C-130 Instruments

The NSF C-130 aircraft instrument payload for VOCALS-REx is given in Table 1. A total of 90 hours research time is requested for the C-130 to make approximately 10 flights of 9 hours duration. Preliminary costs estimates have been provided by NCAR Earth Observing Laboratory (EOL). The C-130 will be based either in Arica (18°S, 70°W) or Iquique (20°S, 70°W).

The C-130 will be equipped with the full range of *in-situ* meteorological, turbulence, and microphysical probes, and a dropsonde system will be used to give the large-scale meteorological context. A scanning backscatter lidar (SABL) will be used in vertically-pointing mode (both up and down) to detect cloud boundaries. The 95 GHz (W-band) Doppler polarization Wyoming Cloud Radar (WCR) will be used above cloud as depicted in Fig. 3 to detect the structural and kinematic structure of drizzle within and below stratocumulus clouds using dual antennas to carry out dual doppler analysis and obtain horizontal wind components along the flight direction. This configuration was employed successfully in the Dynamics and Chemistry of Marine Stratocumulus (DYCOMS-II) campaign in 2001.

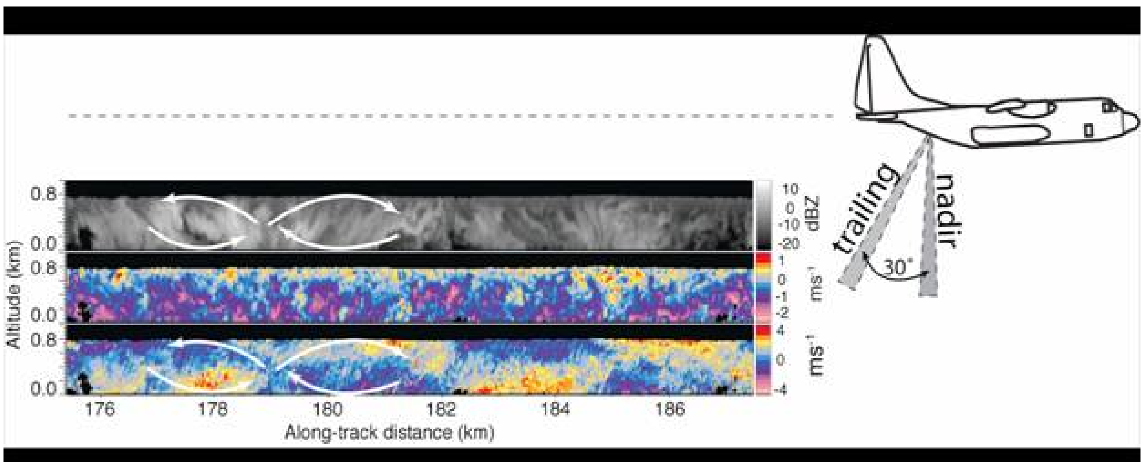


Figure 3: Proposed WCR configuration on the C-130 during VOCALS-REx. Three derived fields are shown (reflectivity, vertical Doppler velocity, and horizontal winds).

A comprehensive chemistry and aerosol sampling suite will be carried on the C-130. This includes atmospheric pressure ionization mass spectrometry (APIMS) measurements of sulfur dioxide and dimethylsulfide (DMS), condensation nuclei (CN) and cloud condensation nuclei (CCN) counters, tandem differential mobility analyzer (DMA) aerosol size distributions and humidity growth factors for particles from 5-500 nm in diameter, scattering nephelometer measurements, and cascade impactor size-resolved aerosol chemical speciation. The suite is a slightly reduced version of that employed during ACE-ASIA. See Table 2 in Section I of the SPO (included at the end of this document) for a complete list of the proposed instrumentation in the C-130 chemistry and aerosol suite.

Passive remote sensing measurements will be made with high spatial resolution using NCAR's Multichannel Radiometer (MCR) and Advanced Imaging Microwave Radiometer (AIMR). These instruments will provide the measurements of cloud liquid water path, optical depth, and the effective radius of cloud droplets necessary to quantify how cloud microphysical properties affect the optical and structural properties of low clouds over the SEP.

Table 1: NSF C-130 aircraft instrument requirements

Instrument	Observations	Funding source	Contact
Wyoming Cloud Radar (WCR)	Cloud and precipitation structure, dynamics of precipitating systems	NSF Deployment pool	Leon (University of Wyoming)
FSSP, 2D-C, 260X, PCASP Gust probe, temperature and humidity sensors	Cloud microphysics, thermodynamics, turbulence, dynamics	NSF Deployment pool	NCAR RAL (standard instrument suite)
Dropsondes (15 per flight)	Lower tropospheric and boundary layer structure	NSF Deployment pool	NCAR RAL
Scanning Aerosol Backscatter Lidar (SABL)	Cloud top and base height	NSF-Clim	NCAR RAL
APIMS (Atmospheric Pressure Ionization Mass Spectrometry)	SO2 and DMS high frequency gas phase measurements	NSF-Chem (SOLAS)	Bandy, Thornton (Drexel University)
CCN Spectrometer	Cloud condensation nuclei	NSF-Clim	Snider (University of Wyoming)
Aerosol physicochemical measurement suite	Aerosol number concentration, size distribution, chemical composition, optical properties	NSF-Chem (SOLAS)	Howell and Huebert (University of Hawaii)
Multi Channel Radiometer (MCR)	Passive remote sensing of cloud effective radius and optical depth	NSF Deployment pool	Tschudi (NCAR EOL)
Airborne Imaging Microwave Radiometer (AIMR) [37 and 90 GHz]	Passive remote sensing of cloud liquid water path	NSF Deployment pool	Haggerty (NCAR EOL)

NOAA R/V Ronald H Brown instruments

The R/V Ronald H Brown (RHB) instrument payload is given in Table 2. The RHB has already been requested as part of NOAA CPPA proposal by Chris Fairall at NOAA ESRL. A total of 45 days have been requested, of which approximately 35 during the entire month of October will constitute the intensive observational phase of VOCALS-REx. The C-130 and RHB deployments will be fully overlapped in time to maximize the synergy between the two platforms.

The RHB will be equipped with a set of cloud remote sensing instrumentation which will sample almost continuously throughout the cruise. A vertically-pointing stabilized 35 GHz sensitive millimeter radar will provide high vertical resolution (≈20 m) reflectivity profiles along with doppler spectral information for the determination of the size distribution of falling drizzle drops and from this the precipitation rate. A three-channel (20.6, 31.6 and 90 GHz) microwave radiometer will be used to determine the cloud liquid water path, and a Vaisala CT-25K ceilometer will provide measurements of cloud base and the surface area of drizzle drops.

A scanning C-band (5 cm wavelength) precipitation radar with a sensitivity of -12 dBZ will be used to determine horizontal and vertical structure, kinematics and evolution of the precipitation field within a 30 km radius of the ship (Fig 4). The C-band beamwidth is better than 500 m within 30 km of the ship, and the antenna is electronically stabilized to remove ship motion. There is negligible attenuation within drizzling stratocumulus. These measurements have also been invaluable in providing the first accurate determination of the statistical properties of precipitation in marine stratocumulus. A scanning strategy similar to that carried out in EPIC 2001 will be used in VOCALS-REx.

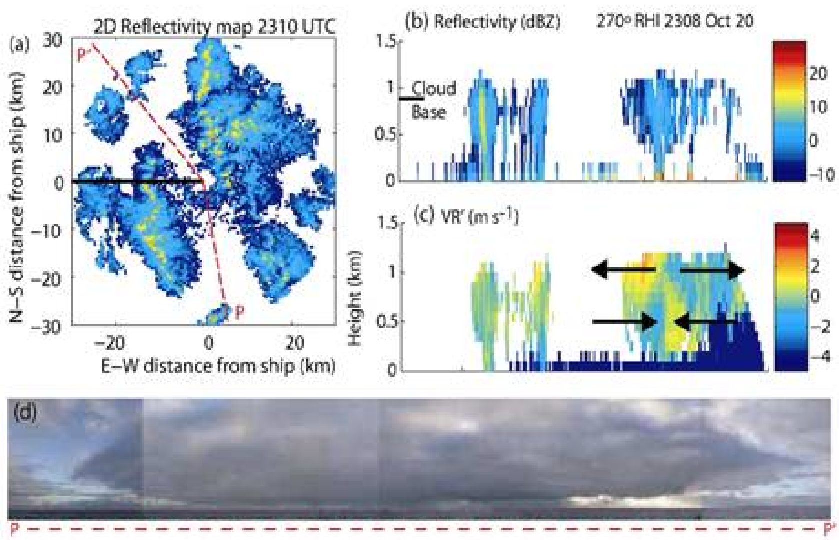
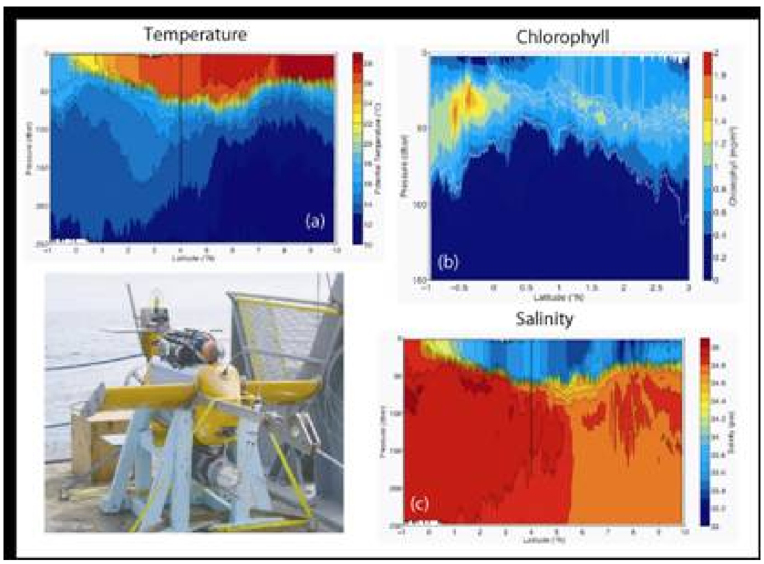


Figure 4: Example of C-band capability for observation of drizzle cells in stratocumulus cloud. (a) horizontal reflectivity map showing cellularity; (b,c) RHI scans showing vertical cross sections (along solid line in marked in (a)) detailing the structure and kinematics of the inflow and outflow regions of the mesoscale cell pictured in the photograph composite between P and P'.

The RHB will also carry an extensive suite of in situ aerosol instruments, with which to record a time-series of aerosol physical and chemical properties. These will include integrated measurements of bulk and size-distributed aerosol chemistry as well as physical size distributions and light scattering and absorption. We hope to also have a single-particle aerosol mass spectrometer aboard, with which to look at issues such as the presence of organic carbon and halogens in small sulfate aerosols. These will all be focused on aerosol indirect forcing of climate: what controls the nucleation of new particles and their growth into the CCN size range? Since most of the aerosol growth is expected to be via sulfate condensation, we will also measure ozone and the gas-phase precursors DMS and SO_2. The latter two will be measured by APIMS-ILS, so that we can constrain the MBL sulfur budget by measuring their surface fluxes throughout the cruise via eddy correlation. Rapid measurements of sea water DMS will allow us to derive gas exchange velocities from the DMS fluxes. It is also planned to make remotely sensed aerosol measurements from the RHB using an aerosol lidar operated by NOAA ESRL. See Table 3 in Section I of the SPO (included at the end of this document) for a complete list of the proposed instrumentation in the RHB chemistry and aerosol suite.

Measurements in the upper 300 m of the ocean will be made using the SeaSoar platform (Pollard 1986) towed behind the RHB (Fig. 5), which will be equipped with a range of instrumentation including a SBE 9/11 CTD temperature, conductivity and pressure sensor, a dissolved oxygen sensor, and a fluorometer to measure chlorophyll content. The optical properties of sea water will be used to infer phytoplankton types and determine the radiative heating rates within the water column. These will be measured at nine wavelengths within the visible band using a WetLabs AC9+ spectrometer attached to the top of the Seasoar. Dissolved nitrate (NO3) concentration will be measured using a Satlantic ISUS NO3 sensor mounted to the underside of the Seasoar. The ISUS-NO3 will be calibrated against bottle sampled NO_3 measurements at various locations.



The horizontal current velocity, which cannot be measured using the SeaSoar will be measured at a range of depths using an Acoustic Doppler Current Profiler (ADCP) mounted on the RHB to examine mesoscale flow variability. Characterization of the mesoscale variability of the upper ocean will also be complemented with measurements from closely-spaced XBTs, surface drifters, thermistor chains, and sea water DMS measurements.

Complementary additional oceanographic measurements from the RHB, that are desirable, but not an absolutely essential component of the VOCALS-REx strategy include the deployment of SkinDeEP (Skin Depth Experimental Profilers) that capture the very near-surface thermal structure to a depth of 6 meters. These profilers provide data necessary to examine, with high vertical resolution, the vertical structure and physical processes associated with the response of the ocean surface to atmospheric forcing including penetrating solar radiation and the heat loss due to evaporation, sensible heat transfer, and infrared radiation at the skin of the ocean. A second set of additional instruments that would yield important information on the microstructure and turbulent mixing in the upper ocean, and particularly the ocean mixed layer are the Absolute Velocity Profiler (AVP) and the Modular Microstructure Profilers (MMP) of the University of Washington/Applied Physics Laboratory. These would provide microscale velocity, temperature, conductivity, and pressure, permitting estimates to be made of the dissipation rate of turbulent kinetic energy and the diapycnal diffusivity.

Figure 5: SeaSoar (bottom left) and examples of observational datasets collected during EPIC 2001 (photograph and figures courtesy of Jack Barth and Hemantha Wijesekera)

Table 2: NOAA R/V Ronald H Brown instrument requirements

Instrument	Observations	Funding source	Contact
Scanning C-band radar	Horizontal and vertical precipitation structure and dynamics within 30 km of the ship	NOAA CPPA and NSF-Clim	Yuter (North Carolina State University) /Fairall (NOAA ESRL)
Vertically pointing 35 GHz cloud radar	Cloud and precipitation vertical structure	NOAA CPPA	Fairall (NOAA ESRL)
Vaisala Ceilometer	Cloud base height, drizzle drop surface area	NOAA CPPA	Fairall (NOAA ESRL)
Rawinsondes (4 per day, 8 during special periods)	Tropospheric thermodynamic and wind profiles	NOAA CPPA	Fairall (NOAA ESRL)
Microwave radiometer (MWR)	Cloud liquid water path, water vapor path	NOAA CPPA	Fairall (NOAA ESRL)
Surface meteorological tower, turbulent flux suite, sea-snake	Ocean surface physics, surface meteorology and turbulent fluxes	NOAA CPPA	Fairall (NOAA ESRL)
Aerosol lidar	Backscatter profiles for aerosol characterization, depolarization ratio	NOAA CPPA	Fairall (NOAA ESRL)
APIMS (Atmospheric Pressure Ionization Mass Spectrometry)	Atmospheric DMS, surface DMS fluxes through eddy correlation	NSF-Chem, SOLAS (already funded)	Huebert and Blomquist (University of Hawaii)
Aerosol physicochemical measurement suite	Aerosol number concentration, size distribution, chemical composition, optical properties	NSF-Chem (SOLAS)	Howell and Huebert (University of Hawaii) or Don Collins (Texas A&M)
Sea Soar	Upper ocean horizontal and vertical structure, oxygen, nitrate, radiative properties, mesoscale ocean eddy structure	NSF-OCE	Wijesekera (Oregon State University)
XBT (200 requested)	Ocean temperature and salinity profiles	NOAA-CPPA	Weller (Woods Hole OI)

Ocean near-surface profiler	High spatial resolution upper ocean profiles	NSF-OCE	Ward (????)

NOAA P3 Instruments

The participation of the NOAA P3 aircraft in VOCALS-REx would add important additional information and characterization of the cloud microphysics, aerosols, and cloud radiative properties. It should be made clear that at this time, although the P3 platform is desirable, it is unclear whether resources and scheduling will permit its participation in VOCALS-REx. We therefore consider that the instrument suite outlined in Table 3 for the P3 during the field program is at an early stage of planning, and may be subject to considerable change.

The P3 will most likely be based at the same location as the C-130, either in Arica (18°S, 70°W) or Iquique (20°S, 70°W). Ideally, the P3 will carry a complete set of cloud microphysical probes, thermodynamic and turbulence measurements, and a set of instrumentation to measure aerosol physicochemical properties. A microwave radiometer, broadband radiative fluxes, and the Miniaturized Differential Absorption Spectrometer (MIDAS) would play important roles in examining the indirect effects of aerosols upon cloud radiative properties by characterizing the cloud liquid water path and droplet effective radius remotely.

Table 3: NOAA P3 instrument requirements

Instrument	**Observations**	**Funding source**	**Contact**
Cloud microphysical suite, dynamics and thermodynamics	FSSP, 2D-C, 260X, PCASP Gust probe, temperature and humidity sensors	NOAA aero-cloud	Feingold (NOAA ESRL)
Microwave radiometer (MWR)	Liquid water path	NOAA aero-cloud	Feingold
Miniaturized differential absorption spectrometer (MIDAS)	Liquid water path, cloud droplet effective radius	NOAA aero-cloud	Solomon (NOAA ESRL)
Aerosol physicochemical suite	Aerosol size distributions	NOAA aero-cloud	Possibly Brock and Middlebrook (NOAA)
Broadband radiative fluxes	Cloud optical depth	NOAA aero-cloud	Feingold

SeaScan Instruments

It is proposed to deploy small SeaScan Unmanned Aeronautical Vehicles (UAVs) during VOCALS-REx to provide additional information on the vertical and horizontal structure of the marine boundary layer. The SeaScan UAVs are manufactured by the Insitu Group (www.insitugroup.com), have an endurance of 15 hours, a speed of 25 m s^{-1}, a lowest altitude of 30 m, and a ceiling of ~5 km. A 1200 km round-trip mission will be possible, which allows the SeaScan to reach and sample POCs several hundred km from the Chilean coast. The SeaScan will be based, and be launched, from a site close to the C-130. The SeaScan carries a digital video camera integrated into an inertially-stabilized pan/tilt nose turret, and a set of meteorological measurements including winds, pressure, temperature, and humidity. Possible additions to the SeaScan payload could include a turbulence measurements and a liquid water probe.

Chilean coastal component platforms and instrumentation

A comprehensive near-coastal sampling strategy is planned for October 2007, which includes atmospheric thermodynamic and dynamic measurements with a light aircraft (Chilean AirForce Twin Otter), a Chilean Servicio Hidrográfico y Oceanográfico de la Armada de Chile (SHOA) research vessel, an elevated land site at a site, El Tofo, on the Chilean coastal range to measure cloud and aerosol microphysical properties, and enhanced meteorological observations at sites along the Chilean seaboard. Funding for most of these activities will be requested from FONDECYT, the Chilean science funding agency, with support from the Chilean Airforce (Twin Otter). Table 4 provides details of the instrumentation for this component of VOCALS-REx.

Table 4: Chilean VOCALS-REx coastal component platforms and instrumentation

Platform	Instruments	Observations	Contact
Chilean Airforce Twin Otter aircraft	AIMMS20 AQ instrument suite	Temperature, humidity, winds, turbulence	Gallardo (Universidad de Chile)
SHOA R/V Atmosphere	Radiosondes, surface meteorological package, NOAA wind profiler	MBL structure and dynamics	Rutllant/Garreaud (Universidad de Chile)
SHOA R/V Ocean	CTD-O, ADCP and thermo-salinograph, water sampling	Upper ocean physical and chemical structure	Pizarro (Universidad de Concepcion)
El Tofo (land site)	Counterflow virtual impactor (CVI), bulk filter measurements, Differential mobility analyzer (DMA)	Cloud and aerosol size distribution and chemical properties, cloud droplet residual properties	Gallardo (Universidad de Chile) and Krejci (MISU, Sweden)
Modeling	PSU/NCAR MM5 regional atmospheric model	MBL/coastal jet structure and variability, diurnal subsidence wave generation	Garreaud (Universidad de Chile)

Peruvian coastal component platforms and instrumentation

As part of the international contribution to VOCALS-REx, a group of Peruvian researchers are proposing a set of enhanced atmospheric measurements and an oceanographic/atmospheric coastal cruise with the Peruvian research vessel. The suite of measurements is given in Table 5. The primary contribution to VOCALS-REx will consist of a 30 day cruise organized by the Instituto del Mar del Perú (IMARPE) to sample oceanography and meteorology along the Peruvian coastal zone from 4-18°S. It is also planned to request the NSF Deployment Pool 915 MHz wind profiler and Radio Acoustic Sounding System (RASS) on the cruise which to provide high time resolution profiling observations of the horizontal wind and virtual temperature in the marine boundary layer and lower free troposphere. The wind profiler is also sensitive to precipitation-sized hydrometeors in low clouds, and will be used to characterize the occurrence of drizzle falling from the near-coastal stratocumulus clouds.

Table 5: Peruvian VOCALS-REx coastal component platforms and instrumentation

Platform	Instruments	Observations	Contact
IMARPE R/V	Surface meteorological suite, wind profiler, 6 hourly radiosondes, CTD ocean profiling, Acoustic Doppler Current Profiler (ADCP)	Surface meteorology, SST, bulk fluxes, MBL wind and turbulence profiles, tropospheric structure Upper ocean currents, temperature and salinity profiles	Silva Instituto del Mar del Perú (IMARPE)
	NSF Deployment Pool 915 MHz wind profiler, radio acoustic sounding system (RASS)	Horizontal and vertical winds, turbulence, virtual temperature profiles	Takahashi/Wood (University of Washington)
Enhanced met sites	Tethered balloon, automatic weather stations	MBL structure and dynamics along the Peruvian costal zone	Takahashi (University of Washington)

Platform deployment and sampling strategy

The VOCALS-REx hypotheses presented above will be tested using carefully designed platform deployment strategies. Table 6 provides a quick-look summary of how the different platforms and components discussed above will contribute to the testing of these hypotheses, with further discussion of the scientific issues and a description of the testing strategy provided in the Scientific Program Overview document. Here we describe the specific sampling patterns, including cruise tracks, flights plans, and coordinated inter-platform activities.

C-130 sampling strategy

Two distinct primary C-130 flight plans will provide the range of sampling necessary to address the VOCALS-REx hypotheses. In addition, subsections of the flights will be used to carry out coordinated sampling with the RHB and/or the NOAA

P3 aircraft, and the C-130 will make some survey flight legs along the Chilean coast to sample the pollutant outflow at the start and/or end of the primary missions. The two primary flight plans are (a) *Cross-section missions* along the 20°S latitude from the coast to either the RHB or the IMET buoy at 85°W; (b) *POCs-drift missions* which target either existing pockets of open cells (POCs) within overcast stratocumulus, or areas prone to POC development, and track these as they advect with the flow. Additional flight plans are described at the end of this section.

(a) *Cross-section missions* (Fig. 6): These flights are designed to sample contrasts in MBL thermodynamics, chemistry, aerosols and clouds between the South American coast and that in the remote SEP. Specific focus will be placed on good sampling 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). These flight are also extremely useful for airborne 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 general idea is to fly from the coast to either the IMET buoy (85W, 20S) or the RHB (which will carry out its pattern moving progressively further away from the coast over 35 days as described below). 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^{-1}. An exact specification of the levels used and the leg-duration will be dependent upon the needs of the key participants. The above cloud runs will be used to sample the drizzle, cloud, and MBL structure using the WCR and SABL lidar, to characterize the free-tropospheric chemistry, aerosol and thermodynamic structure, and to use the MCR and AIMR radiometers to remotely sense the cloud bulk and microphysical properties. Below cloud runs will aim to determine physicochemical properties of aerosols, and to determine lower boundary conditions (SST, surface thermodynamic and DMS 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, this type of flight pattern may be flown in the day or 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.

An important component of the cross-section missions is to devote a portion of the flight (typically at least one hour) to coincident sampling with the RHB. These coordinated sections will serve as a means of comparing the accuracies of the instruments (particularly aircraft aerosol sampling and SST estimates) and will provide important *in-situ* context to remotely sampled cloud and drizzle properties from the RHB. In addition, these sections will be invaluable in helping to determine, using a combination of C-130 and C-band radar measurements, the dynamical structures and mesoscale organization associated with POCs and mesoscale drizzle cells in general. Planned coordinated flight sections are described in plan (d) below.

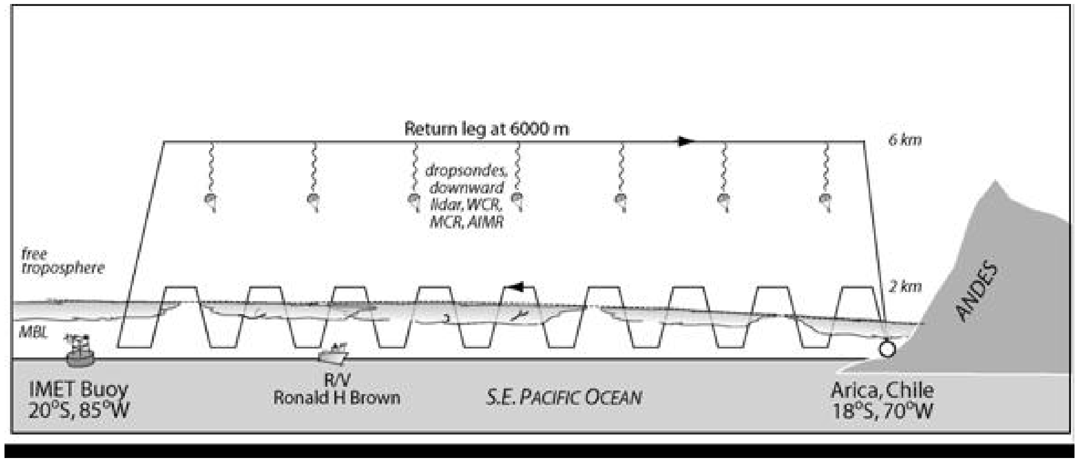


Figure 6: Flight-plan for C-130 Cross-section missions.

(b) *POC drift missions* (Fig. 7): 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 broader boundaries between open and closed cellular convection may also be a focus of these missions. Of particular importance will be a characterization of the aerosol and cloud microphysical properties in the two regions. If possible, these flights will be coordinated with the RHB, whose scanning C-band radar will provide the mesoscale context for the C-130 data, as well as aerosol and cloud characterization within the POC region. The idea is to use geostationary satellite imagery to locate POCs or regions prone to POC formation (using cloud microphysical retrievals to location regions of unbroken but clean clouds), 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 approximately 100 km in length 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) to provide Lagrangian-type measurements of the temporal evolution of the POC. Efforts will be made to sample the same POC on two C-130 flights, or to fly in a POC region that will ultimately advect over the ship.

The SeaScan UAV will also be used both in conjunction with C-130 flights and on standalone missions to determine POC thermodynamic structure. When used in conjunction with the C-130, it is hoped that the SeaScan will permit Lagrangian continuity during the daytime between two C-130 night flights in and around the same POC. The excellent video capability on the SeaScan will be used to determine the boundary between the POC and the surrounding overcast stratocumulus: profiles and horizontal sampling legs with the SeaScan will be devised accordingly.

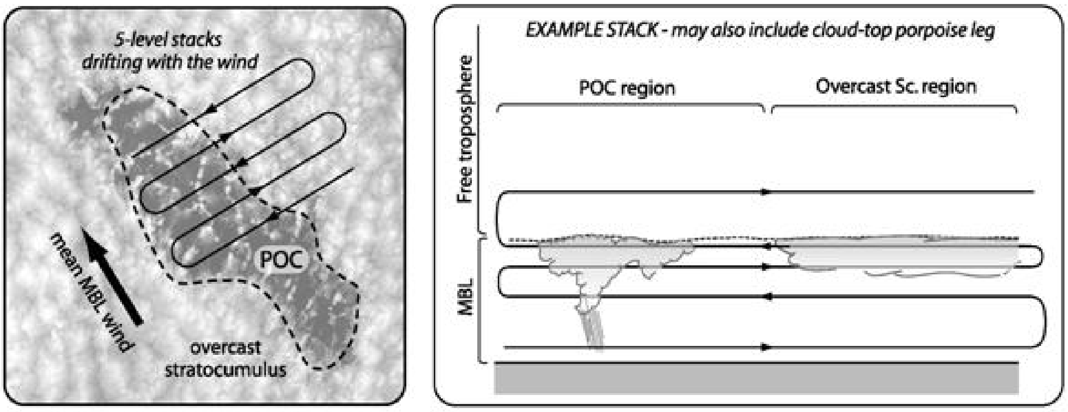


Figure 7: Lagrangian-type C-130 flight plan for POCs-drift missions.

(c) *Coordinated flights with other platforms*: There will be opportunities during VOCALS-REx for periods where the capabilities of the C-130 can be enhanced by coordinated flights in conjunction with the RHB and/or the P3 aircraft. For periods during the cross-section and/or POCS-drift missions we envisage periods of approximately 2 hours where the platform sampling strategies can be synchronized.

For the C-130/RHB combination, the goals will be (i) to intercompare ship and aircraft aerosol measurements in the subcloud region; (ii) to study the structure and dynamics of the drizzle cells using collocated C-130 data and C-band radar data. The C-130 will collect in-situ data from drizzling cells in a direction perpendicular to and parallel to the alongwind RHI scan line (see below for details of the C-band radar scan strategy). These data would be used to improve our conceptual model of the physical processes taking place in the transition from closed to open cells by providing quantitative measurement of the mesoscale cell structure.

For the C-130/P3 combination, the goal will be to first obtain simultaneous measurements of the cloud microphysical properties and the subcloud aerosol properties, and then to simultaneously sample cloud and drizzle microphysics with the P3 while remotely sensing the cloud from above with the MCR, AIMR and WCR. These measurements constitute important tests of the aerosol first and second indirect effects.

(d) *Coastal aerosol survey legs:* When time permits at the start or end of flights, we hope to carry out 2-3 legs and vertical profiles in a roughly north-south direction along the Chilean coast at different altitudes to sample the chemical and aerosol characteristics of the airmass advecting from Northern Chile over the SEP. A vertical profile up to 6000 m will be carried out to identify elevated pollution layers (these have been observed using spaceborne lidars and reflect the elevations of copper smelters on the west Andean slopes). These will then be sampled using horizontal legs. If interesting horizontal structure is observed, these legs can be extended southwards to sample plume variability. The SABL lidar will also be used to characterize the elevated layers remotely.

Table 6a: Contribution of different observational platforms to testing of Aerosol-Cloud-Drizzle hypotheses

Hypothesis	NSF C-130	NOAA RHB	NOAA P3	El. Tofo
1a: *Variability in the physicochemical properties of aerosols has a measurable impact upon the formation of drizzle in stratocumulus clouds over the SEP.*	In-situ aerosol, cloud and drizzle microphysical measurements from cross-section and POCs-drift flight patterns WCR drizzle rate estimates	Near-continuous aerosol sampling over 35 day period at a range of distances from the coast Cloud and drizzle remote sensing	Aerosol and cloud microphysical measurements	Chemistry of aerosols and cloud droplet residuals at continental outflow site
1b:*Precipitation is a necessary condition for the formation of pockets of open cells (POCs) within stratocumulus clouds.*	Detailed Lagrangian observations of the evolving cloud and precipitation structure within POCs	Simultaneous observations of precipitation and cloud structure as POCs advect over the ship.	Sampling of the aerosol and cloud properties in POCs and surrounding cloud	N/A
	C-130 and/or P3 flights coordinated with RHB C-band radar to observe mesoscale dynamics of drizzle cells			
1c*: The small effective radii measured from space over the SEP are primarily controlled by anthropogenic, rather than natural, aerosol production, and that entrainment of polluted air from the lower free-troposphere is an important source of cloud condensation nuclei (CCN).*	DMS and SO_2 chemistry, aerosol chemical composition, cloud microphysical measurements, MCR/AIMR remote sensing Entrainment fluxes of aerosols and precursors using DMS/turbulence measurements	DMS and SO_2 chemistry, aerosol chemical composition, remotely sensed cloud microphysics during daytime	Aerosol chemical composition, horizontal gradients in cloud microphysics	Cloud microphysical measurements and aerosol source attribution
1d*: Depletion of aerosols by coalescence scavenging is a major sink term for cloud condensation nuclei over the SEP.*	WCR precipitation and Lagrangian-type sampling of evolving aerosol population. Eddy correlation aerosol and cloud droplet flux measurements to close CCN budget	Simultaneous in-situ aerosol and C-band precipitation estimates	N/A	N/A

Table 6b: Contribution of different platforms to testing of Coupled Ocean-Atmosphere-Land hypotheses

Hypothesis	C-130	RHB	Chilean	Peruvian

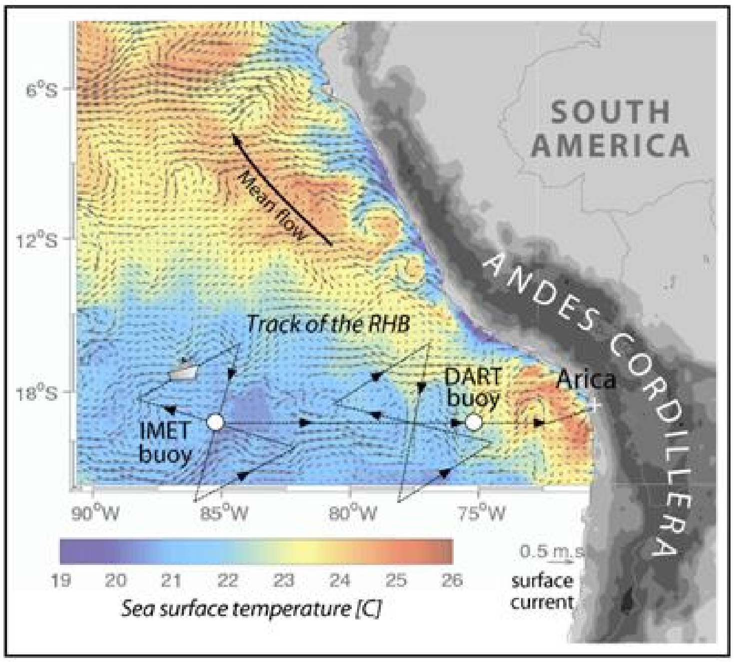
			coastal	**coastal**
2a: Oceanic mesoscale eddies play a major role in the transport of heat and fresh water from coastally upwelled water to regions further offshore.	N/A	Upper ocean butterfly pattern sampling with SeaSoar, ADCP, XBTs	Upper ocean spatial sampling in eddy-generation zone	Upper ocean spatial sampling in eddy-generation zone
2b*: Upwelling, by changing the physical and chemical properties of the upper ocean, has a systematic and noticeable effect on aerosol precursor gases and the aerosol size distribution in the MBL over the SEP.*	Atmospheric DMS/SO_2 measurements, mesoscale variability in SST, surface DMS fluxes, and aerosol physicochemical properties	Surface DMS fluxes. Simultaneous measurement of mesoscale ocean eddies, nutrients, DMS, and aerosols	Contextual information on the variability and strength of coastal upwelling	Contextual information on the variability and strength of coastal upwelling
	VOCALS modeling will be used to test aspects of this hypothesis by incorporating the relevant physical and chemical processes into the modeling framework.			
2c*: The depth, phase speed, and vertical structure of the diurnal subsidence wave ("upsidence wave") originating on the Andes slopes in northern Chile/southern Peru is well predicted using regional model simulations.*	Atmospheric structure in the vertical plane along wave propagation direction from cross-section flights at different phases of the diurnal cycle	Continuous sampling of lower troposphere (rawinsondes, clouds, surface meteorology) over several days along 20°S latitude at 77.5°W and 85°W	Diurnal sampling of winds and free-tropospheric structure using R/V in near-coastal region	Diurnal sampling of winds and free-tropospheric structure using R/V in near-coastal region

Table 6c: Contribution of different platforms to evaluation of satellite cloud remote sensing issues

	NSF C-130	**NOAA RHB**	**NOAA P3**
Can satellite estimates of stratocumulus cloud microphysical properties (e.g. effective radius or cloud droplet number concentration from MODIS) and precipitation (from CloudSat or MODIS) be refined to perform in a satisfactory manner even under conditions of broken cloudiness on the pixel scale?	Airborne remote sensing at similar wavelengths to satellite instruments but at much higher spatial resolution. Near coincident in-situ cloud microphysical and drizzle measurements for validation	Continuous remotely sensed cloud and precipitation measurements for direct satellite evaluation	Airborne microwave and broadband fluxes with near coincident in-situ cloud microphysical and measurements for validation
	Coordinated stacked C-130 and P3 flights over the ship for simultaneous *in-situ* cloud microphysics and remote sensing from above (C-130) and below (P3 and RHB) cloud Flights coordinated with satellite overpasses where possible		

RHB deployment strategy

The RHB will provide critical oceanographic and atmospheric measurements in VOCALS-REx. The RHB cruise track is shown in Fig. 8 and consists of a 35 day period on task (with approximately 10 days of transit for a total of 45 days requested). The deployment strategy consists of two stationary extended measurement periods of 6 days each at 20°S, 85°W and at 20°S, 75°W (where maintenance work will be carried out on the instrumented IMET and SHOA buoys). Continuous sampling of DMS and SO_2, aerosols, meteorology, vertical atmospheric structure, and remotely sensed cloud and drizzle properties will take place during the stationary periods. In addition to the stationary periods, the RHB will carry out two ocean mesoscale survey butterfly patterns 500 km on a side at a speed of 8 kts. The butterfly patterns, centered on the IMET buoy at 20°S, 85°W and on 20°S, 77.5°W respectively, will be used to sample the mesoscale structure of the upper ocean including obtaining high vertical and horizontal resolution sampling of the upper 100 m of ocean using the SeaSoar vertical profiler towed behind the RHB. The total duration for each butterfly pattern is approximately 7 days. The butterfly patterns are a larger version of those used to effectively and efficiently sample mesoscale variability and eddy structure in the upper ocean during the Intertropical Convergence Zone component of the East Pacific Investigation of Climate field program in 2001.



Atmospheric measurements will be made continuously during the butterfly patterns, but caution will be taken to screen the data for times when the ship exhaust could be sampled by the chemical and aerosols instrumentation. The orientation of the butterfly patterns is chosen to provide legs in the across and downwind directions (these are also parallel and perpendicular to the direction of the mean surface currents). Because the cloud and drizzle structures advect with the mean wind (typically 6-10 m s^{-1} from the ESE), their evolution can only be tracked for roughly 1.5-2 hours with the C-band radar on a stationary ship. The downwind legs therefore allow us to track drizzling cells for almost twice as long (3-4 hours) which will provide important information on the their evolution and longevity. Another advantage of the chosen butterfly orientation is that the combination of the mesoscale butterfly surveys centered on 77.5°W and 85°W will result in an almost complete longitudinal upper ocean cross section from 87.5°W to the Chilean coast.

Figure 8: Track of the RHB overlaid on SST and surface current field from a regional eddy-resolving ocean model (ROMS, figure from Penven et al. J. Geophys. Res., ***110****, 10.1029/2005JC002945, 2005).*

C-Band radar scan strategy: Because a key focus of VOCALS-REx is to quantify, and determine the structural properties of precipitation in and below stratocumulus, it is important to design an efficient scan strategy for the C-band radar on the RHB. As in the 2001 East Pacific Investigation of Climate (EPIC) cruise, the C-band radar will conduct (a) volumetric scans at intervals of 5 minutes using PPIs at different elevation angles to build up a 3-dimensional volume over a 60 km diameter region centered on the ship; (b) vertical cross sections at a fixed azimuth angle using (range-height indicators, RHIs) for improved sampling of the vertical structure of the precipitating cells. Sector scans using a number of RHIs taken over a narrow range of azimuth angles may also be used during periods where the C-130 is making measurements around the RHB. These will provide high vertical resolution sampling of a few drizzle cells where the C-130 is making simultaneous, collocated in-situ measurements. The combination of the two platforms sampling the same drizzle cells will provide an unprecedented dataset on the structure and kinematics of drizzling stratocumulus.

Ocean mesoscale survey sampling strategy: The mesoscale survey will use a combination of the SeaSoar to provide multivariable sawtooth-pattern (series of slanted profiles) sampling which will capture sharp horizontal gradients associated with the mesoscale eddies. XBTs will measure temperature only, but these will provide truly vertical profiles with a vertical resolution higher than that of the SeaSoar approximately every 50 km along the butterfly pattern. The ADCP will be used to provide vertical profiles of the current velocity continuously which are corrected for ship motion using a sophisticated Ashtech GPS system. The ADCP data will be used in conjunction with both the SeaSoar and the XBT data to examine the advective term in the upper ocean heat budget, and also to look for vertical shears associated with propagating waves and mixing.

NOAA P3 sampling strategy

The P3 will primarily be used to sample aerosols and cloud microphysical properties during VOCALS-REx. Satellite data and forecast fields from numerical models will be used to plan flights, and these plans chiefly aim to sample strong gradients in cloud microphysical properties in regions where there are only weak or no corresponding gradients in the large scale meteorology, to ascertain the potential strengths of the aerosol indirect effects upon the cloud radiative properties. As with the C-130 the P3 is expected to have capability for making remote sensing measurements, and so flight legs will be carried out below, in, and above cloud. Coordinated flights with both the C-130 and the RHB are also envisaged (See C-130 flight plan (c) above).

VOCALS-REx Coastal component sampling

The near coastal oceanographic and atmospheric sampling during VOCALS-REx, including measurements from land sites, will largely be carried out by research groups from Chile and Peru, augmented with NSF C-130 and possibly NOAA P3 flight legs specifically devoted to chemistry and aerosol sampling along the Chilean coast. An overview of the Chilean observational capabilities is presented in Fig. 9, while the track of the Peruvian coastal ocean/atmosphere research cruise is shown in Fig. 10.

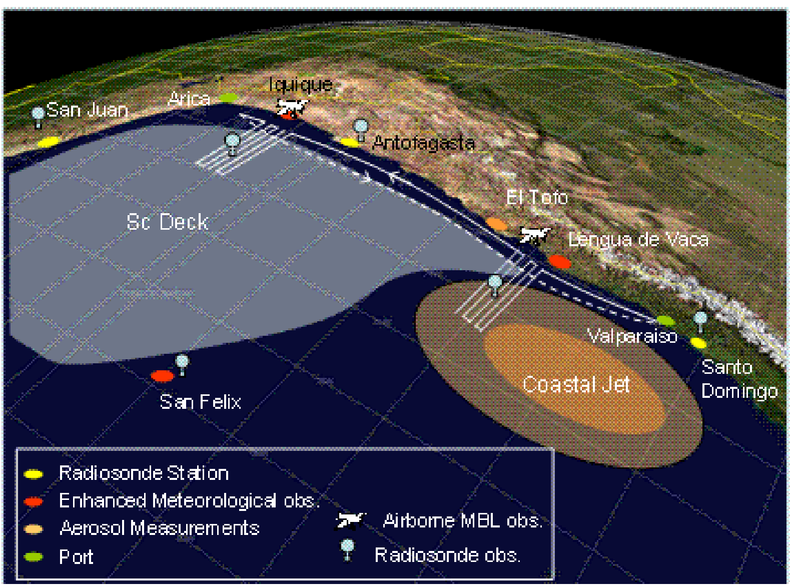


Figure 9: Observational capabilities of the Chilean component of the VOCALS-REx field campaign.

The oceanographic aims of the VOCALS-REx coastal component are to improve our understanding of the structure and spatial variability of the Humboldt current system along the west coasts of Peru and Chile. The Peruvian and Chilean cruises will be used to determine the vertical thermodynamic and dynamic structure of the coastal upwelling at a number of different locations along the coast, where satellite ocean color imagery shows strong local variability most likely related to topographic coastal features. Regional ocean modeling at high resolution will be used in conjunction with the oceanography measurements to better understand both the spatial and the temporal variability in the upwelling and eddy generation.

Particular sections of this coastline, most notably southern Peru (at 15°S) and central Chile (30-40°S) exhibit particularly strong ocean eddy activity and the cruise data will be used to examine how these features affect the MBL and cloud structure using wind profiler, radiosondes, and thermodynamic data from the cruises. In addition, the Chilean Airforce Twin Otter will be used to sample the near-coastal marine boundary layer, in particular to examine the structure and variability of the coastal low level jet that forms at the location of the peak in ocean eddy kinetic energy along the Chilean coast. The air-sea interactions between the oceanic eddy structure and the strength of the coastal jet will be explored using the cruise and the airborne data. The MM5 regional atmospheric model will be run for the VOCALS-REx period and will be used to examine aspects of the interactions of the coastal jet with the cloud and MBL structure, and to examine the factors controlling the diurnal subsidence wave generated along the west Andean slopes of Northern Chile and Southern Peru.

Along the Southern Peruvian coast are regions (especially 13-17°S) where there is near-permanent stratus cloud clearing. The structure of the MBL in these regions (area inside red circle in Fig. 10) will be studied using data from a tethered balloon and from enhanced automatic meteorological observations along the coastline. The Peruvian 30 day coastal cruise organized by the Instituto del Mar del Perú (IMARPE) will provide upper-ocean and lower atmosphere measurements, with focus upon the southern Peruvian coast. The NSF wind profiler and RASS data will be used to characterize the MBL structure associated with the coastal jet, and to provide important data from the lower free troposphere on the diurnally generated subsidence wave close to the South American coast. These data, together with wind profiler data from the Chilean coastal cruise will provide information on the geographical structure of the diurnal subsidence wave.

Atmospheric aerosol, chemistry, and cloud measurements will be carried out at an elevated site (850 m amsl) in the Chilean coastal range at El Tofo (29.5°S, 71°W). El Tofo is well positioned to sample the airmass leaving Chile and advecting over the SEP, and is directly downwind of the major copper smelters in central Chile (Fig. 2 in the SPO) and the Santiago urban region. It is also sufficiently far from local urban centers that it can be considered to be a site that is representative of the 'Chilean plume' that is hypothesized to be responsible for the small cloud droplet effective radii over the broader SEP ocean. The elevation of the site means that it is frequently in cloud (the site is used for community water provision through fog-collection). The site will be used for both cloud and aerosol sampling. Counterflow virtual impactor (CVI) measurements of the physicochemical properties of the cloud droplet residuals will be made by MISU (Department of Meteorology, Stockholm University, Sweden) to determine the sources and levels of anthropogenic pollutants in the cloud droplets.

In addition to the El Tofo site, the NSF C-130 will sample low level and elevated pollution layers in the coastal region of northern Chile at 18-20°S (see flight plan (d) above). Together with spaceborne lidar sampling from CALIPSO, these flight sections will be useful in determining the composition and structural properties of smelter plumes.

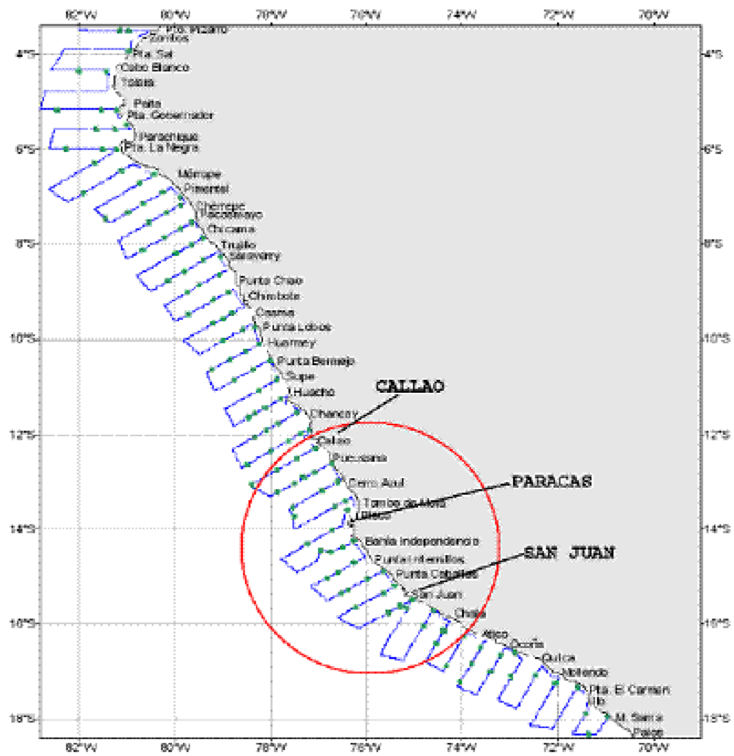


Figure 10: Observational capabilities of the Peruvian component of the VOCALS-REx field campaign. The proposed cruise track is shown in blue, with green circles representing XBT deployments. The red circle shows the region of atmospheric focus.