US CLIVAR Workshop on Future US Earth System Reanalysis

Reanalysis with a focus on high-latitudes: atmosphere, ocean, sea ice

An T. Nguyen
The University of Texas at Austin

The University of Texas at Austin
Oden Institute for Computational Engineering and Sciences

Vision for the future of US reanalysis efforts:

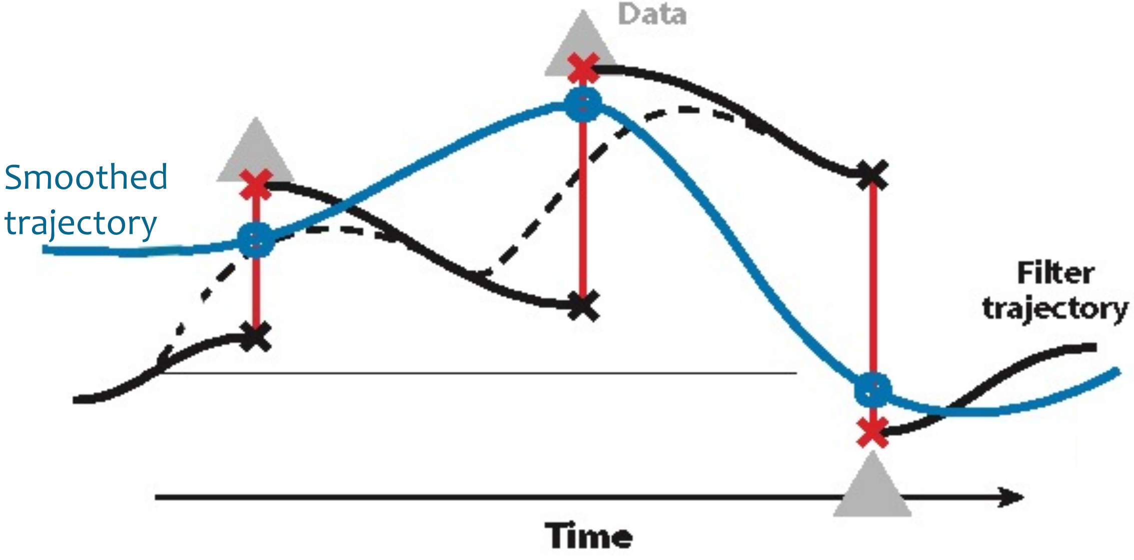
1. Identify **scientific goals** for the next generation of reanalysis from the atmospheric, oceanographic, and cryosphere perspectives.

2. Identify opportunities for exploiting technological advancements in Earth system models, data assimilation systems, observations, and computational infrastructure.

3. Identify priorities and opportunities for tighter collaboration between the US institutions, the US and the international reanalysis communities, and between reanalysis and observational communities.

Identifying Scientific Goals

- Forecasting?
- Prediction/Projection?
- Climate research?
- Dynamical consistency?
- Budget closure?
- Uncertainty estimate?



Data Assimilation approach, Filter vs. Smoother

[Stammer et al., 2016]

Examples of high-latitude ocean-sea ice reanalyses

- ASTE R1 (UT Austin, Nguyen et al., 2021)
- TOPAZ4 (NERSC, Sakov et al., 2012)
- PIOMASS (U. Washington, Zhang & Rothrock 2003)

- ORAS5 (ECMWF, Zuo et al., 2018)
- SODA3 (U. Maryland, Carton et al., 2018)
- GECCO3 (Hamburg Univ., Köhl 2020)
- ECDA3 (GFDL/NOAA)
- Others (e.g., Uotila et al., 2018, An asessement of ten ocean reanalyses in the polar regions)

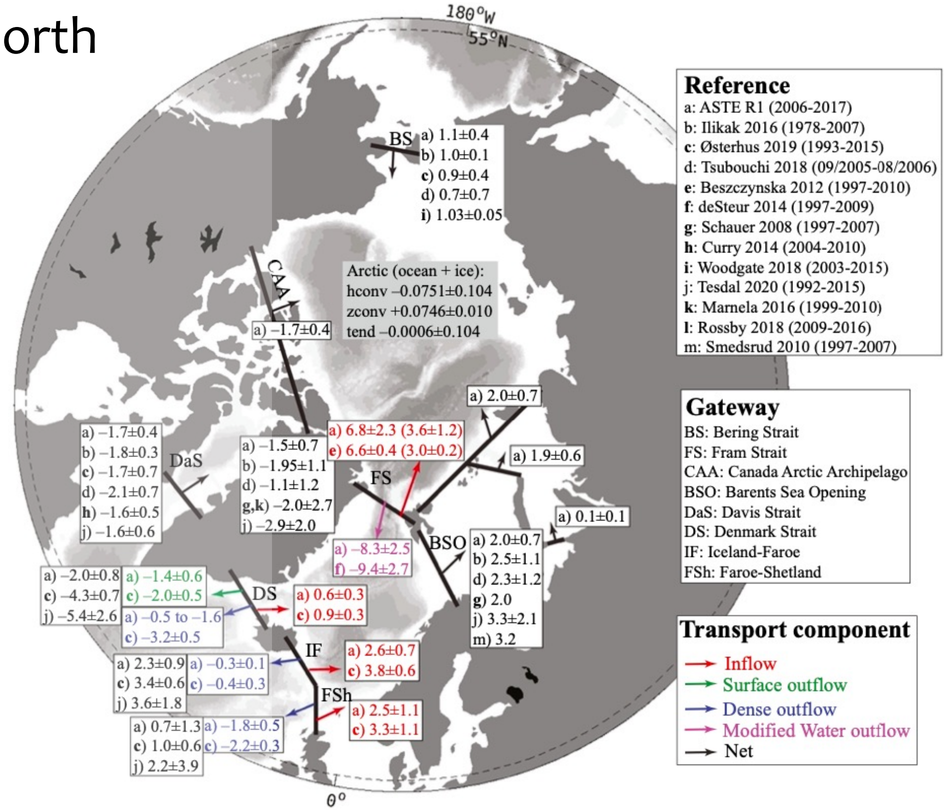
Atmospheric forcing:

ERA-interim/ERA5
MERRA2
JRA55
NCEP
CORE-II, others

Arctic Subpolar gyre sTate Estimate (ASTE) Release 1

The first of its kind for Arctic & subpolar North Atlantic ocean-sea ice reanalysis:

- (multi-)decadal, for climate studies
- Fit to diverse > 10^9 satellite & high-latitude in situ observations
- Model dynamics – interpolator where there is no data
- Adjoint-based non-sequential
  - → **Dynamically consistent**
  - → **Budget closures** for mass, heat, salt, momentum
- Accounts for **uncertain input parameters** (surface forcing, internal mixing, initial conditions)



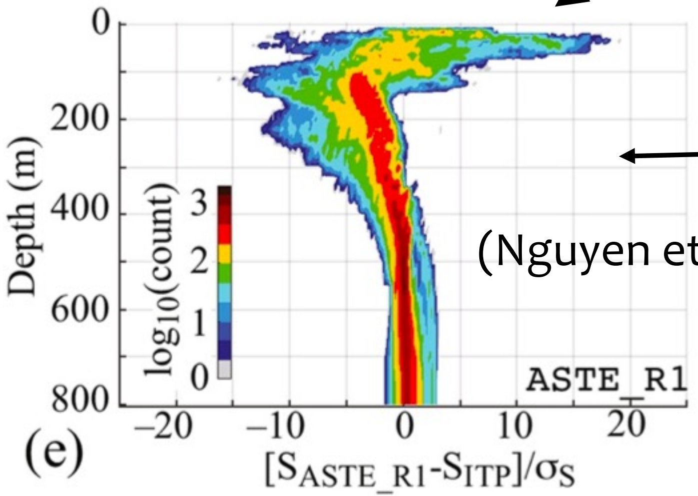
(Nguyen et al. 2021)

ASTE Release 1: Observational constraints

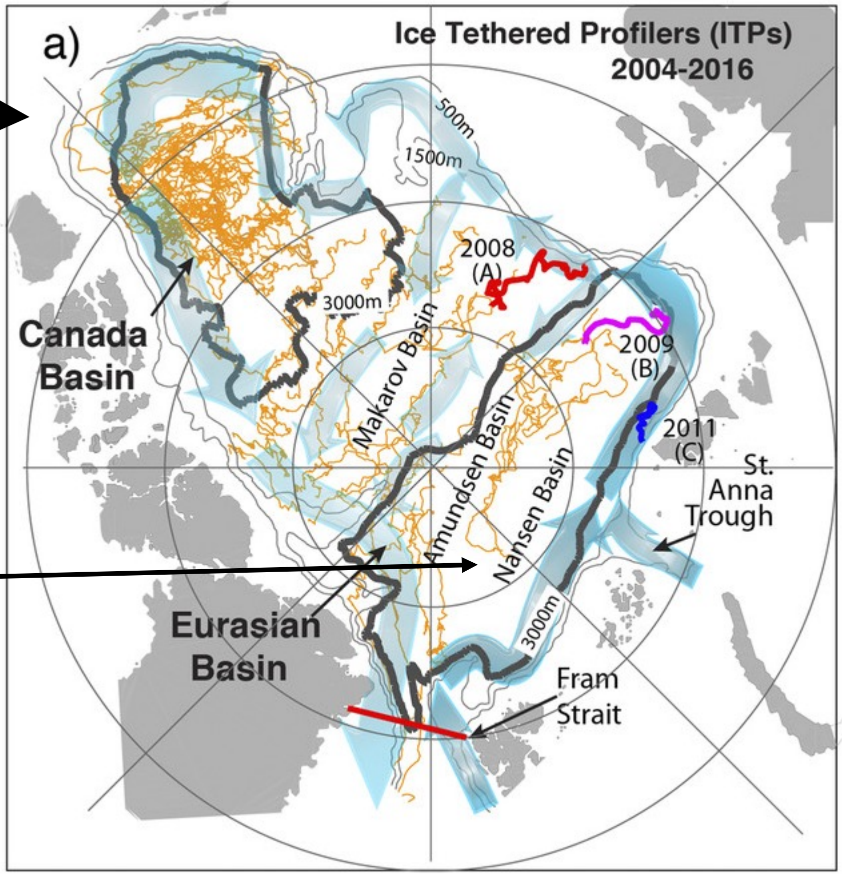
Lack of observations

→ non-unique ways to improve uncertain / highly unconstrained input parameters

→ persistent reanalysis errors/biases



(Nguyen et al. 2021)



(Nguyen et al. 2020)

Advocate for dynamical consistency – Arctic atmospheric reanalyses

Graham et al., 2019,
Evaluation of Six Atmospheric Reanalyses over Arctic Sea Ice from Winter to Early Summer

Collow et al., 2020,
Recent Arctic Ocean Surface Air Temperatures in Atmospheric Reanalyses and Numerical Simulations

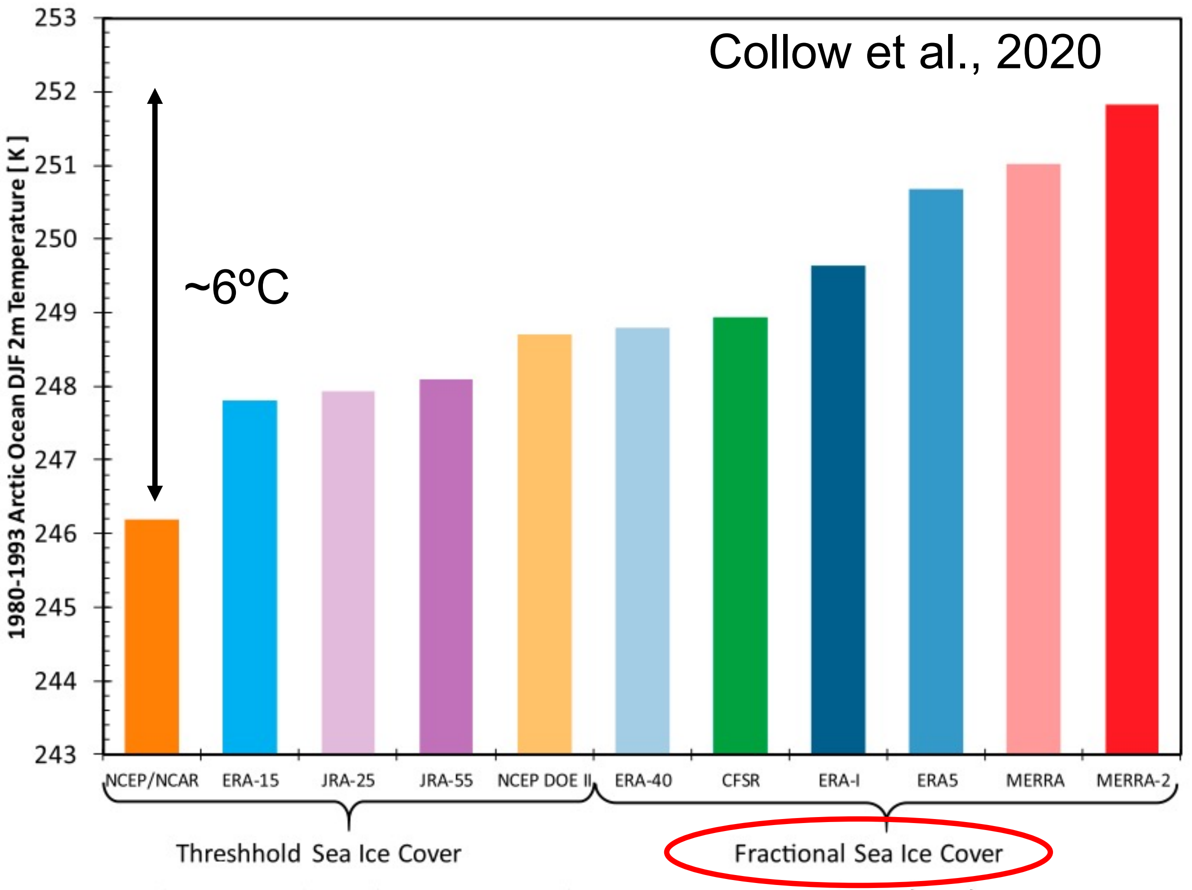


FIG. 6. Averaged Arctic Ocean 2-m air temperatures for winter (DJF) 1980–93.

Advocate for dynamical consistency

Cullather et al. 2016, Systematic Improvements of Reanalyses in the Arctic, IARPC white paper

"Compared to mid-latitudes, the Arctic has a paucity of in situ observations. Additionally, both infrared and microwave satellite sensors have difficulty in profiling the lower atmosphere over snow- and ice-covered surfaces, and geostationary satellites do not cover the high latitudes."

Thus, an atmospheric reanalysis in the Arctic:

- A forward **unconstrained** run (with associated model errors)
- **Trends:** artificial (?) from background forecast (e.g., "trend in time toward larger analysis increment values in MERRA" [Laliberté & Kushner, 2014])

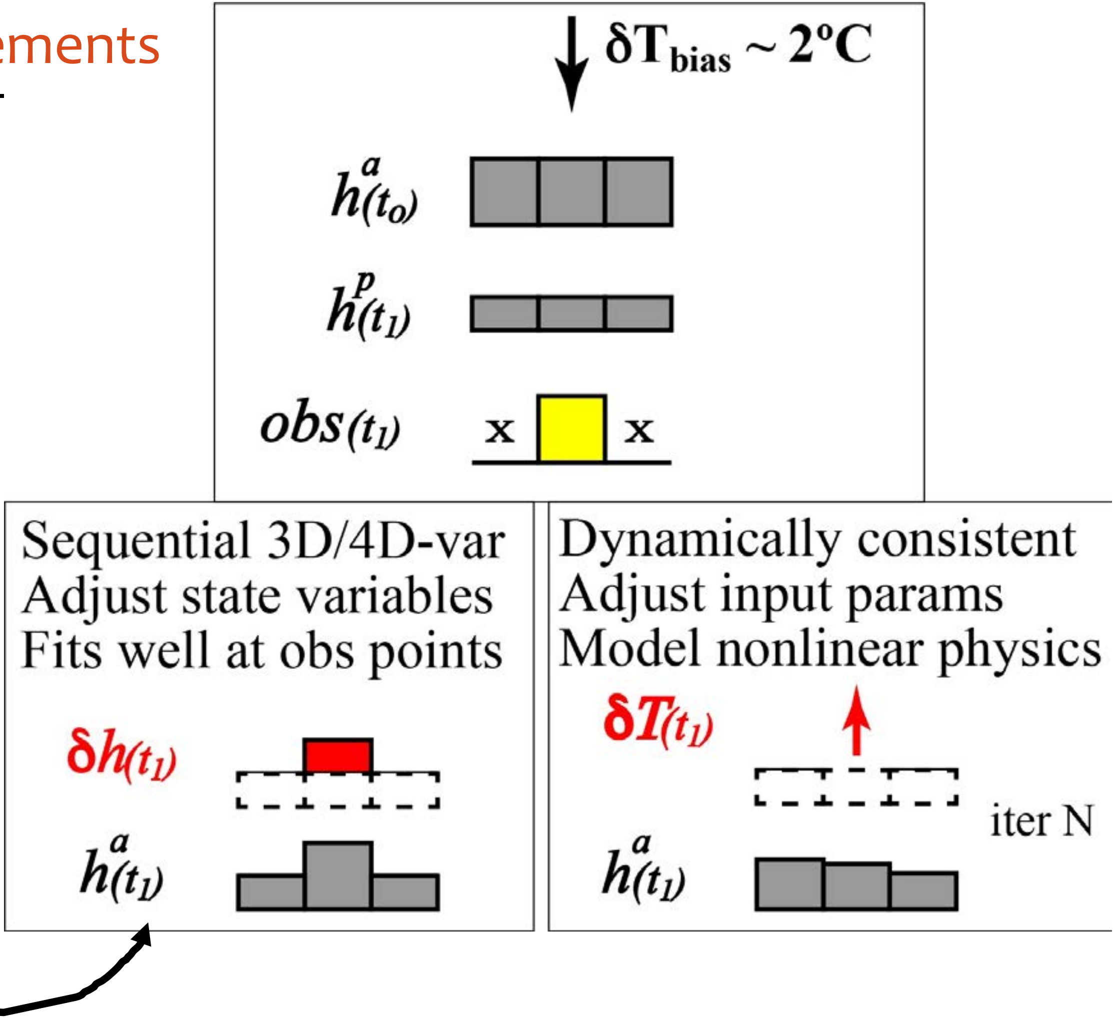
Consequences of analyses increments

Example: ~2-6°C bias in T_{air}

→ forcing Arctic coupled ocean-sea ice Reanalyses:

→Where to map this error/bias in atmospheric reanalysis to?

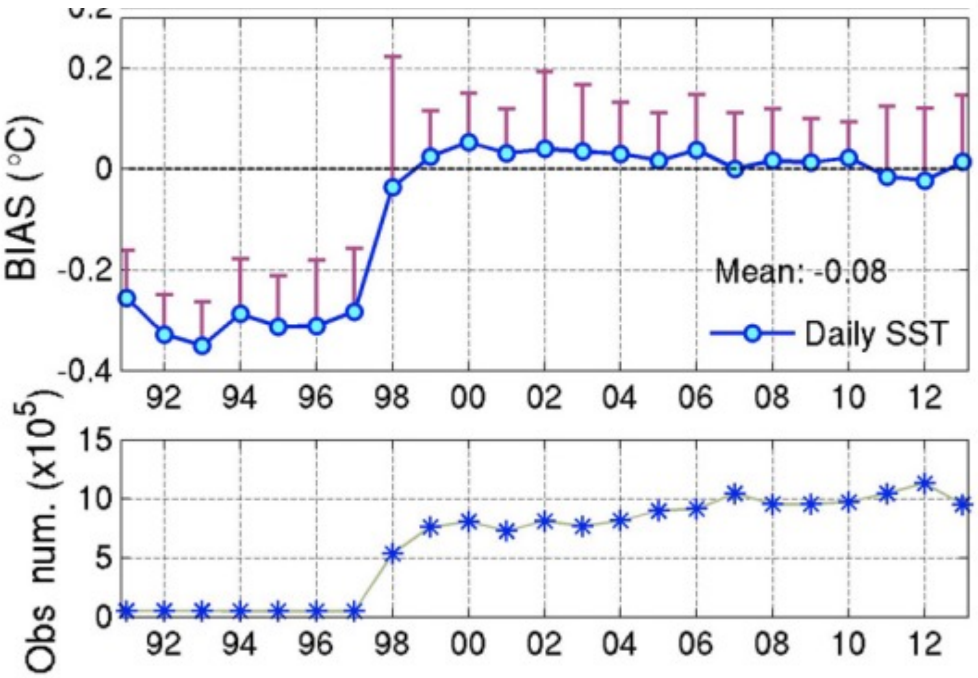
- "extra" heat sink
- Artificial temporal/spatial jumps/trends related to data availability



Consequences of inhomogeneous obs system

Artificial temporal/spatial jumps/trends due to data availability

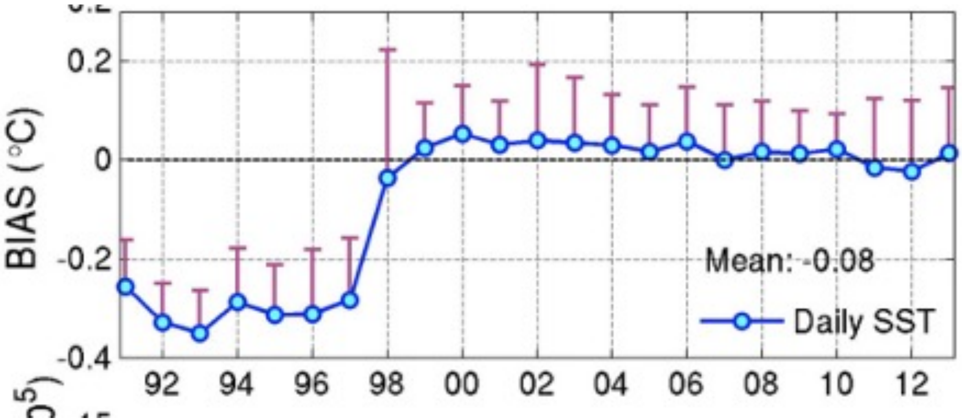
(Analysis increments can be leading term in budget
-- D. Trossman's unpublished work)



Xie et al., 2017 (TOPAZ4)

Caution when investigation of changes

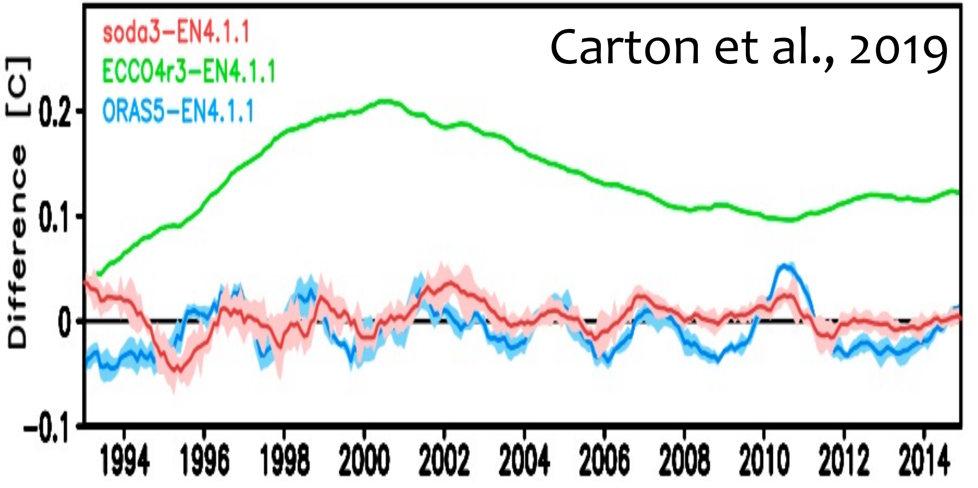
Xie et al., 2017



Carton et al., 2019
"Concerns of biases in .. heat and salt storage, volume transports, sea level,.. caused ocean reanalyses to have limited roles in IPCC.. "

"To evaluate bias and accuracy of the reanalyses **only** where observations are actually available…"

"Following the examination of misfits, we explore interannual to decadal variability of global and regional ocean heat content **changes**."



Summary: advocating parameters estimation and dynamical consistency

2. What do you see are the most significant barriers to progress in the field of reanalysis?

Analyses increments can be large in space and time

→ unclear what small changes in the reanalyses mean;

Lack of obs. in ocean, but also large errors coming in from (input) atm reanalyses

→ Consequence for uncertainty in biogeochemistry & ecosystem analyses that depend on ocean/sea ice/atmospheric states [Fennel et al. 2019]

4. What are the critical requirements for consistent Earth system reanalysis?

Improve model physics, maintain dynamical consistency

5. What observational datasets are required to support these requirements?

7. How is uncertainty quantified for your application?

Are there significant barriers for quantifying uncertainty in your field?

Not well observed, uncertain parameters that have large impact on model trajectory/drift

US Climate Variability and Predictability Program
Workshop on Future US Earth System Reanalysis
Scope:
Workshop on Future US Earth System Reanalysis aims at developing a shared scientific, technological, and application vision for the future of US reanalysis efforts
1. Identify scientific goals for the next generation of reanalysis from the atmospheric, oceanographic, and cryosphere perspectives.
2. Identify opportunities for exploiting technological advancements in Earth system models, data assimilation systems, observations, and computational infrastructure.
3. Identify priorities and opportunities for tighter collaboration between the US institutions, the US and the international reanalysis communities, and between reanalysis and observational communities.

give a ~20 minute presentation (15 minute talk + 5 minute Q&A) **on the development of the reanalysis products focused on high-latitudes**, including the cryosphere, land, atmosphere, biogeochemistry, and surface fluxes. Your talk will help set the stage for in-depth discussions during plenary and in breakout sessions. A final agenda will be shared with you in the upcoming months with additional details on timing and discussion time.

keep in mind the below questions when designing your presentation. We understand that some questions may be more applicable to your talk than others. We ask that you answer as many as you can that are relevant, and prepare one slide addressing those questions at the end of your presentation.
1. What do you see are the most significant advances for the field of reanalysis in 5-10 years?
2. What do you see are the most significant barriers to progress in the field of reanalysis?
3. Which collaborations are currently working and which collaborations need to be fostered?
4. What are the critical requirements for consistent Earth system reanalysis?
5. What observational datasets are required to support these requirements?
6. What modeling components are mature enough to enable reanalysis for your specific science question or application?
7. How is uncertainty quantified for your application? Are there significant barriers for quantifying uncertainty in your field?

Target Participants
This workshop will be open to the broad Earth sciences community. Experts from data assimilation communities, operational and research centers, academia, and users of the reanalysis products are encouraged to attend. The Scientific Organizing Committee anticipates about 100 participants with a mix of in-person and virtual.

Talk time:
Session 1: Scientific and application requirements for consistent climate reanalysis,
Moderators: Isla Simpson, NCAR, Patrick Heimbach, University of Texas at Austin, and Cecile Rousseaux, NASA
09:20-09:40, Reanalysis with a focus on high-latitudes: Cryosphere, land, atmosphere, bio, fluxes, and ice