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Assessing the Impact of Tidal-Stream Turbine Rows on the Overtides of the M_2

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Introduction

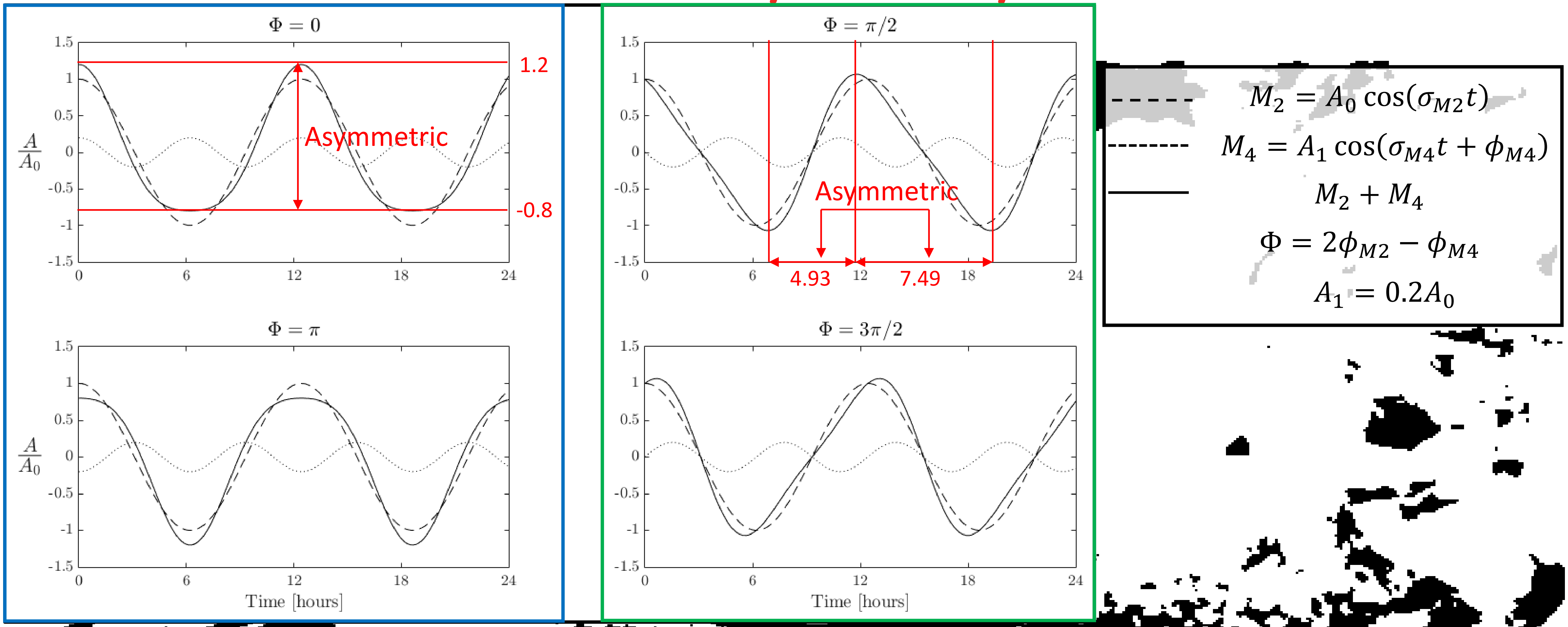
- The distortion to a sinusoid can be represented by an infinite series of harmonic waves.
- If one thinks of the tide as a wave then one can use this method to “measure” the distortion of to the tide in shallow waters.
- Origin of shallow water tidal harmonics.
- Distortion can lead to asymmetry in the tide.

Introduction – Tidal Asymmetry

- Vertical Tide[1]:
    - Variation of surface elevation,
    - **T**idal **D**uration **A**symmetry (TDA)[2]
    - **T**idal **E**levation **A**symmetry (TEA)
- Horizontal Tide[1]:
    - Tidal currents associated with the change in water surface elevation,
    - **F**low **D**uration **A**symmetry (FDA)[2]
    - **F**low **V**elocity **A**symmetry (FVA)[2]

[1]Wang et al. (1999), *Technical Report Z2749 WL Delft*, [2]Gong et al. (2016), *Ocean Dynamics*, **66**:637-658

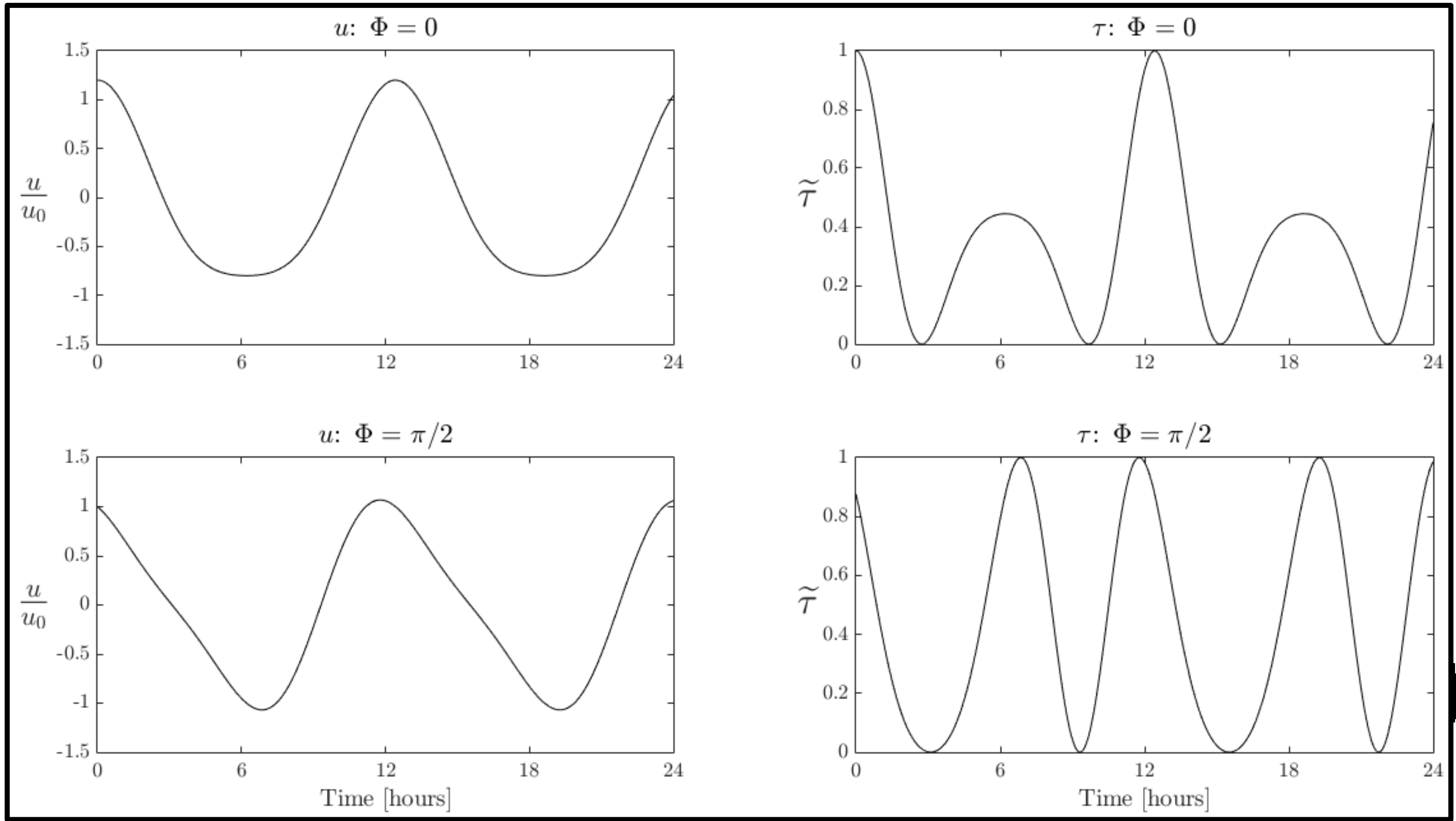
Introduction – Tidal Asymmetry



FVA / TEA

FDA / TDA

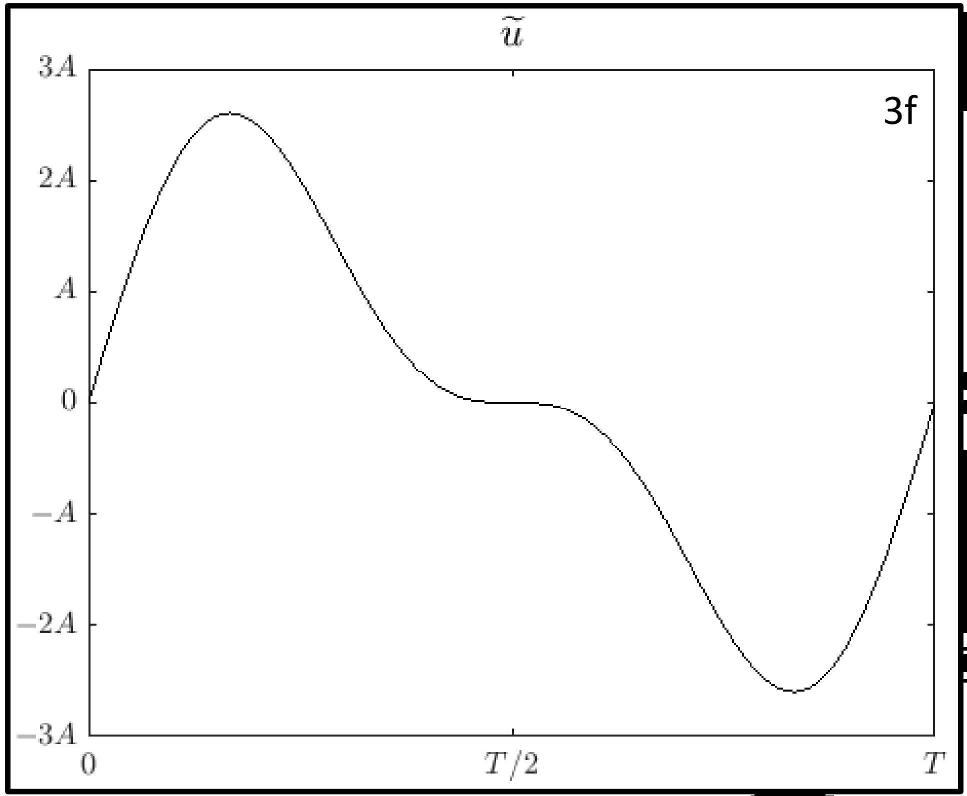
Introduction – Tidal Asymmetry & Transport



$\tilde{\tau} = |\tau/\max(\tau)|$

- Coarser Particles (Bed-Load):
  - Asymmetry in u exaggerated in τ
  - Residual τ in direction of flood → Net transport in flood direction.

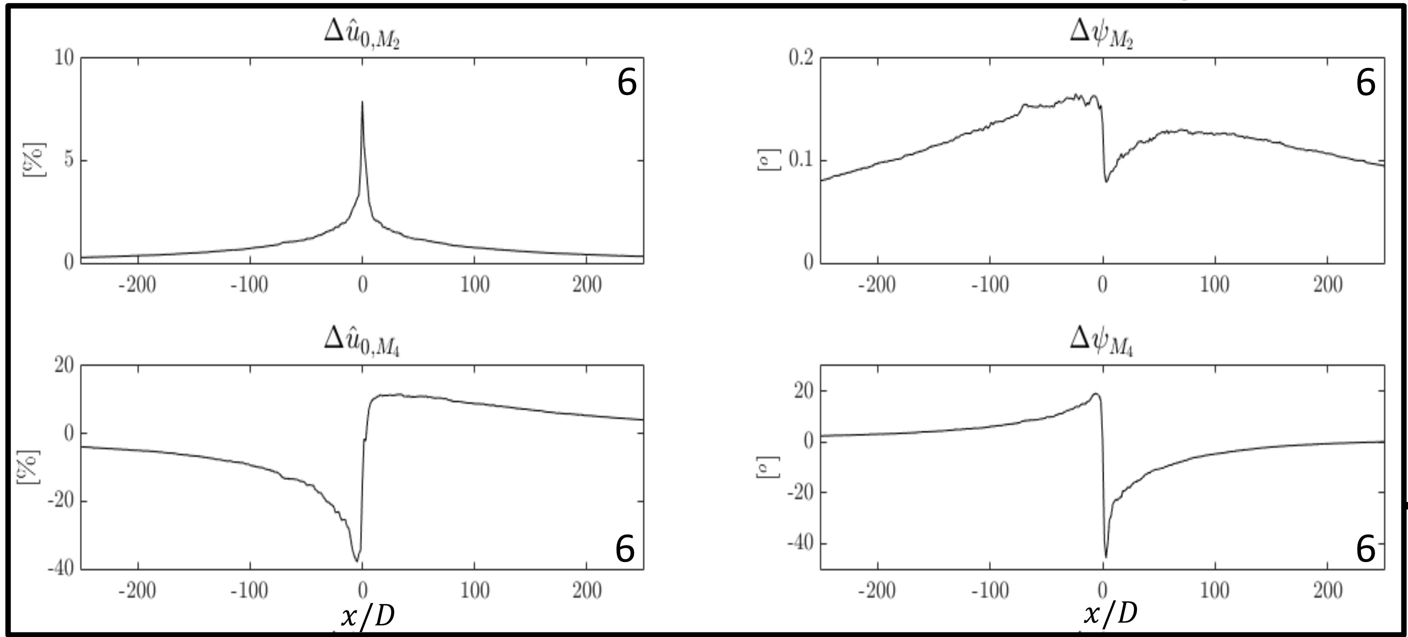
Introduction – Tidal Asymmetry & Transport

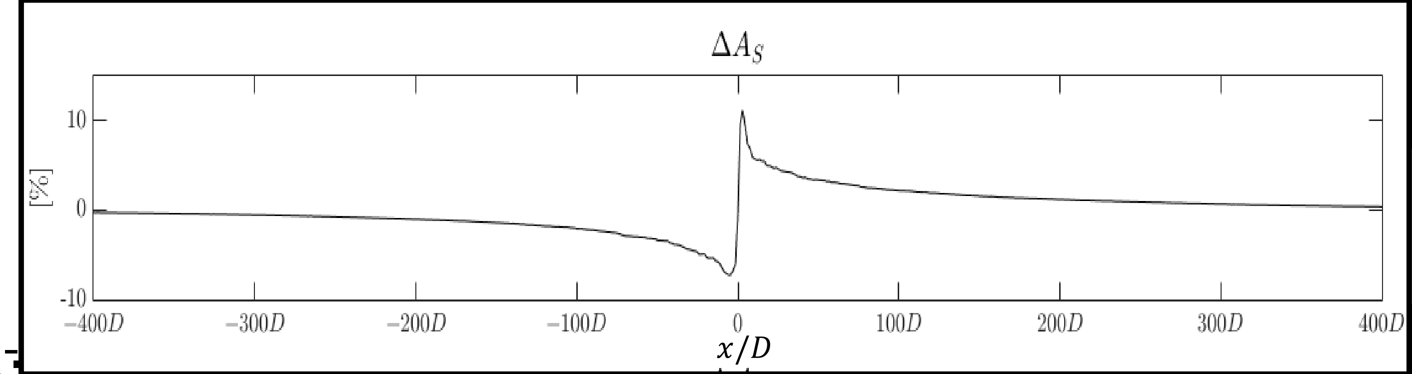


- Finer Particles (Suspended-Load):
  - Time lag for initiation/cessation of transport[4].
  - Longer slack after flood → Net transport in flood direction[3].

[3]Groen (1967), *Netherlands Journal of Sea Research*, **3**(4):564-574 [[f]Reproduced], [4]Postma (1954), *Archives Néerlandaise de Zoologie*, **10**:405-511.

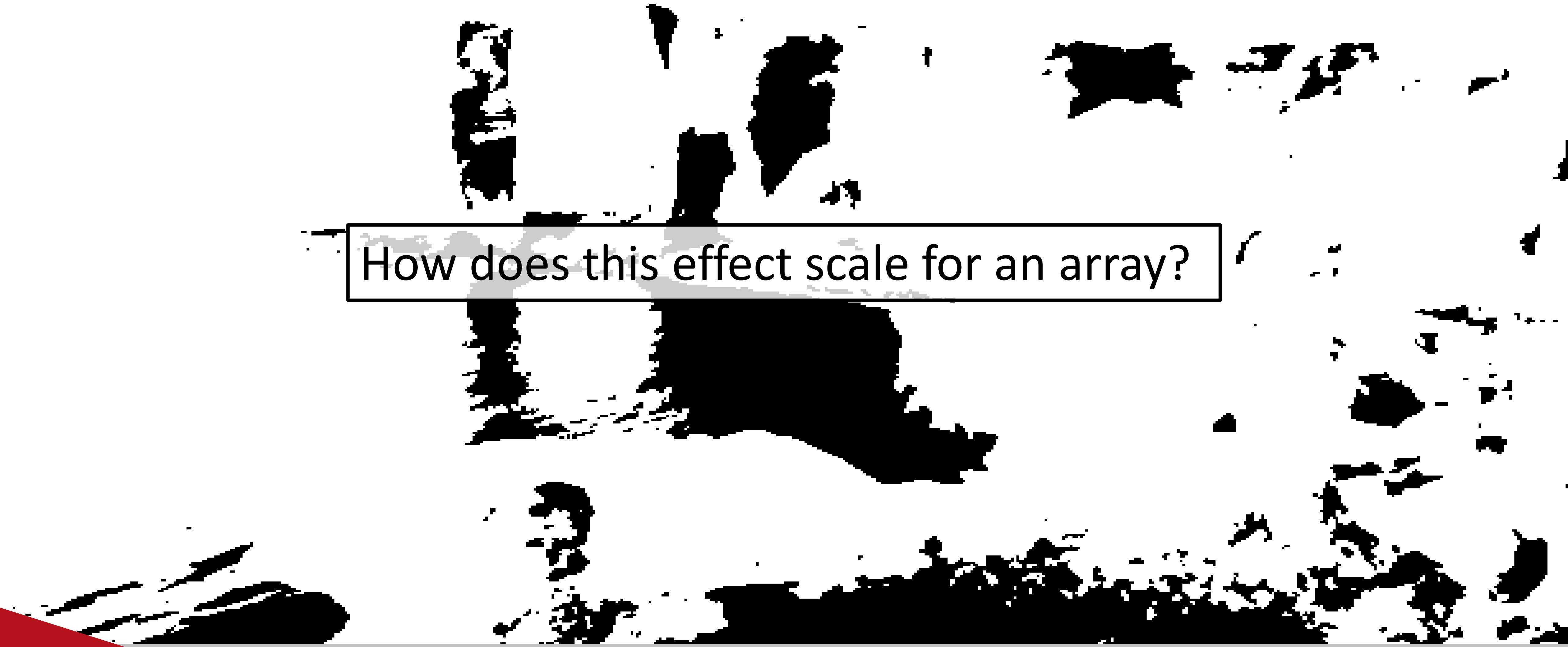
Introduction – Tidal Asymmetry & Turbines





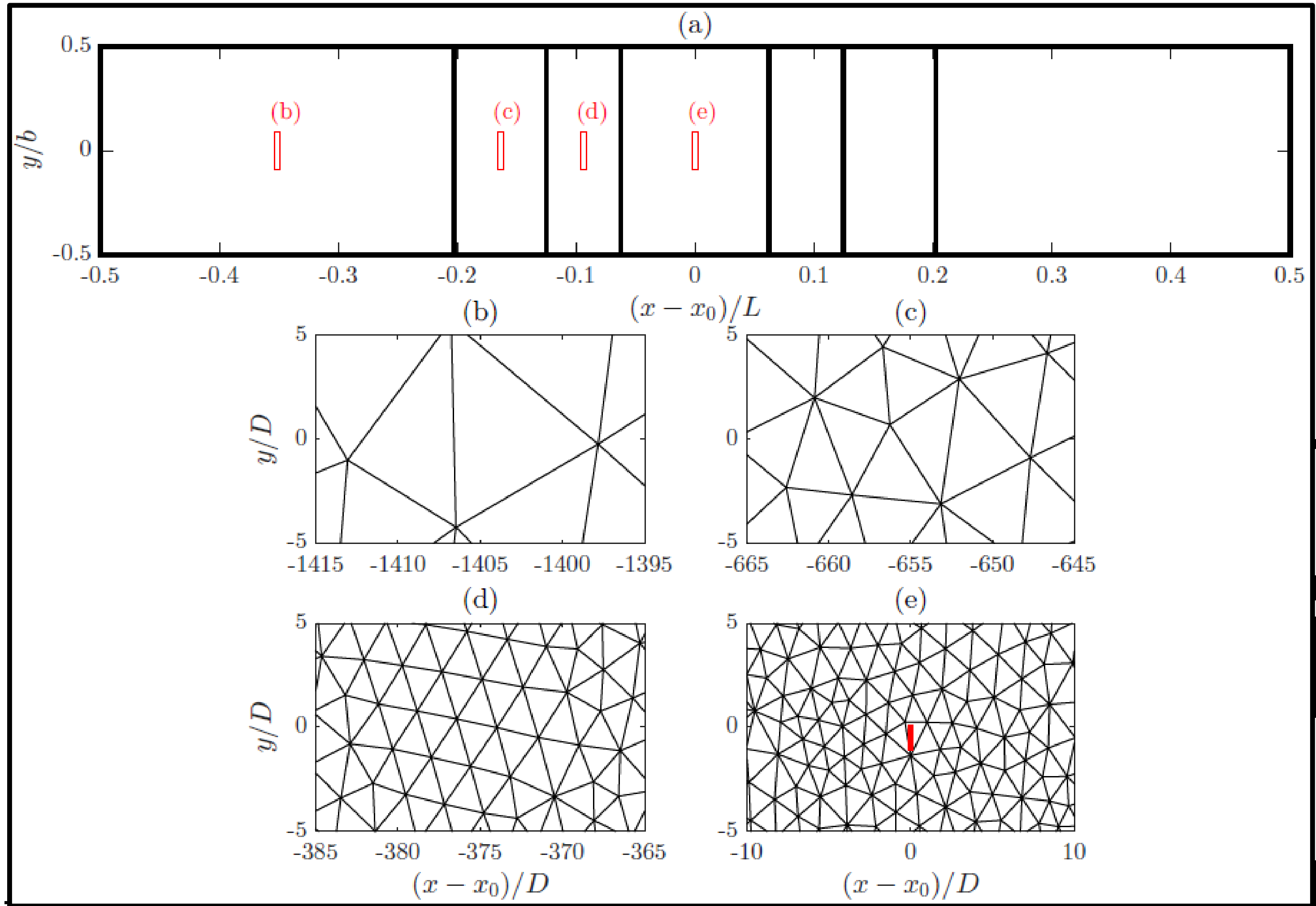
- Tidal turbine alters FVA (A_S) in vicinity of turbine:
  - Reduction to east (→)
  - Augmentation to west (←)
- Change to A_S driven by changes to M_4 current.
- Changes the result of the turbine wake

[6]Potter et al. (2018), *Renewable Energy*, (submitted)



How does this effect scale for an array?

Model Domain



$L = 80$ km

$b = 1{,}080$ m

$h = 36$ m

$D = 20$ m

$C_T = 0.85$

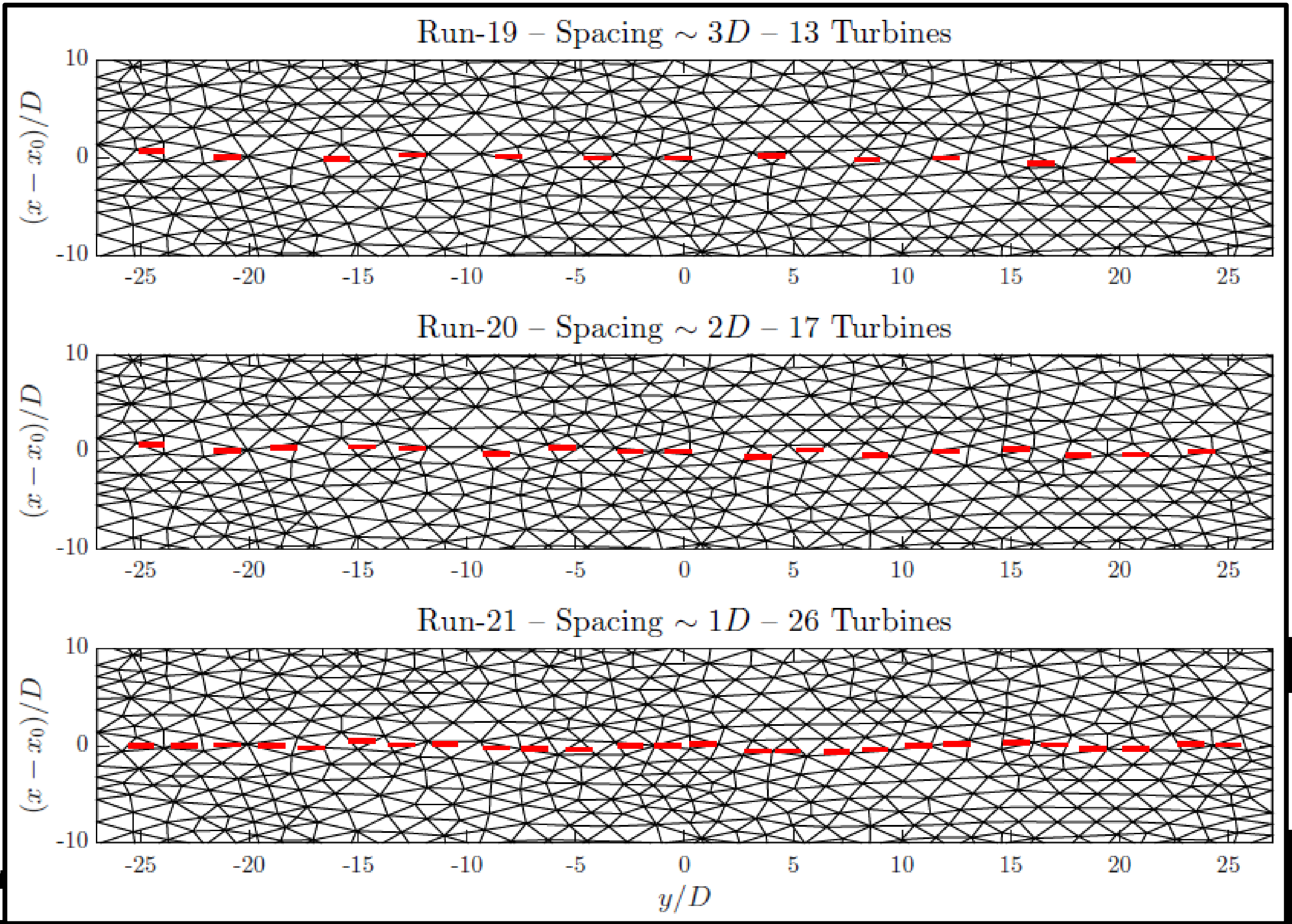
$\eta_0 = 5$ m

$\delta\phi = 100^o$

Multi-Scale Unstructured Mesh

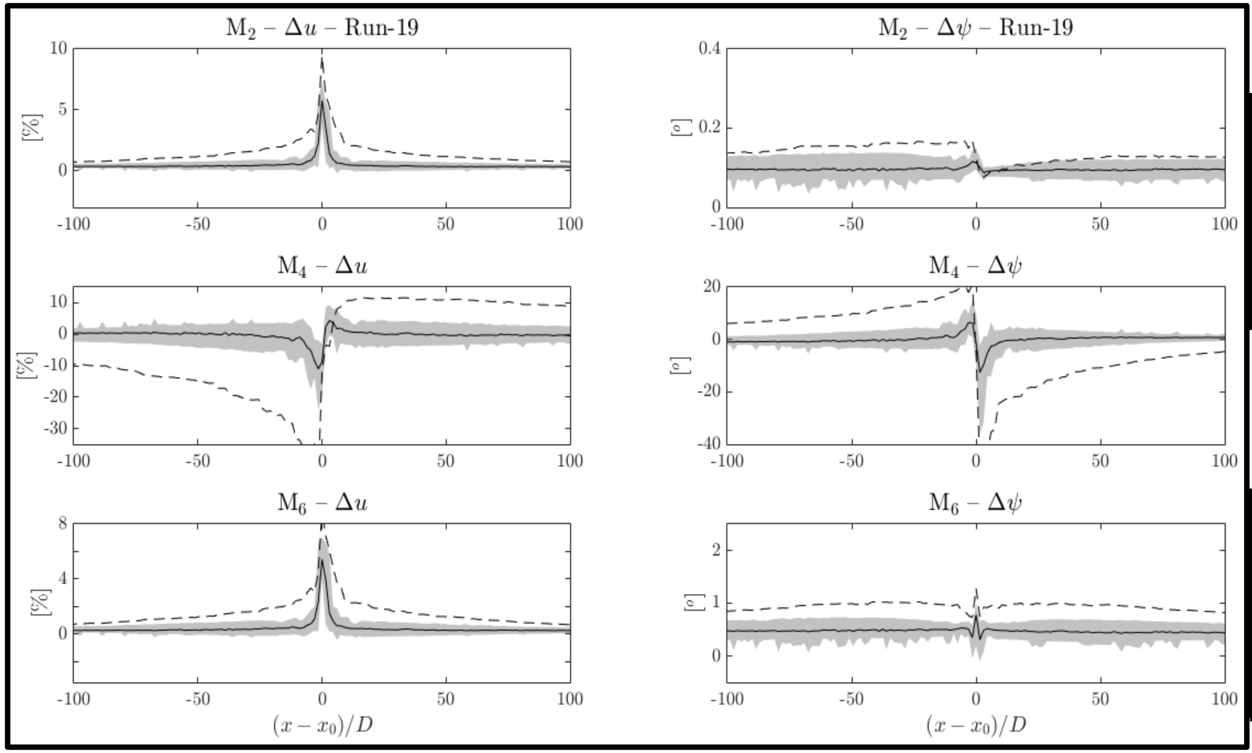
Sub-Plot	Element Area	Approx. Element Face Length
(e)	~750 m²	~30–40 m
(d)	~1,600 m²	~60 m
(c)	~6,300 m²	~120 m
(b)	~25,000 m²	~240 m

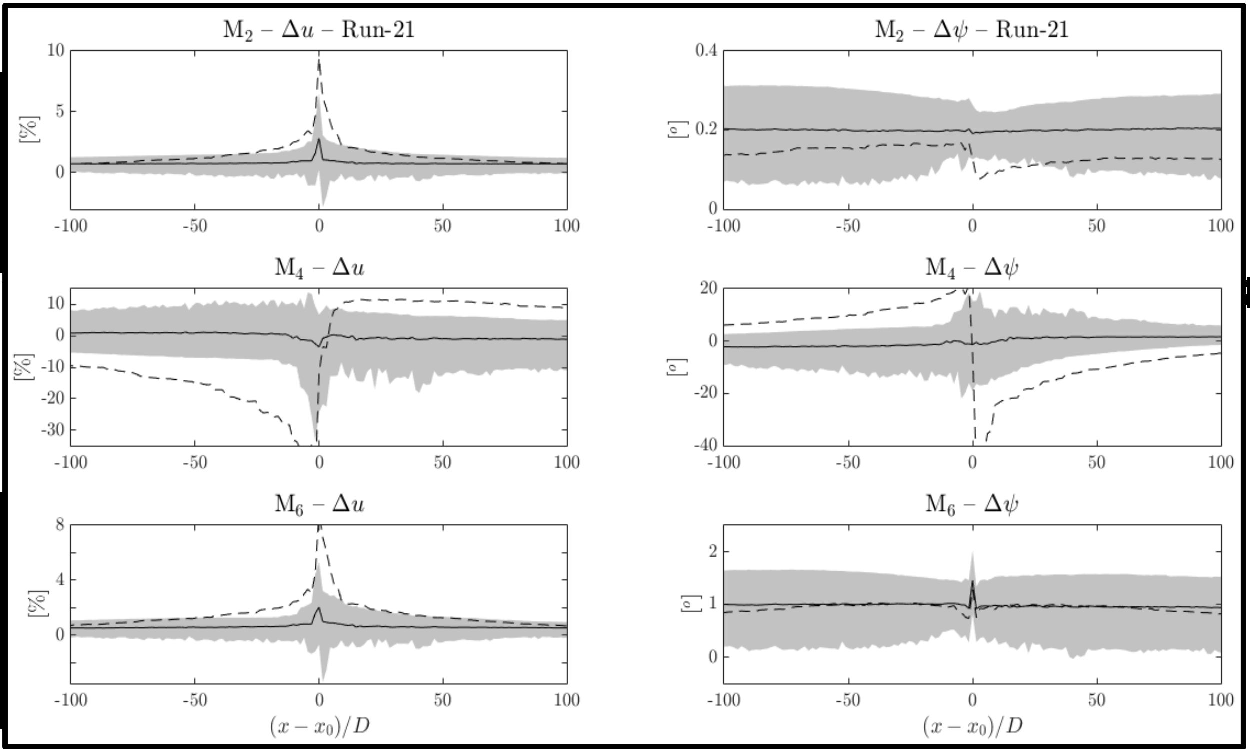
Multiple Turbines – Row



Spacing	No. Turbines
1D	26
2D	17
3D	13
4D	10
5D	9

Multiple Turbines – Row





- Average impact of turbines in array smaller than that of an individual turbine
- Greater variability of profiles for denser row
  - Due to the variability of inter-turbine spacing and longitudinal turbine spacing

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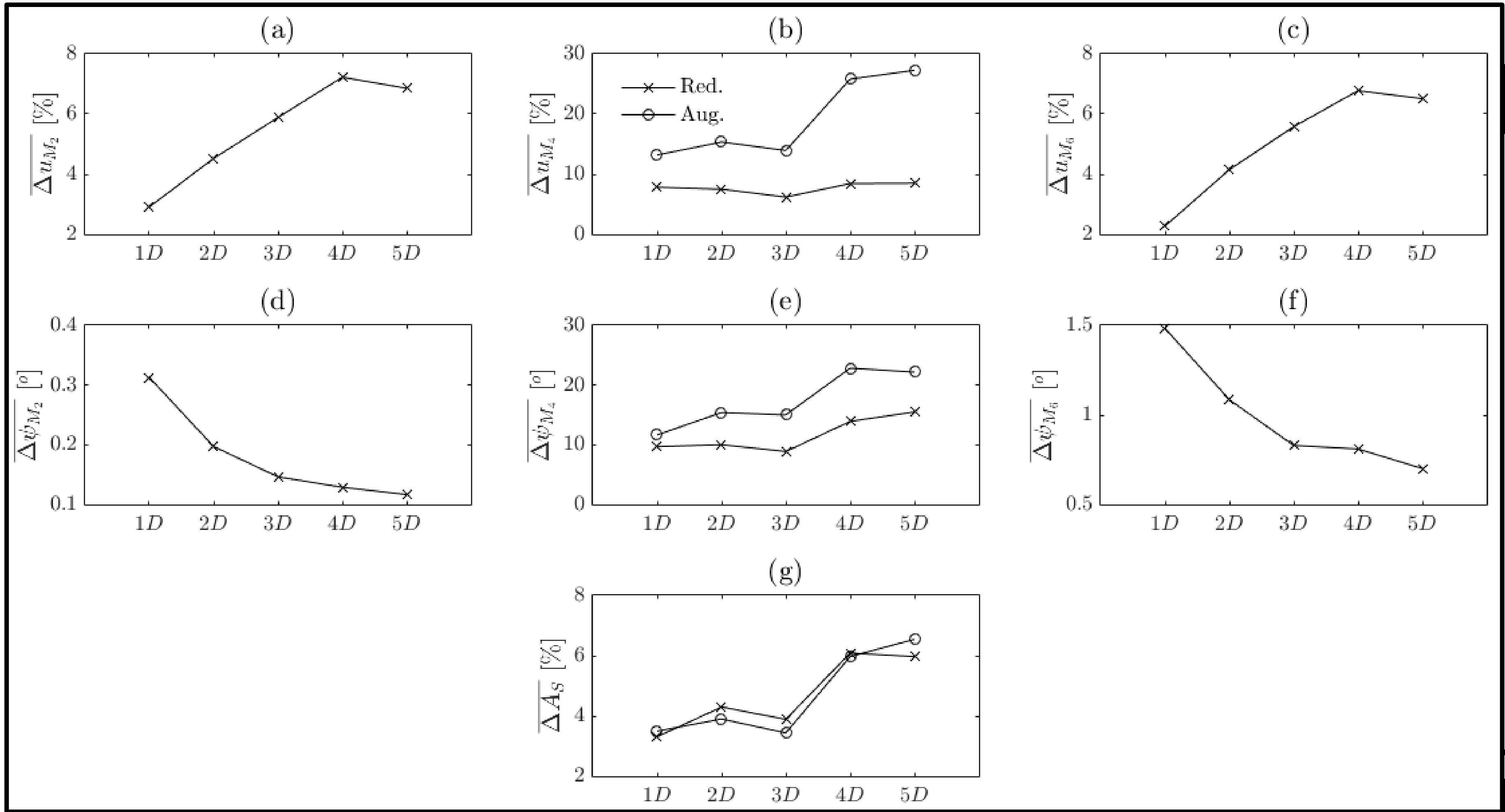
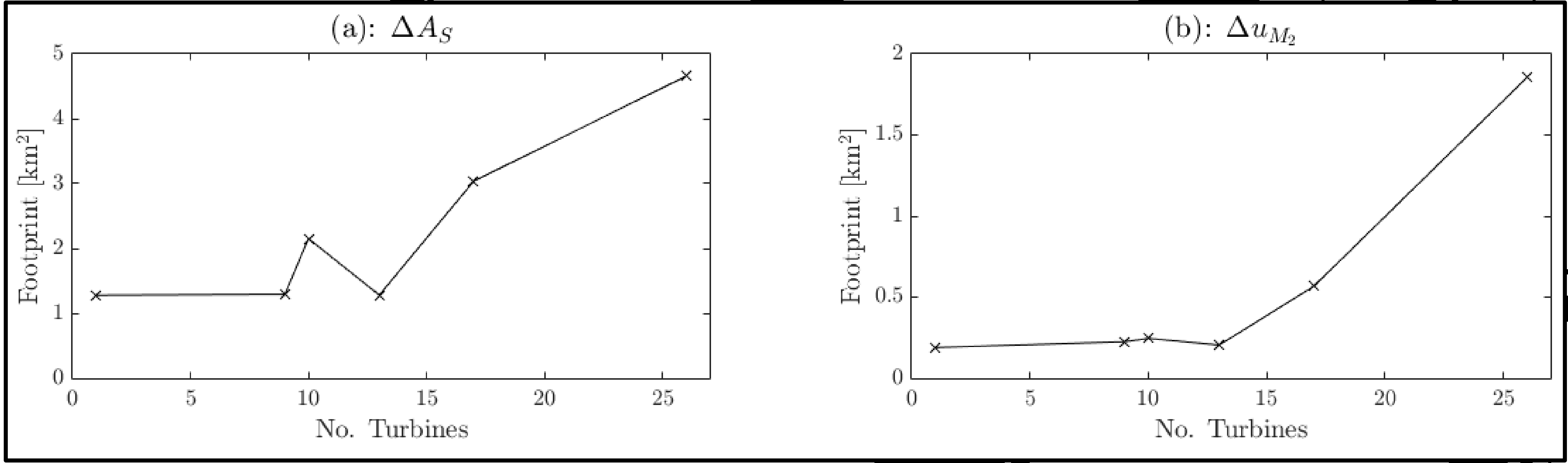
Multiple Turbines – Row



- Less reduction / augmentation to M2, M4 & M6 amplitude and M4 phase *per turbine* the more turbines in row.
- Greater blockage → greater phase lag to M2 & M6 phase.
- Less reduction / augmentation to FVA *per turbine* the more turbines in row

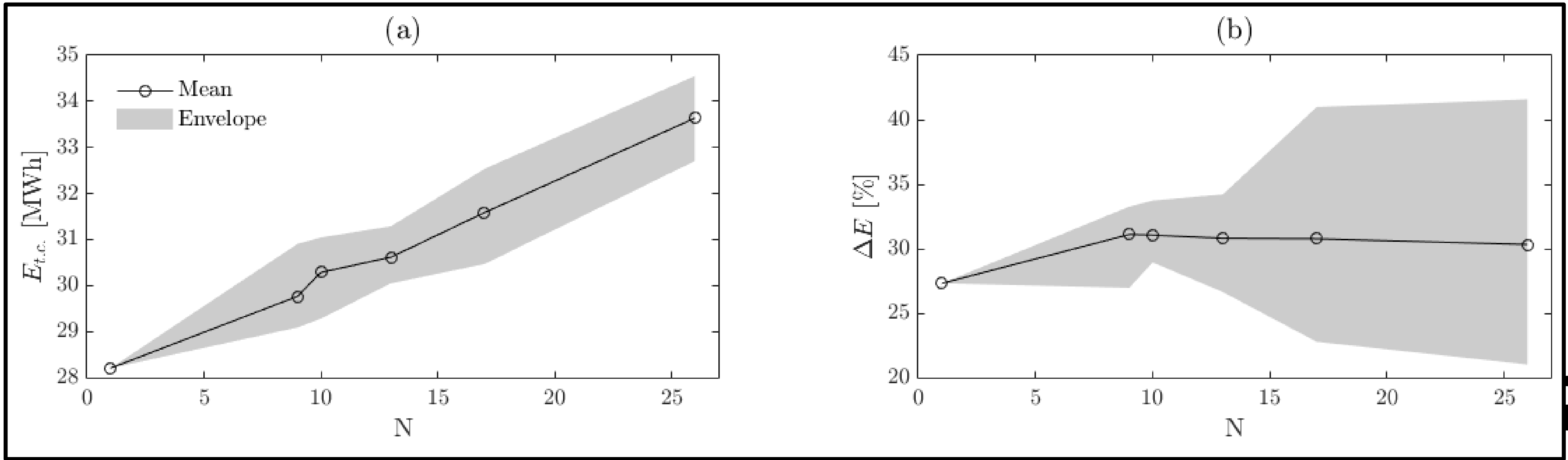
Multiple Turbines – Row

N	1	9	10	13	17	26
ε_0	0.008	0.073	0.081	0.105	0.137	0.210



- Balance between reduced impact *per turbine* and number of turbines?
- Beyond 13 turbines: larger array → larger footprint.
- Most reduction / augmentation between ~1–2%.

Multiple Turbines – Row – Energy Removal



$$E_{f,e} = \int_{f,e} P\,dt \qquad E_{t.c.} = E_f + E_e \qquad \Delta E = 100 \times \frac{2(E_f - E_e)}{E_{t.c.}}$$

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Thanks for your attention

Also, thanks to…

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Summary

- With more turbines in the row the average change to harmonic amplitudes *per turbine* reduces.
  - Phase-lag increases.
- Likewise the *per turbine* change to FVA also reduces with more turbines in the row.
- Possible balance between reduced turbine impact and number of turbines w.r.t. array footprint (Area where $|\Delta X| > 1\%$).
- More Energy removal (generation) *per turbine* in denser rows.
- Little impact to flood-ebb asymmetry conditions of turbines due to lateral neighbours.