Towards Coastal Inundation in JULES

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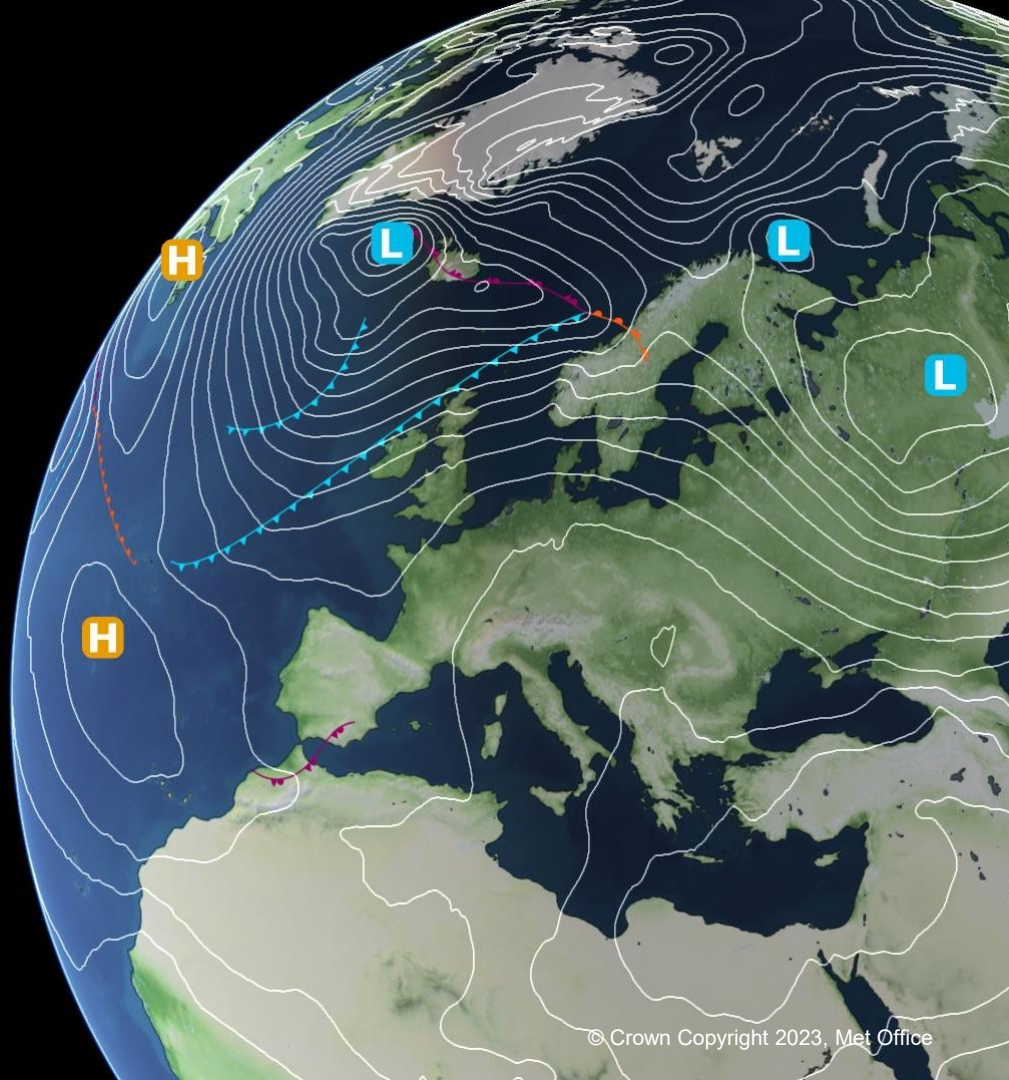


Coastal Hazards

- Enhancing the capability to predict extremes is an important motivation for developing environmental models
- Extreme events are often compound events (Zscheischler et al. 2018)

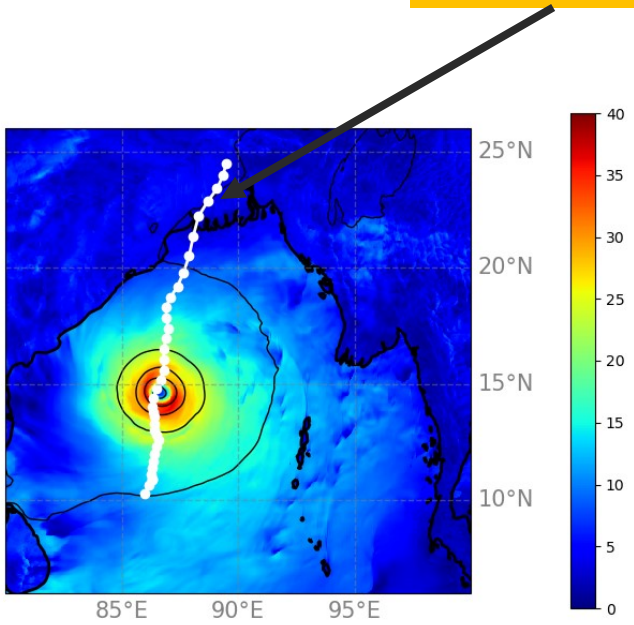
- Coastal regions, less than 10 m above sea level are densely populated and population density is increasing (McGranahan et al. 2007)
- Sea level rise due to climate change will increase the frequency of coastal flooding significantly (Taherkhani et al. 2021)

Sea level

- The geoid: Mean sea level allowing for gravity and the Earth's rotation, but neglecting winds and tides (extended below land areas)
- Deviations from the geoid
  - Tides
  - Atmospheric effects, especially storm surges
    - Surface Stress exerted by wind
    - Surface pressure
- Waves
  - Swash: Short-term transient changes in water level
  - Set-up: Mean water level higher in-shore from breaker line
- Climate change: thermal expansion
- (Changes in land elevation in some coastal areas)

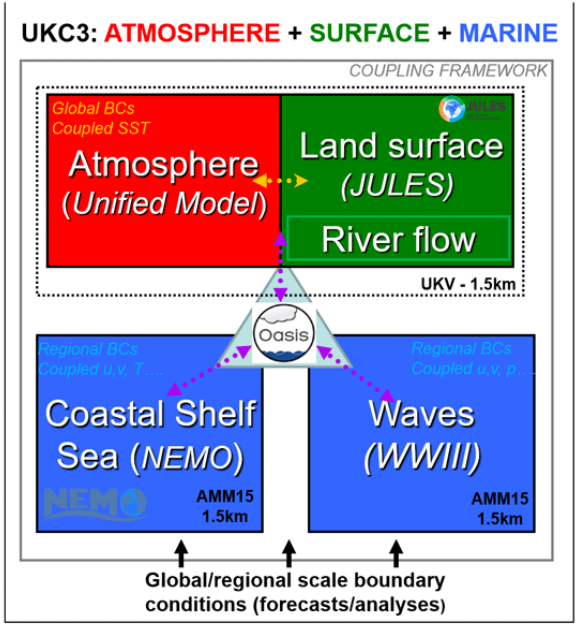
Tropical Cyclone Amphan: May 2020

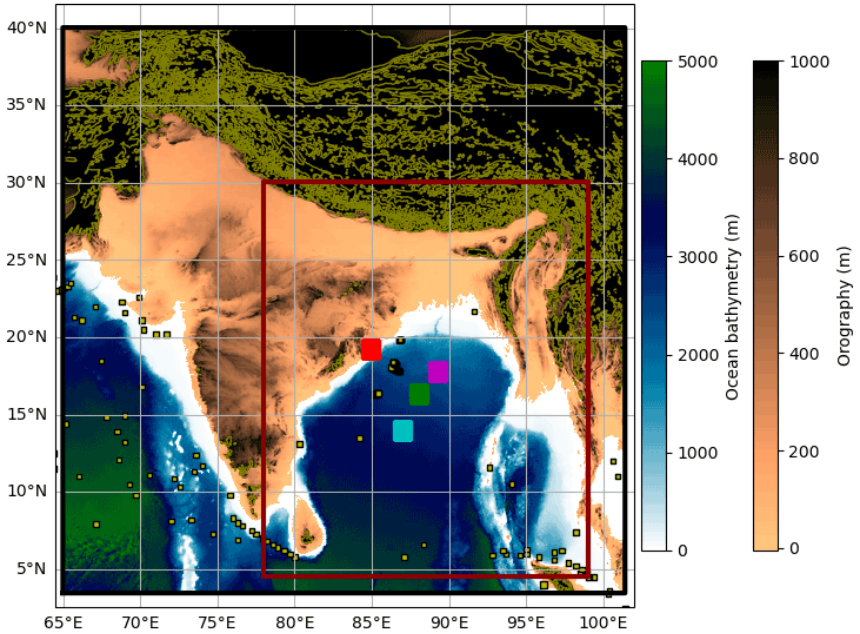
- Rapid intensification from 12 UTC on 17th May
- Most Intense at 12 UTC on 18th May: Min p = 901 hPa, wind 74ms^{-1}
- Weakened by shear over the next 24 hours
- Landfall at 9 UTC on 20th May, Min p = 964 hPa, wind 40 ms^{-1}



Simulated wind speed at 12 UTC on 18/5/20

The Regional Coupled Suite (RCS)



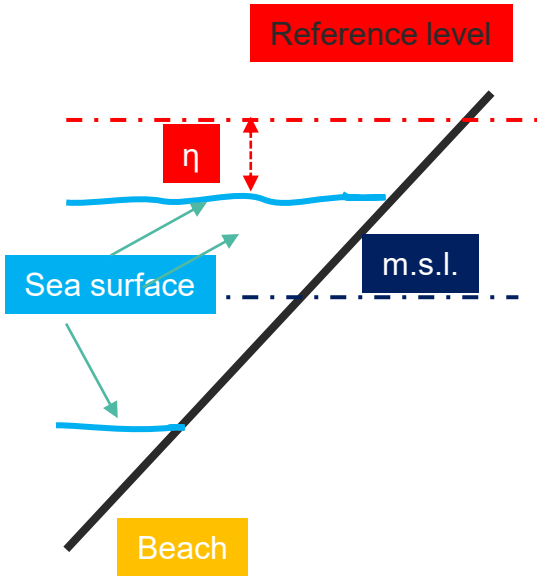


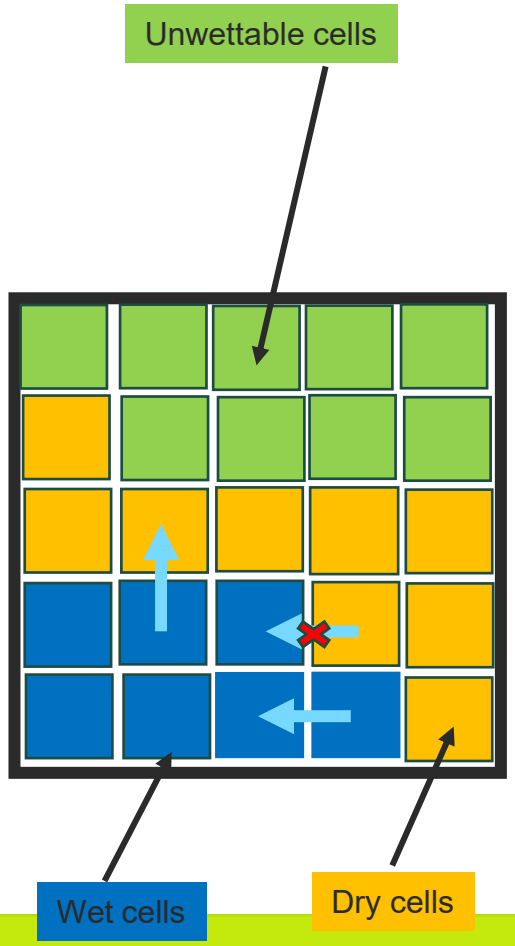
Lewis et al. (2019) GMD

Castillo et al. (2022) GMD

Wetting and Drying in NEMO

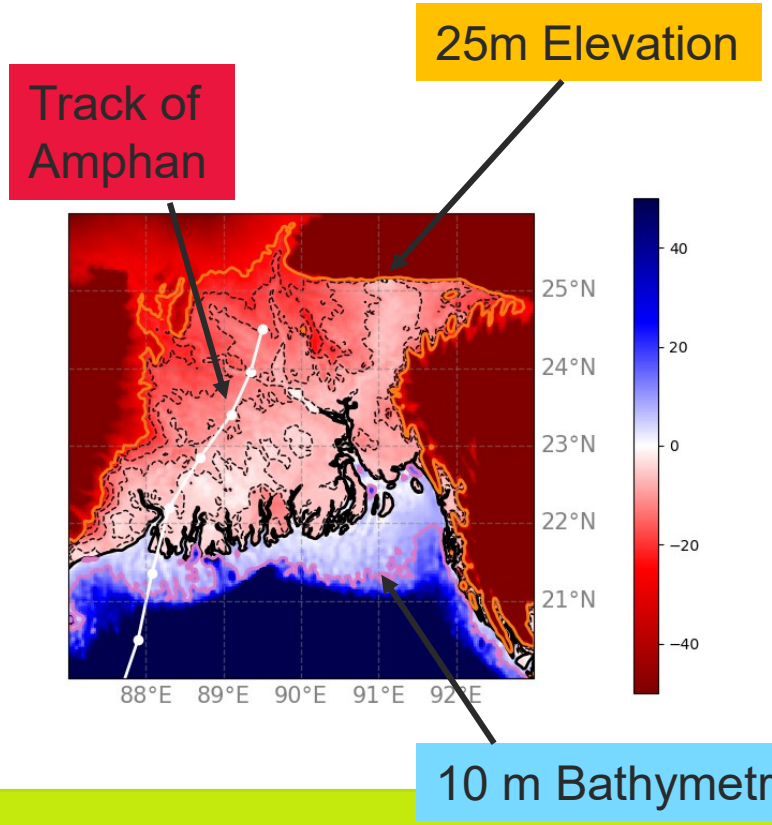
- O'Dea et al. (2020) – **Flux Limiter**
- Define maximum wettable domain below reference height
- Cells are either wet or dry (min. water level in dry cells)
- No flux out of dry cells



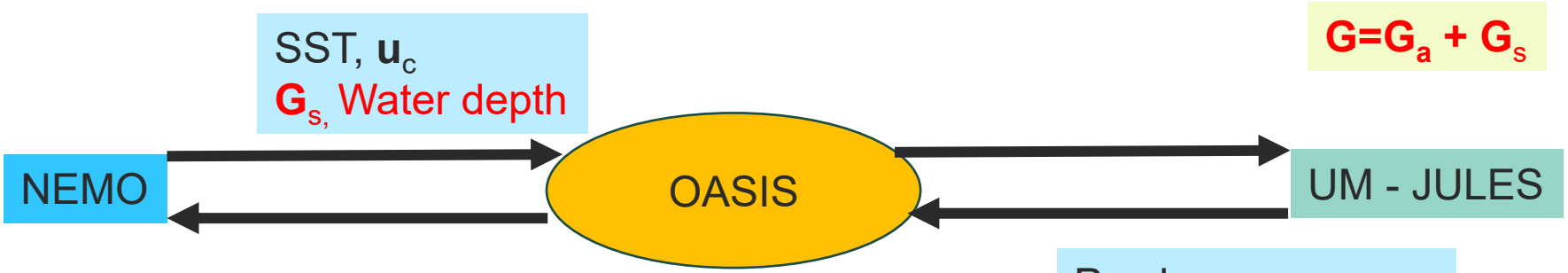


Wetting and Drying in the RCS with JULES

- Extend domain of JULES outwards to include all areas that might be exposed at low tide
  - Here down to 10 m bathymetry
- Extend domain of NEMO inland to allow for high tide, surge and wave effects
  - Here 25 m elevation as a generous estimate
- Need to regenerate the land surface ancillaries and NEMO domain_cfg.nc file



Coupling Fields: Initial Atm.-Ocean Version



Coupling to the seabed allows scaling of surface fluxes in shallow water to be turned off in NEMO

Met Office

Boundary and Initial Conditions

- Atmospheric boundary conditions from the UM
- Ocean boundary conditions on original ocean domain generated by NOC, but only up to 2019, before Amphan
- New boundary conditions generated directly from Copernicus data
- Initial ocean state taken from long spin-up of ocean-only run on original domain – still not happy with the ocean state here
- **Barotropic transports must be preserved to avoid initialization shocks**
- **Initial currents in the coastal zone on the new domain are scaled down to avoid initialization shocks**

Met Office

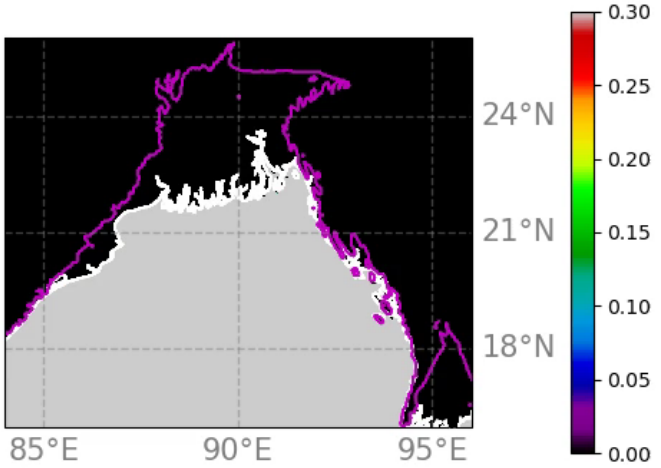
Modifications in NEMO

- Time-stepping of ocean velocities takes place in two stages
  - Update the free-surface height and depth-integrated (barotropic) velocities explicitly
  - Apply vertical diffusion of momentum to 3D velocities in column of fixed depth implicitly
  - Adjust 3D velocities so that depth-integrated values match barotropic estimate
- …Acceleration in the barotropic solver
  - This scheme works well in deep water, but gives large barotropic accelerations in shallow water
  - Barotropic bottom friction requires modification for consistency with evolving currents
- Other modifications
  - Limit length-scales in GLS turbulence and ensure diffusivity cannot vanish in shallow water
  - Turn on adaptive implicit vertical advection

Current simulation of Amphan

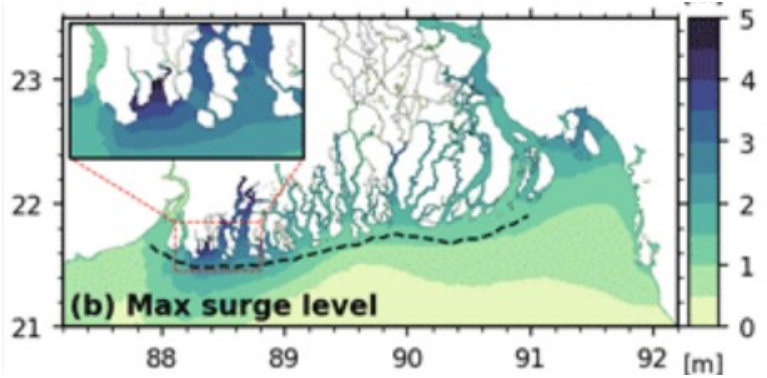
Coastline: white
Wettable domain: magenta

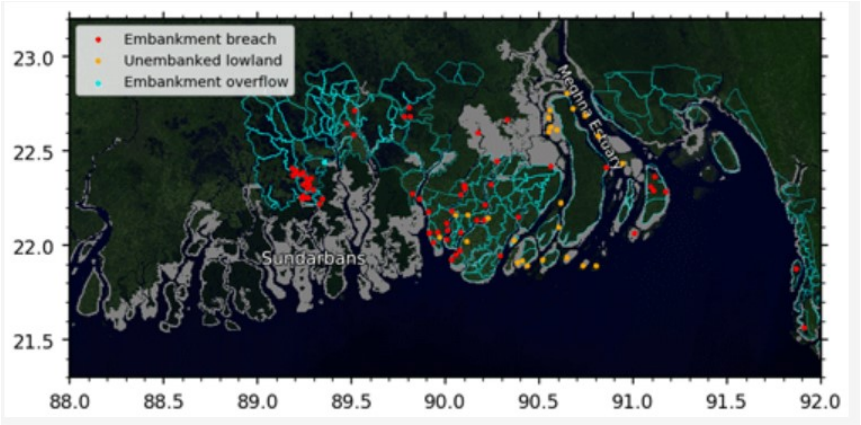
- Simulation runs from 0Z on 17th May to 0Z on 22nd May
  - Colours show water depth (note range)
  - Contours show PMSL
- Surge currently seems too low and runs too far inland
  - The momentum budget of the column requires careful analysis



High-Resolution Modelling of Amphan (Khan et al., 2021)

- Dedicated hindcast simulations on an unstructured mesh
  - SCHISM coastal ocean model (Zhang et al. 2015)
  - Unstructured mesh down to 250 m
  - WW3 wave model
  - Wind forcing from GFS + Vortex
- Importance of embankments and local flood defences





Summary

- Basic version of wetting and drying running within the RCS
- Significant further work is required to develop a fully working system
  - Improvements needed to match the performance of alternative uncoupled models (e.g. Khan et al. 2021) – nesting?
  - Tuning
  - Drag on land including submerged vegetation
  - High-resolution topography and coastal defences