Outflow representation in HYCOM

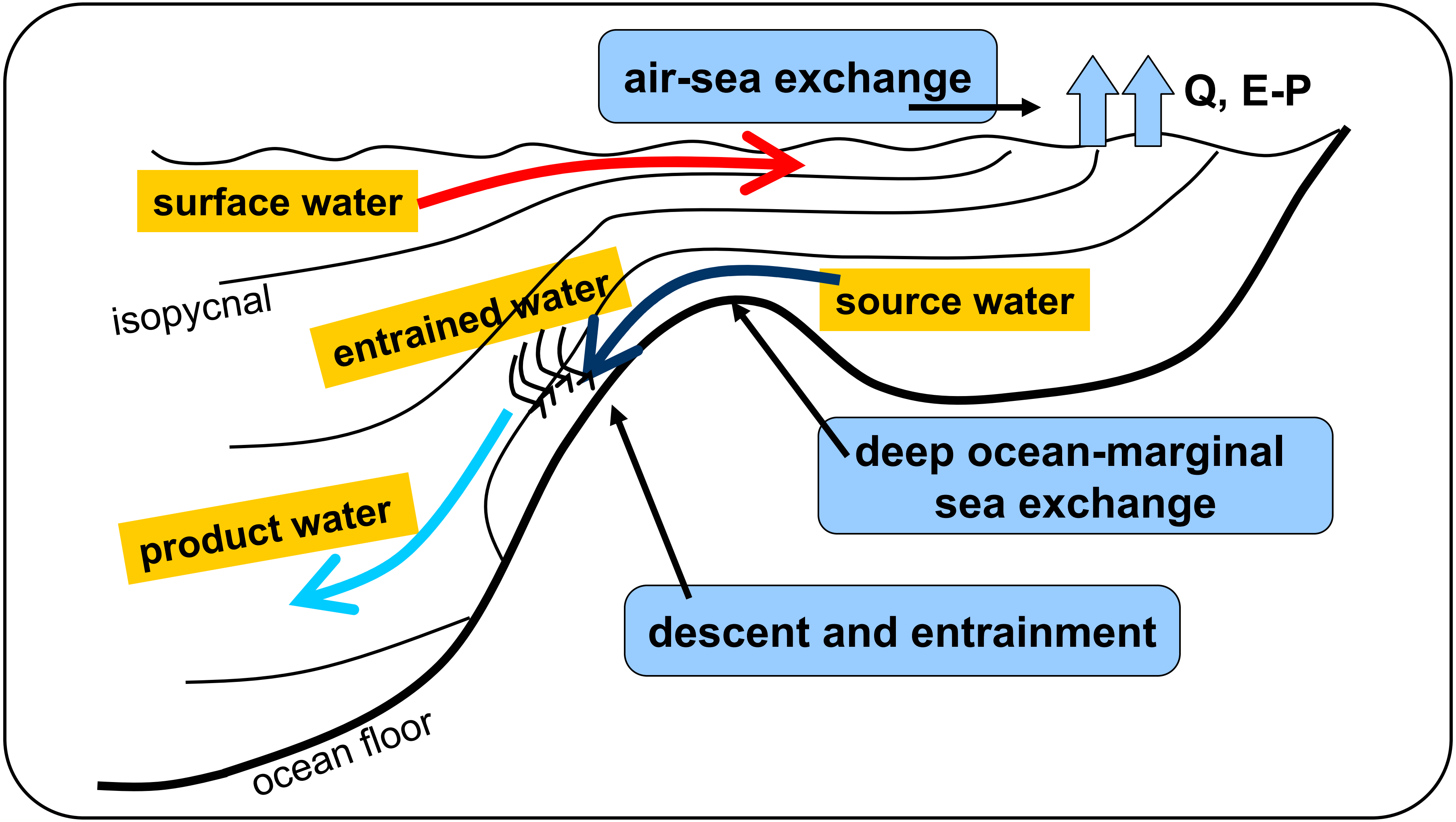
Xiaobiao Xu

MPO/RSMAS, University of Miami

Department of Marine Science,

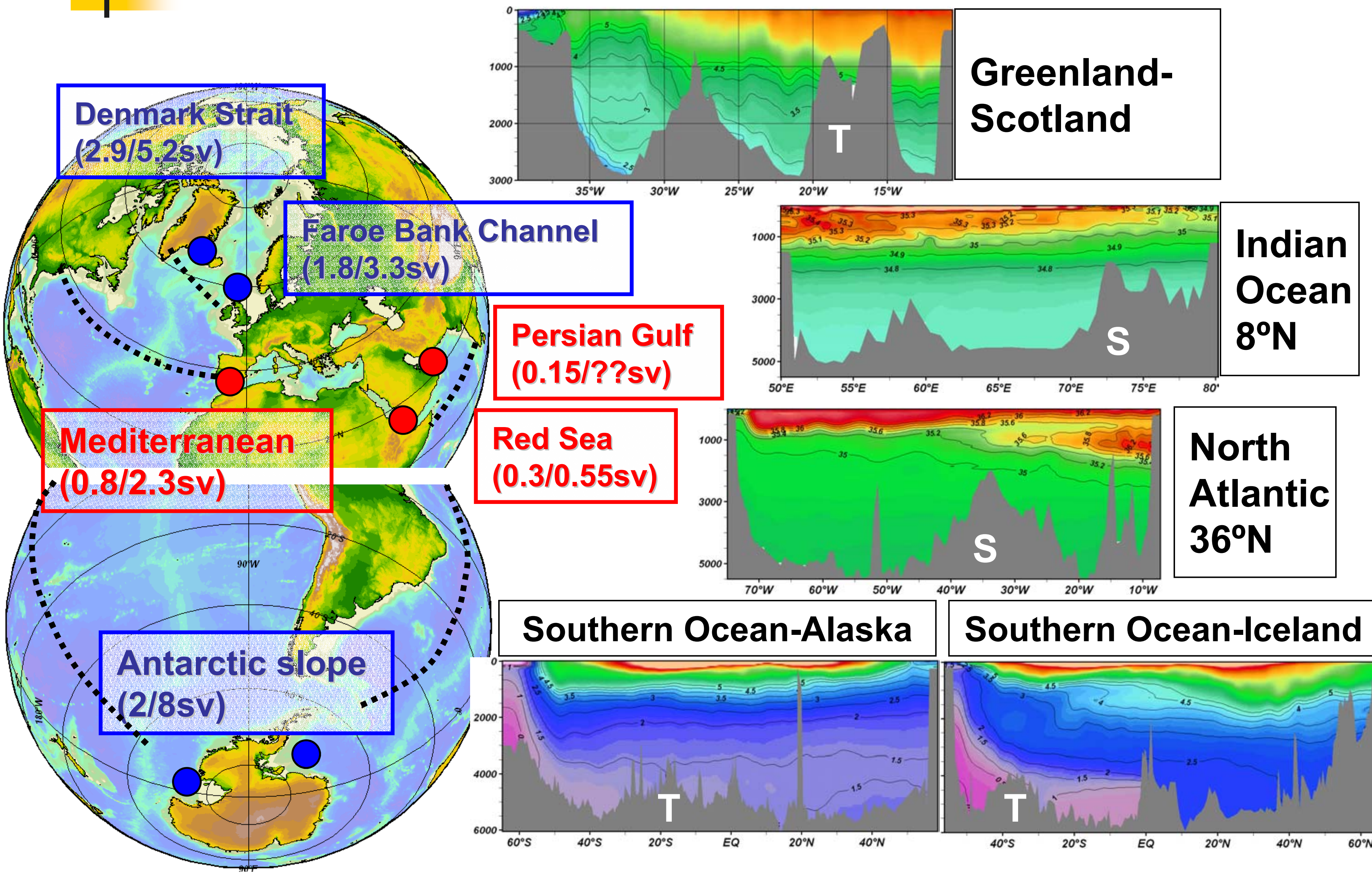
University of Southern Mississippi (now)

Outflow physical components



A typical dense water outflow from a high-latitude or marginal sea

Major outflows of the world ocean



Research motivation

- **The dense water outflows from high latitude and marginal seas play an important role in the Earth's climate and climate change**

  - They carry dense water resulting from air-sea interaction into the deep ocean, set up the water properties and circulation of the deep ocean, and provide a connection between the atmosphere and the deep ocean.
  - The downward fluxes and spreading of outflow water mass in the deep ocean initiate upwelling elsewhere and return flow in the upper ocean, therefore completing an overturning cell.

The Challenges

- **Outflow representation in oceanic general circulation models is challenging**
  - High computational cost to resolve the fine topographic details.
  - The difficulty to prescribe the entrainment process.

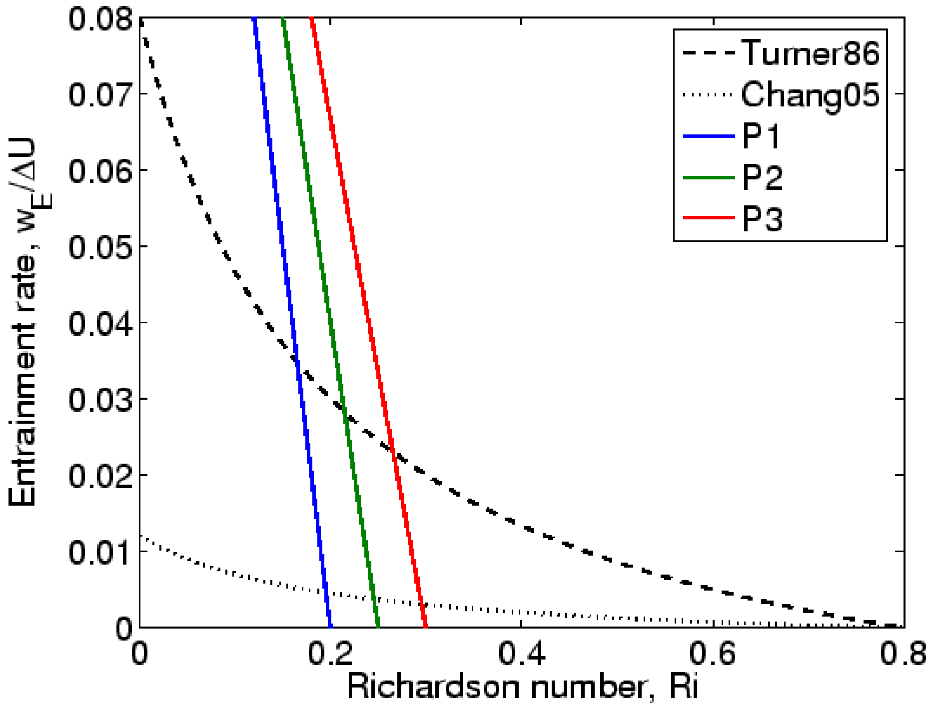
- **Different model formulations have different levels of challenge**
  - Fixed coordinate OGCMs (z or terrain-following σ) suffer from excessive numerically induced diapycnal mixing. In particular, z-coordinate OGCMs do not have enough vertical resolution to resolve the outflow plume.
  - Isopycnic coordinate models have no numerically induced diapycnal mixing. The focus is to prescribe the entrainment explicitly.

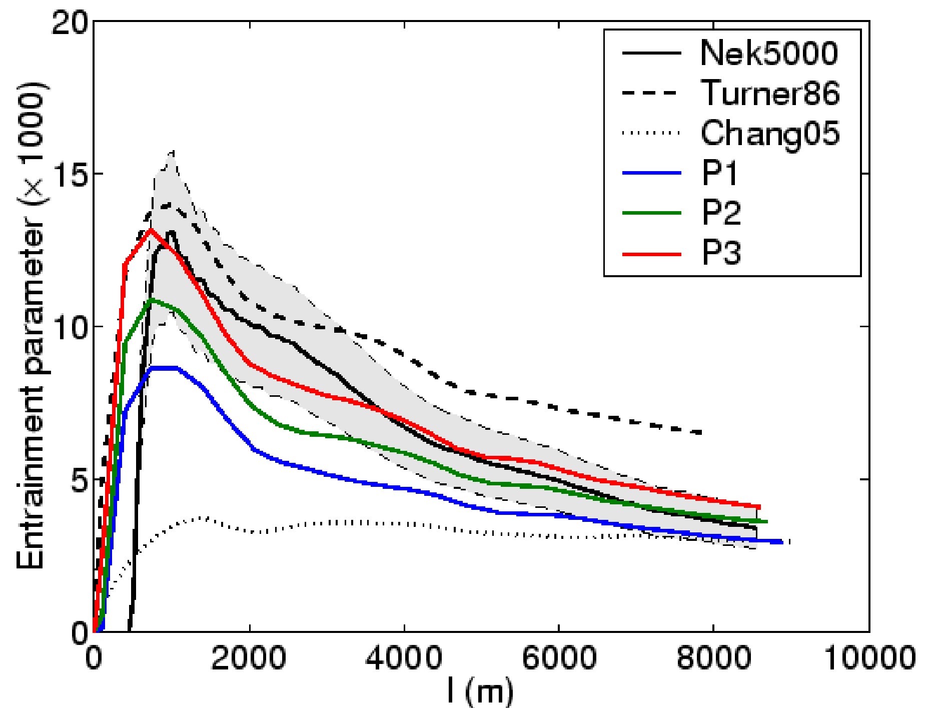
Outline

1. Development of an entrainment parameterization for HYCOM (Xu et al., 2006)
2. Evaluation of the new parameterization by comparing a regional simulation to field data
3. Sensitivity study of the parameterization to horizontal and vertical resolutions
4. Evaluation of the Price-Yang marginal sea boundary condition using regional HYCOM simulations
5. Conclusions

Summary (1)

- A linear function, E=0.2(1-Ri/0.25), was found to reproduce quite well the fundamental aspects of the outflow as predicted by a nonhydrostatic model.
- The parameterization is consistent with the fundamental theoretical and laboratory results of stably-stratified flows: the shear-induced turbulence grows (decays) in the regime of Ri less (larger) than 1/4, respectively.

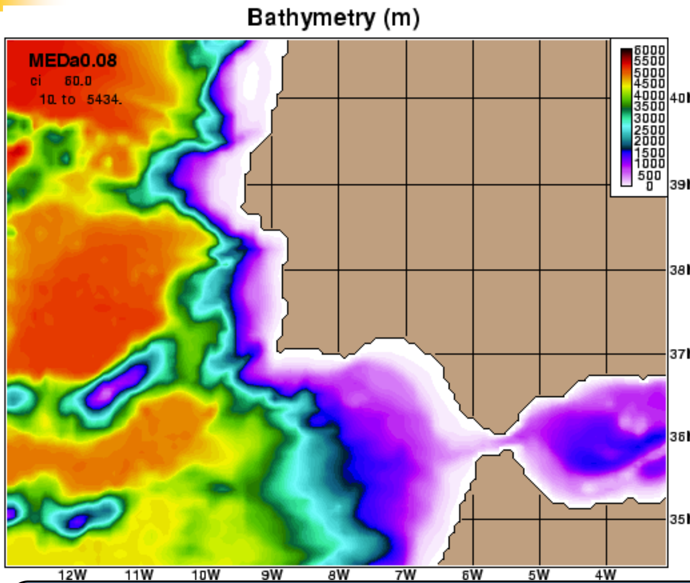




Outline□

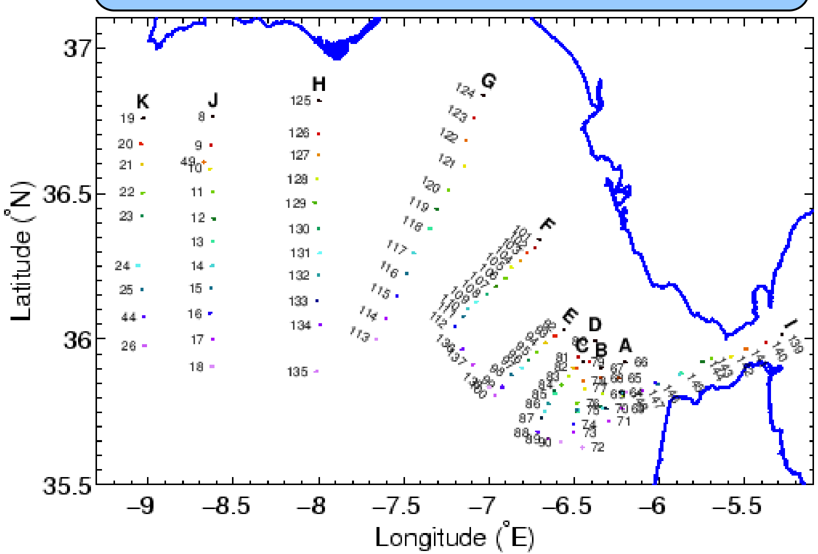
1. Development of an entrainment parameterization for HYCOM (Xu et al., 2006)
2. Evaluation of the new parameterization by comparing a regional simulation to field data
3. Sensitivity study of the parameterization to horizontal and vertical resolutions
4. Evaluation of the Price-Yang marginal sea boundary condition using regional HYCOM simulations
5. Conclusions

Model and observations

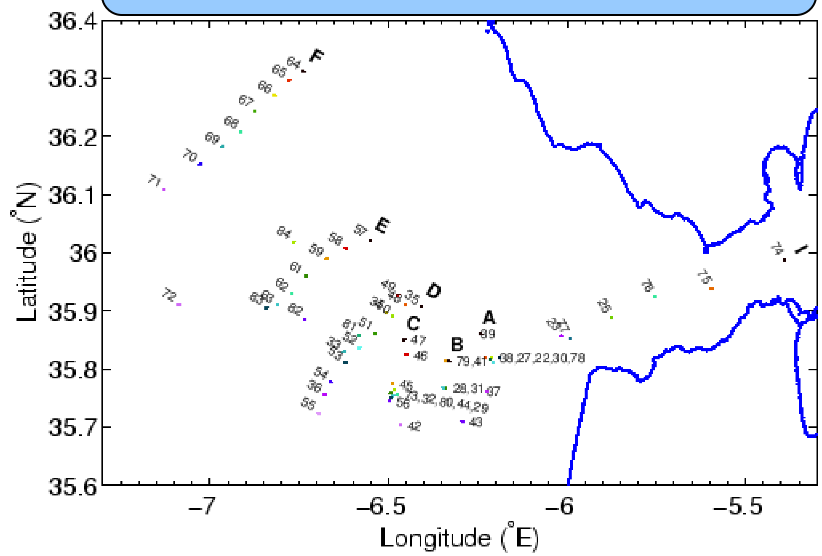


- Bathymetry (DBDB2)
- Initial condition (GDEM3)
- Boundary relaxation
- No surface forcing
- Diapycnal mixing, Xu et al. (2006)

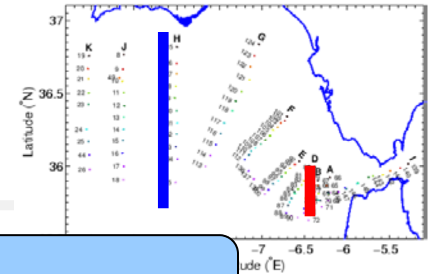
CTD stations



XCP stations

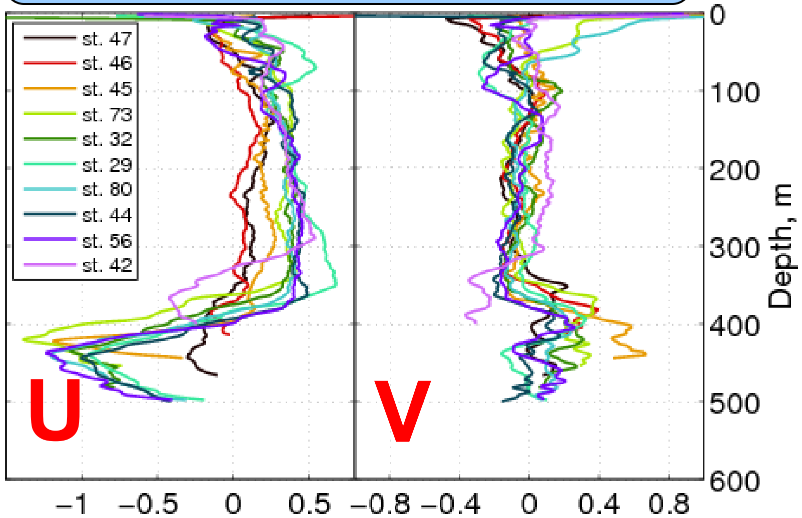


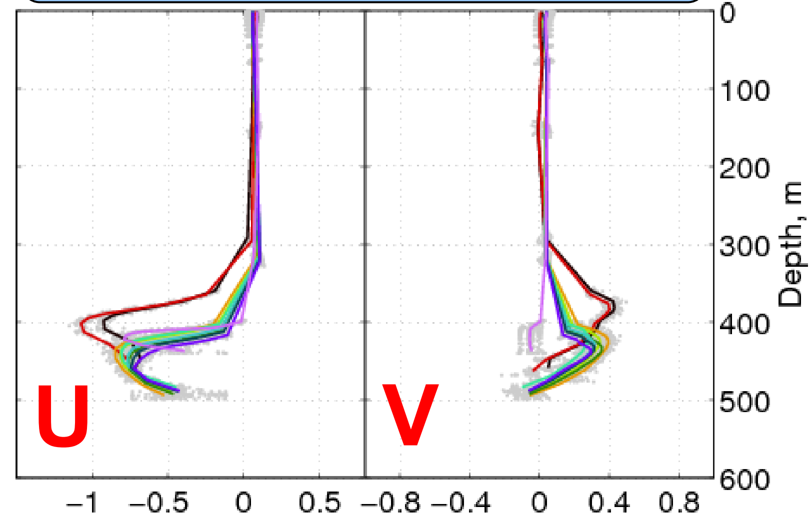
Comparing profiles



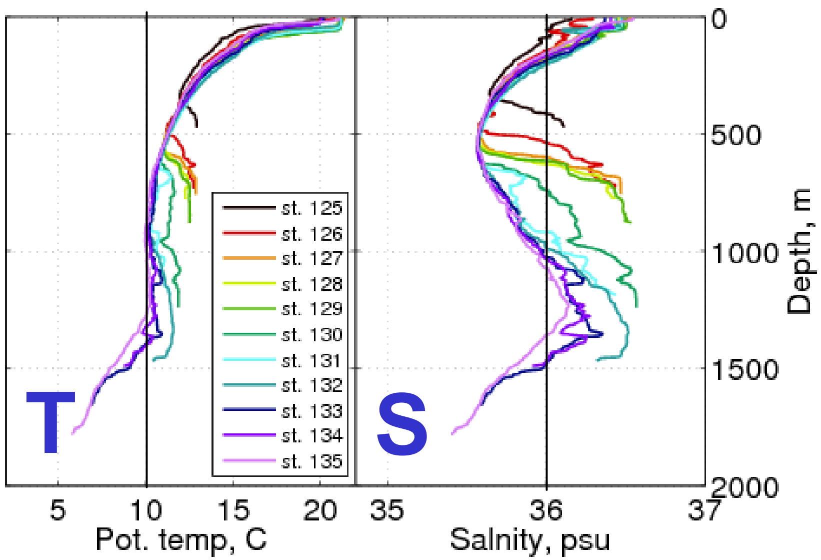
Observations | **Model**

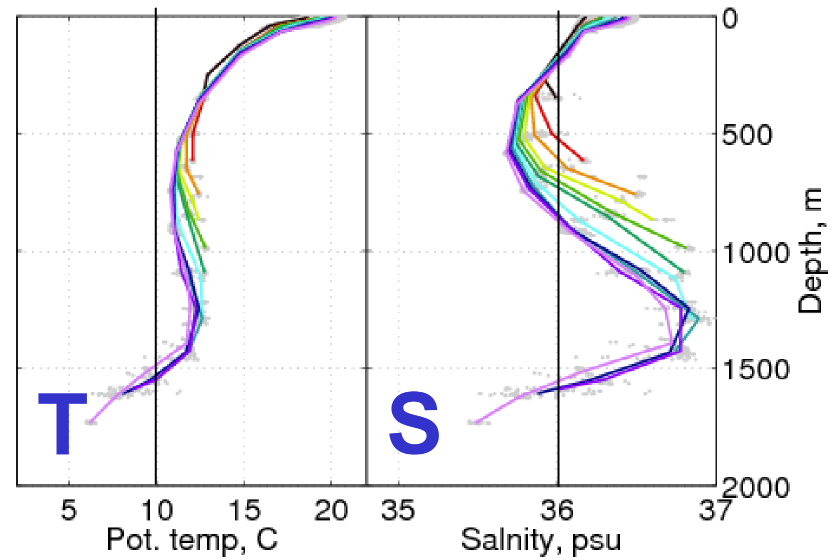
Section C



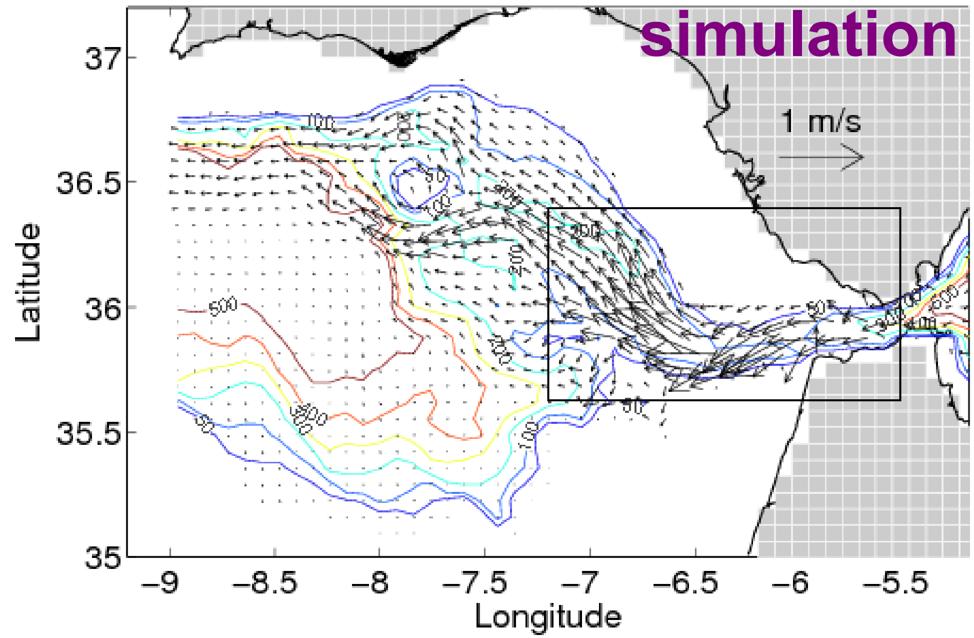


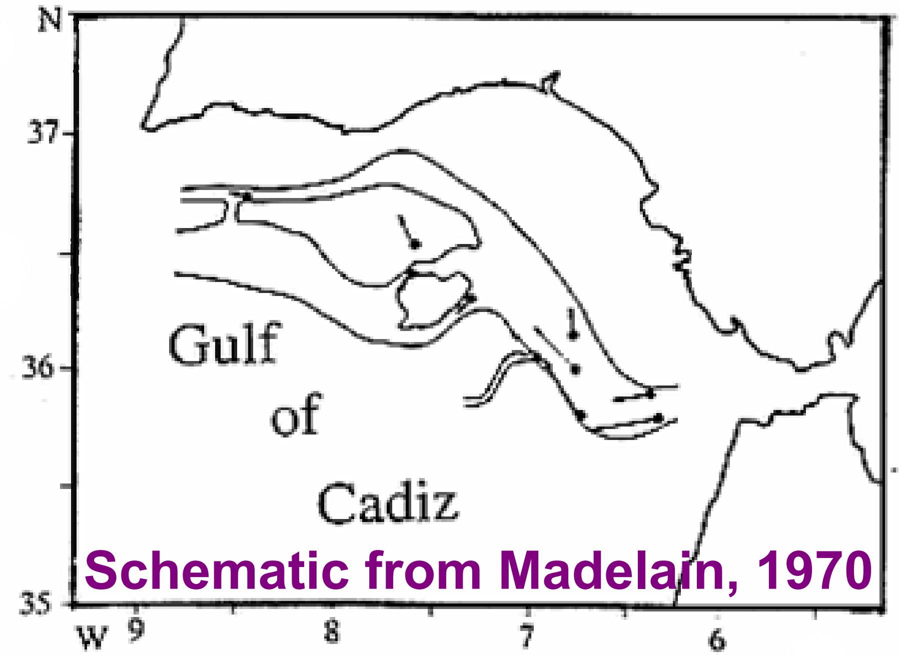
Section H



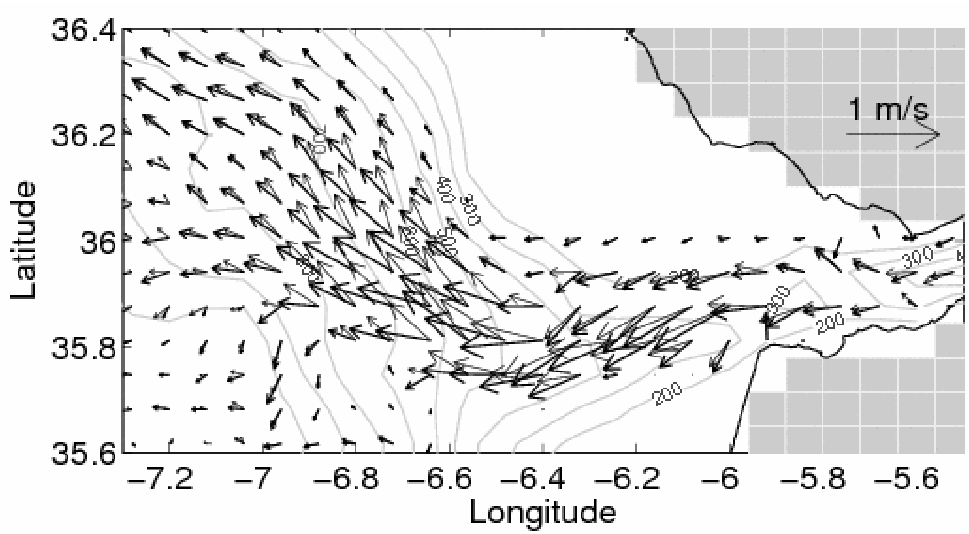


Plume structure





Schematic from Madelain, 1970



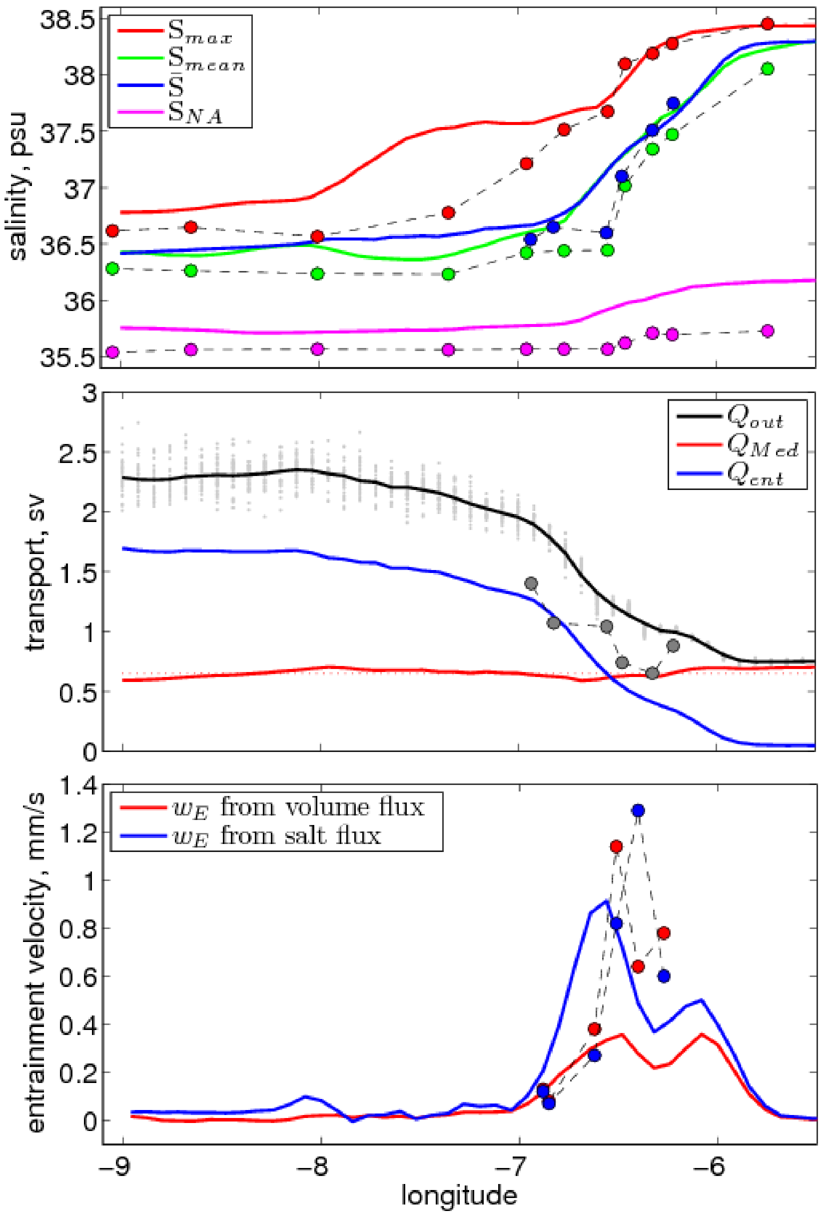
An average angle of **12.6º** between the velocity vector above and below the velocity maximum. **8.6º by Baringer and Price, 1997)**

Salinity, transport, entrainment

maximum salinity, mean salinity, velocity weighted salinity of the MOW and the minimum salinity of the NACW as a function of longitude.

total volume transport, source water, and entrained water as a function of longitude.

entrainment velocity based on the volume flux, and salt flux as a function of longitude.



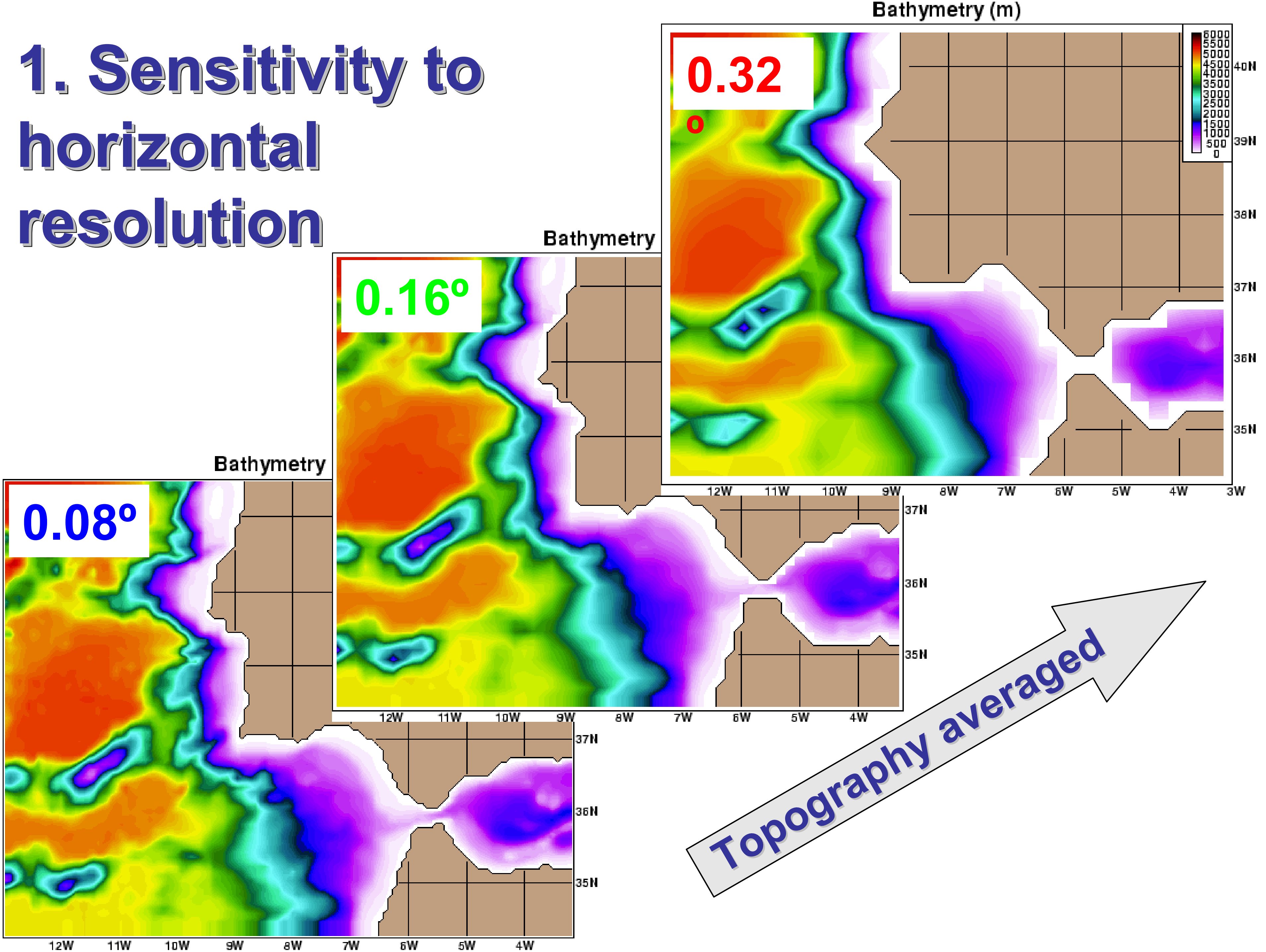
Summary (2)

Regional HYCOM simulation reproduced the main features of the observed Mediterranean outflow in the Gulf of Cádiz, including the evolution of plume behavior, the spreading and descent of the plume, and the downstream evolution of water properties and volume transport, which was controlled by the localized entrainment just west of the strait.

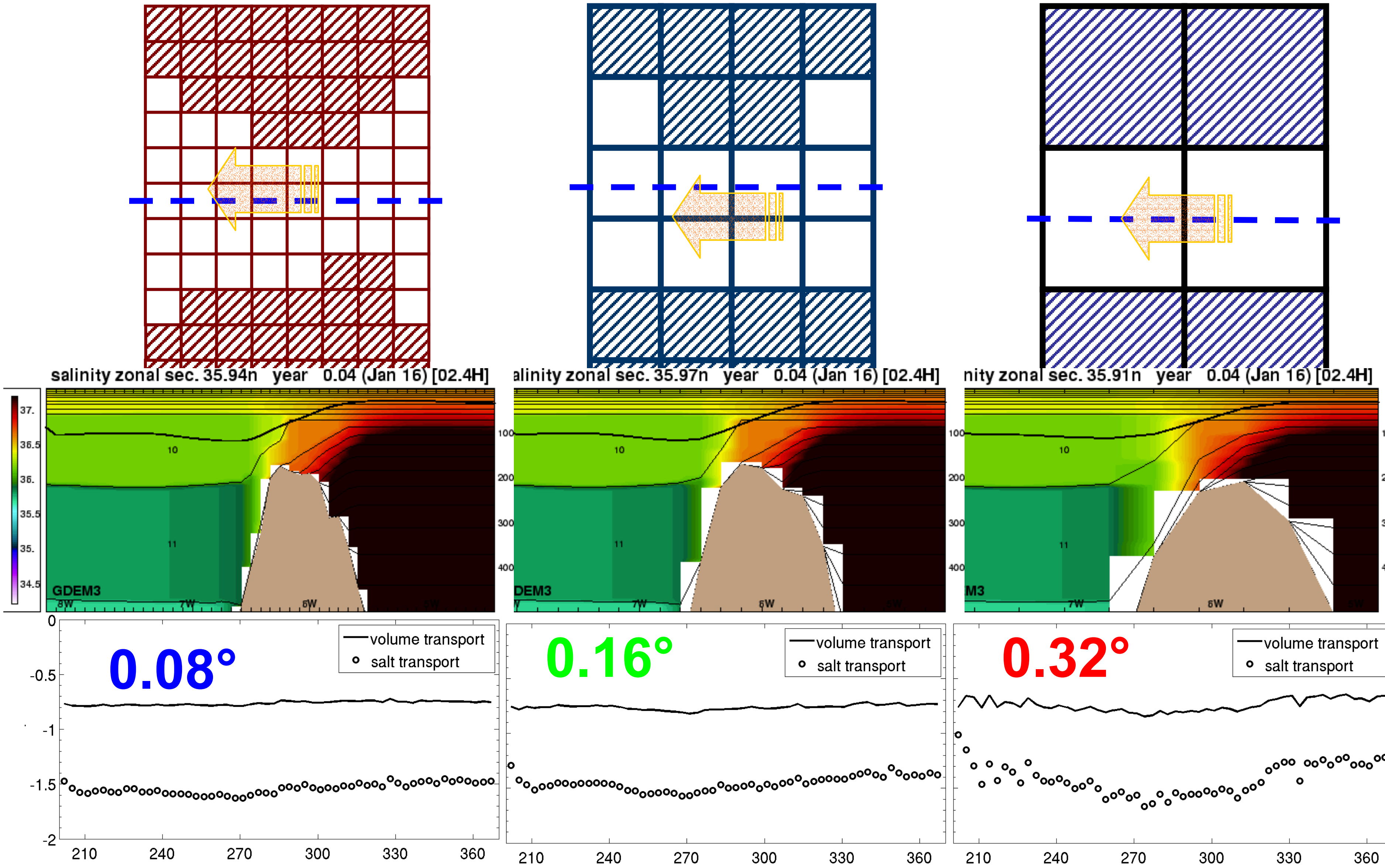
Outline

1. Development of an entrainment parameterization for HYCOM (Xu et al., 2006)
2. Evaluation of the new parameterization by comparing a regional simulation to field data
3. **Sensitivity study of the parameterization to horizontal and vertical resolutions**
4. Evaluation of the Price-Yang marginal sea boundary condition using regional HYCOM simulations
5. Conclusions

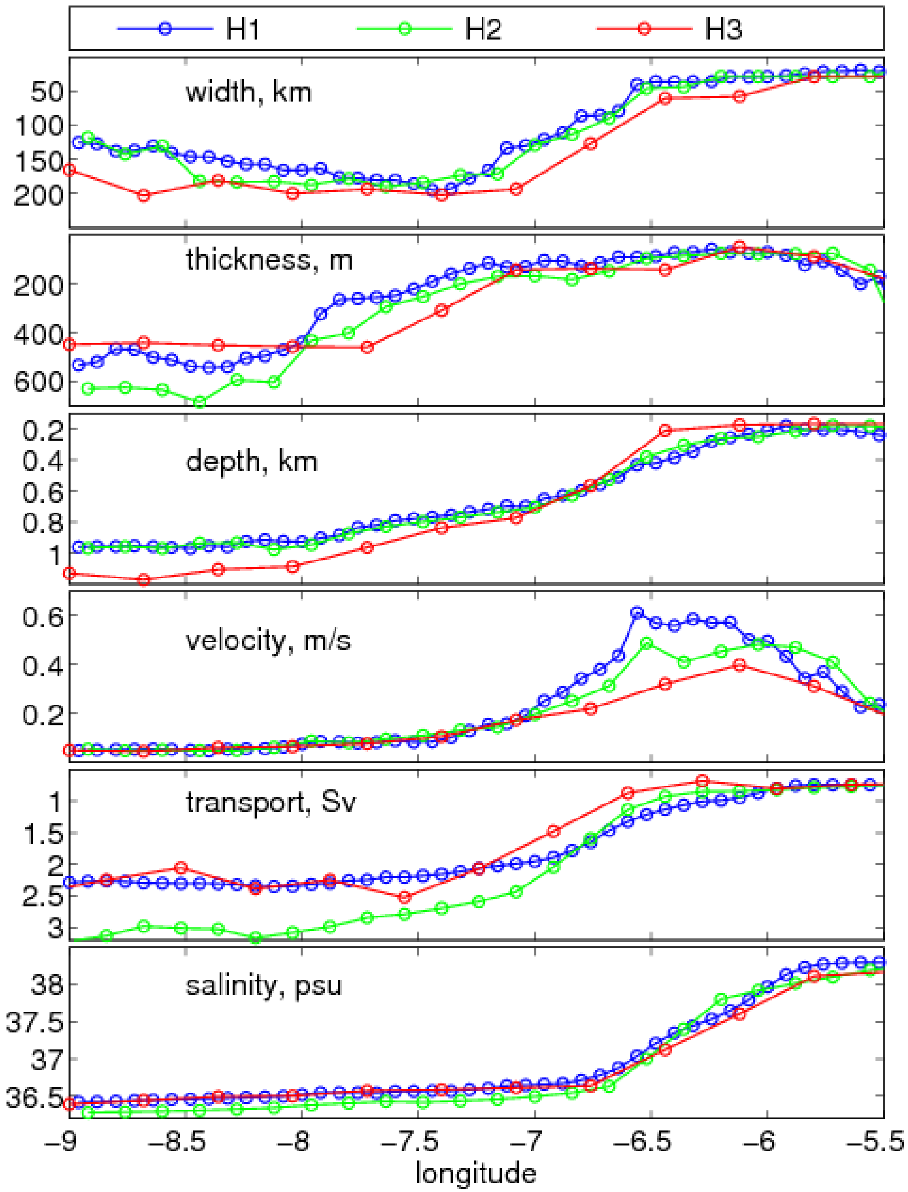
1. Sensitivity to horizontal resolution

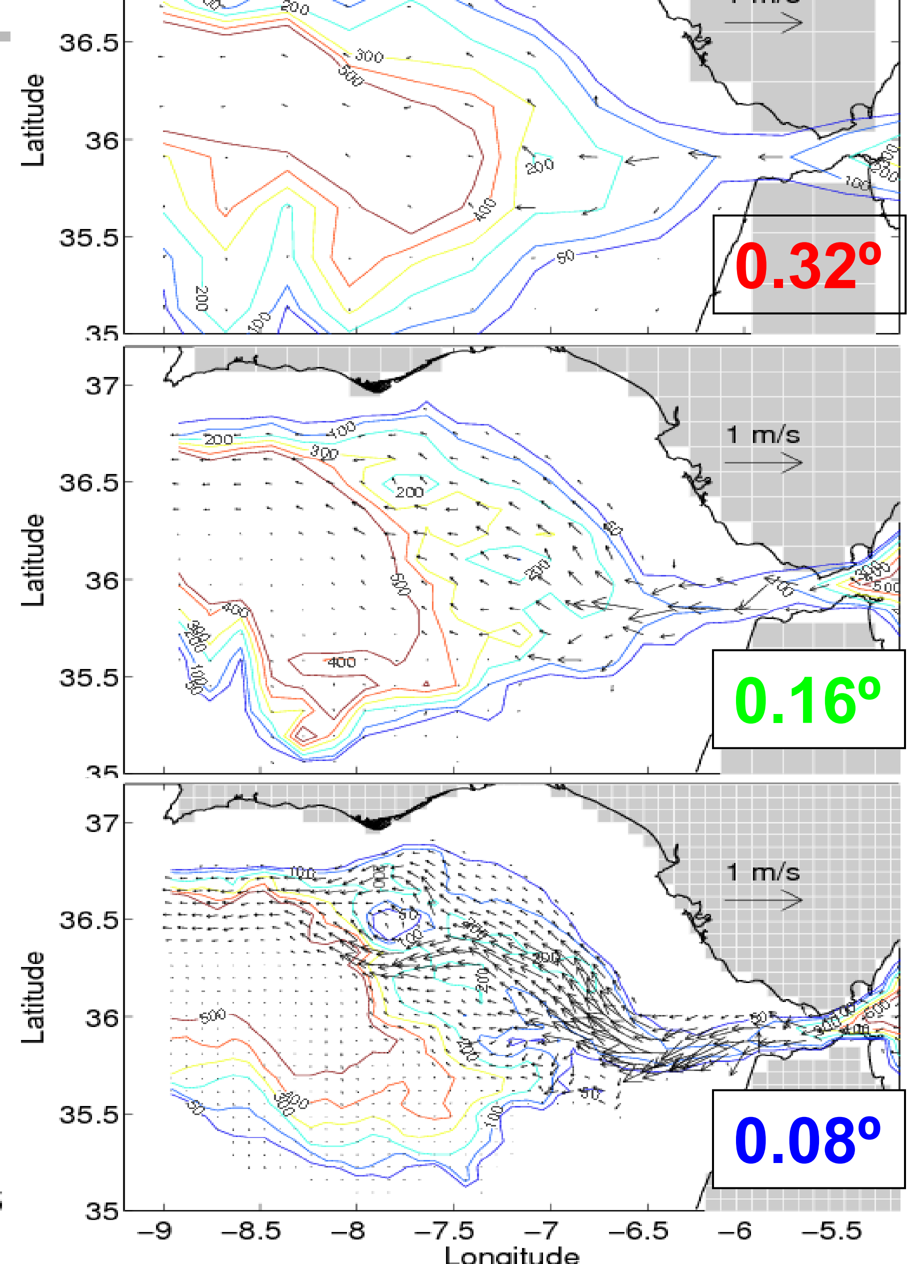


The Strait of Gibraltar

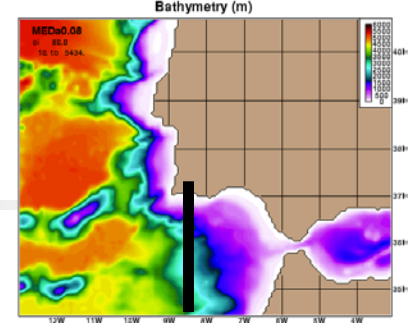


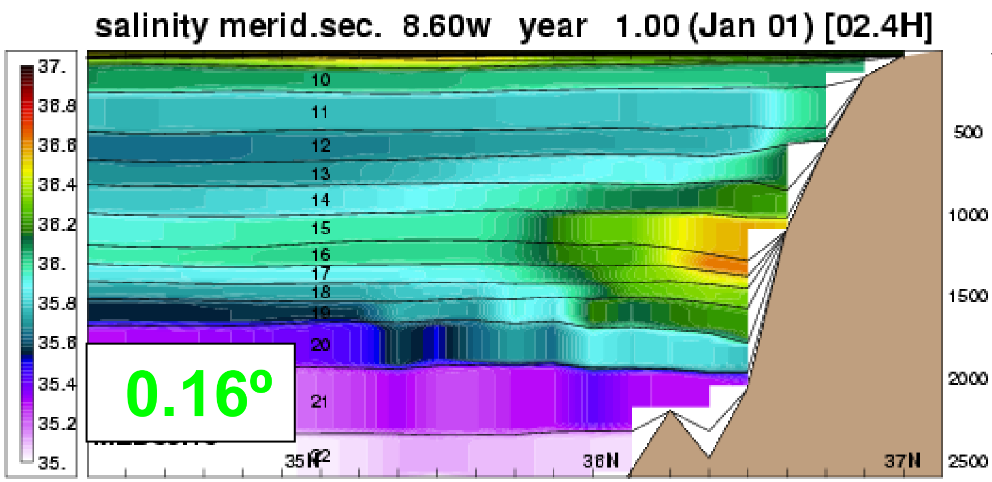
Plume structure and statistics

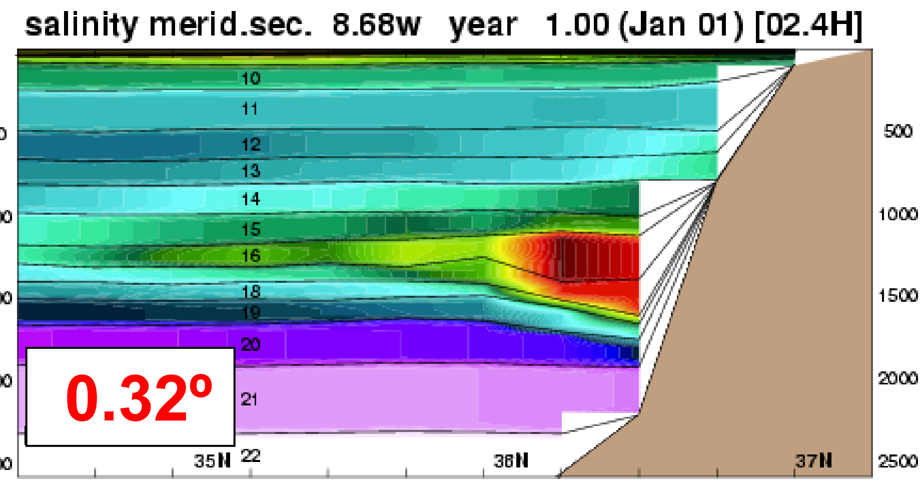


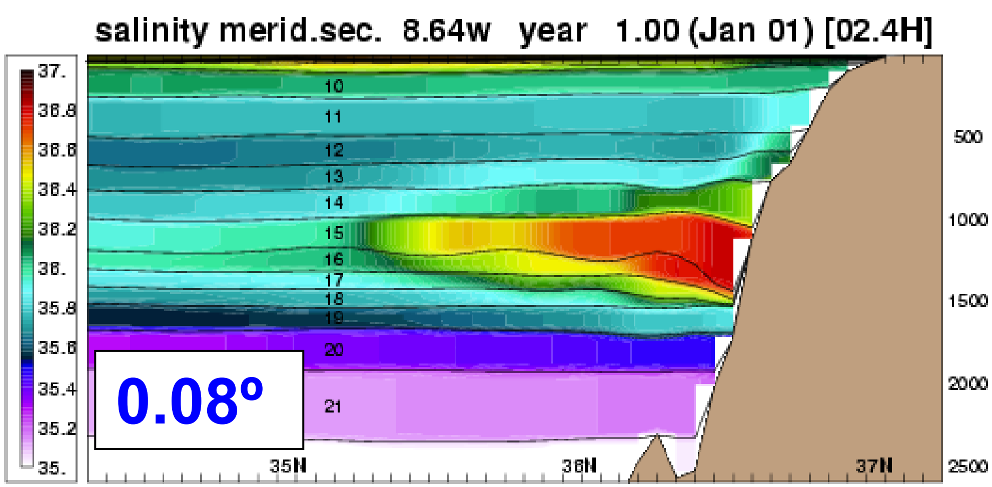


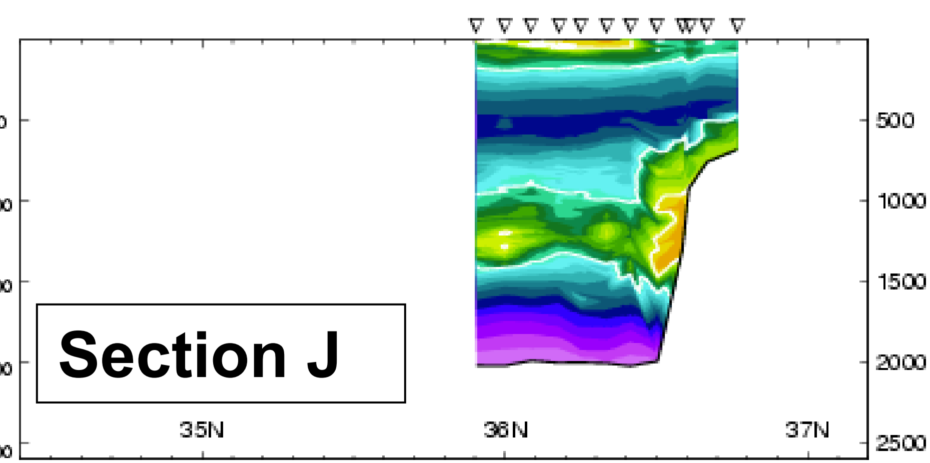
Salinity distribution



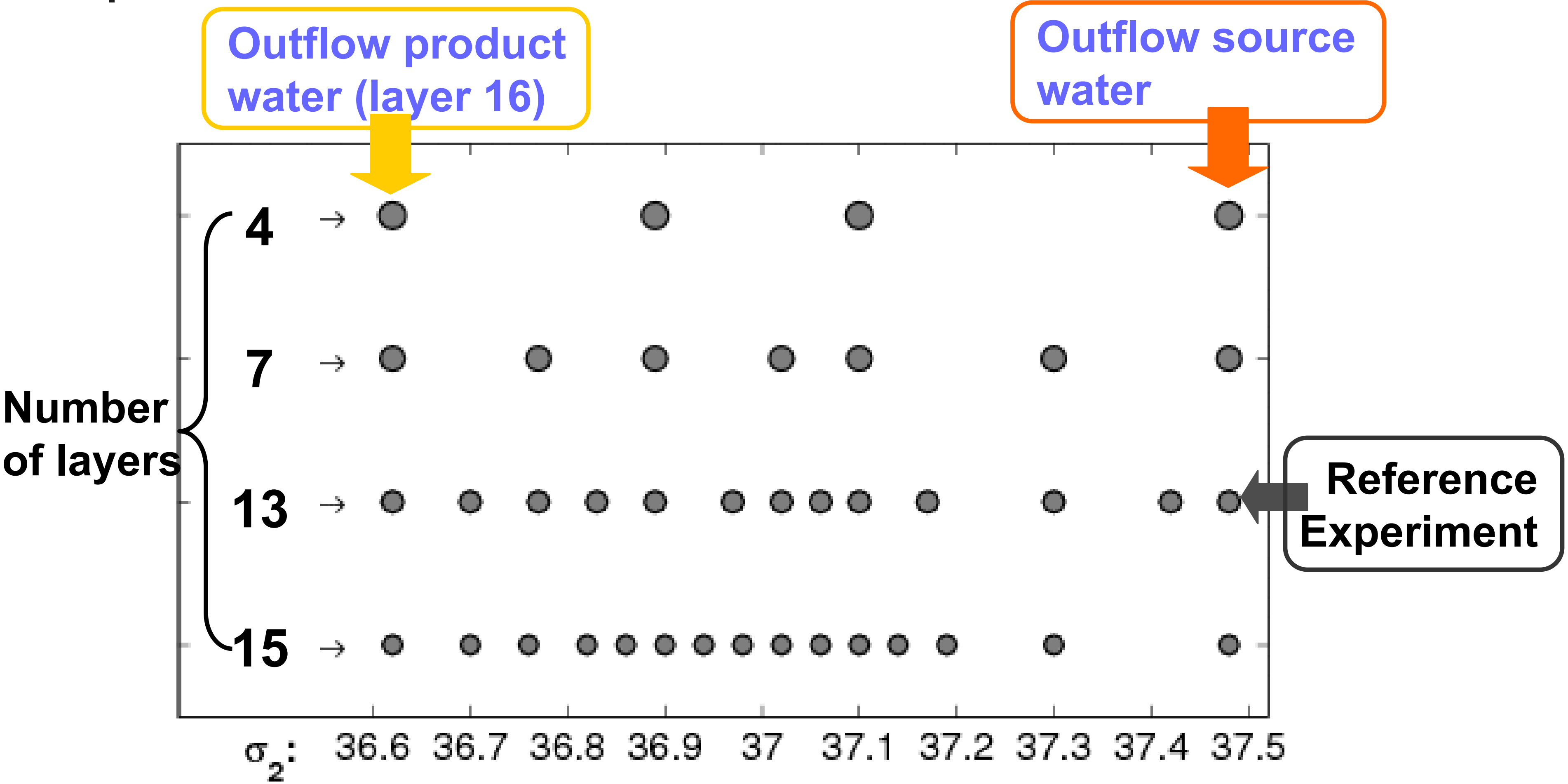






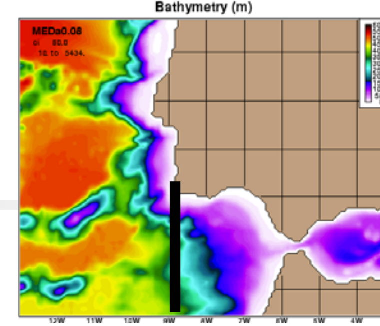


2. Sensitivity to vertical resolution

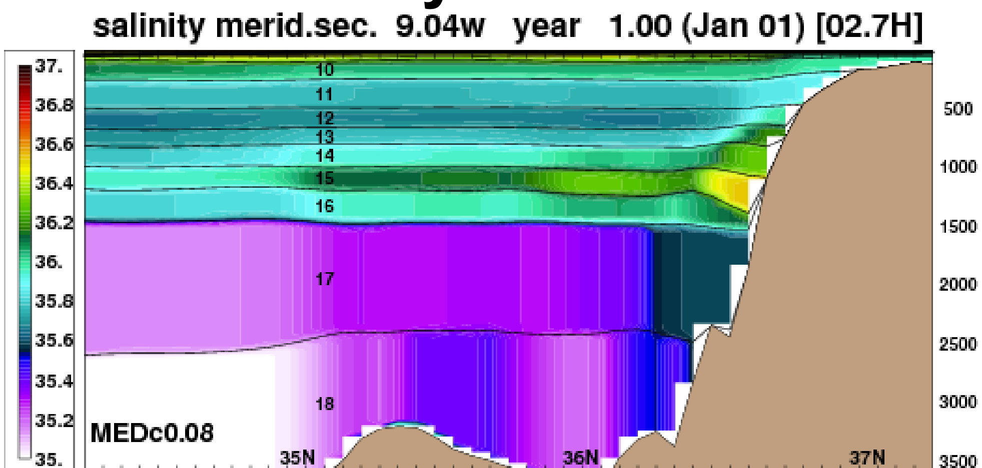


Layer distribution between σ_2 of 36.62 to 37.48 kg m^{-3}

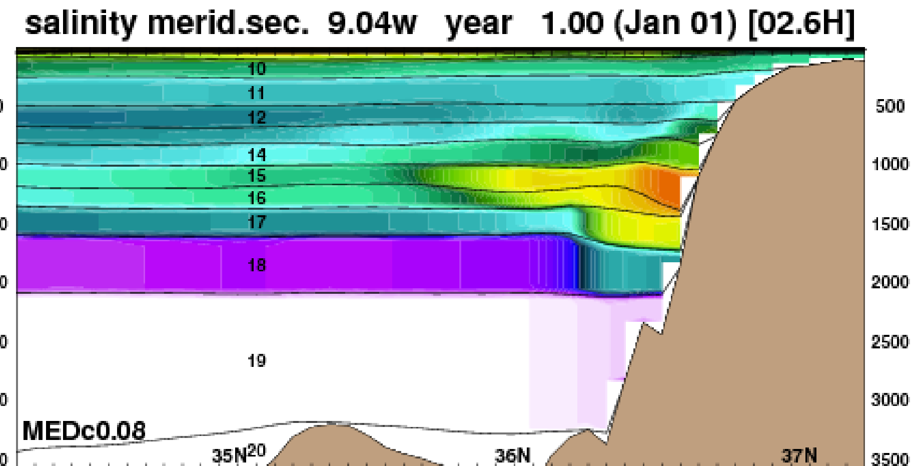
Salinity distribution

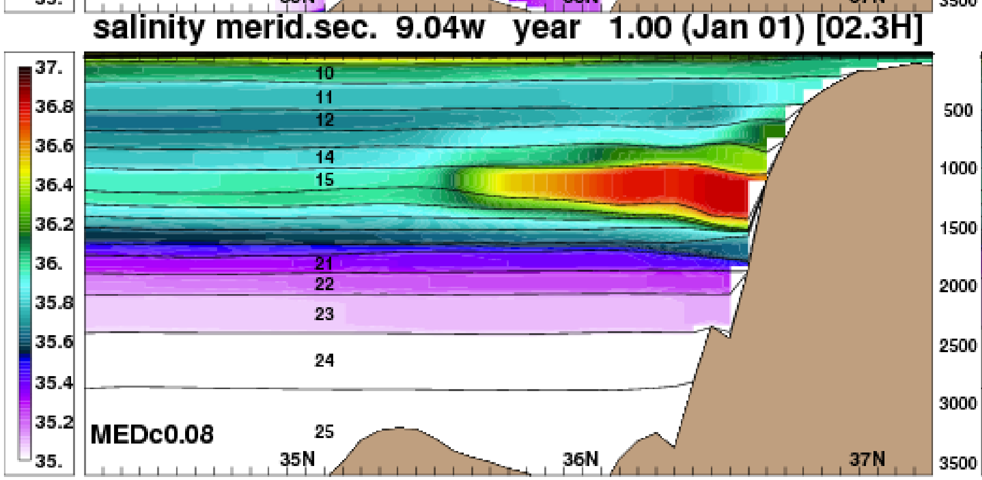


4 layers

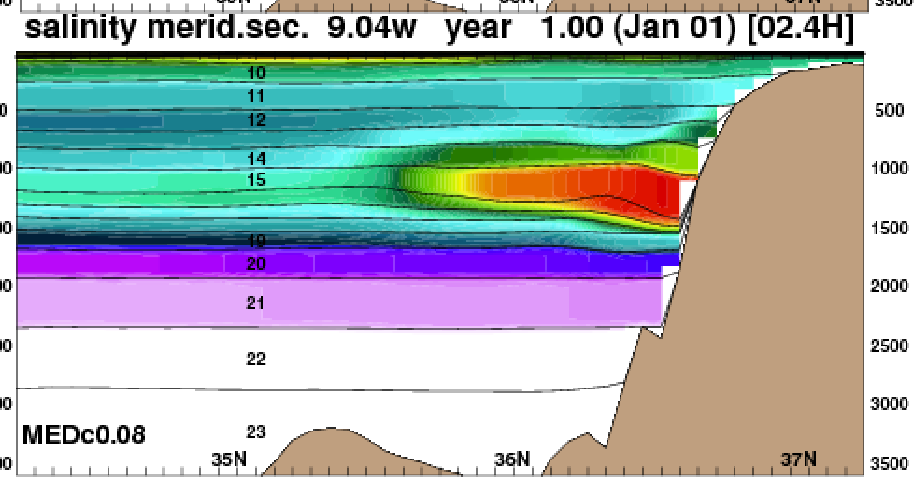


7 layers





15 layers



13 layers

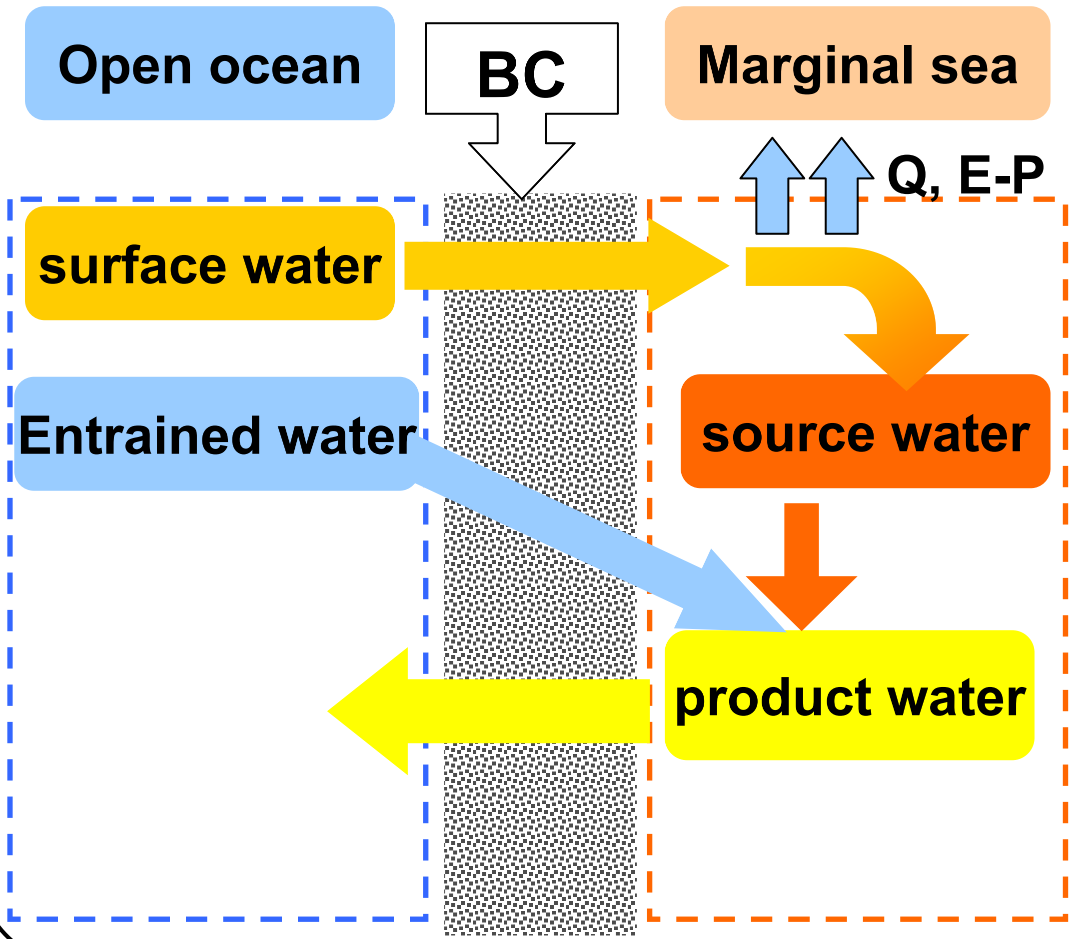
Summary (3)

- The representation of topography plays an important role in simulating an outflow since the outflow is bottom-trapped and flows across the isobath.
- The performance of the entrainment parameterization varies when the horizontal resolution changes, in specific, the entrainment becomes weaker as resolution decreases.
- The performance of parameterization is greatly affected by the vertical resolution. The simulated MOW descends to the bottom when there is only 4 layers between outflow source water and product water.

Outline

1. Development of an entrainment parameterization for HYCOM (Xu et al., 2006)
2. Evaluation of the new parameterization by comparing a regional simulation to field data
3. Sensitivity study of the parameterization to horizontal and vertical resolutions
4. **Evaluation of the Price-Yang marginal sea boundary condition using regional HYCOM simulations**
5. Conclusions

Price -Yang MSBC



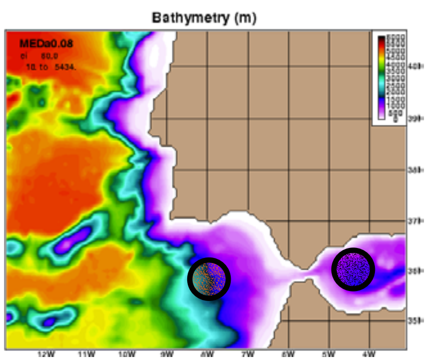
How it works

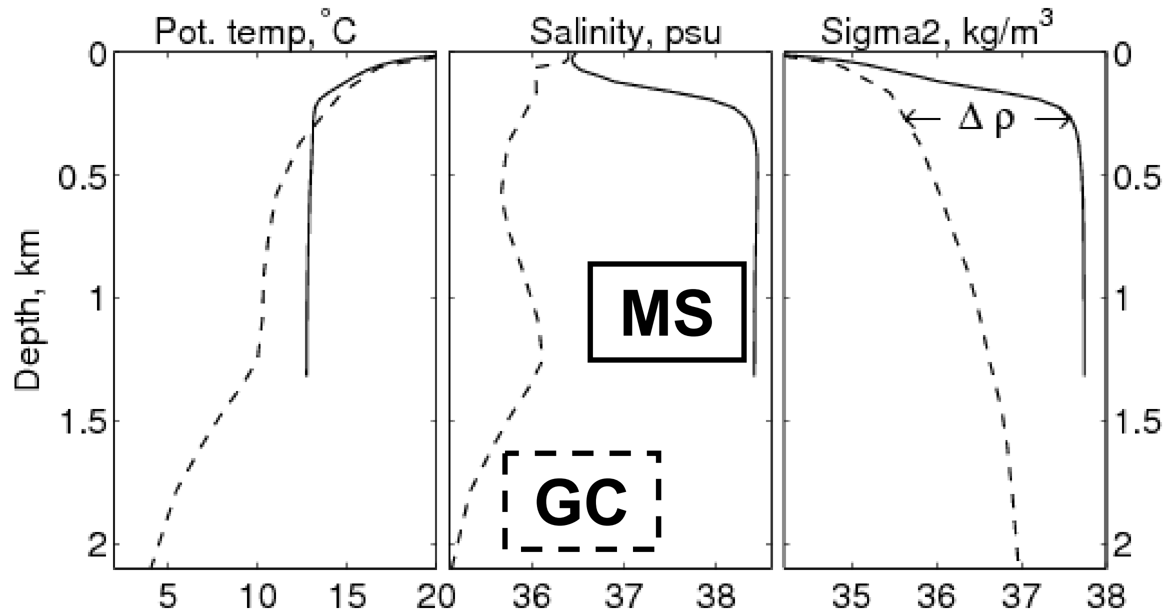
Source water:
conservations of T, S, and mass, and a hydraulic control
Ms=f(Δρ)

Product water:
conservations of T, S, and mass, and a entrainment parameter
Φ=g(Δρ)

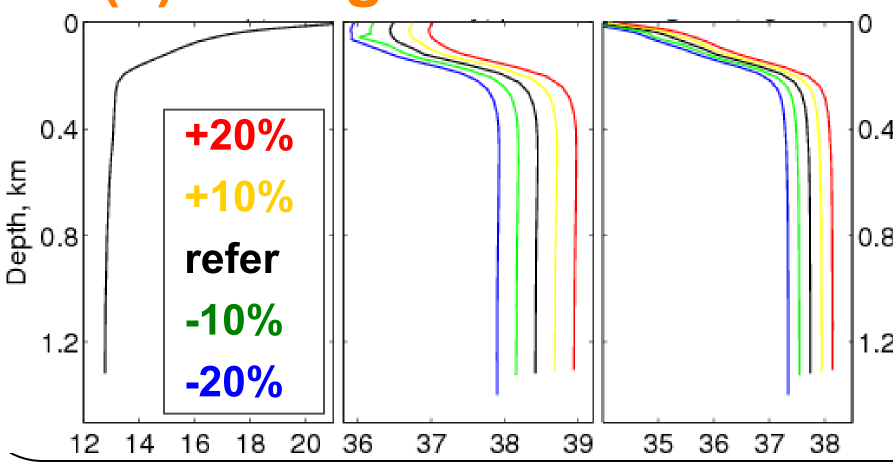
Experiment configurations

Reference Experiment

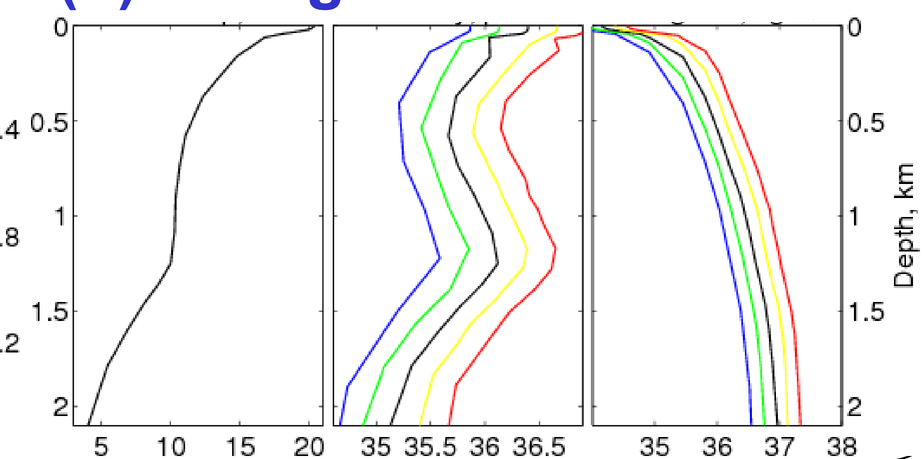




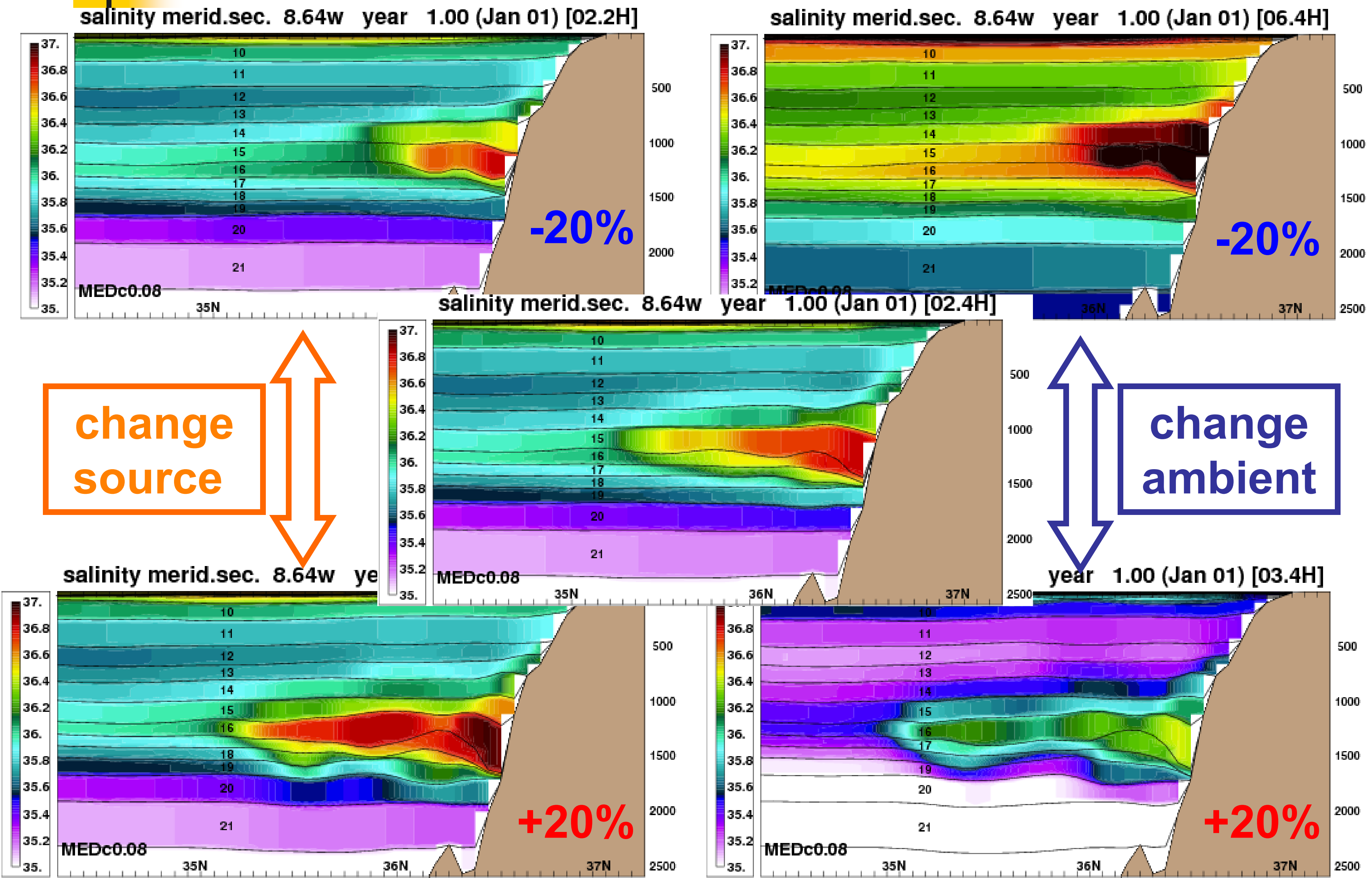
(a) change source water



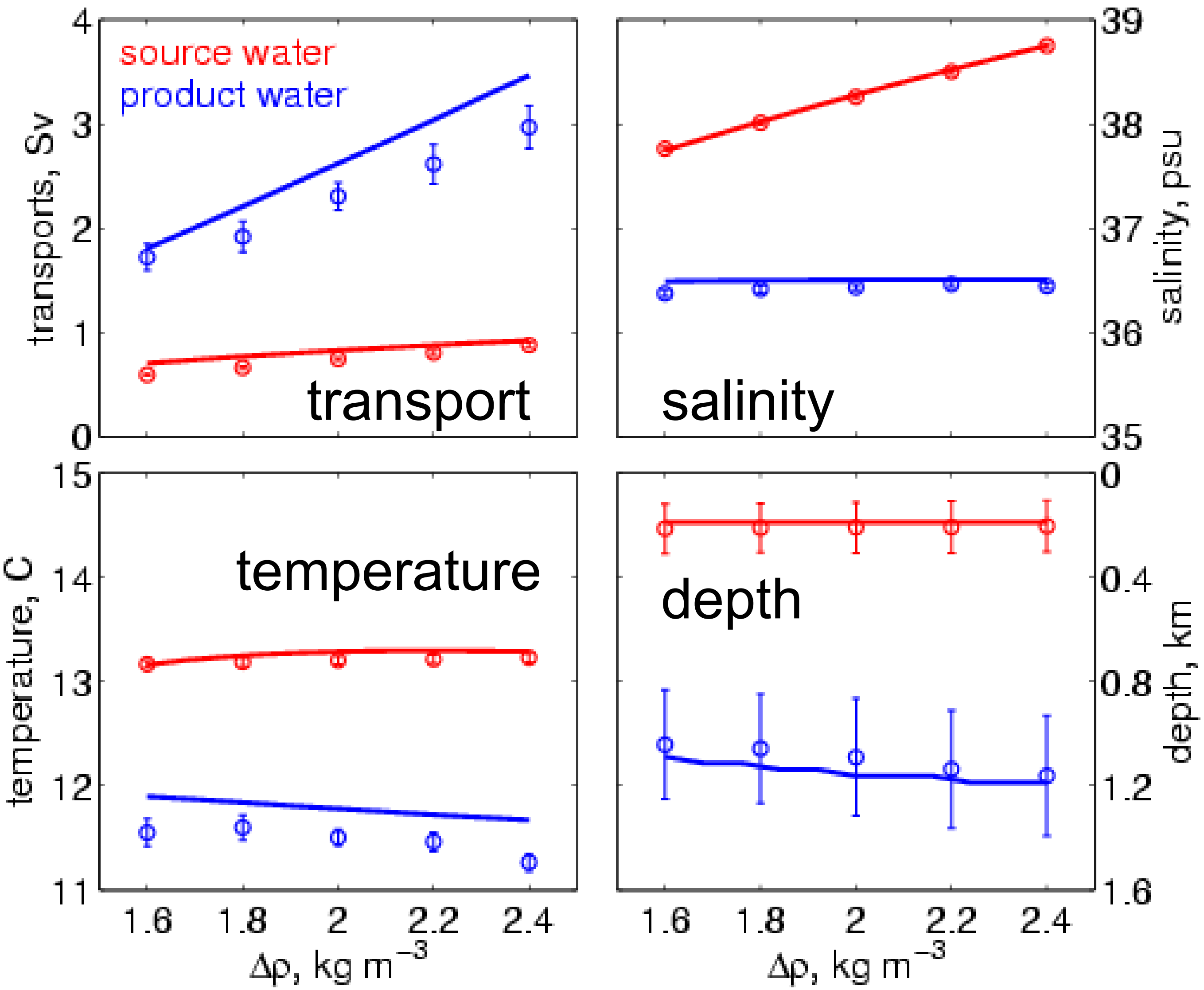
(b) change ambient water



Salinity snapshots

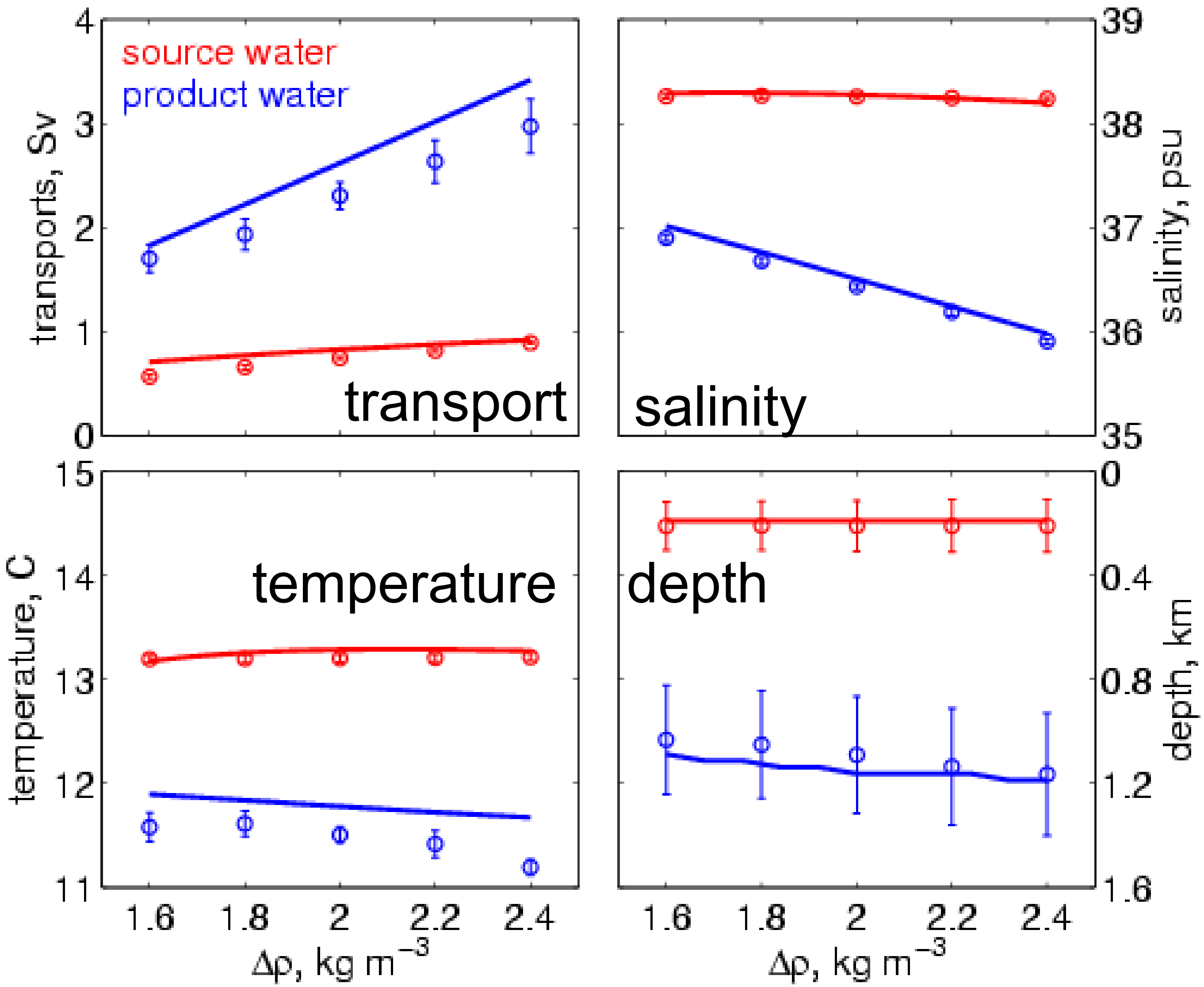


HYCOM versus MSBC (a)



- Lines are MSBC; circles are HYCOM;
- **Red** and **Blue** are outflow **source** and **product** water;
- Error bars are time variations for transport, salinity, and temperature, but are plume thickness for depth.

HYCOM versus MSBC (b)



- Lines are MSBC; Circles are HYCOM;
- **Red** and **Blue** are outflow **source** and **product** water;
- Error bars are time variations for transport, salinity, and temperature, but are plume thickness for depth.

Summary (4)

Although the Price-Yang MSBC does not resolve any detail of the outflow as the regional HYCOM simulations, it reproduces comparable outflow variations associated with the changes in the outflow source water and the ambient ocean water.

Conclusions

- Given an adequate resolution, HYCOM simulations with the entrainment parameterization put forward by Xu et al. (2006) are able to reproduce the observed evolution of the Mediterranean outflow in the Gulf of Cádiz.
- The same parameterization performs differently as the resolution varies, especially, the parameterization does not work well with coarse vertical resolution, the simulated MOW descends to the bottom with 4 layers between source and product water.
- When compared to the output of HYCOM simulations, the Price-Yang MSBC produces fairly realistic variations in product water associated with the changes in the outflow source water and the ambient ocean water.

Outlooks

- Can the Xu et al. entrainment parameterization work for other outflows than the Mediterranean?
- Can it be applied throughout the Atlantic basin? In particular, is the parameterization valid for the EUC?
- Is representation of finer topography (i.e.< 0.08º) important in simulating the Mediterranean outflow in the Gulf of Cádiz?