A Multidisciplinary Study of the Tropical Climate: VOCALS Report and Relevance for the Atlantic Workshop

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Observed annual mean SST

Outline

• The SEP climate
• Motivators for a research program
• VOCALS strategy
• Selected findings
• Relevance for Atlantic Workshop
THE SOUTH EASTERN PACIFIC

- Cold SSTs, coastal upwelling
- Coastally trapped Kelvin waves and ocean eddies
- Unresolved issues in heat and nutrient budgets
- Important links between clouds and aerosol

- Cloud-topped ABLs
- Important links between clouds and aerosol
- Influenced by and influential on remote climates (ENSO)
- A challenge for coupled atmosphere-ocean GCMs
Model biases in the Atlantic Warm Pool can contribute to model error over the SEP

CFS Model SST Bias

In the southeastern Pacific, most CGCMs used in climate projections have difficulties with the ITCZ and SPCZ south of the equator, and/or the SST under the stratocumulus decks.
At the ocean surface insolation is too high, evaporation is too high, net heat flux into the ocean is too low, and SSTs are too high.
In the SEP near the polluted coast POCS rarely develop, but away from the coast they are more frequent and extended than in other Scu regions. POCS strongly affect cloud albedo.
Southern Spring Season (SON)

Mean cloud droplet effective radius from MODIS; mean surface winds from Quikscat; Sulphur sources.

Shortwave cloud forcing [W m$^{-2}$] due to geographic variations in effective radius, inferred from MODIS.
Principal Motivators of a Research Program in the SEP

- Eliminate systematic errors of CGCMs in key regions of the Pacific Ocean
- Improve knowledge and model simulation of PBL clouds and coastal upwelling
- Better understanding and simulation of aerosol transport and aerosol-cloud interactions
- Improve estimates of indirect aerosol effects on climate
R. Wood (U. Wash., REx-PI), C. R. Mechoso (UCLA, Chair), C. Bretherton (U. Wash.), R. Weller (WHOI), C. Fairall (NOAA), H. Coe (Manchester U., UK), F. Straneo (WHOI), C. Grados (IMARPE, Peru), R. Garreau (U. Chile), G. Feingold (NOAA), B. Huebert (U. Hawaii), J. L. Brenguier (M. France), S. de Szoeke (NOAA), M. Kohler (ECMWF), T. Toniazzo (U. Reading, UK), and many others...

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VOCALS Goals
Elimination of CGCM systematic errors in the SEP, and improved model simulations of the coupled system in the region and global impacts of its variability.

Improved understanding and regional/global model representation of aerosol indirect effects over the SEP.

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Oper. Centers
BMRC Australia
CPTEC Brazil
ECMWF Int.
JMA Japan
MetOffice UK
NCEP US
**VOCALS Strategy**

- **Monitoring**
  - Buoys, Satellites, Cruises

- **Modeling**
  - Operational Centers, Research Institutions, Universities

- **Airborne**
  - NCAR C130
  - DOE EG-1 CIRPAS
  - Twin Otter UK146
  - NERC Dornier 228

- **Ship**
  - RV Ron Brown
  - RV Jose Olaya

- **VOCLAS**

- **REx**
1. Improvement of CGCMs performance in the SEP is key to the successful simulation of the ITCZ/SPCZ, complex, which will also benefit simulation of other regions.

A significant improvement can be achieved through better representing the effects of stratocumulus clouds on the underlying surface fluxes and those of oceanic mesoscale eddies in the transport of heat.
Coupled Ocean-Atmosphere-Land Hypotheses

2. Oceanic mesoscale eddies play a major role in the transport of fresh water from the coastal upwelling region and in the production of sea water and atmospheric DMS in the coastal and offshore regions. 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.
Coupled Ocean-Atmosphere-Land Hypotheses

3. The diurnal subsidence wave ("upsidence wave") originating in northern Chile/southern Peru has an impact upon the diurnal cycle of clouds that is well-represented in numerical models.

4. The entrainment of cool fresh intermediate water from below the surface layer during mixing associated with energetic near-inertial oscillations generated by transients in the magnitude of the trade winds is an important process to maintain heat and salt balance of the surface layer of the ocean in the SEP.
Aerosol-Cloud-Drizzle Hypotheses

1. Variability in the physicochemical properties of aerosols has a measurable impact upon the formation of drizzle in stratocumulus clouds over the SEP.

2. Precipitation is a necessary condition for the formation and maintenance of pockets of open cells (POCs) within stratocumulus clouds.
3. The small effective radii measured from space over the SEP are primarily controlled by anthropogenic, rather than natural, aerosol production, and entrainment of polluted air from the lower free-troposphere is an important source of cloud condensation nuclei (CCN).

4. Depletion of aerosols by coalescence scavenging is necessary for the maintenance of POCs.
PreVOCA: Mean Boundary Layer Depth Along 20°S

Preliminary “Exercise”
Use WRF-chem to determine transport pathways of point sources and understand uncertainties in the prediction of stratocumulus

**Preliminary Results:**
- $\text{SO}_2$ 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?)

Use of WRF-chem for PreVOCA Exercise

Inner Grid $\rho_{\text{scale}} = 15$ km

Simulated COD, 12 UTC October 15, 2006
Potential Temperature and Specific Humidity Profiles (20S, 85W)
VOCALS 20S cloud and boundary-layer structure

Ten dedicated and 6 partial missions sampled 1500 km offshore along 20S (flight plan at right)

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

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

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

Subsidence over the ocean in association with convection over the continent to the east.

Very cold coastal waters in association with strong low-level jet along the coast and upwelling.
In the equatorial Pacific SST (4S~4N), annual mean and seasonal cycle are more realistic with improved convection
(deviation from zonal mean)

Ma, Mechoso, Xue, 2011
Model biases in the Atlantic Warm Pool can contribute to model error over the SEP.

Wang, Lee and Mechoso, J. Climate 2010
Improved Scu Forecasts in SEP (ECMWF)

Figure 2. GOES12 satellite 10.8 μm infrared band brightness temperature are compared to model generated images. The model was initialized on 20081018 00UTC. Panels (b) and (d) correspond to 18 and 30 hour forecasts representing daytime (10-14LT) and nighttime (22-02LT) respectively.
The Southern Tropical Pacific (10-20S)

Transition to deep convection

Shallow convection

Transition to shallow convection

Coastal clearing Aerosol

VOCALS Paradigm  
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Hypothesis on the heat budget of the ocean column

Surface flux > 40 W/m² (heating)

Base of mixed layer

250 m

Vertical advection and mixing (<1 W/m²)

(1) Heat transport by turbulence processes
(2) Heat transport by submesoscale eddies
(3) Heat transport by processes such as mixing associated with near-inertial oscillations, with a possible contribution by others such as salt fingering.

Weak horizontal cooling above the thermocline (~ 0-10 W/m² from current meters and satellite SSTs).

Horizontal advection at and below the thermocline (cooling) due to processes that vary with region; it is partly by transient eddies.
VOCALS/VAMOS strategy

- There was a **strong motivating consensus** for a program in the SEP in view of CGCM difficulties and paucity of data for model verification.
- A number of focused workshops generated “**VOCALS Hypotheses**” to guide future activities.
- A multidisciplinary project started in the framework of **U.S. CLIVAR “Good Practices.”**
- A **major international field campaign** provided the centerpiece for the research program.
- Modeling centers were convinced of the need for the program and dedicated resources to it.
- **Results came fast** from preliminary exercises. This was followed by a special journal issue.
Southern Hemisphere stratocumulus clouds do not peak during the southern monsoon seasons.
Monsoon: Interhemispheric influences
VOCALS Experience and Atlantic Workshop

- There are both important similarities and differences between the SEP and SEA climates.
- CGCM difficulties in the SEA seem to be at least, if not more, serious than in the SEP.
- Similarly with the aerosol
- Possible strategy for Atlantic Research:
  1. Document program motivators (e.g. model errors)
  2. Formulate Hypotheses
  3. Design meaningful preliminary exercises
  4. Enlist Agency and Oper Center Support
  5. Set up the basis for an international field campaign
African topography also promotes Namibian Sc

Stratocumulus Incidence August