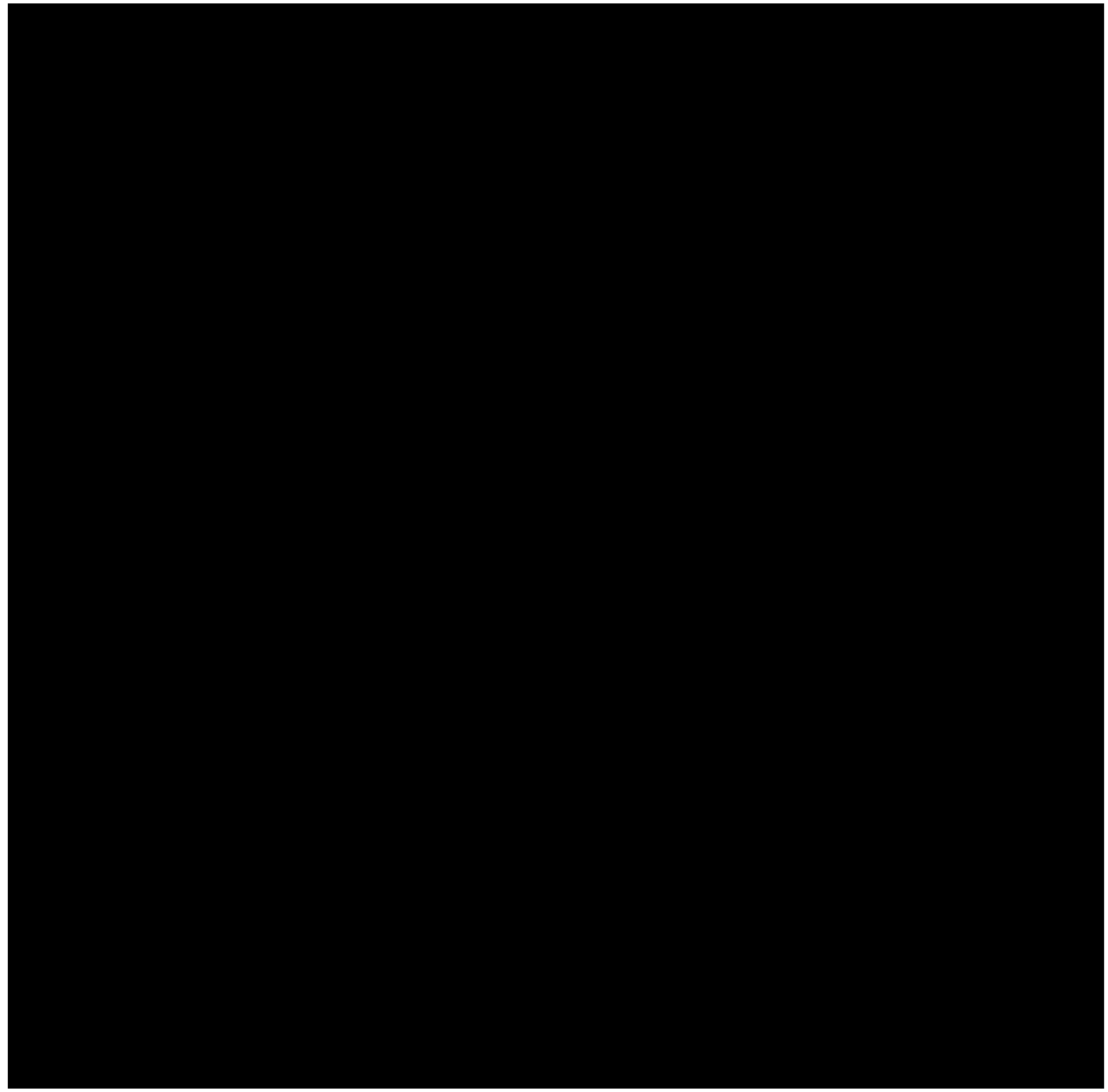
VOCALS Regional Experiment (REx) Goals and Hypotheses

Robert Wood, University of Washington
many contributors

[redacted]

THE VOCALS STRATEGY



VOCALS Regional Experiment (REx)

- Joint NOAA/NSF funded field program in October/November 2008. Additional support from ONR and DoE and international agencies
- REx will provide observations of poorly understood aspects of the SEP climate system
- Main platforms: NSF C-130, NOAA Ronald H Brown, CIRPAS and Chilean Twin Otter, DoE G-1, FAAM BAe-146, Chilean land site, Peruvian ship, second (UNOLS) ship.

VOCALS-REx Platforms and Samplin[redacted]

Oct-Nov 2008

Aircraft:

NSF C-130

CIRPAS Twin Otter

DoE G-1

UK BAe-146

Ships:

NOAA Ronald H[redacted] Brown

UNOLS Wecoma

Jose Olaya

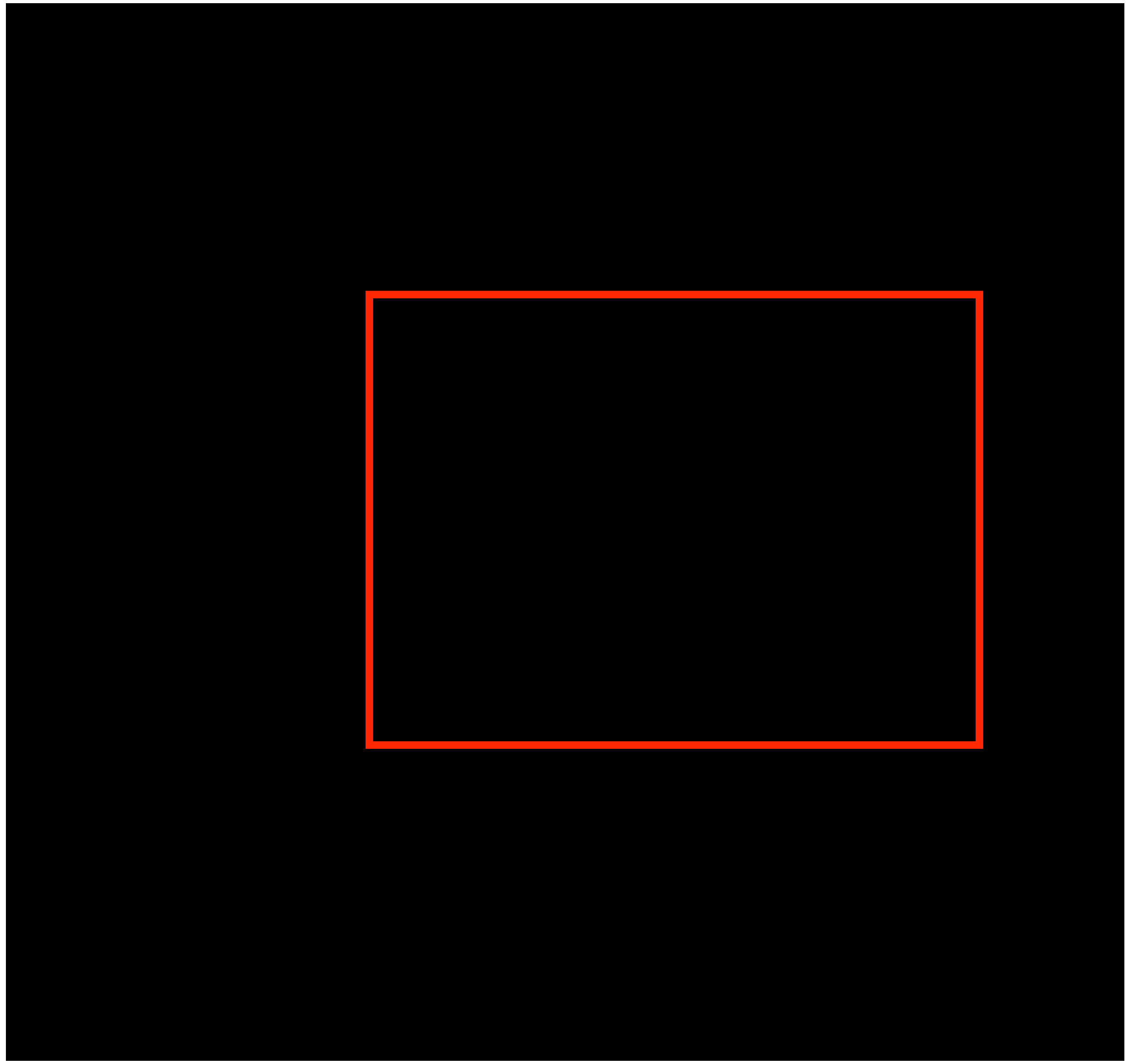
Land sites

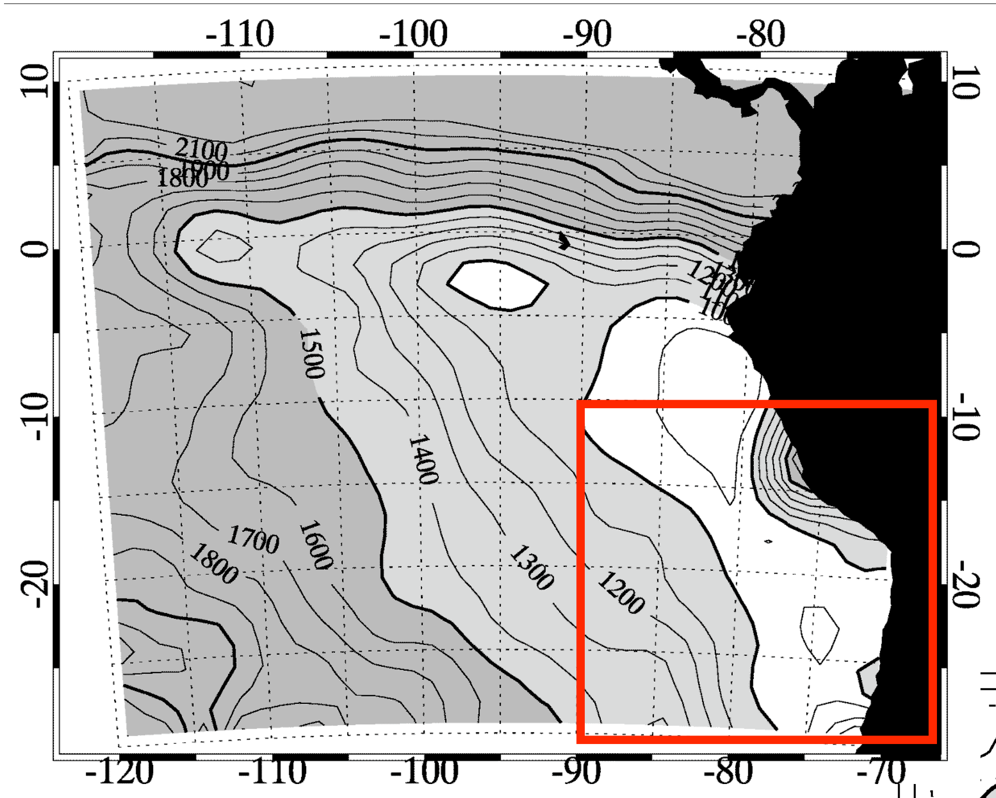
Meteorological context

SST (Reynolds)

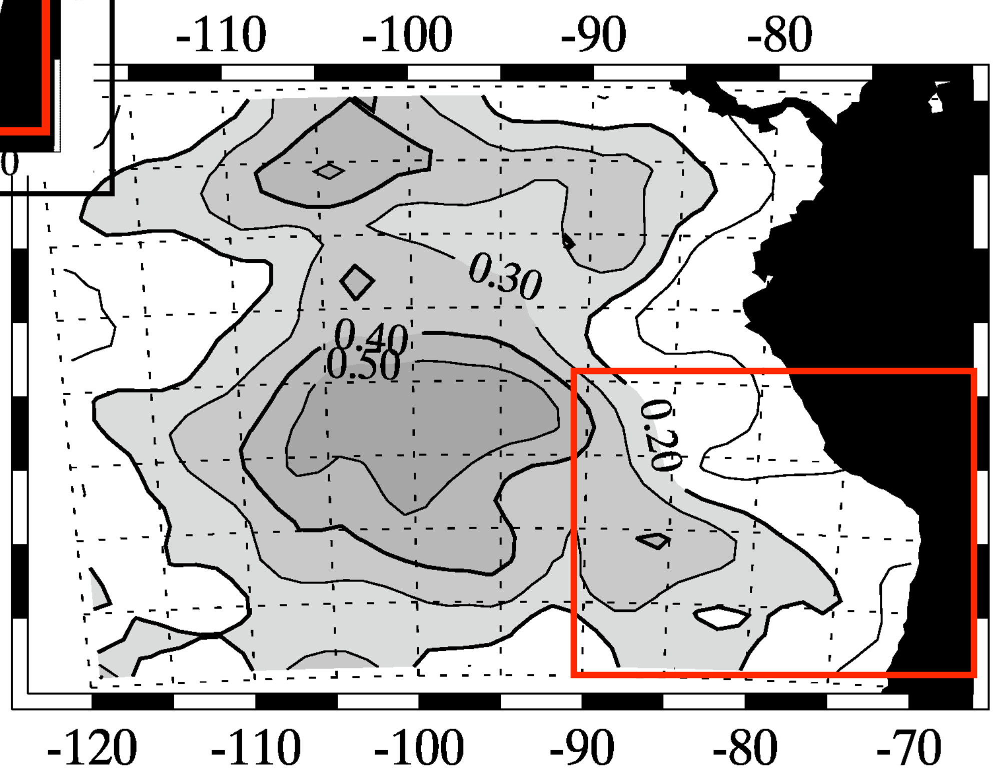
Surface winds (Quikscat)

Sep-Nov climatology





MBL depth



Open cell frequency

E-W transect 20ºS

VOCALS-REx Science Goals

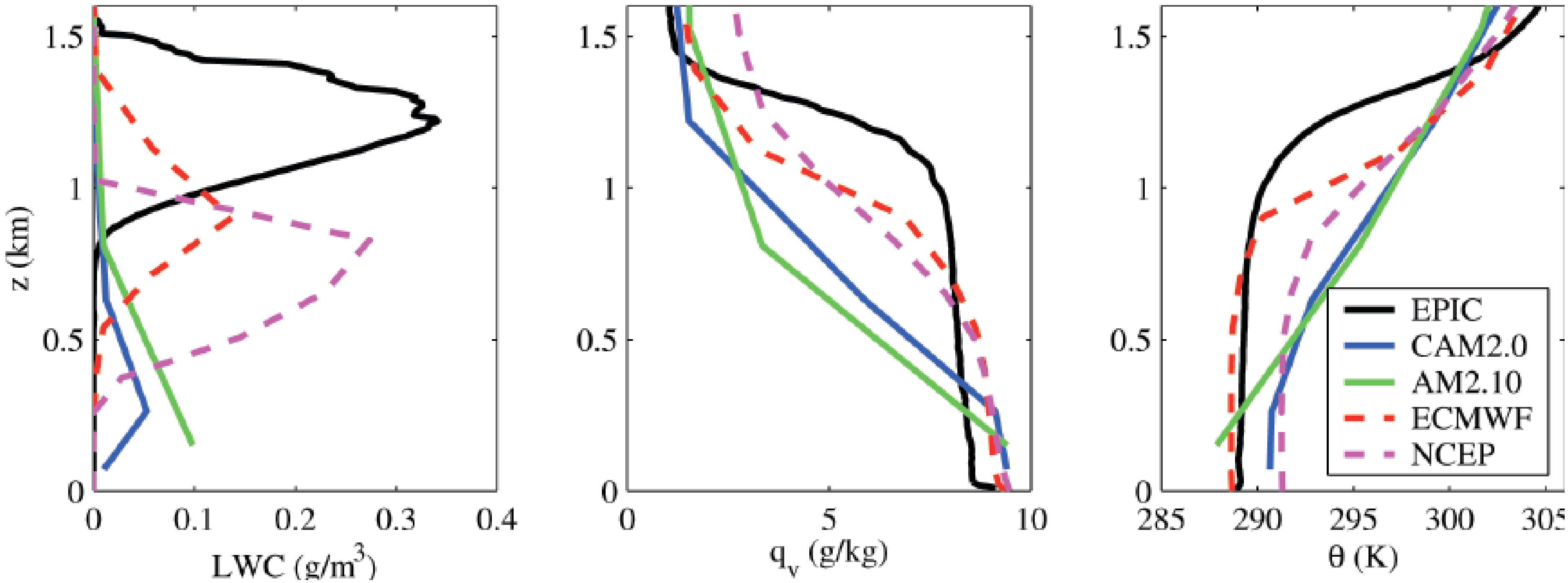
1. AEROSOL-CLOUD-DRIZZLE GOALS

Factors controlling the stratocumulus cloud thickness, cover, and optical properties over the SE Pacific

2. COUPLED OCEAN-ATMOSPHERE-LAND GOALS

Physical and chemical links between the topography, coastal oceanic upwelling and the marine boundary layer

SEP stratocumulus in GCMs

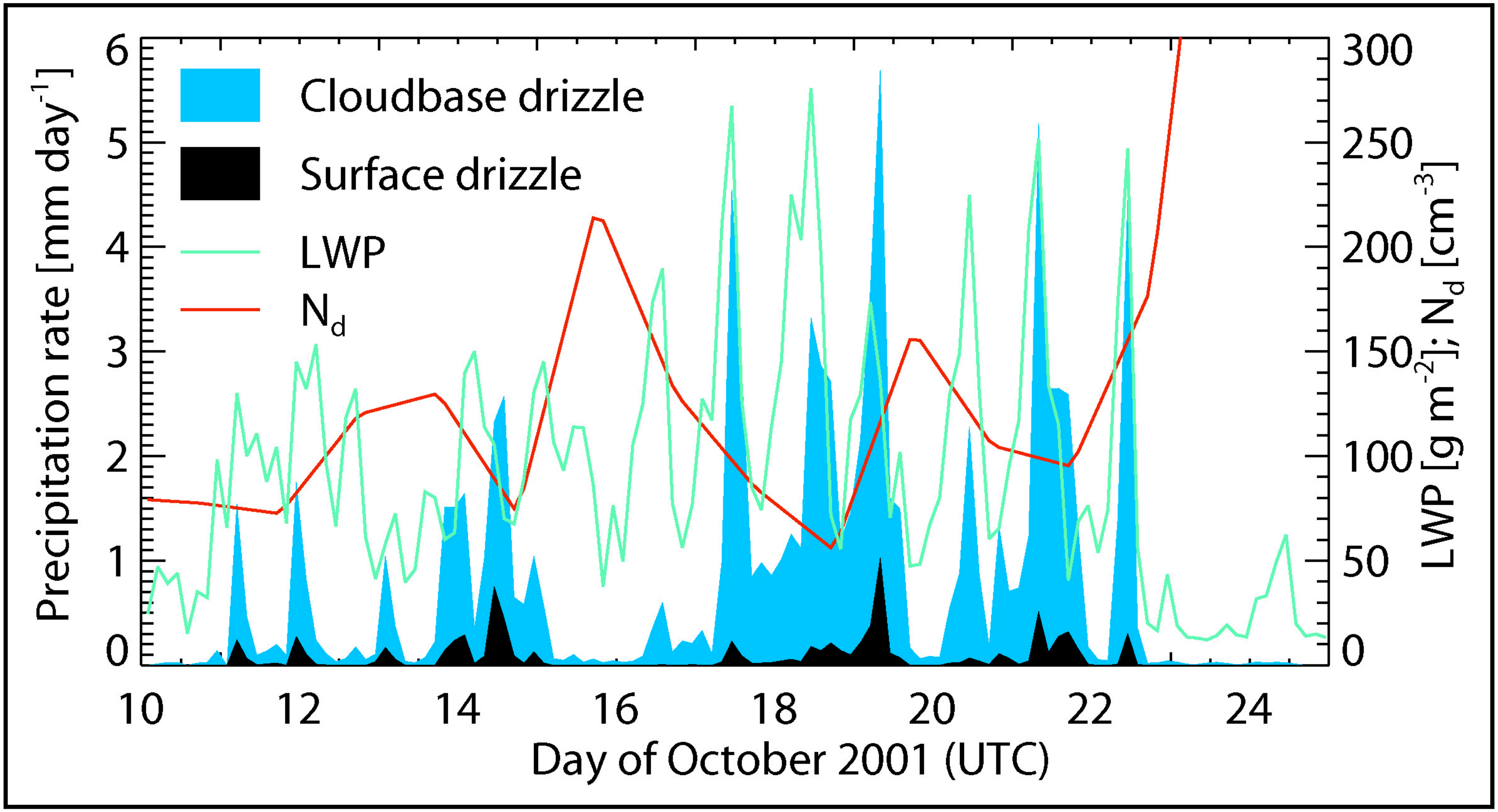


Poor representation of the vertical structure of stratocumulus-topped boundary layers – improved parameterization central to improved global models

Bretherton et al. 2004, *BAMS*

AEROSOL-CLOUD-PRECIPITATION HYPOTHESES	
#	*Hypothesis*
1A	**Variability in the physicochemical properties of aerosols has a measurable impact upon the formation of drizzle in stratocumulus clouds over the SEP.**
1B	**Precipitation is a necessary condition for the formation and maintenance of pockets of open cells (POCs) within stratocumulus clouds.**
1C	**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.**
1D	**Depletion of aerosols by coalescence scavenging is necessary for the maintenance of POCs.**

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



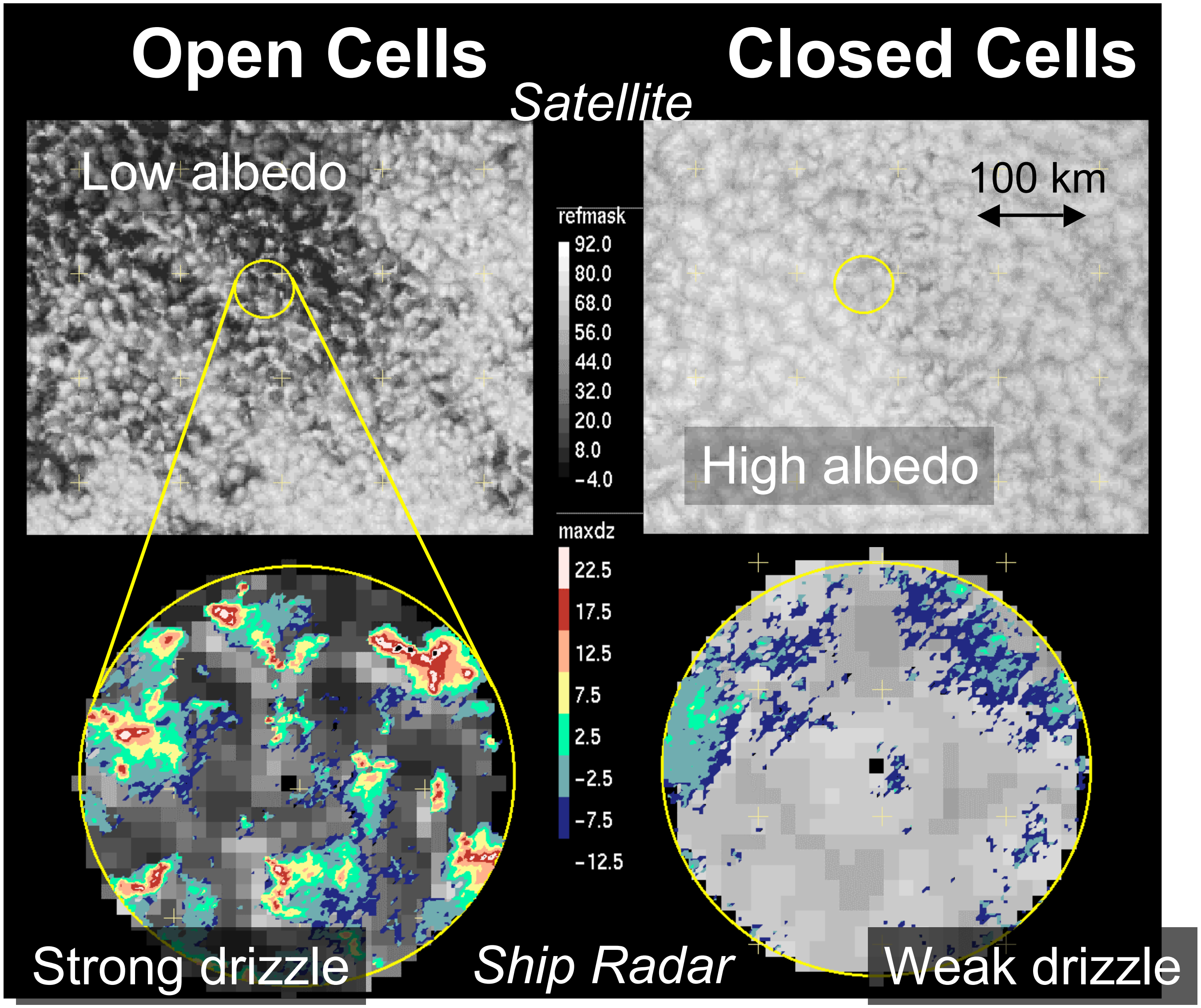
EPIC data, Bretherton et al. (2004)

1B	**Precipitation is a necessary condition for the formation and maintenance of pockets of open cells (POCs) within stratocumulus clouds**

- Cloud albedo strongly dependent upon open/closed cells

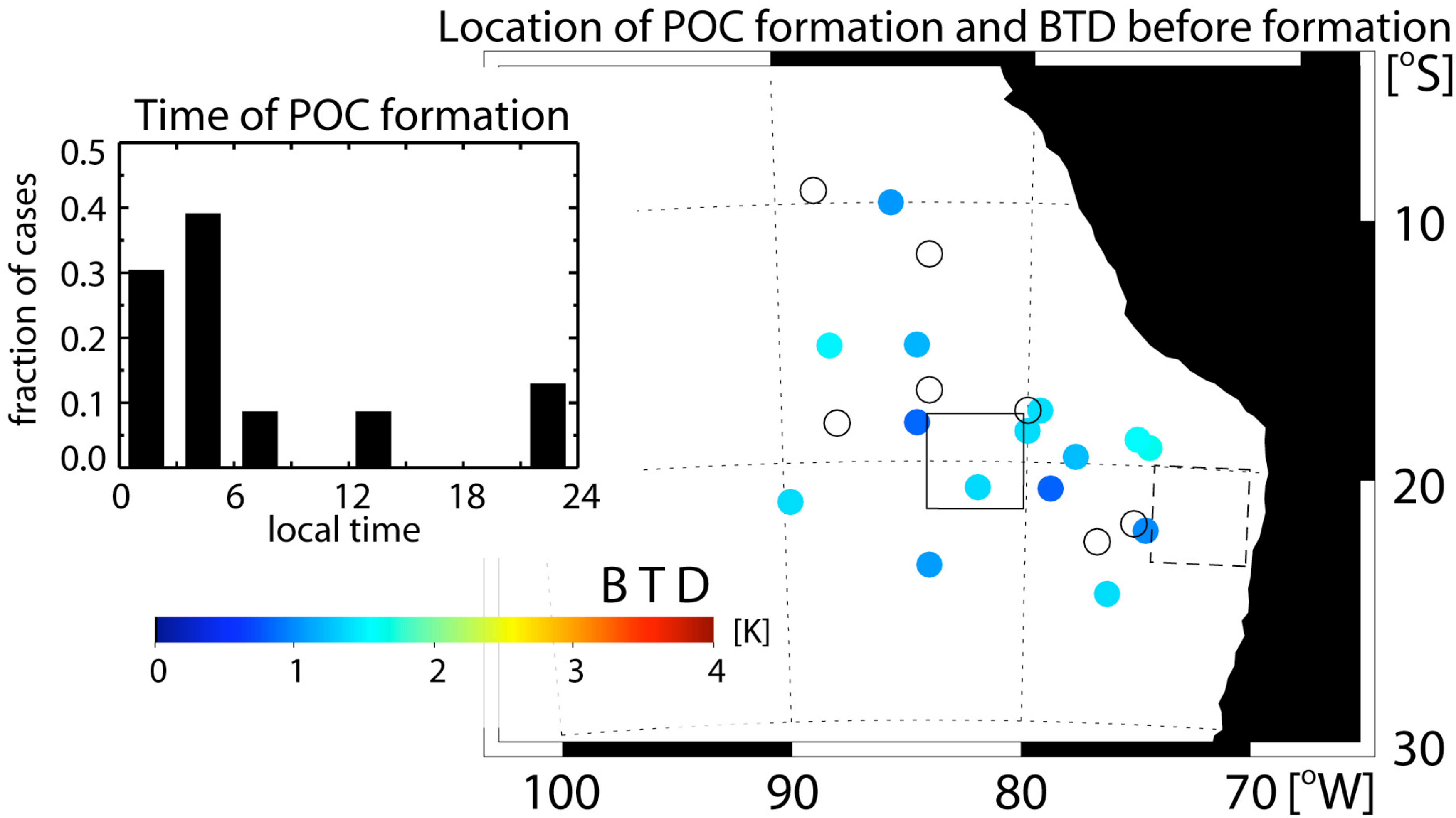
- Strong precipitation associated with open cell structure

- **In-situ aircraft measurements of the mesoscale dynamics needed**



Sandra Yuter, NCSU

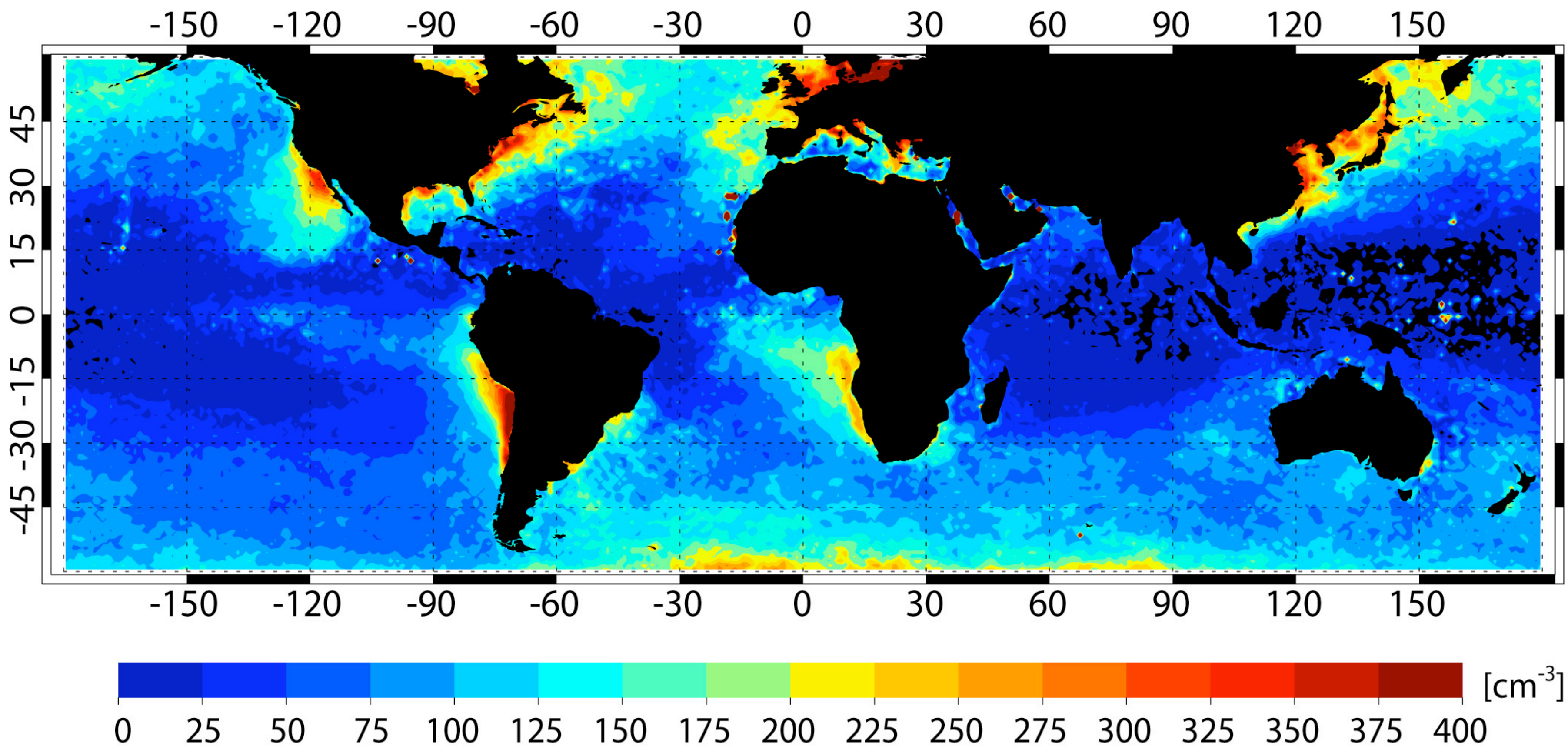
POC formation



Kim Comstock

Flight-plan for C-130
POC-Drift missions

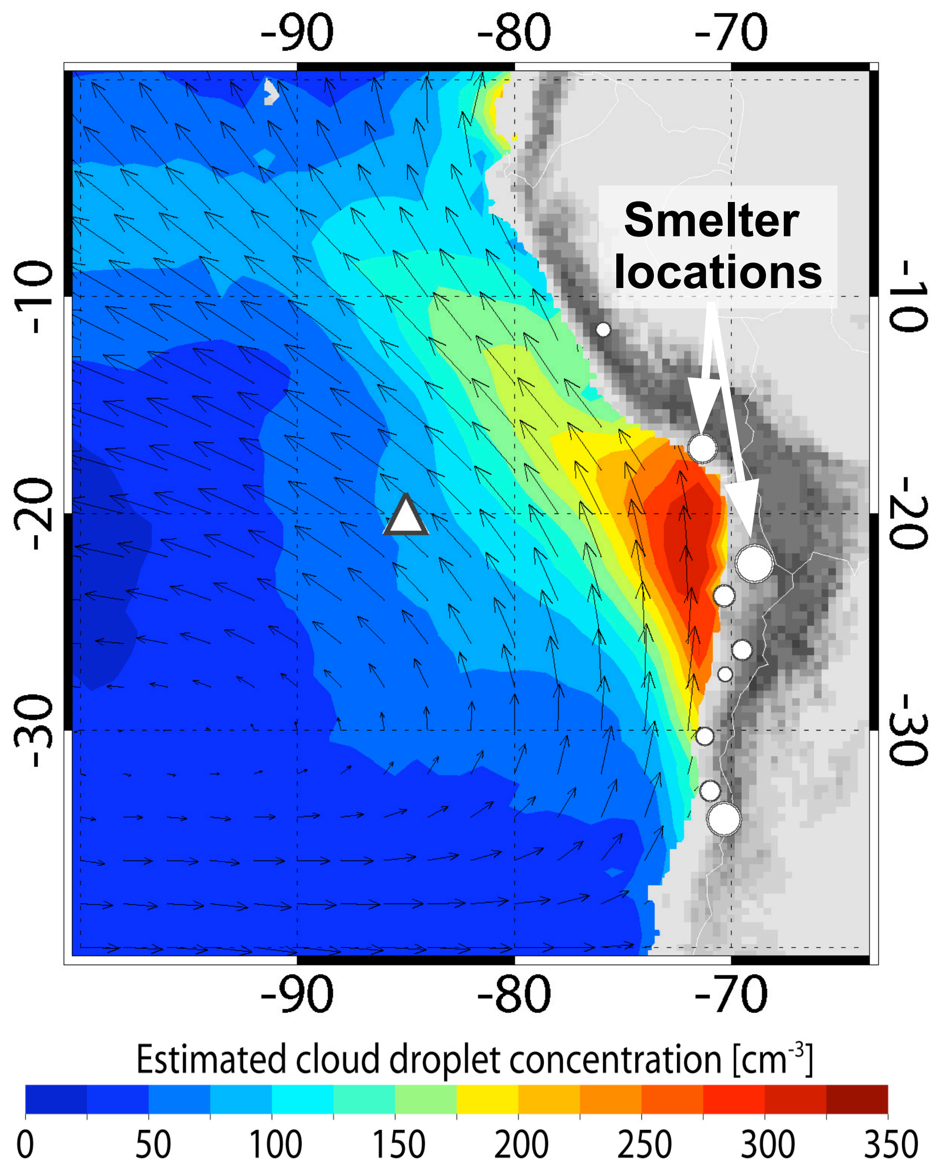
1C	The small effective radii measured from space over the SEP are primarily controlled by anthropogenic, rather than natural, aerosol production, and entrainment of polluted air from the lower free-troposphere is an important source of cloud condensation nuclei.



CLOUD DROPLET CONC. from MODIS (Ann. Mean 2001-2004)

Cloud Microphysical Variability

- 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 SO2 emissions from seven smelters!
- Andes mountains prevents eastward transport

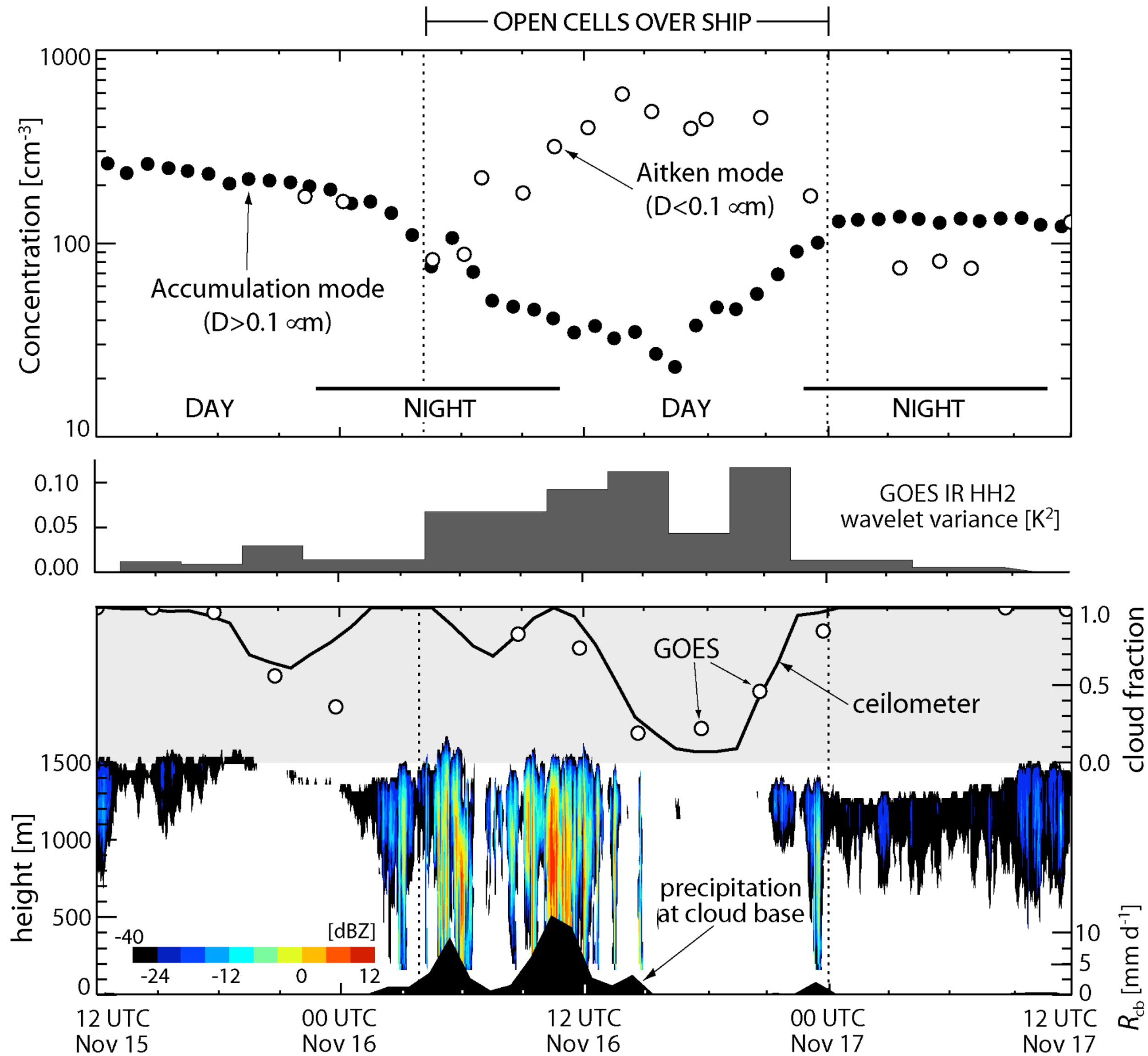


VOCALS-REx Cross-Section Sampling

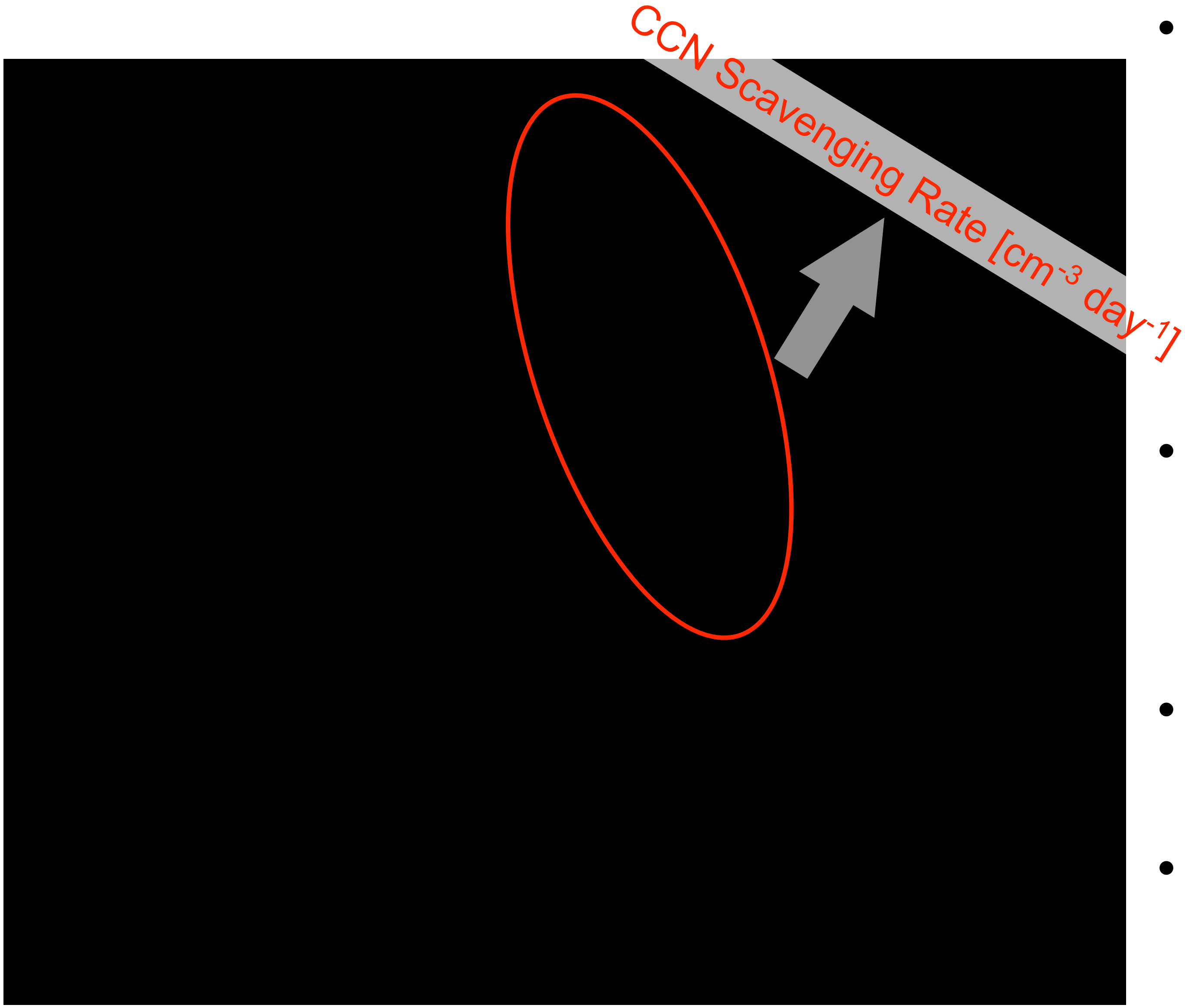
Combined NOAA Ronald H Brown and NSF C-130 Missions

- direct evaluation of GCM lower tropospheric structure

1D	Depletion of aerosols by coalescence scavenging is necessary for the maintenance of POCs



Loss rate of CCN due to drizzle



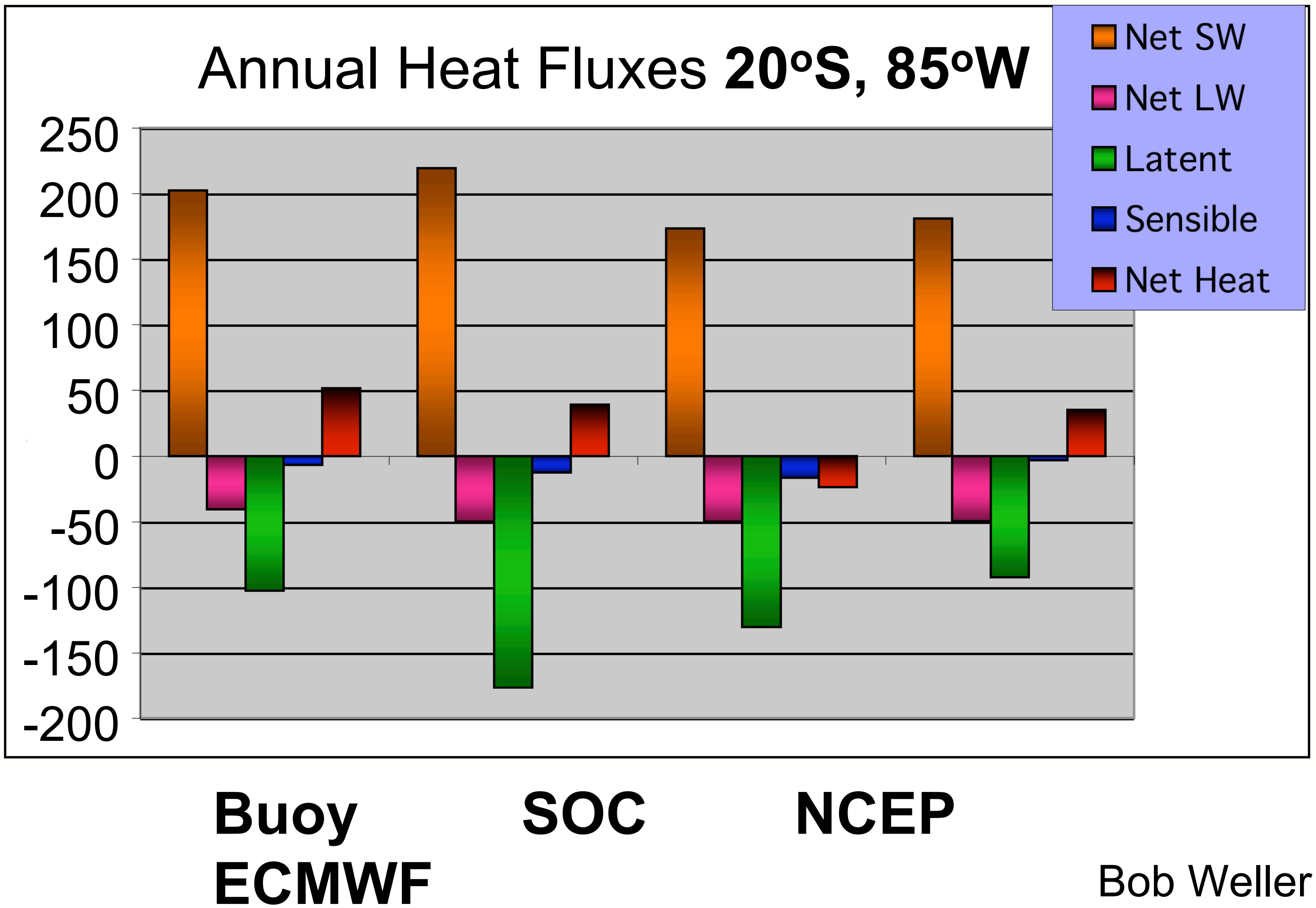
- Accurate precipitation rate obs. and microphysical measurements required (C-130)
- Cloud droplet concentration budget estimates
- Microphysical modeling
- Captured in GCMs?

COUPLED OCEAN-ATMOSPHERE LAND HYPOTHESES	
#	*Hypothesis*
2A	**Oceanic mesoscale circulations play a major role in the transport of heat and fresh water from coastally upwelled water to regions further offshore.**
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.**
2C	**The diurnal subsidence wave ("upsidence wave") originating in northern Chile/southern Peru has an impact upon the diurnal cycle of clouds and provides a useful framework for analysis of numerical model performance on diurnal time scales.**
2D	**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 ocean surface layer.**

Ocean surface heat budget

Reanalaysis surface fluxes are not accurate, for example, NCEP has a longer, cooler winter and little net heating of the ocean.

- Buoy obs show more surface net heat gain than models; NCEP shows a loss
- NCEP stress 30% stronger
- Models: rain (.07 to .3 m yr^{-1}) Buoy: no rain to .03 m yr^{-1}



Bob Weller

Sea surface temperature and salinity

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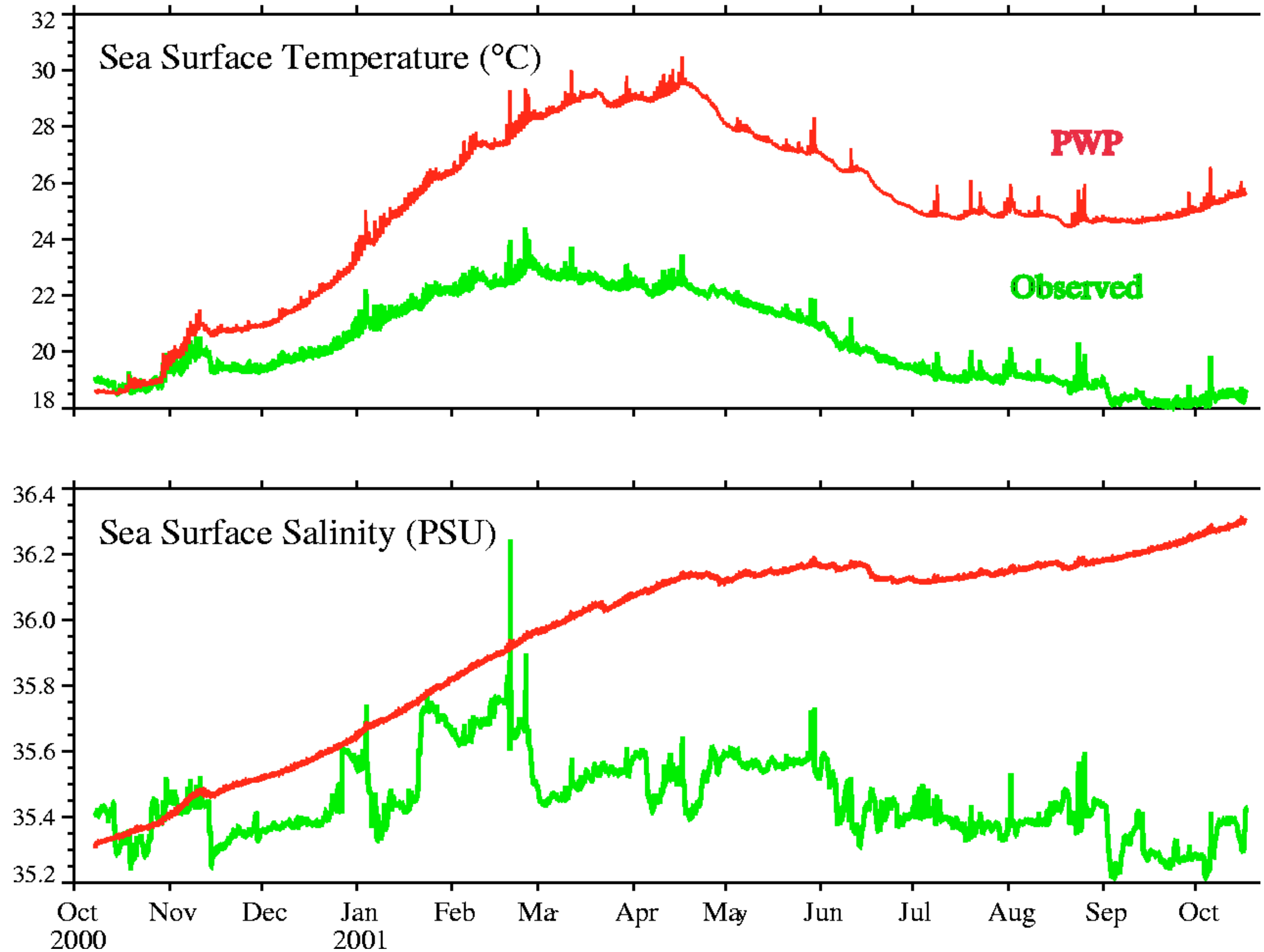
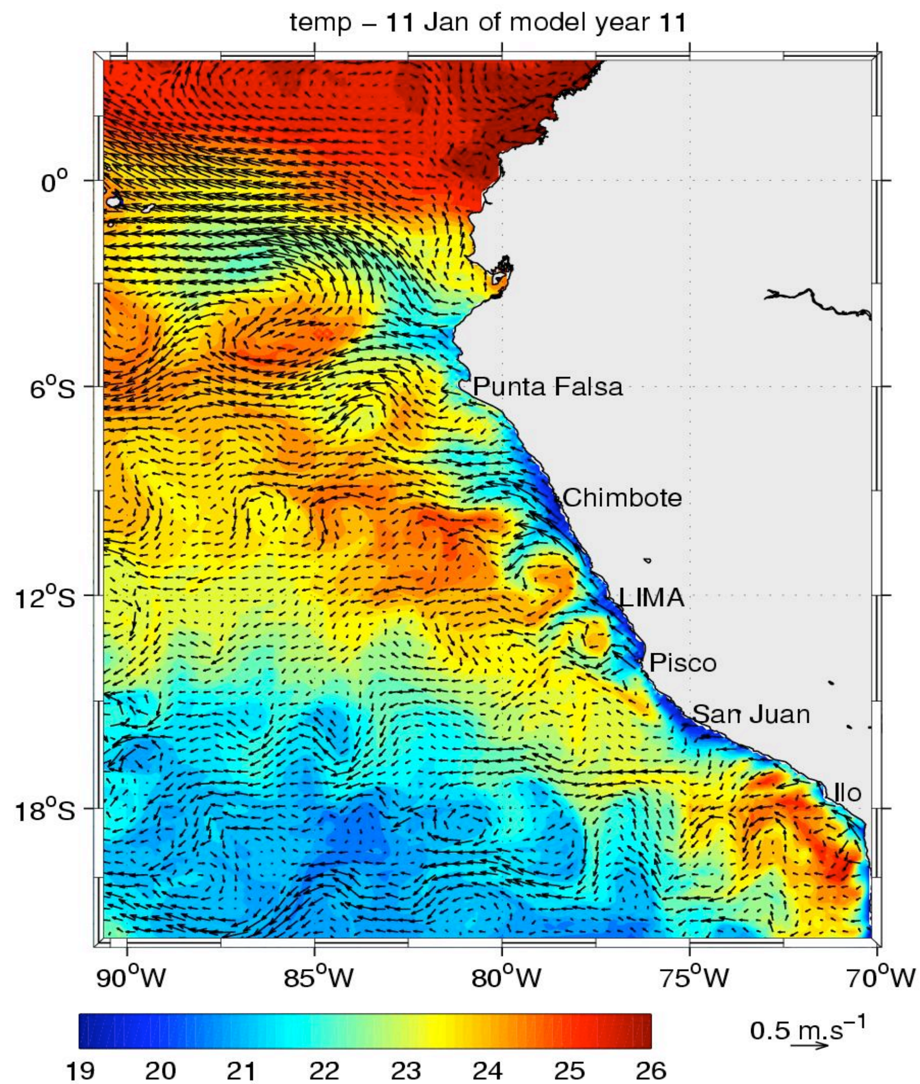
Surface forcing from buoy driving a one-dimensional ocean model (PWP) produces a surface layer that is too warm and too salty.



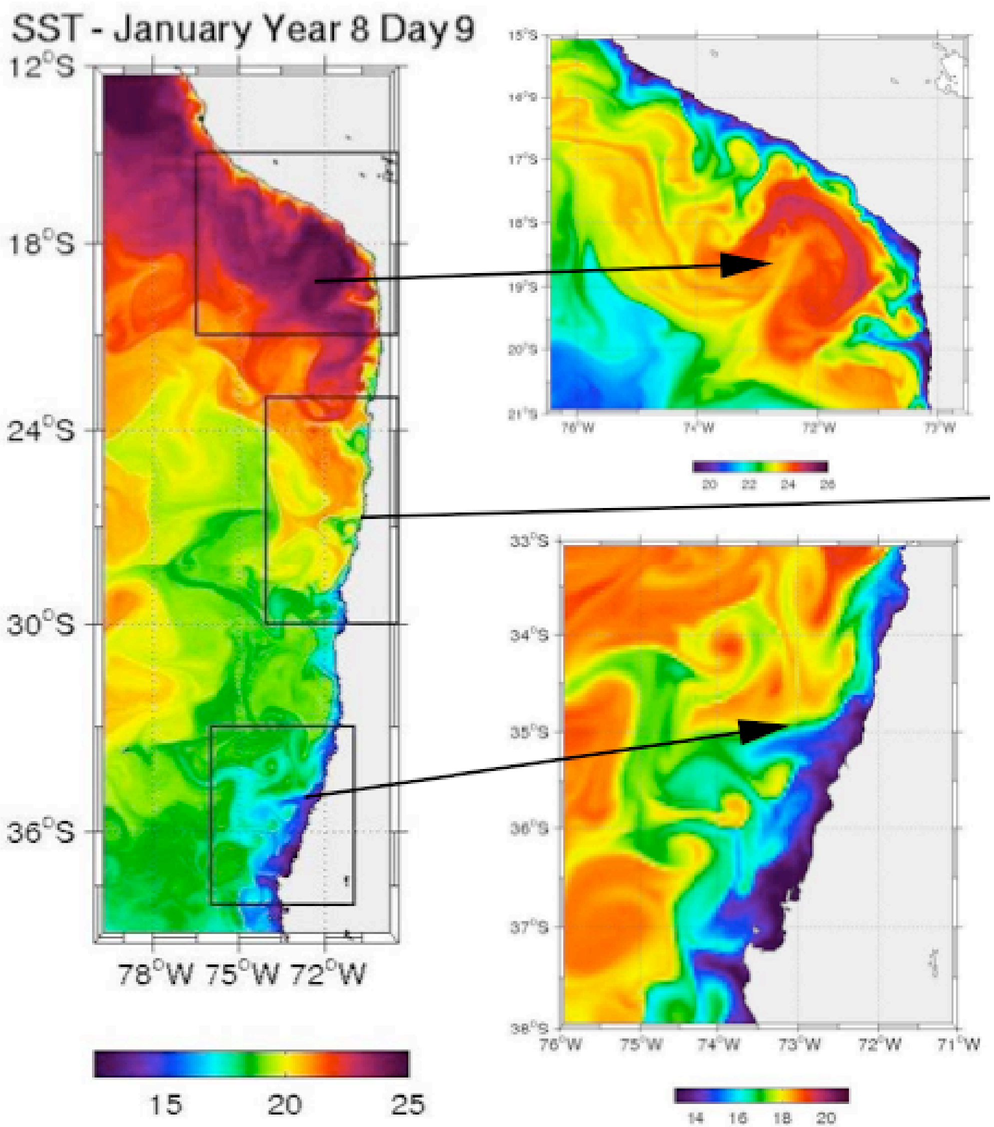
Bob Weller

2A	**Oceanic mesoscale circulations play a major role in the transport of heat and fresh water from coastally upwelled water to regions further offshore**

- Mesoscale ocean eddies form in coastal upwelling regions and propagate westward
- Their impact on the heat, nutrient, and freshwater budgets is poorly known
- They are not resolved in coupled GCMS

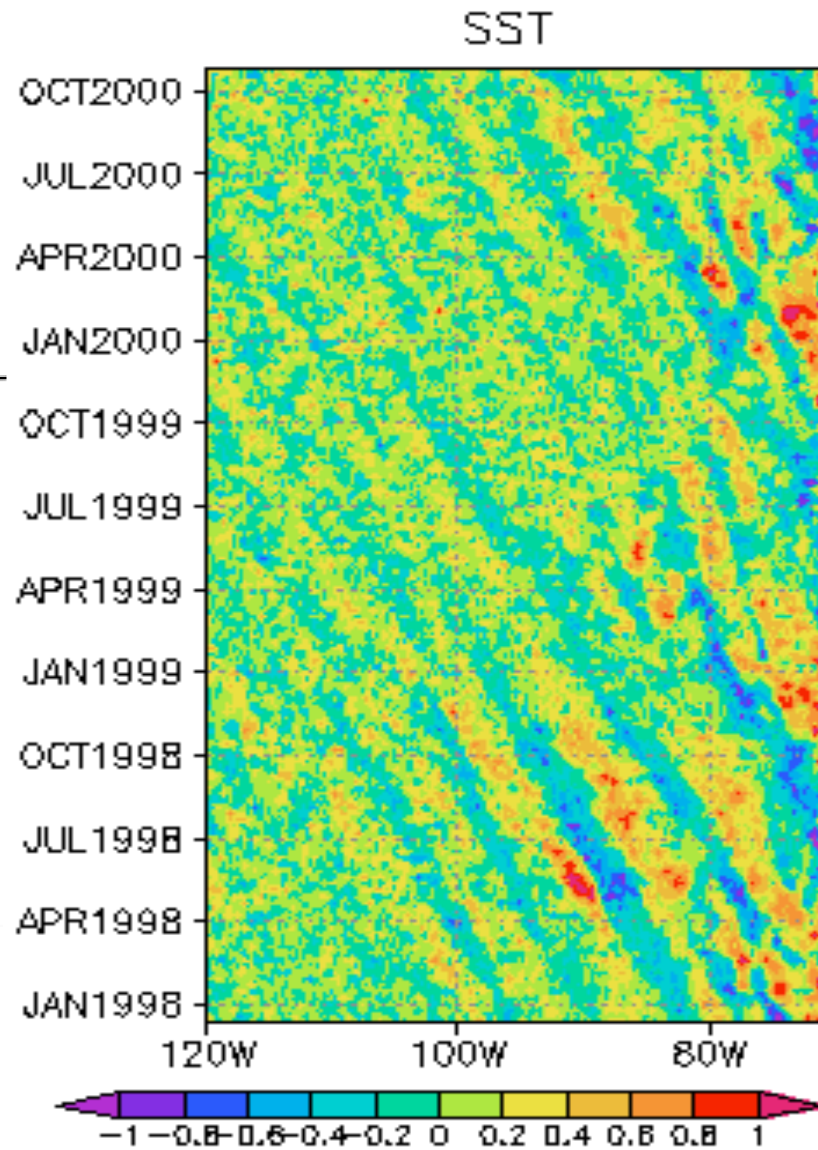


Art Miller, Scripps



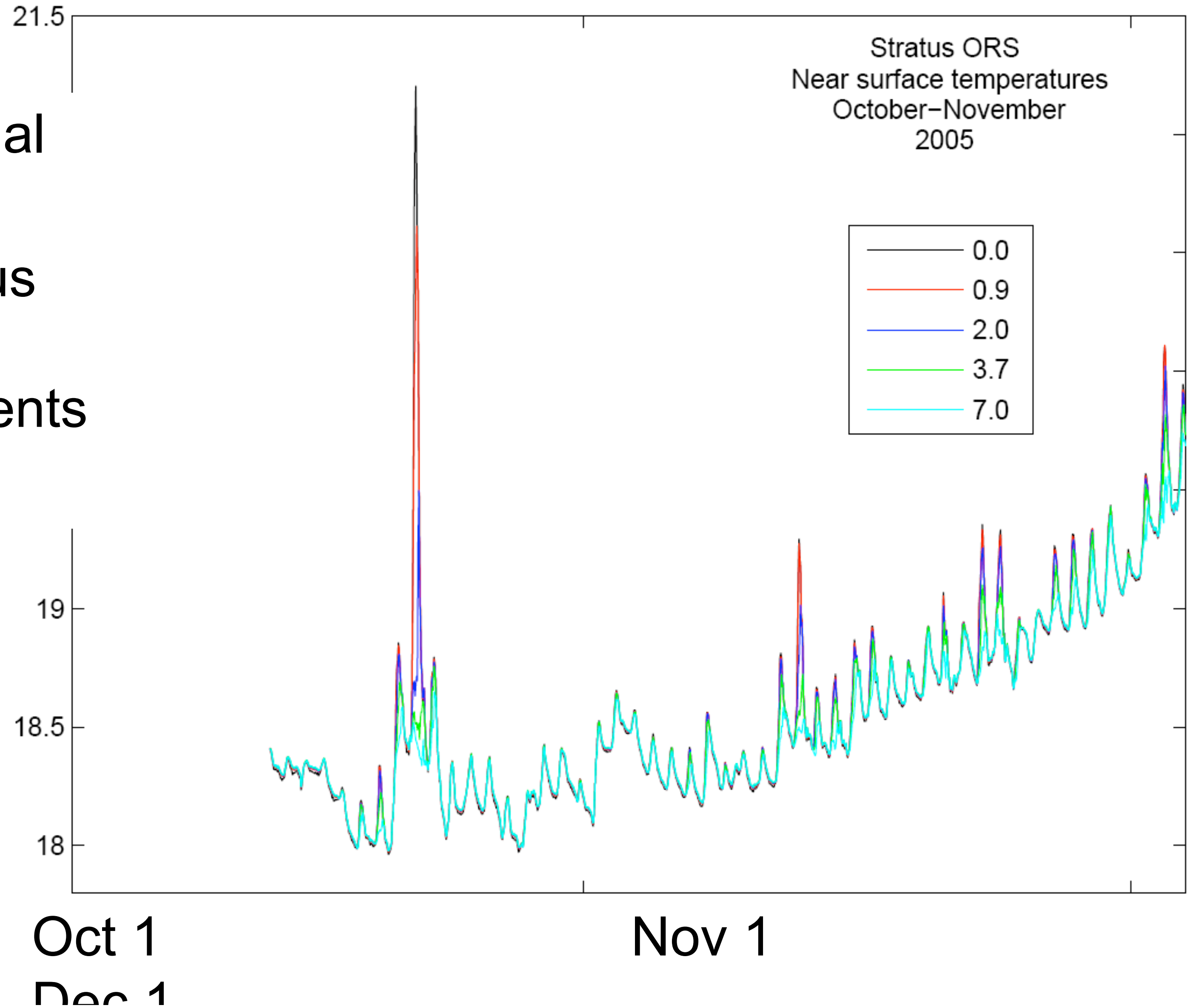
(From J. McWilliams)

S-P. Xie



SST at IMET Buoy (20^{o}S, 85^{o}W)

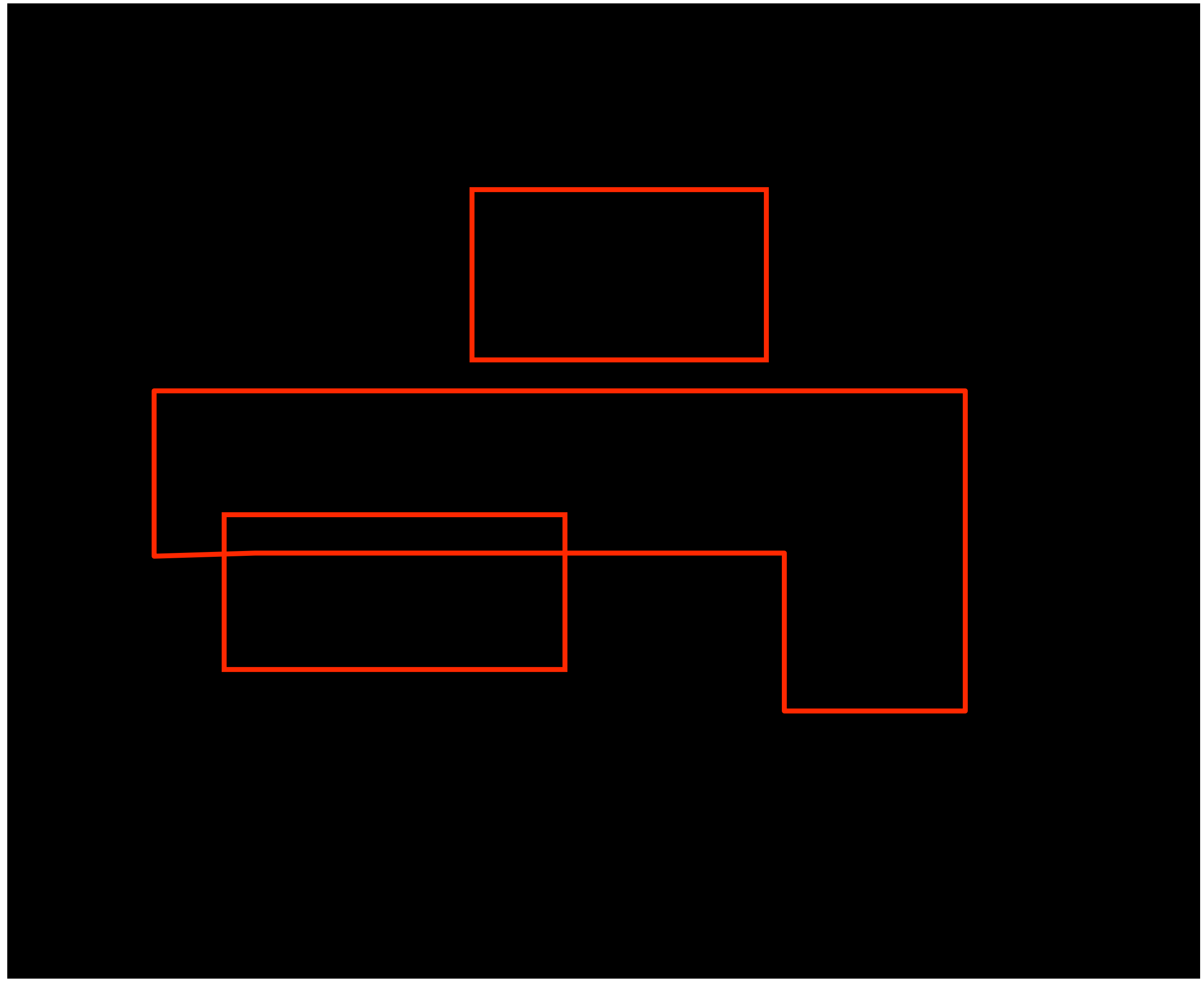
- Strong diurnal signature
- Simultaneous submonthly warming events

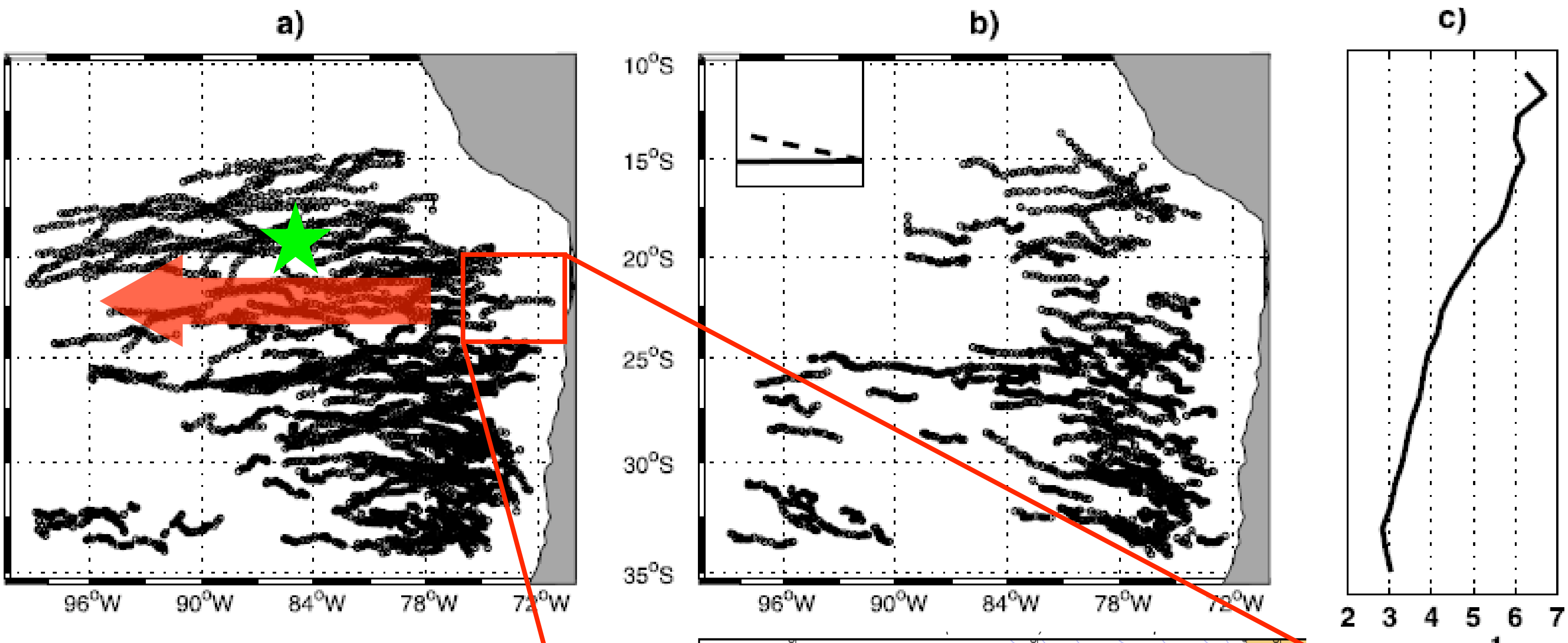


VOCALS-REx: Ship sampling

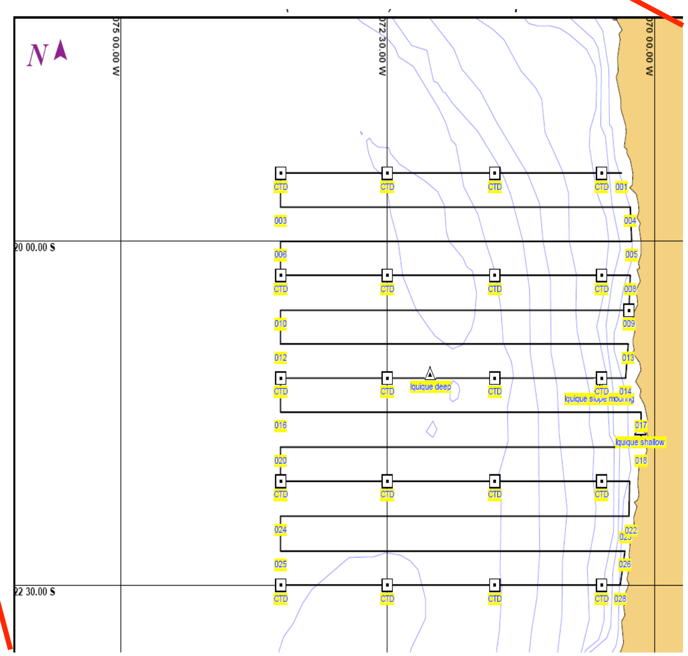
- **Phase 1 (3 wks)**: RHB sits for 6 days at each buoy (20°S, 85+75^{o}W) and concertina transit between the buoys; Wecoma carries out a survey of the eddy-genesis region.

- **Phase 2 (3 wks)**: Wecoma surveys oceanic mesoscale variability around the RHB (using SeaSoar)





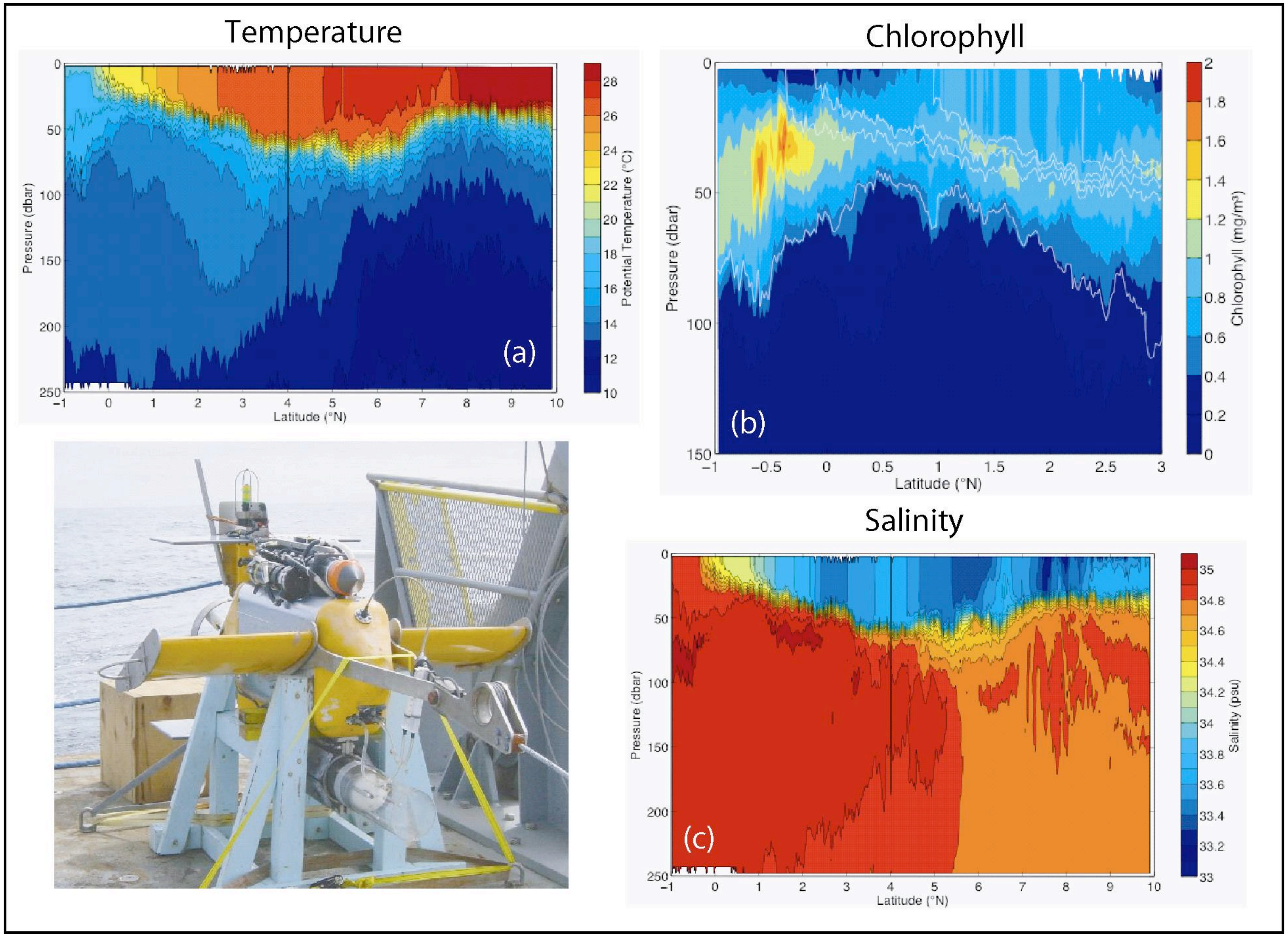
Chaigneau and Pizarro



- **Second ship coastal sampling**
- **Capture eddies in genesis region**

SeaSoar TUV (towed undulating vehicle)

- Upper ocean horizontal and vertical structure
- oxygen, nitrate, chlorophyll, salinity
- radiative properties
- mesoscale ocean eddy structure

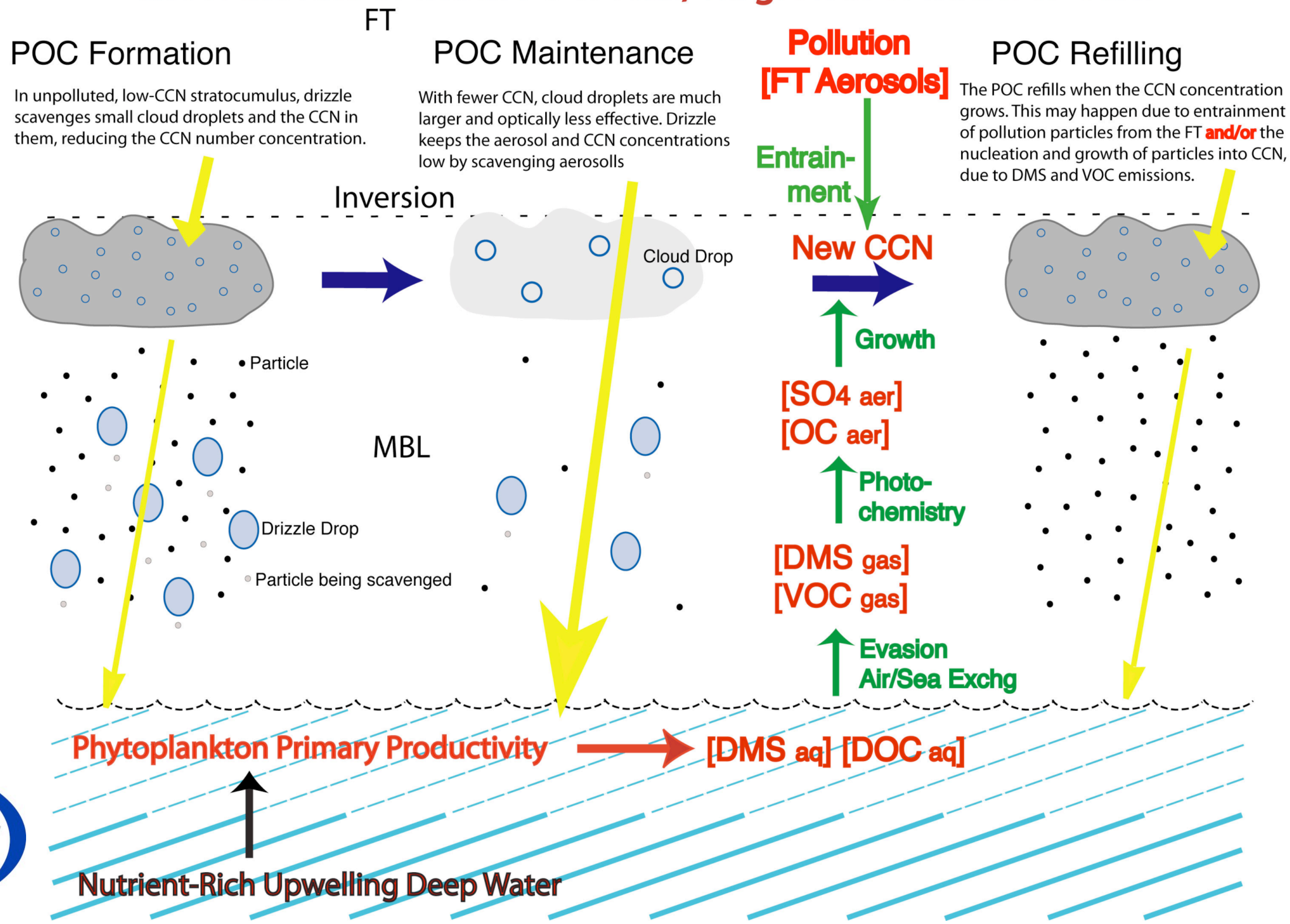


Examples from EPIC, Wijisekera, OSU

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

POCs and Upwelling

Do filaments of upwelled water affect the rate at which POCs refill, via growth of nuclei to CCN?

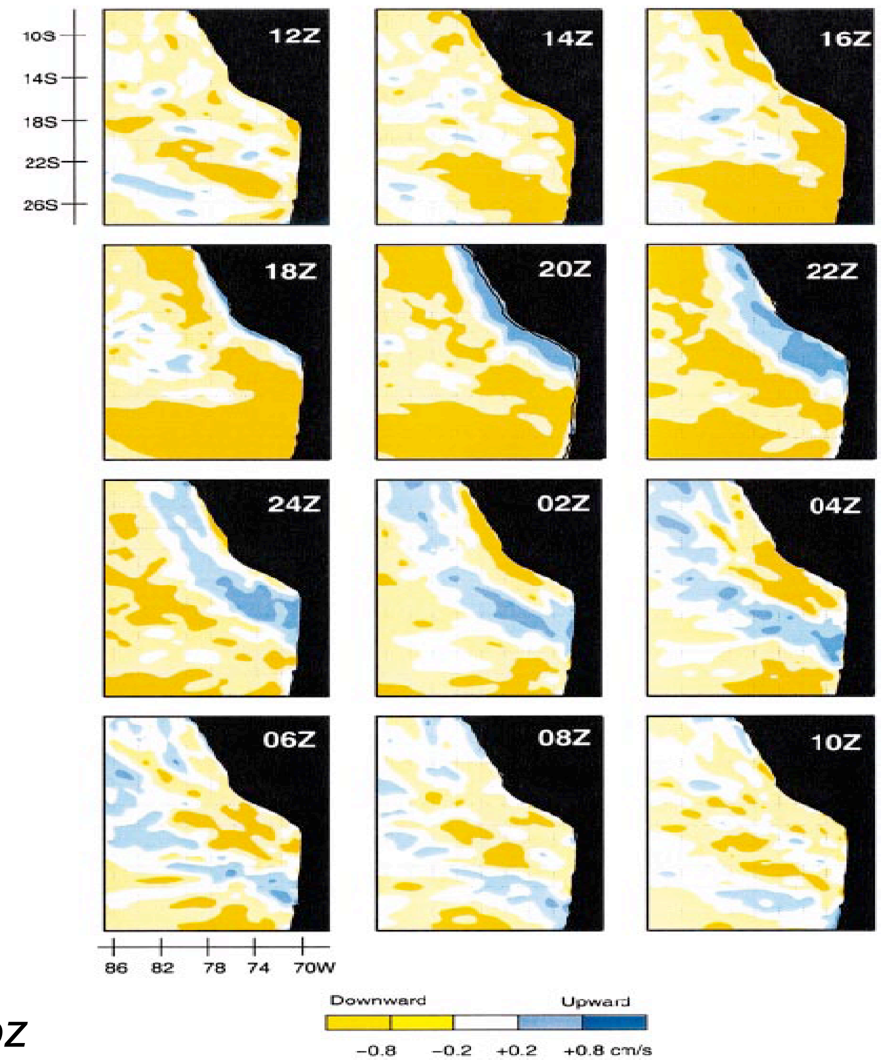


Barry Huebert

solas
surface.ocean lower.atmosphere.study

2C	**The diurnal subsidence wave ("upsidence wave") originating in northern Chile/southern Peru has an impact upon the diurnal cycle of clouds and provides a useful framework for analysis of numerical model performance on diurnal time scales.**

- Strong diurnal cycle in lower tropospheric subsidence in MM5
- Strong diurnal cycle in MBL and clouds observed during EPIC (+satellites)
- RHB, Chilean land site will make measurements of the free-troposphere at different distances from the coast

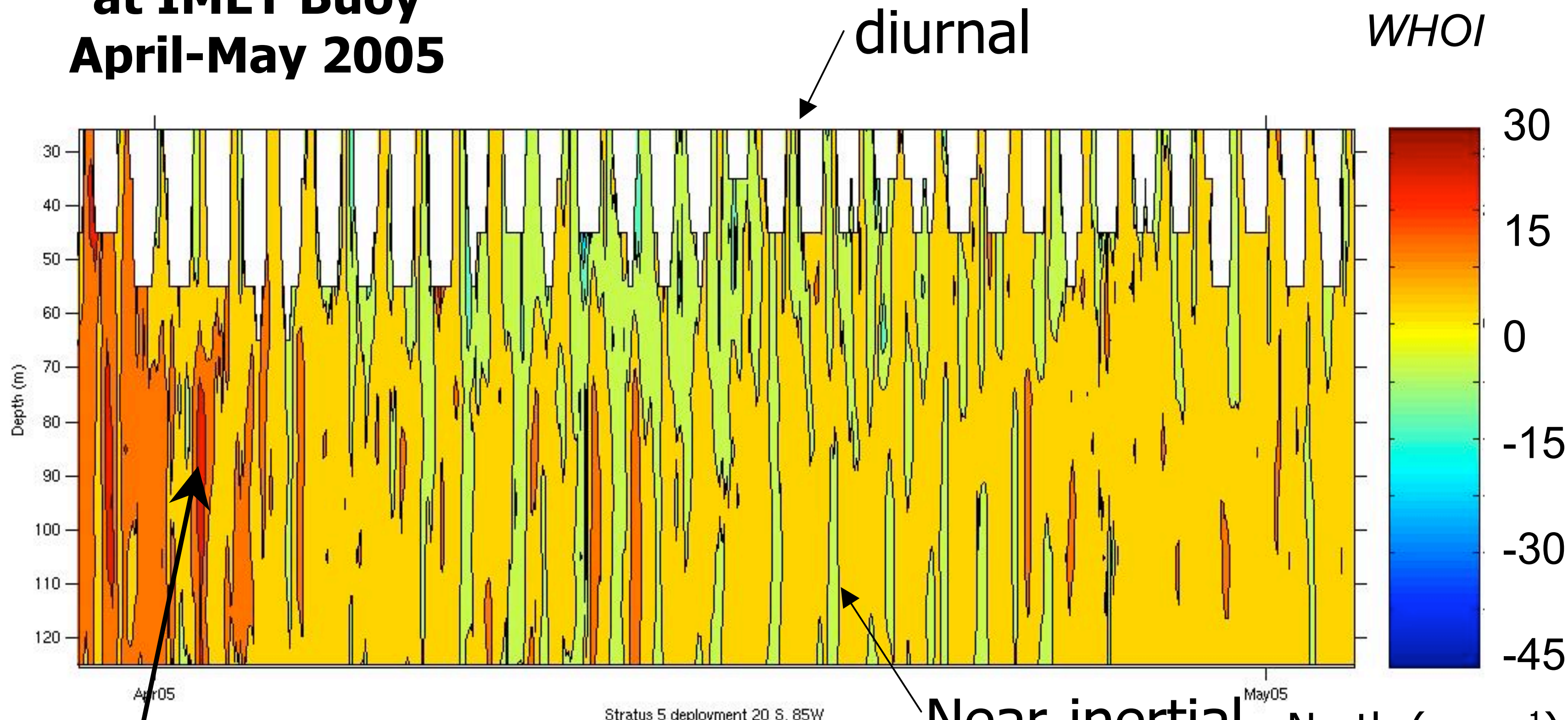


Garreaud and Muñoz

2D	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 ocean surface layer

Northward current velocity at IMET Buoy April-May 2005

Bob Weller WHOI



Note strong (30 cm/s), subsurface velocities, strong shears.

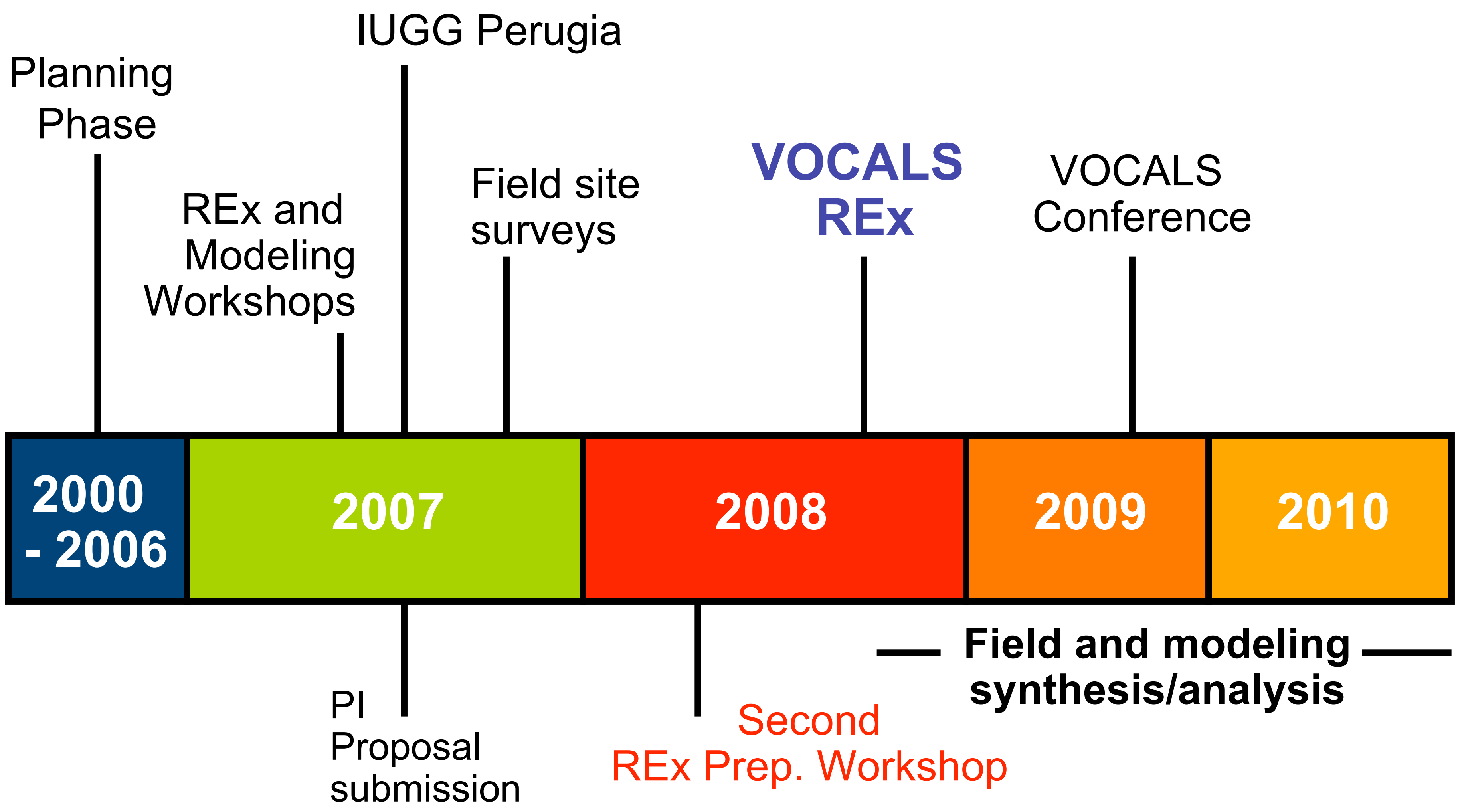
AEROSOL-CLOUD-PRECIPITATION HYPOTHESES

#	Hypothesis	Platforms	Obs. PI Teams
1A	Variability in the physicochemical properties of aerosols has a measurable impact upon the formation of drizzle in stratocumulus clouds	C-130, RHB, Twin Otter, G-1, 146	Howell/Huebert/Clarke Bandy/Blomquist Wood/Bretherton Covert/Bates/Quinn Albrecht Feingold Daum
1B	Precipitation is a necessary condition for the formation and maintenance of POCs within stratocumulus clouds	C-130, RHB, G-1	Wood/Bretherton Fairall/Yuter Leon/Snider Feingold Albrecht Daum
1 C	The small r_e measured from space is primarily controlled by anthropogenic rather than natural aerosol production; entrainment of polluted air from the FT is an important source of CCN	C-130, RHB, G-1, Twin Otter, 146 Land site	Huebert/Clarke Covert/Bates/Quinn Gallardo/Cordova Zuidema Wood/Thorton/Zaveri Twohy/Collett/Anderson
1 D	Depletion of aerosols by coalescence scavenging is necessary for the maintenance of POCs	C-130	Leon/Snider Feingold

COUPLED OCEAN-ATMOSPHERE LAND HYPOTHESES

#	Hypothesis	Platforms	Obs. PI Teams
2A	Oceanic mesoscale circulations play a major role in the transport of heat and fresh water from coastally upwelled water to regions further offshore.	RHB, R/V Wecoma, R/V Olaya, C-130	Weller/Straneo Grados Paulson/Letelier/Dever/Pizarro Miller Garreaud Strub/Chelton
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.	C-130 RHB	Huebert/Matrai Blomquist/Huebert Covert/Bates/Quinn Strutton/Hales
2C	The diurnal subsidence wave originating in northern Chile/southern Peru has an impact upon the diurnal cycle of clouds and provides a useful framework for analysis of numerical model performance on diurnal time scales.	RHB C-130 Twin Otter Land site Quikscat	Garreaud/Rutllant Bretherton/Wood Takahashi/Silva
2D	The entrainment of cool fresh intermediate water from below the surface layer during mixing associated with energetic NIOs generated by transients in the trade winds is an important process to maintain surface heat and salt balance.	RHB R/V New Horizon	Gregg Weller/Straneo Ward

VOCALS Timeline



ADDITIONAL SLIDES

AEROSOL-CLOUD-PRECIPITATION HYPOTHESES

#	Hypothesis	Obs	Models	Model Teams
1A	**Variability in the physicochemical properties of aerosols** has a measurable impact upon the formation of **drizzle** in stratocumulus clouds over the SEP.	C-130, RHB, Twin Otter, G-1,	LES WRF Chem GCMs	**Wood/Bretherton Feingold Cotton/Carrio PNNL**
1B	**Precipitation is a necessary condition** for the formation and maintenance of **pockets of open cells** (POCs) within stratocumulus clouds.	C-130, RHB	LES COAMPS	**Feingold Wood/Bretherton NRL, Wang**
1C	**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.	C-130, RHB, G-1, Twin Otter, A-Train, Land site	WRF Chem CTMs Parcel Model GCMs	**Gallardo/Cordova Donner/Golaz Wood/Zaveri PNNL**
1D	**Depletion of aerosols by coalescence scavenging** is necessary for the maintenance of POCs.	C-130, A-Train	Parcel model LES GCMs	**Feingold PNNL Donner/Golaz**

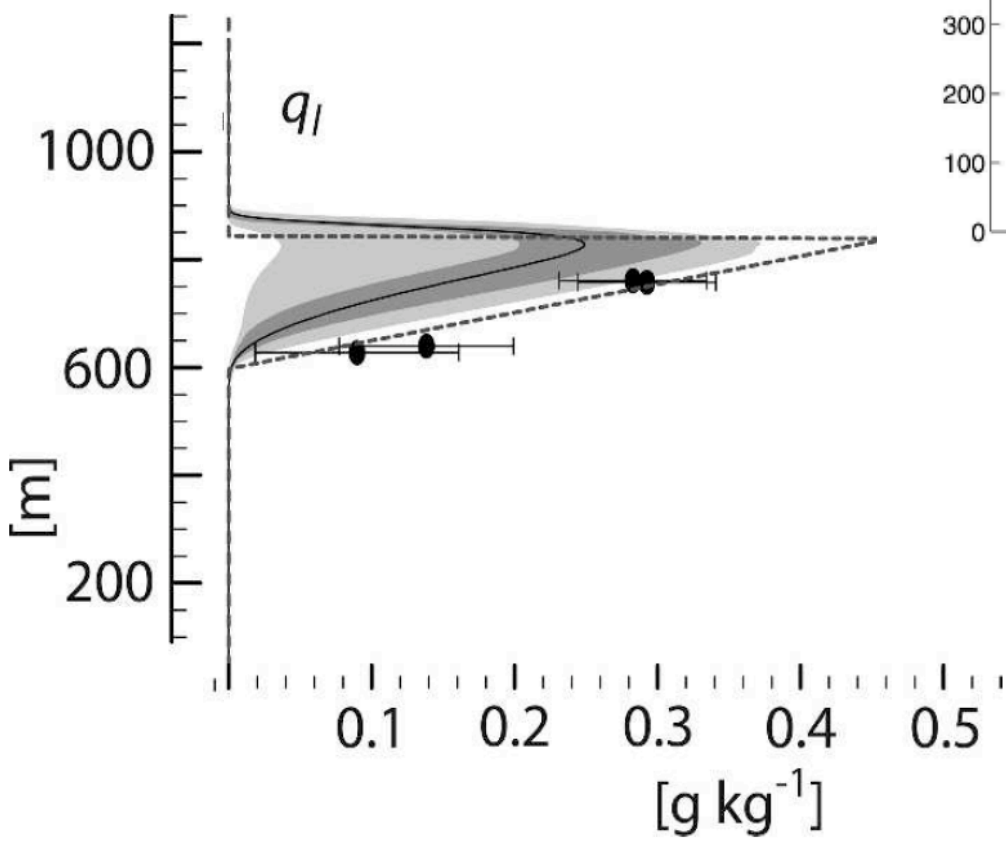
COUPLED OCEAN-ATMOSPHERE LAND HYPOTHESES

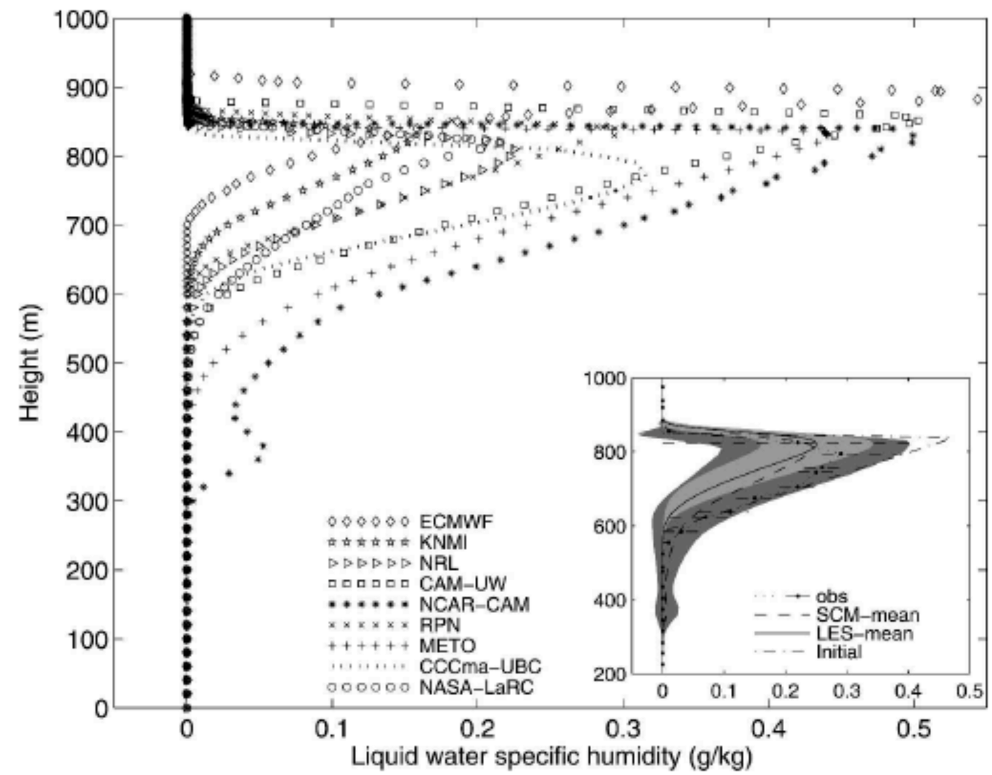
#	Hypothesis	Obs	Model	Model Teams
2 *A*	**Oceanic mesoscale circulations** play a major role in the **transport of heat and fresh water** from coastally upwelled water to regions further offshore.	RHB, New Horizon, Olaya, JASON	ROMS CGCMs	**Miller McWilliams/Hall/ Gruber/Large Garreaud? Strub/Chelton**
2 *B*	**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.	C-130 RHB	WRF-Chem GCMs	**PNNL**
2 *C*	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.	RHB C-130 Twin Otter Land site	MM5/WRF GCMs	**Garreaud/Rutllant Bretherton/Wood NRL**
2 *D*	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 ocean surface layer.	RHB R/V New Horizon	Parcel Model LES	**Gregg Weller/Straneo Ward**

REx - GCM EVALUATION HYPOTHESES

#	Hypothesis	Obs	Model Teams
3 A	**Poor representation of the vertical structure and depth of the stratocumulus-topped MBL contributes significantly to systematic GCM model errors in cloud cover, precipitation, and aerosol indirect effects over the SEP.**	C-130 Cross Sections RHB vertical structure Chilean land site IMET buoy long term data	**McWilliams/Hall/Gruber /Large Mechoso/Pan Kohler Garreaud Wang/Xie/deSzoeke Bretherton Donner/Golaz S. Wang**
3 B	**Errors in near-coastal winds contribute to errors in upwelling intensity in coupled ocean-atmosphere GCMs**	Second Ship coastal data IMET/SHOA buoy Quikscat	**Mechoso/Pan McWilliams/Hall/Gruber /Large McWilliams Wang/Xie/deSzoeke**

Sophisticated models

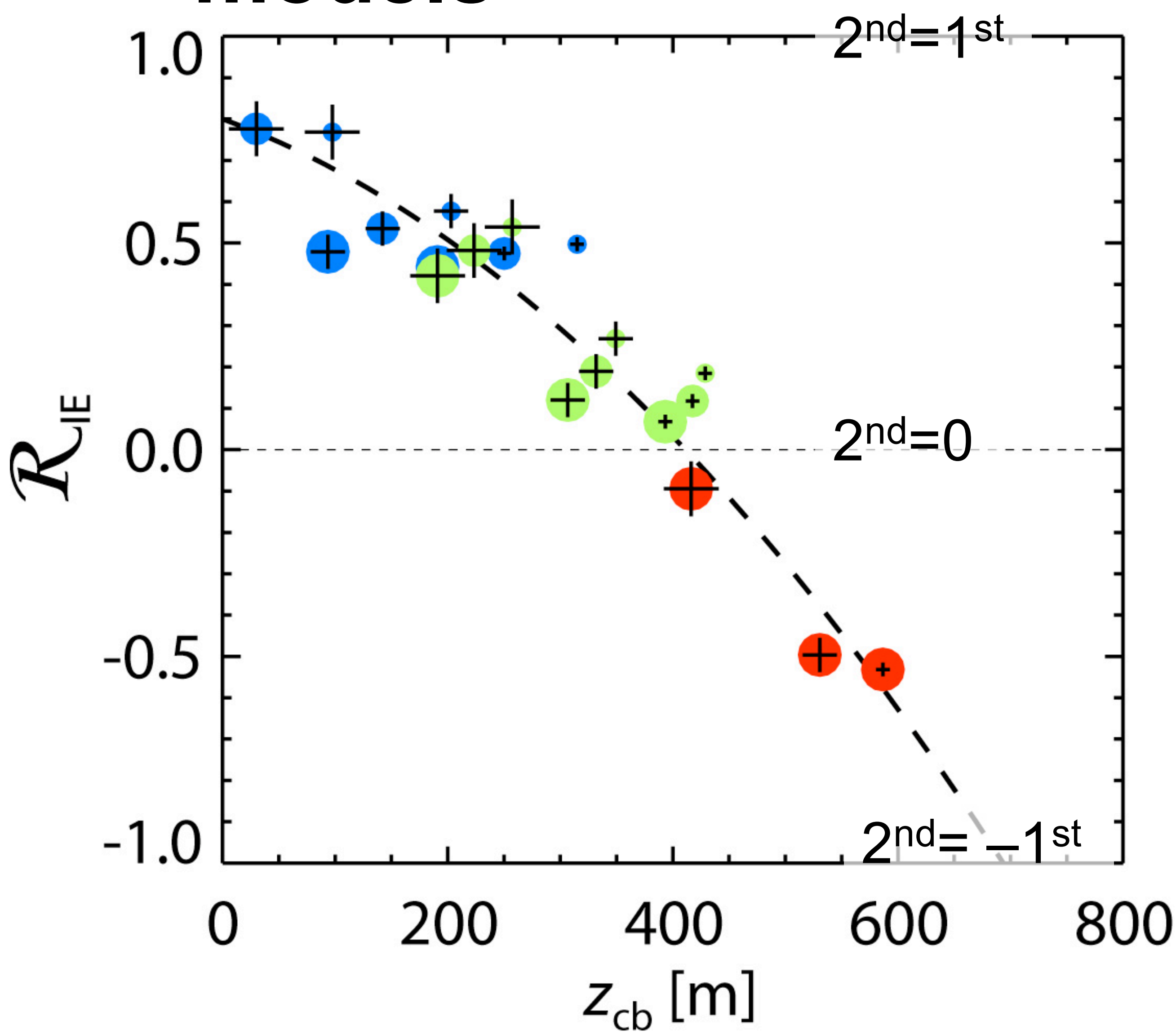




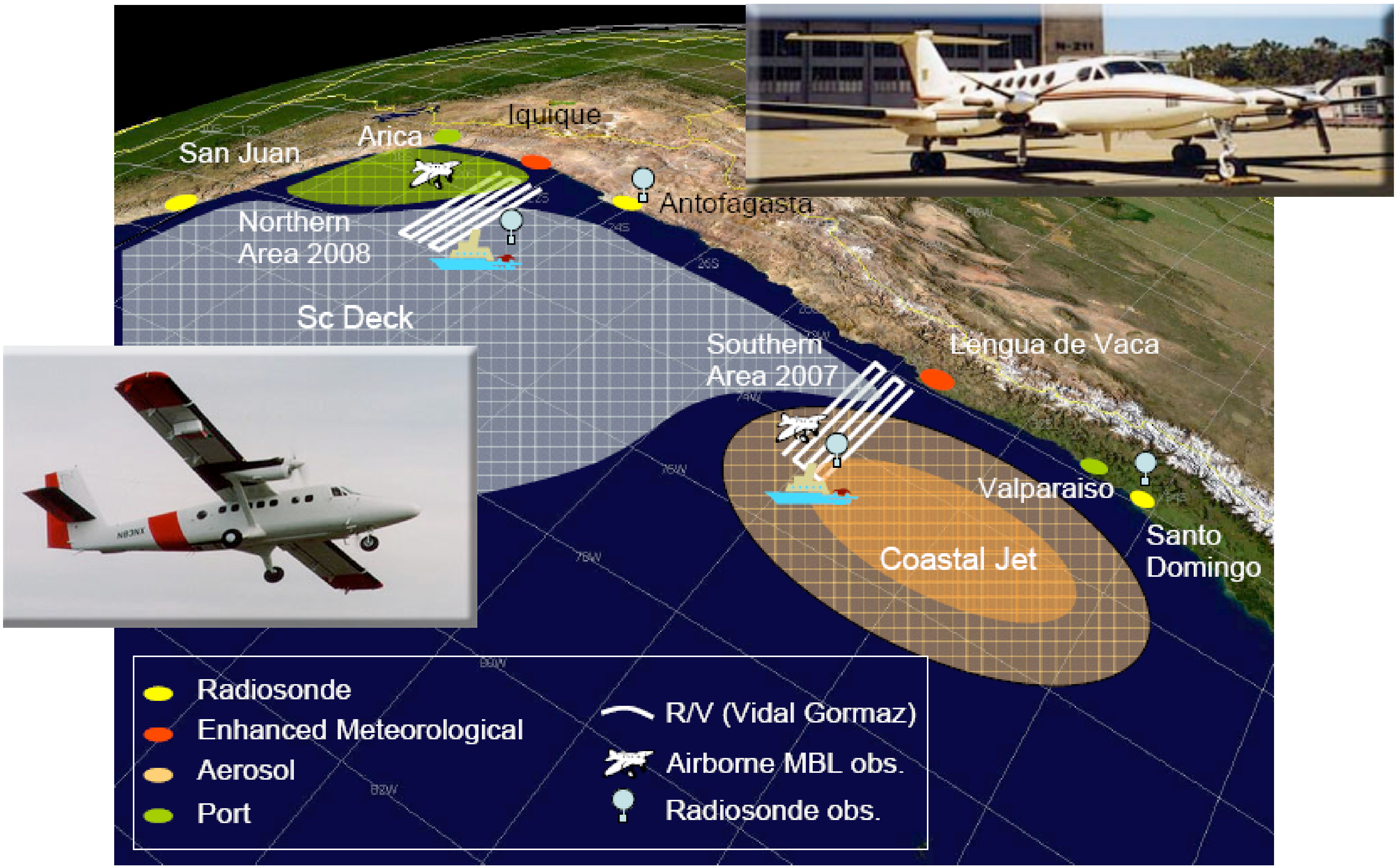
Single column models

Aerosol indirect effects in climate models

Strength of second indirect effect (drizzle suppression) is strongly dependent upon the depth of the cloud base



VOCALS Coastal Program



Nature, *326*, 655-661, 1987.

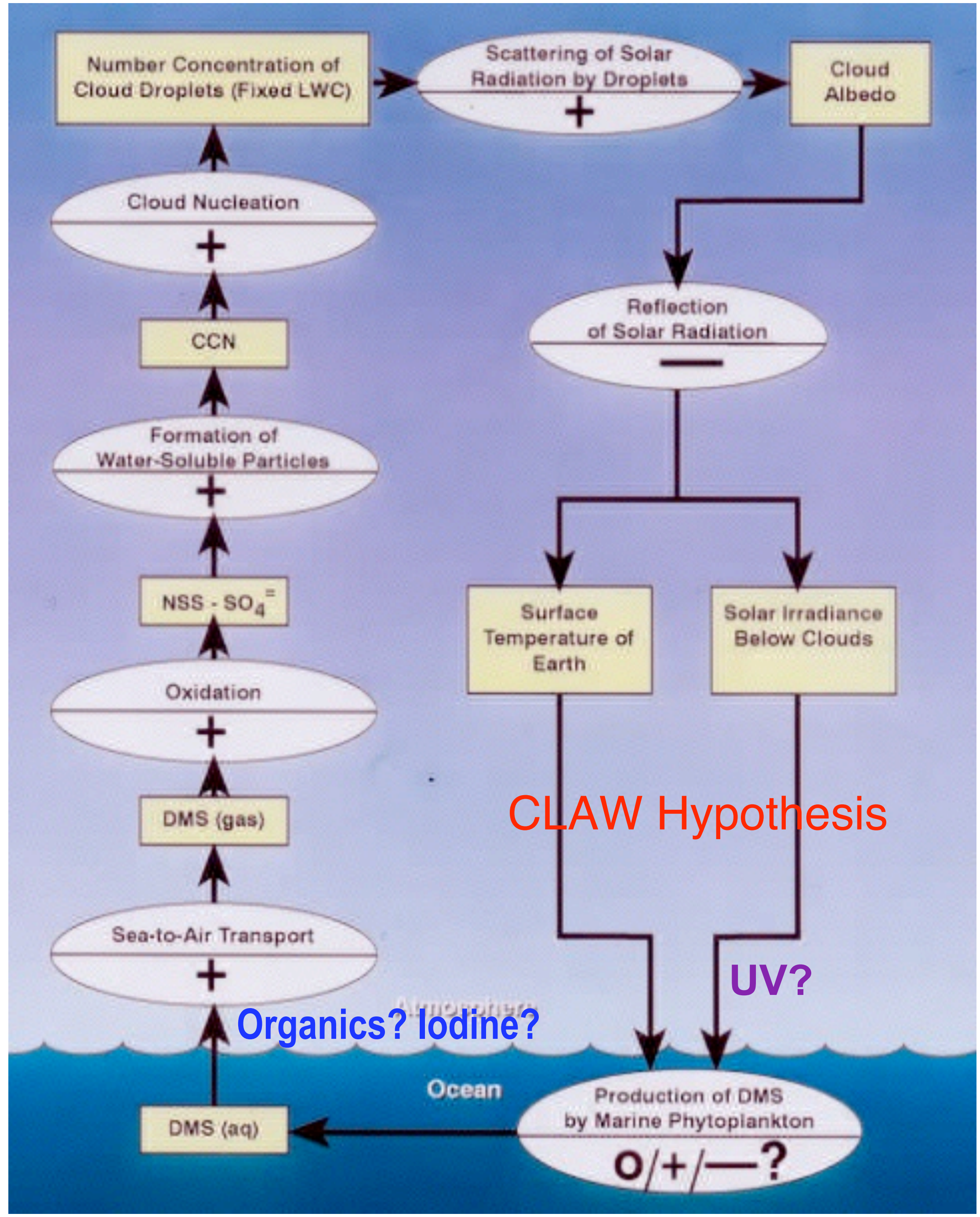
CCN = f(Biology)

Biology = f(CCN)

Cloud properties in remote regions are controlled in part by marine algae.

SOLAS scientists seek to quantify that linkage, so that models of changed climates will be realistic.

The controls on gas exchange rates are poorly understood.



VOCALS Extended Observations

IMET Buoy (WHOI):

Instrumented mooring (WHOI) – 6 years continuous dataset (meteorology/oceanography/radiation) at 20˚S, 85˚W

EPIC/PACS Fall Cruises (NOAA ESRL):

Ship measurements: 2001 (EPIC), then annually 2003-2006, remote sensing, meteorology, oceanography, aerosols

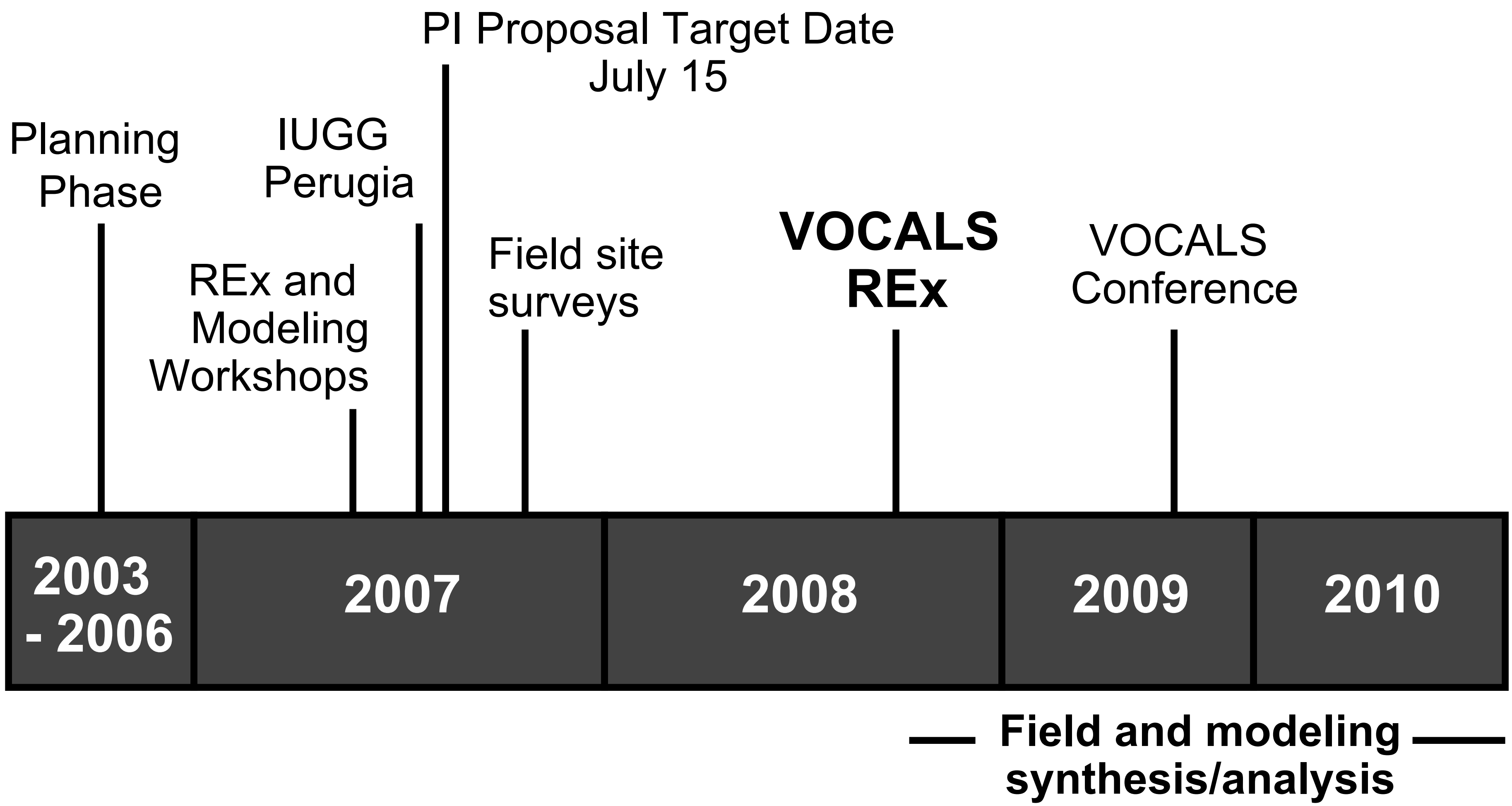
San Felix (Universidad de Chile):

Meteorological station on remote oceanic location under Sc deck

Satellite Measurements:

GOES/MODIS/JASIN/AMSR/Quikscat, now Cloudsat and Calipso

VOCALS Timeline



AEROSOL-CLOUD-PRECIPITATION HYPOTHESES

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1B	**Precipitation is a necessary condition** for the formation and maintenance of **pockets of open cells** (POCs) within stratocumulus clouds.	C-130, RHB	LES COAMPS	**Feingold Wood/Bretherton NRL, Wang**
1C	**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.	C-130, RHB, G-1, Twin Otter, A-Train, Land site	WRF Chem CTMs Parcel Model	**Gallardo/Cordova Wood/Zaveri PNNL**
1D	**Depletion of aerosols by coalescence scavenging** is necessary for the maintenance of POCs.	C-130, A-Train	Parcel model LES	**Feingold PNNL**

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OUTLINE

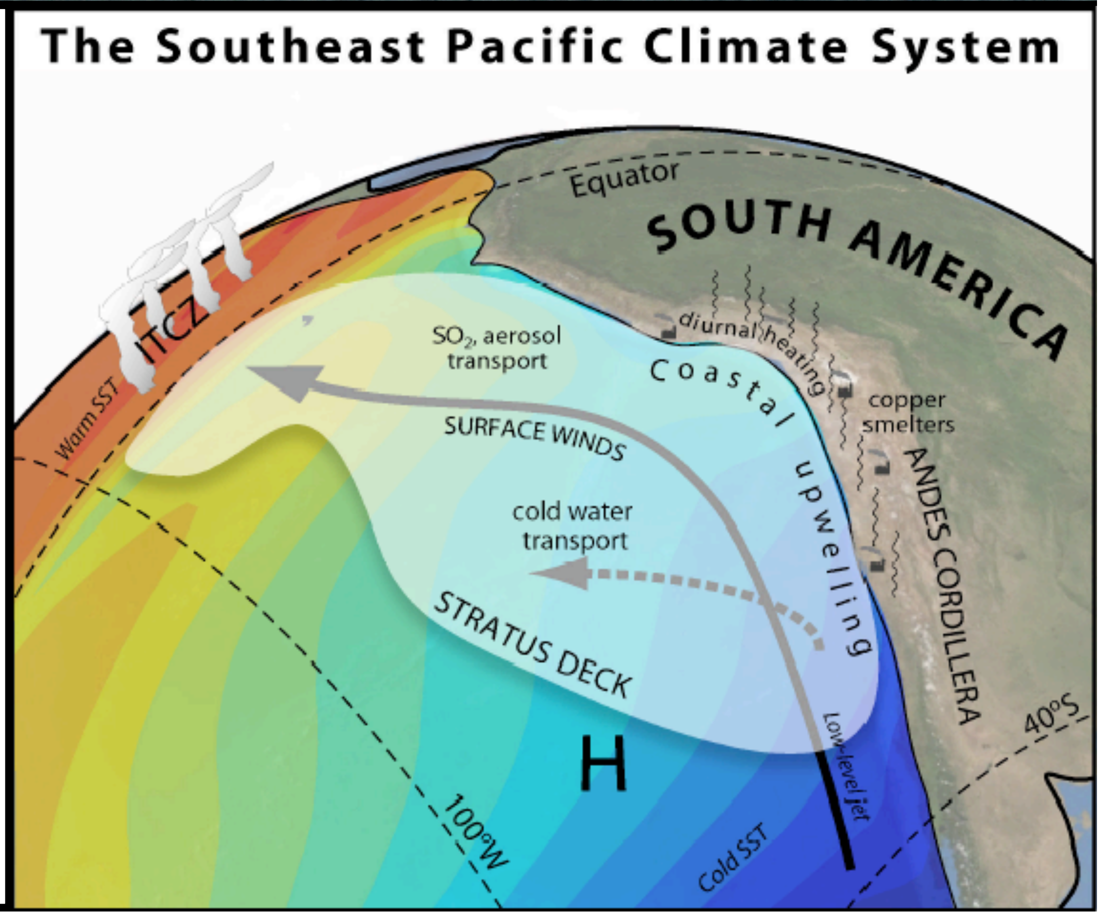
- Background on REx
- The REx hypotheses
  - Aerosol-Cloud-Precipitation Hypotheses
  - Coupled Ocean-Atmosphere-Land Hypotheses
- REx and Modeling

VOCALS Goal

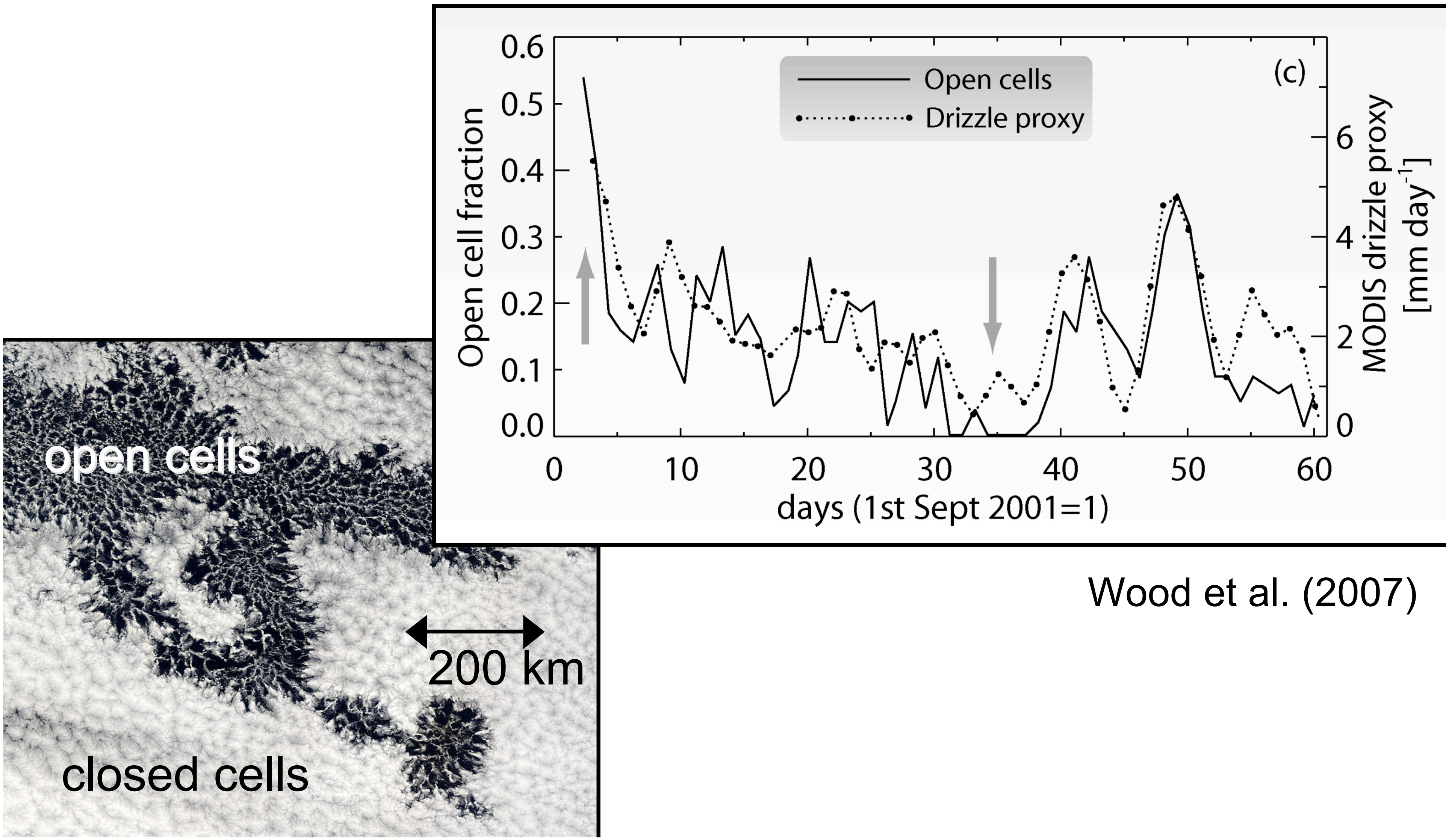
To develop and promote scientific activities leading to improved understanding of the Southeast Pacific (SEP) coupled ocean-atmosphere-land system on diurnal to inter-annual timescales.

The Southeast Pacific Climate

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

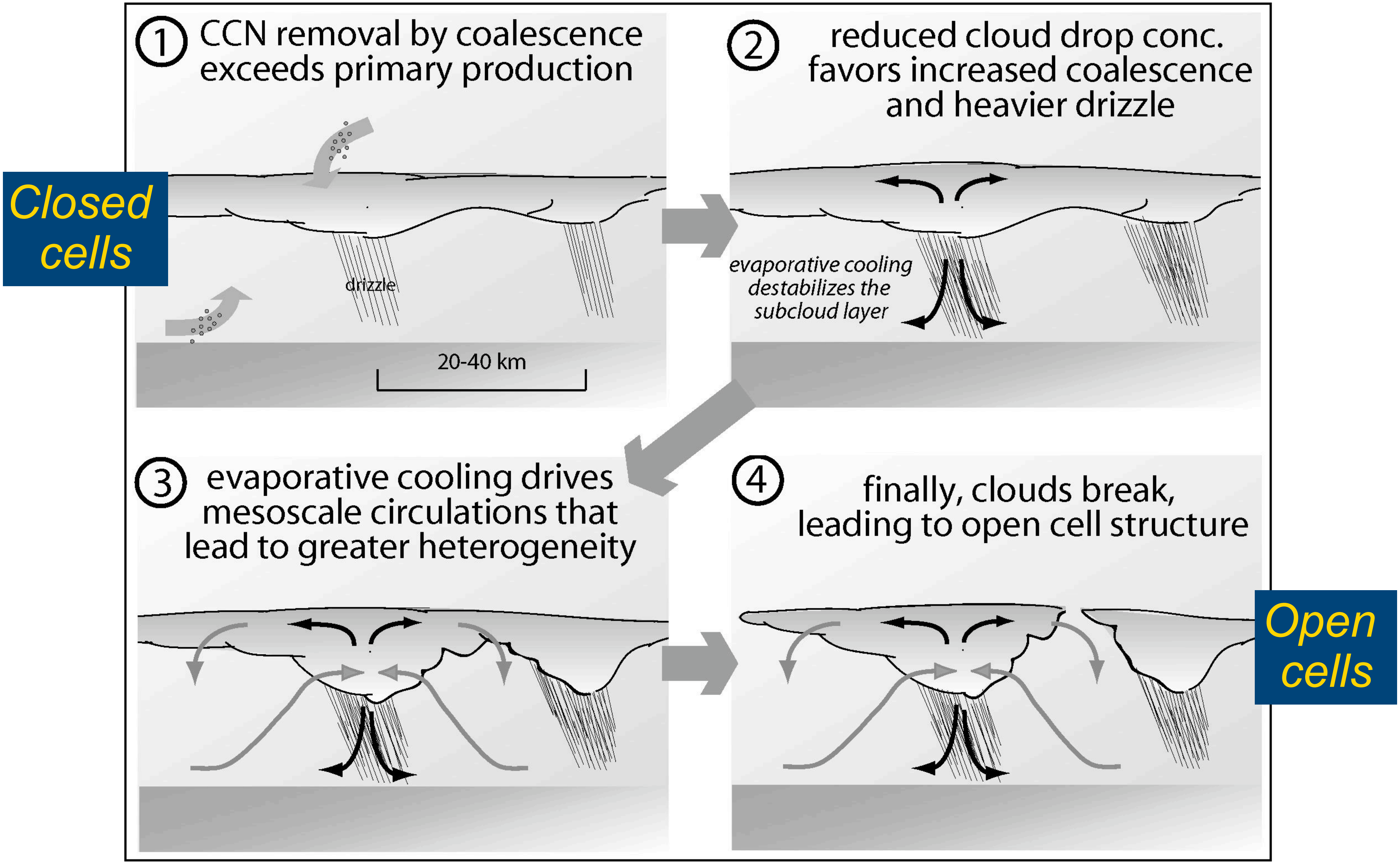


1B	**Precipitation is a necessary condition for the formation and maintenance of pockets of open cells (POCs) within stratocumulus clouds**



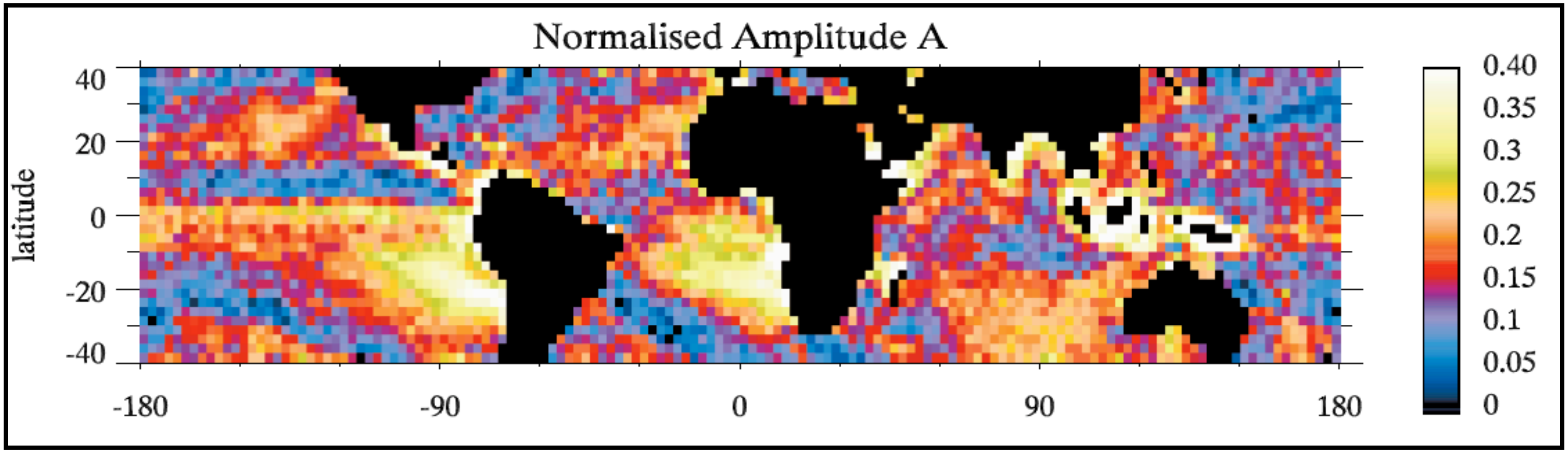
Wood et al. (2007)

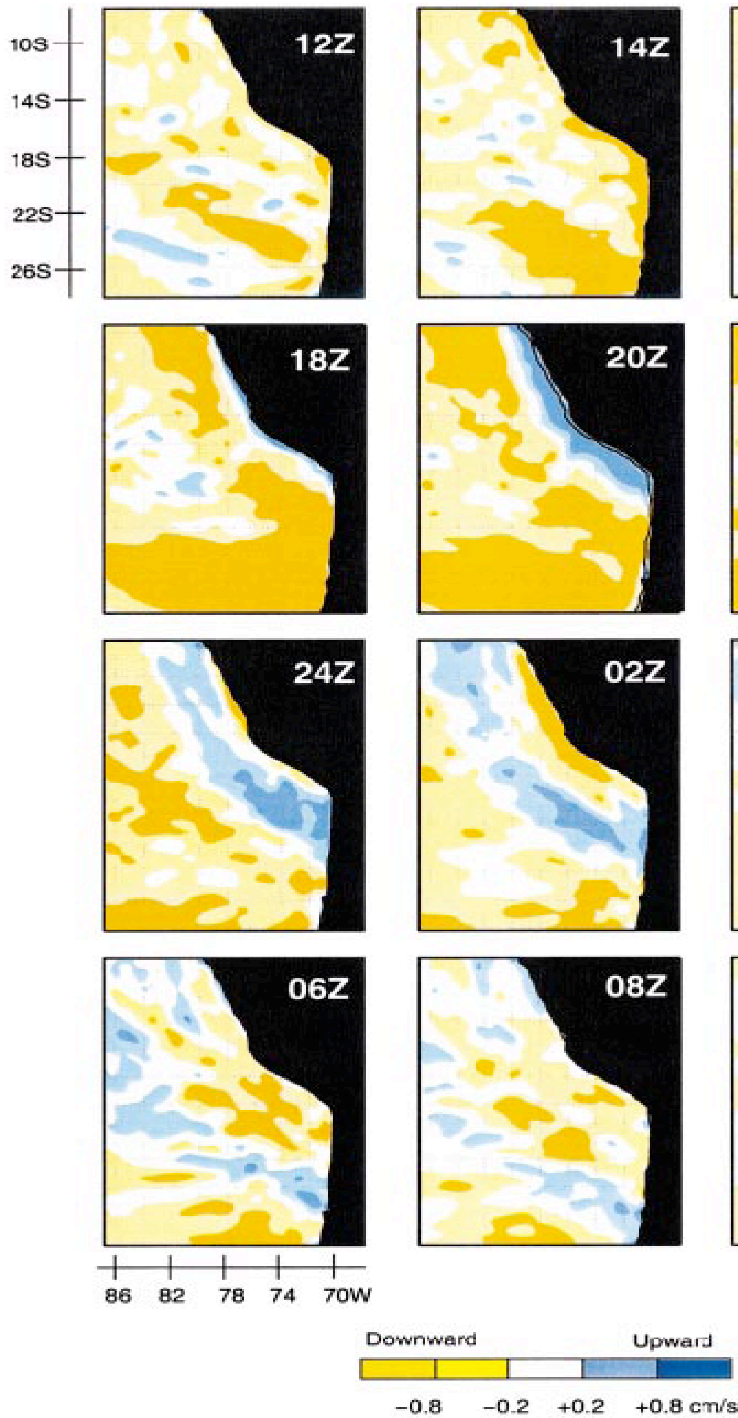
Conceptual model of POC formation



Strong diurnal cycle over SEP

TMI data, Wood et al. (2002)





"UPSIDENCE WAVE"

MM5, Garreaud and Muñoz (2004)