Predictability of Japan / East Sea (JES) System to Uncertain Initial / Lateral Boundary Conditions and Surface Winds

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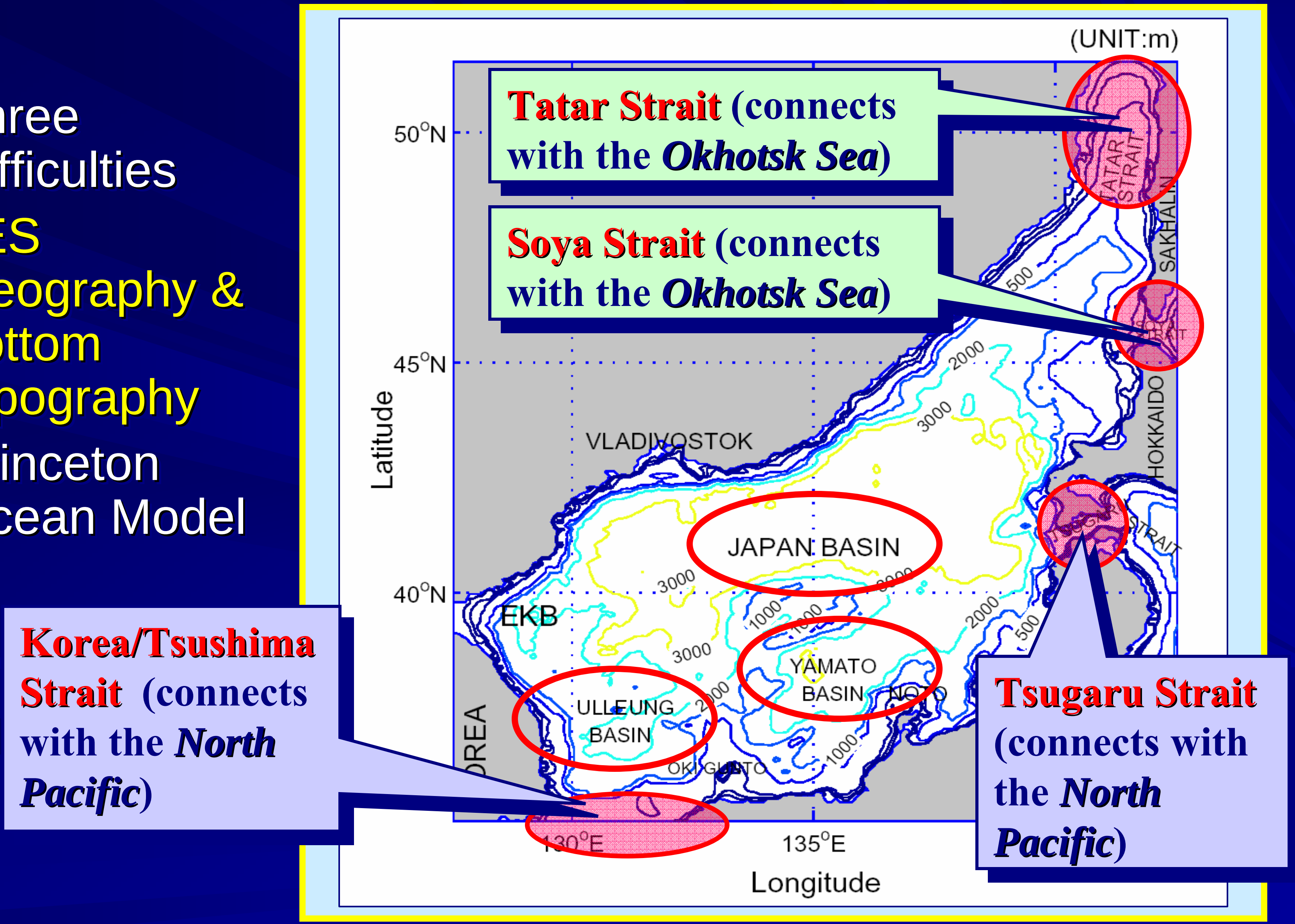
Outline

- Introduction
- Experimental design
- Statistical analysis methods
- Results
- Conclusions

Introduction

- Three Difficulties
- JES Geography & bottom topography
- Princeton Ocean Model



Introduction

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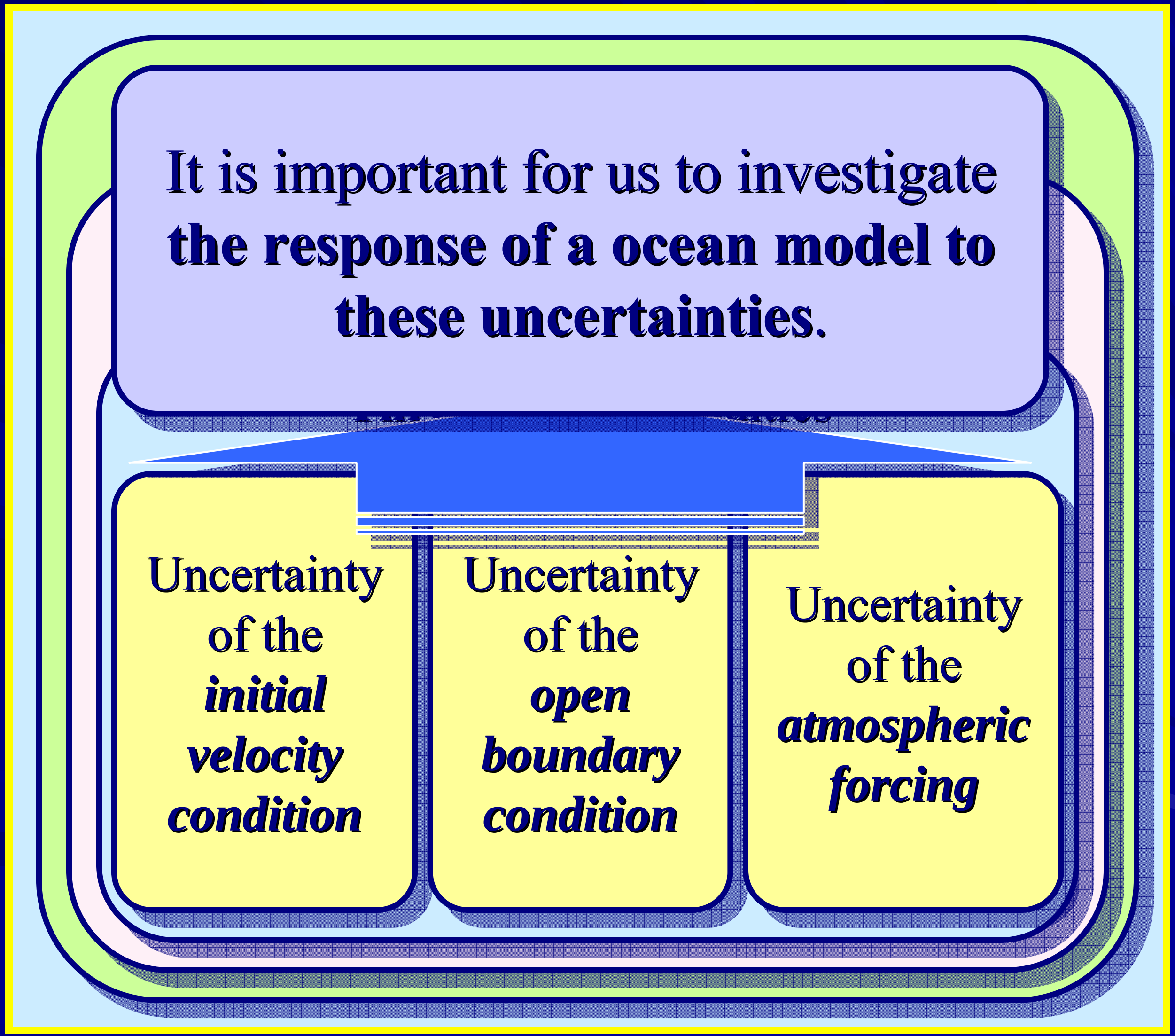
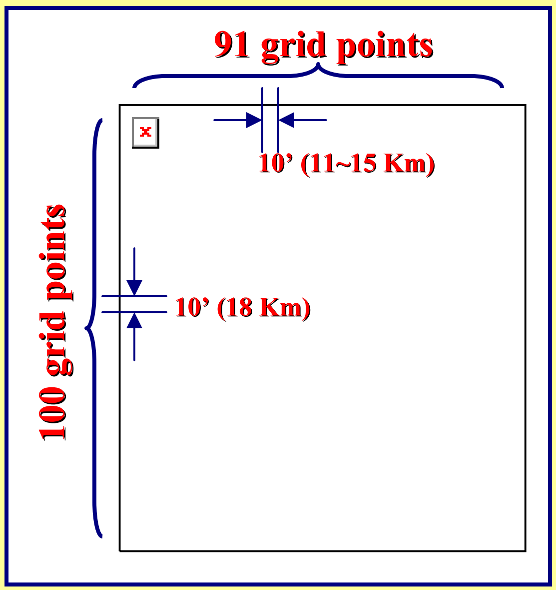
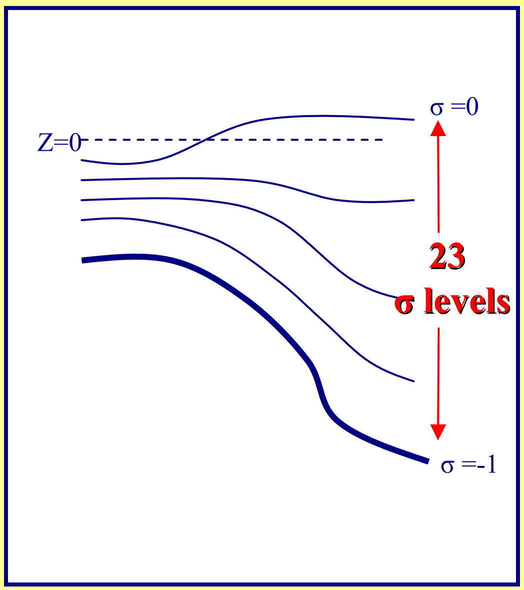


Introduction

- Three Difficulties
- JES Geography & bottom topography
- Princeton Ocean Model
  - General information
  - Surface & lateral boundary forcing
  - Two step initialization

POM : a time-dependent, primitive equation model rendered on a three-dimensional grid that includes realistic topography and a free surface.





Introduction

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- **Wind stress at each time step is interpolated from monthly mean climatological wind stress from COADS (1945-1989).**

- **Volume transports at open boundaries are specified from historical data.**

Month	*Feb*	*Apr*	*Jun.*	*Aug*	*Oct*	*Dec*
Tatar strait (*inflow*)	0.05	0.05	0.05	0.05	0.05	0.05
Soya strait (*outflow*)	-0.1	-0.1	-0.4	-0.6	-0.7	-0.4
Tsugaru strait (*outflow*)	-0.25	-0.35	-0.85	-1.45	-1.55	-1.05
Tsushima strait (*inflow*)	0.3	0.4	1.2	2.0	2.2	1.4

Unit: Sv, 1 Sv = 10^6 m^3s^{-1}

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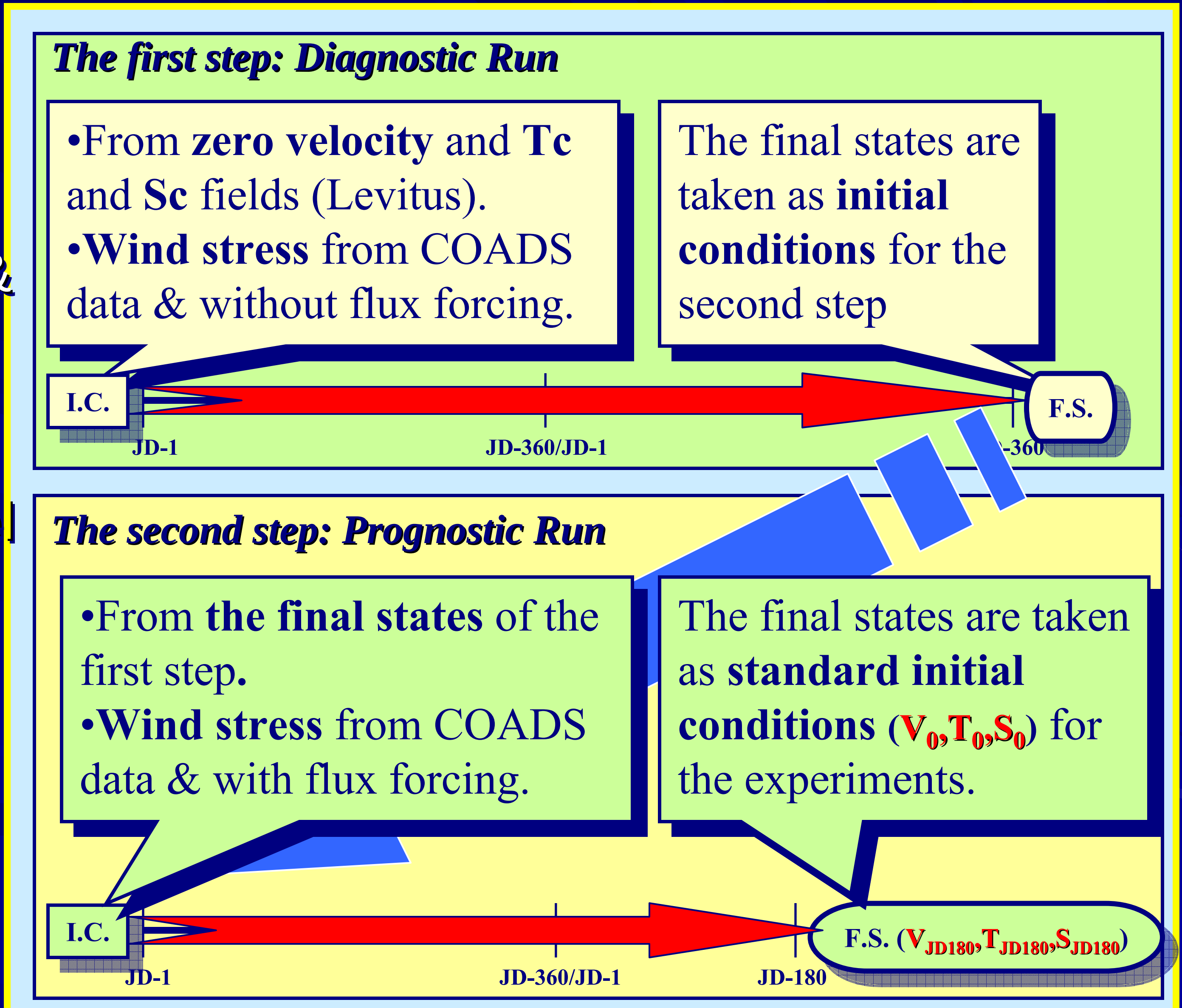
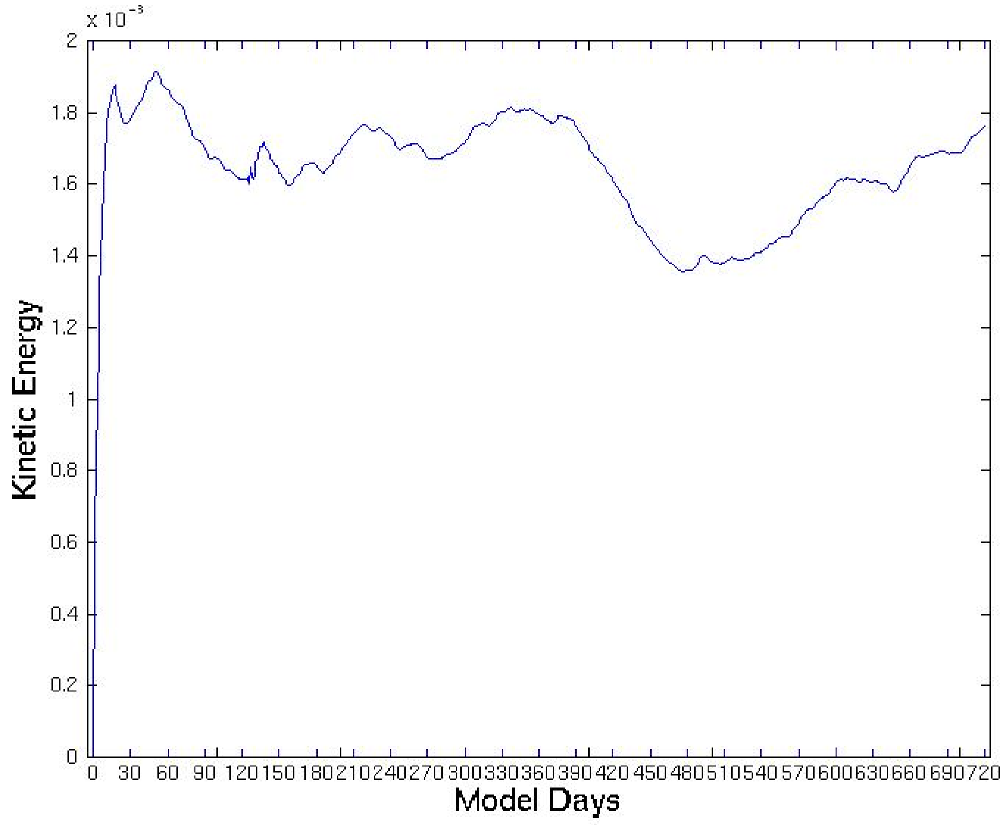


Temporal Variation of the Kinetic Energy During the First Stage



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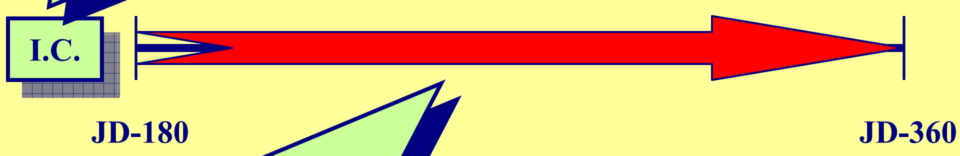
Experimental Design

Experiment	*Property*
0	**Control run**
1	Uncertain **velocity initialization processes**
2	
3	
4	
5	Uncertain **wind stress**
6	
7	Uncertain **lateral boundary transport**
8	
9	**Combination of uncertainty**
10	
11	

Experimental Design

- Control Run
- Uncertain Initial Conditions
- Uncertain Wind Forcing
- Uncertain Lateral Transport
- Combined Uncertainty

•From the **standard initial conditions** $(V_0 = V_{JD180}, T_0 = T_{JD180}, S_0 = S_{JD180})$.
•**Lateral transport** from historical data and **Wind stress** from COADS data & with flux forcing.



The simulated **temperature** and **salinity** fields and **circulation pattern** are **consistent with observational studies** (*Chu et al. 2003*).

Experimental Design

- Control Run
- Uncertain Initial Conditions
- Uncertain Wind Forcing
- Uncertain Lateral Transport
- Combined Uncertainty

Experiment	*Initial Conditions*	*Wind Forcing*	*Lateral Boundary Conditions*
1	$V_0 = 0$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$	Same as Run-0	Same as Run-0
2	$\mathbf{V}_0 = \mathbf{V}_{30D}^{(Diag)}$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$	Same as Run-0	Same as Run-0
3	$\mathbf{V}_0 = \mathbf{V}_{60D}^{(Diag)}$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$	Same as Run-0	Same as Run-0
4	$\mathbf{V}_0 = \mathbf{V}_{90D}^{(Diag)}$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$	Same as Run-0	Same as Run-0

Experimental Design

- Control Run
- Uncertain Initial Conditions
- Uncertain Wind Forcing
- Uncertain Lateral Transport
- Combined Uncertainty

Experiment	*Initial Conditions*	*Wind Forcing*	*Lateral Boundary Conditions*
5	Same as Run-0	Adding Gaussian random noise with zero mean and **0.5 m/s** noise intensity	Same as Run-0
6	Same as Run-0	Adding Gaussian random noise with zero mean and **1.0 m/s** noise intensity	Same as Run-0

Experimental Design

- Control Run
- Uncertain Initial Conditions
- Uncertain Wind Forcing
- Uncertain Lateral Transport
- Combined Uncertainty

Experiment	***Initial Conditions***	***Wind Forcing***	***Lateral Boundary Conditions***
7	Same as Run-0	Same as Run-0	Adding Gaussian random noise with the zero mean and noise intensity being **5%** of the transport (control run)
8	Same as Run-0	Same as Run-0	Adding Gaussian random noise with the zero mean and noise intensity being **10%** of the transport (control run)

Experimental Design

- Control Run
- Uncertain Initial Conditions
- Uncertain Wind Forcing
- Uncertain Lateral Transport
- Combined Uncertainty

Experiment	*Initial conditions*	*Wind forcing*	*Lateral Boundary Conditions*
9	$\mathbf{V}_0 = \mathbf{V}_{30D}^{(Diag)}$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$	Adding Gaussian random noise with **1.0 m/s** noise intensity	Same as Run-0
10	$\mathbf{V}_0 = \mathbf{V}_{30D}^{(Diag)}$, $T_0=T_{JD180}$, $S_0=S_{JD180}$	Same as Run-0	Adding Gaussian random noise with noise intensity being **10%** of the transport (control run)
11	$\mathbf{V}_0 = \mathbf{V}_{30D}^{(Diag)}$, $T_0=T_{JD180}$, $S_0=S_{JD180}$	Adding Gaussian random noise with **1.0 m/s** noise intensity	Adding Gaussian random noise with noise intensity being **10%** of the transport (control run)

Statistical Analysis Methods

Model Error :

$$\Delta\psi(x,y,z,t) = \psi_c(x,y,z,t) - \psi_e(x,y,z,t)$$

Root Mean Square Error (RMSE) :

$$RMSE(z,t) = \sqrt{\frac{1}{My \times Mx}\sum_{j=1}^{My}\sum_{i=1}^{Mx}\left[\Delta\psi_u(x_i,y_j,z,t)^2 + \Delta\psi_v(x_i,y_j,z,t)^2\right]}$$

Relative Root Mean Square Error (RRMSE) :

$$RRMSE(z,t) = \frac{\sqrt{\sum_{j=1}^{My}\sum_{i=1}^{Mx}\left[\Delta\psi_u(x_i,y_j,z,t)^2 + \Delta\psi_v(x_i,y_j,z,t)^2\right]}}{\sqrt{\sum_{j=1}^{My}\sum_{i=1}^{Mx}\left[\psi c_u(x_i,y_j,z,t)^2 + \psi c_v(x_i,y_j,z,t)^2\right]}}$$

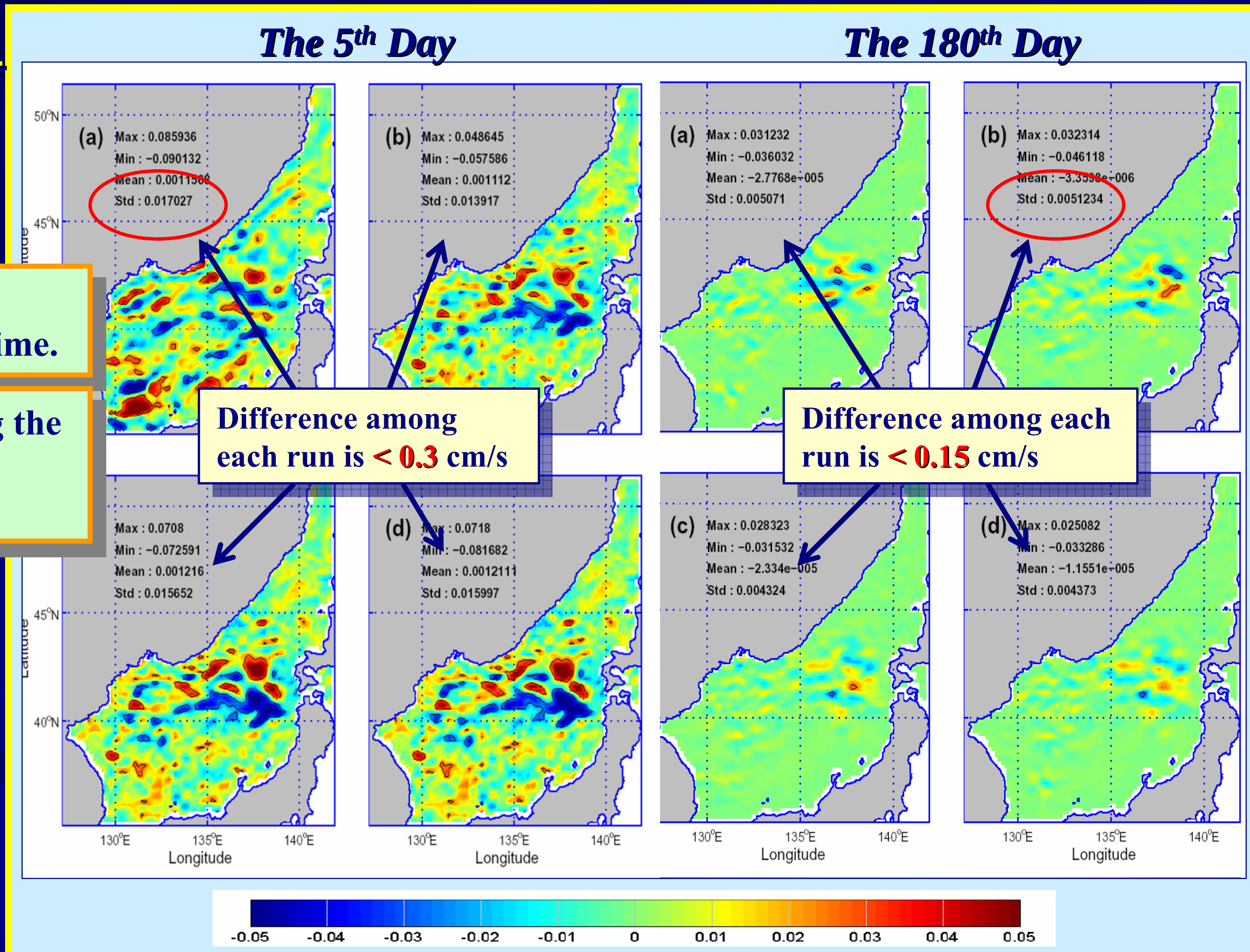
Model Errors Due To Initial Conditions

- Model Error Distribution
  - Horizontal distributio

Model error is decreasing with time.

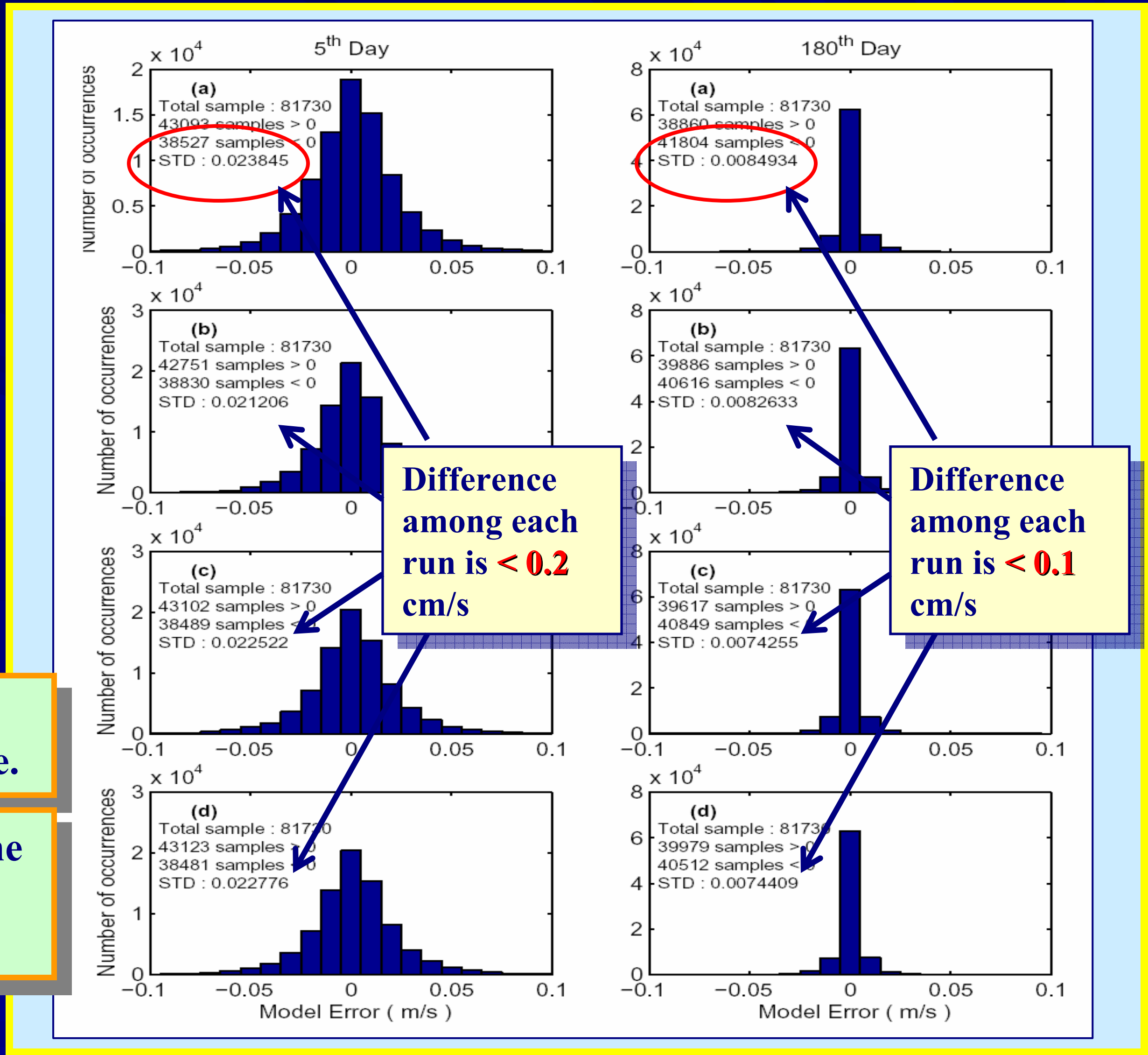
Difference among the four runs is not significant.

1	$V_0 = 0$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$
2	$V_0 = V^{(Diag)}_{30D}$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$
3	$V_0 = V^{(Diag)}_{60D}$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$
4	$V_0 = V^{(Diag)}_{90D}$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$



Model Errors Due To Initial Conditions

- Model Error Distribution
  - Horizontal distributio n
  - Histogram
- Relative Root Mean Square Error

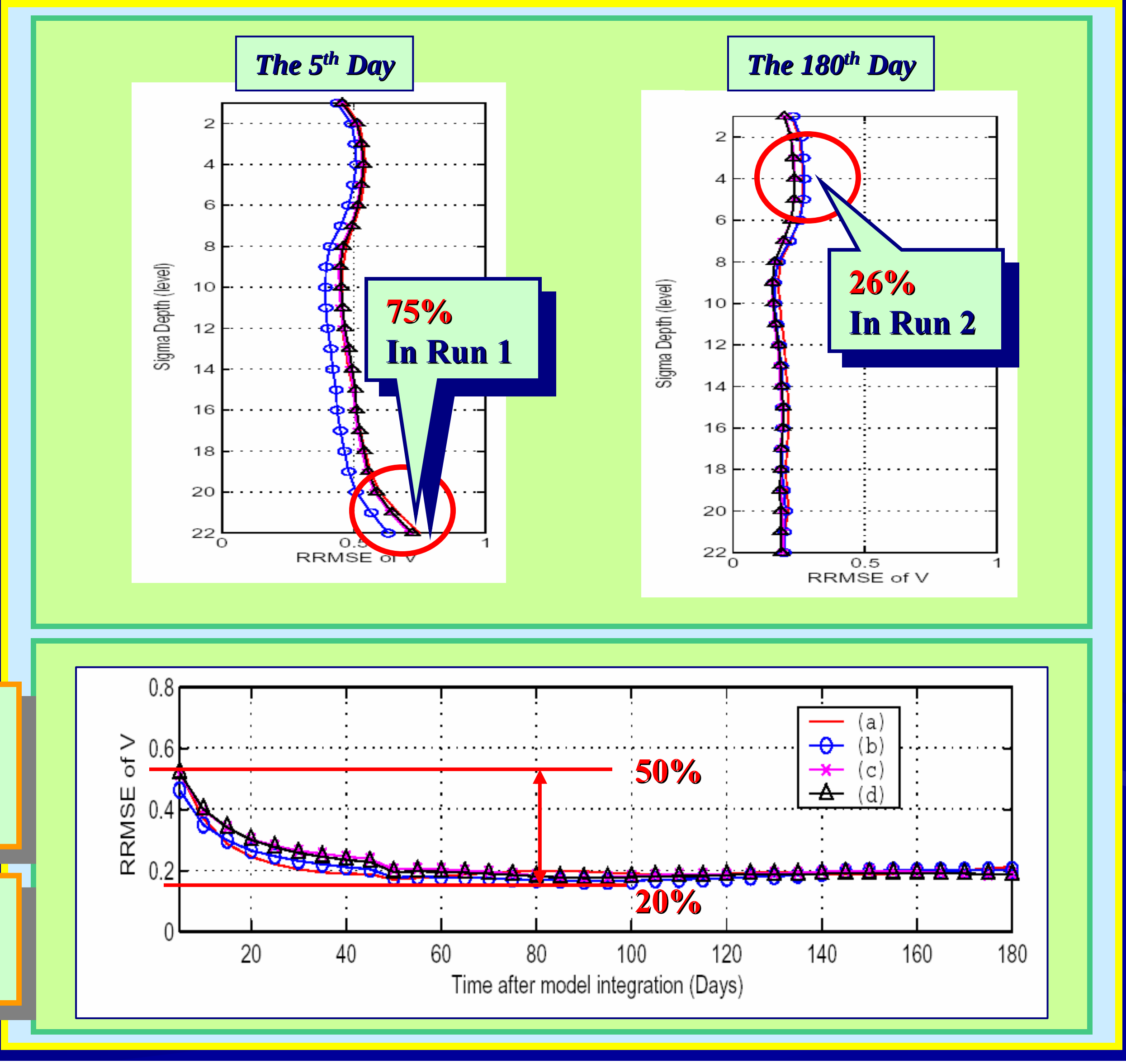


Model error is decreasing with time.

Difference among the four runs is not significant.

Model Errors Due To Initial Conditions

- Model Error Distribution
- Relative Root Mean Square Error (RRMSE)
  - Vertical Variation
  - Temporal



Effects to the horizontal velocity prediction are quite significant.

No obvious difference among these four runs.

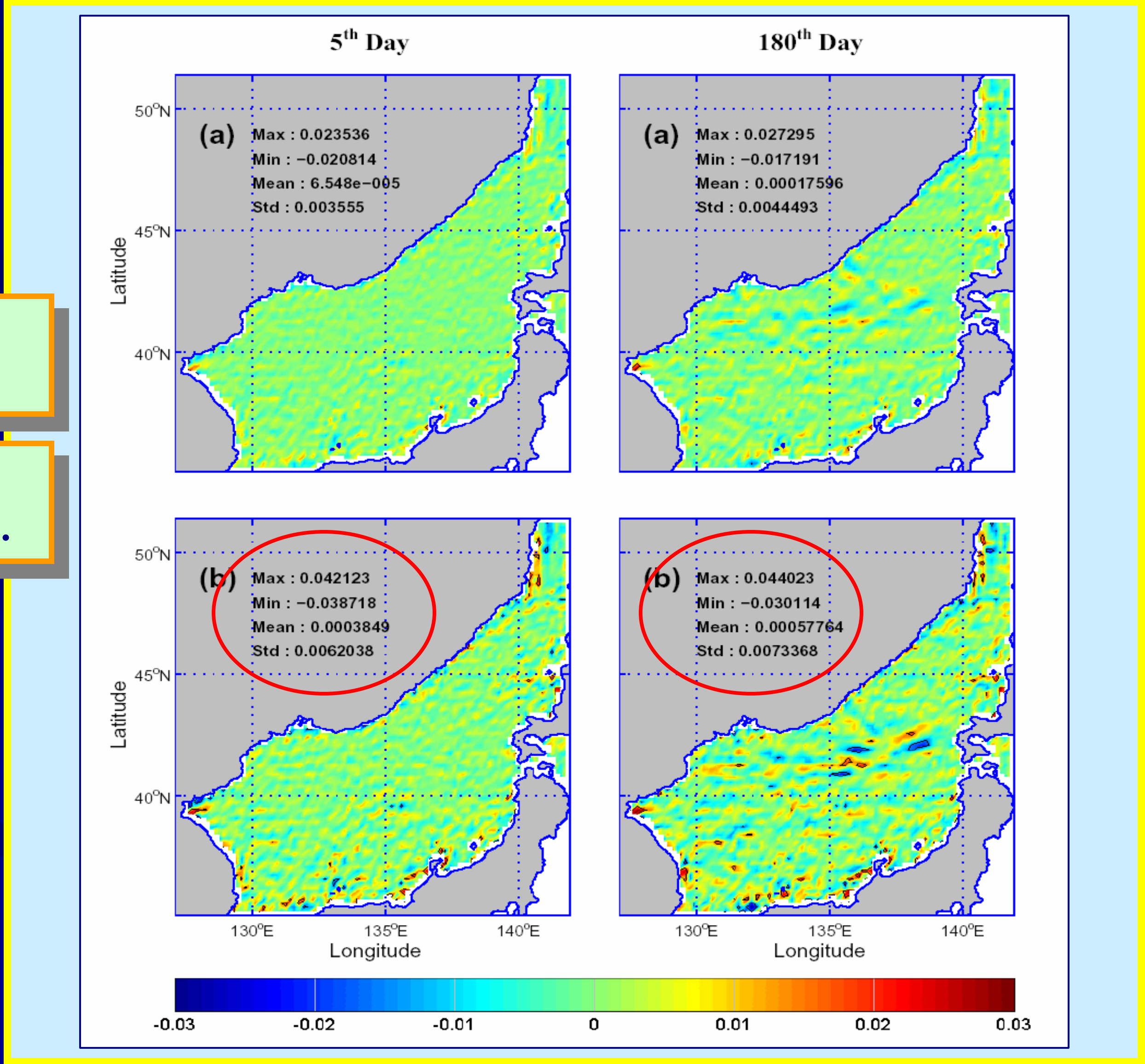
Model Errors Due To Wind Forcing

- Model Error Distribution
  - Horizontal distributio
  - –
- Re
  Ro
  Square

Larger model error in Run 6.

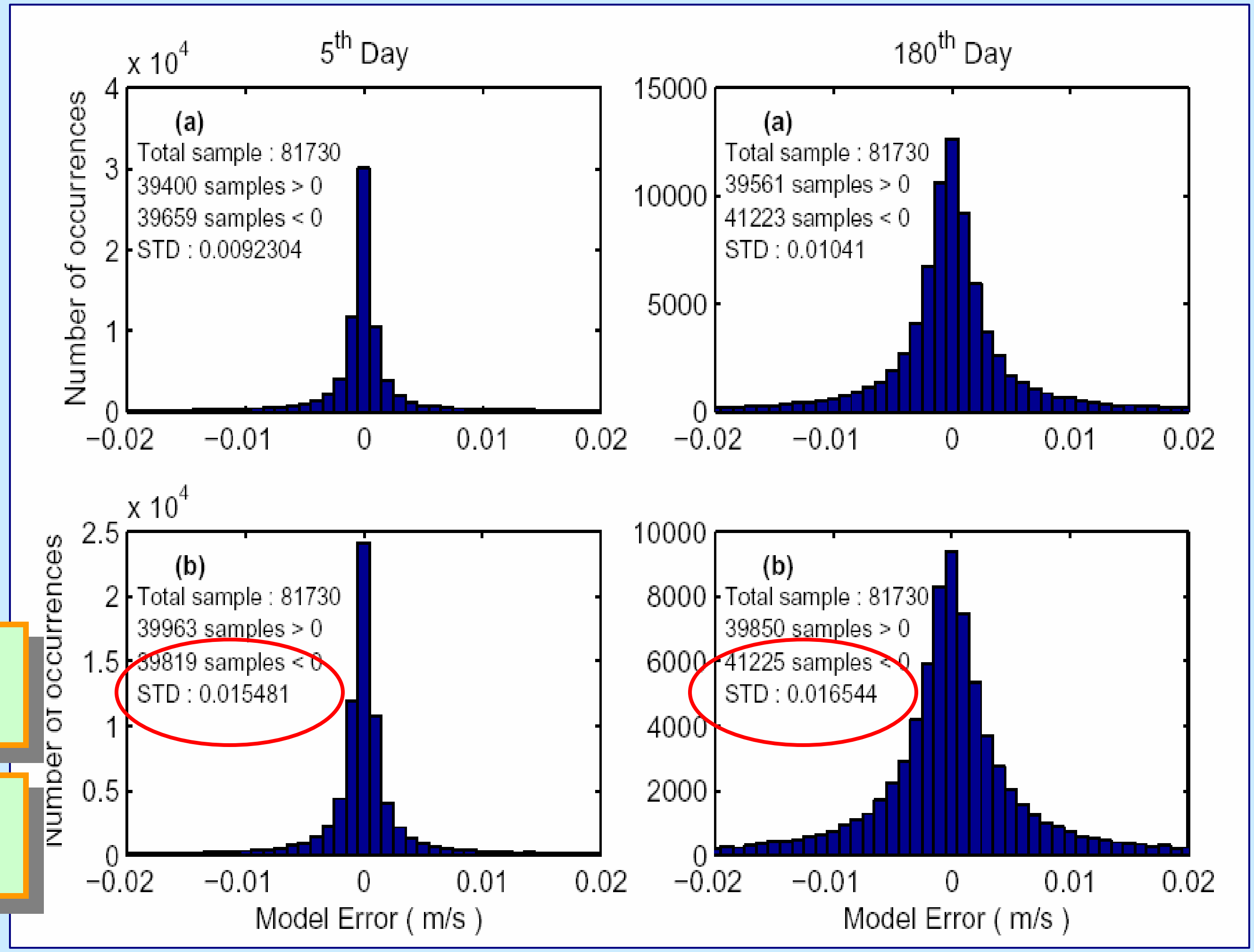
Model error is increasing with time.

Experiment	*Wind Forcing*
5	Adding Gaussian random noise with zero mean and **0.5 m/s** noise intensity
6	Adding Gaussian random noise with zero mean and **1.0 m/s** noise intensity



Model Errors Due To Wind Forcing

- Model Error Distribution
  - Horizontal distributio n
  - Histogram
- Relative Root Mean Square Error

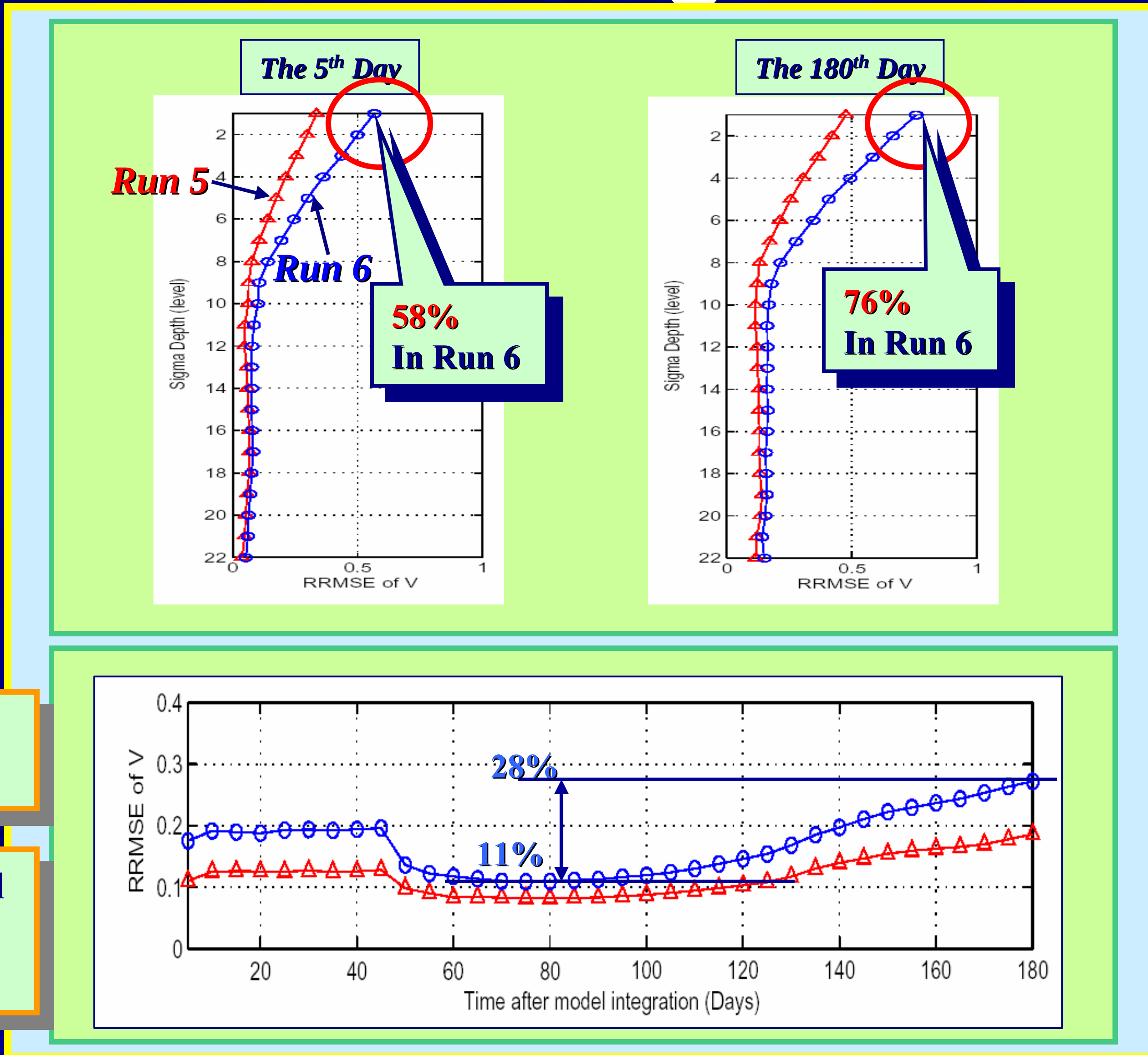


Larger model error in Run 6.

Model error is increasing with time.

Model Errors Due To Wind Forcing

- Model Error Distribution
- Relative Root Mean Square Error (RRMSE)
  - Vertical Variation
  - Temporal



Larger model error in Run 6.

Effects to the horizontal velocity prediction are quite significant.

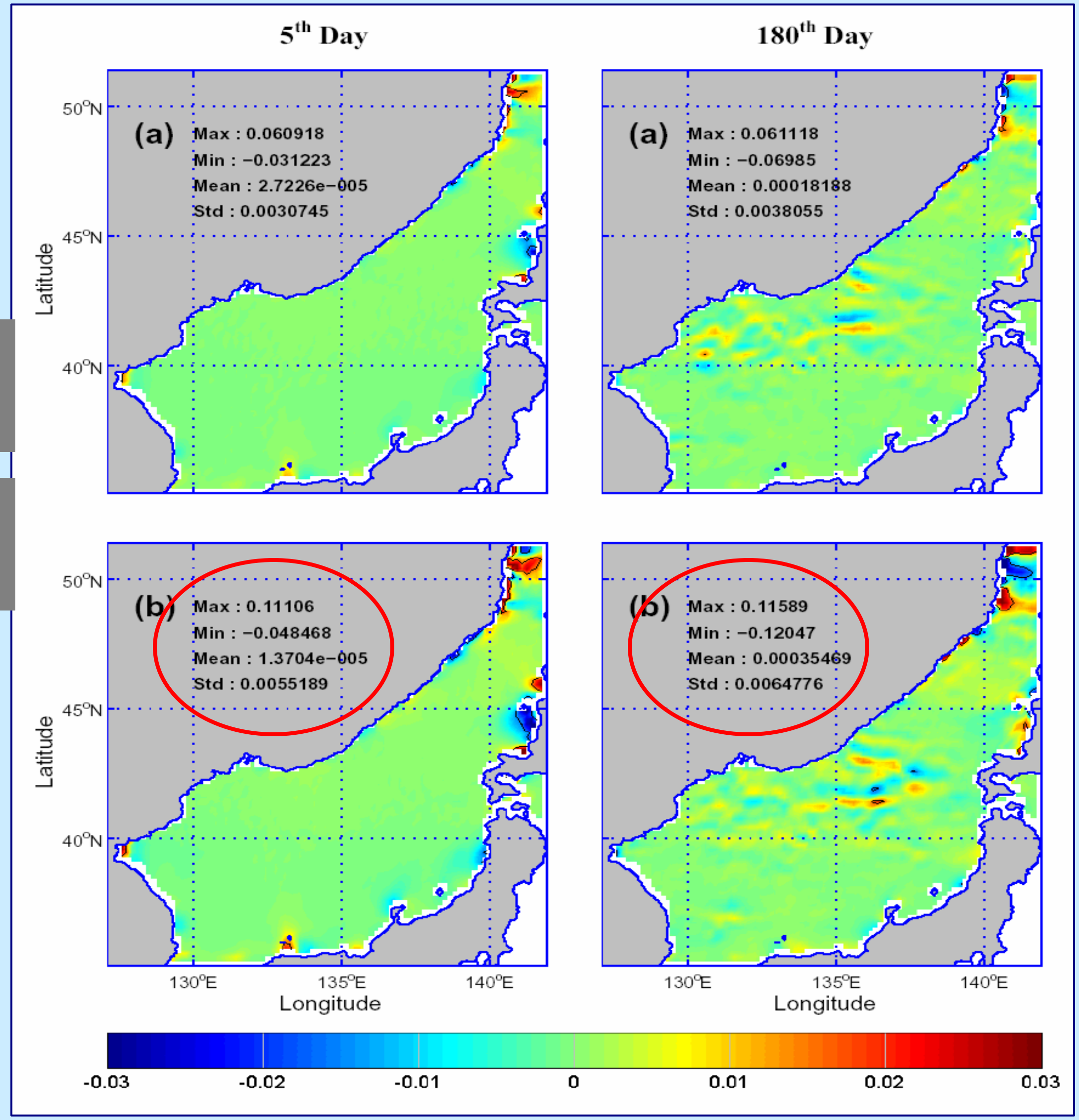
Model Errors Due To Open Boundary Conditions

- Model Error Distribution
  - Horizontal distributio
  - –
- Re
  Ro
  Square
  E
  (

Larger model error in Run 8.

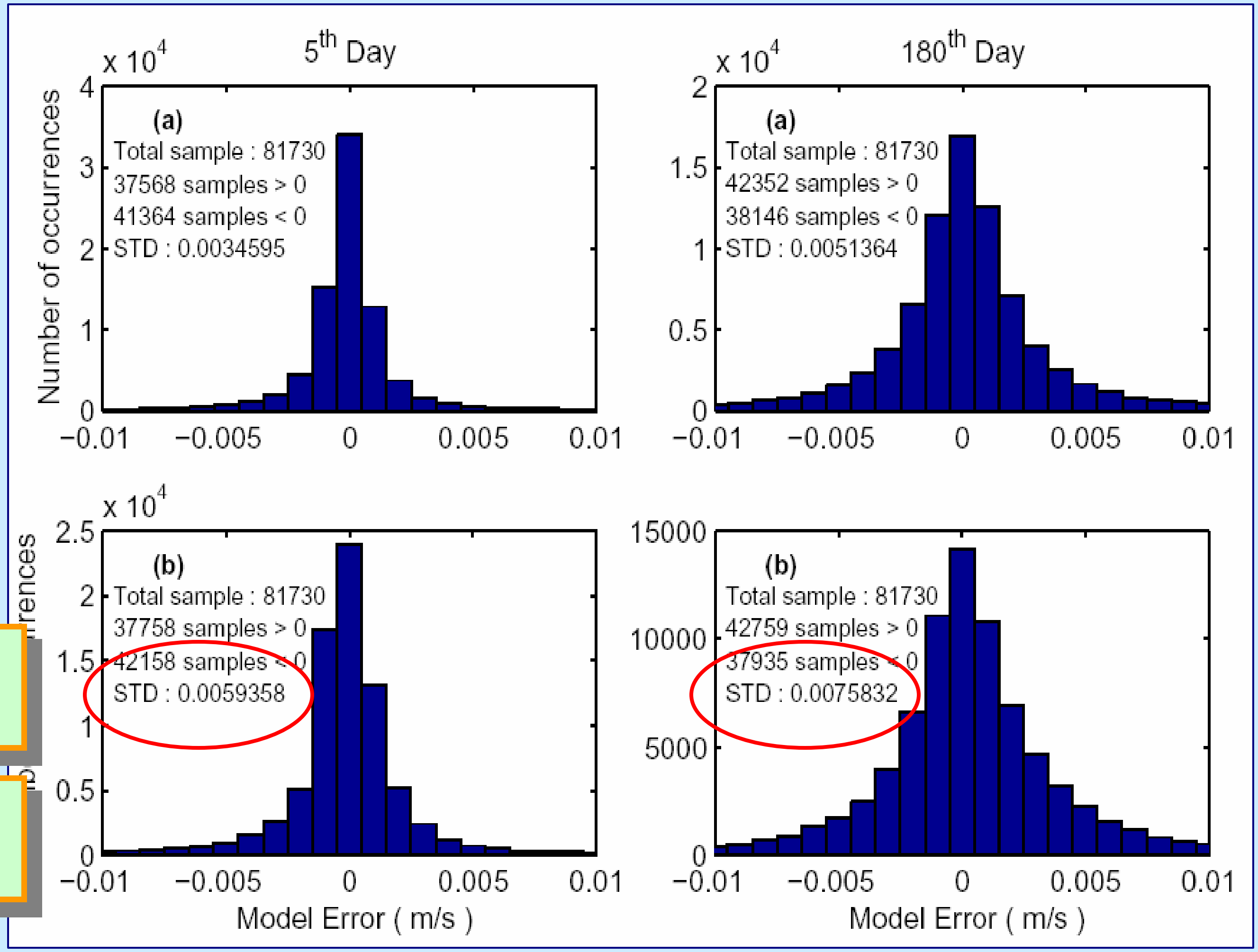
Model error is increasing with time.

Experiment	*Lateral Boundary Conditions*
7	Adding Gaussian random noise with the zero mean and noise intensity being **5%** of the transport (control run)
8	Adding Gaussian random noise with the zero mean and noise intensity being **10%** of the transport (control



Model Errors Due To Open Boundary Conditions

- Model Error Distribution
  - Horizontal distributio n
  - Histogram
- Relative Root Mean Square Error



Larger model error in Run 8.

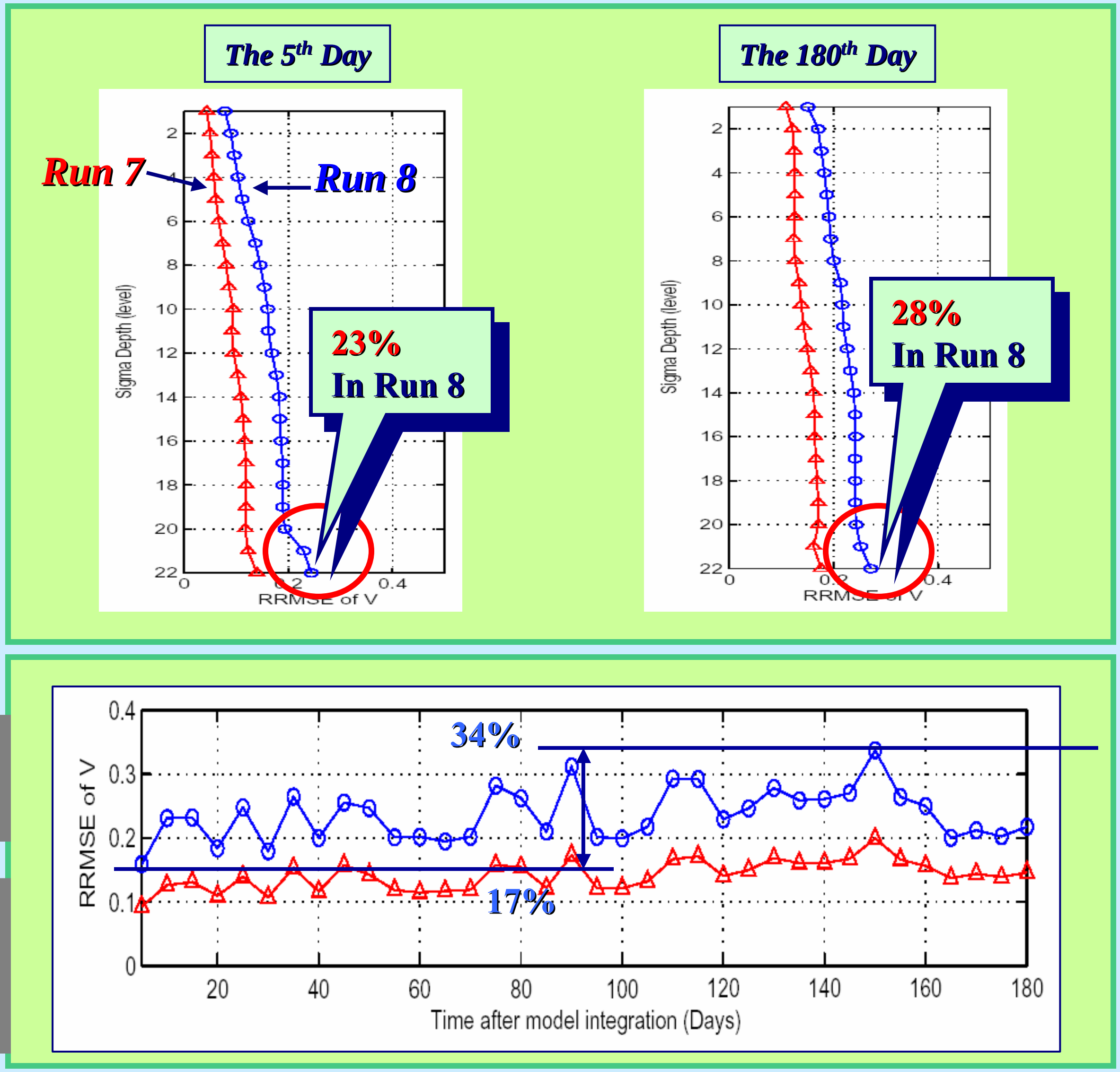
Model error is increasing with time.

Model Errors Due To Open Boundary Conditions

- Model Error Distribution
- Relative Root Mean Square Error (RRMSE)
  - Vertical Variation
  - Temporal

Larger model error in Run 8.

Effects to the horizontal velocity prediction are quite significant.



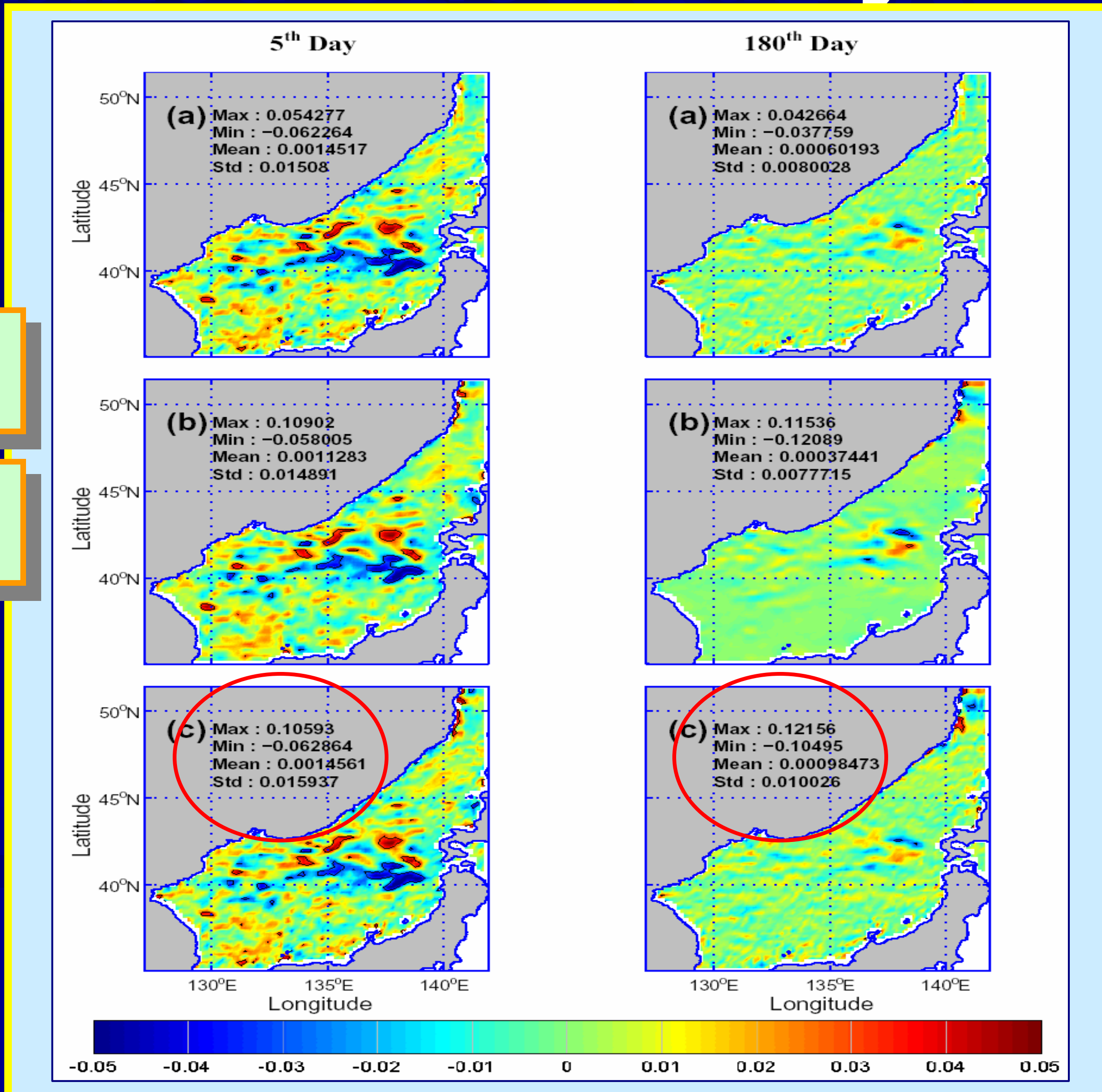
Model Errors Due To Combined Uncertainty

- Model Error Distribution
  - Horizontal distributio n
  - H
- Rela

Larger model error in Run 11.

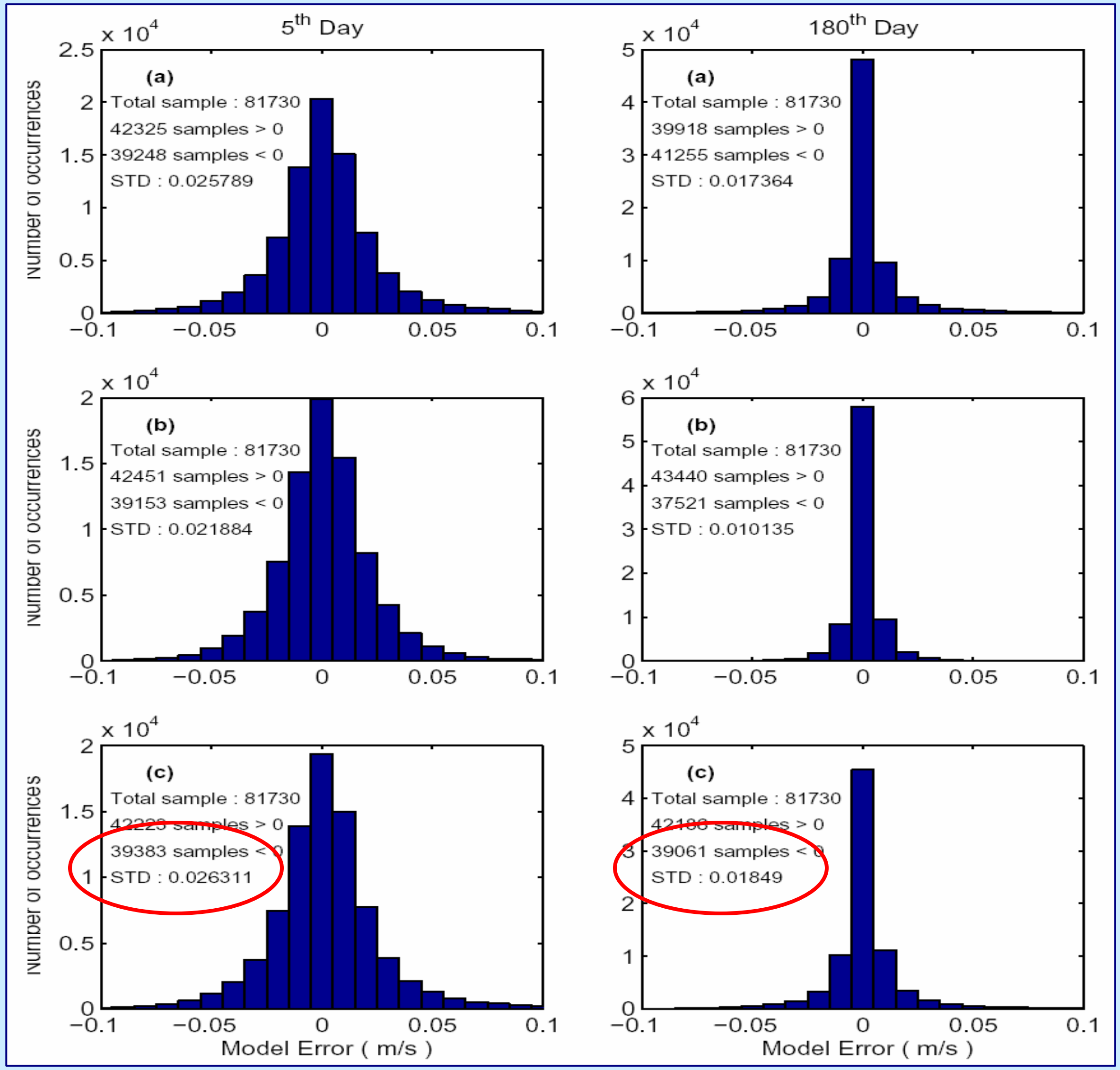
Model error is decreasing with time.

Expe rimen t	*Init conditions*	*forcing*	*Condition s*
9	$\mathbf{V}_0 = \mathbf{V}_{30D}^{(Diag)}$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$	with **1.0 m/s** noise intensity	Same as Run-0
10	$\mathbf{V}_0 = \mathbf{V}_{30D}^{(Diag)}$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$	Same as Run-0	with noise intensity being **10%** of the transport
11	$\mathbf{V}_0 = \mathbf{V}_{30D}^{(Diag)}$, $T_0 = T_{JD180}$, $S_0 = S_{JD180}$	with **1.0 m/s** noise	with noise intensity being **10%** of the



Model Errors Due To Combined Uncertainty

- Model Error Distribution
  - Horizontal distribution
  - Histogram
- Relative Root Mean Square Error (

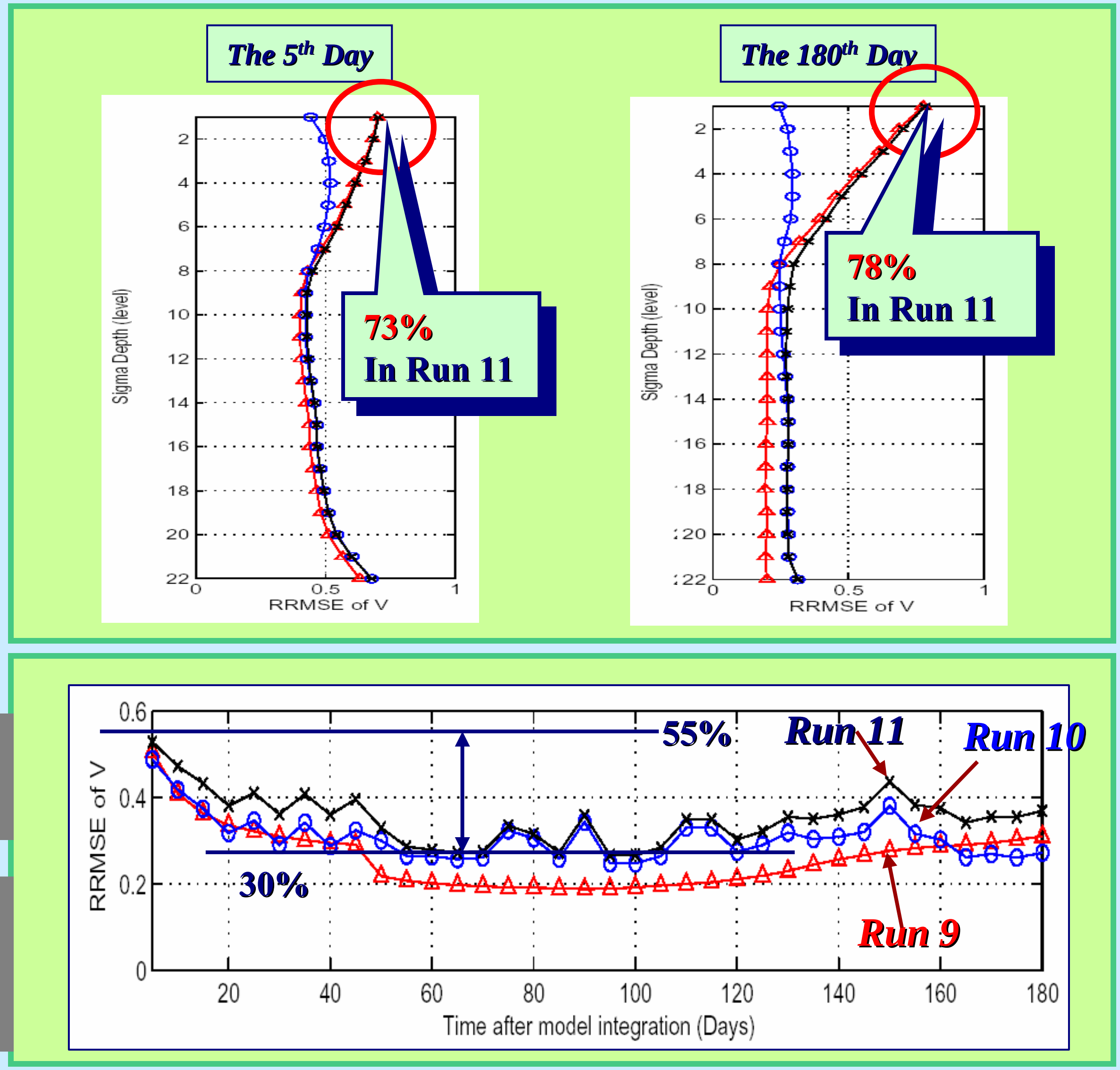


Larger model error in Run 11.

Model error is decreasing with time.

Model Errors Due To Combined Uncertainty

- Model Error Distribution
- Relative Root Mean Square Error (RRMSE)
  - Vertical Variation
  - Temporal



Larger model error in Run 11.

Effects to the horizontal velocity prediction are quite significant.

Conclusions

For uncertain **velocity initial conditions** :

- The model errors **decreases** with time.
- The model errors with and without ***diagnostic initialization*** are quite **comparable and significant**.
- The **magnitude of model errors** is **less dependent** on the ***diagnostic initialization period*** no matter it is *30 day,60 day or 90 day*.
-

Experiment	Vertically averaged RRMSE		Max. RRMSE	
	Min.	Max.	5th Day	180th Day
For uncertain **velocity initial conditions**	**20%**	**50%**	**70%** near the *surface*	**25%** near the *surface*

Conclusions

For uncertain **wind forcing** :

- The **model error** increases with **time** and **noise intensity**.
-

Experiment	Vertically averaged RRMSE		Max. RRMSE	
	Min.	Max.	5th Day	180th Day
For **0.5 m/s** noise intensity	**8%**	**19%**	**35%** near the *surface*	**50%** near the *surface*
For **1.0 m/s** noise intensity	**11%**	**28%**	**60%** near the *surface*	**80%** near the *surface*

Conclusions

For uncertain **lateral boundary transport** :

- The **model error** increases with **time** and **noise intensity**.
-

Experiment	Vertically averaged RRMSE		Max. RRMSE	
	Min.	Max.	5^{th} Day	180^{th} Day
For noise intensity as **5%** of transport	**9%**	**20%**	**14%** near the *bottom*	**18%** near the *bottom*
For noise intensity as **10%** of transport	**17%**	**34%**	**24%** near the *bottom*	**28%** near the *bottom*

Conclusions

For **combined uncertainty :**

Experiment	Vertically averaged RRMSE		Max. RRMSE	
	Min.	Max.	5th Day	180th Day
For uncertain **initial condition** and **wind forcing**	**20%**	**52%**	**70%** near the *surface*	**77%** near the *surface*
For uncertain **initial condition** and **lateral boundary transport**	**27%**	**50%**	**65%** near the *bottom*	**35%** near the *bottom*
For uncertain **initial condition, wind forcing** and **lateral boundary transport**	**30%**	**55%**	**73%** near the *surface*	**78%** near the *surface*