EGU 2017
Vienne, April 27

Paradigm change in ocean studies: multi-platform observing and forecasting integrated approach in response to science and society needs

Combining Scientific Excellence & Technology Development

with… Impact and Relevance to and for Society

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The Story…

New multi-platform ocean observing systems are transforming the interplay between humans and the oceans

- New capacities that are not yet routine, but that will become routine in next years.

- Major scientific breakthroughs and enhanced response to society needs.

3 Messages:

1. Changes in Science: in how we do science and in Ocean Observation.
2. Mediterranean leadership and new Ocean Observatories/Infrastructures; the SOCIB case & some examples; connecting pieces of an N dim. Planet Ocean puzzle.
3. Changes in how science interacts with society: “Science with and for Society”.

Changes in science…

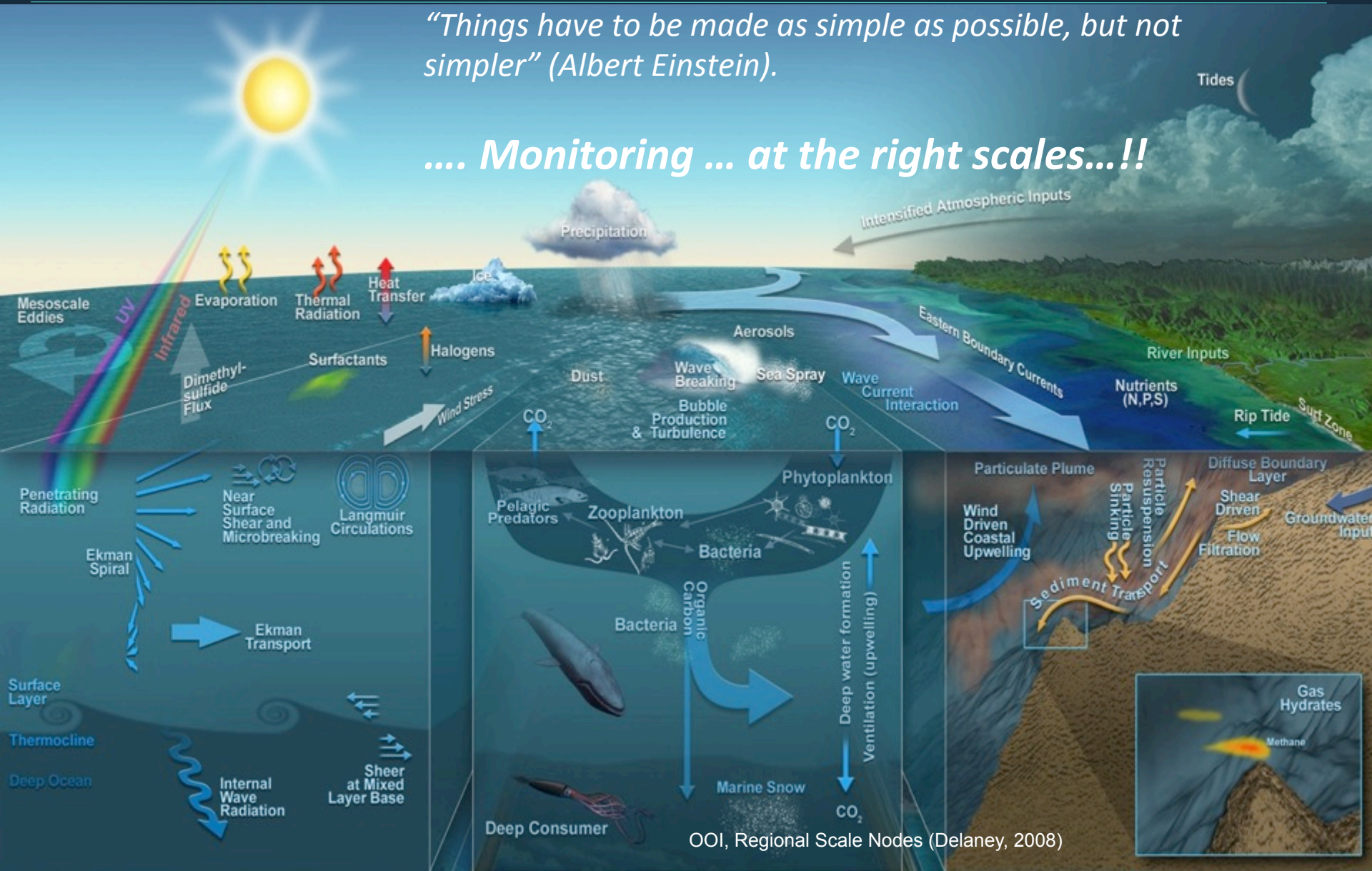
Upper Limits on the Stochastic Gravitational-Wave Ba
2009-2010 LIGO and Virgo Data

bbott[1], R. Abbott[1], T. Abbott[2], M. R. Abernathy[1], T. Accadia[3], F. Ac
, T. Adams[8], P. Addesso[5], R. X. Adhikari[1], C. Affeldt[9], M. Agathos[10],
. Ain[13], P. Ajith[14], A. Alemic[15], B. Allen[9,16,17], A. Allocca[18,19], D. Ama
S. B. Anderson[1], W. G. Anderson[16], K. Arai[1], M. C. Araya[1], C. Arcene
. Astone[23], P. Aufmuth[17], C. Aulbert[9], L. Austin[1], B. E. Aylott[24], S. Ba
, S. W. Ballmer[15], J. C. Barayoga[1], M. Barbet[6], B. C. Barish[1], D. Bark
rsotti[11], M. Barsuglia[30], M. A. Barton[28], I. Bartos[31], R. Bassiri[20], A. Ba
z[9], Th. S. Bauer[10], B. Behnke[25], M. Bejger[33], M. G. Beker[10], C. Belczy
rgmann[9], D. Bersanetti[35,36], A. Bertolini[10], J. Betzwieser[7], P. T. Beyersd
ey[1], J. Birch[7], S. Biscans[11], M. Bitossi[18], M. A. Bizouard[39], E. Black[1],
D. Blair[41], S. Bloemen[42,10], M. Blom[10], O. Bock[9], T. P. Bodiya[11], M.

From: single scientist / single process studies… (still needed!)
To: observing systems of our oceans & interactions

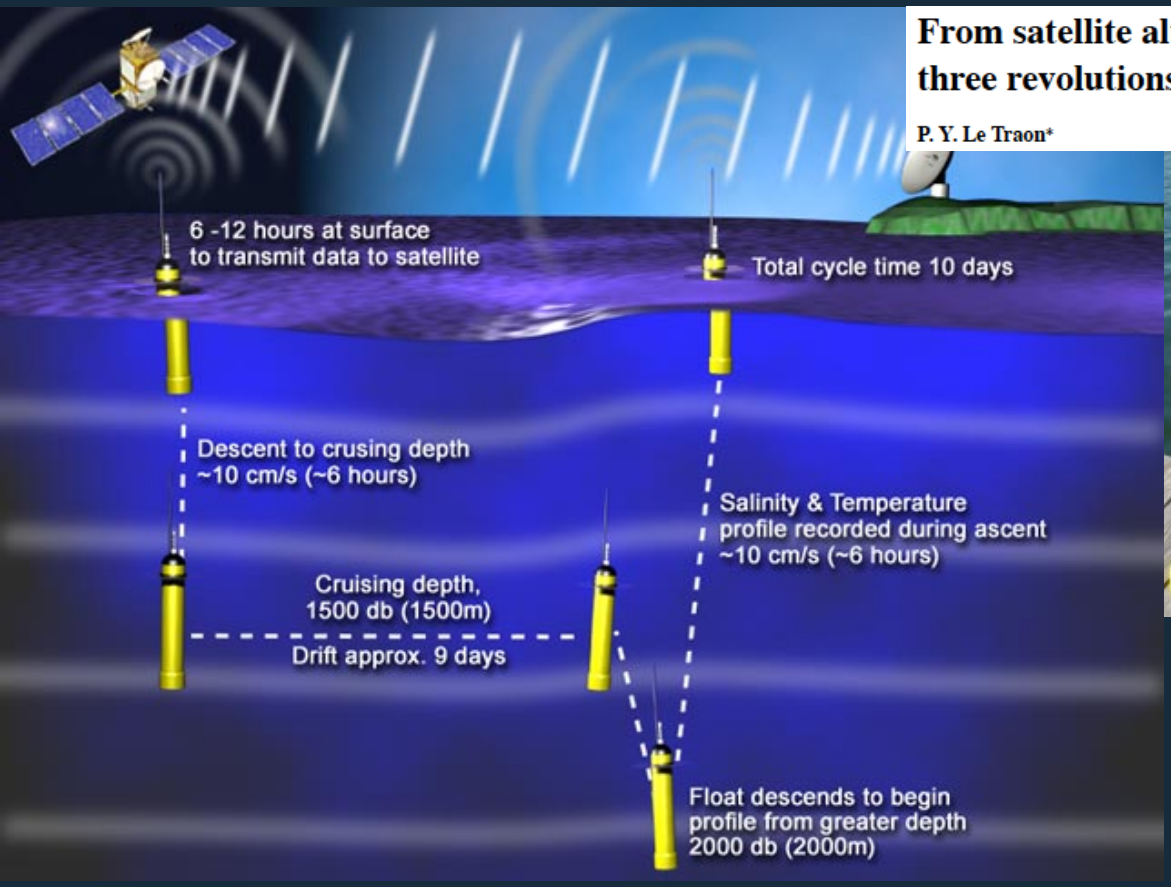
"Things have to be made as simple as possible, but not simpler" (Albert Einstein).

…. Monitoring … at the right scales…!!



OOI, Regional Scale Nodes (Delaney, 2008)

Last decade: characterization of the State of Large Scale open ocean circulation

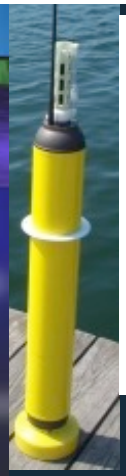


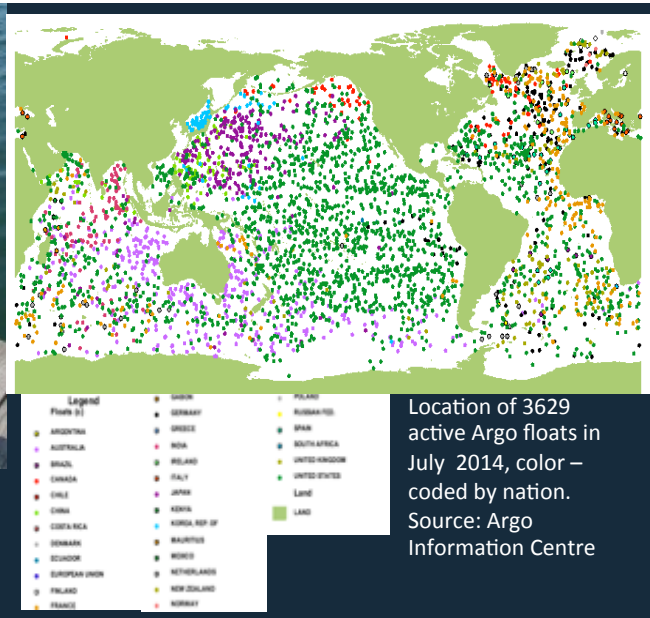
Schematic diagram of a single Argo float cycle

From satellite altimetry to Argo and operational oceanography: three revolutions in oceanography

P. Y. Le Traon*

Ocean Sci., 9, 901–915, 2013





Location of 3629 active Argo floats in July 2014, color – coded by nation. Source: Argo Information Centre

http://www.euro-argo.eu

262 floats with biogeochemical sensors

638 European floats (18%)

Argo programme and satellite altimetry allowed characterisation of the state of the large scale open ocean circulation

Successful international cooperation programme...

Next decade… Ocean Variability at the right scale…yes we can!.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY A

CrossMark click for updates

Phil. Trans. R. Soc. A (2012) **370**, 5461–5479
doi:10.1098/rsta.2012.0397

Changing currents: a strategy for understanding and predicting the changing ocean circulation

BY HARRY L. BRYDEN[1,*], CAROL ROBINSON[2] AND GWYN GRIFFITHS[3]

[1]*Ocean and Earth Science, National Oceanography Centre Southampton, University of Southampton, European Way, Southampton SO14 3ZH, UK*
[2]*School of Environmental Sciences, University of East Anglia, Norwich Research Park, Norwich NR4 7TJ, UK*
[3]*National Oceanography Centre, University of Southampton Waterfront Campus, European Way, Southampton SO14 3ZH, UK*

Within the context of UK marine science, we project a strategy for ocean circulation research over the next 20 years. We recommend a focus on three types of research: (i) sustained observations of the varying and evolving ocean circulation, (ii) careful analysis and interpretation of the observed climate changes for comparison with climate model projections, and (iii) the design and execution of focused field experiments to understand ocean processes that are not resolved in coupled climate models so as to be able to embed these processes realistically in the models. Within UK-sustained observations,

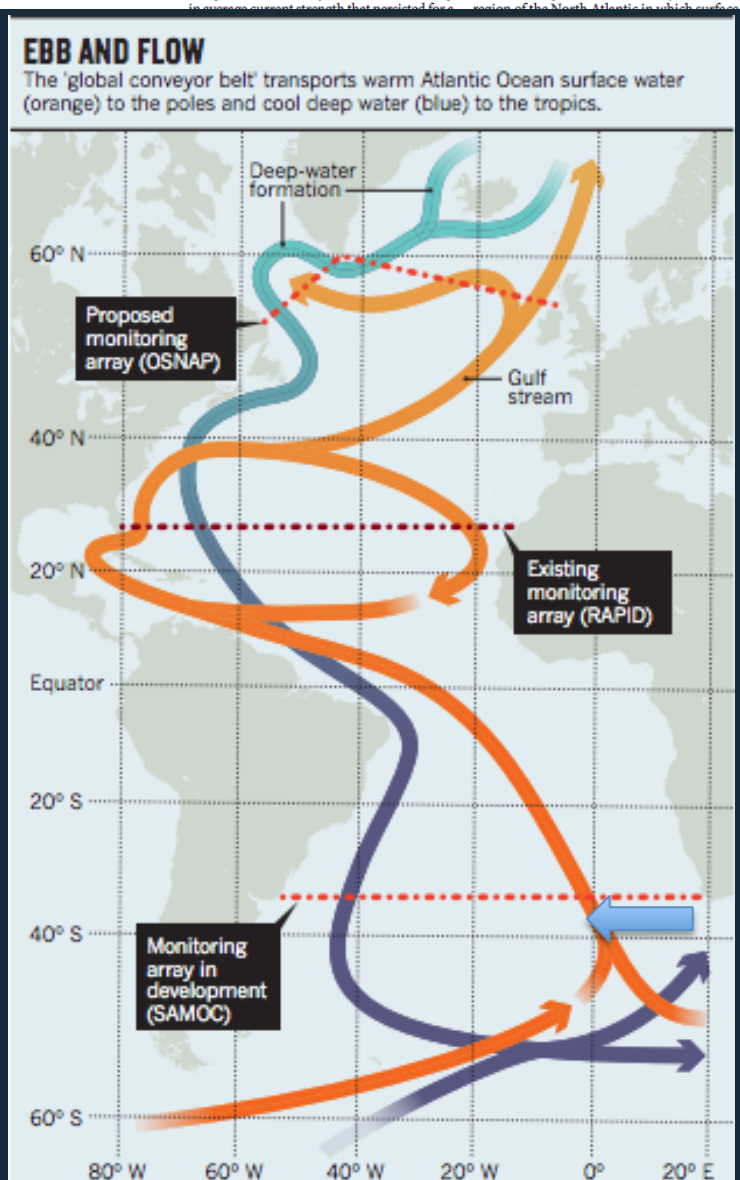
OCEANOGRAPHY

Oceans under surveillance

Three projects seek to track changes in Atlantic overturning circulation currents.

BY QUIRIN SCHIERMEIER

In April 2009, the array recorded[2] a 30% drop … a crucial component of the conveyor belt: the



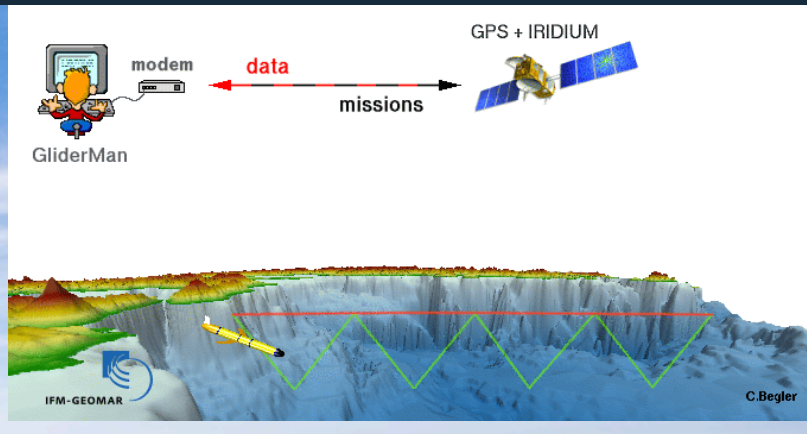
Marine research in the past 20 years has focused on defining the **present day** ocean circulation. From these measurements of ocean circulation, we begin to understand how biogeochemical distributions are set and how the ocean and atmosphere interact to determine the present climate [4].

The key issue for the next 20 years is to understand how the ocean circulation varies on inter-annual to decadal time scales…

And we need… **"Careful analysis and interpretation of climate changes"**

In April 2009, the array recorded a 30% drop in average current strength that persisted for a year, reducing the amount of heat transported to the North Atlantic

New Technologies: drivers of change…. (gliders just an example)



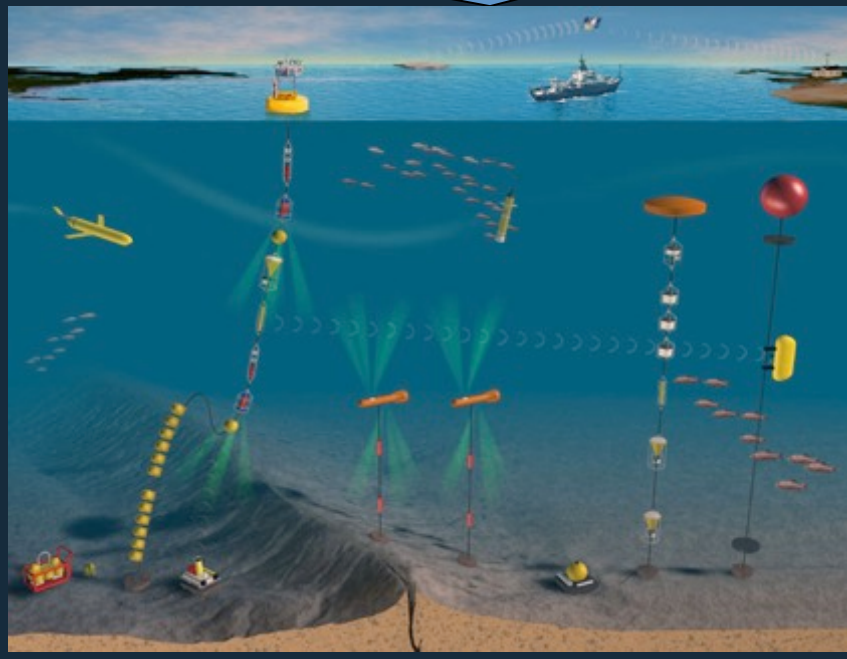
New Technologies: Paradigm Shift
➡ Ocean Observation (and data availability)

From: Single Platform - Ship based observation

To: Multi-platform observing systems

Platform-centric Systems

Network - distributed Systems



(Adapted from Steve Chien, JPL-NASA)

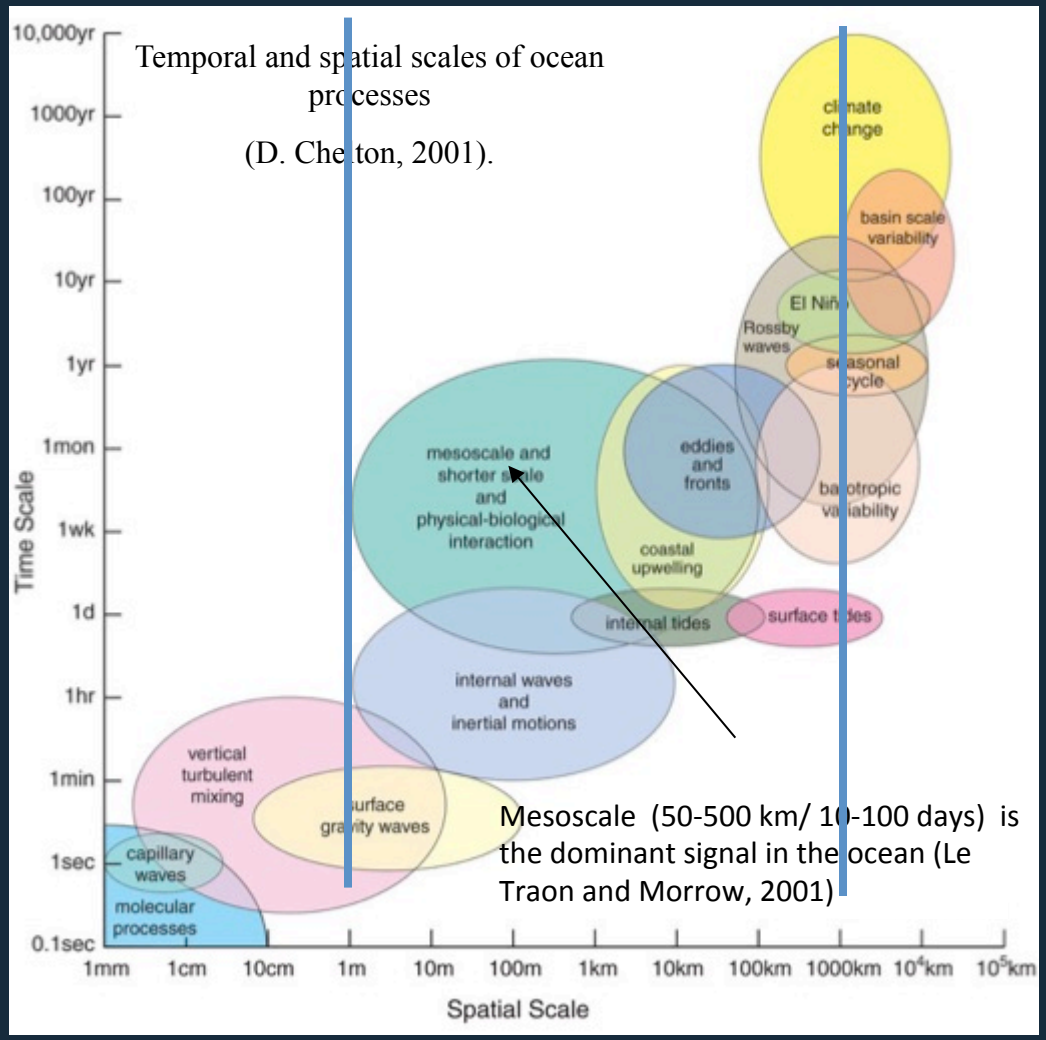
"A single ship can only be in one place at one time. We need to be present in multiple places in multiple times." (John Delaney, Nature, Sept. 25, 2013)

NOW we can….ocean variability at mesoscale/sub-mesoscale, interactions and ecosystem response

Theory and observations have shown that there is a maximum energy at the mesoscale (include fronts and eddies ~10-100km),

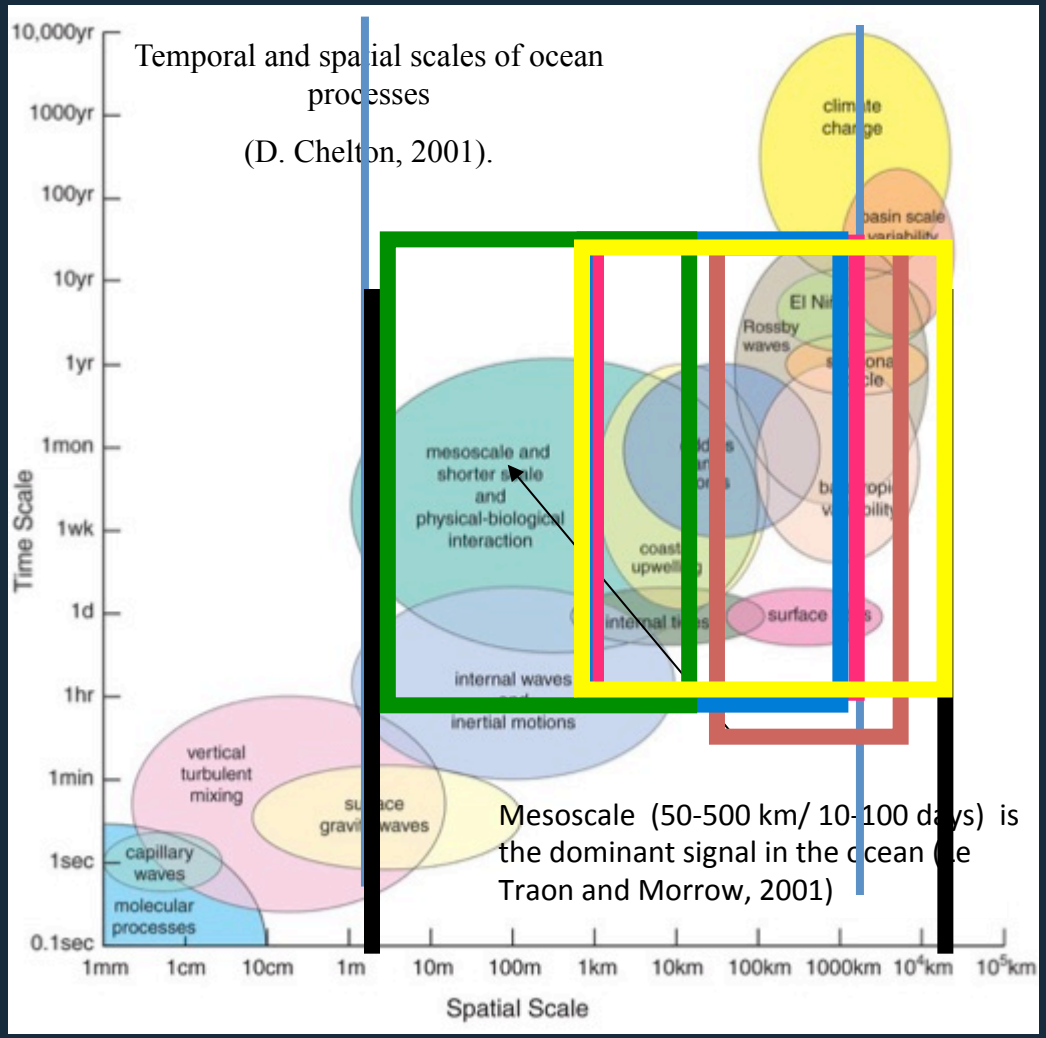
SOCIB focus: mesoscale & submesoscale and their interactions with general circulation and their effects on vertical motions, impact on ecosystem variability.

With inputs from 'both sides'....
(nearshore and coastal ocean and also seasonal/inter-annual and decadal variability)



SOCIB scales

NOW we can….ocean variability at mesoscale/sub-mesoscale, interactions and ecosystem response



Gliders

AUV's

Time series

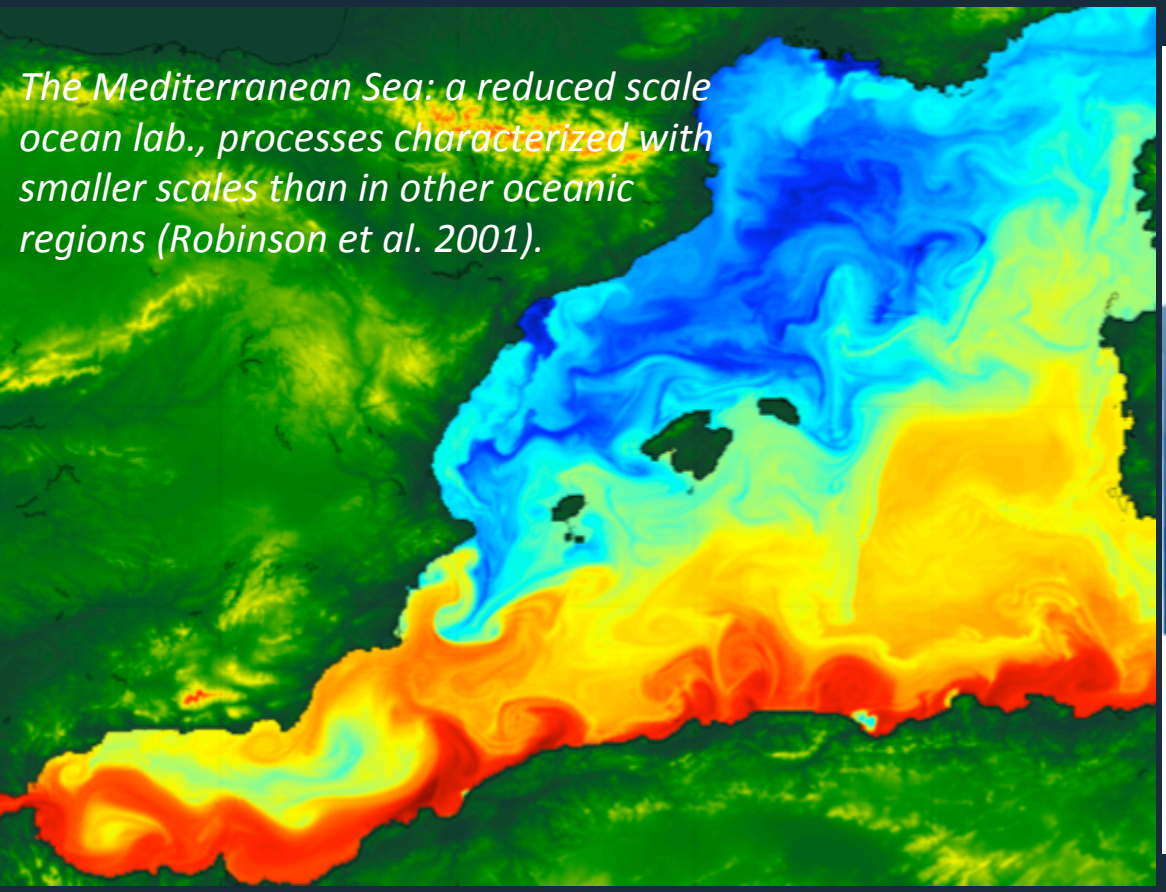
HF radar

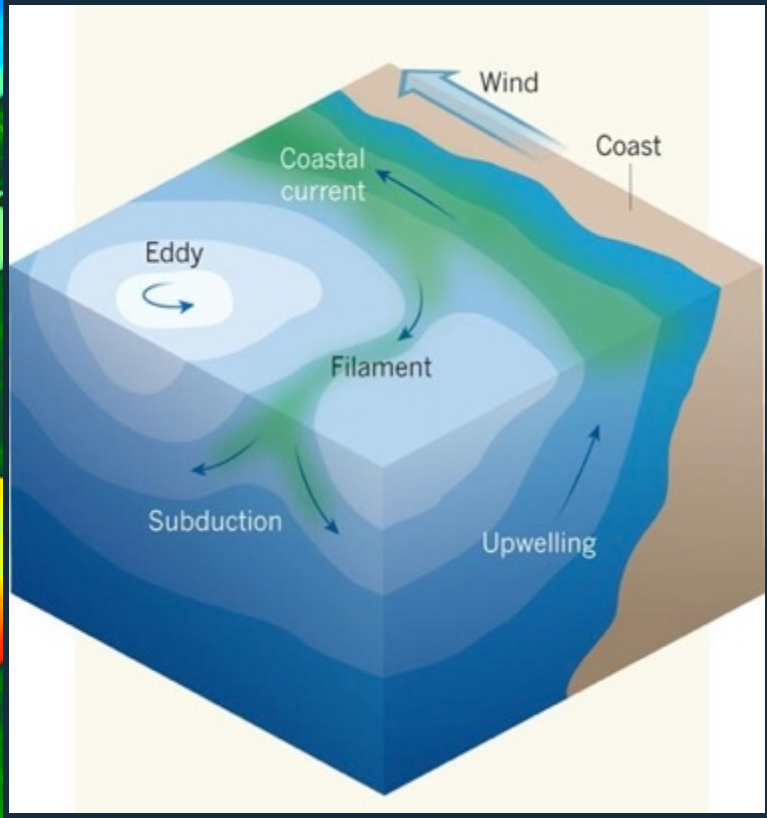
Spatial survey

Satellite

SOCIB scales

Next decade… Ocean Variability and … at the right scale… meso & sub-mesoscale





Theory and observations have shown a maximum energy at the mesoscale/fronts & eddies ~10-100km

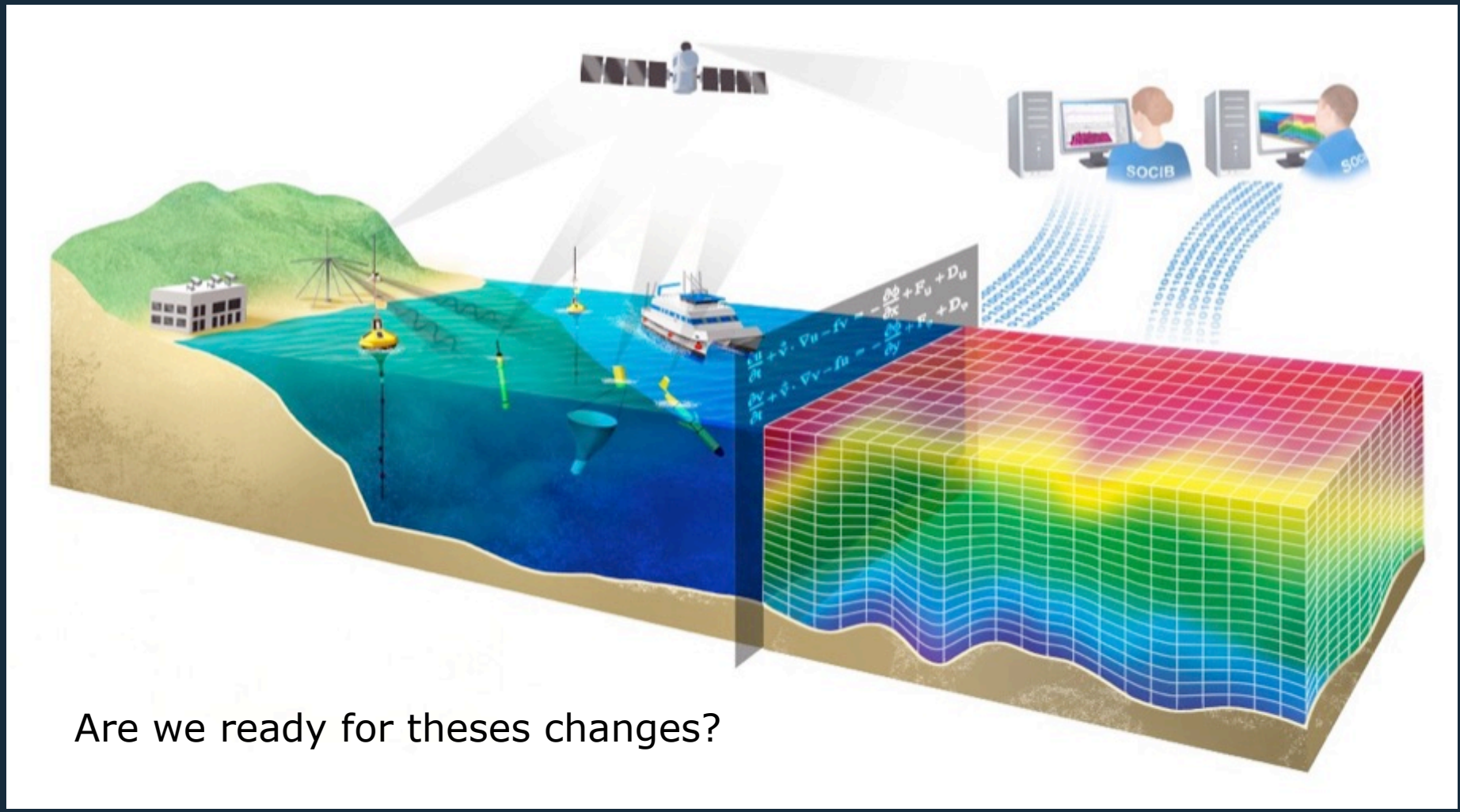
Mahadevan (Nature, 2014)

The real challenge for the next decade…:

<u>To use and integrate</u> these new technologies to carefully and systematically

- Monitor the variability at small scales, e.g. mesoscale/ weeks, to
- Resolve the sub-basin/seasonal and inter-annual variability and by this
- Establish the decadal variability, understand the associated biases and correct them …

Changes in Science: we need Integration & Cooperation for Platforms and Scientists



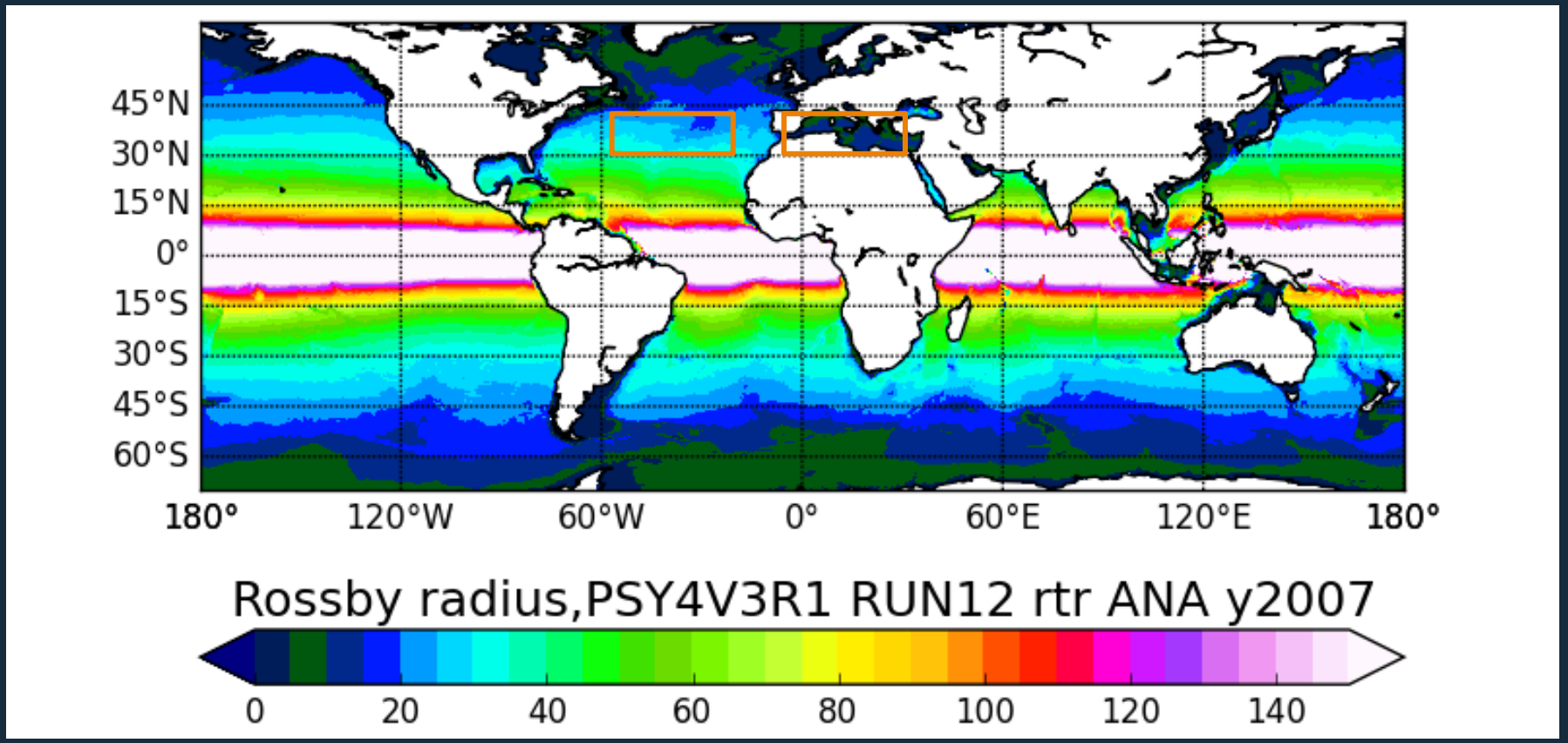
Are we ready for theses changes?

3 Messages:

1. Changes in Science: in how we do science and in Ocean Observation.
2. Mediterranean leadership and new Ocean Observatories/Infrastructures; the SOCIB case & some examples; connecting pieces of an N dim. Planet Ocean puzzle.
3. Changes in how science interacts with society: “Science with and for Society”.

Why the Mediterranean? : scientific motivation

Short spatial scales in the Mediterranean Sea

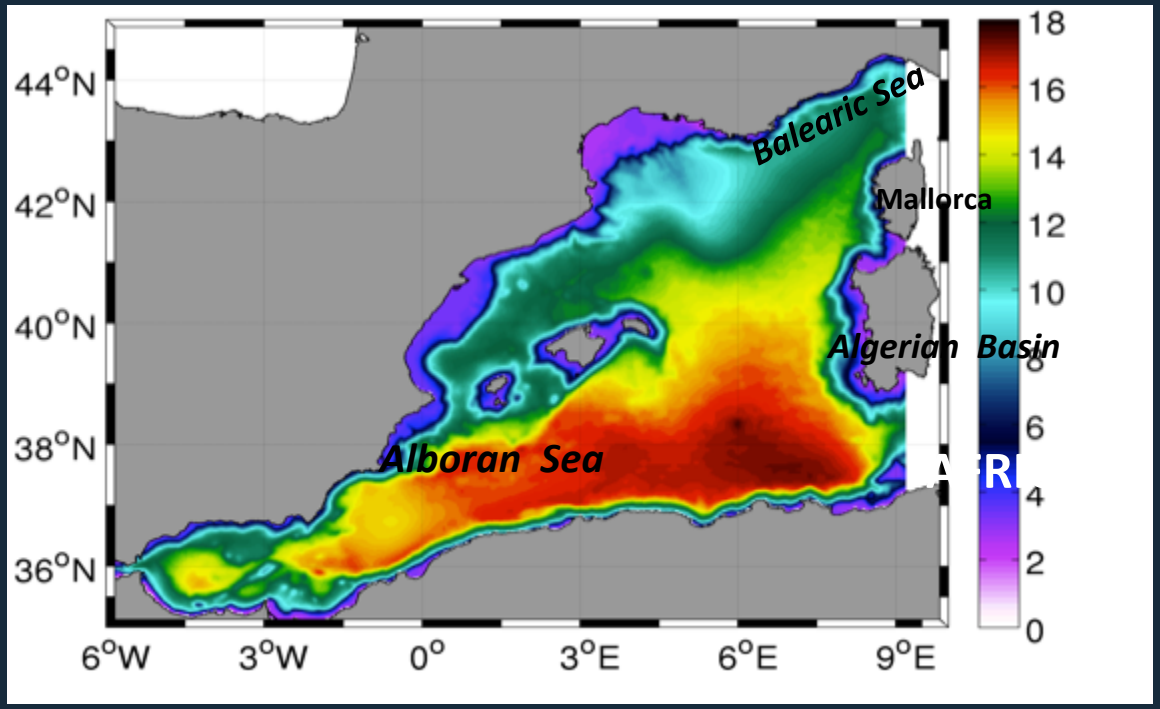


First baroclinic deformation radius (km) from a numerical simulation (Copernicus Marine Service). Courtesy Angélique Melet (Mercator-Ocean)

Why the Mediterranean? : scientific motivation

Small Scale Ocean of key Relevance EU Citizens Scientific, Societal & Political dimensions

Small spatial scales



First Rossby radius of deformation (km) from Escudier et al. (2016).

Objectively …an ideal Lab for Ocean Processes study:

- **Thermohaline circulation**
- **Water Masses formation & spreading**
- **Boundary currents**
- **Meso & sub-mesoscale & vertical exchanges**
- **Interactions and effects on circulation and ecosystem response…**
-

…

Mediterranean Leadership

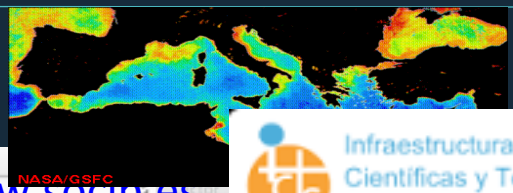
Background: Mediterranean leadership in Europe and worldwide, for 25 years: key process studies, relevance of EU vision with MTP's, Observing systems, Open Data.

The future: Med. better linked to major EU initiatives and Med scientists LEADING again process studies/initiatives of worldwide interest (POEM, Donde va, …)

Good perspectives…

What is SOCIB?: A Marine Research Infrastructure: a multi-platform observing system, from nearshore to open-ocean

Tintoré et al., 2013: *Marine Tech. Soc. J.*, Vol. 47, N. 1, pp. 101-117



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Infraestructuras Científicas y Técnicas Singulares

3 DRIVERS

- Science priorities
- Technology Development
- Society Needs

OPEN DATA PRINCIPLES

ACCESS MODES

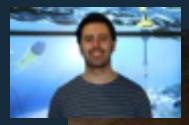
- Free/open data
- Endurance lines
- External Open Access.

Proposal 2006. Approved in 2009. Operational since 2014.

SOCIB & IMEDEA (CSIC-UIB) Team

TEAM WORK: “Connecting the pieces of an N dimensioanl Planet Ocean puzzle”

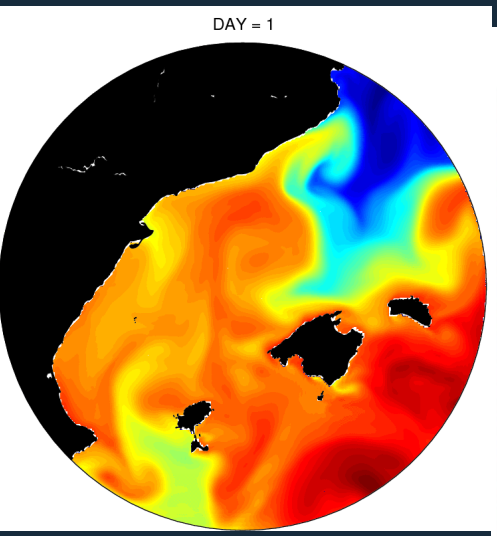
SOCIB Data Centre: Real Time, Free Access & Download, Quality Controlled, Interoperable Data

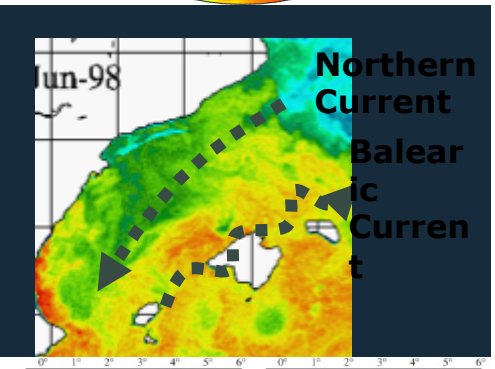


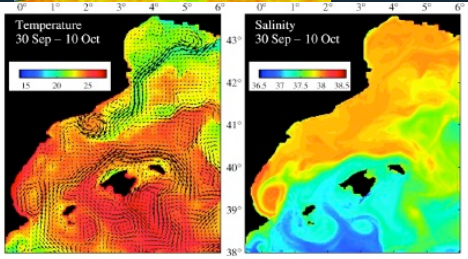
MA Rujula

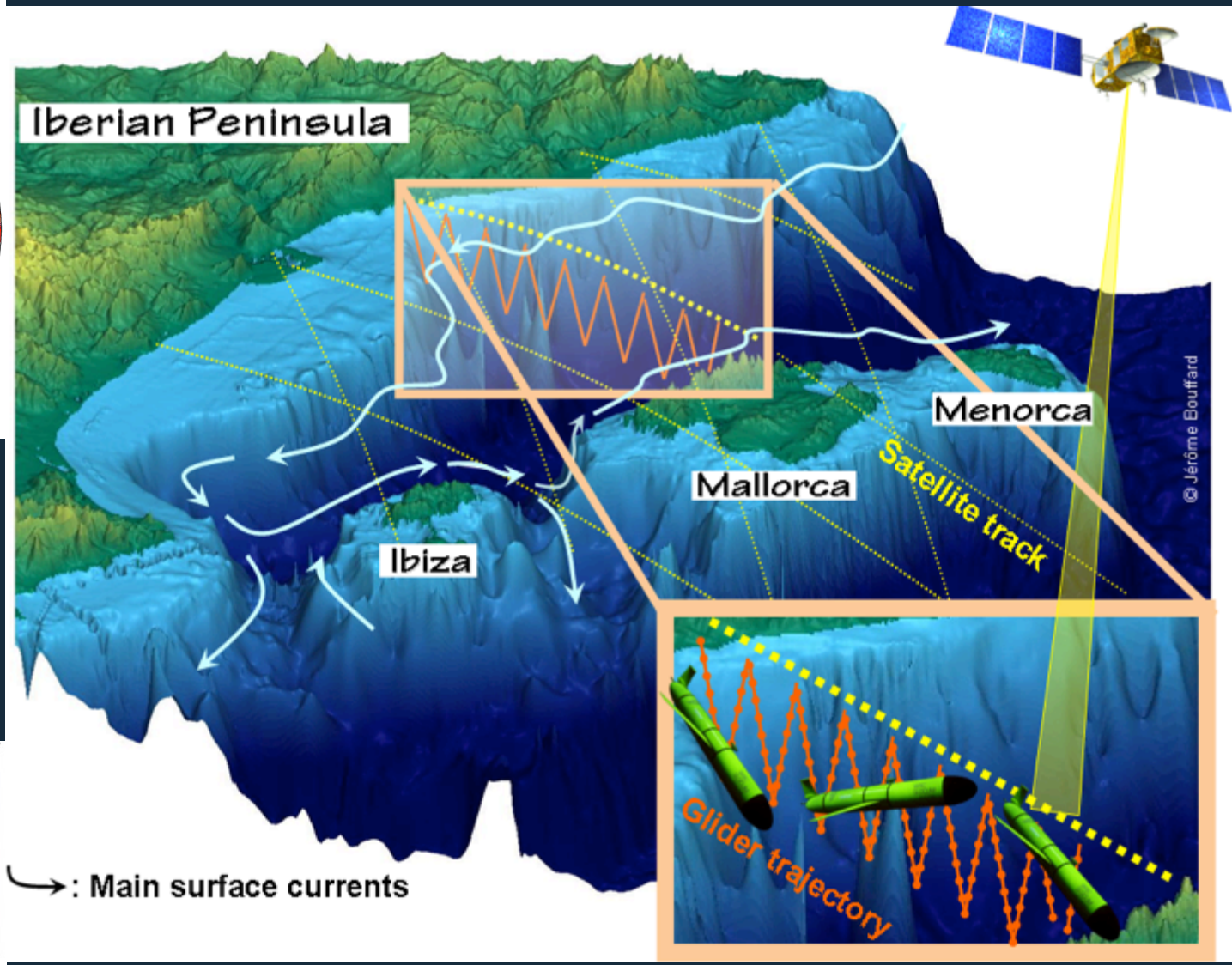
Balearic basin (fronts, mesoscale eddies, blocking, hotspot, ecosystem response)

…. Ideal lab to study global ocean problems









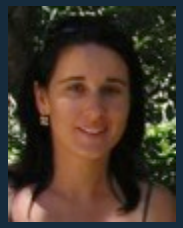
ALBOREX: meso-submesoscale process study/ Multi-platform experiment in Alborán Sea

frontiers

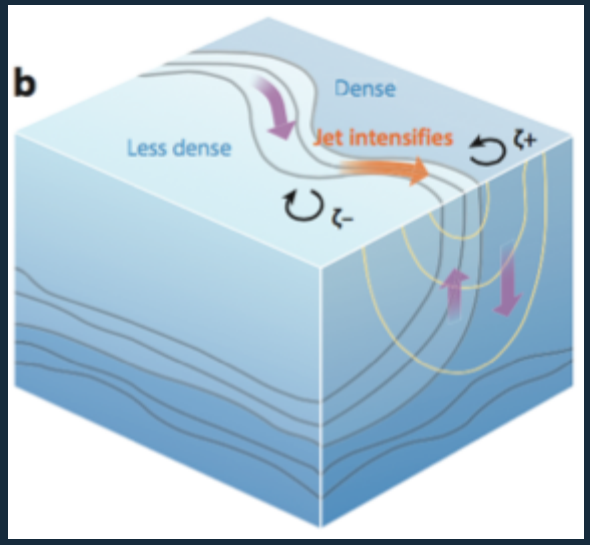
A multiplatform experiment to unravel meso- and submesoscale processes in an intense front (AlborEx)

Ananda Pascual[1*], Simon Ruiz[1], Antonio Olita[2], Charles Troupin[3], Mariona Claret[4, 5], Benjamin Casas[1], Baptiste Mourre[3], Pierre-Marie Poulain[6], Antonio Tovar-Sanchez[7], Arthur Capet[8], Evan Mason[1], John T. Allen[3], Amala Mahadevan[9], Joaquin Tintoré[1, 3]

Lead by CSIC (Dr. Ananda Pascual) with strong involvement from SOCIB, OGS, CNR and collaborations with WHOI, IEO, UMA.



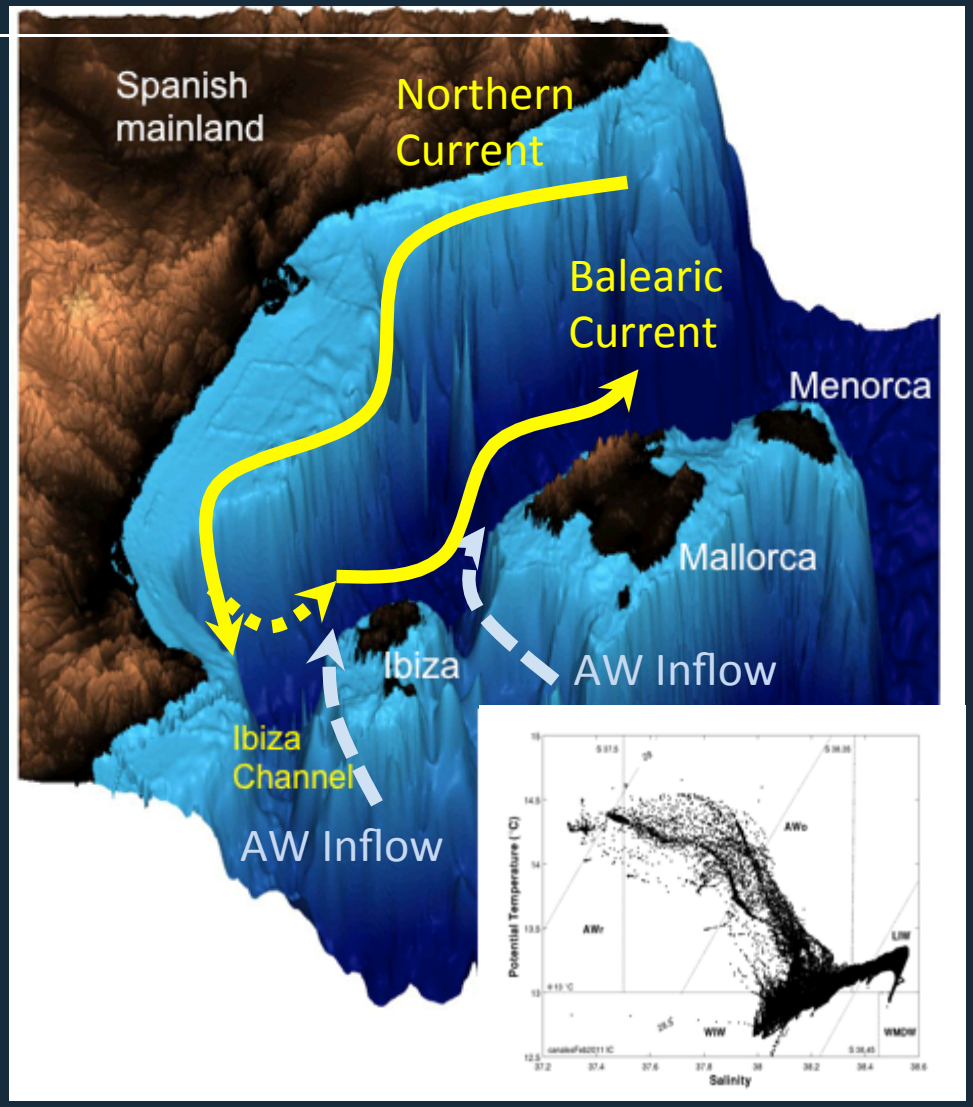
- 25 drifters
- 2 gliders
- 3 Argo floats
- ADCP
- Thermosalinograph
- 80 CTDs
- Nutrients
- Chlorophyll
- Remote sensing
- Modeling



THE IBIZA CHANNEL – CIRCULATION ‘CHOKE’ POINT

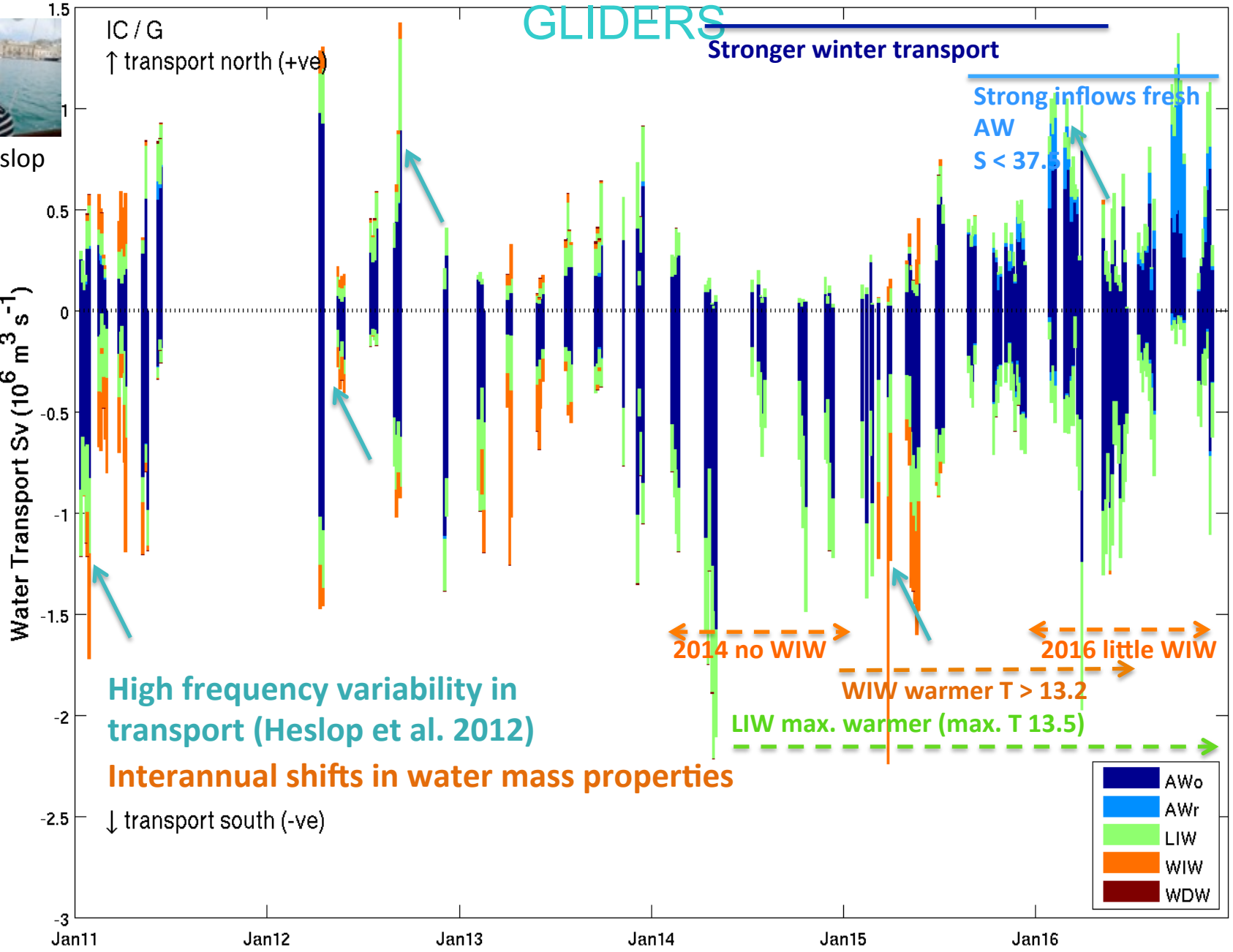
Emma Heslop

Marc Torner

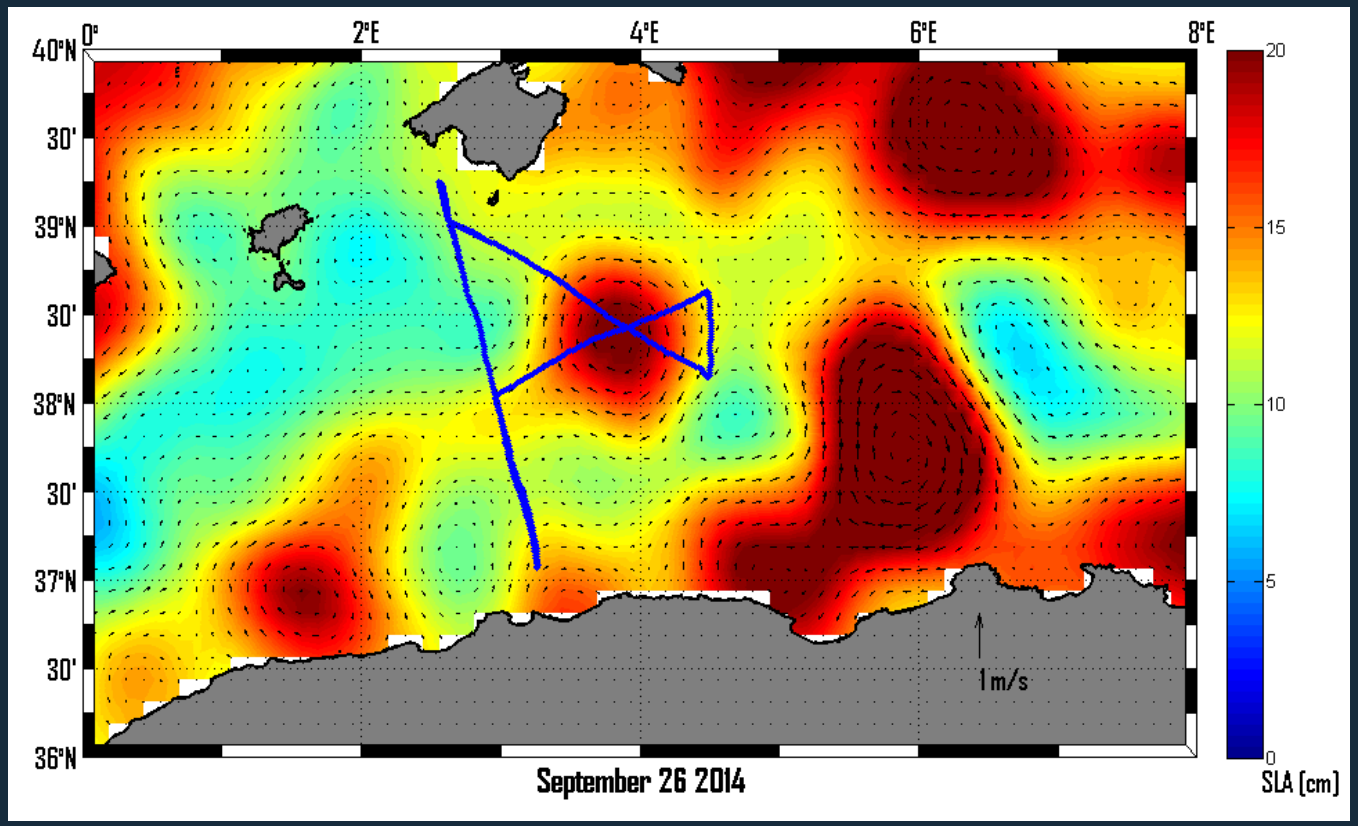


IBIZA CHANNEL – GEOSTROPHIC TRANSPORT FROM GLIDERS

mma Heslop



New oceanography: adaptive monitoring by gliders



Sea Level Anomaly (color scale)
Geostrophic velocity anomalies (black arrows)

Cotroneo et al., 2016

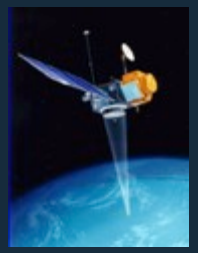
Blue dots show the glider track from 15th Sept to 20th Oct 2014.

Ocean Forecasting Facility: WMOP forecasts systematic evaluation

Delayed mode

Baptiste Mourre

Near real-time



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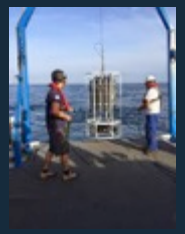
Gliders

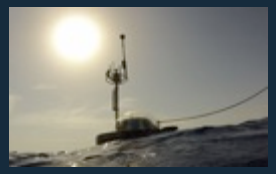


Ship-based CTDs

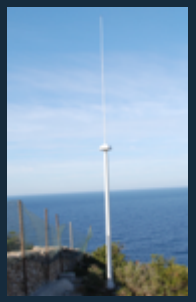
Satellite

WMOP ocean forecasts

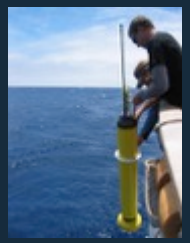
Moorings



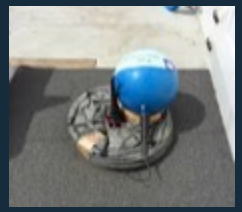
HF radar



Argo floats



Surface drifters

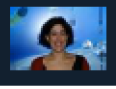


Ocean Forecasting Facility: Multi-Platform Assesment

Multi-platform validation of a high-resolution model in the Western Mediterranean Sea: insight into spatial-temporal variability

Eva Aguiar[1] (eaguiar@socib.es), Baptiste Mourre[1], Emma Heslop[1], Mélanie Juza[1], Evan Mason[1], Romain Escudier[2], Joaquin Tintoré [1,3]

[1]SOCIB, Balearic Islands, Spain; [2] Rutgers University, Rhode Island, EEUU; [3] IMEDEA (CSIC-UIB), Balearic Islands, Spain



1 Motivation

This study focuses on the validation of the high resolution Western Mediterranean Operational model (WMOP) developed at SOCIB, the Balearic Islands Coastal Observing and Forecasting System. This assessment uses multi-platform observations from moorings, gliders and satellite altimetry. A hindcast simulation is evaluated over the period 2009-2015.
The main spatial patterns of variability are then described using the EOF analysis of sea level anomaly (SLA) maps from WMOP in two different regions

2 Multi-platform perspective

1. **Moorings:** 6 stations from Puertos del Estado and SOCIB (Fig. 1a). Hourly surface currents, temperature & salinity
2. **Satellite altimetry:** SLA product in the Western Mediterranean Sea (WMS) from CMEMS (1/8º, daily)
3. **Gliders:** 3 points extracted from SOCIB transect in Ibiza Channel (W, C, E; Fig. 1b). Temperature & salinity. [Heslop et al., GRL, 2012]
4. **Numerical model -WMOP (ROMS):** [Juza et al., JOO, 2016]

- Regional configuration of ROMS in the WMS
- Spatial resolution: 1/50º (~2 km)
- Initial & boundary conditions from CMEMS MED-MFC (1/16º)
- Surface forcing: from AEMET HIRLAM model (3h-5km)
- Free run without data assimilation (2009 - 2015)

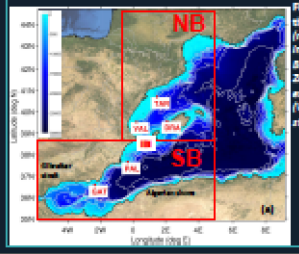


Fig. 1 (a) Model bathymetry in the WMS: Position of moorings (red dots); sub-regions considered in the study (red boxes): North Basin (NB) & South Basin (SB) (b) Zoom in Ibiza Channel (IC): extracted points from glider data (West, Center, East) and mooring station (IBI)

3 Model validation

1 Main axis of ocean current variability

- Good agreement among the model, the moorings and altimetry in terms of the main axis of variability
- TAR, PAL and GAT are located in areas of marked mean currents
- The principal axis is parallel to local isobaths at all stations

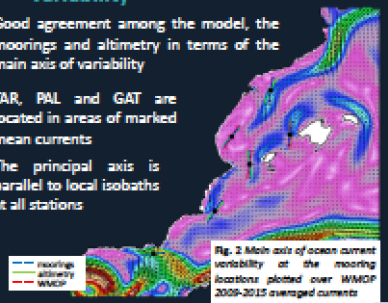


Fig. 2 Main axis of ocean current variability at the mooring locations plotted over WMOP 2009-2015 averaged currents

2 Inter-annual changes of the surface flows

- The intense and anomalous southward flow during 2014 captured by 3 moorings (TAR, PAL, GAT) and gliders in the western part of IC (W), is reproduced by the model
- According to glider data, the central point of IC does not capture the main southward flow occurred in the western part

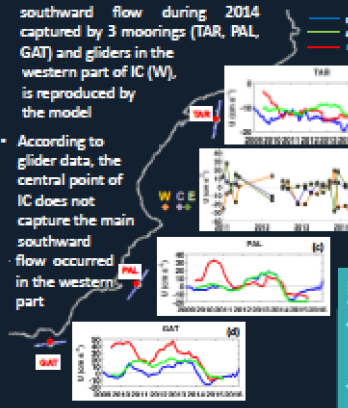


Fig. 3 Low-frequency filtered (365 d) velocities at TAR, PAL and GAT locations from moorings, altimetry and model data (a, c, d) and at Ibiza channel from gliders in W, C and E points (b).

3 Propagation of mesoscale eddies in the Algerian sub-basin

[Escudier et al., JGR, 2016]

- WMOP generates and propagates Algerian eddies but these are not synchronous with observations

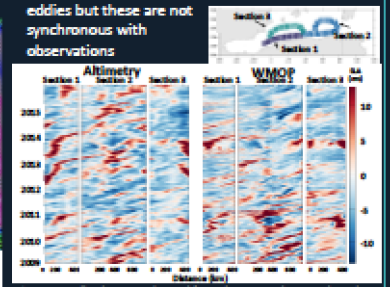


Fig. 4 Hovmöller diagrams obtained from altimetry and WMOP data along the 3 sections represented in the inset.

4 Statistical properties of eddies

- Radius of eddies were calculated from WMOP and altimetry SLA maps using an eddy tracker algorithm [Mason et al., JAOT, 2014]
- The prevalence of small radius eddies using WMOP data still need to be understood
- The use of SLA and/or SSH in WMOP is irrelevant for the detection algorithm

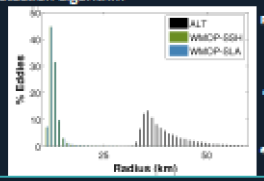


Fig. 5 Radius of eddies detected from altimetry and WMOP (SLA and SSH) data using the eddy tracker algorithm

4 Patterns of variability

- EOF analysis was applied to the SLA maps from WMOP in 2 different regions of WMS
- The first mode is seasonal and explains more variability in the NB than in the SB
- Inter-annual variability in amplitude
- First EOF in NB also describes the intense southward flow produced during 2014
- Inter-connection between basins?
  - ✓ The intensification of the Northern Current (NC) in the NB is generally associated with minimums in the activity of eddies in the SB
  - ✓ The high activity of eddies in the SB is generally associated with a weakening of the Northern Current (NC) in the NB
  - ✓ Exist a lag between these events. Its duration is generally around 30 days but it is not always produced in the same sense

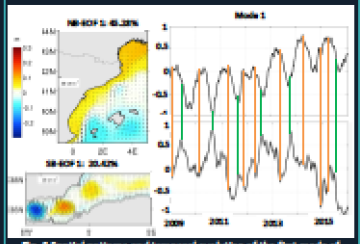


Fig. 6 Spatial patterns and temporal evolution of the first mode of EOF analysis of SLA

5 Conclusions

- The WMOP model reproduces the intensification of southward flow in IC and the generation and evolution of the strong anticyclonic eddies in Algerian basin.
- The WMOP eddy tracker algorithm provides eddies with small radius compared to altimetry
- The circulation in the northern and southern sub-basins have a seasonal cycle. Further work is needed to establish the interconnection between both sub-regions, its causes and consequences.

Ocean Forecasting Facility: Model assessment & HF Radar assimilation

Model velocities assesment and HF radar data assimilation in the Ibiza Channel

Jaime Hernandez Lasheras[1] (jhernandez@socib.es) , Baptiste Mourre[1], Emma Reyes[1], Julien Marmain[3], Alejandro Orfila[2], Joaquin Tintoré[1,2]

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1 Motivation

High Frequency radars (HFR) provide continuous and high-resolution surface current measurements in coastal areas, allowing to better understand surface ocean dynamics and providing valuable data to improve numerical model predictions through data assimilation. Since 2012, SOCIB operates two coastal HFR antennas with the purpose of monitoring the surface currents in the Ibiza Channel (Western Mediterranean Sea).

In this work, we perform the first steps to evaluate the potential of Ibiza Channel HF radar data to improve the WMOP model circulation after data assimilation. The realism of model velocities in terms of mean field and EOF modes is first evaluated to verify the capacity of the model to represent the processes of interest in the area. Then, a single experiment of HF radar data assimilation is presented.

2 Model and data assimilation system

1 WMOP model

- Regional configuration of the ROMS model, hindcast 2009-2015
- Horizontal resolution: ~2km (1/50º), 32 σ-levels
- Initial & Boundary conditions: CMEMS MED-MFC (1/16º)
- Atmospheric forcing: AEMET Hirlam (1/3h,5km)
- Rivers: Var, Rhône,Aude,Hérault, Ebro, Jucar

2 Ensemble Optimal Interpolation

- Ensemble anomalies sampled from three WMOP hindcast simulations (2009-2015) with different initial/boundary forcing and mixing parameters
- Anomalies selected within the same season as the analysis date after having removed the seasonal cycle

→ Multivariate, inhomogeneous and anisotropic 3-dimensional model error covariances characteristic of the mesoscale variability

- Domain localization with a 250-km radius
- 80 ensemble members

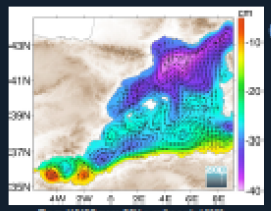


Figure: WMOP mean SSH over the period 2009-2015 and associated surface geostrophic currents

3 Observations

- **SLA:** AVISO products, mapped (1/8º) and along-track
- **SST:** 10km resolution, degraded from MUR-JPL
- **Argo:** TS profiles
- **HFR:** Ibiza Channel (3km, daily total velocities)

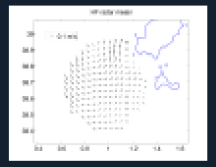
3 Assessment of model velocities

An EOF analysis of surface currents has been performed over the HFR coverage area, with the objective to evaluate the capacity of the model to capture the dominant processes, which is a prerequisite to perform a successful HFR data assimilation.

The mean current and the first two EOF modes show good agreement between HFR and WMOP in terms of spatial pattern, explained variance and seasonal cycle.

Data used: daily mean surface currents between 2012-06-01 and 2014-08-31 (HF radar reconstructed fields through Open-Boundary Modal Analysis)

Mean currents: similar overall circulation pattern. WMOP overestimates velocities in the eastern part of the HFR coverage area.



EOF Mode1:

Accounts for 25% and 31% of total variance for HFR and WMOP respectively.

Represents an overall meridional flow in both cases.

Related to strong winds from storms (Lana et al 2016) and Atlantic water inflows.

Time series correlation (HFR vs WMOP) = 0.53

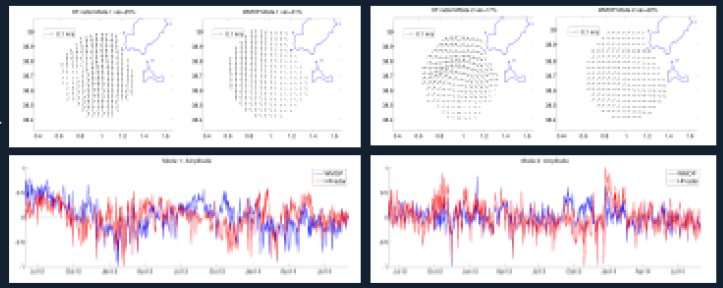
EOF Mode2:

Accounts for 17% and 22% of total variance for HFR and WMOP respectively.

Represents an overall zonal flow in both cases.

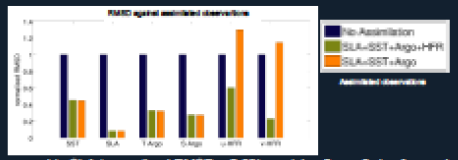
Related to zonal wind events.

Time series correlation (HFR vs WMOP) = 0.61

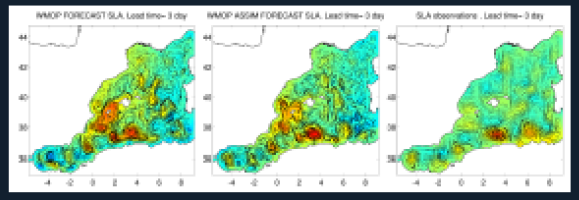


4 Data assimilation results

- Several data assimilation experiments have been performed for a given date (24 February 2016), including or not HFR data in addition to SLA, SST and Argo profiles.
- The RMSD against all type of assimilated data is systematically reduced with the assimilation.
- Radar data are properly ingested in the model, without degrading the improvement in terms of SLA, SST and TS profiles provided by the rest of the observations.



The improvement in SLA (normalized RMSD = 0.83) persists after a 3-day forecast starting from the analysis after SLA+SST+Argo+HFR assimilation.



- Improvement of model velocities in the area of the radar after data assimilation
- Improvement of temperature and salinity profiles
- Smooth transition between HFR observed area and the rest of the domain

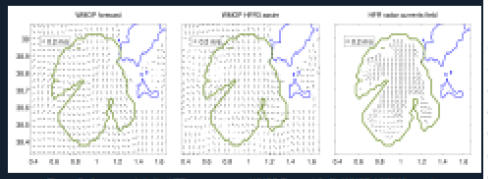


Figure: Surface currents in the HFR coverage area. WMOP Forecast (Left), WMOP Assimilated forecast from SLA+SST+Argo+HFR assimilation (center) and HFR daily mean observation (right)

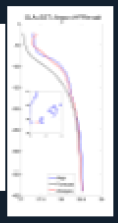


Figure: Salinity profiles in HFR coverage area

5 Conclusions and perspectives

- The main modes of surface current variability in the area covered by the radar are realistically reproduced in the model, however with a rather poor pattern correspondence.
- The WMOP data assimilation system sucessfully ingests HFR observations.
- Further validation to be performed using independent measurements from gliders and surface drifters.

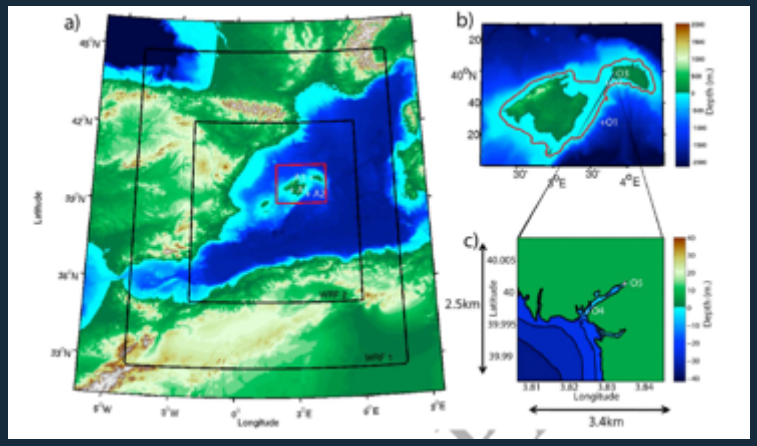
Reference: Lana, A., Marmain, J., Fernández, V., Tintoré, J., & Orfila, A. (2016). Wind influence on surface current variability in the Ibiza Channel from HF Radar. Ocean Dynamics, 66(4), 483-497.

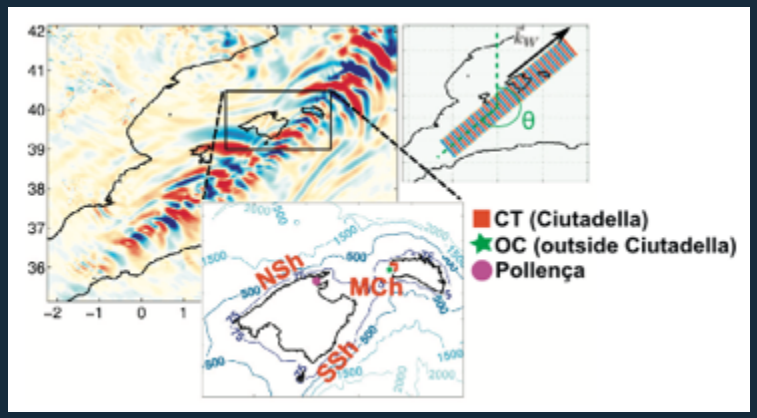
Ocean Forecasting Facility: Meteo-tsunamis forescast

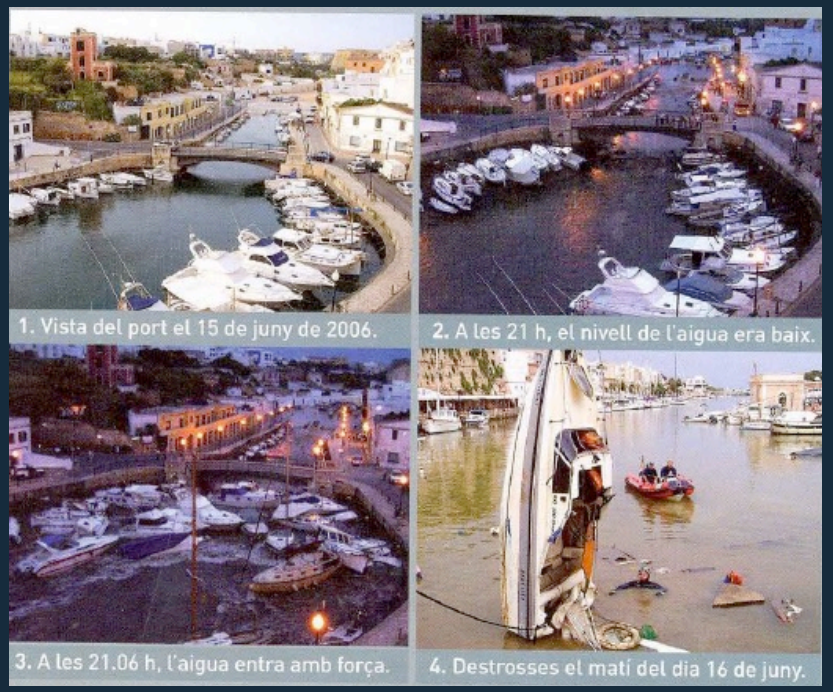
Numerical study of Balearic meteotsunami generation and propagation under synthetic gravity wave forcing

Matjaž Ličer[a,b,*], Baptiste Mourre[a], Charles Troupin[a], Andreas Krietemeyer[a], Agusti Jansá[d], Joaquín Tintoré[a,c]

Ocean Modelling 111 (2017) 38–45



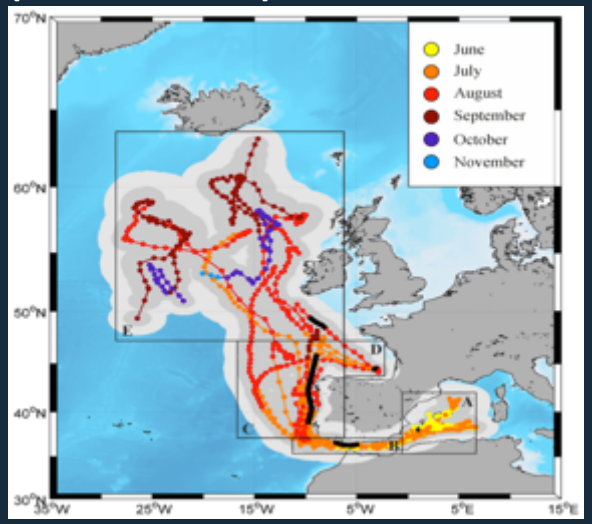




Bluefin Tuna: linking ocean variability & species ecology to improve population stock assessment

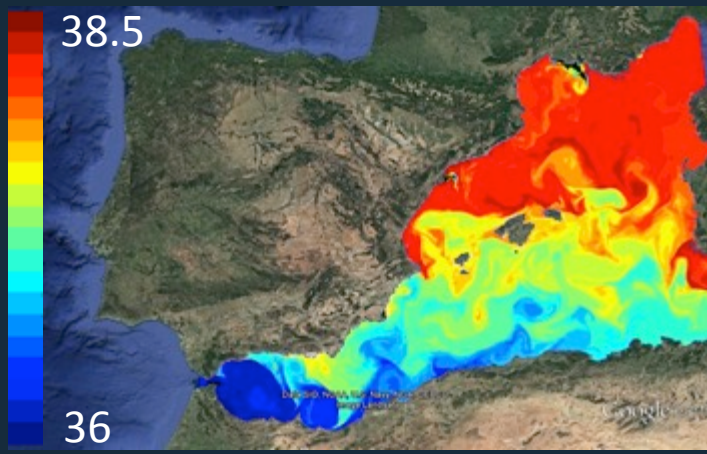
Alvarez-Berastegui D.

Migration patterns along the year (Eastern Stock)



Aranda et al, Pone 2013

Sea Surface salinity (06/2016)

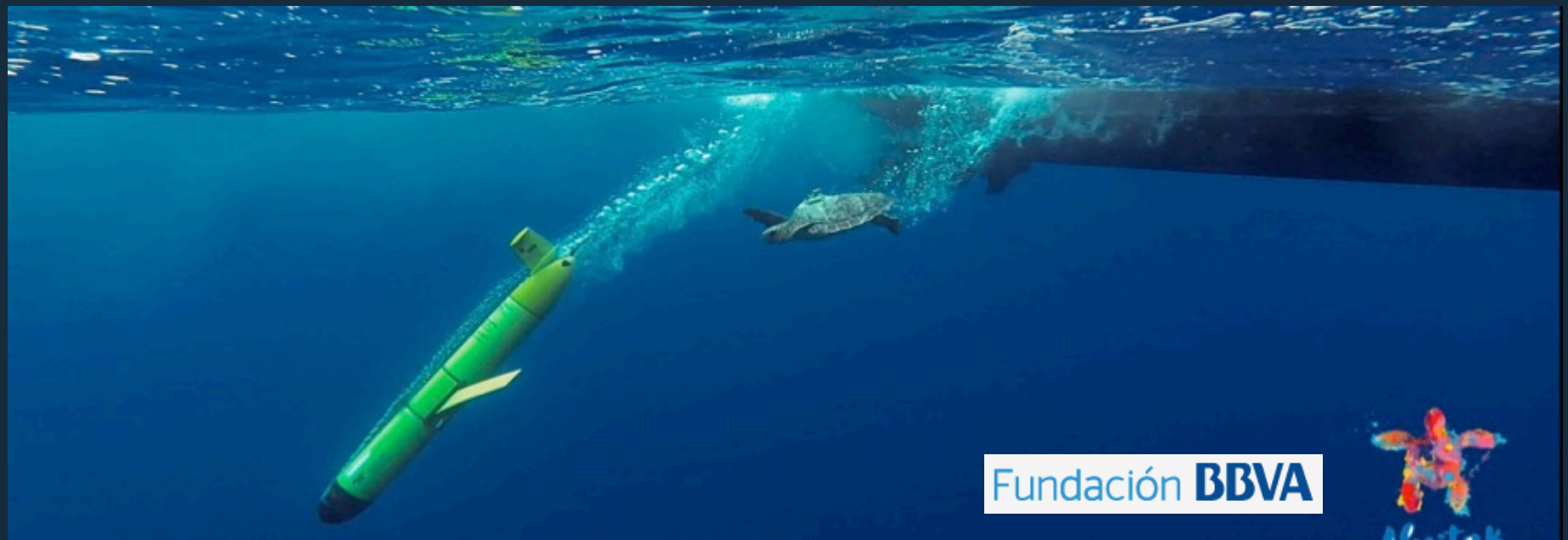


Alvarez-Berastegui et al. (ICES JMSc. 2016)

Seaturtles: Animal-Borne Instruments in Operational Ecology for Dynamic Ocean Management

David March

http://seaturtle.socib.es/en/turtle-viewer/#



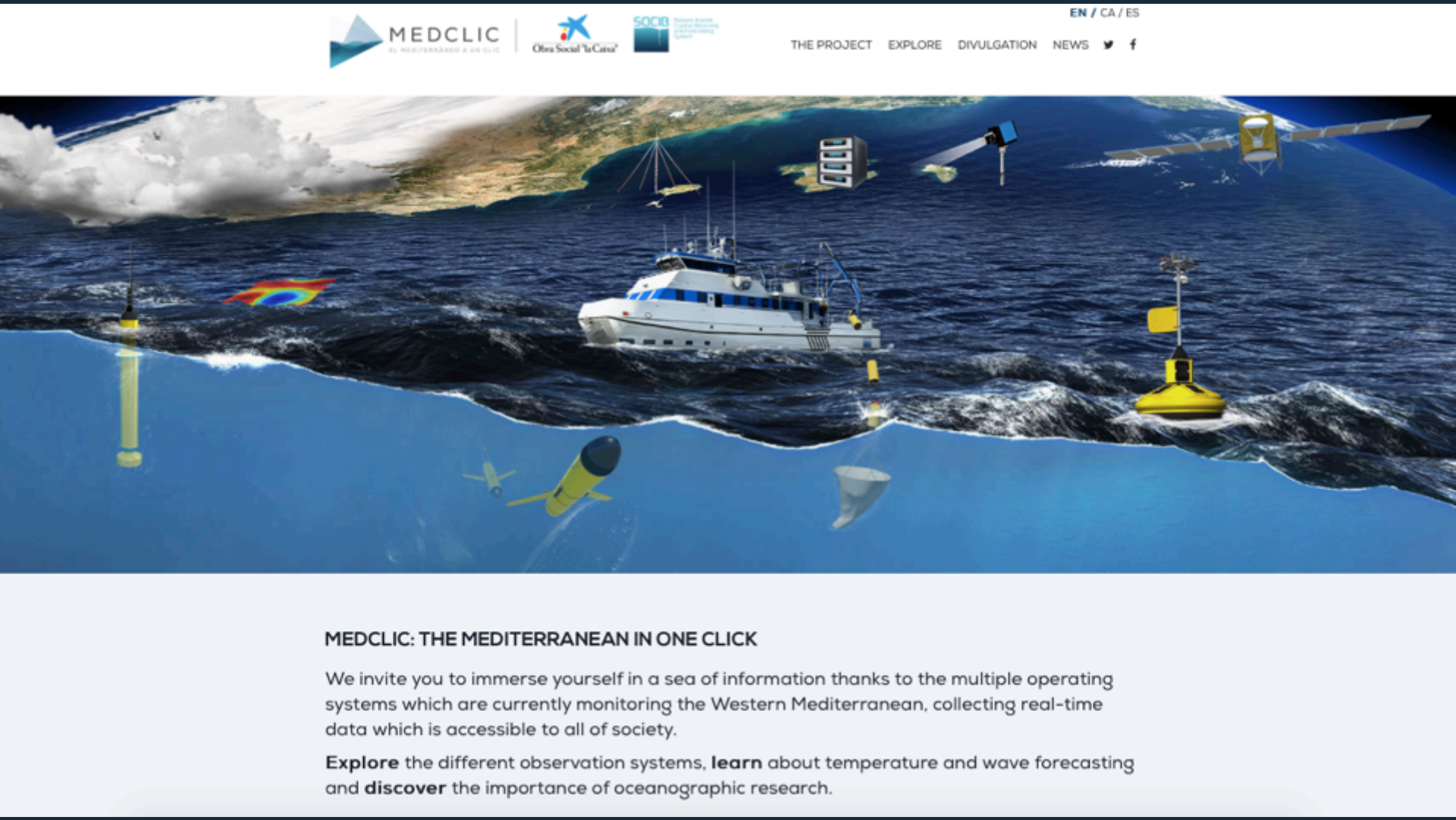
3 Messages:

1. Changes in Science: in how we do science and in Ocean Observation.
2. Mediterranean leadership and new Ocean Observatories/Infrastructures; the SOCIB case & some examples; connecting pieces of an N dim. Planet Ocean puzzle.
3. Changes in how science interacts with society: “Science with and for Society”.

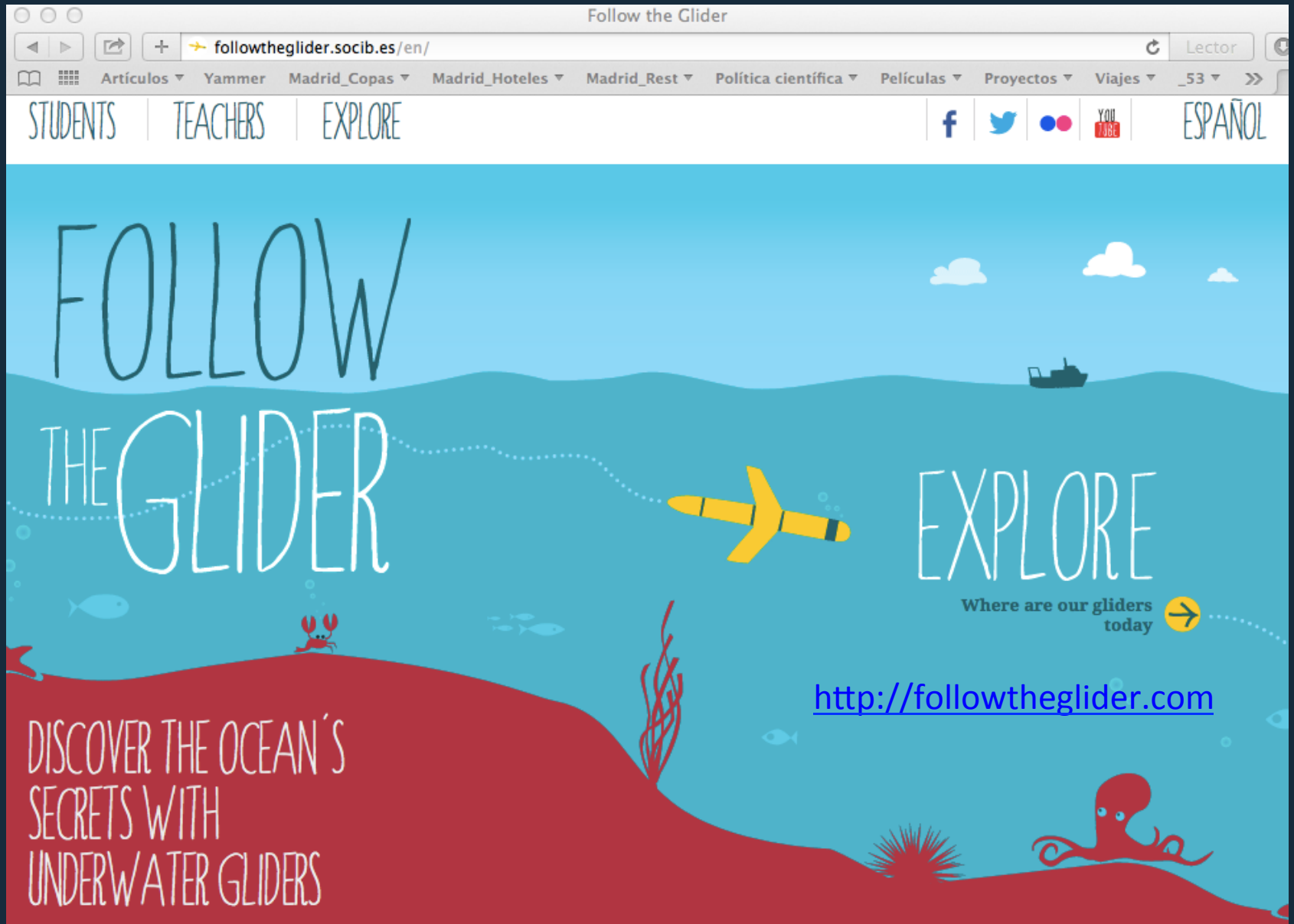
SOCIB Outreach and Education; MEDCLIC

NEW PHASE COMMUNITY ENGAGEMENT; "*We are entering a new phase of community engagement in which scientists and society, educators, are encouraged to use the data, provide feedback on data access ease and quality and in the process, expand our knowledge on the coastal oceans*" – Fulweiler, Gawarkiewicz, Davis, OOI, EOS, August 1st, pag. 9, 2016)

MEDCLIC, www.medclic.es



SOCIB Outreach and Education; MEDCLIC



Summary: 3 Messages

1. Changes in Science: in how we do science and in Ocean Observation.
2. Mediterranean leadership and new Ocean Observatories/Infrastructures; SOCIB examples connecting pieces.
3. Changes in how science interacts with society: “Science with and for Society”.

INTEGRATION & COOPERATION: combining Excellent Science with IMPACT ON SOCIETY….