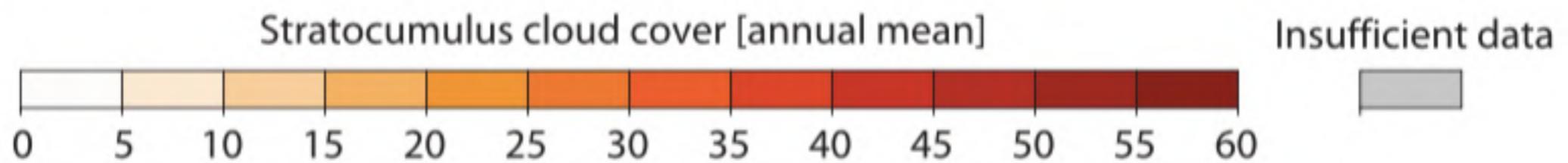
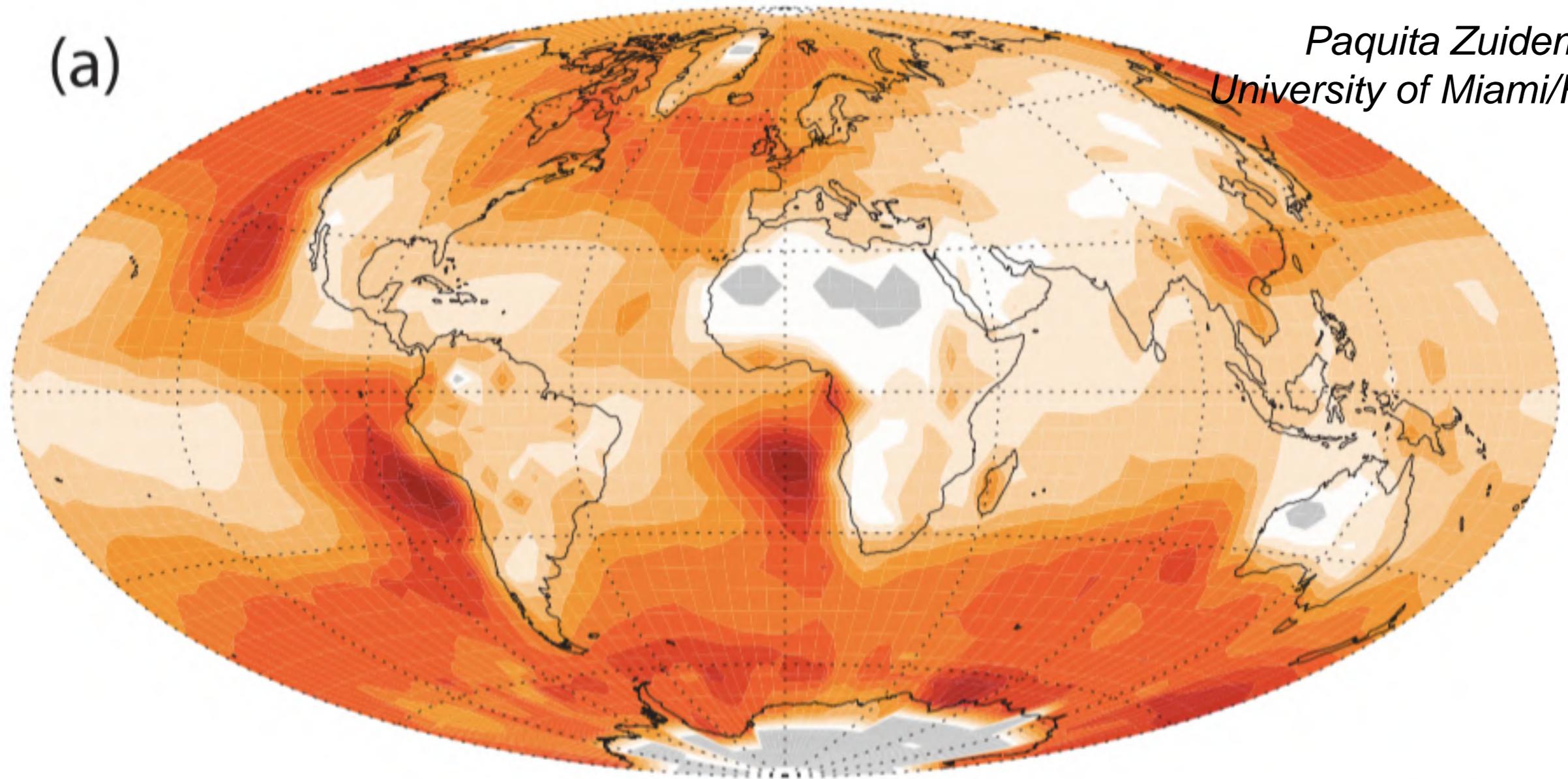


# Processes determining the cloudiness distributions in Eastern Boundary Upwelling System regions: Part 1

## *Large-scale processes*

(a)

*Paquita Zuidema  
University of Miami/RSMAS*

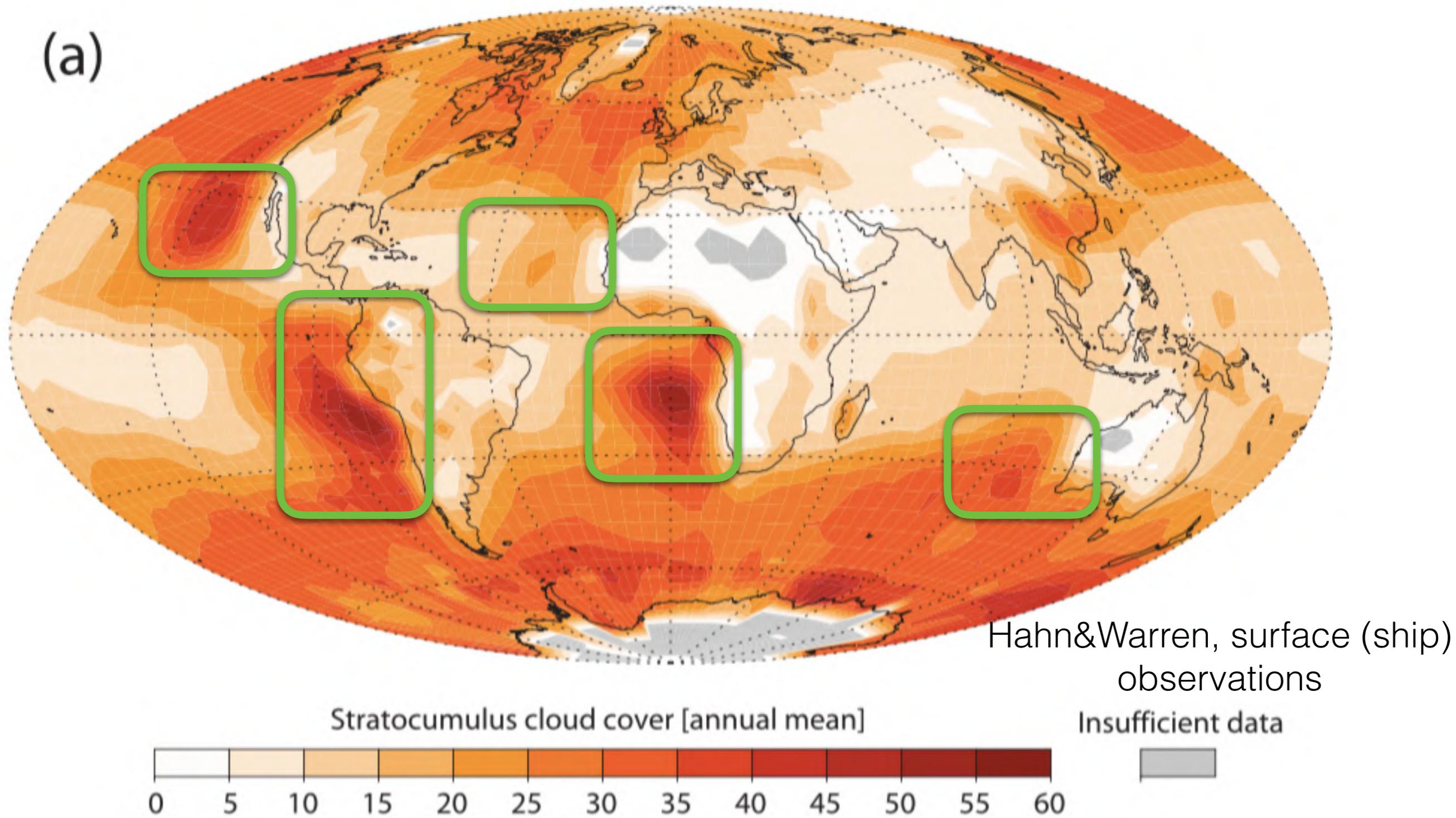


*From Wood, 2012*

*Hahn&Warren, surface (ship) observations*

- Why the stratocumulus decks are where they are
- Their relationship to the ocean surface
- Their relationship to the neighboring continents & seasonal cycle

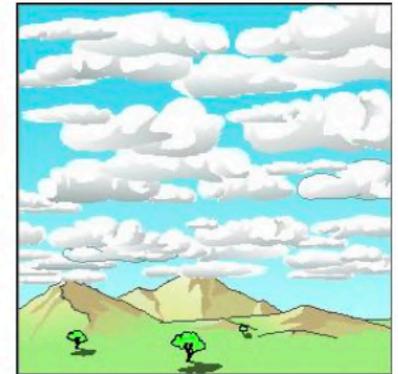
# 23% of the ocean is covered by stratocumulus: dominant cloud type by area covered



Note the close relationship to the EBUS regions

## Definition of Stratocumulus

Grey or whitish, or both grey and whitish, patch, sheet or layer of cloud that almost always has dark parts, composed of tessellations, rounded masses, rolls, etc., which are non-fibrous (except for virga) and which may or may not be merged; most of the regularly arranged small elements have an apparent width of more than 5°.

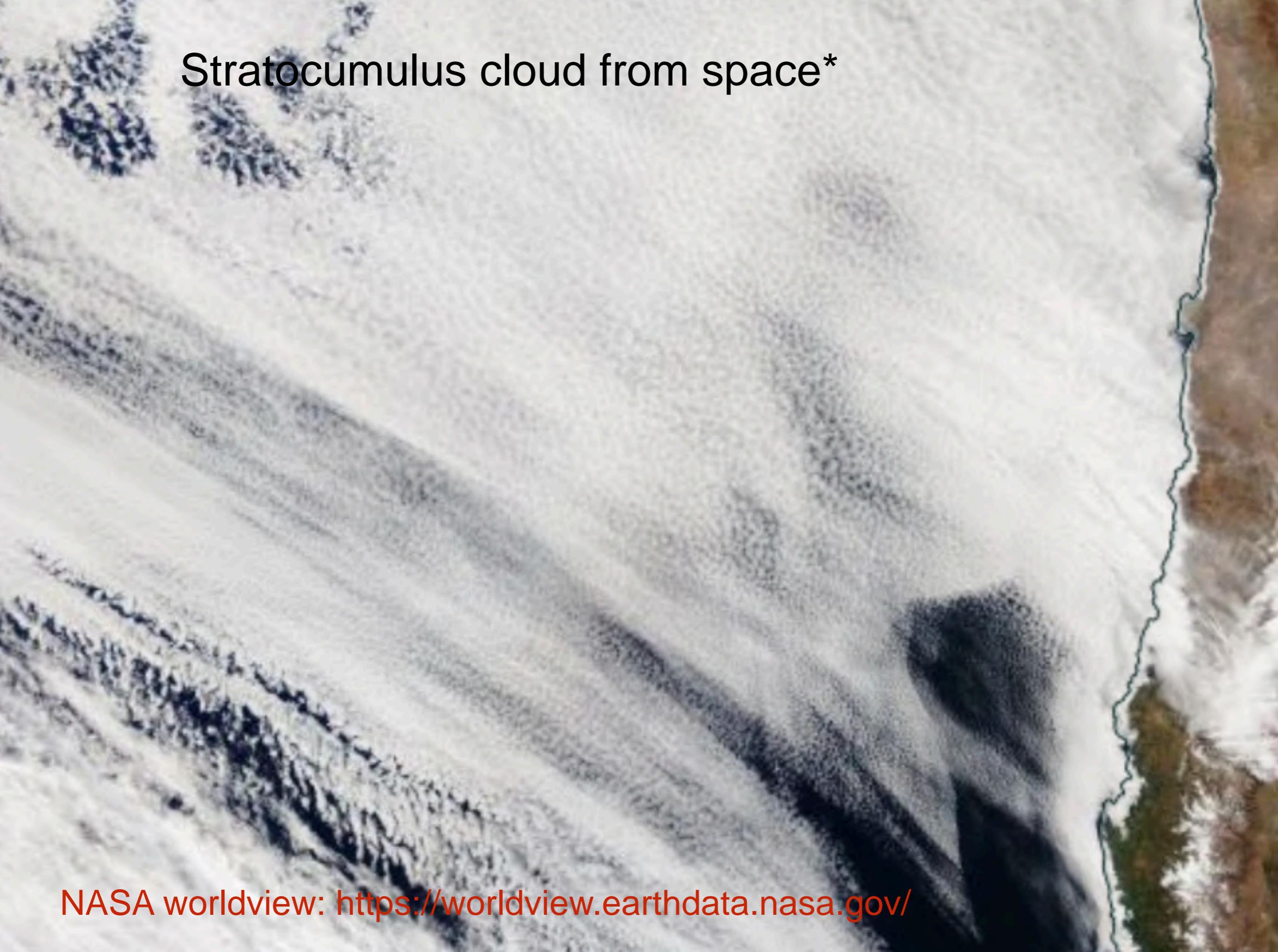


### 1. Introduction

Stratocumulus, from the Latin *stratus* meaning “layer,” and *cumulus* meaning “heap,” is a genus of low clouds composed of an ensemble of individual convective elements that together assume a layered form. The layering is typically achieved through capping by a temperature inversion that is often strong and only tens of meters thick, while the heaping reflects the convective nature of the cloud. Stratocumulus is usefully defined as a low-level cloud system whose dynamics are primarily driven by convective instability caused by cloud-top radiative cooling, a definition that distinguishes stratocumulus from stratus.

[Back to top](#)

# Stratocumulus cloud from space\*



NASA worldview: <https://worldview.earthdata.nasa.gov/>

# Hadley Circulation Cell

Air cools, sinks



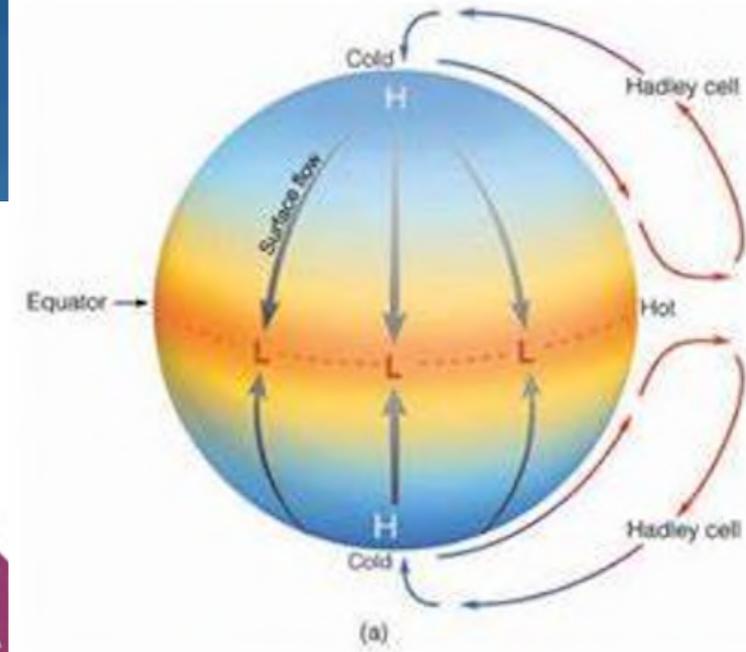
Rising air is replaced

**HIGH**

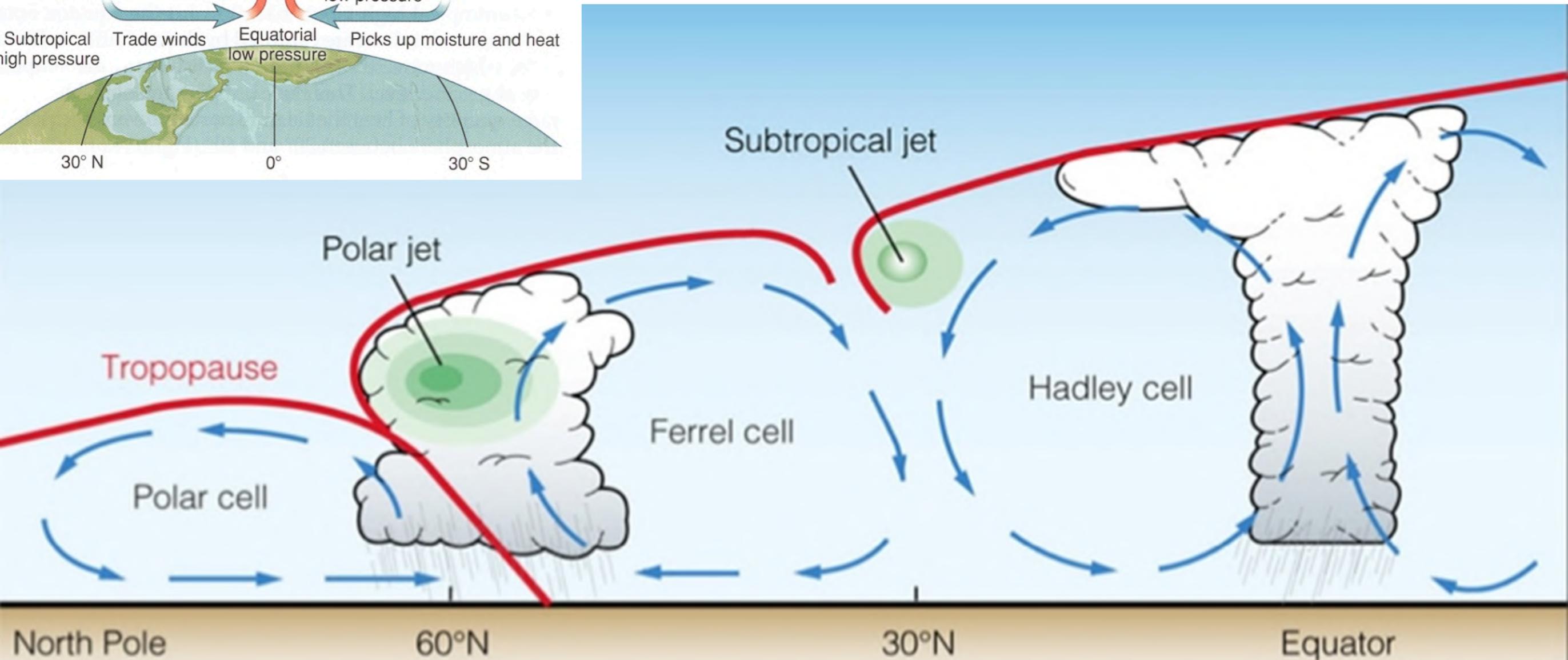
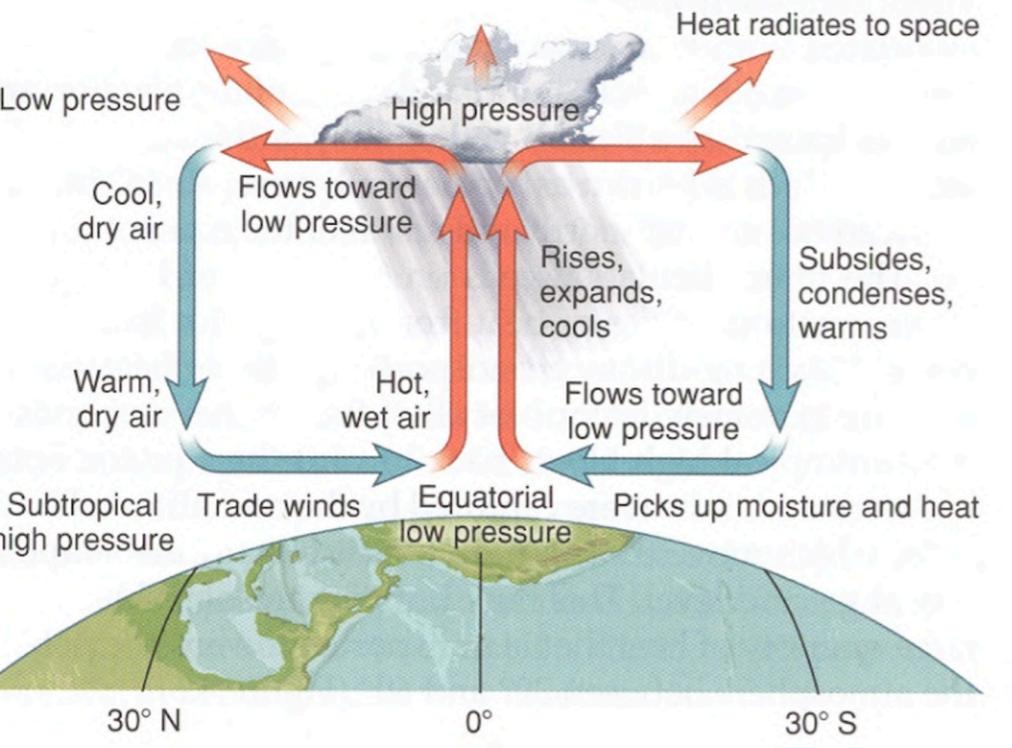
Warm air rises

**LOW**

**HIGH**



Rotation compresses the Hadley cells to near the equator, where the Coriolis force -  $2 \cdot \text{air velocity} \cdot \text{earth's angular velocity} \cdot \sin(\text{latitude})$  - is weak



# The Hadley cell is a zonal-mean construct

$$\phi_H \sim \left( \frac{gH_t}{\Omega^2 a^2} \frac{\Delta_h}{\theta_0} \right)^{\frac{1}{2}}$$

Held and Hou, 1980

Relates width to tropopause height at equator + meridional temperature gradient

$$\phi_H \propto \left( \frac{NH_e}{\Omega a} \right)^{\frac{1}{2}}$$

Lu, Vecchi, 2006

Relates width to local tropopause height + static stability

Doesn't explain the zonal distribution of the subtropical stratocumulus decks

# Subtropical Anticyclones and Summer Monsoons

M. J. RODWELL

*Hadley Centre for Climate Prediction and Research, Met Office, Berkshire, Bracknell, United Kingdom*

B. J. HOSKINS

*Department of Meteorology, University of Reading, Reading, United Kingdom*

(Manuscript received 13 March 2000, in final form 20 December 2000)

## ABSTRACT

The summer subtropical circulation in the lower troposphere is characterized by continental monsoon rains and anticyclones over the oceans. In winter, the subtropical circulation is more strongly dominated by the zonally averaged flow and its interactions with orography. Here, the mechanics of the summer and winter lower-tropospheric subtropical circulation are explored through the use of a primitive equation model and comparison with observations.

By prescribing in the model the heatings associated with several of the world's monsoons, it is confirmed that the equatorward portion of each subtropical anticyclone may be viewed as the Kelvin wave response to the monsoon heating over the continent to the west. A poleward-flowing low-level jet into a monsoon (such as the Great Plains jet) is required for Sverdrup vorticity balance. This jet effectively closes off the subtropical anticyclone to the east and also transports moisture into the monsoon region. The low-level jet into North America induced by its monsoon heating is augmented by a remote response to the Asian monsoon heating.

The Rossby wave response to the west of subtropical monsoon heating, interacting with the midlatitude westerlies, produces a region of adiabatic descent. It is demonstrated here that a local "diabatic enhancement" can lead to a strengthening of the descent. Longitudinal mountain chains act to block the westerly flow and also tend to produce descent in this region. Below the descent, Sverdrup vorticity balance implies equatorward flow that closes off the subtropical anticyclone to the west and induces cool upwelling in the ocean through Ekman transport. Feedbacks, involving, for example, sea surface temperatures, may further enhance the descent in these regions. The conclusion is that the Mediterranean-type climates of regions such as California and Chile may be induced remotely by the monsoon to the east.

Hence it can be argued that the subtropical circulation in summer comprises a set of weakly interacting monsoon systems, each involving monsoon rains, a low-level poleward jet, a subtropical anticyclone to the east, and descent and equatorward flow to the west.

In winter, it is demonstrated how the nonlinear interaction between the strong zonal-mean circulation, associated with the winter "Hadley cell," and the mountains can define many of the large-scale features of the subtropical circulation. The blocking effect of the longitudinal mountain chains is shown to be very important. Subsequent diabatic effects, such as a local diabatic enhancement, would appear to be essential for producing the observed amplitude of these features.

This makes the  
fundamental  
connection between  
land and ocean

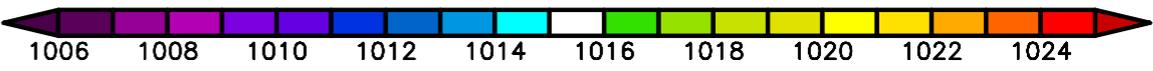
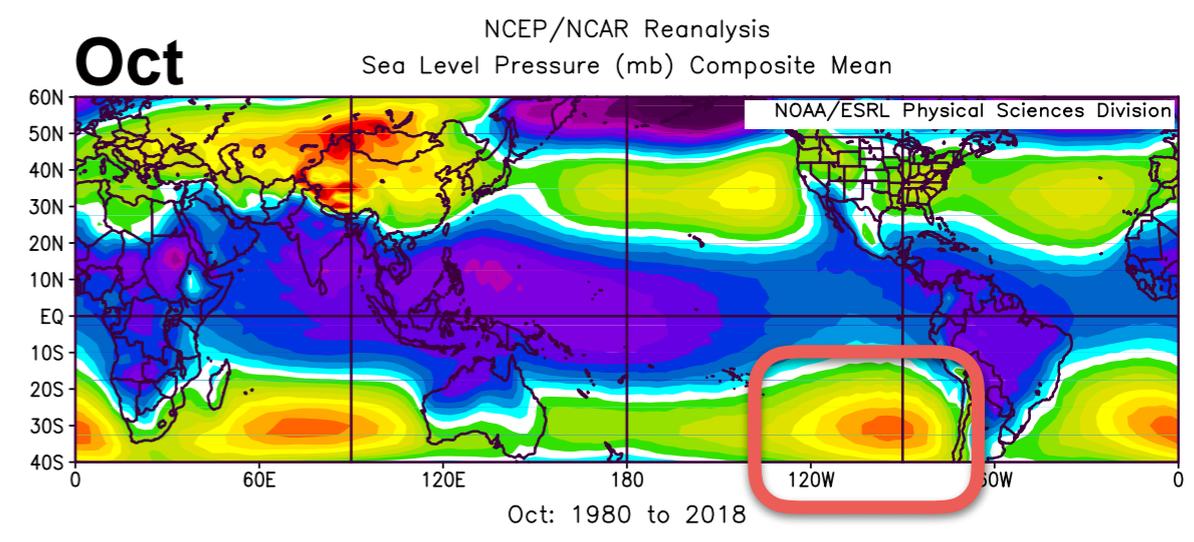
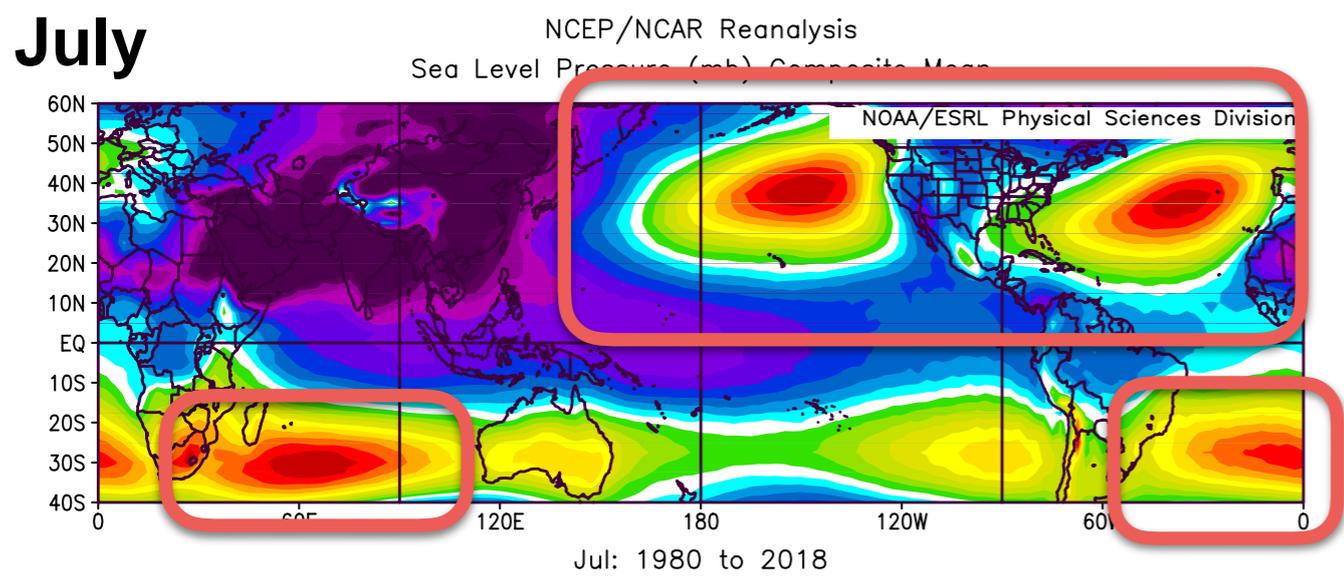
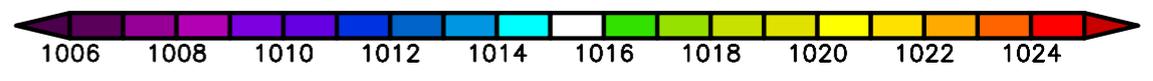
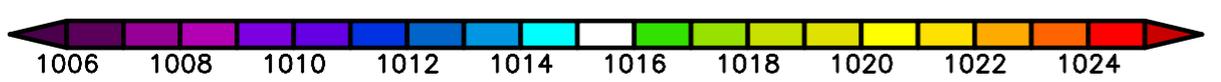
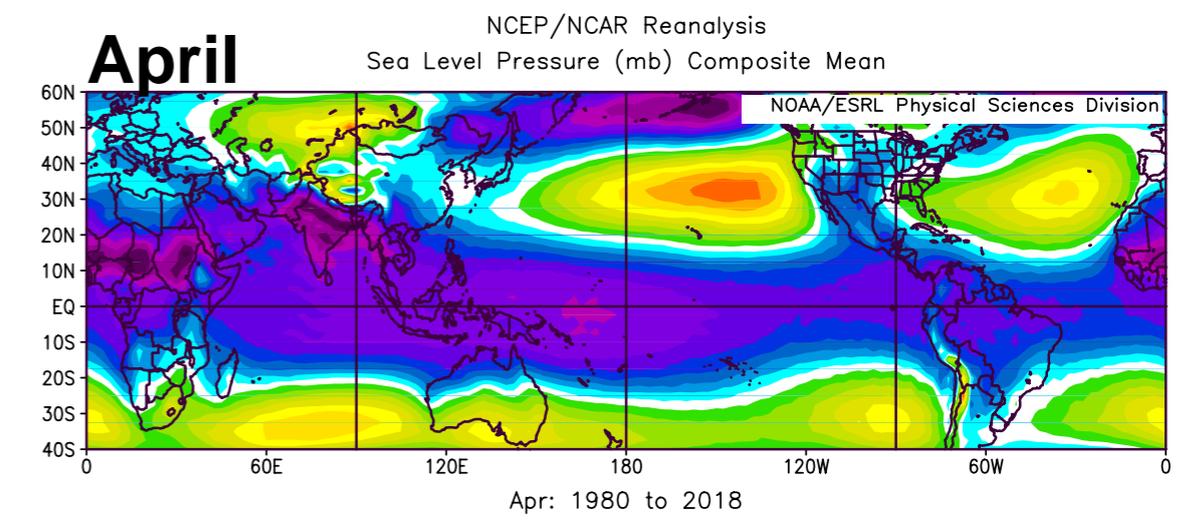
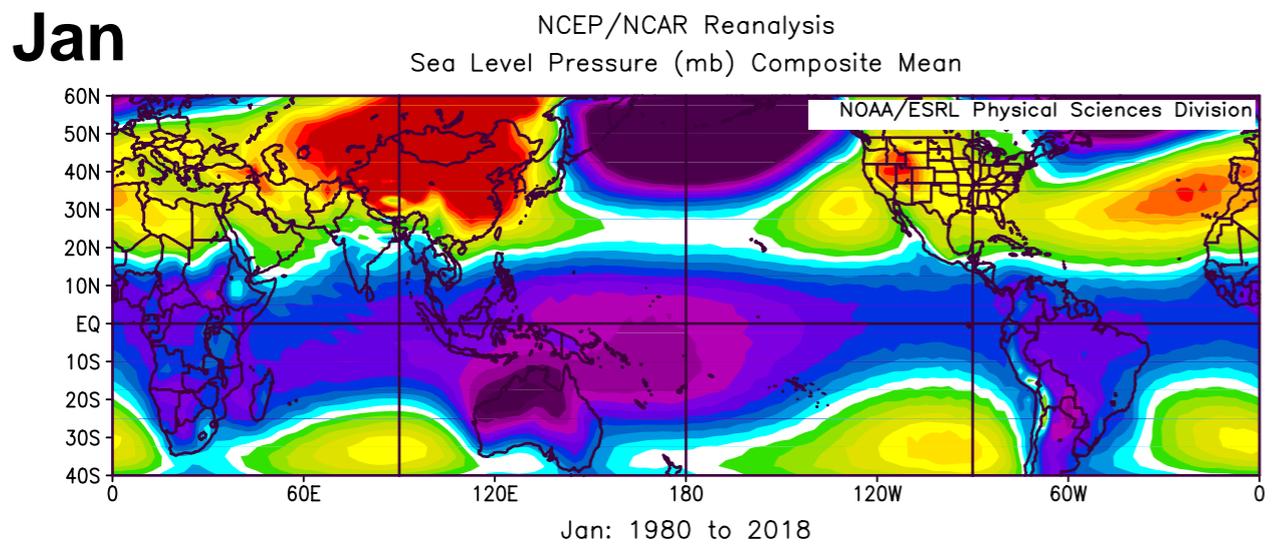
$$\beta v \approx f \frac{\partial \omega}{\partial p}$$

an upper-level  
land-based  
anticyclone drives  
descent to its west -  
meaning the EBUS  
regions

e.g. summer monsoons

# This locates the sea level pressure maxima in the eastern basins

*Note their semi-permanent nature, also reflected within the subtropical stratocumulus decks*



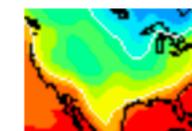
We have transitioned the data files from netCDF3 to netCDF4-classic format on Monday Oct 20th, 2014.

# The NCEP/NCAR Reanalysis Project at the NOAA/ESRL Physical Sciences Division

This page points you to information on the NCEP/NCAR Reanalysis project and the implementation of a netCDF-based, Internet-accessible, data service at NOAA/ESRL PSD for this set of data products.

- [The 6-hourly and daily data currently available on-line.](#)
- [The monthly and other derived data currently available on-line.](#)
- Please read the [problem list](#).
- **Status**
  - [Reanalysis problems list \(Dec 17, 2017\)](#)
- **Inventory/specifications**
  - [Description of data on-line at PSD \(Apr 15, 2016\)](#)
- [Tips for reading the data files.](#)

## Climate Analysis Branch Obtain Data



- [Search all of the NCEP/NCAR Reanalysis available at PSD.](#)
- [FTP 6-hourly data](#)
- [FTP Daily Averages](#)
- [FTP Monthly Averages](#)
- [Read about the 6-hourly and daily data](#)
- [Read about the monthly \(derived\) data](#)

## Plot and Analyze NCEP/NCAR Reanalysis Data

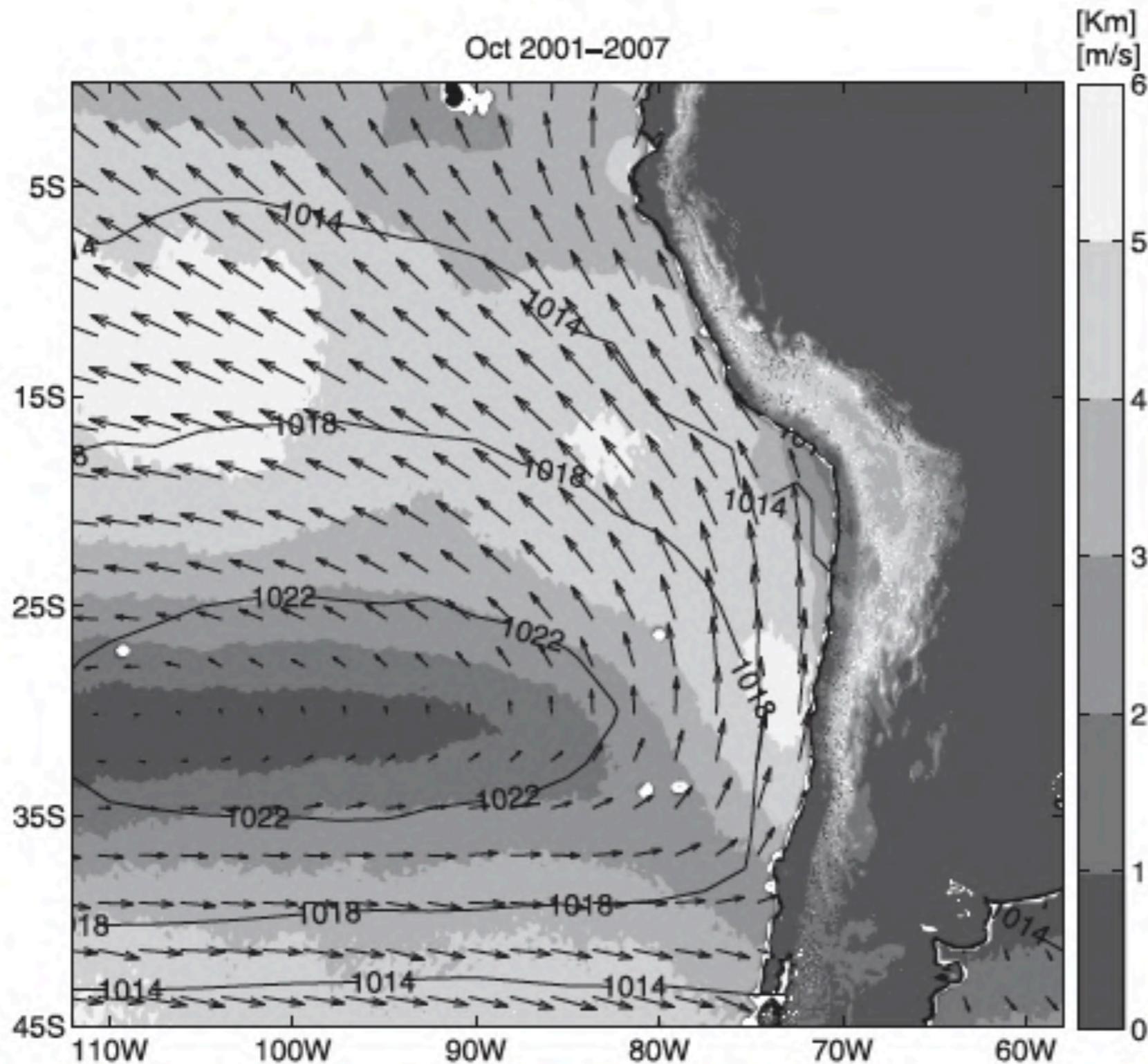


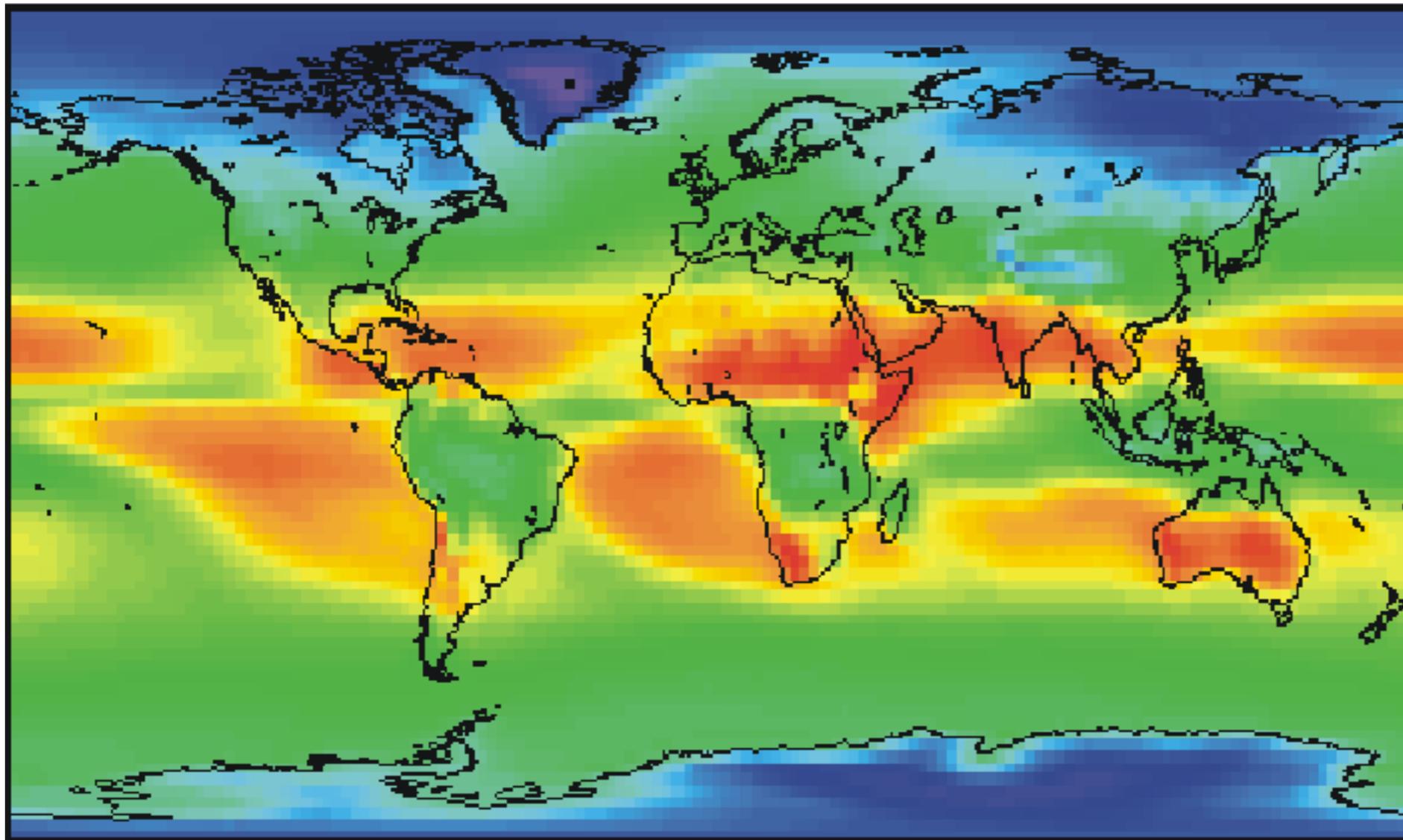
FIG. 8. October-mean (2001–07) NCEP sea level pressure superimposed with corresponding QuikSCAT surface winds and land topography. Shading indicates oceanic wind speeds and land elevations, the latter at 10-min resolution.

*Winds rotate  
anticyclonically  
(counter-clockwise  
in the southern  
Hemisphere)  
about  
the sea level  
pressure  
maxima  
upwelling cooler  
waters, advecting  
cooler air that  
supports stronger  
surface fluxes  
all good for low  
clouds*



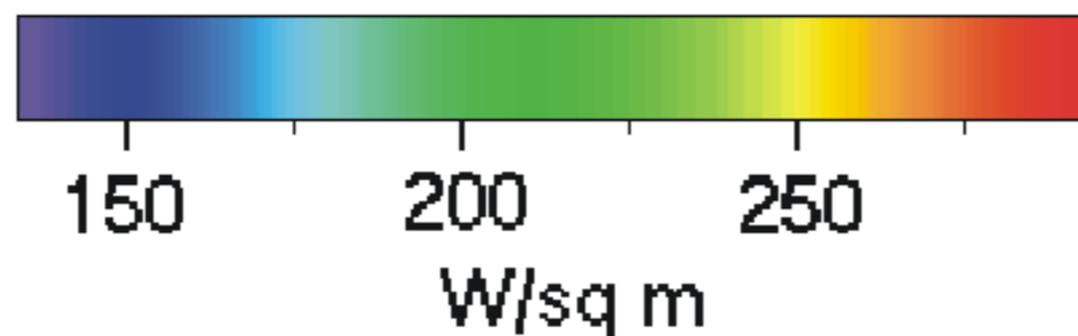
The large-scale subsidence at  $\pm 30^\circ$  off of the ITCZ has important consequences for the Earth's radiative climate

DJF MEAN OF OLR - 1975 to 1999



*“radiator fins”*

*The subsidence also discourages upper-level clouds, exposing the lower clouds to outer space*



# important role for cloud-top long wave cooling

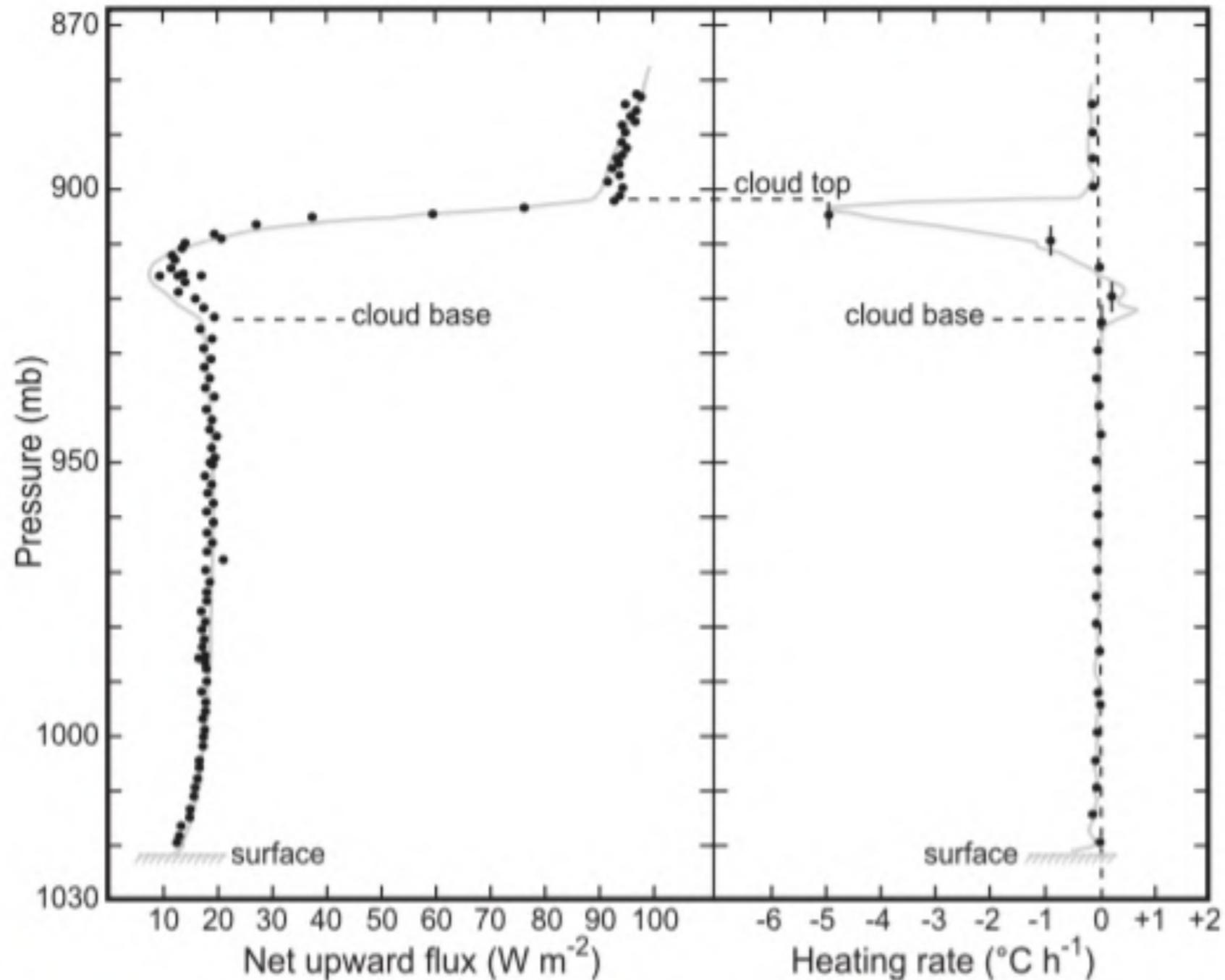


FIG. 18. Profiles of observed (dots) and theoretical (solid lines) (left) net upward infrared flux and (right) associated heating rates for a nocturnal stratocumulus layer. From Slingo et al. (1982a).

- strengthens large-scale subsidence above cloud
- is the primary driver for cloud processes

Top-down convection is very different from what we normally think of as bottom-up buoyancy-driven convection

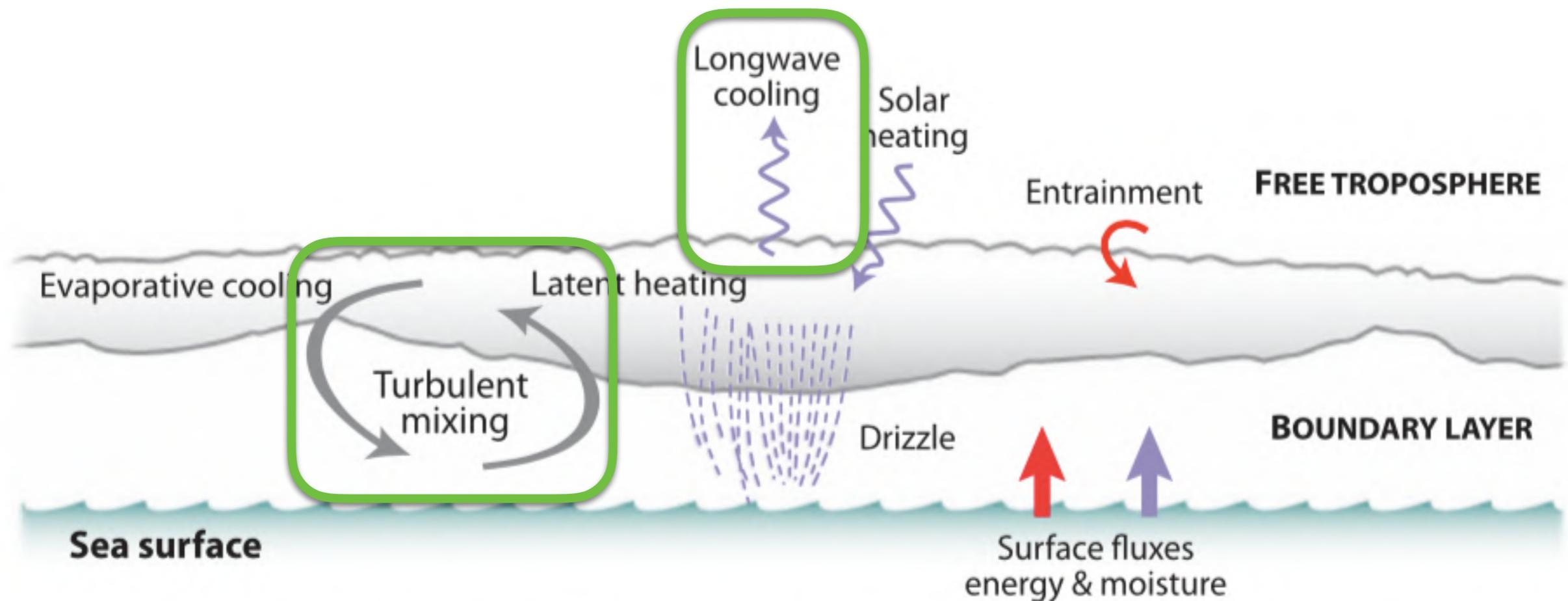
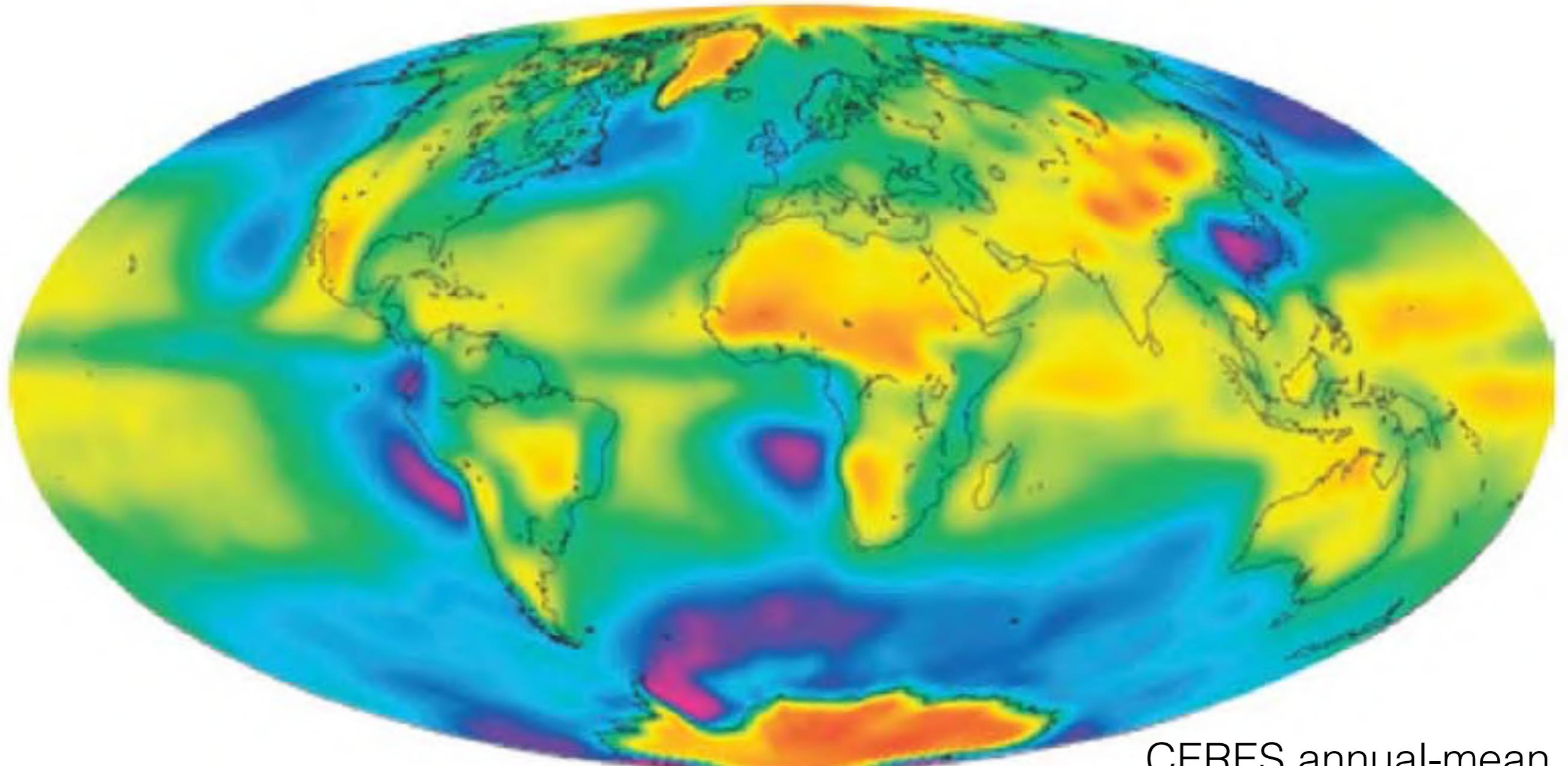


FIG. 2. Schematic showing the key processes occurring in the stratocumulus-topped boundary layer.

+ much sunlight reflected back to space; a net global cooling to climate  $\sim -10 \text{ W/m}^2$



CERES annual-mean,  
2014 I think

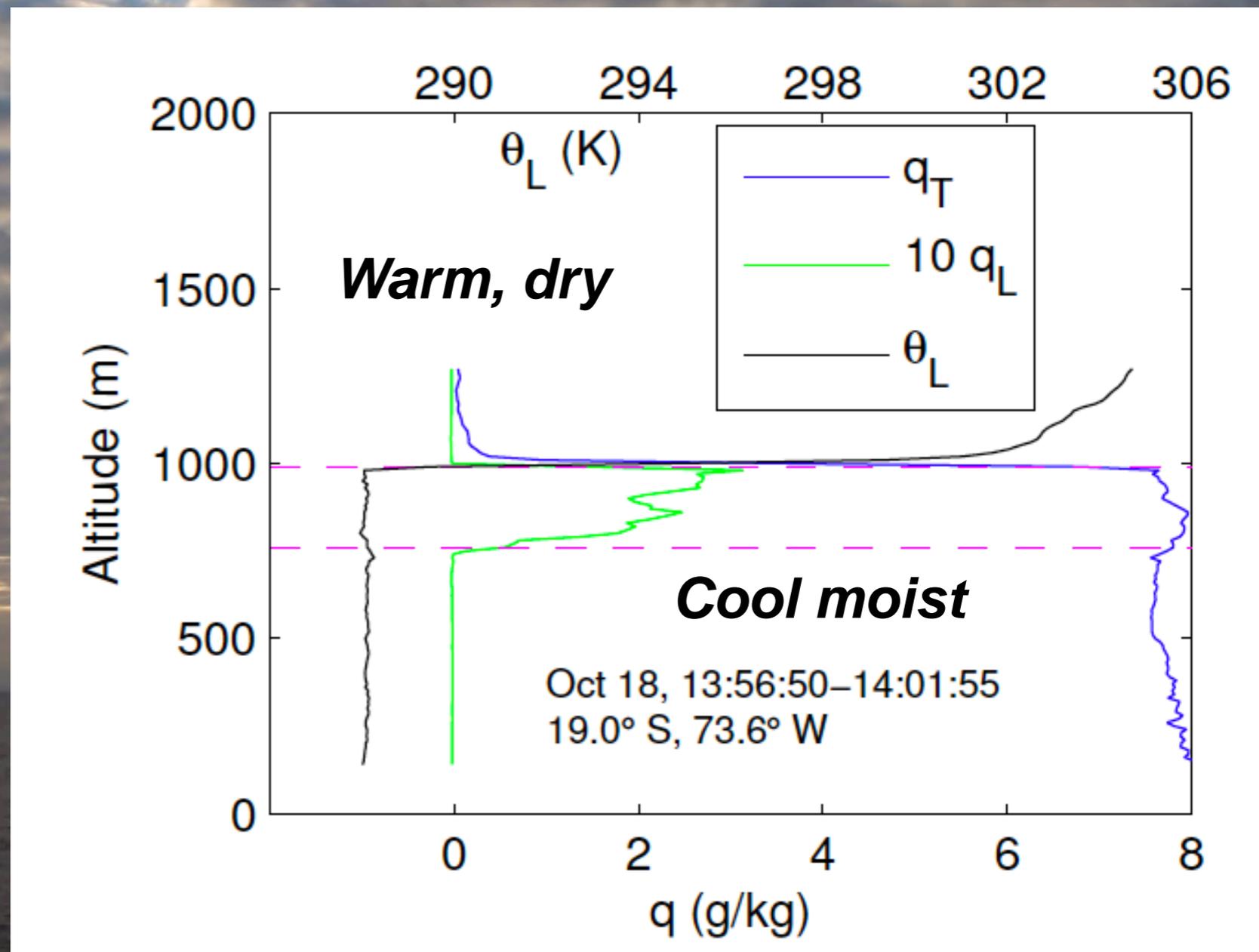


TA014

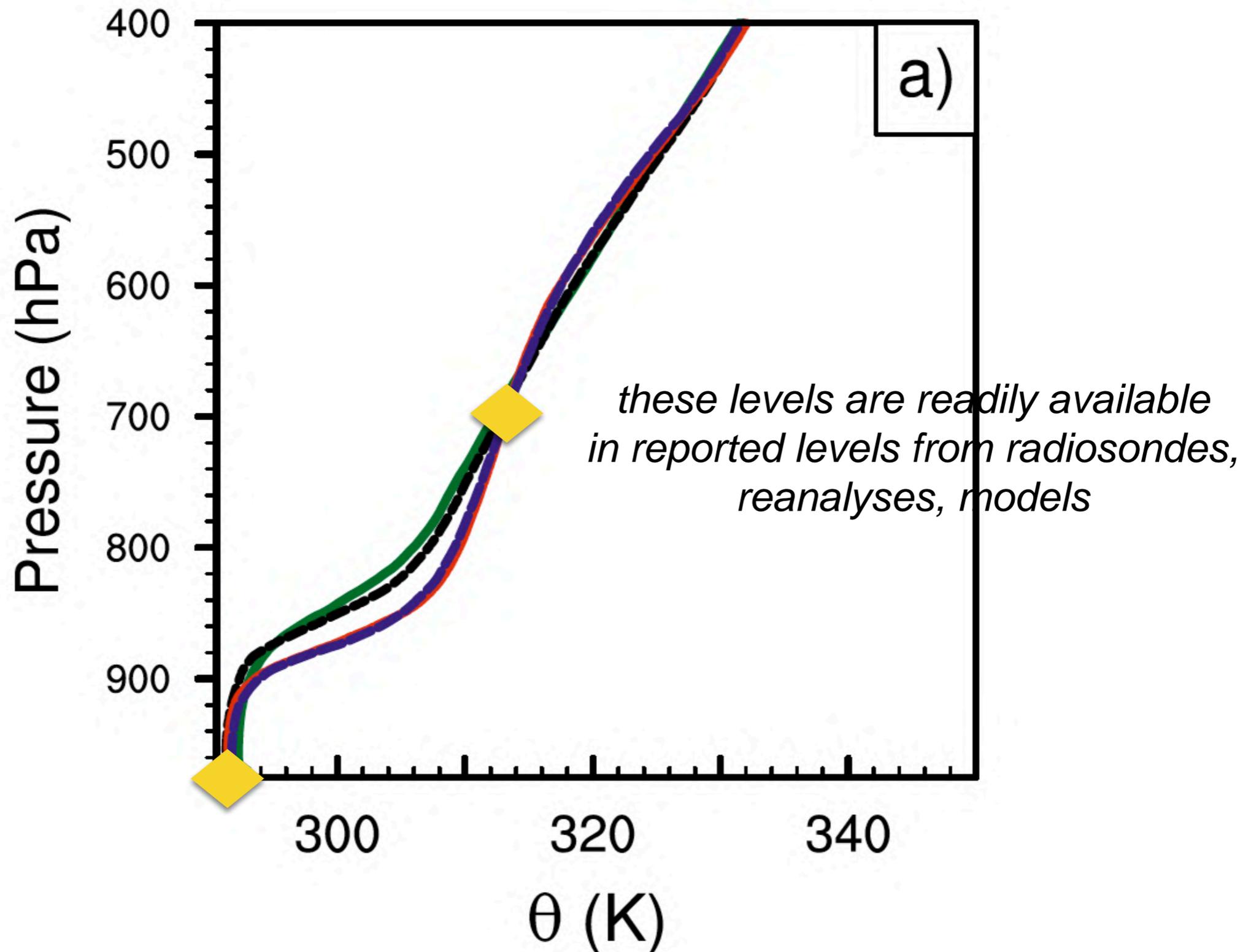
The southern hemisphere decks exert a stronger cooling.  
Why?

The cloud cover is to first-order set by

- 1) the strength of the cloud-top inversion
- 2) the height of the cloud-top inversion



A powerful proxy for the cloud-top inversion strength is the lower tropospheric stability:  $\theta_{700hpa} - \theta_{1000hpa}$



## The Seasonal Cycle of Low Stratiform Clouds

STEPHEN A. KLEIN AND DENNIS L. HARTMANN

*Department of Atmospheric Sciences, University of Washington, Seattle, Washington*

(Manuscript received 21 August 1992, in final form 11 January 1993)

### ABSTRACT

The seasonal cycle of low stratiform clouds is studied using data from surface-based cloud climatologies. The impact of low clouds on the radiation budget is illustrated by comparison of data from the Earth Radiation Budget Experiment with the cloud climatologies. Ten regions of active stratocumulus convection are identified. These regions fall into four categories: subtropical marine, midlatitude marine, Arctic stratus, and Chinese stratus. With the exception of the Chinese region, all the regions with high amounts of stratus clouds are over the oceans.

In all regions except the Arctic, the season of maximum stratus corresponds to the season of greatest lower-troposphere static stability. Interannual variations in stratus cloud amount also are related to changes in static stability. A linear analysis indicates that a 6% increase in stratus fractional area coverage is associated with each 1°C increase in static stability. Over midlatitude oceans, sky-obscuring fog is a large component of the summertime stratus amount. The amount of fog appears to be related to warm advection across sharp gradients of SST.

# Stratus Cloud Amount vs. Stability

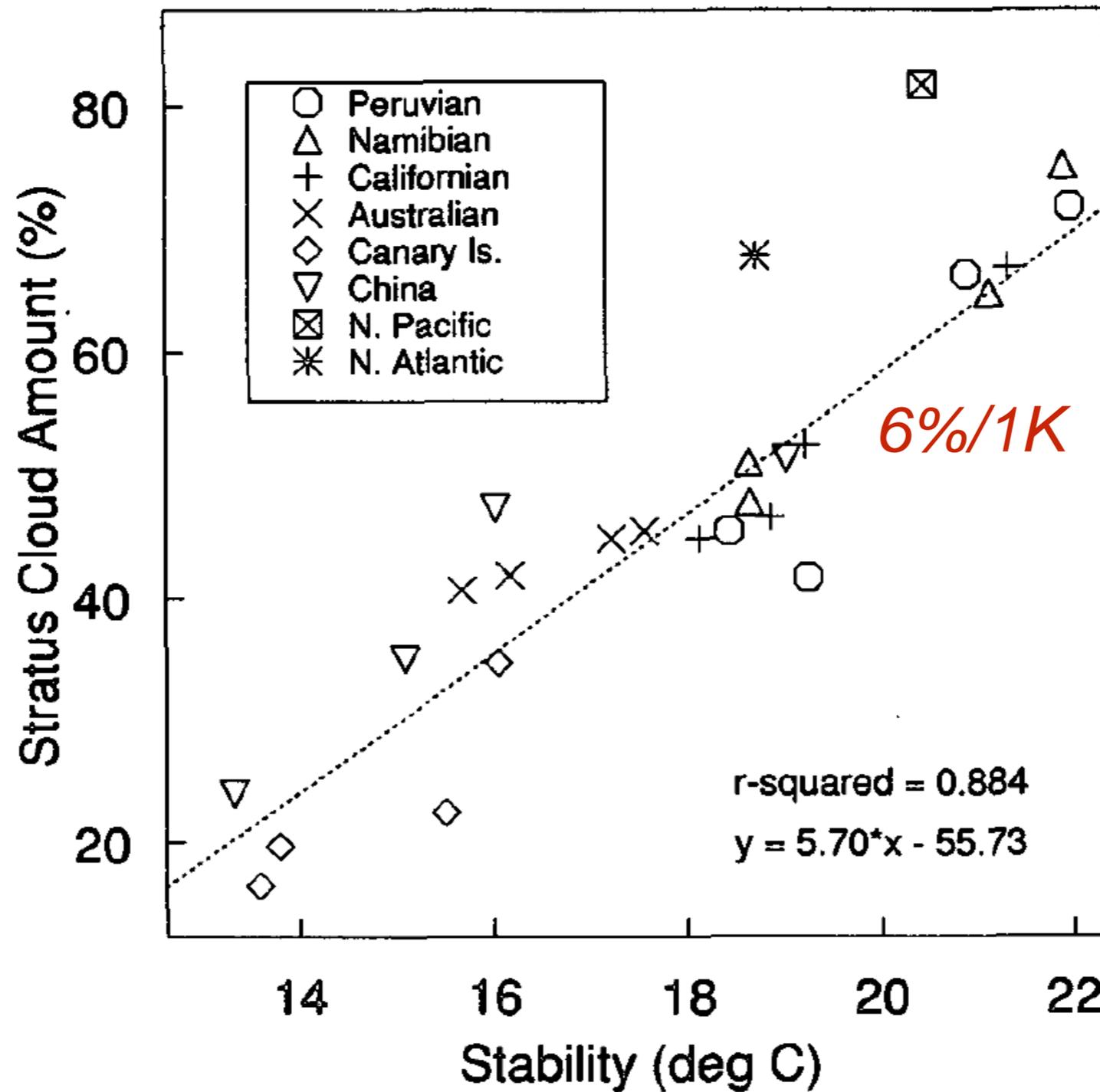
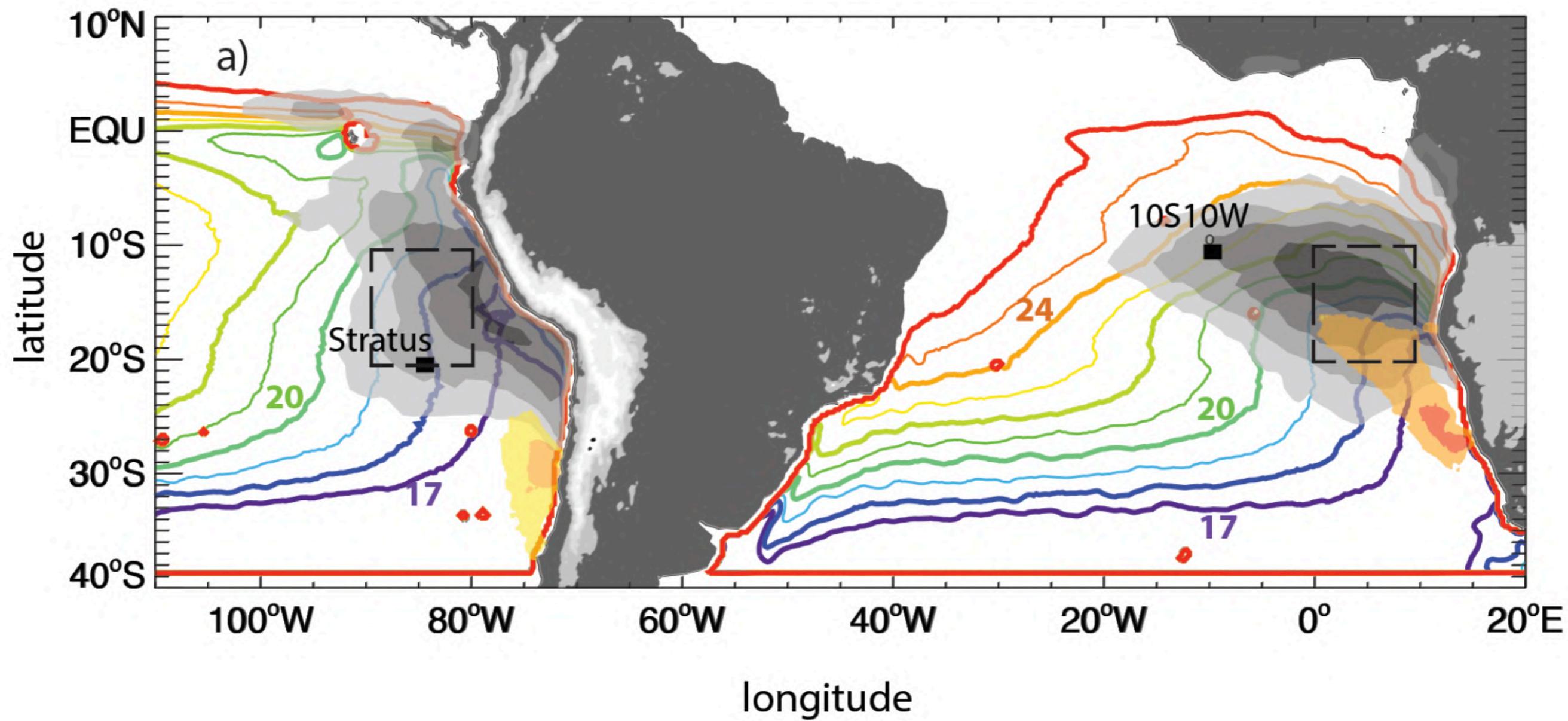
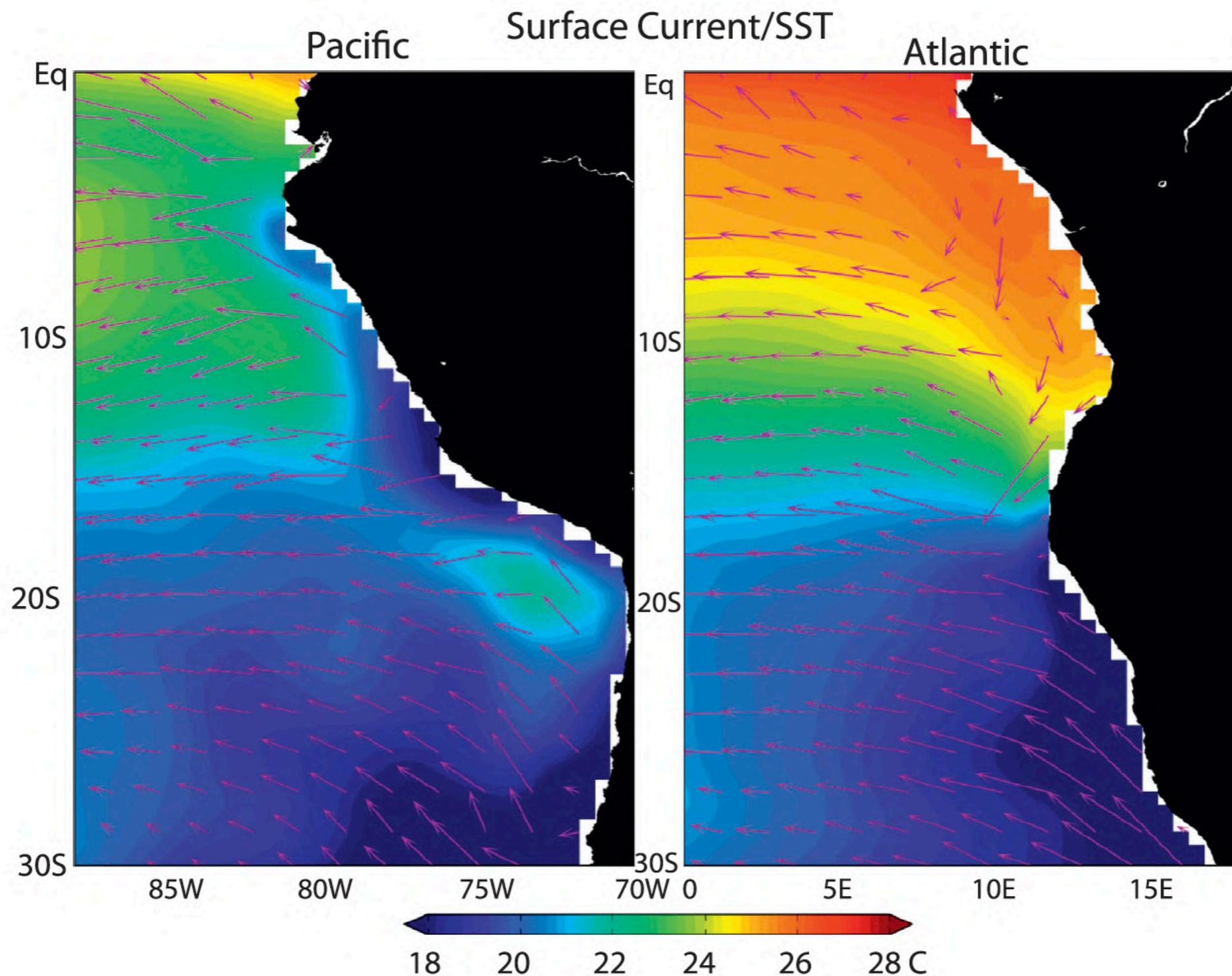


FIG. 13. Scatterplot of seasonally averaged stratocumulus cloud amount with seasonally averaged lower-tropospheric stability for the five subtropical oceanic regions and the Chinese stratus region. In addition, the June, July, and August seasonally averaged quantities are plotted for the North Pacific and North Atlantic but are not included in the regression.

# Individual influences on the spatial distribution and seasonal cycle of each deck & relation to sea surface temperature

- curvature of continent
- underlying ocean currents
- do clouds cool the ocean or do cooler oceans support more clouds?
- characteristics of the outflow of warm air from the neighboring continent - er, world's most significant deserts

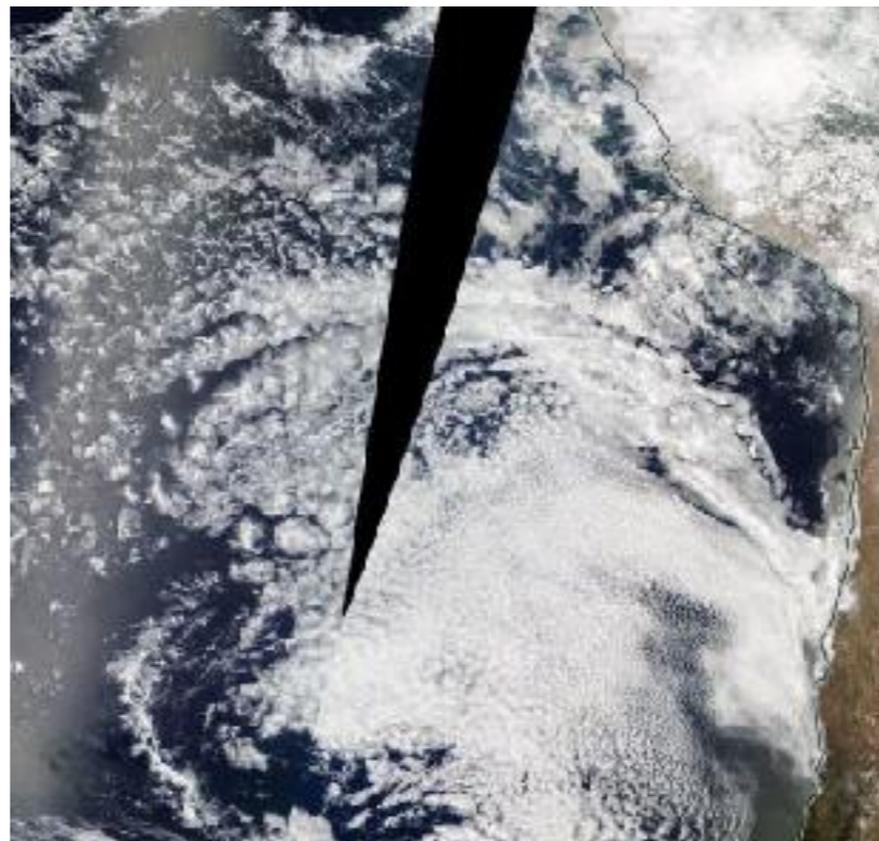
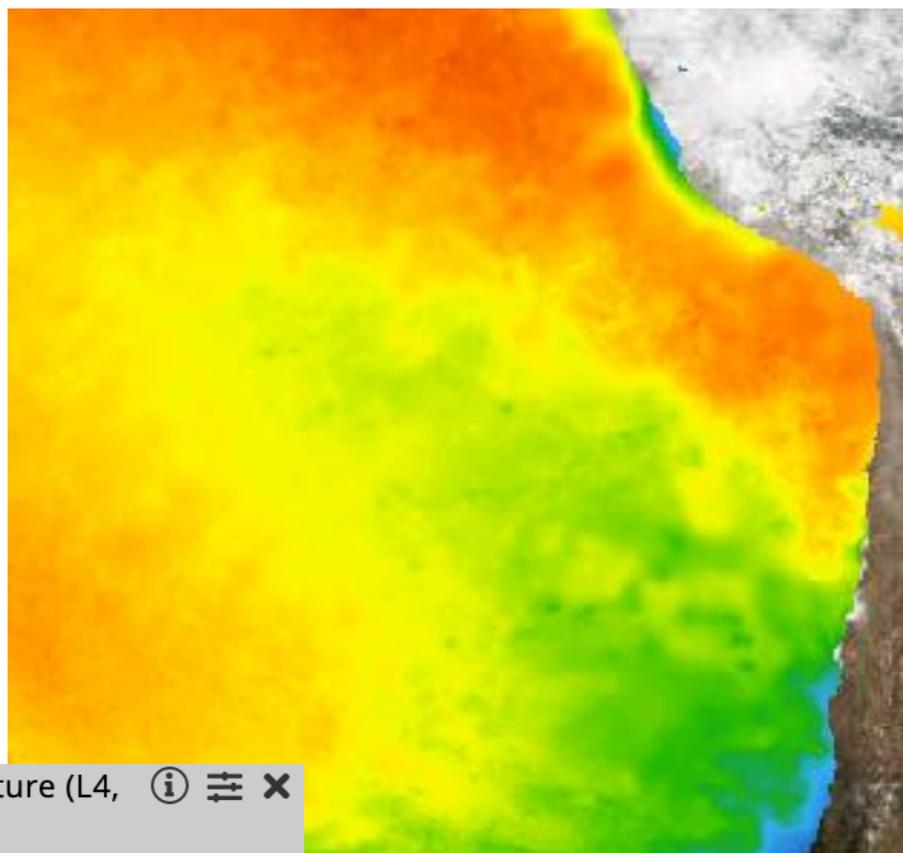




**FIG. 3.** The surface currents help bring colder waters up near the equator in the **Pacific**, whereas in the **Atlantic**, the warm **Angola Current** flows south from the equator to **15°S**, establishing a strong **SST gradient** with the northward-flowing cool **Benguela Current** to its south. Annual-mean SST and surface current data from the **Simple Ocean Data Assimilation** reanalysis.

Does the ocean warm because low clouds decrease?  
Or do low clouds decrease because the ocean warms?

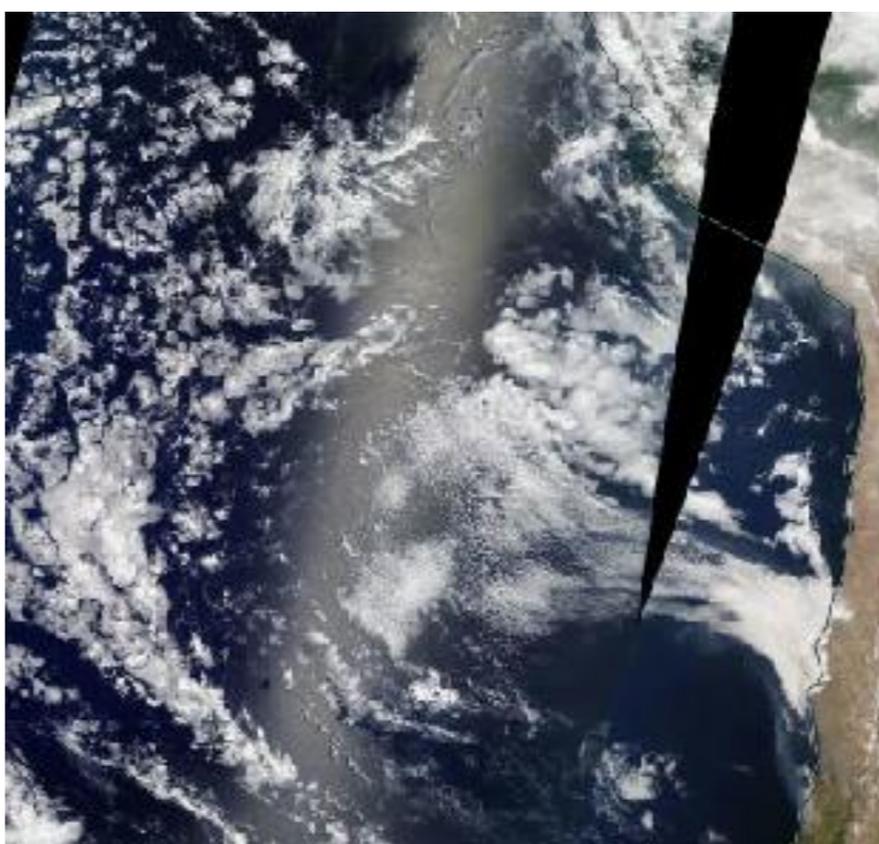
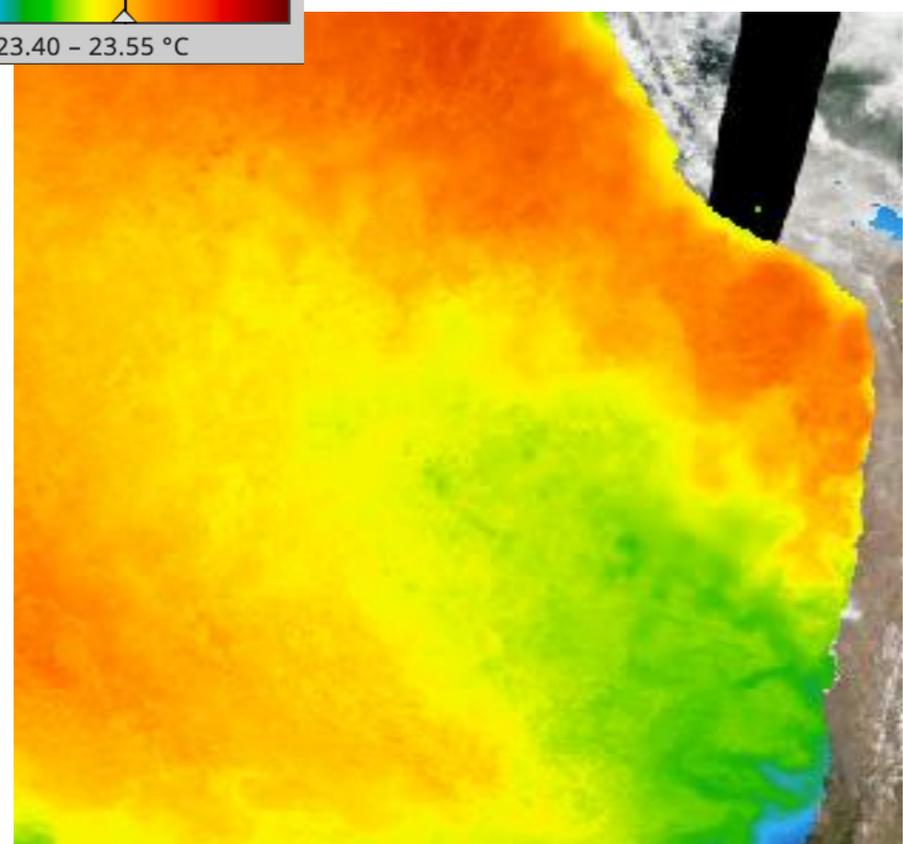
*Jan 14,  
2017*

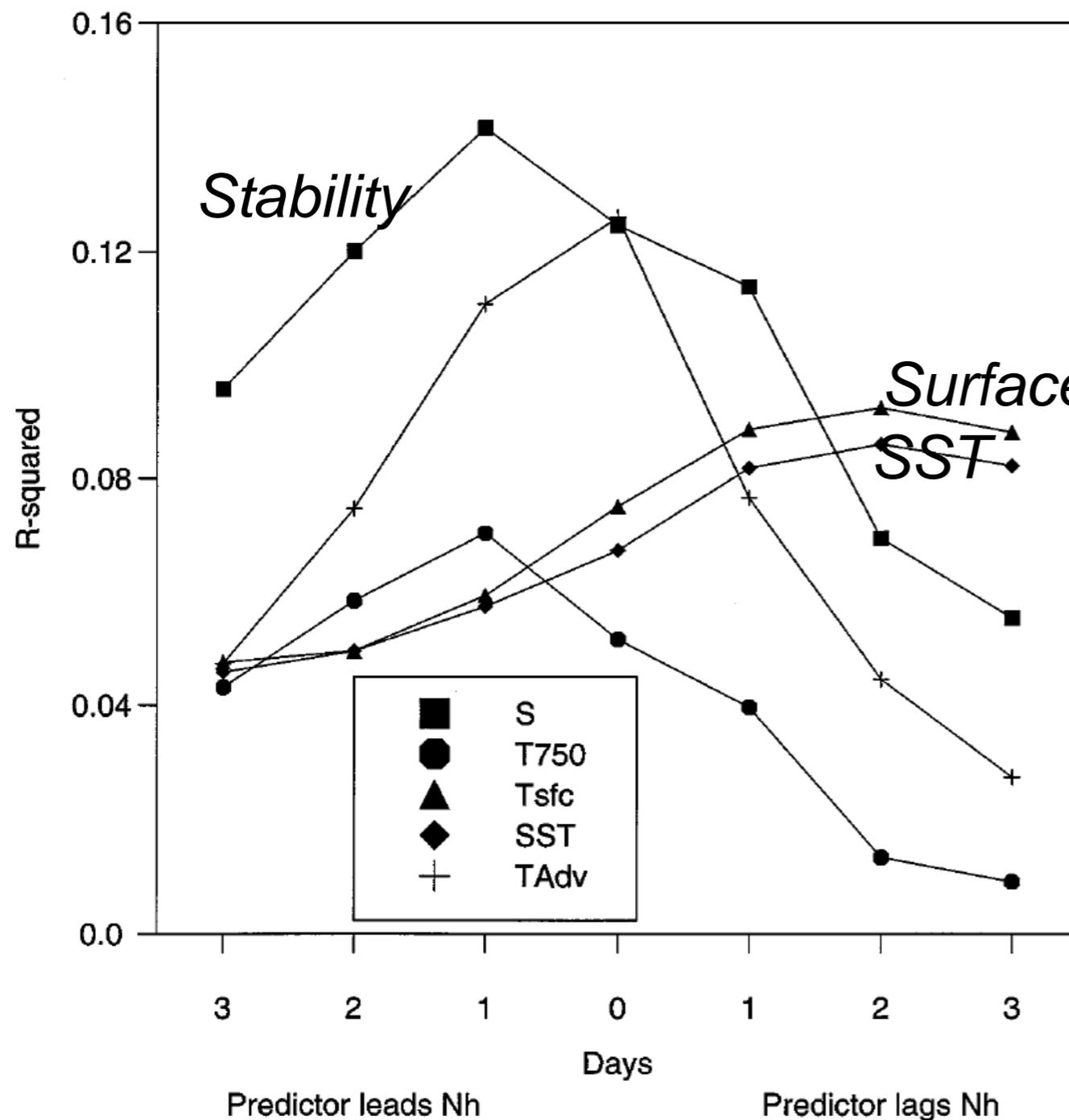


Sea Surface Temperature (L4, MUR)  
Multi-mission / GHRSSST

23.40 - 23.55 °C

*Jan 20,  
2017*





Free-tropospheric temperatures  
Surface air temp. Warm =>

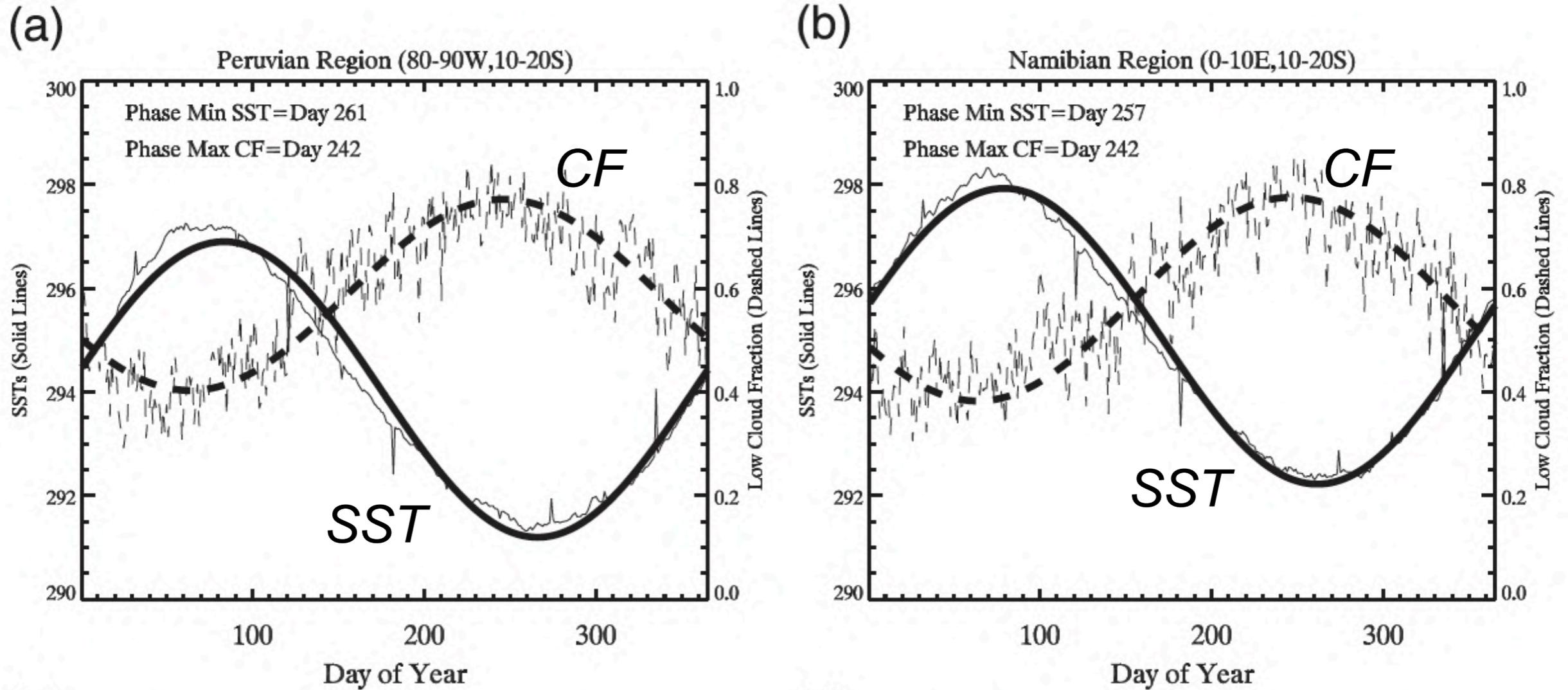
Increasing stability =>

More clouds =>

SST cools

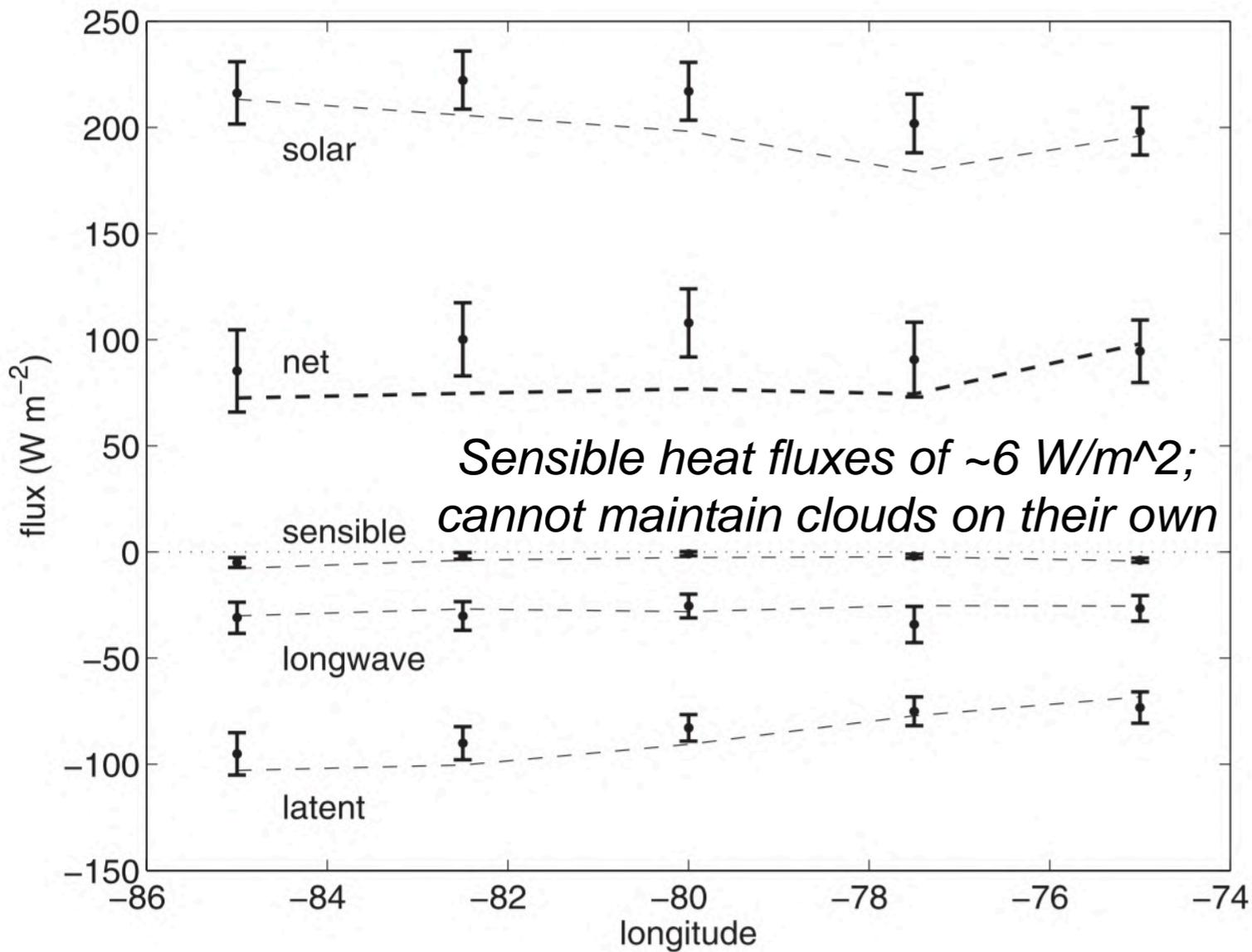
FIG. 4. Fraction of variance in nighttime low-cloud amount (“Nh”) explained by the stability of the lower troposphere (“S”), the 750-mb temperature (“T750”), the surface air temperature (“Tsf”), the sea surface temperature (“SST”), and the temperature advection (“TAdv”) as a function of the lead/lag time. The dataset used was the full dataset including the monthly means. The stability of the lower troposphere and the temperature at 750 mb are positively correlated with low-cloud amount, while the surface air temperature, the sea surface temperature, and the temperature advection are negatively correlated with low-cloud amount.

*Klein, 1995*



Cloud fraction lead minimum SST by 15-20 days

amplifying the annual cycle



Measurements of the surface energy budget within the southeast Pacific EBUS region: net warming of the ocean by the sun of 85-120 W m<sup>-2</sup>

enough to heat a 50-m ocean mixed layer by 1-1.4K/month

FIG. 3. Longitude-binned (2.5°) surface heat flux averaged from the nine 20°S transects (dots) and the five transects in October (dashed lines). Whiskers are the sampling standard error of the measurements.  
*De Szoeke et al., 2010, iclim*

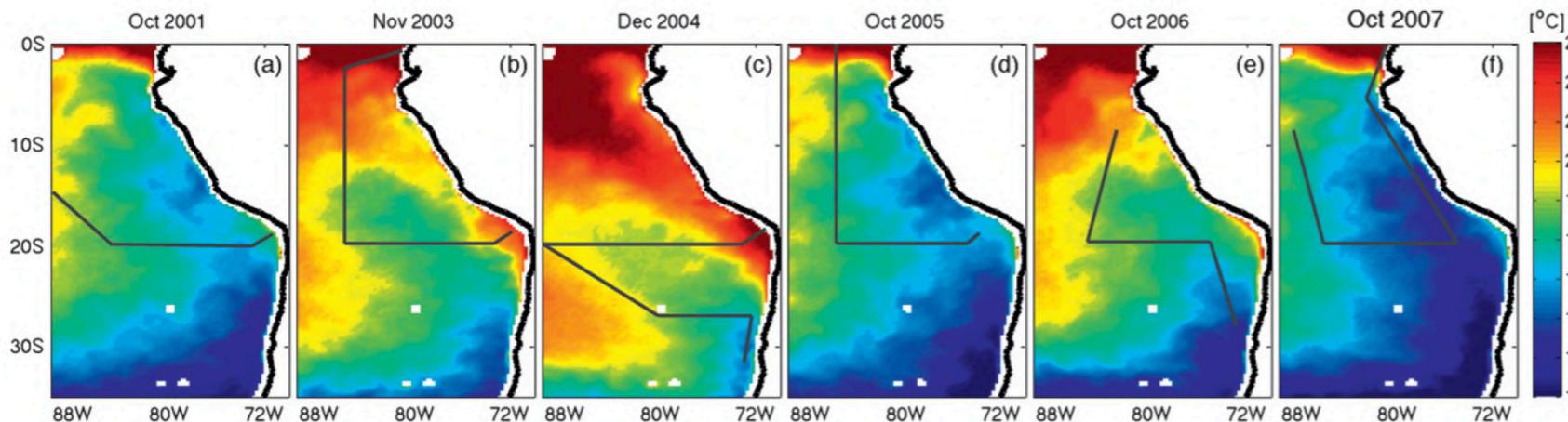


FIG. 1. Monthly mean TMI sea surface temperature with black lines indicating the ship track for the cruise during (a) October 2001, (b) November 2003, (c) December 2004, (d) October 2005, (e) October 2006, and (f) October 2007.



*Zuidema et al., 2009, iclim*

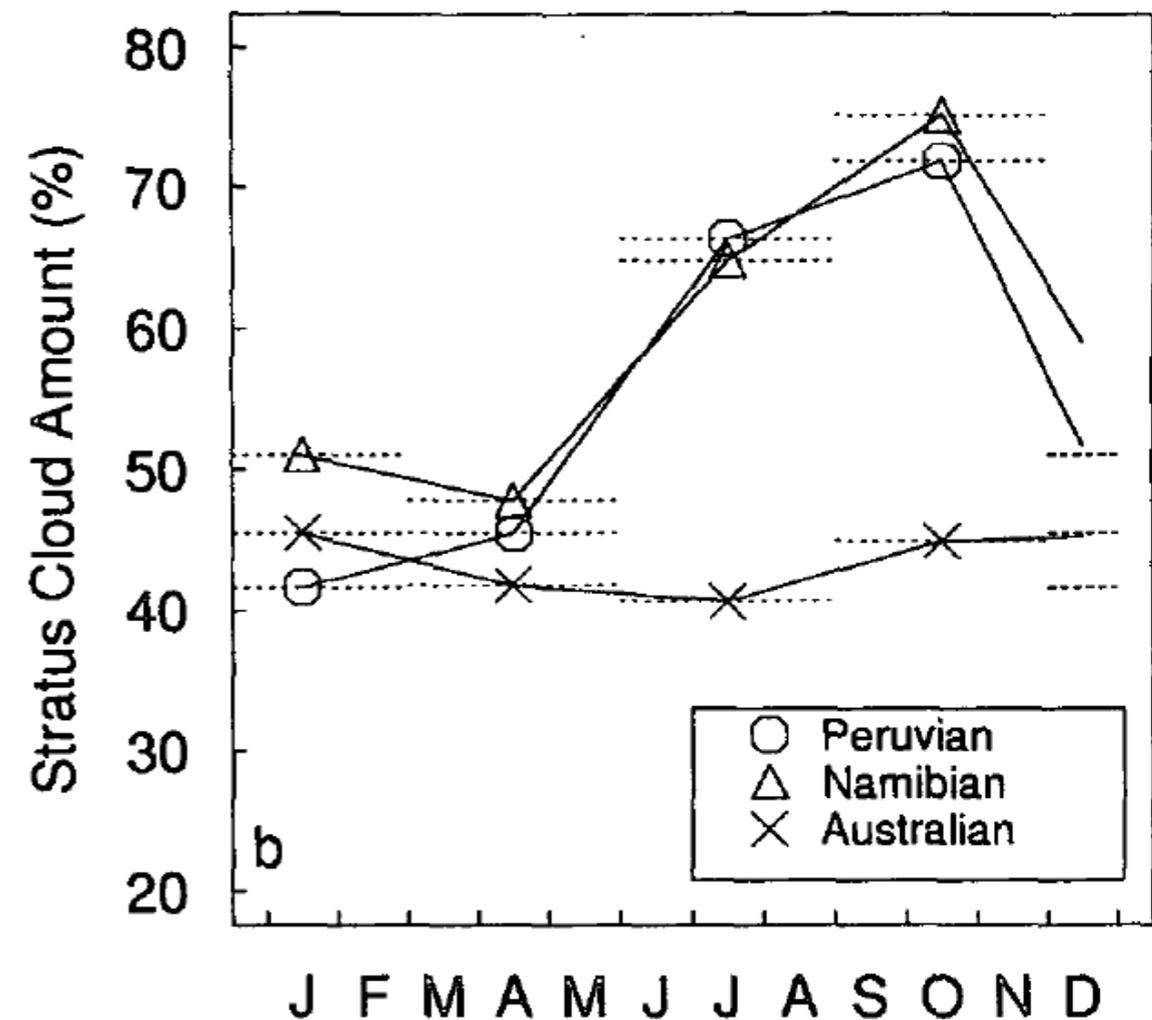
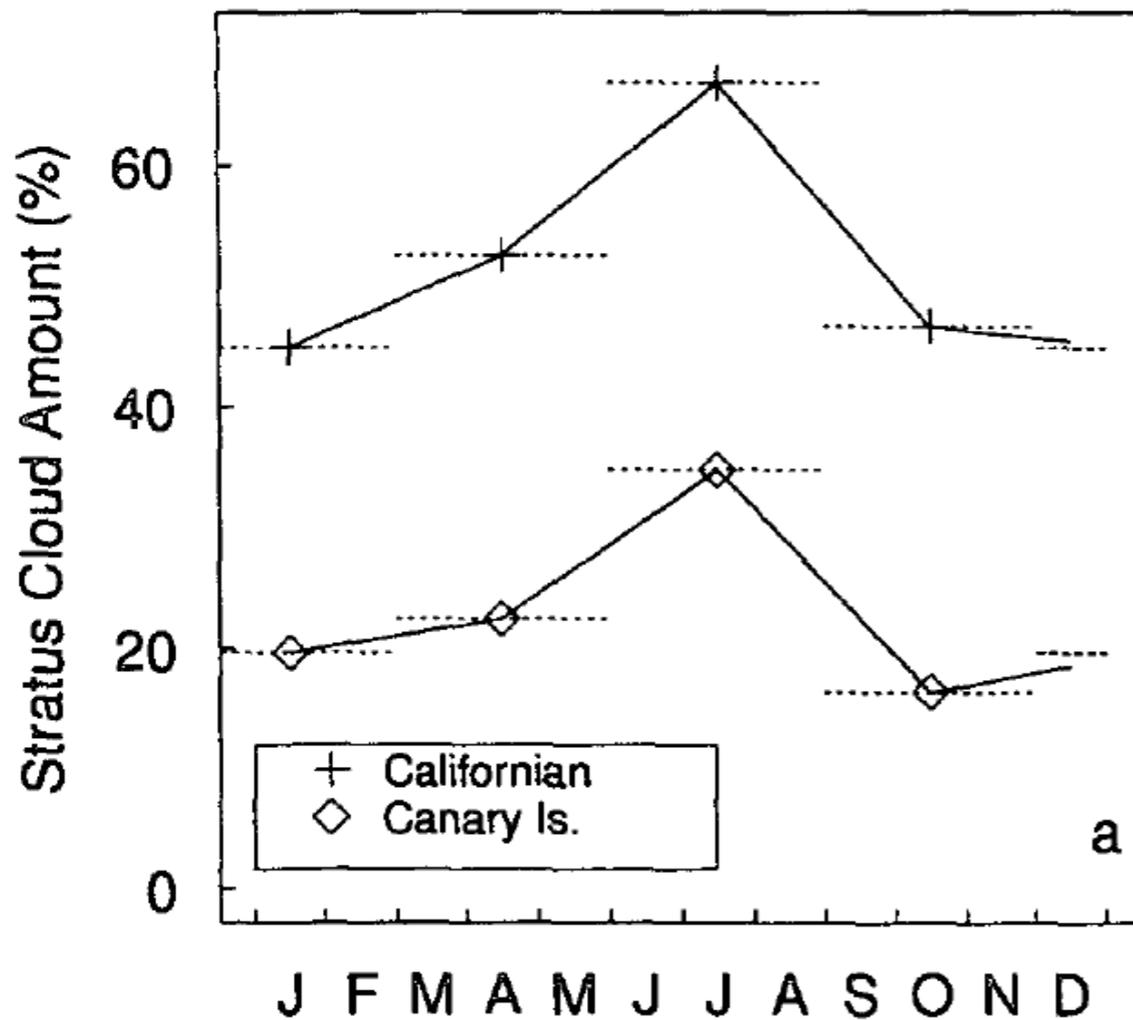
# The seasonal cycles differ in interesting ways

Northern hemisphere decks maximum in July  
Southern Hemisphere decks maximum in Sept-Oct

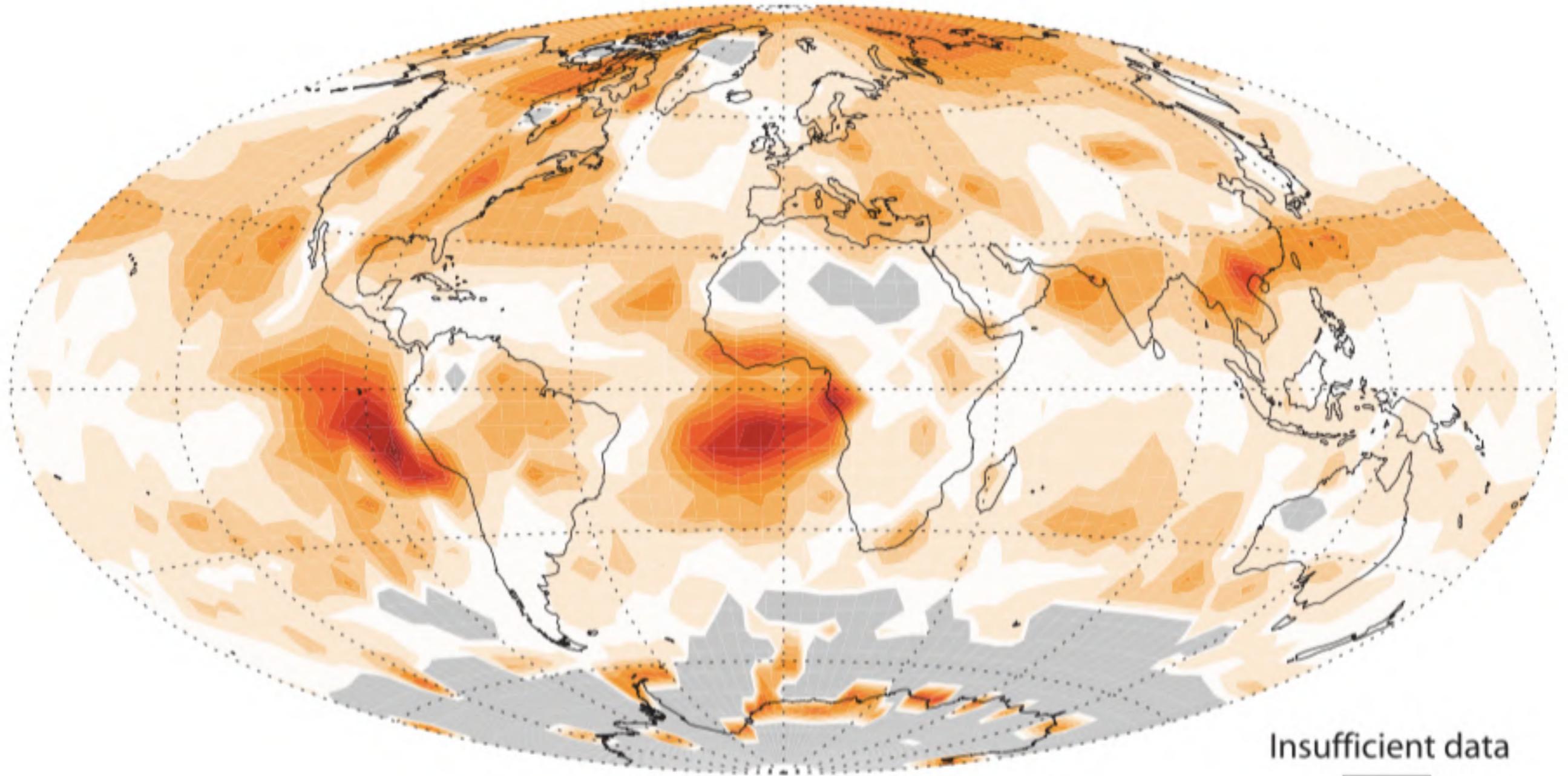
AUGUST 1993

KLEIN AND HARTMANN

1593



the southern hemisphere  
subtropical decks seasonal cycle is more pronounced



(a) Seasonal amplitude (max - min)



Insufficient data



*Wood, 2012*

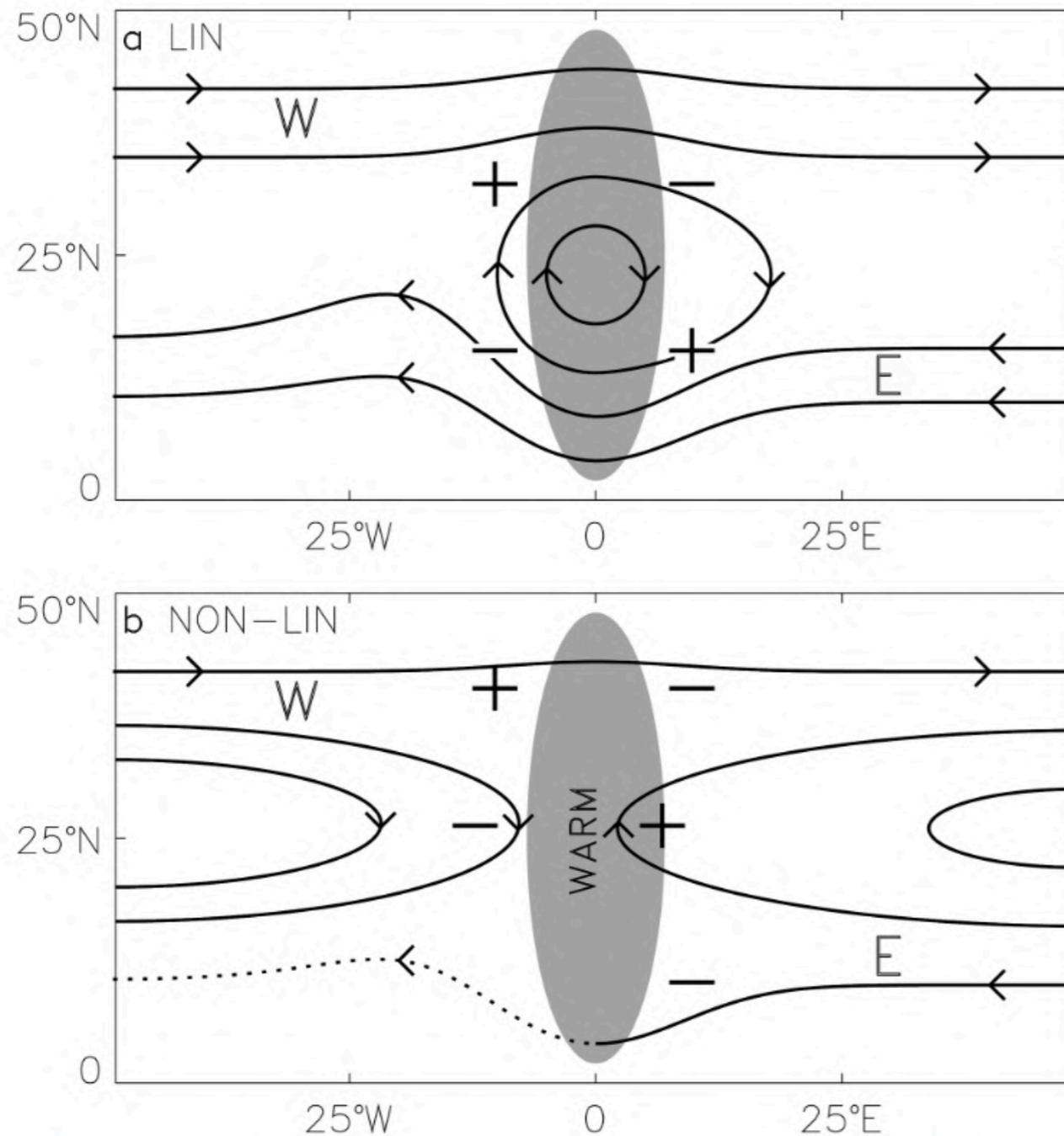


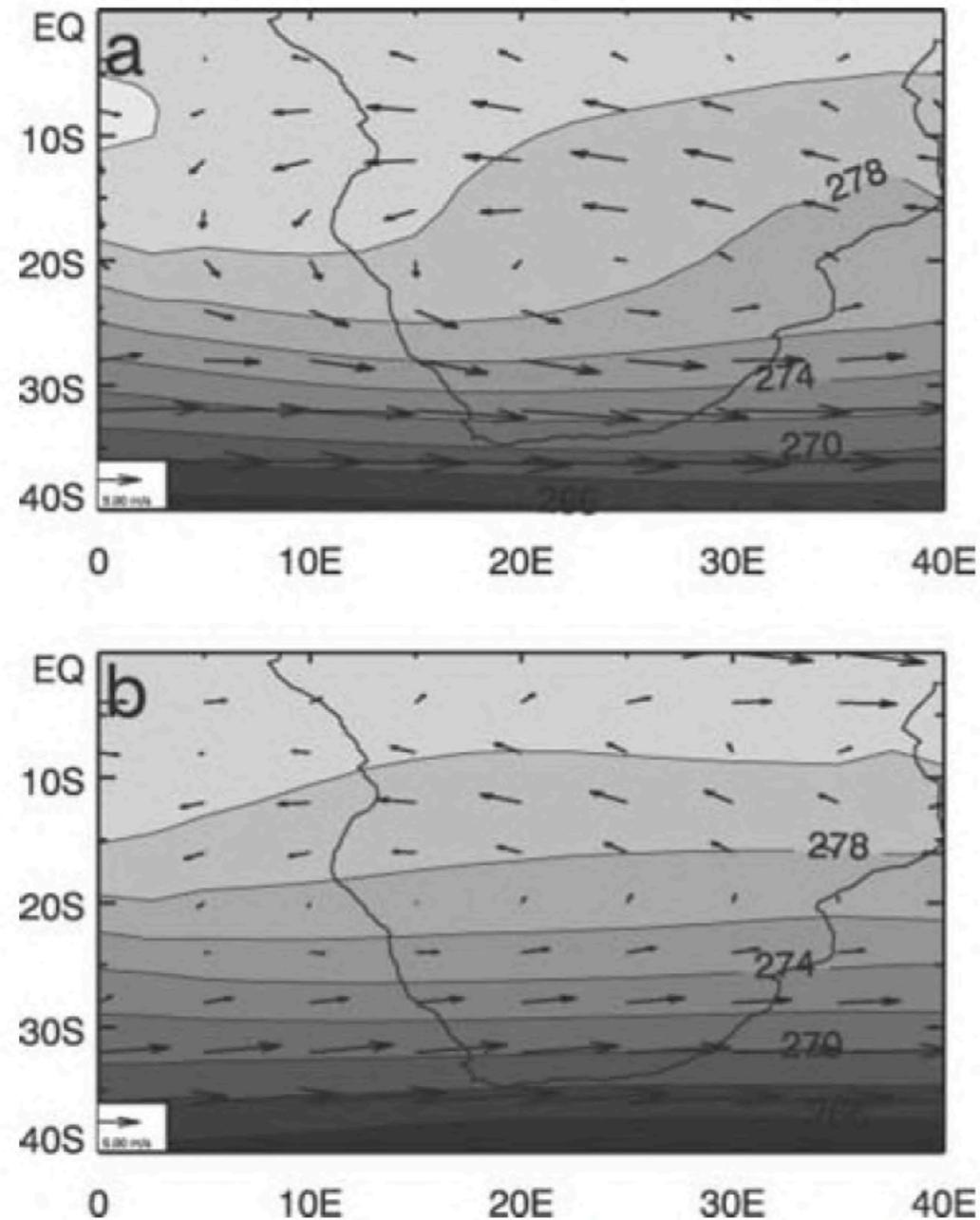
FIG. 12. Schematic diagrams depicting the adiabatic interaction between the zonally averaged flow and an idealized mountain (shaded) based on (a) linear theory in which isentropes do not intersect the mountain in the zonal plane, (b) nonlinear theory in which isentropes can intersect the mountain in the zonal plane. Contours depict low-level streamfunction. Here “+” indicates ascent and “-” indicates descent.

*In the winter months in particular, subsidence strengthened by interaction of prevailing westerlies with orography*

# Orographic influences on the annual cycle of Namibian stratocumulus clouds

2004, GRL

I. Richter and C. R. Mechoso



Orography strengthens  
warming  
at 700 hPa in  
austral winter

deflects mid-latitude  
westerlies equator ward  
in Sept-Oct,  
increasing surface  
cold temperature  
advection

**Figure 3.** Wind and temperature [K] at 700 hPa in August for (a) Control, and (b) No-Orography. The contour interval is 2 K. The reference vector shown in the bottom left corner of each panel denotes a magnitude of 5 m/s.

# The height of the marine boundary layer is crucial for low cloud processes - and whether they are even there; If the height is too low, clouds will not form

1 SEPTEMBER 2009

ZUIDEMA ET AL.

4663

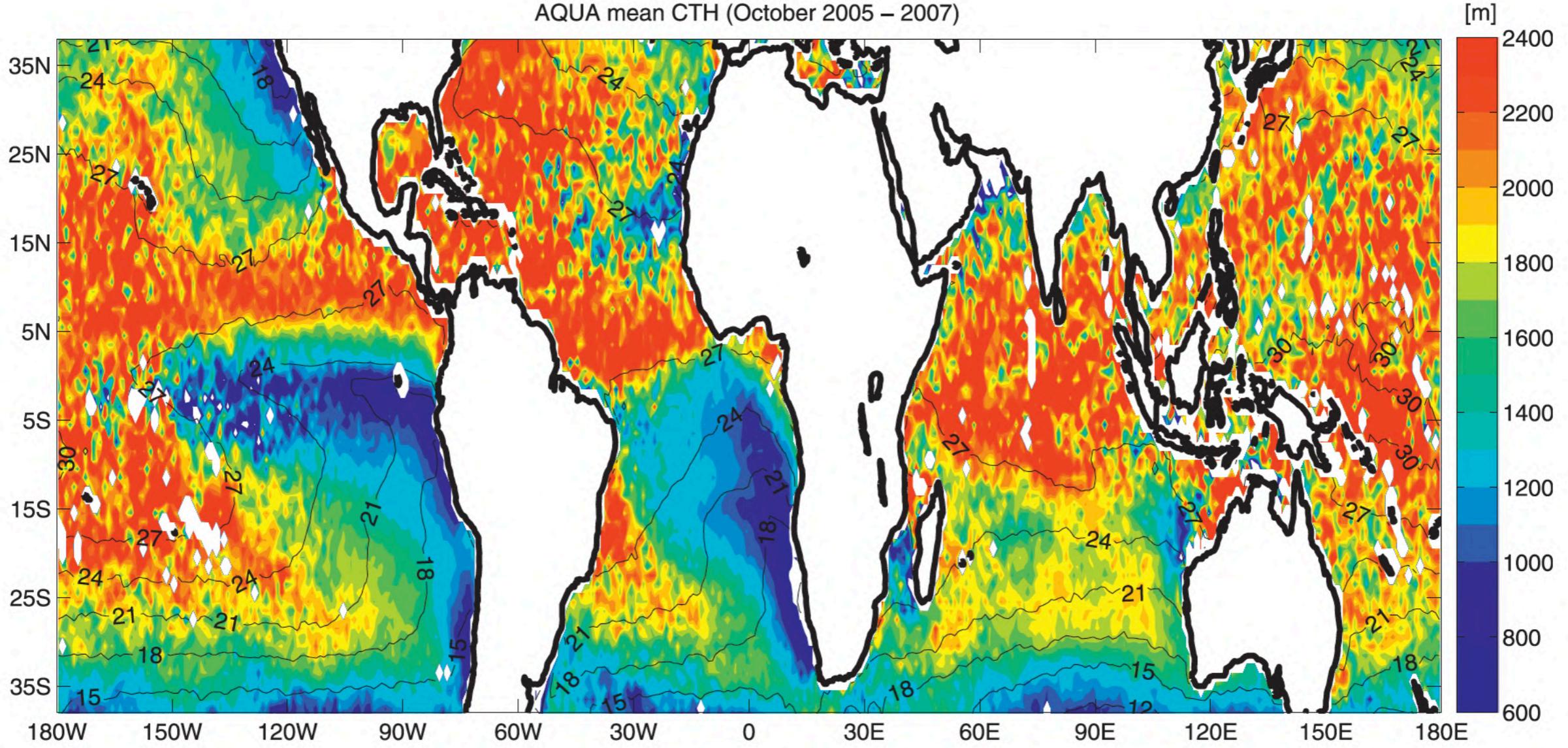


FIG. 12. Mean day + night *Aqua* October 2005, 2006, and 2007 cloud-top heights, with SST indicated as contours. The 40°N–40°S latitude span is set by the TRMM orbit. Only 5-km pixels with warm ( $T_{\text{top}} > 273$  K) cloud fractions  $>0.9$  are included, with no data threshold set; “noisier” regions indicate less available data.

# Cloud observations along 20S off of the coast of Chile

indicate height of low cloud deck ~ height of Atacama plateau  
how the low clouds adapt to the stability profile

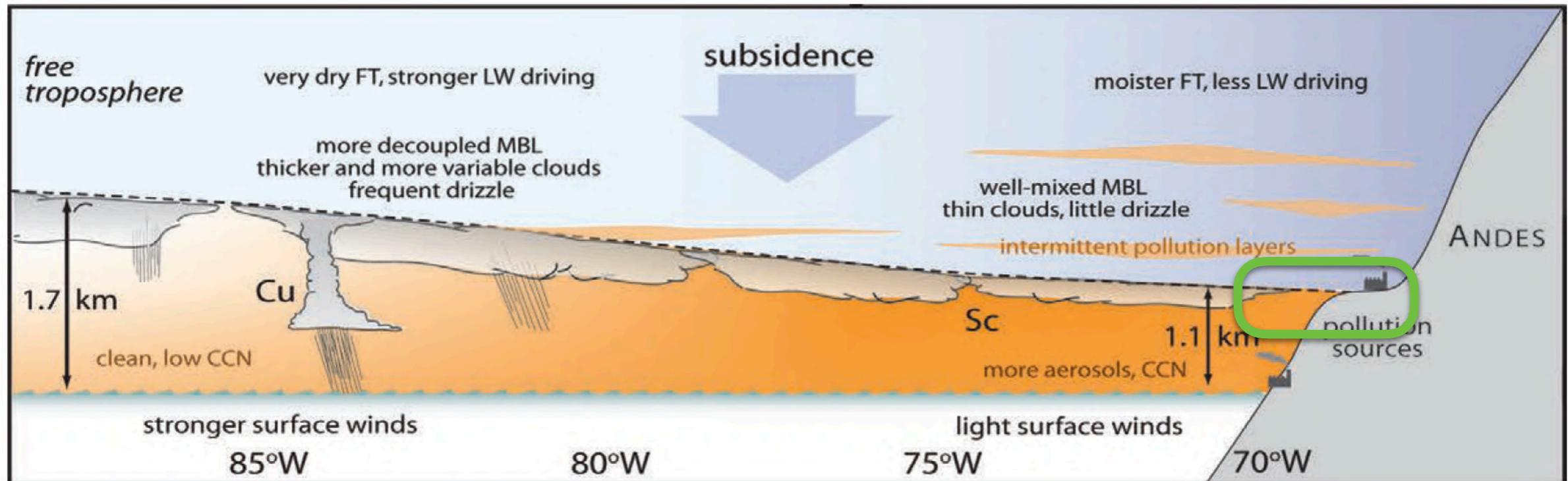


FIG. 9. Schematic summarizing the key aerosol, cloud, and precipitation changes from the South American coast to the remote ocean along 20°S.

**Cool SST**

**Cooler SST**

*Mechoso et al., 2014, BAMS: "Ocean-cloud-atmosphere-land interactions in the Southeastern Pacific: the VOCALS program"*

## Take-aways:

- Low clouds in the eastern ocean boundary regions are strongly coupled to both the underlying ocean & continents to their west
- Offshore the low clouds lead the SST, amplifying the SST annual cycle
- Interactions with orography are important for setting the seasonal cycle, through affecting both free-tropospheric and surface temperature (at different times)

*Yuter et al., 2018*

