Current and hydrographic response of the continental shelf of the Gulf of Tehuantepec, Mexico

Abstract

Introduction

J'ai réalisé mon PPL au sein de l'IIM (Instituto de Investigaciones Marinas) à Vigo, en Espagne, durant les mois de juin et juillet 2005, sous la direction du Dr. Des Barton, chercheur à l'IIM.

Dans le cadre d'une nouvelle collaboration entre Dr. Barton et ses collègues Mexicains, j4ai dû analiser des données non publiées, collectées au cours d'une campagne menée dans le Golfe de Tehuantepec, au Mexique, entre décembre 1988 et février 1989.

J'ai ainsi pu acquérir des techniques de base en traitement de données, et j'ai appris à tracer des sections hydrographiques et des diagrammes TS, avec le logiciel ODV.

Du fait de la courte durée du stage, il ne constitua qu'un travail préliminaire à la publication d'un nouvel article, et pourrait être approfondi avec plus de temps.

Contexte

Le Golfe de Tehuantepec, situé à l'est de l'océan Pacifique tropical, est une importante zone de pêche à la crevette.

Cette zone est influencée par de forts vents intermittents, sous la forme de jets soufflant à travers l'isthme de Tehuantepec, qui génèrent des tourbillons anticycloniques et cycloniques jouant un rôle primordial dans la dynamique et la biologie locales.

Les tourbillons cycloniques sont des zones de divergence, présentant par conséquent un upwelling en leur centre. Ils constituent donc des zones de forte biomasse, ce qui explique l'intérêt des océanographes pour l'étude de la circulation océanique dans cette zone.

Durant la campagne, les navires océanographiques mexicain El Puma et américain Wecoma travaillèrent dans le Golfe du 7/01/88 au 10/02/89. sept mouillages furent déployés, quatre dans les eaux peu profondes à l'intérieur du golfe, et trois 200 km au large, perpendiculairement à l'axe du jet de vent.

Dans Barton et al., 1993, seulement une partie de ces données furent analysées, la circulation près des côtes ayant été laissée de côté.

J'eus à analyser les données suivantes :

- les données de vent recueillies à bord du Wecoma
- les données des courant-mètres situés sur les quatre mouillages peu profonds
- les données ADCP (courant-mètres acoustiques) des trois mouillages du large
- les données CTD (Conductivité-Température-Profondeur) fournises par El Puma

Les stations météorologiques côtières utilisées lors de la campagne n'ayant pas fonctionné, j'ai cherché à compléter les données de vent à partir de la base de données COADS.

Le but du stage était de rendre exploitables ces données en les convertissant en graphes, en faire des études statistiques simples, préparer des sections hydrographiques, et étudier la structure TS de la zone.

Méthode

1. <u>Relation vent / courants</u>

Pour chaque ensemble de données j'ai suivi la démarche suivante :

- tracer les séries temporelles de la vitesse
- tracer la vitesse sous forme de vecteurs au cours du temps
- statistiques
- calculer la direction de l'axe principal
- calculer la corrélation entre le vent et les courants
- tracer les pseudo-trajectoires
- faire une analyse par ondelettes

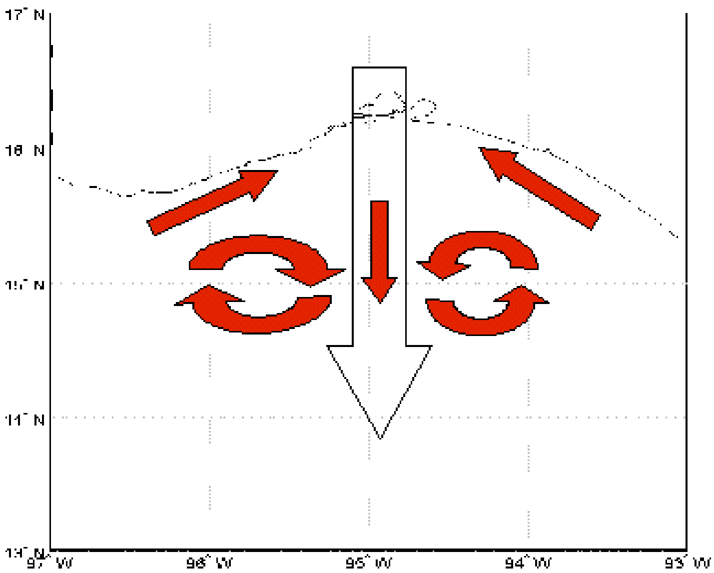
J'ai également tracé les données ADCP sous forme de contours.

Les coefficients de corrélation entre le vent et les courants que j'ai obtenu sont beaucoup plus faibles que ce qu'on attendait, ce qui peut être dû au fait que :

- les courant-mètres se trouvaient en-dessous de la thermocline, se qui atténue l'effet du vent.
- la période de recouvrement entre les données de vent et de courants n'excédait jamais deux semaines
- je n'ai pas supprimé le signal de marée, ni le signal inertiel, faute de temps, les signaux présentent donc beaucoup de variabilité

2. <u>Données hydrographiques</u>

L'étude des sections hydrographiques permirent de déduire la circulation suivante dans la zone :



<u>Conclusion</u>

Ce travail peut être amélioré, notamment au niveau des statistiques.
La circulation générée par ces jets de vent se met en place moins d'un jour aprés l'apparition du jet, et joue un rôle fondamental dans la biologie de la zone.

Introduction

I realized my Personal Project in Laboratory in the IIM (Instituto de Investigaciones Marinas) in Vigo, Spain, during June and July 2005. My supervisor was Dr. Des Barton, Research Professor in the IIM.

As part of a new collaboration between Mexican researchers and Dr. Barton, I had to analyze some unpublished data from a previous campaign in the Gulf of Tehuantepec, Mexico, to accelerate the preparation of a new paper on the subject. The main objective of this work was the study of the oceanographic circulation in the Gulf area, in response to some intermittent strong wind events characteristic of the zone. Such wind events generate persistent eddies of great interest for oceanographers.

I learnt how to use some basic tools in data processing, and how to draw hydrographic sections and TS diagrams with the software ODV. As the internship lasted only two months, this could only be a preliminary work. It could have been improved in many ways with some more time, as it will be discussed, but it allowed me to follow the different steps through data collecting to drawing some conclusions.

I also had the opportunity to attend the ASLO (American Society of Limnology and Oceanography) summer meeting in Santiago, where I could listen to many talks by researchers from all over the world, and get a better idea about the extent and the diversity of oceanography.

In the following, I will explain the campaign background, and then the method I used to analyze, first, the relation between wind (forcing function) and currents (response), and, finally, hydrographic data.

I. Background

The Gulf of Tehuantepec - located in the eastern tropical pacific - is an important area for shrimp fisheries. It is influenced by intense intermittent wind events which lead to the formation of mesoscale eddies which play an important role in the dynamics and biology of the zone. Those wind jets occur in the center of the Gulf, mainly in winter, producing two types of eddies : cyclonic ones on the eastern side of the jet and anticyclonic ones on the western side.

Cyclonic eddies are divergence zones, characterized by upwelling of subsurface waters in their center. Therefore, they are areas of colder and nutrient-rich waters, promoting a stronger biomass than the surrounding waters. That is why they are subjects of interest for fisheries research.

The wind jets also induce a strong vertical mixing in the central part of the Gulf, and a slight upwelling along the coast (see fig.1c).
These wind jets blow across the isthmus of Tehuantepec in Mexico (see fig.1a), when the atmospheric pressure in the Atlantic side of the Gulf – normally retained behind the mountain ranges of Mexico - rises to high levels, the pressure in the Pacific side remaining low.

During my internship I had to analyze the data from a campaign led in this zone between mid-December 1988 and February 1989. The aim of this campaign was to observe the spatial and temporal variability of the wind field over the Gulf of Tehuantepec and its consequent effect on the hydrograhic structure and circulation.

Two ships – the Mexican research vessel El Puma, and the U.S. research vessel Wecoma - worked in the Gulf from 7/01 to 10/02. Seven moorings were deployed - four in the shallow inner gulf and three in deep waters 200 km offshore, perpendicular to the axis of the wind jet (see fig.1b).
In Barton et al., 1993, only a part of the data was discussed and the nearshore circulation, which has a more direct effect on local fisheries and coastal ecology, had been largely ignored

I analyzed the following datasets :

- wind observations (eastward component U, northward component V) measured on board Wecoma (from the 15/01 to 8/02)

- current meter data from the four shallow moorings (U, V, and temperature T) at different depths
    - A1 : at 40m, between 13/12 and 26/01
    - A4 : at 40m, and 150m, between 17/12 and 10/01
      at 270m, between 16/12 and 09/01
    - B4 : at 40m, 150m, and 270m, between 12/01 and 28/01
    - A5 : at 40m, between 14/12 and 27/01

- ADCP (Acoustic Doppler Current Profiler) data from the three deep moorings (U, V, vertical component of the velocity)
    - D1 : 19/01 -> 04/02
    - D2 : 18/01 -> 02/02
    - D3 : 21/01 -> 05/02

- CTD (Conductivity-temperature-depth) profiles (T, salinity S, and density sigma-T) carried out over the continental shelf by el Puma, between 08/01 and 10/01

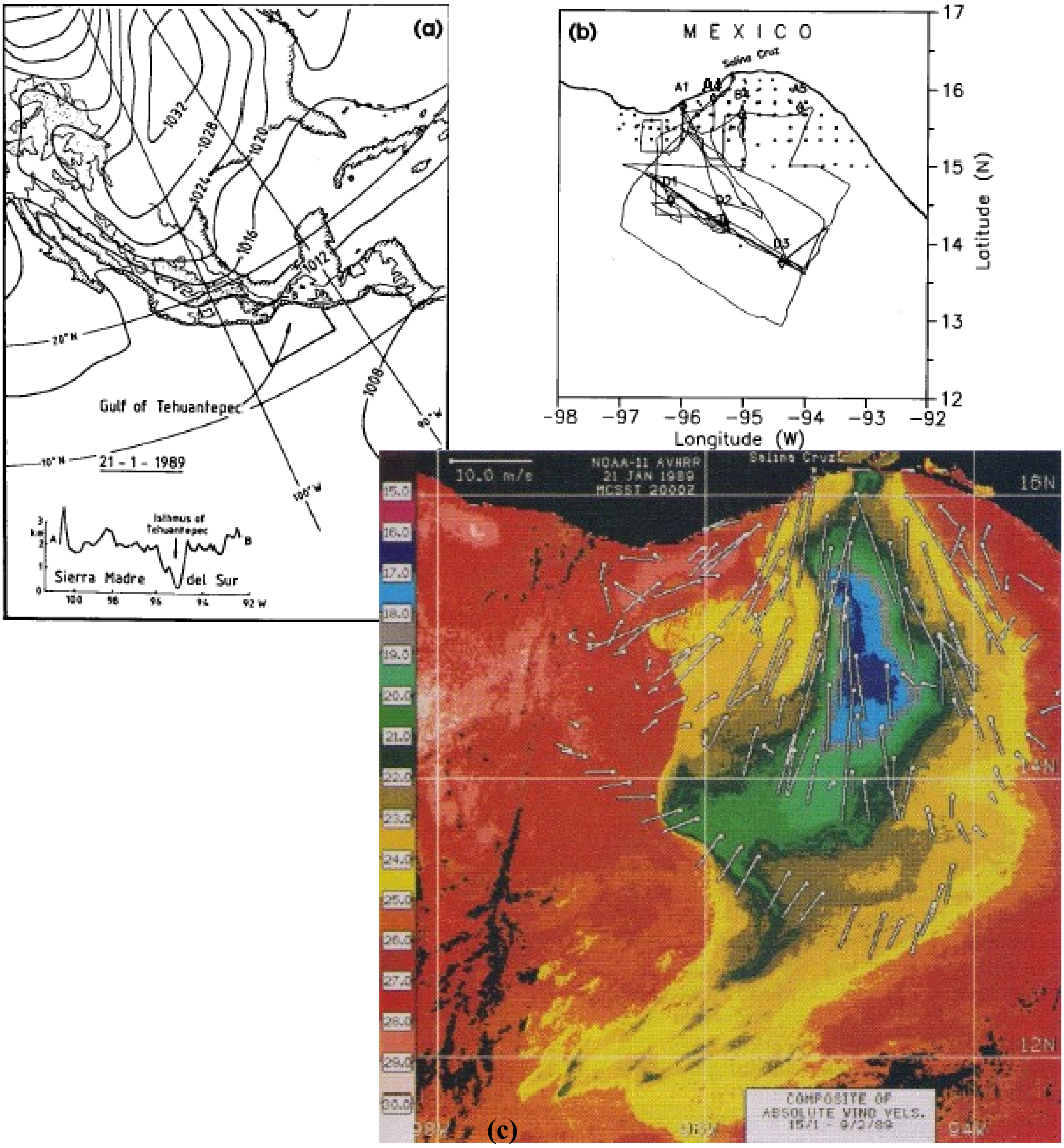


Fig.1 : (a) Sea-level pressure distribution over central America 21 January 1989. Higher pressures retained to the Atlantic side of the continental mountain ranges. The wind jets are forced through the gap at the Isthmus of Tehuantepec, sketched in the inset. (b) Cruise track for Wecoma (line), CTD stations (dots), and mooring positions (A1, A4, B4 and A5 shelf moorings; D1, D2, D3 deep ADCP and meteorological moorings). (c) Sea-surface temperature image of the Gulf of Tehuantepec 21 January 1989. Overlaid on the figure is a composite of ship wind observations, averaged over the observation period.

To get more wind data, I downloaded COADS data for the 01/12/88 to 28/02/89 period.

The project consisted in :

1. the editing, checking and display of the current meter data and their summarization by simple statistics and time series analysis;
2. the preparation of hydrographic sections of temperature, salinity, density and other derived variables;
3. the definition of the T-S structure of the shelf and slope waters and its changes associated with the horizontal and vertical variation of the flow field;
4. the relative importance of mixing and upwelling produced by the wind event that took place during the fieldwork.

II. Method

1. Wind/Currents

I spent the first weeks editing, checking, displaying and analyzing the wind (forcing function) and current (response) data I had, following for each of the dataset the following procedure :

- time-series plots
- quiver plots
- statistics
- principal axis
- correlations
- progressive vector diagrams
- wavelet analysis

I will illustrate the following with the graphics made for the current meter A1. The corresponding graphics for each of the other current meters and the wind observations can be found in annex.

The time-series plotting consisted in the simple display of U, V and T versus time.

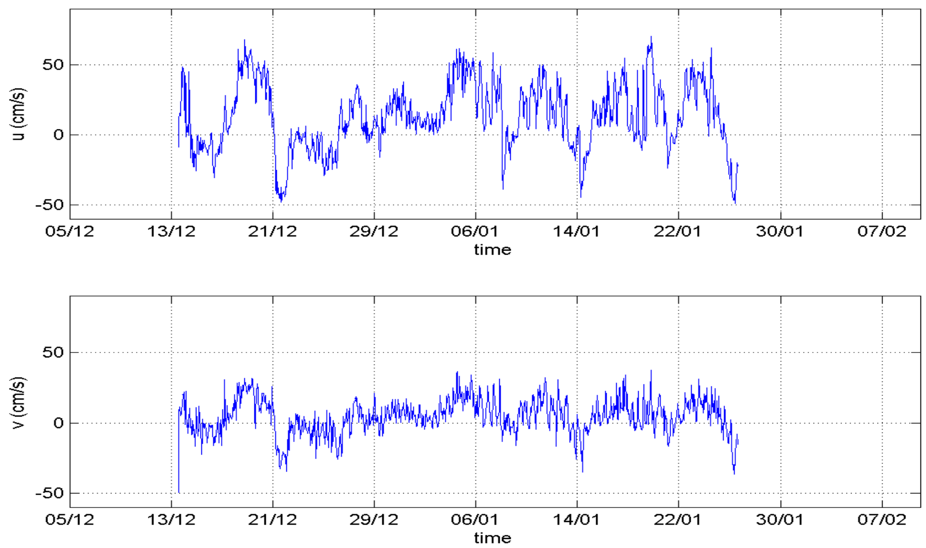


Fig.2 : U and V time-series for A1

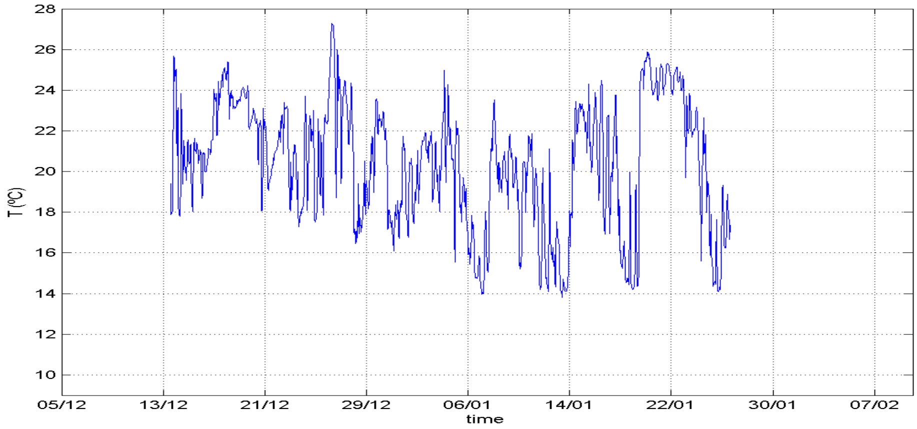


Fig.3: Temperature time-serie for A1.

Then I plotted velocities as vectors, using a modified version of the Matlab function « quiver plot », suppressing the auto scaling which altered the direction of the vectors, making them fit the screen. On the following graphic, north is up.

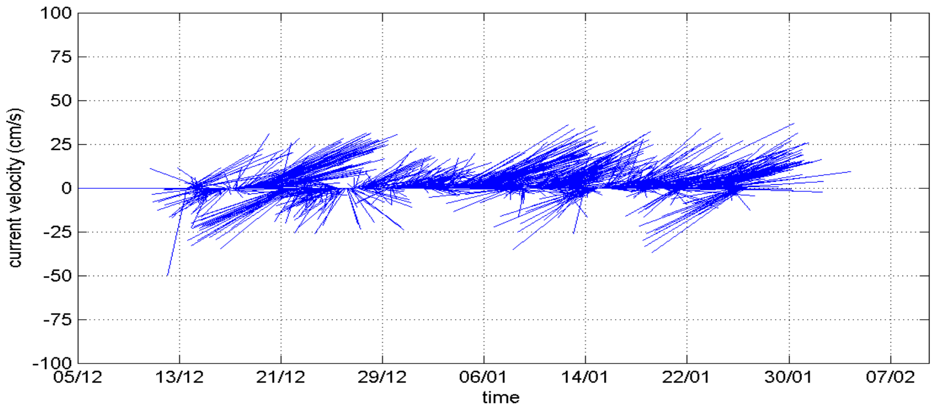


Fig.4 : Current velocity for A1.

We can see that, on this mooring, the current followed the orientation of the coast : South-West/North-East (see fig.1b).

Then, I calculated the basic statistics for each dataset, that is : mean, standard deviation, variance, kurtosis, skew, maximum and minimum :

	East comp. (cm/s)	North comp. (cm/s)	Temperature (ºC)
Mean	13,05	4,59	20,4
Std Dev	23,54	12,25	3,06
Variance	84,12	35,79	0,2
Kurtosis	2,63	3,58	2,29
Skew	-0,09	-0,3	-0,29
Maximum	70,1	37,3	27,28
Minimum	-49,2	-49,5	13,8

Table 1 : Statistics for the mooring A1.

and the direction of the principal axis, which is the direction of maximum variation of the data : for this mooring, this direction was 236º, so again, in the South-West/North-East direction.

Once obtained the direction of the principal axis, I projected all the data on this axis, and calculated the correlation coefficients between the current and the wind, for U and V.
Projecting the data on their principal axis maximizes the correlation.
Table 2 shows the correlation coefficients for each mooring, during the period of series overlap – Su (respectively Sv) being the correlation coefficient between the eastern (respectively northern) component of the current and the northern component of the wind (which is the one acting on the water, as the wind jet orientation is N-S).
There was no overlap between the mooring A4 and wind observations from Wecoma.

	Su	Sv
A151/wind	0.2134	-0.2186
A550/wind	-0.1419	-0.3253
B04/wind	0.2797	0.2855
B15/wind	0.0944	-0.2652
B27/wind	0.0065	-0.3908

Table 2 : Correlation coefficients.

We can see that :

- correlations are generally low
- the higher correlation is at shallower levels

Because of projection on the principal axis, and as the principal axis is defined modulo 180º, the sign of correlation coefficients is not significant.

We can see that the coefficient for B27 (270m depth) is quite stronger than the one for B04 (40m depth), but this is not really significant, as the variability at deeper levels was much weaker than at 40m depth. We did not have time to calculate the number of degrees of freedom, which could help determine the significance of correlation coefficients for each mooring.

We expected correlation between currents and wind to be stronger. These low values can be due to :

- current meters were relatively deep (not above the thermocline, as we will see on the sections later. So the effect of the wind is less intense)
- series overlap was short (no more than two weeks)
- we didn't remove neither tidal nor inertial (see wavelet analysis above) signals from the time series before calculating correlations. This could really improve the correlation coefficients.
- the wind observations are from the Wecoma. Since during some of the time, the ship was not in the central gulf, observations do not truly represent wind variation at a single point.

As this was not really convincing, I downloaded some data from ICOADS (International Comprehensive Ocean-Atmosphere Data Set) website, to get more wind data over the study period. Indeed, we did not have any additional wind data from the campaign, since the coastal meteorological stations used did not work.

Then, I drew the distribution map of the available data for the study period, in the area of the Gulf of Tehuantepec :

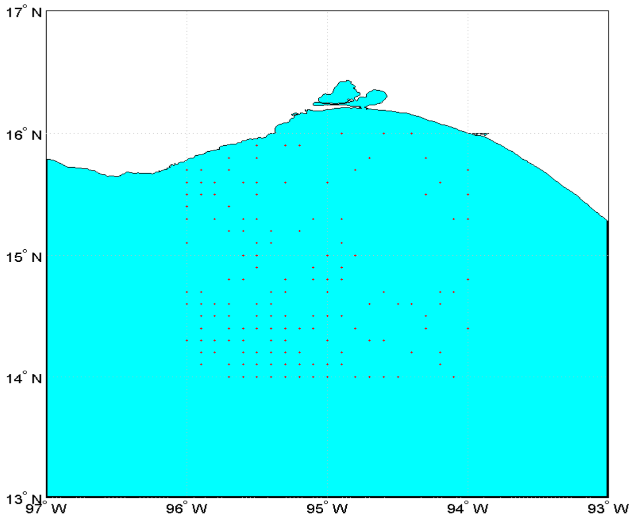


Fig.5 : Distribution map of ICOADS data.

As they are also ship observations, the distribution is not homogeneous, neither in space, nor in time. Most of the data are located in the western side of the Gulf, whereas we are mostly interested in what happens in the central part, where the wind jet occurs.

When I had several values for the same time, I calculated the averaged value, and then, made a daily average of all data and a cubic interpolation to fill the gaps.

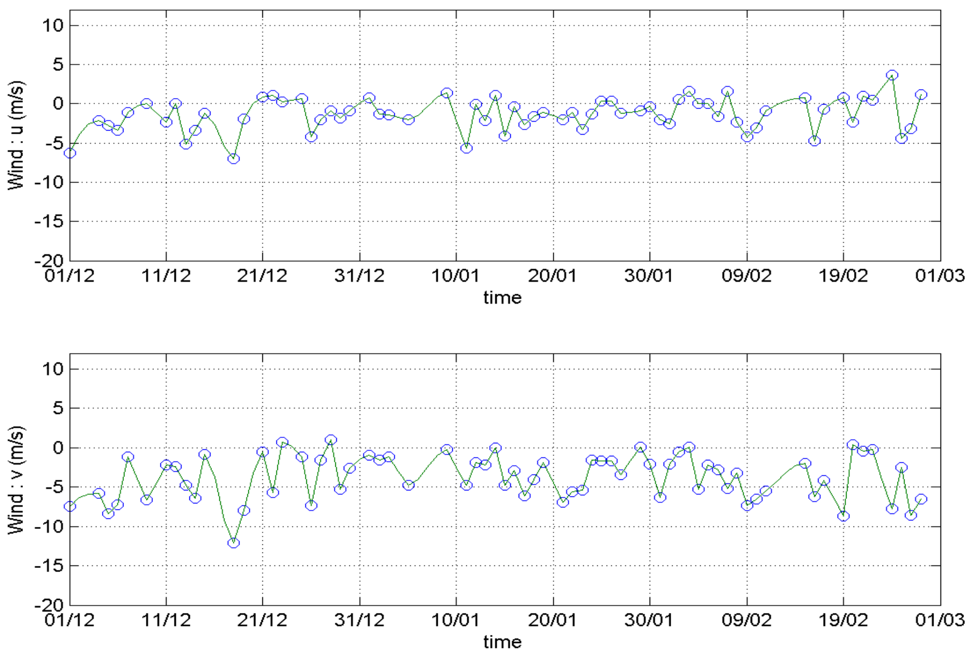


Fig.6 : ICOADS data. circles : daily averaged ICOADS data, line : cubic interpolation

If we focus on the Wecoma study period and compare those interpolated data to the Wecoma ones, we can see (Fig.7), that the general variation seems to be the same, but the ICOADS winds are significantly weaker. This is probably because they are daily averages of a few points, whereas the Wecoma data are hourly averages of continuous records.

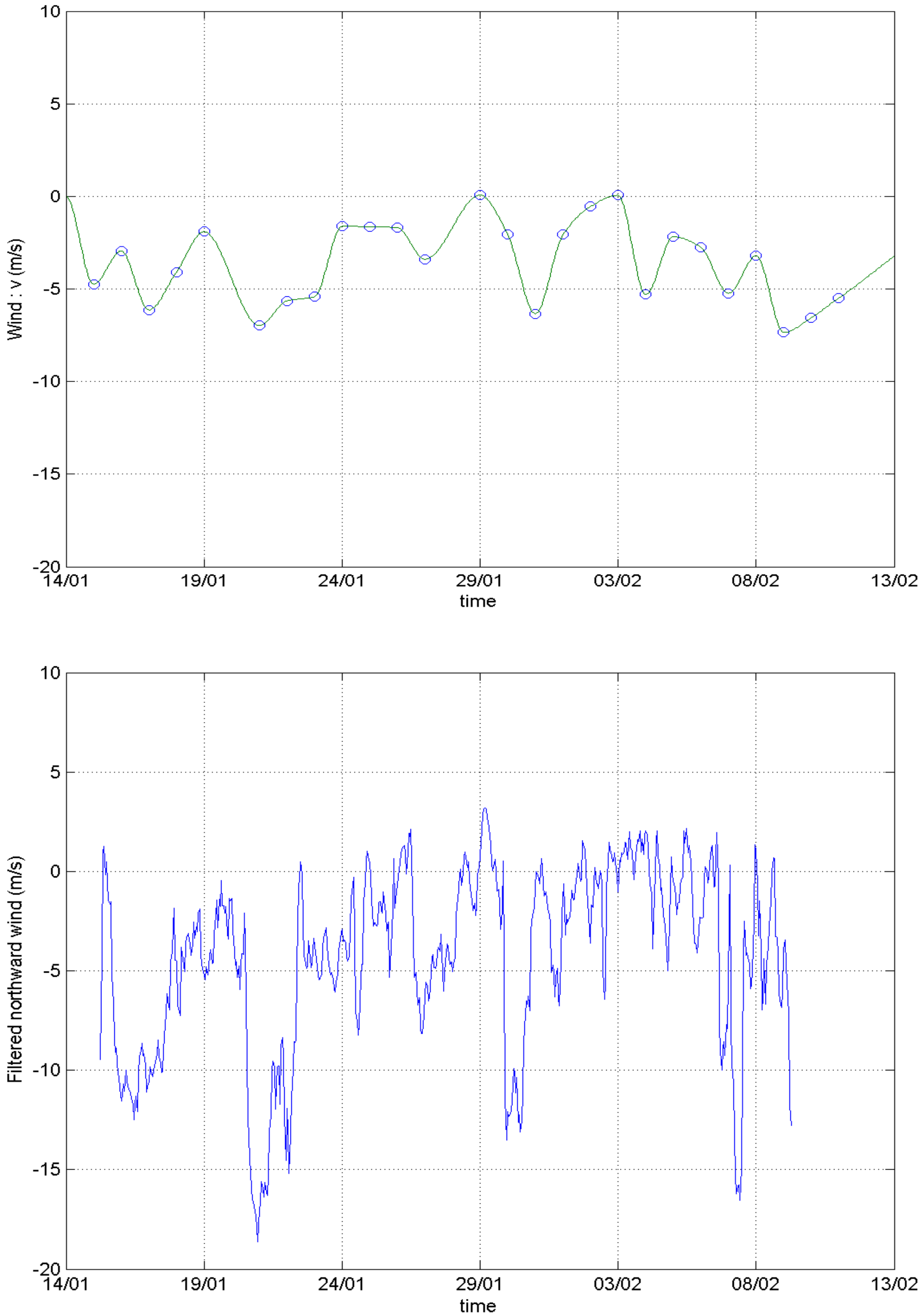


Fig.7 : wind northward component. above : focus on the ICOADS data.. below : time-series from Wecoma.

So, I calculated the daily average of the Wecoma data. (see Fig.8)

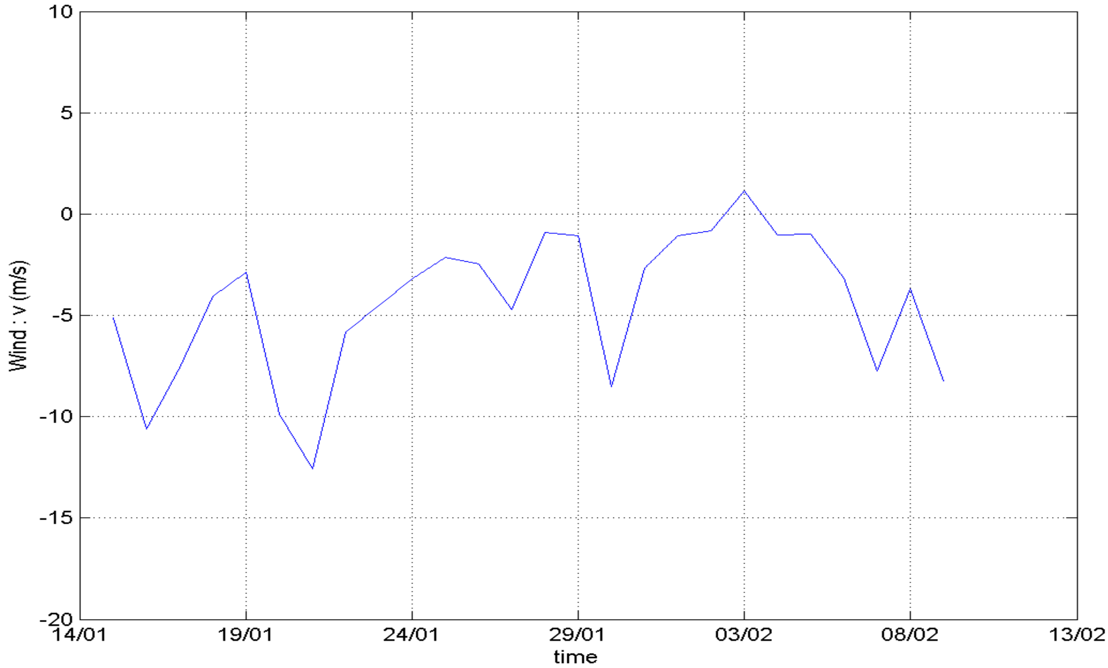


Fig.8 : Daily average of wind data from Wecoma.

As expected, this signal is smoother and less intense than the raw one, but again, even though the general variation is the same, the Wecoma winds seem much stronger.
Because of the gappy nature of the COADS data, further analysis was not pursued.

Then, for each mooring, I plotted <u>progressive vector diagrams</u> which are Lagrangian displays of the data. These diagrams show how the water parcel would have moved if the current would be the same wherever the particle went.

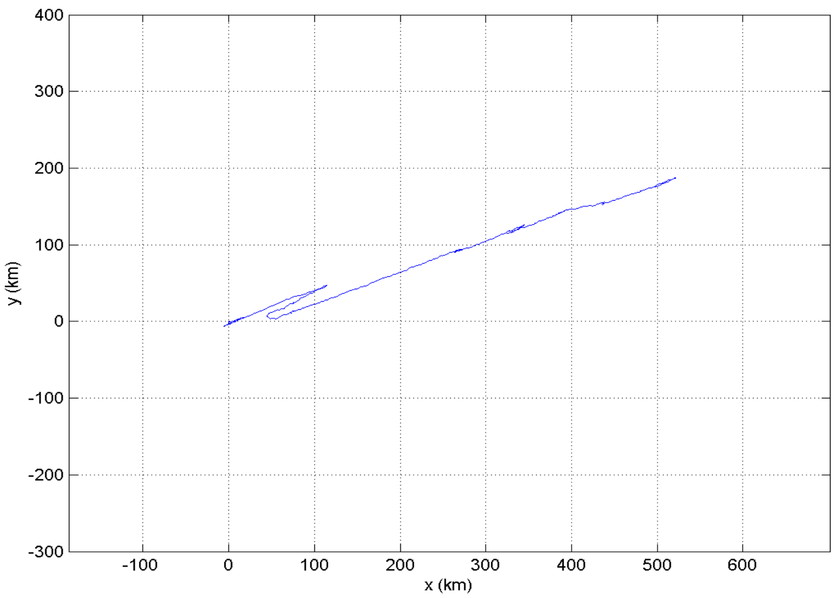


Fig.9 : Progressive vector diagram for A1.

In Fig.9, we can see again that the current is along the coast at this mooring.

Finally, I made a wavelet analysis of the moorings and wind data.
Wavelet software was provided by C. Torrence and G. Compo, and is available at URL : http://paos.colorado.edu/research/wavelets/ I used the Matlab functions provided on this website, to contour plot the wavelet power spectrum and its cone of influence, and the global wavelet spectrum. I used the Morlet mother wavelet function.

The aim of such analysis is to give a representation of the signals allowing to reveal simultaneously temporal information (localization in time, duration) and frequential, thereby facilitating the identification of the physical characteristics of the source of the signal.
The cone of influence (COI) is the region of the wavelet spectrum in which edge effects become important. It is the area below the black line. Information in this area is suspect.
The global wavelet spectrum is equivalent to the Fourier spectrum.

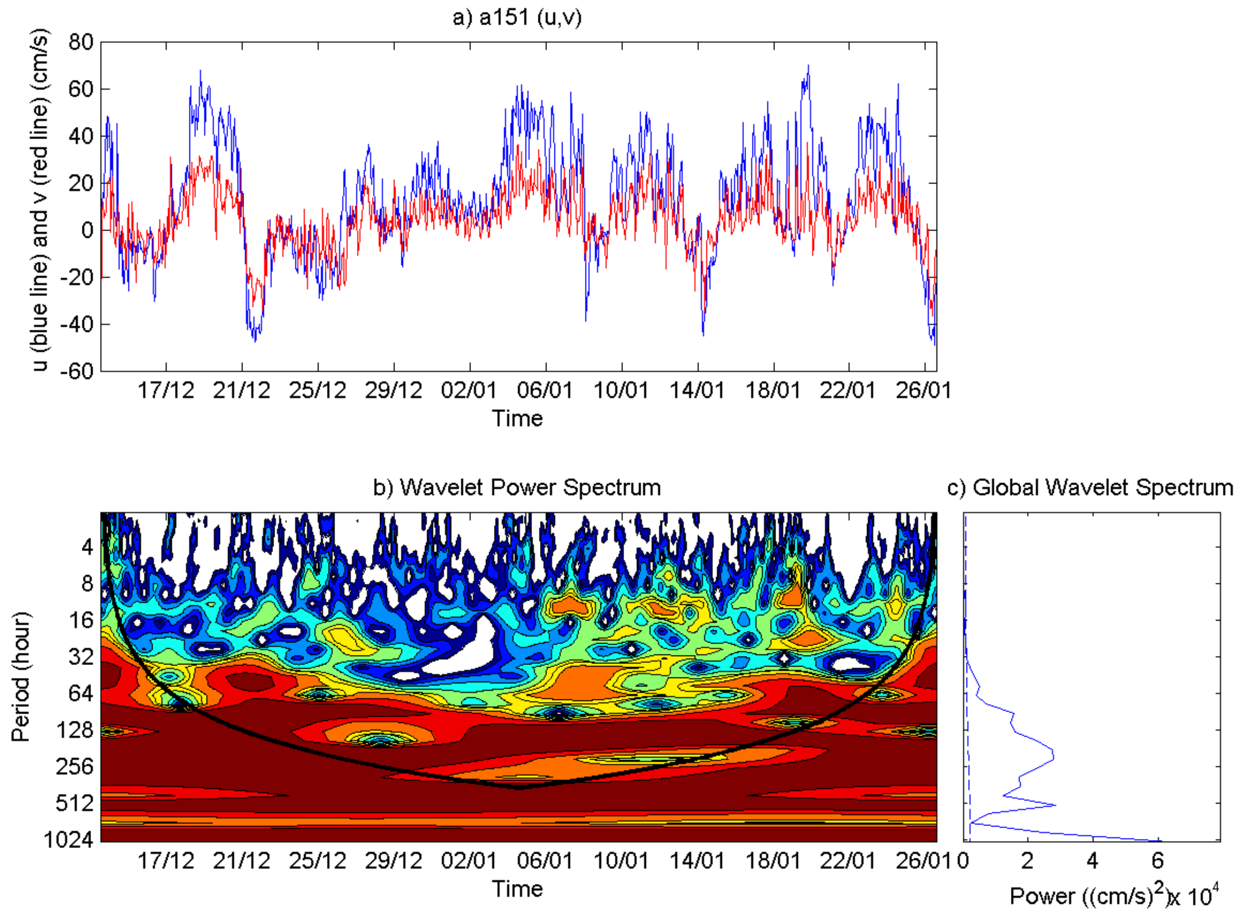


*Fig.10 : Wavelet analysis for A1. U, V as a complex : U+i*V.*

In Fig.10, we can see three easily interpretable periods :

- T1=12h : semi-diurnal tide
- T2=24h : diurnal tide
- T3=44h : inertial oscillations

The amplitudes of T1 and T2 are not constant, which is mainly due to the spring-neap cycle (15 days period), but there is also a lot of variability.
Due to the pulse-like nature of the wind jet, we expected internal oscillations to be generated, as we can see on the graphic. The inertial period is T3=12h/sin(lat), with lat=15,775° at this mooring.

To conclude the study of current meters data, I <u>contour plotted the ADCP data</u> from the three deep moorings.

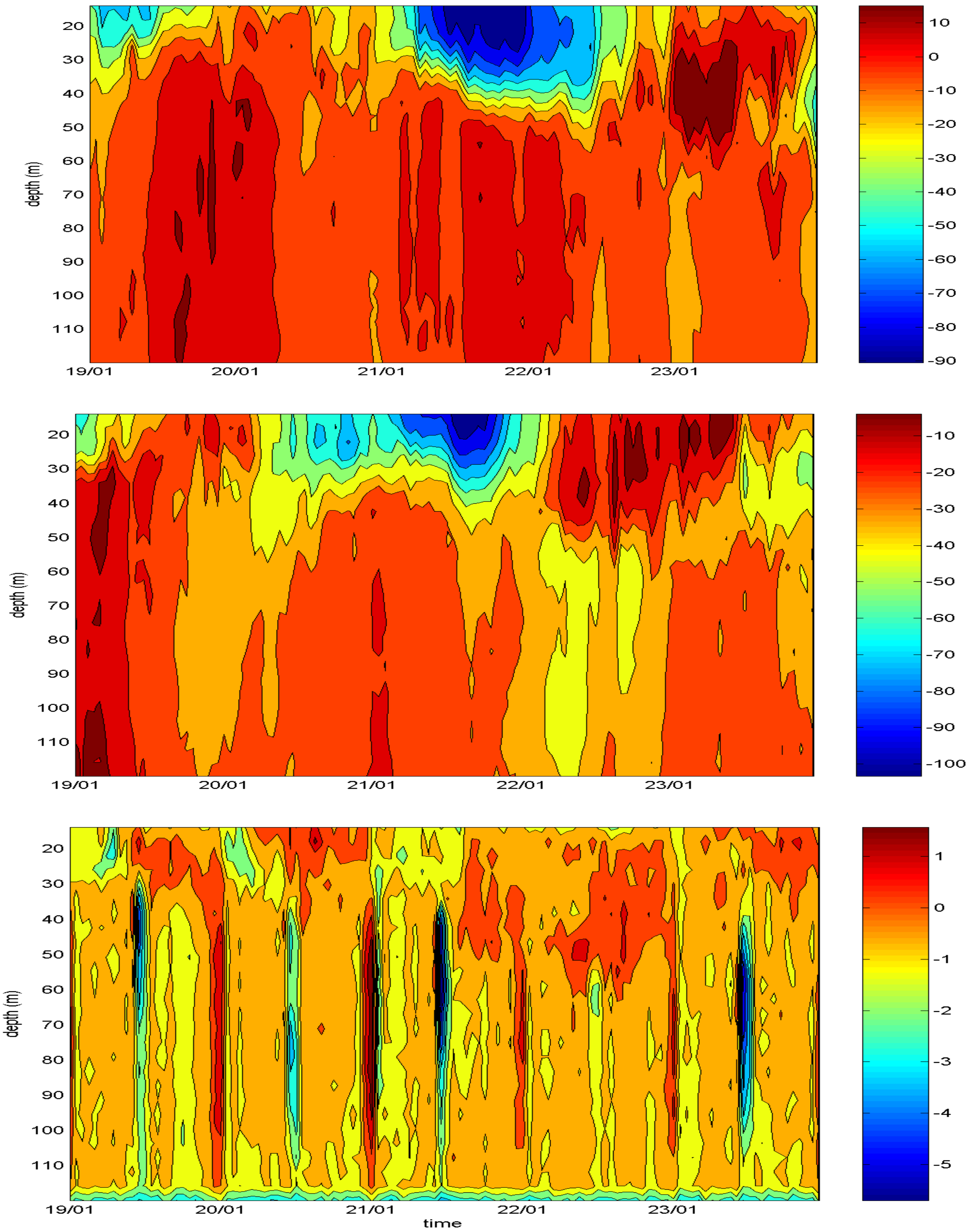


Fig.11: Contour plots of ADCP data for D2, between 19/01 and 24/01. Top : U, middle : V, bottom : vertical velocity

The mooring D2 was located in the axis of the wind jet. Fig.11 shows the currents quick response to the wind event which occurred on the 21st of January (see Fig.8), leading to the formation of a South-West current around the 22nd.
As there is a very strong pycnocline in the study area (see sections above), the vertical mixing does not reach deeper levels.
After the wind event, the current seems to decrease and disappear.

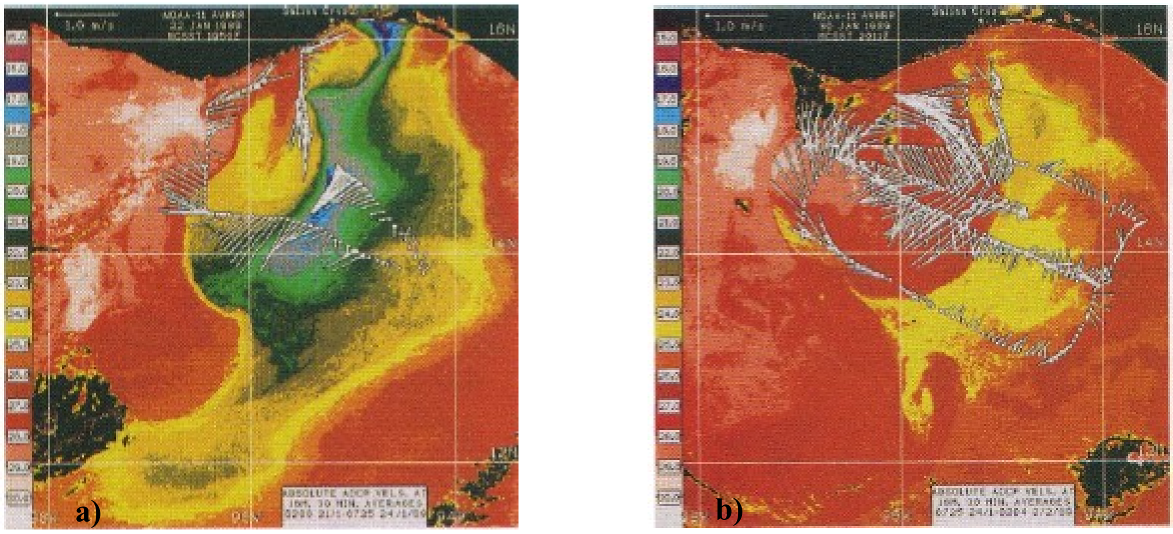


Fig.12 : a) Sea surface temperature image on 22nd January. Current vectors at 22m depth from the Wecoma ADCP are overlaid. b) Same records for 30 January, a week later. Note the strong anticyclonic eddy.

As we can see in Fig.12, the current showed on ADCP records, at D2, is really the swirl velocity of an anticyclonic eddy generated by the wind jet. Once the wind fans out and weakens, the eddy persists, but migrates southwestwards, which is why the ADCP record at D2 shows a decrease of the current, followed by its disappearance.

The plot for vertical velocity is quite difficult to construe because of vertical mixing taking place beneath the wind jet. Even in the center of the anticyclone at D1, where sinking motion might be expected, the ADCP record of vertical velocity is unclear with no coherent patterns. This probably means that the resolution of the ADCP was insufficient to detect the vertical component of flow.

Besides, we did not eliminate tide and inertial oscillation in the signal before contour plotting the ADCP data. That way, the current signals would have been smoother and clearer.

2. Hydrography

To study the CTD data from El Puma, I used the software ODV (Ocean Data view), available at URL : http://www.awi-bremerhaven.de/GEO/ODV

This software allows the display of T-S diagrams and hydrographic sections.

For each part of the campaign (part A : 08-16/01, part B : 17-22/01, part C : 24-26/01, 26-30/01, and 30-31/01), I drew the T-S diagrams for the stations concerned.
Then I drew temperature, salinity, and density sections.

a) T-S diagrams :

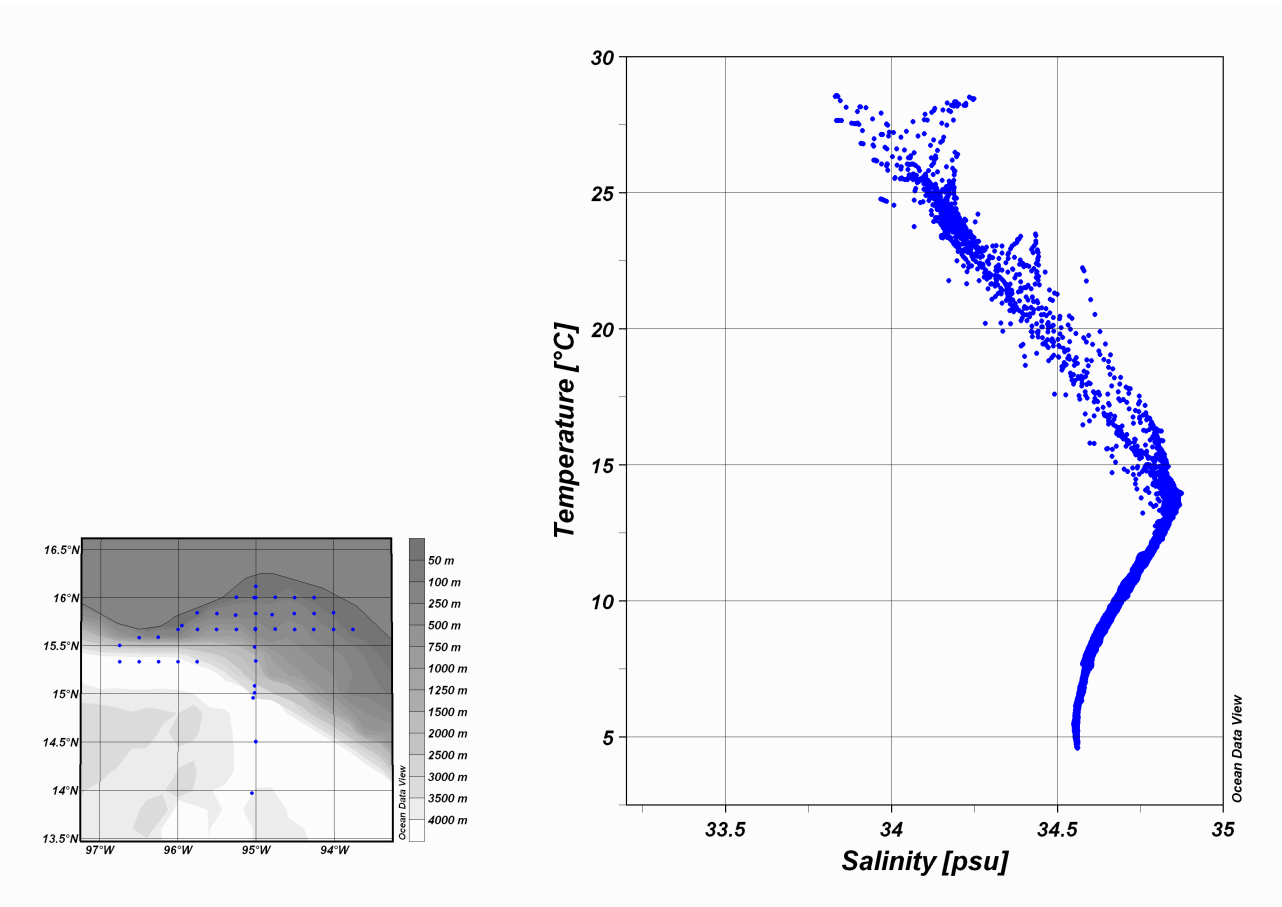


Fig. 13 : T-S diagram for the period 17-22/01.

In Fig. 13, we can see that there is a uniform TS relation initially with decreasing T and increasing S as we go down.

When the wind blows over the central Gulf, strong mixing produces a uniform T and S over the upper layer, where T and S are the average values for the wind mixed layer. So the TS relation is reduced to a single point (see Fig. 14b).
After wind ceases, continual heating produces a deviation towards higher temperature (see Fig. 14c).

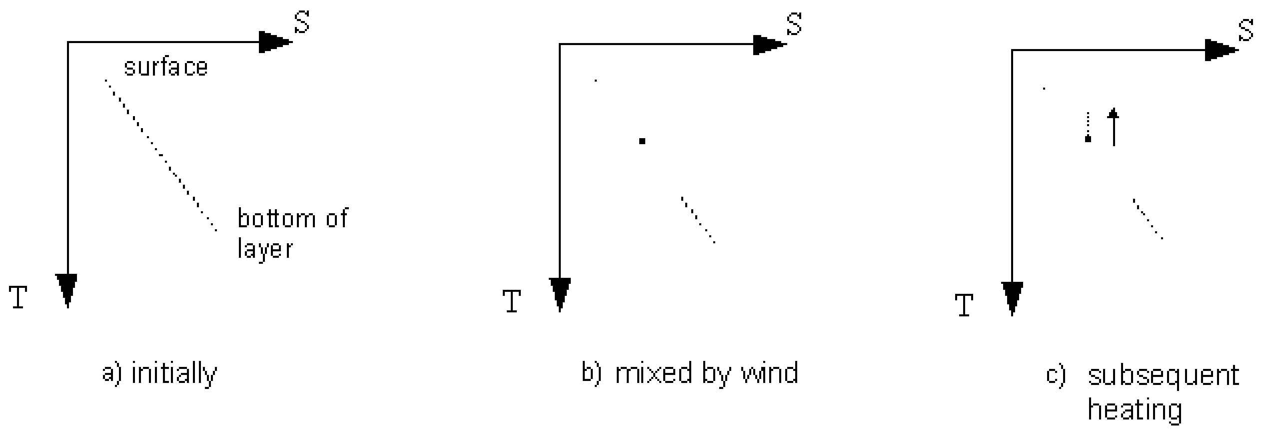


Fig. 14 : Mixing-heating processus.

Deeper layers are relatively unaffected by wind and consist of mainly Pacific Equatorial Water above 1000m.

At the surface, higher salinity waters reflect the influence of subtropical conditions of decreasing precipitation further to NW. Lower surface salinity found at SE stations are of more tropical high rainfall origin.

b) <u>Sections</u> :

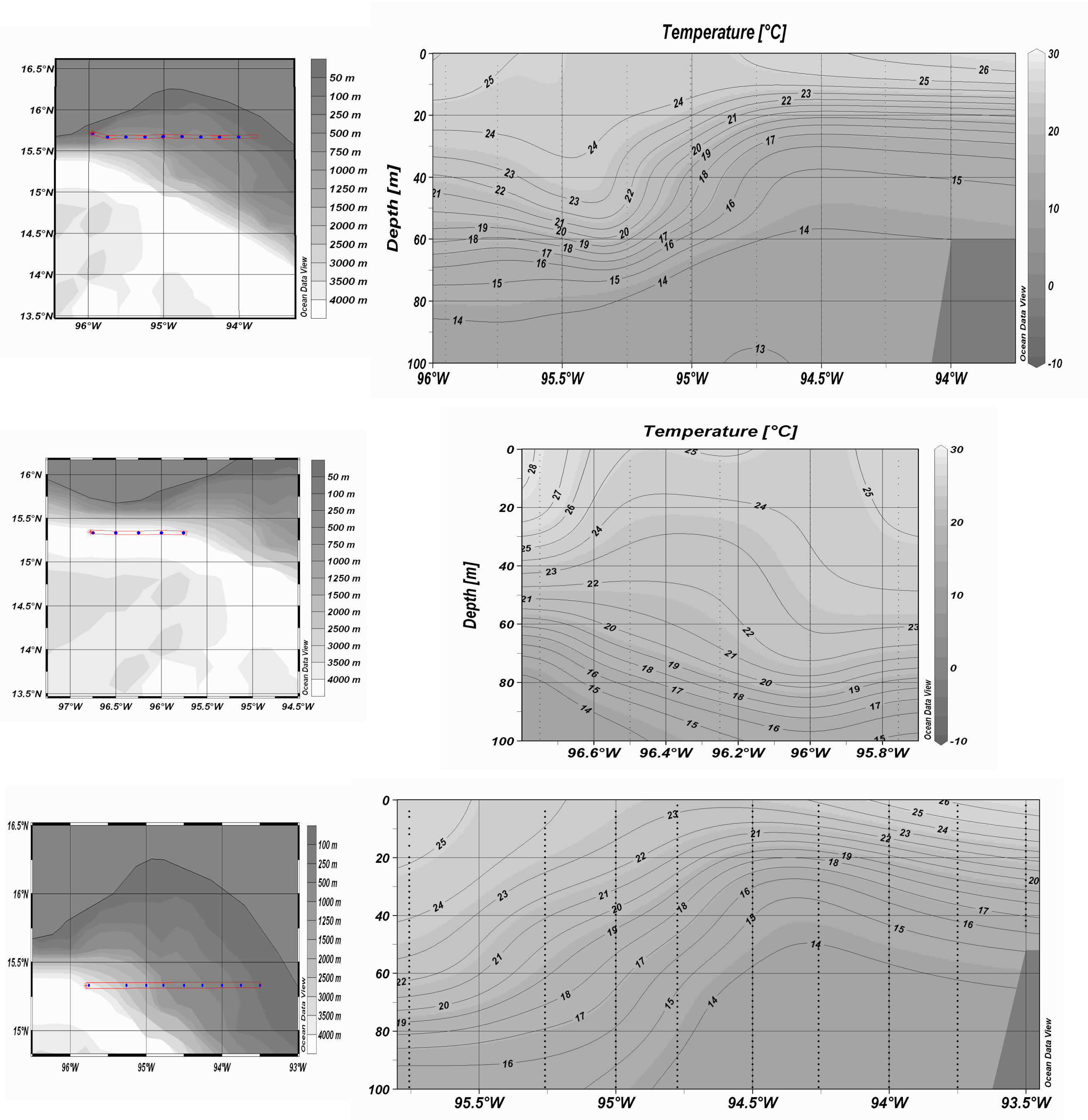


Fig. 15 : Temperature sections. Above : center Gulf, 21/22 January. Middle : western side, 21/22 January. Below : center and eastern side, 24/26 January.

We can see on those sections that the thermocline is really strong in the study area .
In the central part, where were located the current meters (see first section, in Fig.15), the top of the thermocline can be found between 20 and 40 meters. Therefore, none of the current meters was located above the thermocline, which can explain why the correlation coefficients were so low.

In geostrophic flow, particles move along isobars, with high pressure on their right in the northern hemisphere. Since the pressure at any depth is determined by the wight of the water above, high and low pressure are equivalent to high sea level and low sea level. Geostrophic flow is therefore related to the shape of the sea surface. And as the slope of the sea surface is opposite to the slope of the thermocline, flow can be deducted from the hydrographic sections.

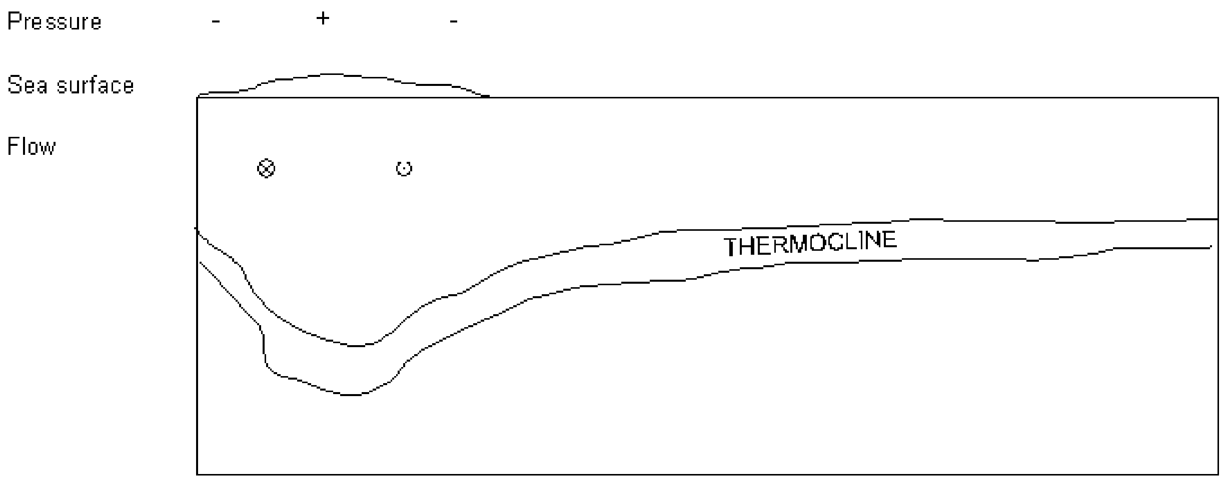


Fig. 16 : deducted circulation for the first section : anticyclonic gyre in the western side of the Gulf.

Following the same process for every section, we can deduce the general circulation in the Gulf (see Fig.17) and the mechanism leading to this situation (see Fig.18).

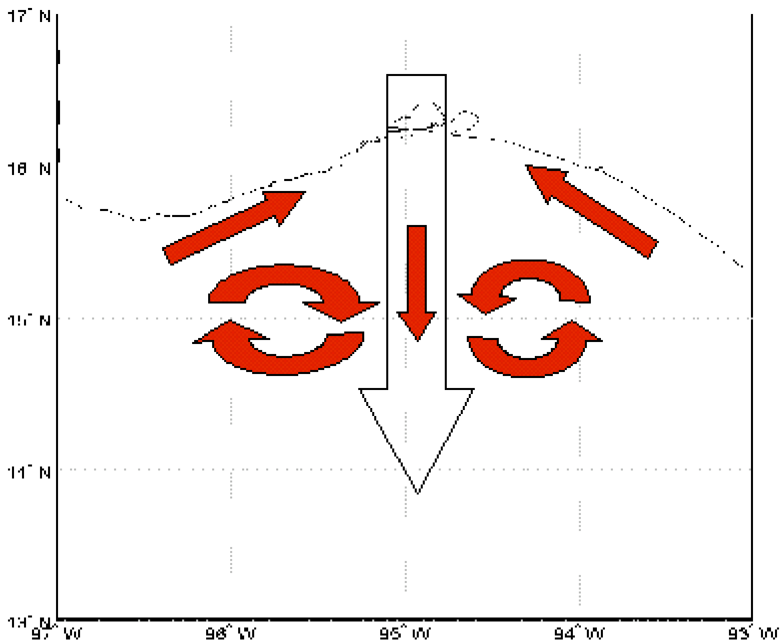


Fig. 17: Circulation observed in the Gulf of Tehuantepec. White arrow : wind jet. Red arrows : circulation. The cyclonic gyre in the eastern side of the jet was not observed during this campain, but models showed that there had to be one generated by the wind jet, which was confirmed by further observations.

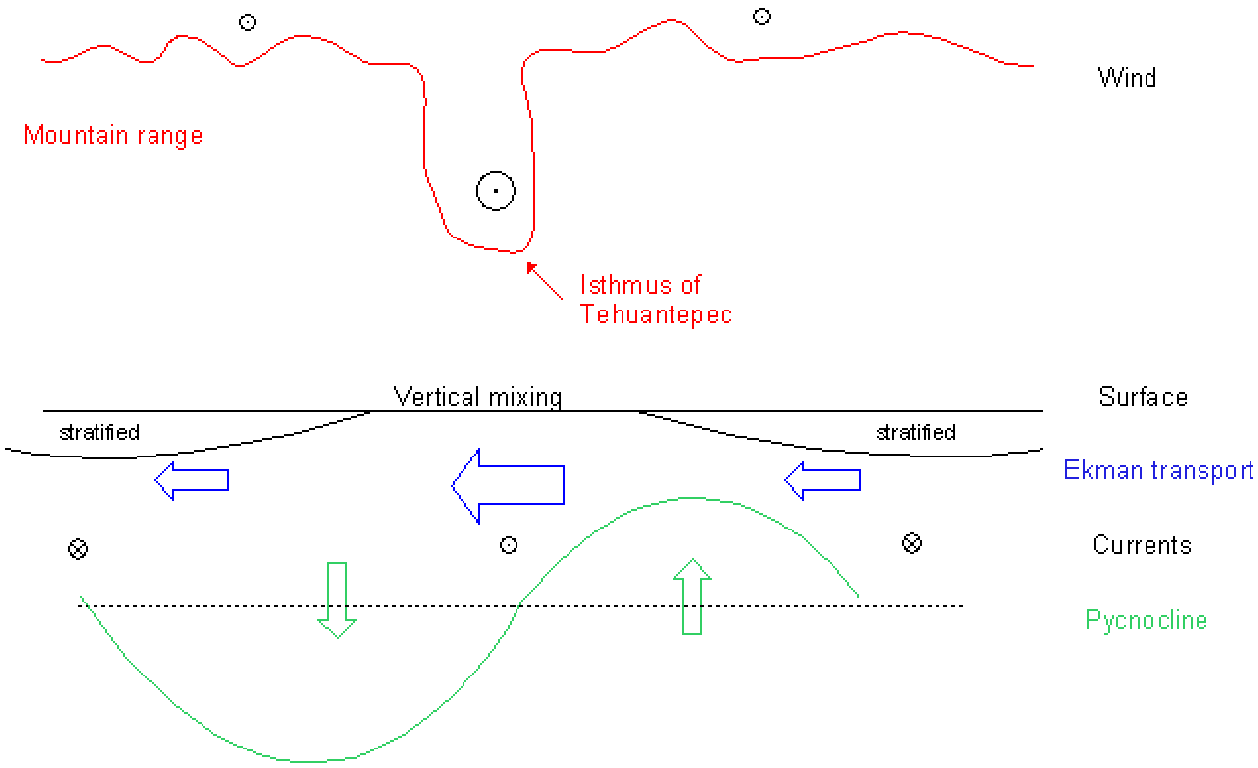


Fig. 18 : Mechanism occurring in the Gulf of Tehuantepec.

The wind jet pulls waters away from the coast, leading to the coastal upwelling, and producing water on both sides to rush towards the north of the inner Gulf to shoal the consequent "gap". Strong vertical mixing beneath the wind jet leads to the spreading of the thermocline which shows a strong asymmetry across the Gulf. On the western, convergent side of the wind, the pycnocline deepens to form an energetic anticyclonic eddy.

Conclusion

The analysis of the different datasets allowed us to deduce the general circulation in the study area, generated by intermittent winds blowing across the isthmus of Tehuantepec in Mexico.

However, we did not find a correlation between wind and currents as strong as we expected, probably because we did not have time to do some complete statistical analysis of the data, and because the current meters were not above the thermocline.

Also, we did not have time to make a quantitative study of the relative importance of mixing and upwelling. Satellite images show that after a wind event, there is a local upwelling along the coast beneath the wind jet, and a strong vertical mixing in the central part of the Gulf.

This great response to wind events occurs within a day as we saw on ADCP records.

Finally, Fig.19 shows the general circulation in the zone on 4th January 2005.

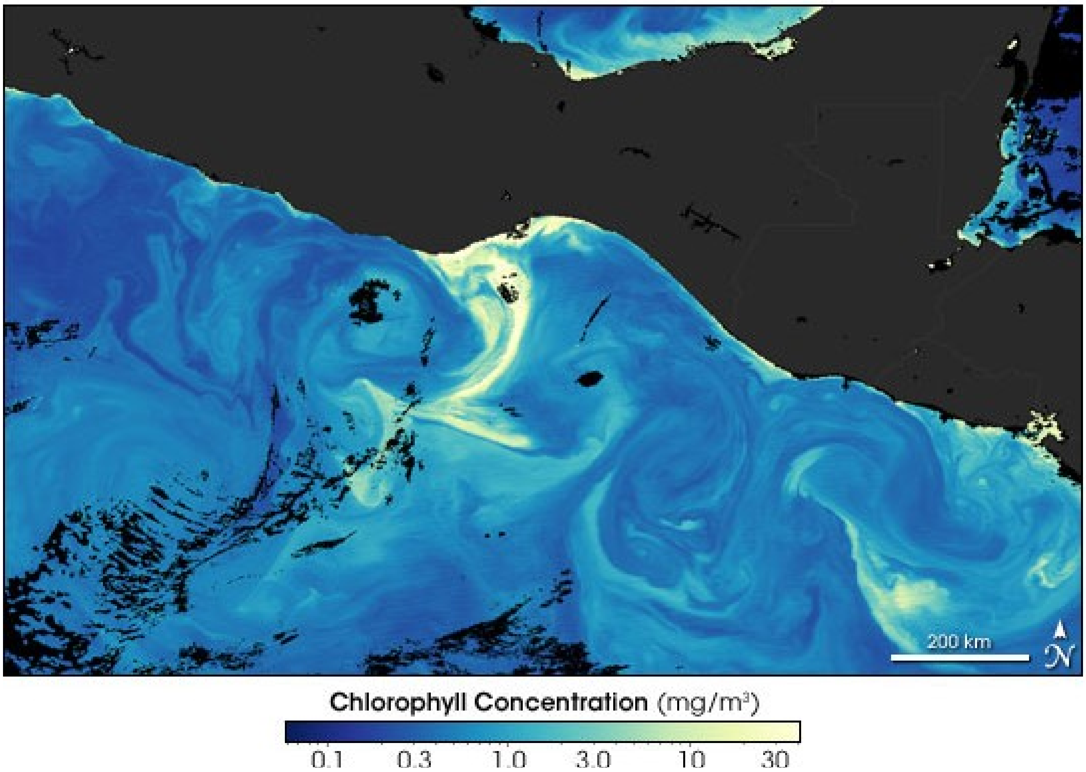


Fig. 19: This water-color-like image of the Pacific Ocean (bottom), the Isthmus of Tehuantepec in Mexico (center), and the Gulf of Mexico (top) shows chlorophyll concentrations observed on January 4, 2005, by the Moderate Resolution Imaging Spectroradiometer (MODIS) on NASA's Aqua satellite.

We can clearly see on Fig.19 a local coastal upwelling, a large plume induced by strong vertical mixing extending off-shore, an anticyclonic gyre on the western side of the plume, and a cyclonic one on the eastern side.

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