Spatial-Temporal Changes of Ocean Waves Generated by Explosive Cyclones

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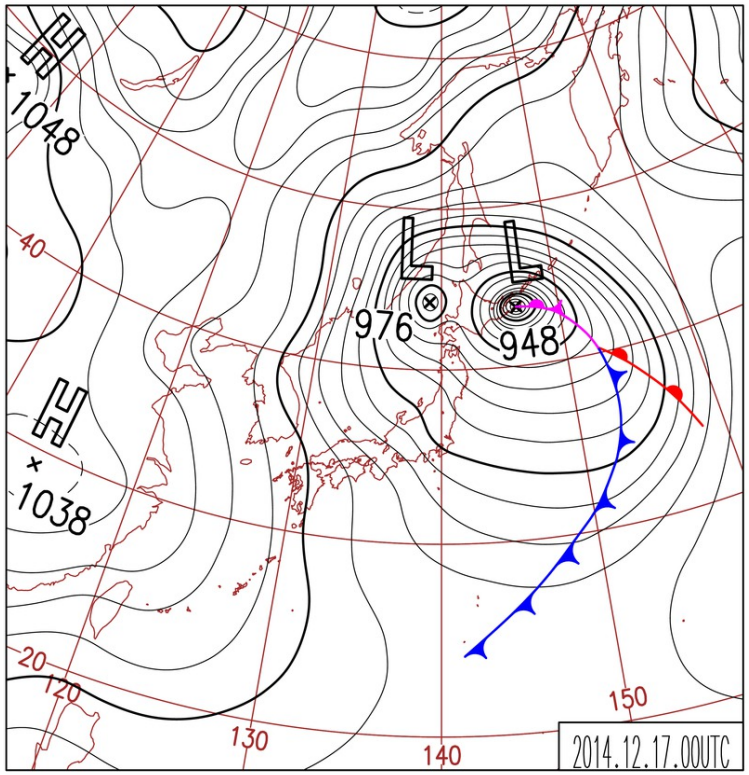
*JSPS Fellowship (DC1)

Supported by JSPS KAKENHI Grant Number 17J07627

Waves under Explosive Cyclones

- An **extratropical cyclone** is generated in high baroclinicity areas in mid-latitude zones. When it is intensified rapidly, which is called **"Explosive Cyclones (ExpC) "** (e.g. Sanders and Gyukum, 1972).
- Like a **tropical cyclone (TC)**, it can generate extremely high waves, resulting in severe disasters.

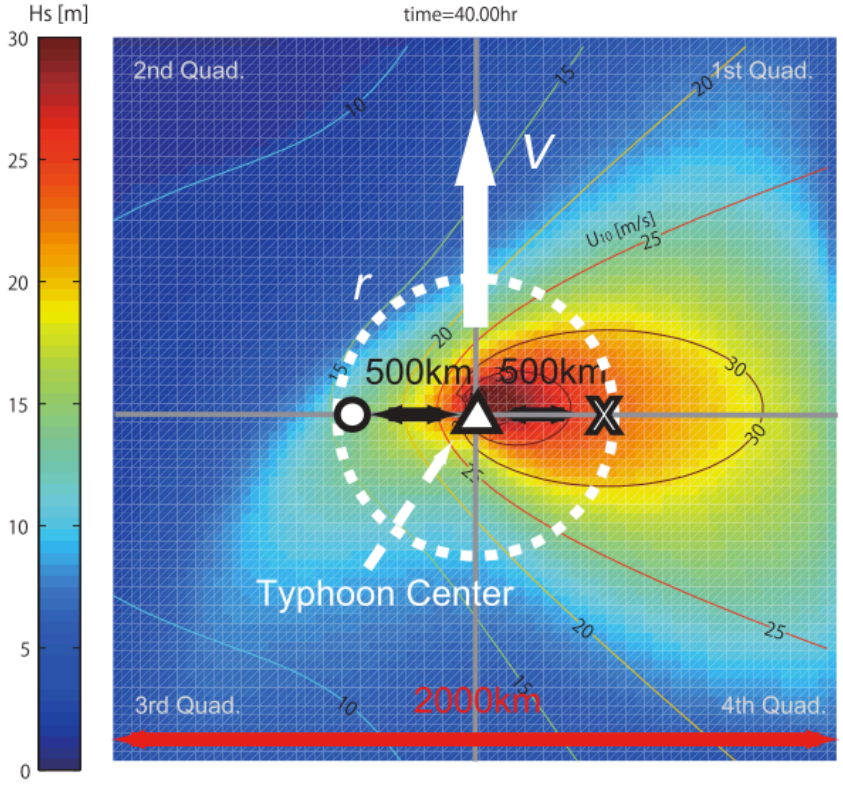
Ocean waves generated by ExpC at Hokkaido, on middle December, 2014 (Asahi Shimbun)



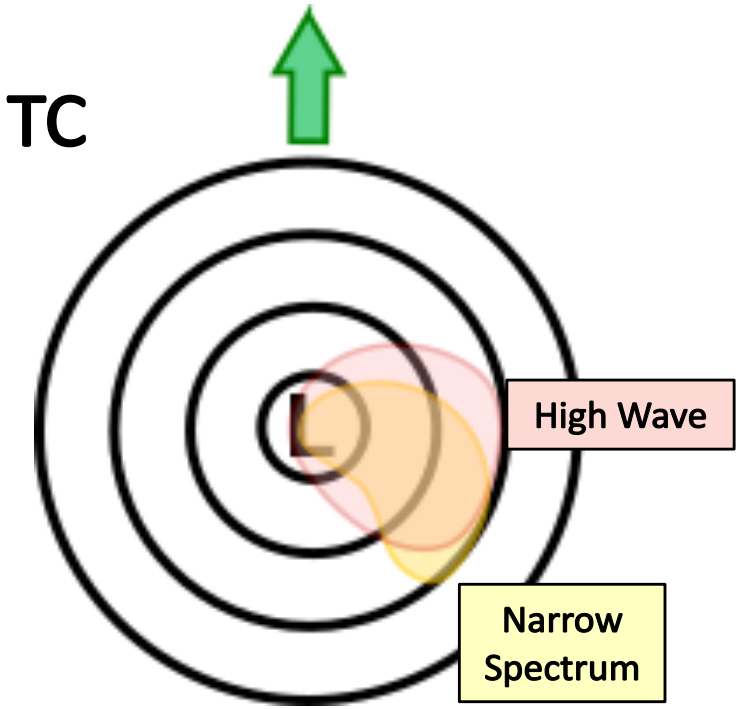
Original: Japan Meteorology Agency
Processed in "Digital Typhoon Database" by NII

Previous studies

- For all quadrants of the hurricane, with the exception of the right rear quadrant, the spectra are dominated by swell (Young 2005).
- Mori (2012) investigated freak waves under ideal TC conditions. Freak waves resulting from nonlinear wave interaction are favorable in the rear right quadrant of TC.



Significant wave heights (shade) and surface wind (contour) under an ideal TC condition (Fig.1, Mori 2012)



Specifications of Extratropical Cyclones

- Unlike TCs, extratropical cyclones have an asymmetric structure in winds. Extratropical cyclones has **cold and warm fronts**, which transforms with their developments.
- Extratropical cyclones generally **move more quickly** than TCs.
- ExpCs develop more rapidly than normal ones (e.g. 24hPa/hrs drop)

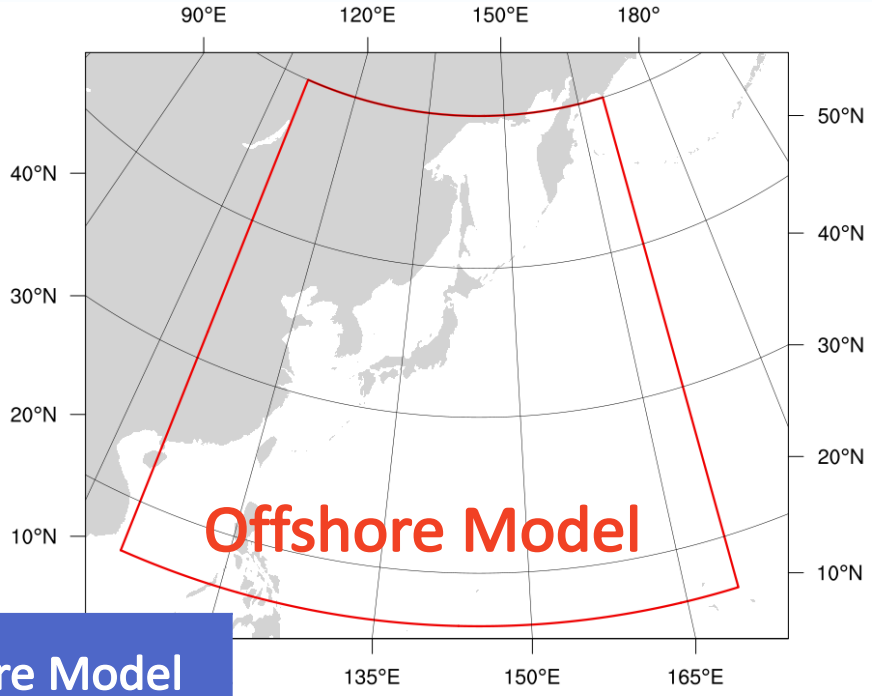
To understand spatial-temporal changes of ocean waves under ExpCs and its development mechanism comparing with TC cases, we implemented and analyzed numerical ocean wave simulation around Japan during 1994-2014.

Methods

✓ WAVEWATCH III for 20 years around Japan
✓ Composite analysis of ocean waves under hundreds of ExpCs
✓ Spectral analysis of ocean waves in one ExpC on Nov 2005

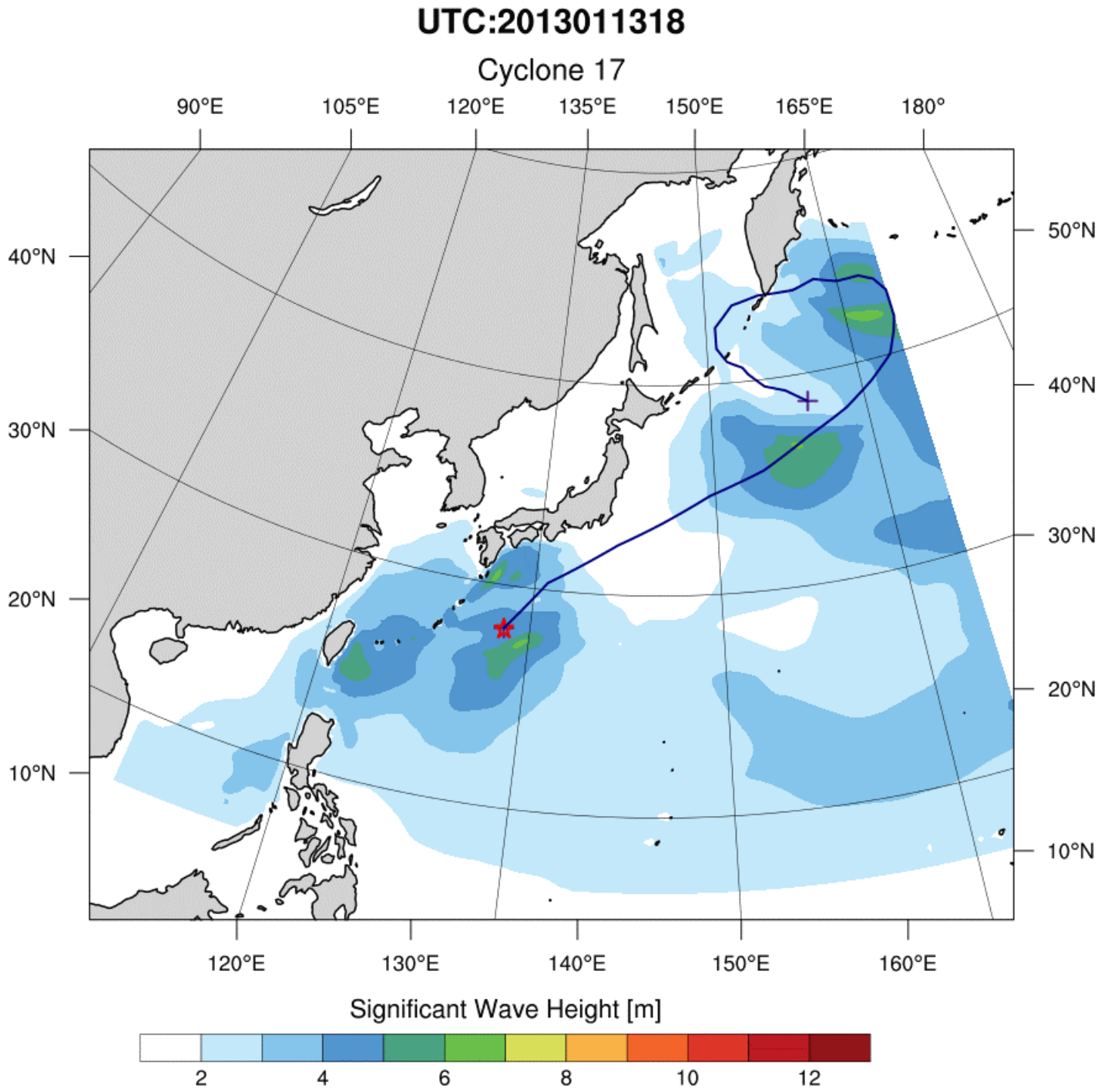
Ocean Waves Hindcast Simulation: TodaiWW3

- **WAVEWATCH III** hindcast simulation around Japan for 21-yrs: 1994-2014 (Webb et al. 2016; Waseda et al. 2016).
- It was validated with coastal observations.
- Data Access: http://www.todaiww3.k.u-tokyo.ac.jp/nedo_p/en/



TodaiWW3	Pacific Model	Offshore Model
Spatial Resolution	lat 0.6°×lon 0.75°	lat 0.2°×lon 0.25°
Domain	$101°E:70°W$ $75°S:75°N$	$110°E:170°E$ $10.2°N:60°N$
Spectral Resolution	35 frequencies (0.04118~1.05Hz) 36 directions	
Forcing	The wind and sea ice (CFSR) No ocean current	
Wind-Wave Interaction	ST4 (Ardhuin et al. 2010)	

Example of the Simulation: 2013 Jan



Cyclones Tracking

- Atmospheric Reanalysis Data: **NCEP CFSR**
  - Period: 1994~2014
  - Area: Eastern Asia, North Pacific (100°E:160°W, 10°N:70°N)
- Based on the method in Kyushu University cyclone database*, a local minimum in **MSLP** (Mean Sea Level Pressure) is tracked.
- TCs: Cyclones emerges in the southern of 25°N
- Development rate of ExpC $\varepsilon > 1$; $\varepsilon = \frac{p_{t-6}-p_{t+6}}{12}\frac{\sin 45^\circ}{\sin\phi_t}$ [hPa/hours]

p: MSLP
ϕ: latitude

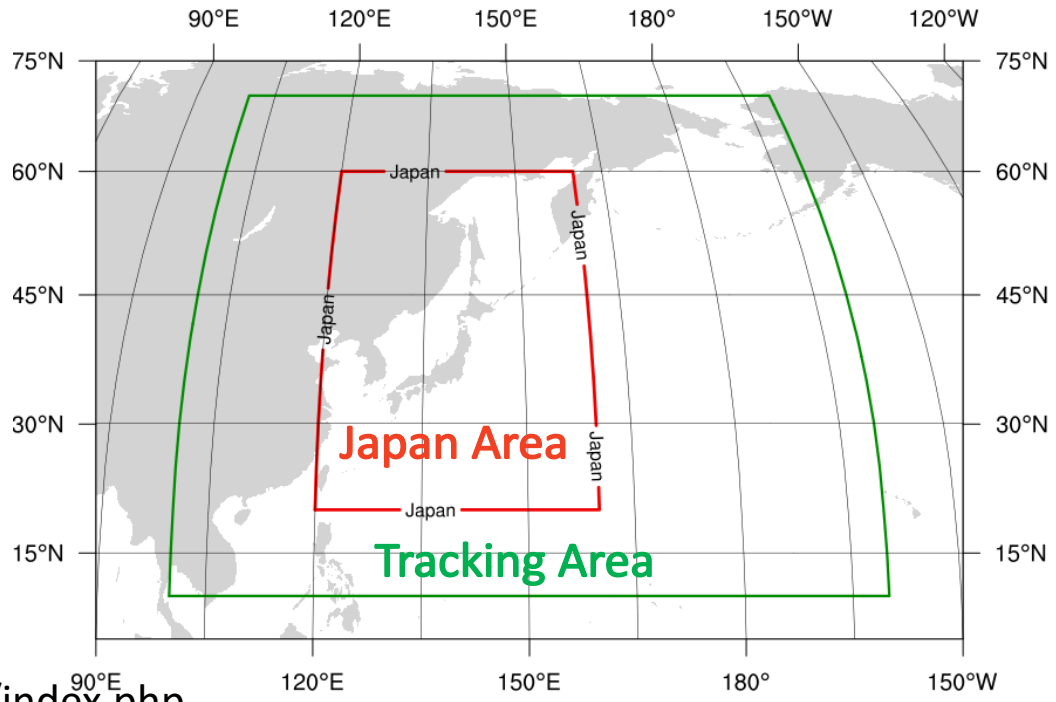
Annual Average Number

All Cyclones： 539.0

Tropical Cyclones： 27.2

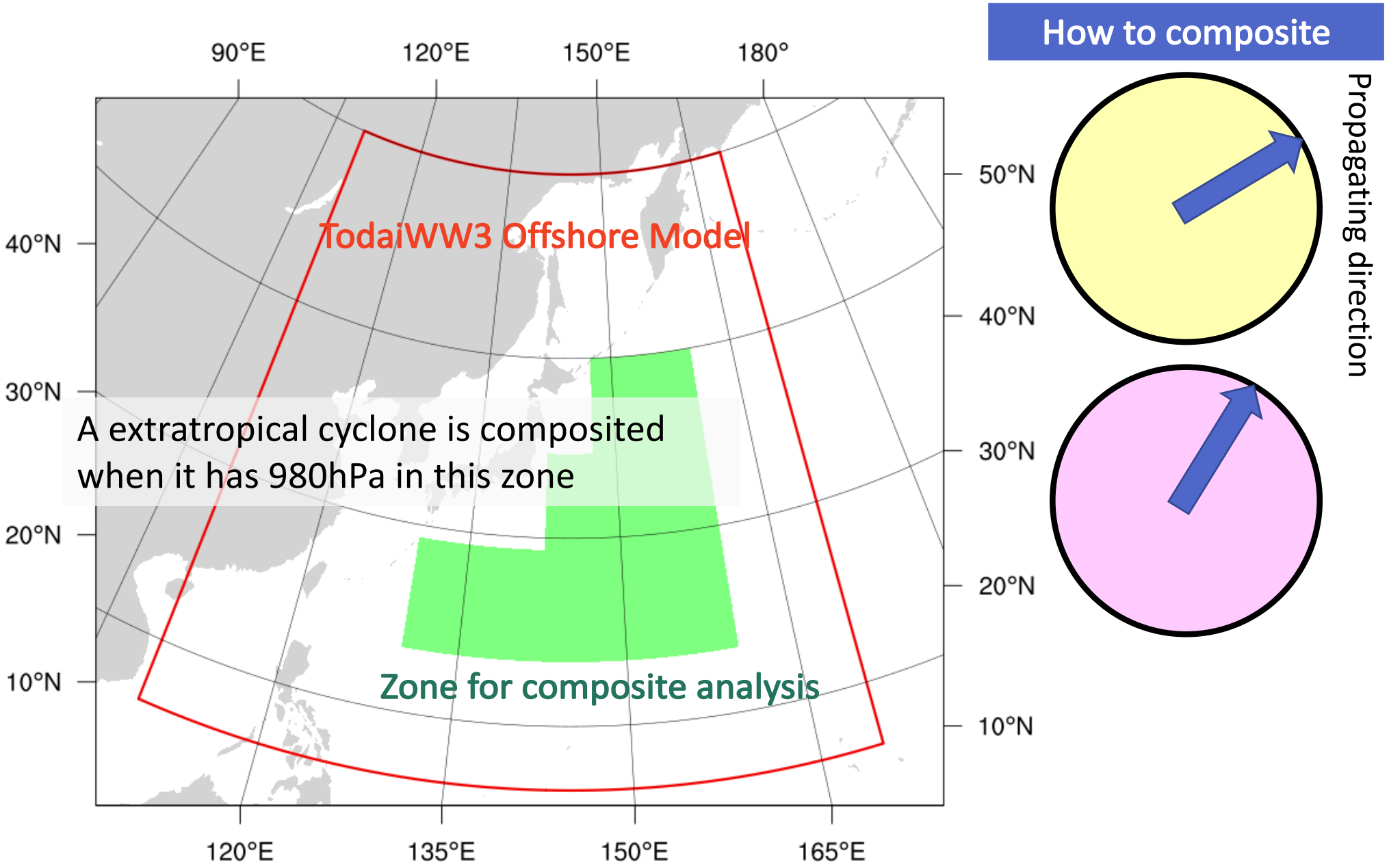
Explosive Cyclones： 38.6

Explosive Cyclones(Japan)： 19.2



* http://fujin.geo.kyushu-u.ac.jp/meteorol_bomb/index.php

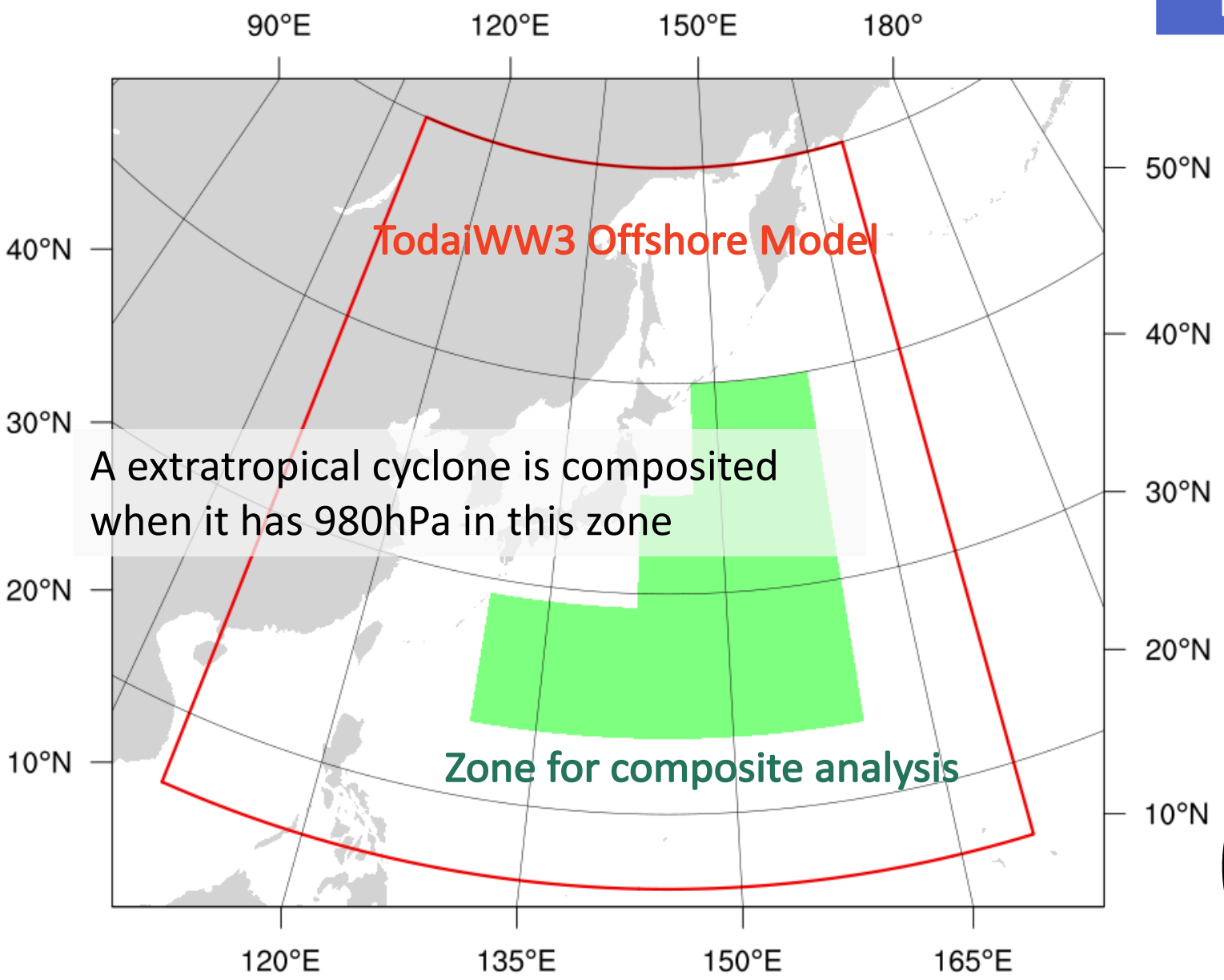
Composite Analysis



How to composite

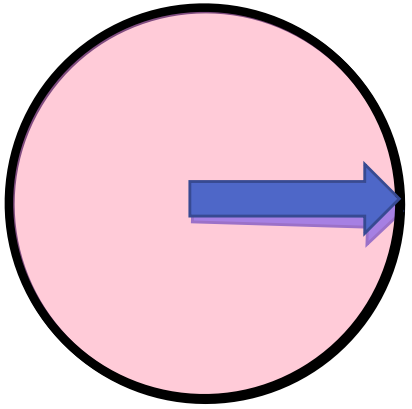
Radius: 10°(lat, lon)

Composite Analysis



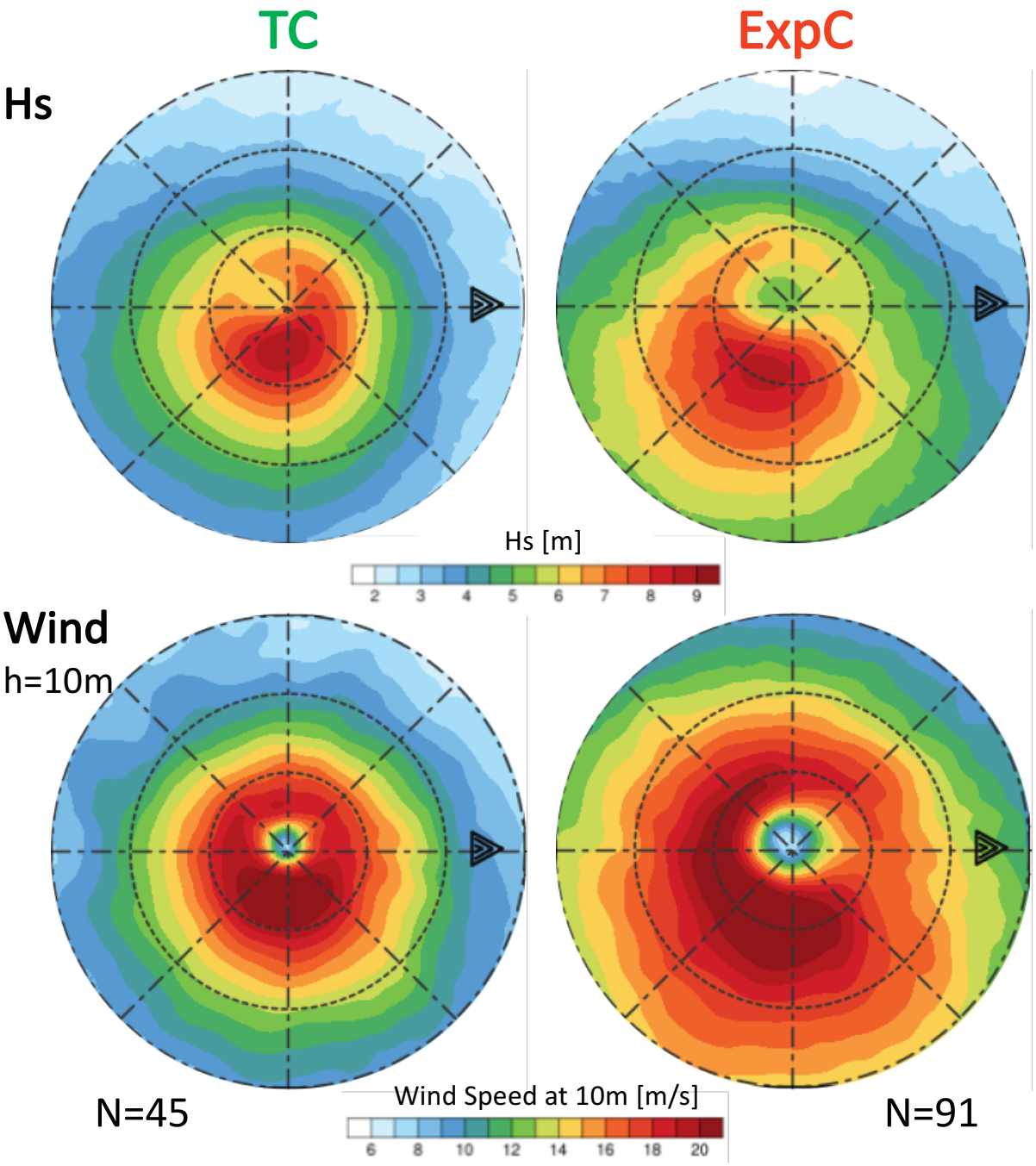
How to composite

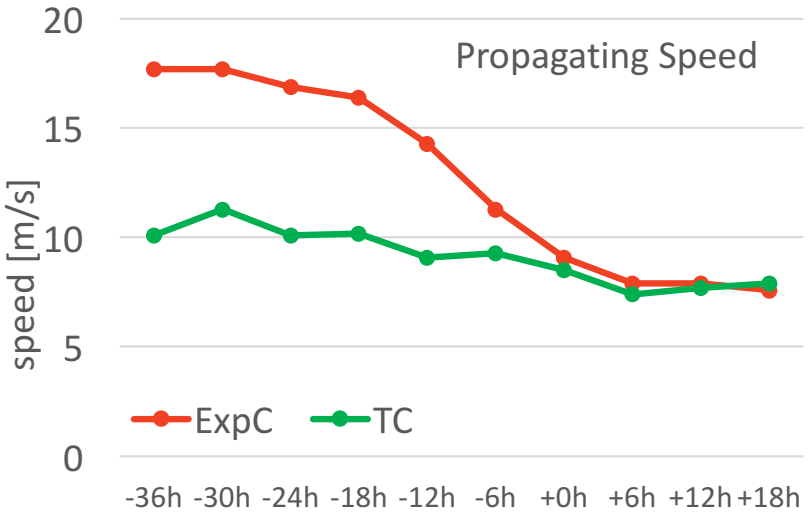
Propagating direction



Radius: 10°(lat, lon)

Ocean Waves Specifications under ExpCs and TCs

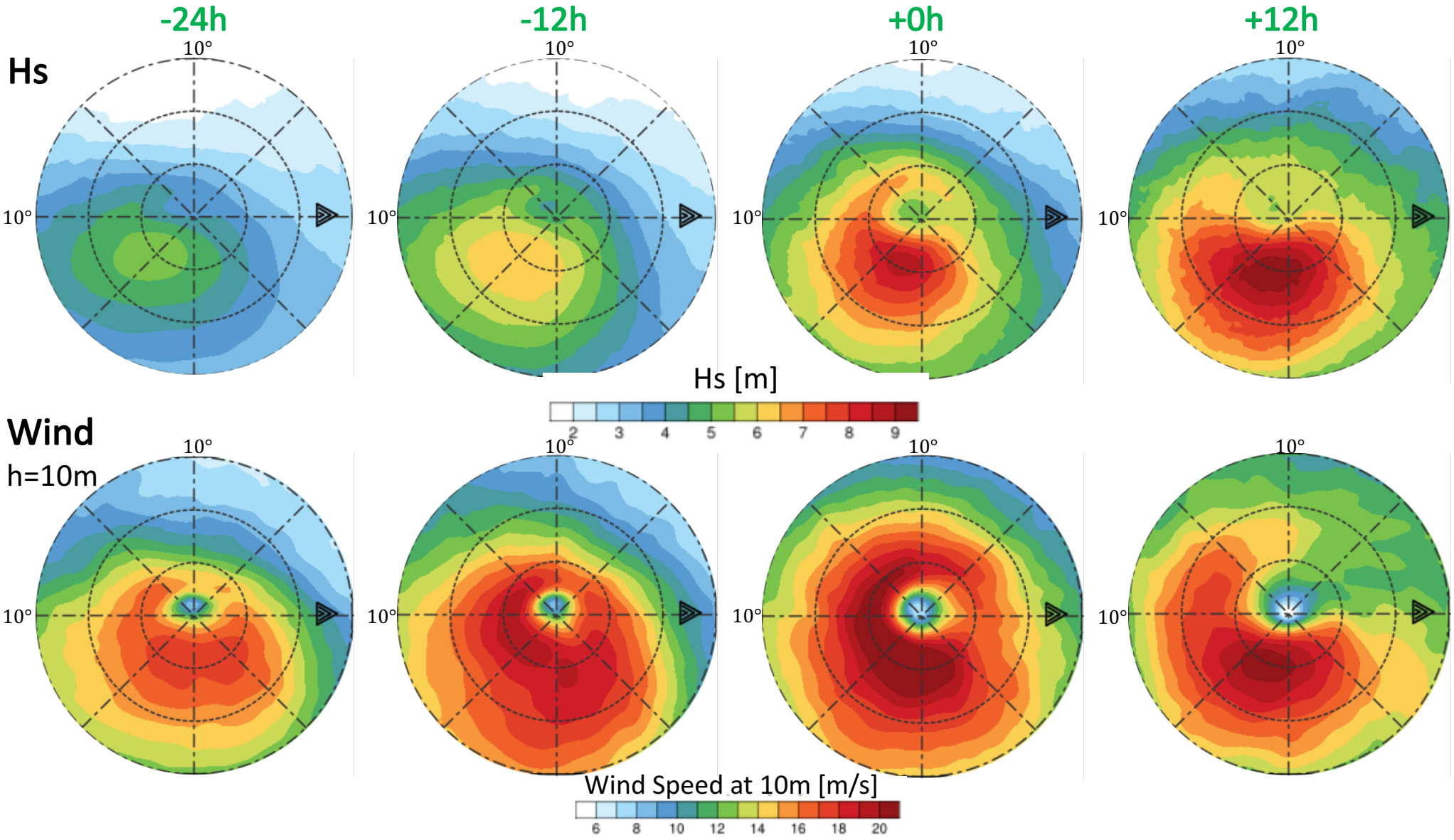




- ExpCs have larger area of high Hs than TCs.
- Propagating speed of ExpCs is higher in their early stage than that of TCs.

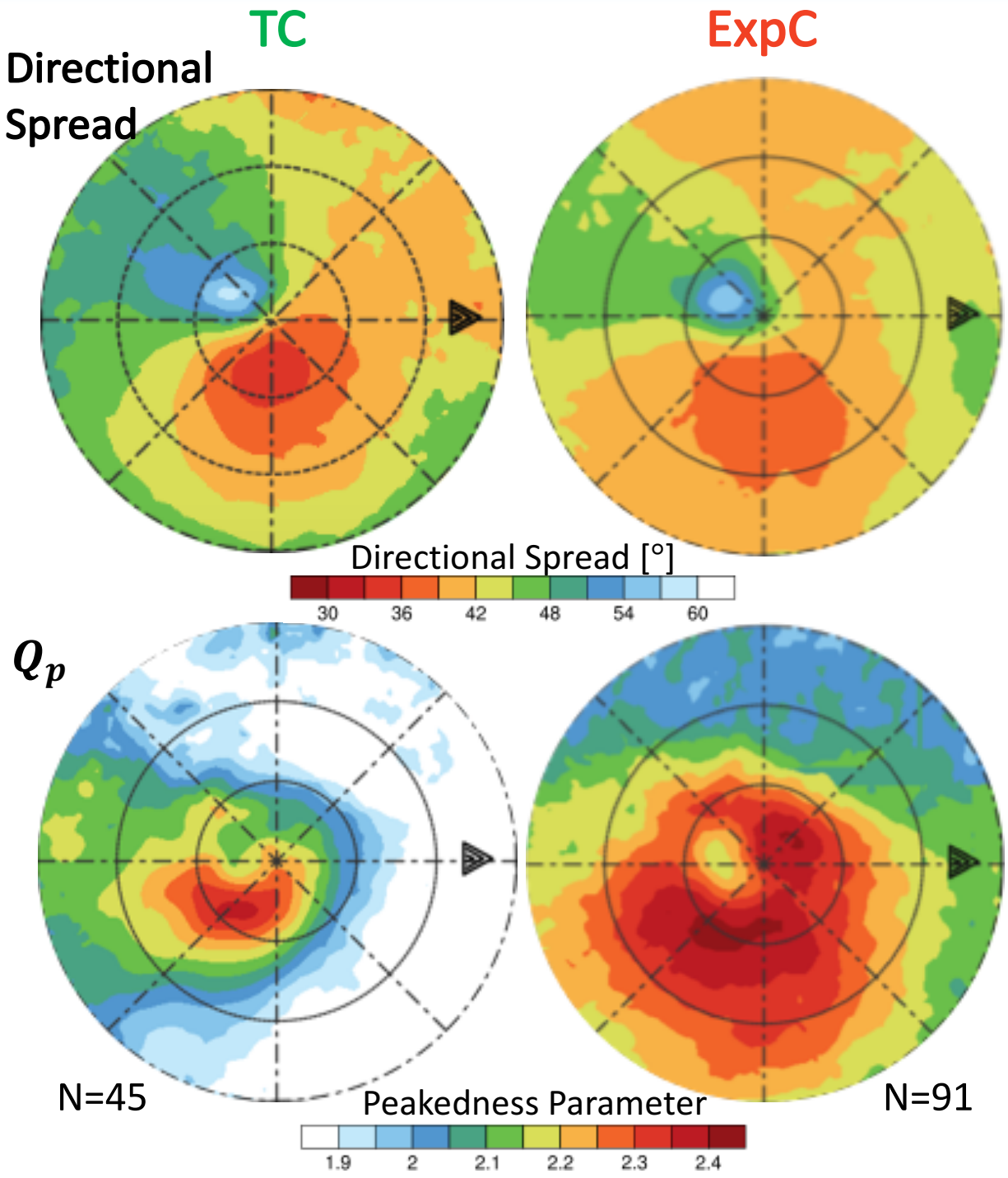
* +0h: the time when MSLP is at the deepest

Ocean Waves Development under ExpCs



- As an ExpC develops, winds and ocean waves also enhance.
- After an ExpC begins to weaken, ocean waves still continue to grow.

Ocean Waves Specifications under ExpCs and TCs

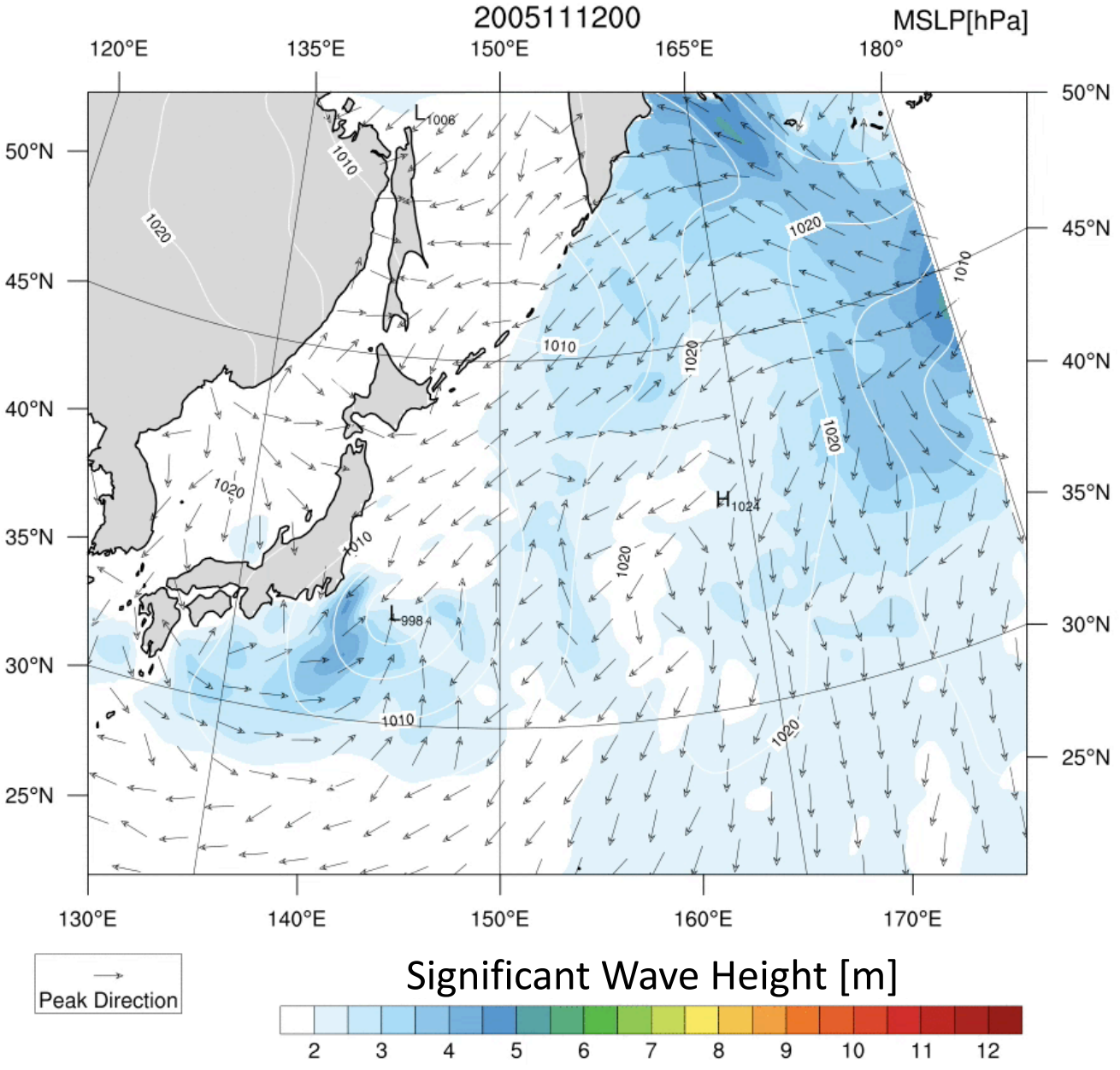


- Peakedness factor Q_p is defined as (Goda, 1970)

$$Q_p = \frac{2}{m_0^2}\int \omega E^2(\omega)\mathrm{d}\omega$$

- Directional spread is a standard deviation of the directional spectrum.
- The right and front areas of ExpCs have narrow spectral.

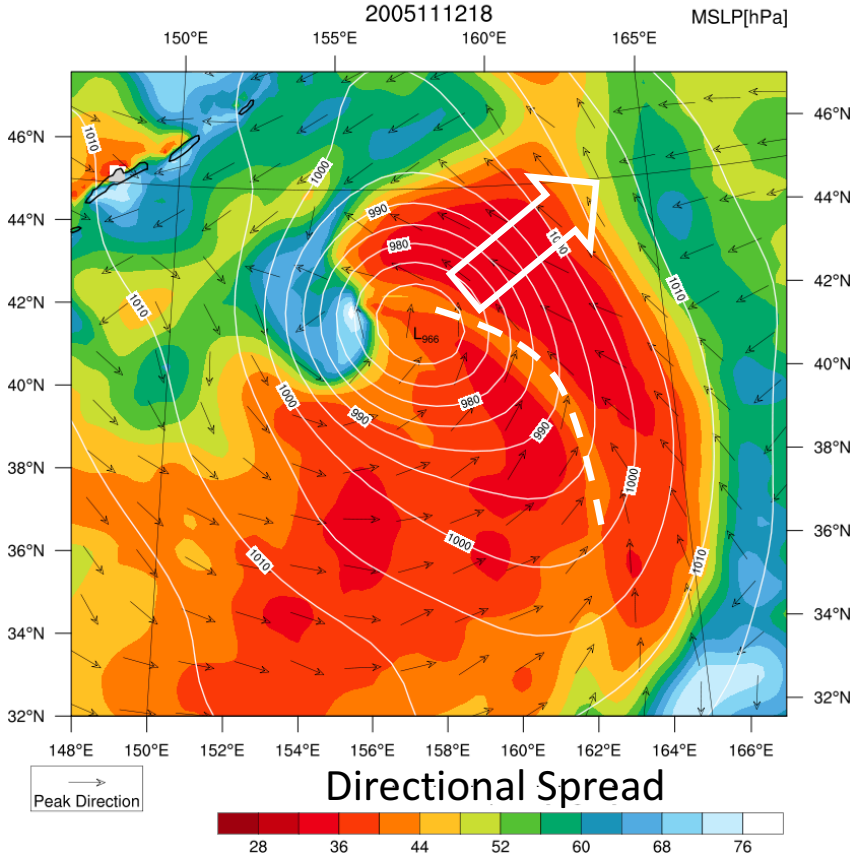
Case Study: 2005 Nov ExpC

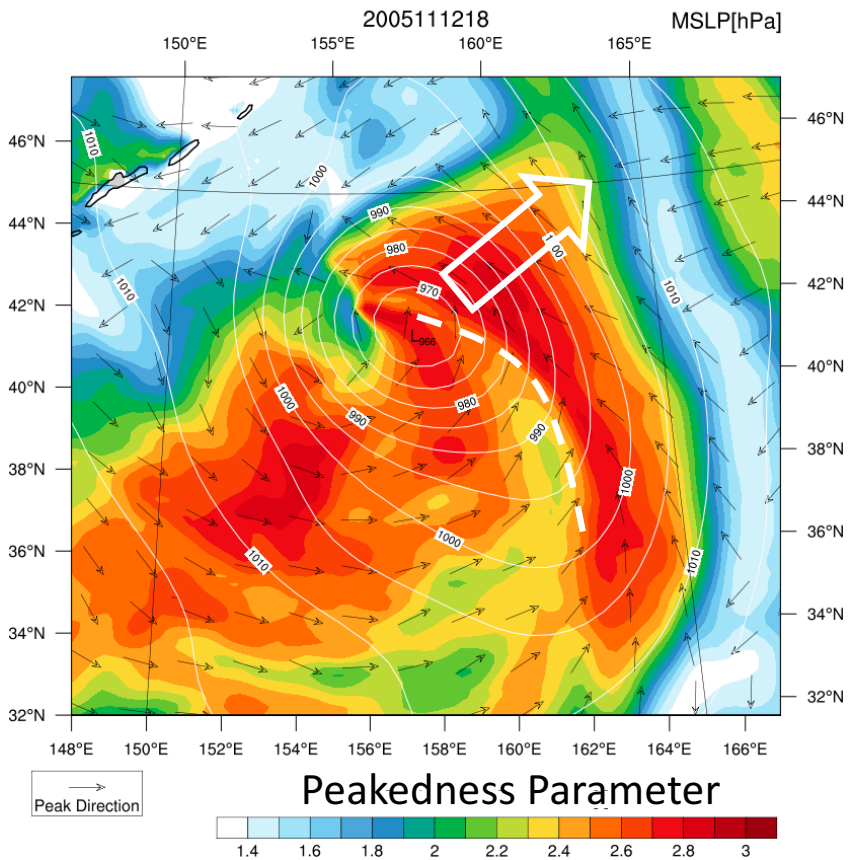


Ocean Waves: 1800, 12 Nov 2005

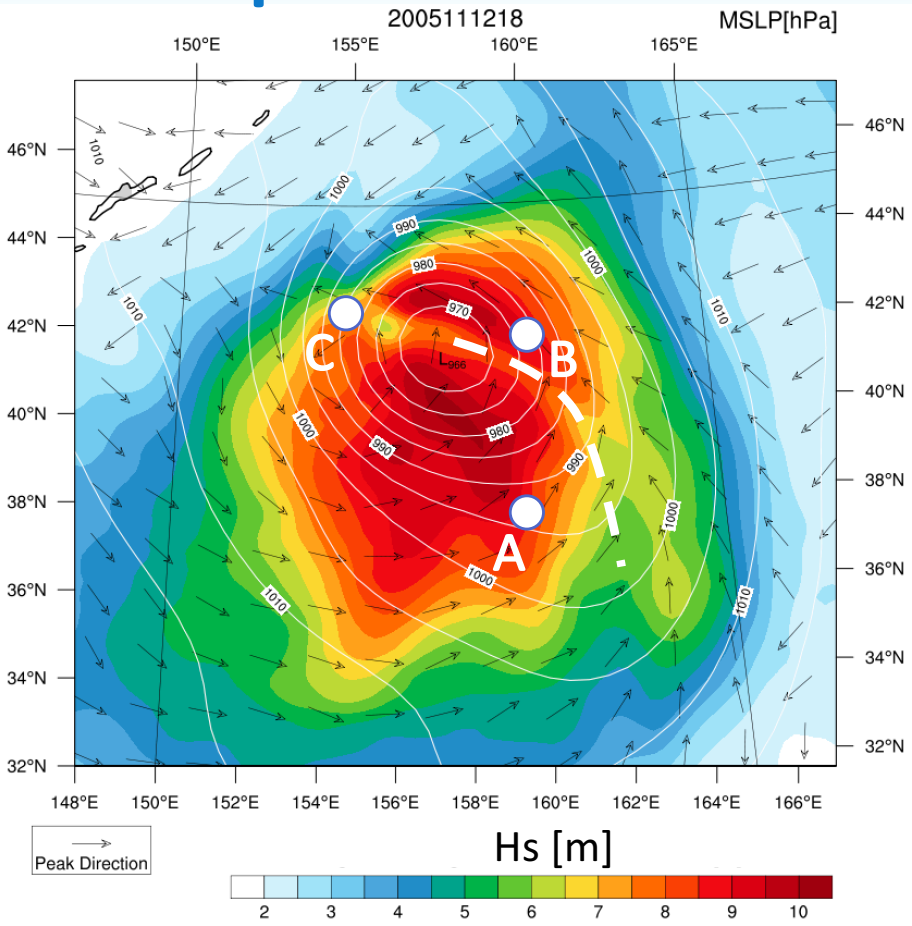
- When the MSLP of this ExpC reached the deepest, two areas have narrow spectrum:
  1. Right of the ExpC
  2. Front of the warm front line

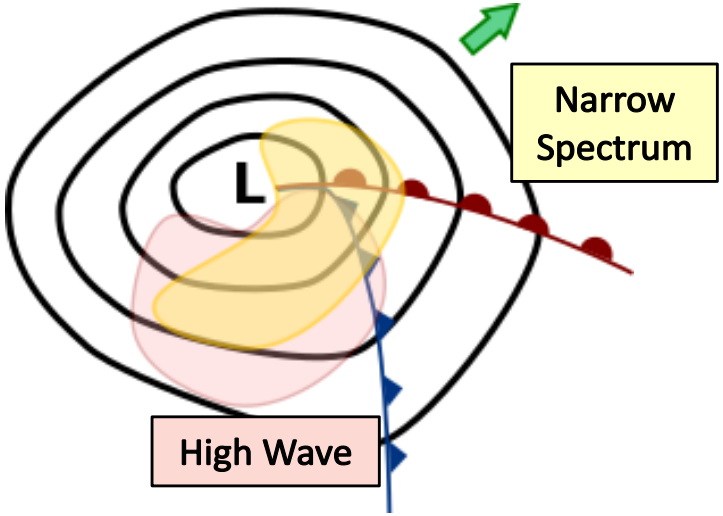
- Tamura et al. (2009) showed that coexistence of swell and wind-sea was a precursor to the development of the narrow spectrum.

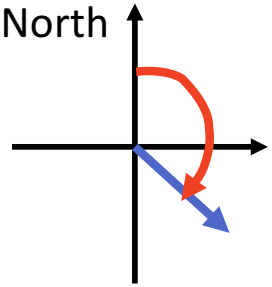


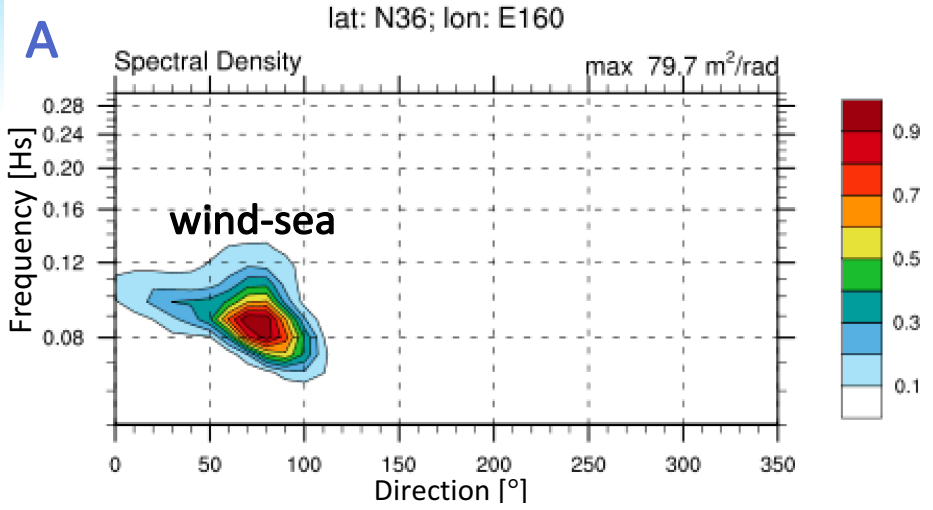


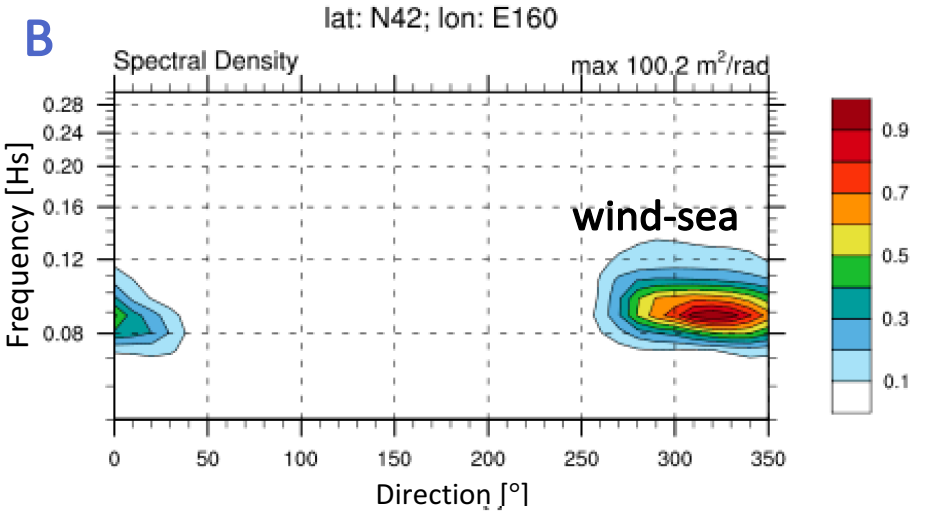
Wave Spectra at 18:00

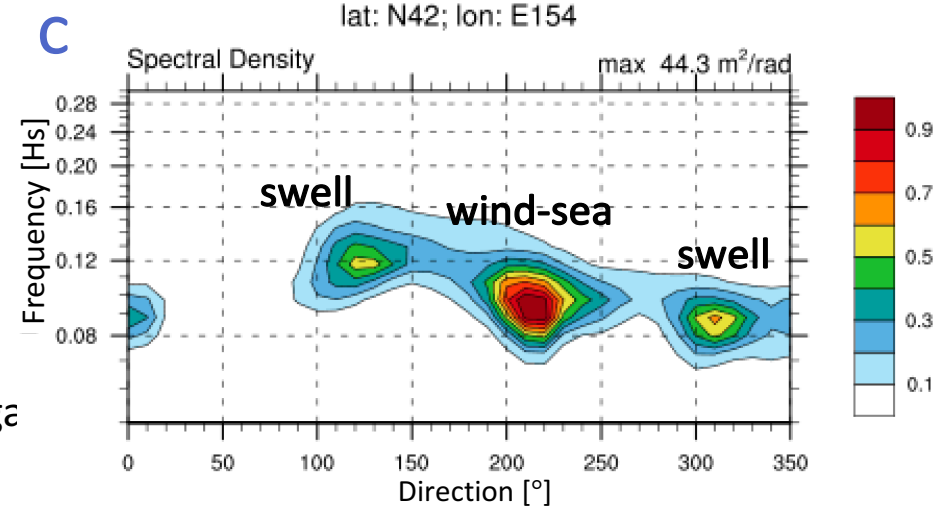




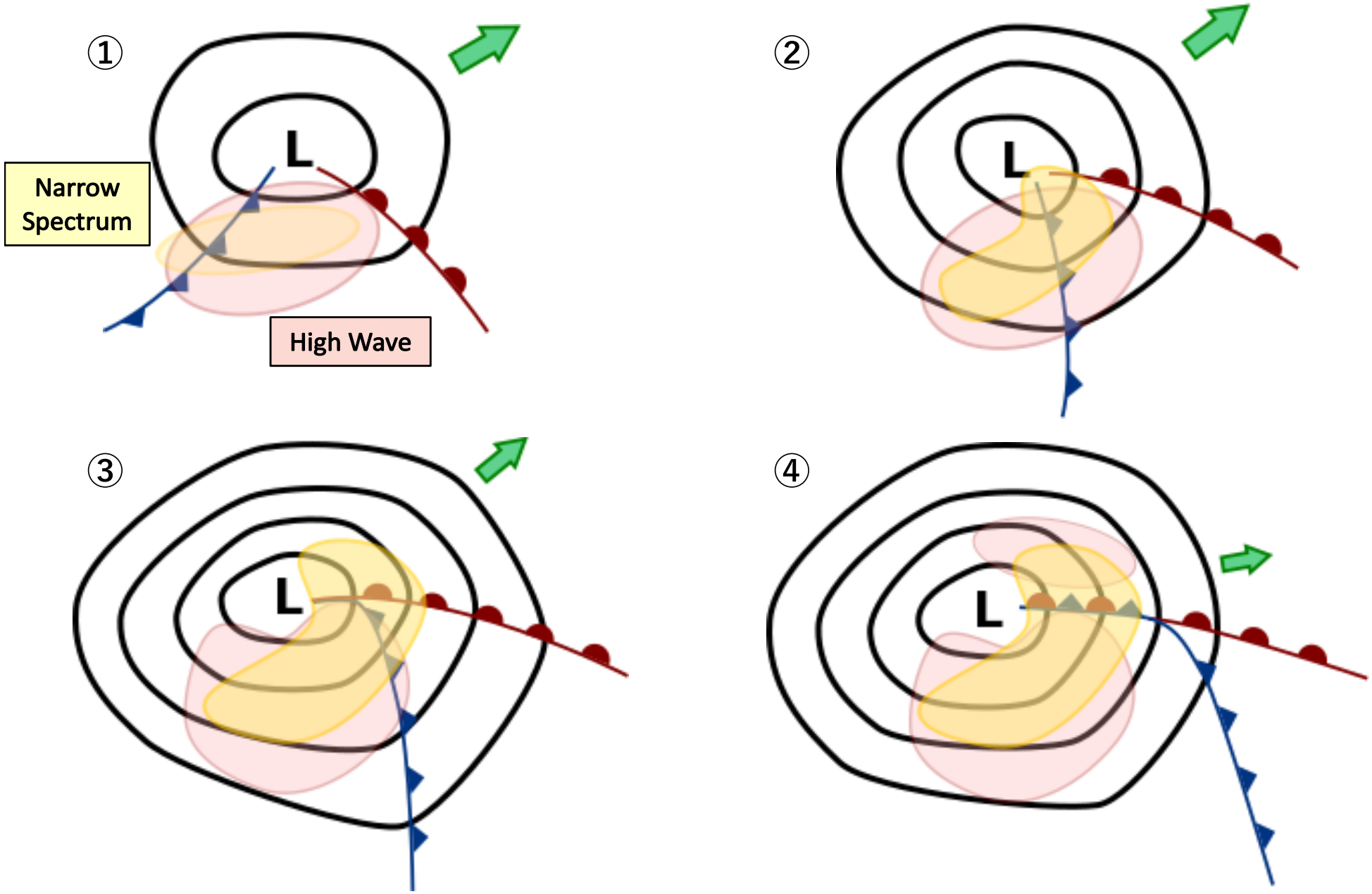








Conceptual Diagram of Ocean Waves under ExpCs



Summary

- High wave zones of ExpCs is generally larger than that of TCs. Both of them have high wave zones at the right to the center.
- After an ExpC begins to weaken, ocean waves still continue to grow.
- When an ExpC sufficiently develops, right zones to the center and front zones of the warm front have narrow spectrum, which is favorable for freak waves.
- For the next step, a ocean wave simulation with an ideal ExpC condition should be conducted.