Causal inference of root zone soil moisture performance in drought

CL3.1.2 Hall X5

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Introduction

1. Root zone soil moisture (RZSM) plays a vital role in surface hydrology, vegetation growth, and the atmospheric water cycle.
2. It serves as a direct link between meteorological and agricultural drought, making it crucial for drought monitoring.
3. Most spatially continuous soil moisture data come from satellite observations and model simulations, which often show inconsistencies.
4. These inconsistencies may introduce bias and uncertainty, especially when analyzing both meteorological and agricultural droughts.

Architecture

1. Validate SM products using ISMN observations (1980–2022).
2. Reclassify eco-zones and extract root-zone SM at relevant depths.
3. Compare spatiotemporal patterns between SM products and observations.
4. Apply PCMCI to infer causal links between SM and drought events.

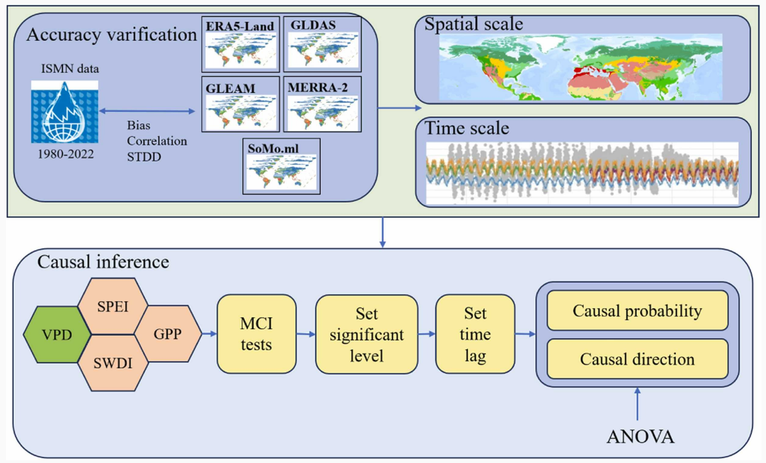


Fig. 1: Flow diagram of accuracy verification and causal inference.

VPD: Vapor Pressure Deficit; SWDI: Soil Water Deficit Index; SPEI: Standardized Precipitation Evapotranspiration Index; GPP: Gross Primary Productivity.

Comparison between products and in-situ observations

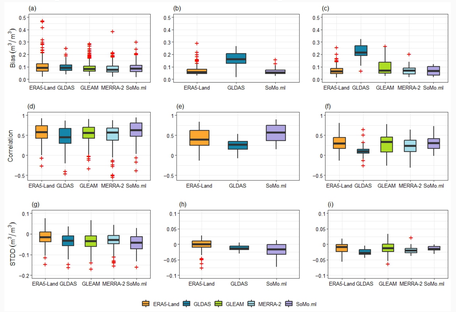


Fig. 2: The Bias value (a–c), Pearson correlation coefficients (d–f), and difference of standard deviation (STDD, g–i)

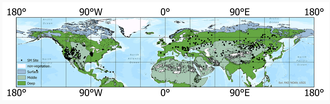


Fig. 3: Spatial distribution of the 802 soil moisture stations.

1. ERA5-Land shows large bias outliers 0.5 (m^3/m^3) despite similar surface-layer performance across products.
2. GLDAS has the lowest correlation and highest STDD.
3. GLDAS in middle and deep layers are consistently lower than other products and in-situ data.

Differences in vegetation types

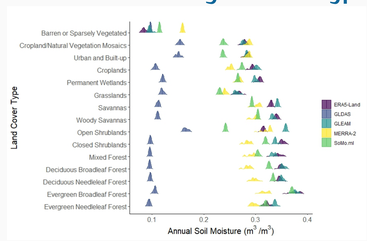


Fig. 4: Probability density of annual soil moisture value of IGBP land cover types.

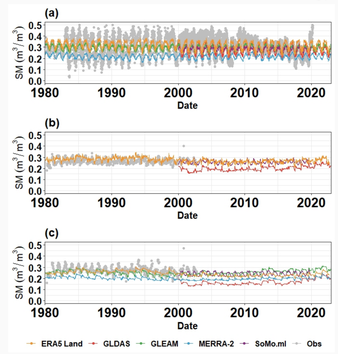


Fig. 6: Time series in the surface(a), middle(b), and deep layer(c).

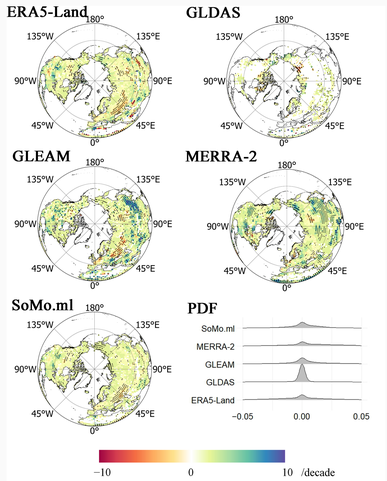
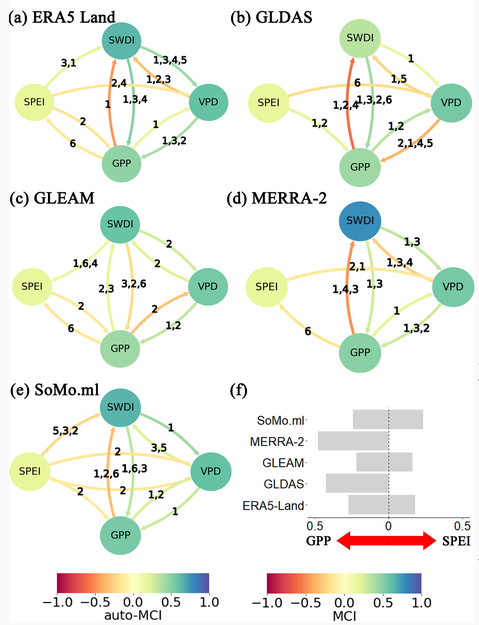


Fig. 5: M-K trendand probability density of annual soil moisture value over two decades.

1. ERA5-Land and GLEAM report higher SM.
2. GLDAS shows consistently low SM, unaffected by vegetation except in deserts.

Propensity in meteorological drought and agricultural drought



(a–e) Causal links (arrows) between SPEI and SM-based SWDI for five products. Arrow color = MCI strength; node color = auto-MCI. Numbers show lag months. (f) Propensity direction and probability. E.g., in (a), SPEI → ERA5-Land SWDI at 1/3-month lags.

Fig. 7: The cause-effect of five SWDIs.

1. MERRA-2 and GLDAS link weakly to meteorological but strongly to agricultural drought.
2. VPD explains >95% of variance in GPP and SPEI; SoMo.ml contributes most via SWDI, MERRA-2 the least.
3. SWDI–SPEI are mostly positively correlated; MERRA-2 shows the highest rate.

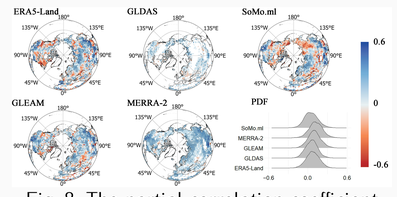


Fig. 8: The partial correlation coefficient between monthly SPEI and SWDI with 3-months lag when VPD was controlled.

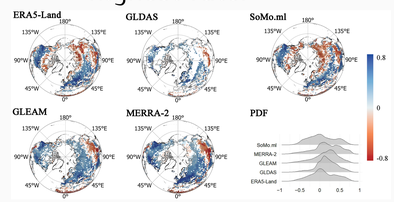


Fig. 9: The partial correlation coefficient between monthly SWDI and GPP with a 3-month lag when VPD was controlled.

Conclusion

1. SoMo.ml/ERA5-Land show higher spatial detail.
2. MERRA-2/GLDAS have weak drought links—use with caution.

Reference

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2. Xue, Shouye, and Guocan Wu. 2024. "Sensitivities of Vegetation Gross Primary Production to Precipitation Frequency in the Northern Hemisphere from 1982 to 2015" Remote Sensing 16: 1—21.
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