Geophysical Research Letters

Supporting Information for

Tracking major storms from microseismic and hydroacoustic observations on the seafloor

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Introduction

The supporting information for our article "Tracking major storms from microseismic and hydroacoustic observations on the seafloor" contains 3 text sections, one figure and two movies. Section S1 contains details on the seismometers and hydrophones used for the RHUM-RUM experiment. S2 describes the 2013 tropical cyclone "Dumile" as characterized by Météo France, including explanations on storm system classifications in the South-West Indian Ocean. Section S3 contains details on the shape parameters of particle ground motion used in the polarization analysis. Supplementary Figure S1 shows the maximum absolute noise level as a function of storm-station distance and storm intensity. Movies S1 and S2 are animations showing the spatiotemporal evolution of microseismic noise amplitudes across the seismological network during the storm. References for the supporting information are given at the end.

S1. Seismic and hydroacoustic instruments of the RHUM-RUM experiment

The French-German collaborative experiment RHUM-RUM (Réunion Hotspot and Upper Mantle – Réunions Unterer Mantel) deployed 57 seismological stations on the ocean bottom in Oct-Nov 2012, and recovered them in Oct-Dec 2013. The network geometry is shown in Figure 1 of the main article. The exact deployment locations and schedules are documented in the report of the deployment cruise (Cruise report Marion Dufresne MD192, DOI: 10.13140/2.1.2492.0640) and recovery cruise (Cruise report Meteor M101, DOI: 10.2312/cr_m101, https://getinfo.de/app/details?id=awi:doi~10.2312%252Fcr_m101)

Each station was equipped with a broadband seismometer that continuously measured ground velocity of the seafloor along three components (two horizontals and one vertical), and with a broadband hydrophone that recorded pressure variation in the water. The ocean-bottom network was complemented by 37 terrestrial stations deployed on La Réunion and Mauritius islands, on Madagascar, and on the Iles Eparses in the Mozambique Channel. This enables comparisons between microseisms recorded on land and on the seafloor (Figs. 3 and 4).

The ocean-bottom network consisted of 9 stations from the French INSU pool (Institut National des Sciences de l'Univers, more information on http://parc-obs.insu.cnrs.fr/), and of 48 stations from the German DEPAS network, managed by AWI Bremerhaven ("**De**utscher Geräte-**P**ool für **a**mphibische **S**eismologie, more information on http://www.awi.de/en/research/research_divisions/geosciences/geophysics/depas_german_instrument_pool_for_amphibian_seismology/).

The 9 INSU stations were equipped with L-Cheapo acquisition, with Nanometrics trillium sensors (corner period 240 s, sampling rate 62.5 Hz), and with NPH Series NovaSensor - GE Sensing hydrophones (corner period 100 s, upper cut-off frequency 8 Hz).
The 48 DEPAS stations were equipped with SENDCOM data loggers, with Guralp CMT40 seismometers (corner periods of 60 or 120 s, sampling rate 50 or 100 Hz), and with HighTechInc HTI-04-PCA/ULF hydrophones (corner period 100 sec, upper cut-off frequency 8 kHz). The hydrophones in particular functioned very reliably, with few problems noted in the yield and the data quality. The yield and quality of the seismograms were more variable, but the large majority of stations yielded usable recordings for at least part of the deployment period.

After an embargo period, the data will be freely downloadable at the RESIF seismological data center (http://portal.resif.fr).

S2. Meteorological characterization of the 2013 tropical cyclone "Dumile"

The storm system first formed as an area of disturbed weather on December 27, 2012 near the island Diego-Garcia in the Chagos archipelago. The term **disturbance** is used for a tropical storm system in which the maximum average surface wind speed (MASWS) remains below 27 knots (50 km/h, force 6 on the Beaufort scale). Moving W-SW slowly, Dumile strengthened to a **depression** – MASWS 28 to 33 knots (51 to 62 km/h, force 7 in the Beaufort scale) – but it was slow to develop. On January 1st, the system was upgraded to a **tropical storm** (MASWS 34 to 63 knots (63 to 117 km/h, Beaufort scale from 8 to 11), and changed its trajectory to southwest, moving around 15 km/h. The storm increased in strength until January 2, now moving southward at more than 30 km/h. The red alert stage was declared on La Réunion Island on January 3 at 6:00 UTC when the storm center was located 100 km west of the island. Weather conditions were favorable for its development, and as it passed west of La Réunion, Dumile became a **cyclone of category 1** (MASWS above 64 knots (118 km/h, Beaufort scale 12). Continuing southward at 20-25 km/h, the storm reached its maximum intensity on January 4 at 00:00 UTC, when it was located about 370 km south-southwest of La Réunion, its minimum pressure estimated at 967 hPa and maximum sustained surface winds at 138 km/h. Dumile continued southeastward over the open ocean and weakened to an **extra-tropical storm** (i.e., outside of the tropics) on January 5.

During its cyclone stage, Dumile generated strong winds across La Réunion Island, peaking at 180 km/h and producing heavy rains that affected much of the island, with a maximum value of 1187 mm recorded over a span of 48 hours. The cyclone also generated a very strong swell arriving from north, with maximum wave heights of 11 meters recorded on La Réunion on January 3, compared to a much lower value of 6.3 m significant wave height predicted by the model WavewatchIII [*Tolman and Chalikov*, 1996].

More details on the classification of tropical storm systems in the South-West Indian Ocean can be found on the WEBCMRS website:
http://www.meteo.fr/temps/domtom/La_Reunion/webcmrs9.0/#

S3. Shape parameters of the particle ground motion

The covariance matrix is formed from a principal component analysis [*Fontaine et al.*, 2009] applied to the three component seismic records. The covariance matrix is equal to $(1/N)(D^TD)$, where N is the number of points in the time window, D is a N by 3 mean centered matrix with the three orthogonal records as it columns (two horizontal components X and Y, and a vertical component Z). D is mean centered by column. D^T is the transpose of D.

The degree of rectilinearity of the particle motion [*Jurkevics*, 1988] is given by $CLin$=1-$((\lambda_2+\lambda_3)/2\lambda_1)$, where λ_1, λ_2 and λ_3 are the eigenvalues of the covariance matrix and $\lambda_1 \geq \lambda_2 \geq \lambda_3$. $CLin$ = 1 when $\lambda_2 = \lambda_3 = 0$ and $\lambda_1 \neq 0$ as expected for rectilinear polarization and for pure body waves. $CLin$ is close to 0 for an almost circular polarization. Pure Rayleigh wave motion is expected to be elliptical. The dominant signal direction can be estimated using the normalized eigenvector a that corresponds to the maximum eigenvalue. The apparent angle of incidence is obtained from the vertical direction using $Vpol = \cos^{-1} a_Z$, where a_Z are the Cartesian coordinates of a in the vertical plane.

We can also compute a principal component analysis using only the horizontal components (Y and X) and thus obtain the degree of rectilinearity of particle motion in the horizontal plane CpH [*Flinn*, 1965; *Montalbetti and Kanasewich*, 1970]:

$$CpH = 1 - \frac{e_2}{e_1} \qquad (1)$$

where e_2 and e_1 are the eigenvalues of the covariance matrix obtained from the two horizontal components and $e_2 \leq e_1$. CpH =1 for perfectly linear motion in the horizontal plane. CpH =0 indicates no rectilinearity.

The apparent azimuth θ of ground motion in the horizontal plane is:

$$\theta = \tan^{-1}\left(\frac{u_X}{u_Y}\right) \qquad (2)$$

where u_X and u_Y are the Cartesian coordinates of u, the eigenvector corresponding to the highest eigenvalue of the covariance matrix.

We can determine the longitudinal component L by $L = \cos(\theta)\, Y + \sin(\theta)\, X$; where Y and X are the horizontal components. Using the longitudinal and vertical components, we can then determine a third covariance matrix and the degree of rectilinearity of the particle motion in the vertical plane:

$$CpZ = 1 - \frac{f_2}{f_1} \qquad (3)$$

where f_2 and f_1 are the eigenvalues of the covariance matrix determined using L and Z components and $f_2 \leq f_1$. CpZ =1 for a perfectly linear polarization in the vertical plane, and CpZ =0 indicates circular particle motion.

Fig. S1

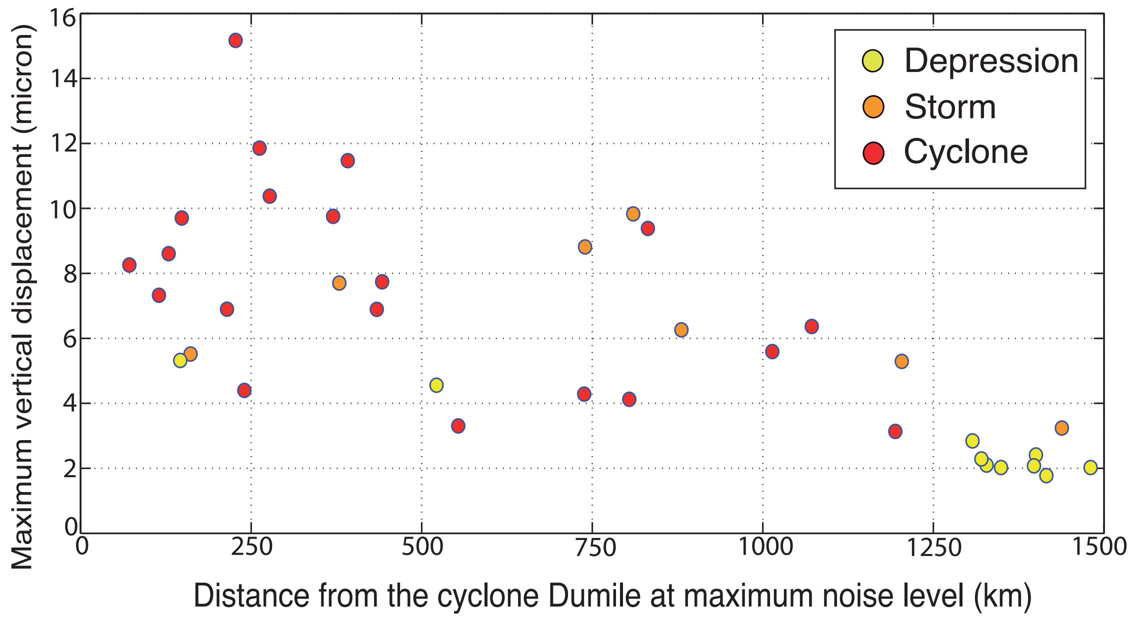

Figure S1. Maximum absolute microseismic amplitudes, as a function of storm-station distance and of storm intensity. Maximum vertical RMS displacement in microns at all the available ocean-bottom seismometers. Storm category is indicated by color. At each station, the observed maximum microseismic noise amplitude depends on both the distance and the intensity of the cyclone. See text in the article for interpretation.

Movie S1:

Spatiotemporal evolution of the *normalized* microseismic noise amplitude across the OBS network and some terrestrial stations.

This animation shows the hourly variations of the RMS amplitude of the vertical components, normalized for each seismic station between its lowest and highest level during the entire cyclonic event (i.e., from 2012 Dec. 27, 06:00 to 2013 Jan. 06, 12:00). OBS and terrestrial stations are represented by circles and by triangles, respectively. The black circle shows the location of the center of cyclone Dumile estimated by Météo France, superimposed on its track (black line). A progressive increase in the noise level is observed across the whole network as the cyclone approaches.

Movie S2:

Spatiotemporal evolution of the *absolute* microseismic noise amplitude across the OBS network and some terrestrial stations.

This animation shows the hourly variations of the RMS amplitude of absolute vertical displacement (in microns) for each seismic station during storm Dumile, (i.e., from 2012 Dec. 27, 06:00 to 2013 Jan. 06, 12:00). OBS and terrestrial stations are represented by circles and by triangles, respectively. The black circle shows the location of the center of cyclone Dumile estimated by Météo France, superimposed on its track (black line). The colour bar is saturated in blue below 1 micron and in red above 10 microns. The area of maximum microseismic noise is seen to lie in the vicinity of the meteorologically estimated storm center.

References for the supporting information:

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