An unstructured-grid, finite-volume model of the Irish Sea and Celtic Sea: Application to tides, surges, and temperature evolution.

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Introduction

Advantages of unstructured girds;

Applications of finite element models at NOC

(e.g., TELEMAC, ADCIRC, ICOMS);

A model of Irish Sea and Celtic Sea based on FVCOM (ICS-FVCOM).

An introduction to FVCOM

Developed at Massachusetts-Dartmouth (Chen et al, 2003);

Hydrostatic, terrain-following σ co-ordinate (similar to POM, BOM or POLCOMS);

Finite-volume method on triangle grids;

Tracer advection: MPDATA (Smolarkiewicz 2005); Mellor-Yamada turbulence closure;

Advantages including grid flexibility at complex coastal line, better conservation, etc. ;

Many modules: sediment, ecosystem, wind waves, ice, etc.,

Long-term integration of the model has not been tested;

Improvements are made for the model of the Irish Sea.

Application to tides, surges and temperature evolution in the Irish Sea and Celtic Sea

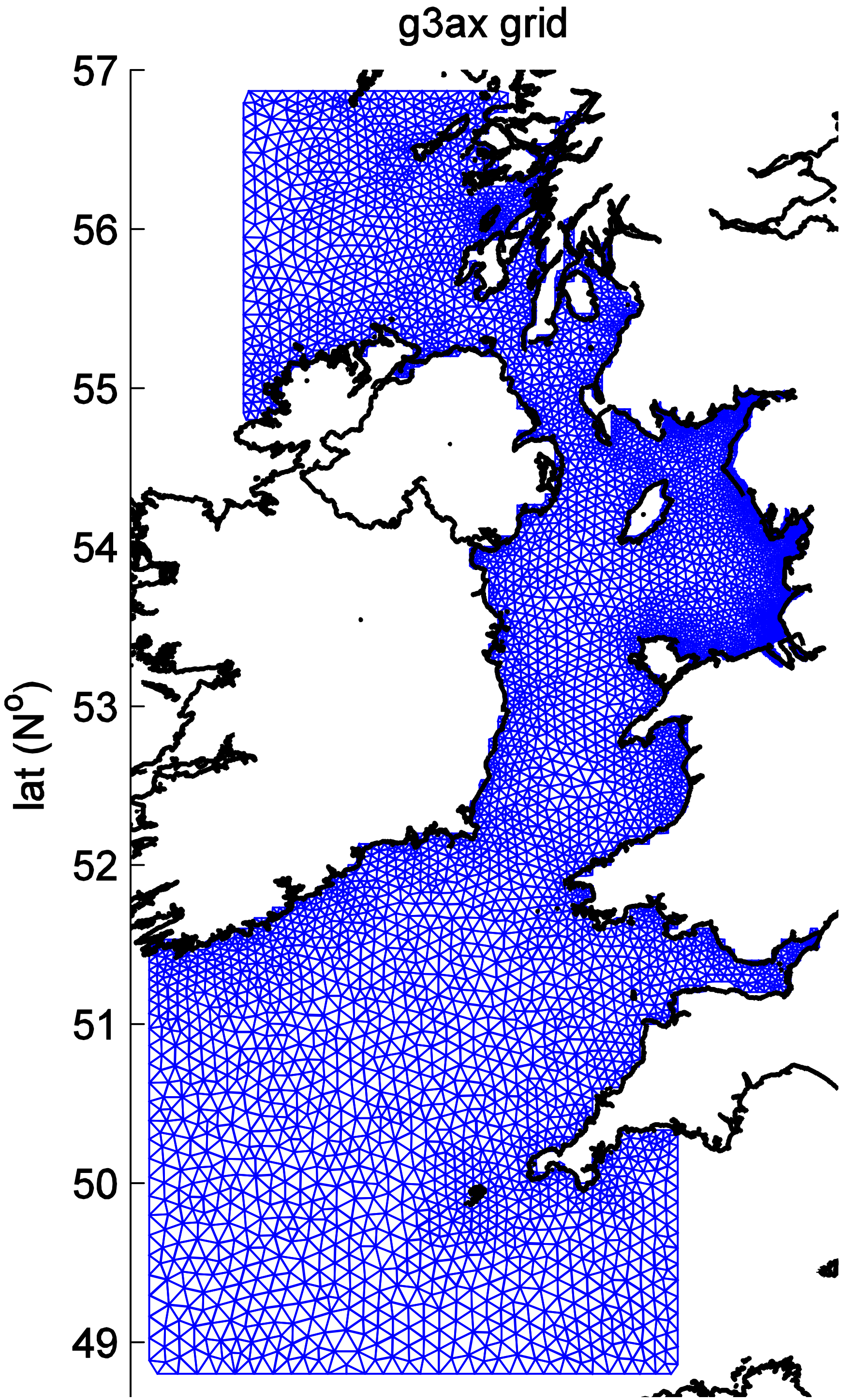
1. Bartropic tides: forced at the open boundary

   Jones + Davies (Ocean Modelling, 2007) ;

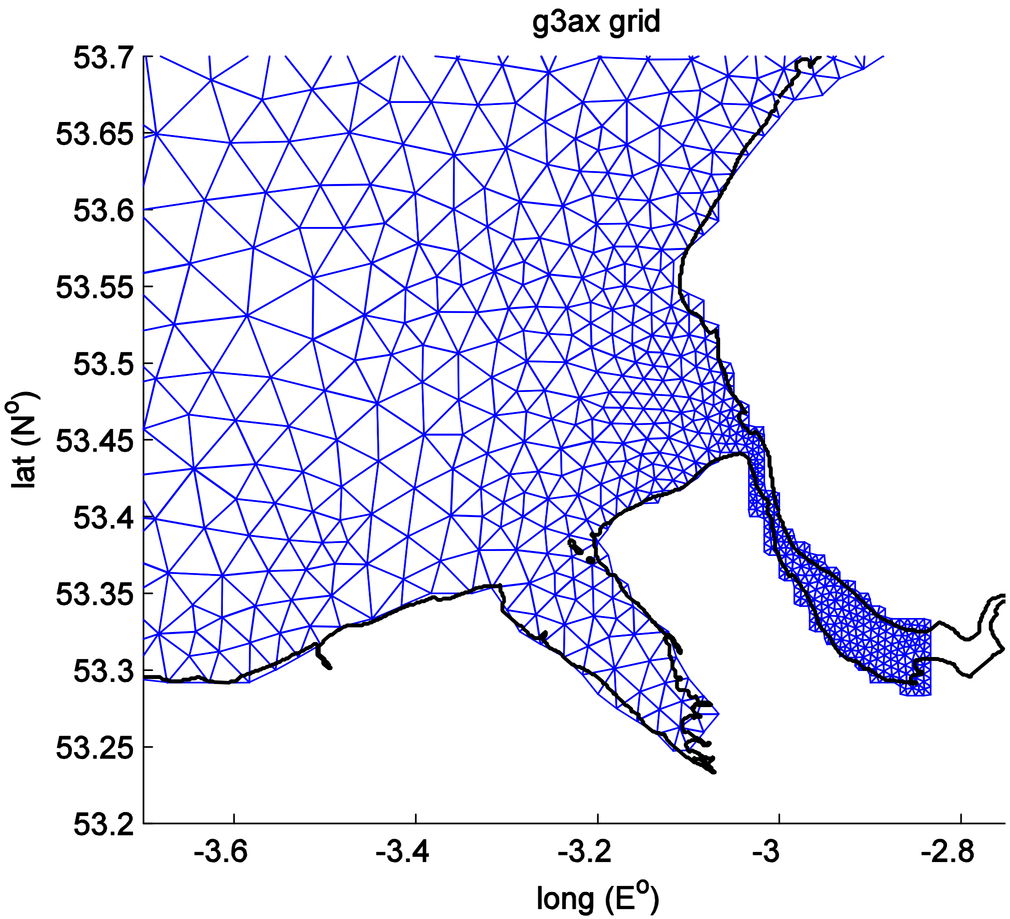
2. Idealized wind force of 1 N/m^2 (effects of breaking wases)

3. Realistic meteorological forcing due to wind and heating and tides (temperature evolution);

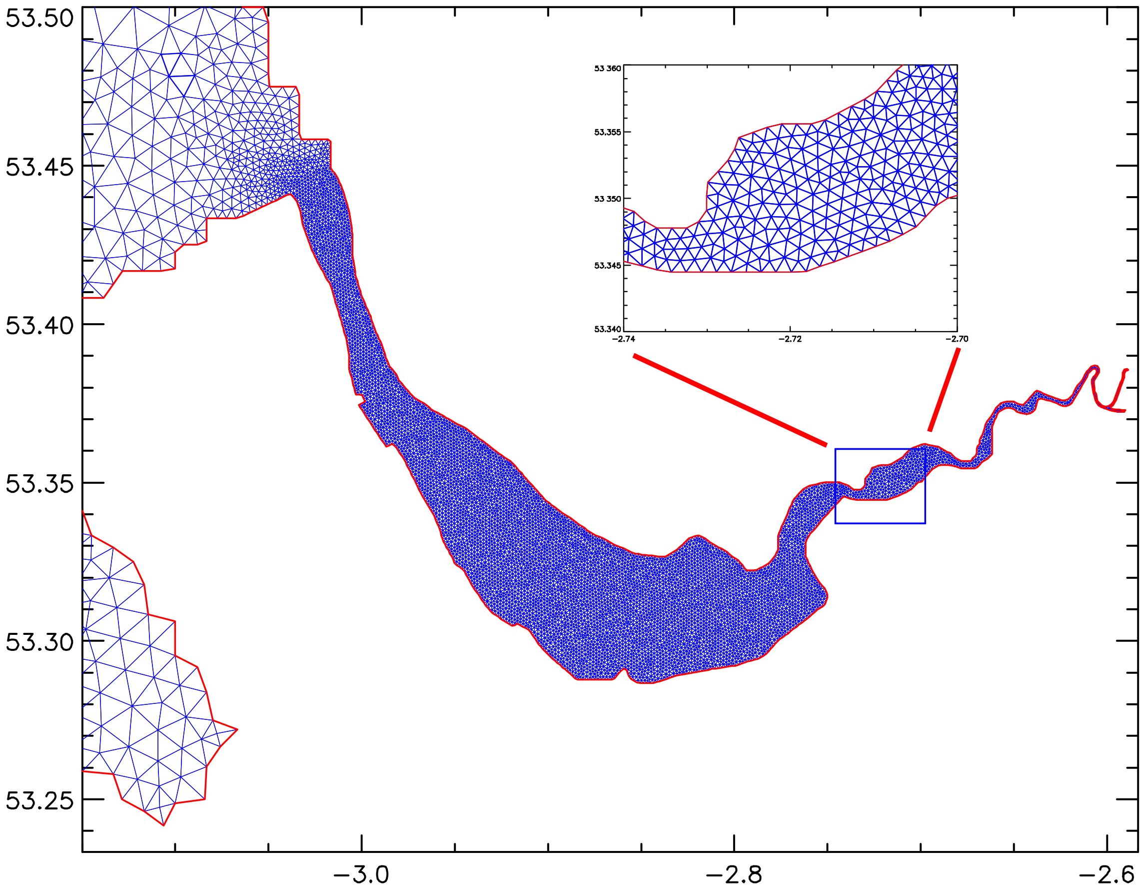
4. ROFI in Liverpool Bay .



Irish sea model grids (g3ax)

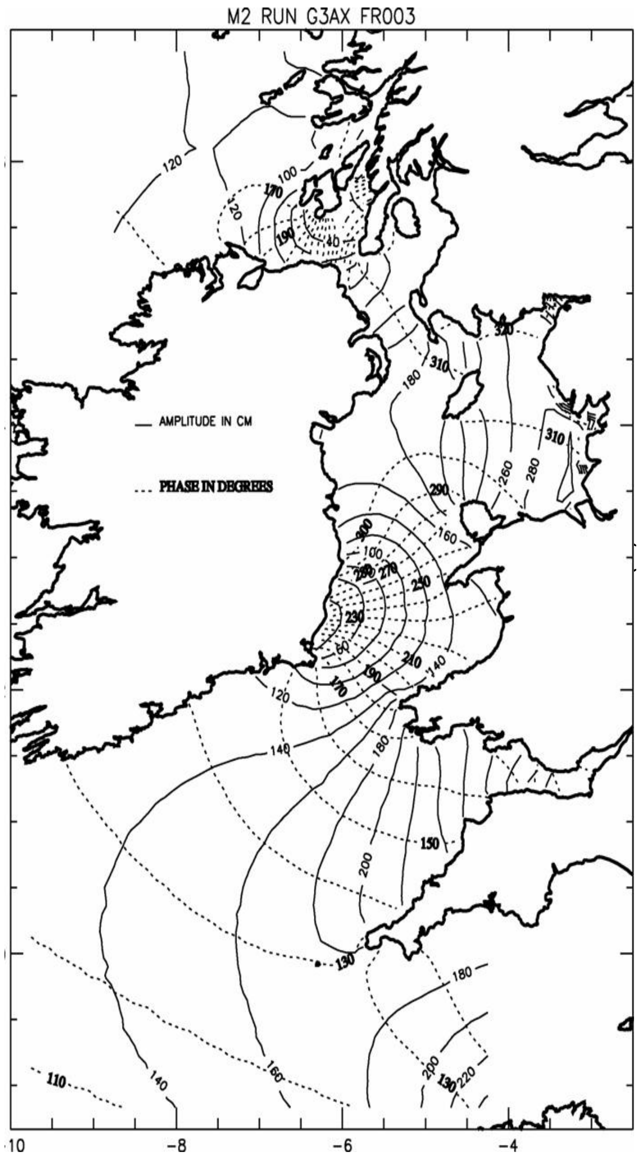


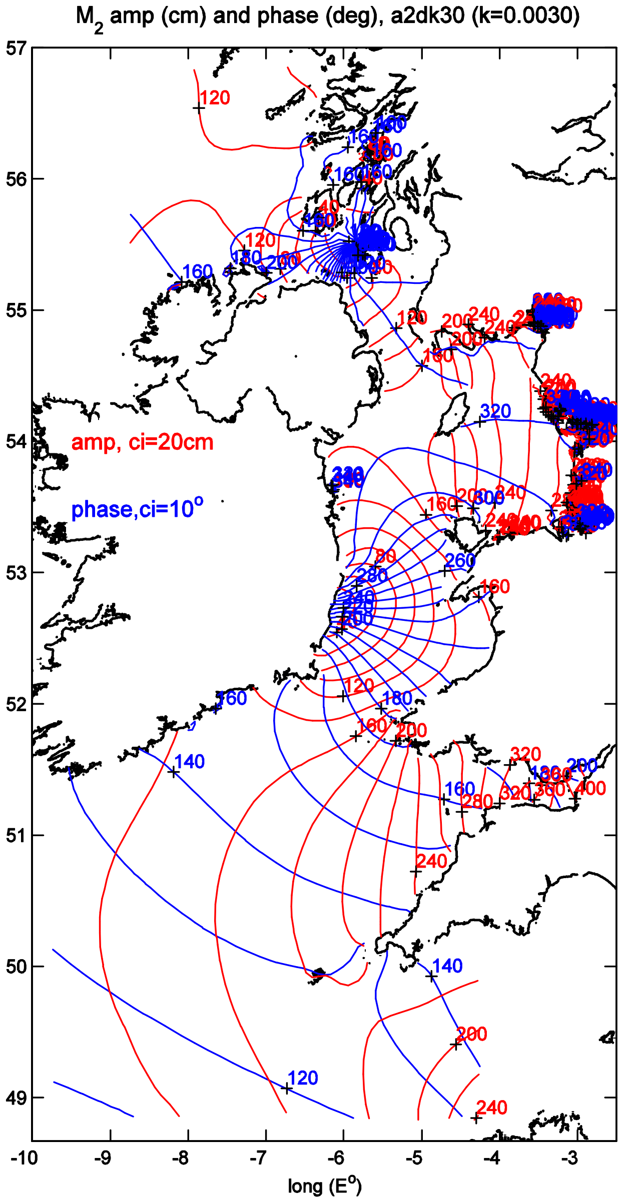
Refined grids in river Mersey

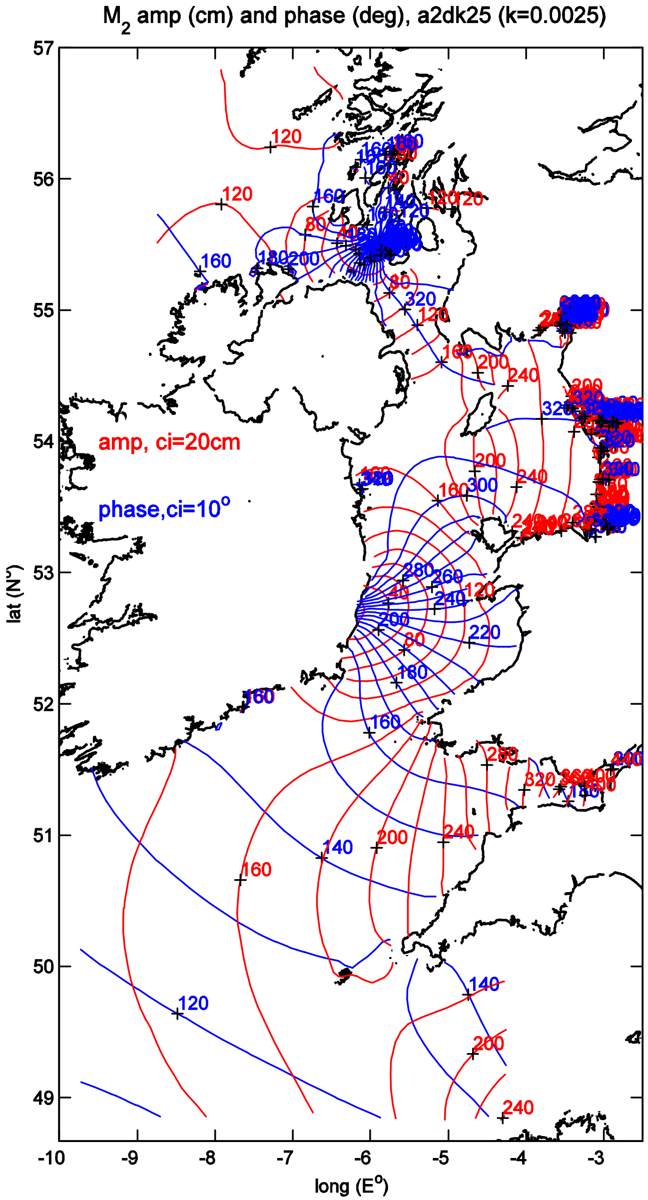


M2 tide:

TELMAC 2D (k=0.003) | ICS-FVCOM (k=0.003) | ICS-FVCOM(k=0.0025)

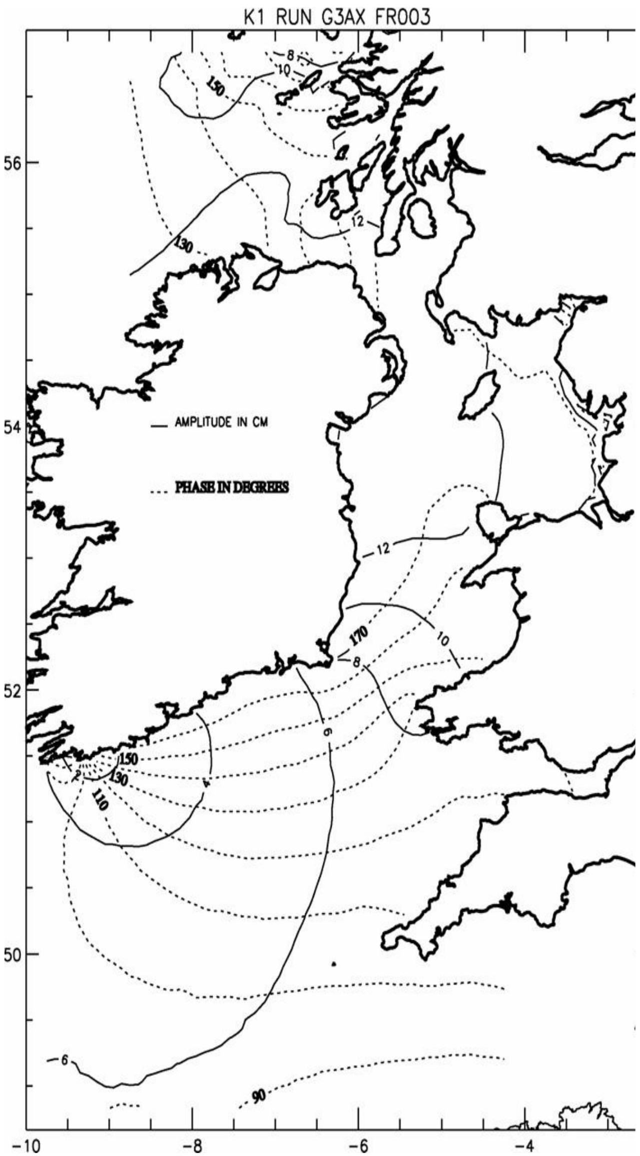




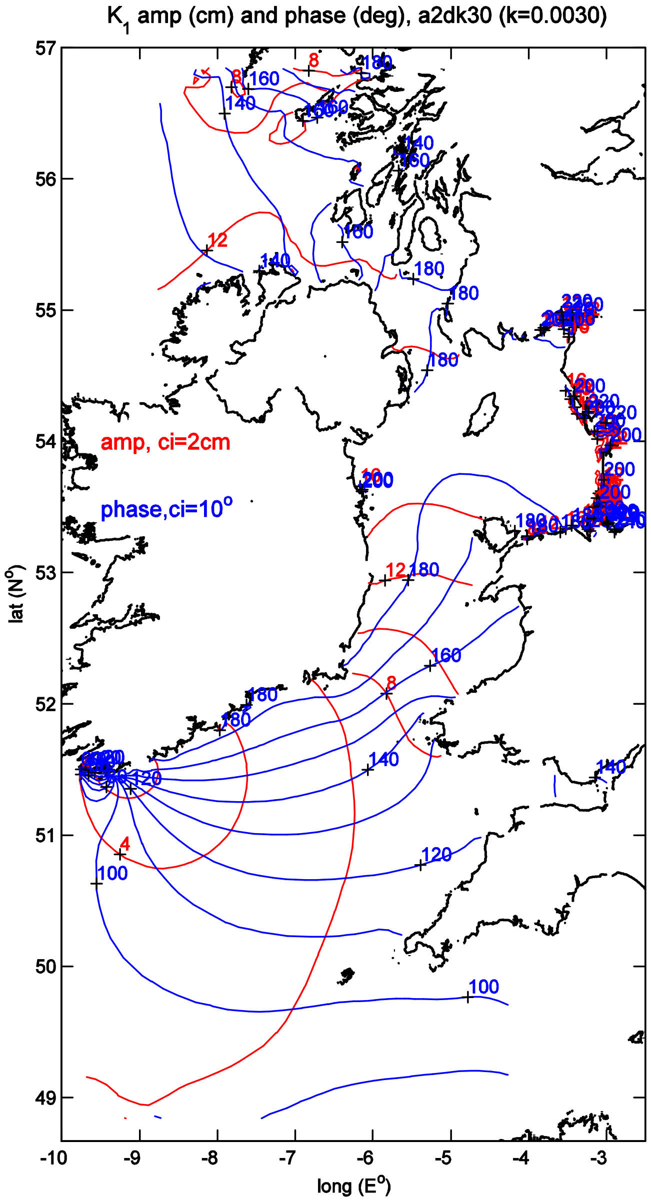


K1

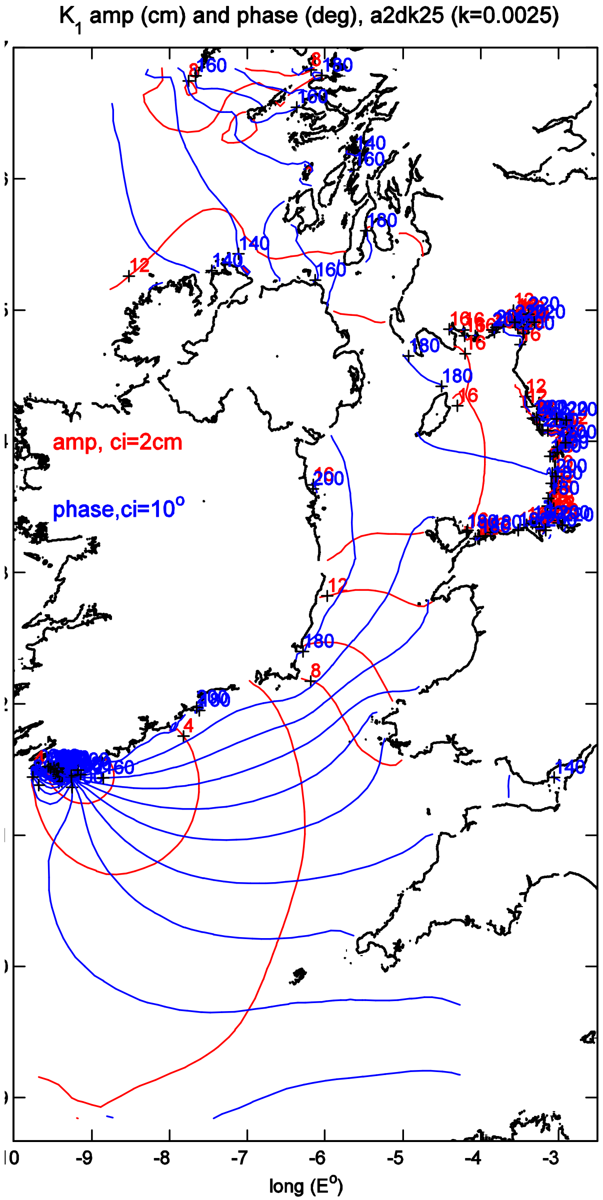
TELMAC 2D (k=0.003)



ICS-FVCOM (k=0.003)

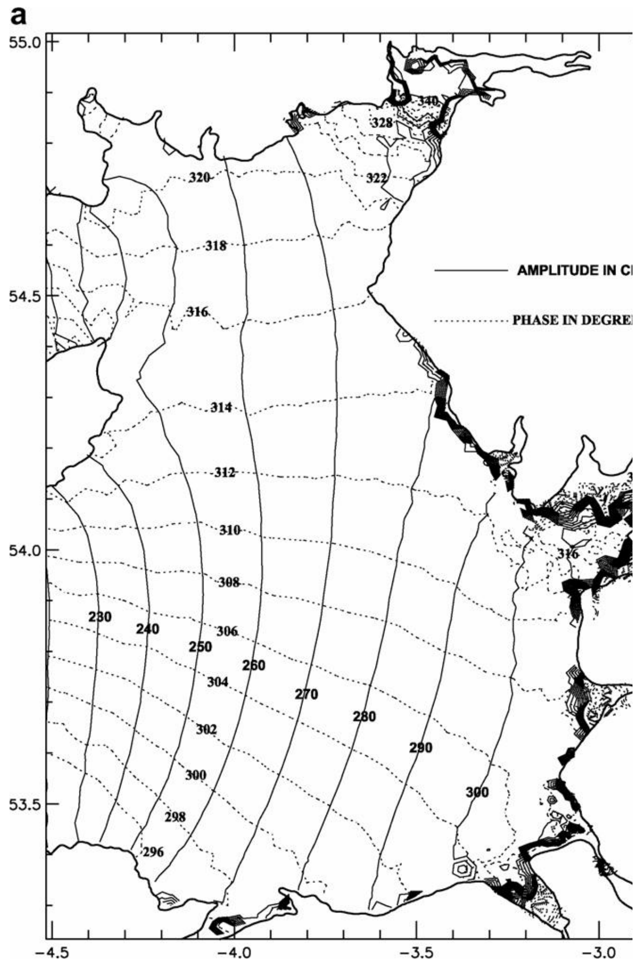


ICS-FVCOM(k=0.0025



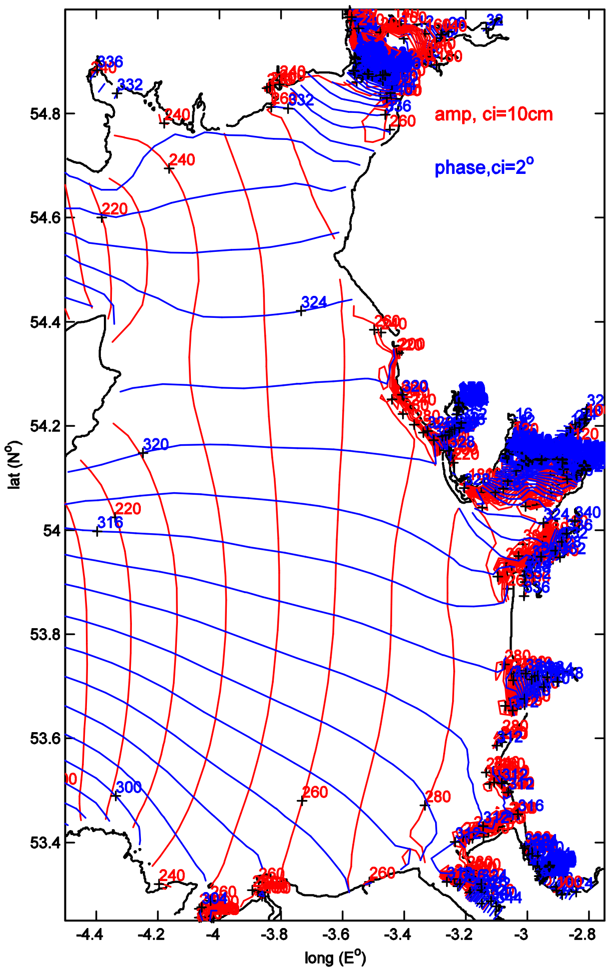
Computed M2 tide in the Eastern Irish Sea

TELEMAC 2D



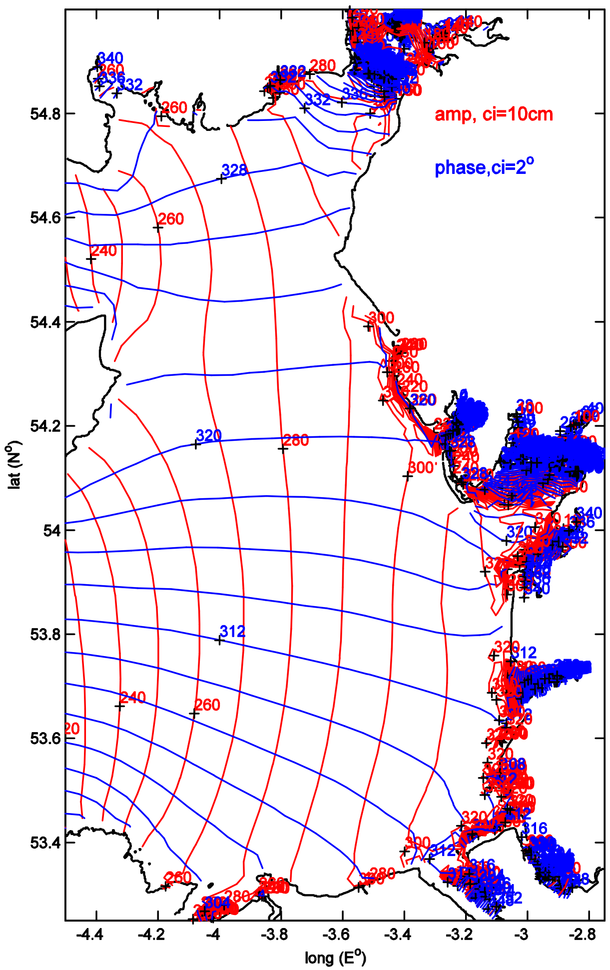
ICS-FVCOM 2D

M_2 amp (cm) and phase (deg), a2dk30 (k=0.0030)



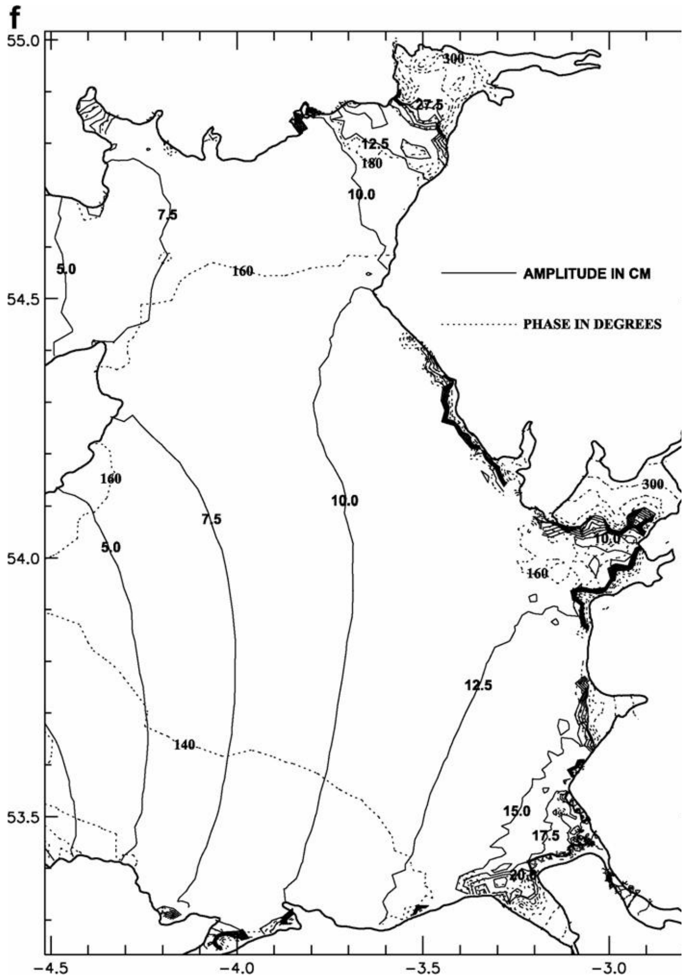
ICS-FVCOM 3D

M_2 amp (cm) and phase (deg), a3d

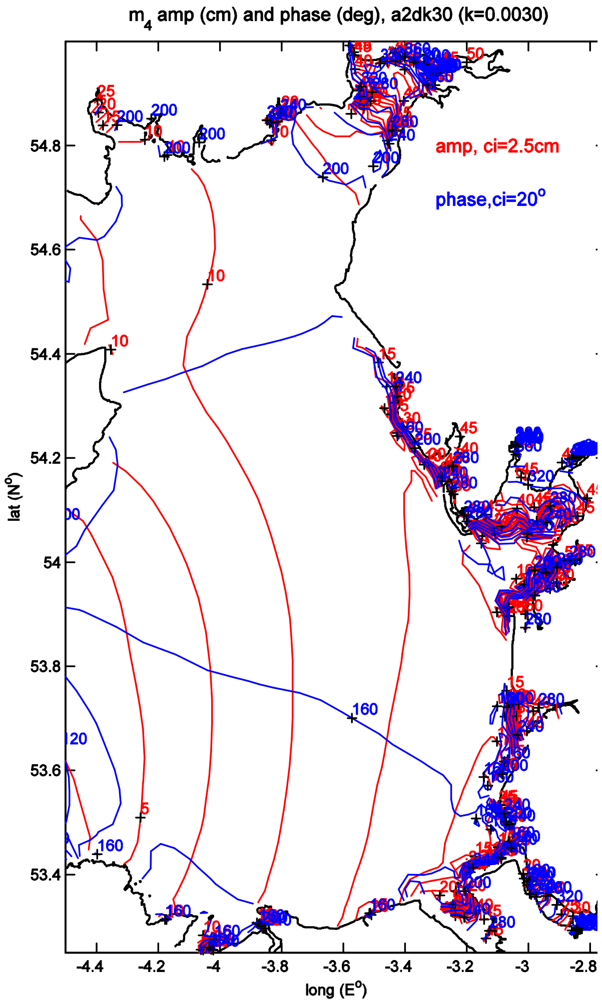


Computed M4 tide in the Eastern Irish Sea

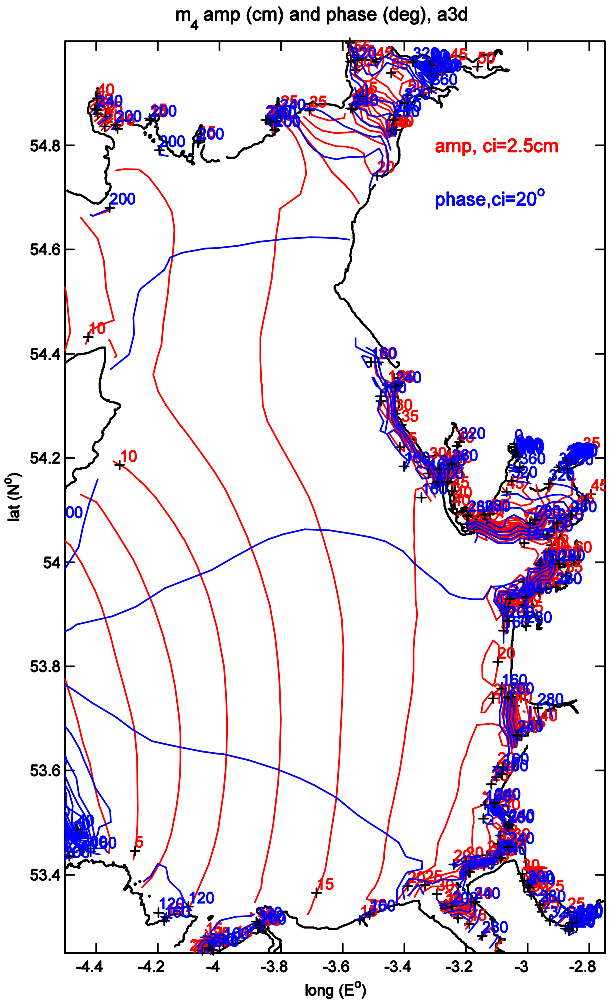
TELEMAC 2D



ICS-FVCOM 2D

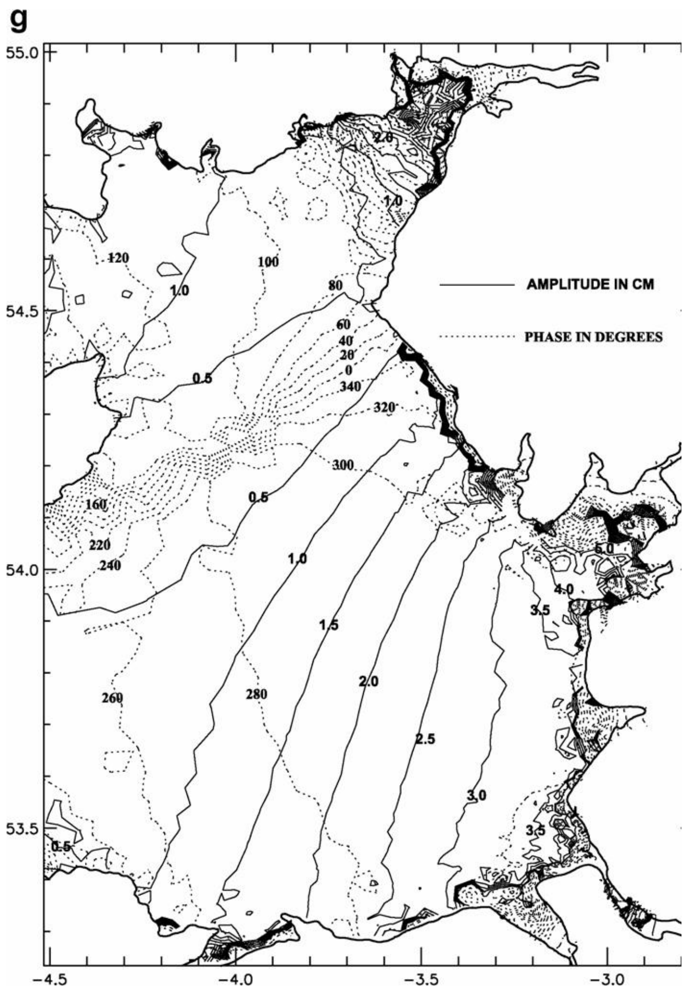


ICS-FVCOM 3D



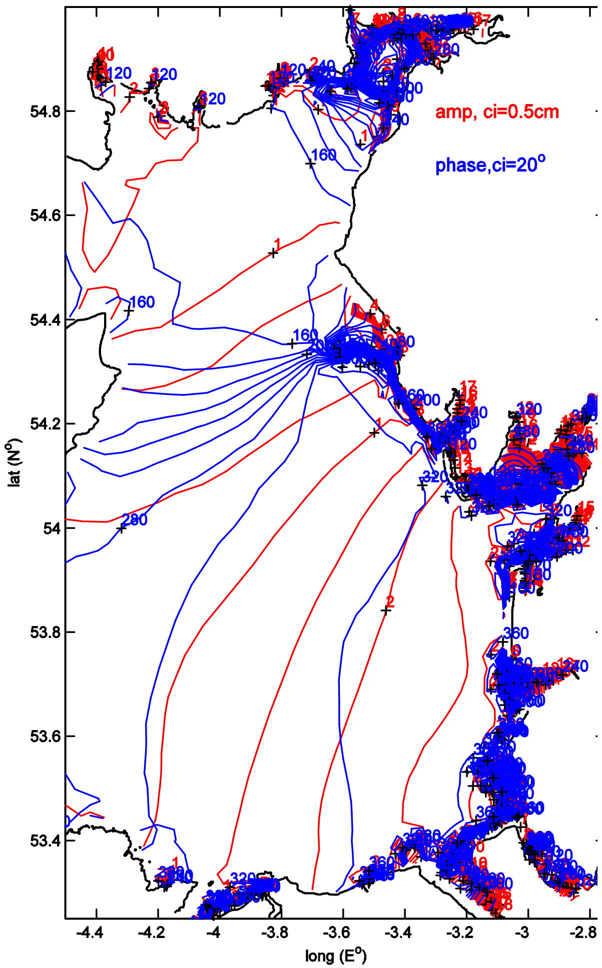
Computed M6 tide in the Eastern Irish Sea

TELEMAC 2D



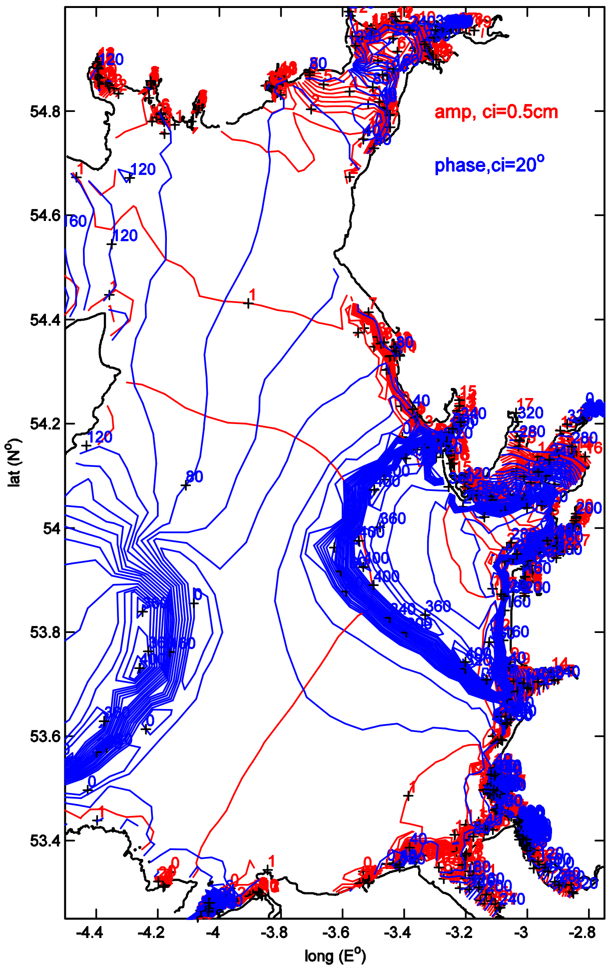
ICS- FVCOM 2D

M_6 amp (cm) and phase (deg), a2dk30 (k=0.0030)

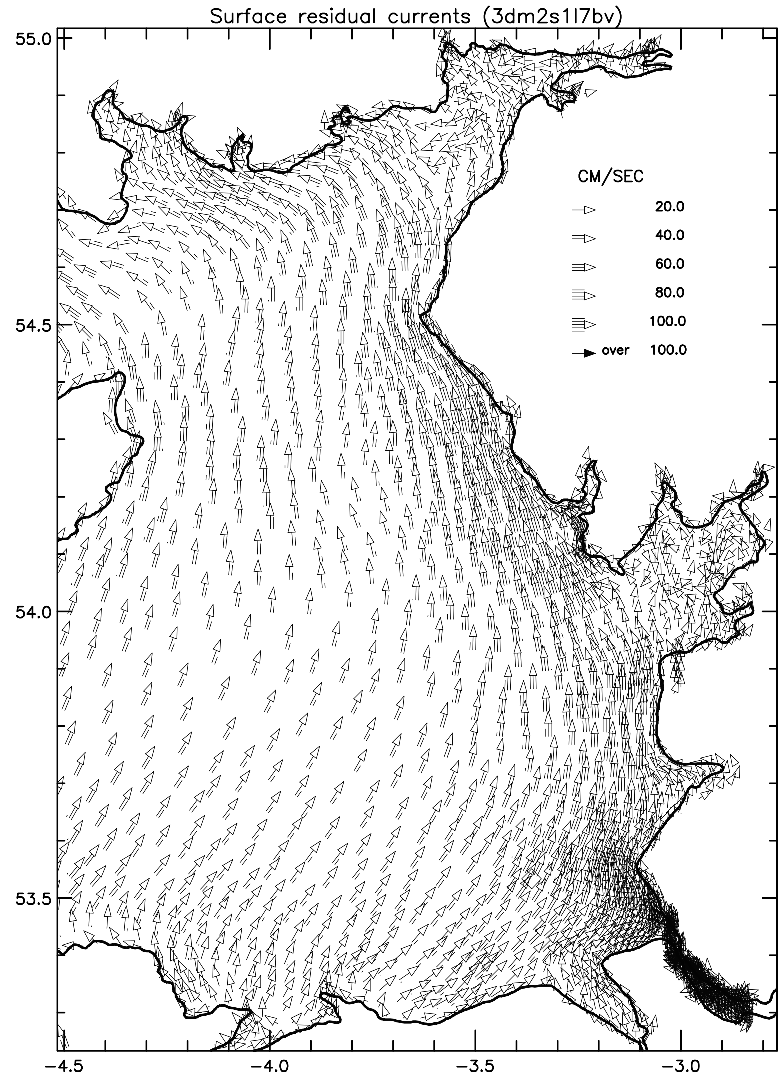


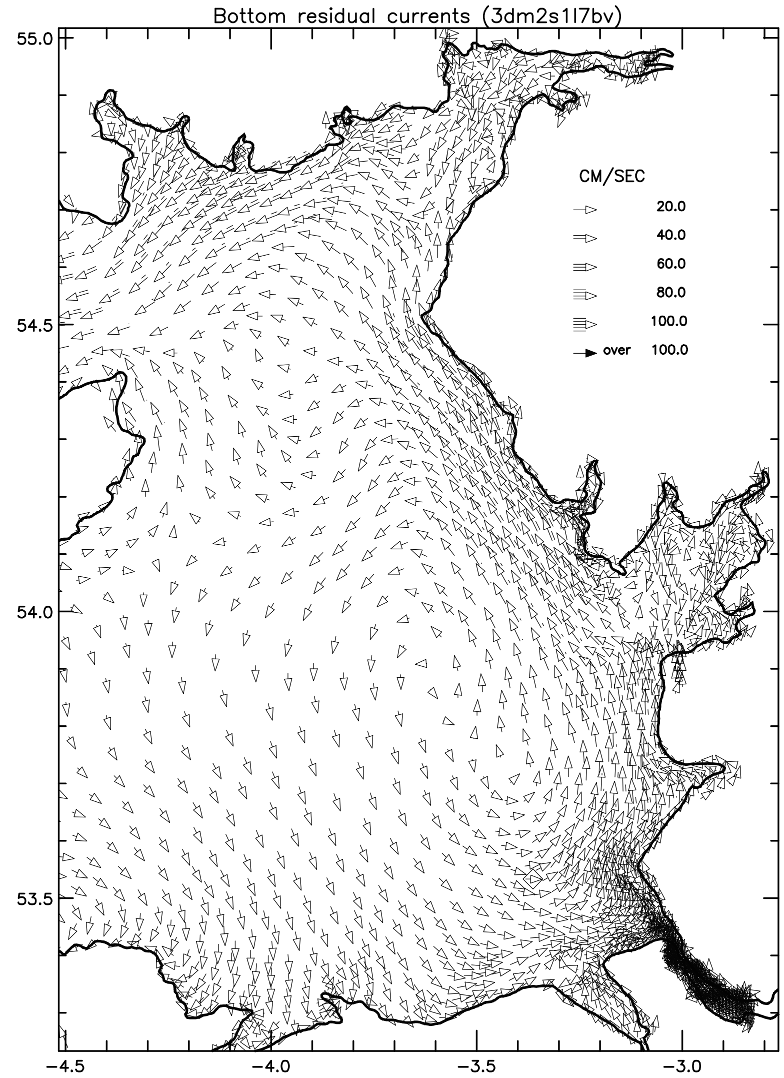
ICS- FVCOM 3D

M_6 amp (cm) and phase (deg), a3d

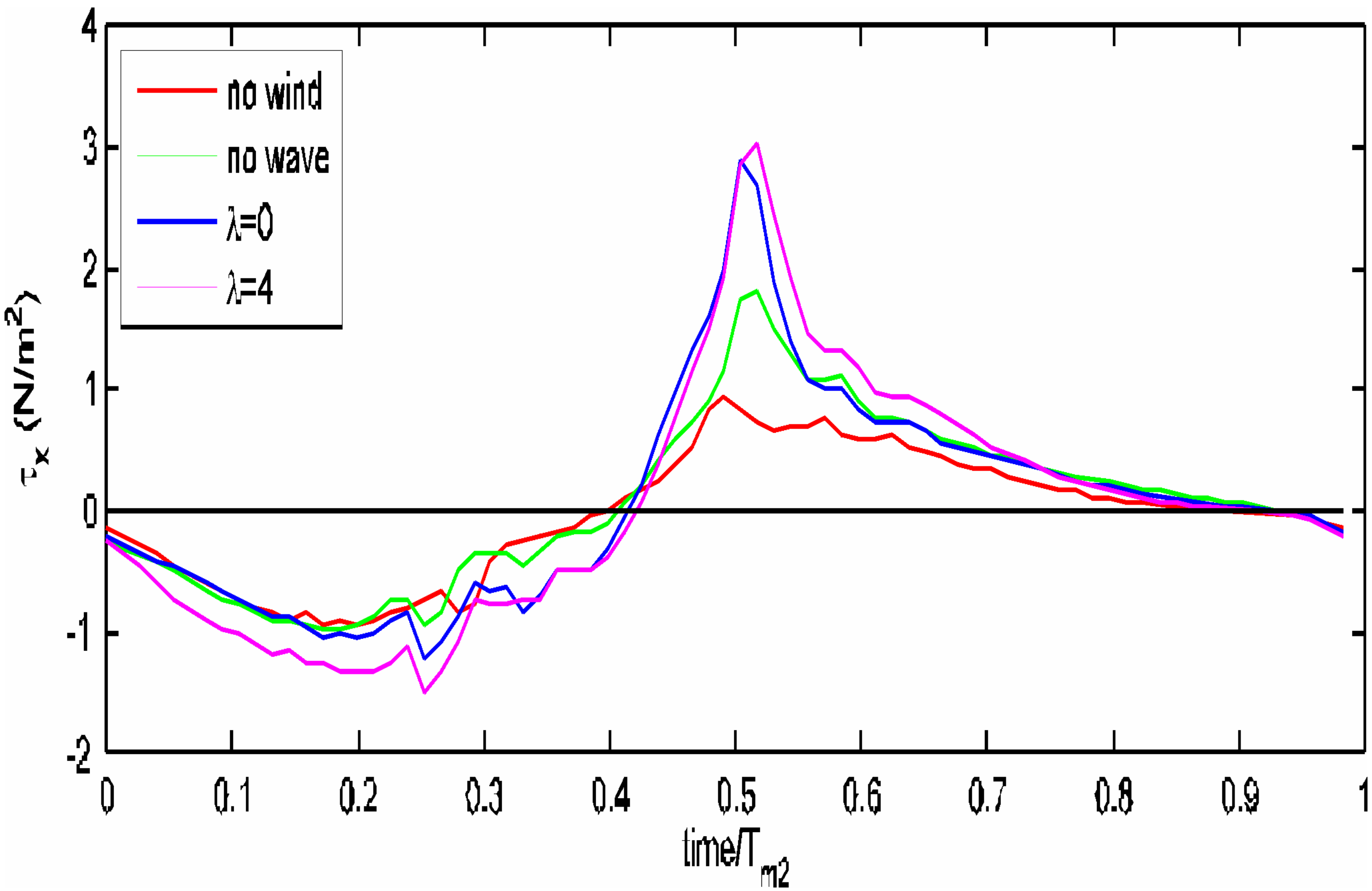


Surface and bottom currents (south wind stress 1pa)

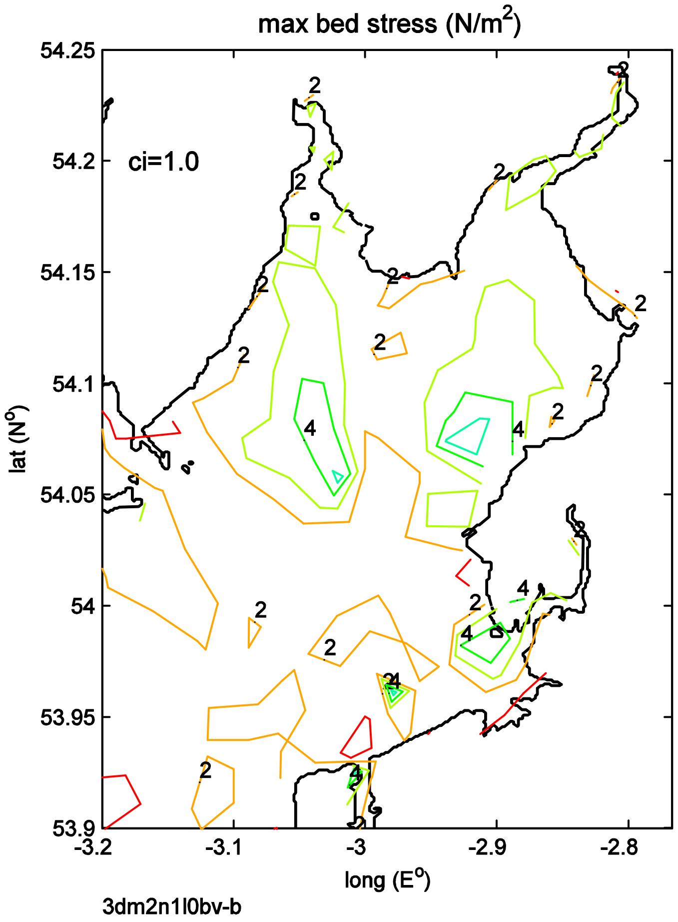


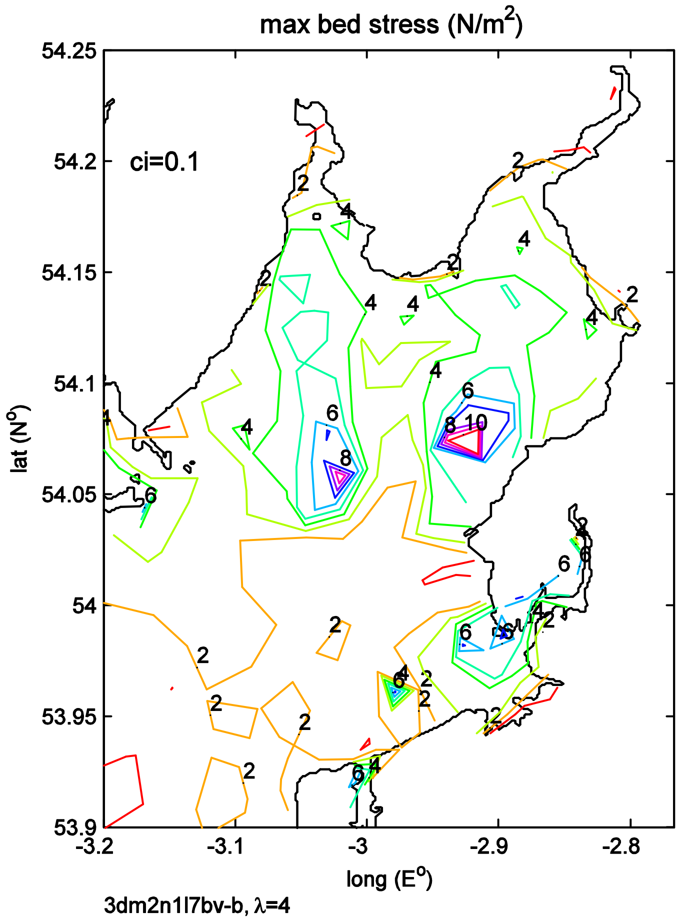


Bed stress at a location in the Liverpool Bay



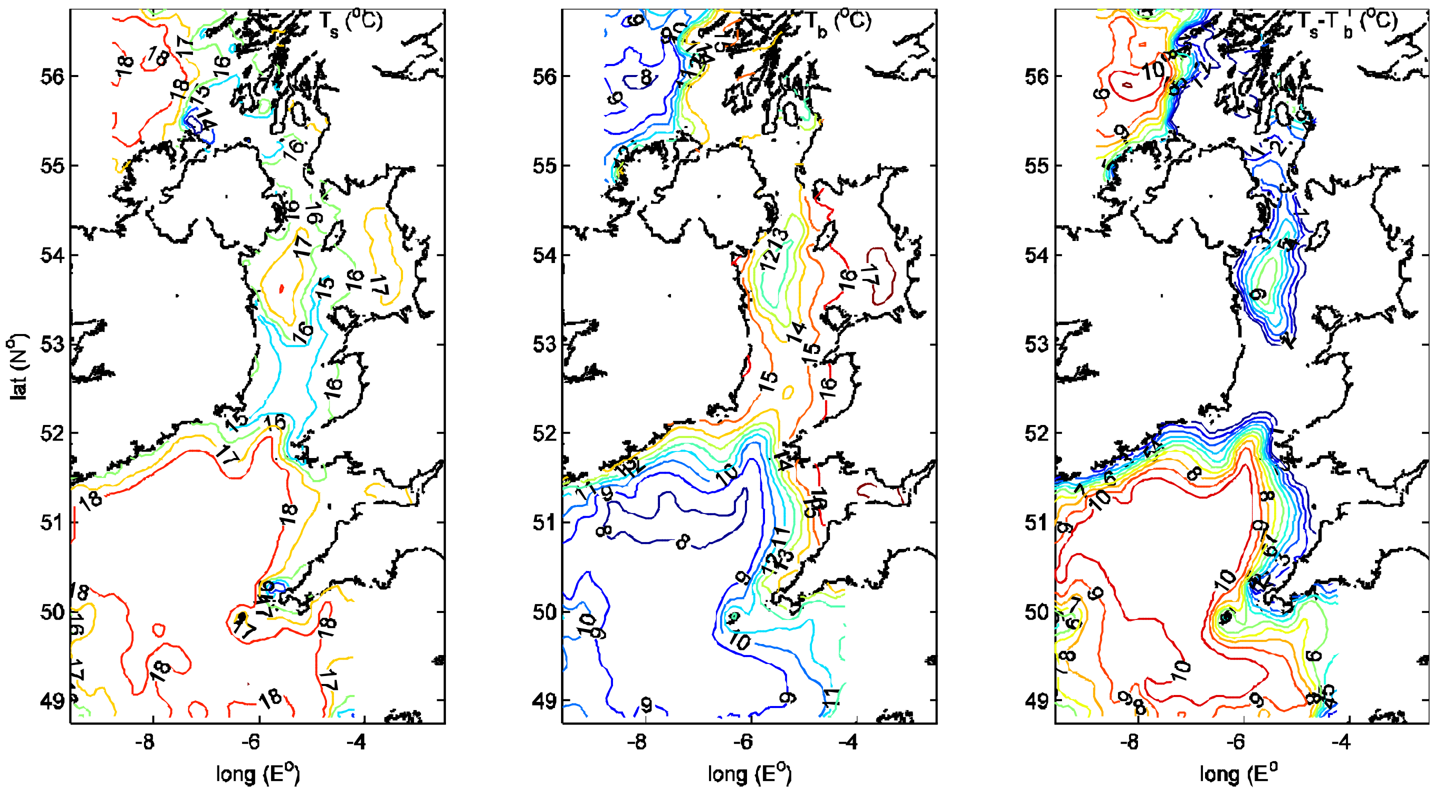
Effects of wave breaking parameterization on maximum bed stress in the shallow water region





Temperature on 16 Aug. 1995

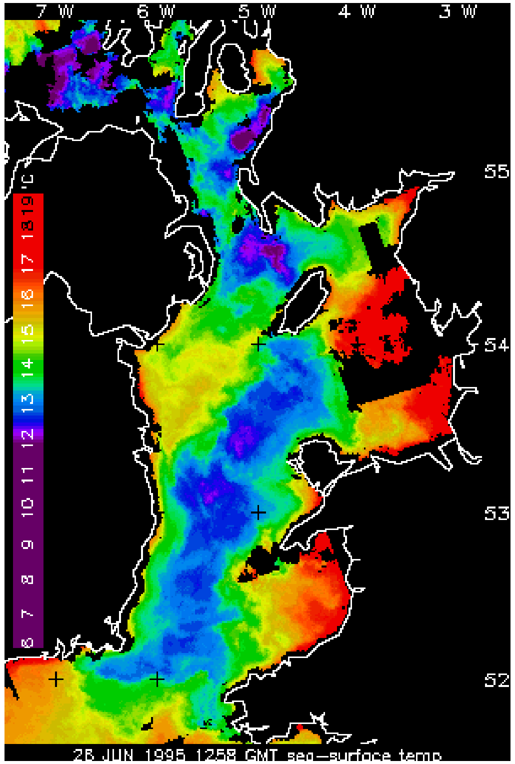
Surface temp (Ts) Nearbed temp (Tb) Ts-Tb



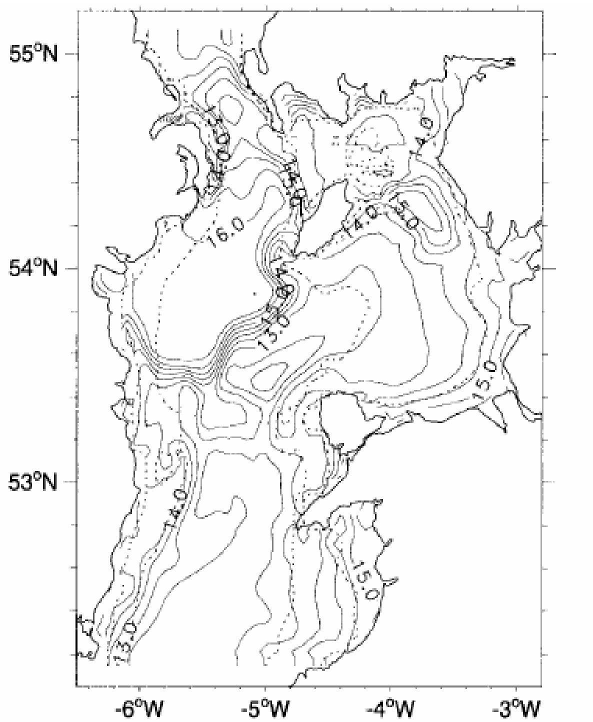
g0w9aqt2-kh2b-sph, day= 148

Surface temperature on 26 June 1995

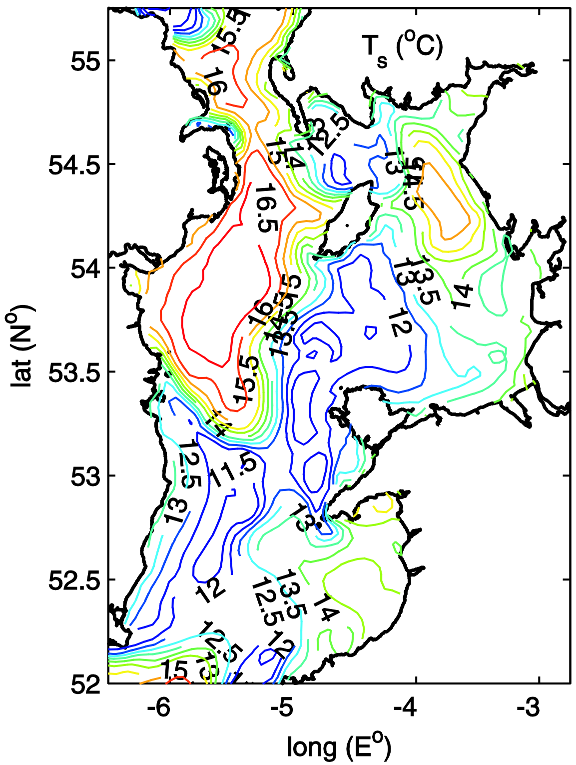
OBS



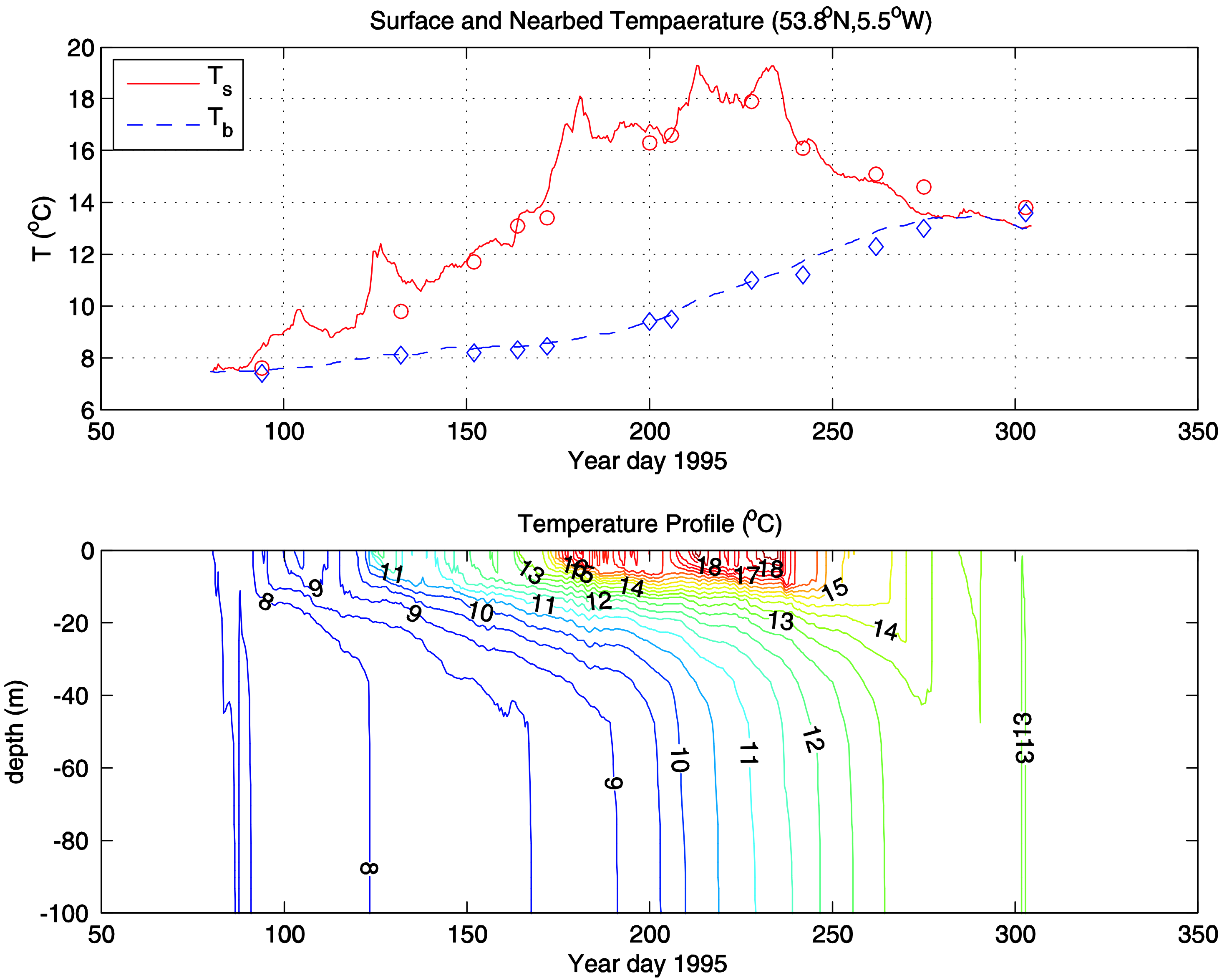
Xing+Davies JPO 2000



ICS-FVCOM

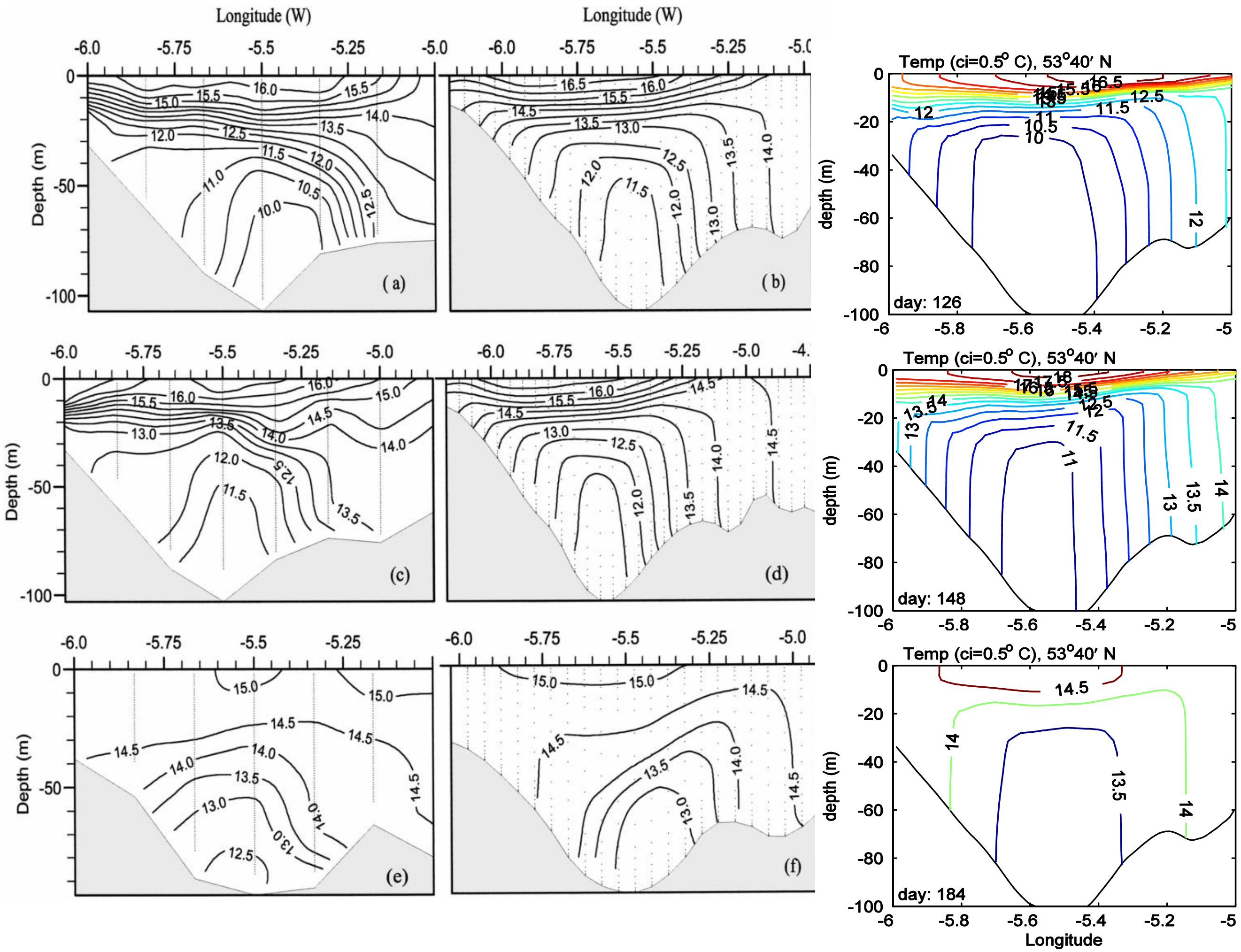


Time series of temperature at the West Irish sea



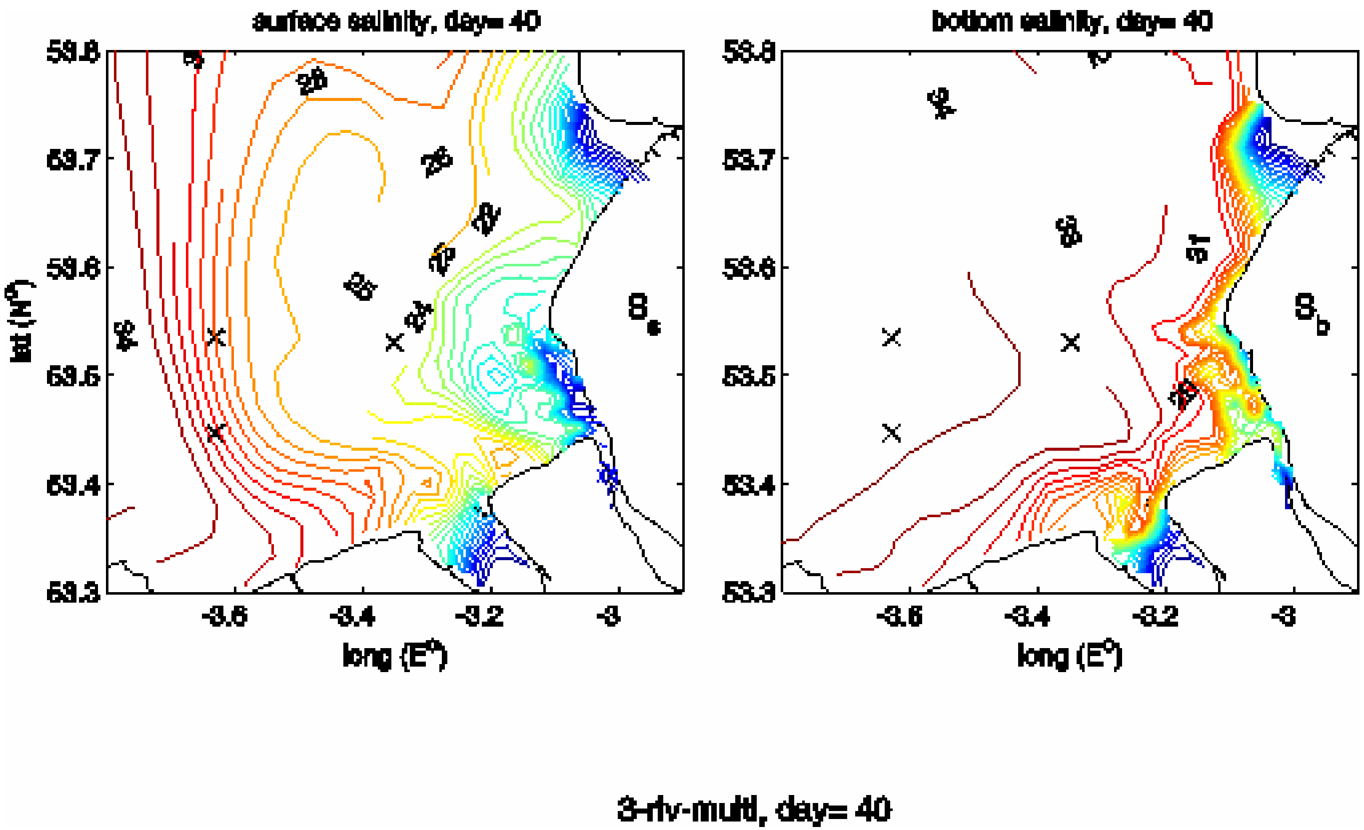
(x-z) section of temperature along 53º 40′ N from observations, models of POM and ICS-FVCOM

OBS   Horsburgh+Hill JPO 2002   ICS-FVCOM



ROFI: fresh water discharge in Liverpool Bay

Surface salinity | bottom salinity



Conclusions

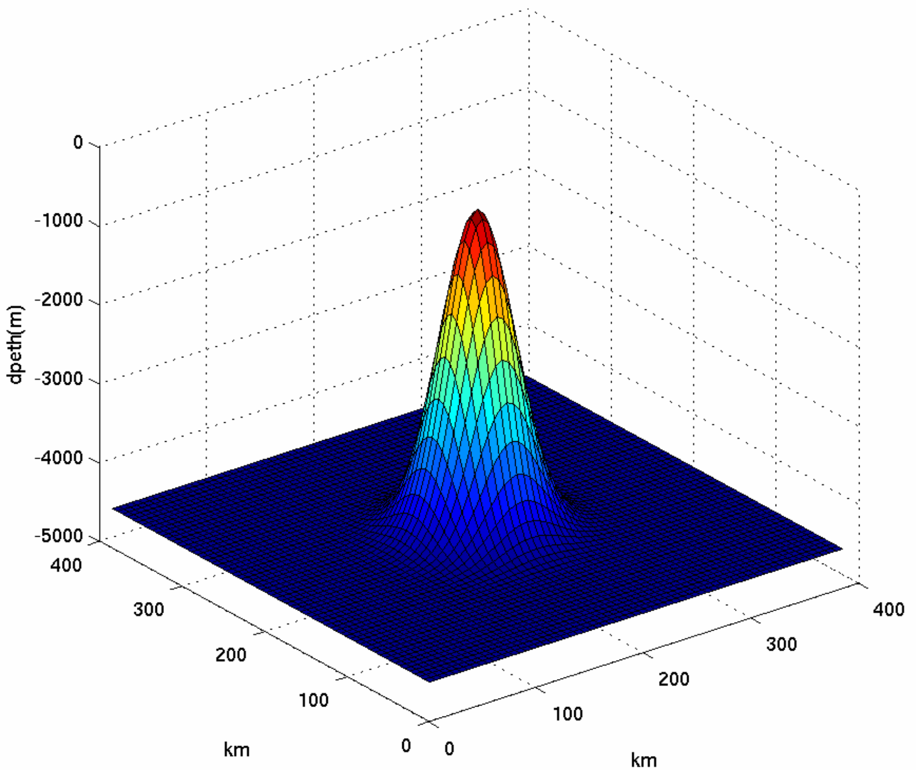
A robust finite-volume, unstructured-grid model of the Irish sea based on FVCOM is established;

Validation work is in progress (bartropic tides are well reproduced);

A shelf wide finite-volume unstructured-grid model for the purpose of climate study is achievable in the near future;

Future improvements: turbulence, HPG, efficiency …

The seamount test case (Haidvogel+Beckman, Berntsen+Furnes 2005, etc.)



Model setup and parameters

FVCOM v2.7 (full non-linear hydrostatic model), with uniform resolution 3, 6 km

No vertical diffusion and bottom friction

No horizontal diffusivity

Horizontal viscosity (10^3 , 10^2 m^2/s)

A Gaussian form of topog. (450-4500m)

An initial exponential density profile ($\Delta\rho$=1.5 kg/m^3)

Internal pressure gradient in σ-coordinate system, [σ=(z-ζ)/D] and finite volume method (Chen et al)

u equation and internal pressure gradient term:

$$\frac{\partial Du}{\partial t}+\nabla\cdot(\vec{V}Du)+\ldots \quad =-\frac{g}{\rho_0}\left[D\frac{\partial}{\partial x}\left(D\int_{\sigma}^{0}\sigma\frac{\partial\rho}{\partial\sigma}d\sigma\right)+D^2\frac{\partial\rho\sigma}{\partial x}\right]+\ldots$$

$$IPG \quad =-\frac{g}{\rho_0}\left\{\iint D\frac{\partial}{\partial x}\left[D\left(\int_{\sigma}^{0}\sigma\frac{\partial\rho}{\partial\sigma}d\sigma\right)\right]dxdy+\iint D^2\frac{\partial\rho\sigma}{\partial x}dxdy\right\}$$

$$=-\frac{g}{\rho_0}\left\{\overline{D}\oint\left(D\int_{\sigma}^{0}\sigma\frac{\partial\rho}{\partial\sigma}d\sigma\right)dy+\overline{D}^2\oint\rho\sigma dy\right\}$$

Green's Theorem:

$$\oint -Ndx+Mdy=\iint\left(\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}\right)dxdy$$

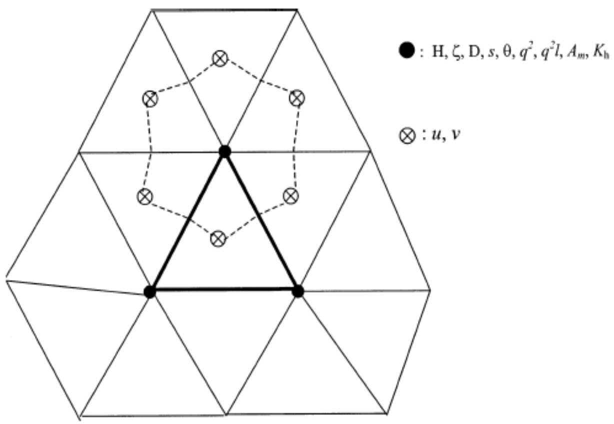
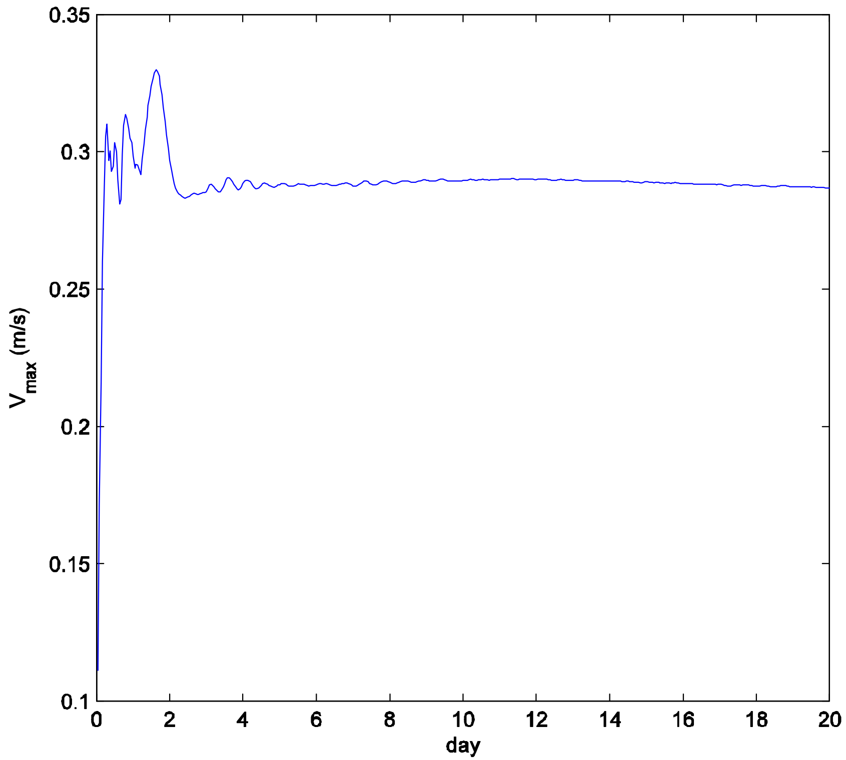
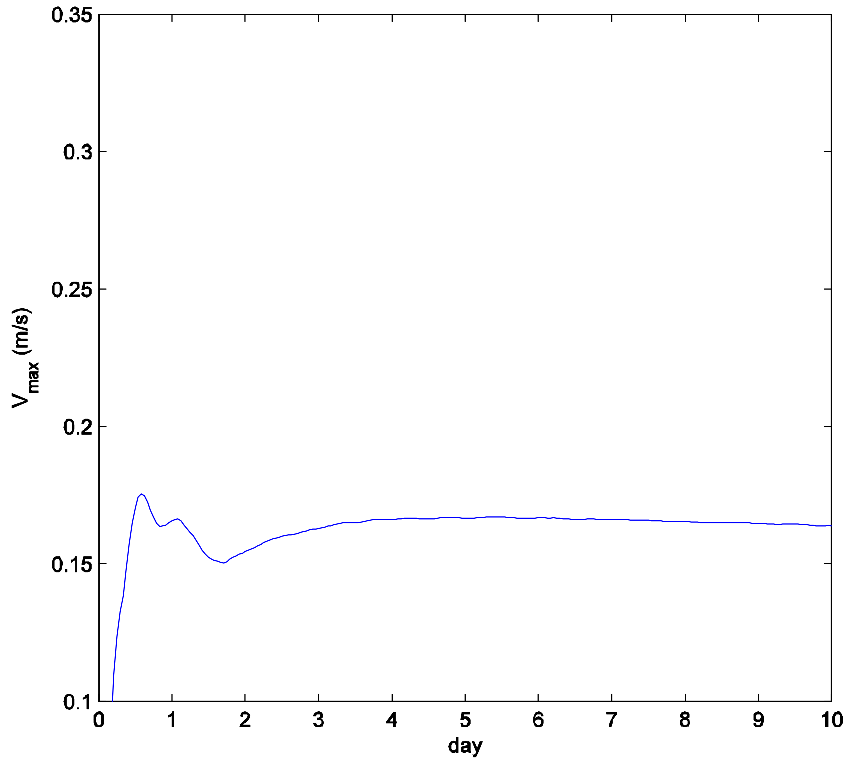


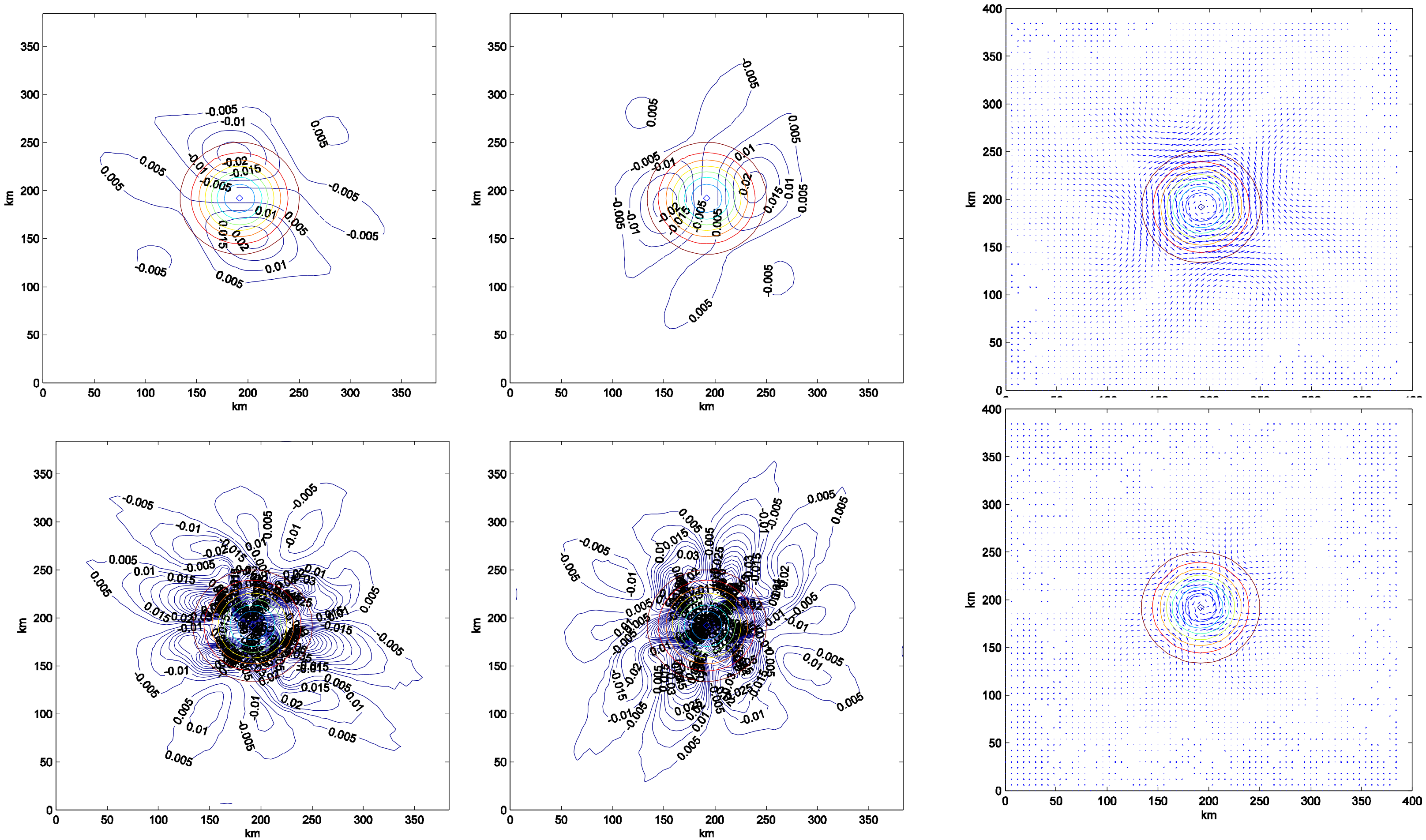
FIG. 1. The unstructured grid for the finite-volume model.

Maximum velocities (Ah=1000m^2/s) (isosceles, resolution, left: 6km, right: 3km)

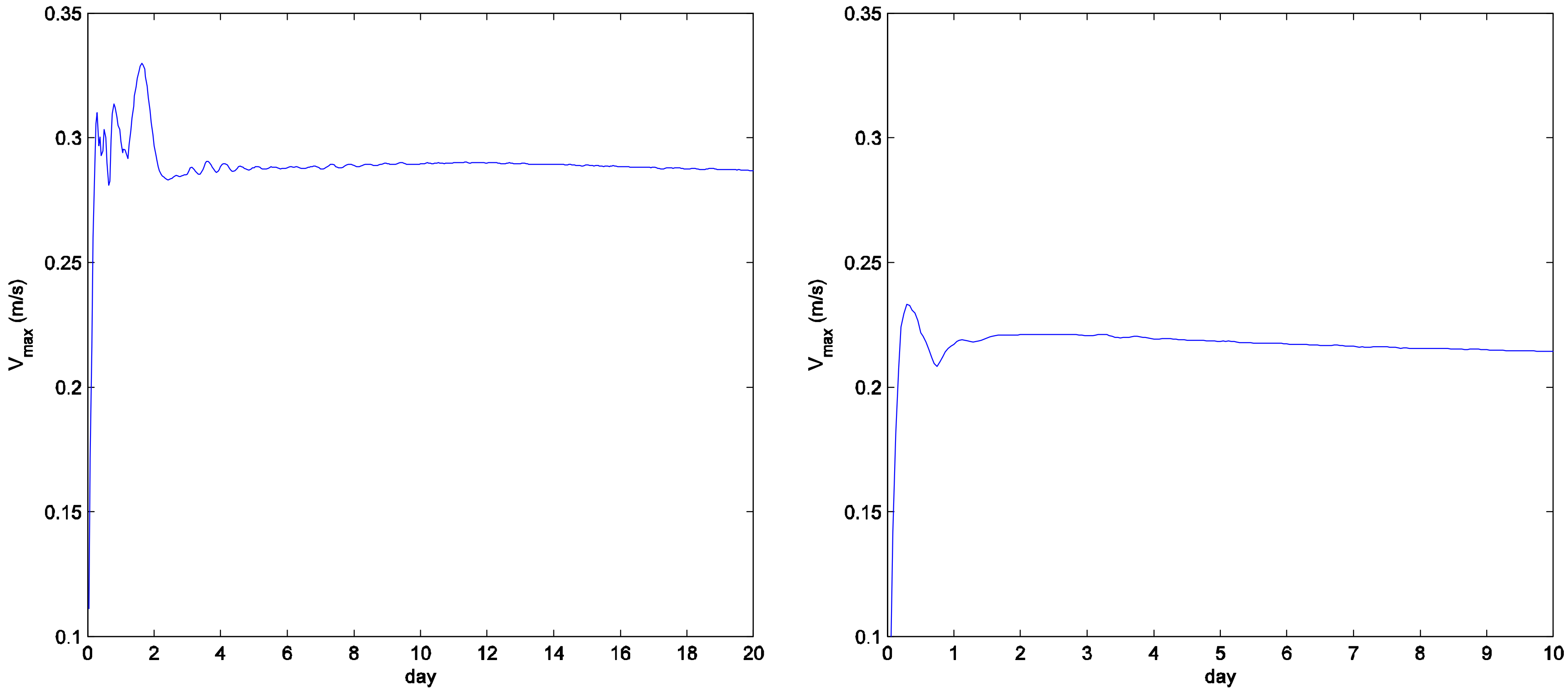




Top and bottom layer (u,v) at day 10 (ci=0.5 cm/s, isosceles,res=3km)



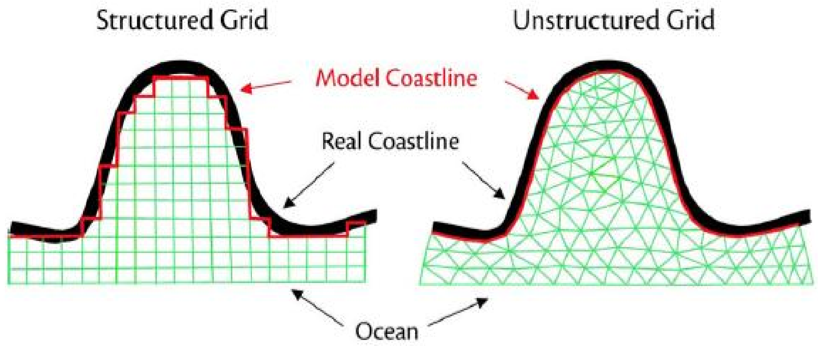
Maximum velocities (Ah=1000m^2/s)
(left: isosceles, right: equilaterals)



Thank you for your attention !

An introduction to FVCOM

- Developed at Massachusetts-Dartmouth (Chen et al, 2003);
- Hydrostatic ; terrain-following σ c ordinate (similar to POM);
- Second-order accurate discrete flu calculation in the integral form of equations;
- Trace advection: MPDATA (Smolarkiewicz 2005); horizontal diffusion: Smagorinsky; vertical: Mellor Yamada closure scheme;
- Advantages include grid flexibility at complex coastal line, better conservation, etc. ;
- Long-term integration of the model has not been tested yet;
- Improvements are made for the model Irish Sea.



Example of the continuity eq.

$$\iint \frac{\partial \varsigma}{\partial t} dxdy = -\iint \left(\frac{\partial uD}{\partial x} + \frac{\partial vD}{\partial y}\right) dxdy$$

$$= -\oint V_n D ds$$

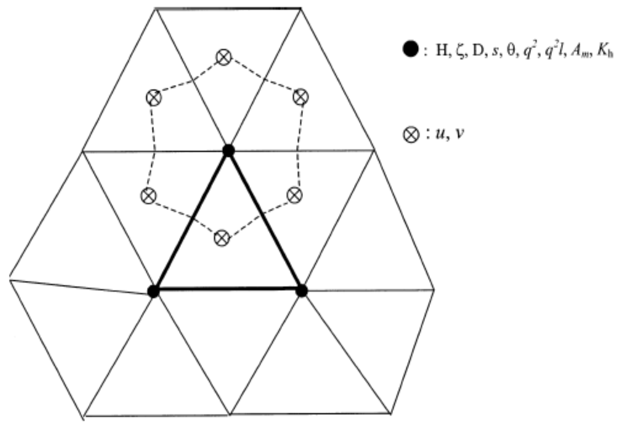


FIG. 1. The unstructured grid for the finite-volume model.

Internal pressure gradient in σ-coordinate system, [σ=(z-ζ)/D] and finite volume method (in FVCOM)

u equation and internal pressure gradient term:

$$\frac{\partial Du}{\partial t}+\nabla\cdot(\vec{V}Du)+\ldots=-\frac{gD^2}{\rho_0}\int_\sigma^0\left[\frac{\partial\rho}{\partial x}-\frac{\sigma}{D}\frac{\partial D}{\partial x}\frac{\partial\rho}{\partial\sigma}\right]d\sigma+\ldots=-\frac{g}{\rho_0}\left[D\frac{\partial}{\partial x}\left(D\int_\sigma^0\sigma\frac{\partial\rho}{\partial\sigma}d\sigma\right)+D^2\frac{\partial\rho\sigma}{\partial x}\right]+\ldots$$

$$=-\frac{gD}{\rho_0}\left[-\frac{\partial D}{\partial x}\int_\sigma^0\sigma\frac{\partial\rho}{\partial\sigma}d\sigma+D\frac{\partial}{\partial x}\int_\sigma^0\rho d\sigma\right]+\ldots$$

$$\int_\sigma^0\sigma\frac{\partial\rho}{\partial x}d\sigma=-\sigma\rho-\int_\sigma^0\rho d\sigma$$

$$\iint(\ldots)dxdy=-\frac{gD_m}{\rho_0}\left\{\iint-\frac{\partial D}{\partial x}\int_\sigma^0\sigma\frac{\partial\rho}{\partial x}d\sigma dxdy+\iint D\frac{\partial}{\partial x}\int_\sigma^0\rho d\sigma dxdy\right\}$$

$$=-\frac{gD_m}{\rho_0}\left\{-\left(\int_\sigma^0\sigma\frac{\partial\rho}{\partial x}d\sigma\right)_m\iint\frac{\partial D}{\partial x}dxdy+D_m\iint\frac{\partial}{\partial x}\int_\sigma^0\rho d\sigma dxdy\right\}$$

$$=-\frac{gD_m}{\rho_0}\left\{-\left(\int_\sigma^0\sigma\frac{\partial\rho}{\partial x}d\sigma\right)_m\oint Ddy+D_m\oint\int_\sigma^0\rho d\sigma dy\right\}$$

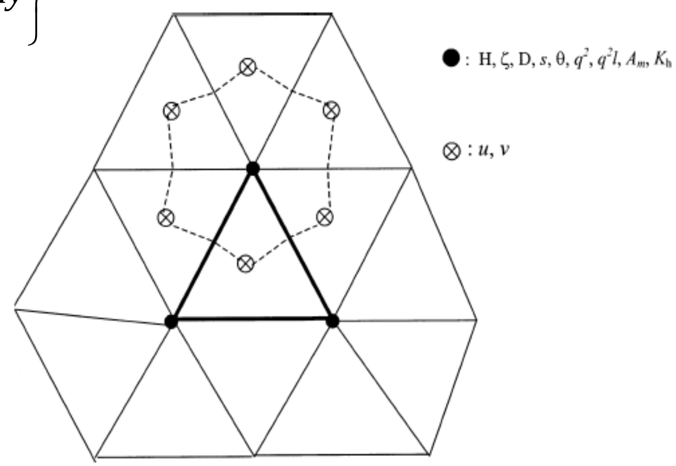


FIG. 1. The unstructured grid for the finite-volume model.

Green's Theorem:

$$\oint -Ndx+Mdy=\iint\left(\frac{\partial M}{\partial x}+\frac{\partial N}{\partial y}\right)dxdy$$