The VASCO-CIRENE experiment

J.P. Duvel (1[1]), J. Vialard (2) and Collaborators

(1) Laboratoire de Météorologie Dynamique, ENS, Paris, France (2) Locean, Université Paris VI, Paris , France

Abstract

Recent studies based on Tropical Rainfall Measuring Mission's (TRMM) Microwave Imager (TMI) data shows that tropical intraseasonal perturbations of the deep convection may be associated to Sea Surface Temperature (SST) variations of several degrees, especially south of the equator in the western Indian Ocean (55°E-80°E, Eq-15°S) during boreal winter. While this variability is partly reproduced by forced or coupled Ocean models, the relative role of different physical processes (warm layer formation, Ekman pumping, sub-surface cooling due to vertical mixing, surface fluxes) in these intraseasonal SST perturbations still has to be established. Since there are very few in situ observations in this region, an experimental campaign is needed to confirm the hypotheses that can be built using numerical modeling.

The objective of the VASCO-CIRENE campaign is to measure the impact of the different physical processes listed above on SST perturbations from diurnal (warm layer) to intraseasonal time-scales. This aims to better explain (i) the mechanisms of the intraseasonal variability of the SST and (ii) the feedback of these SST variations on the atmosphere. The CIRENE ship campaign, within the west Indian Ocean will be synchronized with the VASCO observing system (Aeroclippers and pressurized balloons launched from the Seychelles). During CIRENE, physical oceanography, air-sea fluxes and atmospheric measurements will be collected and a special care will be taken in measuring the diurnal cycle in the surface layer since it is believed to play an important role in intraseasonal SST variability. Biogeochemical measurements (nutrients, pigments) will also be collected because they can provide useful information on the physical processes at the origin of the SST perturbation. These measurements will be combined with those from VASCO and from Provor/Argo floats. Both the scientific objectives and the geographical location of this campaign fit into CLIVAR IOP objectives and the CIRENE region is now recognized as a key region for the development of intraseasonal events.

---

[1] Corresponding Author:
J.P. Duvel
Laboratoire de Météorologie Dynamique, IPSL
École Normale Supérieure
24, rue Lhomond, 75231 Paris, Cedex 05
jpduvel@lmd.ens.fr

1. Overview

The intraseasonal variability (ISV) of the deep convection has maximum amplitude over the Indo-Pacific region and is one of the most organized and reproducible large-scale perturbations in the Tropics. The ISV of the convection may have a strong impact on the seasonal predictability in the tropics. During winter, the maximum amplitude of the convective perturbation is located between the equator and 15°S (Fig.1a). This perturbation propagates eastward from the West Indian Ocean to the Central Pacific. This winter variability is generally referenced as the Madden-Julian oscillation (MJO, see Madden and Julian 1994 for a review). These perturbations are associated with westerly wind bursts generating important surface flux perturbations (e.g. Weller and Anderson 1996; Duvel et al. 2004) and that may play a role in the onset of El Niño events (e.g. McPhaden 1999; Lengaigne et al. 2002).

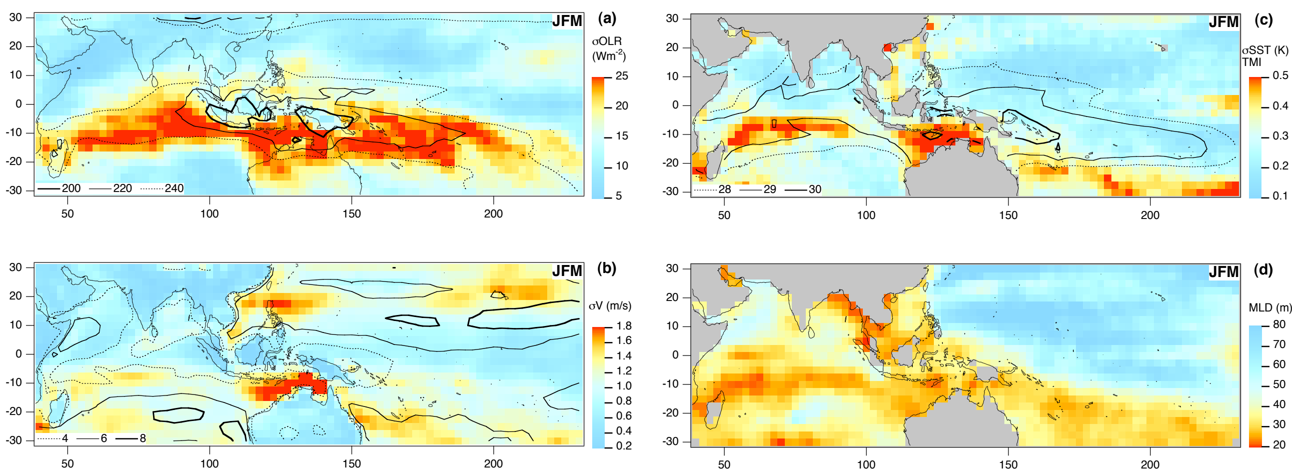

Figure 1: JFM seasonal average (contours) and 20-90 day band standard deviation (colors) for (a) the NOAA-OLR, (b) the NCEP surface wind module and, (c). the TMI SST. (d). Seasonal average of the mixed layer depth from the de Boyer Montégut (2004) climatology. (from Duvel and Vialard, 2006)

The mechanisms for the generation and the evolution of the intraseasonal variability of the deep convection over the Indo-Pacific region are not perfectly understood. However, recent modelling studies suggest that air-sea interactions could play an important role both during summer and winter (e.g. Waliser et al. 1999; Inness and Slingo 2003; Maloney and Sobel 2004). Observations also have revealed SST perturbations up to 3K in relation with the ISV of the convection in the China Sea (Kawamura 1988), in the Bay of Bengal (Sengupta and Ravichandran 2001) and in the western Pacific (e.g. Anderson et al, 1996). Recent satellite measurement of the SST by the Tropical Rainfall Measuring Mission's (TRMM) Microwave Imager (TMI) (Wentz et al 2000) also revealed large SST perturbations in the Indo-Pacific region (Harrison and Vecchi 2001; Duvel et al 2004; Duvel and Vialard 2006). These SST perturbations are particularly strong south of the equator in the Indian Ocean during NH winter (Fig.1c) and is associated to a relatively thin mixed layer (Fig.1d). This determined the choice of the region and the season for the VASCO-CIRENE experiment. These large SST variations, identified with the TMI satellite dataset, were confirmed by in situ data and show a potentially important role of warm layers in the intraseasonal amplitude of the SST (Fig.2).

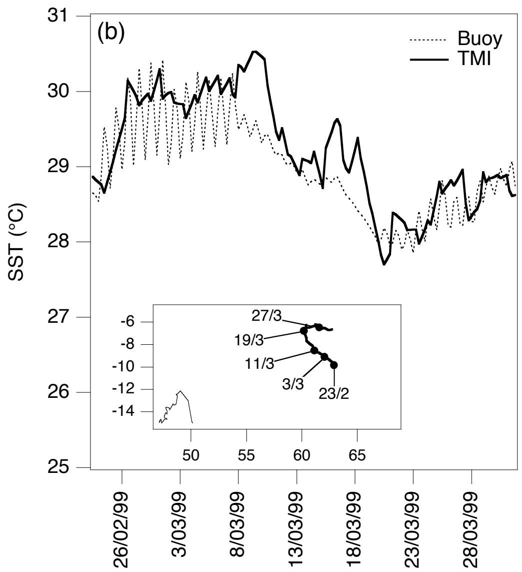

Figure 2: Comparison between the SST measurement of drifting buoys and the deduced TMI SST along the path of the buoy. TMI SST at the location of the buoy is obtained by horizontal bi-linear interpolation and linear temporal interpolation in daily TMI fields. The inlay shows the trajectory of the WMO 14549 between February 25 and March 30 1999. (from Duvel et al, 2004)

The physical origin of these large SST perturbations over the south equatorial Indian Ocean may be due (i) to vertical and horizontal heat transport in the ocean mixed layer, (ii) to the surface fluxes and, (iii) to the formation of warm layers prior to the cooling event that might contribute to enhance the SST perturbation at intraseasonal time-scales. The shallow thermocline between 5°S and 10°S, due to average Ekman pumping during NH winter, certainly is a fundamental feature to explain the large observed SST perturbations. This shallow thermocline makes cold water readily available to cool the surface by vertical mixing or local upwelling and it also limits strongly the depth of the mixed layer, making it more responsive to surface forcing.

This surface forcing perturbation itself is due to various physical processes that may have different phasing relative to the maximum convective activity. For the surface heat fluxes, the western Indian Ocean during winter is more affected by the surface wind (Fig.1b) associated to convection further East than to the local convection (the opposite is observed over the Eastern Indian Ocean). Duvel et al (2004) showed that the latitudinal position of maximum SST variability was the result of a consensus between the position of the region of maximum flux perturbation (spanning the equator) and the region where the thermocline is shallow (between 5°S and 12°S). Results of the forced OGCM also showed that the salinity perturbation induced by the strong rain under convection and the intraseasonal Ekman pumping perturbation could play some role in the large SST response by limiting the mixed layer deepening induced by the wind perturbation.

The aim of the Vasco-Cirene experiment is to trace the physical source of the intraseasonal perturbation of the SST in the Western Indian Ocean south of the equator during the January-March season.

2. Instrumentation

Atmospheric quasi-Lagrangian VASCO measurements

Two kinds of balloon will be used in Vasco. The pressurized balloons (Fig.3) are isopycnal balloons flying at about 850hPa in a quasi-Lagrangian trajectory. Similar balloons were already used during the INDOEX experiment. They are performing measurements of pressure, temperature, humidity and wind with a temporal resolution of about 15mn. The average horizontal wind is deduced from GPS positioning.

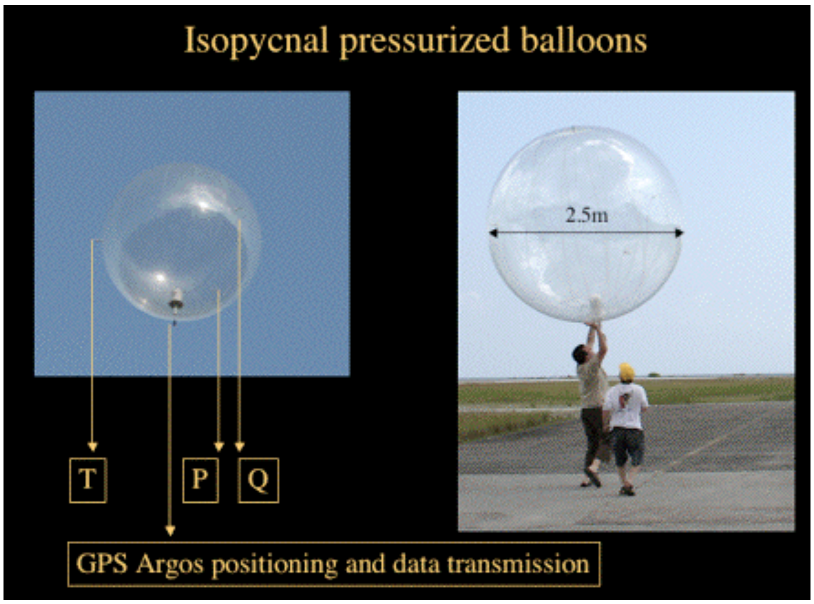

Figure 3

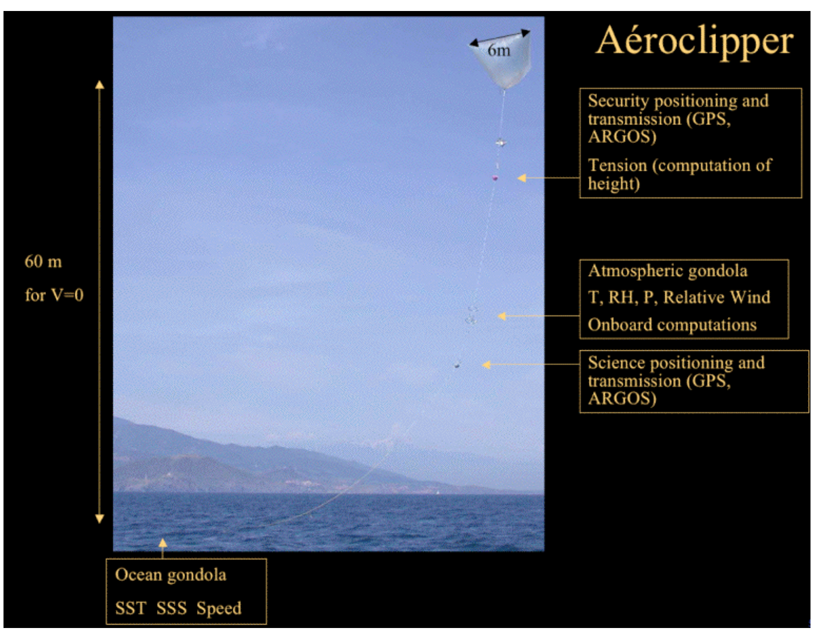

Figure 4a

The second type of balloon, the Aeroclipper (Fig.4a), is a new system developed jointly by CNRS and CNES. The Aeroclipper is a balloon equipped with a cable extended by a guide rope in contact with the surface of the ocean.

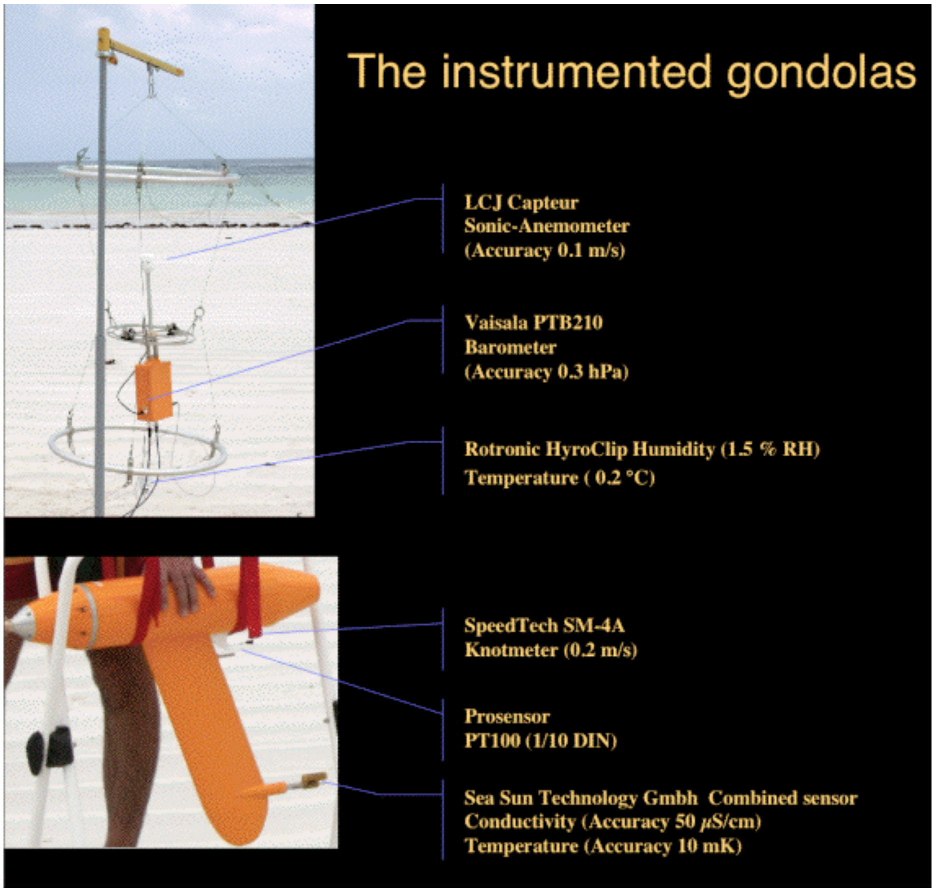

Figure 4b

The balloon is vertically stabilised at a given height (currently 40 to 60m above the sea surface) and move on quasi-Lagrangian trajectories depending on the surface wind. The sensors are distributed on one atmospheric and one oceanic gondola (Fig.4b). The aim is to measure surface physical parameters (air and sea surface temperatures, sea surface salinity, wind, pressure and humidity) and to derive turbulent fluxes of moisture, heat and momentum. The Aeroclippers will give legs of the different parameters at a temporal resolution of 15mn and thus information on the perturbation of these parameters at mesoscale. The equilibrium between the aerodynamical drag of the balloon and the hydrodynamical drag of the oceanic gondola gives a displacement speed of about half of the wind speed. First tests of the Aeroclipper were done in the Indian Ocean in February 2005 and January 2006. These tests show that the system is well able to give reliable and interesting measurements of the variability of the surface parameters. However, some problems linked to the mechanics of the system (distributions of the gondolas along the guide rope) and to the robustness of the tetrahedral balloon still have to be addressed prior to the Vasco campaign in 2007.

CIRENE instrumentation

In addition to rather classical measurements (CTD with L-ADCP, transmissiometer, fluorometer and PAR sensors; radiosondes), additional instrumental systems will be used during Cirene:

An ATLAS mooring (M. McPhaden PMEL) will be deployed at 67°E, 8°S (one of the locations of the flux reference sites decided by the Indian Ocean Panel of CLIVAR) during CIRENE. Informations about ATLAS moorings can be found at

http://www.pmel.noaa.gov/tao/proj_over/mooring.shtml

The ASIP (Air Sea Interactions Profiler) is developed by B. Ward (WHOI; Ward et al, 2004). It is an autonomous profiler with a depth range of 0-100m. ASIP can be programmed to perform repeated profiles between a reference depth and the surface. Its sensors have been designed in order to obtain very high vertical resolution that enable, in particular, to resolve the formation of warm layers. The sensors include temperature and conductivity microstructure, shear, oxygen, pressure, fluorometer, PAR (Fig.5).

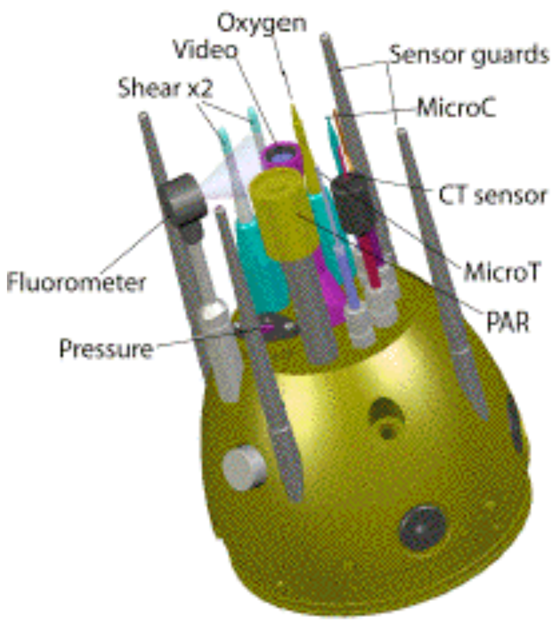

Figure 5: Sensors on the head of the Air-Sea Interaction profiler.

A VMP 5500 autonomous profiler (Rockland oceanography, Canada) will be operated once or twice a day to obtain a deep profile of oceanic microstructure. The microstructure data will later be used to estimated vertical profiles of eddy diffusivity (P. Bouruet Aubertot, LOCEAN)

In collaboration with R. Weller (WHOI), drifting thermistance chains will also be deployed. These thermistance chains have a 50cm resolution from 0.5m to 12m and will be complemented with self recording thermometers (every 5m down to 60m) and a pressure gauge to monitor the mixed layer depth and mixed layer temperature horizontal variability. These drifters will be drogued at about 500m. This should slow them down considerably and maintain them in the vicinity of the ship during the station period duration.

The RSMAS group (P. Minett, Univ. Miami) has developed an instrumental suite to monitor surface skin temperature of the ocean, surface emissivity, near-surface air temperature, and profiles of temperature and humidity through the lower troposphere (Table 1). The principal instrument is the M-AERI (Marine-Atmosphere Emitted Radiance Interferometer; Minnett et al., 2001), a Fourier-Transform Infrared Spectro-radiometer capable of withstanding the rigors of at-sea deployment. Every ten minutes, it produces well-calibrated spectra of the infrared emission from the atmosphere and ocean in the wavelength range from 3 to 18 µm. From these spectra, skin sea-surface temperature, near-surface air temperature, and profiles of atmospheric temperature and humidity to a height of about 3km are derived. Other products, such as cloud optical depth and cloud particle effective radius, may also be calculated from M-AERI spectra. Other parameters that can be measured by the others instruments in the RSMAS package are listed in Table 1.

Table of measured and derived variables and sensors.

Variable	Ship-based Sensor
Skin sea-surface temperature	M-AERI, ISAR
Bulk sea-surface temperature	Surface-following float
Infrared spectra of surface emitted radiation	M-AERI
Infrared spectra of atmosphere emitted radiation	M-AERI
Direct/diffuse SW↓; aerosol optical thickness	MFRSR
Cloud type and cover	All-sky camera
Insolation (SW↓)	Gimbaled Eppley pyrometer
Incident thermal radiation (LW↓)	Gimbaled Eppley pyrgeometer
Atmospheric humidity profiles	Radiosondes
Atmospheric temperature profiles	Radiosondes
Columnar water vapor	Microwave radiometer
Rainfall	Optical rain gauge
Air Temperature	Thermistor*
Relative humidity*	Vaisala "Humicap" *
Wind speed*	R. M. Young anemometer*
Wind direction*	R. M. Young anemometer*
Barometric pressure*	Digital barometer*
**Part of Coastal Environmental System's "Weatherpak"*	

Table 1: List of parameters measured by the RSMAS package.

The CETP group has developed a mast that can estimate the net air sea fluxes with an estimated 15% accuracy for 30 minutes averages. The turbulent components of the fluxes are estimated using the correlation method, and effects of the flow distortion around the ship and mast are corrected on the basis of numerical simulations. The measured quantities to estimate the turbulent component include the platform motion (6 degrees of freedom), wind, humidity and temperature (at an accurate 1 Hz sampling, and a high frequency sampling of 50 Hz).

3. Experimental strategy

VASCO campaign

The balloons will be launch form the Mahe Island (Seychelles). One aim is to sample the region of interest close to the position of the Suroît ship that is the centre of the CIRENE campaign.

Another aim is to extend the CIRENE measurements to a wider area in order to well sample the dynamical (westerly wind burst at the surface and at 850hPa) and thermodynamical perturbations associated to the intraseasonal perturbations in the Indian Ocean South of the equator. This includes precise measurements of the surface parameters using the Aeroclipper, in particular for the short time and space variability of the SST and the surface salinity and an estimate of the surface turbulent fluxes using bulk algorithms.

The decision to launch one or more pressurized balloons and Aeroclippers will be taken using prediction of the balloons trajectories computed using ECMWF "deterministic forecast " and "ensemble prediction system" (EPS) (see http://www.lmd.ens.fr/tromeur/VASCO/ for some examples). This prediction system was tested during the pre-campaigns of February 2005 and January 2006 and gave satisfactory results. The launch of one ore more balloons will also depends on the actual and predicted large-scale conditions in order to optimize the distribution of the measurements over the Indian Ocean South of the equator.

CIRENE campaign

The Cirene campaign will start from the Seychelles and will head directly towards 67°E, 3°S. During all the transits within the "Cirene box", XBTs and radiosondes will be launched regularly. A few Argo floats with a specific programming (cycles every day from 500m to the surface) will be also deployed along 67°E, at 3°S, 5°S and 7°S. The ATLAS mooring will be deployed at its nominal location (67°E, 8°S).

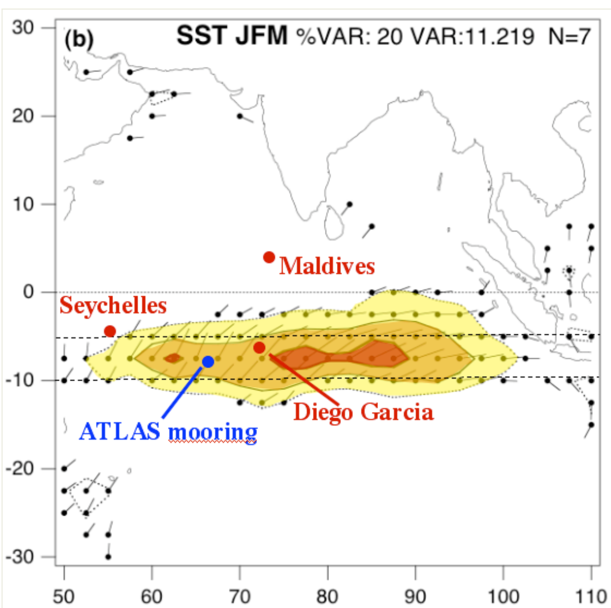

Figure 6: Multivariate average pattern of intraseasonal variation of the SST the January-March season (7 events). The corresponding variance percentages for each parameter and each season are reported in the figure. The segment length is proportional to the standard deviation and the angle of the segment represents the relative phase. The angle increases clockwise with time (e.g. northward propagation for a segment rotating clockwise toward the north). The contour lines represent the standard deviation of this average pattern (0.2, 0.3 and 0.4K).

The Suroît ship will remain in the region of climatological maximum response of the SST to the OLR. The latitude of this maximum is around 7°S (Fig.6), but the longitude cannot be established precisely for a given year. However, past time series show interesting signals at 7°S almost everywhere from 60°E to 90°E. There will be a potential zonal adjustment depending on real time OLR and TRMM SST data. To avoid shortening excessively the station time, the Suroît will stay west of 75°E. Drifting buoys will be deployed to sample the mixed layer structure variability in the vicinity of the station point. The use of a deep drogue (~500m) should slow them down significantly to allow an easier recovery later.

A station point will then be started for about 25 days. The following measurements will be collected during this period:

- CTD+L-ADCP down to ~300m with PAR sensor, fluorometer, transmissiometer, water samples (for biogeochemistry), every two hours.
- ASIP will be deployed as often as possible, especially during quiescent phases of the intraseasonal oscillation to monitor the warm layer diurnal and interdiurnal evolution.
- A microstructure autonomous profiler will be deployed once or twice per day and deliver a deep profile of the turbulence in the water column.
- Air-sea fluxes will be estimated on a continuous basis by the CETP package
- The RSMAS package will be operated continuously.
- Two to four radiosondes will be launched every day.

"Le Suroît"

After this station period, the WHOI drifters will be recovered. A stop at the ATLAS mooring is also programmed for more calibration and mooring maintenance and/or recovery of some instruments. The Suroît ship will then head back towards the Seychelles. The total duration of the campaign is ~35 days with a start in early January 2007.

4. Data processing

The main objective of Cirene is to estimate the various causes of SST perturbations due to convective intraseasonal oscillation. Quantitative heat and freshwater budgets of the upper ocean will be used to this aim. The CTD data will have a high-resolution sampling, and a preliminary processing should enable to remove influence of inertial waves, gravity waves and, to some extent, mesoscale variability. In this respect, the data from the neighbouring WHOI drifters, ATLAS mooring and Argo floats as well as Vasco measurements and satellite data should be useful to recognise large scale variability due to the MJO from the influence of more local phenomena. 1D modelling (forced from measured fluxes and initialised from the data) will be use to better understand the physical processes. The microstructure profiles from ASIP and the VMP5500 will be used to estimate vertical eddy diffusivity and evaluate the role of mixing in the budgets. The vertical profiles of fluorescence will be used in conjunction with chlorophyll measurements in water samples to estimate the profile of light penetration into the ocean and to assess if its variability impacts significantly the heat budget.

The pressurized balloons and aeroclipper measurements will serve as a base of validation for the meteorological fields given by ECMWF and that will be used to describe the large-scale environment for the Cirene measurements. The Coare 3.0 (Fairall et al, 2003) bulk flux algorithm is used to derive the surface turbulent fluxes from the Aeroclipper measurements. The height of the atmospheric measurements is estimated using the relative wind measurements and a mechanical model of the Aeroclipper system. The Aeroclipper measurements will be typically used to do the link between the precise Eulerian measurements of Cirene and the large-scale fields given by satellites and by meteorological analyses of ECMWF. These measurements will also give a statistics on the spatial homogeneity of the surface parameters and on their short time and space variability related to the diurnal cycle and to the convective precipitation events, in particular on the surface salinity and temperature and on the turbulent flux perturbations.

5. Expected results

For the Vasco-Cirene experiment, particular emphasis will be put on the relative role of the three processes invoked above, e.g.: modulation of the mixed layer temperature by mixing with deeper ocean layers (and/or modulation of upwelling by Ekman pumping); modulation of the mixed layer temperature by the surface fluxes with a precise estimate of the relative role of the solar and the latent heat fluxes; formation and destruction of warm layer depending on the intraseasonal modulation of the surface wind. The Cirene observations will give also information on the role of the salinity (modulated by the rainfall) on the surface temperature and current and more generally on the dynamics of the mixed layer.

Also, a particular emphasis will be put on the chlorophyll (and nutrients) signal associated with intraseasonal events. This signal may be indeed interpreted as a sign of exchange (through Ekman pumping or mixing) between the surface and the subsurface that contains more nutrients. The biological activity may be also strong enough to change the upper ocean heat budget by modifying the penetration of light in the upper ocean.

In addition to these local Eulerian measurements, the Vasco balloon measurements will give information on the large-scale dynamics at the surface and at the top of the boundary layer. These measurements will be used as a validation set for the analysed meteorological field by numerical prediction centres (ECMWF, NCEP) and a complement to the radiosondes performed at the ship location. Also, the Aeroclipper balloons used in Vasco will give a larger statistics on in situ measurements of surface parameters (including surface salinity) and surface turbulent fluxes. This will extend the Eulerian and precise measurements made by Cirene and give a larger basis of validation/correction for the satellite remote sensed variables.

References

Anderson, S. P., R. A. Weller, and R. Lukas, 1996 : Surface buoyancy forcing and the mixed layer of the western Pacific warm pool: Observations and 1D model results. *J. Climate*, **9**, 3056-3085.

de Boyer Montégut C., G. Madec, A. S. Fischer, A. Lazar, and D. Iudicone, 2004: Mixed layer depth over the global ocean: an examination of profile data and a profile-based climatology, *J. Geophys. Res*., **109**, C12003, doi:10.1029/2004JC002378.

Duvel, J.-P. and J. Vialard, Indo-Pacific Sea Surface Temperature Perturbations Associated with Intraseasonal Oscillation of the Tropical Convection, *J. Clim*., 2006 (in press)

Duvel, J-P., R. Roca and J. Vialard, 2004: Ocean Mixed Layer Temperature Variations induced by Intraseasonal Convective Perturbations over the Indian Ocean. *J. Atmos. Sci*., **61**, 1004-1023.

Fairall, C.W., E.F. Bradley, J.E. Hare, A.A. Grachev, and J.B. Edson, 2003: Bulk parameterization of air-sea fluxes: Updates and verification for the COARE algorithm. J. Climate 16, 571-591.

Harrison, D.E., and A. Vecchi, 2001: January 1999 Indian Ocean cooling event. *Geophys. Res. Let*., **28**, 3717-3720.

Inness, P. M., and J. M. Slingo, 2003: Simulation of the Madden–Julian Oscillation in a Coupled General Circulation Model. Part I: Comparison with Observations and an Atmosphere-Only GCM. *J. Climate*, **16**, 345–364.

Kawamura, R, 1988 : Intraseasonal Variability of Sea Surface Temperature over the Tropical Western Pacific, *J. Meteor. Soc. Japan*, **66**, 1007-1012.

Lengaigne, M., J.-P. Boulanger , C. Menkes, S. Masson, P. Delecluse et G. Madec, Ocean response to the March 1997 westerly wind event, *J. Geophys. Res.,* **107**, 2002.

Madden, R.A., and P.R. Julian, 1994: Observations of the 40-50 day tropical oscillation - A review, *Month. Wea. Rev,* **122**, 814-836.

Maloney, E.D. and A. H. Sobel. 2004: Surface Fluxes and Ocean Coupling in the Tropical Intraseasonal Oscillation. *J. Climate,* **17**, 4368–4386.

Minnett, P. J., R. O. Knuteson, F. A. Best, B. J. Osborne, J. A. Hanafin, and O. B. Brown, 2001: The Marine-Atmospheric Emitted Radiance Interferometer: A high-accuracy, seagoing infrared spectroradiometer. *J. Atmos. Oceanic Technol.,* **18**, 994–1013

McPhaden, M. J., 1999: Genesis and evolution of the 1997-1998 El Niño, *Science*, **283**, 950-954.

Sengupta, D., and M. Ravichandran, 2001: Oscillations of Bay of Bengal sea surface temperature during the 1998 summer monsoon, Geophys. Res. Lett., **28**, 2033-2036.

Waliser, D. E., K. M. Lau, J.-H. Kim, 1999: The Influence of Coupled Sea Surface Temperatures on the Madden–Julian Oscillation: A Model Perturbation Experiment. *J. Atmos. Sci*., **56**, 333–358.

Ward, B., R. Wanninkhof, P. J. Minnett and M. J. Head, 2004: SkinDeEP: A Profiling Instrument for Upper-Decameter Sea Surface Measurements. *Journal of Atmospheric and*

Oceanic Technology, **21**, 207–222.

Weller, R.A., and S.P. Anderson, 1996: Surface Meteorology and Air-Sea Fluxes in the Western Equatorial Pacific Warm Pool during the TOGA Coupled Ocean-Atmosphere Response Experiment. *J. Climate*, **9**, 1959–1992.

Wentz,F.J., C. Gentemann, D.Smith, D.Chelton, 2000: Satellite measurements of sea-surface temperature through clouds. *Science,* **288**, 847-850.