# CFD Simulation of Storm Surges on the Irish West Coast Using MÉRA Data

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US-Ireland Project "Understanding Extreme Nearshore Wave Events through Studies of Coastal Boulder Transport"
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**Slides**: available upon request.

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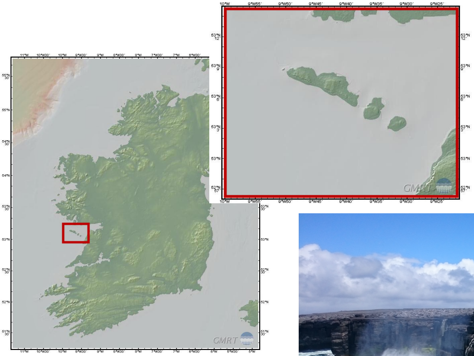
Dá bhfuil romhainn
Science Foundation Ireland
For what's next

# Boulders on the Aran Islands, Co. Galway

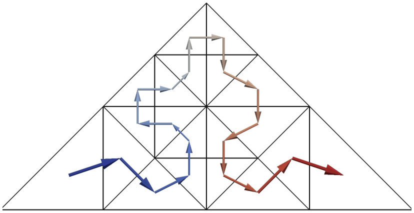


# Discontinuous Galerkin Model: StormFlash2d [in short]

- Non-linear 2D Shallow Water Equation (in strong form):

$$\int_{\Omega_i} \mathbf{U}_t \varphi_j \mathrm{d}\mathbf{x} + \int_{\Omega_i} \nabla \cdot \mathbf{F}(\mathbf{U})\, \varphi_j \mathrm{d}\mathbf{x} + \int_{\partial\Omega_i} (\mathbf{F}^*(\mathbf{U}) - \mathbf{F}(\mathbf{U})) \cdot \mathbf{n}\, \varphi_j \mathrm{d}S = \int_{\Omega_i} S(\mathbf{U}) \varphi_j \mathrm{d}\mathbf{x}$$

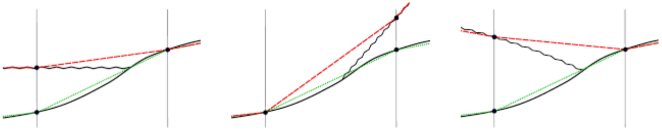
- Nodal DG Discretization with explicit Runge-Kutta Integration (cf (Giraldo & Warburton, 2008, Hesthaven & Warburton, 2008))
- Control Inundation and Fluxes with Slope Limiters (Kuzmin, 2010, Vater et al., 2015)
- Adaptive Mesh Refinement (Behrens et al., 2005, Behrens, 2006)



# Slope Limiters I

(Vater, B & Behrens, 2017)

Remove artificial gradients:



Slope limiters scale locally, e.g.

$$\hat{H}(x) = H_c + \alpha_e (\nabla H)_c \cdot (x - x_c), \quad 0 \leq \alpha_e \leq 1,$$

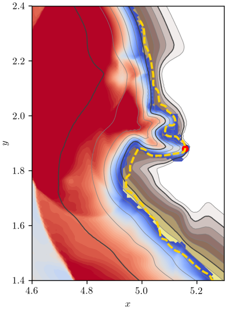
# Slope Limiters II

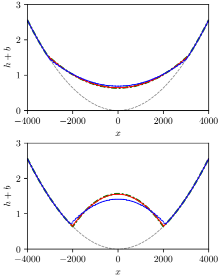
**Velocity-Based Wetting and Drying Treatment**

1. Flux modification: $g \leftarrow 0$ (in semi-dry cells).
2. Limiting of fluid depth
   - Slope limit total height $H = h + b$.
   - Apply PP procedure following Bunya et al., 2009 to limited $\hat{h}$ obtained from $\hat{H}$.
3. Limiting of momentum
   - Slope limit velocities at triangle vertices.
   - Extrapolate in-cell velocity distribution from two out of three vertex values.
   - Determine discrete in-cell velocity variation from the three distributions.
   - Compute limited momentum from velocities with smallest variation and limited fluid depth.

# Applications of StormFlash2d

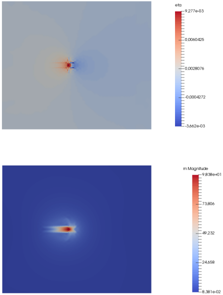
Okushiri Tsunami (1993)




Long wave resonance in a parabolic basin (Thacker, 1881)

Simplified Hurricane Propagation

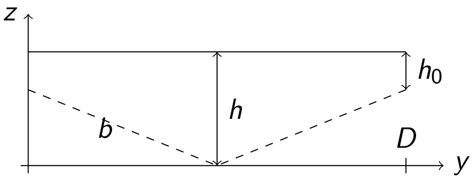


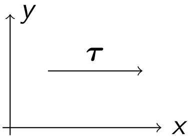
# Circulation in a Semi-Enclosed Basin I

In a rectangular domain $\Omega = [0, 100, 000] \times [0, D]$ with $D = 50, 000$ a triangular bathymetry of depth $h \in \mathbb{R}$ of the form

$$b(\mathbf{x}) = \frac{2(h - h_0)}{D}\left|y - \frac{D}{2}\right|$$

and minimum water depth $h_0$, a constant wind field $\boldsymbol{\tau}$, aligned with the $x$-axis is prescribed.



# Circulation in a Semi-Enclosed Basin II

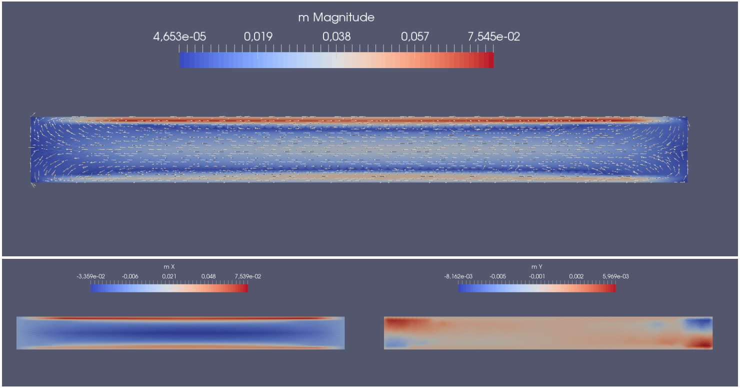



Figure: Circulation in a Semi-Enclosed Basin: Momentum (magnitude) top; $x$-, and $y$-component of momentum bottom

# A Closer Look at Source Terms

## Flux Function

$$\mathbf{F}(\mathbf{U}) = \begin{bmatrix} h\mathbf{u} \\ h\mathbf{u} \otimes \mathbf{u} + \frac{g}{2} h^2 \mathbf{I}_2 \end{bmatrix}$$

- $h$ height of water column
- $\mathbf{u}$ 2D velocity

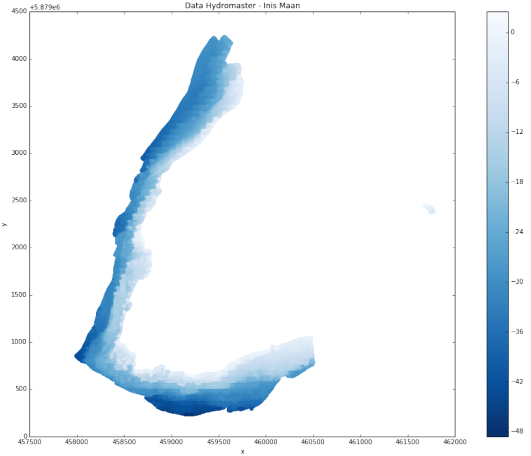
## Source Term

$$S(\mathbf{U}) = - \begin{bmatrix} 0 \\ gh\nabla b - \frac{\gamma_\tau \boldsymbol{\tau}}{h\rho} + \frac{h}{\rho}\nabla p_A + fh\mathbf{u} + \boldsymbol{\tau}_b \end{bmatrix}$$

- $b(\mathbf{x})$ bathymetry
- $\boldsymbol{\tau}$ wind stress and $\boldsymbol{\tau}_b$ is the bottom friction
- $p_A$ atmospheric pressure
- $f$ Coriolis parameter

# Aran Islands Bathymetry Data

Mainly: INFOMAR (Chatton, 2018)
+ EMODnet (.125°) and GEBCO
+ Hydromaster



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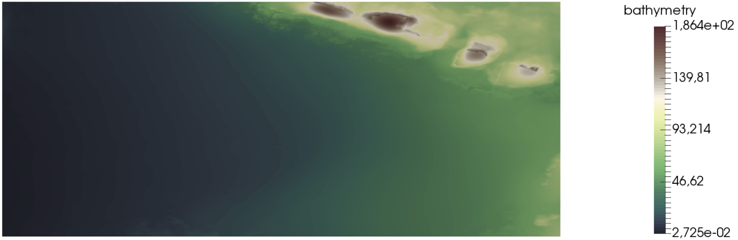
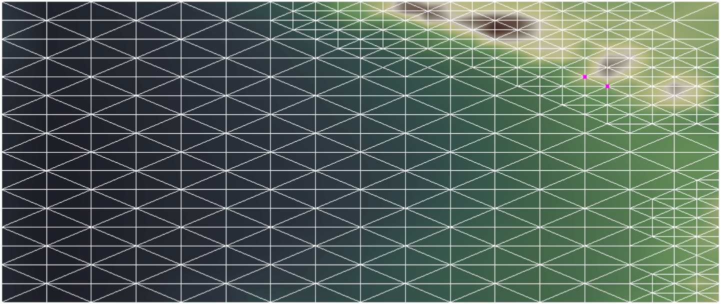


# Reduce Computations → Adaptive Mesh

Heuristic refinement indicator $\eta_{\text{ref}}(\mathbf{x}) = \nabla b(\mathbf{x})$
$+$ tolerance $\lambda_{\text{ref}} = 0.2$
$+$ next neighbour refinement



# MÉRA Data

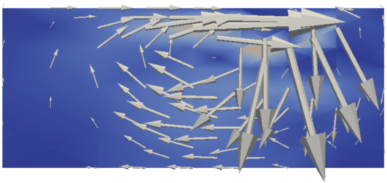
We took cut outs from

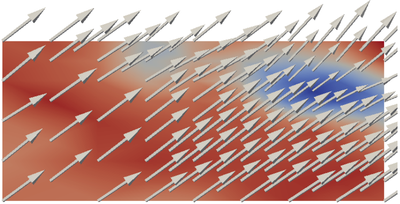
- 10m winds
- surface pressure
- Region lon/lat in $[-10, -9] \times [52, 54]$

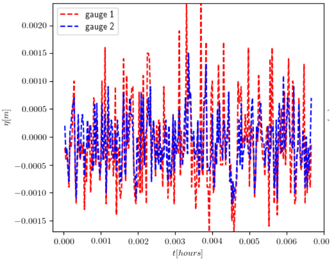
**Convert to Netcdf using CDO**

cdo -f nc setgridtype,curvilinear filein fileout.nc
cdo sellonlatbox,lon_min,lon_max,lat_min,lat_max fileout.nc fileoutCUTOUT.nc

# First Results ($t \ll 1$ hour)








Bottom friction with $n = 0.01$.

# What's to come...

## Summary

- Introduction DG model StormFlash2d for storm surges
- Viability of MÉRA data for use in DG flood model

## Outlook

- Run DG model for longer times (several months)
- Train grid generator to use dynamic refinement indicators such as { bathymetry gradients } + { large wind speeds }
- Data analysis and post-processing