MADDEN–JULIAN OSCILLATION

Increased impacts on US West Coast

The Madden–Julian oscillation causes teleconnections that impact mid-latitudes. Now research predicts dramatic eastward shifts of these impacts in the Pacific–North America region as the climate warms, leading to higher winter rainfall variability along the US West Coast and California in particular.

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The Madden–Julian oscillation (MJO)[1] is a phenomenon that causes tropical rainfall to alternate between enhanced and suppressed periods within a season, beginning as enhanced convection and precipitation in the Indian Ocean and propagating slowly eastward along the equator into the West Pacific and beyond. Its reach, however, is much broader, influencing everything from the Indian monsoon to tropical cyclones in the western North Pacific, and heatwaves, droughts and flooding in the US[2]. Such widespread impacts have motivated numerous studies seeking an understanding of how the MJO might change with anthropogenic warming[3]. As the tropical climate warms, the intensity of rainfall and winds associated with the MJO as well as their patterns may change, leading to intense debate and scrutiny of how mid-latitude weather will be affected. Writing in *Nature Climate Change*, Zhou and co-authors[4] show that the US West Coast may experience much more MJO-associated rainfall variability by the end of the century due to the eastward shift of the dynamics controlling these mechanisms.

The MJO is often discussed in terms of which of eight phases it is in based on the location of its centre of convection (Fig. 1). Phase 1 exhibits convection and rainfall over the Indian Ocean, and the phase number increases as it travels east, eventually reaching the central Pacific Ocean in phase 8. This entire cycle takes about 30–60 days, and the impacts of the MJO depend on the location of its convection centre at a given time. To understand how global warming changes the way the MJO affects mid-latitude weather, one therefore needs to consider what drives MJO teleconnections — far-reaching impacts at higher latitudes — both in present and future climate. When MJO rainfall occurs, it is associated with ascending motion that causes diverging winds in the upper tropical troposphere. This signal forces planetary waves — alternating pathways of high and low pressure — that are transported horizontally toward higher latitudes through interaction with the subtropical jets, creating connections between the tropical and extratropical regions (Fig. 1). These waves can accumulate, amplify and propagate via interactions with the exit region of the subtropical jets, which are avenues of high winds in the upper troposphere located in the east Pacific and Atlantic Oceans. The mid-latitude flow is in turn altered by these interactions, resulting in changes in atmospheric circulation that translate to impacts on surface air temperature and rainfall[5,6].

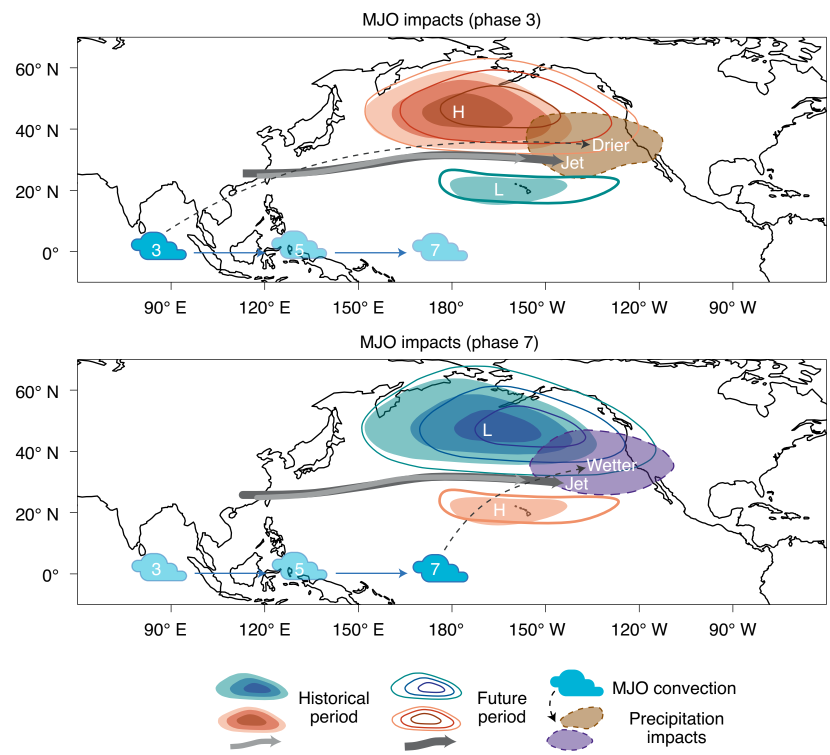

Fig. 1 | Schematic of MJO impacts under current and future climate. This schematic shows impacts during phases 3 (top) and 7 (bottom) of the MJO cycle, each containing information on historical and future change. Phase 3 is associated with teleconnection patterns that bring less precipitation to the US West Coast, and phase 7 is the opposite. The approximate centre of convection is identified with clouds near the Equator. The subtropical jet is shown in the historical (light grey) and future (dark grey) climate. Upper-level geopotential height anomalies are shown as filled contours marked with 'H' (high) and 'L' (low) pressure centres. Changes to these wave patterns are shown as coloured contour lines. US West Coast precipitation impacts are identified as 'drier' or 'wetter'. Zhou and colleagues[4] show that under climate warming, the subtropical jet strengthens and its terminus shifts eastward. This causes MJO teleconnections to extend further eastward, resulting in intensified impacts from phases 3 and 7. The impacts for both wetter and dryer conditions increase due to warming, leading to amplified California winter precipitation variability.

In a future, warmer climate, both the MJO itself and the subtropical jets are expected to change. Earth system models have shown that moisture in the lower atmosphere will increase, causing changes to convection that would augment MJO rainfall in the tropics. However, the associated MJO winds, which serve as a mechanism to translate this phenomenon eastward in the global tropics, are projected to increase at a slower rate or even weaken[7]. Some studies[8] have suggested that the impact of MJO on many weather and climate phenomena may weaken as a result. However, aside from such amplitude changes, the region across which tropical MJO rainfall propagates is expected to extend further eastward into the central Pacific with climate warming[3,7]. In mid-latitudes, climate models also predict an eastward extension of the North Pacific jet stream with warming, extending the storm track toward the California coast[9]. How do all of these changes affect the MJO teleconnection in mid-latitudes in the future?

Zhou and co-authors[4] have shown, based on a group of Coupled Model Intercomparison Project Phase 5 (CMIP5) and CMIP6 models, that the Northern Hemisphere teleconnection pattern associated with the MJO tends to extend further east under global warming, implying that the impact of MJO on the northeast Pacific and North American West Coast will be stronger. The researchers focus on the impacts of MJO phases 3 and 7, which are well represented in models. In the historical climate, phase 3 is associated with less precipitation along the US West Coast, while phase 7 exhibits opposite behaviour (Fig. 1), often associated with large plumes of rain-bringing moisture called atmospheric rivers[10]. Under a high-emissions scenario, the authors show that the impacts of both phases shift eastward, leading to a more than 50% increase in MJO-associated rainfall variability — both highs and lows — during the California winter by the end of this century. According to the authors, this prediction is consistent across many state-of-the-art climate models and their simplified counterparts. Interestingly, this eastward extension of MJO teleconnections is largely attributed to the eastward shift of the subtropical jet exit, with little effect due to the eastward extension of the MJO rainfall in the tropics itself.

Despite strong evidence that the MJO teleconnection pattern extends further east with warming, changes in teleconnection amplitude are uncertain. However, because neither the change in teleconnection amplitude nor tropical MJO intensity predicts the MJO impact on the US West Coast, the authors[4] suggest that the change in MJO pattern is most important for understanding the change in impacts.

The work by Zhou and colleagues[4] provides another piece of the puzzle for how the MJO and its impacts respond to global warming. Extension of this analysis to other parts of the world, as well as to other seasons, may help further complete the picture. Finally, the enhanced sub-seasonal variability illustrated here adds an additional aspect of precipitation volatility to an already vulnerable region[11], and this has implications for future sub-seasonal rainfall predictions and California water resources. ❒

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References

1. Madden, R. A. & Julian, P. R. *J. Atmos. Sci.* **28**, 702–708 (1971).
2. Zhang, C. *Bull. Amer. Meteor. Soc.* **94**, 1849–1870 (2013).
3. Maloney, E. D. et al. *Nat. Clim. Change* **9**, 26–33 (2019).
4. Zhou, W. et al. *Nat. Clim. Change* https://doi.org/10.1038/s41558-020-0814-0 (2020).
5. Seo, K.-H. & Son, S.-W. *J. Atmos. Sci.* **69**, 79–96 (2011).
6. Matthews, A. J. et al. *Quart. J. Roy. Met. Soc.* **130**, 1991–2011 (2014).
7. Bui, H. X. & Maloney, E. D. *Geophys. Res. Lett.* **45**, 7148–7155 (2018).
8. Wolding, B. O. et al. *J. Adv. Model. Earth Syst.* **9**, 307–331 (2017).
9. Neelin, J. D. et al. *J. Climate* **26**, 6238–6256 (2013).
10. Guan, B. et al. *Mon. Weather Rev.* **140**, 325–342 (2012).
11. Swain, D. L. et al. *Nat. Clim. Change* **8**, 427–433 (2018).