Processes determining the cloudiness distributions in Eastern Boundary Upwelling System regions: Part 2

*Expectations with climate change*

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The ability of low clouds to cool the Earth provided hope. They could get us out of a net climate warming.....

CERES annual-mean, 2014 I think
How do we expect clouds to evolve with a warming climate?

- warming SSTs reduce LTS* -> reducing cloud cover
- BUT: the troposphere warms more than the surface
- increasing LTS -> increasing low cloud cover

*LTS=lower tropospheric stability
As of Feb 2003 the experts did not agree

more physically-based parameterizations of convection

Inversion strength parameterization
The model cloud radiative effect, compared to CERES satellite observations, indicate sunlight reaching the surface in EBUS areas is ~40 W/m^2 too high in models -> indicating far too little low cloud

A comparison to simulations in which the SST is perfect still indicates the low cloud amount is too low in climate models - the problem is clearly with the atmospheric component of the models

Zuidema et al., 2016, bams, fig. by Brian Medeiros
This led to a renewed - and continuing - focus on understanding low cloud processes. Some of which are very difficult to parameterize (well).
boundary layer thermodynamic structure varies from well-mixed,

shallower BL
- strong narrow downdrafts
- broader updrafts
- more ‘top-down’

deeper BL
- stronger updrafts
- broader downdrafts
- more ‘bottom-up’

to cumulus-coupled
subtle conditional instability in cumulus-coupled boundary layers
\[(d(\theta_e)/dz>0)\]

**Fig. 12.** Vertical profiles of water vapor \(q\) and liquid water \(q_L\) mixing ratios, equivalent potential temperature \(\theta_e\), temperature \(T\), and easterly/northerly wind components (\(u\) and \(v\)) for a summertime decoupled STBL observed over the North Sea. Adapted from Nicholls and Leighton (1986).
surface precip of 1 mm/day = cloud layer warming of 30 W m$^{-2}$

Figure from Tristan L’Ecuyer

Warm Rain (0.019)  

Drizzle (0.035) ($<0.5$ mm h$^{-1}$)
Fig. 17. Schematic of the entrainment interfacial layer (EIL) atop a layer of marine stratocumulus. A similar schematic appears in Stevens et al. (1999).
Low-Cloud Feedbacks from Cloud-Controlling Factors: A Review

Stephen A. Klein\textsuperscript{1} \cdot Alex Hall\textsuperscript{2} \cdot Joel R. Norris\textsuperscript{3} \cdot Robert Pincus\textsuperscript{4,5}

Table 1: Most prominent cloud-controlling factors affecting tropical low clouds, their physical explanation, and their support from observational and large-eddy simulation modeling studies

<table>
<thead>
<tr>
<th>Cloud-controlling factor</th>
<th>Physical explanation</th>
<th>Observational support</th>
<th>Modeling support</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strengthened inversion stability</td>
<td>Reduced mixing across inversion keeps boundary layer shallower, more humid and more cloudy</td>
<td>Wood and Bretherton (2006)</td>
<td>Bretherton et al. (2013)</td>
</tr>
<tr>
<td>Reduced subsidence</td>
<td>Deeper boundary layer increases cloud</td>
<td>Myers and Norris (2013)</td>
<td>Blossey et al. (2013)</td>
</tr>
<tr>
<td>Increased horizontal cold advection</td>
<td>Greater destabilization of the surface–atmosphere interface increases upward buoyancy flux promoting more clouds</td>
<td>Norris and Iacobellis (2005)</td>
<td>N/A</td>
</tr>
<tr>
<td>Increased free-tropospheric humidity</td>
<td>Entrainment drying is reduced, thus moistening the boundary layer and increasing cloud</td>
<td>M16</td>
<td>van der Dussen et al. (2015)</td>
</tr>
<tr>
<td>Decreased downward longwave radiation</td>
<td>Reduced downward longwave radiation increases cloud-top radiative cooling, driving more turbulence supporting cloud</td>
<td>Christensen et al. (2013)</td>
<td>Bretherton et al. (2013)</td>
</tr>
<tr>
<td>Colder Sea-surface temperature (SST)</td>
<td>Colder temperature reduces the efficiency of entrainment necessitating more cloud to produce a given entrainment rate</td>
<td>Q15</td>
<td>Bretherton and Blossey (2014)</td>
</tr>
<tr>
<td>Increased surface wind speed</td>
<td>Increased surface driven shear mixing increases latent heat flux and cloud</td>
<td>Brueck et al. (2015)</td>
<td>Bretherton et al. (2013)</td>
</tr>
</tbody>
</table>

In the first column, the direction of the cloud-controlling factor corresponds to that that would increase low clouds. Only the single most prominent study supporting the cloud-controlling factor is listed in the third and fourth columns.
disparate studies conclude a positive cloud feedback: climate warming => less low clouds
but what about in the EBUS regions?

The CGILS experimental design to investigate low cloud feedbacks in general circulation models by using single-column and large-eddy simulation models

Minghua Zhang, Christopher S. Bretherton, Peter N. Blossey, Sandrine Bony, Florent Brient, and Jean-Christophe Golaz

![Image of diagrams showing low clouds, total clouds, SST, and SLP distributions](image)

**Figure 1.** (a) Averaged amount of low clouds in June-July-August (%), and (b) total cloud amount from the C3M satellite data. Note the different color scales. The black line is the GPCI (see text); the symbols “S6”, “S11” and “S12” are the three locations used in the paper. (c and d) The corresponding sea surface temperature (SST) and sea level pressure (SLP).
Subtropical anticyclones expected to intensify with climate change

Falvey and Garreaud, 2009: “Regional cooling in a warming world: temperature trends along the coast of Chile, 1979-2006” JGR
Should get more low clouds
0.9°C/100 yr warming in surface air temperature

1 cm/100 yr decrease in precipitation

Thinning stratocumulus?

RYAN EASTMAN AND STEPHEN G. WARREN
Department of Atmospheric Sciences, University of Washington, Seattle, Washington

2012, jclim

b) Stratiform
Global Mean: 
\( -0.15\% / \text{Decade} \)
also an intensified subtropical anticyclone, displaced poleward

Understanding long-term (1982–2013) multi-decadal change in the equatorial and subtropical South Atlantic climate

Edward K. Vizy¹ · Kerry H. Cook¹

(f) ISCCP Trend

(g) PATMOSX Trend

Shows decrease in Coastal clouds. Contradicts Surface observers.
Observational Evidence That Enhanced Subsidence Reduces Subtropical Marine Boundary Layer Cloudiness

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(Manuscript received 12 October 2012, in final form 19 March 2013)

ABSTRACT

Conventional wisdom suggests that subsidence favors the presence of marine stratus and stratocumulus because regions of enhanced boundary layer cloudiness are observed to climatologically co-occur with regions of enhanced subsidence. Here it is argued that the climatological positive correlation between subsidence and cloudiness is not the result of a direct physical mechanism connecting the two. Instead, it arises because enhanced subsidence is typically associated with stronger temperature inversions capping the marine boundary layer, and stronger temperature inversions favor greater cloudiness. Through statistical analysis of satellite cloud data and meteorological reanalyses for the subsidence regime over tropical (30°S–30°N) oceans, it is shown that enhanced subsidence promotes reduced cloudiness for the same value of inversion strength and that a stronger inversion favors greater cloudiness for the same value of subsidence. Using a simple conceptual model, it is argued that enhanced subsidence leads to reduced cloud thickness, liquid water path, and cloud fraction by pushing down the top of the marine boundary layer. Moreover, a stronger inversion reduces entrainment drying and warming, thus leading to a more humid boundary layer and greater cloud thickness, liquid water path, and cloud fraction. These two mechanisms typically oppose each other for geographical and seasonal cloud variability because enhanced

Coastal jets
Do coastal SST biases really advect offshore, dissipating cloud erroneously?
Attribution and Impacts of Upper-Ocean Biases in CCSM3

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(Manuscript received 16 December 2004, in final form 21 October 2005)

ABSTRACT

The largest and potentially most important ocean near-surface biases are examined in the Community Climate System Model coupled simulation of present-day conditions. They are attributed to problems in the component models of the ocean or atmosphere, or both. Tropical biases in sea surface salinity (SSS) are associated with precipitation errors, with the most striking being a band of excess rainfall across the South Pacific at about 8°S. Cooler-than-observed equatorial Pacific sea surface temperature (SST) is necessary to control a potentially catastrophic positive feedback, involving precipitation along the equator. The strength of the wind-driven gyres and interbasin exchange is in reasonable agreement with observations, despite the generally too strong near-surface winds. However, the winds drive far too much transport through Drake Passage [>190 Sv (1 Sv = $10^6$ m$^3$ s$^{-1}$)], but with little effect on SST and SSS. Problems with the width, separation, and location of western boundary currents and their extensions create large correlated SST and SSS biases in midlatitudes. Ocean model deficiencies are suspected because similar signals are seen in uncoupled ocean solutions, but there is no evidence of serious remote impacts. The seasonal cycles of SST and winds in the equatorial Pacific are not well represented, and numerical experiments suggest that these problems are initiated by the coupling of either or both wind components. The largest mean SST biases develop along the eastern boundaries of subtropical gyres, and the overall coupled model response is found to be linear. In the South Atlantic, surface currents advect these biases across much of the tropical basin. Significant precipitation responses are found both in the northwest Indian Ocean, and locally where the net result is the loss of an identifiable Atlantic intertropical convergence zone, which can be regained by controlling the coastal temperatures and salinities. Biases off South America and Baja California are shown to significantly degrade precipitation across the Pacific, subsurface ocean properties on both sides of the equator, and the seasonal cycle of equatorial SST in the eastern Pacific. These signals extend beyond the reach of surface currents, so connections via the atmosphere and subsurface ocean are implicated. Other experimental results indicate that the local atmospheric forcing is only part of the problem along eastern boundaries, with the representation of ocean upwelling another likely contributor.
coastal cooling = too much upwelling
atmospheric energy budget mattered little

atmospheric model errors offshore
confined coastal region
more closely with time

Fig. 2 Ensemble-mean fast SST errors in the a high-resolution and b low-resolution CCSM4 simulations in the Southeast Pacific
Climate models with ‘perfect’ atmospheric forcing still produce SST biases, most pronounced in the upwelling regions.

**Fig. 10.** Ocean simulations with fixed atmosphere forcings (termed OMIP) also produce SST biases, if less pronounced than in CMIP simulations, as shown in the 22-ensemble OMIP SST bias relative to CORE2 surface forcing for (a) the Pacific and (b) the Atlantic (Danabasoglu et al. 2014). This suggests oceanic origins also contribute to the SST biases.

Zuidema et al., 2016, bams, f
take-aways

• Free troposphere will warm more than the surface in response to CO\textsubscript{2} increases.

• Overall, marine low cloud cover anticipated to decrease (SST increase dominates; sets up a positive feedback encouraging)

• in regions with the coldest SSTs (e.g. near coasts) low clouds may increase in response to the increase in the static stability.

• how well are large-scale cloudiness changes reflected in the EBUS regions? Likely not well!