

observationalists led by Mike Wallace (atmosphere) and Michael McPhaden (ocean). And the answer was that the data was not there. First EPIC and later VOCALS were born to fill that void in the SEP and have created unprecedented datasets on the coupled ocean-clouds-atmosphere-land system. The eastern tropical Atlantic is waiting its turn. VOCALS has started to leave a legacy in the many datasets available at the programme's web site, and is beginning to think about a long-term future.

Acknowledgements.

It is practically impossible to acknowledge all the people who have contributed to VOCALS, but we can attempt to recognize the various groups that have dedicated their resources, efforts, sweat and tears to the planning and execution of the programme. First, we need to thank the teams led by Bob Weller at WHOI that deployed and maintained with annual cruises the IMET buoy, which has provided almost a decade of high quality meteorological, radiation and oceanographic measurements. Thanks to Chris Fairall and coworkers at ESRL, and the scientists involved in the EPIC Stratocumulus cruise, these ship-borne programmes have led to a wealth of scientific data. We are extremely grateful to the support staff, crew

and scientists who helped make the VOCALS-REx a success. These include the PIs of the six aircraft platforms (the NSF/NCAR C-130, the UK FAAM BAe-146, the DoE G-1, the CIRPAS Twin Otter, the UK NERC Dornier 228, and, in the 2010 CupEx phase, the Chilean King Air), the two ships (the NOAA Ronald H Brown, and the Peruvian IMARPE José Olaya), and the land stations at Iquique and Paposo. The NCAR Earth Observing Laboratory, and José Meitin in particular, are thanked for their dedication to coordinating and executing field logistics and data archive support for VOCALS Rex. Finally, the cooperation of our hosts in Chile and Peru who provided various critical facilities and support during REx is gratefully acknowledged. It is also a great pleasure to recognize our two science monitors in the U.S.: NSF's Walter Robinson and NOAA's Jin Huang. And there were constant friends at CLIVAR's International and US CLIVAR's Project Offices: Howard Cattle, and David Legler.

Reference

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

The project web site is at www.eol.ucar.edu/projects/vocals.

VOCALS-CUPEx: The Chilean Upwelling Experiment

Garreaud, R.D¹, J. Rutllant^{1,2}, R. Muñoz¹, D. Rahn¹, M. Ramos² and D. Figueroa³

¹Department of Geophysics, Universidad de Chile, ²Center for Advanced Studies in Arid Zones (CEAZA), Chile, ³Department of Geophysics, Universidad de Concepción

Corresponding author: rgarreau@dgf.uchile.cl

1. Presentation

The VAMOS Ocean-Cloud-Atmosphere-Land Study (VOCALS) is an international program that targets the subtropical Southeast Pacific region (Wood et al., 2006; see also paper by Mechoso and Wood in this issue). To address the many VOCALS' science questions, a major regional experiment, VOCALS-REx (see online description at <http://www.eol.ucar.edu/projects/vocals/rex.html>), was carried out during October and November 2008 off northern Chile and southern Peru, including an unprecedented number of atmospheric and oceanographic measurements taken concurrently from five aircrafts, two research vessels and two land sites.

It was originally planned that VOCALS-REx would include a coastal component encompassing the near-shore region at about 30°S. In practice, most of the action during VOCALS-REx took place in a zonal band between 25°S and 16°S because of logistic constraints. About a year later, however, several Chilean institutions (Table 1) have teamed to conduct an additional field experiment to fill our observational gap. The so-called Chilean Upwelling Experiment (CUPEx) is therefore a regional component of VOCALS aimed at understanding the atmosphere-ocean dynamics that characterize the nearshore (0-200 km) region off north-central Chile (30-35°S). VOCALS-CUPEx not only has relevance for regional climate studies but is also important in a broader context, as many of the transient features that populate the SE Pacific are originated along the semiarid coast of Chile and are subsequently advected offshore (e.g., Rahn and Garreaud, 2009).

2. The study region

The semiarid coast of Chile (25-35°S) is under the year-round influence of the southeast (SE) Pacific anticyclone, resulting in predominantly southerly (coastal parallel) low-level winds, and a strong temperature inversion that caps a cool atmospheric marine boundary layer (AMBL). The surface stress exerted by the southerly winds foster the upwelling of cold, nutrient-rich waters supporting a wealth of fishery resources. The synoptic-scale variability in this region is associated with the occurrence of coastal lows (Garreaud and Rutllant, 2003) that are in turn forced by the passage of surface anticyclones farther south. During the coastal low development, the near-surface wind forms an intense coastal jet –in turn fostering upwelling episodes– and the AMBL depresses, often resulting

in coastal clearing (Garreaud and Muñoz, 2005). The coastal low demise typically features a relaxation of the southerlies and the recovery of the cloud-topped AMBL.

The Chilean coast is oriented almost straight north-south between 33°S and 30°S (Point Lengua de Vaca; LdV), bounded to the east by a mountain range with average elevation between 500 and 1000 m above sea level (ASL, Figure 1). The coastal mountains in this area are interrupted by several river valleys in contrast with a much more continuous coastal cliff of (that stand at) about 1000 m ASL farther north (between Paposo and Arica; 25-18°S). To the north of LdV the coastline sharply retracts eastward about 40 km, forming a wide embayment, including the bays of Tongoy and Coquimbo, and returns to the west at about 29°S (Point Choros).

The southerly flow along the semiarid coast of Chile often exhibits a low-level jet structure, with its core about 100 km off the coast (Garreaud and Muñoz, 2005). Accordingly, the coastal strip features marked cross-shore gradients of wind, sea surface temperature (SST), and MBL depth. The amplitude of the diurnal cycle of wind and cloudiness also increases strongly over this strip forced by the continental heating/cooling cycle. Another conspicuous feature of the semiarid coast is the along-shore structure in cloudiness (and presumably in MBL depth). Of particular relevance are the semi-permanent low-clouds intercepting the coastal mountains just south of 30°S which maintain fog-dependent green forests, in an otherwise arid landscape, and the coastal clearing tendency just north of LdV.

3. Experimental setup

Despite its proximity to land, processes embedded in the near-coastal strip around 30°S have been poorly documented because of the lack of observational platforms. To fill this gap, VOCALS-CUPEx includes long-term monitoring, an intensive two-week field campaign and ongoing off-shore research flights (Figure 1). Surface meteorology (air temperature, humidity, barometric pressure, wind and solar radiation) is recorded every 15 min in five automatic weather stations (AWS) along the coast. From south to north, the first AWS is located at Talcaruca, about 15 km to the south (upstream) of LdV where the coastline is straight. The next station is at point LdV, followed by one station in the sheltered bay of Tongoy.

Platform & Instruments	PI	Funding
AIMMS-20 on BE90	R. Garreaud (DGF)	FONDECYT-Grant 1090492, DGF-UCH, DGAC
AWS, Radiosondes at Tongoy and Talcaruca	J. Rutllant (DGF) R. Muñoz (DGF)	FONDECYT-Grant 1090492, DMC, CNE, DGF-UCH
Tongoy bay buoy and AWS Islote Pajaros	M. Ramos (CEAZA)	CEAZA, INOVA-Corfo 07CN13IXM-150, FONDECYT 1080606
Surface Current Radars	Dante Figueroa (DGEO)	FONDEF-Grant D031-1104
Ocean moorings	Oscar Pizarro (DGEO)	FONDECYT-Grant 1090791

DGF : Department of Geophysics, Universidad de Chile
 DGEO: Department of Geophysics, Universidad de Concepción
 CEAZA: Centro de Estudios Avanzados de Zonas Áridas
 DGAC: Dirección General de Aeronáutica Civil
 DMC: Dirección Meteorológica de Chile
 CNE: Comisión Nacional de Energía

The AWS at Tongoy was complemented with a laser ceilometer providing cloud frequency and cloud base height every 1 minute. The northernmost coastal AWS is at 29°S where the coastline curves back to the west. Surface meteorology is also recorded at a coastal buoy in the bay of Tongoy and at Islote Pájaros (Figure 1). All these AWSs were installed during (or prior to) November 2009 and will be maintained for a year, providing a long-term context of the low-level circulation in the CUPEx area.

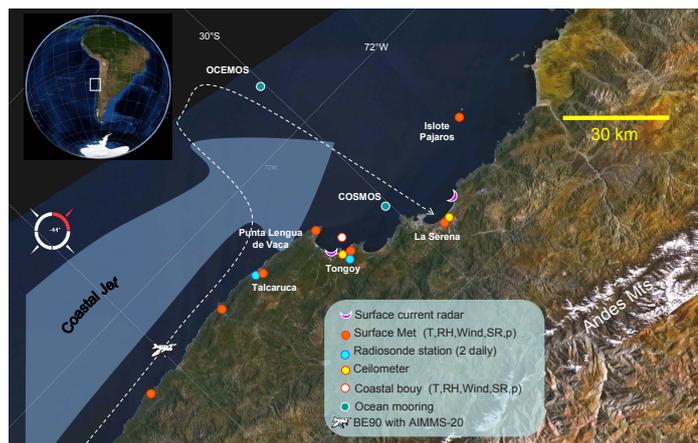


Figure 1. The VOCALS-CUPEx region. The different platforms are indicated in the topographic map.

The intensive observation period (IOP) extended from 21 November to 5 December, 2009. The IOP exhibits typical spring-time conditions, with a well developed coastal jet, except for two brief periods at the beginning and at the middle of the campaign when the southerlies relaxed in connection with the demise of a coastal low. During this period, we launched radiosondes at 08:00 and 17:00 LT (1200 and 2100 UTC) at Talcaruca (upstream of LdV) and Tongoy (downstream of LdV) in order to capture the differences in the MBL and low-level circulation between the straight-coastline sector and the bay of Tongoy. These radiosondes provide the first systematic tropospheric observation at 30°S. The nearest routine radiosondes are launched by the National Weather Service at Santo Domingo (33.5°S) and Antofagasta (23°S). During the IOP and several weeks prior to it, two high-frequency radars (Figure 1) provided near-continuous measurements of the surface waves and ocean currents from the coast up to about 50 km offshore over the Tongoy-La Serena bay area. These data will be key in assessing the ocean response to the strong surface winds in the near-shore strip.

To complement the coastal observations and explore the offshore MBL structure VOCALS-CUPEx airborne meteorological observations were conducted off the central Chile coast. We

installed an Aircraft Integrated Meteorological Measurement System (AIMMS-20) under the wing of a Beechcraft King Air BE-90. The aircraft belongs to the Chilean Civil Aviation Directorate (DGAC) and its two turboprops provide more than 2500 km of endurance. The AIMMS-20 measures air temperature, relative humidity, wind speed and direction (three components), pressure and aircraft position (latitude-longitude-elevation) at 1 Hz. The AIMMS-20 was developed by Aventechn Inc. in Canada and its has been used by meteorology research groups at the University of Manchester, UK, (Beswick et al. 2008) and Duke University, USA, (Avisar et al., 2009). At the time of writing this paper we have performed three scientific missions off central Chile described on line at <http://www.dgf.uchile.cl/rene/AIMMS20/>

4. Preliminary results

Since most of the measurements associated with VOCALS-CUPEx took place at the end of 2009 (and some of them are occurring now) this section only provides a glimpse of the scientific results expected from this project. Figure 2 shows the morning (07-09 LT) and afternoon (16-18 LT) near-surface winds averaged during November-December 2009 around 30°S. The inland stations and those along the bay of Tongoy/Coquimbo show a marked diurnal cycle in speed and direction associated with the development of a sea breeze during afternoon, as a response to the surface heating and topography. A dramatic case occurs at Tongoy where the afternoon wind blows from the north in an area otherwise dominated by southerly flow. The northerly flow at Tongoy is, however, restricted to the first 200 m capped by southerlies aloft (Figure 3a). The surface stations south of

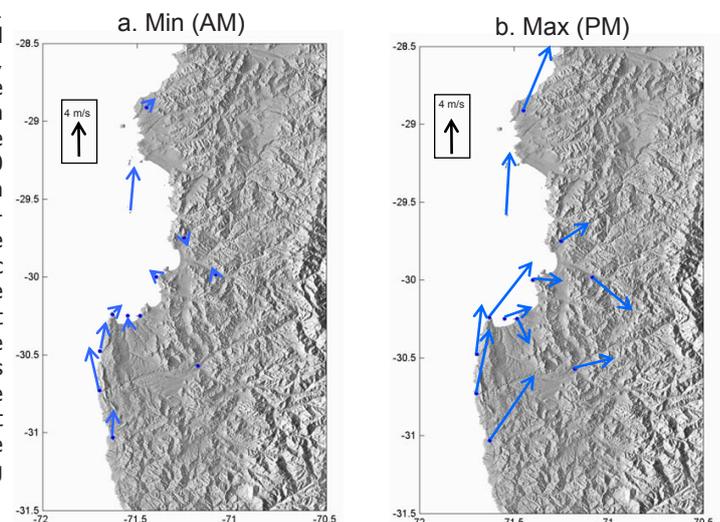


Figure 2. November-December 2009 average of 10-m winds from automatic weather stations associated with VOCALS-CUPEx. Left panel: early morning conditions (07-09 LT). Right panel: afternoon conditions (16-18 LT).

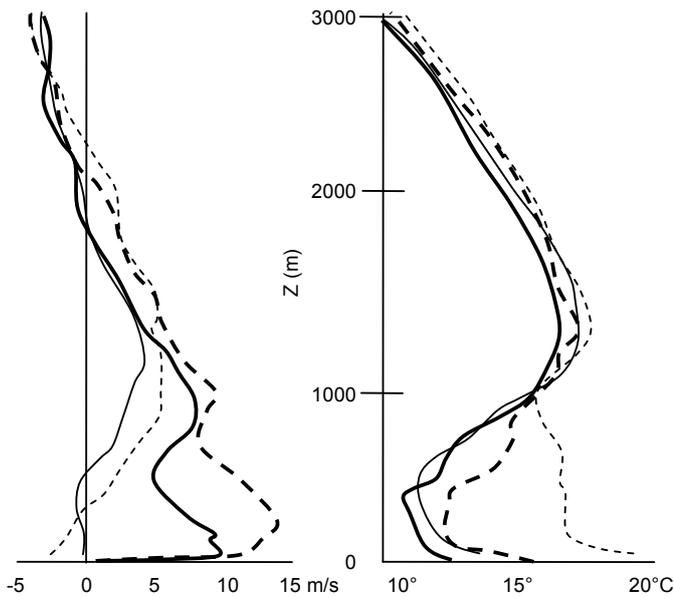


Figure 3. Average vertical profiles during VOCALS-CUPEx from radiosonde observations at Talcaruca (thick lines) and Tongoy (thin lines) at 08:00 LT (solid line) and 17:00 LT (dashed). Left panel: meridional wind; right panel: air temperature.

LdV and Islote Pájaros show a weaker diurnal cycle in wind speed, and the direction remains nearly fixed from the S-SW during the whole day.

Figure 3 shows the AM and PM vertical profiles of meridional wind and air temperature at Tongoy and Talcaruca averaged during VOCALS-CUPEx. In both stations the MBL is about 400 m deep capped by a temperature inversion that extends up to about 1500 m. In the morning there is little difference between the temperature profiles at the two locations. During the day both profiles show a warming of the MBL and the inversion layer, but relatively modest in Talcaruca (2°C) and very strong in Tongoy. The Tongoy profiles also exhibit a significant afternoon drying of the MBL (not shown). We hypothesize that the afternoon warming/drying at Tongoy signals the arrival of continental air parcels. The advection of continental air over the Tongoy bay could explain the clear sky conditions that often characterize this area in an otherwise cloudy region.

Research flights with the AIMMS-20 mounted in the wing of the BE90 occurred in late December and January, when the core of the coastal jet has moved to the south of the Tongoy region. For this reason, our flight missions were flown offshore

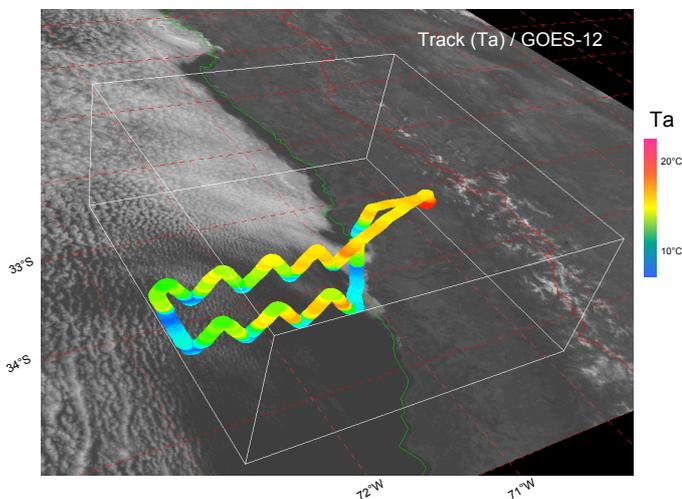


Figure 4. Track of the BE90 during research flight No. 2 (January 7, 2009, from 11:00 to 13:00 LT) colored according to air temperature measured by the AIMMS-20. The track was superimposed on the GOES-12 visible image corresponding at the time of aircraft landing.

of 33.5°S (instead of 30°S) attempting to sample the MBL near the exit of the coastal jet as well as the wind and MBL gradients in the coastal strip. The missions have occurred under weak, moderate and strong southerly flow. Figure 4 shows an example of the air temperature during the 2nd research mission (January 7) superimposed over a satellite image. Considering the intra-flight and inter-flight datasets we have found significant correlations between wind speed, MBL depth and cloudiness, such that the strongest winds develop atop of shallow MBL with little or no clouds. This unprecedented aircraft data is being used to assess operational numerical simulations and better characterize the MBL, including a prominent near-shore jet north of LdV (Figure 5).

Acknowledgements

VOCALS-CUPEx is supported by several research grants from CONICYT (Chile). In particular, we acknowledge FONDECYT grants 1090492, 1080606 and 1090791, as well as FONDEF grant D03I-1104 and INNOVA-Chile 07CN13IXM-150. We also thank the National Weather Service (DMC) and the National Civil Aviation Directorate (DGAC) for their support during the intensive observation period and the research flights.

References

Avissar, R., H. Holder, N. Abehserra, M. Bolch, K. Novick, P. Canning, K. Prince, J. Magalhaes, N. Matayoshi, and G. Katul, 2009: The Duke University Helicopter Observation Platform. *Bulletin of the American Meteorological Society*, **90**, 939-954.

Beswick, K., M. Gallagher, A. Webb, E. Norton, and F. Perry, 2008: Application of the Aventech AIMMS20AQ airborne probe for turbulence measurements during the Convective Storm Initiation Project. *Atmos. Chem. Phys*, **8**, 5449-5463.

Garreaud, R. and J. Rutllant, 2003: Coastal lows in north-central Chile: Numerical simulation of a typical case. *Mon. Wea. Rev.*, **131**, 891-908

Garreaud, R. and R. Muñoz, 2005: The low-level jet off the west coast of subtropical South America: Structure and variability. *Monthly Weather Review*, **133**, 2246-2261.

Rahn, D., and R. Garreaud, 2009: Marine boundary layer over the subtropical southeast Pacific during VOCALS-REX. Part II: Synoptic variability. *Open Discussion Atmospheric Chemistry and Physics. VOCALS-REx Special Issue*. November 2009

Wood, R., and others, 2006: VOCALS REX: Scientific program overview. http://www.atmos.washington.edu/~robwood/VOCALS/VOCALS_SPO_Complete.pdf

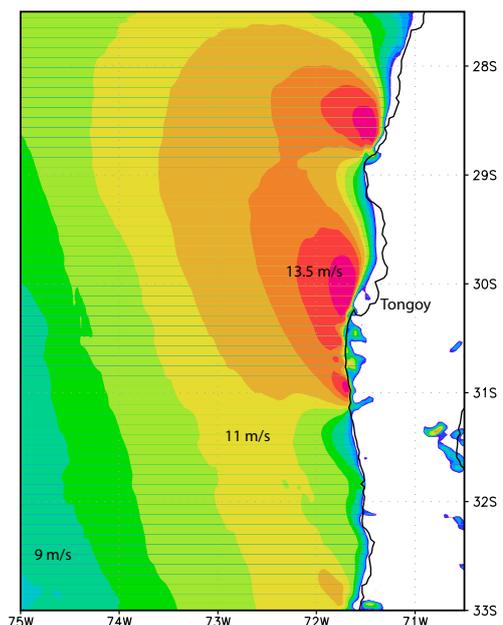


Figure 5. Evening (5-7 PM) average of surface wind speed simulated by WRF during CUPEx.