

Supplementary Materials for
**Predicting regional gray swans via translocation: AI weather models and
Dubai's unprecedented 2024 rainfall**

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Sci. Adv. **12**, eady9406 (2026)
DOI: 10.1126/sciadv.ady9406

This PDF file includes:

Figs. S1 to S6

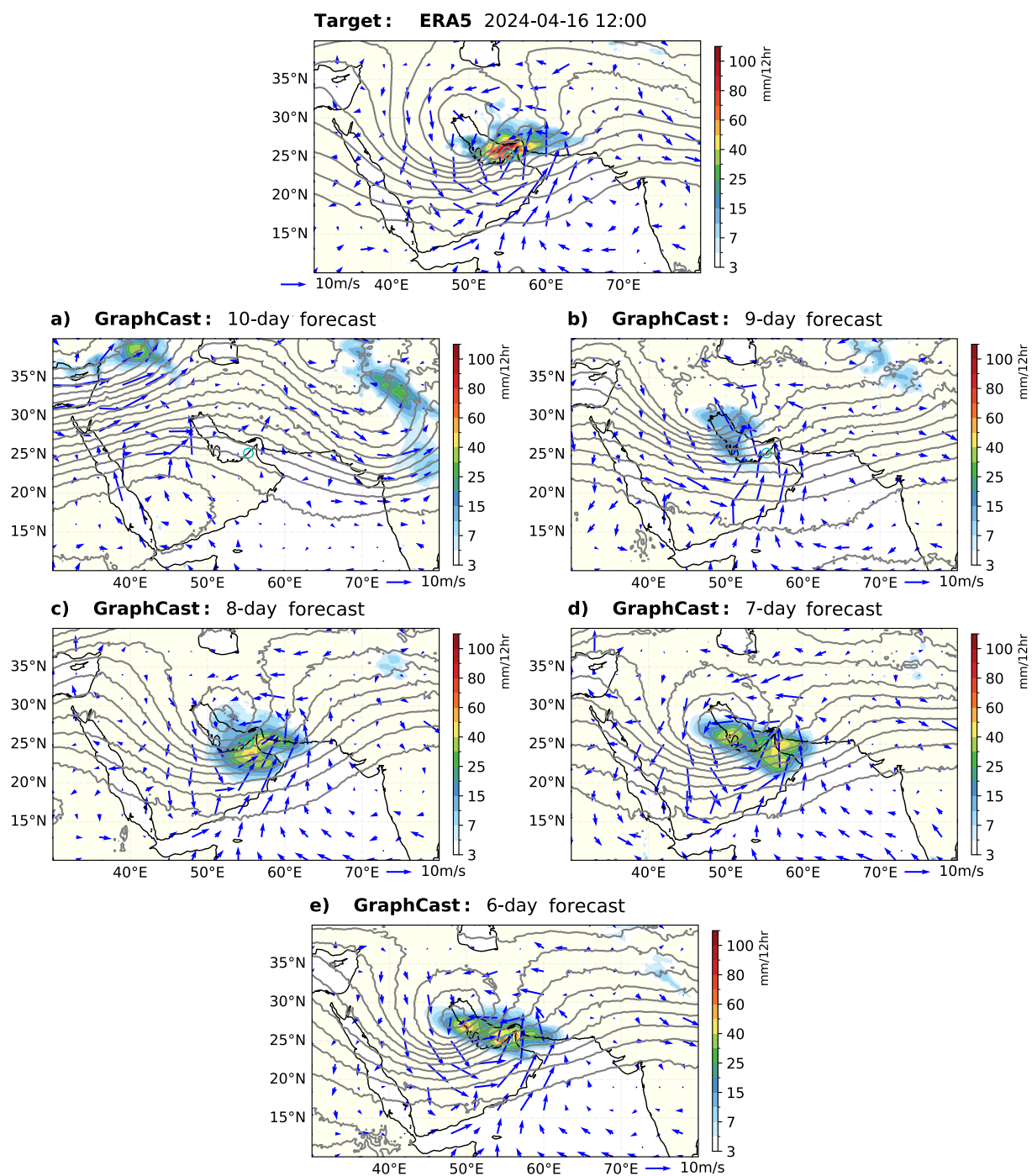


Figure S1: GraphCast forecasts of the Dubai event at various lead times. (a) 10 days; (b) 9 days; (c) 8 days lead time, note the correct location and the precipitation amplitudes that exceed the training maximum near Dubai already; (d) 7 days; (e) 6 days.

Target: ERA5 2024-04-16 12:00

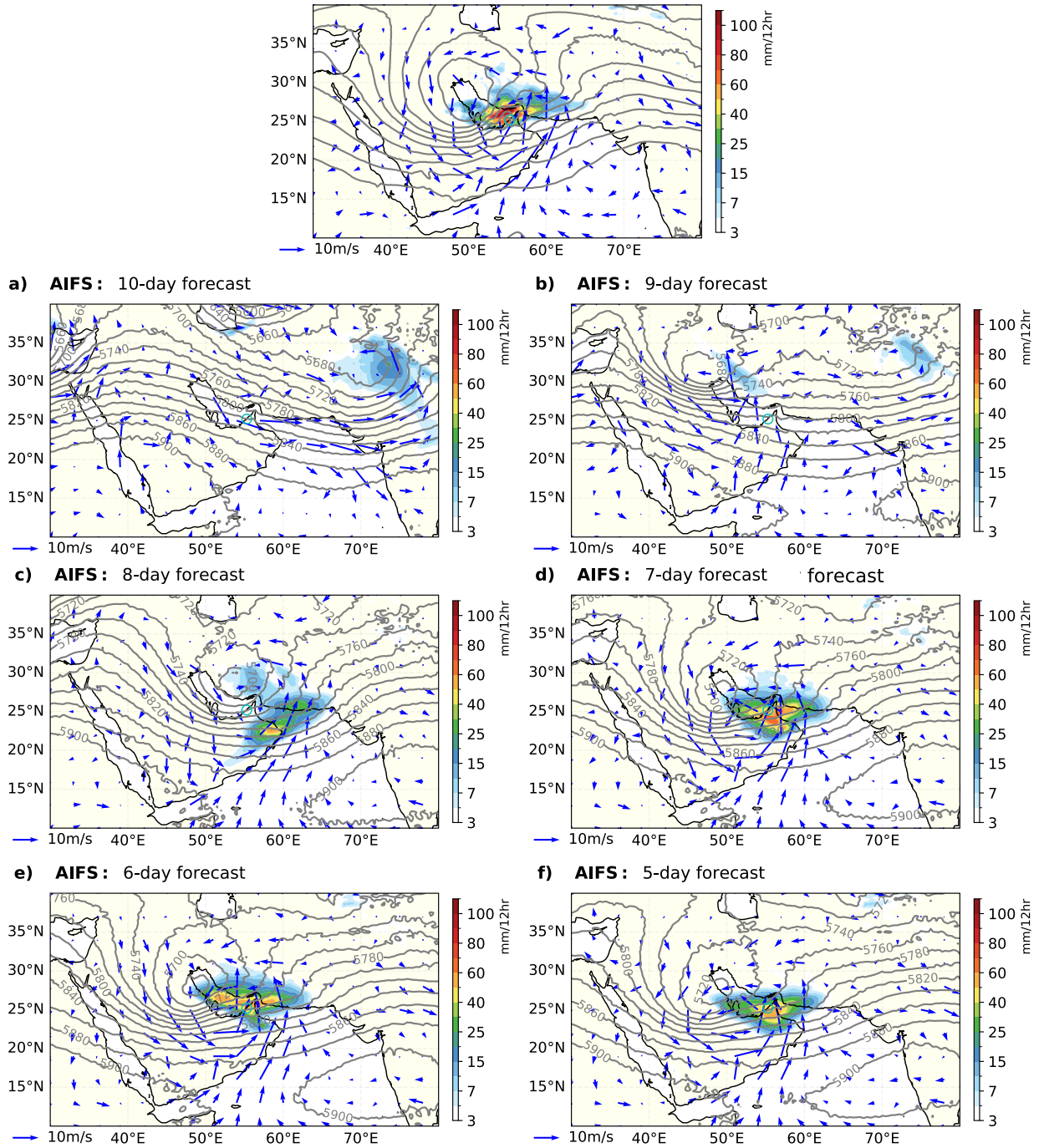


Figure S2: AIFS forecasts of the Dubai event at various lead times. (a) 10 days; (b) 9 days; (c) 8 days; (d) 7 days; (e) 6 days; (f) 5 days.

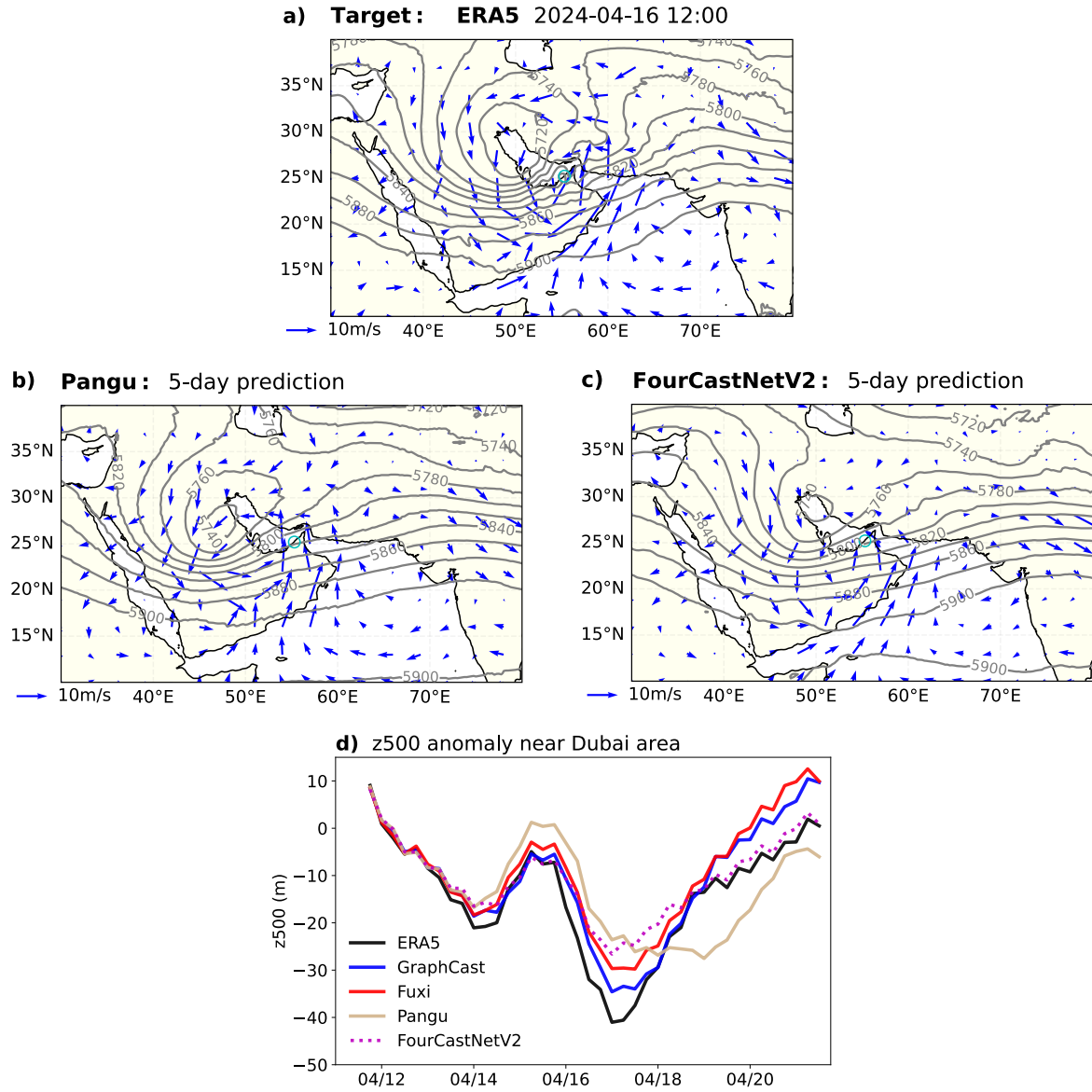


Figure S3: Forecasts by the Pangu-Weather and FourCastNetV2 models for the event. (a) Geopotential height at 500 hPa (z500) and 850 hPa wind vector from ERA5 reanalysis; **(b)** Forecast from the Pangu-Weather model, initialized on April 11th; **(c)** Forecast from the FourCastNetV2 model, initialized on April 11th; **(d)** Time evolution of the area-averaged geopotential height over the Dubai region as represented in ERA5 and in forecasts produced by the four AI models in this study.

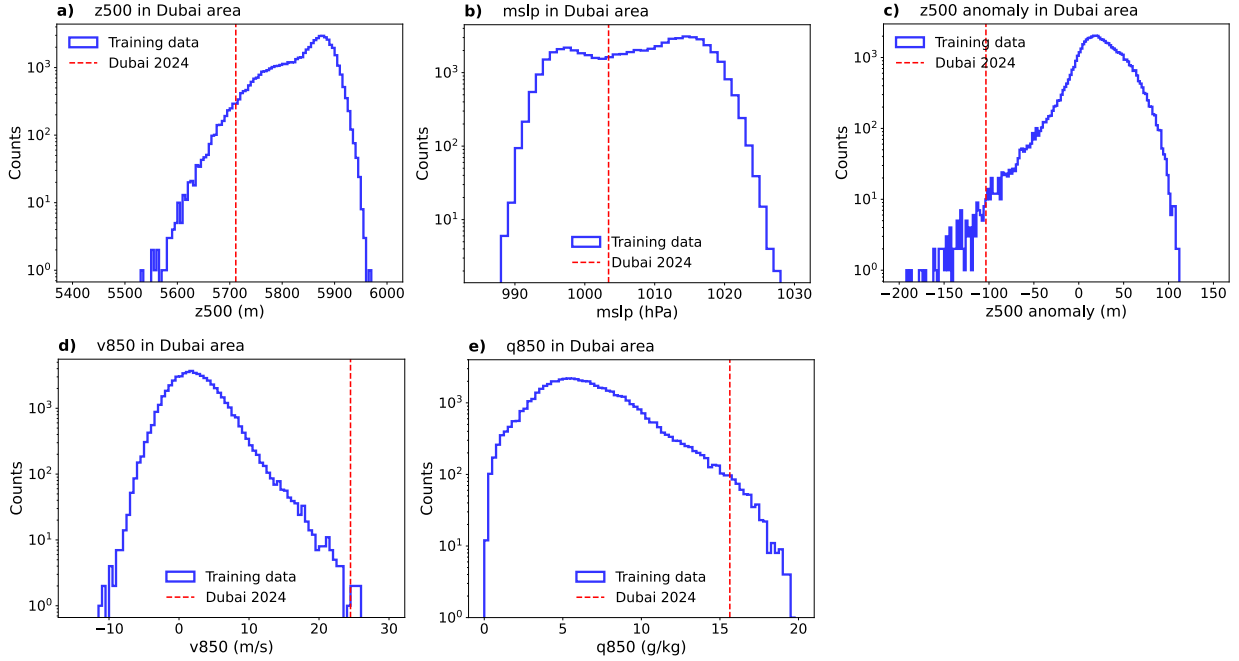


Figure S4: Rarity of the Dubai event in different variables. (a) Geopotential height at 500 hPa (z500); (b) Mean sea level pressure (mslp); (c) Geopotential height anomaly at 500 hPa (z500 anomaly); (d) Meridional wind at 850 hPa (v850); (e) Specific humidity at 850 hPa (q850). When examined individually, none of these variables is OOD. Nonetheless, when considered together, some of the joint distributions, most notably that of v850-q850, indicate unprecedented meridional moisture transport (Figure 2D in the main text).

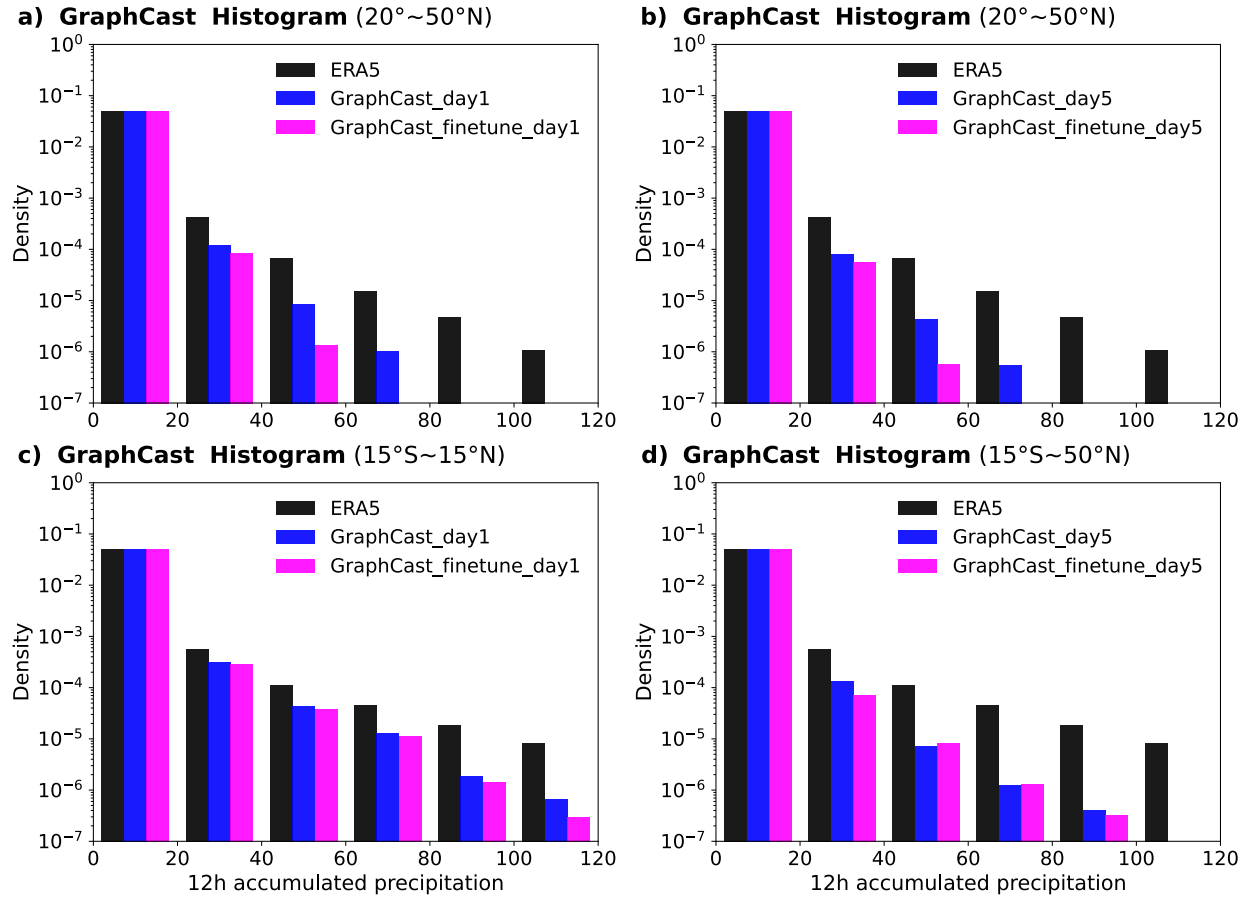


Figure S5: Differences in precipitation histograms between the original GraphCast and the fine-tuned version after capping rainfall in dynamically similar events (mid-latitude storms). (a–b) Northern Hemisphere midlatitudes ($20^{\circ}\text{N}\sim 50^{\circ}\text{N}$); (c–d) Tropics ($15^{\circ}\text{S}\sim 15^{\circ}\text{N}$). Histograms include all events, not just dynamically similar ones. The precipitation capping of the Northern Hemisphere midlatitude cyclone has a substantially large impact on the Northern Hemisphere mid-latitudes but limited effects on the tropics, where the extreme precipitation has different dynamics.

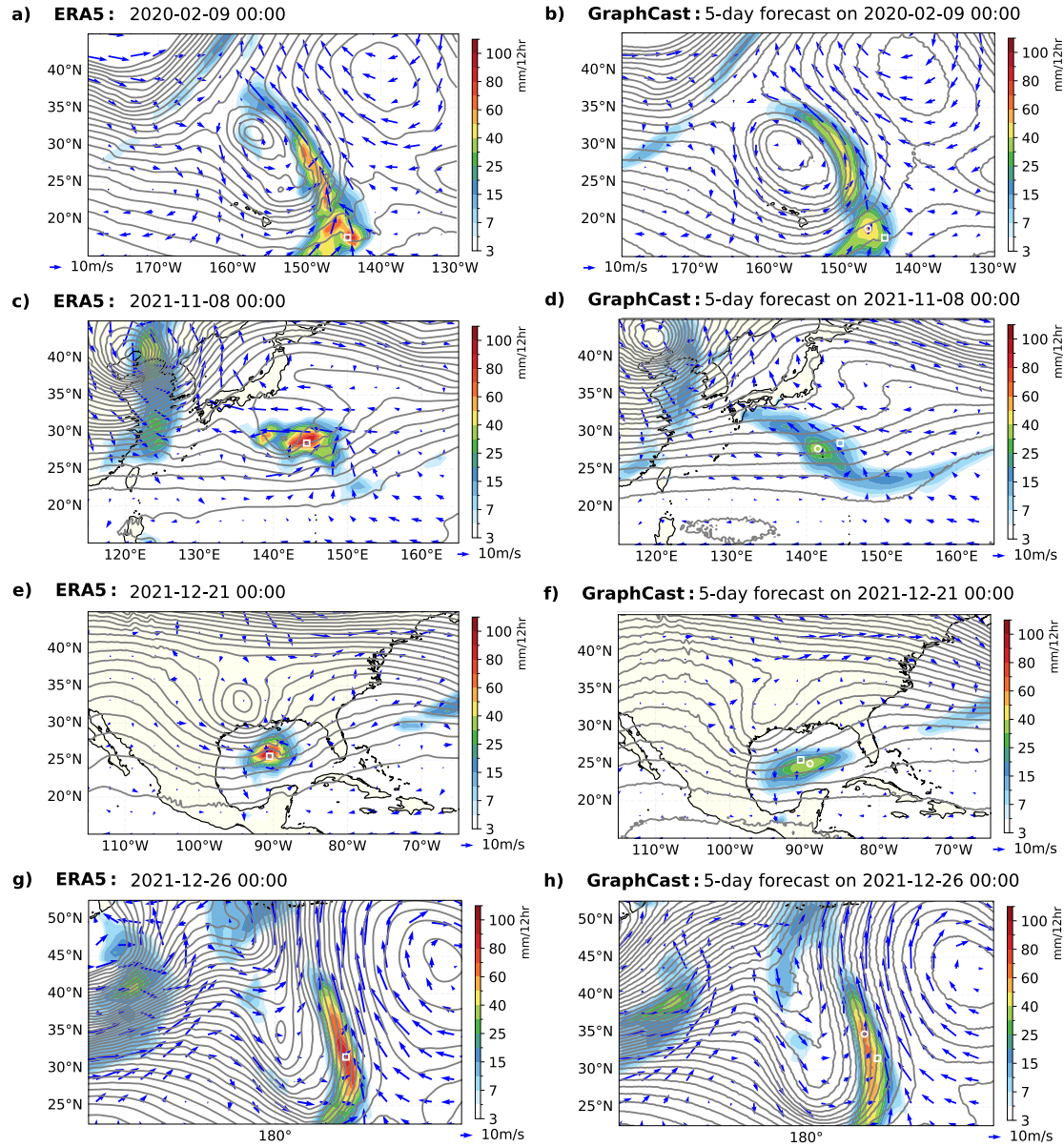


Figure S6: GraphCast forecasts of global extreme events. Similar to Figure 6 in the main text, this figure presents four additional cases. The left column shows ERA5 reanalysis data for extreme rainfall events, while the right column displays GraphCast's 5-day forecasts for the same fields. In all cases, the predicted precipitation is significantly weaker than the observed values.