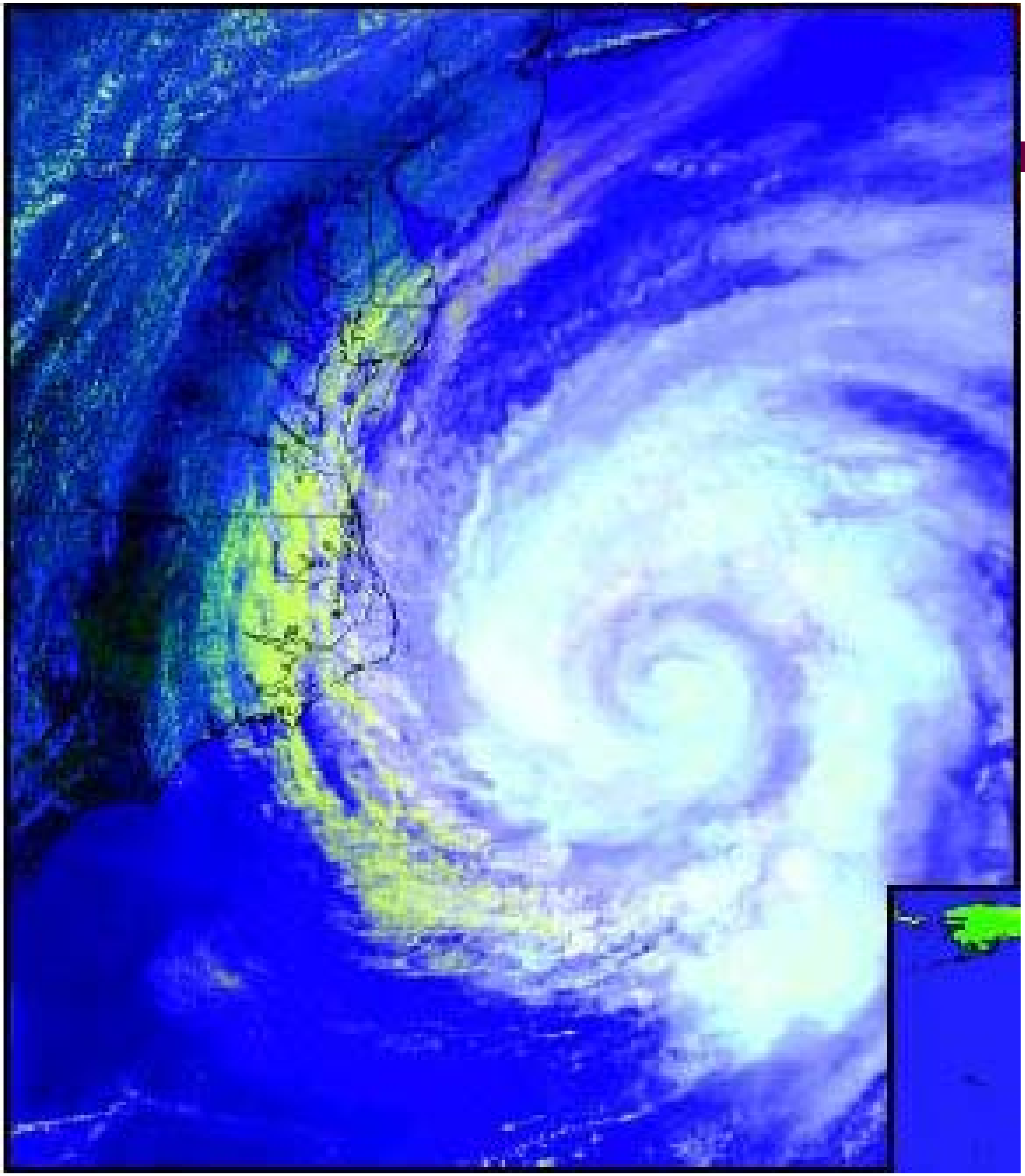
PICES 12th Ann. Meeting
2003.10.10 ~ 18, Seoul

A Sensitivity Analysis of Typhoon Wind Models with Wind Observations in Northeast Asian Sea

See-Whan Kang

Ki-Cheon Jun
Kwang-Soon Park
Sang-Ik Kim

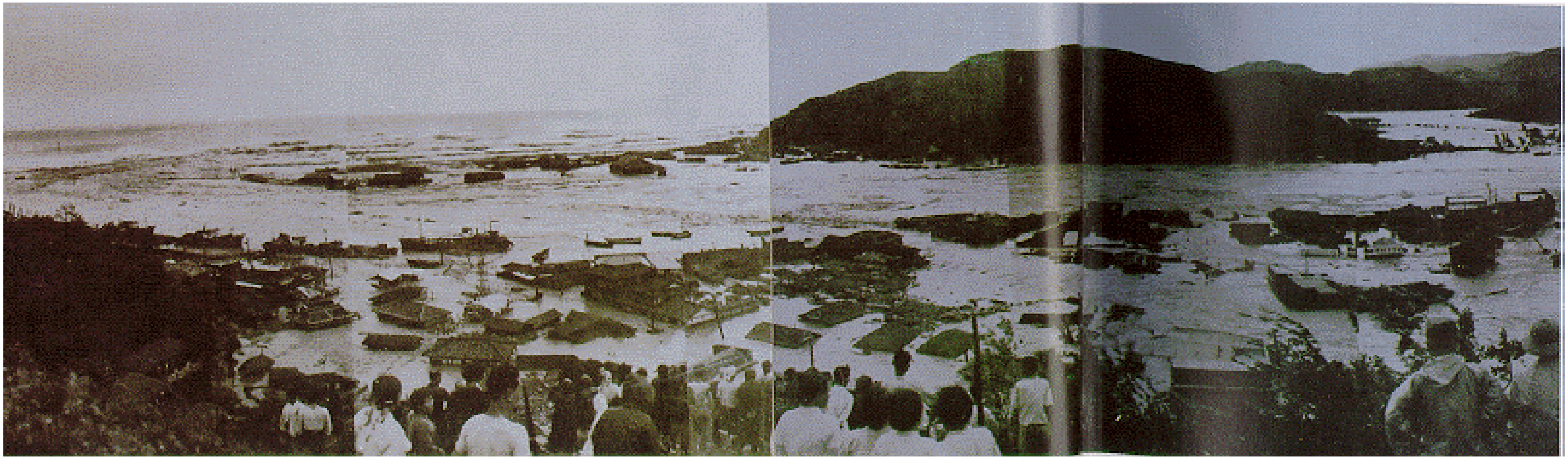
Korea Ocean Research & Development Institute



Visible and infrared composite view of Hurricane Felix, 150 miles Southeast of Cape Hatteras.

Photographed from NOAA-14, using AVHRR visible and infrared data, on August 16, 1995.

태풍해일로 2천톤급의 유조선이 방파제에 충돌하는 사고(1994/부산/김웅배)



태풍”사라”로 인하여 침수된 영덕군 강구면 시가지(59. 9.

해수범람으로 농어촌도로 유실 - 인천 옹진군 (1997. 8. 19 ~ 8. 21)

Typhoon Parametric Model (TPM)

Gradient Wind Relation

$$\frac{U_g^{\,2}}{r} + fU_g = \frac{1}{\rho}\frac{\partial P}{\partial r}$$

$$U_g = -\frac{fr}{2} + \sqrt{\left(\frac{fr}{2}\right)^2 + \frac{r}{\rho}\frac{\partial P}{\partial r}}$$

U_g : gradient wind speed
r : distance from center
f : Coriolis parameter
ρ : air density

Pressure Profile

$$(P - P_0)/(P_\infty - P_0) = Ae^{(-B\frac{r_0}{r})}$$

$$\frac{r}{\rho}\frac{\partial P}{\partial r} = \frac{\Delta P}{\rho}\frac{r_0}{r}e^{-\frac{r_0}{r}}$$

P_0 : central pressure
P_∞ : ambient pressure at infinite radius
A, B : scaling parameters
e: base of natural logarithms
r_0 : radius of maxium wind
ΔP : storm pressure ($= P_\infty - P_0$)

Vectorial Addition of Storm Motion to the Wind Fields

$$\vec{U}_{SM} = \frac{r_0 r \vec{V}_F}{r_0^{\,2} + r^2}$$

$$\vec{U} = \vec{U}_g + \vec{U}_{SM}$$

$\vec{U}$: surface wind speed
$\vec{U}_{SM}$: convective term which is added vectorially to the wind velocity
$\vec{V}_F$: velocity of the storm center

Primitive Vortex Model (PVM)

Momentum Equation

$$\frac{d\vec{V}}{dt} + f\vec{k} \times (\vec{V} - \vec{V}_g) = -\frac{1}{\rho}\vec{\nabla}P_c + \vec{\nabla}\cdot(K_H\vec{\nabla}\vec{V}) - \frac{C_D}{h}\left|\vec{V} + \vec{V}_c\right|(\vec{V} + \vec{V}_c)$$

$$f\vec{k} \times (\vec{V}_g + \vec{V}_c) = -\frac{1}{\rho}\vec{\nabla}\overline{P}$$

$\vec{V}$: horizontal wind speed relative to the center
f : Coriolis parameter
$\vec{k}$: unit vector in the vertical direction
$\vec{V}_g$: effective geostrophic wind relative to the center
ρ : mean air dencity
P_c : pressure field representing the tropical cyclone
K_H : horizontal eddy viscosity coefficient
C_D : drag coefficient
h : depth of PBL
$\vec{V}_c$: velocity of the moving reference system
$\overline{P}$: large-scale pressure field

Primitive Vortex Model (PVM) (continued)

Pressure Profile

$$P = P_c + \overline{P}$$

$$P_{c(r)} = P_0 + \Delta P e^{-r_0/r}$$

P_0: central pressure

ΔP: storm pressure ($= P_\infty - P_0$)

e: base of natural logarithms

r_0: radius of maxium wind

Horizontal Eddy Viscosity Coefficient

$$K_H = 2\kappa^2 \left(\frac{\Delta x}{2} \right)^2 \left[\left(\frac{\partial u}{\partial x} - \frac{\partial v}{\partial y} \right)^2 + \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right)^2 \right]^{1/2}$$

κ: von Karman's constant ($= 0.4$)

Δx: grid point spacing

Drag Coefficient

$$C_D = \frac{\kappa^2}{(\ln \hat{z}_0 + A_m)^2 + B_m^{\ 2}}$$

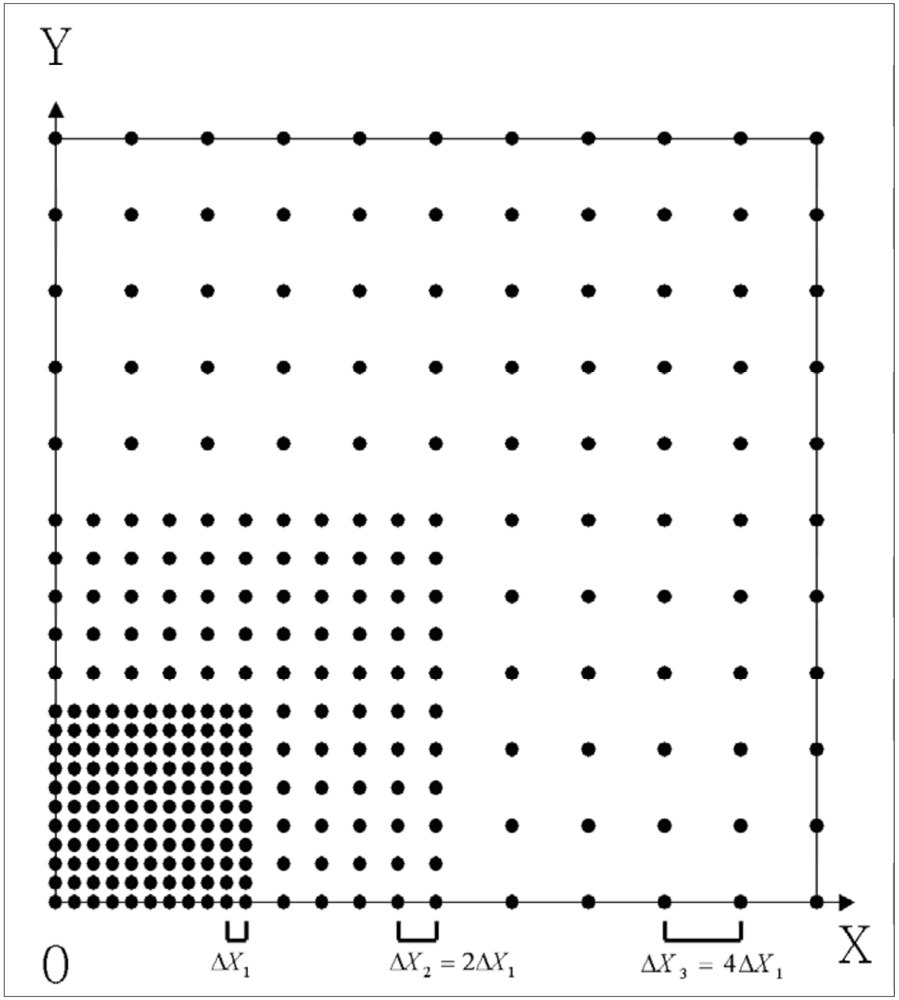
$\hat{z}_0$: normalized roughness length ($= z_0/h$)

z_0: roughness lengh

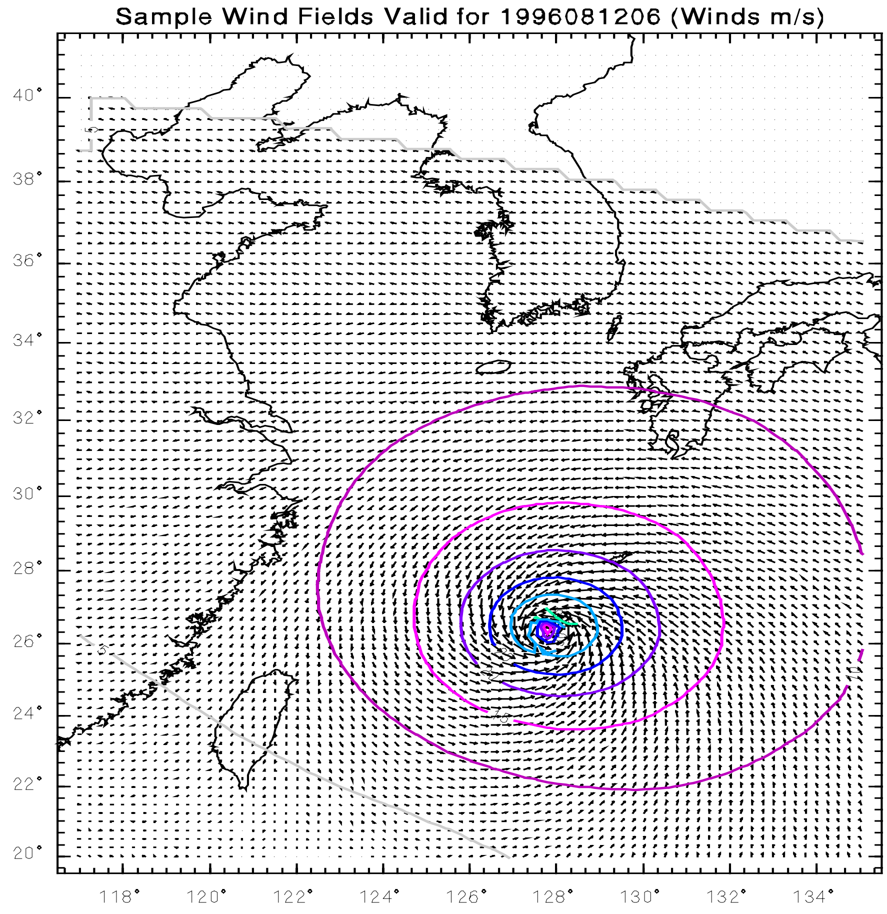
h: depth of PBL

A_m, B_m: universal functions of dimensionless similarity parameters

Nested Moving Grid System for PVM Simulation



Surface Wind Fields by PVM

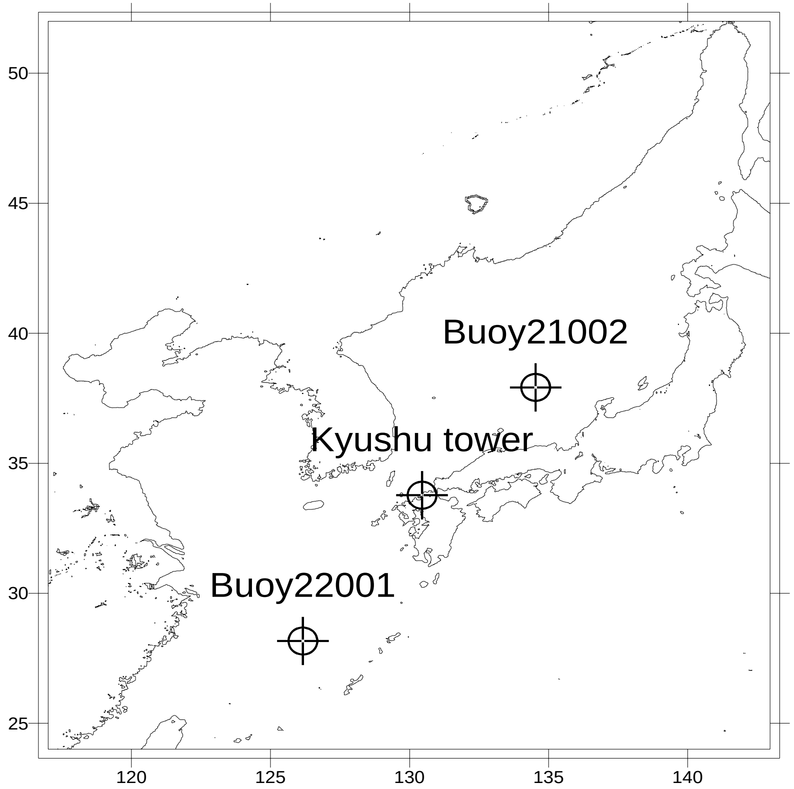


(06 Z, Aug.12, 1996)

Typhoons for Wind Model Simulations

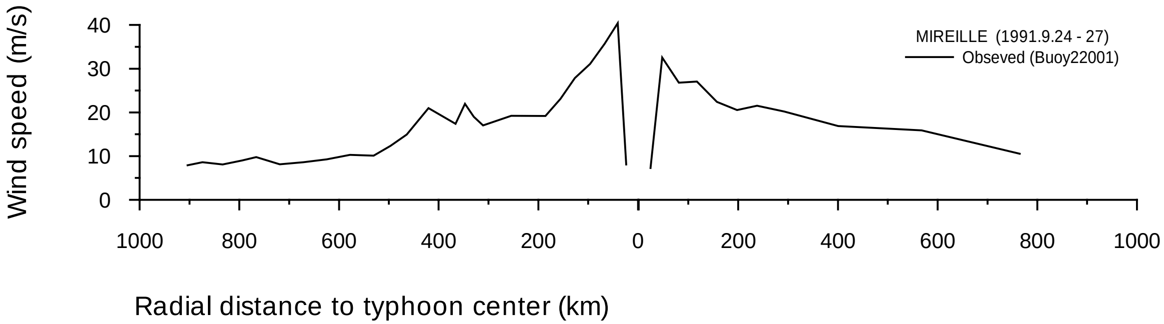
Year	Name
79	Irving, Judy
80	Ellen, Ida, Orchid, Wynne
81	Ike, June, Ogden, Agnes, Clara
82	Cecil, Ellis
83	Forrest
84	Ed, Gerald
85	Hal, Jeff, Kit, Lee, Mamie, Odessa, Pat, Brenda
86	Nancy, Vera, Abby
87	Thelma, Alex, Dinah, Kelly
89	Judy, Vera
90	Robyn, Zola, Abe
91	Caitlin, Gladys, Kinna, Mireille
92	Irving, Janis, Polly, Ted
93	Percy, Robyn, Yancy
94	Walt, Brendan, Doug, Ellie, Orchid, Seth
95	Faye, Janis
96	Kirk,
97	Peter, Tina, Winnie
98	Yanni
99	Neil, Olga, Paul, Ann

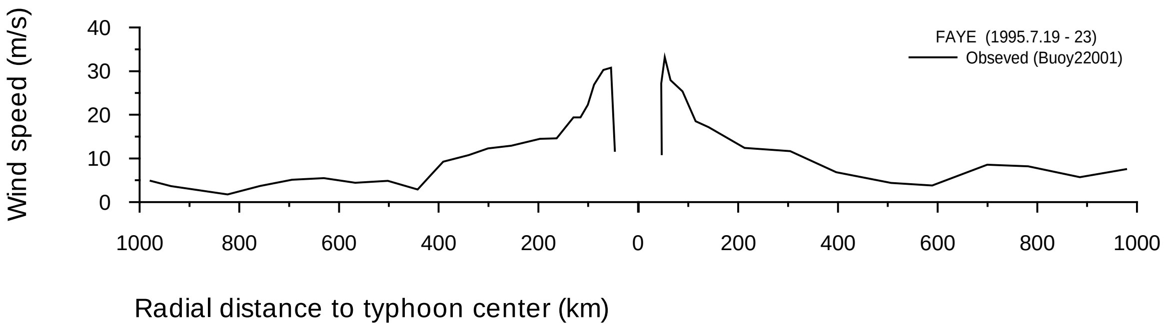
Locations of the JMA Ocean Buoys and the Kyushu Ocean Tower

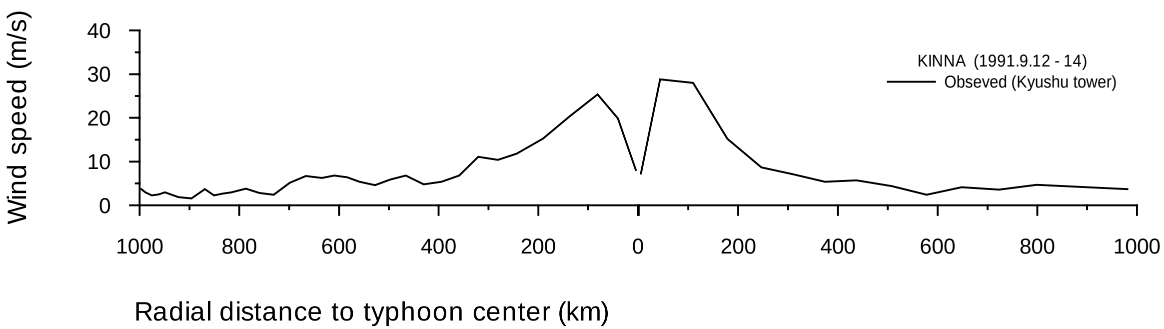


Name	Location	Height of anemometer
Ocean buoy 21002	37.92°N, 134.53°E (East Sea)	8.5m
Kyushu ocean tower	33.77°N, 130.45°E (Kyushu)	17m
Ocean buoy 22001	28.17°N, 26.17°E (East China Sea)	8.5m

Observed Typhoon Wind Profiles

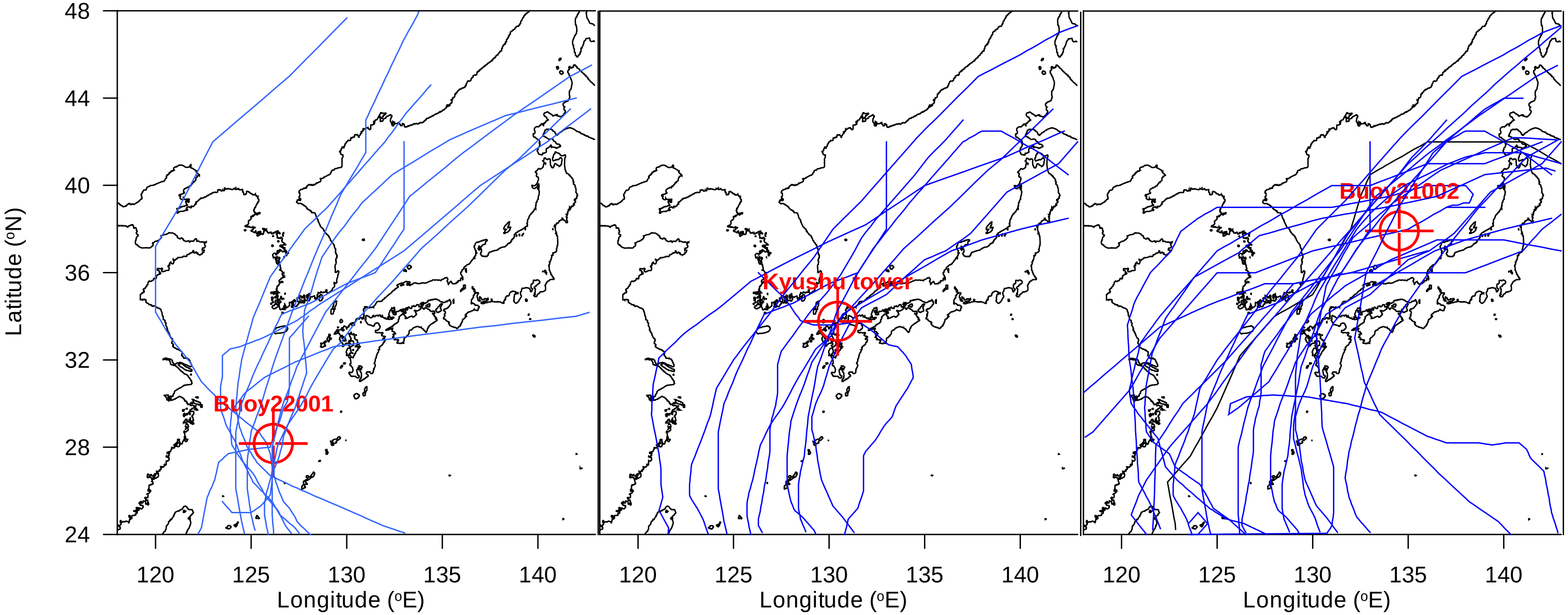




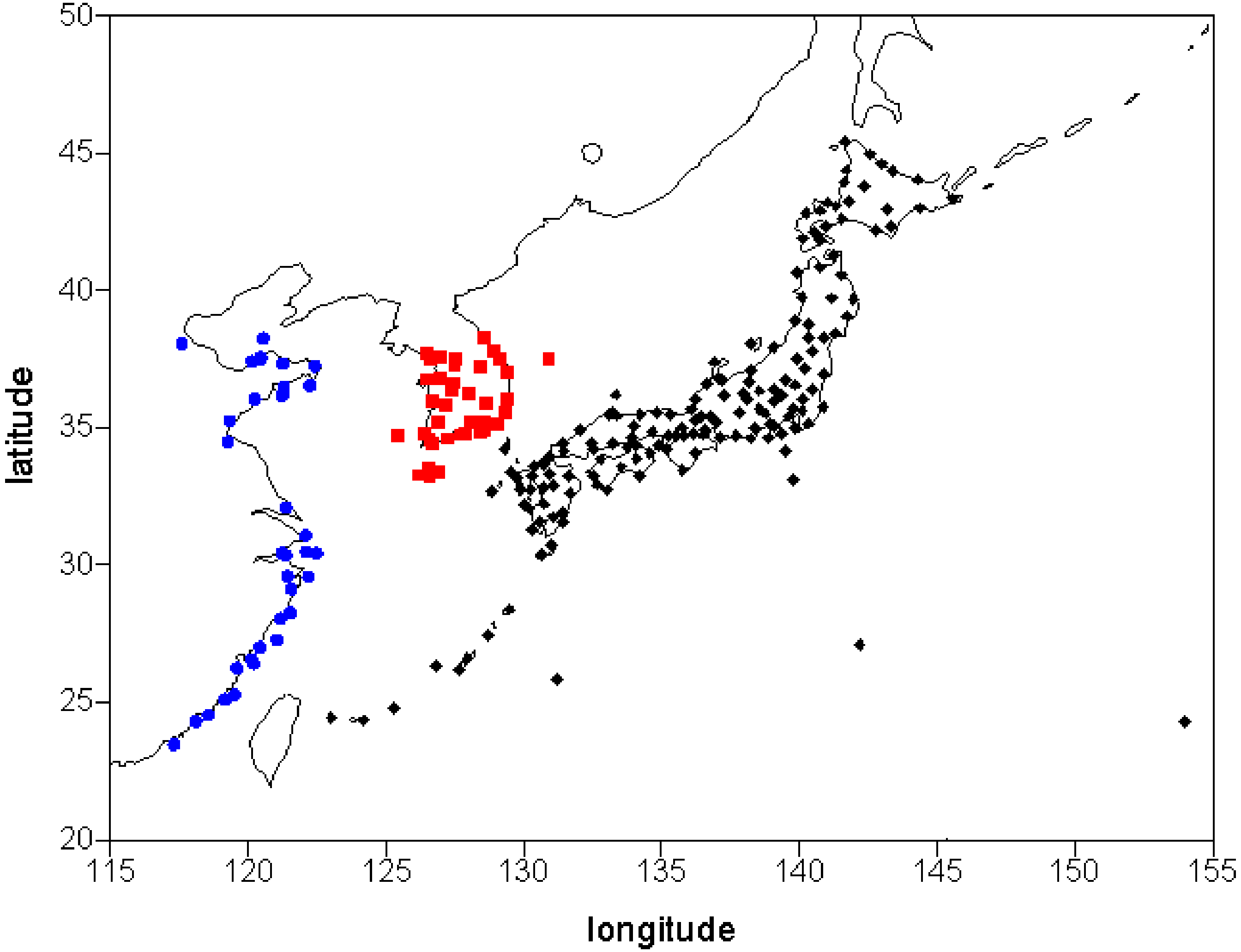


KORDI

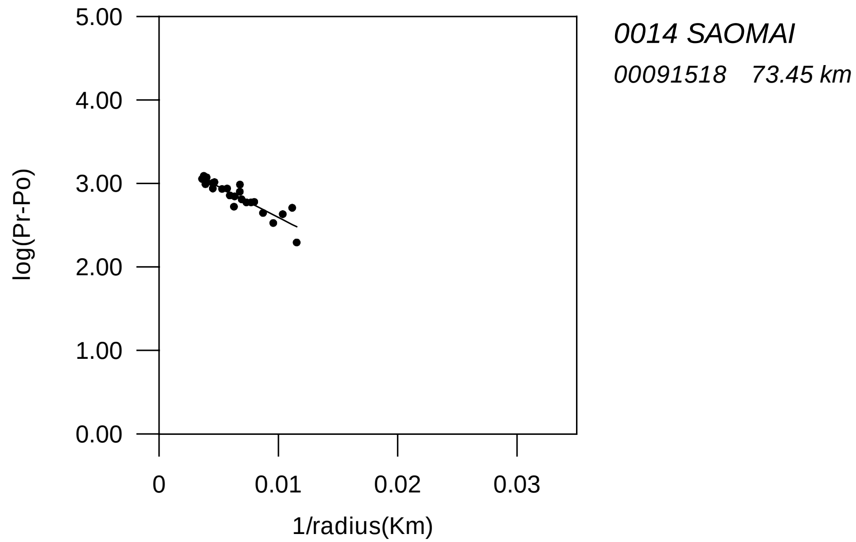
Typhoon Tracks for Wind Model Simulation

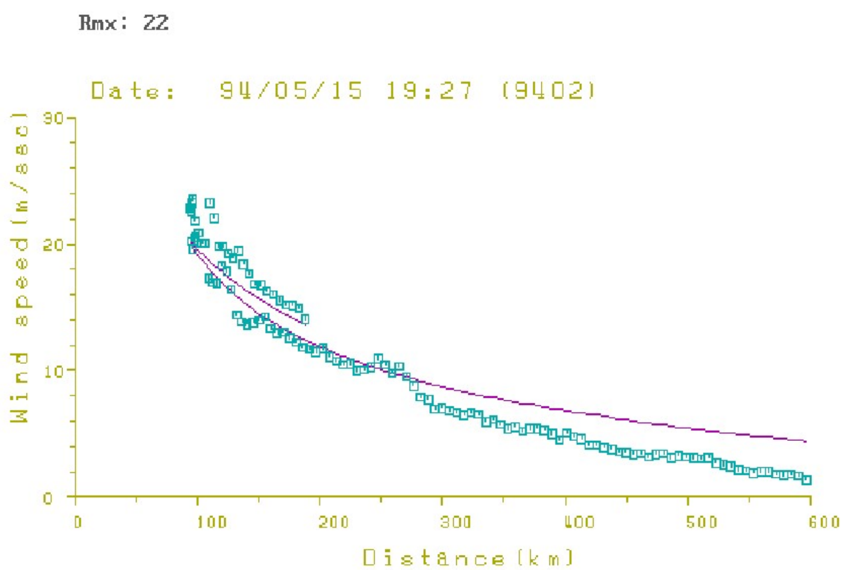


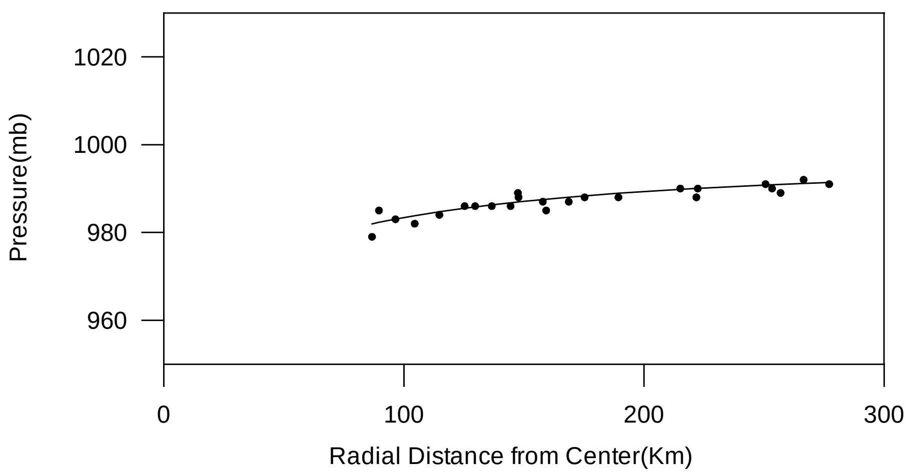
Location of Meteorological Stations



RMW Analysis from Observed Pressure Data of Typhoon Saomai(2000)





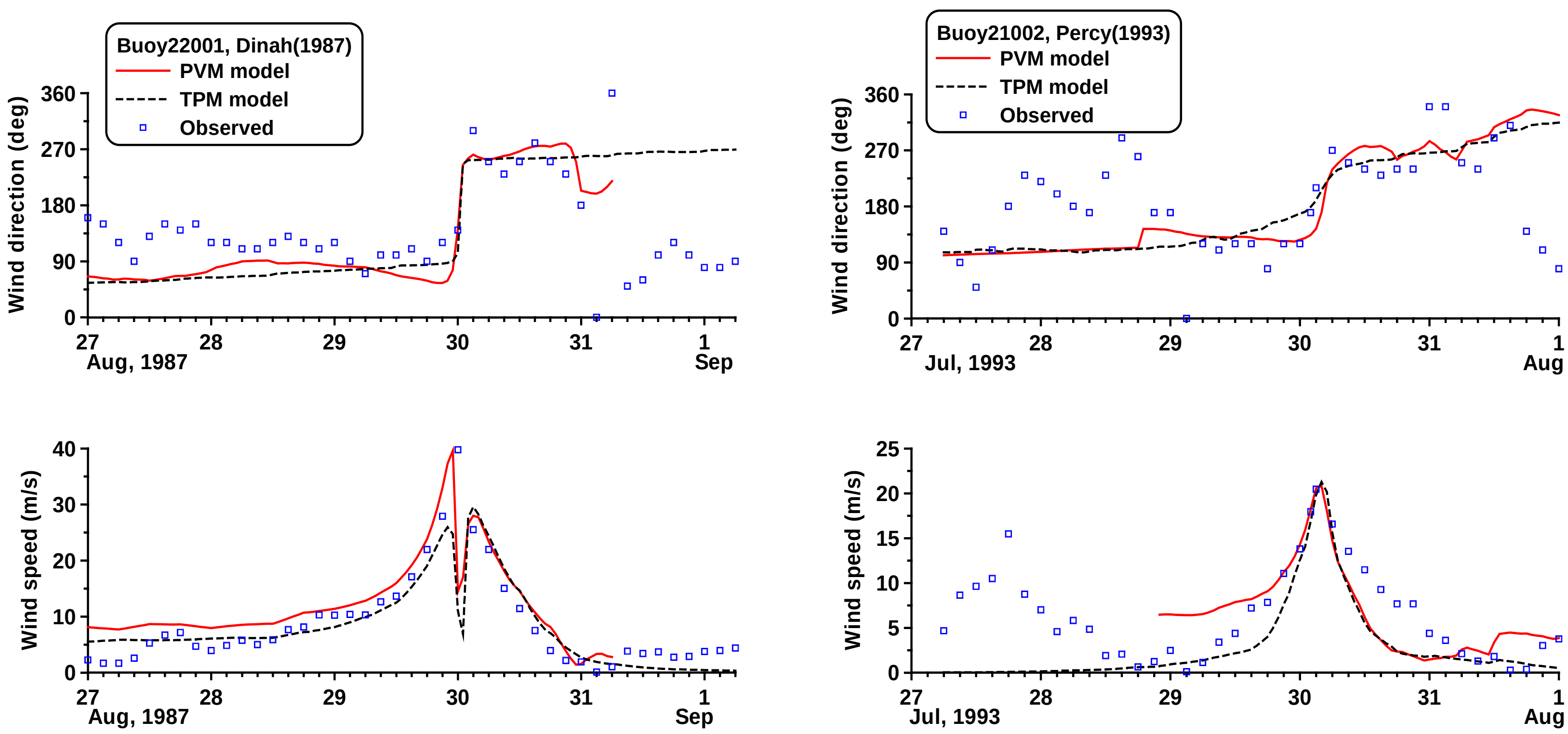


Comparison of PVM winds with TOPEX satellite data(dashed: TOPEX, solid:PVM)

Typhoon Faye Parameters Analyzed from U.S. Air Force Data

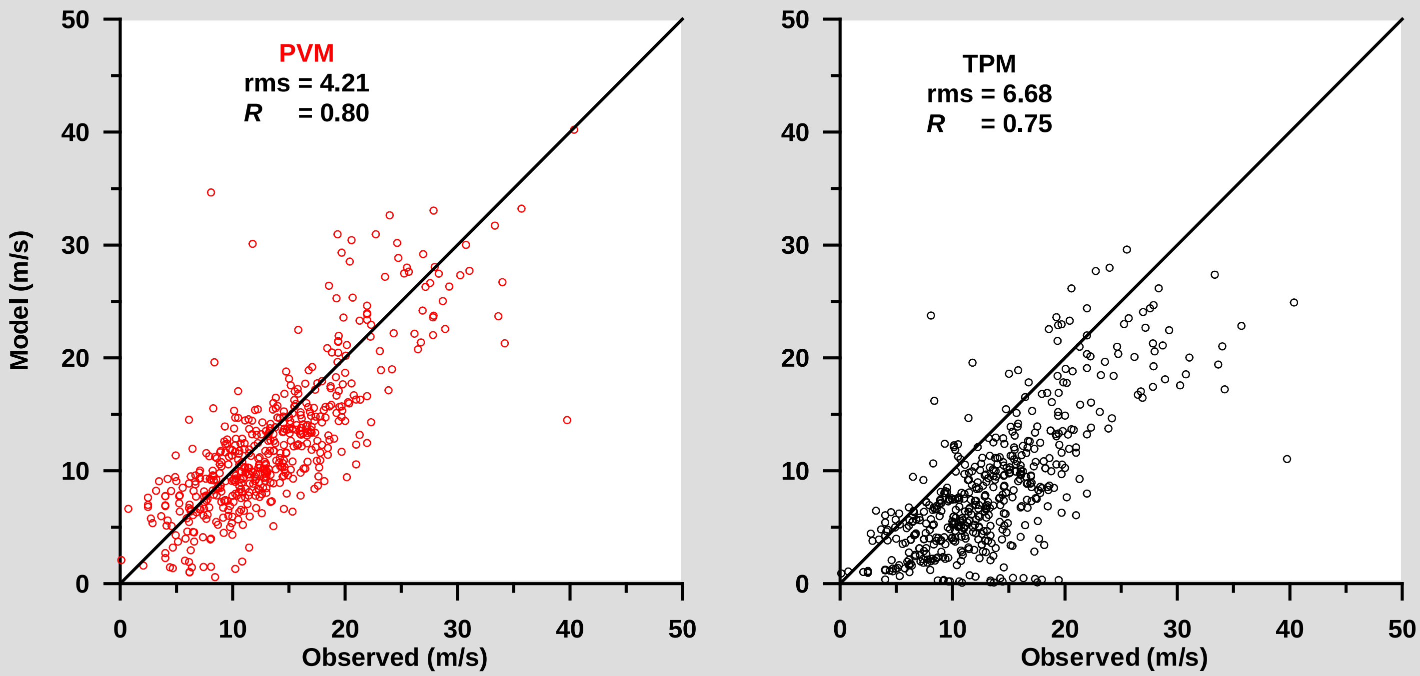
Typhoon Name	Date (GMT)	Pc (mb)	Rmax (km)	Pa (mb)
Faye (9503)	95071806	986	59.2	1012
	95071906	975	51.2	1012
	95072006	975	43.2	1012
	95072012	968	38.4	1012
	95072112	940	33.6	1011
	95072200	938	32.0	1010
	95072212	938	32.0	1010
	95072306	950	27.2	1010
	95072400	993	40.0	1010
	95072506	1004	56.0	1010

Comparisons of Model Winds with JMA Ocean Buoy Data



Comparison of Model Hindcast and Observed Winds

Buoy22001



rms : root mean square error

$$= \sqrt{\frac{\sum (V_m - V_o)^2}{n}}$$

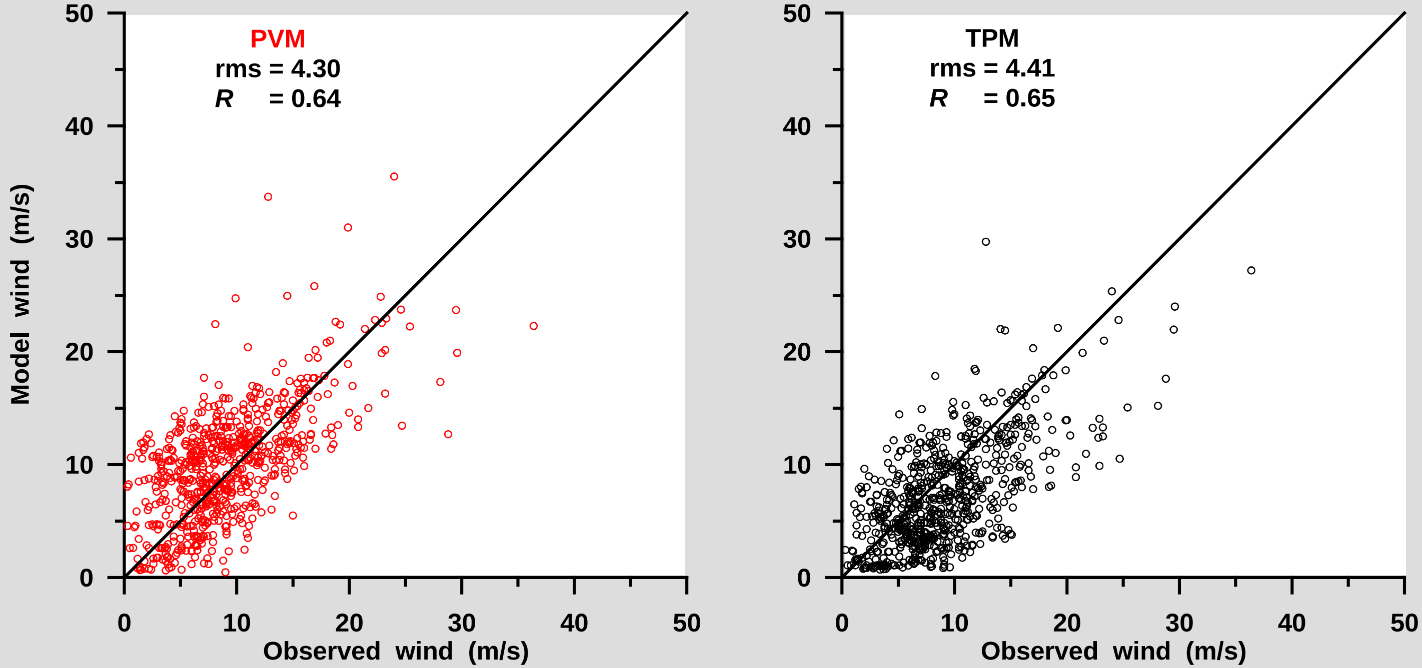
R **: coefficient of correlation**

$$= \frac{1}{n-1} \sum \left(\frac{V_o - \bar{V}_o}{\sigma_o} \right) \cdot \left(\frac{V_m - \bar{V}_m}{\sigma_m} \right)$$

V : wind speed
σ : standard deviation
m : model
o : observation
n : number of sample

Comparison of Model Hindcast and Observed Winds

Kyushu tower



rms : root mean square error

$$= \sqrt{\frac{\sum (V_m - V_o)^2}{n}}$$

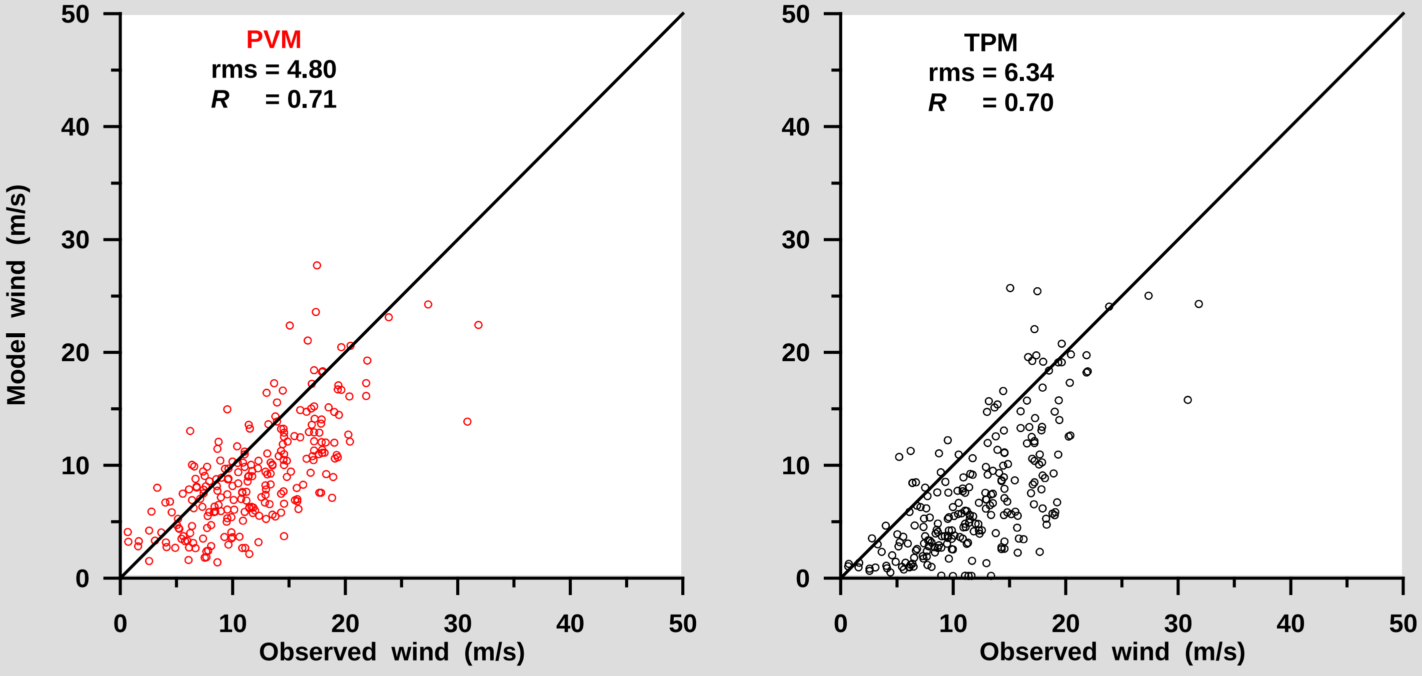
***R* : coefficient of correlation**

$$= \frac{1}{n-1} \sum \left(\frac{V_o - \bar{V}_o}{\sigma_o} \right) \cdot \left(\frac{V_m - \bar{V}_m}{\sigma_m} \right)$$

V : wind speed
σ : standard deviation
m : model
o : observation
n : number of sample

Comparison of Model Hindcast and Observed Winds

Buoy21002



rms : root mean square error

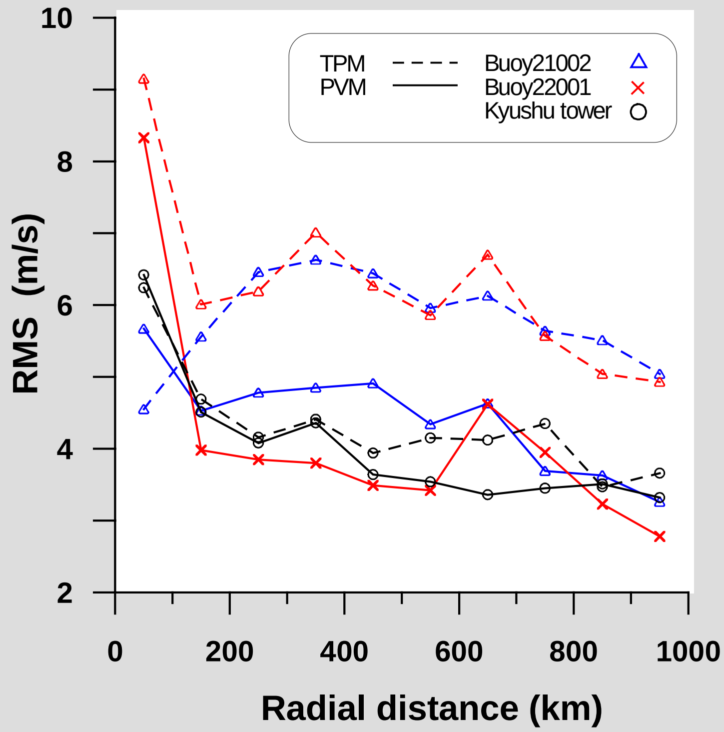
$$= \sqrt{\frac{\sum (V_m - V_o)^2}{n}}$$

R **: coefficient of correlation**

$$= \frac{1}{n-1} \sum \left(\frac{V_o - \bar{V}_o}{\sigma_o} \right) \cdot \left(\frac{V_m - \bar{V}_m}{\sigma_m} \right)$$

V : wind speed
σ : standard deviation
m : model
o : observation
n : number of sample

RMS Errors of Wind Speed with the Radial Distance

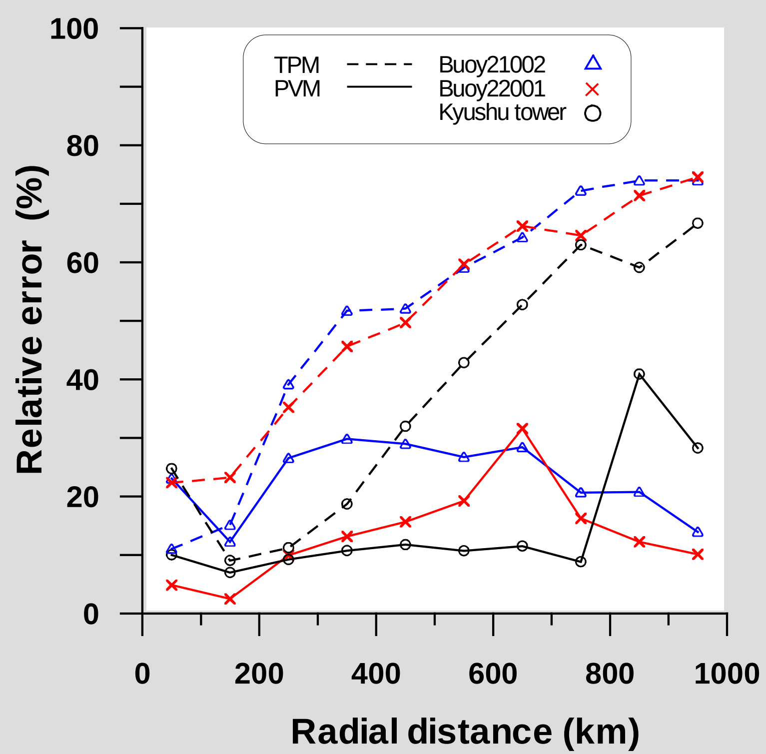


RMS : Root mean square error

$$= \sqrt{\frac{\sum (V_m - V_o)^2}{n}}$$

V : wind speed
m : model
o : observation
n : number of sample

Relative Errors of Wind Speed with the Radial Distance



Relative error

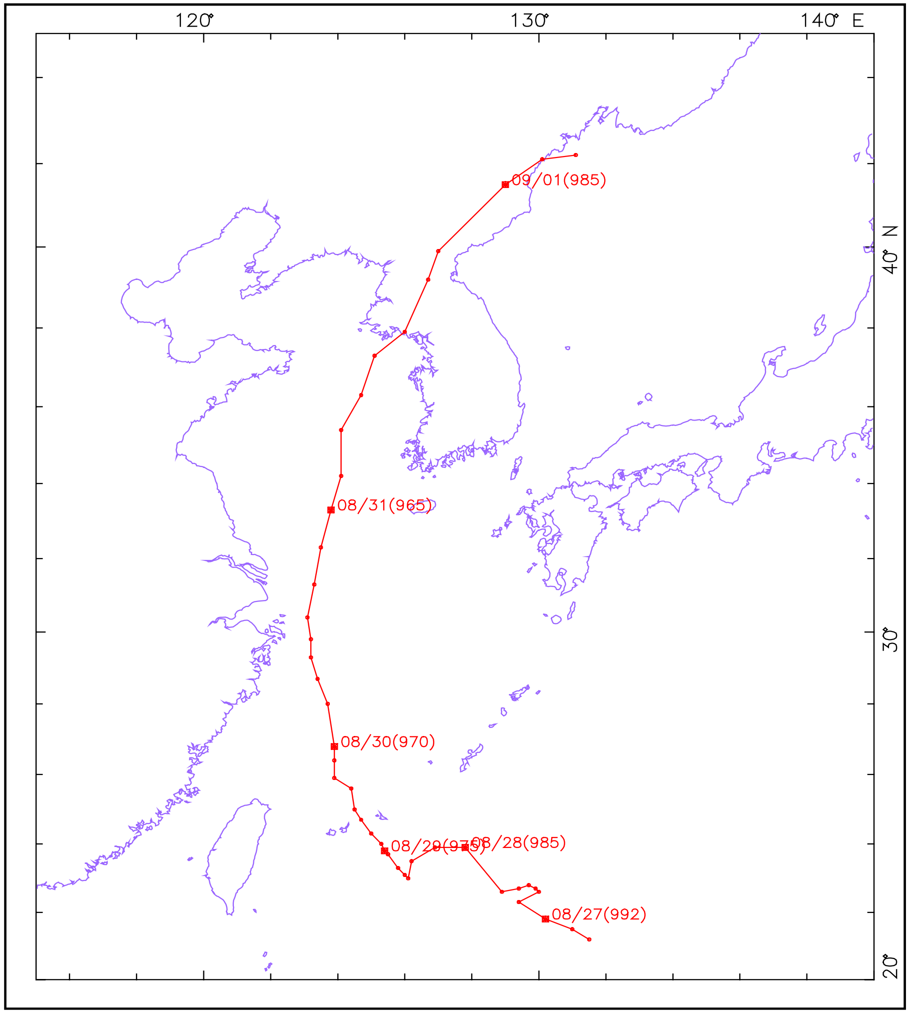
$$= \frac{\left|\overline{V}_m - \overline{V}_o\right|}{\overline{V}_o} \times 100$$

$\overline{V}$: running mean of wind speed
m : model
o : observation
n : number of sample

Error Analysis for Molel Hindcast winds

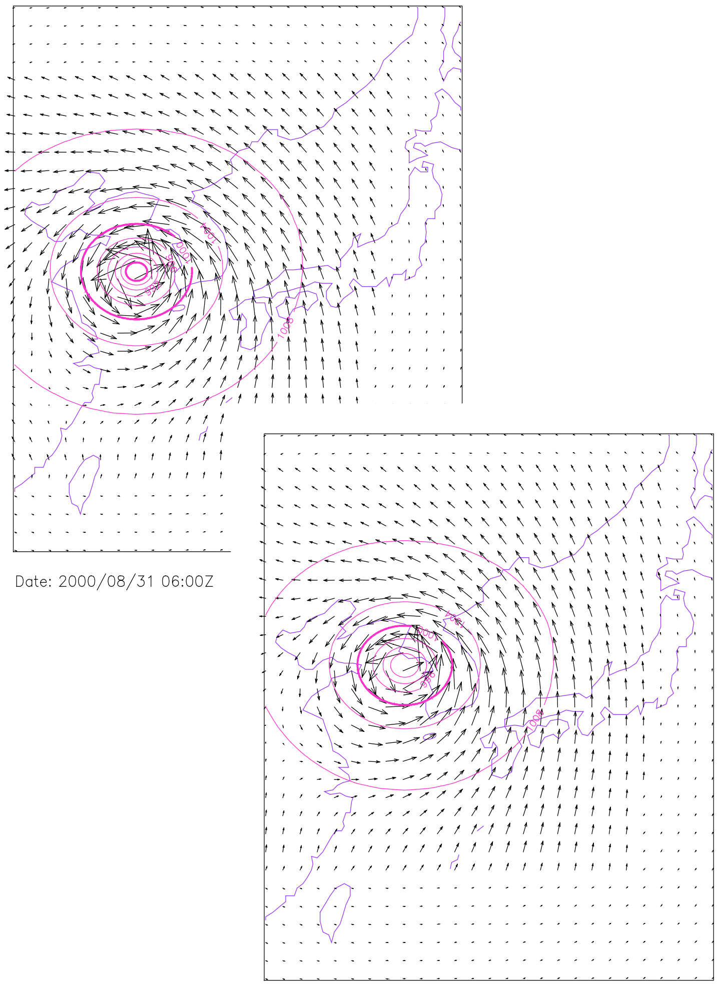
Station	Range (unit: 100km)	Observed Mean speed (m/s)	PVM				TPM			
			Mean speed	Abs. error	*R*	RMS	Mean speed	Abs. error	*R*	RMS
Buoy 22001 (East China Sea)	0～1	21.65	22.70	1.05	**5**	8.33	16.81	-4.84	**22**	9.15
	1～2	18.88	18.41	-0.47	3	3.98	14.49	-4.40	23	6.01
	2～3	14.19	12.78	-1.41	10	3.85	9.19	-5.00	35	6.19
	3～4	12.32	10.70	-1.62	13	3.8	6.70	-5.62	46	7.01
	4～5	9.96	8.40	-1.55	16	3.49	5.01	-4.95	50	6.27
	5～6	8.21	6.63	-1.58	20	3.42	3.31	-4.90	60	5.86
	6～7	8.07	5.52	-2.55	32	4.62	2.73	-5.34	66	6.70
	7～8	6.46	5.41	-1.04	16	3.95	2.29	-4.17	65	5.57
	8～9	5.80	5.09	-0.71	12	3.23	1.66	-4.14	71	5.04
	9～10	5.54	4.98	-0.56	**10**	2.78	1.41	-4.13	**75**	4.93
Kyushu Tower	0～1	11.48	12.63	1.15	10	6.42	8.64	-2.84	25	6.24
	1～2	12.59	13.47	0.88	7	4.51	11.45	-1.13	9	4.69
	2～3	10.42	11.38	0.96	9	4.08	9.25	-1.17	11	4.16
	3～4	8.29	9.18	0.90	11	4.36	6.74	-1.55	19	4.41
	4～5	7.32	8.18	0.86	12	3.64	4.98	-2.34	32	3.94
	5～6	6.63	7.34	0.71	11	3.54	3.79	-2.84	43	4.15
	6～7	5.99	6.68	0.69	12	3.36	2.83	-3.16	53	4.12
	7～8	5.32	5.79	0.47	9	3.45	1.97	-3.35	63	4.35
	8～9	4.01	5.65	1.65	41	3.51	1.64	-2.36	60	3.47
	9～10	4.14	5.31	1.17	28	3.32	1.38	-2.76	67	3.66
Buoy 21002 (East Sea)	0～1	17.36	21.36	3.99	23	5.67	19.28	1.91	11	4.55
	1～2	14.94	13.11	-1.82	12	4.53	12.68	-2.26	15	5.56
	2～3	12.77	9.38	-3.40	27	4.78	7.77	-5.00	39	6.46
	3～4	10.73	7.53	-3.20	30	4.85	5.18	-5.55	51	6.63
	4～5	10.77	7.65	-3.12	29	4.91	5.16	-5.61	52	6.44
	5～6	8.66	6.38	-2.27	27	4.34	3.52	-5.08	60	5.96
	6～7	8.31	6.00	-2.31	29	4.63	2.93	-5.27	64	6.13
	7～8	7.18	5.76	-1.41	21	3.69	1.96	-5.10	72	5.64
	8～9	6.48	5.22	-1.26	21	3.63	1.68	-4.77	74	5.51
	9～10	5.96	5.13	-0.83	14	3.26	1.53	-4.35	74	5.04

Track of Typhoon Prapiroon(2000)



Hindcast Wind Fields of Typhoon Prapiron(2000)

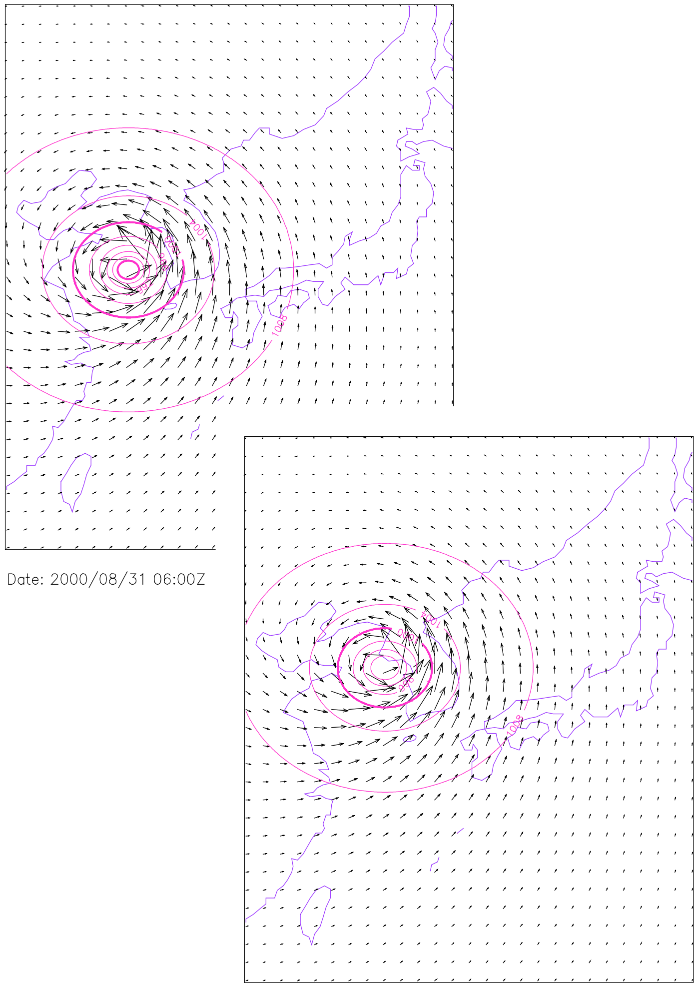
PVM



Date: 2000/08/31 06:00Z

Date: 2000/08/31 12:00Z

TPM

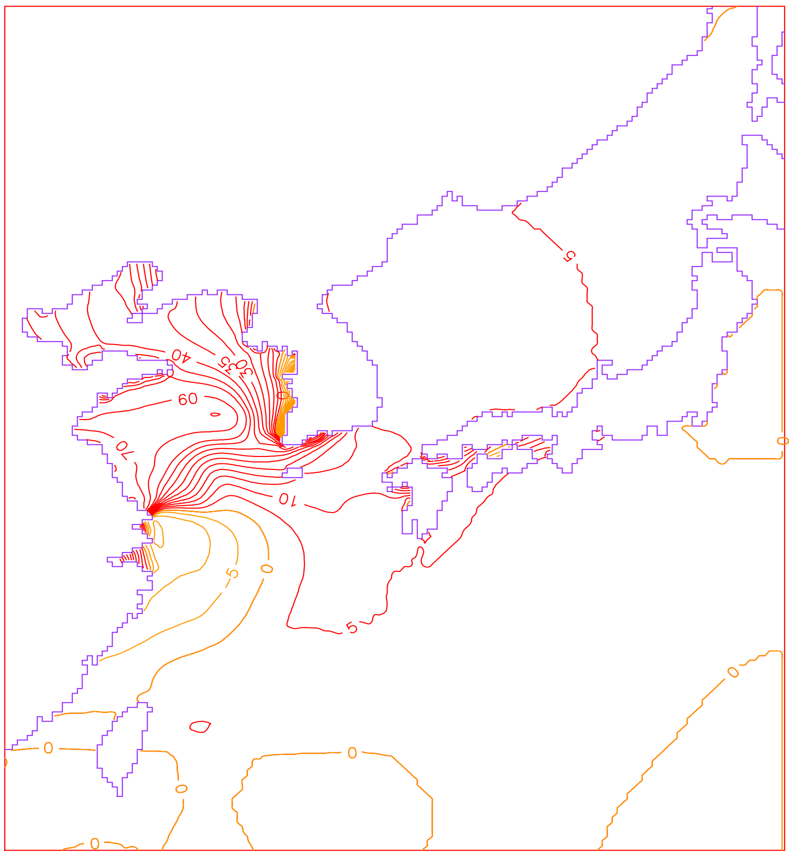


Date: 2000/08/31 06:00Z

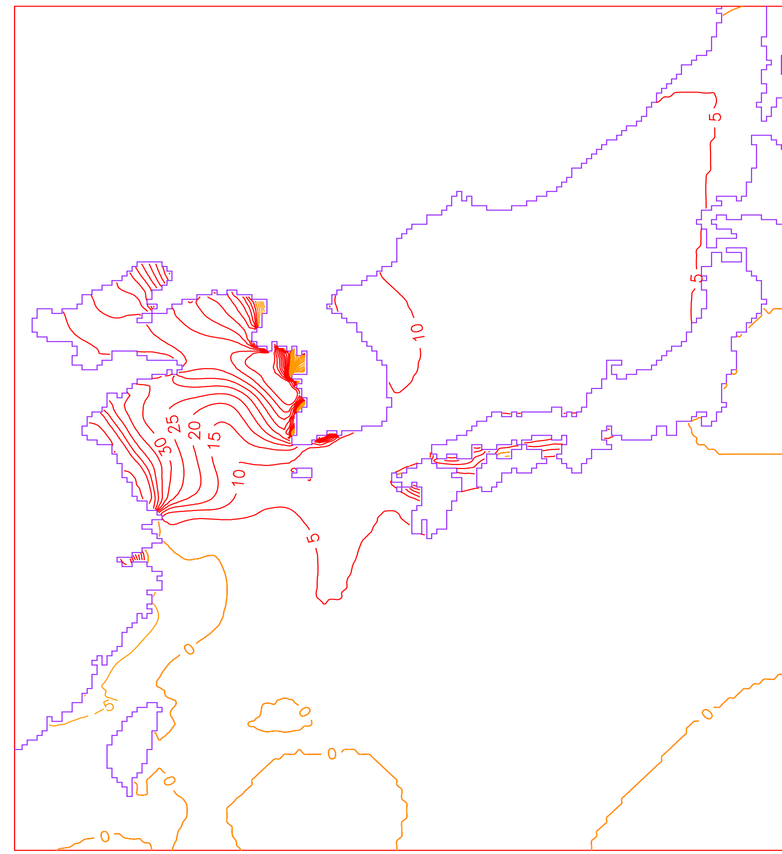
Date: 2000/08/31 12:00Z

KORDI

Storm Surges Computed by PVM Hindcast Winds



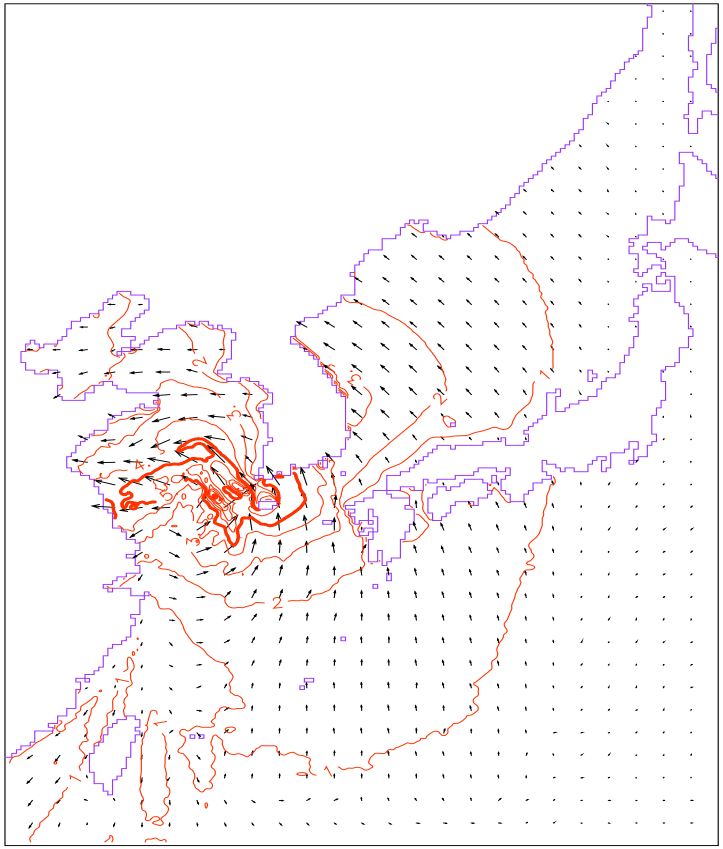
Date: 2000/08/31 06:00



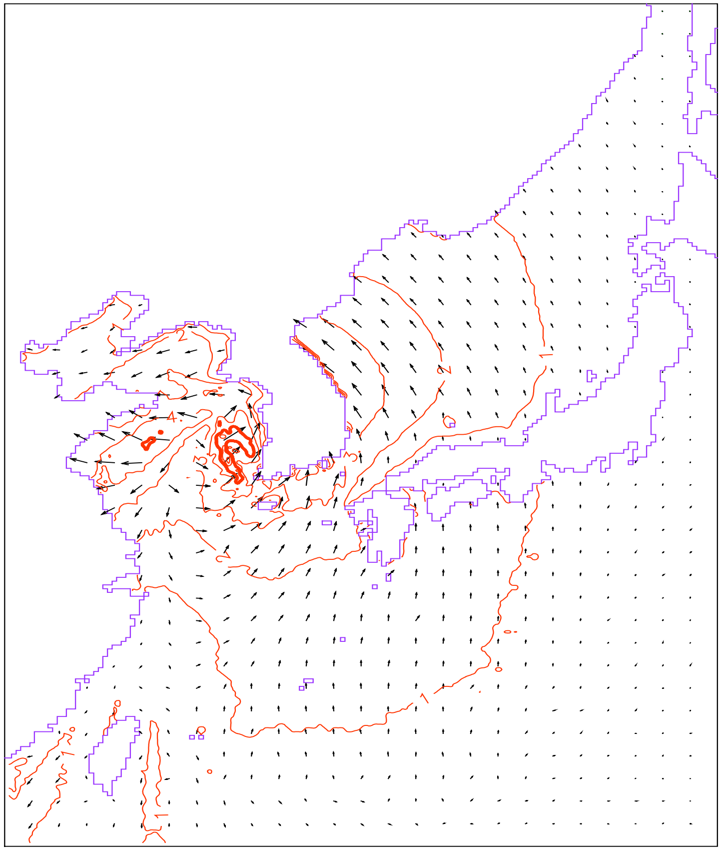
Date: 2000/08/31 12:00

KORDI

Wind Waves Computed by PVM Hindcast Winds



Date: 2000/08/31 06:00Z



Date: 2000/08/31 12:00Z

Discussion and Conclusion

■ The sea-surface winds during the passages of 64 typhoons for 1979-1999 were simulated using two different typhoon wind models, ie, typhoon parametric model(TPM) and primitive vortex model(PVM). The model hindcast winds were compared with the winds observed at JMA ocean buoys(22001 and 21002) and Kyushu ocean observation tower.

■ Both hindcast winds of TPM and PVM underestimate the observed typhoon winds, but PVM winds are more closer to the observations with less rms and relative errors.

Ave. rms error in wind speed : TPM ~ 6 m/sec
PVM ~ 4 m/sec

Discussion and Conclusion

■Relative errors(Er) of two model winds were relatively small within 200km from typhoon center :

- JMA Buoy 22001 (East China Sea)

  For $r \leq 200$ km : TPM's Er ~ 23%

  PVM's Er ~ 5%

- JMA Buoy 21002 (East Sea / Japan Sea)

  For $r \leq 200$ km : TPM's & PVM's Er ~ 15%

  For $r > 200$ km : TPM's Er > 50%

  PVM's Er < 30%

- Kyushu Tower

  For $r \leq 200$ km : TPM's and PVM's Er ~ 10%

  For $r > 200$ km : TPM's Er > 30%

  PVM's Er ~ 10%

Discussion and Conclusion

- TPM's relative errors increase up to 70% as the radial distance(r) from typhoon center increases r > 200km
- PVM's relative errors remain in 20% with less sensitive to the radial distance from typhoon center

■ PVM produces more accurately the sea-surface wind during typhoons than TPM, especially in the region of radial distance from typhoon center beyond > 200 km