NSCAT and QUIKSCAT Winds
Reveal the Mysterious
Somali Jet

David Halpern
Jet Propulsion Laboratory
California Institute of Technology


In the Arabian Sea, the winds in Jan
blow towards the southwest and are
typical of the tropical southwest tradewinds.

Notice the change in direction in July
when the southwest monsoon occurs.

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

Halsen et al. (1995)
Ship data are few in number and widely scattered.

SHIP messages July 1995

Total data: 109311

1°×1° COADS Ship Locations

13-14 Jun
17-18 Jun
15-16 Jun
19-20 Jun
Location of the WHOI buoy

Accuracy of ERS wind vectors

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

(A) IMET - IFR2

Wind Speed Difference, m s$^{-1}$

N = 74
r = -0.64
rms diff. = 0.8 m s$^{-1}$
line slope = -0.2
< residual > = 0.0 m s$^{-1}$

< IMET > = 9.7 m s$^{-1}$

(B) IMET - IFR2

Wind Direction Difference, deg

2° ± 13°
n = 43

9° ± 8°
n = 31

Halpern et al. (1998)
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 $1^\circ \times 1^\circ$ 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

\[
[\text{curl}_2 \tau^0 = \frac{\partial \tau_y^0}{\partial x} - \frac{\partial \tau_x^0}{\partial y}, \quad f = 2\pi \sin \theta, \quad \beta = \frac{2\pi \cos \theta}{R}] \]

- vertical
  \[\iint_{xy} (\frac{1}{\rho f})(\text{curl}_2 \tau^0 + \beta \frac{\tau_x^0}{f}) \, dx \, dy\]

- y-component Ekman
  \[\int_{x} \frac{-\tau_x^0}{\rho f} \, dx\]

- Sverdrup
  \[\int_{x} \left(\frac{\text{curl}_2 \tau^0}{\rho} \right) \, dx\]

---

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

[ Gulf Stream transport \sim 100 \text{ Sv} ]

[ River transport \sim 1 \text{ Sv} ]

Rain, freshwater transport = 10 \text{ Sv}
The vertical velocity at the bottom of the Ekman layer associated with divergence and convergence in the Ekman layer is

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

\[ \rho = 1025 \text{ kg m}^{-3} \]
\[ f = 2 \Omega \sin \theta \]
\[ \beta = \frac{df}{dy} = \frac{2 \Omega \cos \theta}{R} \]
\[ M_y^E = \text{Ekman mass transport (per unit width) in y-direction} = -\frac{\tau_x}{f} \]
\[ \text{curl}_z \tau = \frac{\partial \tau_y}{\partial x} - \frac{\partial \tau_x}{\partial y} \]
\[ (\tau_x, \tau_y) = \rho_a \cos (u,v) (u^2 + v^2)^{1/2} \]
\[ \rho_a = 1.225 \text{ kg m}^{-3} \]
Sverdrup Transport

\[ u = u_E + u_g \]
\[ v = v_E + v_g \]
\[ M_y = \int_{z=0}^{Z_{LNM}} \rho v \, dz \]

\[ M_y = \frac{c u E \lambda T}{\beta} \]

Sverdrup Transport per unit zonal width integrated north-south (current from \( z=0 \) to \( Z_{LNM} \))

\[ \text{Sverdrup Transport} = \int_x M_y \, dx \]
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.

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

Integrated Water Vapor (Total Precipitable Water), mm

Integrated Cloud Liquid Water Content (0.1 mm)
AVHRR $1^\circ \times 1^\circ$ \[ \Delta SST = SST_{2\text{-day}} - SST_{1\text{-14 Jun}}, \text{°C} \]

\[ \Delta SST (\text{°C}) = -0.6 S (\text{m s}^{-1}) + 0.3 \]

Wind Speed, m s$^{-1}$
$W_{E}, \ 10^{-6} \text{ m s}^{-1} \quad [\text{CI} = 10 \times 10^{-6} \text{ m s}^{-1}]$
QuikScat
not contaminated by rain
Wind Speed, m s$^{-1}$

- 12
- 13
- 14
- 15
- 16
- 17
- 18

Rain Gap
Sensor Gap

20°N 24 Jul 99
10°N
50°E 60°E 70°E

20°N 25 Jul 99
10°N
50°E 60°E 70°E

20°N 26 Jul 99
10°N
50°E 60°E 70°E

20°N 27 Jul 99
10°N
50°E 60°E 70°E

20°N 28 Jul 99
10°N
50°E 60°E 70°E

20°N 30 Jul 99
10°N
50°E 60°E 70°E

20°N 31 Jul 99
10°N
50°E 60°E 70°E
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)

July '99 | August '99 | September '99

![Graph showing daily NOAA SSMI iCLW and divergence](image)

Data Lat Limits = 8°N to 24°N

$r = -0.$
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)

<table>
<thead>
<tr>
<th></th>
<th>July '99</th>
<th>August '99</th>
<th>September '99</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>25</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>04</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>09</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>19</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>24</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>29</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>03</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>08</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>13</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>23</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>28</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean Daily NOAA SSMI Rain Rate, 10^{-2} mm hr^{-1}

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

$r = 0.74$
SUMMARY

Eastern Arabian Sea

\[ \nabla_H \cdot \underline{u} \downarrow_{\text{conv}} \]

\[ \text{IWV} \uparrow \uparrow \text{ no change} \]

\[ \text{ICLW} \uparrow \]

\[ \text{RainRate} \uparrow \]