

Identifying the Opportunities and Barriers in the Intraseasonal Prediction of the Indian Summer Monsoon

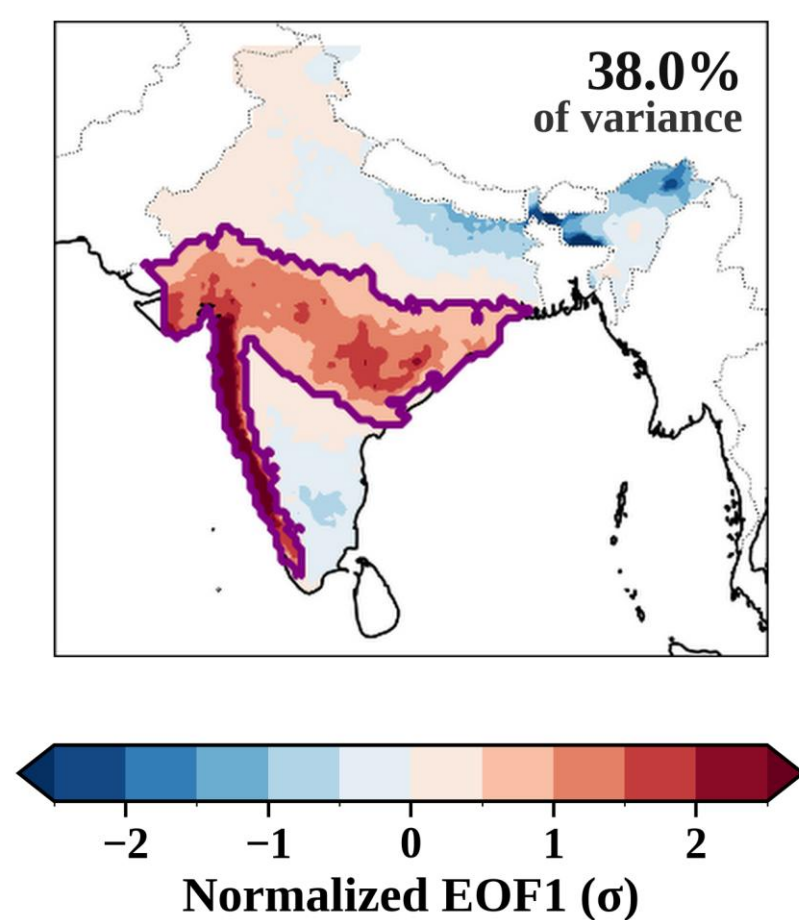
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Introduction

- The 30-60-day monsoon intraseasonal oscillation (MISO) drives the active and break spells that decide floods, dry spells, and crop stress over India.
- Forecasts two to four weeks ahead (subseasonal-to-seasonal, S2S) matter most for this, yet ECMWF skill varies strongly from event to event: some MISO events are forecast weeks ahead, others are missed.
- Here we compare 88 well- and poorly predicted MISO events (2005–2024). We ask whether the precursors separate them, whether failures come from the model or the atmosphere, and whether forecast reliability can be judged when a forecast is issued.

Study region: the 30-60-day homogeneous region



The leading EOF of 30-60-day rainfall (38% of variance) defines the region: central India and the Western Ghats (purple, normalized EOF > 0.5).

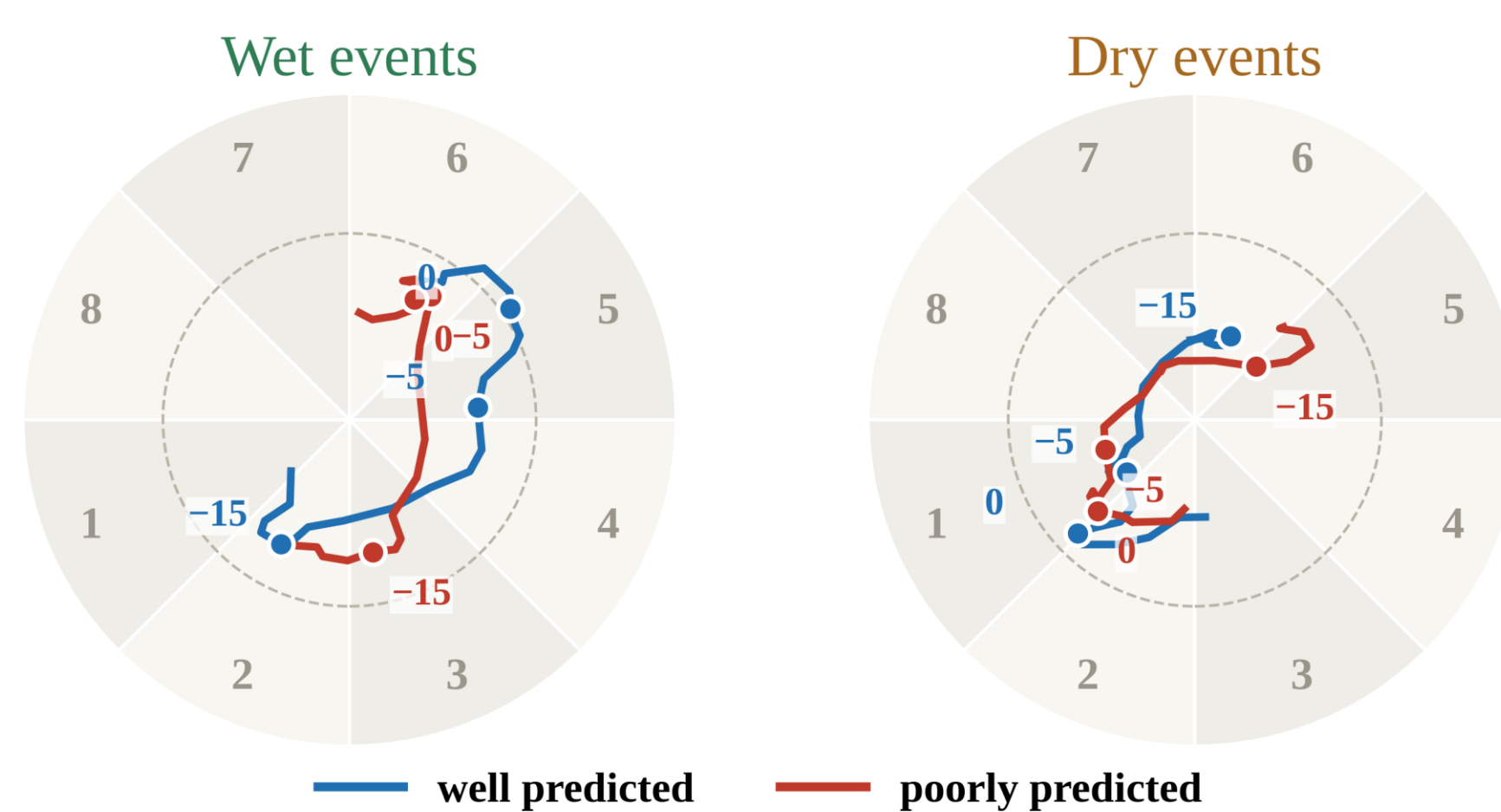
Objectives

- Identify the tropical and extratropical conditions that separate well- from poorly predicted MISO events.
- Determine whether poor forecasts reflect **model error** or an **inherently unpredictable** atmosphere.
- Test whether these conditions are known on the day a forecast is issued, for **reliability**.

Data and methods

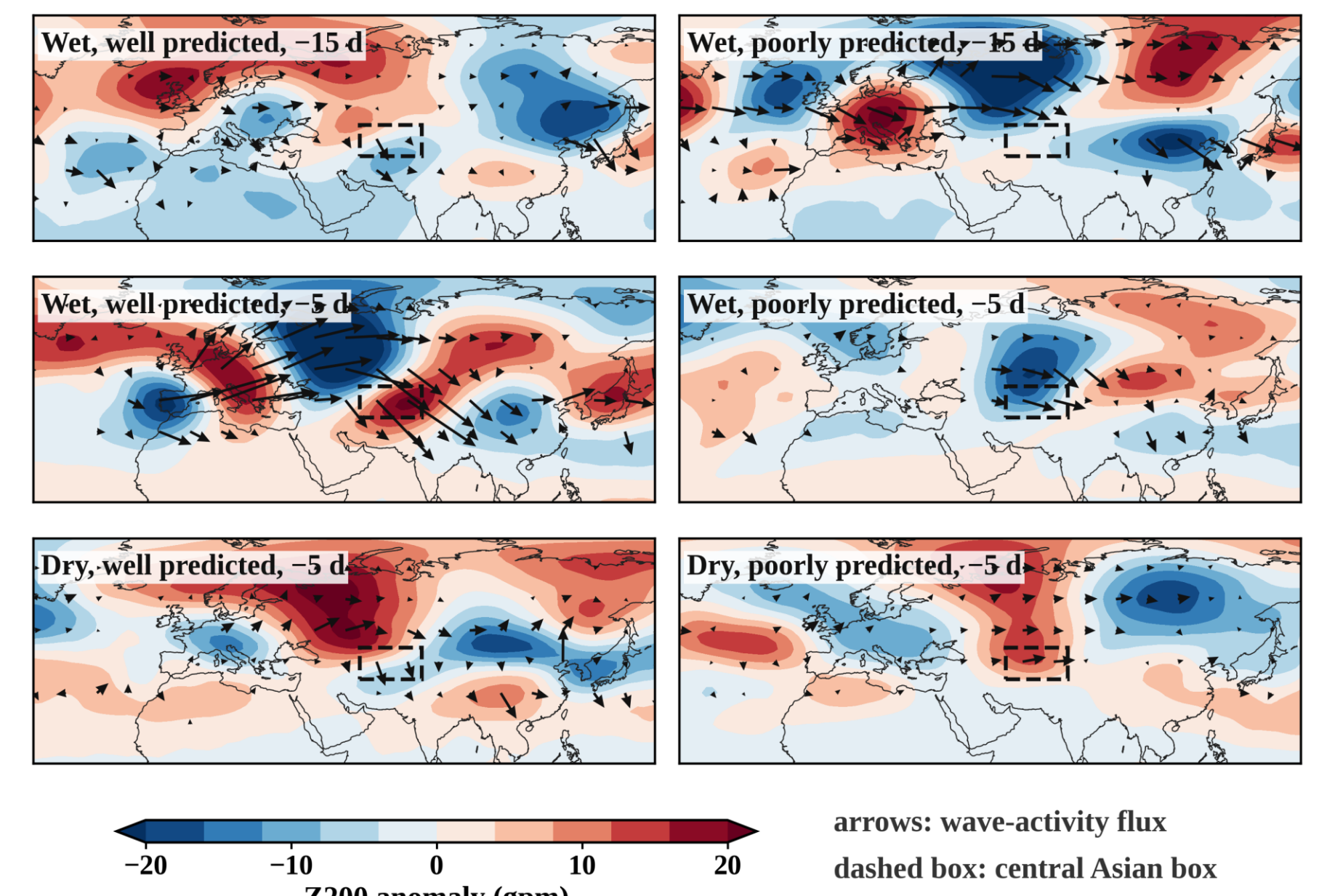
- Data:** IMD 0.25° rain; ECMWF S2S hindcasts, JJAS 2005–2024; ERA5 Z200, Z850 and winds; APCC BSISO index; Niño 3.4.
- Events:** peaks and troughs of 30-60-day rain over the homogeneous region: 88 events (46 wet, 42 dry).
- Labels:** ratio score (forecast ÷ observed anomaly, leads 7-14 d) against events of similar amplitude: 40 well, 48 poorly predicted.

Tropical driver: BSISO phase



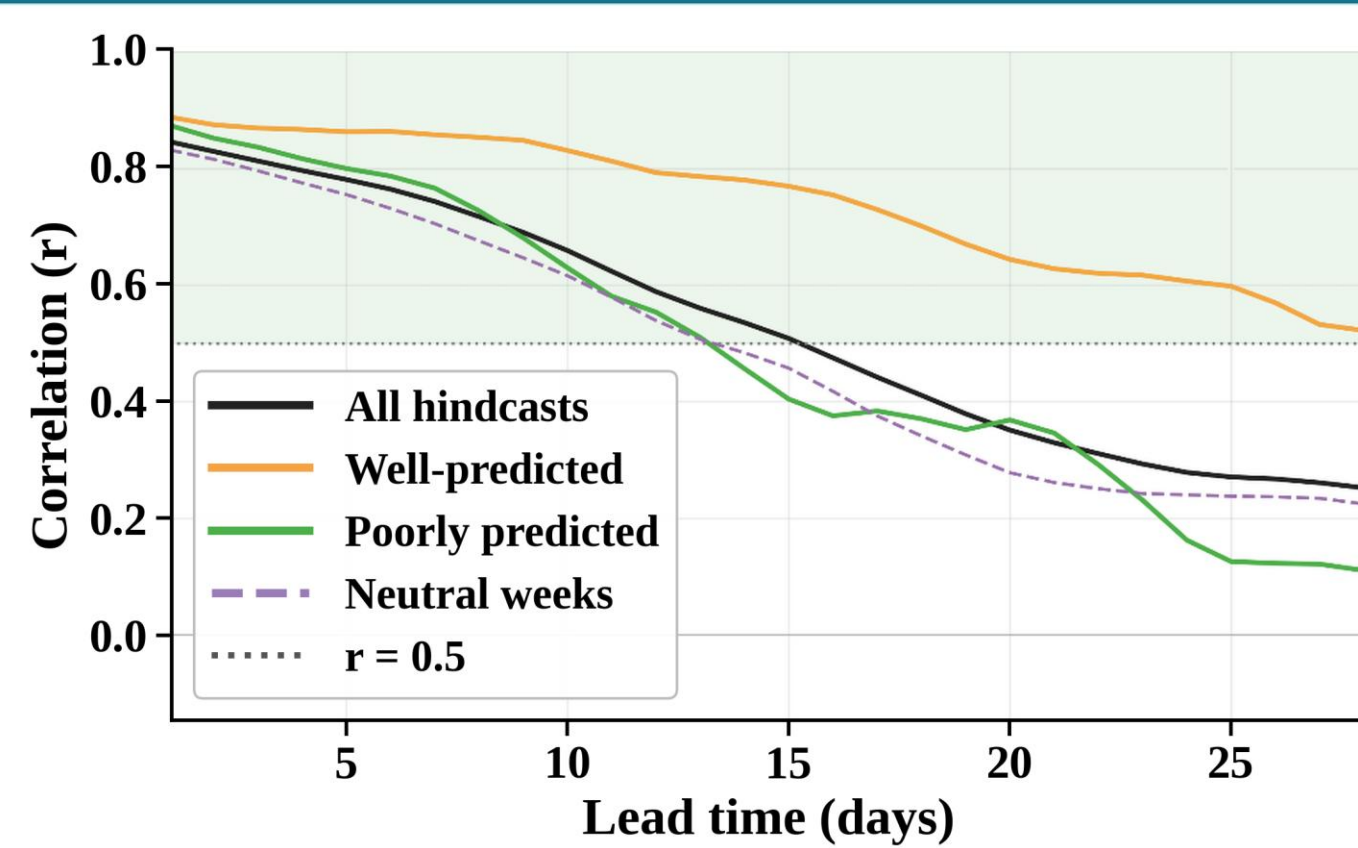
Well-predicted wet events start in BSISO **phase 5**, poorly predicted ones a phase later ($p = 0.013$ at -5 d), and this is known at issue time (AUC 0.73, $p = 0.004$). Dry events show no BSISO difference.

A Eurasian wave train builds the high



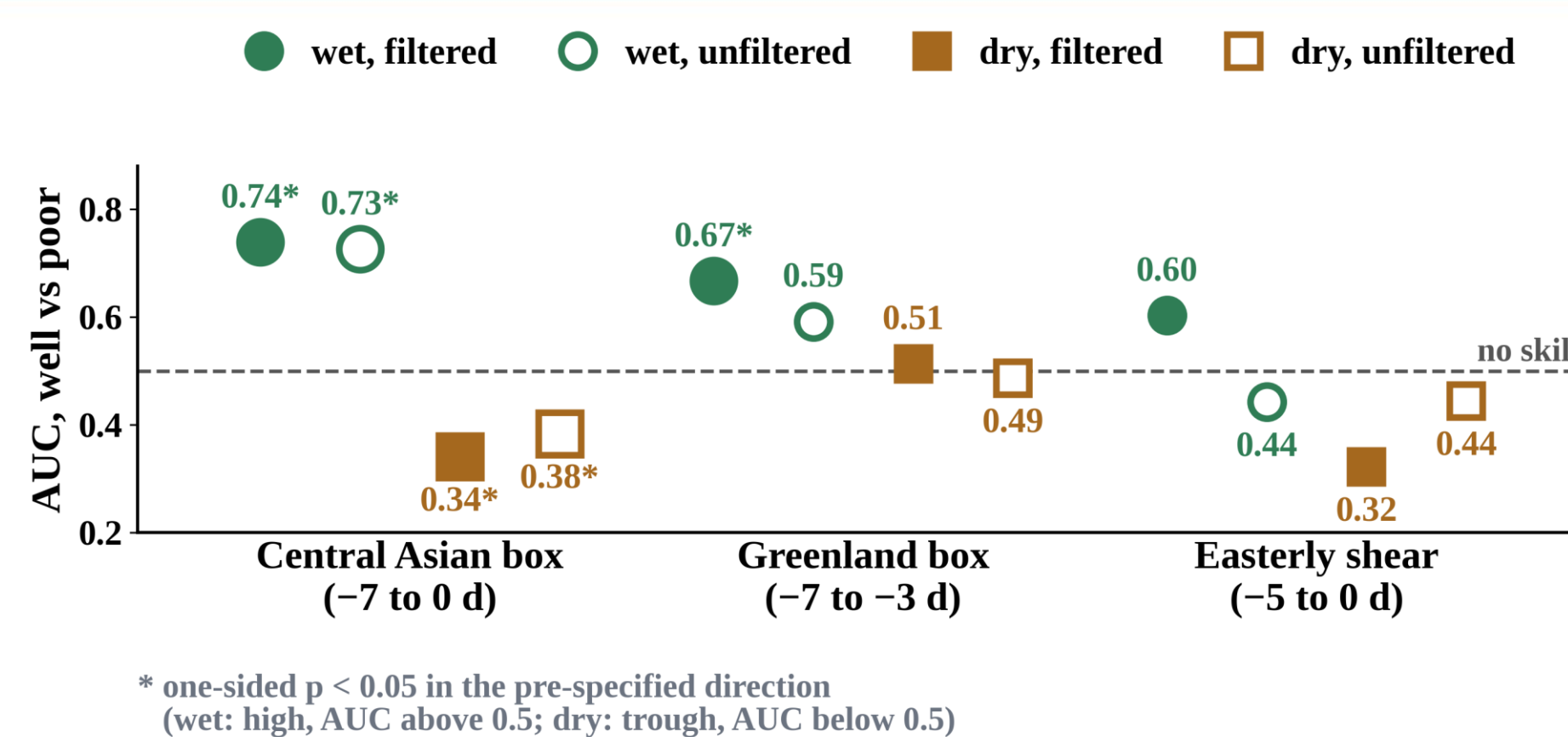
Before well-predicted wet events, wave activity crosses Europe (-5 d, $p \leq 0.001$) and reaches the Urals at onset; before poor ones it sits over the Urals about 15 d earlier ($p \leq 0.005$).

Well-predicted events keep skill to 28 days



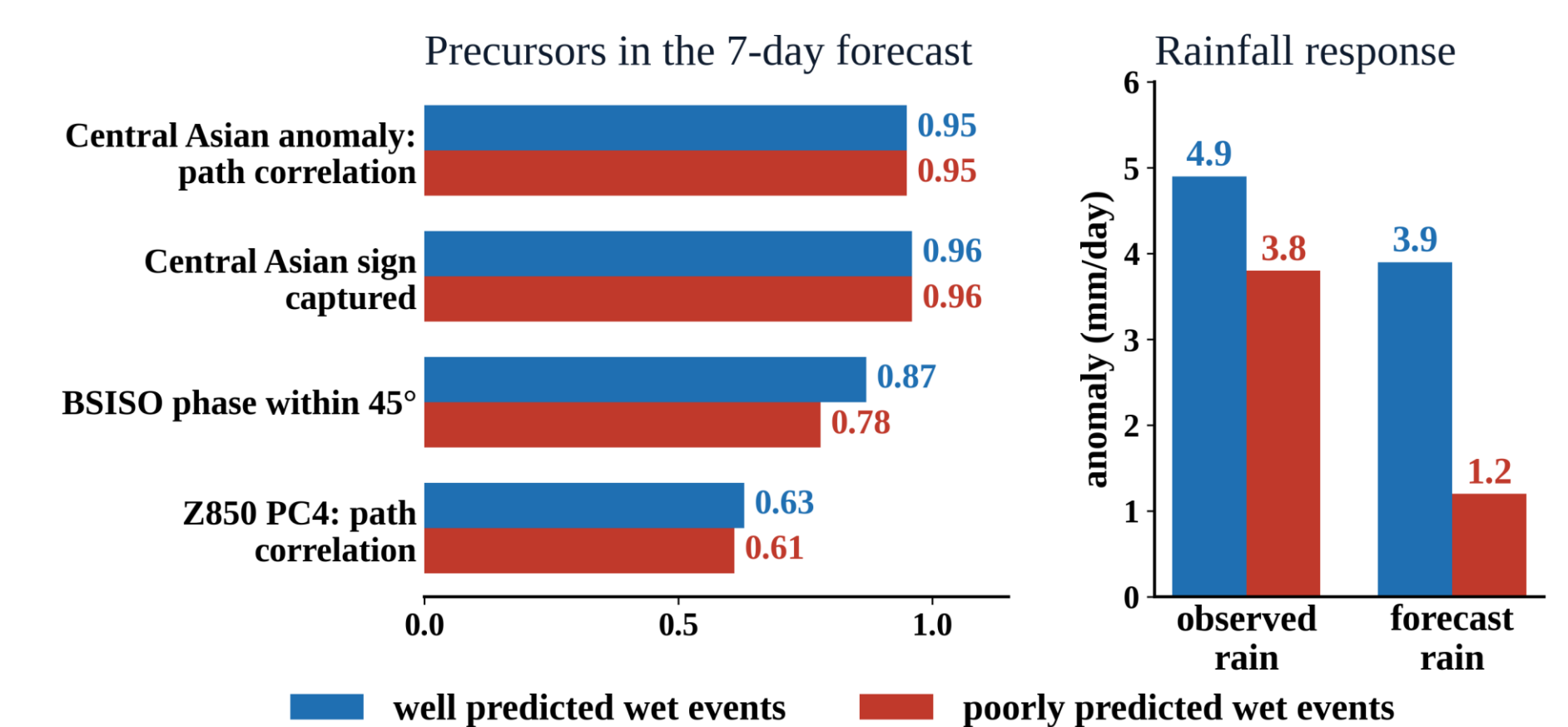
Correlation stays above 0.5 to 28 days for well-predicted events, but falls below it near day 13 for poorly predicted ones.

Extratropical driver: central Asian box



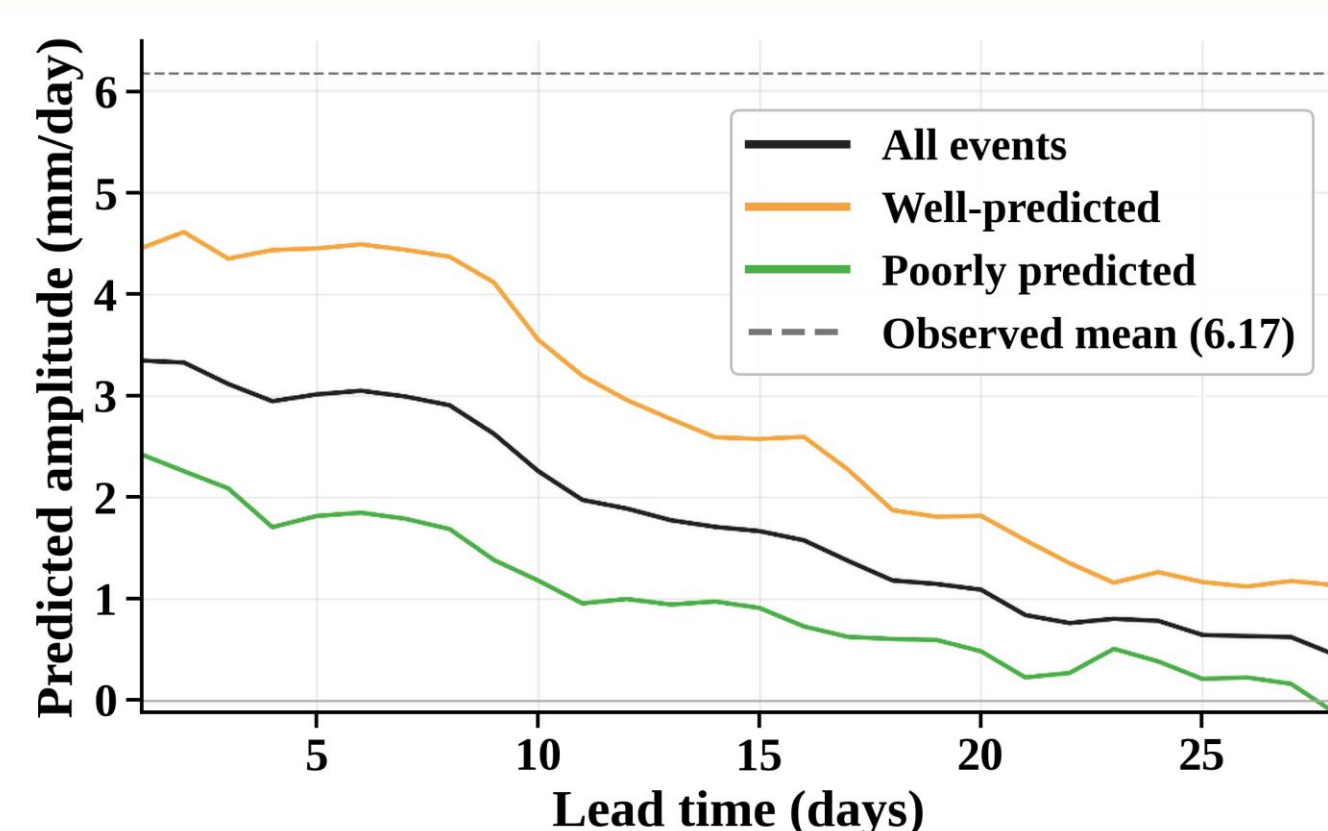
A central Asian **high** precedes well-predicted wet events (AUC 0.74), independent of the BSISO ($p = 0.001$ -0.016); a mirror **trough** precedes well-predicted breaks (AUC 0.34). Easterly shear is not found.

Precursors captured, not rain



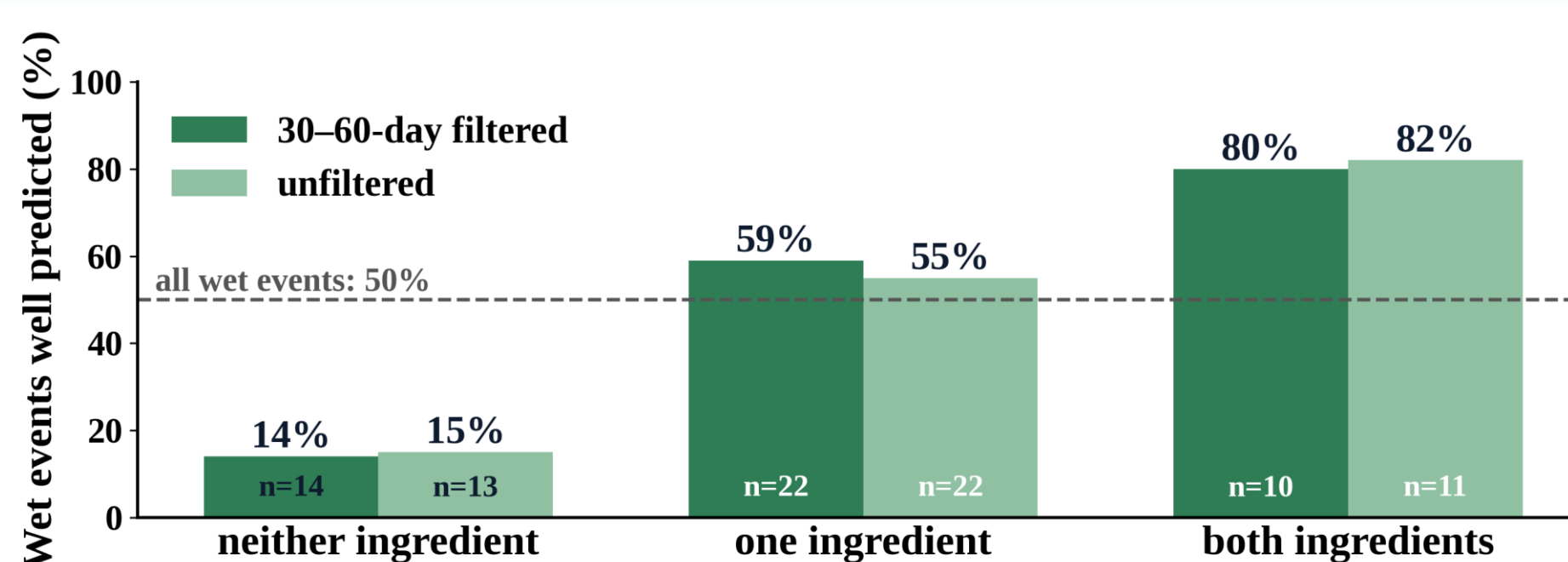
ECMWF forecasts both precursors correctly before 74% (wet) and 68% (dry) of failures, with no larger ensemble spread (1.10 vs 1.26); the error lies in turning the large-scale state into rain.

Forecast amplitude decays, most for poor events



All forecasts underestimate the observed amplitude (6.17 mm/day); poorly predicted events start below half of it.

The two ingredients add up

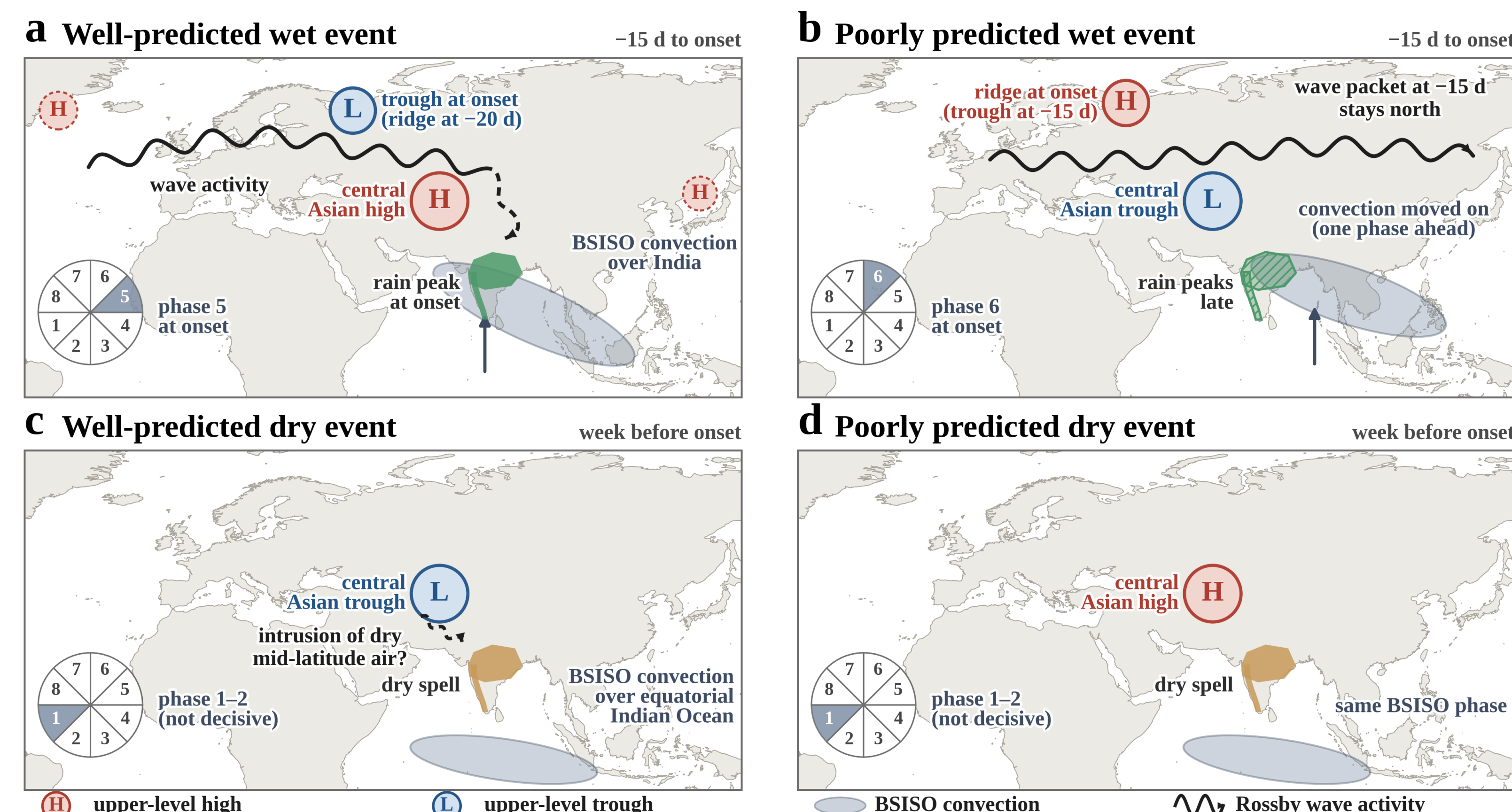


The two are uncorrelated: 14% of wet events are well predicted with neither, 80% with both (leave-one-year-out AUC 0.76-0.81, $p = 0.002$).

Other checks

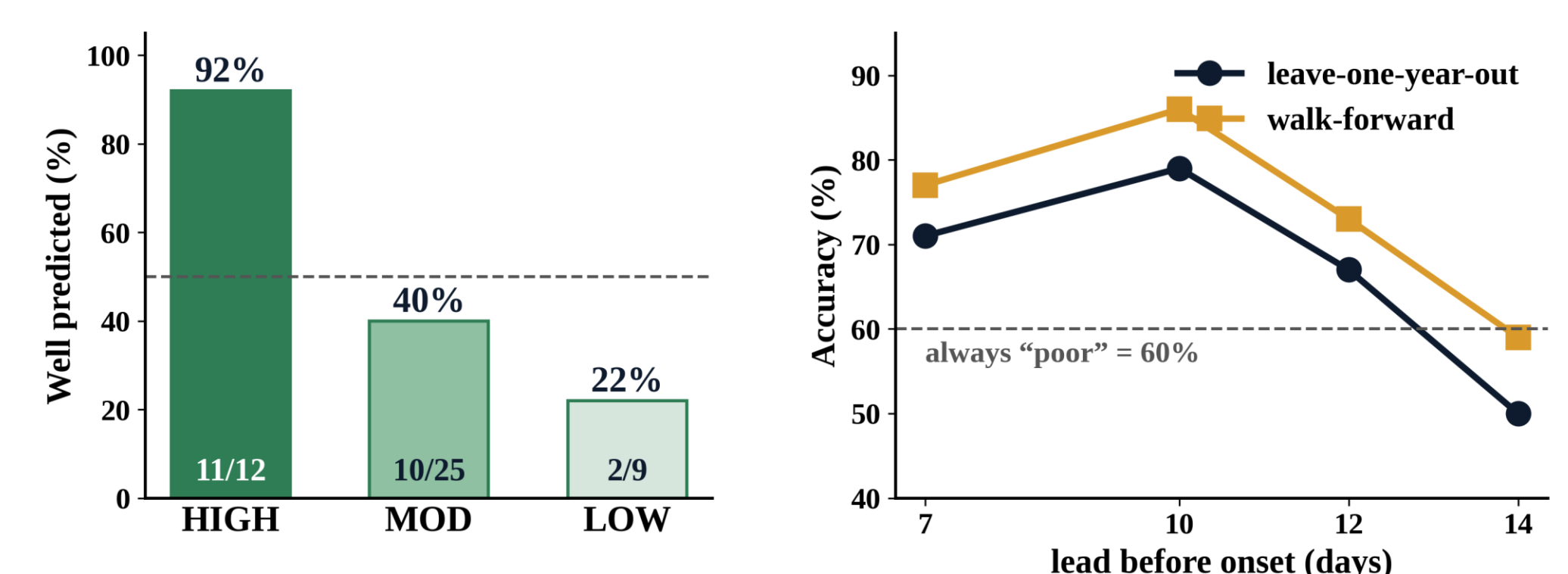
- Convection at onset:** poor wet events have a weaker, eastward-shifted signal (OLR 6.8 vs 21.4 W m⁻², $p \approx 0.10$), which ECMWF also forecasts.
- La Niña summers:** 2 of 10 wet events well predicted vs 21 of 36 elsewhere ($p = 0.018$).

The mechanism



Well- (a, c) and poorly predicted (b, d) wet and dry events. Dashed elements are suggestive, not demonstrated.

Reliability Indicators



Wet: both precursors favourable → 11 of 12 well predicted (walk-forward AUC 0.74, $p = 0.024$).
Dry: forecast PC4 flag, walk-forward accuracy 86% ($p = 0.008$).

Conclusions

- Good forecasts need supportive **tropical** (BSISO phase) and **extratropical** (central Asian high or trough) conditions.
- ECMWF forecasts these precursors correctly even before most failures: the error is in turning the **large-scale state into rain**.
- La Niña summers** are a warning sign: ECMWF misses most of their wet spells, so its active-spell forecasts deserve **less trust** in those years.