XI Brazil/Japan International Workshop
Energy, Biofuels and Sustainable Development

Ocean Wave Model and its Applications to Waves under Typhoon

Environment and Renewable Energy Systems
Gifu University

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Ocean Wave Forecasting

Applications:

- Environment Assessment
  - Bio-enviroment in Ocean and Coasts
- Navigation
  - Scheduling of Navigations
  - Searching Safety Passes
- Structures (Offshore and Nearshore)
  - Construction Planning and Design
  - Maintenance

Observations and Simulations

	Onsite Observations	Wave Model Simulations
Period	Past	Past and Future
Target Points and Domain	(Observed) Points	Points and Domains
Confidence (Accuracy)	Observed	Estimated

Today's Topics

1. **Characteristics of Ocean Waves**
2. Ocean Wave Model
3. Waves under Typhoon
   - Typhoons are …
   - Target Typhoon
   - Wave Simulation

Ocean Waves

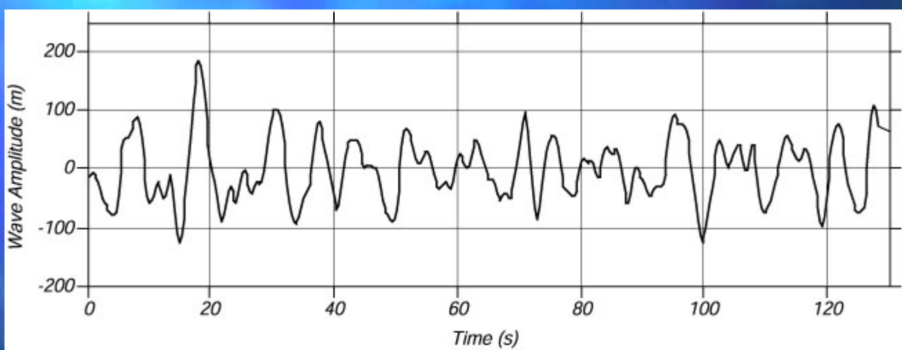
Irregular waves

- Wave Height } Random
- Wave Length } Random

In Space…

- Multi direction

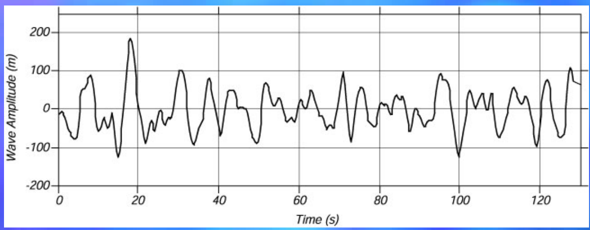
Irregular Wave Analysis



Wave Height } Random
Wave Period } Random

http://oceanworld.tamu.edu/resources/ocng_textbook/chapter16/Images/Fig16-2.htm

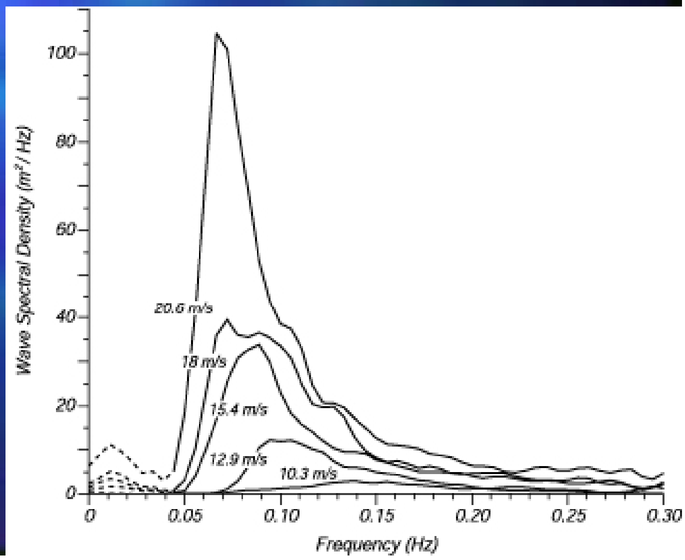
Irregular Wave Analysis



Real Space

Fourier Analysis

Spectrum Space



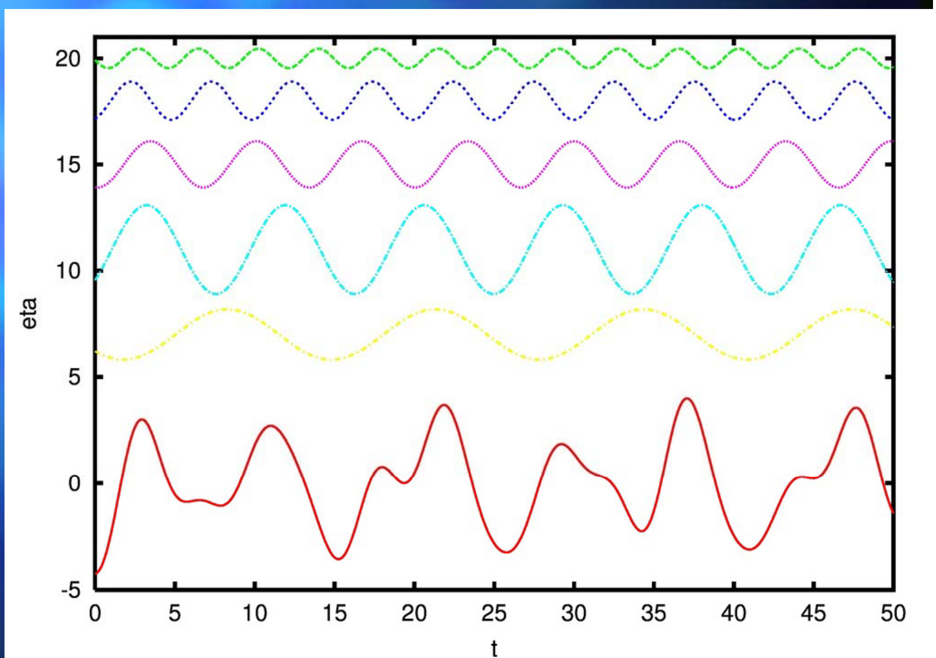
http://www.wikiwaves.org/files/9/99/Fig16-7s.jpg

Irregular Wave Analysis

Regular Waves

Fourier Analysis

Ocean Waves



Ocean Wave Velocity

Wave Length

$$C = \sqrt{\frac{gL}{2\pi}\tanh\left(2\pi\frac{h}{L}\right)}$$

Wave Velocity

Wave Velocity C is depend on the Wave Length L
(also depend on the Wave Period T

Shorter $\leftarrow L \rightarrow$ Longer
Slower $\leftarrow C \rightarrow$ faster

Ocean Wave Energy

Wave Energy E

$$E = \frac{1}{2}\rho g H^2$$

Wave Height

Ocean Wave Energy

Wave Energy E

$$E = \frac{1}{2}\rho g H^2$$

Energy Transfer Speed Cg

$$C_g = \frac{1}{2}\left\{1 + \frac{4\pi h / L}{\sinh\left(4\pi h / L\right)}\right\}\sqrt{\frac{gL}{2\pi}\tanh\left(2\pi\frac{h}{L}\right)}$$

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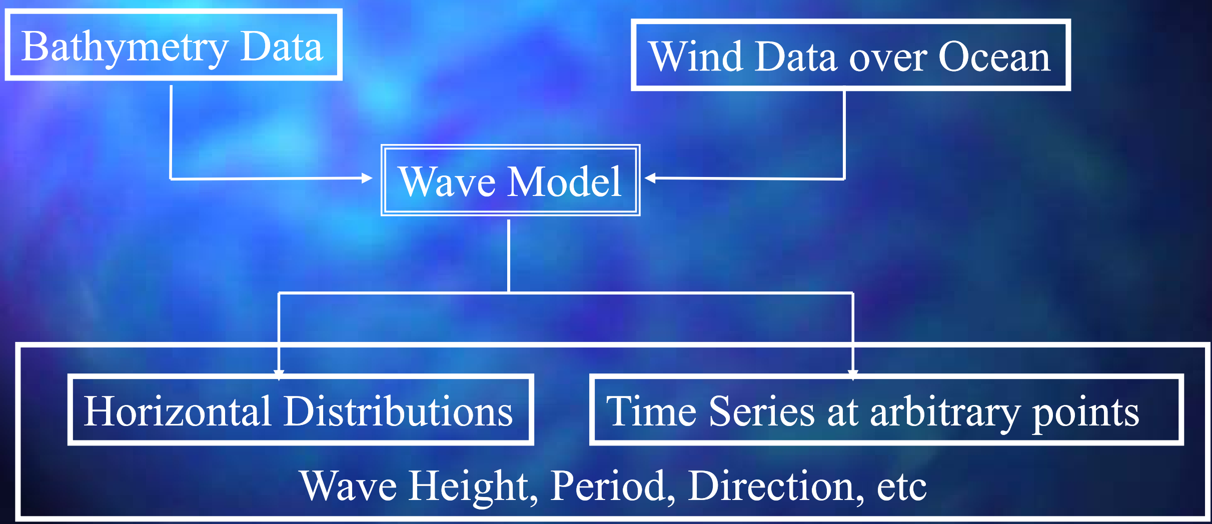
Ocean Wave Model



Variables in Wave Model

Target Area is TOO LARGE for the individual waves

Wave Profile in Real Space → **Wave Energy in Spectrum Space**

↑ Conserved quantity

Ocean Wave Model

Fundamental Equations

Wave Energy

$$\frac{\partial N}{\partial t} + (\text{Advection Term}) = S_{\text{in}} + S_{\text{nl}} + S_{\text{ds}}$$

Energy Inflow from Wind

Wave – Wave Interaction

Energy Dissipation
due to breaking

Ocean Wave Model : Fundamental Equations

Advection terms in X-Y plane

Source Terms

$$\frac{\partial}{\partial t}N + \frac{\partial}{\partial x}(c_x N) + \frac{\partial}{\partial y}(c_y N) + \frac{\partial}{\partial \sigma}(c_\sigma N) + \frac{\partial}{\partial \theta}(c_\theta N) = \frac{S(\sigma, \theta)}{\sigma}$$

Wave Energy

Advection Terms

Advection Terms on the Earth surface

$$\frac{\partial}{\partial t}N + (\cos\phi)^{-1}\frac{\partial}{\partial \phi}(c_\phi \cos\phi\, N) + \frac{\partial}{\partial \lambda}(c_\lambda N) + \frac{\partial}{\partial \sigma}(c_\sigma N) + \frac{\partial}{\partial \theta}(c_\theta N) = \frac{S(\sigma, \theta)}{\sigma}$$

Latitude

Longitude

S_{in} :Energy inflow from Wind

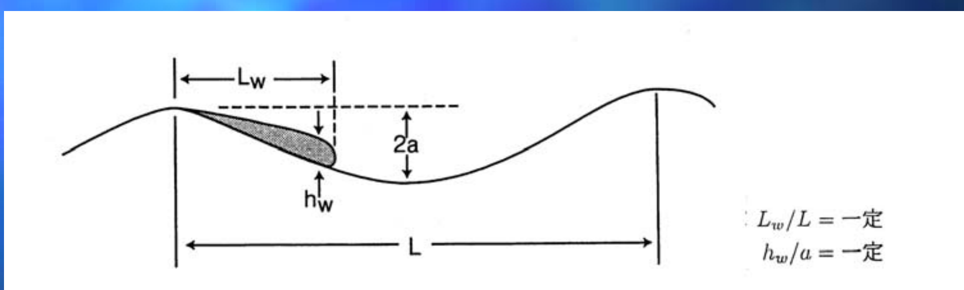
$$S_{\text{in}} = A + B\,E(\sigma,\theta)$$

- A ← Phillips's Resonant theory
- $B\,E(\sigma,\theta)$ ← Miles's Interactive theory

S_{ds} :Energy Dissipation due to Breaking

Hasselmann's(1974) whitecap model (Offshore breaking model)

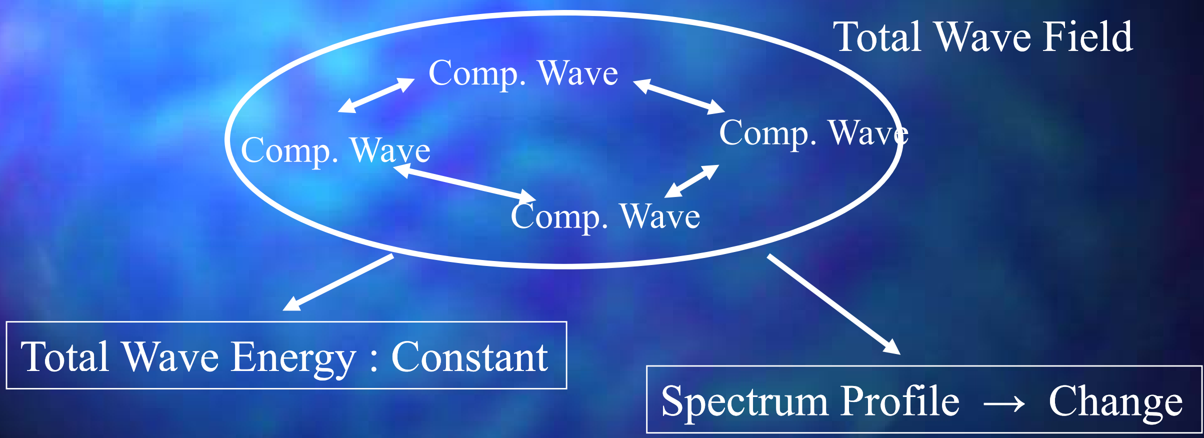
→ Assuming the similarity of breaking wave profiles



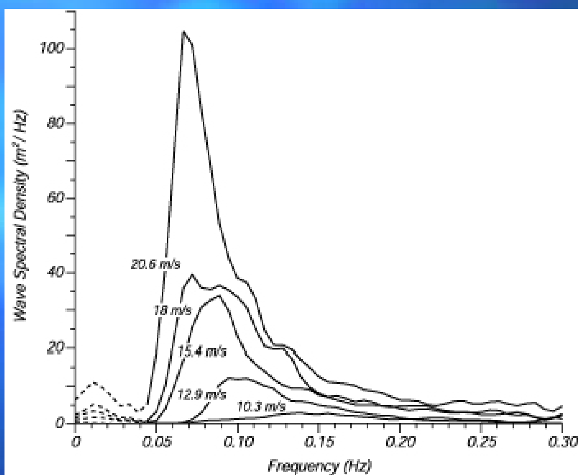
$$S_{\text{ds}}(\sigma,\theta) = -\Gamma\tilde{\sigma}\frac{k}{\tilde{k}}E(\sigma,\theta)$$

- Unstable phenomena → Modeling is difficult → Rough model
- Working well in the wave model

S_{nl} :Wave – Wave Interaction



S_{nl} : Wave – Wave Interaction



(In Low Frequency Zone)
Energy is dissipated due to Breaking (S_{ds})

Energy Transfer With S_{nl}

(In High Frequency Zone)
Energy is Inflow from Wind (S_{in})

S_{nl} : Wave – Wave Interaction

$$S_{\rm nl} = \frac{\partial N(\boldsymbol{k}_4)}{\partial t}$$
$$= \sigma_4 \int_{-\infty}^{\infty}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} G(\boldsymbol{k}_1,\boldsymbol{k}_2,\boldsymbol{k}_3,\boldsymbol{k}_4)\,\delta(\boldsymbol{k}_1+\boldsymbol{k}_2-\boldsymbol{k}_3-\boldsymbol{k}_4)\,\delta(\sigma_1+\sigma_2-\sigma_3-\sigma_4) \times [N_1N_3(N_4-N_2)+N_2N_4(N_3-N_1)]\,d\boldsymbol{k}_1\,d\boldsymbol{k}_2\,d\boldsymbol{k}_3$$

Computation is complicate ←×→ Key Term of Wave Model

↓

Approximate Computation is applied

Source Terms

Source Terms

$$S(\sigma,\theta) = S_{\rm in} + S_{\rm ds} + S_{\rm br} + S_{\rm bf} + S_{\rm nl} + S_{\rm tri}$$

S_{in} : Energy Inflow from Wind

S_{ds} : Energy Dissipation due to Breaking (Whitecap, offshore)

S_{br} : Energy Dissipation due to Breaking (Shallow breaking, nearshore)

S_{bf} : Energy Dissipation due to Friction on the sea bed

S_{nl} : Wave – Wave Interaction in Deep Water

S_{tri} : Wave – Wave Interaction in Shallow Water

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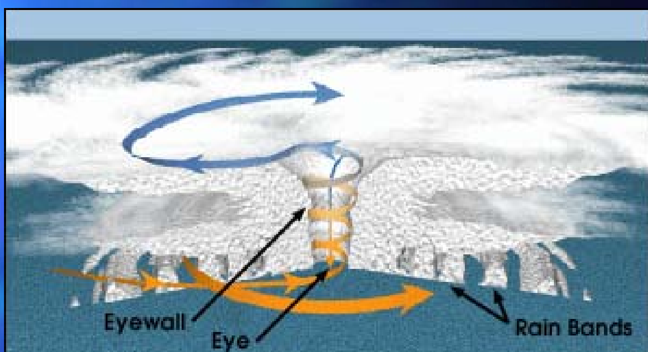
Typhoons



Structure

http://ja.wikipedia.org/wiki/

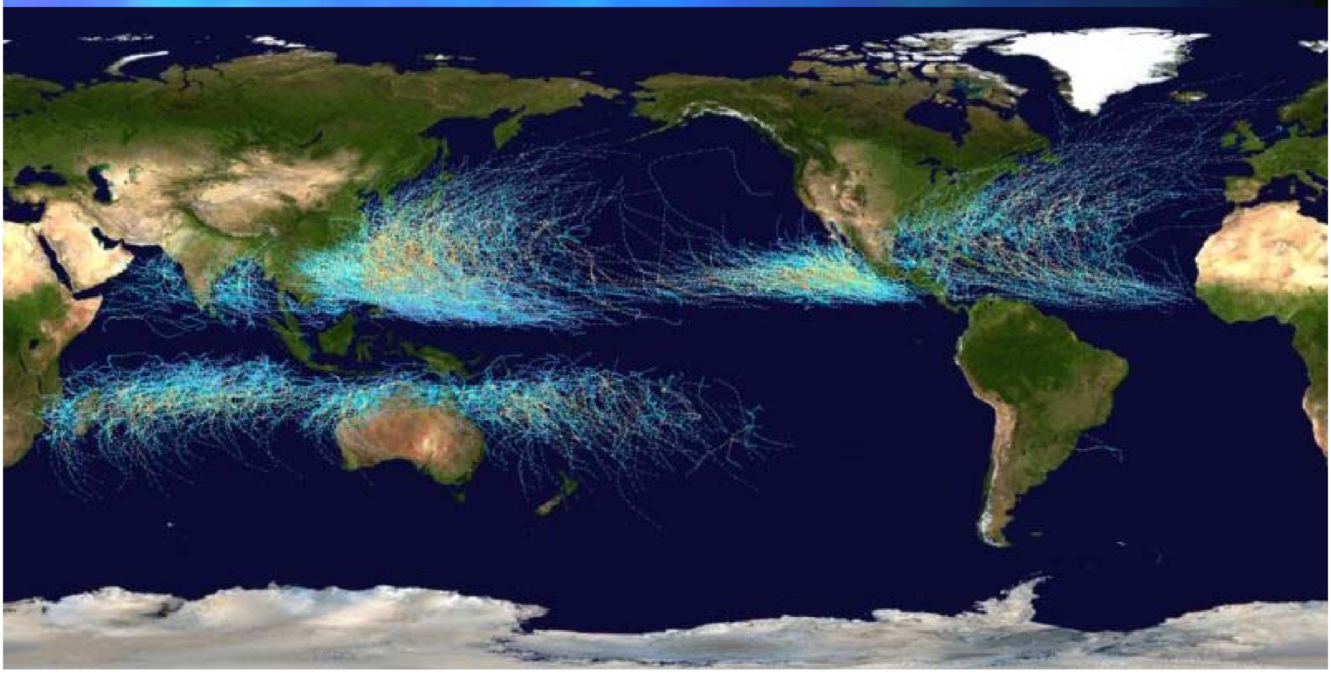
Hurricanes Katrina（2005）

http://ja.wikipedia.org/wiki/

Typhoons

Paths of Typhoons, Hurricanes and Cyclones（1985～2005）

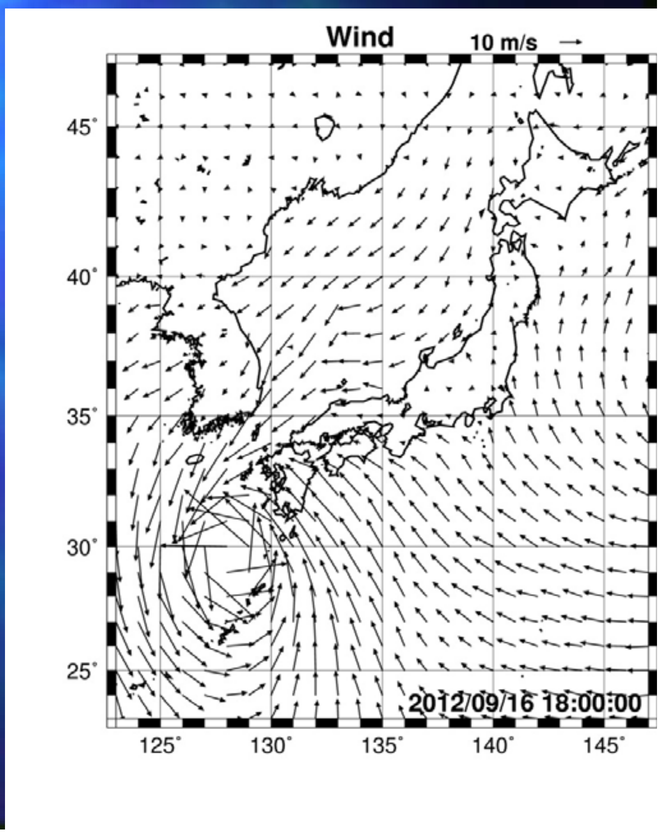
http://en.wikipedia.org/wiki/File:Global_tropical_cyclone_tracks-edit2.jpg



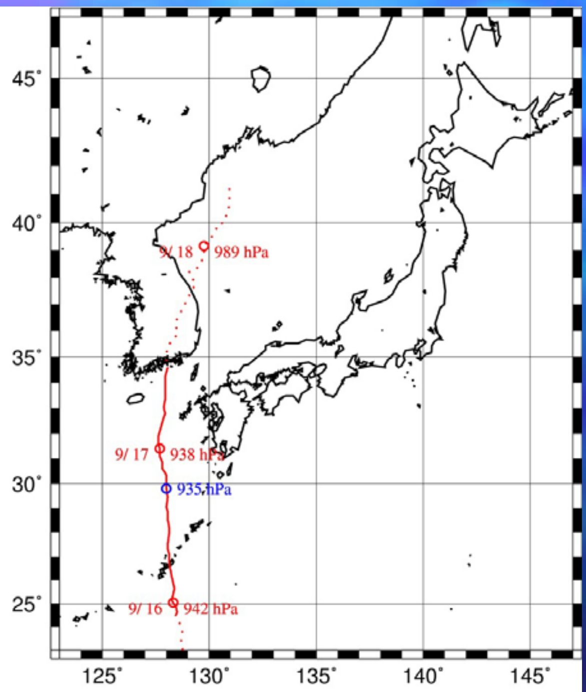
Typhoons

Rotation Direction

- Northern Hemi-Sphere : Counter Clock Wise
- Southern Hemi -Sphere : Clock Wise



Target Typhoon

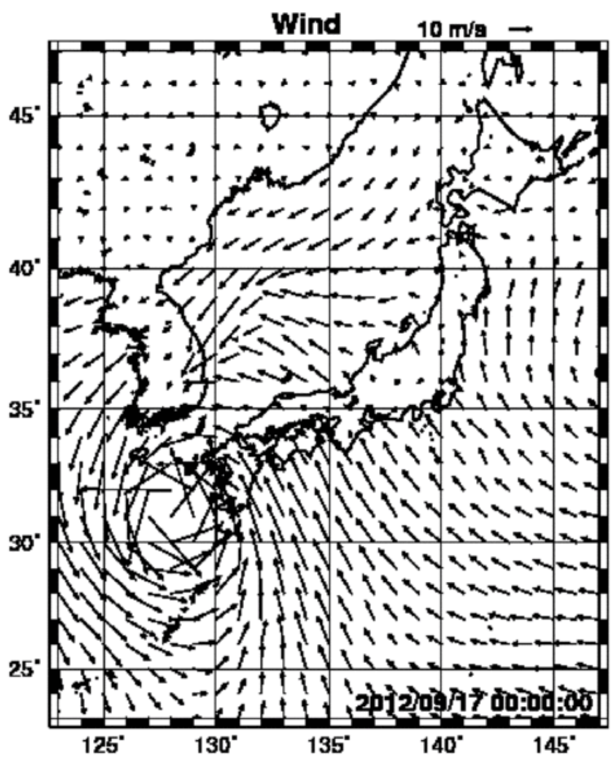


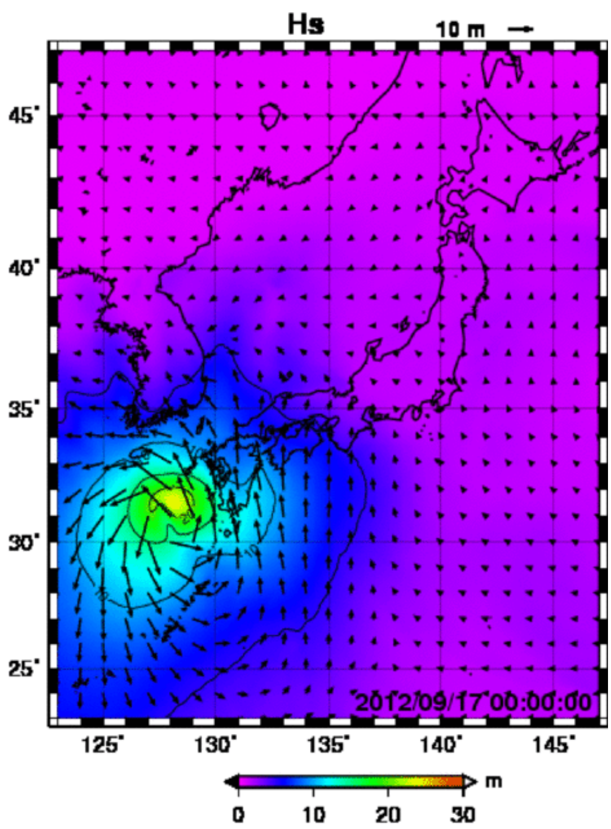
Typhoon No.16, 2012

Minimum pressure :
935 hPa,
at the center of the Typhoon

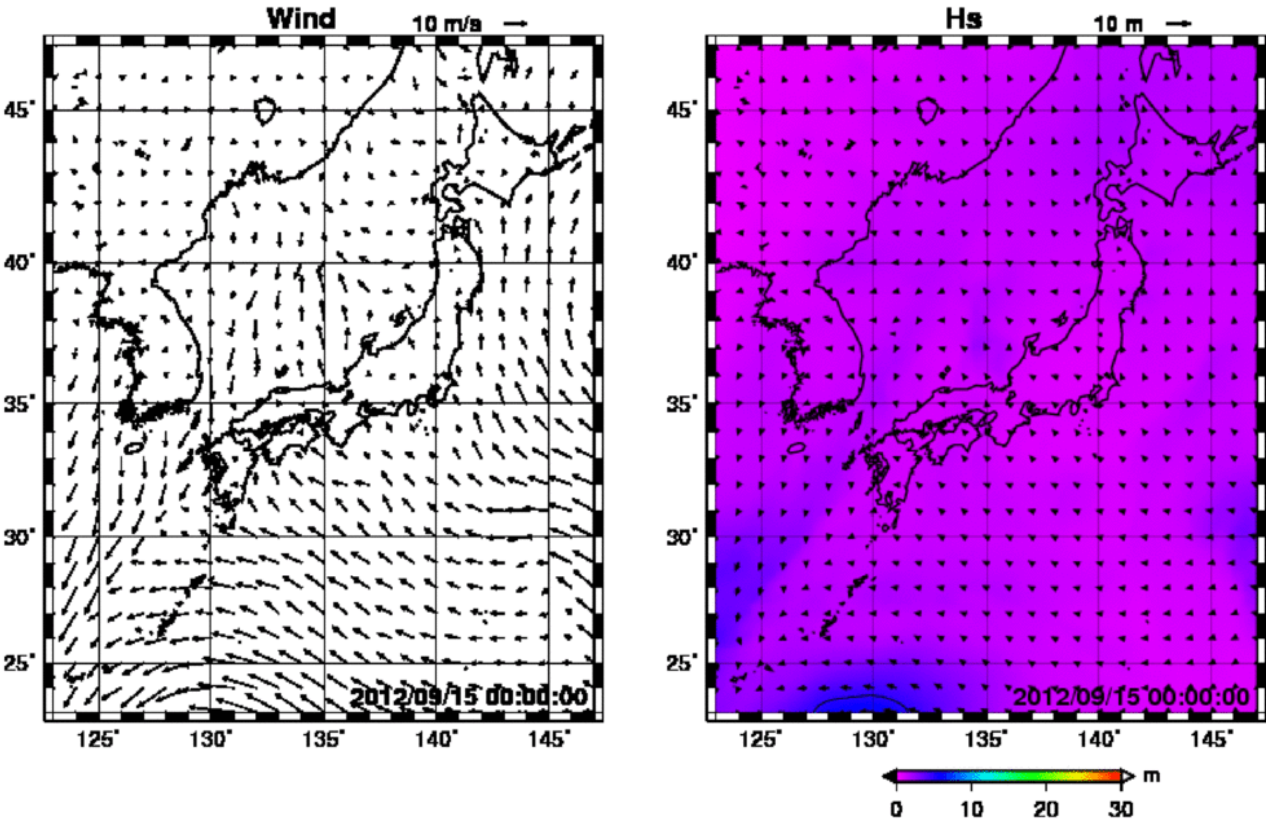
Maximum Wind Speed :
55 m/s (200 km/h)

Significant Wave Height : Hs

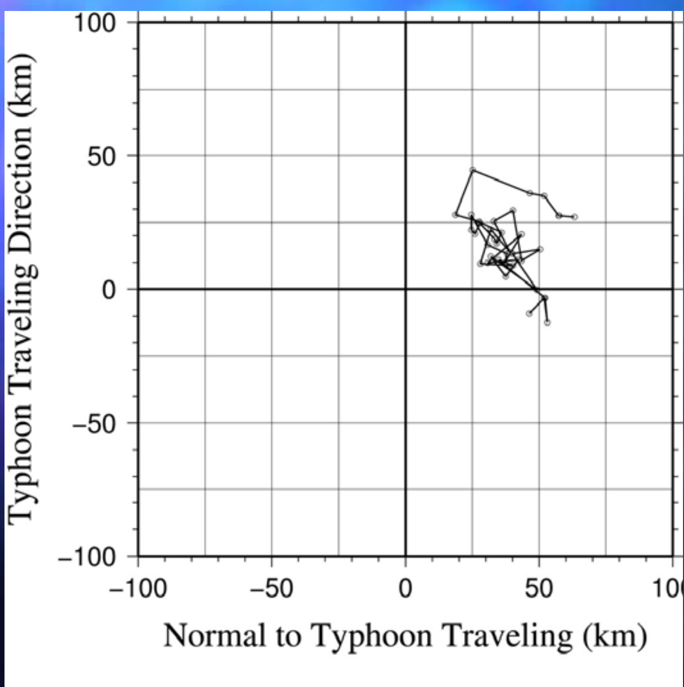




Significant Wave Height：Hs



Significant Wave Height：Hs



Origen :

Typhoon's Center

Plotted data :

Relative peak location of Wave Height Hs

Conclusions

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