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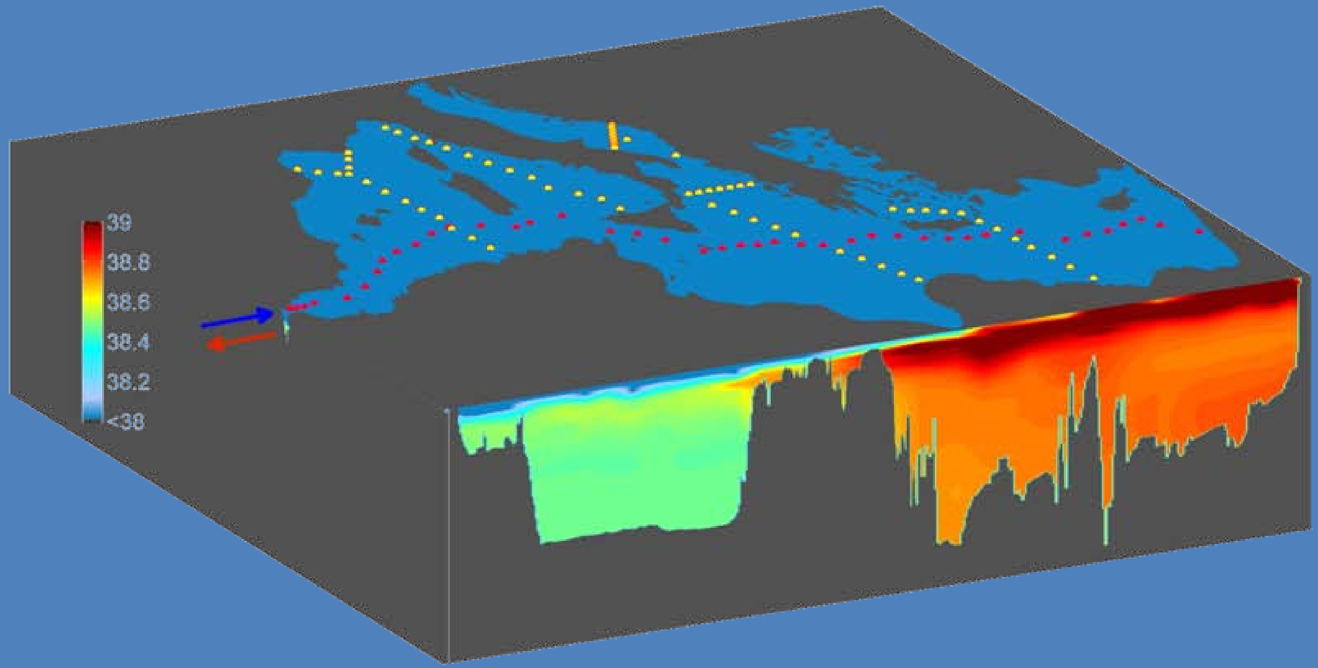

Modern view of Western Mediterranean hydrography

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Outline

- Introduction
- Warming and salinification
- The Western Mediterranean Transition
- WMT propagation
- Abyssal mixing in the WMED
- Ship-based hydrography
- Conclusions

Introduction

"Miniature ocean"

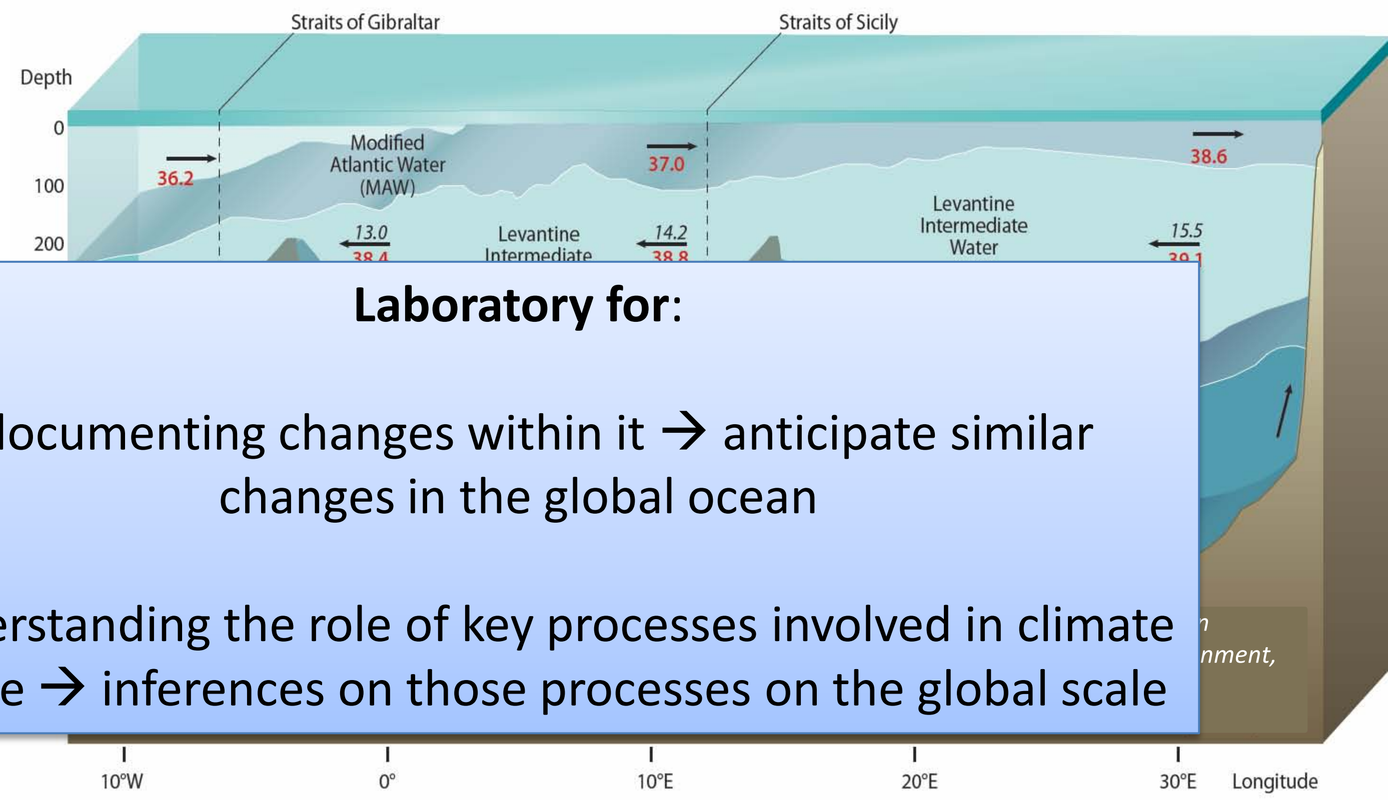
Deep water formation varying on interannual time scales

Well defined overturning circulation

Distinct surface, intermediate & deep water masses circulating between W and E

Useful for climate change studies

Much shorter time scales than the global ocean (60 yrs turnover vs 500 yrs)

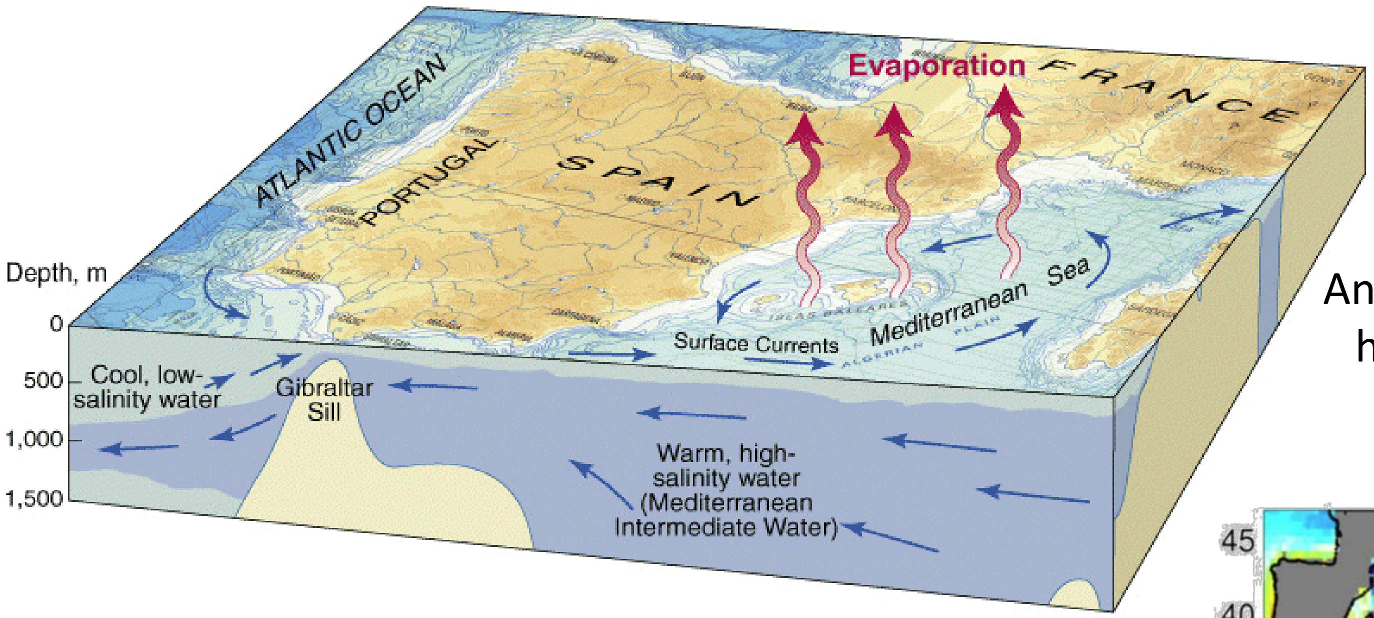


Laboratory for:

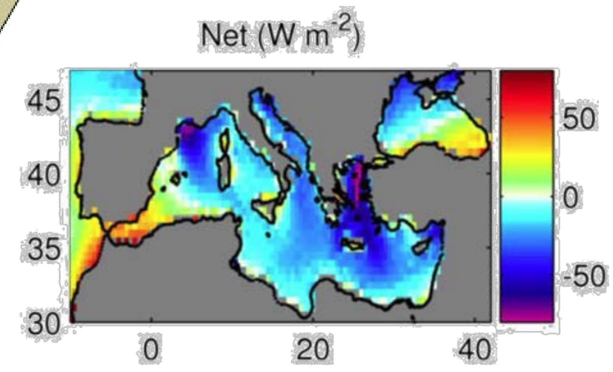
- documenting changes within it → anticipate similar changes in the global ocean

- understanding the role of key processes involved in climate change → inferences on those processes on the global scale

Introduction



Annual mean field of net heat flux (1958-2006)
(Schroeder et al., 2013)



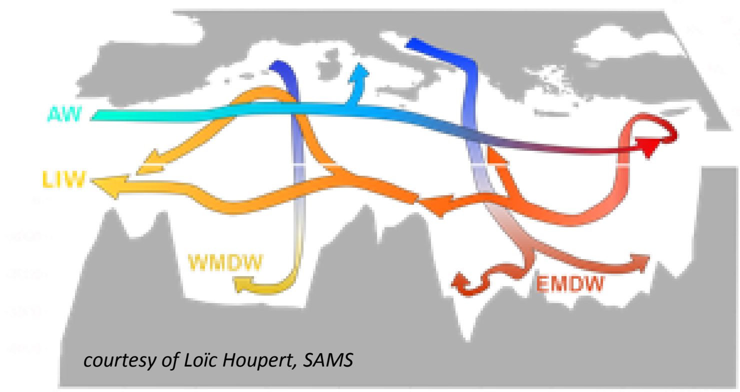
Concentration basin

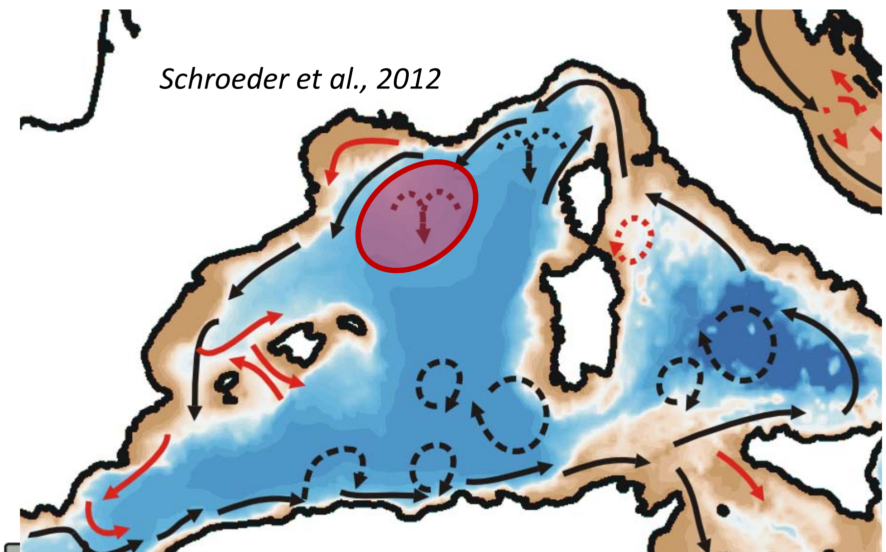
higher salinity than the outer ocean due to **evaporation** exceeding precipitation
Surface inflow of fresher water and subsurface outflow of saltier water

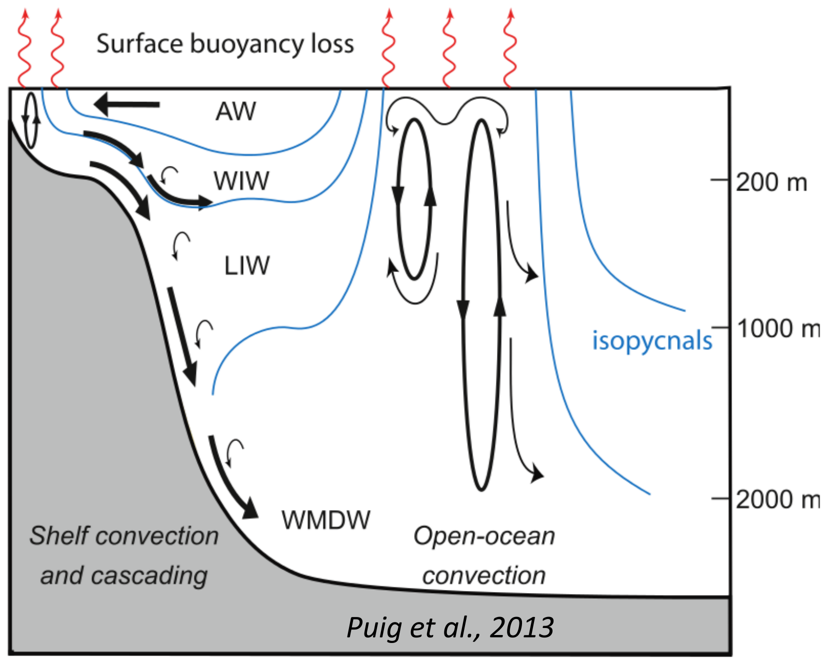
Introduction

In the North western Mediterranean Sea shelf and open sea **convection** occasionally occurs, generating new deep waters:

- atmospheric cooling
- general cyclonic circulation



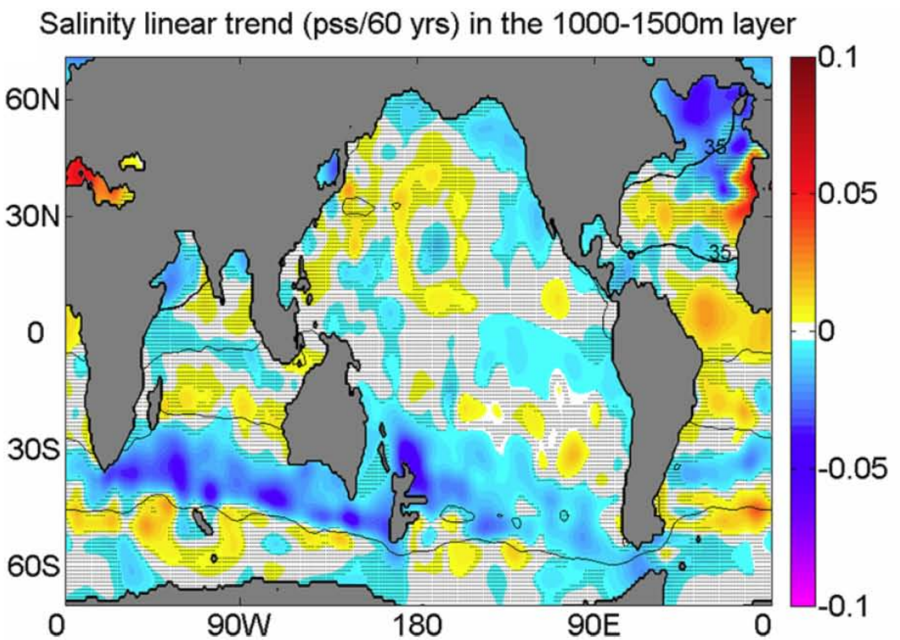


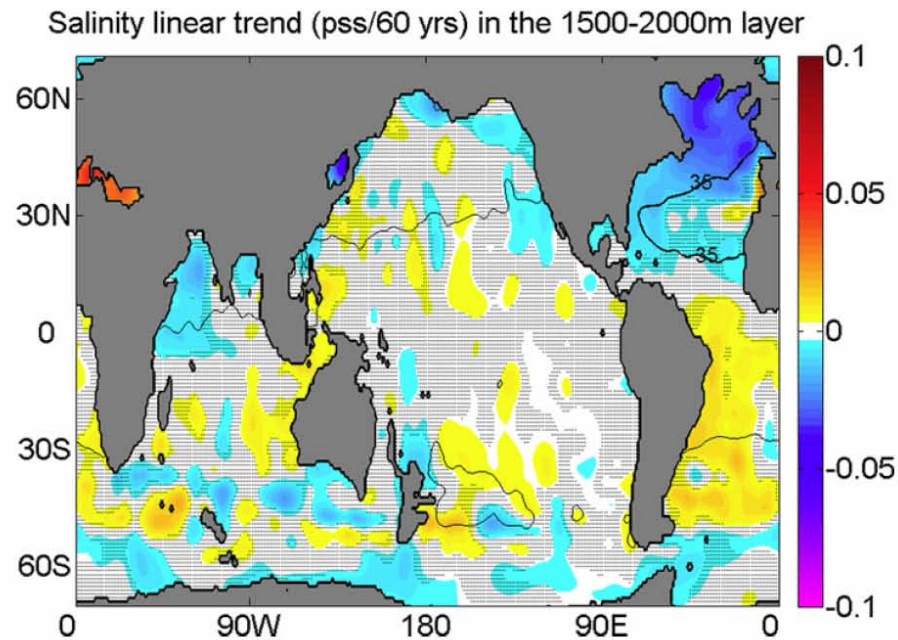


Warming and salinification

1950-2010: below 1000 m the Mediterranean underwent the strongest salinity gain **anywhere in the world ocean**

→ "**Mediterranean signal**" clearly imprinted in the N-Atlantic IL





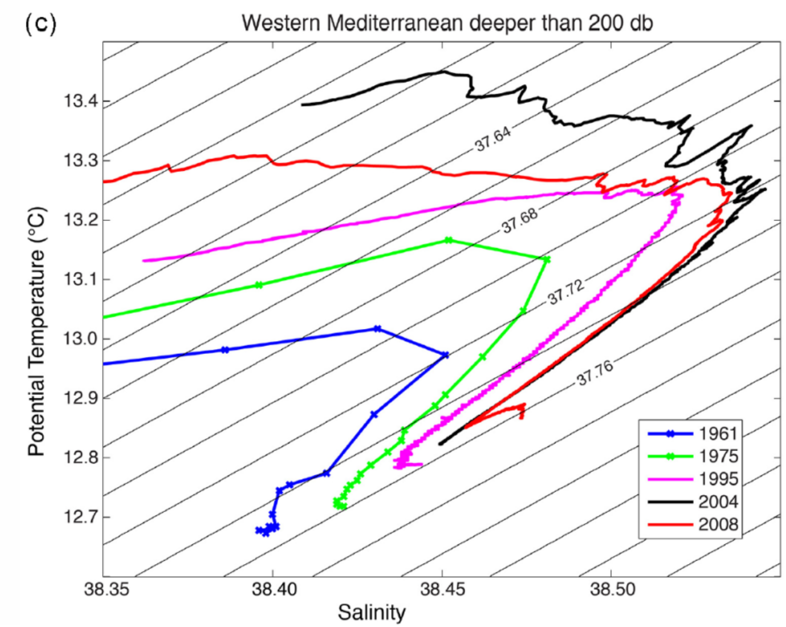
Skliris et al., 2014

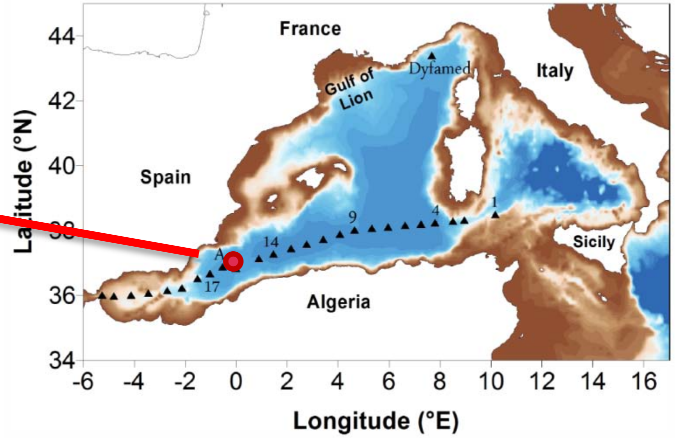
Warming and salinification

The deep waters of the WMED became gradually saltier and warmer for at least the past **40 years**

- **0.015 and 0.04 °C per decade!**

Depth averaged values > 200 dbar		
Year	Salinity	Pot. temp
1961	38.406	12.766
1975	38.431	12.822
1995	38.452	12.879
2004	38.477	12.966





From Borghini et al., 2014

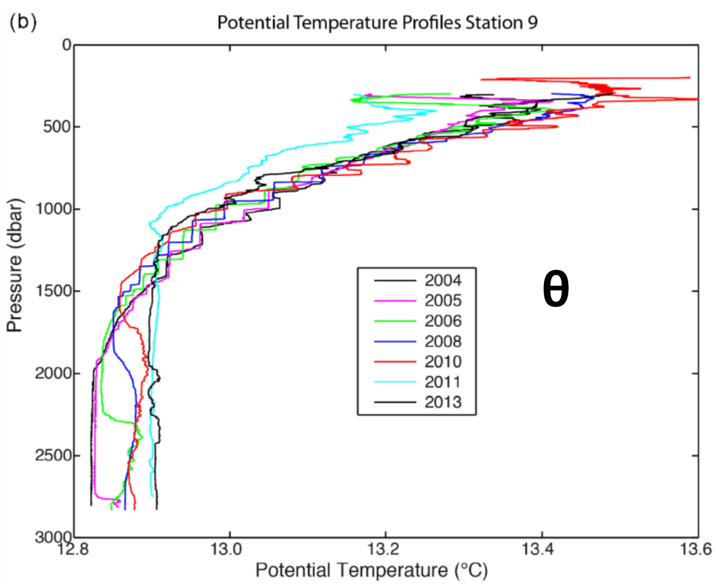
Western Mediterranean Transition

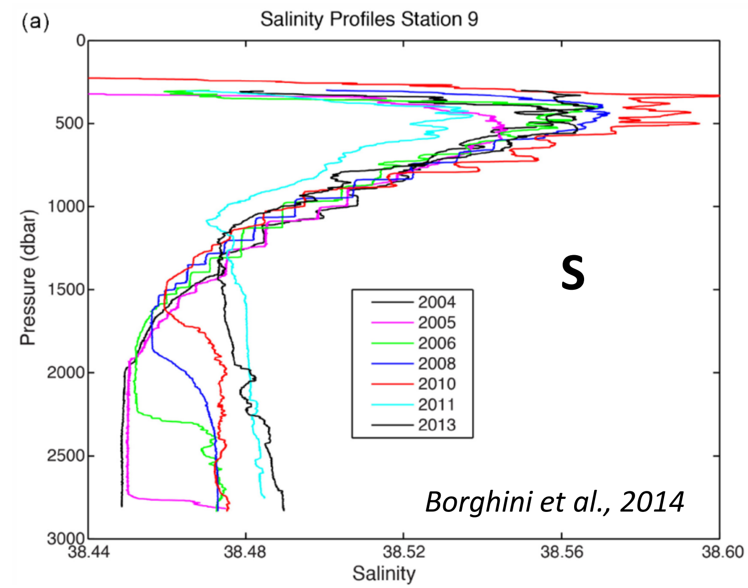
Enhanced thermohaline variability during WMT

Features occurring in the last 10 yrs not previously observed to this extent:

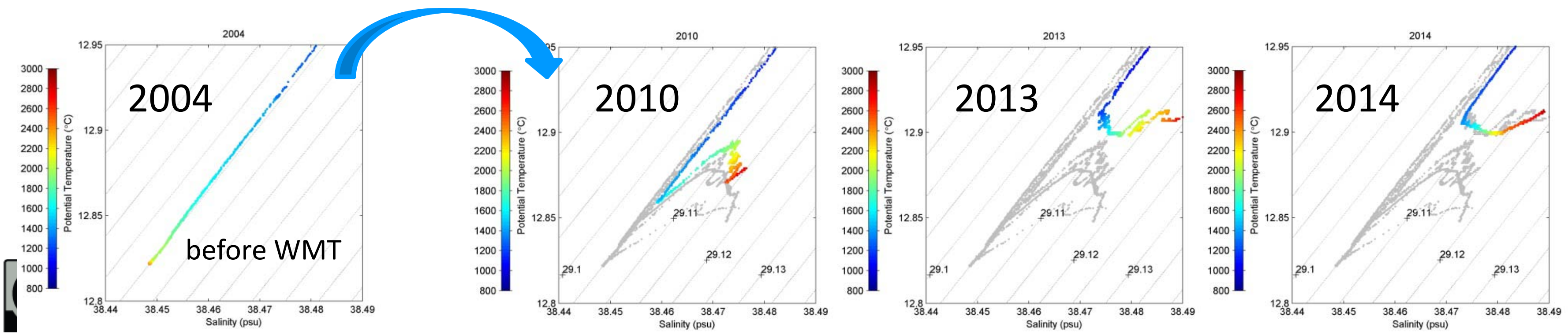
1. the **filling up** of the WMED with **new anomalous dense water**
2. a significant and **stepwise warming, salinification, densification** and **ventilation** of deep waters
3. a **warming and salinification** of the **thermocline/halocline** between the intermediate water and the new deep water
4. a substantial **modification of deep θS diagrams**, with the appearance of complex hooks and inversions
5. a **new stratification** prone to different **double diffusive mixing** regimes
6. potential **modification of the MOW** (Mediterranean Outflowing Water)
7. a **perturbation of the deep Tyrrhenian** Sea, due to the propagation of these anomalies through the Sardinian Channel

Western Mediterranean Transition

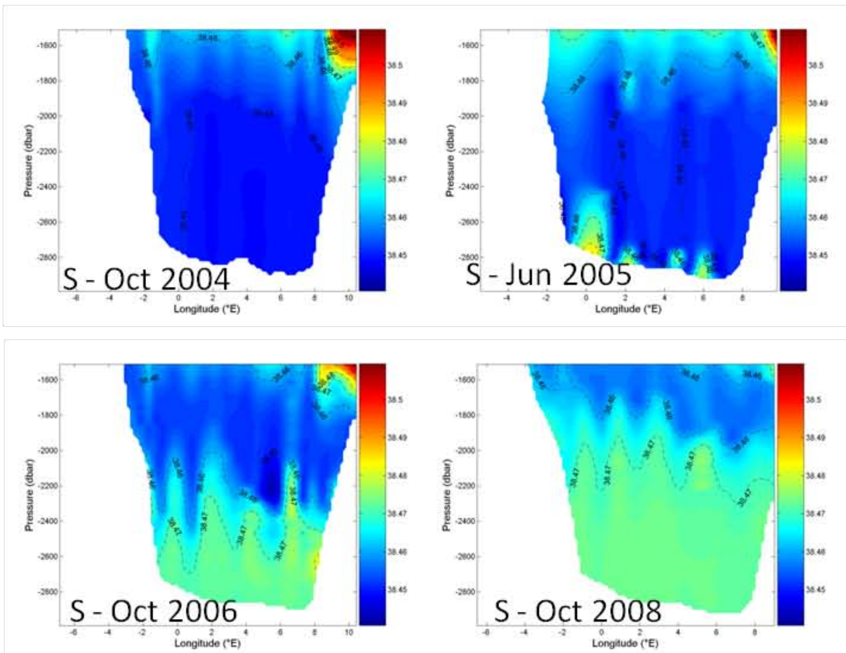


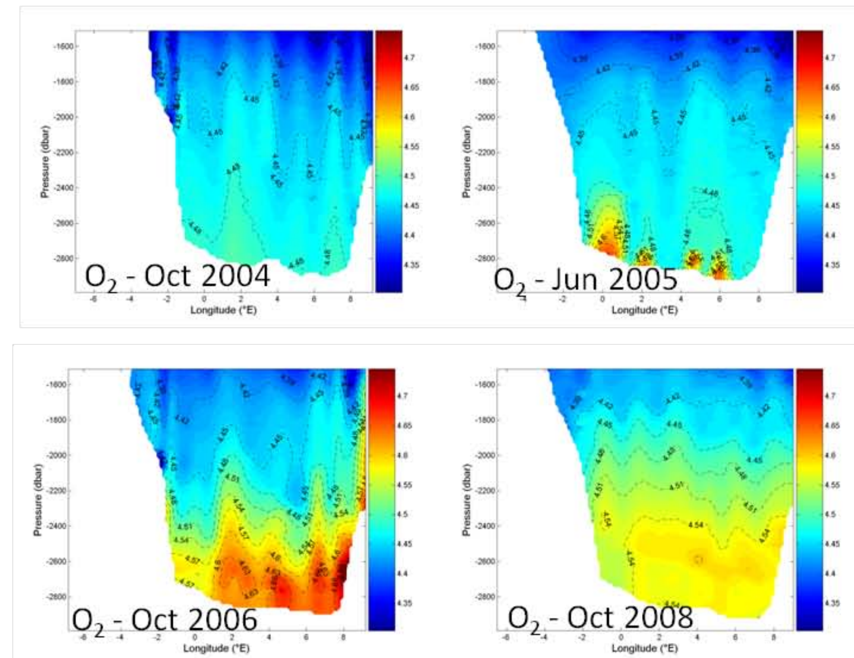


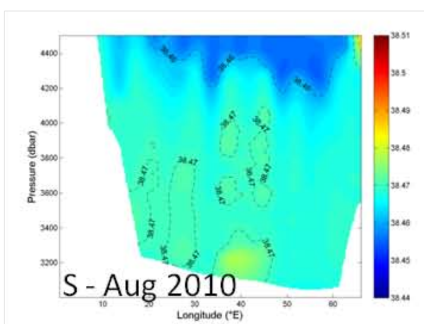
- ✓ Since 2004 increases in deep water T and S were **2 times faster** than during 1961-2004
- ✓ Winter 04/05 sets the **beginning of WMT**: exceptional DWF changed basic structure of the IL and DL

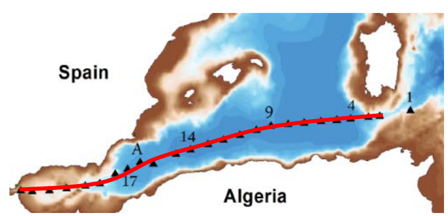


Western Mediterranean Transition

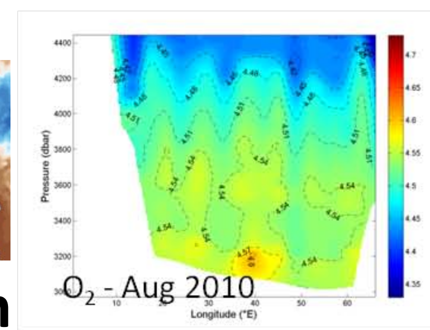








section > 1500 m



Salinity

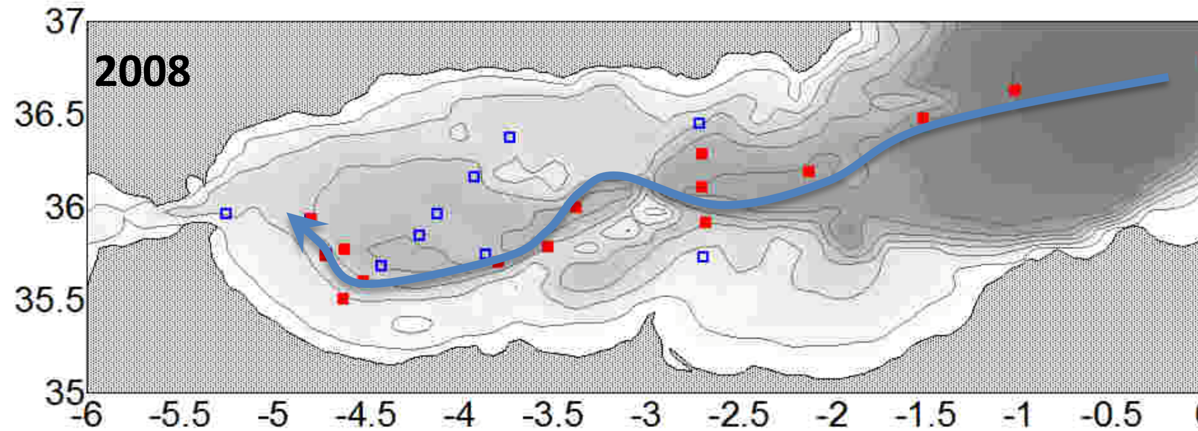
Dissolved oxygen

WMT propagation to the west

- **2008**: new WMDW has been sucked by **Bernoulli aspiration** to much shallower depths in the Alboran Sea (in the Algerian Sea the same isopycnal was found 1 km deeper)

- westward flow along the Moroccan **continental slope** → anticyclonic Alboran gyre throughout the water column.

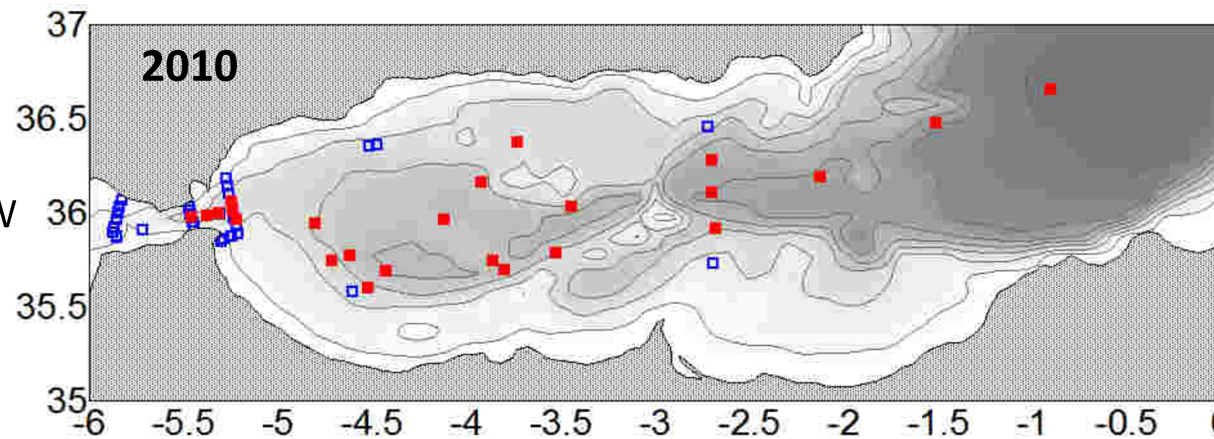
σ> 29.108 kg m^{-3} (higher than σ of old WMDW)



- **2010**: new WMDW **within the strait** at 5.46 °W; no signature 20 km further west

- The **equilibrium depth** of MOW in the Atlantic could change

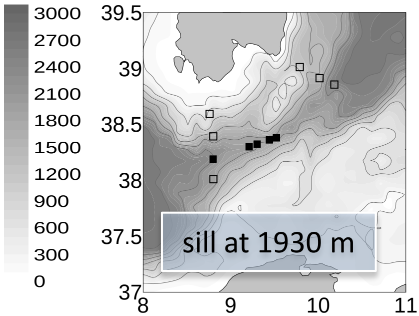
σ> 29.11 kg m^{-3}



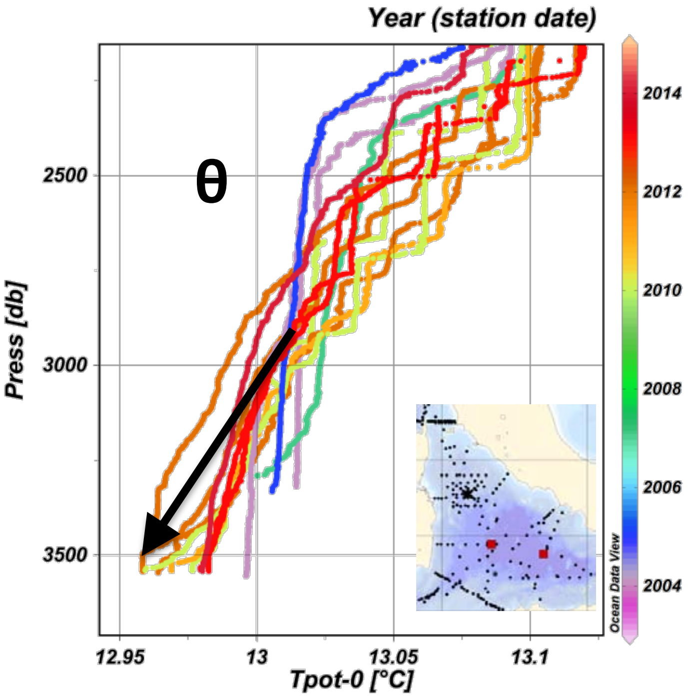
WMT propagation to the east

- **2005**: only the "classical" old WMDW was found
- **2006-07**: first signatures of the new denser WMDW
- **2009**: first signature along the trench axis in the Sardinia channel
- **2010**: first signature inside the Tyrrhenian (335 m thick)
- **2010-2014**: whole layer below LIW (> 500 m), has densified > 29.11-29.12 kgm^{-3} → denser then the "classical" resident deep water

→WMT signature is well evident in the whole basin: deep ventilation



- nWMDW dense enough to cascade down to the bottom of the Tyrrhenian and ventilate it (> 3 km)
- Tyrr has higher resident heat and salt contents: <u>negative</u> jump in T-S
- different stratification than in the WMED: **salt fingers** → efficient downward mixing of T and S

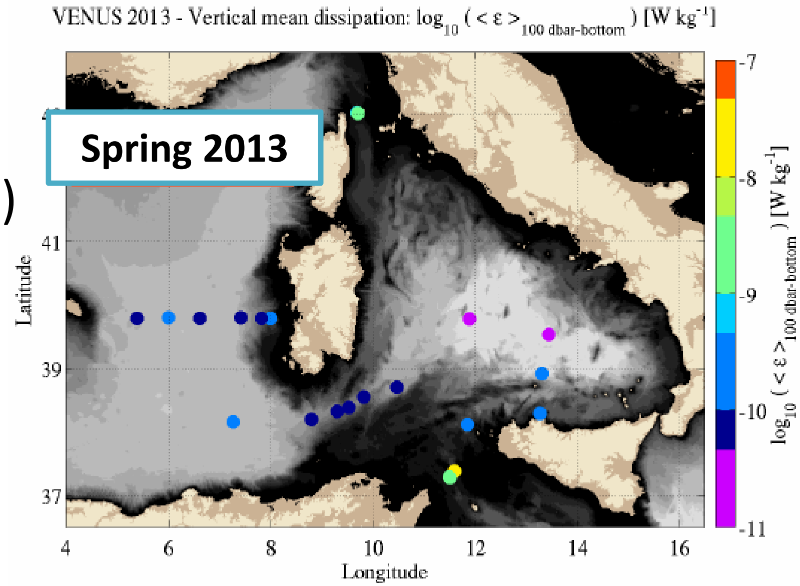


Abyssal mixing in the WMED

- Assess **mixing levels** associated to WMT
- First **distribution maps** of TKE and vertical diffusivities in the deep WMED
- Identify **sources of turbulence** (tide, wind and topography)

Dissipation rates (vertical mean > 100 dbar)

- **weak <ε>** (0.5-1 x 10^{-10} Wkg^{-1}) in deep sea
- **slight intensification** (up to 1-5 x 10^{-10} Wkg^{-1}) along coastal slopes
- **enhanced values** (10^{-9} to 10^{-7} Wkg^{-1}) in channels → turbulence hotspots



Abyssal mixing in the WMED

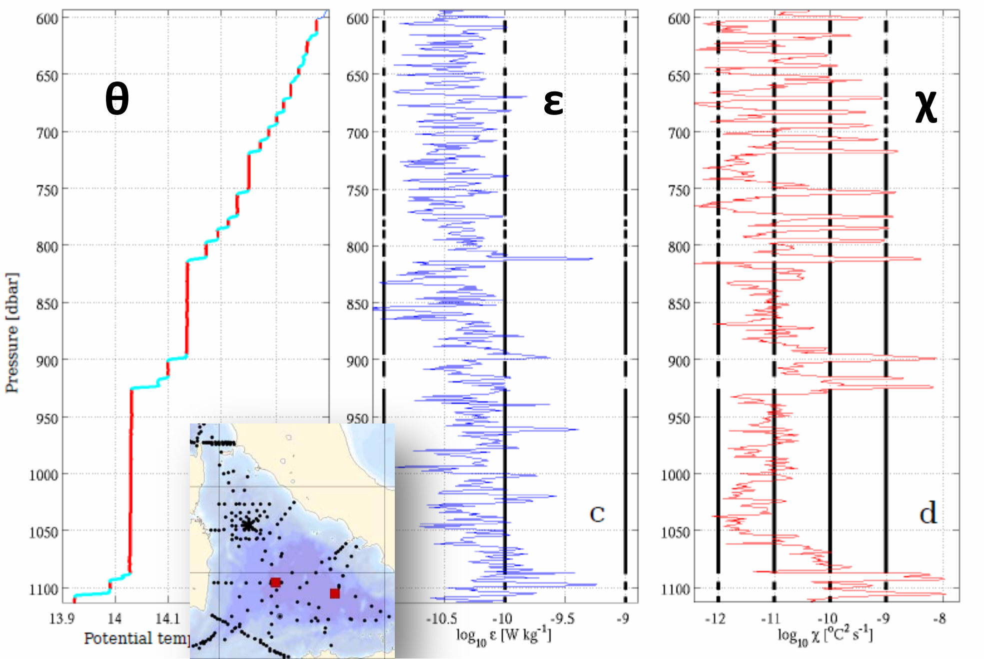
Deep Tyrrhenian Sea → extremely low dissipation values

• **<u>quasi-permanent</u> thermohaline staircases** (salt finger mixing)

•**VMP** measured similar **dissipation of turbulent kinetic enenrgy ε** (very weak, <10^{-10} W kg^{-1}) in layers and steps

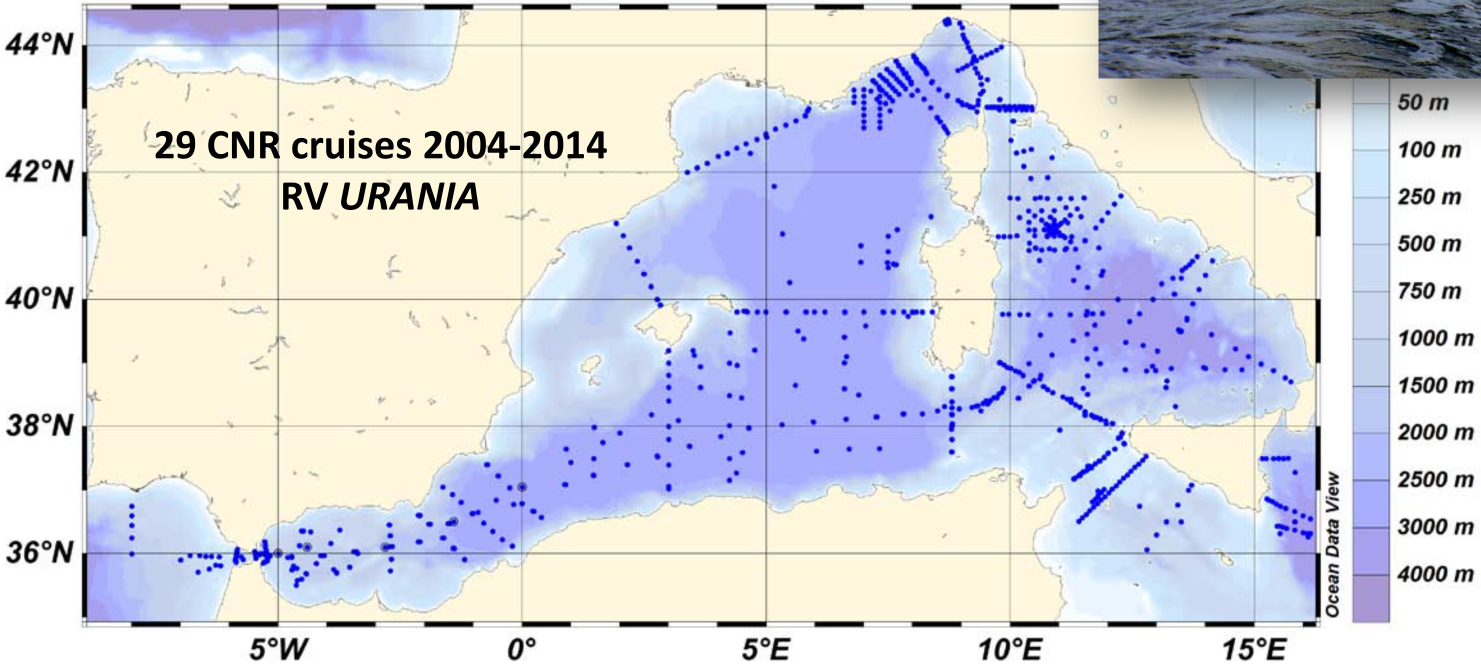
• strong differences for **dissipation of temperature variance: χ** is higher by 2-3 orders of magnitude in the steps as compared to the layers

Mixing occurs mainly by **diffusion** of properties, and the **turbulent** component is nearly absent



Ship-based hydrography

Sustained ship-based monitoring gave insights into the spreading of the new deep water from its formation region into the WMED interior, towards Gibraltar and the Tyrrhenian Sea.

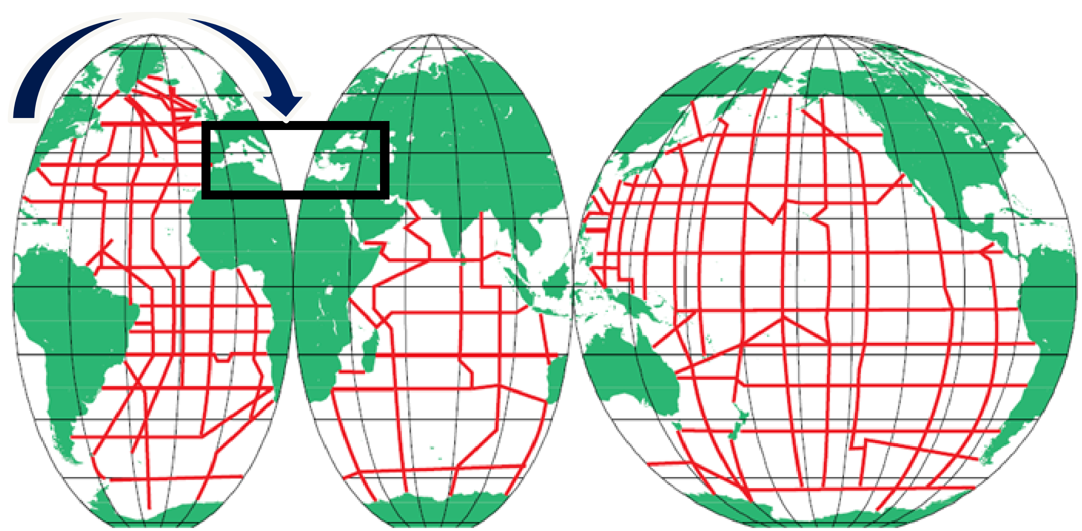


Ship-based hydrography

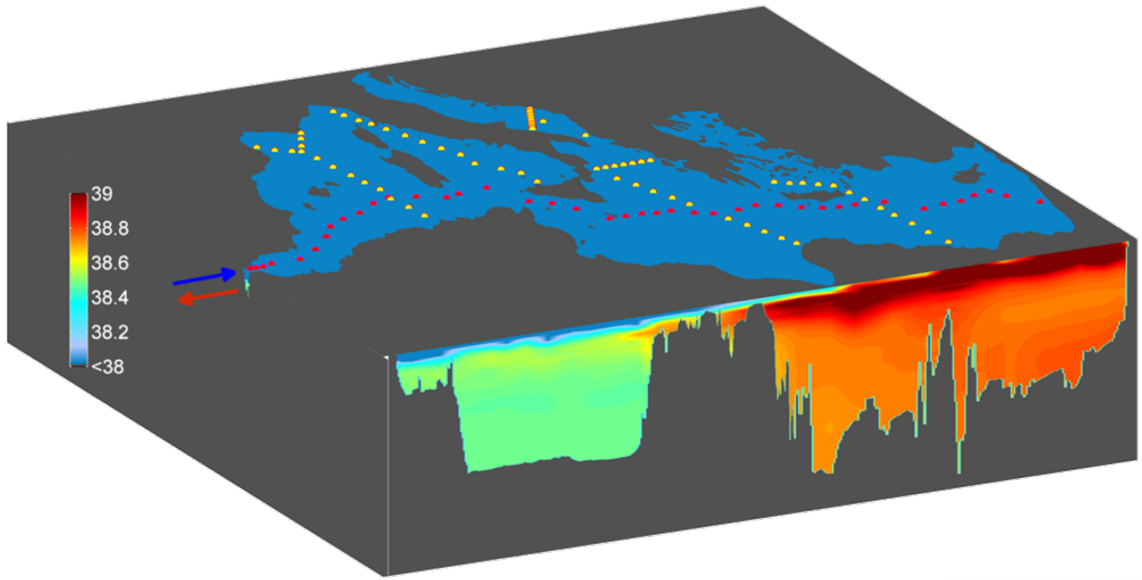
- An important component of a suitable **monitoring strategy** should rely on regular ship-based surveys, to provide data over the entire water column (more than **20% of Mediterranean volume** is deeper than **2000 m**)
- **Ship-based** component of the **observing system** in the Mediterranean is not yet as well defined as other component

Global hydrographic surveys since the 70s (GEOSECS, WOCE / JGOFS, CLIVAR, GOSHIP)

The Mediterranean Sea was not included

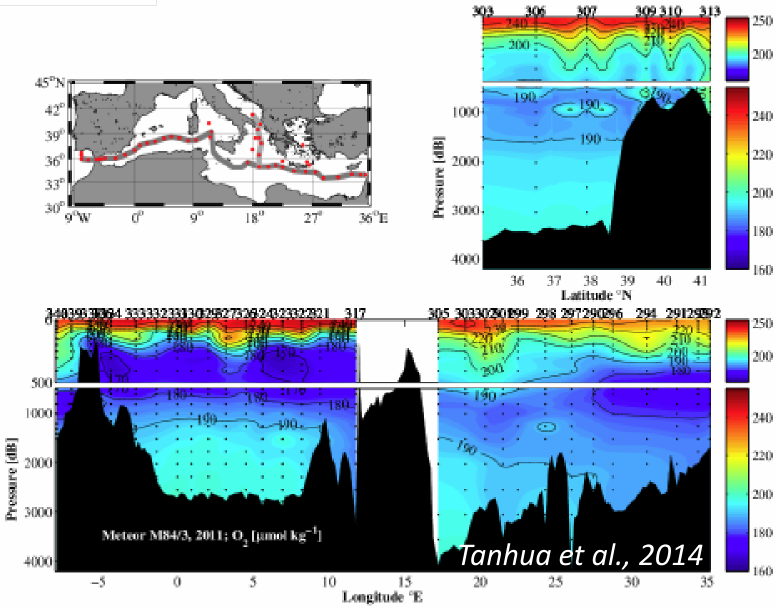


Ship-based hydrography



Primary **objectives** for the **Med-SHIP** repeat hydrography

(1) to observe long-term changes in physical and biogeochemical **properties**
(2) to observe changes in the thermohaline **circulation**



Med-SHIP is a CIESM initiative, www.ciesm.org

Conclusions

- Mediterranean is a **climate change hot spot**: we expect a continuation of the **warming** and **salinification** process in the WMED
  - **MOW** properties and outflowing depth may **change**
- a **salty – warm** anomaly in the WMED produced a **fresh – cold** anomaly in the Tyrrhenian Sea, triggering its **deep ventilation**
  - the **Tyrrhenian** will continue to be **ventilated** at the bottom
- **WMT** induced different **mixing regimes** in different **layers** of the water column and in different **areas**
- First **direct mixing measurements** in the deep WMED
  - the Tyrrhenian is an end-member of **extremely low dissipation values**
- **Med-SHIP** should become part of the GOOS as a reference component for **long term studies of processes, events and changes** in the Mediterranean.

Acknowledgement

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My husband, my "big" son and my little twins