Extreme precipitation in the southern US Great Plains in the spring of 2015: mechanisms and prediction

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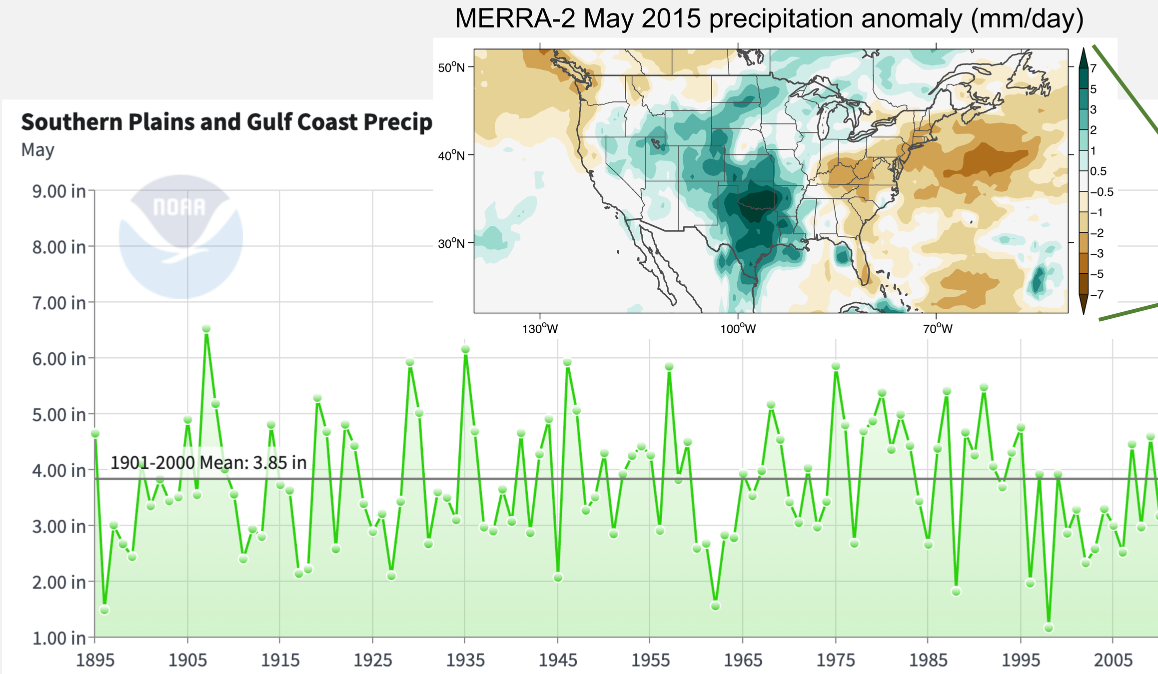
Overview

During May of 2015, the southern US Great Plains and adjacent Gulf Coast region experienced more than twice the long-term mean precipitation, making it the wettest May since 1895. We investigate the physical mechanisms associated with this event using a suite of large-ensemble regional replay AGCM simulations from the NASA-GEOS model. In these simulations, certain regions of the globe are constrained to closely follow observations while the remainder of the domain is free running, allowing for the isolation of the remote regions that were important for the event. The AGCM results (and supplemental analysis with a stationary wave model) suggest that the extreme southern US precipitation was linked in part to positive precipitation anomalies in the central and eastern tropical Pacific via a wave train, which ultimately caused anomalous moisture flux from the Gulf of Mexico. An analysis of Subseasonal Experiment (SubX) model output was conducted to explore the subseasonal prediction skill of the event. Several models, including NASA's GEOS-S2S model, are able the predict the presence of positive precipitation anomalies in or near the southern US at lead times exceeding 10 days, albeit with errors in the locations and magnitude of the heaviest precipitation anomalies. The prediction skill stems from the ability to reasonably predict the positive tropical Pacific precipitation anomalies and the initiation of the Rossby wave train that is believed to be linked to the event.

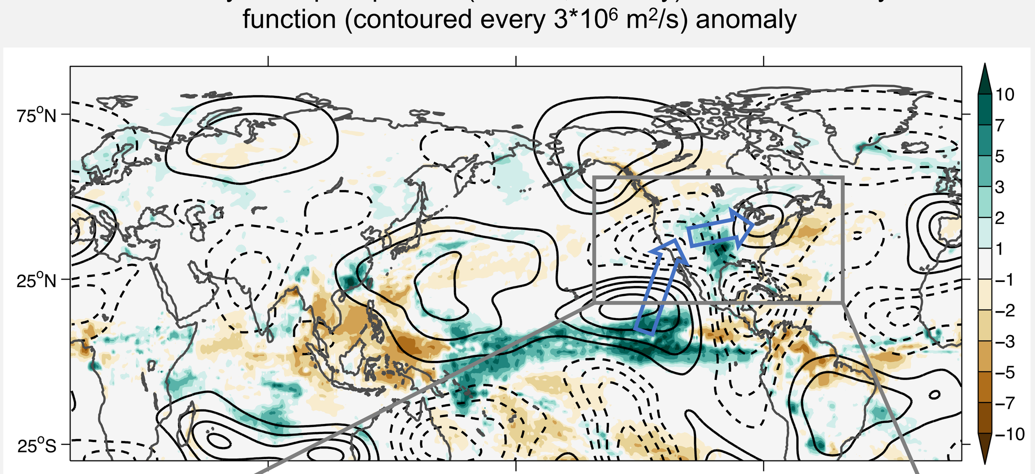
MERRA-2 May 2015 precipitation anomaly (mm/day)



Wettest May over the past ~130 years!

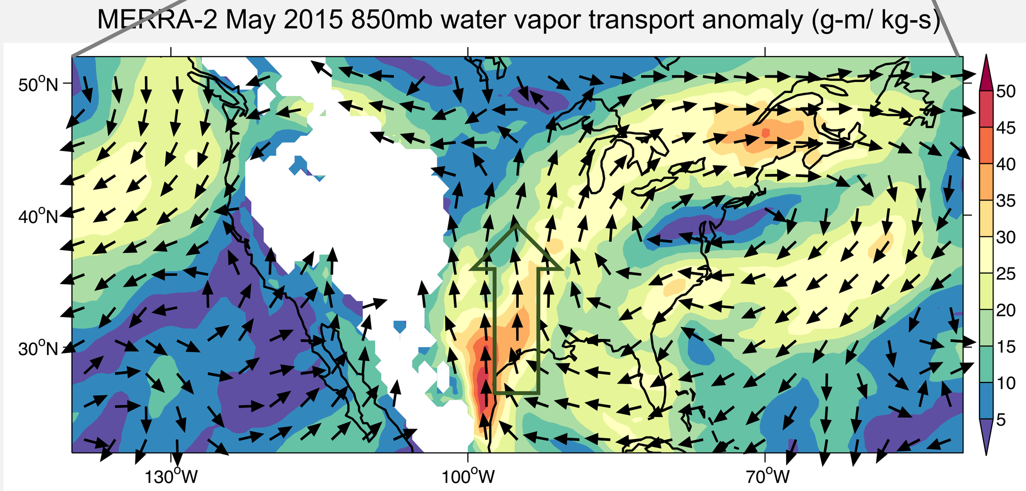
https://www.ncei.noaa.gov/access/monitoring/climate-at-a-glance/regional/time-series

MERRA-2 May 2015 precipitation (shaded, mm/day) and 200mb eddy stream function (contoured every 3*10⁶ m²/s) anomaly



Hypothesis:
Eastern tropical Pacific precipitation anomalies induced a wave train that traveled to the US

MERRA-2 May 2015 850mb water vapor transport anomaly (g-m/ kg-s)

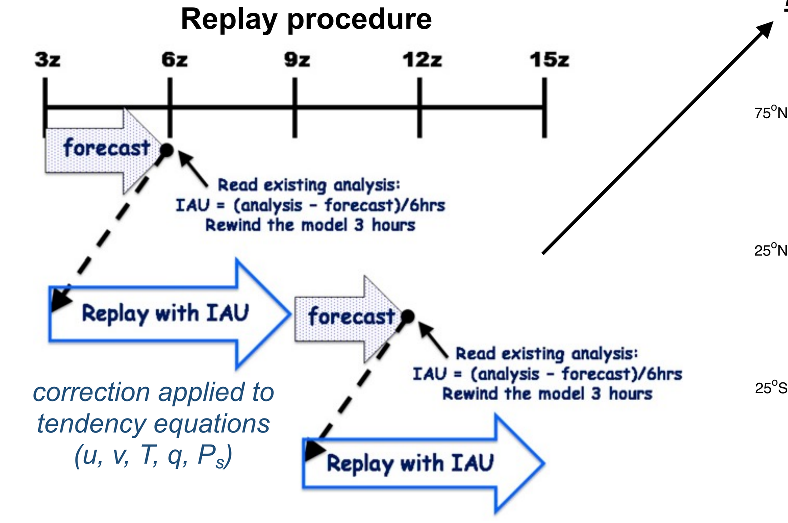


Which caused enhanced water vapor transport from the Gulf of Mexico

Exploring the remote drivers of the event with model simulations

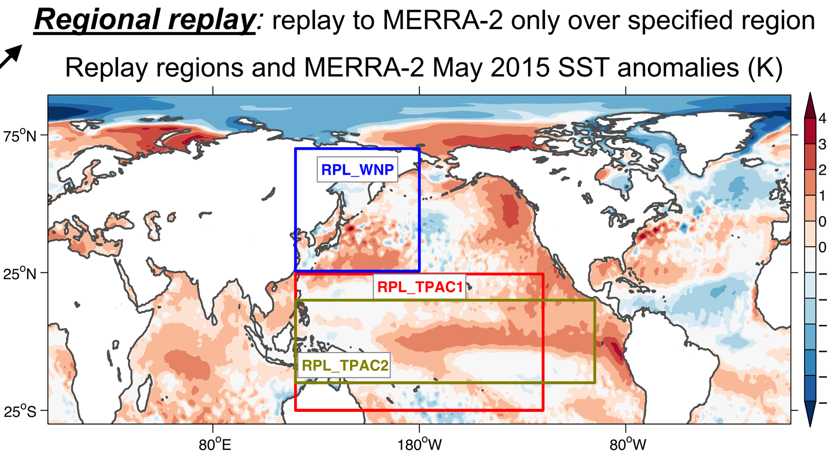
1. AGCM analysis

Methods:



Regional replay: replay to MERRA-2 only over specified region

Replay regions and MERRA-2 May 2015 SST anomalies (K)



RPL_WNP – Western North Pacific (120-180E, 25-70N)
RPL_TPAC1 – Tropical Pacific 1 (120E-120W, 25S-25N)
RPL_TPAC2 – Tropical Pacific 2 (120E-95W, 15S-15N)

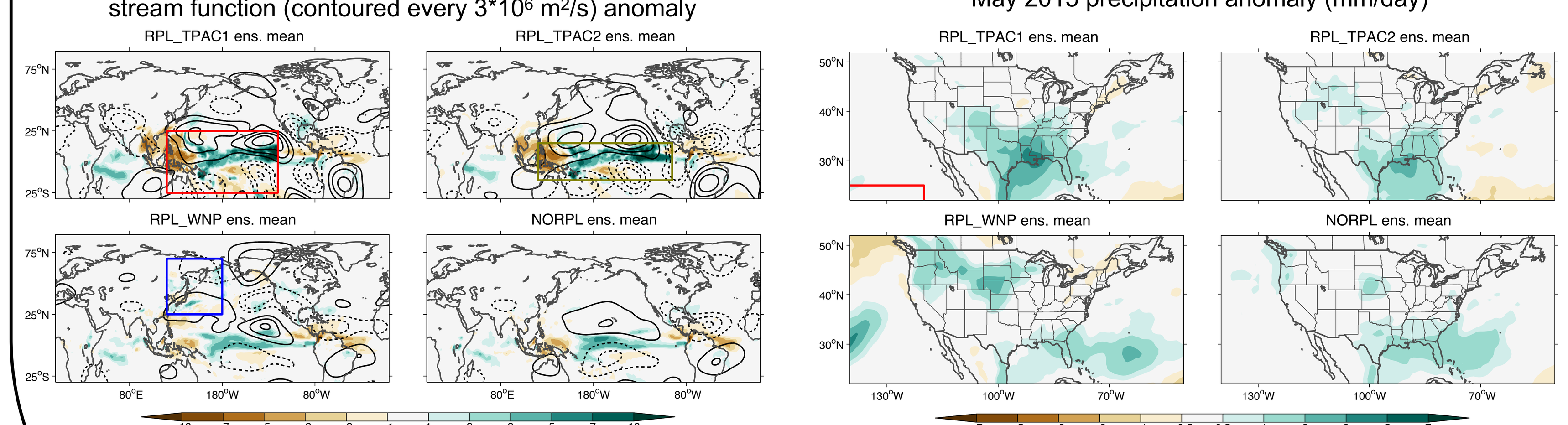
Experimental setup:

(i) GEOS AGCM MERRA-2 model at 1 degree (c90) resolution, with tendency bias correction (TBC)* applied globally.
(ii) Prescribed SSTs and sea ice from MERRA-2.
(iii) 45-member ensemble for each replay region (and no replay, NORPL), each member run from Jun 2014 through Dec 2015.
(iv) 39-year climatology (1981-2019) for each replay region (and NORPL).

*TBC - average of MERRA-2 analysis increments over 1980-2015 applied directly to tendency equations during the model run.
Reference: Chang et al. 2019, Journal of Climate, doi: 10.1175/JCLI-D-18-0598.1

Results:

May 2015 precipitation (shaded, mm/day) and 200mb eddy stream function (contoured every 3*10⁶ m²/s) anomaly | May 2015 precipitation anomaly (mm/day)



The tropical Pacific is important for inducing a wave train to the US and subsequent precipitation anomalies near the Gulf Coast. Secondary influence from the extratropical North Pacific.

2. Stationary wave model analysis

Methods:

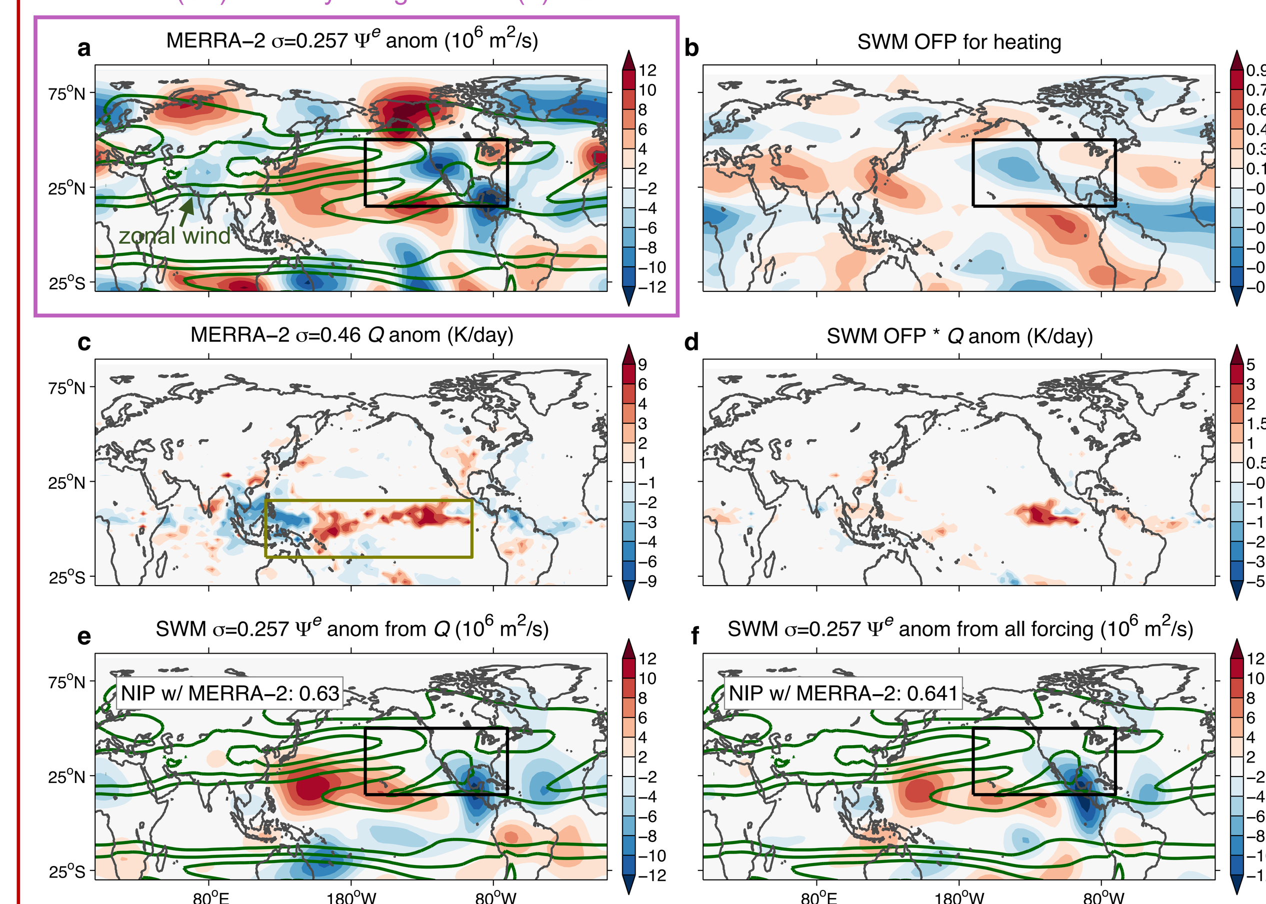
Stationary wave model (SWM):

(i) Dry dynamical core of an AGCM; based on primitive equations and with excessive damping to suppress transients.
(ii) Prognostic equations for vorticity, divergence, temperature, and surface pressure.
(iii) Solves for anomaly relative to 3-D basic state (MERRA-2 May 1980-2020). Reaches steady solution after ~30 days.
(iv) Can be forced with diabatic heating and transient flux forcing of vorticity, divergence, and temperature.

References: Ting and Yu 1998, Journal of the Atmospheric Sciences, doi: 10.1175/1520-0469(1998)055<3565:SRTTHI>2.0.CO;2
Schubert et al. 2011, Journal of Climate, doi: 10.1175/JCLI-D-10-05035.1

Results:

(a) Verification: MERRA-2 May 2015 eddy stream function (Ψ^e) anomaly at sigma level (σ) 0.257



(b) Optimal forcing pattern (OFP) for diabatic heating (Q): The ideal spatial pattern of Q anomalies that would produce the wave response over the black outlined region in (a), based on SWM simulations with idealized forcing.

(c) MERRA-2 May 2015 Q anomaly at $\sigma = 0.46$.

(d) The Q anomaly in (c) scaled by the OFP in (b). This represents the key regions where Q anomalies in 2015 were conducive to generating the wave response in (a).

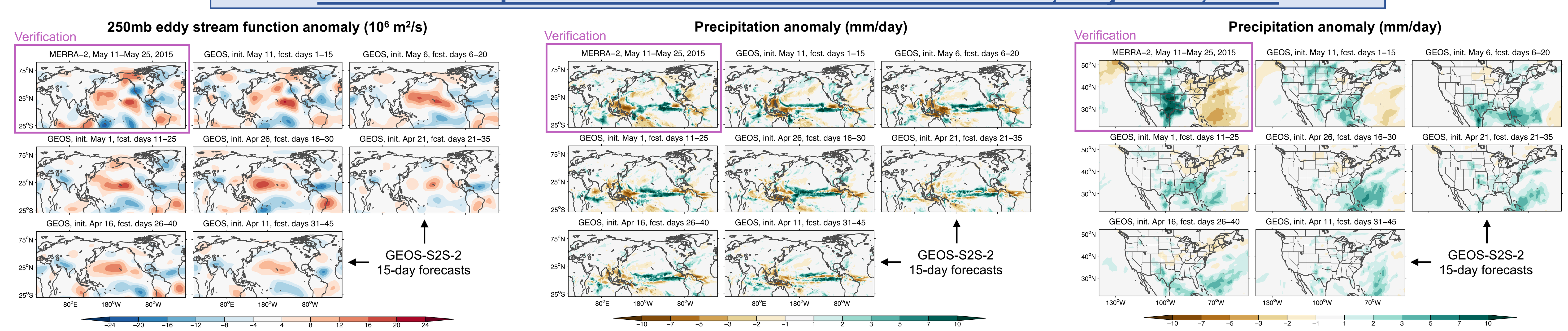
(e) The SWM response to the observed Q forcing over the brown outlined region in (c). (Ψ^e anomaly at $\sigma = 0.257$)

(f) The SWM response to the observed Q and transient flux forcings over the box in (c).

Based on a stationary wave model, diabatic heating anomalies in the eastern tropical Pacific provide an important source of forcing for a wave train stretching from the subtropical eastern Pacific to the southern US. Additional evidence that tropical Pacific diabatic heating in May 2015 was important for cyclonic flow in the Gulf of Mexico.

Subseasonal prediction skill in the GEOS-S2S-2 model, May 11-25, 2015

250mb eddy stream function anomaly (10⁶ m²/s) | **Precipitation anomaly (mm/day)** | **Precipitation anomaly (mm/day)**



Modest skill for leads ~10-30 days, a consequence of skill in predicting tropical precipitation and circulation. Position of US precipitation anomalies less skillful.

Moving forward

- Clarify the role of the extratropical upstream forcing (e.g., over the Pacific) in shaping the circulation pattern over the US. What role did internal variability play?
- Look more closely at subseasonal forecasts. What can we learn from intra-ensemble forecast spread? What causes different anomaly patterns across models/members?
- Examine the event in a broader context. How common are wave trains like that in May 2015? Are such events forecasts of opportunity? How can forecasts be improved?

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