Boundary Currents: Progress and forward looking to OceanObs’19

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**Figure:** Conceptual global network of boundary current arrays. Send et al. (2010) Boundary Current white paper.
Why observe boundary currents (BCs)?

One of the important ways society experiences the changes in the global ocean is through the ocean’s boundaries.
Why observe western BCs (WBCs)?

Key drivers of climate variability
Meridional heat/freshwater transport
Surface and deep conduits for thermohaline circulation
Sea level variations

*Figure: Surface speeds from Global Drifter climatology. Color indicates orientation of meridional velocity (brown = northward, blue = southward).*
Why observe eastern BCs (EBCs)?

Societally relevant effects of climate
Upwelling, cross-shore exchange (nutrients, carbon)
Ecological hotspots
Equatorial interactions (ENSO-blob)
Oxygen minimum zones (OMZs)

**Figure:** Surface temperatures from RSS Combined Microwave for June-August 2015. Blue = cold SSTs, brown = warm SSTs.
Why observe low-latitude, high-latitude, marginal sea BCs?

**Low-latitude BCs**: equatorward mass and property flux, ENSO

**High-latitude BCs**: Water mass formation/transport, interbasin exchanges

**Marginal Sea BCs**: Coastal-open ocean exchange, water mass formation

*Figure: Pink = low-latitude BCs, yellow = high-latitude BCs, brown = interbasin exchange. Send et al. (2010) Boundary Current white paper.*
Where are BCs being observed?*
*List incomplete, a census is needed

<table>
<thead>
<tr>
<th>Subtropical WBCs</th>
<th>Subtropical EBCs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Atlantic:</strong> Gulf Stream, Florida C., Antilles C., Guiana C., North Brazil C., Brazil C., Malvinas C., DWBC</td>
<td><strong>Atlantic:</strong> Canary C., Guinea C., Angola C., Benguela C.</td>
</tr>
<tr>
<td><strong>Pacific:</strong> Oyashio C., Kuroshio C., East Australian C., East Auckland C.</td>
<td><strong>Pacific:</strong> California C., Peru-Humboldt C., Chile C.</td>
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<tr>
<td><strong>Indian:</strong> Somali C., Agulhas C.</td>
<td><strong>Indian:</strong> Leewin C.</td>
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**Low-latitude BCs:** Indonesian Throughflow, Mindanao C., New Guinea Coastal C., Solomon Sea

**High-latitude BCs:** Labrador C., E/W Greenland C., Norwegian C., East Iceland C., North Atlantic C., Alaska C., Antarctic Circumpolar C., Weddell Sea

**Marginal Sea BCs:** Mediterranean, Gulf of Mexico
Technology (*multidisciplinary)

Moored buoys (T, S, current meters, ADCPs, PIES, O2*, Carbon*, …)
Cabled observatories, integrated observational networks*
Research vessels*
Ship of opportunity program (XBTs, XCTDs, ADCPs)
Underwater autonomous gliders*
Argo profiling floats*
Surface drifting buoys
Sail drones*
Coastal HF-Radar
Satellites*
Blended *in situ*-satellite products

Some Examples…
(a subset)
Moored buoy arrays

OceanSITES

Overturning in the Subpolar North Atlantic

Southwest Atlantic MOC

Weddell Sea Transport Station

Agulhas System Climate Array
Cabled observatories, integrated observational networks

RAPID/MOCHA/WBTS/ABC

Kuroshio Extension

Moored Climate, Carbon, BGC, and Ecosystem, South California Current

Processes driving Exchange at Cape Hatteras
Research vessels, SOOP

GO-SHIP

XBT network

* : Boundary currents sampled by the HRX Network

Oleander Project

CalCOFI (hydrography, biology)

Drake Passage
Autonomous underwater gliders
OceanGliders boundary ocean observing network

California Underwater Glider Network
Glider Surveillance of Gulf Stream

Australia National Facility for Ocean Gliders

Giders in the Solomon Sea
Blended data, drifting buoys, saildrones

**XBT + Argo + altimetry (EAC)**

Global Drifter Program Climatology in Gulf Stream

SailDrones in Gulf of Mexico (shelf-slope interaction)

Zilberman et al. (sub)

Laurindo et al. (2017)
Towards integrated BC observing systems...

Focus topics identified at IMSOO meeting:

1. How ecosystem structure/dynamics in coastal ocean is affected by interannual variability of currents and water properties, including O$_2$/OMZs, pH/acidification (large-scale)

2. Cross-shore exchange between land, shelf and deep ocean (mesoscale)

3. Ecological hotspots, episodic (e.g. fronts, eddies, upwelling) and persistent (e.g. canyons, headlands, shelf break)

Implementation of Multi-Disciplinary Sustained Ocean Observations (IMSOO), Feb 2017
IMSOO phased approach

Update societal rationale for BC observation

Organize review of two BC observing systems (**short term**):

- California Current
- East Australian Current

Develop white papers for OceanObs’19 (**short term**)

Develop concept for “backbone” observing system (**mid term**)

Develop concept for “pilot flexible/re-locatable” observing systems (**long term**)

Do we want to identify additional long-term/mature observing systems to undergo similar process? (**if funds are available**).
Recommendations...

Census of BC observational networks (U.S. and international)

Fund a web designer to do survey and a postdoc (oceanography, social science) to analyze results. Results will be complex as not one-size-fits-all. Will need program managers to spread word to get high response rate. Need a companion model census.

Series of workshops to bring together diverse communities, foster collaboration

(1) Coastal-open ocean (GOOS-IOOS), (2) Observational-modeling, (3) Multi-disciplinary, or (4) Scientists-Stakeholders-Applications

Identify a few BC regions with long-term/mature observing systems to undergo a self-evaluation process (similar to IMSOO)

Need to have discussion about what is limiting growth/maturation of observing networks and get guidance from funding agencies on likelihood of future expansion/longevity of BC observational networks in those regions.
Informal summary of informal survey
Progress towards OceanObs’19

Has the global ocean boundary current network grown since OceanObs’09?

Yes. We are observing in some new boundary currents (e.g., Agulhas, East Australian Current, Solomon Sea, AMOC arrays). Many programs have now produced decadal time series. Increased use of glider arrays in some BCs. We’ve lost some observational programs (e.g., Line W, Drake Passage moored array).

Have we learned what are essential components of boundary current arrays?

Not clear yet (even for physical EOVs). Observational arrays develop in organic fashion depending on regional processes/scales and available resources (e.g., ship time, funding). Moorings can provide high-frequency temporal variability at key locations. Other platforms are better suited to resolve cross- and along-shelf variability. Shipboard measurements still needed to measure full suite of physical (and BGC, biological) parameters. Gliders can be used in some BCs to observe in remote regions, connect coastal-open ocean, and make interdisciplinary measurements. Need global (or downscaled) models with fidelity in BC regions to be able to use those models to design integrated observing systems.
Informal summary of informal survey
Progress towards OceanObs’19

How have we advanced in our ability to make interdisciplinary observations?

More BGC sensors available on moorings, Argo floats, and gliders. Optical sensors for biological parameters, acoustic sensors for animal detection have been developed.

How have we advanced in our ability to use new technology?

Underwater gliders have been proven in a number of BC regimes. Increased use of in-situ measurements (e.g., Argo, drifters, XBTs) paired with altimetry in BC regions. Pilot deployments of Deep Argo/Deep gliders which can be used to observe deep BCs. Improvements in numerical model’s ability to portray BCs and use real-time data.

How have we progressed in connecting the open ocean with coastal ocean?

Soon we will have satellites with better coastal resolution (e.g., swath altimetry, winds). Expansion of coastal HF radar networks. Gliders and emerging technology (e.g., Sail drones) can help connect coastal-open ocean. Caveat: these new technologies are personnel intensive and there is a learning curve. We need to develop more merged data sets (e.g., autonomous systems with ship surveys, in situ with satellite data).
Informal summary of informal survey
Progress towards OceanObs’19

Pilot activities we can engage in prior to drafting OceanObs’19 white paper?

Census. Clarify our achievements. Review some long-term observing systems and develop multidisciplinary backbone system for EBCs and WBCs (IMSOO approach). Develop more along-shelf BC systems. More development of optical sensors for BCs. Pilot system for whole western BC system in tropical Pacific. More ADCPs on ships.

How can we better leverage existing U.S. resources as well as international investments through partnerships/collaborations?

Continued, increased support for sustained BCs is needed. More cross-line office interaction, cooperation, sharing of resources, and expertise. Cross-agency sharing is important (e.g., OOI Endurance array). Networks become cheaper/more efficient with economies of scale. Long-term observational networks often require international partnerships for ship time, resources, ability to collect measurements in EEZs. Need to promote partnerships with local people, especially key in less developed/remote areas. Work with international efforts (e.g., GOOS, OOPC).