Numerical study of wave-current interaction using high resolution coupled model in the Kuroshio region

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Introduction

Global and regional wave forecasts

The demand for further improvements

Engineering: ship navigation, avoidance of extreme sea..

Climate research: wave climatology, ocean mixing..

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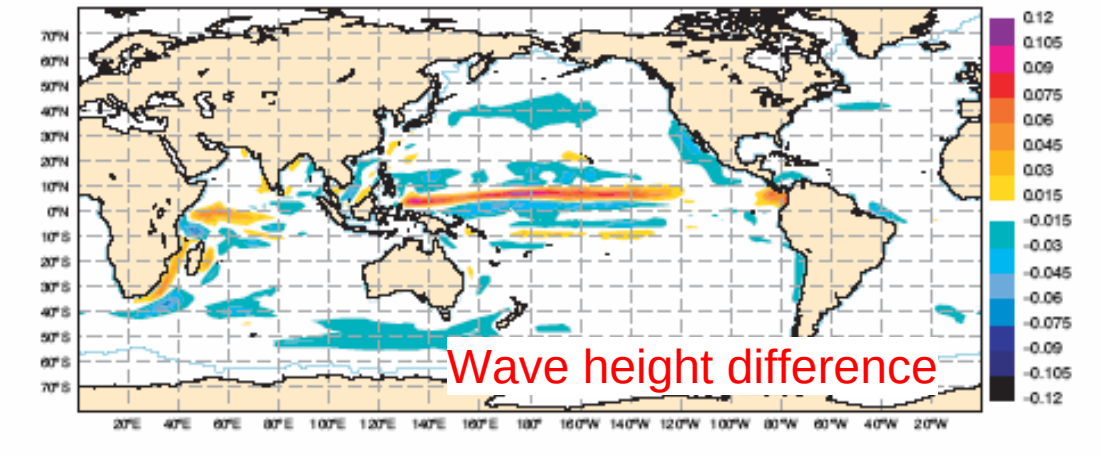
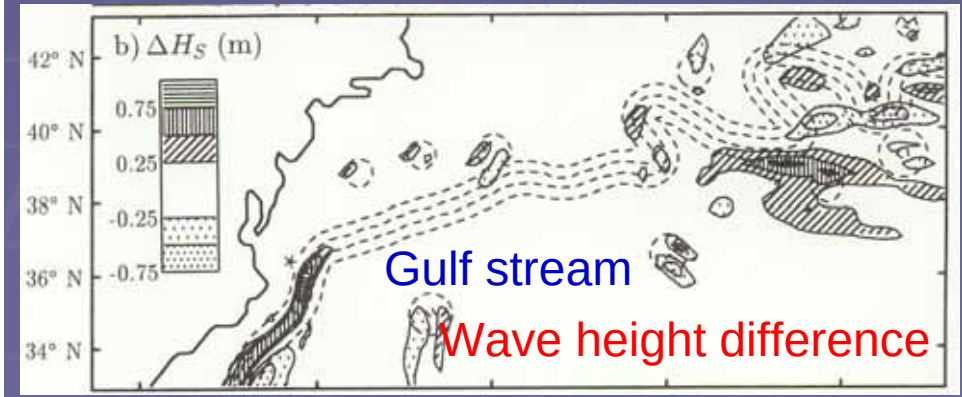
Because of the lack of high resolution current forecast, most wave forecasts do not include wave-current interaction.

Demonstrating the significance of the wave-current interaction

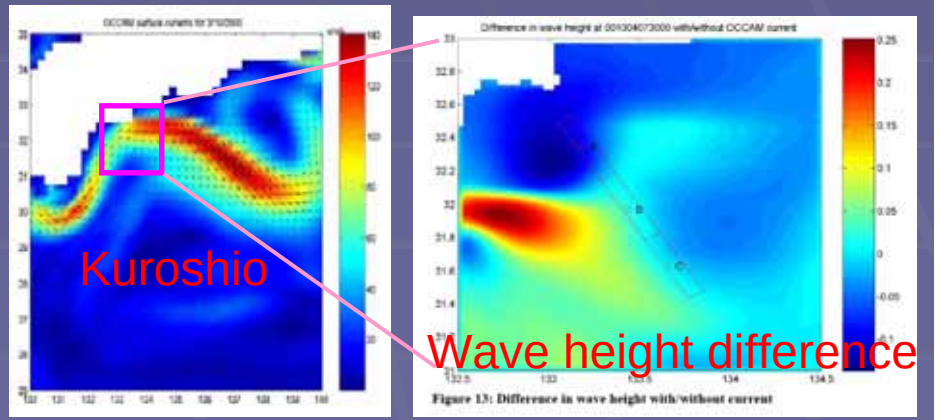
Global : Janssen et al. 2005 (ECMWF wave model)



Regional (Gulf stream)
: Tolman et al., 1994



Regional (Kuroshio)
: Wolf, 2002



WAVE-JCOPE PROJECT

Goal : To establish a realistic high-resolution coupled wave-current prediction model.

the influence of ocean current upon waves

WAVE-JCOPE
High resolution Japan Regional wave model
1/12 deg.

Existing forecast products

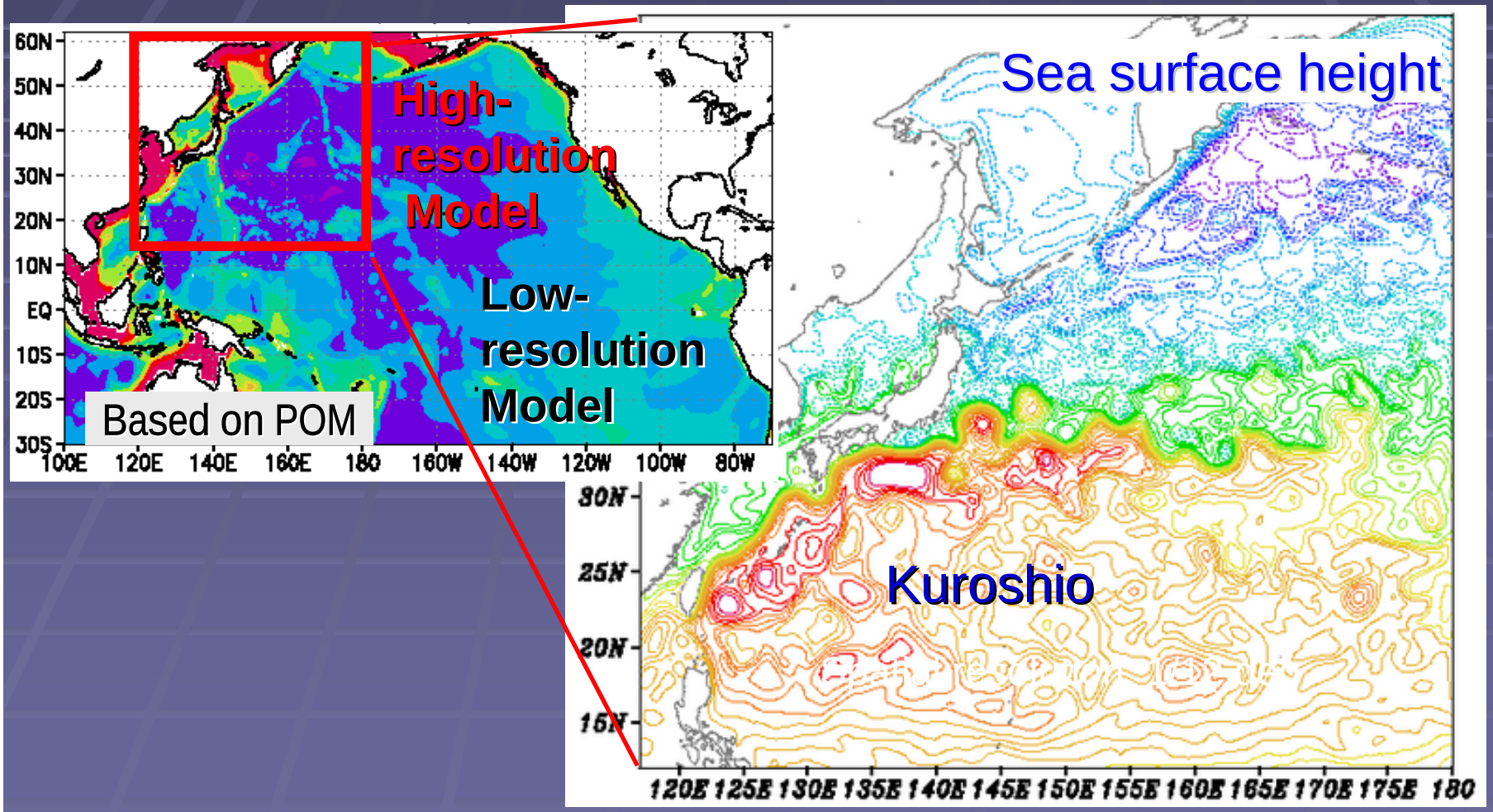
JMA wind field data
1/10 deg.

JCOPE current field data
1/12 deg.

To specify the Kuroshio current..

Japan Coastal Ocean Predictability Experiment

JCOPE: Miyazawa et al./FRCGC



The prediction of today's Kuroshio

WAVE-JCOPE v0.2

Third-generation wind-wave model

WAVEWATCH-III v2.22 (Tolman, 2002)

Parameterization schemes implemented

Propagation : U-QUICKEST
Wind input :Snyder (1981) Dissipation :Snyder (1981)
Nonlinear interactions :DIA Bottom friction :JONSWAP

↳ SRIAM (Komatsu & Masuda, 1996)

Essential for the improved estimation of the wave-current interaction

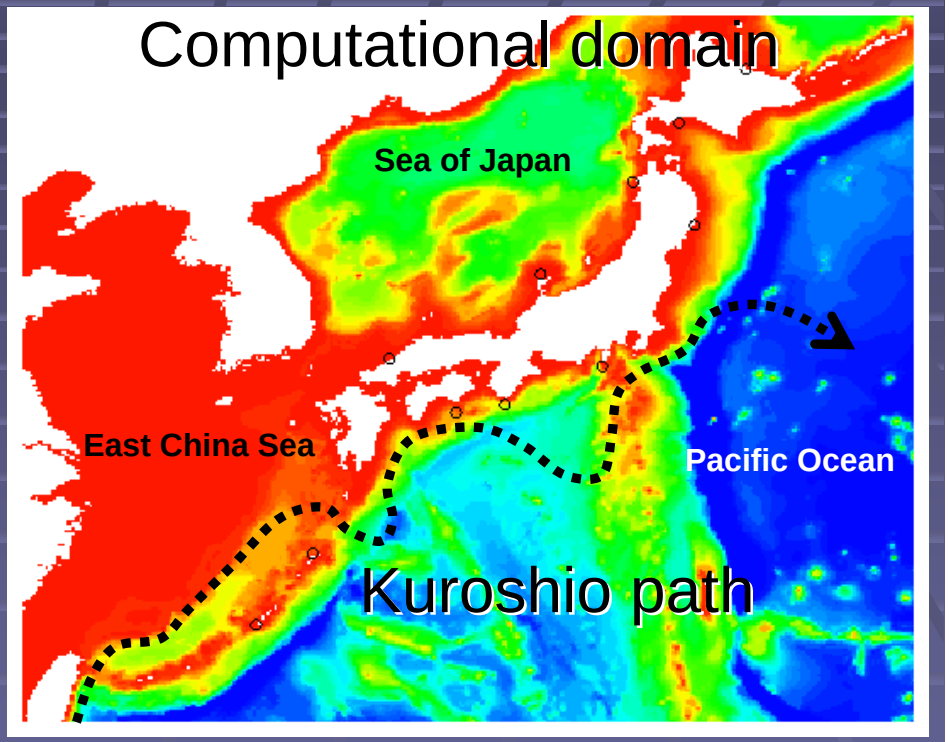
Computational conditions of the High-Resolution wave model

- WAVE-JCOPE -

Spatial resolution
: 1/12 deg. (349 x 277)

Frequency range
: 0.042-0.41 Hz (25)

Directional increment
: 10 deg. (36)



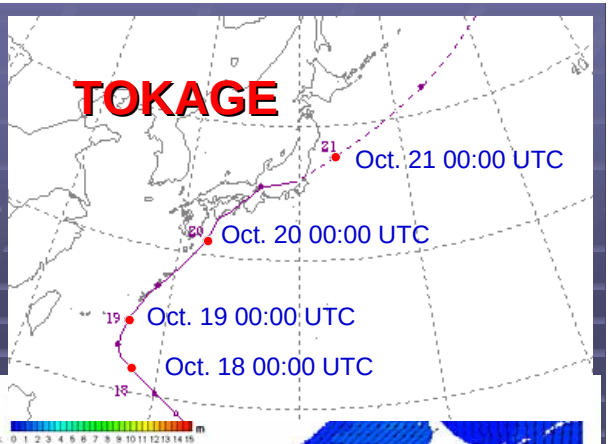
Wind data (JMA Re. anal.)

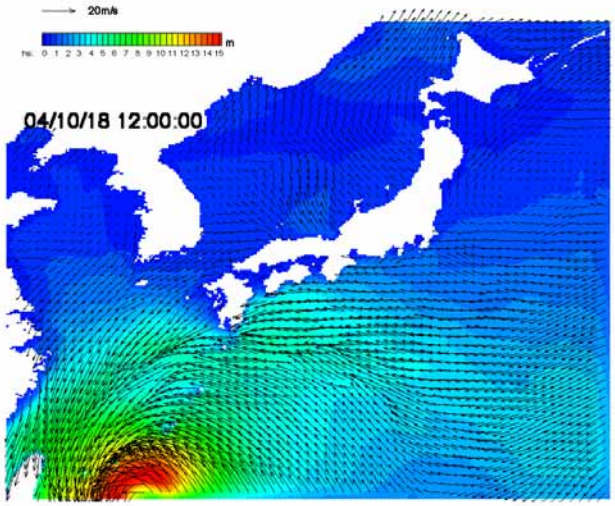
6 hourly, 1/8 -1/10deg.

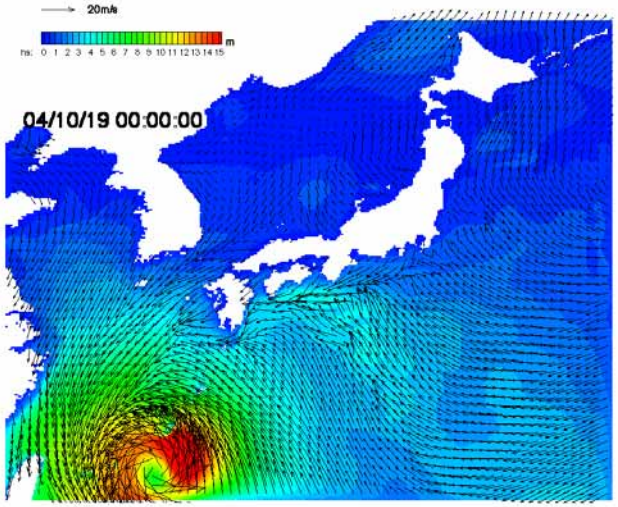
Current data (JCOPE Re. anal.)

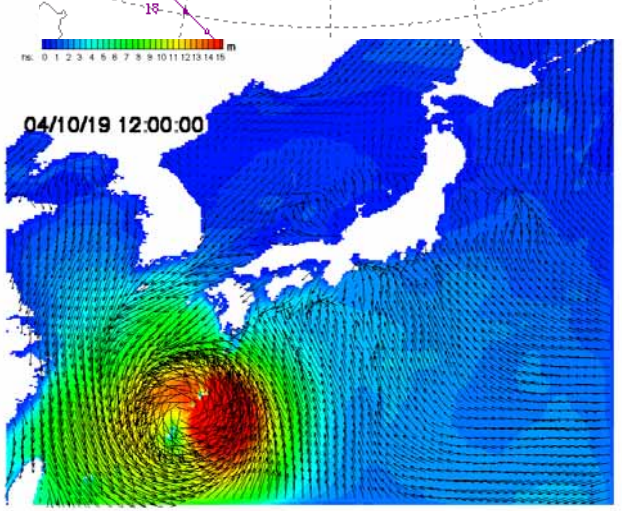
2-day mean, 1/12 deg.

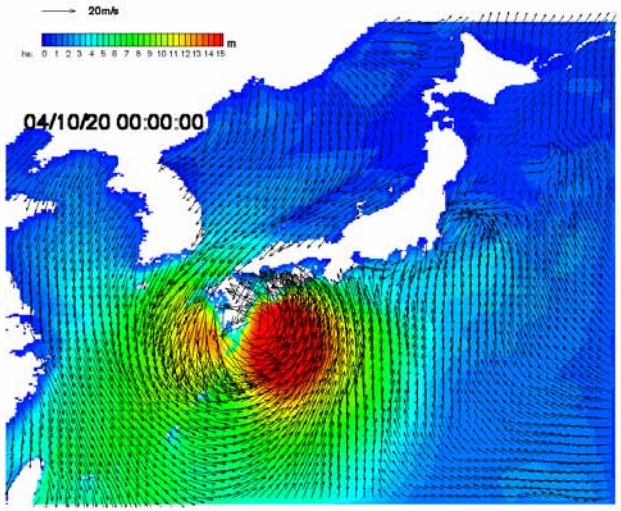
Temporal evolution of the significant wave height

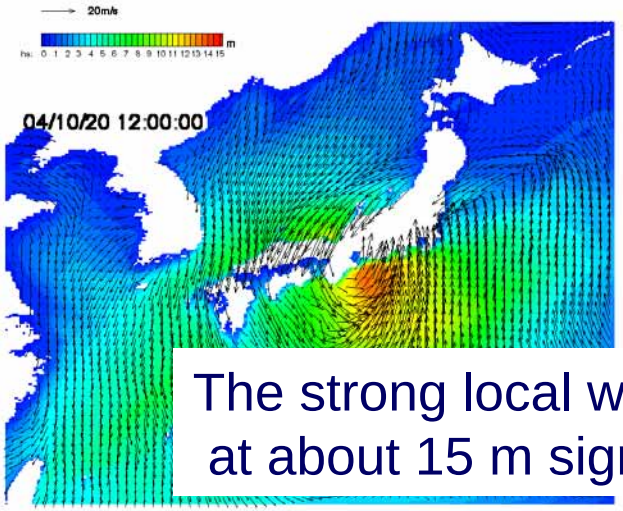


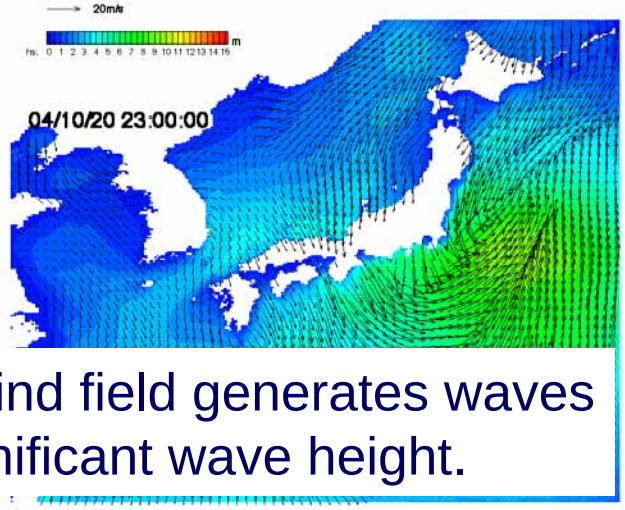










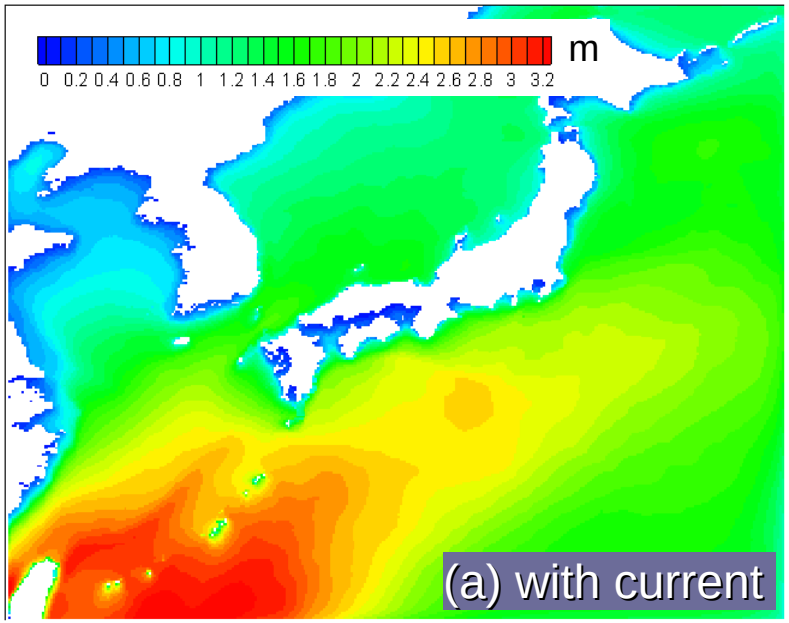


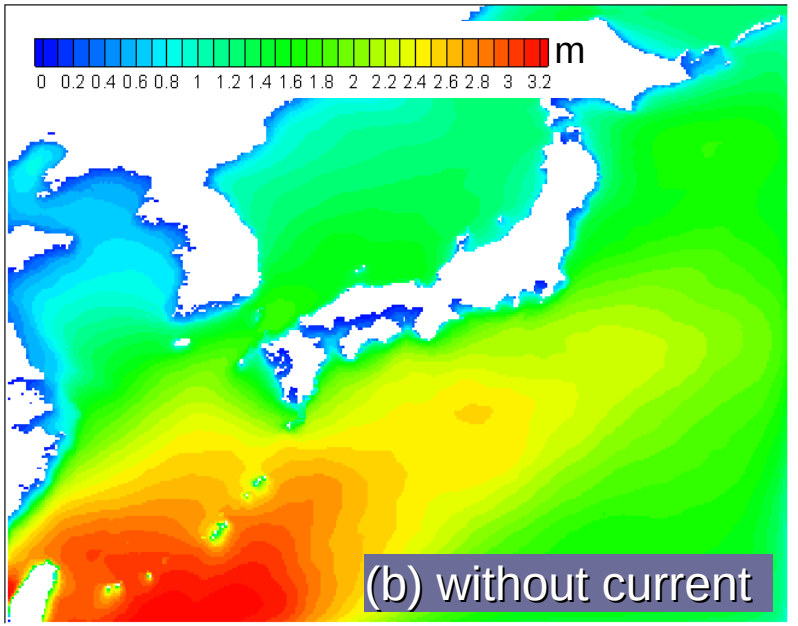
The strong local wind field generates waves at about 15 m significant wave height.

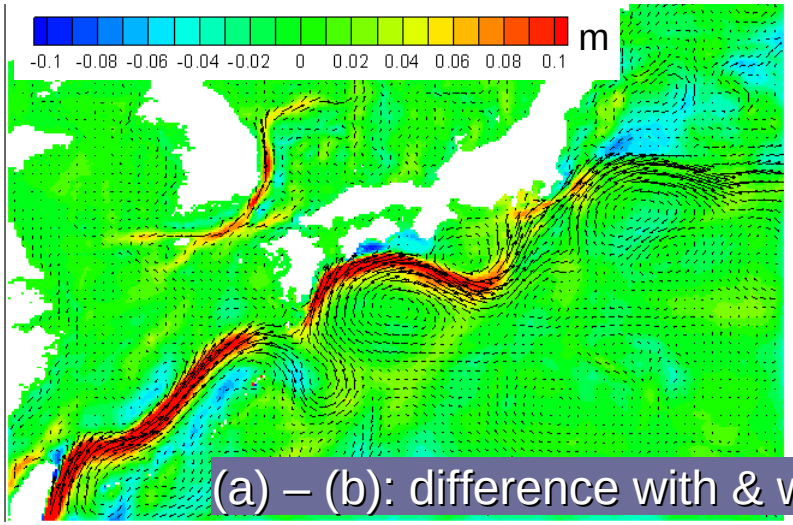
Impact of wave-current interaction

Monthly average significant wave height

Period : Oct. 2004

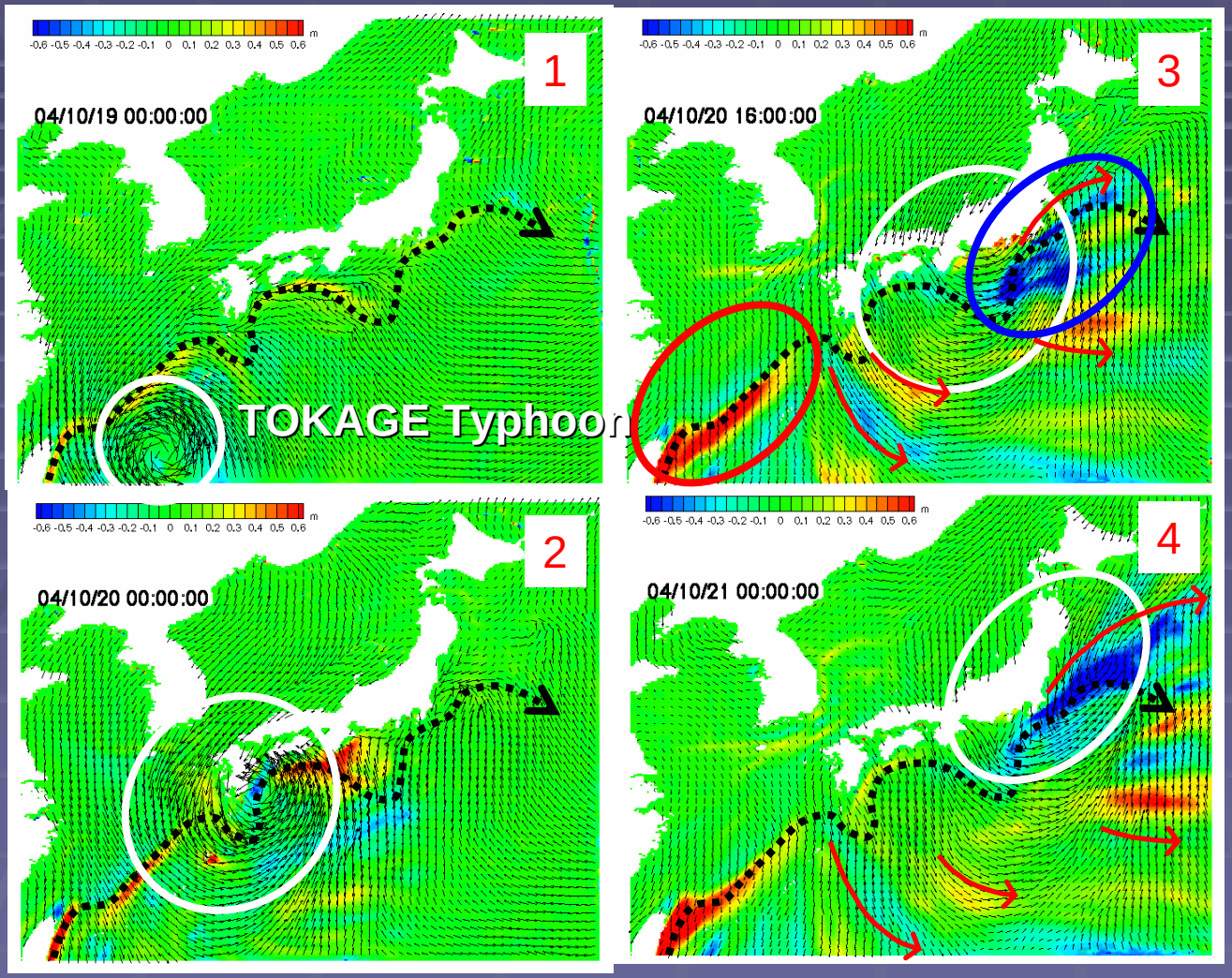






The difference of the wave height over the Kuroshio is quite eminent and is in accord with the earlier work.

Impact of wave-current interaction (temporal evolution of wave height difference)



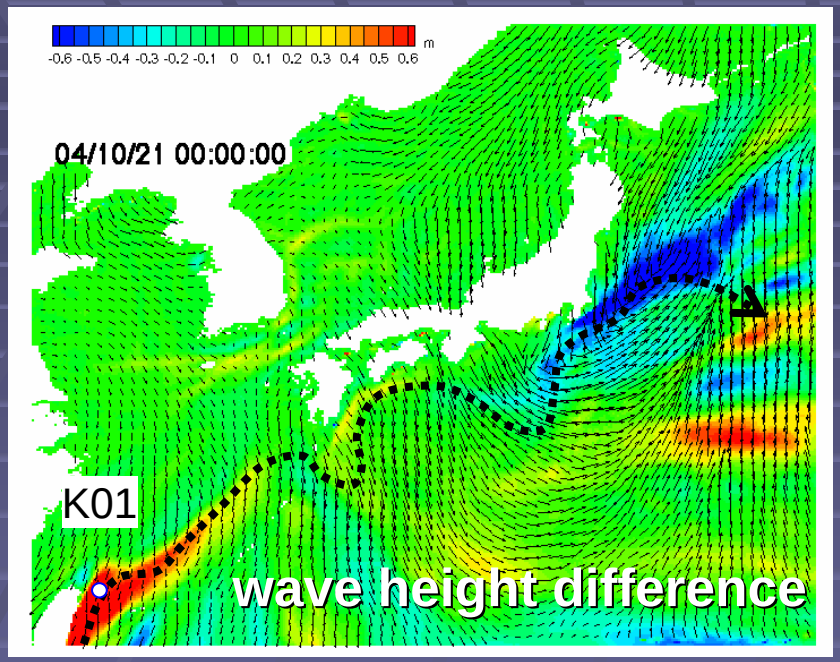
the divergence of wave propagation

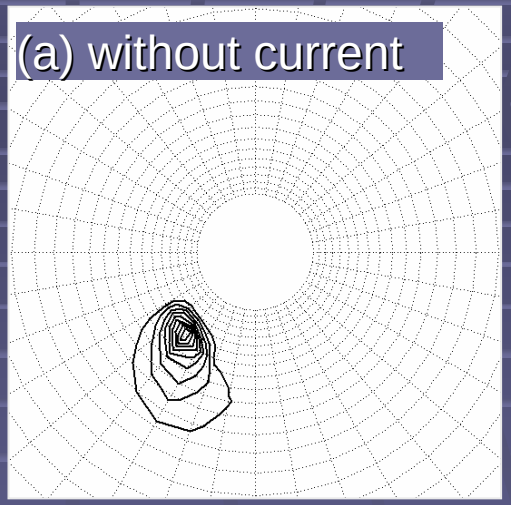
the convergence of wave propagation

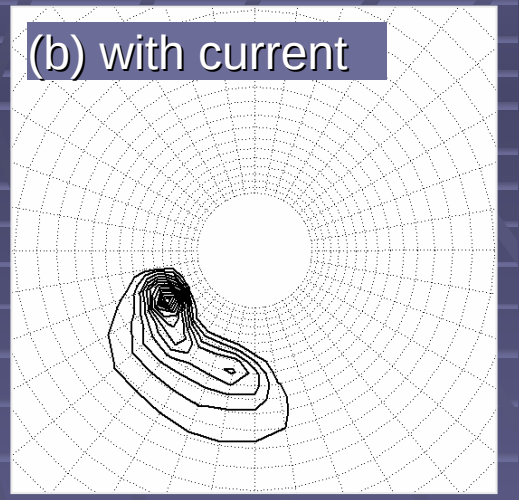
Highly sensitive to the small scale current structure

The realistic representation of the current field is very important for high-resolution wave forecast

Impact of wave-current interaction (frequency-directional spectrum)







wave energy to SSW-ward direction is added to the SW-ward spectrum

This component may be considered as the trapped wave by Kuroshio

For the improved estimation of the wave spectrum by the wave-current interaction… -> RIAM and SRIAM methods

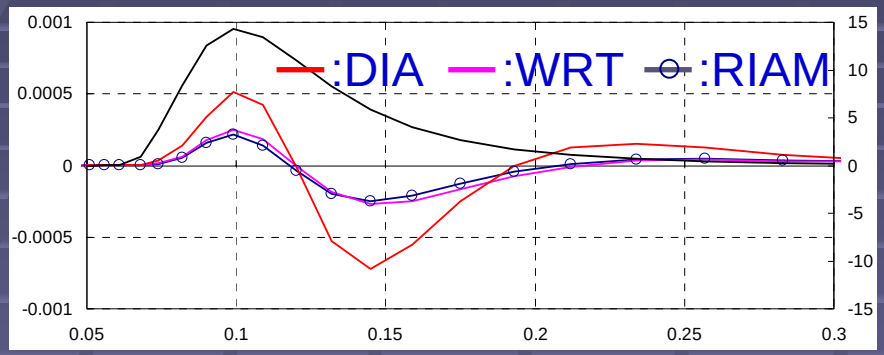
Implementation of RIAM as the nonlinear source term

RIAM method (Komatsu and Masuda, 1996)

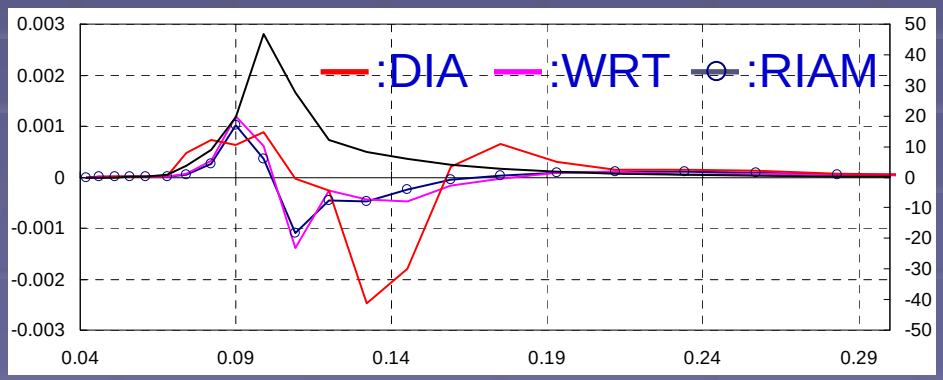
- developed on the basis of a stable and rigorous algorithm by Masuda(1980)
- 300 times faster than the Masuda method
- high accuracy even for spectra of narrow band widths or bimodal spectra

Non-linear transfer functions of DIA, WRT and RIAM method

Pierson-Moskowiz, Mitsuyasu-Hasselmann



JONSWAP (γ=3.3), M-H



RIAM shows good agreement with WRT

Computational times of WRT and RIAM method are almost same. (2000 times slower than DIA)

Implementation of SRIAM method as the nonlinear source term of WAVE-JCOPE model

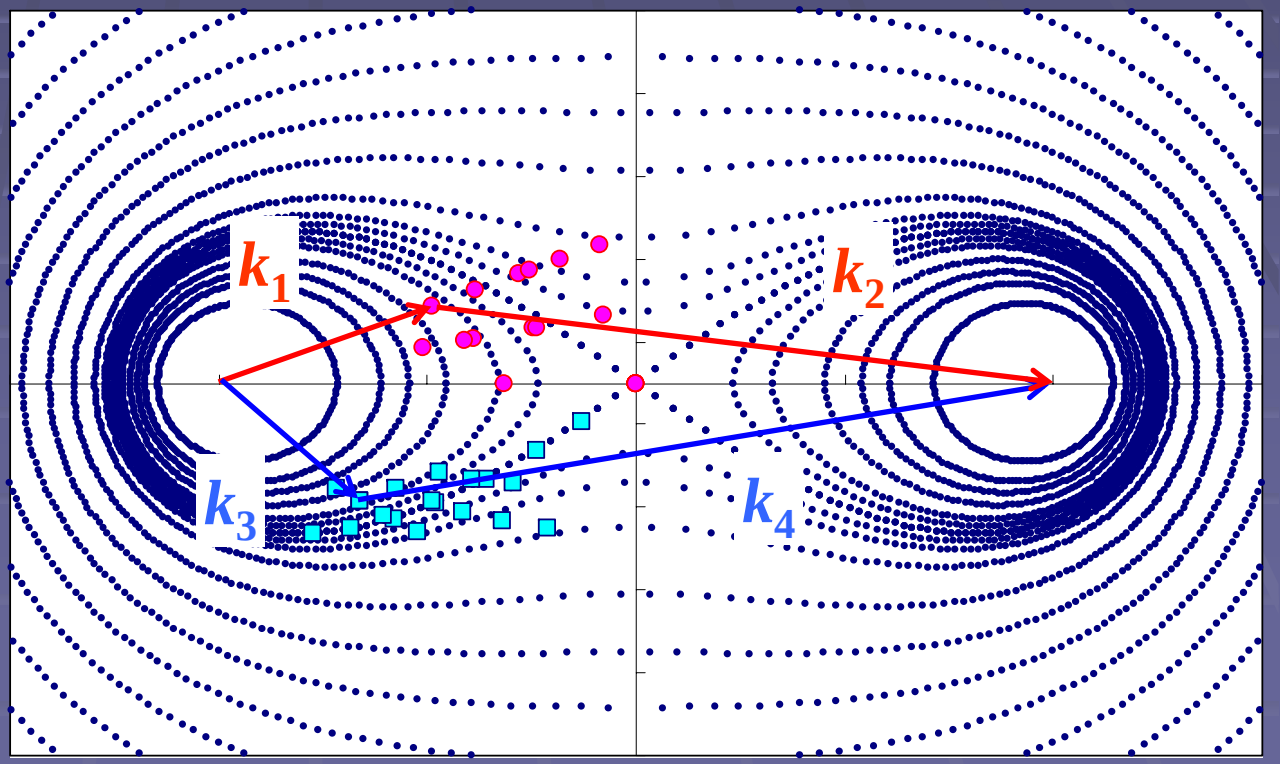
SRIAM (Komatsu, 1996): an efficient scheme for operational use

Optimization based on the parameter settings

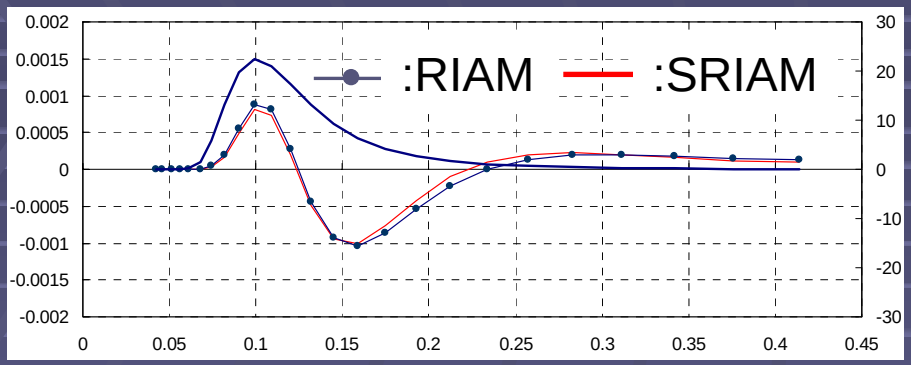
8 wave spectra

peakedness: γ
1.0 - 9.0
$\cos^s\theta$: s
2.0 - 10.

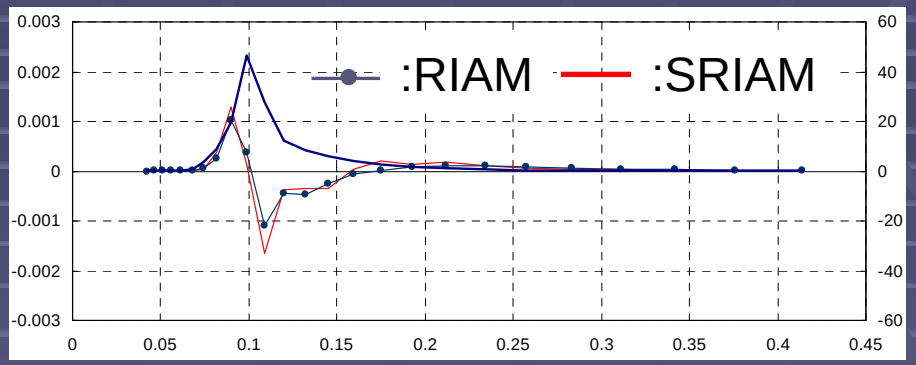
20 pairs of resonance configurations of SRIAM method



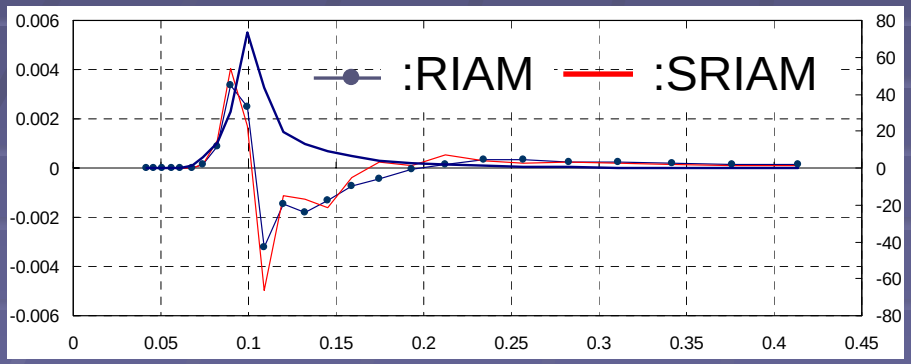
Comparison of RIAM and SRIAM methods



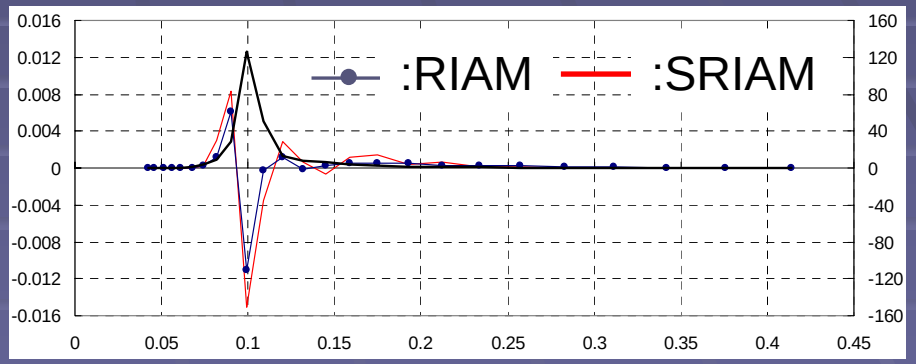
Pierson-Moskowitz, $\cos^2\theta$



JONSWAP (γ=3.3), Mitsuyasu-Hasselmann



JONSWAP (γ=3.3), $\cos^2\theta$



JONSWAP (γ=9), Mitsuyasu-Hasselmann

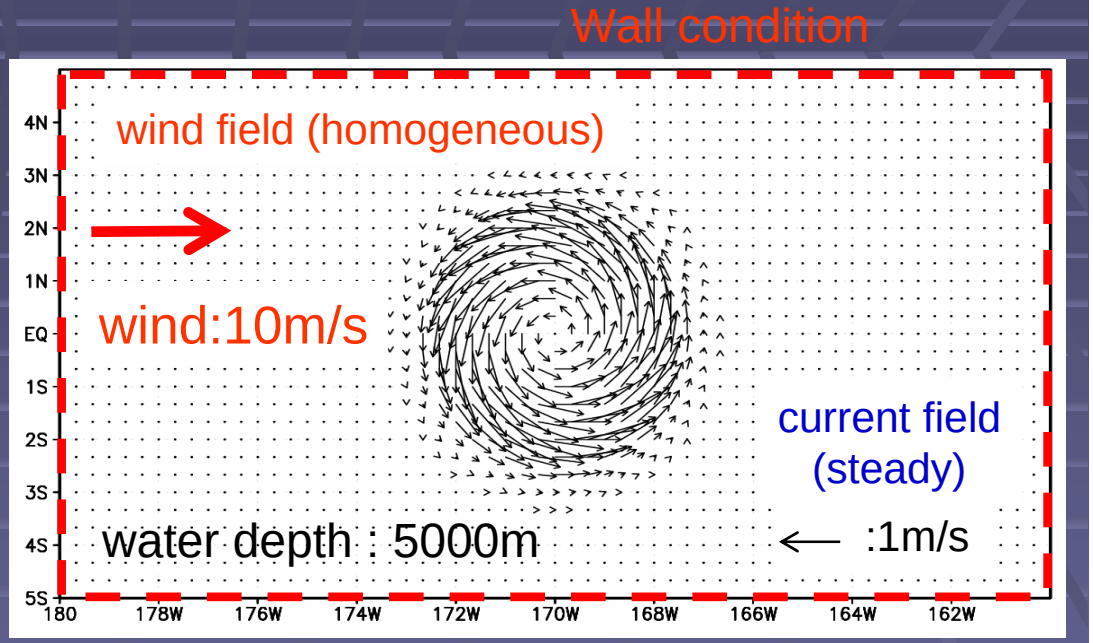
About 100 times faster than RIAM method with high accuracy !! (20 times the DIA computation)

Numerical experiment of wave refraction by an eddy current field

Spatial resolution
: 1/12 deg. (241 x 121)

Frequency range
: 0.042-0.41 Hz (25)

Directional increment
: 10 deg. (36)



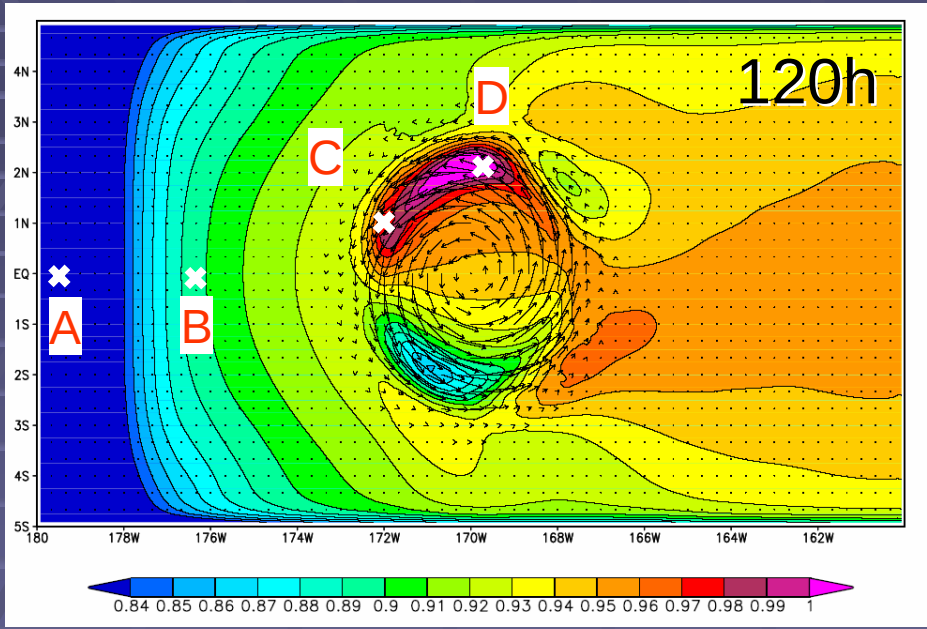
Nonlinear interactions :DIA & SRIAM

Propagation : U-QUICKEST

Wind input & Dissipation :Snyder (1981)

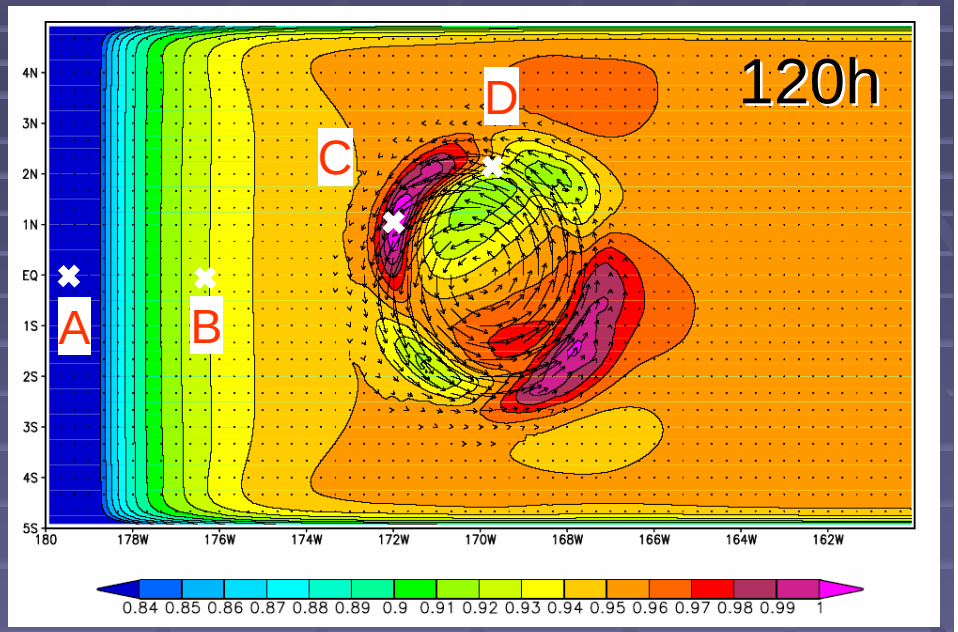
Spatial distribution of significant wave height

DIA H_{max}=2.1m



H_s/H_{max}

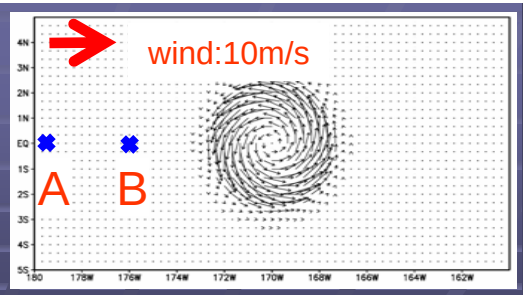
SRIAM H_{max}=1.85m



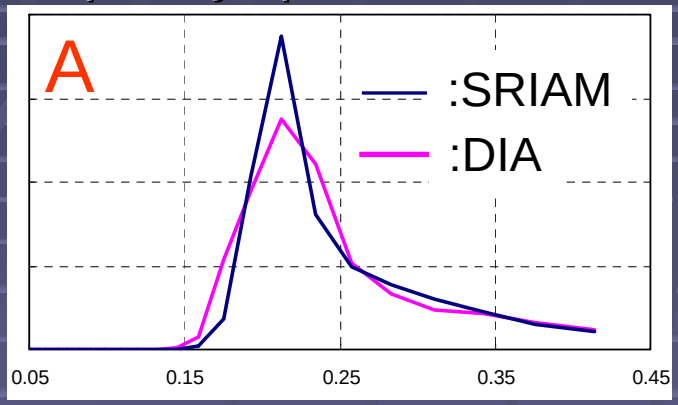
H_s/H_{max}

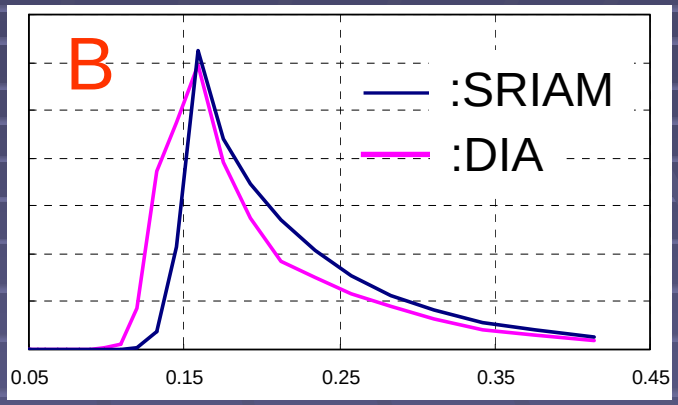
- Decrease of wave height near the wall is much larger for the DIA computation.
- Location of focal points by current are considerably different

Frequency spectra and directional spreading

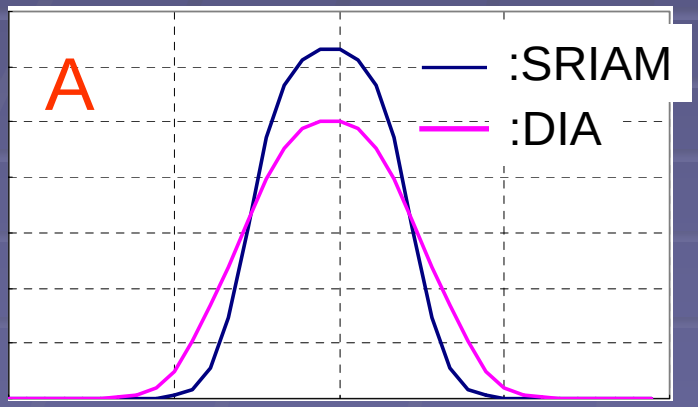


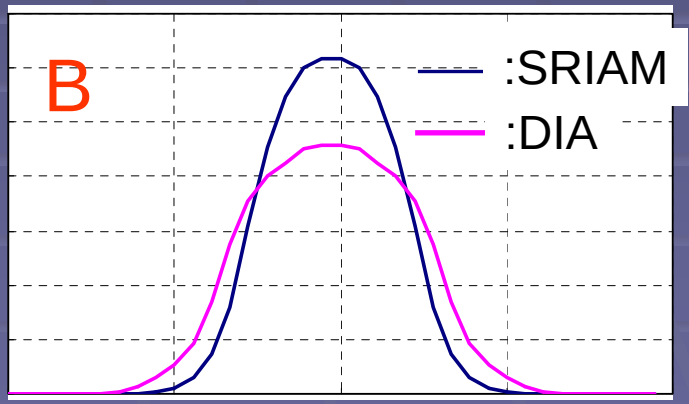
Frequency spectrum





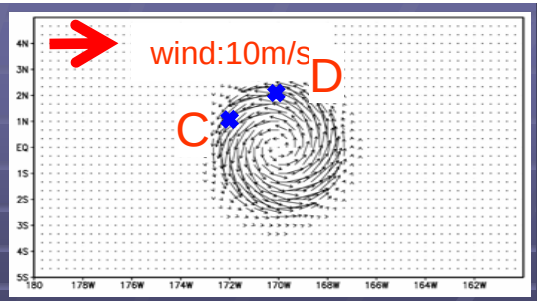
Directional spreading $\int S(\sigma,\theta)d\sigma \Big/ \int\int S(\sigma,\theta)d\sigma d\theta$



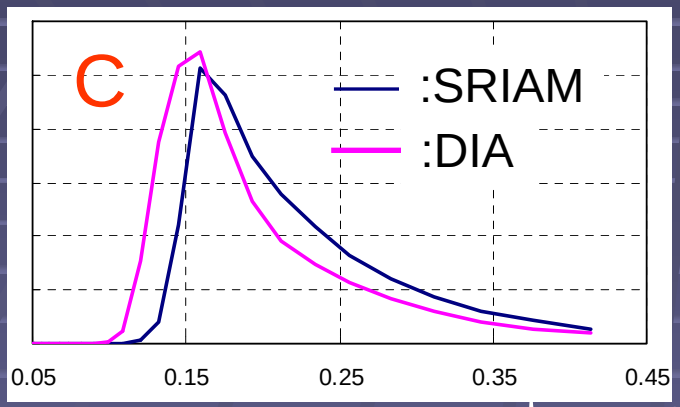


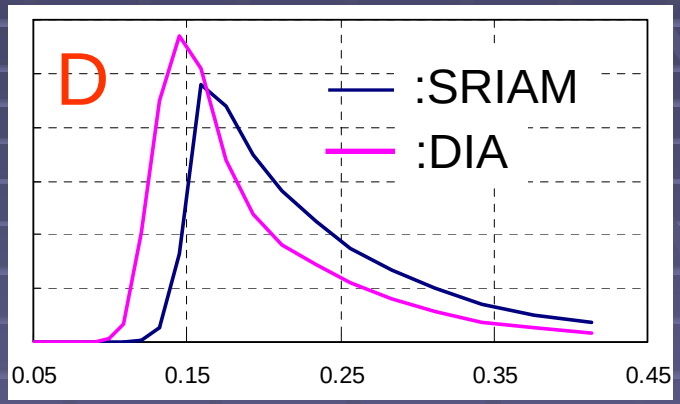
- spectral shapes calculated by SRIAM are more peaked than that of DIA
- spectral spreading by SRIAM is clearly narrower compared with DIA

Frequency spectra and directional spreading

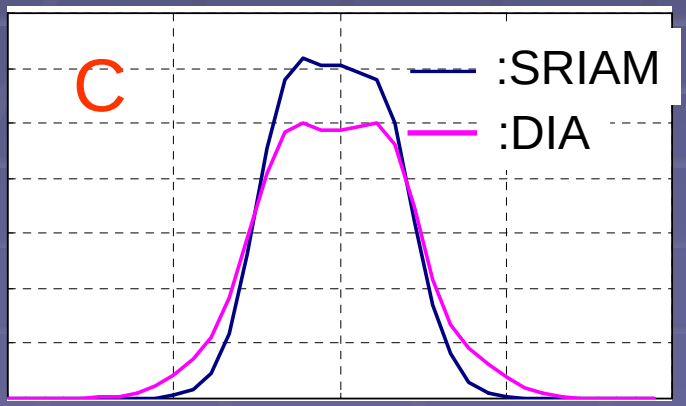


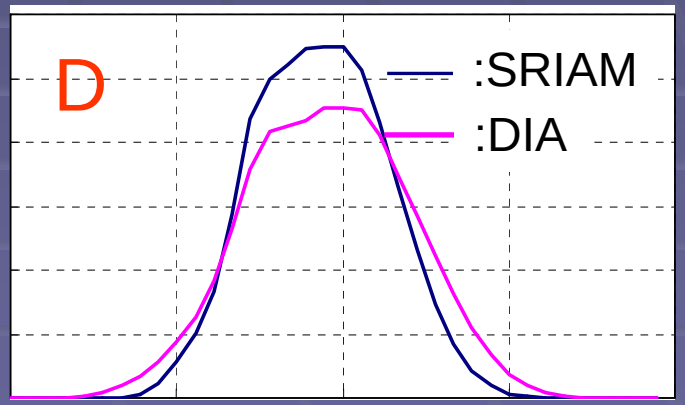
Frequency spectrum





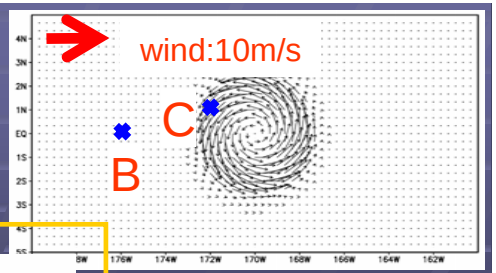
directional spreading $\int S(\sigma,\theta)d\sigma \Big/ \iint S(\sigma,\theta)d\sigma d\theta$

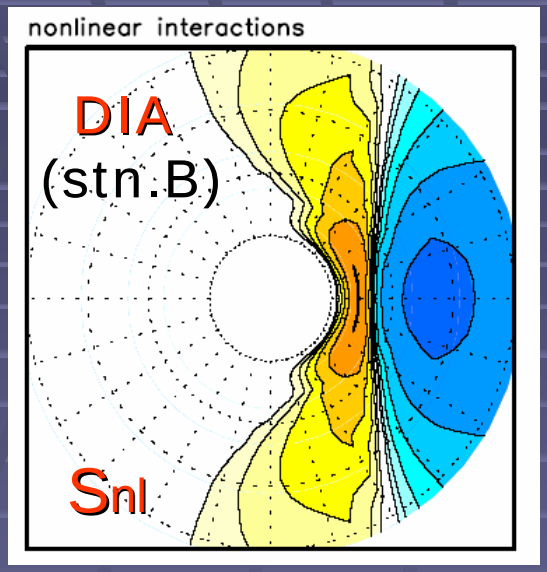


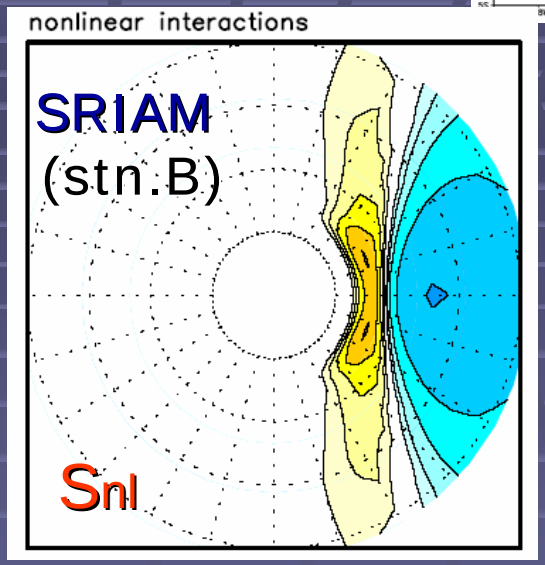


- Down shifting of frequency spectrum is remarkable for DIA
- Mean wave directions are shifted by the current effect and directional spreading is narrower for SRIAM

Non-linear source functions

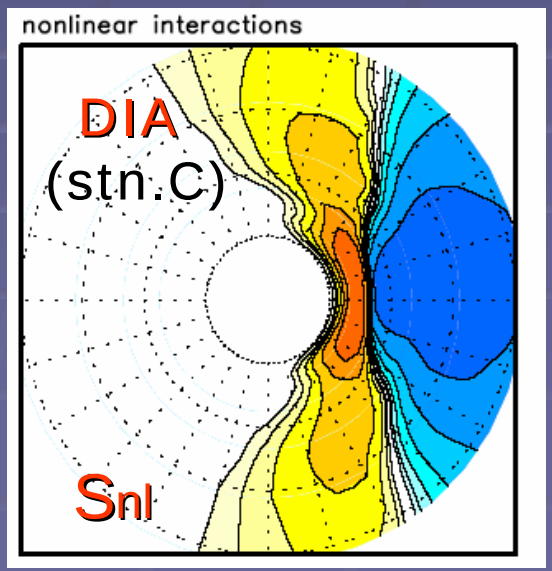


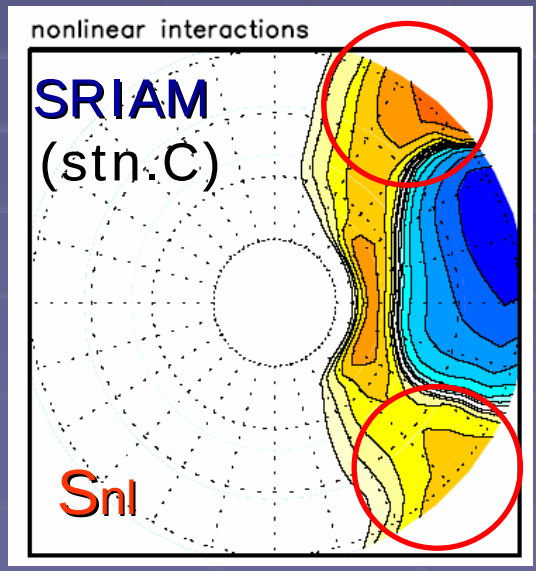




Similar pattern but DIA tends to broad

Similar pattern in spite of the current effect





Positive peak values appear at high freq. regions

Conclusions

- Comparing the monthly-averages with and without current, the difference of the spatial distribution of the significant wave height, over the Kuroshio is quite eminent.
- Instantaneous differences extend for quite a distance away from the Kuroshio downwind.
- The shapes of the directional wave spectra calculated with and without wave–current interactions are also quite different.
- For the improved estimation of the spectral shape by the wave-current interaction, we implemented RIAM and SRIAM method to evaluate the non-linear interaction.
- Spatial distribution of significant wave height are completely different with DIA and SRIAM.

Thank you