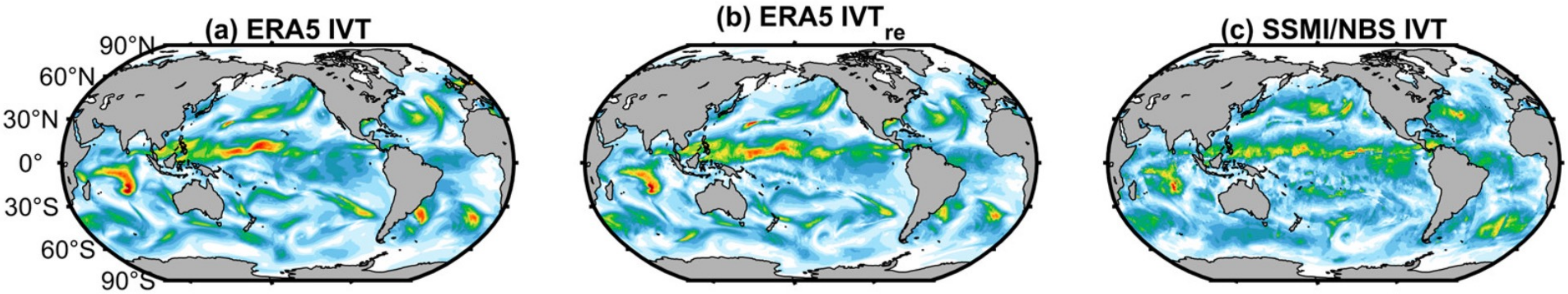
An Algorithm to Develop a Satellite-Based Atmospheric River Database

Shineng Hu[1], Tianying Liu[2]
[1]Duke University, [2]Ohio State University



ERA5 truth

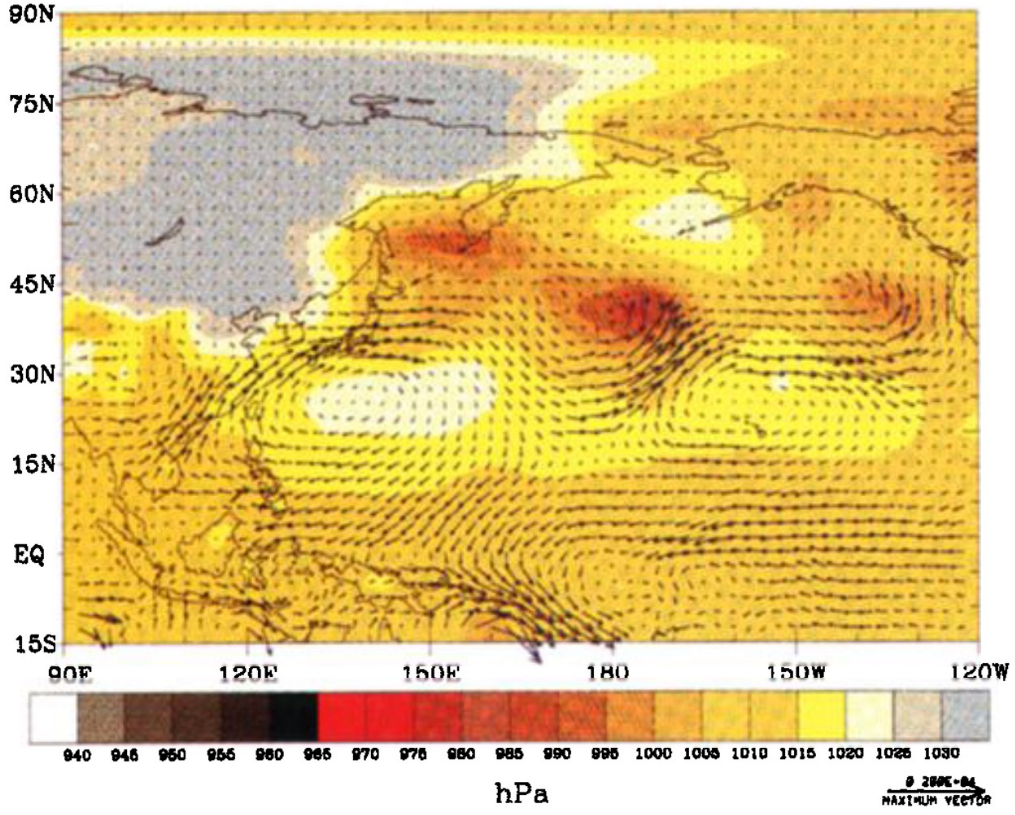
ERA5 reconstruction

Satellite reconstruction

May 6, 2025 @ IOVWST Meeting (virtual participation)

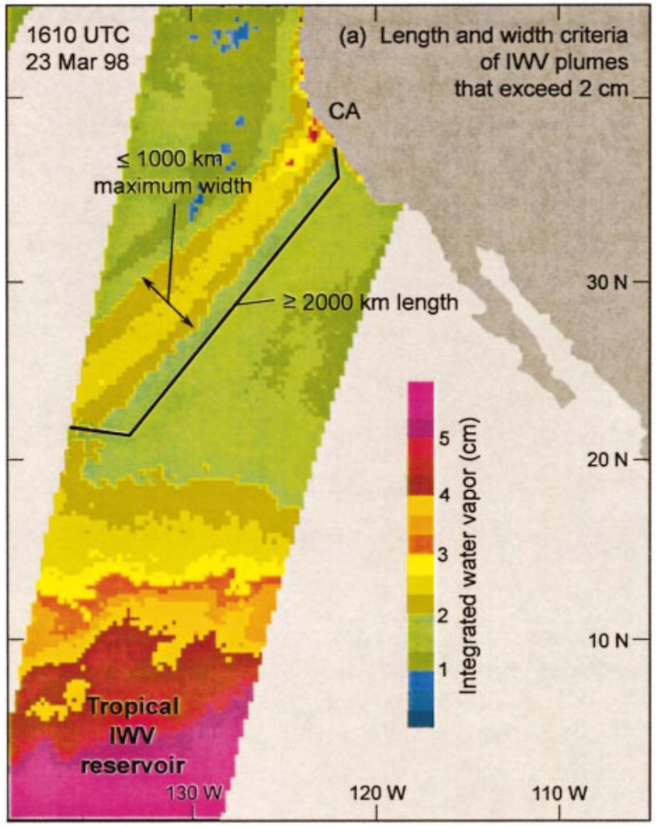
Atmospheric rivers defined with IVT versus IWV

Integrated Vapor Transport (IVT)



Newell (1992); Zhu and Newell (1994)

Integrated Water Vapor (IWV)



Ralph et al. (2004)

- Different definitions and detection algorithms have been proposed (see Shields et al. 2018 for a recent review).
- Atmospheric reanalyses have been popular datasets to compute IVT.
- Satellite measurements have also been extensively used, but mostly for IWV.

Estimating IVT with satellite measurements: a recent attempt

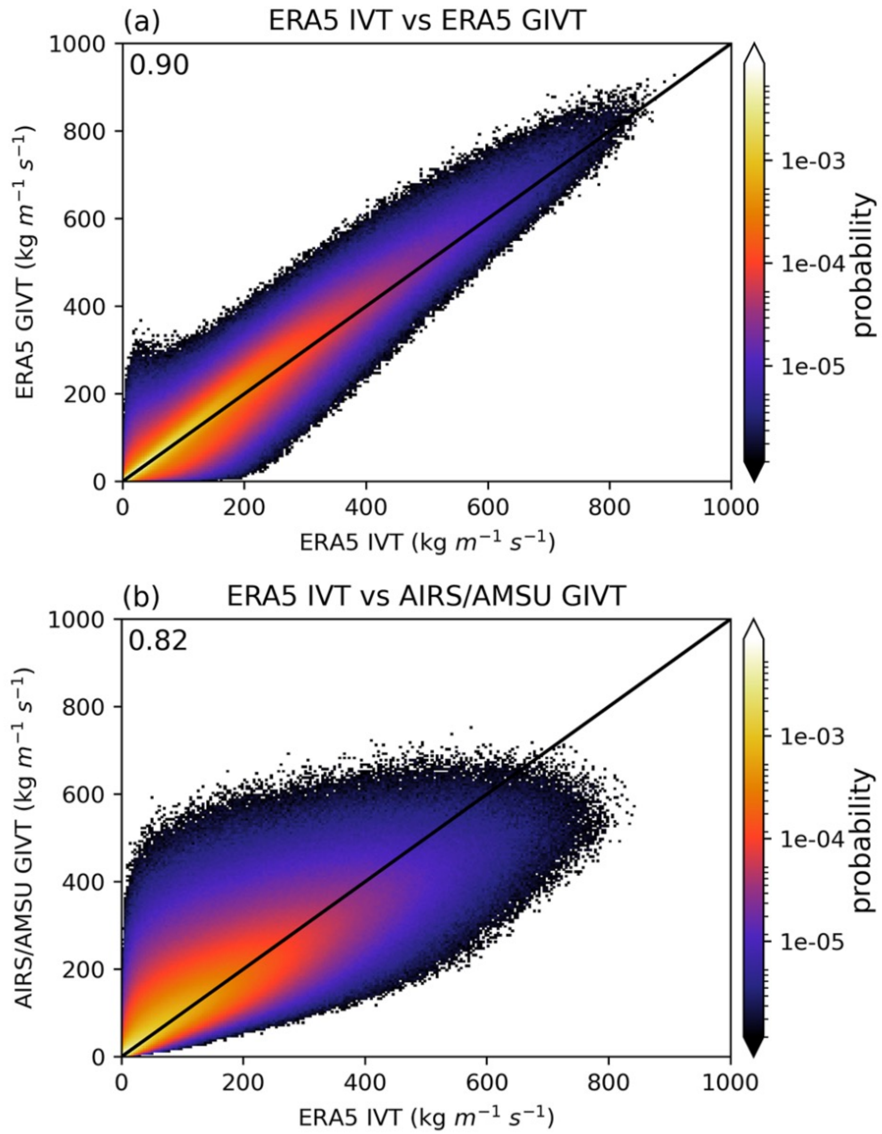
Satellite-based estimate of IVT using geostrophy:

$$\langle U_g \rangle = \frac{U_{925} \times 37.5 + U_{850} \times 112.5 + U_{700} \times 125 + U_{600} \times 50}{(37.5 + 112.5 + 125 + 50)}$$

$$\langle U_g \rangle = \frac{V_{925} \times 37.5 + V_{850} \times 112.5 + V_{700} \times 125 + V_{600} \times 50}{(37.5 + 112.5 + 125 + 50)}$$

$$\mathrm{GIVT} = \sqrt{(\mathrm{IWV} \times \langle U_g \rangle)^2 + (\mathrm{IWV} \times \langle V_g \rangle)^2}$$

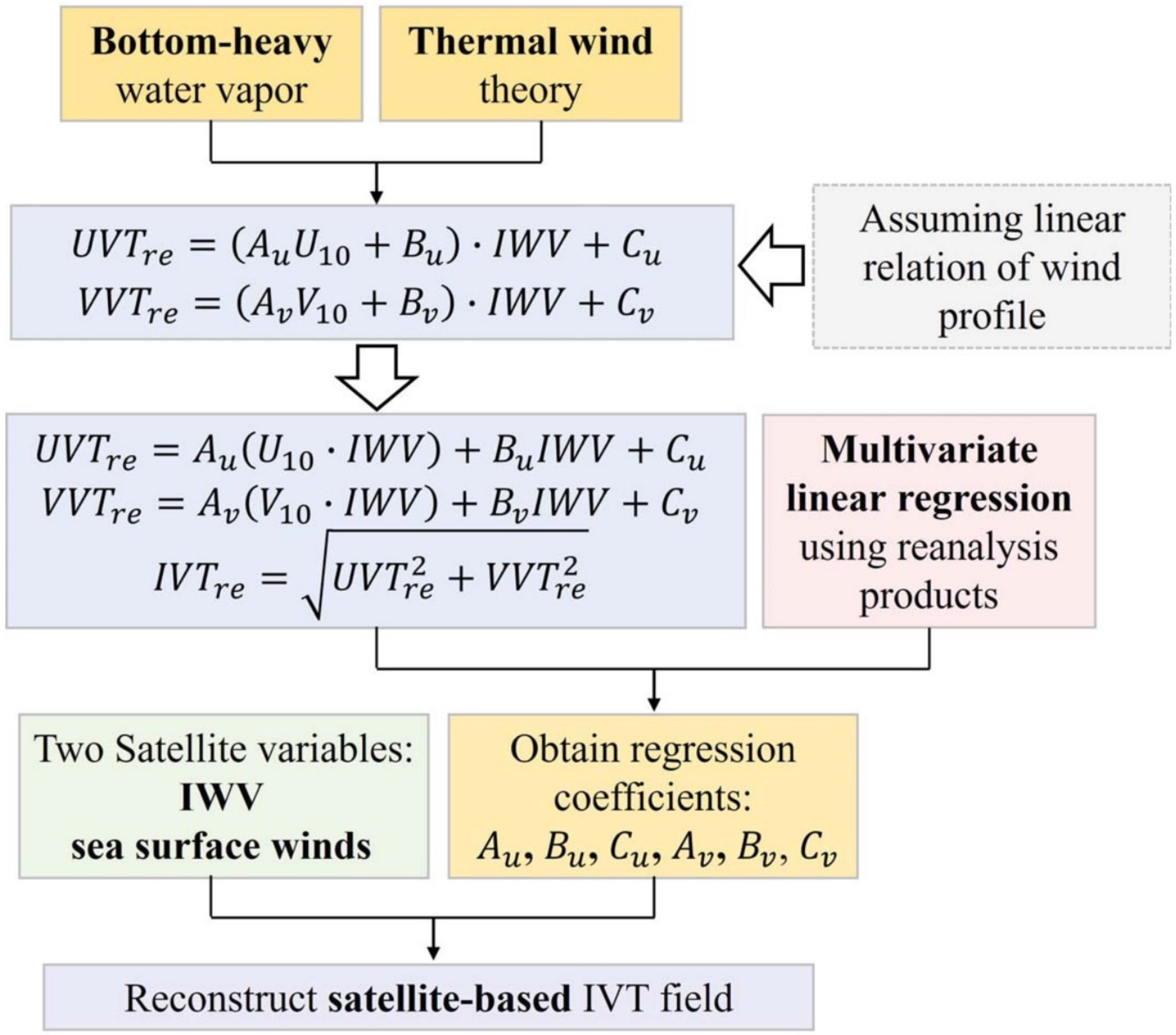
- Purely observational and physics based
- Globally covered with high resolutions in space and time



Ma et al. (2023)

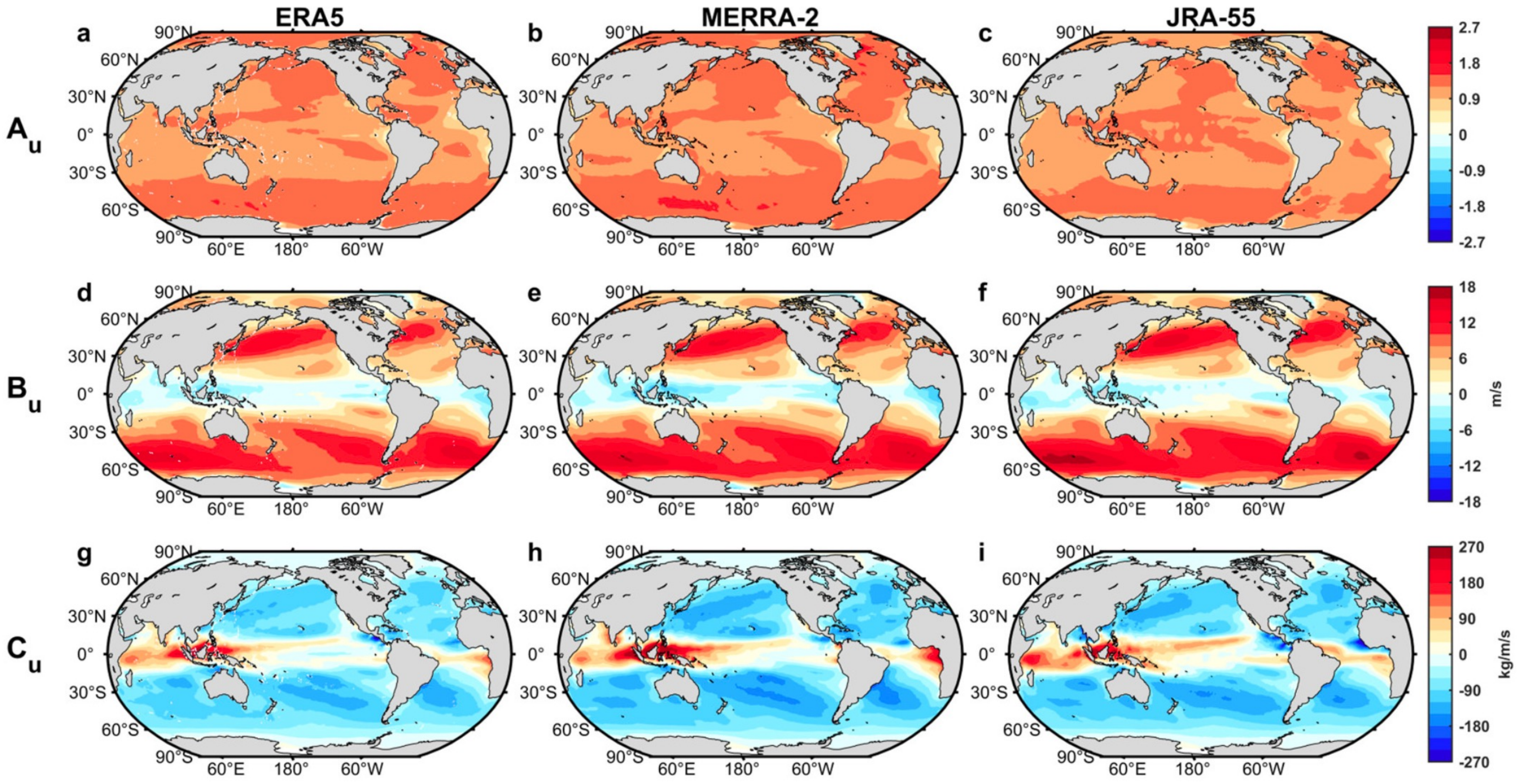
Estimating IVT with satellite measurements: our attempt

- Physics informed but statistically trained
- Relying on IWV and 10-m wind (satellite-based; ocean only)
- Relatively longer period: 1990-2022 (interannual studies)
- No restriction on geostrophy
- Another independent satellite-based approach for cross validation
- Data
  - IWV: SSM/I and SSMIS (Wentz et al. 2012)
  - 10-m ocean surface wind: National Centers for Environmental Information Blended Seawinds version 2.0 (Saha and Zhang 2022)
  - 0.25°x0.25°; daily; from1990 to 2023



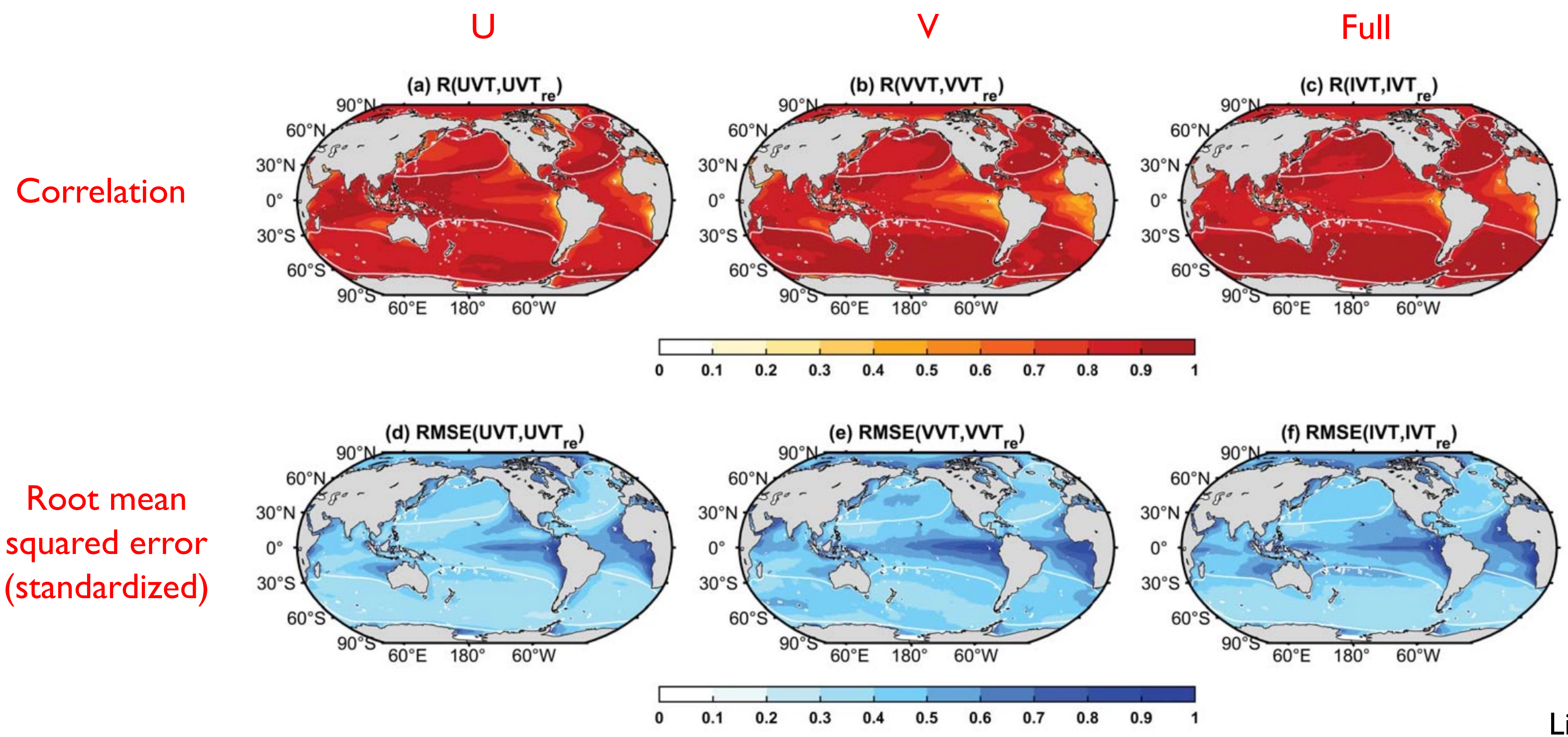
Liu and Hu (2025) *GRL*

Consistent best-fit parameters found across different reanalysis products



Liu and Hu (2025) *GRL*

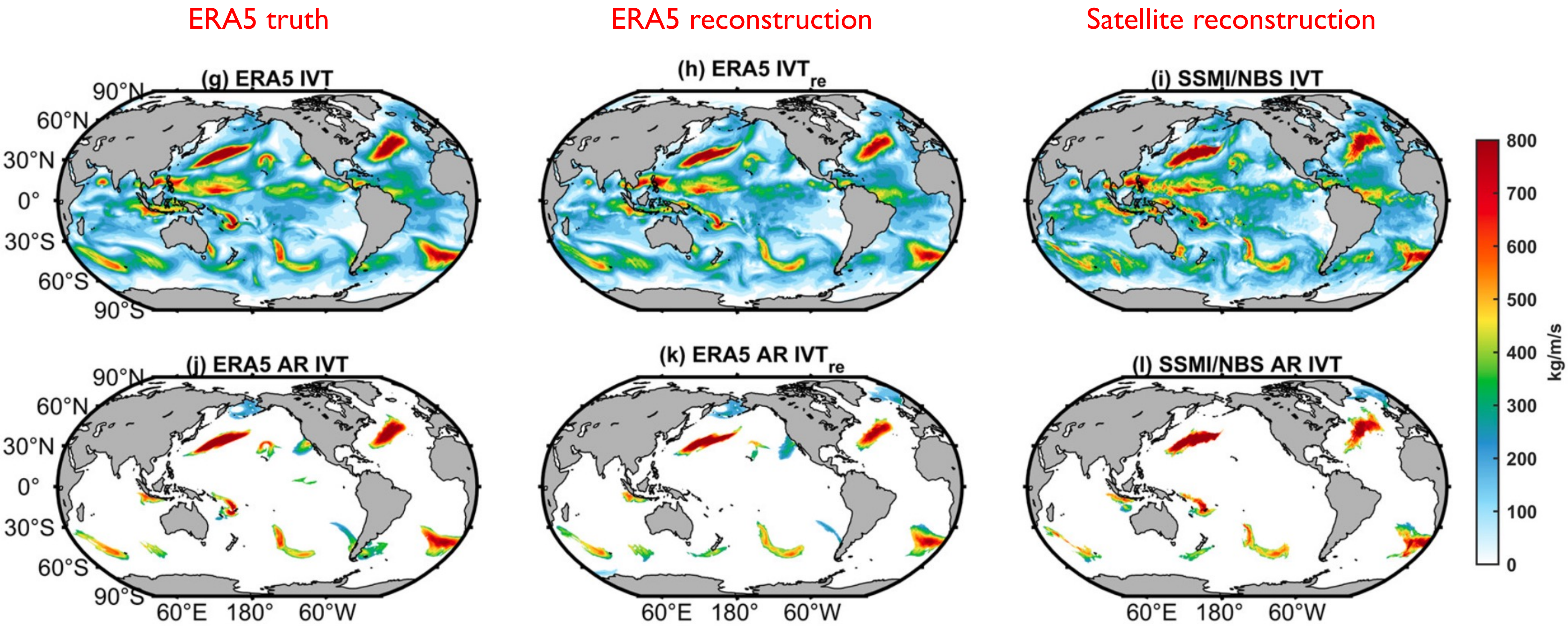
Performance of IVT reconstruction in ERA5



Liu and Hu (2025) *GRL*

- Generally good agreement (r>0.8) except for equatorial cold tongue regions (due to weak IVT variability).

AR example on December 16, 2016



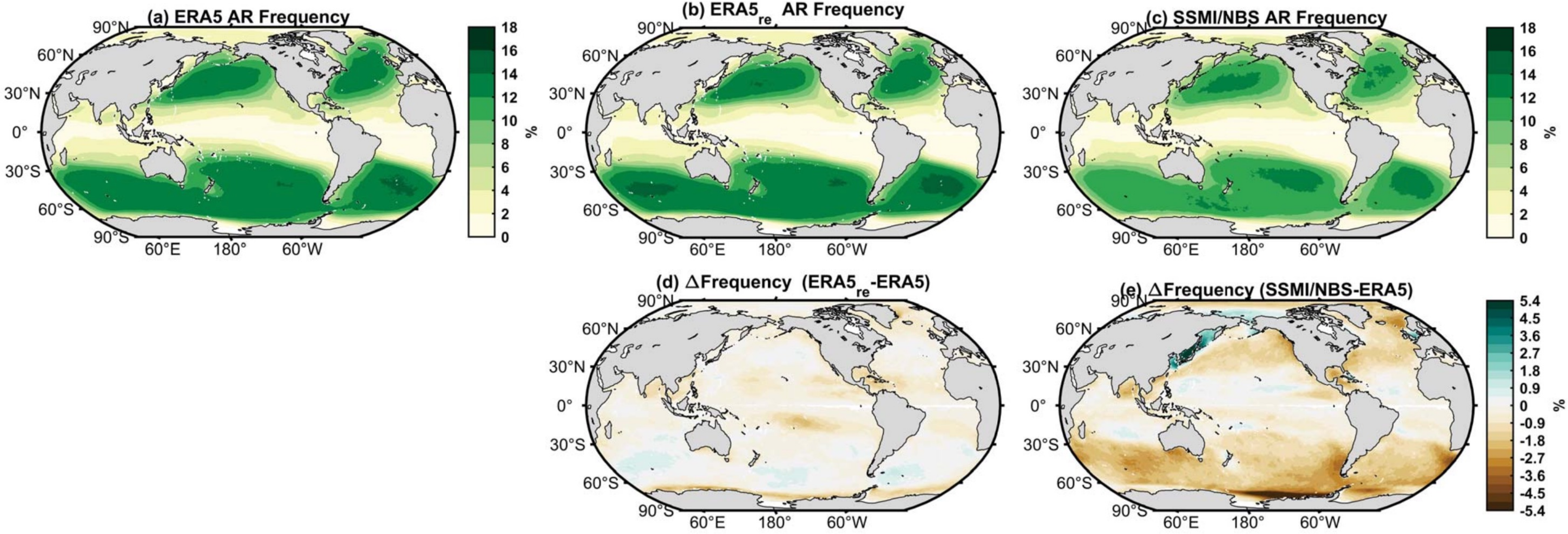
- AR detection algorithm (Guan and Waliser 2015): IVT > 85% and 100 kg/m/s/; length > 2000 km; length-to-width-ratio > 2; poleward & away from the equator

Reconstructed AR frequency (climatology)

ERA5 truth

ERA5 reconstruction

Satellite reconstruction



- Satellite-based, reconstructed IVT has a generally lower climatological AR frequency, except for coastal Northwestern Pacific.

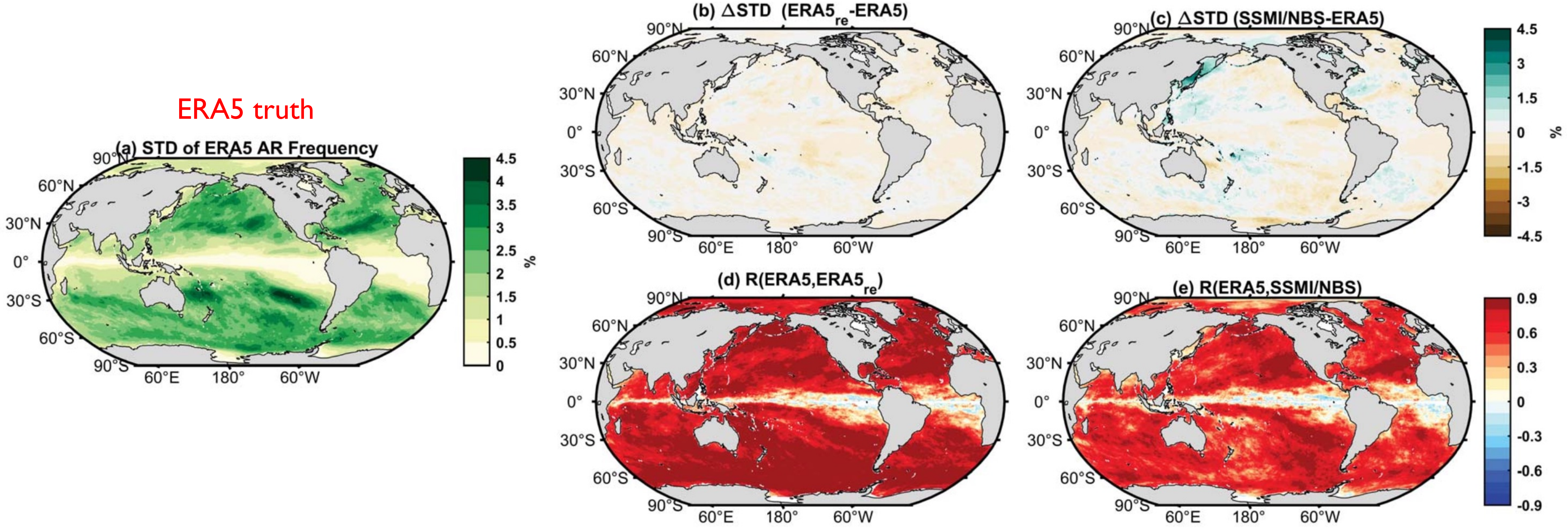
Liu and Hu (2025) *GRL*

Reconstructed AR frequency (interannual variations)

ERA5 truth

ERA5 truth vs. reconstruction

ERA5 vs. Satellite reconstruction



- Interannual variations in AR frequency are generally correlated between ERA5 and satellite-based reconstruction but can significantly differ over higher-latitudes oceans.

Liu and Hu (2025) *GRL*

Theoretical basis

Exponentially decaying vapor mixing ratio: $q(z) = q_s e^{-z/H_w} \mathcal{H}(z)$

C-shape tropospheric relative humidity: $\mathcal{H}(z) = 1 - lz$

Linear wind profile: $U(z) = U_{10} + kz$

$H_w \approx 2$ km is the scale height of water vapor
q_s is the surface saturation vapor mixing ratio

$l > 0$ in the lower troposphere

Sign of k varies in space

$$IWV \equiv \int_0^\infty q(z)dz = q_s H_w - l q_s H_w^2$$

$$UVT \equiv \int_0^\infty q(z)U(z)dz = \cdots = U_{10} IWV + kH_w IWV - klq_s H_w^3$$

$$UVT_{re} = (A_u U_{10} + B_u) \cdot IWV + C_u$$

Theory predicts that:

$A_u \approx 1;$

$B_u \sim k$

$C_u \sim -B_u\, q_s$

Hu and Liu, in prep.

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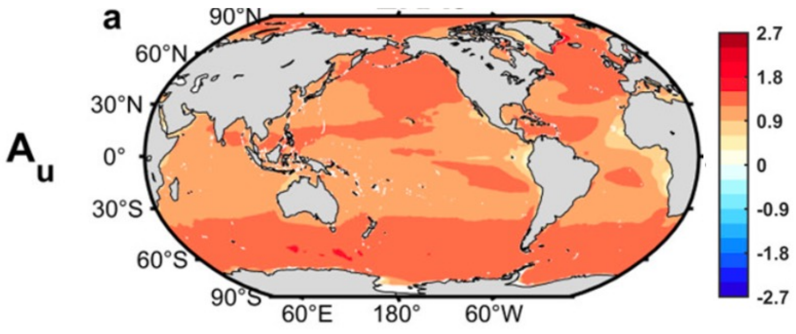
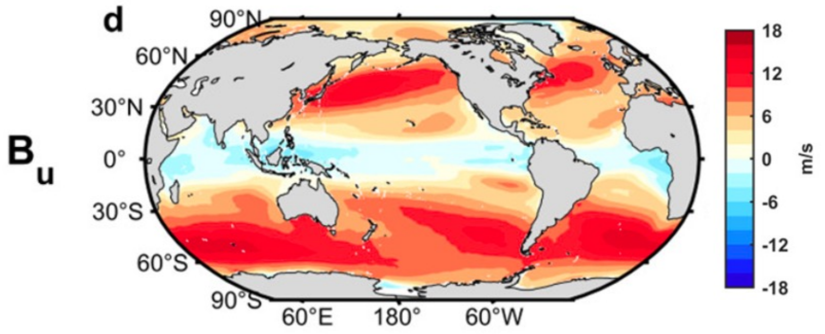
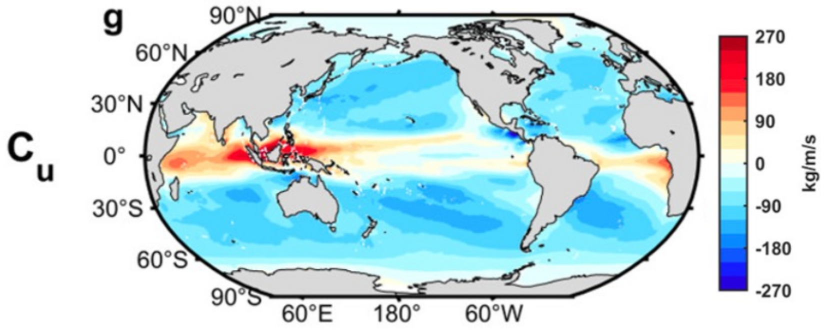


$B_u \sim k;$



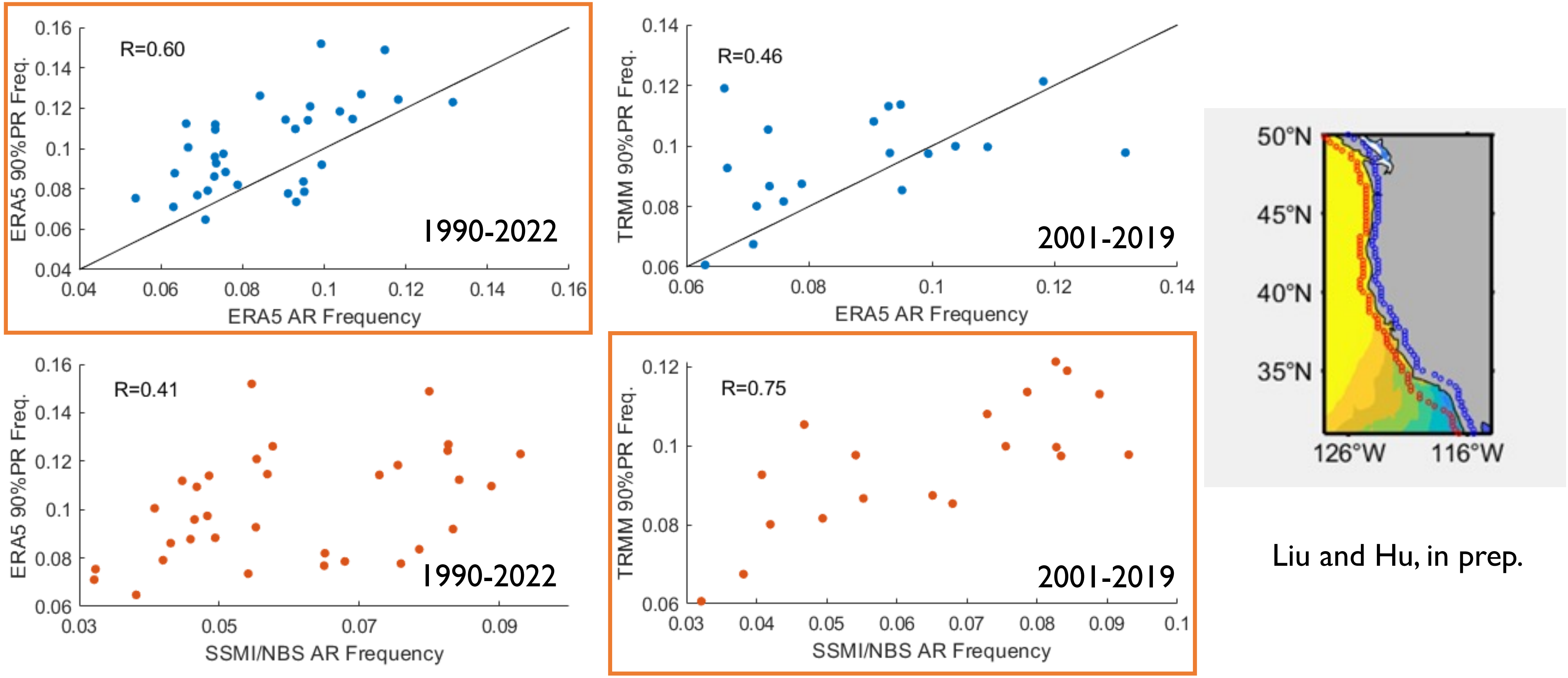
$C_u \sim -B_u\, q_s$



Results based on ERA5

Hu and Liu, in prep.

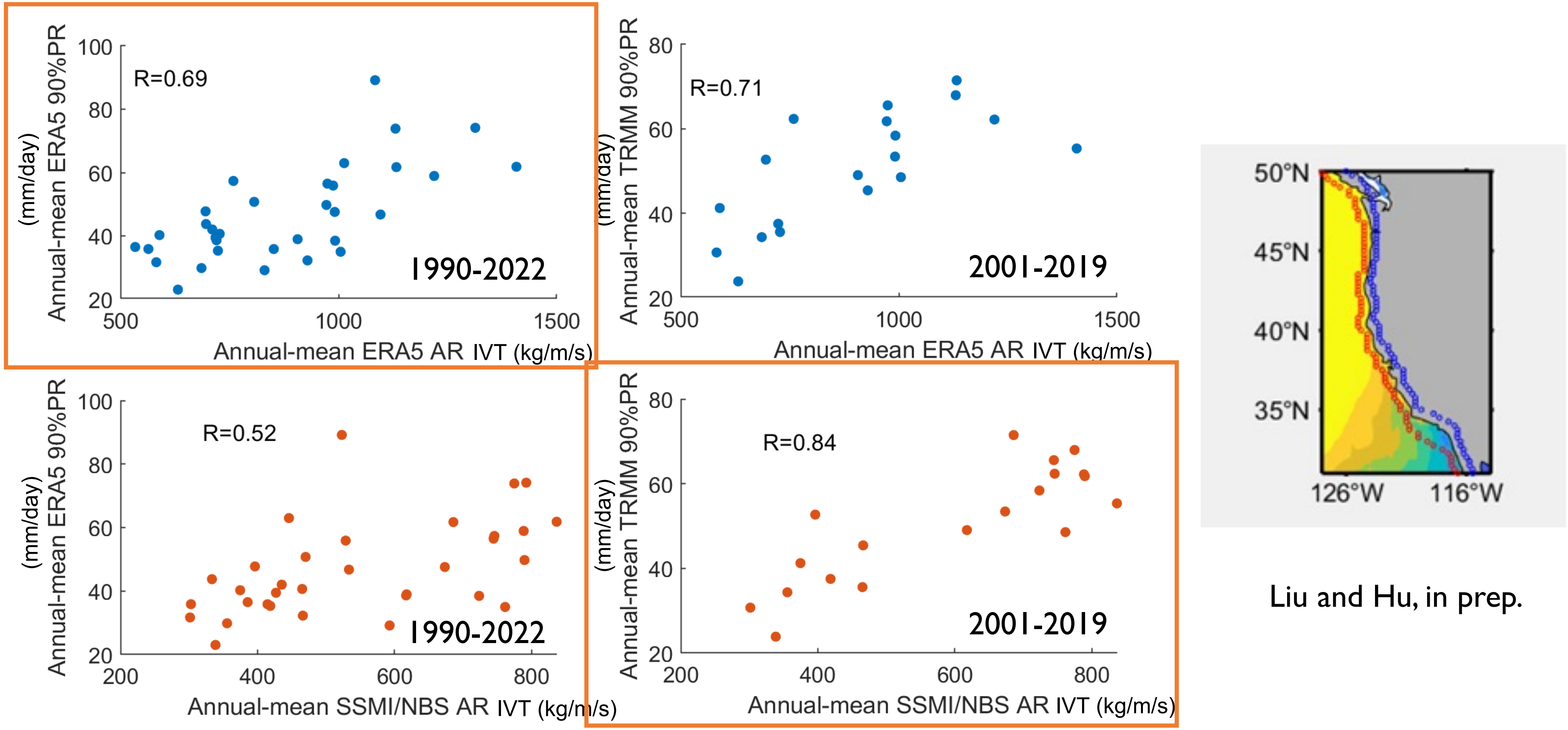
Extreme precipitation frequency vs. AR frequency



Liu and Hu, in prep.

- Satellite-based ARs agree better with satellite-based extreme precipitation events for the western U.S.
- Atmospheric reanalysis is self consistent (i.e. AR and precipitation) but may have mismatch with satellite observations.

Extreme precipitation (mm/day) vs. AR IVT (kg/m/s)



Liu and Hu, in prep.

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Summary

- A physics-informed algorithm was developed to reconstruct IVT from satellite-based measurements of IWV and ocean near-surface winds.

- Satellite-based AR database has similar spatial structures as atmospheric reanalysis products but exhibits distinctive features.

- Applications
  - Exploring satellite-based AR-extreme rainfall relation (better agreement than reanalysis AR)
  - Evaluating model bias in moisture transport (connection to wind shear, humidity profile, etc.)
  - Reducing data storage for high-res simulations (only 2-D IWV and surface wind needed to obtain IVT)

Liu, T., & Hu, S. (2025). An algorithm to develop a satellite-based atmospheric river database. *Geophysical Research Letters*, 52(5), e2024GL111316.

Contact: shineng.hu@duke.edu