

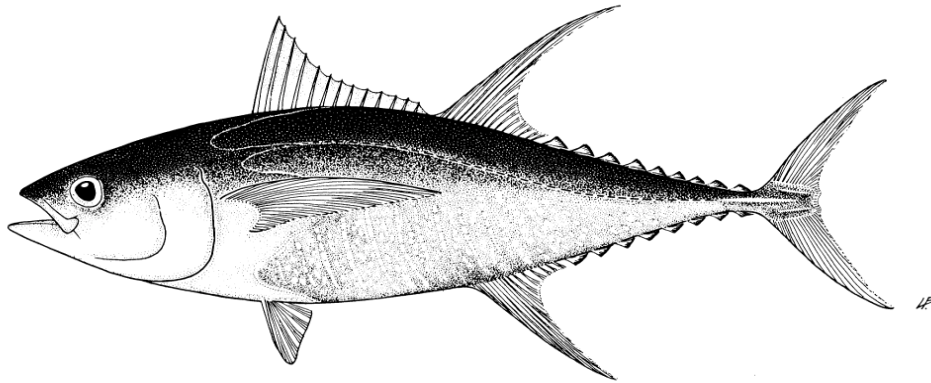


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**Implementation of SEAPODYM model for the South Pacific albacore stock; focus on the
New Caledonia EEZ**

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INTRODUCTION

This study is focused on the albacore tuna in the South Pacific region and the relationship between stock abundance, fisheries and environment at global and local spatial scales. Adult albacore are primarily caught by distant water longline fleets and domestic longline fisheries of several Pacific Island countries between 10°-30°S, whereas juvenile albacore are mainly targeted by surface fisheries (troll and gillnet) in New Zealand coastal waters and in the central Pacific in the region of the STCZ (Subtropical Convergence Zone) below 30°S. Catch rates in the subequatorial waters peak in December–January and May–July, indicating migration of albacore to the south during early summer and to the north during winter. This migration tends to coincide with the seasonal oscillation of the position of the 23–28° C isotherm of sea surface temperature (Langley, 2004). Albacore distribution and abundance are strongly influenced by environmental conditions such as temperature, dissolved oxygen and food. Tuna diet consists of small crustacean, squid, and fish. All of these forage groups depend on the oceanic primary production. Environmental data from two coupled physical-biogeochemical models were used as input for the ecosystem model SEAPODYM (Spatial Ecosystem and Population Dynamics Model) to estimate forage dynamics, albacore biomass and catch. SEAPODYM was first fed with environmental data from a mixed OPA-ORCA2 global ocean general circulation model (Madec *et al.*, 1998) and PISCES (Pelagic Interaction Scheme for Carbon and Ecosystem Studies) at 2° resolution and fitted to fisheries data (catch-at-age data by region and fisheries size composition data from the South Pacific). We obtained good estimates of albacore biomass, with even better correlations between predicted and observed catches in the southern part of the basin. Then, a regional coupled model composed by ROMS (Regional Oceanic Modeling System) and PISCES was implemented at higher resolution (1/3°) in the south-western Pacific and injected in the global model to focus on New Caledonia EEZ to investigate potential island effects. This paper is a summary of the ZoNéCo (<http://www.zoneco.nc/>) joint project conducted in 2008-2009 by IRD and SPC in Nouméa, in collaboration with CLS in Toulouse. The complete analysis is available in Marchesiello *et al.* (2009). Those results are preliminary and need to be improved in the following years. The longer-term goal is to provide tools for improving the general knowledge of the albacore population dynamics and its management.

METHODS

Although albacore parameterization was made at 2° resolution on a global Pacific basin scale, the studied area was restricted to the south western Pacific between 8°-30°S/143E-170W, which included the New Caledonia EEZ (Figure 1). In this study, we implemented and developed a chain of models for an ecosystem approach to tuna fisheries management. We adapted the existing estimated SEAPODYM parameters and developed a capacity of refinement for the model resolution. This approach required a prior study of the plankton ecosystem and biogeochemical cycles which led to new results on the functioning of this oligotrophic region. The two regional models used for generating oceanographical data were the hydrodynamic model ROMS and the biogeochemical model PISCES. One preliminary step of this study consisted in the validation of the 3D coupled ROMS-PISCES model at 1/3° using data from World Ocean Atlas 2001 (WOA01) and CSIRO Atlas of regional Seas 2006 (CARS06) as well as SeaWiFS satellite data and observations from a sea campaign conducted in the south of New Caledonia EEZ (ZONALIS cruise).

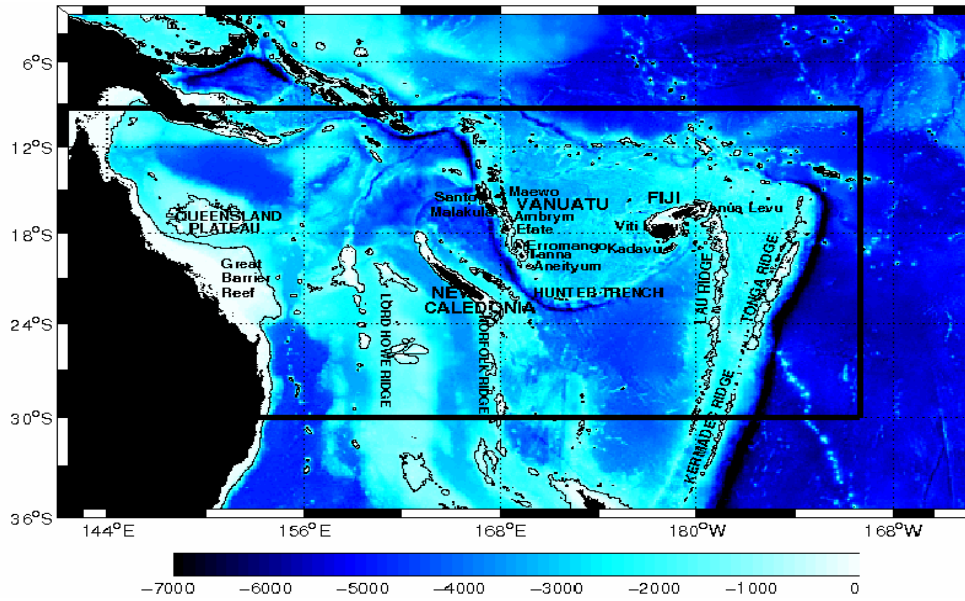


Figure 1. South Pacific topography and studied area (from Couvelard *et al.*, 2008)

The seasonal cycle and data range of each parameter (temperature, mixed layer depth, chlorophyll *a*, nitrate, phosphate) predicted by ROMS-PISCES coupled model were examined and compared visually to observed data (see some examples in the annex). The validated environmental data were then used as input data in the coupled SEAPODYM tuna-forage model (Figure 2).

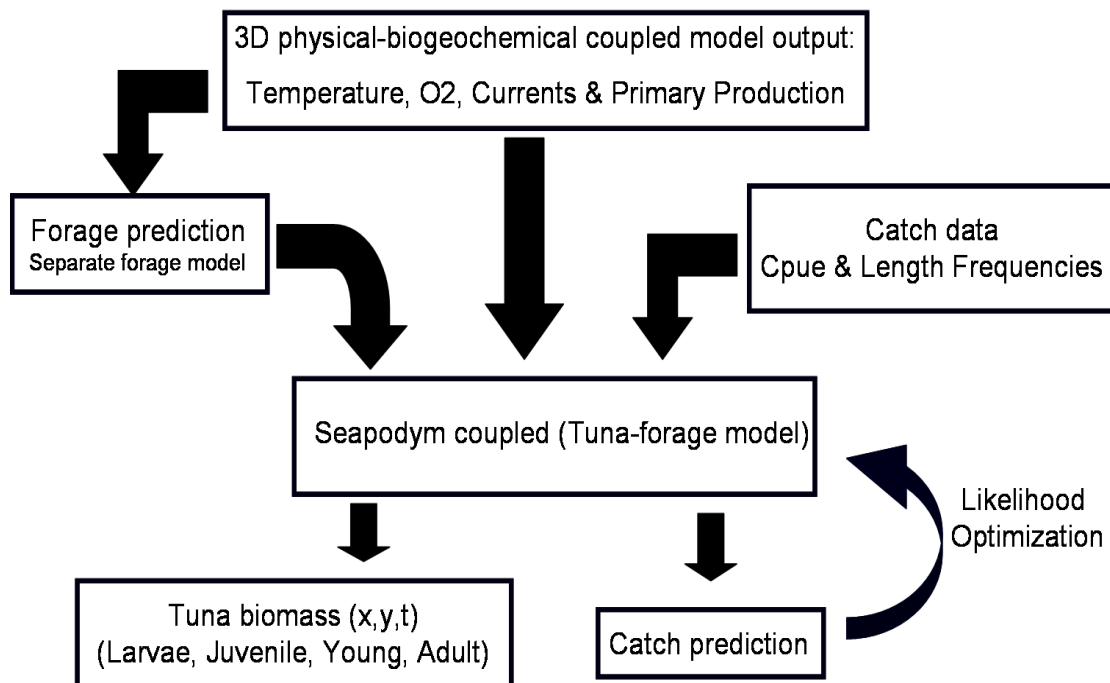


Figure 2. General representation of SEAPODYM

The SEAPODYM model has been developed for the integration of all knowledge available on tuna biology and the pelagic ecosystem, trying to keep at a reasonable level the number of parameters needed for describing the spatial and temporal dynamics of the mid-trophic levels organisms, the tuna populations and the fisheries. Thus, SEAPODYM includes a simplified representation of micronektonic organisms, which can be considered as tuna forage (Figure 3). These organisms are classified within six functional groups according to their vertical distribution and migratory behavior. The forage biomasses are calculated using the energy transfer coefficient E , from primary production to each forage component. This coefficient varies according to the forage component and is derived from the literature. The time spent in each layer is also dependant on day length which varies according to latitude and date (Lehodey, 2005). Prey accessibility depends on the species and age of the top predator.

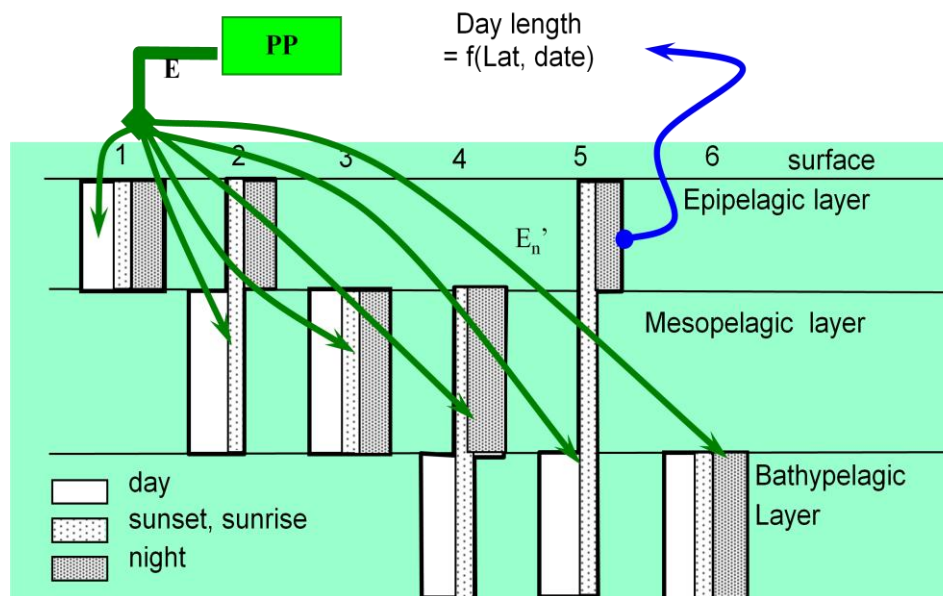


Figure 3. Diagram of the daily vertical distribution patterns of the micronekton preys used in the SEAPODYM forage model. 1, epipelagic; 2, mesopelagic migrant; 3, mesopelagic non-migrant; 4, bathy-pelagic migrant; 5, bathy-pelagic highly migrant; 6, bathypelagic non-migrant; PP, primary production; E, energy coefficient (from Lehodey, 2005)

The estimates of prey abundance are then used in SEAPODYM to define tuna habitat indices (Figure 4). Two different types of habitat indices, the feeding index and spawning habitat index, were used to direct the tuna migration according to their degree of maturity. The movement of non-mature albacore depends only on the feeding habitat index whereas for mature albacore, the migration depends on the feeding habitat index and the spawning habitat index, with a seasonal switch between them. Each habitat index is based on several ecological parameters. For example, the feeding habitat index depends on prey biomass, temperature, oxygen, while the spawning habitat index depends on temperature and the predator-food for larvae ratio.

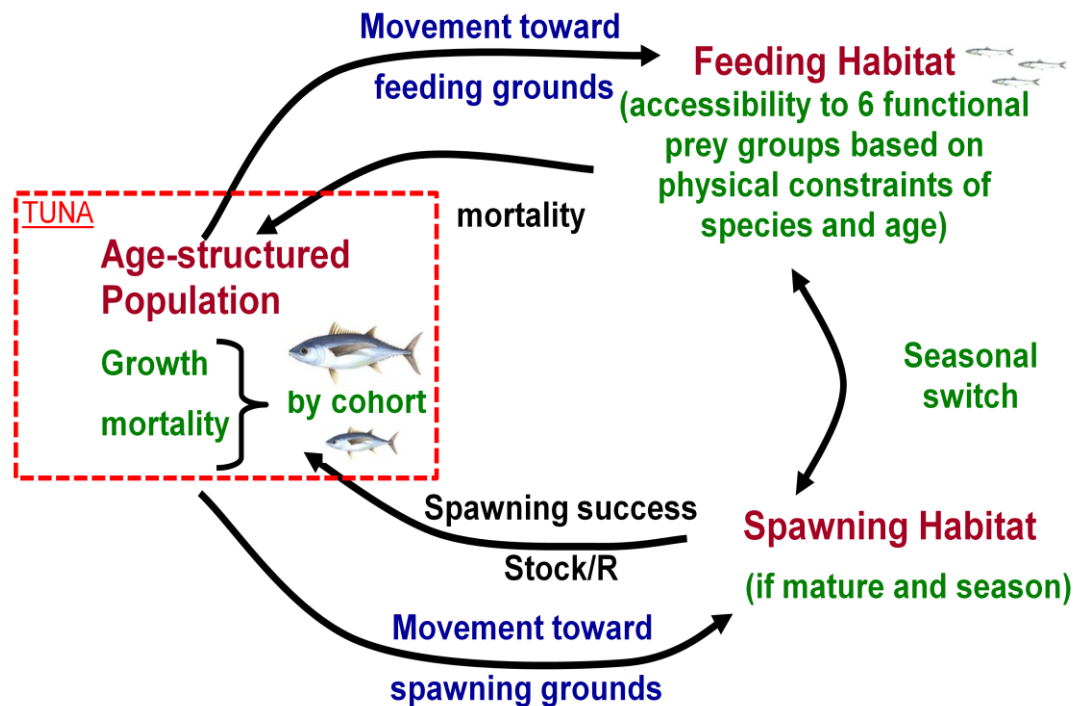


Figure 4. General representation of the tuna dynamics used in SEAPODYM (Lehodey, personal communication)

The SEAPODYM model is also based on advection-diffusion equations describing the fish migration toward the different habitats. The conditions in each habitat will define the total biomasses of tuna structured by age using biological parameters such as natural mortality or spawning success. Here the model distinguishes the age classes due to their difference in ecological processes and movement. Finally, fishing data, including catches, effort and fisheries size composition were used as observed data in the likelihood optimization procedure to fit the model (Figure 2). In this case, albacore parameter optimization was made for the whole Pacific basin scale using ORCA-PISCES data at 2° resolution. Once albacore parameterization was validated on the global scale, we applied the same parameters at a regional scale.

RESULTS

1. Environment variability and productivity in the south western Pacific region

Our study of the physical-biogeochemical coupling highlighted the central role of regional circulation in the southwest Pacific. The surface anticyclonic circulation which surrounds New Caledonia and the Coral Sea is structured by the presence of its tropical islands and by three major currents, including the Subtropical counter-current STCC (Figure 5).

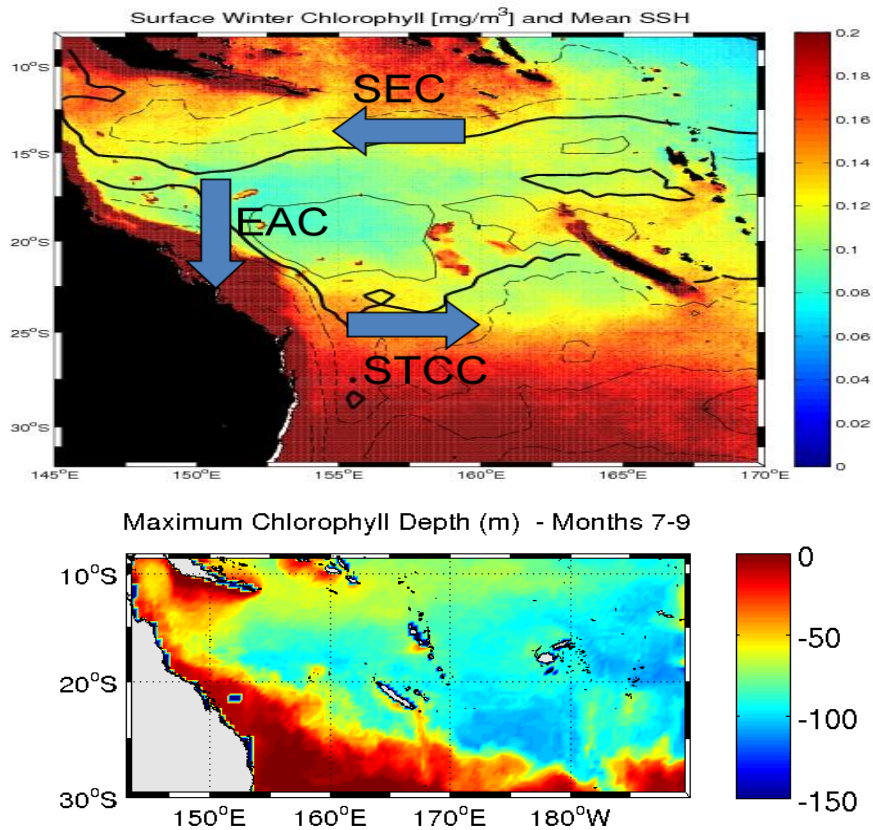


Figure 5. Upper part: Major current circulation (SEC: Southern Equatorial Current; EAC: Eastern Australian current; STCC: Sub Tropical Counter Current), mean dynamic topography (black lines) and winter sea surface chlorophyll (mg/m^3) from SeaWiFS in the Coral Sea (1992-2002). Lower part: Winter surface chlorophyll a predicted by ROMS-PISCES model.

This current is produced by the southward transport by the trade winds of light tropical water over heavier subtropical water, which forms a frontal region around 25°S , which is an important limit separating different primary production regimes (Figure 5). North of this limit, the anticyclonic circulation centered around $15\text{-}20^\circ\text{S}$ produces a zone of depression of the thermocline and nutricline which is unfavorable for the primary production, although the warm surface water has a favorable contribution to the spawning fish habitat. The satellite imagery partly confirms an anomaly of primary production in the anticyclonic zone, although it appears most clearly at depth in the model. The seasonal variability of the primary production and the oligotrophic characteristic of the area described by the ROMS-PISCES regional model agree with other studies made in the region (Dandonneau and Gohin., 1984; Dandonneau *et al.*, 2004). Our analysis shows that the nutricline depth is so depleted that the winter mixing cannot manage to enrich the surface waters around New Caledonia. Similarly, in the summer, the New Caledonia upwelling manages to reach the seasonal thermocline but not the deeper nutricline, which explains the weak response of the ecosystem to these recurring events. These events suggest a decoupling between seasonal thermocline and nutricline which is rather singular but perfectly explainable by the fact that the euphotic zone is always deeper than the seasonal thermocline. The data of the ZONALIS cruise, which was part of the ZoNéCo project, confirm this important result of the model.

2. Albacore distribution estimated by SEAPODYM

a- Global scale

On the global Southern Pacific scale, the tuna model shows encouraging results but difficult to validate. In particular, there is very little information concerning micronekton and therefore possible model errors in this respect are difficult to evaluate. Nevertheless, the forage model seems to provide an adequate intermediate level for the albacore tuna occurrence since its modeled biomass presents strong correlations with actual captures. Nevertheless, this aspect of the model should be better validated in the future. For adult tuna, the capture zones coincide with their average habitat which is well represented by the intersection of favorable feeding and spawning habitats that include the New Caledonia region (Figure 6).

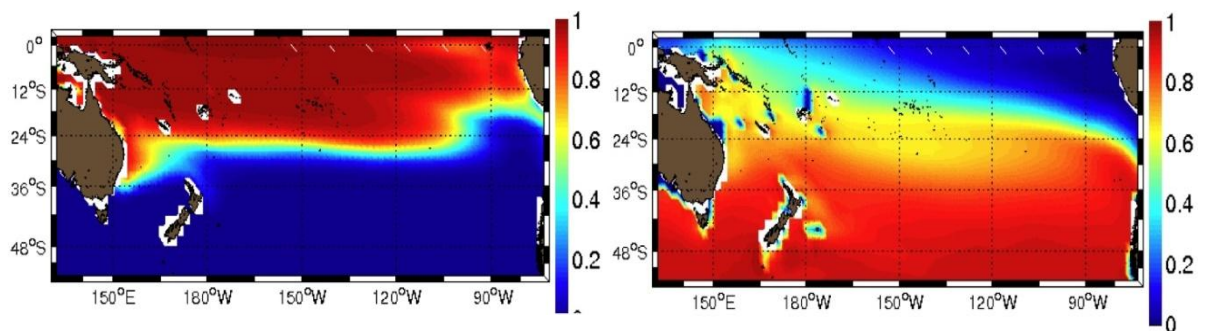


Figure 6. Spawning habitat (left) and feeding habitat (right) of South Pacific albacore simulated by SEAPODYM model

Model results suggest the adults migrate seasonally, but this migration is limited in the model to approximately 40°S, because further south the habitat gradients become too weak to encourage migration. A zone of relative maximum of the tuna biomass is nevertheless present south of 40°S (Figure 7); we understand this could be an artifact of the model which cannot allow the recruits at high latitudes to migrate towards warmer waters. It is undoubtedly a point of the model which will have to be re-examined. For young (immature) tuna, the consistency between modeled biomass and actual captures is rather satisfactory on these scales. Displacement of young tuna is related to seasonal changes of feeding habitat, which remain minor compared with of the migration of adults towards the spawning habitat. The feeding habitat tends to concentrate the young tuna around New Zealand (Figure 6-7) coinciding with the actual captures.

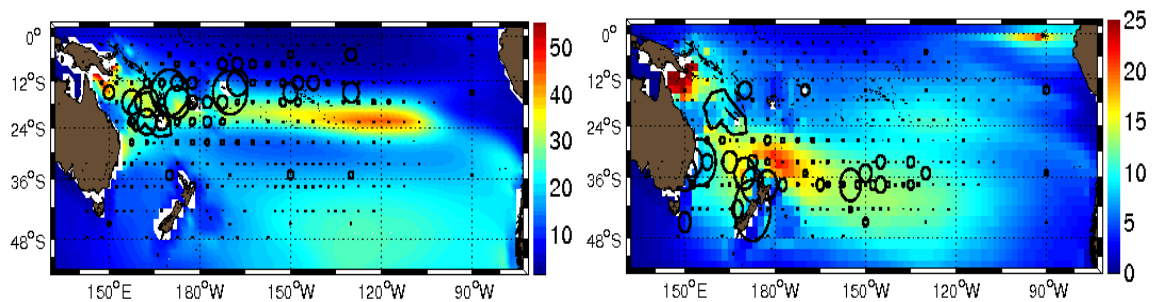


Figure 7. Biomass (kg/km²) of adult albacore (left) and young albacore (right) obtained after optimization of the model OPA/ROMS/PISCES/SEAPODYM at 2° resolution. Circles represented mean observed catches and the dimension of the circle is proportional to the catch.

Nevertheless, the model does not represent a zonal displacement of young tuna biomass, contrarily to what is suggested by the captures. That raises some questions, either about the incapacity of the model to represent a possible zonal migration, or on the fishing conditions which can vary with the season.

b. Local scale

At the local (EEZ) scale, our grid refinement opened new doors and raised new questions. The forage model results show for example a phenomenon that is consistent with the theory of optimal window of prey capturability. Indeed, the actual captures seem to coincide with intermediate values of prey concentration, rather than with the maximum ones (Figure 8). A previous statistical study made in New Caledonia EEZ provided preliminary data on this phenomenon at 1° resolution, showing a clear positive relationship between albacore CPUE and epipelagic and mesopelagic forage density, with a threshold value where albacore CPUE tend to decrease because the bait might become less attractive in area where the prey density is too high (Briand, 2005). Other acoustic studies made in the French Polynesia and the American Samoa supported the same hypothesis, showing that in an area of high forage density, albacore tuna tend to feed on live prey rather than longline baits (Bertrand *et al.*, 2002 ; Domokos *et al.*, 2007). This point needs to be further addressed. At the regional scale also, both epi- and mesopelagic temperatures are warm in the New Caledonia region because of the southward drift of surface tropical waters and the deeper impact of the previously noted anticyclonic regional circulation. These warm waters could have a significant impact on the spawning and feeding habitat and may largely explain the presence of tuna in this area but the low primary productivity of the Coral Sea region should be unfavorable for the tuna habitat.

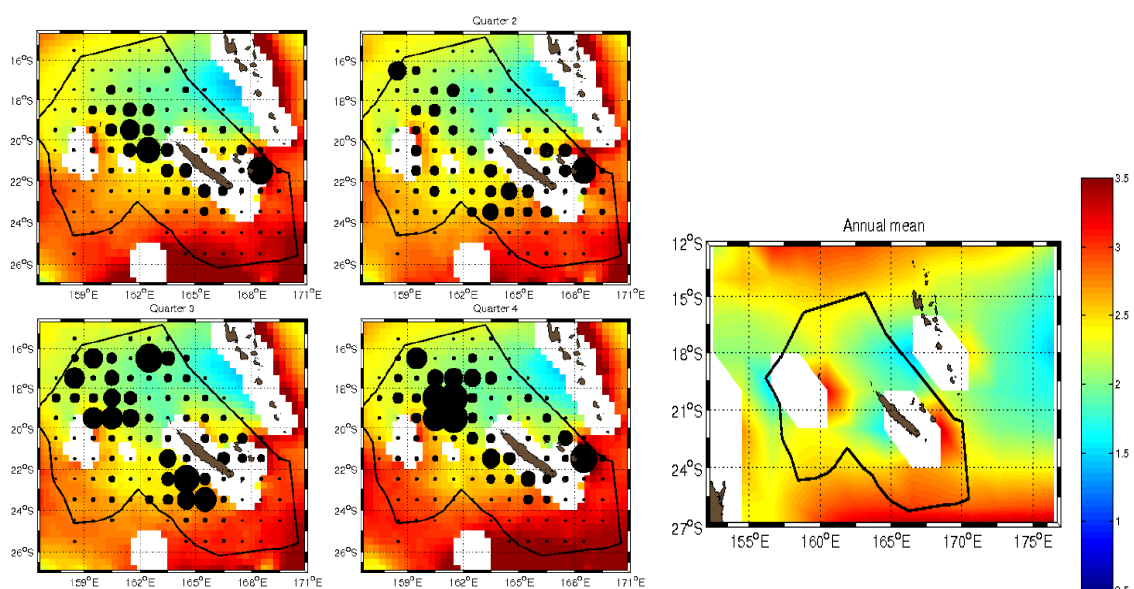


Figure 8. Annual mean (right) and seasonal variability (left) of prey concentration predicted by the ROMS-PISCES-SEAPODYM coupled model (color) at $1/3^\circ$. Black circles represent albacore total catches.

On the other hand, the local prey concentrations appear to be structured by convergence/divergence of currents (SEC) interacting with the islands rather than by phytoplankton distributions. Figure 8 shows a possible “island effect” with a forage accumulation on the eastern sides of the island or banks (Chesterfield, Loyalties Islands and Vanuatu) and a forage deficit on the western side. This forage repartition is different from chlorophyll annual distribution (see Figure 5 and annex). This would tend to invalidate the relevance of satellite images of water color for fishing activities and emphasize the importance of prey aggregation as a good predictor of albacore tuna occurrence and distribution within the area. However, more research needs to be done on SEAPODYM at local scale, especially to understand the discrepancy between the albacore biomass predicted by the coupled model and the observed CPUE at EEZ scale (Figure 9). For the moment, the biomass repartition is quasi uniform within the EEZ and the model is not able to explain yet the two seasonal peaks observed in the regional longline CPUE in December-January and June-August. Further work is planned to focus on these problematic.

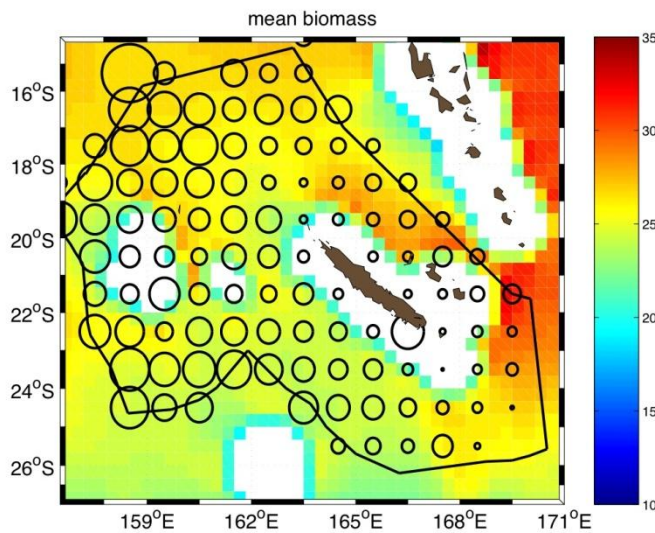


Figure 9. Albacore (adult) biomass predicted by the ROMS-PISCES-SEAPODYM coupled model and albacore CPUE on the 1998-2008 period.

CONCLUSION

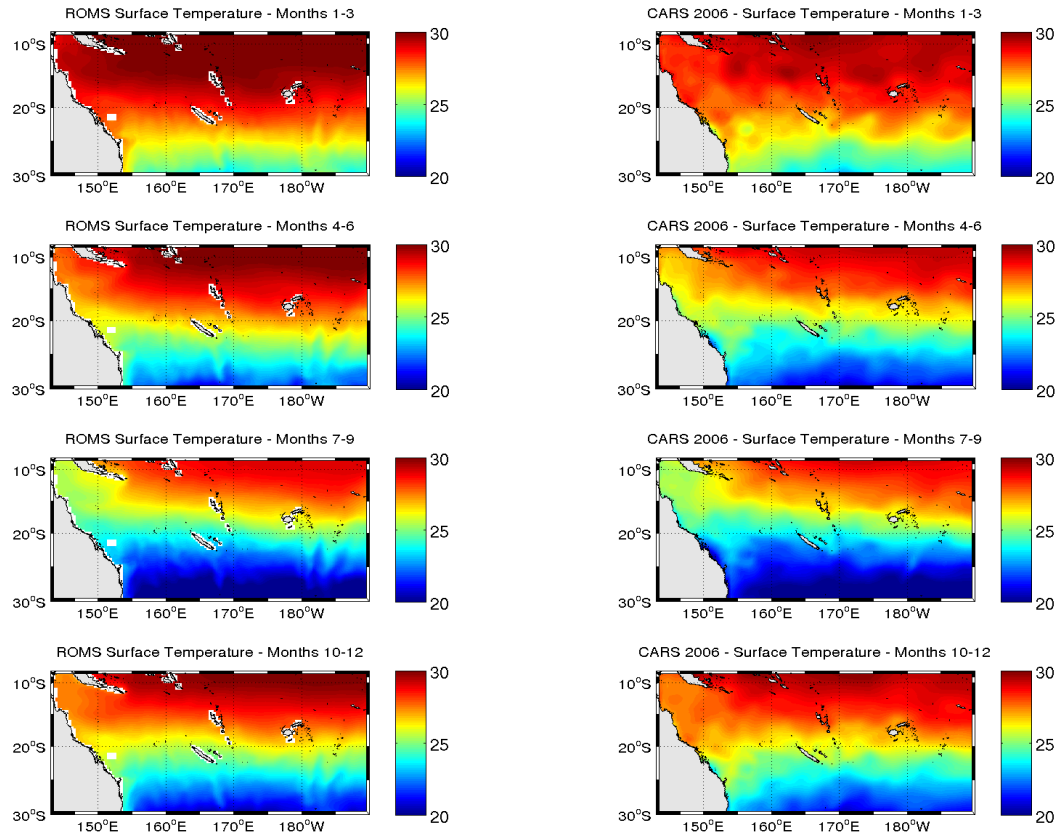
The results of the tuna model are encouraging although a certain number of questions still need to be addressed and further refinement of the model parameterizations are required, in particular at the regional scales. In summary, it seems that our modeling system is relevant for the comprehension of the ecosystem and population dynamics of albacore tuna at large scales. We primarily limited ourselves to understand the average distributions and seasonal variations, while the role of climatic variability, such as El Niño, remains to be explored. Concerning the local scales, which we approached at the end of the project, some progress remains to be made in the adjustment of the model parameters and in the understanding of smaller-scale processes, but the model suggests an interesting island contribution to the small-scale structures of tuna prey and habitat. With this intention, it seems relevant to organize part of the future effort on a better understanding of the dynamics of the tuna preys and on corresponding model development. This is the subject of the 2009 IRD-CPS joint proposal that has been recently released to ZoNéCo.

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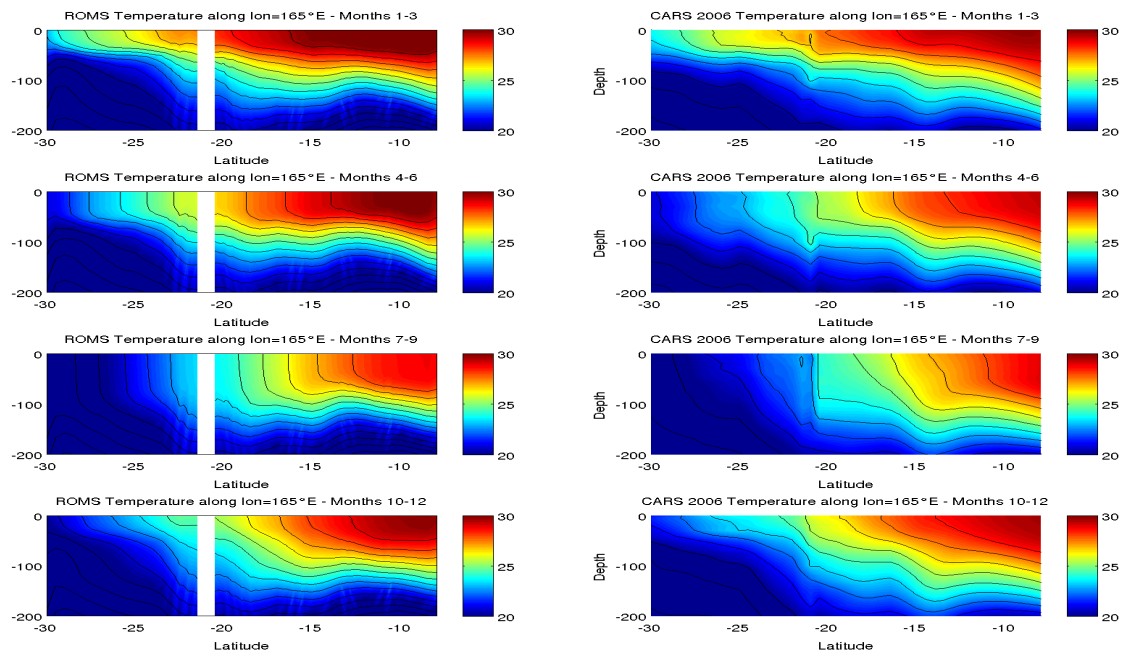
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ANNEX- Comparison of data from ROMS-PISCES model and observations in the Southern Pacific ($1/3^\circ$ resolution)

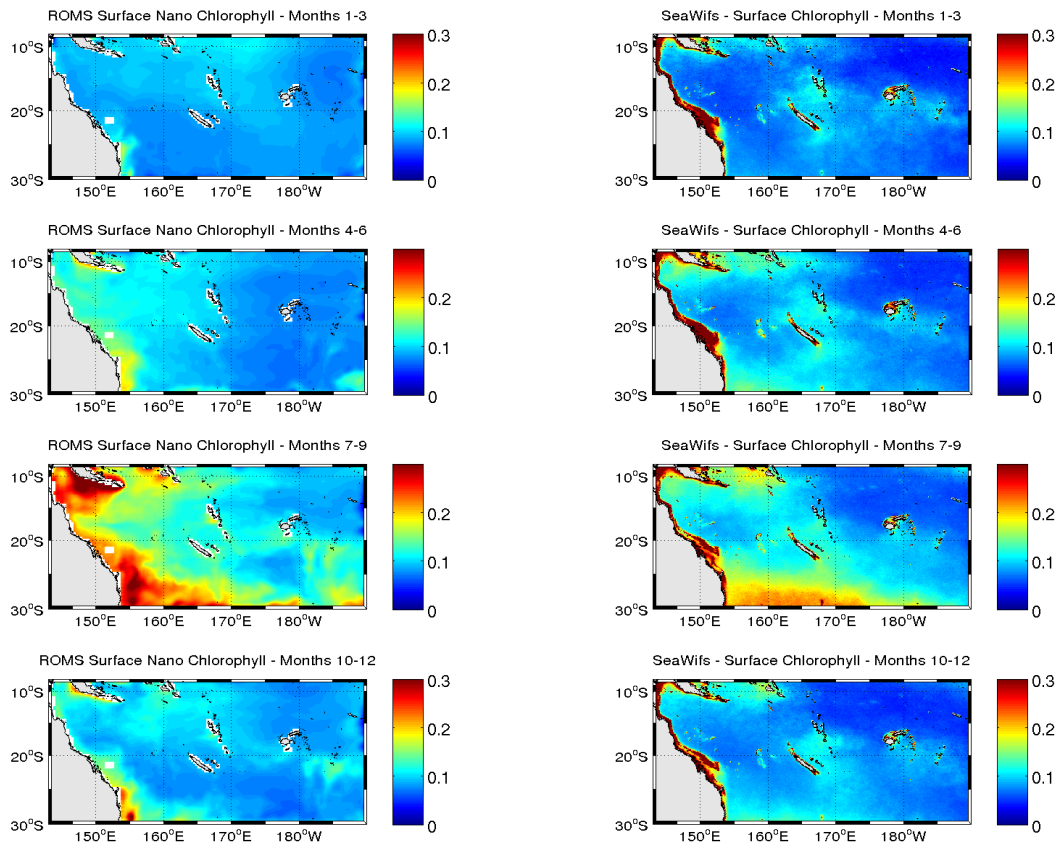
- a) Horizontal distribution of sea surface temperature from ROMS (left) and CARS06 (right) by season



- b) Vertical distribution of sea surface temperature along 165° longitudinal section from ROMS (left) and CARS06 (right) by season



c) Horizontal distribution of chlorophyll *a* from ROMS-PISCES model (left) and SeaWiifs satellite data (right) by season



d) Vertical distribution of chlorophyll *a* from ROMS-PISCES model (black line) and observations from ZONALIS campaign (grey line) at different stations of the EEZ

