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How does dust modify marine heatwave – low chlorophyll compound extremes?

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1. Introduction

Marine heatwaves (MHW) and **low-chlorophyll** (LChl) extremes have been **increasing in frequency and intensity** over the satellite record[1]. Extremes can be more damaging to ecosystem health than a slow shift in the mean condition[2]. This damage is amplified when **multiple extreme events overlap**, creating a compound event.[3] Since compound MHW-LChl extremes can be driven by changes in the availability of light and nutrients, adding dust to the system may impact the formation or progression of MHW-LChl events. **Dust fertilizes the sea surface** with iron, nitrogen, and phosphorus and has been linked to phytoplankton blooms[4,5]. Studies in the Arabian Sea found that adding dust to the water reduces the phosphorus limitation on phytoplankton growth[6], with an increase of 2-9 mg/m^3 in the chl-*a* concentration after dust storms[7]. However, at very high AOD values (>0.5-0.6), **dust's light-blocking effects may inhibit phytoplankton growth**[8,9]. Dust may also have a small effect on MHWs directly. A recent study found that aerosol forcing in preindustrial-climate simulations reduces MHW frequency by 34%, but did not change MHW intensity or duration, relative to preindustrial simulations without aerosol forcing[10]. Additionally, the major 2023 North Atlantic MHW was recently shown not to be caused by the low aerosol conditions that season[11]; thus, there is still uncertainty around where and when aerosols act to mitigate SST extremes. In a changing climate, where **dust distributions may change and MHW-LChl events are expected to become more frequent**, understanding these phenomena could have **implications for fisheries** and other resource management during, and in the recovery after, compound extreme events.

2. Methods

Data Sources

We utilized daily sea surface temperature (SST), chlorophyll, and atmospheric dust data at 1° x 1° horizontal resolution from 60°N-60°S with daily observations.

- SST data came from Copernicus's GLORYS reanalysis.
- Chlorophyll was sourced from Globcolour, a satellite-derived product.
- Dust data was from CAMS and represented AOD at 550nm.

Defining Single and Compound Extreme Events

We used the Hobday[1] definition of extreme events, a period of at least five consecutive days above the 90th percentile/below the 10th percentile threshold, relative to a seasonal climatology.

To normalize multivariate anomalies, we weighted each single anomaly against its extreme threshold[12]

$$anom_{\text{normed}} = \frac{value - climatology}{threshold - climatology}$$

and then obtain the compound anomaly by taking the L2 vector norm of the normalized anomalies

$$compound\ anomaly = \sqrt{anom_1{}^2 + anom_2{}^2 + \ldots + anom_n{}^2}$$

Compound intensity is identical to compound anomaly when all variables are above their extreme threshold and 0 otherwise.

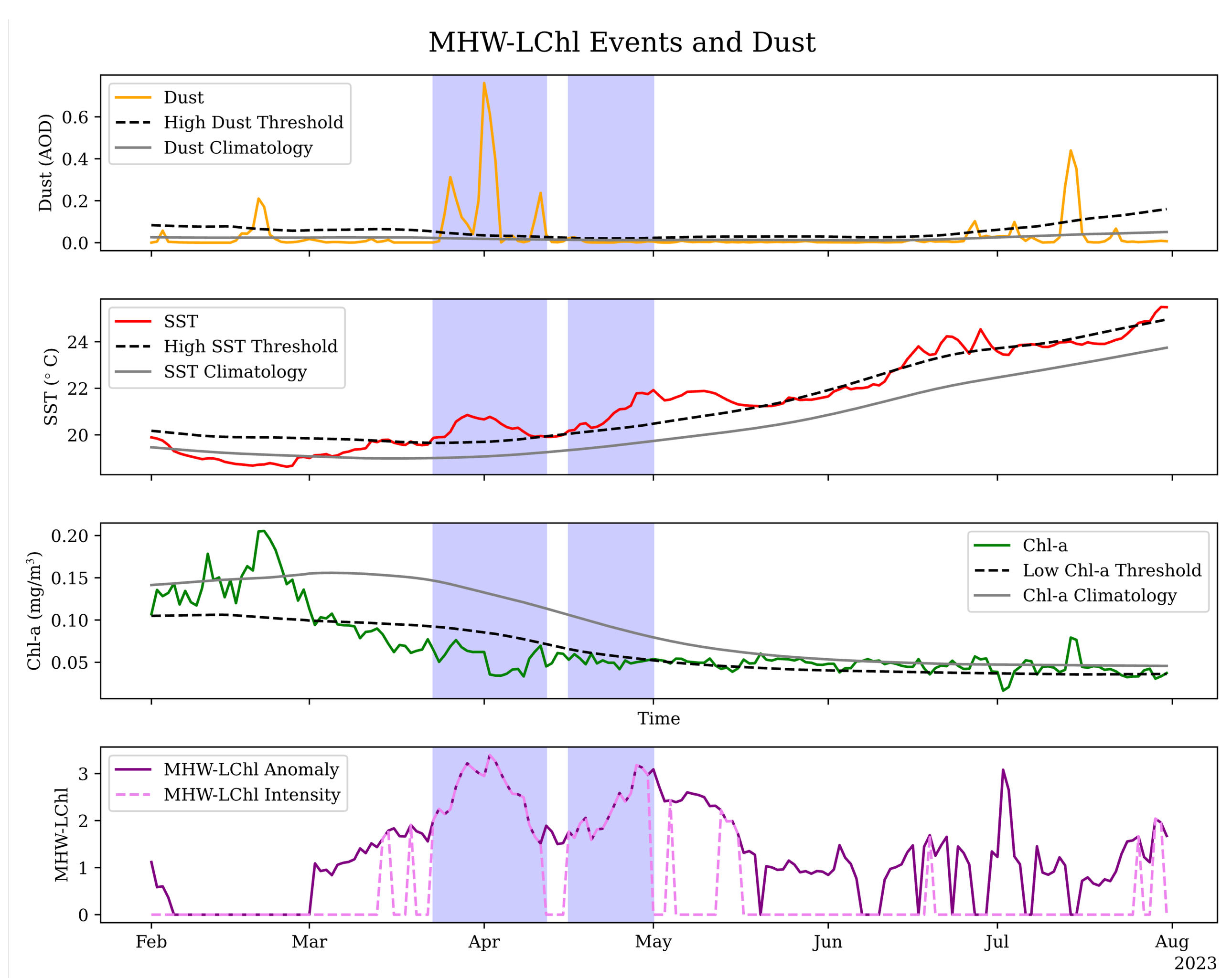


Figure 1: Dust, SST, chl-*a*, and MHW-LChl anomaly and intensity over February to August 2023 at 31.5°N, 23°S. Grey solid lines represent the Hobday seasonal climatology and black dotted lines are the Hobday extreme threshold. The shaded blue regions each represent one MHW-LChl event lasting at least five days.

3. Results

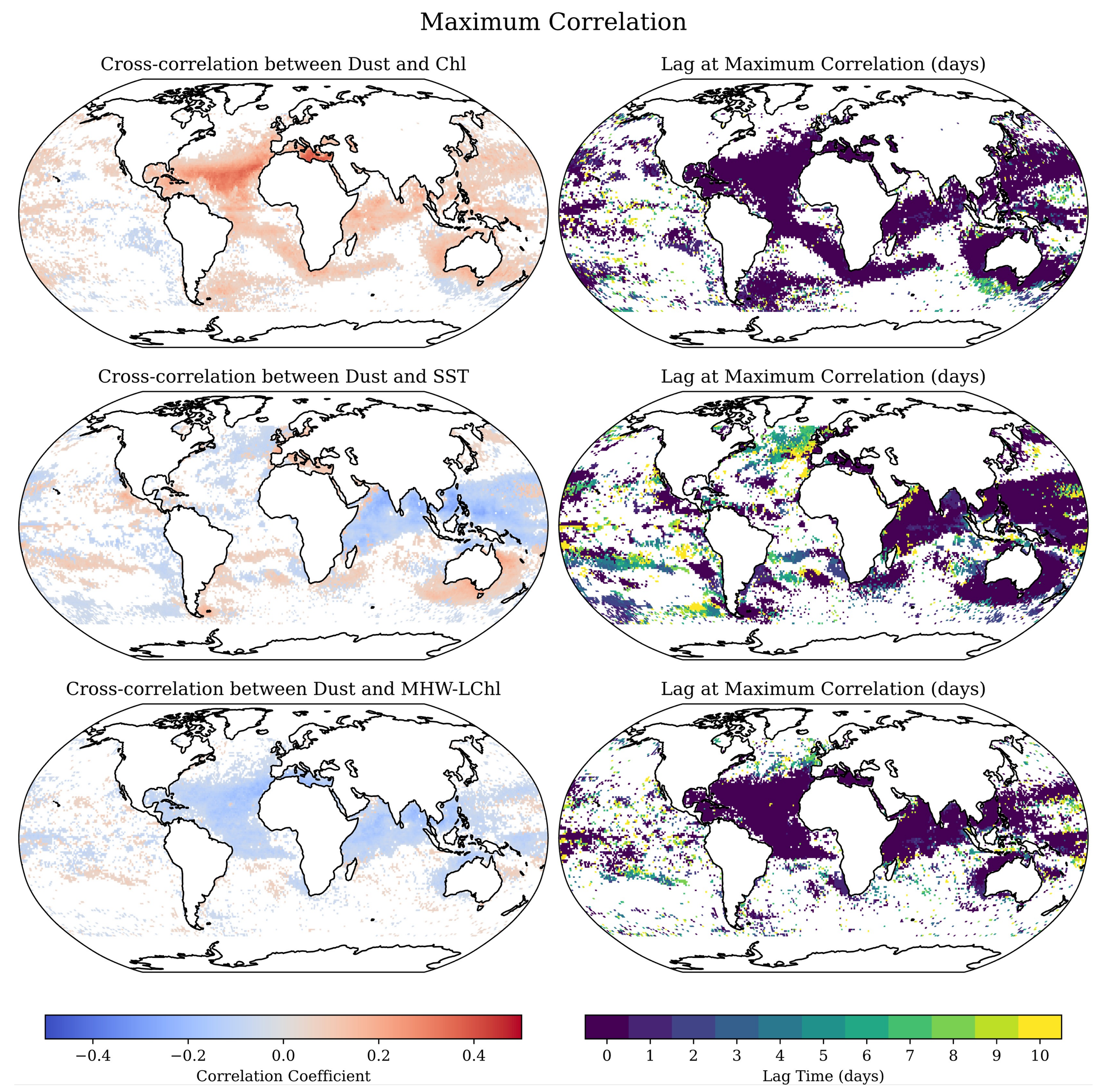


Figure 2: Temporal cross-correlation at each grid cell of dust against chl-*a*, SST, and MHW-LChl anomalies, assessed over lags of 0-10 days, with dust leading the other variable. All anomalies are filtered with a 90-day high-pass Butterworth filter to remove long-term climate variability and indices such as ENSO. The left column shows the maximum cross-correlation, and the right column shows the lag which that value occurs.

3b. Seasonal comparisons

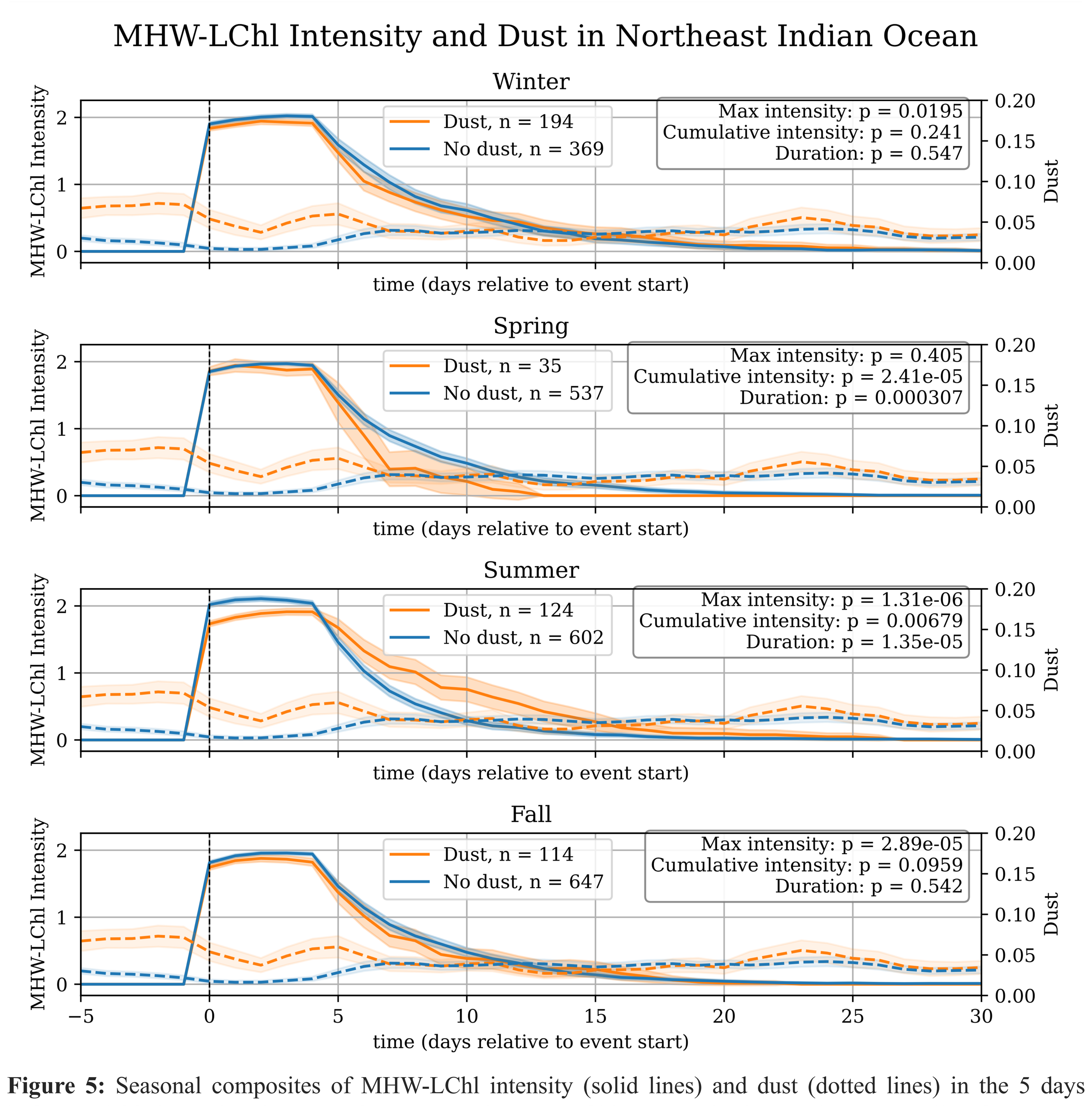
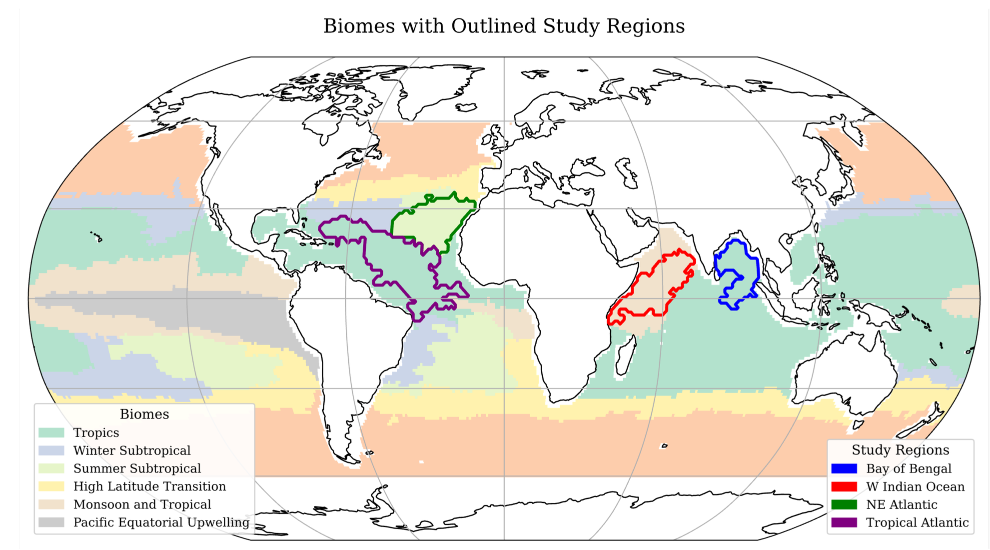


Figure 5: Seasonal composites of MHW-LChl intensity (solid lines) and dust (dotted lines) in the 5 days before and 30 days after the start of a compound MHW-LChl extreme in the Northeastern Indian Ocean/Bay of Bengal, with or without a concurrent dust extreme event in the five days prior to or first five days of the MHW-LChl event. Events are found independently for each grid cell, then the mean is taken to find the composite. Shaded areas represent the 95% confidence interval.

3a. Regional comparisons

Figure 3: Phytoplankton biomes[13] used to control for different regional chlorophyll responses. Selected regions are the per-biome regions where cross-correlation of dust and MHW-LChl anomaly was >|0.1|.



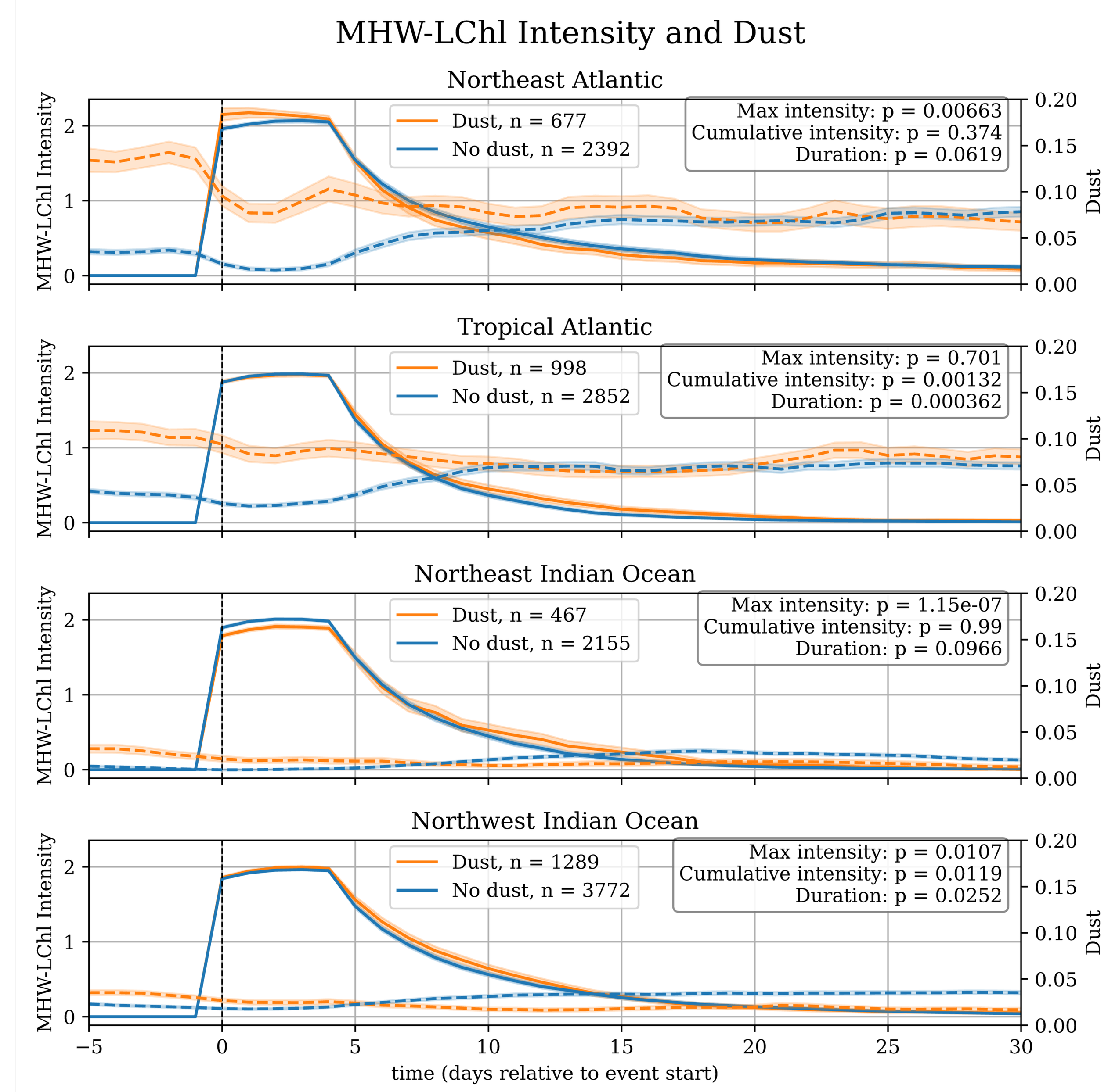


Figure 4: Composites of MHW-LChl intensity (solid lines) and dust (dotted lines) in the 5 days before and 30 days after the start of a compound MHW-LChl extreme, with or without a concurrent dust extreme event in the five days prior to or first five days of the MHW-LChl event. Events are found independently for each grid cell, then the mean is taken to find the composite. Shaded areas represent the 95% confidence interval.

4. Conclusions/Outlook

- Dust has little effect on MHW-LChl extremes across the whole year, but it may mitigate or amplify some effects seasonally.
- The **Northeastern Indian Ocean** displays the greatest changes associated with dust, especially in the summer.
  - Dust is associated with **significantly lower maximum intensity** in winter, summer, and fall.
  - Dust events correlate with **significantly shorter events in spring and significantly longer events in summer**. The spring/summer boundary roughly corresponds to the monsoon onset in this region, so these correlations may reflect timing or extent of the monsoon rains in particular years.
- Regions with more dust do not display stronger dust-associated differences in intensity or duration.
- Changes in dust correlate to ENSO and other modes of climate variability, so the results presented here are highly preliminary; we cannot yet say how much, if any, of these differences can be ascribed to dust.

Next steps

- Control for ENSO, IOD, NAO, and MLD when assessing whether dust causes or merely correlates with these changes.
- Determine whether the dominant extreme (MHW or LChl) alters the response to dust (if any).
- Analyse frequency of dust events in the days surrounding the start of a MHW-LChl event.

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And see references