Pacific Northwest NATIONAL LABORATORY

WACCEM
WATER CYCLE AND CLIMATE EXTREMES MODELING

Uncovering the Interannual Predictability of the 2003 European Summer Heatwave and its Connection to the Tibetan Plateau

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U.S. DEPARTMENT OF ENERGY BATTELLE

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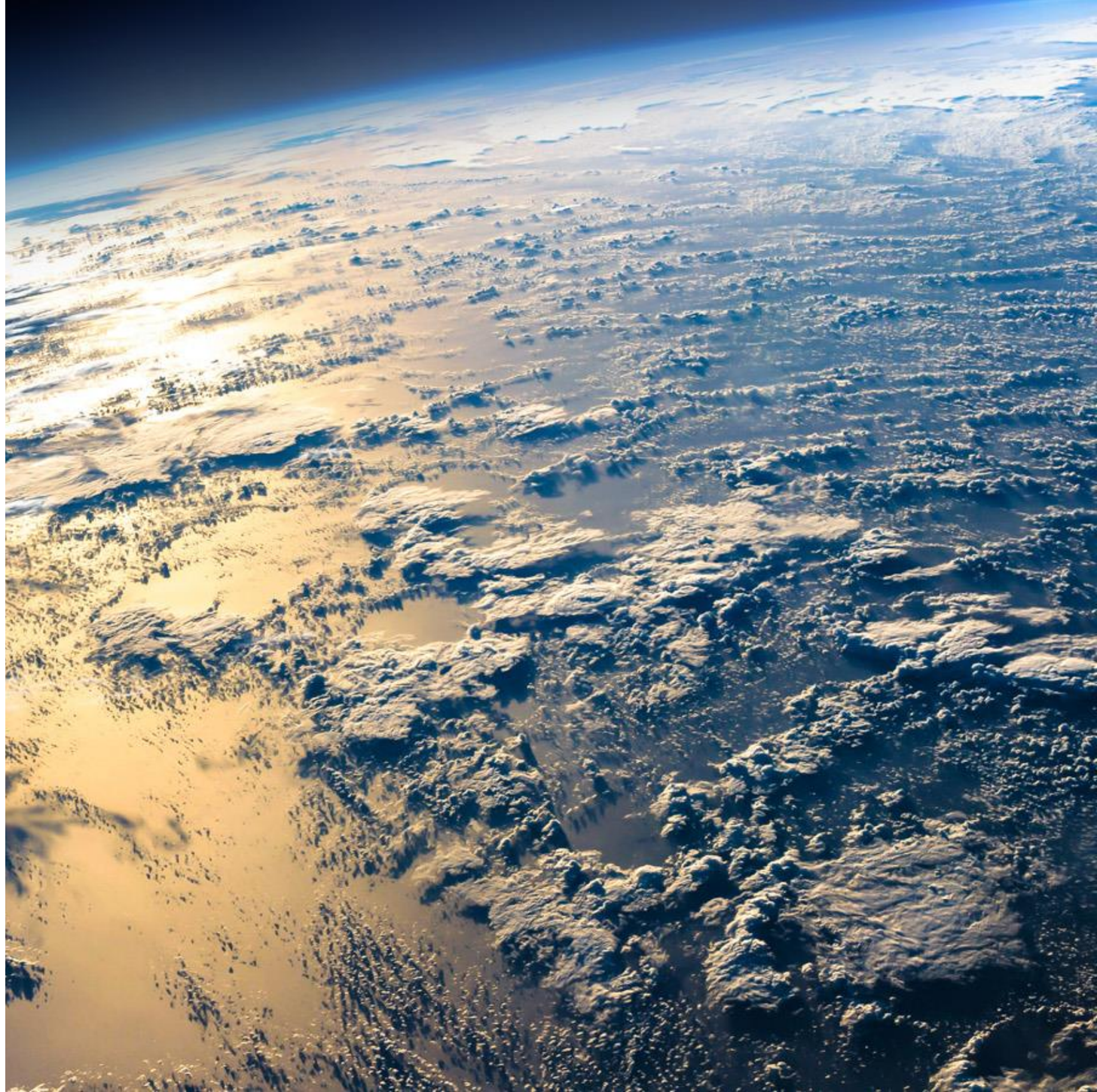
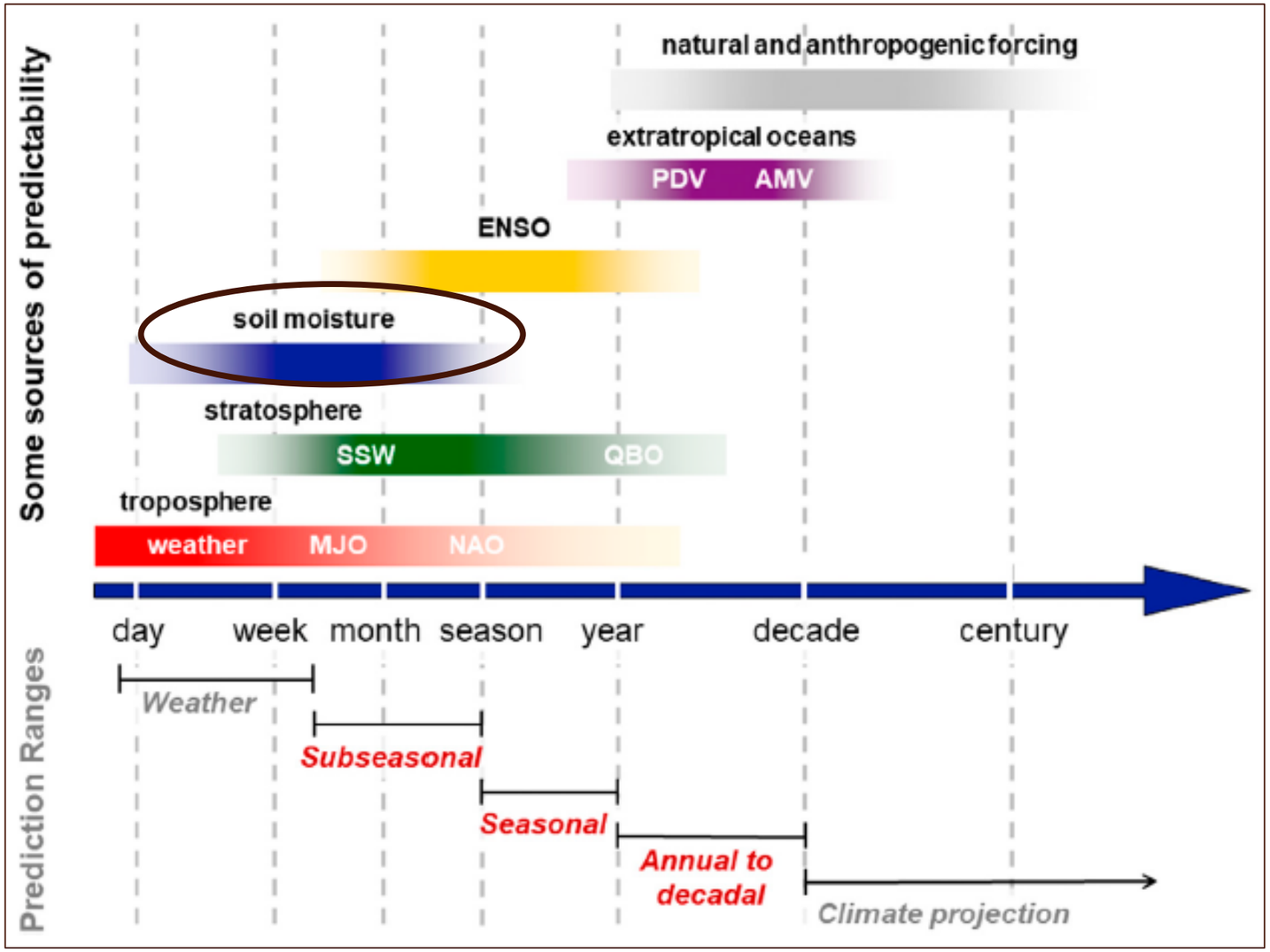


Sources of predictability at different timescales

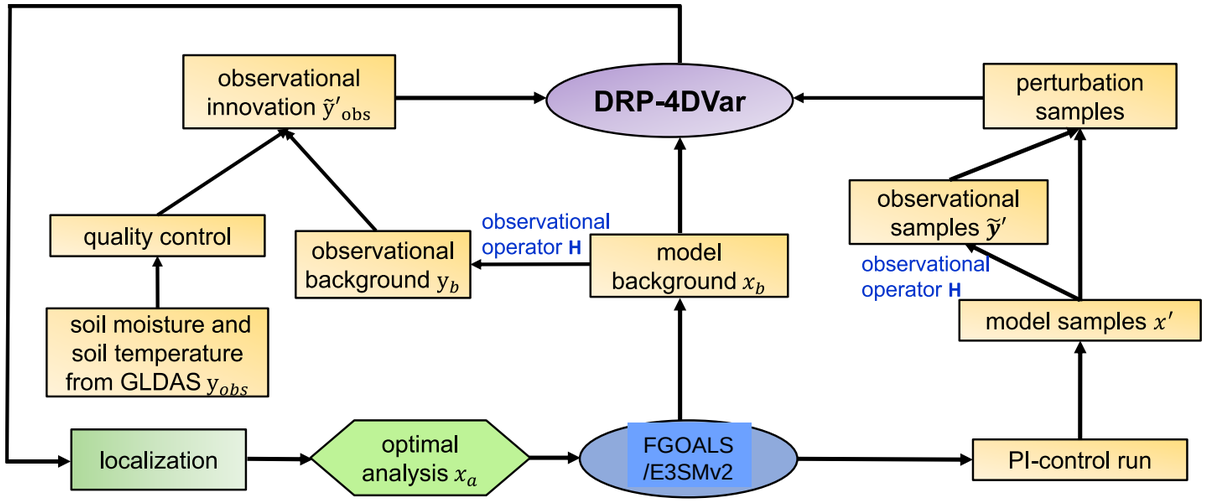


(Merryfield et al. 2020 BAMS)

Could soil moisture and temperature provide predictability at interannual-to-decadal timescale through **longer memory land processes** and/or their **influence on ocean with longer memory**?

Land as a source of predictability at decadal timescale

A weakly coupled land data assimilation system based on 4DEnVar



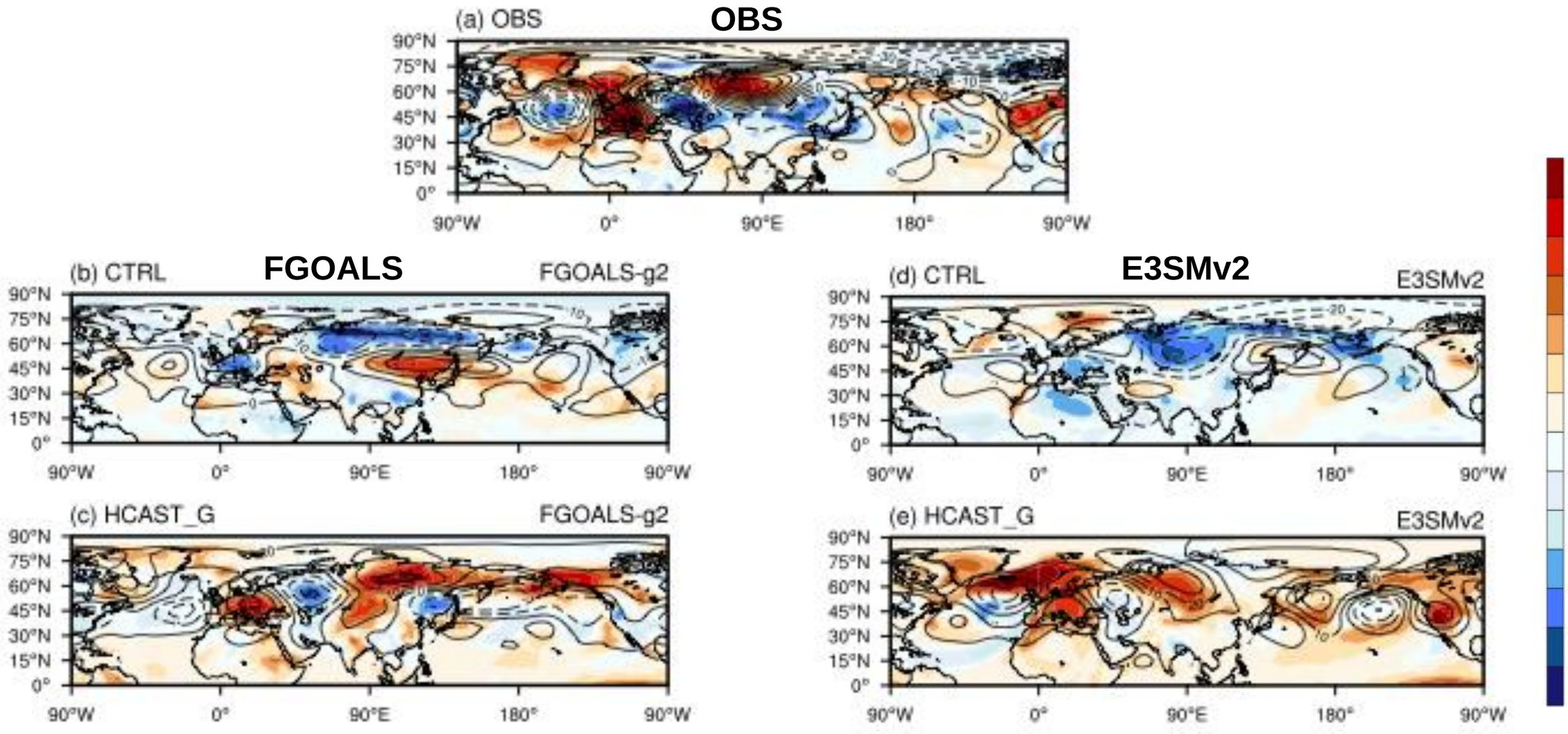
Experiment	Description
CTRL	Free running **fully coupled** simulation
ASSIM_G and ASSIM	Assimilate monthly mean **soil moisture and temperature globally (ASSIM_G) and over Tibetan Plateau only (ASSIM)** into a fully coupled climate simulation
HCAST_G and HCAST	**Initialized using the coupled model states from ASSIM_G and ASSIM** to perform hindcast simulations

- CTRL, ASSIM_G, and ASSIM: 36-year long continuous simulations (1980-2015)
- HCAST_G and HCAST: 5-year long simulations consisting of 10 ensemble members initialized one month apart (April – Jan) and separated by 5 years (1981, 1986, 1991, 1996, 2001, 2006) using restart files from ASSIM_G and ASSIM as initial conditions, respectively

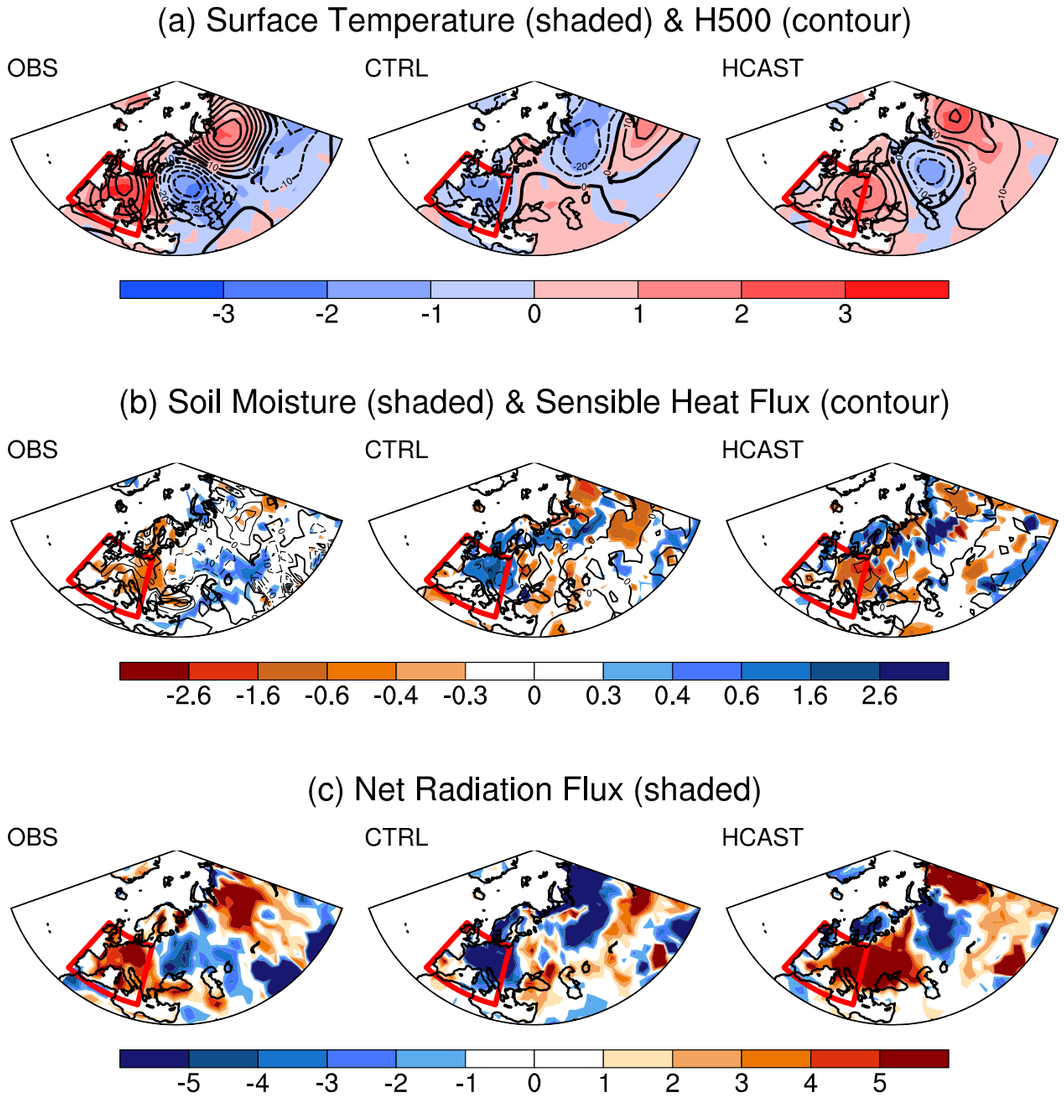
(Shi et al. 2021 Earth's Future; Shi et al. 2024 GMD; Shi et al. in review)

HCAST_G reproduces the observed Rossby wave train and anomalous warming in Europe

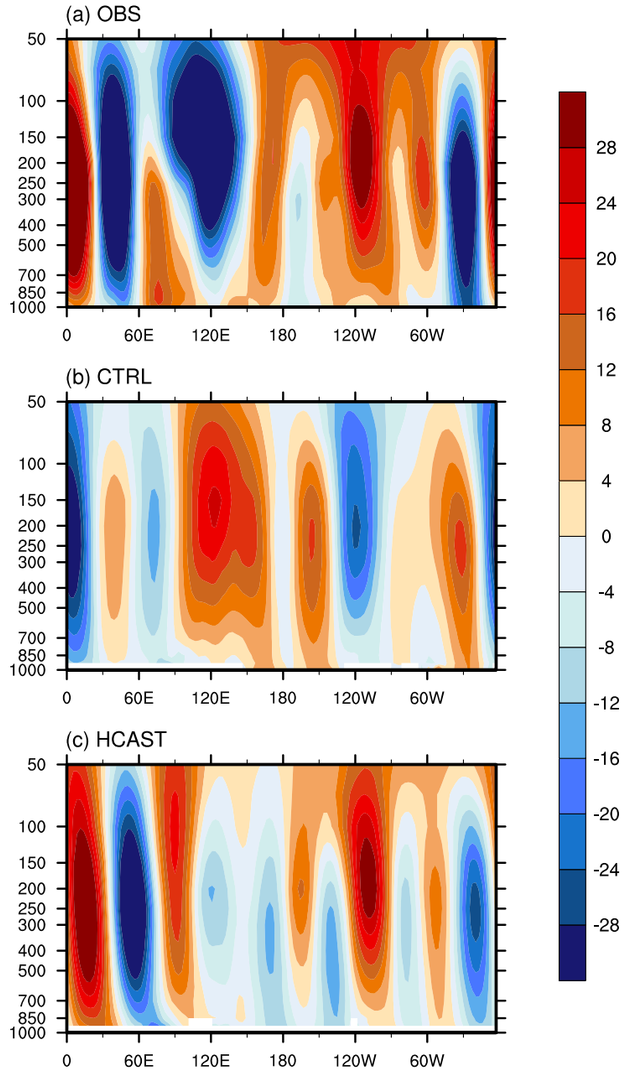
Surface temperature and 500 hPa anomalies



HCAST initialized in 2001 captures the 2003 European summer heatwave



Barotropic structure of height anomalies indicate long-range propagation



Hindcast sensitivity experiments to isolate the sources of predictability

Pattern correlation between experiments and observation of surface temperature over Europe in 2003

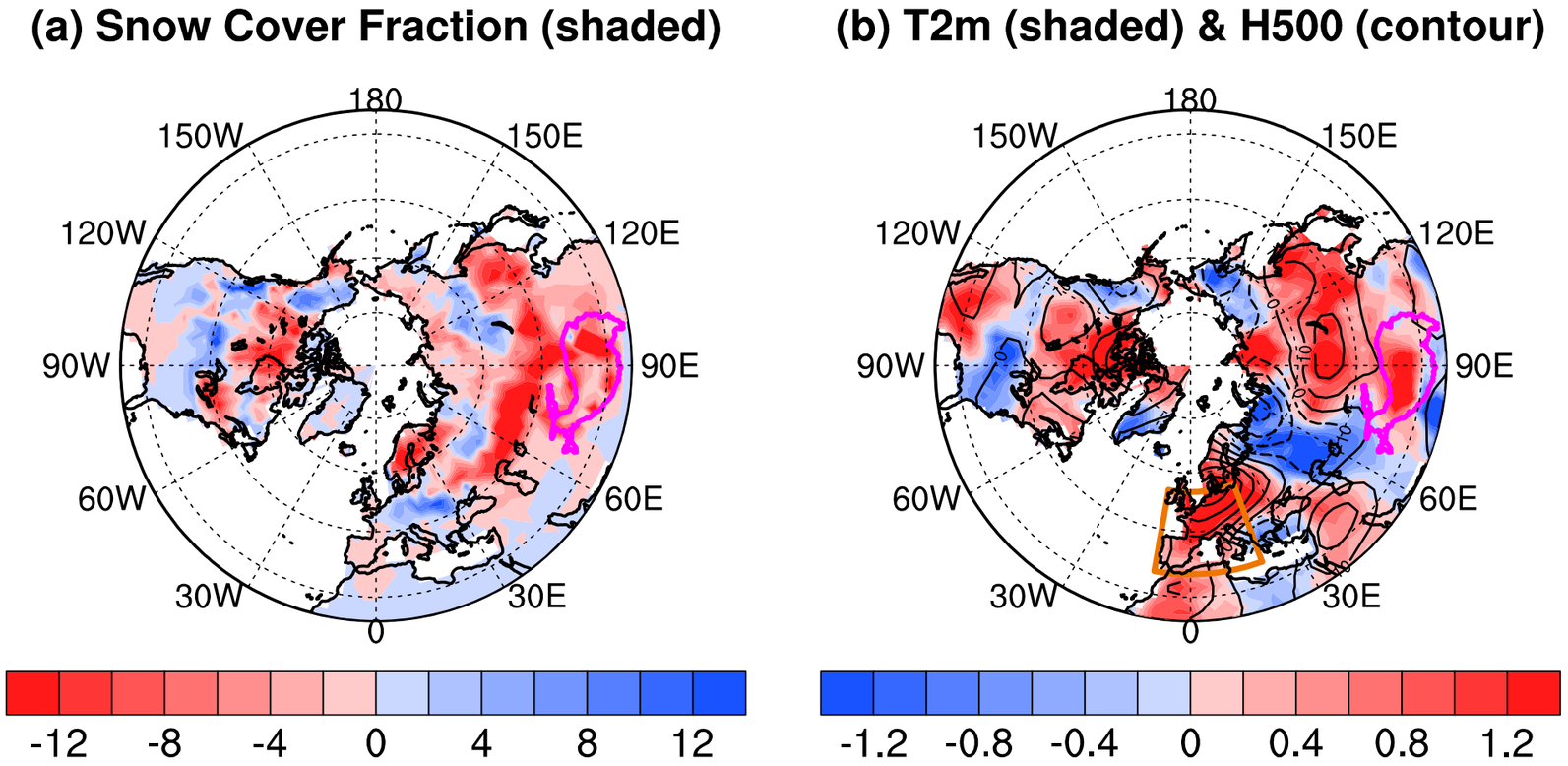
Experiment	Atmosphere	Land	Ocean	PCC
HCAST	ASSIM	ASSIM	ASSIM	**0.82**
SNS1	ASSIM	CTRL	ASSIM	-0.21
SNS2	ASSIM	ASSIM only over Tibetan Plateau	ASSIM	**0.80**
SNS3	CTRL	ASSIM only over Tibetan Plateau	CTRL	**0.56**
SNS4	CTRL	ASSIM only over Tibetan Plateau	ASSIM	**0.65**
SNS5	ASSIM	ASSIM only over Tibetan Plateau	CTRL	**0.55**
SNS6	CTRL	CTRL	ASSIM	-0.41

Impact of land

Impact of ocean

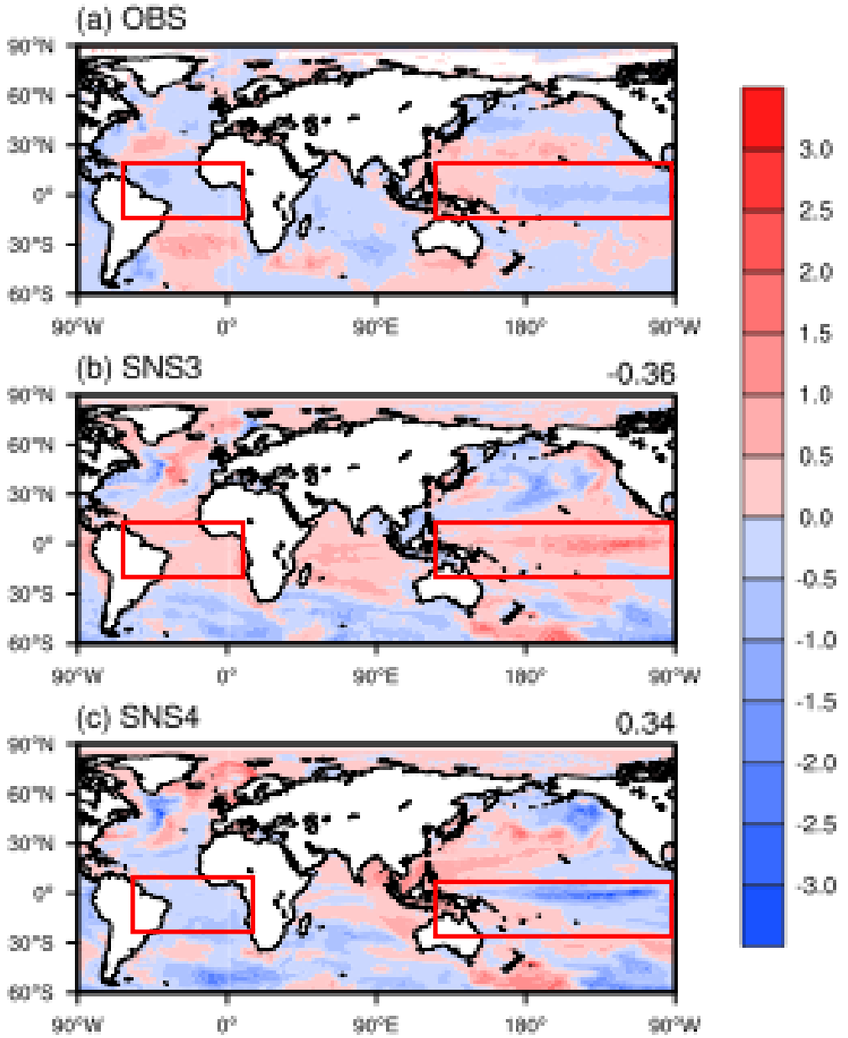
Large differences in snow cover and surface temperature between SNS1 (from CTRL) and SNS2 (from ASSIM) in spring 2003

Reduced snow cover and warmer surface temperature in spring of 2003 when initialized from ASSIM in 2001

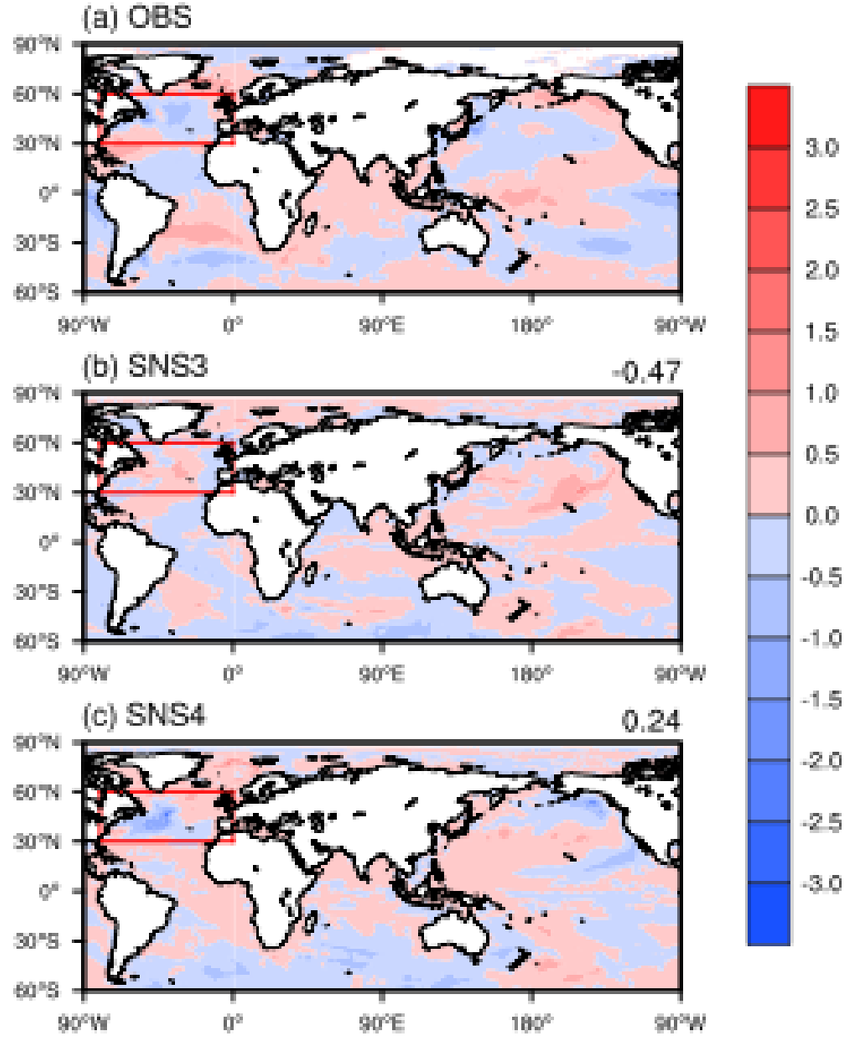


Large differences in the SST initial conditions between SNS3 (from CTRL) and SNS4 (from ASSIM) in 2001 that persist in 2003

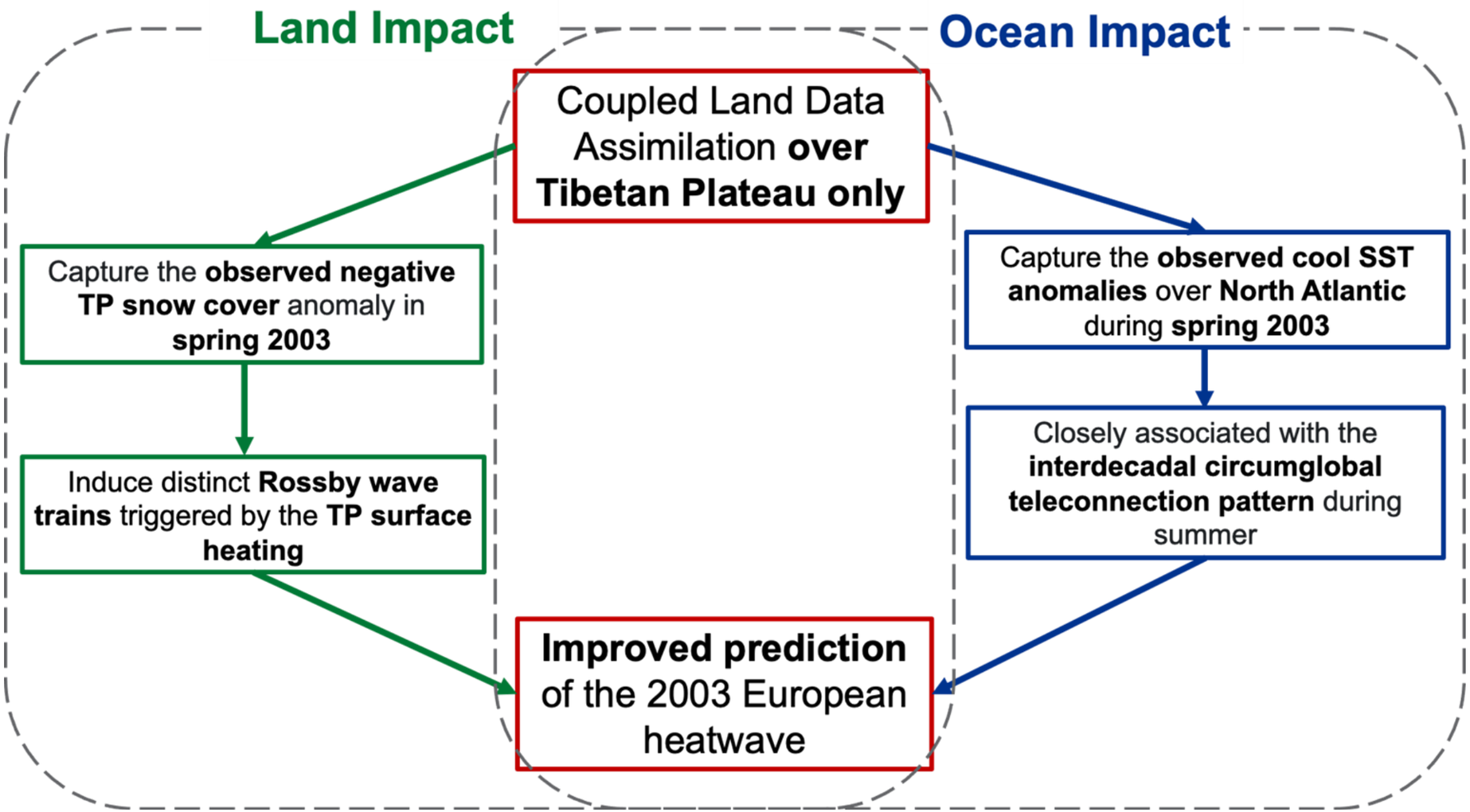
SST anomalies in January 2001



SST anomalies in January 2003



Mechanistic connections: remote influence of land over land and ocean



(Shi et al. in review)

Gaps and Opportunities

- Data assimilation can play an important role in hindcast experiments to understand predictability and improve predictions of extreme events
- Data assimilation approaches may have different impacts (e.g., uncoupled or coupled, 3D vs. 4D approaches) – more systematic analysis and comparison with hindcast experiments are needed to understand the impacts of DA
- How land influence atmosphere/ocean locally and remotely to provide predictability of extreme events needs more research
- A model hierarchy can help understand predictability of extreme events
- Extreme events in the extratropics are strongly influenced by atmospheric circulations – storyline simulations that isolate the thermodynamics effects may be insufficient to provide actionable information about future changes in extreme events (probability and intensity)

Summary

- Soil moisture and temperature has important effects on interannual-to-decadal variability
- Assimilating soil moisture and temperature over the TP alone improves hindcast of the 2003 European summer heatwave in both FGOALS and E3SMv2
  - HCAST initialized from ASSIM in 2001 better predicts anomalies of **snow cover (low)** and **surface temperature (warm)** over the TP and **North Atlantic SST anomalies (cool)**, contributing to predictability of the 2003 European heatwave 2 years in advance
  - Initializing hindcasts using the balanced states from ASSIM enhances skill
- DRP-4DVar implemented in FGOALS and E3SM confirmed that DRP-4DVar reduces model drift by assimilating analysis data through fitting them to the trajectory of the coupled model in the one-month assimilation window (He et al. 2017)

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Thank you