Improving understanding, model simulations, and prediction of the Southeast Pacific Climate System

Modeling Projects Outline

Compiled by C. R. Mechoso

First VOCALS Meeting, Boulder, CO, 17-20 March 2008

VOCALS Themes

Themes	Topics
Aerosol-cloud-precipitation interactions	• **Aerosol-cloud interaction** • **Impact of aerosol on drizzle and POC formation** • **Role of upwelling in aerosol properties** • **Anthropogenic vs natural generation of aerosols**
Ocean-land-atmosphere interactions	• **Simulation of Scu, PBL, winds and ocean currents** • **Role of heat transport by transient ocean eddies** • **Diurnal cycle and role of subsidence wave** • **Role of mixing associated with near-inertial oscillations in trade winds**

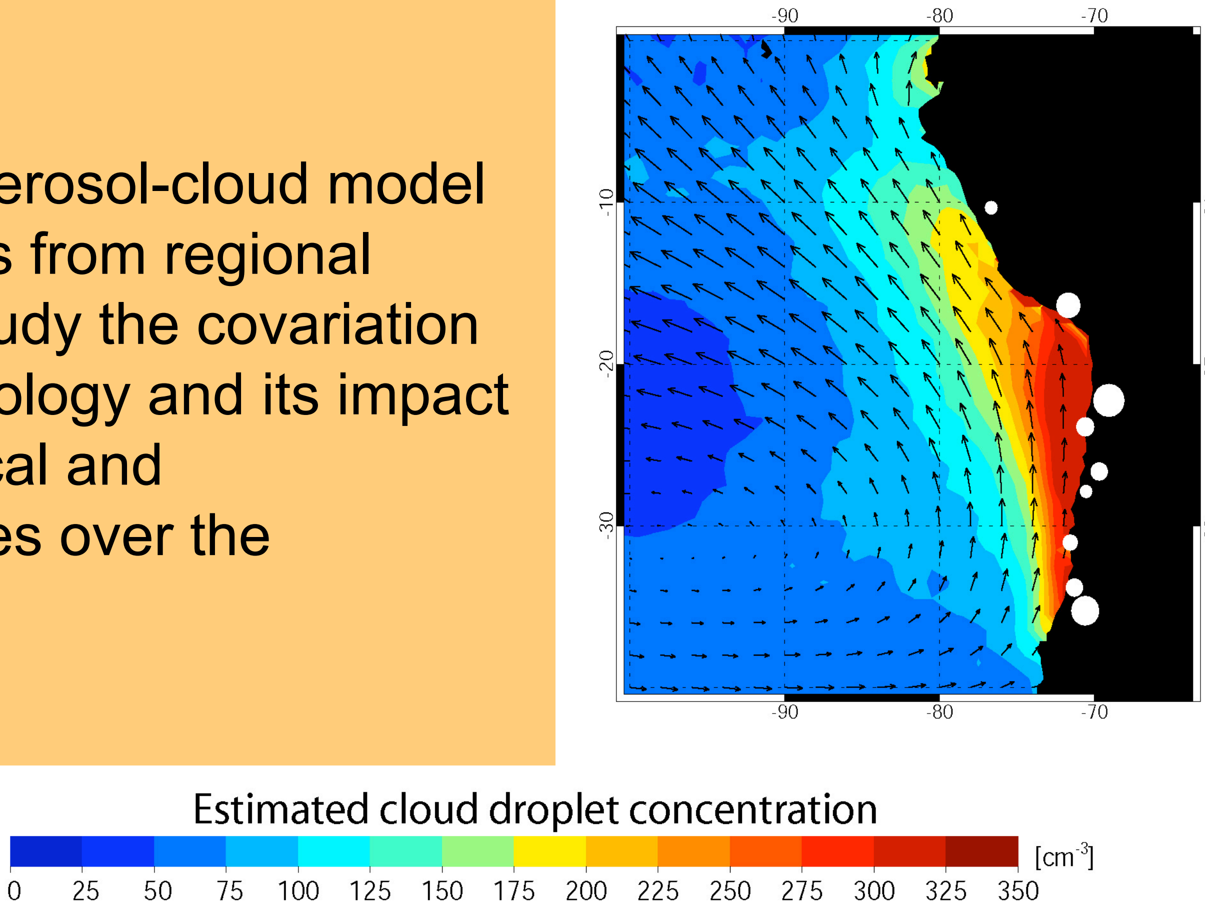
Lagrangian observations and modeling of aerosol-cloud interaction

Robert Wood, Rhea George (University of Washington)
Rahul Zaveri (Pacific Northwest National Laboratory)

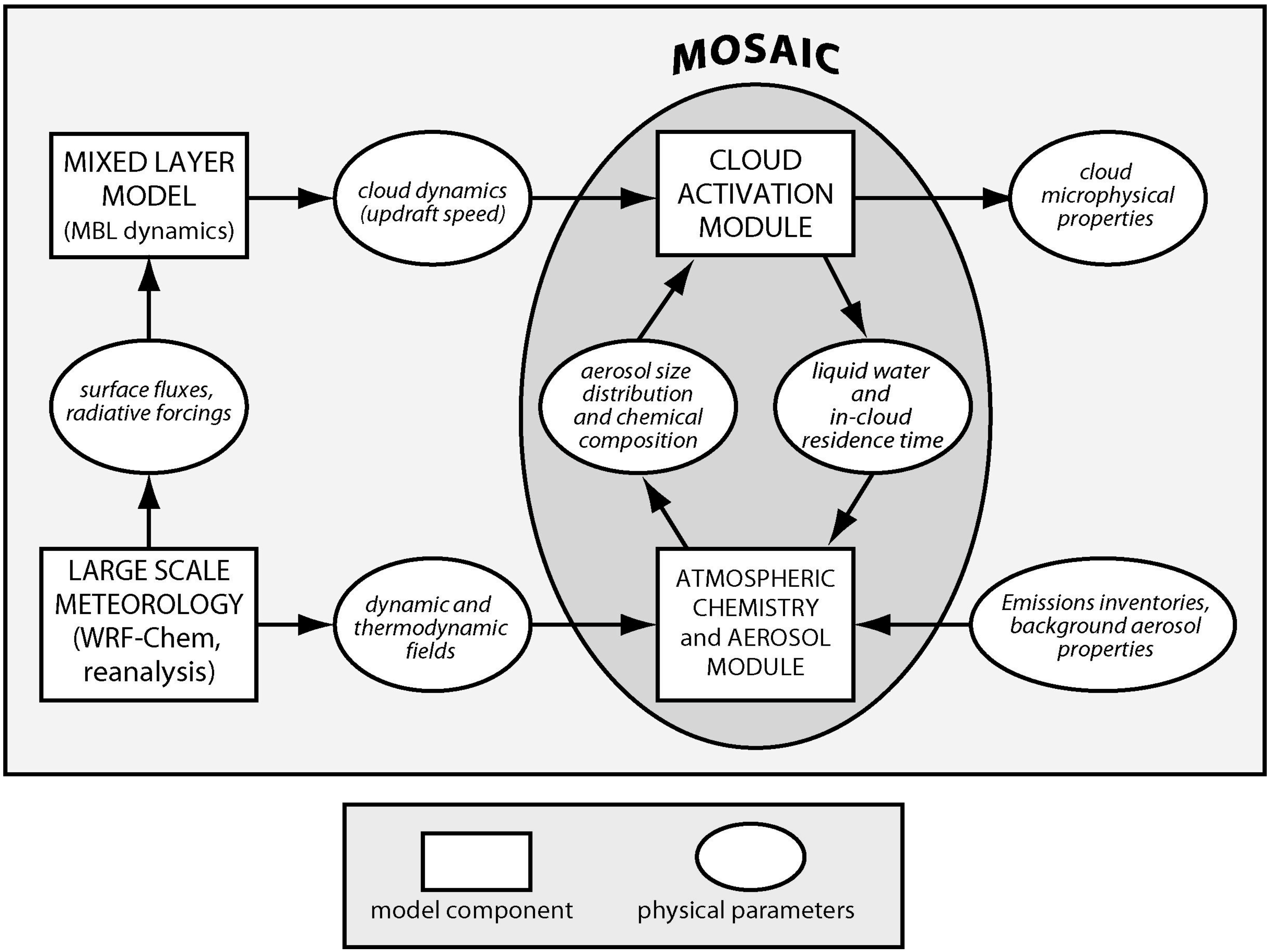
Goal:

To use a simple MBL aerosol-cloud model forced using trajectories from regional models/reanalysis to study the covariation of aerosols and meteorology and its impact upon cloud microphysical and macrophysical properties over the Southeast Pacific

Agency: NOAA ACC



Modeling framework



Cloud Modeling

Robert Wood, Chris Bretherton (University of Washington)

- **PreVOCA/VOCA:** Assessment of clouds and aerosols variations over the SE Pacific by regional/global models.

  PreVOCA pilot - ongoing, using data for Oct. 2006.

  VOCA - will be based on REx data

  Goals: To test and improve the performance of the moist turbulence and stratiform cloud parameterizations in CAM, focusing on the 20 S section.

- **LES studies** (with bulk microphysics and a highly idealized aerosol model; coordinated with Feingold's project).

  Goals: To simulate the initiation and evolution of POCs. Compare with REx clean/dirty Lagrangian observations. Look for Baker-Charlson type 'bistability' in LES results.

Modeling Aerosol – Cloud – Precipitation Interactions

Team: Mikhail Ovtchinnikov, Dick Easter, Steve Ghan, Rahul Zaveri
Pacific Northwest National Laboratory (PNNL), Richland, WA

Office of Science
U.S. DEPARTMENT OF ENERGY

Goal: Use VOCALS data to evaluate and improve model representations of the aerosol-cloud interaction. Focus on ***cloud effects on aerosols***.

Questions:

- How do properties of anthropogenic aerosols evolve as air masses are advected away from pollution sources?
- What changes in aerosol properties are observed?
- Are current detailed models capable of simulating these transformations?
- Which effects are retained in simplified parameterizations? What is lost?
- Does anthropogenic aerosol influence location or frequency of POCs?

Tools: Two complementary models

CRM/LES:

- interactive dynamics, thermodynamics, and microphysics but …
- computational intensity limits simulations in number, scale, length and in complexity of microphysics and chemistry.

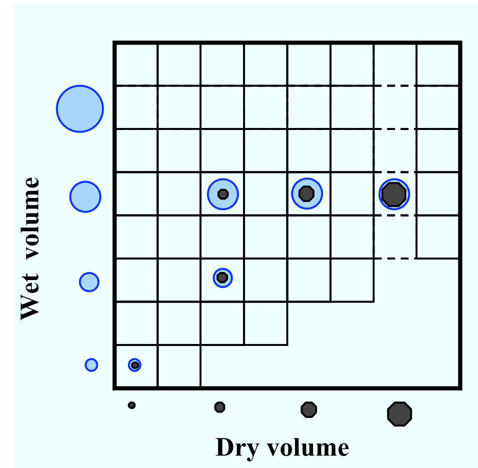
Trajectory Ensemble Model (TEM):

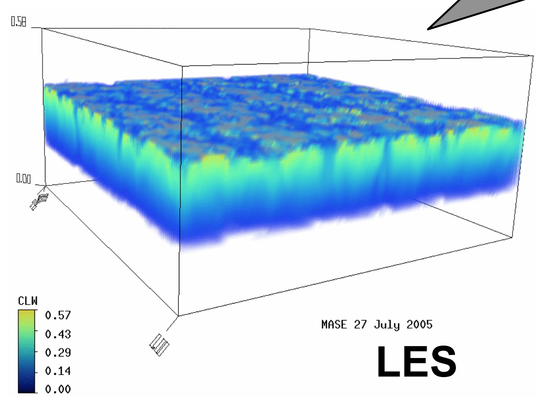
- a parcel (box) model driven along trajectories from LES;
- complex microphysics and chemistry and multiple aerosol distributions but …
- Parameterized, if any, interaction with dynamics, mixing, sedimentation

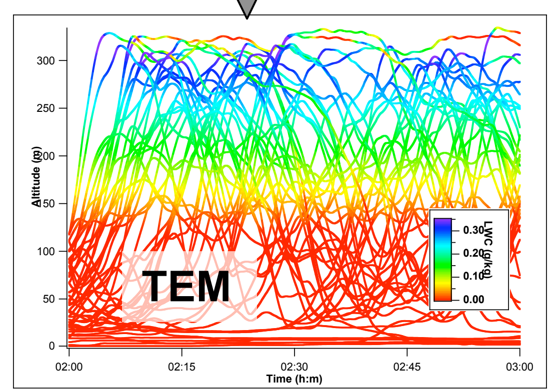
Modeling Aerosol – Cloud – Precipitation Interactions

Approach:

- In cycling through clouds, aerosol size distributions are affected by aqueous chemistry, coagulation, sedimentation, etc.
- Many of these changes cannot be explicitly modeled using separate 1D representations for aerosol and cloud particle spectra.
- **2D microphysics** can help in addressing some of the problems
  - – Two dimensions are dry and total volumes
  - – Conceptual simplicity in consistently tracking aerosols inside and outside of droplets
  - – Computationally challenging as it requires 30 dry size bins × 50 wet size bins ≈ 1,200 bins
  - – Implemented in both LES and TEM







Contact: Mikhail Ovtchinnikov
(mikhail@pnl.gov)

Regional Modeling of Particulate Chemistry and its Effect on Cloud-Aerosol Interactions

Office of Science
U.S. DEPARTMENT OF ENERGY

Team: Jerome Fast, Elaine Chapman, Weiguo Wang, and others

Primary Objectives:

- Integrate modeling and measurements to examine aerosol chemistry downwind of points sources (smelters and power plants), quantify importance of chemistry on CCN and cloud effects, and determine the relative role of natural (DMS, volcanic, dust) versus anthropogenic sources on cloud-aerosol interactions
- Use regional model to test new cloud-aerosol interaction treatments developed by higher-resolution cloud-resolving models

PNNL's Version of WRF-chem:

- *MOSAIC aerosols:* 2-moment (mass & number), sectional size distribution, internal mixing, 11 species (SO_4, NO_3, NH_4, Na, Cl, OM, BC, OIN, Ca, CO_3, aerosol water)
- *Cloud-aerosol interactions:* modified Lin microphysics, interstitial and cloud-phase aerosols, activation, aqueous chemistry, scavenging
- *Feedbacks:* aerosol direct effect, first and second indirect effects

Methodology:

- Nested grid config. (Δx = ~45, 15, 5 km, 44L) to simulate synoptic and regional
- Control simulation of field campaign period with sensitivity simulations that vary 1) cloud-aerosol interaction treatment, and 2) primary emissions
- Utilize extensive measurements regarding conclusions drawn from model

Use of WRF-chem for PreVOCA Exercise

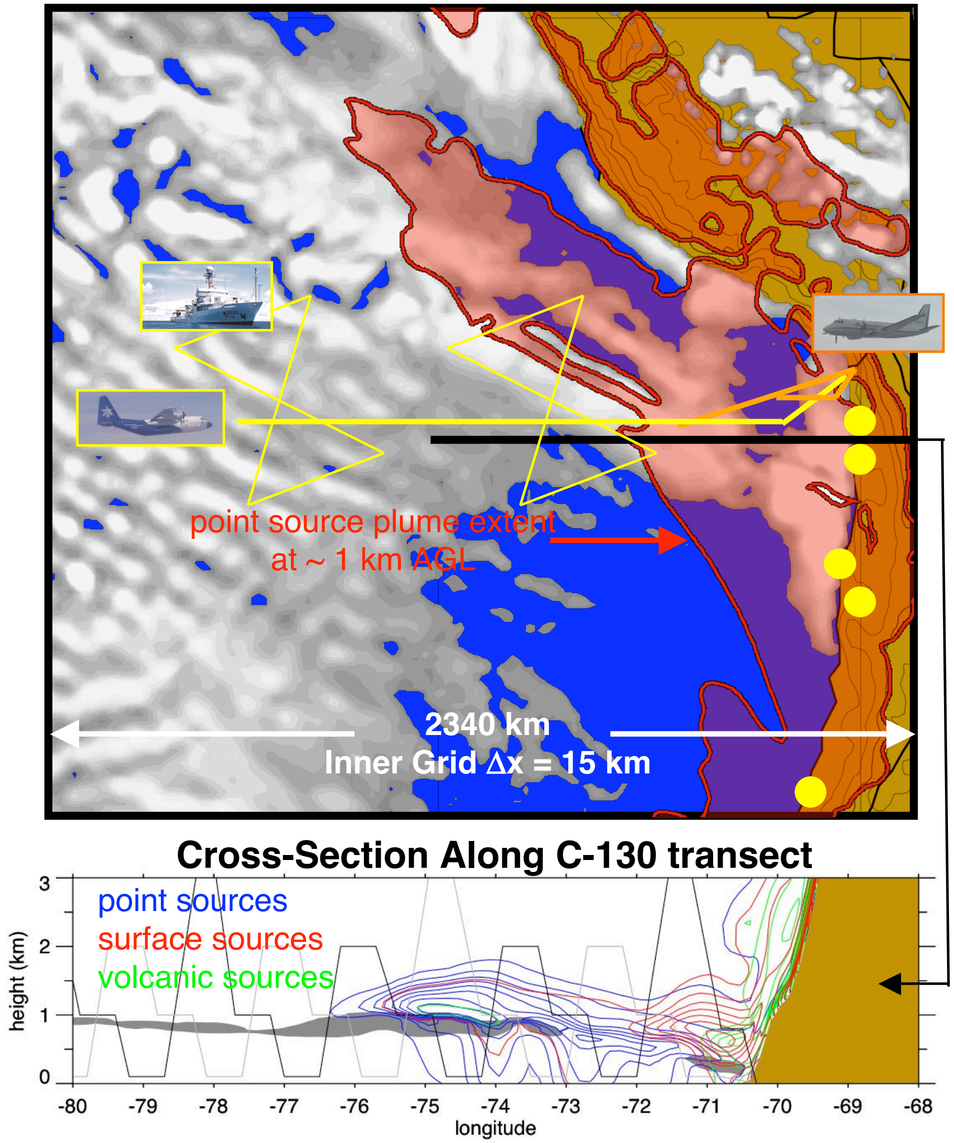
What are we doing? Participating in the model inter-comparison study to critically assess predictions of strato-cumulus and aerosols over the SE Pacific Ocean

Why? Use WRF-chem to determine transport pathways of point sources and understand uncertainties in the prediction of stratocumulus

Preliminary Results:

- SO_2 from point sources transported hundreds of km west of coast
- Model performance in simulating stratocumulus clouds mixed
- Can use model results to evaluate aircraft flight sampling strategies
- Cloud-aerosol interactions reduce cloud amount, but their impact is smaller than resolution and microphysics effects (which is more important for climate modeling?)

Simulated COD, 12 UTC October 15, 2006



Natural and anthropogenic gas phase emissions and cloud properties in the South-East Pacific region

J. Kazil G. Feingold R. Garreaud R. Schmitz

Test the following hypotheses:

- Aerosol nucleation above the SEP cloud deck from anthropogenic aerosol precursors ...
  - is an important source of CCN, and primarily responsible for the small effective radii measured from space over the SEP
  - delays or prevents the formation of drizzle and of POCs
- In the closed SEP stratocumulus deck, DMS contributes mainly to aerosol mass, rather than to aerosol number
- In POCs, the opposite is the case: The reduction of aerosol surface area and of cloud optical depth, accompanied by enhanced actinic fluxes, triggers new aerosol formation from the gas phase that is fueled by DMS from the ocean, followed by growth of the new particles to CCN sizes.
- The open cell convection inside POCs transports these new CCN into the cell walls, thereby inhibiting drizzle formation there, preventing cell growth, and leading to a stabilization of the cell structure.

Natural and anthropogenic gas phase emissions and cloud properties in the South-East Pacific region

J. Kazil   G. Feingold   R. Garreaud   R. Schmitz

Methodology:

- Identify the air mass transport over the SEP region to locations sampled in VOCALS-REx by means of back-trajectory calculations in a WRF regional run.
- Distinguish trajectories originating from clean and polluted regions
- Run the Lagrangian aerosol model MAIA (Kazil et al., ACP 2007), which simulates aerosol nucleation in detail, along the trajectories
- Compare the properties of the simulated aerosol with in-situ measurements
  - ➔ This will show if and how much aerosol nucleation contributes to the CCN population above the cloud deck
- Implement aerosol nucleation in WRF
- Initialize a nested WRF LES with aerosol from the Lagrangian simulations at locations upstream of VOCALS-REx sampling locations
- Run the WRF/LES and track the development of the cloud deck (drizzle/POCs)
- Compare with reference LES simulations where nucleation is switched off

Cloud Variability

Shouping Wang (NRL) in collaboration with Qingfang Jiang (UCAR)

- **Objectives**
  - Aerosol-drizzle-cloud interaction
  - Large- and meso-scale environment and stratocumulus cloud structure
  - Interaction of SST, mesoscale eddies, and marine boundary layer structure
- **Approach**
  - Perform COAMPS real time forecast for VOCALS-Rex;
  - Conduct high-resolution COAMPS and COAMPS-LES case studies;
  - Conduct coupled COAMPS/NCOM simulations;
  - Perform simple theoretical model studies (such as mixed-layer model);
  - Analyze and compare observations and model results;
  - Develop new turbulence and cloud parameterizations for COAMPS.

Models

- **COAMPS (Coupled Ocean/Atmosphere Mesoscale Prediction System)**
  - Navy weather forecast operational model
  - Comprehensive atmosphere and ocean data assimilation system
  - Physical parameterizations: Fu-Liou radiation, bulk microphysics, K-K drizzle scheme, TKE prediction PBL, Kain-Fritch cumulus convection etc.
  - Dust aerosol physics and transport
- **COAMPS-LES**
  - COAMPS can be performed as a LES with two-moment microphysics;
  - LES domain can be nested in COAMPS.
- **NCOM (Navy Coastal Ocean Model)**
  - Two-way or one-way coupling with COAMPS
- **Simple Stratocumulus Mixed-Layer Model**
  - Various entrainment parameterizations and Fu-Liou radiation scheme

The dynamics and modeling of Andes-induced perturbations and their impact on stratocumulus and coastal upwelling

Qingfang Jiang (UCAR, NSF) in collaboration with Shouping Wang (NRL PI)

Research Objectives:

- Modeling and dynamics of Andes-induced perturbations
- Modeling and dynamics of coastal low-level jet
- Interaction between diurnal subsidence wave and stratocumulus over SEP
- Interaction between CLLJ and SST

Tools and Approaches:

- COAMPS real-time forecast (in support of field observations)
- COAMPS high-resolution simulations and reanalysis (for model validation and case studies)
- COAMPS idealized modeling (to examine fundamental physics and dynamics)
- Observational data analysis (for model validation and case studies)
- Quasi-analytical model studies (of dynamics and physics)

COAMPS™

Coupled Ocean/Atmosphere Mesoscale Prediction System

Atmospheric Model:

Numerics: Nonhydrostatic, nonlinear, compressible, Nested Grids, Sigma-z

Physics: PBL, Convection, Explicit Moist Physics, Radiation, Surface Layer

Complex Data Quality Control

- Multivariate Optimum Interpolation Analysis (MVOI) of Winds and Heights
- NRL Atmospheric Variational Data Assimilation System (NAVDAS) [3DVAR]

Navy Operational Model:

- Globally Relocatable (5 Map Projections)
- Operational at FNMOC:
  - 9 Areas, Twice Daily, using 81/27/9 km or 81/27 km grids
  - Forecasts to 72 hours
- Operational at all Navy Regional Centers (w/GUI Interface)

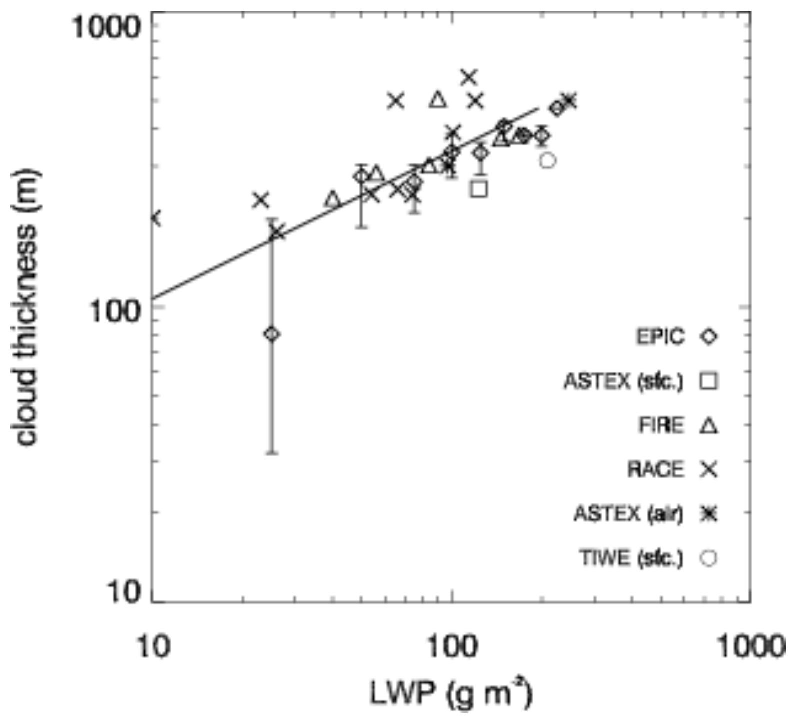
Research Model:

- COAMPS-LES (large eddy simulation)
- COAMPS/NCOM (air-sea coupling)
- COAMPS-AEROSOL (aerosol model).

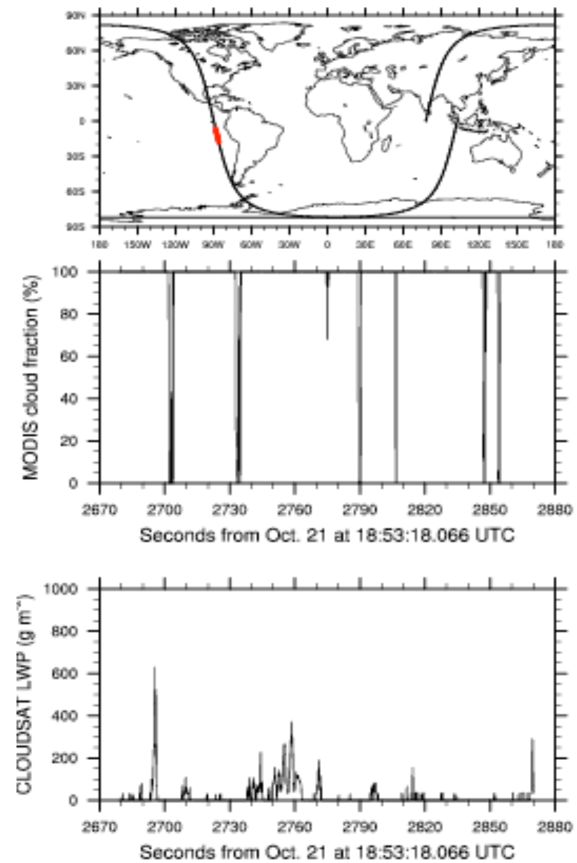
Using VOCALS and Satellite Data to Improve the Treatment of Marine Boundary Layer Clouds and Turbulence

Xubin Zeng and Michael A. Brunke

The University of Arizona



Compare and contrast SEP BL and St observed by VOCALS w/ in-situ data from 16 other cruises.



Evaluate consistency between CLOUDSAT and MODIS data.

Using VOCALS and Satellite Data to Improve the Treatment of Marine Boundary Layer Clouds and Turbulence

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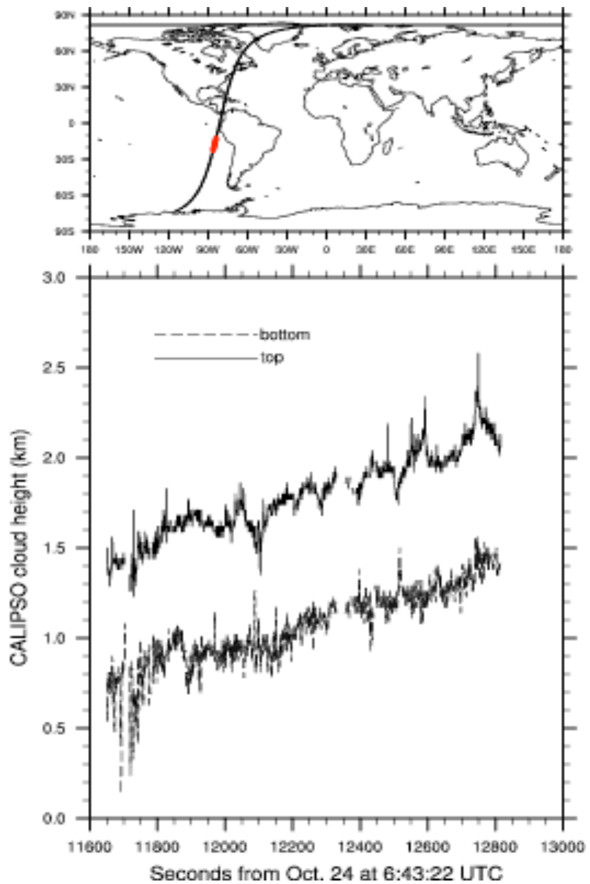
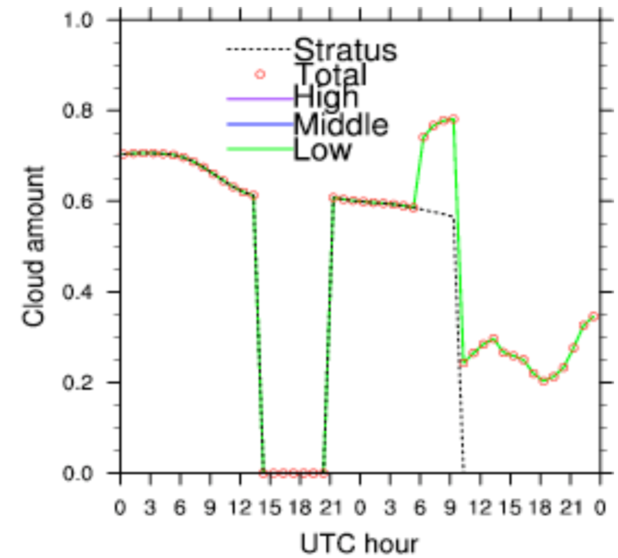
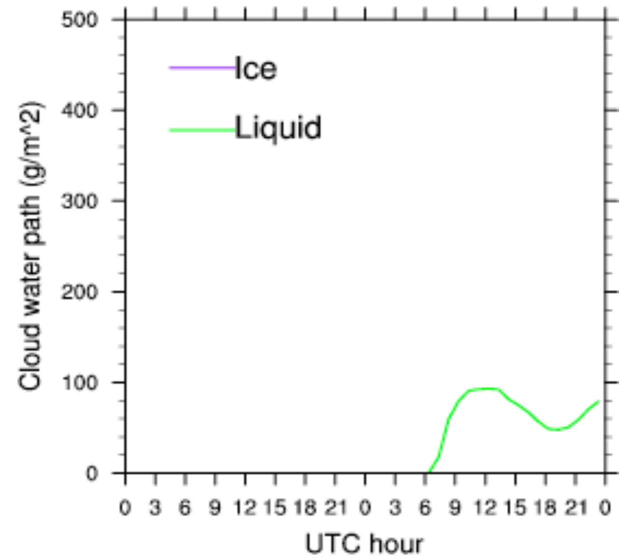






Using satellite and in-situ data, we will evaluate model simulation of cloud properties.

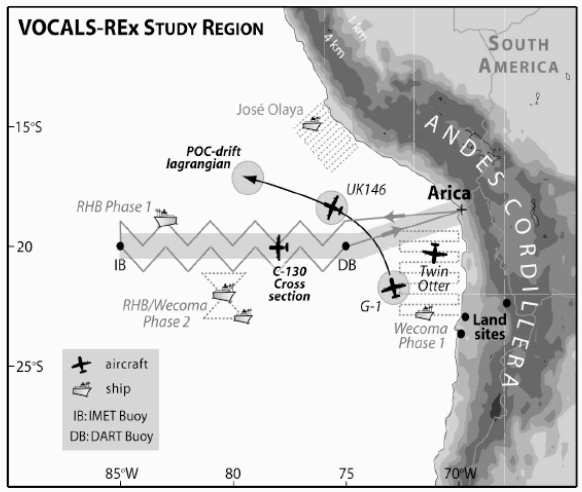
Data will be made available to the VOCALS group.

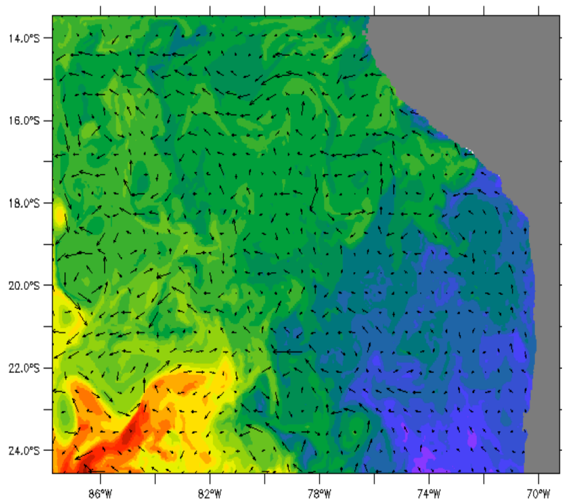
VOCALS Mesoscale Ocean Dynamical Analysis with Synoptic Data Assimilation and Coupled Ocean-Atmosphere Modeling (NSF)

Arthur J. Miller, Aneesh Subramanian, Dian Putrasahan (**Scripps Institution of Oceanography**)
Hyodae Seo (UCLA)

1. Ocean Data Assimilation

What processes control oceanic mesoscale variability of the Peru-Humboldt Current System and its consequent influence on the heat transport and SST over the SEP?





Ocean model (ROMS) hindcasts will assimilate the VOCALS *in situ* and satellite observations to provide a dynamically consistent representations of the physical oceanographic conditions over the region

- diagnose the processes that control the observed physical variability that determines the heat transport, surface flux processes, nutrient transport and mixing properties observed in the surveys.

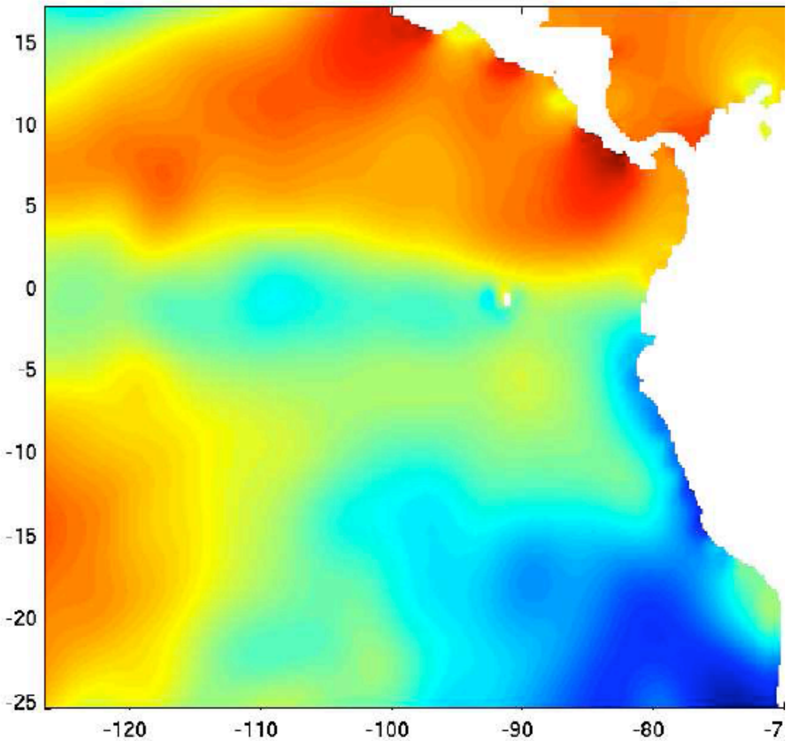
- compute the sensitivities of the oceanic flows in the SEP to atmospheric forcing and remote oceanic forcing with Generalized Stability Analysis tools.

- provide 4D physical forcing for ecosystem models and for observed biological diagnostics.

VOCALS Mesoscale Ocean Dynamical Analysis with Synoptic Data Assimilation and Coupled Ocean-Atmosphere Modeling (NSF)

Arthur J. Miller, Aneesh Subramanian**,** **Dian Putrasahan** **(Scripps Institution of Oceanography)**
Hyodae Seo **(UCLA)**

2. Coupled O-A Modeling



What is the effect of mesoscale ocean-atmosphere coupling on the distribution of SST, mesoscale eddy statistics, cloud variability and regional-scale oceanic and atmospheric mean circulation?

Regional ocean-atmosphere (SCOAR: ROMS-RSM) model downscaled hindcasts of large-scale observed atmospheric flows will allow full ocean-atmosphere coupling, orography and land-sea distribution

- compare coupled O-A runs to uncoupled atmosphere and uncoupled ocean model runs during VOCALS and other longer time periods

- compute statistics of intraseasonal through interannual variability of ocean mesoscale and local atmosphere

- determine mechanisms that control mesoscale eddy characteristics and distribution in the SEP and links between large-scale climate-scale forcing and variability of the SEP.

VOCALS UK - Regional and cloud scale (non-climate) modelling strategy

Participants: A. Blyth, T. Choularton, P. Connolly, A. Gadian, G. McFiggans, S. Mobbs + many others.

Tasks

(1) Test the importance of aerosol and ultra giant CCN ingested into clouds on drizzle formation

(2) Assess the importance of cloud-top entrainment of pollution aerosols into the Sc for its effects microstructure and drizzle.

(3) Demonstrate any effects of strong longwave radiative cooling at cloud-top to 3-D cloud structure and boundary layer turbulence.

(4) Investigate the effects of aerosols and drizzle on the 3-D structure of the cloud.

Models to be used

Weather Research and Forecast Model (and CHEM) – WRF will be used as a 3-D meso-scale model.

The UKMO Large Eddy Model (3-D large eddy simulation (LES) model)

Aerosol-Cloud-Precipitation Interactions Model (ACPIM; column)

VOCALS UK - Objectives

- Determine if drizzle formation can be explained by the activation of cloud droplets on aerosol particles including giant and ultra-giant aerosol particles
- Use the available aircraft measurements of calculate entrainment rate and perform model sensitivity tests to its effects on drizzle and effective radius.
- Investigate the effects of cloud macrostructure on drizzle and characterize the spatial variability of drizzle.
- Explore the effects of aerosol on the fine 3-D cloud structure of the Sc.
- Investigate the microphysical effects of entrainment of environmental air at cloud top on the formation of drizzle, and on bulk parameters such as effective radius, cloud structure and precipitation rate.
- Experimentally examine the cellular structure of the stratocumulus clouds and relate to the modelling
- Determine the sensitivity to aerosol properties in the formation of drizzle, and formation, maintenance and destruction of open cells

IGP LEGOS IRD Institut de recherche pour le développement IMARPE

Models configurations for VOCALS experiments

- MM5 real time weather forecast with the Domain 1 and 2
- Atmospheric simulations with changes in topography, SST, winds

MM5

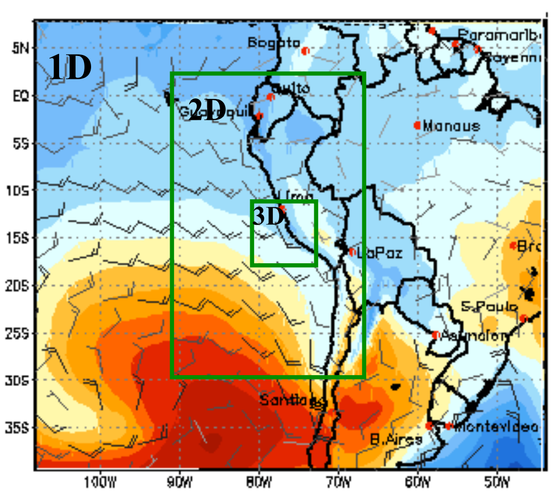
Physics: Grell CPS, Simple Ice EM, Blackadar high resolution PBL and Burk-Thompson

Domain and resolution:

1 D: 110-45ºW/40ºS-10ºN; 36x36km

2 D: 90-68°W/35ºS-2ºN; 12x12 km

3 D: 80-73ºW/ 18-12ºS; 4x4 km



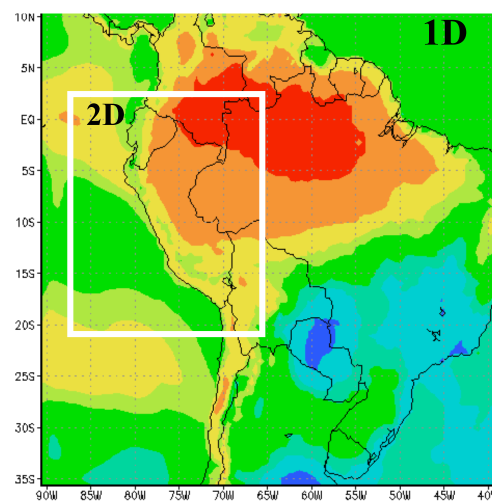
RegCM3

Physics: Grell-Fritsch–Chappell CPS, Zeng and BATS fluxes

Domain and resolution:

1 D: 110-40ºW/40ºS-10ºN; 50x50km

2 D: 90-68°W/23ºS-2ºN; 20x20 km



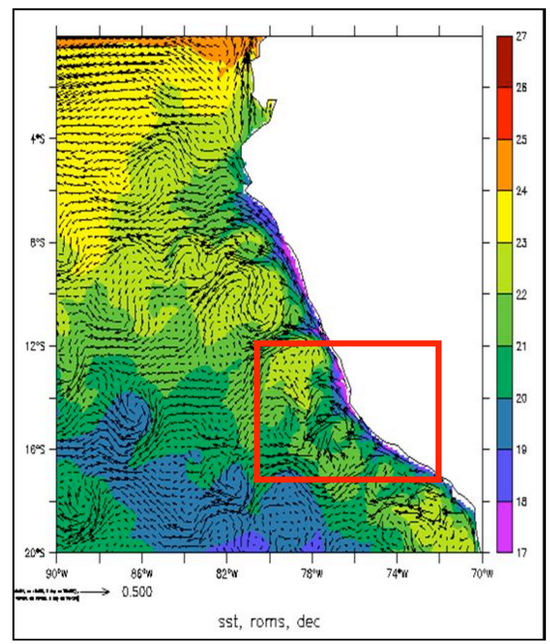
ROMS

(Embedded into MERCATOR (French Assimilation Global System 1/4°x1/4°)

Domain and resolution:

1 D: 110W-45ºW/5ºN-21°S; 1/9°

2 D: 80°W-72°W/12ºS-17ºS; 1/27°

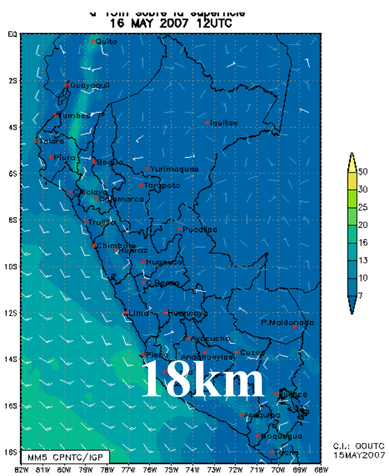


On-going modeling activities:

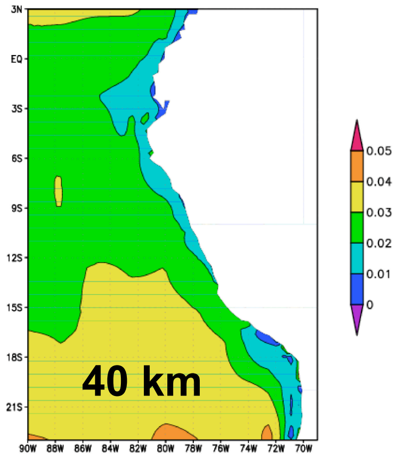
IGP IMARPE

Atmospheric models configurations

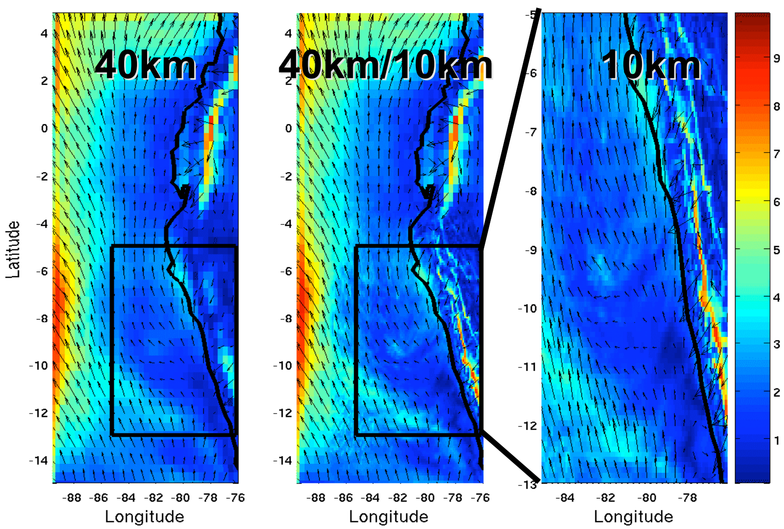
MM5 (operational)



WRF

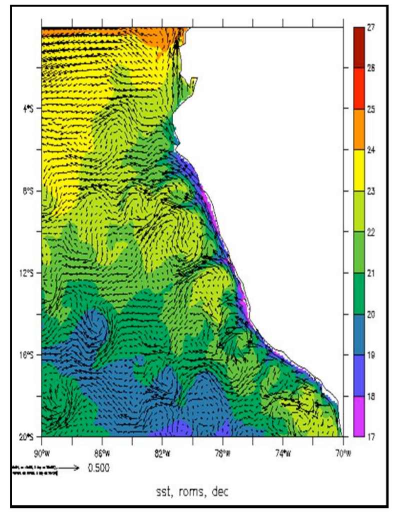


Filamentos domain



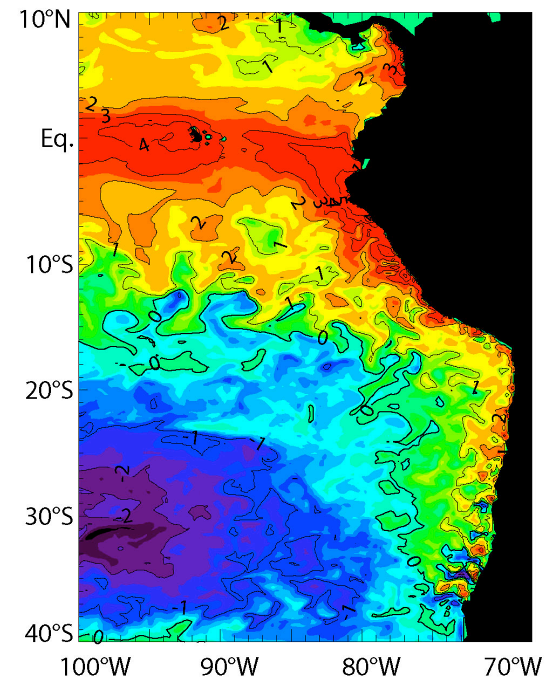
Oceanic model configurations

ROMS (1/9°) – Config. Penven et al. (2005)

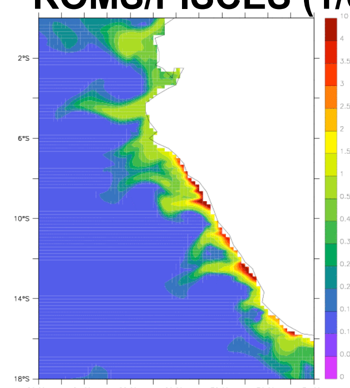


ROMS (1/6°) – PCCC project config.

SSTA - 15th of February, 1998



ROMS/PISCES (1/6°)



Under development: WRF (1/9°) – ROMS (1/27° - Chimbote and Pisco) – ROMS/PISCES (1/27°)

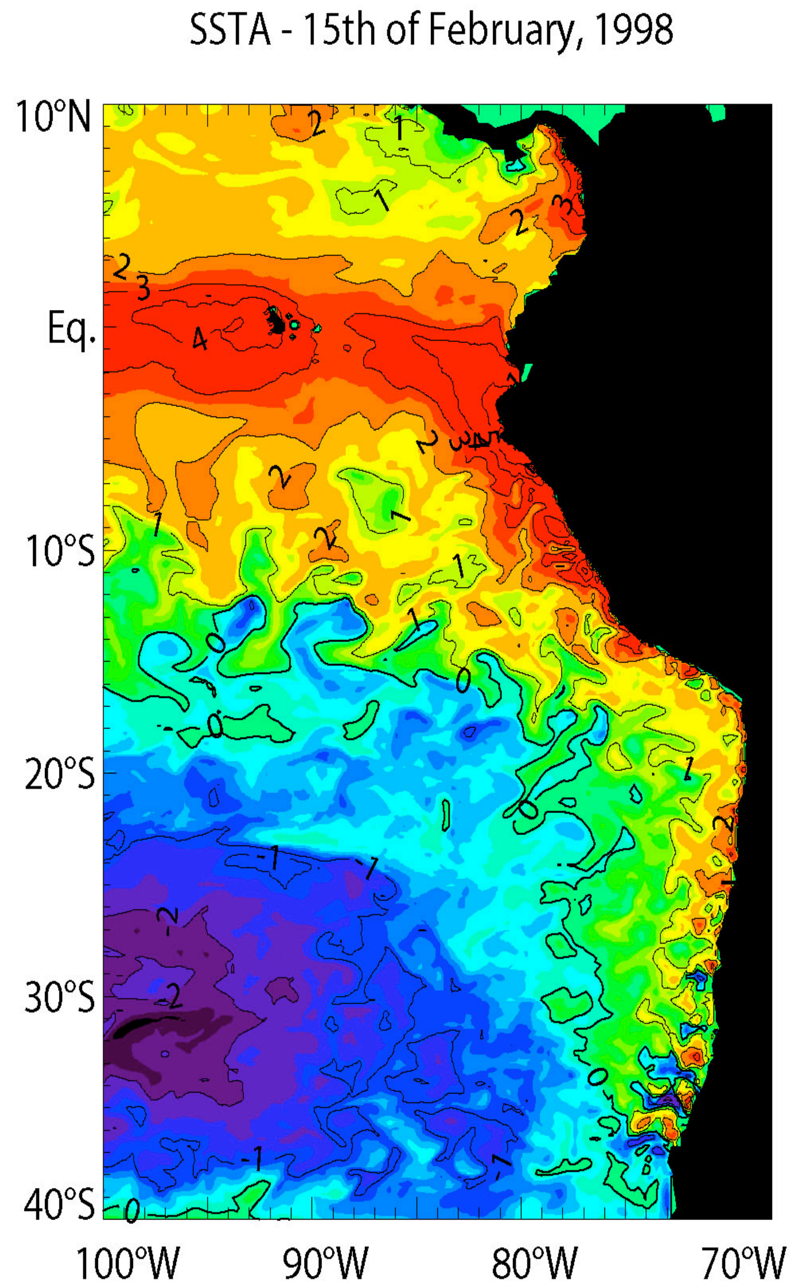
- Statistical downscalling of the atmospheric Reanalyses and IPCC atmospheric runs (PCCC project)

<u>Project</u>: Impact of Climate Change in the Chile- Peru upwelling system (IPCC)

P.I.: Boris Dewitte (LEGOS)

Main question: ‘How climate change as simulated by the state-of-the-art Coupled General Circulation Models [IPCC data base] is likely to impact the Peru-Chile upwelling system?’.

A downscaling strategy using high-resolution regional models (ROMS(1/6°); LMDz(40km)) and statistical methods, will be used to provide a description of the regional circulation in a warmer climate and understand the mechanisms that control the low frequency variability of mesoscale activity influenced by ENSO. Historical data and proxy data as derived from sediment core collected off Peru will be used for model validation and interpretation of the different regional simulations that account for pre-industrial, present and future climate variability.



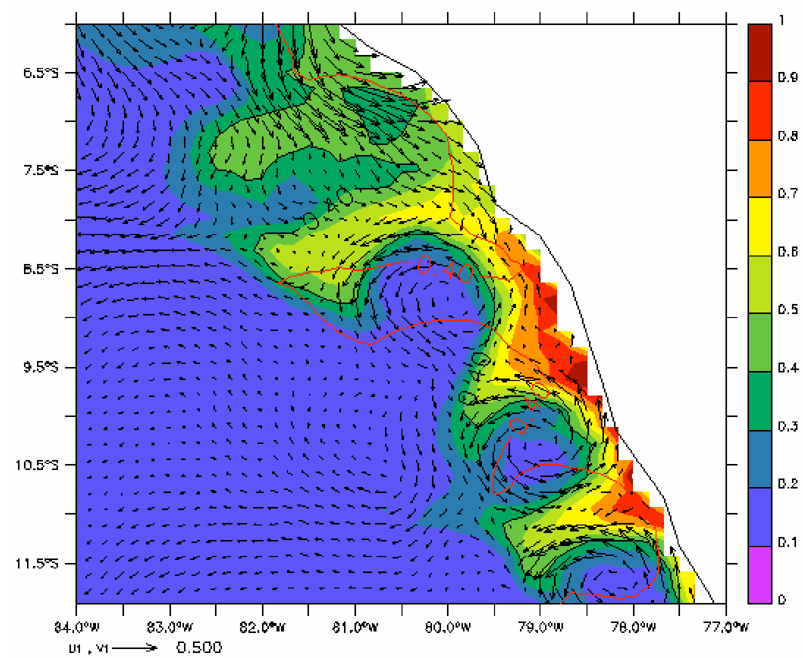
Model config.: ROMS simulation (1/6°) of SSTA (ERS wind forcing + Mercator at the boundary)

Project: Mesoscale and submesocale physical/ biogeochemical coupling in the north Humboldt system

P.I.: Vincent Echevin (LOCEAN)

Objectives:

- Study the impact of mesocale structures on surface productivity and higher trophic levels (small pelagics).
- Reproduce the dynamics with a coupled model ROMS/PISCES, to help for the interpretation of the FIlamentos cruise observations (3D circulation, time evolution during several months).
- Validate the model parameterizations
- Use the numerical simulations to characterize the meso and submesoscale variability (filament formation sites, seasonality) and quantify its impact on biology off Peru.

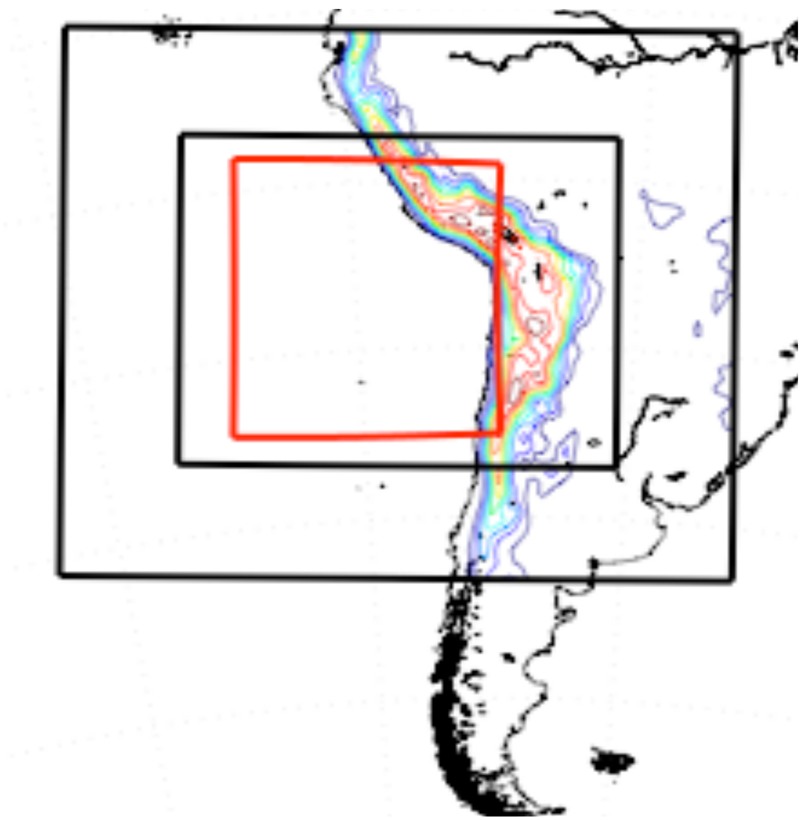


Surface chlorophyll (mgChl m^{-3}), and velocity (ms^{-1}) in November 2005 from the ROMS/ PISCES coupled regional model for the Chimbote (9°S) region. A similar model configuration will be used in the VOCALS region.

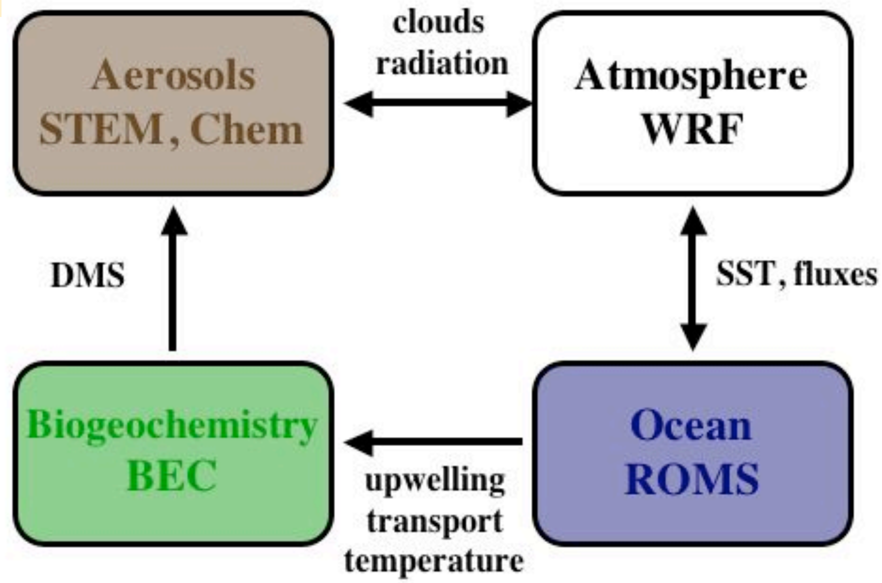
UCLA regional modeling

A. Hall, J. McWilliams,
G. Carmichael, C. Deutstch

Domains to be used for the simulations. The WRF domains (black) consist of a 12-km grid nested within a 36-km grid. The ROMS domain (red) has a resolution of 4km.



Information flows among models



PLANNED SIMULATIONS

Atmospheric forecasting during VOCALS-REx (WRF/STEM).

Retrospective VOCALS-REx simulation with full atmospheric chemistry and oceanic biogeochemistry (WRF-Chem/ROMS-BEC).

Recent interannual variability with coupled model (WRF/ROMS) and observed B.C.

Embedded coupling (WRF/ROMS) forced by global model (CCSM/UCLA).

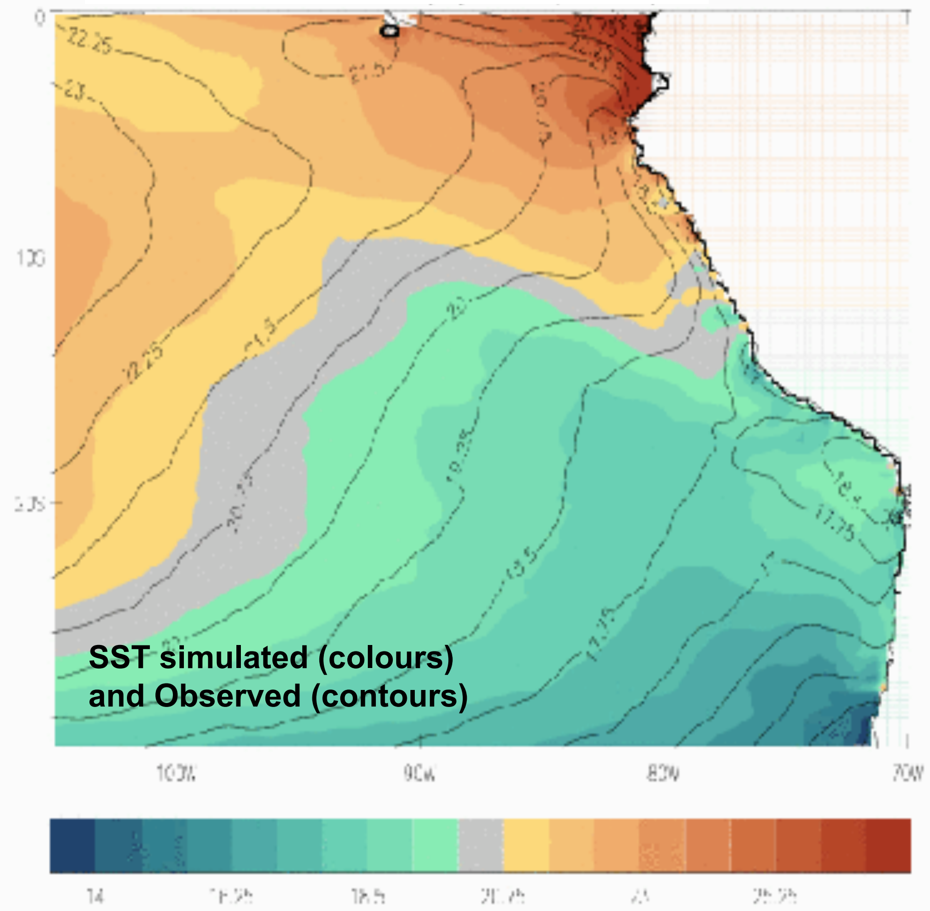
SCIENTIFIC FOCI

- **Fine-scale coupled climate dynamics.** How do coupling among air, land, and ocean maintain the mean state and produce variability?
- **Oceanic controls on biogeochemical cycling.** How do eddies and upwelling influence distributions of biological activity and DMS?
- **Aerosol distribution and evolution.** What is the distribution and relative importance of aerosol sources and sinks?
- **Aerosol-cloud Interaction.** How are aerosols scavenged in clouds, and how do aerosols affect cloud properties?
- **Upscaling effects of VOCALS region.** How does the regional simulation compare to its global counterpart and what are implications of the differences?

VOCALS-UK consortium proposal: the climate modelling side

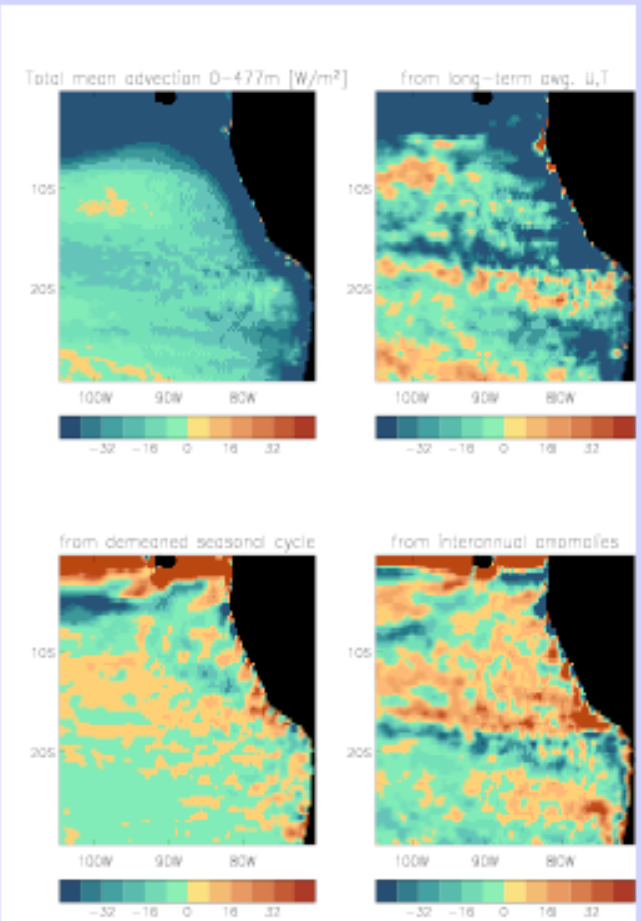
- Based on a range of global coupled models at different resolutions (HadCM3, HadGEM1.x, HiGEM, NUGAM)
- Taking advantage of our ability to perform multi-decadal, global coupled integrations at high resolution in both the ocean (1/3°x1/3°) and the atmosphere (N144 coupled, N216 atm. done & coupled under way)
- Involving analysis, perturbed integrations and sensitivity experiments (3-4 centennial coupled runs at high-res)
- The HiGEM model shows a considerable improvement in the simulation of the SEP

Julia Slingo, Thomas Toniazzo, Len Shaffrey, U. Reading

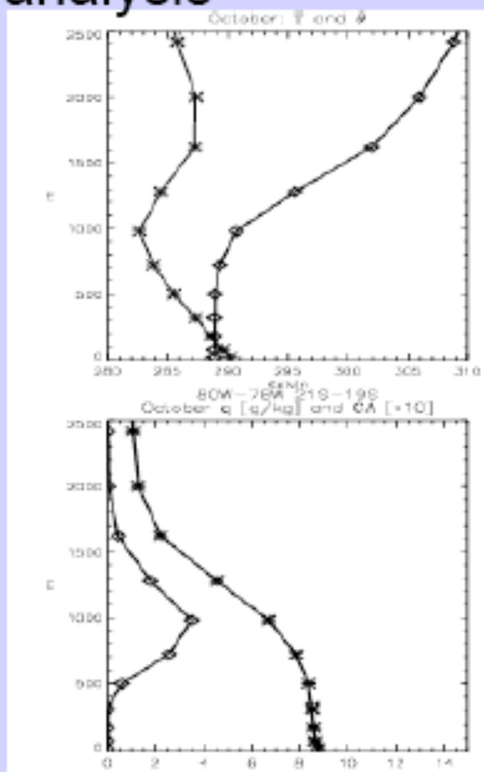


Proposed modelling activities

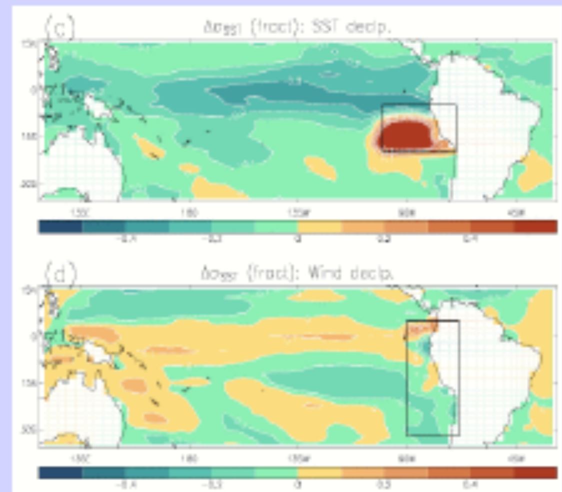
I. Mechanistic analysis of existing model integrations on the coupled dynamics of the SEP climate

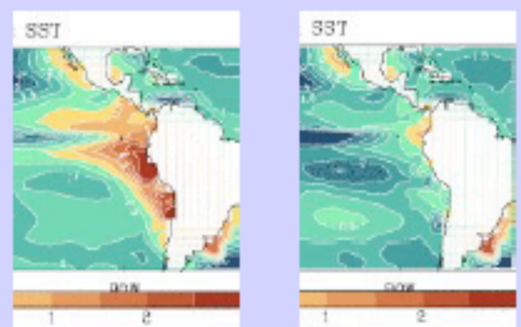


II. Study of model errors (N216) and their dependence on processes and interactions via initial-tendency analysis



III. Coupled sensitivity experiments at different model resolutions to test hypotheses





To improve modeling, simulation and precipitation of the tropical climate with coupled GCMs

Hualu Pan (NCEP), Ruiyu Sun (NCEP),
C. R. Mechoso (UCLA), Heng Xiao (UCLA)
Collaborators: A. Arakawa (UCLA) and Steve Lord (NCEP)

The metric for success of this project is the elimination of the NCEP Climate Foecast System (CFS) and UCLA AGCM systematic errors in the simulation of 1) eastern Pacific rainfall, and 2) diurnal and intraseasonal variability of American monsoon systems. Start development of VOCALS multiscale prediction system.

Themes	Topics	Projects
Aerosol-cloud-precipitation interactions	**Aerosol cloud-interaction**	Wood, Zaveri Wood, Bretherton Ovtchinnikov, Easter, Ghan, Zaveri Fast, Chapman, Wang Wang, Jian A. Blyth, T. Choularton, P. Connolly, A. Gadian, G. McFiggans, S. Mobbs
	Aerosol impact on drizzle and POC formation	Wood, Bretherton J. Kazil G. Feingold R. Garreaud R. Schmitz
	Anthropogenic vs natural generation	J. Kazil G. Feingold R. Garreaud R. Schmitz
Ocean-land-atmosphere interactions	**Simulation of Scu, PBL, winds and ocean currents**	Jian, Wang Silva, Grados, Slingo, Toniazzo, Shaffrey Zeng, Brunke Pan, Mechoso
	Role of heat and nutrient transport by transient ocean eddies	Miller, Subramanian, Putrashan Grados, Silva, DeWitte, Echevin Slingo, Toniazzo, Shaffrey Pan, Mechoso
	Diurnal cycle and role of subsidence wave	Kazil, Feingold, Garreaud, Schmitz