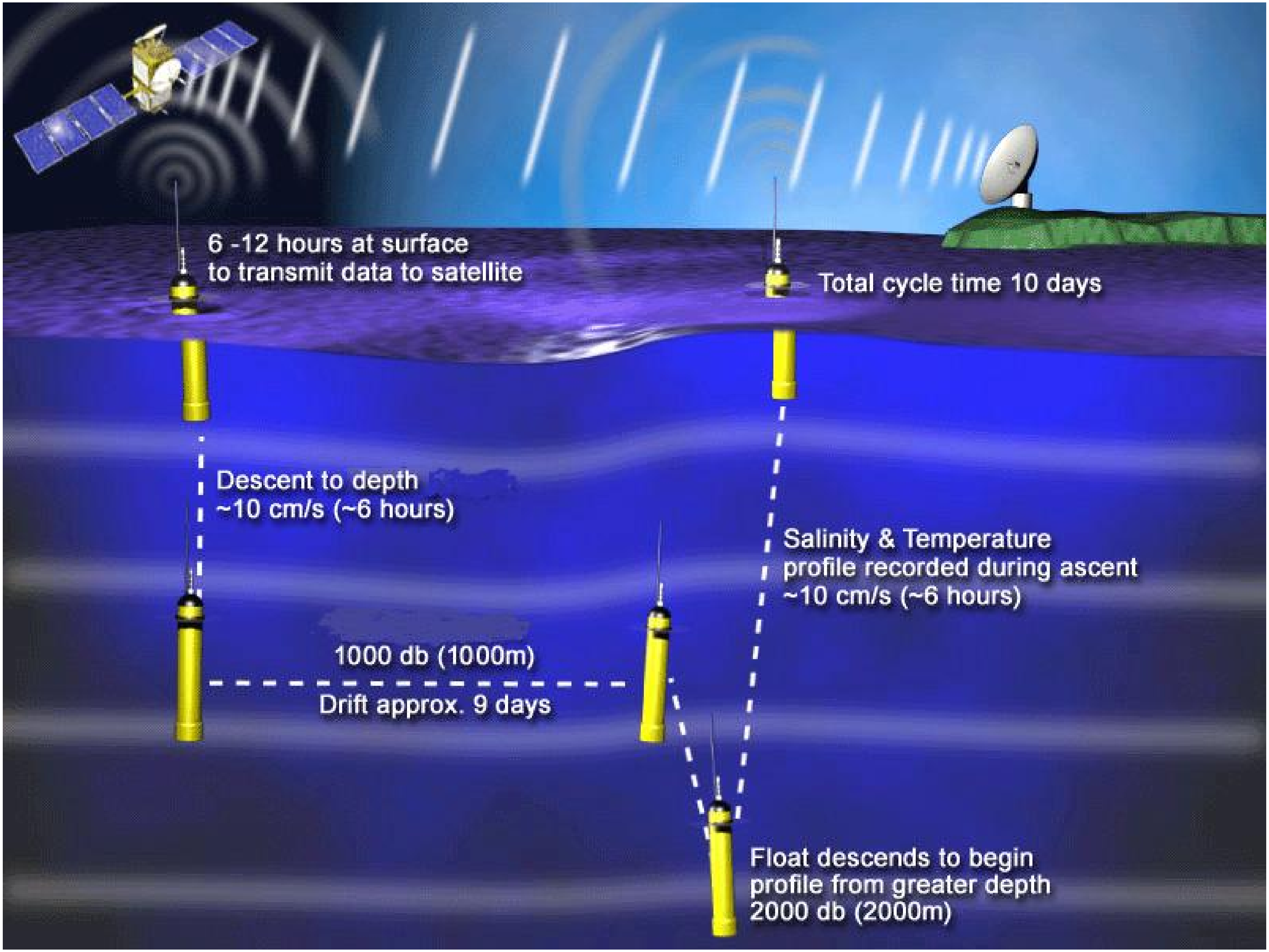
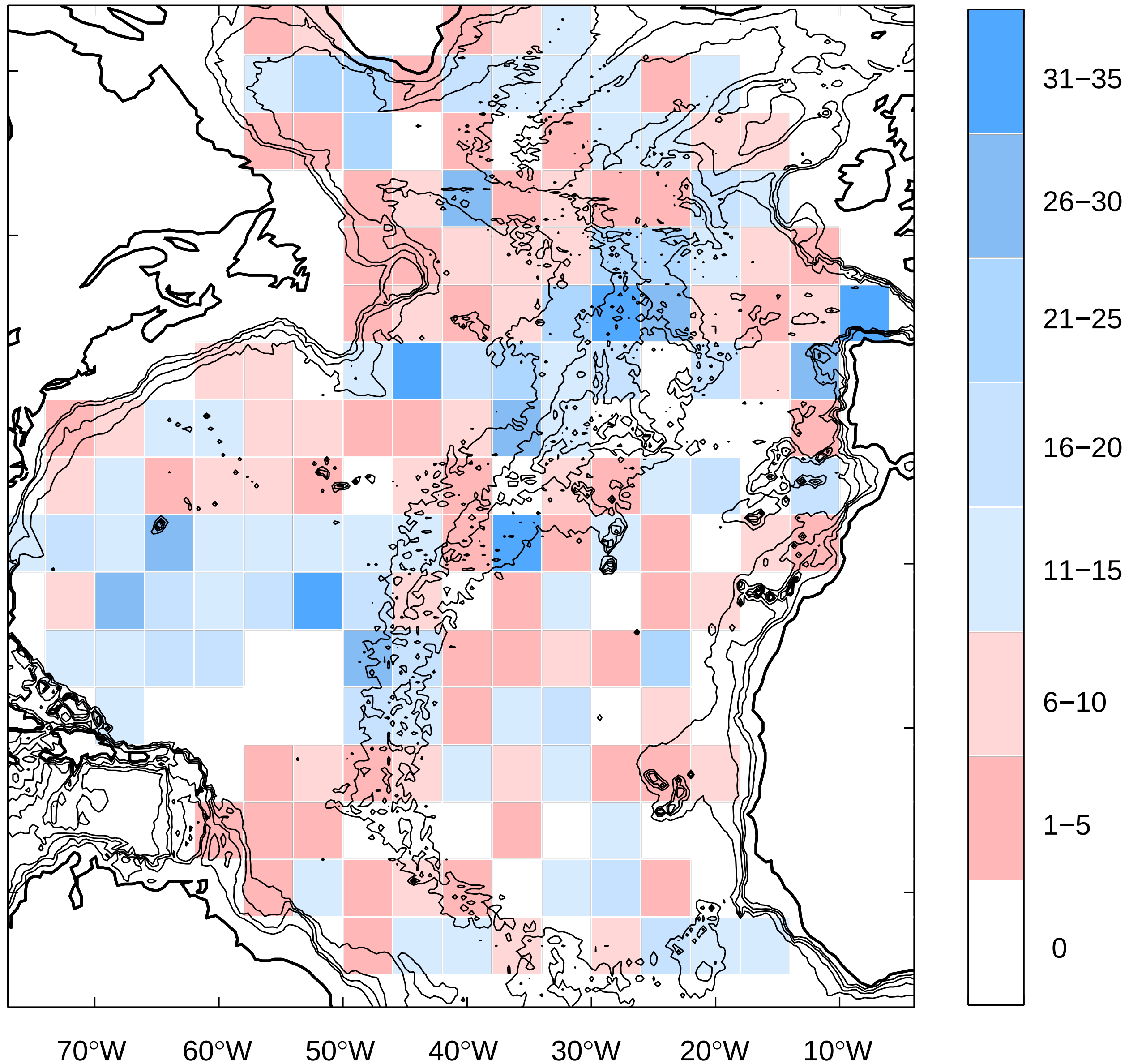
Large-Scale Mid-Depth North Atlantic Circulation Identified from ARGO Float Trajectory Data

Peter C Chu, Leonid Ivanov, Oleg Melnichenko
Naval Postgraduate School
Monterey, CA 93943
chu@nps.navy.mil
http://www.oc.nps.navy.mil/~chu

N. Wells
Southampton Oceanographic Center, UK

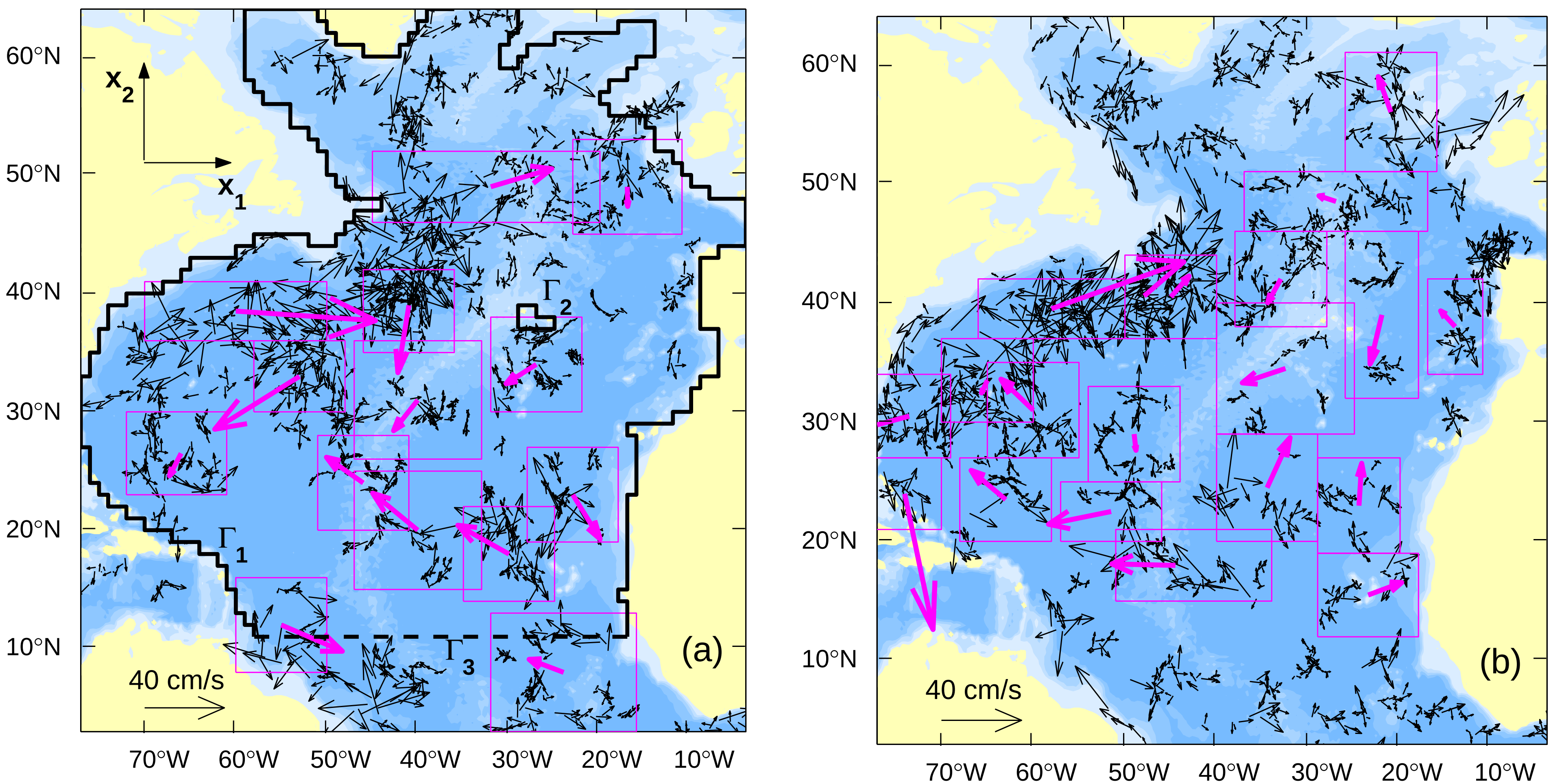

6 -12 hours at surface
to transmit data to satellite
Total cycle time 10 days
Descent to depth
~10 cm/s (~6 hours)
Salinity & Temperature
profile recorded during ascent
~10 cm/s (~6 hours)
1000 db (1000m)
Drift approx. 9 days
Float descends to begin
profile from greater depth
2000 db (2000m)

ARGO Float Coverage (Aug-Dec 2004)



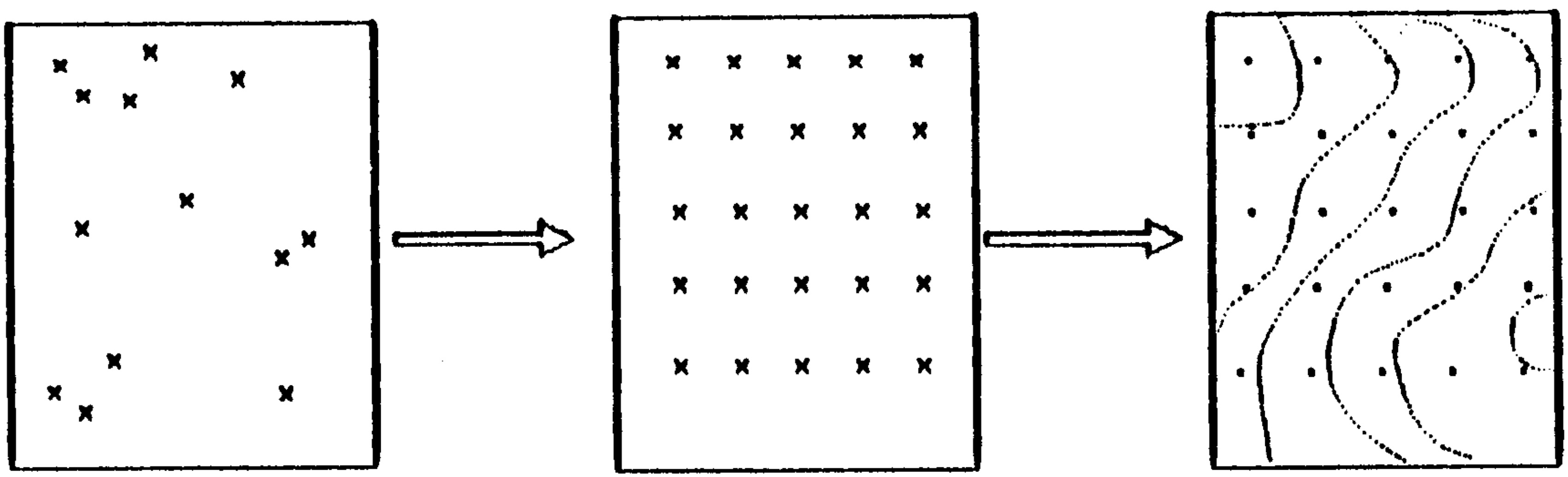
Circulation velocities (thin arrows) at 1000 m estimated from the original ARGO float tracks (bin method)

Dec 2003–Mar 2004 | Aug 2004–Nov 2004



Most Popular Method for Ocean Data Analysis

Optimum Interpolation (OI)



OI Method Requires:

- (1) First guess field
- (2) Known autocorrelation functions

Ocean velocity data

- (1) First guess field (?)

- (2) Unknown autocorrelation function

Two Ways Out

- (1) Using numerical model to calculate the first guess field and autocorrelation function (Davis, 2002, 2004)

- (2) Using the OSD method

OSD
Spectral Representation

$$c(\mathbf{x}, z_k, t) = A_0(z_k, t) + \sum_{m=1}^{M} A_m\left(z_k, t\right)\ \Psi_m\left(\mathbf{x}, z_k\right),$$

Spatial Variability is represented by the basis functions

References

- Chu, P.C., L.M. Ivanov, T.P. Korzhova, T.M. Margolina, and O.M. Melnichenko, 2003a: Analysis of sparse and noisy ocean current data using flow decomposition. Part 1: Theory. Journal of Atmospheric and Oceanic Technology, 20 (4), 478-491.

- Chu, P.C., L.M. Ivanov, T.P. Korzhova, T.M. Margolina, and O.M. Melnichenko, 2003b: Analysis of sparse and noisy ocean current data using flow decomposition. Part 2: Application to Eulerian and Lagrangian data. Journal of Atmospheric and Oceanic Technology, 20 (4), 492-512.

- Chu, P.C., L.M. Ivanov, and T.M. Margolina, 2004: Rotation method for reconstructing process and field from imperfect data. International Journal of Bifurcation and Chaos, 14 (8), 2991-2997.

- These papers can be downloaded from:
- http://www.oc.nps.navy.mil/~chu

Two approaches to obtain basis functions

- EOFs

- Eigenfunctions of Laplace Operator
- (closed lateral boundary)

$$\nabla_h^2 \Psi_m = -\lambda_m \Psi_m, \quad \Psi_m |_\Gamma = 0, \quad m = 1, 2, \ldots, M$$

Basis Functions of Laplace Operator (Open Boundaries)

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

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

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

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

Spectral Decomposition

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

Optimal Mode Truncation

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

Vapnik (1983) Cost Function

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

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

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

Optimal Truncation

- ARGO Data (Mid-Depth North Atlantic)

  Kopt = 38, Mopt = 24

Determination of Spectral Coefficients (Ill-Posed Algebraic Equation)

$$\mathbf{A}\hat{\mathbf{a}} = \mathbf{QY},$$

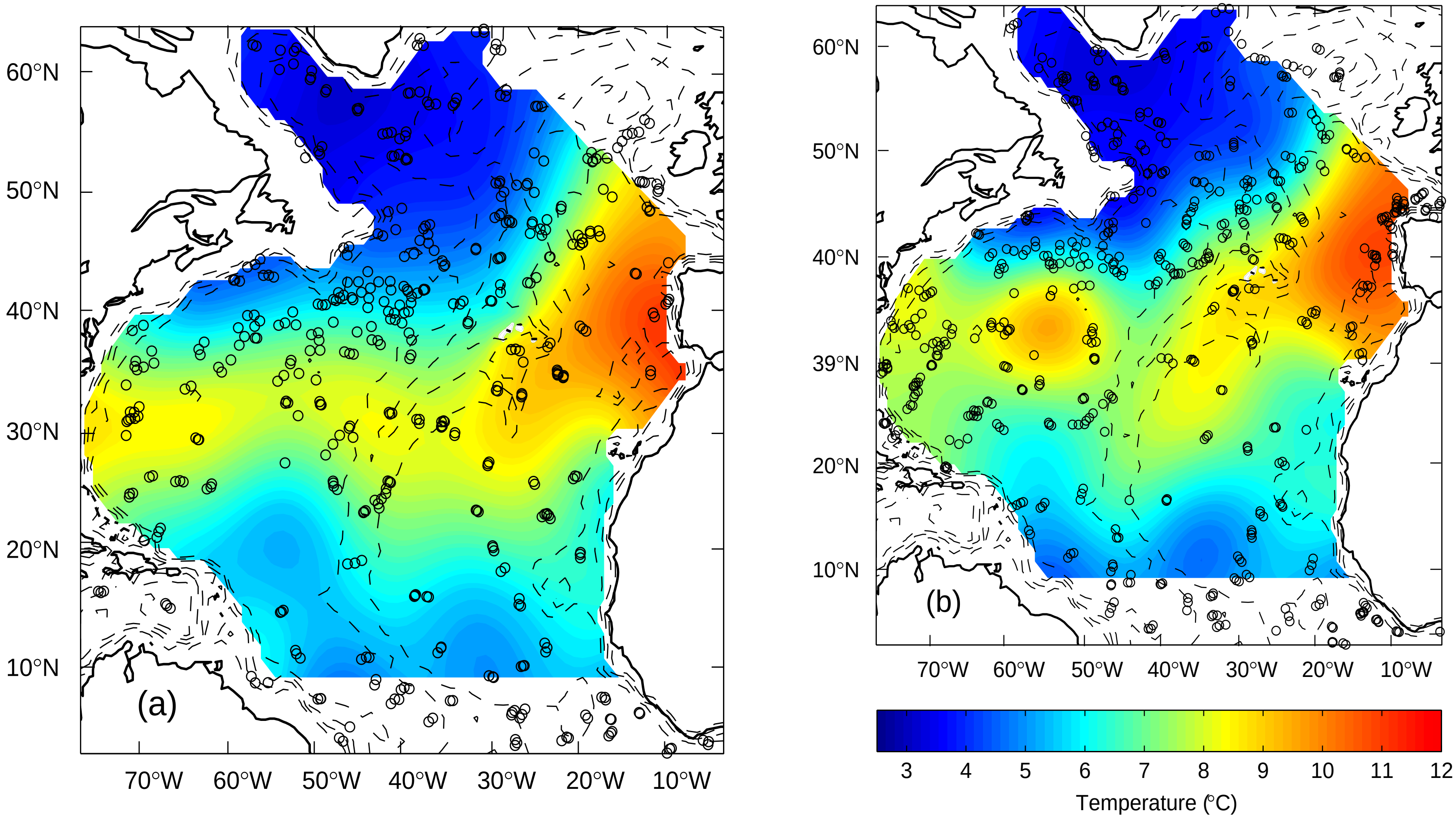
Rotation Method for Solving Ill-Posed Algebraic Equation (Chu et al., 2004)

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

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

Temperature

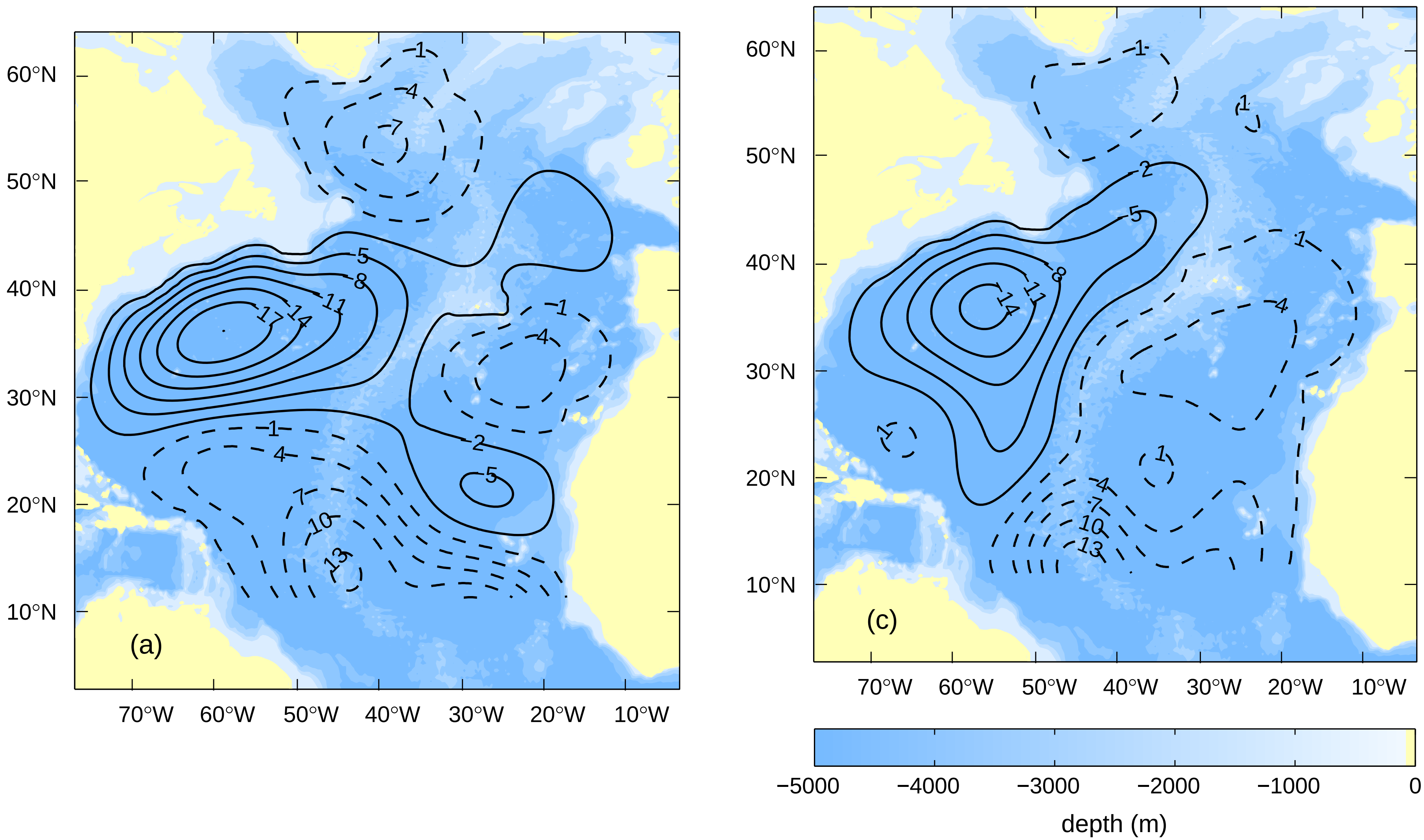
Feb 04 (Mode-1) Dec04 (Mode-2)



Streamfunction (10^3 m^2/s)

Mode-1
Dec03 – Mar04

Mode-2
Aug-Dec04



Bi-Modality Structure

- Mode-1: Advection pathways to cross the mid-Atlantic Ridge
- Mode-2: No advection pathways
- Reid (1994) identified Mode-2 as the mid-depth north Atlantic Circulation pattern.

Conclusions

- OSD is a useful tool for processing real-time velocity data with short duration and limited-area sampling especially the ARGO data.
- The scheme can handle highly noisy data.
- The scheme is model independent.
- The scheme can be used for velocity data assimilation.