The CLIVAR
Eastern Boundary
Upwelling Systems (EBUS)
Research Focus

Motivation—
• Coupled models exhibit some of the largest surface-ocean biases in EBUS regions.
• Historical observations and hypotheses suggest close association between EBUS dynamics and large-scale climate conditions.
• EBUS are of disproportionate ecological, economical, and biogeochemical importance.

Overarching questions:
• How are EBUS dynamics represented in models?
• How are these dynamics associated with larger-scale climate change?
• What are the feedbacks between EBUS and larger-scale climate properties?
• What are the implications of EBUS changes for ecosystems and biogeochemical conditions?
4, semi-permanent, eastern boundary upwelling systems
SST biases in CGCMs largest in EBUS regions

Prevailing winds and currents advect those biases downwind and affect the low cloud cover downstream.

BAMS, 2016, doi:10.1175/BAMS-D-15-00274.1
adapted from Toniazzo and Woolnough, 2014
Anthropogenic changes in wind intensity are fairly subtle...

Rykaczewski et al. (2015)
Anthropogenic changes in wind intensity are fairly subtle...

Upwelling intensity tends to increase in the poleward halves...

... but decrease in the equatorward portions of the upwelling systems.

Rykaczewski et al. (2015)
**Broad questions**

Links between large-scale climate processes and EBUS

What *processes* control the atmospheric dynamics associated with EBUS?  
How are these processes represented in *global and regional models*?  
What mechanisms relate EBUS atmospheric and oceanic variability to *large-scale climate patterns*?  
What are the *effects of upwelling* on the regional and global air temperatures, precipitation and wind patterns?  
How can the *temporal and spatial variability* of upwelled waters be described?

Biogeochemical responses and consequences

What key physical and biological processes control primary *production*, air-sea *CO₂ flux*, and carbon *export* in EBUS?  
What are the *relative contributions of EBUS* to large-scale productivity and intensity of oxygen minimum zones?  
How will natural and anthropogenic factors influence *carbon cycling and deoxygenation* in EBUS?  
How do mixing, stratification, and source-water properties influence the composition of the *plankton community* and survival of larval *fishes*?
“Eastern Boundary Upwelling Systems: Assessing and understanding their changes and predicting their future”

The school will stimulate discussion and new ideas concerning the mechanisms that influence the responses of EBUSs to climate variability and change.

The school will be followed by an EBUS Research Focus meeting.
<table>
<thead>
<tr>
<th>Time</th>
<th>DAY 1: Monday, July 15</th>
<th>DAY 2: Tuesday, July 16</th>
<th>DAY 3: Wednesday, July 17</th>
<th>DAY 4: Thursday, July 18</th>
<th>DAY 5: Friday, July 19</th>
</tr>
</thead>
<tbody>
<tr>
<td>09:00-09:45</td>
<td>Introduction of Lecturers and Participants</td>
<td>Processes determining cloudiness distributions in EBUS regions: Part 1 (P. Zuidema)</td>
<td>Response of the ocean to wind fields (M. Schmidt)</td>
<td>Large-scale biogeochemistry and plankton ecology in EBUS (R. Rykaczewski)</td>
<td>Equatorail and coastal wave teleconnections in the EBUSs (A. Lazar)</td>
</tr>
<tr>
<td>09:45-10:30</td>
<td>Eastern Boundary Upwelling Systems: importance and critical processes (co-Organizers)</td>
<td>Atm. circulation and coastal topography (R. Garreaud)</td>
<td>Transport and mixing at the ocean mesoscale (A. Bracco)</td>
<td>Role of (sub)Mesoscale for biogeochemistry and ecology in EBUS (I. Frenger)</td>
<td>Variability and equatorial teleconnections (R. Garreaud, A. Miller)</td>
</tr>
<tr>
<td>10:30-10:45</td>
<td>Break</td>
<td>Break</td>
<td>Break</td>
<td>Break</td>
<td>Break</td>
</tr>
<tr>
<td>10:45-11:30</td>
<td>Historical variability in EBUS and considerations about their future (R. Rykaczewski)</td>
<td>Drivers of coastal along-shore winds and their variability (T. Toniaszzo)</td>
<td>Processes controlling SSTs (A. Lazar)</td>
<td>Biogeochemical Models in EBUS (I. Frenger)</td>
<td>Downscaling of climate change impacts on EBUS biogeochemistry (F. Chai)</td>
</tr>
<tr>
<td>11:30-12:15</td>
<td>Climatology of the atmospheric circulation (T. Toniaszzo)</td>
<td>Cloud impacts across time scales (R. Garreaud)</td>
<td>Transport and mixing at the ocean submesoscales (A. Bracco)</td>
<td>Upwelling impacts on the world’s largest fishery, the Peruvian anchoveta (F. Chai)</td>
<td>EBUS biases and uncertainties in global and regional models (T. Toniaszzo, R. Farneti)</td>
</tr>
<tr>
<td>12:15-13:00</td>
<td>Climatological ocean dynamics (M. Schmidt)</td>
<td>Processes determining cloudiness distributions in EBUS regions: Part 2 (P. Zuidema)</td>
<td>Coupled atmosphere-ocean feedbacks (A. Miller)</td>
<td>Data assimilation; adjoint models (A. Miller)</td>
<td>Alongshore winds in IPCC model projections (R. Rykaczewski)</td>
</tr>
<tr>
<td>13:00-16:00</td>
<td>Lunch/Swim</td>
<td>Lunch/Swim</td>
<td>Lunch/Swim</td>
<td>Lunch/Swim</td>
<td>Lunch/Swim</td>
</tr>
<tr>
<td>16:00-17:30</td>
<td>The NetCDF format, data sources, and analysis tools (Introduction: M. Schmidt, supervision: Lecturers)</td>
<td>Data Analysis/Case Study (Introduction: R. Garreaud, R. Rykaczewski, T. Toniaszzo, P. Zuidema; supervision: Lecturers)</td>
<td>Participants’ Poster Session</td>
<td>The ICTP regional coupled model and the West Africa EBUS (R. Farneti)</td>
<td>Debate on climate change in EBUS: selection of hypotheses from the literature (Students)</td>
</tr>
<tr>
<td>17:30-17:45</td>
<td>Break</td>
<td>Break</td>
<td>Break</td>
<td>Break</td>
<td>Break</td>
</tr>
<tr>
<td>17:45-19:00</td>
<td>Welcome Reception</td>
<td>Data Analysis/Case Study (supervision: Lecturers)</td>
<td>Participants’ Poster Session</td>
<td>TBD (A. Lazar, R. Farneti)</td>
<td>Debate on climate change in EBUS: discussion on hypotheses (Students)</td>
</tr>
</tbody>
</table>
Friday evening “debate”

How will EBUS respond to future climate change?

Different, mutually inconsistent hypotheses have been proposed.

Based on the literature and what you learn during the week, we hope to have a group discussion, LED BY YOU, about some of these ideas.

What are the merits of hypotheses of future change in EBUS?
What are weaknesses or shortcomings of the ideas?
What steps need to be taken to help better understand EBUS responses?
Some potentially useful papers:


https://drive.google.com/drive/folders/1kesLephEOaNtqdtuZn21K064O0ZkvAK3
Some potentially useful papers (cont.):


Some background on our key questions...
Basic theory attributes the eastern boundary oceanic upwelling to the low-level wind spatial structure

SCOW along-shore windstress [mPa] and windstress curl [N/km³] annual average

along-shore windstress (lines) => Ekman divergence

wind stress curl (color) => Ekman pumping

Coarse-resolution models are typically too dissipative, overestimating upwelling induced by wind-stress curl.

fig. by Thomas Toniozzo
Scatterometer, with 10-km res., ID’s 2 distinct coastal jets, missed in coarser models.

Wind-stress maximum is placed too far offshore in coarse models, excessive cyclonic wind-stress curl forces warm, southward current (Xu et al. 2014; Small et al. 2015); too diffuse thermoclines reinforce the SST bias.

Fig. 12. Coastal southeast Atlantic (a)–(d) meridional winds at 10 m and (e)–(h) surface wind stress curls differ significantly between observations and models and depend on spatial resolution: (a),(e) 0.25° SCOW ocean surface wind vectors, averaged 1999–2009; (b),(f) 1° CORE2 ocean forcing dataset, averaged 1999–2009; (c),(g) CMIP5 multi-model mean, averaged 1984–2004; and (d),(h) a 9-km simulation with the Weather Research and Forecasting Model, averaged 2005–08. See further discussion in Patricola and Chang (2016, manuscript submitted to Climate Dyn.).

doi:10.1175/BAMS-D-15-00274.1, see Patricola and Chang, 2017, Climate Dynamics for more
Subsidence is driven by radiative cooling over the EBUS in approximate balance with baroclinic meridional poleward winds.

\[ \beta v \approx f \partial_p \omega. \]

**Northern Hemisphere 25N-35N**

ERA-Interim data. omega=contours; meridional wind=color

**Southern Hemisphere 25S-35S**
Relationship between low cloud cover and the coastal jets varies between the EBUS regions, affects the EBUS surface energy balance.
Nevertheless, each EBUS will be affected differently by topography/bathymetry
e.g., the atmospheric structure establishing the capping stability inversion and its relationship to cloudiness

The coastal SE Pacific has a high cloud cover capping the oceanic upwelling region, with a strong diurnal cycle in the cloud top height driven by the neighboring land heating

=> impacts the surface energy budget

Zuidema et al., 2009, JCLI
In contrast, extensive SE Atlantic coastal clearings more likely linked to strong coastal subsidence producing very low inversions => surface moisture cannot reach its lifting condensation level.
Improvements in model resolution reduce SST bias overall, but.....

high vs low resolution CCSM4-RSMAS,
$SST(day=2-5) - SST(day=1)$, initialized January 1, 27 year ensemble (NAMME)

0.1$^\circ$ ocean
0.5$^\circ$ atm

1.125$^\circ$ ocean
0.9$^\circ$ atm

reduced SST biases

sign of coastal SST biases has flipped!
We currently think (speculate) the cause is related to precipitation on east Andes, encouraging atmospheric ascent.

Reasonable to expect fast-SST error growth will depend differently on resolution in this model.
2018 Ocean Sciences Meeting: Session EP34B –

Biophysical Dynamics of Eastern Boundary Upwelling Ecosystems in a Changing Ocean: Closing the Gap Between Wind Stress and Ecosystem Productivity

Co-chairs Ryan Rykaczewski, Enrique Curchitser, Ruben Escribano, and Michael Jacox

2018 ECCWO symposium: Session 7 –

Eastern Boundary upwelling systems: diversity, coupled dynamics and sensitivity to climate change”

Co-chairs Ivonne Montes and Ryan Rykaczewski
Any advice from ARP?
extra slides
inter annual variability (of SST?)

inter seasonal variability
but, each EBUS will be affected differently by topography/bathymetry

mean seasonal cycle in equatorward along-shore wind-stress offshore distance of the wind-stress maximum (green lines)

(SCOW)