CLIVAR Tiger Team 4

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1. TITLE: Marine biophysical interactions and the dynamics of upwelling systems

2. DESCRIPTION:

Upwelling regions of the oceans are the most productive fisheries areas in the world. For example, approximately 7% of primary production and 20% of the total global marine fish catches come from eastern boundary upwelling areas alone but occupy <2% of the total ocean area (Pauly and Christensen, 1995). These include the Humboldt Current off Peru, the California Current, the Northeast Atlantic off the Iberian Peninsula and NW Africa, and the Benguela Current off southern Africa. They are examples of coastal upwelling driven by wind-induced Ekman divergence against a coastline. Upwelling favourable winds force warmer near surface waters offshore to be replaced by colder, lower oxygenated, high nutrient rich waters. This often results in high primary production and sometimes in hypoxia (Chan et al., 2008). Wind-induced upwelling also occurs around Antarctica owing to the mean anticyclonic winds. However, many other types of upwelling systems exist. Upwelling occurs in western boundary currents, e.g. the Kuroshio, the Gulf Stream, the Agulhas Current, and the East Australian Current. These currents, being in approximate geostrophic balance, have a strong tilt in the density surfaces, and subsequently the thermocline, upwards towards the shelf. Velocity changes in the currents lead to variability in the thermocline depth and can bring cold nutrient-rich water onto the shelf. This is called dynamic uplift. Likewise, an eddy that bumps up against the shelf can also lift the thermocline up and onto the shelf. Upwelling also occurs along the equator owing to the trade winds, coupled with the change in the sign of the Coriolis force across the Equator. This upwelling leads to increased phytoplankton production around the equator that is clearly seen in satellite imagery. Seasonal upwelling, owing to reversal of winds such as caused by monsoons, are also important in regions such as the Arabian Sea and the Bay of Bengal.

Upwelling systems typically are poorly represented in global models owing to their relatively small spatial scales, resulting in warm temperature biases in these regions. Large and Danabasoglu (2006) suggested that better resolution of the subtropical eastern boundary regimes in global climate models produces better simulations of the regional climate and through feedbacks affect the large-scale climate system. Merging a regional climate model into a global model, Curchister et al. (2011) were able to show much reduced biases. Studying the California Current systems they also revealed far-field effects from the upwelling, even stretching into the North Atlantic Ocean. Conversely, Rykaczewski and Dunne (2010) showed the importance of considering basin-scale physics in understanding regional upwelling dynamics. Even if the ocean models were able to produce the 'correct' amount of upwelling, the characteristics of upwelling water masses can be wrong. This can be a result of problems with the oceans interior circulation, the upwelled water masses including their dissolved oxygen and nutrient concentrations, and/or stratification. Remote forcing can also influence the amount of upwelling and may explain differences between upwelling regions under similar local forcing (Richter et al., 2010).

The rate and duration of upwelling influences the amount of biological production as well as the occurrence of hypoxia. The upwelling rate determines the phytoplankton cell size, with small phytoplankton dominating when the upwelling rate is too high or too low. Nutrient stoichiometry of the upwelled water can also impact cell size, e.g., upwelling in high nutrient, low chlorophyll regions are dominated by small cells due to iron limitation. Small cells result in reduced production of fish since small phytoplankton production is mainly channeled through a microbial food web before reaching fish. This adds extra trophic levels between the algae and the fish, and subsequently a loss of energy. On the other hand, with a moderate rate of upwelling, large size phytoplankton dominate and production can be transferred more directly to fish via large zooplankton grazers (e.g. Van der Lingen et al. 2011). This leads to a more efficient energy transfer and higher fish production. Thus knowledge of the mechanisms controlling the rate and duration of upwelling is important for understanding the fish production.

Current global and regional biophysical models have focused mainly on the physics and the lower trophic levels, i.e. phytoplankton and zooplankton. Efforts to extend regional models to higher tropic levels, e.g. fish, are making progress but few of these have focused on upwelling regions. While including fish in such models greatly increases their complexity, such models are progressing and offer great potential for progress in terms of our ecosystem understanding. Greater efforts are needed to apply such models in upwelling regions. The wasp-waist ecosystem control model has been assumed to be present in all upwelling ecosystems, and be different than other systems (Cury et al., 2000). This model states that an intermediate trophic level (such as sardines or anchovies) controls the abundance of predators through a bottom-up interaction and the abundance of prey through a top-down interaction However, this assumption is now being questioned (Madigan et al., 2012). Resolving this issue will be important for developing end-to-end ecosystem models of upwelling regions. Fisheries in eastern boundary upwelling systems (EBUS) are usually dominated by small pelagic schooling fish. Such regions are often characterized by the alternation of anchovy and sardine periods on the multi-decadal scale (Schwartzlose et al. 1999), e.g. in the Humboldt Current. Switching between these different production regimes has been traced back in California Current sediments for the last 2 millennia (Baumgartner et al. 1992). Climate-driven changes in basin-scale circulation seem to control zooplankton dynamics in the California Current (Keister et al. 2011) and there is evidence that the dynamics of sub-tropical and sub-polar gyres affect productivity regimes in other EBUS. Investigations are needed on spatial distribution of the productivity. For example, some of the upwelling-derived production is retained in coastal locations (such as the Southern California Bight or Vizcaino Bay in the California Coastal System, or Talcahuano in Humboldt). Little is known of the physical characteristics that lead to the high production in such areas, although higher retention is expected. The relative amount of production in such embayments compared to that offshore is unclear, as is the energy flow efficiency and total fish production in such areas.

One of the major issues of our day is anthropogenic climate change. Bakun (1990) proposed that increased winds under climate change will result in increased upwelling, a result supported by temperature data from the California Current system. Evidence for recent increased upwelling has also been found in other upwelling regions (e.g. McGregor et al., 2007; Narayanan et al., 2010) but decreased upwelling has occurred off the Canaries (Gomex-Gesteira et al., 2008) and no trend has been detected off Peru (Demarcq, 2009). 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.

3. THE MAJOR THEMES

Based on the above, the team will seek to address the following major questions.

- What controls interannual variability in upwelling systems?
- What is the interaction between upwelling and large-scale atmospheric climate systems?
- What is the role of upwelling systems in shaping mean biases in coupled climate models reducing predictability in those regions?
- What is the connection between large-scale climate indices (ENSO, PDO, NAO, AMO/AMV, etc.) and upwelling?
- How do climate and fisheries affect the ecological dynamics of upwelling ecosystems, including exploited species such as small pelagic fish? Can a better understanding be achieved to inform management and policy?
- What is the expected physical response in the upwelling areas under climate change?
- How will these changes affect plankton and fisheries production?

4. THE WAY FORWARD

In an attempt to address the above questions the team will organize and promote the following activities.

- Focused workshops to address one or more of these questions (Main activities)
- Theme sessions at international meetings
- Special issues in primary publications
- Encourage CLIVAR panels to hold meetings on issues related to upwelling

Such meetings should, where possible, include climatologists, physical oceanographers, biologists, and fisheries scientists.

As a first task, the team will develop short summary documents on both some of the major issues related to upwelling, with special emphasis on biophysical processes and gaps in our knowledge that have a fair success at being filled. Secondly, it should organize a workshop and due diligence exercise, which would consider links at the international level as well as national level, investigating what activities are already underway, and how a CLIVAR/IMBER collaboration could complement or add value to existing activities, or begin to fill some of the gaps. Such a workshop will be undertaken in 2014 at a location and time to be determined.

It was noted that the Indian Ocean Panel of CLIVAR and the SIBER regional programme of IMBER have initiatives already to form an Eastern Indian Ocean Upwelling Research Initiative. The objective of this multi-disciplinary research initiative is to advance our understanding of the physical and biogeochemical/ecological variability in the eastern Indian Ocean associated with upwelling systems. Two international workshops are scheduled in 2013, one that took place in April at JAMSTEC in Japan, and the other to take place in November at the First Institute of Oceanography in Qingdao, China, to develop the Science Plan and Implementation Strategy. Also, a proposal for a workshop as part of the IMBER Open Science Meeting to be held in Bergen at the end of June 2014 has been submitted.

5. KNOWLEDGE EXCHANGE

Knowledge exchange will primarily be in the form of workshops and their reports, articles in Exchanges, IMBER updates and other relevant newsletters, dedicated webpages, review papers, peer-reviewed papers, and media outlets.

6. CAPACITY BUILDING

In its early stages, capacity building will principally be in the form travel support for early career scientists and graduate students working on relevant topics, pending the necessary funding. Scientists from developing countries will especially be targeted. Depending on the success of the Team and the interest, dedicated workshops or summer schools aimed at training young scientists will be attempted. The focus of such activities should be on the interaction of physics and biology. Some of these might be undertaken by CLIVAR Panels in combination with IMBER Regional Programs, e.g. Indian Ocean Panel and SIBER.

7. COMMUNICATION CHALLENGES

Within this task team there are two main challenges. The first is unique to this team as it comprises two different scientific communities, CLIVAR and IMBER. The physicists and biologist need to familiarize themselves with the others language (so they are talking along similar lines and understand the other) and way of thinking. Second is the communicate of the issues and the teams results funding agencies, decision makers and the general public.

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