Initial implementation plan for CLIVAR biophysics and upwelling research focus

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Background:

Eastern boundary upwelling systems (EBUS) cover less than 3% of the world ocean surface yet they have a significant role in the climate system (Large and Danabasoglu, 2006), and are home to the largest contribution of ocean biological productivity with up to 40% of the reported global fish catch (FAO, 2004; Pauly and Christiansen, 1995). Coupled with the vast coastal human populations, these regions play key biological and socio-economical roles. There are common features to eastern boundary upwelling regions: wind-driven flows, alongshore currents, steep shelves and large vertical and offshore nutrient transports. Despite the commonality, each of the main upwelling systems (California, Humboldt and Benguela Current Systmes), exhibits substantial differences in primary productivity, phytoplankton biomass, and community structures. The reasons for these differences are not fully understood.

Many coupled climate models generate very large SST biases in the coastal upwelling regions of the California Current System (CCS), the Humboldt Current system (HCS) and the Benguela Current System (BCS), where simulated mean SSTs are much warmer than observed (typically in excess of 3°C and as high as 10^{oC}C). Furthermore, these SST biases have significant remote effects on surface and subsurface temperature and salinity, and on precipitation and hence atmospheric heating and circulation (Collins et al. 2006). Large and Danabasoglu (2006) showed, in particular, with observed SSTs imposed along the BCS coast in an otherwise freely-evolving CCSM3 simulation there are significant improvements in precipitation in the western Indian Ocean, over the African continent and across the Equatorial Atlantic. Imposed SSTs along the HCS coast reduce precipitation in the so-called double ITCZ region of the south tropical Pacific. The warm temperature biases associated with EBUS strongly limit the prediction of future evolution of these regions. Increased model resolution improves simulations of the regional climate and affects the large-scale climate system through feedbacks (Large and Danabasoglu, 2006; Curchitser et al., 2011). Basin-scale physics must also be considered to understand regional upwelling variability (Rykaczewski and Dunne, 2010).

For the biogeochemistry, the rate and duration of upwelling influence the amount of biological production, hypoxia and pH levels. Upwelling rate determines the phytoplankton cell size (Van der Lingen et al., 2011); small phytoplankton dominate when the upwelling rate is extreme, resulting in extra trophic levels between the algae and fish, which reduces fish production. In contrast, large-sized phytoplankton dominate under moderate upwelling and production can be transferred more efficiently to fish via large zooplankton grazers. Further, upwelling rate may determine the plankton and fish community structure, given that different fish species are better suited to preying upon plankton of different sizes (van der Lingen et al., 2006).

The impacts of climate-scale variability on fish resources have recently become widely accepted (e.g., Lehodey et al. 2006; Parrish et al. 2000). One of the most compelling examples of climate-driven fish stock changes is the fluctuations of sardines and anchovies described since the early 1980s, the so-called Regime Problem (Lluch-Belda et al. 1989, 1992; Schwartzlose et al. 1999). Landings of sardines show synchronous variations off Japan, California, Peru, and Chile, with populations flourishing for 20 to 30 years and then practically disappearing for similar durations. Periods of low sardine abundance have coincided with increases in anchovy populations. Benguela Current sardine and anchovies in the Atlantic Ocean appear to be in synchrony with Pacific stocks, but in opposite phase. As demonstrated through paleo-reconstructions (Baumgartner et al. 1992), and because synchrony takes place despite different fishery management schemes (Schwartzlose et al. 1999), fluctuations appear to be fishery-independent. Furthermore, because of the large spatial and coherent temporal scales involved, a single global driver linked to large-scale atmospheric or oceanic forcing has been proposed to explain the variations across the different systems (Bakun 1996). Synthesis from fish catch series, has been related to the low-frequency component of different climate series, including the PDO and the NAO (Chavez et al. 2003) and to the low-frequency signature in global ocean temperature (Tourre et al. 2007). What remains elusive is a mechanistic basis for how the physics, biogeochemistry, and biology combine to result in the various patterns of synchronous variability across widely separated systems.

Beyond model biases and incomplete understanding of bio-physical interactions, a major current issue is anthropogenic climate change. Projected increased winds under climate change in EBUS could result in increased upwelling (Bakun, 1990) but global warming should strengthen thermal stratification and cause a deepening of the thermocline and reduce upwelling (Bopp et al., 2005). Recent observational evidence in different regions have shown increases (Bakun, 1990; McGregor et al., 2007; Narayanan et al., 2010; Blamey et al. 2012), decreases (Gomez-Gesteira et al., 2008) or no change (Demarcq, 2009) in upwelling intensity. The upwelling response depends on the interactions between land, atmospheric structures and the ocean. Further work on the upwelling trends under climate change is needed to determine the balance between cooling due to increased upwelling (where it exists) and warming due to climate change as how the rate, duration and seasonality of upwelling, and hence fisheries, will be affected.

Objective:

Given recent advances in atmosphere, ocean and biogeochemical models and observations, it is timely to re-visit the physical and biological science of EBUS and develop research recommendations for modelling and observations and to improve quantification of the potential for ecosystem changes under climate change and the effects on their dependent societies.

Improving upon the coastal upwelling-related biases in the climate model will require a more realistic representation of the physics of the eastern boundary regions. The dynamics in coastal upwelling regions exhibit a range of phenomena from well-understood Ekman divergence (Feduriuk and Allen, 1995) to complex instabilities in meso- and sub-mesoscale flows (e.g., Capet et al., 2008) and distinct linear and non-linear flow regimes (Springer et al., 2009). In a study of the California upwelling system, Marchesiello et al. (2003) conclude that the CCS is strongly shaped by oceanic intrinsic variability in response to the large-scale wind forcing with an equilibrium solution that exhibits eddies, fronts, jets and filaments. In a more recent study, Pringle and Dever (2009) suggest that the depth of the origins of the upwelled waters, and therefore its temperature, is controlled by the along-isobath pressure gradient and thus by large-scale dynamics.

Globally, the oceanic uptake of anthropogenic CO2 is estimated as ~2 Pg C year-1 (Takahashi et al., 2002; Sabine et al., 2004; Fletcher et al., 2006). These global ocean estimates have not fully accounted for carbon fluxes on the continental margins where dynamics, biological processes, sediment-water interactions terrestrial inputs and human-induced perturbations complex. The importance of the continental margins in the global carbon budget has been repeatedly pointed out though their role as either a source or sink of CO2 is yet to be quantified (Thomas et al., 2004; Chen, 2004; Bates, 2006; Jahnke, 2009; Cai et al., 2006).

Study topcis:

Potential topics to be addressed by a CLIVAR group are:

1. On the role of coastal upwelling regions in the climate system:
    i. What are the dynamical mechanisms linking the upwelling regions with the large-scale climate patterns.
    ii. What are the effects of upwelling on the regional and global air temperatures, precipitation and wind patterns.
    iii. How will these patterns evolve in response to future climate change.
    iv. How does a more accurate representation of coastal upwelling in climate simulations improve existing regional and global biases such as in SST and precipitation.

2. On the role of coastal upwelling systems in regulating biogeochemical processes:
    i. What are key physical and biological processes controlling air-sea CO2 flux and carbon export in the eastern boundary upwelling systems.
    ii. What are the relative contributions of regional biological productivity and basin-wide circulation to the extent and intensity of oxygen minimum zones in these systems.
    iii. How will the natural and anthropogenic factors change the carbon cycle and ocean acidity in the eastern boundary upwelling regions.
    iv. What is the sensitivity of the oxygen minimum zones to climate variability and to future global warming scenarios.

3. On the climate and fisheries connection leading to synchronous low-frequency fluctuations of fish populations:
    i. What is the source of upwelled waters and nutrients.
    ii. Air/sea conditions leading to sardine/anchovy dominance.
    iii. Mixing rates versus stratification (size of particles eaten by fish).
    iv. What physical processes affects the survival of fish eggs.
    v. How will fish populations respond to climate change.

The next steps:

The study topics outlined above are necessarily broad. We propose to convene a targeted workshop inviting ocean, atmosphere, and ecosystem scientists to both narrow and fine-tune study topics for a research plan to be fulfilled in the 3-5 year timeframe. The group should consist of physicists, biologists, modelers and observationalists. An enthusiastic group in the upwelling break out session during the Pan-CLIVAR meeting in The Hague this past summer started the conversation for potential targets, with the topic of the roles of mesoscale variability emerging often in the discussion (e.g., role of eddies in the coastal-basin exchange, role of eddies in heat budgets of upwelling zones, role of eddies in air-sea interactions). The main outcomes of the workshop should be to:

1. Develop the study topics in detail
2. Review the state-of-the-science related to outcome (1)
3. Produce a white paper related to (2)

Based on the outcome of the workshop we will then propose a panel to continue the work assembling the correct mix of scientists to carry out the objectives of this research theme.

Confirmed participation:

Annalisa Bracco, Gokahn Danabasoglu, Enrique Curchitser, Ryan Rukaczewski, Paquita Zuidema, Jack Barth, Art Miller, Riccardo Farneti, Emin Ozsoy, Alban Lazar, Thomas Toniazzo, Carl Van der Lingen, Antonio Bode, Colleen Moloney, Reuben Escribano.

Format:

We have 15 confirmed participants for the 1.5 day meeting. We would like to spend most of the time in discussion and perhaps some writing. Thus we suggest for each participant to prepare a short presentation of 10-15 minutes highlighting:

1. Their previous interest/work in upwelling regions
2. State-of-the-science in their topic of interest /important papers
3. Outstanding scientific questions
4. Vision for possible way forward (i.e., data and model needs, comparative studies, etc.)

We can spend Friday morning with the presentations, the afternoon in discussions and hopefully Saturday morning writing outlines.