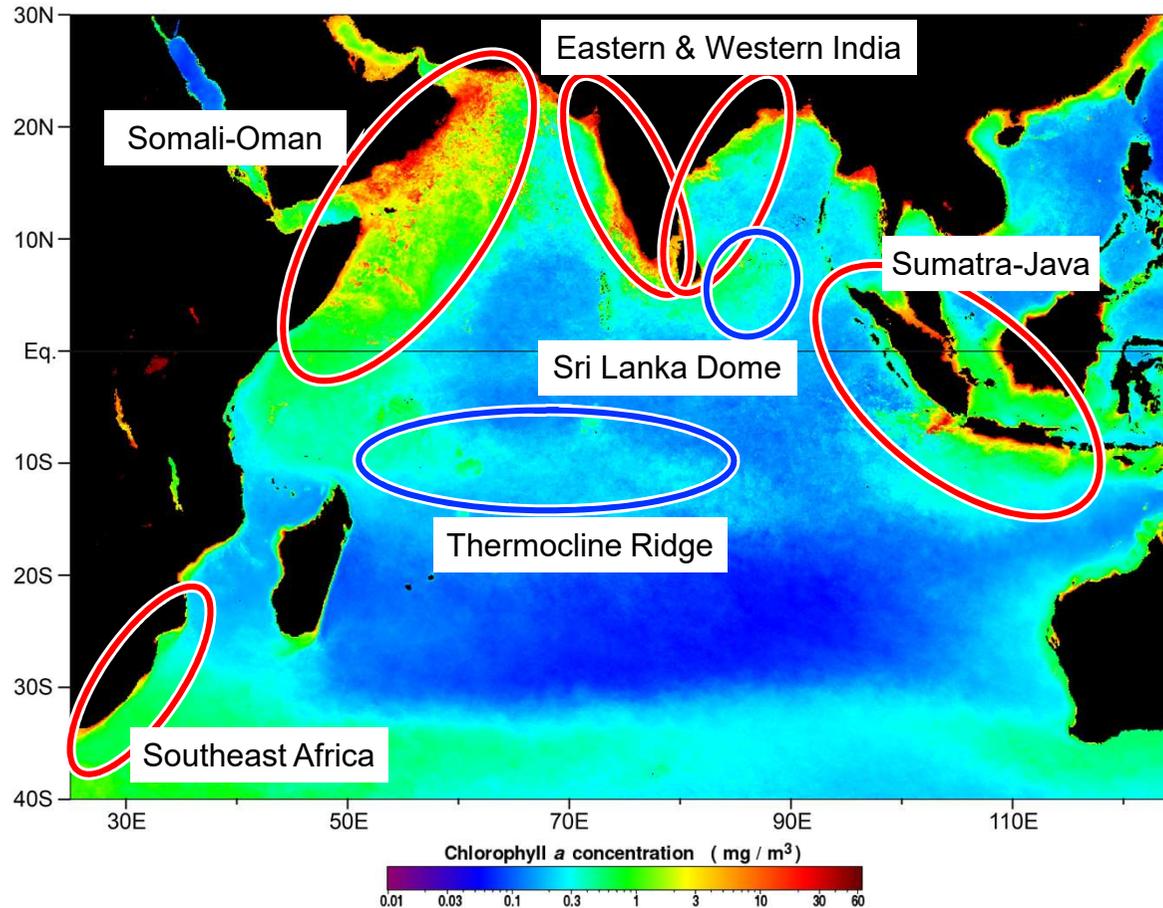


3. Upwelling, coastal-open ocean interactions, and ecosystems

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Upwelling in the Indian Ocean



Climatological distribution of Aqua MODIS Chlorophyll concentration in September. The major upwelling regions are indicated by higher chlorophyll concentration with green/orange color shade, except for regions very close to the coasts.

✓ Coastal Upwelling systems

- Somali-Oman
- Sumatra-Java
- Eastern & Western India
- Southeast Africa

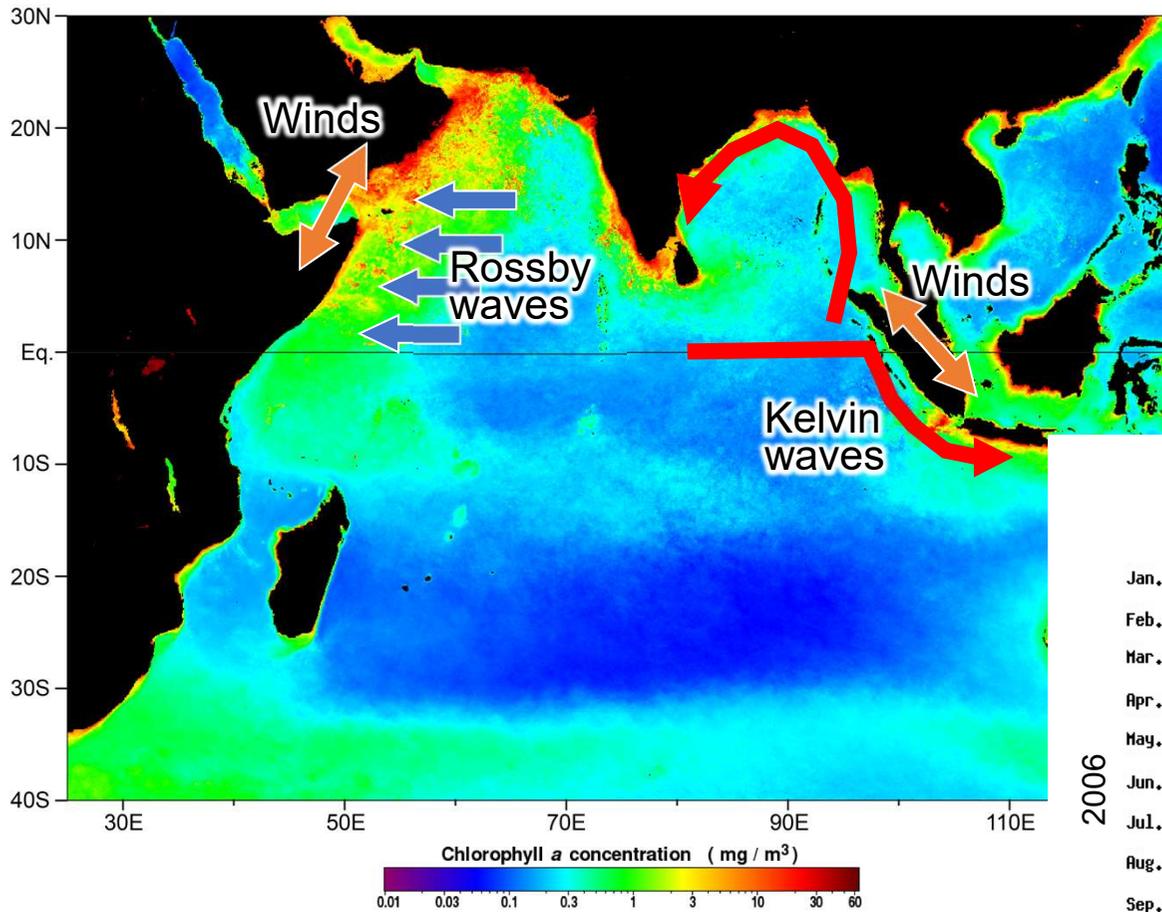
✓ Open Ocean Upwelling

- Thermocline Ridge
- Sri Lanka Dome

Roles of Upwelling

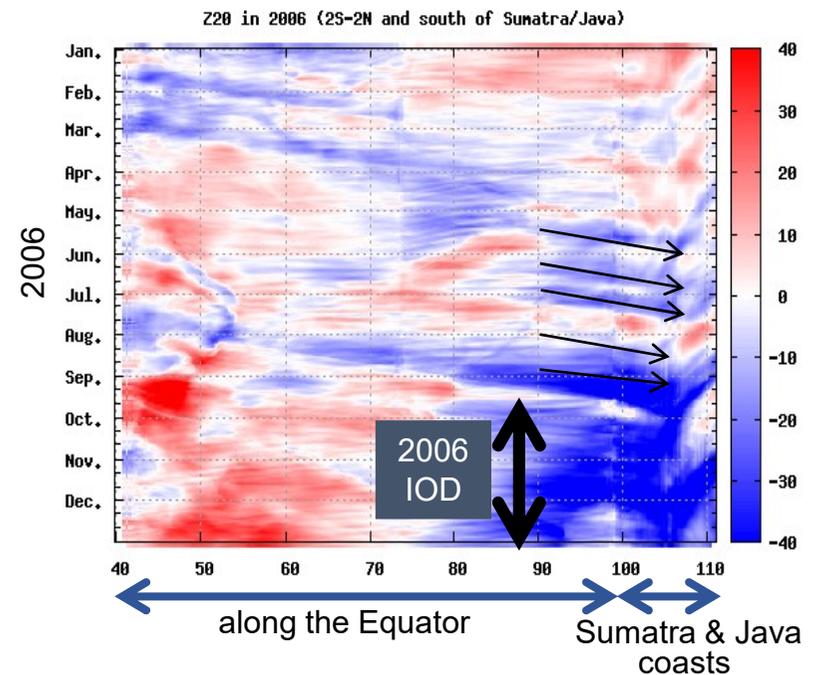
- ✓ Upwelling is a key process in three-dimensional ocean circulation, bringing cooler and nutrient rich water up into surface layer, thereby affecting weather and climate over the region through the surface temperature and marine food web and fishery activities via primary productivity.
- ✓ Upwelling zones are geographically confined, they represent ascending branches of basin scale circulation patterns such as the Subtropical Cell and Cross Equatorial Cell. Thus, the upwelling systems should also be considered in the basin scale context, in which they are embedded.
- ✓ Our understanding of the characteristics and mechanisms of the upwelling systems, their roles in larger systems in the ocean and climate, and their response to the climate system internal variability and anthropogenic forcing are very limited due mainly to scarcity of in situ observations both in physical and biogeochemical parameters.

Coastal upwelling variability

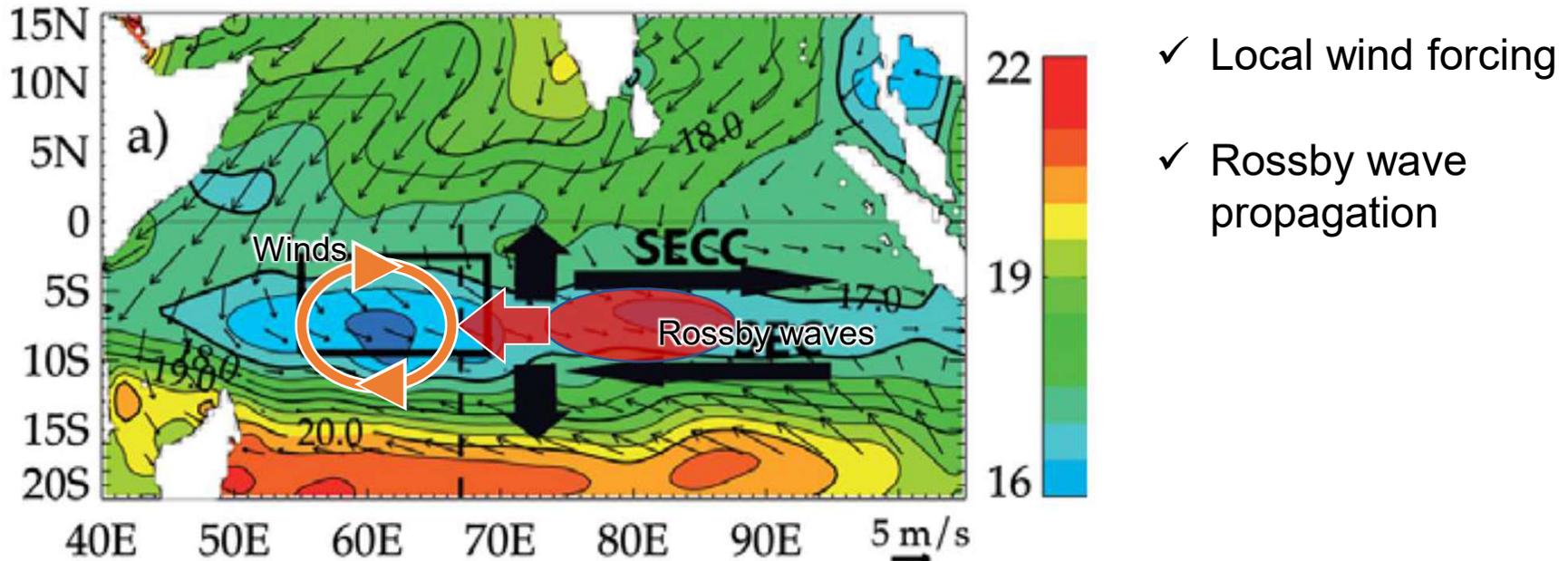


- ✓ Daily or shorter time scales
- ✓ Intraseasonal
- ✓ seasonal
- ✓ interannual
- ✓ Decadal or longer time scales

- ✓ Local wind forcing
- ✓ Kelvin wave propagation
- ✓ Rossby wave propagation



Open ocean upwelling variability



- ✓ Daily or shorter time scales
- ✓ Intraseasonal
- ✓ seasonal
- ✓ interannual
- ✓ Decadal or longer time scales

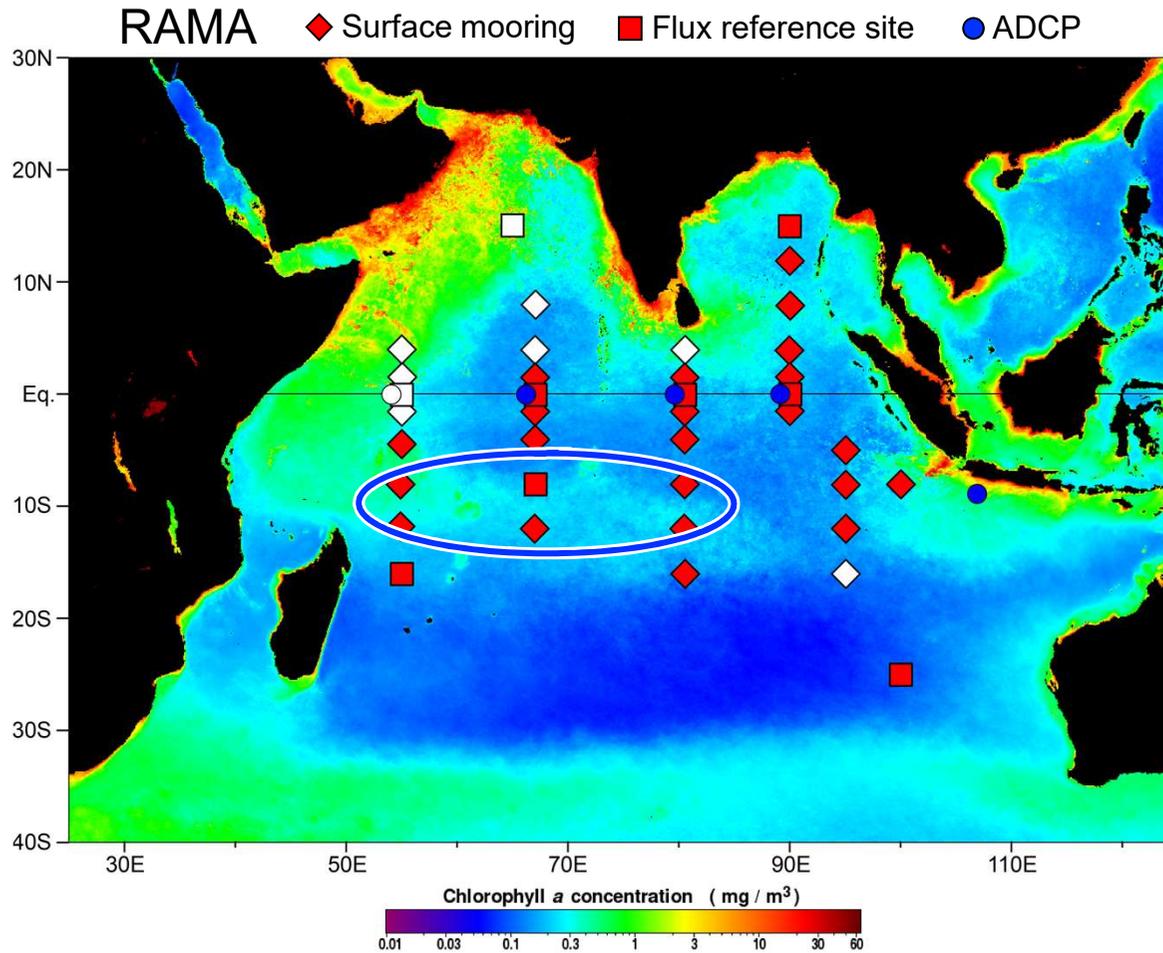
In both coastal and open ocean upwelling regions, multiscale dynamics and their implications for the biological, biochemical processes and fisheries resources have yet to be fully explored.

Physical-biological-biogeochemical interactions

- ✓ Diverse physical mechanisms in upwelling regions in the Indian Ocean lead to large uncertainties in the [sources and fluxes of nutrients](#) and their ecological and biogeochemical implications
(e.g., nitrogen fixation, subsurface plankton blooms, the oxygen minimum layer)
- ✓ Fundamental questions remain in the Indian Ocean regarding the impact of upwelling on [nutrient stoichiometry](#) (e.g., N, Si, and Fe), associated influence on nutrient limitation controls, and the subsequent species composition of upwelling-induced phytoplankton blooms.
- ✓ Enhancement and transport of [plankton production and distribution and variability of the plankton community](#), which has important implications for higher trophic levels and fisheries, are also affected by physical processes in the upwelling systems.

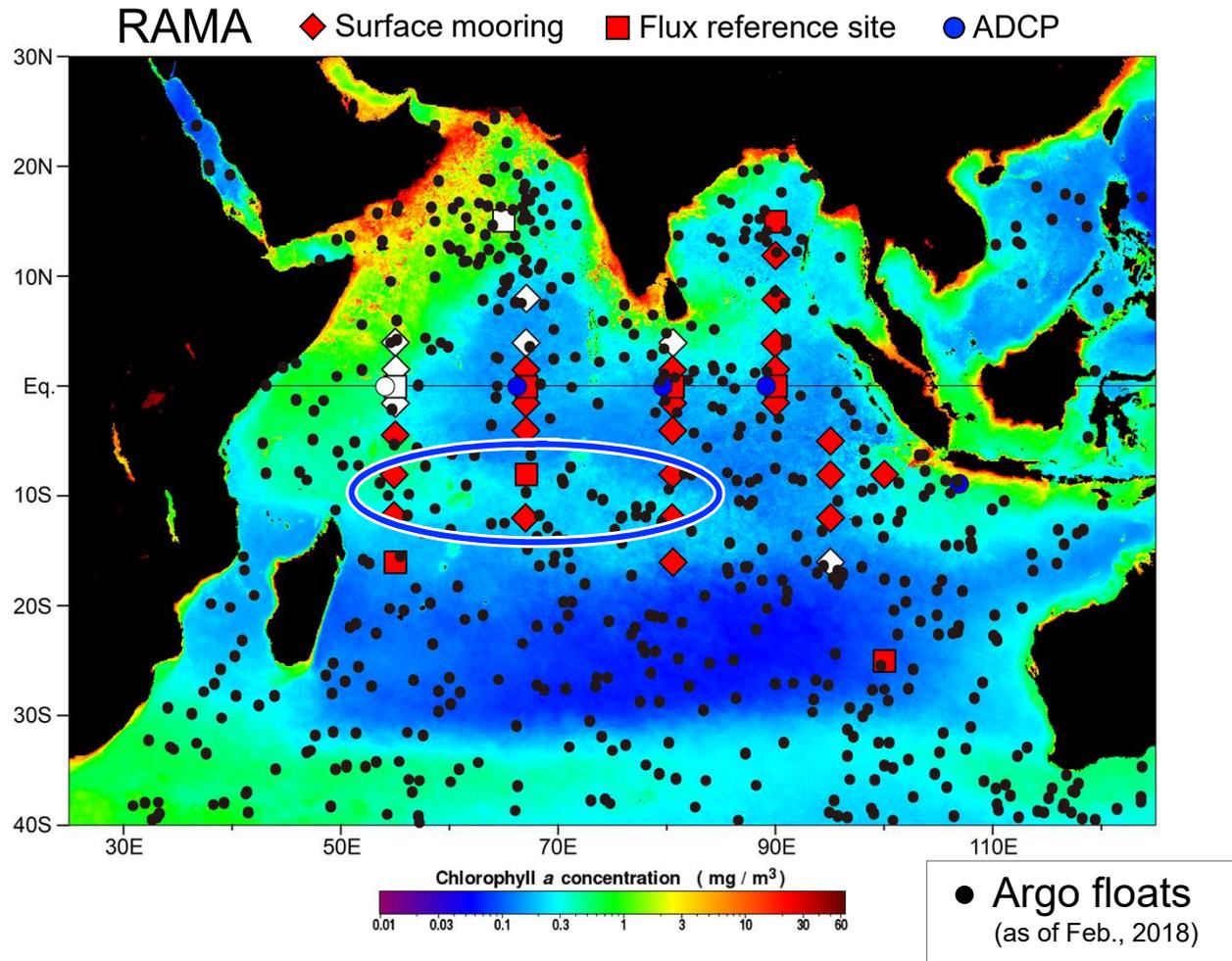
However, these parameters can only be obtained by ship-based measurements.

Upwelling and IndOOS



- ✓ Existing RAMA surface moorings cannot cover coastal upwelling regions
- ✓ Several moorings do cover thermocline ridge

Upwelling and IndOOS



- ✓ Existing RAMA surface moorings cannot cover coastal upwelling regions
- ✓ Several moorings do cover thermocline ridge
- ✓ Some Argo floats occupy upwelling regions, both coastal and open ocean

Moorings capture marine meteorological data as well and obtain data with very fine temporal resolution

Essential Ocean Variables

For upwelling studies, detailed structures of physical, biological and biogeochemical parameters with **temporal resolution high enough to resolve intraseasonal variability** are needed.

- ✓ A combination of moorings and frequent hydrographic observations along fixed sections for **temperature and salinity down to 1000 m** is required. **Argo floats** add data covering wider areas and complement the moorings and hydrographic observations. **Microstructure measurements** are also needed to evaluate vertical mixing processes.
- ✓ Distributions of biogeochemical and ecological parameters, such as **nutrients, chlorophyll, oxygen, pH, and CO₂**, along the transects across the upwelling regions would be required seasonally, hopefully as frequent as possible, with several locations measuring **plankton community structures**. **Bio-Argo floats** are a useful new platform for sustained observations of biogeochemical parameters as well as temperature and salinity profiles.
- ✓ **Satellite** data can cover **SST, ocean color, surface winds, and SSH**. **Tide gauge station** data is also needed to validate and complement the satellite SSH data.

Recommended actions

1. Continue RAMA array along 8°S and in the equatorial region to obtain temperature and salinity data in the thermocline ridge region and the equatorial wave guide
2. Conduct microstructure measurements in the upwelling regions to evaluate vertical mixing processes (e.g. 8°S, 65°E; Somali/Oman; Sumatra/Java)
3. Extend the IndOOS observing network in the eastern tropical basin into the Sumatra/Java upwelling region, by enhancing deployment of Argo and Bio-Argo floats and/or glider sections across the region.
4. Develop new observing platforms within the Somali/Oman upwelling region, hopefully new RAMA buoys, Bio-Argo deployment, and/or glider sections

These observations should focus on upwelling on intraseasonal to interannual time scales and phenomena responsible for mixed-layer processes and their interactions.