NSCAT and QUIKSCAT Winds

Reveal the Mysterious

Somali Jet

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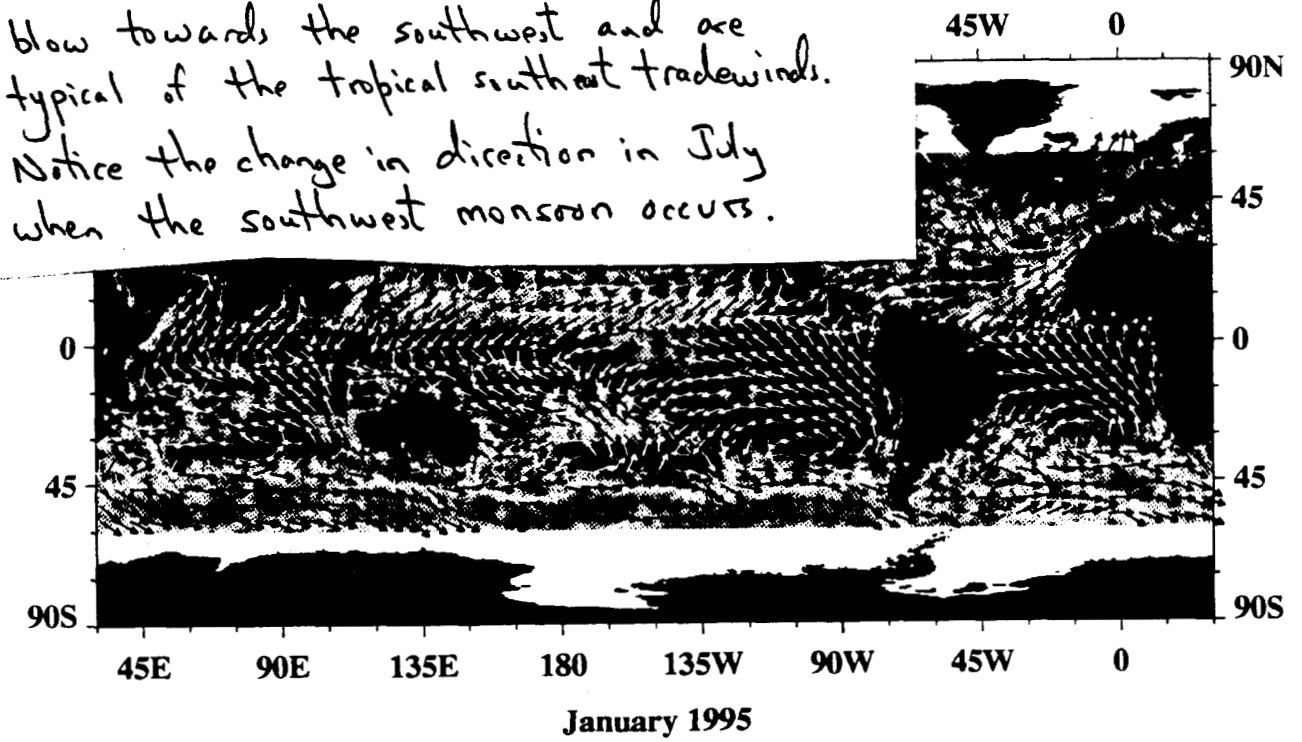
Halpern, D., M. H. Freilich and R. A. Weller (1998) Arabian Sea surface winds and ocean transports determined from ERS-1 scattereometer. *J. Geophys. Res.*, *103*, 7799-7805.

Halpern, D., M. H. Freilich and R. A. Weller (1999) ECMWF and ERS-1 surface winds over the Arabian Sea during July 1995. *J. Phys. Oceanogr.*, *29*, 1619-1623.

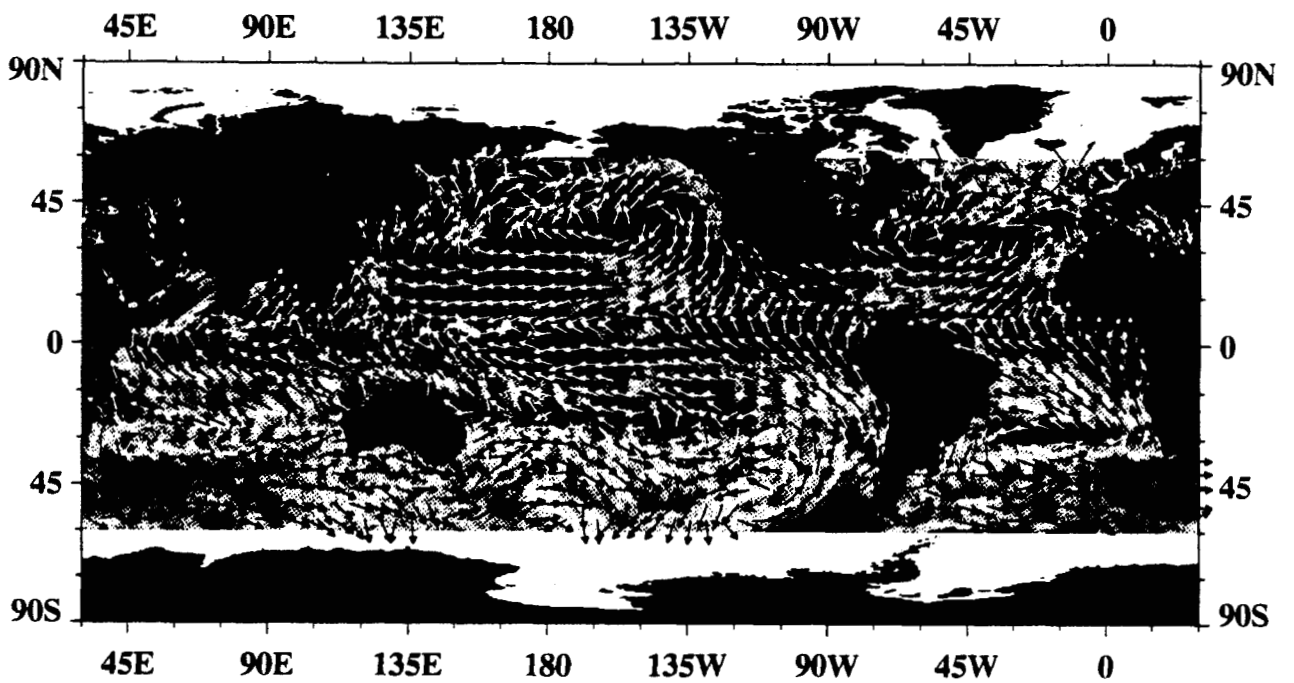
Halpern, D. and P. M. Woiceshyn (1999) Onset of the Somali Jet in the Arabian Sea During June 1997. *J. Geophys. Res.*, *104*, 18041-18046.

Halpern, D., V. Zlotnicki, P. Woiceshyn, O. Brown, M. Freilich and F. Wentz (1998) An atlas of monthly mean distributions of SSMI surface wind speed, AVHRR/2 sea sureface temperature, AMI surface wind velocity, and TOPEX/POSEIDON sea surface height during 1995. JPL Publication 98-5, Jet Propulsion Laboratory, Pasadena, 73 pp.

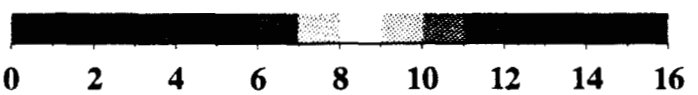
In the Arabian Sea, the winds in Jan blow towards the southwest and are typical of the tropical southeast tradewinds. Notice the change in direction in July when the southwest monsoon occurs.



January 1995

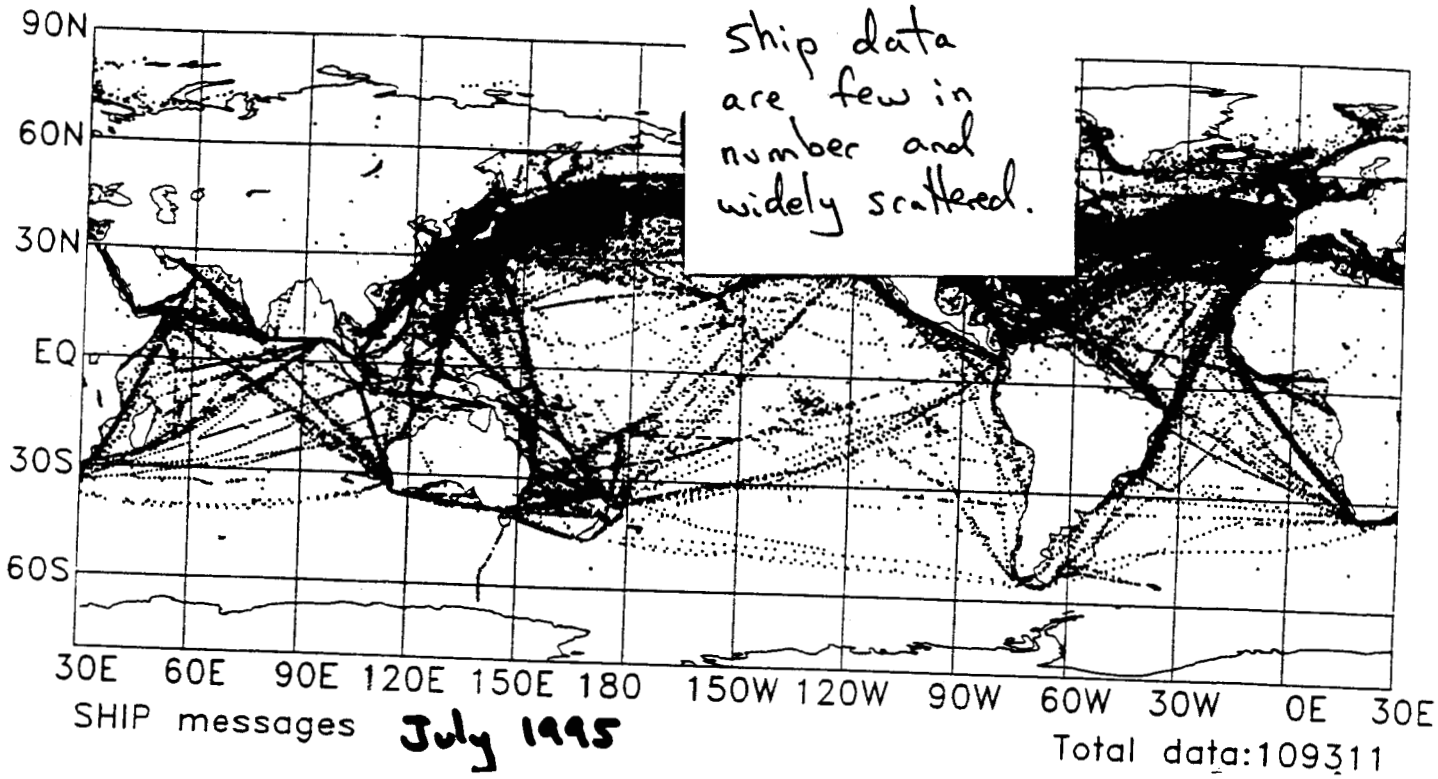


July 1995



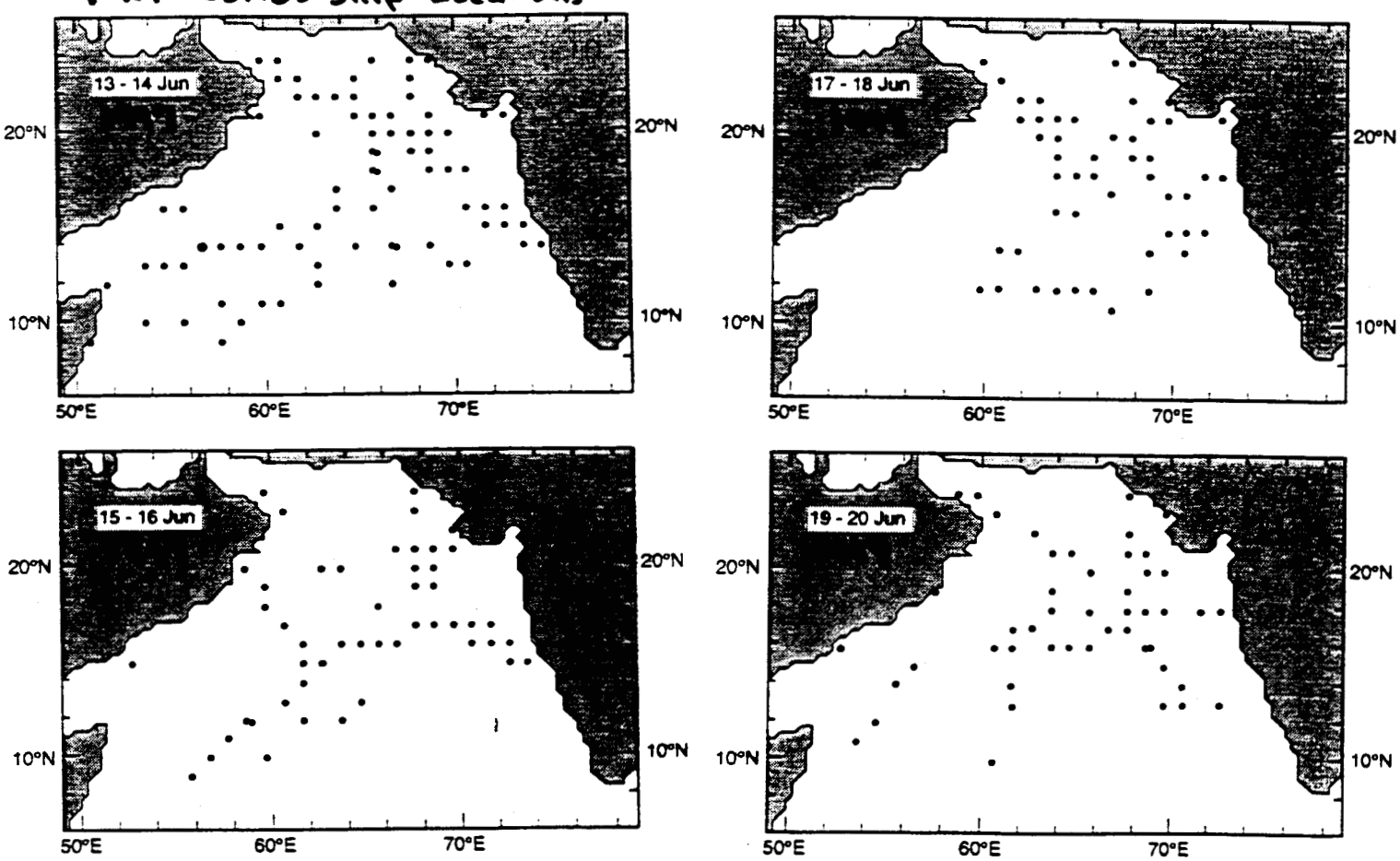
ERS-1 AMI 10 m Wind Vector, m s^{-1}

Halpern et al. (1998)

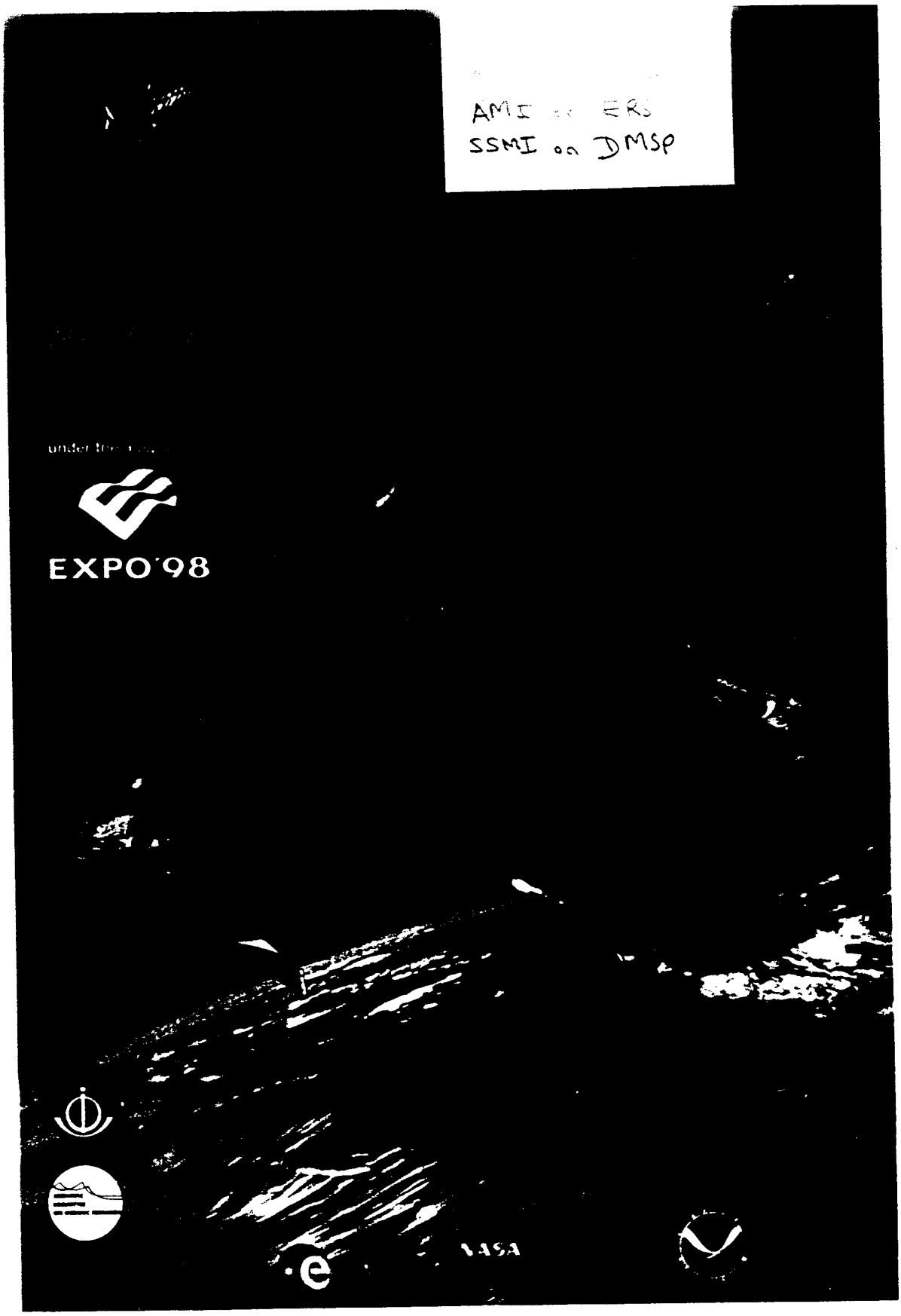


Ship data are few in number and widely scattered.

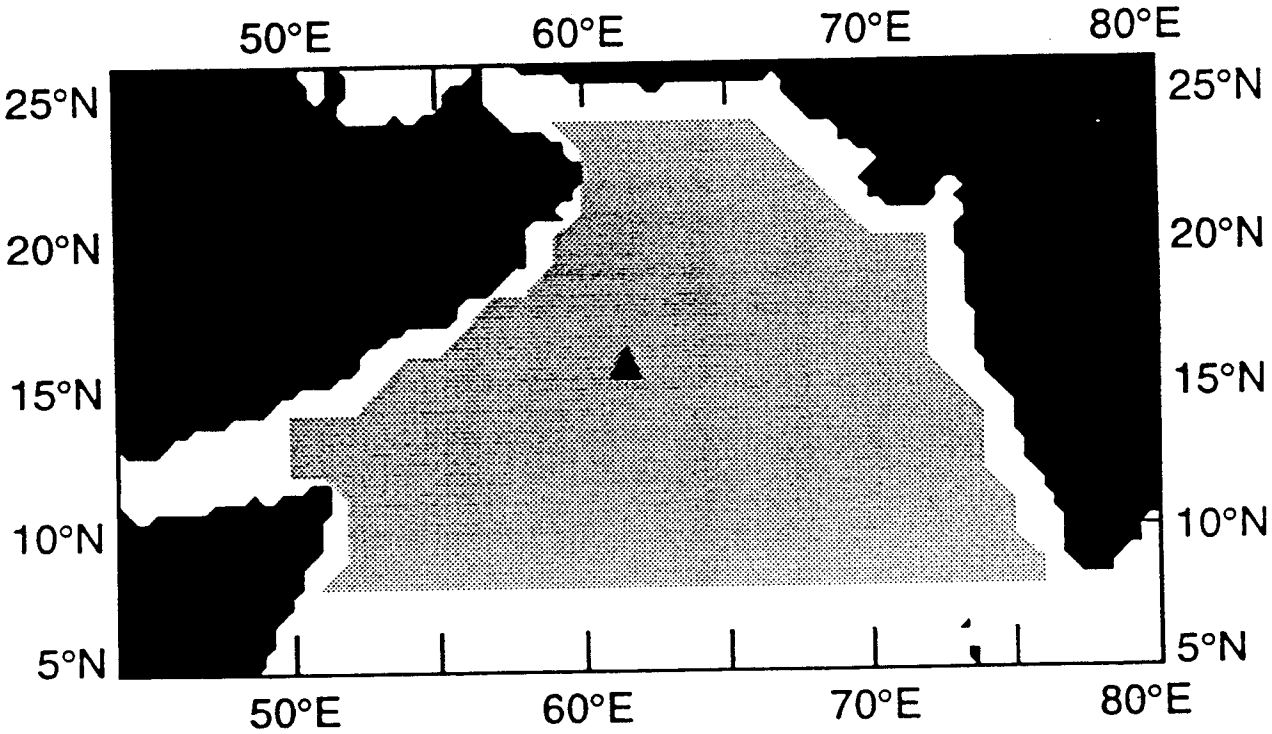
1°x1° COADS Ship Locations



AMI on ERS
SSMI on DMSP



Location of the
WHOI buoy

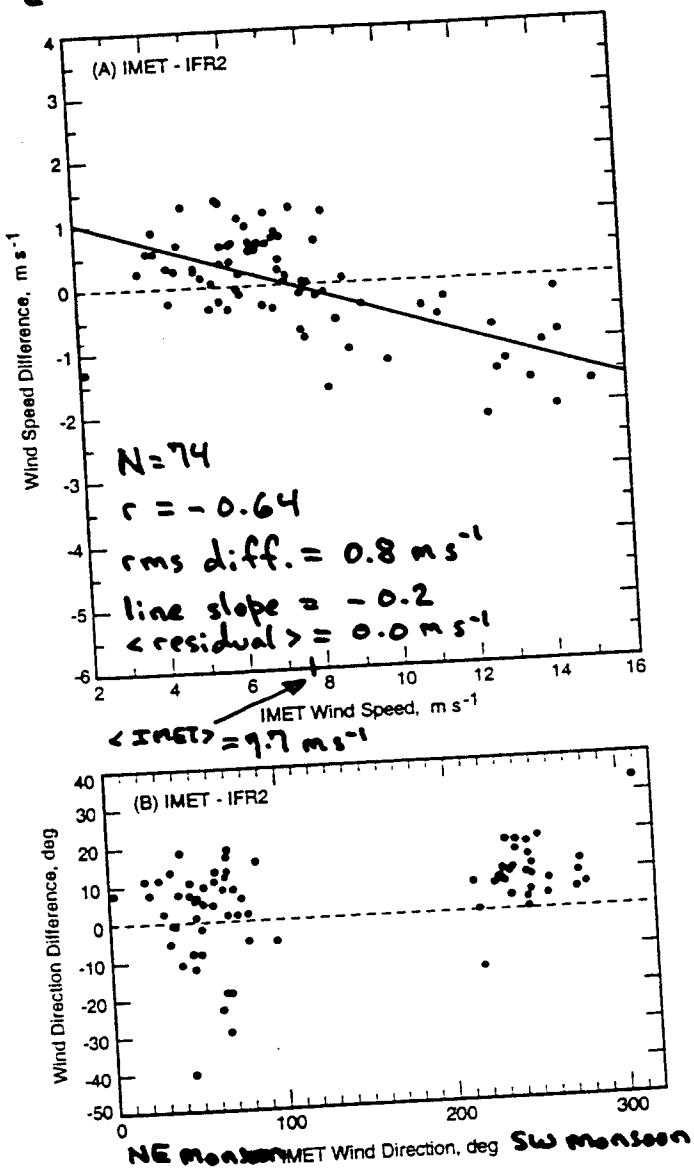


▲ IMET (Improved Meteorological) mooring [R. Weller, WHOI]
Oct 1994 – Oct 1995, redeployment in April 1995

Accuracy of ERS wind vectors

Mention FD and CMOD4

[IMET, 1-hr centered at IFR2
IFR2, 12.5 km within IMET]



This side will not be shown

$2° \pm 13°$ $\quad$ $9° \pm 8°$

$n=43$ $\quad$ $n=31$

Halpern et al. (1998)

Time of
onset of monsoon

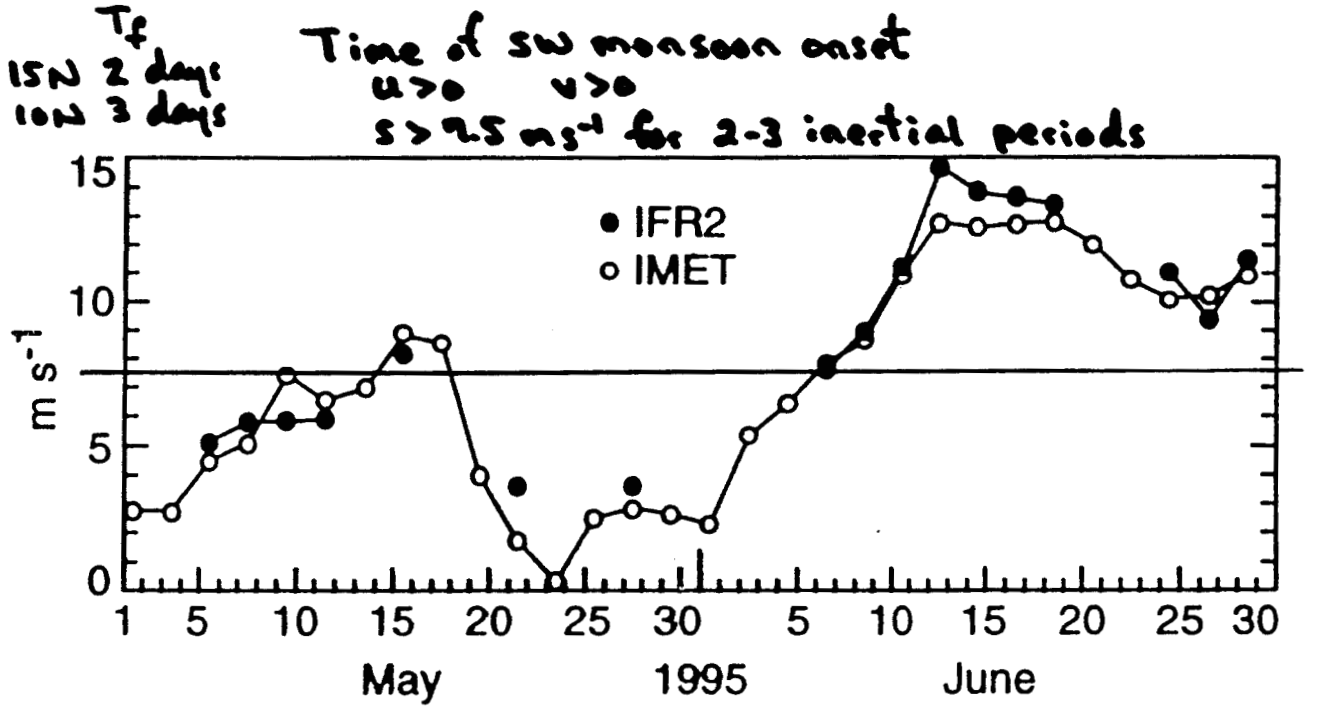


Figure 4. Time series of 2-day average wind speed computed from IMET (open circles) and IFR2 (solid circles) data. About 17 individual IFR2 wind vectors were averaged to form a 1° × 1° 2-day value centered at the IMET location.

Halpern et al. (1998)

Satellite records small-scale structures.

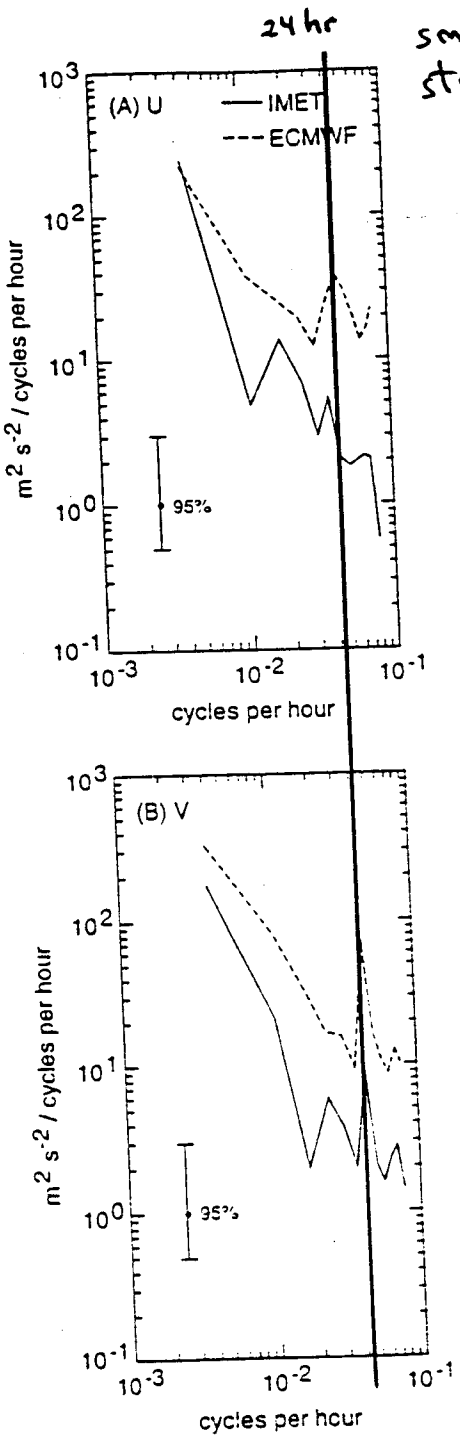


FIG. 3. Frequency spectra of (a) east–west, u, and (b) north–south, v, wind velocity components for IMET and ECMWF data during July 1995. The 95% represents the 95% confidence levels determined from the chi-square distribution.

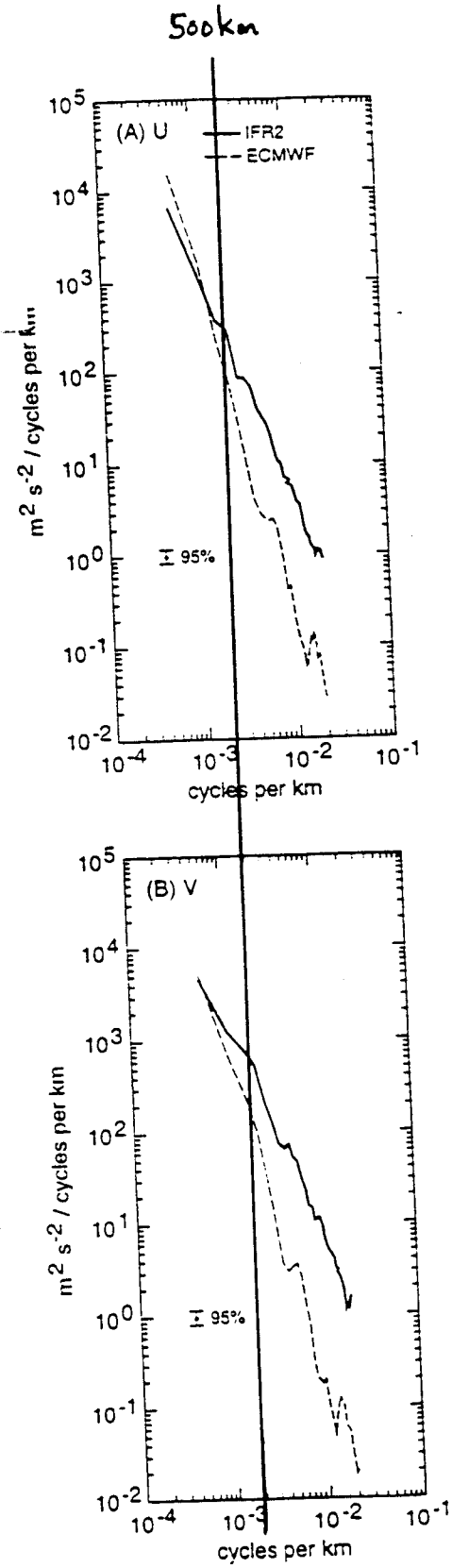


FIG. 4. Wavenumber spectra of (a) east–west, u, and (b) north–south, v, wind velocity components for ECMWF and *IFR2* data during July 1995 in the central Arabian Sea. The 95% represents the 95% confidence levels determined from the chi-square distribution.

Halpern et al. (1999)

Wind-Driven Ocean Transports

$$\left[\mathrm{curl}_z \tau^\circ = \frac{\partial \tau_y^\circ}{\partial x} - \frac{\partial \tau_x^\circ}{\partial y} \,, \quad f = 2\Omega \sin\theta \,, \quad \beta = \frac{2\Omega \cos\theta}{R} \right]$$

- vertical $$\int_x \int_y \left(\frac{1}{\rho f} \right) \left(\mathrm{curl}_z \tau^\circ + \beta \frac{\tau_x^\circ}{f} \right) dx\, dy$$

- y-component Ekman $$\int_x - \frac{\tau_x^\circ}{\rho f}\, dx$$

- Sverdrup $$\int_x \left(\frac{\mathrm{curl}_z \tau^\circ}{\rho \beta} \right) dx$$

$$1 \ \mathrm{Sv} = 1 \times 10^6 \ \mathrm{m}^3 \ \mathrm{s}^{-1}$$

[Gulf Stream transport ~ 100 Sv]

[River transport ~ 1 Sv]

Rain, freshwater transport = 10 Sv

The vertical velocity at the bottom of the Ekman layer associated with divergence and convergence in the Ekman layer is

$$\boxed{W_E = \frac{1}{\rho f}\left[\mathrm{curl}_z\,\tau - \beta M_y^E\right]}$$

$\rho = 1025\ \mathrm{kg\ m^{-3}}$

$f = 2\Omega \sin\theta$

$\beta = \frac{df}{dy} = \frac{2\Omega\cos\theta}{R}$

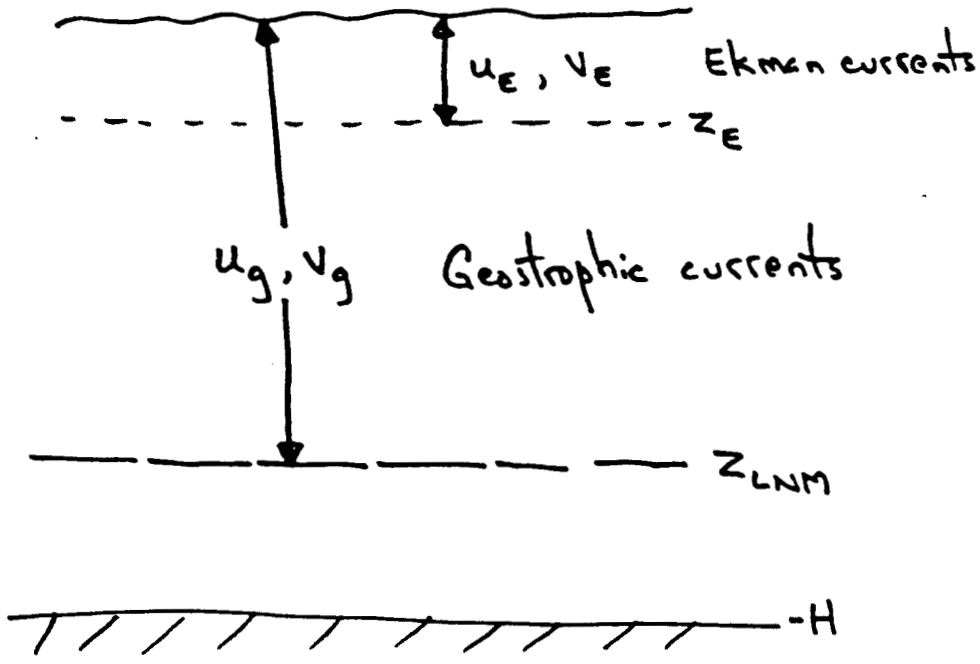
M_y^E = Ekman mass transport (per unit width) in y-direction $= -\frac{\tau_x}{f}$

$$\mathrm{curl}_z\,\tau = \frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y}$$

$$(\tau_x, \tau_y) = \rho_a C_D (u,v)(u^2+v^2)^{1/2}$$

$\rho_a = 1.225\ \mathrm{kg\ m^{-3}}$

Sverdrup Transport



$$u = u_E + u_g$$

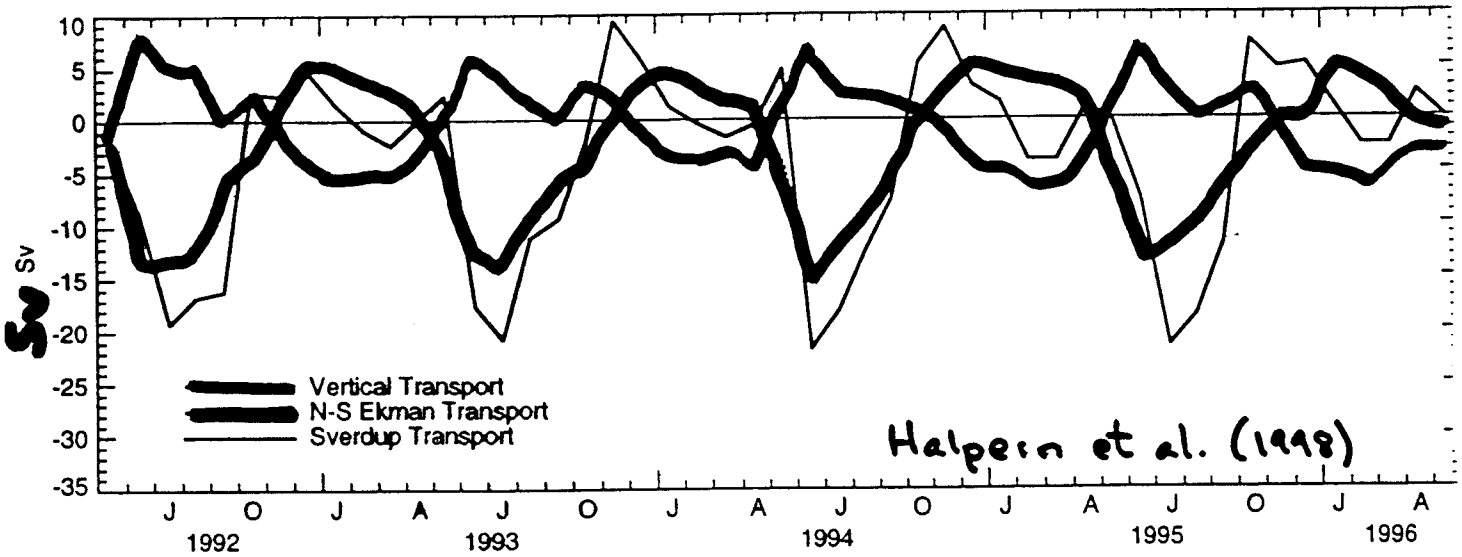
$$v = v_E + v_g$$

$$M_y = \int_{z_{LNM}}^{z=0} \rho v \, dz$$

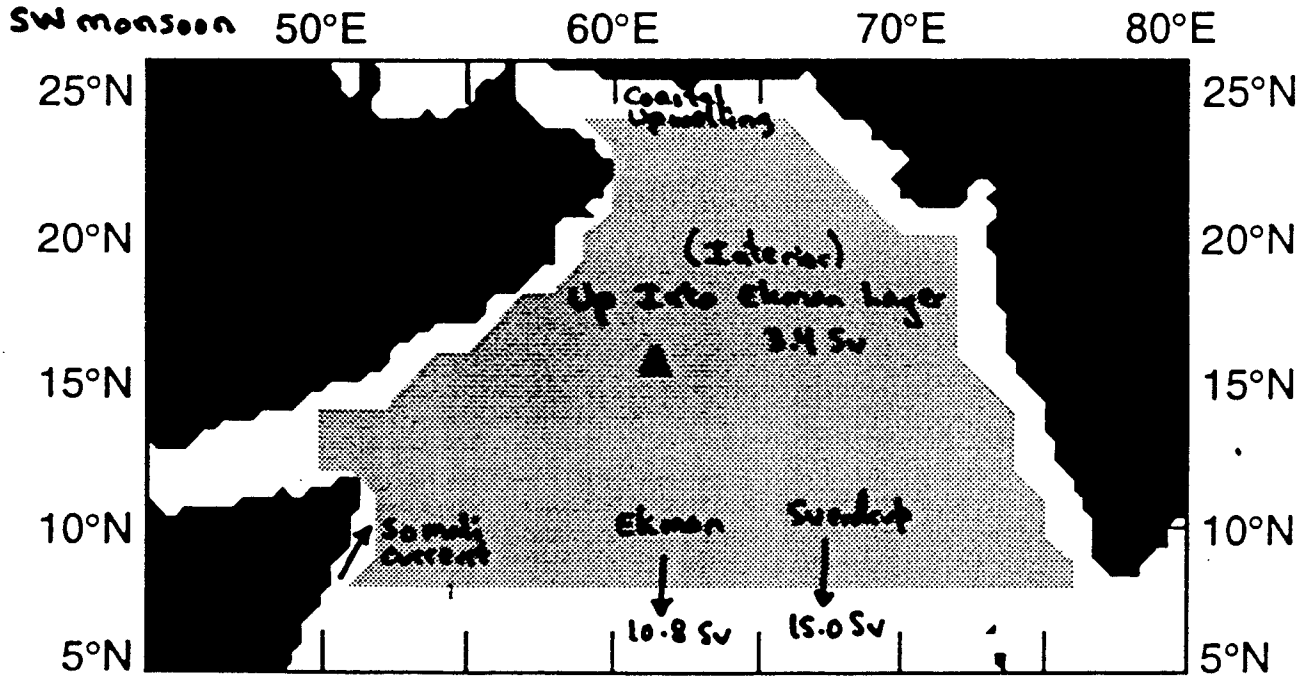
$$M_y = \frac{\mathrm{curl}_z \, \tau^*}{\beta}$$

Sverdrup transport per unit zonal width [integrated north-south current from $z=0 \rightarrow z_{LNM}$]

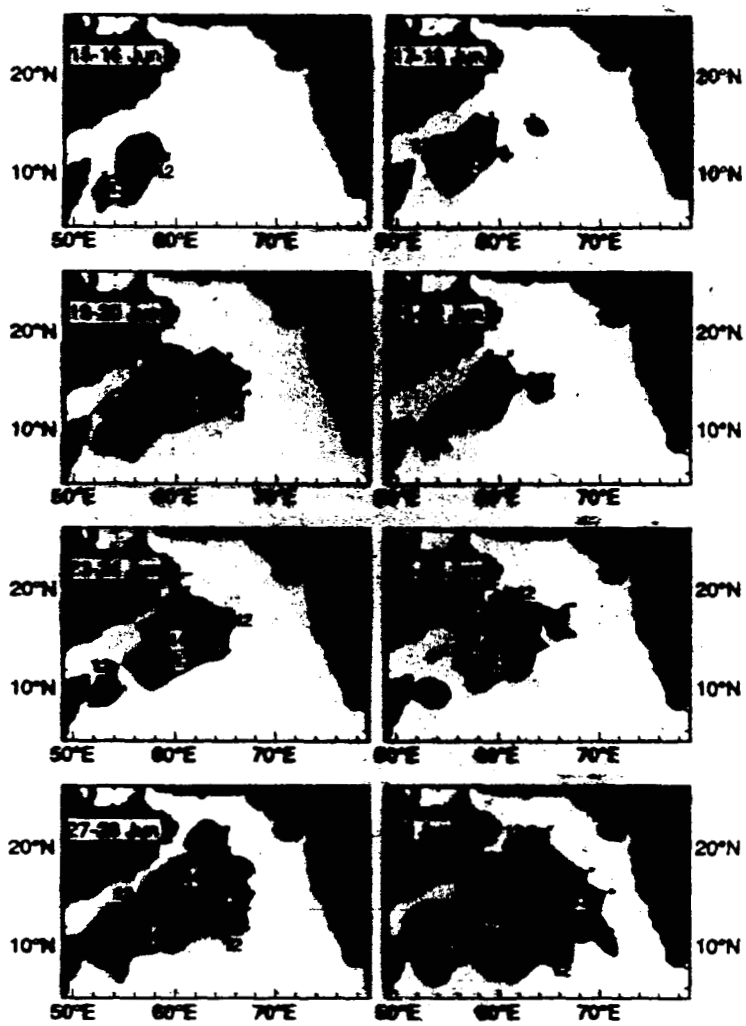
$$\text{Sverdrup Transport} = \int_x M_y \, dx$$



	4-year Mean	SW Monsoon 4-year Jun - Sep Mean	NE Monsoon 4-year Dec - Mar Mean
Vertical	-0.5	3.4	-4.8
N-S Ekman	-2.7	-10.8	3.8
Sverdrup	-4.0	-15.0	0.3



NSCAT Provides First Look at Somali Jet Pulsation

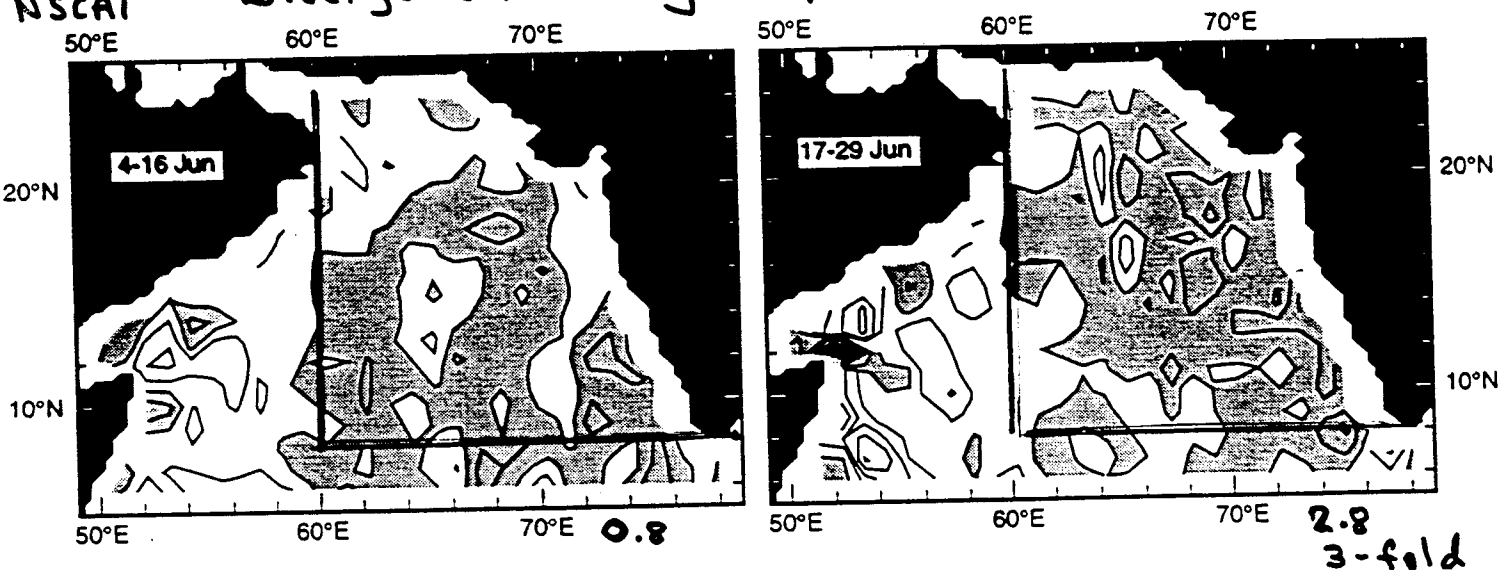


Pulsations of the Somali Jet, which is the intense southwesterly surface winds over the Arabian Sea, were undetected over the Arabian Sea until the launch of NSCAT because of insufficient simultaneous wind vector observations.

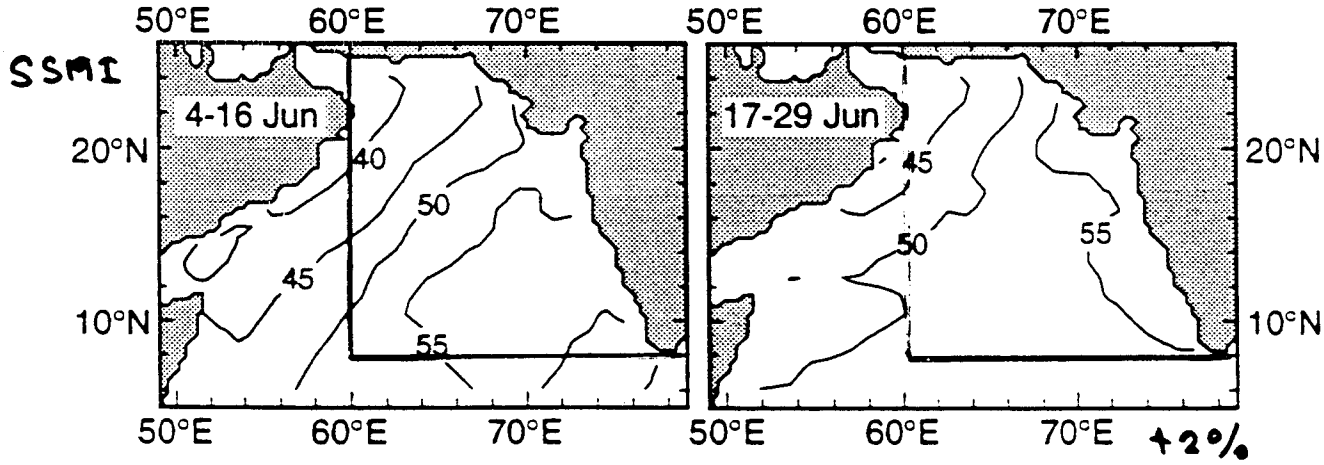
The diagram shows the eastward expansion of Somali Jet high winds (> 12 m s^{-1}) at 2-day intervals. The initial onset of high winds preceded by 3-4 days the time of onset of rainfall in Goa, which is on the west coast of India at about 15°N. Associated with the eastward advance of the Somali Jet were substantial increases in NSCAT-derived surface wind convergence and SSMI-derived integrated cloud liquid water content. Additional studies are necessary to show that Goa rainfall was related to the eastward propagating Somali Jet.

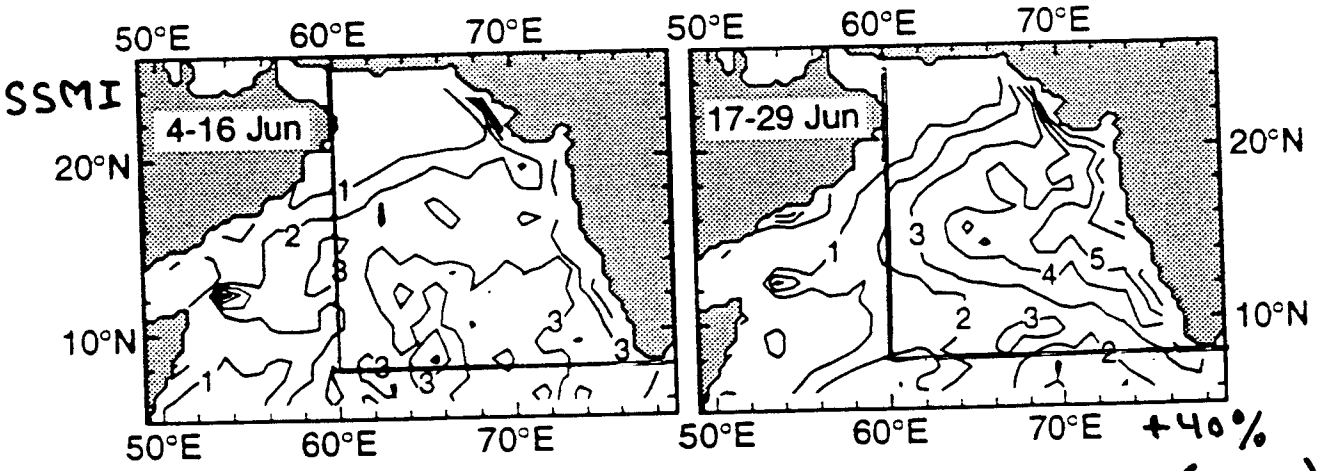
Halpern, D. and P. Woiceshyn, Onset of the Somali Jet in the Arabian Sea During June 1997. *Journal of Geophysical Research*, *104*, [redacted], 1999.

NSCAT Divergence / Convergence, $10^{-6}\ s^{-1}$ [CI = $10 \times 10^{-6}\ s^{-1}$]



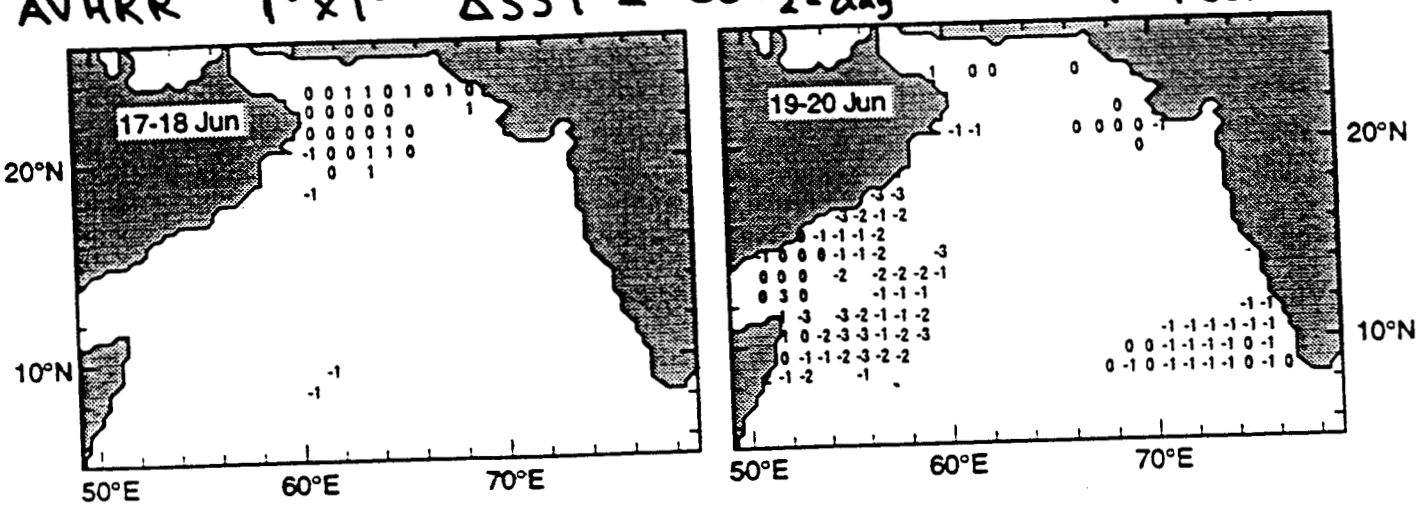
Integrated Water Vapor (Total Precipitable Water), mm

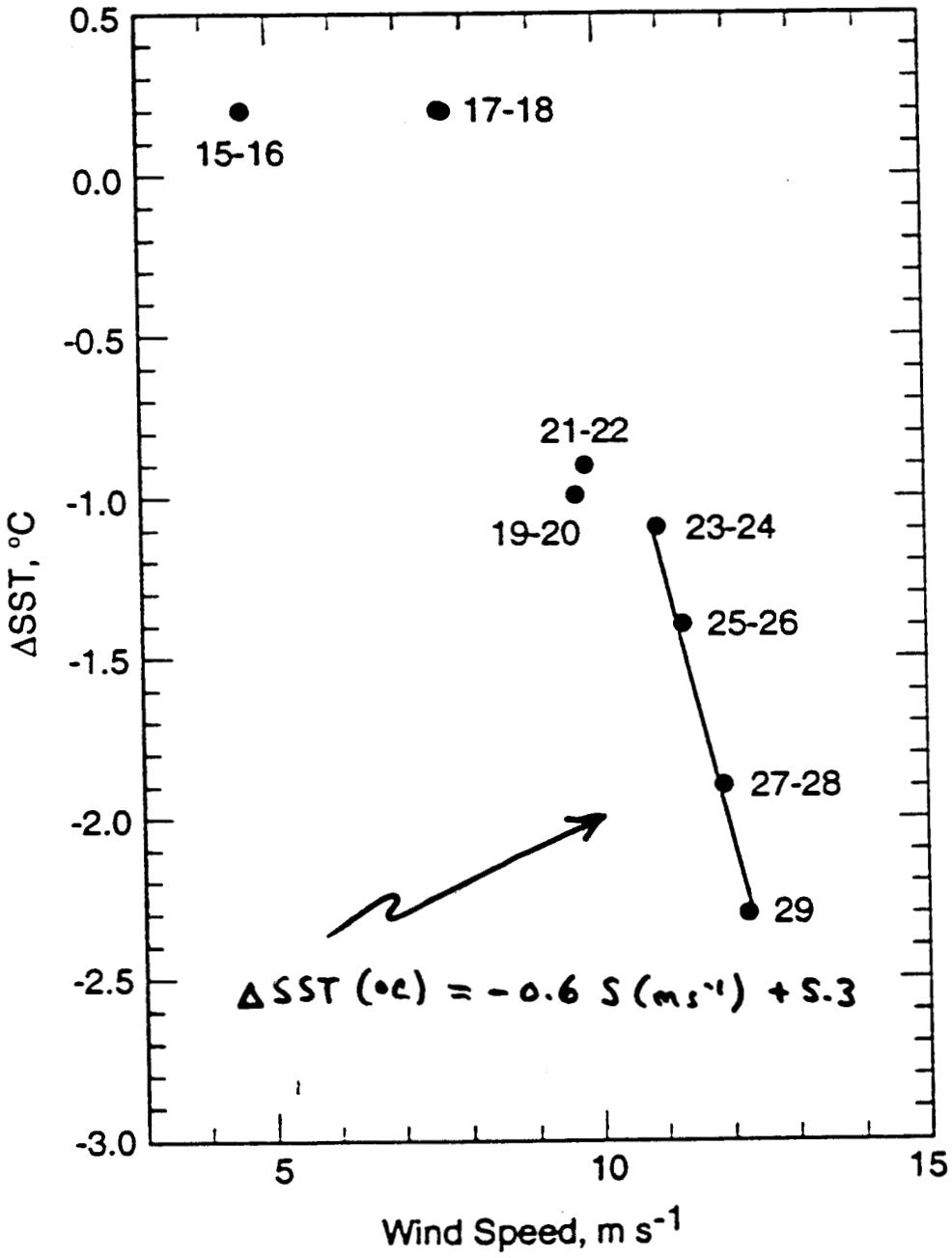




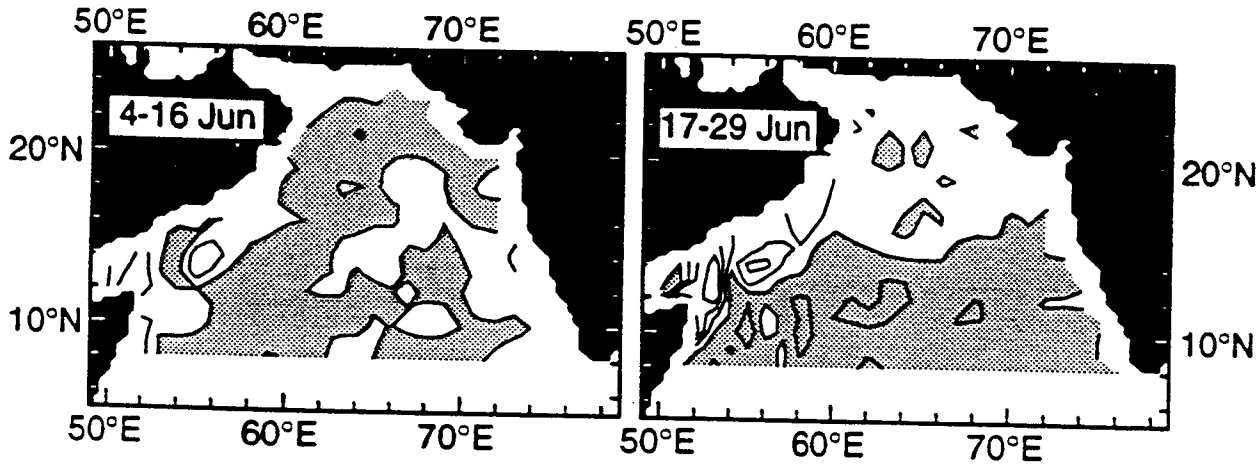
Integrated Cloud Liquid Water Content (0.1mm)

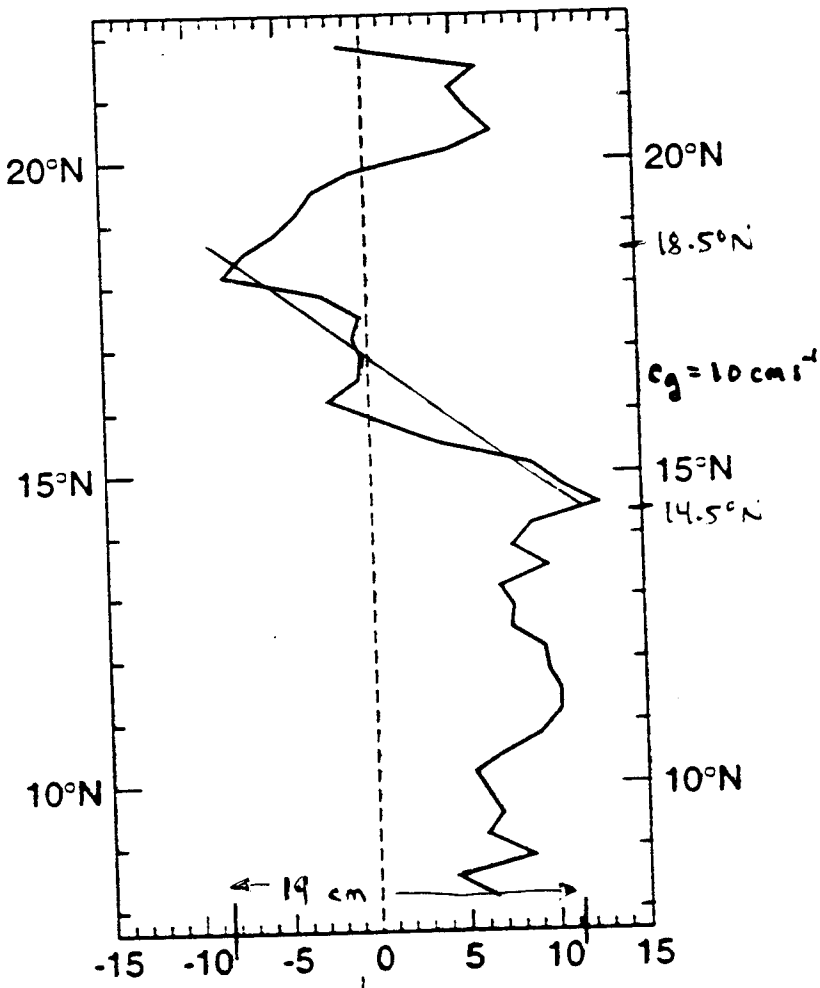
AVHRR 1°×1° $\Delta SST = SST_{2\text{-}day} - SST_{1\text{-}14\ Jun}$, °C





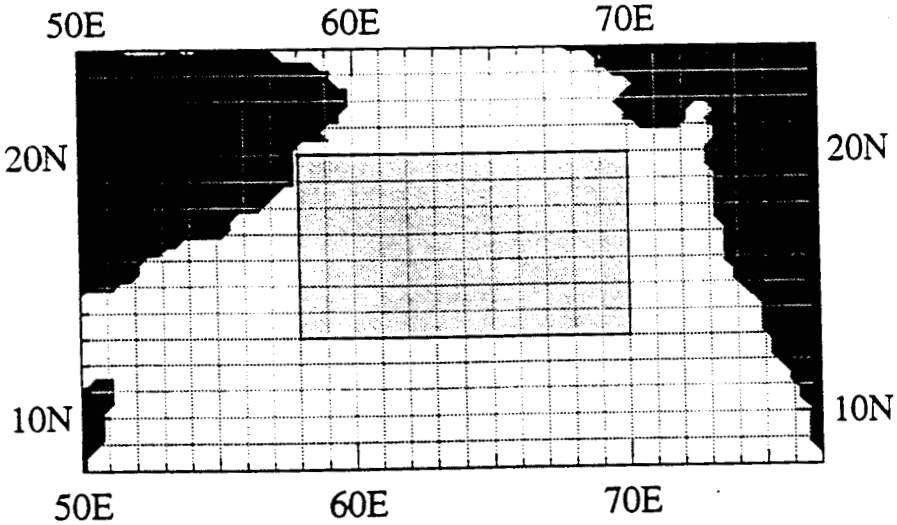
W_E, 10^{-6} m s^{-1} [CI = 10×10^{-6} m s^{-1}]

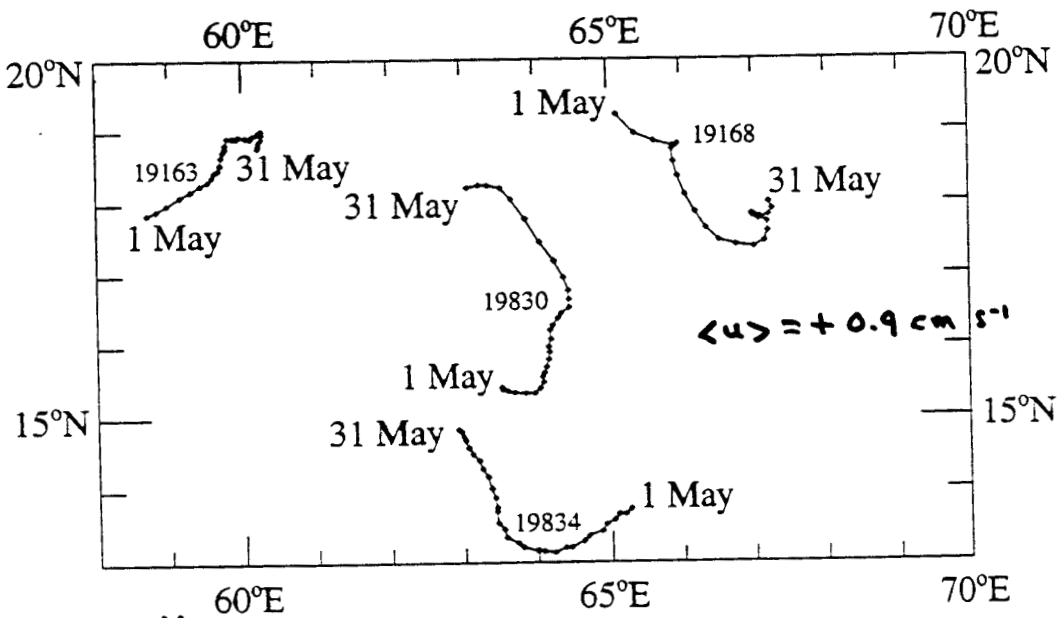




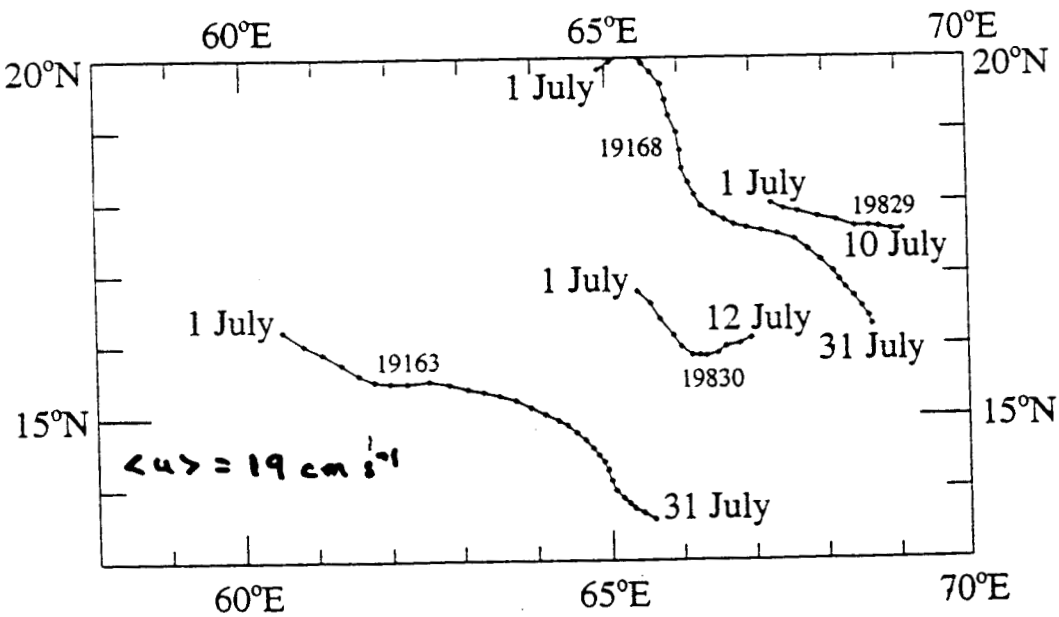
July-minus-May 1997

Daily Buoy Locations in May and July1997

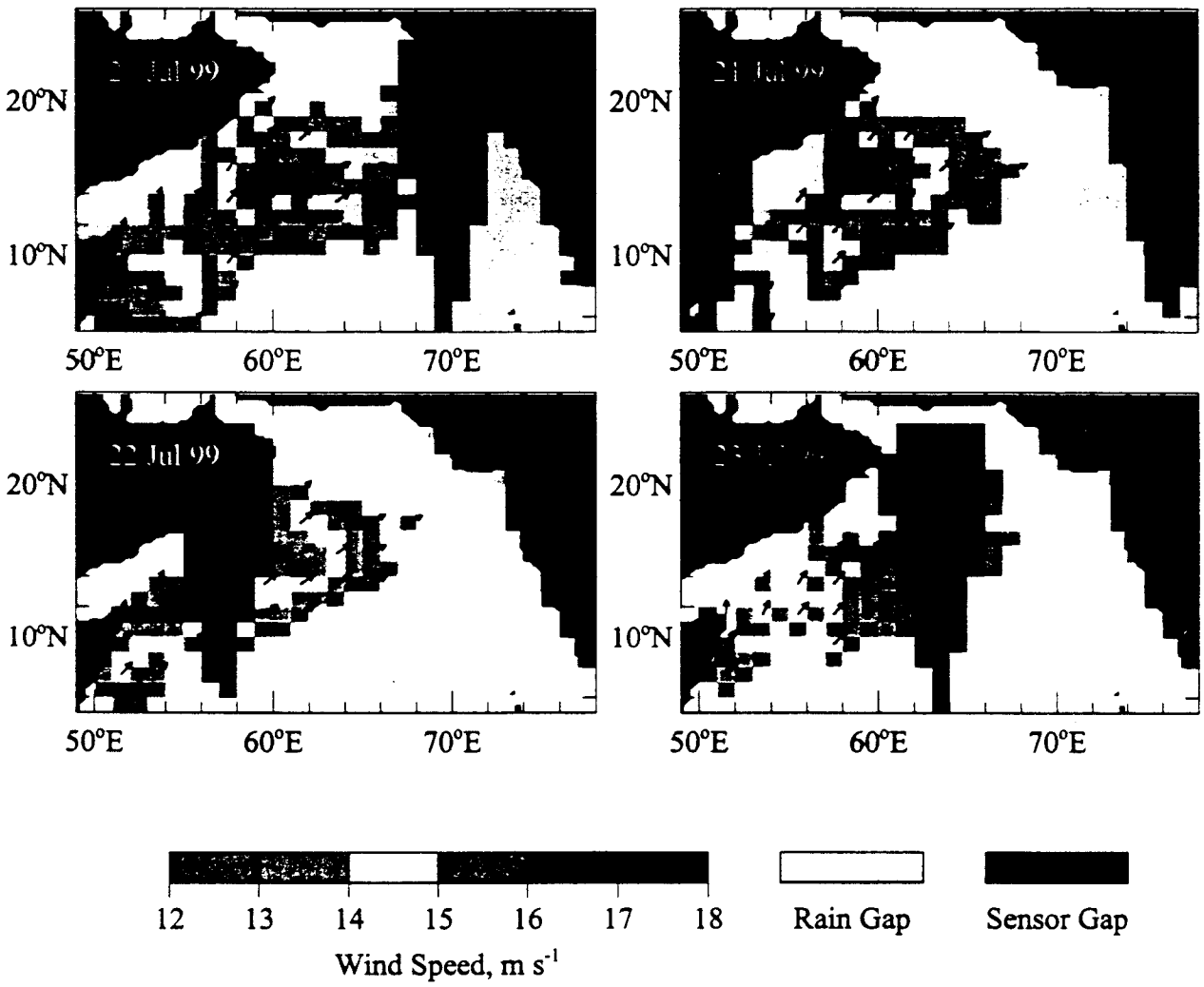


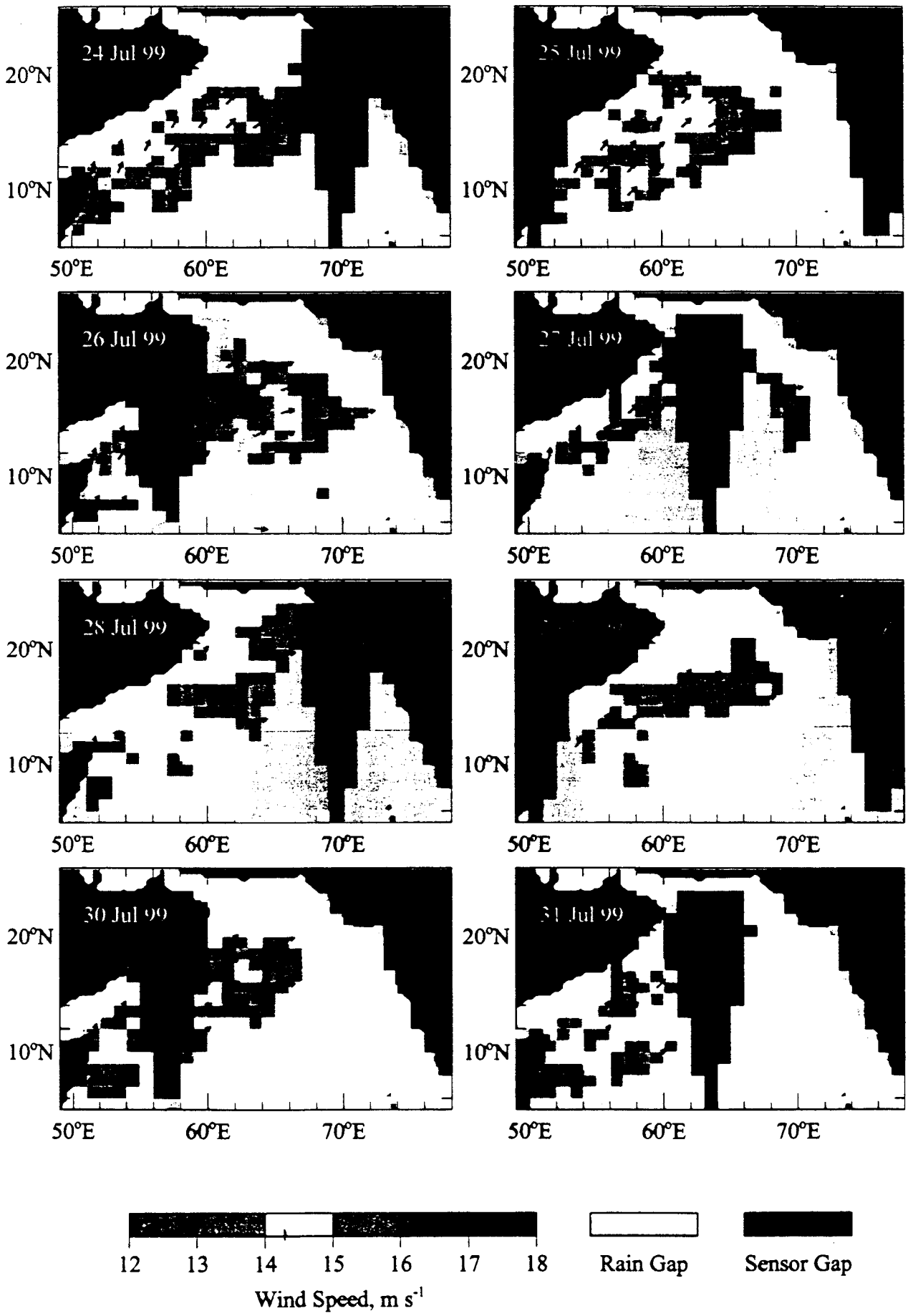


~15m depth



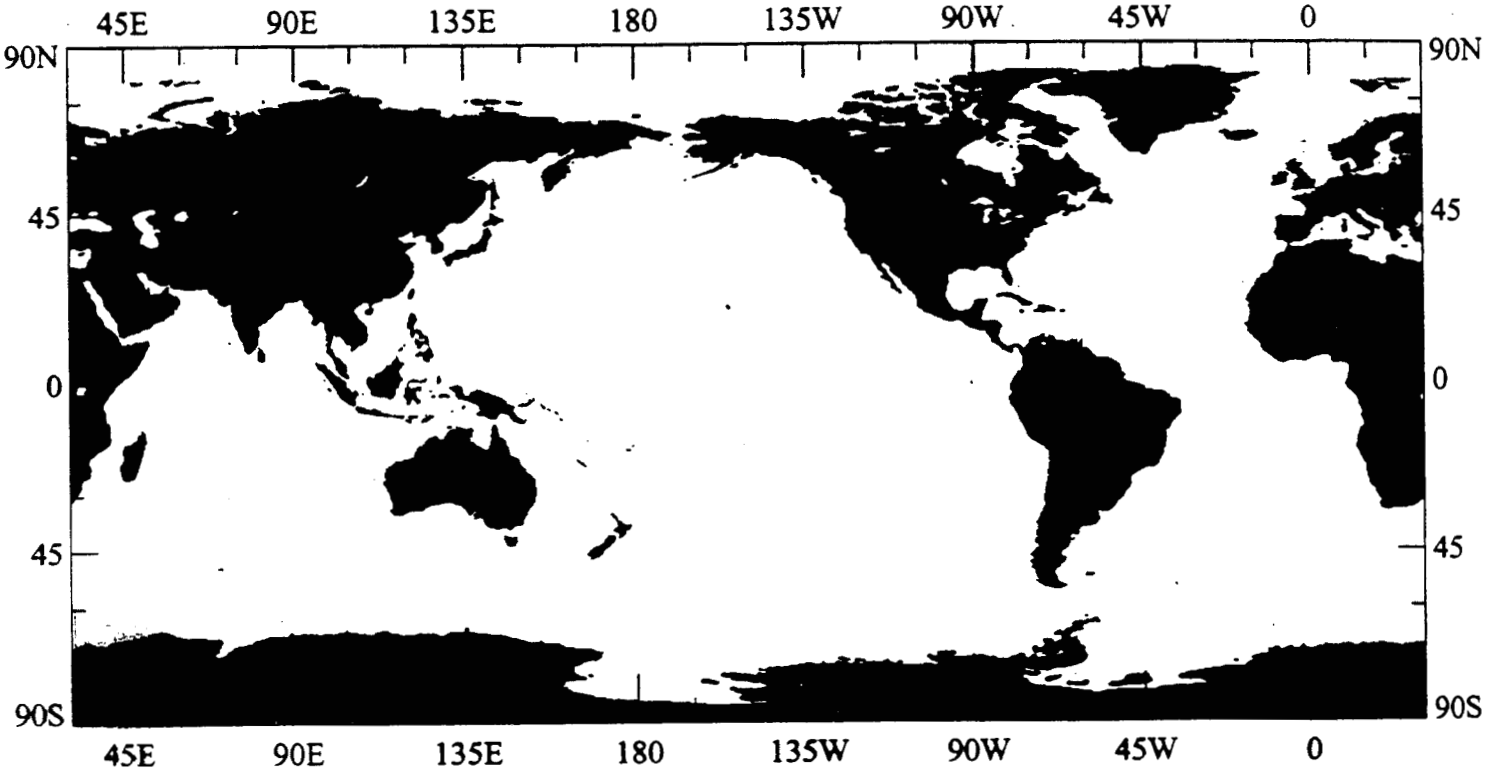
QuikScat
not contaminated by rain




24 Jul 99
25 Jul 99
26 Jul 99
27 Jul 99
28 Jul 99
30 Jul 99
31 Jul 99
20°N
10°N
50°E
60°E
70°E
12
13
14
15
16
17
18
Wind Speed, m s-1
Rain Gap
Sensor Gap

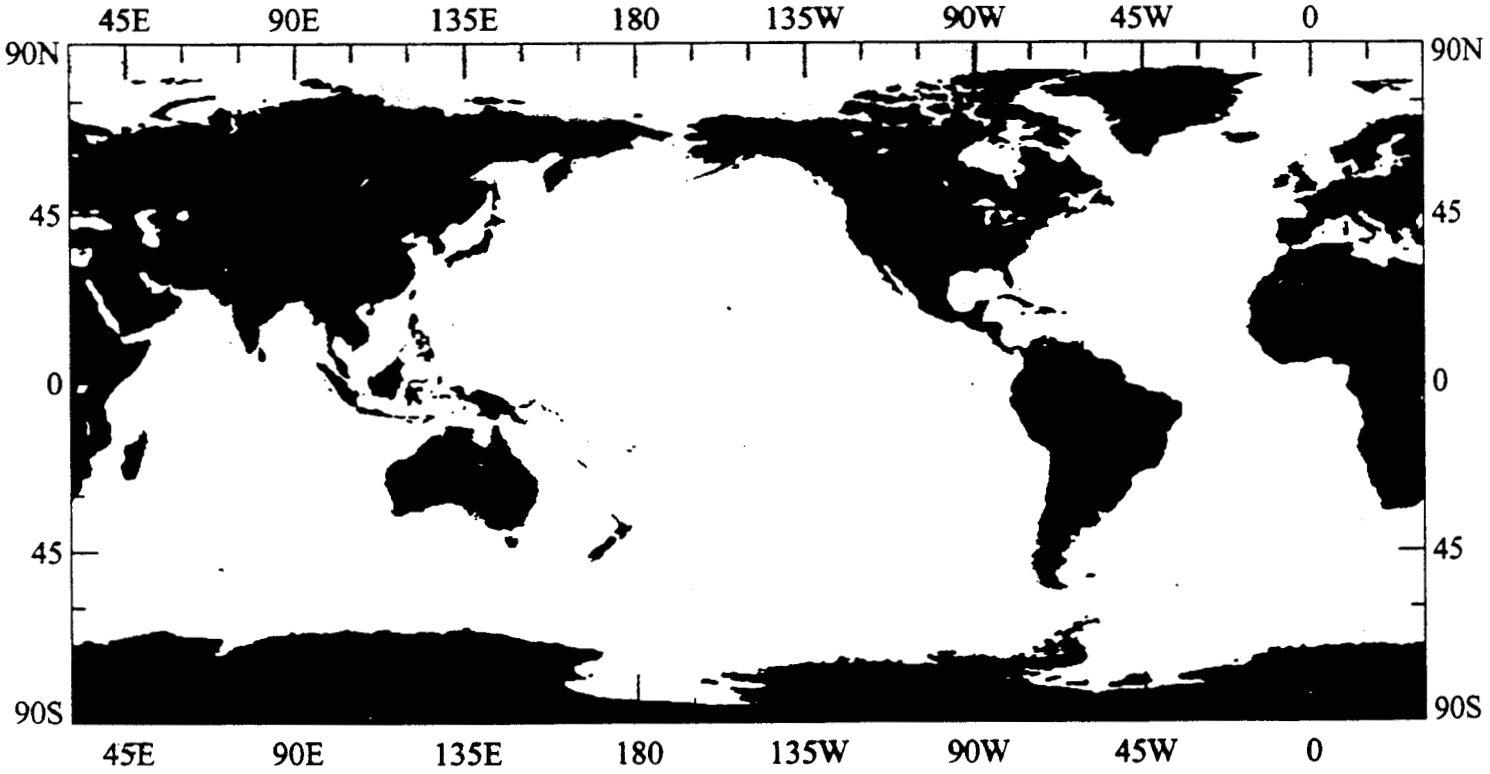
26 October 1999 - QuikScat (prelim) - 1°x1° (Y.M.)

Data Gaps Shown by Green Areas



27 October 1999 - QuikScat (prelim) - 1°x1° (Y.M.)

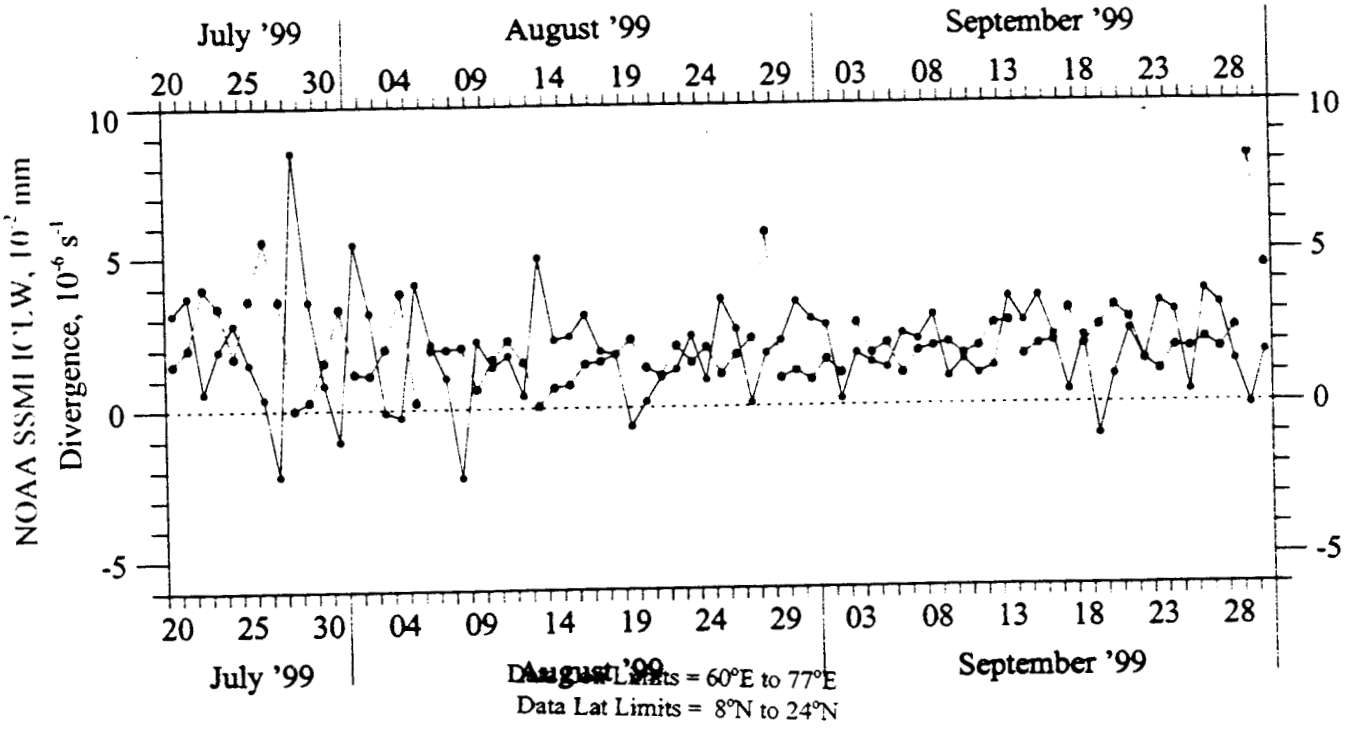
Data Gaps Shown by Green Areas

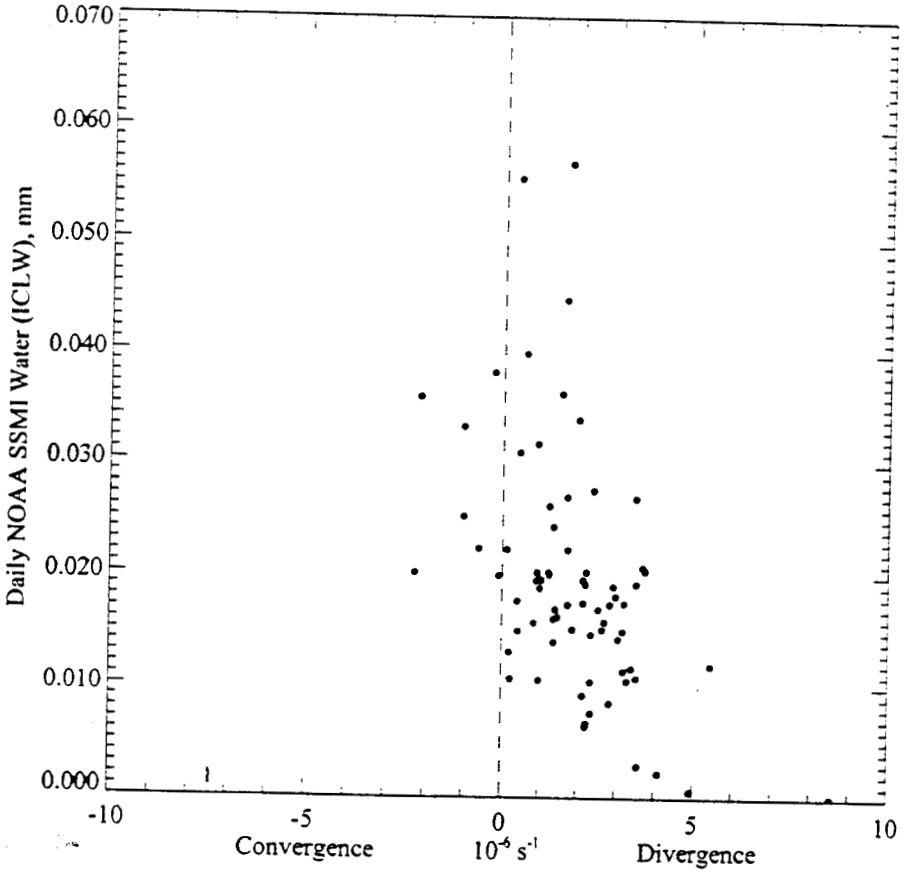


8°N - 24°N, 60°E - 77°E

Mean Daily NOAA SSMI ICLW at QuikScat/Prelim Data Locations (RED)

Daily QuikScat/Prelim (Not Contaminated by Rain) Mean Divergence (BLUE)



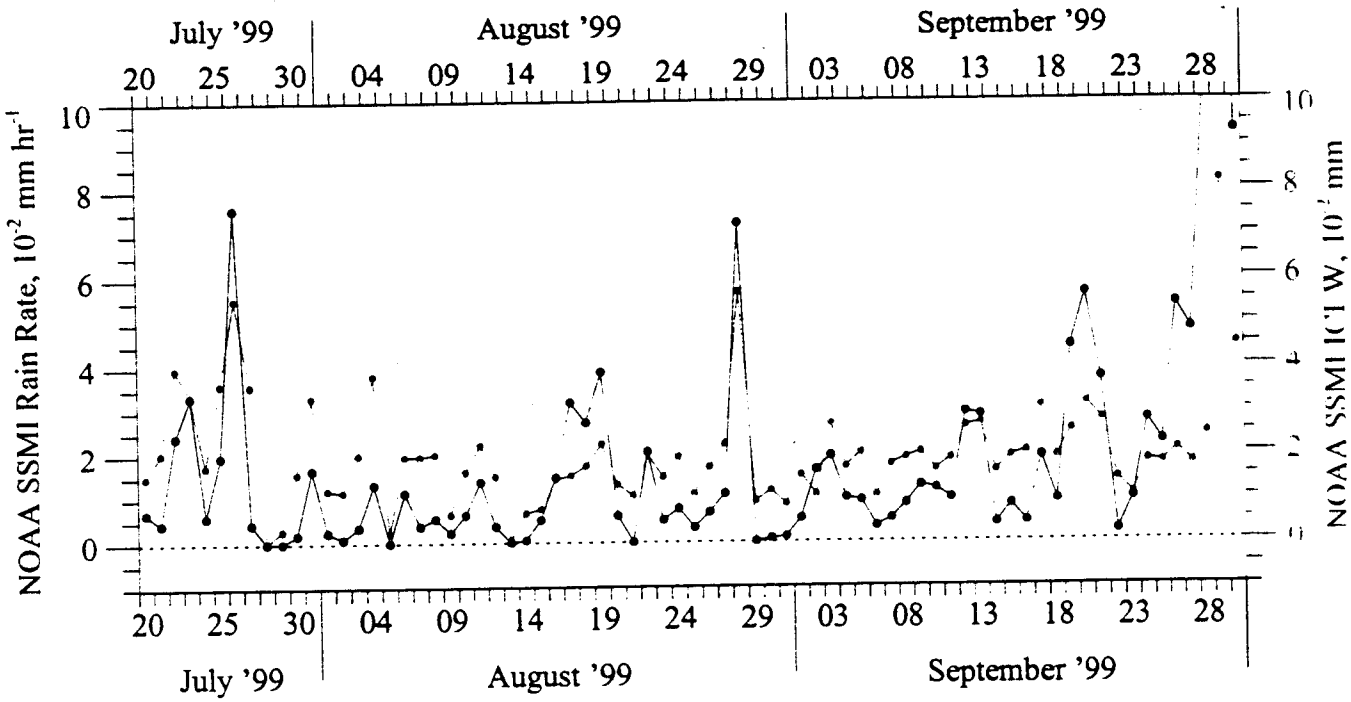


r = - 0.

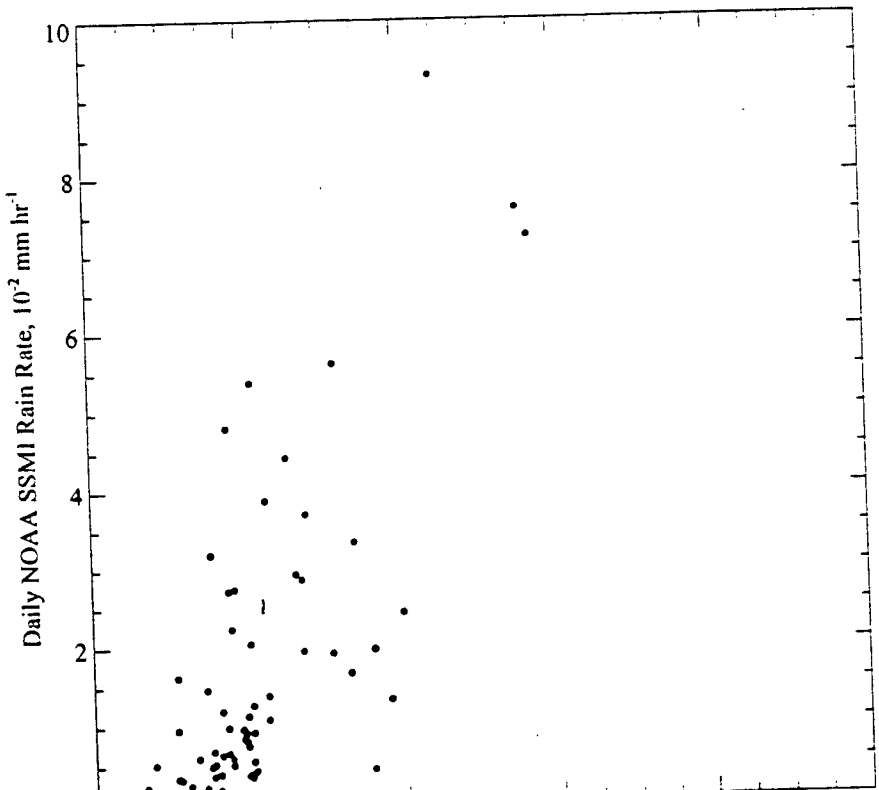
8°N - 24°N, 60.5°E - 77°E

Mean Daily NOAA SSMI Rain at QuikScat/Prelim Divergence Data Locations (BLUE)

Mean Daily NOAA SSMI ICLW at QuikScat/Prelim Divergence Data Locations (RED)



Data Lon Limits = 60.5°E to 77°E
Data Lat Limits = 8°N to 24°N



r = 0.74

SUMMARY

Eastern Arabian Sea

$\nabla_H \cdot \vec{u} \downarrow$ div / conv

IWV $\uparrow\downarrow$ no change

ICLW $\uparrow$

RainRate $\uparrow$