Determined of Volume Transport From Hydrographic and Wind Data Using the Ekman-Munk Model

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Western Boundary Currents and Indonesian Throughflow (Fine et al 1994)

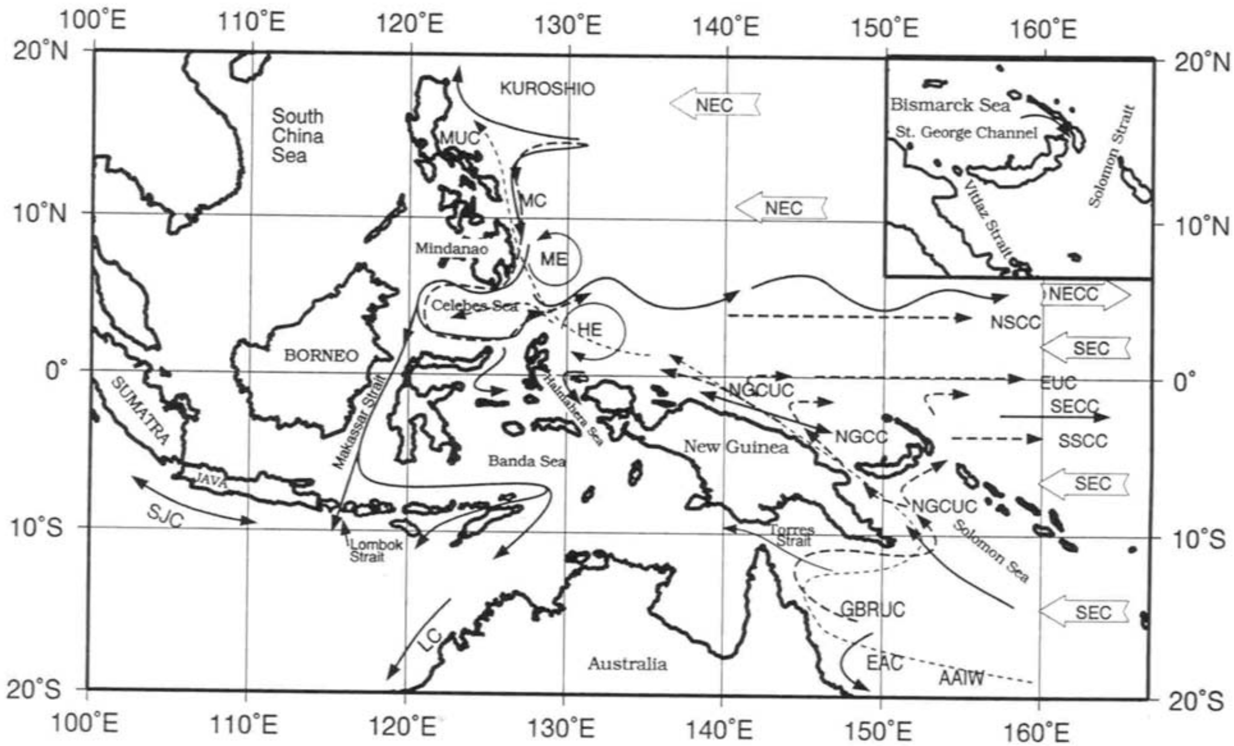


Figure 1. Map of the western tropical Pacific Ocean and Indonesian Seas showing the major geographic names and surface to intermediate depth currents, including the Kuroshio, Mindanao Current (MC), North Equatorial Current (NEC), North Equatorial Countercurrent (NECC), New Guinea Coast Current (NGCC), South Equatorial Current (SEC), South Equatorial Countercurrent (SECC), East Australia Current (EAC), South Java Current (SJC), and the Leeuwin Current (LC). The subsurface currents are the New Guinea Coastal Undercurrent (NGCUC), Equatorial Undercurrent (EUC), Northern and Southern Subsurface Countercurrents (NSCC and SSCC), Mindano Undercurrent (MUC), and Great Barrier Reef Undercurrent (GBRUC). The Mindanao Eddy (ME) and Halmahera Eddy (HE) are also indicated. Solid lines indicate surface flow, thick dashed lines indicate thermocline flow, and thin dashed lines indicate the flow of Antarctic Intermediate Water (AAIW). The inset shows the region of Vitiaz Strait east of New Guinea at 5°S, 148°E [after *Fine et al.*, 1994].

Estimates of Mean Indonesian Throughflow Transport (Godfrey 1996)

Table 1. Estimates of Mean Indonesian Throughflow Transport

Reference	Method	Result, 10^6 m^3 s^{-1}	Remarks
Wyrtki [1961]	geostrophy	1.7	top 200 m
Godfrey and Golding [1981]	geostrophy, 11 Indian Ocean sections	10	sections unclosed, 32°S
Wunsch et al. [1983]	inverse calculation, 43°S and 28°S Pacific sections	<<10	
Piola and Gordon [1984]	freshwater budget, Pacific and Indian Oceans	14	
Fine [1985]	tritium budget	5	top 300 m
Fu [1986]	inverse calculation, Australia-Timor	7	Timor Strait only
Toole et al. [1988]	salinity budget, West Pacific	<5	sensitive to Indonesian salinity
Murray and Arief [1988]	current meter survey	1.5	Lombok Strait only
Godfrey [1989]	geostrophy, Australia-Sumatra, Levitus annual mean data	12	boundary currents unresolved
Toole and Warren [1993]	inverse estimate, Indian Ocean 32°S	7	
Wijffels et al. [1992]	heat budget, closed box, 14°S-165°E-10°N	0-8	
Fieux et al. [1994]	geostrophy, Australia-Bali, plus current meters	18.6±7	August 1989 snapshot
Fieux et al. [this issue]	geostrophy, Australia-Bali, plus current meters	-2.6±7	February-March 1992 snapshot
Meyers et al. [1995]	time series from expendable bathythermograph sections	5	top 400 m

What is the simplest model to determining the Throughflow transport?

The Ekman-Munk Model

Dynamical System

$$-f(v - v_g) = A_z \frac{\partial^2 u}{\partial z^2} + A_h \nabla^2 u$$

$$f(u - u_g) = A_z \frac{\partial^2 v}{\partial z^2} + A_h \nabla^2 v$$

$$\frac{\partial p}{\partial z} = -\rho g$$

$$u_g = -\frac{1}{f\rho_0}\frac{\partial p}{\partial y}, \quad v_g = -\frac{1}{f\rho_0}\frac{\partial p}{\partial x}$$

Ekman Number

$$E = \frac{O(|A_h \nabla^2 \mathbf{V}|)}{O(|f\mathbf{V}|)} = \frac{A_h}{|f|\,L^2}$$

- $A_h \sim 5 \times 10^5\ m^2/s$
- Extra-Tropical: $E \sim 0.125$
  - (Small Horizontal Diffusion)
- Tropical (8°S- 8°N): $E > 0.5$

Extra-Tropical (Ekman Model)

- Small Horizontal Diffusion

$$-f(v - v_g) = A_z \frac{\partial^2 u}{\partial z^2}$$

$$f(u - u_g) = A_z \frac{\partial^2 v}{\partial z^2}$$

Tropical (Munk Model)

- Large Horizontal Diffusion

$$\beta v = A_z \frac{\partial^2}{\partial z^2}\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) + A_h \nabla^2\left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right)$$

Vertically Integrated Velocity & Transport Streamfunction

$$(U, V) = \int_{-H}^{\eta} (u, v) dz,$$

$$U = -\frac{\partial \Psi}{\partial y}, \quad V = \frac{\partial \Psi}{\partial x}$$

Ekman-Munk Model

- $$\nabla^2\psi = \Pi$$

- Extra-Tropoical Region (Ekman Model):
  - $$\Pi = \Pi_1 + \Pi_2 + \Pi_3$$

- Tropical Region (Munk Model)
  - $\nabla^2\Pi = \beta V/A_h - [\partial/\partial x(\tau_y/\rho_0) - \partial/\partial y(\tau_x/\rho_0)]/A_h$

Π -Terms

$$\Pi_1 = (\frac{\partial \widetilde{V}_g}{\partial x} - \frac{\partial \widetilde{U}_g}{\partial y})$$

$$\Pi_2 = (\frac{\partial V_r}{\partial x} - \frac{\partial U_r}{\partial y})$$

$$\Pi_3 = -[\frac{\partial}{\partial x}(\frac{\tau_x}{f\rho_0}) + \frac{\partial}{\partial y}(\frac{\tau_y}{f\rho_0})].$$

Π -Terms (Continued)

- Integrated Baroclinic Geostrophic Velocity (Relative to the Bottom)

$$(\hat{U}_g, \hat{V}_g) = \frac{g}{f\rho_0}\left(\int_{-H}^{\eta}\int_{-H}^{z}\frac{\partial\rho}{\partial y}dz'dz, -\int_{-H}^{\eta}\int_{-H}^{z}\frac{\partial\rho}{\partial x}dz'dz\right).$$

- Integrated Barotropic Geostrophic Velocity

$$U_\tau = Hu_{-H} - \frac{C_D}{f}\sqrt{u_{-H}^2 + v_{-H}^2}\,u_{-H},$$

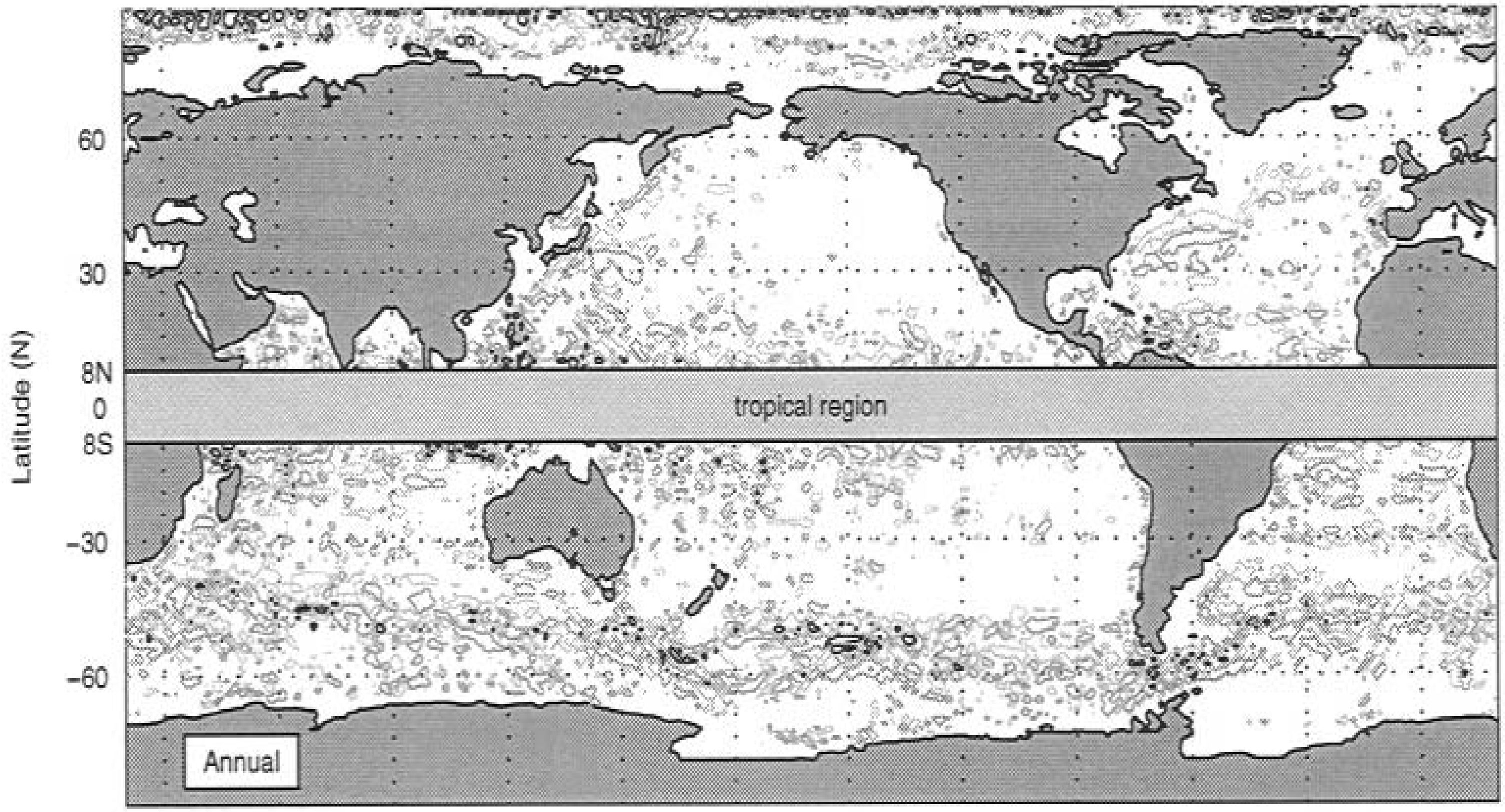
$$V_\tau = Hv_{-H} + \frac{C_D}{f}\sqrt{u_{-H}^2 + v_{-H}^2}\,v_{-H}.$$

Climatological Values of the Π -Terms

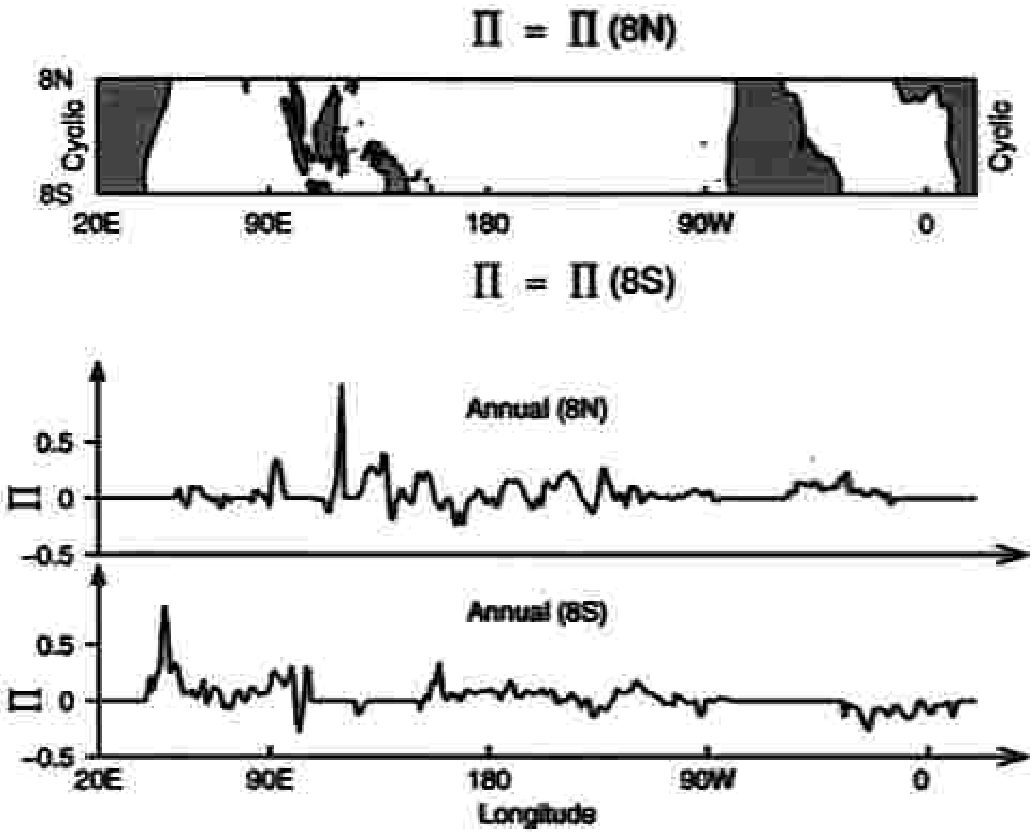
- T, S (Levitus 1994) $1^o \times 1^o$
  - Π_1 (Geostrophic)
  - Π_2 (P-Vector Inverse Method)

- Winds (COADS) $1^o \times 1^o$
  - Π_3

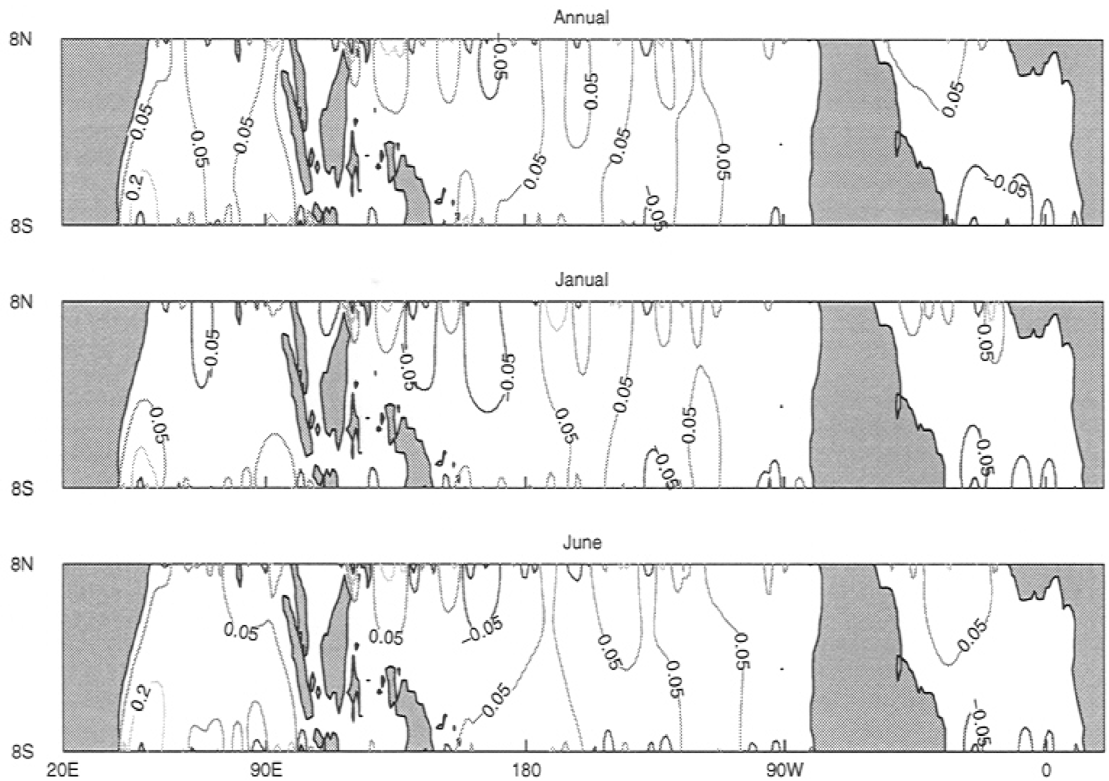
Climatological Values of the Π -Terms in Extra-Tropics (Noisy)



Boundary Conditions for $\nabla^2\Pi$ = Forcing (Tropics)



Climatological Values of the Π -Terms in the Tropics ($\nabla^2 \Pi$ = Forcing)



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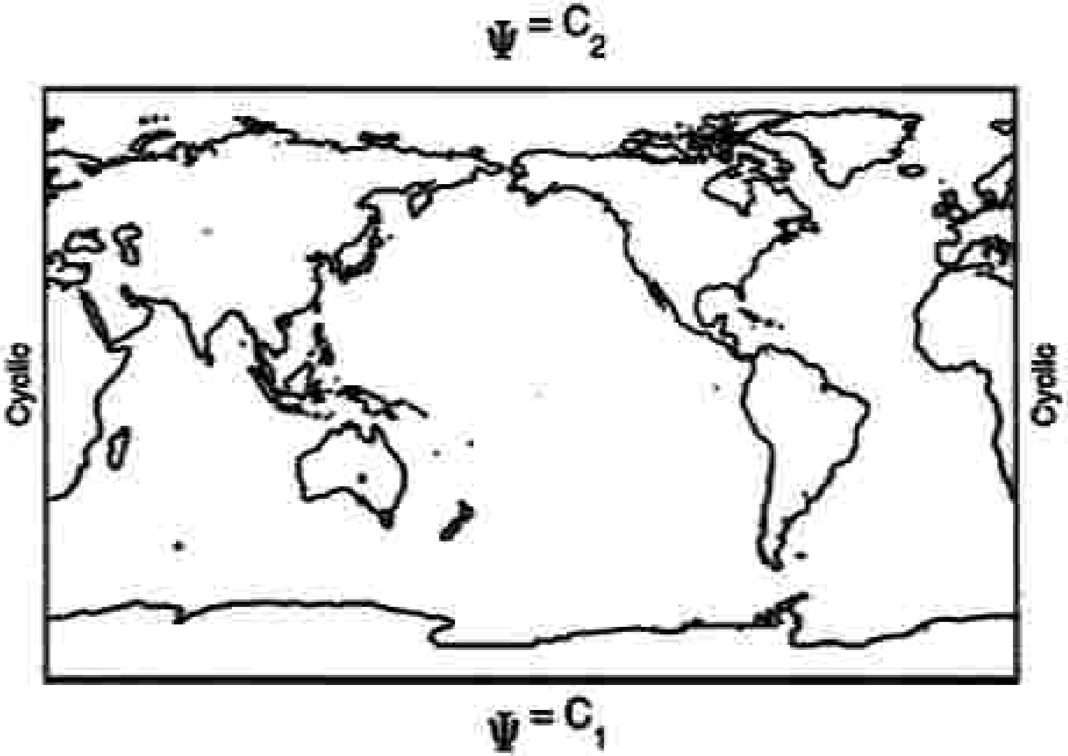
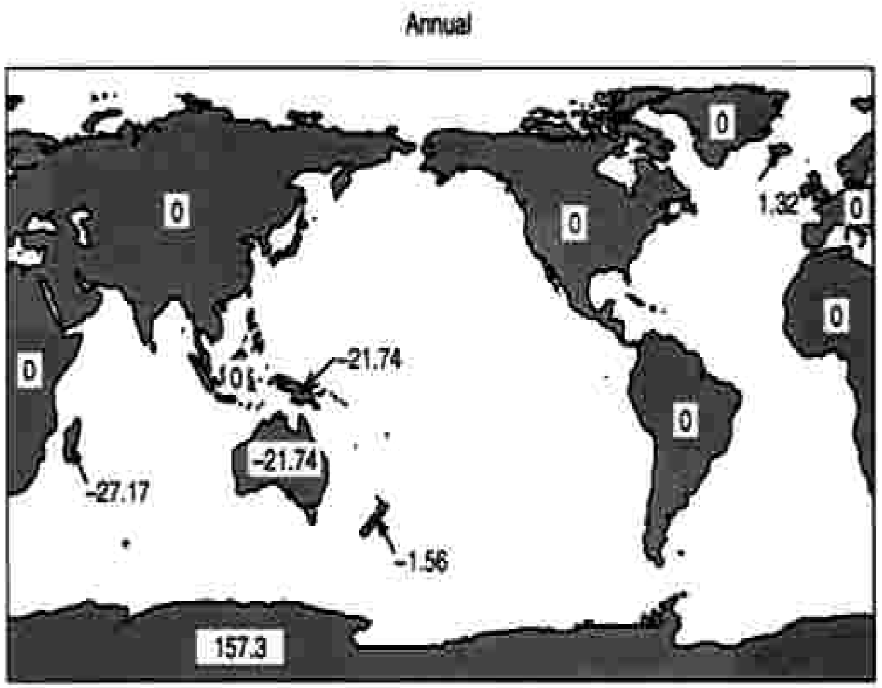
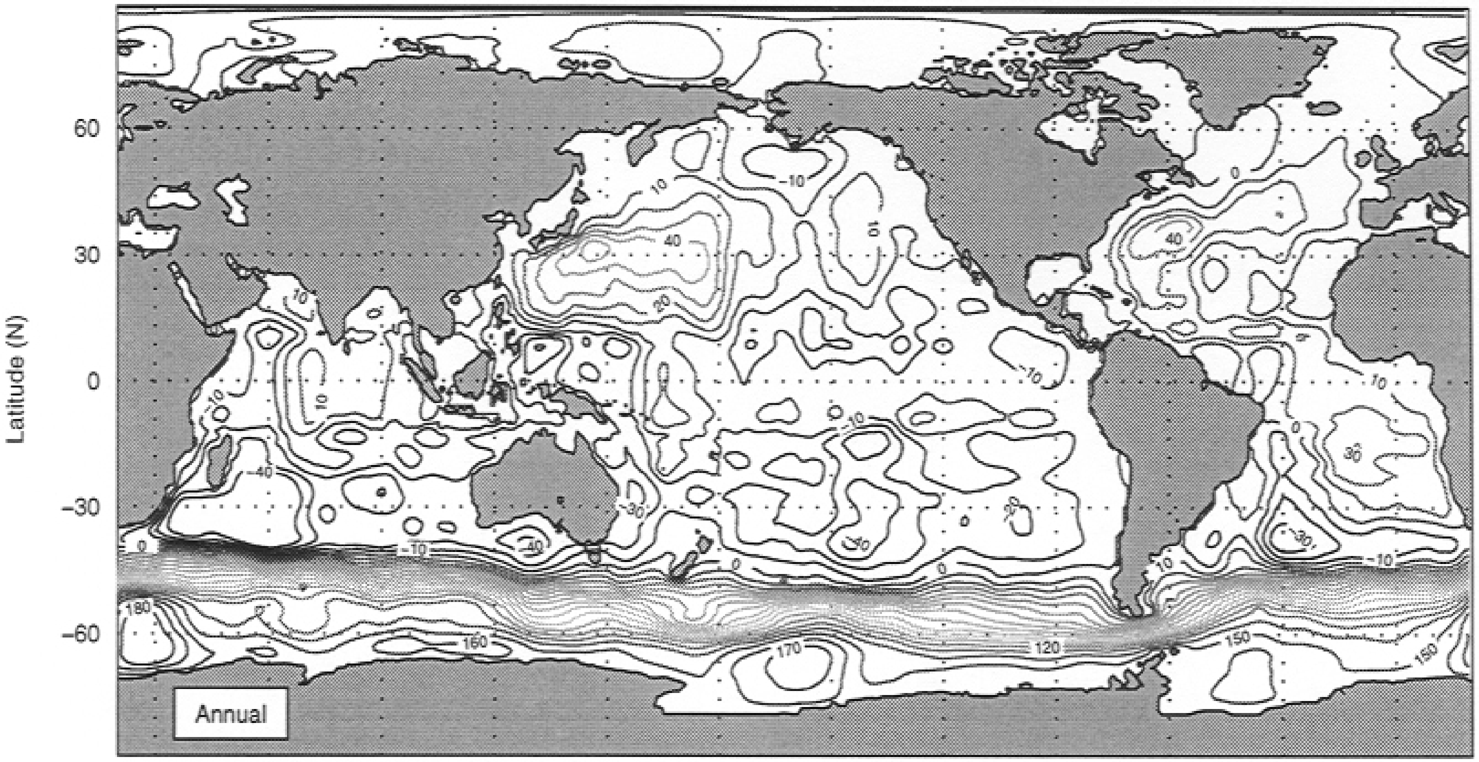
Boundary Conditions for $\nabla^2\psi = \Pi$



Determination of ψ - values for Continents/Islands

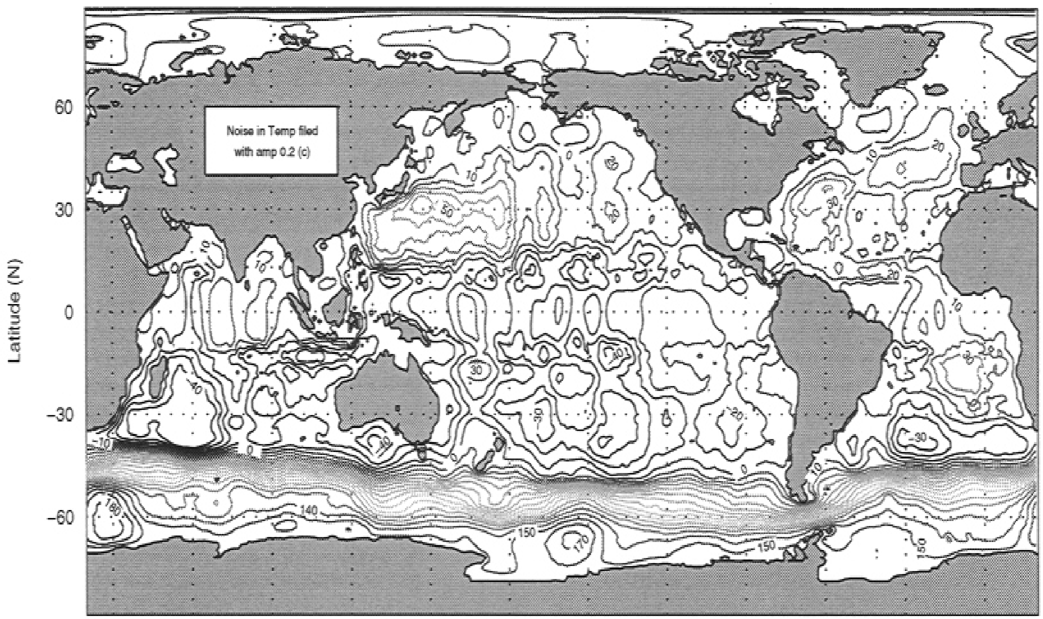


Global ψ - Field



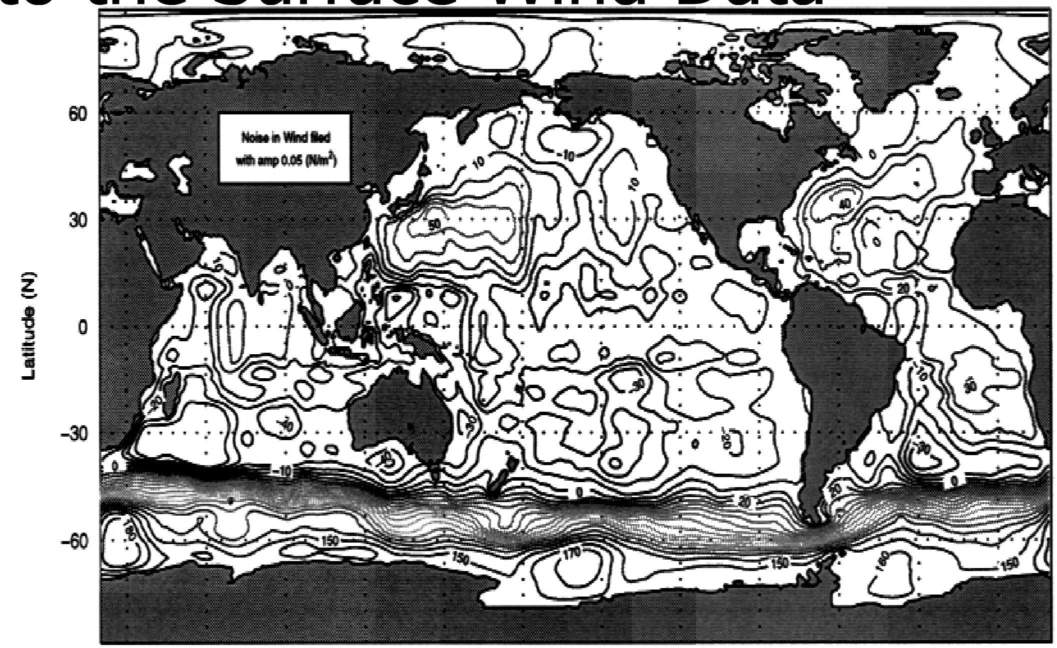
Error Estimation

- Gaussian-Type Random Error (0 mean, $0.2^{o}C$ standard Deviation) Introduced into 3D T Field

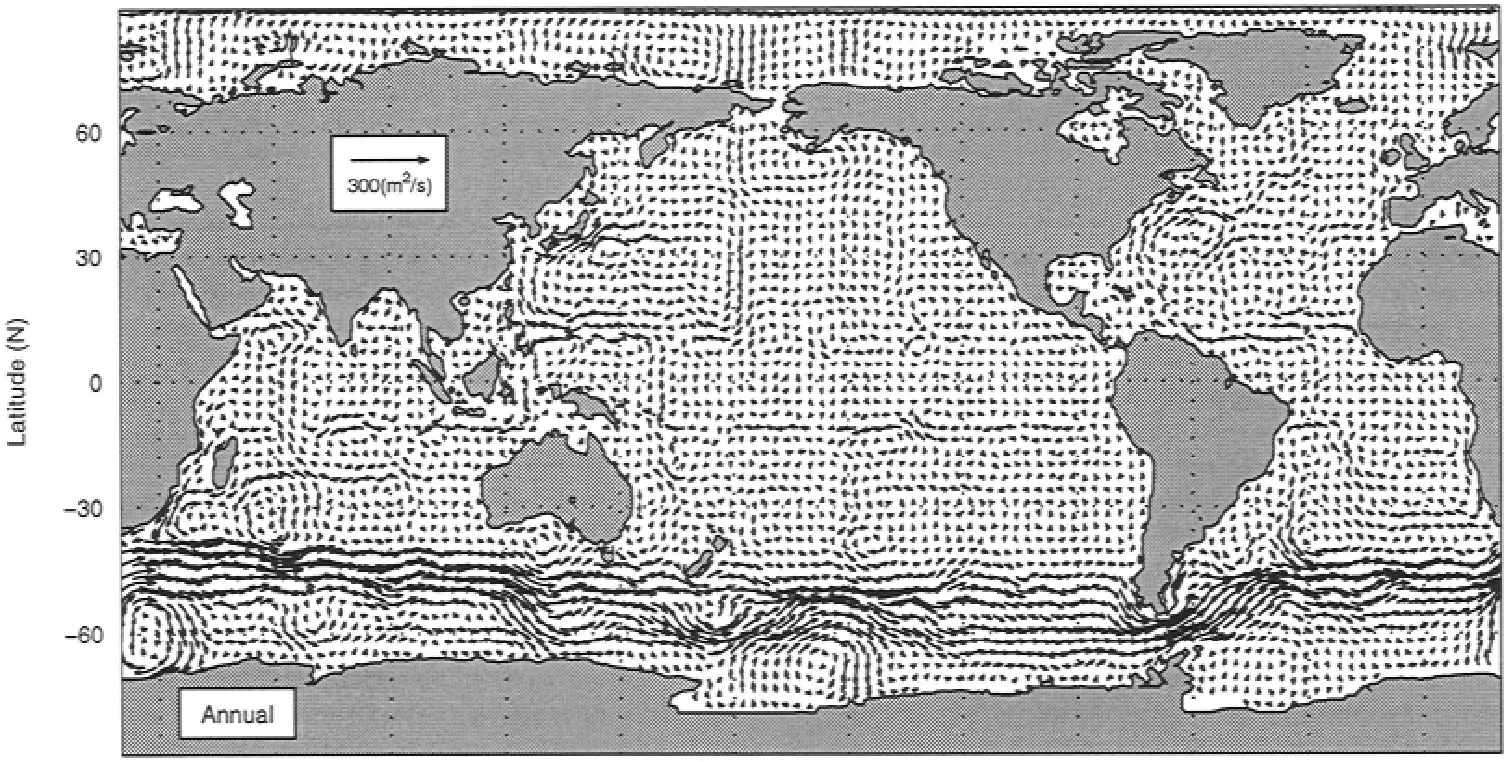


Error Estimation

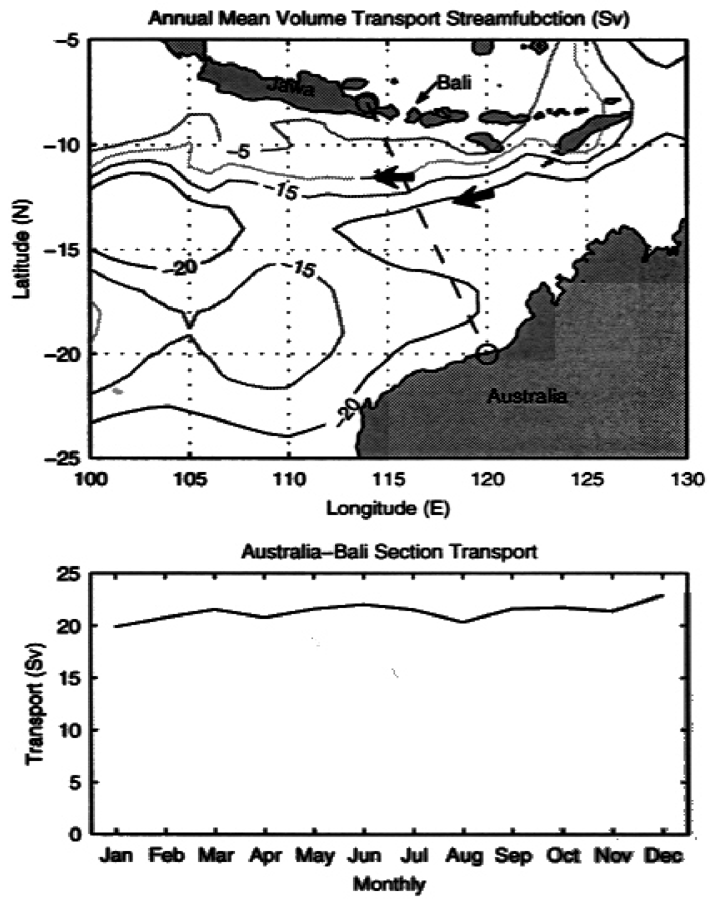
- Gaussian-Type Random Error (0 mean, 0.05N/m^2 standard Deviation) Introduced into the Surface Wind Data



Vertically Integrated Velocity Vector Field



Monthly Throughflow Transport Computed Using the Ekman-Munk Model



Comparing to Earlier Estimates (Fieux et al. 1994)

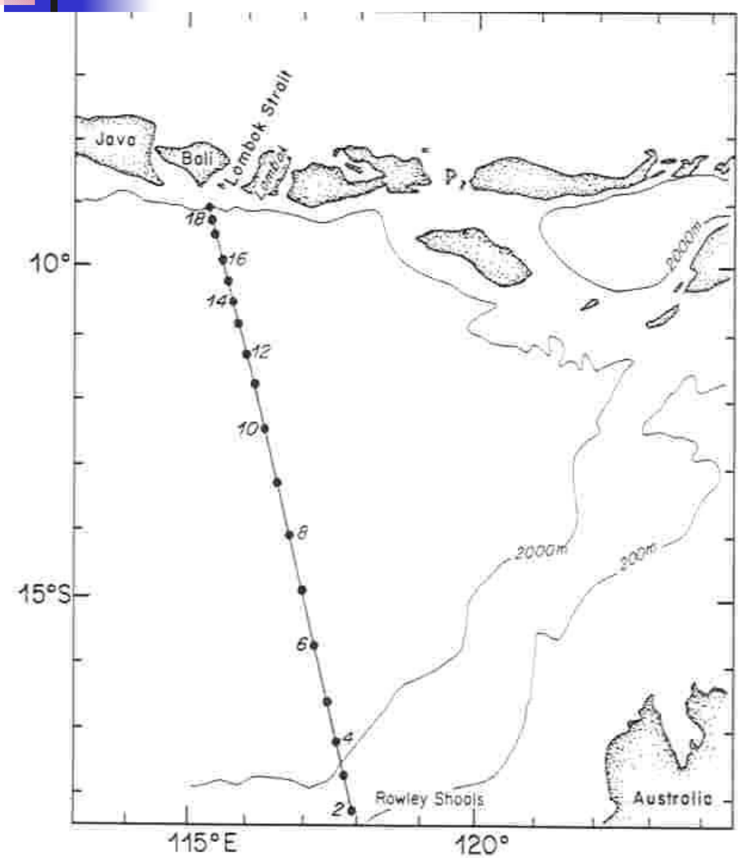
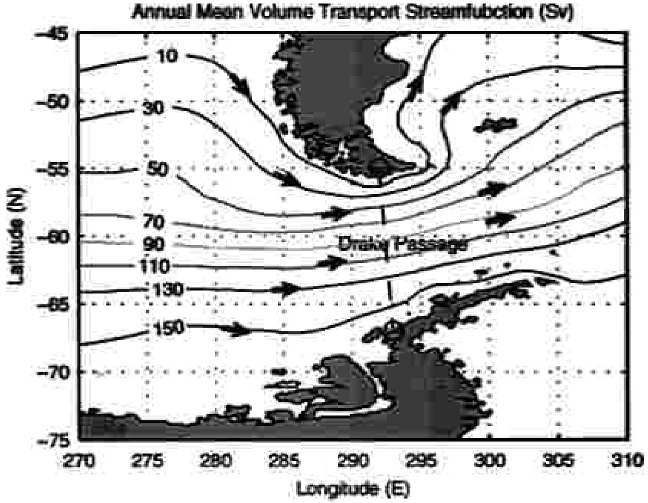


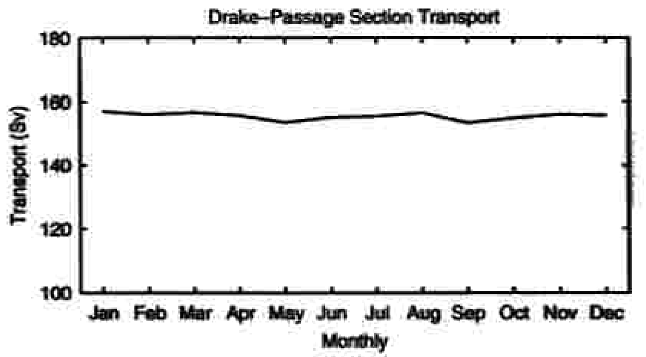
Table II-14: Australia–Bali Section Transports (in Sverdrups; adapted from Fieux *et al.*, 1994)

Layers	Transport*
0–200 db	–23.1
200–500 db	–2.7
Total 0–500 db	–25.8
500–2000 db	+9.6
Total 0–2000 db	–16.2

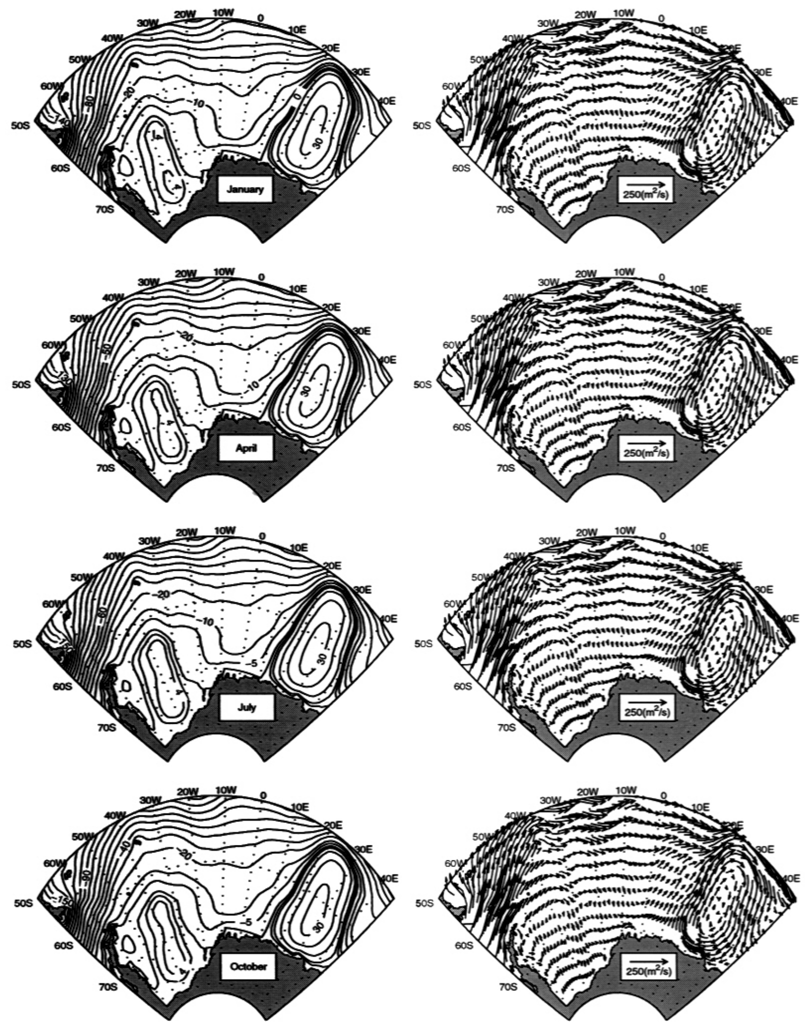
*Minus signs indicate westward flow.

Transport Through Drake Passage

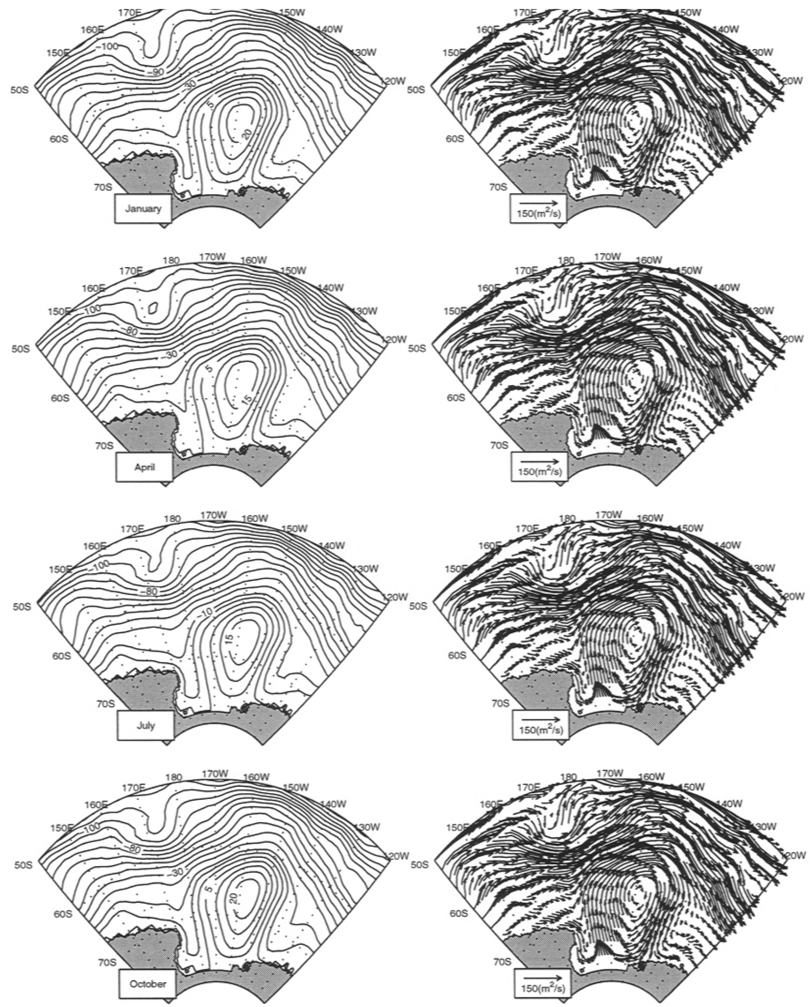




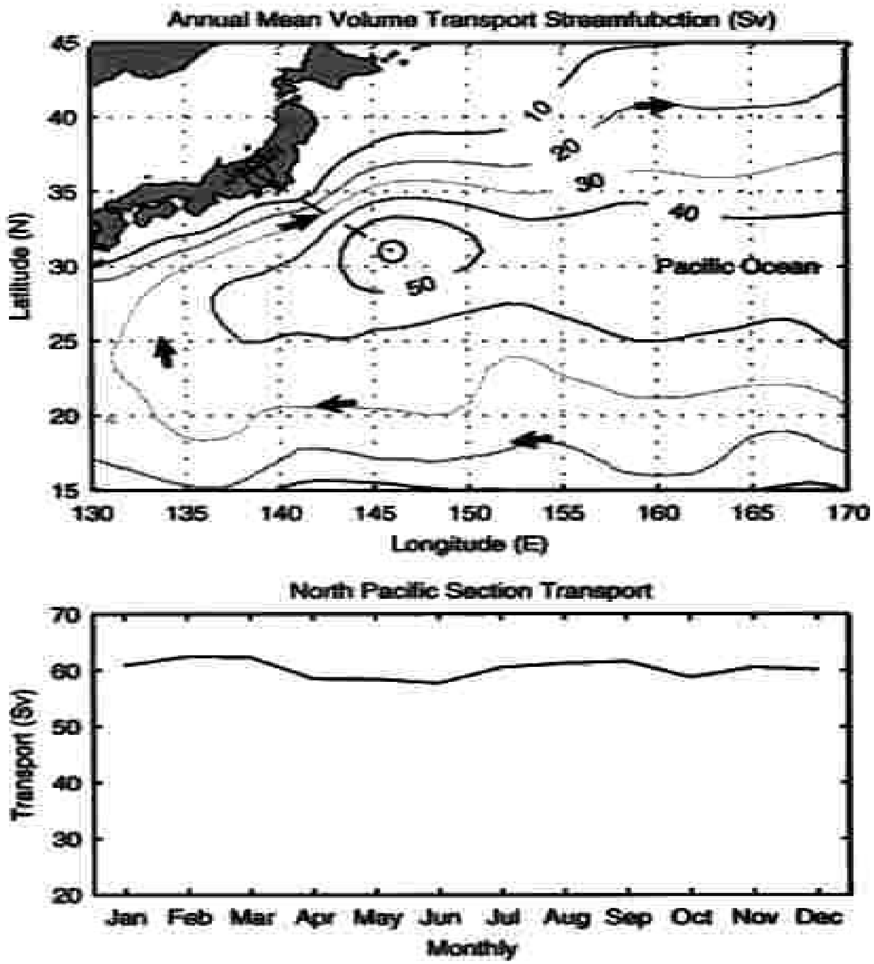
Weddell Sea Double Gyres



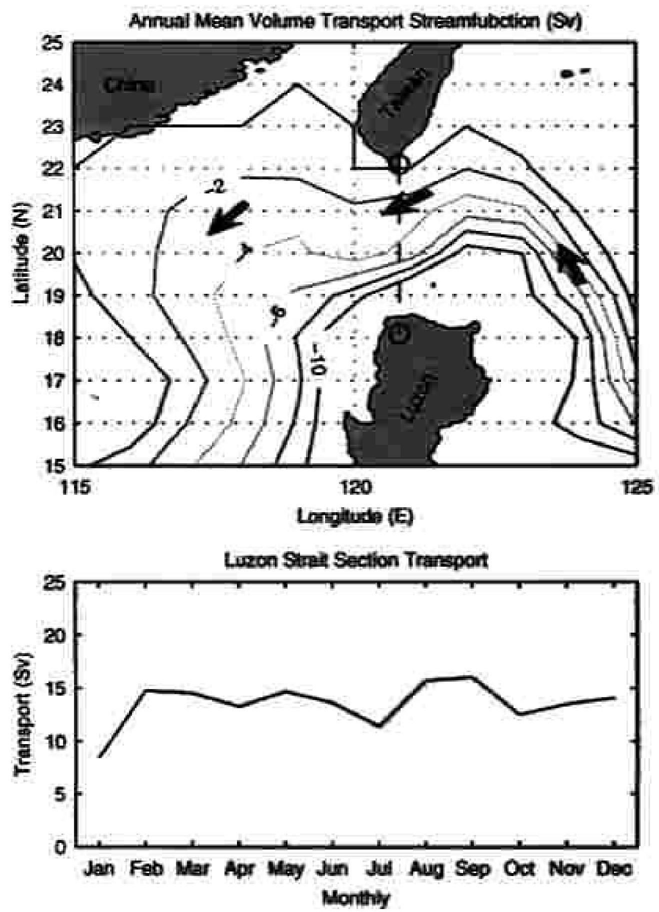
Ross Sea Gyre



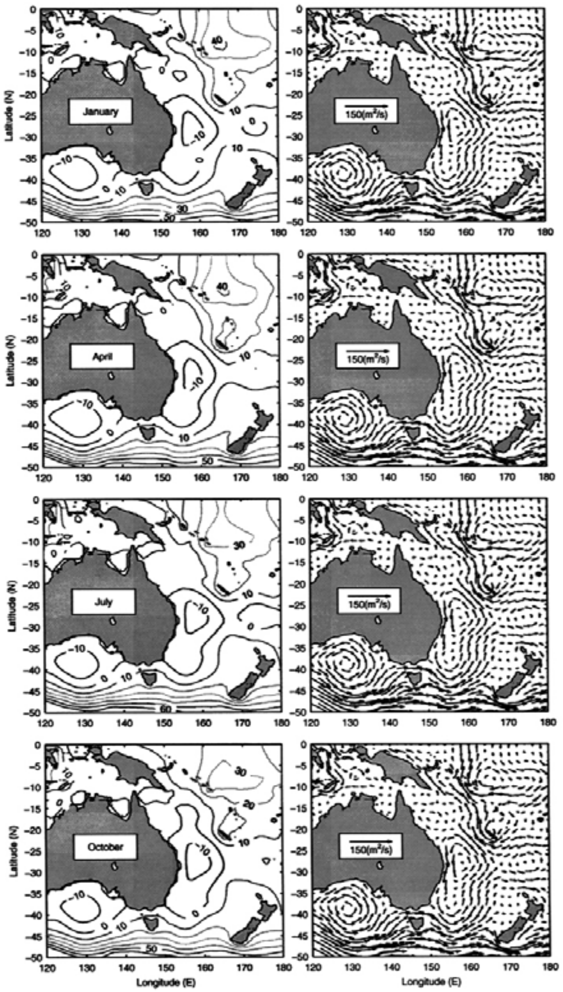
Kuroshio Transport (Sv)



Kuroshio Intrusion into the South China Sea



Circulation in the Australian Meditterrean



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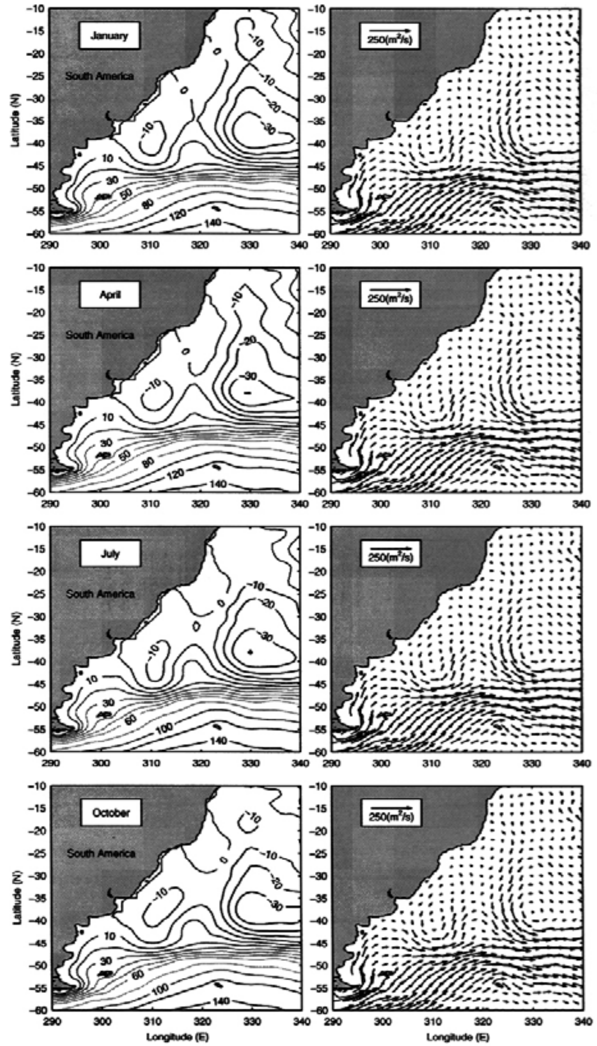
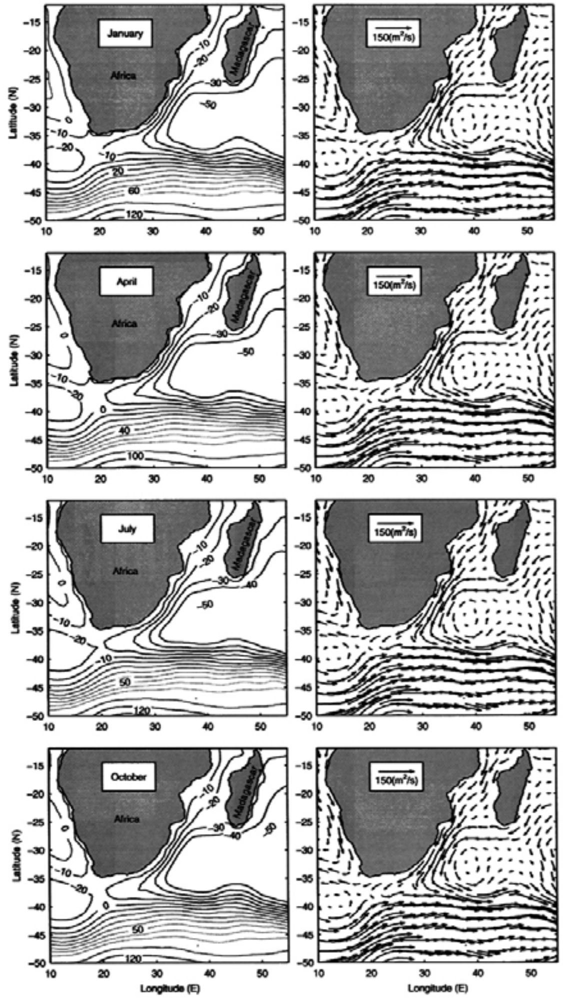
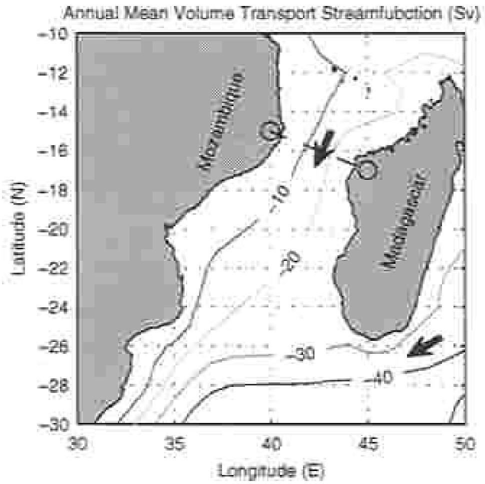
Bazil-Malvinas Confluence

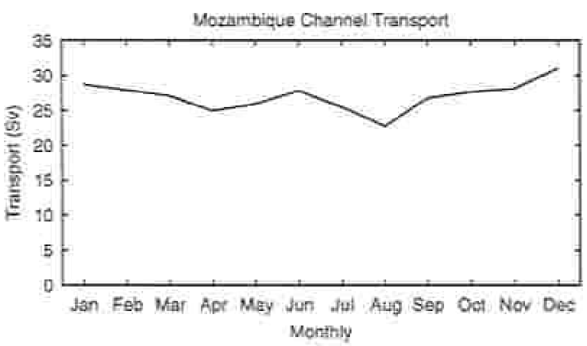


Agulhas Retroflection



Monthly Volume Transport Through the Mozabique Channel





Conclusions

- The Ekman-Munk model has the capability to determine the volume transport from the hydrographic and wind data.
- The model uses realistic topography.
- The model contains two integrations of the Poisson equation. Thus, the model has the capability to filter out noises in the input data.