Workshop on Predictability of Climate in the North Atlantic Sector

Multi-Scale Climatic Impacts of Midlatitude Oceanic Frontal Zones

*Hisashi Nakamura[1, 2]

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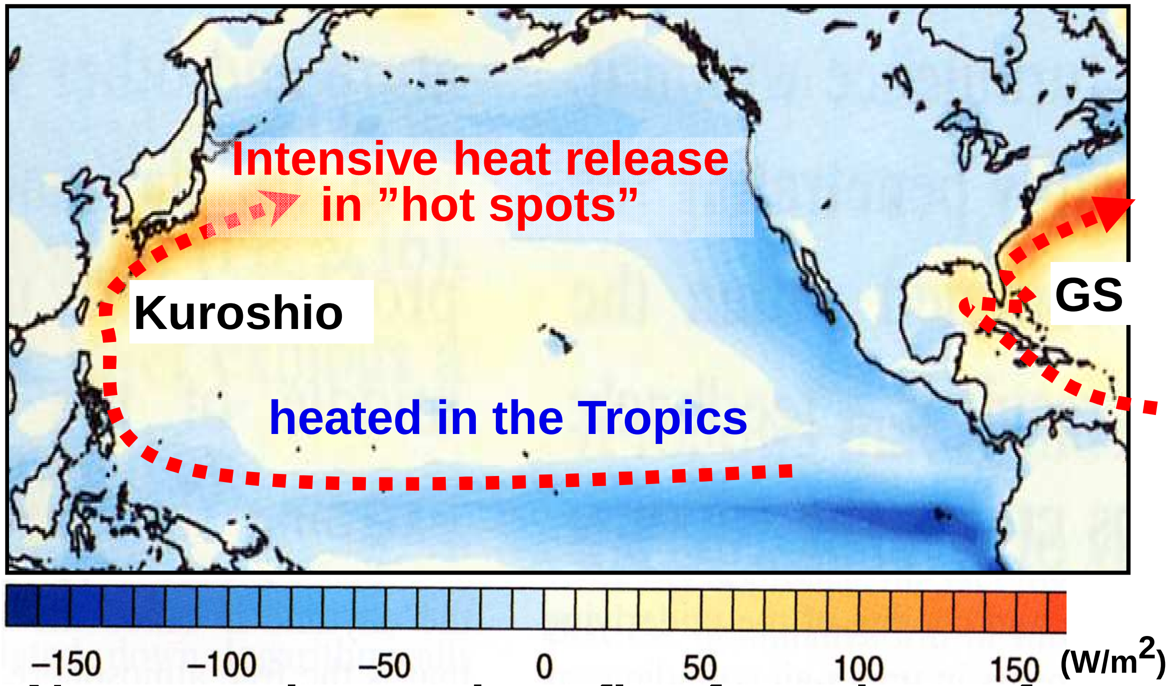
A "Hot Spot" in the Climate System:
A new Japanese initiative on
extra-tropical air-sea interaction study

with focus on multi-scale air-sea interaction under the East-Asian Monsoon



Net annual-mean heat flux from the surface

A "Hot Spot" in the Climate System: A new Japanese initiative on extra-tropical air-sea interaction study

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- MEXT-sponsored nation-wide project
  with ~65 scientists, ~10 postdocs and ~30 grad. students

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- MEXT-sponsored nation-wide project
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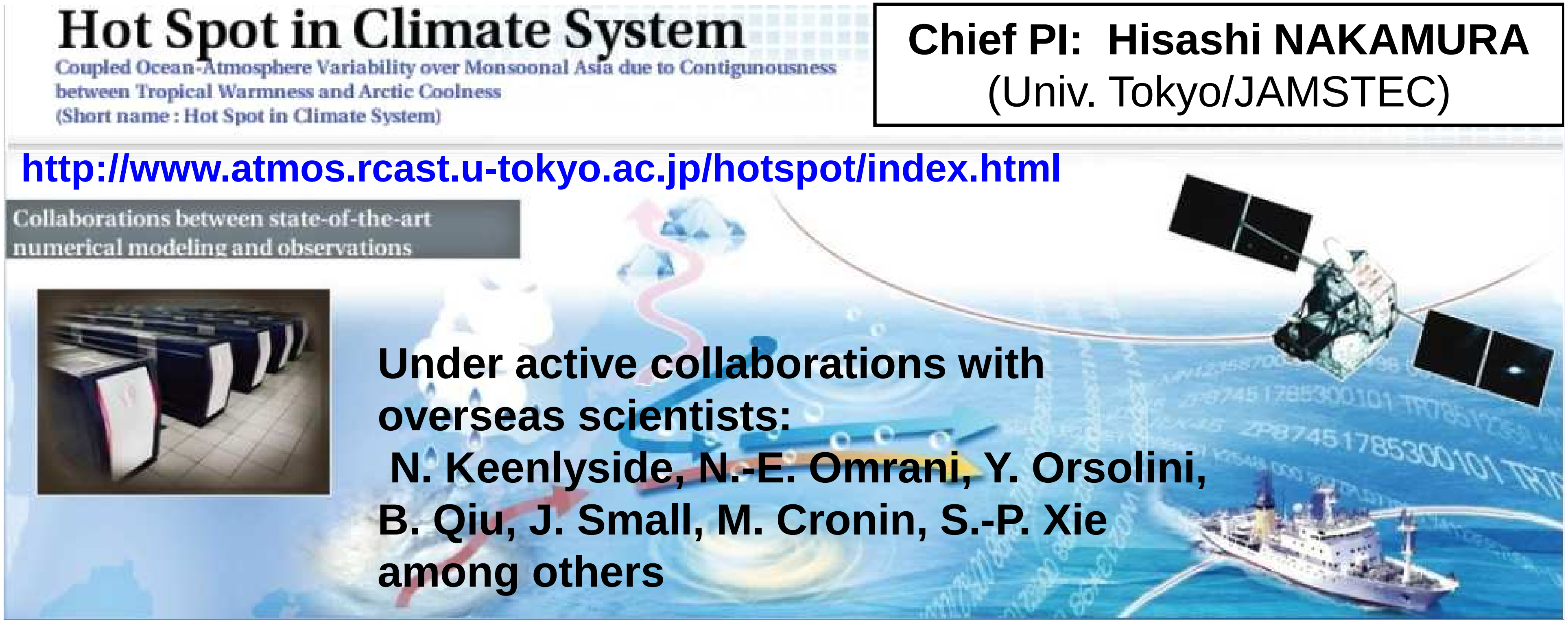
- Organized into 9 main programs (FY2010~2014 (Mar. 2015))
  + 9 supplementary programs (FY2011~12; FY2013~14)



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

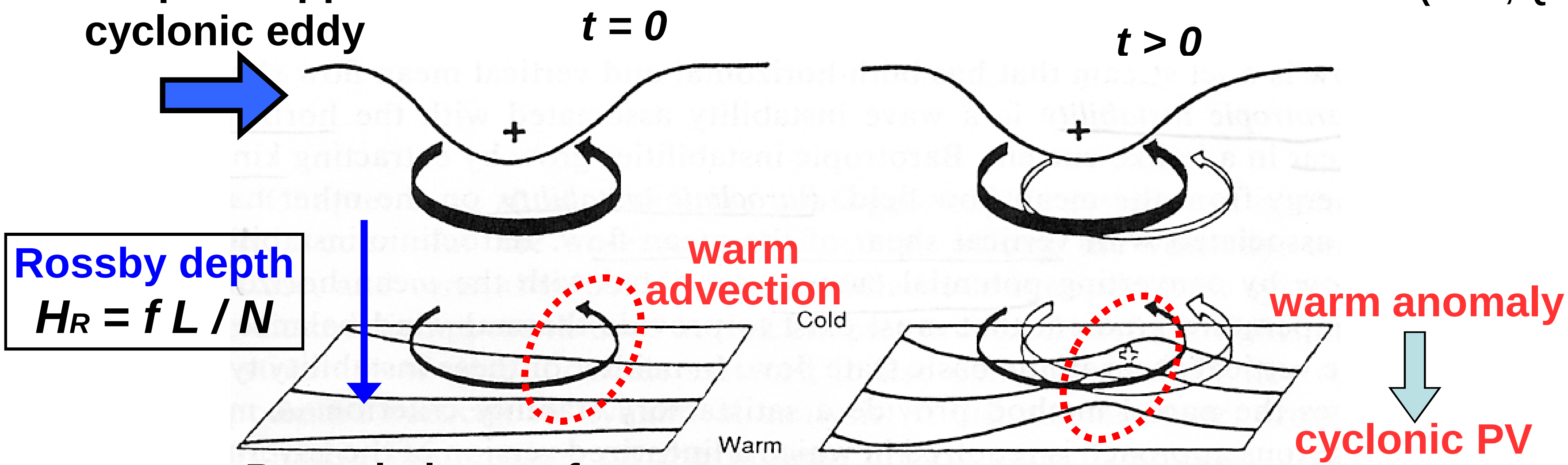
Basin-scale free-tropospheric impacts of midlatitude oceanic fronts

Review papers by Nakamura et al. (2004, AGU monogr.), Kwon et al. (2010, JC)

Cyclone development along a surface baroclinic zone

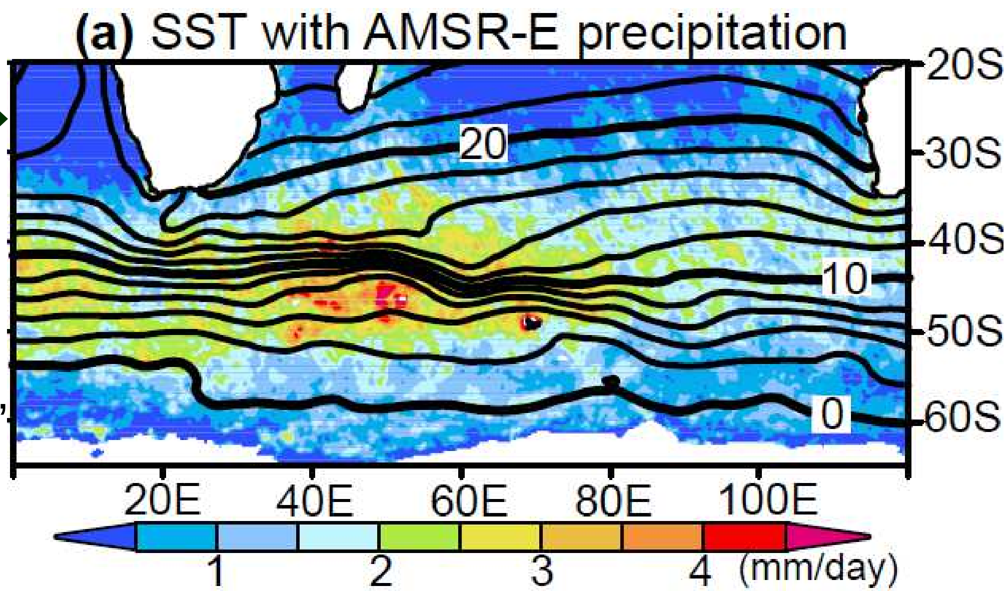
Incipient upper-level cyclonic eddy

Hoskins *et al.* (1985; QJRMS)



Pre-existing surface baroclinic zone

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)

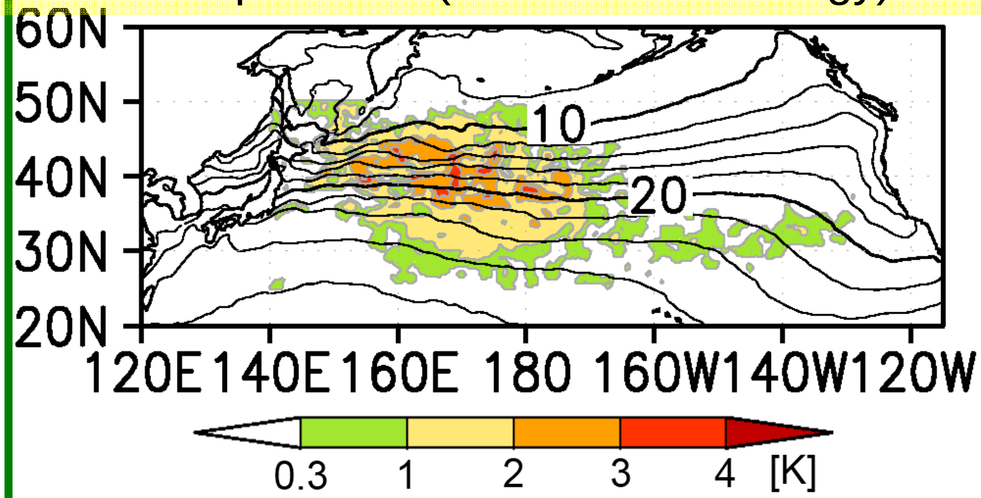
Observed SST anomalies in 2011 summer/autumn

Okajima, Nakamura, Nishii, Miyasaka, Kuwano-Yoshida (2014, J.Clim. In press)

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

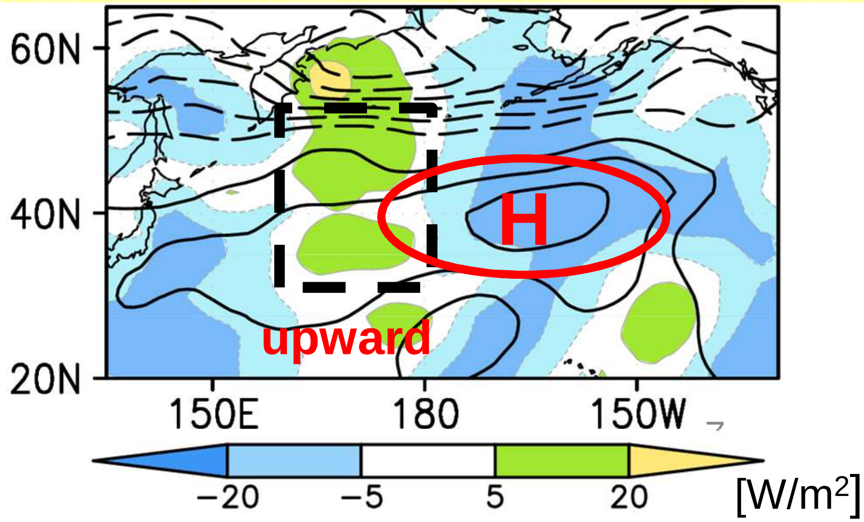
October SST anomaly prescribed for AGCM MID experiment (contour: climatology)



➢ 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° X0.25° OISST

Anomalous upward turbulent heat fluxes (contour: SLP anomaly [hPa])



Influence of using climatological SST in CLIM

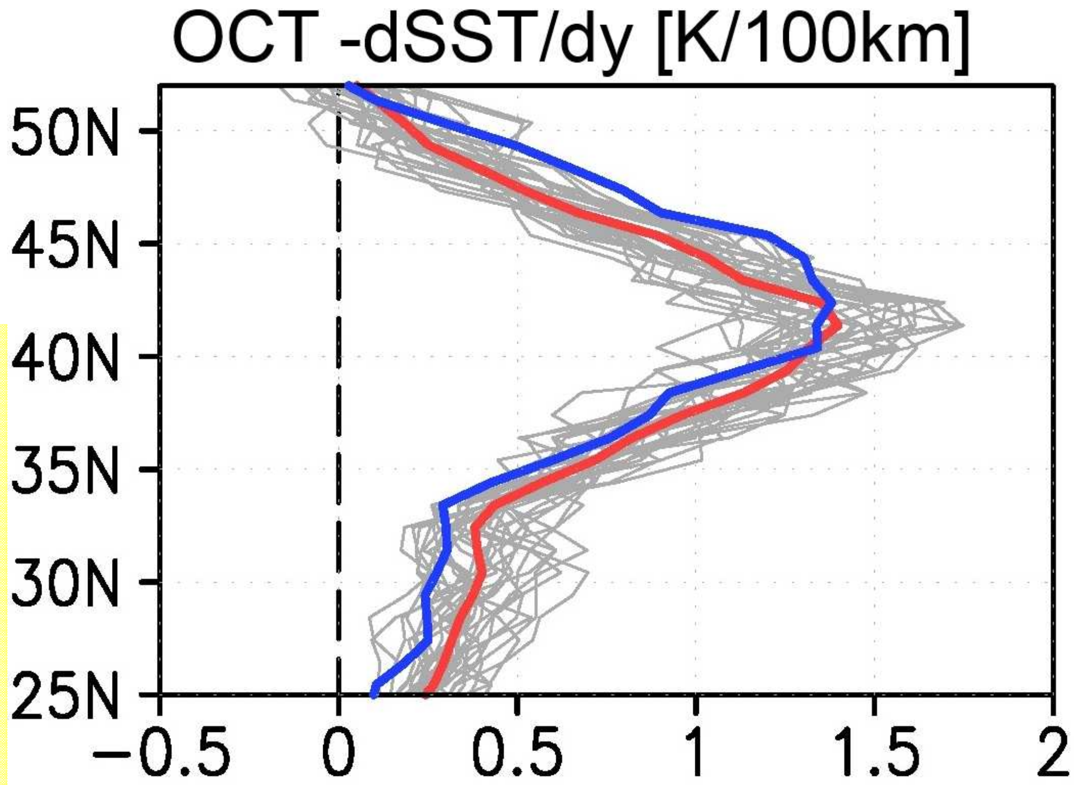
In 1982-2010:

- 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



Zonally-averaged (150°E-180°E) meridional SST gradient in October [°C/100km]

Gray contours: 1982-2010

Blue contour: 2011

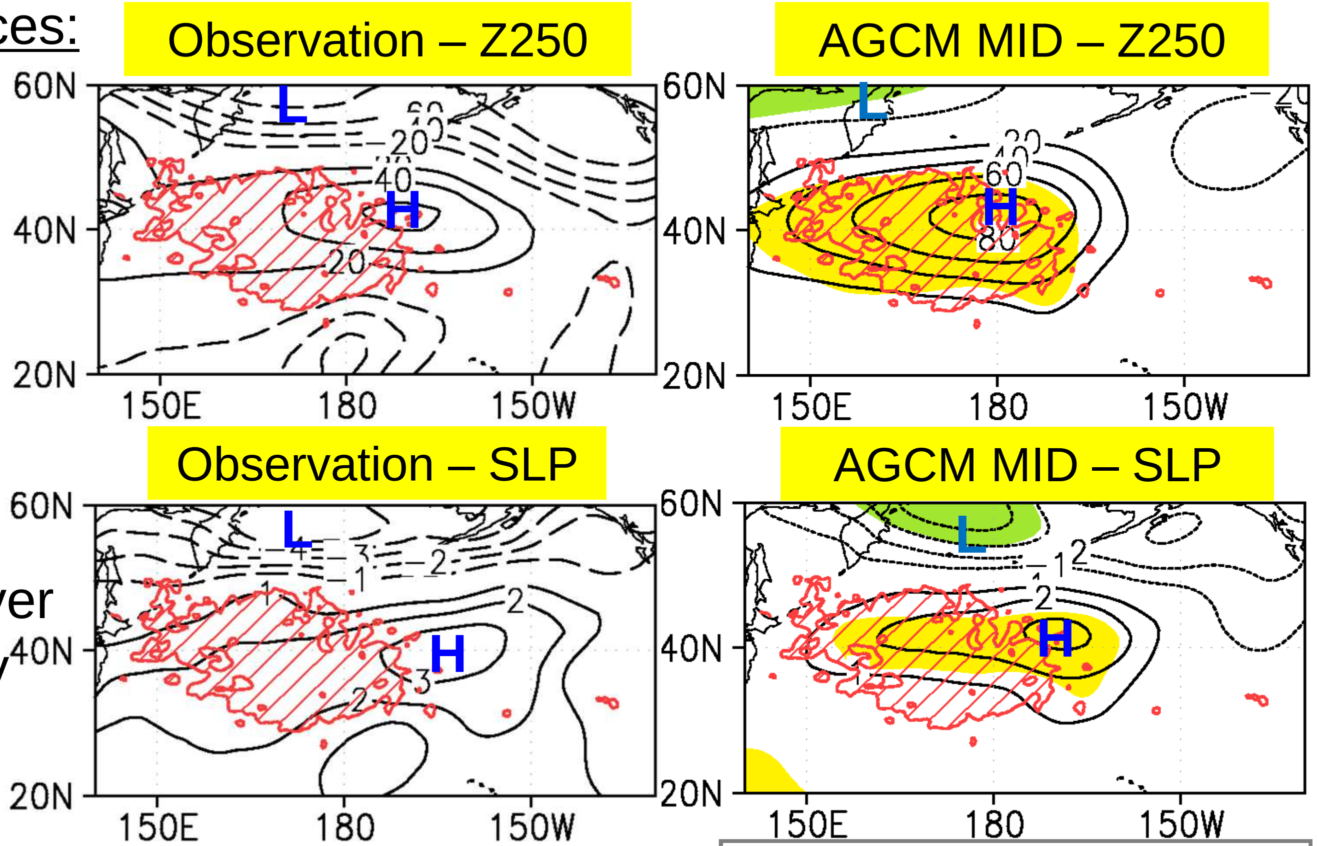
Red contour: climatological SST

Observed and simulated circulation anomalies in October

Okajima, Nakamura, Nishii, Miyasaka, Kuwano-Yoshida (2014 J.Clim. In press)

<u>MID experiment reproduces:</u>

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



Red hatches :SSTA > +1°C

c.i. = 20m and 1hPa
Color: 95% confidence level

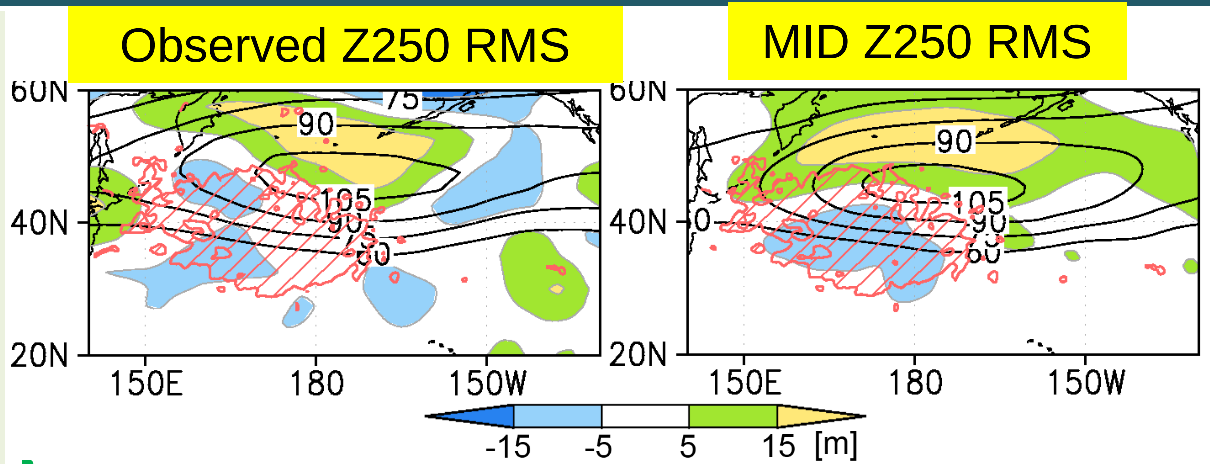
<u>These anomalies arise from:</u>

- 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

Transient eddy feedback forcing in 2011 October

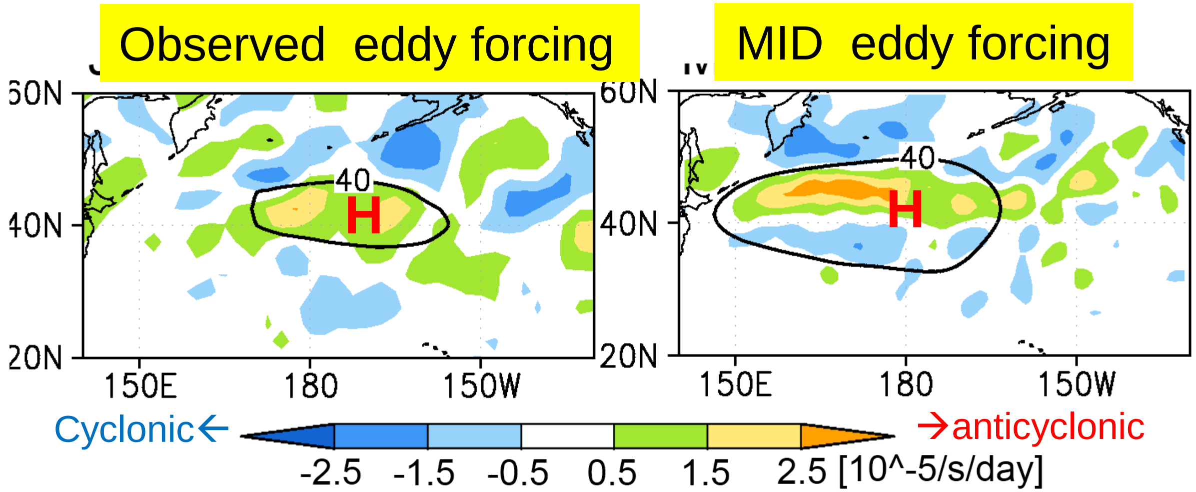
Okajima, Nakamura, Nishii, Miyasaka, Yoshida (2014, J.Clim. In press)

- Stormtrack is intensified and shifted poleward,
- consistent with enhanced surface baroclinicity on the northern flank of the warm SST anomaly.



RMS of sub-weekly Z250 fluctuations
Contour: climatology; Color: anomalies

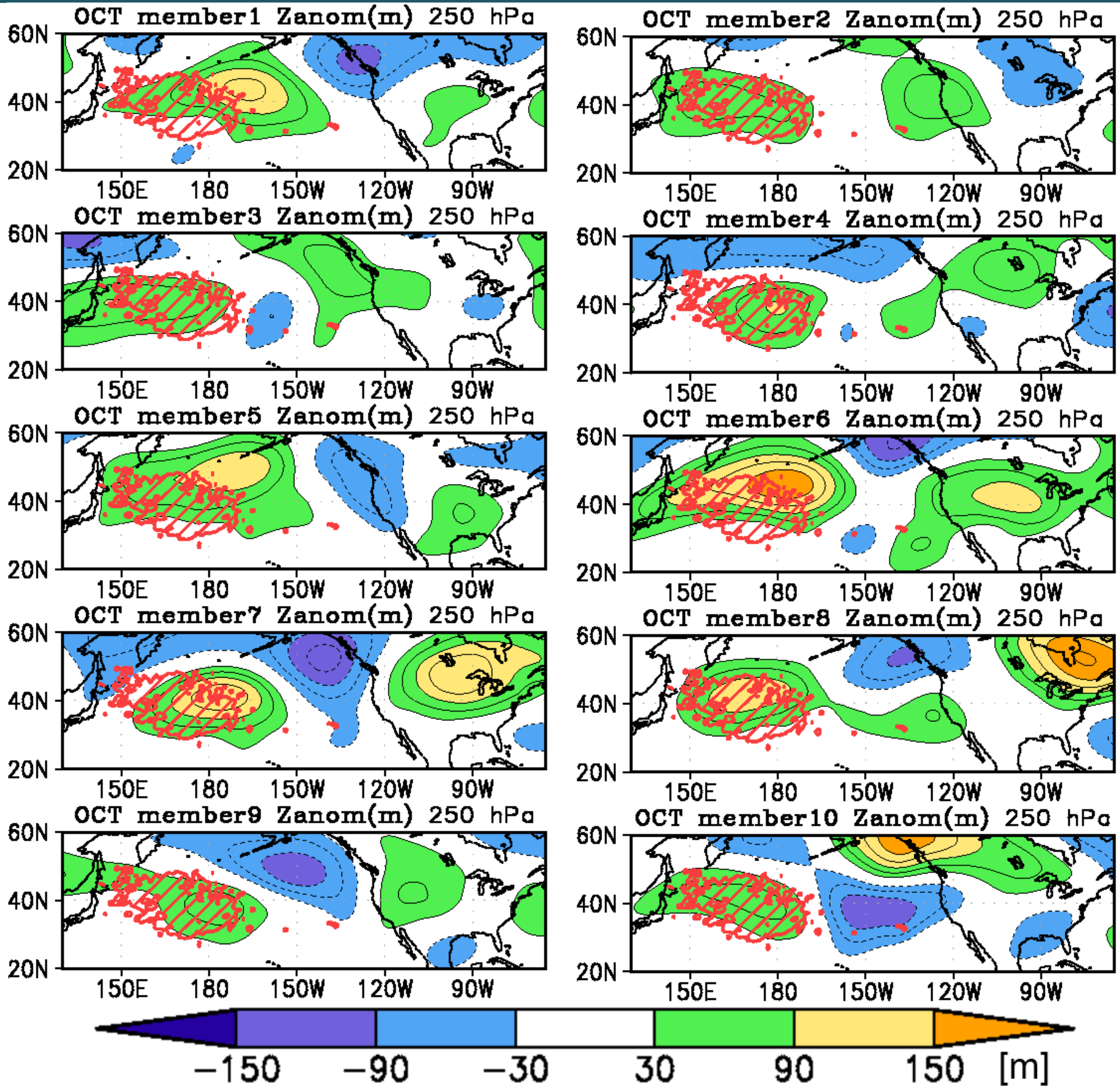
- Anomalous anticyclonic forcing by anomalous divergence of eddy vorticity flux south of the stormtrack.
- Resultant anomalous subsidence and anomalous divergence of eddy heat flux contribute to the maintenance of the surface anticyclonic anomaly.



Color: Anomalous eddy vorticity flux convergence
Contour: Z250 anomaly [m]

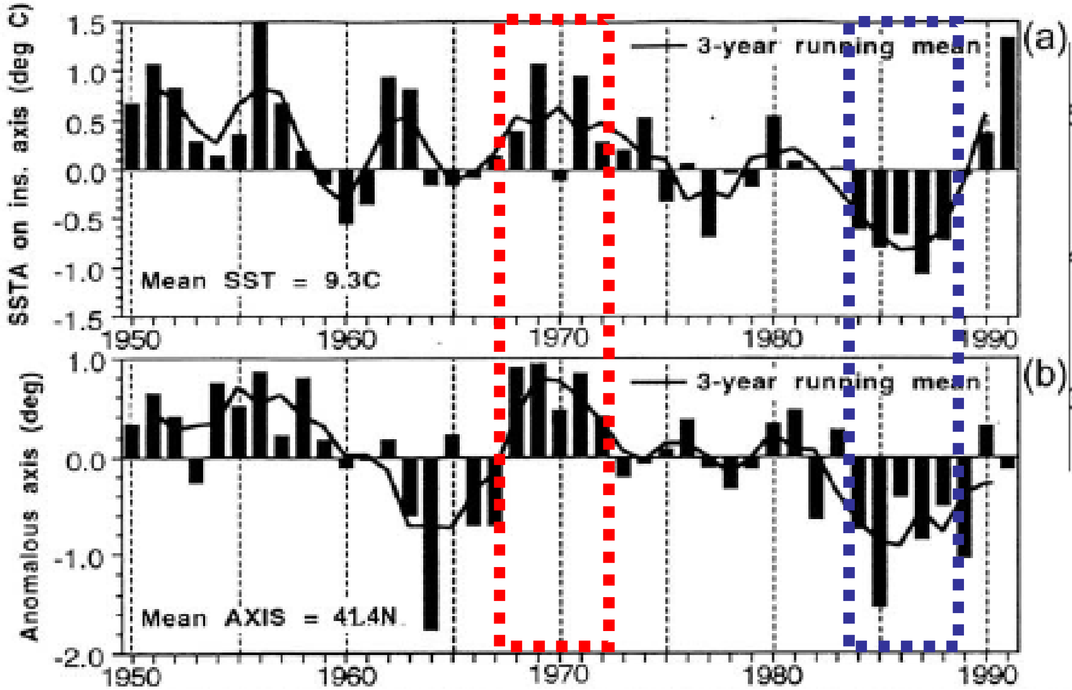
Z250 response in individual ensemble members – MID October

Okajima, Nakamura, Nishii, Miyasaka, Kuwano-Yoshida (2014 J.Clim. In press)



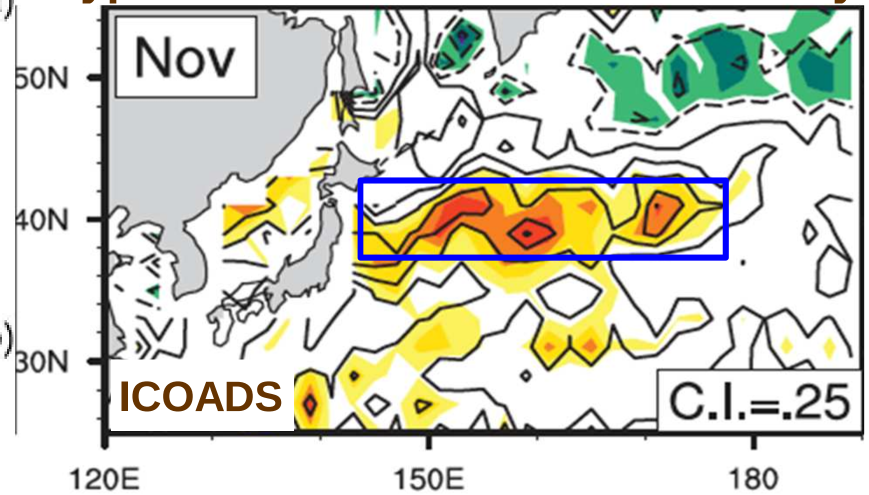
Observed variability of the NPAC subarctic front

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



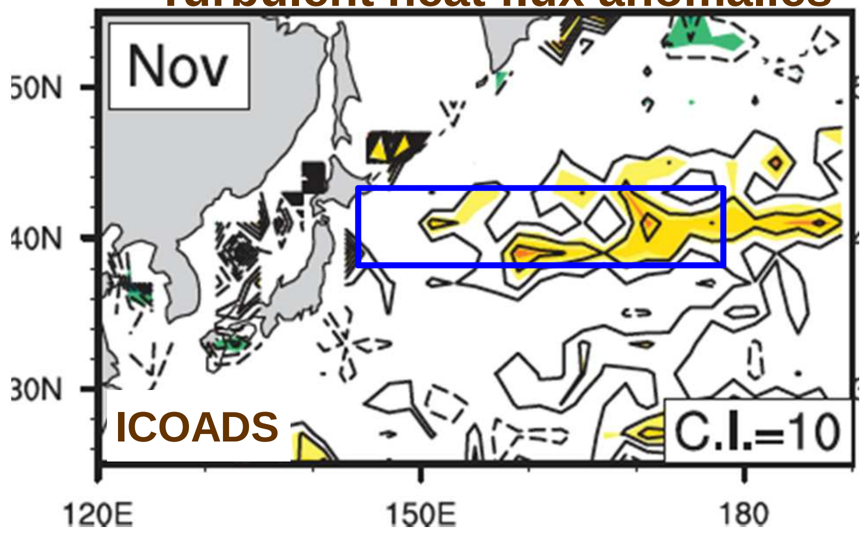
40~60% of SST variability in the North Pacific subarctic frontal zone is caused by oceanic processes (Smirnov et al. 2014 JC).

Typical decadal-scale SST anomaly



Enhanced heat release from warmed oceanic frontal zone

Turbulent heat flux anomalies

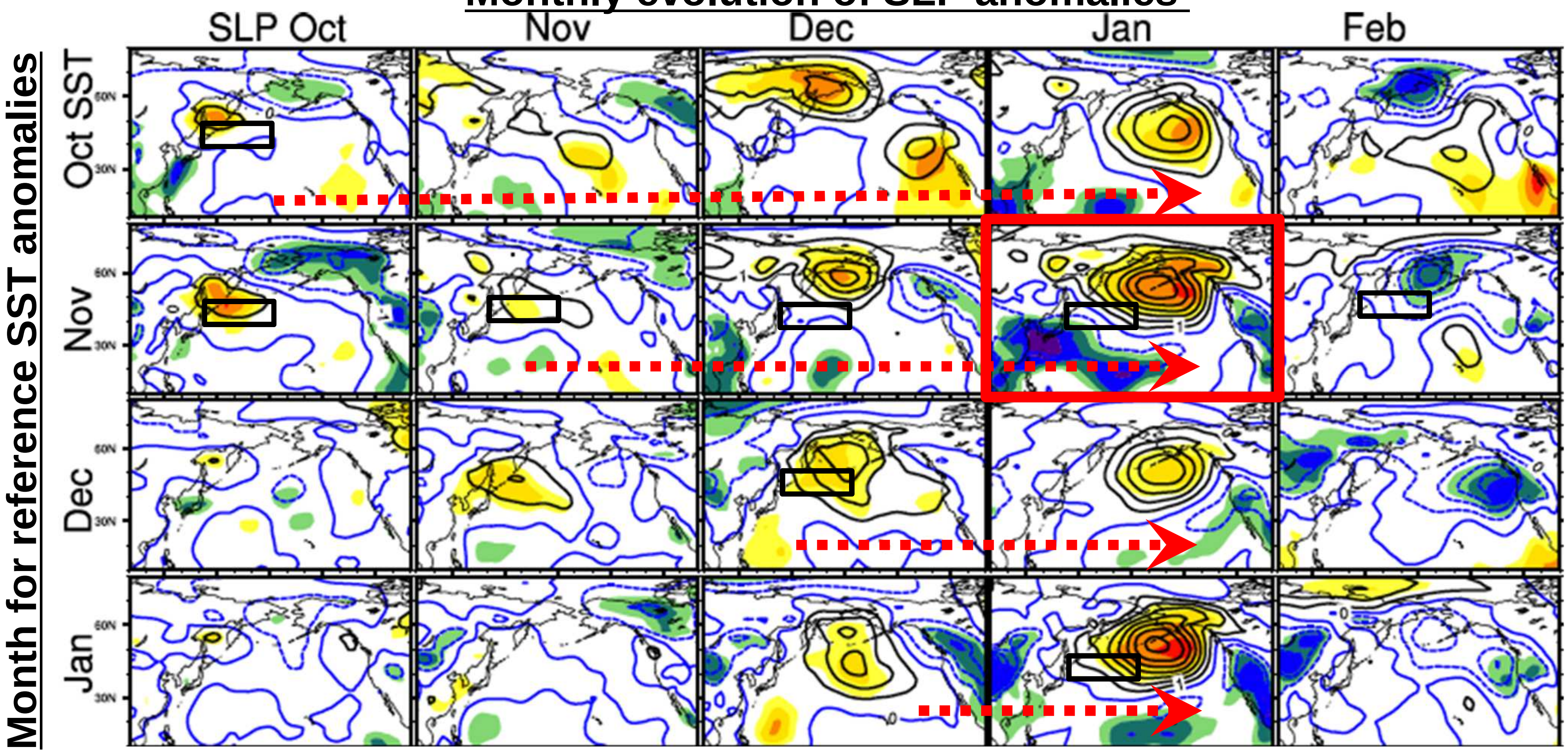


Large-scale atmospheric anomalies forced by decadal SST anomalies in the subarctic frontal zone

Taguchi, Nakamura et al. (2012, J. Clim.) c.f. Frankignoul et al. (2011 JC)

- 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.

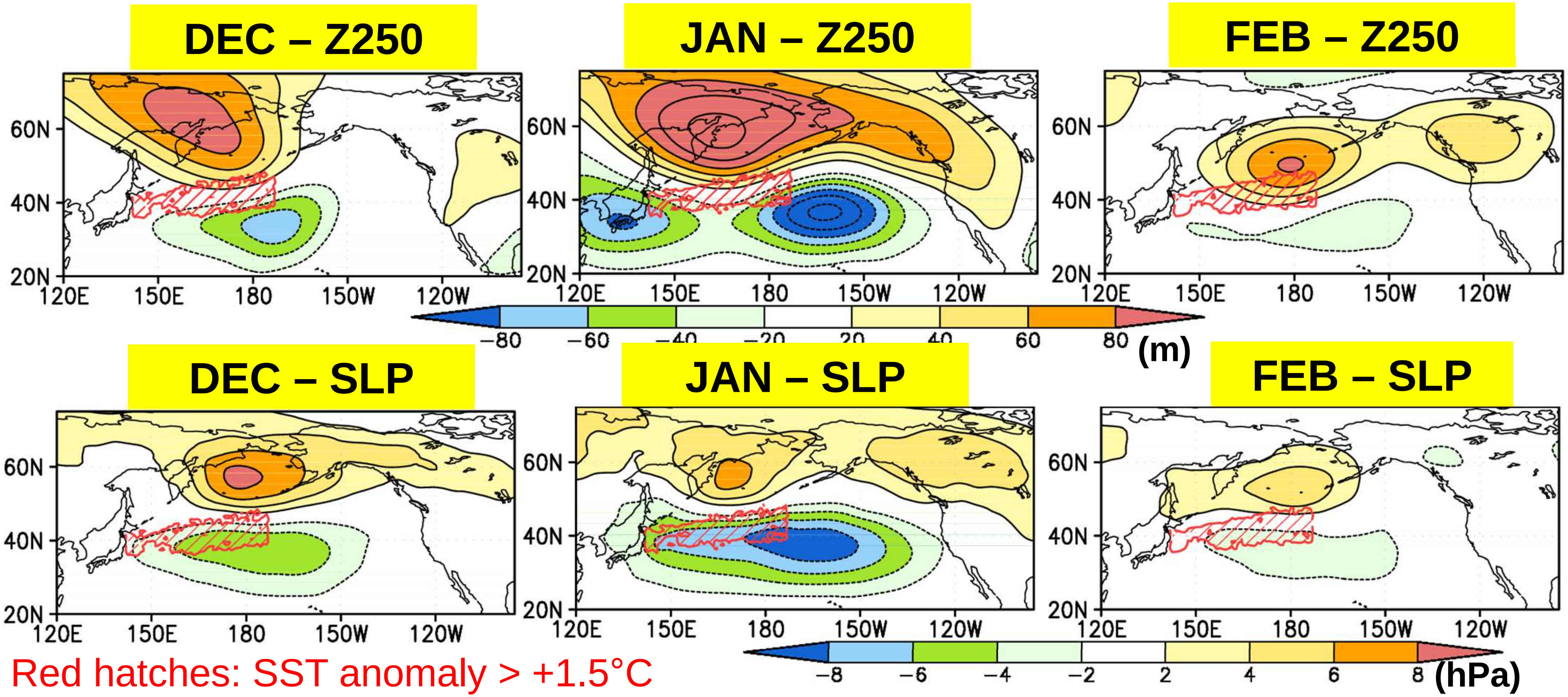
Monthly evolution of SLP anomalies



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)

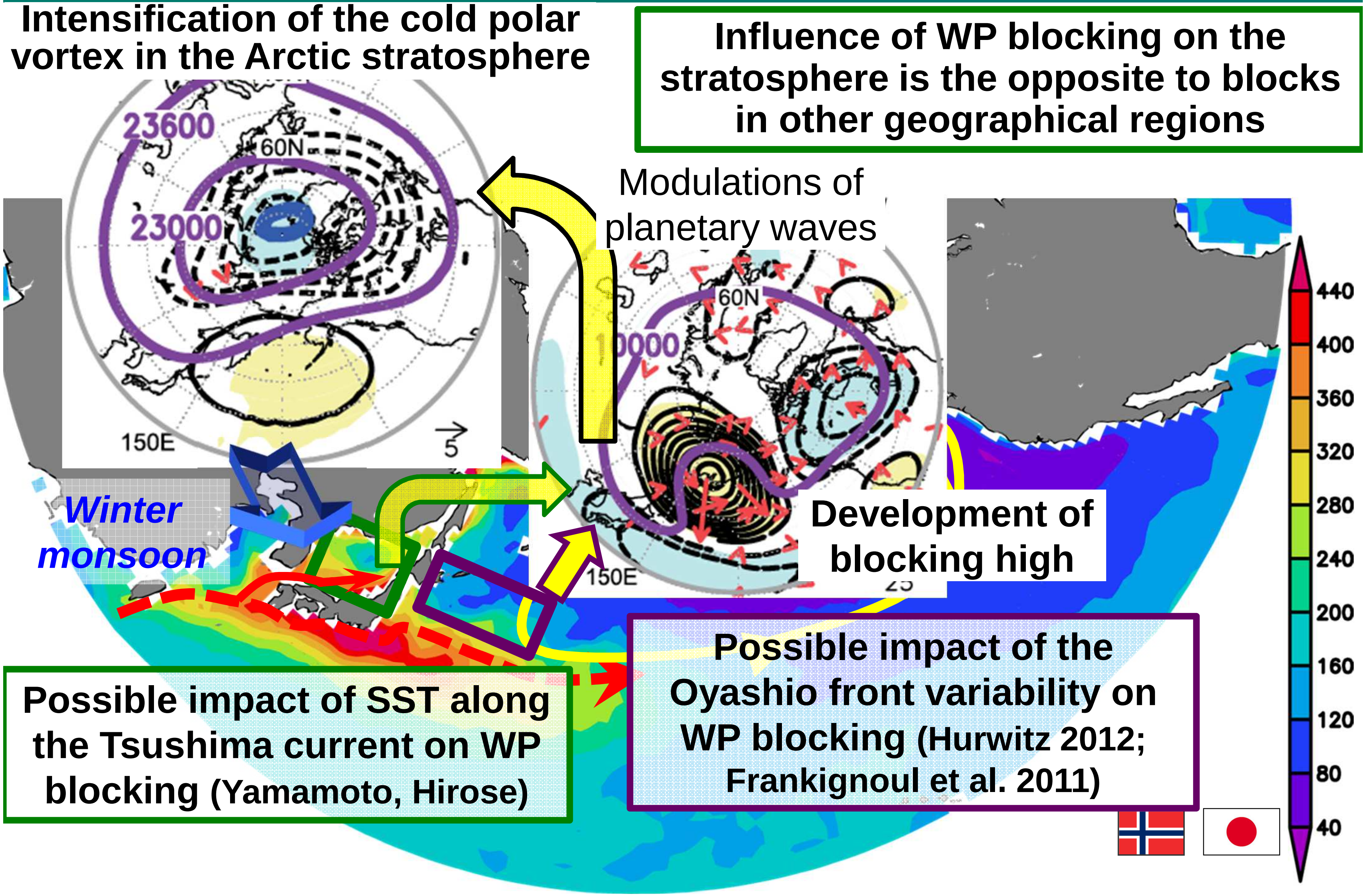


Red hatches: SST anomaly > +1.5°C

- 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

Nishii, Nakamura, Orsolini (GRL2010, J.Clim.2011), Yamamoto, Hirose (GRL2011)



Meso/regional-scale impacts of midlatitude oceanic fronts

Review papers by Small et al. (2008 DAO), Kelly et al. (2010, JC)

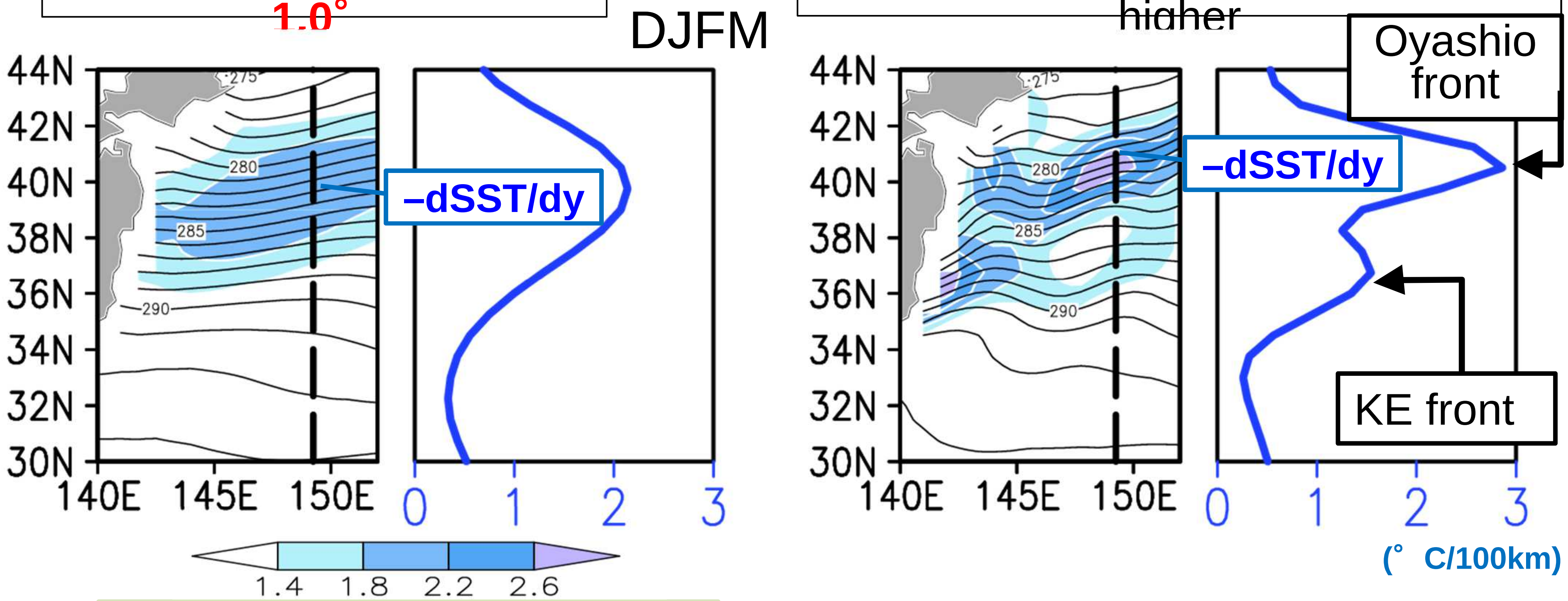
SST prescribed for the ERA-Interim reanalysis

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

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)

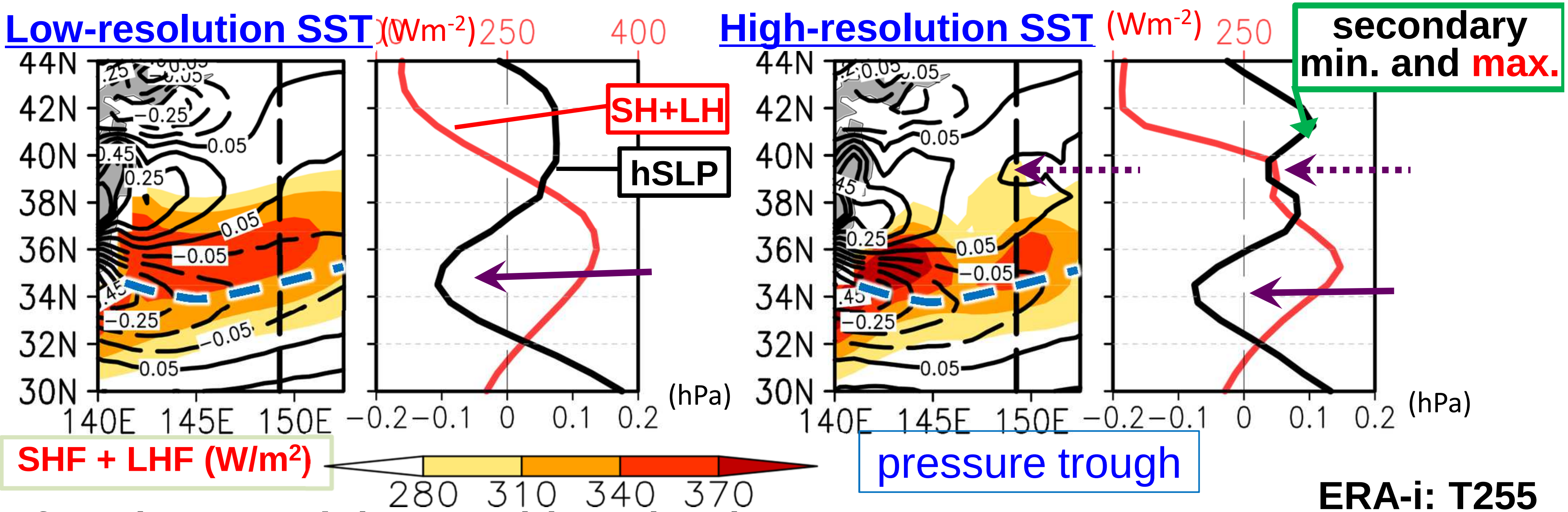
1979~2001 (23 years) SST with resolution of 1.0°	2002~12 (11 years) SST with resolution of 0.5° or higher



shading: –dSST/dy (° C/100km)

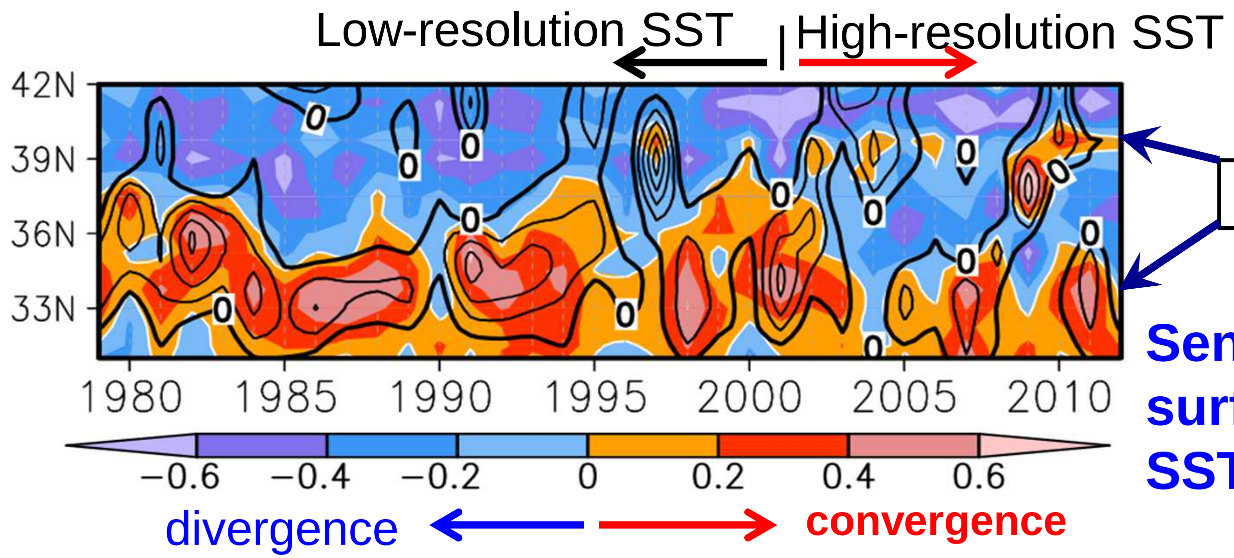
Winter SLP trough in KOE: Apparent variability in ERA-interim

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



ERA-i: T255

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



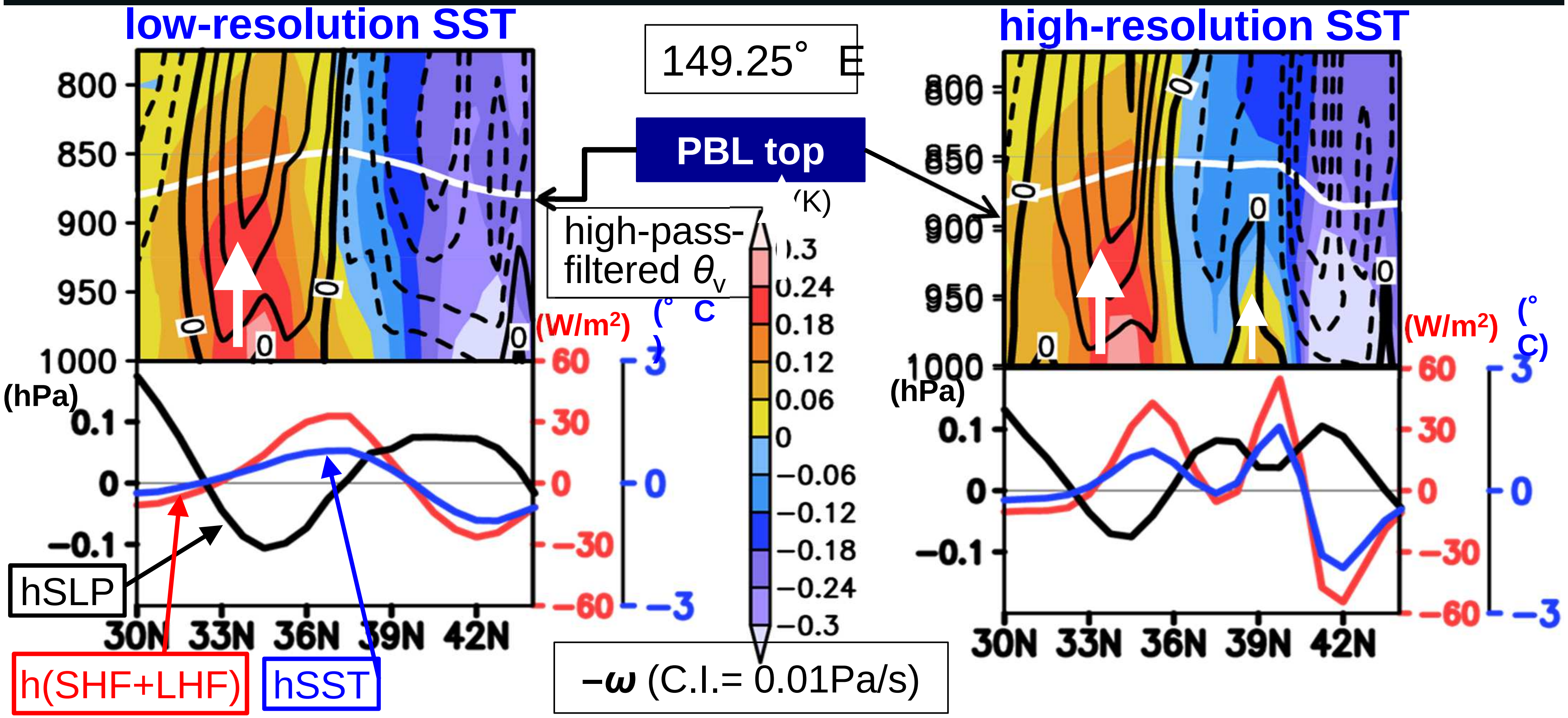
January at 149.25° E

contour: high-pass SLP trough

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

SST impact on virtual potential temperature (θ_v) and vertical motion

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

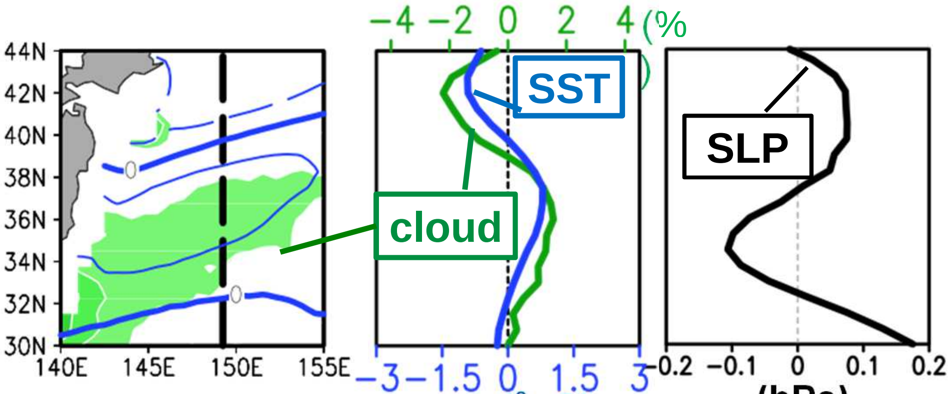


- Well-defined maximum of high-pass filtered θ_v and ascent into the free troposphere is evident south of KE in both periods.
- Shallow maximum of high-pass filtered θ_v, ascent and local deepening of PBL just to the south of the Oyashio front analyzed only in high-resolution SST period.

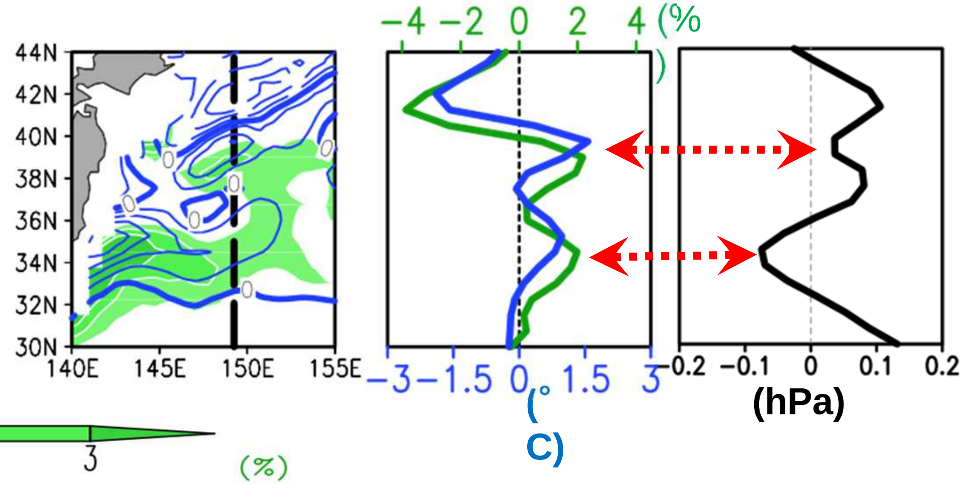
Wintertime cloudiness in KOE: Apparent variability in ERA-interim

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

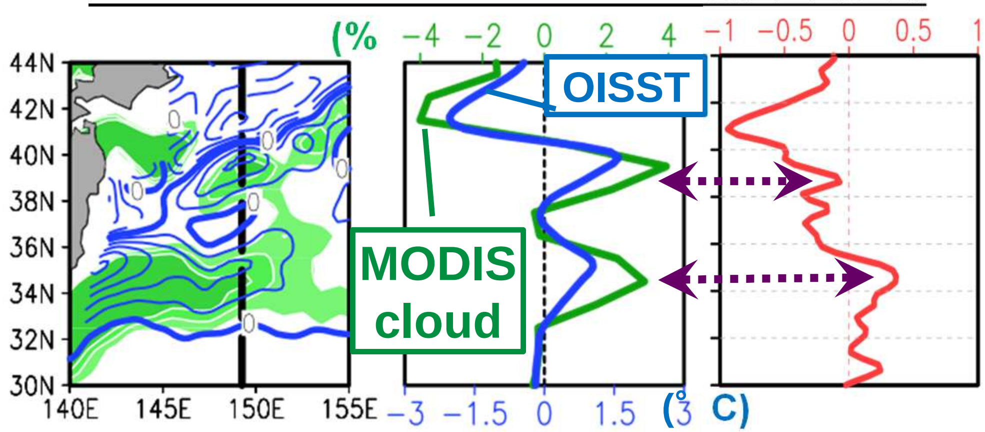
Latitudinally high-pass-filtered profiles (smaller than 6°)

c.f. Tokinaga et al. (2009, JC)

ERA-Interim for the recent high-resolution SST period is consistent with satellite observations.

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

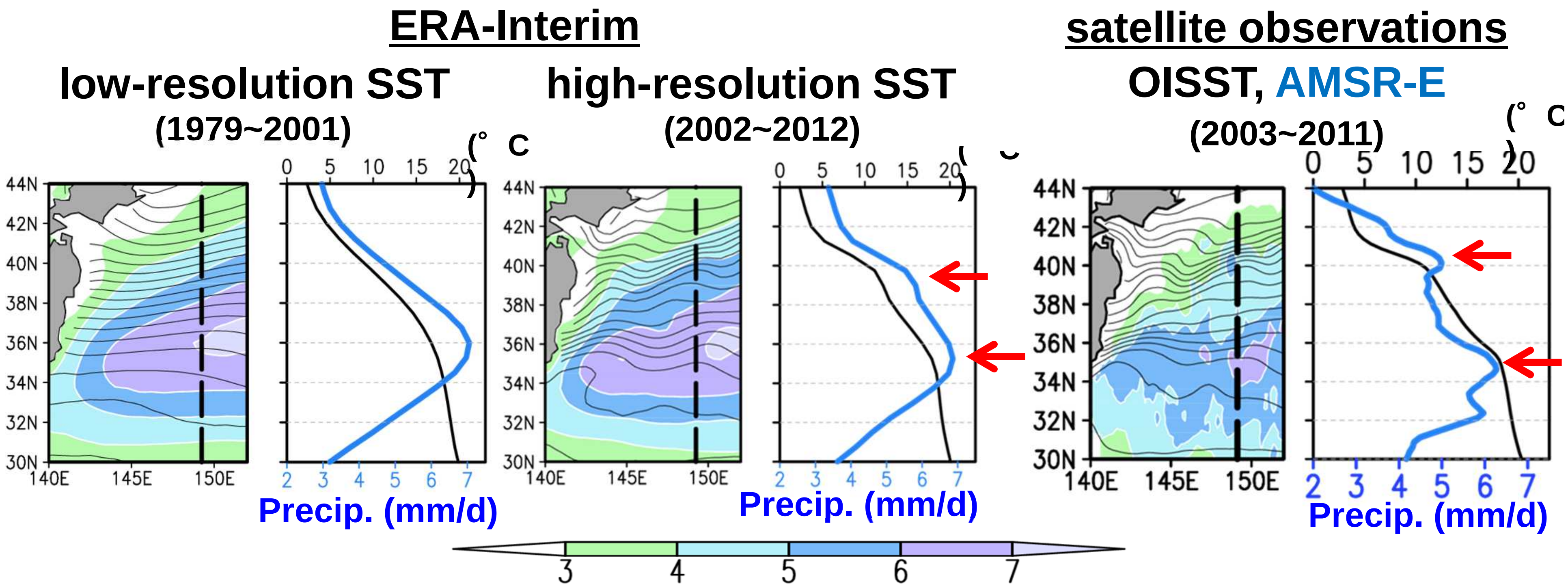
Satellite measurements 2002~2011



QuikSCAT surface wind convergence (1999~2009, DJFM)

Climatological precipitation: Satellite data v.s. ERA-Interim

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

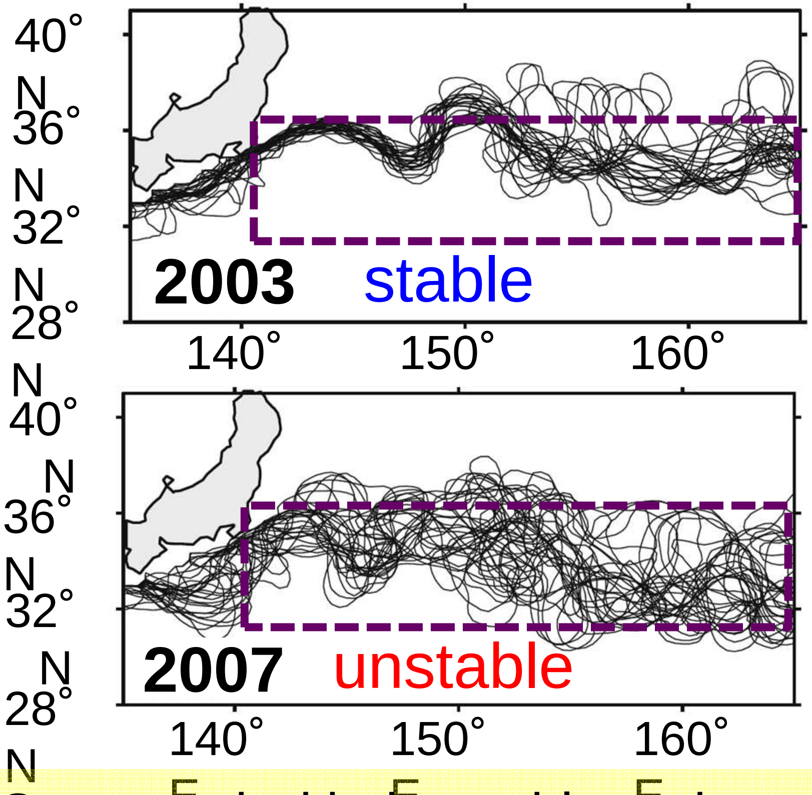


- Consistent with satellite observations, ERA-Interim (convective) precipitation maximizes along the warm KE.
- In addition, only in its high-resolution SST period, ERA-Interim (convective) precipitation is enhanced on the warmer flank of the Oyashio front, with higher consistency with satellite observations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

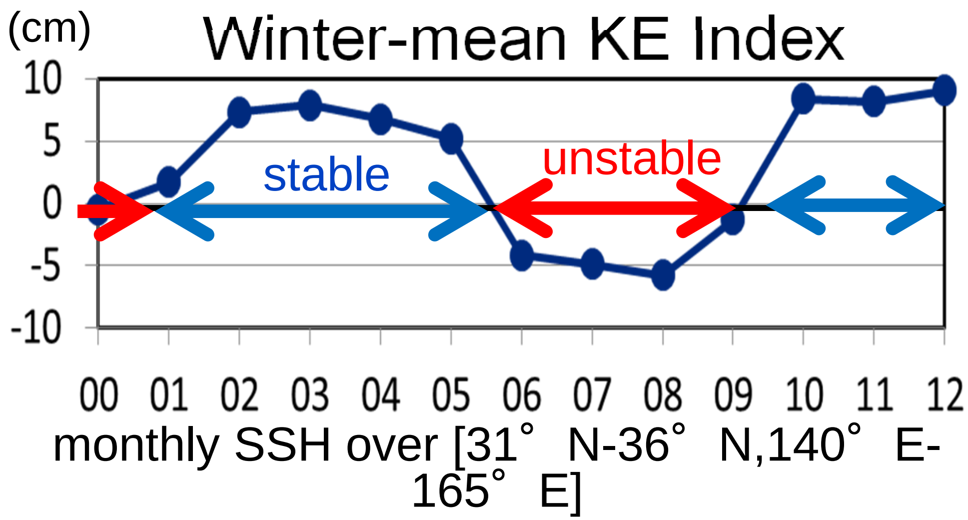
Quasi-decadal variability of KE

Qiu, Chen (2005, 2010, 2014), Masunaga, Nakamura et al. (2014 JC to be submitted)

Weekly KE paths (SSH = 170cm)

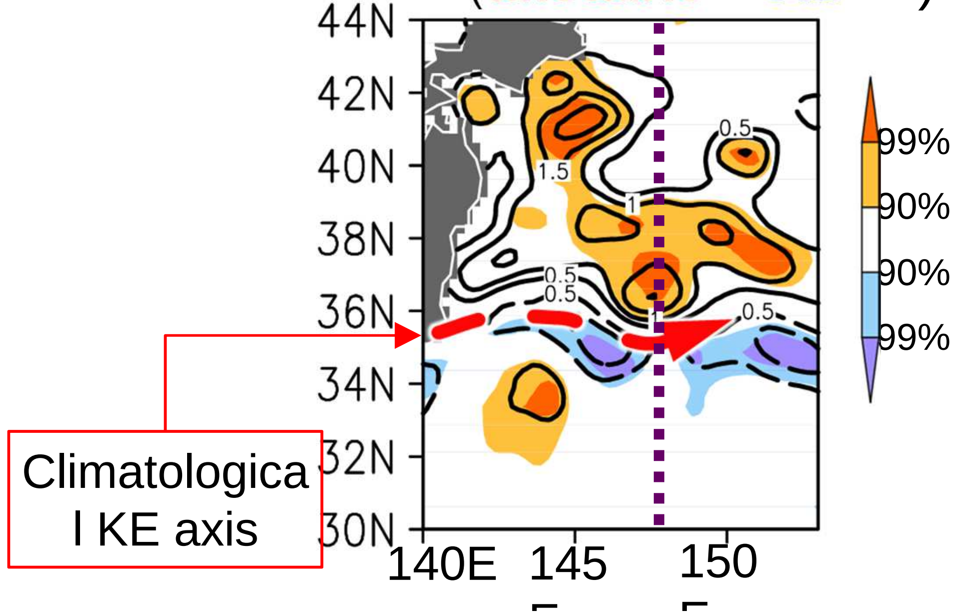


Winter-mean KE Index



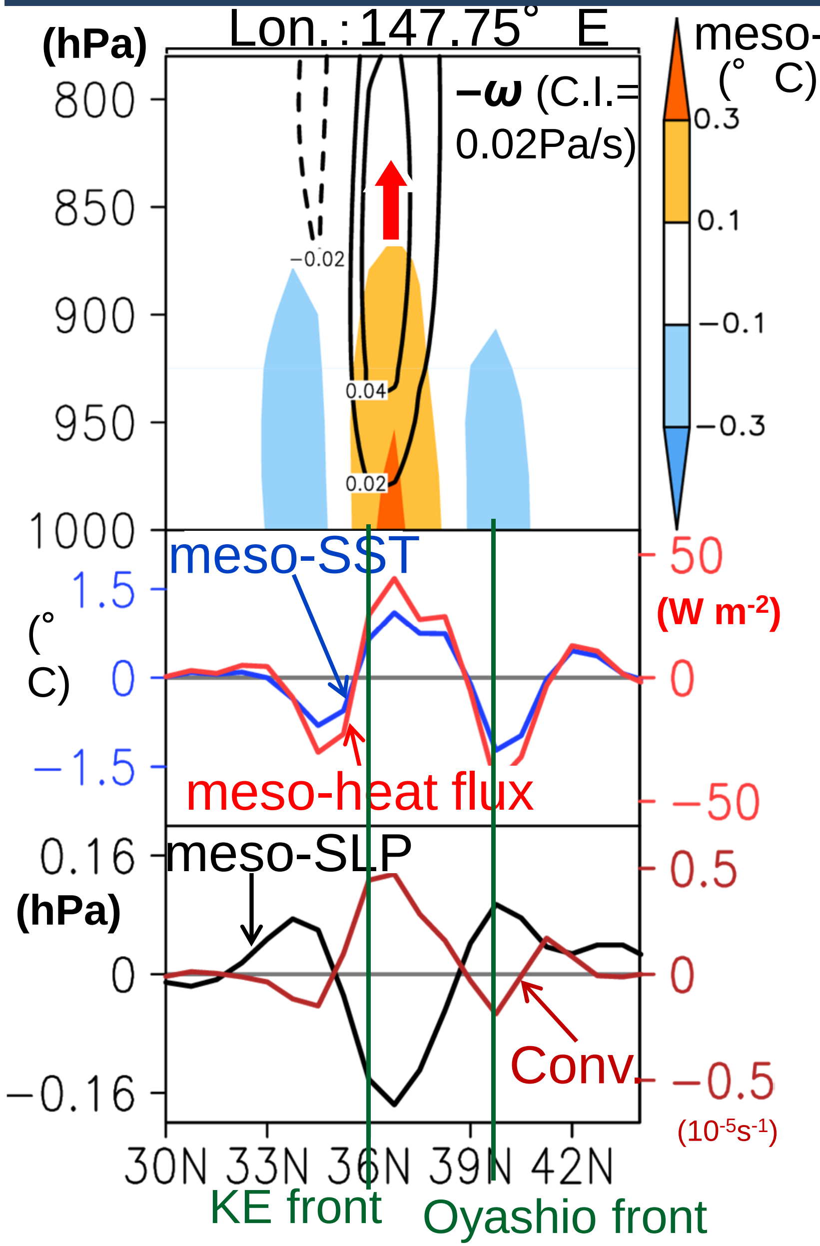
Compared with the stable regime, the unstable regime is characterized by more active warm core eddies in the frontal zone with higher SST and enhanced heat release from the ocean (Sugimoto, Hanawa 2011 JC).

Composite difference of satellite SST (**unstable** – **stable**)



Lower-tropospheric response to quasi-decadal KE variability

Masunaga, Nakamura, Miyasaka, Nishii, Qiu (JC 2014 to be submitted)



Composite differences based on ERA-I (**unstable** – **stable**), featuring unstable regime

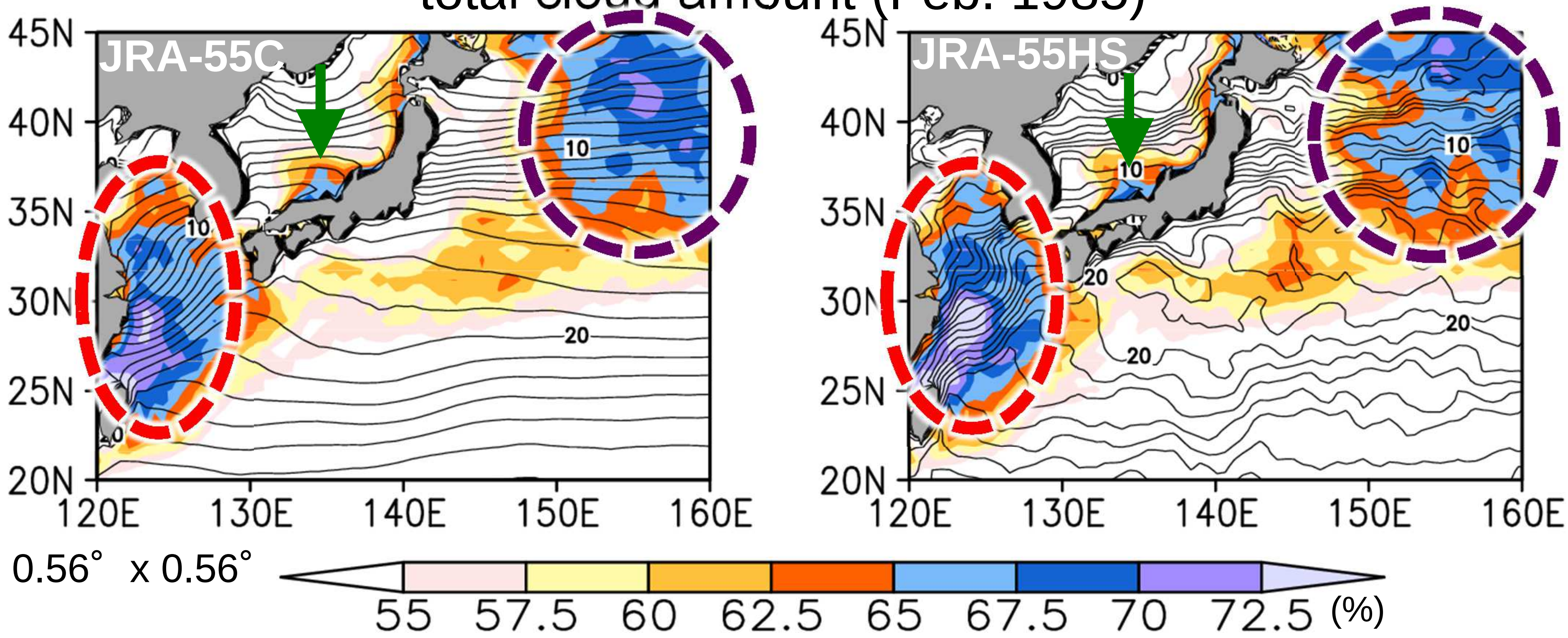
In the unstable regime, enhanced heat release from the ocean north of the climatological KE axis warms PBL locally, **lowering SLP** via hydrostatic effect.

The anomalous frictional convergence in PBL accompanies anomalous ascent that reaching into the free troposphere, locally enhancing cloudiness and precipitation.

Additional product of JRA-55 (new global atmospheric reanalysis) with 0.25° satellite SST (JRA-55HS) from 1985 to 2012

JMA-MRI-"Hot-Spot" joint project

total cloud amount (Feb. 1985)



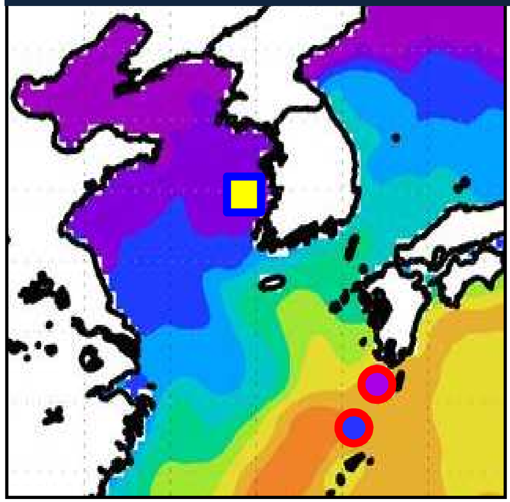
<u>**Compared with JRA-55C, JRA-55HS cloudiness**</u>

- **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

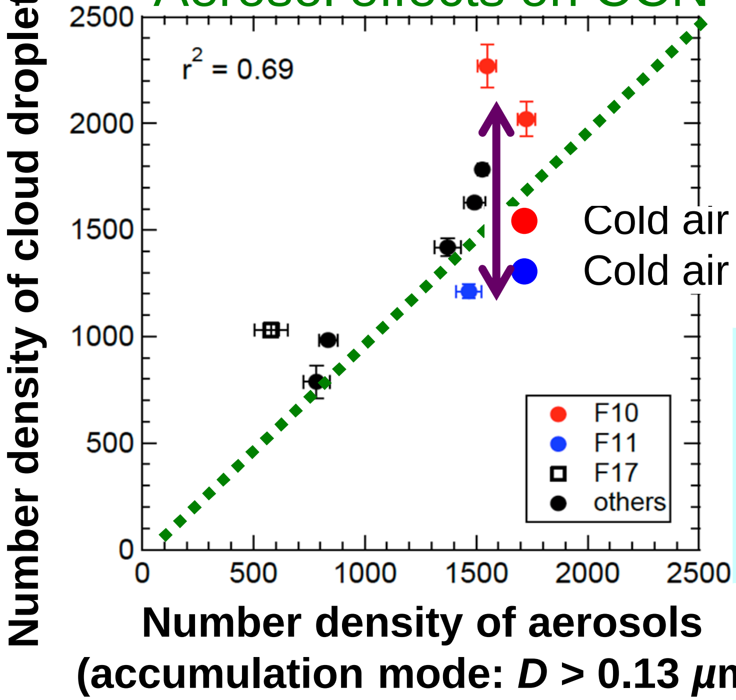
Cloud microphysics modulated by the Kuroshio

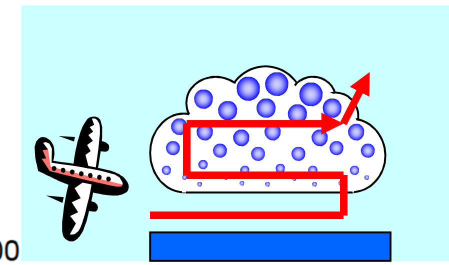
Koike, Takegawa, Moteki, Kondo, Nakamura et al. (2012, JGR); Koike et al. (2014)

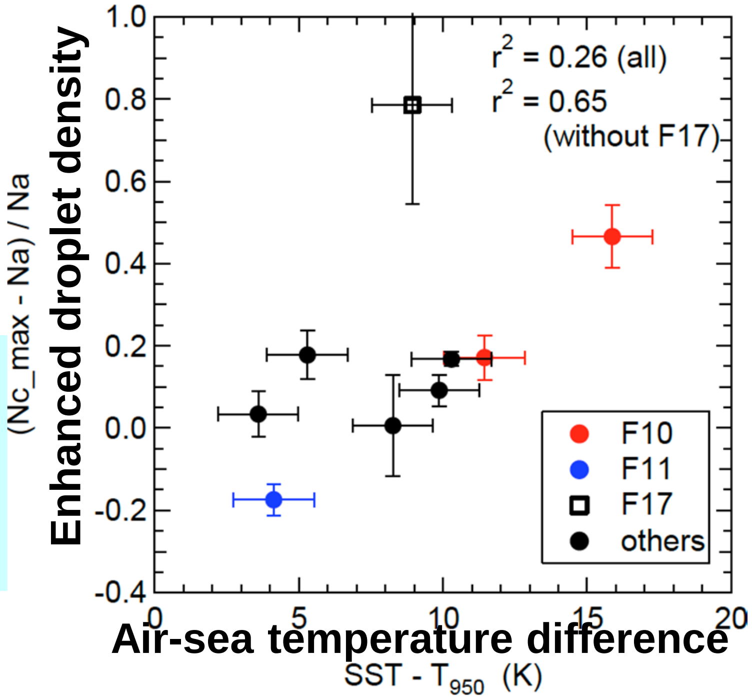


Cold-air outbreak from the continent onto the Kuroshio
→ reduced stratification
→ enhanced updraft [0.4 → 1.2 m/s]
→ enhanced associated adiabatic cooling
→ higher super-saturation level
→ activation of smaller aerosols as CCN
→ **higher cloud albedo** [fractional increase: 11%]
→ **enhanced cloud radiative forcing** [–4.7 W/m^2]

Aerosol effects on CCN



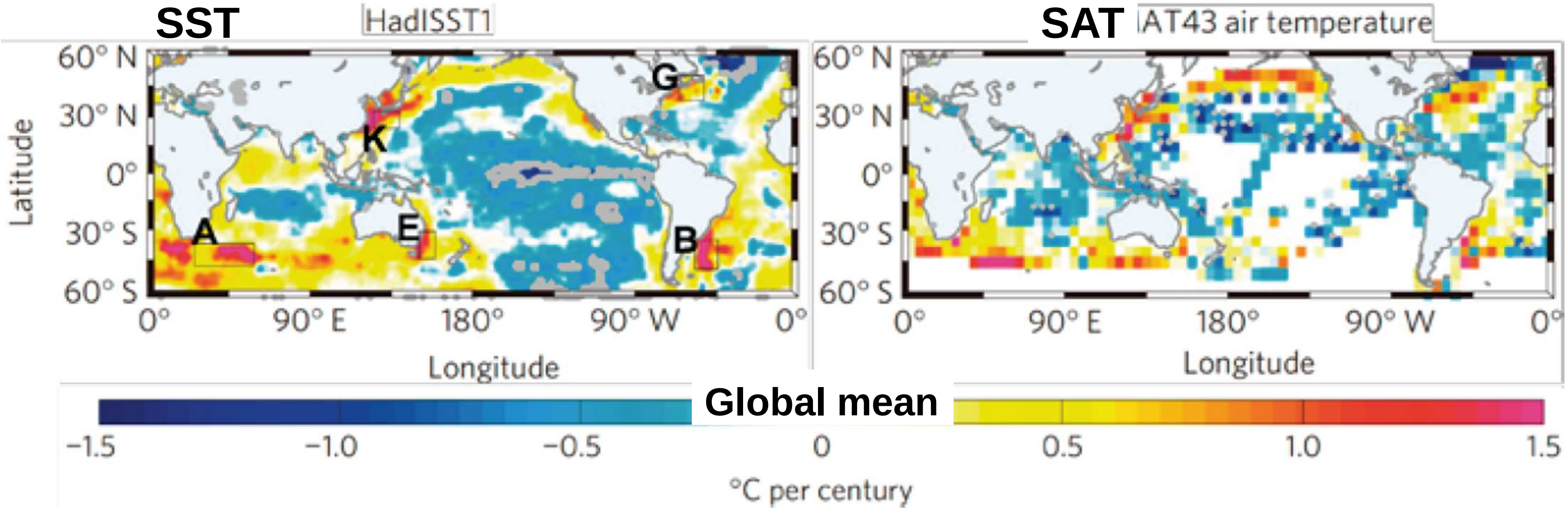




Enhanced warming along the western boundary currents

L. Wu, W. Cai, L. Zhang, H. Nakamura, et al. (Nature Climate Change, 2012)

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).