# Observation-Model Compatibility in Coastal Data Assimilation

## -Filtering & Optimal Spectral Decomposition -

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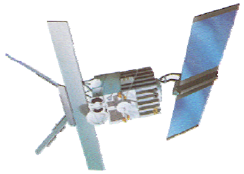
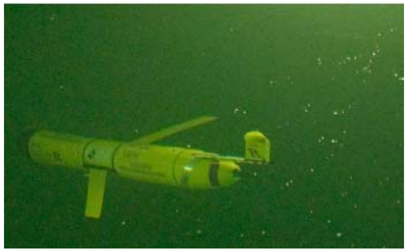
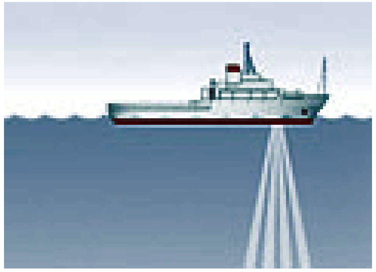




How can we effectively use observational ocean data to represent and to model/predict the ocean state?




# Outline

- (1) Model-Data Compatibility
- (2) Filtering Observational Data
- (3) Optimal Spectral Decomposition

  (Chu et al., 2003 a, b JTECH)

  – ARGO Data: Baroclinic Rossby Waves in Tropical Atlantic (Chu et al. JGR 2007)
  – Surface Drifting Buoy Data: Synoptic Current Reversals on the Texas-Louisiana Continental Shelf (Chu et al. 2005 JPO)

# Part-1

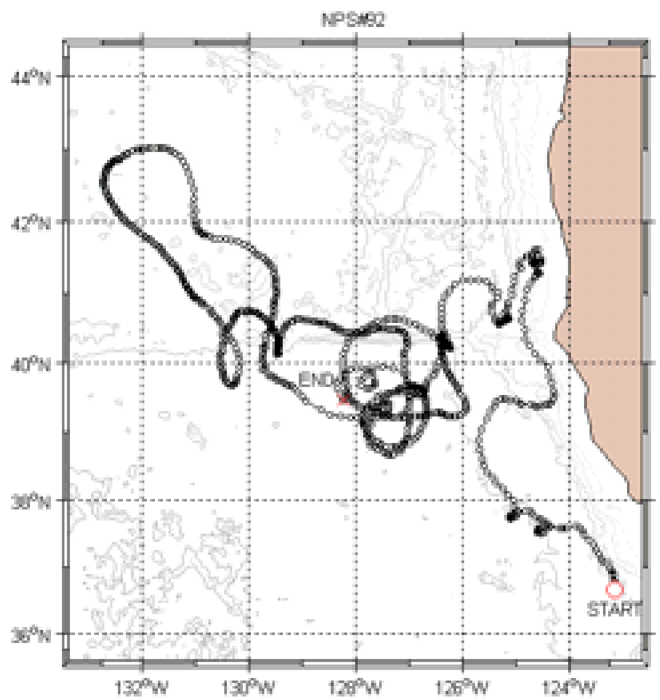
# Model-Data Compatibility

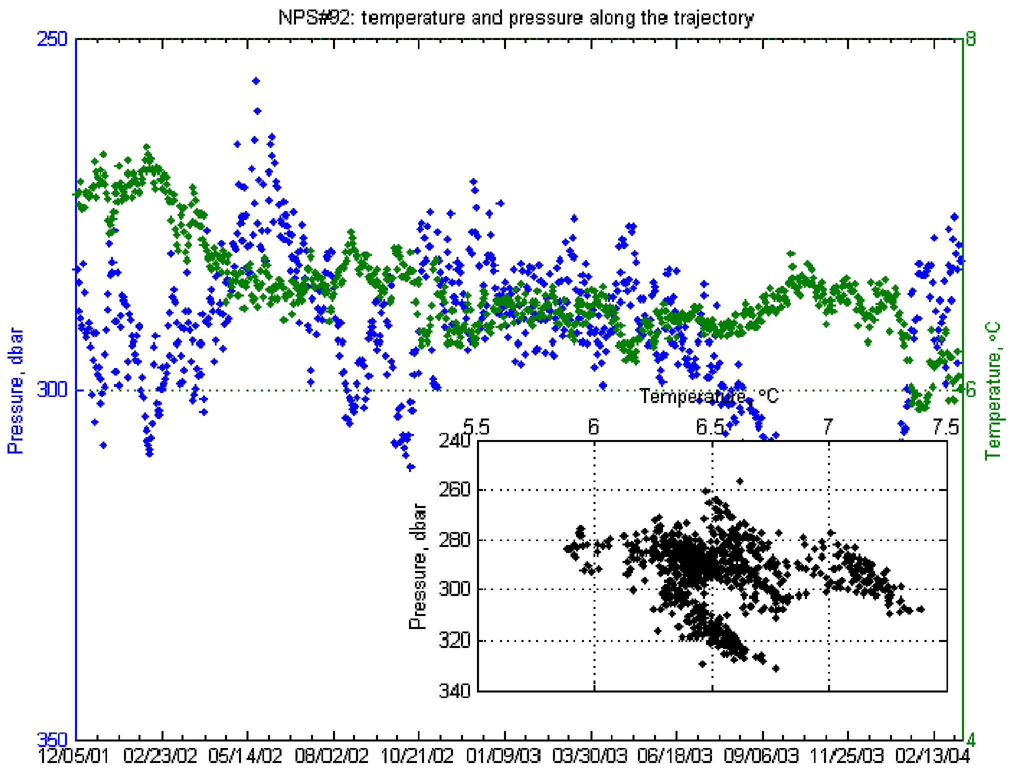
# Difference between modeled and observed data

- Model
  - Regular in (t, x, y, z)
  - Representing mean value of a grid cell

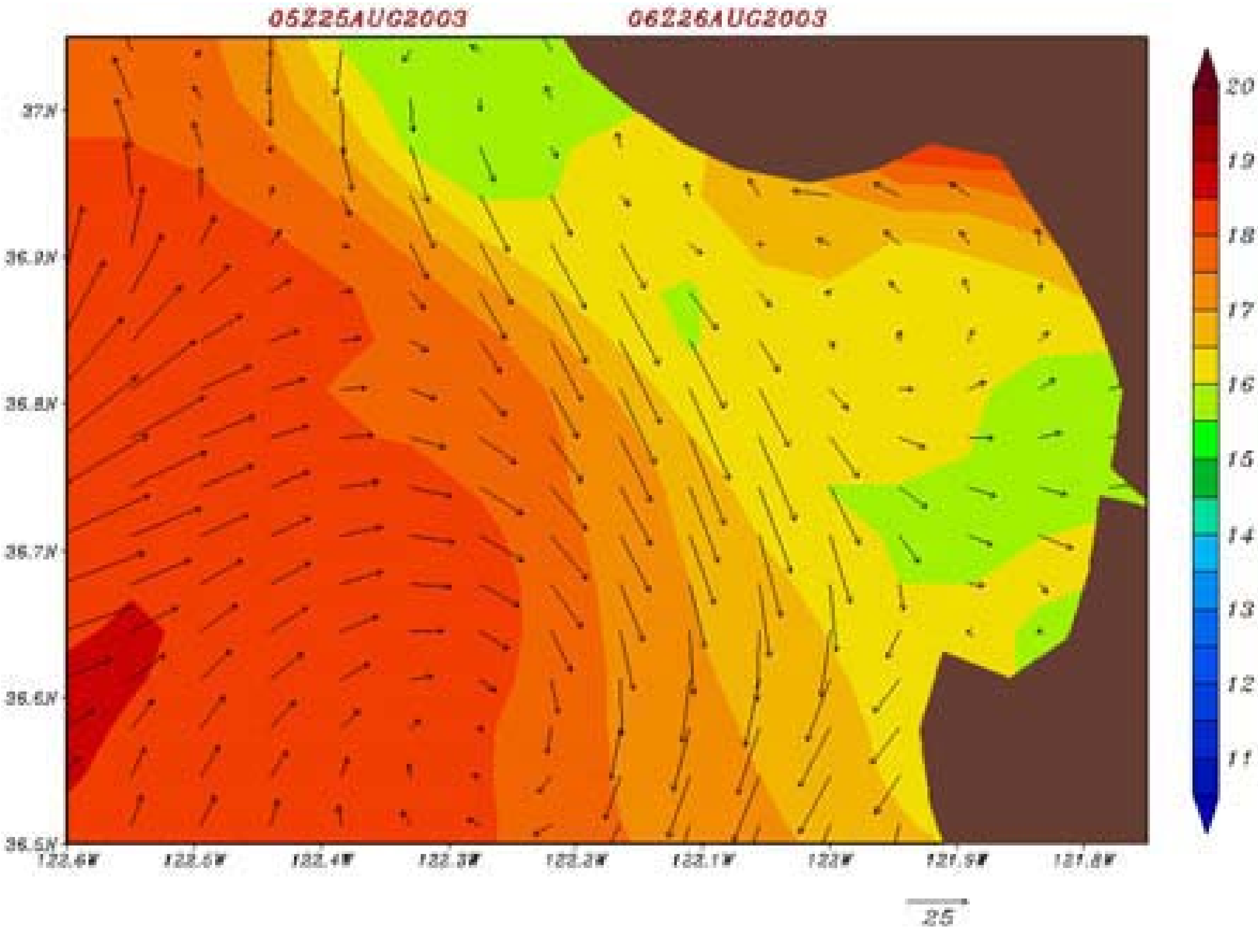
- Observation
  - Irregular in (t, x, y, z) usually noisy and sparse
  - Representing value at the observational point

# Example: RAFOS Floats (NPS#92) in Monterey Bay (Collins' website)



# NCOM Model Data (Hong et al. 2005)

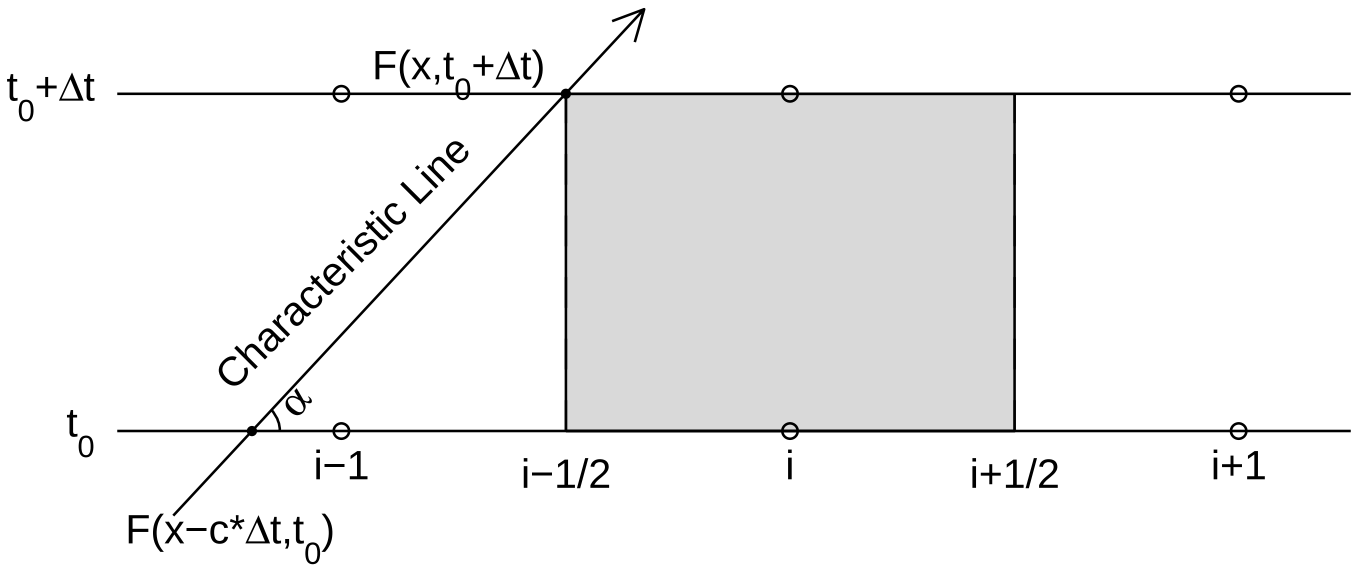


# Advection-Diffusion Equation

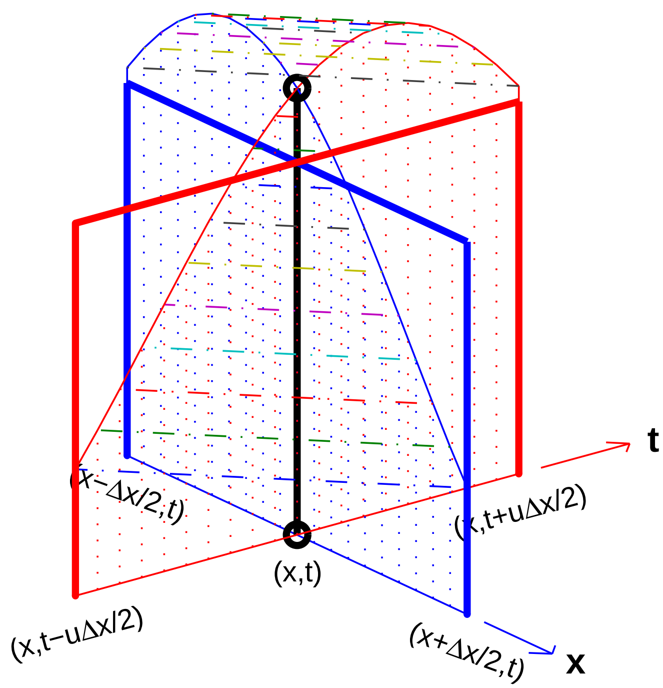
$$\frac{\partial \Phi}{\partial t} + \nabla \bullet (\mathbf{V}\Phi) = \nabla \bullet (\kappa \nabla \Phi) + S \,.$$

$$\frac{\tilde{\Phi}^{n+1}_{i,j,k} - \tilde{\Phi}^{n}_{i,j,k}}{\Delta t} = \frac{\overline{\langle F \rangle}_{i+\frac{1}{2},j,k} - \overline{\langle F \rangle}_{i-\frac{1}{2},j,k}}{\Delta x} + \frac{\overline{\langle G \rangle}_{i,j+\frac{1}{2},k} - \overline{\langle G \rangle}_{i,j-\frac{1}{2},k}}{\Delta y} + \frac{\overline{\langle H \rangle}_{i,j,k+\frac{1}{2}} - \overline{\langle H \rangle}_{i,j,k-\frac{1}{2}}}{\Delta z} + \hat{S}_{i,j,k} \,,$$

# Characteristic Line



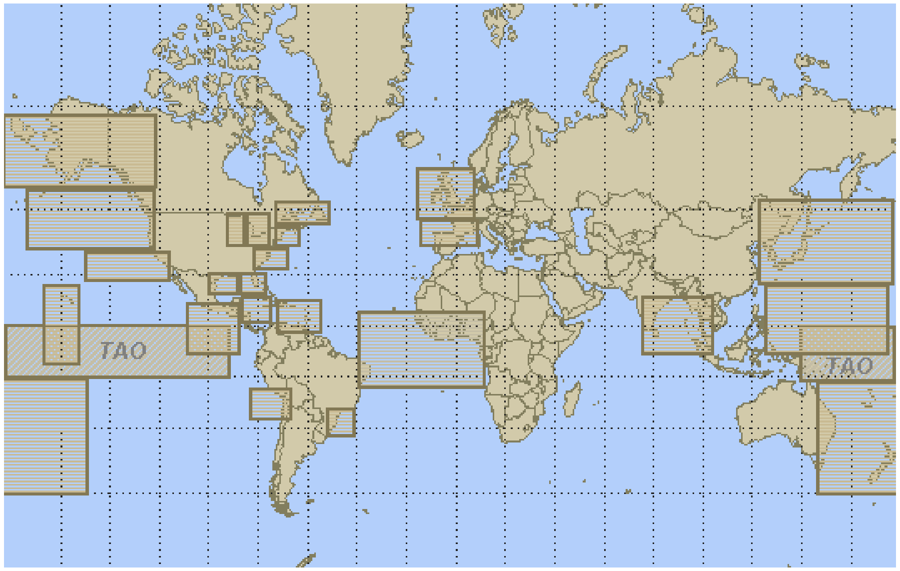
# Modeled-Observational Data Difference at the same location




- (1) Observation → along the red curve
- (2) Model → spatial mean (upper blue line)
- (3) Temporal mean of observation ←→ Model

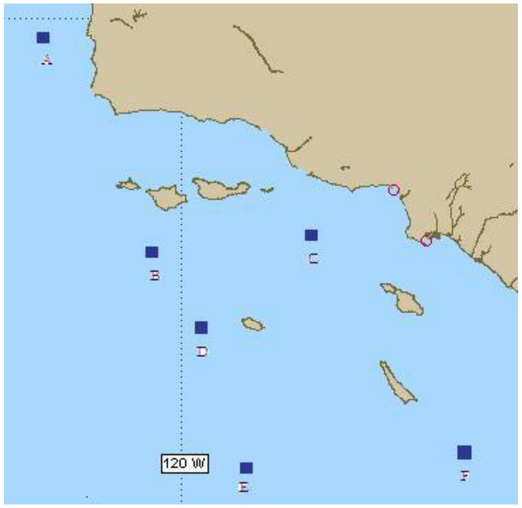
# NOAA Buoy Data Center ←→WAM

significant wave height




WAM-4 model
(Galanis et al., 2006)

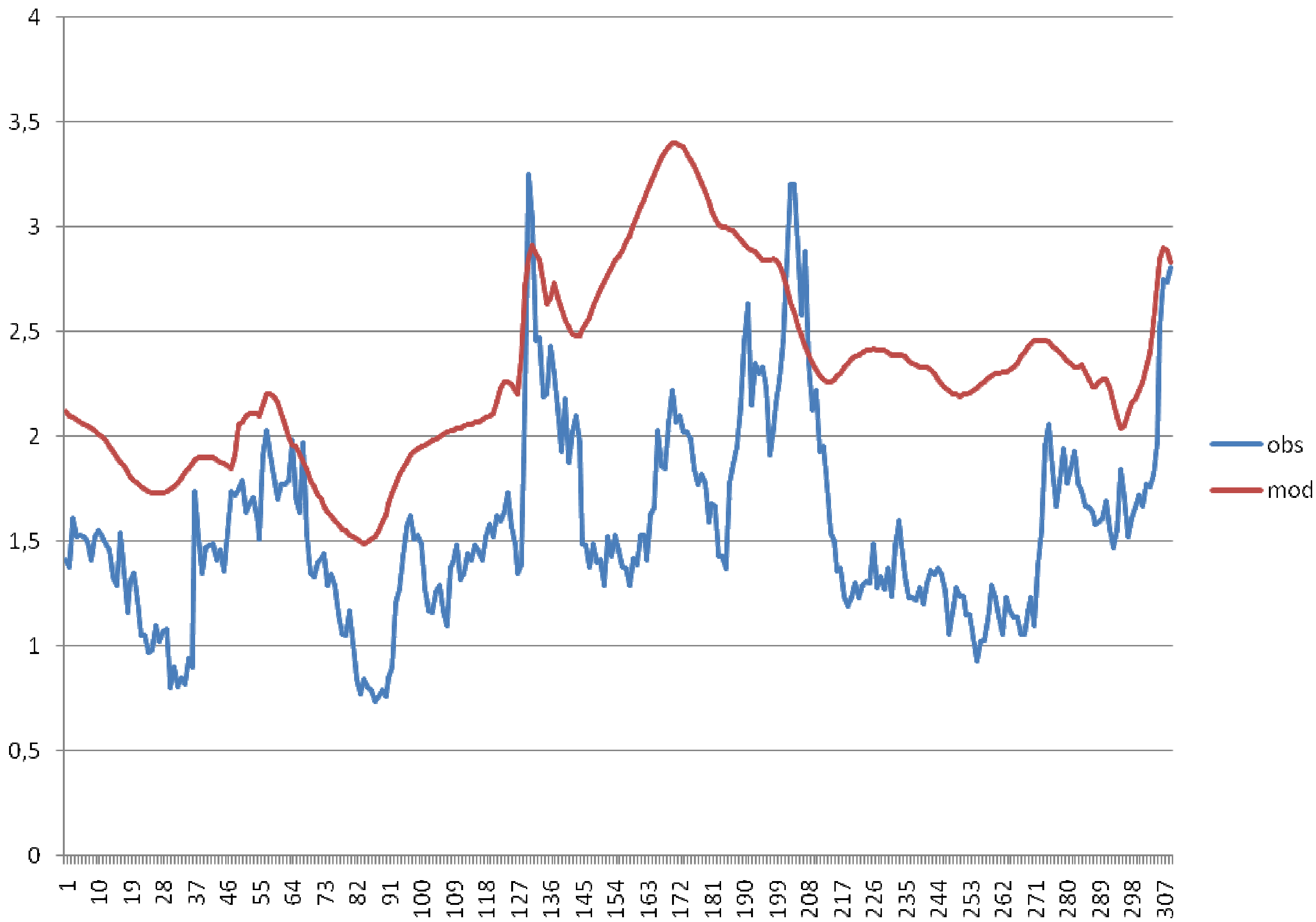
Near California Coast



# WAM -4

- (1) Integrating on 30 frequencies and 24 directions.
- (2) First integration frequency → 0.0417 Hz
- (3) Time step → 300 seconds
- (4) Spatial grid → $0.5^o$ x$0.5^o$
- (5) Wind input (10 m) → NCEP/GFS $0.5^o$ x$0.5^o$

# Observational and  WAM Modeled Data



# Part-2 Data Filtering

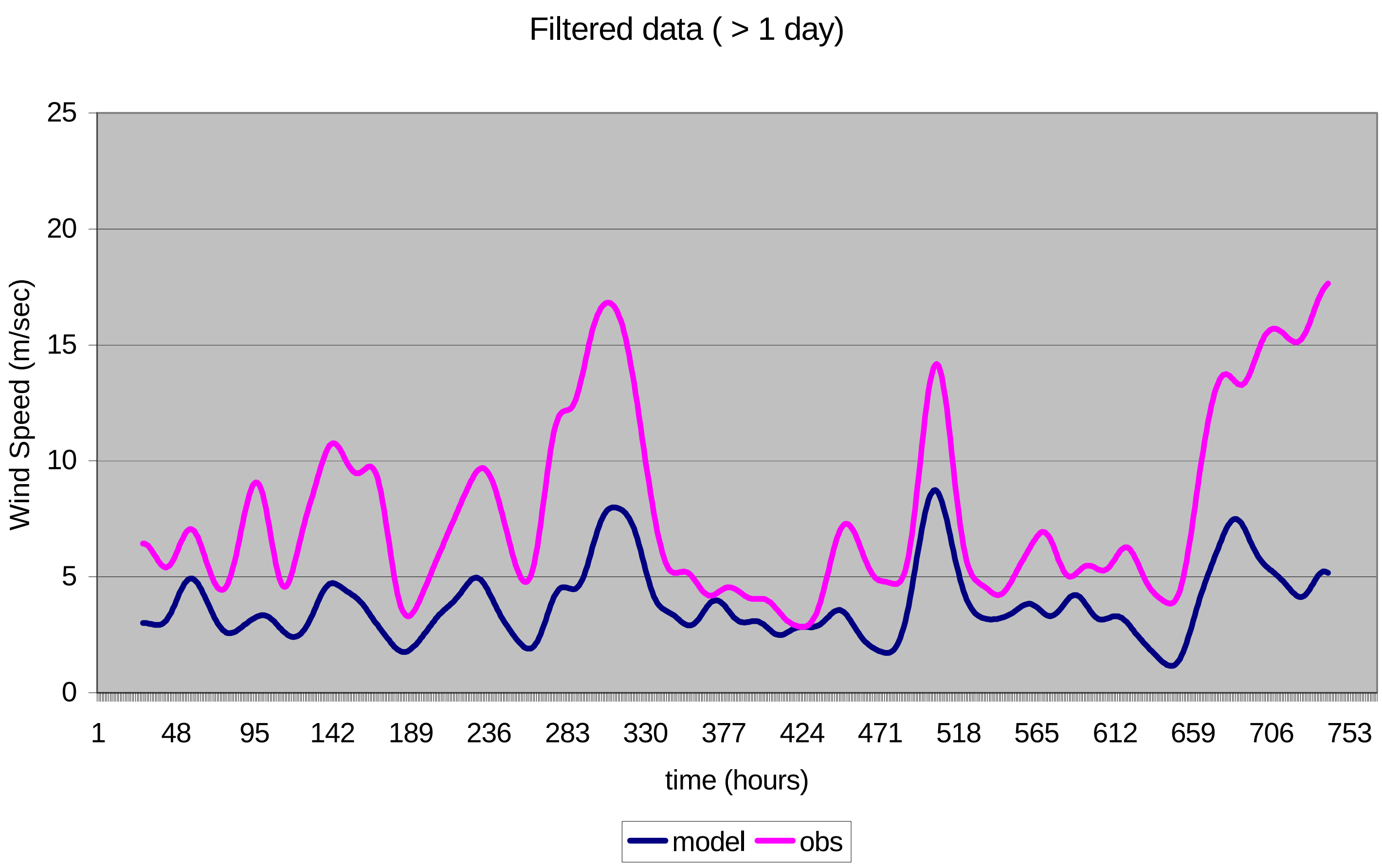
# Kolmogorov-Zurbenko (KZ) Filter

# KZ Filter

- Original Data $x_i^0$
- First Iteration $$x_i^1 = \frac{1}{2q+1} \sum_{j=-q}^{q} x_{i+j}^0$$
- Second Iteration $$x_i^2 = \frac{1}{2q+1} \sum_{j=-q}^{q} x_{i+j}^1 ,$$
- Number of Iteration (N) $$(2q+1) \cdot \sqrt{N} \le P$$
- P → Time Steps

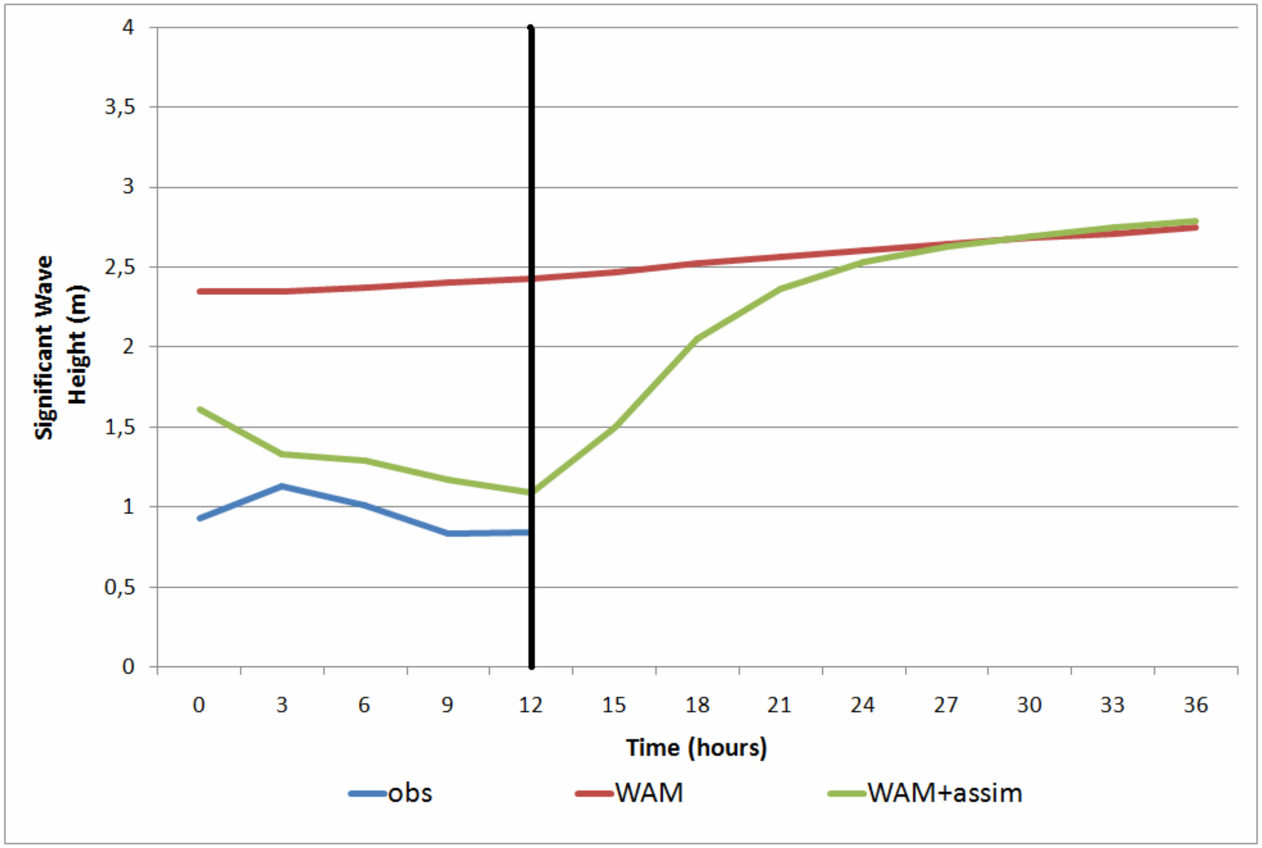
- Appropriate selection of the parameters ($N$, $P$, $q$) leads to smoothed time series of observational and modeled data

# *Observations vs Forecasts*




Daily variability has been removed.
The systematic error has not been affected.

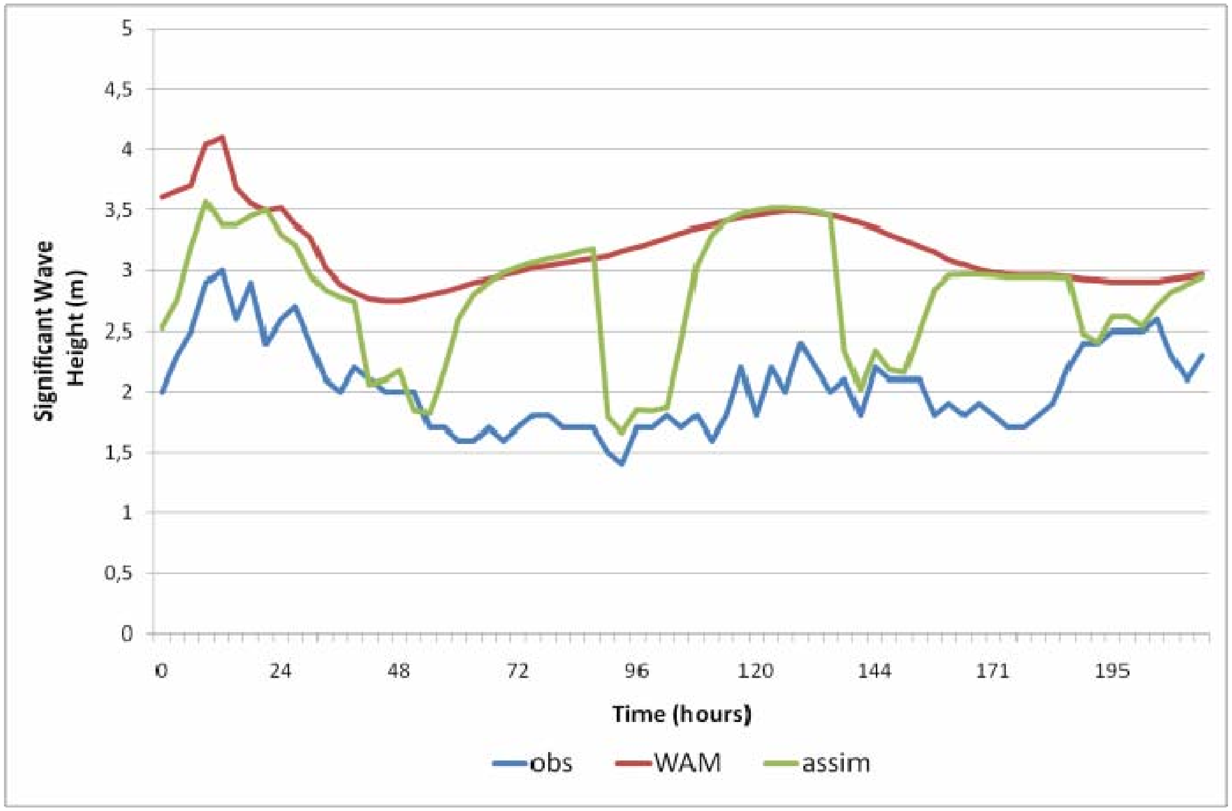
# Data Assimilation Window (12 hrs)




Assimilating SWH for 12 hrs and running the model for 24 hrs

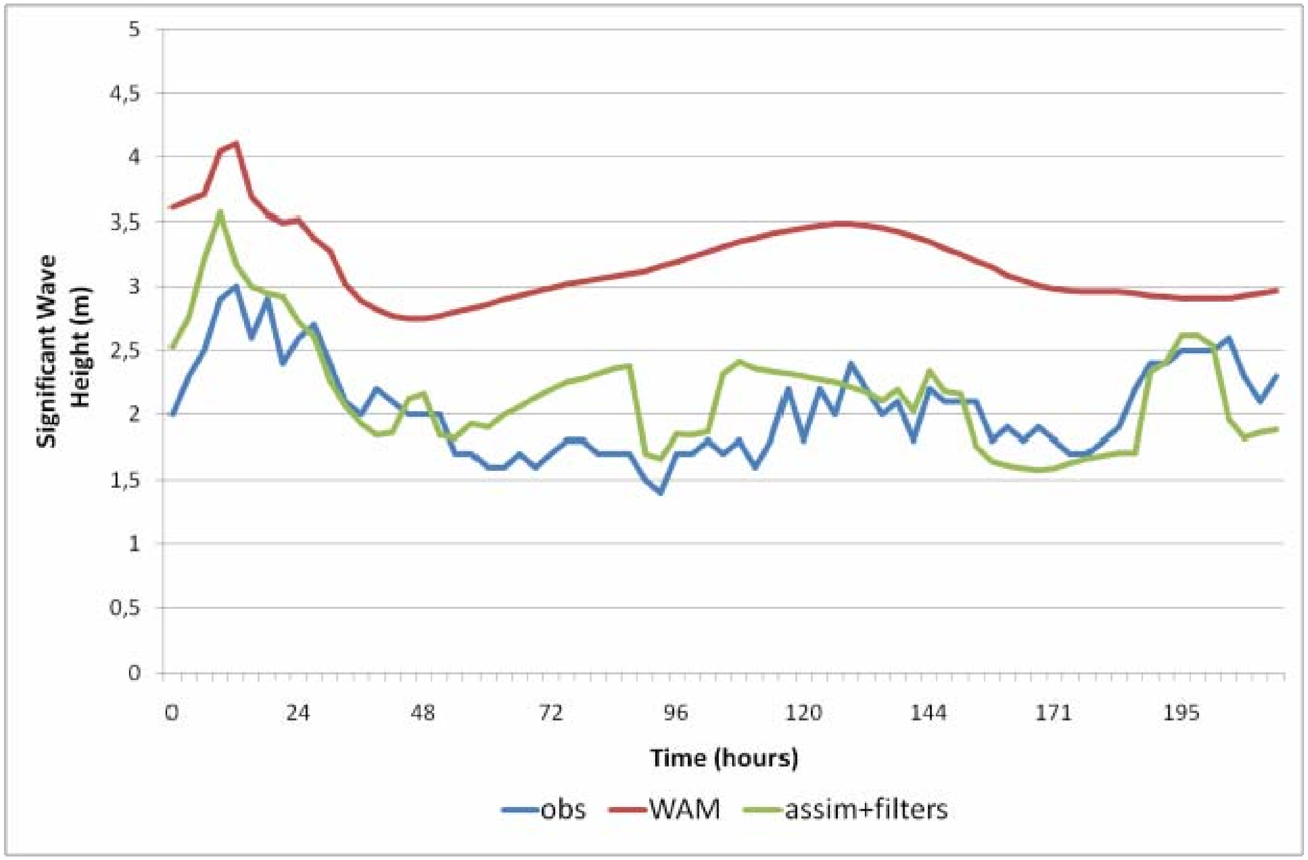
Assimilation → Kalman Filter

# Model with data assimilation (Kalman Filter) and no KZ (Buoy- D)




Data (Significant Wave Height) input → Every hours

# Model with data assimilation (Kalman Filter) and KZ (Buoy- D)



# Impact of Data Assimilation and Filtering

WAM-no assimilation and KZ filtering
WAM2 –assimilation and no KZ filtering
WAM3 – Assimilation and KZ-filtering

| | Buoy A | | | Buoy B | | | Buoy C | | |
|---|---|---|---|---|---|---|---|---|---|
| | WAM | WAM2 | WAM3 | WAM | WAM2 | WAM3 | WAM | WAM2 | WAM3 |
| **Bias** | 0.51 | 0.21 | 0.02 | 0.39 | 0.08 | -0.19 | 0.99 | 0.72 | 0.33 |
| **RMSE** | 0.70 | 0.55 | 0.46 | 0.64 | 0.49 | 0.47 | 1.10 | 0.89 | 0.55 |
| **Nbias** | 0.42 | 0.28 | 0.21 | 0.33 | 0.22 | 0.17 | 1.05 | 0.73 | 0.40 |
| | **Buoy D** | | | **Buoy E** | | | **Buoy F** | | |
| | **WAM** | **WAM2** | **WAM3** | **WAM** | **WAM2** | **WAM3** | **WAM** | **WAM2** | **WAM3** |
| **Bias** | 0.68 | 0.39 | 0.10 | 0.62 | 0.27 | -0.02 | 0.88 | 0.44 | 0.02 |
| **RMSE** | 0.80 | 0.60 | 0.38 | 0.79 | 0.56 | 0.42 | 0.96 | 0.65 | 0.27 |
| **Nbias** | 0.44 | 0.27 | 0.16 | 0.43 | 0.24 | 0.15 | 0.74 | 0.38 | 0.15 |

# Part-3

# Optimal Spectral Decomposition

# Spectral Decomposition

$$
\begin{aligned}
u_{KM} &= \sum_{k=1}^{K} a_k(z,t^\circ)\frac{\partial\Psi_k(x,y,z,\kappa^\circ)}{\partial y} + \sum_{m=1}^{M} b_m(z,t^\circ)\frac{\partial\Phi_m(x,y,z)}{\partial x}, \\
v_{KM} &= -\sum_{k=1}^{K} a_k(z,t^\circ)\frac{\partial\Psi_k(x,y,z,\kappa^\circ)}{\partial x} + \sum_{m=1}^{M} b_m(z,t^\circ)\frac{\partial\Phi_m(x,y,z)}{\partial y}
\end{aligned}
$$

# Basis Functions (Open Boundaries)

(Chu et al., 2003 a,b JTECH)

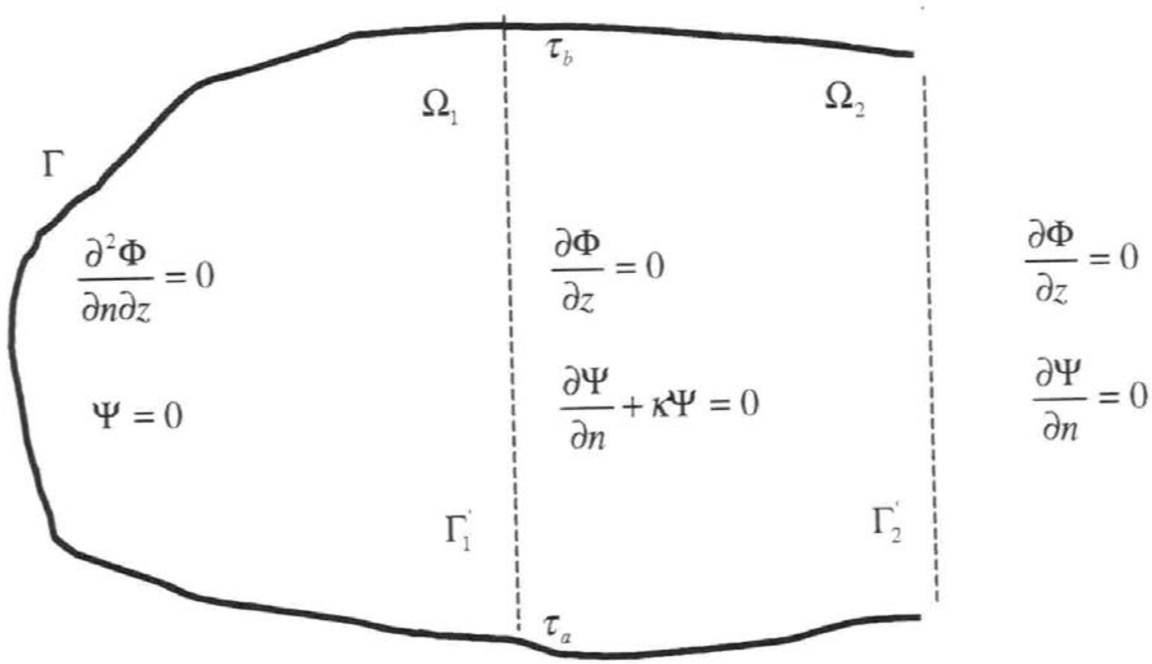
$$\triangle \Psi_k = -\lambda_k \Psi_k,$$

$$\triangle \Phi_m = -\mu_m \Phi_m,$$

$$\Psi_k|_\Gamma = 0, \quad \frac{\partial \Phi_m}{\partial n}|_\Gamma = 0,$$

$$\left[\frac{\partial \Psi_k}{\partial n} + \kappa(\tau)\Psi_k\right]|_{\Gamma_1'} = 0, \quad \Phi_m|_{\Gamma_1'} = 0,$$

# Boundary Conditions



# Benefit of Using OSD

- Ocean Topographic Configuration →

  Basis Functions  (Pre-Determined)

# Vapnik (1983) Cost Function →Optimal Mode Truncation

$$J(a_{1,\ldots,}a_K, b_{1,\ldots,}b_M, \kappa, P) = \frac{1}{2}\left(\left\|u_p^{obs} - u_{KM}\right\|_P^2 + \left\|v_p^{obs} - v_{KM}\right\|_P^2\right) \rightarrow \min,$$

$$J_{emp} = J(a_{1,\ldots,}a_{K,}b_{1,\ldots,}b_M, \kappa, P).$$

$$\mathrm{Prob}\left\{\sup_{K,M,S} |\langle J(K,M,S)\rangle - J_{emp}(K,M,S)| \geq \mu\right\} \leq g(P,\mu)$$

$$\lim_{P\rightarrow\infty} g(P,\mu) = 0$$

# Optimal Truncation

- Gulf of Mexico, Monterey Bay, Louisiana-Texas Shelf, Tropical Atlantic
- $K_{opt} = 40$, $M_{opt} = 30$

Determination of Spectral Coefficients
(Ill-Posed Algebraic Equation)

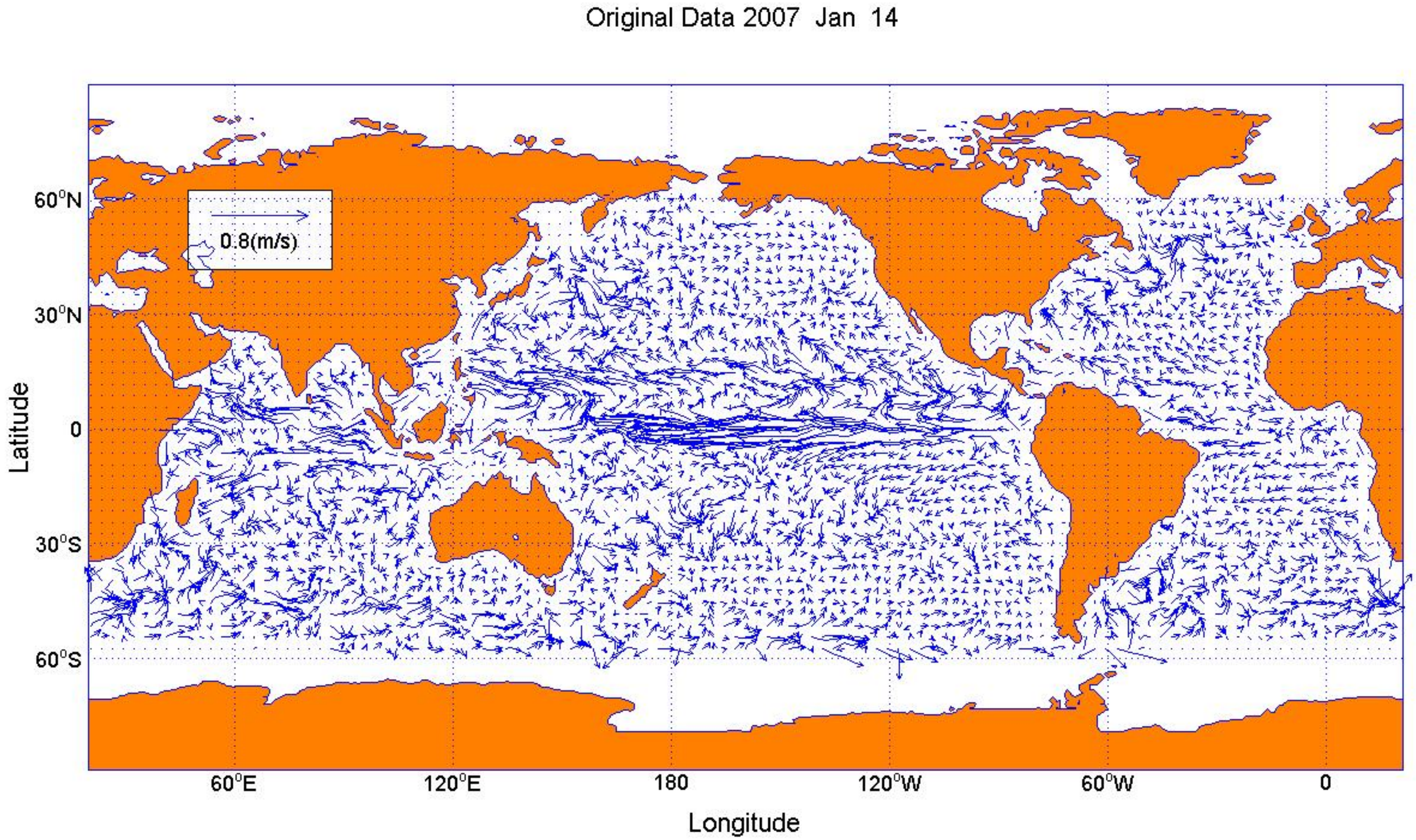
$$\mathbf{A}\hat{\mathbf{a}} = \mathbf{Q}\mathbf{Y},$$

# Rotation Method (Chu et al., 2004)

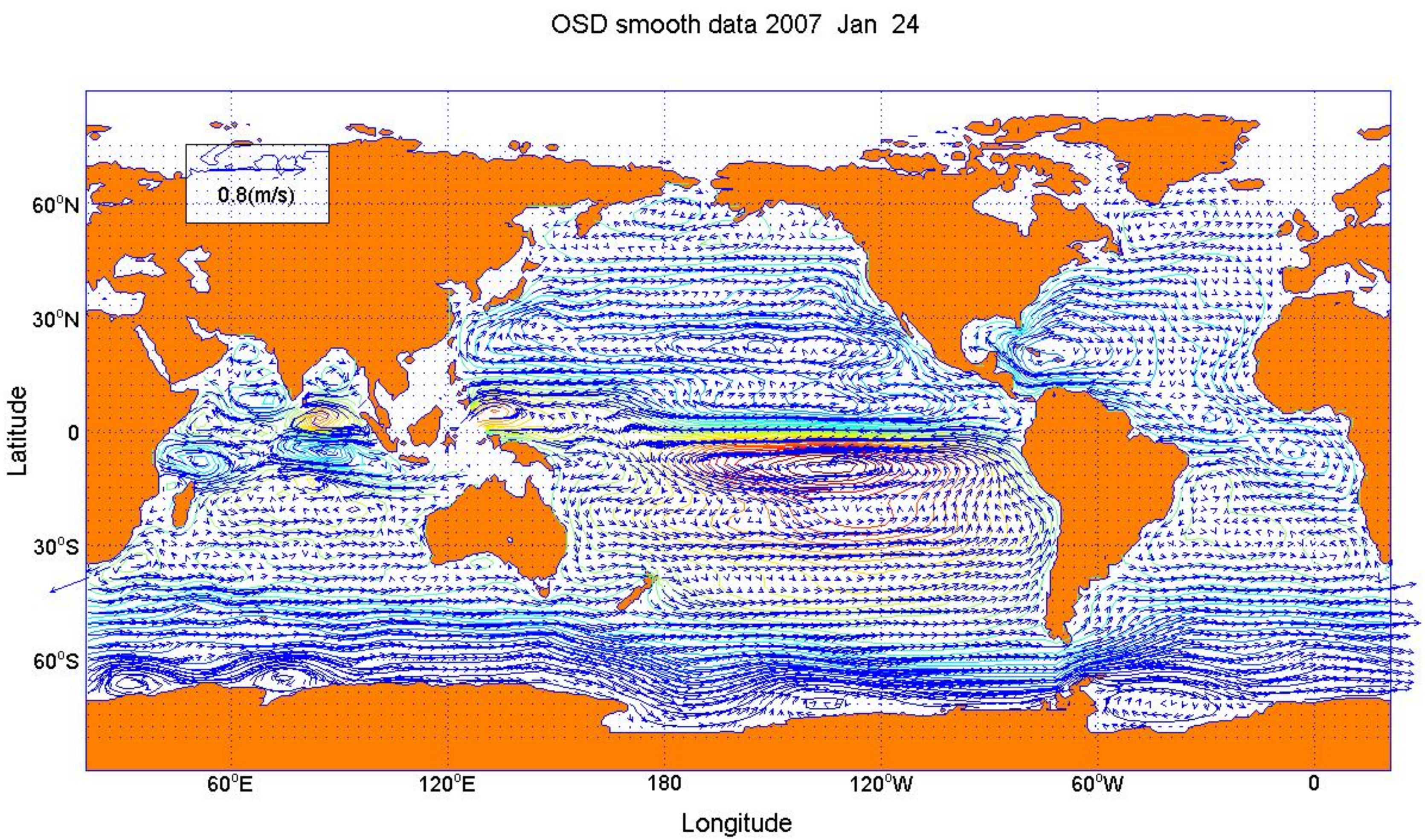
$$\mathbf{SA}\hat{\mathbf{a}} = \mathbf{SQY},$$

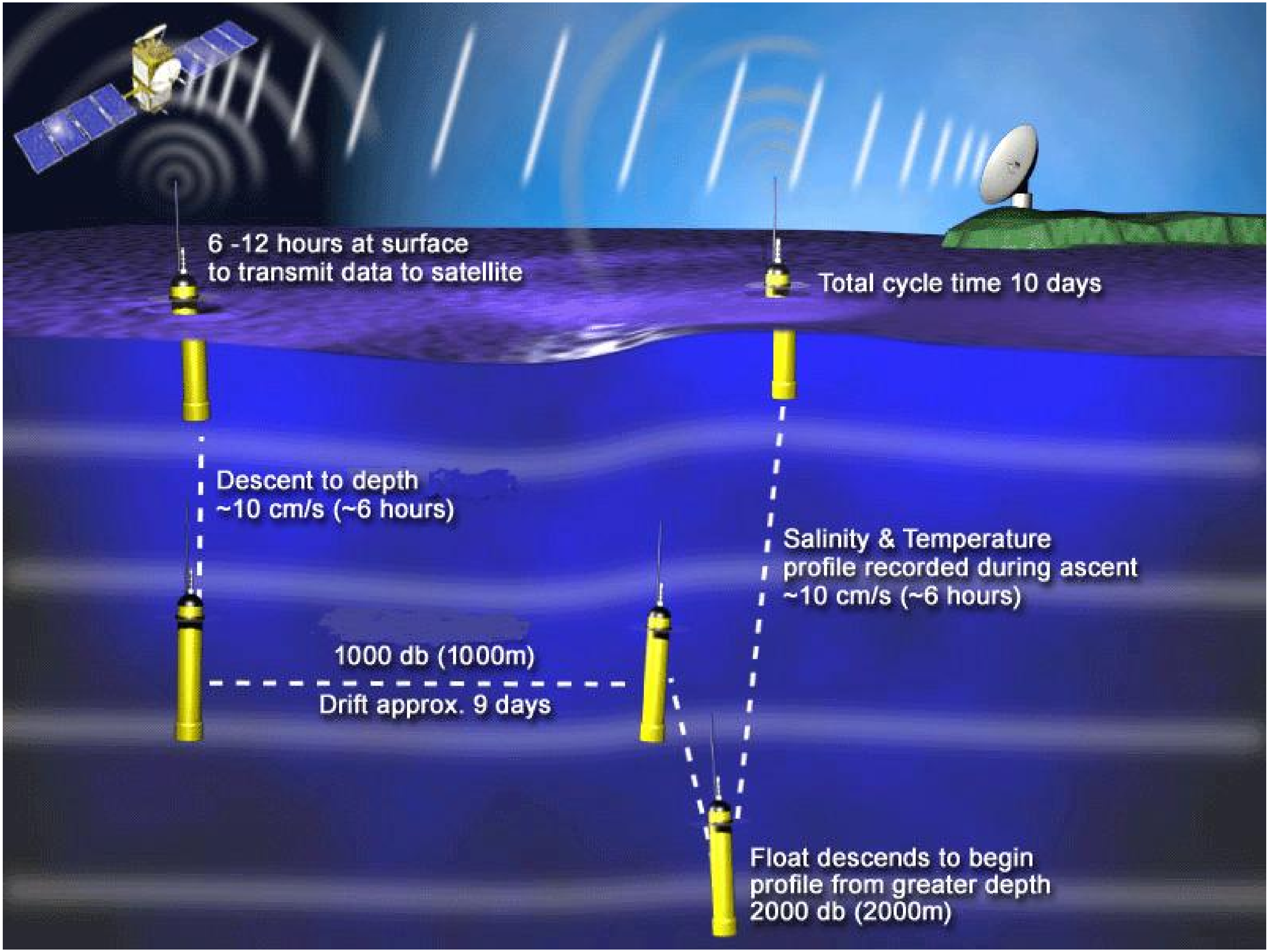
$$J_1 = \|\mathbf{A}\|^2 - \frac{\|\mathbf{SQY}\|^2}{\|\mathbf{a}\|^2} \rightarrow \max,$$

Near-realtime ocean surface currents derived from satellite altimeter and scatterometer data
NOAA OSCAR Data: http://www.oscar.noaa.gov/



# OSD on OSCAR Data

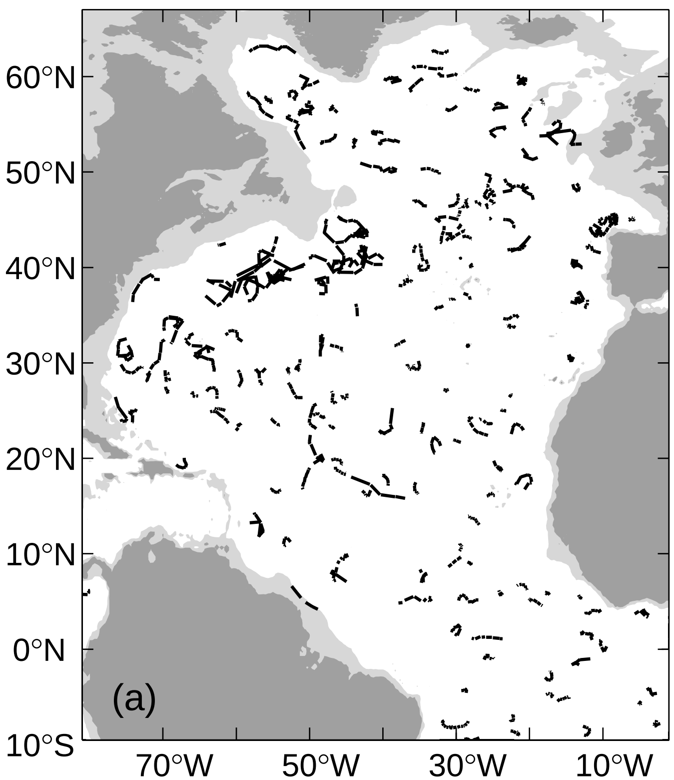


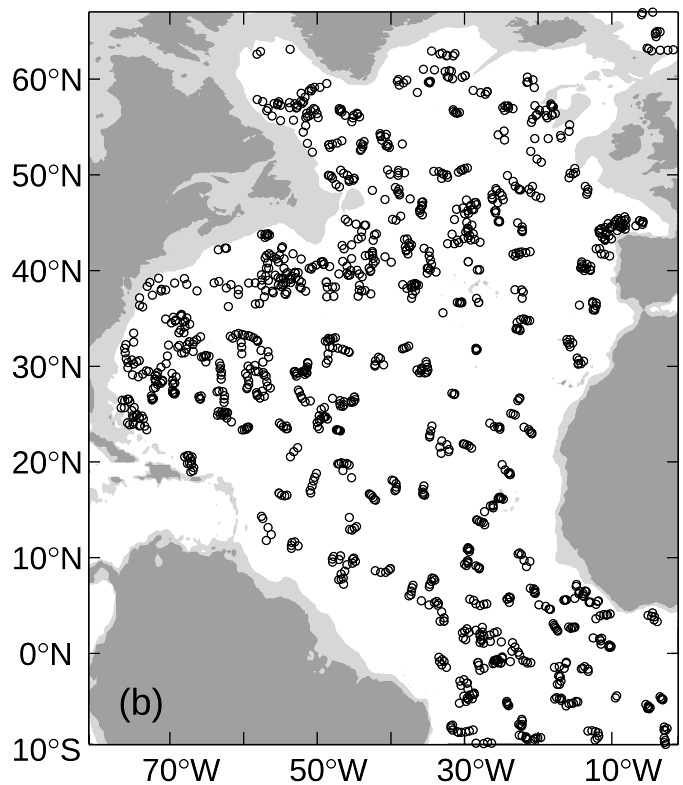

6 -12 hours at surface
to transmit data to satellite
Total cycle time 10 days
Descent to depth
~10 cm/s (~6 hours)
Salinity & Temperature
profile recorded during ascent
~10 cm/s (~6 hours)
1000 db (1000m)
Drift approx. 9 days
Float descends to begin
profile from greater depth
2000 db (2000m)

# ARGO Observations (Oct-Nov 2004)

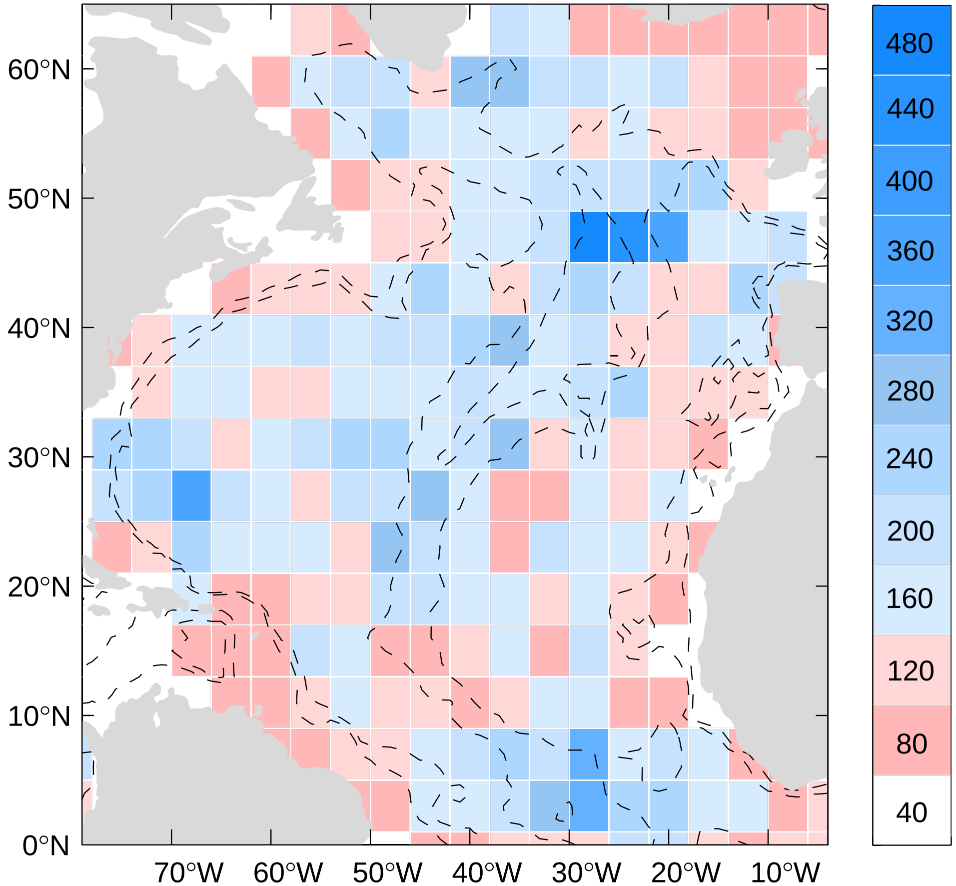
(a) Subsurface tracks

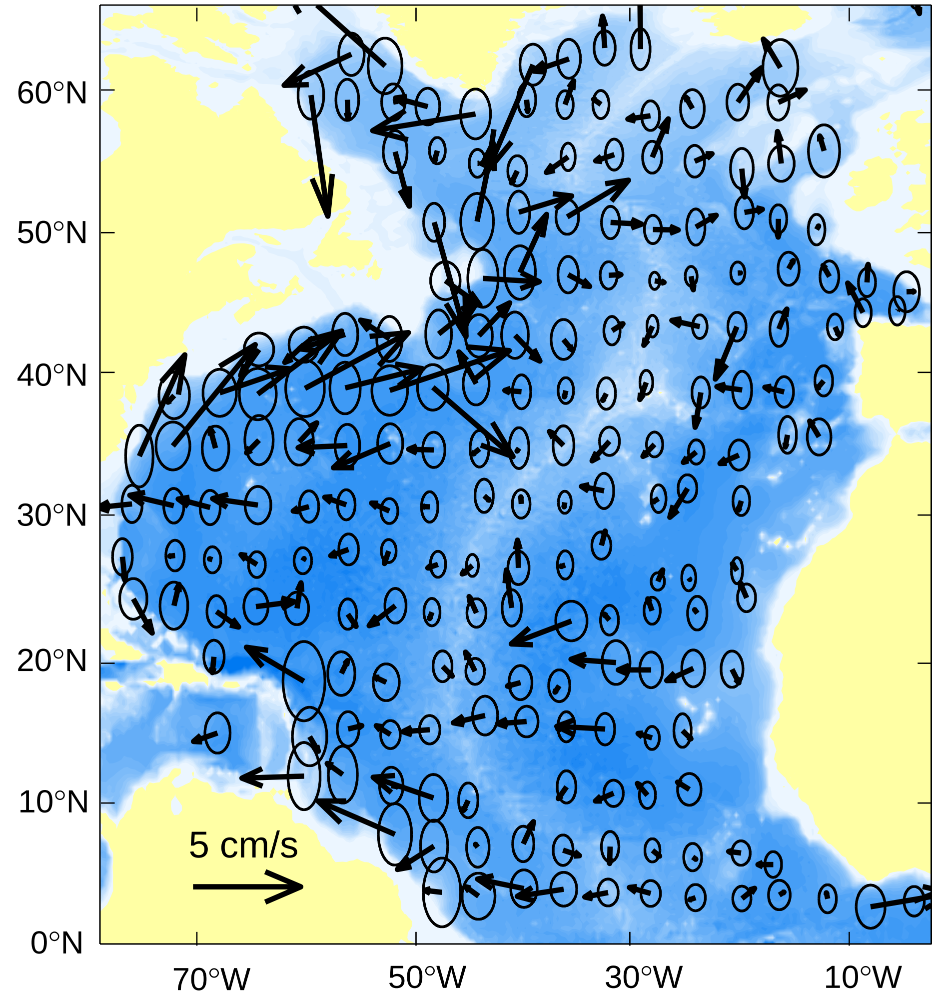
(b) Float positions where (T,S) were measured



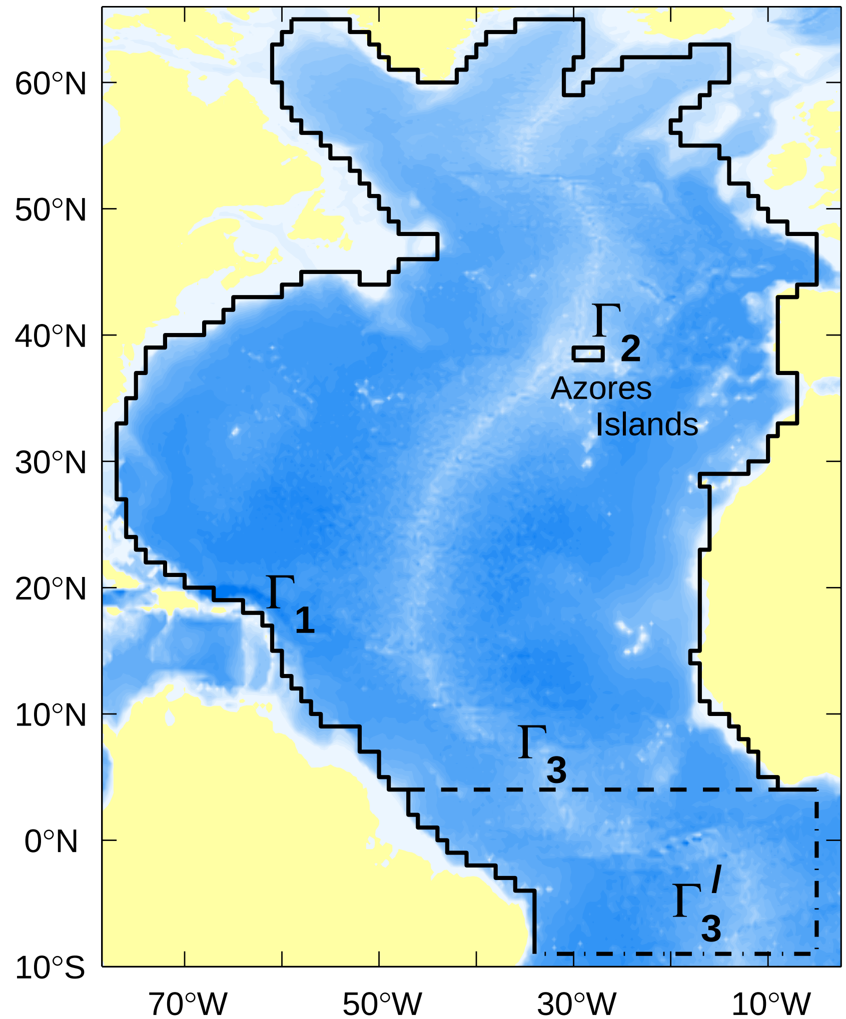
# Circulations at 1000 m estimated from the original ARGO float tracks (bin method)
# April 2004 – April 2005



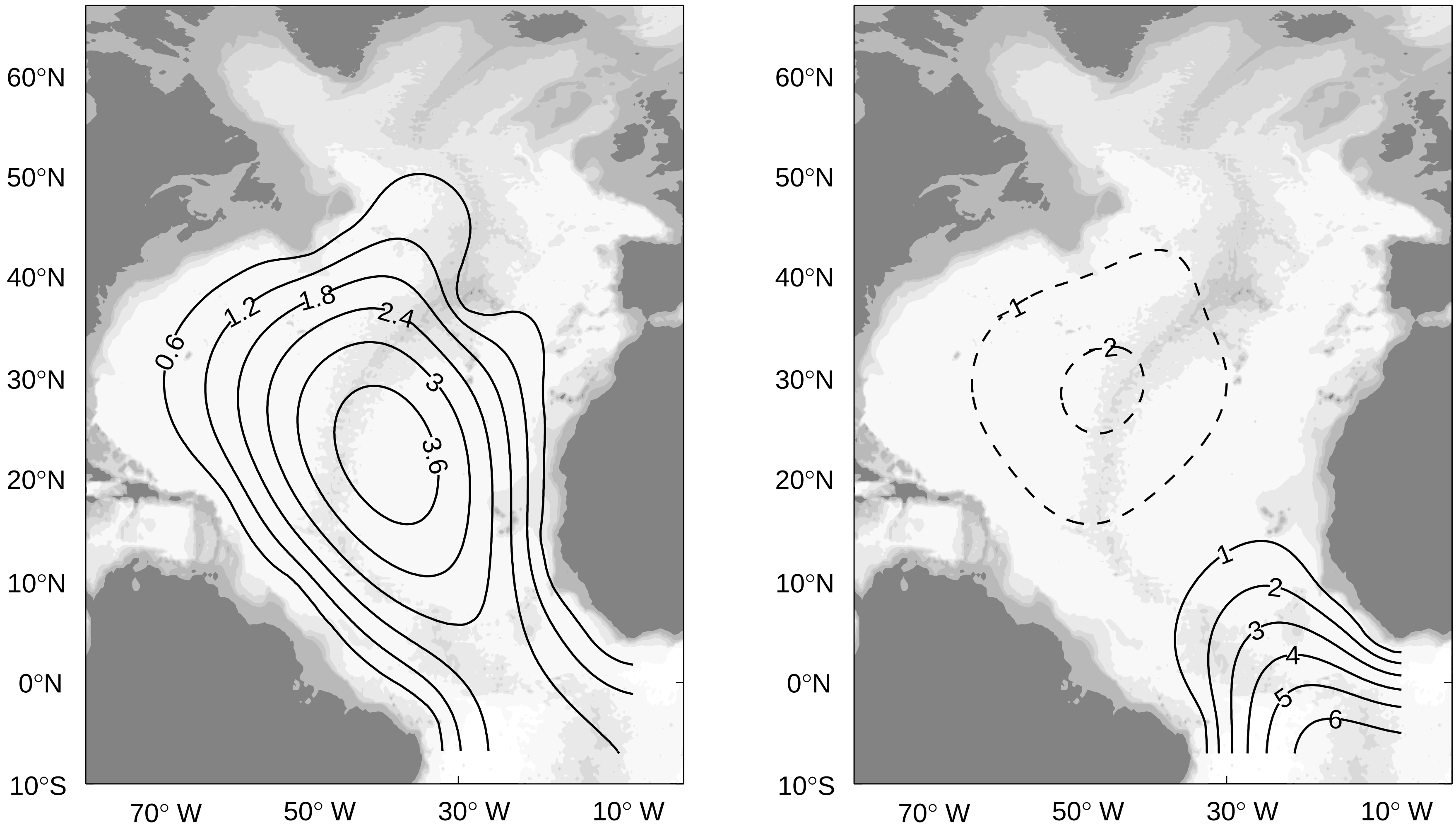




It is difficult to use such noisy data into ocean numerical models.

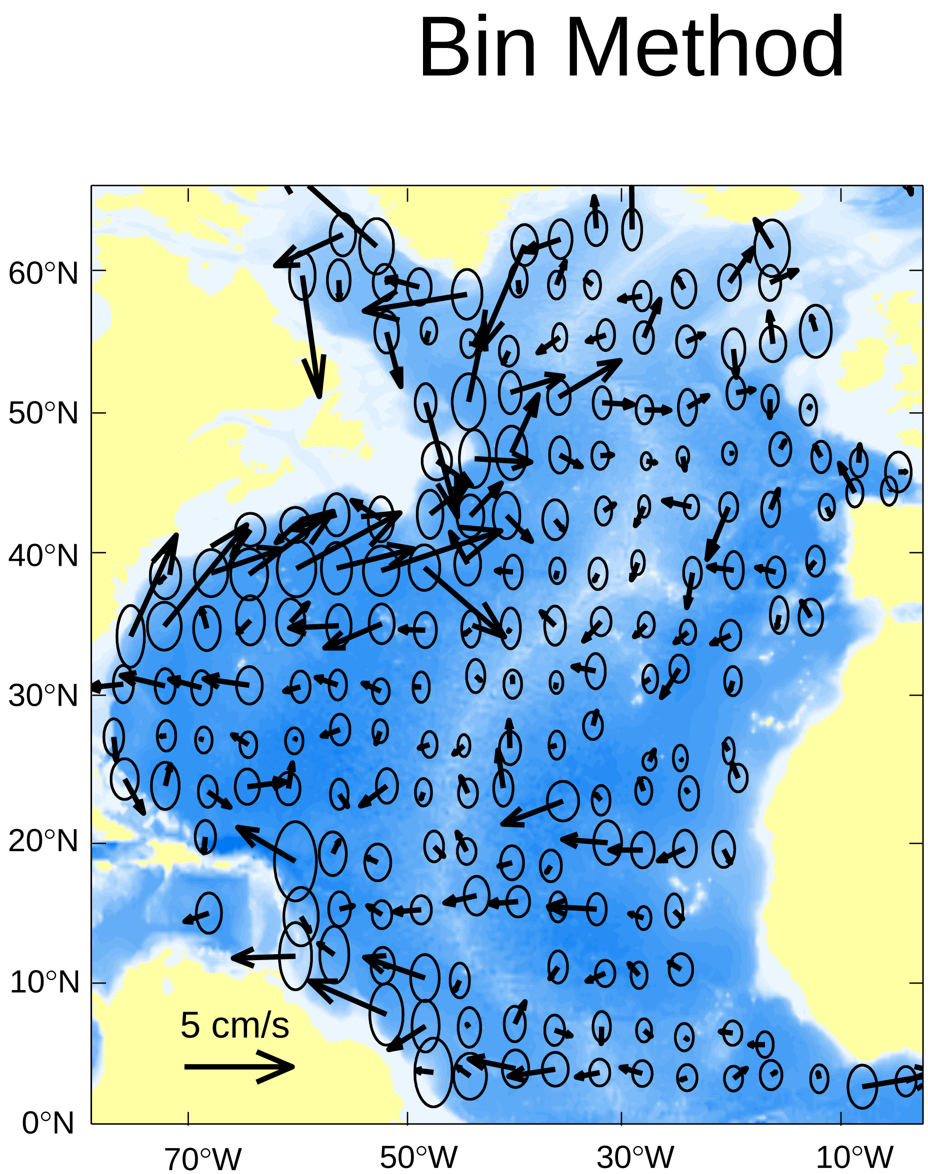
# Boundary Configuration → Basis Functions for OSD

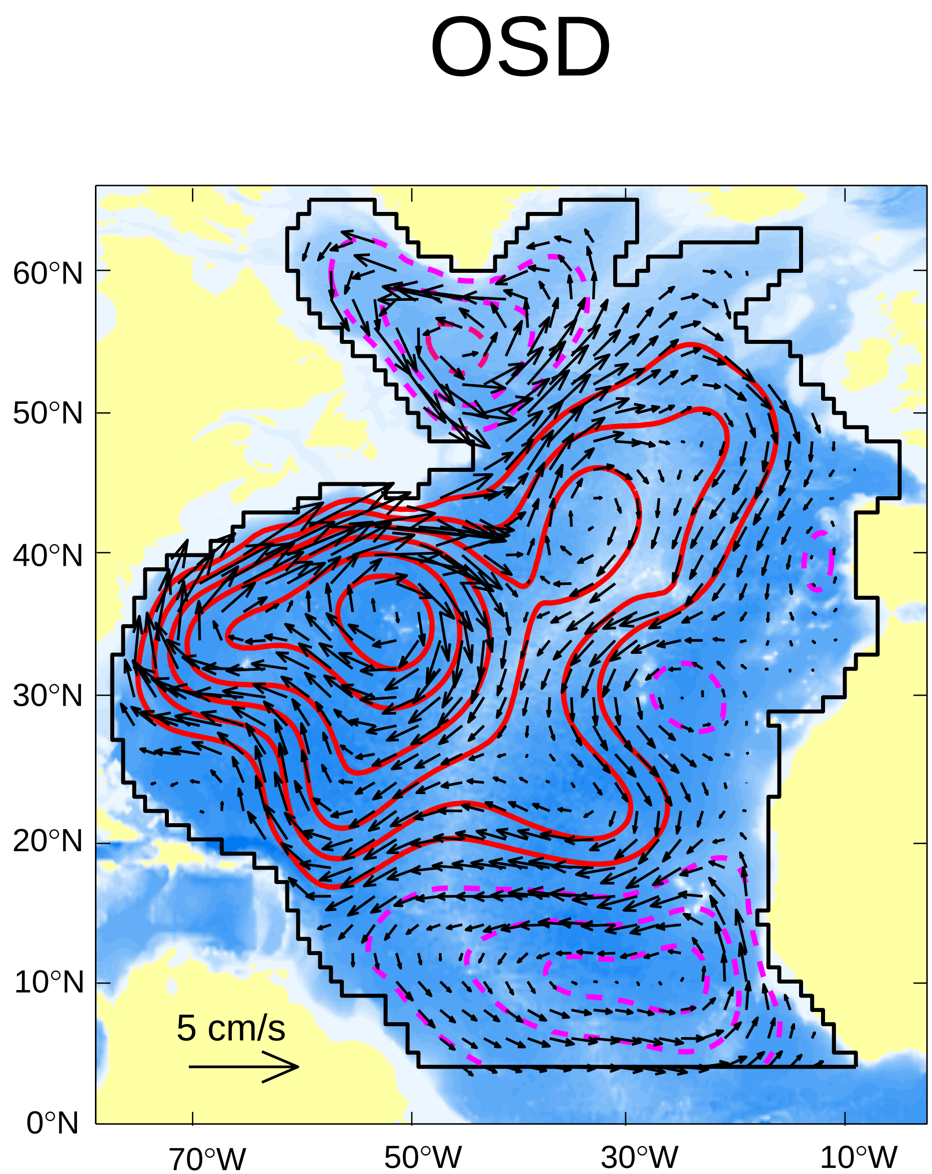


# Basis Functions for Streamfunction Mode-1 and Mode-2

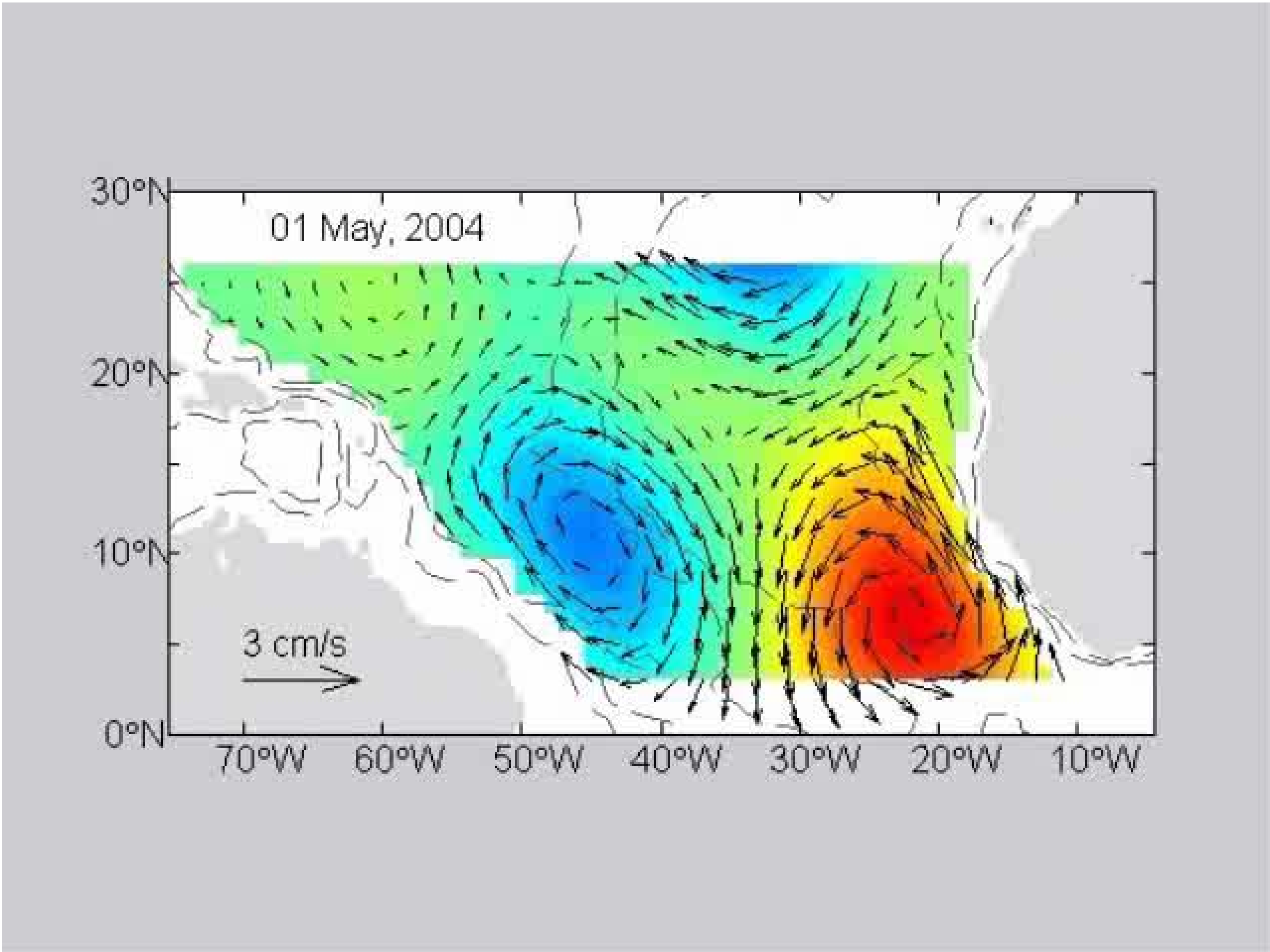


# Circulations at 1000 m (March 04 to May 05)

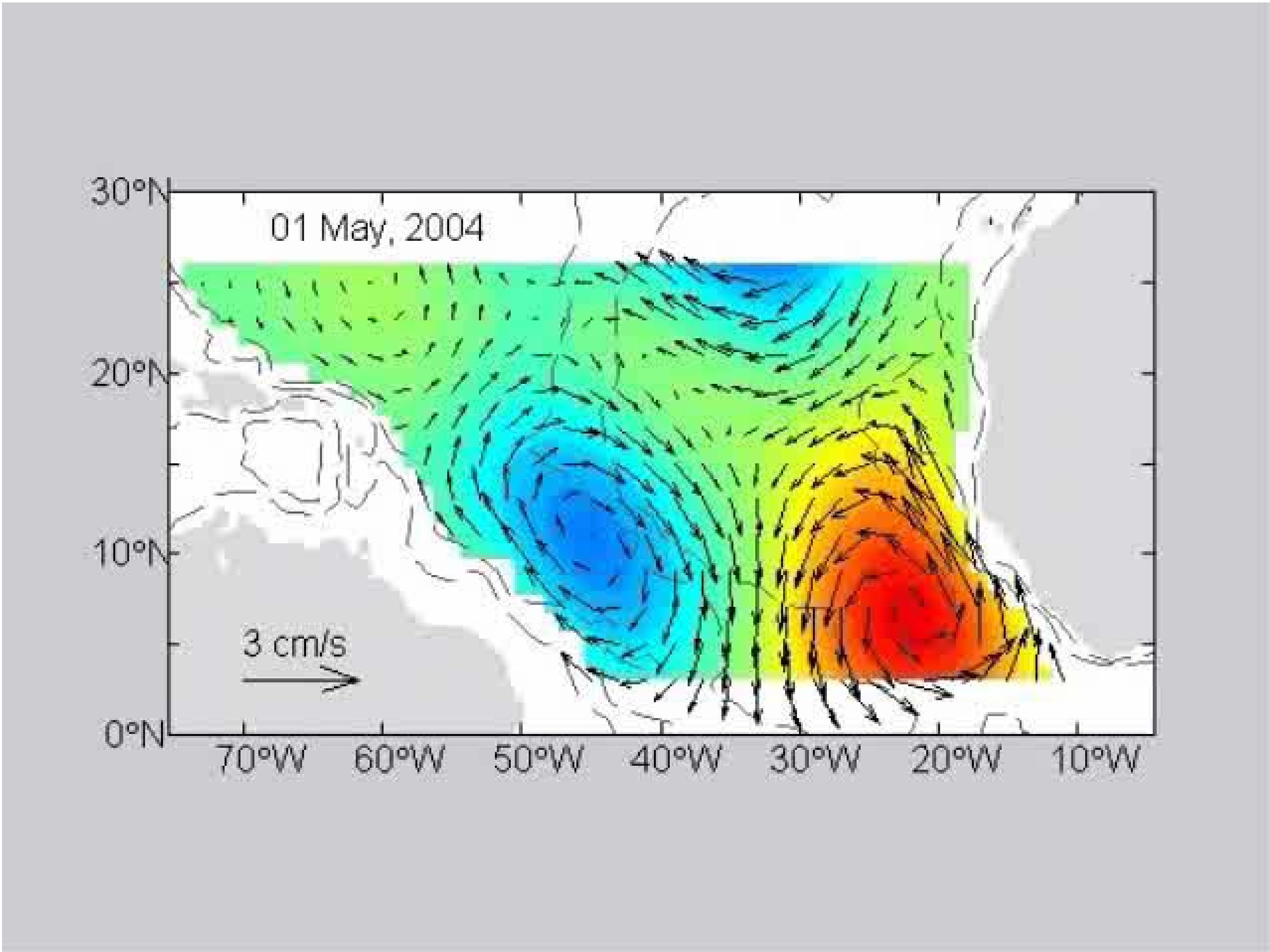


# Annual Component

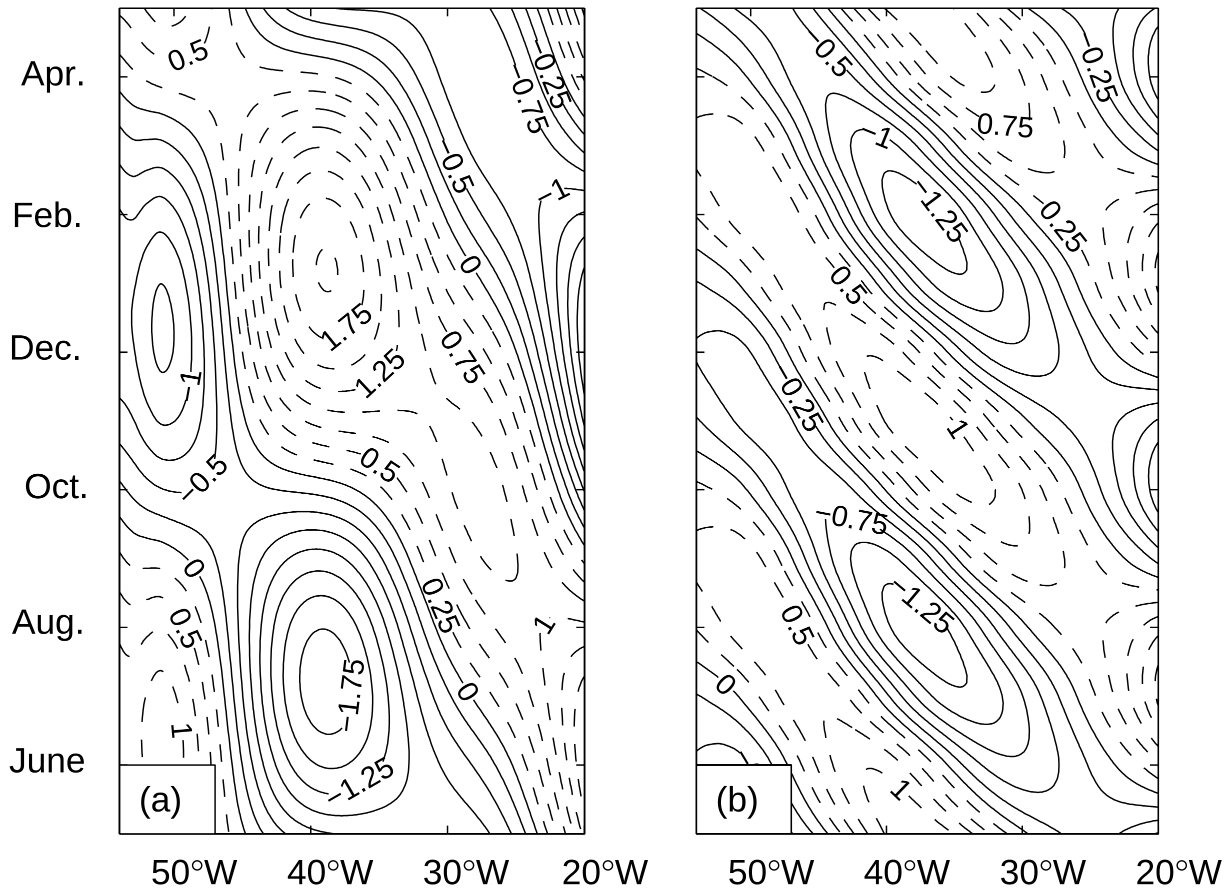


# Semi-annual Component



# Time –Longitude Diagrams of Meridional Velocity

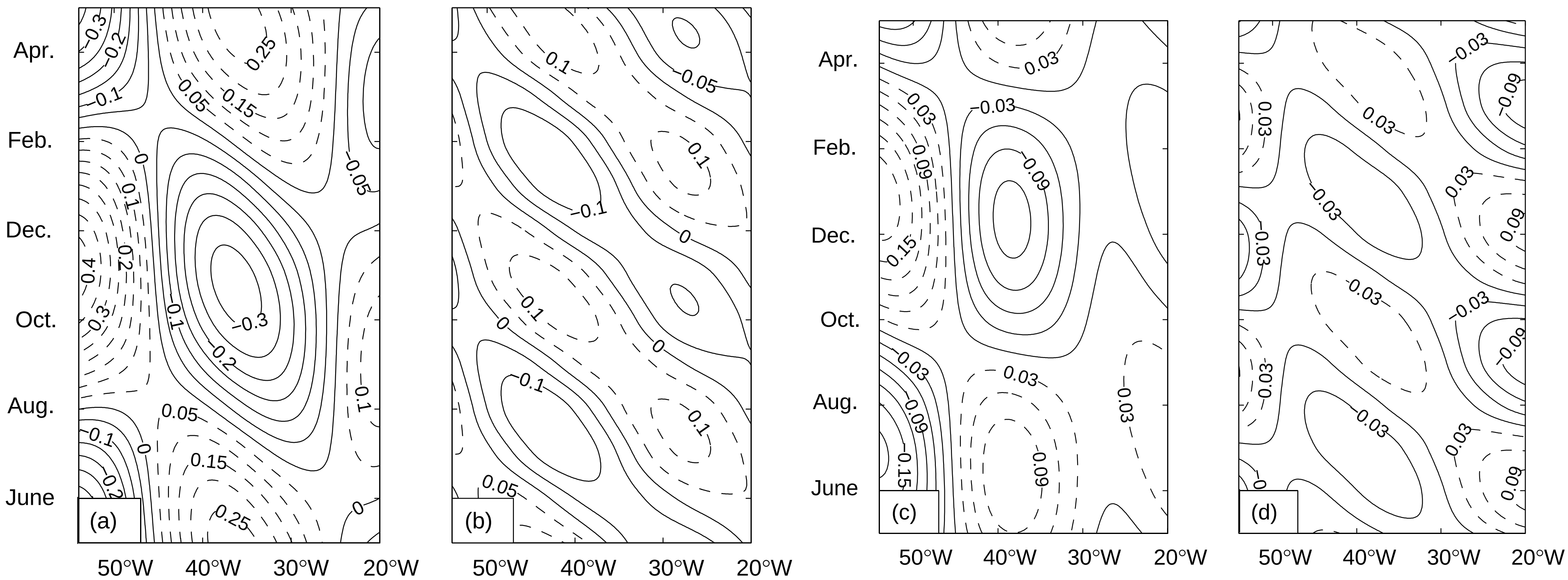
# Along 11ºN




Annual

Semi-Annual

# Time –Longitude Diagrams of temperature Along 11$^{o}$N




Annual

Semi-Annual

Annual

Semi-Annual

550 m

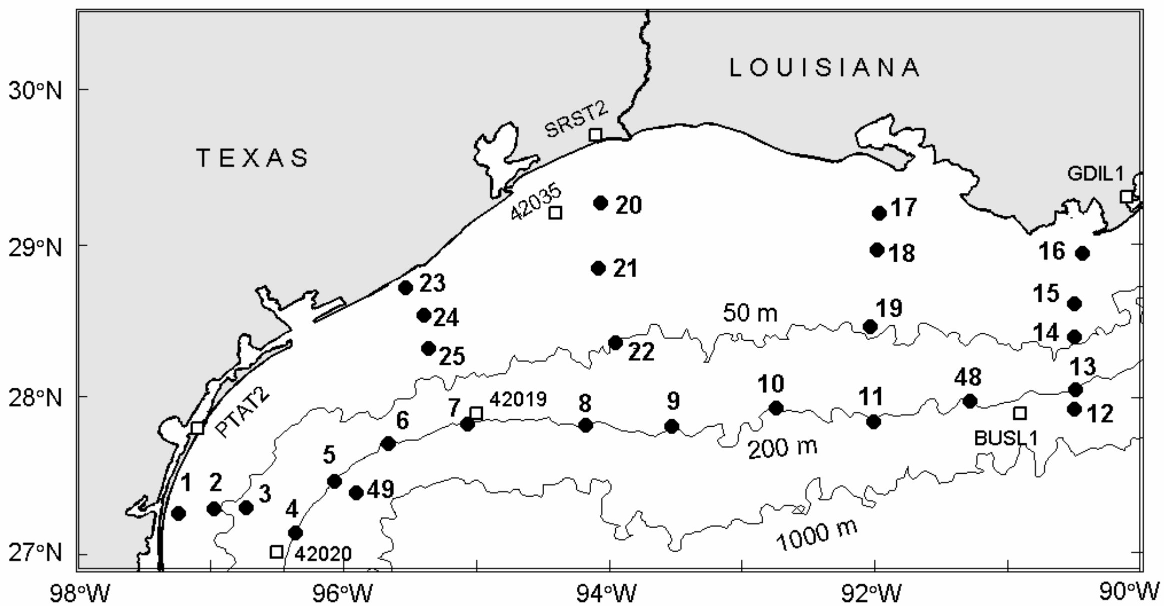
950 m

# OSD for Analyzing Combined Current Meter and Surface Drifting Buoy Data

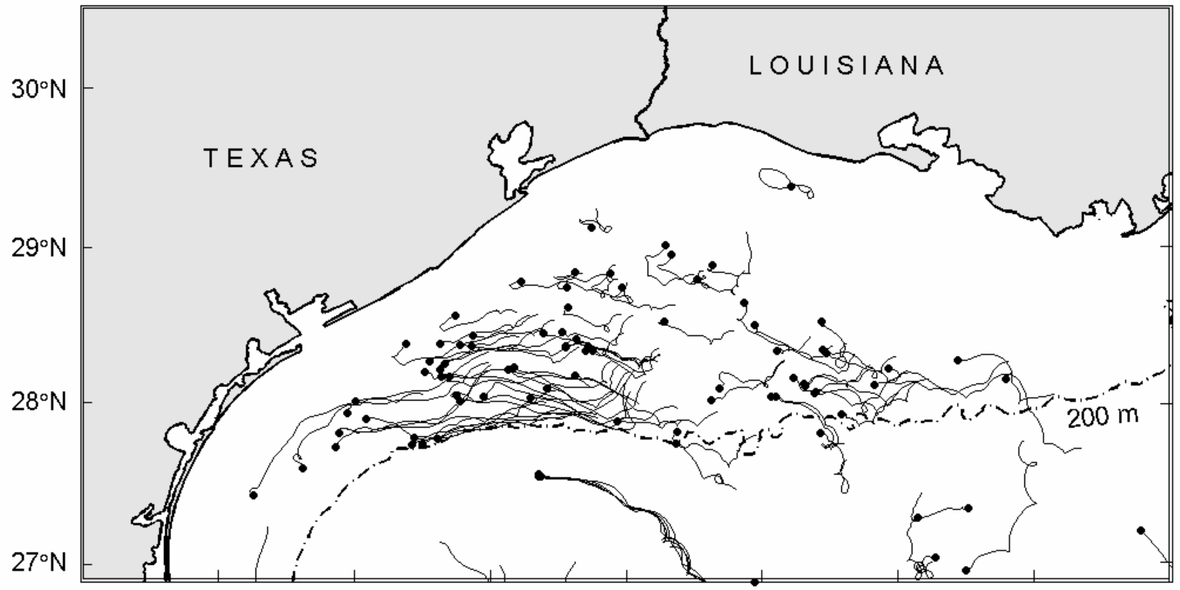
# Ocean Velocity Observation

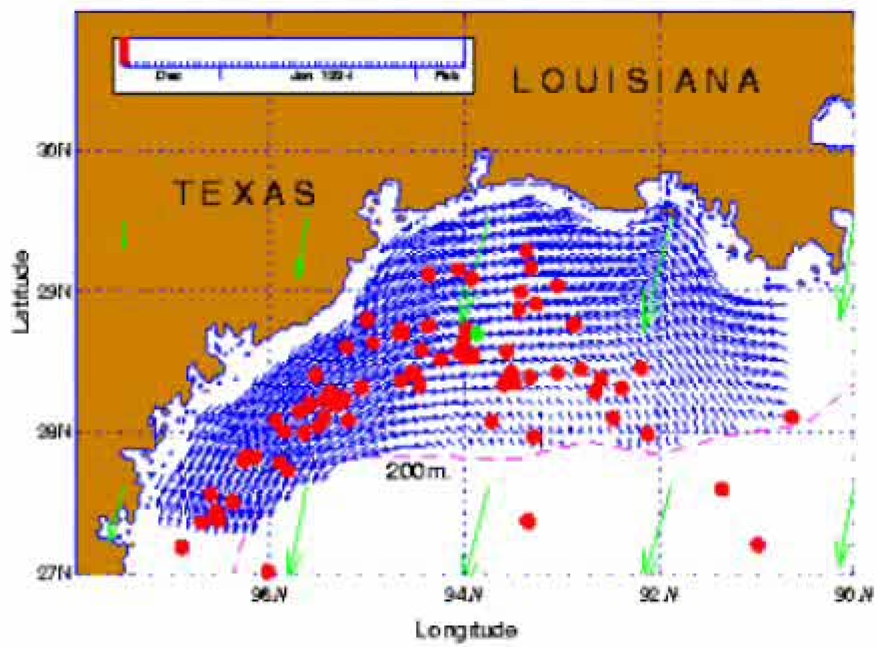
- 31 near-surface (10-14 m) current meter moorings during LATEX from April 1992 to November 1994
- Drifting buoys deployed at the first segment of the Surface Current and Lagrangian-drift Program (SCULP-I) from October 1993 to July 1994.

# Moorings and Buoys



# LTCS current reversal detected from SCULP-I drift trajectories.





Dec
Feb
LOUISIANA
TEXAS
Latitude
200m.
27N
Longitude

# Conclusions

- (1) Data analysis is important for coastal modeling and prediction.
- (2) KZ filter reduces model-data incompatibility.
- (3) OSD is an effective method for establishing gidded data from sparse and noisy ocean observations.