The coupling of river flows with regional ocean models

Coastal Hydrology and Surface Processes linked to Air/Sea Modeling:
1st community of users workshop, Madeira, Sept. 2017

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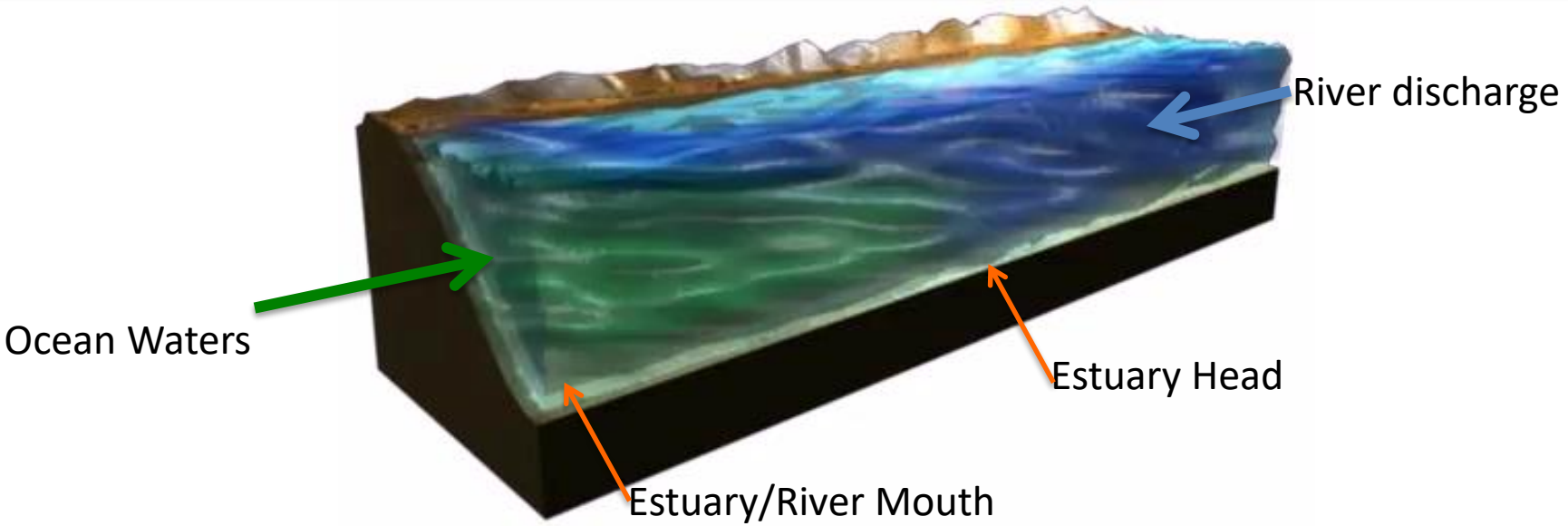
Outline

- **Open problems & the coupled modeling strategy (W**eather, **HYD**rology and **E**stuarine dynamics**-WHYDE)**
- **River discharge simulations with WHYDE in Southern Italy: a study case –**
  - ✓ **Verri et al. (2017)** A meteo-hydrological modeling system for the reconstruction of river runoff: the case of the Ofanto river catchment, **Natural Hazards and Earth System Science, in press**
- **Estuarine dynamics: the Estuarine Box Model (EBM) approach**
  - ✓ Apprications to 2 case studies: the highly stratified estuary (Ofanto river) and the partially mixed delta (Po river)
- **Coupling of WHYDE with the regional ocean modeling**
  - ✓ The impact of the EBM on the shelf dynamics
- **Concluding Remarks**

The open problems



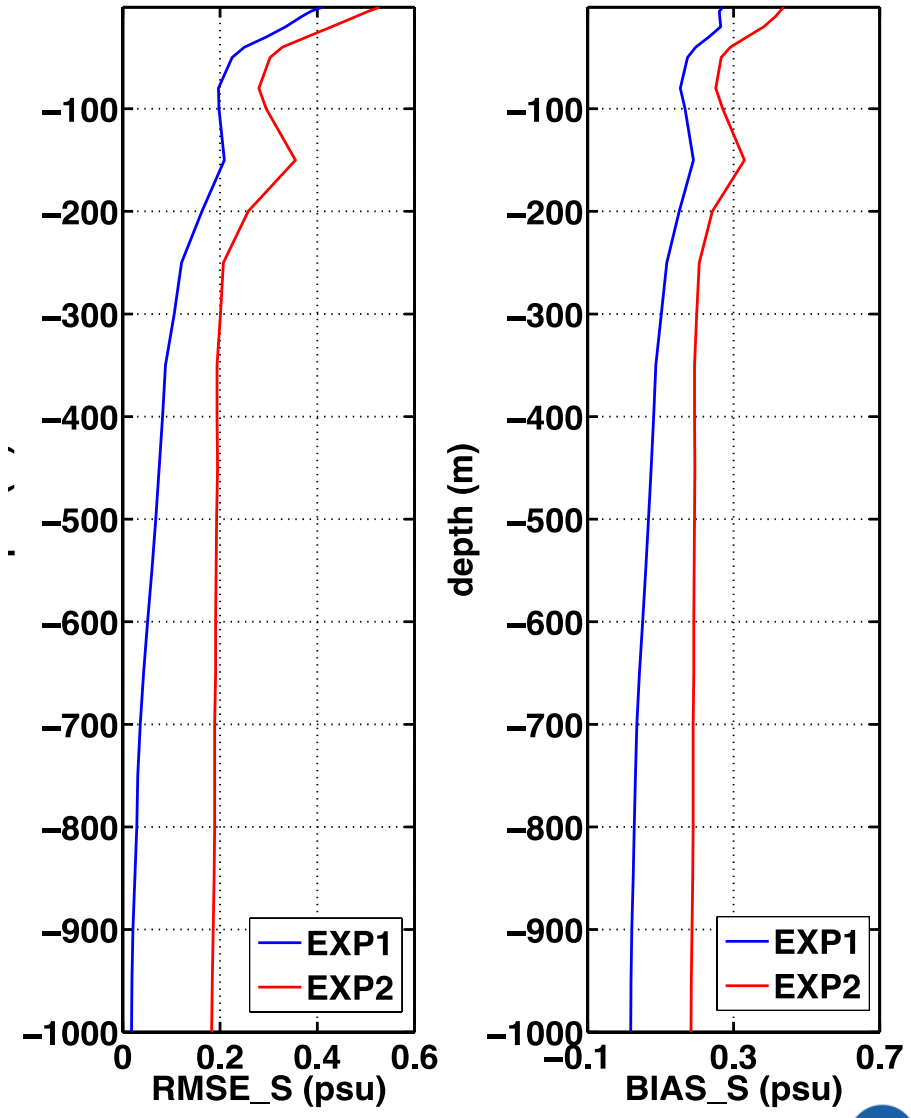
From: Estuary water exchange from NOAA Ocean Service Education

- **Forecasting Regional ocean models have O(1 km)** resolution and cannot resolve the estuarine dynamics.
- **Regional ocean models** usually consider directly the **river discharge instead of the real outflow at the estuary mouth.**
- Very often a ***zero salinity value is imposed at the river mouth of regional ocean models*** generating unrealistic salinity gradients in the coastal and shelf Regions Of Freshwater Influence.

The effects of rivers on the deep ocean salinity

RMSE and BIAS between
ARGO floats
and model simulation
EXP1 – Adriatic rivers on
EXP2 – Adriatic rivers off

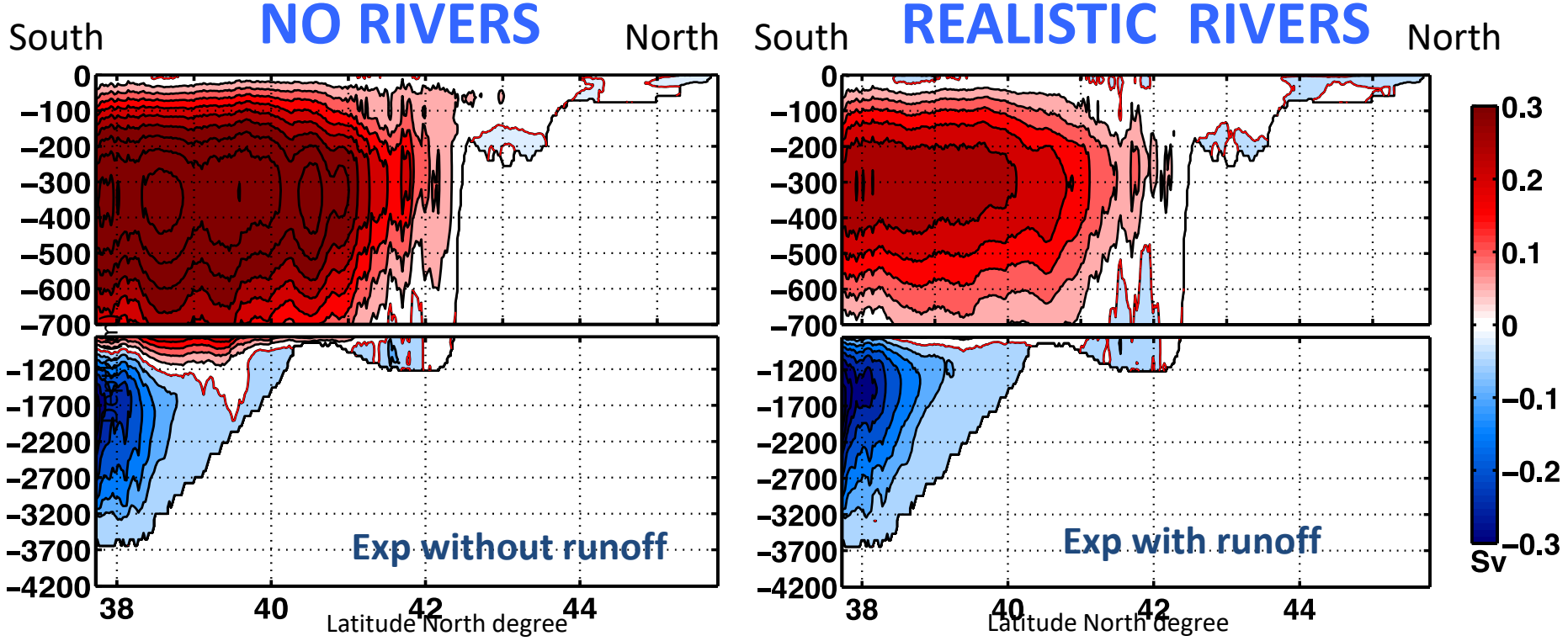
From:
G. Verri et al. 2017. River runoff influences on the Central Mediterranean Overturning Circulation. Climate Dynamics
doi: 10.1007/s00382-017-3715-9



River influence on the Overturning Circulation

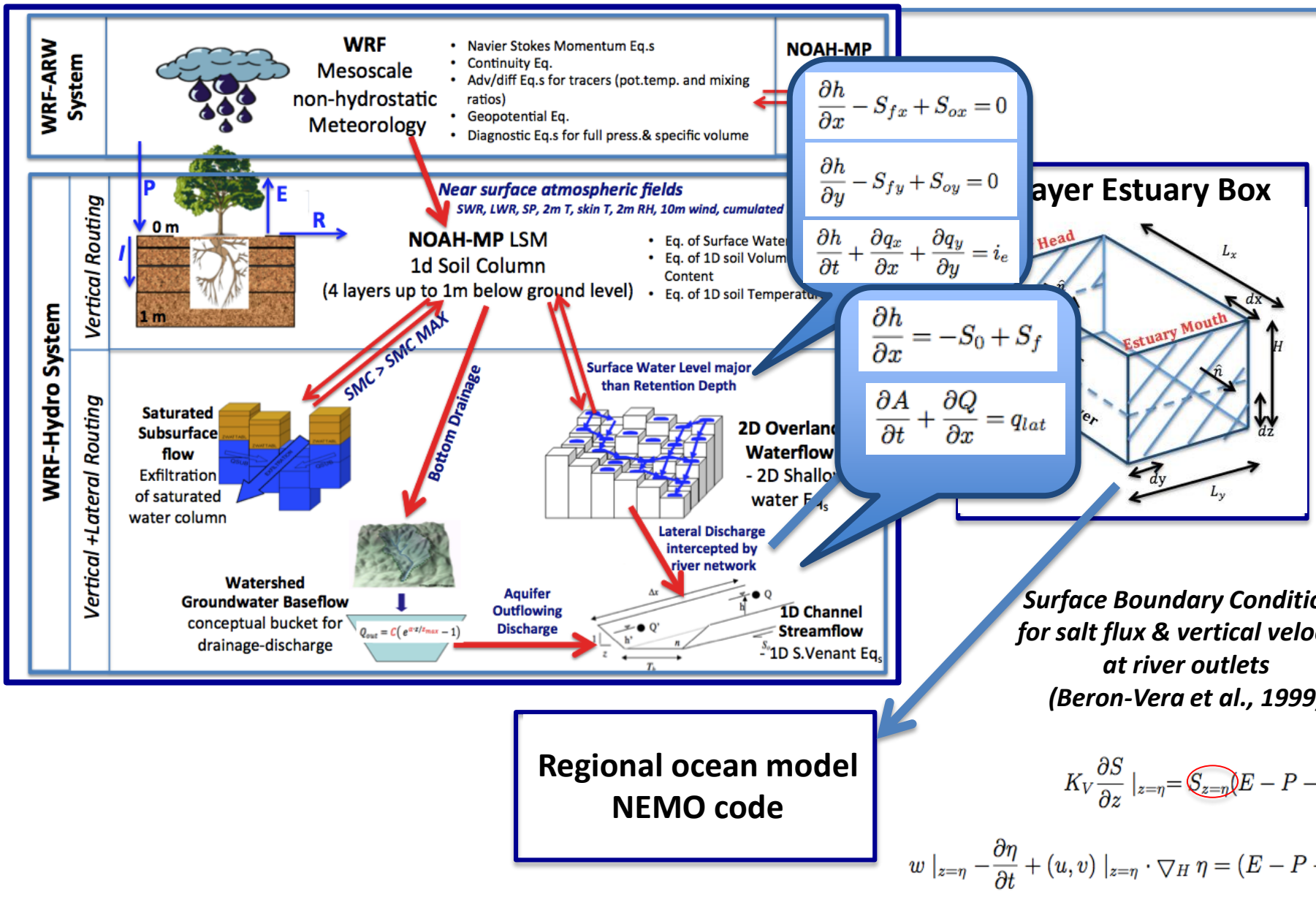
Do rivers play a significant role in the Meridional Overturning Circulation of the CENTRAL MEDITERRANEAN SEA?

Multiannual Meridional Transport Streamfunction (Sv)



G. Verri et al. 2017 River runoff influences on the Central Mediterranean Overturning Circulation. Climate Dynamics doi: 10.1007/s00382-017-3715-9

The coupled water modeling Strategy (WHYDE)



Regional ocean model NEMO code

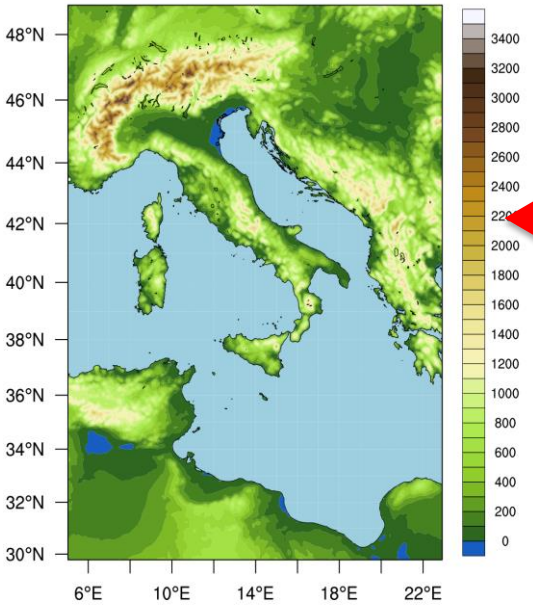
Surface Boundary Conditions for salt flux & vertical velocity at river outlets (Beron-Vera et al., 1999)

$$K_V \frac{\partial S}{\partial z}\Big|_{z=\eta} = S_{z=\eta}(E - P - \frac{R}{A})$$

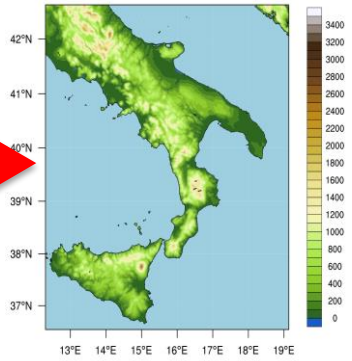
$$w\Big|_{z=\eta} - \frac{\partial \eta}{\partial t} + (u,v)\Big|_{z=\eta} \cdot \nabla_H \eta = (E - P - \frac{R}{A})$$

The WHYDE study area: the Ofanto river

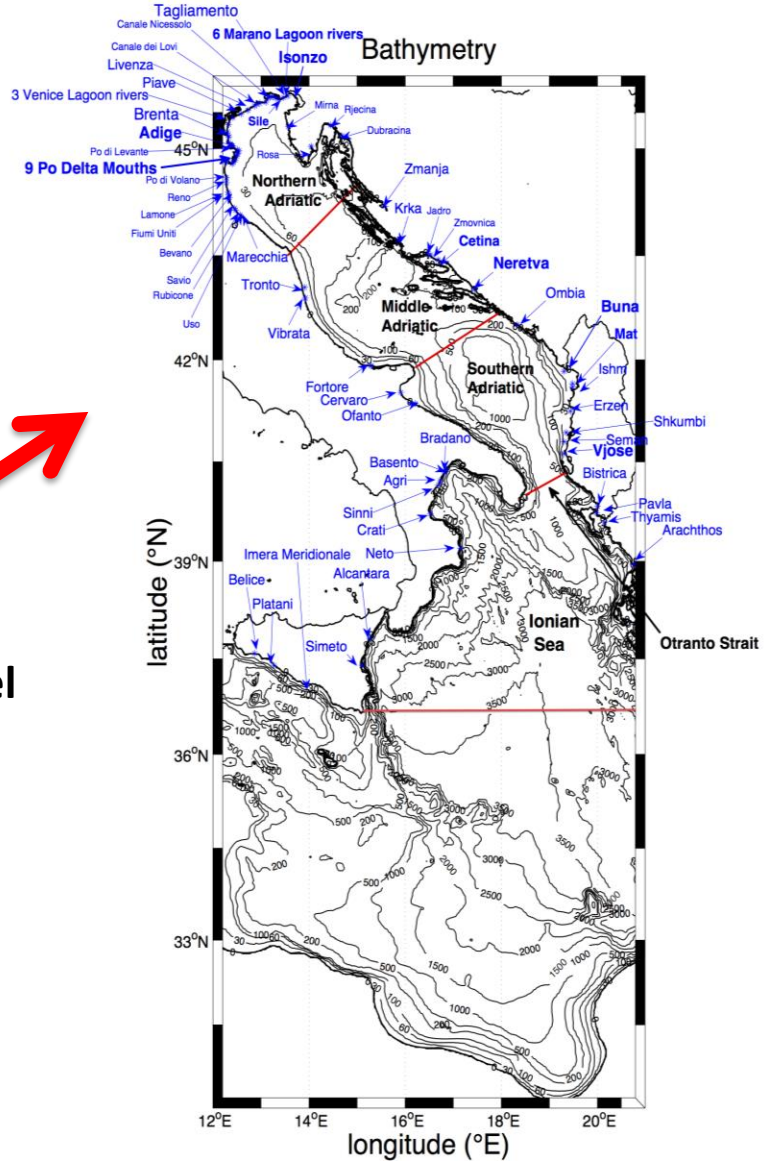
WRF Coarse domain



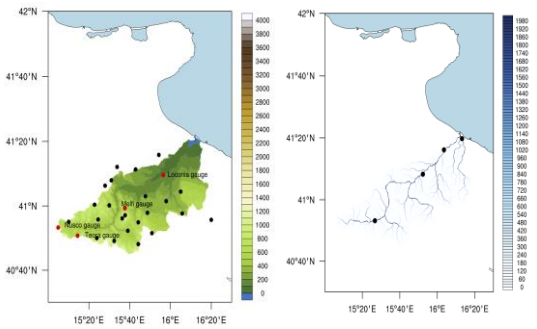
WRF Inner Domain/ WRF-Hydro Domain



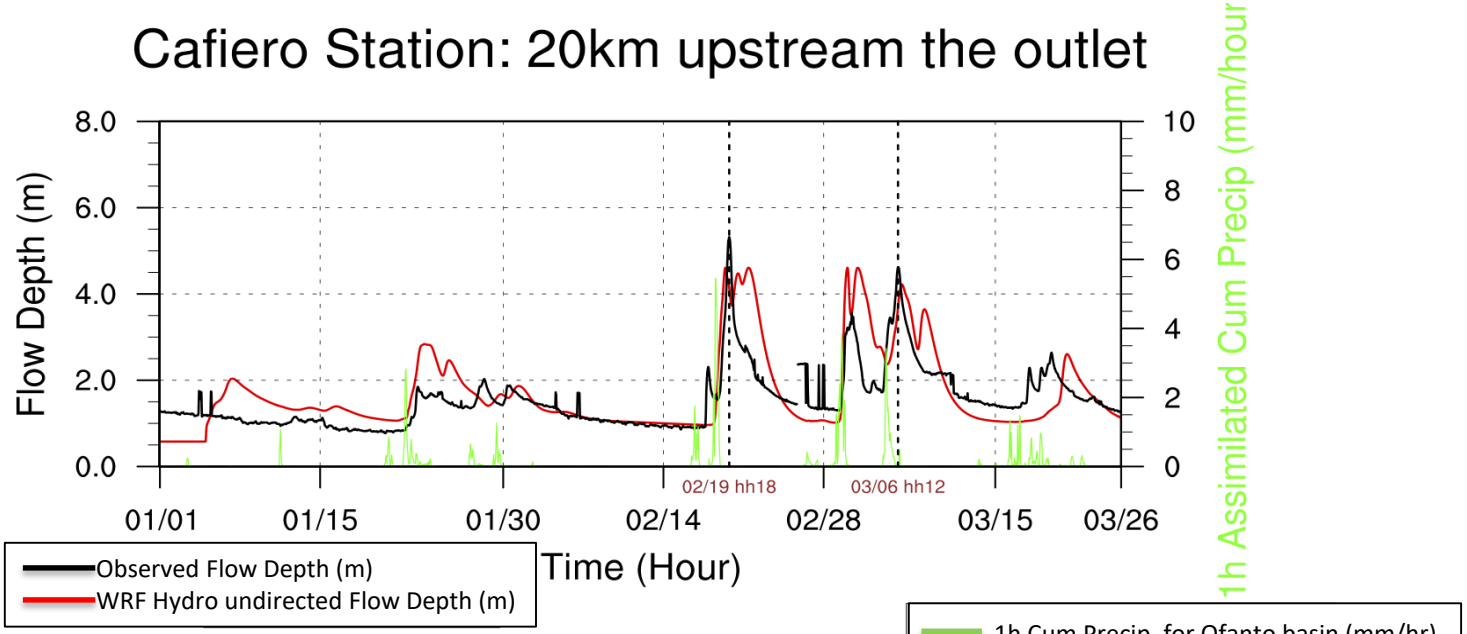
NEMO regional ocean model domain



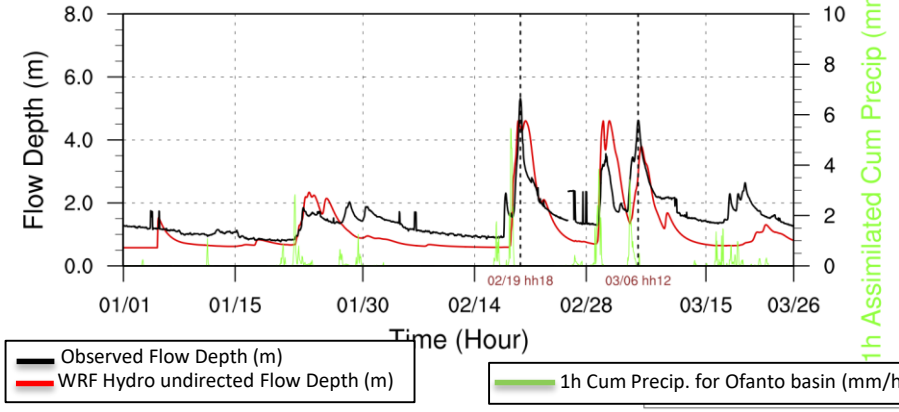
Ofanto river catchment
River network + Estuary Box Model



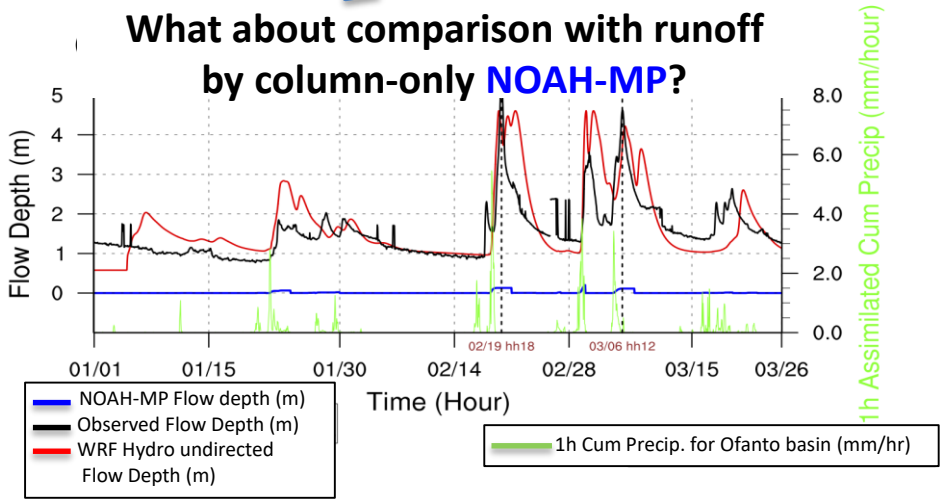
WRF+HYDRO results: validation



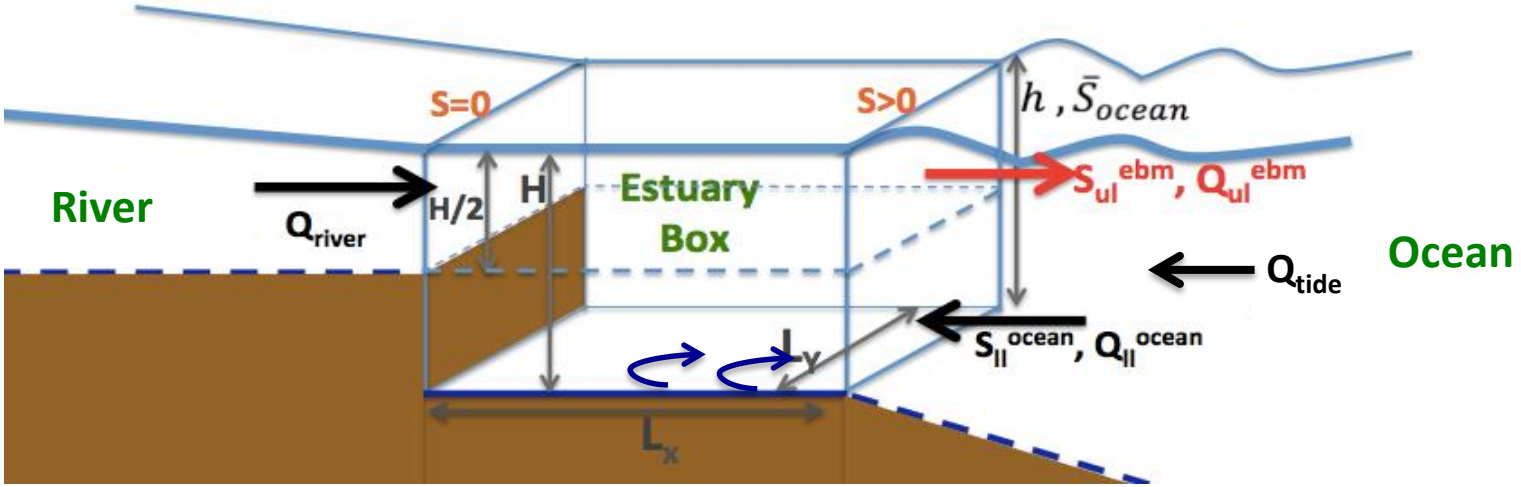
What about the aquifer switched off?



What about comparison with runoff by column-only NOAH-MP?



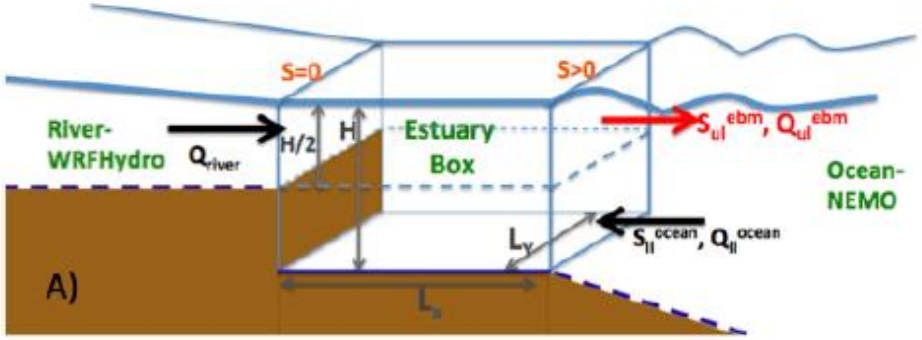
Estuarine Box Modelling: the theory



- A **two-layer rectangular box** with constant L_y, H and L_x. Surface and bottom faces are flat and closed. The input forcings are river discharge, inflowing seawater, and tidal current
- The Estuarine Box **governing equations** are tidally-averaged, laterally-averaged, and steady-state.
- The tidally averaged estuarine box model is a good compromise to represent **unresolved estuarine processes in global/regional ocean** models

Estuarine Box Modeling: the 3 models

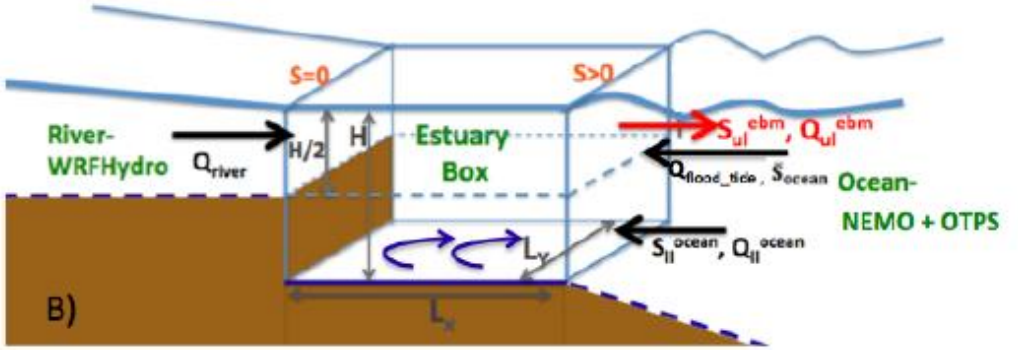
Knudsen model



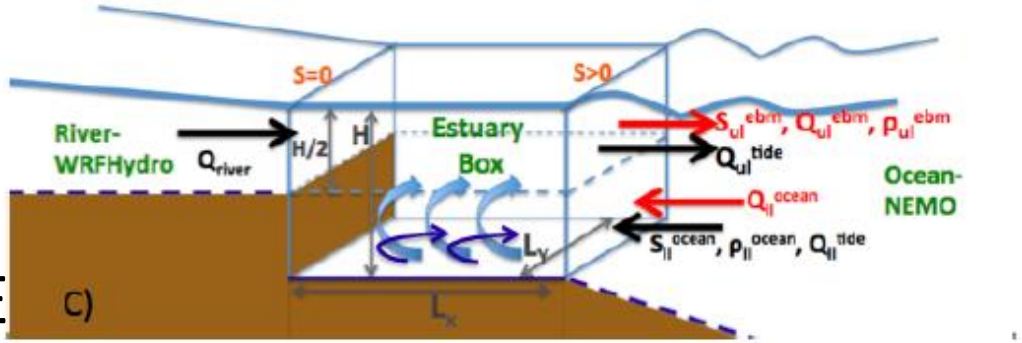
Red are Unknowns

Black input fields

CMCC-EBM Mesoscale regional Ocean models



UCONN-NCAR (Sun et al., 2017) NON-MESOSCALE



Estuarine Box Modeling: the governing equations

1. The Knudsen's relation (1900)

$$Q_{ul}^{ebm} = Q_{river} + Q_{ll}^{ocean}$$ *(units: $m^3 s^{-1}$)*

$$S_{ul}^{ebm} Q_{ul}^{ebm} = S_{ll}^{ocean} Q_{ll}^{ocean}$$ *(units: psu $m^3 s^{-1}$)*

Represented estuarine processes:

1. River freshwater inflow
2. Ocean water inflow
3. Estuarine water outflow
4. Tidal pumping
5. Tidal mixing
6. Shear mixing at layer interface

2. The UCONN-NCAR EBM (Sun et al., 2017)

$$Q_{ul}^{ebm} = Q_{river} + Q_{ll}^{ocean}$$ *(units: $m^3\ s^{-1}$)*

$$\rho_{ul}^{ebm} Q_{ul}^{ebm} = \rho_{ll}^{ocean} Q_{ll}^{ocean} + \rho_0 Q_{river} + (\rho_{ll}^{ocean} - \rho_{ul}^{ebm}) m_{tides} Q_{ul}^{tides} /2$$ *(units: kg s^{-1})*

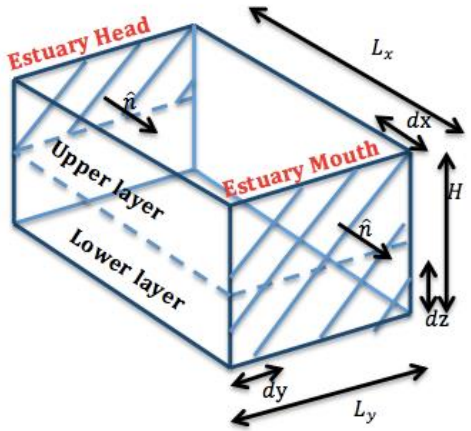
$$PEF_{ul} = PEF_{river} + PEF_{ll} + PEF_{tp} + PEF_{tm} + PEF_{sm}$$ *(units: J s^{-1})*

3. The CMCC EBM (Verri et al., submitted)

$$Q_{ul}^{ebm} = Q_{river} + Q_{ll}^{ocean} + H L_y u_{tide\,f}$$ *(units: $m^3 s^{-1}$)*

$$S_{ul}^{ebm} Q_{ul}^{ebm} = S_{ll}^{ocean} Q_{ll}^{ocean} + \overline{S}_{ocean} H L_y u_{tide\,f} + K_{S_H} H L_y \frac{\overline{S}_{ocean}}{L_x}$$ *(units: psu $m^3 s^{-1}$)*

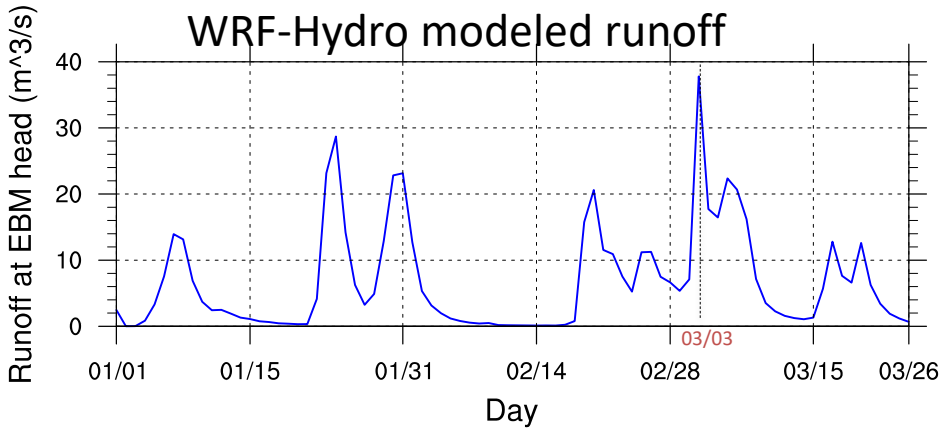
FIRST STUDY CASE: the **Ofanto river, highly stratified**



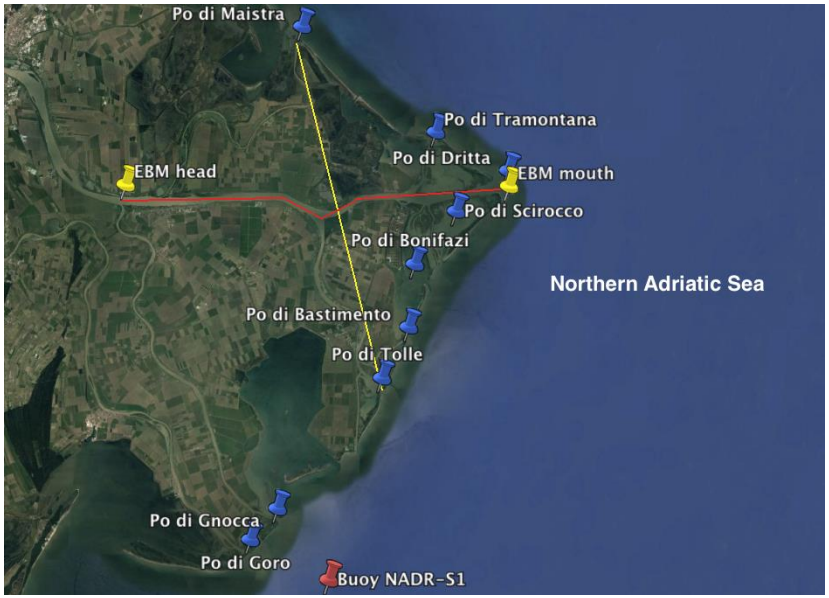
- The Ofanto estuary is a **"highly stratified" estuary** (Fischer et al., 1979):

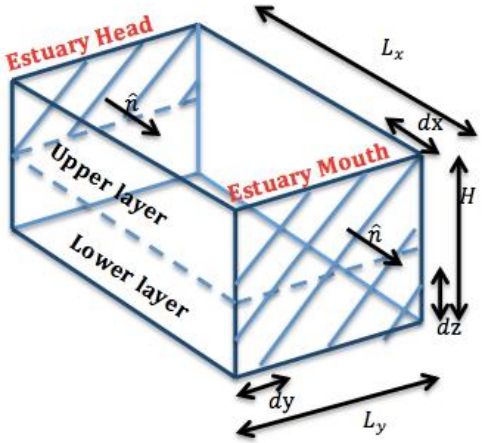
$$flow\ ratio = \overline{u}_{tide}/\overline{u}_{river} \text{ =0.01}$$

- EBM geometry**: H=5m, L_y=25m, L_x =1km** which complies with IRSA CNR campaign

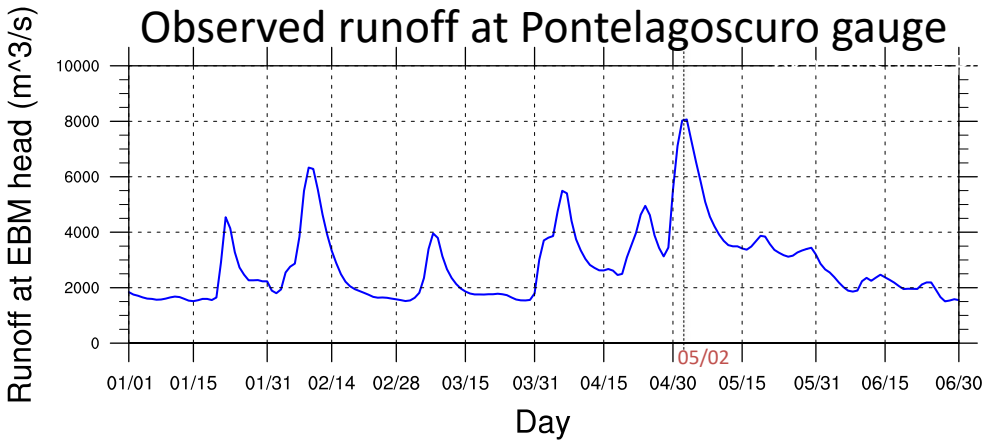


SECOND STUDY CASE: the **Po river, weakly stratified**



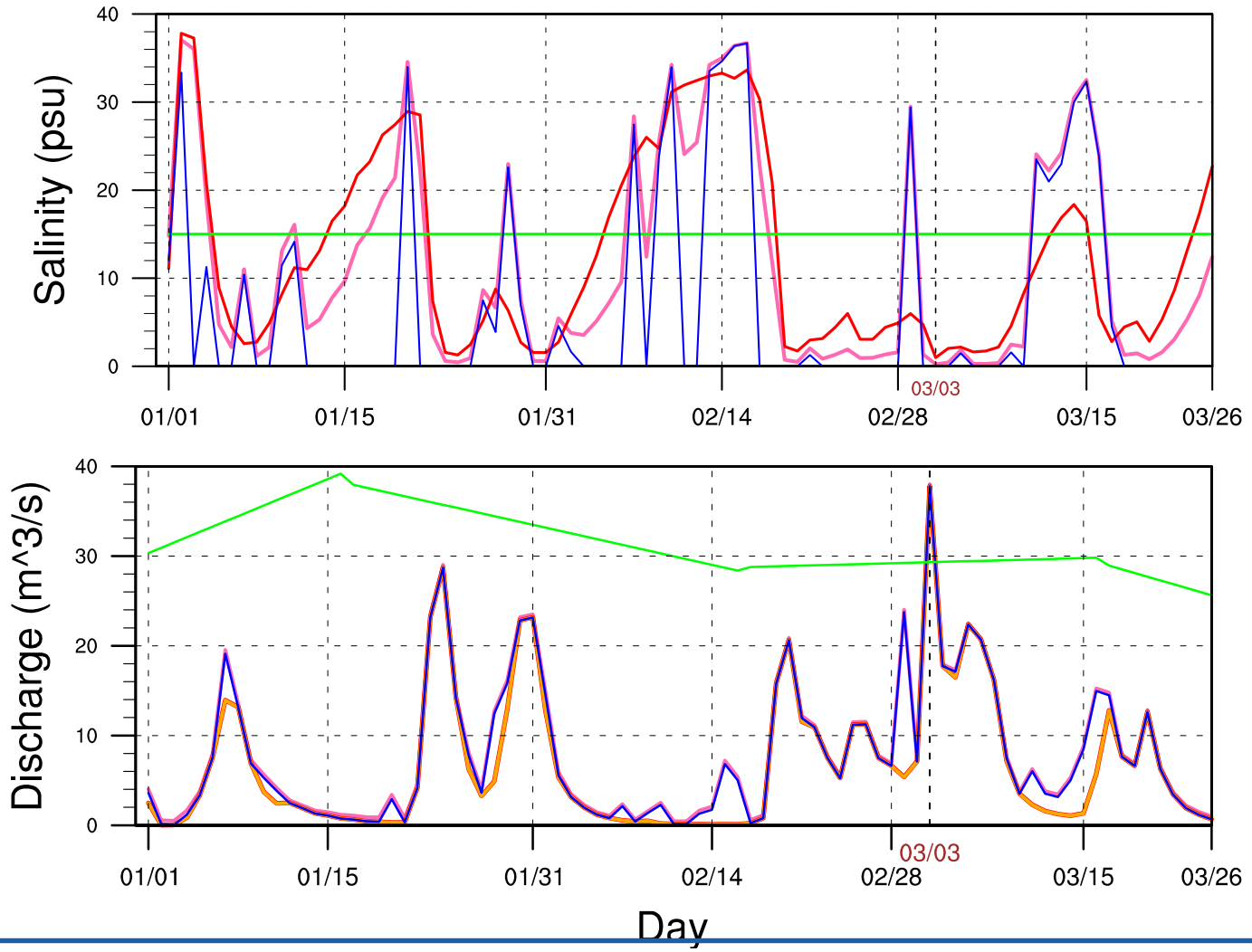


- Po EBM length, L_x **=20km**
- The Po delta is **"partially mixed"** (Fischer et al., 1979): $flow\ ratio = \overline{u}_{tide}/\overline{u}_{river}$ =0.43



Intercomparison of EBM solutions for the Ofanto river

Outflowing Salinity and Volume flux :
CMCC and UCONN-NCAR **EBMs give similar values**



Intercomparison of EBM solutions for the Po river

Outflowing Salinity and Volume flux :
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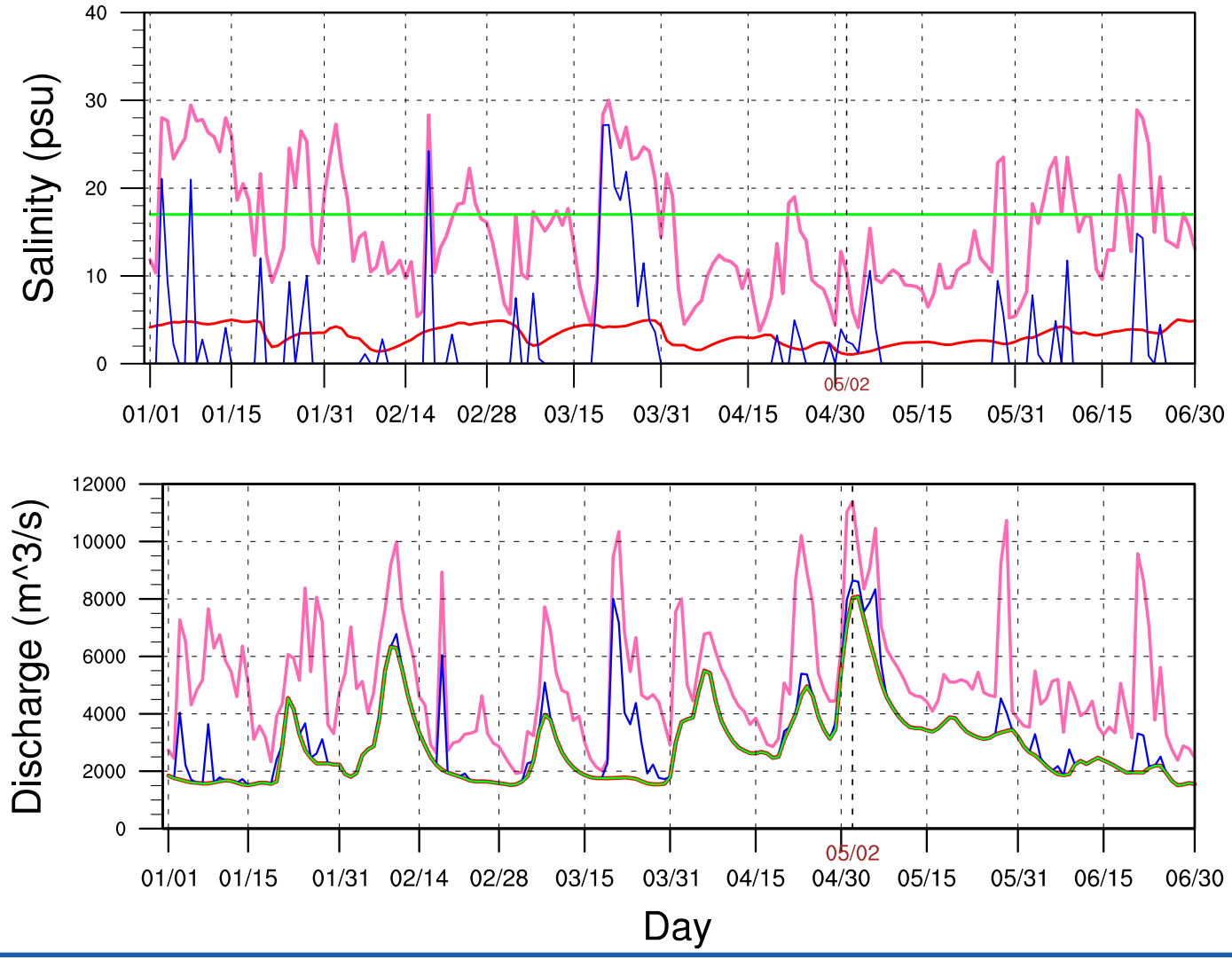


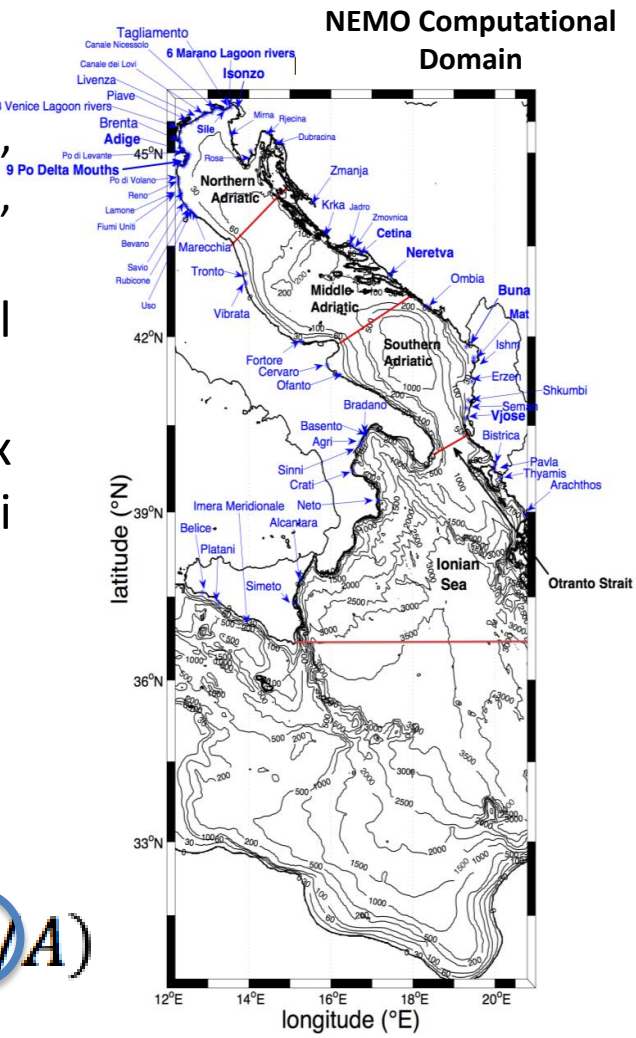
Coupling with the ocean model: the method

River Release representation into a regional ocean model (2km horiz. res.):

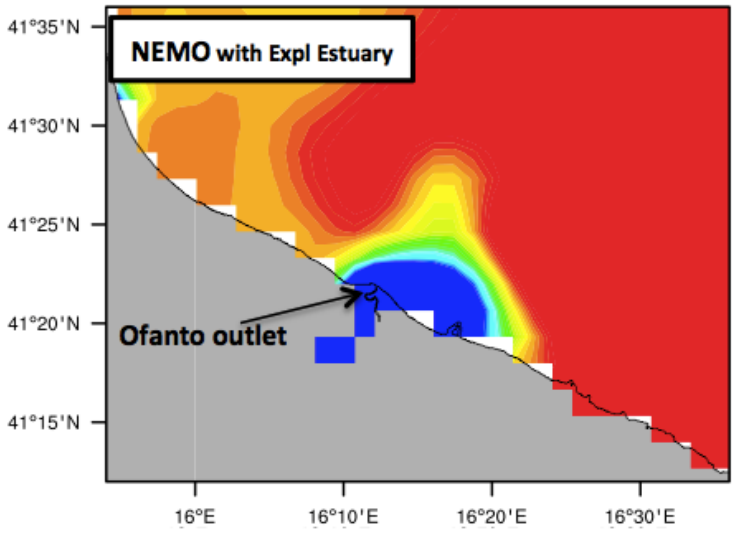
- **We use the "natural boundary conditions"** (Huang, 1993; Kourafalou, 1996; Skliris et al., 2007; Vervatis et al., 2013):
  - river **volume flux**, **R**, specified in the vertical velocity boundary condition
  - **salinity**, **S**, at river outlets specified in the salt flux boundary condition (Beron-Vera 1999; Simoncelli et al., 2011)

$$K_t \left.\frac{\partial S}{\partial z}\right|_{z=\eta} = S_{z=\eta}(E - P - R/A)$$

$$w|_{z=\eta} - \frac{\partial \eta}{\partial t} - \boldsymbol{u}|_{z=\eta} \cdot \nabla_H \eta = (E - P - R/A)$$

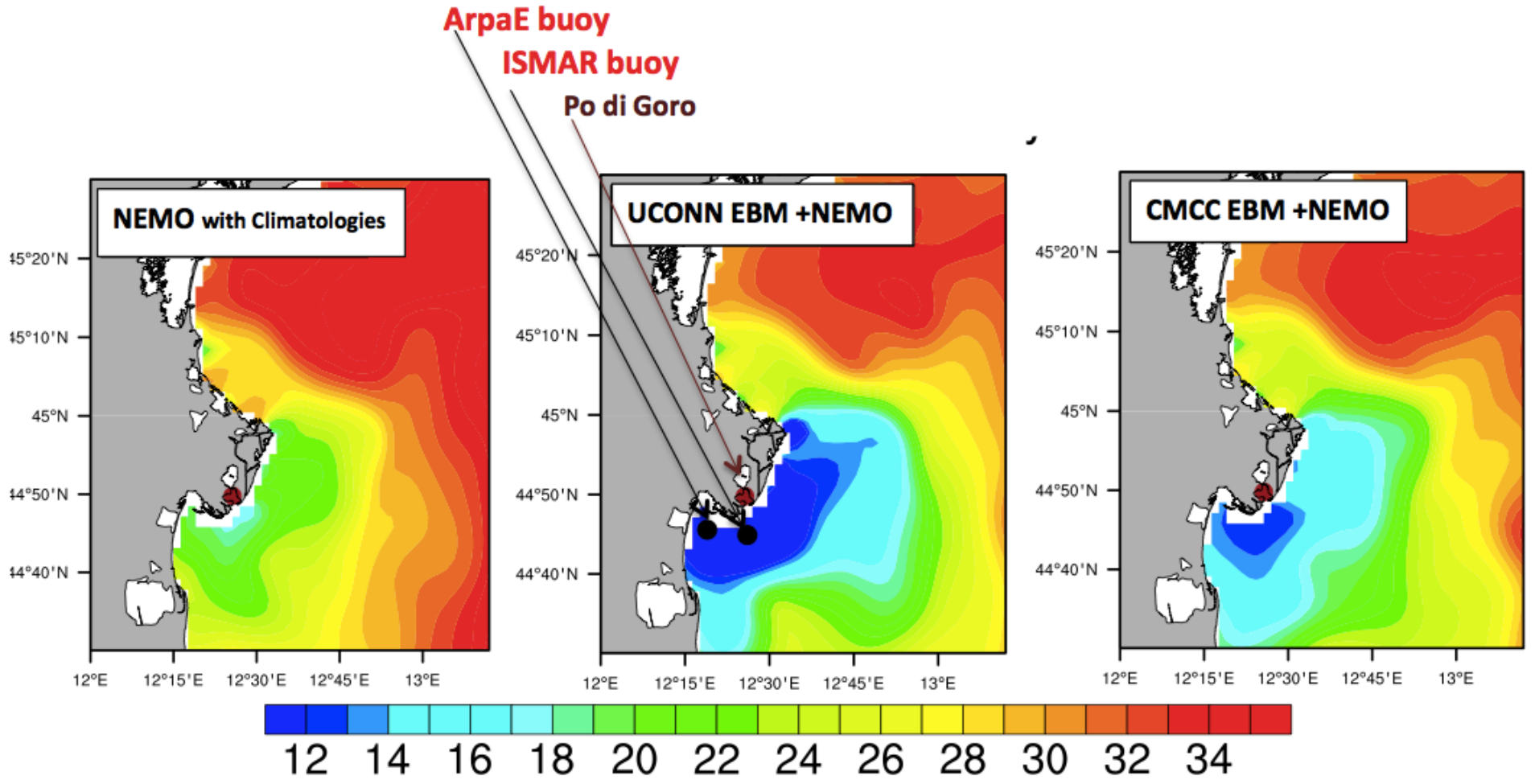


Effects of EBMs on ROFI off the Ofanto estuary



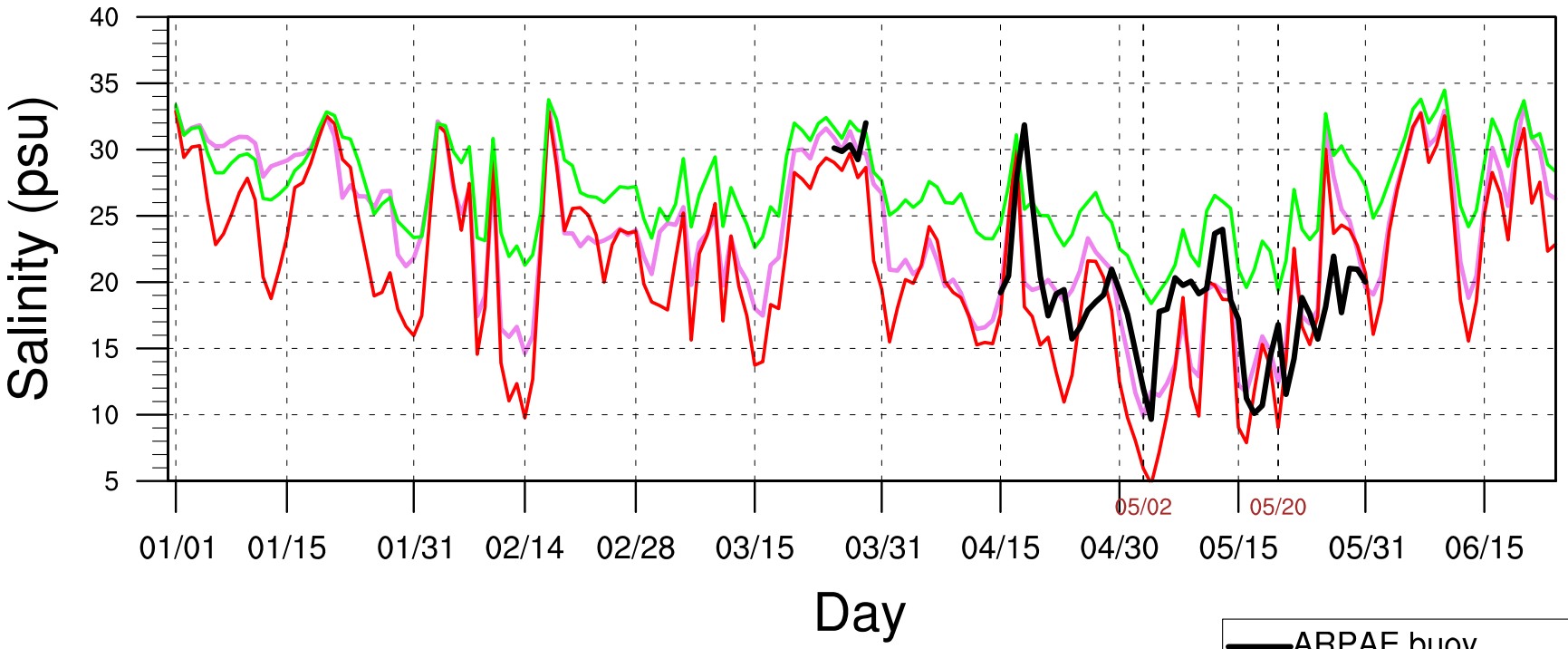
- **"Explicit Estuary" Experiment** is our **benchmark** as no observations off the Ofanto outlet

Effects of EBMs on ROFI off the Po estuary



- Pictures relate to **upwelling favorable wind regime** (i.e. Libeccio on 2009/05/22)

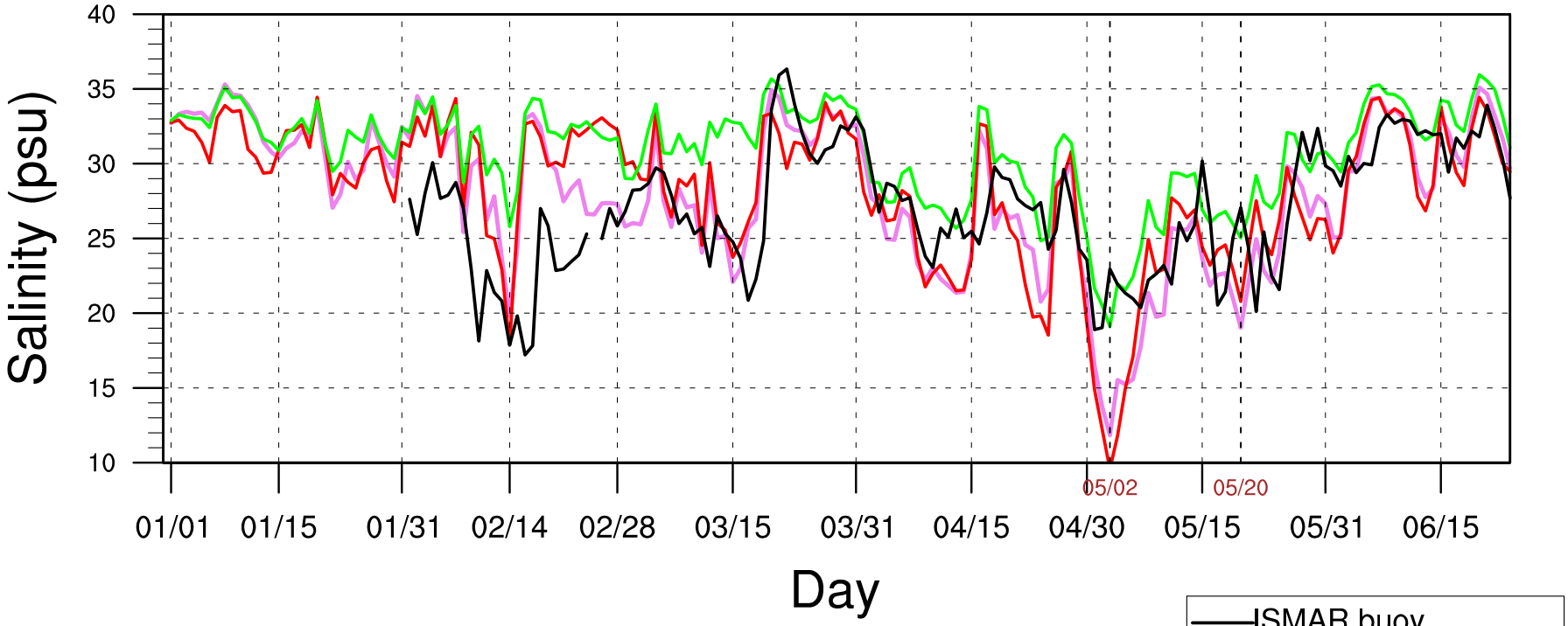
Effects of EBMs on ROFI off the Po Delta



- **ArpaE buoy** is **7 km** offshore the mouth of Po di Goro and **1m** depth

Statistics on Salinity	RMSE	BIAS	CORR
CMCC EBM +NEMO	**4.45**	**0.05**	**0.69**
UCONN EBM +NEMO	5.48	-2.06	0.67
CLIM +NEMO	6.67	5.43	**0.69**

Effects of EBMs on ROFI off the Po Delta



- **ISMAR CNR buoy** is **5 km** offshore the mouth of Po di Goro and **1.7m** depth

Statistics on Salinity	RMSE	BIAS	CORR
CMCC EBM +NEMO	**4.05**	**+0.25**	**0.61**
UCONN EBM +NEMO	4.66	+0.61	0.49
CLIM +NEMO	5.06	+3.53	0.55

Summary and Conclusions

- **The WHYDE approach gives realistic estimates of runoff and river plumes on the shelf.** A wider implementation of the EBM system for ocean forecasting at global (UCONN-NCAR EBM) and regional scales (CMCC-EBM) has started.

- Three EBMs have been intercompared for different estuaries. CMCC EBM and UCONN-NCAR EBM give similar results for stratified estuaries while *results differ significantly* for *"partially mixed" estuaries.*

- **Weaknesses of the present approach: the steady, tidally averaged dynamics of the EBM.**

- The next step: better EBM and high-resolution unstructured hydrodynamic modeling from the coasts to upstream river runoff (may be WRF-HYDRO)

Publications

- G. Verri et al., ***In prep.*** The estuarine dynamics for ocean modelling: a method to solve the subtidal estuarine dynamics and to interface river release with regional ocean models

- G. Verri, N. Pinardi, P. Oddo, S.A. Ciliberti, G. Coppini, 2017. River runoff influences on the Central Mediterranean Overturning Circulation. ***Climate Dynamics 1-29*** DOI: 10.1007/s00382-017-3715-9

- G. Verri, N. Pinardi, D. Gochis, J. Tribbia, A. Navarra, G. Coppini, and T. Vukicevic, 2017. A meteo-hydrological modelling system for the reconstruction of river runoff: the case of the Ofanto river catchment.***Nat. Hazards Earth Syst. Sci.*** *Accepted In Press.*, DOI:10.5194/nhess-2017-102