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Earth System Modelling and Observations

WCRP
World Climate Research Programme

Initializing subseasonal to decadal predictions

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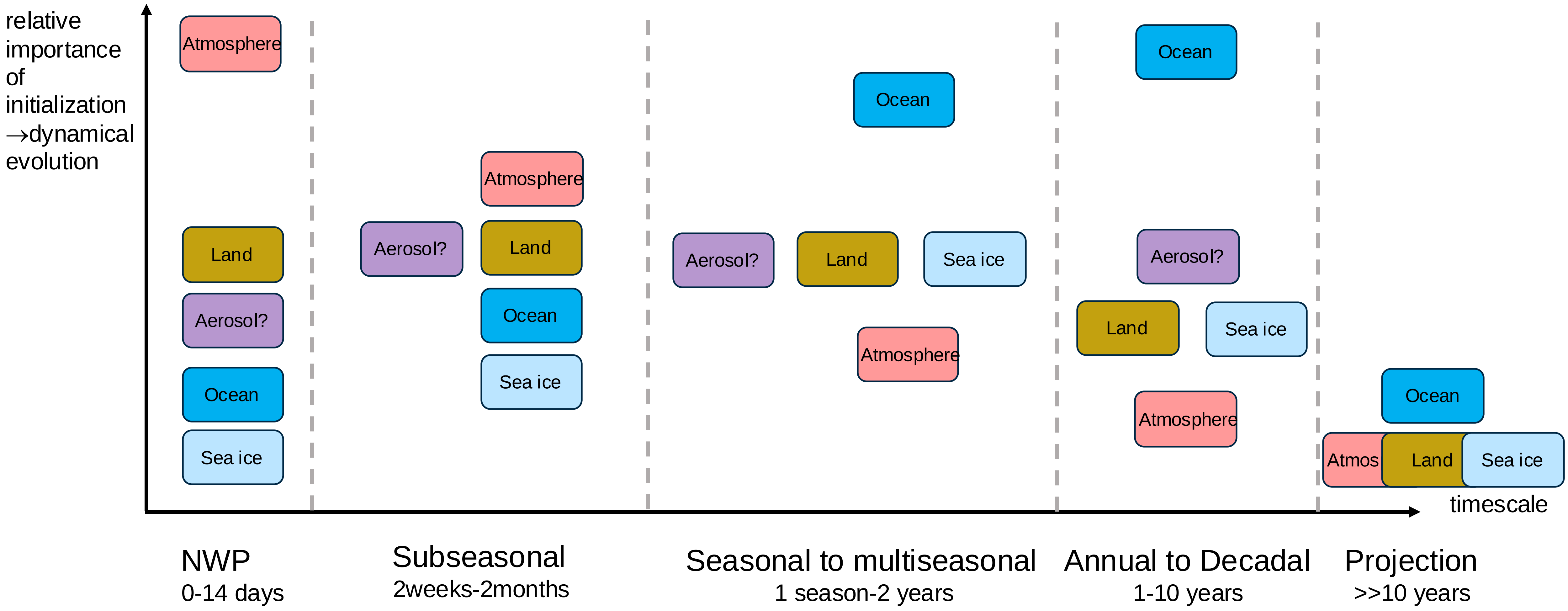
Initialization influences and practices across time scales (conventional wisdom)



Two main approaches to ESM initialization for climate prediction

1) "Uncoupled Assimilation"

- Assemble separately produced atmospheric, land, ocean/sea ice (re)analyses
- Land initialization: forcing offline with imported atmospheric reanalysis
- Ensemble generated by IC perturbations and/or stochastic/perturbed parameters and/or lagged IC

Advantages:

- "Accurate" initial conditions obtained from current generation (re)analyses
- Relatively simple to assemble IC from different components (except possibly for land)

Disadvantages:

- IC contain inconsistencies with & between model components, particularly when using analyses originating from a different model
- Does not provide IC for Earth system variables such as ocean BGC that aren't provided by the (re)analysis used

Two main approaches to ESM initialization for climate prediction

2) (Weakly) "Coupled Assimilation" or "Assimilation run" approach

- Assimilate (or "nudge" model components to separately produced atmospheric, ocean/sea ice (re)analyses) across hindcast & real time periods
- Ensemble can be obtained from multiple assimilation runs or as for uncoupled assimilation

Advantages:

- Initialization of consistent land and other non-data-constrained components
- Potential for lesser IC incompatibilities, "shocks" between different components

Disadvantages:

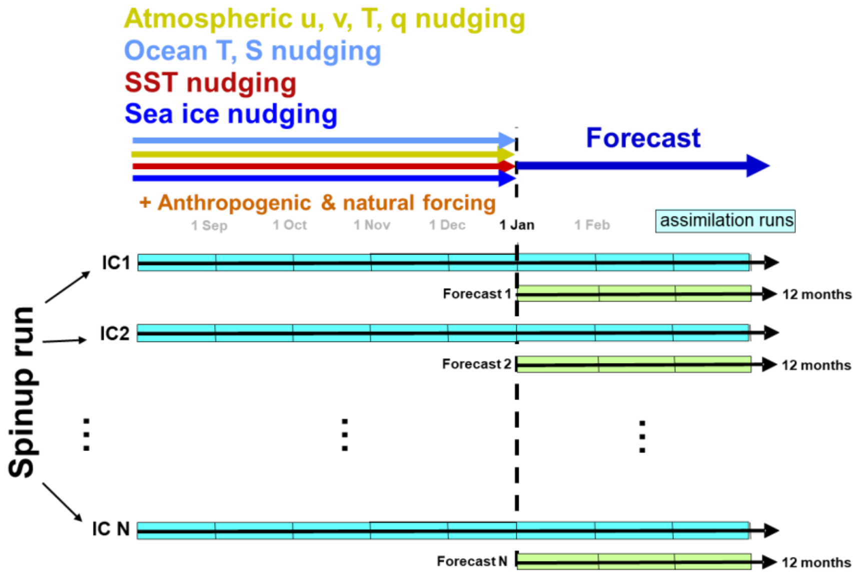
- Requires nudging or DA infrastructure in data-constrained model components
- Tradeoff between stronger constraints potentially leading to imbalances and weaker, "friendlier" constraints allowing model biases to degrade IC

Examples from operational and research systems

- Current seasonal forecast systems:

Uncoupled Assimilation:
- CMCC SPS3.5
- ECCC GEM5.2-NEMO
- ECMWF SEAS5
- JMA/MRI CPS3
- Météo-France System 8
- NCEP CFSv2
- UKMO GloSea6

Coupled Assimilation:
- DWD GCFS 2.1
- ECCC CanESM5.1p1bc →
- NASA/GEOS-S2S
- GFDL Spear



- Current annual to decadal forecast systems:

Uncoupled assimilation:
- CMCC CAM5/NEMO
- MOHC HadGEM3-GC3.1-MM
- RHMC INM-CM5

Coupled Assimilation:
- BSC EC-Earth3.3 (ocean only)
- DWD MPI-ESM-LR (atmosphere only)
- CCCma CanCM4i→ CanESM5.1p1bc (coupled)
- IITM MoES (ocean only)
- MIROC (coupled)

Unique Aspects of Initialization of decadal forecasts

- Initialization methods for annual to decadal forecasts have tended to differ from those for shorter timescales, emphasizing ocean initialization
- Examples include
  - Anomaly initialization of ocean = observed anomalies added to model climatology, e.g. BCCR NorCPM1, IPSL CM62-ESMCO2, LASG FGOALS-f3-L, MIROC6
  - Ocean initialization using forced-ocean–sea-ice (FOSI) runs of ocean model, e.g. repeating cycles of 1958–2018 atmospheric forcing for NCAR SMYLE system
  - Atmospheric component not initialized, e.g. BCCR NorCPM1, IPSL CM62-ESMCO2, LASG FGOALS-f3-L

Impact and Applications of Initialization Methods

Two major (perhaps related) issues related to initialization:

1. Drift – Initial coupled state is not on the model's attractor.
2. Initialization shock due to dynamical imbalance

Clear metrics to isolate both of these impacts are needed.

Existing Evaluation includes:

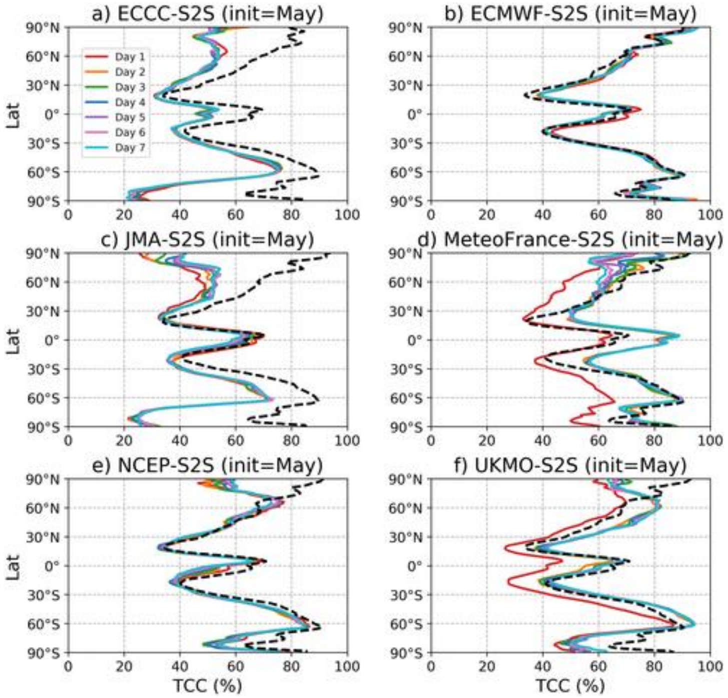
- Examination of initial evolution of forecast fields (Saurral et al, 2021)
- Comparison of forecast skill of forecasts initialized with and without coupled assimilation (eg., KMA, GFDL).
- Includes impact on meteorology/ocean for subseasonal, seasonal and decadal lead times.

Applications:

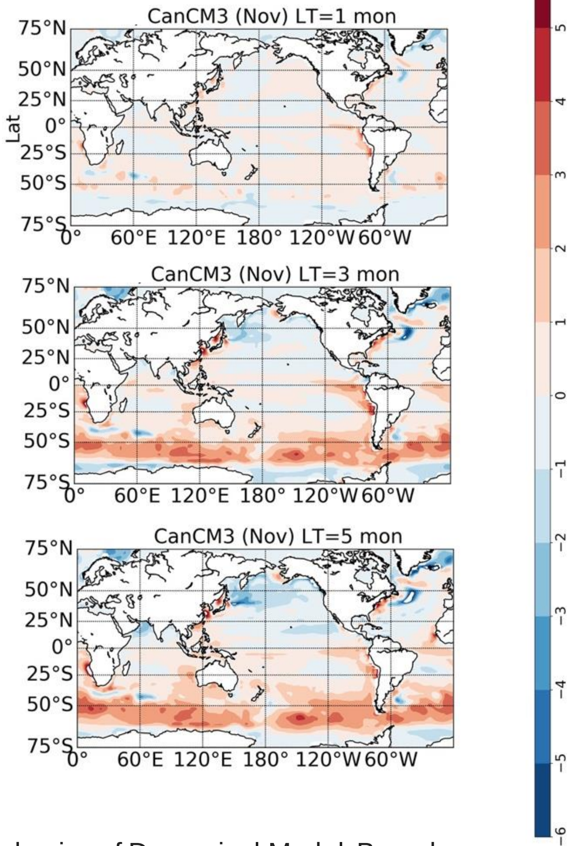
- Atmospheric and Ocean Prognostic Fields
- Atmospheric aerosol (standard practice at NASA/GMAO)
- Ocean biogeochemistry – experiments to evaluate impact of assimilating PACE observations

Existing Evaluation of initialization shock/drift behavior across time scales

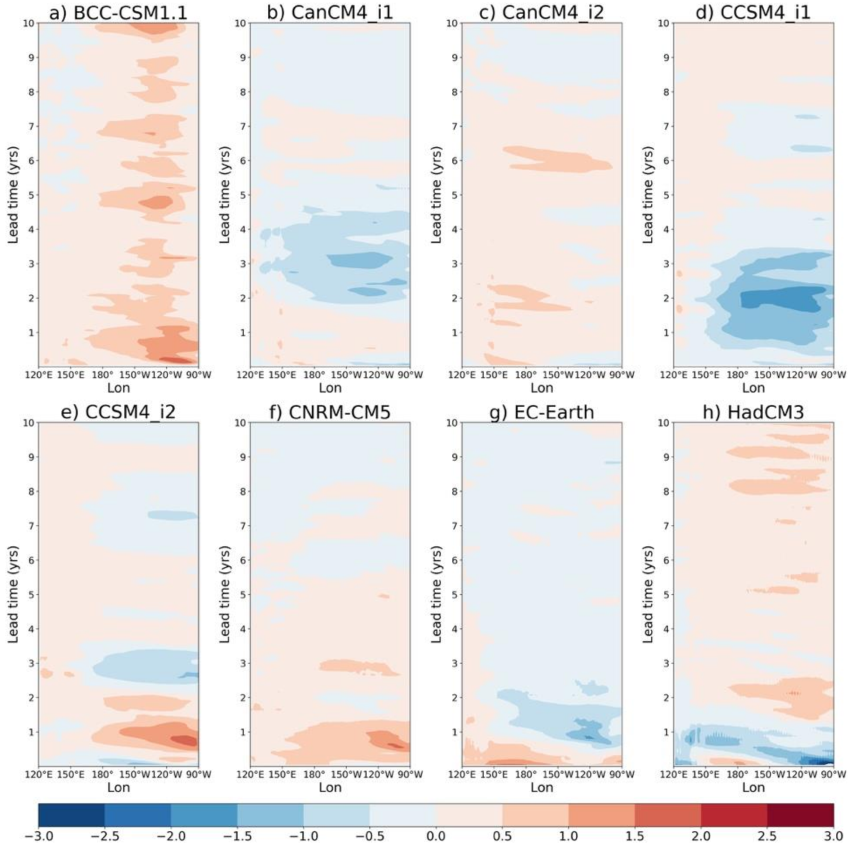
Subseasonal: Evolution of zonal mean Total Cloud Cover compared to ERA-Interim (dashed) over forecast days 1-7 in S2S models



Seasonal: Development of Nov SST biases vs OISSTv2 at lead times of 1, 3, and 5 months in CanCM3



Decadal: Evolution of differences in equatorial Pacific SST vs corresponding historical runs over decadal prediction years 1-10 in CMIP5 models



Saurral, R.I. et al. 2021: A Data Set for Intercomparing the Transient Behavior of Dynamical Model-Based Subseasonal to Decadal Climate Predictions. *JAMES*, 13, https://doi.org/10.1029/2021MS002570.

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Example: Impact of Dynamically Balanced Initial State on Initial Shocks

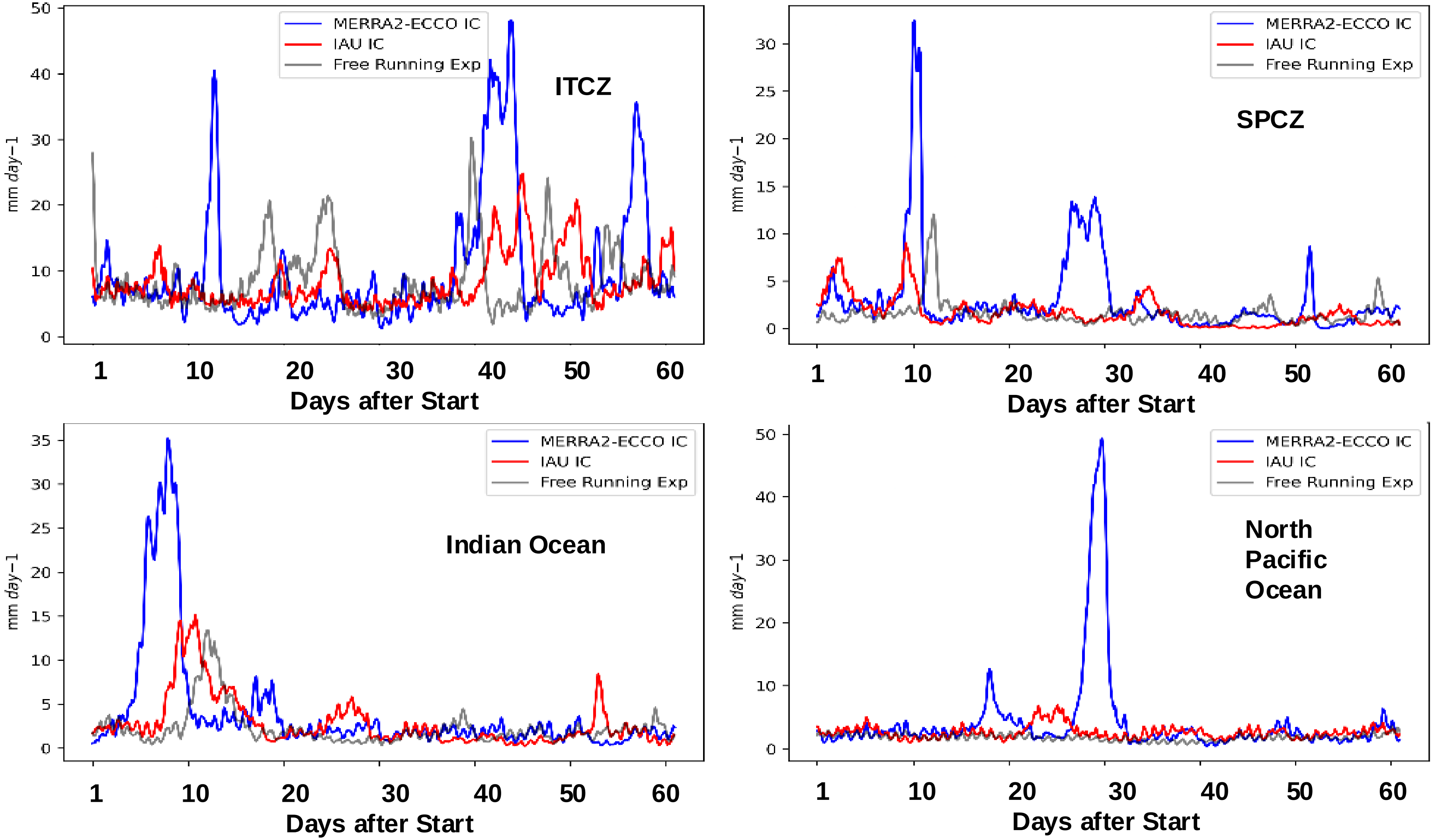
Experiments:

1. **Uncoupled Assimilation:** Use “start time” initial states for the atmosphere, aerosol and land from MERRA-2, and for the MITgcm ocean from ECCO to run forecast
2. **Coupled Assimilation:** Begin 3 months prior to forecast start time
   - Use initial states for the atmosphere, aerosol and land from MERRA-2 and for the MITgcm ocean from ECCO
   - Run coupled model with “replay” of atmosphere to MERRA-2 and ocean to ECCO for 3 months (no ”replay” of aerosol in this experiment)
   - Use the dynamically balanced atmosphere and ocean states from the end of the “replay” to initialize the coupled model forecast
3. **Free Running:** Begin 3 months prior to forecast start time
   - Use initial states for the atmosphere, aerosol and land from MERRA-2 and for the MITgcm ocean from ECCO
   - Run coupled model for 3 months, use the dynamically balanced atmosphere and ocean states to initialize the coupled model forecast

Experiments/Analysis from: Abdullah Fahad, GMAO

Coupled initialization: Impact of Dynamically balanced initial state

Total Precipitation

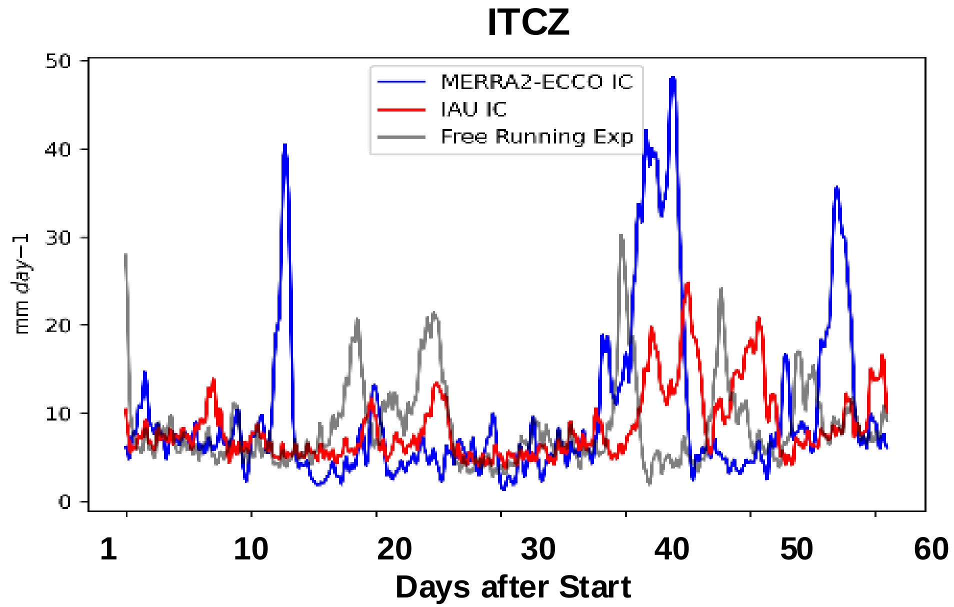


"Spikes" in precipitation with varying time scale around the globe are the atmospheric indicators of the response to a dynamical imbalance

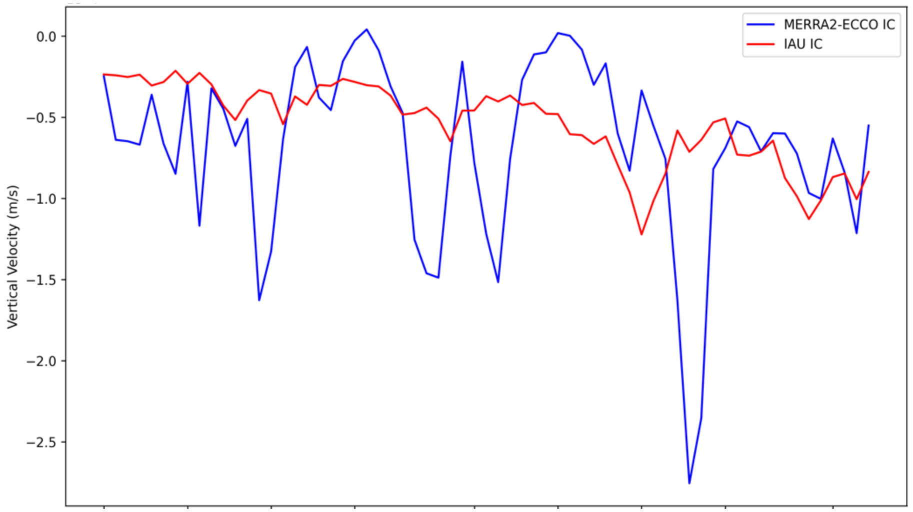
Experiments/Analysis from: Abdullah Fahad, GMAO

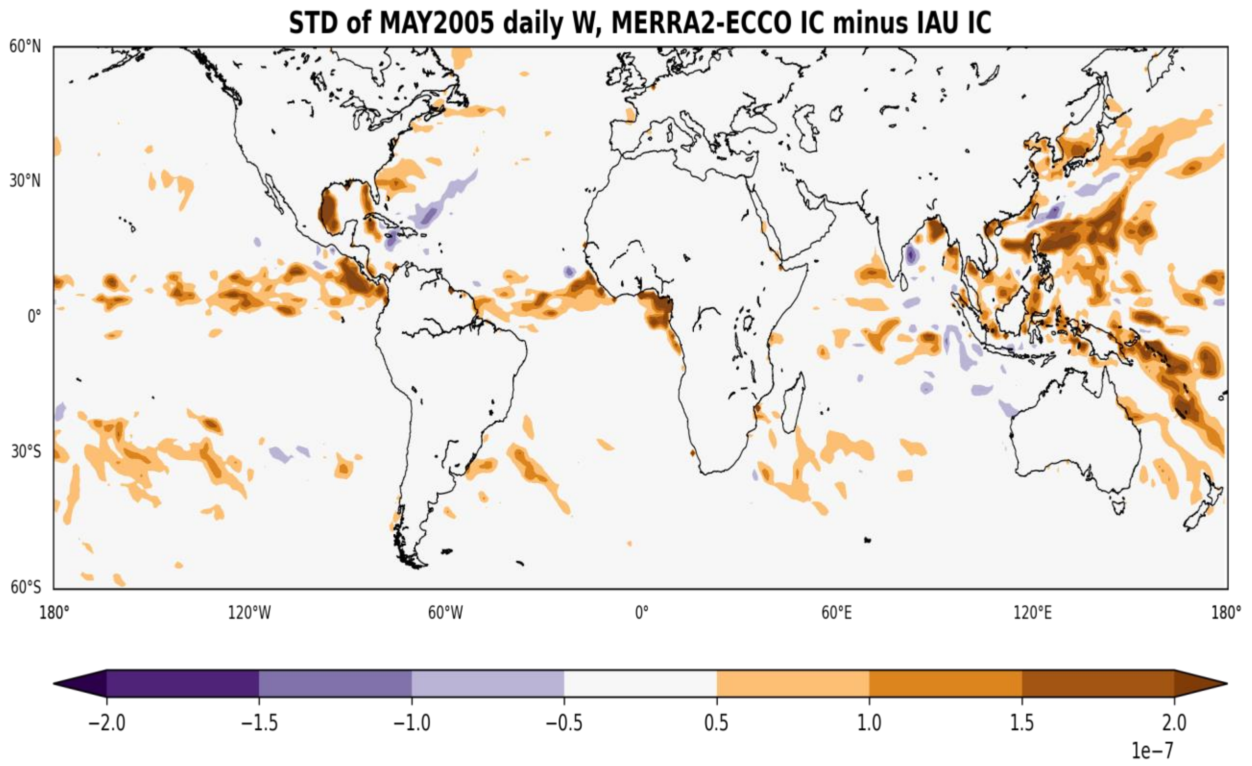
Coupled initialization: Impact of Dynamically balanced initial state

PRECIP



Ocean Vertical Velocity (5m)





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Concluding Thoughts/Remarks

- Coupled assimilation, using either nudging or atmospheric and/or ocean analyses, are in practice in a growing number of subseasonal to decadal forecast producing systems.
- (Limited) studies comparing forecasts initialized with coupled vs uncoupled assimilation show a clear benefit of coupled assimilation subseasonal to decadal lead times.
- Examples of studies using different metrics show that forecasts initialized with coupled assimilation display smaller initial drift, lower root mean squared error, better skill and reduced high temporal frequency

- Clearly defined metrics for characterization of loss of skill due to initial shock and drift are needed, in an attempt to distinguish between them and understand potential benefits of techniques to address them.