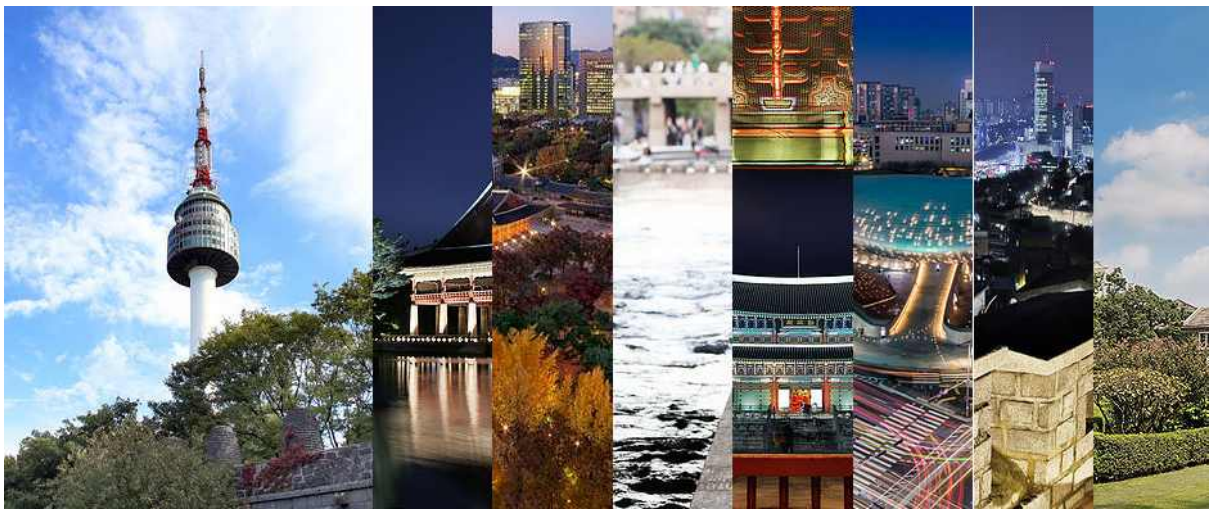
# 9th International Workshop on Modeling the Ocean (IWMO)

July 3 - 6, 2017,

Yonsei University (Seoul, Korea)



## *Sponsorship*

The Korean Society of Oceanography, Korea Institute of Ocean Science and Technology, Korea Hydrographic and Oceanographic Agency, Yonsei University(College of Science), Seoul National University

## *INVITATION*

The IWMO evolved from a small group meeting of the Princeton Ocean Model (POM) **http://www.ccpo.odu.edu/POMWEB/**, but it is open to the ocean modeling community at large. The IWMO focuses on all aspects of ocean and coupled air-wave-sea, ice and current-sediment modeling: processes, analysis and prediction. The earth system is inter-connected on a broad range of temporal and spatial scales, and we welcome coastal, regional and basin-scale studies, as well as interdisciplinary topics. As in the past workshops, we particularly encourage participation from young scientists – graduate students and postdocs – and will again host the Outstanding Young Scientist Awards competition. Selected works of IWMO presentations will be published as a special issue in Ocean Dynamics.

## *CONFERENCE TOPICS*

- Climate dynamics and modeling
- Coastal modeling
- Circulation and dynamics
- Turbulence and Waves
- Marine ecosystem modeling
- Data Assimilation and ocean prediction

## *VENUE*

Yonsei University, Seoul, Korea

## *International Steering Committee*

Lie-Yauw Oey (National Central Univ. Taiwan & Princeton Univ. USA)
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Jarle Berntsen (University of Bergen, Norway)
Bo Qiu (University of Hawaii, USA)
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Jia Wang (NOAA/GLERL, USA)
Ricardo de Camargo (Univ. Sao Paulo, Brazil)
Humio Mitsudera (Hokkaido Univ., Japan)

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Yangki Cho (Seoul National University, Korea)
Soon-Il An (Yonsei University, Korea)
Young-Ho Kim (KIOST)
Do-Seong Byun (KHOA)

# Oral Presentations

| 03 July 2017 Monday | | |
|---|---|---|
| 8:30-9:00 | Registration | |
| 9:00-9:30 | Welcome | |
| **Climate dynamics and modeling I (Session Chair : L. Oey)** | | |
| 9:30-10:00 | Oceanic Mesoscale vs. Submesoscale Variability: Dynamics and Observability (invited) | Bo Qiu (U. Hawaii, U.S.A) |
| 10:00-10:20 | Long-term trends of typhoon-induced rainfall over Taiwan: in situ evidence of poleward shift of typhoons in western North Pacific in recent decades | L. Oey (NCU, Taiwan) |
| 10:20-10:40 | Climate variability responsible for poor recruitment of the Japanese eel | C. R. Wu (NTNU, Taiwan) |
| 10:40-11:00 | Sensitivity of ITF Transport to Model Bathymetry and Smoothing: Lessons learned from a Regional Pacific-Indian Ocean Model | L. Liang (SCSIO, China) |
| 11:00-11:20 | Reducing SST warm bias in eastern boundary upwelling systems in the medium-low resolution climate models (OYSA) | J. Ma (Tsinghua U., China) |
| 11:20-13:00 | Lunch | |
| **Climate dynamics and modeling II (Session Chair : B. Qiu)** | | |
| 13:00-13:20 | Role of ocean dynamics in driving the asymmetrical feature of El Niño and La Niña | S. I. An (Yonsei U., Korea) |
| 13:20-13:40 | Weather noise leading to El Niño diversity in an ocean general circulation model | S. W. Yeh (Hanyang U., Korea) |
| 13:40-14:00 | Interannual-to-Decadal Variability and Trends of Oceanic Barrier Layers in the Tropical Pacific (OYSA) | L. Wang (Tsinghua U., China) |
| - | Modeling seasonal and interannual variability of Great Lakes ice cover using FVCOM+ice model (cancelled) | J. Wang (NOAA, U.S.A) |
| 14:00-14:20 | Bayesian Projections of Atlantic Overturning with Thorough Accounting for Relevant Uncertainties (OYSA) | R. Olson (Yonsei U., Korea) |
| 14:20-14:40 | Impacts of the Southern Hemisphere westerly winds on the sea-ice/ocean interaction and global ocean circulation | W. G. Cheon (ADD, Korea) |
| 14:40-15:00 | Coffee Break | |

| Coastal modeling Ⅰ (Session Chair : H. Xue) | | |
|---|---|---|
| 15:00-15:30 | Responses of estuaries to human interventions: A brief story of recent coastal development where things have gone right and wrong (invited) | X. H. Wang (UNSW, Australia) |
| 15:30-15:50 | Bottom Intrusion to the Bungo Channel in a high-resolution ocean data assimilation data: JCOPE-T-NEDO | T. Miyama (JAMSTEC, Japan) |
| 15:50-16:10 | Tide-surge interaction intensified by the Taiwan Strait | W. Z. Zhang (Xiamen, U., China) |
| 16:10-16:30 | Using All-Source Green's Functions to Establish Virtual Tidal Gauges (VTGs) for Canadian Eastern Coasts | Z. Xu (MLI, Canada) |
| 16:30-18:00 | Poster Session & Cocktail | |

# 04 July 2017 Tuesday

| Coastal modeling Ⅱ (Session Chair : X. H. Wang) | | |
|---|---|---|
| 8:30-8:50 | Cross-shelf Exchange along the eastern Maine coast | H. Xue (U. Maine, U.S.A.) |
| 8:50-9:10 | The adaptation of ROMS model to the Porsanger fjord, Norway (OYSA) | P. Aniskiewicz (CPS, Poland) |
| 9:10-9:30 | Lagrangian timescales in the Gulf of Finland | B. Viikmäe (Tallin U., Estonia) |
| 9:30-9:50 | High resolution coastal ocean modeling for research and applications | S. M. Varlamov (JAMSTEC, Japan) |
| 9:50-10:10 | Coffee Break | |

| Circulation and dynamics Ⅰ (Session Chair : J. Sheng) | | |
|---|---|---|
| 10:10-10:30 | Numerical modeling on seasonal variations of the Bering Slope Current and associated eddies | H. Mitsudera (Hokkaido U., Japan) |
| 10:30-10:50 | Spectral descriptions of submesoscale surface circulation in a coastal region off the East Coast of Korea | S. Y. Kim (KAIST, Korea) |
| 10:50-11:10 | The role of Ekman drainage in numerical investigations of dense water cascading on a slope: Sensitivity to vertical resolution and bottom boundary condition | J. Berntsen (U. Bergen, Norway) |
| 11:10-11:30 | Intrinsically and extrinsically forced circulation and associated biogeochemical response in China Seas | J. Gan (HKU., Hong Kong) |
| 11:30-11:50 | Reconstruction of ocean's interior from observed sea surface information | L. Liu (SCSIO, China) |
| 11:50-13:00 | Lunch | |
| **Circulation and dynamics Ⅱ (Session Chair : J. Berntsen)** | | |
| 13:00-13:20 | Development and Applications of Shelf Circulation Models for the Eastern Canadian Shelf | J. Sheng (Dalhouse U., Canada) |
| 13:20-13:40 | Storm surges in the Western South Atlantic: patterns of generation and propagation from long hindcast simulations | R. Camargo (U. Sao Paulo, Brazil) |
| - | Inertial instability and phase error in centered differencing and Euler-forward predictor-corrector schemes (cancelled) | J. Wang (NOAA, U.S.A.) |
| 13:40-14:00 | Evaluation and analysis of high-resolution models for oceans around Canada | Y. Lu (BIO, Canada) |
| 14:00-14:20 | Investigation of intrinsic ocean variability on the low-frequency variability of the northwestern Pacific subtropical mode water volume in a global ocean general circulation model (OYSA) | S. Y. Kim (KMOU, Korea) |
| 14:20-14:40 | Coffee Break | |

| Turbulence and Waves Ⅰ (Session Chair : Y. Noh) | | |
|---|---|---|
| 14:40-15:10 | Large Eddy Simulations of Wind- and Wave-Driven Turbulence; Implication from In-situ observations (invited) | Y. Yoshikawa (U. Kyoto, Japan) |
| 15:10-15:30 | Parameterizing TC-induced ocean cooling using neural networks (OYSA) | G. Jiang (Peking U. China) |
| 15:30-15:50 | Simulation of wave-current interactions under hurricane conditions using FVCOM: The impact on Wave | Y. Sun (BIO, Canada) |
| 15:50-16:10 | The effect of diurnal cycle of surface heat flux on the ocean mixed layer (OYSA) | Y. Ushijima (U. Kyoto, Japan) |
| 16:10-16:30 | Scaling of the mixed layer depth under surface heating by using LES - the effect of initial stratification. (OYSA) | Y. Choi (U. Yonsei, Korea) |
| 16:30-18:00 | Poster Session & Cocktail | |

# 05 July 2017 Wednesday

| Turbulence and Waves Ⅱ (Session Chair : V. Vlasenko) | | |
|---|---|---|
| 8:30-8:50 | Arctic wave field reanalysis and observation in 2016 | A. Webb (U. Tokyo, Japan) |
| 8:50-9:10 | Application of a nested wave model for wave energy resource assessment | K. Sasmal (U. Tokyo, Japan) |
| 9:10-9:30 | A numerical study of scattering of CTWs into Jervis Bay, Australia (OYSA) | F. Liao (UNSW, Australia) |
| 9:30-9:50 | Approximate dispersion relation for surface waves atop an arbitrarily depth-varying current (OYSA) | Yan Li (NUST, Norway) |
| 9:50-10:10 | Coffee Break | |
| **Turbulence and Waves Ⅲ (Session Chair : Y. Yoshikawa)** | | |
| 10:10-10:30 | Tidal energy focusing over an isolated underwater bank: observations and modelling | V. Vlasenko (U. Plymouth, U.K.) |
| - | Long-range propagation and associated variability of internal tides in the South China Sea (cancelled) | Z. Xu (Ins. Ocean., China) |

| | | |
|---|---|---|
| 10:30-10:50 | Equatorial waves and their impact on circulation and air-sea interaction in the Somali Current region | T. G. Jensen (NRL, U.S.) |
| 10:50-11:10 | Impact of the incorporation of the salinity effect into atmospheric model on simulated precipitation | E. Lee (KIAPS, Korea) |
| 11:10-13:00 | Lunch | |
| **Marine ecosystem modeling Ⅰ (Session Chair : F. Chai)** | | |
| 13:00-13:30 | Role of Ocean bio-geochemical processes in Arctic climate variability (invited) | J. S. Kug (Postech, Korea) |
| 13:30-13:50 | Eddies affect marine biology in the South China Sea: Interactions with wind mixing | P. Xiu (SCSIO, China) |
| 13:50-14:10 | Impact of vertical mixing changes on air-sea CO2 fluxes in the Southern Ocean | H. Song (MIT, U.S.A.) |
| 14:10-14:30 | The physical and biological roles of mesoscale eddies on migration of Japanese eel larvae in western Pacific Ocean | Y. E. Chang (NTNU, Taiwan) |
| 14:30-14:50 | Coffee Break | |
| **Marine ecosystem modeling Ⅱ (Session Chair : H. Song)** | | |
| 14:50-15:10 | Natural and Artificial Iron Fertilization in the Ocean | F. Chai (Univ. Maine) |
| 15:10-15:30 | Modelling of larvae dispersion over isolated seamount | N. Stashchuk (U. Plymouth, U.K.) |
| 15:30-15:50 | The Oceanic Control of Atmospheric CO2: An Insight from a Model Study | E. Y. Kwon (IBS/PNU, Korea) |
| 15:50-16:10 | Physical-biological model and its scientific research in the Taiwan Strait | Y. Jiang (Xiamen U., China) |
| 16:10-16:30 | Spatial variability of phytoplankton assemblages during the intermonsoon in baler bay, outer and inner casiguran sound, aurora, northeastern philippines (OYSA) | A.L.D Pena (U. Philippines, Philippines) |
| 16:30-17:30 | - Discussion on IWMO 2018<br>- Presentation of Awards and Prizes | |
| 19:00- | Banquet: Han River Dinner Cruise | |

# 06 July 2017 Thursday

| | | |
|---|---|---|
| **Data assimilation and ocean prediction Ⅰ (Session Chair : Y. H. Kim)** | | |
| 8:30-9:00 | Ocean forecasting: from descriptive to quantitative science (invited) | N. Pinardi<br>(U. Bolgona, Italy) |
| 9:00-9:20 | Predicting tides for new sites using 25 hour sea-level observations | D. S. Byun<br>(KHOA, Korea) |
| 9:20-9:40 | Operational tide/storm surge and wave prediction system at KMA | K. Y. Byun<br>(KMA, Korea) |
| 9:40-10:00 | The effect of density stratification on the prediction of global storm surges | T. Kodaira<br>(U. Tokyo, Japan) |
| 10:00-10:20 | Coffee Break | |
| **Data assimilation and ocean prediction Ⅱ (Session Chair : N. Pinardi)** | | |
| 10:20-10:40 | Applications and studies using adjoint models based on the Meteorological Research Institute Community Ocean Model (MRI.COM) (invited) | Y. Fujii<br>(MRI, Japan) |
| 10:40-11:00 | Updating ocean model/data assimilation components of the JCOPE2 operational ocean forecast system for biogeochemical applications | Y. Miyazawa<br>(JAMSTEC, Japan) |
| 11:00-11:20 | Climate initialization applying ocean data assimilation for a ENSO prediction system | Y. H. Kim<br>(KIOST, Korea) |

# Poster Presentations

| Climate dynamics and modeling | |
|---|---|
| An epoch-dependent change in driver of heat storage rate variability during recent decades in the upper western North Pacific | Gyundo Pak (KIOST, Korea) |
| A global spectral element model for Poisson equations and advective flow over a sphere | Huan Mei (Hohai U., Korea) |
| Potential decline of Atlantic Meridional Overturning Circulation under melting Greenland Ice Sheet (OYSA) | Mao-Cheng Huang (National Taiwan Normal U., Taiwan) |
| Feedback Process Responsible for Inter-Model Diversity of ENSO variability (OYSA) | Eun-Sook Heo (Yonsei U., Korea) |
| The evaluation on high frequency ground wave radar surface current observation system in Gulf of Thailand | Xunqiang Yin (SOA, China) |
| **Coastal modeling** | |
| Case Study on the three-dimensional structure of meso-scale eddy in the South China Sea based on a high-resolution model | Xia Changshui (SOA, China) |
| Observational Study of the Cold Waters over the Southwestern Yellow Sea in Summer 2016 (OYSA) | Zhanyuan He (Hohai U., China) |
| Episodic surface intrusions of Yellow Sea Warm Current in late winter | Zifeng Hu (Hohai U., China) |
| Revisit simulation of 1953 storm surge in the North Sea | Byung Ho Choi (Sungkyunkwan U., Korea) |
| Revisit Simulation of D-day : Normandy Invasion on 6th of June, 1944 | Byung Ho Choi (Sungkyunkwan U., Korea) |
| Response of hydrodynamics to coastline changes in Hangzhou Bay, China | L. Li (SIO, China) |

| Circulation and dynamics | |
|---|---|
| Interannual variation of the surface circulation in the Japan/East Sea by external forcing and intrinsic variability | Byoung-Ju Choi (Chonnam National U., Korea) |
| Eddy induced cross-slope transport in the northern South China Sea | Na Liu (Chinese Ac. of Sci., China) |
| Numerical study of seasonal circulation and variability over the inner shelf of the northern South China Sea | Xiaomei Ji (Hohai U., China) |
| Evolution of wind-driven flows in the Yellow Sea during winter (OYSA) | Yong-Jin Tak (Seoul National U., Korea) |
| Role of the cold water in the formation of the East Korea Warm Current in the East/Japan Sea : numerical experiment (OYSA) | Yongyeop Kim (Seoul National U., Korea) |
| Variability of the Pacific North Equatorial Current from 1993 to 2012 Based on a 1/8° Pacific Model Simulation | Zhichun Zhang (Chinese Ac. of Sci., China) |
| Seasonal Characteristics and Dynamic Mechanism of the Surface Kuroshio Branch intrusion into the South China Sea | Jingsong Guo (SOA, China) |
| **Turbulence and Waves** | |
| Large eddy simulation of diffusion of a buoyancy source in ocean mixed layer (OYSA) | Bong-Gwan Kim (Seoul National U., Korea) |
| Simulation of typhoon-induced wave and surge using a coupled Ocean-Wave model | Ji-Seok Hong (Jeju National U., Korea) |
| Investigation of Air-Sea interaction in tropical Africa region using Regional Climate Model (RegCM4) | Kenfack Sadem Christian (U. Dschang, Cameroon) |
| Frontogenesis and turbulent mixing (OYSA) | Zhang Shuwen (Guangdong Ocean U., China) |

| Marine ecosystem modeling | |
|---|---|
| Harmful Algae Bloom models for Cochlodinium polykrikoides off the south coast of Korea (OYSA) | Il-Kyeong Ma (Pusan National U., Korea) |
| **Data assimilation and ocean prediction** | |
| Data assimilation of physical and chlorophyll observations in the California Current System using two biogeochemical models | Hajoon Song (MIT, U.S.A) |
| Prediction of M2 tidal surface currents by a global baroclinic ocean model and evaluation using observed drifter trajectories | Tsubasa Kodaira (U. Tokyo, Japan) |

# ABSTRACTS

## Oral

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# *Oral Presentations*

## Climate dynamics and modeling I

3 July 2017 (Monday) 9:30 - 11:20

(Chair: L. Oey)

### **Oceanic Mesoscale vs. Submesoscale Variability: Dynamics and Observability** (Invited)

**Bo Qiu,** Shuiming Chen, Patrice Klein, and Hide Sasaki
(*University of Hawaii, U.S.A.*; bo@soest.hawaii.edu)

This presentation will focus on two aspects of mesoscale-submesoscale variability in the subtropical gyre circulation in the North Pacific Ocean. First, we analyze the output from a 1/30-deg high-resolution OGCM simulation and the AVISO gridded satellite altimetry product to contrast the seasonal Subtropical Countercurrent (STCC) variability in the mesoscale vs. submesoscale ranges. Importance of two types of baroclinic instability are emphasized. The second topic utilizes the theoretical framework of effective surface quasi-geostrophic (eSQG) dynamics and explores the potential of reconstructing the 3D upper ocean circulation features, including the vertical velocity (w) field, from high-resolution sea surface height data expected from the forth-coming NASA-CNES's Surface Water and Ocean Topography (SWOT) mission.

# Long-term trends of typhoon-induced rainfall over Taiwan: in situ evidence of poleward shift of typhoons in western North Pacific in recent decades

**Leo Oey** and Alice Yu
(*National Central University, Taiwan*; lyooey@gmail.com)

Tracks of tropical cyclones or typhoons in the western North Pacific have recently been shown to shift northward in the past several decades; the poleward shift has been attributed to the expansion of the tropics due to climate warming. Here we use 64-year, hourly rainfall observations around Taiwan, and take advantage of the unique terrain and geographic location of the island with respect to typhoon tracks, to show that since 1950 the typhoon-related rainfalls have been rising on the western side of the island, but decreasing on the eastern side. We show that these extraordinary rainfall patterns, despite the smallness of Taiwan, are indicative of a northward shift of typhoons related to the changes in the wind fields and surface warming over the Indian and Pacific tropical/subtropical regions.

# Climate variability responsible for poor recruitment of the Japanese eel

**Chau-Ron Wu** and Yong-Fu Lin
(*National Taiwan Normal University, Taiwan*; cwu@ntnu.edu.tw)

Satellite data and model simulations are used to investigate fluctuations for the catch of the Japanese eel (Anguilla japonica) in eastern Asian countries. It is found that the salinity front extends farther south which shifts eel's spawning ground to the lower latitude and results in a lower eel catch in 1983, 1992 and 1998. Interannual variability of the eel catch is strongly correlated with the combination mode (C-mode), but not El Niño–Southern Oscillation (ENSO). The eels spawn within the North Equatorial Current (NEC) still, yet the salinity front migrates south during a canonical El Niño. On the other hand, during the C-mode of climate variability, the spawning ground accompanied with the salinity front extends farther south while eel larvae fail to join the nursery of the NEC, resulting in poor recruitment in East Asia. Finally, we propose an appropriate SST index to project the abundance of the Japanese eel larvae.

# Sensitivity of ITF Transport to Model Bathymetry and Smoothing: Lessons learned from a Regional Pacific-Indian Ocean Model

**Linlin Liang** and Huijie Xue
(*Chinese Academy of Sciences, China*; lianglin@scsio.ac.cn)

The tropical Pacific and Indian Oceans are connected by the Indonesian Through-flow (ITF) via the complex passages of the Indonesian Archipelago. ITF is one of the important links for the global conveyer belt, and it has profound influences on the general circulation and climate change at long time scale. However, exceedingly complicated topography of the Indonesian Archipelago exerts great difficulties in both observations and numerical modeling. In this work, the Regional Ocean Modeling System (ROMS) was implemented for the western Pacific and northern Indian oceans, and the model was used to quantify the transport though the various crucial straits and passages of the Indonesian Archipelago. The model results showed that the Pacific's low latitude western boundary currents are the sources of the ITF. The flow through the Makassar Strait (~10Sv) originates in the Mindanao Current, while, the flow entering the Halmahera Sea (~4.5Sv) originates from the New Guinea Coastal Current (NGCC) of South Pacific waters. The ITF exits the Indonesian Archipelago through three principal routes: Lombok Strait (~2.7Sv), Ombai Strait (~3Sv) and Timor Passage (~3Sv). It is found that the circum-island flow is strengthened (weakened) if we increase (decrease) the topography gradient adjacent to the islands, which lead to redistribution of outflow from these three passages. Sensitivity to inflows and outflows at the open boundaries (e.g., the North Equatorial Counter Current and the Leeuwin Current) were also examined.

## **Reducing SST warm bias in eastern boundary upwelling systems in the medium-low resolution climate models** (OYSA)

**Jialiang Ma** and Shiming Xu
(*Tsinghua University, China*; mjl14@mails.tsinghua.edu.cn)

Warm sea surface temperature (SST) biases in the eastern boundary upwelling systems (EBUS) are common in most coupled climate models. Many previous studies attribute the bias to 2 factors: underestimation in low-level stratus cloud in atmosphere model and the weak upwelling system in the simulation. Underestimated low-cloud fraction and consequent massive radiation have great connection with offshore SST warm bias, while onshore warm bias is mainly dominated by the weak coastal wind stress and stress curl. In our analysis based on fully coupled CESM experiments with nominal 0.5° and 1° resolution in atmosphere components respectively, the increase in the atmospheric model resolution results in stronger wind stress and stress curl with the maximum closer to the coast, causing strong upwelling and reduction in SST bias.

Further work is carried out to reduce the warm bias in medium-low resolution coupled climate model (nominal 1 resolution in atmosphere and ocean components) by designing new interpolation methods in air-sea coupled process to reduce numerical diffusion in current method. The meridional wind has an increment of almost 10% in Benguela region by interpolating directly from atmosphere center grid point to ocean center grid point. Although the value is lower than 20% the increase amplitude of atmosphere resolution from 1° to 0.5°, the improvement is promising. Besides, we take into consideration the lower boundary type for the interpolation of atmospheric wind to the ocean, by adjustments to the interpolation weight coefficients with respect to the underlying surface. As a result, the coastal wind in the Peru-Chile region has witnessed drastic increase. Lastly, modifications to the topography in low resolution coupled models could improve the coastal wind representation in EBUS, especially for regions with high mountains, resulting in a more accurate modeling of SST.

# Climate dynamics and modeling II

3 July 2017 (Monday) 13:00 – 14:20

(Chair: B. Qiu)

## Role of ocean dynamics in driving the asymmetrical feature of El Niño and La Niña

**Soon-Il An**, Ji-Won Kim and Seul-Hee Im

(*Yonsei University, Korea*; sian@yonsei.ac.kr)

La Niña, an opposite phase of El Niño, is not a simple mirror image of El Niño. Their amplitude, duration, transition features are different. To understand why El Niño is stronger than La Niña, ENSO stability index is computed. The large growth rate of the El Niño compared to La Nina's is primary due to the stronger sensitivity of the ocean's dynamic response to wind stress in El Niño. We also analyze the inherent asymmetry in a delayed negative feedback loop, in order to figure out why El Niño frequently followed by La Niña while the opposite occurs rarely. We found that the asymmetrical response of the ocean wave to wind is much larger than any other process in the negative feedback loop. Strong oceanic response during El Niño compared to La Niña is presumably due to the relatively shallow mean thermocline over the western Pacific, which efficiently traps the atmospheric momentum in the shallow upper ocean, and the asymmetrical wind pattern response to SST.

# Weather noise leading to El Niño diversity in an ocean general circulation model

**Sang-Wook Yeh**, Jong-Won Lee and Hyun-Su Jo
(*Hanyang University, Korea*; swyeh@hanyang.ac.kr)

The frequency of Central Pacific (CP) El Niño occurrences has increased since the late 1990s. In spite of a wealth of studies, however, the physical mechanisms that have caused the change remain unclear. We hypothesize that atmospheric weather noise plays a role in these occurrences. To test this hypothesis, we conduct four simulations using Modular Ocean Model version 4 (MOM4) forced by atmospheric weather noise. In this study, the atmospheric weather noise is defined as the random noise obtained from the European Centre for Medium-Range Weather Forecasts atmospheric datasets. In the first experiment, MOM4 is forced by atmospheric weather noise before 1999 along with the corresponding climatological mean state. In the second experiment, MOM4 is forced by atmospheric weather noise after 1999 along with the corresponding climatological mean state. The third and fourth experiments are similar to the first two experiments except the time periods of the climatological mean state are switched. The results show that atmospheric weather noise may play a more important role than the climatological mean state in the increase of CP El Niño occurrences. This implies that the El Niño diversity could be caused by the modulation of atmospheric weather noise. Therefore, it is important to explore how the atmospheric weather noise might change in light of global warming.

# **Interannual-to-Decadal Variability and Trends of Oceanic Barrier Layers in the Tropical Pacific** (OYSA)

**Lingxia Wang** and Fanghua Xu
(*Tsinghua University, Korea*; darlingwlx@126.com)

Major features of the isothermal layer depth(ILD), mixed layer depth(MLD), and barrier layer thickness(BLT) in tropical areas were brought to light through the analysis of salinity and temperature data from 1979 to 2015 derived from the Met Office Hadley Center Observations datasets (EN4.0.2). The results show that both ILD and MLD generally have increasing trends in the tropical Pacific. Because ILD increases faster than MLD, BLT has an increasing trend as well.

Precipitation(P)/Evaporation(E), surface heat flux, wind stress and its curl are investigated to reveal the mechanisms responsible for the variability and trends of ILD, MLD and BLT. In general, ILD and MLD are negatively correlated with P-E, heat flux and wind stress curl, while positively correlated with wind stress. The dominant factor varies in different regions. In the western Pacific, especially in the warm pool, the variability of ILD and MLD corresponds well with the change of heat flux and wind stress curl, while in the central and eastern Pacific, P-E along with wind stress plays an important role on the variations of ILD and MLD. P-E has larger influence on MLD, while the variability of BLT is largely determined by the change of ILD. In equatorial regions, the influence of wind stress curl is negligible.

In addition, the EOF analysis reveals that both ILD and MLD show close connections to Pacific Decadal Oscillation (PDO). During PDO positive phase, negative temperature anomaly occurs at 100-200m in western Pacific mainly due to the equatorward movement of subtropical cold water. The ILD shoals in western Pacific and deepens in eastern Pacific and correspondingly causes smaller BLT in western Pacific and larger BLT in eastern Pacific. Besides, the eastward shift of heavy rainfall and negative surface heat flux as well as the westerly wind anomaly which can forces surface water convergence all contribute to deepen the BLT in eastern Pacific. The situation is reversed in the PDO negative phase.

## Modeling seasonal and interannual variability of Great Lakes ice cover using FVCOM+ice model (Cancelled)

**Jia Wang**, James Kessler, Haoguo Hu and Ayumi Fujisaki-Manome
(*NOAA Great Lakes Environmental Research Laboratory, U.S.A.*; jia.wang@noaa.gov)

A 3-d, unstructured Finite Volume Coastal Ocean Model with ice model was applied to all five Great Lakes simultaneously to simulate circulation and thermal structure from 1993 to 2008. Model results are compared to available observations of currents and temperature and ice cover. Seasonal cycle and interannual variability for all the five Great lakes were presented. Lake circulation was reasonably reproduced in comparison to the existing observation. The temperature structure was also reproduced reasonably well. The lake dynamics and thermodyanmics exhibit significant annual and interannual variations. Simulated lake ice cover was validated with satellite-measured ice cover for both seasonal cycle and interannual variability. Sensitivity study was conducted on 1) surface wind-wave mixing parameterization, 2) different forcing fields, and 3) different numerical time integration schemes.

## **Bayesian Projections of Atlantic Overturning with Thorough Accounting for Relevant Uncertainties** (OYSA)

**R. Olson**, S.-I. An and M. Stuecker
(*Yonsei University, Korea*; romanolson@yonsei.ac.kr)

While previous studies addressing future changes in Atlantic Meridional Overturning Circulation (AMOC) have made a few advances, they still suffer from a number of shortcomings. Namely, they do not cross-validate or drift-correct the projections, do not fully account for internal variability or model error, do not use temporal information from North Atlantic to weight the models, and consider only a small subset of models.

Here we attempt to improve on previous work by considering 13 Coupled Model Intercomparison Project phase 5 (CMIP5) models. The models are weighted using Bayesian Model Averaging by their skill in terms of mean AMOC strength during years 1957-2004, as well as time series of north Atlantic temperature-based AMOC Index during roughly the past century. All observations and model output are drift corrected using information from the preindustrial control runs. The projections account for model error, as well as internal variability. The method is cross-validated using observation system simulation experiments.

We find that AMOC has likely already started slowing down. Our projections are at the low end of previously available estimates. We find mean changes of -4.0 Sv and -6.8 Sv between 1960-1999 and 2060-2099 for the RCP4.5 and RCP8.5 scenarios, respectively. The corresponding 90% credible intervals for the two scenarios are [-7.2, -1.2] and [-10.5, -3.7] Sv.

# Impacts of the Southern Hemisphere westerly winds on the sea-ice/ocean interaction and global ocean circulation

**Woo-Geun Cheon**
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An oscillation in intensity of the Southern Hemisphere (SH) westerly winds is one of the major characteristics of the Southern Annular Mode (SAM). Its impact upon the sea-ice/ocean interactions in the Weddell/Ross Seas that provide most of the Antarctic Bottom Water (AABW) is investigated by a sea-ice/ocean general circulation model (GCM) coupled to an energy balance model (EBM). This oscillating wind forcing over the Southern Ocean (SO) plays a significant role both in intensifying/weakening near-boundary convection maintained by coastal polynyas and in creating/destroying open-ocean convection maintained by open-ocean polynyas. With the intensifying (weakening) westerly winds, the sea-ice concentrations in the western Weddell and Ross coasts decrease (increase), meaning an increase (decrease) in the formation of coastal polynya, and the ice-to-salt flux due to sea-ice newly forming within coastal polynyas increases (decreases). Although smaller in size and repetition rate than in the Weddell Sea, open-ocean polynya and deep convection appeared to occur in the Ross Sea via a similar triggering mechanism leading from an instantaneous spin-up to upwelling of warm deep water and the ensuing surface warming. The oscillation in intensity of SH westerly winds affects the global ocean circulation not only with the buoyancy-driven teleconnection (BDT) mode due to the sea-ice/ocean interaction that directly controls the AABW formation but also with the Ekman-driven teleconnection (EDT) mode due to the underlying northward Ekman transport that remotely influences the North Atlantic Deep Water (NADW) formation. The intensifying (weakening) SH westerly winds act to intensify (weaken) not just the surface Western Boundary Currents (WBCs) in both the Atlantic and Pacific but also the Kuroshio Extension (KE). While the northward bottom currents in the Atlantic are in a seesaw balance with the NADW outflow directly linked to the Ekman divergence-driven upwelling of the Circumpolar Deep Water (CDW), those in the Pacific are significantly influenced by the SH sea-ice/ocean interaction and the ensuing buoyancy fluxes that determines the formation rate of AABW. The Drake Passage through-flow indicative of the volume transport of Antarctic Circumpolar Current (ACC) is mainly controlled by the AABW formation but is also affected by the outflow of NADW.

# Coastal modeling I

3 July 2017 (Monday) 14:40 - 16:10

(Chair: H. Xue)

### **Responses of estuaries to human interventions: A brief story of recent coastal development where things have gone right and wrong** (Invited)

**Xiao Hua Wang**

(*The University of New South Wales, Australia*; x.h.wang@unsw.edu.au)

Many world estuaries and coast environments are under tremendous stress in response to the increased anthropogenic forcing and climate change. A good understanding of the current state of these marine environment and lessons learnt from these human influences would be extremely valuable to restore and protect these habitats and ecosystems from further environmental degradation and catastrophe. This talk uses several case studies to tell a brief story about how these coastal environments respond to severe human-induced perturbation, and where things have gone right or wrong from environmental and resource management point of view. Suggestions/recommendations on how we should document and address these issues will be offered to remediate the problems and prevent future failure in the other world estuaries.

# Bottom Intrusion to the Bungo Channel in a high-resolution ocean data assimilation data: JCOPE-T-NEDO

**Toru Miyama**, Sergey M. Varlamov, Yasumasa Miyazawa, Xinyu Guo and Yushi Morioka
(*Japan Agency for Marine-Earth Science and Technology, Japan*; tmiyama@jamstec.go.jp)

To the Bungo Channel in Japan, two types of intrusions from the Pacific Ocean are well known: a Kyucho and a Sokoiricho (bottom intrusion). While Kyucho is an intrusion of warm water in the surface layer., Sokoiricho is an intrusion of cold water to the Bungo Channel in the bottom layer. In this study, we investigated the bottom intrusion using a high-resolution ocean reanalysis, namely JCOPE-T-NEDO reanalysis. JCOPE-T-NEDO is based on a concurrent simulation of ocean circulation and tides in the Western North Pacific using an ocean general circulation model with a horizontal resolution of 1/36°. Observed features of geostrophic phenomena including the Kuroshio and mesoscale eddies are included through nudging of the temperature and salinity fields provided by a data-assimilative JCOPE2 model with a relaxation time scale of 5 days. The reanalysis data reproduced frequent occurrence of the bottom intrusions. Multi-resolution analysis using a discrete wavelet analysis showed that the signals of bottom intrusion are included in 8- and 16-day time scales components. The combination of the 8 and 16-day time scale components in the multi-resolution analysis well describes the events of the bottom intrusions. It was found that the frequency is strongly tied to the spring-neap tidal cycle: the bottom intrusions occur during neap tide periods. The reanalysis data also showed that the bottom intrusion has seasonality: it is weak in winter. A spatial map of the temperature variance showed that the bottom intrusions are active over the continental shelf in the Bungo Channel. These features of the bottom intrusion in JCOPE-T-NEDO reanalysis are consistent with past observational studies.

# Tide-surge interaction intensified by the Taiwan Strait

**Wen-Zhou Zhang**, Fengyan Shi, Hua-Sheng Hong, Shao-Ping Shang and James T. Kirby
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The Taiwan Strait is a long and wide shelf channel where the hydrodynamics is extremely complex, being characterized by strong tides, and where storm surges frequently occur during the typhoon season. Obvious oscillations due to tide-surge interaction were observed by tide gauges along the northern Fujian coast, the west bank of the Taiwan Strait, during Typhoon Dan (1999). Numerical experiments indicate that nonlinear bottom friction (described by the quadratic formula) is a major factor to predict these oscillations while the nonlinear advective terms and the shallow water effect have little contribution. It is found that the tide-surge interaction in the northern portion of the Taiwan Strait is intensified by the strait. Simulations based on simplified topographies with and without the Island of Taiwan show that, in the presence of the island, the channel effect strengthens tidal currents and tends to align the major axes of tidal ellipses along the channel direction. Storm-induced currents are also strengthened by the channel. The pattern of strong tidal currents and storm-induced currents along the channel direction enhances tide-surge interaction via the nonlinear bottom friction, resulting in the obvious oscillations along the northern Fujian coast.

# Using All-Source Green's Functions to Establish Virtual Tidal Gauges (VTGs) for Canadian Eastern Coasts

**Zhigang Xu**
(*Fisheries and Oceans Canada, Canada*; zhigang.xu@dfo-mpo.gc.ca)

A virtual tidal gauge (VTG) is a mathematical transfer function that is derived from a numerical ocean model. It transfers global tidal forcing and atmospheric forcing fields to sea level responses at a point of interest (POI). Once calibrated with short-term observations, the function yields water level responses (tides + storm surges) that are close to those observed by a physical tidal gauge. Maintaining a physical tidal gauge in a remote area or harsh environment is costly or even infeasible. A VTG is a suitable substitute.

The NASA/JPL ephemerids data are used for tidal generating potential and the MERRA and GEM4 atmospheric model outputs are used for atmospheric forcing. The core technique is the All-SourceGreen's Function (ASGF, Xu 2007, 2011, 2015a,b), which connects a POI to the world ocean. A convolution of the ASGF with the global forcing fields produces sea level time series at the POI.

Taking a real tidal gauge located in Sept-Iles Quebec as an illustrative POI, this talk will show how the VTG can recursively assimilate real-time data stream and predict the sea levels for next 48 hours (as long as the weather forecast), while accumulating the history of hindcast.

# Coastal modeling II

4 July 2017 (Tuesday) 08:30 - 09:50

(Chair: X. H. Wang)

## Cross-shelf Exchange along the eastern Maine coast

**Huijie Xue**, LeAnn Conlon and Phillips Yund
(*University of Maine, U.S.A.*; hxue@maine.edu)

A better understanding of cross-shelf exchange and the processes contributing to it is crucial for assessing the movement of marine particulates and dissolved materials, both natural and anthropogenic. Cross-shelf exchange in a region with many influencing factors (e.g., coastal geomorphology, tides, winds, etc.) can be complex and variable, both spatially and temporally. We investigated cross-shelf exchange along the eastern Maine coast using an unstructured grid ocean circulation model coupled with an offline particle tracking code. The edge of the Eastern Maine Coastal Current (EMCC) was delineated, and the particles moving across this boundary were analyzed to quantify the exchange between the nearshore water in bays and the coastal current offshore. Overall, 48.3% of particles remain nearshore after two weeks. Primary exchanges occur at locations where tidal currents interact with topographic protrusions (prominent headlands or a group of islands separating neighboring bays) to form eddies. Tide is the most important factor controlling temporal variation in cross-shelf exchange, although there are significant differences in monthly averages in exchange as well, likely due to changes of the nearshore density distribution. Wind has limited effect on particle movement, possibly due to the low occurrence of strong wind events or the strength of other factors, such as the tide.

## **The adaptation of ROMS model to the Porsanger fjord, Norway** (OYSA)

**Paulina Aniśkiewicz** and Małgorzata Stramska
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aniskiewicz.paulina@gmail.com)

The main long-term goal of the project is to develop improved understanding of mechanisms responsible for interactions between Arctic fjords and large-scale atmospheric and oceanic conditions. In this presentation we have focused on modeling with high spatial resolution of the hydrodynamic conditions in the Porsanger fjord using Regional Ocean Modeling System (ROMS). The fjord is located in the coastal waters of the Barents Sea and based on the bathymetry can be divided into three zones: inner (0-30 km), middle (30-70 km) and outer (70-100 km). The environment in the inner part differs significantly from the other zones and holds a unique arctic ecosystem, e.g. sea surface salinity is lower (27-28 PSU) than in the other zones (35-36 PSU). To simulate hydrodynamic conditions in the fjord we have used high-spatial resolution grid of the fjord and surrounded ocean. The bathymetry data have been provided by National Centers for Environmental Information (NOAA) and by the Norwegian Mapping Authority. The range of geographical coordinates of the bathymetry data is about 70°N-72°N and 26°E do 28°E. The grid spatial resolution about 0.5 minute is obtained by interpolation 1 minute bathymetry data ETOPO1.

To assess the accuracy of the model we have compared the results of simulations with in situ data provided by the Nordflux project. We have compared surface currents with data from high frequency (HF) WERA radar system from 10th June to 11th October 2014 and from 28th May to 17th August 2015. Subsurface currents and water temperatures have been compared with data from Nortek Continental 190 kHz ADCP deployed on a mooring (8th June – 24th June 2014). Thanks to in situ experiment taking place from 6th to 29th June 2014 and from 29th May to 18th June 2015 we could compare model results with vertical profiles of salinity and water temperature.

The project has been financed from the funds of the Leading National Research Centre (KNOW) received by the Centre for Polar Studies for the period 2014-2018. It has been also funded by the Norway Grants through the Polish-Norwegian Research Programme at the National Centre for Research and Development (contract No. 201985), Nordflux Project entitled: ‘Application of in situ observations, high frequency radars, and ocean color, to study suspended matter, particulate carbon, and dissolved organic carbon fluxes in coastal waters of the Barents Sea’.

# Lagrangian timescales in the Gulf of Finland

**Bert Viikmäe** and Tomas Torsvik
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Accurate prediction of surface currents is crucial for many applications, such as environmental monitoring, offshore commercial operations, military operations, marine renewable energy and shipping and safety at sea. Although numerical models can be used for such predictions, observational data of currents is still scarce for many sea areas.

The study of Lagrangian motion can be divided into the study of individual trajectories and the study of relative motion within a group, usually analyzed by particle pairs. Single particle analysis provides information about mean transport properties and diffusivity. A key parameter for such study is the Lagrangian "integral time", which depends on the velocity autocorrelation for single trajectories, and provides a basic indicator of Lagrangian predictability.

In this study we use observational data from field experiments carried out in the Gulf of Finland, in the Baltic Sea in order to determine Lagrangian timescales for our study area. We carried out several field experiments during 2014, involving passive surface drifters. We used a total of 20 passive drifters with 5 different deployments in spring, summer and autumn months.

The idea is to look at the ratio between the acceleration and velocity time scales y = Ta / Tv to separate Lagrangian trajectories in homogeneous classes in order to determine if motion can represented as a typical advection-diffusion problem (the classical approach) or if there is an evolution of the gflow on intermediate scale that should be accounted for. It has been observed in the surface drifters data in theworld's ocean basins, that that trajectories having different values of y are characterized by different shapes, correlation, and dispersal properties. If the trajectories have similar values of Ta and Tv, this is an indication of the influence of eddies.

The results demonstrate the complexity of surface current field in theGulf of Finland and provide us necessary input to numerical models for parameterisation of eddy diffusivity in order to obtain reliable current predictions.

# High resolution coastal ocean modeling for research and applications

**Sergey M. Varlamov**, Yasumasa Miyazawa and Toru Miyama
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Driven by practical requests, JCOPE group have acquired good expertise in development and implementation of high resolution nested ocean models with resolved horizontal scales of order 100-500 m. Compared to the lower resolution (~3 km) models that already resolved tidal variability, including internal tidal waves, these second-level nested models not only reproduce more details of ocean variability but also demonstrates re-distribution of energy to smaller scales and localized ocean phenomena. As an example, values of ocean current available kinetic energy in some coastal areas increases twice and more when estimated with 200 m resolution model compared with the lower 3 km resolution estimates. Other interesting example is the non-linear transformation of internal tidal waves approaching the coast which can not be reproduced by lower resolution models.

Our experience shows that these high resolution coastal models can provide to users the reliable, timely and detailed estimates for ocean dynamics. Such models can be used to predict surface and deep tidal currents, storm surges and other abrupt sea level changes, changes of thermal and bio-chemical conditions. With these goals in mind, an Application Laboratory of JAMSTEC developed system of nested downscaled ocean model for Japanese coastal waters. Highest resolution models are tested for the North-Eastern coast of Japan (Tohoku area), Wakayama, Tokara Strait and Bungo Channel areas. Examples of ocean modeling system implementations will be demonstrated and discussed.

An important issue is validation of such models. The behavior of internal tidal waves generated by tide on the shelf slopes, then propagating in ocean waters creating sharp shifts in ocean currents, could be compared with an available satellite images for this phenomena. Good consistency between observed and simulated propagation of such waves supports the reliability of used models.

# Circulation and dynamics I

4 July 2017 (Tuesday) 10:10 - 11:50

(Chair: J. Sheng)

## Numerical modeling on seasonal variations of the Bering Slope Current and associated eddies

**Humio Mitsudera** and Youichi Hirano

(*Hokkaido University, Japan*; humiom@lowtem.hokudai.ac.jp)

The Bering Slope Current (BSC) flows over the continental slope off the Bering Shelf. The BSC exhibits distinct seasonal variations; it is intensified over the continental slope during winter, and moves off-shelf during spring and summer. Eddies are generated associated with the BSC's off-shelf migration. In this paper we will discuss the seasonal variations of the BSC and the eddies using a high-resolution ocean model output. It was found that the BSC is intensified when a deepening signal of the pycnocline arrives from the Alaskan Stream as a topographic Rossby wave, passing through the straits along the Aleutian Islands. Eddies are generated as a result of baroclinic instability when the BSC is intensified. This implies that the seasonalvariations of the BSC and associated eddies are controlled remotely by the wind stress along the coast of the Gulf of Alaska.

# Spectral descriptions of submesoscale surface circulation in a coastal region off the East Coast of Korea

**Sung Yong Kim**, Jang Gon Yoo and Hyeon Seong Kim
(*Korea Advanced Institute of Science and Technology, Korea*; syongkim@kaist.ac.kr)

The spectral characteristics of hourly and 1-km resolution coastal surface currents obtained from an array of high-frequency radars of a coastal region off the East Coast of Korea are described in the frequency and wavenumber domains. The primary variance of the observed surface currents for a period of one year appears in the low-frequency (longer than 2 days), diurnal, and near-inertial frequency bands. The low-frequency surface currents exhibit more consistent variability with the regional geostrophic currents in summer than those in winter because of the relatively weaker wind conditions and a shallower mixed layer during summer. The diurnal surface circulation contains components that are coherent with diurnal land-sea breezes because of the development of the diurnal marine boundary layer. Clockwise near-inertial surface currents present decreasing amplitudes and spatially consistent on-shore phase propagations represented as a coastal inhibition, which is caused by coastal boundary effects on the near-inertial currents. The kinetic energy spectra of the surface currents in the wavenumber domain have decay slopes between $k^{-2}$ and $k^{-3}$, and their seasonal decay slopes are slightly steeper in winter than in summer. These findings can be interpreted that the submesoscale processes in this region can be related to both surface frontogenesis caused by regional mesoscale eddies with weak seasonality and baroclinic instability associated with the seasonal mixed layer and vertical fluctuations modulated by its harmonic frequencies.

# The role of Ekman drainage in numerical investigations of dense water cascading on a slope: Sensitivity to vertical resolution and bottom boundary condition

**Jarle Berntsen**, Guttorm Alendal, Helge Avlesen and Øyvind Thiem
(*University of Bergen, Norway;* jarle.berntsen@math.uib.no)

The flow of dense water along continental slopes is considered. There is a large literature on the topic based on observations, laboratory experiments and mathematical dense water plume models. In addition, there is a long range of numerical studies of dense water flows. In particular, there is a sequence of numerical investigations using the dynamics of overflow mixing and entrainment (DOME) setup. In these papers, the sensitivity of the solutions to numerical parameters such as grid size and numerical viscosity coefficients and to the choices of methods and models is investigated. By studying both the more theoretical papers on the dynamics of dense water flows, and the numerical investigations on the DOME setup, one may find that there are still open science questions. In this talk, some of these open questions are stated, and answers are sought by using a terrain following ocean model and the DOME setup. In particular, we address the sensitivity of the results to vertical grid size, bottom boundary condition for the case of large volume fluxes as in the DOME experiments and for a case with substantial reduced volume flux.

# Intrinsically and extrinsically forced circulation and associated biogeochemical response in China Seas

**Jianping Gan**
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We developed a new three-dimensional, high-resolution coupled circulation-biogeochemistry model for the entire China Seas (CS) region. The model considered the linked physics associated with the western boundary current, monsoonal wind, tidal forcings, and topography in both the CS and the adjacent oceans. From this well-validated model, we derived new insights into the three-dimensional seasonal circulation of the CS controlled by the intrinsic response to monsoonal wind forcing and extrinsic forcing of flow exchange with adjacent oceans through the straits and over the slope around the periphery of the CS. We found that the extrinsic forcings interact coherently with each other and with the interior circulation to jointly shape the CS circulation. Specifically, we revealed respective rotating layered circulations in the South China Sea, East China Sea and Yellow Sea, as well as their linkages with the intrinsic and extrinsic forcing. We also link the circulation with associated biogeochemical response by examining the pathway of waters that facilitates the vertical transport of nutrients and carbon from the depth into the euphotic zone where active biological metabolism takes place.

# Reconstruction of ocean's interior from observed sea surface information

**Lei Liu**
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Observational surface data are used to reconstruct the ocean's interior through the ''interior+surface quasigeostrophic'' (isQG) method. The input data include the satellite-derived sea surface height, satellite-derived sea surface temperature, satellite-derived or Argo-based sea surface salinity, and an estimated stratification of the region. The results show that the isQG retrieval of subsurface density anomalies is quite promising compared to Argo profile data. At 1000 m depth, the directions of retrieved velocity anomalies are comparable to those derived from Argo float trajectories. The reconstruction using surface density input field approximated only by SST (with constant SSS) performs less satisfactorily than that taking into account the contribution of SSS perturbations, suggesting that the observed SSS information is important for the application of the isQG method. Better reconstruction is obtained in the warm season than in the cold season, which is probably due to the stronger stratification in the warm season that confines the influence of the biases in the surface input data (especially SSS) in a shallow layer. The comparison between the performance of isQG with Argo-based SSS input and that with satellite-derived SSS input suggests that the biases in the SSS products could be a major factor that influences the isQG performance. With reduced biases in satellite-derived SSS in the future, the measurement-based isQG method is expected to achieve better reconstruction of ocean interior and thus is promising in practical application.

# Circulation and dynamics II

4 July 2017 (Tuesday) 13:00 - 14:20

(Chair: J. Berntsen)

## Development and Applications of Shelf Circulation Models for the Eastern Canadian Shelf

**Jinyu Sheng**

(*Dalhousie University, Canada*; Jinyu.Sheng@Dal.Ca)

Significant progress has been made by the regional ocean modelling group at Dalhousie University in the development and applications of numerical shelf ocean circulation models with different levels of complexity for coastal and shelf waters over the eastern Canadian sea board. As part of research projects for multi-agency research networks including the Ocean Track Network (OTN) and the Marine Environmental Prediction, Observation and Response (MEOPAR), four different ocean general circulation models have been used in the group, including NEMO (Nucleus for European Modelling of the Ocean, POM (Princeton Ocean Model), CANDIE (Canadian Version of DieCast) and ROMS (Regional Ocean Modelling System). In this presentation, three-dimensional (3D) circulation and hydrography over the eastern Canadian shelf produced by different models will be compared and analyzed. A brief discussion will be made on the implication of the semi-prognostic method and spectral nudging method in the models. These two methods are very simple and effective data assimilation schemes to reduce the systematic seasonal drift in the model by assimilating monthly hydrographic climatology into the model. A brief discussion will also be made on applications of model-calculated 3D, time-varying currents and hydrography in examining how distributions and migration of marine animals such as American eels and Atlantic salmon are affected by physical oceanographic conditions over the study region.

# Storm surges in the Western South Atlantic: patterns of generation and propagation from long hindcast simulations

**Ricardo de Camargo**
(*University of Sao Paulo, Brazil*; ricamarg@usp.br)

Mean sea level variability is a focus for the scientific community. In terms of the intrinsic relationship with the atmospheric transients, the mean sea level variability is something particular to each ocean basin, even considering the fetch extension or the geometry of the shelf. In the Western South Atlantic, the combination of the cyclogenetic area east of the Andes Mountains and the width of the Argentinean shelf is responsible for one of the most energetic places for storm surge generation and propagation. The available sea level records do not cover adequately in terms either of spatial distribution or the extension of the records. Then, a robust hindcast approach was used to perform a long term numerical integration for the period 1948-2010, allowing to specific analysis of the storm surge phenomenon. The modeled results showed good agreement with the coastal data, overestimating the surges in the central Argentina coast, and underestimating in the South-Southeast Brazil. From both observations and model, it is clear that the surges at central and northern Argentina are much higher than those at the southern locations, meaning that the main area for surge generation in the Western South Atlantic is located north of 47oS. The patterns of storm surge generation and propagation obtained with combined EOF methodology can be clearly related to the different stages of evolution of extratropical atmospheric transients, and the first four modes represented almost 75% of the total variability.

## Inertial instability and phase error in centered differncing and Euler-forward predictor-corrector schemes (cancelled)

**Jia Wang**, Ayumi Fujisaki-Manome, James Kessler, Haoguo Hu and Philip Chu
(*NOAA, U.S.A.*; jia.wang@noaa.gov)

This study investigates the inertial stability properties and phase error of numerical time integration schemes in several widely-used ocean and atmospheric models. These schemes include the most widely used centered differencing (i.e., leapfrog scheme or the 3-time step scheme at n-1, n, n+1), 2-time step (n, n+1) Euler scheme, 2nd, 3rd, and 4th-order Euler predictor-corrector schemes. The leapfrog scheme is proven to be neutrally stable with respect to Coriolis force since it preserves a perfect inertial motion with the amplification factor (AF) always being equal to unity, and overestimates phase speed. The Euler forward scheme is proven to be unconditionally inertially unstable since its AF is always greater than unity. To make the 2-time step Euler predictor-corrector schemes inertially stable, a split Coriolis terms must be used with an equal weight on both the old value (n) and the new predicted value (n+1*). It is found that 3rd- and 4th-order predictor-corrector schemes also introduce an artificial numerical solution. The inevitable phase error in a numerical scheme associated with the Coriolis parameter is analyzed in depth for some widely-used schemes. Some schemes overestimate the phase speed, while the others underestimate it. To preserve as best a phase frequency possible in a numerical model, alternating a scheme that has an overestimated phase with a scheme that has an underestimated phase is recommended. Considering all properties investigated, the leapfrog scheme is highly recommended for a time integration scheme. As an example, the comparison between the leapfrog scheme and Euler scheme is presented in the context of Great Lakes coupled ice-lake modeling.

# Evaluation and analysis of high-resolution models for oceans around Canada

**Youyu Lu**
(*Fisheries and Oceans Canada, Canada*; Youyu.Lu@dfo-mpo.gc.ca)

A series of high-resolution ocean forecasting models based on the Nucleus for European Modelling of the Ocean (NEMO), for basins, shelf and coastal seas around Canada, have been developed through efforts at Canadian government laboratories and universities. With horizontal resolutions ranging from 10 to 0.5 km, the models resolve some fine details of ocean variability. This presentation provides examples of evaluation and analysis on several key dynamics aspects, including eddy-circulation interaction, shelf –basin interaction, and coastal upwelling. The implications on improving the understanding of ocean predictability will be discussed.

# **Investigation of intrinsic ocean variability on the low-frequency variability of the northwestern Pacific subtropical mode water volume in a global ocean general circulation model** (OYSA)

**Sang Yeob Kim**, Ho Jin Lee, Jae-Hun Park, Yign Noh and Young Ho Kim
(*Korea Maritime and Ocean University, Korea*; syuip1224@gmail.com)

We here investigate the effect of intrinsic ocean variability on the low-frequency variability of the northwestern Pacific subtropical mode water (STMW) volume using a global Ocean General Circulation Model (OGCM). The OGCM used in this study is the Modular Ocean Model version 4.1 (MOM4p1) with 1/4° horizontal resolution and 50 vertical levels. The Smagorinsky biharmonic scheme is used for the horizontal viscosity and no explicit lateral diffusion is prescribed for the tracer. We use the K-Profile scheme for vertical mixing. In this study, we set up two cases of numerical experiment as different atmospheric forcing, which are MOM-NYF and MOM-IAF, respectively. The MOM-NYF experiment is forced by the annually repeated air-sea flux climatology data, which is the CORE2-Normal Year Forcing dataset, and run for 111 years. The MOM-IAF is initialized from 50 years of spin-up of the MOM-NYF, and then integrated for 61 years during 1949–2009 with the CORE2-InterAnnual Forcing dataset. The last 50 years results are used for the analysis in both models. The observed decrease of STMW volume in late 2000's is well reproduced by the MOM-IAF. The low-frequency variability of the STMW volume is generated, even as the MOM-NYF is forced by the annually repeated atmospheric forcing, and its magnitude is not negligible compared to that of the MOM-IAF and observation. This result implies that a portion of the observed STMW volume variability may be induced by the intrinsic ocean variability.

# Turbulence and Waves I

4 July 2017 (Tuesday) 14:40 - 16:30

(Chair: Y. Noh)

## Large Eddy Simulations of Wind- and Wave-Driven Turbulence; Implication from In-situ observations (Invited)

**Yutaka Yoshikawa**

(*Kyoto University, Japan*; yosikawa@kugi.kyoto-u.ac.jp)

Large-eddy simulations (LESs) are often used to study ocean surface turbulent flows, transports, and mixing. With the so-called "vortex-force term" in the momentum equation, previous LESs show that Langmuir turbulence (turbulence induced by interaction between surface waves and shear flows) exceeds the wind-driven (shear-driven) turbulence and dominates vertical mixing in the surface layer (e.g., Skyllingstad and Denbo 1995; McWilliams et al. 1997; Noh et al. 2004). These LESs also show that vertical velocity scale of the Langmuir turbulence is (U_*^2U_S)^(1/3), where U_* is the surface friction velocity and U_S is the surface Stokes drift velocity (Grant and Belcher 2009). On the other hand, field experiments of vertical velocity in the surface boundary layer (D'Asaro 2001; Tseng and D'Asaro 2004; Gargett and Grosch 2014) show that observed vertical velocity is proportional to U_* rather than (U_*^2U_S)^(1/3). The field experiment of the wind-driven flow in the strait between Japan and Korea (Yoshikawa and Masuda 2009) and corresponding LES (Ide and Yoshikawa 2015) also show that wave effects seem weak in the observed flow variations. In this talk, results of our recent field experiment of surface turbulent flows are shown and possible bridges between the previous LESs of Langmuir turbulence and field experiments are discussed.

## **Parameterizing TC-induced ocean cooling using neural networks** (OYSA)

**Jun Wei** and Guo-qing Jiang
(*Peking University, China*; junwei@pku.edu.cn)

This study proposed an algorithm that can potentially be used to provide flow-dependent sea surface temperature (SST) conditions for typhoon prediction models, based on an innovative technique involving machine-learning (ML). The algorithm is then implemented into a WRF model for the simulation of typhoon Soulik (2013) to assess its effectiveness, and the results show significant improvement in simulated storm intensities by including ocean cooling feedback. The ML-based algorithm is based on a neural network, consisting of multiple layers of input variables and neurons, and produces the best estimate of the cooling structure, in terms of its amplitude and position. Sensitivity analysis indicated that the typhoon-induced ocean cooling is a nonlinear process involving interactions of multiple atmospheric and oceanic variables. Therefore, with an appropriate selection of input variables and neuron sizes, the ML-based algorithm appears to be more efficient in prognosing the typhoon-induced ocean cooling and in predicting typhoon intensity than those algorithms based on linear regression methods.

# Simulation of wave-current interactions under hurricane conditions using FVCOM: The impact on Wave

**Yujuan Sun** and Will Perrie
(*Fisheries and Oceans Canada, Canada*; yujuan.sun@dfo-mpo.gc.ca)

The effect of wave-current interactions on wave field under hurricane conditions is investigated through the application of the unstructured-grid finite-volume community ocean model (FVCOM) coupled with the unstructured-grid surface wave model (SWAVE) in the North Atlantic Ocean. The model domain ranges from 20oN to 70oN and from 80oW to 30oW, which provides a large enough area to study the progression of wave-current interactions during hurricanes Juan (2003) and Bill (2009), in both deep and shallow waters. Simulations of ocean and wave parameters in each hurricane are shown to compare well with buoy and satellite altimeter observations, in terms of winds, significant wave heights, wave energy spectra and wave directions. The effect of currents on significant wave heights is shown to reach 0.4 m for hurricane Juan and 1.0 m for hurricane Bill. Simulation of wave-current interactions is shown to also improve the wave energy spectrum simulation at the peak of the storm

# The effect of diurnal cycle of surface heat flux on the ocean mixed layer
(OYSA)

**Yusuke Ushijima** and Yutaka Yoshikawa
(*Kyoto University, Japan*; usijimay@kugi.kyoto-u.ac.jp)

It is well known that solar radiation induces diurnal variation in both atmospheric and oceanic surface boundary layers. Despite of this evident feature, however, little attention has been paid to the diurnalcycle of upper ocean and its impact on longer-scale atmospheric and oceanic variability. Recently, Bernie et al. (2005) performed one-dimentional ocean mixed layer model and showed that the diurnalcycle of the SST induced by the diurnal cycle of heat flux intensifies intraseasonal variability of the SST in the equatorial Pacific. Furthermore, they implied that the diurnal cycle of heat flux deepens mixed layer depth (MLD) near equator. However, detailed processes of this MLD deepening is not well investigated. Because the MLD plays a critical role in the interaction between atmosphere and ocean by controlling the SST and can affect the longer-scale variability of atmosphere and ocean, we performed Large-eddy simulation of upper ocean under the diurnal cycle of the surface heat flux in order to understand the diurnal cycle effects on the MLD. Here two sets of simulations; one with diurnal cycle of solar radiation and the other without it, were performed for spring season. While heat gained at the surface was distributed over the whole wind-driven mixed layer in the experiment without the diurnal cycle, in the experiment with the diurnalcycle, heat was trapped near the surface in daytime and distributed over the mixed layer in night time. We found that the diurnal cycle of the surface heat flux changes the MLD. Noteworthy is that this effectdepends on latitude; the diurnal cycle makes the MLD deeper (shallower) at lower (higher) latitude. At higher latitude, the SST with the diurnal cycle can become higher by the order of 0.1K than that without the dirunal cycle because of shallower MLD. This might have an impact on longer-scale climate variability.

## **Scaling of the mixed layer depth under surface heating by using LES - the effect of initial stratification.** (OYSA)

**Yeonju Choi** and Yign Noh
(*Yonsei University, Korea*; ywn0709@yonsei.ac.kr)

Recent investigations, based on observation data analysis and LES results (Goh and Noh 2013; Yoshikawa 2015, Lee et al. 2015), revealed that the depth of a seasonal thermocline, formed from the deep mixed layer, can be scaled by the Zilitinkevich scale $L_Z$ (= $u_*^2/(fQ_0)^{1/2}$), instead of by the Monin-Obukhov scale $L_{MO}$ (= $u_*^3/Q_0$) that is previously known (Kraus and Turner 1967; Pearson et al. 2015), where $u_*$ and $Q_0$ are the frictional velocity and the buoyancy flux at the sea surface and $f$ is the Coriolis parameter. On the other hand, in the presence of the shallow preexisting MLD $h_0$, the formation of a seasonal thermocline tends to be suppressed, and $h$ is strongly affected by $h_0$ (Lee et al. 2015; Pearson et al. 2015). In order to clarify the effect of the preexising MLD on the MLD under surface heating, we carried out a large number of LES experiments with different conditions of $Q_0$, $f$, and $h_0$. It is found that presence of shallow $h_0$ tends to suppress the formation of a seasonal thermocline is suppressed, and consequently $h$ is largely determined by $h_0$, rather than by $L_Z$. Further, $h$ is found to become deeper than $h_0$, as $L_Z/h_0$ increases, contrary to the suggestion by Pearson et al. (2015).

# Turbulence and Waves II

5 July 2017 (Wednesday) 8:30 - 9:50
(Chair: V. Vlasenko)

## Arctic wave field reanalysis and observation in 2016

**Adrean Webb**, Takuji Waseda, Kazutoshi Sato and Jun Inoue
(*University of Tokyo, Japan*; adrean.webb@gmail.com)

As part of an ArCS project, The University of Tokyo is setting up a wave forecasting system to help identify hazardous areas and assist with ship navigation along the Northern Sea Route (NSR). Currently the spectral wave model NOAA WAVEWATCH III is one-way coupled with reanalysis data (wind and sea ice) to calculate outputs such as significant wave height and spectral wave periods.

To assist with validation, two drifting type wave buoys were deployed during a JAMSTEC Mirai cruise in September 2016. The buoys drifted for two months in the Beaufort and Chukchi Seas and measured significant wave heights exceeding 4 m during two storm events. Here, we will discuss details of the model setup pertinent for the NSR, analyze and compare model results with buoy measurements, and evaluate different forcing products.

# Application of a nested wave model for wave energy resource assessment

**Kaushik Sasmal**, Adrean Webb, Takuji Waseda and Shogo Miyajima
(*University of Tokyo, Japan*; kaushik.sasmal@gmail.com)

A nested wave model is implemented for wave energy resource assessment in Nakanosaku Port area located on the northeast coast of Japan. A high resolution SWAN model is nested within a coarse resolution SWAN model. The coarse resolution model (outer domain) uses structured grid and it has a resolution of ~1 km. The high resolution model (nested domain) uses unstructured grid and its resolution varies from ~ 5 m near the port to ~500 m on open boundary. Two breakwaters are included in the nested domain and the 5 m resolution unstructured grid is useful to resolve these breakwaters. Numerical simulations were carried out for a period of two years (2013–2014) using NCEP/CFSR hourly wind and JAMSTEC/JCOPE2 daily ocean current. Spectral boundary conditions for the outer domain SWAN model were obtained from a coastal WAVEWATCHIII model. Model simulated significant wave height is compared against NOWPHAS buoy observations at two locations (Fukushimakenoki and Onahama). The significant wave height from the model is consistent with buoy observation. The SWAN modelachieves a good correlation and skill score for significant wave height. In a comparison of significant wave height between structured/regular grid and unstructured grid reveals that the nested model with unstructured grid achieves a better correlation and improved skill score. This signifies the importance of high resolution unstructured grid in wave modeling for a coastal region. The computed waveenergy from SWAN model shows that wave energy of ~10 to 20 kW/m (depending on season) can be generated near the port area. This study indicates that the Nakanosako Port area has a reasonable potential for wave energy generation due to its favorable wave climate and its geographic location.

## A numerical study of scattering of CTWs into Jervis Bay, Australia (OYSA)

**Fanglou Liao** and Xiao Hua Wang
(*University of New South Wales, Australia*; Fanglou.Liao@student.adfa.edu.au)

Coastal-trapped waves (CTWs) is a low frequency long wave, which widely exists along most of coastal waters all around the world. This sub-inertial wave motion can have significant influence on coastal embayment and its exchange process with open shelf water. A typical example of such embayment is Jervis Bay along Australian East coast. It has been found that low frequency baroclinic circulation exists within the bay, and this may be driven by several forcing, one of which is the CTWs propagating along Australian East coast. To further understand the generation mechanism of Jervis Bay's sub-tidal baroclinic circulation, a set of numerical experiments have been designed and conducted based on Princeton Ocean Model (POM), so that the relative importance of local wind stress and remote CTWs is examined. Although the mouth width of Jervis Bay is much shorter than the CTWs wavelength, small internal Rossby radius of deformation makes it possible for open shelf CTWs to scatter part of its energy into Jervis Bay under baroclinic condition. This scatteringprocess has been argued to be the main mechanism generating CTWs in Jervis Bay. We also studied the interaction between the scattered CTWs and the remaining CTWs along East coast . In addition, as a small semi-closed embayment, exchange process with open shelf has significant impact on Jervis Bay's dynamics and environment, and influences from CTWs on the exchange process have been discussed.

## **Approximate dispersion relation for surface waves atop an arbitrarily depth-varying current** (OYSA)

**Yan Li** and Simen Å Ellingsen
(*Norwegian University of Science and Technology, Norway*; yan.li@ntnu.no)

We present and compare different approximate approaches to the dispersion relation for surface water waves on a current whose direction and magnitude may vary arbitrarily with water depth. In particular, we derived a second-order approximation that has been shown to be good at all wavelength. We argue that this new approximation is more robust and has a wider range of applicability than the three dimensional generalization of the widely used approximation by Kirby and Chen [1989] (KCA). The KCA (or its 3D generation) itself is excellent for a wide range of currents, but the exact criteria that explain its applicability have not been shown due to the fact that Kirby & Chen model works well in cases where their assumption on which they obtained their approximation is violated. We have also worked out the proper explanation for this mismatch. We provided several examples including both realistic shear profiles and extreme cases to test and compare different approximate methods.

# Turbulence and Waves III

5 July 2017 (Wednesday) 10:10 - 11:30

(Chair: Y. Yoshikawa)

## Tidal energy focusing over an isolated underwater bank: observations and modelling

**Vasiliy Vlasenko**, Nataliya Stashchuk, and Alex Nimmo-Smith
(*The University of Plymouth, the United Kingdom*; vvlasenko@plymouth.ac.uk)

Focusing of baroclinic tidal energy over Anton Dohrn Seamount (ADS, North Atlantic) is analysed using observational data and numerical modelling. Observed large vertical oscillations of isotherms in the bottom layers at the periphery of ADS and in the surface layers over the ADS summit were replicated numerically using the MITgcm. The elevated internal tidal activity over the ADS is explained in terms of the upward propagation and focusing of multiple internal tidal beams generated at the seamount periphery. The near-circular shape of ADS and steep bottom topography in the deep part (steeper than the tidal beam) create favourable conditions for the lens-like focusing of tidal energy in the ADS centre.. Observations and modelling show that the energy focusing greatly intensifies local diapycnal mixing.

# **Long-range propagation and associated variability of internal tides in the South China Sea** (cancelled)

**Zhenhua Xu** and Yang Wang
(*Chinese Academy of Sciences, China*; xuzhenhua@qdio.ac.cn)

The variability of internal tides during their generation and long-rangepropagation in the South China Sea (SCS) is investigated by driving a high-resolution numerical model. The present study clarifies the notably different processes of generation, propagation and dissipation between diurnal and semidiurnal internal tides. Internal tides in the SCS originate from multiple source sites, among which the Luzon Strait is dominant, and contributes approximately 90% and 74% of the baroclinic energy for M2 and K1, respectively. The tidal beams from the Luzon Strait can travel across the deep basin and finally arrive at the Vietnam coast and Nansha Island more than 1000-1500 km away. During propagation, M2 internal tides maintain a southwestward direction, whereas K1 exhibit complicated wave fields because of the superposition of waves from local sources and island scattering effects. After significant dissipation within the Luzon Strait, the remaining energy travels into the SCS and reduces by more than 90% over a distance of ~1000 km. Inside the SCS, the K1 internal tides with long crests and flat beam angles are more influenced by seafloor topographical features and thus undergo apparent dissipation along the entire path, whereas the prominent dissipation of M2 internal tides only occurs after their arrival at Zhongsha Island.

# Equatorial waves and their impact on circulation and air-sea interaction in the Somali Current region

**Tommy G. Jensen**
(*U.S. Naval Research Laboratory, U.S.A.*; Tommy.Jensen@nrlssc.navy.mil)

The U.S. Navy's Coupled Ocean-Atmosphere Mesoscale Prediction System is used to understand and quantify the upper ocean physical processes that determine the air-sea interaction, mixed layer dynamics, ocean circulation dynamics and space-time variability in the Northwestern Indian Ocean and Arabian Sea.
The COAMPS atmosphere component is fully coupled to the Navy Coastal Ocean Model (NCOM) and the Simulating WAves Nearshore (SWAN) wave model. Data assimilation using a 3D-variational approach is included in hindcast runs performed daily since June 1, 2015.
Our focus is on the impact of equatorial waves on eddies and boundary current along the African coast and the resulting air-sea interaction.
Wind changes over the equatorial belt generate quatorial elvin aves, equatorial Rossby waves, Yanai waves, and equatorial jets. Westward propagating planetary waves affect the Somali Current and its eddies. Equatorial jets affect the reversal of the Somali Current in both monsoon seasons.
Previous studies have concentrated on the strong eastward Wyrtki Jets in May and November. Westward jets have received little attention. It is found that the westward jets increase the SST gradient in the western equatorial Indian Ocean, which affect the deep convection in the atmosphere and can initiate intra-seasonal oscillations. It is also found that positive SST anomalies in the Somali Current eddies, locally increase wind speed in the atmospheric boundary layer, increase significant wave height and increase heat flux to the atmosphere. Negative SST anomalies has the opposite effects.

# Impact of the incorporation of the salinity effect into atmospheric model on simulated precipitation

**Eunjeong Lee**
(*Korea Institute of Atmospheric Prediction Systems, Korea*; ej.lee@kiaps.org)

In atmospheric models, latent heat flux over water is computed through the difference in moisture between the water body and air. In addition, water surface is assumed to be saturated with respect to pure water. In this paper, we address the impact of salinity when computing the saturated vapor pressure (SVP) over the oceans based on Raoult's Law. This revised SVP, which is smaller than that of pure water, is found to enhance vertical mixing in the planetary boundary layer (PBL) by reducing the latent heat flux and increasing the sensible heat flux. In a medium-range forecast testbed, this revised algorithm is found to improve the skill of simulated precipitation by suppressing light precipitation over the tropical oceans.

# Marine ecosystem modeling I

5 July 2017 (Wednesday) 13:00 - 14:30

(Chair: F. Chai)

### Role of Ocean bio-geochemical processes in Arctic climate variability

(Invited)

**Jong-Seong Kug**, Jong-Yeon Park, and Hyung-Gyu Lim

(*Pohang University of Science and Technology, Korea*; jskug1@gmail.com)

Phytoplankton have attracted increasing attention in climate science due to their impacts on climate systems. A new generation of climate models can now provide estimates of future climate change, considering the biological feedbacks through the development of the coupled physical–ecosystem model. Here we present the geophysical impact of phytoplankton, which is often overlooked in future climate projections. A suite of futurewarming experiments using a fully coupled ocean−atmosphere model that interacts with a marine ecosystem model reveals that the future phytoplankton change influenced by greenhouse warming can amplify Arctic surface warming considerably.

The warming-induced sea ice melting and the corresponding increase in shortwave radiation penetrating into the ocean both result in a longer phytoplankton growing season in the Arctic. In turn, the increase

in Arctic phytoplankton warms the ocean surface layer through direct biological heating, triggering additional positive feedbacks in the Arctic, and consequently intensifying the Arctic warming further. Our results establish the presence of marine phytoplankton as an important potential driver of the future Arctic climate changes.

# Eddies affect marine biology in the South China Sea: Interactions with wind mixing

**Peng Xiu**
(*South China Sea Institute of Oceanology, China*; pxiu@scsio.ac.cn)

Mesoscale eddies can influence biogeochemical cycles through both vertical nutrient or plankton flux and horizontal advection of nutrient or plankton in eddy periphery. In this study, we focus on the effects of wind mixing in terms of its modulation on the eddy efficiency changing the biogeochemical structures in the upper ocean. We found that the strong wind mixing before the formation of mesoscale eddies can generally produce stronger phytoplankton blooms than normal preconditions. The dynamics for the difference were further examined by using an analytical eddy model with submesoscale dynamics in it. The results show that the precondition with strong wind mixing is prone to generate submesoscale adjustments associated with strong and patchy nutrient injection which further transfers into phytoplankton biomass. This study highlights the importance of submesoscale dynamics on phytoplankton blooms inside mesoscale eddies.

# Impact of vertical mixing changes on air-sea CO$_2$ fluxes in the Southern Ocean

**Hajoon Song**, John Marshall, Jean-Michel Campin and Dennis J. McGillicuddy Jr.
(*Massachusetts Institute of Technology, U.S.A.*; hajsong@mit.edu)

We report the significant impact of vertical mixing on air-sea CO$_2$ fluxes using offline simulations of a biogeochemical model in the Southern Ocean (SO).
Two sets of carbon cycle simulations are compared. In the first set, the carbon cycle is forced by the ocean circulations with a wide range of eddy activities but with the same mean states including the surface vertical mixing. In the second set, on the other hand, the verticalmixing is determined during the offline simulation by the given ocean states.
While the CO$_2$ flux shows little changes in the first set, reduction in outgassing of CO$_2$ occurs in the second set by up to 0.25 Pg C yr$^{-1}$ in winter, a full 1/3 of the seasonal variability in SO CO$_2$ flux.
Reduction in outgassing rates is a consequence of reduced verticalmixing and associated mixed layer depth (MLD) shallowing, by $O$(100 m). This lowers the supply of carbon-rich deep water into the surface layer and suppresses outgassing.

# The physical and biological roles of mesoscale eddies on migration of Japanese eel larvae in western Pacific Ocean

**Yu-Lin Eda Chang**, Yasumasa Miyazawa, Mélanie Béguer-Pon, Yu-San Han, Kyoko Ohashi and Jinyu Sheng
(*National Taiwan Normal University, Taiwan*; ychang@ntnu.edu.tw)

In this study, we explore the contributions of passive physical trapping and the active biological food-approach behavior in mesoscale eddies to the fish larvae migration using the example of Subtropical Counter Current eddies and the migration of Japanese eel larvae in the western North Pacific Ocean. An idealized experiment is conducted to isolate the effects of eddies, and use a three-dimensional particle-tracking method to simulate virtual eel larvae (v-larvae) migration, including horizontal, vertical swimming, and food-approach behaviors. Considering only the effect of physical trapping, the impact of eddies strongly depends on the swimming speed of v-larvae relative to the eddy speed. Eddies accelerate the movement of v-larvae that swim slower than the propagation speed of the eddy, whereas faster-swimming v-larvae are dragged by eddies. A modified stream function that incorporates biological swimming ability explains the non-uniform trapping of v-larvae in mesoscale eddies. A high swimming speed and/or a small eddy rotation speed results in a weak trapping capacity. V-larvae carrying food-approach behavior can remain in eddies with a longer period in comparison to those with physical trapping only. The rich food source in the cold eddy attracts v-larvae to stay inside eddies for a longer time. The retention time in eddies corresponds to the food supply may further influence the growth of larvae.

# Marine ecosystem modeling II

5 July 2017 (Wednesday) 14:50 - 16:30

(Chair: H. Song)

## Natural and Artificial Iron Fertilization in the Ocean

**Fei Chai**

(*State Key Laboratory of Satellite Ocean Environment Dynamics, China*; fchai@maine.edu)

Iron regulates phytoplankton productivity in high nutrient and low chlorophyll (HNLC) areas of the world ocean. There are several natural pathways for iron entering the upper ocean: iron deposition during atmospheric dust events; volcanic ash deposition; mesoscale ocean eddy transport of iron to HNLC areas. A few examples of natural iron fertilization events that cause phytoplankton blooms in the ocean will be presented. During the past two decades, there were 14 artificial iron fertilization experiments, in which iron is added to the upper ocean in HNLC regions deliberately. Some key results and unresolved issues from these artificial iron fertilization experiments will be discussed. One recent iron fertilization experiment was conducted in August 2012, during which the Haida Salmon Restoration Corporation dumped over 100 tons of an iron-containing substance into surface waters of a Haida eddy in the Gulf of Alaska. Here, we use available satellite bio-optical measurements from the MODIS/Aqua instrument and AVISO altimeter dynamic height data to examine the timing, magnitude and extent of this artificial ironfertilization experiment. This iron fertilization experiment induced the most intensive phytoplankton bloom of the past 10 years in the Gulf of Alaska. The extent to which this localized iron fertilization experiment may impact higher trophic levels such as salmon remains uncertain.

# Modelling of larvae dispersion over isolated seamount

**Nataliya Stashchuk** and Vasiliy Vlasenko
(*The University of Plymouth, the United Kingdom*; nstashchuk@plymouth.ac.uk)

The connection between the population of corrals at different North East Atlantic Seamounts and tides was the aim of 136 research cruise RRS ``James Cook" in May-June 2016. The drop-frame camera and remotely operating vehicle were used to collect and fix biological samples. The main oceanographic part with moorings and CTD-LADCP stations was performed on Anton Dohrn Seamount. The modelling part was done using the MITgcm. For reconstruction of larvae trajectories a Lagrange-type method was used. The larvae were considered as floating particles that can be carried away by tidal currents. We used a method of multivariate interpolation on a 3-dimensional regular grid based on 5-minutes output of the MITgcm velocities to predict the position of particles at some designated moment of time. The time span of 40 days was chosen because of this life time is required for larvae of marine corrals to complete their cycle. From large amount of experiments with particles it was found that some of the particles move around the bank and drop at different areas at the bottom, the other can leave the seamount.

# The Oceanic Control of Atmospheric CO2: An Insight from a Model Study

**Eun Young Kwon**
(*Pusan National University, Korea*; ekwon957@gmail.com)

The global carbon cycle has undergone large changes on various timescales. Present day atmospheric pCO2 has risen to 400 ppm from the preindustrial value of 280 ppm. While the present change in atmospheric pCO2 is anthropogenic in origin, during glacial-interglacial cycles, natural changes occurring between 180 ppm and 280 ppm are most likely driven by oceanic physical and biogeochemical processes. In my presentation, I will talk about how the soft-tissue and carbonate pumps are coupled with ocean circulation to determine the distribution of dissolved inorganic carbon in the ocean and the air-sea carbon partitioning. I will use an offline 3D ocean biogeochemistry model to show the sensitivity of atmospheric CO2 to changes in the strengths of the soft-tissue and carbonate pumps. Using a stable carbon isotope model combined with observations, I will show how changes in deep water residence time can control sequestration of respired carbon in the ocean's interior. From this presentation, I hope to give you an insight into the oceanicrole in the glacial-interglacial carbon cycles.

# Physical-biological model and its scientific research in the Taiwan Strait

**Yuwu Jiang**, Huasheng Hong, Xinyou Lin, Jia wang, Enhui Liao and Zhaoyun Chen
(*Xiamen University, China*; ywjiang@xmu.edu.cn)

The Taiwan Strait Nowcast/Forecast System (TFOR), which is based on the Regional Ocean Modeling System (ROMS), is the first operational ocean model to include physical and biological processes in the Taiwan Strait (TWS). In this study, we assessed the performance of TFOR, thereby illustrating the ability of TFOR to reproduce significant physical and biological processes. With the use of this model, some scientific problems have been studied. This issues include the upwelling dynamics, the cold disaster in 2008, the winter Bloom in the TWS and the Luzon Bloom etc. Besides, a two-way nesting approach is utilized in the model to simulate the hydrodynamic processes in estuaries along the western coast of the TWS. For example, the environmental impact of the warm water discharge from the nuclear power station is assessed, and the sea surface floating garbage from the Jiulong River to the TWS is predicted for maritime office.

# **Spatial variability of phytoplankton assemblages during the intermonsoon in baler bay, outer and inner casiguran sound, aurora, northeastern philippines.** (OYSA)

**Aime L. Dela Pena**, Rhodora V. Azanza, Cesar Villanoy,
Ephrime Metillo and Aletta Yniguez
(*University of the Philippines, Philippines*; aime_mb@yahoo.com)

Phytoplankton community changes in relation to environmental parameters were compared between and within the three interconnected basins. Phytoplankton samples were collected from thirteen stations of Baler Bay and Casiguran Sound, Aurora last May 2013 by filtering 10 L buckets of surface water and 5 L Niskin samples at 20 meters and at 30 to 40 meters depths through a 20um sieve. Duplicate samples per station were preserved, counted and identified up to genus level, in order to determine the horizontal and vertical spatial variation of different phytoplankton functional groups during the summer ebb and flood flow.

Baler Bay, Outer and Inner Casiguran Sound had a total of 89 genera from four phytoplankton groups: Diatom (62), Dinoflagellate (25), Silicoflagellate (1) and Cyanobacteria (1). Non-toxic diatom Chaetoceros spp. bloom (averaged 2.0 x 105 to 2.73 x 106 cells L-1) co-existed with Bacteriastrum spp. at surface waters in Inner and Outer Casiguran. Pseudonitzschia spp. (1.73 x 106 cells L-1) bloomed at bottom waters of the innermost embayment near Casiguran mangrove estuary. Cyanobacteria Trichodesmium spp. significantly increased during ebb tide at the mid-water layers (20 meters depth) in the three basins (ranged from 6, 900 to 15, 125 filaments L-1), forming another bloom. Gonyaulax spp. - dominated dinoflagellate did not significantly change with depth across the three basins. Overall diatoms and dinoflagellates community assemblages significantly changed between sites ($p < 0.001$) while diatoms and cyanobacteria varied within Casiguran Outer and Inner sites ($p < 0.001$) only. Tidal fluctuations significantly affected dinoflagellates and diatom groups ($p < 0.001$) in Inner and Baler sites. Chlorophyll significantly varied between (KW, $p < 0.001$) and within each basins (KW, $p < 0.05$), no tidal influence, with highest value at Inner Casiguran and at deeper waters indicating Deep Chlorophyll Maxima.

Aurora's distinct shelf morphology favoring counterclockwise circulation pattern, advective transport and continuous stratification of the water column could basically affect the phytoplankton assemblages and water quality of Baler Bay and Casiguran Inner and Outer Basins. Observed spatial phytoplankton community changes with multi-species diatom and cyanobacteria bloom at different water layers of the three inter-connected embayments would be vital for any environmental management initiatives in Aurora.

# Data assimilation and ocean prediction I

6 July 2017 (Thursday) 8:30 - 10:00

(Chair: Y. H. Kim)

### **Ocean forecasting: from descriptive to quantitative science** (Invited)

**Nadia Pinardi**, S.Ciliberti, E.Clementi, G.Coppini, M.Drudi, I.Federico, C. Fratianni, A. Grandi, R. Lecci, G. Mannarini, J. Pistoia, S. Simoncelli, A. Sepp-Neves, F. Trotta and G. Verri

(*University of Bologna, Italy*; nadia.pinardi@unibo.it)

Numerical ocean forecasting represents a continuous advancement in oceanographic knowledge and the source of inspiration for practical applications of societal relevance. An historical review of the progress will be presented. The ocean dynamics is multi-scale and nonlinear, limiting the deterministic predictability to few weeks and requiring statistical and deterministic models of the ocean dynamics to be coupled in an attempt to extend such limits. The general methodology for ocean analysis and forecasting is explained and reviewed together with new advancements in the coupling between hydrological and ocean models and new limited area, relocatable models. Ensemble methods of assessing the forecast uncertainty sources will also be shown as well as applications of ocean analyses and forecasts to oil spill mapping and ship routing.

# Predicting tides for new sites using 25 hour sea-level observations

**Do-Seong Byun** and Deirdre E. Hart
(*Korea Hydrographic and Oceanographic Agency, Korea*; dsbyun@korea.kr)

An improved technique for predicting tidal heights for new locations, based on as little as 25 hours of temporary sea level observations plus 28 days or more of reference station records, is described and evaluated. Comparisons are made between the existing prediction methods of 'conventional tidal harmonic prediction' and 'tidal species modulation'. An advanced hybrid procedure is then developed in order to produce a 'complete tidal species modulation (CTSM)' equivalent of the tidal harmonic prediction method, which includes the nodal factors and angles, and astronomical arguments as well as tidal species tidal constant correction terms. The new approach (CTSM+TCC) usingCTSM with tidal constant correction surmounts the sea-level record length restrictions of conventional tidal harmonic constants derived prediction methods. Further, the performance of our CTSM+TCC is conducted and evaluated using sea-level observation data from Korean and New Zealand sites with contrasting tidal regimes. Finally, the results show that the most adequate 25 hour sea-level height sample periods are spring tidal periods and specific annual periods, maximizing tide prediction accuracy.

# Operational tide/storm surge and wave prediction system at KMA

**Kun-Young Byun**, Hyunmin Eom, Homan Lee and Sung Hyup You
(*Korea Meteorological Administration, Korea*; buildg@korea.kr)

The Korea Meteorological Administration (KMA) has operated tide/storm surge and wave prediction system. This study shows the development and the verification of operational ocean models and future plans of KMA. The system consists of regional(8km)/costal(1km) tide/storm surge models on the basis of WAVEWATCH III and global(50km)/regional(8km)/costal(1km) wave models based on Princeton Ocean Model. Sea surface wind and pressure from the Regional Data Assimilation and Prediction System is used for forcing input of regional/costal models. The coastal tide/storm surge and wave models are set up for 5 Regional Offices of Meteorology areas (Seoul Metropolitan, Daejeon/Jeonju, Gwangju, Gangwon, Jeju, Busan/Daegu) with 1-km spatial resolution. The coastal models are running twice a day with every 3 hourly forecasts out to 72 hours. The global moored buoy data (including the coastal buoys operated by KMA) and remote sensing data are used for verification of sea surface wind and significant wave height from the models.

# The effect of density stratification on the prediction of global storm surges

**Tsubasa Kodaira**, Keith R. Thompson and Natacha B. Bernier
(*The University of Tokyo, Japan*; kodaira@edu.k.u-tokyo.ac.jp)

With the long-term goal of developing an operational forecast system for total water level, we conduct a hindcast study of global storm surges for Fall 2014 using a baroclinic ocean model based on the NEMO framework. The model has 19 vertical levels, a horizontal resolution of 1/12°, and is forced by hourly forecasts of atmospheric wind and air pressure. Our first objective is to evaluate the model's ability to predict hourly sea levels recorded by a global array of 257 tide gauges. It is shown that the model can provide reasonable predictions of surges for the whole test period at tide gauges with relatively large tidal residuals (i.e., gauges where the standard deviation of observed sea level, after removal of the tide, exceeds 5 cm). Our second objective is to quantify the effect of density stratification on the prediction of global surges. It is found that the inclusion of densitystratification increases the overall predictive skill at almost all tide gauges. The increase in skill for the instantaneous peak surge is smaller. The location for which the increase in overall skill is largest (east coast of South Africa) is discussed in detail and physical reasons for the improvement are given.

# Data assimilation and ocean prediction II

6 July 2017 (Thursday) 10:20 - 11:40

(Chair: N. Pinardi)

## **Applications and studies using adjoint models based on the Meteorological Research Institute Community Ocean Model (MRI.COM)** (Invited)

Yosuke Fujii and Norihisa Usui
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JMA/MRI have developed an ocean adjoint model based on Meteorological Research Institute Community Ocean Model (MRI.COM), and applied it to a four-dimensional variational (4DVAR) ocean data assimilation system for the western North Pacific. This system have employed for the calculation of the 4DVAR Ocean Reanalysis for the western North Pacific over 30 years (FORA-WNP30). The system improves representation of meso-to-submeso-scale ocean phenomena, including small variations of the Kuroshio path and southward intrusion of the Oyashio, over the three dimensional variational (3DVAR) version of the same system. In addition, accuracy of the coastal sea level variations around Japan is effectively improved. The adjoint ocean model have also allowed us to perform a singular vector analysis for seeking a trigger of the Kuroshio large meander formation. It have also been used for identifying the pathway of the low salinity Oyashio water that reaches south of Japan and forms the North Pacific Intermediate Water.

# Updating ocean model/data assimilation components of the JCOPE2 operational ocean forecast system for biogeochemical applications

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To investigate ocean acidification processes in the north western Pacific, we are developing a carbon cycle model including a NPZD-type marine ecosystem component coupled with the JCOPE2 operational ocean forecast system. Prior to biogeochemical-physical model coupling, we have improved both ocean model and data assimilation parts in the JCOPE2 ocean forecast system. Modification of the model component includes 1) replacement of the baroclinic pressure gradient scheme from the forth order to the rotated one, 2) replacement of the turbulent mixing model from Mellor and Yamada's level 2.5 to its modified version by Nakanishi and Niino, 3) inclusion of a sea ice model, 4) parameterization of fresh water flux from small rivers using coastal precipitation information. The data assimilation part is also modified based on a multi-scale 3DVAR scheme for effective assimilation of high-resolution satellite sea surface temperature and in-situ temperature/salinity profiles data. We discuss improvements in the skill of the modified JCOPE2 forecast system and report the on-going modeling effort for the marine carbon cycle simulation.

# Climate initialization applying ocean data assimilation for a ENSO prediction system

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El Niño and Southern Oscillation is one of the most well-known and important climate phenomena. Although the ENSO appears in the tropical Pacific, it interacts with climate variability over the world, which impacts the human life by various ways. KIOST has been developed an ENSO prediction system by applying the ocean data assimilation and wind bias correction to a fully coupled climate model, GFDL CM2.1. The ocean observation data are assimilated into its ocean component model through the data assimilation system of the KIOST (DASK) while other component models are freely integrated. Even though atmospheric observation variables are not assimilated, the wind bias of the DASK has been corrected through applying a simple wind bias correction when calculating the air-sea fluxes. We evaluated the variability of the ocean climate in the climate reanalysis by the DASK from 1947 to 2012. The DASK represents global temperature and salinity well, not only at the surface but also at intermediate depths in the ocean. The DASK's ocean climate variability also matches well with observations of the ENSO, Pacific Decadal Oscillation and Indian Ocean Dipole. The heat content of the DASK shows a good correlation with real-world observations. In this study, we use the reanalysis data from the DASK as an initial condition of our ENSO prediction system. To evaluate the ENSO prediction system, hindcast experiments have been conducted during 30 years from 1982 to 2011, which suggests that the ocean initialization and wind correction significantly improve the ENSO prediction skill. The sensitivity of the ENSO prediction skills to the ocean initialization and wind bias correction will be discussed in more detail in our study.

# *Poster Presentations*

## Climate dynamics and modeling

### An epoch-dependent change in driver of heat storage rate variability during recent decades in the upper western North Pacific

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The upper 400 m heat budget obtained from a high-resolution ocean general circulation model for recent decades suggests that winter heat storage rate (HSR) on interannual to decadal time scales is mainly determined by oceanic heat advection rather than by net air-sea heat flux (HF) in the western North Pacific region. The role of heat advection in driving the HSR variability becomes particularly prominent after 1990. Similar observation that there is a significant epoch-dependent change in the relative contribution of surface HF and ocean heat advection to winter HSR is also found by analyzing NCEP heat flux and HadISST datasets. The net HF acts to dampen temperature anomalies caused by the ocean dynamics while the HF could play an important role before 1990 due to its stronger variability caused by $\Delta T$ (air-sea temperature difference) variability. On the other hand, the variability of ocean heat advection, which represents ocean dynamics, is not very sensitive to the selection of periods. The ocean dynamics causing the upper-ocean heat storage rate is principally associated with the meridional shift of the Oyashio Extension front, which is significantly correlated with both the West Pacific and Pacific-North America teleconnection patterns.

# A global spectral element model for Poisson equations and advective flow over a sphere

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A global spherical Fourier-Legendre spectral element method (SFL-SEM) is proposed to solve Poisson equation and advective flow over a sphere. In the meridional direction, Legendre polynomials are used and the region is divided into several elements. In order to avoid coordinate singularities at the north and south poles in the meridional direction, Legendre-Gauss-Radau (LGR) points are chosen at the elements involving the two poles. Fourier polynomials are applied in the zonal direction for its periodicity, with only one element. Then the partial differential equations are solved on the longitude-latitude meshes without coordinate transformation between spherical and Cartesian coordinates. For verification of the proposed method, a few Poisson equations and advective flows are tested. Firstly, the method is valid for test cases with smooth solution. The results of Poisson equations demonstrate that the present method exhibits high accuracy and exponential convergence. High-precision solutions are also obtained with nearly negligible numerical diffusion during time evolution for advective flow with smooth shape. Secondly, the results of advective flow with non-smooth shape and deformational flow are also shown to be reasonable and effective. As a result, the present method is proved to be capable of solving flow through different types of elements, and thereby a desirable method with reliability and high accuracy for solving partial differential equations over a sphere.

# **Potential decline of Atlantic Meridional Overturning Circulation under melting Greenland Ice Sheet** (OYSA)

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Atlantic Meridional Overturning Circulation (AMOC), a part of Thermohaline Circulation (THC) in the Atlantic play an important role in the climate system, and it transports large amount of water, heat, and nutrients around the world. The recent Intergovernmental Panel on Climate Change (IPCC) report indicated that the AMOC is getting weaker but is unlikely to break down in the end of this century. In recent decades, melting in Greenland Ice Sheet (GrIS) is accelerating and the melting water has increased significantly. However, the melting effect from GrIS was not taken into account for AMOC projection in the IPCC report.
GrIS melting ice could provide abundant freshwater into north Atlantic Ocean and the sea surface salinity could decline in the Greenland region. The idealized experiment is conducted based on the Princeton Ocean Model to simulate the change of ocean circulation in North Atlantic Ocean under the large melting ice (freshening) condition.

# **Feedback Process Responsible for Inter-Model Diversity of ENSO variability** (OYSA)

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The El Nino-Southern Oscillation (ENSO) is a phenomenon with a dominant interannual variability over the tropical Pacific. Because of its severe global impact, the accurate forecasting ENSO is very important issue for society and ecosystem. Despite of the continues improvement of climate model, the inter-model diversity in simulating ENSO still clearly exists. Here, the origin of inter-model diversity of ENSO variability is examined by computing coherent eigen modes (SVD mode) between the inter-model tropical Pacific sea surface temperature anomalies (SSTA) variance and inter-model ENSO stability index (BJ index). In the first mode, SSTA variance has ENSO-like pattern and the most relative feedback is the thermocline feedback. Inter-model thermocline feedback is mainly related to inter-model β_h coefficient, which is the sensitivity of the zonal thermocline gradient response to the zonal wind in equatorial Pacific. Inter-model β_h is correlated to meridional shape and intensity of inter-model off-equatorial wind stress curl. Therefore, it can be inferred that the wind response to ENSO-related SST can cause the inter-model diversity of ENSO variability by affecting the off-equatorial oceanic Rossby wave.

# The evaluation on high frequency ground wave radar surface current observation system in Gulf of Thailand

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Taking the high frequency radar system of the Gulf of Thailand as an example, we established a three-dimensional ocean circulation model using FVCOM. A series of observation system evaluation experiments were carried out to assess the performance of the existing highfrequency ground wave radar surface current observation system. The simulated surface current data in three observation regions were assimilated sequentially using an efficient ensemble kalman filter data assimilation method. The experimental results showed that the coastal surface current observation system could play a positive role in improving the current estimation in numerical simulation. Compared with the control experiment without assimilation, simulation precision of surface and subsurface current in the entire study area had been improved to some degree after the simulated surface current data being assimilated into model. So to some extent, the existing observation system could meet the needs of forecasting work in operation. But the improvement effect for different observation regions was more discrepant. The average contribution rate to surface current simulation was 58.3%, 7.8% and 1.9% which meant the needs of an additional optimization in the future. In addition, this study used the ensemble transform Kalman filter optimal observation scheme to explore the ideal deployment of observational stations, which could be a useful guidance for future re-design of this observation system.

# Coastal modeling

## Case Study on the three-dimensional structure of meso-scale eddy in the South China Sea based on a high-resolution model

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Meso-scale eddies are important features in the South China Sea (SCS). The eddies with diameters of 50-200 km can greatly impact the transport of heat, momentum, and tracers. A high-resolution wave-tide-circulation coupled model was developed to simulate the meso-scale eddy in the SCS in this study. The aim of this study is to examine the model ability to simulate the meso-scale eddy in the SCS without data assimilations
The simulated Sea Surface Height (SSH) anomalies agree with the observed the AVISO SSH anomalies well. The simulated subsurface temperature profiles agree CTD observation data from the ROSE (Responses of Marine Hazards to climate change in the Western Pacific) project. The simulated upper-ocean currents also agree with the main circulation based on observations. A warm eddy is identified in winter in the northern SCS. The position and domain of the simulated eddy are confirmed by the observed sea surface height data from the AVISO. The result shows that the model has the ability to simulate the meso-scale eddy in the SCS without data assimilation. The three-dimensional structure of the meso-scale eddy in the SCS is analyzed using the model result. It is found that the eddy center is tilted vertically, which agrees with the observation. It is also found that the velocity center of the eddy does not coincide with the temperature center of the eddy. The result shows that the model has the ability to simulate the meso-scale eddy in the SCS without data assimilations. Further study on the forming mechanism and the three-dimensional structure of the meso-scale eddies will be carried out using the model result and cruise observation data in the near future.

# **Observational Study of the Cold Waters over the Southwestern Yellow Sea in Summer 2016** (OYSA)

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This study examines characteristics of a cold water patch (CWP) in coastal waters off Jiangsu Province in the southwestern Yellow Sea based on in-situ oceanographic observations using CTD and remote sensing data made by the Advanced Very High Resolution Radiometer (AVHRR). Analysis of the CTD data demonstrates that relatively cold waters occurred at different depths from the sea surface to 30 m over the study region in summer 2016, with the center of the cold waters leaning to the east at deeper depths. This confirms the transportation of cold subsurface waters from the bottom of theYellow Sea to the Jiangsu coast. From the AVHRR data, thecharacteristics of the CWP are quantified based on the radius and intensity of the CWP at the sea surface, and daily differences in thesea surface temperature (SST) between the center of the CWP and the nearshore area. The effect of the surface wind forcing on the CWP is also examined using a correlation analysis of the estimated radius and intensity of the CWP with surface winds. To identify the main physical processes affecting the CWP and associated three-dimensional circulation in the study region, the Princeton Ocean Model (POM) is used with the model forcing including wind stress, thenet heat and freshwater fluxes at the sea surface, tides, and freshwater discharge. Model results using different combinations of model forcing are analyzed and presented.

# Episodic surface intrusions of Yellow Sea Warm Current in late winter

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As the northward intrusion is against the prevailing winter monsoon, whether the Yellow Sea Warm Current (YSWC) is a persistent or transient flow remains controversial in observations and model simulations. In this study, the surface currents over the Yellow and East China Seas are mapped from the Geostationary Ocean Color Imager (GOCI). The composite of daily mean surface currents from six strong winter intrusion events reveals a prominent YSWC in the late winter. The observed transient YSWC intrusion is concentrated along the Yellow Sea trough, and is accompanied by a strong northward current over the broad East China Sea shelf; the latter has never been documented in the past. From the corresponding surface winds, the episodic northward surface flow bursts appear to be associated with abrupt changes from the strong northerly winds to weak southerly winds during cold front passages. A three-dimensional model driven with observed surface winds is used to simulate the observed shelf-wide response to the northerly wind events. There is an outstanding agreement between simulated and observed surface flow pattern. In particular, it is shown that the observed strong northward current in the East China Sea is primarily associated with coastal trapped waves originated from the Yellow Sea. The unprecedented capability of GOCI satellite in providing a regional circulation pattern, in conjunction with the validated model simulations, will contribute greatly to understanding of the dynamics of the East and Yellow China Seas.

# Revisit simulation of 1953 storm surge in the North Sea

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The 1953 North sea floods were the worst natural disaster in Europe in modern times. A rapidly moving low pressure system caused a strong storm surge - the largest ever recorded on the UK east coast - which killed over 2100 in the Netherlands, UK and elsewhere along the North Sea coast. The storm led directly to the decision to construct flood defences such as the dutch deltawerken and the UK Thames Barrier. The floods were caused by a deep low pressure system (min pressure 966 Mb) which moved rapidly southeast across the North Sea, causing strong northwesterly gales. Although not an especially deep system, it moved close to the land, giving sustained winds (0ver 50 knots for 24 hours). The night of 31st January was a high spring tide, exacerbating the effects of the storm surge (www.storm-surge.info/north-sea-flood-1953). A coupled process based tide-wave-surge model has been used to simulate the storm surge that occurred in Europe in January-February 1953. Meteorological forcing inputs for the period, the end of January – early February,1953 are prepared via ECMWF as background meteorological conditions. The water elevation (tide+surge) determined from the estimation of the Japanese NAOTIDE (National Astronomical Observatory) database was imposed at the tidal open boundary. The tidal charts of eight constituents were shown here. The storm surge and wave parameters such as significant wave height and period were calculated. Tide, storm-surge and wave during disastrous 1953 Storm Surge in the North Sea were reproduced using the coupled process based tide-surge-wave model (FEM model consists of 139,887 nodes and 270,743 elements) reasonably well. The resulting modeling system can be used extensively for the prediction of the storm surge, wave of extreme condition and usual barotropic forecast.

# Revisit Simulation of D-day : Normandy Invasion on 6th of June, 1944

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Known as one of the greatest military secrets of all time "Operation Overlord," the cross-Channel invasion of the northern coast of France on June 6, 1944, called for the Allies with accurate wave and tidal forecast for land operation. The entire plan was dubbed "Operation Neptune" on all documents after September 1943 to uphold the utmost confidentiality. Some details are now reported for wave forecast (Charles C. Bates, "Sea, Swell and Surf Forecasting for D-Day and Beyond: The Anglo-American Effort, 1943- 1945", 2010, a.p.) and tidal predictions for Normandy coasts (Bruce Parker, "The tide predictions for D-Day", 2011, Physics Today 64(9), 35). Times of small wave height and low tidal conditions were essential for successful landing. We are now revisiting the forecasts via modern day updated numerical modeling based on coupled tide-wave-storm surge physics.

The wind conditions are reproduced by using the meteorological conditions (air pressure, air and water temperature) supplied from ECMWF data assimilation group led by Dr. Beresfored, Reading University). An integrally coupled tide-surge-wave model based on the identical and homogeneous mesh of unstructured grid system were used for correct resolving of the physics of tide-wave-surge interaction and performing for each transect, perpendicular to the beach, respectively. The model domain widely covers the total North West Europe continental shelf region and the fine meshes with 20 meters resolution in the Normandy beach by consideration of water depth and geometry gradient. We carried out the real time tidal simulation and compared with Doodson Lege tidal prediction machine re-coded in PC. The prediction time sequential results are posted in the website, sites.google.com/bhchoiskku/dday, near the landing time, 6th June 6:30AM.

The tidal prediction (Doodson's Tidal Predictor and present simulation) at invasion time at Omaha Beach was accurate, just (about 10 centimeters ) above Local Mean Sea Level avoiding high tidal time of submerging obstacles for beach landing craft as basic requirements( Half tide conditions (low water in rising tide) so landing craft could get close to shore and since the tide would be rising, could turn about and get out of the way of the next craft Half tide conditions so infantry would not have to cross as much beach Low tide meant visibility of exposed rocks (Juno) and obstacles (2500 on Gold) Germans thought the attack would come at high tide, so attackers would have less beach to cross. The Germans began their defenses (Tetrahedras etc) at the high water mark and never finished the low water obstacles.

SWH predicted was still 1 meter at 6:00 AM - 7:00 AM, possibly maximum heights were over 1.5 meters , which is critical for LCVP operation (Professor Munk mentioned at Chapter One of his book: W. Munk, H. von Storch, and K. Hasselman. Seventy Years of Exploration in Oceanography. Springer, 2010). Immdiate offshore SWH were 2 meters, is high for which unloading the tanks. SHAEFF 5-day forecast were similar.

# Response of hydrodynamics to coastline changes in Hangzhou Bay, China

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As one of the famous macro-tidal estuaries around the world, Hangzhou bay is known as its magnificent tidal bore all over the world. The bay, located on the coast of East China Sea, is the estuary of Qiantang River. Hangzhou Bay-Qiangtang River system and their major tributaries serve as important cultural, economic, and ecological resources for the local and national China. The changes of coastlines were obtained from remote sensing images of LandSat. Most of the changes happened at the south bank near Andong before 2005. After 2005, some of the changes happened at the north bank near Yanguan. From 1962 to 2015, the width of Ganpu was reduced by 760m by 2005, 3% of the width (23.1km) in 1962, and further reduced by about 3,233m until 2015 (14% of the width in 1962). The total reduction of the width near Zhapu was 4,866m, 14.5% of the width (33.7km) in 1962. Numerical model showed that the changes of coastlines amplified the high and low water levels near Ganpu. The current speeds during spring tides were also slightly amplified. The magnitudes and directions of current ellipses were obviously changed near Caoejiang. The main tidal channel moved towards northern bank and became narrow near Ganpu. The magnitudes of vertically averaged residual currents near Ganpu were dampened from 1962 to 2015.

# Circulation and dynamics

## Interannual variation of the surface circulation in the Japan/East Sea by external forcing and intrinsic variability

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Sang-Ho Lee and Do-Seong Byun
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The interannual variation of the surface ocean current is as large as the seasonal variation in the Japan/East Sea (JES). To find the major factors which cause the interannual variability of the surface ocean circulation in the JES, the surface circulation was simulated from 1998 to 2009 using a three-dimensional model. Contributions of atmospheric forcing (ATM), open boundary data (OBC), and intrinsic variability (ITV) of the flow on the interannual variability of the surface ocean circulation were separately examined using numerical simulations. The variability of surface circulation was quantified in terms of the variance in sea surface height, 100-m depth water temperature, and surface currents. The ITV was the dominant factor which induces the interannual variabilities of the surface circulation, the main path of the EKWC, and the surface kinetic energy with time scale of 2–4 years. The contributions from OBC and ATM were secondary factors. The interannual variation of the ATM changed the separation latitude of the EKWC and increased the variability of the surface circulation in the Ulleung Basin. The interannual variation of the OBC enhanced the low-frequency changes in the surface circulation and eddies in the Yamato Basin and it modulated the basin-wide uniform oscillations of sea level. This study suggests that precise estimation of the initial condition using data assimilation is essential for the long-term prediction of the surface circulation in the JES.

# Eddy induced cross-slope transport in the northern South China Sea

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Mesoscale eddies occur frequently in the northern South China Sea (SCS). After formation, most of the eddies move to the southwest along the continental slope, which consequently facilitates the dynamic exchange between shelf and deep ocean in terms of water mass, material, and energy. So far, a lot of progress have been made to understand the upper ocean circulation in the northern SCS. However, the dynamics and controlling factors of cross-slopeexchange still remain largely unknown, especially for contributions from mesoscale eddies due to lack of observations that can efficiently capture transient eddies. In this study, we combine multiple data sources from in-situ measurements and satellite altimeter data with a high-resolution numerical model to examine characteristics and dynamics of eddy induced cross-slope exchange in the northern SCS by conducting numerical sensitivity studies and budget balance diagnosis. We focus on the variability of eddy-induced transports and their three-dimensional structures at seasonal and intra-seasonal timescales. With this study, the properties of mesoscale eddies in the northern SCS and their contributions to cross-slope exchange are statistical quantified, which will advance our understanding on the dynamic nature of upper ocean circulation in the northern SCS.

# Numerical study of seasonal circulation and variability over the inner shelf of the northern South China Sea

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This study examines seasonal circulation, hydrography, and associated spatial variability over the inner shelf of the northern South China Sea (NSCS) using a nested-grid coastal ocean circulation model. The model external forcing consists of tides, atmospheric forcing and open boundary conditions based on global ocean circulation and hydrography reanalysis produced by the Hybird Coordinate Ocean Model. Five numerical experiments are conducted with different combinations of external forcing functions to examine main physical processes affecting the seasonal circulation in the study region. Model results demonstrate that the monthly mean circulation in the study region features the Guangdong Coastal Current (GCC)over coastal waters and the South China Sea Warm Current (SCSWC) in the offshore deep waters. The GCC produced by the model flows nearly southwestward in winter months and northwestward in summer months, which agrees with previous studies. The SCSWC flow roughly northeastward and is well defined in summer months. In winter months, by comparison, the SCSWC is superseded by southwestward strong wind currents. Analysis of model results in five different experiments demonstrates that the monthly mean circulation over coastal and inner shelf waters of the NSCS can be approximated by barotropic currents forced by the southwestward monsoon winds in winter months. In summer months, by comparison, the monthly mean circulation in the study region is affected significantly by baroclinic dynamics associated with freshwater runoff from the Pearl River and advection of warm and saline waters carried by the SCSWC over the NSCS.

## **Evolution of wind-driven flows in the Yellow Sea during winter** (OYSA)

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To examine the evolution of the wind-driven flows in the Yellow Sea (YS) during winter, ocean circulation was simulated using a three-dimensional ocean model with realistic topography and atmospheric forcing. The simulated sea surface temperature, ocean currents, and path of the Yellow Sea Warm Current (YSWC) agreed with observations. Southward currents along the Korean coast and the Chinese coast in winter were also effectively identified. Spectra of the daily mean winds and the YSWC velocities in the subsurface layer had dominant peaks at 12 and 20 day periods. Time-lagged correlation analysis suggested that the downwind flow in the surface layer reacts concurrently to the northwesterly wind in winter whereas the subsurface layer responds with a delay. One day after the wind burst, an upwind current in the subsurface layer appeared in the center of the trough, whereas the downwind flow in the surface layer decreased significantly. Two days later, the upwind flow in the subsurface layer shifted to the west of the trough while the downwind flow along the Korean coast strengthened. These flow responses to the wind variations resulted in a clockwise circulation in the YS during winter.

## **Role of the cold water in the formation of the East Korea Warm Current in the East/Japan Sea : numerical experiment** (OYSA)

**Yongyeop Kim**, Young Ho Kim and Yang-Ki Cho
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The East/Japan Sea (EJS) is a marginal sea of the western Pacific with an average depth of 2,000 m. The water exchange between the EJS and the Pacific occurs through the Korea Strait and Tsugaru Strait corresponding to the inlet and outlet respectively. The Tsushima Current flowing into the ESJ through the Korea Strait is divided into two main branches, the Nearshore Branch flowing along the Japanese coast, and the East Korean Warm Current (EKWC) heading northward along the Korean coast. Many previous studies reported the effects of cold water on the formation of the EKWC using 2-dimensional model in the Korea Strait. However, three-dimensional structure of the cold water in relation to the EKWC has not been examined. In this study, we investigated the effects of cold water on the formation of the EKWC using 3-dimension numerical model. Model results indicate that the thickness of the upper layer decreases due to the presence of the lower cold water along the Korean coast. The decrease of the layer thickness causes the negative relative vorticity which intensifies the EKWC along the Korean coast.

# Variability of the Pacific North Equatorial Current from 1993 to 2012 Based on a 1/8° Pacific Model Simulation

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Based on a multi-decadal Pacific basin model simulation, inter-annual variations of the North Equatorial Current (NEC)are investigated. The model reproduces well the characteristics of the NEC and its inter-annual variability. Calculated as an integral of the westward velocity from 6º N to 21º N and from the surface to the 1200 m depth, the magnitude and standard deviation of the NEC transport increase from 46.5 and 3.9 Sv at 175° E to 66.7 and 6.5 Sv at 130° E, respectively, and both peak around 132 º E prior to entering the separation region. The NEC transport tends to be higher during positive Oceanic Niño Index (ONI) years but lower during negative ONI years with the maximum difference of more than 20 Sv. The inter-annual variability of the NEC transport is closely related to changes of the sea surface height in the tropical Pacific Ocean, and the increase of the NEC is mostly balanced by the increase in the North Equatorial Counter Current (NECC) on the tropical gyre side. The present study further suggests a long-term decline of the NEC transport from 1993 to 2012, which is consistent with the patterns in the trend of wind stress curl.

Transport anomalies reconstructed from the normal modes of zonal velocity suggest that the 1st baroclinic mode captures about 95% of the variance in the NEC transport, while the 2nd mode adds only additional 3-4%. A 1.5-layer reduced gravity model further reveals that the 1st (2nd) baroclinic mode is driven primarily by the wind (thermal) forcing, respectively, and that the wind forcing plays a predominant role in determining the inter-annual variability in the NEC transport while the effect of the thermal forcing is rather limited.

# Seasonal Characteristics and Dynamic Mechanism of the SurfaceKuroshio Branch intrusion into the South China Sea

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Abstract Using the observational data of the Argos satellite-tracked drifters from 1988 to 2012, we analyzed the surface Kuroshio Branch (KB) intrusion into the South China Sea (SCS). The analysis results are as follows. The surface KB mostly originates from the southern Balintang Channel (SBLTC) and the southern Babuyan Channel (BBYC). It starts in late September, reaches its peak (in terms of both speed and intrusion probability) in December-January and declines at the end of March. The mean speed of the drifters during traversing the Luzon Strait (LS) was 43% faster than that during the two days before entering the LS when the flow originated from the SBLTC, but there was no significant increase in speed when the flow came from the BBYC. The observations showed that in wintertime the monthly-mean sea-level anomalies (SLAs) were positive southwest of Taiwan Island and extended to the northern LS, and were negative northwest of Luzon Island and extended to the southern LS. The SLAs were accompanied by an anticyclonic circulation and a cyclonic circulation, which acted like a pump, forcing a part of the Kuroshio water westward into the SCS, especially for the water originated from the SBLTC. The condition under which the KB forms is solved by the equations of motion. The theoretical results indicate that whether the Kuroshio Surface Water can cross the LS into the SCS depends upon the sea-level gradient at the central LS and the region to the west, as well as the position, velocity and direction of the Kuroshio SurfaceWater when it enters the LS.
Key words: surface Kuroshio Branch, Luzon Strait, dynamicmechanism

# Turbulence and Waves

## **Large eddy simulation of diffusion of a buoyancy source in ocean mixed layer** (OYSA)

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Large eddy simulations (LES) are being recently employed to reproduce the turbulent ocean phenomena, which cannot be considered by traditional ocean models using Reynolds-averaged Navier-Stokes equations.
It is important to predict the behavior of heated or waste water dumped into the upper ocean, which impact on the environment. The movement of buoyancy source (thermal) is basically turbulent and influenced by background turbulence in the mixed layer. The ocean mixed layer is developed by turbulence generation of wave breaking and Langmuir circulation.
In this study, the diffusion of thermals in ocean mixed layer was simulated by LES and the result was analyzed. Modified Parallelized LES Model (PALM) which includes physical processes in ocean mixed layer such as wave breaking and Langmuir circulation was used for LES. The effect of wave breaking and Langmuir circulation on the thermals diffusion were evaluated. Various buoyancy relative to ambient water will be simulated and discussed.

# Simulation of typhoon-induced wave and surge using a coupled Ocean-Wave model

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Typhoon-induced wave fields and surge are of interest operationally for predicting potential hazards on coastal regions. In this study, the impact of coupled ocean-wave model on typhoon-induced wave and surge simulation around the Korean Peninsula was investigated through a set of comparative experiments for typhoon Bolaven in 2012. The experimental results of wave fields were compared with buoy observations of ocean wave to validate the simulated typhoon-induced surface wave fields. Without coupling ocean currents and water level variations the wave model exhibited a maximum significant wave height (Hs) on the right side of the typhoon tracks, and tended to overestimate Hs measured by buoys around the Korean Peninsula. However, when the current effect was included the simulated Hs was significantly reduced on the right side of the typhoon tracks regardless of tidal forcing, indicating that the influence of the current on typhoon-induced waves was limited to the right side of the track. The simulated storm surge was compared with observed surge which was derived by subtracting harmonically simulated water level from recorded water level. The detailed explanation of validation results and the effect of waves on surge accuracy by considering the wave-setup will be discussed.

# Investigation of Air-Sea interaction in tropical Africa region using Regional Climate Model (RegCM4)

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This study evaluates the ability of the Abdus Salam International Center for Theoretical Physics (ICTP) version 4 Regional Climate Model (RegCM4) to reproduce the observed rainfall and wind magnitudes and distributions over the tropical Africa region. The Simulations are performed for two contrasting years of Atlantic Cold Tongue depicted by the Caniaux's index. Simulations were done at a resolution of 50 km. The variables investigated are precipitation and 850-hPa winds. Results show that the model realistically reproduces the tropical African climate, with a few discrepancies due to the different cumulus convection schemes and the domain sizes used. This scheme performs better on larger, than smaller, domains. It is shown that some sub-regions are very sensitive to ACT. It could be said that the GFC scheme is capable of reproducing the amount and distribution of the precipitation for the two years in two regions, and failed to reproduce the rainfall in three regions; while the KUO scheme reproduces well in these three zones.

## **Frontogenesis and turbulent mixing** (OYSA)

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A hydrological investigation was conducted in the shelf of the eastern Hainan Island in July 2012. With the in-situ measurements from four cross-shelf sections and satellite data, the seasonal
variability of sea surface thermal fronts and their structural characteristics of fronts are discussed. The results indicate that intense fronts are mostly distributed in the upwelling area, roughly following the 100m isobath in summer. The width of
the frontal zone is 20 - 40 km. With the increase of depth the fronts fade and the spatial position moves
offshore.The O(1) Rossby number is positive on the dense side and negative on the light side. The Maxinum along-frontal velocity is 0.45m/s and the stretching is strengthened by the strong horizoontal shear, also is the potential vorticity. We obtained the ageostrophic secondary circulation by Quasi-Geostrophic equatioin and in-situ measurements, as well as the enhanced turbulent mixing in the region of the front.

# Marine ecosystem modeling

## **Harmful Algae Bloom models for Cochlodinium polykrikoides off the south coast of Korea** (OYSA)

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Harmful Algae Bloom (HAB) occurs in the coastal waters in most countries, causing massive damage to the fishery industry. For instance, Cochlodinium polykrikoides (C. polykrikoides) is one of the typical species which cause the HAB off the coast of Korea.

Purpose of this study is to develop and solve governing equation for C. polykrikoides bloom. Its optimal growth rate is calculated using data from National Institute of Fisheries Science, and mortality is modeled based on observations.

In addition, the biological interaction between C. polykrikoides and other plankton species is indirectly estimated using optimization. Thus, the developed C. polykrikoides bloom model is operated as a zero-dimensional model and verified based on observation from Red-tide alert system.

In particular, we focus on the cases of 2014 and 2016; each year represents its blooming year and non-blooming year, respectively. Furthermore, environmental factors that control C. polykrikoides bloom are discussed by analyzing the governing equation of the model.

# Data assimilation and ocean prediction

## Data assimilation of physical and chlorophyll observations in the California Current System using two biogeochemical models

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Biogeochemical numerical models coupled to physical ocean circulation models are commonly combined with data assimilation in order to improve the models' state or parameter estimates. Yet much still needs to be learned about important aspects of biogeochemical data assimilation, such as the effect of model complexity and the importance of more realistic model formulations on assimilation results. In this study, 4D-Var data assimilation is applied to two biogeochemical ocean models: a simple NPZD model with 4 biogeochemical variables (1 phytoplankton, 1 zooplankton) and the more complex NEMURO model, containing 11 biogeochemical variables (2 phytoplankton, 3 zooplankton). Both models are coupled to a 3-dimensional physical ocean circulation model of the U.S. west coast based on the Regional Ocean Modelling System (ROMS). Chlorophyll satellite observations and physical observations are assimilated into the model, yielding substantial improvements in state estimates for the observed physical and biogeochemical variables in both model formulations. In comparison to the simpler NPZD model, NEMURO shows a better overall fit to the observations. The assimilation also results in small improvements for simulated nitrate concentrations in both models and no apparent degradation of the output for other unobserved variables. The forecasting skill of the biogeochemical models is strongly linked to model performance without data assimilation: the improved fit obtained through assimilation degrades at similar rates, but drops to different levels. Given the higher computational cost of NEMURO, the choice of model and desired level of complexity should depend on the model application and the data available for assimilation.

# Prediction of M2 tidal surface currents by a global baroclinic ocean model and evaluation using observed drifter trajectories

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Global M2 tidal surface currents are predicted using a global baroclinic ocean model with horizontal grid spacing of 1/12° and 19z-levels in the vertical. After first showing the predicted tidal elevations are in reasonable agreement with observations made by bottom pressure recorders and altimeters, the
predicted tidal surface currents are evaluated by comparing them with independent estimates based on observed drifter trajectories. Both predicted and observed tidal surface currents can exceed 0.1m/s in the deep ocean. Internal tides are shown to make a significant contribution to the predicted tidal surface currents. Phase locking of the surface and internal tides causes spatial changes in the predicted tidal surface currents that vary with approximately the same wavenumber as that of the lowest mode internal tide. Qualitatively similar, small-scale variations are also detected in the observed estimates but the variations do not line up exactly with the predictions. Possible explanations for the mismatch are given. The seasonal variation of M2 tidal surface currents, and the energy conversion rate from surface to internal tides, is also predicted by initializing, and restoring, the model to an observed seasonal climatology of temperature and salinity. Compared to tidal elevation, the seasonal change of tidal surface current can be large (order 10% for each hemisphere). It is caused by seasonal variations in the vertical structure of the baroclinic modes and the energy conversion rate. In the vicinity of major bathymetric features, the seasonal variation of second and higher order modes can be much larger (up to 50%).

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