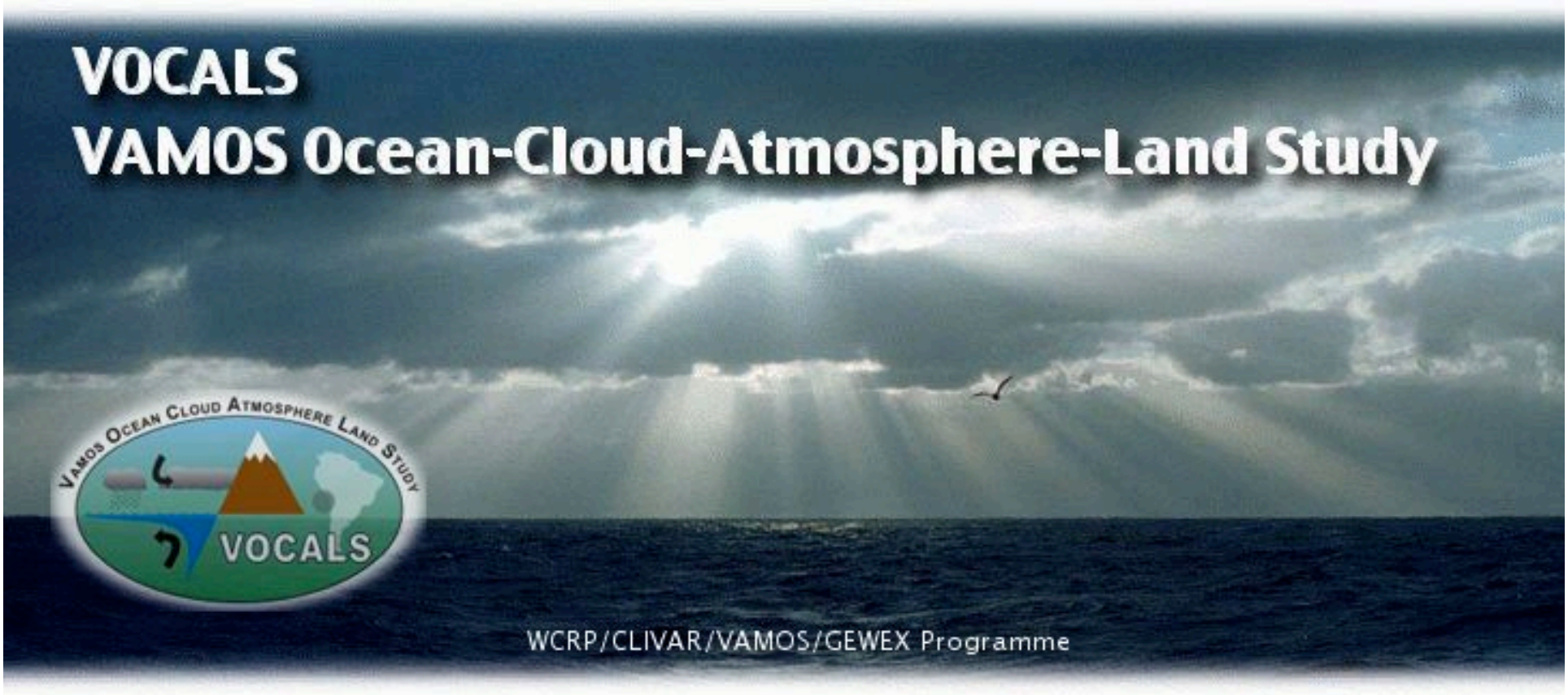
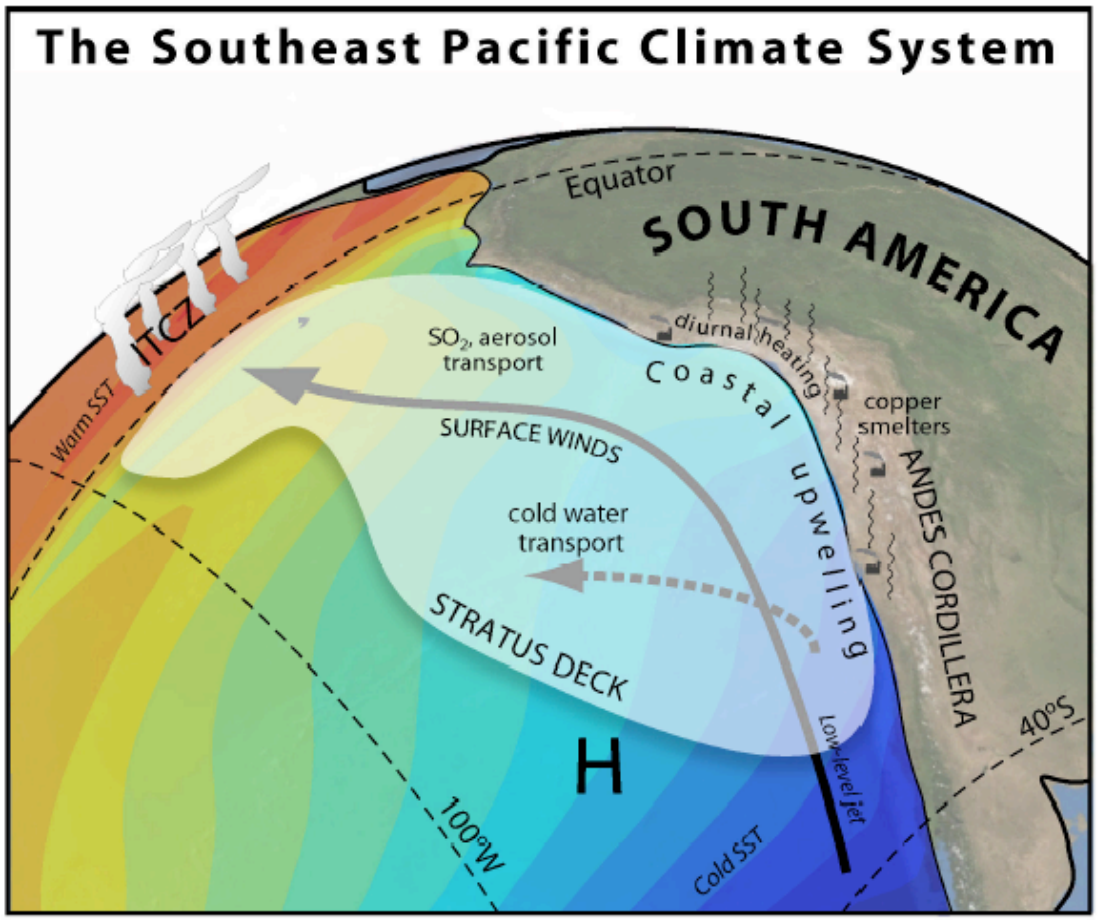
VOCALS Status Report

Robert Wood, University of Washington
on behalf of the VOCALS Scientific Working Group





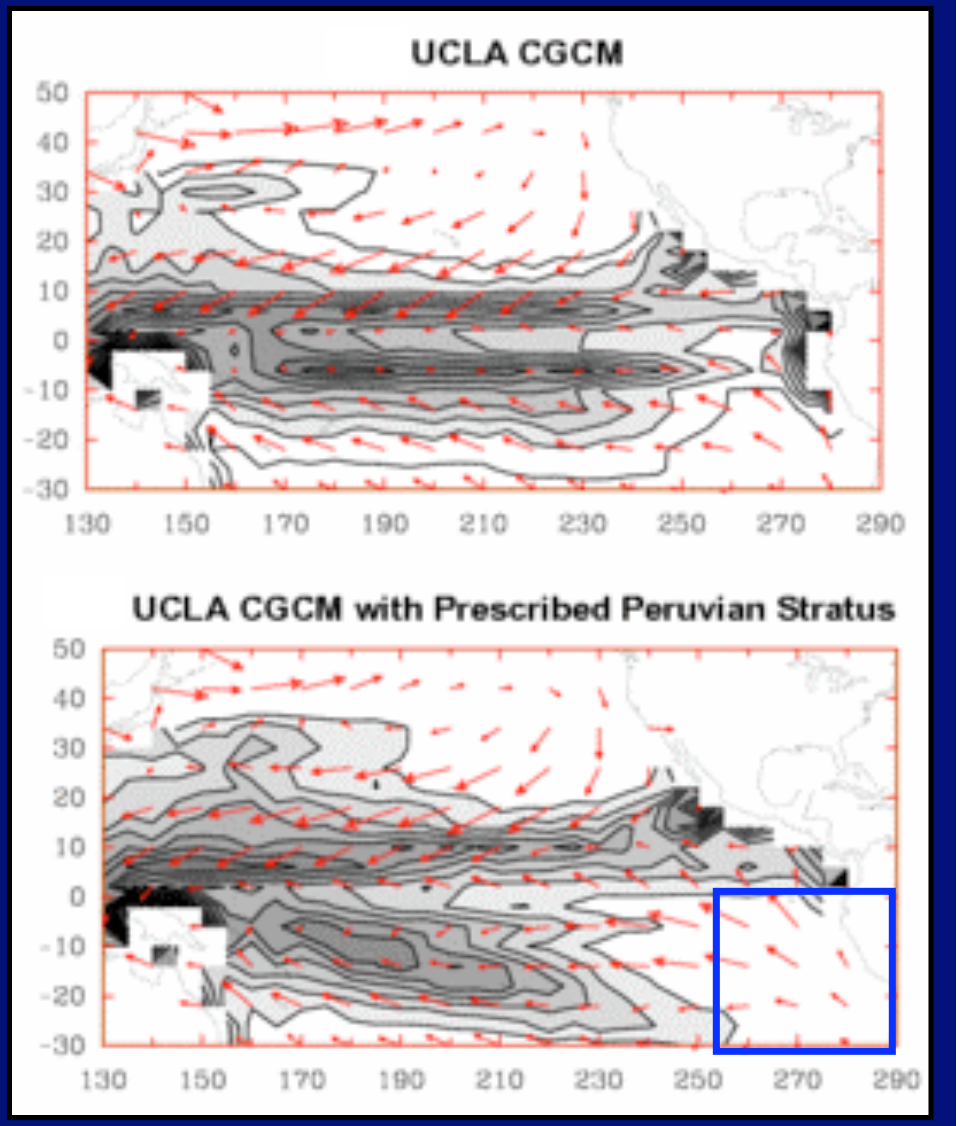
- Cold SSTs, coastal upwelling
- Cloud-topped ABLs
- Influenced by and influential on remote climates (ENSO)
- Poorly simulated by atmosphere-ocean GCMs
- Unresolved issues in heat and nutrient budgets
- Important links between clouds and aerosol

VOCALS Science Issues

- Atmospheric, oceanic, and coupled model biases and model improvement in the Southeast Pacific (SEP) and other subtropical cool-ocean regimes.
- SEP aerosol-cloud interaction; implications for aerosol indirect effect and regional climate.
- SST distribution and the ocean heat budget in the SEP.
- Role of South America and remote forcing from tropics and midlatitudes, on diurnal to interannual (ENSO) timescales.

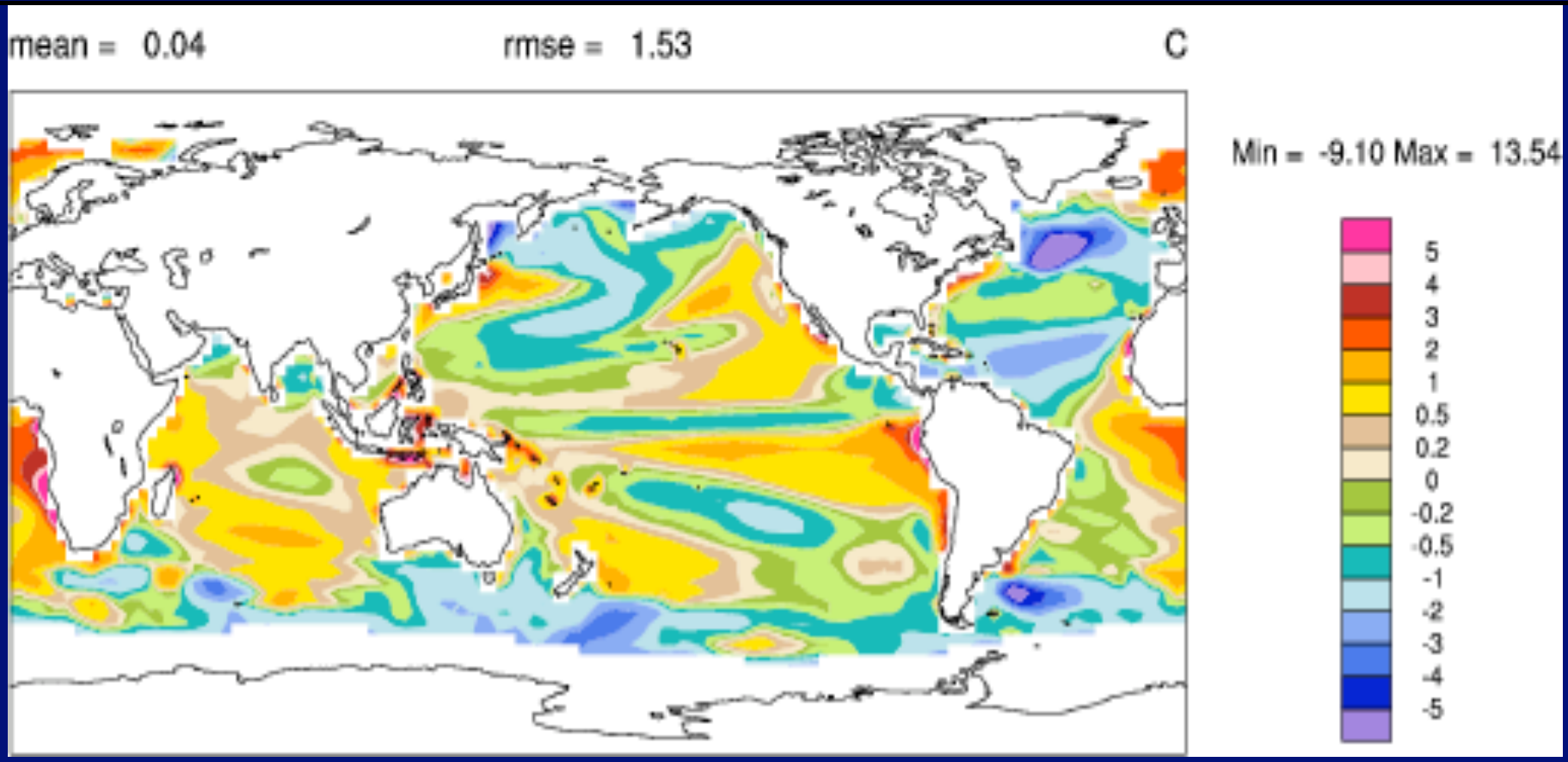
A coupled problem

- Correct prediction of stratus properties is important for the correct prediction of the climate over the tropical warm pool
  - connections with ITCZ through both ocean and atmosphere



Yu and Mechoso 2001

SST Biases



Annual-mean SST biases in CCSM3 1990 control run (Collins et al. 2005)

VOCALS 3-Pronged Approach

(1) **MODELS**: Diagnosis and advancement of atmosphere, ocean, and coupled regional and global model simulations of the SEP

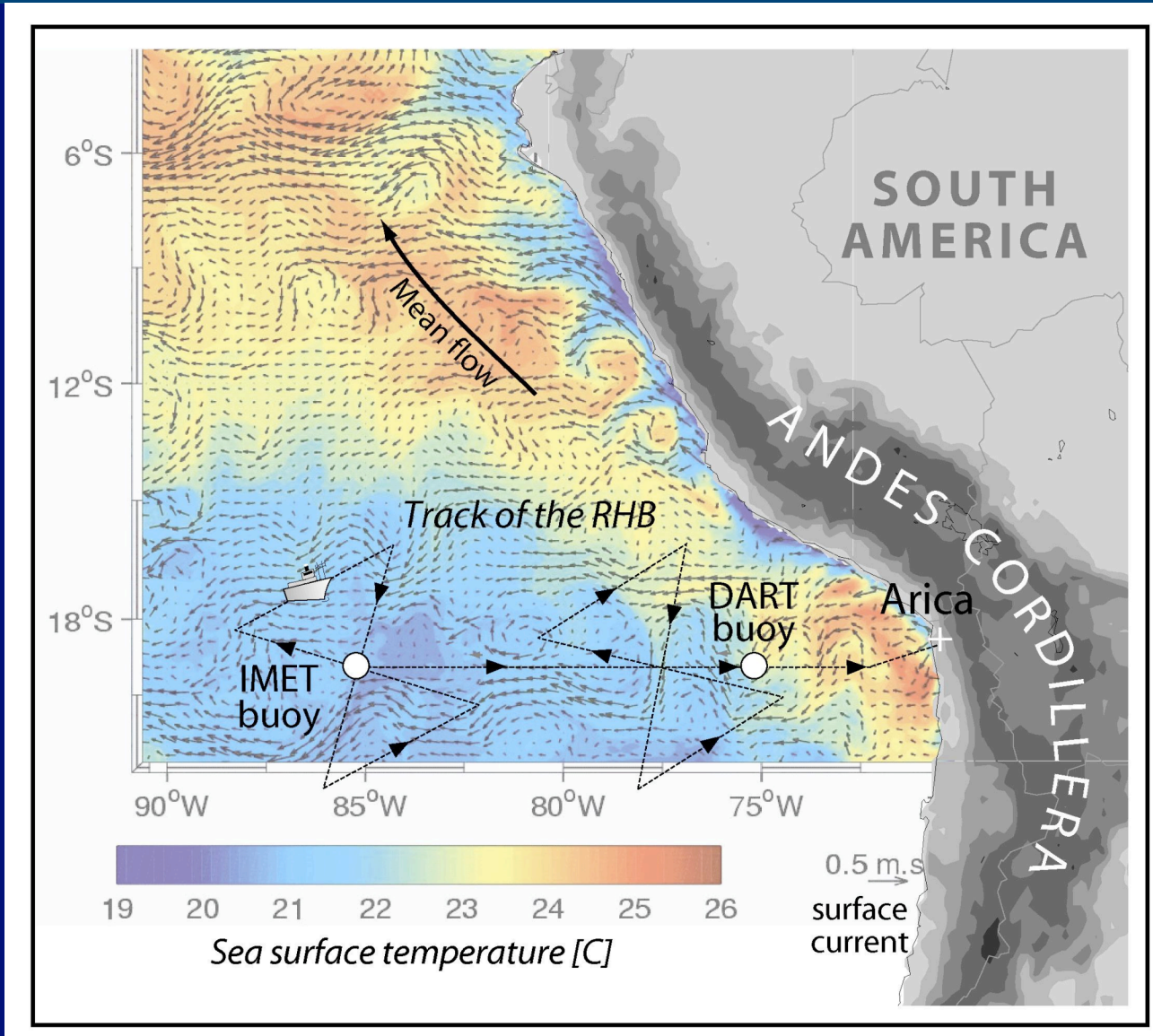
(2) **EXTENDED OBSERVATIONS:** Diagnostic studies of existing and targeted new observations in the SEP, coordinated between several research groups and feeding into the modeling activities.

(3) **FIELD PROGRAM:** The VOCALS Regional Experiment (VOCALS-REx) field program.

(1) MODELS

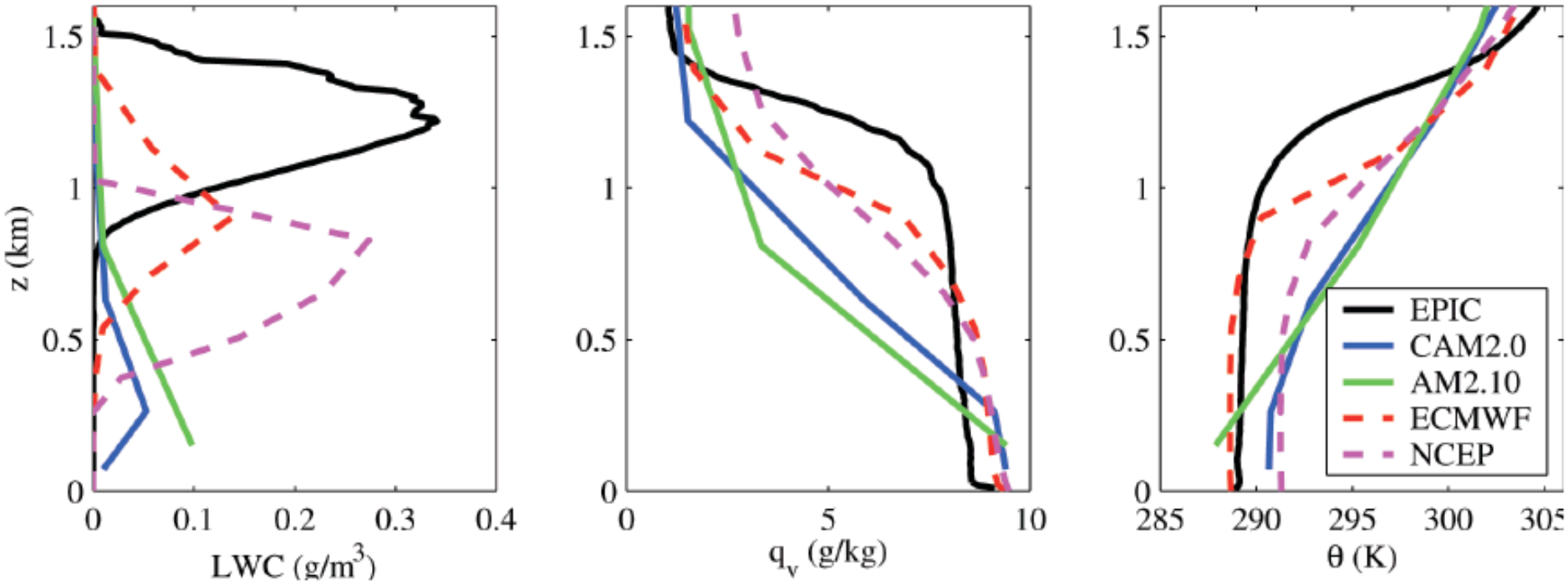
- VOCALS Modeling Workshop to be held at NCEP, early summer (groups from NCEP, NCAR, GFDL, UCLA… y otros)
- Coordination with other activities and centers (CPT, Tropical Biases)
- Coordinated modeling proposals:
  - aerosol-cloud-precip-ocean interactions (Wang, Pullen, NRL and Liu, NASA) to NASA
  - coupled ocean-atmosphere (Mechoso, Liou, Wood) to NOAA CPPA/ACC

Mesoscale eddies – Regional Ocean Modeling



Penven et al. 2005

SEP stratocumulus in GCMs



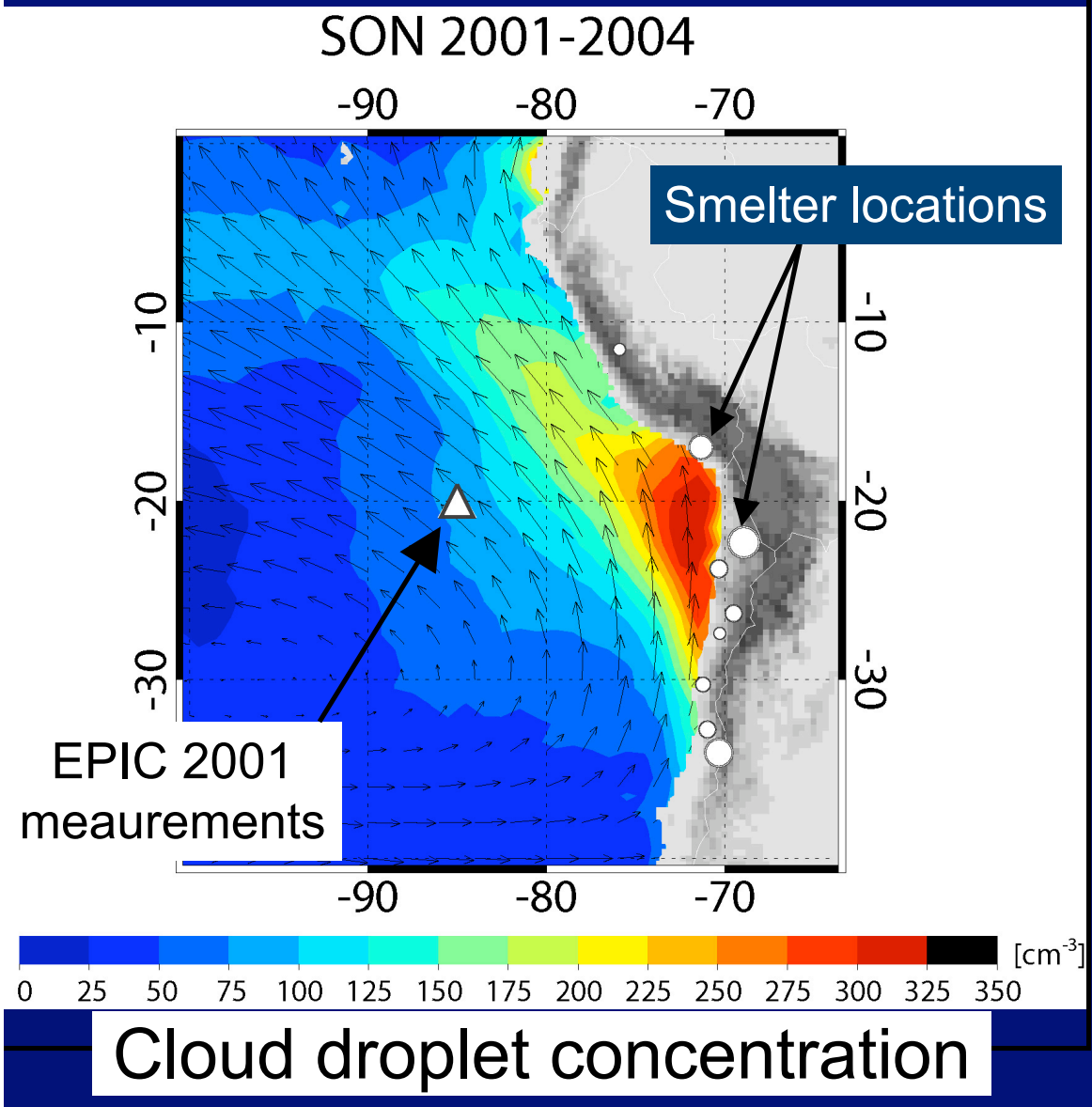
Poor representation of the vertical structure of stratocumulus-topped boundary layers – improved parameterization central to improved global models

Bretherton et al. 2004, *BAMS*

(2) EXTENDED OBSERVATIONS

- Buoy maintenance/PACS/EPIC cruises from 2001, 2003, 2004, 2005. Additional cruise planned for 2006
  - New measurements include aerosols (2003/2004, Texas A&M University) and improved cloud radar (Fairall)
- Continued high quality dataset from IMET buoy
- Automated meteorological observations from San Felix Island (Garreaud/Rutllant, U de Chile)
- Satellite datasets being analysed (Wood/Bretherton, U Washington) – Cloudsat/Calipso to be launched this week

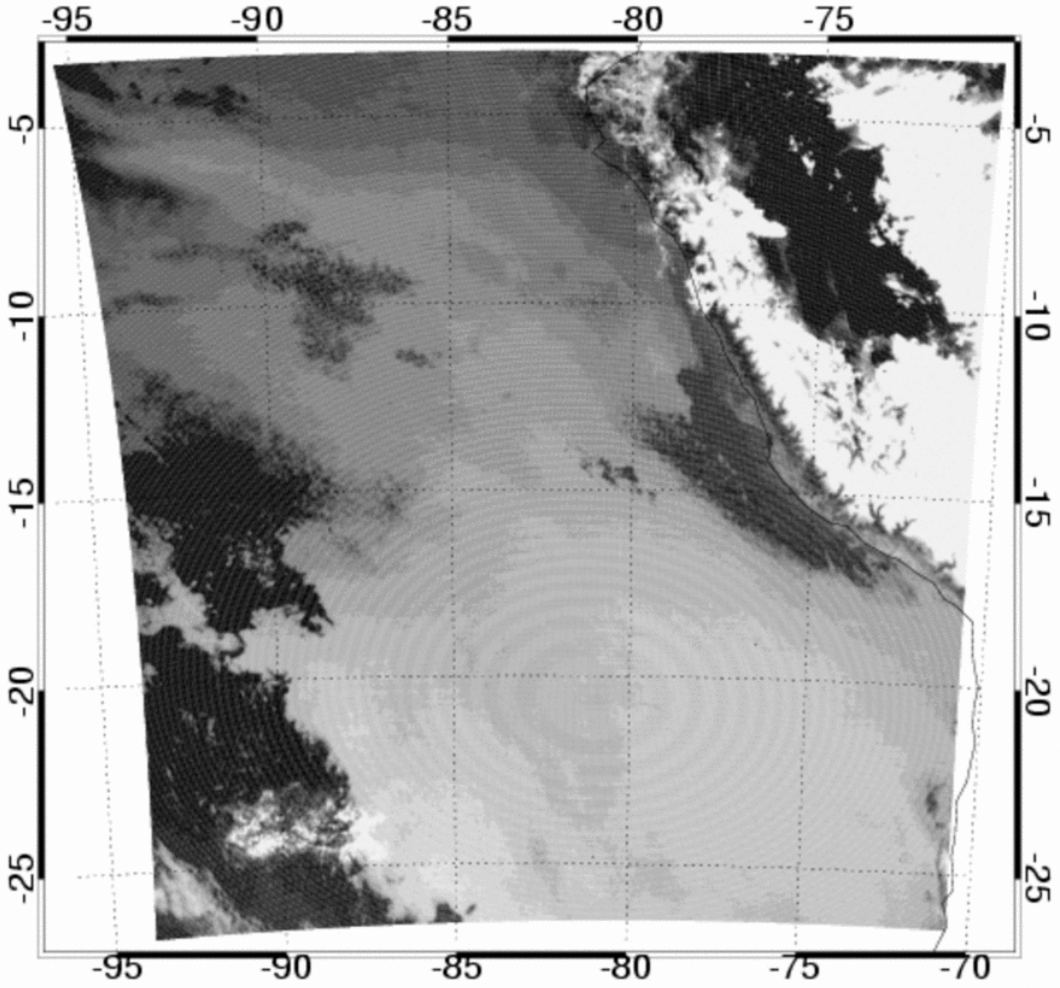
Pollution plumes in the SE Pacific



Cloud droplet concentration

- Chile is world's largest copper producer
- Copper smelting SO_2 emissions from Chile (1.5 TgS yr^{-1}) comparable to total SO_2 emissions in Germany
- 90% of Chilean SO_2 emissions from seven smelters!
- Andes mountains prevents eastward

The formation of pockets of open cells (POCs)



GOES thermal IR animation (images every 3 hours spanning 6 days)

(3) FIELD PROGRAM: VOCALS Regional Experiment (REx)

- Joint NOAA/NSF funded field program in October 2007 (or 2008?)
- Main platforms: NSF C-130, NOAA Ronald H Brown, Chilean and Peruvian research vessels
- Scientific Program Overview (SPO) and Experimental Design Overview (EDO) submitted to NSF for peer review January 2006 – expected response May/June 2006

VOCALS-REx Science Goals

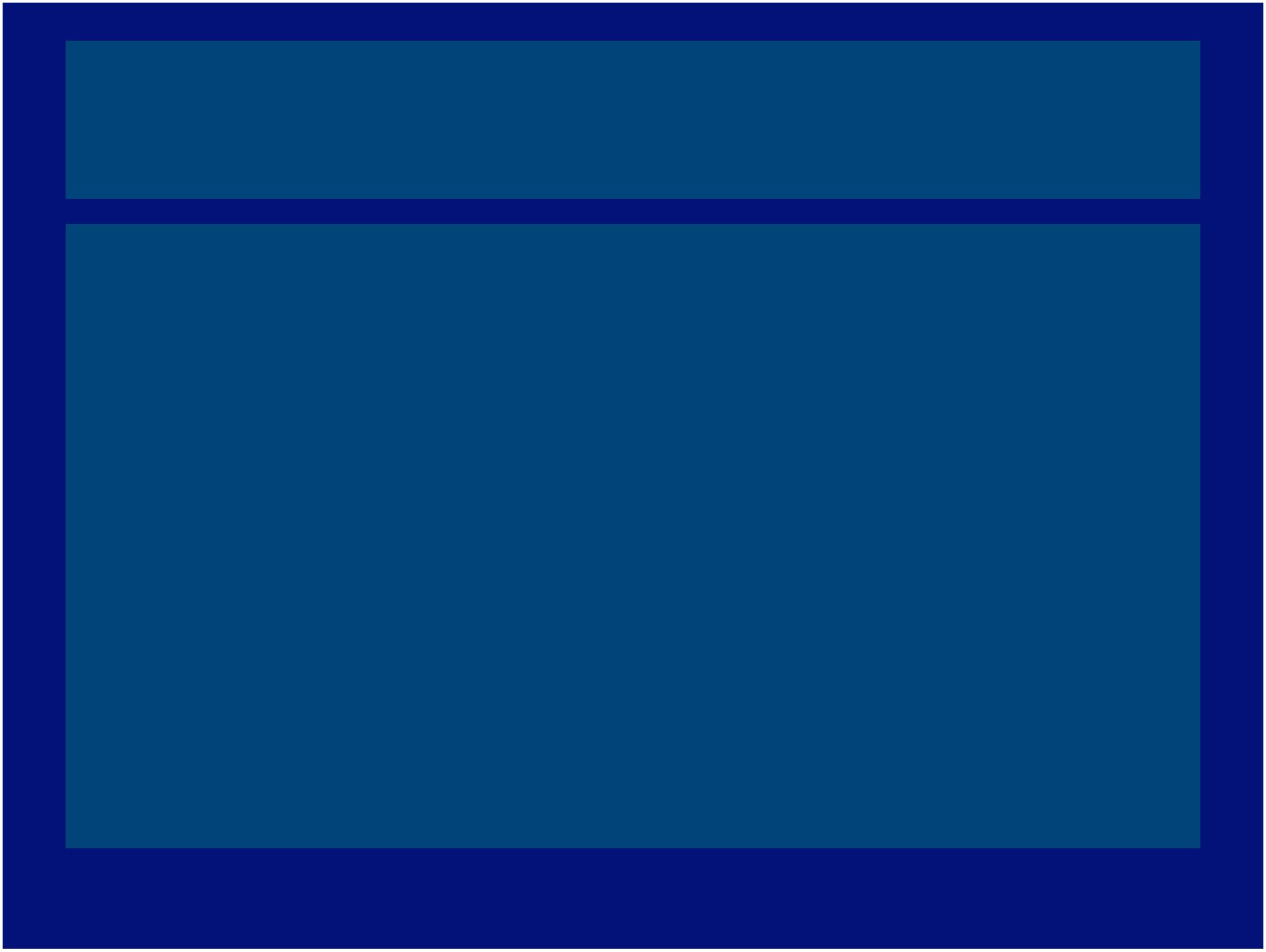
- **AEROSOL-CLOUD-DRIZZLE GOALS**
  - *Factors controlling the stratocumulus cloud thickness, cover, and optical properties over the SE Pacific*
- **COUPLED OCEAN-ATMOSPHERE-LAND GOALS**
  - *Physical and chemical links between the topography, coastal oceanic upwelling and the marine boundary layer*

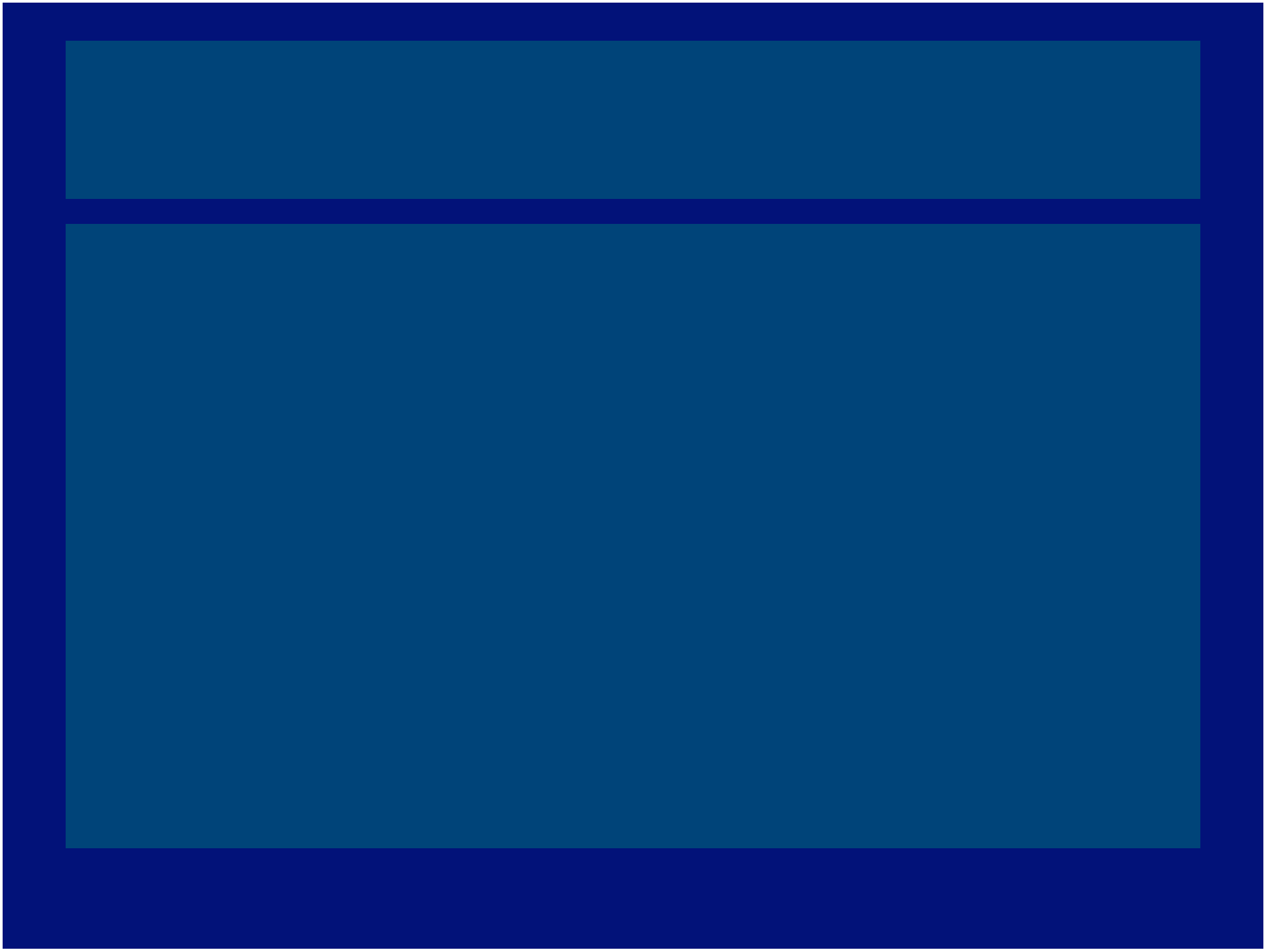
Status of VOCALS-REx 1

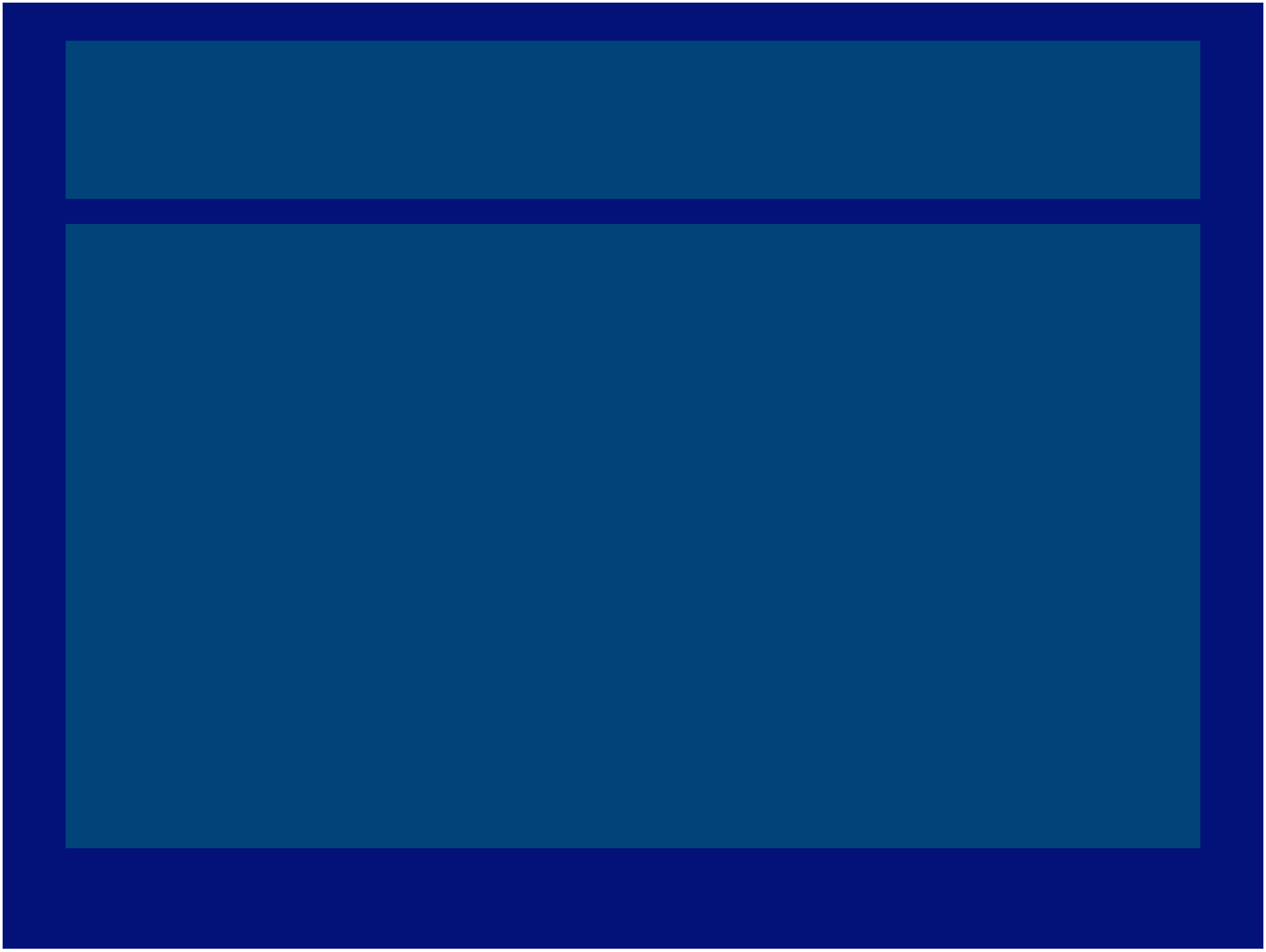
- Interagency briefing held in Washington DC in December. Well attended by NSF, NOAA and NASA
- Positive response from NOAA Climate (a call for VOCALS-related proposals will be made soon)
- NSF participation contingent upon outcome of peer review of SPO/EDO
- Chilean and Peruvian contributions (coastal cruises)
- NSF Chemistry interested in VOCALS but nothing definite as yet – coordination with other initiatives

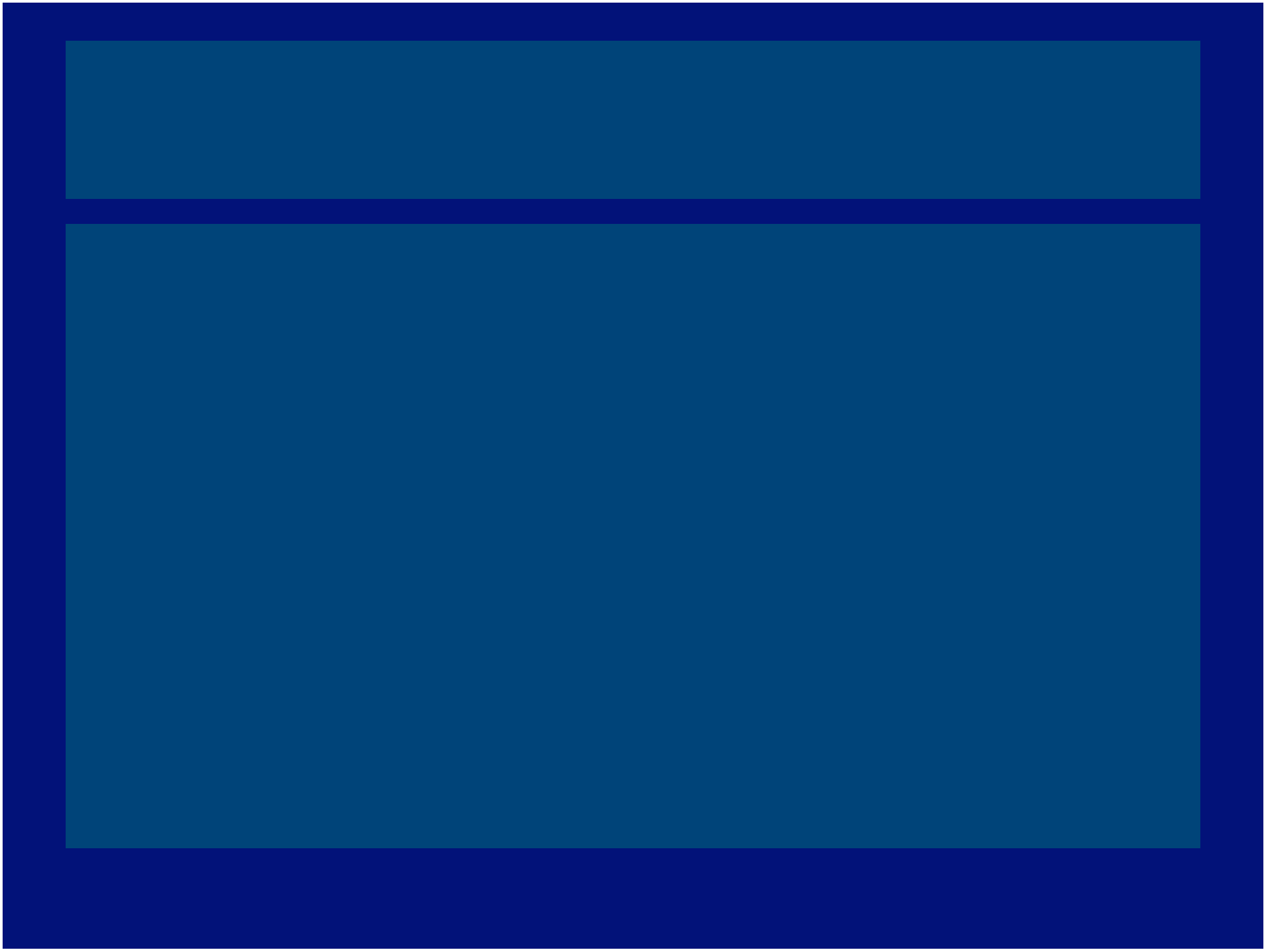
Status of VOCALS-REx 2

- Interest of NSF OCE uncertain, but proposals from Weller and others submitted; Wijisekera to submit proposal for SeaSoar when second ship can be identified
- Huebert has NSF funds to study DMS fluxes on the Ronald H Brown
- Interest from NASA (remote sensing), but nothing definite. Will push this during 2006 (radiation conference). Proposal expected to use VOCALS-REx data for validation of satellite programs









VOCALS Open Ocean: Science and Logistics

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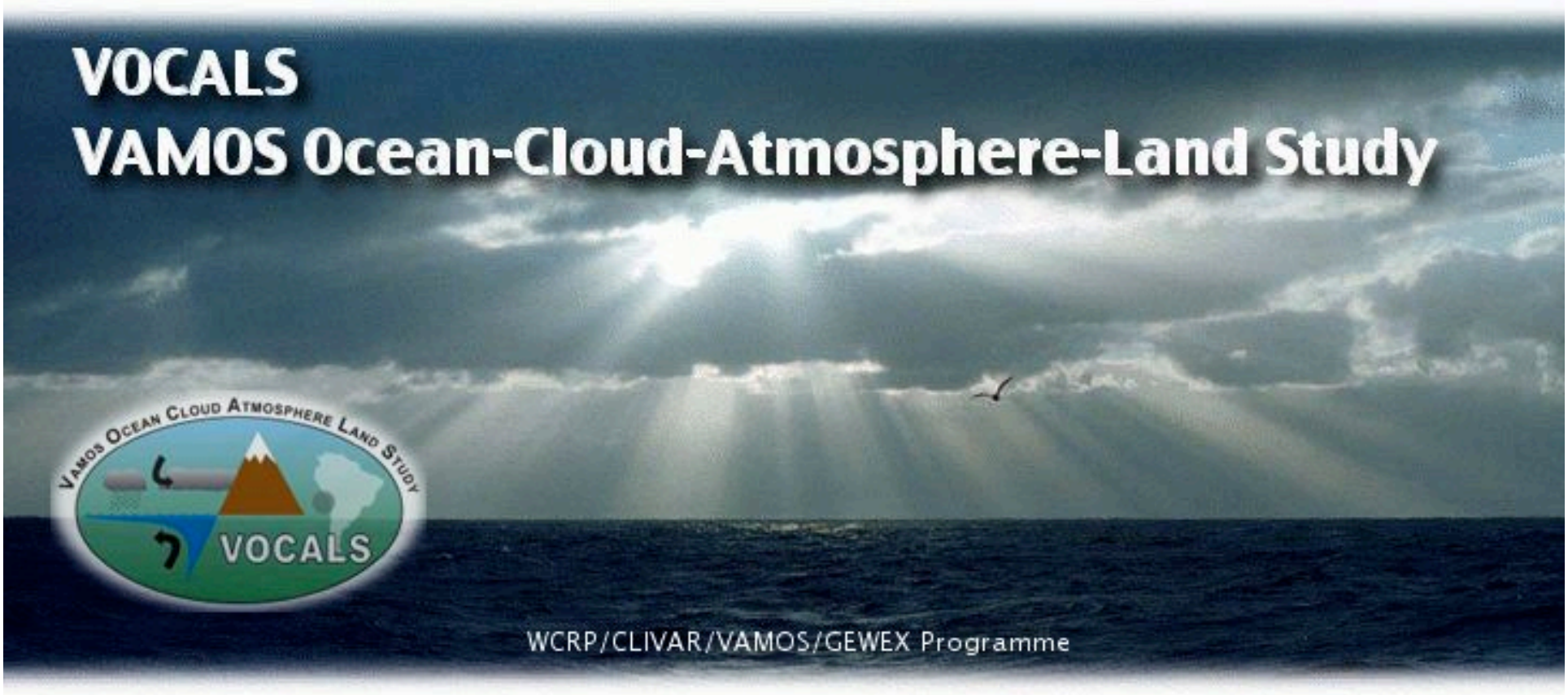

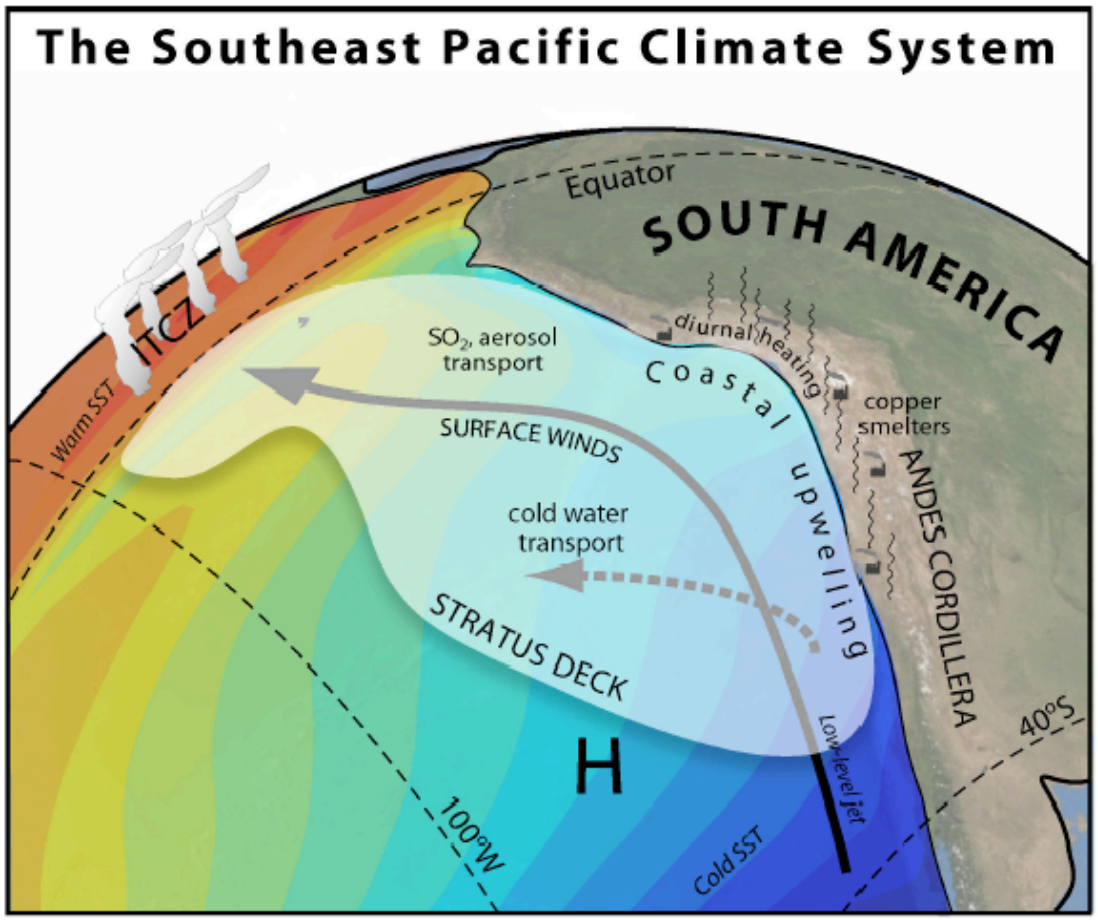

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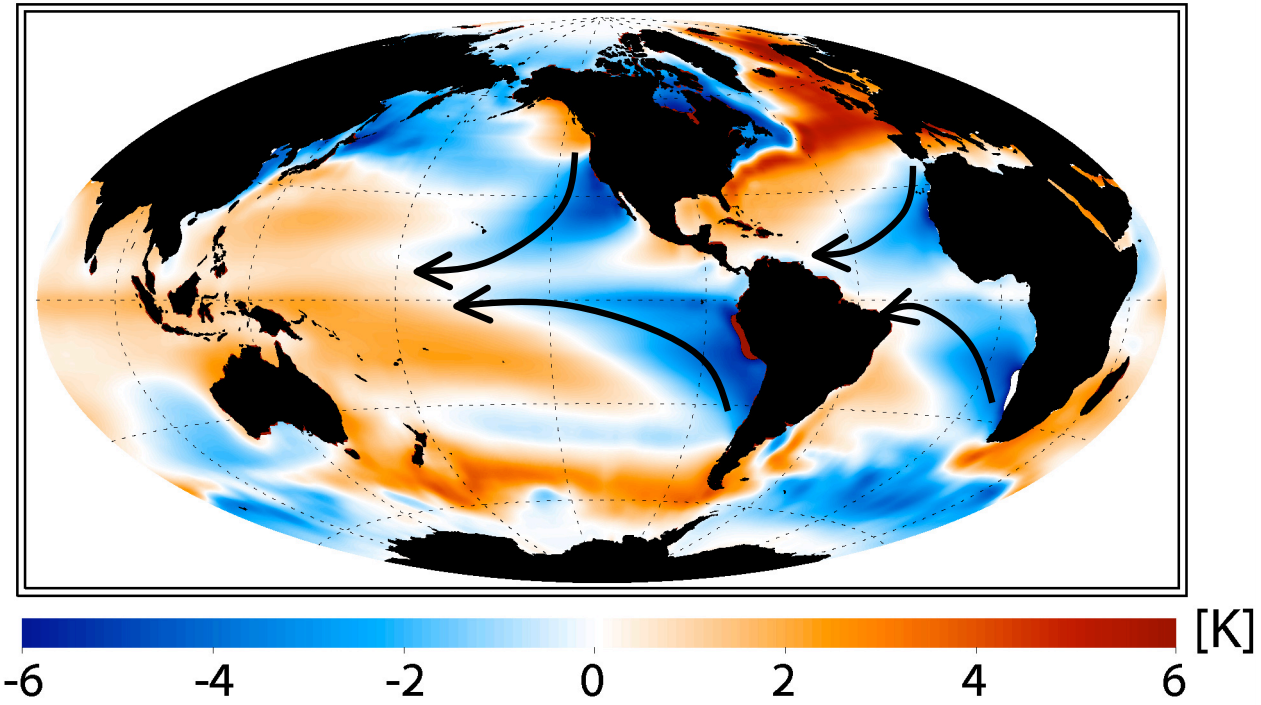
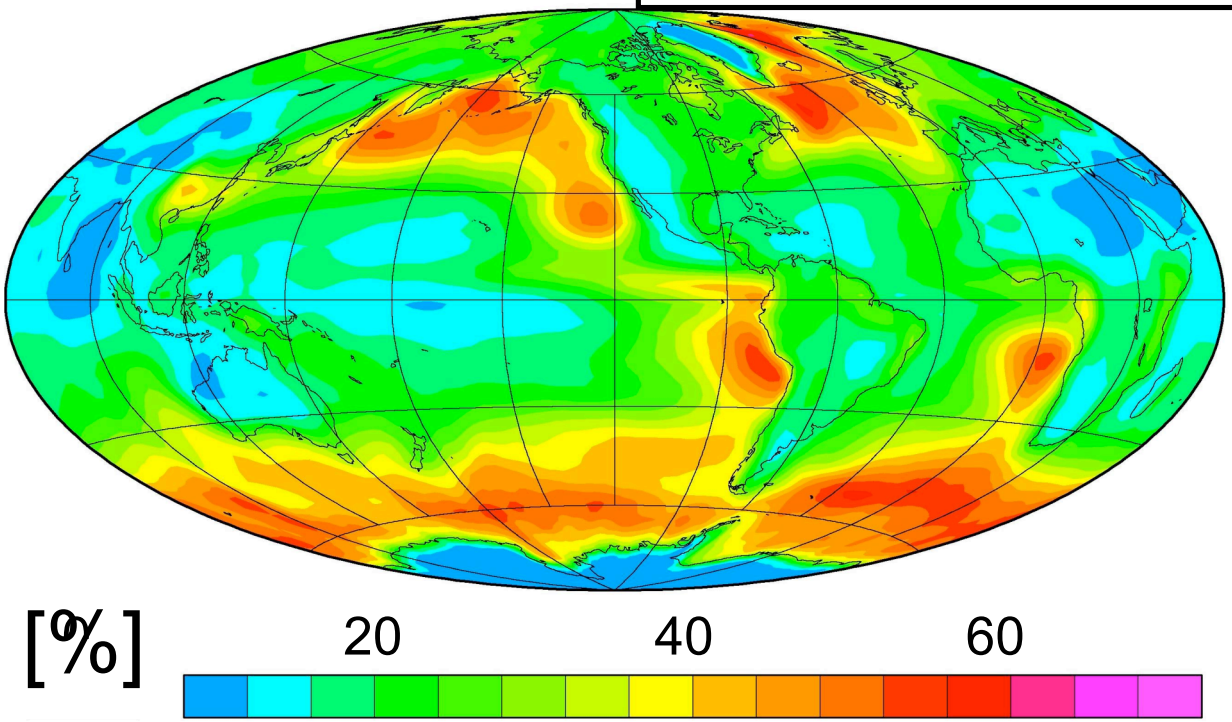
SST anomaly from zonal mean

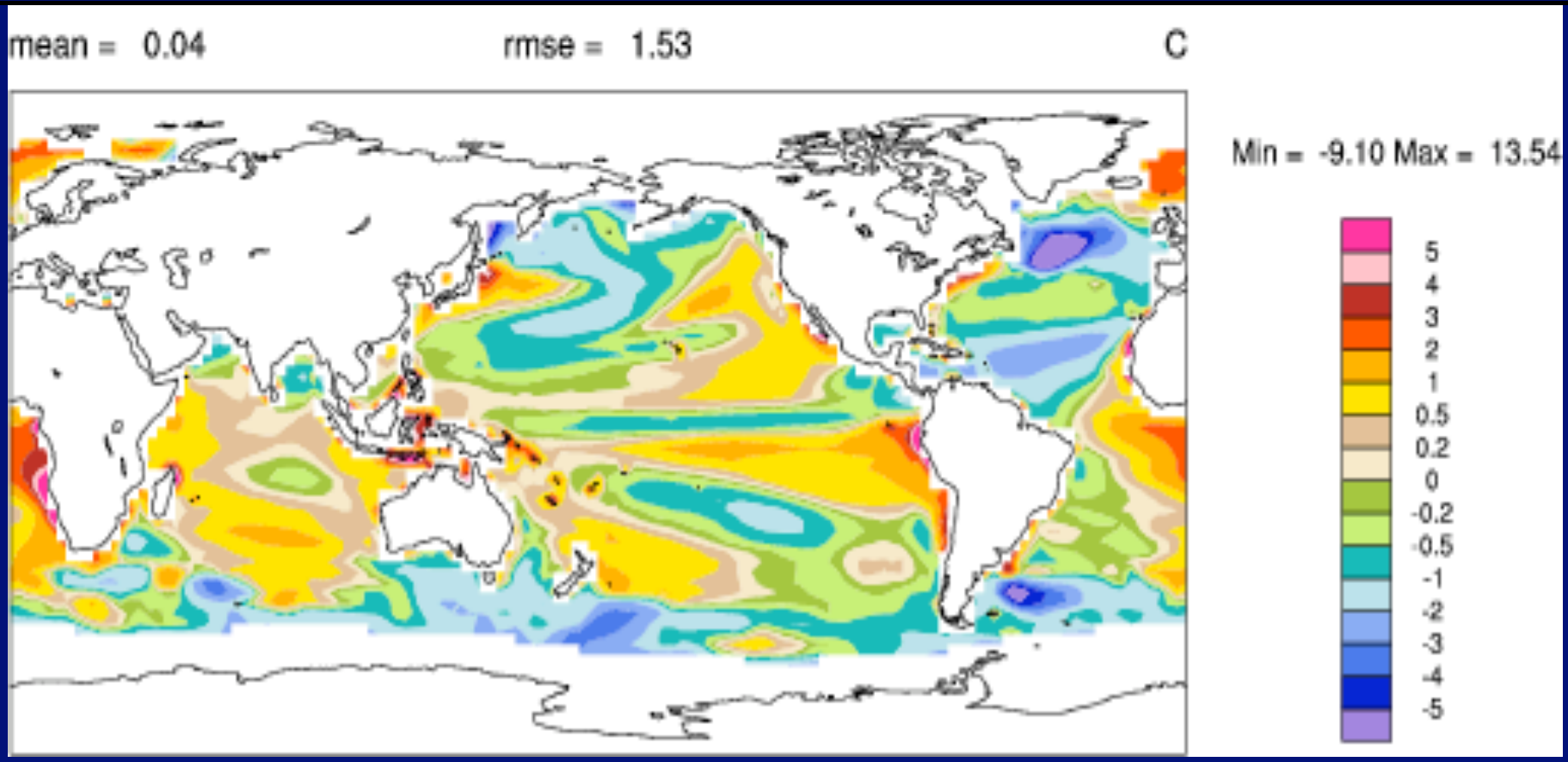


highly reflective low clouds



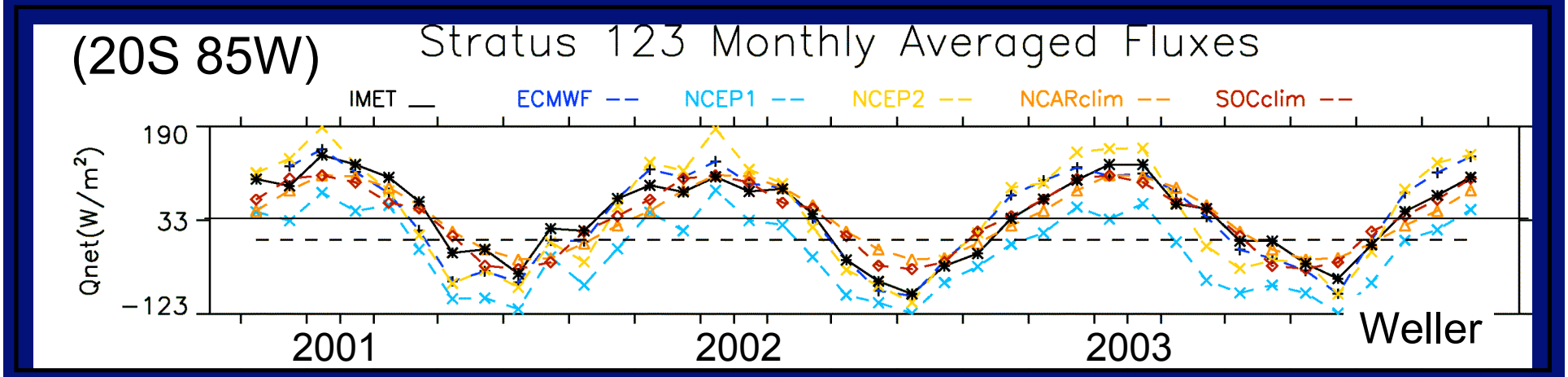
ISCCP inferred St/Sc amount

SST Biases



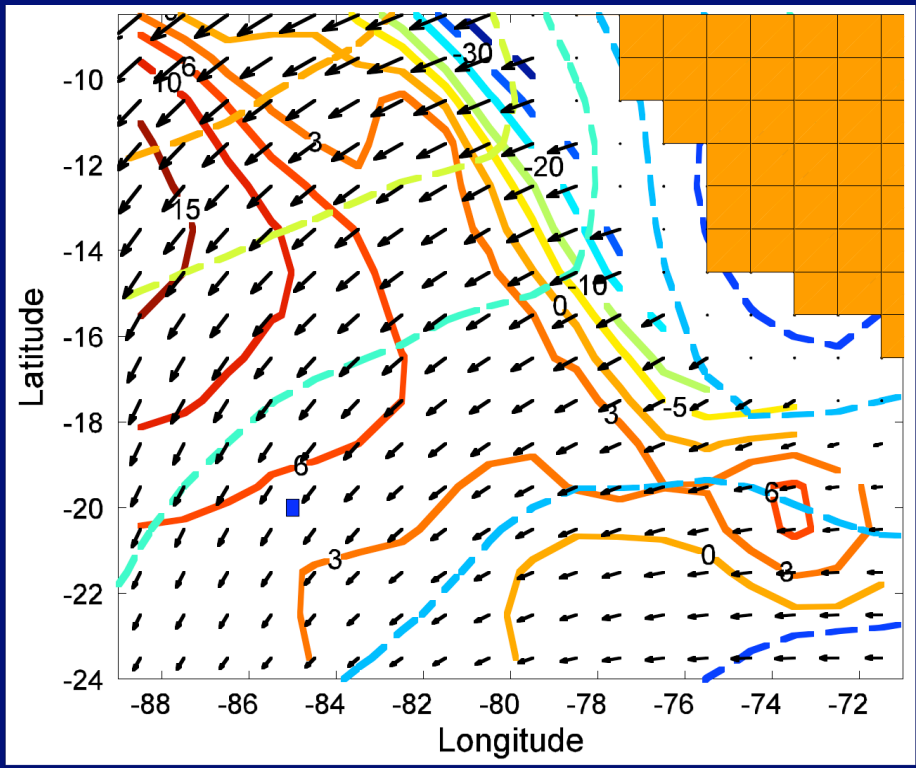
Annual-mean SST biases in CCSM3 1990 control run (Collins et al. 2005)

Issues in ocean transports

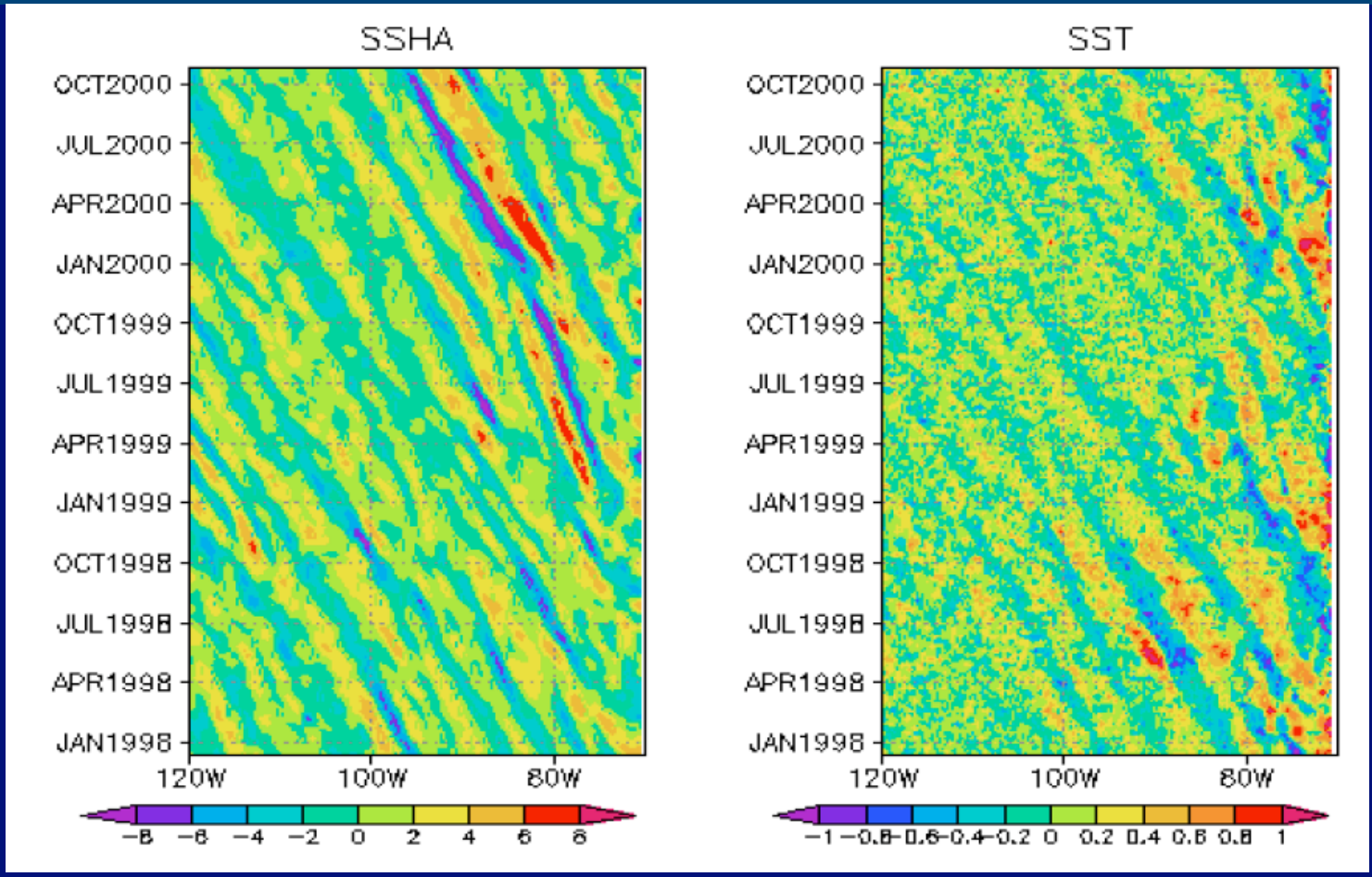


Annual-mean heat flux **into** ocean ~ 30 W m^{-2} at 1500 km offshore under persistent low cloud!

How is this net warming at the surface balanced by ocean heat transports?



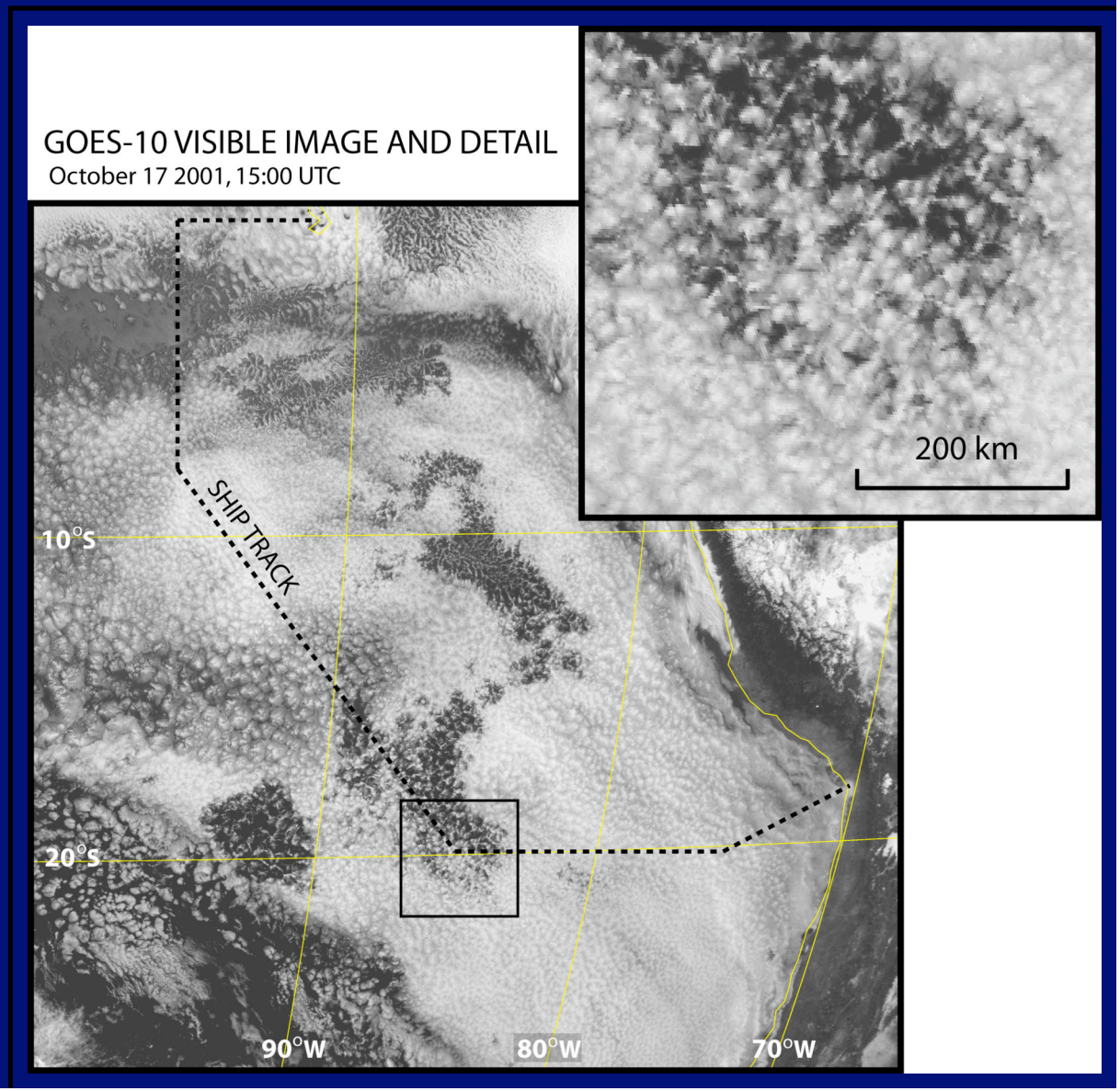
Mesoscale ocean eddies?



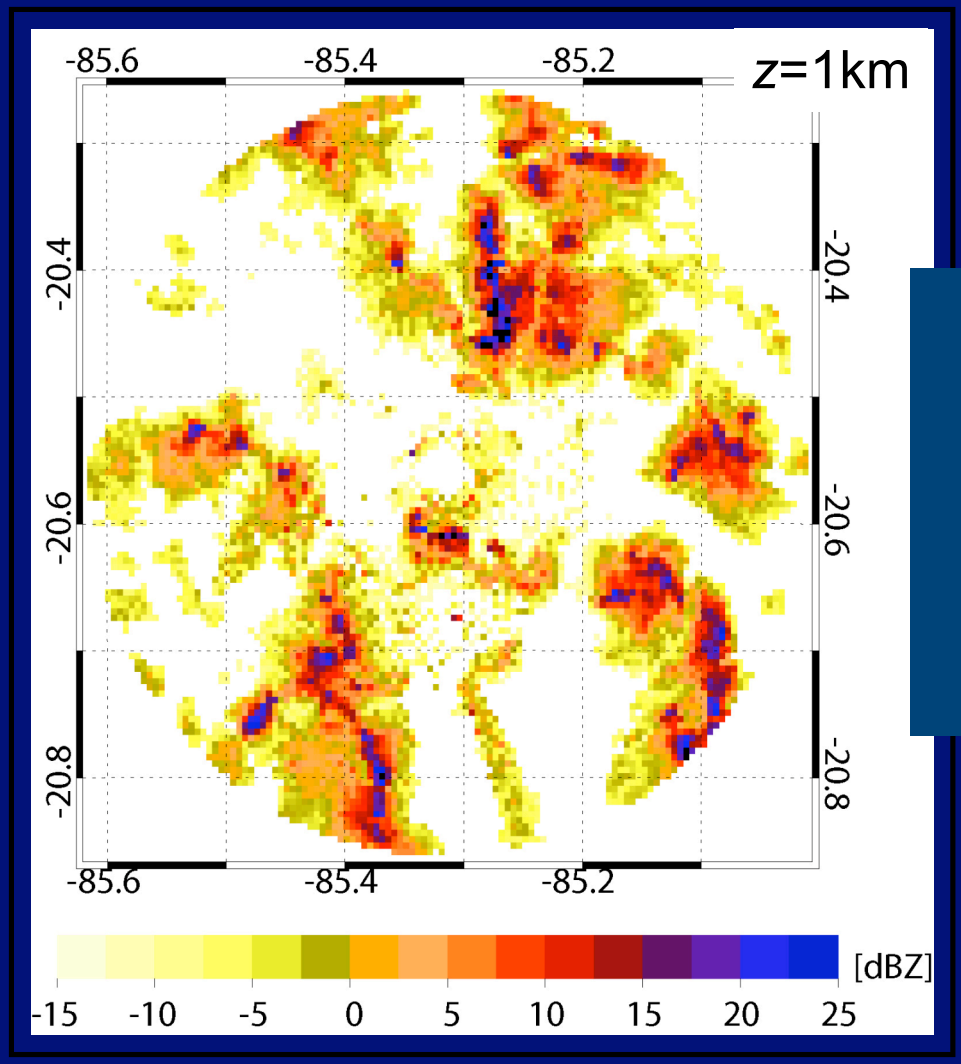
Bandpassed satellite-derived sea-surface height and temperature meridionally averaged from 18-22°S. Note anomalies propagating westward at 5-10 cm s-1 (S-P Xie).

Cloud and MBL issues

- Sharp transitions between overcast stratocumulus and open cellular convection
- Pockets of open cells (POCs) form spontaneously – prefer to form in clean clouds

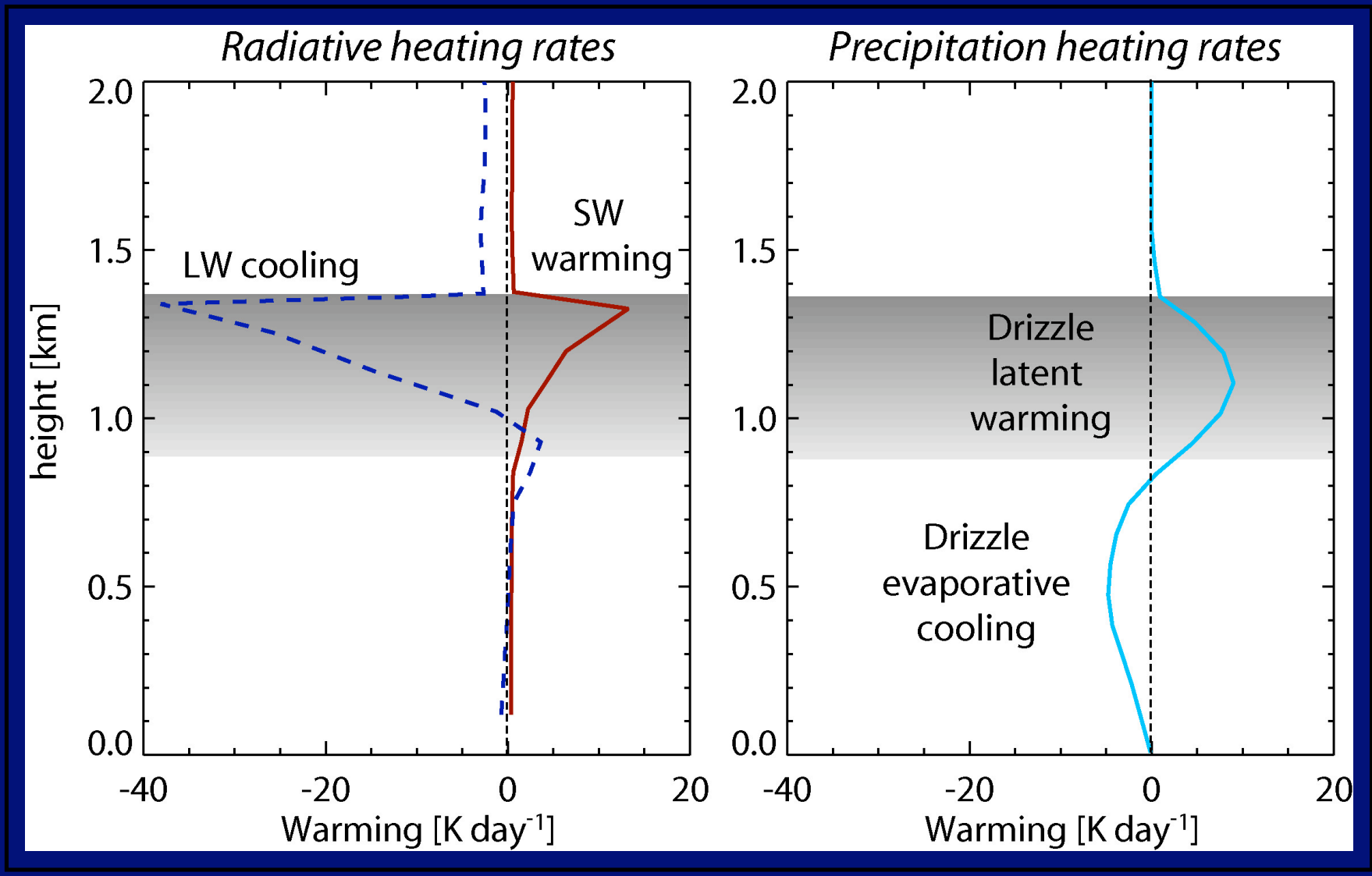


Structural properties of precipitating stratocumulus



50% of the accumulated precipitation comes from rain rates > 9 mm day^{-1}, but originates from only 3% of the area

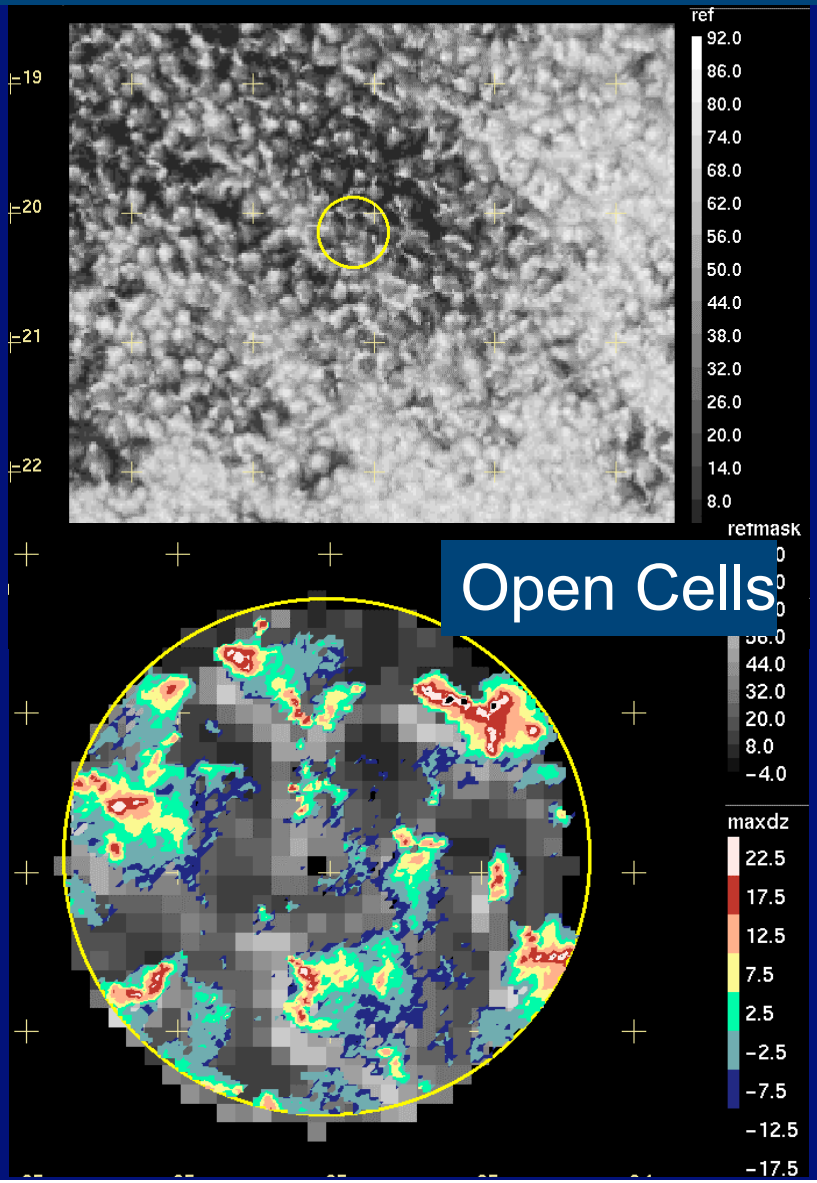
Can drizzle affect MBL dynamics?

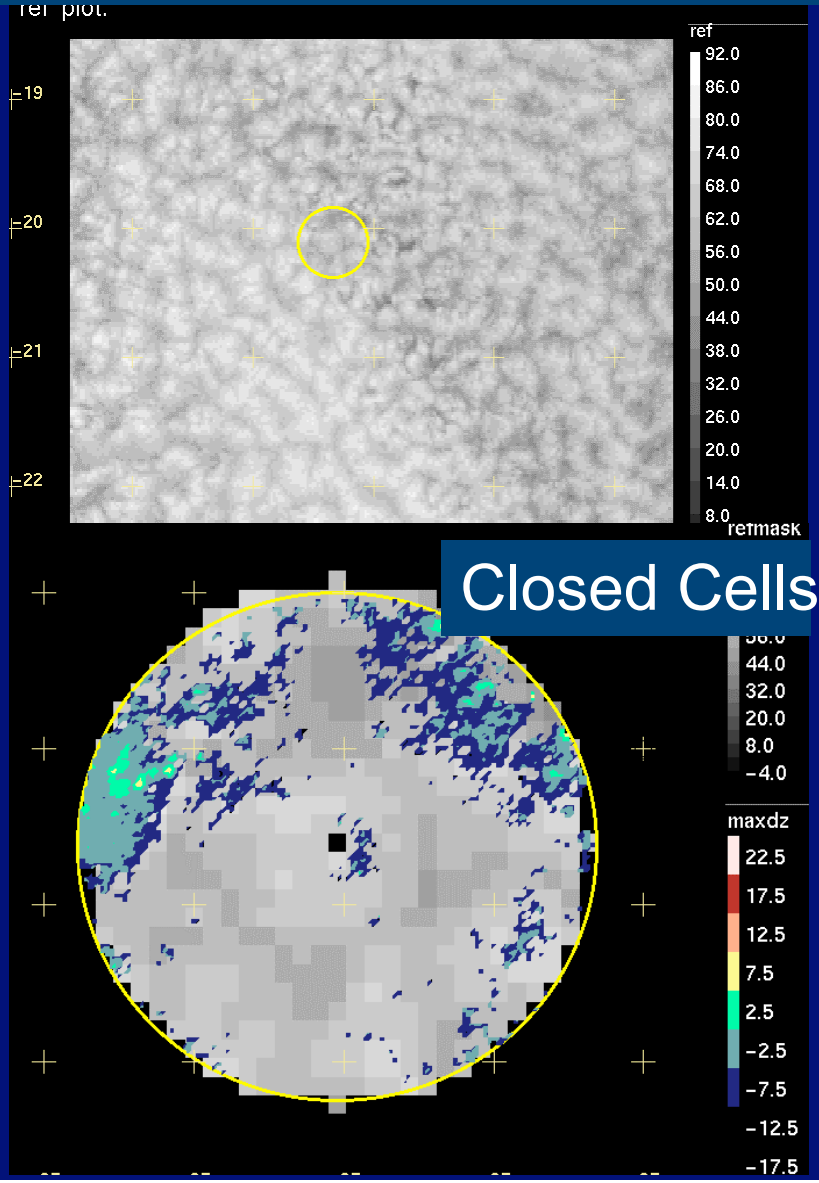


Open cells associated with drizzle (EPIC 2001)

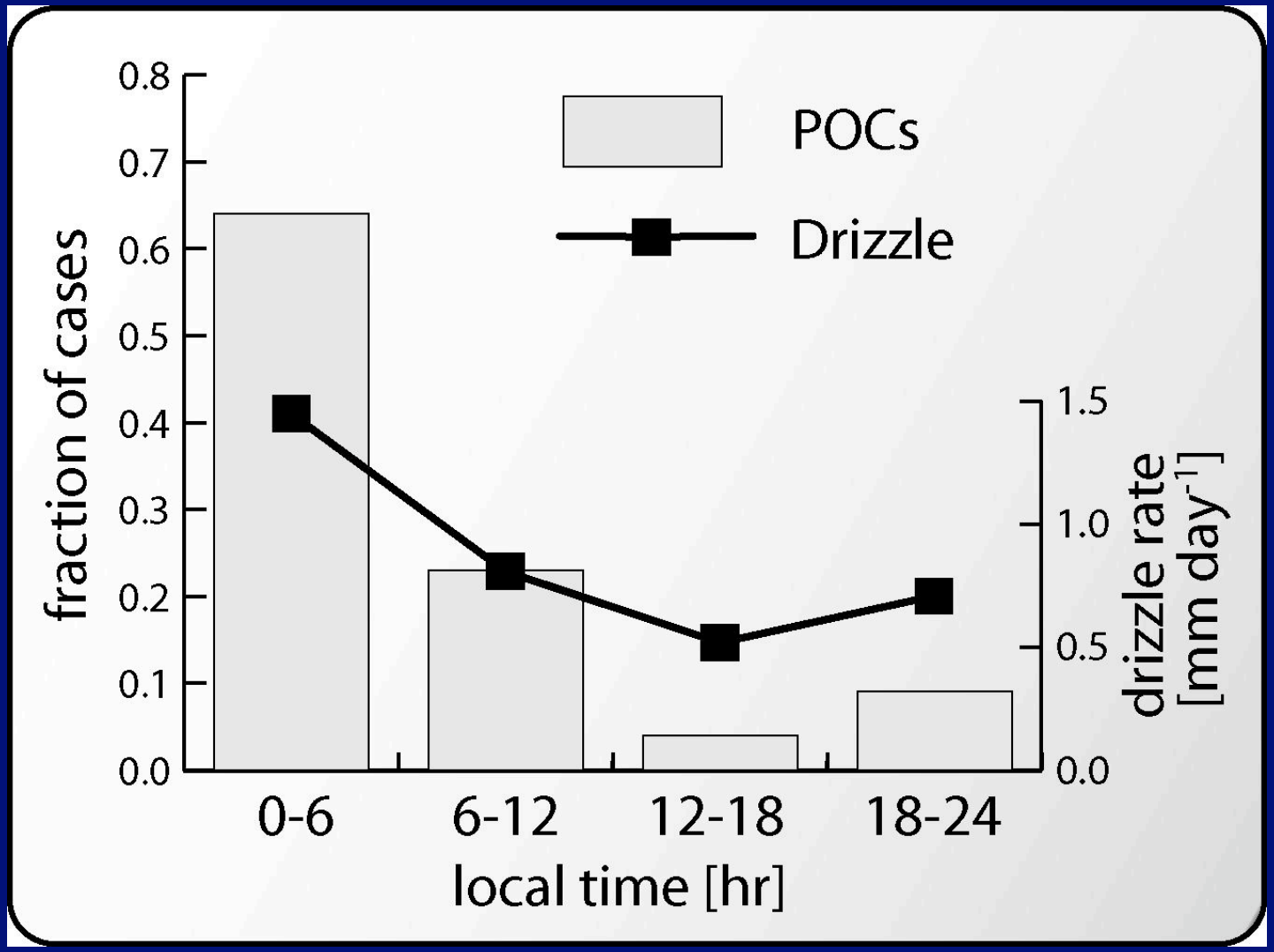
Visible Satellite

Ship Radar

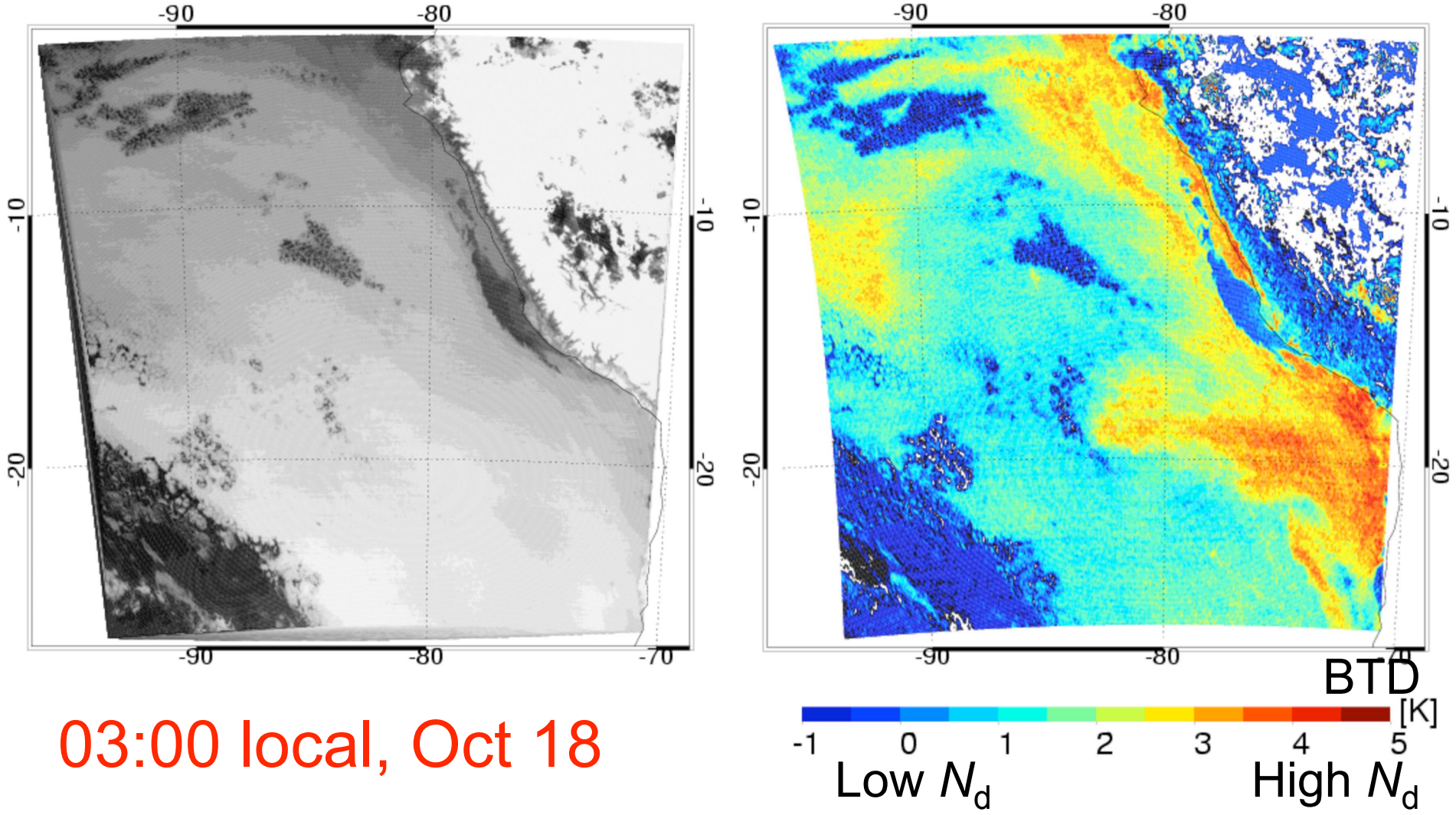




POCs prefer to form at night



GOES IR (left) and 11-3.7 μm brightness temperature difference (right)

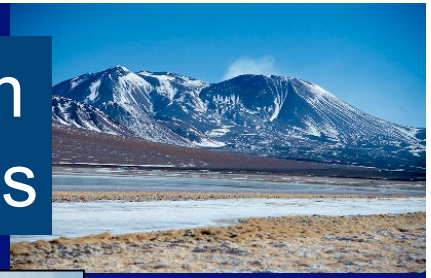


03:00 local, Oct 18

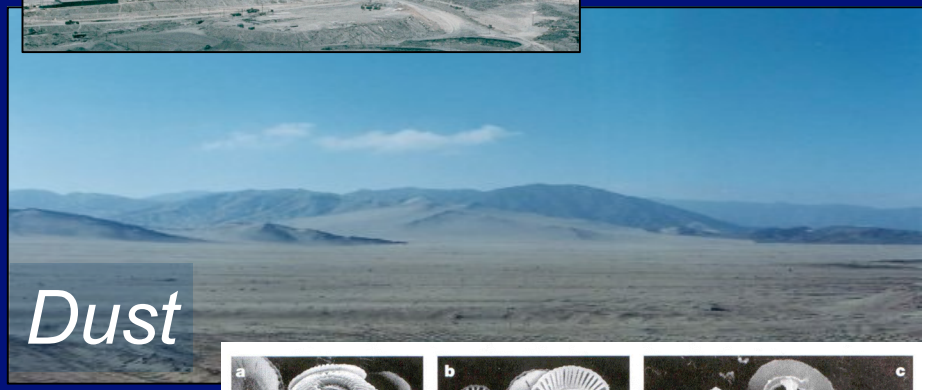
Aerosol issues in SEP

- Locations and strengths of sources of natural and anthropogenic aerosols and precursors
- Regional distribution of aerosol. Relative contribution of anthropogenic and natural sources
- Effects of aerosol on micro and macrophysical cloud properties

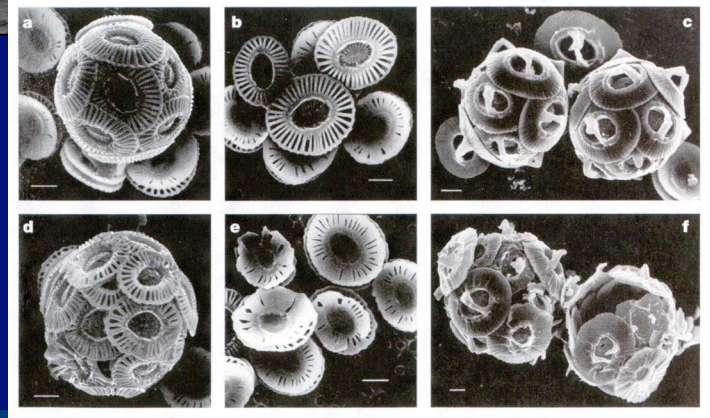
SO_2 from volcanoes



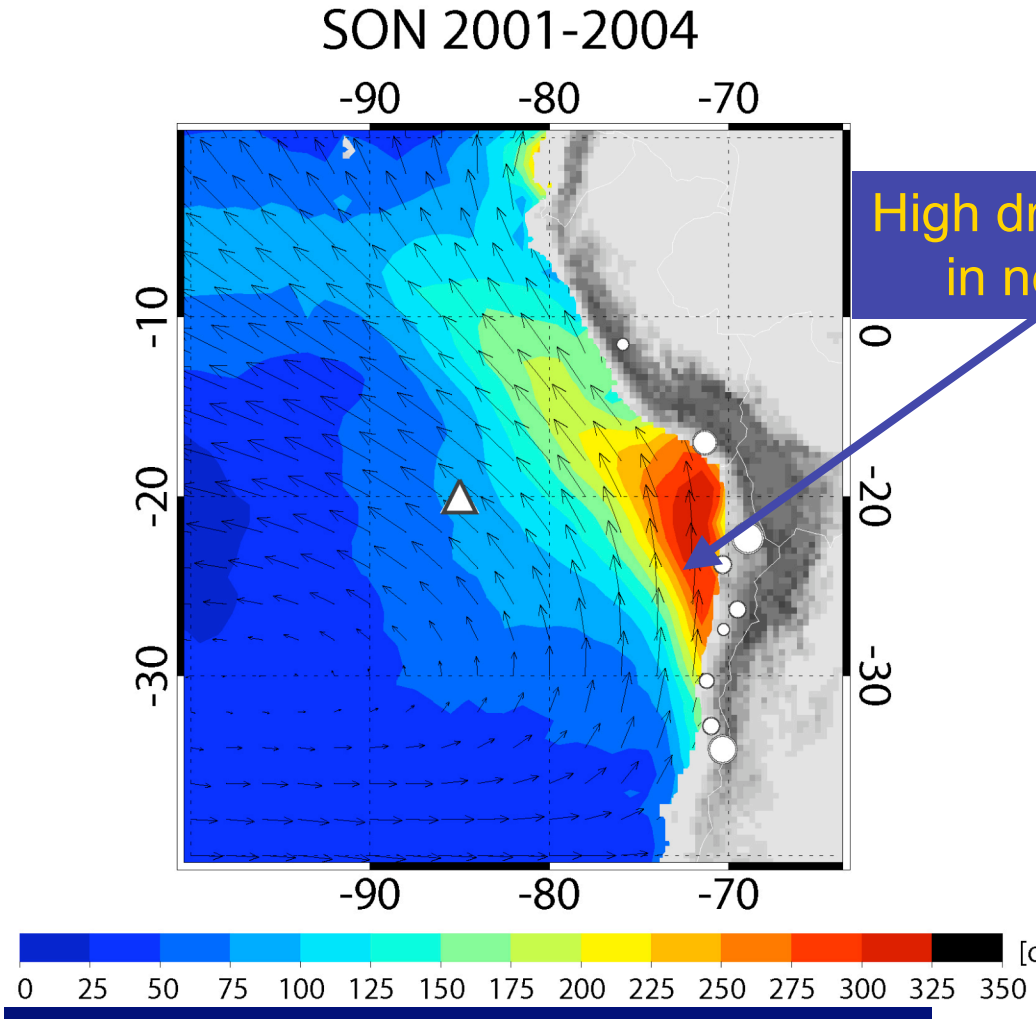
SO_2 from smelters



Dust



DMS, biogeochemistry



High droplet concentrations in near coastal clouds

Cloud droplet concentration

MODIS satellite measurements

Ship aerosol measurements (November 2004)

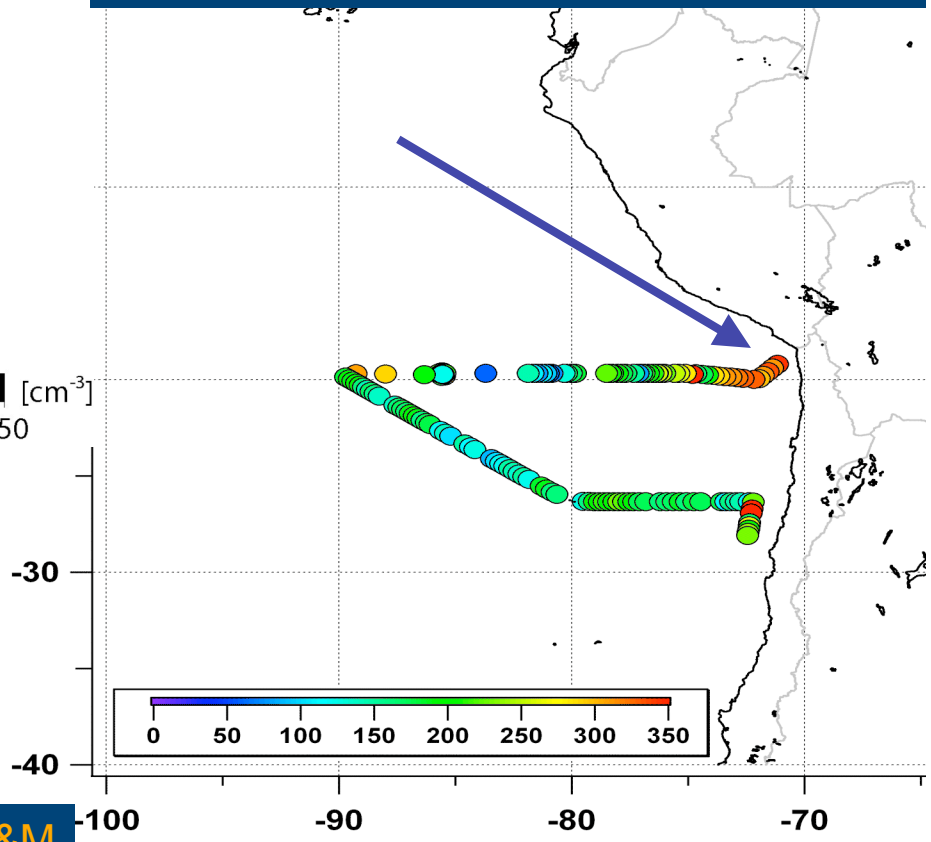
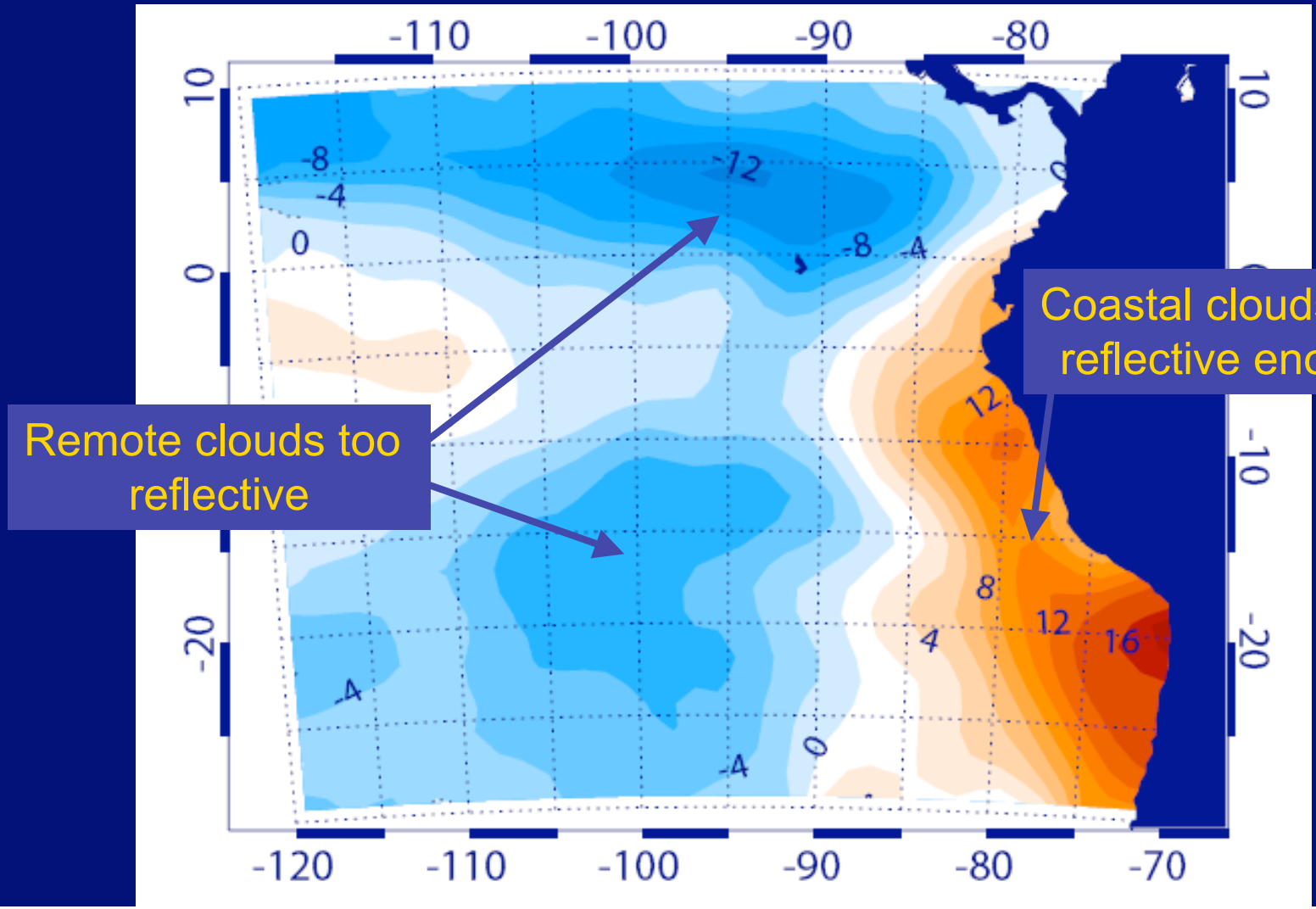
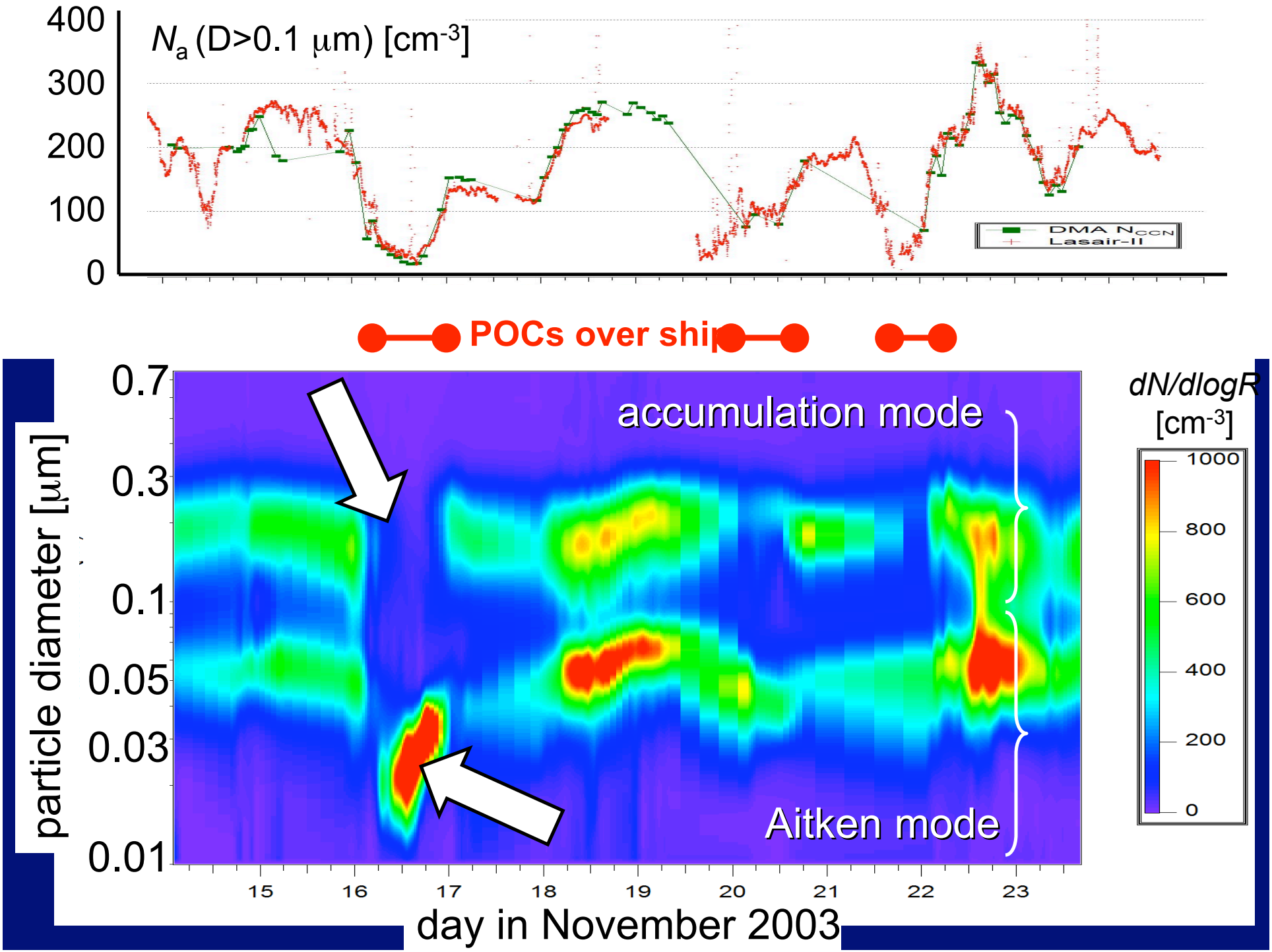


Image courtesy Jason Tomlinson, Texas A&M

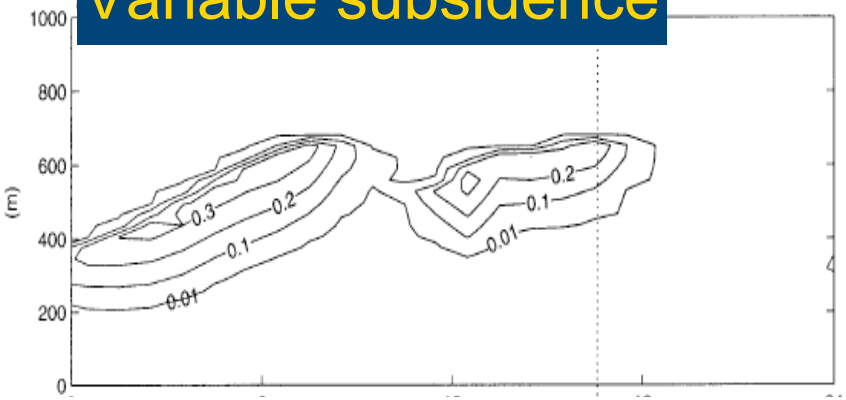
Error in TOA net SW radiation (W m^{-2}) caused by assumption of constant cloud droplet effective radius (here assumed to be 15 microns)



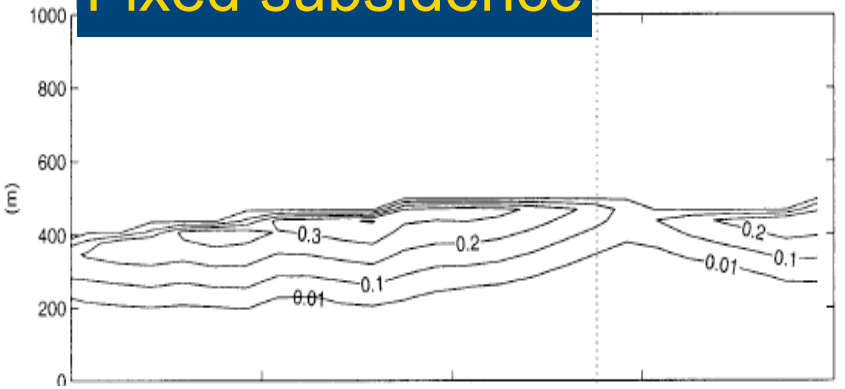

400
300
200
100
0
N_a (D>0.1 μm) [cm^{-3}]
DMA N_{CCN}
Lasair-II
POCs over ship
0.7
0.3
0.1
0.05
0.03
0.01
particle diameter [μm]
accumulation mode
Aitken mode
15
16
17
18
19
20
21
22
23
day in November 2003
dN/dlogR
[cm^{-3}]
1000
800
600
400
200
0

Diurnal subsidence waves

Variable subsidence



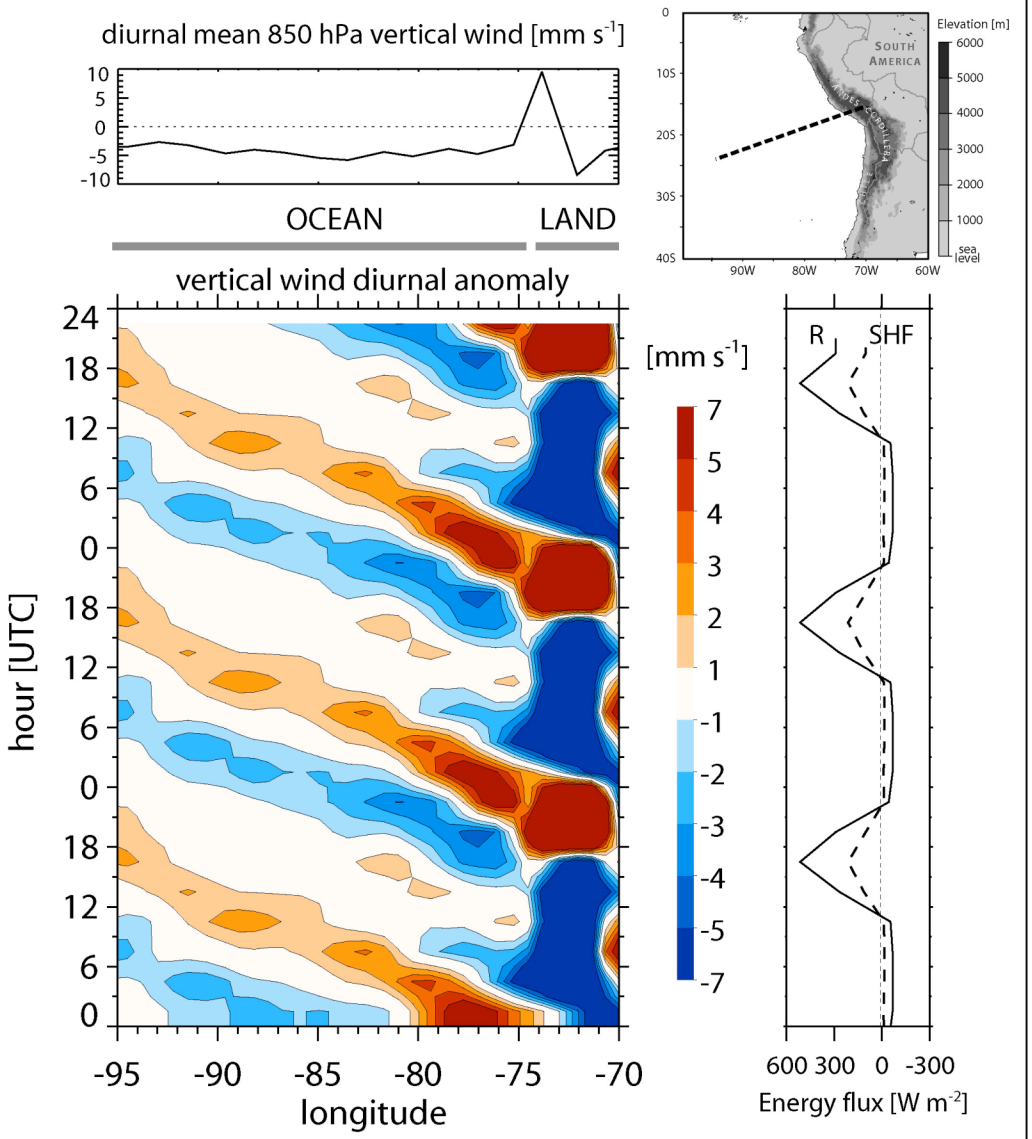
Fixed subsidence



18 0 6 12 18

Time (local)

Garreaud and Muñoz (2004)

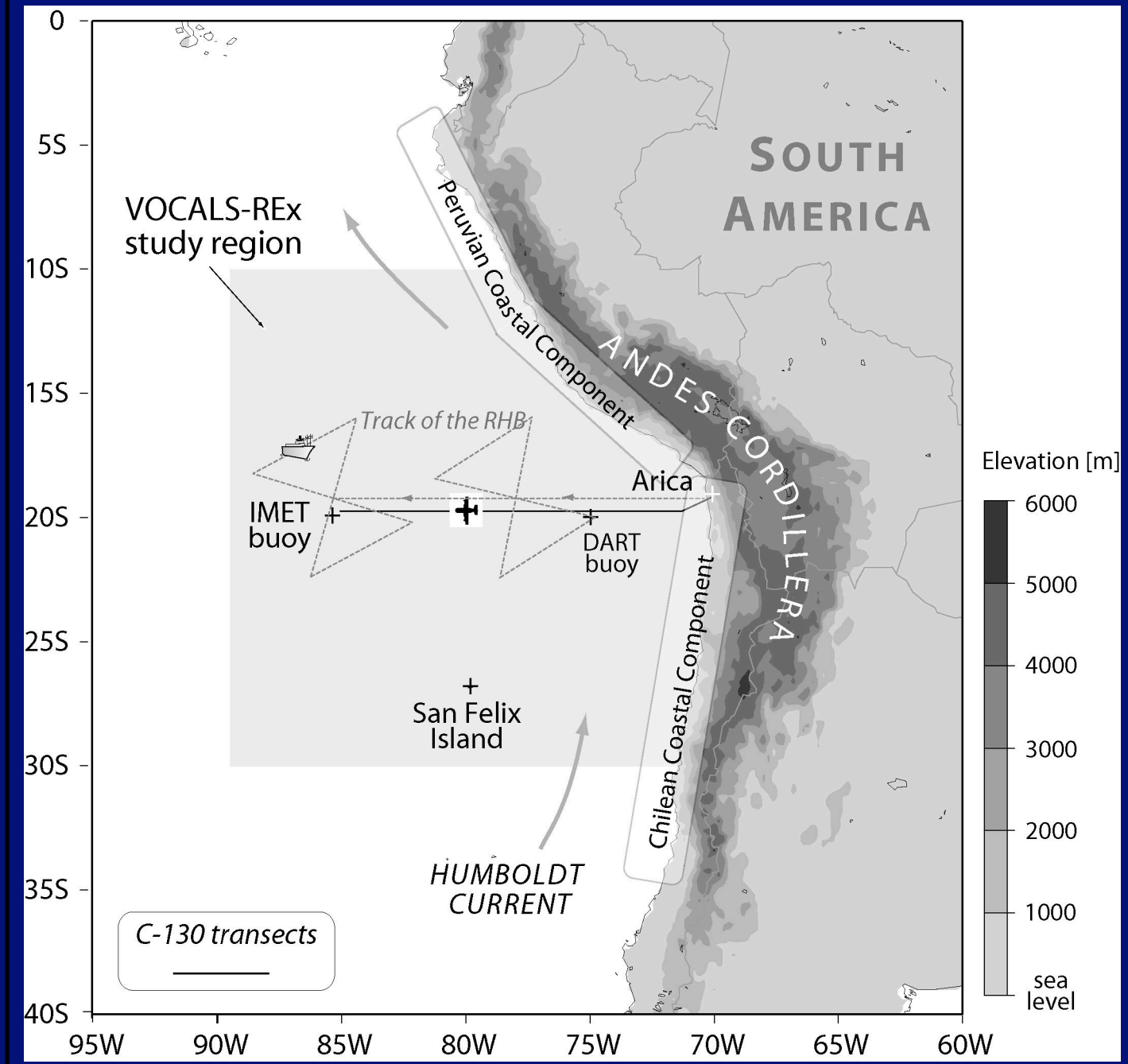


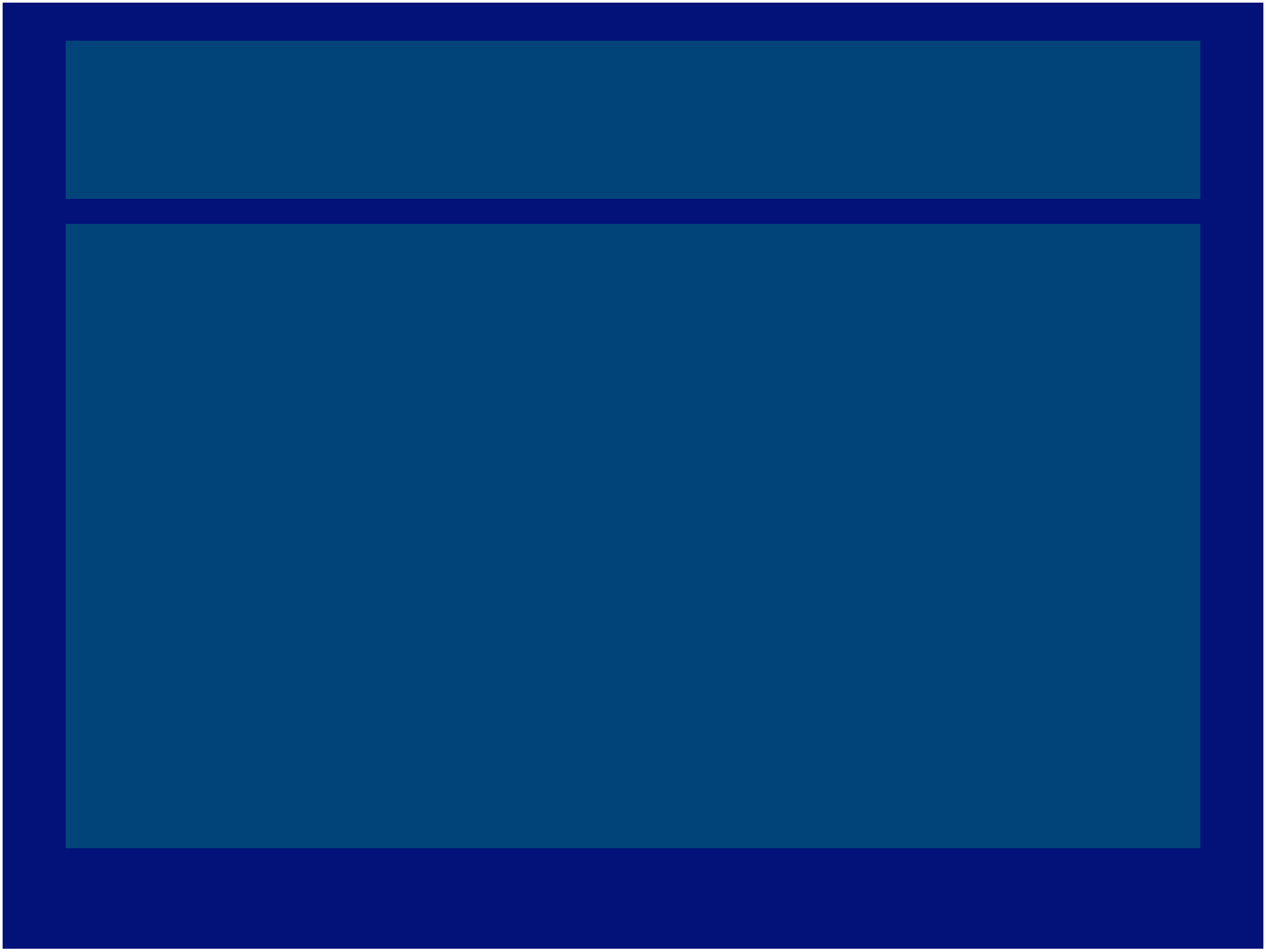
VOCALS-Regional Experiment (VOCALS-REx) Science Goals

- **AEROSOL-CLOUD-DRIZZLE GOALS**
  - *Factors controlling the stratocumulus cloud thickness, cover, and optical properties over the SE Pacific*
- **COUPLED OCEAN-ATMOSPHERE-LAND GOALS**
  - *Physical and chemical links between the topography, coastal oceanic upwelling and the marine boundary layer*

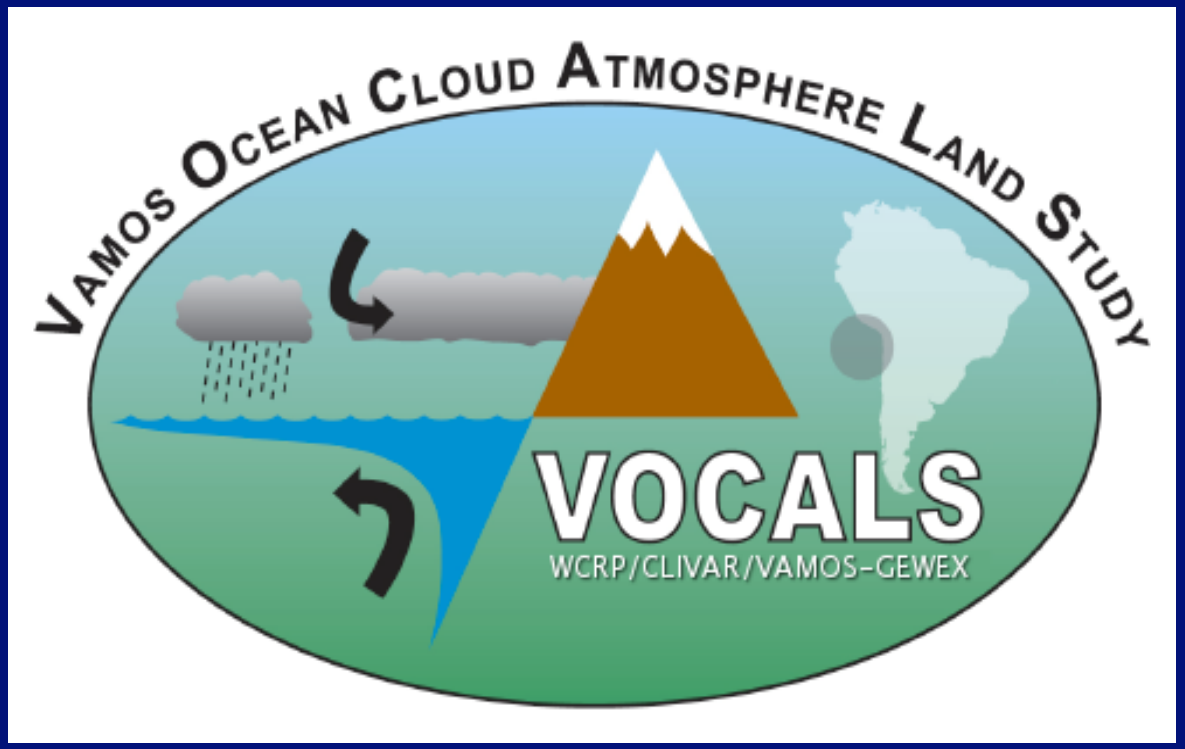
- **AEROSOL-CLOUD-DRIZZLE GOALS**
  - *Determining the impact of the physicochemical properties of aerosols upon the formation of drizzle in stratocumulus clouds over the SE Pacific.*
  - *Examining the role of drizzle in the formation of pockets of open cells (POCs) within stratocumulus clouds.*
  - *Determining the importance of anthropogenic and natural sources of cloud condensation nuclei (CCN).*
  - *Assessing whether coalescence scavenging is*

- **COUPLED OCEAN-ATMOSPHERE-LAND GOALS**
  - *Examining the mechanisms by which heat and fresh water are transported from coastally upwelled water to regions further offshore.*
  - *Studying links between coastal upwelling, upper ocean biogeochemistry, and the atmospheric sulfur budget.*
  - *Improving understanding of how diurnal subsidence waves originating on the Andes slopes propagate over the SE Pacific Ocean.*

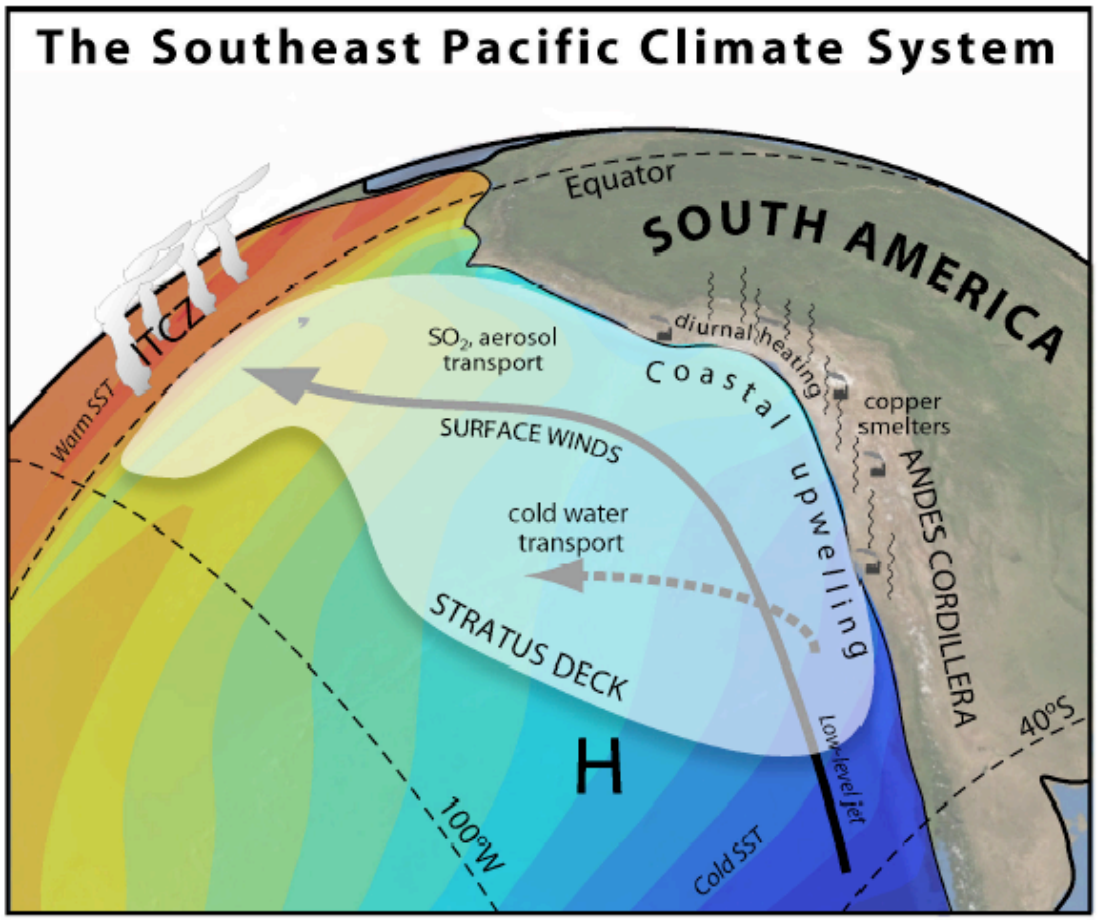

0
5S
10S
15S
20S
25S
30S
35S
40S
95W
90W
85W
80W
75W
70W
65W
60W
SOUTH AMERICA
VOCALS-REx study region
Peruvian Coastal Component
ANDES CORDILLERA
Track of the RHB
Arica
IMET buoy
DART buoy
San Felix Island
Chilean Coastal Component
HUMBOLDT CURRENT
C-130 transects
Elevation [m]
6000
5000
4000
3000
2000
1000
sea level



VOCALS Regional Experiment
VOCALS-REx



An international field experiment designed to better understand physical and chemical processes central to the coupled climate system of the Southeast Pacific (SEP)



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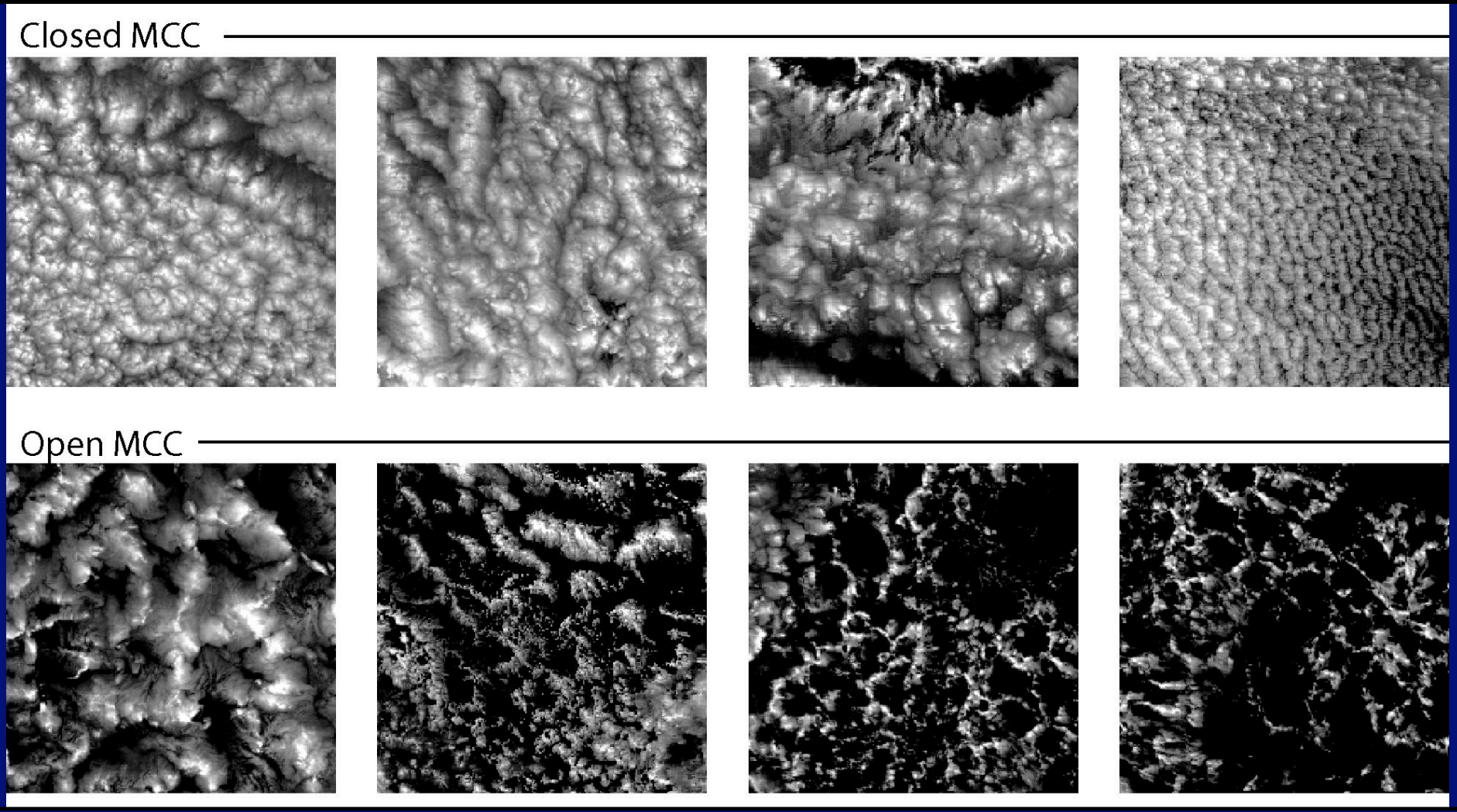
  - *Assessing whether coalescence scavenging is necessary to maintain POCs.*
- **COUPLED OCEAN-ATMOSPHERE-LAND GOALS**
  - *Examining the mechanisms by which heat and fresh water are transported from coastally upwelled water to regions further offshore.*
  - *Studying links between coastal upwelling, upper ocean biogeochemistry, and the atmospheric sulfur budget.*
  - *Improving understanding of how diurnal subsidence waves originating on the Andes slopes propagate over the SE Pacific Ocean*

Motivation

- Marine stratocumulus clouds have a profound impact on the earth's radiation budget
- Factors determining the coverage and thickness of stratocumulus over the world's oceans remain poorly understood. Important unresolved aspects of this problem include
  - *Transitions from closed to open mesoscale cellular convection*
  - *The role of precipitation*
  - *The importance of aerosols*

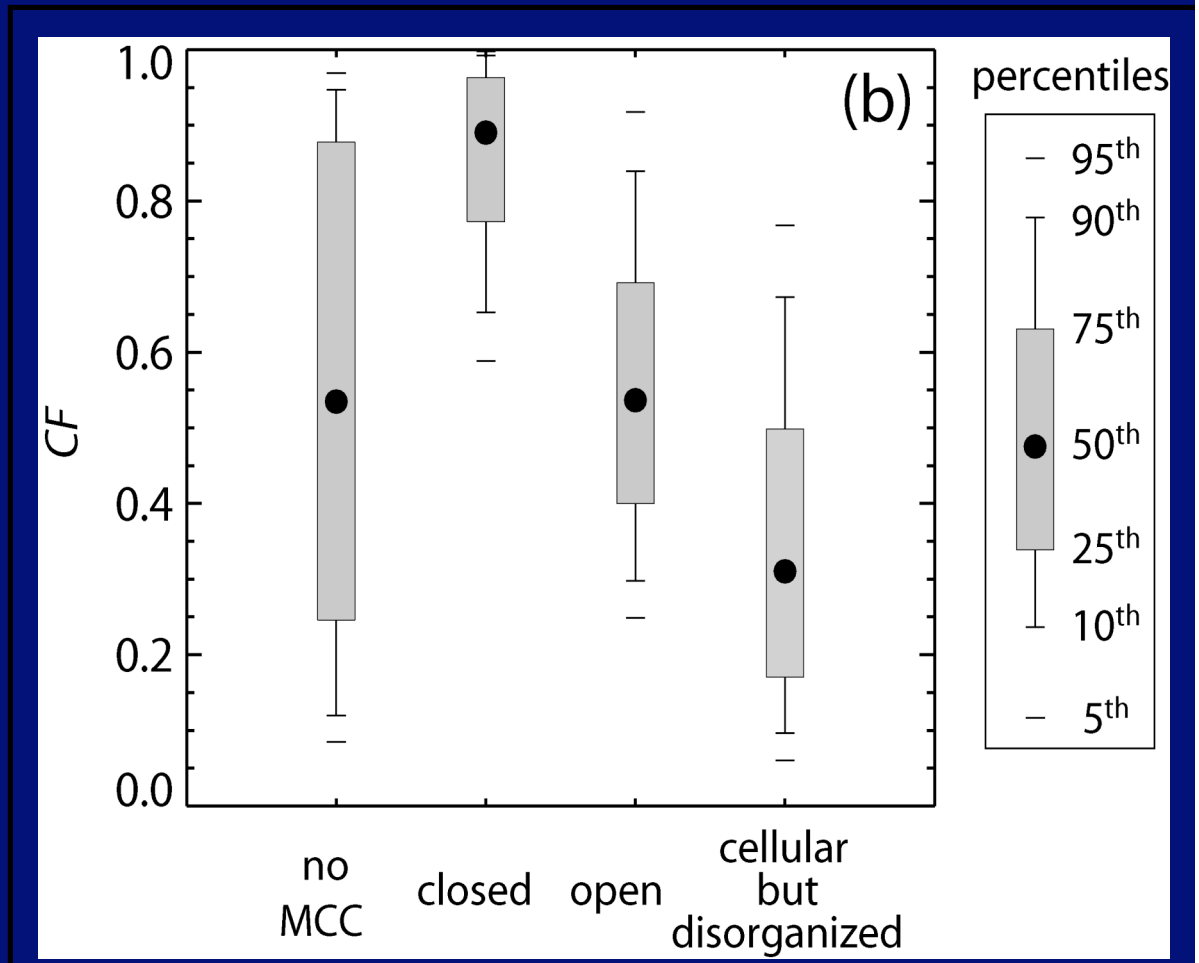
Shallow convection modes in the subtropical MBL



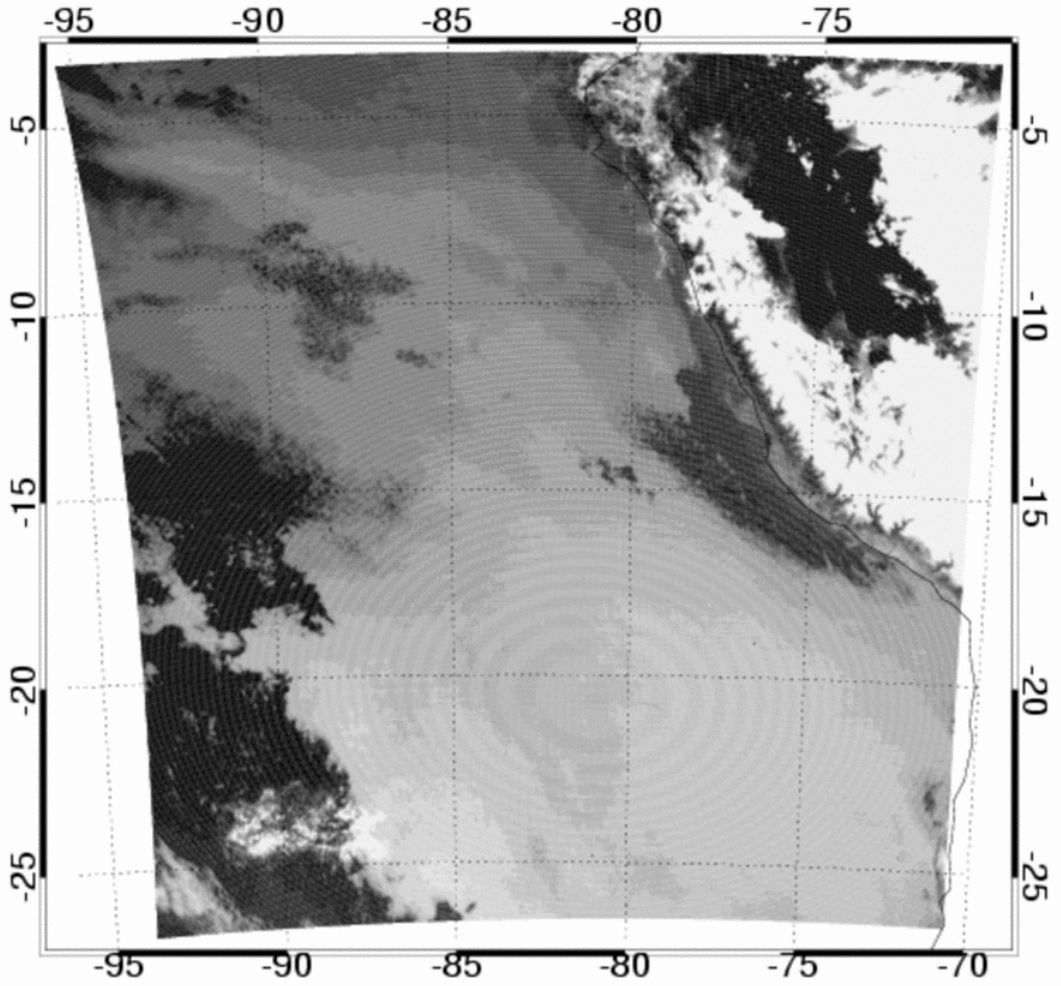
Wood and Hartmann, *J. Clim.*, in press

Cloud cover associated with of different convection modes

Over large regions of the subtropical oceans, a significant fraction of the synoptic variability in cloud fraction can be explained by variability of the mode of shallow convection (open *vs* closed MCC)



The formation of pockets of open cells (POCs)

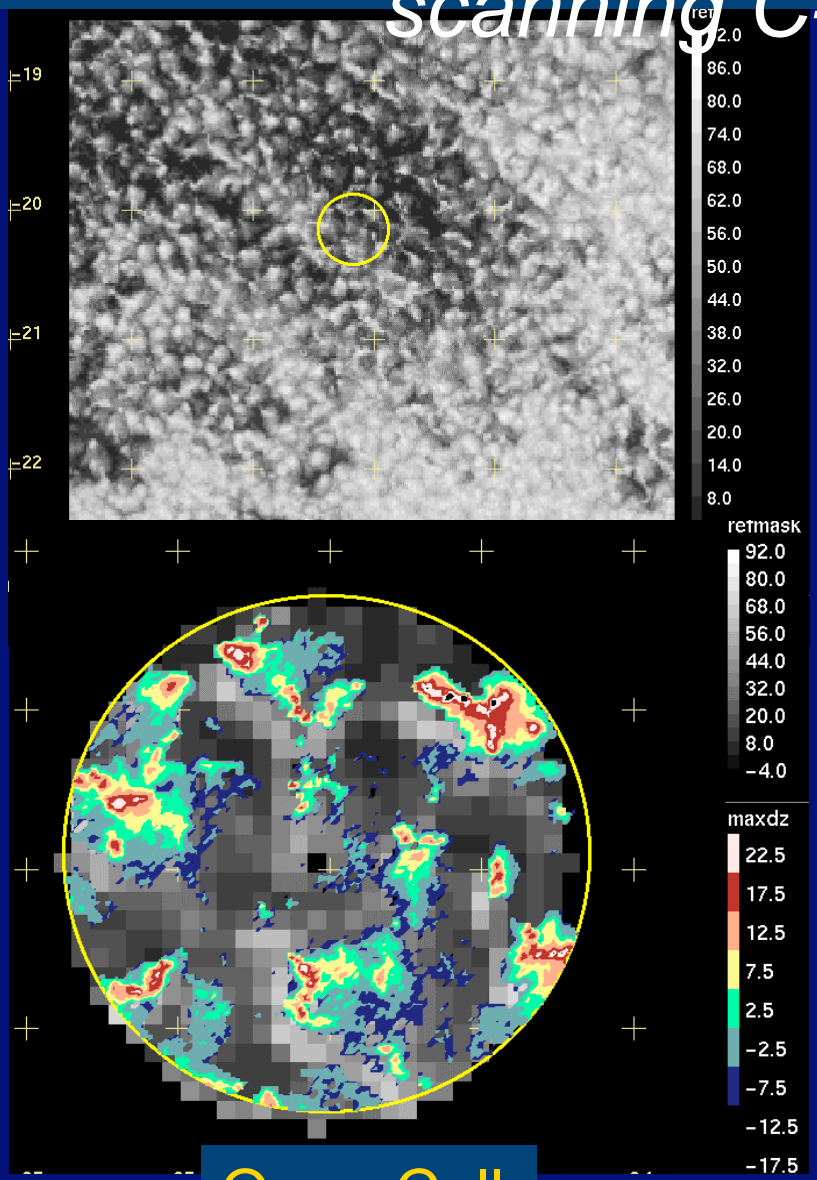


GOES thermal IR animation (images every 3 hours spanning 6 days)

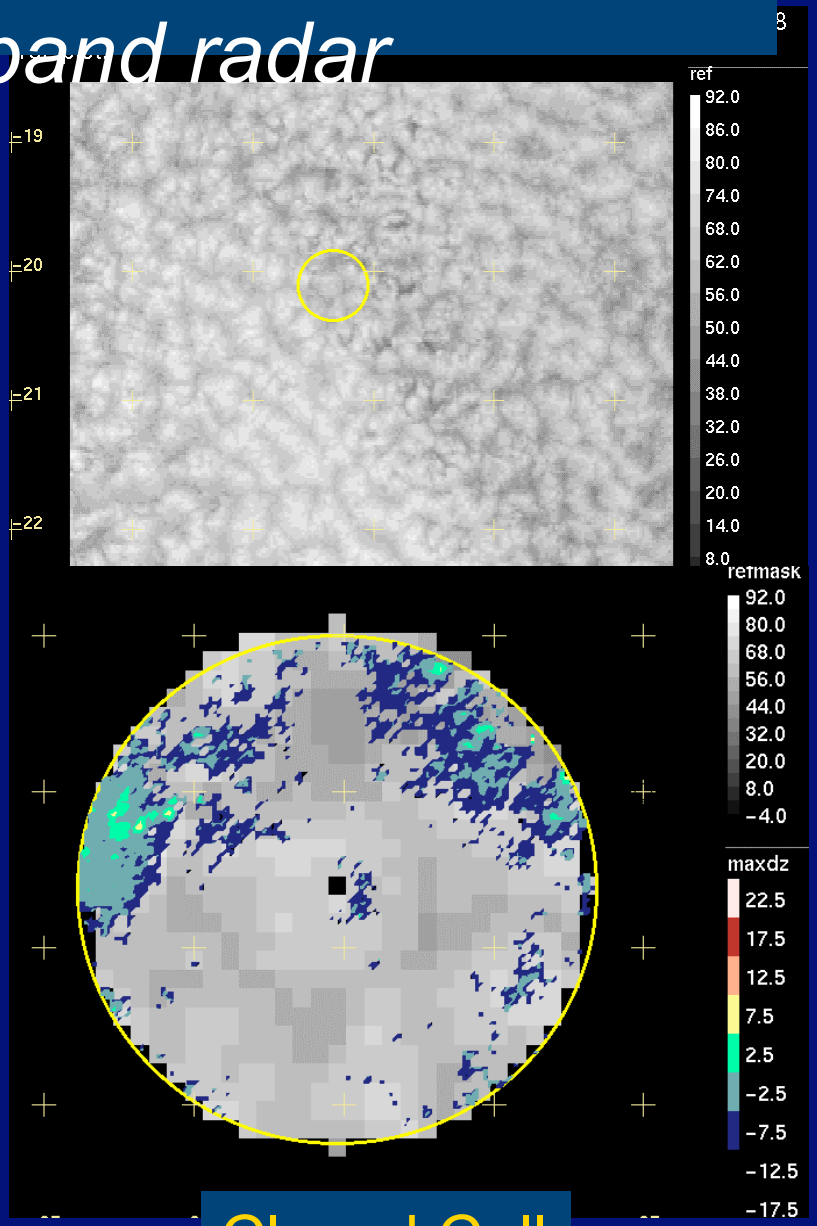
East Pacific Investigation of Climate (2001)
scanning C-band radar

Visible Satellite

Ship Radar

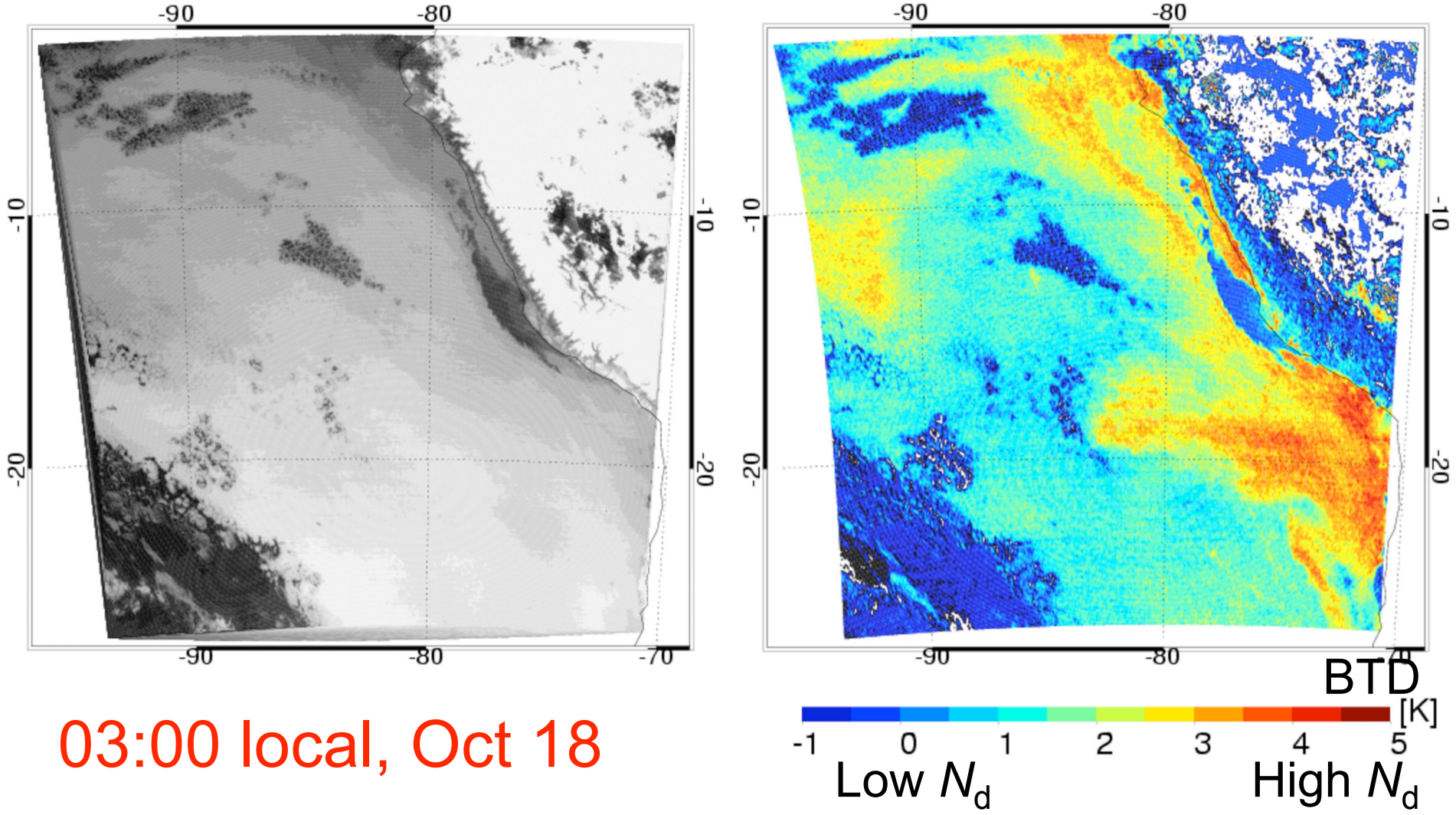


Open Cells



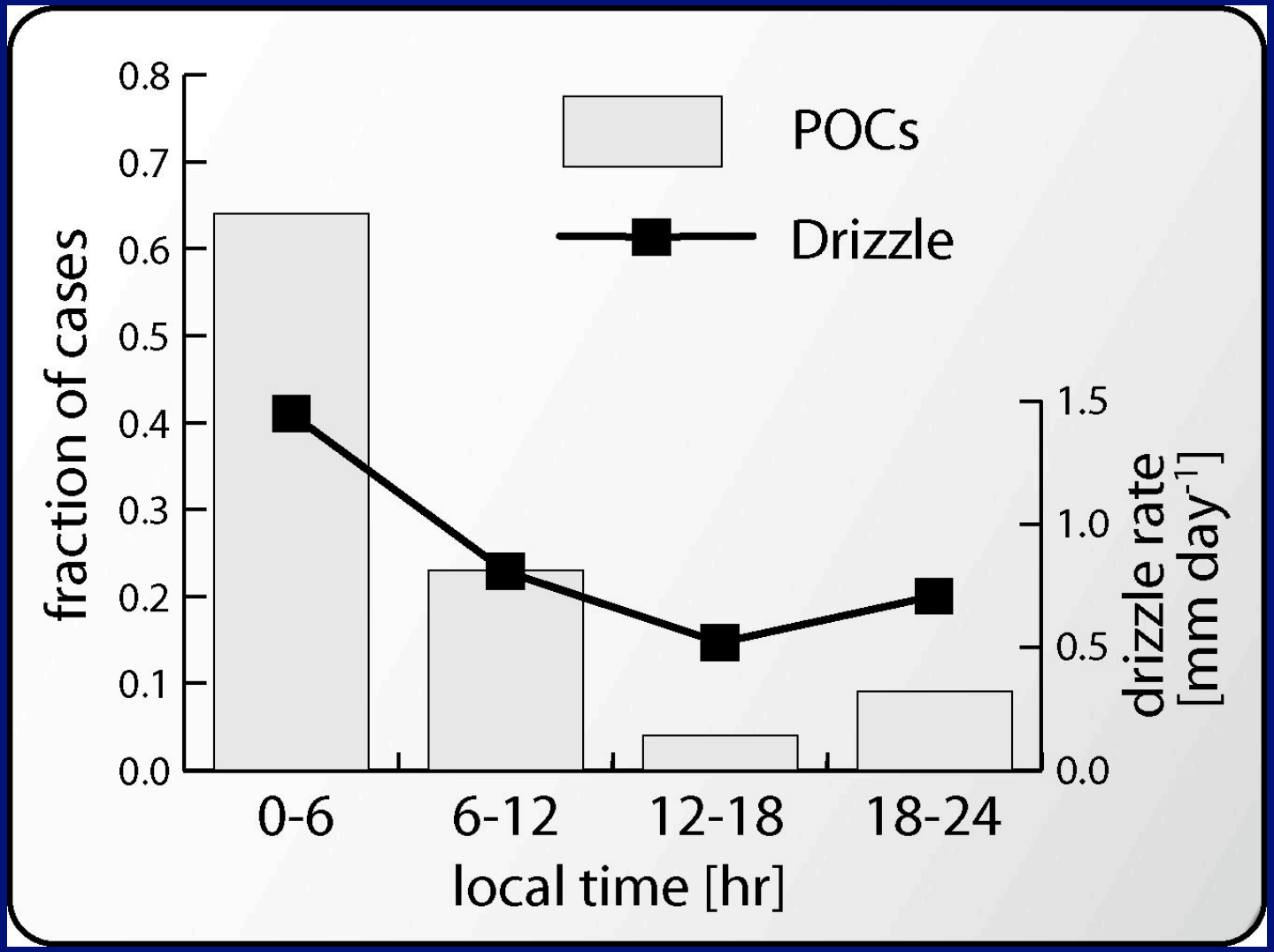
Closed Cells

GOES IR (left) and 11-3.7 μm brightness temperature difference (right)

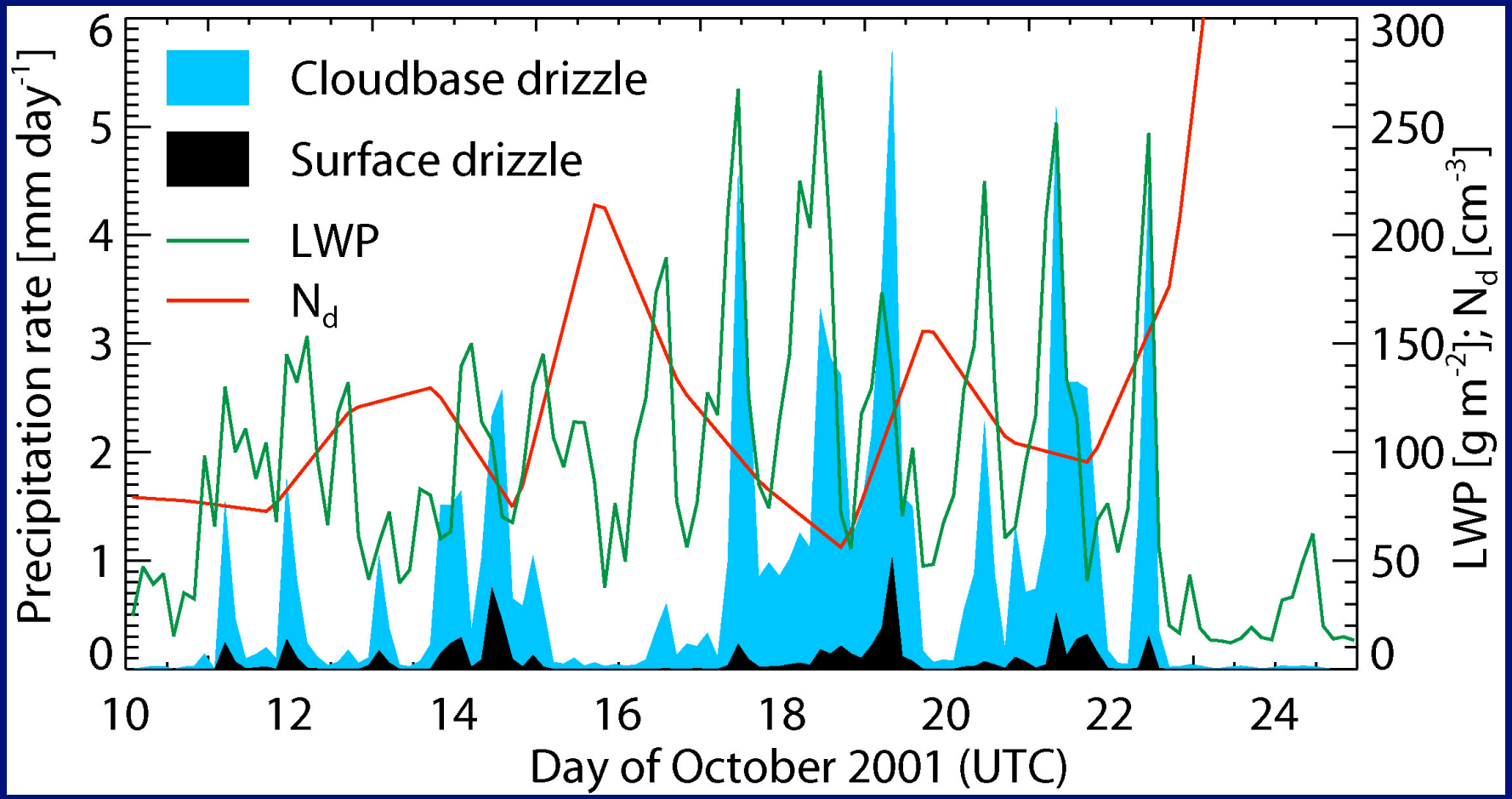


03:00 local, Oct 18

POCs prefer to form at night

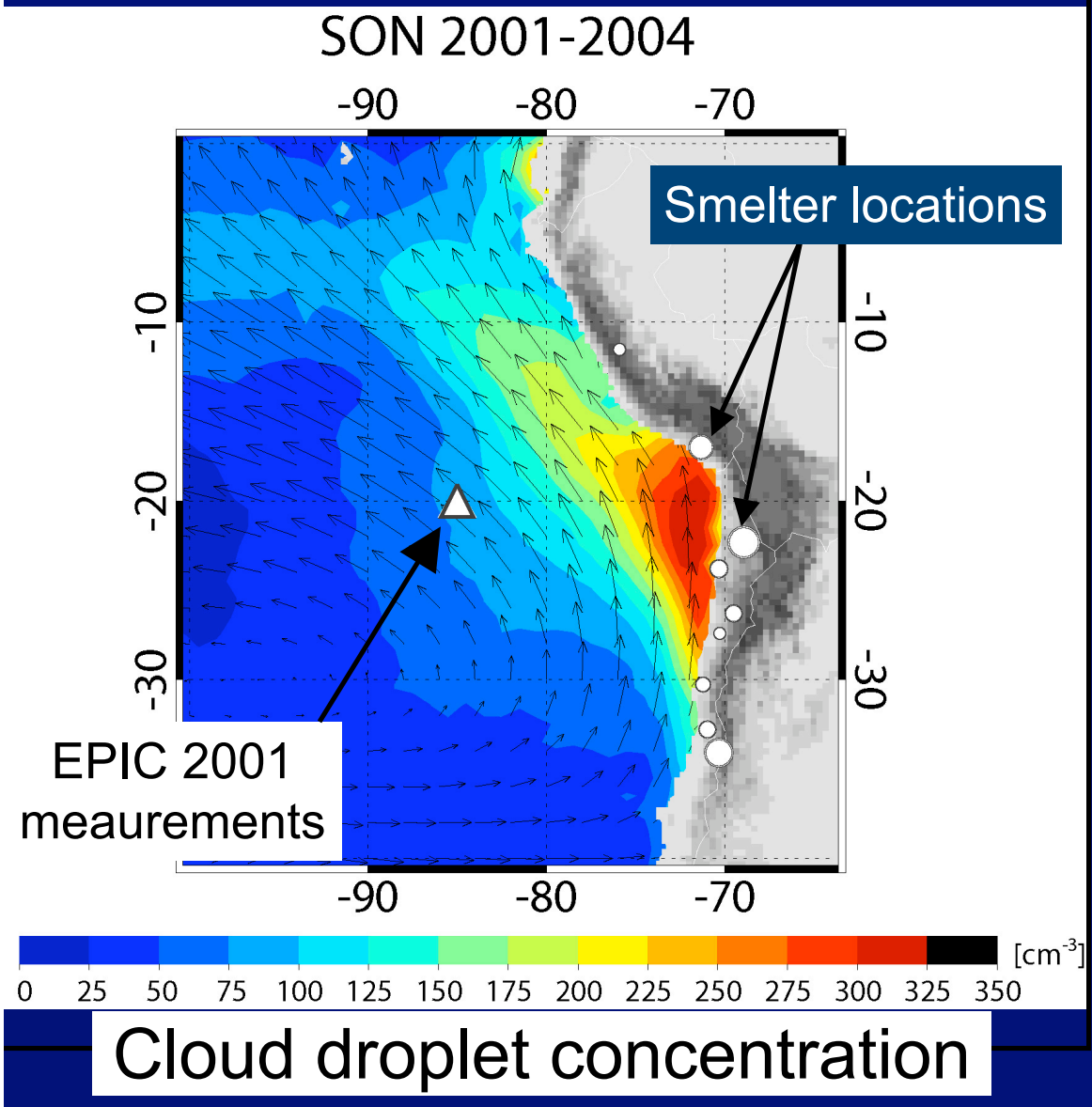


Microphysics and drizzle production



Results from EPIC 2001, Bretherton et al. (2004

Pollution plumes in the SE Pacific

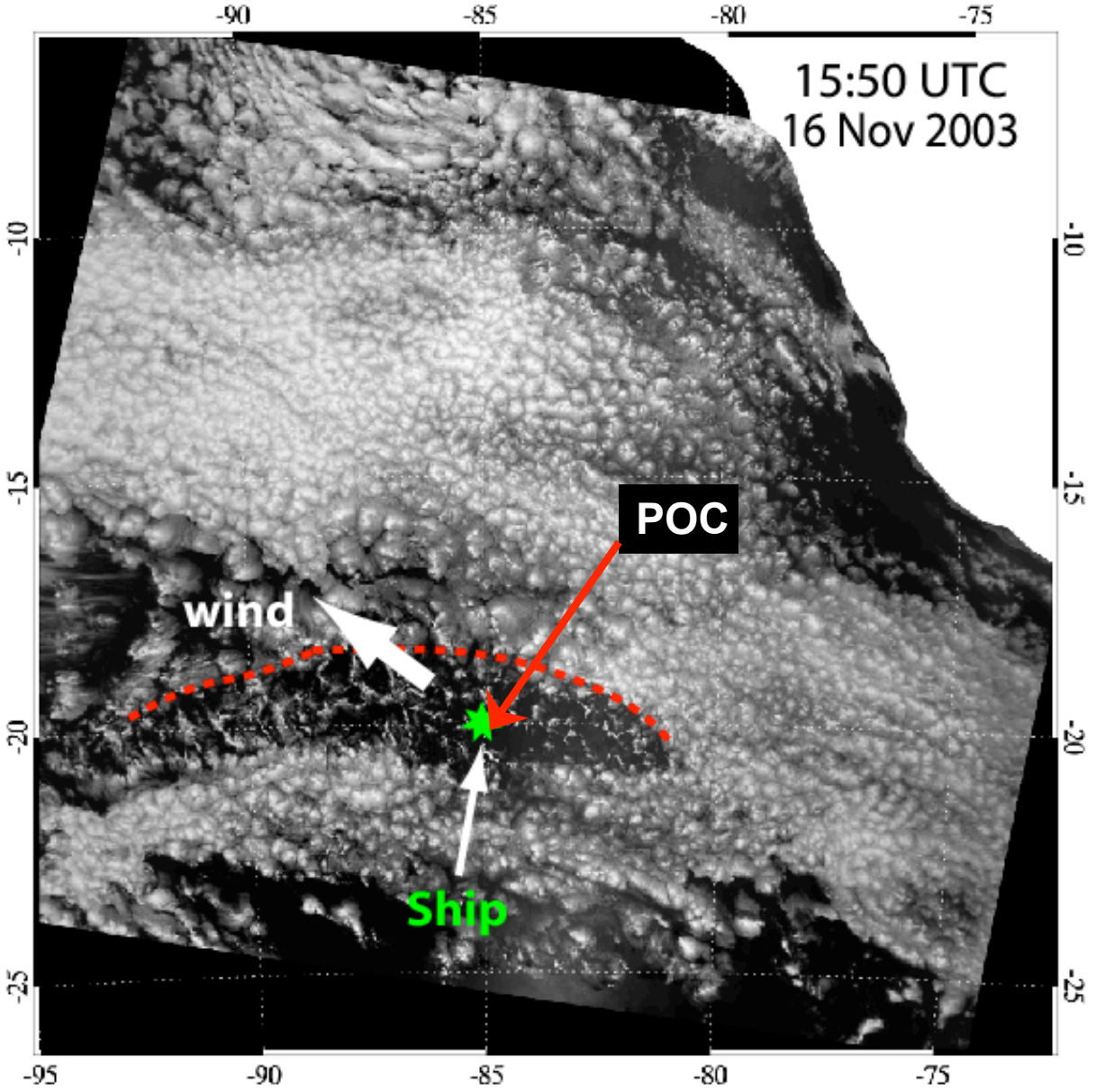


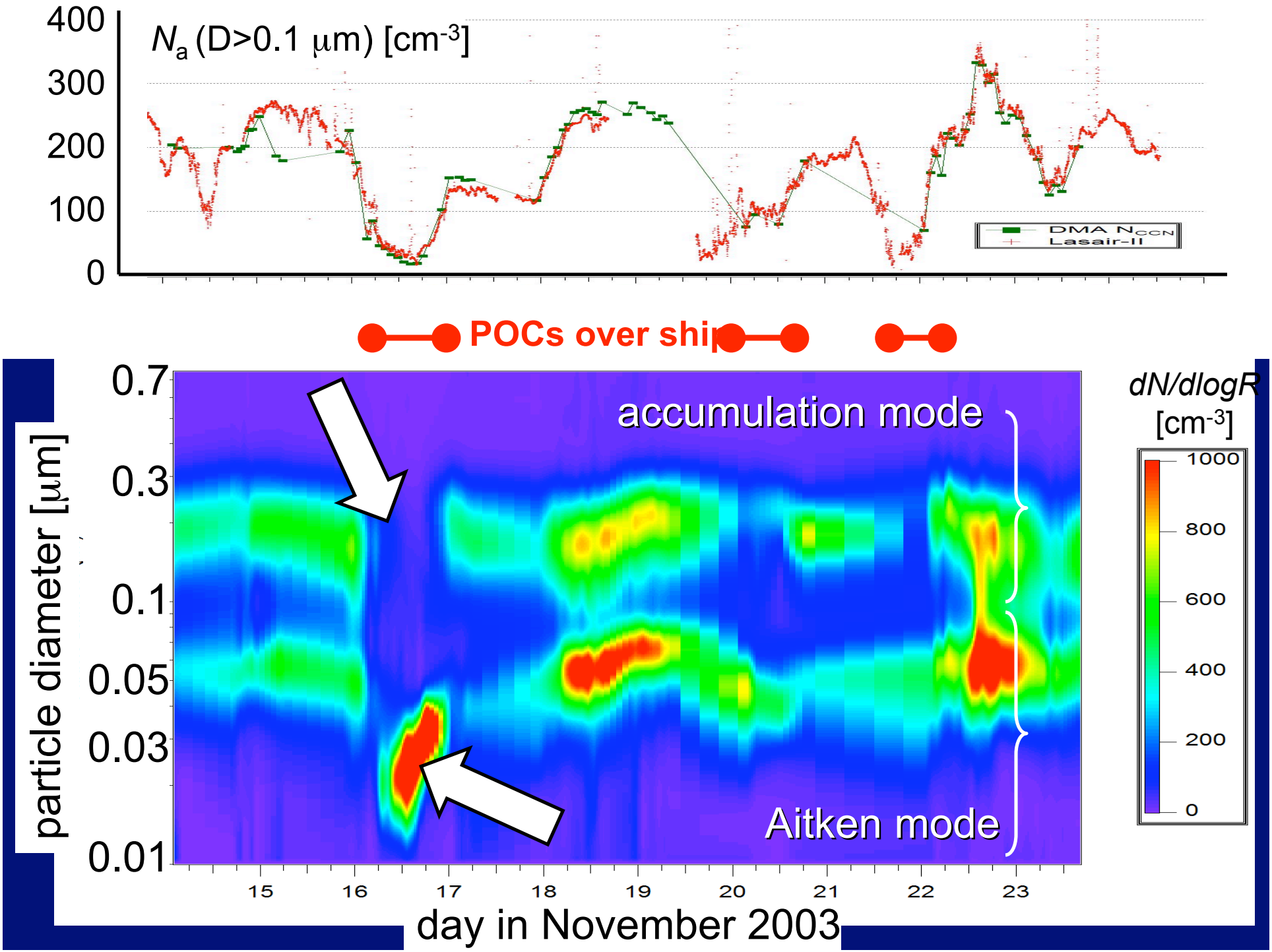
Cloud droplet concentration

- Chile is world's largest copper producer
- Copper smelting SO_2 emissions from Chile (1.5 TgS yr^{-1}) comparable to total SO_2 emissions in Germany
- 90% of Chilean SO_2 emissions from seven smelters!
- Andes mountains prevents eastward

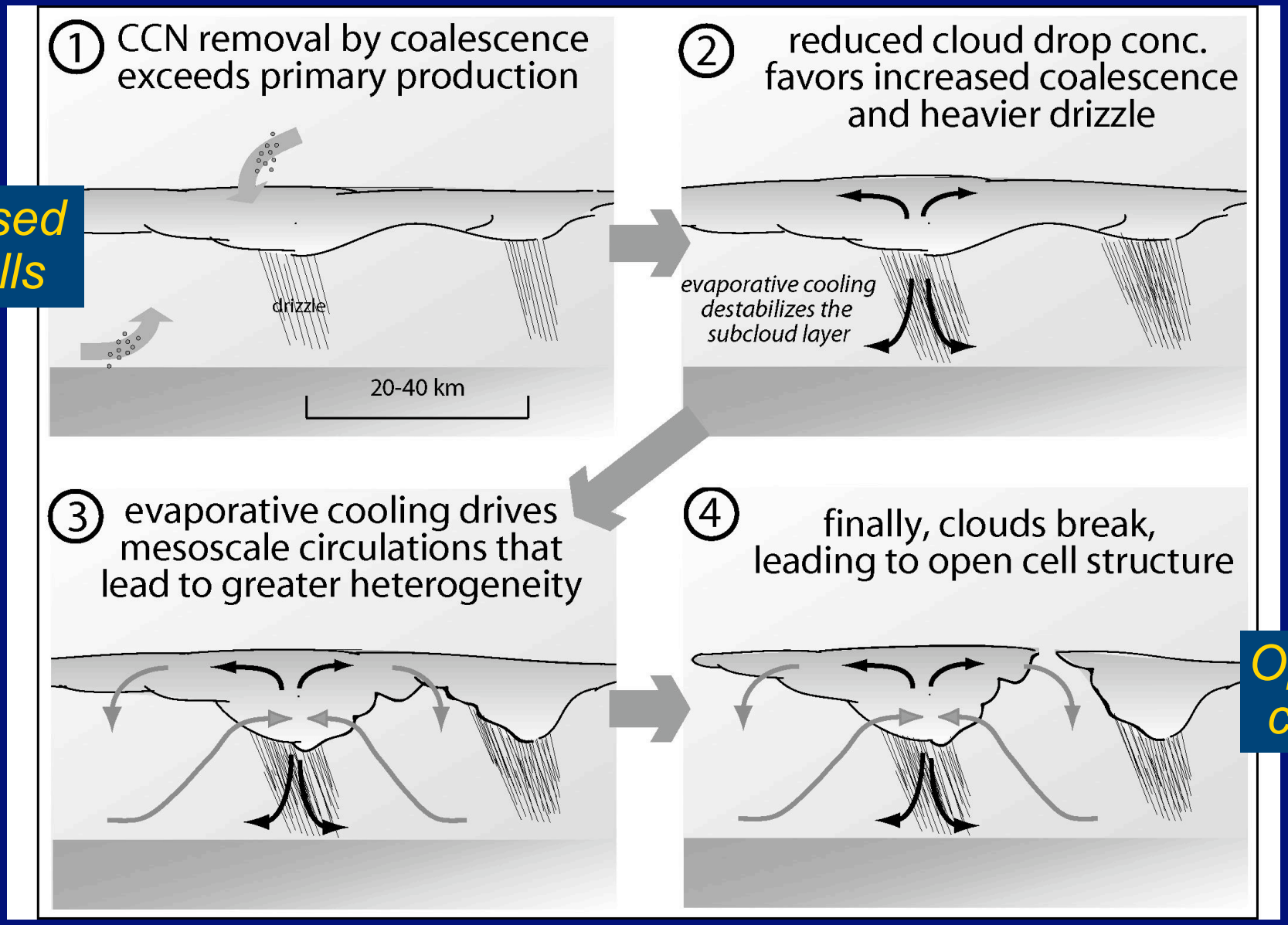
Aerosols and cloud morphology

- Pockets of open cells (POCs) are strongly drizzling and almost completely depleted of cloud forming aerosols
- Highly suggestive of strong links between cloud microphysical and macrophysical structure




400
300
200
100
0
N_a (D>0.1 μm) [cm^{-3}]
DMA N_{CCN}
Lasair-II
POCs over ship
0.7
0.3
0.1
0.05
0.03
0.01
particle diameter [μm]
accumulation mode
Aitken mode
15
16
17
18
19
20
21
22
23
day in November 2003
dN/dlogR
[cm^{-3}]
1000
800
600
400
200
0

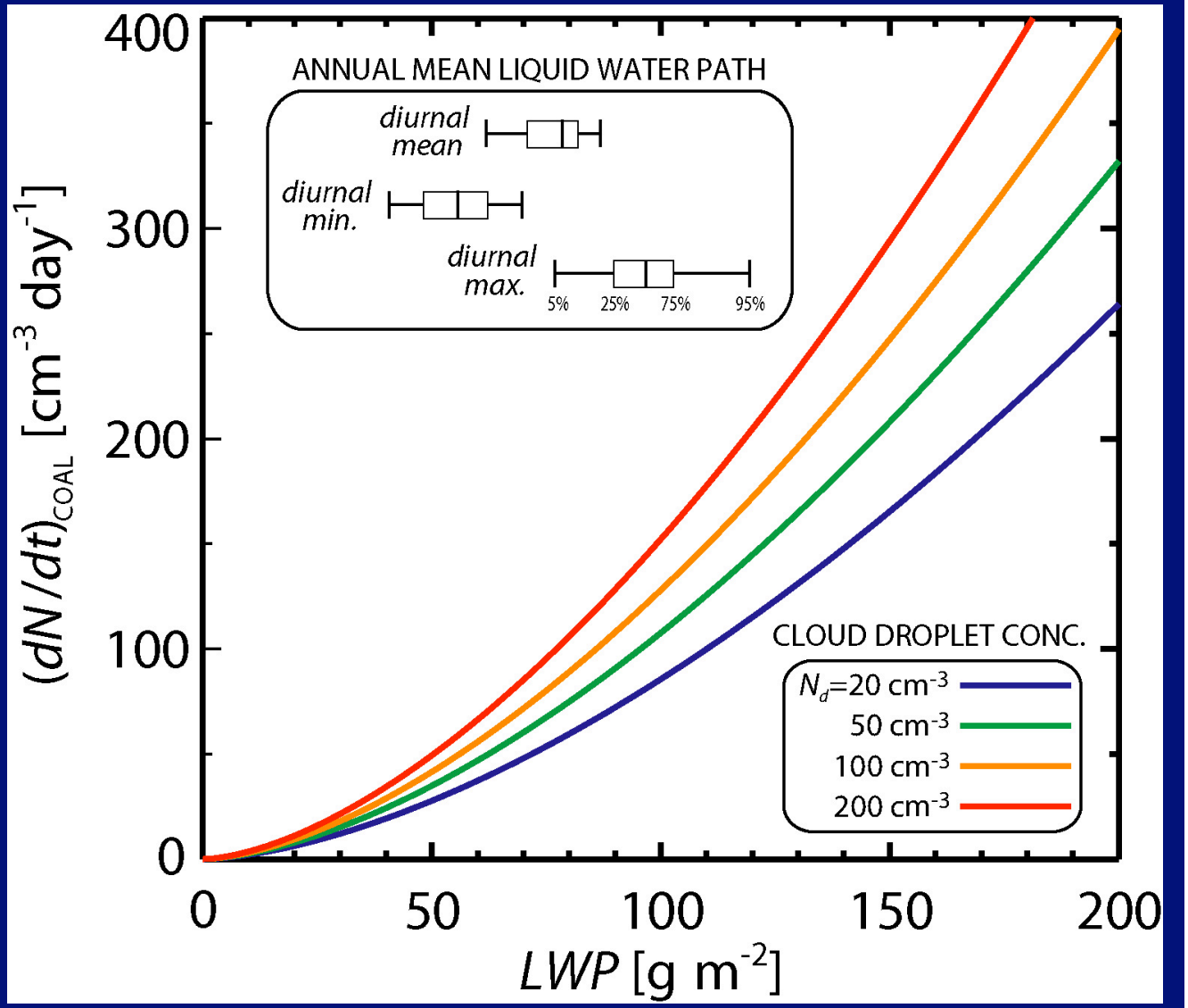
Conceptual model of POC formation



Coalescence and CCN depletion

- Loss rate of CCN number concentration through coalescence

$$\propto LWP^{2}$$



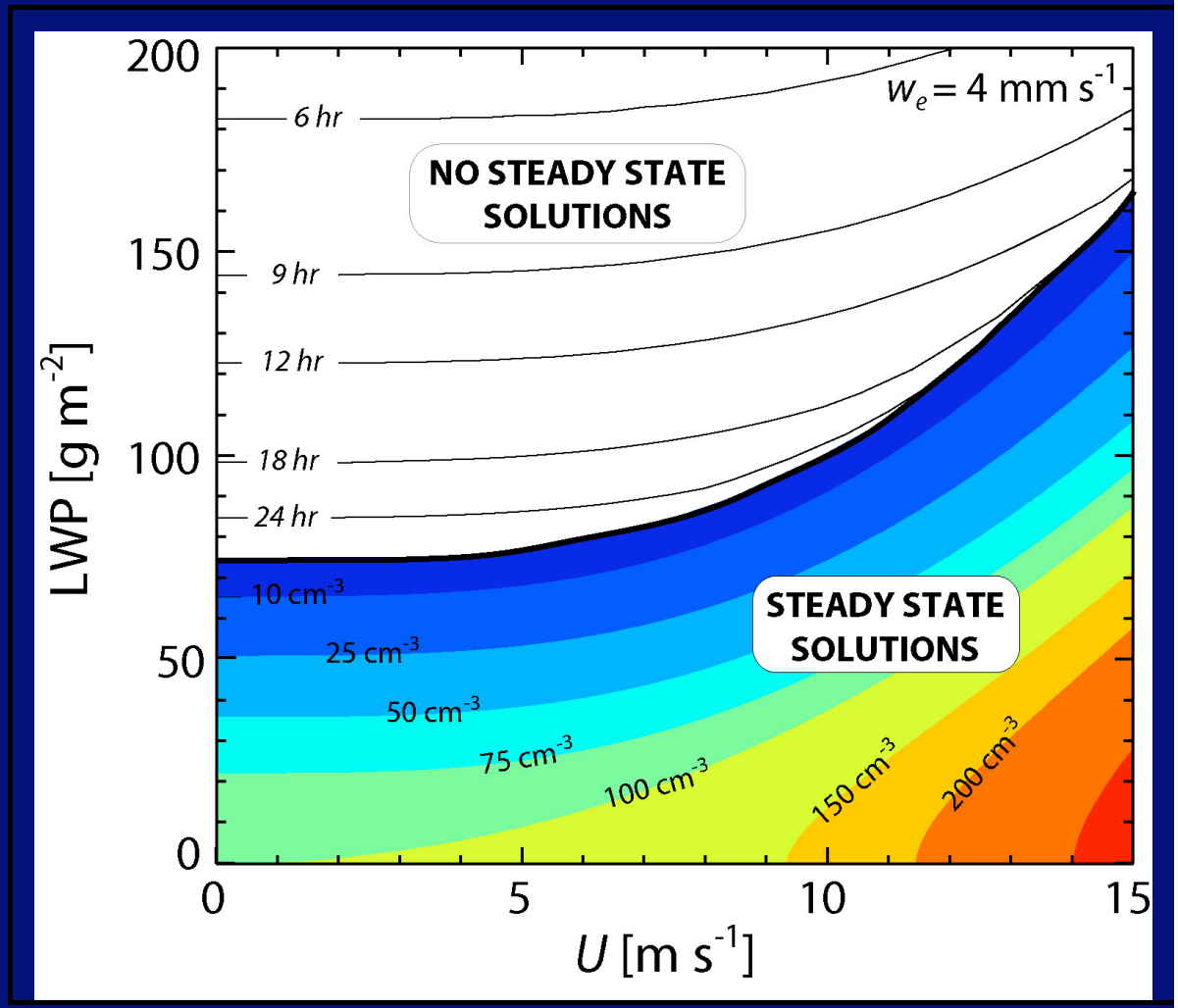
Steady-state aerosol model

Assumptions:

1. Wind-driven sea-salt production and entrainment of 100 cm^{-3} from free-troposphere are only aerosol sources.

2. Coalescence scavenging is the only loss term

3. Examine steady state solution for CCN concentration



Conclusions

- Transition from closed to open cellular convection is a major contributor to the variability in cloud cover (and albedo) over the SE Pacific Ocean
- Transition appears to be intimately related to drizzle formation and tends to be accompanied by strong depletion of CCN
- Because drizzle depletes CCN, it is suggested that large regions of stratocumulus over the remote oceans may be microphysically unstable. Aerosol loss rates can exceed production rates => positive feedback that results in POC formation and transition to open cells