A Holistic Earth System Modeling Framework

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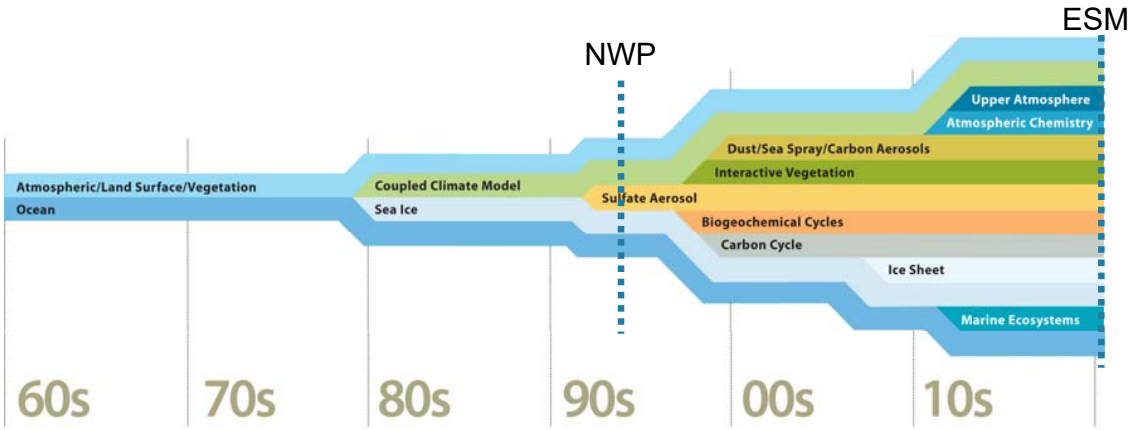
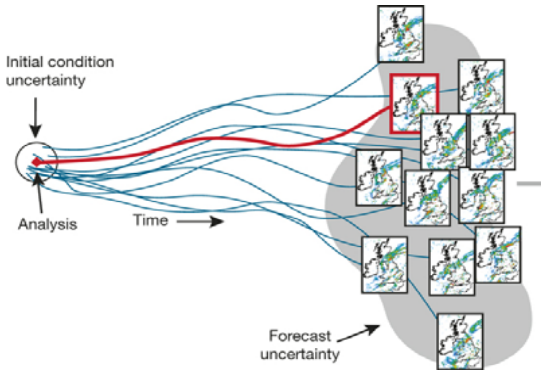
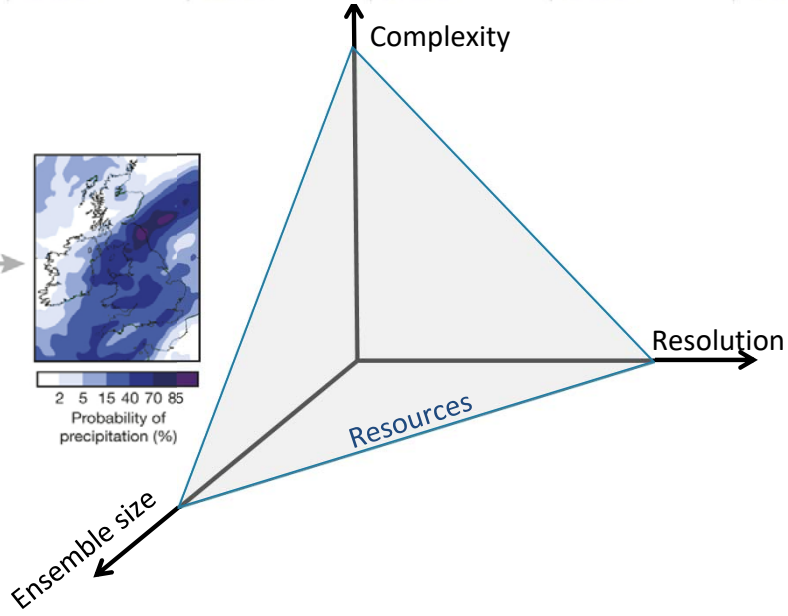
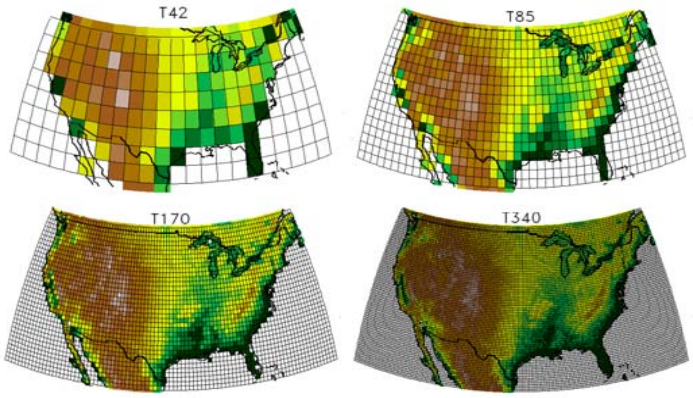
Earth System Predictability research under limited resources

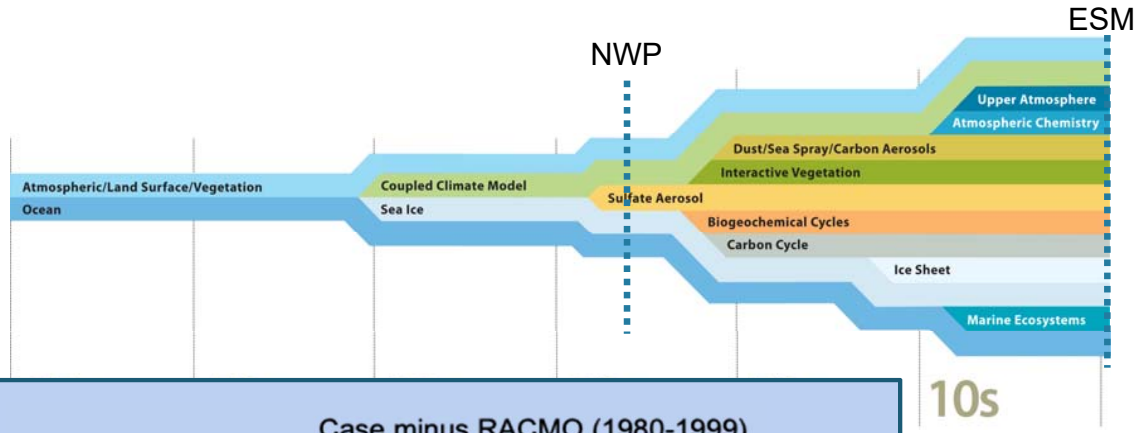

ESM
NWP
Upper Atmosphere
Atmospheric Chemistry
Dust/Sea Spray/Carbon Aerosols
Interactive Vegetation
Atmospheric/Land Surface/Vegetation
Coupled Climate Model
Ocean
Sea Ice
Sulfate Aerosol
Biogeochemical Cycles
Carbon Cycle
Ice Sheet
Marine Ecosystems
60s
70s
80s
90s
00s
10s

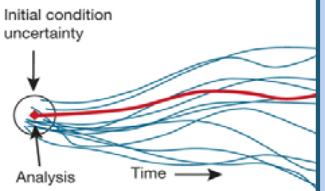

Initial condition uncertainty
Analysis
Time
Forecast uncertainty

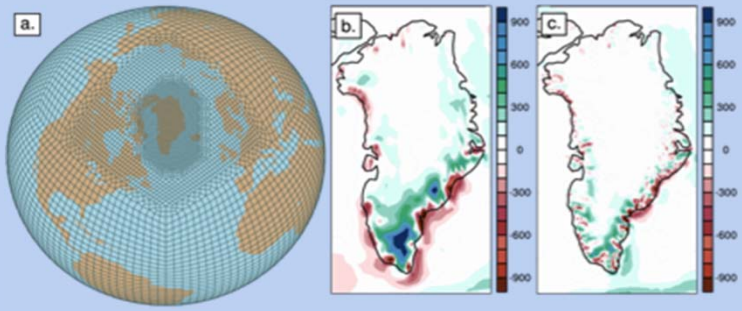
2 5 15 40 70 85
Probability of precipitation (%)


Complexity
Resolution
Resources
Ensemble size

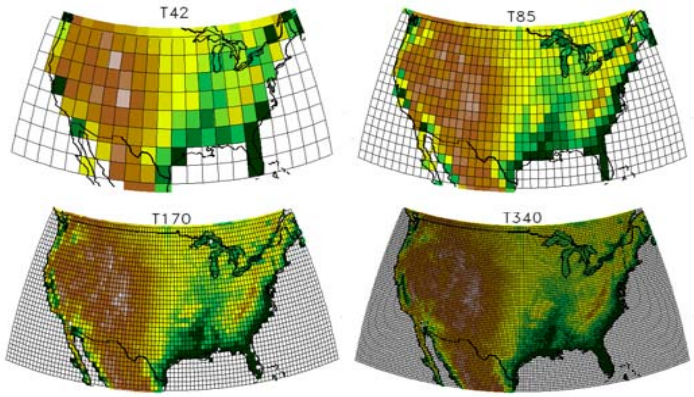

T42
T85
T170
T340

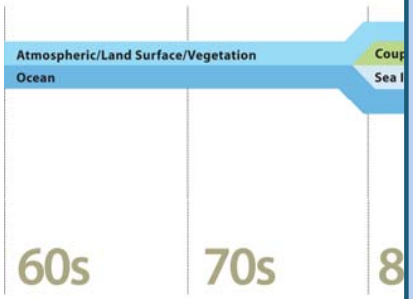




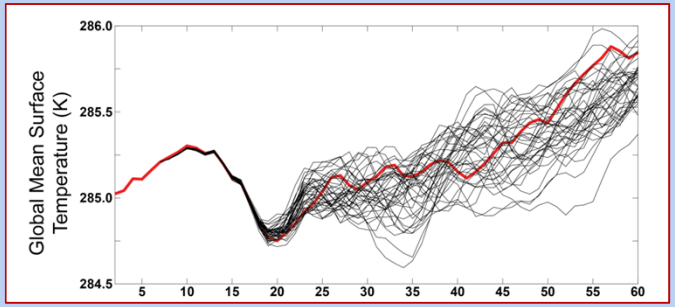


Reduced precipitation bias using regional refinement in the Community Atmosphere Model over Greenland (1 degree vs a) grid). Simulations are compared to the RACMO regional model at high resolution (i.e. the "truth"). Unpublished work by A. Gettelman and A. Herrington (NCAR)

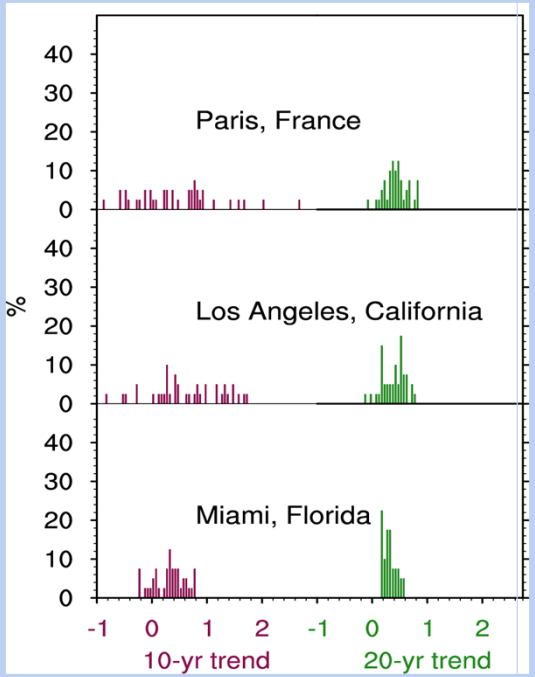


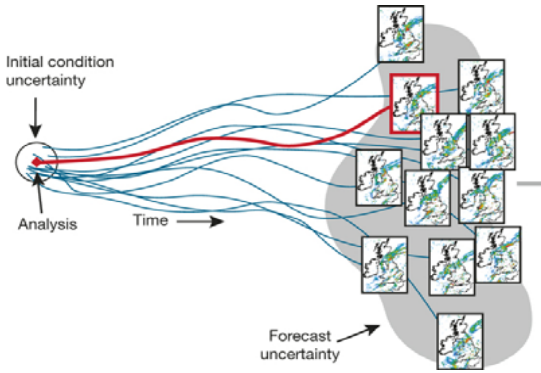


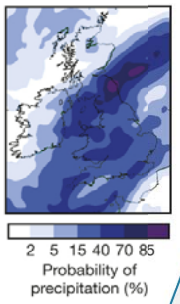
40-member "Large Ensemble" using CESM1 1920-2100, initialized with air temperature perturbations on the order of 10^{-14} K . (Kay et al., 2015)

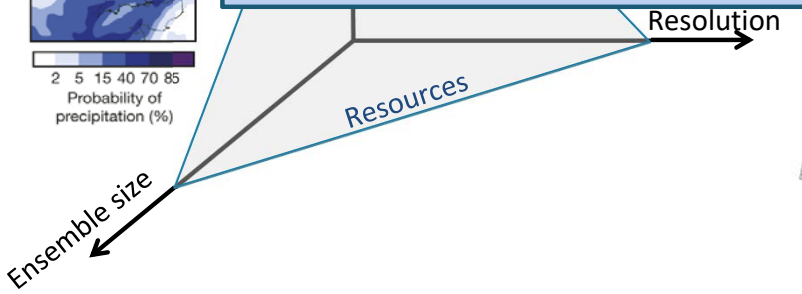


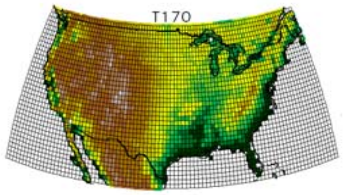
PDF of annual temperature trend since 2020 (°C per decade). Figure by J. Hurrell (CSU)

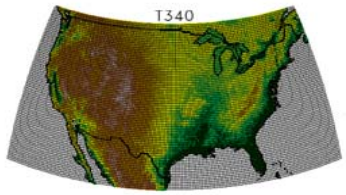






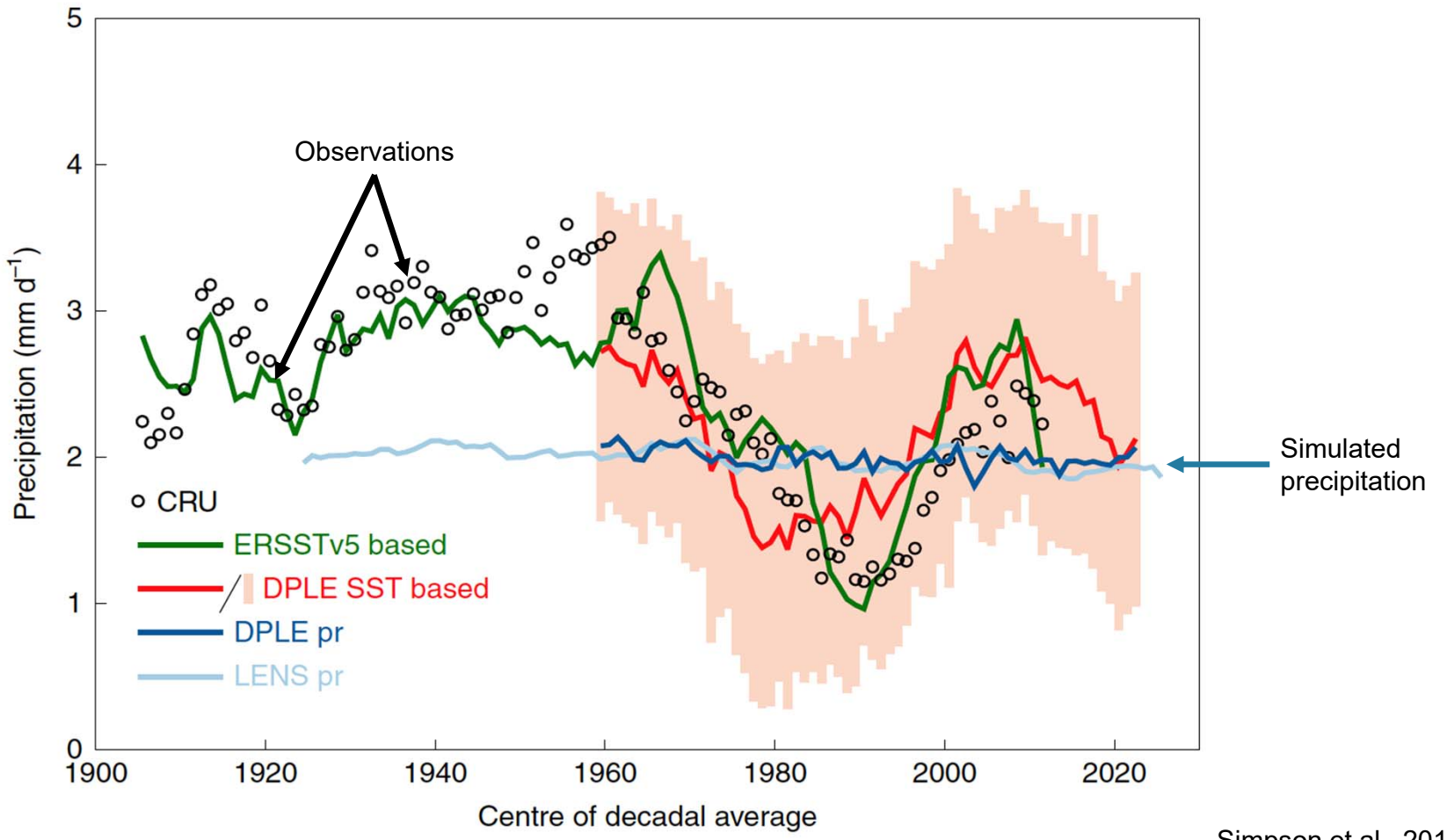






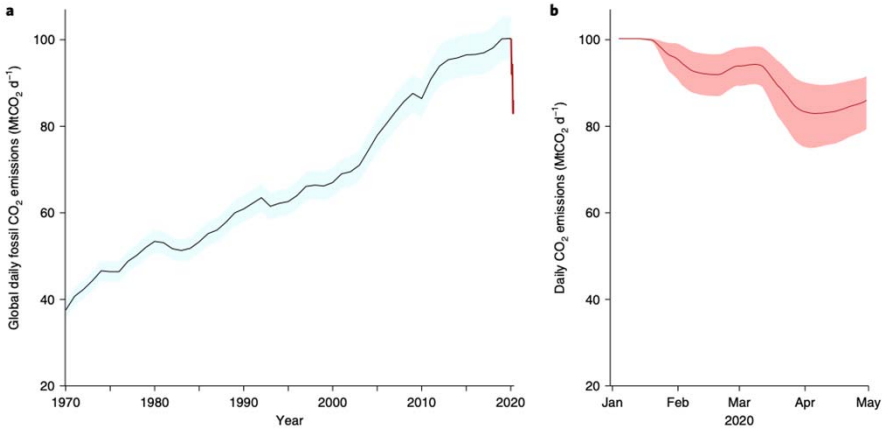
Models are biased/deficient but they can still be useful

Decadal average of March Precipitation over the UK

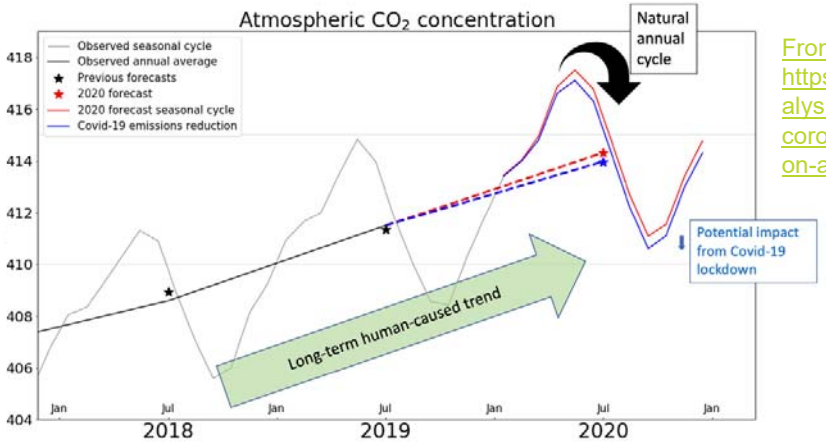


Simpson et al., 2019

Global Daily CO2 emissions



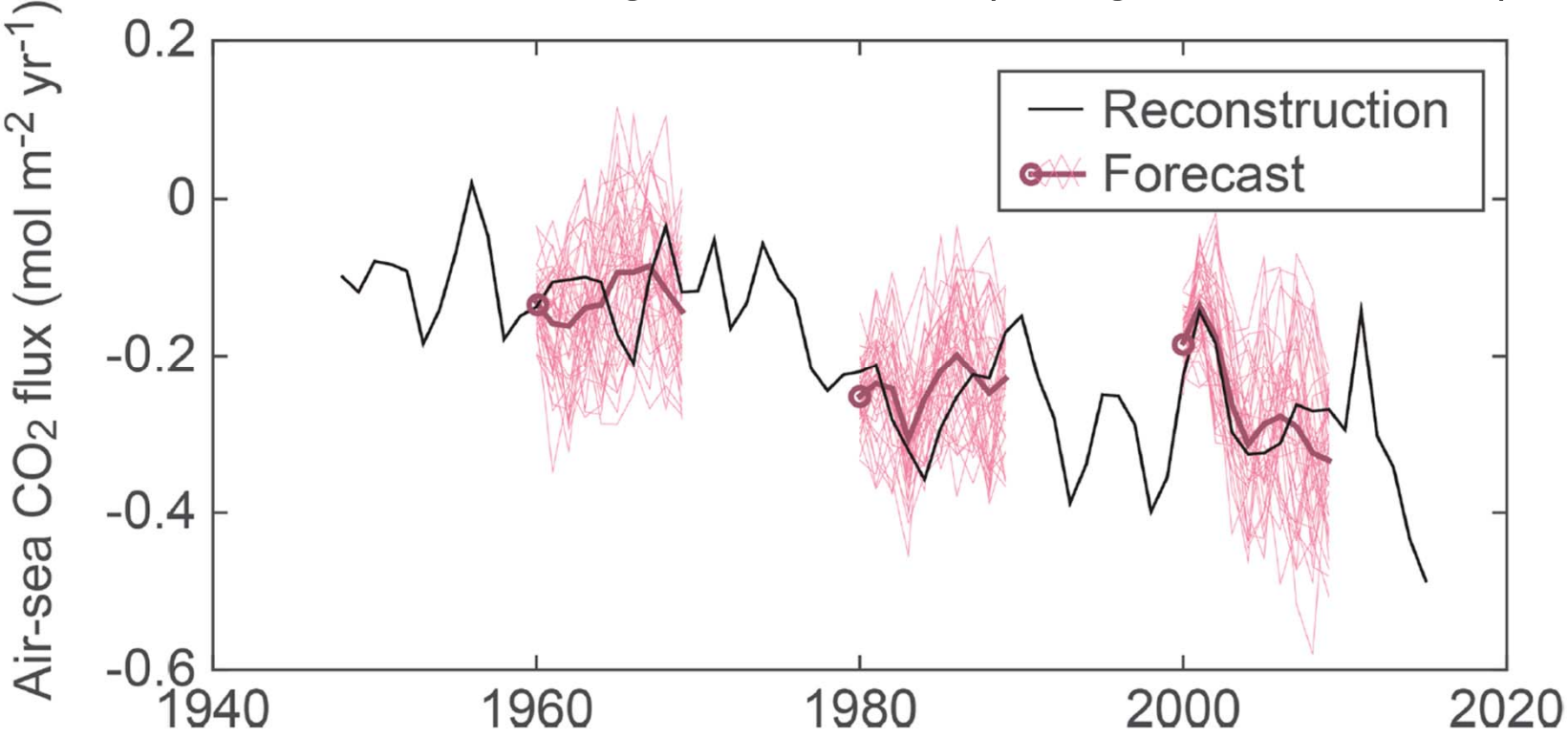
Le Quéré et al., 2020



From https://www.carbonbrief.org/analysis-what-impact-will-the-coronavirus-pandemic-have-on-atmospheric-co2

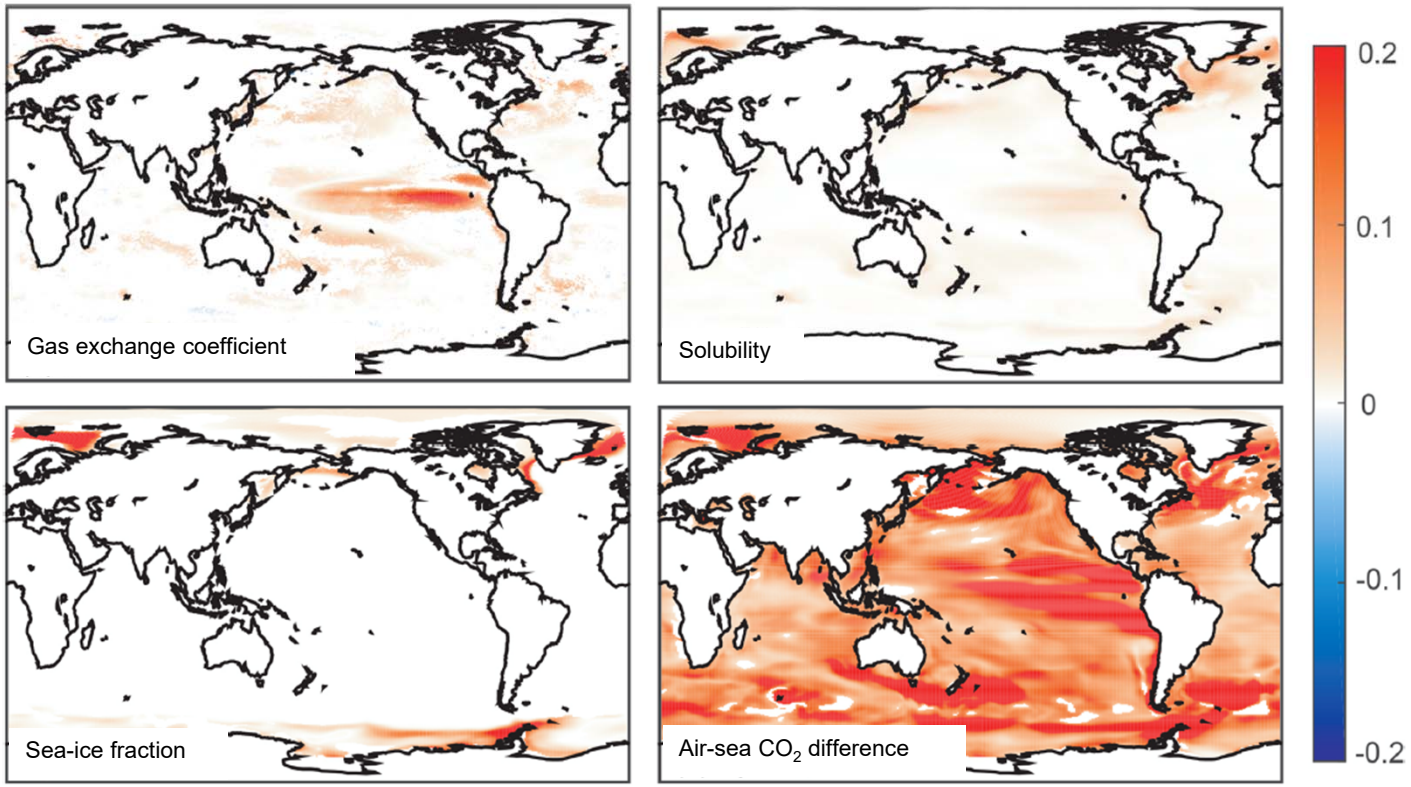
PREDICTABILITY BEYOND PRECIPITATION AND TEMPERATURE

Multi-year prediction of air-sea CO_2 flux using the Decadal Prediction Large Ensemble (Yeager et al., 2018)



Lovenduski et al., 2019

Drivers of predictability in air-sea CO_2 flux



Lovenduski et al., 2019

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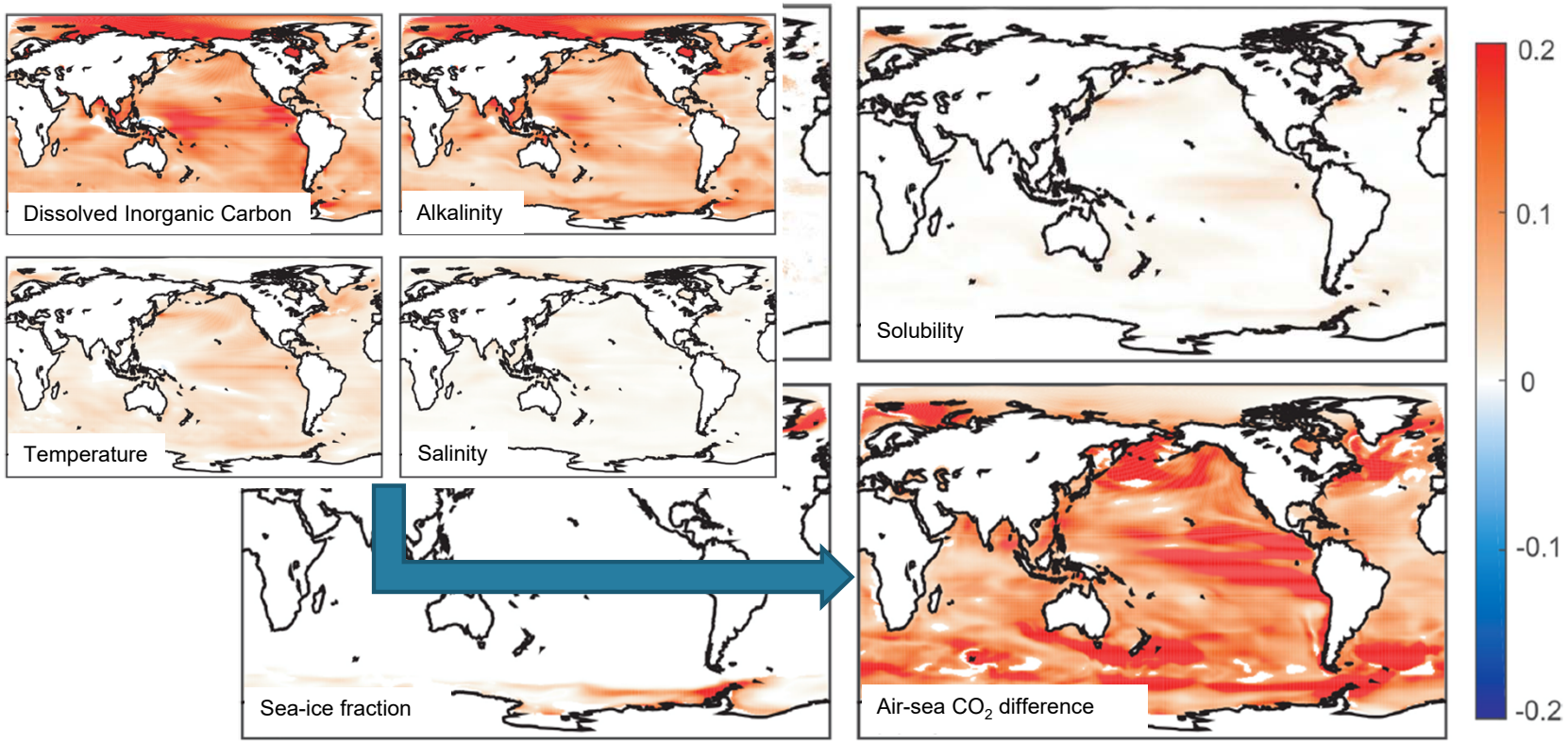

Lovenduski et al., 2019

Predictability in the Earth System

- What is driving the predictability? Where does the memory reside?
- Are we representing it accurately in the model?

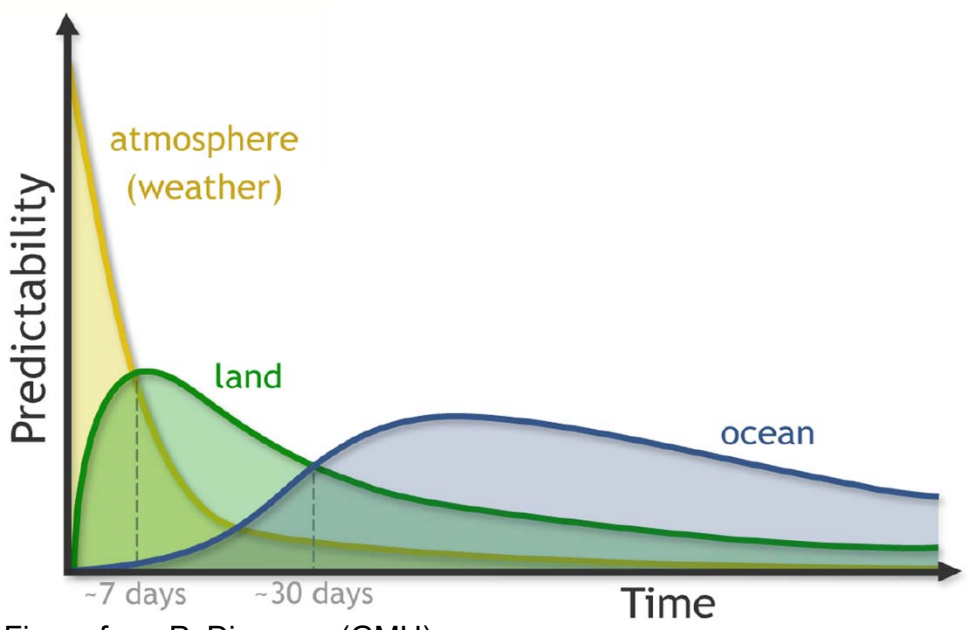

Figure from P. Dirmeyer (GMU)

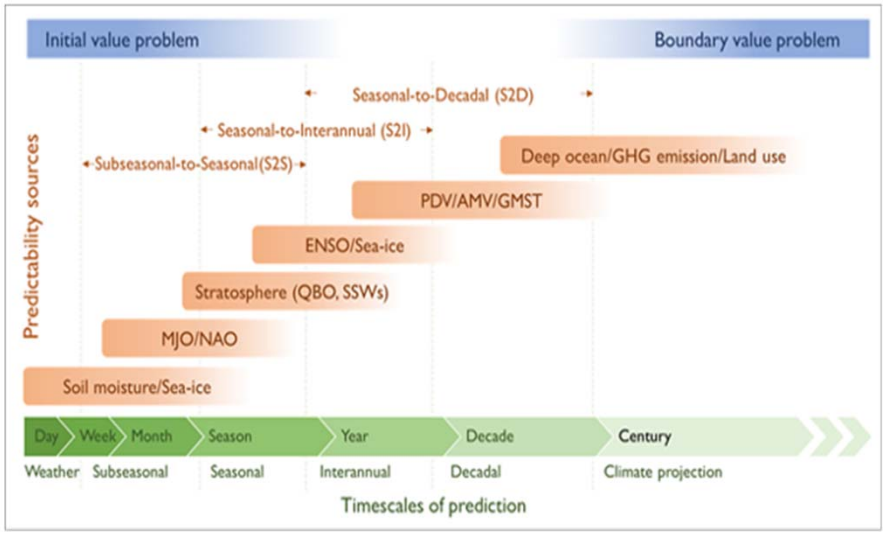

Figure from J. Meehl (NCAR)

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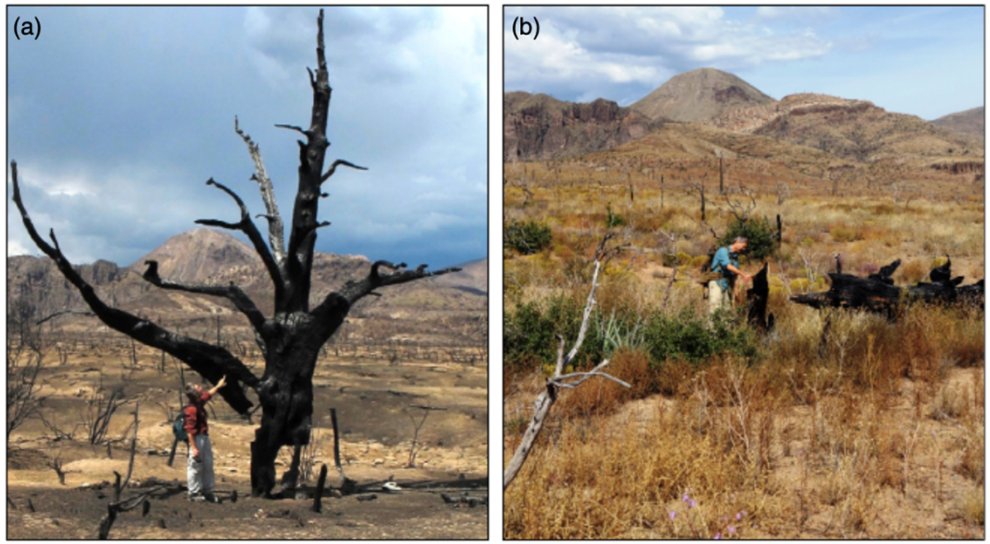
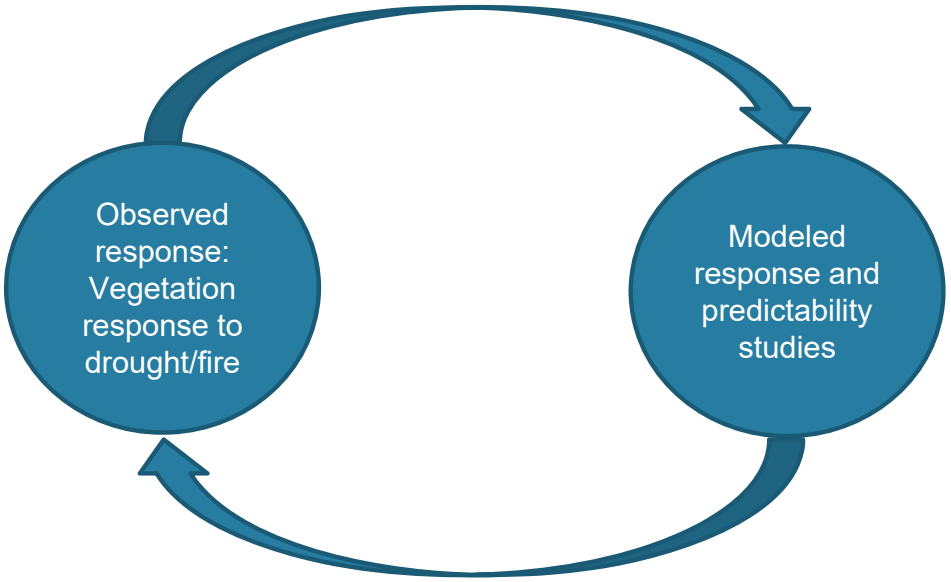


Johnstone et al., 2016

Key points to a Holistic Earth System Modeling Framework

- Multi-disciplinary teams of observations, models and data analysis



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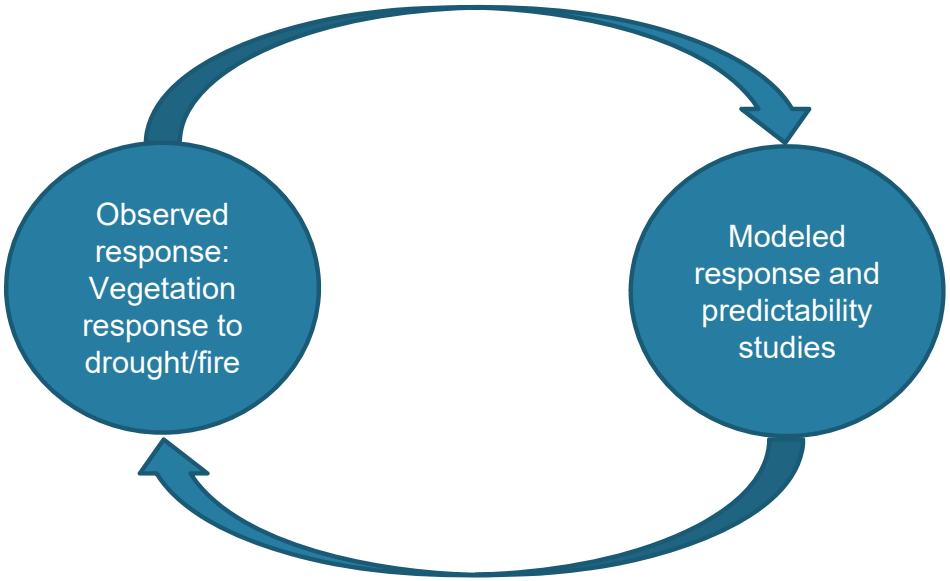
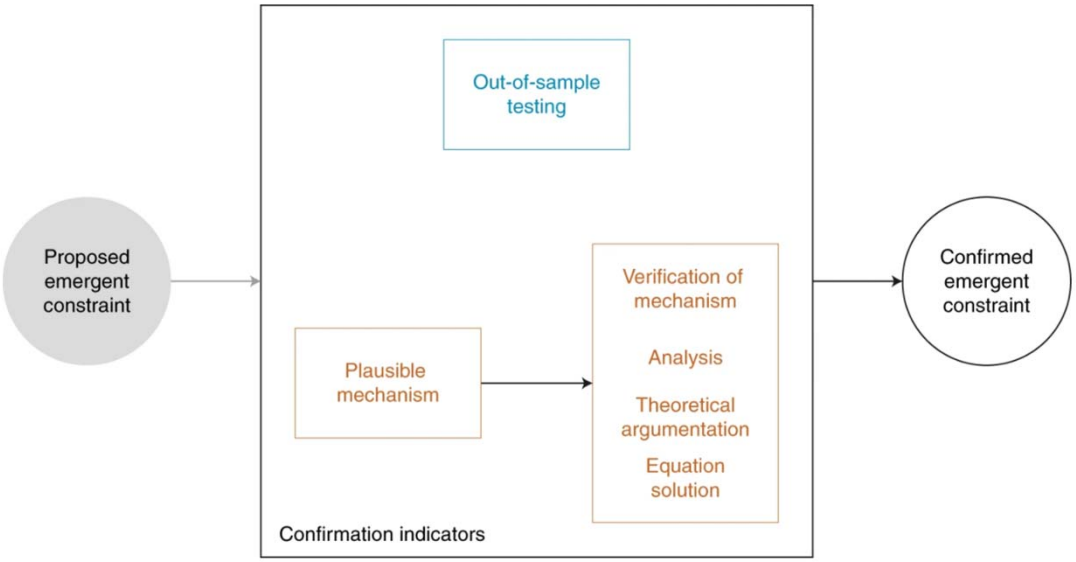
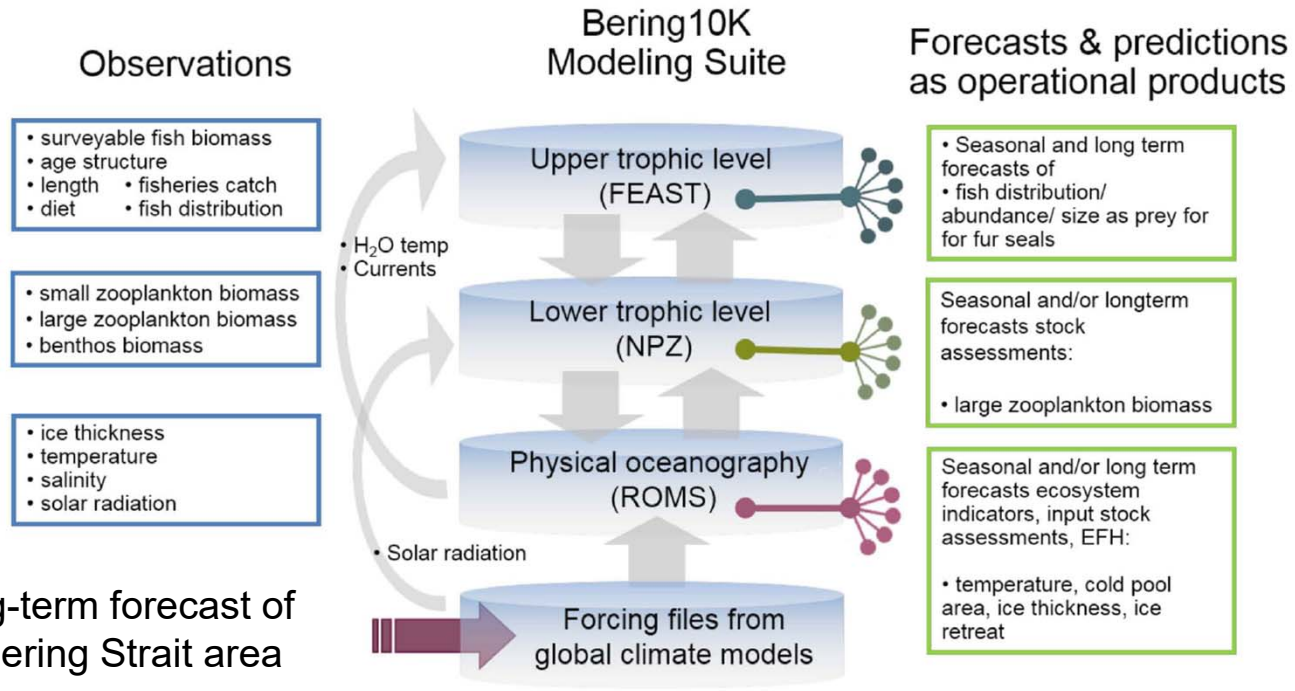




Hall et al., 2019

Key points to a Holistic Earth System Modeling Framework

- Multi-disciplinary teams of observations, models and data analysis
- Interoperability of data and models

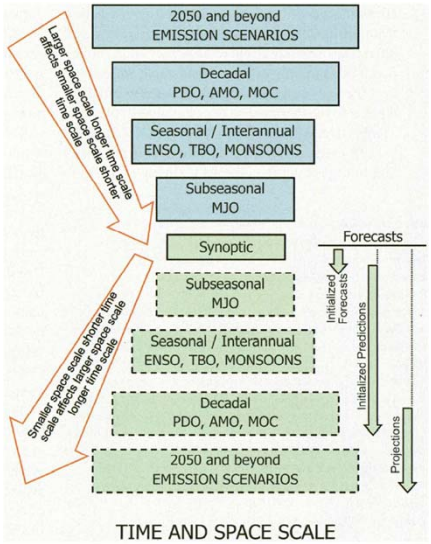


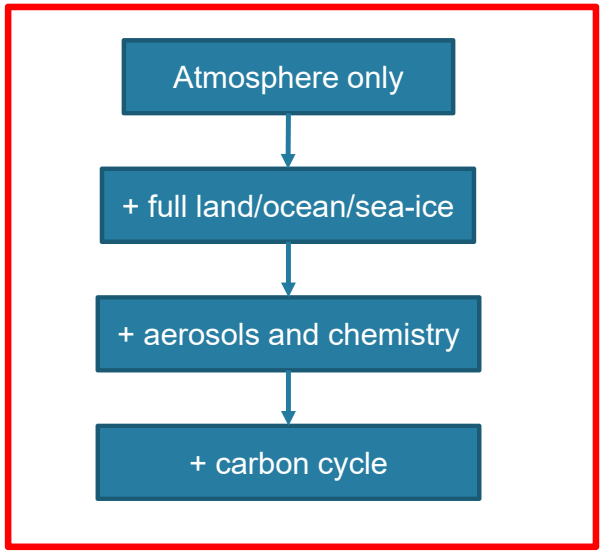
Seasonal and long-term forecast of fish stock in the Bering Strait area

Capotondi et al., 2019

Key points to a Holistic Earth System Modeling Framework

- Multi-disciplinary teams of observations, models and data analysis
- Interoperability
- Hierarchy of modeling systems -> models are built for a purpose!





Unified framework requires co-design

Hurrell et al., 2009

Key points to a Holistic Earth System Modeling Framework

- Multi-disciplinary teams of observations, models and data analysis
- Interoperability of data and models
- Hierarchy of modeling systems -> models are built for a purpose!
- Large ensembles are required -> this is particularly critical if predictability of extremes is a target

  - Doubling horizontal resolution increases the model cost by a factor of 10
  - Ensembles are embarrassingly parallel
  - How “large” is a research question, and target-specific

Key points to a Holistic Earth System Modeling Framework

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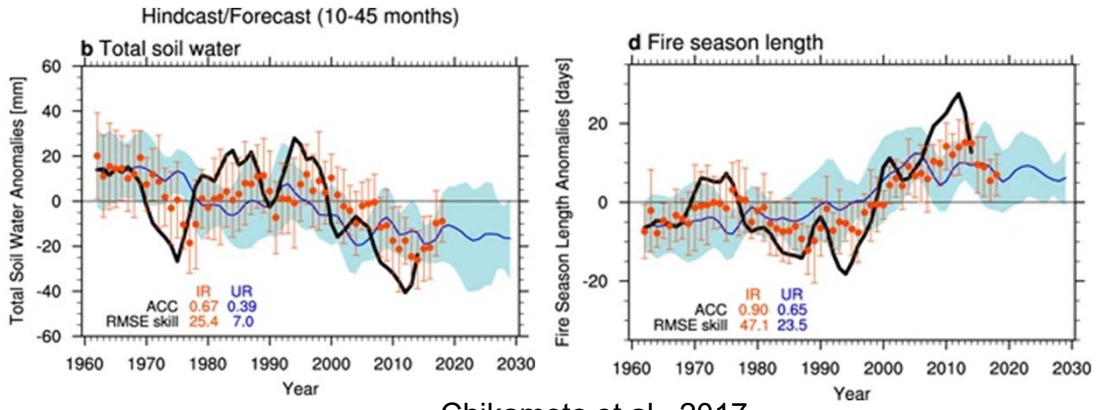
- Interoperability of data and models
- Hierarchy of modeling systems -> models are built for a purpose!
- Large ensembles are required -> this is particularly critical if predictability of extremes is a target
- Any forecasts requires knowledge of current emissions (especially aerosols) and their forecasts
  - Wildfires
  - Dust storms
  - Anthropogenic emissions



Chikamoto et al., 2017

Key points to a Holistic Earth System Modeling Framework

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- Hindcasts are critical to understand where models are good or bad

  - This requires an alignment of observations with model needs
  - It provides an opportunity for data assimilation and identification of error growth

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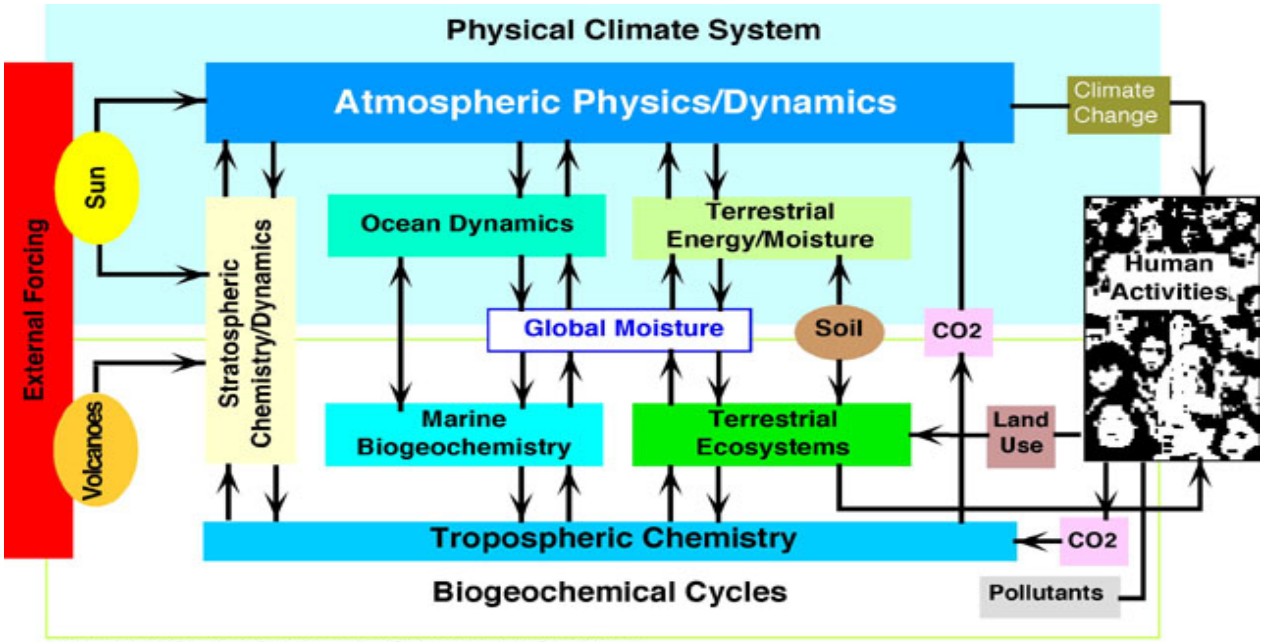
- Any forecasts requires knowledge of current emissions (especially aerosols) and their forecasts
- Hindcasts are critical to understand where models are good or bad
- ➢ Modeling progress will be attained through a combination of process knowledge, high resolution and statistical/machine learning methods

Questions?
Comments?



(from Earth System Science: An Overview, NASA, 1988)