EBUS alongshore winds as simulated by IPCC-style climate projections

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Relevant hypotheses describing future nutrient supply

What physical processes can conceivably alter the supply of macronutrients to upwelling ecosystems in response to anthropogenic global warming?

1) The magnitude of upwelling favorable winds along the coast. Bakun (1990)

2) Stratification of the water column that might alter the depth from which upwelling waters are drawn.

3) Changes in the nutrient concentrations in source waters.
   A. Change in concentration within a source-water mass
   B. Change in the relative contributions of different water masses to the region

4) Changes in the frequency or intensity of variability or extreme events.

Subtropical Eastern Boundary Current Upwelling Systems

- California Current
- Canary Current
- Humboldt Current
- Benguela Current
Alongshore, equatorward winds driven by large-scale pressure fields

Huyer (1983)
Bakun (1973)
Upwelling winds show clear seasonal and latitudinal patterns

Schwing et al. (1996)
This is a captivating hypothesis, involving:

global warming/climate,
atmospheric science,
oceanography, and
ecological impacts

all tied together in a fairly straightforward conceptual explanation.
Bakun’s proposed mechanism of upwelling intensification

Bakun suggested that global warming would enhance summertime upwelling winds in eastern boundary currents.

Differential heating of the surface air over the landmass relative to the ocean…

…will result in intensification of the thermal Low over the Southwest, generating a stronger pressure gradient.
Some issues with observational datasets come to mind:

Although the durations of observational time series have increased, so too has our recognition of decadal scale variability. *Time series are short.*

The magnitude of historical climate change is rather small relative to what is expected in the future. The “signal” is relatively weak.
Issues with reliance on an observational approach

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In this manuscript, we examined upwelling in the California Current as simulated by 40-members of the Community Earth System Model Large Ensemble Project (CESM-LE) under “historical” and “RCP 8.5” conditions.
The magnitude of the “forced signal” in vertical velocity over the 1946-1988 period is rather small relative to the internal variability. 

Brady et al. (2017)
Models can be useful in examining the intensification concept

Atmosphere-ocean coupled climate models (IPCC-style) alleviate some of these issues:

- Not limited by data length or magnitude of historical forcing.
- Not limited by data quality or methodology.
- Offer comprehensive and quantitative results, as well as the ability to test each step (not just the final result).
Steps to explore

In each of these models, three steps of the hypothesis can be explored:

1. Increases in the land-sea surface temperature gradient?
2. Increased sea-level pressure gradient between the ocean and land?
3. Consistent intensification of upwelling-favorable winds in summer?
Land-sea temperature differences do, indeed, increase
Land-sea temperature differences do, indeed, increase.
However, continental SLP does not uniformly decrease

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

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

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

<table>
<thead>
<tr>
<th>Region</th>
<th>Complete region</th>
<th>Poleward portion</th>
<th>Equatorward portion</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>-8% (±10 s.d.)</td>
<td>-2% (±18 s.d.)</td>
<td>-13% (±10 s.d.)</td>
</tr>
<tr>
<td>Canary</td>
<td>10% (±10 s.d.)</td>
<td>26% (±18 s.d.)</td>
<td>2% (±11 s.d.)</td>
</tr>
<tr>
<td>Humboldt</td>
<td>10% (±12 s.d.)</td>
<td>47% (±34 s.d.)</td>
<td>-9% (±9 s.d.)</td>
</tr>
<tr>
<td>Benguela</td>
<td>1% (±7 s.d.)</td>
<td>9% (±10 s.d.)</td>
<td>-6% (±9 s.d.)</td>
</tr>
</tbody>
</table>

Rykaczewski et al. (2015)
Poleward shifts in high-pressure systems are dominant over land-sea temperature gradients.
Projected changes are not limited to the summer seasons

In the eastern North Pacific, springtime upwelling winds (March-April) are projected to intensify in north of Point Conception but weaken in summer in the equatorward portion of the domain.
Projected changes are not limited to the summer season.

Increased upwelling in poleward portions of the regions

California
Canary
Humboldt
Benguela

Rykaczewski et al. (2015)
Analysis of the CESM-LE substantiates the latitudinal and seasonal dependency of projected changes in the California Current

There is evidence of future changes in upwelling associated with RCP 8.5 anthropogenic climate forcing.

However, the changes are subtle and not evident (anywhere along the coast) until the latter half of the century.

Brady et al. (2017)
What physical processes can conceivably alter the supply of macronutrients to upwelling ecosystems in response to anthropogenic global warming?

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3) Changes in the nutrient concentrations in source waters.
   A. Change in concentration within a source-water mass
   B. Change in the relative contributions of different water masses to the region

4) Changes in the frequency or intensity of variability or extreme events.
1) Intensification of upwelling-favorable winds is NOT clearly projected for the California Current.

2) Model projections suggest that upwelling-favorable winds may intensify in the poleward portions of upwelling systems but weaken in equatorward portions for those systems.

3) Resolution of global models remains rather coarse to properly resolve coastal winds. Additionally, poor representation of marine stratus clouds may further bias coastal temperatures and winds.
Thanks for your attention!