Supporting Information for "Large-scale drivers of tropical extreme precipitation events: the example of French Overseas Territories"

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Introduction

The supplementary information:

- illustrates the topography of each territory (Text S1 and Figure S1)
- documents the methodological approach to assess the statistical significance of our results (Text S2);
- shows the geographical spread of the rain-gauge network of each territory, together with the 99th percentile of each station (Figure S2);
- provides the sensitivity analysis of the fraction of cyclonic EPEs regarding the maximum distance between TCs and rain gauges (Figure S3);
- illustrates the sensitivity of cyclonic EPEs to the distance threshold used to define cyclonic days (500 km and 1500 km in Figures S4 and S5, respectively);
- documents the TC contribution to rainfall (a), the fraction of cyclonic days in the whole period study (b), and the average rainfall during a cyclonic day (c) (Figure S6);
- indicates at the scale of each rain gauge the difference in mean intensity between cyclonic and non-cyclonic EPEs (Figure S7);
- exhibits the large-scale patterns (OLR, PW, and 850-hPa wind anomalies) associated with non-cyclonic EPEs for Mayotte, French Guiana, Martinique, New Caledonia, Wallis & Futuna, Society islands, Marquesas islands and Gambier islands (Figures S8 and S9);
- shows the PDFs of 850-wind direction for all days and the wind direction of anomalies during non-cyclonic EPEs (Figures S10 and S11).
- documents the contribution of the different time scales to the OLR anomaly associated with non-cyclonic EPEs (Figure S12).

Text S1: Geographic details about territories and rain gauges

Most of the islands studied have significant topographic features. The highest point is in Reunion (3050m, Piton des Neiges), and many mountains are over 2000m on the same island. Tahiti is the second-highest island, with a mountain reaching 2241m (Mount Orohena). Then came New Caledonia (with mountain ranges reaching 1618m with the Mount Humboldt), Martinique, and Guadeloupe, with mountains between 1000m and 1500m, such as in Society Islands (except Tahiti). Marquesas islands are just a degree below, with mountains of 900m to 1000m. French Guiana has several mountains reaching 600 to 800m. Finally, reliefs in St-Barthelemy, Mayotte, Wallis & Futuna, Gambier, and Austral islands reach only several hundred meters. Tuamotu archipelago is only composed of atolls with no significant relief.

Text S2: Significance tests

This section describes how the statistical significance of results in Figures 2c, 3, 4, S3c, S4c, S6, and S7 is determined. Statistical significances of the change in EPE probability (Figures 2c, S3c, S4c) and composite maps (Figures 3, S6, and S7) are adapted from the study of Peyrillé et al. (2023).

Change in cyclonic EPE probability

The statistical significance of the change in cyclonic EPE probability ($\Delta P_{EPE,c}$, definition in Section 2.2) is tested against the null hypothesis corresponding to random EPE occurrence with respect to cyclonic days, with a bootstrap approach (Efron, 1979). N_r is the number of rain gauges for each territory. The number of cyclonic days N_c associated

with a given TC category is first computed from the climatology for each rain gauge. Then, 1000 random samples are generated as follows:

1. a rain gauge of the territory is randomly selected, and an ensemble of N_c dates are randomly sampled among all the days of the studied period, with replacement;

2. the number of EPEs within this ensemble of N_c dates is then computed, and the change in EPE probability is deduced from this number of EPEs obtained previously.

3. the two previous steps are repeated N_r times by selecting a new rain gauge with replacement. The average over the N_r change in EPE probability provides the value of $\Delta P_{EPE,c}$.

The computed 1000 $\Delta P_{EPE,c}$ describes the $\Delta P_{EPE,c}$ distribution for the null hypothesis of the given territory and the given TC category. The change in EPE probability is finally considered statistically significant at the 95% confidence level when it is either larger than the 97.5th percentile or smaller than the 2.5th percentile of this $\Delta P_{EPE,c}$ distribution. These thresholds are displayed by vertical bars in Figures 2c, S3c, and S4c.

Composite maps of non-cyclonic EPEs

The statistical significance of the non-cyclonic EPE composite mean is assessed with a bootstrap approach. The null hypothesis is that large-scale conditions associated with EPEs are ordinary in climatology. As previously, N_r is the number of rain gauges within a given territory, and, for each rain gauge, we have $N_{EPE_{nc}}$ the number of non-cyclonic EPEs (as defined in Section 2.3, noted here EPE$_{nc}$). We then define Non-EPE$_{nc}$ for each rain gauge as all the dates with the same day and month as EPE$_{nc}$ for all years between 1979 and 2021 that are not non-cyclonic EPEs. The bootstrap approach follows:

1. a rain gauge is randomly selected, and an ensemble of $N_{EPE_{nc}}$ dates are sampled among all the EPE$_{nc}$ and Non-EPE$_{nc}$ dates, with replacement;

2. the composite for the rain gauge is computed by averaging the data over the previous ensemble of dates.

3. the two previous steps are repeated N_r times by selecting a new rain gauge replacement. The average over the N_r rain gauge provides a null composite.

The computed 1000 null composites describe the composite distribution for the null hypothesis. Then, for each data grid point, the statistical significance of the EPE$_{nc}$ composite mean is evaluated against this null distribution using a two-tailed test at the 95% confidence level. Only significant values are shown in Figures 3, S6, and S7.

PDFs during non-cyclonic EPEs

PDFs of atmospheric parameters during EPE$_{nc}$ (Figure 4 and S8) are compared with the same PDF but for non-EPE$_{nc}$ dates using a Mann–Whitney U test (Mann & Whitney, 1947). This test compares the combined rank of the values of both PDFs, supposed to be independent, to determine which is greater than the other. The following hypotheses are tested with a one-tailed test:

- H_1, the EPE$_{nc}$ PDF is higher for PW (lower for OLR) than the Non-EPE$_{nc}$ one;
- the null hypothesis H_0, the EPE$_{nc}$ PDF is not higher for PW (lower for OLR) than the Non-EPE$_{nc}$ one.

If the p-value is inferior to 0.05 (95% confidence level), H_1 is considered valid and distributions are significantly different. This significance diagnostics is performed for each rain gauge. Almost all EPE$_{nc}$ PDFs (for PW and OLR and their anomalies) are

significantly different from the non-EPE$_{nc}$ PDFs (not shown), indicating that averaged PDFs can also be considered significantly different (superior for PW and inferior for OLR) from those derived from the Non-EPE$_{nc}$ dates. The same diagnostics computed against climatological PDFs also indicate significantly positively (negatively) skewed PW (OLR) PDFs during non-cyclonic EPEs.

References

Efron, B. (1979). Bootstrap Methods: Another Look at the Jackknife. *The Annals of Statistics*, *7*(1), 1–26. doi: 10.1214/aos/1176344552

European Space Agency, & Sinergise. (2021). *Copernicus Global Digital Surface Model.* OpenTopography. Retrieved 2024-06-11, from `https://opentopography.org/meta/OT.032021.4326.1` doi: 10.5069/G9028PQB

Mann, H. B., & Whitney, D. R. (1947). On a Test of Whether one of Two Random Variables is Stochastically Larger than the Other. *The Annals of Mathematical Statistics*, *18*(1), 50–60. doi: 10.1214/aoms/1177730491

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Welch, B. L. (1947). The generalization of 'Student's' problem when several different population variances are involved. *Biometrika*, *34*(1-2), 28–35. doi: 10.1093/biomet/34.1-2.28

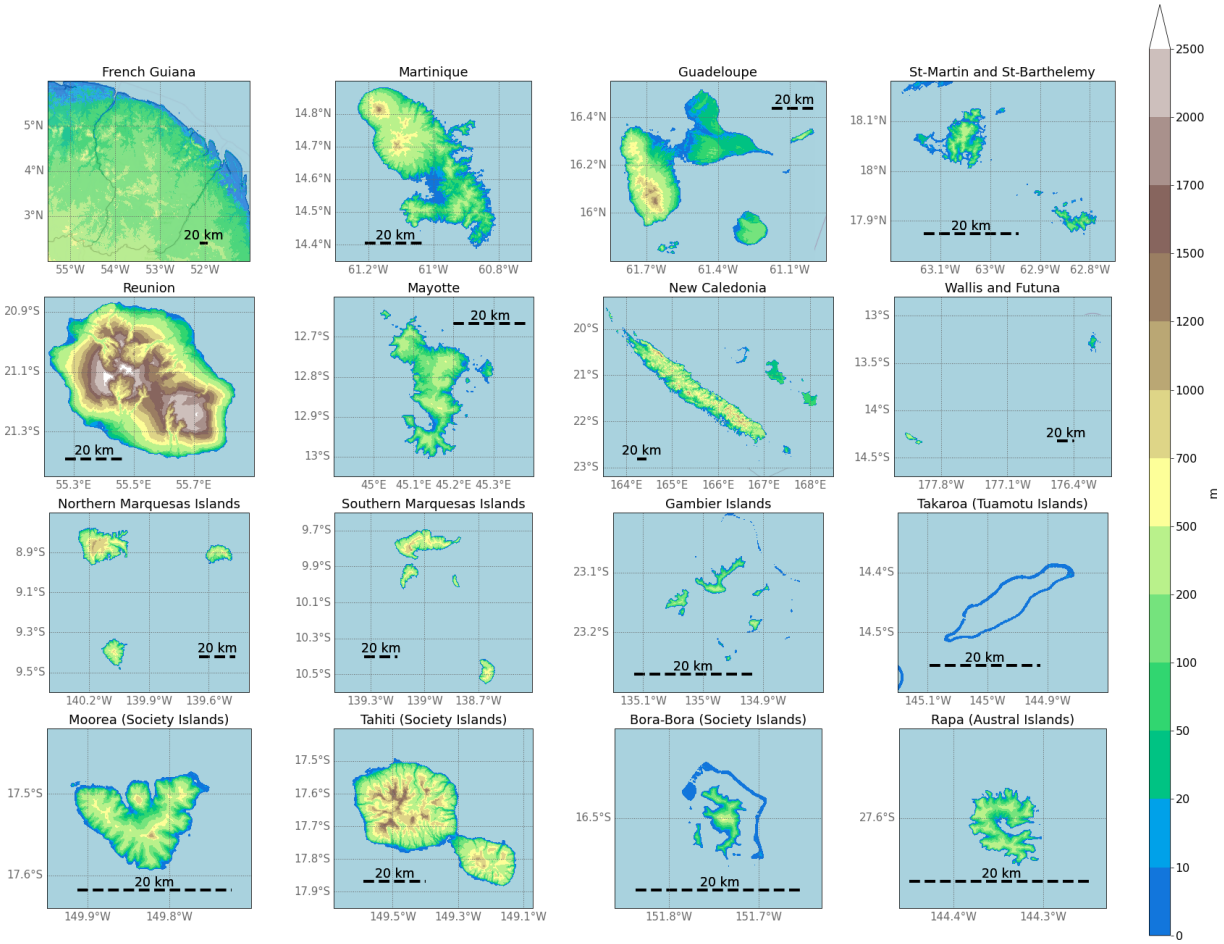

Figure S1. Topographic maps of the French Overseas Territories involved in the study (where at least one rain gauge can be found). A map scale of 20 km is indicated in each subplot. Data were extracted from OpenTopography (European Space Agency & Sinergise, 2021)

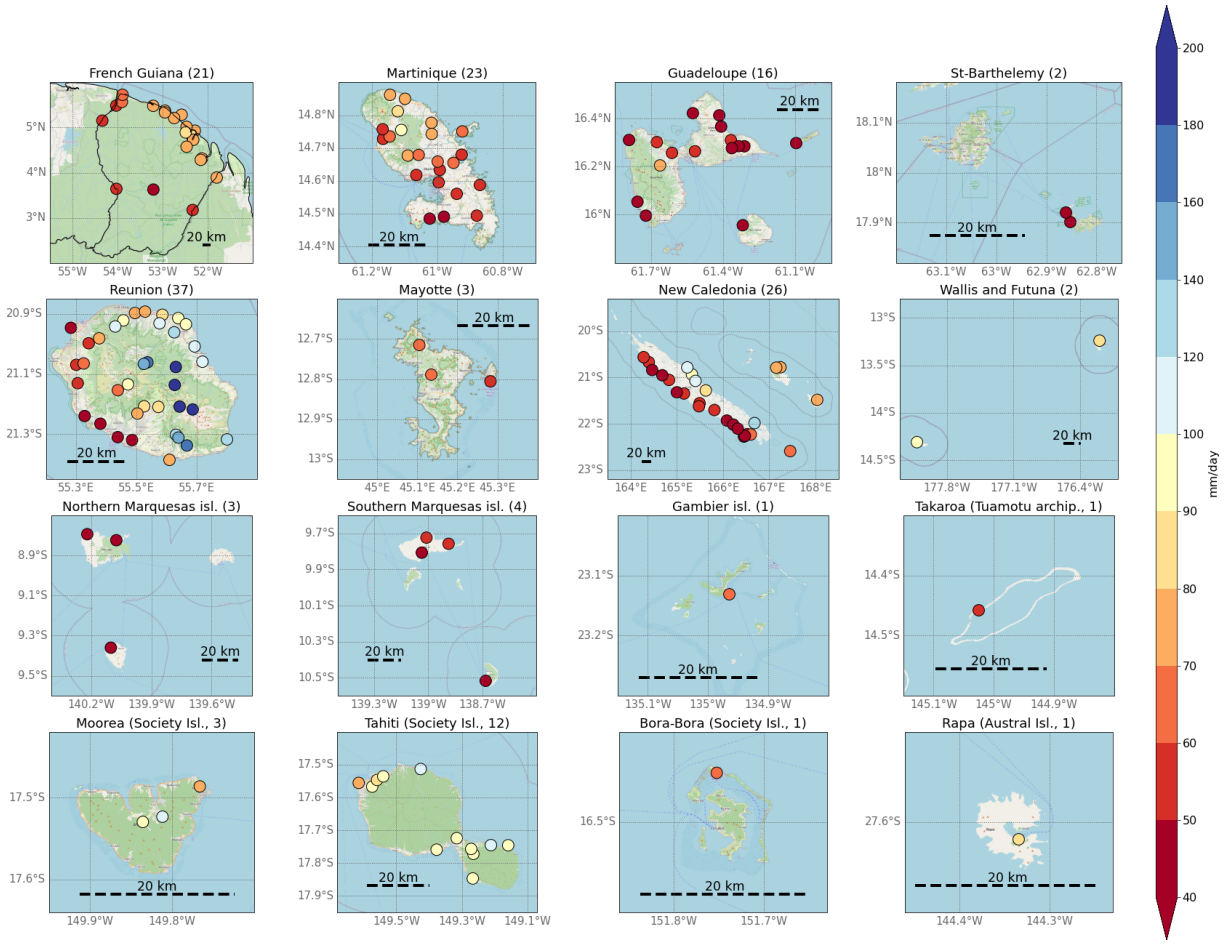

Figure S2. 99th all-day rainfall percentile (in mm day^{-1}) of each rain gauge for each territory network used in our study (number of rain gauges indicated in each panel title in brackets).

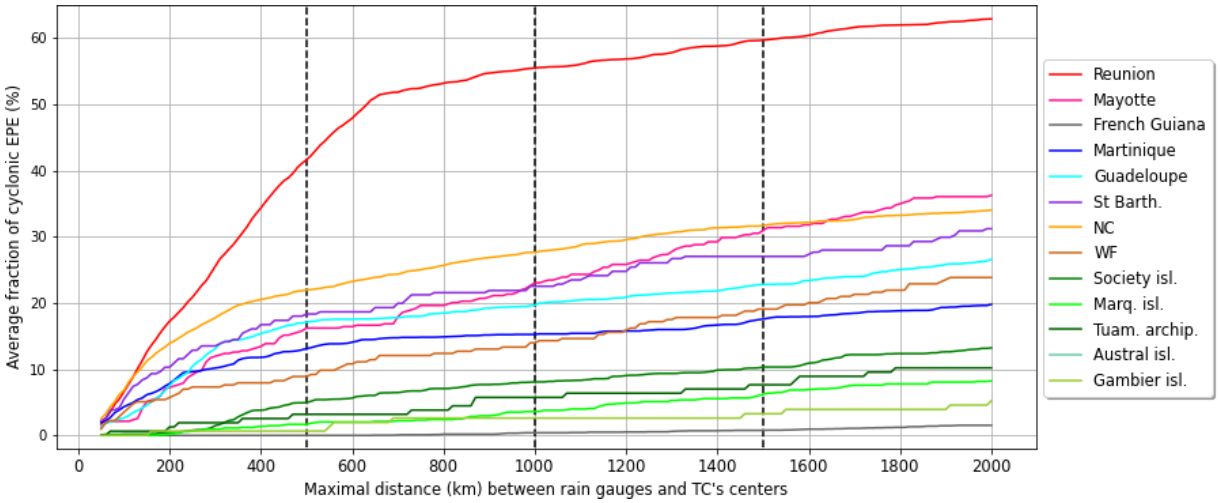

Figure S3. Fraction of cyclonic EPEs averaged over the rain gauges of each territory as a function of the threshold distance used to attribute an EPE to a TC. The distance corresponds to the maximum distance between the rain gauge and the TC center. Thresholds of 500, 1000, and 1500 km chosen for sensitivity assessment (Figures 2, S4, and S5) are indicated by vertical black dashed lines.

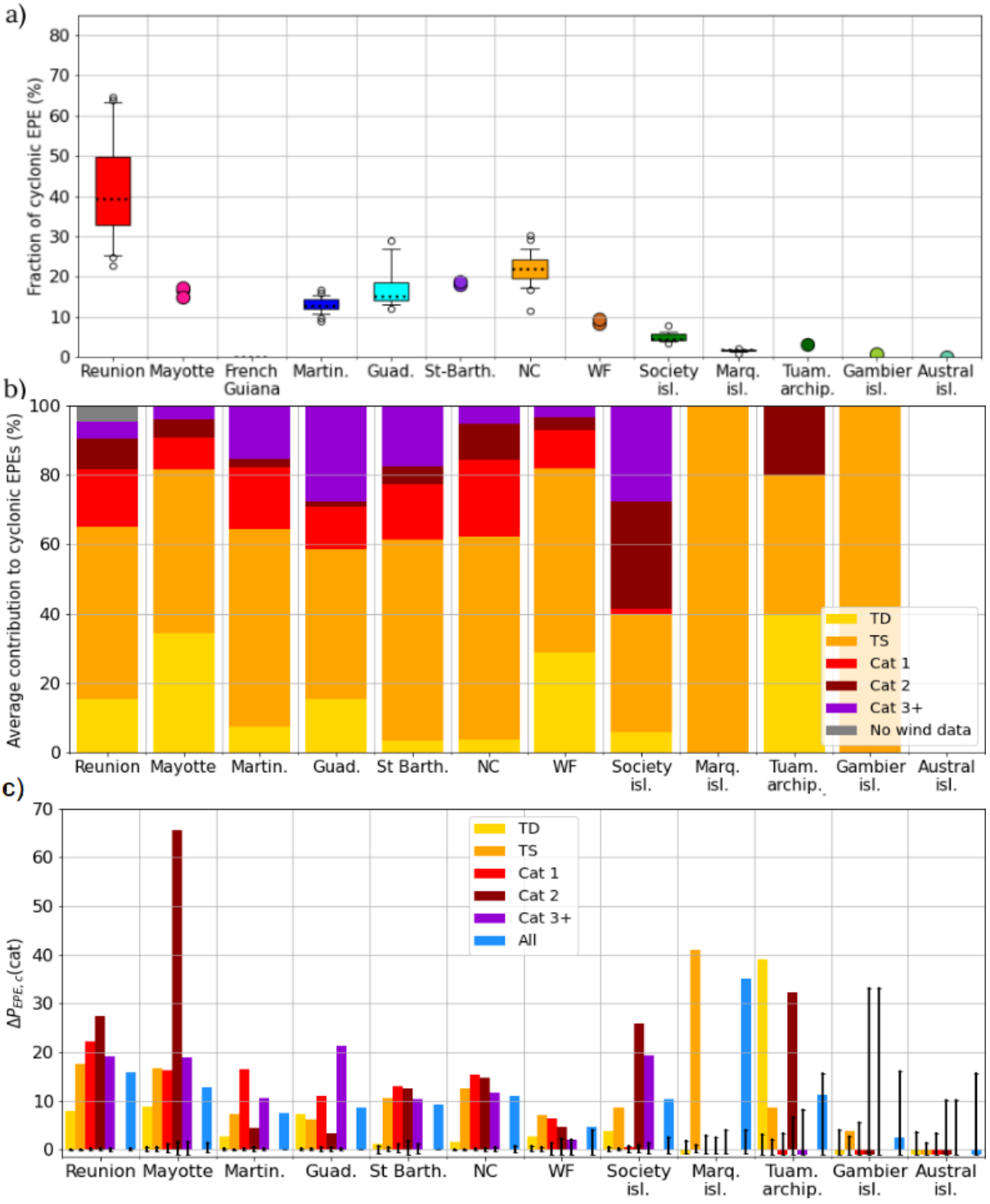

Figure S4. Same as Figure 2 but defining cyclonic days and cyclonic EPEs with a 500-km threshold

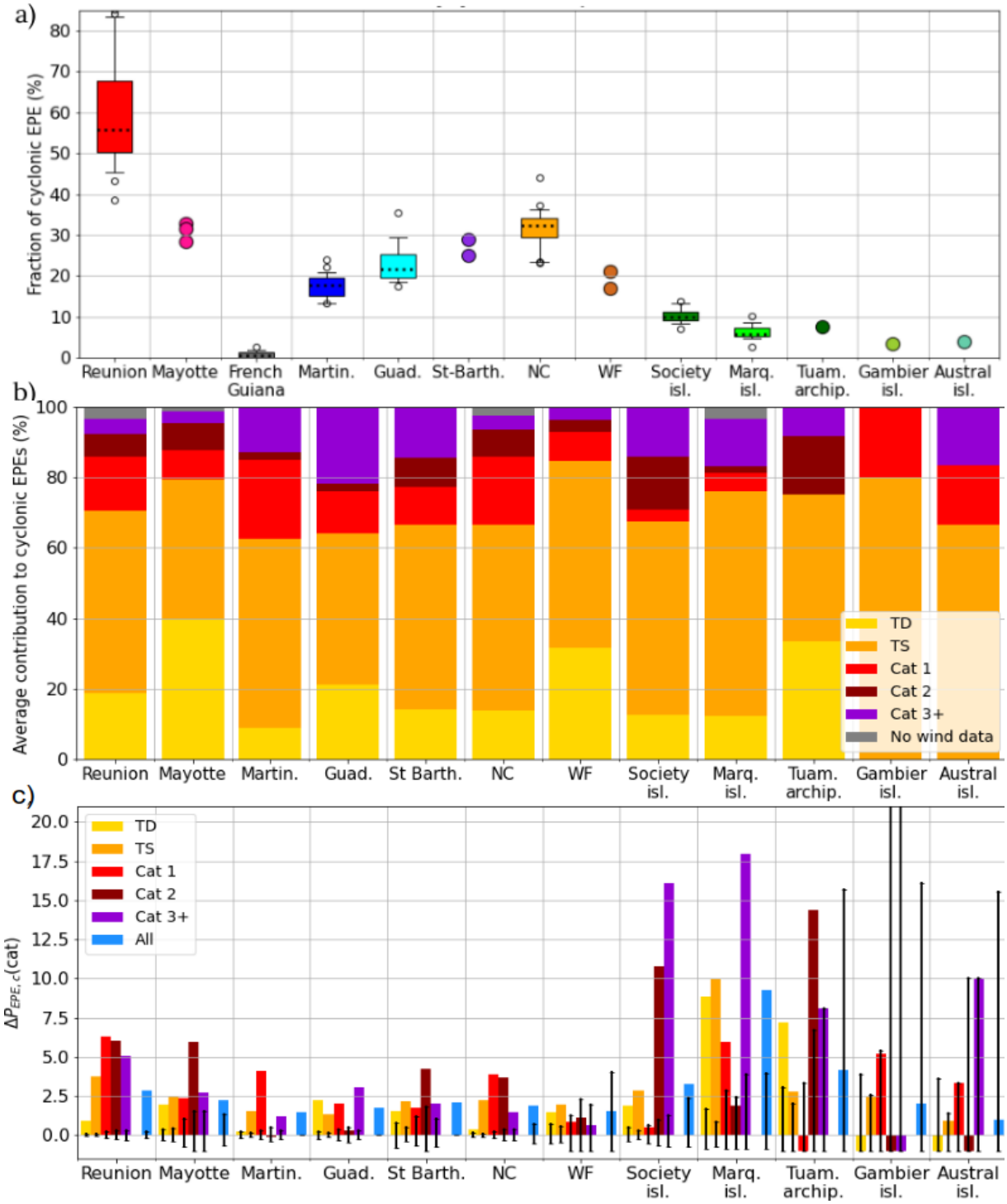

Figure S5. Same as Figure 2 but defining cyclonic days and cyclonic EPEs with a 1500-km threshold

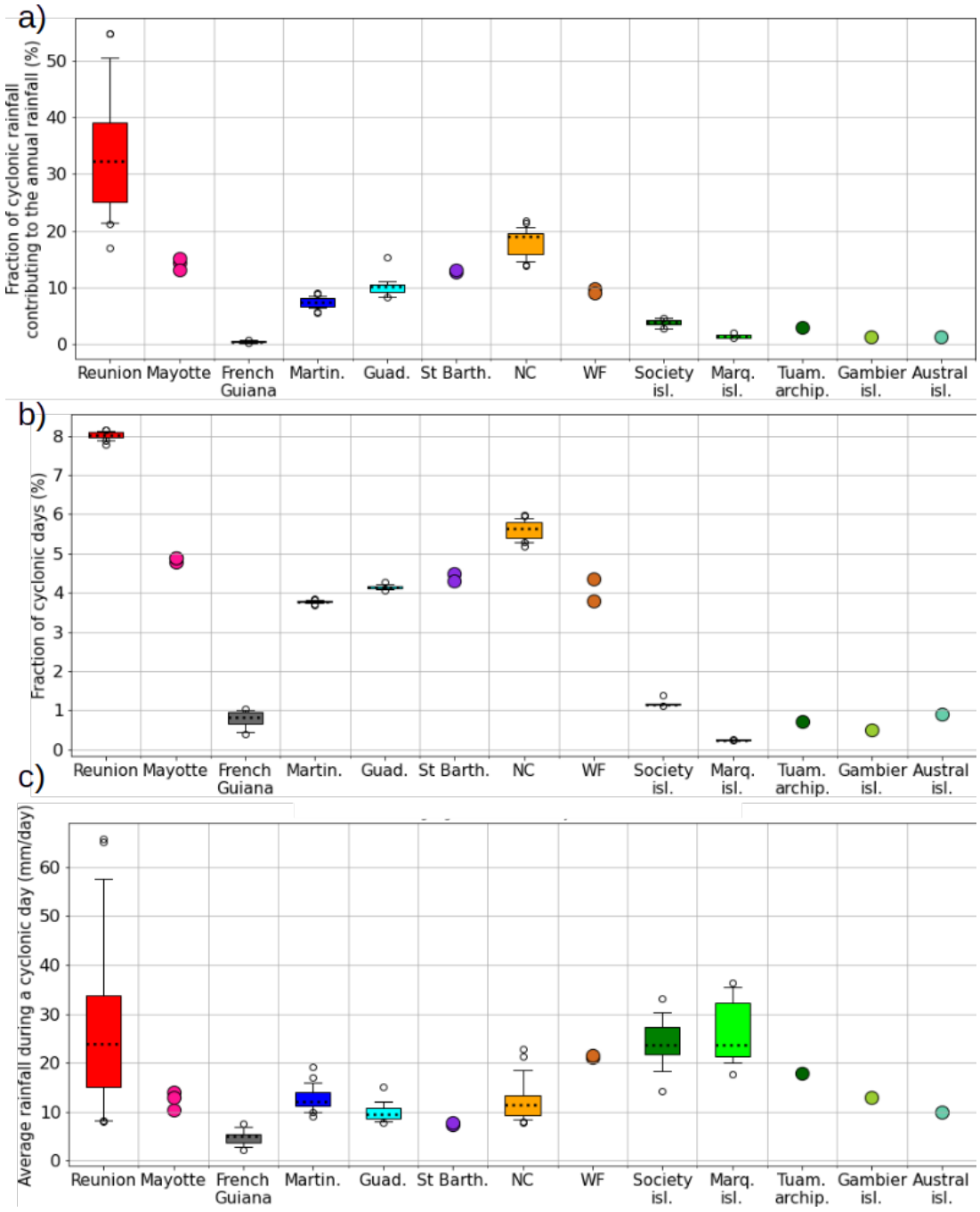

Figure S6. For each territory, distribution across its rain-gauge network of the TC contribution to rainfall (a), the fraction of cyclonic days in the whole period study (b), the fraction of cyclonic days among rainy days (more than 1mm/day) (c), and the average rainfall during a cyclonic day (d) (same boxplots as in Fig 1).

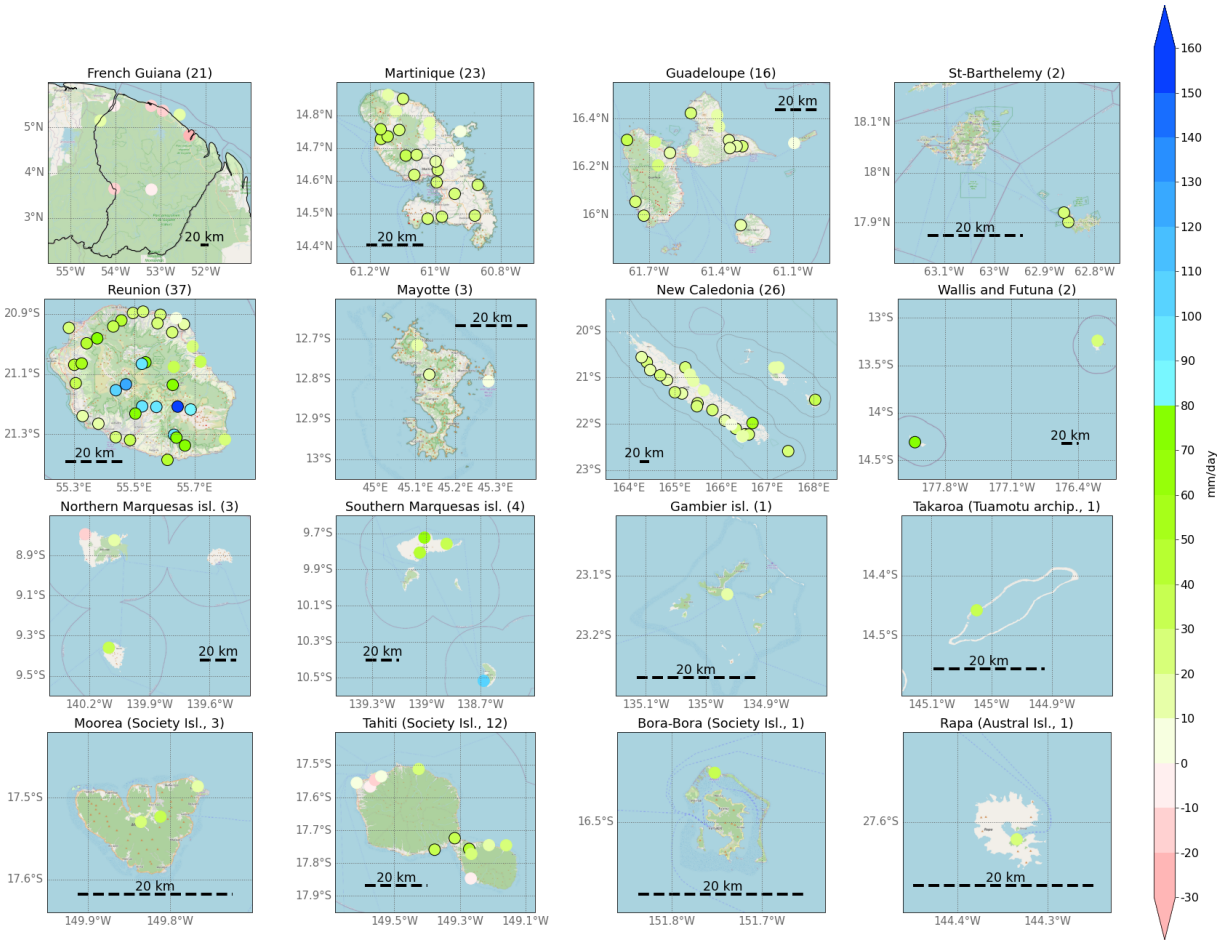

Figure S7. Mean rainfall amounts (in mm day^{-1}) difference between cyclonic and non-cyclonic EPEs. Rain gauges with a black circle indicate that the difference is significant at the 95% confidence level according to a Welch's t-test (Welch, 1947).

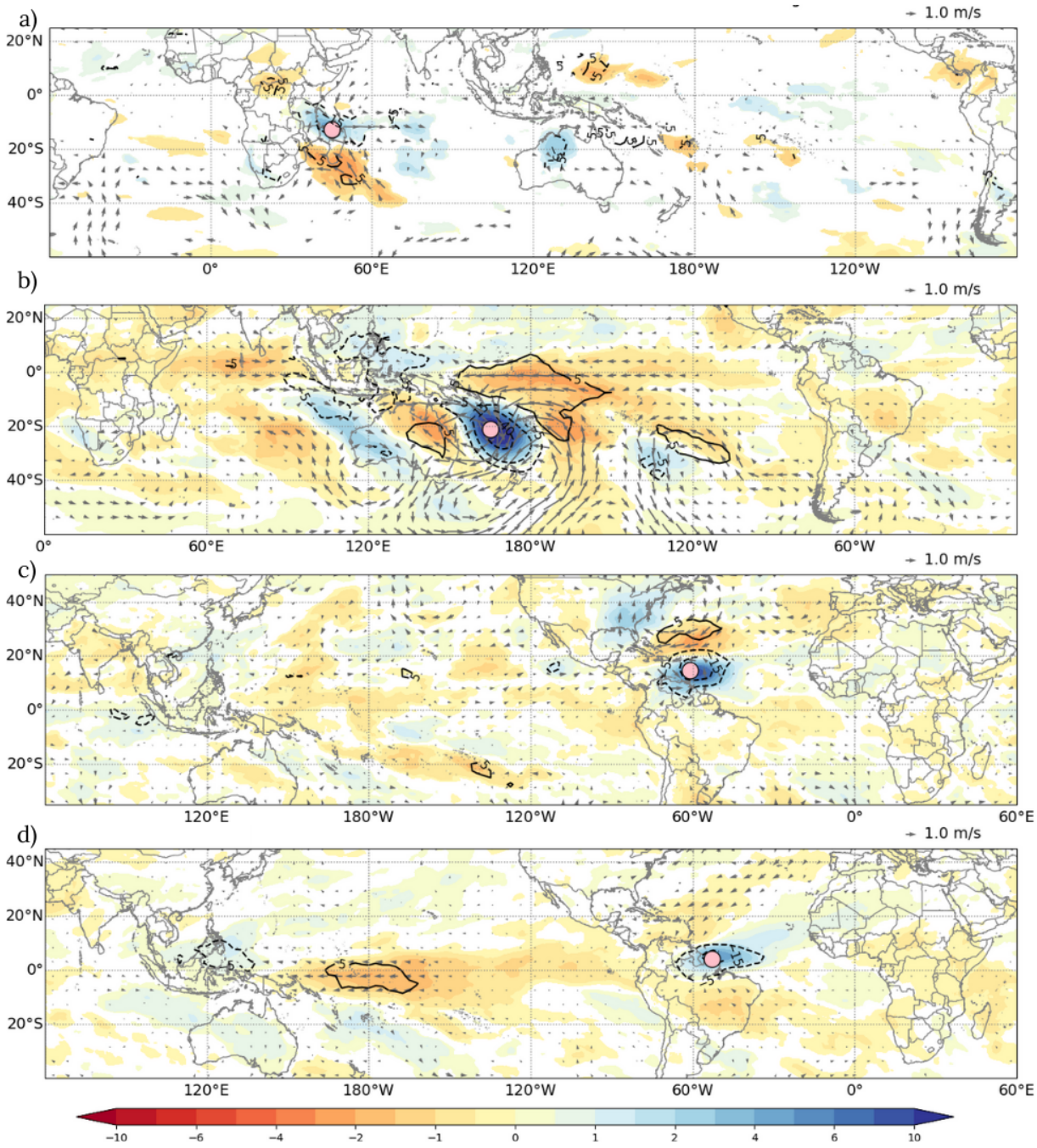

Figure S8. Same as Figure 3a but for other territories: Mayotte (a), New Caledonia (b), Martinique (c), and French Guiana (d). Composite maps for Guadeloupe and St-Barthelemy are similar to Martinique (not shown).

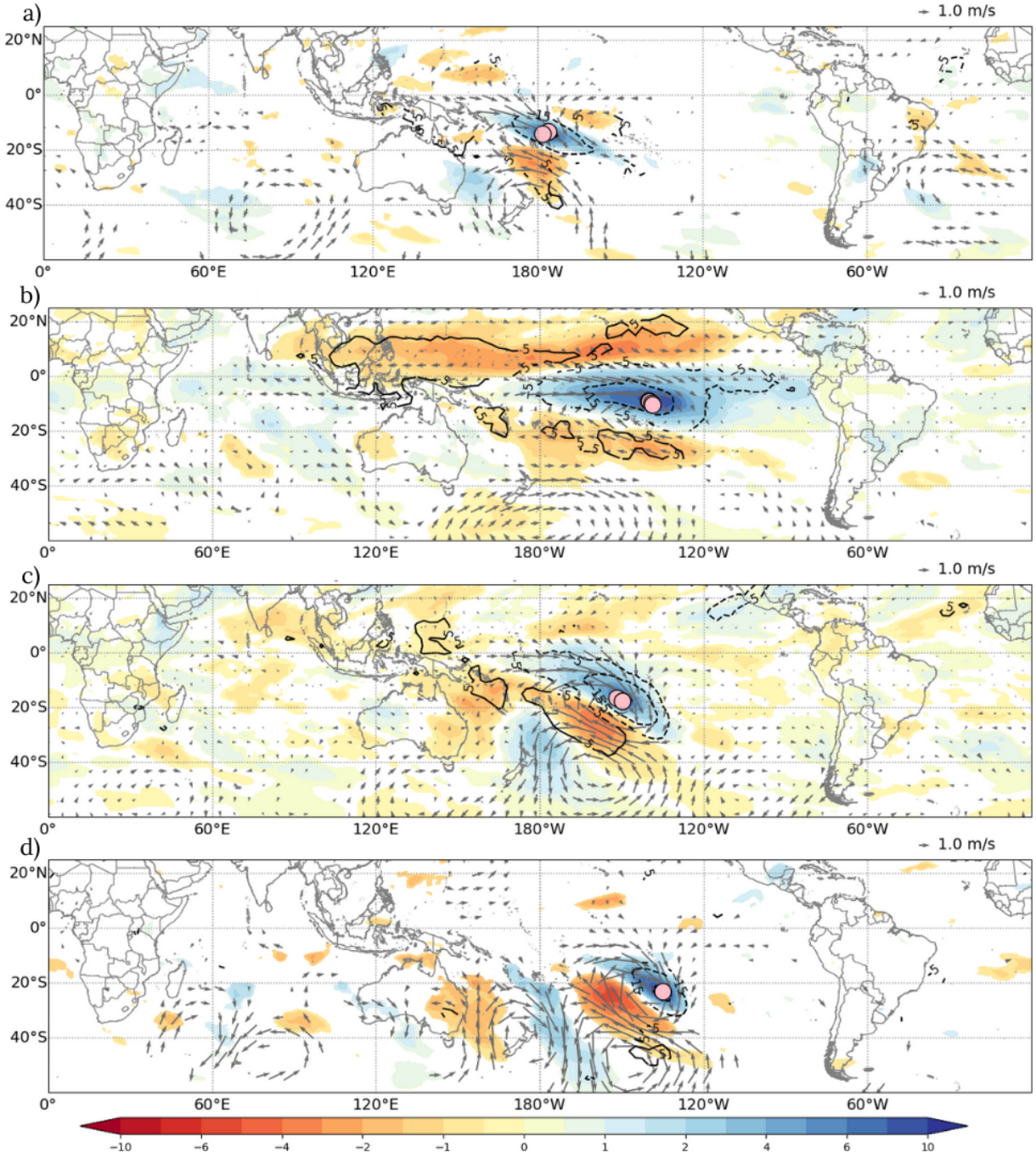

Figure S9. Same as Figure 3a but for other territories: Wallis & Futuna (a), Marquesas islands (b), Society islands (c), and Gambier islands (d). The map for the Tuamotu Islands is similar to the Society Islands, and the composite map of the Austral Islands is similar to the Gambier Islands (not shown).

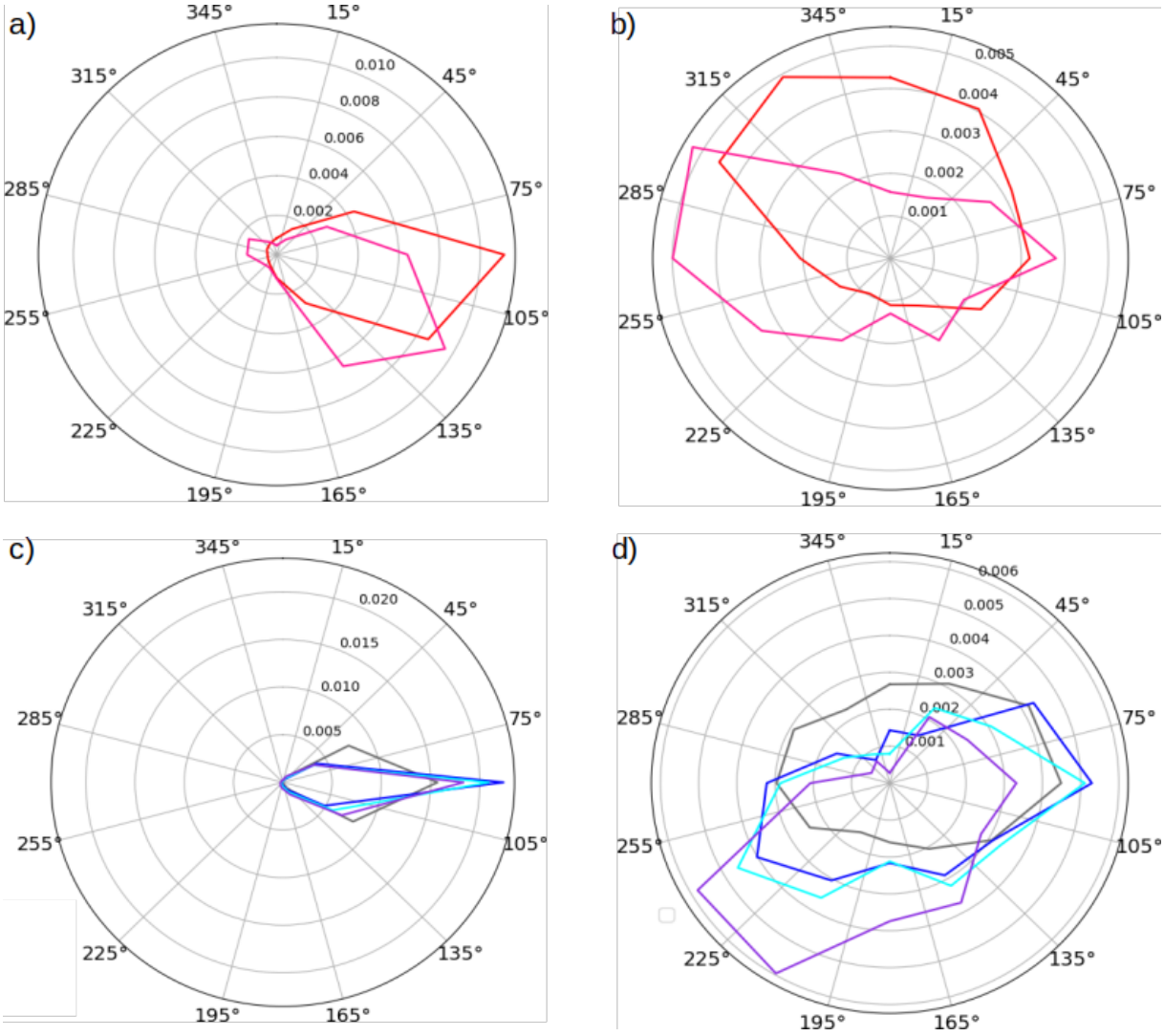

Figure S10. Mean wind rose of 850-hPa wind for each territory (a and b: Reunion and Mayotte; c and d: French West Indies and French Guiana; same colors as Figures 1, 2a, 4a, b). The radius corresponds to the normalized frequency of occurrence within sectors indicated with labels. Left: Climatological wind; right: direction of 850-hPa wind anomaly.

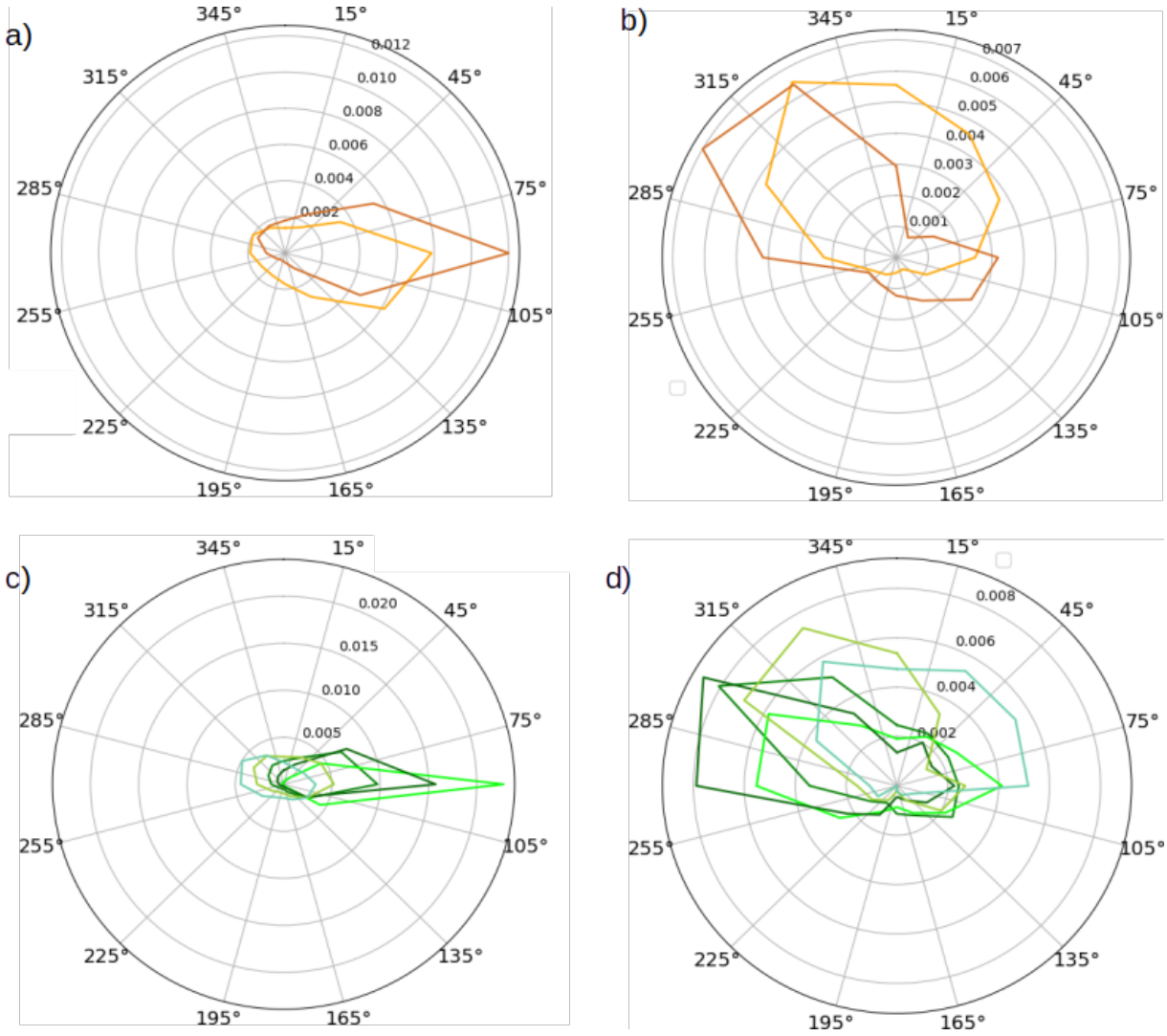

Figure S11. Same as Figure S10 but for New Caledonia and Wallis & Futuna (a,b) and for French Polynesia (c,d)

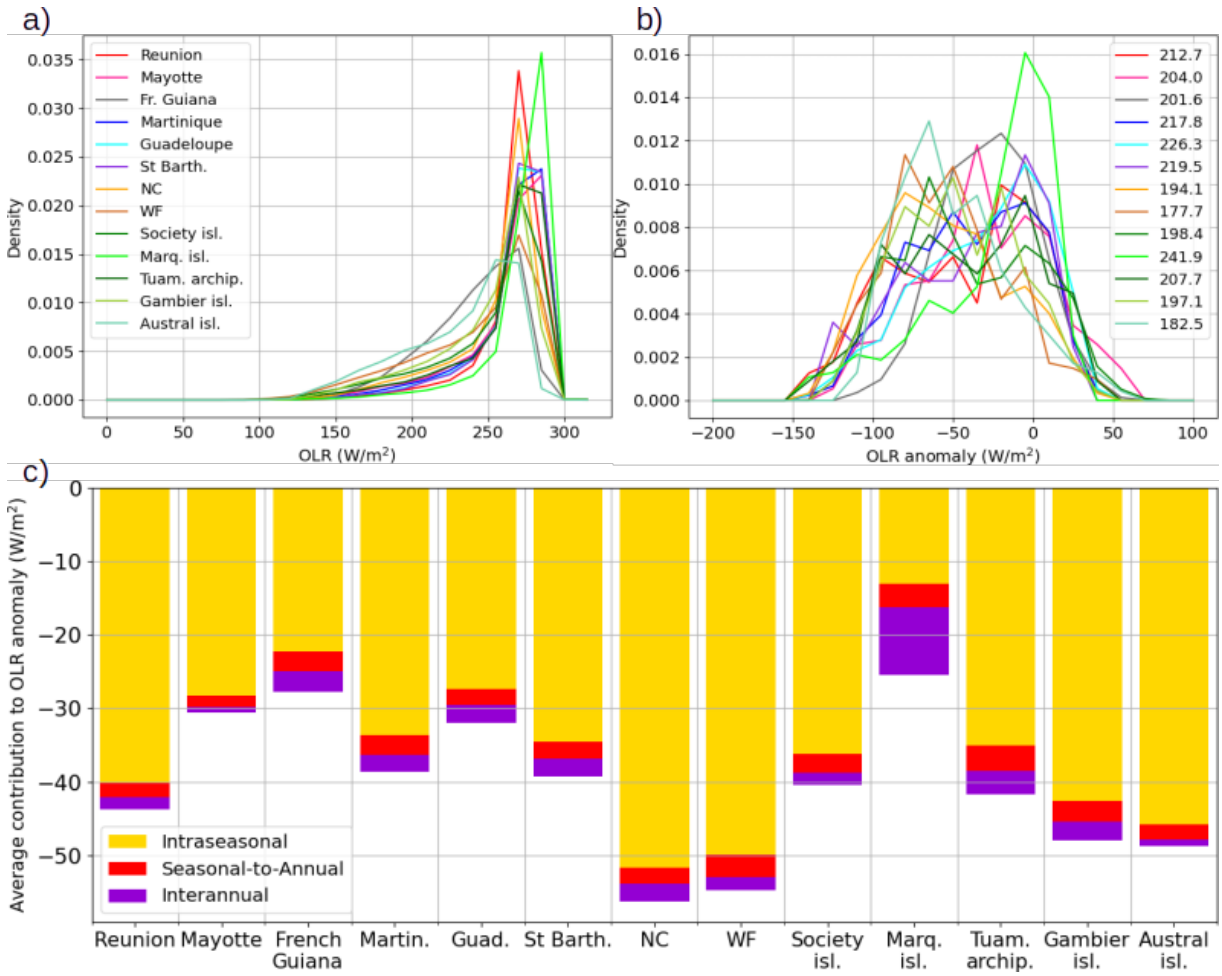

Figure S12. Same as Figure 4 but for OLR. Bins are 15 W m^{-2} wide. In (b), the mean value of OLR during non-cyclonic EPEs is indicated in the legend. These mean values correspond between the 7th percentile (Reunion, NC) and the 15th percentile (French Guiana) of climatological PDFs. About 75% (French Guiana and Mayotte) to 92% (WF) of non-cyclonic EPEs are associated with negative OLR anomalies