Anticipated Effects of Climate Change on Coastal Upwelling Ecosystems

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Current Climate Change Reports (2015)

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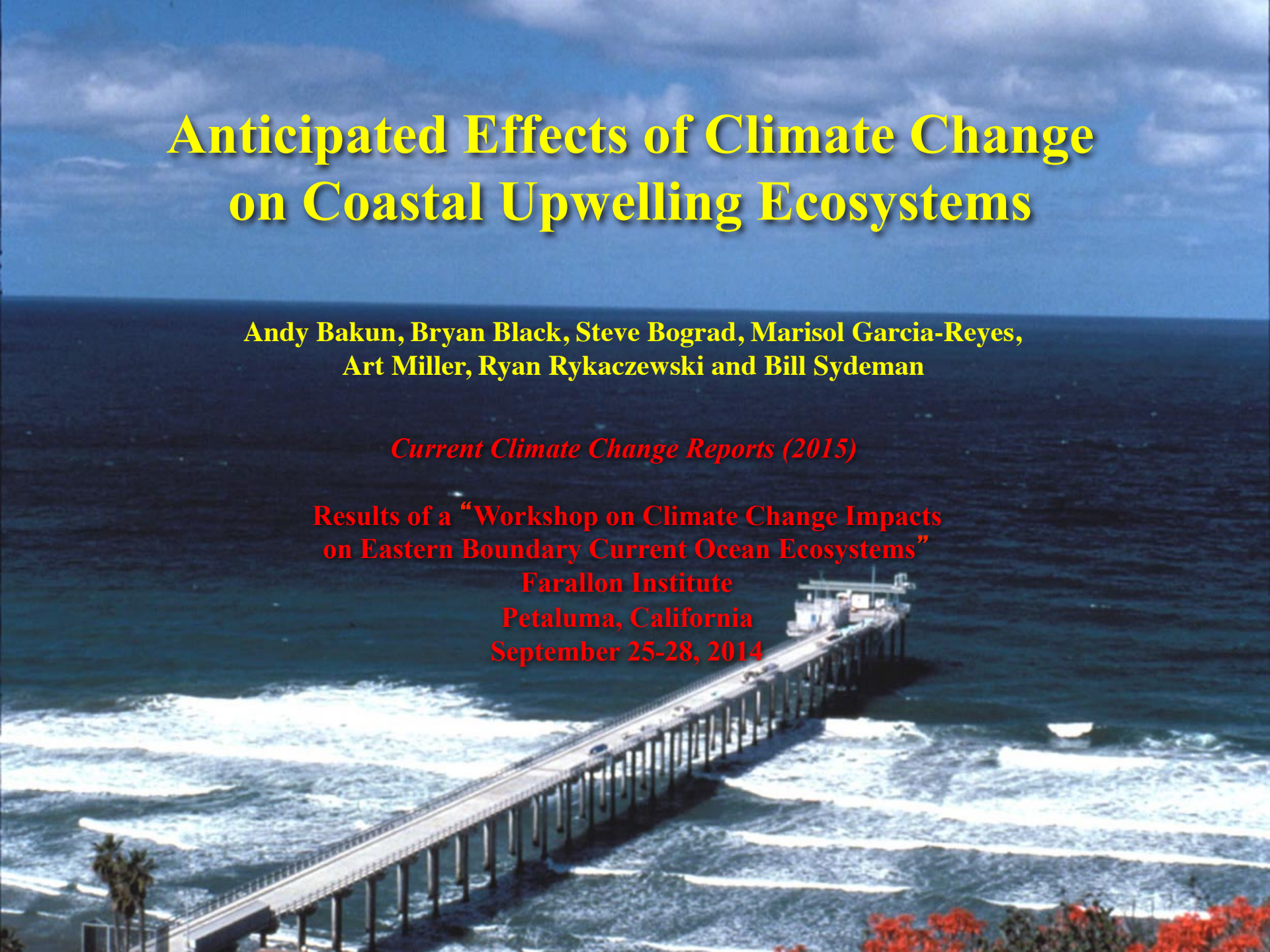
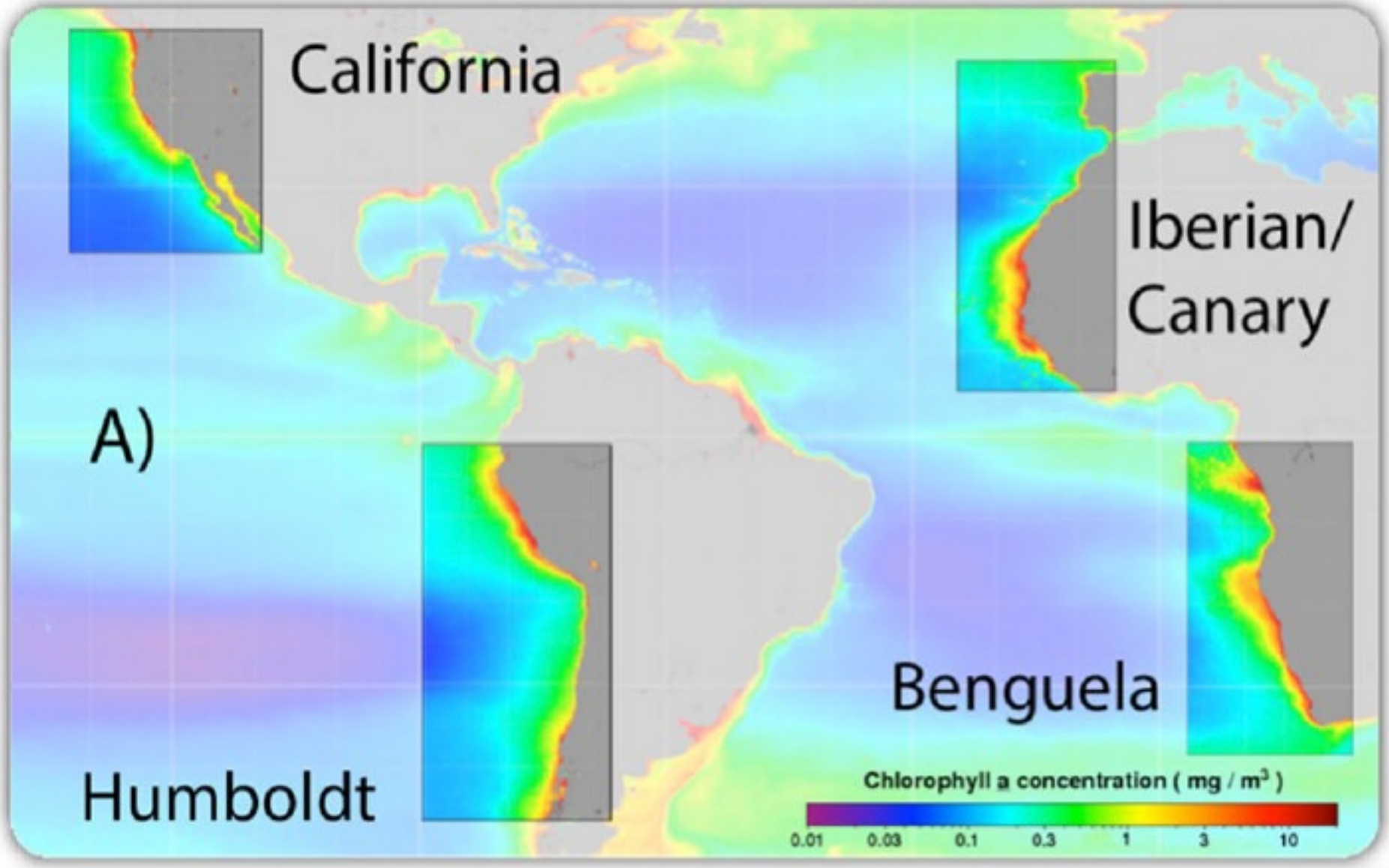


Global chlorophyll-a annual average concentrations and the locations of major coastal upwelling zones



General Considerations

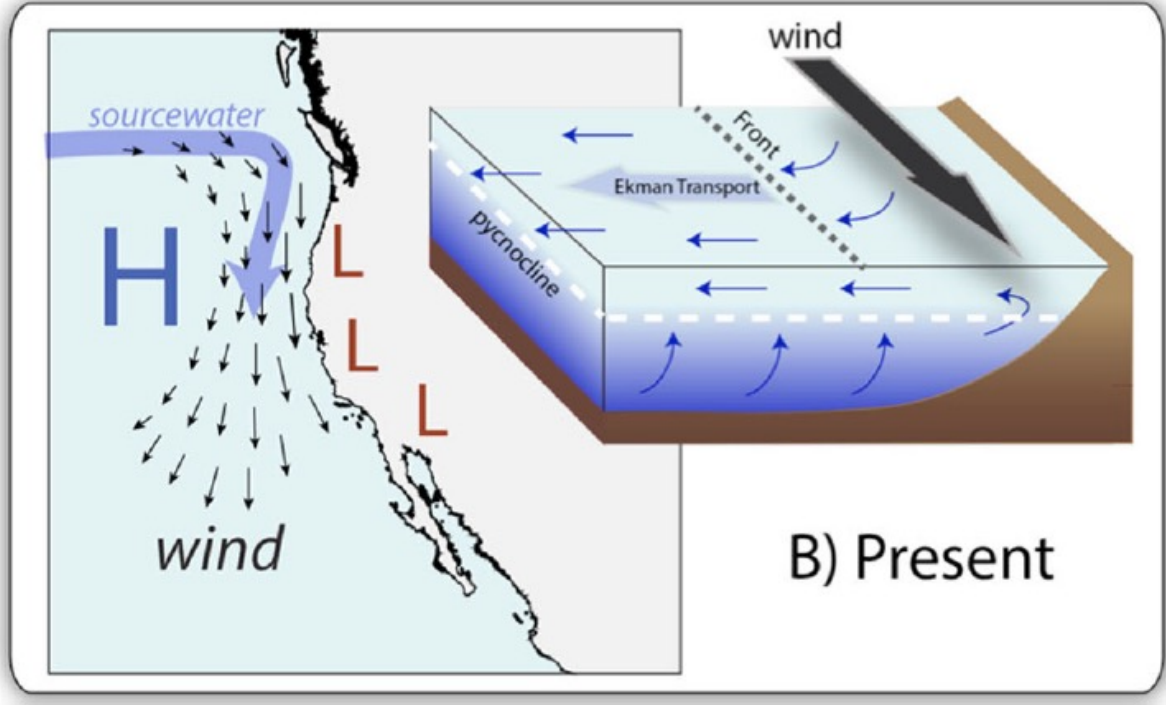
- GCMs forced by increasing greenhouse gas concentrations clearly show warming in the lower troposphere with impacts on surface land and ocean temperatures
- Beyond the direct consequences of increasing global ocean temperatures (e.g., increased ocean stratification, altered pathways of subduction, etc.), local-to-regional responses in EBUS temperature fields are likely to show extensive spatial variations due to changing wind distributions and consequential impacts on coastal and offshore upwelling.

General Considerations

- Spatial or temporal (phenological) mismatch between production and consumption
- Changes in composition or intensity of primary productivity with direct trophic linkages to and subsequent changes in community composition of heterotrophs
- Redistribution of populations through habitat changes
- Geochemical impacts on biology via noxious gas, acidification, and lack of oxygen.

- GCM predictions indicate that the **Hadley Cells** that influence the distribution of the pressure systems that force upwelling-favorable winds will be altered in both latitudinal extent and intensity
- The Hadley Cells are predicted to **expand poleward** in both hemispheres suggesting that the regional EBUS may expand poleward in both hemispheres.
- Due to the **asymmetric response** of surface temperatures in the northern (more land) and southern (less land) mid-latitude oceans, combined with tropical warming, the Northern Hemisphere Hadley Cell is predicted to **decrease in intensity** while that of the Southern Hemisphere will **increase in**

- Local thermodynamic arguments suggest that regional upwelling winds in the EBUS may increase due to increased land-sea temperature contrast (**Bakun Hypothesis**)
- Under global warming, continental temperatures will rise faster during the local heating seasons than will temperatures in the nearby ocean, thereby **steepening the cross-shore pressure gradients** that drive upwelling-favorable winds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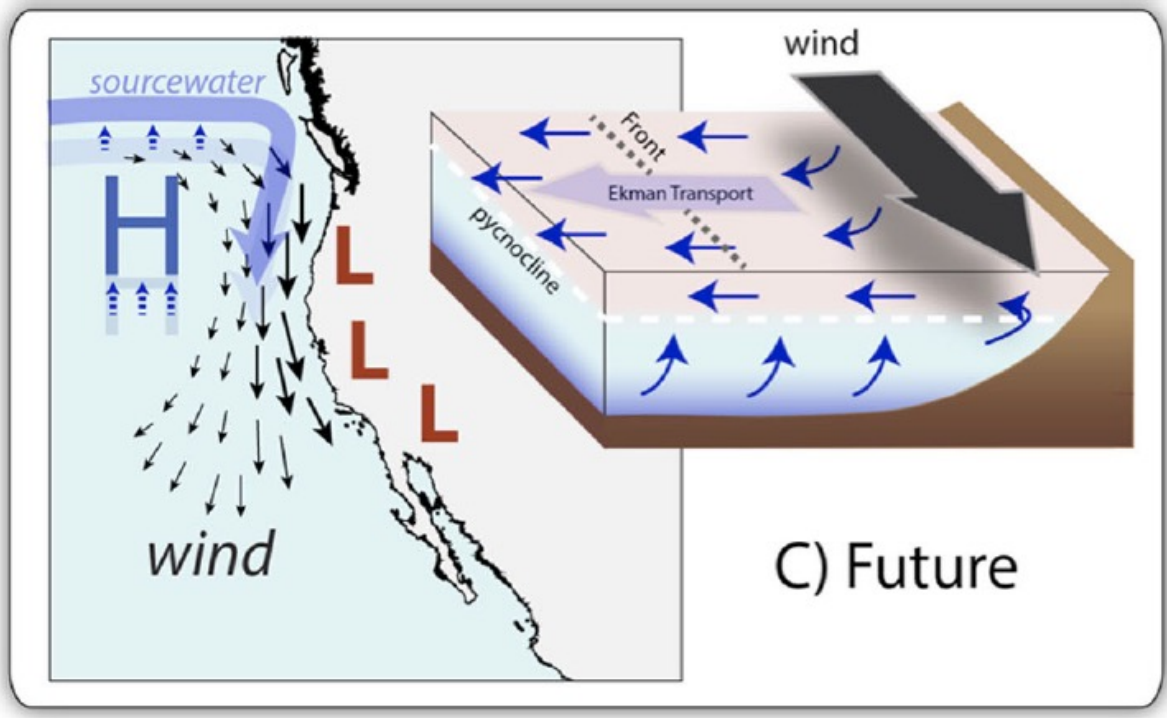
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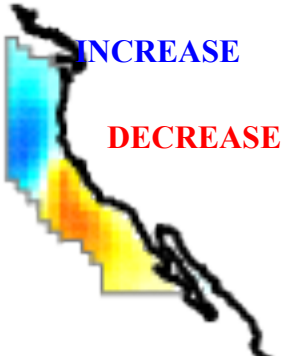
C) Future

- Sydeman et al. (2014) **meta-analysis**: “confirms” general pattern of positive trends in upwelling-favorable wind intensity in a majority of upwelling regions (California, Benguela, and Humboldt) during past decades
- IPCC **Models** do not show this consensus

Projections for the CCS under global warming scenarios

- Bakun (1990) suggested an increased land-sea temperature gradient would enhance coastal upwelling: **Rykaczewski** (in prep, 2014) shows it is not so simple…

Change in alongshore Wind Stress: 21st – 20th century



Projected responses of alongshore winds do not confirm Bakun's (1990) predictions.

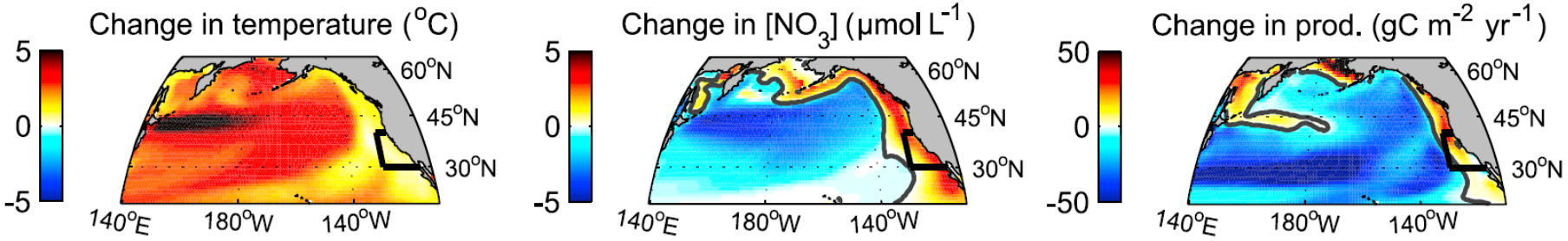
Multi-model comparison does, however, demonstrate some consistent responses when examining seasonal and latitudinal trends across the four upwelling systems.

Biophysical Responses

- Physiology and Habitat
- Enhanced Coastal Upwelling
- Enhanced Offshore Transport
- Changes in Ocean Vertical Structure
- Remote Changes: Surface waters (higher lats) and Upwelling Source Waters (nutrients, pH, O2)

Projections for the CCS under global warming scenarios

- **Rykaczewski and Dunne** (2010) showed that general warming of the North Pacific in the 21st century can enhance nutrients and phytoplankton in the CCS due to deeper, richer source waters of upwelling



Biophysical Responses

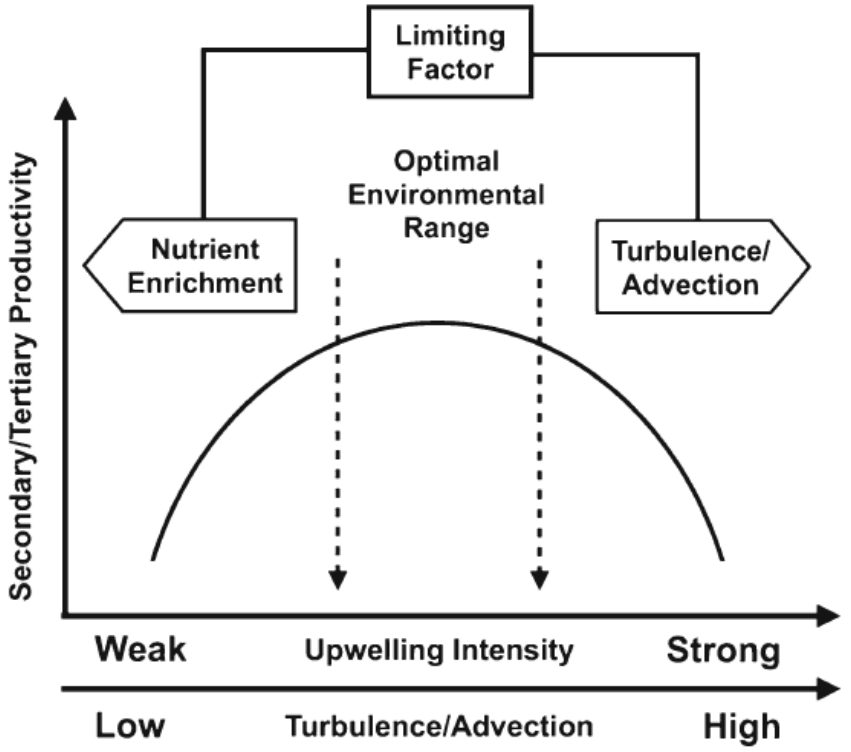
- Enhanced stratification and reduced ventilation: Shoaling of **oxygen minimum** zones
- Enhanced **productivity** and increased respiration: Hypoxia and Dead Zones, and Acidification
- **Anoxic** zones: Methane (CH4) bubbles can collect poisonous hydrogen sulfide gas (H2S) leading to massive eruptions
- **Reduction in pH** via the dissolution of CO2 into seawater: Increasingly difficult for important lower trophic level marine organisms, e.g. oysters and pteropods, to

Trophic Interactions, Match-Mismatch, and Phenological Responses

- Changes in the **timing** and **amplitude** of coastal upwelling
- In the CCS in 2005 a significant **delay in the spring transition** appears to have led to ecosystem changes affecting primary production, to zooplankton, to fish, birds, and mammals

Upper Trophic Responses

- Commercially Important Fish Populations
- Dominated by small pelagics, controlled by **Optimal Environmental Window**



Upper Trophic Responses

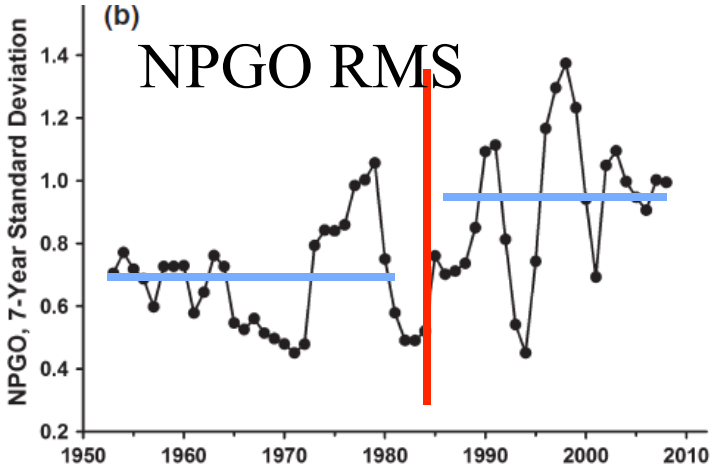
- Best fish production occurs when the **timing or spatial distribution of prey** is well-matched to the ecological needs of the fish: Match-Mismatch Hypothesis
- **Fixed** haulouts and nesting grounds: Changing ocean production and timing may be difficult to deal with

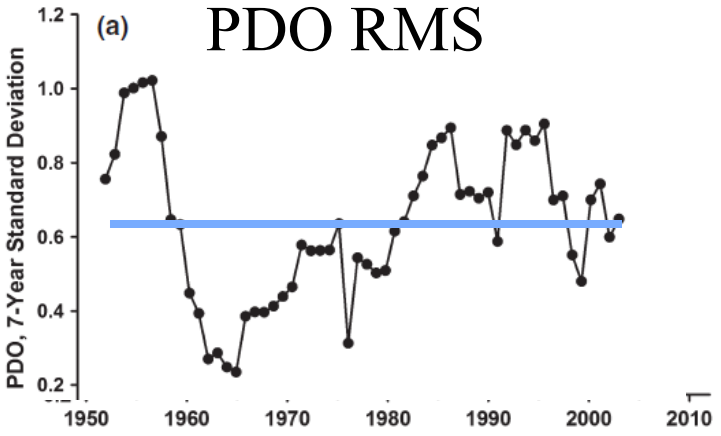
Ecosystem Variability

- EBUS are known to be **highly variable** across a wide spectrum of spatial and temporal scales, in both the forcing and response of the system.
- EBUS can therefore be characterized as both **resilient** (quick recovery from disturbances) and **robust** (maintenance of ecosystem function and relatively high productivity) to natural climate variability
- However, the **scale of future responses** to anthropogenic climate change may be beyond the historical scales of variability

Projections for the CCS under global warming scenarios

- Furtado et al. (2011) examined AL/PDO and NPO/NPGO statistics in the AR4 future climate model projections: No significant changes in space-time statistics
- Sydeman et al. (2013) suggest a significant change in NPGO variance occurred in the observational record (not so for PDO or ENSO) after 1985, which may be associated with increase variance in ocean biology



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Thanks!