A 1-D model for predicting surf zone waves around the Irish Coast

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European Geosciences Union

Abstract: *Ireland's extended coastline and its vulnerability to extreme wave events make it crucial to understand wave climate and its changes around the Irish coast. The* ***DeWaPIC*** *project intends to create a model framework for predicting waves around Ireland on time scales of seasons to decades. This contribution will present the approach taken to the development of a 1-D SURF zone model.*

Why Ireland?

- Its location in Northeast Atlantic.
- Most Irish cities are coastal.
- More than 50% of population resides within a radius of 15 km of the coast [Flood et.al, 2020].
- Complicated geomorphology.
- High rates of waves in Southwest of Ireland.

Source (5)

Research Questions ?

- Is it possible to predict waves around the Irish coast on climatological scales?
- How waves around the coast of Ireland change on different time scales from seasonal to decadal?
- Can statistical methods be applied for improving the climatological wave predictions around the Irish coast?

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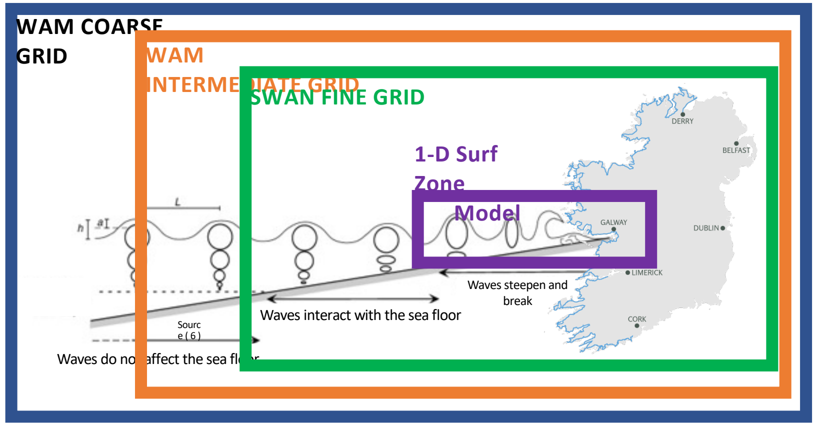
Methodology



WAM: Wave Action Model
SWAN: Simulating WAves Nearshore
1-D Surf Zone Model : 1 – Dimensional Surf Zone Model

Numerical scheme employed for developing 1-D Surf zone model

1 D Boussinesq equation [Madsen & Sorensen, 1992] is used to compute the surface elevation

$$\eta_t + q_x = 0 \quad (1)$$

$$\bar{q}_t + (\frac{q^2}{d} + \frac{q\eta^2}{2} + gh\eta)_x = g\eta h_x - \frac{q|q|}{d^2C^2} + Bgh^3\eta_{xxx} + 2Bgh^2h_x\eta_{xx} \quad (2)$$

$$\bar{q} = q - (B + \frac{1}{3})h^2q_{xx} - \frac{1}{3}hh_xq_x \quad (3)$$

Eq (1) & (2) takes form $U_t + F_x = S$ and on implementing Lax Wendroff two step method :

$$(U_{i+\frac{1}{2}}^{n+\frac{1}{2}})_{LW} = \frac{1}{2}(U_{i+1}^n + U_i^n) - \frac{\Delta t}{2\Delta x}(F_{i+1}^n + F_i^n) - \frac{\Delta t}{4}(S_{i+1}^n - S_i^n) \quad (4)$$

$$(U_i^{n+1}) = U_i^n - \frac{\Delta t}{2\Delta x}[(F_{i+\frac{1}{2}}^{n+\frac{1}{2}})_{LW} + (F_{i-\frac{1}{2}}^{n+\frac{1}{2}})_{LW}] + \frac{\Delta t}{2}[(S_{i+\frac{1}{2}}^{n+\frac{1}{2}})_{LW} + (S_{i-\frac{1}{2}}^{n+\frac{1}{2}})_{LW}] \quad (5)$$

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1. Flood, S., Paterson, S., O'Connor, E., O'Dwyer, B., Whyte, H., Le Tissier, M., Gault, J. 2020. National Risk Assessment of Impacts of Climate Change: Bridging the Gap to Adaptation Action. EPA Research Report (2016-CCRP-MS.39). 78p. ISBN: 978-1-84095-948-2.
2. Liang, D., Liu, H., Tang, H., & Rana, R. (2013). Comparison between Boussinesq and shallow-water models in predicting solitary wave runup on plane beaches. *Coastal engineering journal*, *55*(04), 1350014.
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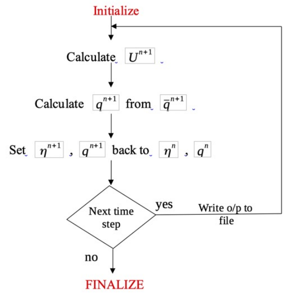
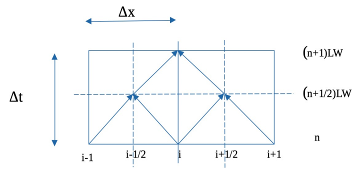
4. Madsen, P. A., & Sørensen, O. R. (1992). A new form of the Boussinesq equations with improved linear dispersion characteristics. Part 2. A slowly-varying bathymetry. *Coastal engineering*, *18*(3-4), 183-204.
5. https://geology.com/world/ireland-satellite-image.shtml
6. https://ars.els-cdn.com/content/image/3-s2.0-B0123693969004949-gr2.jpg.

Computational procedure and stencil





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doi:10.1115/1.4003394

Conclusion

- We develop a 1-D model (Madsen & Sorensen equation) for the surf zone.
- The 1-D model fed by inputs from SWAN can be used to simulate the waves near shore.
- It can be used to study the impacts of waves on the coast, like wave overtopping.
- Wave changes around Ireland with different water level and extreme conditions will be investigated.

Background

Our coasts face huge challenges due to future sea level rise. The main reason for this are the changes in waves which are expected to become more powerful. The prediction of wave changes play an important role in coastal adaptation and in industries like offshore wind energy. The model framework will provide better understanding on wave climate around the Ireland. Also, it investigates the seasonal to decadal variability which is of great importance for planning decisions.

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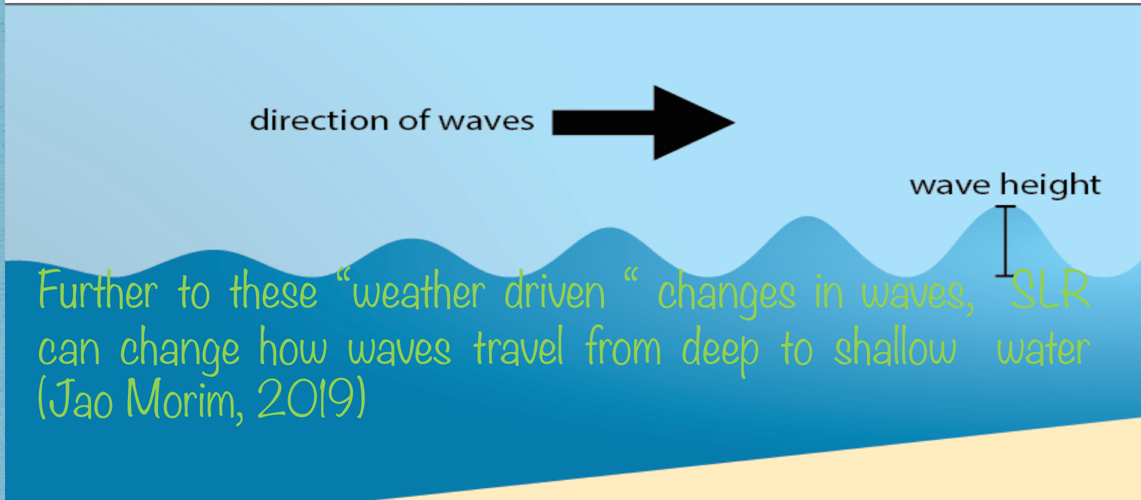
Motivation

How coastline responds to the future climate change?

Sea Level Rise (S.L.R) associated with climate change is the major concern for many islands and coasts.

Is SLR the only way climate change affecting the coast??

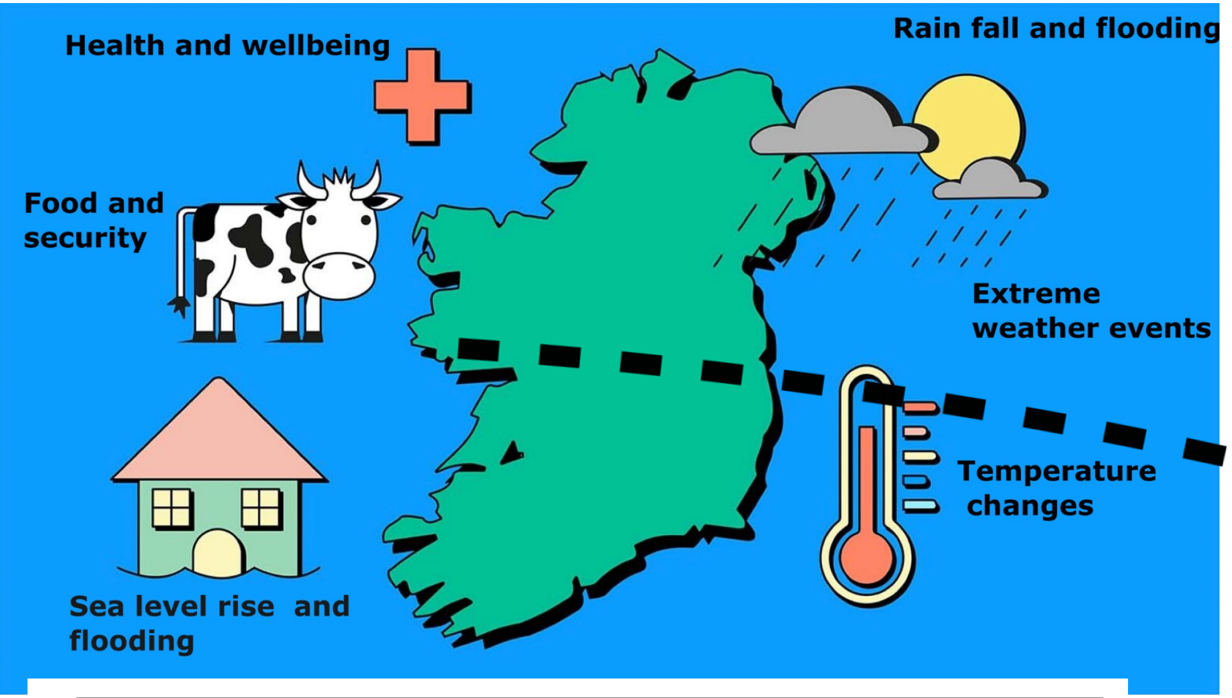
Warming planet will also alter the ocean waves (Jao Mori , 2019)

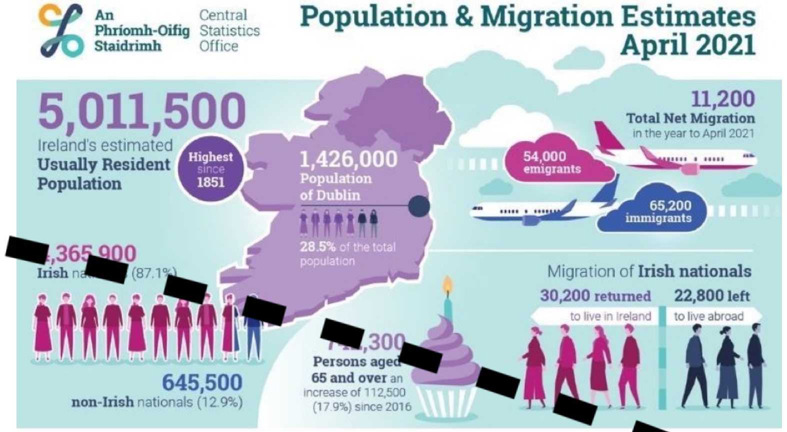


Further to these "weather driven " changes in waves, SLR can change how waves travel from deep to shallow water (Jao Morim, 2019)

Source: https://sp-ao.shortpixel.ai/client/to_webp,q_lossy,ret_img,w_300,h_150/https://hydrizon.com/wp-content/uploads/2021/12/Wave-shaper.png

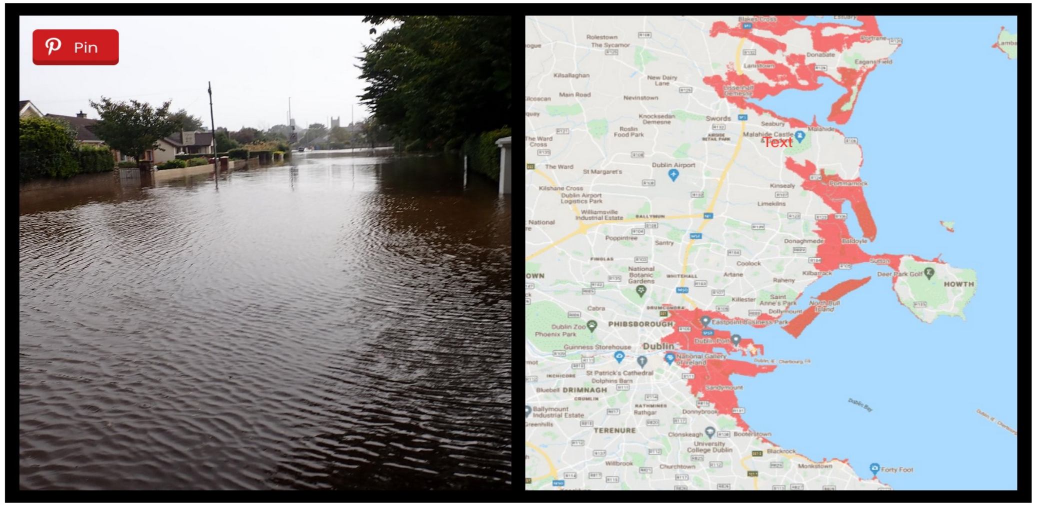
Why Ireland?





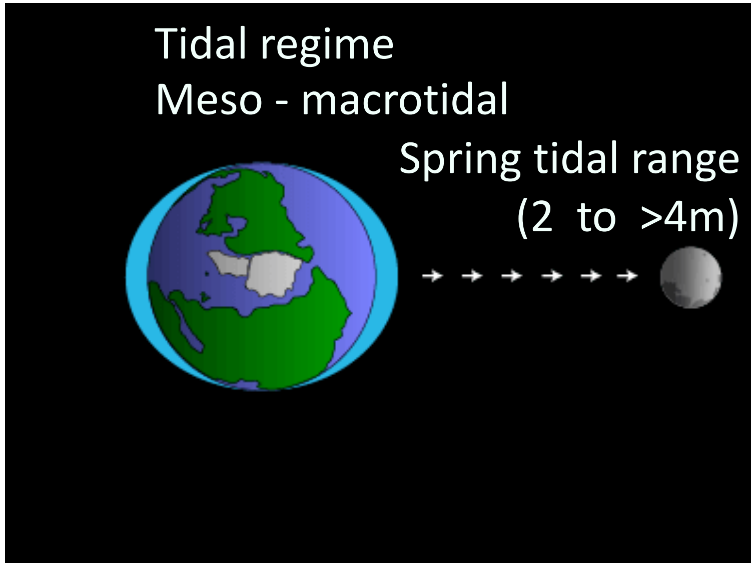
> 50% live within 15 km of coastline (Robert et.al, 2008)

Source : https://www.irishcentral.com/uploads/assets-v2/2021/8/Population.CSO.



A shocking report released by the UN has shown that much of Ireland's coast could be underwater by 2030.

Source: https://www.irelandbeforeyoudie.com/wp-content/uploads/2021/11/underwater.jpg



Source: https://scijinks.gov/tides/tides3.png

Exposed to full effects to eastward moving cyclones and swell energy from N. Atlantic

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Approaches taken for developing the 1D Surf zone model

Shallow water equation

$$\frac{\partial u}{\partial t} = -g\frac{\partial \eta}{\partial x}$$

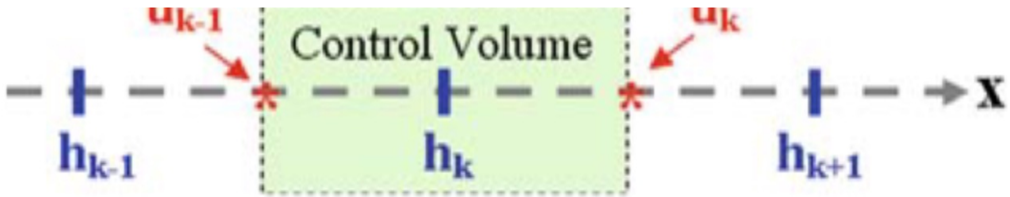
$$\frac{\partial \eta}{\partial t} = -\frac{\partial (u\ h)}{\partial x}$$

Numerical Scheme Shallow water equation
Forward scheme in time and backward scheme in space

$$u_k^{n+1} = u_k^n - \Delta t\ g\left(\eta_{k+1}^n - \eta_k^n\right)/\Delta x$$

$$\eta_k^* = \eta_k^n - \Delta t\left(u_k^{n+1}\ h_e - u_{k-1}^{n+1}\ h_w\right)/\Delta x$$

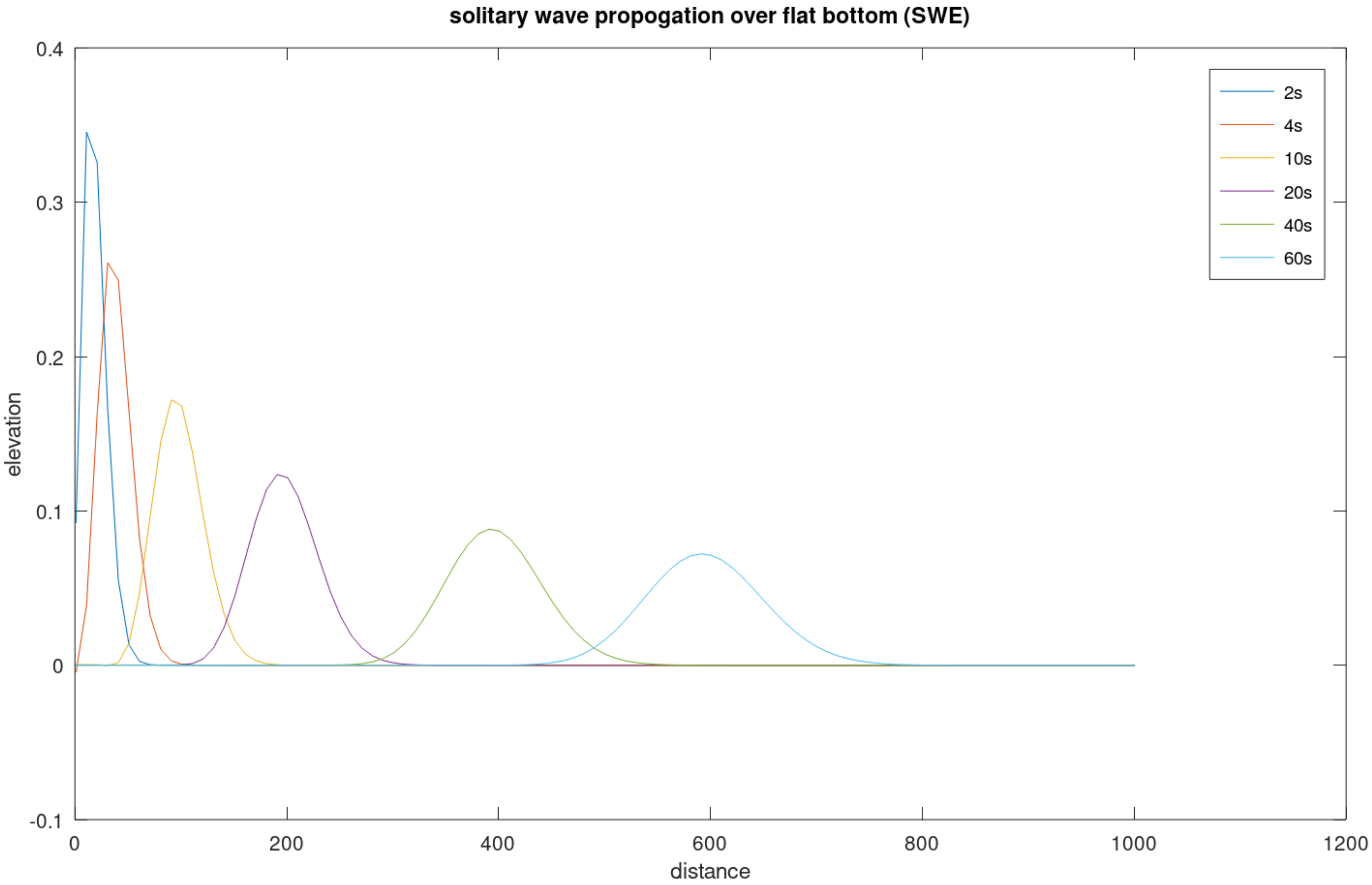
$$\eta_k^* = \eta_k^n - \Delta t/\Delta x\left(u_k^+\ h_k^n + u_k^-\ h_{k+1}^n - u_{k-1}^+\ h_{k-1}^n - u_{k-1}^-\ h_k^n\right)$$

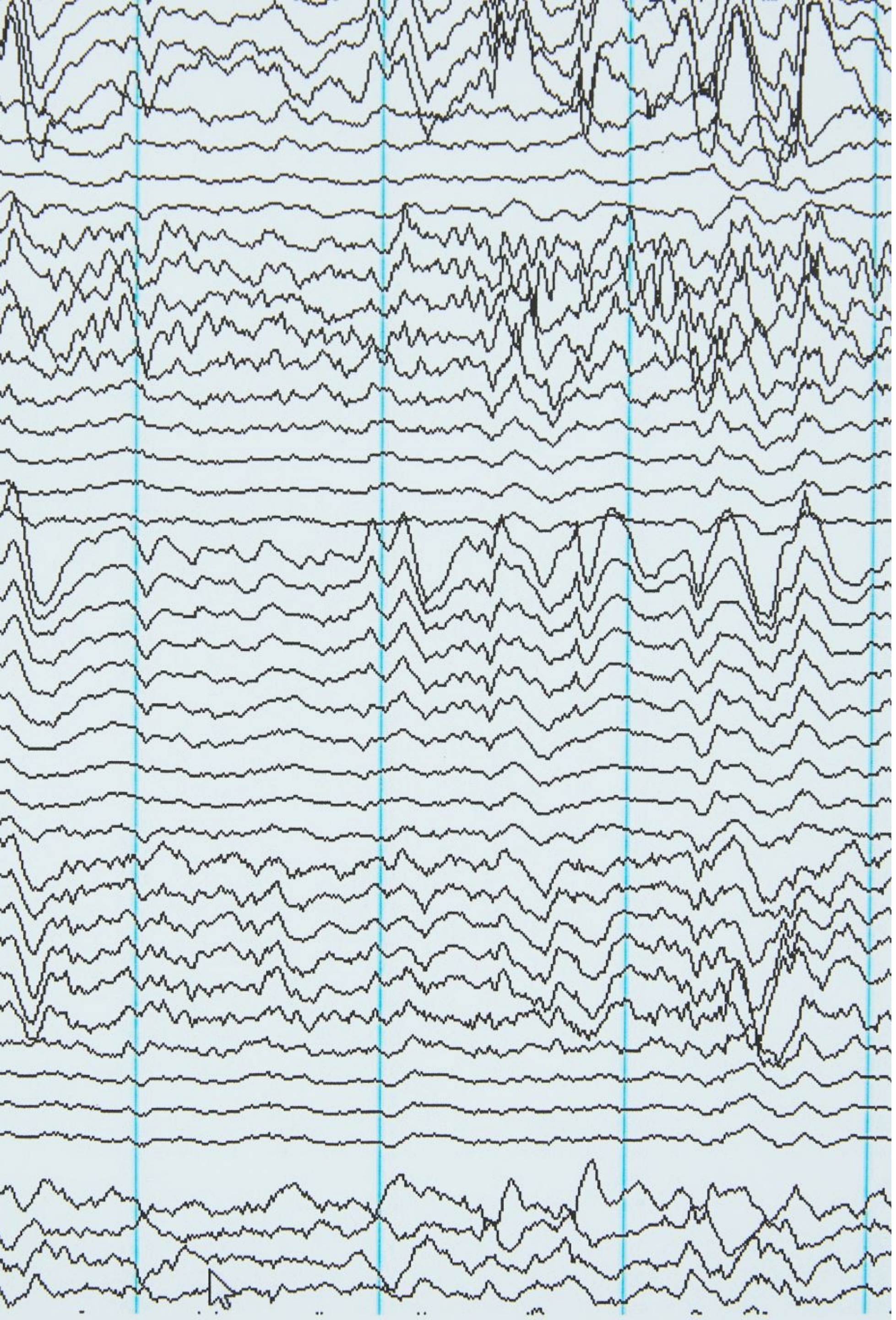


$$u_k^+ = 0.5\left(u_k^{n+1} + \left|u_k^{n+1}\right|\right) \text{ and } u_k^- = 0.5\left(u_k^{n+1} - \left|u_k^{n+1}\right|\right)$$

$$\eta_k^{n+1} = (1-\epsilon)\eta_k^* + 0.5\epsilon(\eta_{k-1}^* + \eta_{k+1}^*)$$

Solitary wave propogation over flat bottom





Why Boussinesq Equation?

- Shallow water equation (SWE) :

The frequency dispersion of water waves is neglected.

Didn't consider short waves.

In propagating the solitary wave using the SWE there has a high amount to attenuation in amplitude.

Non linear dispersive properties of the model can be improved by including the information on the vertical structure of flow.

Boussinesq type model uses some higher order terms in Taylor expansion to include the effects of wave dispersion

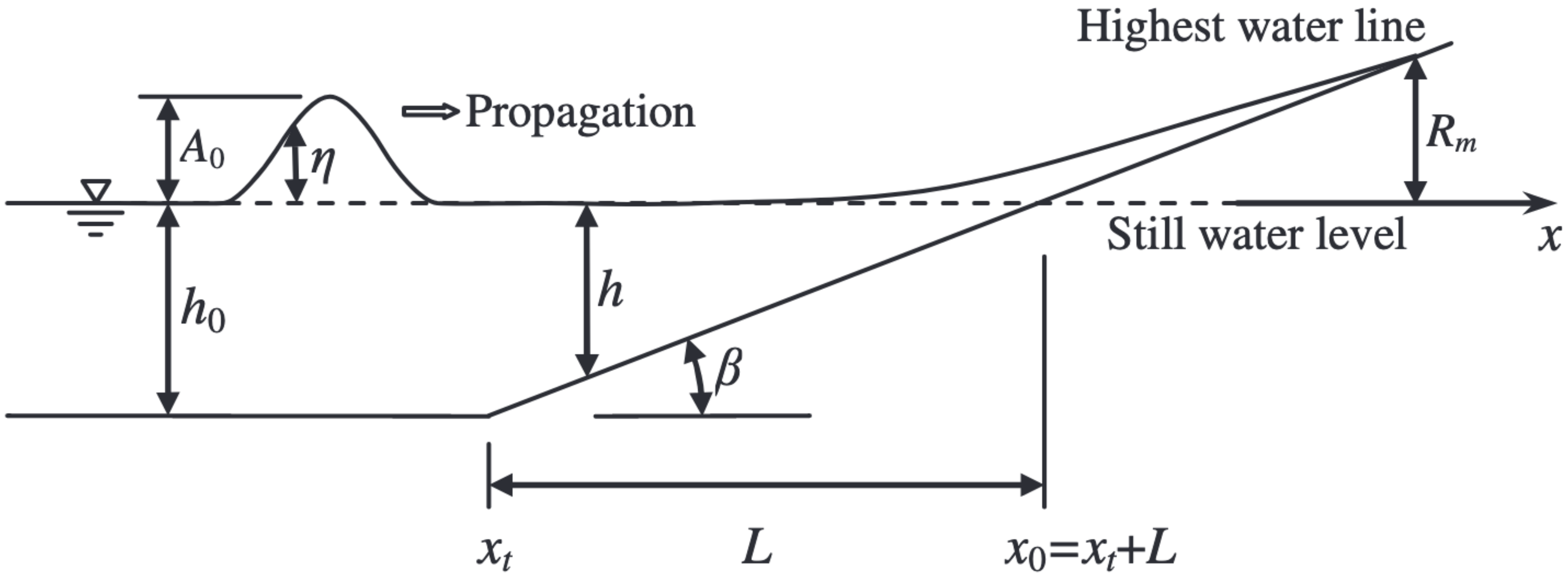
Boussinesq type equation

$$\eta_t + q_x = 0$$

$$q_t + \left(\frac{q^2}{d} + \frac{g\eta^2}{2} + gh\eta\right)_x = g\eta h_x - \frac{\eta^2 g q|d|}{d^{7/3}} + \phi$$

$$\bar{q}_t + \left(\frac{q^2}{d} + \frac{g\eta^2}{2} + gh\eta\right)_x = g\eta h_x - \frac{gq|d|}{d^2 C^2} + Bgh^3\eta_{xxx} + 2Bgh^2 h_x \eta_{xx}$$

η = elevation above still water level
q = volumetric discharge per unit width
h = undisturbed water depth
d = total water depth
g = acceleration due ¿ gravity
$B = 1/15$: dispersion relation
C = Chezy roughness value



Two step Lax Wendroff scheme

$$U_t + F_x = S$$

$$U^{n+\frac{1}{2}}_{i+\frac{1}{2}\;LW} = \frac{1}{2}\ \left(U^n_{i+1} + U^n_i\right) - \frac{\Delta t}{2\Delta x}\ \left(F^n_{i+1} - F^n_i\right) + \frac{\Delta t}{4}\ \left(S^n_{i+1} + S^n_i\right)$$

$$\left(U^{n+1}_i\right)_{LW} = U^n_i - \frac{\Delta t}{\Delta x}\ \left[\left(F^{n+\frac{1}{2}}_{i+\frac{1}{2}}\right)_{LW} - \left(F^{n+\frac{1}{2}}_{i-\frac{1}{2}}\right)_{LW}\right] + \frac{\Delta t}{2}\ \left[\left(S^{n+\frac{1}{2}}_{i+\frac{1}{2}}\right)_{LW} + \left(S^{n+\frac{1}{2}}_{i-\frac{1}{2}}\right)_{LW}\right]$$

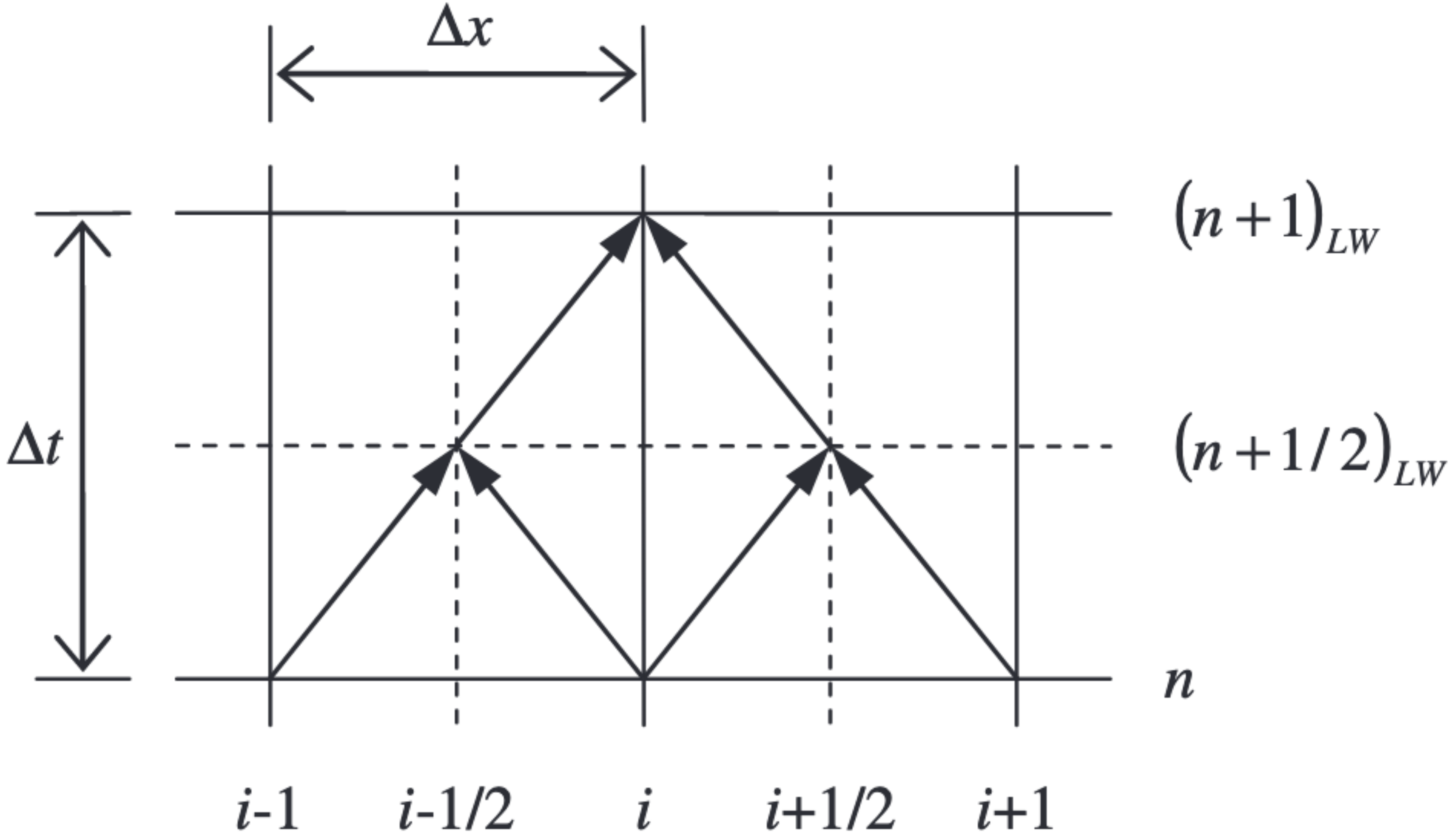
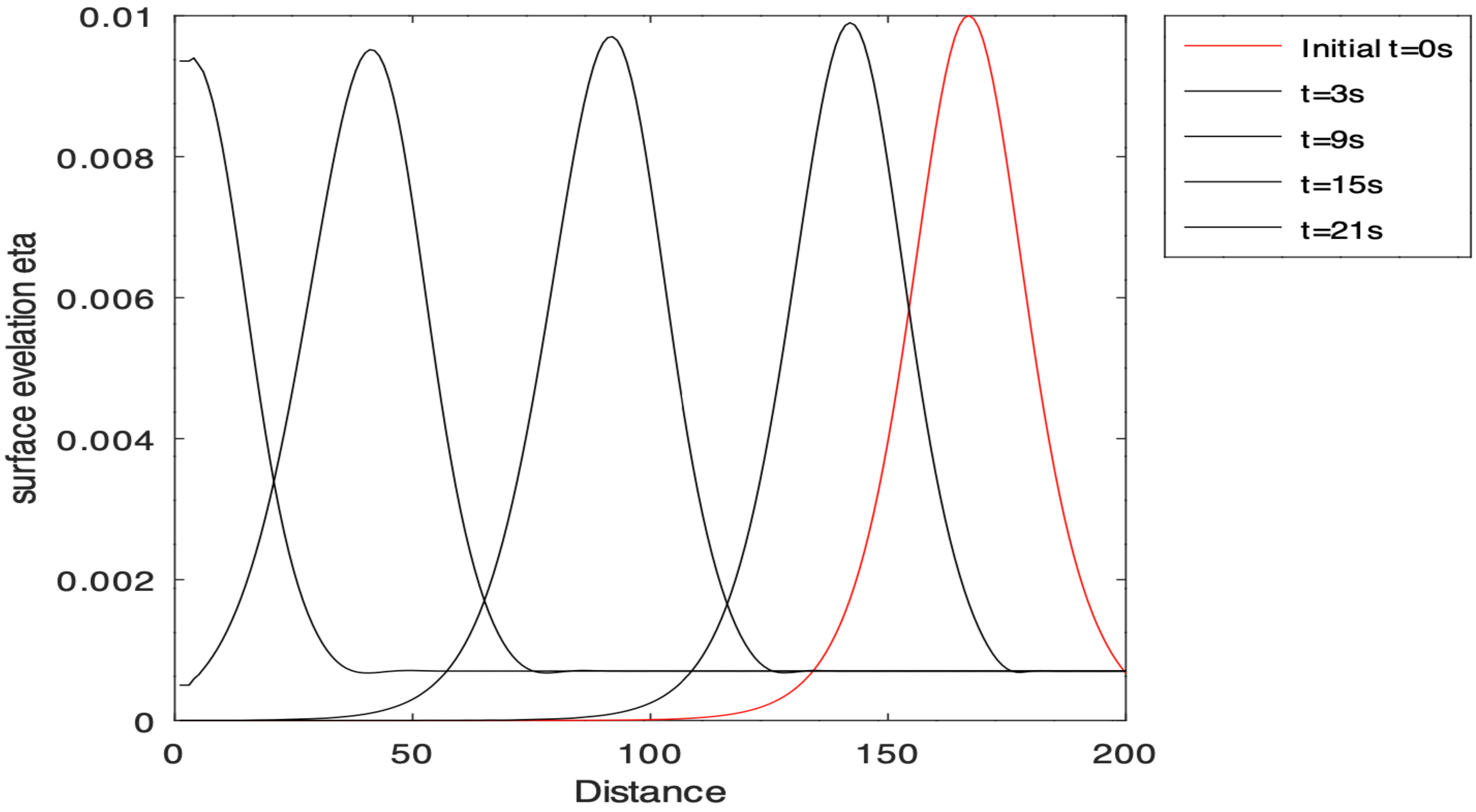


Fig. 2. Sketch of the standard two-step Lax–Wendroff scheme.

Solitary wave propogation over flat bottom using Boussinesq equation



Challenges:

- As it involves higher order derivatives, complex numerical schemes are required to solve the equation.
- Moreover, a large stencil is needed to approximate the high order derivatives
- The development of higher order scheme is not an easy task.