VOCALS REx / The VAMOS Ocean Cloud Atmosphere-Land Study: The Peruvian Contribution to VOCALS REx / CLIVAR Program

Carmen Grados[1], Yamina Silva[2], Luis Vásquez[1], Michelle Graco[1], Yves du-Penhoat[3], Boris Dewitte[3], Alexis Chaigneau[4], Sonia Sánchez[1], Patricia Ayón[1], Jesús Ledesma[1], Gérard Eldin[3], Ken Takahashi[2], Vincent Echevin[4], Lionel Renault[3], Jorge Tam[1], Miguel Saavedra[1], David Correa[1], José Pasapera[1], A. Bertrand [5]

[1] Instituto del Mar del Perú (IMARPE), Perú; [2] Instituto Geofísico del Perú (IGP), Perú; [3] Institut de Recherche pour le Développement (IRD) / Laboratoire d'Etudes en Geophysique et Oceanographie Spatiales (LEGOS), France; [4] Laboratoire d'Océanographie et de Climatologie: Expérimentation et Analyse Numérique (LOCEAN) / IRD, France

E-mail: cgrados@imarpe.gob.pe

1. INTRODUCTION

VOCALS (VAMOS[1] Ocean-Cloud-Atmosphere-Land Study) is an international CLIVAR program, is dedicated to the study of the South Eastern Pacific (SEP) coupled ocean-atmosphere-land system on diurnal to inter-annual timescales. The scientific motivations of this program encompass a variety of issues which go from the aim to resolve the biases in large scale general circulation coupled models to understanding the variability of the upwelling ecosystems of Peru-Chile.

VOCALS is organized in two tightly components: 1) a modeling program (VOCALS-Mod) which is based on the use and development of coupled model (ocean-atmosphere-land-biogeochemistry) platforms both at the large and regional scales, 2) a Regional Experiment (VOCALS-REx) which focuses on coastal zones, one off the coast of Chile and the other one off the coast of Peru.

This presentation focus on the Peruvian contribution to VOCALS-REx.

The Peru Coastal VOCALS project aims at understanding air-sea-land-cloud interactions near 15°S (Pisco) and its impact on the local ecosystem. In this frame, the oceanic and atmospheric circulations, thermodynamical and biogeochemical structures will be documented through historical data, high-resolution model simulations and a specific a coastal cruise which will take place in November 2008. The data collected during this cruise include measurements of the main ecosystem compartments (Table. 1) in the Pisco-San Juan region and thus will provide a comprehensive description of the oceanic, atmospheric and biogeochemical variability of this coastal upwelling region.

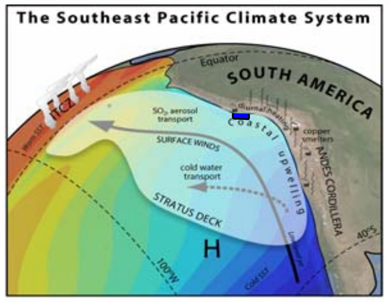

Figure. Key features of the SEP climate system and Peru VOCALS cruise area shaded in blue (Adapted from Wood, et al, 2007).

2. SCIENTIFIC THEMES

The Pisco region is the siege of highly variable along-shore atmospheric coastal jet associated with strong coastal upwelling events and important oceanic mesoscale activity which makes it particularly interesting for the study of coupled processes at the regional scale. Important effects on the upwelling ecosystem are expected which might play a significant role on the offshore transport of coastal upwelled water properties.

Five broad scientific themes are considered in the Peru Coastal VOCALS project:

- Impacts of the synoptic-scale features upon the lower troposphere circulation, thermo-dynamical structure and cloudiness within the nearshore region;
- Impact of remote forcing (equatorial oceanic Kelvin waves and the large scale atmospheric circulation) on the coastal current systems;
- Impact of the thermal (e.g. land heating) and topographic forcing on the atmospheric MBL circulation and thermodynamical structures and clouds in the coastal strip (0-50 km);
- Feedbacks between MBL circulation, clouds, Sea Surface Temperature and mesoscale eddies in the coastal strip;
- Influences of the atmospheric /oceanic variability in the coastal strip on the offshore region.

The specific questions, hypotheses, observational strategies are presented.

3. MAIN OBJECTIVE AND HYPOTHESIS

The main objective of the Peru VOCALS Coastal Component is to investigate the meso and submesoscale ocean-atmosphere interaction in the upwelling zone off southern Peru (Pisco-San Juan) and to determine the associated biogeochemical responses. Two main hypotheses are considered:

H1. ***There is a strong feedback/interaction between the variability of the atmospheric coastal wind, the upwelling cell and the instabilities of the associated thermic front and cloud clearing between Pisco and San Juan.***

H2. ***Mesoscale eddies play an important role for the export of coastal water properties and are involved in the maintaining of low surface ocean temperatures away from the coast.***

4. THE SCIENTIFIC QUESTIONS

- What is the three-dimensional structure of the near-coastal low-level wind off Peru? How is this structure influenced by topography and land-sea thermal contrasts?
- What produces the cloud clearing to the northwest of 15ºS and how does it interact with the flow field?
- How does large-scale atmospheric variability at synoptic time scales affect the near-coastal winds?
- How does the near-coastal wind interact with mesoscale ocean processes as eddies, filaments and upwelling?
- How are water masses distributed due to advective processes of the upwelling plume?
- Are the coastal winds and the upwelling front coupled?
- What is the chemical structure and the PCO_2 behaviour of eddies and filaments compared with the surrounding waters? Are eddies and filaments a source or sink of PCO_2?
- Is there an evolution of the chemical properties and PCO_2 along a filament, onshore-offshore?
- What is the community structure of phytoplankton (diatoms, dinoflagellates and phytoflagellates) in the water column (0-75 m depth) based on the distribution, composition and abundance of particle sizes (0.5 - 75 µm) and the distribution of biomass in a mesoscale and submesoscale environment related with the surrounding waters?
- Is there a relationship between chemical structure, phytoplankton community and PCO2 exchange?
- What are the relative contribution of advection and vertical mixing in the mesoscale structure to the phytoplankton community structure?
- Do and how fish aggregations take place?
- To which extend high-resolution regional coupled (ocean-atmosphere-biogeochemical) models can account for the observed mesoscale and submesoscale variability?, Are they useful tools for process studies, forecasting and fishery management in this region?

Within the broad scientific themes listed, this project will also address (through modeling and from the available observations) **specific questions** that are believed to be relevant to the understanding of variability in the Pisco-San Juan region and its impact on the large scale. These are:

SQ1. Spatial structure of the low-level atmospheric circulation (15°S)

Hypothesis:

1.1: The near-coastal wind around 15S has a narrow jet structure.

1.2: The near-coastal wind structure is strongly influenced by topography and land-sea thermal contrasts.

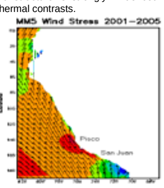

Figure. The MM5 wind stress showed a maximum near the coast at about 14°S and 76°W [Saavedra et al, 2007]

Observational / Modeling requirements:

Wind speed and direction measurements from coastal automatic weather stations located in Pisco, Paracas, Ocucaje and San Juan will be made. To represent the thermal structure of the coastal boundary layer, vertical temperature profiles (up to 2 Km) using a tethered balloon every 3 hr will be achieved at Pisco and San Juan, as well as wind observations using pilot balloons. The same parameters will be measured during the VOCALS cruise and for the vertical temperature and wind profiles, radiosounding will be made approximately every 10 km) within 50 km from the coast and at lower frequency farther offshore. Surface winds from satellite observations, SST and cloudiness will complement the *in-situ* measurements.

A high-resolution numerical simulation of the low-level near-coastal flow off Peru will be performed using MM5 and WRF. The models validation using satellite data, such as scatterometer winds for the offshore region and using available meteorological surface and upper level observations will be done. Model experiments will be performed to determine the important factors controlling the coastal atmospheric structure in the study region.

SQ2. Quasi-permanent coastal clearing (~15ºS)

Hypothesis:

2.1 : The coastal clearing is closely linked to the strong near-coastal wind and the boundary layer structure.

2.2 : The interactions between alongshore winds, topography, cloudiness, land heating and coastal upwelling might all be climatologically important in this region.

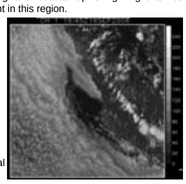

Figure. GOES Visible image from Sept. 19, 2006. The strong coastal clearing is showing.

Observational / Modeling requirements:

Humidity, air temperature, wind speed and direction from the coastal automatic weather stations will be made. To represent the thermal and moisture structure of the coastal boundary layer, the vertical temperature and humidity profiles (up to 2 Km) using a tethered balloon every 3 hr will be available at Pisco and San Juan, as well as wind observations using pilot balloons. The same parameters for the 3-D temperature, humidity and wind vertical profile will be measured on the cruise by radiosounding. The radiative effects of the cloud clearing will be determined from data obtained using radiometers. Satellite (GOES) observations of cloudiness will complement the *in-situ* measurements.

High-resolution MM5 numerical simulations will be performed for 3 domains with 54 Km resolution (South America), 18 Km (Peru) and 6 Km (Pisco-San Juan). Different PBL and MBL scheme will be used to compare the cloud representation for the region. The model validation using GOES satellite data and available meteorological surface and upper level observations will be done.

SQ3. Strongest coastal upwelling and eddy activity

Hypothesis:

3.1 : The coastal upwelling in the study region is influenced mainly by local forcing such as bathymetry, the coastal line and the local wind system.

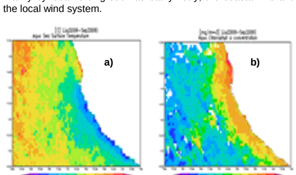

Figure. a) Winter SST (°C) 2006; b) Winter Chlorophyll-a, from MODIS in the 'child' grid.

Observational / Modeling requirements:

Complementary to measurements described in the SQ 1- SQ 2, the oceanographic measurements will be done to get the SST, salinity, oxygen and Chlorophyll-a to analyze the upwelling system and related water masses.

The relationship between wind stress changes and vertical profiles of upwelling parameters will be investigated. Offshore transport of physical and biogeochemical properties (nutrients and chlorophyll) will be estimated with different wind forcings.

Simulations with ROMS-AGRIF and ROMS-NPZP/PISCES models, forced with WRF or MM5, QuikSCAT, *in situ* and hybrid winds will be performed to characterize the atmospheric forcing, its climatology and interannual variations in the region of interest. Each simulation will use nested grids (parent grid 1/12º and child grid 1/36º). The spatial and temporal variability of simulated oceanographic conditions will be analyzed. Simulated upwelling dynamics, biogeochemical processes, mesoscale and sub mesoscale structures will be validated with satellite and *in situ* data.

SQ4. Coastal Jet events and their impacts on the vertical structure oceanic variability

Hypothesis:

4.1: Air-sea coupling associated to CJ event in the Pisco region explains the characteristics of the upwelling cell (amplitude and variability) around 15°S

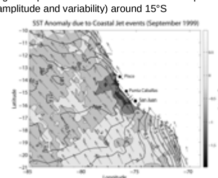

Figure. Spatial structure of the SST (TMI) cooling related to a well defined CJ (about 7 days) which occurs at the beginning of Sept.1999 [Renault, et al, 2007].

Observational / Modeling requirements:

Coordinated coastal vertical profiles and ship-borne observations during a CJ event are required. Satellite and *in situ* SST measurements (and satellite estimates) should provide the evolution of the SST field in the near-costal area during the CJ lifecycle. Ship-borne and historical data from the IMARPE cruises would document changes of ocean temperature and currents with depth. Ship-borne measurements of air-sea fluxes are also important.

A regional high-resolution coupled model (ROMS/OASIS /WRF-MM5) is necessary to simulate the observed variability during the CJ event.

SQ5. 4-D Structure of mesoscale features and associated cross-shore transports

Hypothesis:

5.1 : The destabilization of the coastal upwelling front generates mesoscale structures (filaments, eddies) that participate to the cross-shore transport of coastal water properties

5.2 : The mesoscale structures (filaments, eddies) present a spatial evolution onshore-offshore in the chemical and the phytoplankton community structure that influence the PCO_2 exchange between the water column and the atmosphere.

5.3 : The mesoscale structures (filaments, eddies) present a physical structure that determine a spatial succession of phytoplankton communities.

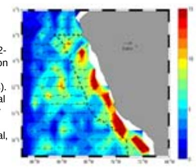

Figure. Mean climatology of eddy genesis occurrence for the time period October 1992-August 2006. Average motion vectors for eddy centers are superimposed (black quivers). Bold lines display the "coastal region" where temporal eddy characteristics variations are investigated [Chaigneau, et al, 2007, submitted].

Observational / Modeling requirements:

To test **H 5.1**, a fleet of gliders (1-3) and near-surface drifters (5-10) and the regional modeling platform is proposed, in order to: i) Investigate the 4-D physical (Temperature, Salinity) and possibly bio-optical (Oxygen, Chlorophyll, fluorescence) structure of the wind-forced upwelling plume and associated mesoscale structures; ii) Collect measurements of physical and bio-optical parameters for model validation and to motivate and guide detailed measurements of processes such as fronts, filaments, eddies, plumes.

A survey of the filament structures will be conducted to map the evolution of the chemical and phytoplanktonic structure in filaments, onshore-offshore, and insight the eddies. Additionally several short transects will be performed associated with filaments, eddies and the surrounded areas in order to determine the PCO_2.

Once validated, modeling platform will be used to estimate the cross-shore transport associated with mesoscale vortices.

5. METHODOLOGY

In order to adequately respond to the proposed objectives, this project is based on four distinct approaches:

- A retrospective analysis of existing data (historical *in situ* data and satellite measurements),
- Planned pre-VOCALS cruise complementary activities (September 2007-October 2008)
- An intensive observation phase based on a cruise of 13-day duration,
- Diverse modeling experiments using a multidisciplinary model platform (including atmospheric, oceanic and biogeochemical components).

Modeling activities:The VOCALS REx Peru modeling component is based on several modeling tools: ROMS for the ocean physics, WRF/ MM5 for the atmosphere, PISCES for the biogeochemistry. These tools are already used for the entire Peru area [Penven et al., 2003; 2005, Echevin et al., 2007] and for central Chile [Renault et al., 2007] and will be implemented for the study area. The modeling of the ocean circulation uses a model with two nested grids: a coarse grid (1/9°~13 km) over the Northern Peru region and a fine grid (1/27°~ 4 km) focusing in the coastal region of the cruise.

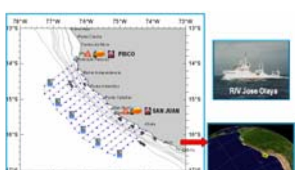

Figure. Map of the cruise track planned. The main region of study is between Pisco and San Juan.

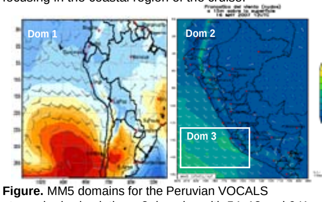

Figure. MM5 domains for the Peruvian VOCALS atmospheric simulations, 3 domains with 54, 18 and 6 Km resolution.

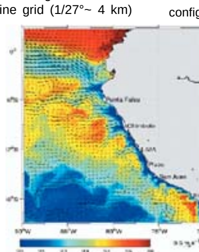

Figure. Modeled surface currents and SST (°C) associated with mesoscale structures [Penven et al, 2003]

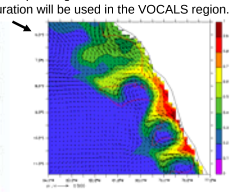

Figure. Surface chlorophyl-*a* (mgm^{-3}), and velocity ($m\ s^{-1}$) in Nov.2005 from the ROMS/PISCES coupled regional model for 9°S. A similar configuration will be used in the VOCALS region.

6. THE EXPECTED RESULTS

- Improve the understanding of the SEP upwelling system dynamics.
- Provide information on the hydrological, dynamical, biogeochemical and biological characteristics of the meso and submesoscale structures in southern Peru.
- Determine propitious regions for filament/eddies generation and identify the responsible physical forcing (topography, capes, wind). These results will highlight resemblances or discrepancies with other upwelling systems (California, Canaries, Benguela).
- Document the relationship and identify potential feedbacks between oceanic filaments/eddies and atmospheric forcing.
- Determine the role of mesoscale environments related with nutrients and chlorophyll-a concentrations and PCO_2 fluxes between the ocean and the atmosphere.
- Determine the impact of the chemical structure of mesoscale environments in the phytoplankton community and on the PCO_2 ocean-atmosphere interaction.
- Document the vertical community structure of phytoplankton, the biomass and cellular carbon, the response of phytoplankton to environmental forcing in a mesoscale environment.
- Describe the impact of physical forcing at sub-mesoscale on zooplankton and fish 3D organization.
- Validate a high-resolution regional model platform which will be used to forecast the dynamic and biogeochemical activities related to the mesoscale activity at a regional scale and help for political decisions on fishery management.

7. REFERENCES

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[1] VAMOS-Variability of the American Monsoon Systems, a CLIVAR sponsored program to study the American monsoons in the context of the global climate. Additional information at *http://www.eol.ucar.edu/projects/vamos/*