Quantifying sources of subseasonal prediction skill in CESM2

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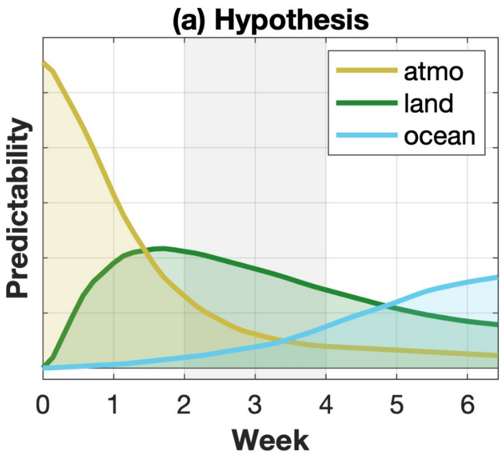
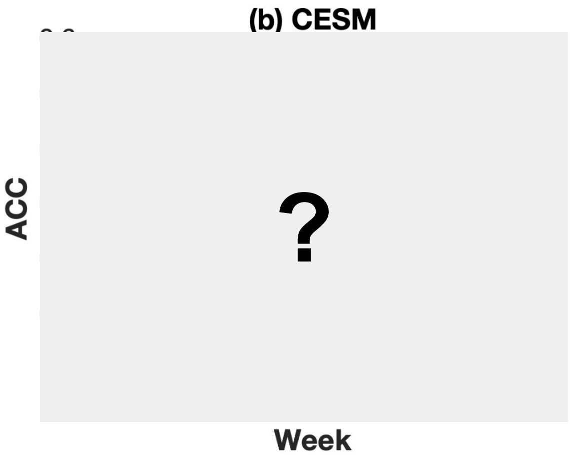
Goal

To <u>quantify</u> how much subseasonal predictability comes from the <u>initial state</u> of atmosphere, land, and ocean/sea-ice.

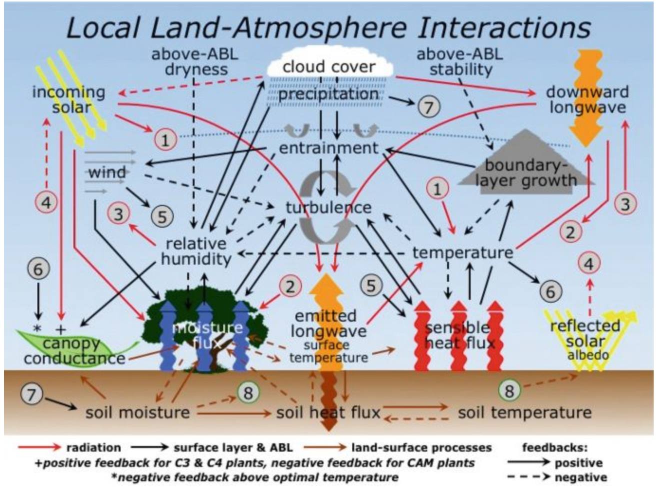


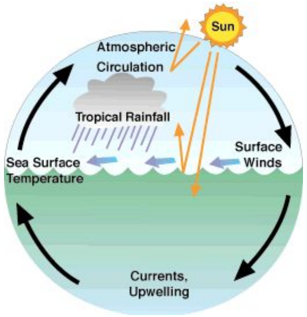
Recreated figure by Paul Dirmeyer: representative of predictability of mid-latitude surface temperature over land

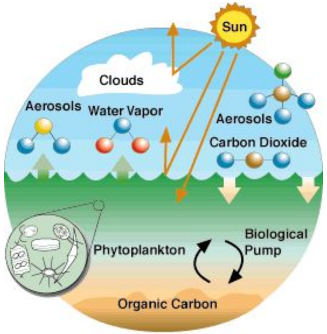


Additional Sources?

- Diagram assumes ATM, LND, OCN are independent, but they are not ….
- Land and atmosphere are tightly coupled near the surface: Land-atmosphere interact with each other very quickly
- Atmosphere & ocean interact as well (slower timescale)





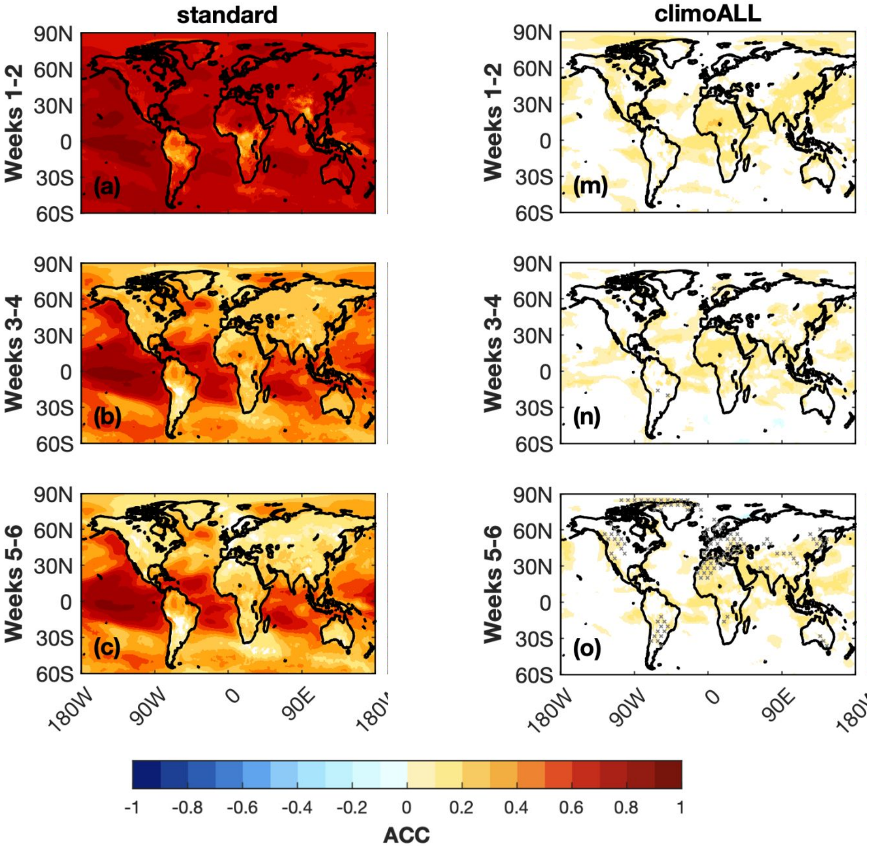


Methods

- **Calculate skill for 2m Temperature and Precipitation: Weeks 1- 2, Weeks 3-4, Weeks 5 -6**
  - Anomaly Correlation Coefficient (ACC)
  - "Observations" come from ERA5 (2m Temperature) and GPCP (Precipitation) although CPC is comparable
- **Standard reforecast set** (realistic ATM, LND, OCN initialization)
  - 1999 - 2020; weekly initializations; 11 member ensemble
- **Seven additional reforecast sets with various initial states set to climatology**
  - climoATM
  - climoLND
  - climoOCN
  - climoOCNclimoLND
  - climoOCNclimoATM
  - climoATMclimoLND
  - climoALL (all components climo)

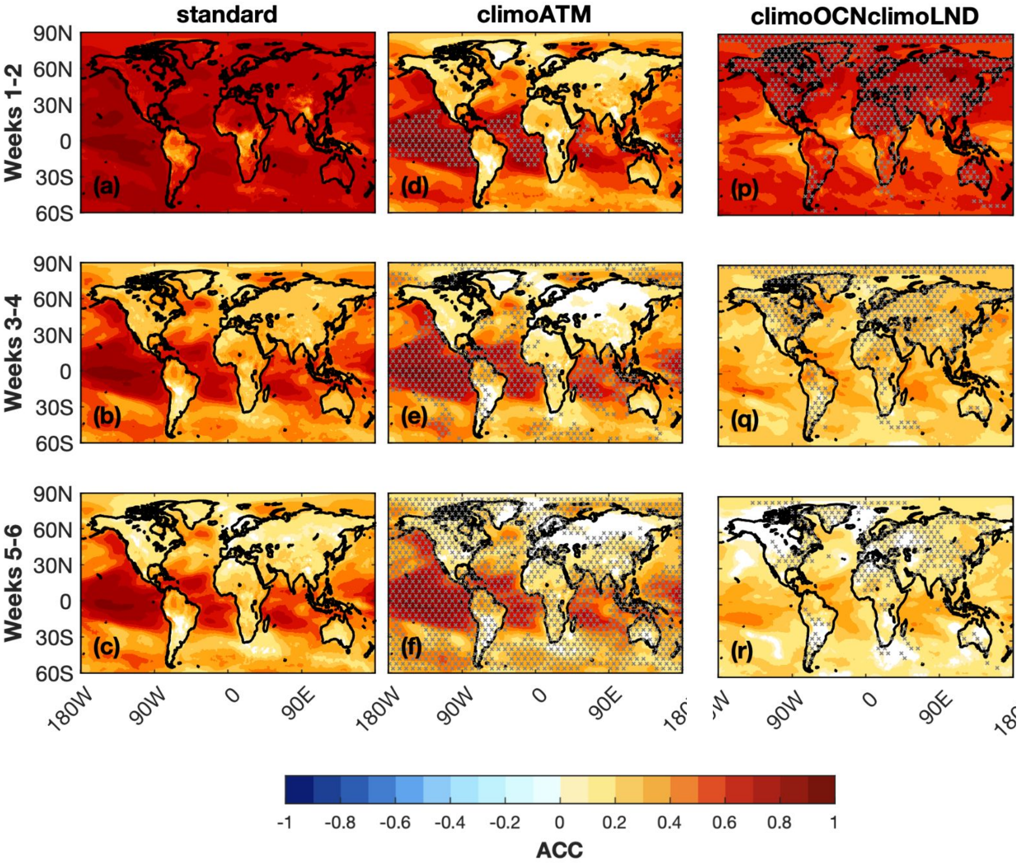
Annual Mean 2m Temperature ACC

- 2m T skill over land decreases very quickly with time
- Most skill:
  S. America, parts of Africa
- ACC over tropical oceans ~ 1



- No skill in climoALL runs through week 4

Annual Mean 2m Temperature ACC: Role of Atmosphere



Weeks 1-2: Almost all skill in NH land regained just with ATM initialization; Not true over S. America

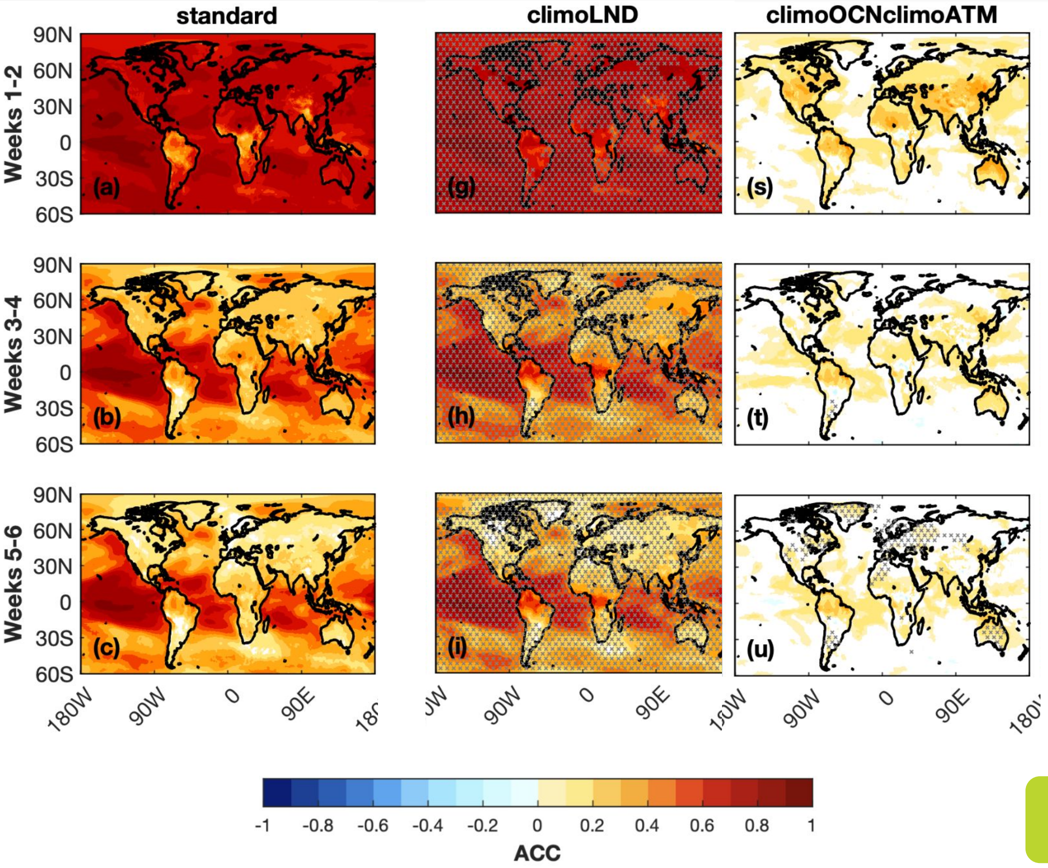
Weeks 3-4: Majority of skill gained from ATM initialization (not all) over NH land

Weeks 5-6: Mostly not statistically different from standard forecast

Annual Mean 2m Temperature ACC: Role of Land

Weeks 1-2: No loss of skill with climatological initialization
Gain of skill in S. America
Parts of Africa

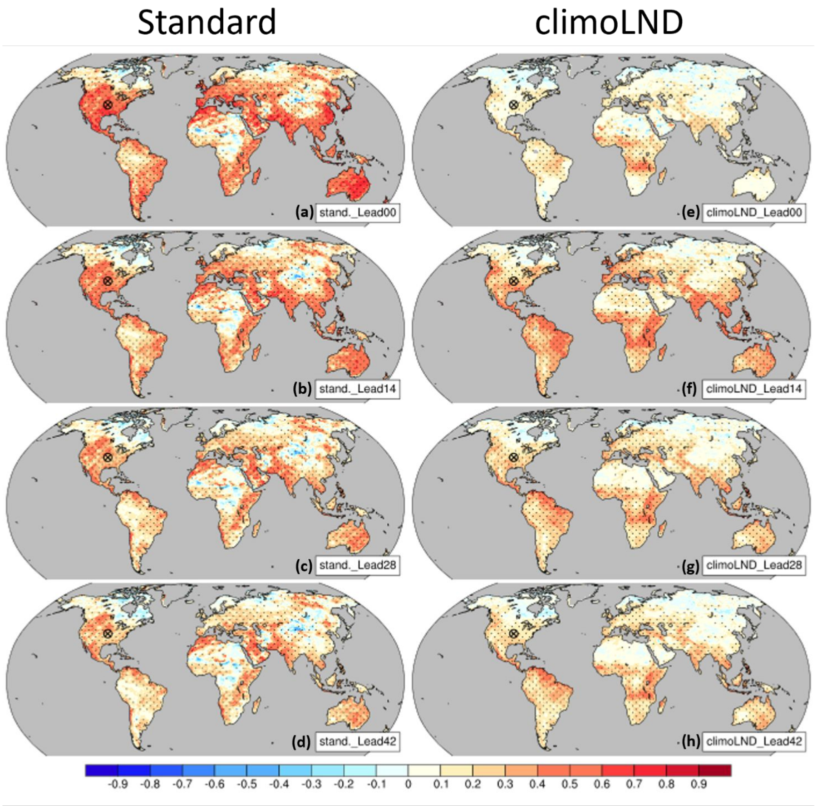
Weeks 3-6: Gain of skill over S. America & central Africa from climatological conditions



Initializing land only brings in some skill (much more than lost due not initializing)

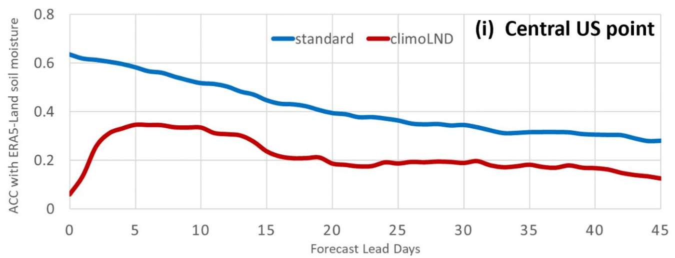
Not expected!

Soil Moisture Forecast



Soil Moisture forecast as expected:

Better forecast when initialized realistically
(Not translating to better 2m T forecast - why?)



By week 2 (beyond), over S. America and central Africa, better soil moisture skill with climoLND initialization

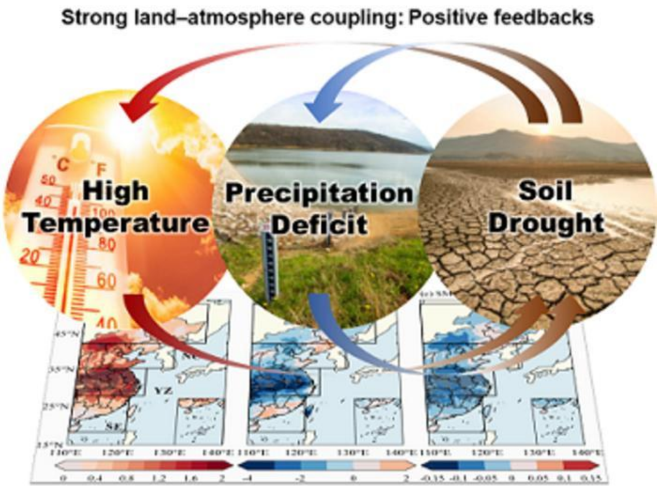
Land-atmosphere Coupling

- **High-soil moisture** -> increased evaporative cooling
  -> Negative T anomalies

- **Soil drought** - > positive T anomalies

- **Highest interaction:** both strong soil moisture-evaporation coupling and long soil moisture memory (Guo et al 2011)

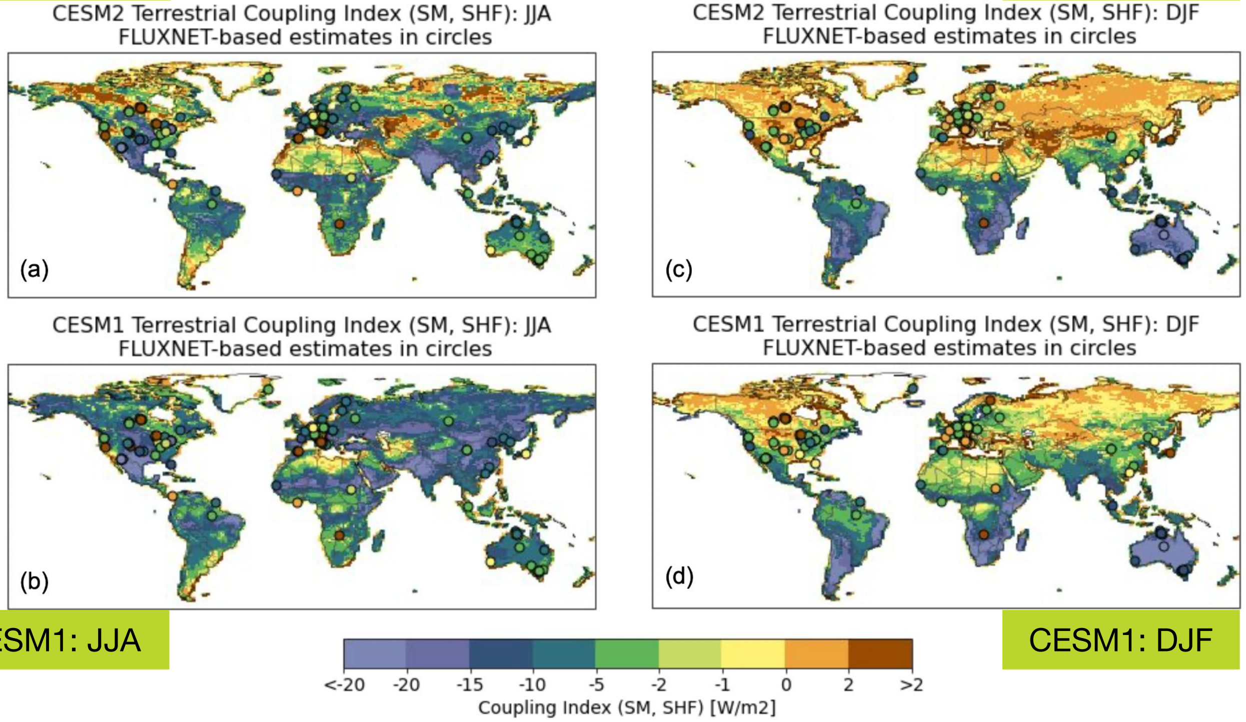
- High soil moisture predictability in N. America throughout Spring and Summer, however Low atmospheric predictability due to low atmos-land coupling strength (Guo et al 2011)



Land-atmosphere coupling

CESM2: JJA

CESM2: DJF



CESM1: JJA

CESM1: DJF

CESM2: Strong and negative coupling in summer hemisphere

SH: similar to CESM1 (and to OBS)

NH: weaker in CESM2 than in CESM1

Weaker impact of soil moisture on surface fluxes in NH winter in CESM2

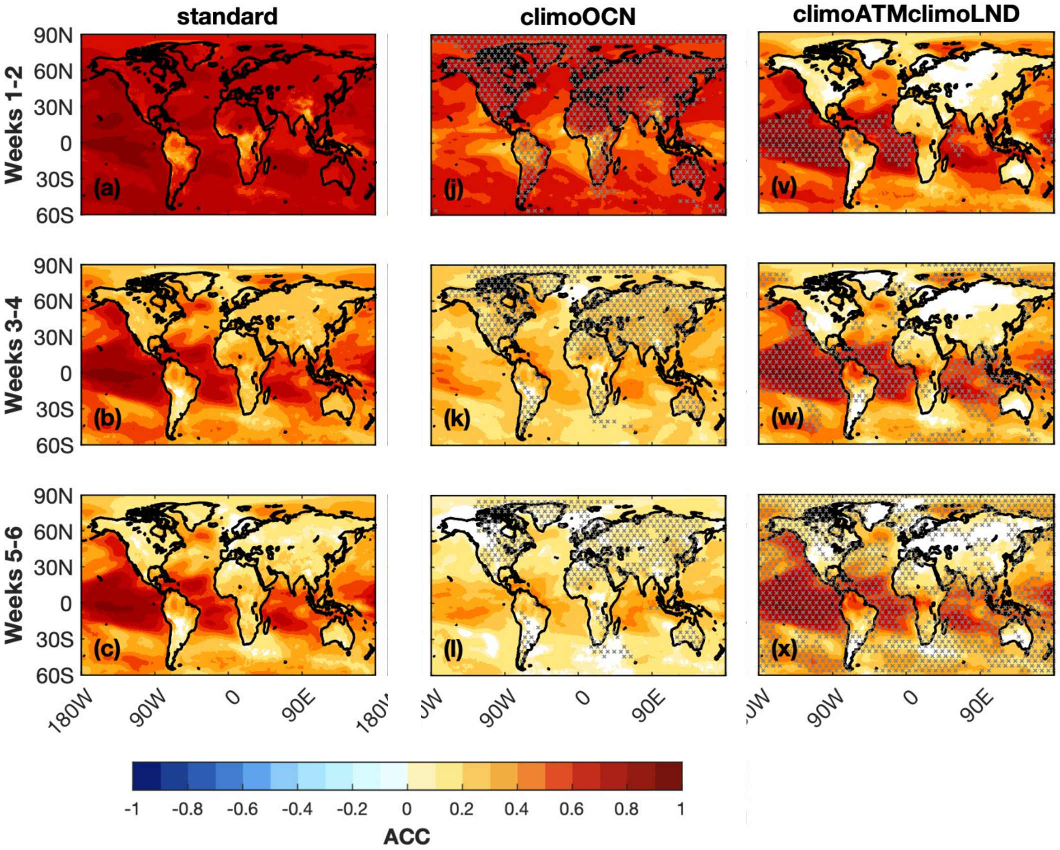
Fig from Meg Fowler

Annual Mean 2m Temperature ACC: Role of Ocean

Weeks 1-2: No loss of skill with **over land** climatological initialization

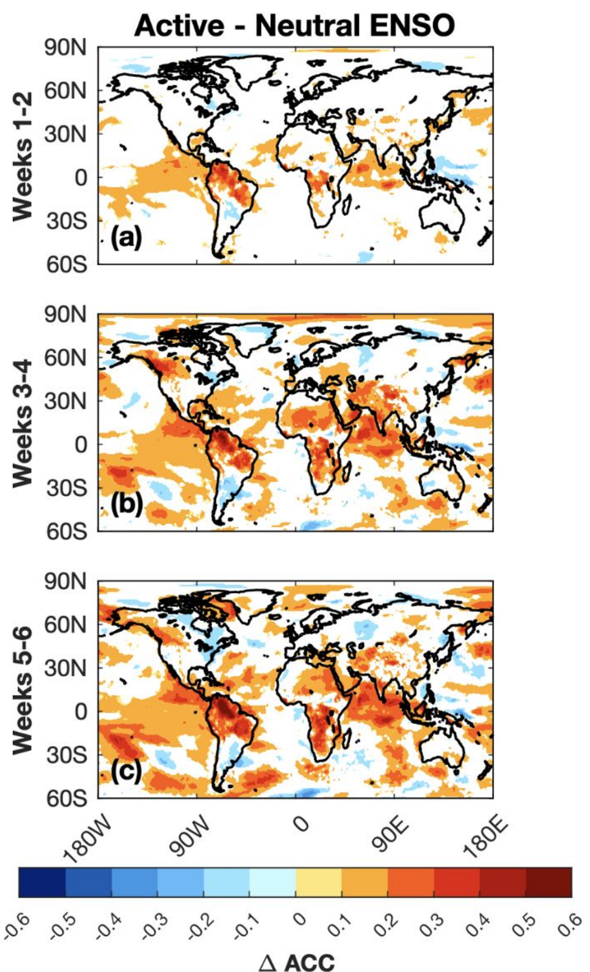
Weeks 3-4: Little loss of skill **over land** with climatological initialization

Weeks 5-6: Little loss of skill **over land** with climatological initialization in extratropics
Reduced skill over Tropical Land



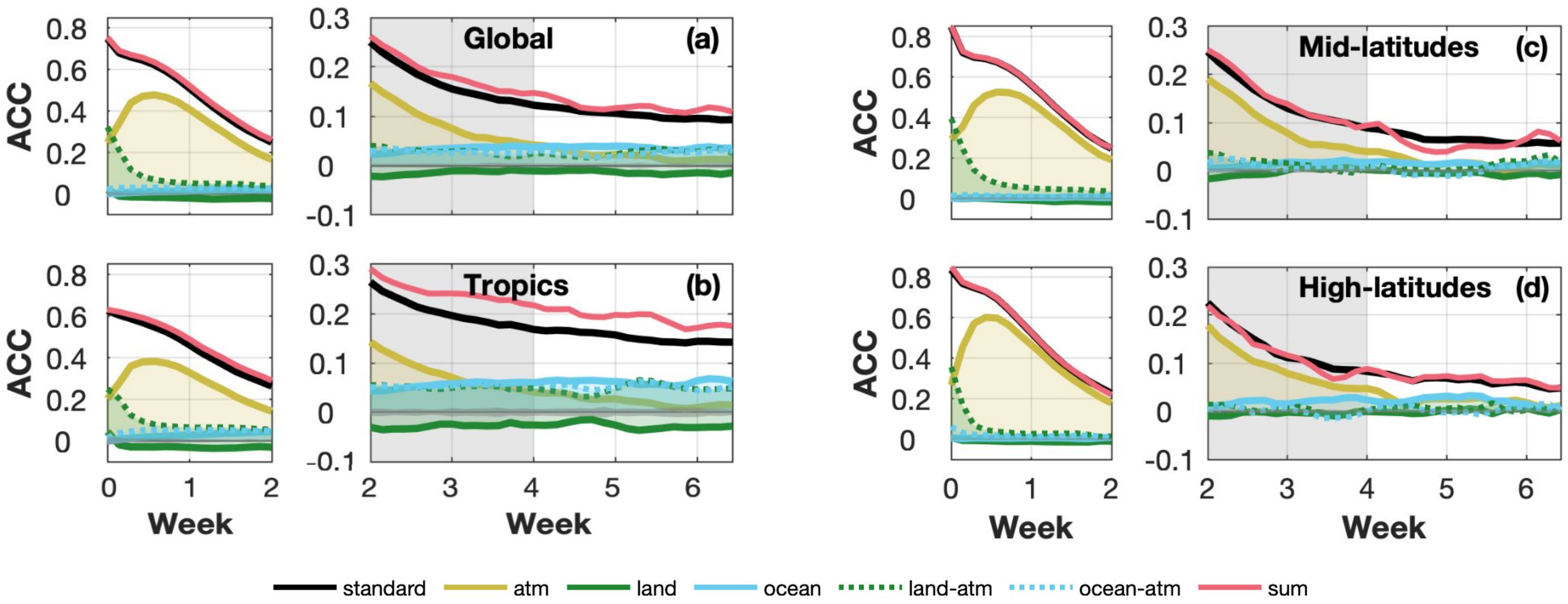
Role of ENSO

- Increased T skill in ENSO years;
- Benefit in weeks 3-4 and week 5-6
- Mostly in the Tropics: S. America and Africa
- Also in North-West N. America



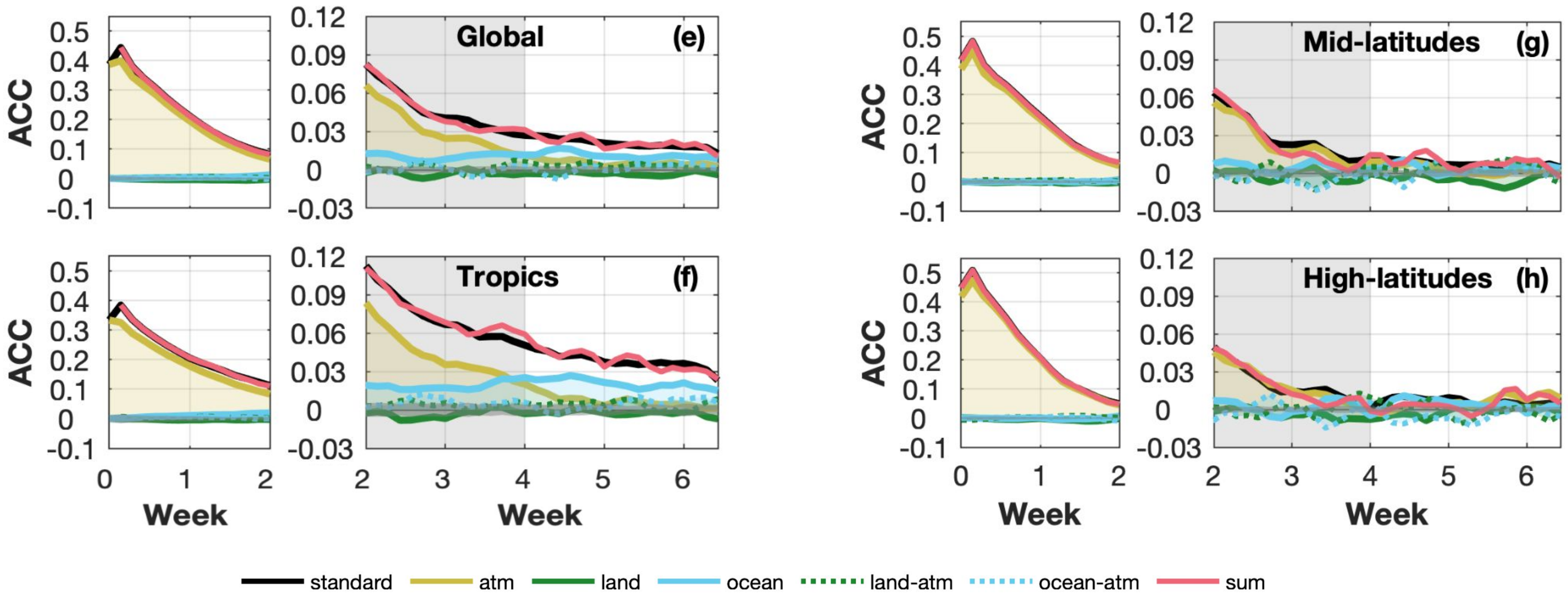
Role of ocean beginning to grow in subseasonal window

Annual Mean 2m Temperature ACC



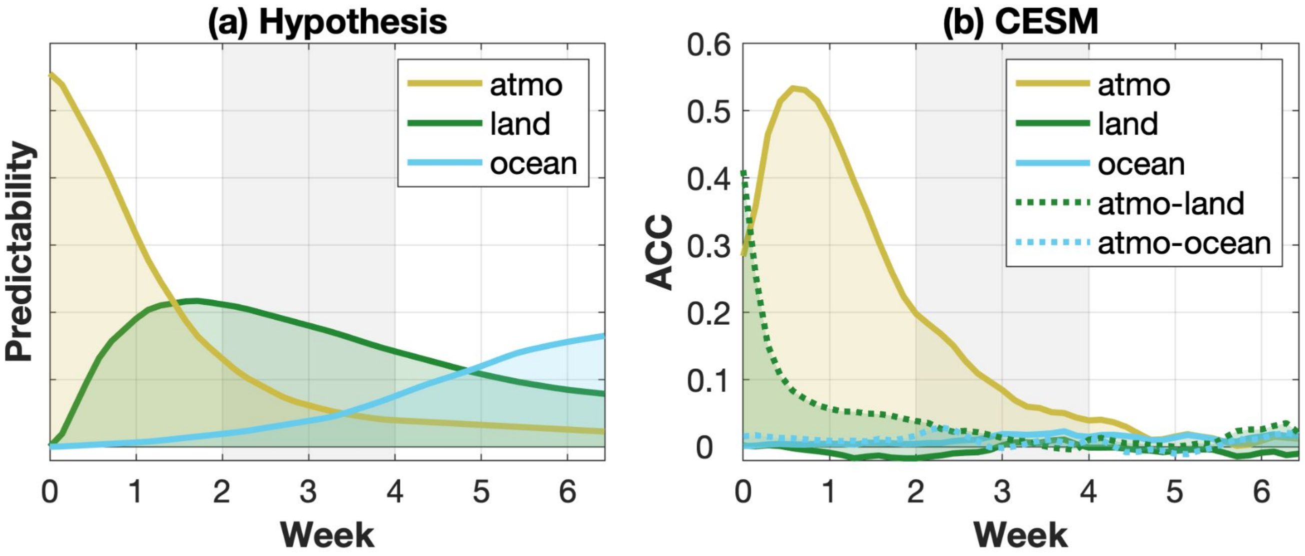
Response is pretty linear

Annual Mean Precipitation ACC



Response is pretty linear

Mid-Latitude (30N-60N) Annual Mean 2m Temperature ACC



Predictability sources very different from hypothesis in CESM

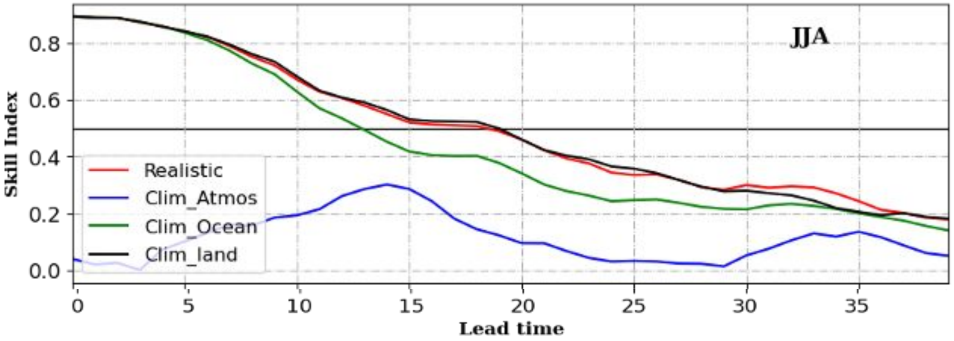
Discussion

- Results suggest that **atmospheric initial state is the dominant source of 2m air temperature predictability through weeks 3-4** for the majority of land areas, especially in the extratropics
- **Land IC plays a small role in the CESM2(CAM6) subseasonal system** and higher subseasonal skill for surface temperature can be obtained with climatological land initialization
    - Land-coupling not strong enough in CESM2
- Predictability from the **ocean initial state** comparable to that in the atmosphere **in the tropics only**
    - slightly increased skill during active ENSO
- Atmospheric initial state is the main driver of subseasonal **precipitation** skill over extratropical land
    - except for South America and SE Asia/Australia
- Prediction skill seems to be fairly linear

Work published on March 4 in NPJ Climate & Atmospheric Science:
https://www.nature.com/articles/s41612-024-00595-4

Data & Next Steps

- Raina Roy (Monash U) looking at MJO



- Yanan Duan & Sanjiv Kumar (Auburn U) looking at soil moisture in detail

- Available online: https://www.earthsystemgrid.org/dataset/ucar.cgd.cesm2.s2s_hindcasts.cesm2.climo.html
- NCAR casper: /glade/campaign/cesm/development/cross-wg/S2S/CESM2/
- DOI: https://doi.org/10.5065/0s63-m767

Sources of Predictability

Reforecast Set	climatology of all 3 components	variability due to anomalies			coupling between components		
	$Clim_{ALL}$	V_A	V_L	V_O	C_{AL}	C_{AO}	C_{LO}
climoALL *ATM: climatology* *LND: climatology* *OCN: climatology*	Clim	X	X	X	X	X	X
climoOCNclimoLND *ATM: realistic* *LND: climatology* *OCN: climatology*	Clim		X	X			X
climoOCNclimoATM *ATM: climatology* *LND: realistic* *OCN: climatology*	Clim	X		X		X	
climoATMclimoLND *ATM: climatology* *LND: climatology* *OCN: realistic*	Clim	X	X		X		

How do we quantify the sources of predictability?

(1) **standard** = $Clim_{ALL} + \mathbf{V_A + V_L + V_O} + C_{AL} + C_{AO} + C_{LO}$

(2) **climoATM** = $Clim_{ALL} + V_L + V_O + C_{AL} + C_{AO} + C_{LO}$
(3) **climoLND** = $Clim_{ALL} + V_A + V_O + C_{AL} + C_{AO} + C_{LO}$
(4) **climoOCN** = $Clim_{ALL} + V_A + V_L + C_{AL} + C_{AO} + C_{LO}$

(5) **climoOCNclimoLND** = $Clim_{ALL} + V_A + C_{AL} + C_{AO}$
(6) **climoOCNclimoATM** = $Clim_{ALL} + V_L + C_{AL} + C_{LO}$
(7) **climoATMclimoLND** = $Clim_{ALL} + V_O + C_{AO} + C_{LO}$

(8) **climoALL** = $Clim_{ALL}$

(9) sum = $Clim_{ALL} + V_A + V_L + V_O + C_{AL} + C_{AO}$
(10) sum ≈ **standard**

When **climatological** initial conditions are **used for a single component**, we can remove that component's variability term. We assume that the average coupling between the components do not change much between the reforecast sets.

When **climatological** initial conditions are **used for two components**, we assume their two variability terms are negligible, along with their shared coupling term

Assuming that the **land-ocean coupling C_{LO} is nearly zero** over land, we can then use the earlier variability results (V_L and V_O) to solve for C_{AL} and C_{AO}. If the linearity assumption holds, we should be able to retrieve the standard ACC by adding the individual components.