Adaptive Bias Correction for Improved Subseasonal Forecasting

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MACHINE LEARNING FOR SubS - MOTIVATION

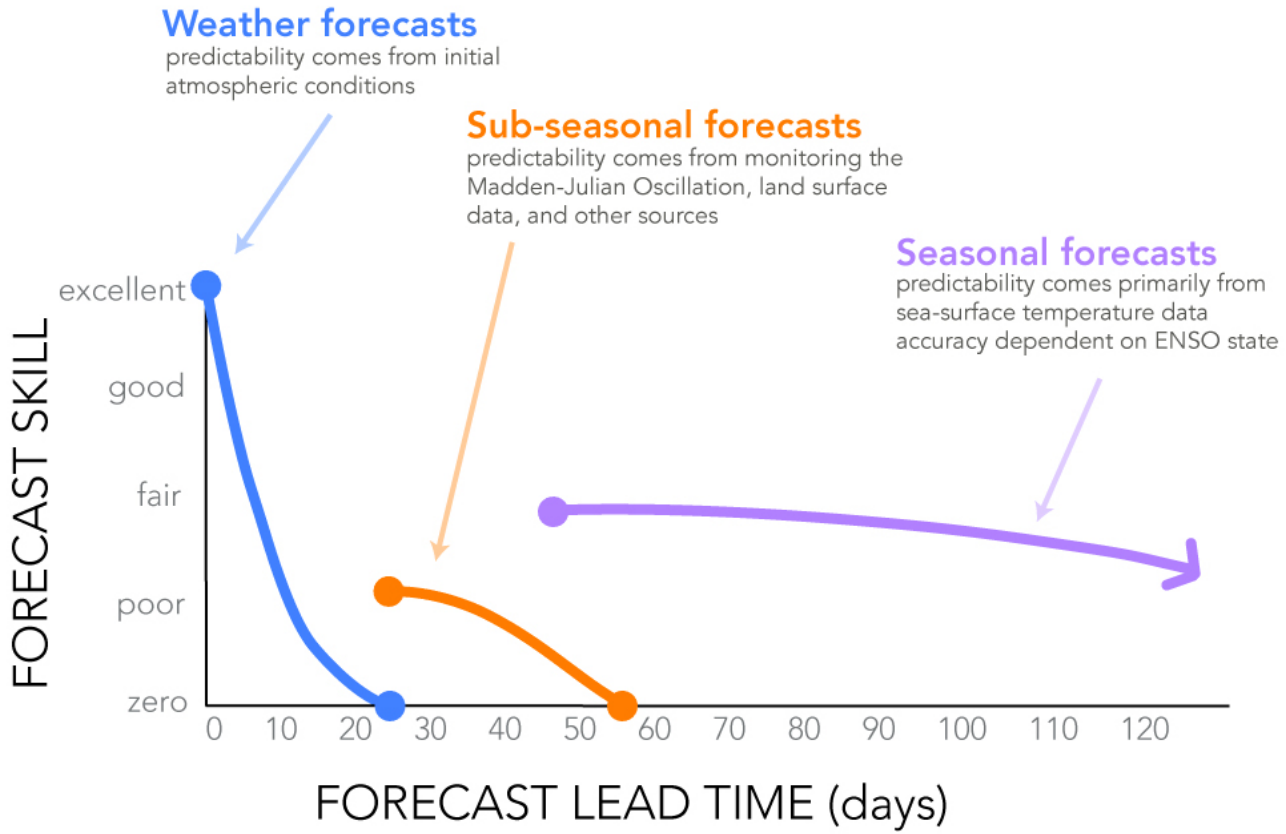
- **What:** Predicting temperature and precipitation 2 – 6 weeks out

- **Why:**

  Allocating water resources
  Managing wildfires
  Preparing for weather extremes
  Energy pricing

- **Problem:** **Subseasonal forecasts** have poor skill

MACHINE LEARNING FOR SubS - MOTIVATION



Source: https://iri.columbia.edu/news/qa-subseasonal-prediction-project/

Concern:

- Community not making the best use of historical data in weather and climate forecasting
- Landscape dominated by **dynamical models**, purely physics-based models of atmospheric and oceanic evolution

MACHINE LEARNING FOR SubS - METHODS

Forecasting tasks

Target variables:
- Average temperature
- Accumulated precipitation

Lead times:
- Weeks 3-4 ahead
- Weeks 5-6 ahead

Geographical region: U.S., 1°x1° resolution

Loss function: RMSE

Dataset: Subseasonal Climate USA dataset

Models

Baseline models:
- Climatology
- CFSv2
- Persistence

Learning models:
- Autoknn
- Informer
- Localboosting
- MultiLLR
- N-BEATS
- Prophet
- Salient 2.0

Our toolkit:
- Climatology++
- CFSv2++
- Persistence++

MODEL SKILL ON TEST DATA (2011 - 2020)

Model	% Improvement over Mean Deb. CFSv2 RMSE				Average % Skill			
	Temperature		Precipitation		Temperature		Precipitation	
	weeks 3-4	weeks 5-6	weeks 3-4	weeks 5-6	weeks 3-4	weeks 5-6	weeks 3-4	weeks 5-6
Climatology++	2.06	4.83	**8.86**	**8.57**	18.61	18.87	15.04	14.99
CFSv2++	5.94	**7.09**	8.37	8.06	32.38	**29.19**	**16.34**	**16.09**
Persistence++	**6.00**	6.43	8.61	7.89	**32.4**	26.73	13.38	9.77

Want: An Ensemble of these 3 Learning Models

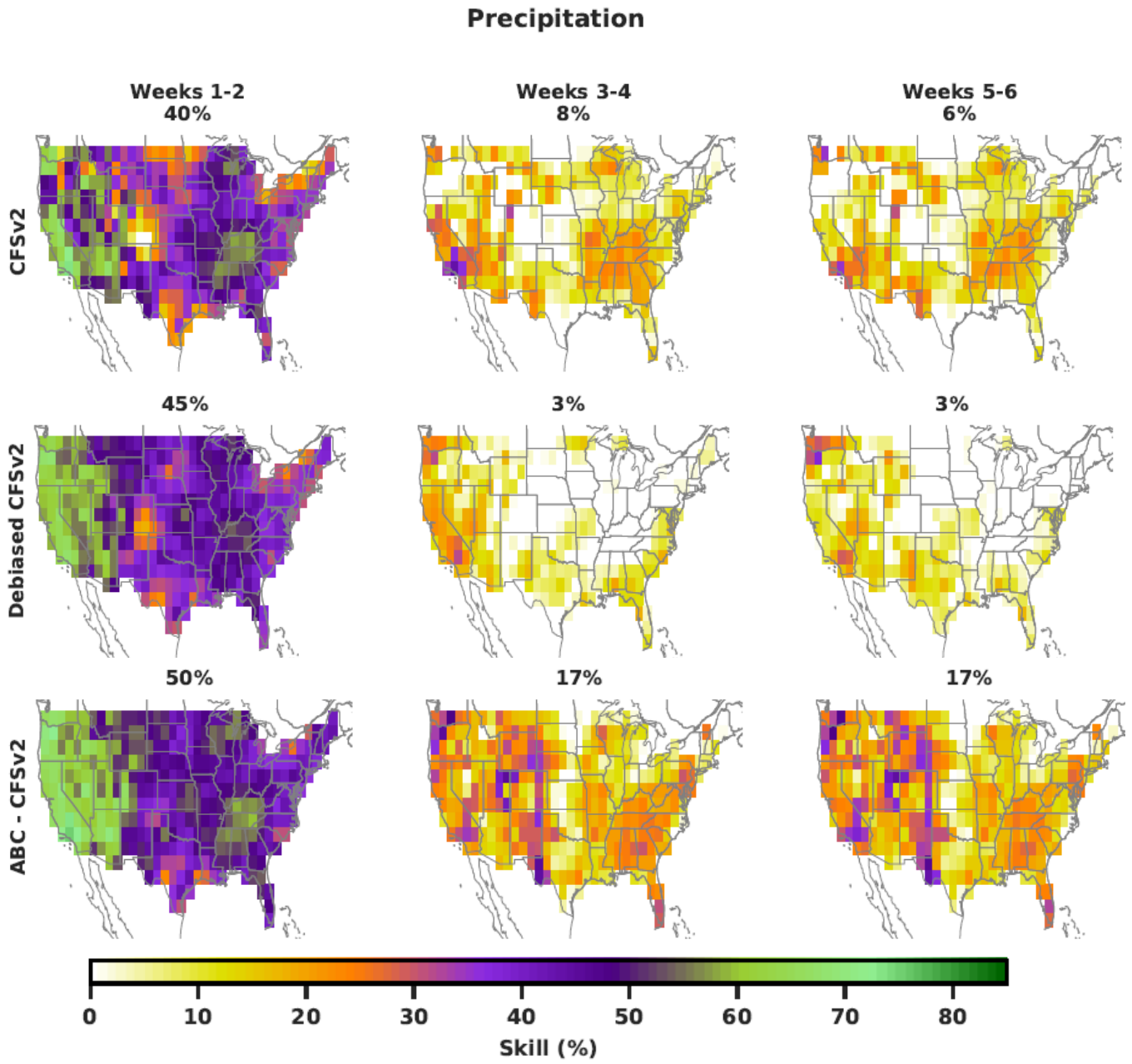
➔ **Adaptive Bias Correction (ABC)**

MODEL SKILL ON TEST DATA (2011 - 2020)

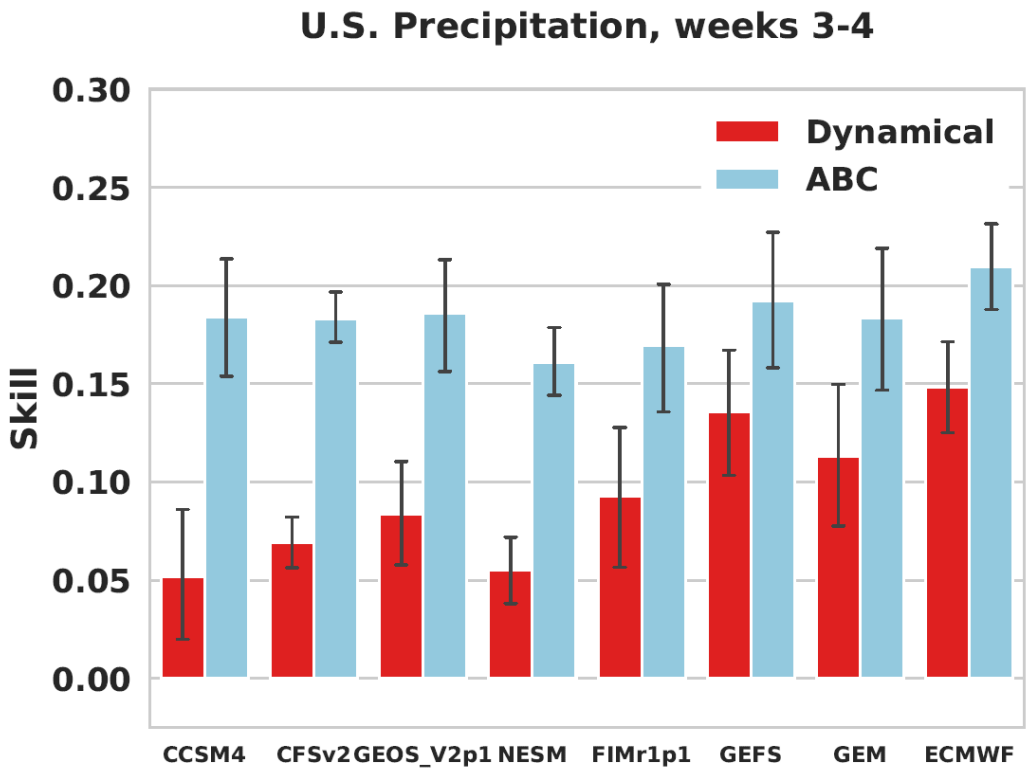
CFSv2 = Climate Forecasting System v2,
US operational dynamical model

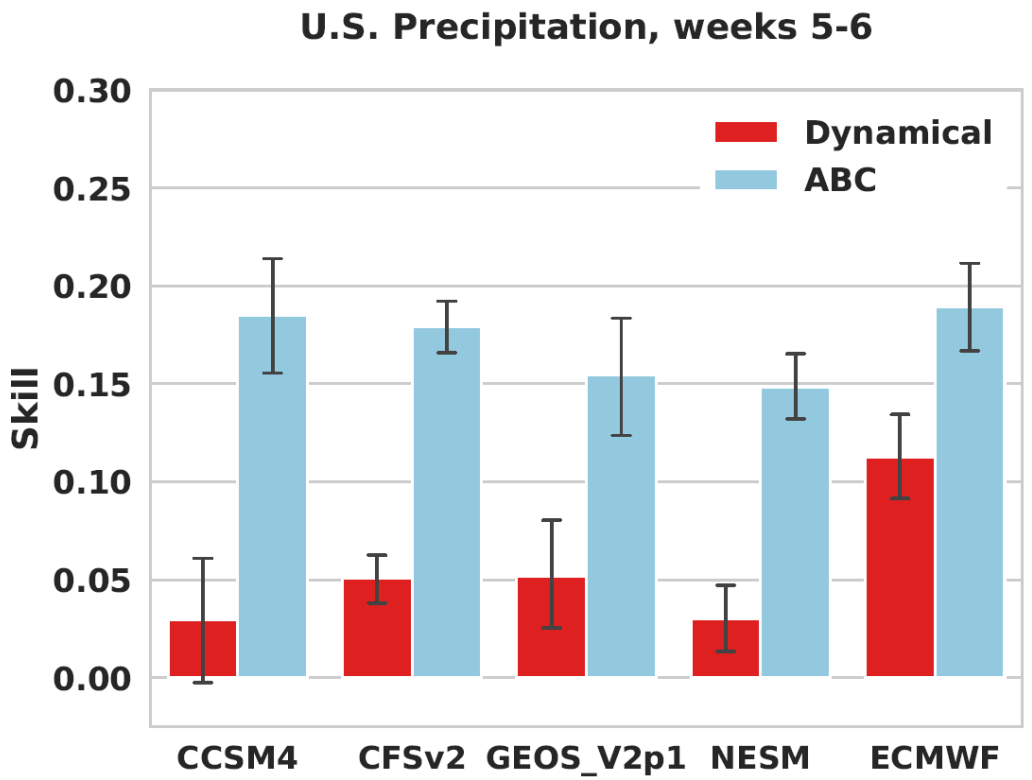
Debiased CFSv2

Adaptive Bias Correction (ABC)



Adaptive Bias Correction (ABC): Hybrid Physics + Learning Model

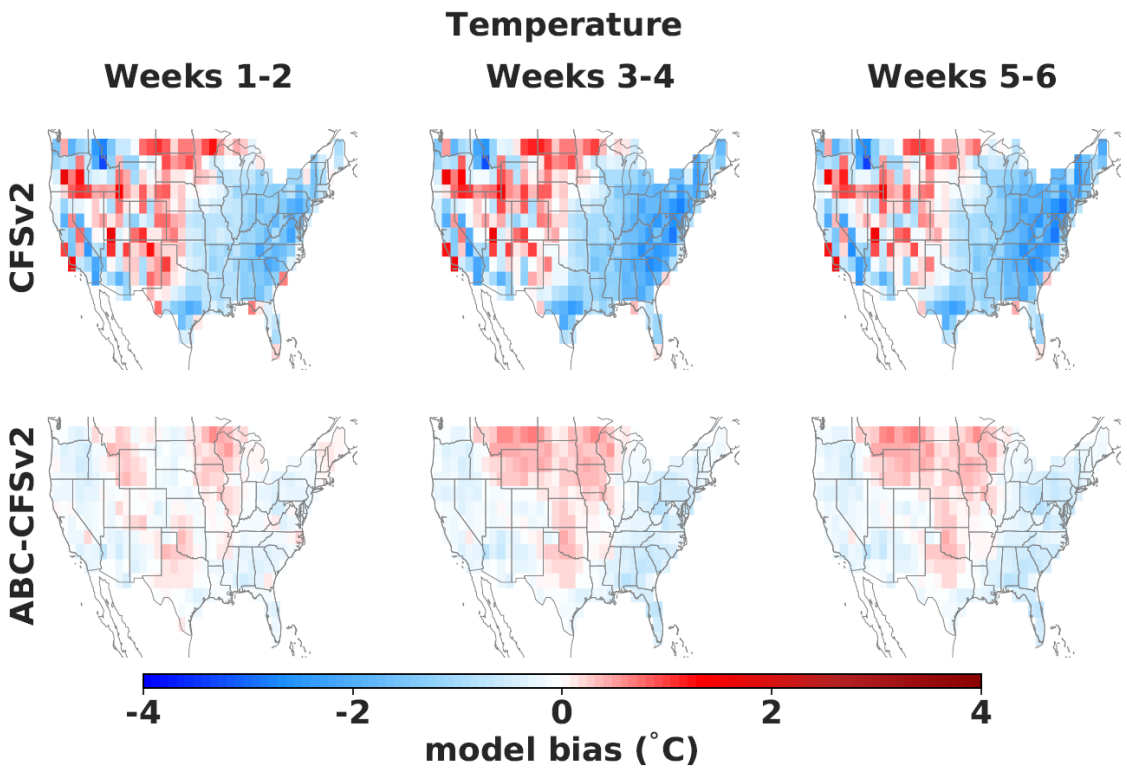


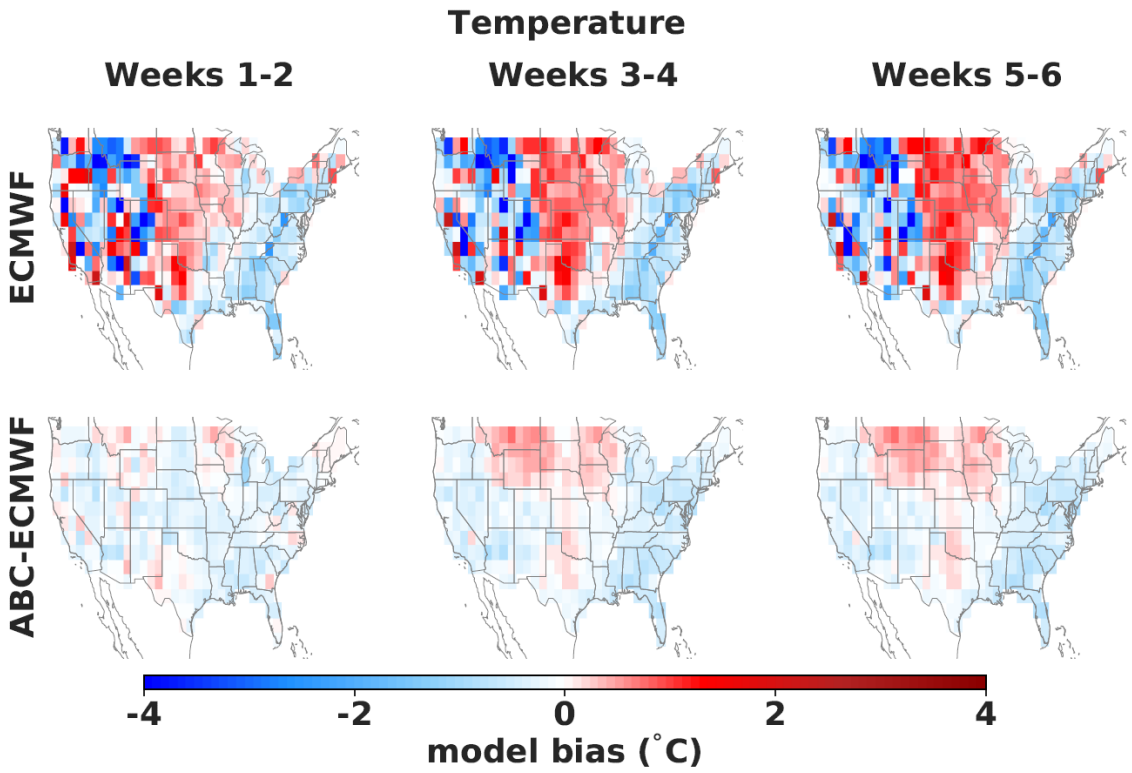


- **Takeaway:**
  - ABC can be used to correct any dynamical model
  - including ECMWF (European Centre for Medium-Range Weather Forecasts), the leading subseasonal model

ABC Reduces Systematic Model Bias

Spatial distribution of model bias over the years 2018–2021



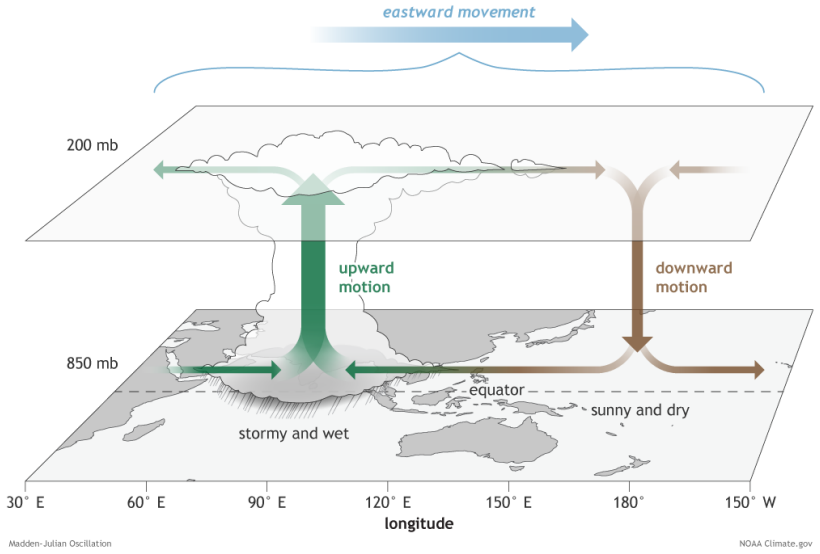


CFSv2 = U.S. operational dynamical model

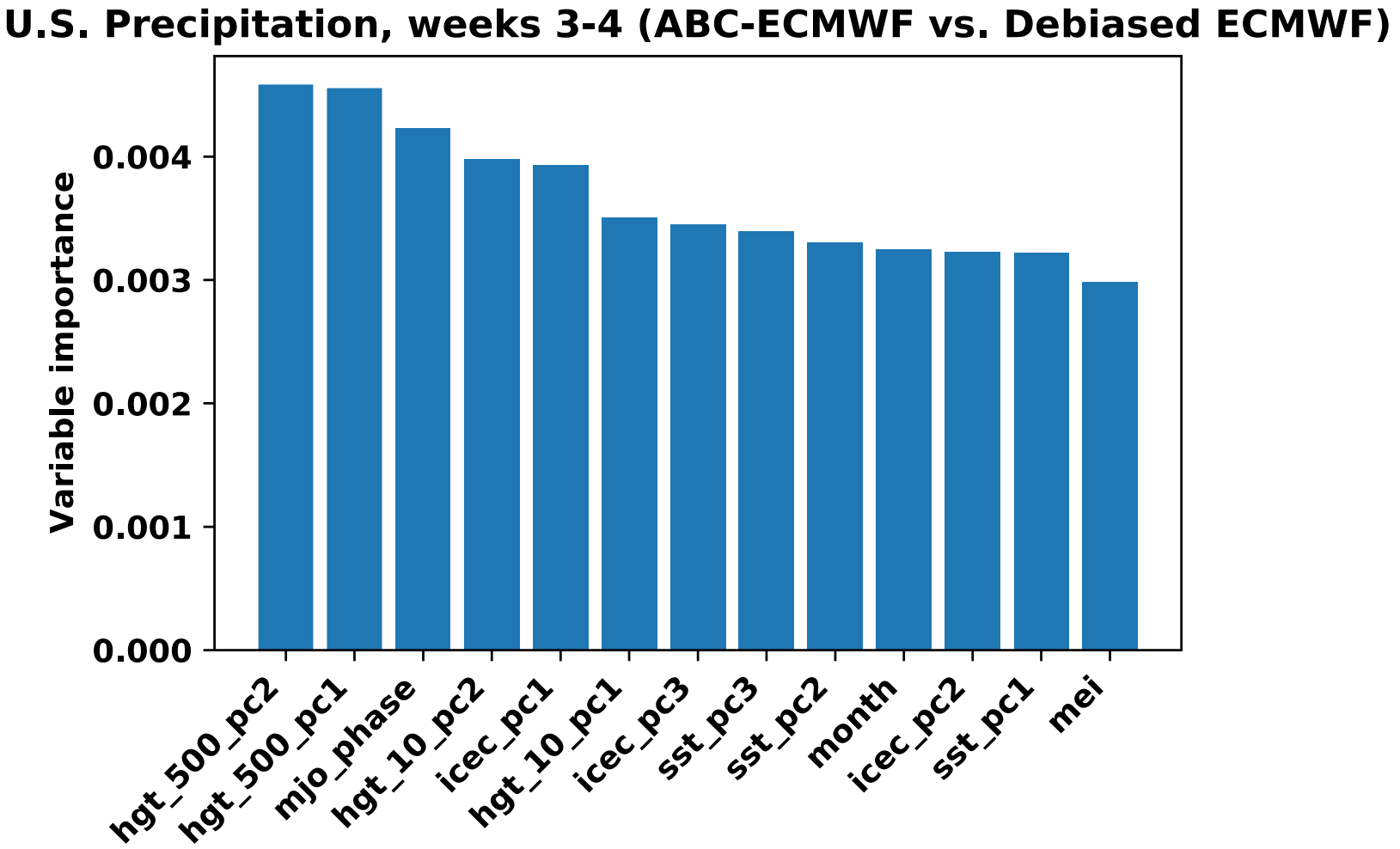
ECMWF = leading subseasonal model

Explaining ABC Improvements

- **Question:** When is ABC most likely to improve upon its input model?
- **Answer: Opportunistic ABC workflow**
  - Based on the optimal credit assignment principle of Shapley (1953)
  - Measures impact of explanatory variables on individual forecasts using Cohort Shapley (Mase et al., 2019) and overall using Shapley effects (Song et al., 2016)
- **Example:** Explain ABC improvements for weeks 3-4 precipitation using
  - **500 hPa geopotential height (HGT)**
    - Captures thermal structure, synoptic circulation
  - **Madden Julian Oscillation (MJO) phase**
    - 30-90 day oscillation in tropical atmosphere
  - **10 hPa geopotential height (HGT)**
    - Captures polar vortex variability
  - **Sea ice concentration (ICEC)**
    - Impacts near-surface temperatures
  - **Sea surface temperatures, multivariate ENSO index, target month, …**

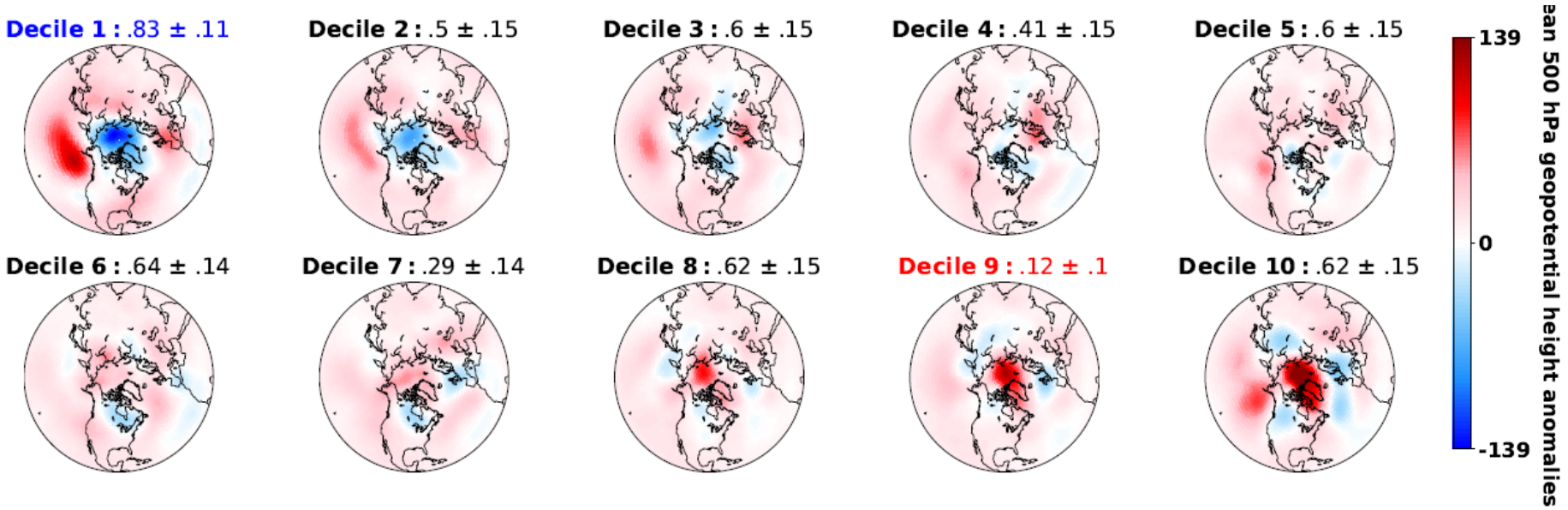


Explaining ABC Improvements

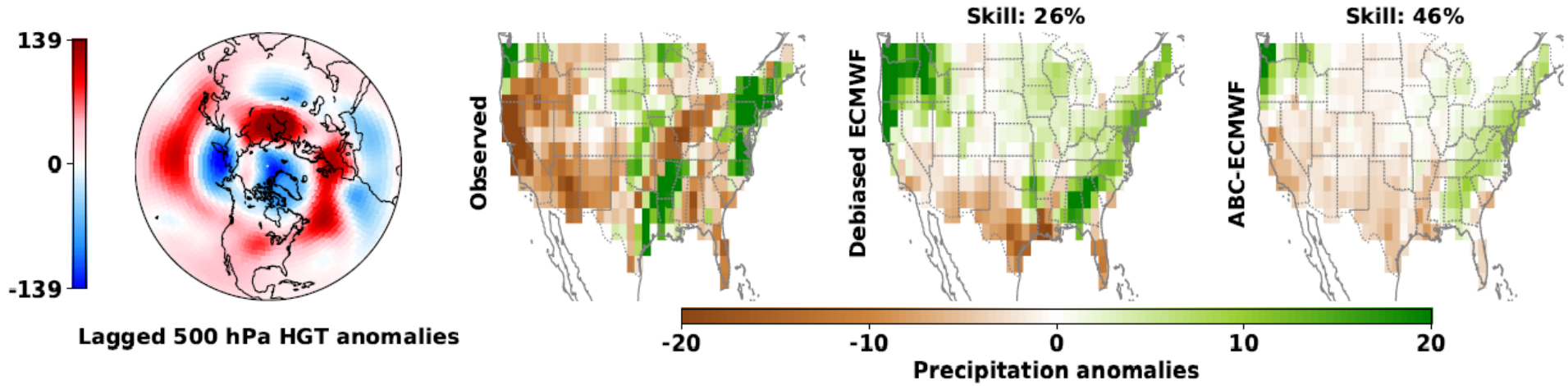


Global importance of each variable in explaining skill improvement

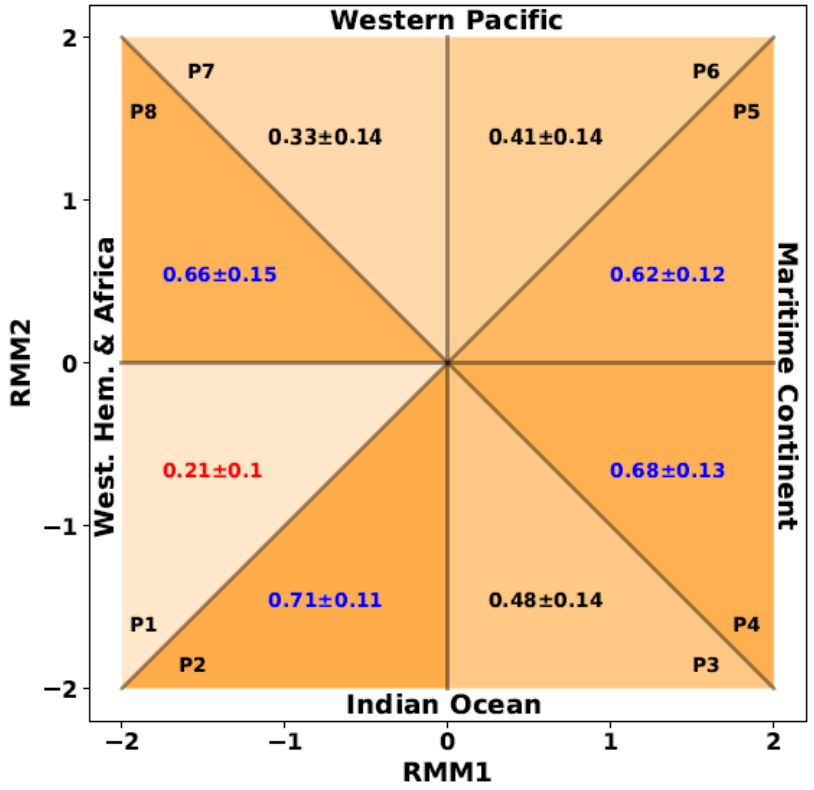
Positive impact of HGT 500 PC1 on ABC skill improvement



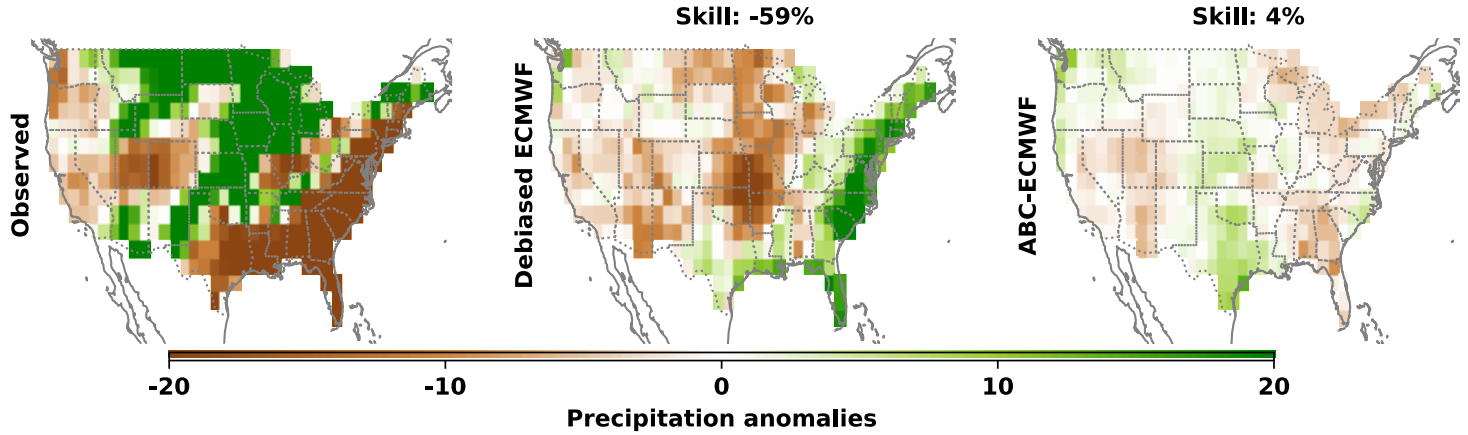
- Most likely in decile 1: features positive Arctic Oscillation pattern
- Least likely in decile 9: features opposite phase Arctic Oscillation



Positive impact of MJO phase on ABC skill improvement

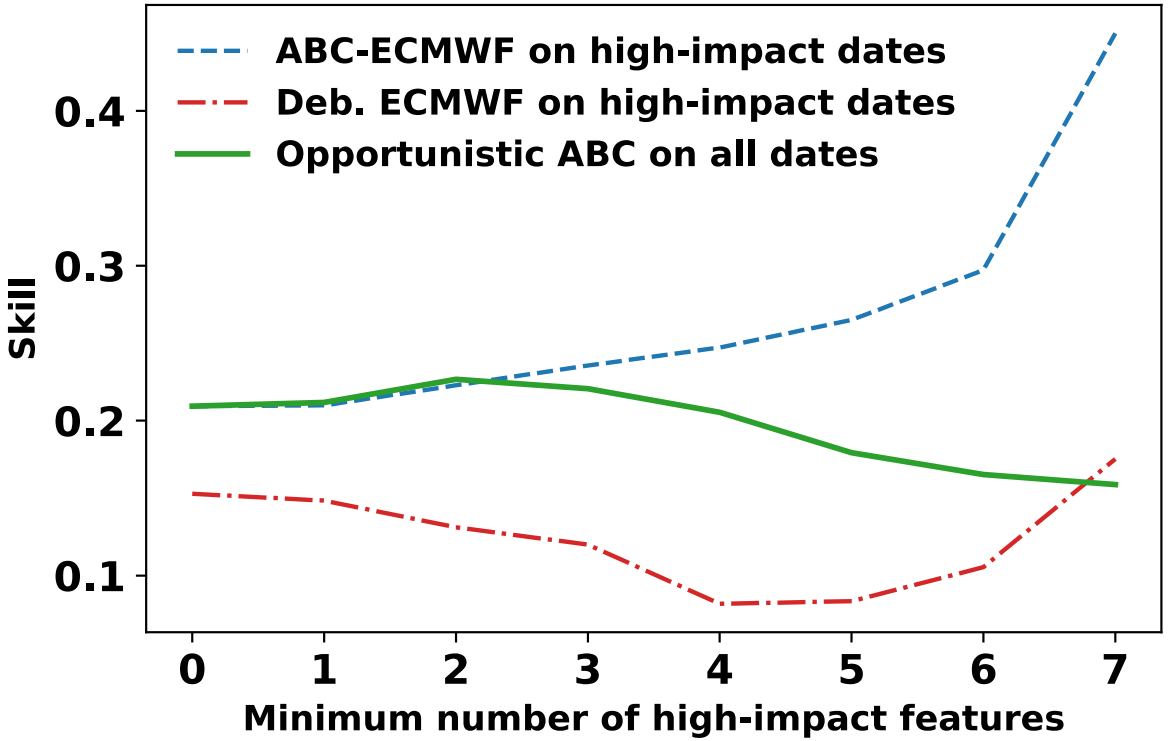


Forecast with largest MJO phase impact in deciles 2, 4, 5, 8



FORECASTS OF OPPORTUNITY

# High-impact variables	% Forecasts using ABC	High-impact skill (%) ABC	Debiased
0 or more	100.00	20.94	15.28
1 or more	95.93	20.99	14.84
2 or more	80.62	22.29	13.12
3 or more	58.61	23.56	12.00
4 or more	31.82	24.72	8.18
5 or more	14.59	26.51	8.35
6 or more	6.46	29.72	10.55
7 or more	2.15	45.00	17.53



- **Idea:** Apply ABC opportunistically when multiple explanatory variables are in high-impact state and use baseline debiased dynamical model otherwise
- **Want:** Effectively defining windows of opportunity based on variables observable at forecast issuance date
- **Question:** How many high-impact variables should we require when defining these windows of opportunity?

NEXT STEPS AND OPEN QUESTIONS

- **Extend forecasting region to the entire globe**
  - How should skill be measured? Overall? By region? Which regions?

- **Complement deterministic forecasts with probabilistic forecasts**
  - Forecast probability of each tercile (near normal, above normal, below normal)
  - Evaluate using Ranked Probability Skill Score

$$\mathrm{RPSS}(\hat{\boldsymbol{p}}, \boldsymbol{p}) = 1 - \frac{(\hat{p}_1 - p_1)^2 + (\hat{p}_3 - p_3)^2}{(\frac{1}{3} - p_1)^2 + (\frac{1}{3} - p_3)^2}$$

  - How well do deterministic forecasting techniques translate into this setting?

- **Improved multimodel ensembling**
  - Standard in the field is equal weighted averaging
  - But relative model performance varies over time and space
  - Flaspohler et al. (2021) use optimistic online learning to deal with delayed feedback

LINKS

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Hybrid learning + physics model (Adaptive Bias Correction)

- **Doubles or triples forecasting accuracy** of operational models
- Paper: https://arxiv.org/abs/2209.10666
- Package: https://github.com/microsoft/subseasonal_toolkit

Python implementation:
https://github.com/microsoft/subseasonal_toolkit

Code:

Paper:

Subseasonal Climate USA dataset

- **Public dataset for training / benchmarking forecasting models**
- Updated daily on Azure
- Package: https://github.com/microsoft/subseasonal_data

Python package:

https://github.com/microsoft/subseasonal_data

Code: