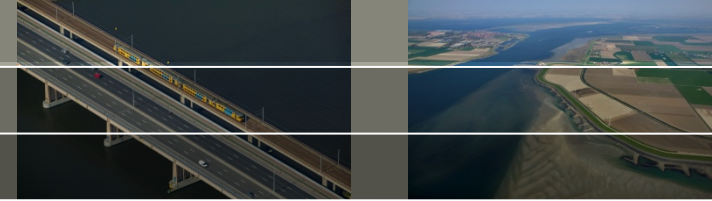


After calibration

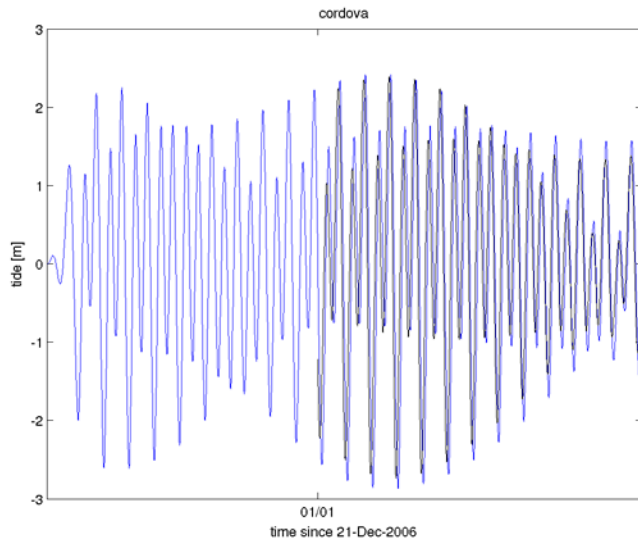
South Pacific Ocean (-135.00, 0.00), RMSE = 0.052 m, $r = 0.994$



Sample coastal time-series

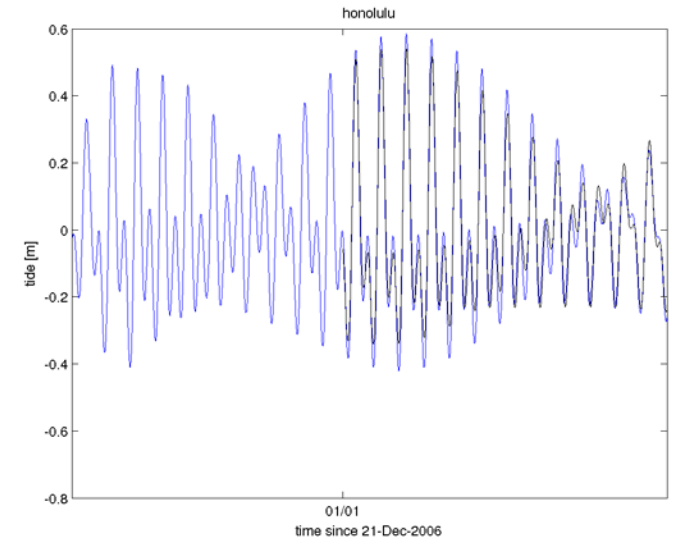


Cordova

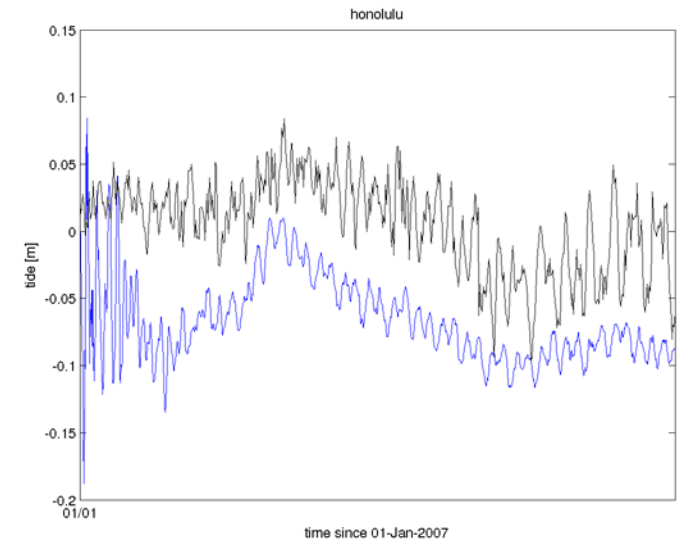
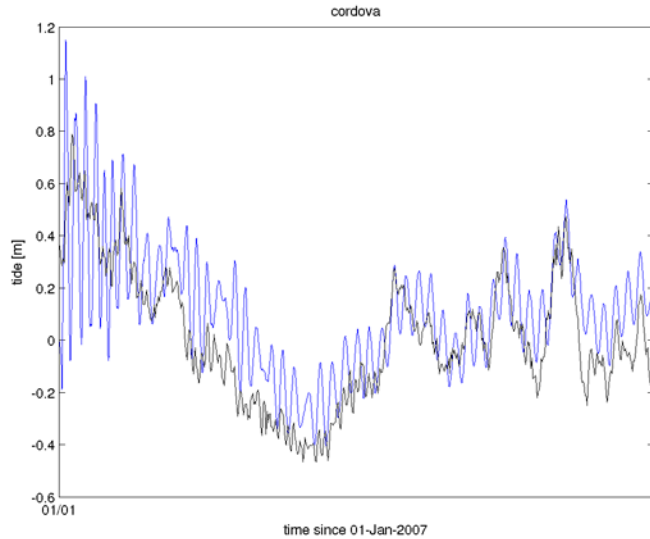


Tide

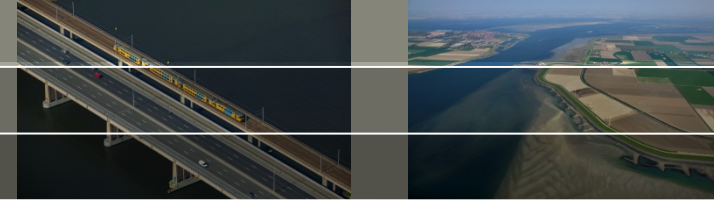
Honolulu



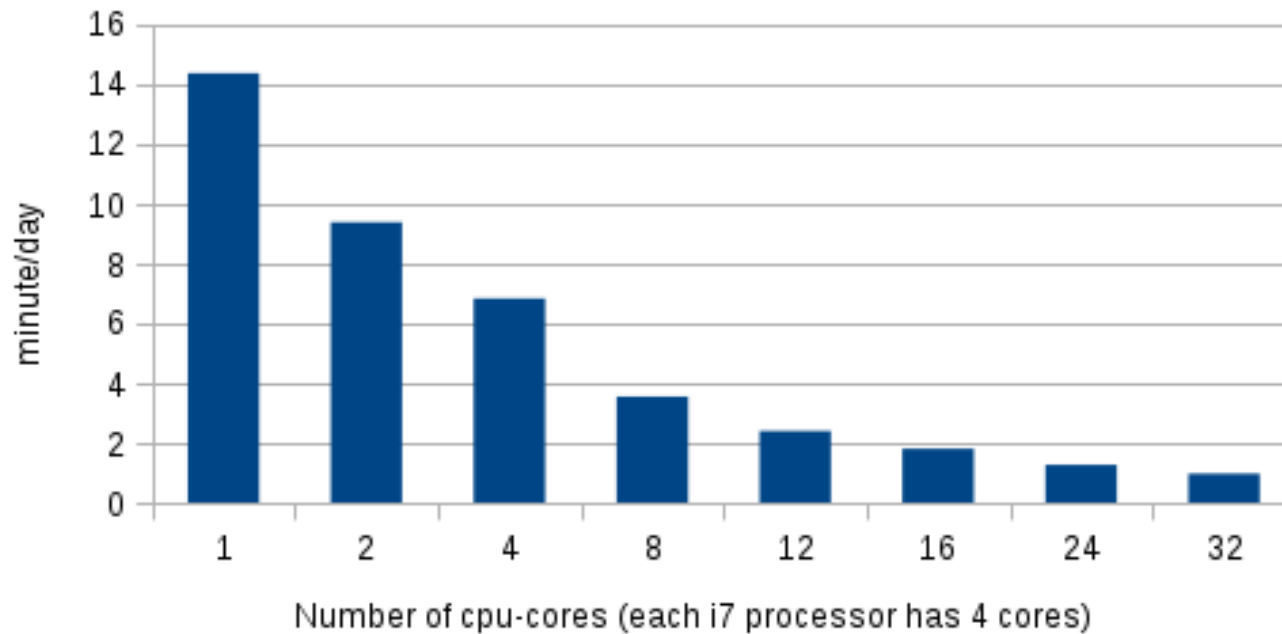
Surge



Computational performance

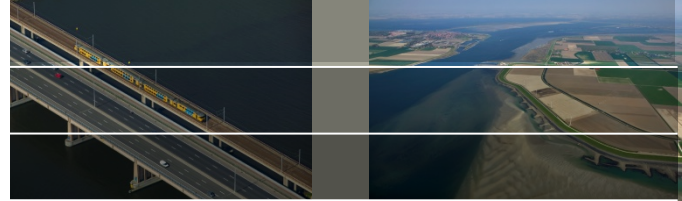
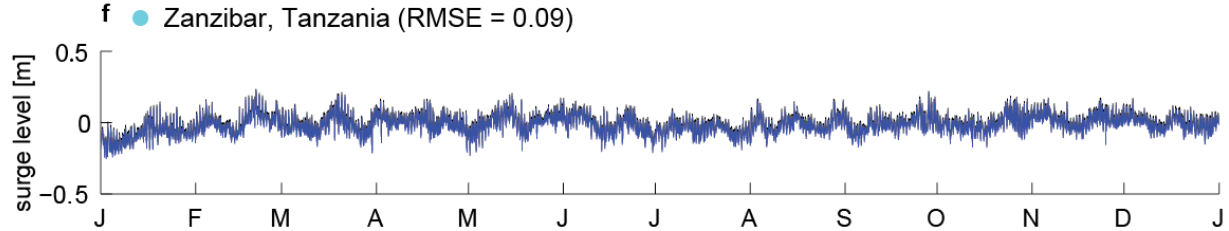
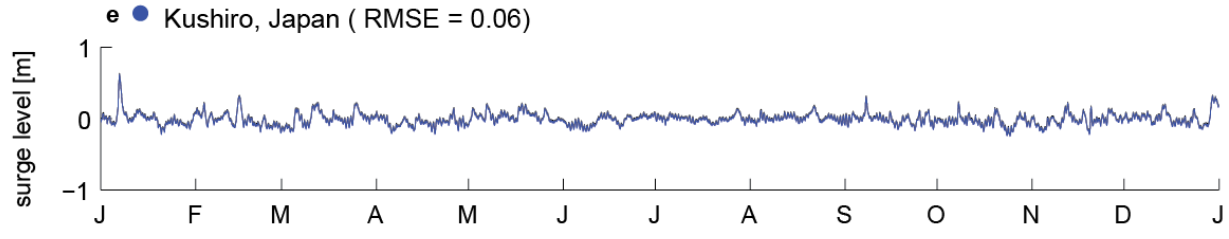
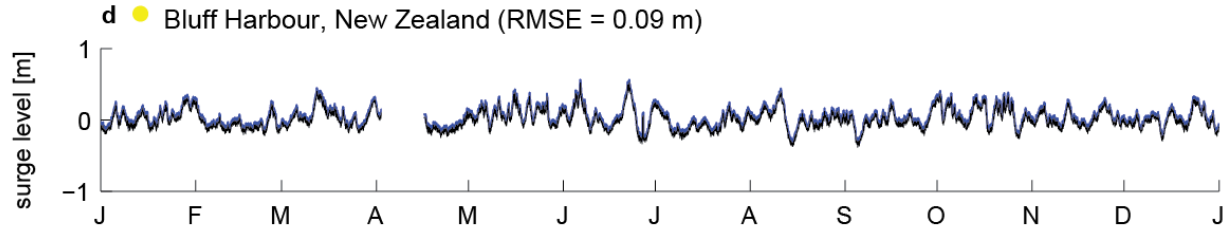
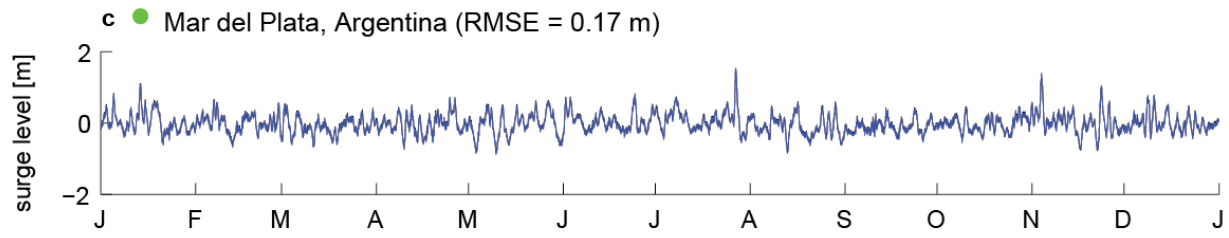
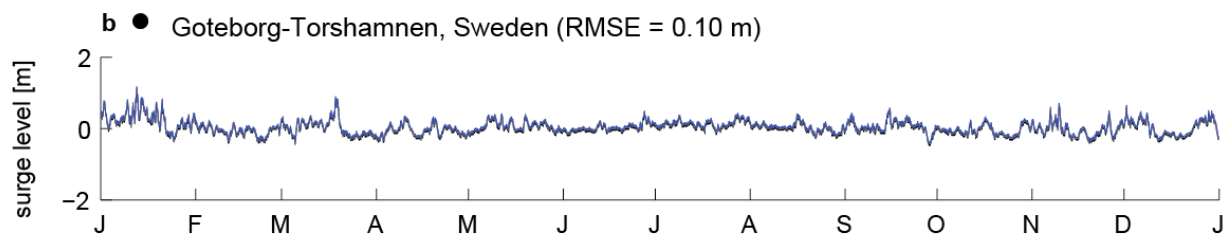
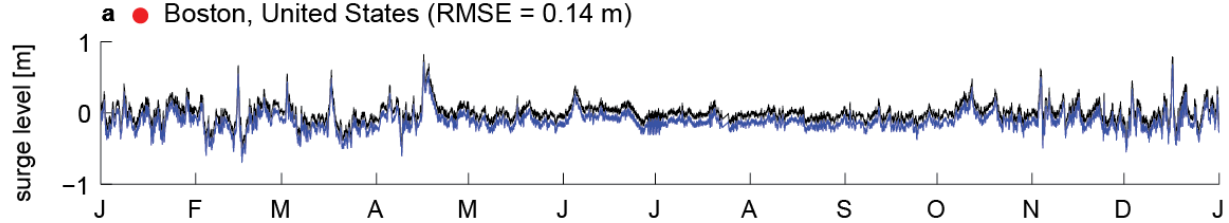


GTSM computation time on a cluster
wall-clock in minutes per simulation day

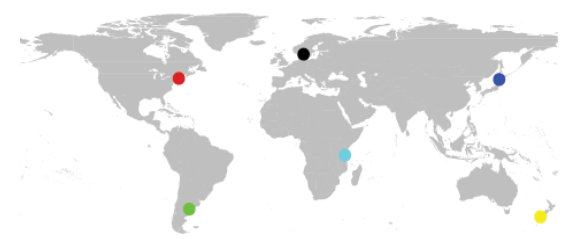
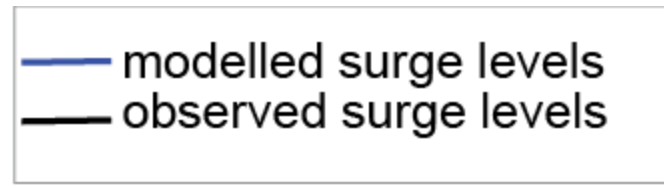


An aerial photograph showing a coastal landscape. A large body of water is on the left, separated from the land by a dike. The land is divided into various agricultural plots, some green and some brown. A small town or village is visible in the distance on the left. The sky is clear and blue.

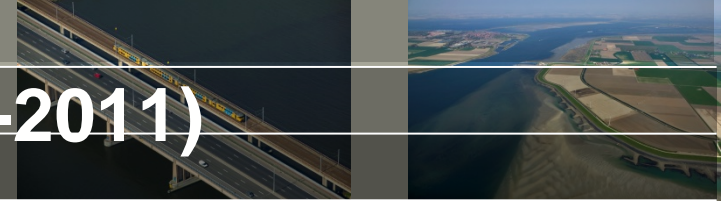
Reanalysis of extreme sea-levels using ERA-interim wind data cooperation with VU



2007



Validation ERA-interim (1980-2011)

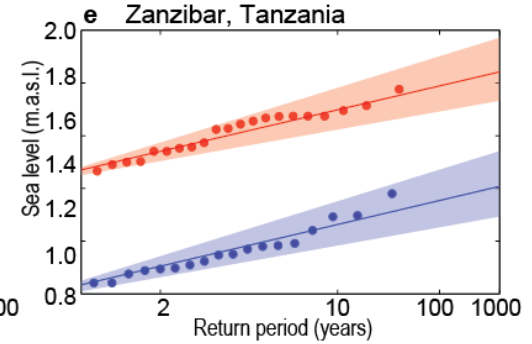
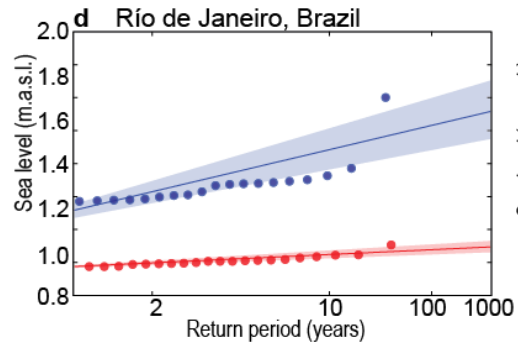
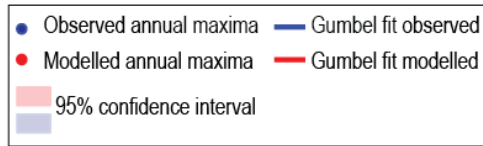
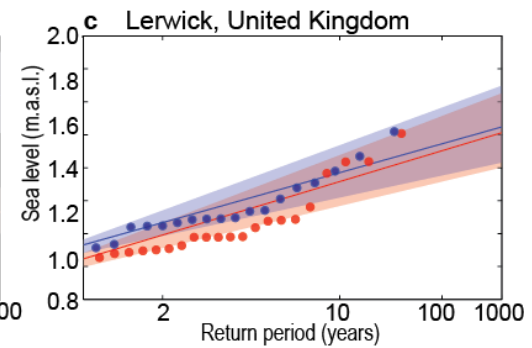
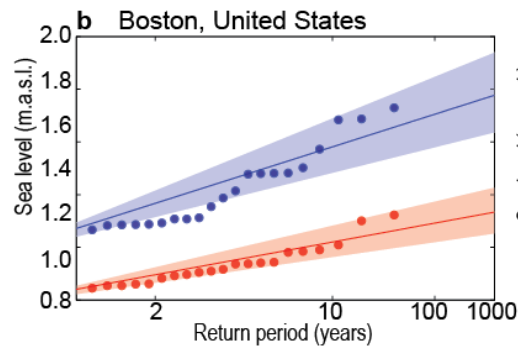
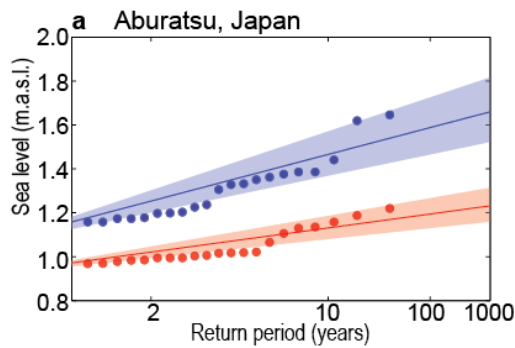
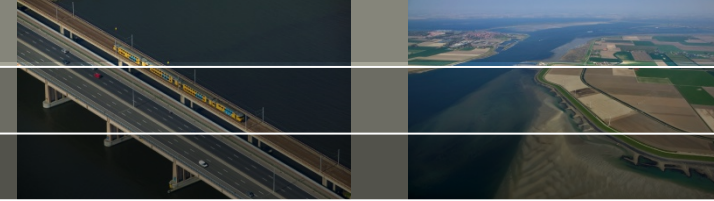


Surge errors

a

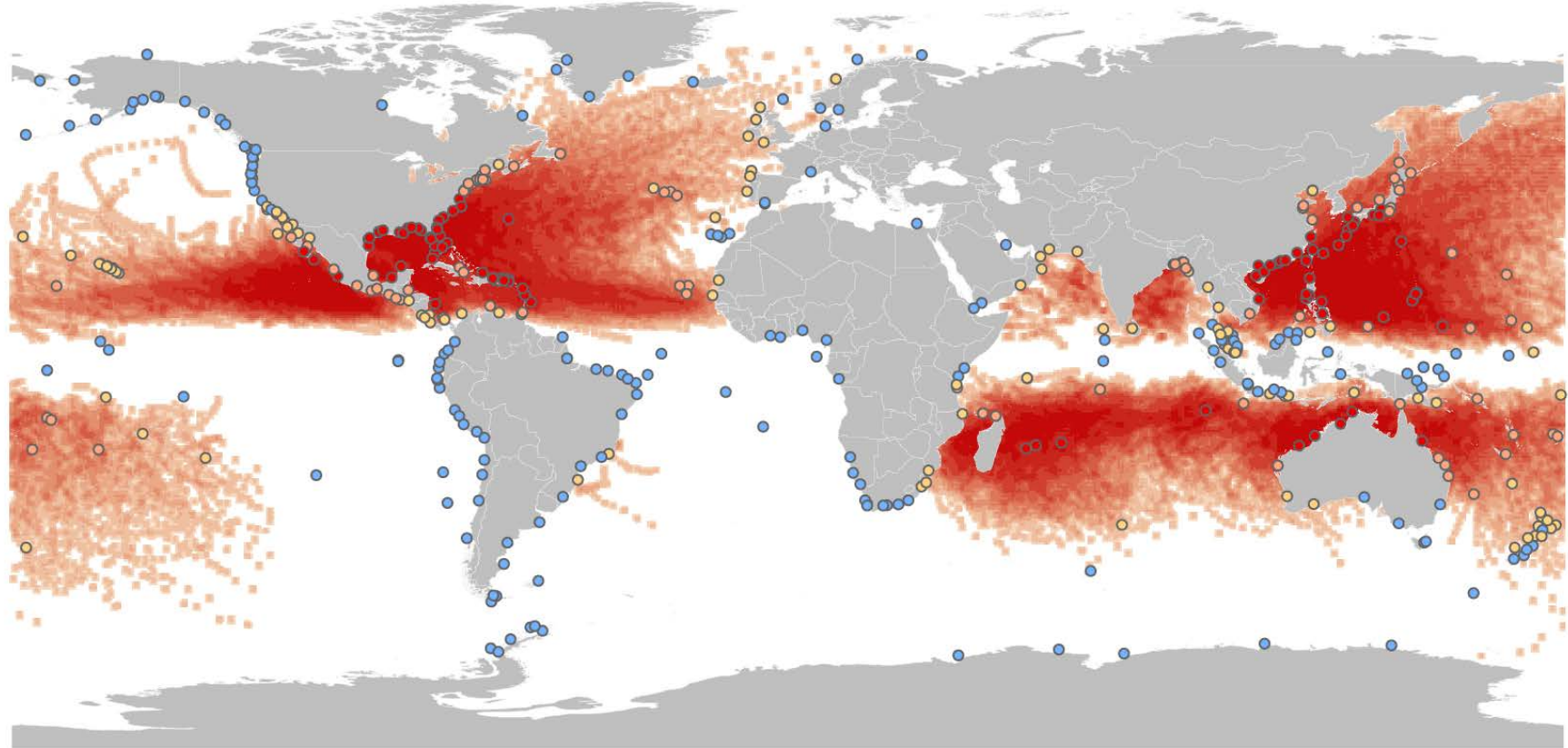


Validation of return periods

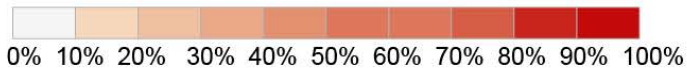


Tropical Cyclones – work is under way

Distribution of cyclones



Tropical cyclone frequency distribution



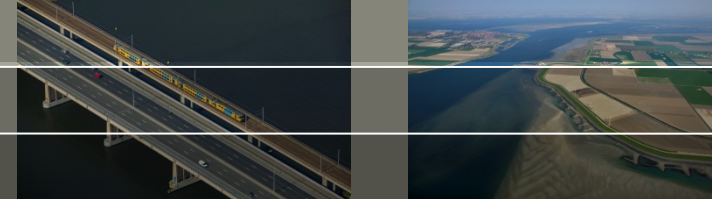
UHSLC observation stations

- no risk
- low risk 0 - 40%
- moderate risk 50 - 70%
- high risk 80 - 100%

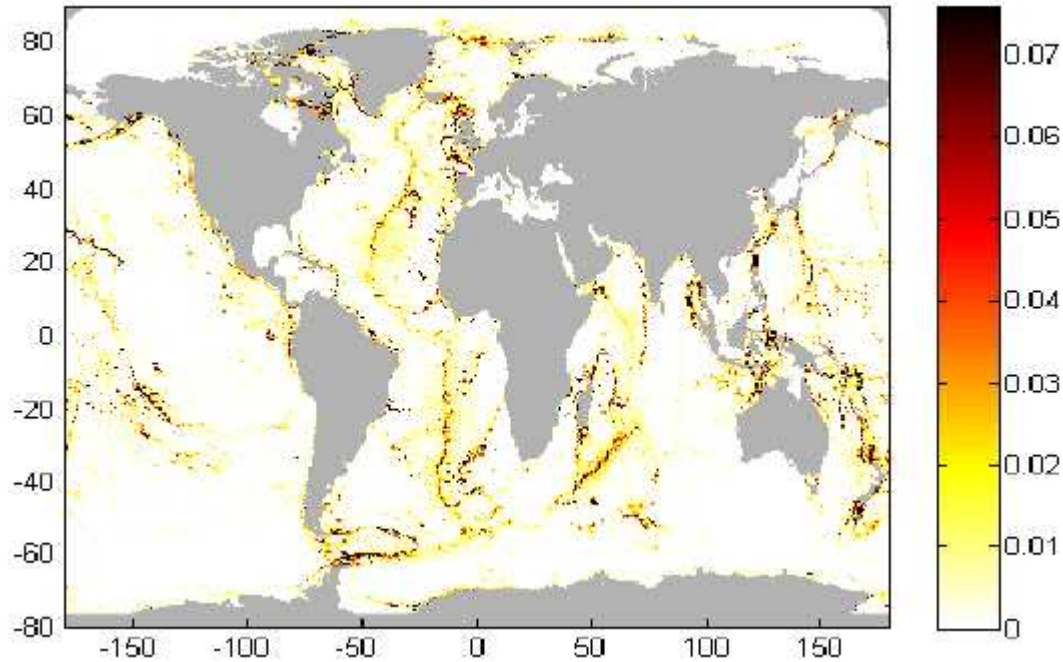
An aerial photograph of a coastal region. A large body of water, likely a bay or estuary, occupies the left and bottom-left portions of the frame. A prominent dike or levee runs along the right side of the water, separating it from a large area of agricultural land. The fields are divided into various colored plots, including green, brown, and tan. In the background, a small town or village is visible on the left side. The sky is clear and blue.

Model improvements towards GTSM v2.0

Dissipation by internal tides



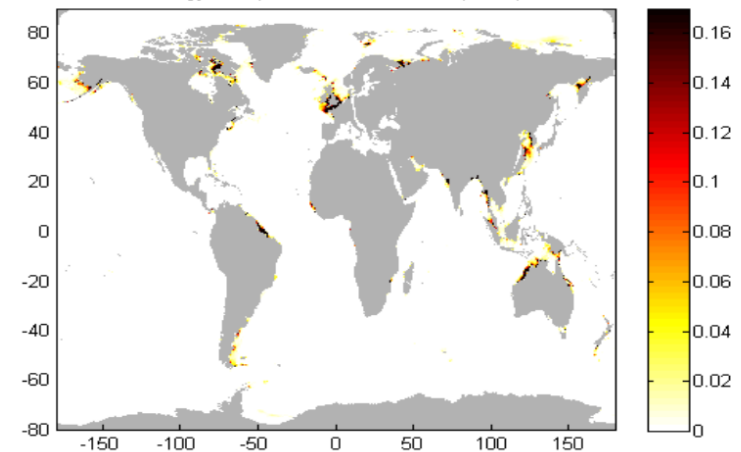
Energy Dissipation - Internal (W/m^2)



Simplified formulation

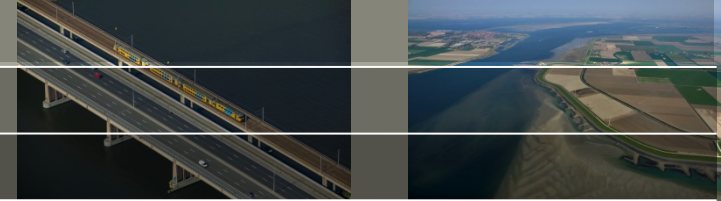
Work of: Shobhit Jain

Energy Dissipation - Bottom Shear (W/m^2)



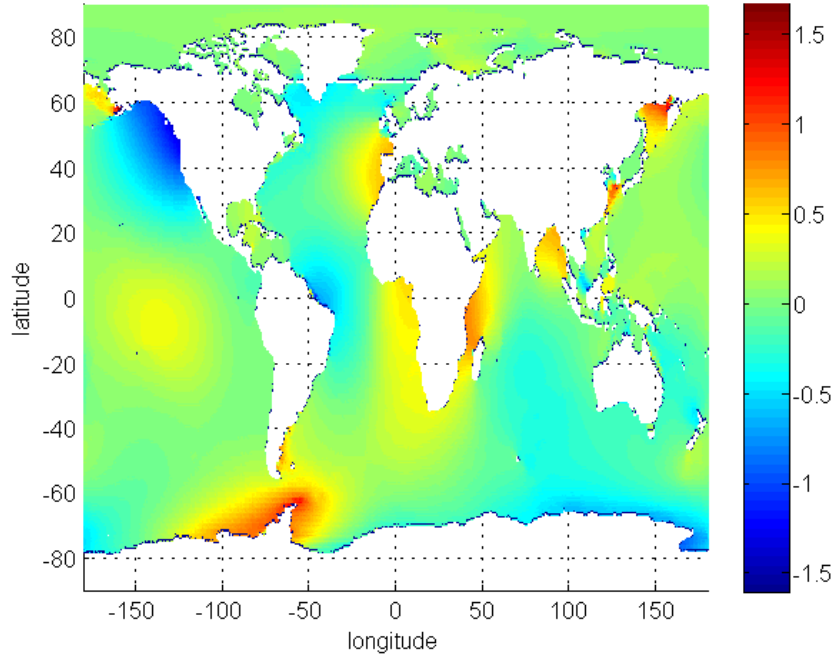
Dissipation type	Sum [TeraWatts]
Bottom drag	0.95
Internal tides	2.30
Total	3.26

SAL-term



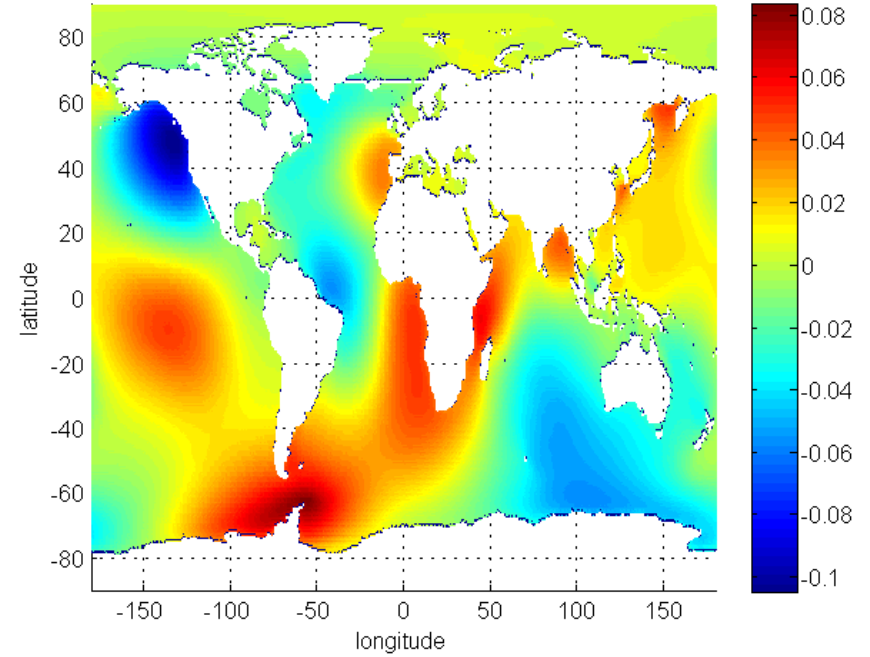
Tide

Tide



SAL tide

SAL tide



Work of: Camille le Coz

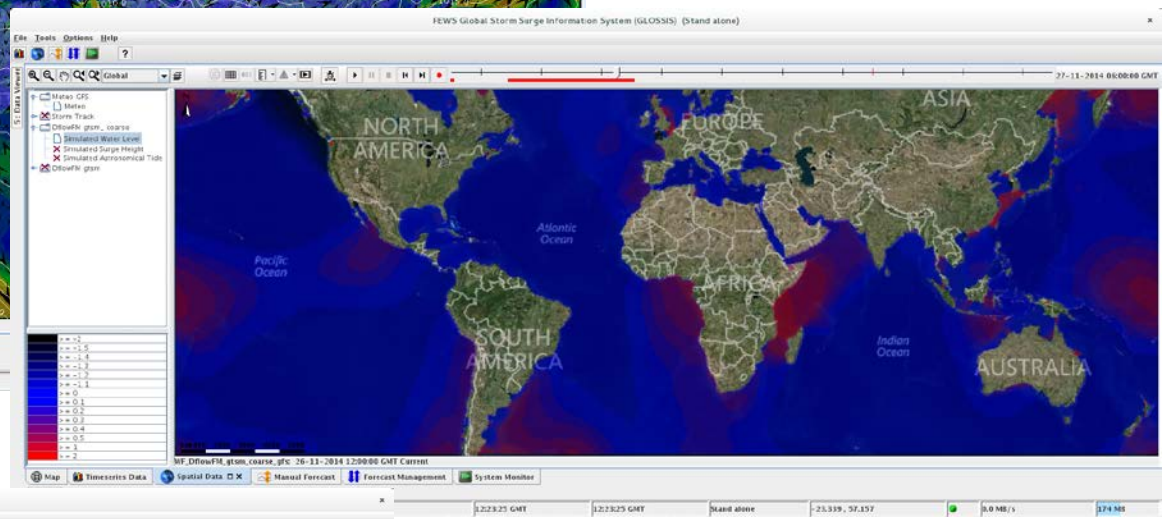
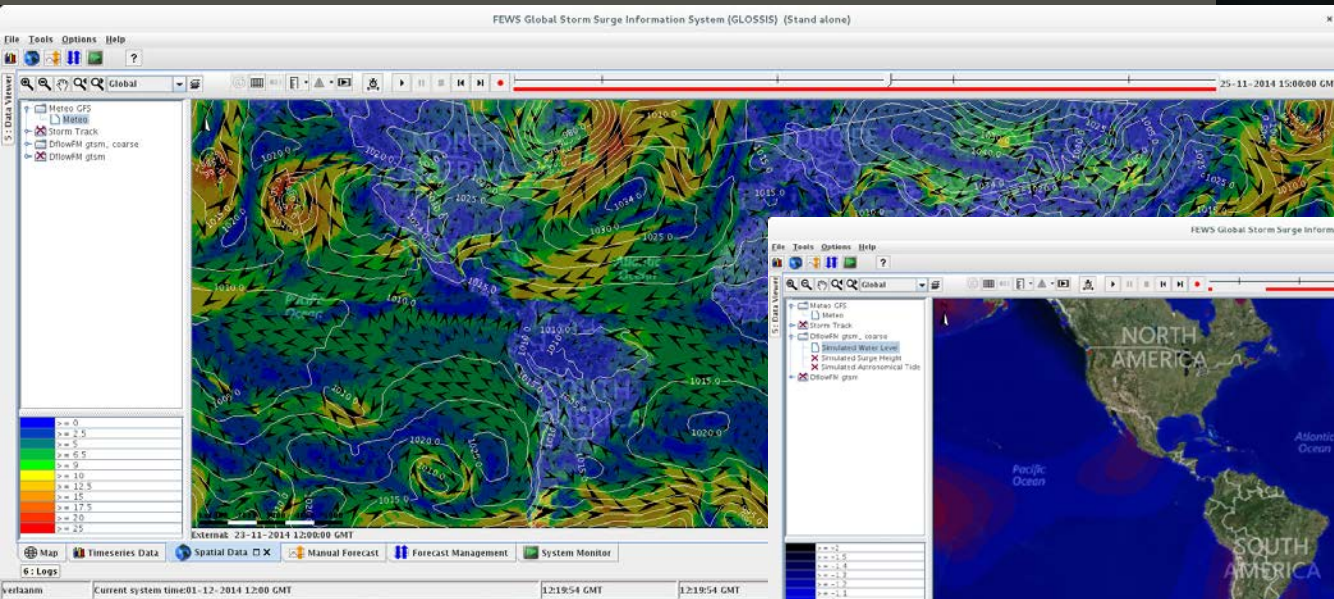
An aerial photograph of a coastal region. A large body of water, likely a bay or estuary, occupies the left side of the frame. A prominent dike or levee runs along the water's edge, separating it from a large area of agricultural land. The fields are divided into various colored plots, including green, brown, and tan. In the background, a small town or village is visible, surrounded by more fields and some buildings. The sky is clear and blue.

GLOSSIS operational forecasting

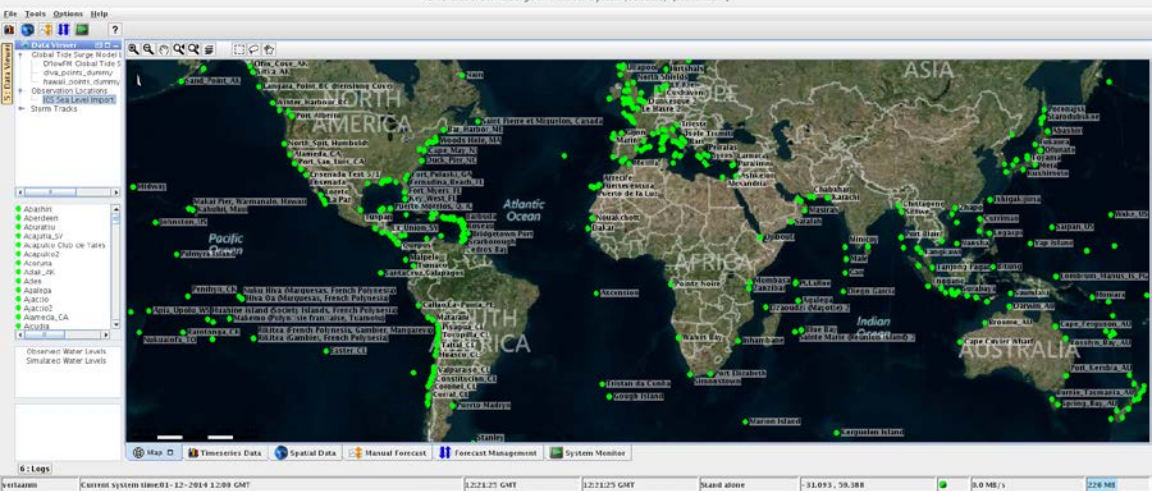
GLOSSIS – global operational storm surges



Running in ID-Lab



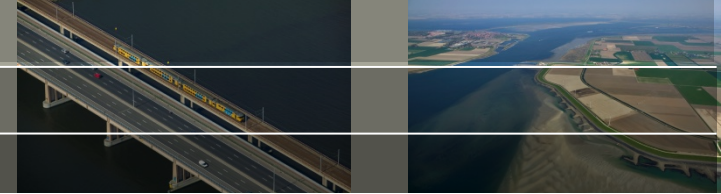
Real-time observations from IOC



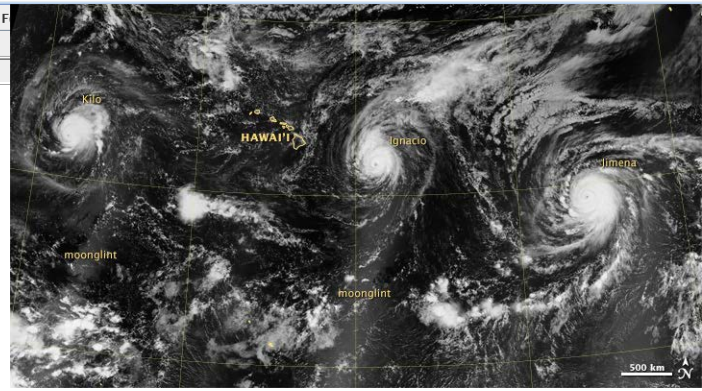
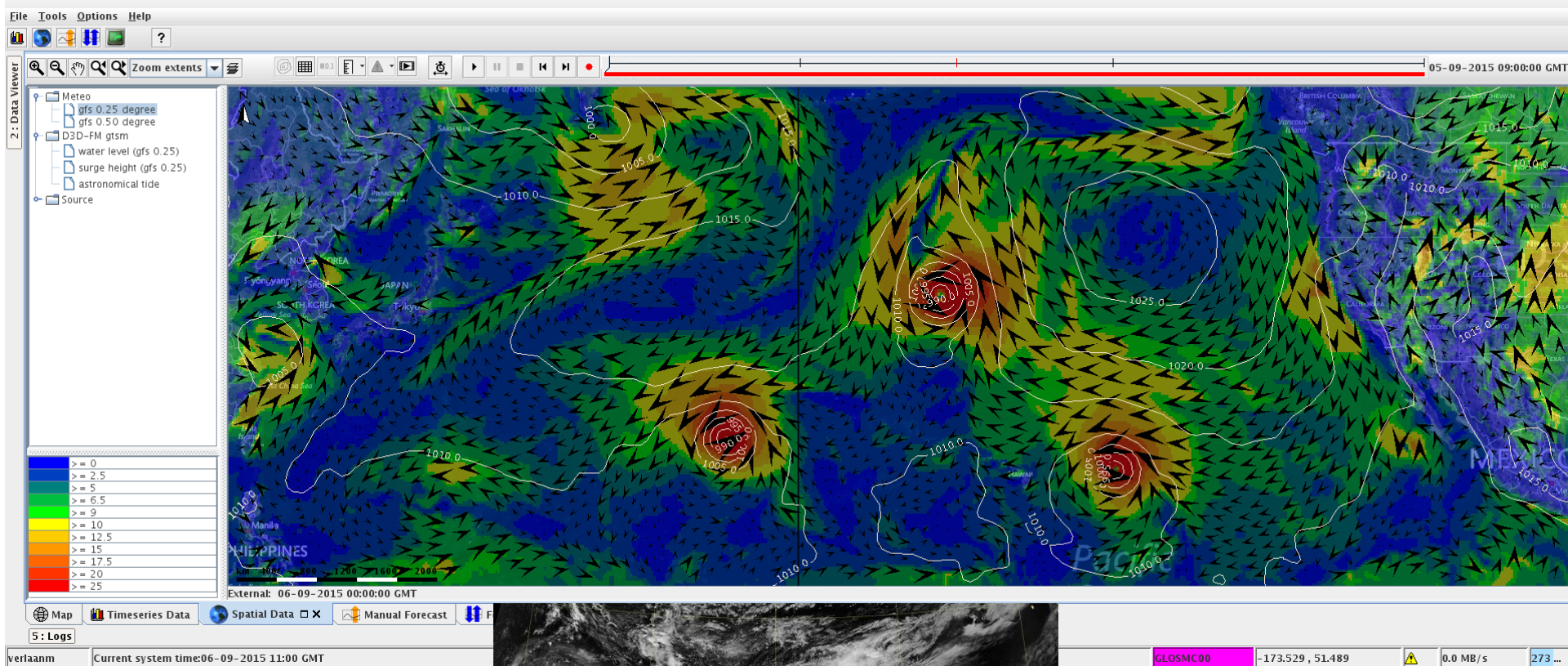
Work of: Lora Buckman



Pacific start Sept 2015



FEWS Global Storm Surge Information System (GLOSSIS) (Operator Client)



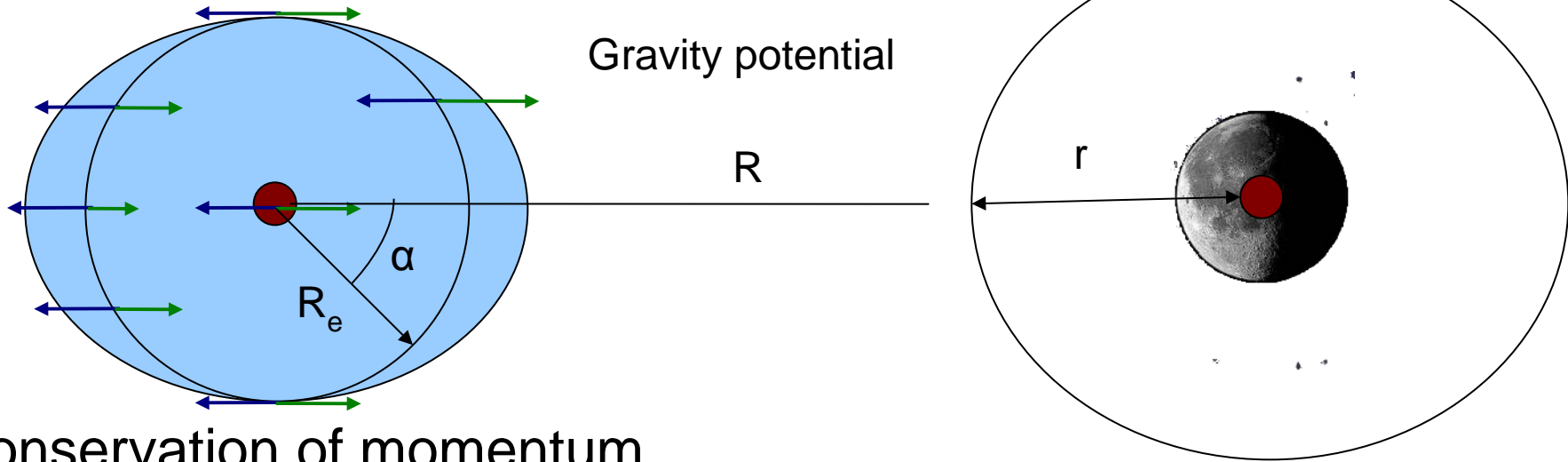
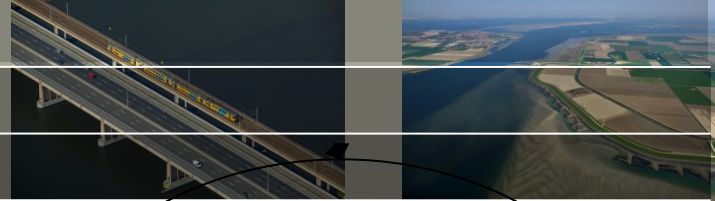
Nasa: aug 30

Deltares

An aerial photograph showing a coastal landscape. On the left, a large body of water (likely a bay or estuary) meets a dike. The dike runs along the coast, separating the water from a large area of agricultural fields. The fields are divided into various colored plots, including green, brown, and tan. In the background, a small town or village is visible. The sky is clear and blue.

Thanks and Questions?

Modified equations



Conservation of momentum

$$\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} + g \frac{\partial h}{\partial x} - \frac{\zeta - \beta h}{\partial x} - fv + \frac{gu\sqrt{u^2 + v^2}}{C^2 H} + \frac{\alpha \kappa N d^2 \sqrt{\omega^2 - f^2}}{2\omega H} u = 0$$

$$\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + g \frac{\partial h}{\partial y} - \frac{\zeta - \beta h}{\partial y} + fu + \frac{gv\sqrt{u^2 + v^2}}{C^2 H} + \frac{\alpha \kappa N d^2 \sqrt{\omega^2 - f^2}}{2\omega H} v = 0$$

1. tidal forcing
2. SAL
3. dissipation by internal tides