Workshop on Predictability of Climate in the North Atlantic Sector

Multi-Scale Climatic Impacts of Midlatitude Oceanic Frontal Zones

*Hisashi Nakamura\textsuperscript{1, 2}
S. Okajima\textsuperscript{1}, R. Masunaga\textsuperscript{1}, K. Nishii\textsuperscript{1}, T. Miyasaka\textsuperscript{1},
B. Taguchi\textsuperscript{2}, M. Nonaka\textsuperscript{2}, A. Kuwano-Yoshida\textsuperscript{2},
M. Koike\textsuperscript{1}, Y. Tanimoto\textsuperscript{3}, B. Qiu\textsuperscript{4}

\textsuperscript{1}University of Tokyo,
\textsuperscript{2}JAMSTEC, \textsuperscript{3}Hokkaido University, \textsuperscript{4}University of Hawaii
A “Hot Spot” in the Climate System: A new Japanese initiative on extra-tropical air-sea interaction study with focus on multi-scale air-sea interaction under the East-Asian Monsoon

Net annual-mean heat flux from the surface (W/m²)

- Intensive heat release in “hot spots”
- Heated in the Tropics
A “Hot Spot” in the Climate System: A new Japanese initiative on extra-tropical air-sea interaction study with focus on multi-scale air-sea interaction under the East-Asian Monsoon

- MEXT-sponsored nation-wide project with ~65 scientists, ~10 postdocs and ~30 grad. students
A “Hot Spot” in the Climate System: A new Japanese initiative on extra-tropical air-sea interaction study with focus on multi-scale air-sea interaction under the East-Asian Monsoon

- MEXT-sponsored nation-wide project with ~65 scientists, ~10 postdocs and ~30 grad. students
- Organized into 9 main programs (FY2010~2014 (Mar. 2015)) + 9 supplementary programs (FY2011~12; FY2013~14)

Chief PI: Hisashi NAKAMURA (Univ. Tokyo/JAMSTEC)

http://www.atmos.rcast.u-tokyo.ac.jp/hotspot/index.html

Under active collaborations with overseas scientists: N. Keenlyside, N.-E. Omrani, Y. Orsolini, B. Qiu, J. Small, M. Cronin, S.-P. Xie among others
Basin-scale free-tropospheric impacts of midlatitude oceanic fronts

Review papers by Nakamura et al. (2004, AGU monogr.), Kwon et al. (2010, JC)
Cyclone development along a surface baroclinic zone

Incipient upper-level cyclonic eddy

\[ t = 0 \]

Pre-existing surface baroclinic zone

Rossby depth

\[ H_R = \frac{f L}{N} \]

Warm advection

\[ \text{warm anomaly} \]

\[ \text{cyclonic PV} \]

JJA climatology for the South Indian ocean

Nakamura et al. (GRL 2008)

Recurrent development of storms under efficient restoration of SAT gradient through cross-frontal differential heat release: "oceanic baroclinic adjustment"

- Nonaka et al. (2009 JC)
- Hotta, Nakamura (2011 JC)
Observed SST anomalies in 2011 summer/autumn

In the **midlatitude North Pacific**:
- prominent warm SST anomalies
  - were strongest since 1982
  - with maximum exceeding +3°C in every month
  - persisted over summer/autumn
- Anomalous **upward heat fluxes** over the warm SST anomalies in October (oceanic thermodynamic forcing)
- Anticyclonic anomalies in the vicinity of the SST anomalies

- **AGCM:** AFES– T119L56
- **10-member ensemble** from late May
- **MID:** positive SST anomalies *only* over the midlatitude North Pacific v.s.
- **CNTL:** with climatological SST
- 0.25° X 0.25° OISST
In 1982-2010:
• Dominant variability of the sharpness of the front in October (41°N-42°N)

In October 2011:
• Prominent poleward shift of the SST front
• Enhanced SST gradient between 42°N and 50°N
• Associated with prominent warm SST anomaly around 40°N

→ The CLIM & MID experiments examine the influence of the northward shift of the oceanic front to the atmosphere
Observed and simulated circulation anomalies in October

MID experiment reproduces:

- Observed lower- and upper-tropospheric anticyclonic anomalies,
- Cyclonic anomaly over the Bering Sea
- Anomalous upward turbulent heat fluxes over the warm SST anomaly

These anomalies arise from:

- prominent poleward shift and expansion of the oceanic frontal zone,
- associated with prominent warm SST anomaly around 40°N
- With no significant change in frontal intensity
• Stormtrack is intensified and shifted poleward,

• consistent with enhanced surface baroclinicity on the northern flank of the warm SST anomaly.

• Anomalous anticyclonic forcing by anomalous divergence of eddy vorticity flux south of the stormtrack.

• Resultant anomalous subsidence and anomalous divergence of eddy heat flux contribute to the maintenance of the surface anticyclonic anomaly.
Z250 response in individual ensemble members – MID October
Observed variability of the NPAC subarctic front

Nakamura, Kazmin (2003; JGR), Tanimoto et al. (2003, JGR), Taguchi et al. (2012, J.Clim.)

Typical decadal-scale SST anomaly

40~60% of SST variability in the North Pacific subarctic frontal zone is caused by oceanic processes (Smirnov et al. 2014 JC).
Large-scale atmospheric anomalies forced by decadal SST anomalies in the subarctic frontal zone


• Signal of the anomalous Aleutian Low (and PNA pattern aloft) observed as a response to fall-early winter SST anomalies in the subarctic frontal zone tends to be strongest in January but break down rapidly in February.
• Same seasonality is reproduced in 100-yr integration of coupled model CFES.

Monthly evolution of SLP anomalies

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<tr>
<th>Month for reference SST anomalies</th>
<th>SLP Oct</th>
<th>Nov</th>
<th>Dec</th>
<th>Jan</th>
<th>Feb</th>
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<td>Oct SST</td>
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<td>Jan</td>
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[Figure showing monthly evolution of SLP anomalies from October to February]
AGCM reproduction of seasonality of atmospheric response
Okajima, Nakamura, Nishii, Miyasaka, Yoshida (2014)

AFES (T119, L56) ensemble response to (tripled) SST anomalies in SAFZ,
(differential response to positive and negative anomalies)

Red hatches: SST anomaly > +1.5°C
• North-south dipolar response is reproduced, with the weakened Aleutian Low associated with warm SST anomalies.
• As observed, the response matures in January before rapid decay in February.
Planetary-wave modulation by Western Pacific pattern and possible influence from the ocean

Intensification of the cold polar vortex in the Arctic stratosphere

Influence of WP blocking on the stratosphere is the opposite to blocks in other geographical regions

Development of blocking high

Possible impact of SST along the Tsushima current on WP blocking (Yamamoto, Hirose)

Modulations of planetary waves

Possible impact of the Oyashio front variability on WP blocking (Hurwitz 2012; Frankignoul et al. 2011)

Winter monsoon
Meso/regional-scale impacts of midlatitude oceanic fronts

Review papers by Small et al. (2008 DAO), Kelly et al. (2010, JC)
Atmospheric reanalysis is suited for examining interannual variations of the pressure trough, but its quality, especially within PBL, can be sensitive to SST distribution prescribed for data assimilation.

**ERA-Interim** model resolution: T255 (constant)

1979~2001 (23 years)
SST with resolution of 1.0°

2002~12 (11 years)
SST with resolution of 0.5° or higher

**Shading**: $-\Delta\text{SST}/\Delta y$ ($°\ C/100\ km$)

**Oyashio front**

**KE front**
Winter SLP trough in KOE: Apparent variability in ERA-interim

Masunaga, Nakamura, Miyasaka, Nishii, Tanimoto (JC 2014 submitted)

Low-resolution SST (W/m²)

High-resolution SST (W/m²)

contour: high-pass SLP trough

c.f. Tanimoto et al. (2011, JC) based on iCOADS

Sensitivity of SLP and surface wind convergence to SST given for assimilation

ERA-i: T255

January at 149.25° E

divergence  convergence

Secondary min. and max.
Well-defined maximum of high-pass filtered $\theta_v$ and ascent into the free troposphere is evident south of KE in both periods.

Shallow maximum of high-pass filtered $\theta_v$, ascent and local deepening of PBL just to the south of the Oyashio front analyzed only in high-resolution SST period.
Wintertime cloudiness in KOE: Apparent variability in ERA-interim

Masunaga, Nakamura, Miyasaka, Nishii, Tanimoto (JC 2014 submitted)

ERA-i **low-resolution SST** 1979~2001

ERA-i **high-resolution SST** 2002~12

ERA-i: T255
Latitudinally high-pass-filtered profiles (smaller than 6°)
c.f. Tokinaga et al. (2009, JC)

Satellite measurements 2002~2011

Dual local maxima of cloudiness and surface wind convergence coincide with local SLP troughs near local SST maxima south of SST fronts.

QuikSCAT surface wind convergence (1999~2009, DJFM)
• Consistent with satellite observations, ERA-Interim (convective) precipitation maximizes along the warm KE.

• In addition, only in its high-resolution SST period, ERA-Interim (convective) precipitation is enhanced on the warmer flank of the Oyashio front, with higher consistency with satellite observations than in its low-resolution SST period.
Quasi-decadal variability of KE

Weekly KE paths (SSH = 170cm)

Compared with the stable regime, the unstable regime is characterized by more active warm core eddies in the frontal zone with higher SST and enhanced heat release from the ocean (Sugimoto, Hanawa 2011 JC).
In the unstable regime, enhanced heat release from the ocean north of the climatological KE axis warms PBL locally, lowering SLP via hydrostatic effect. The anomalous frictional convergence in PBL accompanies anomalous ascent that reaching into the free troposphere, locally enhancing cloudiness and precipitation.
Compared with JRA-55C, JRA-55HS cloudiness
• exhibits finer distribution over KOE with multiple SST fronts,
• is enhanced over the East China Sea in the presence of higher SST,
• is enhanced also along the warm Tsushima Current.
Meso/micro-scale impacts of midlatitude oceanic fronts
Cloud microphysics modulated by the Kuroshio
Koike, Takegawa, Moteki, Kondo, Nakamura et al. (2012, JGR); Koike et al. (2014)

Cold-air outbreak from the continent onto the Kuroshio
→ reduced stratification
→ enhanced updraft [0.4 → 1.2 m/s]
→ enhanced associated adiabatic cooling
→ higher super-saturation level
→ activation of smaller aerosols as CCN
→ higher cloud albedo [fractional increase: 11%]
→ enhanced cloud radiative forcing [–4.7 W/m²]

Aerosol effects on CCN

Number density of cloud droplets

Air-sea temperature difference
Enhanced droplet density

Number density of aerosols
(accumulation mode: $D > 0.13$ µm)

$\text{SST} - T_{950}$ (K)
Enhanced warming along the western boundary currents

Local trend (1900~2008) as a departure from the global-mean trend

Enhanced warming around the midlatitude/subtropical warm western boundary current (WBC) regions, probably as a concentrated manifestation of wind field changes through oceanic Rossby waves

Increasing importance of the WBC regions as “hot spots” in the climate system
Summary

KOE (Kuroshio-Oyashio Extension) region is

• a center of action of decadal SST variability, where strong SST anomalies can force basin-scale atmospheric response in January by modulating the Pacific storm-track activity.

• The same kind of a basin-scale atmospheric response was forced by extreme warmth of KOE in October 2011 with teleconnection into North America.

• Multiple SST fronts leave climatological mesoscale imprints on the atmospheric boundary layer, specifically on local baroclinic zones, local pressure troughs and associated local enhancement of wind convergence, cloudiness and (convective) precipitation.

• Reproducibility of these mesoscale imprints in atmospheric models, including reanalysis, is sensitive to SST resolution assigned, suggesting its importance in dynamical downscaling for the oceanic state, especially for coastal areas.
AMS special collection on
“Climate Implications of Frontal Scale Air-Sea Interaction”
(Short title: Frontal air-sea)
JC, JPO, JAS, MWR etc.

Coordinators: R.J. Small, M.A. Alexander, C. Frankignoul, Y.-O. Kwon, H. Nakamura

19th Conference on Air-Sea Interaction, in the AMS Annual Meeting
Jan 4-9, 2015 @Phoenix, AZ (abstract due Aug. 1)

Town Hall Meeting: “Hotspot Project”: What can we learn and what's next?
The day for this lunch time town hall meeting will be set once the program for the 19th Conference on Air-Sea Interaction has been organized. The town hall will be scheduled on the day of the session(s) on “Air-sea interaction at the mesoscale, and effect on planetary scale climate” and/or “The role of air-sea interaction in climate variability”.

Midlatitude air-sea interaction, including the climatic impacts of strong western boundary currents and associated oceanic fronts, is drawing increasing attention from climate science community. These impacts have been studied extensively during a 5-year Japanese "Hotspot Project" launched in 2010. An overview and the main outcomes of this project are introduced in this Town Hall Meeting. We will discuss how the community can utilize the unique data obtained by the intensive observation campaigns around the Kuroshio Extension, and how we can coordinate international collaborations in future. Grab your lunch and join us for a lively discussion on the “hotspots of our climate system”.

For additional information, please contact Hisashi Nakamura (hisashi@atmos.rcast.u-tokyo.ac.jp).