U.S. CLIVAR
December 2009, Vol. 7, No. 3
VARIATIONS

The Impact of Field Campaigns

by David M. Legler, Director

Field campaigns/process studies are a major suite of activities in CLIVAR. Over the past ten years CLIVAR has helped plan and coordinate a number of such studies including EPIC, SALLJEX, NAME, CLIMODE, and KESS. Such campaigns are necessary to increase understanding of important physical processes, improve physical parameterizations important for climate models (and provide observations to calibrate them), and also to guide requirements for enhanced observational systems in critical regions (see Cronin et al, BAMS, Vol.9, Iss.7 for more on best practices for process studies).

This issue of Variations features some results from the 2008 VAMOS Ocean-Cloud-Atmosphere-Land Study (i.e., VOCALS), an international CLIVAR experiment focusing on the Southeast Pacific coupled ocean-atmosphere-land system and its important climate processes, particularly those in the upper ocean and lower atmosphere. Several hypotheses on aerosol-cloud-drizzle processes and coupled ocean-

Continued on Page Two

IN THIS ISSUE

Constraining the Southeastern Tropical Pacific Heat Budget with Observations

Simon P. de Szoeke, Oregon State University, Corvallis, OR

Southeasterly winds round the subtropical High and blow on the surface of the Pacific Ocean along the South American coast of Chile and Peru. The alongshore wind drives offshore ocean Ekman transport and coastal upwelling of cold nutrient-rich water. Cool sea surface temperature (SST) extends westward into the southeastern tropical Pacific Ocean due to the ocean transport and atmosphere-SST feedbacks. SST also stays cool due to the shade of a canopy of stratocumulus clouds. A strong inversion between the cool marine air and warm potential-temperature air subsiding from above caps the clouds. Warmer SST and deeper convection are found north of the equator because north Pacific-American winds cross the Central American isthmus and blow offshore, unfavorable for upwelling.

The meridional asymmetry of eastern tropical Pacific SST and atmospheric heating is a basic element of the observed Hadley circulation and its seasonal cycle, yet it is poorly simulated in most general circulation models (GCMs). Simulated southeastern tropical Pacific SST is usually too high (+1.6°C median), and models simulate a variety of well-known "double intertropical convergence zone (ITCZ)" errors (Mechoso et al. 1995, de Szoeke and Xie 2008). Models have difficulty in resolving and parameterizing processes, especially wind flowing around the high and narrow Andes Mountains, offshore ocean eddy heat transport, and persistent shallow stratocumulus clouds and their interaction with aerosols and drizzle. Hypotheses tailored to improve our understanding of these key processes were tested in the VAMOS Ocean Cloud Atmosphere Land Study (VOCALS). To best effect model improvement, VOCALS brings together a hierarchy of models in the VOCALS Model Assessment along with field observations from the VOCALS Regional Experiment (REx) in October-December 2008 (Wood et al., this issue).

The NOAA research vessel Ronald H. Brown made the first of a series of Stratocumulus cruises to the southeast Pacific in 2001 during the East Pacific Investigation of Climate (EPIC, Bretherton 2002). The Stratocumulus research cruises culminated with two cruises for VOCALS REx in 2008. In all, 7 Stratocumulus research cruises were made in years 2001 and 2003-2008 to the Woods Hole Oceanographic Institution (WHOI) Stratus buoy at 20°S, 85°W. The track of the Stratocumulus cruise in each year is marked in Figure 1a-g. Each Stratocumulus cruise traversed the 20°S parallel between 85° and 75°W, collecting observations of surface meteorology, SST, surface radiative and turbulent fluxes, and cloud fraction, cloud base and top height, and liquid water path. Rawinsondes were also released around the clock providing winds and the thermodynamic profiles of the

U.S. CLIMATE VARIABILITY AND PREDICTABILITY (CLIVAR)
1717 Pennsylvania Avenue, NW, Suite 250, Washington, DC 20006• www.usclivar.org

U.S. CLIVAR

Continued from Page One

atmosphere-land processes were investigated.

As VOCALS completes its analysis activities and future process studies make their way through the planning process, the climate and weather model development enterprise is focusing on how to evaluate and improve its models. WCRP is surveying the observational, theoretical and process (observational and modeling) communities as well as the climate and NWP modeling communities. The WCRP Survey will provide input to the strategic planning for model improvement activities coordinated through WCRP, WWRP and THORPEX. It is important for the observational and process study community to provide input to this Survey in order to help the respective communities identify needs, opportunities, and priorities to further develop climate-modeling capabilities.

Lastly, the IPCC Fifth Assessment process is ramping up in earnest. Modeling centers are finalizing production plans for completing a wide array of model integrations. IPCC model output will start becoming available within the next year (with all information accessible by the end of 2010). CLIVAR is working closely with US agencies and WCRP on planning/evaluation/analysis activities.

Variations

Published three times per year
U.S. CLIVAR Office
1717 Pennsylvania Ave., NW
Suite 250, Washington, DC 20006
usco@usclivar.org

Staff: **Dr. David M. Legler**, *Editor*
Cathy Stephens, *Assistant Editor and Staff Writer*
Roberto Mechoso, *Guest Editor*

This newsletter is supported through contributions to the U.S. CLIVAR Office by NASA, NOAA—Climate Program Office, and NSF.

marine atmospheric boundary layer (MABL) and entire free troposphere. These seven years of observations provide seasonal climate data suitable for assessing GCMs and gridded analysis products in this remote climatically important region (de Szoeke et al. 2010, submitted).

Developing gridded global and basin-wide atmosphere-ocean surface flux data sets are another recent advance for atmosphere-ocean interaction studies (e.g. ISCCP FD, Zhang et al. 2004; UW Hybrid, Jiang et al. 2005; WHOI OAFlux, Yu and Weller 2007; NCAR CORE, Large and Yeager 2008). The gridded flux data are compared with the seven years of ship observations along 20°S. Figure 2 shows all the terms of the surface heat flux for the October climatology of three research-quality gridded flux products, NOAA Physical Sciences Division (PSD) ship observations, and WHOI buoy observations. Solar radiation (Figure 2c) is the only warming term in the budget. Latent heat flux (evaporation, Figure 2a) is the largest cooling, followed by longwave thermal radiation (Figure 2d). Sensible heat flux (Figure 2b) is small. The eastern tropical Pacific, with difficult-to-simulate climate feedbacks and relatively few historic observations, is a challenging test of the gridded surface flux products, yet the gridded products perform remarkably well. All three gridded products agree to within sampling variability of the ship data at almost every longitude. This suggests that studies can proceed to use these convenient gridded flux data sets for model evaluation. This article refers to observationally constrained gridded flux data sets as "observations" when they are compared to model simulations.

The net heat flux in Figure 2e is not zero. Part of the imbalance of the surface heat fluxes results in a 0.7°C per month warming tendency of the SST along 20°S in October. This SST tendency consumes 50 W m^{-2} for a 50 m mixed layer, leaving a residual 30 Wm^{-2} surface heat flux. The cooling must be provided from within the ocean, either laterally or from below, for the SST to warm by only the observed amount.

While previous studies have stressed the importance of clouds in maintaining the cool southeastern tropical marine climate, even under observed clouds the imbalance of surface fluxes requires the ocean to remove additional heat from the surface mixed layer.

Errors in the heat budget could explain the substantial simulated SST errors in the southeastern tropical Pacific Ocean. How well do models simulate the observed heat balance? Figure 2f shows observed and modeled heat budgets for October averaged along 20°S, 75-85°W, ranked by solar radiation. All but one model has too-strong latent and sensible turbulent heat fluxes, and some models have sensible heat flux errors several times the observed (10 W m^{-2}). The lowest simulated solar flux is 30 W m^{-2} stronger than the highest observed solar flux, consistent with a lack of cloud radiative forcing in the models.

On average 2/3 of the solar excess is compensated by stronger longwave cooling, with the longwave and solar radiative errors correlated among models at r= –0.86. After canceling the compensating radiative errors, the net radiation error is smaller than the magnitude of the net turbulent flux error for most models. Figure 2g shows the heat budget term errors relative to the mean of the three gridded flux products and ship observations.

The total turbulent heat flux error combines sensible and latent heat flux errors. It is a cooling error for all simulations. The increased turbulent flux reflects increased wind speed and lower air-sea temperature differences. The simulated eastern Pacific heat budgets in Figure 2g reveal that the ocean provides too little cooling of the surface mixed layer in all but 3 of the 16 models. Therefore, in addition to their inadequate cloud radiative forcing, coupled model ocean simulations need to transport and deposit more cooling into the offshore southeastern Pacific surface mixed layer.

The flux balance illustrates how simulations reach a new equilibrium with higher SST: Higher than observed solar flux due to a lack of clouds warms the ocean surface. In addition, the ocean too weakly cools the mixed layer. The SST

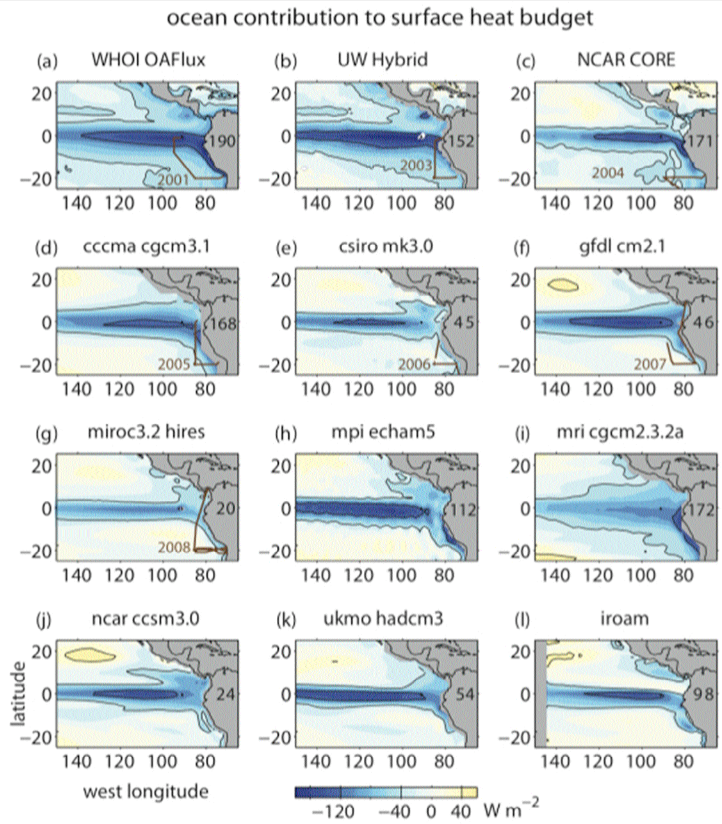

Figure1. Plan view of ship tracks for EPIC 2001, Stratocumulus 2003-2007, and VOCALS REx 2008 research cruises (brown lines, panels a-g). Colored contours show the annual-average ocean contribution required to balance the surface heat budget. Negative values imply the ocean is cooling the surface mixed layer. Panels (a-c) are 3 observation-based gridded flux products, while (d-l) are 9 coupled model simulations. The number printed on South America is the north-south asymmetry of the area-integrated ocean contribution (terawatts) east of 90°W and equatorward of 20°S.

reaches a warmer state, whereby turbulent flux (mostly evaporation) and thermal emission give off more heat to balance the solar excess and subsurface ocean cooling deficit.

VOCALS REx sought evidence of processes responsible for subsurface ocean cooling, which may be poorly represented in GCMs. Cooling could be achieved by vertical mixing in near-inertial oscillations, advection of temperature across differentially-inclined temperature and salinity gradients by geostrophic eddies (Toniazzo et al. 2009), or horizontal eddy heat flux divergence (Colbo and Weller 2007).

The ocean's contribution to the annual average surface heat budget is calculated as the residual of the surface heat fluxes by assuming the long term tendency of SST is negligible. Gridded flux products (first row Figure 1a-c) show the spatial distribution of the ocean contribution to the surface heat budget. With low SST in the eastern Pacific, the strong tropical solar warming is not completely balanced by longwave radiation and turbulent surface flux. Thus the ocean gains heat through the surface. This is especially true of the cold-SST upwelling zones, with strongest cooling along the equator and South American coast. The three observational data sets have ocean heat budget contributions with cooling of –40 W m^{-2} to about 100°W, 20°S. The ocean heat flux from nine coupled model simulations follows in Figure 1d-l. There is variety among the models in the overall strength of the ocean cooling contribution. Most models predict the cooling in the equatorial upwelling region well, but underpredict cooling along the coast of Peru.

The meridional north-south hemisphere difference in area-integrated (90°W to the coast, equator to ±20° latitude) ocean cooling is a metric of its meridional asymmetry. This metric (in terawatts, TW) is printed on South America for each realization in Figure 1. The three observational data sets have asymmetry of 171±19 TW. Only models (d) and (i) have asymmetry in this range. Models (e,f,g,j) and (k) have north-south asymmetry less than 1/3 of observed, with equal or more ocean cooling in the northern hemisphere than the southern hemisphere South American coast.

The surface heat budget observed in the southeast tropical Pacific Ocean from the 7 years of Stratocumulus research cruises between EPIC 2001 and VOCALS REx 2008 (mostly in October) shows a 30 W m^{-2} imbalance. The imbalance implies the ocean must be transporting cold water into, and removing heat from, the surface mixed layer in boreal autumn. Along with stratocumulus clouds, this ocean cooling contributes to lower SST in the southern-hemisphere tropical Pacific. Gridded flux data sets corroborate the ocean's cooling contribution to the surface heat budget and show its spatial pattern. Most models simulate the strong ocean cooling contribution along the equator, but many have too weak an ocean cooling contribution along the South American coast and too little cooling distributed offshore to the stratocumulus region. Diagnoses of ocean and coupled model experiments are required to understand how models succeed or fail to simulate ocean cooling through coastal upwelling, geostrophic eddies, offshore transport, and vertical mixing processes in the southeastern tropical Pacific. Subsurface ocean observations from VOCALS REx will help quantify these important processes.

Acknowledgement

The author acknowledges Chris W. Fairall, Daniel E. Wolfe, Ludovic Bariteau, and Paquita Zuidema for their collaboration on the Stratocumulus research cruise data set of 7 years of ship observations, and the crew and scientists aboard the ships Ronald H. Brown and Roger Revelle from which these data were collected. Support for VOCALS and for this work was provided by grants from the National Ocean and Atmospheric Administration (NOAA) Climate Prediction Program

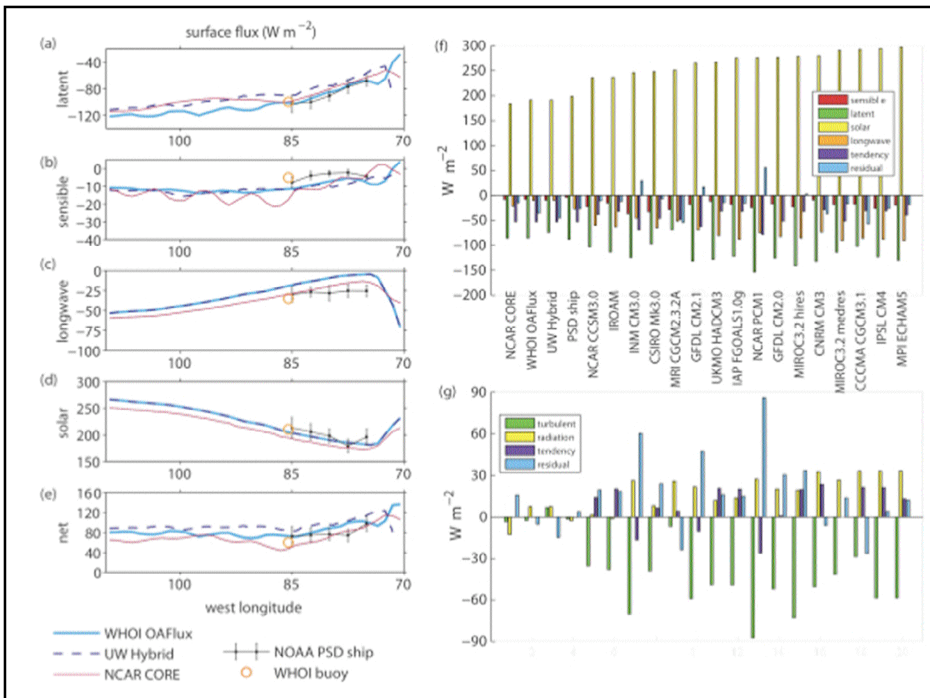

Figure 2. Left (a-e): October climatology along 20°S of three gridded air-sea flux products compared with NOAA PSD ship and WHOI buoy in situ observations. Radiative fluxes for the gridded products are based on the ISCCP Flux Data (FD). Latent (a) and sensible (b) turbulent flux, and thermal longwave (c) and solar (d) radiative flux, and the net sum of all terms (e). Right (f and g): October flux component climatology averaged along 75-85°W, 20°S for the three gridded flux products, ship observations, and 16 coupled model simulations. Data sets are ranked by solar radiation. Panel (g) shows anomalies relative to the mean of the four observational data sets.

for the Americas (CPPA). Model data were downloaded from the Program for Climate Model Diagnosis and Intercomparison (PCMDI) Coupled Model Intercomparison Project (CMIP3), supported by the Office of Science, U.S. Department of Energy. Data provided by the UK Met Office Hadley Centre are under Crown copyright, 2005.

References

Bretherton, C. S., 2002: The EPIC 2001 Stratocumulus Study: Is Drizzle a Swizzle? Variations, 1, 4-6.

Colbo, K., and R. Weller, 2007: The variability and heat budget of the upper ocean under the Chile-Peru stratus. J. Mar. Res., 65, 607-637.

de Szoeke, S. P., and S.-P. Xie, 2008: The tropical eastern Pacific seasonal cycle: Assessment of errors and mechanisms in IPCC AR4 coupled ocean-atmosphere general circulation models. J. Climate, 21, 2573-2590.

de Szoeke, S. P., C. W. Fairall, D. E. Wolfe, L. Bariteau, P. Zuidema, 2010: Surface flux observations on the southeastern tropical Pacific Ocean and attribution of SST errors in coupled ocean-atmosphere models. J. Climate, submitted.

Large, W. G., and S. G. Yeager, 2008: The global climatology of an interannually varying air–sea flux data set. Climate Dynamics.

Jiang, C., M. F. Cronin, K. A. Kelly, and L. Thompson, 2005: Evaluation of a hybrid satellite- and NWP-based turbulent heat flux product using Tropical Atmosphere-Ocean (TAO) buoys. J. Geophys. Res., 110.

Mechoso, C. R., and Coauthors, 1995: The seasonal cycle over the tropical Pacific in coupled ocean-atmosphere general circulation models. Mon. Wea. Rev., 123, 2825-2838.

Toniazzo, T., C. R. Mechoso, L. Shaffrey, and J. M. Slingo, 2009: Ocean surface heat budget and ocean eddy transport in the South-East Pacific in a high-resolution coupled model. Climate Dynamics.

Yu, L., and R. Weller, 2007: Objectively Analyzed air-sea heat Fluxes for the global ice-free oceans (1981–2005). Bull. Amer. Meteorol. Soc., 88, 527-539.

Zhang, Y. C., W. B. Rossow, A. A. Lacis, V. Oinas, and M. I. Mishchenko, 2004: Calculation of radiative fluxes from the surface to top of atmosphere based on ISCCP and other global data sets: Refinements of the radiative transfer model and the input data. Journal of Geophysical Research-Atmospheres, 109.

U.S. CLIVAR Call for Membership

Nominations are sought for the three U.S. CLIVAR Panels: 1) Predictability, Prediction and Applications Interface Panel (PPAI), 2) Process Study Model Improvement Panel (PSMI), and 3) Phenomena, Observations and Synthesis Panel (POS). These panels aid in developing and coordinating climate research plans and activities and also providing feedback to agency implementation. Further information and terms of reference for these panels can be found at www.usclivar.org/Organization.html. Each panel is seeking members to enhance current strengths while adding expertise in new areas. The PSMI Panel is specifically seeking expertise in atmospheric GCMs and land surface processes, as well as in polar/cryosphere processes, downscaling climate information to the regional and coastal scale, and the Southern Ocean. The PPAI panel specifically seeks those interested in ENSO prediction, decadal prediction and initialization, polar climate modeling and prediction, modeling of extremes, as well as those interested in the application of seasonal/decadal forecasts. Finally, the POS Panel is seeking expertise in decadal variability/phenomena as well as coupled assimilation.

To nominate and be considered for Panel membership, please submit the following:

- 2-page vitae noting the most relevant publications
- A paragraph describing qualifications, research interests, and the Panel of interest

Materials should be sent electronically to the U.S. CLIVAR Office (usco@usclivar.org) noting "Nomination" in the subject heading. **The deadline for submission is 31 January 2010**. The U.S. CLIVAR Committee, in consultation with agency representatives, will review applications. Accepted applicants will be notified by 28 February 2010.

Preliminary Confrontation of the VOCALS Hypotheses with Observations and Modeling

Robert Wood, University of Washington, C. Roberto Mechoso, UCLA with Christopher Bretherton, Robert Weller, Barry Huebert, Anthony Clarke, Hugh Coe, Fiamma Straneo, Byron Blomquist, and Sandra Yuter.

In the southeast Pacific (SEP), interactions between the atmosphere and ocean and effects of the South American continent are extremely important for the regional climate, with impacts on the global climate system. The great height and continuity of the Andes Cordillera form a sharp barrier to zonal flow, resulting in strong low-level winds parallel to the coasts of Chile and Peru. This coastal jet drives intense oceanic coastal upwelling, bringing cold, deep, nutrient/biota rich waters to the surface. As a result, sea-surface temperatures (SSTs) in the SEP are colder along the Chilean and Peruvian coasts than at any comparable latitude elsewhere. The cold SSTs, in combination with warm, dry air aloft, provide an ideal environment for the formation of marine stratocumulus clouds and the largest and most persistent subtropical stratocumulus deck in the world. The presence of such a cloud deck has a major impact upon the earth's radiation budget by reflecting solar radiation. The clouds help maintain the cool SSTs, resulting in tight coupling between the upper ocean and lower atmosphere in this region.

The albedo of the stratocumulus deck is controlled by several factors including clouds thickness, coverage, and microphysical properties such as droplet concentration. The latter depends strongly upon the physical and chemical properties of the aerosols ingested into them, which have poorly constrained important natural and anthropogenic sources that comprise major copper smelters in Peru and Chile. Factors controlling the coverage, thickness, and microphysical properties of the stratocumulus over the SEP and elsewhere remain poorly understood, and are a major cause for uncertainties in the current ability to understand and simulate aerosol indirect effects. Precipitation formation, in the form of drizzle, is now recognized as having a critical role in determining cloud cover, in particular through its role at driving mesoscale cloud transitions strikingly illustrated by the formation of pockets of open cells (POCs) in overcast stratocumulus. Drizzle is suppressed by increased aerosol concentrations, but there is limited quantitative understanding of aerosol-cloud-precipitation interactions in stratocumulus. Drizzle itself is a major sink for aerosols, which may help to limit the offshore extent of continental aerosol plumes and, in clean air masses, help to drive the transition from closed to open cells.

Numerical climate models (CGCMs) have great difficulties in the successful simulation of such a complex system. Most CGCMs obtain too warm SSTs and too little clouds in SEP, and unrealistic features in the simulation of the Inter Tropical and South Pacific Convergence Zones (IPCZ and SPCZ, respectively). In addition, there are major uncertainties in the key physical processes. For example, studies of the heat budget well offshore of the coastal upwelling zone indicate a complex and time-varying flow, and a deficit of cold, fresh water (Colbo and Weller 2008). The supply mechanism must be controlled by subgridscale ocean processes. but these are unclear at the present time. One candidate process is mesoscale ocean eddies advecting westwards from the coastal zone. Another candidat mechanism is entrainment of cold, fresh water from below the ocean mixed layer. Little is known about eddy processes in the SEP, not only regarding their role in cold water transport over the broader SEP but also their potential importance for transport of aerosol precursors such as dimethylsulfide and complex organic species.

These science issues are central to the VOCALS (VAMOS Ocean-Cloud-Atmosphere-Land Study). VOCALS is an international CLIVAR program to develop and promote scientific activities leading to improved understanding, model simulations, and predictions of

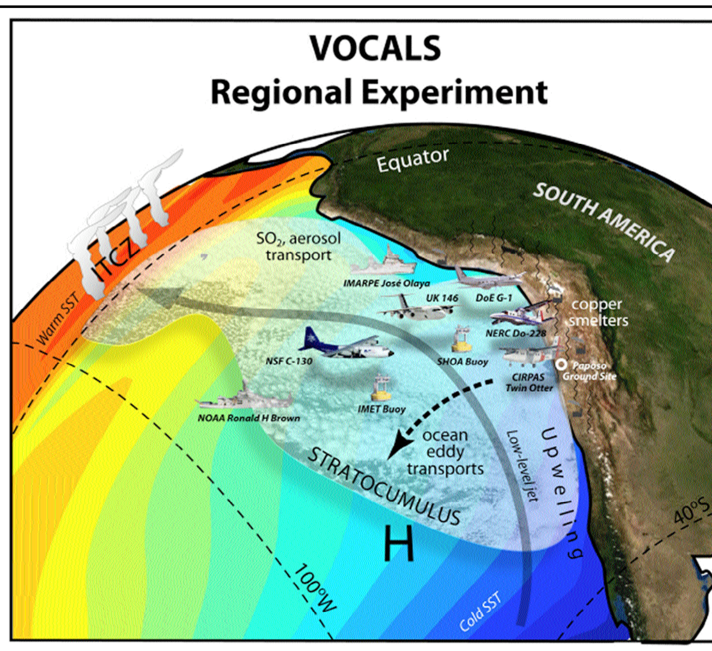

Figure 1. Major climatic features of the southeast Pacific, and sampling platforms deployed in VOCALS-REx

the southeastern Pacific (SEP) coupled ocean-atmosphere-land system, on diurnal to interannual timescales (Wood et al. 2007). VOCALS is ultimately driven by a need for improved numerical model simulations of the coupled climate system in both the SEP and over the wider tropics and subtropics. At the root of VOCALS approach is the synergy between numerical experimentation, empirical analysis, and field work.

During October and November 2008 some 150 scientists from 40 institutions in 8 nations took part in the VOCALS Regional Experiment (VOCALS-REx). VOCALS-REx was designed to gather data to test the scientific hypotheses given in Table 1 in conjunction with extended observations (such as the IMET WHOI buoy (20.15S, 85.15W) measurements, annual NOAA cruises, and satellite data) and a broad range of modeling activities (Wood and Mechoso 2008). A total of five aircraft including the NSF C-130, the DoE G-1, the CIRPAS Twin Otter, and two aircraft from the UK, and two research vessels (the NOAA Ronald H Brown [RHB] and the Peruvian IMARPE José Olaya) sampled the lower atmosphere and upper-ocean during REx (see Figure 1). These platforms were complemented by two land-based sampling sites at Paposo and Iquique.

TABLE 1. VOCALS HYPOTHESES

1) AEROSOL-CLOUD-DRIZZLE HYPOTHESES

a) Variability in the physicochemical properties of aerosols has a measurable impact upon the formation of drizzle in stratocumulus clouds over the SEP.

b)Precipitation is a necessary condition for the formation and maintenance of pockets of open cells (POCs) within stratocumulus clouds.

c) The small effective radii measured from space over the SEP are primarily controlled by anthropogenic, rather than natural, aerosol production, and entrainment of polluted air from the lower free-troposphere is an important source of cloud condensation nuclei (CCN).

d)Depletion of aerosols by coalescence scavenging is necessary for the maintenance of POCs.

2) COUPLED OCEAN-ATMOSPHERE-LAND HYPOTHESES

a)Improvement of CGCMs performance in the SEP is key to the successful simulation of the ITCZ/SPCZ, complex, which will also benefit simulation of other regions. A significant improvement can be achieved through better representing the effects of stratocumulus clouds on the underlying surface fluxes and those of oceanic mesoscale eddies in the transport of heat.

b)Oceanic mesoscale eddies play a major role in the transport of fresh water from the coastal upwelling region and in the production of sea water and atmospheric DMS in the coastal and offshore regions. Upwelling, by changing the physical and chemical properties of the upper ocean, has a systematic and noticeable effect on aerosol precursor gases and the aerosol size distribution in the MBL over the SEP.

c) The diurnal subsidence wave ("upsidence wave") originating in northern Chile/southern Peru has an impact upon the diurnal cycle of clouds that is well-represented in numerical models.

d)The entrainment of cool fresh intermediate water from below the surface layer during mixing associated with energetic near-inertial oscillations generated by transients in the magnitude of the trade winds is an important process to maintain heat and salt balance of the surface layer of the ocean in the SEP.

Testing the VOCALS Hypotheses

In the following we present a synthesis of how the preliminary findings from VOCALS analysis are being used to confront and test the VOCALS hypotheses.

Aerosol-Cloud-Drizzle Hypothesis #1a: Variability in the physicochemical properties of aerosols has a measurable impact upon the formation of drizzle in stratocumulus clouds over the SEP

Data from radars, lidars, microwave radiometers, and in-situ aerosol and cloud instruments on board the airborne platforms and the RHB in REx are shedding important new light on drizzle formation processes. Preliminary analysis supports the hypothesis: in areas with higher accumulation mode aerosol concentrations below clouds (or, alternatively higher droplet concentrations), drizzle rates from stratocumulus clouds of a given liquid water path (LWP) are lower. This complements recent CloudSat observations (Leon et al. 2008: Lebsock et al. 2008: Kubar et al. 2009), which show a role for microphysical precipitation suppression in weakly precipitating clouds. However, LWP is also a critical control on drizzle, and in the SEP may be as important at promoting drizzle as variations in aerosols.

Aerosol-Cloud-Drizzle Hypothesis #1b: Precipitation is a necessary condition for the formation and maintenance of pockets of open cells (POCs) within stratocumulus clouds

Several successful POC cases were sampled in REx, especially by the C-130 which was able to transit sufficiently far offshore. This is providing an unprecedented set of observations to study the transition from closed to open cells. Most POCs sampled in REx contained drizzling cells, but the surrounding overcast stratocumuli commonly also supported considerable drizzle (up to 2 mm/day at cloud base in one case). Thus drizzle does not appear to be sufficient to cause transition of closed-cell convection into a POC. Preliminary large eddy simulation results indicate that meteorological variability may also be effective at driving POC formation by increasing precipitation.

Aerosol-Cloud-Drizzle Hypothesis #1c: The small effective radii measured from space over the SEP are primarily controlled by anthropogenic, rather than natural, aerosol production, and entrainment of polluted air from the lower free troposphere is an important source of cloud condensation nuclei (CCN).

All airborne platforms, the RHB, and the Paposo land site are all contributing important information regarding aerosol chemical and physical properties and how they vary in time and space. An array of state-of-the-art and conventional aerosol characterization techniques was employed during REx, and most aircraft measured cloud microphysical properties. Measured cloud droplet concentrations in REx were well correlated with those of accumulation mode aerosol particles, with a large fraction of the aerosols activating as cloud condensation nuclei (CCN). Aerosol concentrations were higher closer to the coast, and there is good evidence that these coastal enhancements mainly derive from pollution sources, which provides support for the first part of the hypothesis. At 20°S the aerosols appear mainly to be transported from sources within the MBL, but further to the south entrainment of sulfur dioxide (SO2) and particle-rich air from the free-troposphere may be a significant source. Although DMS is probably important to establishing clean marine boundary layer aerosol, no evidence was found that biogenic DMS production in this region controls the observed geographic gradient of cloud droplet number. Aerosols were rich in sulfate consistent with SO2 from smelters being an important source, but other sources also appear to be important, such as urban pollution and biomass burning. There is some good evidence that sulfate and organic aerosol components may be largely externally mixed (sulfate and organics mostly do not occur together in the same particles), which has implications for their sources, radiative, and cloud-forming effects.

Further offshore in the remote marine region only weakly impacted by continental pollution, the most important source for new sulfate mass is DMS rather than entrainment. However, entrainment may still play an important role in the budget of aerosol number concentration in the remote marine environment. The entrainment of thin tongues of high SO2 far offshore may also impact cloud droplet concentrations even 1500 km or more from the coast, but such events are likely rare. **Aerosol-Cloud-Drizzle Hypothesis #1d:** Depletion of aerosols by coalescence scavenging is necessary for the maintenance of POCs.

All POCs sampled in REx exhibited much lower CCN concentrations than in the surrounding regions. In addition, air exiting from their cloudy updrafts was often observed to be almost entirely cleansed of condensation nuclei of any size. Of the cases studied thus far, the presence of this ultraclean layer appears to be ubiquitous close to the top of the boundary layer within the POC. It is difficult to understand how processes other than precipitation could be responsible for such a layer. Thus it appears that the precipitation is of sufficient frequency and magnitude to severely deplete aerosols within POC regions. However, REx observations alone are insufficient to determine whether aerosol depletion is necessary for the maintenance of POCs. REx case studies are currently being used to initialize and evaluate high resolution models to test the hypothesis.

Coupled Ocean-Atmosphere-Land Hypothesis #2a: Improvement of CGCMs performance in the SEP is key to the successful simulation of the ITCZ/SPCZ, complex, which will also benefit simulation of other regions. A significant improvement can be achieved through better representing the effects of stratocumulus clouds on the underlying surface fluxes and those of oceanic mesoscale eddies in the transport of heat.

Major progress has been achieved in the parameterization and simulation of marine stratocumulus, which has alleviated the systematic errors with the ITCZ/SPCZ transition, transition to other cloud regimes, and SST errors in the eastern tropical oceans. Work with the High resolution Global Environment Modelling (HiGEM) CGCM has produced a heat flux by ocean eddies with a magnitude comparable to the observational estimates at the IMET WHOI buoy site (Toniazzo et al. 2009). Nevertheless, the PreVOCA study (Wyant et al. 2009) has shown us that the representation of the cloudy marine boundary layer remains a difficult challenge.

Coupled Ocean-Atmosphere-Land Hypothesis #2b: Oceanic mesoscale eddies play a major role in the transport of fresh water from the coastal upwelling region and in the production of sea water and atmospheric DMS in the coastal and offshore regions. By changing the physical and chemical properties of the upper ocean, upwelling has a systematic and noticeable effect on aerosol precursor gases and the aerosol size distribution over the SEP.

Several mesoscale eddies were surveyed with the RHB during VOCALS-REx. Cyclonic eddies were found to be associated with anomalously cold sea-surface temperatures and low salinities due to the exposure of sub-surface waters of high latitude origin. The properties of these eddies suggest that they originate from instabilities of the boundary current in the upwelling region and that contribute to the cooling of the offshore upper ocean.

DMS concentrations were not strongly elevated near the coastal upwelling zone. However, photochemical destruction of DMS seemed to be the dominant source of new sulfate far offshore, dominating SO2 entrainment from the free troposphere. REx is providing novel insight into the concentration of the hydroxyl radical (OH), the key species for the oxidation of DMS to SO2, and a key determinant of the potential sulfate production rate (Yang et al. 2009). The frontal regions at the edge of the sampled mesoscale eddies, and the embedded submesoscale eddy structures, are associated with increased oceanic productivity, large seawater DMS and correspondingly large atmospheric DMS fluxes. As such, the ocean mesoscale and submesoscale structures appear to modulate the production of DMS in the offshore region and hence determine its role in producing aerosol.

Coupled Ocean-Atmosphere-Land Hypothesis #2c: The diurnal subsidence wave (“upsidence wave”) originating in northern Chile/southern Peru has an impact upon the diurnal cycle of clouds that is well represented in numerical models.

There is strong evidence from VOCALS modeling (Garreaud and Munoz 2004, Rahn and Garreaud 2010) and observational studies (Wood et al. 2009) that a significant diurnal subsidence wave is generated on the Andean slopes of Peru and Northern Chile, and

The UK Contribution to VOCALS

Hugh Coe and the VOCALS-UK team

A UK Consortium consisting of the Universities of Manchester, Leeds and Reading, the National Centre for Atmospheric Science (NCAS) and the Met Office is making a significant contribution to VOCALS through both VOCALS-Mod, the VOCALS modelling programme, and VOCALS-REx. The UK participation in the intensive field programme during VOCAS-REx involved two UK research aircraft, a BAe-146 and a Dornier 228, which made in situ and remote sensing measurements of the cloud and aerosol fields in the South-East Pacific (SEP) region during October and November 2008. The BAe-146 operated along 20ºS between 70ºW and 80ºW in conjunction with the NCAS C-130 to provide a time series of data along the same track on multiple days throughout the VOCALS-REx period. In addition, flights to sample Pocket of Open Cells (POCs), at least two of which were samples of the same POC as the C-130 sampled at a different time of day. Sampling of coastal pollution was also carried out. The Do-228 sampled elevated aerosol plumes over the region using an airborne backscatter lidar and was able to measure the wavelength resolved shortwave upwelling radiation from the stratocumulus(Sc) cloud top using a pair of hyperspectral imaging systems. These activities were supported by forecast information from the Met Office Unified Model at 17 and 40 km resolution, which was also used to provide pollution forecasts using the NAME model.

Model support for these activities in the UK covers a wide range of scales. Cloud resolving models are being used to conduct sensitivity studies to investigate the impact of including a number of different processes such as drizzle precipitation and cloud droplet scavenging on the cloud microphysical and radiative properties. A lagrangian cloud particle model driven by and interacting with an LES dynamical simulation that includes a specific treatment of activation is being used to assess the effects of entrainment of dry air into the stratocumulus deck. Within the Met Office, there are plans to repeat the global and regional-scale forecasts at higher resolution in both the horizontal and vertical. Studies will include the impact of such resolution changes on the forecasting of inversion strength, cloud top height and liquid water path. The impact of aerosols on drizzle formation will be studied by incorporating the aerosol schemes from the Hadley Centre climate configuration of the UM into trial NWP simulations. Until recently, climate models failed to adequately capture stratocumulus clouds, the effects of the Andes on the atmospheric circulation, and the thermodynamic structure of the upper ocean, and uncertainties arising from the sensitivity of the global climate system to the radiative balance of the SEP region have remained significant. To address these questions VOCALS-UK is taking advantage of recent advances in high resolution coupled climate modelling achieved in the UK-HiGEM programme (UK-HiGEM - High resolution Global Environment Modelling), an atmosphere-ocean GCM with a resolution of approximately 90 km in the atmosphere and 1/3º globally in the ocean

A listing of available VOCALS-UK data sets can be found at the NCAR-EOL website. The VOCALS-UK data is now available through the British Atmospheric Data Centre (http://www.badc.ac.uk) or by contacting the VOCALS-UK Coordinator, Dr Grant Allen (grant.allen@manchester.ac.uk).

propagates offshore at a speed of 25-30 m/s. The wave extends up to around 5-7 km in altitude, with peak ascent around midnight local time at 20°S, 85°W. Wave amplitudes are uncertain and will require more detailed analysis. The cloud liquid water path diurnal was observed to be significantly different during REx at 75°W vs 85°W, and this may be attributed to the phase of the subsidence wave (see also Wood et al. 2008). The PreVOCA model assessment (Wyant et al. 2010) finds that most models can realistically reproduce the diurnal cycle of liquid water path at 20°S, 85°W, but further work will be required to isolate the effect of the subsidence wave compared with solar warming.

Coupled Ocean-Atmosphere-Land Hypothesis #2d: The entrainment of cool fresh intermediate water from below the surface layer during mixing associated with energetic near-inertial oscillations generated by transients in the magnitude of the trade winds is an important process to maintain heat and salt balance of the surface layer of the ocean in the SEP.

Vertical microstructure data (measuring the shear in velocity, temperature and salinity) collected both in the coastal and offshore regions, inside and outside of eddies and fronts, will shed light on the different mixing regimes in these diverse environments. These data, combined with the microstructure instruments mounted during VOCALS-REx on the IMET WHOI buoy site, will provide us with information on the role of mixing on the SST in the SEP.

Web Site:
www.eol.ucar.edu/projects/vocals

References

Colbo, K. and R. Weller, 2007: The variability and heat budget of the upper ocean under the Chile-Peru stratus. J. Marine. Res., 65, 607-637.

Kubar, T., D. L. Hartmann, and R. Wood, 2009: Understanding the importance of microphysics and macrophysics for warm rain in marine low clouds: Part I. Satellite observations. J. Atmos. Sci., 66, 2953-2972.

Garreaud, R.D., and R. Muñoz, 2004: The Diurnal Cycle in Circulation and Cloudiness over the Subtropical Southeast Pacific: A Modeling Study. J. Climate, 17, 1699–1710.

Leon, D. C., Z. Wang, and D. Liu (2008), Climatology of drizzle in marine boundary layer clouds based on 1 year of data from CloudSat and Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO), J. Geophys. Res., 113, D00A14, doi:10.1029/2008JD009835.

Lebsock, M. D., G. L. Stephens, and C. Kummerow (2008), Multisensor satellite observations of aerosol effects on warm clouds, J. Geophys. Res., 113, D15205, doi:10.1029/2008JD009876.

Rahn, D. A, and R. Garreaud, 2009: Marine boundary layer over the subtropical southeast Pacific during VOCALS-REx. Part I: Mean structure and diurnal cycle. Atmos. Chem. Phys. Discuss. Submitted.

Toniazzo, T., C. R. Mechoso, L. C. Shaffrey, and J. M.Slingo, 2009: Upper-ocean heat budget and ocean eddy trans - port in the South-East Pacific in a high-res - olution coupled model, Clim. Dyn., in press DOI : 10.1007/s00382-009-0703-8.

Wood, R., C. R. Mechoso, C. Bretherton, B. Huebert, and R. Weller, 2007: The VAMOS Ocean-Cloud-Atmosphere-Land Study (VOCALS). U.S. Clivar Variations. 5(1), 1-5.

Wood, R., and C. R. Mechoso, 2008: Southeastern Pacific Coupled Climate Field Experiment. Eos Trans. AGU, 89(33), 303.

Wood, R., M. Köhler, R. Bennartz, C. O'Dell, 2009: The diurnal cycle of surface divergence over the global oceans. Quart. J. Roy. Meteorol. Soc., 135, 1484-1493.

Wyant, M. C., R. Wood, C. S. Bretherton, C. R. Mechoso, J. Bacmeister, M. A. Balmaseda, B. Barrett, F. Codron, P. Earnshaw, J. Fast, C. Hannay, J. W. Kaiser, H. Kitagawa, S. A. Klein, M. Köhler, J. Manganello, H.-L. Pan, F. Sun, S. Wang, and Y. Wang, 2009: The PreVOCA experiment: modeling the lower troposphere in the Southeast Pacific. Atmos. Chem. Phys. Discuss., 9, 23909-23953.

Yang, M., B. W. Blomquist, and B. J. Huebert, 2009: Constraining the concentration of the hydroxyl radical in a stratocumulustopped marine boundary layer from sea-to-air eddy covariance flux measurements of dimethylsulfide. Atmos. Chem. Phys. Discuss., 9, 16267–16294.

Eddies in the Southeast Pacific and Their Influence on the Upper Ocean

Fiammetta Straneo[1], Carlos Moffat[1†], Robert Weller[1]
[1] Woods Hole Oceanographic Institution
[†] University of Concepción, Chile

An extensive survey of the Southeast Pacific's (SEP) upper ocean properties was conducted in October and November 2008 as part of VOCALS-REx (VOCALS Regional Experiment) – a large, international, multidisciplinary and collaborative field program to investigate the ocean-atmosphere-land coupling in a region characterized by a persistent stratocumulus cloud deck (Wood and Mechoso, 2008). While the long-term goal of the ongoing ocean measurements (which included a synoptic survey, the recovery and re-deployment of two moorings carrying oceanic and meteorological sensors, and the deployment of floats and drifters) is to improve our understanding of the processes that influence the upper ocean structure, and its variability on diurnal to interannual time scales, the focus of the synoptic measurements described here was to map the mean to sub-mesoscale features of the SEP's upper ocean. The particular interest in the eddies is motivated by their hypothesized role in maintaining the cold sea surface temperature (SST) tongue that stretches across the SEP (Colbo and Weller, 2007).

The survey was centered along 20 ºS from the coast of Chile to 85 ºW (Figure 1). This region covers the ~150 km coastal band, characterized by upwelling driven by the along-shore winds (Brink et al. 1983; Strub et al. 1998), and the wider offshore region that is part of the S. Pacific subtropical gyre. The survey took place in the boreal spring of 2008 just as the wintertime mixed layer was beginning to re-stratify. It included over 400 underway Conductivity-Temperature-Depth (uCTD; Rudnick and Klinke 2007) profiles, with a spatial resolution from 1 to 20 km and a depth range from 200 to 800m, 35 CTD casts extending to 1000-3000 m, shipboard Acoustic Doppler Current Profiler measurements (0-500 m) and the deployment of 10 Profiling SOLO floats and 20 surface drifters (Figure 1).

The region of interest is the northeast extension of the subtropical gyre of the South Pacific and its waters are strongly influenced by the advection of waters from neighboring but distinct oceanic regions. The water column is temperature stratified to the extent that salinity is a useful tracer for water mass origin. From the surface down the upper ~500 m contain: 1) warm, salty Subtropical Surface Water (STSW; Tsuchiya and Talley 1998), 2) fresh, relatively cold Eastern South Pacific Intermediate Water (ESPIW) readily identified as a salinity minimum around 100-200m, that is associated with the subduction of cold, fresh waters from the southeastern edge of the subtropical gyre, off the coast of Chile between 33 and 38 ºS (Schneider et al. 2003), 3) Equatorial Subsurface Water (ESSW) characterized by a salinity maximum and low oxygen content and 4) Antarctic Intermediate Water (AAIW) – low salinity and high oxygen content (see water mass stacking in Figure 2b). The depth at which these water masses are found increases westward across the SEP consistently with the bowl shape of the subtropical gyre. Similarly, the strong permanent pcynocline which coincides with the salinity minimum layer (ESPIW) outcrops in the upwelling region but deepens to ~250m at 85 ºW (Figure 2 and 3).

Key to understanding the ocean-atmosphere coupling in the SEP is identifying which oceanic processes influence the mixed layer properties and, in particular, the SST. Global climate models (e.g. Delworth et al. 2002; Wittenberg et al. 2006) exhibit a warm bias in the region suggesting that ocean processes that contribute to a 'colder' SST may not be adequately represented in these models. Since there exist both lateral temperature gradients (both due to coastal upwelling and to the bowl shape of the subtropical gyre) as well as vertical temperature gradients, it is possible that either lateral or vertical advective/mixing processes (or a combination of both) which are ill-represented in models may be responsible for the models' biases. Here, we present some evidence based on preliminary and ongoing analysis that both sub-mesoscale and mesoscale eddy structures can contribute to a cooling of the surface layers of the SEP.

Our surveys revealed that the SEP's upper ocean is characterized by a high degree of sub-mesoscale and mesoscale variability on scales ranging from a few to 100 km, that are embedded on the larger scale structure of the subtropical gyre. The sub-mesoscale variability is evident, for example, in the patchiness within the salinity minimum layer (the ESPIW) or in the salty ESSW layer beneath (Figure 2b). In addition, we were able to map six large mesoscale

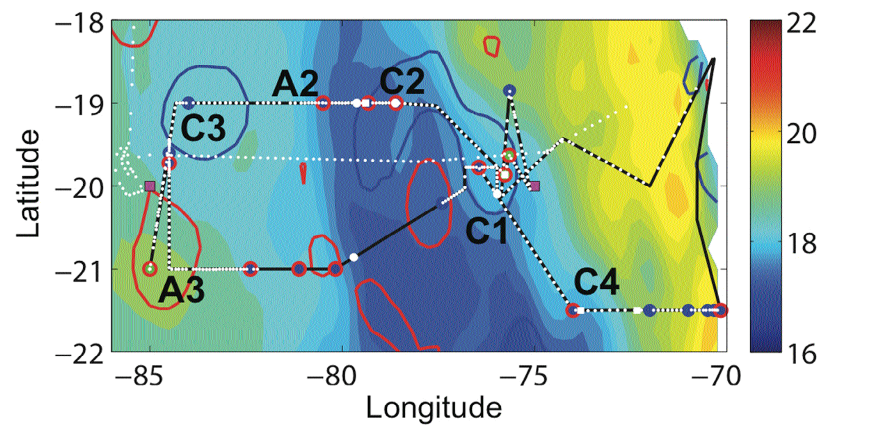

Figure1. Upper ocean survey during VOCALS-REx from the R/V Ron Brown superimposed on the SST field for November 18th 2008 and showing the 5cm positive (red) and negative (blue) SSH contour from the same day (both courtesy of P. Gaube and D. Chelton, OSU). The letters indicate the 4 cyclones (C1 to C4) and the 2 anticyclones surveyed (A2 and A3). The measurements included over 400 underway CTD (white dots), 35 CTDs (blue circles), 15 VMPs (red open circle), 10 float (white squares) and 20 surface drifters deployments (white circles).

eddies (4 cyclones, C1 to C4, and 2 anticyclones, A2 and A3) whose horizontal scales were on the order of 100-200 km (Figures 1 to 3).

The observed anticyclones are wide, surface intensified features that rapidly decay with depth. Their properties are not distinct from the neighboring waters except for the surface 'bowl' of warmer, saltier waters. Anticyclones are associated with a depression of the thermocline and with deeper-than-neighboring mixed layers. The cyclones, on the other hand, were all characterized by thicker and more distinct sub-surface core of salty ESSW water (of equatorial origin) and an uplift of the AAIW beneath – resulting in pinching of isopycnals around 300 m (see, for example, C1 and C2 in Figure 2). The velocity structure reflects a narrow ~20 km subsurface rotating core that coincided with the equatorial water thermostad, and a wider (but not necessarily more intense) cyclonic circulation at the surface (Figure 2d). The cyclones were, in all cases, associated with a shallower, fresher and colder mixed layer relative to the neighboring waters and with an uplift of the thermocline (salinity minimum layer).

The thicker layer of salty, subsurface equatorial water contained in the cyclones suggests that they originate from an instability of the Peru-Chile Undercurrent, a sub-surface and offshore current (Tsuchiya and Talley 1998; Chaigneau and Pizzarro 2005) which carries Pacific Equatorial 13º C Water (TDW, thirteen degree water; Tsuchiya 1981) poleward along the coast of S. America, Figure 3. The fact that one of the cyclones observed in the proximity of the upwelling region contained a thick core of equatorial water which was otherwise only observed in the undercurrent is indeed suggestive of this mechanism (Figure 3). The cyclones strongly resemble the eddies described in a recent study of Argo float profiles from the SEP which shows that they are long-lived and widespread throughout the region (Johnson and McTaggart 2009).

The mesoscale eddy surveys suggest that there exists a relation between the proximity of the thermocline/salinity minimum layer to the surface and the properties of the mixed layer. Specifically, an uplift (depression) of the thermocline as found in the cyclones (anticyclones) is associated with a shallower (deeper) and colder/fresher (warmer/saltier) mixed layer. Furthermore, we observed that this relation holds not only for the eddies but for all of the profiles (uCTD and CTD) collected during VOCALS-REx. We illustrate this by showing that the mixed layer temperature throughout the SEP is strongly correlated with the depth of the salinity minimum layer (Figure 2c). (Note that the salinity minimum layer itself does not need to out-

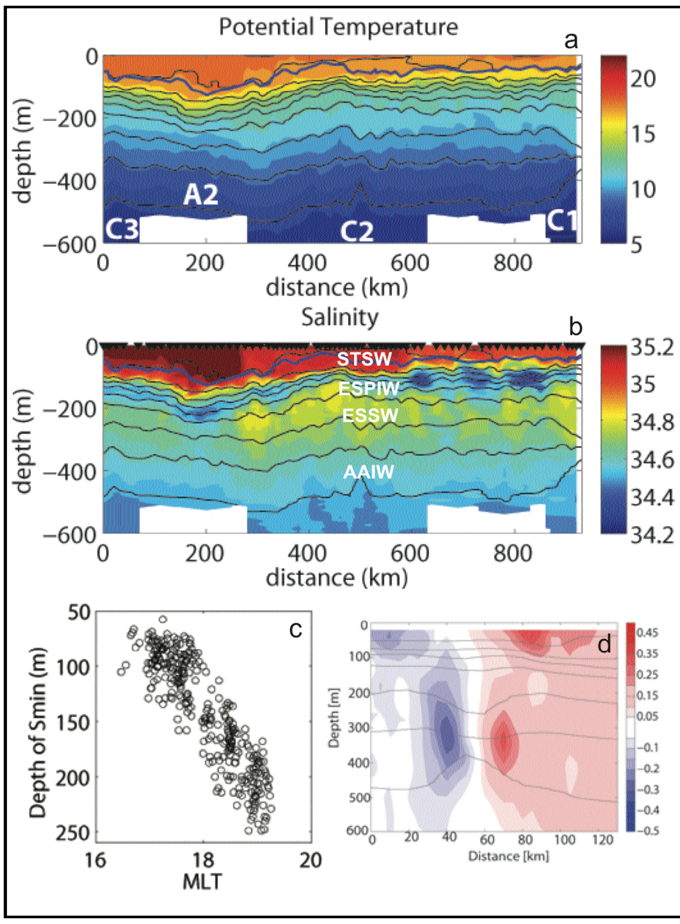

Figure 2. Impact of mesoscale and sub-mesoscale structures on the upper ocean. Hydrographic section from C3 to C1 (mostly along 19 S starting from 85 W (0 km) ending at 75 W (900 km), see Figure 1) showing a) Potential Temperature b) Salinity. Isopycnals are overlaid in black, and the mixed layer depth is overlaid as a thick blue line. The location of C1, C2, C3 and A2 is indicated on a). The station locations are indicated in b) as inverted triangles at the top. The approximate location of the water masses described in the paper is shown in b). c) Depth of the salinity minimum layer versus temperature of the mixed layer (MLT) for ALL profiles collected during VOCALS-REx. d) Velocity (m/s) across C1 showing the narrow subsurface core and the shallow wider surface flow.

crop to induce a cooling.) Indeed all of the mixed layers observed end at the large vertical stratification associated with the salinity minimum layer.

Our results thus suggest that both sub-mesoscale and mesoscale structures displace the thermocline (and associated ESPIW) feedback onto the mixed layer properties and, presumably, the SST . Amongst the various eddies observed, cyclones that appear to originate from instability of the Peru-Chile Undercurrent contribute to colder, fresher and shallower mixed layers through an uplift of the thermocline. We also found that the depth of the salinity minimum layer is a good indicator for the mixed layer properties throughout the large SEP region. These results support the VOCALS hypothesis which suggests that oceanic mesoscale eddies (and cyclones in particular) play a role in 'cooling' the SEP. However, the mechanism by which they do it is not simply through the advection of cold, upwelled surface waters offshore. Instead, their influence is through the uplift of the thermocline which, in turn, feedbacks on the mixed layer properties. These findings do not rule out that vertical mixing processes (driven, for example, by the large inertial oscillations observed) which may result in cooling the surface layers by mixing the cold waters of the thermocline into the mixed layer. Rather, it is entirely possible that sub-mesoscale and mesoscale eddies that associated with enhanced vertical mixing may amplify this feedback.

Finally, we also found that the eddies' boundaries were characterized by strong frontal regions which, invariably, were associated with increases both in the dissolved and in the airborne DMS (dimethylsulfide). This not only suggests that the oceanic mesoscale contributes to creating a highly heterogeneous oceanic DMS distribution but, also, that oceanic processes may influence aerosol production and hence cloud formation.

Acknowledgements

We thank the crew of the R/V Ron Brown and all the colleagues who helped in collecting the hydrographic data and underway CTD data during VOCALS-REx. Particular thanks also go to Sean Whelan, Jeff Lord and the entire Upper Ocean Process group at WHOI. We are also greatly indebted to Peter Gaube and Dudley Chelton (OSU) for providing us with near real-time sea-surface height and SST gridded fields which enabled us to locate the eddies. The authors acknowledge support from NOAA's Climate Program Office.

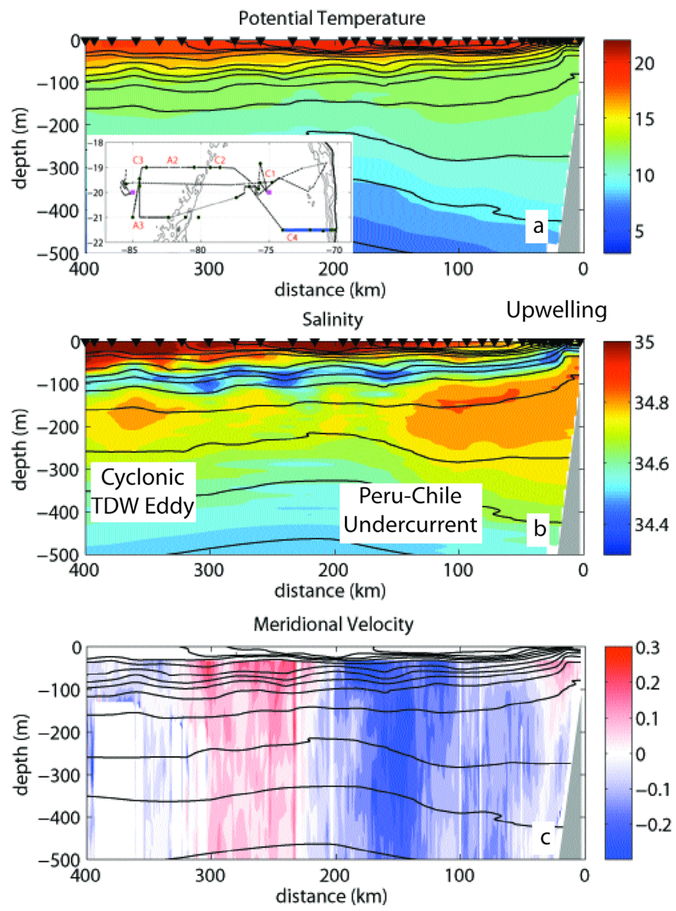

Figure 3. Section along 19.5º S from 74 W to the coast (see inset in a) showing upwelling of cold, low salinity waters at the coast and the associated surface trapped, equatorward surface flow. Approximately 150km offshore is the Peru-Chile Undercurrent, a subsurface, poleward current characterized by opposite (to the upwelling front) sloping isopycnals and characterized by a core of salty, Pacific Equatorial 13 ºC Water (TDW). A cyclonic lens of TDW, associated with a thermostad centered at 150 m and a salty core is visible 350 km offshore. The properties of its core are very close to those of the undercurrent. a) Potential Temperature (ºC). b) Salinity c) Meridional velocity (m/s) from the shipboard Acoustic Doppler Current Profiler. Isopycnals are overlaid on all three panels (black lines).

References

Brink, K. H., D. Halpern, A. Huyer, and R. L. Smith, 1983. The physical environment of the Peruvian upwelling sys - tem. Prog. Oceanogr., 12(3), 285-305.

Chaigneau, A. and O. Pizarro, 2005. Eddy characteristics in the eastern South Pacific. J. Geophys. Res., 110, doi:10.1029/2004JC002815.

Colbo, K. and R. A. Weller 2007a: The variability and heat budget of the upper ocean under the Chile-Peru stratus. J. Marine Res., 65, 607-637.

Delworth, T. L., R. J. Stouffer, K. W. Dixon, M. J. Spelman, T. R. Knutson, A. J. Broccoli, P. J. Kushner, and R. T. Wetherald, 2002. Review of simulations of climate variability and change with the GFDL R30 coupled climate model. Climate Dynamics, 19, 555-574.

Johnson, G. C. and K. E. McTaggart. 2009. Equatorial Pacific 13°C Water eddies in the eastern subtropical South Pacific Ocean. Journal of Physical Oceanography, in press, doi:10.1175/2009JPO4287.1.

Rudnick, D. L. and J. Klinke, 2007. The underway conductivity-temperature-depth instrument. J. Atmos. Ocean. Tech., 24, 1910-1923.

Schneider, W., R. Fuenzalida, E. Rodriguez-Rubio, and J. Garcés-Vargas, 2003. Characteristics and formation of Eastern Pacific South Pacific Intermediate water. Geophys. Res. Let, 30 (11), doi:10.1029/2003GL017086.

Strub P.T., Mesías J., Montecino V., Ruttland J., Salinas S.,1998 Coastal ocean circulation off western South America. In Robinson A.R. and Brink K.H. (Eds.). The Sea (John Wiley, New York) pp. 273–312

Tsuchiya, M. and L. D. Talley, 1998. A Pacific hydrographic section at 88°W: water property distribution. J. Geophys. Res. 103 (C6), 12899-12918.

Wittenberg, A. T., A. Rosati, N.-C. Lau, and J. J. Ploshay, 2006. GFDL's CM2 Global Coupled Climate Models. Part III: Tropical Pacific Climate and ENSO. J. Climate, 19, 698-722.

Wood, R., and C. R. Mechoso (2008), Southeastern Pacific Coupled Climate Field Experiment, Eos Trans. AGU, 89(33), doi:10.1029/2008EO330003.

U.S. CLIVAR

Calendar of CLIVAR and CLIVAR-related meetings

Further details are available on the U.S. CLIVAR and International CLIVAR web sites: www.usclivar.org and www.clivar.org

Predicting the Climate of the Coming Decades
11-14 January 2010
Miami, FL
Attendance: Limited
http://www.clivar.org/organization/decadal/rsmas_decadal.php

American Meteorological Society Annual Meeting
17-21 January 2010
Atlanta, GA
Attendance: Open
http://www.ametsoc.org

Ocean Observations Panel for Climate (OOPC) Meeting
19-22 January 2010
Miami, FL
Attendance: Invited

Ocean Sciences Meeting
22-26 February 2010
Portland OR
Attendance: Open
http://www.agu.org

CLIVAR Atlantic Panel Meeting
28 February - 2 March 2010
Maimi, FL
Attendance: Invited
http://www.clivar.org

State of the Arctic Climate Conference
16-19 March 2010
Miami, FL
Attendance: Open
http://soa.arcus.org/

US CLIVAR High Latitude Surface Flux Workshop
17-19 March 2010
Boulder, CO
Attendance: Open
http://www.joss.ucar.edu/events/2009/seaflux/index.html
Abstract Deadline: February 1, 2010. Abstracts will be collected during the registration process. Limited travel support available for students, post-docs, and young scientists. Applications for travel support due January 15, 2010, and applicants will be notified by February 1, 2010.

Background:
High latitudes are regions of rapid climate change, and tracking this change will require a good understanding of exchanges between the components of the climate system: atmosphere, ocean, and ice. However, efforts to determine high latitude surface fluxes face formidable challenges. Observations are sparse and difficult to obtain in conditions marked by high winds, rough seas, and icing conditions. The unique conditions in high latitude regions mean that lessons learned in equatorial and subtropical regions do not necessarily translate into improvements in high latitude fluxes. Perhaps because of these challenges, available flux climatologies differ markedly, and with little or no in situ data available as ground truth, there is no clear consensus about the relative performance of these flux products. (The US CLIVAR Working Group on High Latitude Surface Fluxes reviews has submitted a manuscript to the Bulletin of the American Meteorological Society describing major concerns for high latitude surface fluxes. See http://www-pord.ucsd.edu/~sgille/highlat/hilatr_manuscript_v29s.pdf)

International Drought Symposium
24-26 March 2010
Riverside, CA
Attendance: Open
http://cnas.ucr.edu/drought-symposium/l

CLIVAR International Climate of the 20th Century Project
19-23 April 2010
Beijing, China
Attendance: Open
http://www.iges.org/c20c/index.html

Atlantic Meridional Overturning Circulation Annual Meeting
7-9 June 2010
Miami, FL
Attendance: Limited
http://www.atlanticmoc.org

US CLIVAR Summit
7-9 July 2010
Denver
Attendance: Invited

U.S. CLIVAR OFFICE
1717 Pennsylvania Avenue, NW
Suite 250
Washington, DC 20006

Subscription requests, and changes of address should be sent to the attention of the U.S. CLIVAR Office (cstephens@usclivar.org)

U.S. CLIVAR contributes to the CLIVAR Program and is a member of the World Climate Research Programme