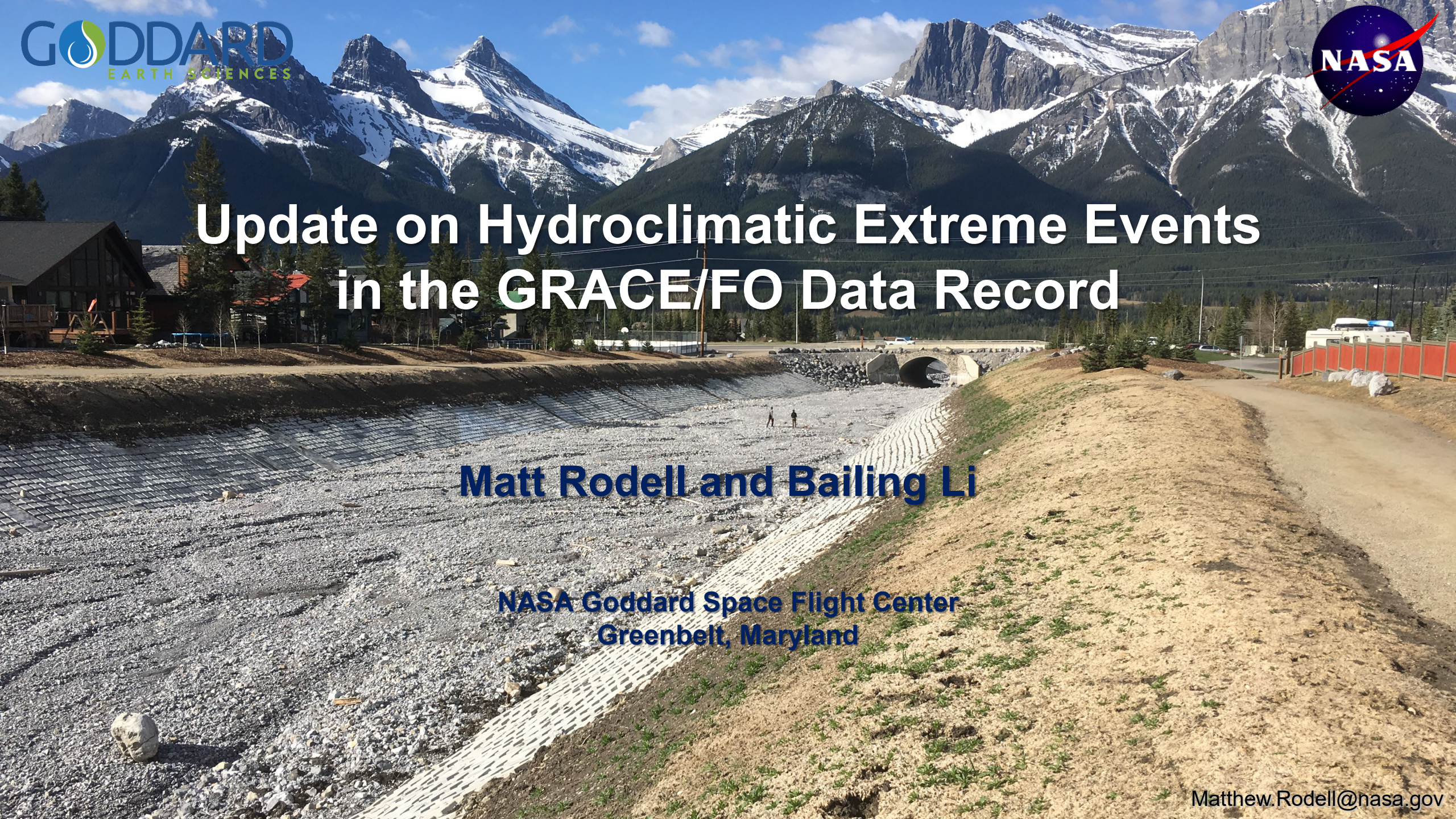

Update on Hydroclimatic Extreme Events in the GRACE/FO Data Record

Matt Rodell and Bailing Li

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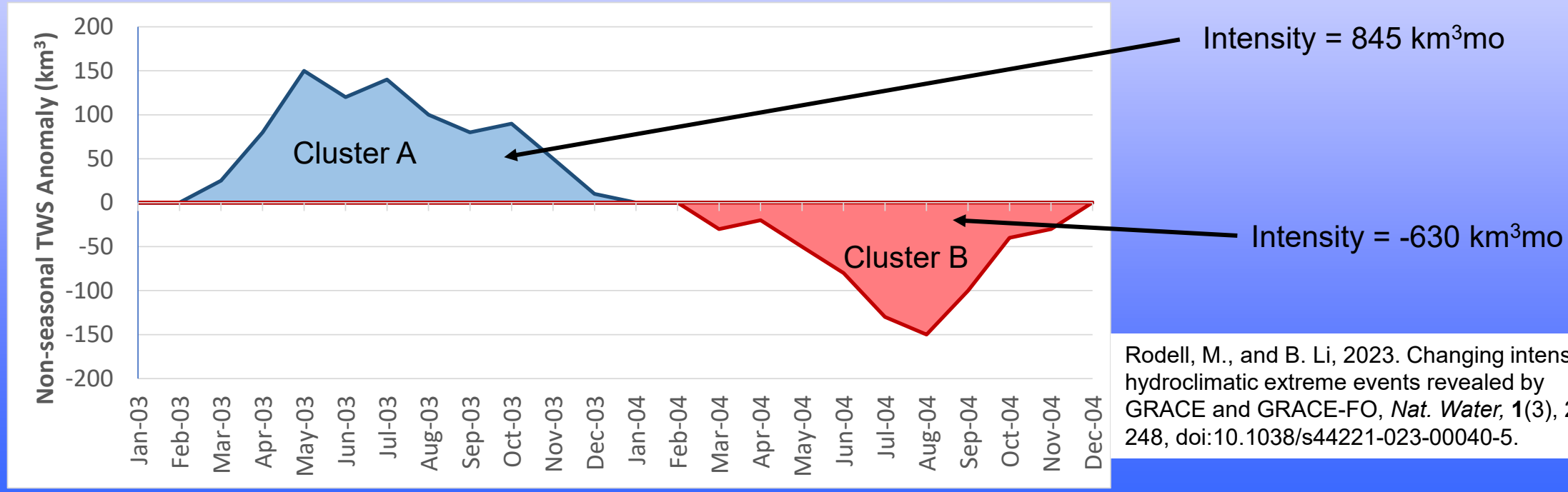
Identifying and Quantifying Water Cycle Extremes

Clustering and quantifying the intensity of events

- An automated routine is used to identify cells experiencing extreme terrestrial water storage (TWS) anomalies (GRACE/FO data) and group them logically into “clusters”
- Only cells that exceed 1 σ from the mean seasonal cycle are considered “extreme”
- Intensity = the integral of the non-seasonal TWS anomaly over the areal extent and period of the clustered event, following the *Thomas et al. (GRL, 2014)* definition of drought severity



Rodell, M., and B. Li, 2023. Changing intensity of hydroclimatic extreme events revealed by GRACE and GRACE-FO, *Nat. Water,* **1**(3), 241-248, doi:10.1038/s44221-023-00040-5.

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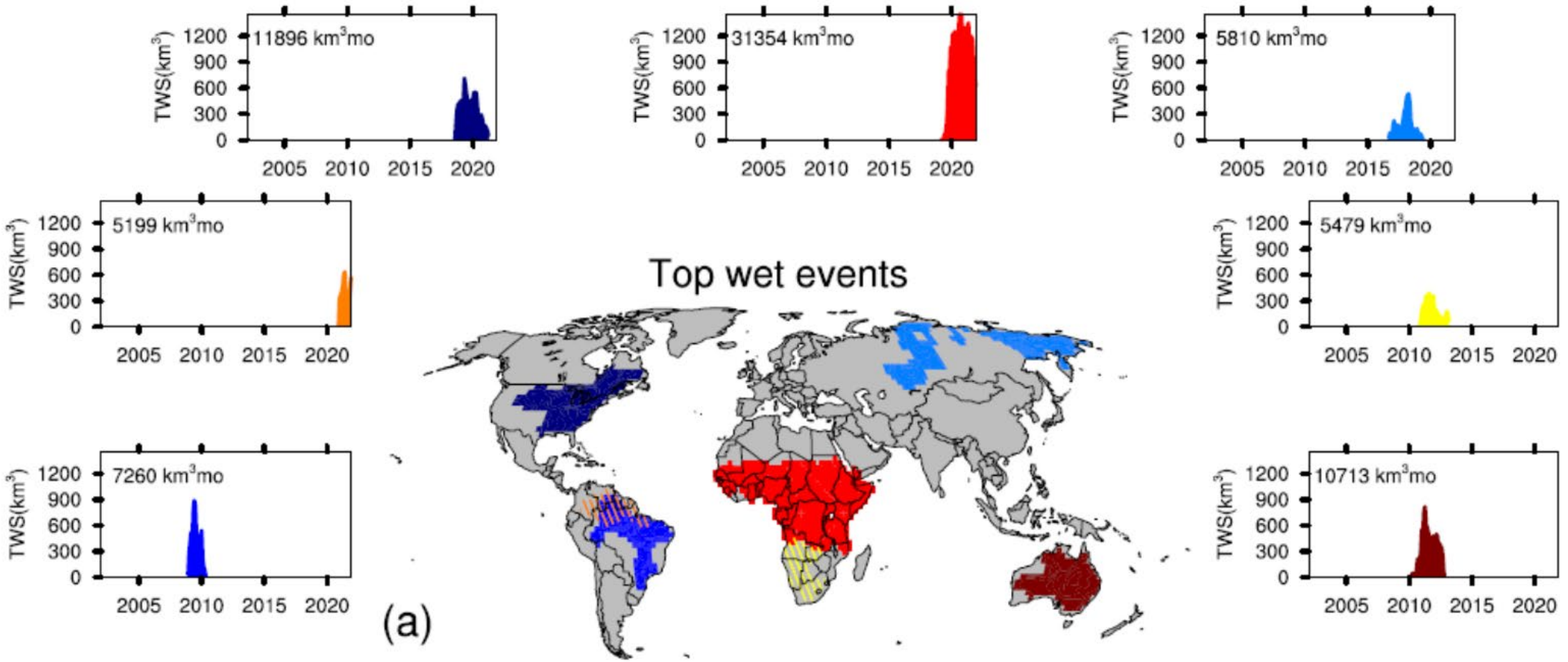
Most Intense Pluvials 2002-2021



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https://rdcu.be/c7vQC

Spatial extents of the top seven most intense wet events globally and the associated TWS anomaly (km³) time series (color coded). The intensity (km³mo) of an event is equivalent to the integral under its time series.

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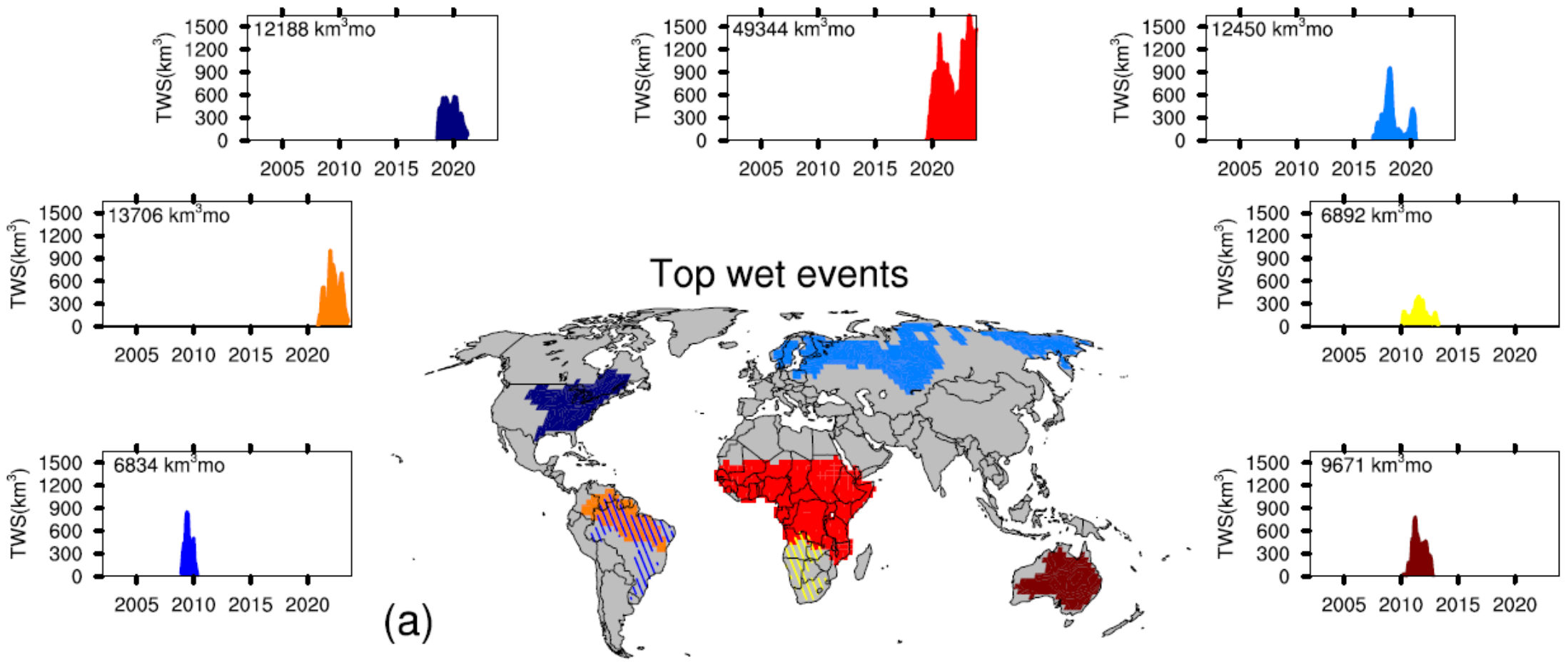
Most Intense Pluvials 2002-2023



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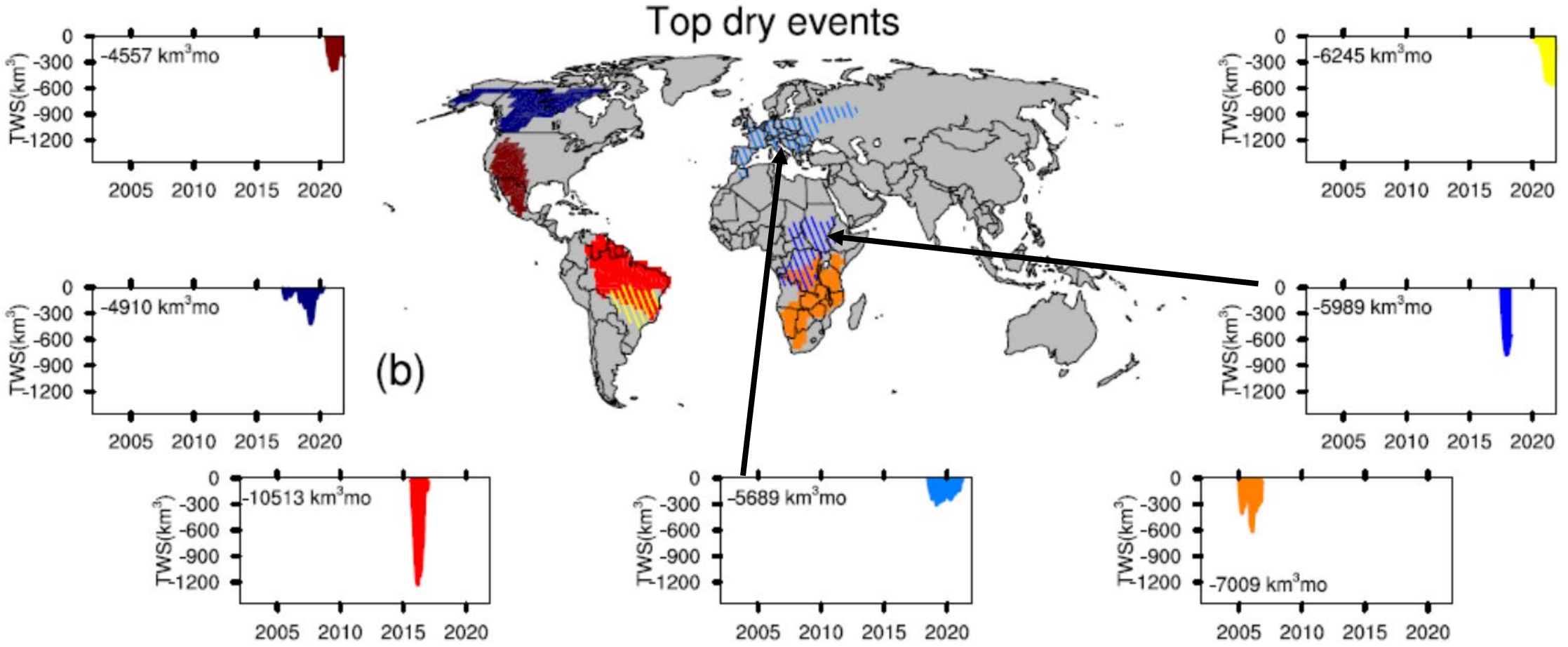
Most Intense Droughts 2002-2021



Spatial extents of the top seven most intense dry events globally and the associated TWS anomaly (km³) time series (color coded). The intensity (km³mo) of an event is equivalent to the integral under its time series.

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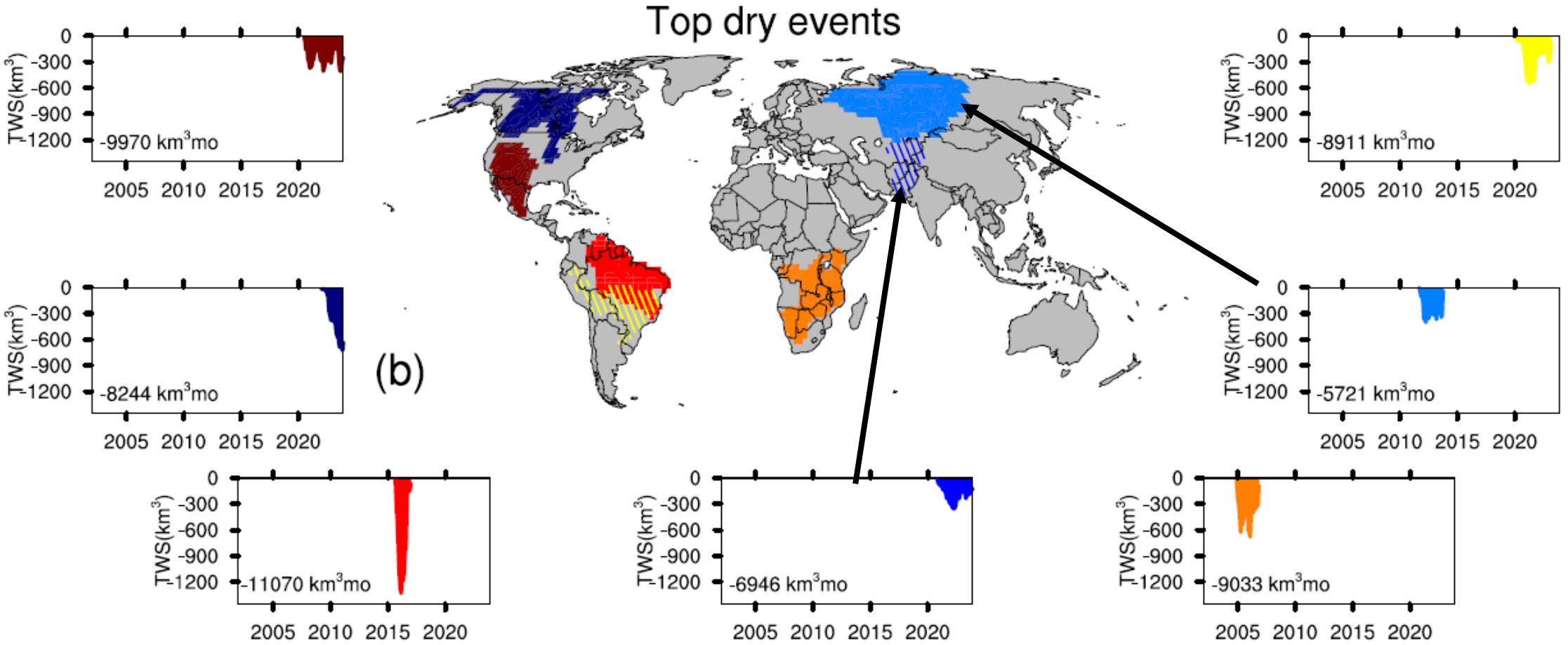

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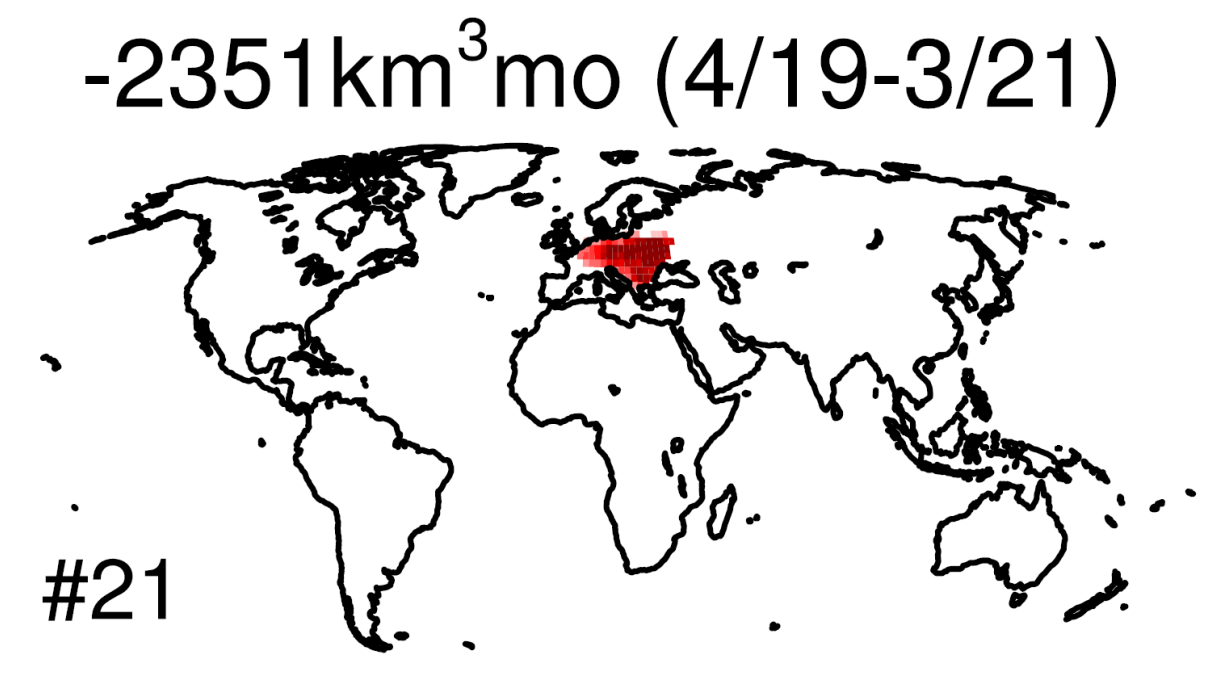
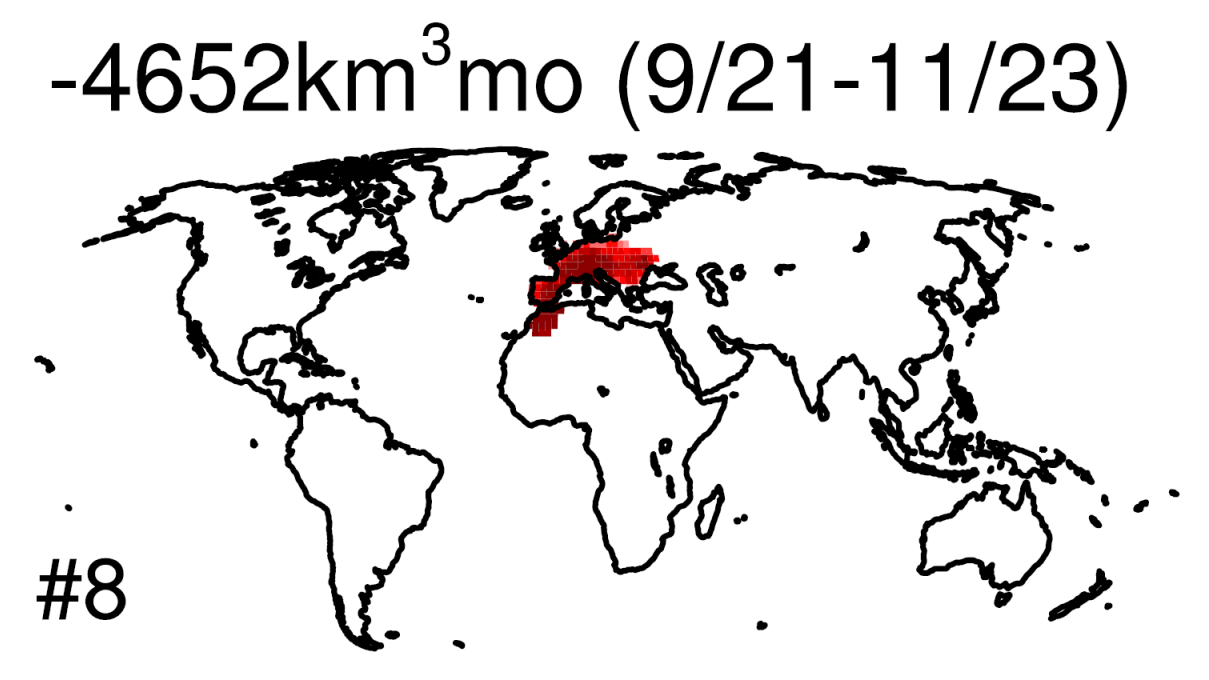
Most Intense Droughts 2002-2023: Europe





The clustering algorithm determined that the recent European drought was two separate droughts with a 6-month respite between them, ranked #21 and #8. Their summed intensity is 7003 km^{3}mo, which would be ranked 6th.

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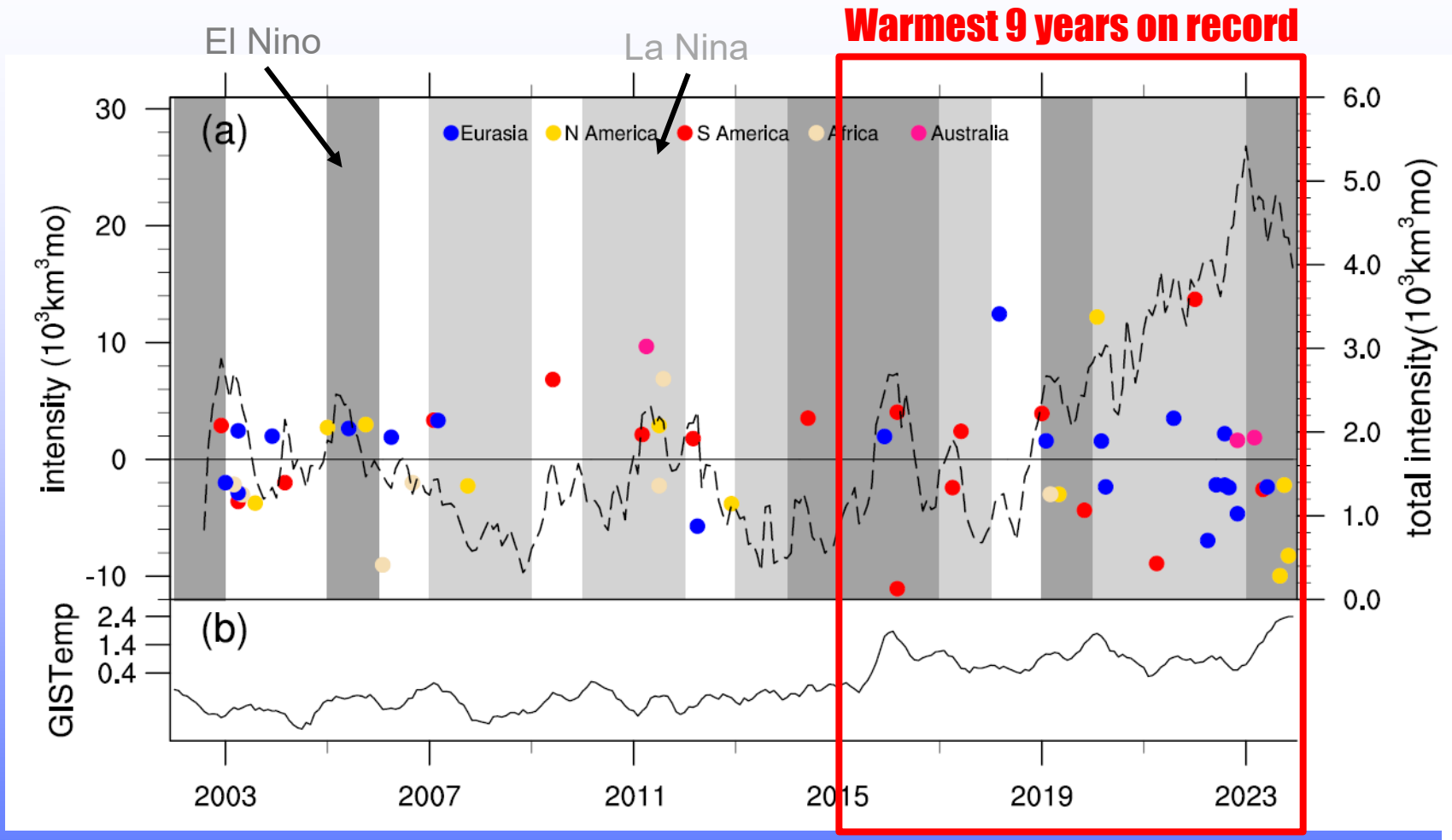
Global Total Intensity of Extreme Events



Relationships between extreme events, ENSO, and global surface temperature. Dots indicate intensity (10^3 km^{3}mo) of the global top 30 most intense wet (positive values) and top 30 most intense dry (negative values) events versus the month of max/min TWS anomaly. The dashed line shows the monthly total intensity (sum of the absolute value of monthly TWS anomalies of all active events). Plotted below is a time series of global mean surface temperature anomalies (NASA/GISS).

Global total intensity of wet and dry extreme events is highly correlated with global mean temperature (r = 0.58 and 0.56, respectively), more so than with ENSO or other climatic oscillations

Rodell, M., and B. Li, 2023. Changing intensity of hydroclimatic extreme events revealed by GRACE and GRACE-FO, *Nat. Water,* **1**(3), 241-248, doi:10.1038/s44221-023-00040-5.
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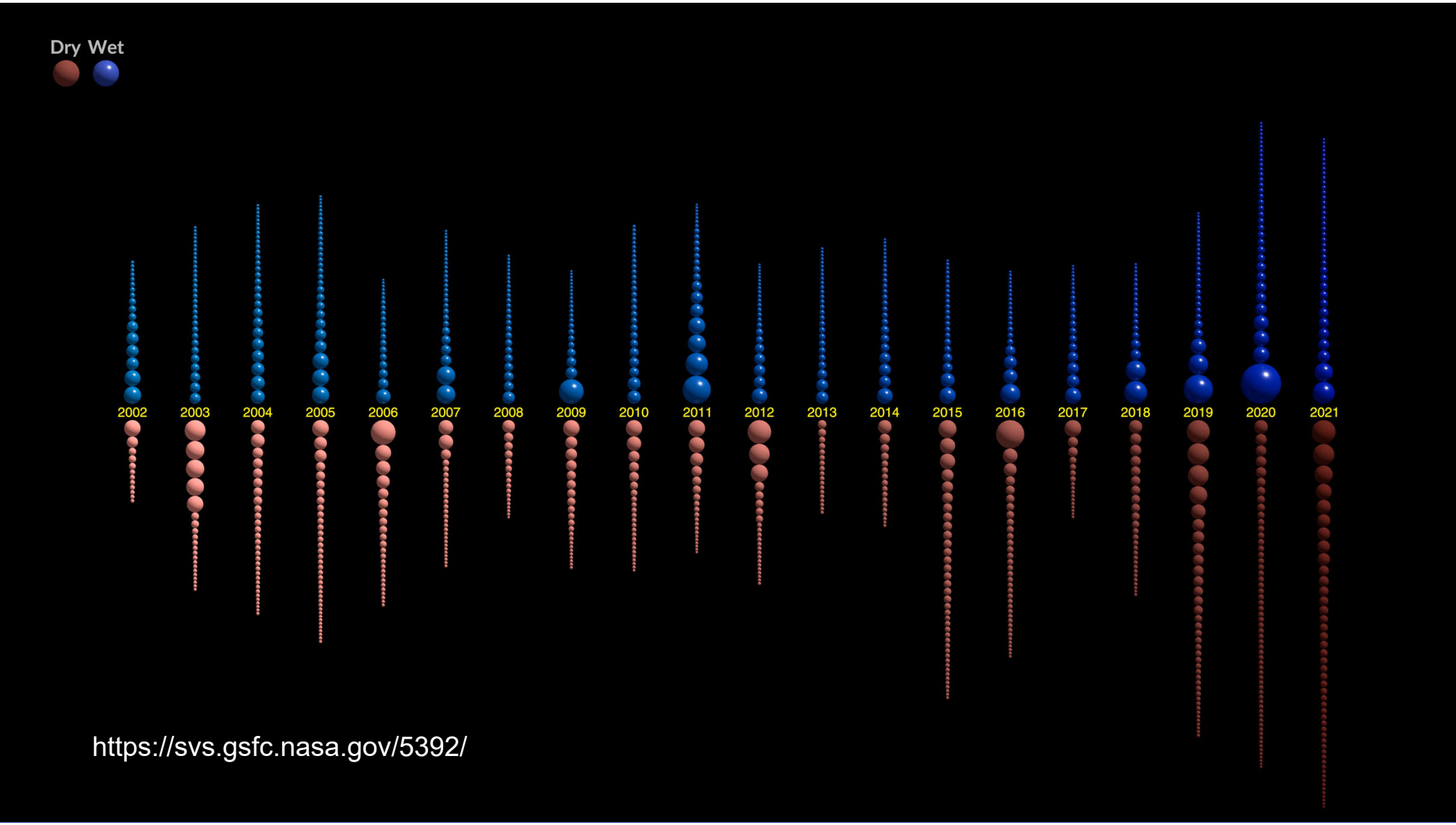
Dry Wet
2002
2003
2004
2005
2006
2007
2008
2009
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2013
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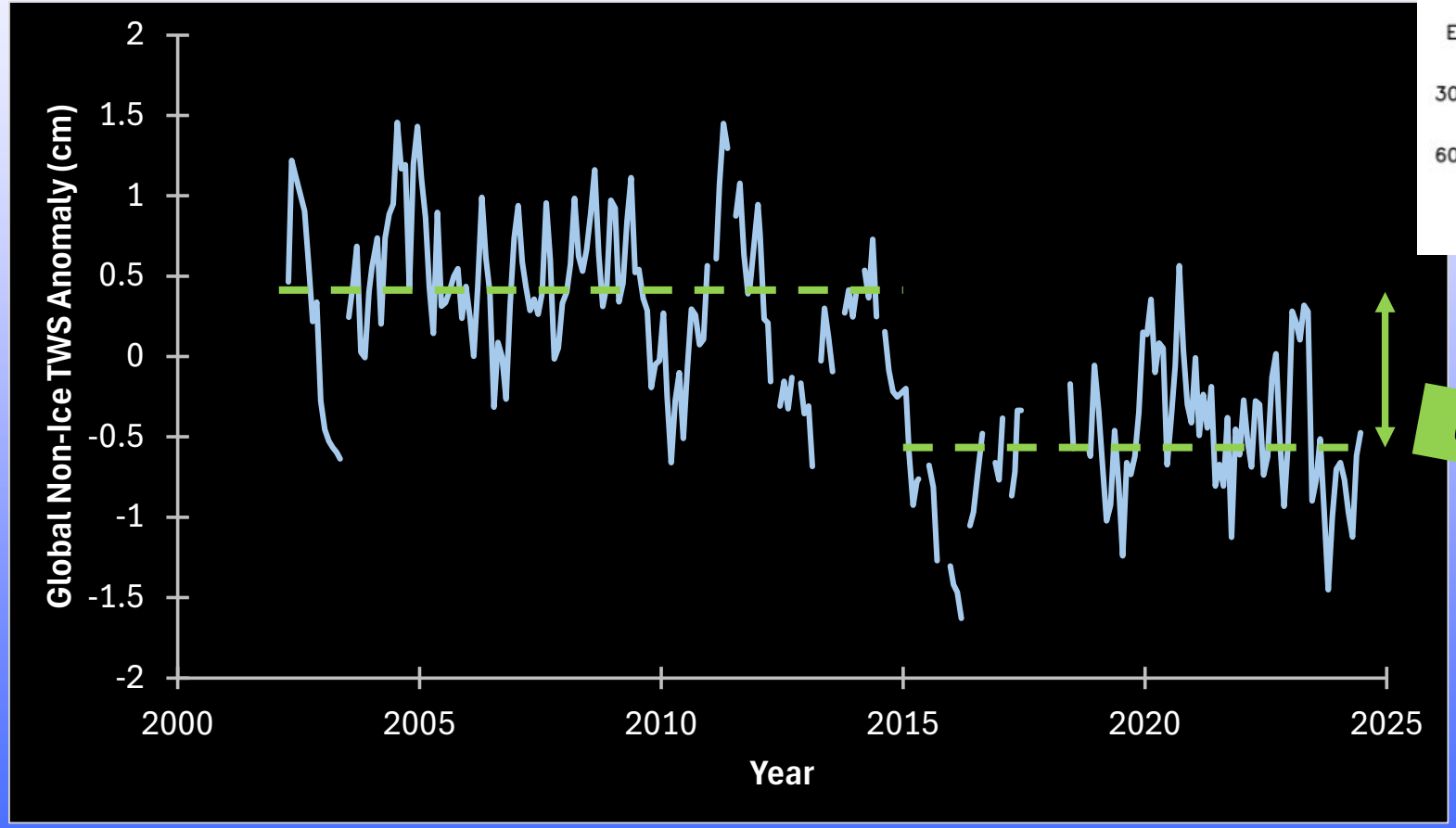
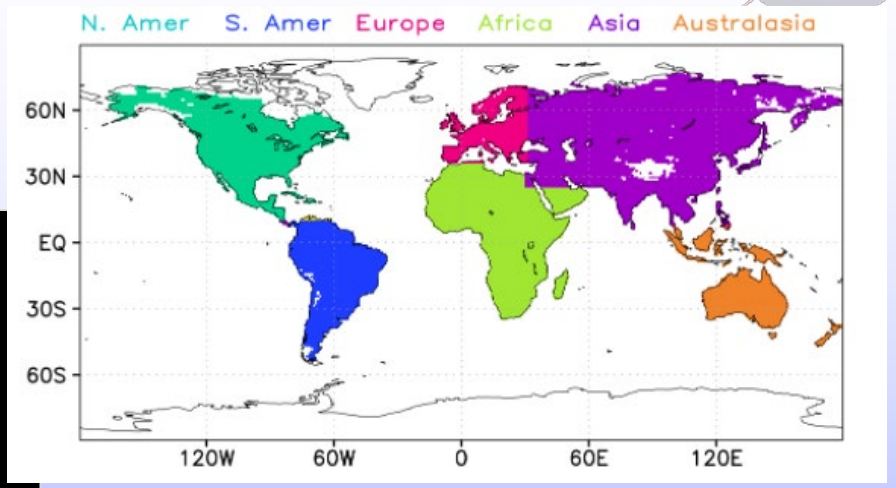
2015
2016
2017
2018
2019
2020
2021
https://svs.gsfc.nasa.gov/5392/

An Abrupt Decline in Global Non-Ice TWS

Global terrestrial water storage, excluding ice sheets and glaciers, declined to a new, lower range of variability starting ~2015





Ice sheet and glacier regions excluded from the mean are shown in white.

0.91 cm ≈ 1,183 km³

2.5 x volume of Lake Erie

Rodell, M., A. Barnoud, F. Robertson, R. Allan, A. Bellas-Manley, M.G. Bosilovich, D. Chambers, F. Landerer, B. Loomis, R.S. Nerem, M.M. O'Neill, D. Wiese, and S.I. Seneviratne, An abrupt decline in global terrestrial water storage and its relationship with sea level change, *Surveys in Geophysics*, accepted, 2024.

Time series of anomalies of terrestrial water storage, excluding ice sheets and glaciers, from GRACE/FO (JPL mascons).

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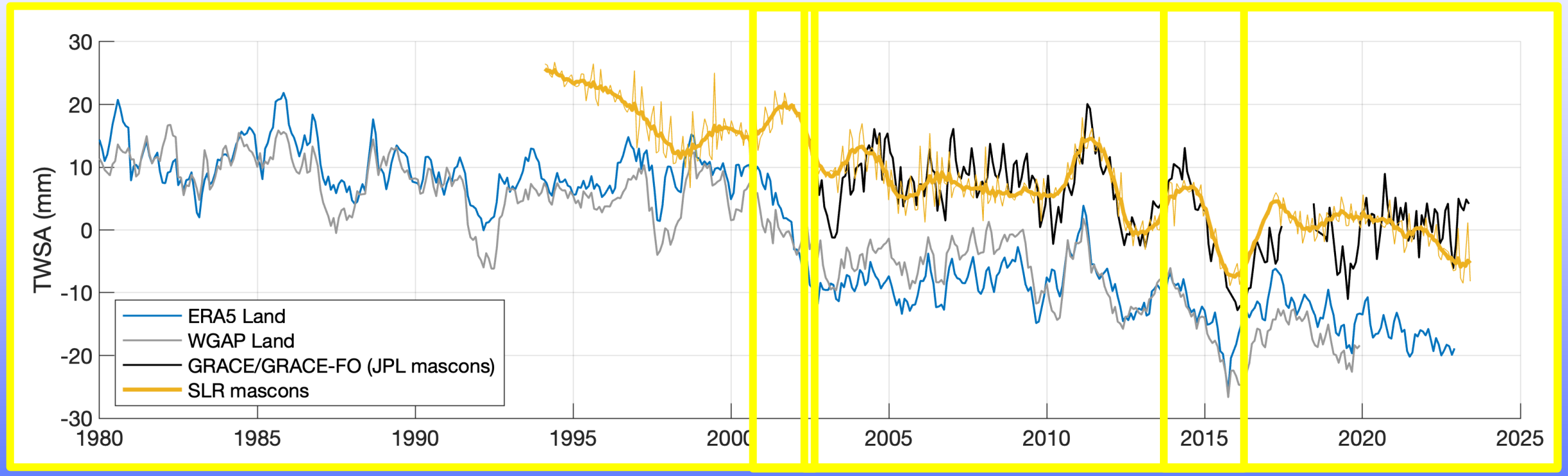
Was the 2015 TWS Decline Unusual?

- Satellite laser ranging (SLR) and models generally agree well with GRACE/FO
- ERA5 Land indicates a similarly steep decline to a new TWS range after 2001-02, but that is not corroborated by SLR or the WaterGAP global hydrological model
- Analysis shows the abruptness and persistence of the 2015 decline were unique in the past 43 years



Time series of terrestrial water storage anomalies, excluding ice sheets and glaciers, from GRACE/FO (JPL mascons), satellite laser ranging (GSFC mascons), ERA5, and the WaterGAP model. The vertical offset between time series is for clarity; it is not meaningful.

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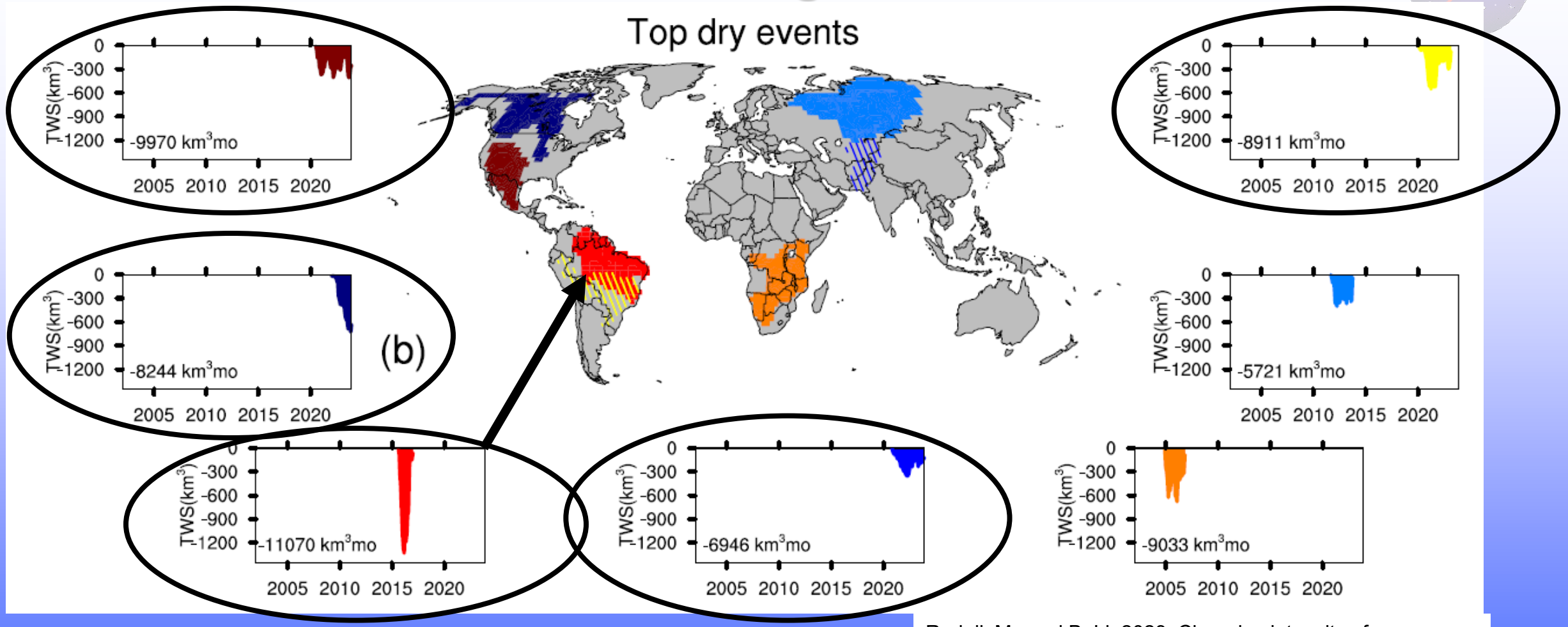
Most Intense Droughts 2002-2023



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Summary

- Results of a clustering algorithm applied to GRACE/FO terrestrial water storage data indicate that the most intense droughts and pluvials since 2002 are largely the same as those first reported in 2023
- By far the most intense event is an ongoing pluvial in central Africa (49,344 km^3mo)
- Global total wet and dry intensities remain highly correlated with global mean temperature, more so than with ENSO or other climate oscillations
- Global total non-ice TWS declined abruptly around 2015 and has not recovered, a period coinciding with Earth's warmest nine years on record
- The abruptness and persistence of the decline appear to be unprecedented in the past 43 years

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