Supporting Online Material for

Deep Ocean Impact of a Madden-Julian Oscillation Observed by Argo Floats

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This PDF file includes:

Materials and Methods
Fig. S1
References
Supporting online material

Gridding of Argo data

The Argo float profiles (1) were extracted from the real-time quality controlled Argo data base at [http://www.argo.ucsd.edu](http://www.argo.ucsd.edu). Only profiles flagged as “good” were used. Each profile had a latitude and longitude location, and temperature measurements (with a stated accuracy of 0.005°C) at non-standard pressure levels (accurate to 5 dbar). Temperature data from each Argo float profile were then interpolated onto standard vertical levels with a 5 dbar resolution, from a pressure of 5 dbar (the “sea surface temperature”) to 2000 dbar. An empty 4-dimensional grid was created, with a horizontal resolution of 1° longitude × 1° latitude, a vertical resolution of 5 dbar, and a time resolution of 7 days. For a given target grid point at a given target time, a search ellipse was constructed, centred on the target grid point, with a semi-major axis of \( x_0 = 1000 \) km in the zonal (\( x \)) direction, and a semi-minor axis of \( y_0 = 250 \) km in the meridional (\( y \)) direction. All available Argo temperature measurements within the search ellipse, on the same level, and within a 7-day search window centred on the target time, were then used to construct the gridded temperature value \( \overline{T} \). The observations were Gaussian-weighted by their distance from the target grid point,

\[
\overline{T} = \frac{\sum_{i=1}^{n} T_i \exp \left[ \left( \frac{x_i - x_0}{x_0} \right)^2 + \left( \frac{y_i - y_0}{y_0} \right)^2 \right]}{\sum_{i=1}^{n} \exp \left[ \left( \frac{x_i - x_0}{x_0} \right)^2 + \left( \frac{y_i - y_0}{y_0} \right)^2 \right]},
\]

where \( n \) is the number of Argo observations within the search ellipse, \( T_i \) is the temperature value of the \( i \)th observation, and \( x_i \) and \( y_i \) are the \( x \) and \( y \) coordinates of the \( i \)th observation. If there were \( n < 3 \) observations within a search ellipse, the gridded value \( \overline{T} \) was flagged as

1
Removal of annual cycle and interannual variability

To interpolate over occasional missing values, a smooth curve was fitted through the time
series of temperature at each grid point. The smoothing procedure used a locally weighted
scatter plot technique with least squares linear polynomial fitting that was resistant to out-
liers. The actual temperature values were retained where they existed, but missing values
were replaced by values from the fitted curve. If there was greater than 3 consecutive miss-
ing values, then the whole time series at that grid point was set to missing. For each grid
point, the mean and first two annual harmonics of the time series were calculated over the
two-year period 2004–05 and subtracted to produce an anomaly time series. The interannual
variability was then removed by subtracting an 11-point (11-week) running mean.

Processing of OLR and wind data

The OLR (2) and 1000-hPa NCEP–NCAR reanalysis wind (3) data were extracted as daily
means. The mean and first 3 harmonics of the annual cycle were calculated over the 26-year
period 1980–2005 and subtracted to produce anomaly fields. A 7-day running mean was
then applied to the data.

Theoretical equatorial Kelvin wave structure

Vertically propagating equatorial waves obey the dispersion relation

\[ c = \frac{N}{m}, \]
where \( c \) is the phase speed, \( N \) is the buoyancy frequency and \( m \) is the vertical wavenumber \((4)\). The mean density stratification was calculated from the Argo temperature and salinity data and gave \( N = 0.017 \text{ s}^{-1} \) in the thermocline. Using the observed phase speed of \( c = 2.8 \text{ m s}^{-1} \), the theoretical vertical wavenumber is \( m = 6.1 \times 10^{-3} \text{ m}^{-1} \) and the corresponding vertical wavelength is \( 2\pi/m = 1030 \text{ m} \), consistent with the estimated observed vertical wavelength of 800 m. However, the stratification weakens considerably with depth to around \( N \approx 4 \times 10^{-3} \text{ s}^{-1} \) at a depth of 500 m, with a correspondingly much larger vertical wavelength of approximately 4000 m. Hence, the vertical wavelength would be expected to increase with depth, with the consequence that phase lines would tilt back towards the vertical. This is consistent with the observed vertical structure on 21 January, where the zero anomaly contour near 130°W, between the warm water to the west and colder water to the east, slopes eastward and downward between depths of 200 and 800 m, but is vertical below that.

References


Figure S1. Longitude–time section (Hovmöller diagram) of equatorial (averaged 5°S–5°N) Argo temperature anomaly at the 150 dbar level. Contour interval is 1°C. See legend for shading. The thick solid line indicates the phase propagation of the downwelling Kelvin wave at the 850 dbar level, as in Fig. 2.