

**VAMOS Ocean-Cloud-Atmosphere-Land Study (VOCALS)**

**Implementation Plan**

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*Prepared by the VOCALS Scientific Working Group*

## **1. Introduction and brief summary of science plan**

The VAMOS Ocean-Cloud-Atmosphere-Land Study (VOCALS), a subsection of the CLIVAR VAMOS (Variability of the American MONsoonS) program, is an initiative designed to develop and promote scientific activities leading to improved understanding, model simulations, and predictions of the southeastern Pacific (SEP) coupled ocean-atmosphere-land system, on diurnal to interannual timescales. The scientific issues driving VOCALS, detailed in the VOCALS Science Plan, can be broadly divided into four categories:

- Atmospheric, oceanic, and coupled model biases and model improvement in the SEP;
- Factors regulating the radiative and microphysical characteristics of SEP stratocumulus;
- The SST distribution and the ocean heat budget in the SEP;
- Role of S America and remote forcing from tropics and midlatitudes, on diurnal to interannual timescales.

In each of these categories a number of specific scientific questions have been raised in the VOCALS Science Plan. This Implementation Plan aims to provide the methodology that will be used to answer these questions. The implementation of VOCALS will use three distinct, but overlapping approaches:

- Diagnosis and advancement of model simulations (coupled, atmosphere-only, and ocean-only) of the SEP on a range of temporal and spatial scales;
- Diagnostic studies of existing and targeted new observations in the SEP;
- The VOCALS Radiator Fin (RF) field experiment and associated ARM mobile facility deployment on San Felix Island.

The VOCALS Implementation Plan is intended as a companion document to the VOCALS Science Plan, but is sufficiently independent to stand alone as a guide to the scientific activities within VOCALS. The following three sections detail the three approaches and how they will be used to address the overall VOCALS goals.

## **2. Diagnosis and advancement of model simulations**

The VOCALS Science Plan outlines a number of modeling goals that will form the focus of the modeling efforts within the program. The primary motivation for the modeling is ultimately to reduce the well known but poorly understood biases that have been documented over the SEP. The processes to be addressed in VOCALS span a broad range of time and space scales, and it is necessary to parameterize many of these processes in large-scale models. Improving parameterizations of small scale processes is one of the key ways in which model biases can be reduced. The specific focus in VOCALS will be to improve parameterizations relevant to boundary layer cloud and ocean mixing. A hierarchy of models from complex coupled ocean-atmosphere general circulation models (GCMs)

that simulate ocean-atmosphere-land interaction on interannual-decadal timescales through to small-scale eddy resolving and microphysical models is required to conceive, develop and test these parameterizations. We also plan to collaborate with the NOAA Climate Testbed (CTB), a recently formed initiative to accelerate the transition from new research into NOAA's operational climate forecast models, and with the NOAA Climate Process Teams (CPT), an initiative to improve the parameterization of physical processes that have crucial impacts upon model climatology. The CTB initiative aims to make NOAA's climate models available to be run in forecast mode; these models can then be compared directly with VOCALS observational datasets.

In this section, we outline the specific models tasks that will be used, and describe how their use addresses the specific scientific issues of VOCALS. Table 1 outlines the model types, key issues, and participants.

### *2.1 Global coupled ocean-atmosphere GCM*

The ocean and atmosphere in the SEP are coupled on seasonal-interannual timescales through the sea surface temperature (SST). The spatial and temporal variability in SST over the SEP has a strong influence on the cloud cover and on the strength of the trades which provide feedback mechanisms that are poorly understood. Coupled ocean-atmosphere GCMs contain the necessary physics to better understand these feedbacks, and will serve as testbeds for new and improved parameterization schemes, especially with regard to how the parameterizations affect the large-scale climate of the SEP. These models will also be used to quantify and better understand the oceanic heat budget over the coastal and remote SEP, which has remained difficult to close observationally. Two global coupled ocean-atmosphere GCMs will be used in VOCALS. The UCLA GCM (Ma et al. 1994) is a relatively computationally inexpensive coupled GCM that will provide a good testbed for parameterization development. The more complex Community Climate System Model (CCSM, Collins et al. 2005) will also be used as this has the capability to explicitly represent the effects of natural and anthropogenic aerosols upon clouds and cloud-ocean feedbacks.

### *2.2. Regional atmospheric and coupled models*

The ability of regional atmospheric models to predict the diurnal and synoptic variability of radiative fluxes over the SEP, and the subtropical oceans in general, is largely unknown, although the observational datasets necessary to do this are now available. Regional models, with boundary conditions provided by global model analyses/reanalyses, will be used to perform studies of this type. The focus will be on how well the models simulate the diurnal cycle and daily-monthly synoptic variability of cloud cover as observed using both satellite datasets such as ISCCP and MODIS, long-term, single-location data from the IMET Buoy at 85W, 20S, and data from intensive field observations (EPIC, PACS, and VOCALS-RF). Regional models also provide an ideal testbed for parameterizations as they can be compared directly with field observations while allowing interaction between the dynamics and cloud physics. Further details of the observational datasets are given in Sections 3 and 4 below. Regional coupled models such as the International Pacific

Research Center (IPRC) and Coupled Ocean-Atmosphere Mesoscale Prediction System/Regional Ocean Modeling System (COAMPS-ROMS) models will be used to examine feedbacks between aerosols, clouds and the ocean on synoptic to seasonal timescales, and to study ocean-atmosphere coupling in the coastal zone, where rapid changes of SST from coastal upwelling can lead to strong boundary layer interactions.

Table 2: VOCALS model types, science issues, specifics, and participants.

<i>Model type</i>	<i>Key science issues</i>	<i>Specific models/ key participants</i>
Global atmospheric/ocean	<ul style="list-style-type: none"> <li>• Quantification of terms in the ocean heat budget</li> <li>• Large scale ocean-atmosphere-land interaction on seasonal, interannual and longer timescales</li> <li>• Testbed for parameterizations</li> </ul>	<ul style="list-style-type: none"> <li>• UCLA coupled GCM (Ma et al. 1994) [Mechoso]</li> <li>• NCAR Community Climate System Model (CCSM, Collins et al. 2004)</li> </ul>
Regional atmospheric/coupled	<ul style="list-style-type: none"> <li>• Diurnal and synoptic atmospheric variability of SEP cloud and precipitation.</li> <li>• Aerosol-cloud-ocean feedbacks</li> </ul>	<ul style="list-style-type: none"> <li>• NCAR MM5 (atmospheric) [Garreaud/Rutllant]</li> <li>• IPRC Hawaii (coupled) [Xie]</li> <li>• COAMPS-ROMS at OSU [Skylingstad, Samelson]</li> </ul>
Eddy resolving ocean	<ul style="list-style-type: none"> <li>• Oceanic mesoscale eddy dynamics</li> </ul>	<ul style="list-style-type: none"> <li>• ROMS [Samelson, Rutllant]</li> </ul>
Single column	<ul style="list-style-type: none"> <li>• Cloud response to forcing variability</li> <li>• Boundary layer physics and aerosol-cloud microphysics parameterization development</li> </ul>	<ul style="list-style-type: none"> <li>• CAM SCM (SCAM) [Bretherton]</li> </ul>
Large eddy simulation	<ul style="list-style-type: none"> <li>• Cloud-drizzle-turbulence feedbacks</li> <li>• Diurnal cycle of cloud and entrainment</li> </ul>	<ul style="list-style-type: none"> <li>• CSU LES, DHARMA [Bretherton]</li> </ul>

### *2.3 Eddy resolving ocean models*

Mesoscale oceanic eddies are typically 50-200 km in size, which means that most oceanic eddies are poorly resolved in coupled ocean-atmosphere GCMs. Furthermore, in coastal upwelling regions even finer scale eddies and fronts develop from instability of the wind-driven alongshore currents steered by the coastline and continental slope topography. We therefore hope to use a state of the art oceanic eddy resolving model to quantify the role that eddy motion plays in transporting cold, upwelled water from coastal regions to further offshore, thereby influencing the geographical and temporal distribution of SST in the SEP. We anticipate using the Regional Ocean Modeling System (ROMS, Shchepetkin and McWilliams, 2004) primitive equation ocean model for this purpose. Versions of this model have been used successfully in a range of eastern boundary current and coastal ocean regimes, including the California Current System and upwelling flows over the continental shelf (e.g., Marchesiello et al., 2003; Durski and Allen, 2005). A version of this model also forms the ocean component of the OSU COAMPS-ROMS coupled ocean-atmosphere model (E. Skillingstad, personal communication). Use of this model will facilitate comparison and interplay between the regional eddy-resolving ocean modeling and the coastal coupled ocean-atmosphere modeling components of the VOCALS project. A range of model domains will be used for these purposes, spanning different portions of the SEP and the coastal zone, with grid resolutions of order 5-15 km for the larger-scale SEP domains, and 1-5 km for the coastal simulations. The regional atmospheric models will provide the necessary mesoscale detail for wind and surface heat fluxes.

### *2.4 Single column models*

A single column model is here defined as a one (or zero) dimensional atmospheric model that describes the atmospheric state at one location. These models are typically driven with either idealized boundary conditions or those drawn directly from reanalyses. Their merit is that they are extremely computationally cheap and conceptually very simple to analyze and understand, making them ideal for parameterization development and to explore the phase-space of forcings. We plan to use single column models in VOCALS for both these purposes. Many single column models are actually a single column of a more complex model such as the CCSM. Also included in this class are models such as mixed layer models (Lilly 1968) and simple exploratory models (e.g. mixing line models) that can provide physical insight.

Parameterization development for VOCALS will focus upon the representation of turbulent cloud topped marine boundary layers (MBLs) and upon aerosol-cloud-drizzle microphysics, both of which are poorly represented in current large-scale models. Intensive field data from EPIC 2001, PACS 2003, and the VOCALS-RF will be used to provide physically realistic sets of boundary conditions with which to force single column models.

Parameter exploration will be used to examine the sensitivity of different models to changes in forcing conditions. Of particular interest here will be the sensitivity of cloud albedo to changes in cloud condensation nucleus (CCN) concentration, particularly in the role that aerosols play in suppressing drizzle and changing the MBL dynamics and entrainment, which has a feedback effect upon cloud thickness and albedo. We plan to

compare a number of different warm rain parameterizations in the literature to determine each one's sensitivity to changes in CCN. These sensitivities will also be compared to those of a large eddy simulation (see below) with different microphysical formulations.

Single column models that we plan to use for VOCALS work are the NCAR Single column Community Atmosphere Model (SCAM), the University of Washington Mixed layer model (Bretherton and Wyant 1997), and a new mixing line model (Park et al. 2004).

### *2.5 Large eddy simulation*

Large eddy simulation (LES) is the ideal tool to examine the small-scale dynamics of the MBL, especially the sensitivity of turbulence to changes in radiative forcings and to increasing levels of precipitation. For this end, it is proposed that a bulk precipitation formulation (e.g. Khairoutdinov and Kogan 2000) that incorporates a variable cloud droplet concentration, is used to examine the sensitivity of cloud and MBL structure to decreasing cloud droplet concentration. We will use both the University of Washington LES (called DHARMA) The boundary conditions used to initialize the simulations will be the same as those for the single column simulations, which will allow a comparison between the different models of the physical processes that occur in clean and polluted clouds.

Effects of the diurnal cycle of radiative and dynamical forcings upon MBL turbulence and entrainment will also be a focus for study using LES. Data from the EPIC 2001 field program, in which the diurnal cycle of MBL cloud was strong and regular, will be used to provide the boundary conditions and validation for the simulations. Key questions are whether drizzle plays a strong role in modifying the diurnal amplitude of the dynamics and cloud, and whether the diurnal cycle of subsidence, thought to be caused by a diurnally forced gravity wave propagating from the South American continent (Garreud and Muñoz 2004), also plays a strong role.

## **3. Diagnostic studies of existing and targeted new observations**

One of the opportunities that a specific regional initiative such as VOCALS affords, is the chance to bring together and archive observational datasets from a wide variety of sources that can be used by the VOCALS community. In VOCALS we will initially rely heavily on currently available data to aid our research. During the course of VOCALS, a variety of externally-funded observational enhancements will also be available to enrich our perspective on the SE Pacific. We are also proposing as part of VOCALS to make targeted new observations to address the science goals.

### *3.1 Existing/planned observational datasets with VOCALS relevance*

Table 3.1 and 3.2 provides a summary of the existing and planned observational datasets that will be used as part of the VOCALS program but which were initiated outside of VOCALS.

#### *3.1.1. NOAA instrumented buoy (WHOI/IMET) at 85 W, 20 S*

With support from the NOAA Climate Observation Program, a surface instrumented

moored buoy ("WHOI Buoy") has been collecting both oceanographic and atmospheric data continuously at 85°W, 20°S since October 2000. The site was chosen because of its proximity to the location of the climatological maximum in stratus cloud amount in the SEP. The buoy is unique in providing the only current continuous source of data from a subtropical marine stratocumulus regime anywhere on the globe. These data are already proving to be extremely useful in documenting the variability of MBL and cloud properties on timescales from diurnal to seasonal, and even interannual. The atmospheric measurements, at 1 minute temporal resolution, are air temperature humidity, winds, radiative fluxes (from which cloud properties can be inferred), rain rate, and barometric pressure. Accurate bulk flux measurements, which are poorly known over the remote oceans are derived. The atmospheric data from the buoy are not put on the GTS (global telecommunications center, used by weather agencies to share data for assimilation into numerical models) so will serve as independent data for assessing atmospheric and coupled ocean-atmosphere model performance.

Ocean measurements include a floating SST sensor (5 cm depth), 16 temperature and 10 conductivity/temperature loggers in the upper 200 m, 2 Vector Measuring Current Meters, and 1 300 kHz ADCP to measure velocity in the upper 150 m. Velocity is thus sampled at 10 and 20 m and in 7.5 m depth bins from 150 m to the surface. Collocated temperature and conductivity time series are collected at 1, 3, 7, 18, 29, 40.5, 63, 85.5, 130.5, and 168 m depths; and temperature time series are collected at 0.05, 2, 12, 25, 33, 48, 55.5, 70.5, 78, 93, 100.5, 108, 115.5, 138, 145.5, 175, and 200 m. This provides sufficient resolution to resolve the oceanic mixed layer depth and support investigation of the relative contributions of temperature and salinity variability to upper ocean density structure, measure local horizontal velocities, and examine the contribution of vertical shear in the horizontal velocity to local mixing. A subsurface acoustic rain gauge for the mooring has been provided by Jeff Nyusten of the Applied Physics Laboratory at the University of Washington.

Both the atmospheric and subsurface measurements are of tremendous importance oceanographically, as they provide estimates of previously unquantified terms in the ocean heat and salinity budgets. The measurements will also be used to examine remotely-forced ocean variability at the mooring and the possible link via Rossby and coastal trapped waves of that variability back to variability at the equator. Dramatic mesoscale variability in ocean mixed layer properties indicative of the passage of mesoscale oceanic eddies has also been observed and will be used to assess the importance of these eddies in transporting heat from the coastal regions to the remote SEP.

### *3.1.2 Soundings/synoptic observations*

The regular sounding network in Perú (reaching the GTS) includes only Lima-Callao (12°S). Additional operating or planned radiosonde observations (possibly Piura (5°S) and San Juan (15°S)) will also be available via the Peruvian Geophysical Institute (IGP). At Piura there is a BL wind profiler operated by the IGP. Several automatic coastal weather stations will be in operation during the VOCALS period, and data availability is currently being negotiated with the relevant Peruvian organizations. The Chilean network has radiosonde stations at Antofagasta (23.5°S) and Santo Domingo (33.7°S) are the regular

operated by the National Weather Service (DMC). Radiosondes have been launched in the past at Robinson Crusoe Island (33.5°S, 79°W: available GPS radiosonde receiver there) and at San Felix Island (26.2°S, 80°W: no receiver currently available there). Both locations have trained personnel but expendables will need to be provided (gas, balloons and radiosondes). Automatic weather stations (AWS) are planned by both the Chilean National Weather Service and the Navy Weather Service to replace standard synoptic weather stations. At present the Geophysics Department at the Universidad de Chile (DGF) runs coastal AWS's at Caleta Constitución 23°S, at Point Lengua de Vaca (30.2°S) and soon at Point Curaumilla (33.1°S).

### *3.1.3 Reanalysis*

Two reanalysis datasets are currently available and will be used heavily in VOCALS. Both NCEP (spanning time period 1958-present) and the recently released ERA-40 (spanning 1957-2002) reanalyses are available at 4×daily time resolution and at a spatial resolution of 2.5×2.5°. The ERA-40 dataset is the newer of the two and incorporates recent advances in data assimilation and model development at ECMWF. Both datasets are freely available and it is planned that the NCAR Joint Office of Scientific Support (see section 3.3 below) archives a subset of the most relevant variables from these reanalysis for the VOCALS region.

The reanalysis datasets will be used to provide important boundary conditions for regional, single column, and large eddy simulations of the SEP (Section 2 above). Chiefly, these boundary conditions are (a) advective tendencies; (b) radiative fluxes, subsidence, and free atmospheric thermodynamics above the MBL. One of the primary aims for VOCALS will be to set up test cases based upon the combination of detailed field observations (EPIC 2001, PACS 2003 and yearly cruises, and VOCALS-RF) and reanalysis data that will serve as a testbed for parameterization and model intercomparison research.

In addition, reanalysis data will be used to examine the links between large-scale meteorology, cloud and drizzle in the SEP. Reanalysis data will be used to provide trajectories to track the development of pockets of open cells (POCs) as seen in geostationary satellite data. Back trajectories will also be used to attempt to determine whether a particular air mass has been influenced by pollution or has crossed areas of intense coastal upwelling. The source of the air above the MBL may have a strong impact upon both the thermodynamic and the microphysical evolution of stratocumulus, and so back trajectory analysis using the reanalysis fields will be used to examine the origins and history of the air entrained into the MBL.

Reanalysis data will also be used in conjunction with large-scale cloud climatologies such as ISCCP (Table 3.2) to examine the synoptic influence upon cloud cover over the SEP. A strong diurnal cycle of subsidence at 850 hPa is seen in the ECMWF reanalysis, consistent with the simulations of Garreaud and Muñoz (Robert Wood, personal communication) and we plan to examine using compositing of the reanalysis data what the major synoptic controls on the strength of the diurnal cycle.

### 3.1.4 TAO Mooring Array

The TAO moorings provide a nearly unbroken record of surface meteorology, ocean measurements, and radiation in the equatorial region of VOCALS. There are eight buoys in the VOCALS region, at four latitudes (Equator, 2°S, 5°S, 8°S) at 95°W and 110°W. These buoys are instrumented to provide high time resolution information on surface meteorology, precipitation, turbulent and radiative (95°W only) fluxes, SST, and subsurface current, temperature and salinity. These moorings are situated in the regions where coupled models tend to show a spurious double ITCZ, and will be used in VOCALS to examine the relationship between SST, winds, MBL structure, and cloud radiative properties on synoptic to interannual timescales. Ultimately these data will be used to assess whether active feedbacks are operating between the deep convection in the ITCZ and the stratus inflow regions to the south which preclude the generation of a double ITCZ, and why this is so poorly represented in coupled models. In addition, it is well understood from previous data that there is strong variability in moisture above the MBL in the near-equatorial regions to the south of the ITCZ. The TAO data will be used, in conjunction with satellite remote sensing and models, to determine if mid-tropospheric moisture anomalies are associated with observable changes in the MBL structure and winds. As part of VOCALS we hope to enhance the TAO moorings at 110W (8S-equator) and possibly 125W (8S-equator) with broadband radiometers, which could be carried out at a reasonable cost using the ongoing TAO servicing cruises for deployment.

Table 3.1: Existing observational datasets to be used in VOCALS (not satellites)

<i>Dataset/source</i>	<i>Specifics/Science issues</i>
<b>WHOI instrumented buoy</b> Bob Weller, WHOI	<ul style="list-style-type: none"> <li>• Surface meteorology, radiative and turbulent fluxes from October 2000 at 85W, 20S.</li> <li>• Ocean mixed layer profiling of temperature and salinity</li> </ul>
<b>Soundings and synoptic observations</b> Weather services of Pacific S. American nations	<ul style="list-style-type: none"> <li>• Coastal meteorology, coastal jets</li> <li>• Diurnal variability, including subsidence wave generation</li> <li>• Synoptic and seasonal variability of Western Andean slopes</li> </ul>
<b>Reanalysis</b> NCEP (1958-present) ERA-40 (1957-2002)	<ul style="list-style-type: none"> <li>• Large scale meteorological conditions</li> <li>• Boundary conditions for regional and small scale model simulations</li> </ul>
<b>TAO/TRITON buoy array</b> Tropical Atmosphere Ocean Project	<ul style="list-style-type: none"> <li>• Surface moorings at 95°W and 110°W (Equator, 2°S, 5°S and 8°S) giving surface meteorology, turbulent fluxes, sea surface and subsurface data, ocean currents, and radiative fluxes (95°W sites only) since 2000.</li> <li>• Long term monitoring of MBL, cloud, and ocean structure and variability</li> </ul>

### 3.1.5 Existing and upcoming satellite datasets

Table 3.2 summarizes the existing satellite datasets that will be used to further the science goals of VOCALS. Data from these missions are freely available to the scientific user. We outline briefly here how each of the datasets will be used in VOCALS.

ISCCP: International Satellite Cloud Climatology Project datasets provide information on cloud cover, cloud top temperature, and optical properties that will be used to assess both the diurnal, synoptic, and seasonal cycle of clouds over the SEP. Despite the free availability of these data, a detailed study of the geographic variation of the seasonal cycle of low cloud over the SEP is still lacking, and will be addressed in VOCALS.

GOES: Calibrated visible and infrared radiances every three hours are available and will be used to examine the evolution of POCs features in the SEP and the diurnal cycle of cloud cover. Physical retrievals from GOES will be available and are detailed in Section 3.2 below.

MODIS: Multi-channel radiances at 1 km resolution from MODIS will be used to assess the quality of the most state-of-the-art retrievals of both cloud and drizzle by comparing with in-situ data and surface-based retrievals. MODIS also provides retrievals of aerosol in clear sky conditions that will be used to examine anthropogenic aerosol over the SEP.

TMI/AMSR/SSM/I: Microwave radiometer data products will provide data on cloud LWP and SST (TMI and AMSR) useful for several key VOCALS aims. The ability of TMI to sample the complete diurnal cycle makes these data particularly useful for examining the diurnal cycle of cloud and the influence of synoptic features upon it. TMI also measures SST at a spatial resolution (~25 km) sufficient to resolve oceanic eddies.

TOPEX/POSEIDON/JASON: Sea surface altimetry will be used by oceanographers participating in VOCALS to examine ocean currents, waves, and eddies. Additionally, it is possible to infer lateral advection by combining sea surface height (SSH) with SST observations from TMI/AMSR. These estimates will be used to complement advection estimates from the NOAA instrumented buoy (see section 3.2.1 below).

Seawinds on Quikscat: Scatterometer data provides surface wind speed and direction measurements at 25 km resolution twice daily (and 4×daily for a 6 month period during 2003) over the SEP. These data will be used to examine the diurnal, synoptic, and annual cycles of surface divergence over the SEP, and will provide important measurements of the coastal jet along the Chilean coast, and wind/subsidence patterns associated with coastal lows. Preliminary results from the Windsat passive microwave sensor suggest that this instrument and its planned successors on NPOESS may also provide useful information on surface wind and stress fields.

Cloudsat/CALIPSO: Cloudsat will provide the first direct measurements from space of drizzle in low clouds. Validation of these measurements, particularly in low cloud over the remote oceans where surface contamination could pose a serious problem, will be a key goal of VOCALS, because both the yearly maintenance cruises (see section 3.2 below) and

the VOCALS-RF field program will provide unprecedented validation data on the occurrence and profiles of radar reflectivity associated with drizzle over the SEP. Cloudsat data itself will provide unprecedented climatologies of the frequency of drizzle occurrence in MBL cloud, which will be central to VOCALS questions about the importance of drizzle in modifying the structure of stratocumulus clouds. CALIPSO will provide the first direct and regular measurements from space of the MBL inversion height which will be used to assess the quality of numerical model predictions. In addition, the aerosol profiling capability of CALIPSO will be used to determine the occurrence of elevated aerosol layers (particularly those related to biomass burning in the tropical SEP) and their possible entrainment into the MBL.

### *3.2 Targeted new observations and observational datasets for VOCALS*

Besides capitalizing on the recent advances in both satellite and reanalysis data products, VOCALS also aims to spawn targeted new measurements and derived datasets for the data-sparse SEP. Table 3.3 summarizes these datasets, and we describe their benefits to VOCALS below.

#### *3.2.1 NOAA-ETL buoy maintenance cruises*

As part of the maintenance schedule for the moored buoy (85°W, 20°S), yearly cruises will take place using a number of different ships. The first of these that was clearly under the VOCALS initiative was the PACS (Pan American Climate Studies) 2003 cruise which made some of the first detailed aerosol measurement over the remote SEP by scientists at Texas A&M University. The cruises to the IMET mooring are scheduled for some time between October-December each year. Extensive comparisons of shipboard meteorological and air-sea flux sensors with the moored sensors are carried out each year involving C. Fairall (NOAA ETL) to quantify the accuracy of the moored sensors. At the same time radiosondes, radar, and aerosol sampling is done to further characterize the stratus deck region. In recent years the cruise has also provided the opportunity to service a Chilean mooring at 20°S, 75°W. Cruises in 2004, 2005 and 2006 will continue the aerosol sampling in conjunction with enhanced cloud (University of Miami 95 GHz cloud radar) and thermodynamic sampling to provide a rich dataset with which to study aerosol-cloud-drizzle interactions. In 2005 or 2006 direct measurements of DMS flux (University of Hawaii) and ozone flux (University of Colorado) are planned. Additionally, the transits carried out in the maintenance cruises are useful for sampling mesoscale oceanic eddies, and provide an opportunity to determine an appropriate system for sampling mesoscale eddies during the VOCALS-RF field program.

Table 3.2: Existing and planned satellite observational datasets to be used in VOCALS

<i>Dataset/source</i>	<i>Spatial/temporal resolution and availability</i>	<i>Specifics/scientific issues</i>
<b>ISCCP</b>	280×280 km 3 hourly 1983-present	Cloud cover and optical thickness variability at coarse spatial resolution every 3 hours. Will be used with regional model simulations to study synoptic and diurnal variability.
<b>GOES</b>	4/8 km 3 hourly 1980-present	High spatial resolution (4 and 8 km) visible and infrared radiance data on useful for studying evolution of cloud/POCs. VOCALS aim is to archive data from 2000 onwards.
<b>MODIS</b>	1 km 2×daily 2000-present	High spatial resolution, multi channel retrievals of cloud cover and microphysics, and aerosol. Will be used in conjunction with in-situ data from VOCALS-RF and surface remotely sensed data from EPIC 2001/PACS 2003 to validate and develop new satellite microphysical retrievals.
<b>TRMM/ AMSR/ SSMI</b>	25 km > 1×daily 1990-present (SSMI) 1998-present (TMI) 2002-present (AMSR)	Microwave radiometer liquid water path (LWP) measurements will be used to compare with regional models and further examine the diurnal cycle. SST measurements will be used to investigate mesoscale oceanic eddies and role of SST in cloud development
<b>TOPEX/ POSEIDON/ JASON</b>	high resolution but averaging required to reduce noise 1992-present	Laser altimetry of ocean surface to assess oceanic currents, Rossby waves, and mesoscale eddies.
<b>Seawinds on Quikscat</b>	25 km 2×daily 1999-present	Microwave scatterometer provides surface wind speed at 0.25° resolution. Will be used to assess synoptic and diurnal variability. Windsat/NPOESS passive microwave data will also be used if available.
<b>Cloudsat/ CALIPSO</b>	2 km but only along track scanning launch June 2005	Millimeter profiling radar will provide unprecedented information on light precipitation in shallow clouds. Backscatter lidar will provide accurate measures of MBL depth and information about aerosol layers above cloud and in clear regions

Table 3.3: New targeted observational datasets for VOCALS

<i>Dataset/source</i>	<i>Specifics/Science issues</i>
<b>NOAA buoy maintenance cruises</b> Chris Fairall, ETL	<ul style="list-style-type: none"> <li>Yearly cruises from 2003 to 85W, 20S with suite of surface meteorology, radiation, and turbulent flux measuring capability, cloud remote sensing (lidar, ceilometer, radar), aerosol counting and sizing.</li> <li>Boundary conditions for regional and small scale model simulations</li> </ul>
<b>Satellite cloud retrievals</b> Patrick Minnis, NASA Langley	<ul style="list-style-type: none"> <li>GOES geostationary satellite retrievals of cloud cover and microphysical/bulk properties at <math>1 \times 1^\circ</math> resolution 8 times daily over the VOCALS region.</li> </ul>
<b>San Felix Island</b> University of Chile/Chilean Navy	<ul style="list-style-type: none"> <li>Automatic surface meteorological measurements including ceilometer</li> <li>Plans to request the ARM Mobile Facility for a three month period surrounding the VOCALS-RF field program</li> </ul>
<b>ARGO float and surface drifters</b>	<ul style="list-style-type: none"> <li>Ocean surface currents and temperature over wide region of the SEP at nominal <math>3^\circ \times 3^\circ</math> resolution (2003-2015).</li> <li>Temperature and salinity profiles every 10 days from the surface to a depth of 1500-2000 m</li> </ul>
<b>SHOA mooring</b> Chilean Navy	<ul style="list-style-type: none"> <li>Buoy initially instrumented for tsunami warnings, but with the possibility of adding meteorological and radiation measurements as part of a VOCALS initiative</li> </ul>
<b>Other</b>	<ul style="list-style-type: none"> <li>Chilean coastal moorings</li> <li>Cooperative cruises</li> <li>VOS/TAO Tender cruises</li> <li>Chilean enhanced coastal atmospheric monitoring</li> </ul>

### 3.2.2 Satellite cloud retrievals over the stratus regions

Specially commissioned satellite retrievals of cloud microphysical and radiative properties from geostationary satellites (GOES) will be provided by Patrick Minnis at NASA Langley as part of VOCALS ongoing monitoring efforts. These will be archived for use by the VOCALS community. The data will be produced on a  $1^\circ \times 1^\circ$  grid for the entire VOCALS region every three hours. Currently, there are two years (1999-2000) of data archived, and the plan is to extend this out to cover the entire period of VOCALS. These data will be important for developing climatologies of cloud microphysical properties (which are unavailable in the ISCCP dataset) over the SEP, and in determining how these properties change with synoptic state and airmass type.

### *3.2.3. San Felix Island*

San Felix Island (26°S, 80°W) represents an excellent opportunity in being one of the few remote oceanic island located in a subtropical region dominated by stratus/stratocumulus. Annual mean low cloud cover at San Felix has is around 50%, and peaks at 60-70% during October. Since December 2002, the University of Chile and the Chilean Navy have been making automated weather measurements on San Felix. These include surface pressure, temperature, humidity and winds, and a limited ceilometer record of cloud base height is also available. In addition, observer reports have been made on San Felix for many years which could be extremely valuable to VOCALS. As part of an effort to enhance the extended monitoring in the SEP, and to provide valuable context for the VOCALS-RF field program, it is planned to make a formal request for the ARM Mobile Facility (AMF) to locate to San Felix Island for a three month period during September-December 2007. Further details of the AMF are presented under the plans for the VOCALS-RF field program in Section 4.

### *3.2.4 ARGO float and surface drifters*

ARGO is a global oceanographic initiative to deploy a dense and regular network of float and surface drifting measurements over the world's oceans (see [www-argo.ucsd.edu](http://www-argo.ucsd.edu)). As part of the Integrated Ocean Observing System (IOOS) there are ongoing deployments of surface drifters and profiling Argo floats in the southeastern Pacific. The surface drifters are drogued to provide observations of surface currents; they also provide sea surface temperature data used to calibrate satellite measurements. The profiling floats are planned for deployment on a 3° spatial grid, with a profile obtained every 10 days. They are parked at 1500 or 2000m depth between profiles and equipped with temperature and salinity sensors. These sensors will be used in VOCALS for the study of the ocean heat budget. It is expected that some limited information may be obtained from these sensors as to the importance of mesoscale oceanic eddies in the SEP.

### *3.2.5 Chilean Navy mooring (20°S, 75°W)*

The Chilean Navy Hydrographic and Oceanographic Service (SHOA) has installed a surface mooring and accompanying bottom mounted instrument package to detect and provide warning of tsunamis. This surface mooring provides the potential for sampling surface meteorology, radiative fluxes, and upper ocean variability.

### *3.2.6. Other targeted observational opportunities*

#### Cooperative cruises

The CPPS [Comision Permanente del Pacifico Sur], a cooperative effort between four South American nations to study the South Pacific, conducts cruises in the southeastern Pacific each year. These cruises are mainly of an oceanographic nature and typically take place in May each year. In addition, hydrographic cruises coordinated between the Peruvian and Chilean Navies will provide opportunities for additional sampling of the VOCALS region. Efforts began at the VAMOS Panel meeting in Guayaquil, Ecuador in

2004 to establish the dialog between VOCALS and the planners of these cruises.

#### Chilean coastal moorings

Investigators from the University of Concepcion have deployed and are maintaining subsurface moorings to measure temperature and velocity variability in the coastal waters at several sites along the Chilean coast. Further support, most likely from international science agencies, will probably be required to maintain and develop the coastal moorings over the VOCALS period. Possible sources of funding might include the US Office of Naval Research (ONR), which has an office in Santiago, Chile.

#### Enhanced meteorological and oceanographic observations from VOS and TAO tender cruises (US NSF/NOAA)

US CLIVAR is proposing enhanced (high-resolution) XBT observations along a VOS-based oceanographic survey line PX81, between Honolulu and Valparaiso, jointly supported by the USA and Chile. This line is being considered for enhanced IMET instrumentation for surface flux component measurements. US CLIVAR is also considering the utility of more frequent soundings from the TAO cruises.

#### Enhanced coastal atmospheric monitoring proposed for VOCALS

The following atmospheric measurements along the Chilean coast would improve our ability to track coastally trapped disturbances and synoptic variability by augmenting the current coastal station reports. Chilean funding would be required.

- Automatic weather station and/or ceilometer observations at Antofagasta (23.5 S, 70.5 W) and/or Iquique (20.5 S, 70.5 W).
- Wind profiler and RASS at Caldera (27 S, 71 W)..

#### 4. VOCALS Radiator Fin Experiment (VOCALS-RF)

An important component of VOCALS is an international field program which will investigate relations between clouds, aerosols, boundary layer processes, upper ocean dynamics and thermodynamics, coastal currents and upwelling, large-scale subsidence, regional diurnal circulations on the west slope of the Andes, and the effects of synoptic-scale variations in continental convection upon clouds over the SEP. The field experiment is named the VOCALS Radiator Fin experiment (VOCALS-RF) in recognition of the proposed ship sampling pattern and Pierrehumbert's (1995) characterization of the subtropical subsidence regions as the 'radiator fins' of the tropics in which the free troposphere is very dry and infrared radiation efficiently cools the earth system.

The intensive observational period (IOP) comprises enhanced observations for a month long period during October 2007 using a number of platforms as described below. This IOP will combine resources from South American countries and the USA. The intensive field program aims to answer the following specific questions:

1. What factors influence the formation of drizzle in the remote and coastal SEP? What physical processes are responsible for generating and maintaining pockets of open cells (POCs) within otherwise overcast stratocumulus cloud regimes?
2. What are the aerosol characteristics in both the coastal and remote SEP region? How do the contrasts affect cloud microphysics, and how are they related to POCs? Does a POC cause aerosol depletion through scavenging, or is depleted aerosol a POC precursor? What are the major sources and sinks of aerosol over the SEP, both natural and anthropogenic?
3. Do oceanic mesoscale eddies play a dominant role in fluxing heat from coastally upwelled water to regions further offshore? What are the dominant controls on the heat, salinity and nutrient budgets in the offshore regions?
4. Is mesoscale ocean variability in SST and DMS imprinted on the SEP boundary layer clouds or the spatiotemporal distribution of aerosols?
5. Do details of near-coastal upwelling, productivity, and biogenic aerosol production have noticeable effects on the large-scale coupled ocean-atmosphere structure of the region, via their effects upon surface turbulent fluxes and/or cloud microphysics?
6. Do the depth, phase speed, and vertical structure, of the diurnal subsidence wave ("upsidence wave") originating in northern Chile/southern Peru agree with regional model simulations.
7. Are current regional or global numerical models able to accurately simulate the synoptic variability in cloud cover and albedo in the SEP on synoptic timescales? Is this variability in cloud properties significantly affected by space-time variability in cloud droplet concentration and aerosols?

8. How can current and planned satellite retrievals of stratocumulus cloud microphysical properties (e. g. effective radius or cloud droplet number concentration from MODIS) and precipitation (from CloudSat or MODIS) be improved, including under broken cloud conditions?

#### *4.1. Logistics of VOCALS 2007 field program*

An effective study of the processes above cannot possibly be achieved with a single measurement platform, and so we will combine the capabilities of at least two ships, at least one instrumented aircraft, and ground based in-situ and remote sensing measurements at San Felix Island. Such a combination of observations has not been assembled even in the northeast Pacific (NEP) despite many coastally-focused stratocumulus studies off the Californian coast that rely mainly upon aircraft observations. The long, well-calibrated IMET buoy record has no counterpart in the NEP stratocumulus regime, nor is there an island in the NEP that is both well offshore but still in the stratocumulus region. In addition, the absence of coastal megacities along the south American coast is expected to result in sharper, and therefore more easily measurable, contrasts between clean and polluted airmasses. Table 4.1 summarizes the chief measurement platforms, their coverage and the broad scientific goals to be addressed.

#### *4.2. VOCALS 2007 Study Region and platform overview*

The VOCALS field experiment study region is shown in Fig. 4.1, and comprises that part of the SEP east of  $90^{\circ}\text{W}$  and between  $15^{\circ}\text{S}$  and  $30^{\circ}\text{S}$ . All field campaign operations will be conducted within the study region. San Felix Island is at  $80^{\circ}\text{W}$ ,  $27^{\circ}\text{S}$ , the IMET Buoy is at  $85^{\circ}\text{W}$ ,  $20^{\circ}\text{S}$ , and the DART buoy is at  $75^{\circ}\text{W}$ ,  $20^{\circ}\text{S}$ .

The buoy/island locations will form the extrema of a "radiator fin" (RF) pattern (Fig. 4.1) which will be carried out over a four week period by a UNOLS ship, the R/V Wecoma. This pattern is designed to map out the mesoscale variability in the ocean surface and mixed layer and to gather statistics of mesoscale eddy activity. Meanwhile, another research ship the Ronald H Brown (RHB) will conduct measurements of both atmospheric and oceanic parameters along a line linking the DART and IMET buoys, spending several days at three locations on the  $20^{\circ}\text{S}$  latitude at increasing distances from the south American coast ( $75^{\circ}\text{W}$ ,  $80^{\circ}\text{W}$ , and  $85^{\circ}\text{W}$ ). The RHB sampling pattern is designed to study the cloud and aerosol properties at different distances from the coast. A third ship, possibly the Chilean fisheries vessel will conduct a near-coastal sampling pattern to examine aspects of the science goals related to the intense coastal upwelling.

San Felix Island will be instrumented to study cloud and aerosol properties. The ARM mobile facility will be requested for a period centered on the intensive field program.

It is planned to use the NCAR C-130 aircraft to study aerosol, cloud, and marine boundary layer properties over the study region. When possible flights will be coordinated with ship and island activities. A second unmanned aeronautical vehicle may also complement the work of the larger aircraft.

A schematic cross section of the region from coastal northern Chile to the IMET Buoy is given in Fig 4.2.

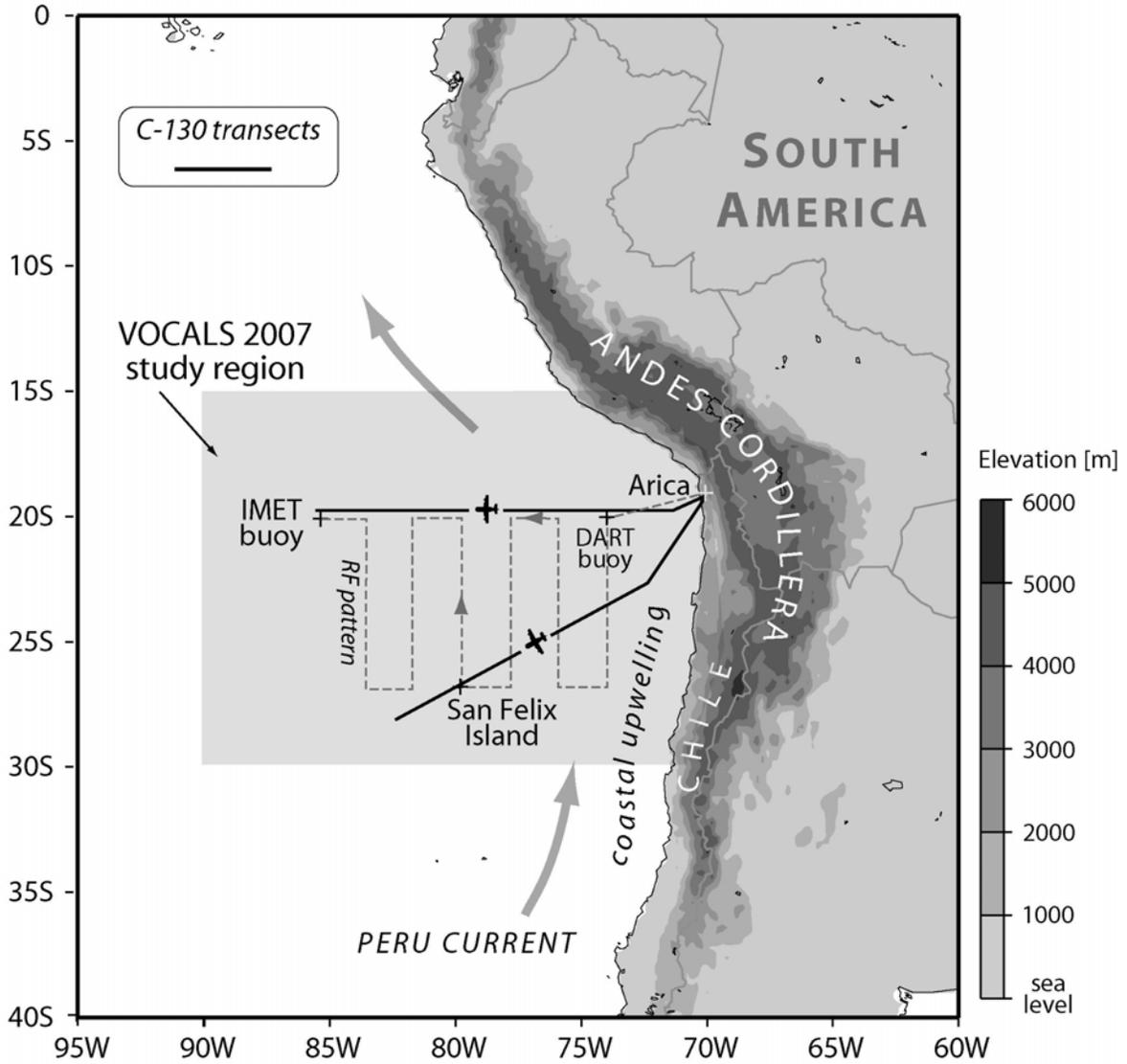


Figure 4.1: Map of the southeast Pacific (SEP), and South American orography. The VOCALS 2007 study region comprises the region between latitudes 15°S and 30°S, and all ocean east of 90°W. The proposed track of the RHB is shown, along with the locations of the IMET Buoy, San Felix Island, and the flight tracks for the cross-section flights with the NCAR C-130.

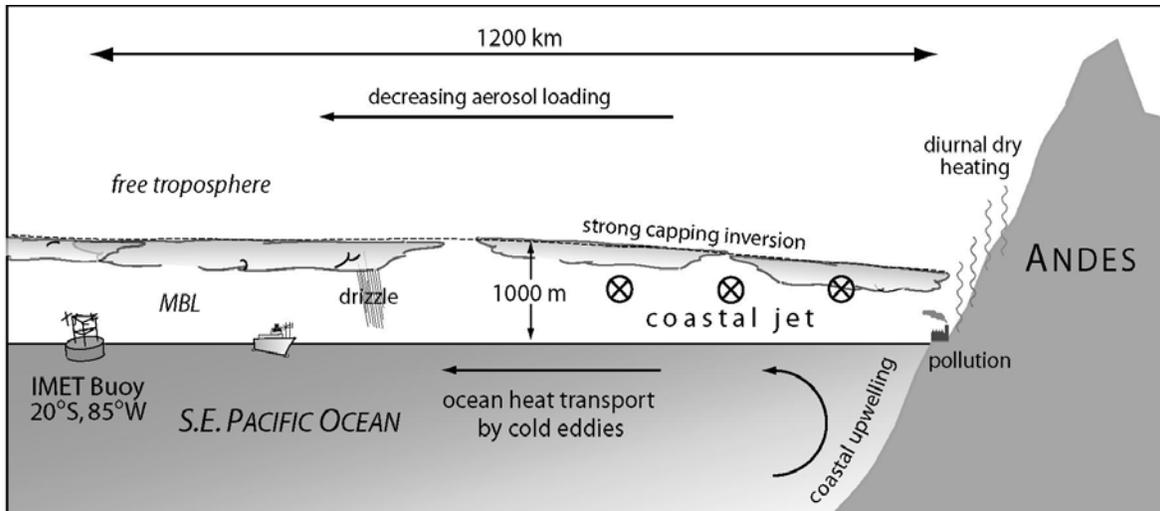


Figure 4.2: Schematic showing an E-W cross section from the IMET Buoy (85°W, 20°S) to the S. American coast, detailing the lower atmospheric and upper oceanic structure and some important processes.

### 4.3. Description of Platform Strategies

The various platforms and their measurement strategies (Table 4.1) during the VOCALS 2007 field program are described in the following subsections.

#### 4.3.1. Aircraft (NSF NCAR C-130, Unmanned Aeronautical Vehicle)

The NCAR C-130 will be the primary aircraft involved in VOCALS 2007. Unmanned Aerial Vehicle (UAV) missions will complement the C-130 observations by increasing temporal sampling of the lower troposphere. There is also a possibility that other aircraft will participate in the field phase (e.g. The Met Office BAe-146), but these are not crucial to the success of the program.

Key measurements on the C-130 will include meteorological parameters and turbulent fluxes, cloud and aerosol microphysical measurements, cloud radar (University of Wyoming Cloud Radar), lidar, multi-channel imaging radiometers to study cloud radiative properties, and dropsondes. Atmospheric aerosol and chemistry measurements will be coordinated by Barry Huebert at the University of Hawaii. These include measurements of aerosol precursor gases, particularly sulfur dioxide (SO<sub>2</sub>) and dimethylsulfide (DMS), aerosol size and composition (using optical particle counters, differential mobility analyzer, filter measurements), cloud condensation nuclei, and residual aerosols within cloud drops (using a counterflow virtual impactor, CVI).

Table 4.1: Measurement platforms, their coverage, and main science goals during the VOCALS RF field program.

<i>Measurement Platform</i>	<i>Coverage/sampling</i>	<i>Main science goals</i>
<b>AIRCRAFT:</b> 1. NSF NCAR C-130 2. Unmanned Aeronautical Vehicle (UAV)	(a) Cross sectional flights between Arica (Chile) and either the IMET Buoy or San Felix Island (Figs 4.1 and 4.3) (b) Lagrangian-type flights to follow and map out POCs and surrounding stratocumulus (Fig 4.4)	<ul style="list-style-type: none"> <li>• Cloud-aerosol-drizzle interactions</li> <li>• Aerosol characterization, sources/nucleation</li> <li>• MBL and cloud structure between the S American coast and the remote SEP</li> </ul>
<b>SHIP 1:</b> NOAA R/V Ronald H Brown (ship)	Stationary measurement periods at three locations along the 20S parallel (75, 80 and 85W) and another at a location to be specified depending upon the mesoscale oceanic eddy activity.	<ul style="list-style-type: none"> <li>• Cloud-aerosol-drizzle interactions</li> <li>• MBL structural properties and energy/moisure budgets</li> <li>• Ocean heat transport, SST and ocean current mapping</li> <li>• Diurnal cycle of MBL and free-troposphere</li> </ul>
<b>SHIP 2:</b> UNOLS R/V Wecoma class	“Radiator fin” pattern from 20°S, 75°W and sampling between 75°W and 85°W, 20°S and 27°S for 18 days, and 1.25°x1.25° butterfly pattern centered at the WHOI/IMET buoy for 6 days. Conduct mesoscale survey near 22°S, 80°W in collaboration with RHB (5 days)	<ul style="list-style-type: none"> <li>• Mesoscale hydrographic, optical, small-scale mixing and velocity structure under the stratus deck.</li> <li>• Lateral transports and the role of oceanic mesoscale eddies</li> <li>• Mesoscale and eddy variability of nutrient transport/aerosol precursor emissions</li> <li>• Mesoscale coupling between SST and cloud variability</li> </ul>
Third ship ???	Coastal sampling pattern to study near-coastal oceanic upwelling, coastal meteorology, aerosol and aerosol precursor (DMS) production.	<ul style="list-style-type: none"> <li>• Coastal upwelling properties</li> <li>• Aerosol precursor distribution</li> </ul>
San Felix Island (80W, 27S)	Fixed location sampling of aerosol, cloud, and drizzle properties using the ARM Mobile Facility (AMF) for 3 month period around field program. Aerosol sampling [Fairall+others]	<ul style="list-style-type: none"> <li>• Cloud-aerosol-drizzle interactions</li> <li>• POCs structure and initiation</li> <li>• Aerosol sources/sinks in the remote SEP</li> </ul>
IMET Buoy (85W, 20S)	Fixed location, surface sampling of MBL properties, radiation, SST, ocean currents (Fig 4.1)	<ul style="list-style-type: none"> <li>• Daily to interannual variability of SST, cloud and MBL properties.</li> <li>• Ocean heat transport</li> </ul>
Coastal Chile/Peru	TBD	<ul style="list-style-type: none"> <li>• Coastal meteorology and cloud cover</li> </ul>

## NCAR C-130 Flight Plans:

Two flight plans (Table 1) have been proposed for C-130 activities:

- (a) *Cross-section missions* (Fig 4.3): These flights are designed to examine contrasts between the MBL and lower atmosphere close to the S. American coast and that in the remote SEP. Specific focus will be placed on examination of aerosol characteristics, MBL structure/depth, cloud morphology, microphysics, and drizzle production (using the University of Wyoming 94 GHz cloud radar, WCR, on the C-130). Other interests include cloud remote sensing, and there will be efforts made to coordinate some of these missions with satellite overpasses, particularly those of Terra and Aqua/Cloudsat/Calipso at roughly 10:30 am/pm and 1:30 am/pm local time. The basic idea is either to fly from the coast to the IMET buoy (85°W, 20°S), or between the coast and San Felix Island (80°W, 27°S). On the outbound section, the mission will comprise a set of straight and level runs below (30 m AMSL daytime, 150 m AMSL nighttime) and above (1800 m AMSL) cloud, and to sample the cloud layer itself using slant profiles ascending at approximately 150 m/minute. An exact specification of the levels used will be dependent upon the needs of the key participants. The above cloud runs will be used to sample the drizzle structure using the MMCR, to characterize the free-tropospheric aerosol and thermodynamic structure, and to use the shortwave imaging radiometer to remotely sense the cloud bulk and microphysical properties. Below cloud runs will aim to determine physicochemical properties of aerosols, and to determine the lower boundary conditions (SST, surface fluxes, winds). The return leg back from the IMET buoy will be carried out at approximately 6km with dropsondes being launched at regular intervals. Because drizzle is expected to be more prevalent during the night, flights will be flown both in the day and at night. This type of flight plan was implemented very successfully during EPIC 2001 for studying southerly cross-equatorial boundary layer inflow into the East Pacific ITCZ (e.g. Raymond et al. 2004, deSzoeko and Bretherton 2004).

An important component of the cross-section missions is to devote a portion of the flight (typically 1 hour) to coordinated sampling with the RHB. These coordinated sections will serve both as a means of comparing the accuracies of the instruments (particularly aircraft aerosol sampling and SST estimates), and to provide important *in-situ* context to remotely sampled cloud and drizzle properties from the RHB. Coordinated flight sections will probably consist of level runs or cloverleaf patterns which pass directly over the ship at three levels (close to the surface, in cloud, and above cloud).

There will be a concerted attempt to coordinate aircraft cross-section missions with satellite overpasses, particularly those of Cloudsat/Calipso which have very narrow swaths, which will provide important validation data.

- (b) *POC drift missions* (Fig 4.4): These flights are designed specifically to examine microphysical and dynamical processes that occur in pockets of open cells (POCs) and in the surrounding cloud. POCs that are completely surrounded by overcast

stratocumulus clouds are of the most interest, but boundaries between open and closed cellular convection will also be a focus of these missions. Of particular importance will be a characterization of the aerosol and cloud microphysics in the two regions. If possible, these flights will be coordinated with the ship which will be able to provide a scanning radar capability (C-band on the RHB) as well as aerosol and cloud characterization. The idea is to use geostationary satellite imagery to locate POCs, and then to target missions accordingly. Once a POC boundary has been reached, the aim is to carry out across-wind stacks of five straight and level runs below, in, and above cloud (with additional porpoising runs to characterize the cloud top and inversion layers). The aircraft will be allowed to drift with the MBL mean wind (i.e. with the advecting POC).

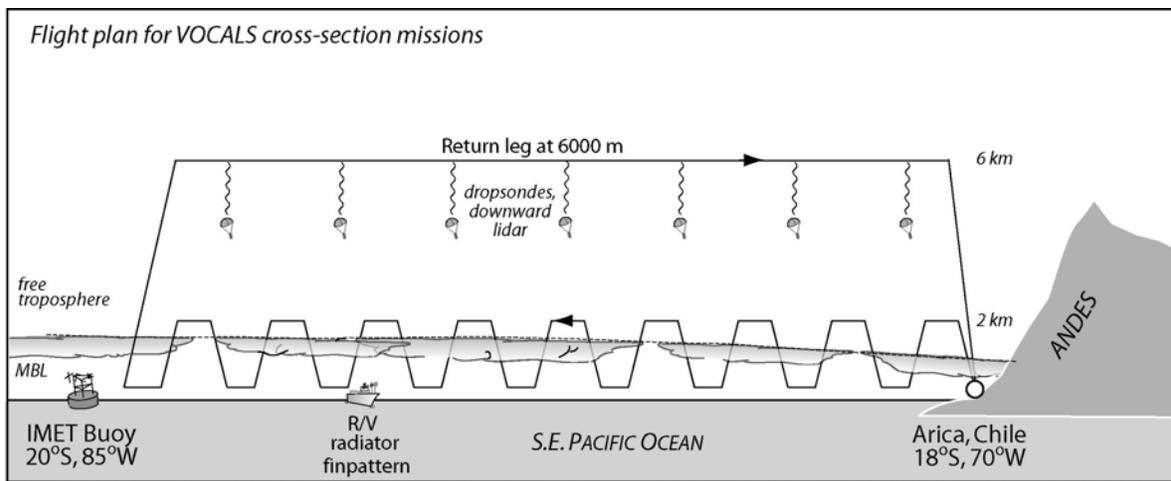


Figure 4.3: Flight plan for C-130 cross-sectional missions. The flight will consist of a set of slant profiles and straight and level runs from the coast out to either the IMET Buoy, or to San Felix Island. Runs above cloud will be used to remotely sense the cloud and drizzle structure. Profiles will be used for in-situ characterization of the cloud and drizzle. On the return leg at approximately 6 km altitude, a series of dropsondes will be launched to map out the vertical structure of the MBL and lower free troposphere across the region.

#### UAV flight plans:

- (a) *UAV POC missions:* These flights will be used to extend the temporal sampling of pockets of open cells (POCs) and their surrounding stratocumulus cloud region. UAV POC missions will complement the intensive sampling during C-130 POC missions by describing the evolution of the winds, temperature, humidity and cloud liquid water fields within the POCs and in the surrounding stratocumulus regions for periods of up to 24 hours. Lagrangian-type missions similar to the plans described above and in Figure A4 will be used. Unlike the C-130, the UAV flights will continuously porpoise between surface and the free tropospheric layer above the stratocumulus clouds (~2km), completing an ascending or descending sounding leg every 20km. To maximize flight time in the vicinity of POCs, UAV operations will

be based in Arica, or perhaps aboard the second research vessel if deck space and funding for installation of marine launch and recovery equipment are available.

- (b) *UAV cross-section missions.* UAVs will also be used to complement the NCAR C-130 cross-section missions. The combination of NCAR C-130 and UAV cross section flights will provide nearly continuous synoptic-scale sampling of the contrast in the the lower tropospheric structure between the S. American coast and the remote SEP during VOCALS 2007. UAV cross-section flight tracks and plans are similar to the NCAR C-130 plans shown in Figures 4.3 and 4.4, with the exception that UAVs will continuously porpoise between the surface and 6km on both outbound and inbound leg, completing a sounding every 50km.

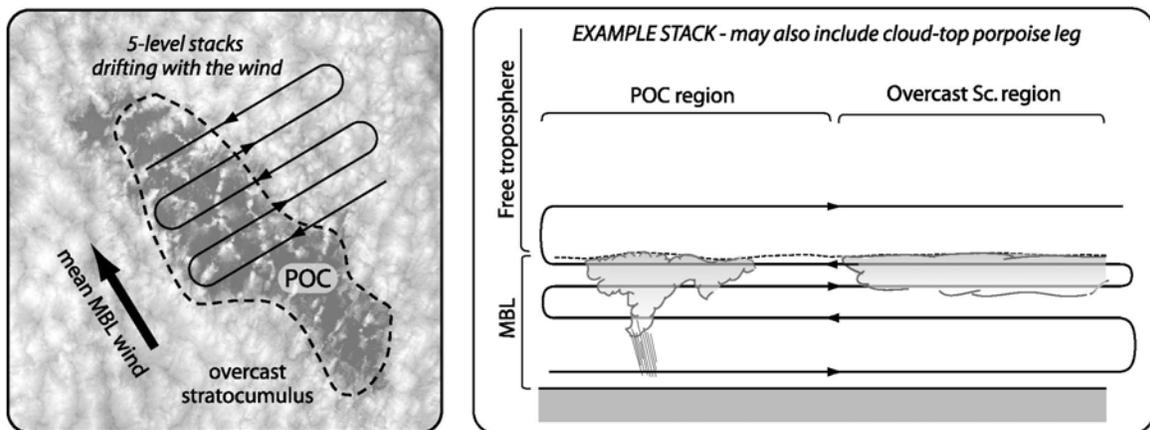


Figure 4.4: Lagrangian-type C-130 flight plan to sample POCs and surrounding overcast stratocumulus. Flight will consist of 4-6 crosswind stacks drifting with the mean MBL wind (left). Each stack will consist of straight and level runs close to the surface, below mean cloud base, just above cloud base, below cloud top, and above cloud. Each run will be approximately 120 km in length, with roughly equal fractions inside and outside of the POC region.

#### 4.3.2 Ship strategy

The VOCALS field program involves a number of atmospheric and oceanic observations to address issues in the temporal and spatial variations of cloud-aerosol interactions, the ocean energy balance, and coupling to oceanic biological-chemical processes (under the SOLAS aegis). The objectives spelled out in this document require careful coordination of two ships operating in quite different modes. The NOAA ship Ronald H Brown (RHB) will perform one set of tasks (beyond its buoy maintenance missions) built around a sampling strategy of stationary time series observations at a series of 4 points extending from the SHOA DART buoy at 20°S 75°W out to the WHOI climate reference buoy at 20°S 85°W. The C-band scanning precipitation radar on the RHB makes it a unique platform to study the mesoscale structure of the stratocumulus clouds. A UNOLS ship will be requested to perform Seasoar/ADCP measurements, initially in a ‘radiator’ survey track (approximately 2 weeks in duration) and then in a series of

‘butterfly’ patterns (approximately 6 days in duration) around the RHB. The UNOLS ship will also measure surface energy budget components and basic cloud properties (base height, top height, drizzle). This two-ship strategy was successfully used in TOGA-COARE and EPIC2001 where energy budgets were closed to  $\sim 10 \text{ W m}^{-2}$  on two-week time scales.

#### RHB measurements and operation:

The RHB measurements will include atmospheric, oceanographic, and interfacial variables. The atmospheric measurements will include: all components of the surface energy and mass budgets, remote sensors for atmospheric profiles (temperature, humidity, winds, cloud boundaries, cloud microphysics, and aerosol backscatter), radar maps of stratocumulus drizzle, aerosols and selected atmospheric chemistry variables, and direct measurements of trace gas ( $\text{CO}_2$ , DMS, and ozone) fluxes. Interfacial measurements will include SST, surface gravity waves, and surfactants plus near-surface water properties from the ship’s underway water sampling system (including  $\text{pCO}_2$  and  $\text{pDMS}$ ). Oceanic measurements will include standard ADCP and CTDs plus water samples for biological and chemical analysis. Rawinsondes will be launched every 3 hours; surface drifters and ARGO floats will be deployed periodically. Research aircraft overflights (primarily during stationary periods) will be required to optimize the cloud microphysical retrievals from ship-based remote sensors, Z-R relations for the C-band radar, and to characterize aerosol/chemistry above the boundary layer. Such overflights will also improve measurement accuracy of some aircraft variables (SST, air temperature and humidity, etc). The C-band radar scan strategy will be similar to that employed during EPIC 2001 (Comstock et al. 2005). The goal of the scan strategy is to obtain high time and spatial resolution data of the mesoscale structure of drizzling Sc. Five minute volume scans will be interspersed with vertical cross-sections to obtain detailed information on both the horizontal and vertical structure of reflectivity and radial velocity patterns within drizzling clouds.

The RHB will operate at four selected stations for buoy maintenance and continuous time series measurements. This strategy is designed to observe the diurnal cycle and the balance of processes as a function of distance from the coast. The 4-day period is considered a reasonable choice to resolve diurnal variations versus other sources of variability. After the RHB leaves port (e.g., Arica, Chile) the DART buoy will be serviced and the RHB will remain at that location (about 400 km from the coast) for a total of 4 days. The time series will be done with the ship stopped (or going slow ahead) and pointed into the wind for optimal sampling by the bow sensors. CTD/Rosette operations will be done in parallel; CTD casts will also be done on transit (approximately one per degree). The ship will transit to  $20^\circ\text{S } 80^\circ\text{W}$  (about 770 km from the coast) and obtain a second time series of 4 days and then to the WHOI buoy site (about 1150 km from the coast). The WHOI buoy will be serviced; the RHB will remain at this location a total of 6 days where it will be joined by the UNOLS ship. The UNOLS ship will perform butterfly pattern surveys to characterize the mesoscale variability and the advection terms in the local energy and mass budgets. Finally, the RHB and the UNOLS ship will move to a location in the interior of the UNOLS ship’s survey pattern. This location will be selected (based on the survey) to straddle a significant ocean mesoscale eddy. The RHB and the UNOLS ship will then

perform a joint 5-day local budget and butterfly operation.

R/V Wecoma measurements and operation:

A UNOLS ship, R/V Wecoma will be requested for 31 days during the VOCALS field program. This second ship will have a complex, multi-measurement mission that aims to address VOCALS-RF science issues that are important and complementary to the fixed point perspective of the mooring. The three main aims of the Wecoma are (i) to survey mesoscale eddy activity to attempt quantitative estimates of the roles of mesoscale oceanic eddies in transporting heat and salt offshore; (ii) in conjunction with the Surface Ocean Lower Atmosphere Study program (SOLAS), biogeochemical measurements will be made to examine the role of mesoscale eddies in determining the biological productivity the SEP. This work will also examine the sea-air exchange of aerosols and aerosol precursor gases and the mesoscale variability in chemical species; (iii) links between the mesoscale variability in sea surface temperature, wind speed, marine boundary layer, and cloud properties, including feedbacks between cloudiness and SST.

The following variables will be measured on the R/V Wecoma underway at a speed of  $4 \text{ m s}^{-1}$ :

- Temperature, salinity, optical properties, conductivity microstructure profiles in the upper 300 m of the ocean from SeaSoar carrying SeaBird 911 CTD, a transmissometer, a fluorometer,  $\text{O}_2$  sensor, and microstructure package. SeaSoar can complete a cycle from the surface to 300 m and back every 3 km at 8 kts.
- Ocean current profiles from acoustic Doppler profiler (ADCP)
- Near surface temperature, salinity, and optical properties from ships flow-through system
- Standard meteorological package to compute air-sea fluxes.
- Atmospheric profiles from radiosondes released every three hours.
- Cloud base, thickness and drizzle from an S-band radar and cloud ceilometer
- Atmospheric chemistry and aerosol sampling

The R/V Wecoma will arrive in the vicinity of  $20^\circ\text{S}$ ,  $75^\circ\text{W}$  at the same time as the RHB. The “radiator fin” pattern will be carried out over the next 17 days, and the Wecoma will arrive at the WHOI buoy at about the same time as the RHB. The Wecoma will conduct a  $1.25^\circ \times 1.25^\circ$  butterfly pattern survey around the WHOI buoy for 6 days (4 complete butterfly patterns), while the RHB is servicing the buoy. After the butterfly survey, both the RHB and the Wecoma will measure oceanic and atmospheric variability near the center of radiator fin,  $22^\circ\text{S}$ ,  $80^\circ\text{W}$  for 5 days before departing from the experimental site. Hydrographic and velocity fields along the radiator pattern will be used to compute statistics of eddy fluxes on scales of the order 100 km. Trial sampling patterns ahead of the VOCALS-RF field experiment will be attempted during the 2005 and 2006 buoy maintenance cruises.

#### 4.3.3. Coastal sampling strategy

Enhanced radiosonde observations at Santo Domingo (34°S), Antofagasta (23°S) and Lima (12S) will be carried out in combination with a twin-engine small airplane equipped with a meteorological package (e.g. AIMMS 20) to sample the MBL and capping subsidence inversion within the 0- 50 km offshore area between 20°S and 38°S. Coastal automatic weather stations and the regular radiosonde network will provide background time series. A coastal ceilometer at 33°S would be highly desirable. Although higher resolution products may become available, current scatterometer surface stress measurements are currently unreliable within 25-50 km of the coast, so aircraft and buoy measurements of surface winds and stress are necessary in the coastal zone.

On some of the NCAR C-130 missions to the more remote ocean we plan to carry out an additional 15 minute leg in the near coastal environment (either just after take-off or just prior to landing at Arica) to measure aerosol and aerosol precursor properties.

A variety of remote-sensing and in-situ measurements of coastal ocean conditions will be made through VOCALS and in collaboration with local ocean researchers and institutions. These are expected to include HF radar measurements of surface ocean currents, and moored and ship-based sampling of sub-surface properties. These measurements are necessary in order to characterize the state and evolution of the coastal ocean and analyze its interaction with the low-level coastal atmosphere.

#### 4.3.4. San Felix Island

A suite of surface in-situ and remote sensing measurements are planned for San Felix Island during the intensive VOCALS field program.

Accumulation mode aerosols will be sampled with a PMS Lasair-2 probe which measures the total aerosol count for particles larger than 0.1  $\mu\text{m}$ . [FURTHER INTEREST FROM AEROSOL COMMUNITY?]

The Atmospheric Radiation Measurement (ARM) Mobile Facility (AMF) consists of an extended monitoring suite of surface thermodynamic and remote sensing measurements (including cloud radar and micropulse lidar) together with regular releases of upper air soundings. The aim is to deploy the AMF on San Felix Island (80°W, 27°S) for a three month period (September-November 2007) centered on the intensive field phase. This deployment will provide an unprecedented dataset from a marine subtropical stratus region free from the influence of land and anthropogenic influence. Such a meteorological regime has not been sampled before by the ARM program. The AMF measurements will provide an extremely rich context for the field measurements, and provide important opportunities to constrain the ARM-related surface retrievals of cloud microphysical properties (e.g. Dong et al. 1998) using aircraft *in-situ* measurements in clean maritime conditions. The AMF dataset will also be extremely useful to characterize the diurnal cycle of clouds and drizzle, and, through conjunction with some aerosol sampling on San Felix, to examine the role that aerosol plays in determining cloud radiative, structural and drizzle properties.

*In-situ* measurement of very low rain rates typically occurring within drizzle is difficult from shipboard because ship vibration and wind effects conspire to reduce rain gauge sensitivity to small drops. We will place a very sensitive rain measurement instrument, such as a Joss-Waldvogel disdrometer, on San Felix Island for the three month period September-November 2007 spanning the VOCALS field phase. These sensitive rain measurements will complement other atmospheric measurements and provide very important information on drizzle occurrence and rate.

## **5. VOCALS data management and archiving**

The development and maintenance of a comprehensive and accurate data archive is a critical step in meeting the scientific objectives of VOCALS. The overall guiding philosophy for the VOCALS data management is to make the datasets available to the world scientific community during the VOCALS period through a number of designated distributed VOCALS Data Archive Centers (DACs) coordinated by the UCAR/Joint Office for Science Support (JOSS). These JOSS activities fall into two major areas:

- establishment of a coordinated distributed archive system and providing data access/support of both research and operational data sets for the VOCALS PIs and the world scientific community;
- development and implementation of an on-line field catalog for the VOCALS-RF field program to provide in-field support and project summaries/updates for the Principal Investigators (PIs) and insure optimum data collection.

JOSS will make arrangements to ensure that “orphan” data sets (i.e. smaller regional and local data sources) will be archived and made available through the VOCALS archive. The JOSS may also quality control and reformat selected operational data sets (e.g. atmospheric soundings or surface data) prior to access by the community as well as prepare special products or composited data sets as determined by the VOCALS scientific requirements.

### *5.1 Data Management Working Group*

Oversight of the VOCALS data management tasks will come from a designated VOCALS Data Management Working Group (DMWG) in collaboration with the VOCALS Scientific Steering Committee, as well as coordination with participating agencies and investigators. The DMWG will have the responsibility to develop the VOCALS Data Management Plan subject to VOCALS endorsement by the U.S. CLIVAR Scientific Steering Committee. This document will: (1) describe data policies and protocol, data compilation and attribution; (2) provide details of the VOCALS data archive system and data submission/access; (3) identify the sources of observations from existing and planned networks. The DMWG will also collaborate with other VOCALS related programs such as the Monsoon Experiment South America (MESA), Variability of the American Monsoon System (VAMOS) including process field studies, and the CLIVAR Pan American Climate Studies (PACS).

## 5.2 Online Field Catalog

The JOSS will develop and maintain an Online Field Catalog that will be functional during and following the VOCALS-RF field program. This catalog will be implemented using a web-based browser interface and will be operational at the VOCALS Operations Center with a "mirror" site in Boulder, CO. Data collection information about both operational and research data sets will be entered into the system in near real time approximately one month before field operations commence. The catalog will permit data entry (data collection details, field summary notes, certain operational data etc.), updates of the status of platforms and instrumentation (on a daily basis or more), data browsing (listings, plots) and limited catalog information distribution. Daily summaries will be prepared and contain information regarding operations (aircraft flight times, major instrument systems sampling times, satellite overpasses, etc.). It is important and desirable for the PIs to contribute graphics (e.g. plots in GIF or Postscript format) and/or data into the Field Catalog for in-field instrumentation comparisons and evaluations. Preliminary data/information may be restricted to the VOCALS Operations Center access only. Public access to status information, mission summaries, and operational and selected research data sets outside of the VOCALS Operations Center will be available from the mirrored field catalog system in Boulder.

## 5.3 Data archiving and access

VOCALS will take advantage of the capabilities at existing DACs to implement a distributed data management system. This system will provide one-stop single point access using the World Wide Web for search and order of VOCALS data from DACs operated by different nationalities/agencies with the capability to transfer data sets electronically from the respective DAC to the user. Access to the data will be provided through a Data Management link available from the VOCALS homepage (<http://www.joss.ucar.edu/vocals/>). This Data Management page will contain general information on the data activities on-going in VOCALS (i.e. documents, reports), the VOCALS DMWG activities, links to related programs and projects, and direct data access via the various DACs.

The data sets residing at UCAR/JOSS will be archived and distributed through the existing JOSS Data Management System (CODIAC). CODIAC offers scientists access to research and operational data. It provides the means to identify data sets of interest, facilities to view data and associated metadata, and the ability to automatically obtain data via internet file transfer or magnetic media. The user may *browse data* to preview selected data sets prior to retrieval.

## Glossary including program websites

AMF	ARM (Atmospheric Radiation Measurement) Mobile Facility
ARGO	A global oceanic observation program, <a href="http://www-argo.ucsd.edu">www-argo.ucsd.edu</a>
AQUA	A NASA EOS multisensor satellite
ARM	Atmospheric Radiation Measurement program, <a href="http://www.arm.gov">www.arm.gov</a>
CAM	Community Atmosphere Model, <a href="http://www.cesm.ucar.edu/models/atm-cam">http://www.cesm.ucar.edu/models/atm-cam</a>
CLIVAR	Climate Variability and Predictability Program, <a href="http://www.clivar.org/index.htm">http://www.clivar.org/index.htm</a>
COAMPS	Coupled Ocean-Atmosphere Mesoscale Prediction System, <a href="http://www.nrlmry.navy.mil/coamps-web/web/home">www.nrlmry.navy.mil/coamps-web/web/home</a>
CPPS	Comision Permanente del Pacifico Sur
CTB	NOAA Climate Test Bed Initiative, <a href="http://www.cpc.ncep.noaa.gov/products/ctb/">www.cpc.ncep.noaa.gov/products/ctb/</a>
DHARMA	Distributed hydrodynamic aerosol and radiation model application.
ECMWF	European Center for Medium Range Weather Forecasting, <a href="http://www.ecmwf.int">www.ecmwf.int</a>
GOES	Geostationary Orbiting Environmental Satellite.
IPRC	International Pacific Research Center, <a href="http://iprc.soest.hawaii.edu">http://iprc.soest.hawaii.edu</a>
ISCCP	International Satellite Cloud Climatology Project, <a href="http://isccp.giss.nasa.gov">http://isccp.giss.nasa.gov</a>
JOSS	NCAR Joint Office of Science Support, <a href="http://www.ofps.ucar.edu">www.ofps.ucar.edu</a>
LWP	Liquid water path
MODIS	Moderate Resolution Imaging Spectroradiometer, <a href="http://modis.gsfc.nasa.gov">http://modis.gsfc.nasa.gov</a>
NCAR	National Center for Atmospheric Research, <a href="http://www.ncar.ucar.edu">www.ncar.ucar.edu</a>
NCEP	National Centers for Environmental Prediction, <a href="http://www.ncep.noaa.gov">www.ncep.noaa.gov</a>
OSU	Oregon State University
ROMS	Regional Ocean Modeling System, <a href="http://marine.rutgers.edu/po/">http://marine.rutgers.edu/po/</a>
SCAM	Single Column version of the Community Atmosphere Model
SOLAS	Surface Ocean Lower Atmosphere Study, <a href="http://www.aoml.noaa.gov/ocd/solas/">www.aoml.noaa.gov/ocd/solas/</a>
SST	Sea surface temperature
TAO	Tropical Atmosphere Ocean Project, <a href="http://www.pmel.noaa.gov/tao/">www.pmel.noaa.gov/tao/</a>
UCLA	University of California Los Angeles
UW	University of Washington
VAMOS	Variability of the American MONsoonS, <a href="http://www.clivar.org/organization/vamos/">http://www.clivar.org/organization/vamos/</a>
VOCALS	VAMOS Ocean-Cloud-Atmosphere-Land Study

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