Modelling processes in the Irish Sea using an unstructured-mesh model

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Celtic Sea and Irish Sea

Previous modelling works:

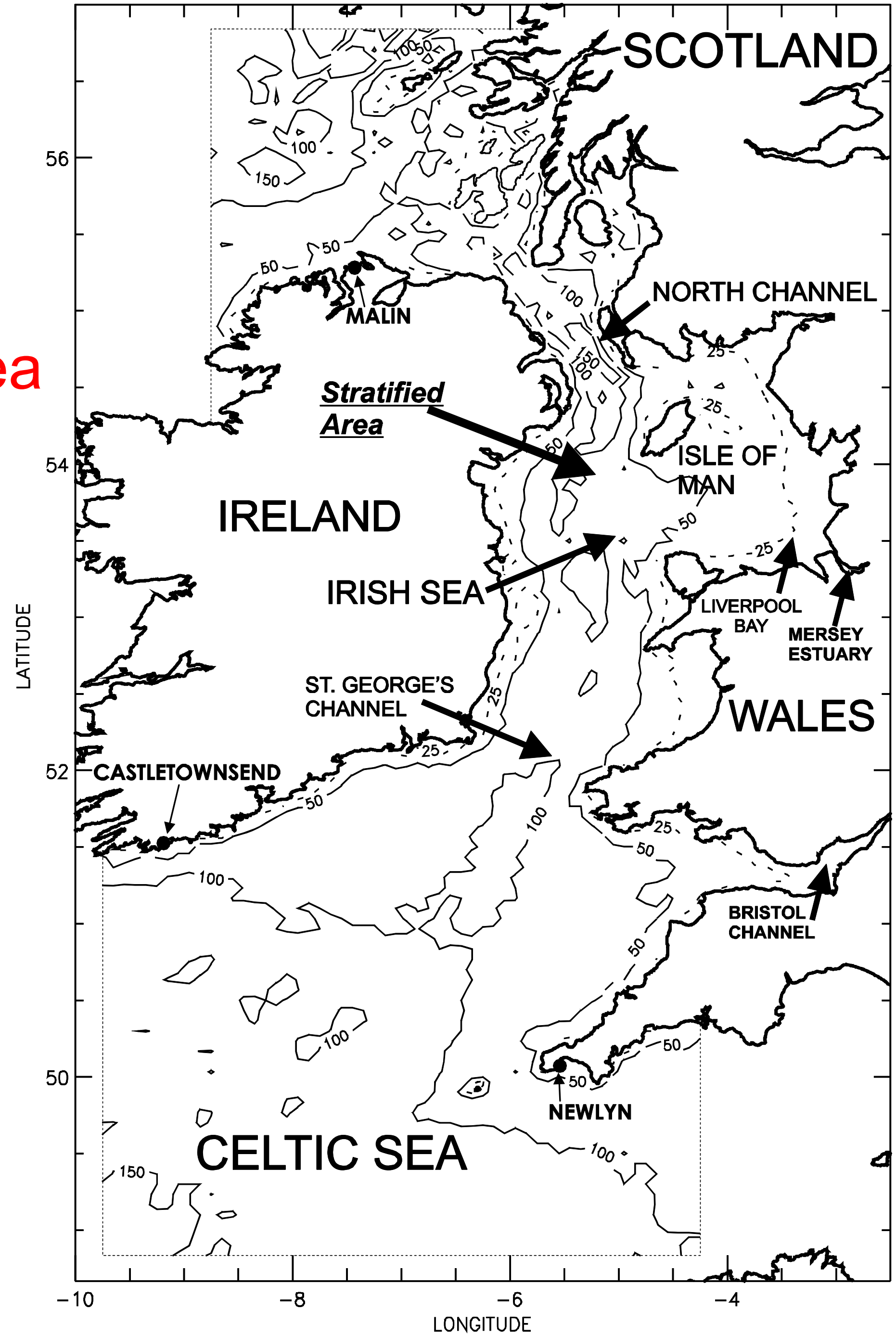
Heaps (1973)

Xing and Davies (2001)

Horsburgh and Hill (2003)

Holt and Proctor (2003)

Xing et al (2011)



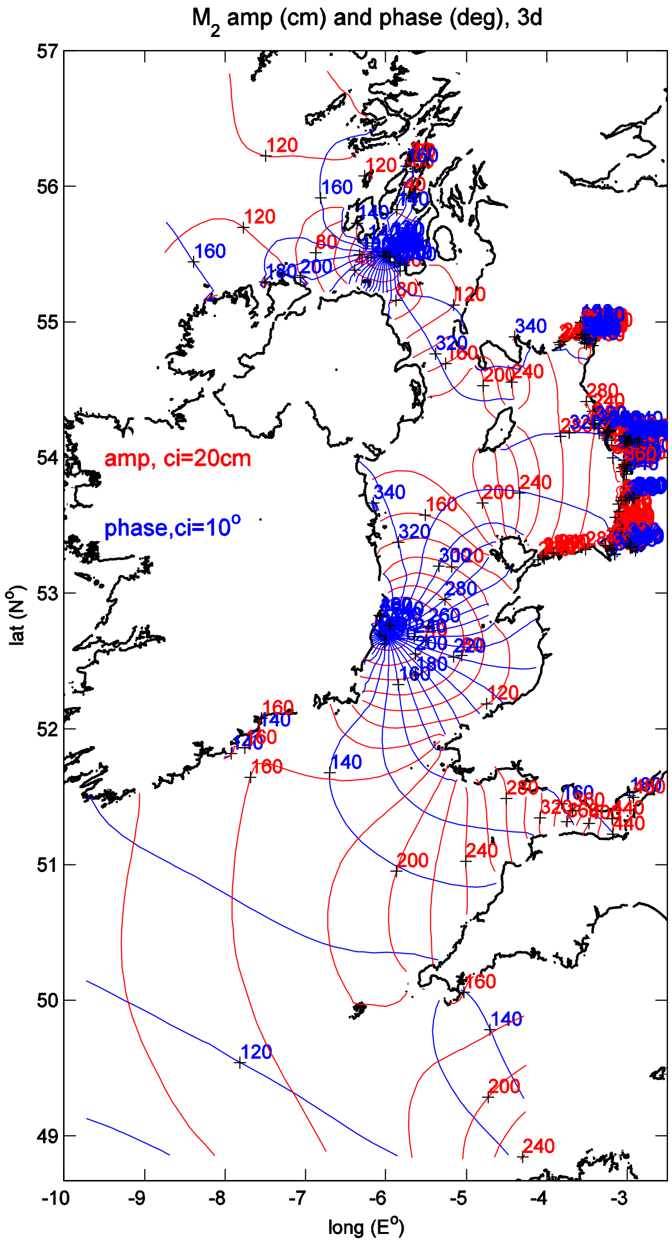
Processes in the Irish Sea

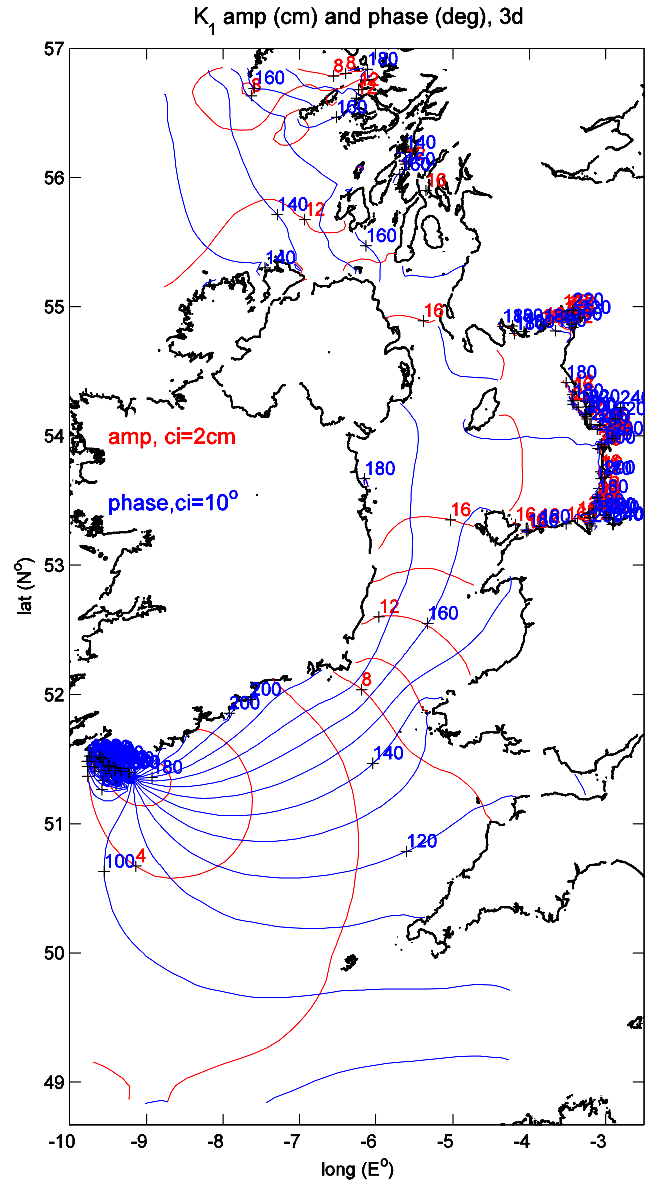
- The Irish Sea unstructured-mesh finite-volume coastal ocean model (IS-FVCOM)
- Processes in the Irish Sea: (after barotropic study)
  - Tidal fronts and eddies
  - ROFI and SIPS
  - Mersey estuary
- Conclusions

An introduction to the Unstructured Grid Finite-Volume Costal Ocean Model (FVCOM)

- Applications of unstructured-grid models at NOC
- Why FVCOM (Chen et al at UMASSD-WHOI) ?
- Solve a set of 3D hydrodynamic equations using finite-volume method on a triangular grid
- Second-order discretization (MPDATA Smolarkiewicz, 1984 for scalar conservation equations)
- Using mode splitting methods on σ-coordinate; new version has options for semi-implicit method and non-hydrostatic (and fewer bugs)
- MPI parallel
- Many modules including:
  - GOTM turbulent models
  - Sediment, ice, water quality, biology, SWAVE, data assimilation etc.

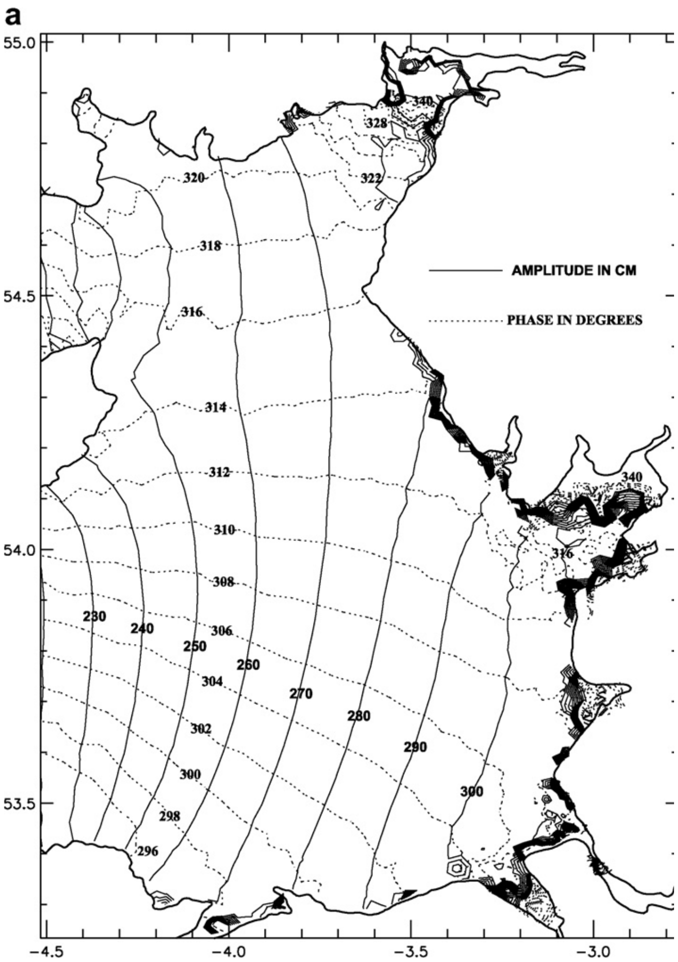
Semi-diurnal (M2) and diurnal (K1) tides are well modelled by different models



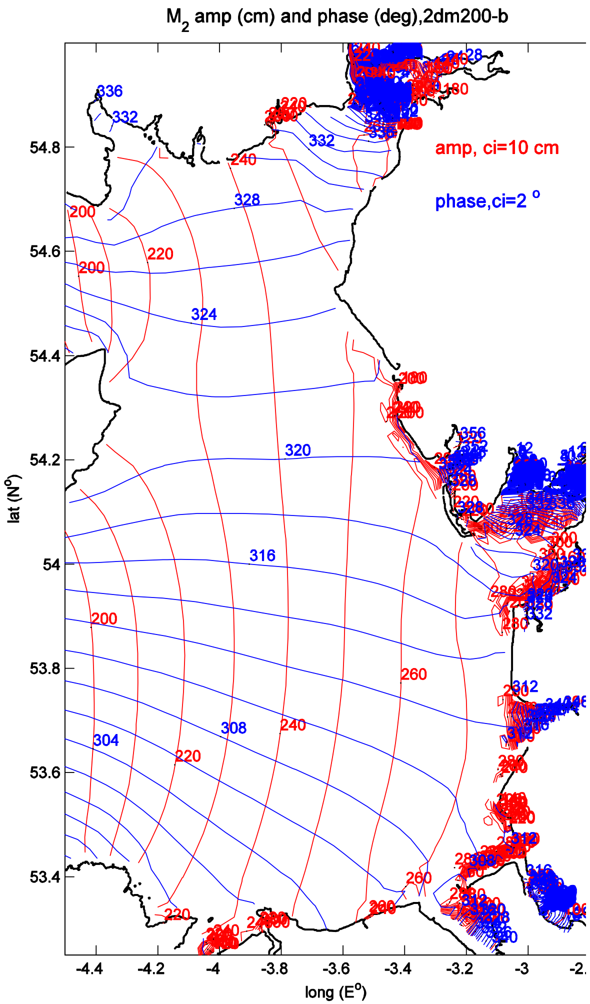


Computed M2 tide over the Eastern Irish Sea
Using TELEMAC as bench mark

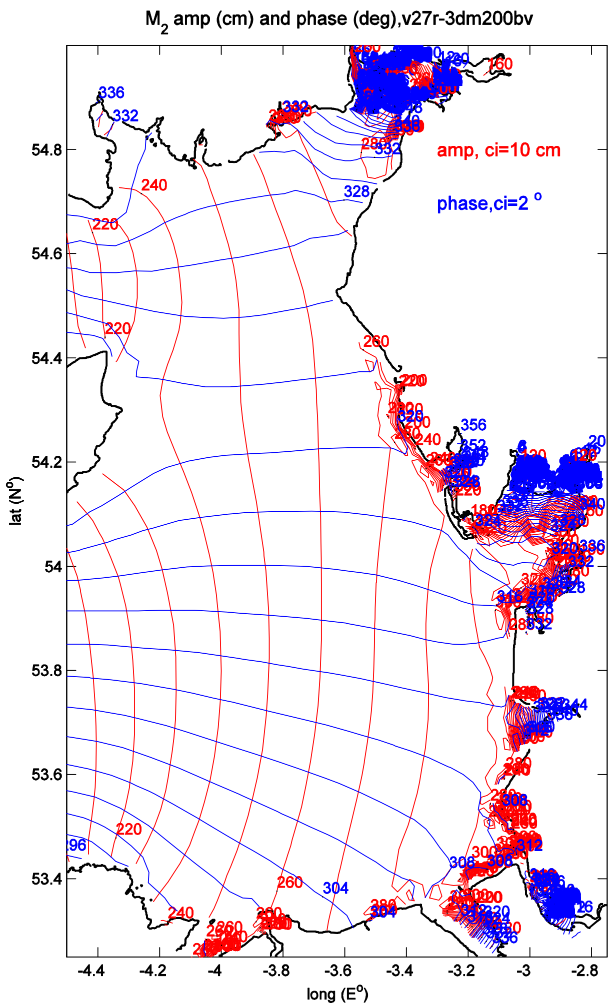
TELEMAC 2D



FVCOM 2D



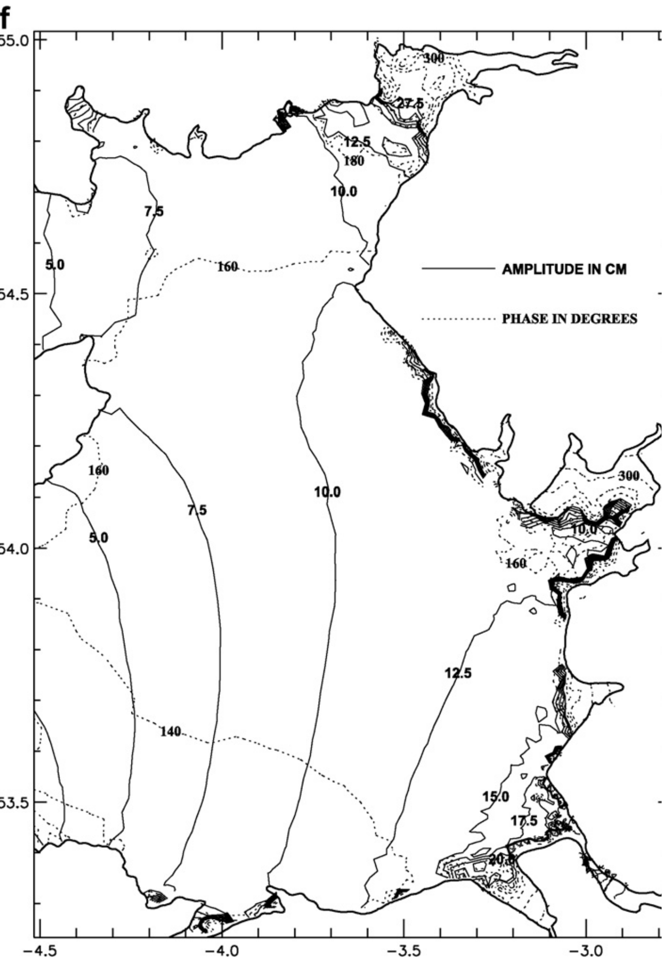
FVCOM 3D



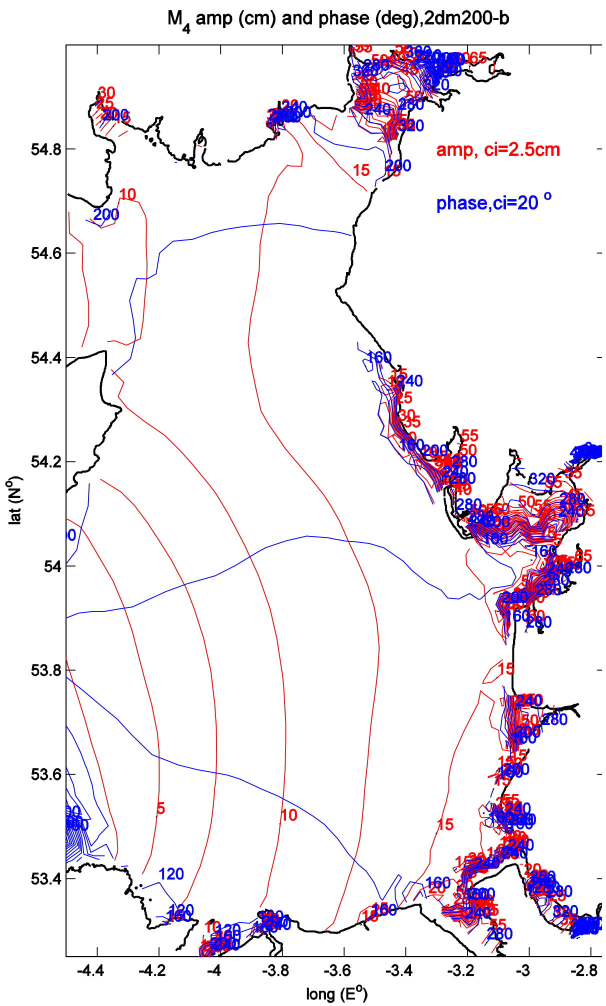
Computed M4 tide over the Eastern Irish Sea

Over tides (M4, M6 etc) are mainly generated in the domain due to non-linear friction and advection.

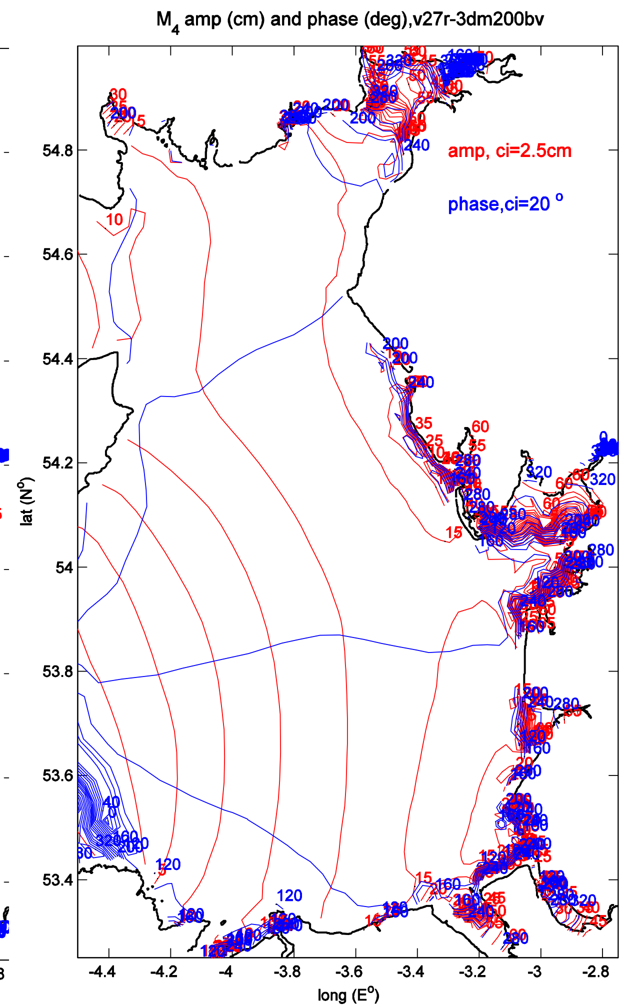
TELEMAC



FVCOM 2D



FVCOM 3D

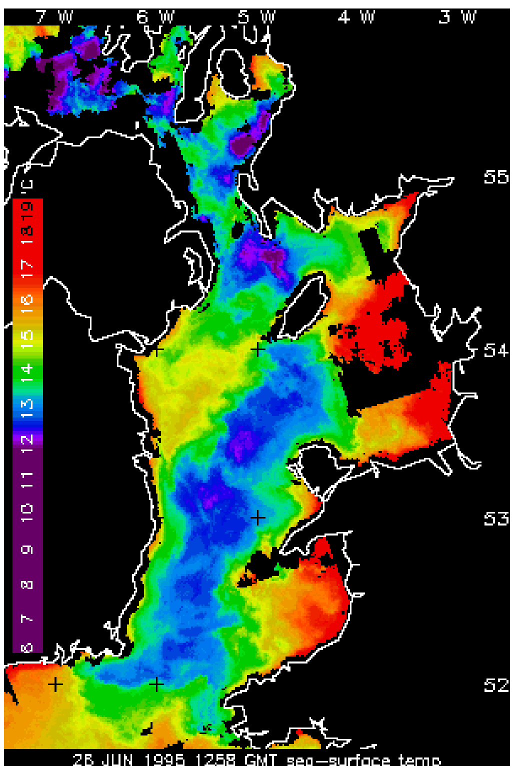


Processes in the Irish Sea: tidal front and eddies

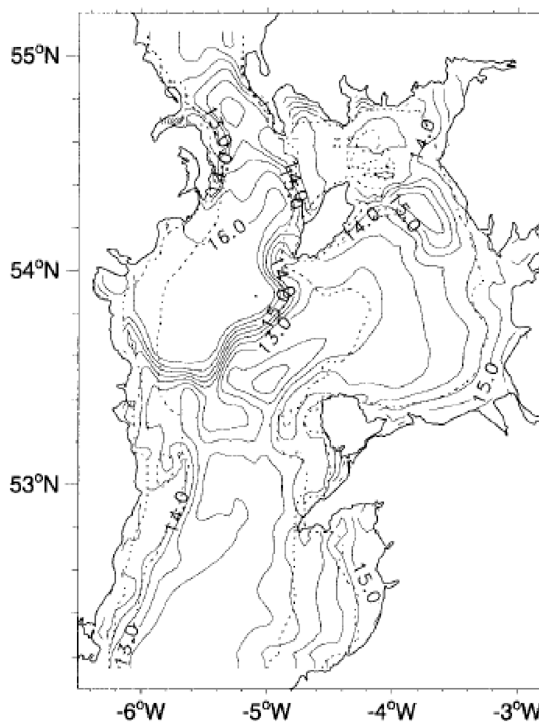
Generation of tidal front in the western Irish Sea, long-term integrations
Previous modelling: Xing & Davies 2001 (XD), Horsburgh and Hill 2003 (HH), Holt and Proctor 2003 (HP)
Robust feature of the front; lack of detailed structures in XD and HH, better in HP

Surface temperature on 26 June 1995

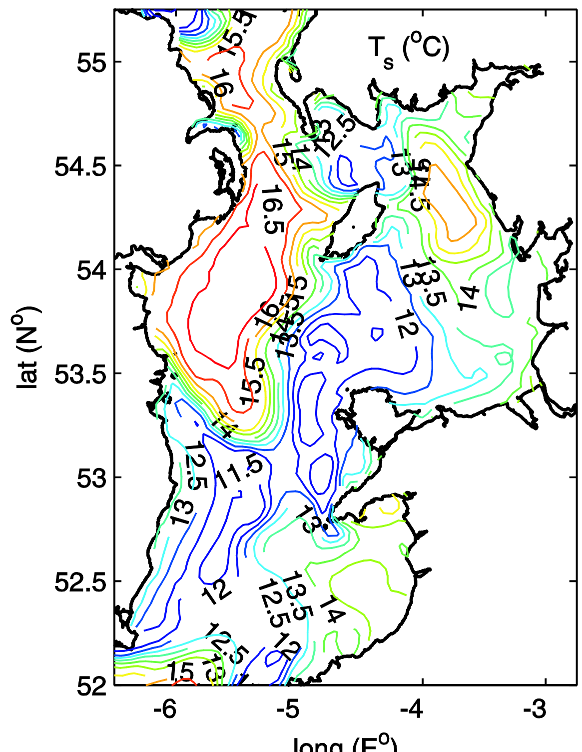
OBS



XD JPO 2001, 3.6km

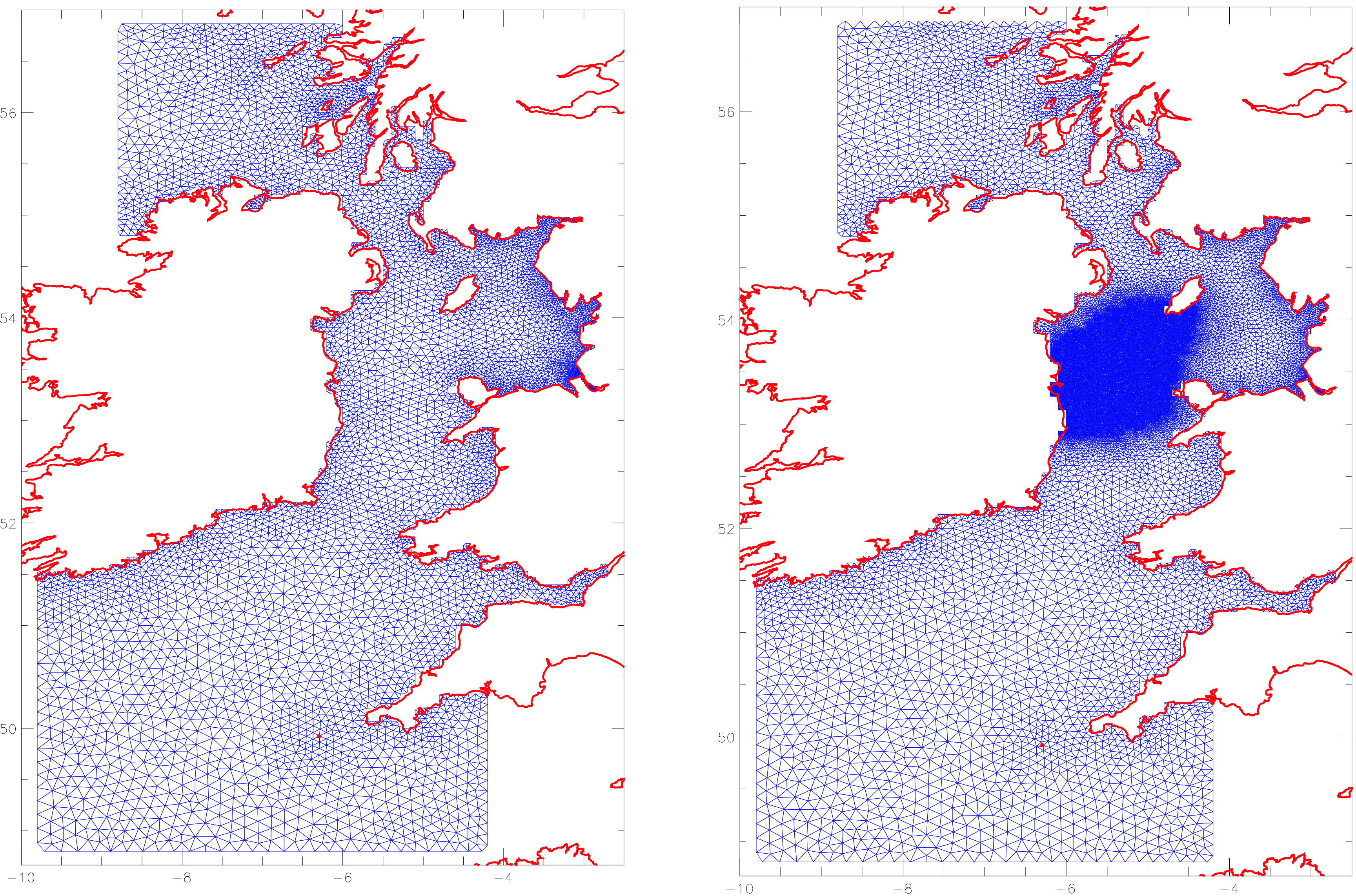


FVCOM low res 7km.



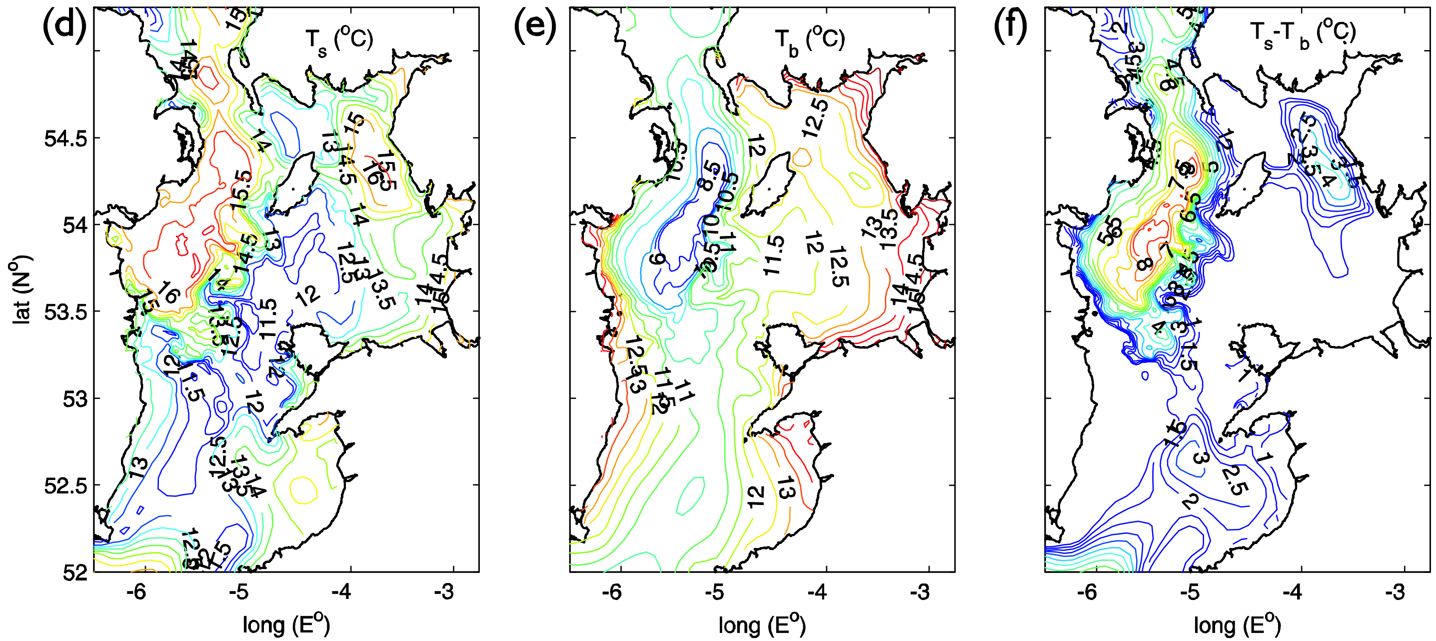
Two different grids :

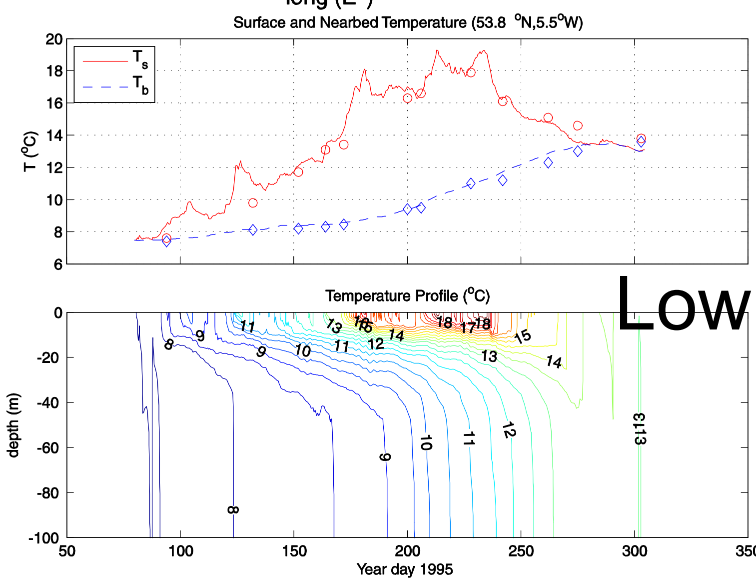
Resolution in the western Irish Sea from ~ 7km (left) to less than 1km



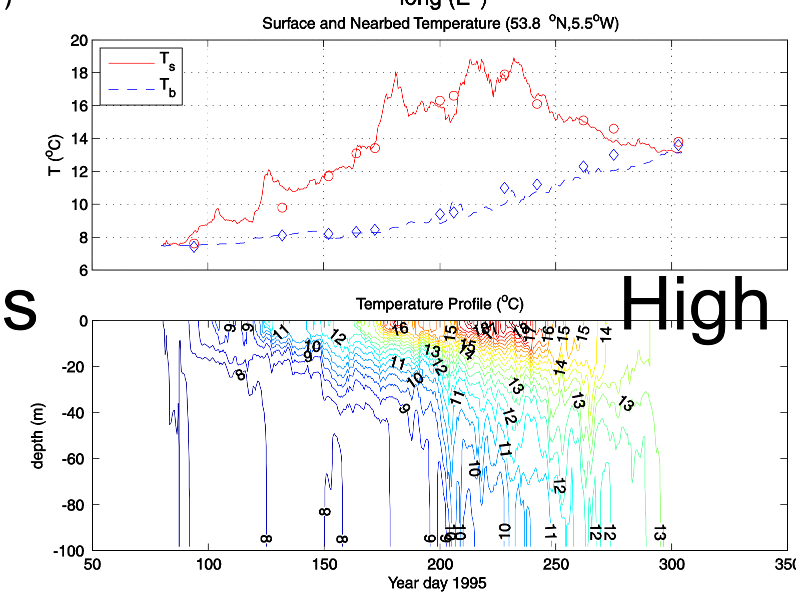
Detailed temperature structure in the frontal zone

Time series of temperature at the centre of the western Irish sea cold water dome (circles and diamonds are observations)





Low res



High res

X sections of temperature , u , v, w through the western Irish Sea.

High resolution

Low resolution

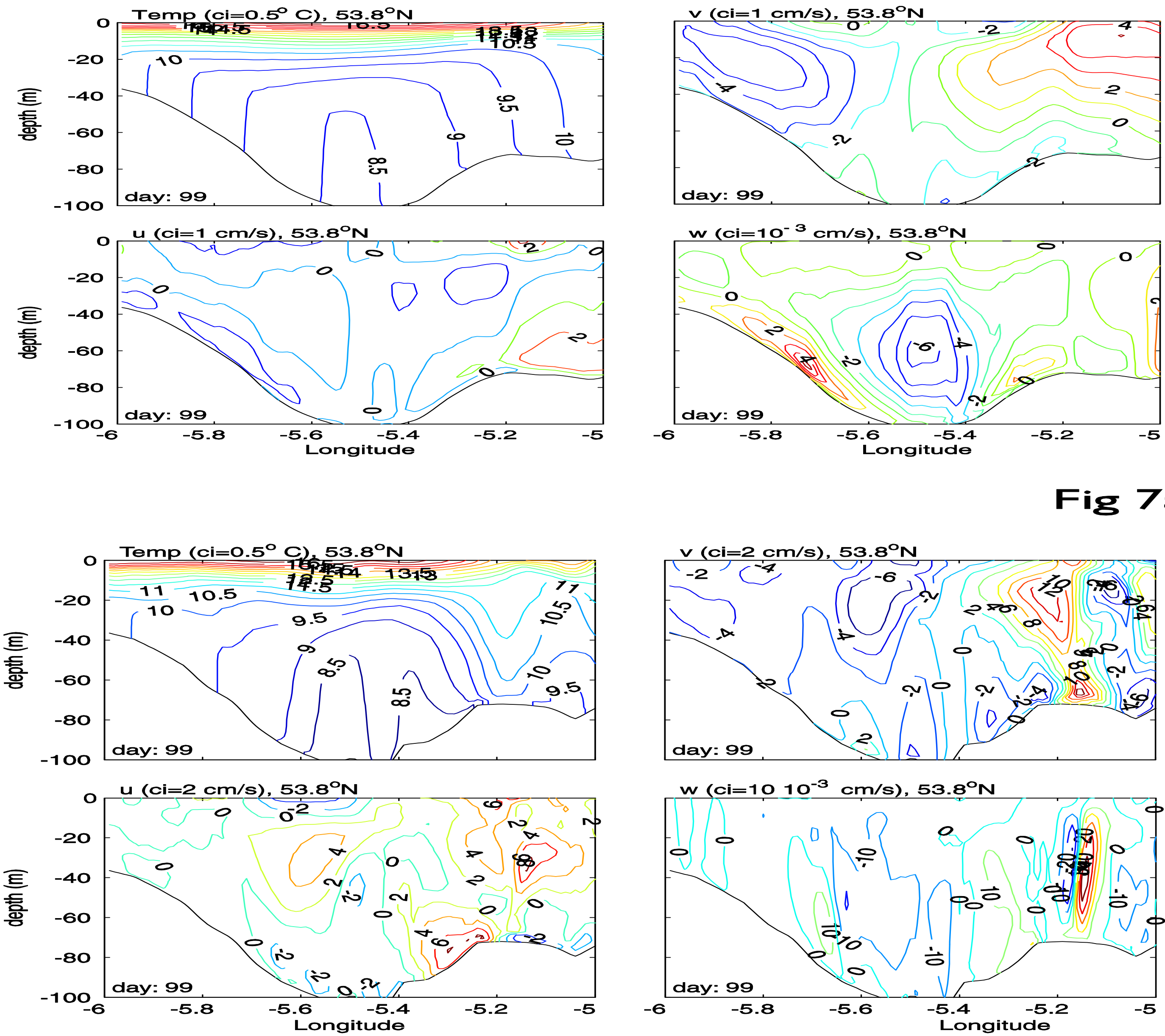
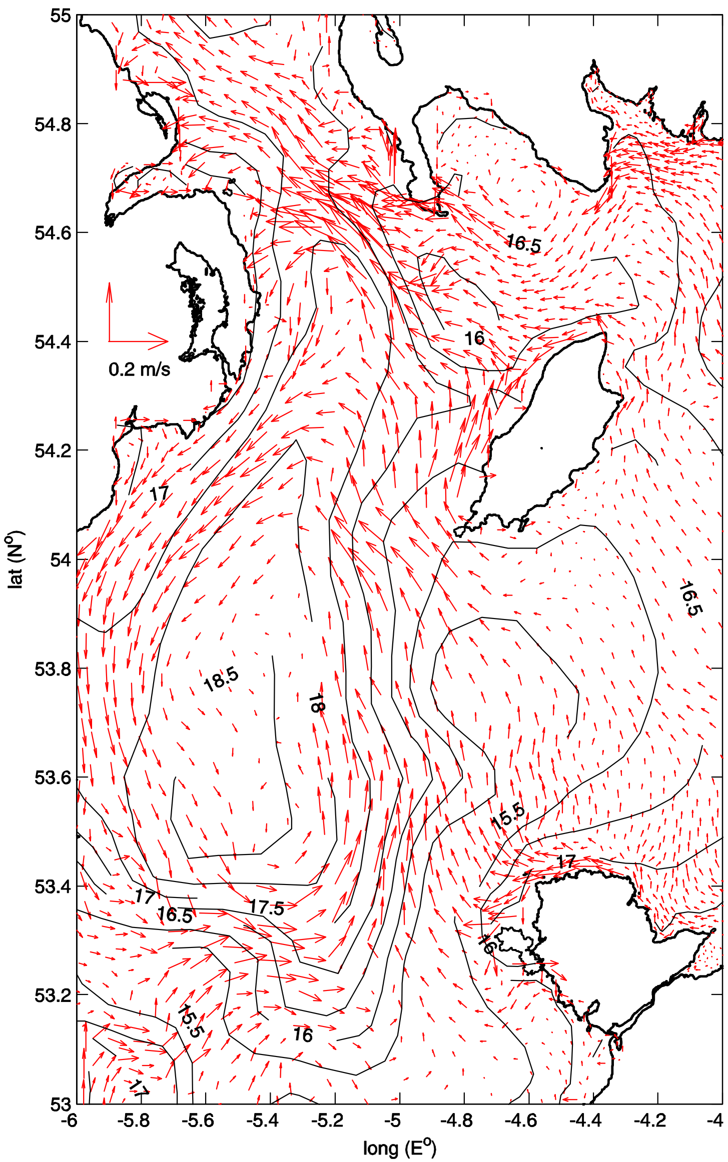


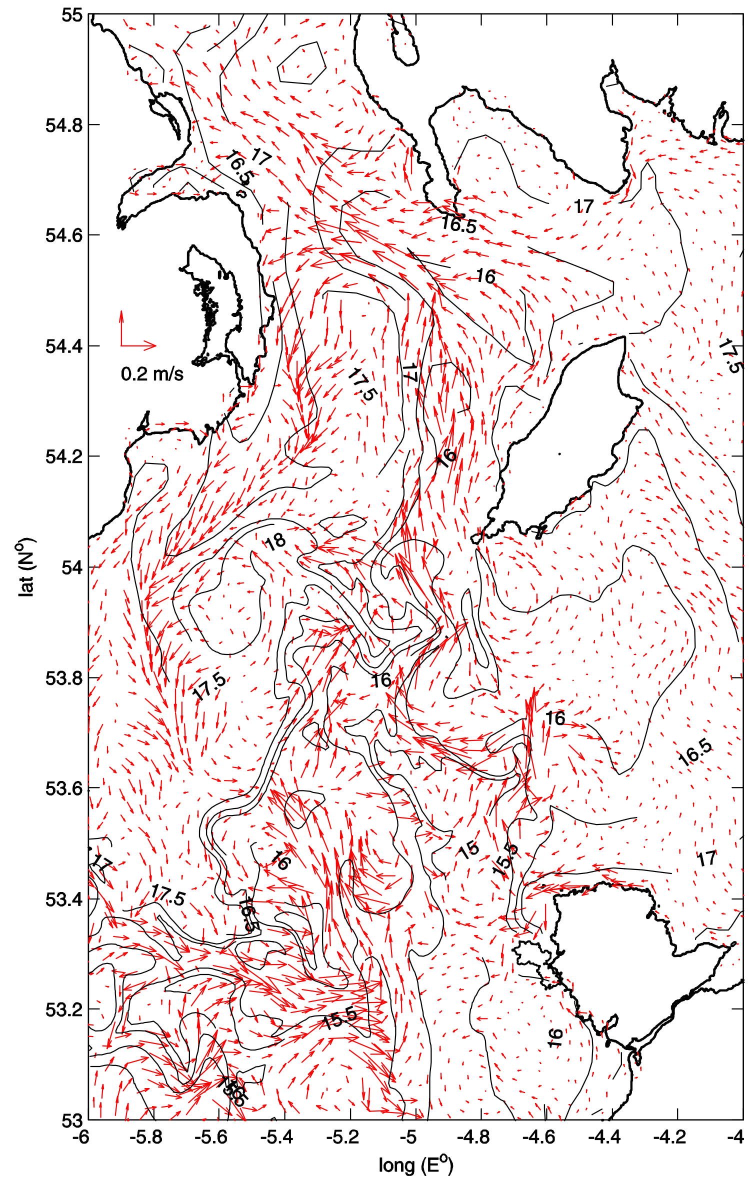
Fig 7a

Temperature driven circulation in the summer

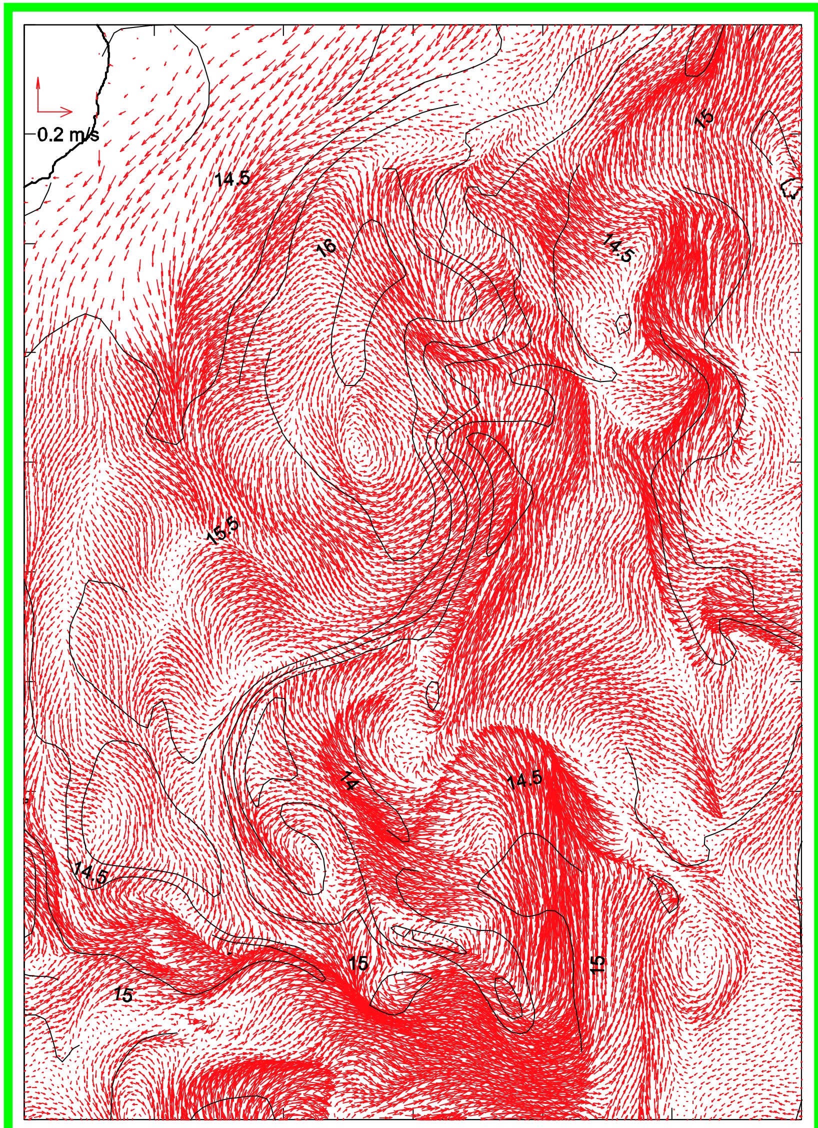
Low resolution

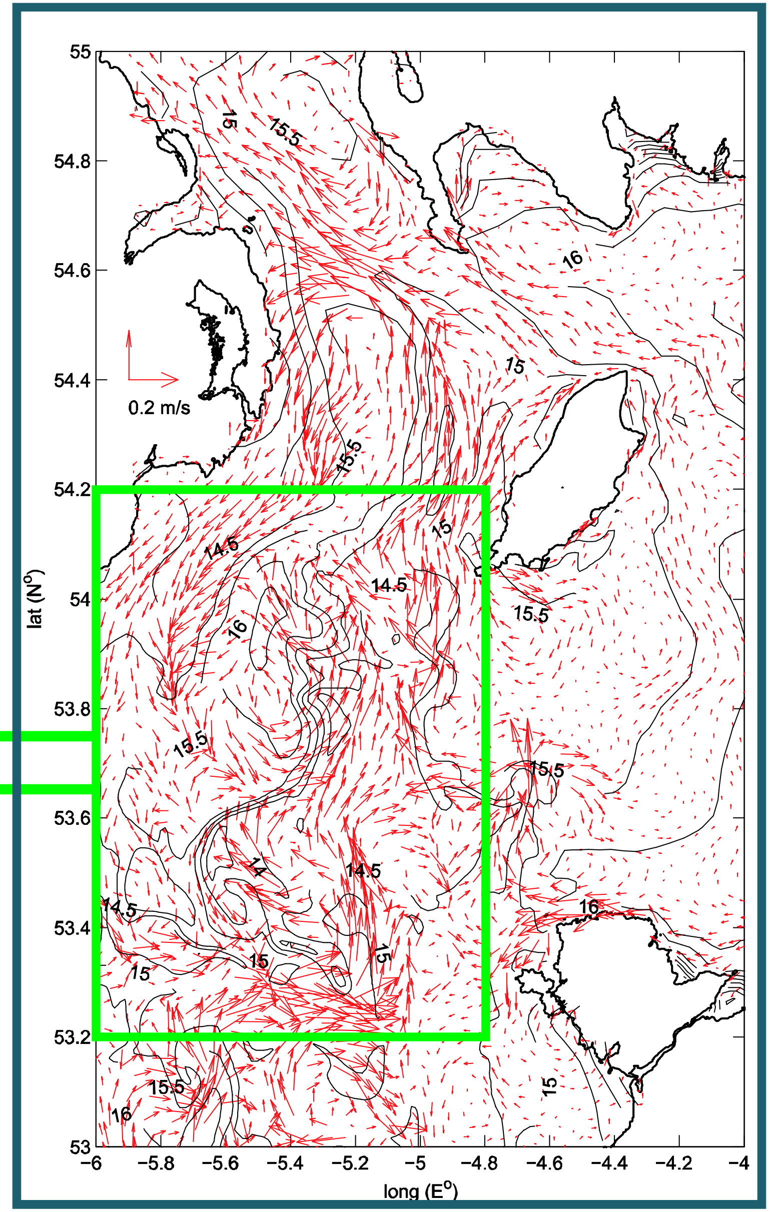


High resolution

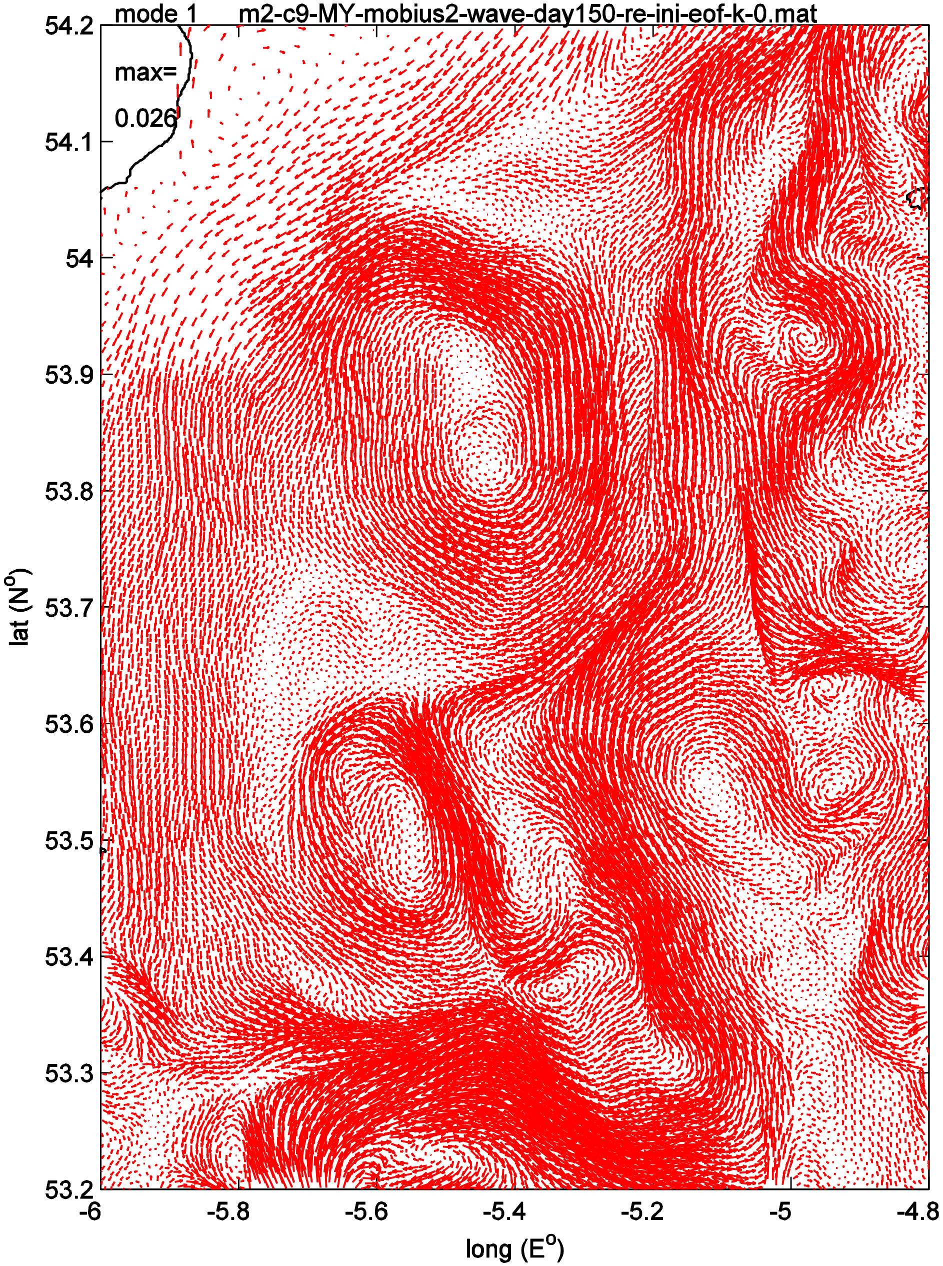


Surface temperature and currents: high resolution model

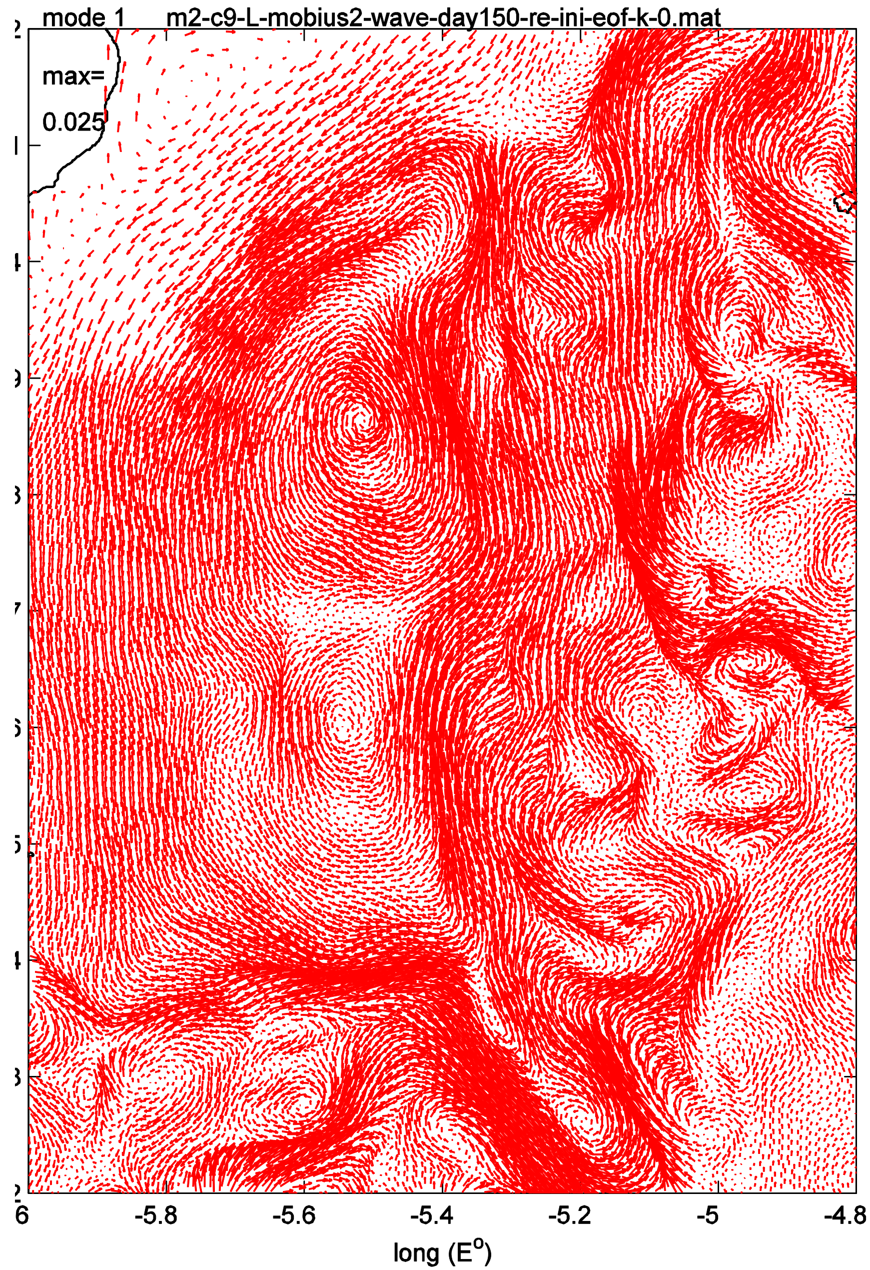




M-Y model



L model

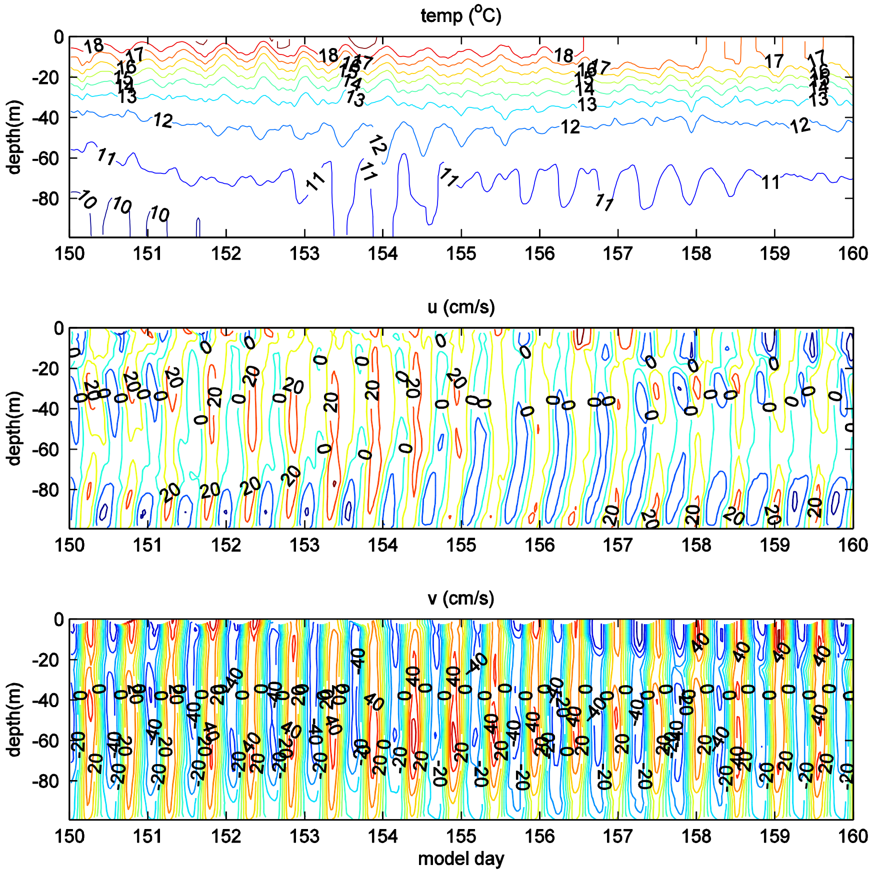


Two different turbulence models for vertical diffusion: first EOF mode

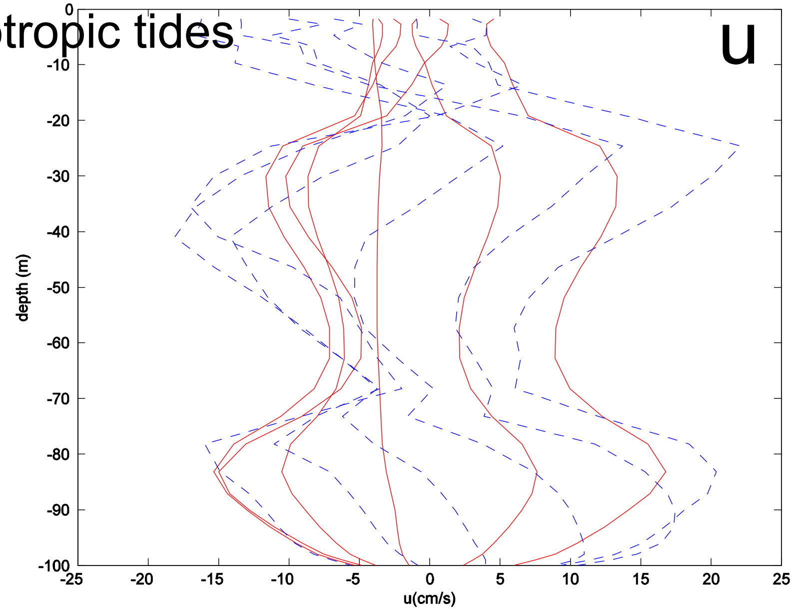
Internal tides can be generated in the western Irish Sea although topography slope is not steep.

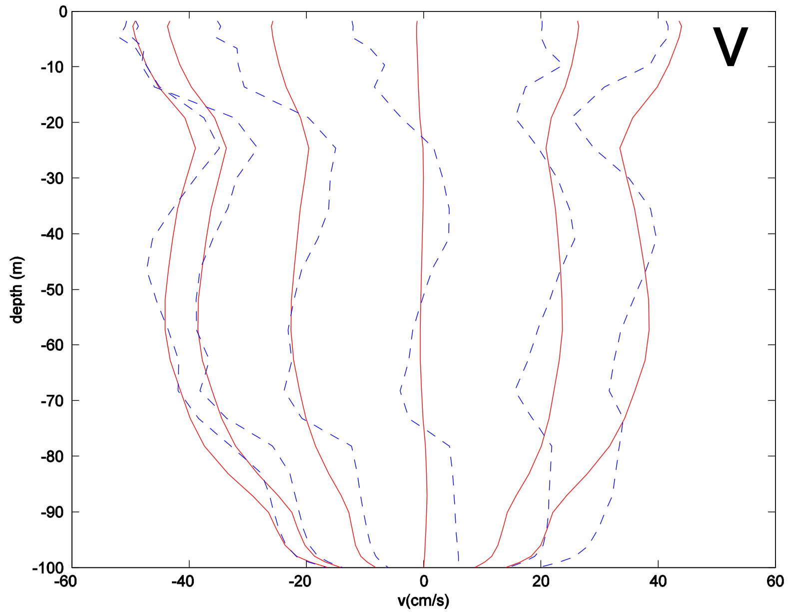
Try to use complex EOF to filter our barotropic tides

(red: first mode, blue: model data)



m2-c9-MY-mobius2-wave-day150-nc @ e26828-A

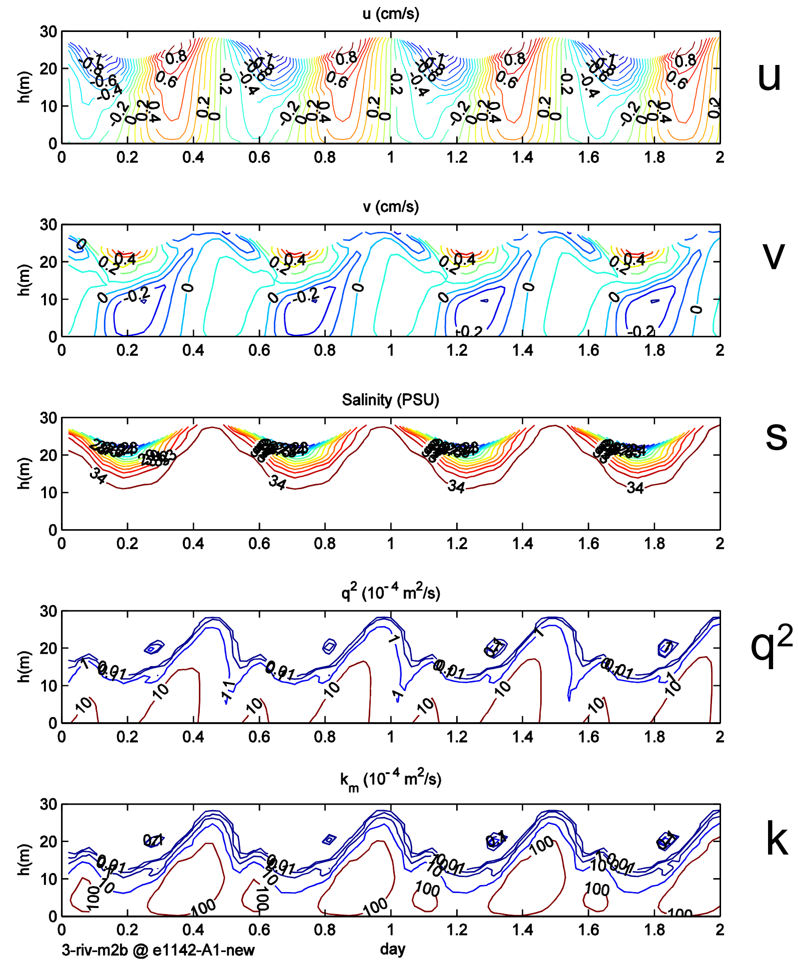


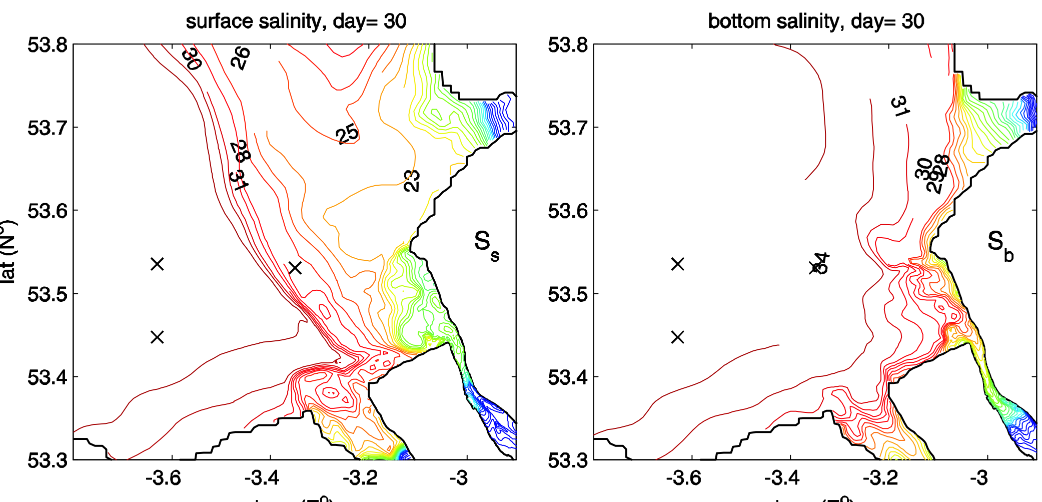


Generation of internal tides

Region of Freshwater influence: strain-induced periodic stratification (SIPS)

Idealized freshwater discharge from Dee,Mersey & Ribble
M_2 at open boundaries
30+2 days model runs
Coast wetting/drying





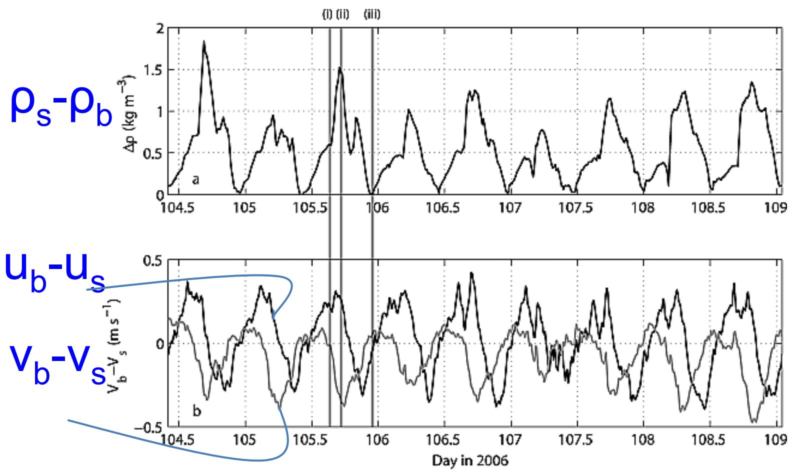
X's are observation locations. Time series of salinity (s) shows SIPS.
for the fresh water study we have a higher resolution in the Liverpool bay and Mersey Estuary.

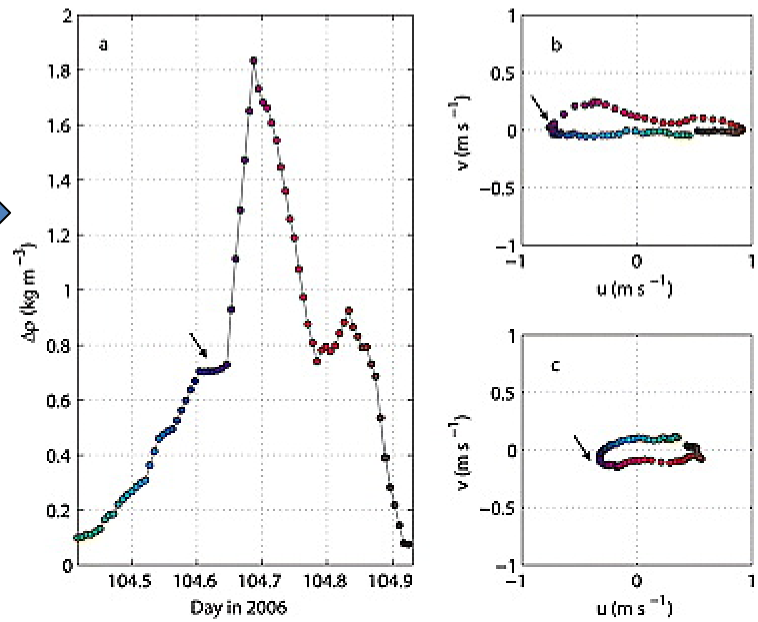
Region of Freshwater influence: strain-induced periodic stratification and tidal ellipse variability

- SIPS: interaction of tidal currents, horizontal density gradient and vertical turbulence mixing
- The feedback on tidal currents:
- Change of vertical density gradient due to the straining.
- Reduction in mixing due to pycnocline has much greater effect on clockwise rotation (Tidal bottom boundary layer depth: $D^c = \left\{ \frac{2K_z}{\omega - f} \right\}^{1/2}, D^a = \left\{ \frac{2K_z}{\omega + f} \right\}^{1/2}$

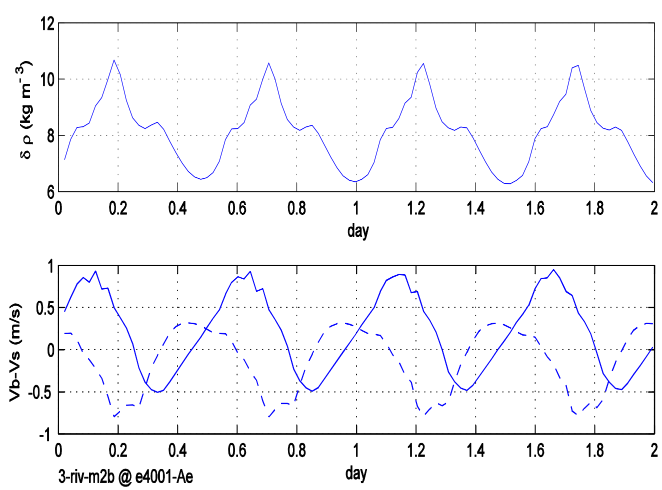
  $D_c >> D_a$)
- Models (until now 1D) work well for this process-smooth progression
- However, data from the coastal observatory in L’pool Bay shows new insight – a more dramatic and abrupt change of stratification (Verpecht et al 2010)

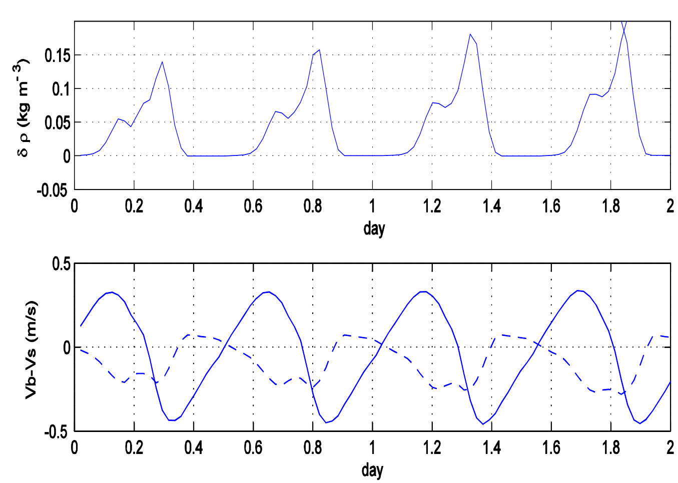
Obervations at Liverpool Bay: Verspcht et al GRL 2010





Model results

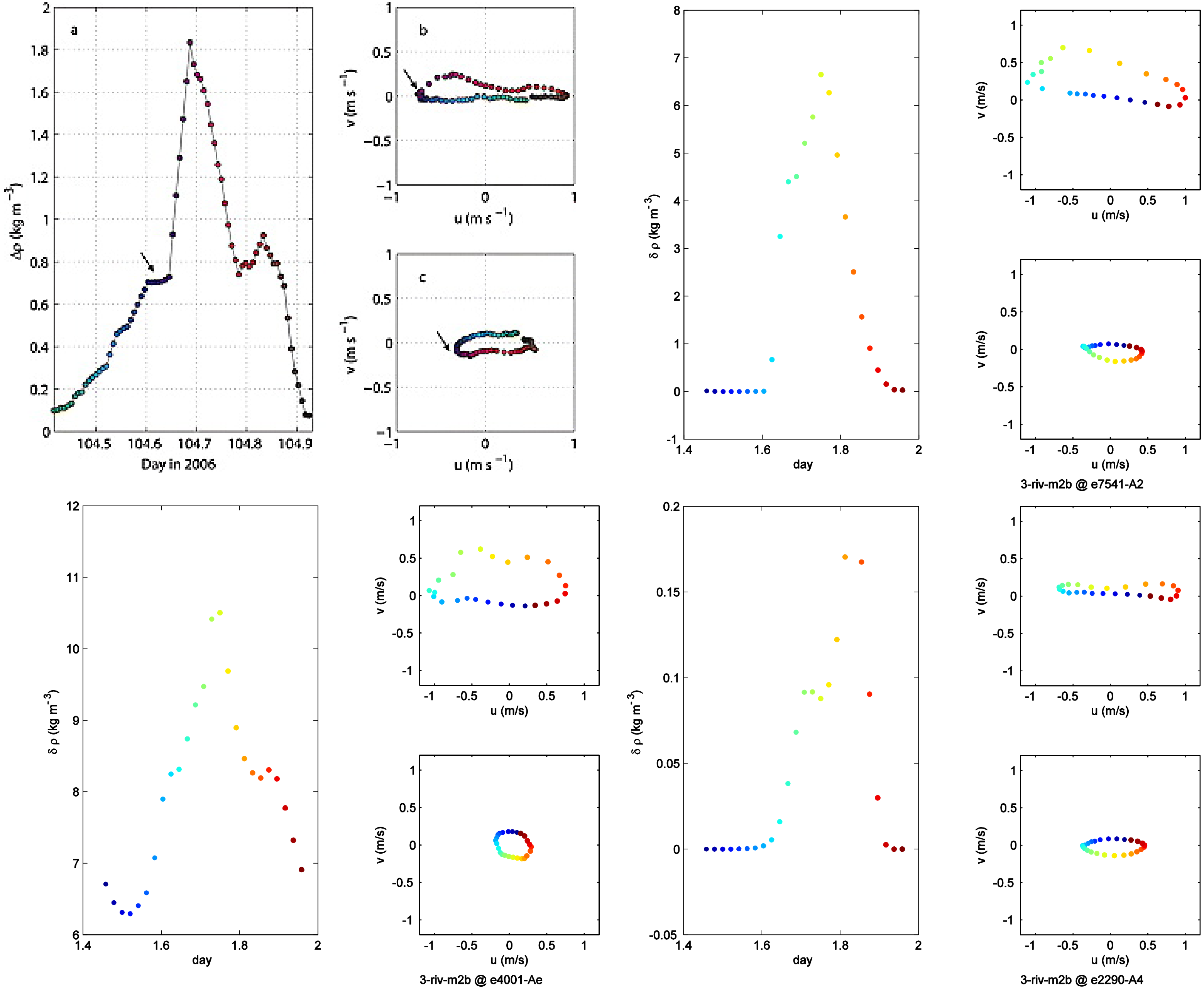




3-riv-m2b @ e2290-A4

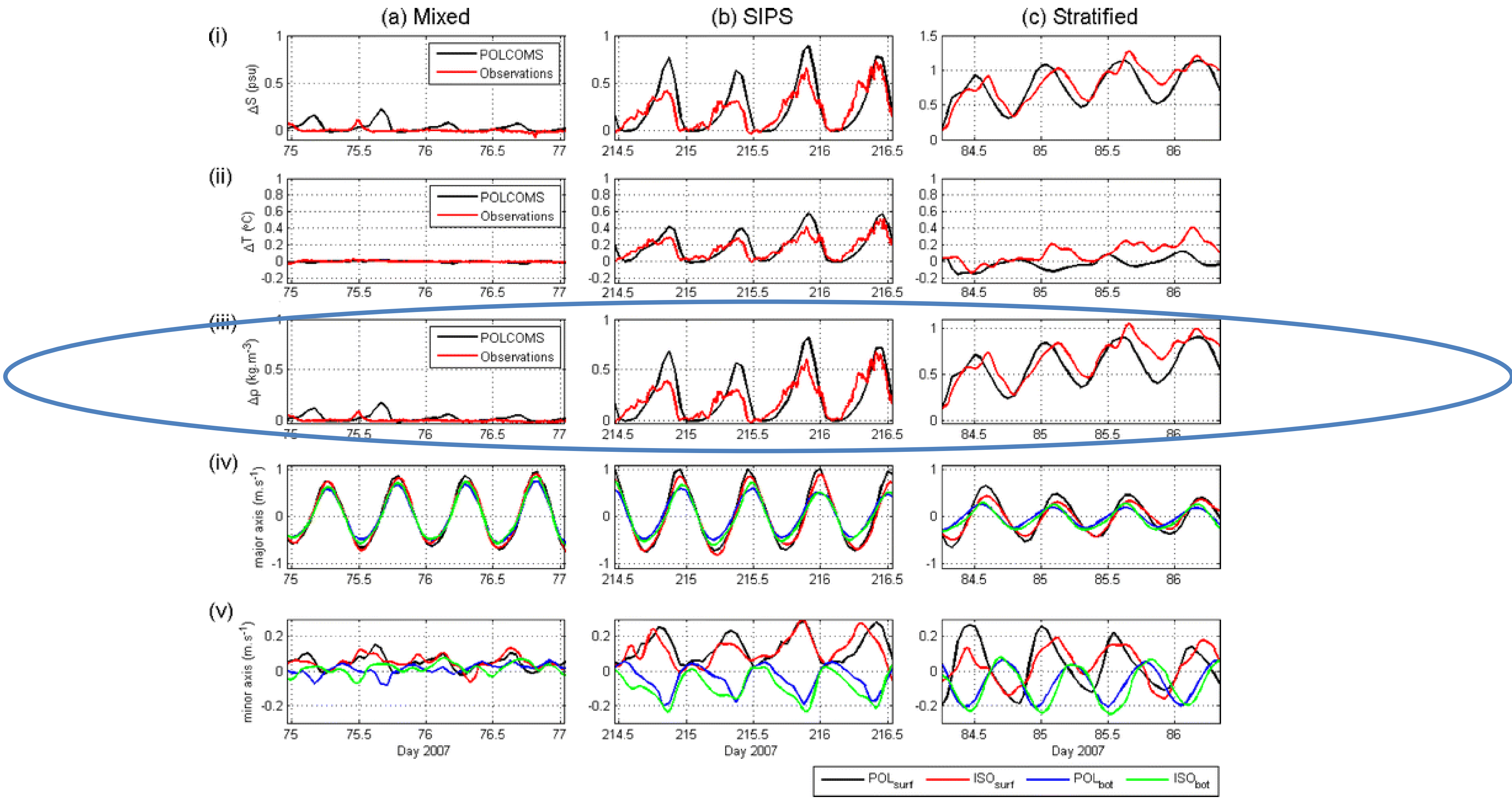
OBS

Model



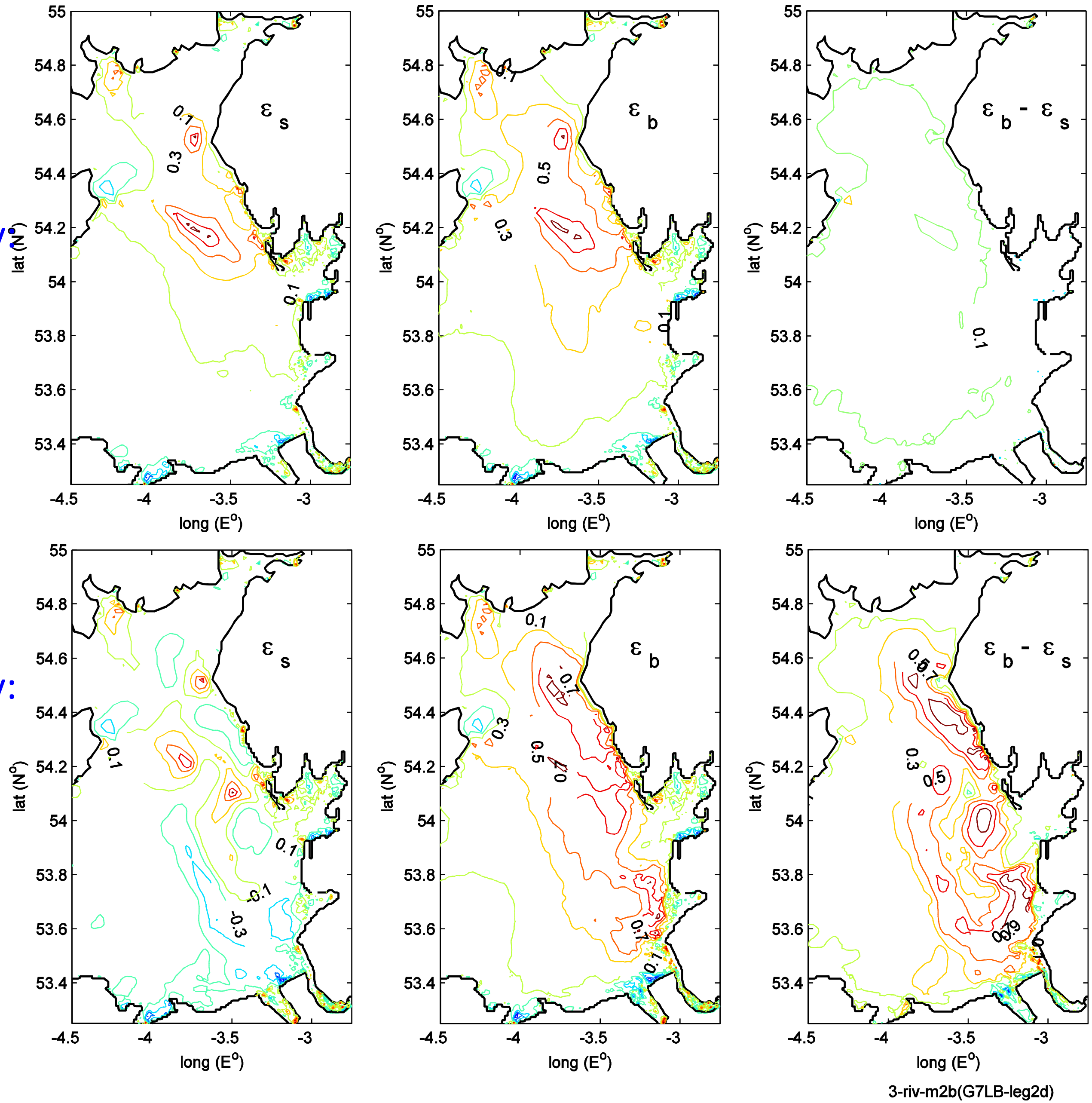
a
b
c
Δρ (kg m⁻³)
Day in 2006
v (m s⁻¹)
u (m s⁻¹)
δ ρ (kg m⁻³)
day
v (m/s)
u (m/s)
3-riv-m2b @ e7541-A2
3-riv-m2b @ e4001-Ae
3-riv-m2b @ e2290-A4

Observations at site B and POLCOMS (Palmer and Polton 2011)

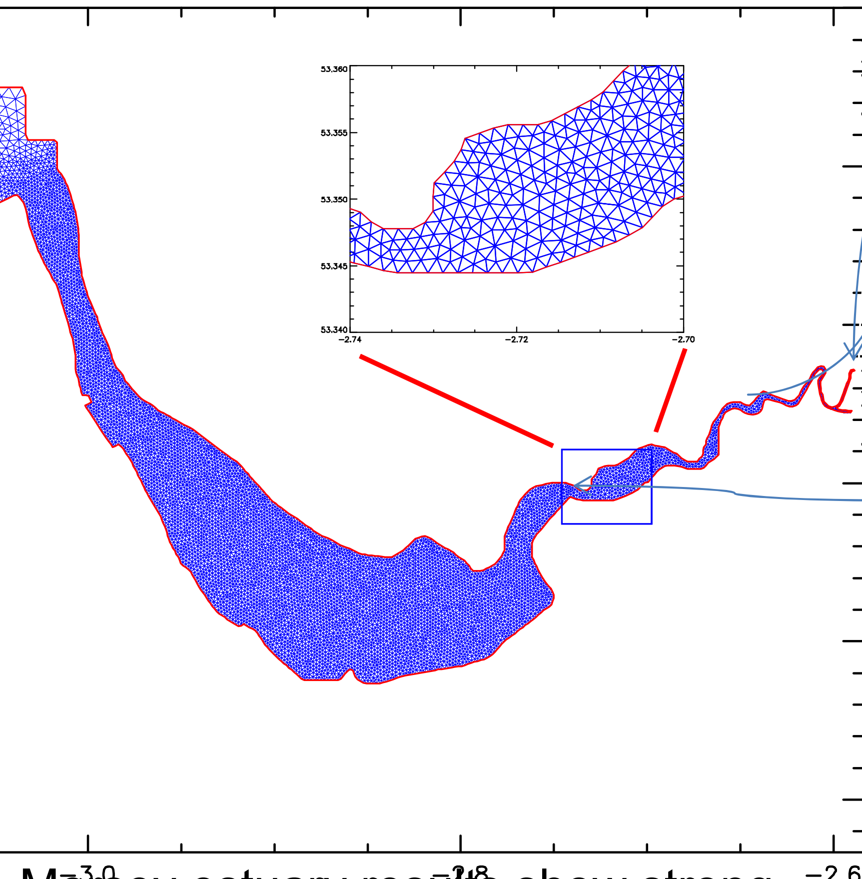


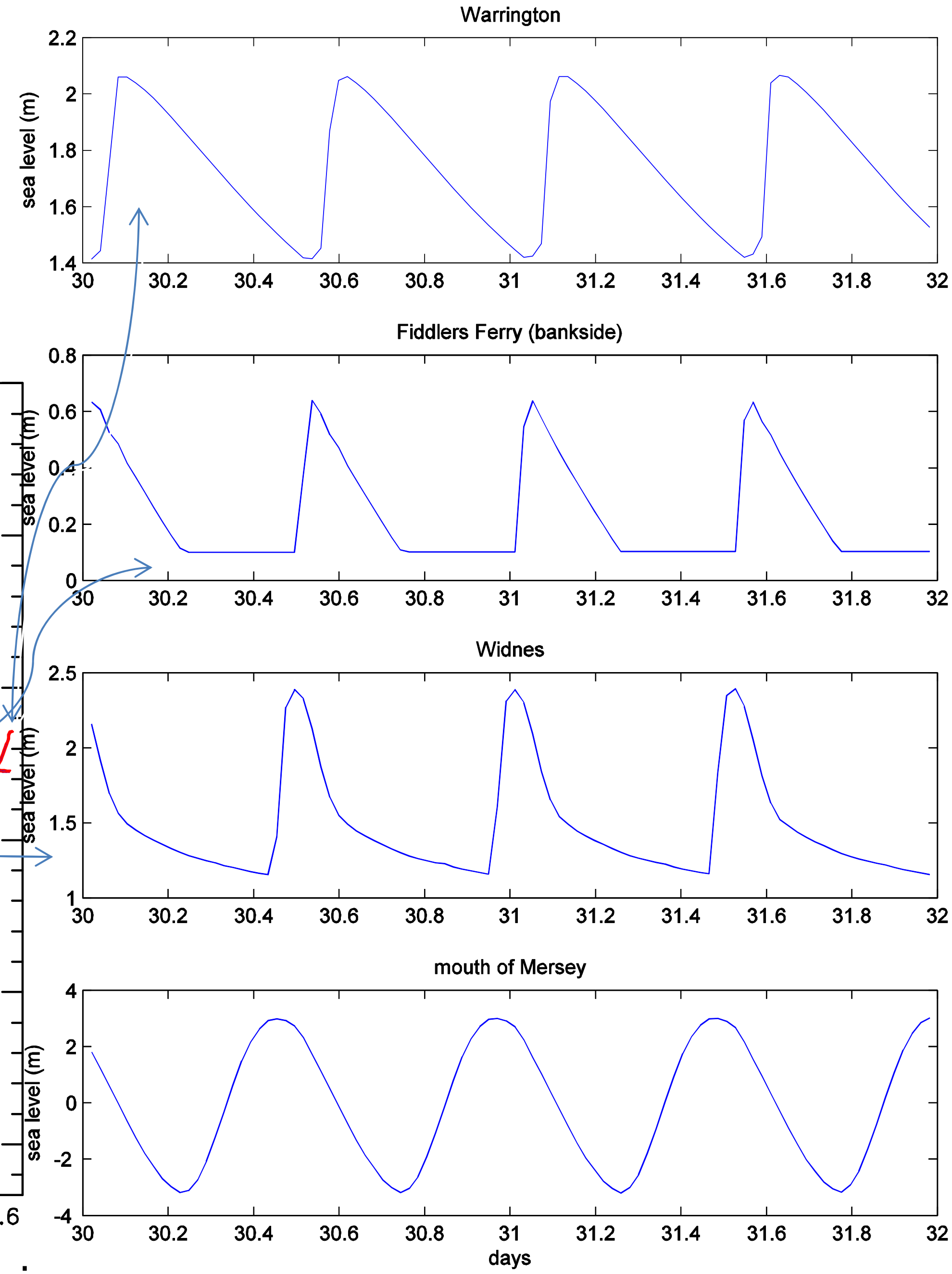
M$_2$ Tidal ellipicity: Barotropic run

M$_2$ Tidal ellipicity: With freshwater



Mersey estuary/river: M2 tide





Mersey estuary results show strong asymmetrical tides, and wetting and drying in the upper river.

Conclusions

- A robust unstructured-mesh model of the Irish Sea capable of long-term integration
- Enhanced resolution in the western Irish Sea enables detailed study of tidal front and eddies (as well as internal tides and turbulence)
- The model can reproduce processes of the inflection point and abrupt change of vertical stratification during SIPS in a ROFI
- Problems associated with the model (e.g., HPG, efficiency)
- Looking forward: more realistic forcing, SWAVE, sediment transport and ecosystem modelling.