Presentation number E144

Analysis of Spatial and Temporal Distribution of Water Elevation, Speed and Fluxes in Inundation Zone of Long Waves

A.C. Yalciner[1], S. Acar[1], B. Aytore[1], A. Zaytsev[2]

[1] METU Department of Civil Engineering, Ocean Engineering Research Center, Ankara, Turkey

[2] Special Research Bureau for Automation of Marine Researches, Far Eastern Branch of Russian Academy of Sciences,

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Tsunami

- generation mechanisms
- split and evolution
- propagation
- coastal amplification, inundation and runup
- near field impact
- long distance propagation and far field impact
- assessment, preparedness and mitigation

Tsunami models compute certain tsunami parameters according to the inputted initial wave and bathymetric conditions.

- **Tsunami modeling covers;**

  i) mathematical description of the problem and initial/ boundary conditions with proper approximations and assumptions,

  ii) solutions of the governing equations with different techniques,

  iii) simulation, visualization.

- **Beyond these;**

  analysis and interpretation of the results and tsunami parameters,

  understanding of their effects in the inundation zone

  developing the mitigation measures accordingly

  using them for educational and public awareness purposes.

Tsunamis can:

1) DRAG AND DAMAGE

drag the whole structures or their units at land or vessels in the sea,

4) OVERTURN DAMAGE

overturn structures by suction of receding or thrust of advancing waves.

Tsunamis can:

3) SCOUR-EROSION-DEPOSITION

undercut foundations and pilings with erosion caused by the receding waves,

2) DEPOSITION

deposition with accumulated shoreline debris by the advancing wave fronts, (i.e. 5km inland of West Sumatra Meulaboh)

Causes by Tsunami in Shallow and Inundation Zone

- Water level rise and fall
- Strong currents
- Forces (drag, impact, uplift, etc.)
- Sea water withdraw and drawdown
- Scour, and morphological changes (erosion, deposition)
- Debris and debris flow
- Dynamic water pressure
- Resonant oscillations and seiches

$$\frac{\partial \eta}{\partial t}+\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}=0$$

$$\frac{\partial M}{\partial t}+\frac{\partial}{\partial x}\left(\frac{M^2}{D}\right)+\frac{\partial}{\partial y}\left(\frac{MN}{D}\right)+gD\frac{\partial \eta}{\partial x}+\frac{gn^2}{D^{7/3}}M\sqrt{M^2+N^2}=0$$

$$\frac{\partial N}{\partial t}+\frac{\partial}{\partial x}\left(\frac{MN}{D}\right)+\frac{\partial}{\partial y}\left(\frac{N^2}{D}\right)+gD\frac{\partial \eta}{\partial y}+\frac{gn^2}{D^{7/3}}N\sqrt{M^2+N^2}=0$$

Non-linear longwave equations

M, N : Discharge fluxes in x&y directions

n : Manning's roughness coefficient

$$M=u(h+\eta)=uD \qquad N=v(h+\eta)=vD$$

Specific Terms (nearshore and inundation Zones):

Run-up: The vertical distance of water level from reference sea level at the end of inundation zone

Maximum positive amplitude - Wave height: Vertical distance of water level from reference sea level

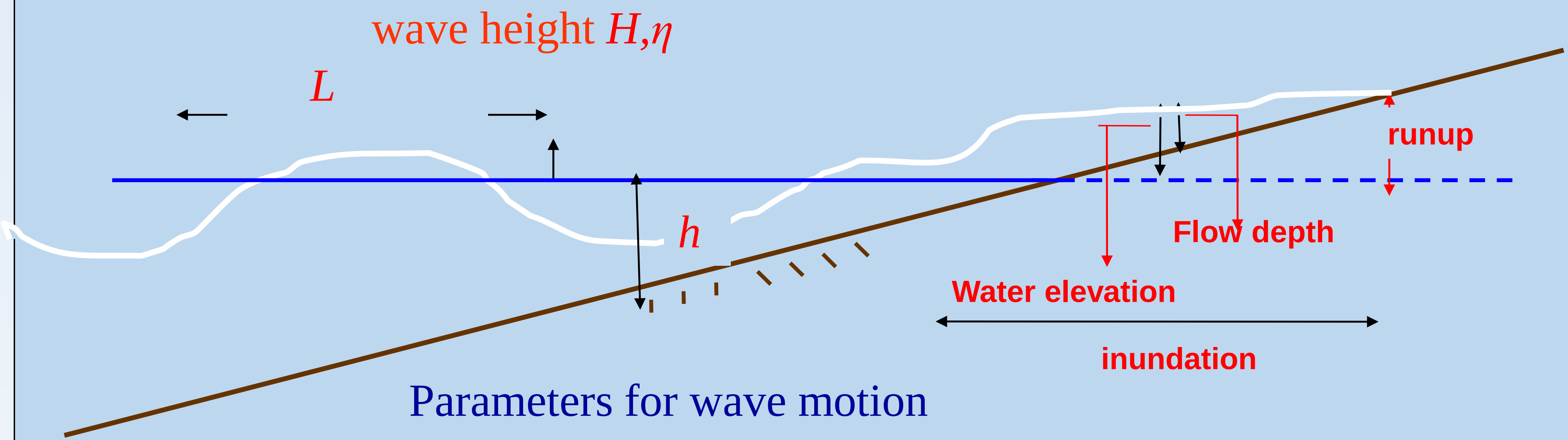
Flow depth: Depth of the flow in inundation zone

Current velocity: Velocity of flow in near shore and inundation zone

Discharge flux : Discharge flux in near shore and inundation zone

Inundation distance: Horizontal distance a tsunami reaches landward from shoreline of reference sea level.

Maximum negative amplitude: The maximum level of subsidence from reference sea level.



Parameters for wave motion

Height	$H = \eta$
Length	L
Local water depth	h
Duration/period	T
Gravity	g

Approaches to Compute Impact Force

1) Harry Yeh (2006) (Drag Force per unit width)

$$F = \frac{1}{2} C_d \, \rho \, h \, u^2$$

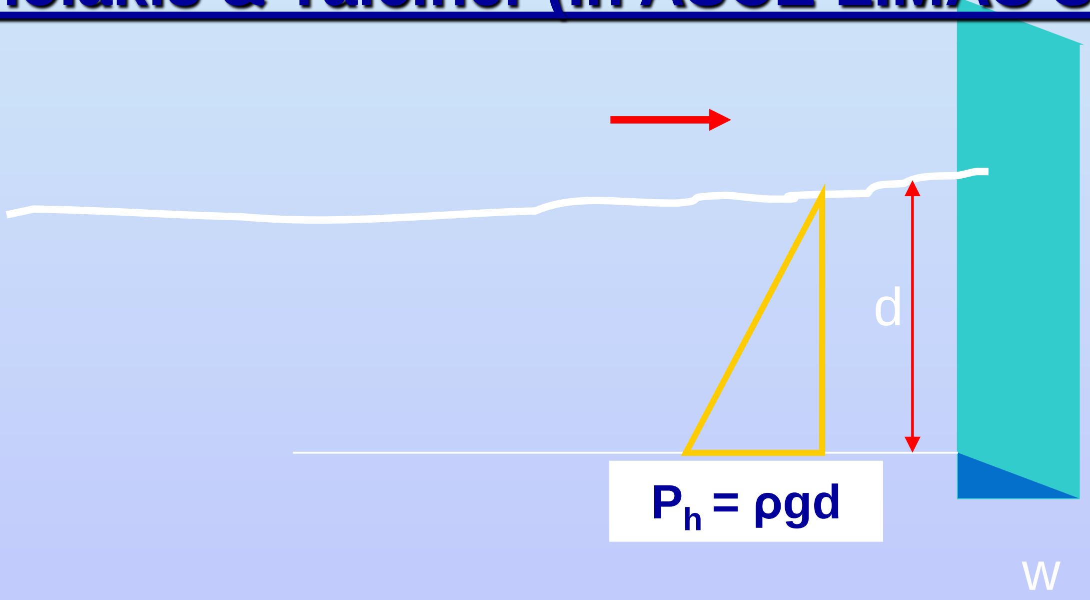
C_d : drag coefficient (≈ 1.0 - 2.0 suggested by Arnason (2004)

h : total flow depth

u : flow velocity

Approaches to Compute Impact Force

2) Synolakis & Yalciner (in ASCE LIMAS Sumer 2005)



Hydrostatic Force $\rightarrow$ $F_h = \frac{1}{2}\rho_w g d^2 w = \frac{1}{2}\rho_w \, g \, d \, A$

Approaches to Compute Impact Force

2) Synolakis & Yalciner (in ASCE LIMAS Sumer 2005)

Drag Force → $$F_d = \frac{1}{2} C_D \rho_w A u^2$$

C_d : drag coefficient

A: cross-sectional area exposed to drag force

u: flow velocity

- **This approach can be applied to compute force of flow onto objects.**

Approaches to Compute Impact Force

2) Synolakis & Yalciner (in ASCE LIMAS Sumer 2005)

Normalization of Drag Force by Hydrostatic Force

$$Damage\,Metric = \frac{F_d}{F_h} = \frac{\cancel{\frac{1}{2}} C_D \cancel{\rho_w} \cancel{A} u^2}{\cancel{\frac{1}{2}} \cancel{\rho_w} g\, d \cancel{A}}$$

$$= C_D \frac{u^2}{g\, d} = C_D * F_R^{\,2}$$

flow velocity

Drag coefficient (shape parameter)

$C_D < 2$

Approaches to Compute Impact Force

3) Ramsden & Raichlen (1990)

$$\frac{F_T}{\frac{1}{2}\gamma b(H_1+d_w)^2}=\left(\frac{\eta+d_w}{H_1+d_w}\right)^2+2C_F N_F{}^2\frac{\eta H_1}{(H_1+d_w)^2}$$

where $C_F=1+(\tan\theta)^{1.2}$: force coefficient ≈ 1.4-2.1

$N_F=\frac{c}{\sqrt{gH_1}}$ → c: bore celerity

(spead of wave shape)

H_1 : surge height

η : surge profile

b : width of wall

d_w : water depth at the wall

- **After appropriate assumptions and simplifications, the equation becomes:**

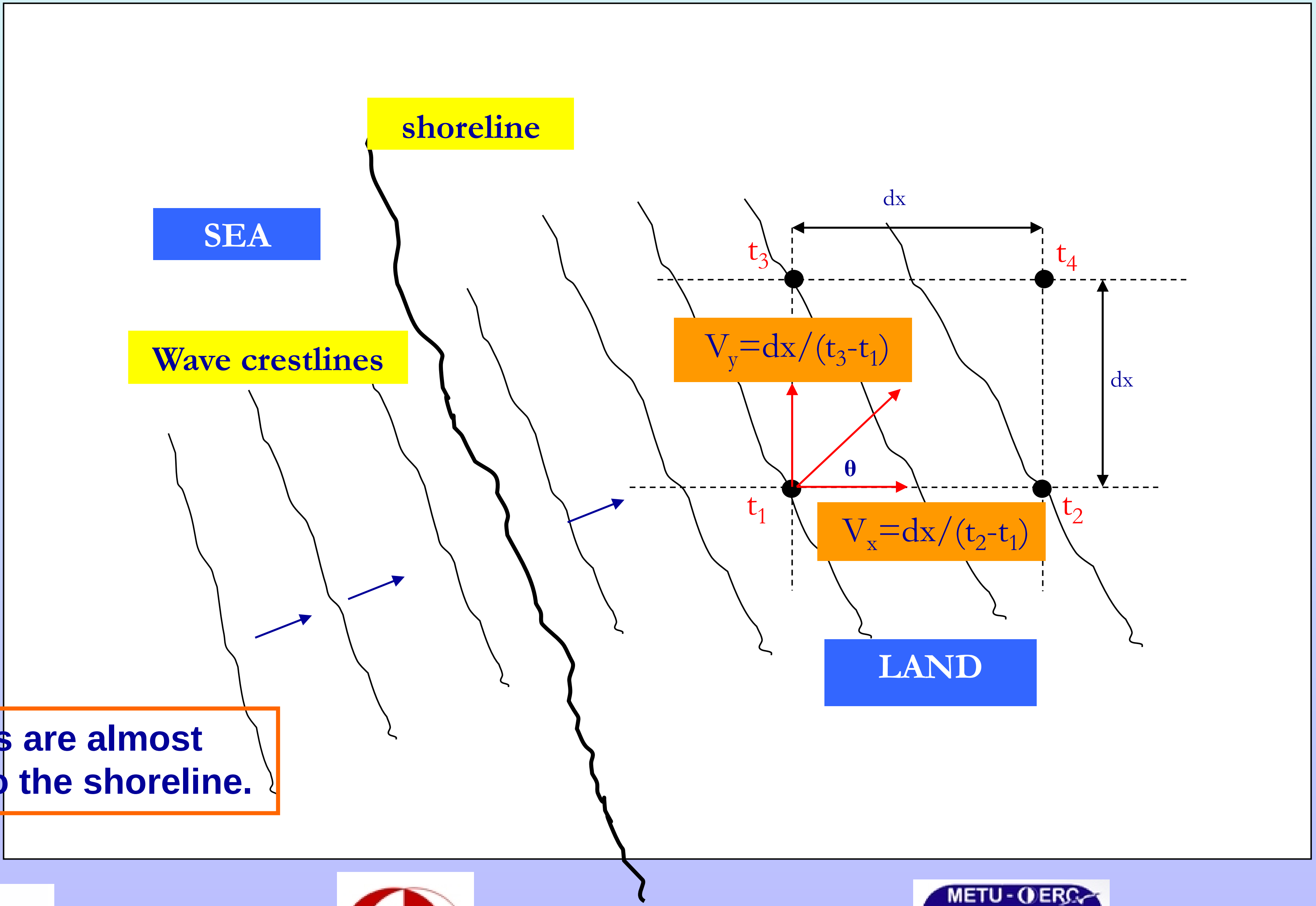
$$\underbrace{\frac{F_T}{\frac{1}{2}\gamma b\left(H_1+d_w\right)^2}}_{exactly\ hydrostatic\ force} = 1 + 2C_F\left(\frac{c^2}{gH_1}\right)\underbrace{\frac{\eta H_1}{\left(H_1+d_w\right)^2}}_{1}$$

$$D_2 = \frac{F_T}{F_H} = 1 + 2C_F\frac{V_f^{\,2}}{gH_1} = 1 + 2C_F F_R^{\,2}$$

Ramsden & Raichlen (1990)

V_f : wave front velocity

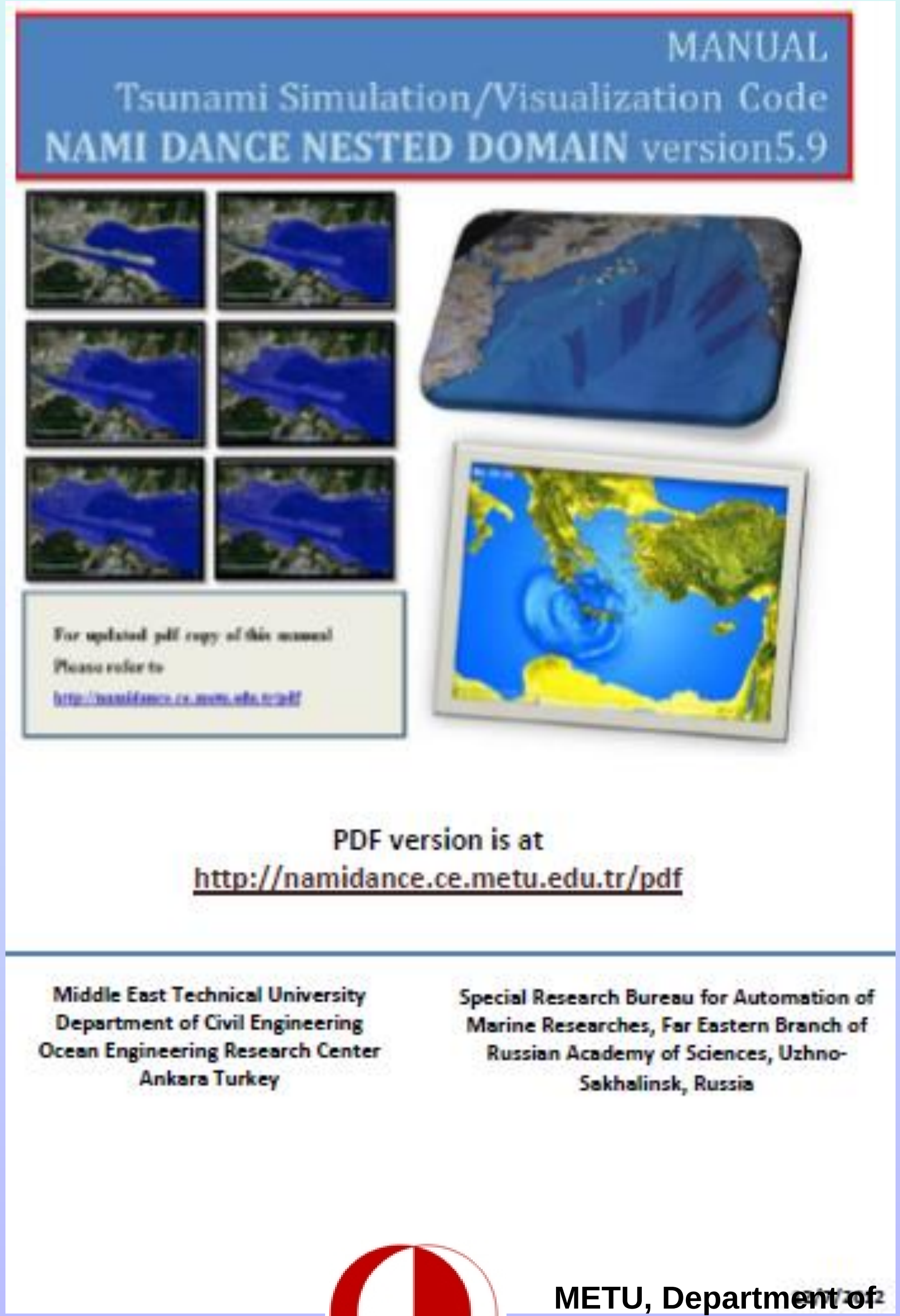
➡ **bore type of flow & compute force onto vertical wall.**



Crestlines are almost parallel to the shoreline.

Importance of Near shore and Inundation Parameters

- Maximum positive amplitude → governs the intensity of the tsunami
- Maximum current velocity → governs erosion, deposition, debris and drag
- Flow depth → indicates the level of flow and force
- Discharge Flux → an instantaneous value depending on water velocity and flow depth. Since current velocity and flow depth are changing independently, the discharge flux also varies with time and location
- Hydrodynamic load → an instantaneous value during inundation depending on water velocity and flow depth. Since current velocity and flow depth are changing independently, the hydrodynamic demans also varies with time and location
- Maximum negative amplitude → essential for the ships and boats at shallow regions and harbors


MANUAL
Tsunami Simulation/Visualization Code
NAMI DANCE NESTED DOMAIN version5.9

For updated pdf copy of this manual
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Middle East Technical University
Department of Civil Engineering
Ocean Engineering Research Center
Ankara Turkey

Special Research Bureau for Automation of Marine Researches, Far Eastern Branch of Russian Academy of Sciences, Uzhno-Sakhalinsk, Russia

Zaytsev A.,
Yalciner, A. C.
Pelinonsky, E.,
Chernov A.,
Kurkin, A.

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Numerical Modeling

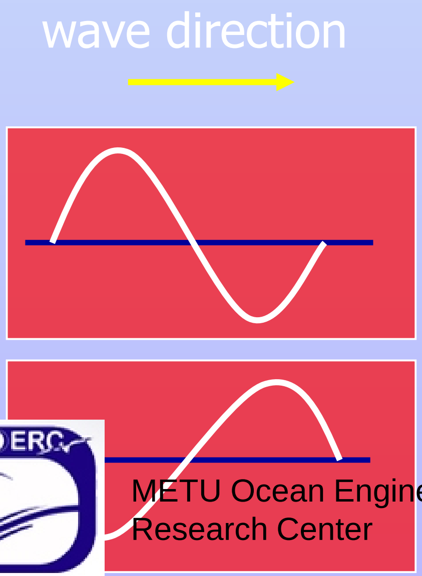
- **Simulation code**

  TUNAMI N2 (authored by Profs. Shuto and Imamura) by inserting a new subroutine to compute above mentioned parameters.

  <u>Dynamic Wave Input</u> :
  - amplitude = 1 m
  - period = 3 min
  - 2 successive sinusoidal waves
  - sea bottom slope = 1/12.5 or 1/50
  - wave shape : Leading Depression Wave

    or

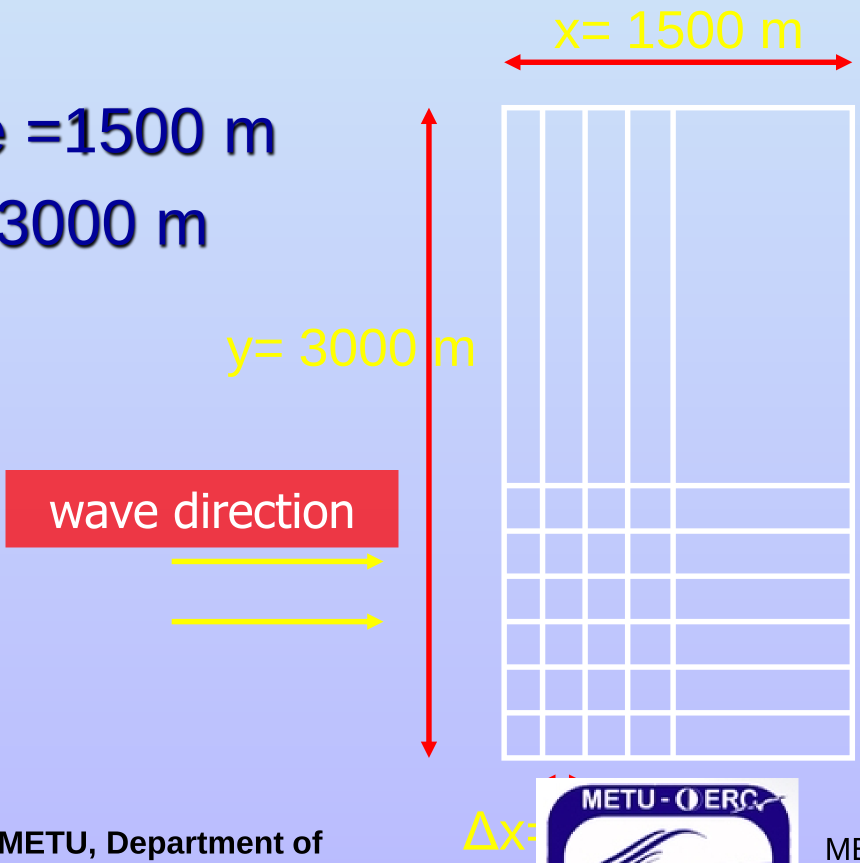
    Leading Elevation Wave



Numerical Modeling

- Sea bottom topography:

- Horizontal distance =1500 m
- vertical distance = 3000 m
- Delta x = 5 m
- Delta t = 0.1 sec



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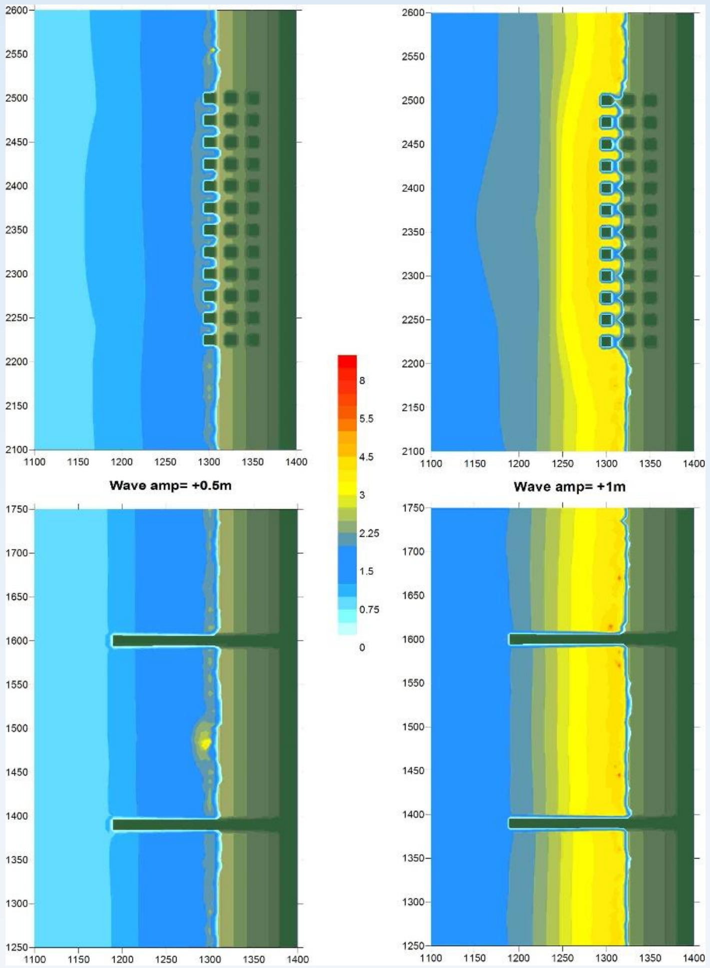

Özer and Yalciner (2010)

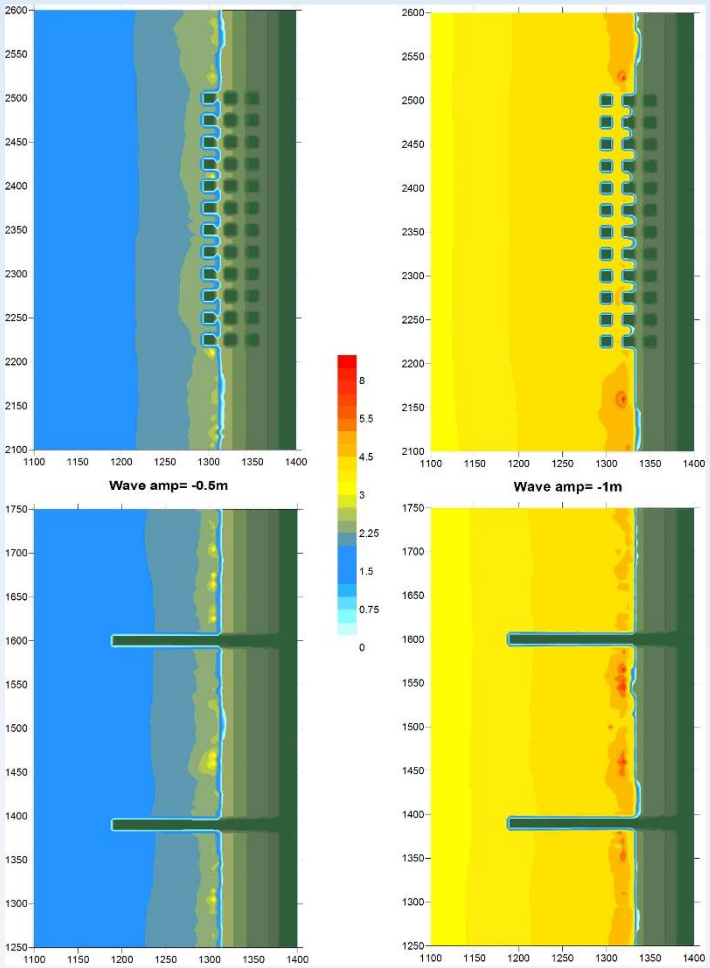

Figure 6: Distribution of maximum positive amplitudes for perpendicular approach of the wave (angle=90º) with period of 3 min. for LEW with the bottom slope of 1/10 (incoming wave amplitudes= +0.5m, +1.0m at the toe)

Figure 7: Distribution of maximum positive amplitudes for perpendicular approach of the wave (angle=90º) with period of 3 min. for LDW with the bottom slope of 1/10 (incoming wave amplitudes= -0.5m, -1.0m at the toe)

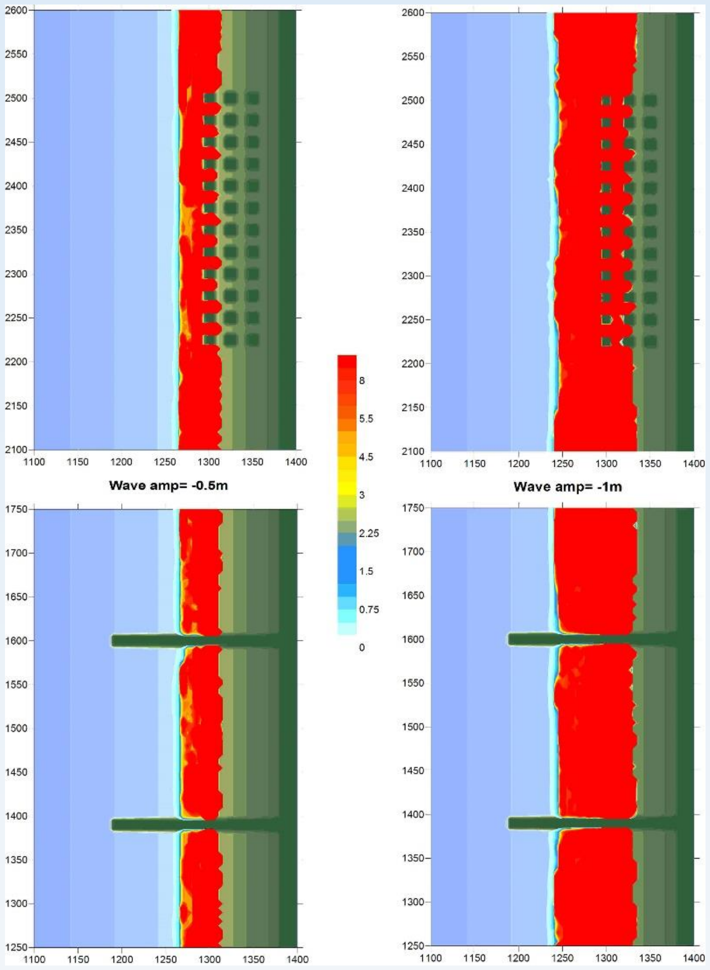

Figure 10: Distribution of maximum hydrodynamic demands for perpendicular approach of the wave (angle=90º) with period of 3 min. for LDW with the bottom slope of 1/10 (incoming wave amplitudes= -0.5m, -1.0m at the toe)

Özer and Yalciner (2010)

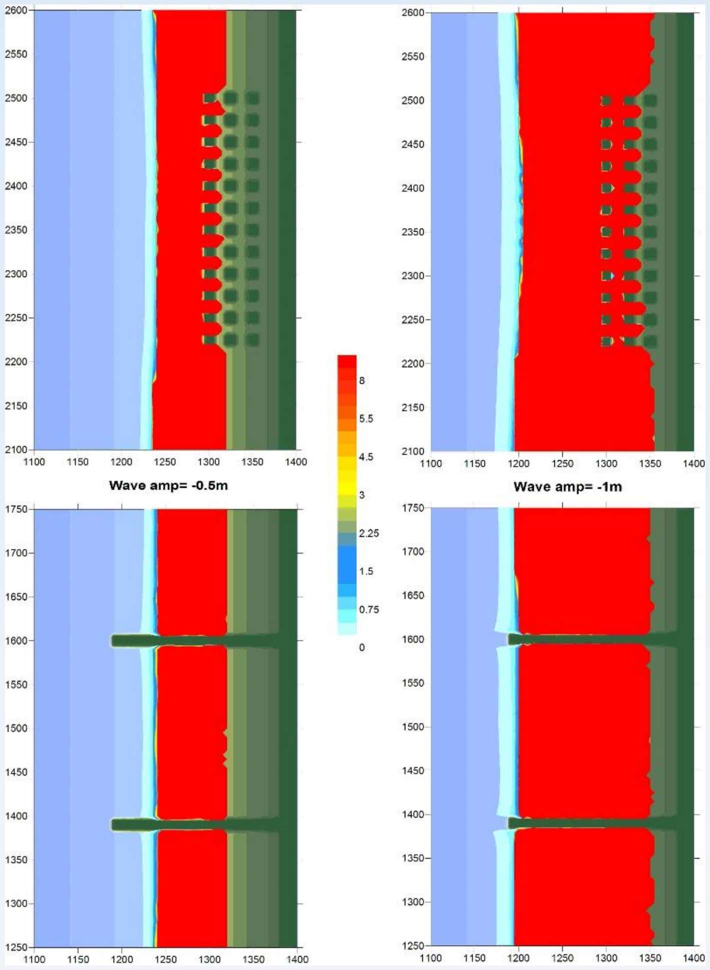

Figure 11: Distribution of maximum hydrodynamic demands for perpendicular approach of the wave (angle=90º) with period of 3 min. for LDW with the bottom slope of 1/20 (incoming wave amplitudes= -0.5m, -1.0m at the toe)

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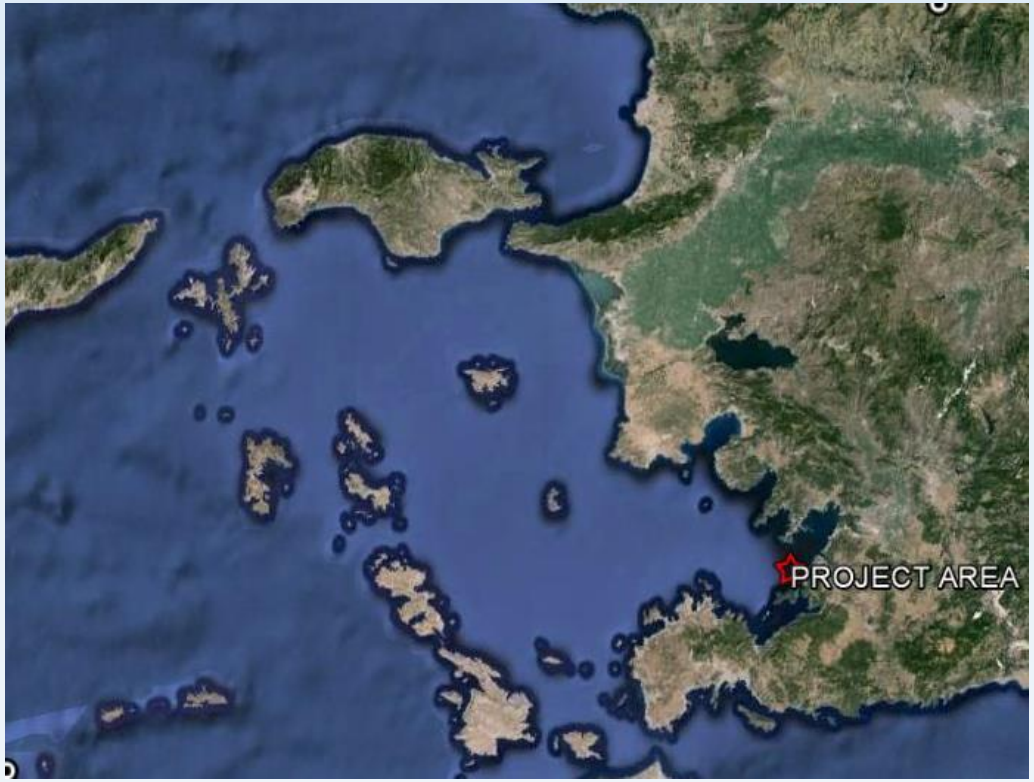

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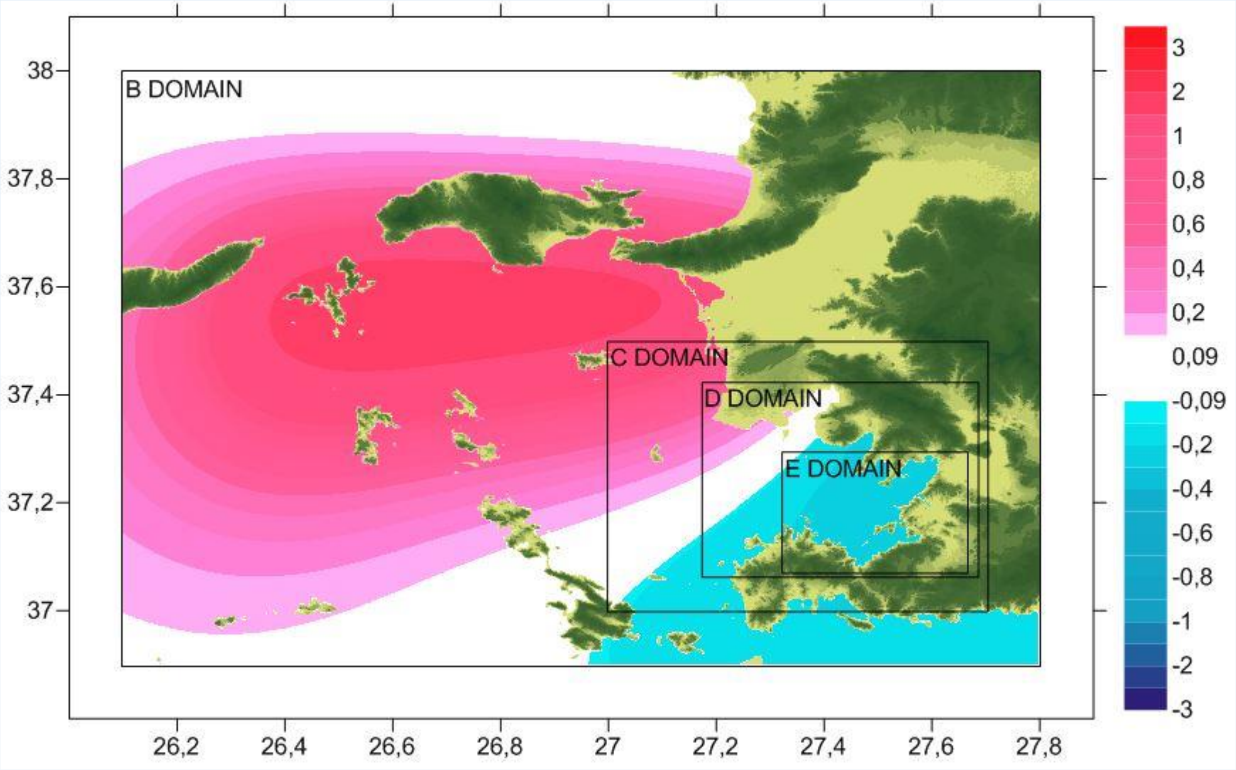
- Rupture Nme: s18-Z22
- Type: Normal
- Epicenter: 26.36E, 37.64N
- Dip : 45°
- Rake : 45°
- Strike : 95°
- Focal Depth(km): 20
- L (km): 95
- W (km): 30
- Displacement   u (m): 4



- Maksimum (+) Amplitude at the source (m): 1.80
- Maksimum (-) Amplitude at the source (m): -0.30

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- Nested Grid System B, C, D ve E Domains

B, C, D ve E alanlarına ait grid aralıkları ve sınır koordinatları

Alan Adı	Sınır Koordinatları	Grid Aralığı (m)
B	26.1° - 27.8° E 36.9° - 38.0° N	270
C	27° - 27.7° E 37° - 37.5° N	90
D	27.18° - 27.66° E 37.065° - 37.42° N	30
E	27.323° - 27.667° E 37.068° - 37.294° N	10

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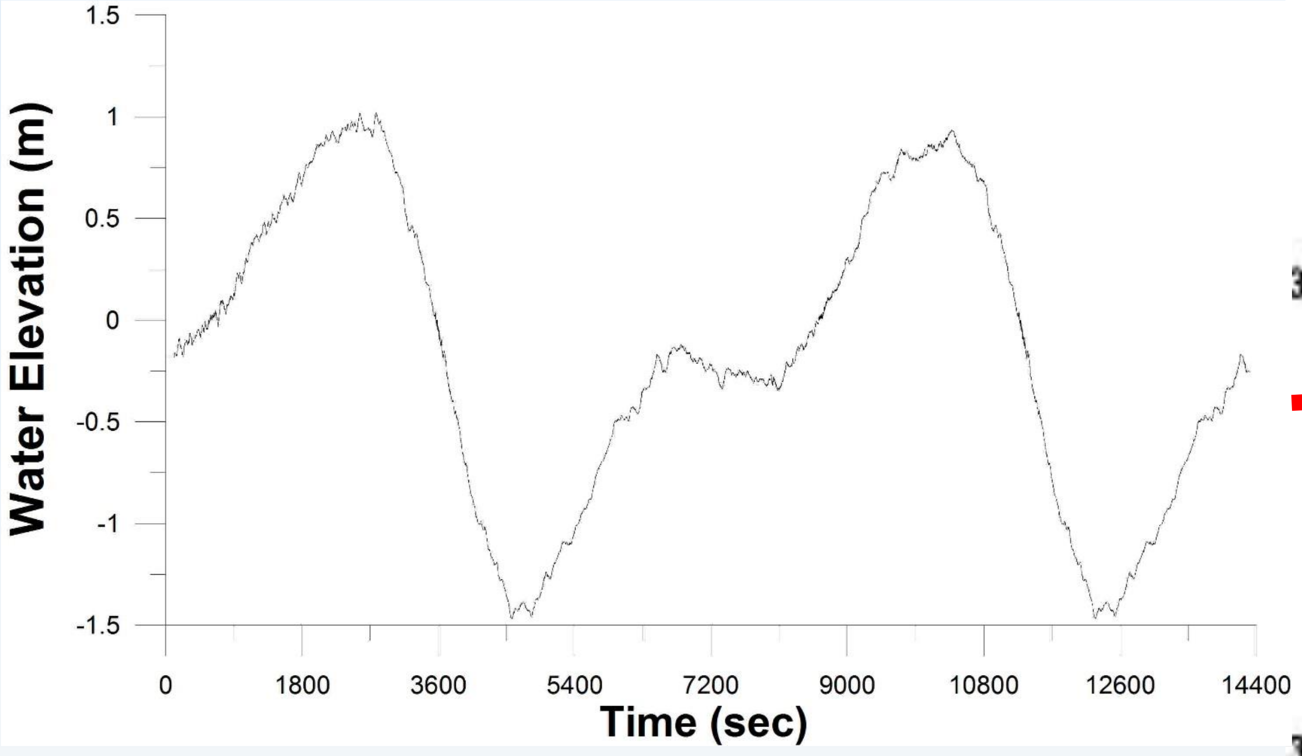
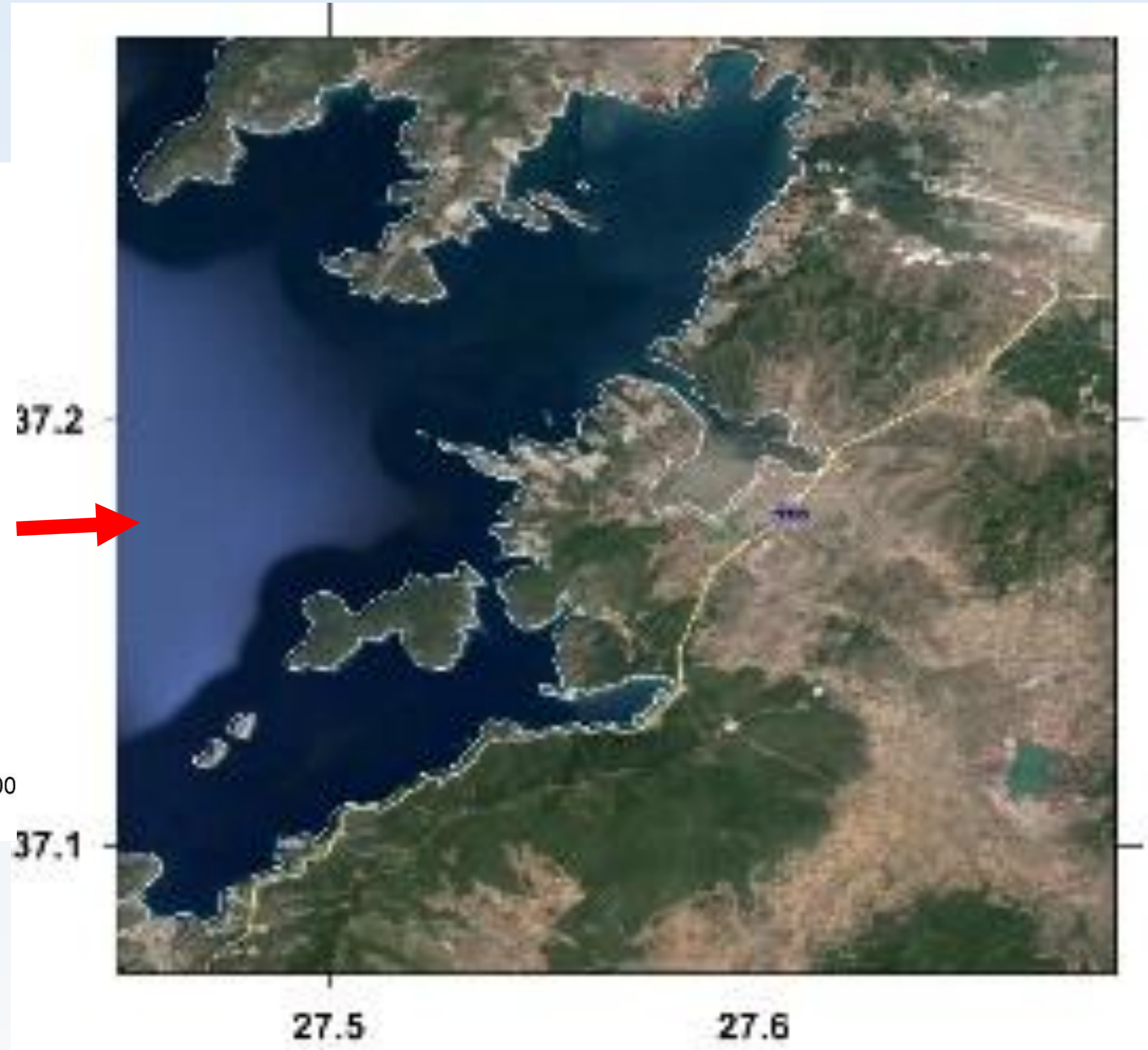
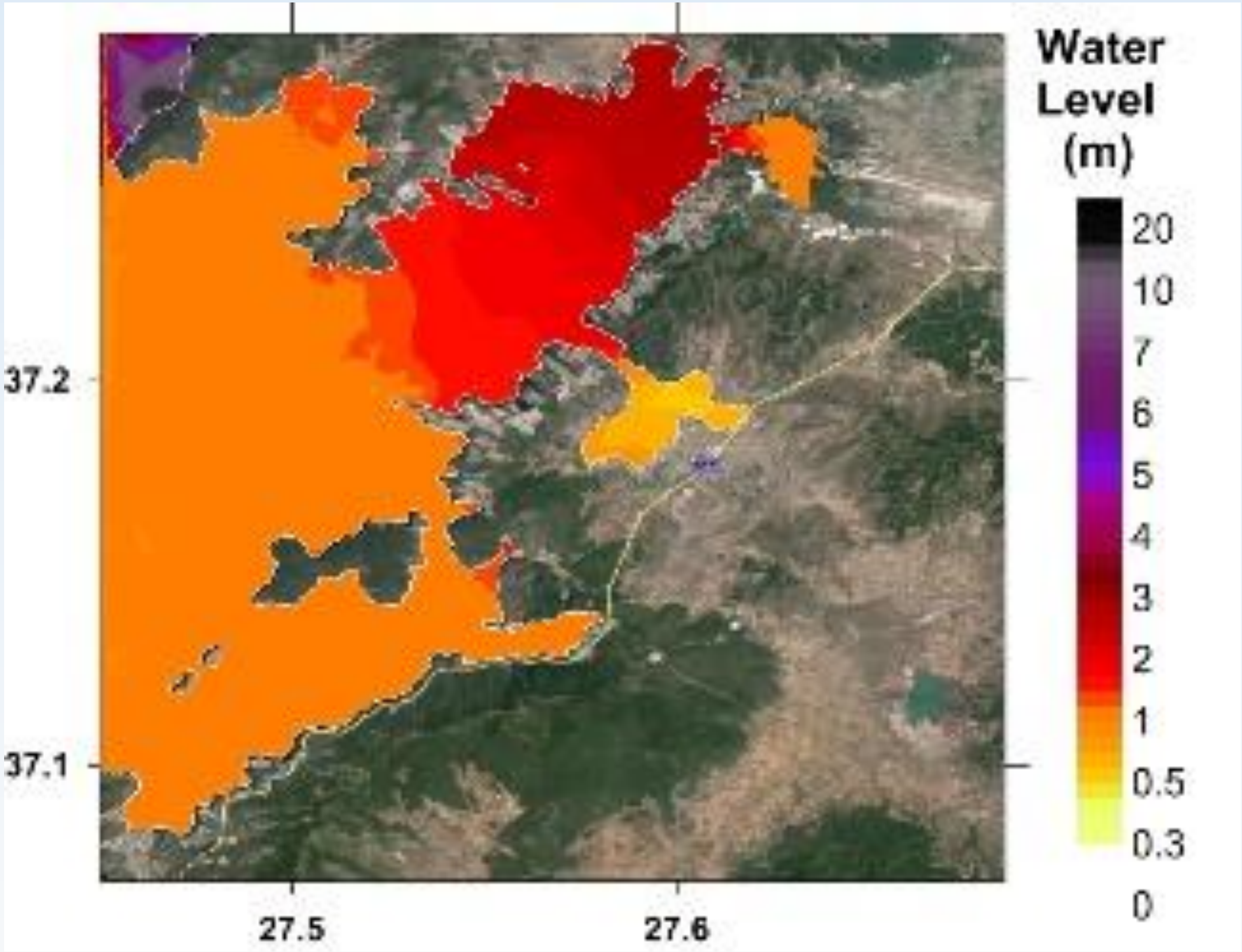

Water Elevation (m)
1.5
1
0.5
0
-0.5
-1
-1.5
0
1800
3600
5400
7200
9000
10800
12600
14400
Time (sec)


37.2
37.1
27.5
27.6



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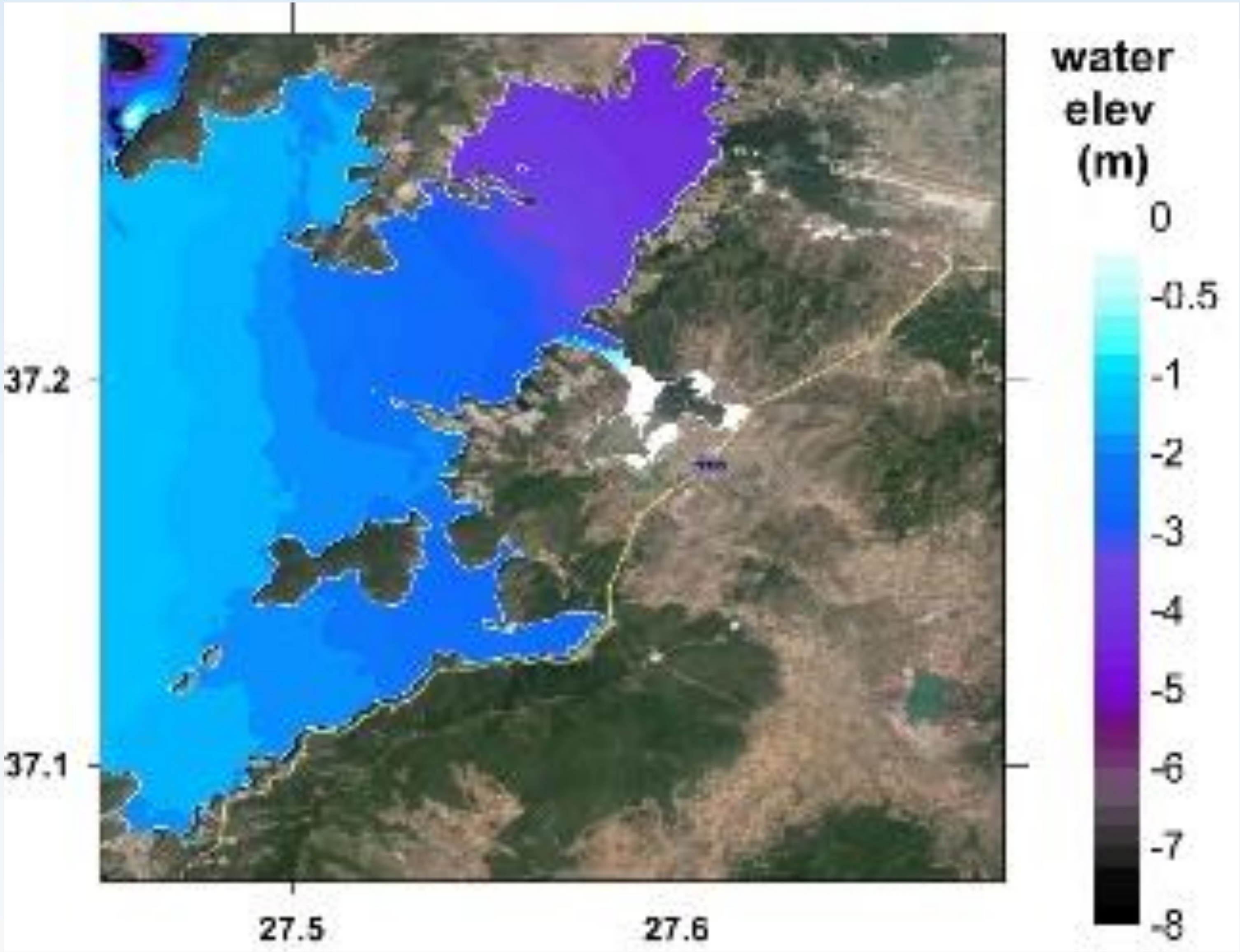

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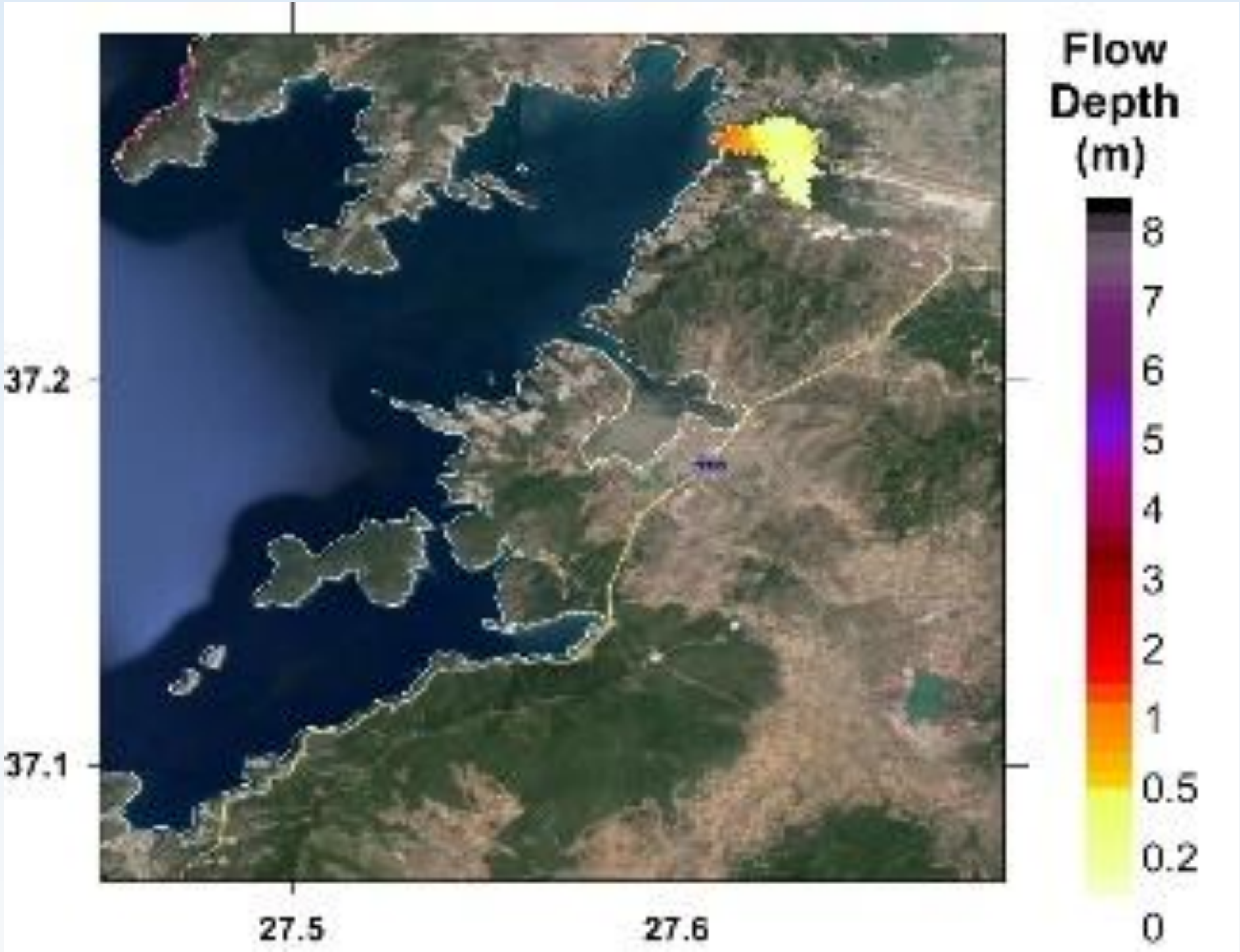
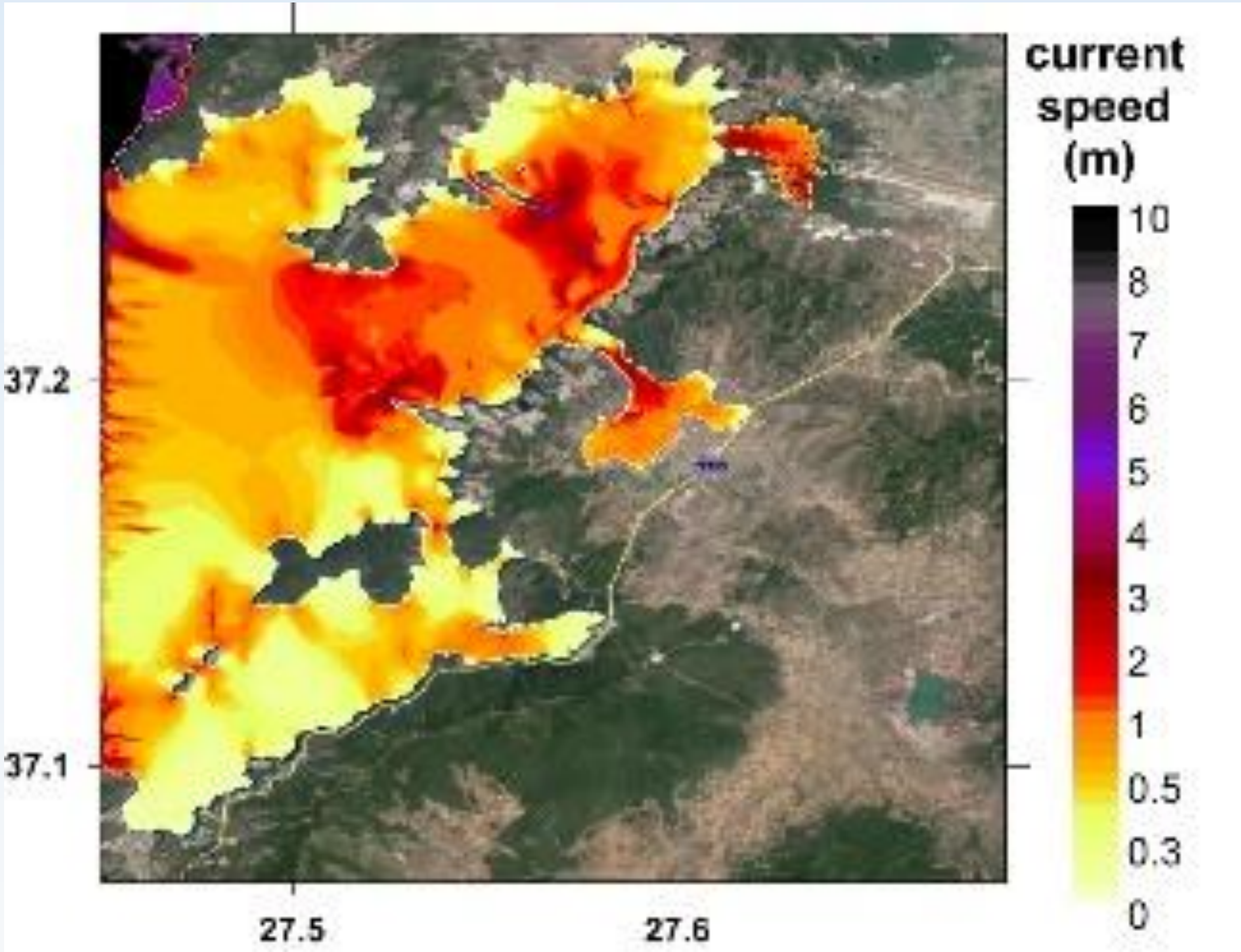
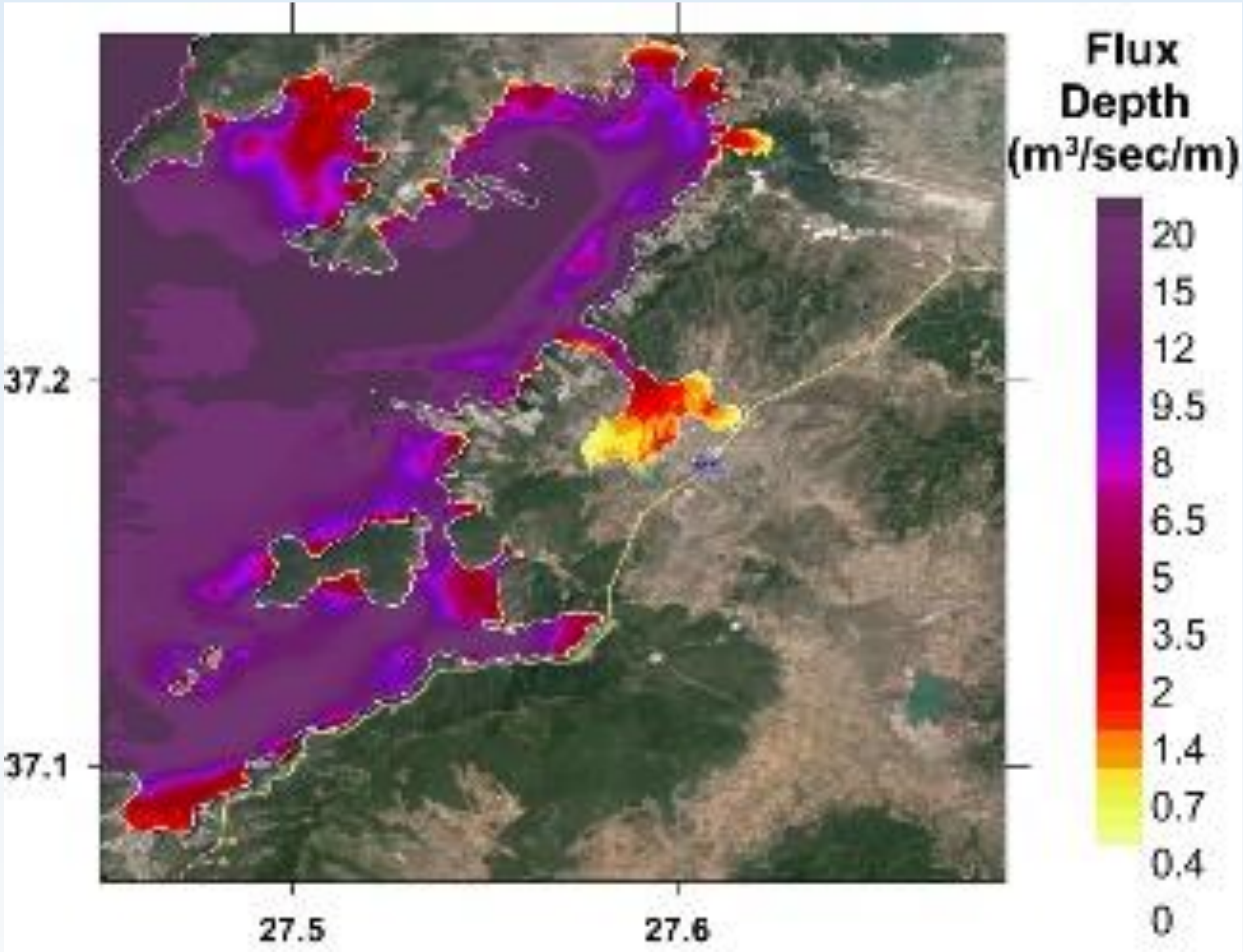
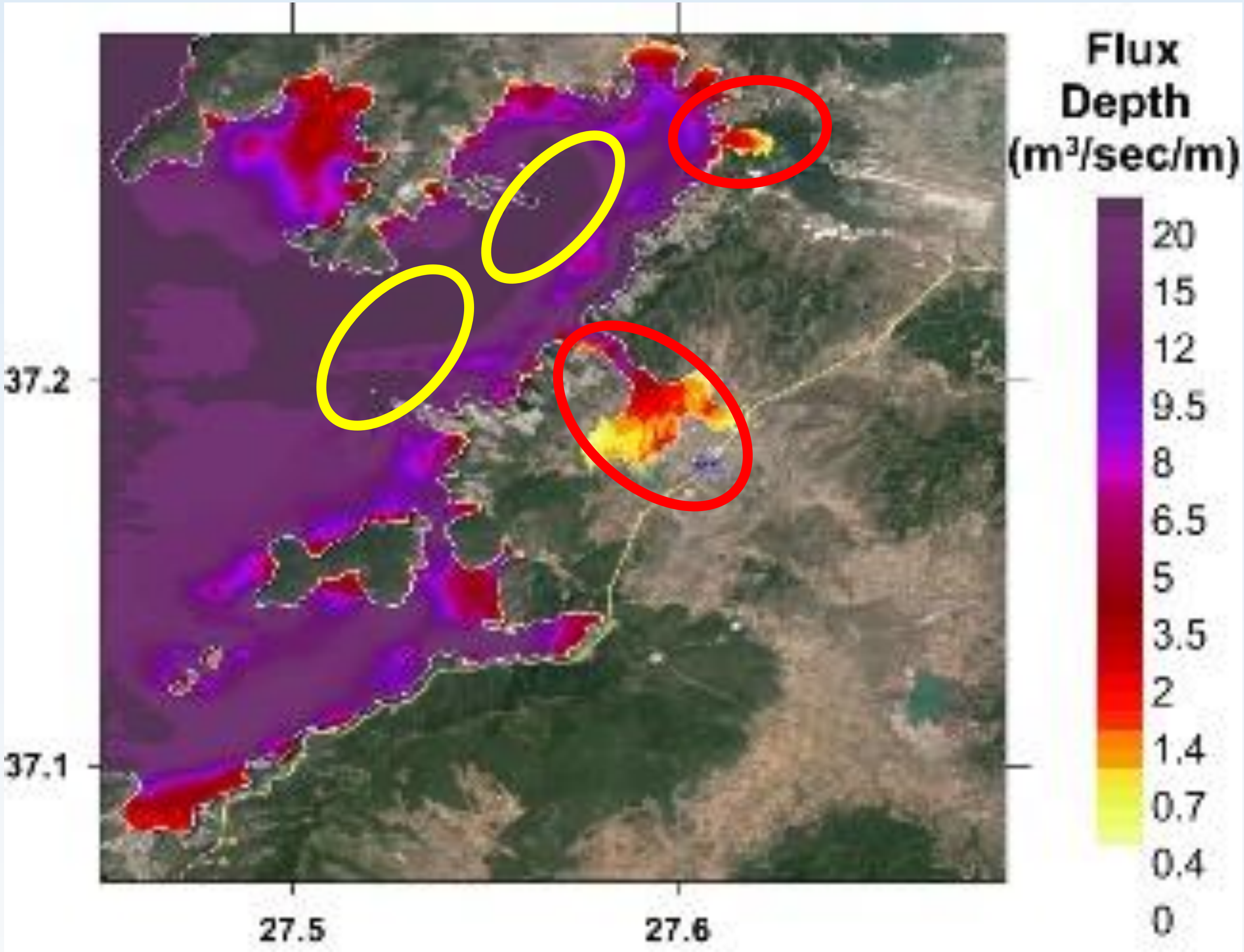

Flow Depth (m)
8
7
6
5
4
3
2
1
0.5
0.2
0
37.2
37.1
27.5
27.6


current speed (m)
10
8
7
6
5
4
3
2
1
0.5
0.3
0
37.2
37.1
27.5
27.6


Flux
Depth
(m³/sec/m)
20
15
12
9.5
8
6.5
5
3.5
2
1.4
0.7
0.4
0
37.2
37.1
27.5
27.6


Flux
Depth
(m³/sec/m)
20
15
12
9.5
8
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2
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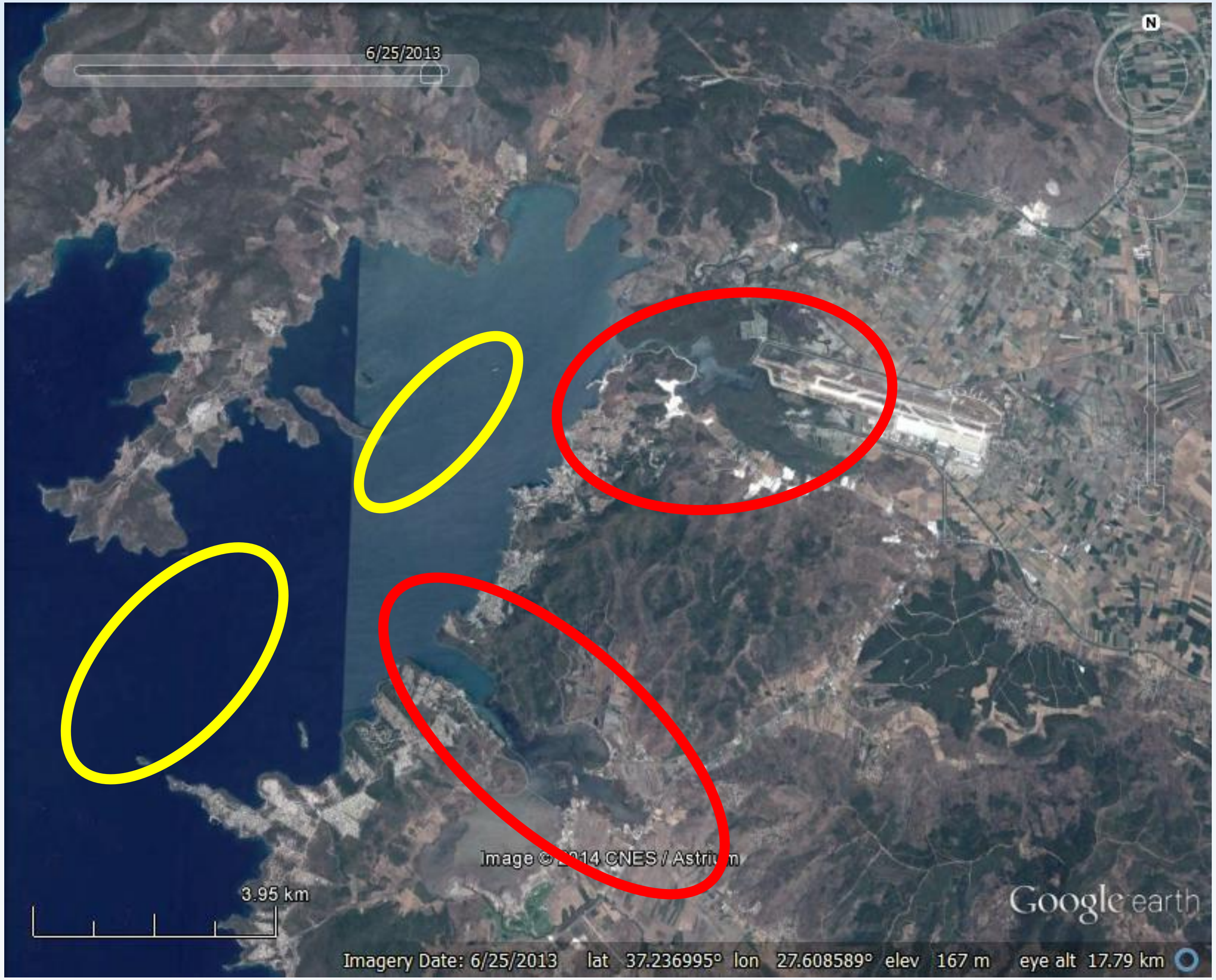
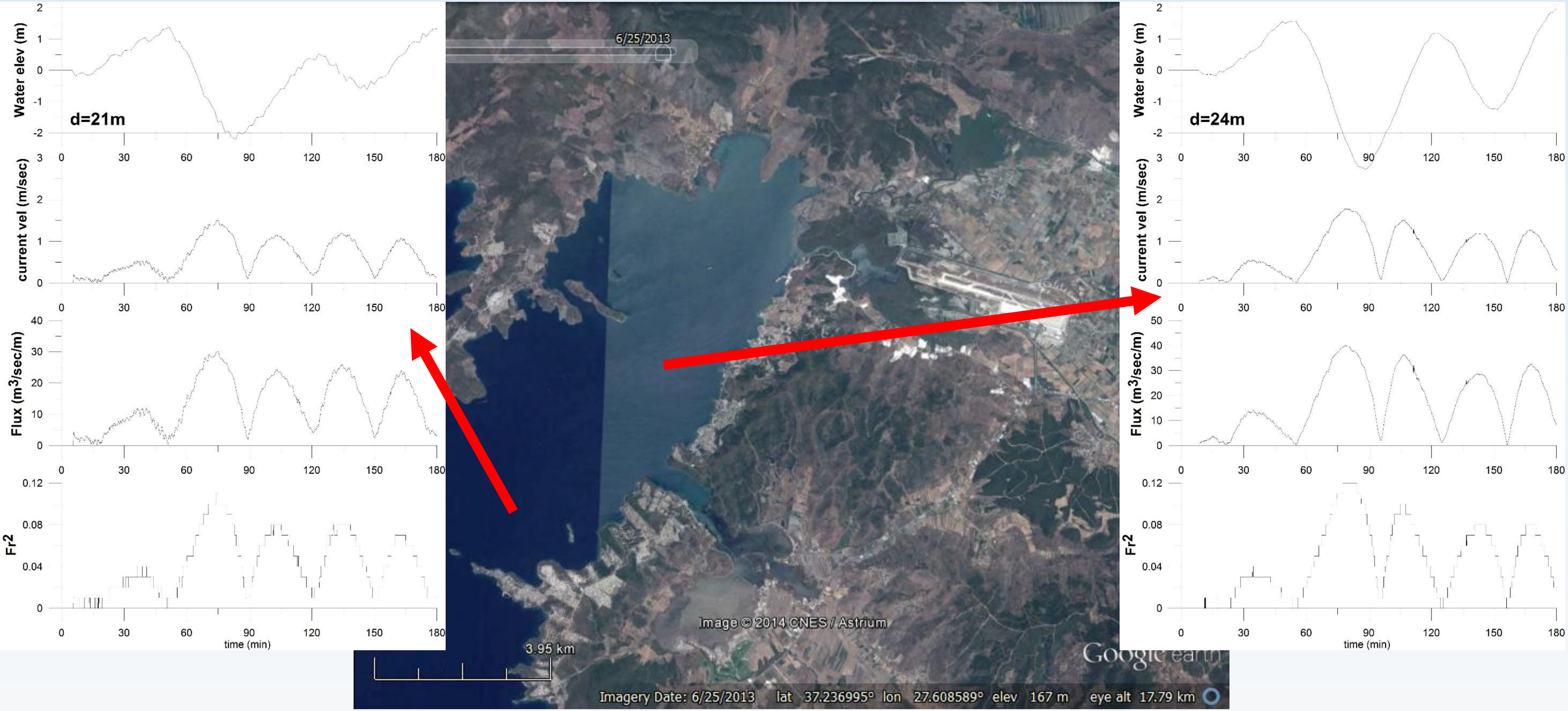
0
37.2
37.1
27.5
27.6


6/25/2013
Image © 2014 CNES / Astrium
3.95 km
Google earth
Imagery Date: 6/25/2013 lat 37.236995° lon 27.608589° elev 167 m eye alt 17.79 km
N



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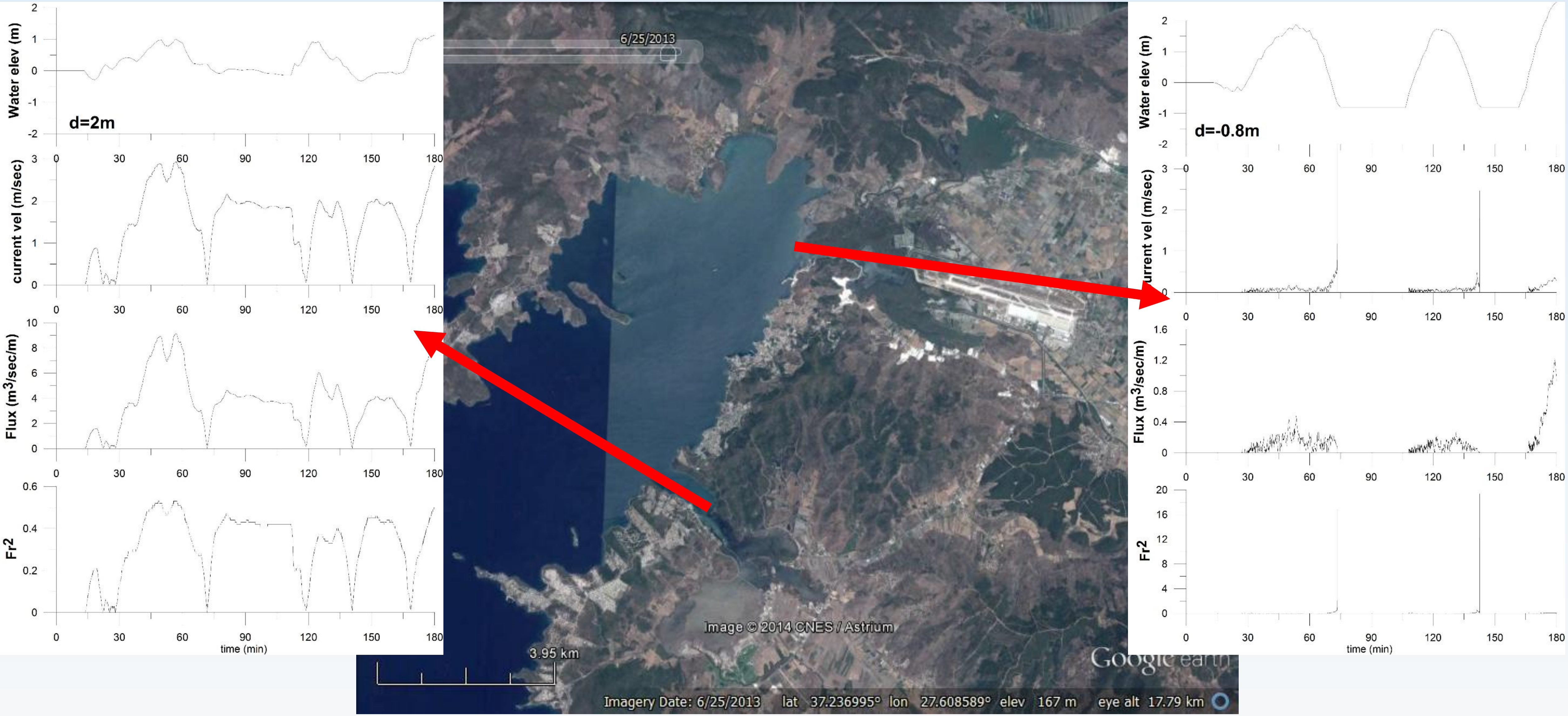

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Concluding Remarks

• Water elevation (rise)	sea and land
• Current velocity	sea and land
• Flow depth	land
• Discharge Flux	land
• Froude number	land
• Water elevation (fall)	sea

Note: The presentation covered a case of small tsunami. Further investigation and comparisons are necessary by using large size tsunami and different near shore conditions for generalization

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THANKS FOR KIND ATTENTION

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