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C. Bretherton (U. Wash.), R. Weller (WHOI), C. Fairall
(NOAA), H. Coe (Manchester U., UK), F. Straneo (WHOI), C.
Grados (IMARPE, Peru), R. Garreaud (U. Chile), G. Feingold
(NOAA), B. Huebert (U. Hawaii), J. L. Brenguier (M. France),
S. de Szoeke (NOAA), M. Kohler (ECMWF), T. Toniazzo (U.
Reading, UK), and many others…

www.eol.ucar.edu/projects/vocals
Universities
Arizona
Arizona State
California Los Angeles
California Irvine
California San Diego
California Santa Cruz
Chile, Chile
Concepción, Chile
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Oregon State
Purdue
Reading, UK
Washington
Wyoming

Research Institutions
Brookhaven Nat.
COLA
CNRM/GAME France
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IMARPE Peru
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LOCEAN France
NASA/GSFC
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NCAS, UK
NOAA/ESRL
NOAA/GFDL
NOAA PMEL
NRL
Pacific Northwest
Scripps
Woods Hole

Institutions Collaborating in VOCALS

Logistic Support: UCAR JOSS

Operational Centers
BMRC Australia
CPTEC Brazil
ECMWF Int.
JMA Japan
MetOffice UK
NCEP US
VOCALS/VAMOS Working Group

Major activities over the past year

- Second VOCALS General Meeting: 12-14 July 2009, University of Washington, Seattle, WA
- Second VOCALS-UK General Meeting: 9 June 2009, Reading University, Reading, UK
- Session at AGU Fall Meeting: 14 December 2009, San Francisco, CA
- Papers in U.S. CLIVAR Variations: Vol. 7, No.2
- Special Issue on VOCALS in Atmospheric Chemistry and Physics, EGU On_line Journals
- The VOCALS Chilean Upwelling Experiment (CUpEx) took place in Nov-Dec 2009. (http://www.dgf.uchile.cl/VOCALS CUpEx)
- CLIVAR Exchanges, VOCALS Issue: Vol. 15, No. 1 (April 2010)
Ten dedicated and 6 partial missions sampled 1500 km offshore along 20S (flight plan at right)

Offshore (80-85 W), typically:
1.5-2 km deep PBL
Decoupled (LCL<clnd base)
Cloud drop conc. <100/cc
Drizzle cells w. high LWP

Nearshore (70-75 W):
1-1.2 km deep PBL
Well mixed
Drop conc. 200-250/cc
Thin clouds, little drizzle

Fig. 2. Longitude-height plot of WCR reflectivity along 20° S for the outbound (top) and return (bottom) portions of C130 RF03. During subcloud legs, the in-situ LCL (green) and the WCL cloud base (black) are superimposed. During cloud legs, the black line shows the cloud base adiabatically derived from in-situ LWC. The grey line traces the aircraft flight track; the top axis labels show UTC time.
Pockets of open cells (POCs) in marine stratocumulus

R. Wood, C. S. Bretherton, D. Leon, A. D. Clarke, P. Zuidema, G. Allen, and H. Coe

**Left:** C-130 radar, lidar, and microwave liquid water path obs. during the RF06 POC mission

**Below:** Satellite and in-situ data show that POCs tend to form in regions with abundant liquid water

**Below:** POC missions are aiding the development of conceptual models of transitions in stratocumulus clouds
Our group is investigating the properties of drizzle observed by the scanning C-Band radar aboard the R.H. Brown. An early result (left) is the diurnal cycle of the number of drizzle cells and drizzling area.

One key component of our research is the development of a drizzle cell tracking algorithm (right) that will be used to investigate the life cycle of precipitation within the radar’s domain.
Observing Boundary-Layer Turbulence with Combined Lidar and Radar Retrievals

PSD Lidar and Radar: Brewer, Ghate, Fairall
Figure. (a) Mean reflectivity from the W-band cloud radar for November 12-15. Thin lines are cloud top height estimated from the radar and cloud base height from the ceilometer. (b) Liquid water path (LWP) from the microwave radiometer (red) and adiabatic LWP from cloud thickness (blue). Bars in (c) show the frequency of occurrence in hours of column maximum reflectivity (dBZ) of 1-minute samples for all 538 hours of the VOCALS cloud radar record. The median and range of 10-minute LWP (g m⁻², red dots and lines) are binned by column maximum reflectivity.
Source Attribution of Climatically Important Aerosol Properties measured at Paposo (Chile) during VOCALS-REx

Duli Chand, D.A. Hegg, R. Wood, G.E. Shaw, D. Wallace and D. S. Covert, L. Gallardo

Left: Sulfate constitutes roughly half of the submicron aerosol mass

Left: Urban/fossil fuel, biomass burning, soil/smelter, and marine sources all represented in aerosols at Paposo

Above: Paposo aerosol measurements were made upwind of offshore VOCALS-REx measurements at an elevated coastal site
Upwelling of fresh and cold waters of subpolar origin to the surface

Cyclonic Eddy with a warm salty sub-surface core

Boundary current with same properties as the eddies’ core

Upwelling of fresh and cold waters of subpolar origin to the surface

F. Straneo (2009)
Surface heat balances along 20°S, 75-85°W

de Szoike et al. 2009, J. Climate 2010

W m⁻²

40 W m⁻²
Pre-VOCA compared 15 regional, forecast, and climate models for October 2006 in the VOCALS region.

Many models had large errors in distribution of low cloud cover.

Most models produced a marine BL too shallow near the coast at 20S.

Most models underestimated LWP at the stratus buoy and to the east of it.
**Recent scientific highlights**

**Improved Scu Forecasts in SEP (ECMWF)**

*Figure 2.* GOES12 satellite 10.8μm infrared band brightness temperature are compared to model generated images. The model was initialized on 20081018 00UTC. Panels (b) and (d) correspond to 18 and 30 hour forecasts representing daytime (10-14LT) and nighttime (22-02LT) respectively.

M. Kohler (2009)
Improvement of low clouds simulation in the Southeast Pacific in the NCEP GFS

R. Sun, S. Moorthi, H. Xiao, and C. R. Mechoso

ISCCO low clouds

Control

Both Modif

No Vert Diff

Scu Criterium
Heat transport by mesoscale ocean eddies

\[ u \cdot \nabla T = u \cdot \nabla T + u' \cdot \nabla T' + u \cdot \nabla T' \]

rectifying non-rectifying

\[ u' = u'_1 + u'_2 \]
e tc.; spatially or temporally filtered components

Toniaszzo et al. (2009) found that geostrophic transients with 4 month < Period < 1 yr are dominant, and organised in large-scale pattern in simulation by HiGEM
Large eddy simulations with detailed coupling of the aerosol-cloud-radiation-chemistry-dynamical system in the marine boundary layer

Jan Kazil¹, Hailong Wang², Graham Feingold¹

¹) Cooperative Institute for Research in Environmental Sciences, U.Colorado / NOAA
²) Atmospheric Sciences and Global Change Division, Pacific Northwest National Laboratory

• Selected results of open cell simulations initialized from VOCALS-REx observations:
  – The model reproduces chemical, aerosol, and cloud properties in open cells observed during VOCALS-REx
  – Ocean emissions of sea salt aerosol can compensate the loss of CCN by cloud processes, and thereby maintain the open cell dynamic structure and cloudiness
  – Ocean emissions of DMS, and transport as well as chemical and cloud processes in open cells result in the formation of new aerosol particles from the gas phase, which contribute to the CCN population and bear upon cloud properties
The affect of aerosols on Stratocumulus clouds; some current results from the VOCALS experiment and proposed further research studies.

Miroslaw Andrejczuk

(Part of the Leeds VOCALS group, M. Andrejczuk, M. Bart, A. Blyth, B. Brooks, A. Gadian, P. Krecl and Jim McQuaid)

A model solution, showing parcel location, size and flow velocity. With red locations of parcels with radius < 10 um are shown, with green parcels with sizes 10 - 20 um, with blue 20 - 50, with purple 50–100 and with yellow bigger than 100 um.
Regional Ocean Data Assimilation During VOCALS REx
Aneesh Subramanian and Arthur J. Miller
Scripps Institution of Oceanography, UCSD

SST (°C)

Before Data Assimilation
(ROMS; QuikSCAT winds, COADS fluxes)

Observations
(Merged OI SST AMSR-E, TMI)
(AVISO SSH Anomaly)

After Data Assimilation
(Data along R. V. Brown track)

SSHA (m)
VOCALS – CUPEx
21 Nov – 6 Dic 2009

- Surface current radar
- Surface Met (T, RH, Wind, SR, p)
- Radiosonde station (2 daily)
- Ceilometer
- Coastal buoy (T, RH, Wind, SR, p)
- Shore SST
- Ocean mooring

BE90 with AIMMS-20
VOCA

M. Wyant, R. Wood, C. Bretherton, Univ. of Wash.
S. Spak, Univ. of Iowa
J. Fast, PNNL

• VOCA will compare and evaluate models during the period of VOCALS REx, October 15 – November 15, 2008.
• 15 modeling groups are planning to participate so far.
• VOCA will further explore aerosol-cloud interactions and try to address the following questions:
  1. Do models simulate the variation of droplet concentration, $N_d$, along 20S?
  2. Is anthropogenic sulfate the main contributor to $N_d$?
  3. What controls $N_d$ in remote ocean regions?
  4. What is the simulated indirect effect of anthropogenic aerosol on clouds and radiative fluxes?

Results are due September 30, 2010. See http://www.atmos.washington.edu/~mwyant/vocals/model/VOCA_Model_Spec.htm
VOCALS/VAMOS Working Group

Major future plans/activities

• Session at AGU Meeting of the Americas, 8-13 August, 2010, Foz do Iguacu, Brazil. (Rene Garreaud and Bob Weller, Convenors)

• Session at AGU Fall Meeting, December 2010 (P. Zuidema, Convener)

• Third VOCALS Science General Meeting, March 2011, RSMAS, Miami, Florida.
VOCALS

Issues and challenges

• Analysis of VOCALS datasets is under way with great enthusiasm and promise of major scientific contributions: Funding should be available to complete the work.

• Similarly, monitoring of the VOCALS region should be continued to obtain longer time series.
• VOCALS Science is organized around a set of hypothesis.

• These can be broadly divided in two sets:
  1) Aerosol-Cloud-Drizzle Hypothesis
  2) Coupled-Atmosphere-Land Hypothesis

• The following slides are a synthesis of how preliminary findings from VOCALS are being used to confront the hypothesis.

• Supporting data comes from modeling work as well as from radars, lidars, microwave radiometers, and in-situ aerosol and cloud instruments on board the airborne and ship platforms during the VOCALS field campaign (REx)
Aerosol-Cloud-Drizzle Hypothesis #1: Variability in the physico-chemical properties of aerosols has a measurable impact upon the formation of drizzle in stratocumulus clouds over the southeastern Pacific (SEP).

Preliminary analysis supports the hypothesis. In the SEP, however, the liquid water path (LWP) of the clouds may be as important at promoting drizzle as variations in aerosols.

Aerosol-Cloud-Drizzle Hypothesis #2: Precipitation is a necessary condition for the formation and maintenance of pockets of open cells (POCs) within stratocumulus clouds.

Data from REx suggests that drizzle is not sufficient to cause transition of closed-cell convection into a POC. Large eddy simulation results indicate that increased precipitation due to meteorological variability may also be effective at driving POC formation.
• **Aerosol-Cloud-Drizzle Hypothesis #3:** *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).*

Support was found for the first part of the hypothesis. No evidence was yet found that biogenic DMS production close to the coast controls the observed geographic gradient of cloud droplet number. DMS appears to be the most important source for new sulfate further offshore.

• **Aerosol-Cloud-Drizzle Hypothesis #4:** *Depletion of aerosols by coalescence scavenging is necessary for the maintenance of POCs.*

All POCs sampled in REx showed an *ultra clean layer* close to the top of the boundary layer within the POC. To fully address this issue, REx case studies are being used to initialize and evaluate high-resolution models.
• **Coupled Ocean-Atmosphere-Land Hypothesis #1:**

*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.*

VOCALS has emphasized and promoted work on the parameterization and simulation of marine stratocumulus, Major progress has been achieved, which has alleviated the systematic errors with the ITCZ/SPCZ transition, transition to other cloud regimes, and SST errors in the eastern tropical oceans. Analysis of a high resolution CGCM simulation has produced a heat flux by ocean eddies with a magnitude comparable to the observational estimates at the IMET WHOI buoy site.
• **Coupled Ocean-Atmosphere-Land Hypothesis #2**: Oceanic mesoscale eddies play a major role in the transport of fresh water from the coastal upwelling region and in the production of seawater 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 cyclonic eddies were found and surveyed during REx. The results suggest that the eddies originate from instabilities of the boundary current in the upwelling region and that contribute to the cooling of the offshore upper ocean. The ocean mesoscale and sub-mesoscale 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 #3:** 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 modeling and observational studies that a such a diurnal subsidence wave propagates offshore at a speed of 25-30 m s$^{-1}$. Work in progress aims to isolate the effect on clouds of the subsidence wave compared with variations in solar warming.

**Coupled Ocean-Atmosphere-Land Hypothesis #4:** 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 important to maintain heat and salt balance of the surface layer of the ocean in the SEP. Analyses are been made of vertical microstructure data collected both in the coastal and offshore regions, inside and outside of eddies and fronts.
More realistic annual mean precipitation with enhanced representation of land surface processes

S. -Y. Ma, C. R. Mechoso, H. Xiao, and Y. Xue