IVM Institute for Environmental Studies

1 VU UNIVERSITY AMSTERDAM

2 Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the Environment

3 Deltares
Enabling Delta Life

Source: AFP PHOTO/CHARISM SAYAT/AFP/Getty Images

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Horizontal resolution effects on tropical cyclone storm surges

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Tropical cyclone storm surges

- Driven by strong winds in combination with low MSLP
- Influenced by TC intensity, size and track, but amplified by shallow coastal bathymetry or local geometry
- One of the most damaging aspect of a TC
  - Almost half of the fatalities are due to storm surges (Rappaport, 2014)

Source: Pixabay.com

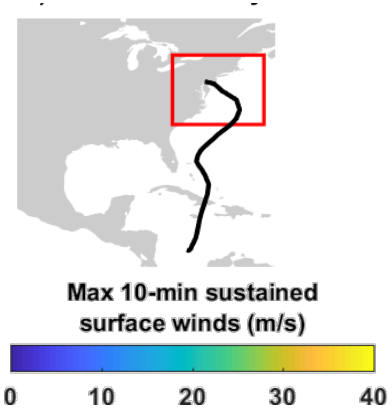
Hurricane Harvey

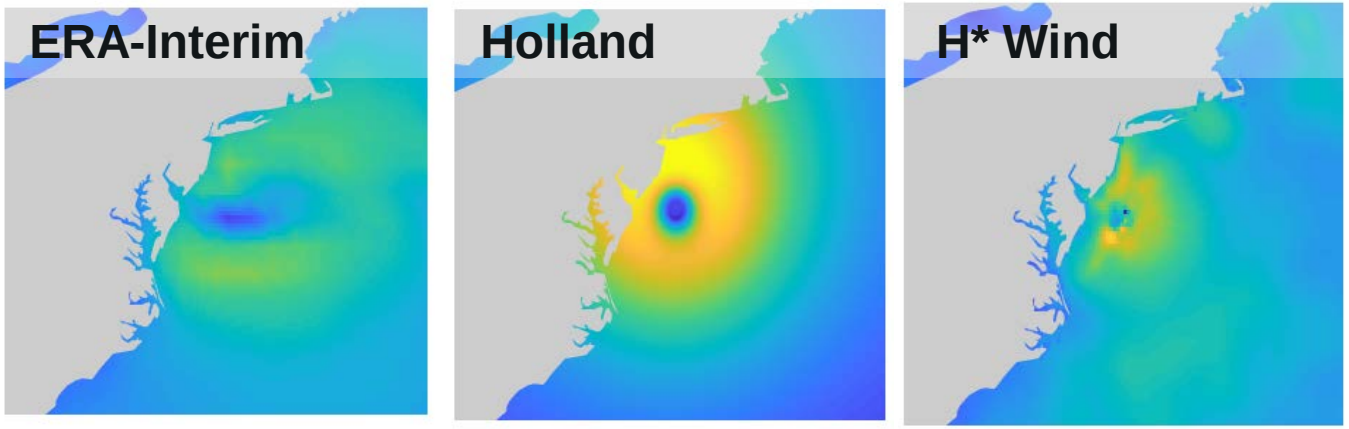
Source: Pixabay.com

Hurricane Dennis

Tropical cyclone storm surges

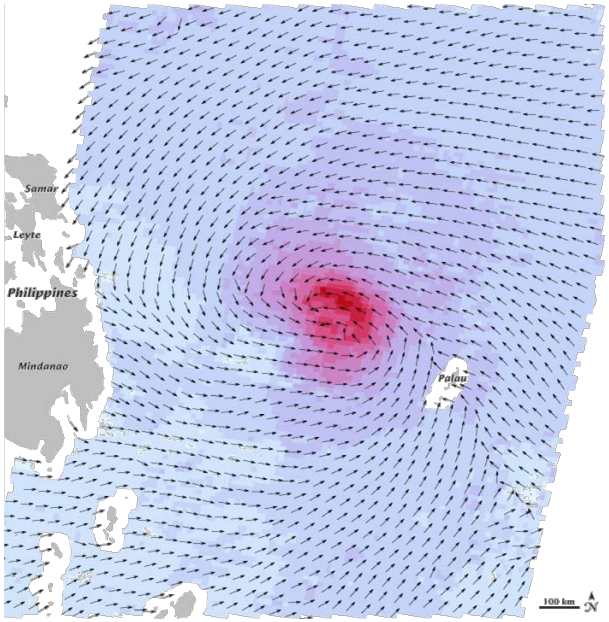
- TC surges are simulated using hydrodynamic models, forcing with 10m wind and MSLP
- Global atmospheric models resolution of 50-200 km
  - Resolution of reanalysis products: ERA-Interim (0.75°), NCEP/NCAR (2°), JMA (1.25°)
- Insufficient to resolve TC intensity, size and track
  - Murakami, 2014; Schenkel & Hart, 2012; Walsh et al., 2007
- Many TC surge studies apply parametric wind models to obtain high-resolution forcing





Tropical cyclone storm surges

- Global atmospheric climate models are now available at high resolution (10-30 km)
  - Operational systems: NCEP-GFS, ECWMF-IFS
  - Climate change: EC-Earth, High-FLOR, CMIP6 models
  - Reanalysis: launch of ECMWF's ERA5 reanalysis

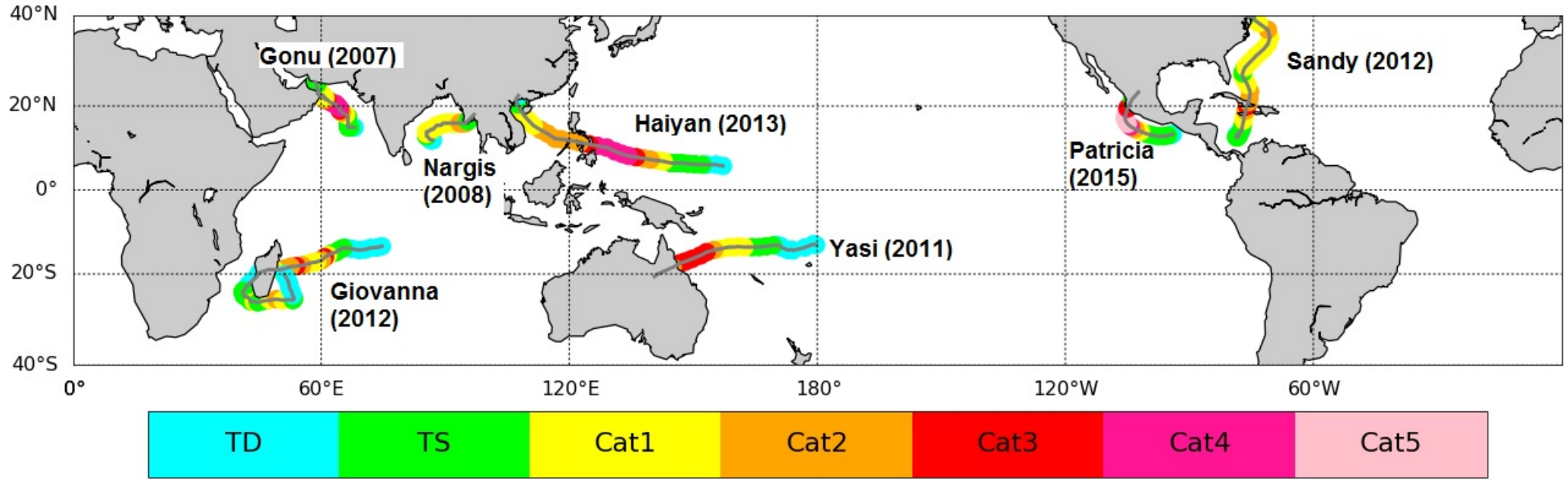


Research questions

How does high-resolution ECWMF forcing perform for TC surge modelling?

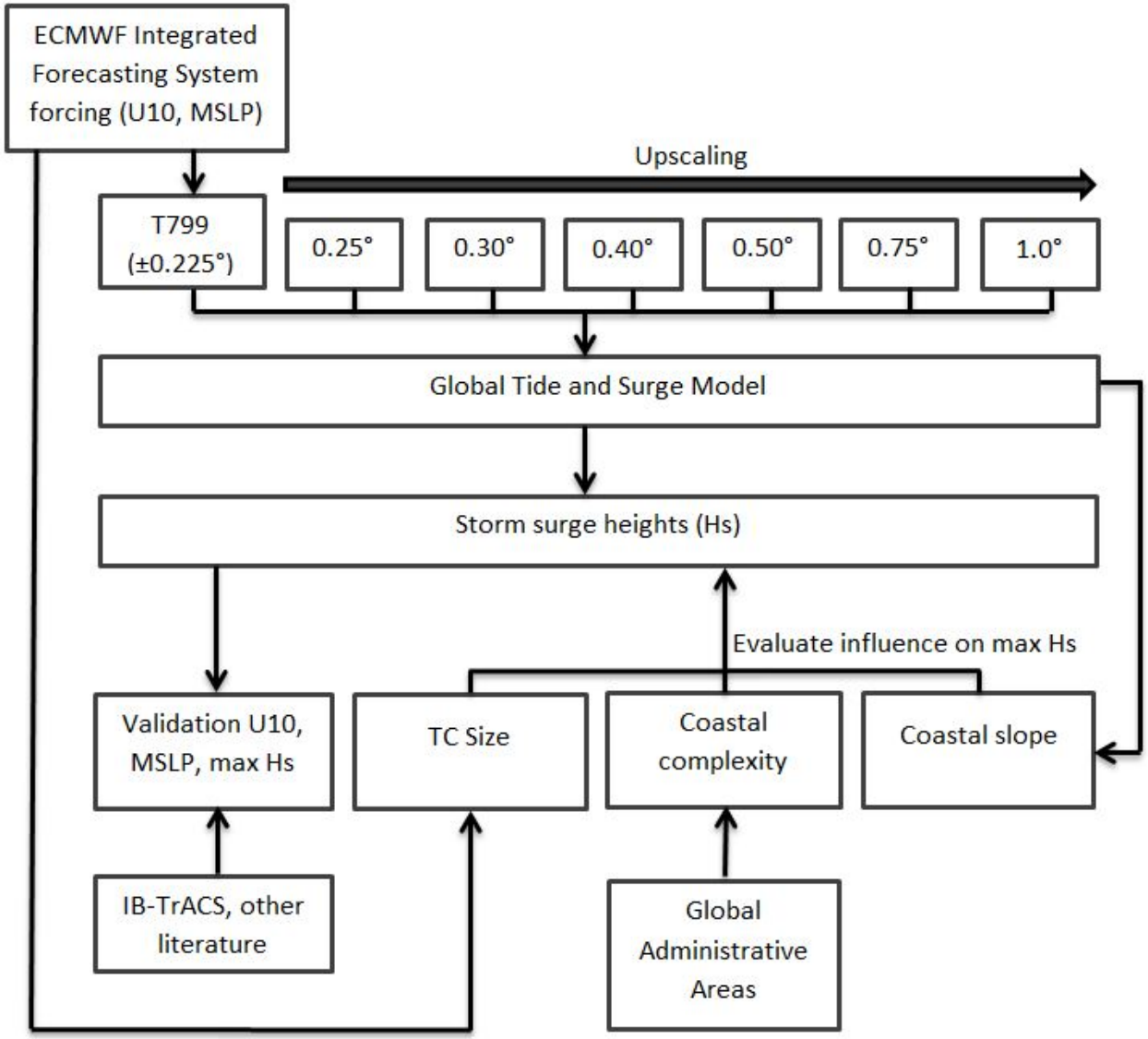
What is the effect of changes in horizontal resolution on TC surge modelling?

Case studies



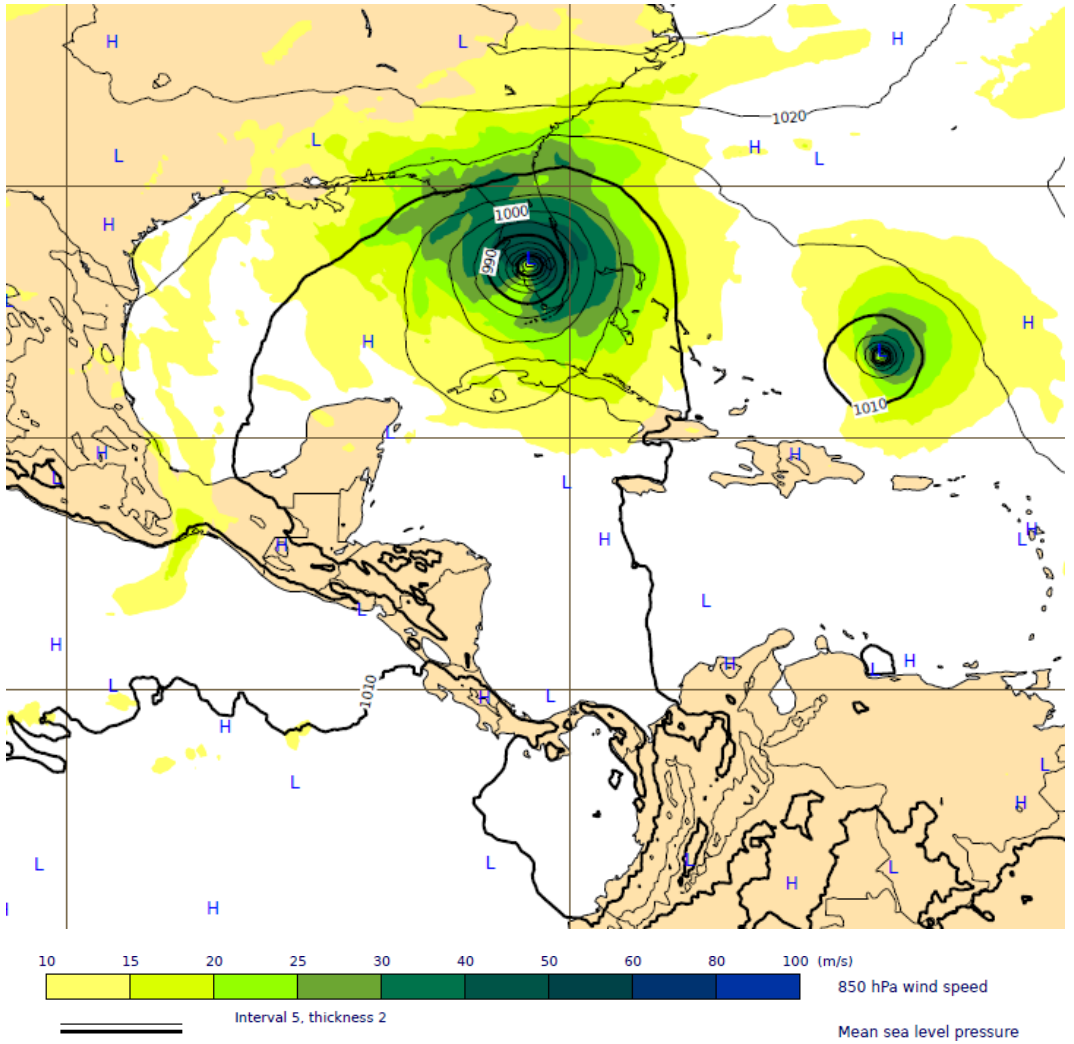
- 1 case study per ocean basin
- Landfall after 5 June 2007 (implementation new 4DVAR scheme)

Approach

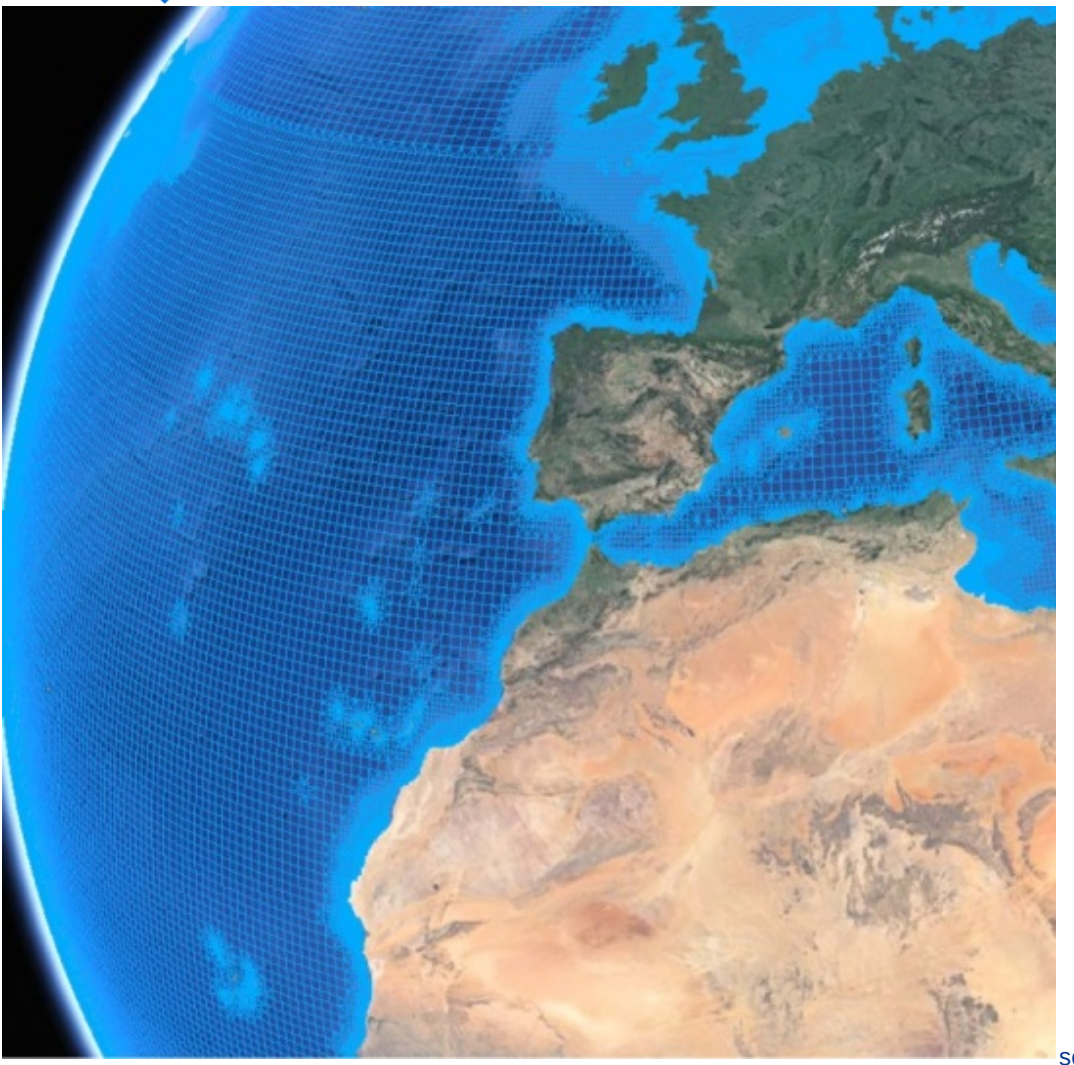

ECMWF Integrated Forecasting System forcing (U10, MSLP)
Upscaling
T799 (±0.225°)
0.25°
0.30°
0.40°
0.50°
0.75°
1.0°
Global Tide and Surge Model
Storm surge heights (Hs)
Evaluate influence on max Hs
Validation U10, MSLP, max Hs
TC Size
Coastal complexity
Coastal slope
IB-TrACS, other literature
Global Administrative Areas

ECMWF IFS

- Integrated Forecasting System
- Horizontal resolution
  - T799 (±0.225°) between 2006 and June 2008,
  - T1279 (±0.14°) from June 2008 onwards
- Temporal resolution 3 hours
- Extract MSLP and 10m wind



Global Tide and Surge Model (GTSM)

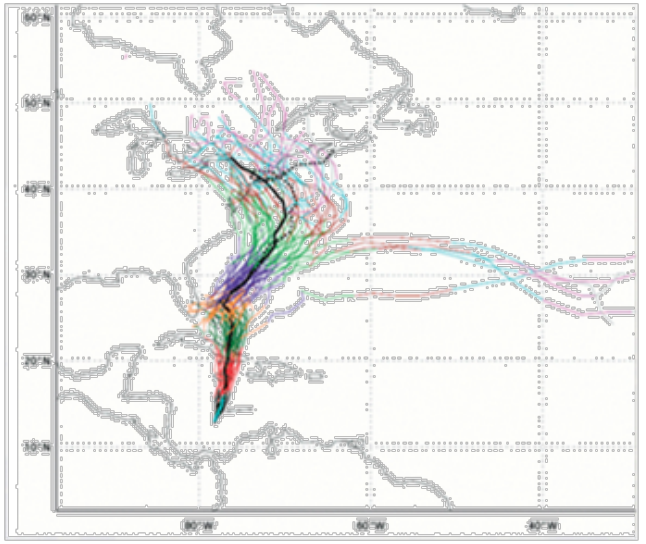


- Global hydrodynamic model with unstructured grids
- Resolution up to 5 km near coasts, up to 50 km over the oceans

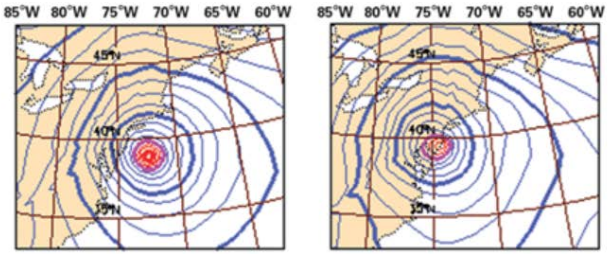
source: Deltares, 2016

Results: hurricane Sandy (2012)

- Damages of 70 billion in today's USD and 159 deaths (NOAA, 2017)
- After crossing the Caribbean, Sandy moved northward and then made a sudden turn westward
- ECWMF system outperformed other forecasts
  - Captured the complex meteorological conditions
  - Forecasts predicted the landfall 7-8 days in advance



A week-ahead hit. Multiple ECMWF track forecasts (colored lines) made 7.5 days ahead had Sandy hitting the U.S. Northeast (actual track in black). CREDIT: ECMWF



Pretty good. Six days ahead of landfall, the ECMWF model's forecast put Sandy (red, *in center of pressure isobars*) off the New Jersey coast (*left*), where eventually it hit (*right*, the actual storm).

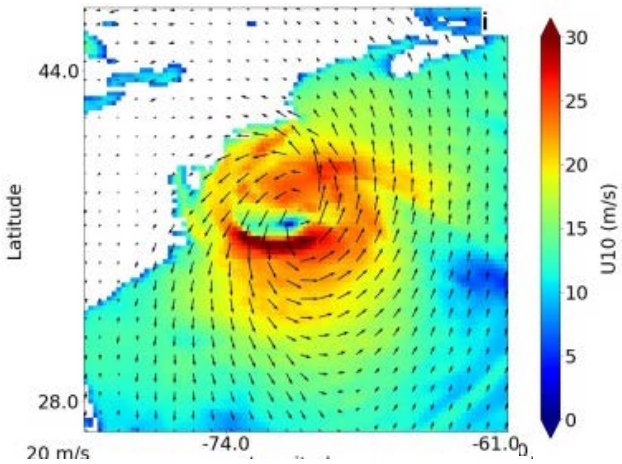
CREDIT: ECMWF

Source: Kerr,(2012). One Sandy forecast a bigger winner than others. *Science*, *338*(6108), 736-737.

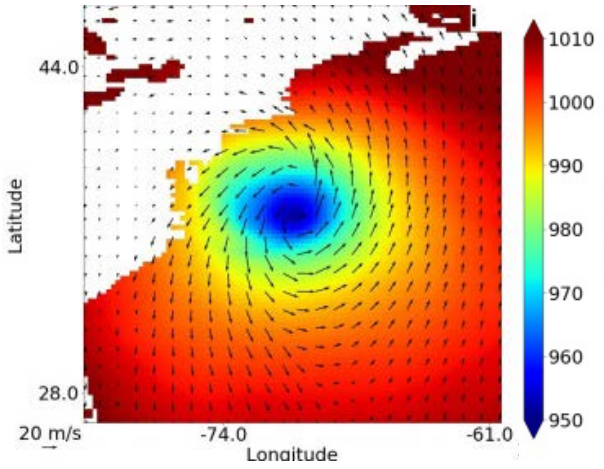
Results: Maximum surge heights Sandy

- Maximum wind speeds of 15.6 m/s
- Minumum pressure 993 hPa
- Maximum surge height of 2.5 m

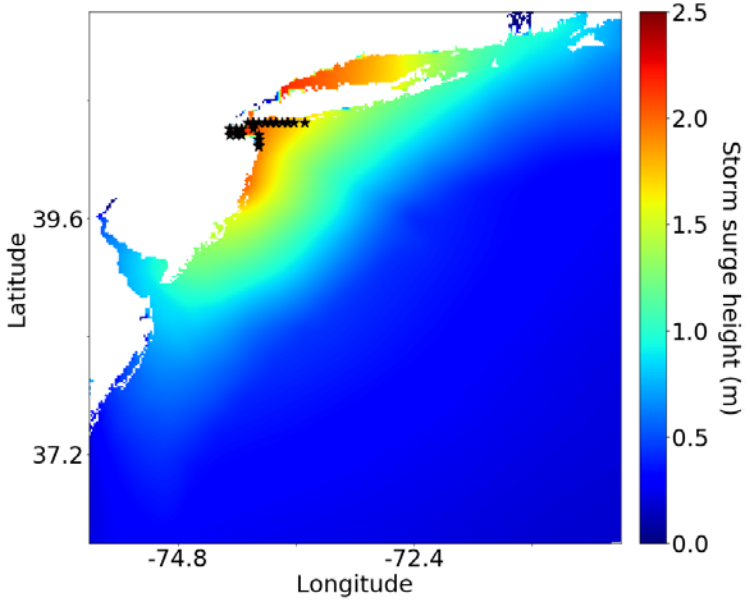
U10



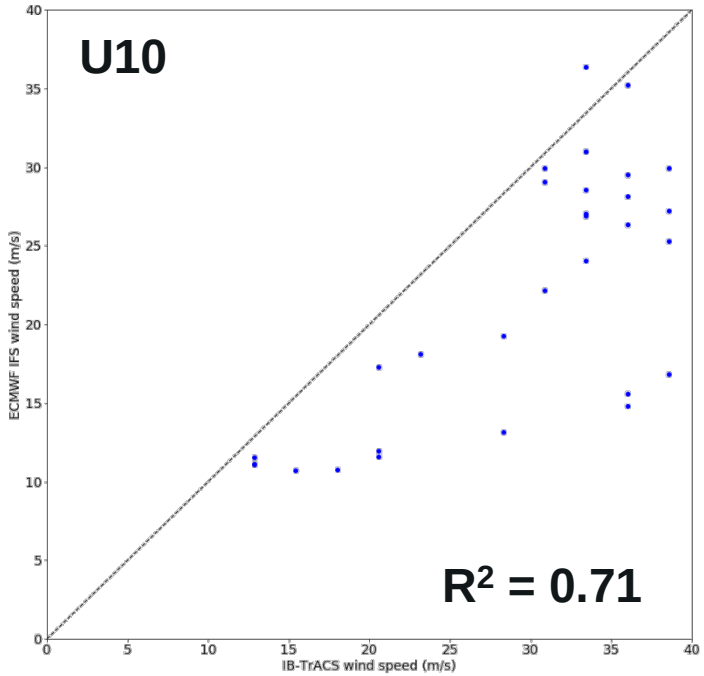
MSLP

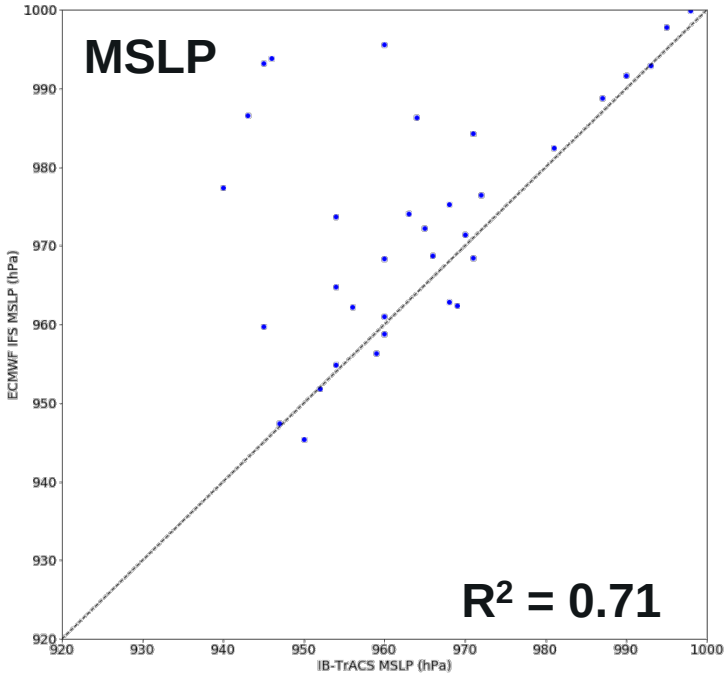


Surge height



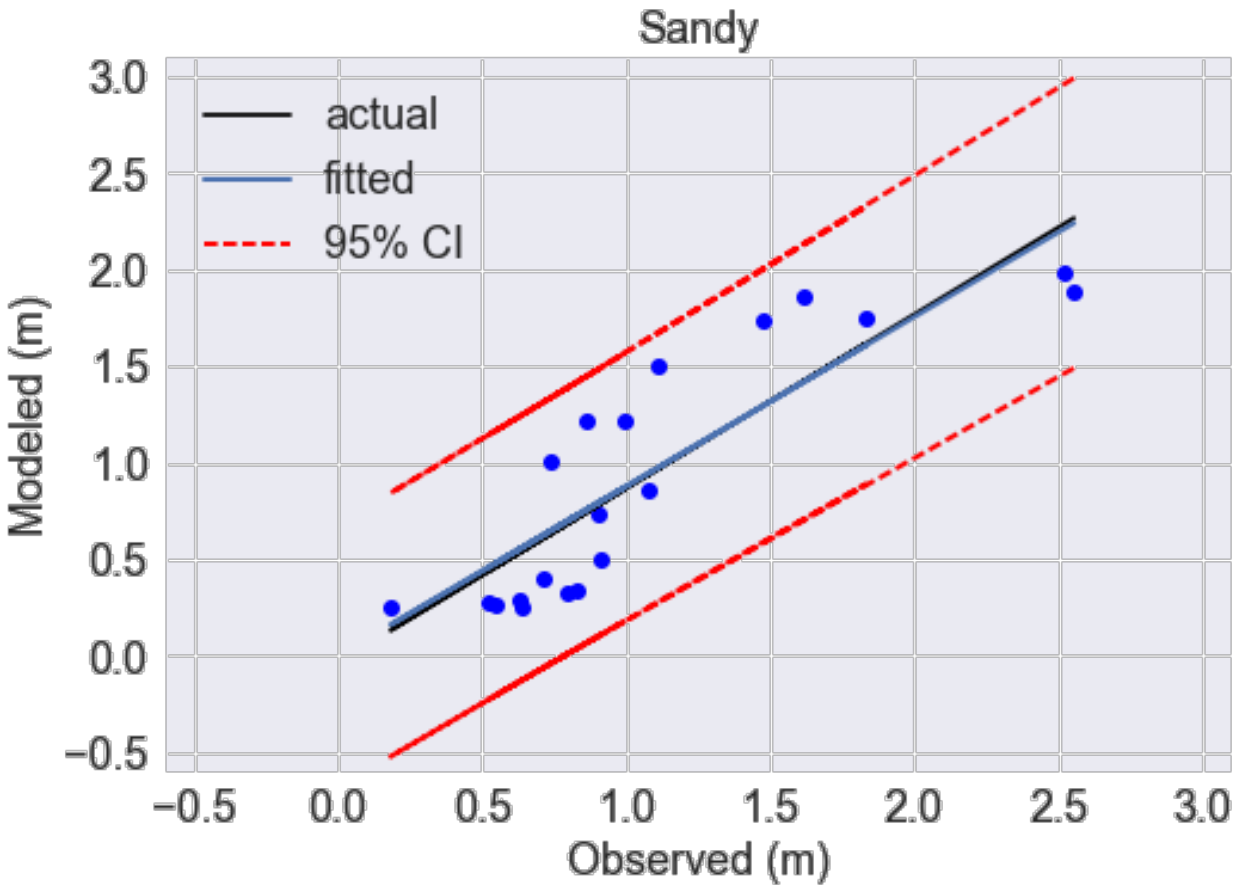
Results: validation of forcing Sandy





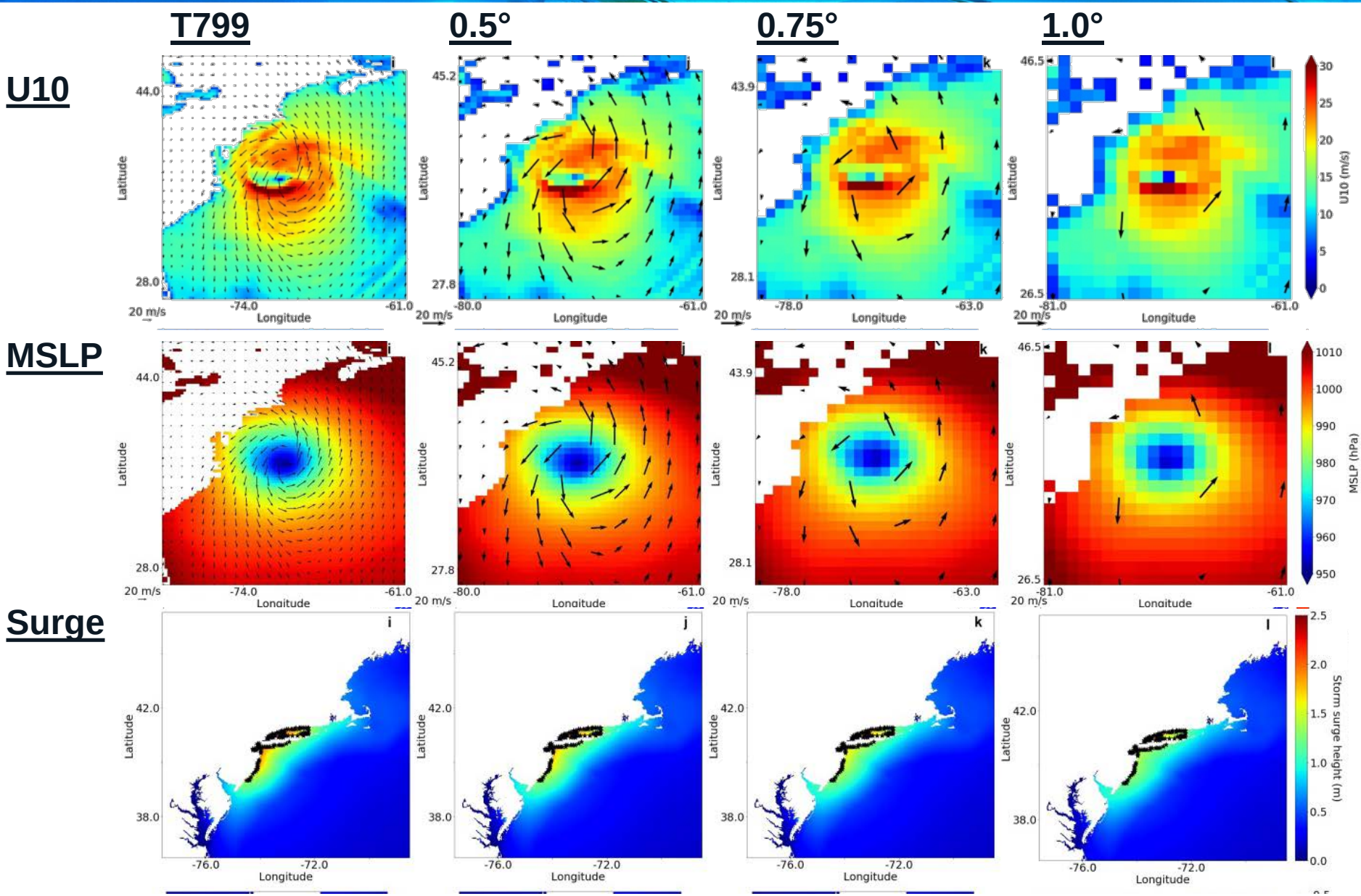
- Validation against observed TC characteristics from IB-TrACS
- Good performance of ECMWF IFS (r^2 >0.7)
  - Overestimation of atmospheric pressure
  - Underestimation of wind speed

Results: Validation of surge for Sandy



Spatial distribution of modelled maximum surge heights is in good agreement with observed maximum surge heights

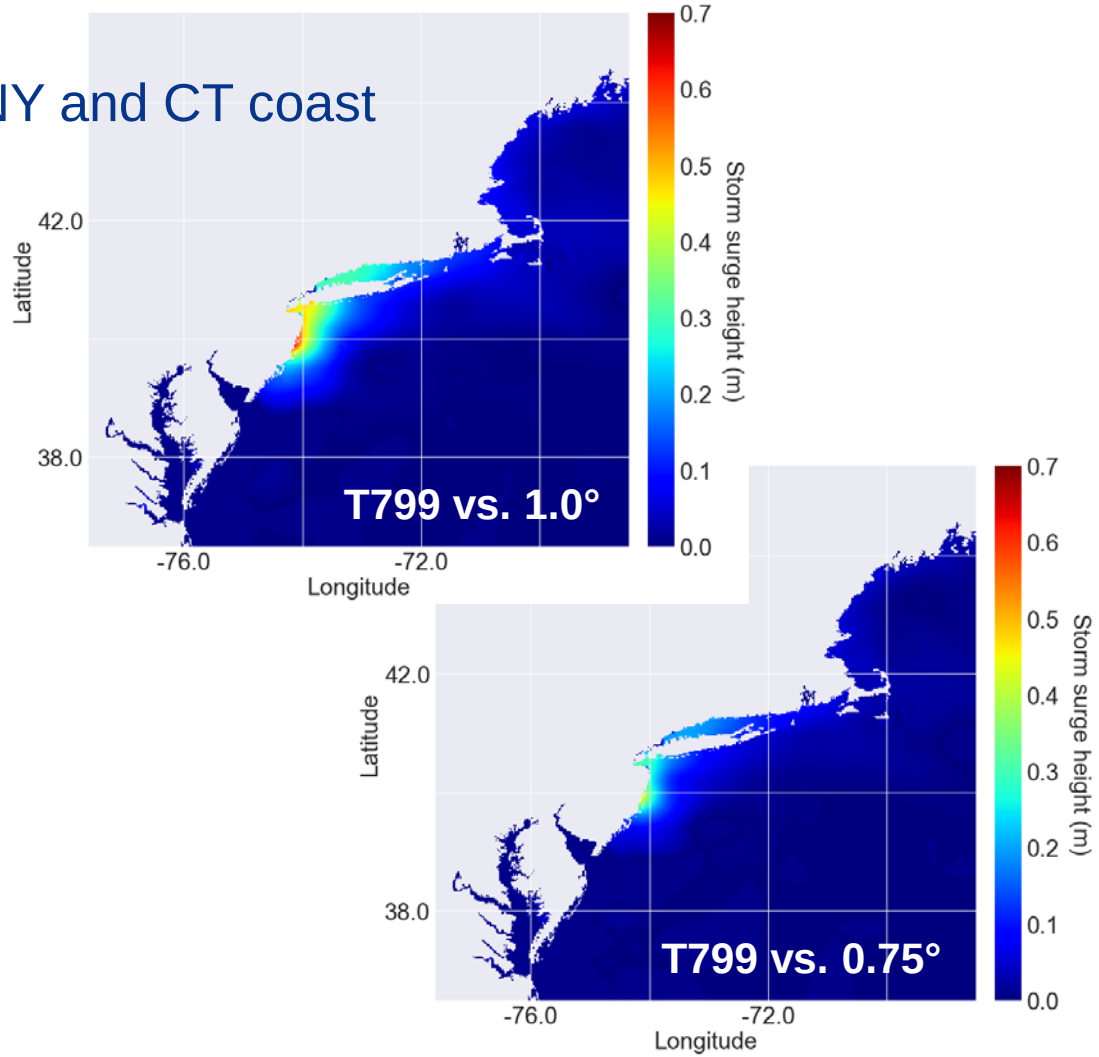
Results: effects of high-resolution forcing



Results: effects of high-resolution forcing

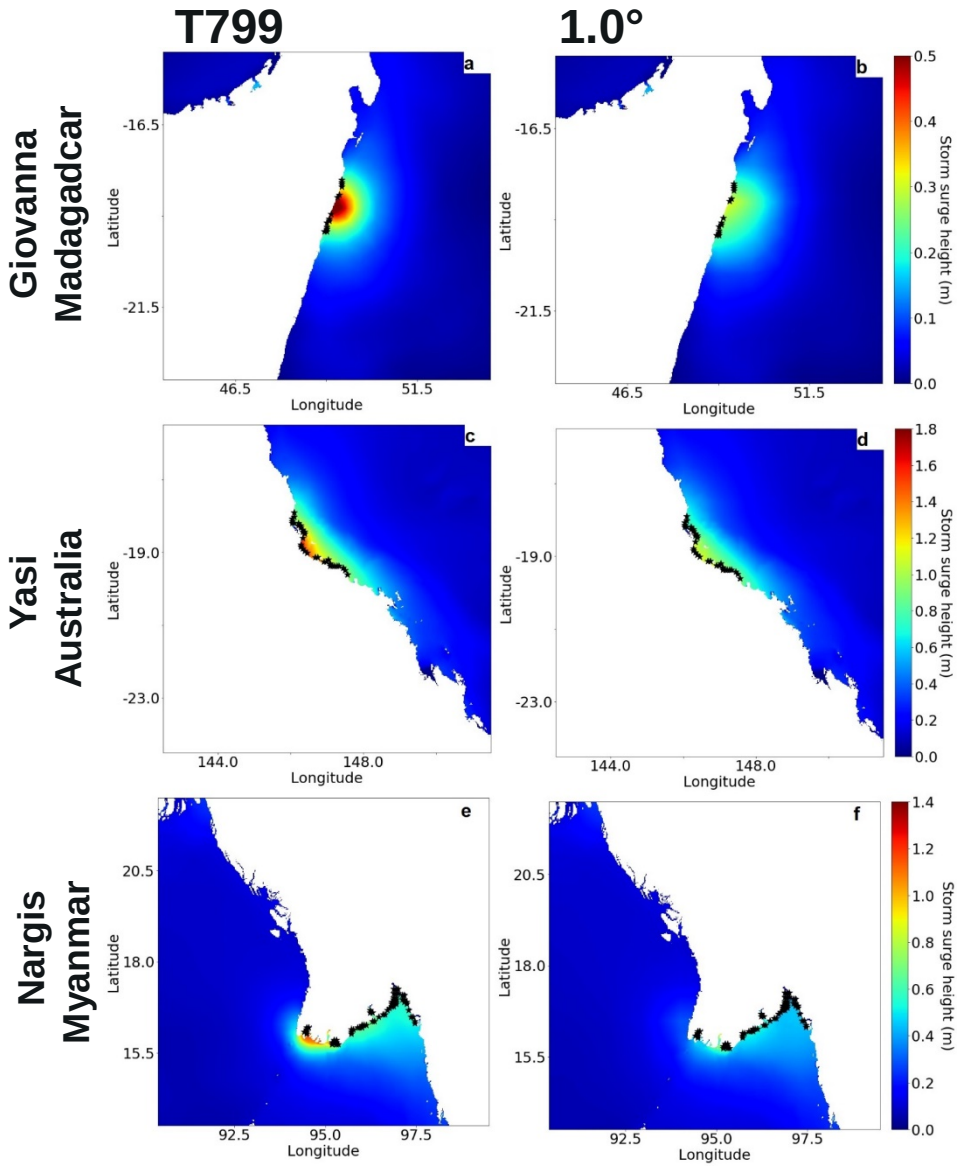
- Large effect of resolution for NJ, NY and CT coast

	Maximum surge (m)	Diff (m)	Diff (%)
T799	1.80		
0.25°	1.80	-0.05	-2
0.30°	1.76	0.07	3
0.40°	1.72	0.12	5
0.50°	1.69	0.22	9
0.75°	1.59	0.44	18
1.0°	1.47	0.57	23



Results: surge heights for other case studies

- Also the other case studies show a strong decrease in maximum surge height



Results: Max. surge heights at different resolutions

TC	T799	0.50°	0.75°	1.0°
Patricia	**0.19**			
Haiyan	**0.92**			
Sandy	**2.47**			
Giovanna	**0.47**			
Yasi	**1.85**			
Nargis	**1.39**			
Gonu	**0.56**			

Maximum storm surge heights (m) and difference (m) compared to T799

Results: Max. surge heights at different resolutions

TC	T799	0.50°	0.75°	1.0°
Patricia	**0.19**	0.01	0.00	0.02
Haiyan	**0.92**	0.28	0.43	0.50
Sandy	**2.47**	0.22	0.44	0.57
Giovanna	**0.47**	0.09	0.13	0.17
Yasi	**1.85**	0.14	0.35	0.52
Nargis	**1.39**	0.52	0.58	0.62
Gonu	**0.56**	0.10	0.15	0.14

Maximum storm surge heights (m) and difference (m) compared to T799

Maximum storm surge heights at different resolutions

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Table 2: Maximum storm surge heights (m) and difference (m) compared to T799

Differences can be split up in two groups: <0.2 m (green) and >0.5 m (red).

Maximum storm surge heights at different resolutions

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Table 2: Maximum storm surge heights (m) and difference (m) compared to T799

Highest storm surges induce the largest differences

Factors like tropical cyclone intensity and size, coastline complexity may also influence

Conclusions

- The current resolution of climate models (10-30 km) enables the direct application to TC surge modelling
- Validation of Sandy shows a good performance of ECWMF IFS forcing
- High-resolution forcing most beneficial in regions with high surge heights, which would be severely underestimation in low-resolution forcing

Thank you for your attention!

- For more information:

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