Circulations in the East Asian Marginal Seas: open-ocean influences and local forcing

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The surface wind stress is in EAMS monsoonal oscillating between a strong northerly in winter to a weak southerly in summer. **The annual mean resembles the winter pattern.**
A remarkable feature of the ocean circulation in the East Asian Marginal Seas (EAMS) is the existence of a perennial warm current system from South China Sea (SCS) to the Japan/East Sea (JES);

The annual mean surface wind stress is southward against the warm current;

This northward warm current persists even in the winter when the surface wind is strongly southward.
The $0^{th}$ order steady balance for an isobathic flow on shelves is mainly between pressure gradient, wind stress and bottom drag (Csanady, 1978).

\[
-\frac{\partial p}{\partial y} + \frac{\tau^y}{\rho h} - \frac{F^y}{\rho h} = f_u
\]

The friction is usually resulted from the velocity itself and is not considered a forcing term.

The $fu$ term is typically small because of small cross-isobathic velocity.

An along-isobathic shelf flow is forced locally by wind stress or induced by a pressure gradient due to either local or remote influences.
In the Northwest Atlantic Ocean, for instance, the equatorward flow from Greenland coast to Cape Hatteras is believed to be sustained mainly by the pressure gradient induced by freshwater discharges from glacial melt and river runoffs (Chapman and Beardsley, 1989).
On the northwest Pacific shelves, there is **NO** large source of freshwater discharge, and the wind stress is against the warm current system.

So there has been a consensus that the warm current system must be related to the open-ocean forcing through the Kuroshio Current (e.g., Su, 1998 and 2004; Guan and Fang, 2006 for reviews).

The debate has been mostly centered on how open ocean induces isobathic pressure gradient to sustain a shelf flow.
Regional Modeling (1/4 degree Princeton Ocean Model, POM) (Ma et al., 2010, JGR)

**Control Run**: open boundary condition from \( \frac{1}{2} \) degree global run + local forcing within small domain;

**EXP-1**: open boundary condition from \( \frac{1}{2} \) degree global run, NO local forcing within small domain

**EXP-2**: forcing is applied ONLY within the small domain
EXP-1 (No local forcing)
EXP-2 (Local forcing only)
Dominant deep-ocean forcing:
Tsushima Warm Current
South China Sea Warm Current
Taiwan Warm Current
South China Sea Throughflow
East Korean Coastal Current

Dominant local forcing:
Yellow Sea Warm Current
West Korean Coastal Current
Example 1: open ocean forcing:

Control Run

No Local Forcing
West of 130E

Only Local Forcing

1-layer barotropic model with realistic topography and forcing (Yang, 2007, JPO)
The mechanism of how Kuroshio drives flow through Taiwan Strait:

\[ P_A - P_B = \int_A^B \tau_{friction} \, dy \]

v=0 and so the Coriolis force is zero for along boundary flow.

The ocean in the other side of the island also feels the same \( \Delta P \) and that tends to forces a boundary flow.

It applies to nonlinear and time-dependent flow as well.
Example 2: Local forcing

Uda (1934) was the first to note the existence of a upwind current along YS Trough in winter northerly monsoon.

A compensating current of the wind driven coastal currents in the Yellow Sea in winter (Hsueh et al, 1986; Lin and Yang, 2011)

The compensation flow theory was first proposed by Csanady in 1970s to explain upwind flow in the Great Lakes.

Rotational effect makes YSWC Shifted westward

Lin and Yang (2011, (JGR) for mechanism; Lin et al. (2011 JGR for observations.)
These currents are connected through topographic waves for both variability and steady flows (through arrested topographic waves, Csnaday, 1978).
Impact of TSWC on circulations in East China Sea

Boundary condition at the Tsushima Strait is specified by using result from the standard run. No any other forcing is used in the model.

Both barotropic model (Yang, 2007) and 3-D GCM (Ma et al., 2010) showed that the Tsushima Warm Current affects the YSWC, TWC and SCSWC.
Challenge: the ocean responds to external forcing through westward propagation of Rossby waves. So the WBCs are on the receiving ends of basin-wide climate forcing. How coastal seas along western boundaries respond to such accumulated basin-wide forcing is an area that should be emphasized in climate studies.
Closing remarks:

• The oceanic circulation in the East Asian Marginal Seas is strongly influenced by both deep ocean processes and local forcing;

• Cross-isobathic interactions between deep open ocean and shelf seas must involve ageostrophic processes and/or direct forcing;

• Ageostrophic processes are intimately tied to local topographic features and circulation characteristics;

• Process studies are useful in identifying and elucidating key processes;

• Changes in WBCs reflect basin-wide forcing and are expected to be amplified in a changing climate. Understanding how western-basin coastal seas respond to WBCs is a new challenge.