Dynamical Mechanisms Underlying the 2022/23 California Flooding: Analysis with a Stationary Wave Model

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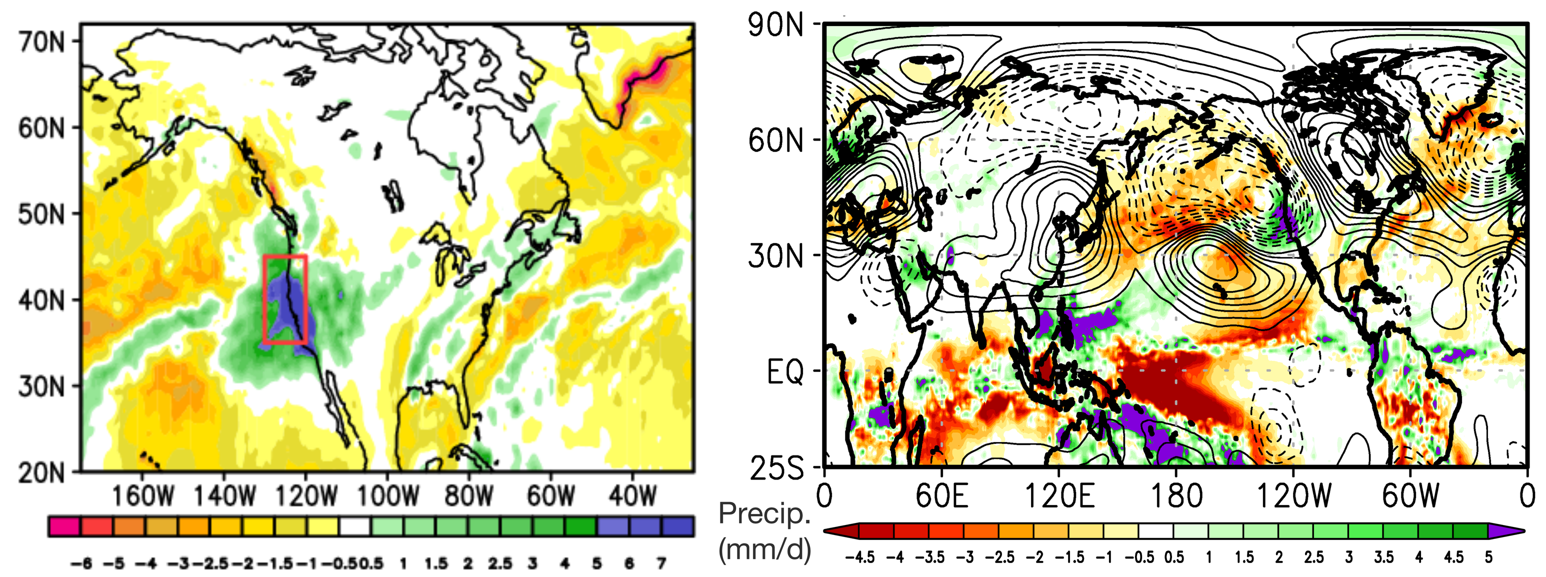
Overview

In late December 2022 and the first half of January 2023, much of California experienced an unprecedented series of atmospheric rivers that produced heavy rains and near-record flooding. Here, we use a stationary wave model (SWM) to elucidate the dynamical and thermodynamical processes underlying the event.

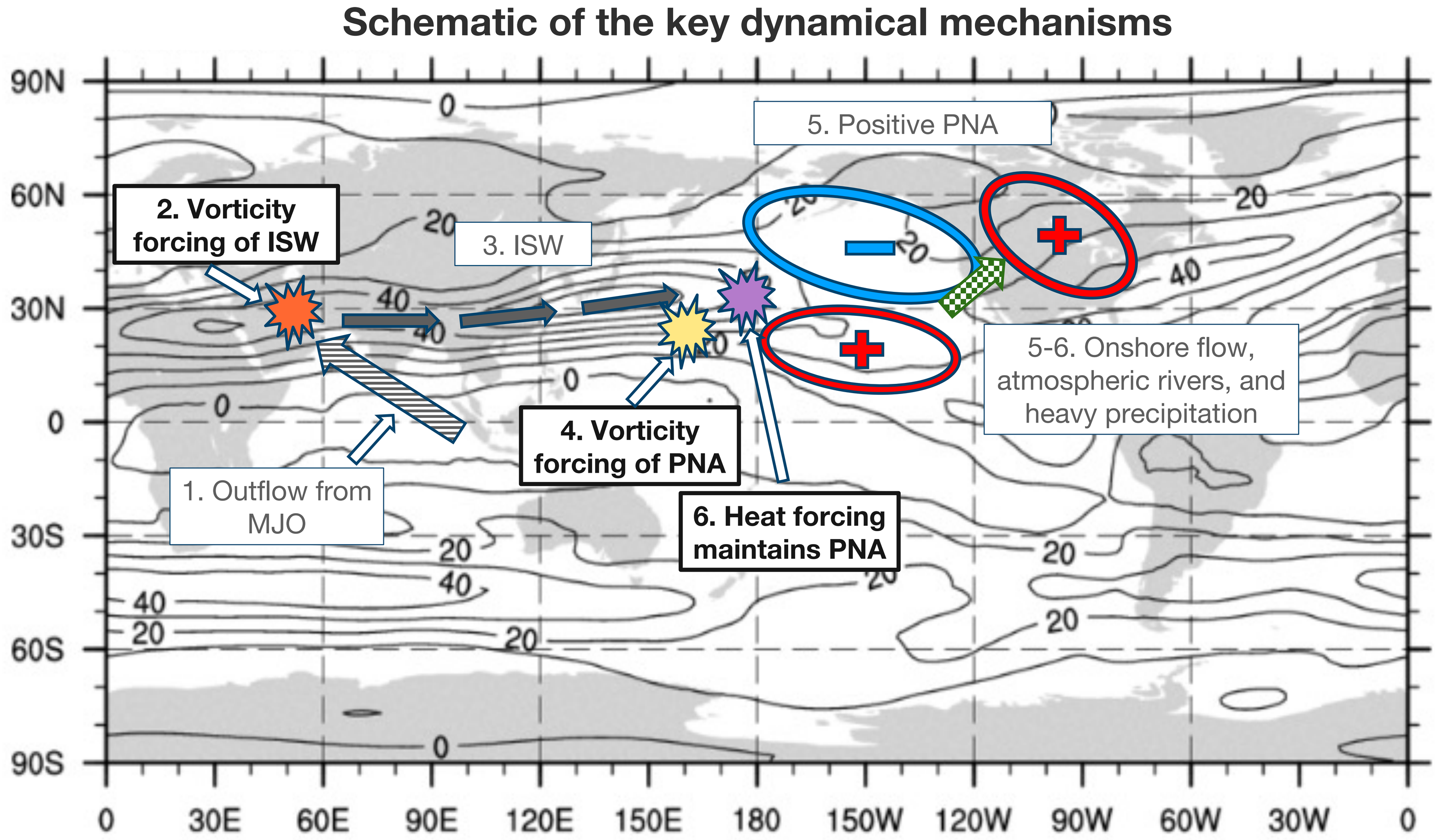
Our analysis (see also *Schubert et al. oral, QR code on bottom of poster*) shows that a chain of dynamical events contributed to the extreme precipitation, including the development of a Rossby wave that emerged from the Indian Ocean in mid-December, and the subsequent development of a persistent positive Pacific-North American (PNA)-like pattern that ultimately directed moisture onto the US West Coast starting in late December.

MERRA-2 precipitation (shaded) and 250mb geo. ht. anomalies (contoured) Dec. 27, 2022 – Jan. 15, 2023



Left: Precipitation anomaly over the flood region (red box).
Right: The large-scale circulation shows a positive PNA-like anomaly associated with the event.

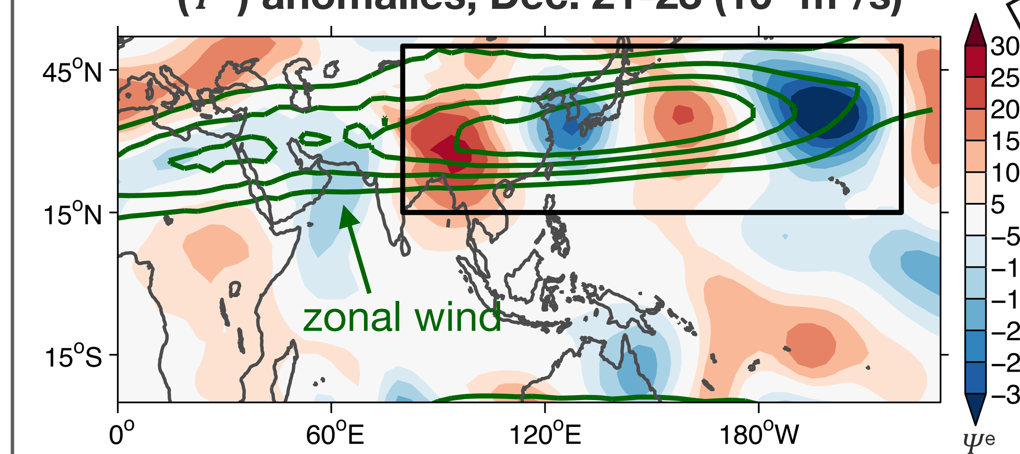
Schematic of the key dynamical mechanisms



The MJO indirectly forced a transient Rossby wave (the Indian Ocean Shortwave, or ISW). The ISW then provided forcing for the PNA, which was maintained by self-induced heating anomalies.

The beginning: Indian Ocean Shortwave (ISW)

The ISW: MERRA-2 σ=0.257 eddy stream function (Ψ^e) anomalies, Dec. 21-23 (10^6 m²/s)



What type of "forcing" led to the ISW?

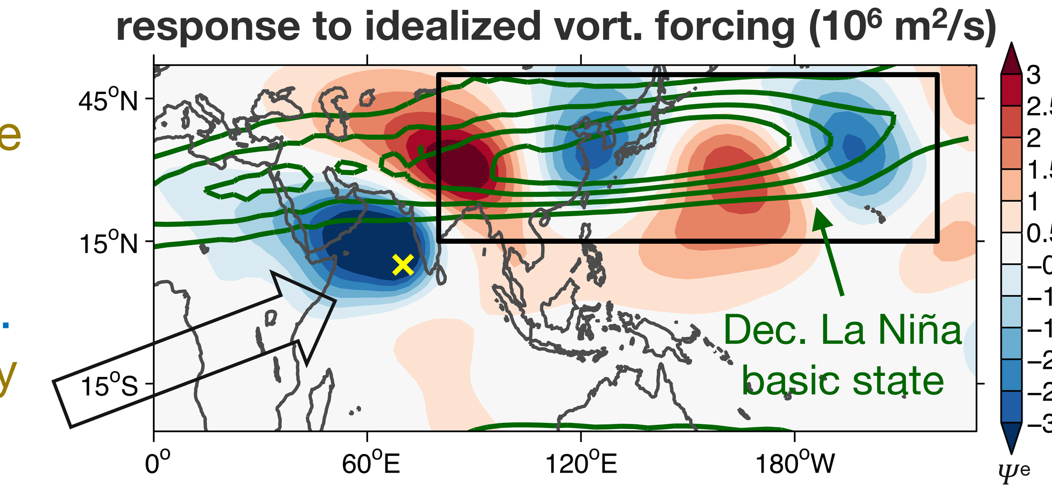
Forcing – persistent anomalies in atmospheric dynamics/thermodynamics.

Use a stationary wave model (SWM) to examine the response to idealized forcing upon a basic state.

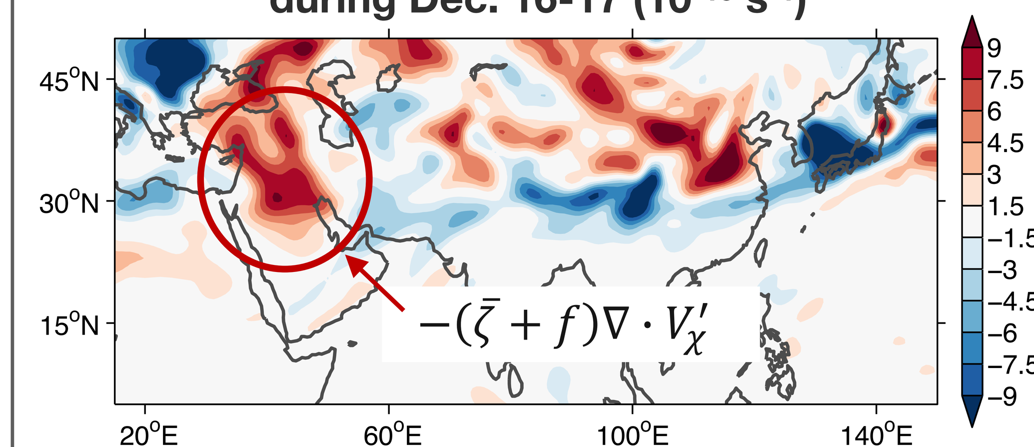
The model is the dynamical core of an AGCM, baroclinic and nonlinear, wavenumber-30 and 14L.

Force the model with an idealized vorticity anomaly in the upper troposphere at the yellow x.

SWM σ=0.257 eddy stream function (Ψ^e) anomaly response to idealized vort. forcing (10^6 m²/s)

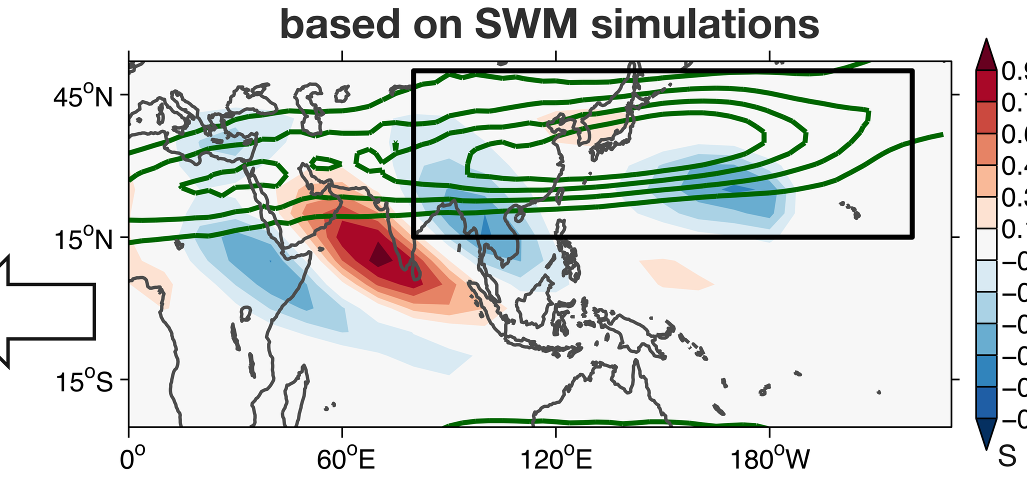


MERRA-2 250mb vorticity stretching anomaly during Dec. 16-17 (10^{-10} s⁻¹)



An area of convergence over the Arabian Peninsula provided a favorable vorticity source.

Forcing sensitivity (S) map for vorticity based on SWM simulations



Positive vorticity over the red region, including the Middle East, can induce the ISW.

Vorticity forcing off the west coast of India is conducive to generating a wave train similar to the ISW, with this background state.

Where else is vorticity forcing important?

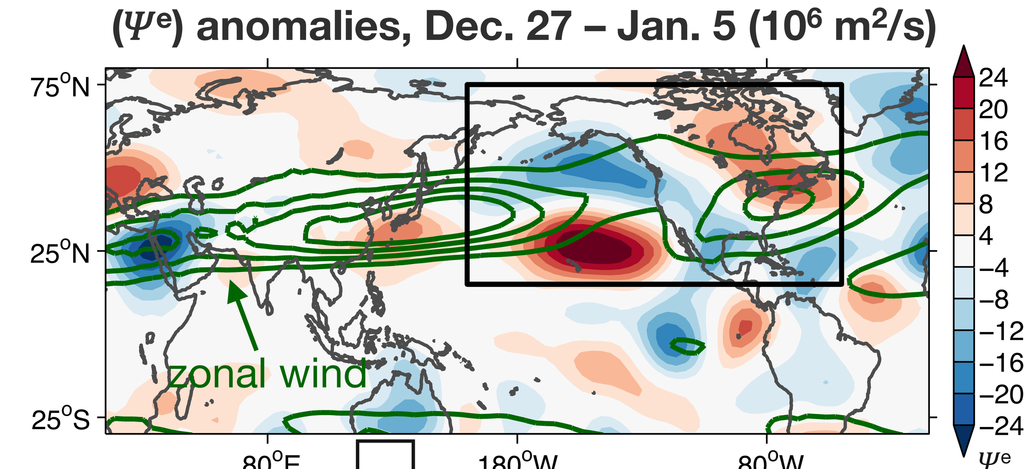
Repeat the experiment at many locations (every 10° lon. and 5° lat.) and summarize using EOFs and inner products.

Scan for more details about the methods

The late-December wave train was likely induced by a vorticity source in the Middle East. Additional analysis shows this forcing was potentially tied to the Madden-Julian Oscillation outflow/circulation (*Schubert et al. oral, QR code on bottom*).

The main event: Pacific-North American (PNA)-like pattern

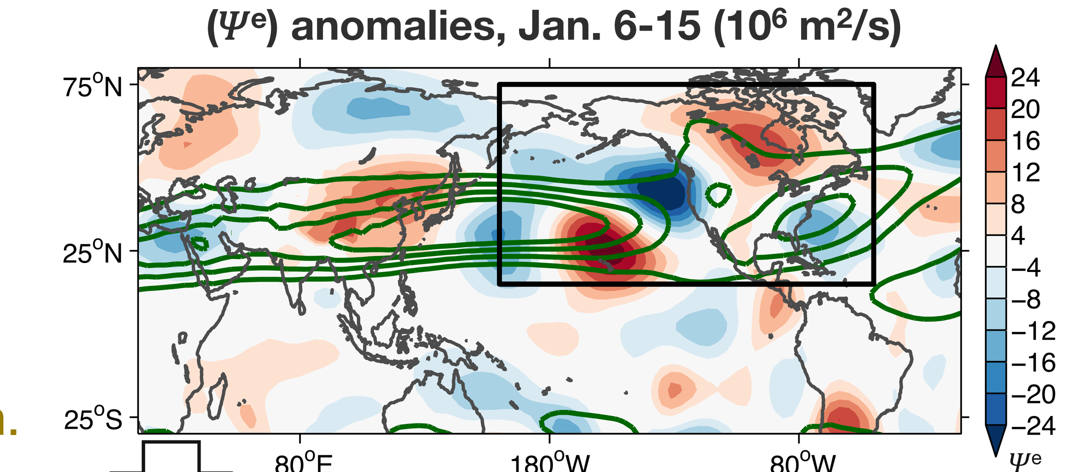
PNA part 1: MERRA-2 σ=0.257 eddy stream function (Ψ^e) anomalies, Dec. 27 – Jan. 5 (10^6 m²/s)



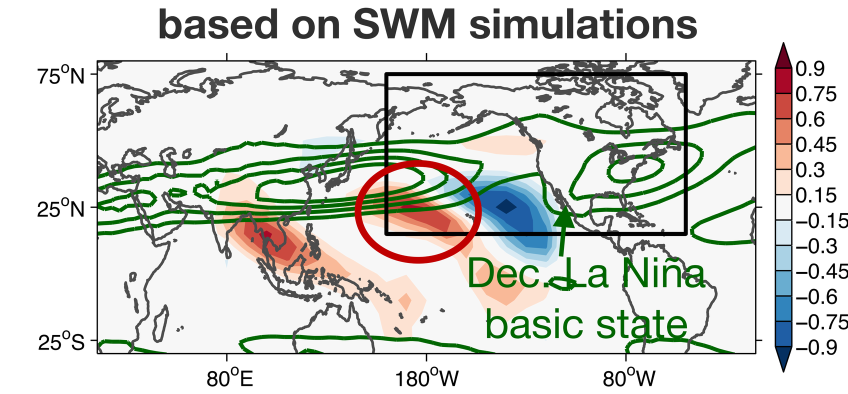
The PNA-like circulation persisted from late December through mid-January, with Pacific circulation anomalies evolving from a south-north to southwest-northeast orientation.

The SWM analysis is applied using the PNA circulation from each subperiod as verification.

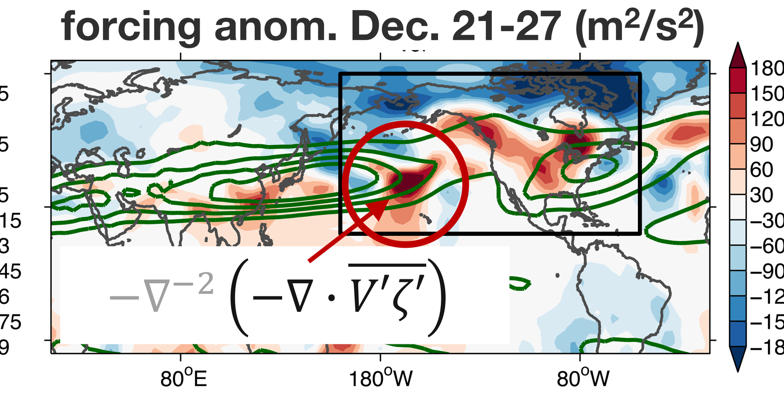
PNA part 2: MERRA-2 σ=0.257 eddy stream function (Ψ^e) anomalies, Jan. 6-15 (10^6 m²/s)



Forcing sensitivity map for vorticity based on SWM simulations

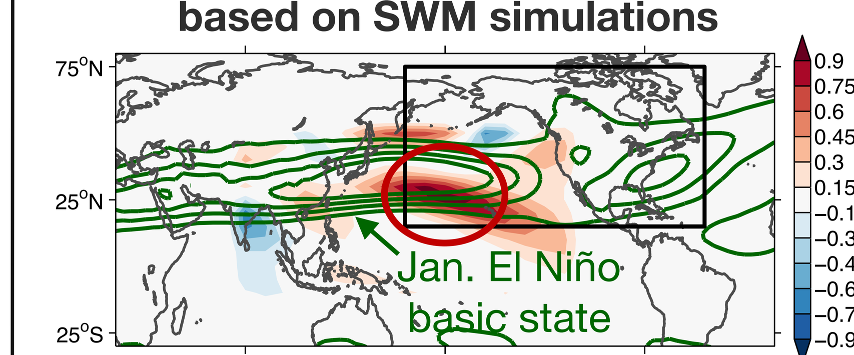


MERRA-2 σ=0.257 transient vorticity forcing anom. Dec. 21-27 (m²/s²)

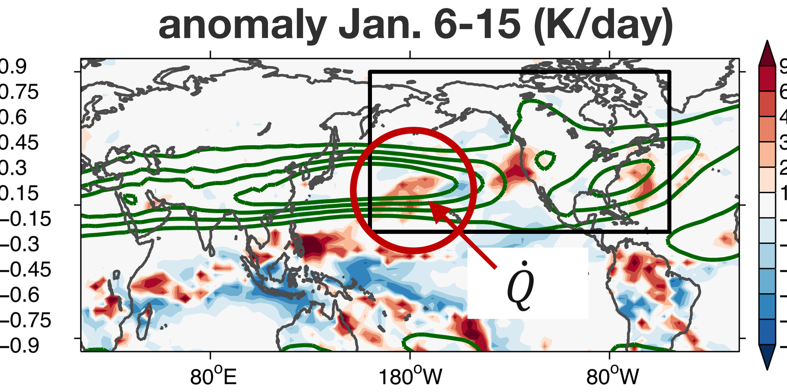


Transients (weather disturbances) associated with the ISW provided favorable vorticity forcing for the PNA onset.

Forcing sensitivity map for heat based on SWM simulations



MERRA-2 σ=0.46 diabatic heating anomaly Jan. 6-15 (K/day)



Diabatic heating from precipitation northwest of Hawaii, linked to the PNA-like circulation, helped sustain the PNA.

Scan for more information about related talk: Schubert et al., J12B.3, Wed 1/31 @5PM

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