IBS Center
for Climate Physics

Multi-year Predictability of Total Soil Water, Drought and Wildfire over the Globe

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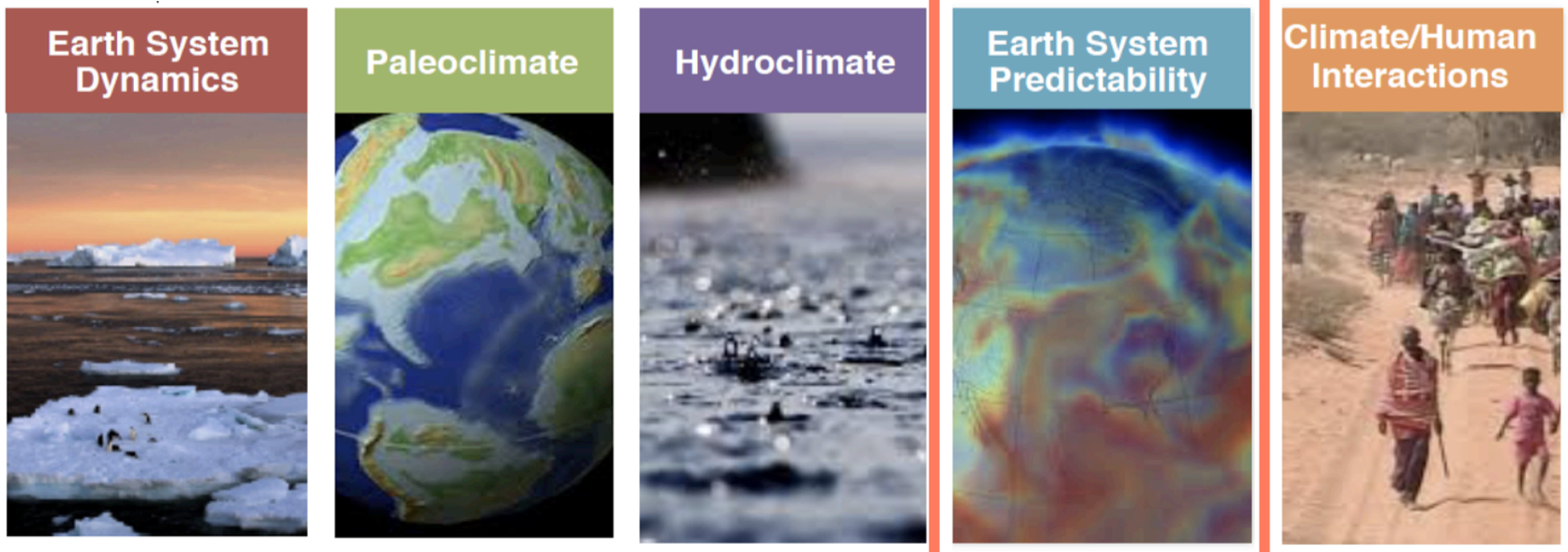
Introduction on IBS Center for Climate Physics (ICCP)

ICCP has started since 2017 with Prof. Axel Timmermann as director, studying earth system dynamics, paleoclimate, hydroclimate, earth system predictability, and climate-human interactions.



The Mission of the Earth System Predictability Project in ICCP

To enhance our predictive capability of Earth System components such as total soil water, wildfire occurrence, marine biogeochemical process, sea level, and statistics of climate extremes on timescales of months to decades using comprehensive Earth System models.

- Understanding of sources of short and longterm predictability
- Development of a high-resolution earth system forecasting framework
- Improvement of prediction of earth system components

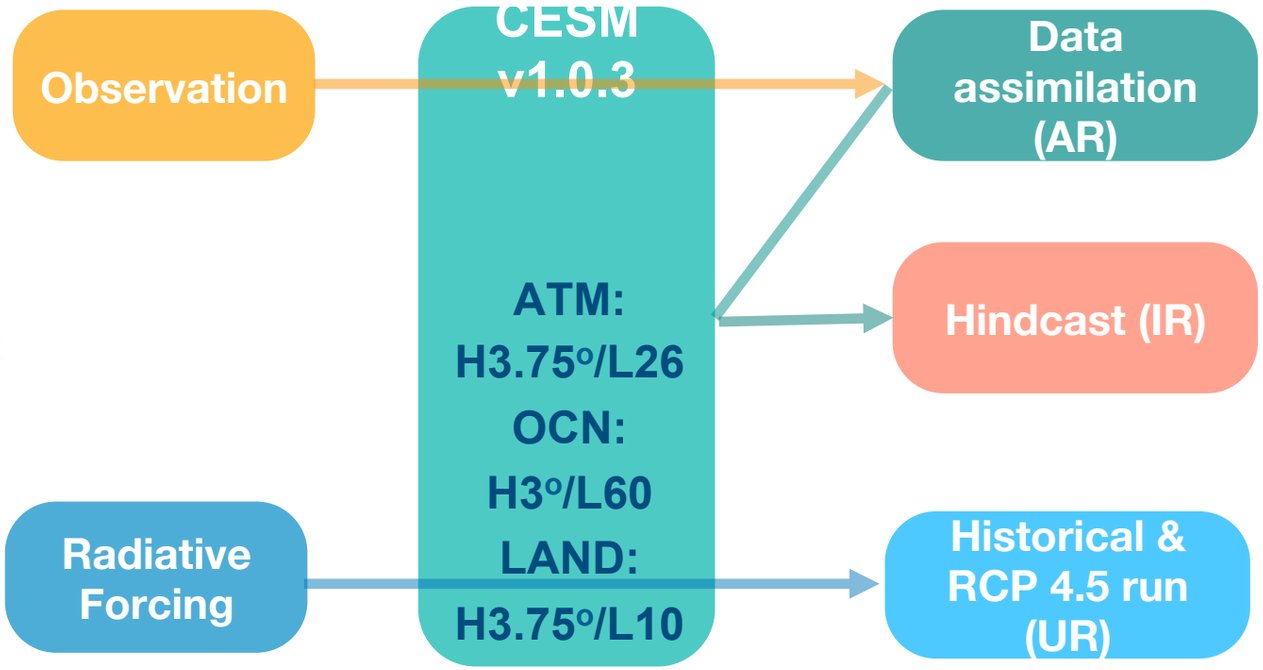
Purpose of This Study

- This study aims to **assess multi-year predictability for total soil water and wildfire occurrence** over the Globe using the multi-year dynamical prediction system based on the Community Earth System Model and to **better understand sources of their predictability**.

Description of Data, Model and Experiments

- CPC Soil Moisture v2 (1958-2015)
- Palmer Drought Severity Index (PDSI) (1958-2014)
- Fire Weather Index (FWI) GFWED (Field et al 2015) (1982-2015)

- Natural & anthropogenic radiative forcing



- AR with global 3-D ocean temperature & salinity fields from ECMWF ORA-S4 (1958-2015)
- 10 ensemble runs initialized once a year (Jan 1st) from AR for 10-year long integration (1958-2015)

- Historical run (1850-2005)
- IPCC RCP 4.5 run (2006-2030)

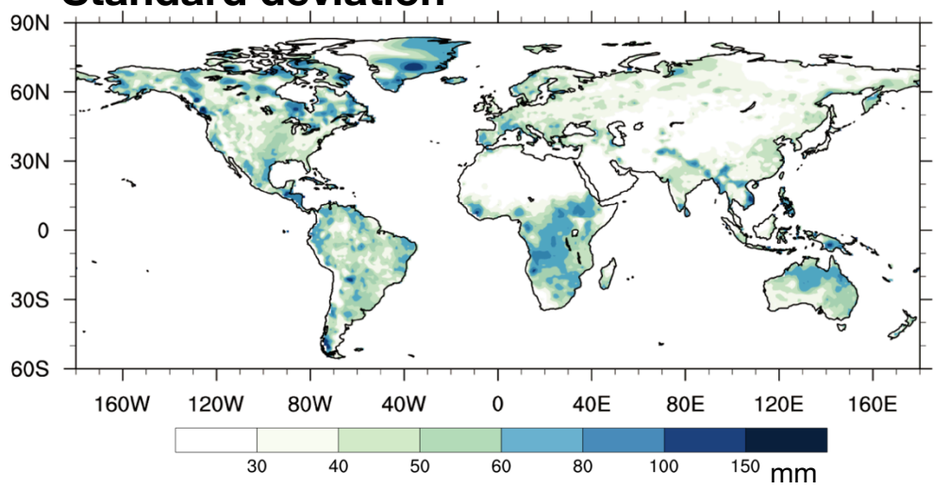
- Definition of water year: October of the previous year to September
- Data analysis period: 1960-2015

Variability and Trend of Total Soil Water

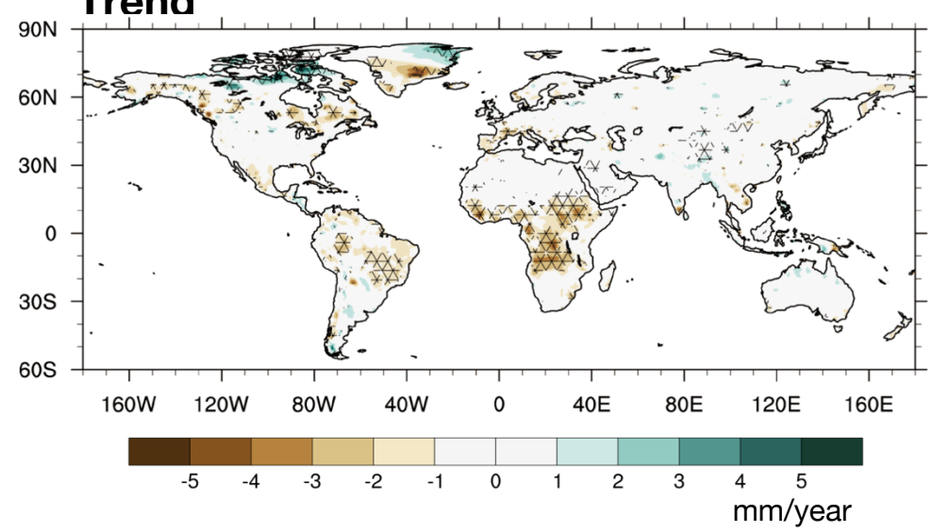
- There are significant interannual to interdecadal variability and long-term trend in total soil water averaged from surface to 3-m depth over the many parts of the globe.
- There is a significant negative correlation between the TSW and Drought Severity.

CPC water-year mean total soil water (TSW; ~3m)
(1960-2015)

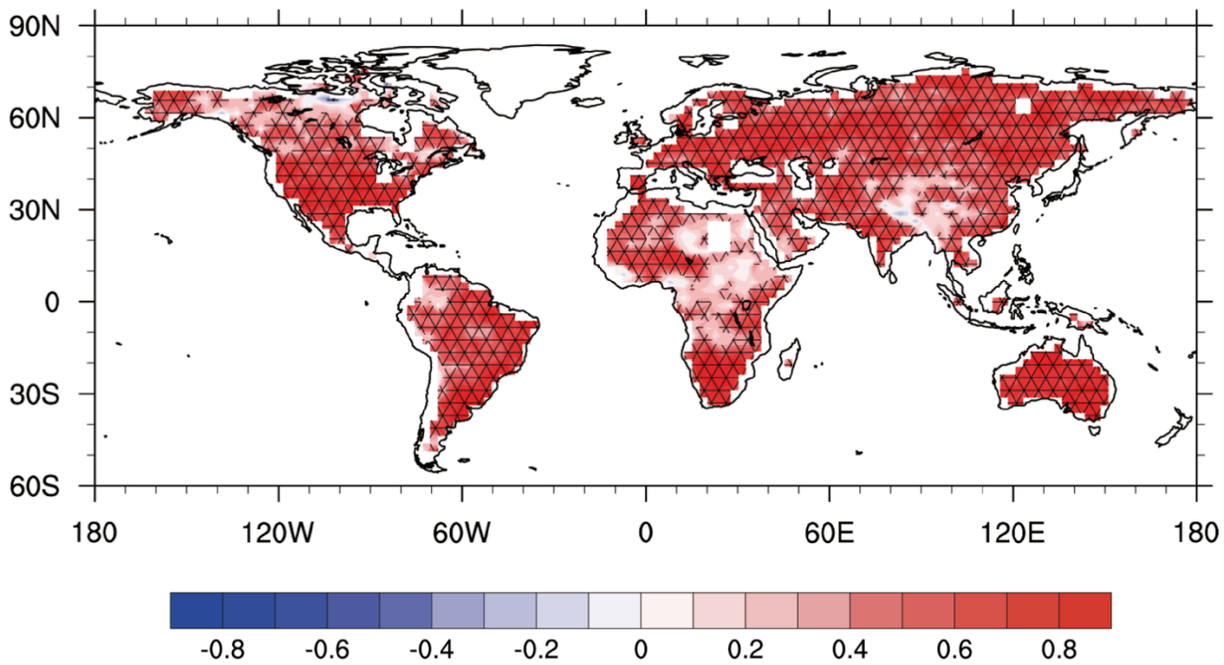
Standard deviation



Trend



Correlation between
CPC TSW and Palmer drought severity index
(Water-year Mean/1960-2014)



* Dotted areas indicate the statistically significance at 99% confidence level on the basis of t-test

Variability and Trend of Total Soil Water

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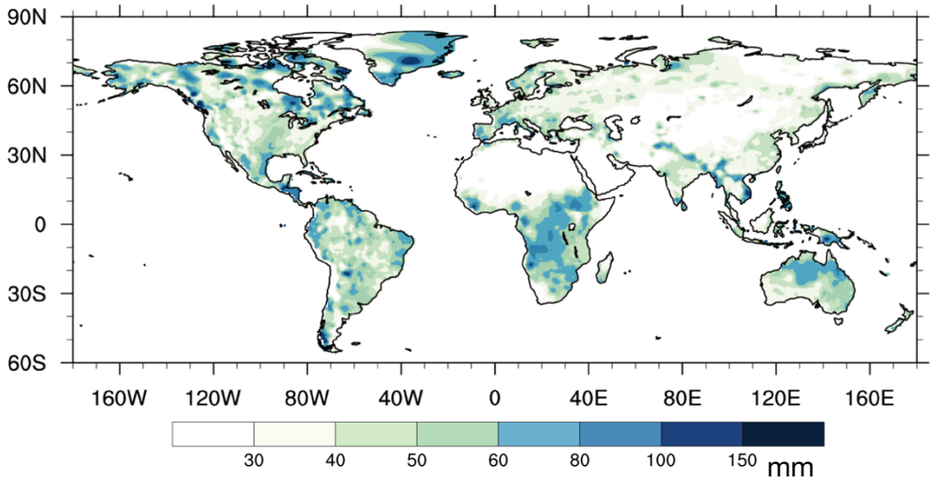
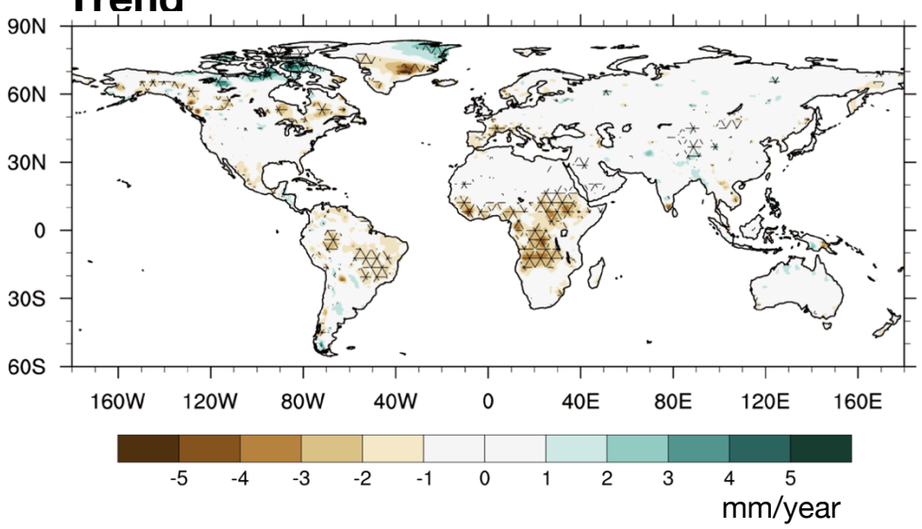
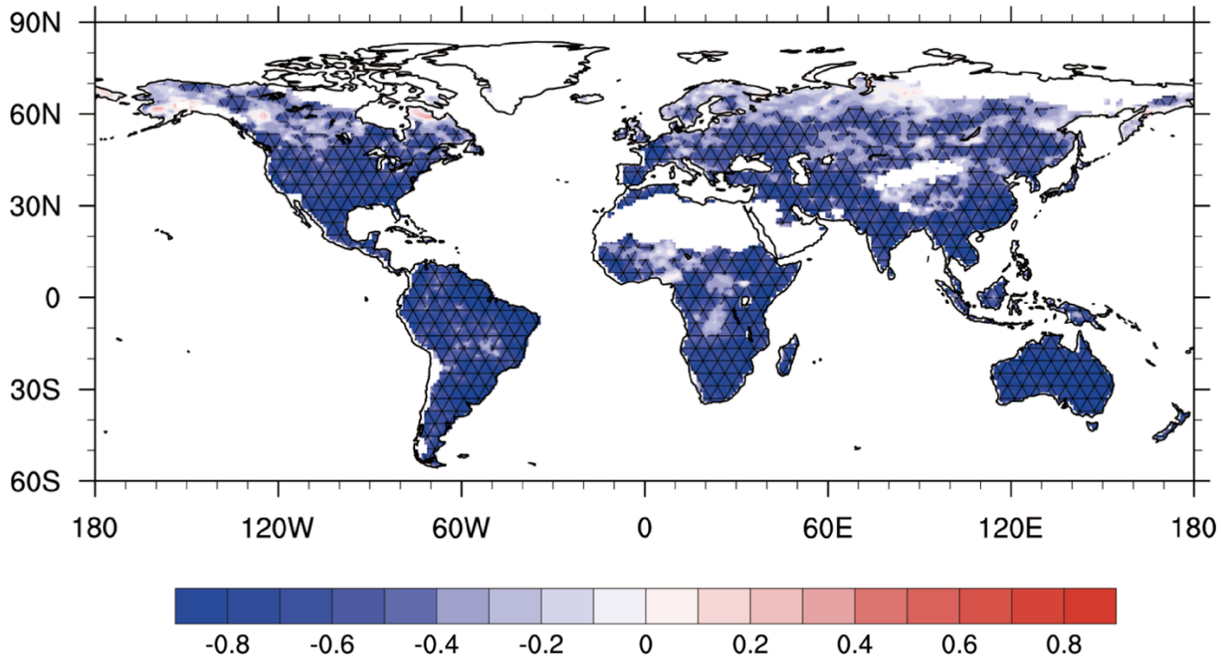


Trend



Correlation Coefficient between CPC TSW and GFWED FWI
Water-year mean, 1982-2015



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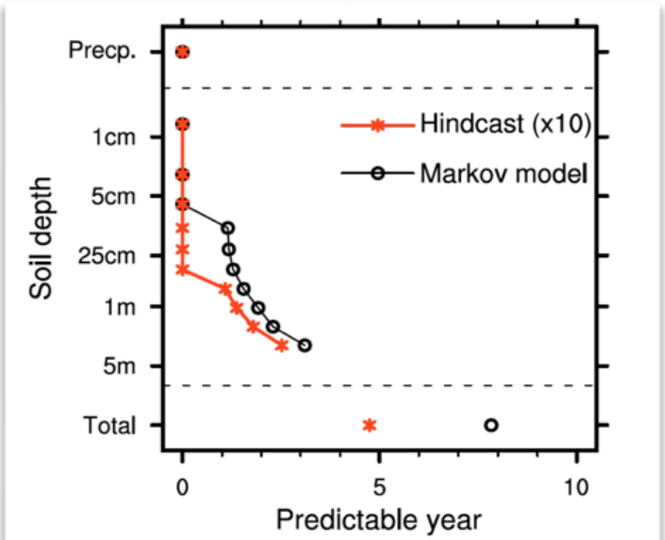
Sources of Multi-year Predictability

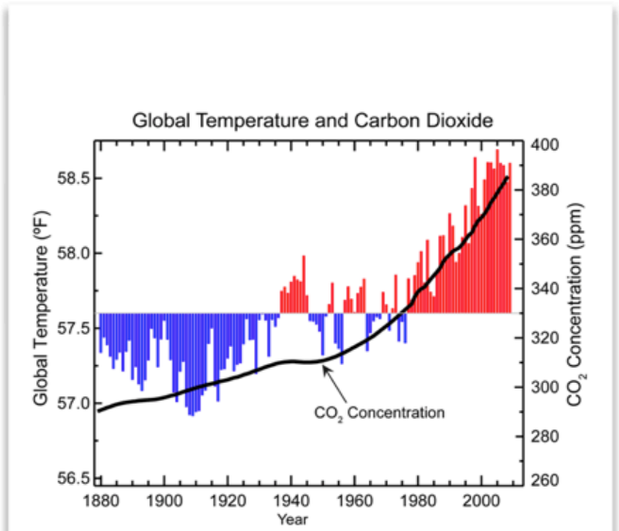
- **The important sources for multi-year predictability of TSW include the low-pass filtering characteristics of soils, the anthropogenic radiative forcing, and the Trans-basin variability (TBV) between the Atlantic and Pacific SST.**



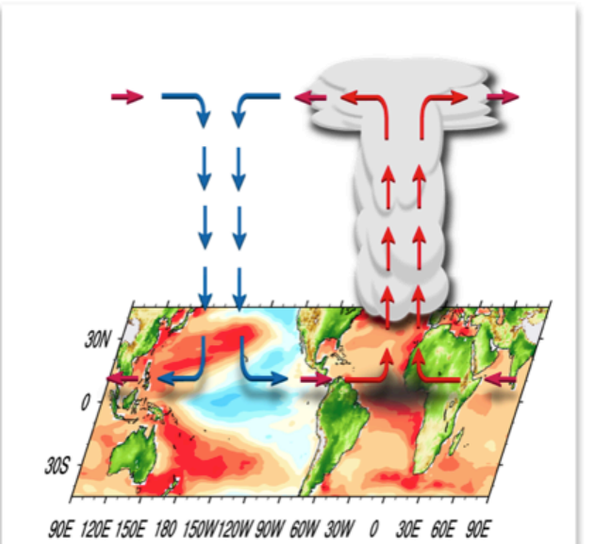
Natural Low-pass Filtering Characteristics of Soil

$$\frac{dW_T}{dt} = -\lambda\, W_T(t) + P(t)$$

Predictability due to the damped persistence



Anthropogenic Radiative Forcing

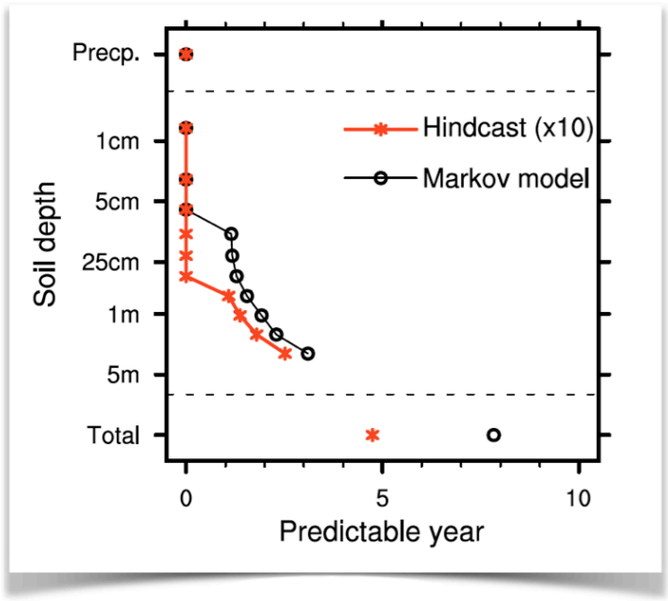


Transbasin Variability (TBV) between the Pacific and Atlantic SST

Chikamoto et al. (2015, 2017)

Sources of Multi-year Predictability

- Soils act as an **integral and natural low-pass filter** of white noise precipitation



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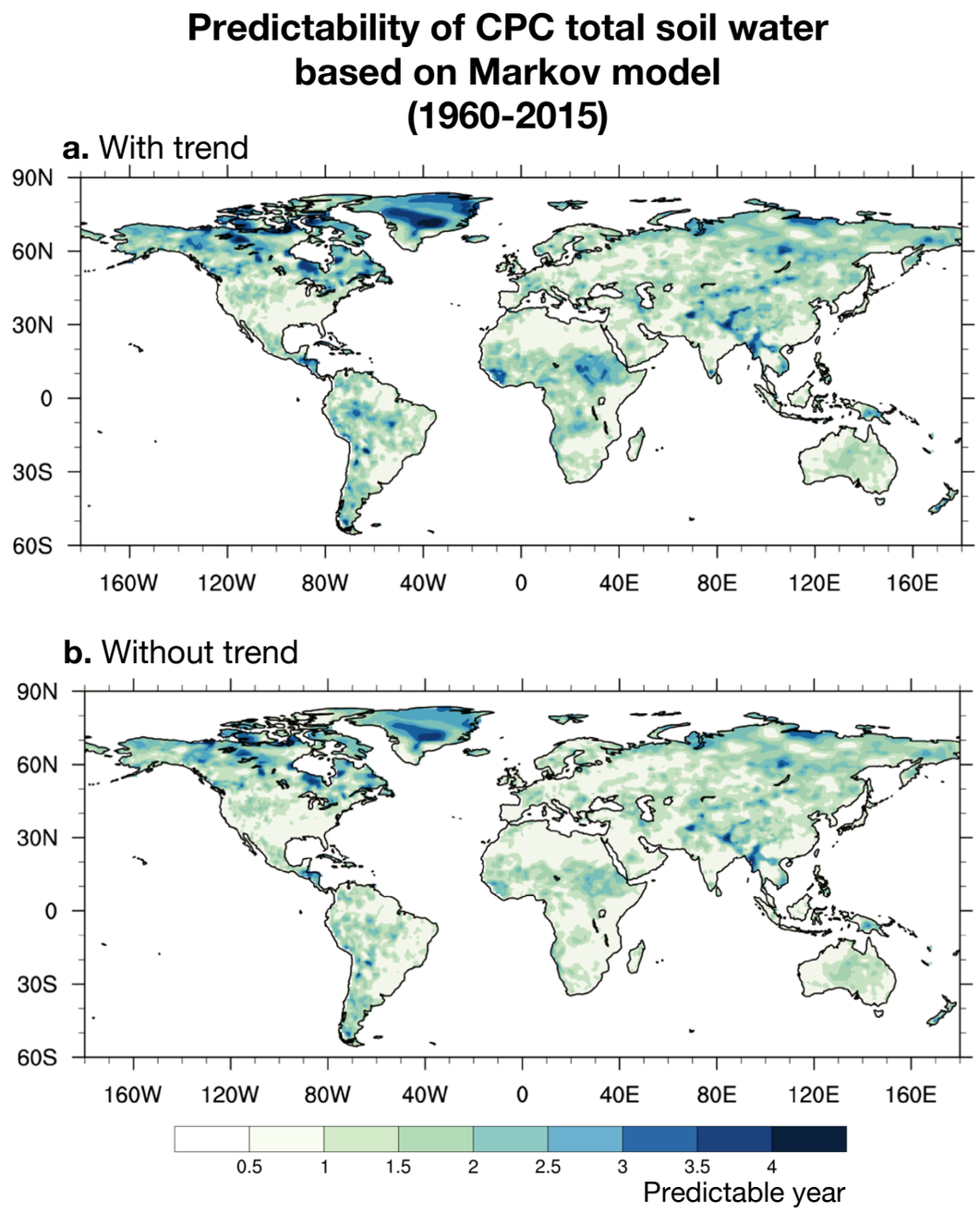
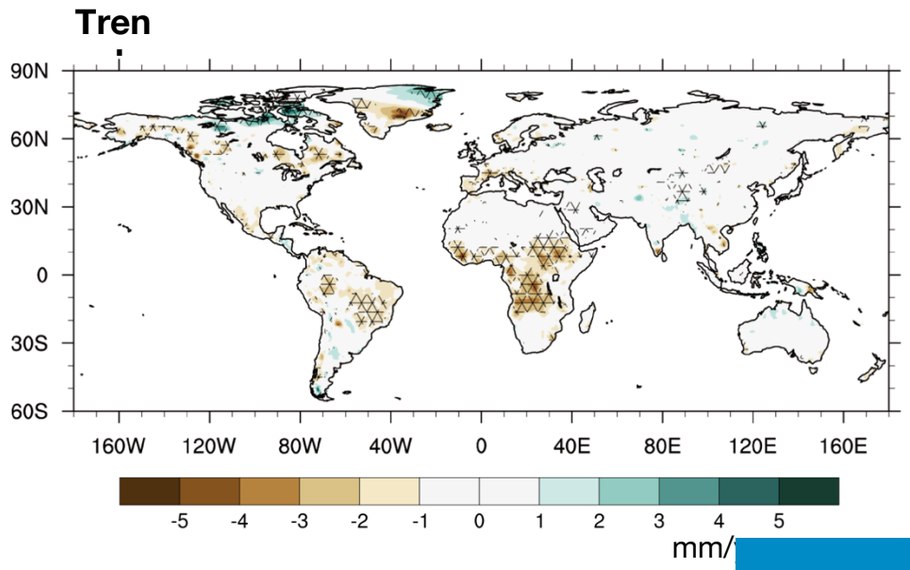
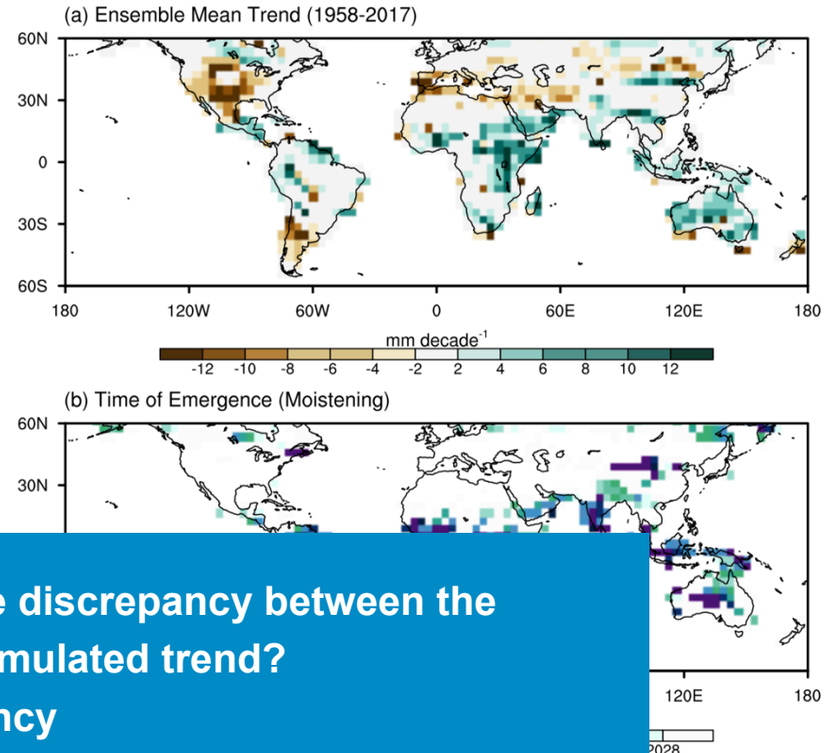
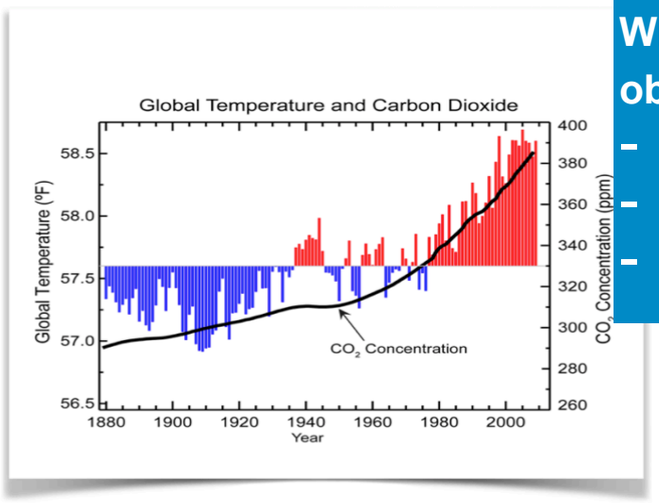


Sources of Multi-year Predictability

- **Long-term trend** also provides near-term predictability



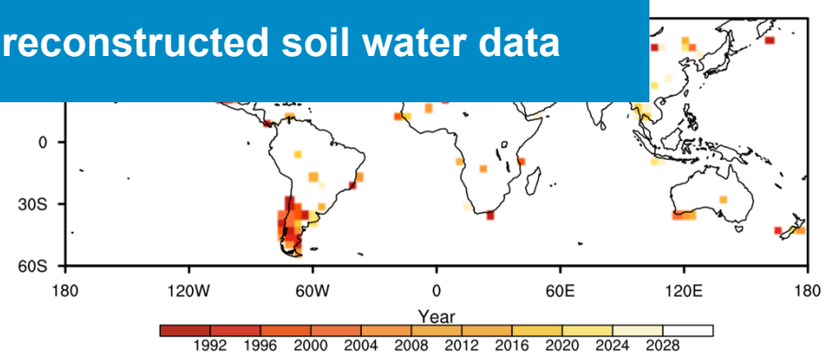




Anthropogenic Radiative Forcing

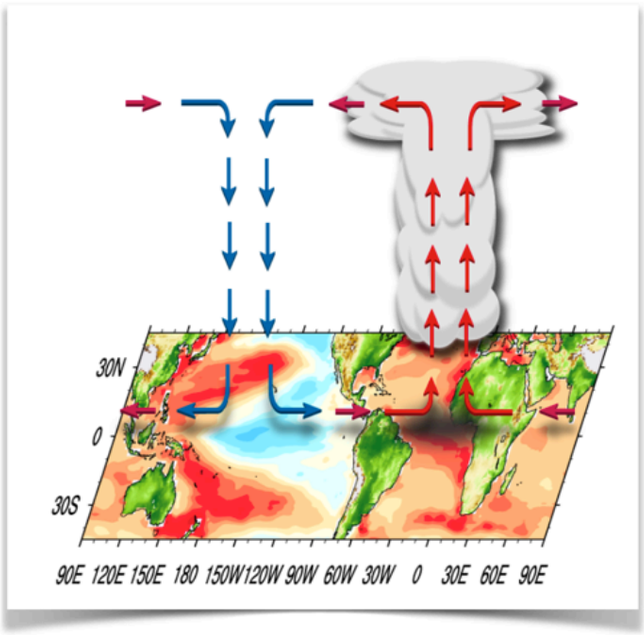
What causes the discrepancy between the observed and simulated trend?

- **Model deficiency**
- **Natural long-term variation**
- **Quality of the reconstructed soil water data**

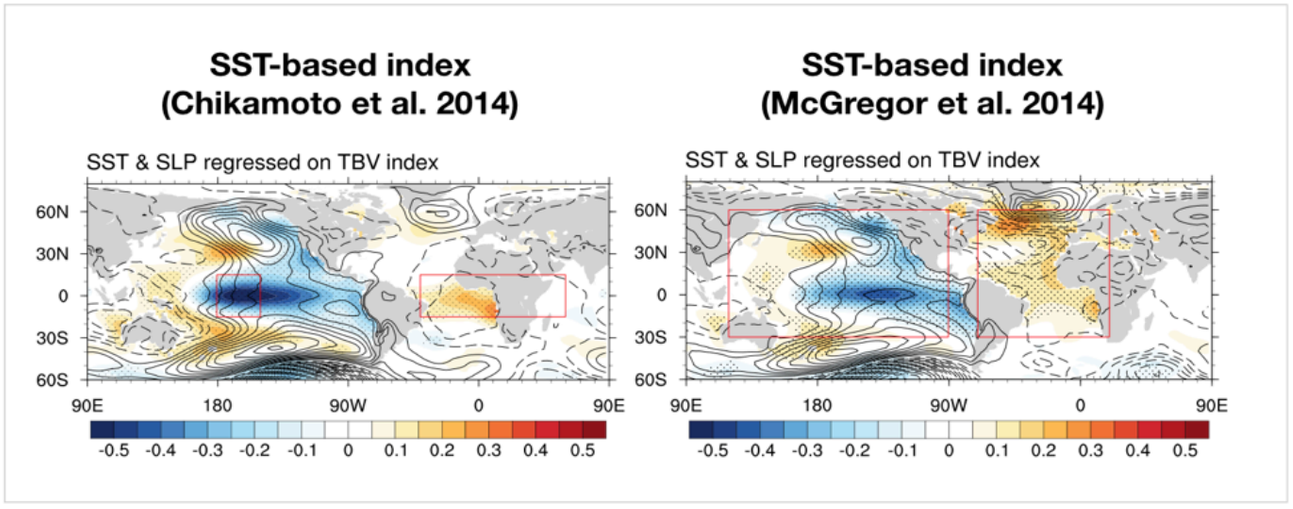


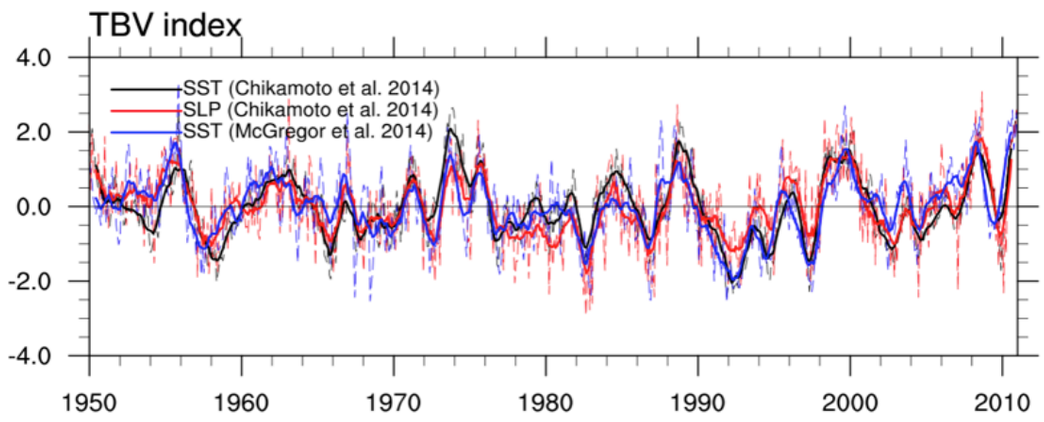
Sources of Multi-year Predictability

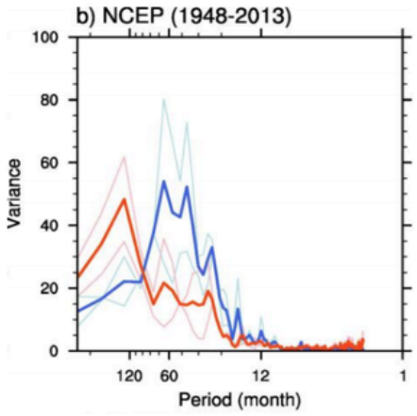
- **The Trans-basin variability (TBV) between the Atlantic and Pacific SST is the key source of multi-year predictability for water-year mean TSW over the many parts of the globe.**



The positive TBV phase: the relatively warmer SST over the Atlantic than the Pacific







Dominant Periods

Blue line for ENSO: 2~7 years

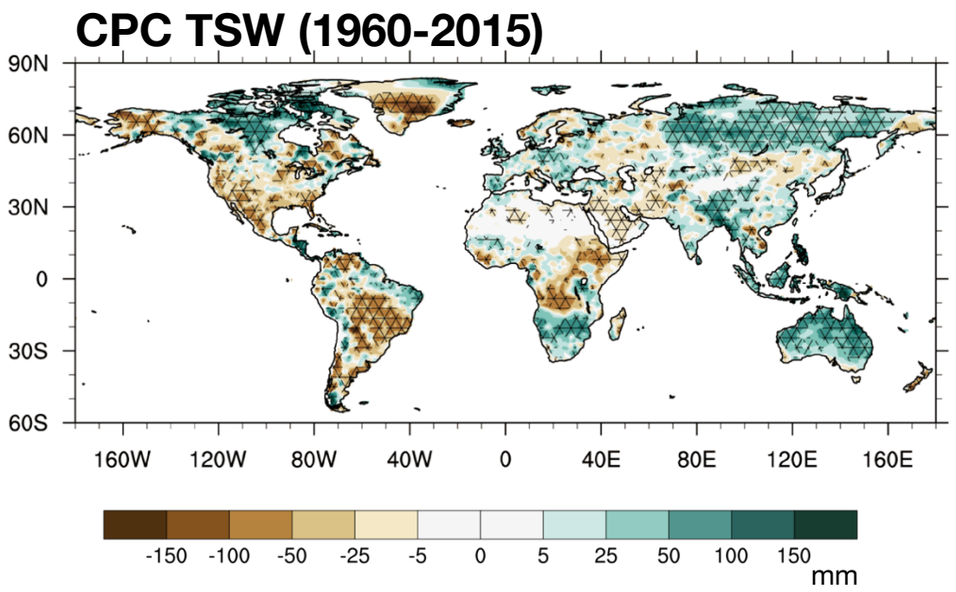
Red line for TBV: 10~20 years

Chikamoto et al. (2014, 2017)

Sources of Multi-year Predictability

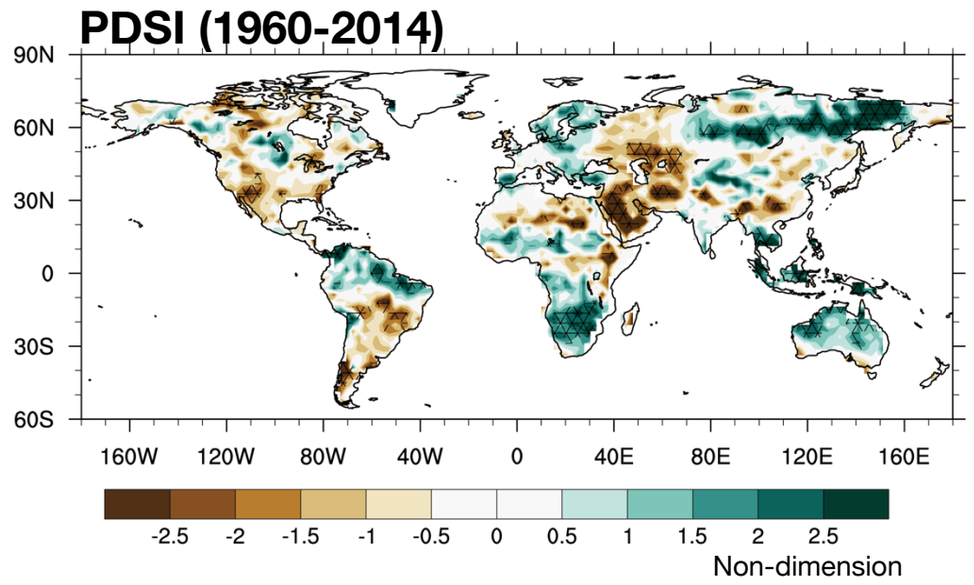
- The **Trans-basin variability (TBV)** between the Atlantic and Pacific SST is the key source of multi-year predictability for water-year mean total soil moisture over the many parts of the globe.

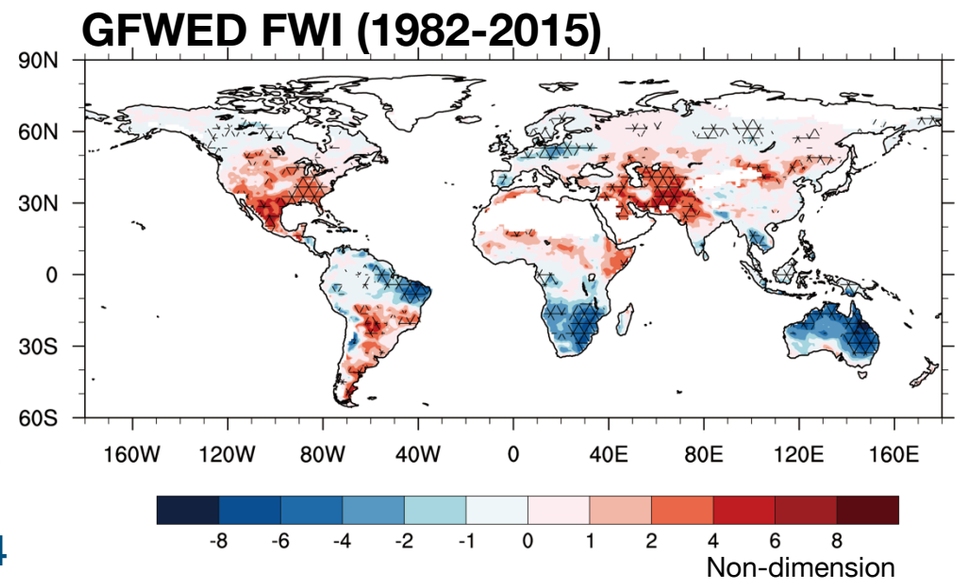
TBV Composite Difference (Water-year mean)



* Areas with a slant line indicate the statistically significance at 90% confidence level on the basis of two-tail Student's *t*-test

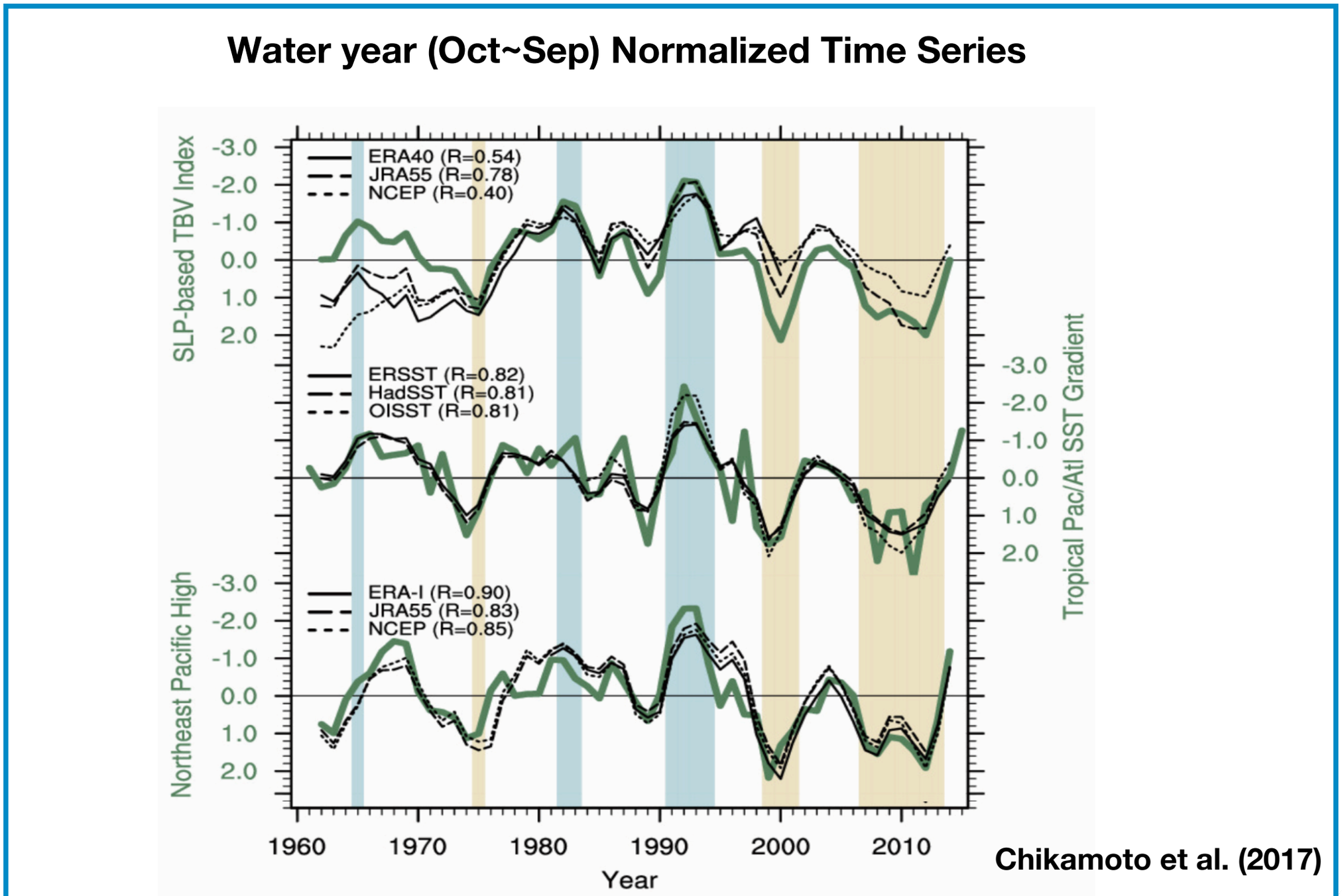
- Positive TBV years: 1975, 1999, 2000, 2001, 2007, 2008, 2009, 2010, 2011, 2012, 2013
- Negative TBV years: 1965, 1982, 1983, 1991, 1993, 1994





Assimilation Results: TBV

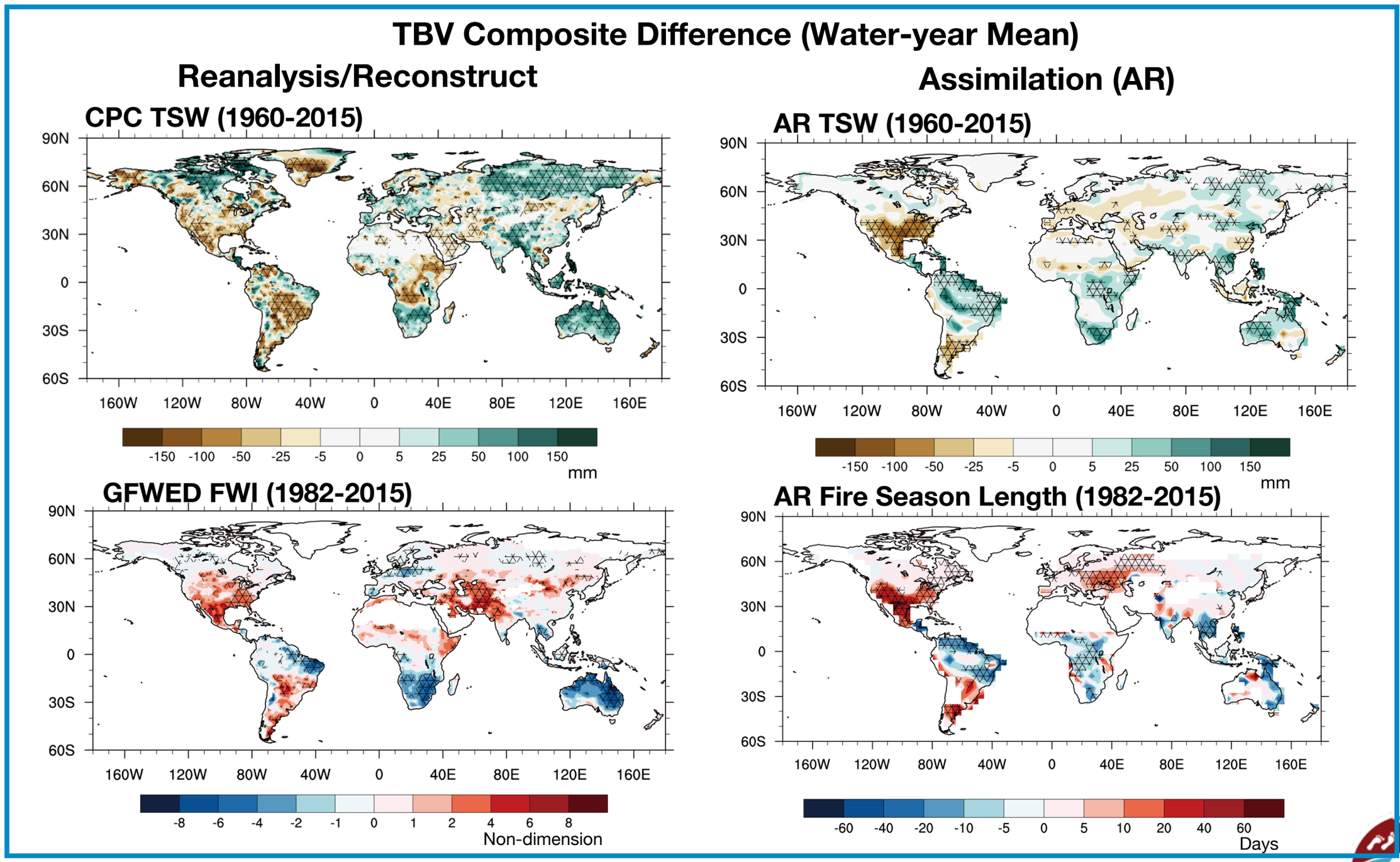
- **Assimilation (AR) with global SST using CESM well captures the observed TBV variation.**



Chikamoto et al. (2017)

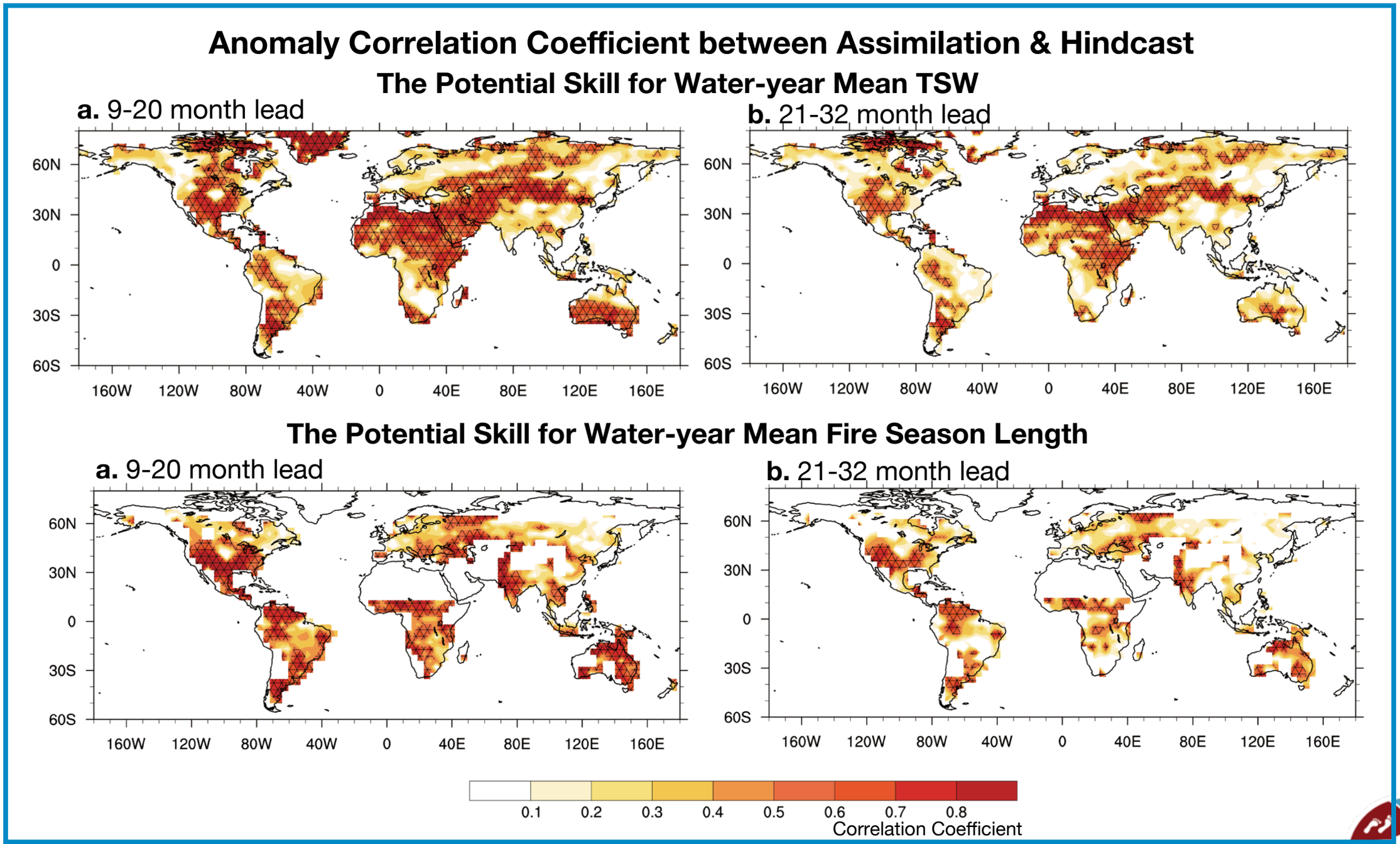
Assimilation Results: TBV Impacts

- **Assimilation (AR) with global SST using CESM is capable of captures the global impact of TBV**



Potential Multi-Year Prediction Skills (IR)

- **The dynamical prediction system has a high degree of potential skill in predicting total soil moisture up to 2~4 year lead time over the many parts of the globe including the southern part of North and South America, Central America, the northern part of South Africa, Maritime Continents, Australia, Europe and Asia.**



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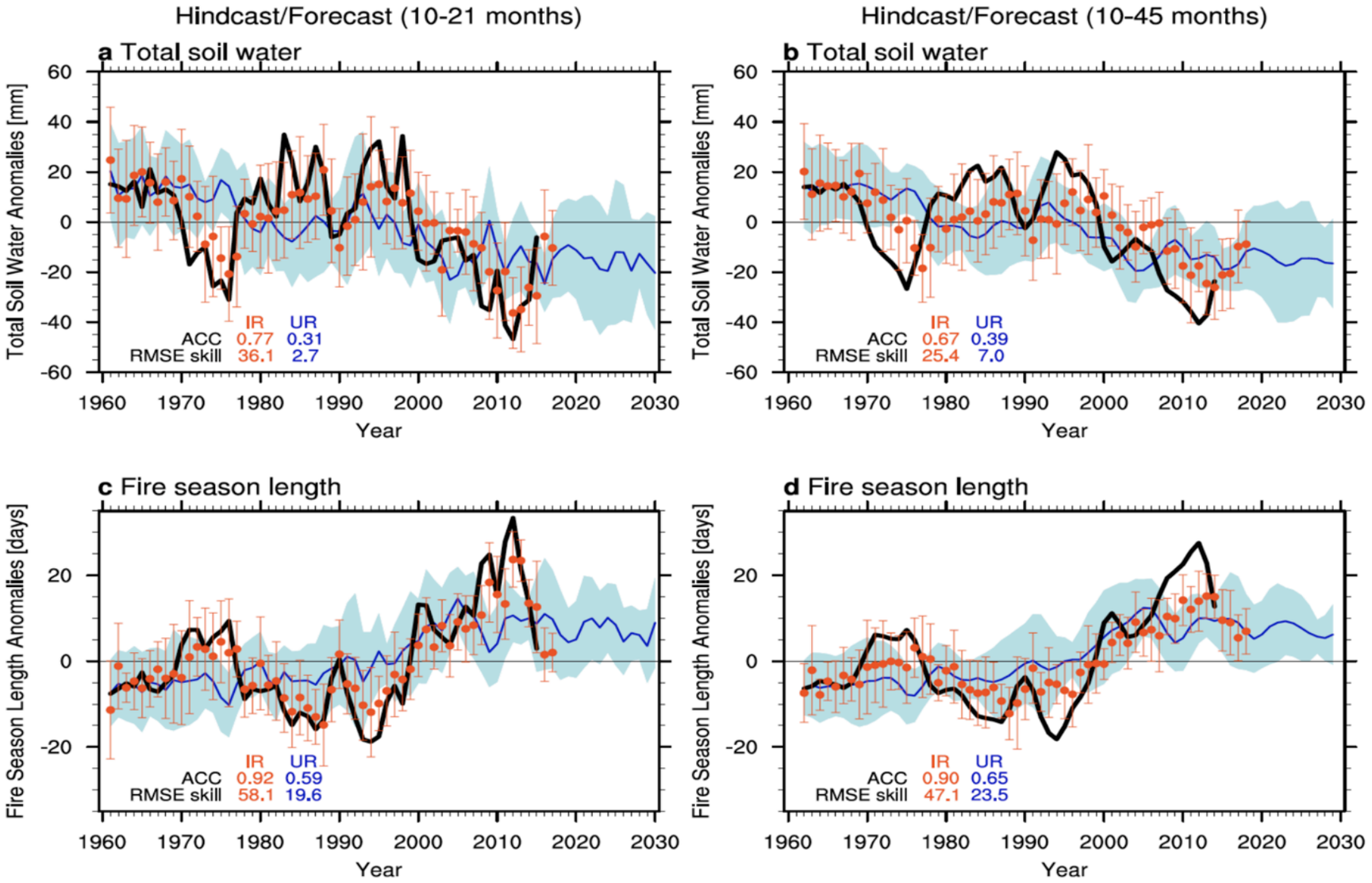
Potential Multi-Year Prediction Skills (IR)

- **The dynamical prediction system is capable of capturing TSW and fire season length anomalies 2~4 years ahead particularly over southwestern North America. Antrhopogenic radiative forcing also contributes to the recent long-term trend of two variables.**



Chikamoto et al. (2017)

Summary

- Severe drought and increased change in wildfire occurrence have significant impacts to a wide range of sectors such as agriculture, energy, food security, forestry, drinking water and tourism. **This study aims to assess multi-year predictability for total soil water and wildfire occurrence over the Globe using the multi-year dynamical prediction system based on the Community Earth System Model and to better understand sources of their predictability.**

- **The important sources of multi-year predictability for soil water include the the low-pass filtering characteristics of soils, the anthropogenic radiative forcing and Trans-basin variability (TBV) between the Atlantic and Pacific SST.** In particular, the positive phase of TBV, characterized by the relatively warmer SST over the Atlantic than the Pacific, is favorable for less precipitation, less soil water, drought, and more wildfire occurrence over the southern part of North and South America, the northern part of South Africa and many parts of Europe and Asia.

- **The dynamical prediction system has a high potential skill in forecasting total soil water and fire season length up to 2~4 year lead time over many parts of the Globe.** However, the actual skill of the system is very limited yet with respect to reanalysis/reconstruction data.

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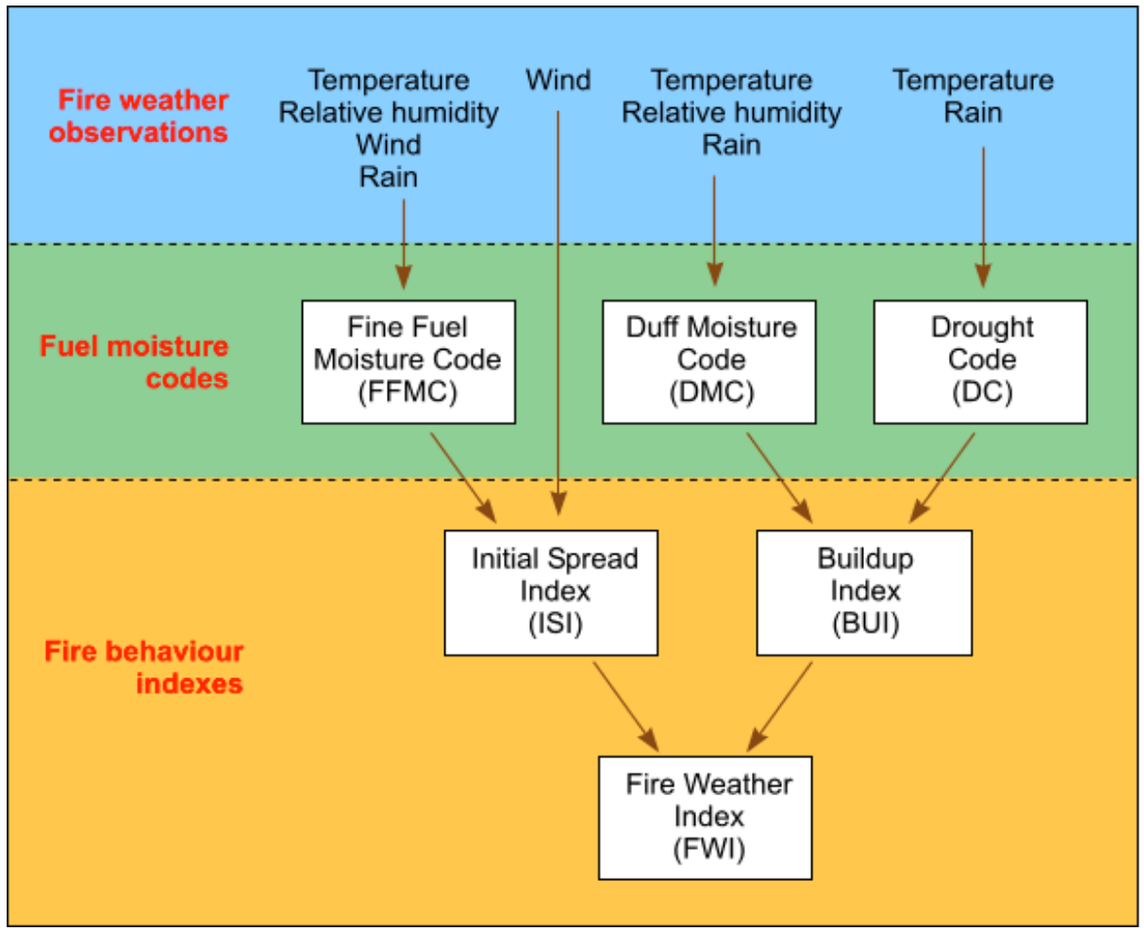
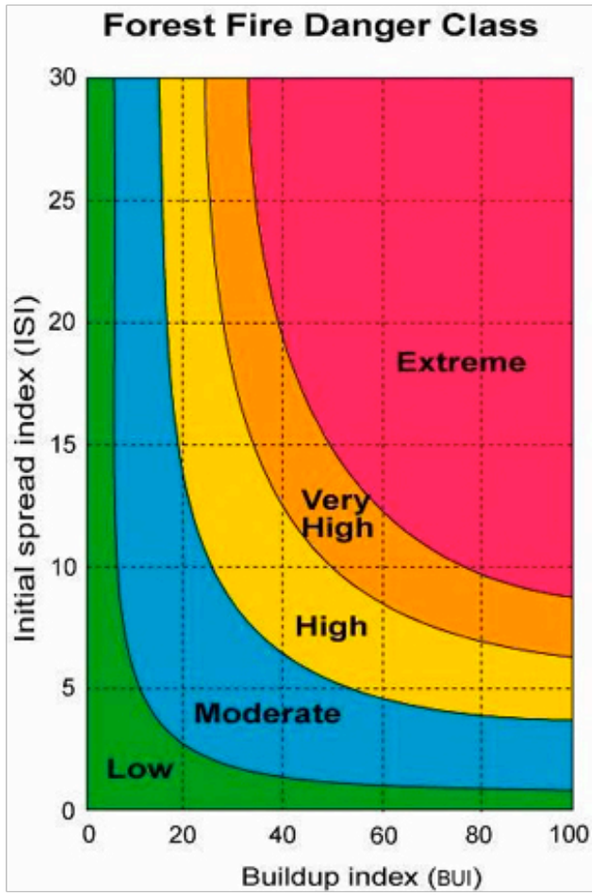
Thank you very much!

Any Question?

Fire Weather Index and Fire Season Length

- **Fire Weather Index** (FWI) : **Fire danger rating index identifies conditions under which vegetation fires can start and spread by modeling the moisture content of different classes of fuels in response to changing weather conditions** (Merrill and Alexander, 1987). **Global Fire WEather Database** (GFWED) is composed of three moisture codes and three fire behavior indices (Field et al. 2015)





- **Fire parameterization in CESM: The daily fire probability in each grid box is parameterized in terms of fuel density from the vegetation carbon, upper soil water content, and surface air temperature.** The area average of annual fire season length reflects on the large-scale fire probability.