Long Baroclinic Rossby Waves Identified in the Tropical Atlantic from ARGO Floats

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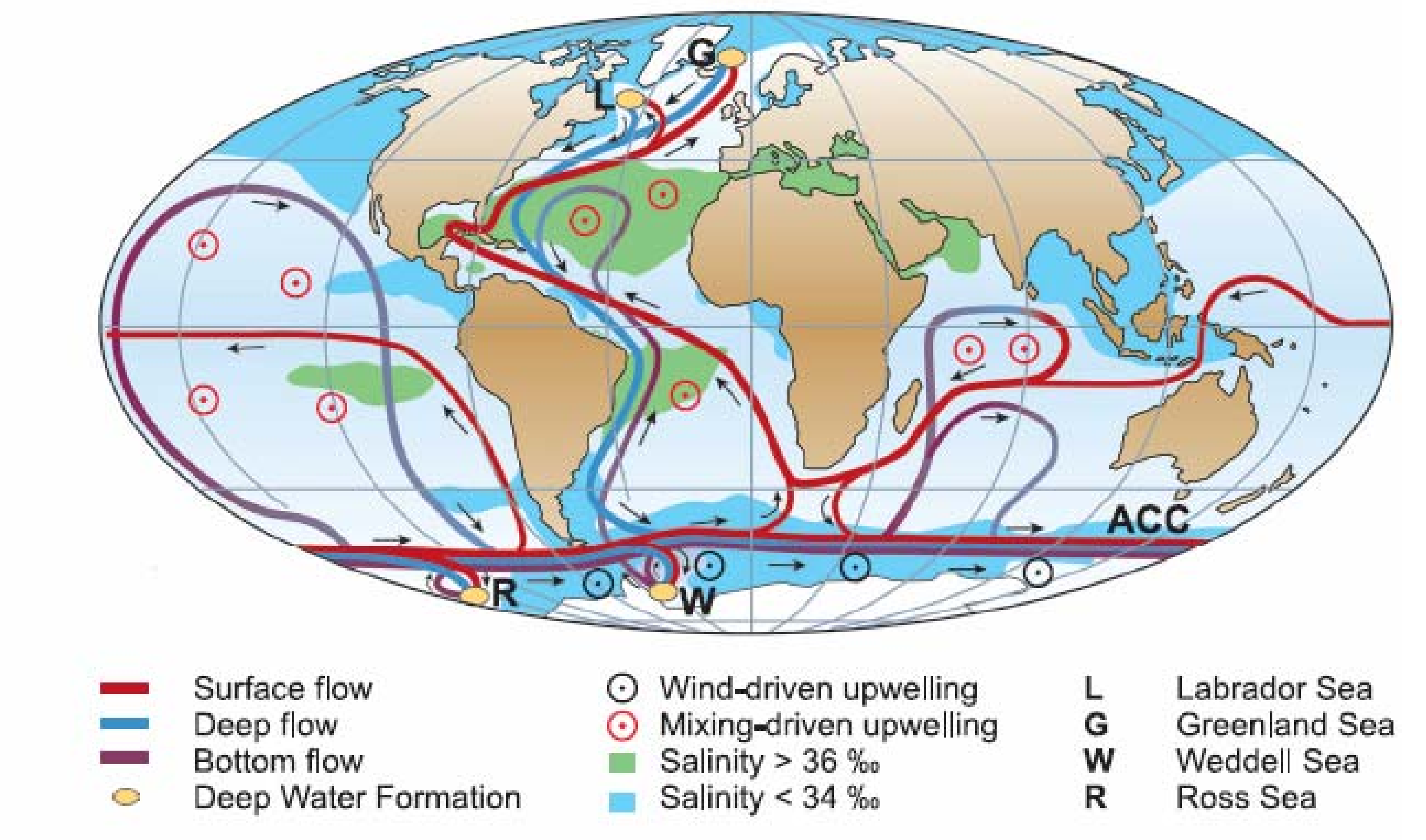
Important Element in Climate System
Meridional Overturning Circulation (MOC)

(Rahmstorf 2006)



Mid-Depth (1000 m) Circulation →

MOC Variation →

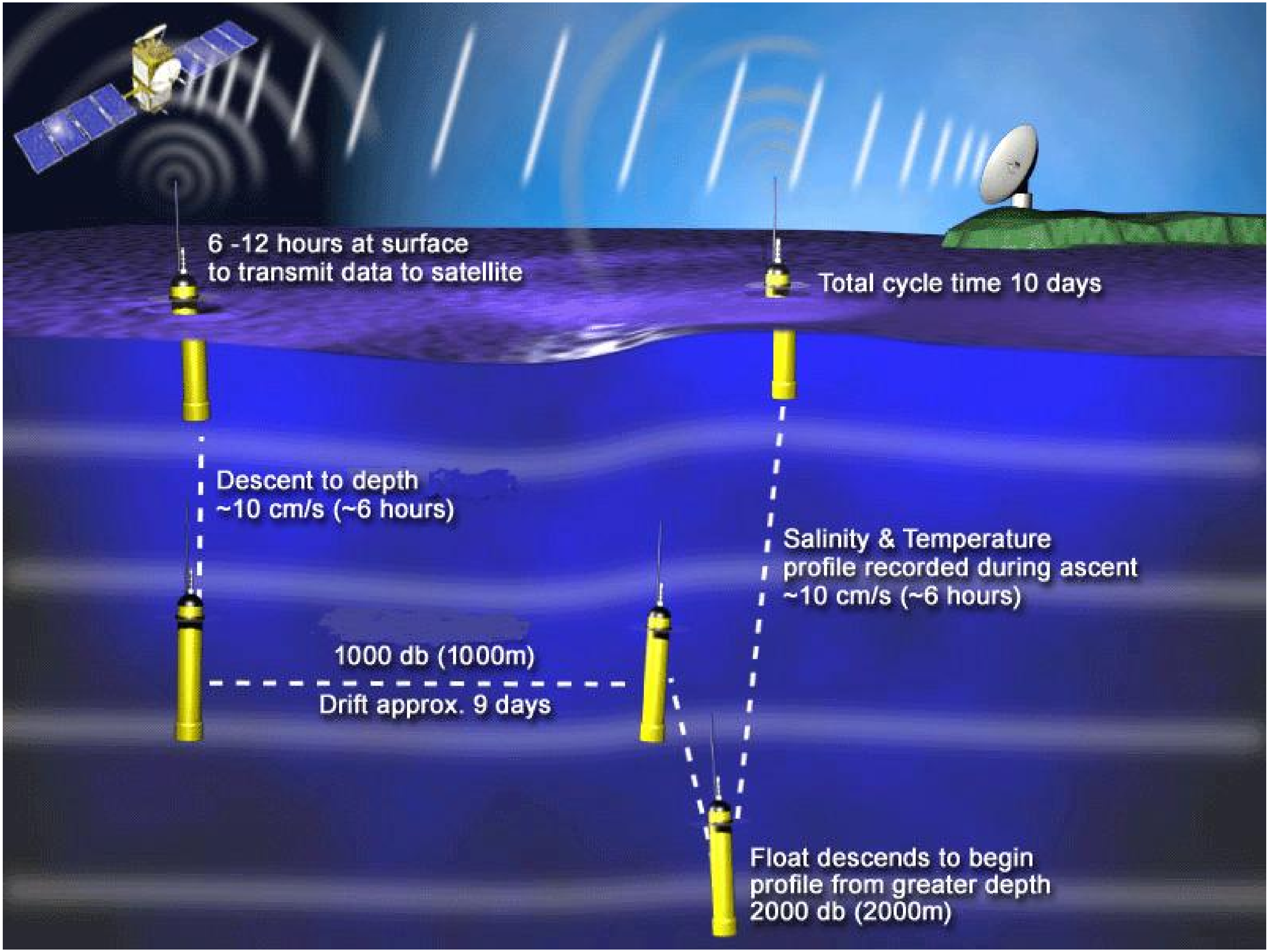
Heat Transport Variation →

Climate Change

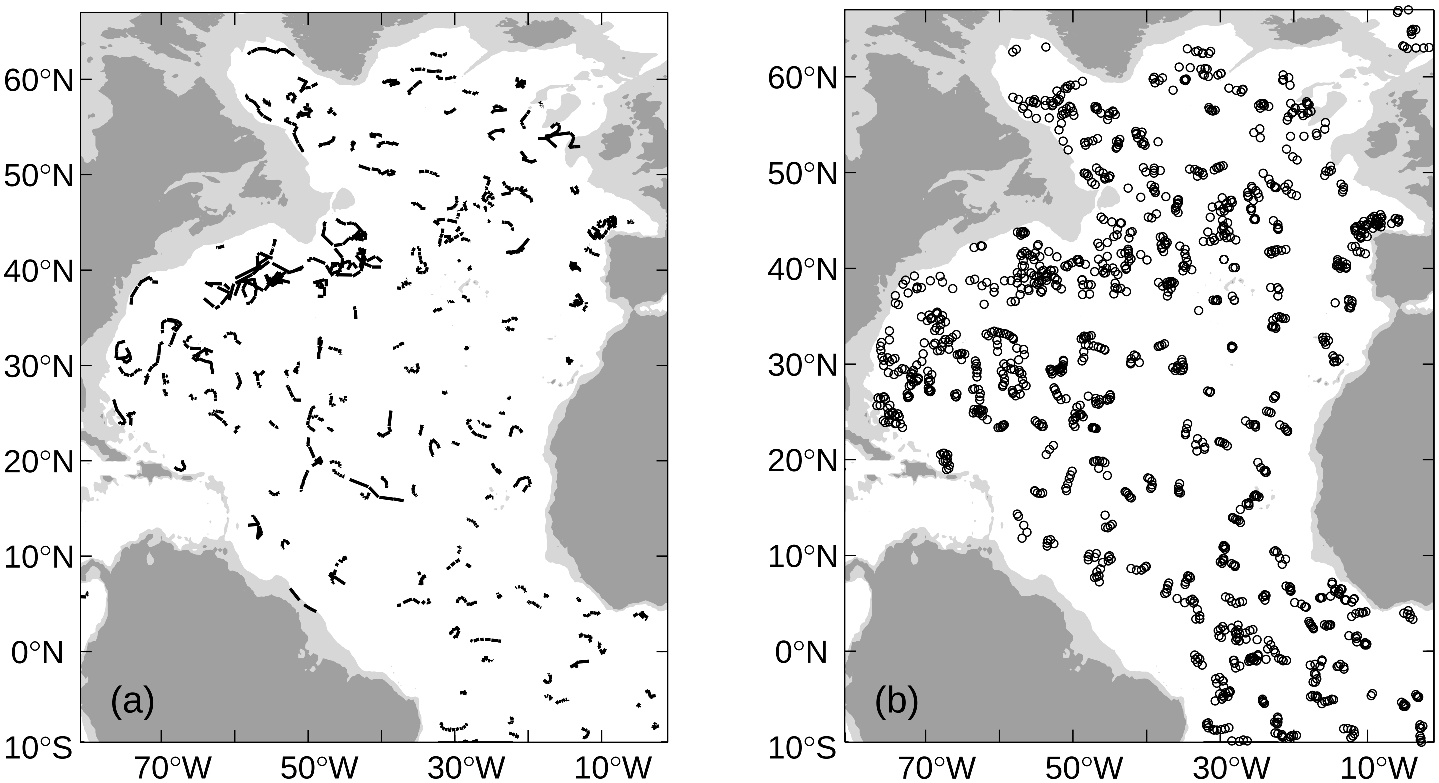
- Q1: Are mid-depth (~1000 m) ocean circulations steady?

- Q2: If not what mechanisms cause the change?

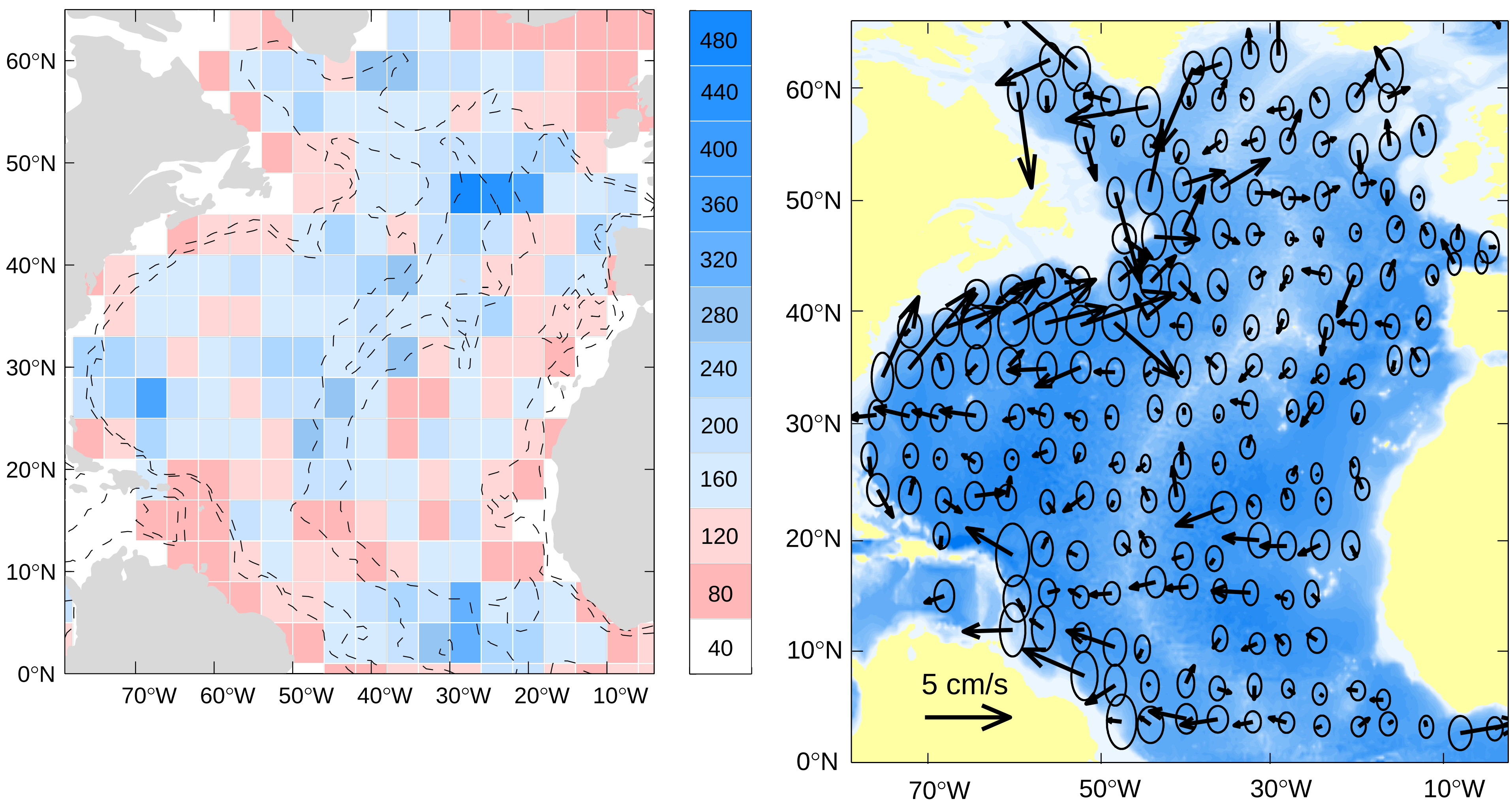
A: Rossby wave propagation


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)

October-November 2004 ARGO (a) float tracks, and (b) float positions where temperature profiles were measured.



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



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.

- Chu, P.C., L.M. Ivanov, and O.M. Melnichenko, 2005: Fall-winter current reversals on the Texas-Lousiana continental shelf. Journal of Physical Oceanography, 35, 902-910

- Chu, P.C., L.M. Ivanov, O.M. Melnichenko, and N.C. Wells, 2007: On long baroclinic Rossby Waves in the tropical North Atlantic observed from profiling floats. Journal of Geophysical Research – Oceans, in press.

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

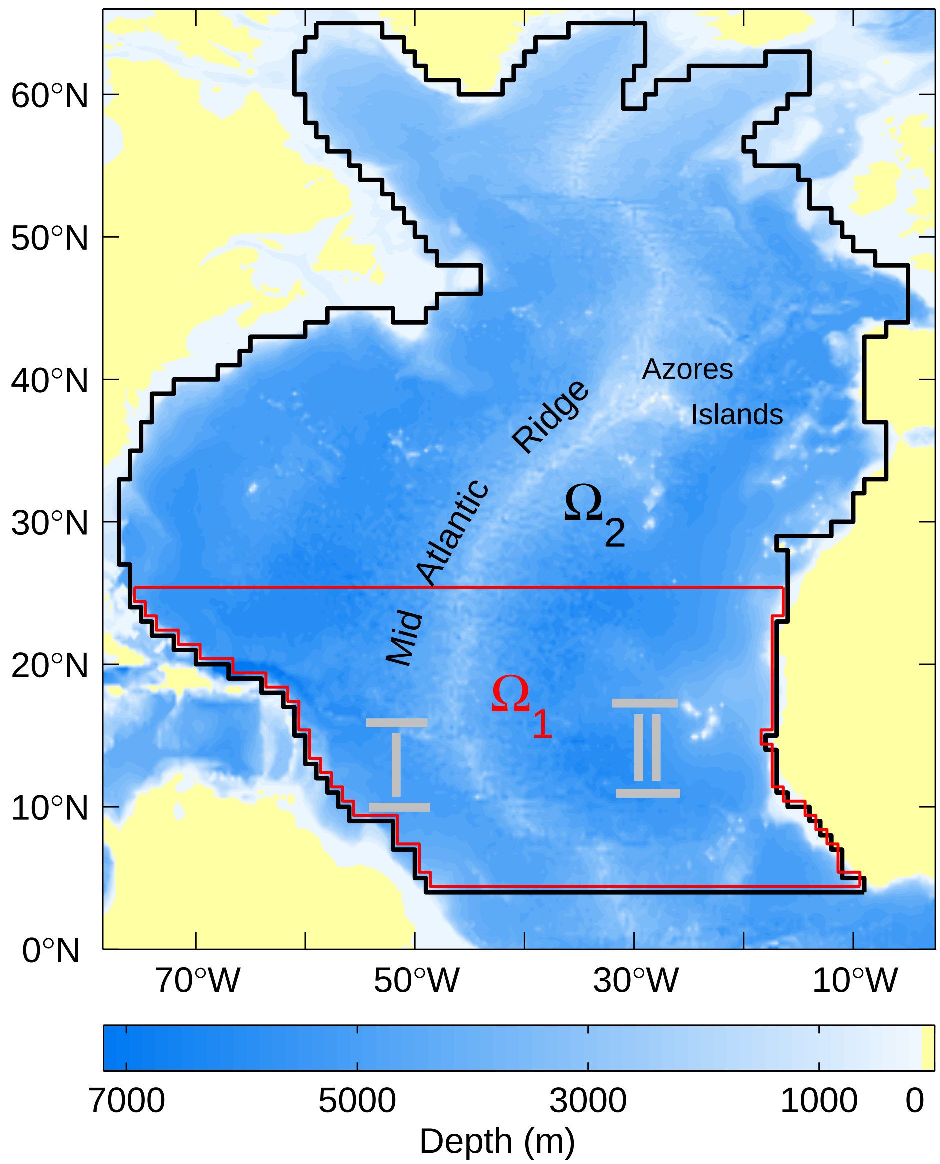
Basis Functions of Laplace Operator (Open Boundaries)

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

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

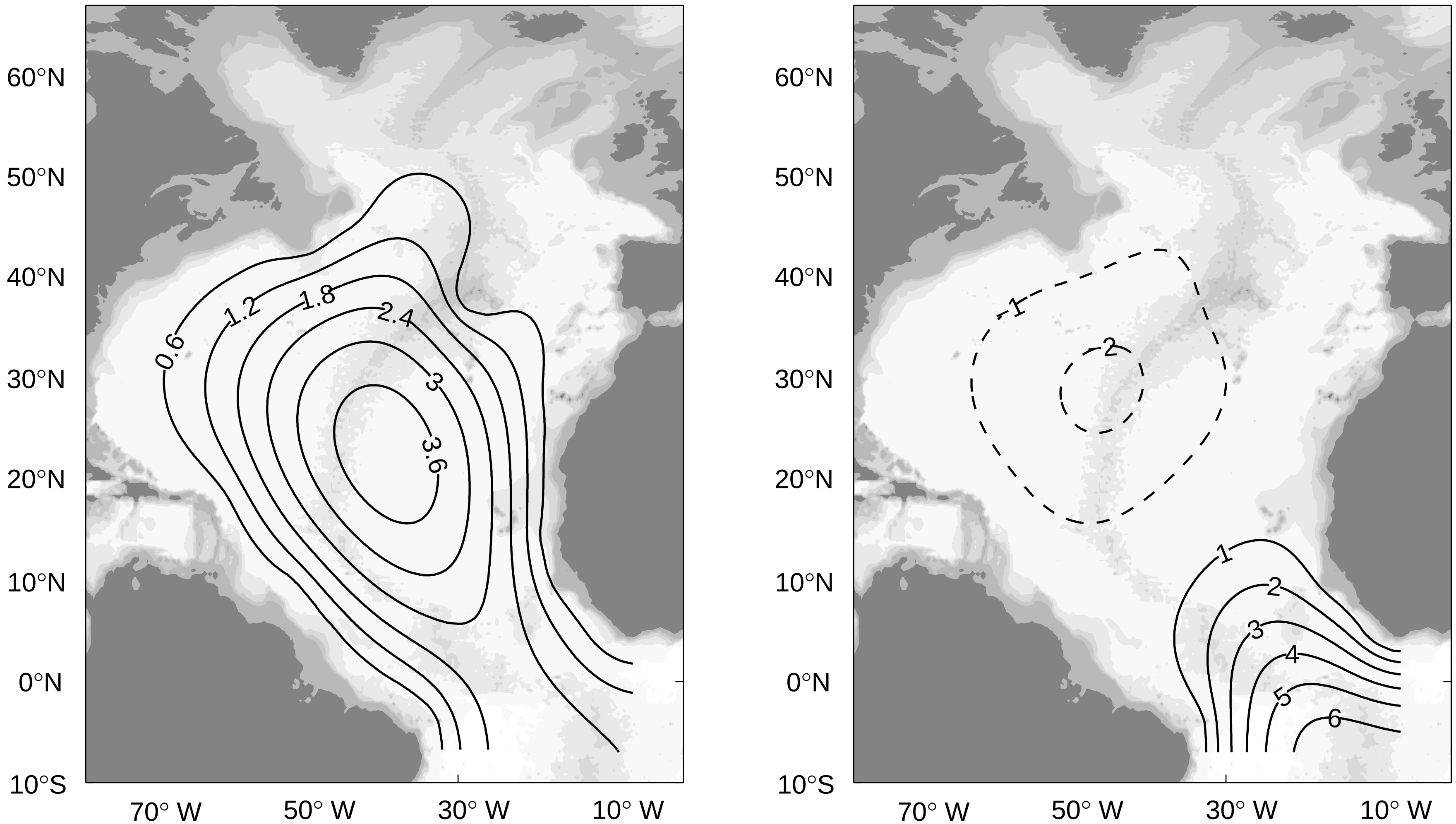
$$\Psi_k|_\Gamma = 0, \quad \frac{\partial\Phi_m}{\partial n}|_\Gamma = 0,$$

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



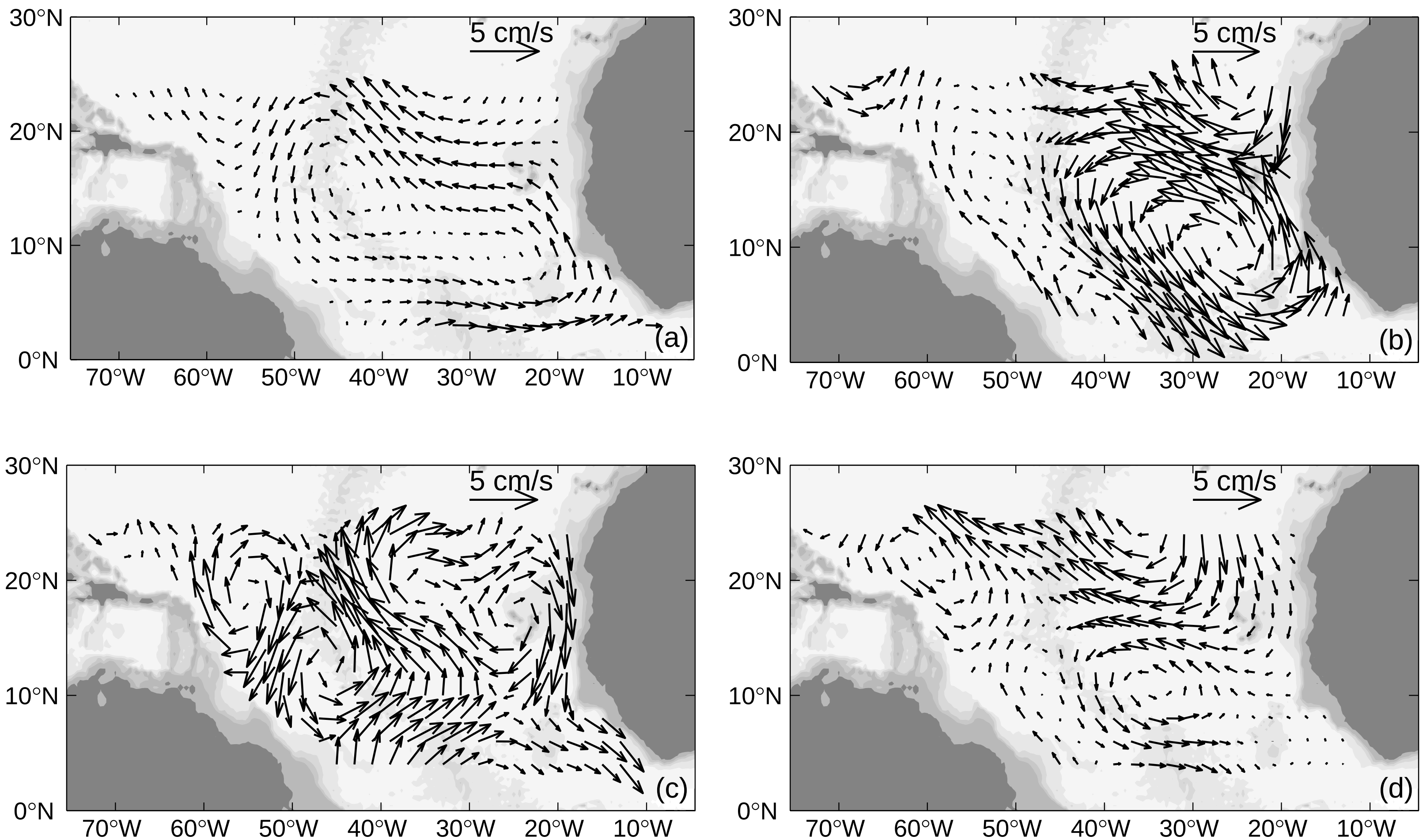
60°N
50°N
40°N
30°N
20°N
10°N
0°N
70°W
50°W
30°W
10°W
Azores
Islands
Mid Atlantic Ridge
Ω_2
Ω_1
I
II
7000
5000
3000
1000
0
Depth (m)

Basis Functions for Streamfunction Mode-1 and Mode-2



Mid-Depth Circulations (1000 m)

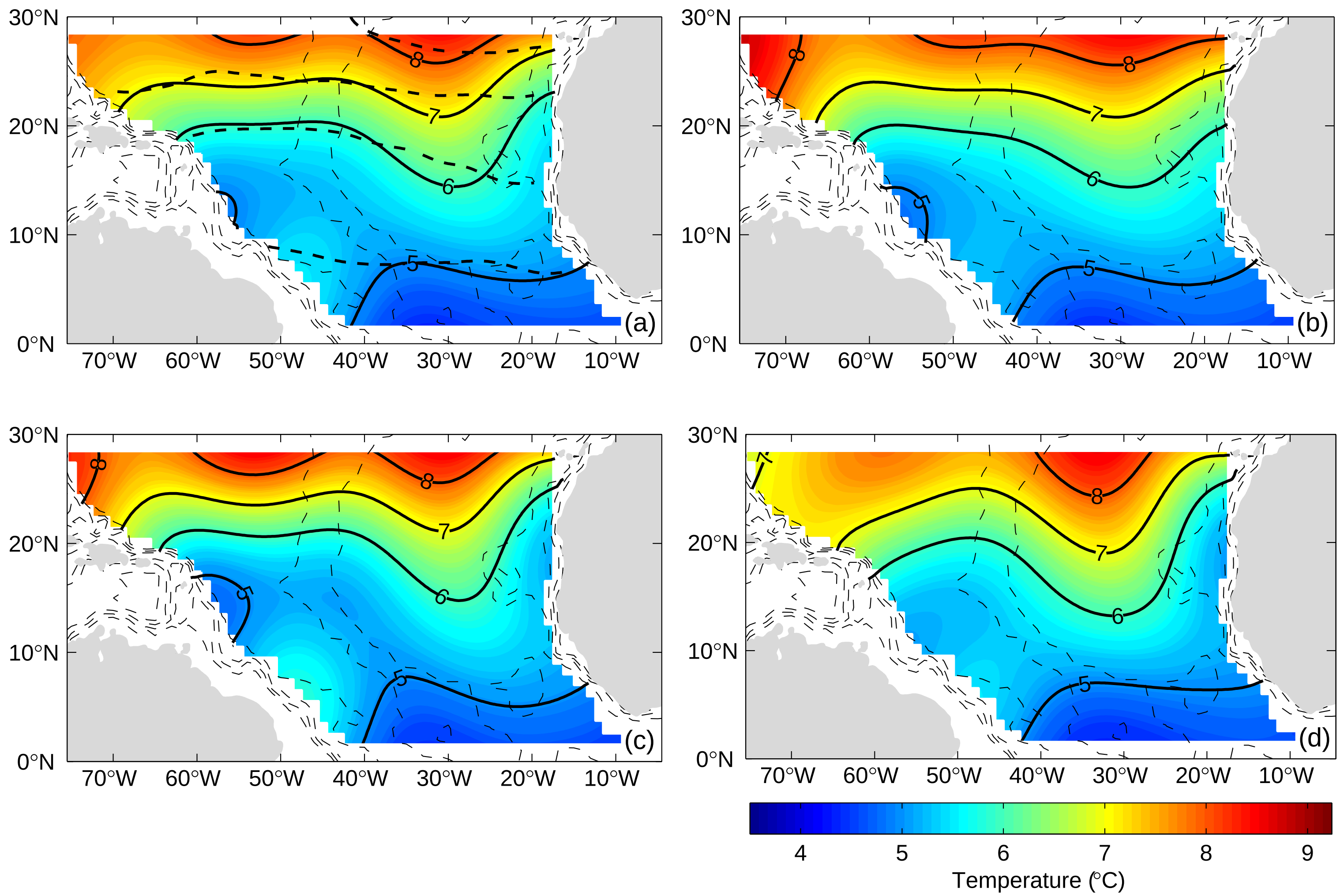
(a) Apr 04-Apr 05, (b) Jun-Jul04
(c) Oct-Nov04, (d) Mar-Apr05



Apr 04 – Apr 05   Jul 04

T
(950 m)

Dashed Curves → WOA



Nov 04   Apr 05

Temporal Decomposition
Annual + Semiannual

$$\hat{\psi} \approx \overline{\psi}(\mathbf{x}_\perp) + \psi_1(\mathbf{x}_\perp, t) + \psi_2(\mathbf{x}_\perp, t),$$

$$\psi_1(\mathbf{x}_\perp, t) = \sum_{s=1}^{2} A_{\omega_1, s} \cos(\omega_1 t + \theta_{\omega_1, s}) Z_s(\mathbf{x}_\perp) + \sum_{k=1}^{K_{opt}} B_{\omega_1, k} \cos(\omega_1 t + \vartheta_{\omega_1, k}) \Psi_k(\mathbf{x}_\perp),$$

$$\psi_2(\mathbf{x}_\perp, t) = \sum_{s=1}^{2} A_{\omega_2, s} \cos(\omega_2 t + \theta_{\omega_2, s}) Z_s(\mathbf{x}_\perp) + \sum_{k=1}^{K_{opt}} B_{\omega_2, k} \cos(\omega_2 t + \vartheta_{\omega_2, k}) \Psi_k(\mathbf{x}_\perp),$$

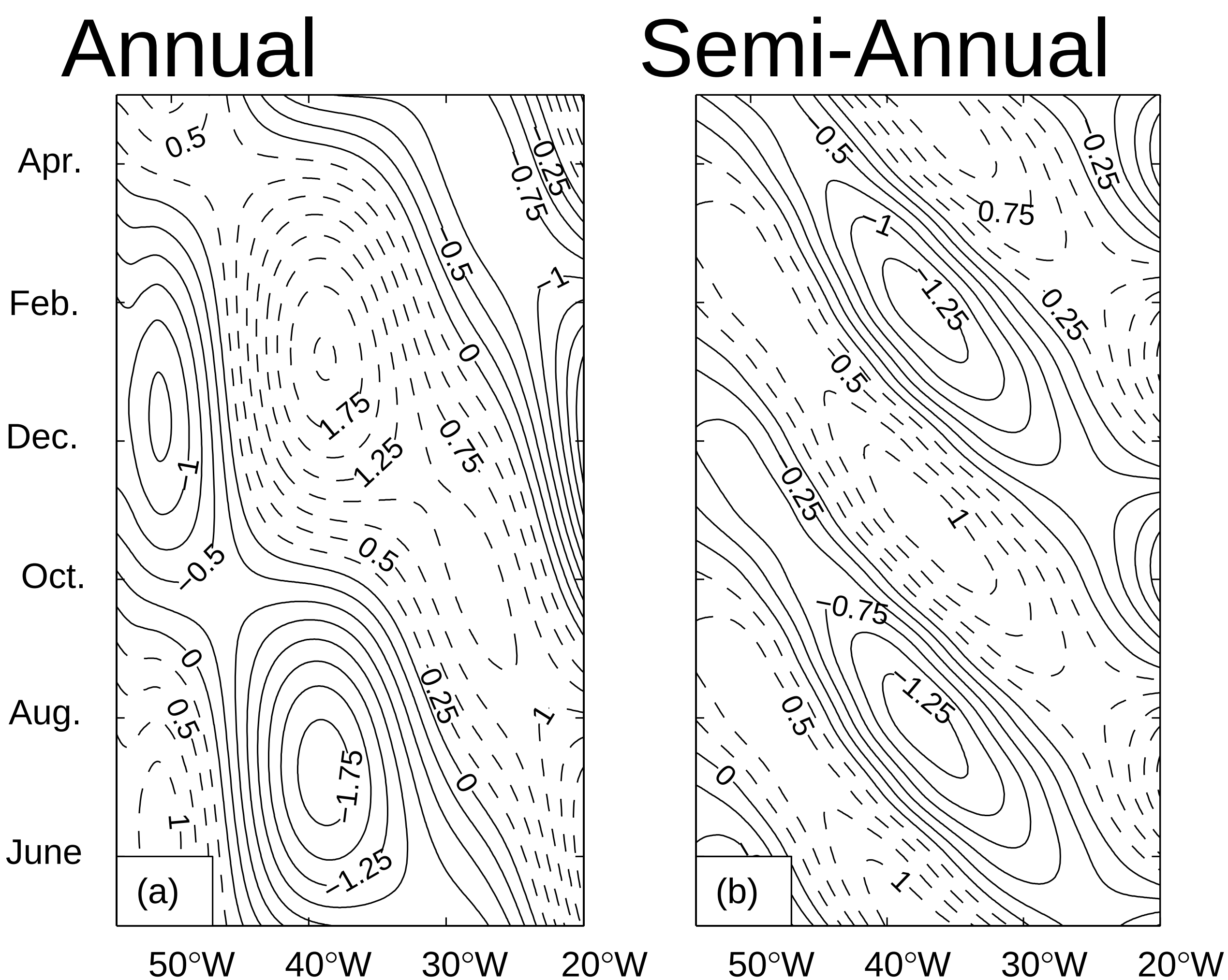
Temporal Decomposition
Annual + Semiannual

$$\hat{T}(\mathbf{x}_\perp, z, t) \approx \overline{T}(\mathbf{x}_\perp, z) + T_1(\mathbf{x}_\perp, z, t) + T_2(\mathbf{x}_\perp, z, t),$$

$$T_1(\mathbf{x}_{\perp,} z, t) = \sum_{m=1}^{M_{opt}} C_{\omega_1, m}(z) \cos[\omega_1 t + \chi_{\omega_1, m}(z)] \Xi_m(\mathbf{x}_\perp, z),$$

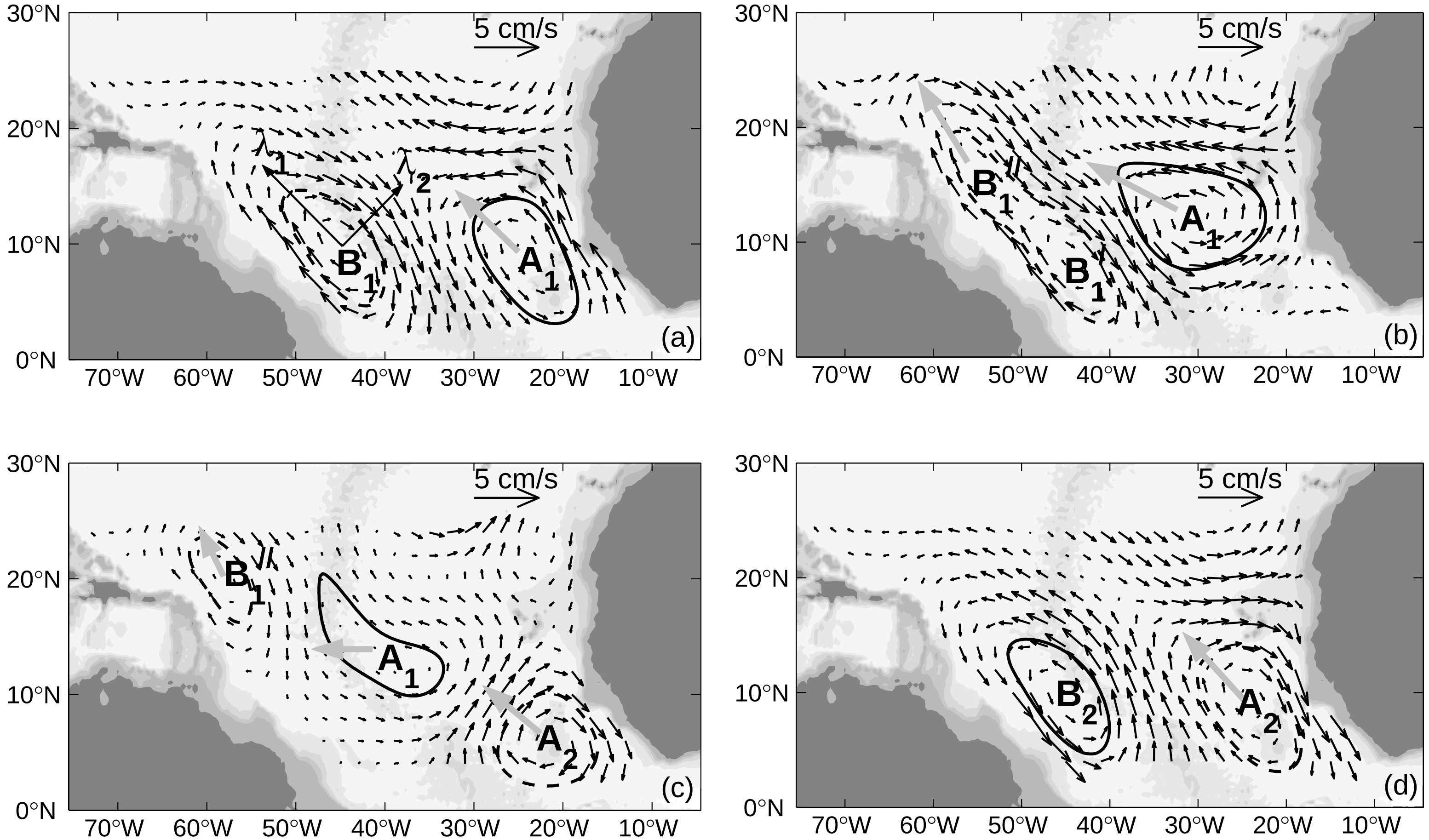
$$T_2(\mathbf{x}_{\perp,} z, t) = \sum_{m=1}^{M_{opt}} C_{\omega_2, m}(z) \cos[\omega_2 t + \chi_{\omega_{21}, m}(z)] \Xi_m(\mathbf{x}_\perp, z),$$

Time-longitude diagrams of meridional velocity along 11^{o}N (cm/s)



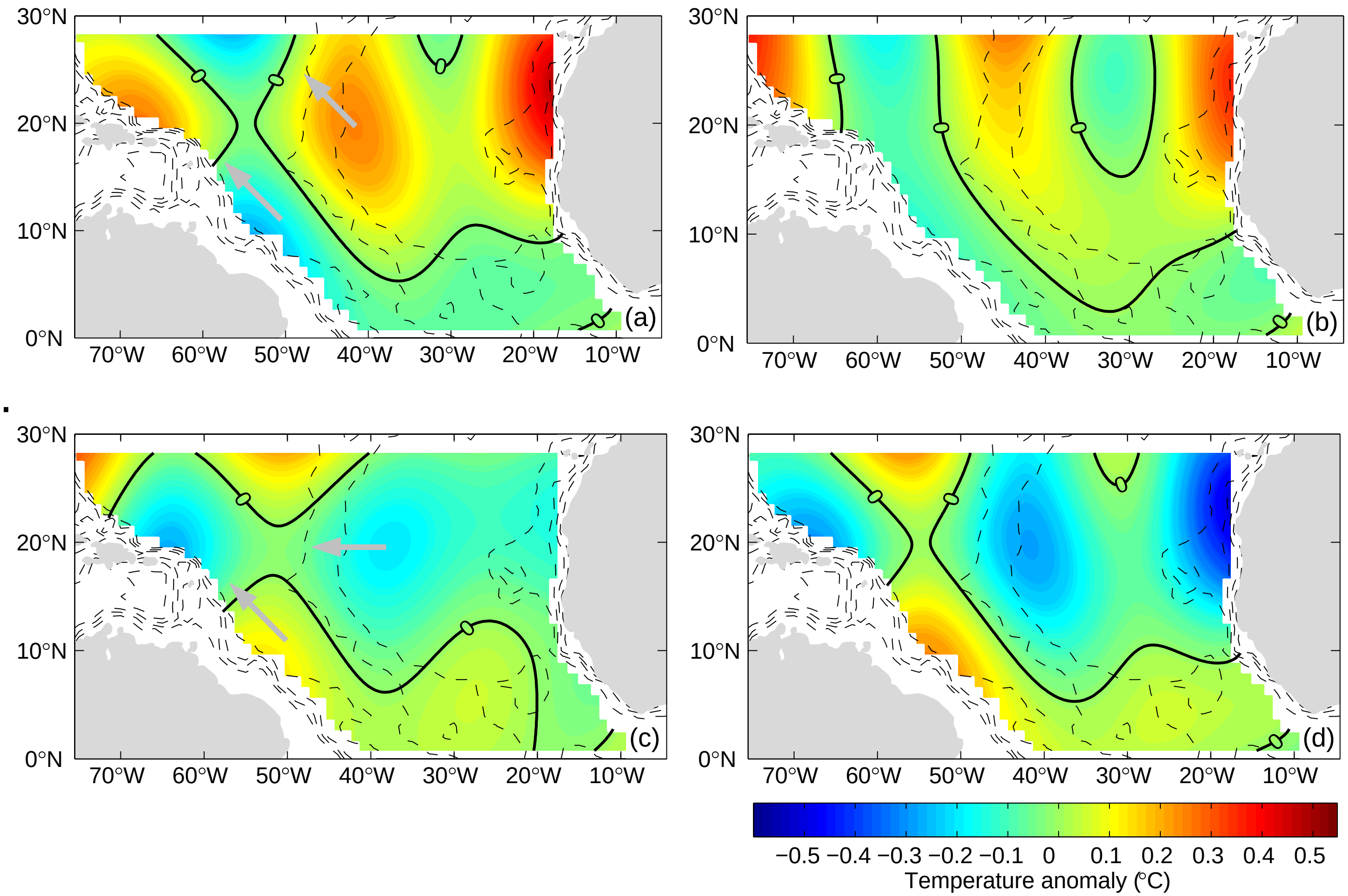
Two wave-like signals in Annual currents

(a)May-Jun 04 (b) Jul–Aug 04
(c) Sep–Oct 04 (d) Nov–Dec 04



Annual monthly temperature anomaly at 950m depth

(a)Jun 04
(b) Aug 04
(c) Oct 04
(d) Dec 04.



Kinematic characteristics of the annual Rossby wave propagating in the eastern sub-basin

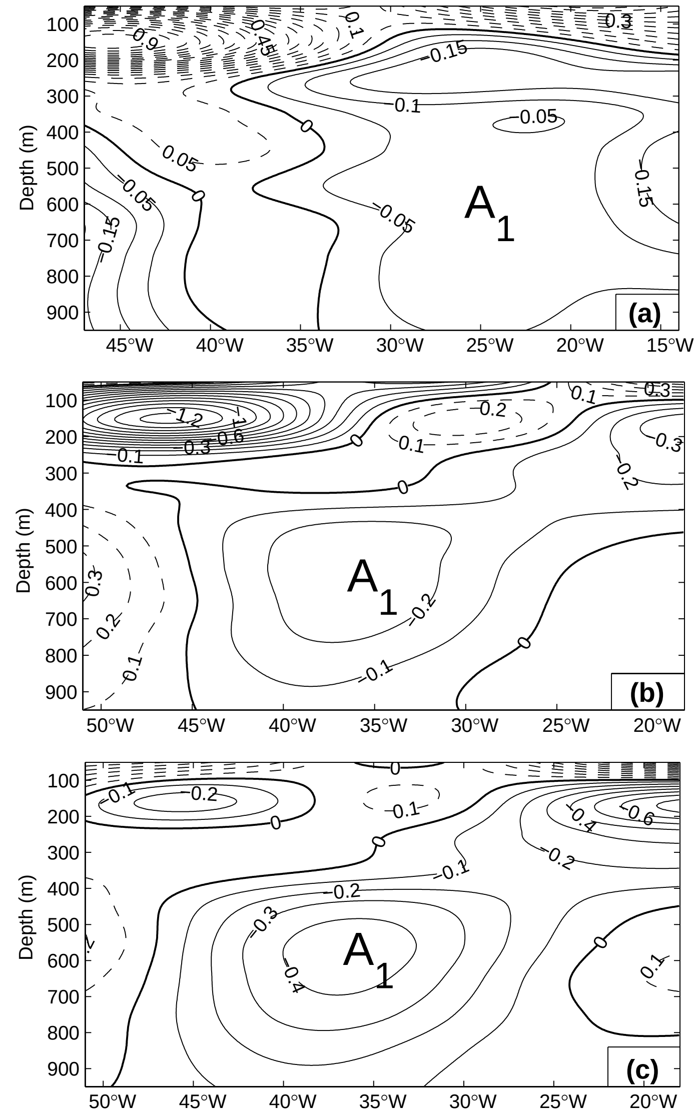
	March, 04 – May, 05 float data			March, 04 – May, 06 float data		
Latitude	c_p (cm/s)	L_1 (km)	L_2 (km)	c_p (cm/s)	L_1 (km)	L_2 (km)
5^0N	12	1200	1100	12	1300	900
8^0N	16	2500	1400	12	2100	1100
11^0N	14	2200	1400	11	1900	1100
13^0N	11	2100	1500	10	2300	1500

Zonal cross-sections of the annual component of the temperature anomaly (^{o}C)

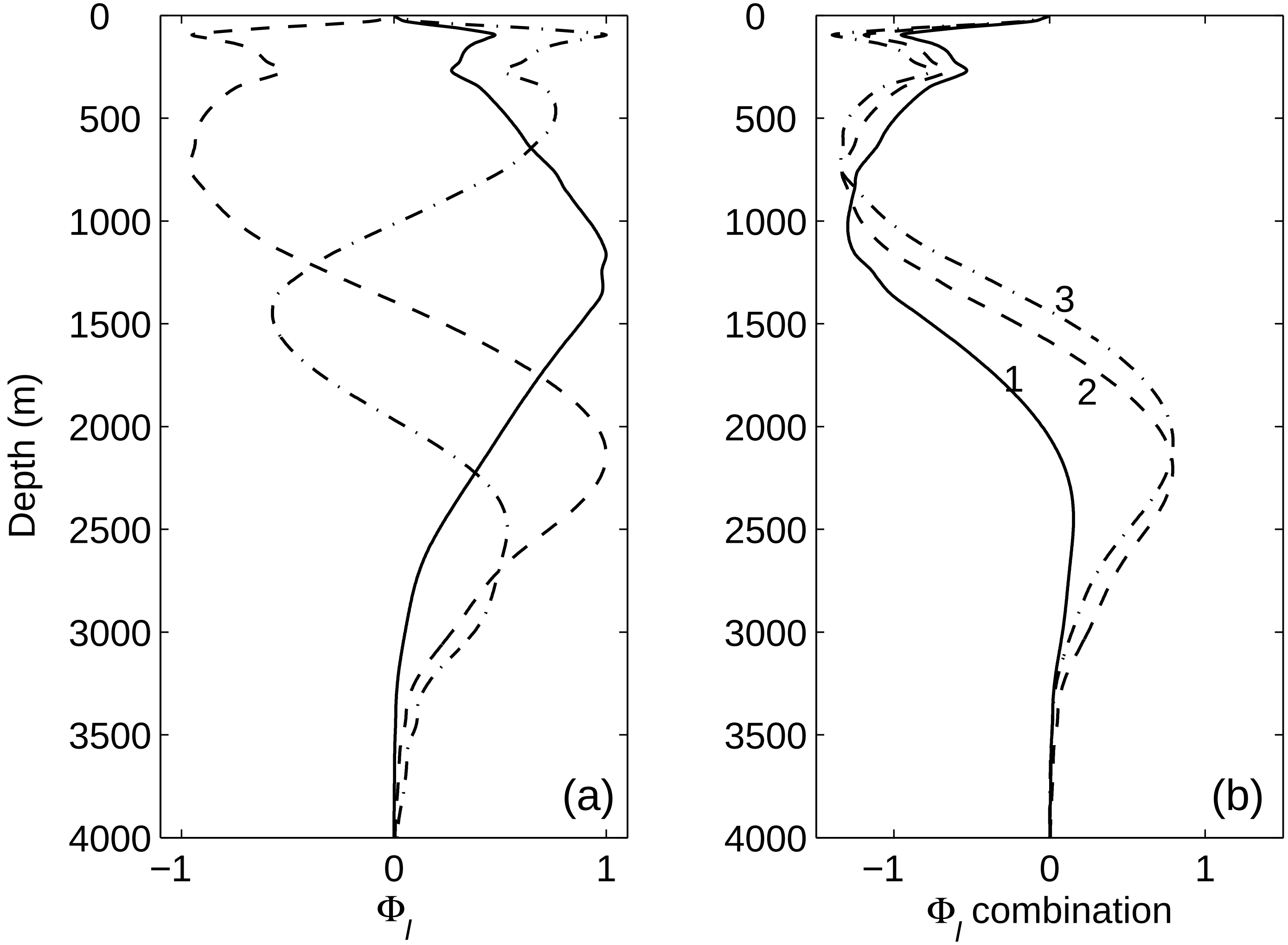
6^{o}N in Jun 04 →

11^{o}N in Oct, 04 →

16^{o}N in Oct 04 →



Baroclinic Modes



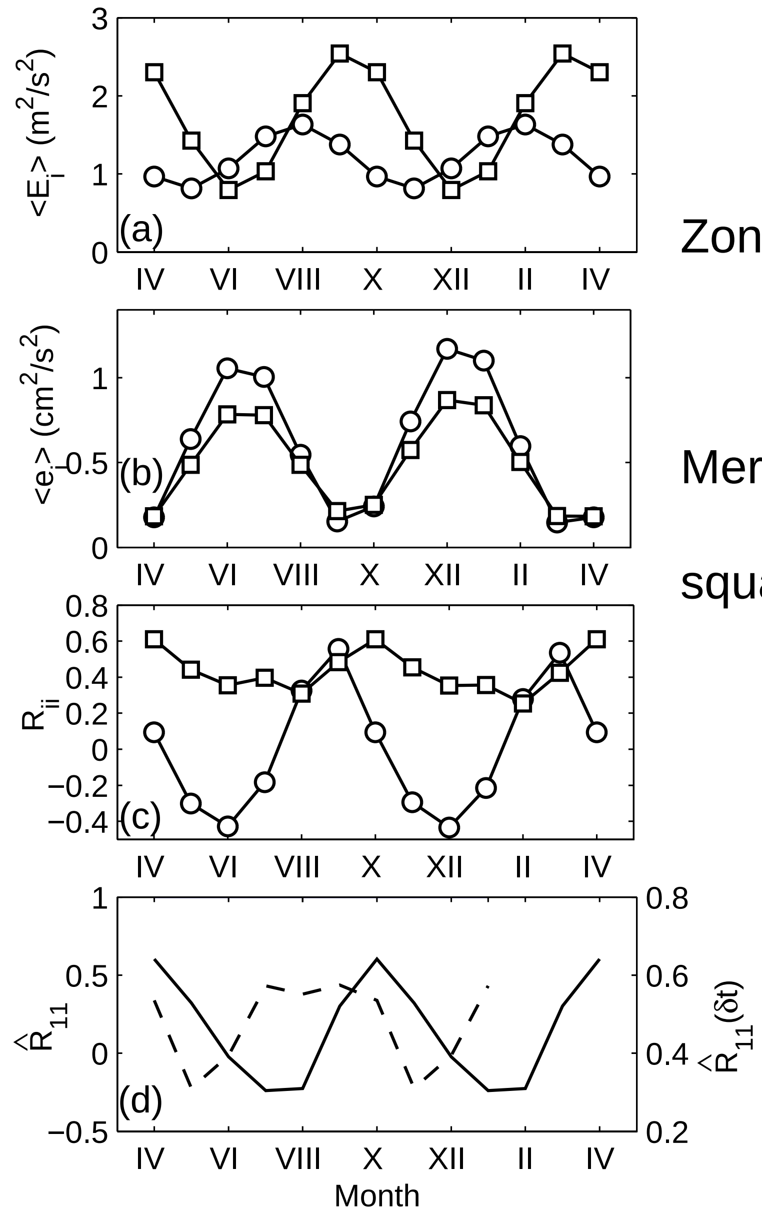
Annual Component in the Western Sub-Basin

Mean wind KE

Mean KE for mid-depth currents

Correlation between Winds and currents

Correlation between wind Stress curl and streamfunction (solid: no-lag, dashed: 3 mon lag



Zonal: circle

Meridional : square

Annual Component in the Eastern Sub-Basin

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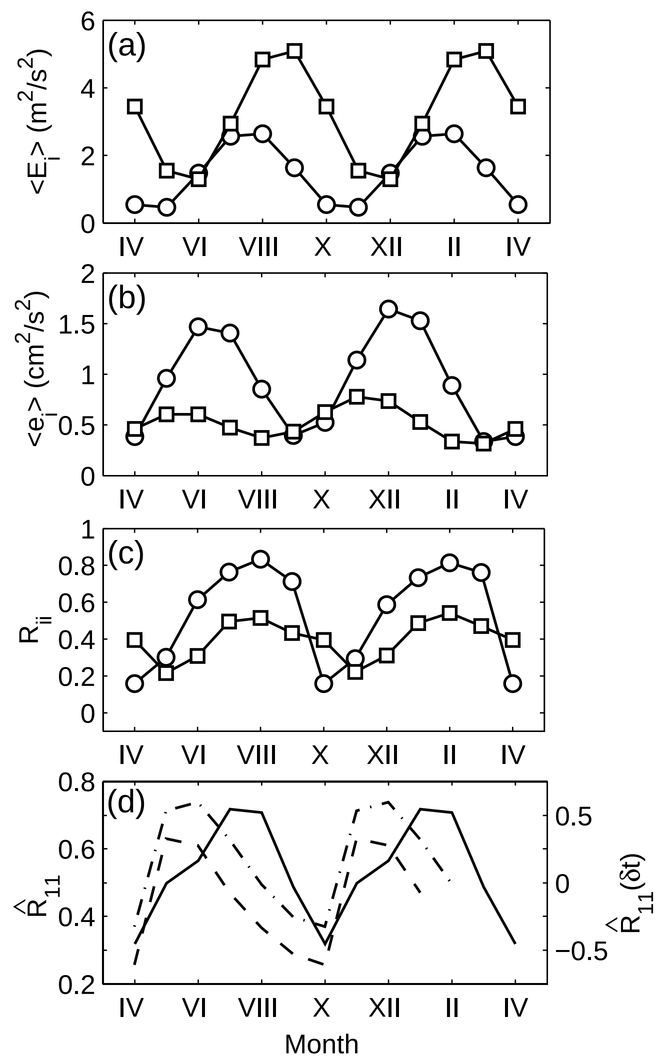
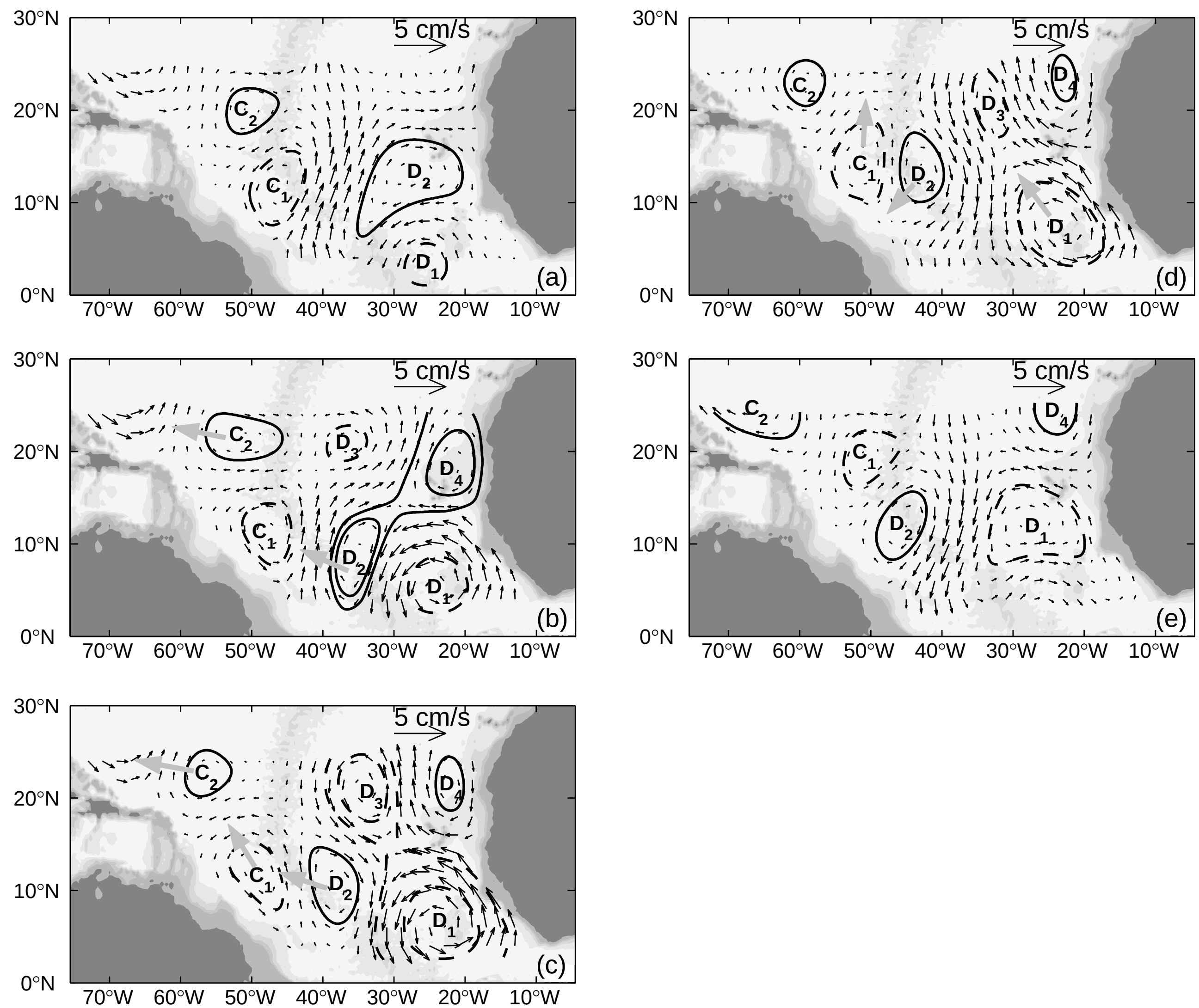


Zonal: circle

Meridional : square

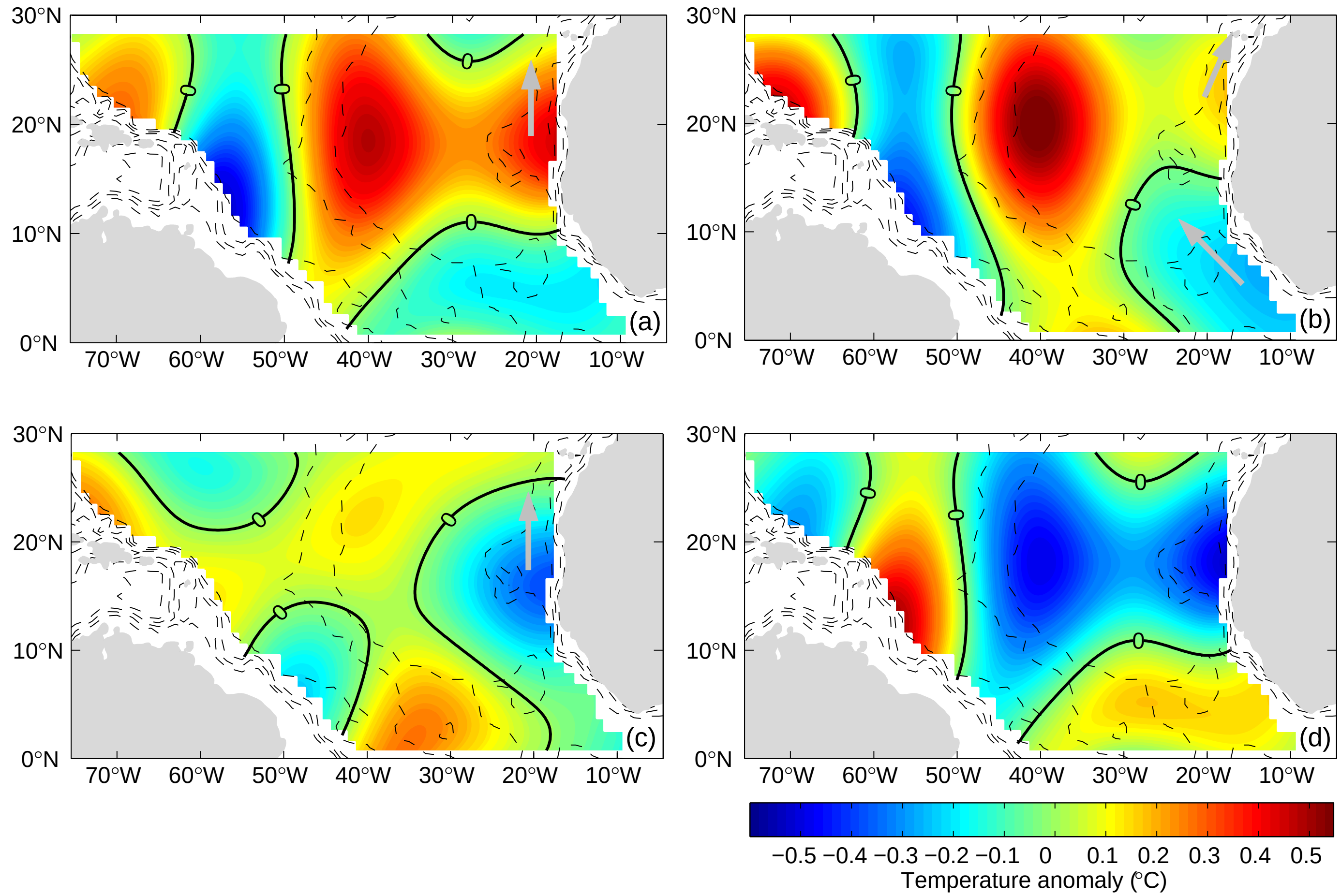
Semi-annual currents at 1000 m depth (2004)

(a)5/15
(b)5/30
(c)6/14
(d)6/29
(e) 7/13



Semi-annual monthly temperature anomaly at 950m depth

(a)Jun 04
(b) Aug 04
(c) Oct 04
(d) Dec 04.



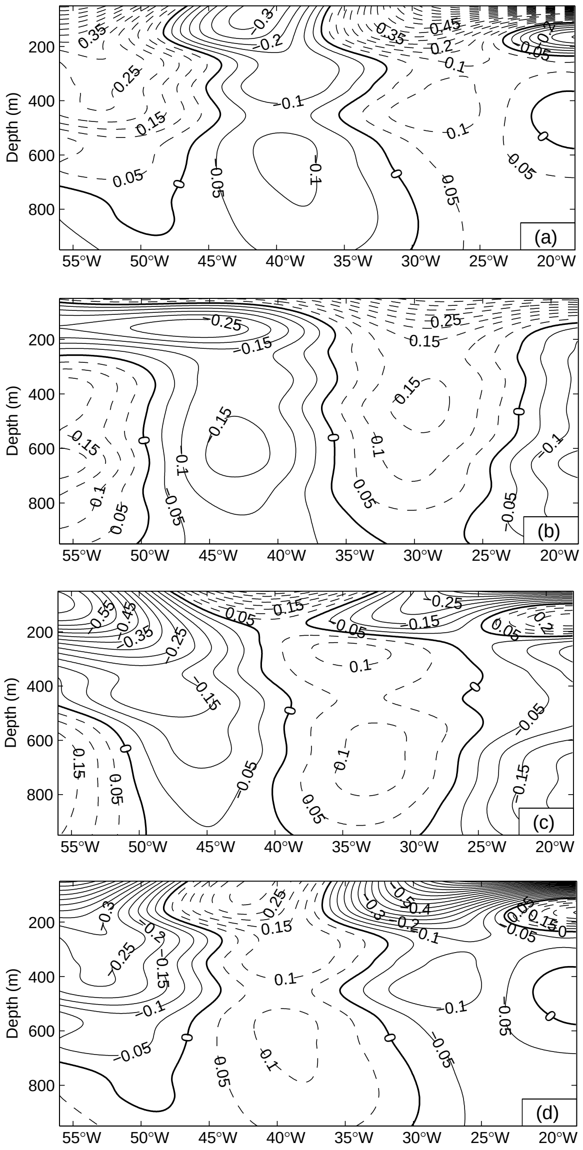
Semi-annual component of monthly temperature anomaly along 11ºN (2004)

(a) 6/4

(b) 7/4

(c) 8/4

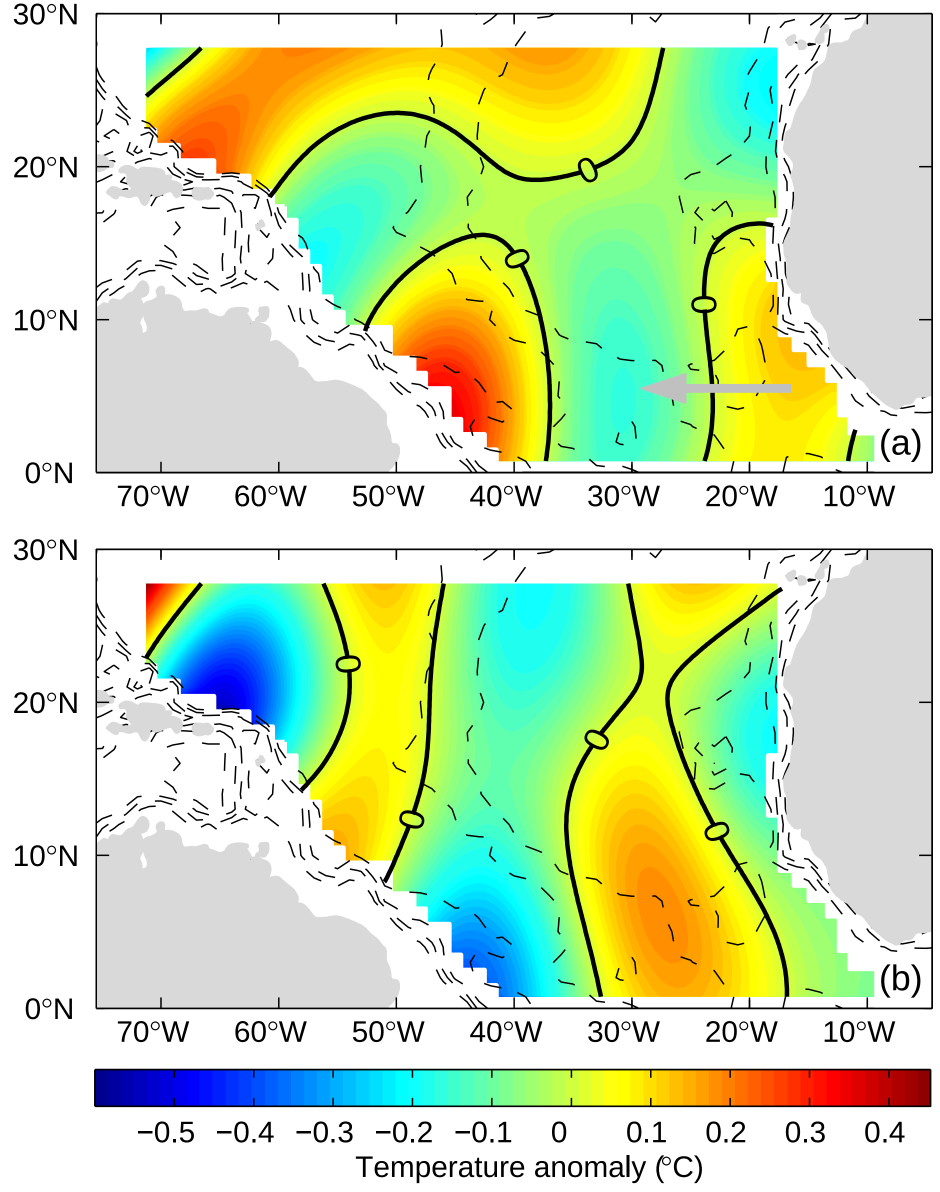
(d) 9/4



Semi-annual temperature anomaly at 550m depth (2004)

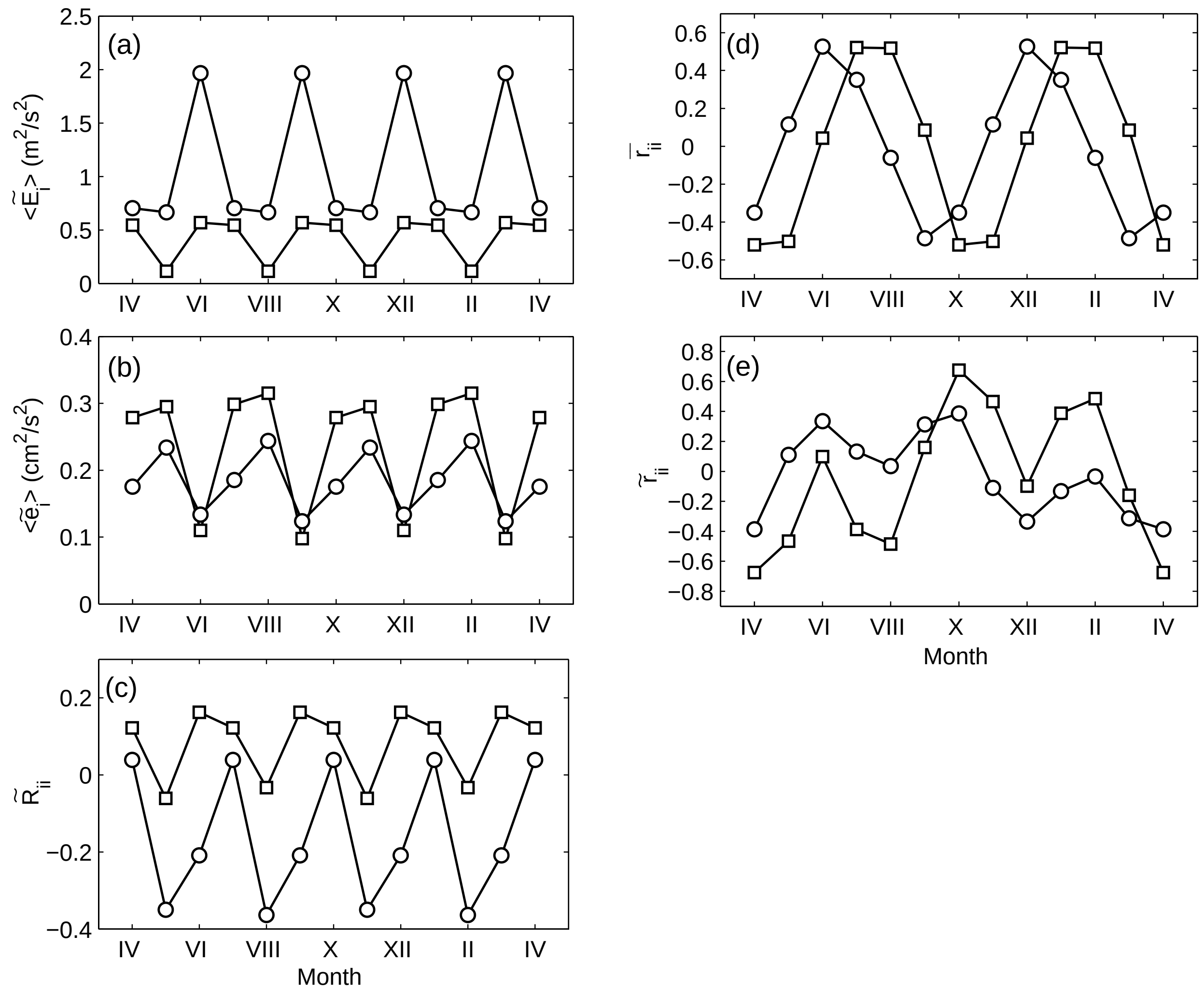
(a) 5/15

(b) 6/29



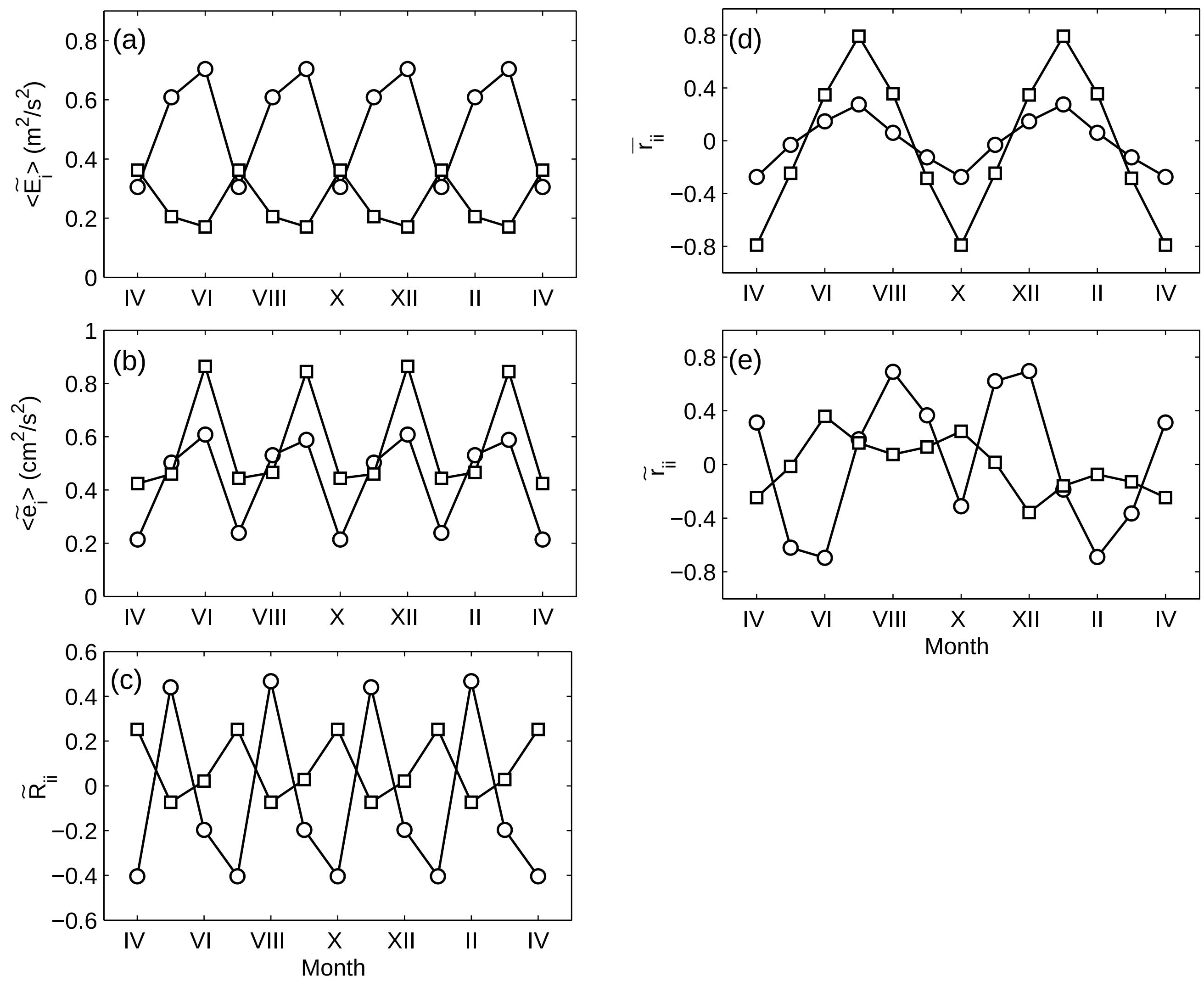
Semiannual Component in the Western Sub-Basin

(a) wind KE
(b) current KE
(c) corr wind
stress and currents
(d) corr between
semi-annual currents
and mean wind
(e) corr between
semiannual currents
and annual wind stress.



Semiannual Component in the Eastern Sub-Basin

(a) wind KE
(b) current KE
(c) corr wind stress and currents
(d) corr between semi-annual currents and mean wind
(e) corr between semiannual currents and annual wind stress



Conclusions

- (1) OSD has capability to process ARGO data
- (2) The annual and semi-annual unstable standing Rossby waves are detected in both the western and eastern sub-basins.
- (3) The wind-driven Ekman pumping seems to be responsible for the standing wave generation in both the sub-basins.