Ocean Current Simulation and Characteristics Analysis in the Southwestern Sea of Taiwan

Tai-Wen Hsu, Distinguished Professor

Jian-Ming Liau, Yi-Feng Chen

Dept of Hydraulic and Ocean Engineering,

National Cheng Kung University

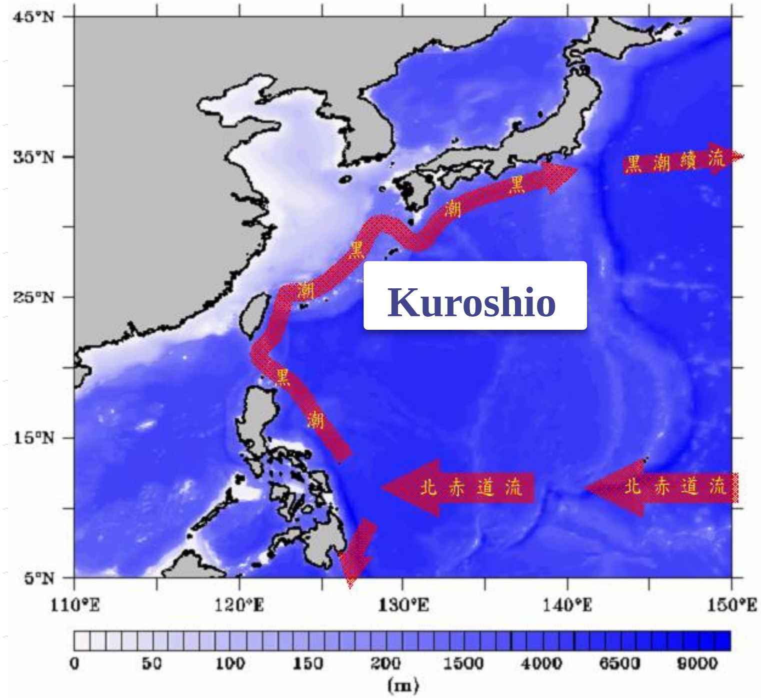
Tainan 701, Taiwan

The 7th Taiwan-Japan Joint Seminar on Natural Hazard Mitigation in 2011

November 25, 2011

Introduction

1. The three-dimensional numerical model can simulate ocean current changes in the complex topography of Taiwan coastal waters.
2. Major objects of this study project are expected to continue to improve the operational procedure of the computational environment of the POM model.
3. The field observations are appled to adjust model parameters and verification.



http://www.imece.ntou.edu.tw/ks/images/Wu1_handout.pdf

Purposes

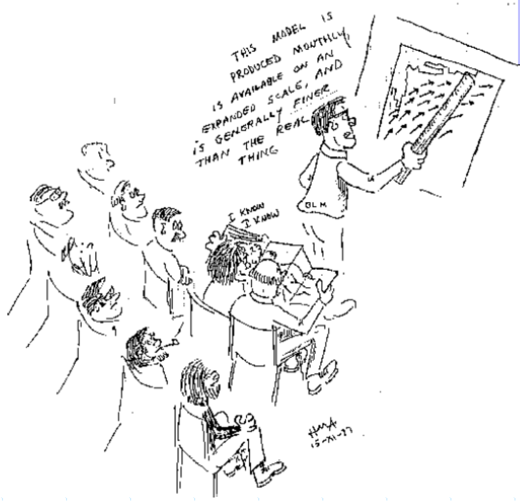
1. Sea surface height variations in the South China Sea are examined using POM model.
2. The South China Sea loop circulation is largely influenced by the reversal of monsoonal winds.
3. Adding tidal boundary condition in the large scale ocean current calculation.

Development of POM model

Where it all started:
Mellor's vision for POM 27 years ago…

"This model is produced monthly is available on an expanded scale and is generally FINER than the real thing…"

G. Mellor, 1977



Sigma atmospheric models
(Phillips, 1957; Smagorinsky, 1967…)

Other s-models developed in parallel:
SPEM, SCRUM, SEOM, ROMS, TOMS
(Rutgers)

Evolved from POM:
NCOM (Navy)
POMnb, POMgcs (Princeton)
ECOM-SI/ **ECOMSED (HydroQual)**

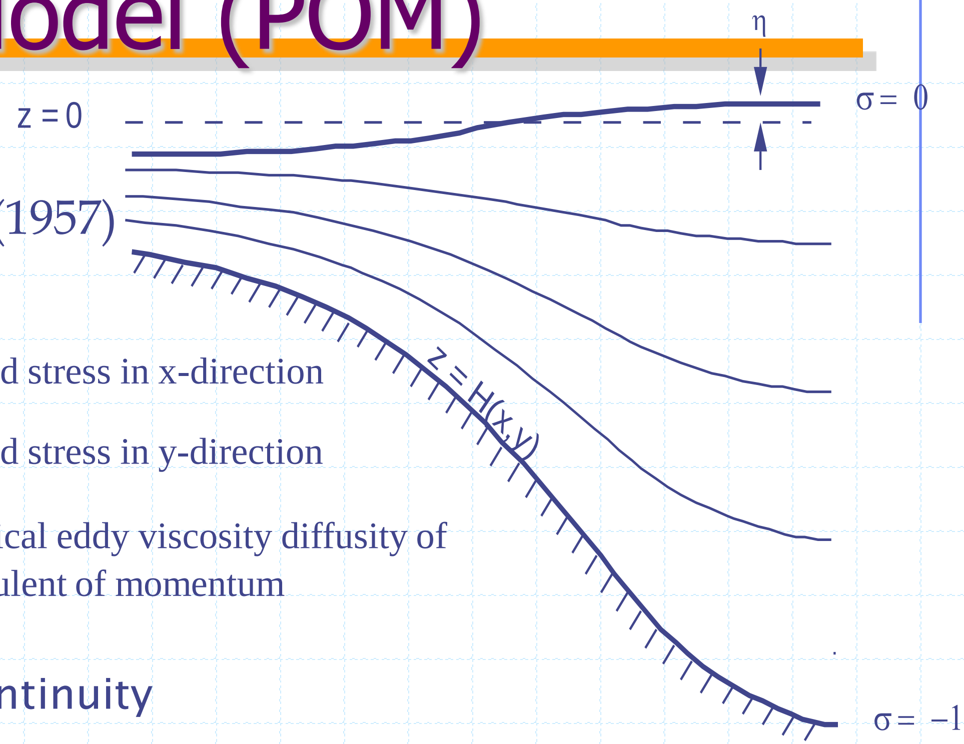
1960s	1970s	1980s	1990s	2000s
turbulent boundary layers, lab exp. & models (Mellor-Yamada)	3-D coastal models (Blumberg-Mellor)	Estuaries, bays Sea-ice modeling	Gulf Stream, Mediterranean, Atlantic, operational forecasting, data assimilation (POM users group)	

http://www.aos.princeton.edu/WWWPUBLIC/htdocs.pom/index.html

The principal attributes of POM model

- It is a sigma coordinate model in that the vertical coordinate is scaled on the water column depth.
- It contains an imbedded second moment turbulence closure sub-model to provide vertical mixing coefficients.
- Complete thermodynamics have been implemented.
- The model has a split time step. The external mode portion of the model is two-dimensional and uses a short time step based on the CFL condition and the external wave speed. The internal mode is three-dimensional and uses a long time step based on the CFL condition and the internal wave speed.

Princeton Ocean Model (POM)



- sigma coordinate system-Philip(1957)

$$x^* = x \qquad y^* = y \qquad t^* = t$$

$$\sigma = \frac{(z-\eta)}{(H+\eta)}$$

F_u : Reynold stress in x-direction

F_v : Reynold stress in y-direction

K_M : vertical eddy viscosity diffusity of turbulent of momentum

- Governing Equations

$$\frac{\partial DU}{\partial x^*} + \frac{\partial DV}{\partial y^*} + \frac{\partial \omega}{\partial \sigma} + \frac{\partial \eta}{\partial t} = 0$$ Equation of continuity

$$\frac{\partial UD}{\partial t^*} + \frac{\partial U^2 D}{\partial x^*} + \frac{\partial UVD}{\partial y^*} + \frac{\partial U\omega}{\partial \sigma} - fVD$$ Momentum equation

$$+ gD\frac{\partial \eta}{\partial x^*} + \frac{gD^2}{\rho_o}\int_\sigma^0 \left[\frac{\partial \rho}{\partial x^*} - \frac{\sigma}{D}\frac{\partial D}{\partial x^*}\frac{\partial \rho}{\partial \sigma}\right] d\sigma = \frac{\partial}{\partial \sigma}\left[\frac{K_M}{D}\frac{\partial U}{\partial \sigma}\right] + DF_u$$

$$\frac{\partial VD}{\partial t^*} + \frac{\partial UVD}{\partial x^*} + \frac{\partial V^2 D}{\partial y^*} + \frac{\partial V\omega}{\partial \sigma} + fUD$$

$$+ gD\frac{\partial \eta}{\partial y^*} + \frac{gD^2}{\rho_o}\int_\sigma^0 \left[\frac{\partial \rho}{\partial y^*} - \frac{\sigma}{D}\frac{\partial D}{\partial y^*}\frac{\partial \rho}{\partial \sigma}\right] d\sigma = \frac{\partial}{\partial \sigma}\left[\frac{K_M}{D}\frac{\partial V}{\partial \sigma}\right] + DF_v$$

U : The velocity in x-direction

V : The velocity in y-direction

W : The transformation to the Cartesian vertical velocity

ω : The velocity component normal to sigma surfaces

Princeton Ocean Model (POM)

- temperature conservation equation

$$\frac{\partial \theta D}{\partial t^*}+\frac{\partial U\theta D}{\partial x^*}+\frac{\partial V\theta D}{\partial y^*}+\frac{\partial \theta\omega}{\partial \sigma}=\frac{\partial}{\partial \sigma}\left[\frac{K_H}{D}\frac{\partial \theta}{\partial \sigma}\right]+DF_\theta$$

- salinity conservation equation

$$\frac{\partial SD}{\partial t^*}+\frac{\partial USD}{\partial x^*}+\frac{\partial VSD}{\partial y^*}+\frac{\partial S\omega}{\partial \sigma}=\frac{\partial}{\partial \sigma}\left[\frac{K_H}{D}\frac{\partial S}{\partial \sigma}\right]+DF_S$$

- turbulent equation

$$\frac{\partial q^2 D}{\partial t^*}+\frac{\partial q^2 UD}{\partial x^*}+\frac{\partial q^2 VD}{\partial y^*}+\frac{\partial q^2\omega}{\partial \sigma}=\frac{\partial}{\partial \sigma}\left(\frac{K_q}{D}\frac{\partial q^2}{\partial \sigma}\right)+\frac{2K_M}{D}\left[\left(\frac{\partial U}{\partial \sigma}\right)^2+\left(\frac{\partial V}{\partial \sigma}\right)^2\right]+\frac{2g}{\rho_o}K_H\frac{\partial \rho}{\partial \sigma}-\frac{2q^3 D}{B_1 l}+DF_q$$

$$\frac{\partial q^2 lD}{\partial t^*}+\frac{\partial q^2 lUD}{\partial x^*}+\frac{\partial q^2 lVD}{\partial y^*}+\frac{\partial q^2 l\omega}{\partial \sigma}=\frac{\partial}{\partial \sigma}\left[\frac{K_q}{D}\frac{\partial (q^2 l)}{\partial \sigma}\right]+\frac{E_1 l}{D}\left\{K_M\left[\left(\frac{\partial U}{\partial \sigma}\right)^2+\left(\frac{\partial V}{\partial \sigma}\right)^2\right]\right\}_l+E_3\frac{g}{\rho_o}K_H\frac{\partial \rho}{\partial \sigma}-\frac{q^3 D}{B_1}\tilde{W}+DF$$

θ : temperature

S : salinity

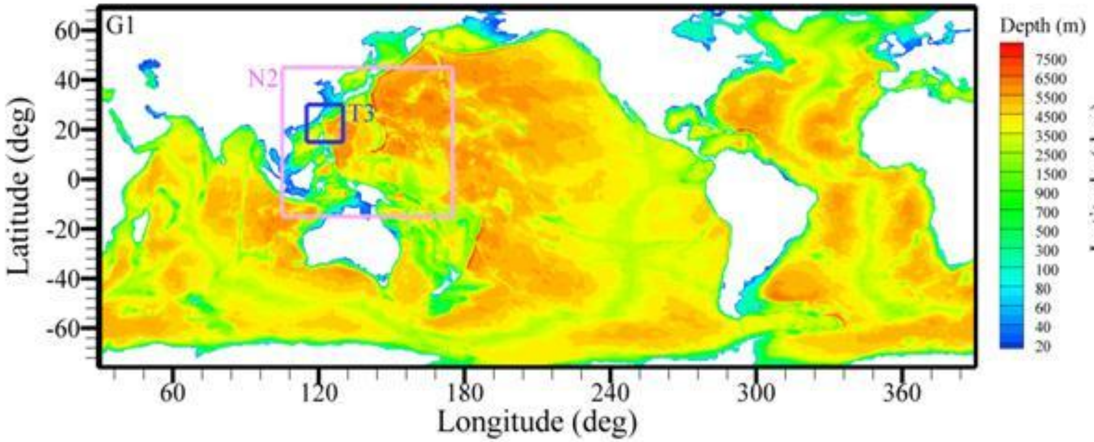
K_H : vertical eddy viscosity diffusity of turbulent of heat and salt

$f=2\Omega\sin\phi$: the Coriolis parameter

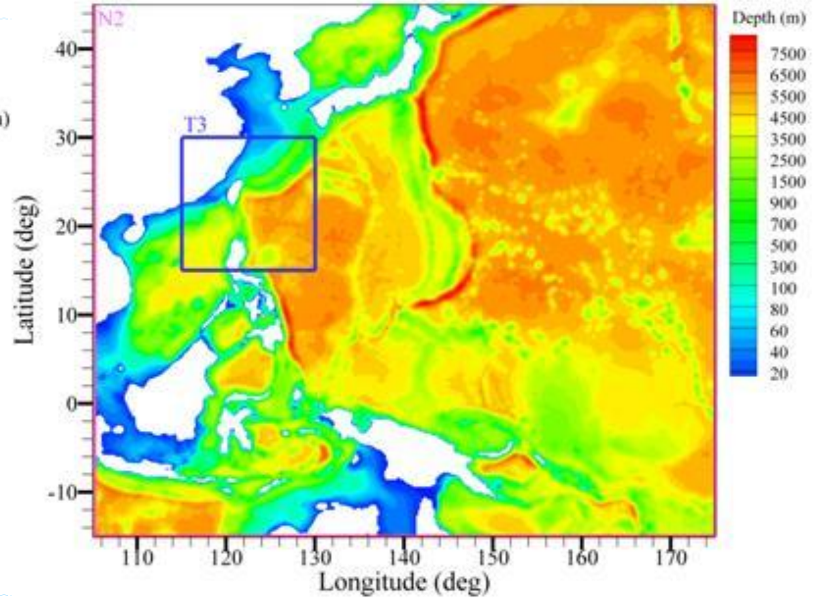
Grid specification

Models	Range	Grid spacing	Grid sizes	dte
G1	180 E~180 W 70 N~75 S	723x292x21	1/2	30 sec
N2	105 E~175 E 15 S~45 N	351x301x21	1/5	20 sec
T3	115 E~130 E 15 N~30 N	241x241x21	1/16	6 sec
T-SW	119 E~122 E 21 N~23 N	161x129x21	1/64	2 sec

Grid specification

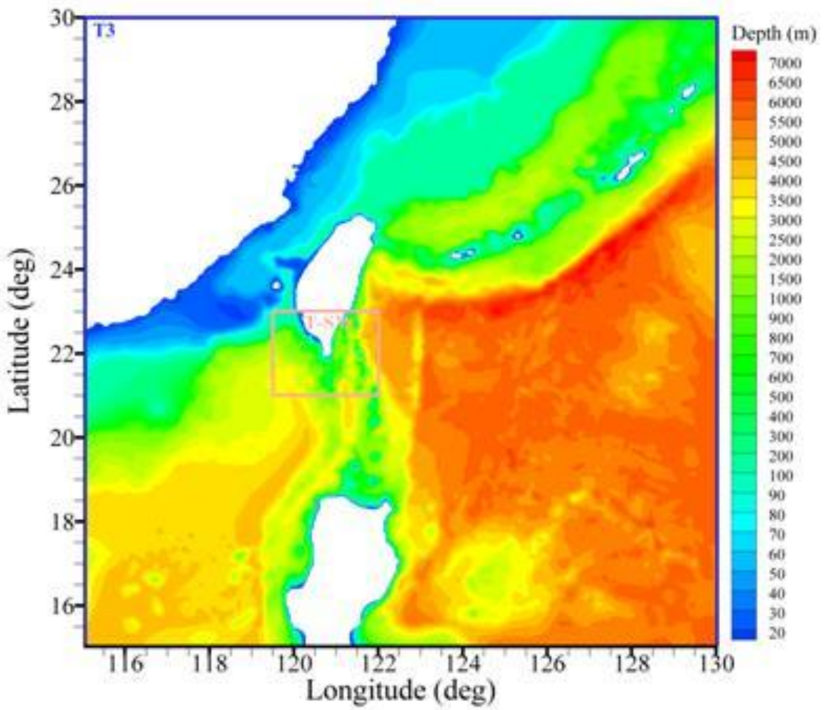


G1

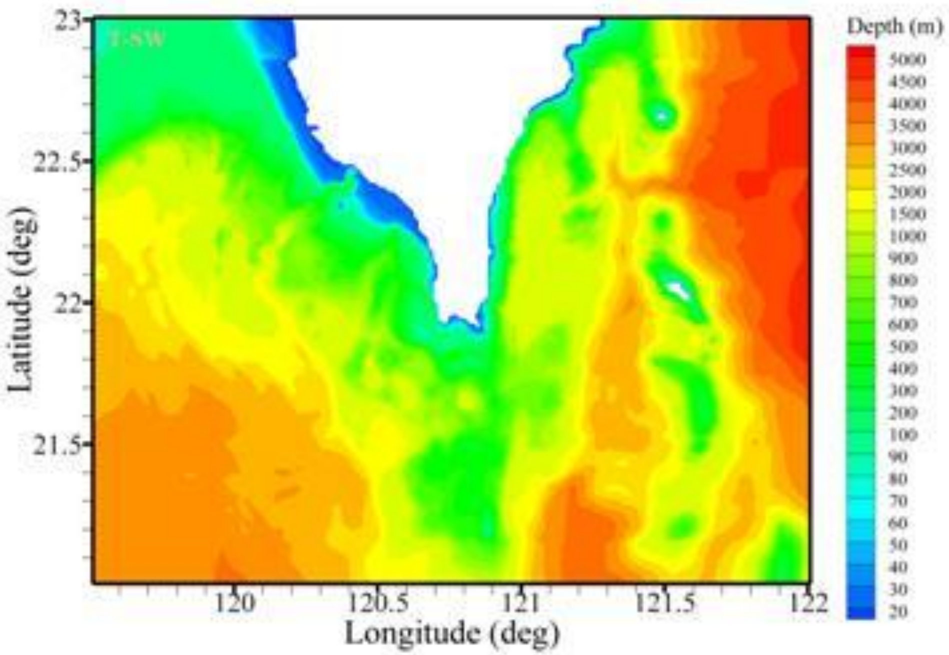


N2

Grid specification

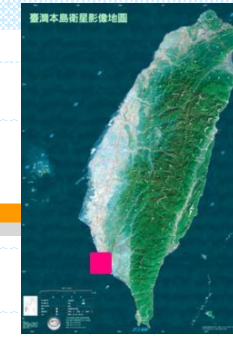


T3

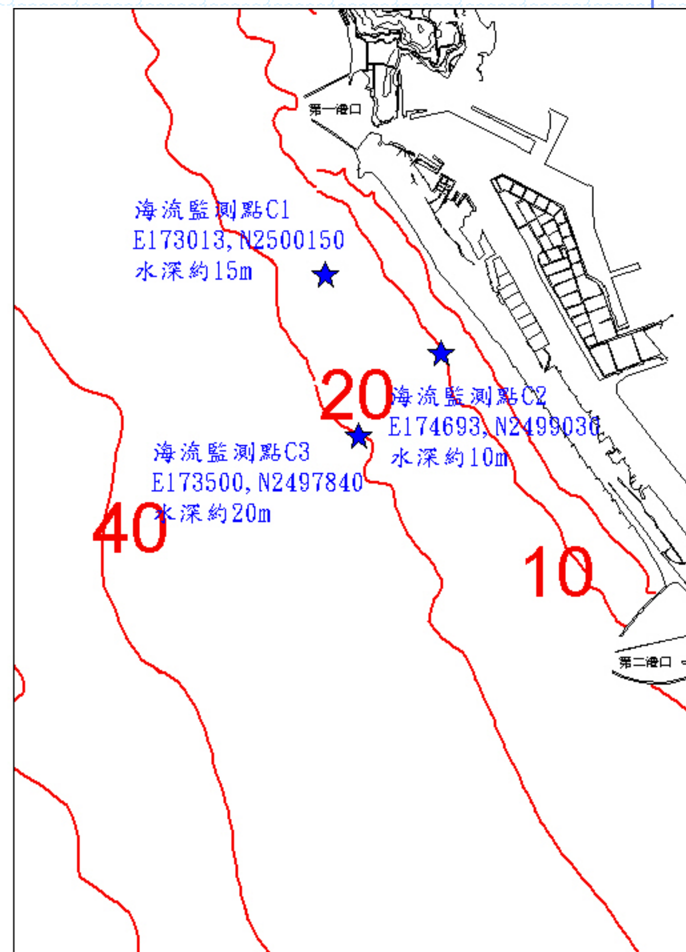


T-SW

Model validation



- Site
  - Kaohsiung Chongchou,
  - C3, (120.256N, 22.579S),
  - water depth is 20m.
- Time:
  - 11/14/2006~11/30/2006
  - 05/15/2007~06/01/2007
  - 12/02/2008~12/18/2005



Models	Grid sizes	Boundary condition
T3-WC	1/16	Ocean current + tidal level
T-SW	1/64	Tidal level
T-SW-WC	1/64	Ocean current + tidal level

Model validation

Statistics

- BIAS

$$BIAS = \frac{1}{N}\sum_{i=1}^{N}(y_i - x_i) = \bar{y} - \bar{x}$$

- Mean absolute error，MAE

$$MAE = \frac{1}{N}\sum_{i=1}^{N}|y_i - x_i| \qquad (15)$$

- Root mean square error，RMS

$$RMS = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(y_i - x_i)^2}$$

x_i ：the field observed value

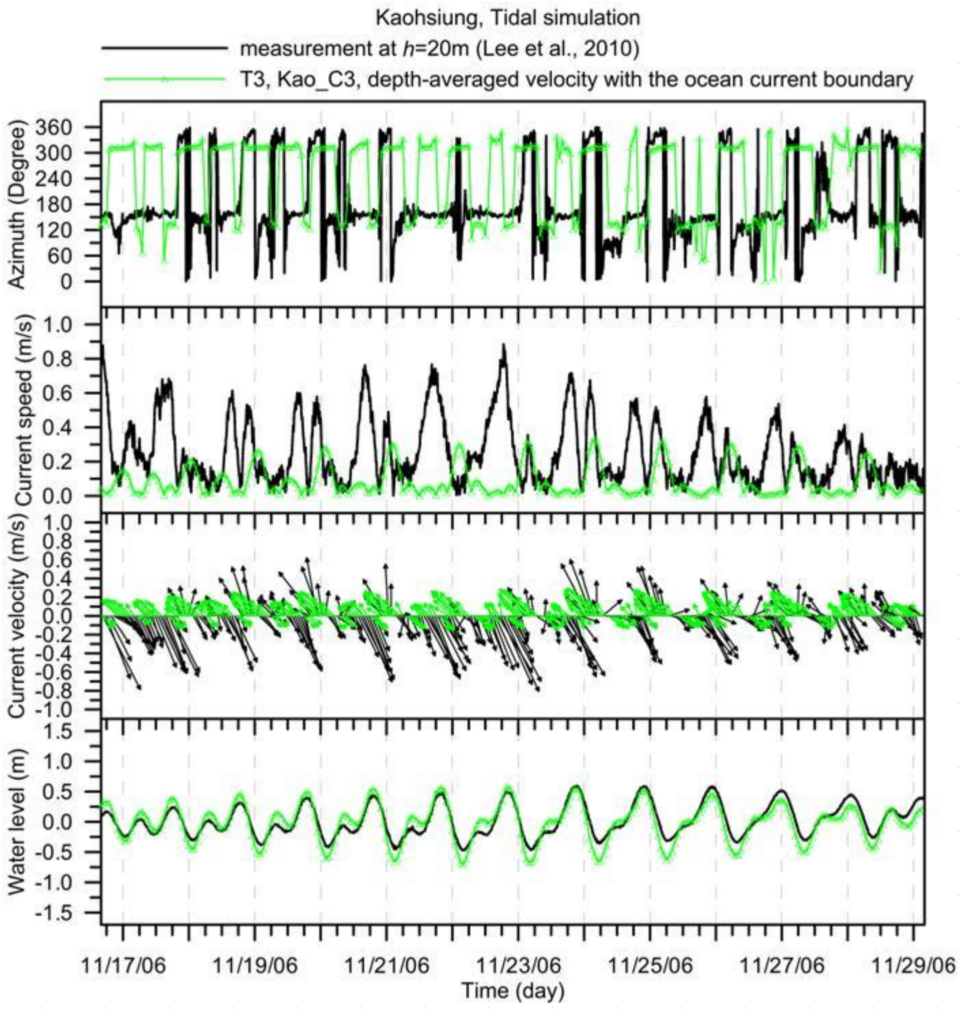
y_i ：the analytical value

$\bar{x}$ ：the average of the field observed value

$\bar{y}$ ：the average of the analytical value

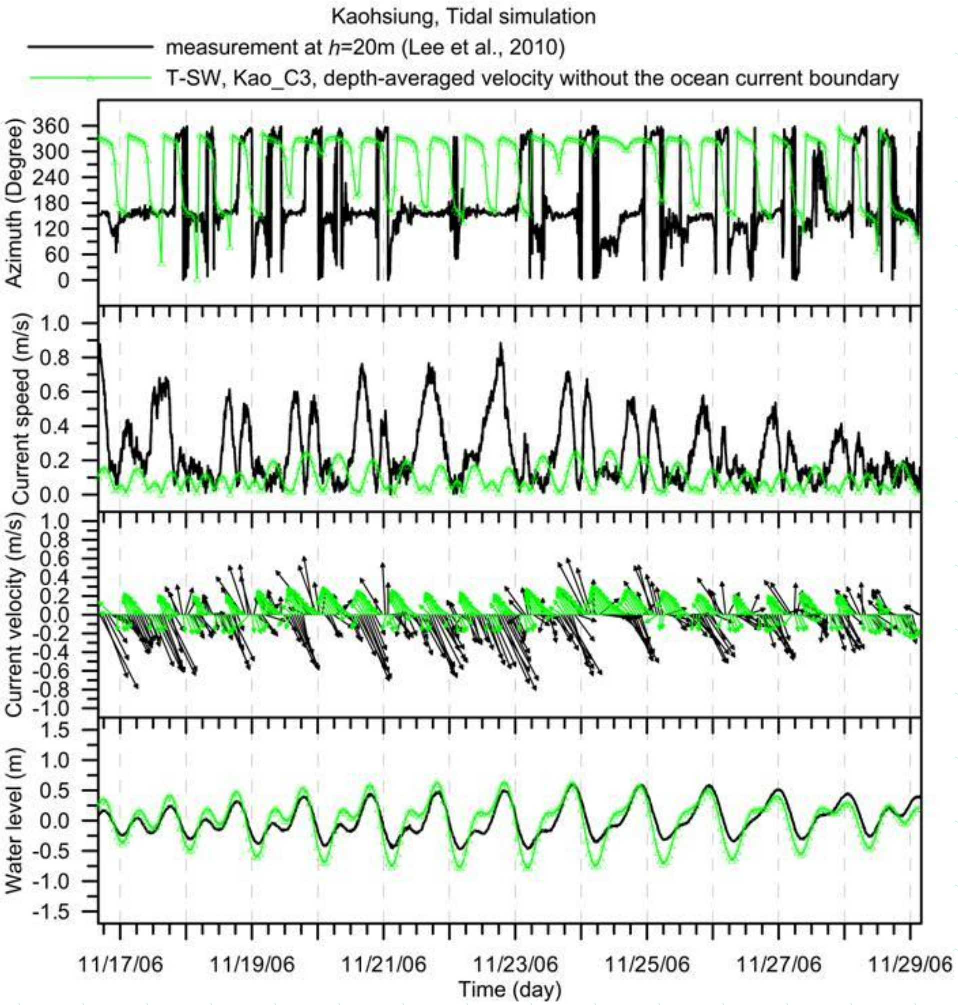
N ：the number of the field observation value

Verification of the model



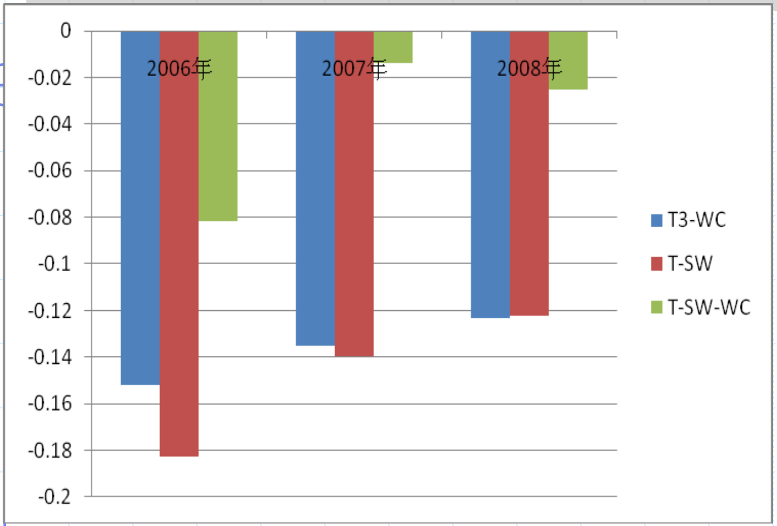
Calculated results of T3-WC model in 2006

Verification of the model

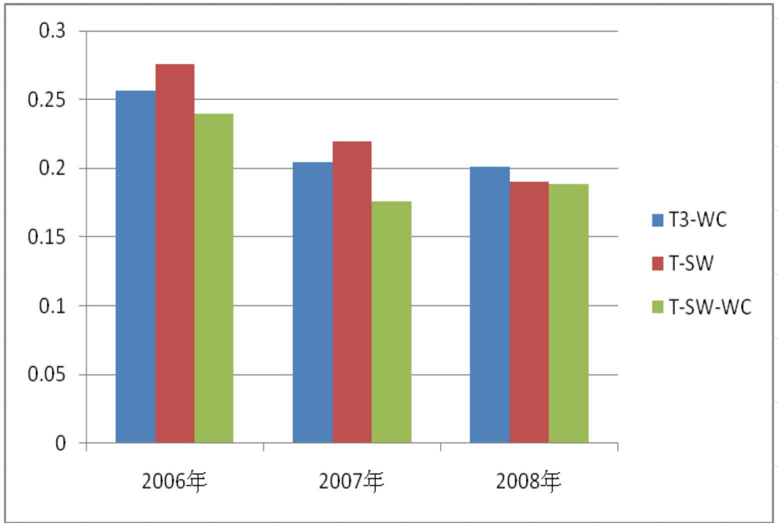


Calculated results of T-SW model in 2006

Verification of the model



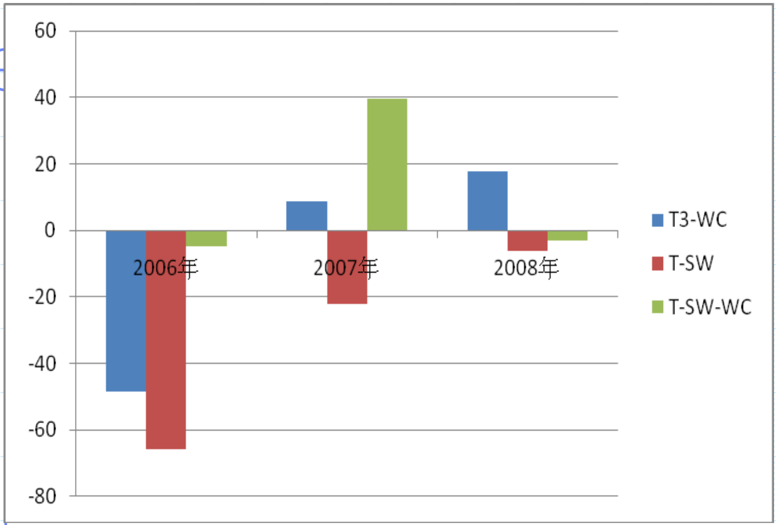
Velocity BIAS



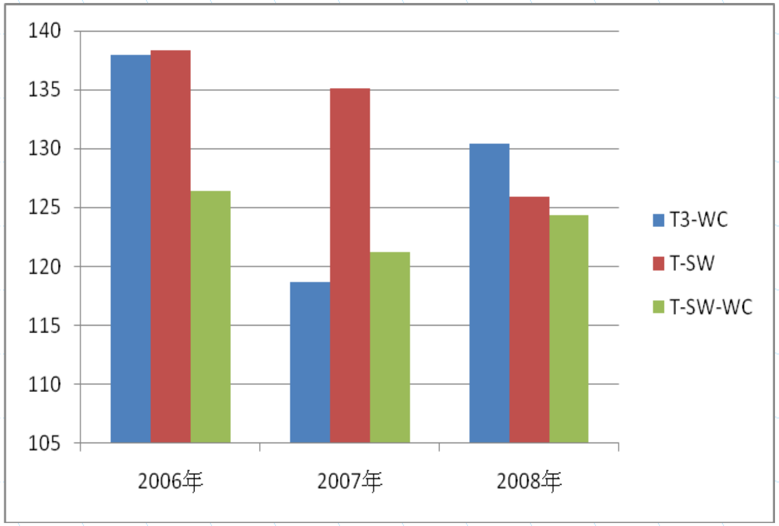
Velocity RMS

Velocity MAE

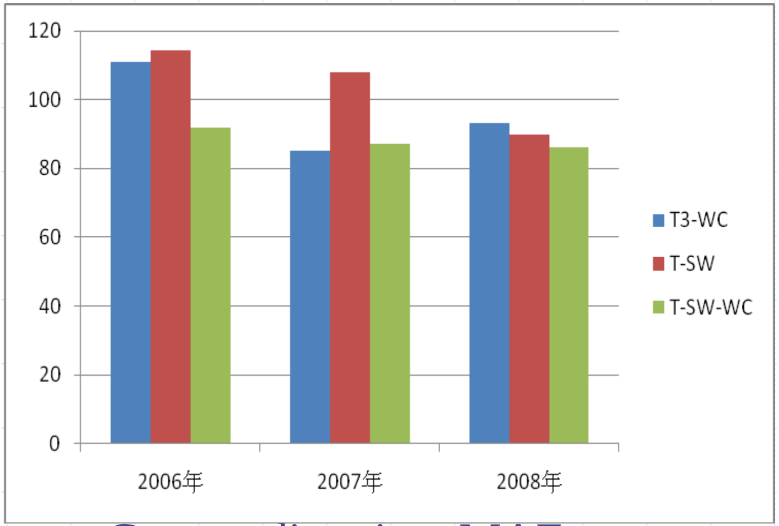
Verification of the model



Current direction BIAS

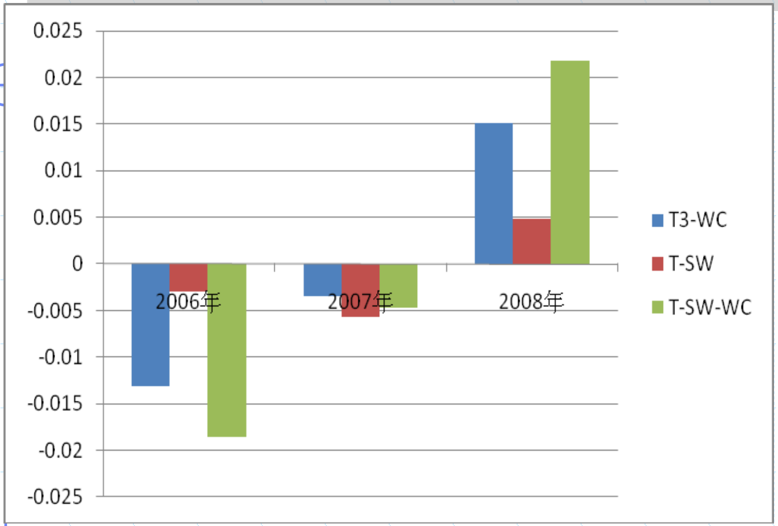


Current direction RMS

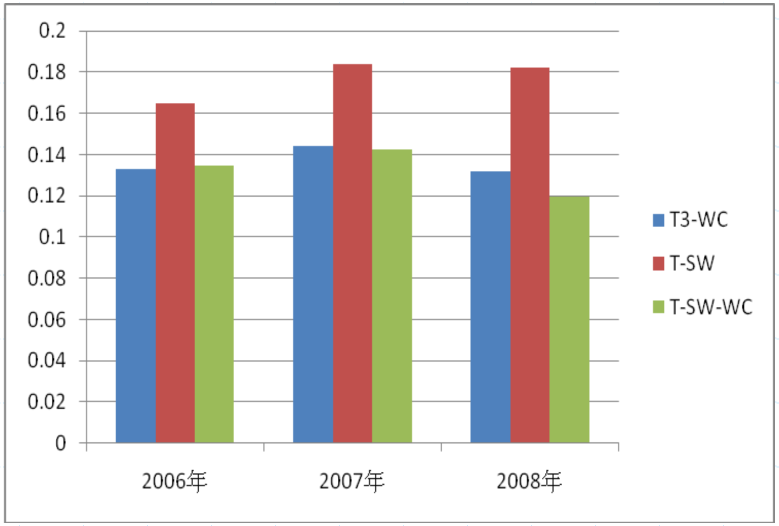


Current direction MAE

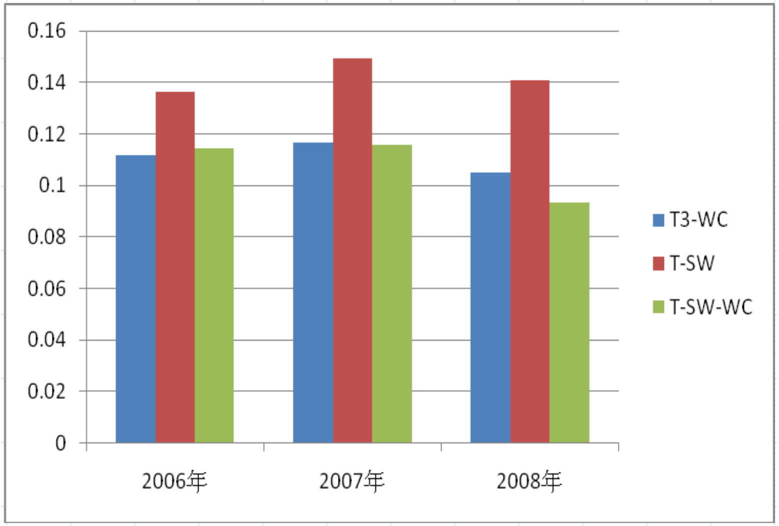
Verification of the model



Water level BIAS

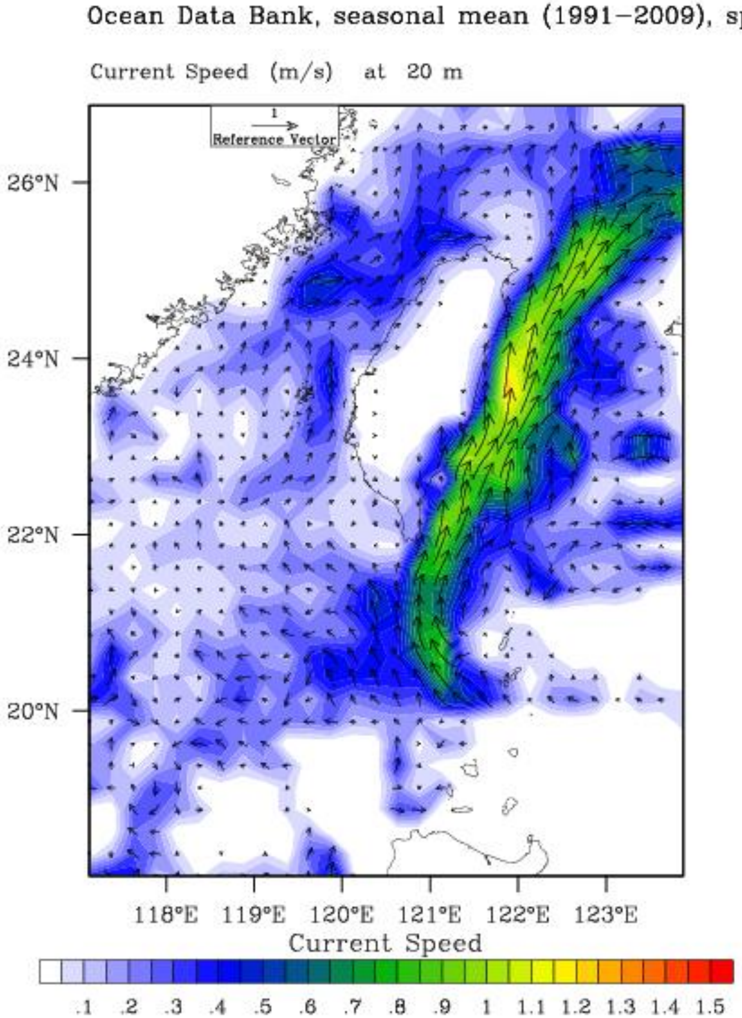


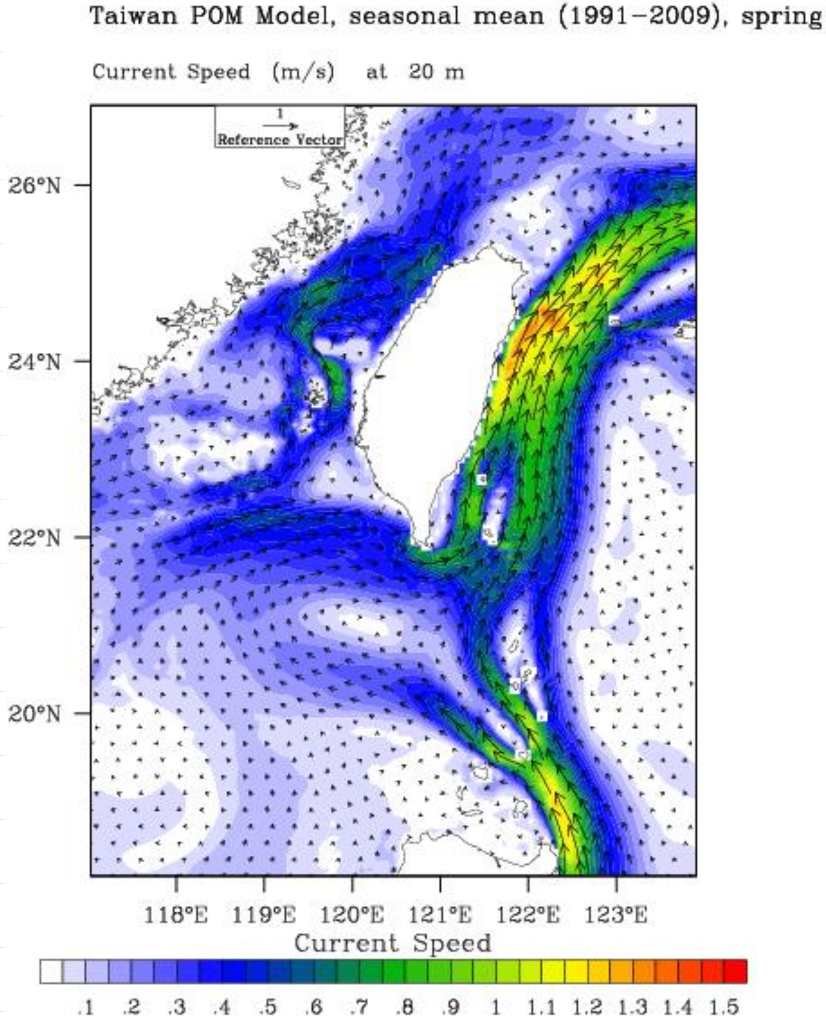
Water level RMS



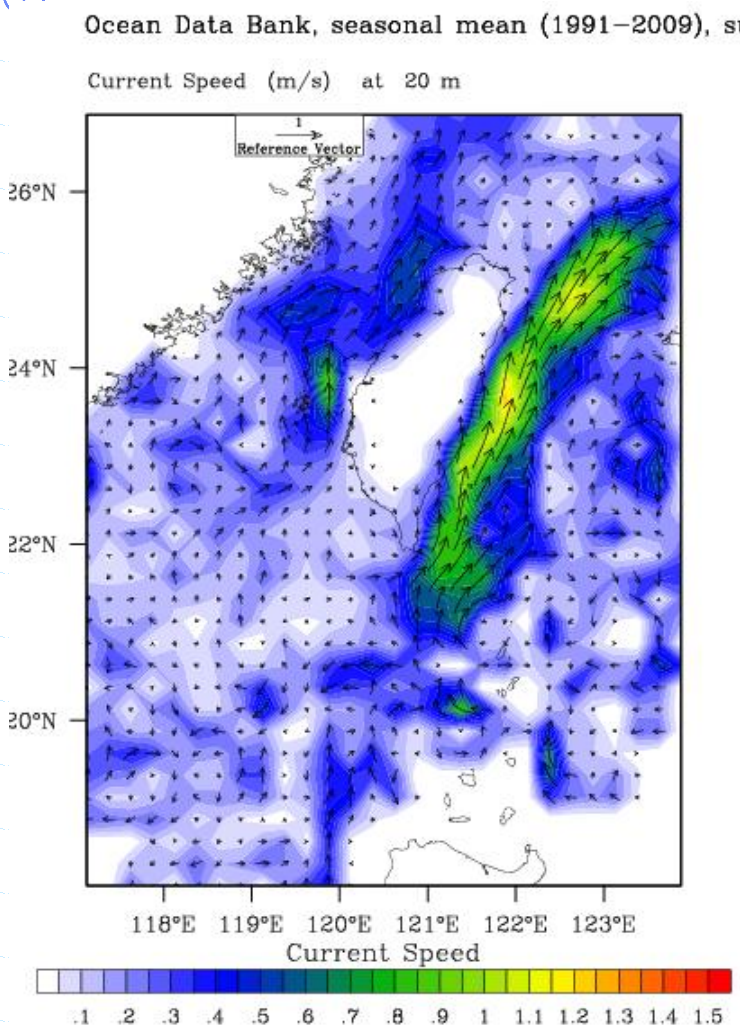
Water level MAE

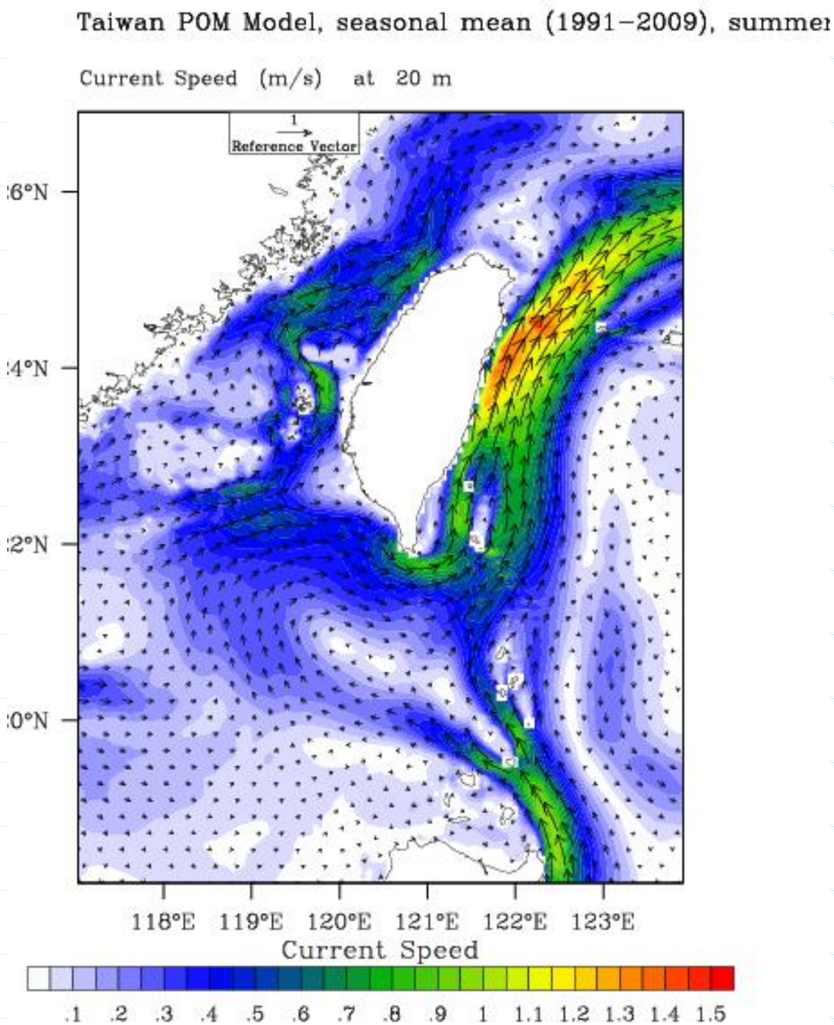
Verification of the model



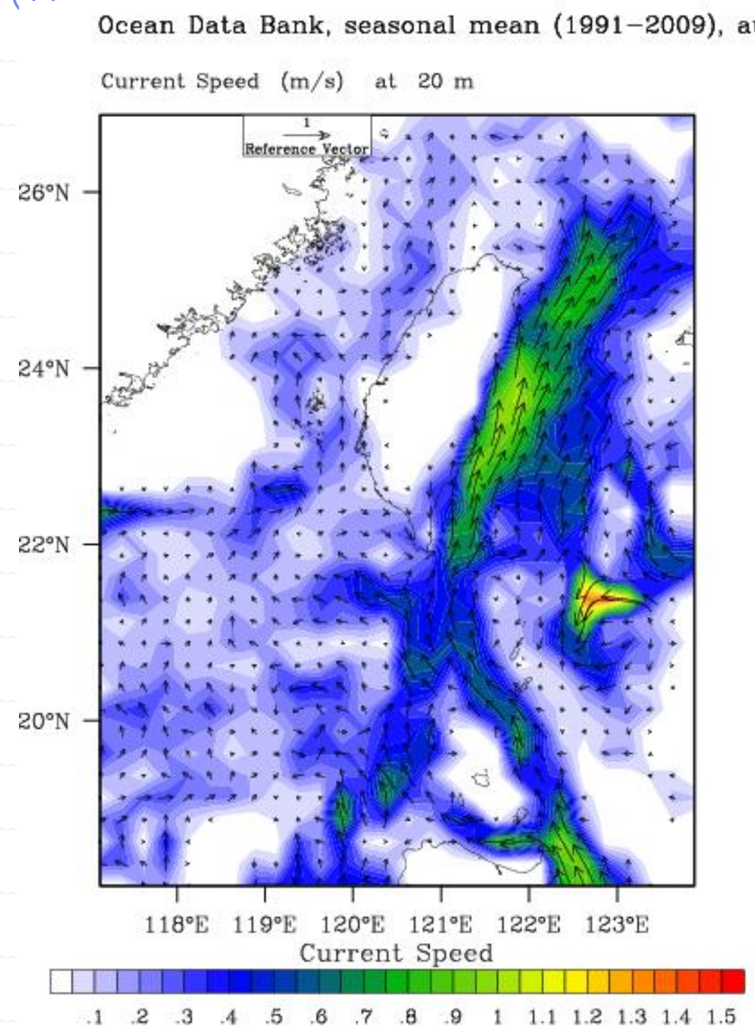


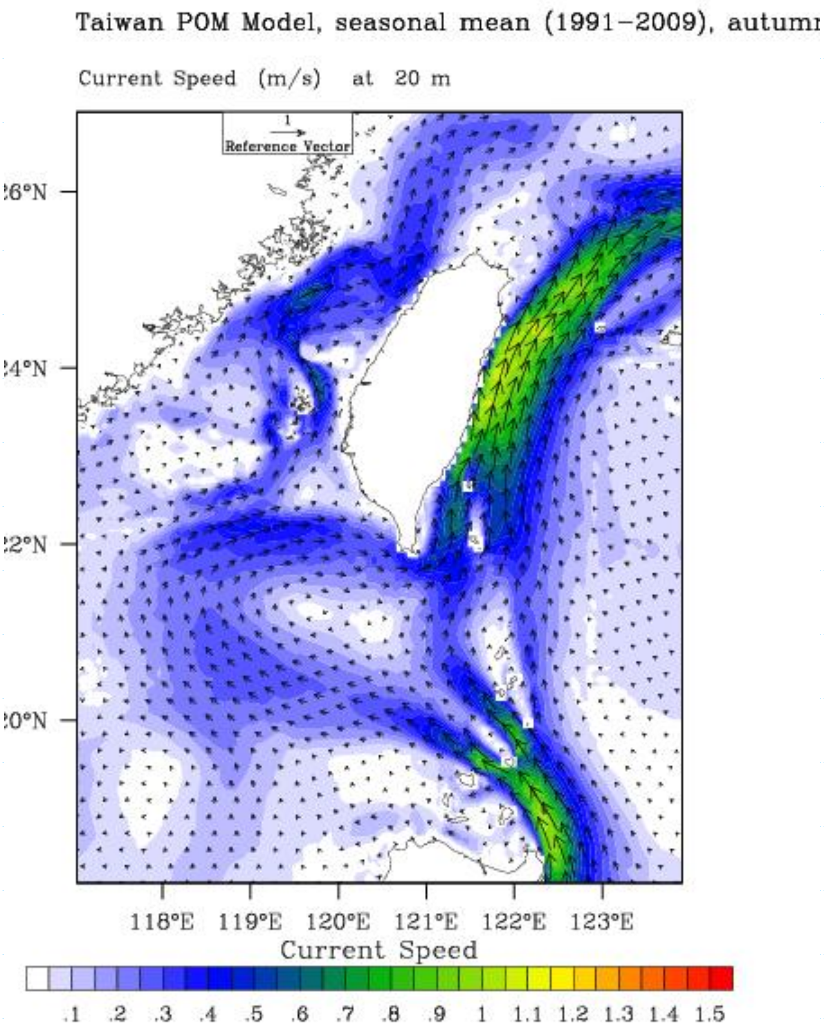
Verification of the model





Verification of the model

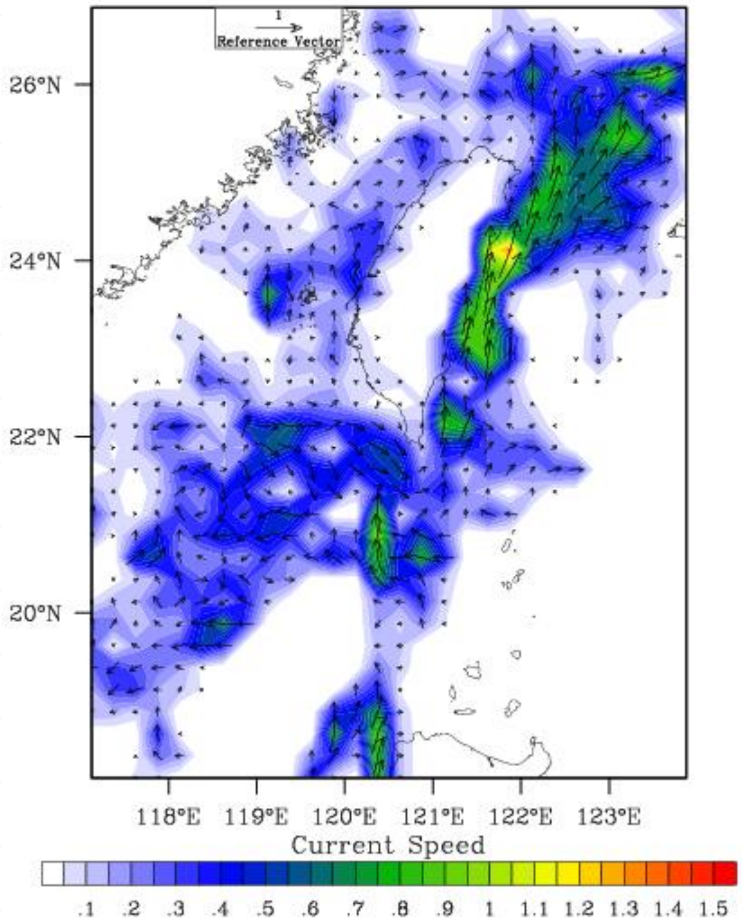




Verification of the model

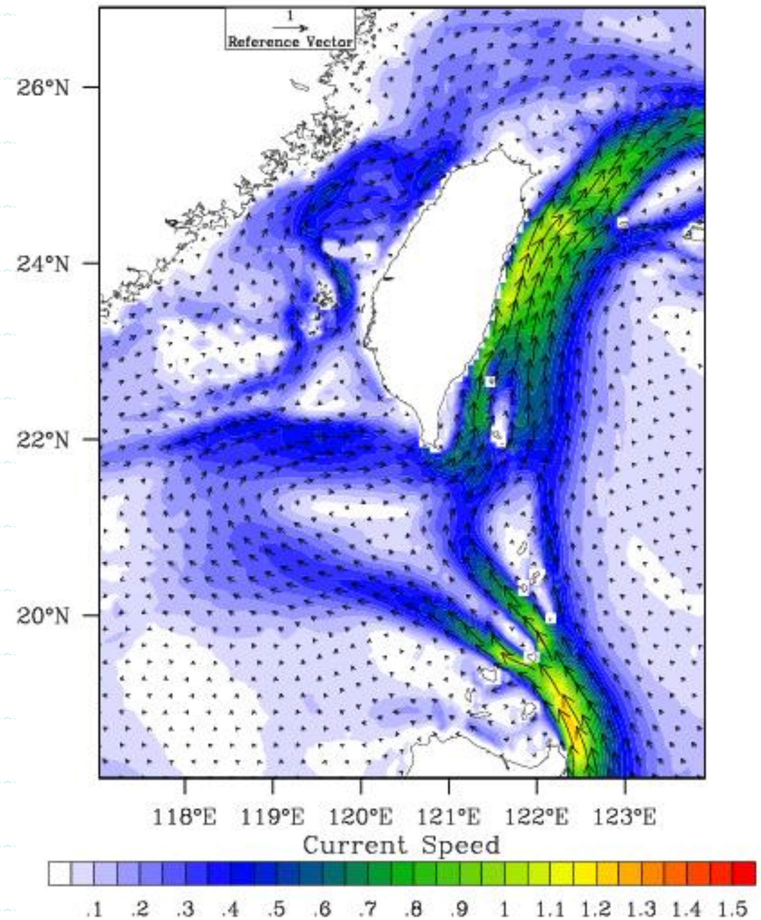
Ocean Data Bank, seasonal mean (1991–2009), winter

Current Speed (m/s) at 20 m



Taiwan POM Model, seasonal mean (1991–2009), winter

Current Speed (m/s) at 20 m



Conclusions

1. A three-dimensional ocean current model around Taiwan is developed by POM (Princeton Ocean Model). In the model, two modes are used, one is external mode and the other one is internal mode. The numerical scheme has the advantage to reduce the time of simulation.

2. The combined effect of tidal and ocean current is included in the present model which will achieve a realistic simulation condition in the ocean. The tidal current boundary is simulated by NAO99b (Matsumoto et al, 2000).

Conclusions

3. The ocean current is simulated using different boundary conditions and grid sizes to achieve a higher resolution in the model. The comparison between the numerical results and measured data is fairly satisfactory.

4. The result of simulation also illustrated the loop current in the southwest waters which is identical to previous investigations.

Thank you for your patience.