Workshop IPEE/CLS – 3-FEB-2010

CLS
COLLECTE LOCALISATION SATELLITES

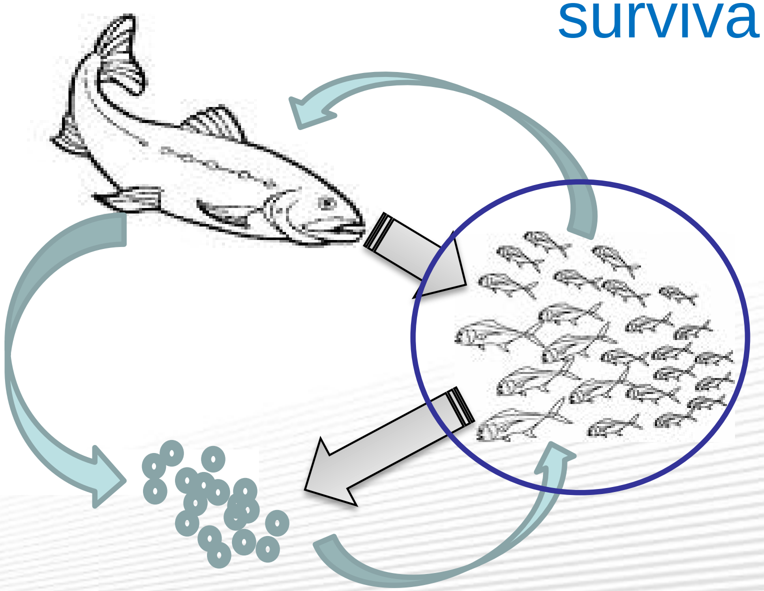
Predicting habitats, behaviours, and population dynamics of large oceanic predators

CLS, MEMMS (Marine Ecosystems Modelling and Monitoring by Satellites), Satellite Oceanography Division, 8-10 rue Hermes, 31520 Ramonville, France

Drivers of behaviour

SURVIVING = Feeding
+ Avoiding unfavourable environment (C, O_{2}, …)
+ Avoiding predators

REPRODUCING = Meeting congeners
+ Optimizing the chance of larvae survival (cf. above)



Micronekton organisms at the intermediate trophic level (i.e., MTL: Mid-Trophic Level) are both prey of adult and predator of eggs and larvae

MTL is a critical component of the system to understand and predict habitats and behaviours of large fish.

For marine mammals (seabirds and most sharks), MTL is key factor for feeding only.

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Outline

I - Modeling the micronekton

II - Modeling the habitats

III - Modeling the movements & behaviours

IV - Modeling the population dynamics

V – Modeling the anthropogenic impact

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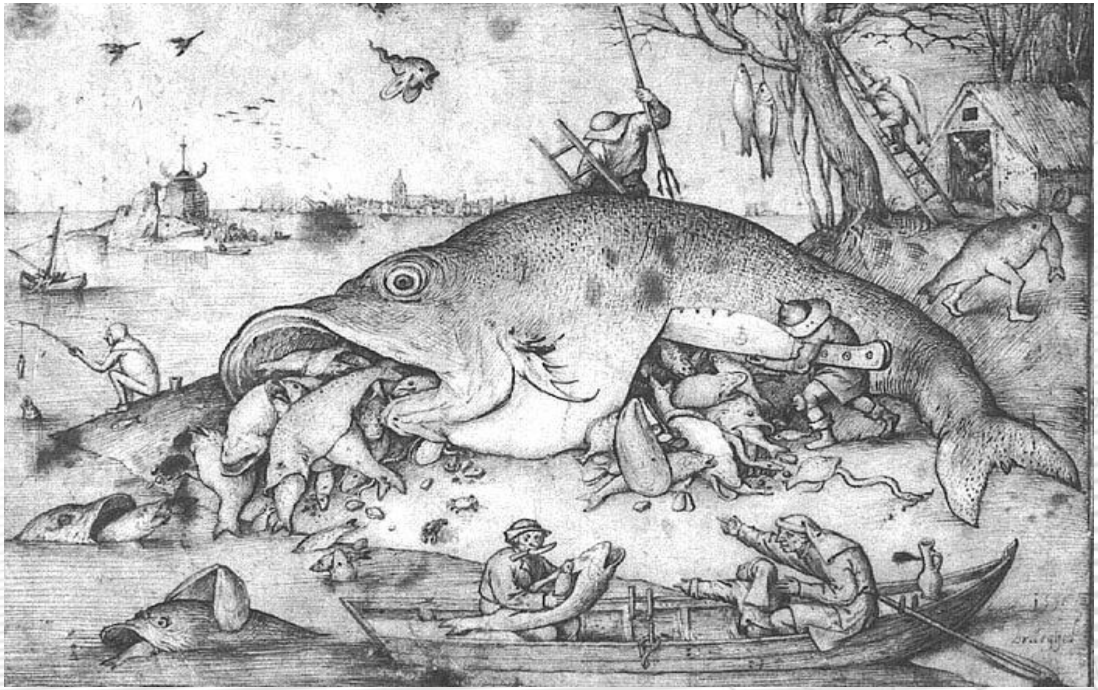
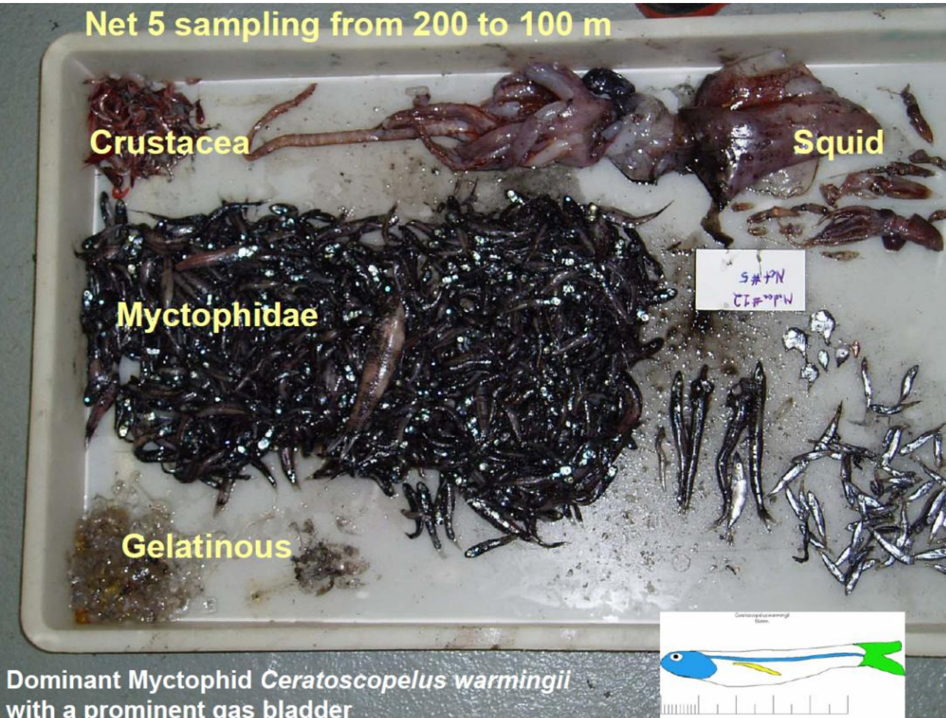
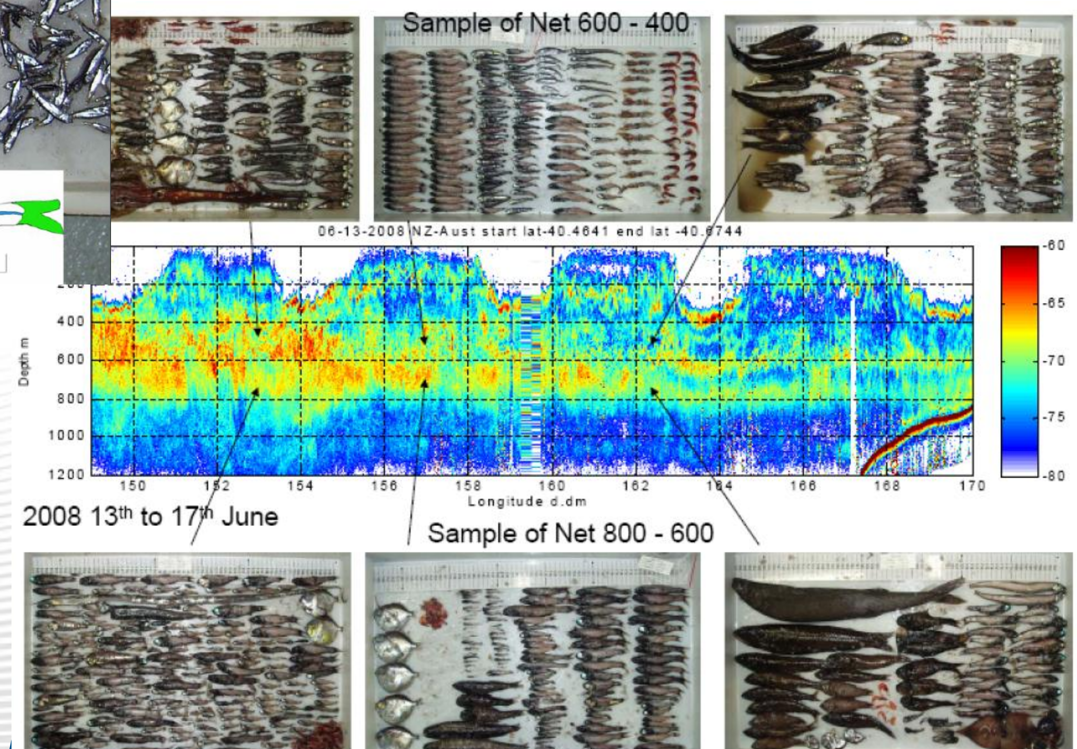
Part I – Modeling the micronekton (mid-trophic level)



The micronekton



Dominant Myctophid *Ceratoscopelus warmingii* with a prominent gas bladder



Credit:
Rudy KLOSER, CSIRO, Australia
Frédéric MENARD, IRD, France

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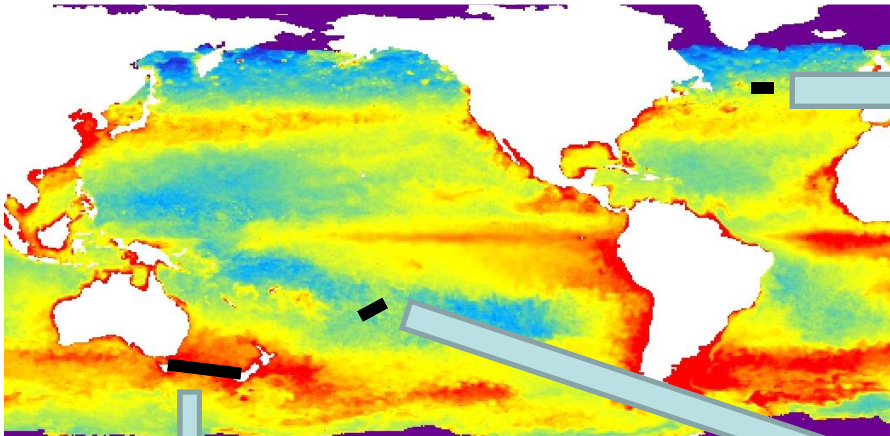
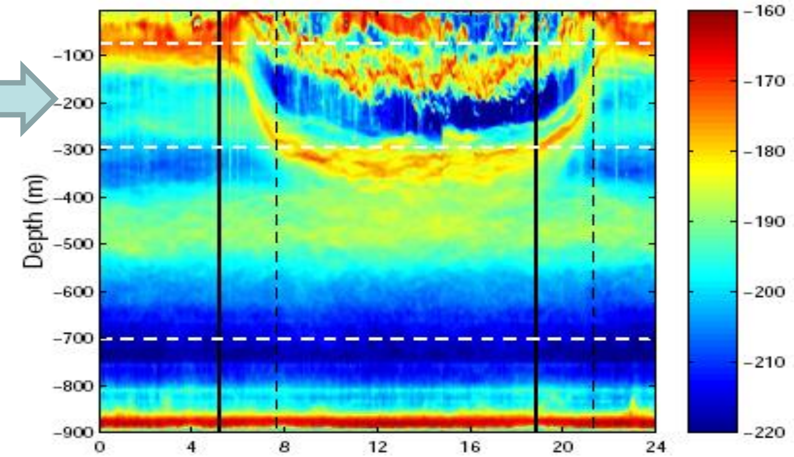
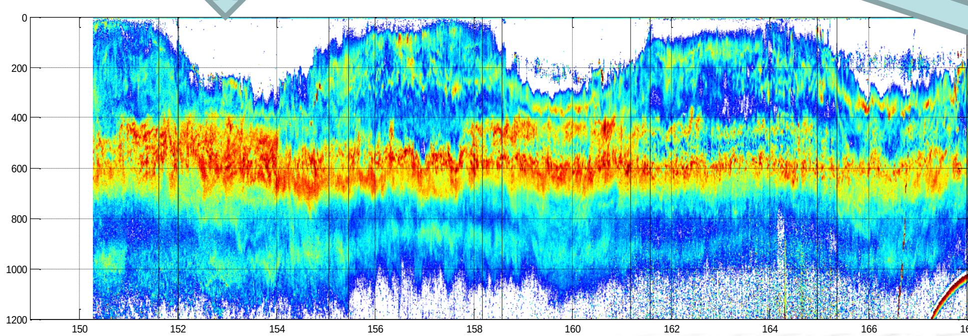
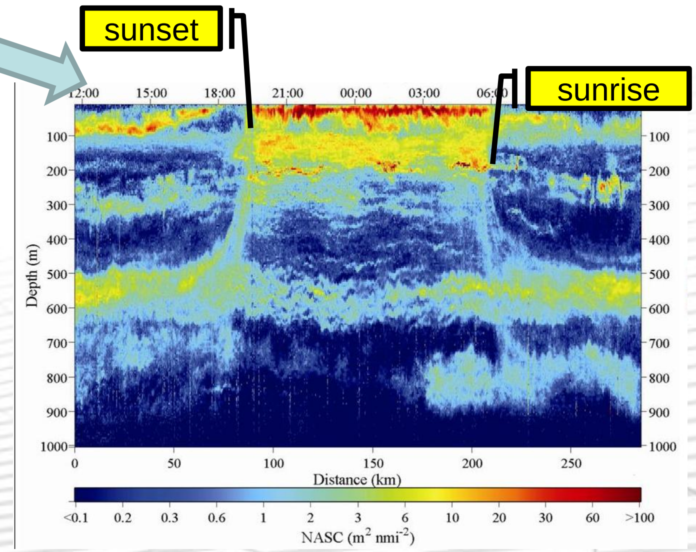
Vertical migration









All the pelagic ecosystem is structured vertically and characterized by diel migration of many (but not all) organisms

Credit: Nils olav HANDEGARD, IMR, Norway
Rudy KLOSER, CSIRO, Australia
Réka DOMOKOS, NOAA, US

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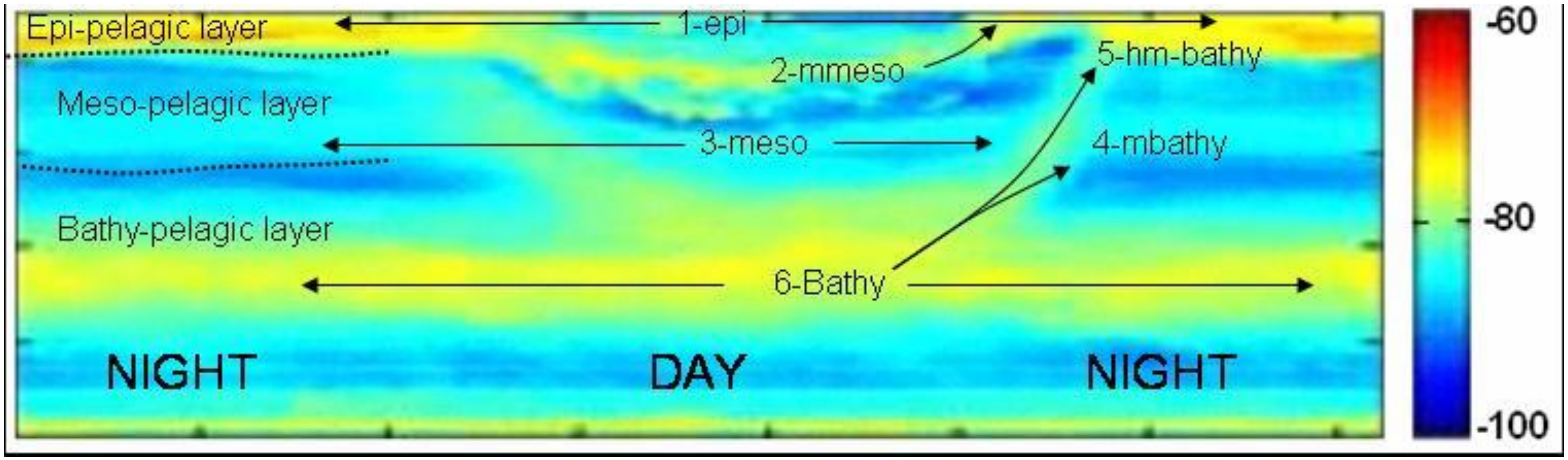
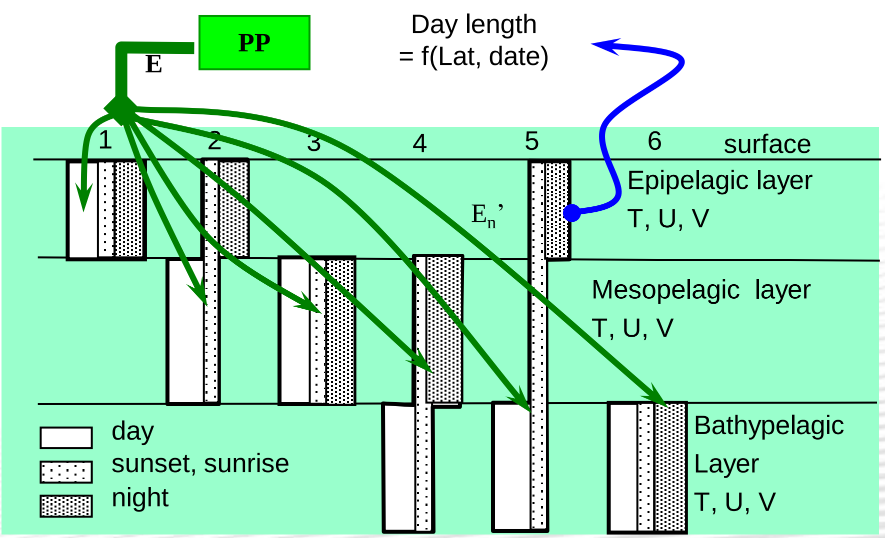
Conceptual model

Mar-ECO station North Atlantic, (IMR, Bergen Norway) showing acoustic detection of micronekton





A model of micronekton (small prey organisms)

The MODEL: 6 functional groups in 3 vertical layers. Three components exhibit diel vertical migrations, transferring energy from surface to deep layers.

The source of energy is the primary production PP.

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Reference

Contents lists available at ScienceDirect

Progress in Oceanography

journal homepage: www.elsevier.com/locate/pocean

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PROGRESS IN OCEANOGRAPHY

Bridging the gap from ocean models to population dynamics of large marine predators: A model of mid-trophic functional groups

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A R T I C L E I N F O

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A B S T R A C T

The modeling of mid-trophic organisms of the pelagic ecosystem is a critical step in linking the coupled physical–biogeochemical models to population dynamics of large pelagic predators. Here, we provide an example of a modeling approach with definitions of several pelagic mid-trophic functional groups. This application includes six different groups characterized by their vertical behavior, i.e., occurrence of diel migration between epipelagic, mesopelagic and bathypelagic layers. Parameterization of the dynamics of these components is based on a temperature-linked time development relationship. Estimated parameters of this relationship are close to those predicted by a model based on a theoretical description of the allocation of metabolic energy at the cellular level, and that predicts a species metabolic rate in terms of its body mass and temperature. Then, a simple energy transfer from primary production is used, justified by the existence of constant slopes in log–log biomass size spectrum relationships. Recruitment, ageing, mortality and passive transport with horizontal currents, taking into account vertical behavior of organisms, are modeled by a system of advection–diffusion-reaction equations. Temperature and currents averaged in each vertical layer are provided independently by an Ocean General Circulation Model and used to drive the mid-trophic level (MTL) model. Simulation outputs are presented for the tropical Pacific Ocean to illustrate how different temperature and oceanic circulation conditions result in spatial and temporal lags between regions of high primary production and regions of aggregation of mid-trophic biomass. Predicted biomasses are compared against available data. Data requirements to evaluate outputs of these types of models are discussed, as well as the prospects that they offer both for ecosystem models of lower and upper trophic levels.

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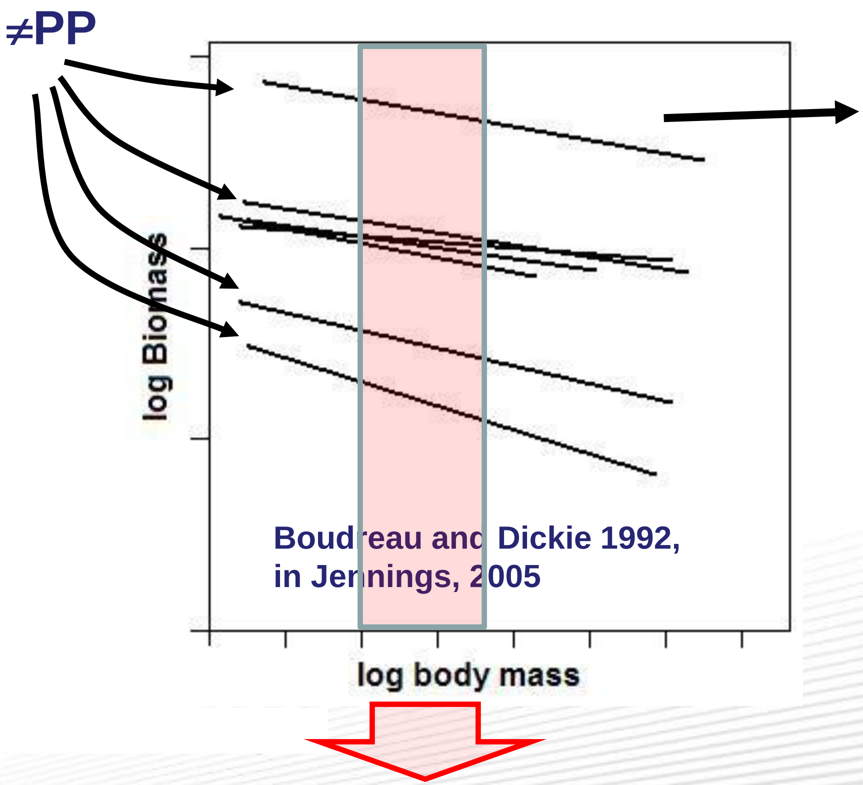
Skip the details: go to results

Dynamics of a functional group

Marine Ecosystem:

- organism size largely determines its function in the ecosystem
- The marine ecosystem is characterized by a size-continuum
- there is an obvious size-abundance relationship



Boudreau and Dickie 1992, in Jennings, 2005

Similar slopes suggest invariant processes leading to constant energy transfer through size spectrum

Lindeman (1942), Schaeffer (1965), Ryther (1969), and Iverson (1990):

$$F'_{yr} = P_{yr}' \cdot E^{l} \cdot c$$

(with l the trophic level)

Vinogradov (1953) : c= const=12x10^{-3}(g C)x2.4 x 3.3 = 0.0948, with 2.4 the ratio between fish dry weight (g) and carbon and 3.3 the ratio between fish wet weight (g) and fish dry weight (g)

Mid-Trophic Level Functional Group
Is a size window of the size spectrum: average trophic level n = 2.5 after phytopk

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Dynamics of a functional group

Mid-Trophic Level Functional Group is a size window of the size spectrum (with an average trophic level n = 2.5 after phytopk)

BUT… size or weight is linked to time (of development)
AND… time (of development) is linked to temperature (they are poikilotherm animals).

THUS, it seems more logical to define the (thermo-) dynamics of the functional group based on these two fundamental variables:
time and temperature

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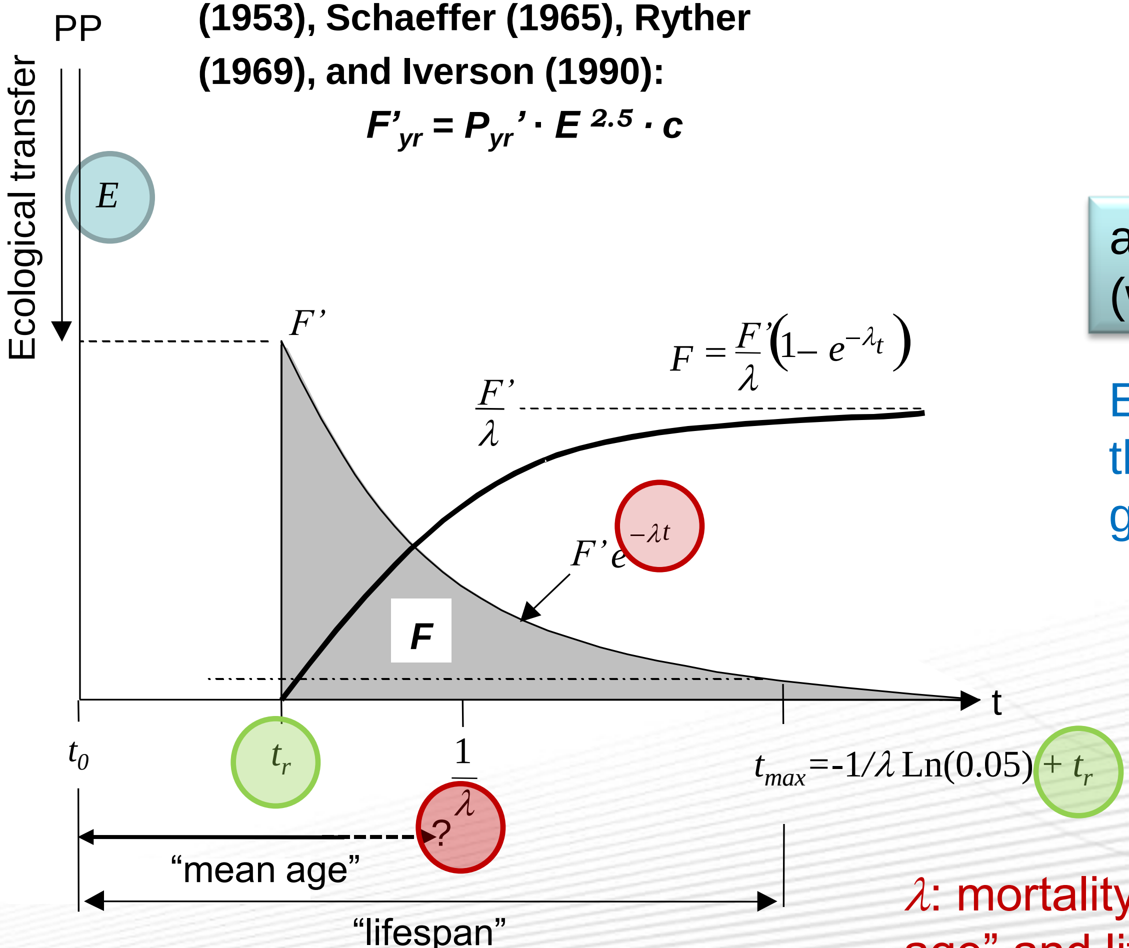
Functional group = multi-species population

Lindeman (1942), Vinogradov (1953), Schaeffer (1965), Ryther (1969), and Iverson (1990):

$$F'_{yr} = P_{yr}' \cdot E^{2.5} \cdot c$$



Lehodey (2001)

a window in the biomass size (weight) spectrum defined by:

E: energy transfer from PP to the functional micronekton group (trophic level ~2.5)

t_r: time of development for reaching the minimum size (weight), linked to temperature

λ: mortality coefficient, control the "mean age" and lifespan, (i.e. the turn over) of the population, also linked to temperature.

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Parameterizing λ

Can we link λ to meaningful biological parameters that are used to characterize the turnover of a population, i.e., generation time (~age at maturity t_m or lifespan t_{max})?

substituting t_{max} by previous definition of lifespan (i.e., $-1/\lambda \, \mathrm{Ln}(0.05) + t_r$), we obtain:

$$t_m^{0.957} = -\frac{\ln(x)}{10^{0.5496} \cdot \lambda} + \frac{1}{10^{0.5496}} \cdot t_r$$

that, given the range of standard error of the original regression, can be simplified as:

$$t_m = 1/\lambda + 1/3\, t_r$$

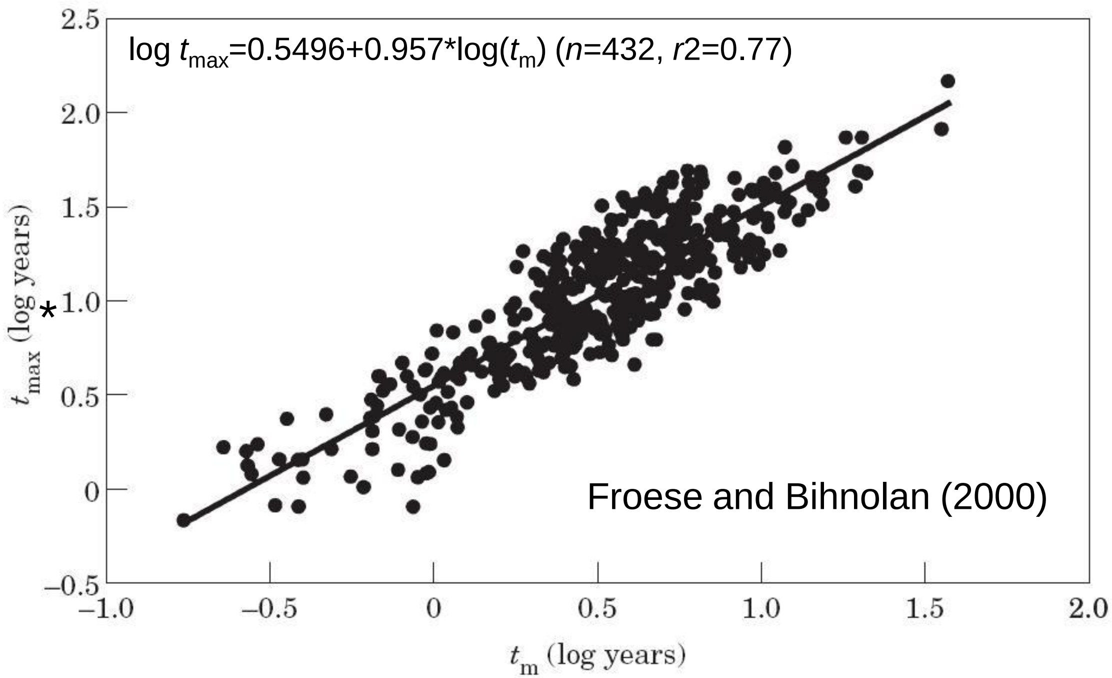

FIG. 4. Relationship between life span (t_{max}) and length at first maturity (t_m).

* t_{max} = age at L_∞*0·95 (Taylor, 1958)

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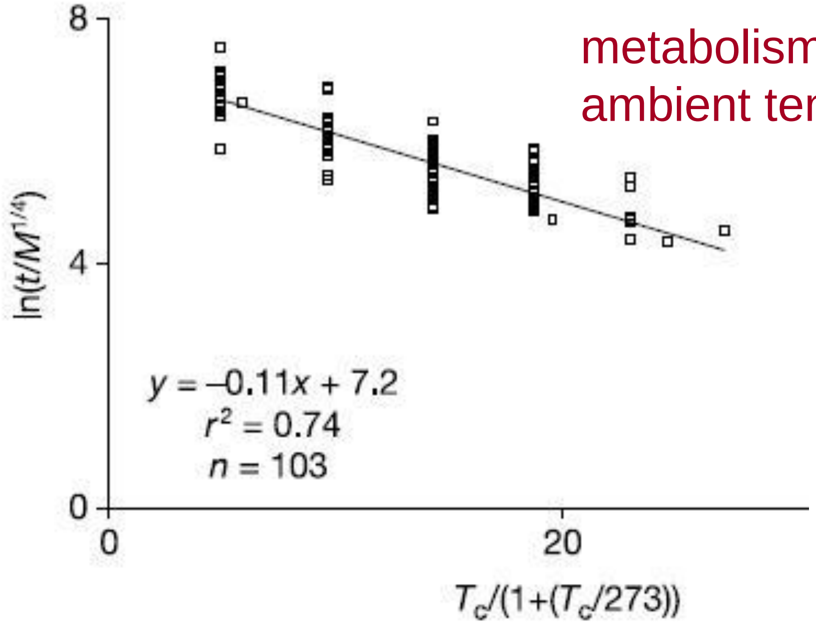
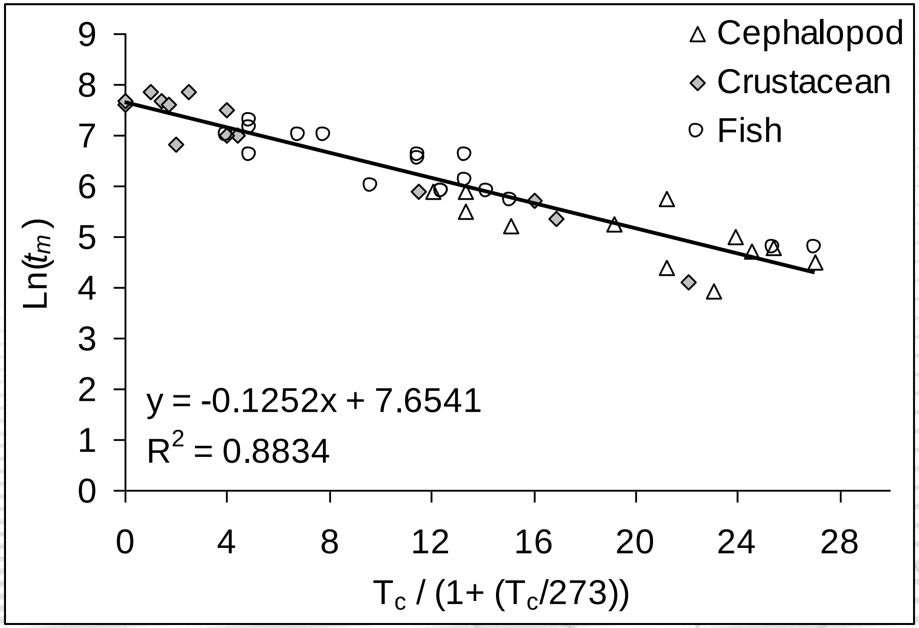
Temperature and development



metabolism of ectotherm animals is linked to ambient temperature

we obtain similar result using age at maturity and ambient temperature of micronekton species

Gillooly et al. (2002) propose a model explaining relation between temperature and development time of post-embryonic (hatching to adult) zooplankton species (rotifers, copepods and cladocerans) incubated at different constant temperatures ranging from 5 to 30 C



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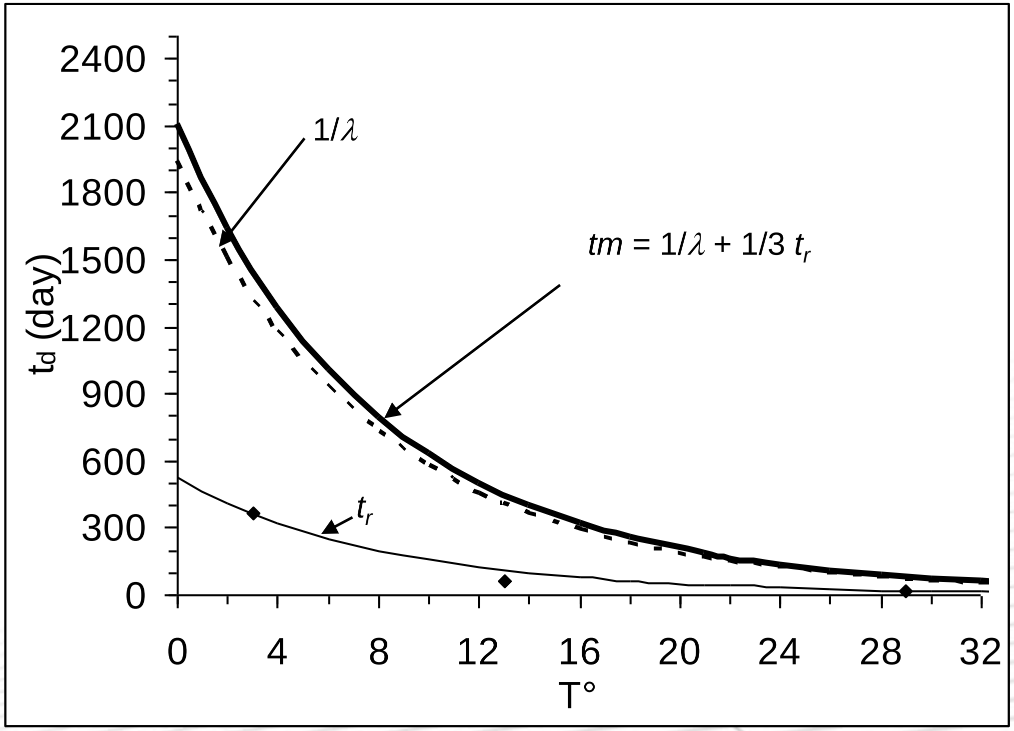
Dynamic of a MTL component

λ is the mortality coefficient that control the turn over of the MTL (Mid-Trophic Level) component, ~ the time of development to the age at maturity

λ is linked to temperature

t_r is the recruitment time, i.e. the minimum time between “birth” coinciding with the apparition of PP and the age at which organisms reach a size large enough to be included (“recruited”) in the MTL



based on a few obs., we fixed t_r to the development time needed to reach a weight of 1g, which is also linked to temperature (with same slope) and lead to $t_r \sim ¼\, t_m$)

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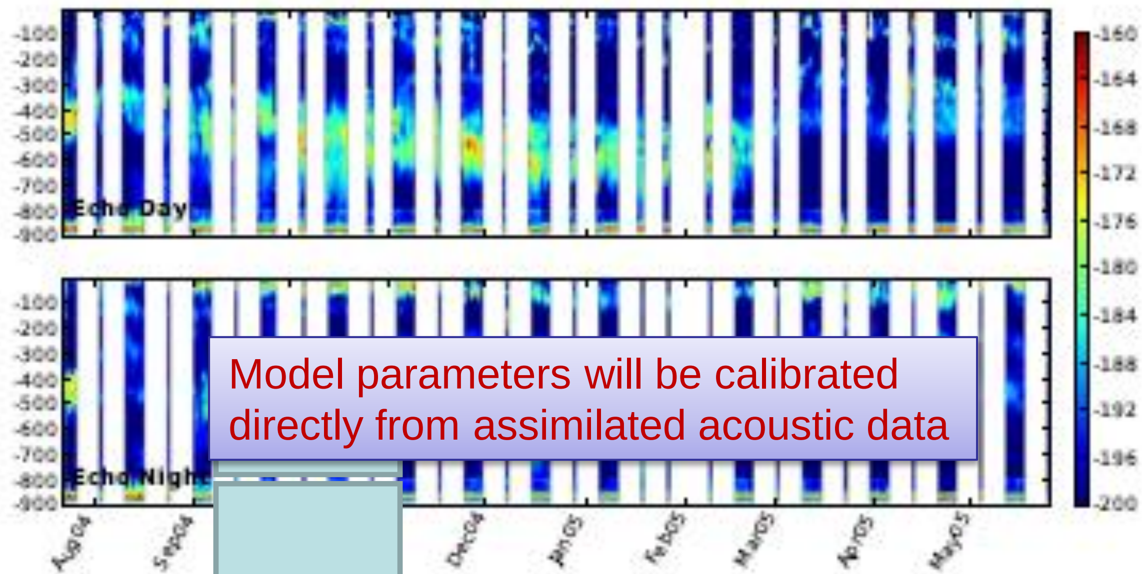
Energy transfer to functional groups

MarEco lander

IMR, Bergen

Kindly from N. O. Handegard.



Model parameters will be calibrated directly from assimilated acoustic data

	Mid-trophic functional groups					
Nb of Layers	epi	meso	m-meso	bathy	m-bathy	hm-bathy
0	0	0	0	0	0	0
1	1	0	0	0	0	0
2	0.34	0.27	0.39	0	0	0
3	0.17	0.10	0.22	0.18	0.13	0.20

Matrix of Energy transfer coefficients used for the 3-layer 6-components mid-trophic levels model, according to the depth and the number of corresponding layers

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Spatial Dynamics

Age '0': $S_{nij}^{0} = cE_n P_{ij}$

Primary production

Oceanic currents

Temperature

Ages (0-tr]: Mid-trophic production

$$\frac{\partial S_n^m}{\partial t} = D\left(\frac{\partial^2 S_n^m}{\partial x^2} + \frac{\partial^2 S_n^m}{\partial y^2}\right) - \frac{\partial}{\partial x}(\hat{u} S_n^m) - \frac{\partial}{\partial y}(\hat{v} S_n^m), \quad n = 1...6, m = 0...tr_{max}$$

$$S_n^m = S_n^{m-1}, \text{ for } 1 \le m \le \lfloor tr_{ij} \rfloor$$

Neumann boundary conditions (impermeability):

$$\hat{u}_{ij} = \hat{v}_{ij} = \frac{\partial S_{ij}}{\partial x} = \frac{\partial S_{ij}}{\partial y} = 0, \quad \forall (i,j) \in \partial\Omega$$

Recruits to mid-trophic populations:

$$F'_{nij} = S_{nij}^{\lfloor tr_{ij} \rfloor}$$

Mid-trophic biomass

$$\frac{\partial F_n}{\partial t} = D\left(\frac{\partial^2 F_n}{\partial x^2} + \frac{\partial^2 F_n}{\partial y^2}\right) - \frac{\partial}{\partial x}(\hat{u} F_n) - \frac{\partial}{\partial y}(\hat{v} F_n) - \lambda F_n + F_n'$$

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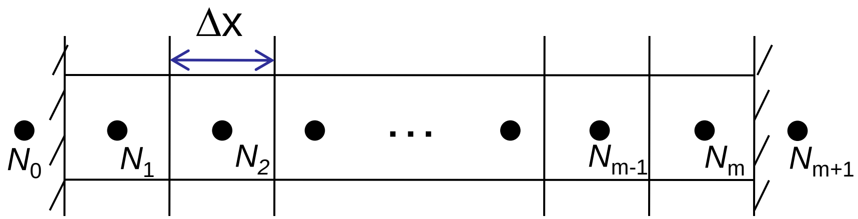
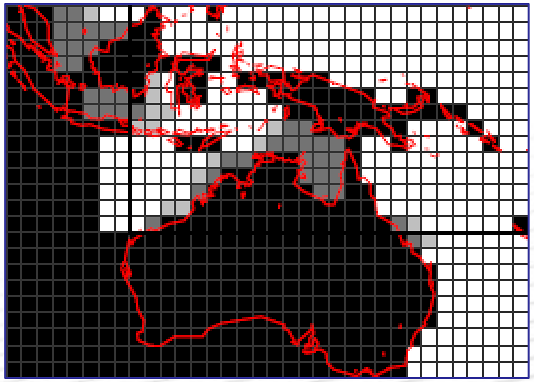
Model = numerical solution of PDEs

Computational GRID



3-layer ocean MASK (etopo2 data)



Finite difference approximation:

- upwind differencing for advection terms
- two-point centered-space differences

Closed boundaries

Initial conditions (climatological “spin-up”)

ADI numerical solver (unconditional convergence)

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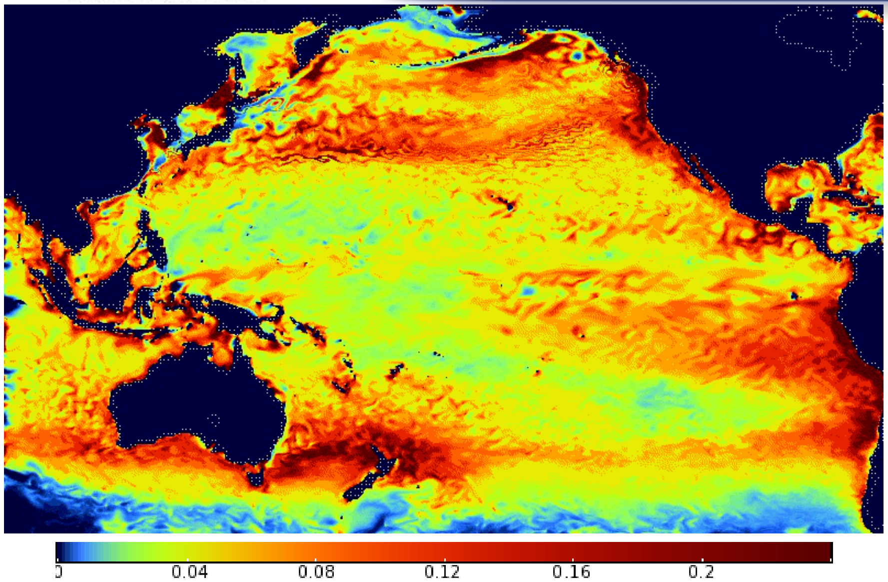
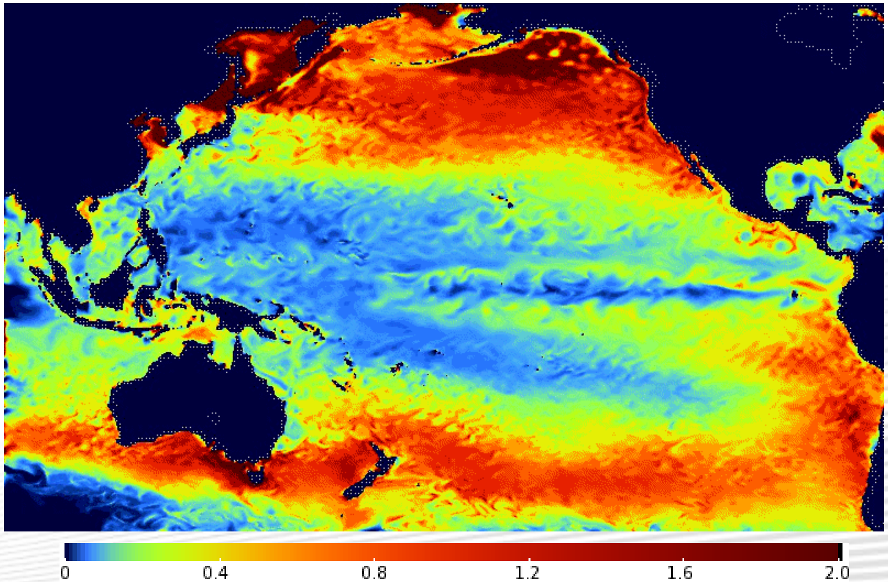
Results: P/B epipelagic micronekton



Epipelagic (daytime) micronekton (2005)

Production (g m^{-2} d^{-1})



Biomass (g m^{-2})

¼ deg x 6 day

Physical fields from MERCATOR (http://www.mercator-ocean.fr/)
Satellite derived Primary production

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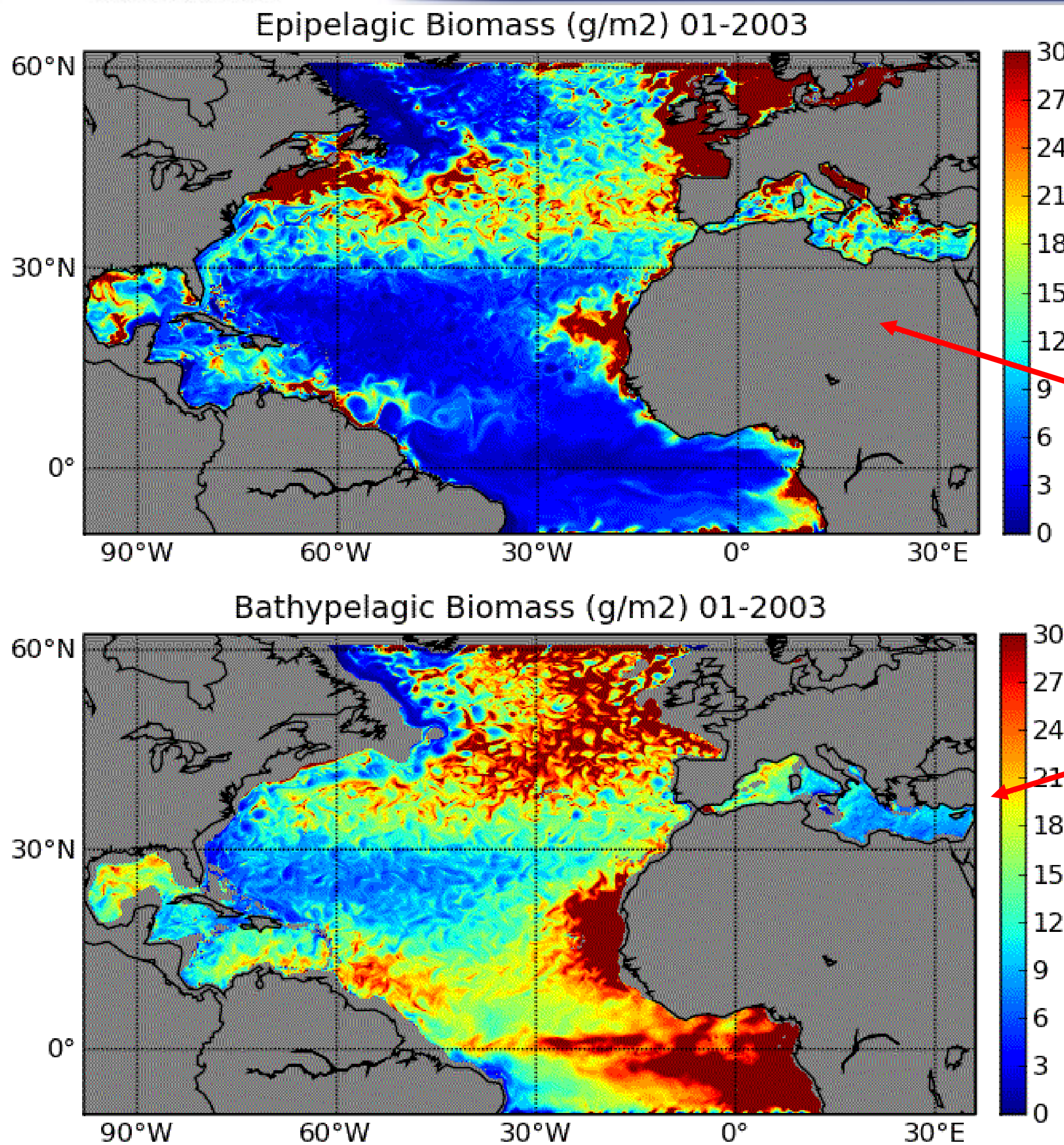
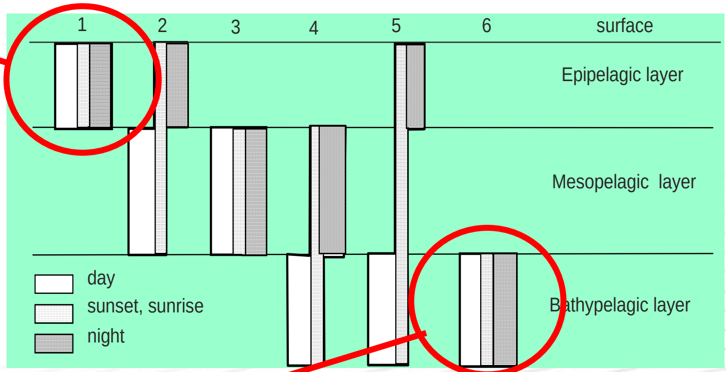
Results: day/night epipelagic biomass



1/12th deg x 6 day

Physical fields from MERCATOR (http://www.mercator-ocean.fr/)
Satellite derived Primary production



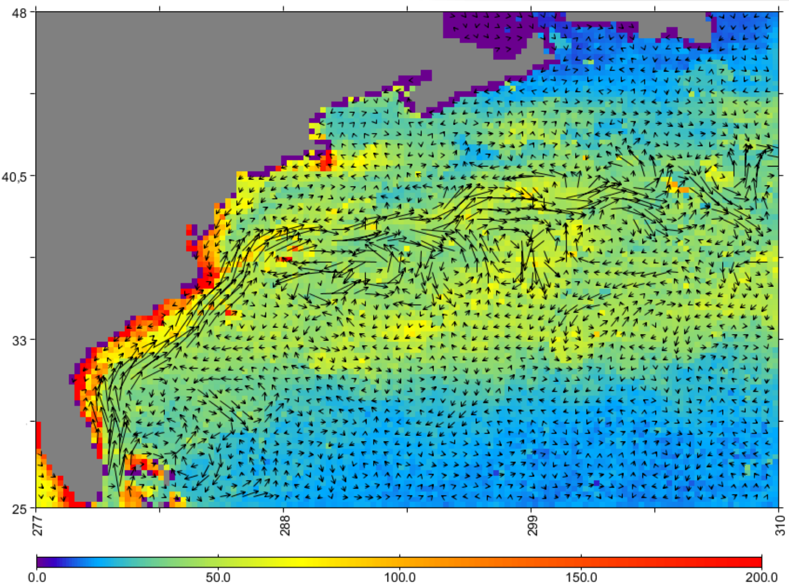
References:

Lehodey et al. (1998). *Fish. Oceanog.*

Lehodey, (2001). *Prog. Oceanog.*

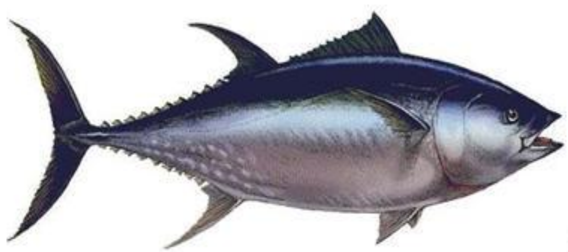
Lehodey et al. (*accepted*) *Prog. Oceanog.*

Observed Tracks and predicted MTL

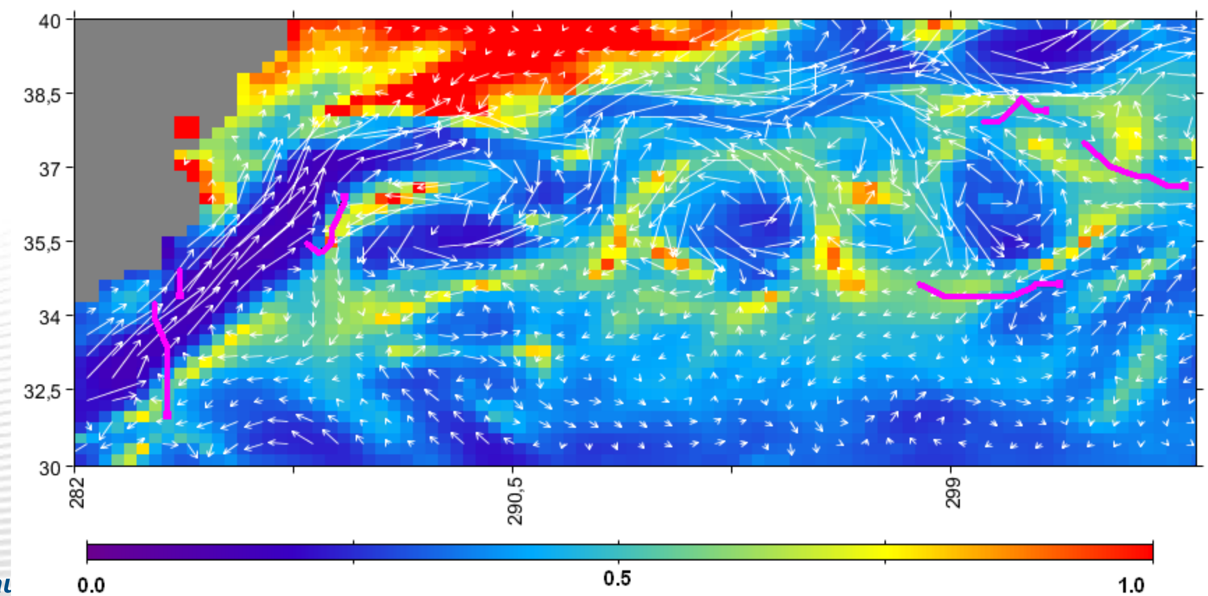


Thanks to data assimilation in ocean circulation models (e.g., MERCATOR-OCEAN), the physics of ocean is now becoming highly realistic and match very well the sea color observed by satellites, and that is used to compute primary production.

This realistic environmental forcing is used to simulate MTL.



Tracks of Atlantic bluefin tuna tagged in the Gulf of Maine and swimming in the Gulf Stream superimposed on predicted surface MTL and currents



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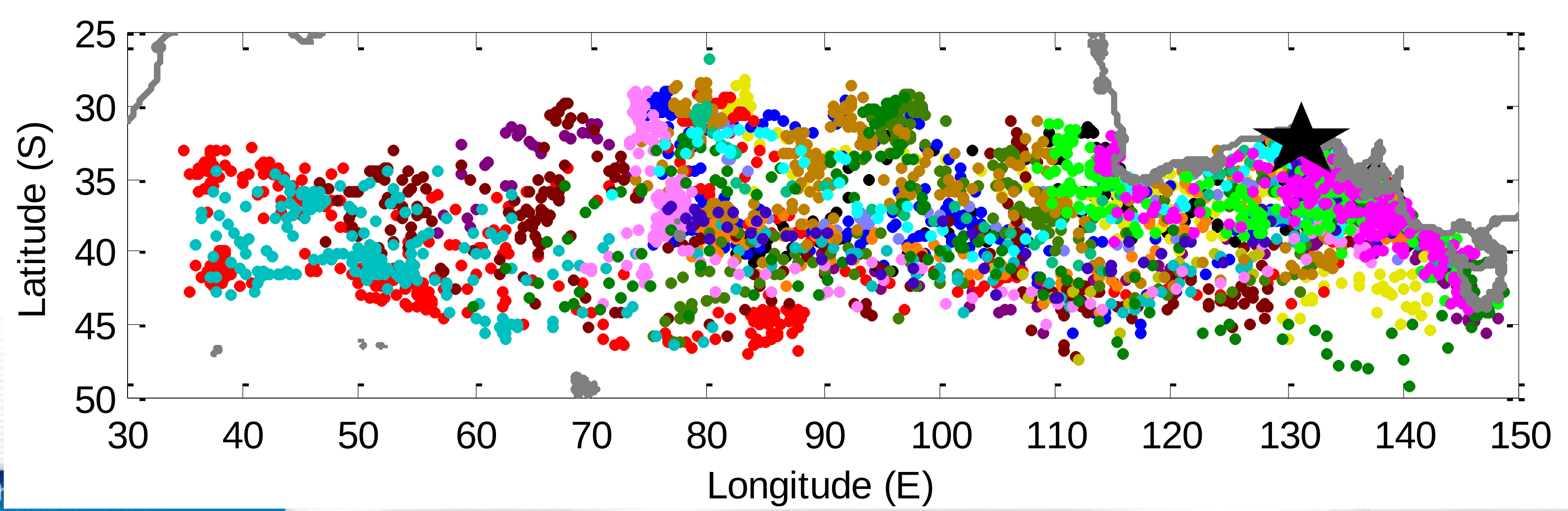
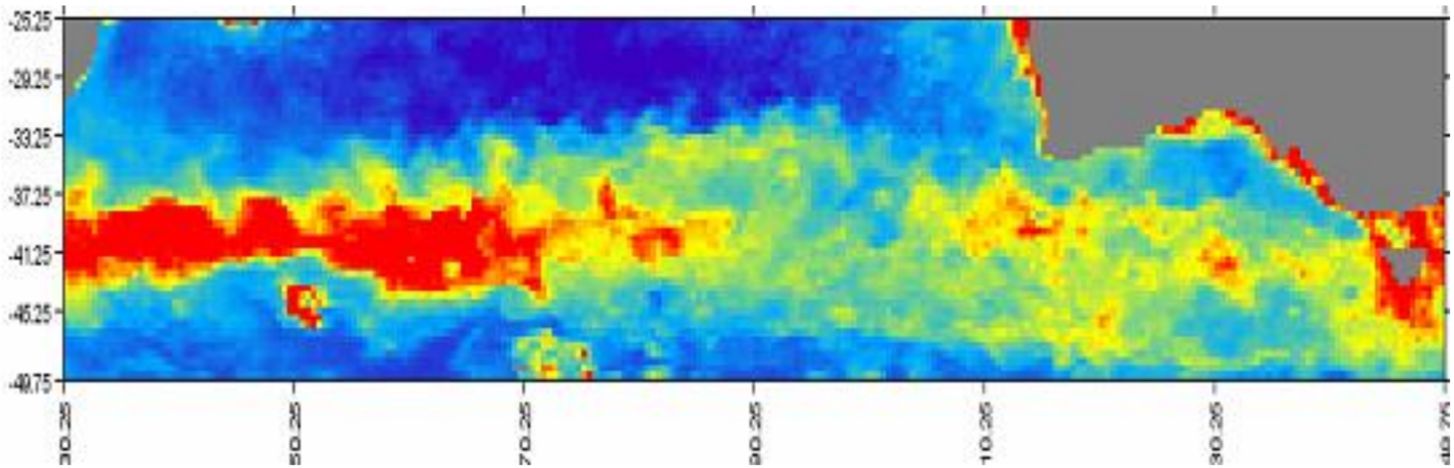
Observed Tracks and predicted MTL

- 1998 – 2000
- Mk7 WC tags
- South Indian Ocean
- N = 19, n = 6221 days
- t_i = 141 – 496 days

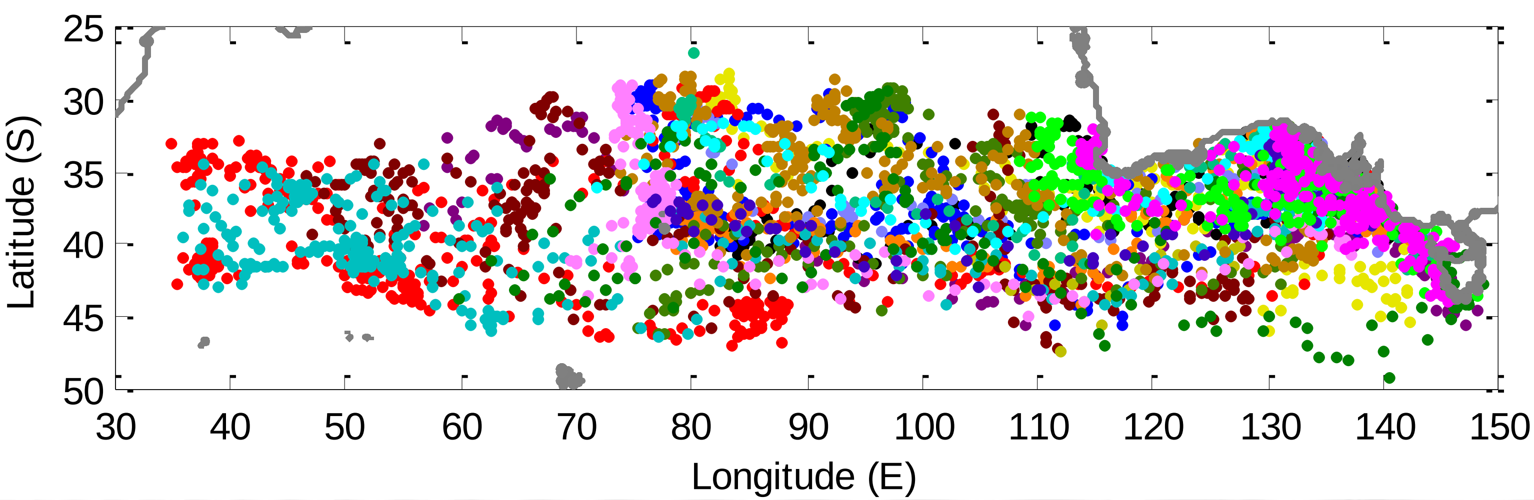
Credit: Sophie Bestley,
CSIRO, Australia



Observed Tracks and predicted MTL



Average (1998-2000) primary production



SBT tracking data (1998-2000) from S. Bestley (CSIRO)

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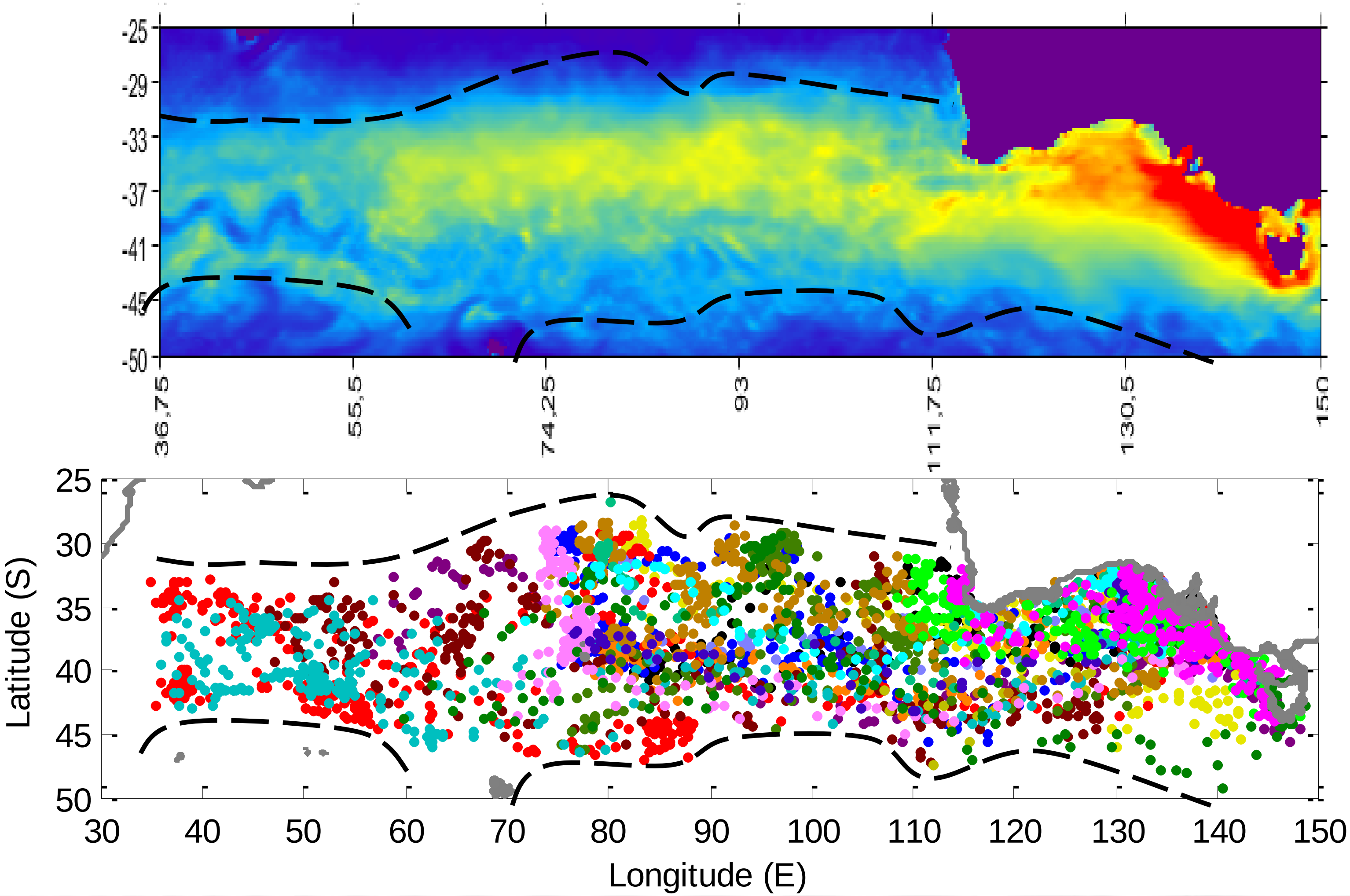
Observed Tracks and predicted MTL



Average predicted epipelagic micronekton for 2002

(1998-00 not yet available!)

SBT tracking data (1998-2000) from S. Bestley (CSIRO)

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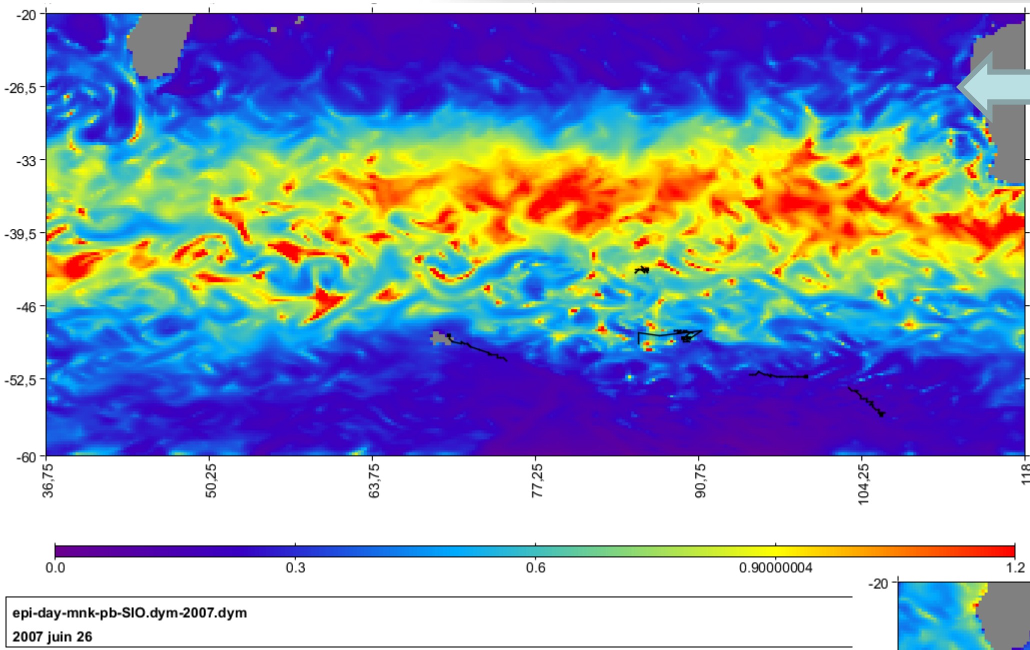
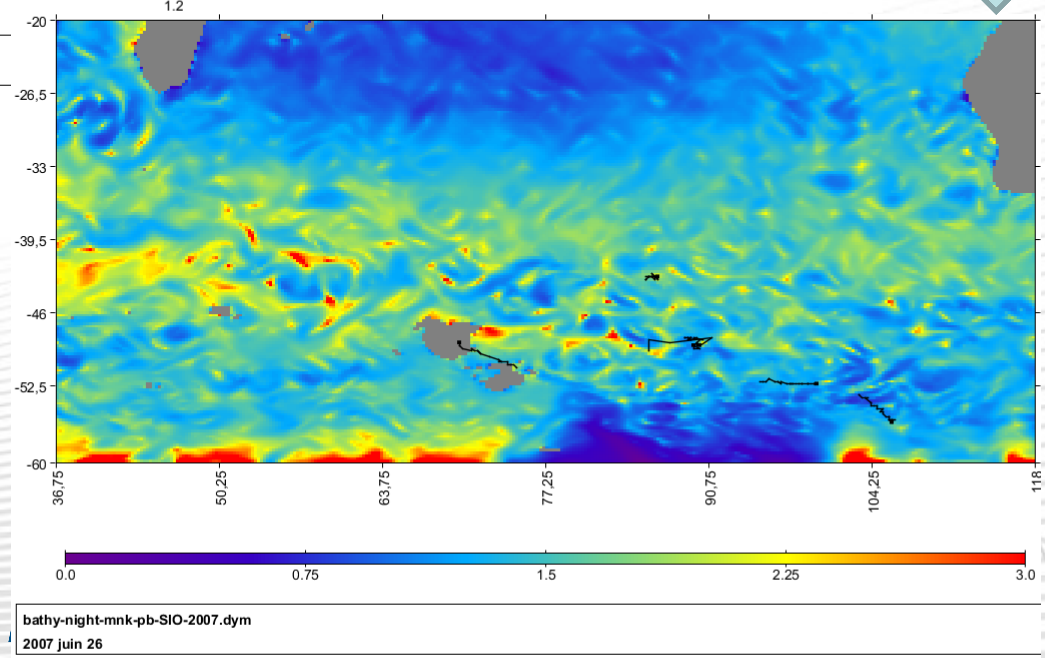
Observed Tracks and predicted MTL



Elephant seals in 2007 and predicted epipelagic micronekton

Idem but with bathy (deep) pelagic micronekton



Note:

- latitudinal shift of deep biomass to higher latitudes
- factor x3 for deep biomass
- very high concentration at the boundary of the domain (need to be extended for this species).

<u>Elephant seals feed on deep forage, diving continuously between 400 and 1000 m</u> !

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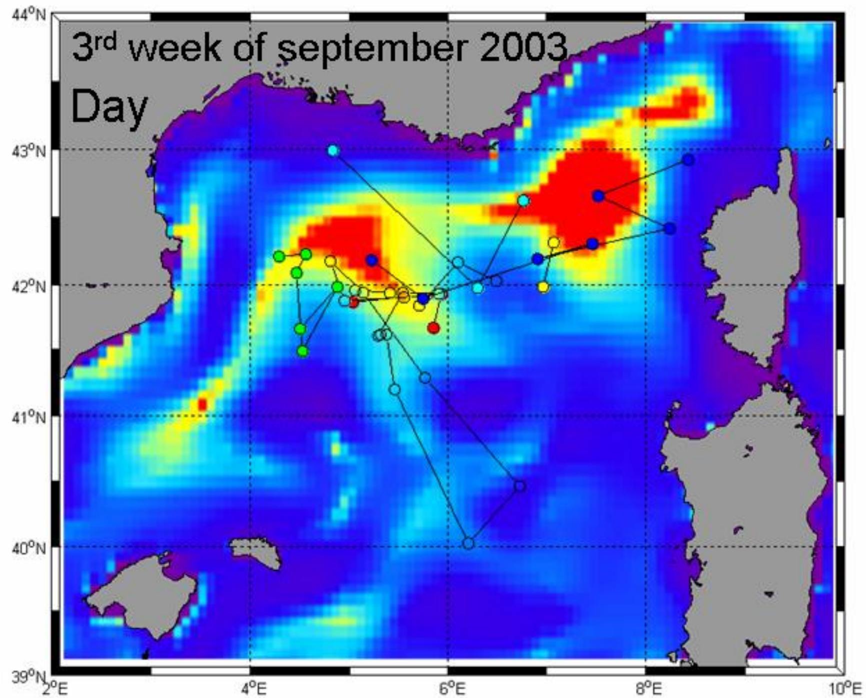
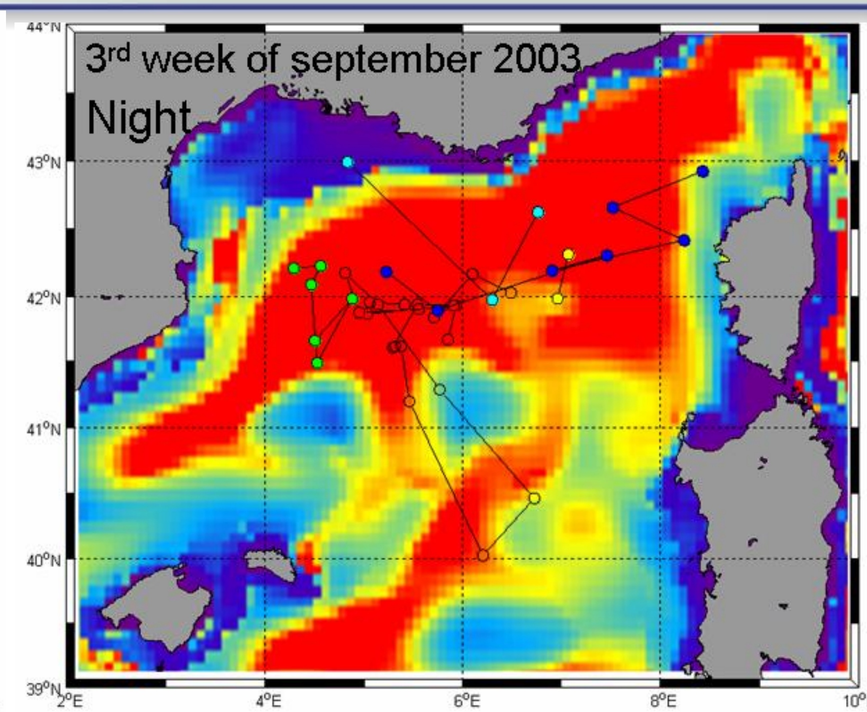
Observed Tracks and predicted MTL

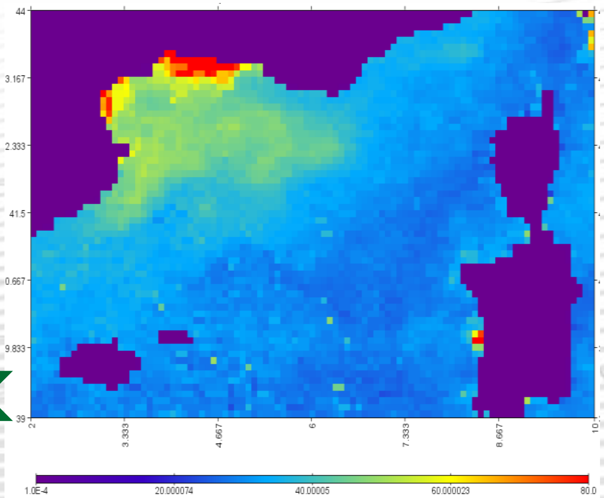




Positions of whales (*Balaenoptera physalus)* (one color by individual) tracked with satellite tags (Cédric Cotté, CEBC) superimposed on predicted micronekton in the surface layer during day and night for the 3rd week of Sep 2003.

Prey sp.: small fish, squids and crustaceans (Mysids and krill).

Primary production (Seawifs derived) for the same week decoupled !



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Conclusion

- MTL modeling is a promising key step to understand behaviour of large marine animals
- Predator species exploit different components of MTL according to their preference and physical abilities
- Knowing these species characteristics and the biomass distribution of surface, subsurface and deep MTL forage organisms during day and night, we can define, predict and forecast specific habitats (see part II)

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