Parameter Sensitivity Analysis in the NOAA UFS Land Data Assimilation System

Session: H42B-02, abstract ID 1409194
Thursday, 14 December 2023; 10:20 – 11:50 PST

Jong Kim[1,5], Michael Barlage[2], Clara Draper[3], Michael Ek[4], Dohyuk Kang[8], Rhae Sung Kim[1,5], Zachary Shrader[1,6], Yi-Cheng Teng[1,7]
Affiliations: [1]NOAA EPIC, [2]NOAA EMC, [3]NOAA PSL, [4]NSF NCAR, [5]STC, [6]RTX, [7]T.IO, [8]FedWriters

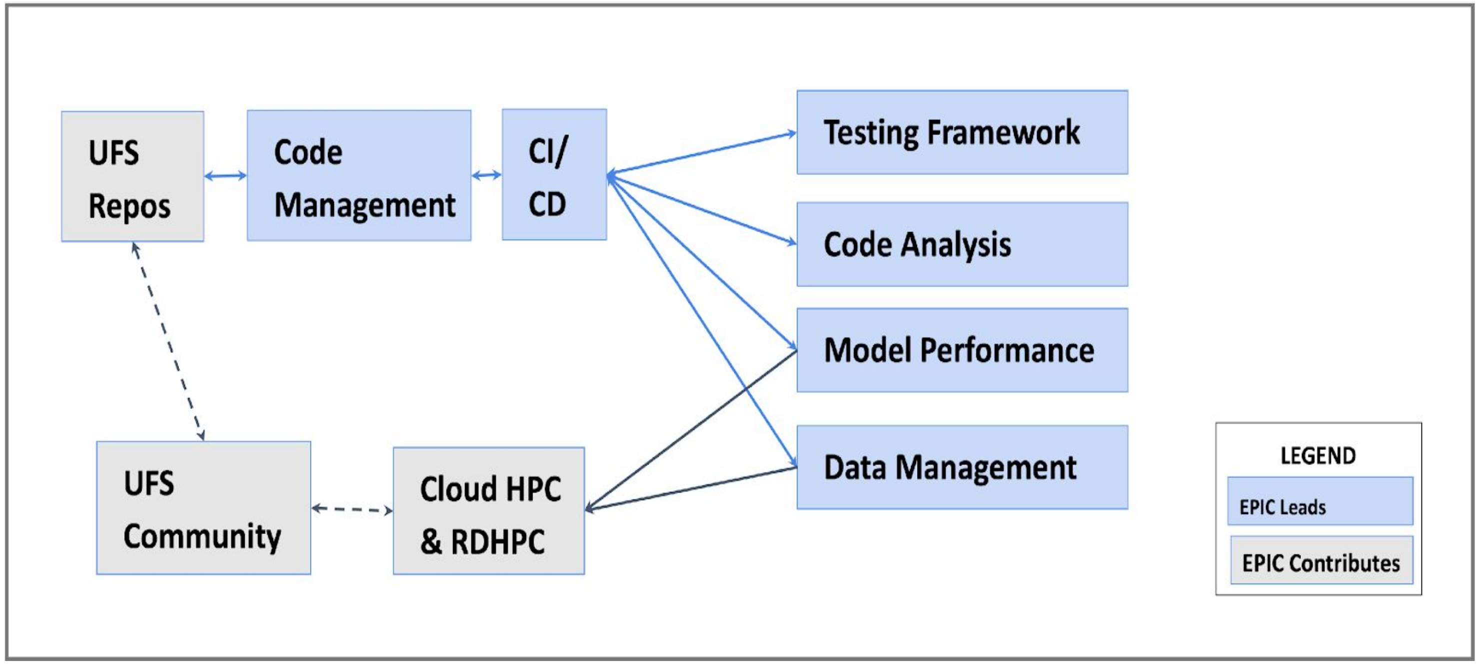
AGU23

Outlines

- NOAA EPIC mission activities
- UFS Land data assimilation (DA) system release and overview
  - UFS Land model: NOAH-MP
  - DA system based on JCSDA JEDI (The Joint Effort for Data assimilation Integration)
  - Snow depth DA with GHCN (Global Historical Climatology Network) data set
- Sensitivity analysis approach based on UFS land DA system
  - Python-based parameter space sensitivity analysis: SAlib
  - Impact of snow and soil thermal conductivity schemes
- Next Steps

EPIC's mission:

NOAA created the Earth Prediction Innovation Center (EPIC) to improve operational weather and climate forecast systems through scientific and technical innovation via model co-development with the Weather Enterprise — government, industry and academia.



Simplified diagram of the main components and infrastructure developmental activities of the EPIC within the broader framework of the UFS.

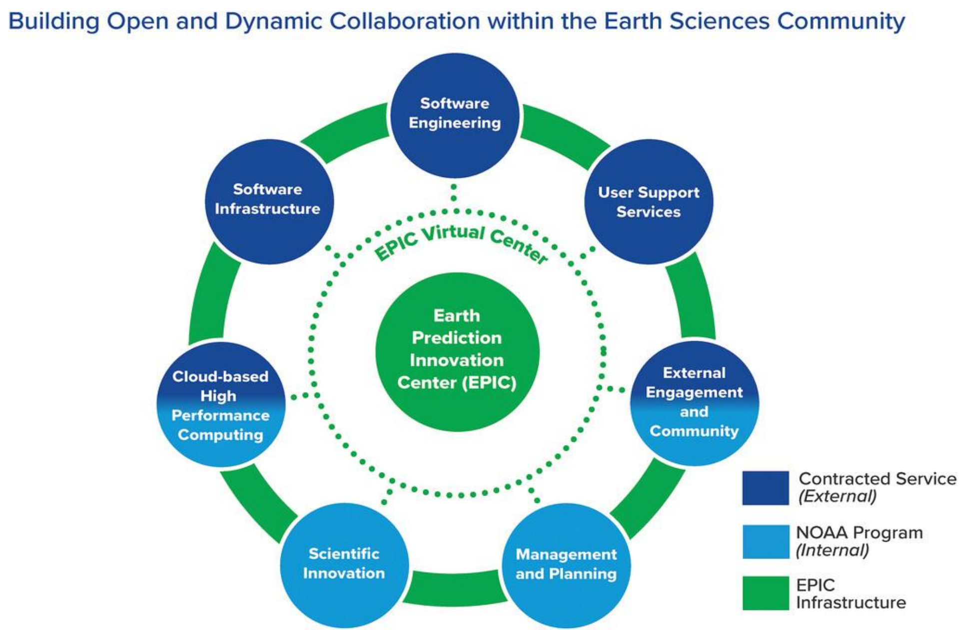
- Develop/provide necessary Software Infrastructure;
- Manage, maintain, test, and evaluate the UFS WM and Apps source code;
- Develop and maintain the appropriate frameworks;
- Support the transition of the UFS WM to Cloud-based HPC

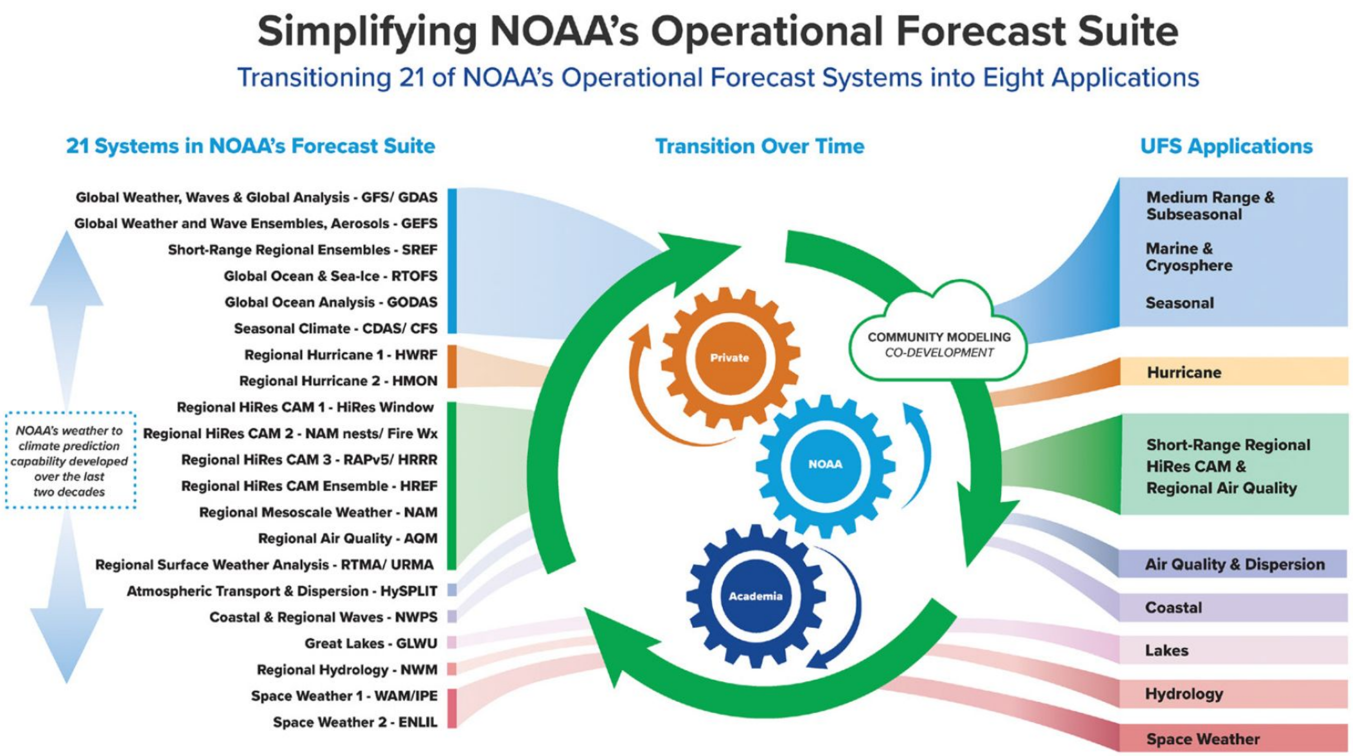
UFS Land DA Release Features

- **Standalone offline land DA workflow:** https://github.com/ufs-community/land-DA_workflow
  - Source code bases are originated from NOAA-PSL
- **Model source codebase: CCPP and UFS Noah-MP land driver**
  - Multiple parameterizations to treat key hydrology, snow and vegetation processes in a single land modeling framework
- **JCSDA JEDI bundle to assimilate snow depth observation data (GHCN)**
  - Land DA running on the cubed sphered native model grid in the UFS Weather model code base
  - Flexibility to apply same data assimilation code base for atmospheric and land model systems
  - Snow depth analysis: pre-processed gridded GHCN product
  - LETKF (LETKF-OI): a pseudo-ensemble and localization to approximate the error covariance functions used in the OI (Frolov et al (2022), QJRMS)
  - Analysis baseline: C96 grid and GHCN (Global Historical Climatology Network - Daily), 2019
  - Support the baseline tests on NOAA RDHPCS and Cloud platforms
  - NOAA NODD data bucket available: https://noaa-ufs-land-da-pds.s3.amazonaws.com/index.html

EPIC Architecture Plan

- Unified Forecast System (UFS)
- UFS Weather and Apps release
  - to support NOAA EPIC mission activities

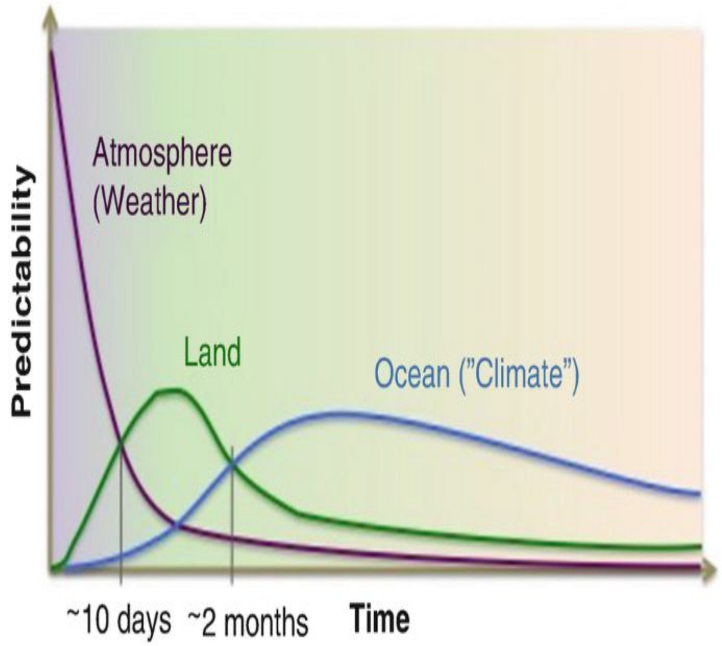




WIDE. OPEN. SCIENCE.

Land DA Motivation

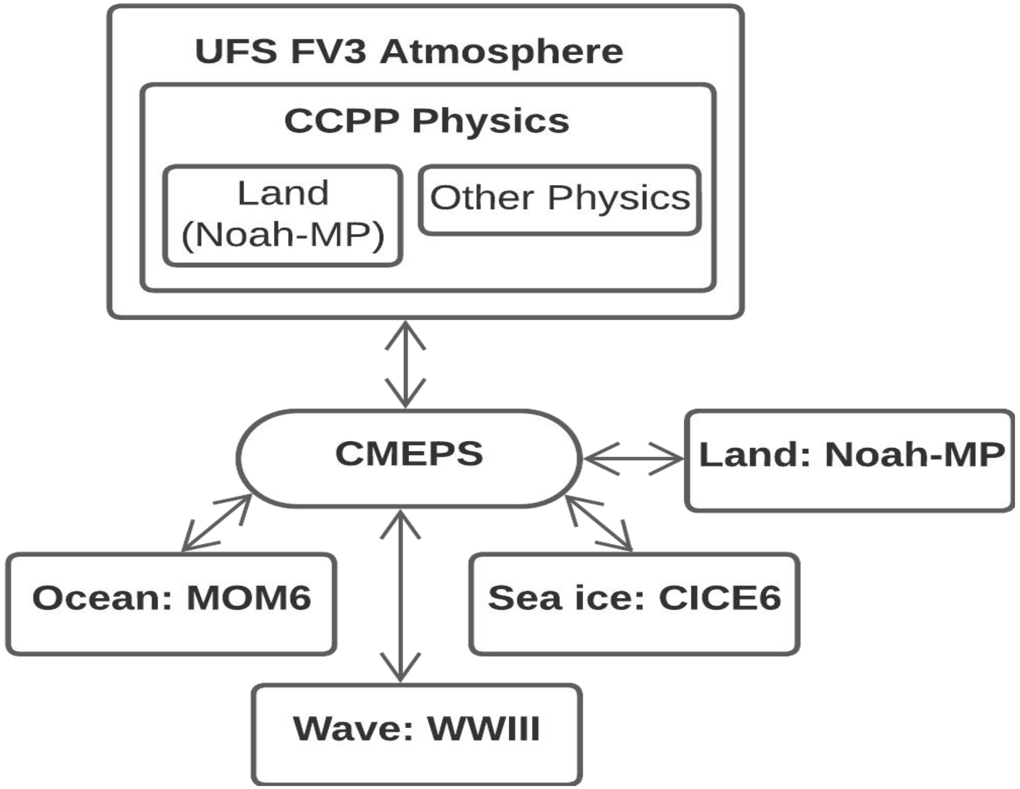
- **Operational forecast models increasingly involve with coupled Earth modeling and data assimilation system**
- **Quantification and prediction of land surface state variability:**
  - Critical for initialization of weather and climate forecasts
  - Hydrological community applications include agricultural forecasting, drought and flood risk assessments, etc.
  - Land states can provide predictability in subseasonal-to-seasonal time scale: soil temperature and moisture, snow temperature, etc.
  - Strong influence of land surface flux and moisture partition on the atmospheric boundary layer
  - **Quantification and correction of forecast bias is important prior to analysis**
    - JEDI Unified Forward Operator (UFO) can be applied to compare forecast results against observations: ***H(x) or HofX for model state variables including*** **soil moisture, soil temperature, and snowpack**



Seasonal to Subsesonal

UFS Weather Model: https://github.com/ufs-community/ufs-weather-model

- Atmosphere
  - FV3 dynamical core
  - CCPP physics driver: Noah-MP LSM
- Ocean
  - MOM6 Modular Ocean Model
- Waves
  - WAVEWATCH III
- Sea Ice
  - CICE6 Los Alamos Sea Ice Model
- Land Surface Model
  - Noah-MP component option is available
- Driver/Mediator
  - NEMS driver
  - CMEPS mediator



Sensitivity experiment setup

- **Snow thermal conductivity formula**

```
!   tksno(iz) = 3.2217e-6*bdsnoi(iz)**2.              ! stieglitz(yen,1965)
!   tksno(iz) = 1.5*3.2217e-6*bdsnoi(iz)**2.
!   tksno(iz) = 2e-2+2.5e-6*bdsnoi(iz)*bdsnoi(iz)  ! anderson, 1976
!   tksno(iz) = 0.35                                    ! constant
    tksno(iz) = 2.576e-6*bdsnoi(iz)**2. + 0.074       ! verseghy (1991)
!   tksno(iz) = 2.22*(bdsnoi(iz)/1000.)**1.88         ! douvill(yen, 1981)
```

- **Dry soil thermal conductivity**

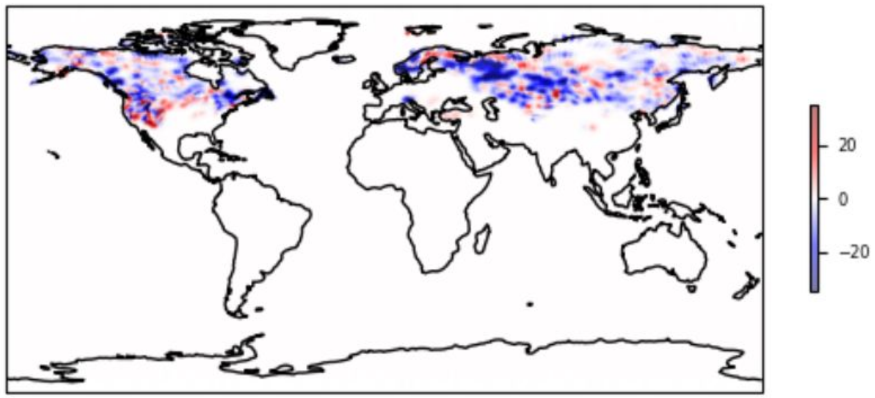
```
gammd = (1. - parameters%smcmax(isoil))*2700.
thkdry = (1.1*0.135* gammd+ 64.7)/ (2700. - 0.947* gammd)
```

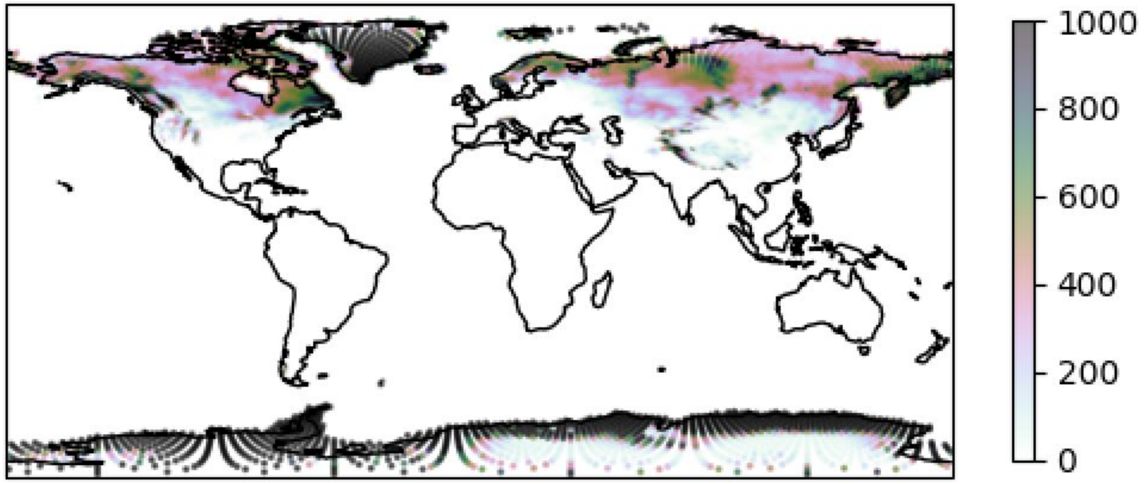
- **DA experiment setup**
  - Global C96 grid resolution and GHCN for 2019 Dec 21-29: ERA5 atmospheric forcing
- **Sensitivity indices computed with python SAlib packages**
  - Sobol method with Saltelli sampling: 60 sets of snow and soil conductivity parameter space

Preliminary experiment result

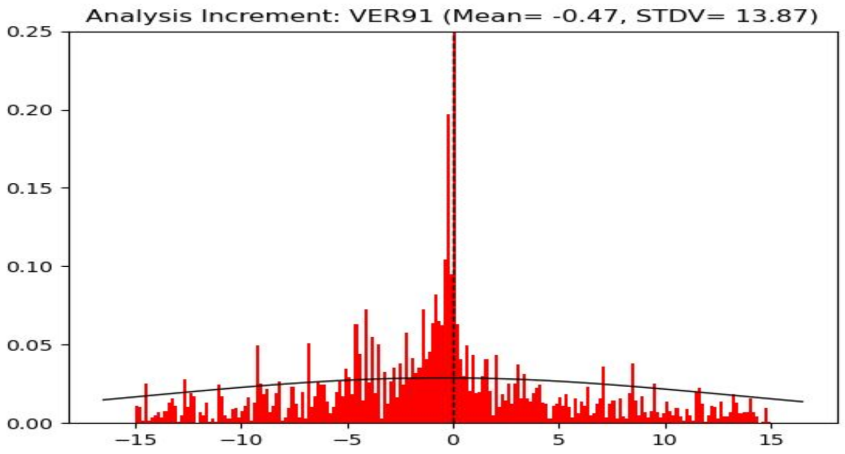
- **Snow depth analysis field (bottom) and increment (right)**
  - Analysis date: 2019-Dec-22 with default snow thermal conductivity scheme: Verseghy, 1991
  - Analysis increment results show positive model bias: histogram (right bottom)

JEDI xainc.sfc_data: totalSnowDepth (mm)



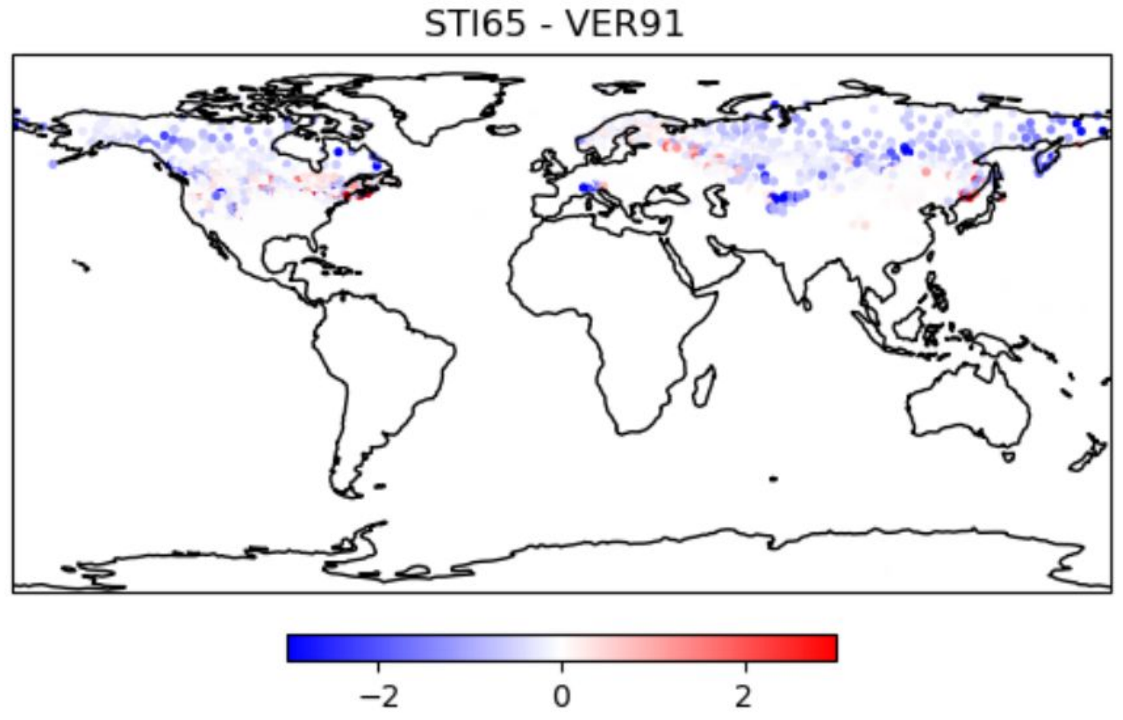


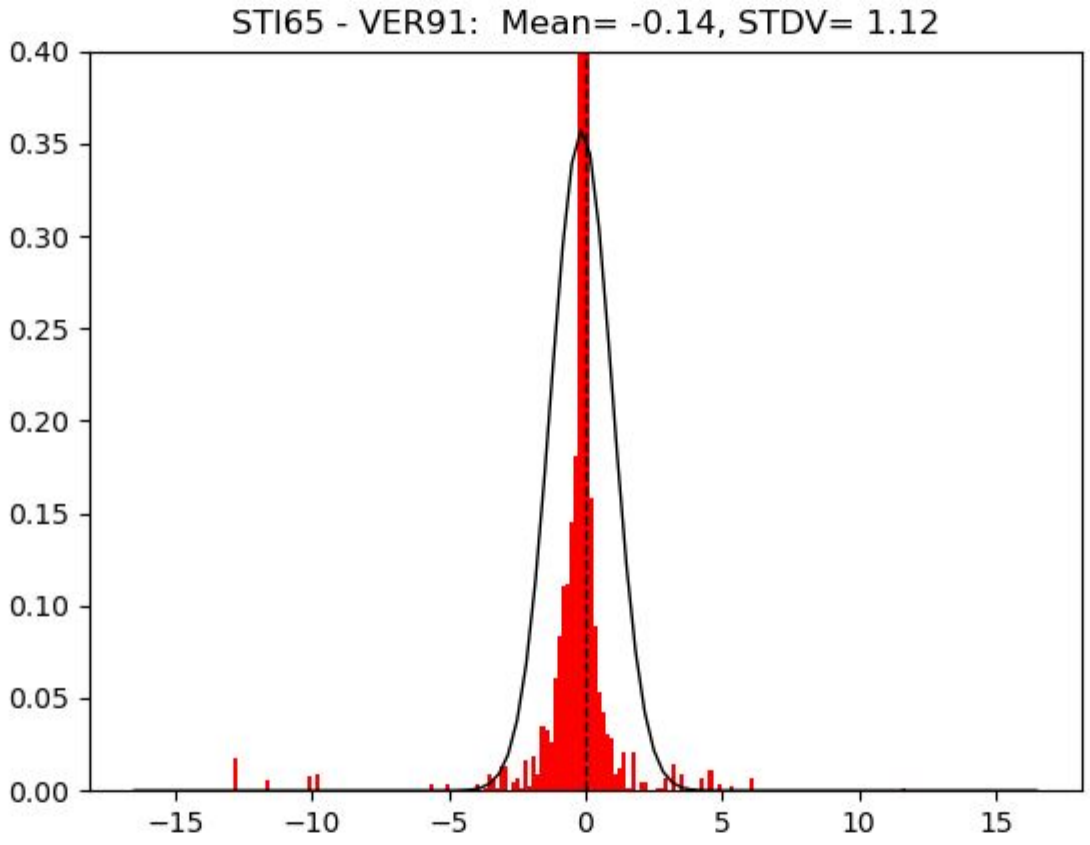
Assimilated snow depth (mm) 12/22/2019



Preliminary experiment result

- **Impact of snow thermal conductivity formula**
  - Snow depth analysis field difference computed with Verseghy-91 and Stieglitz/Yen-65 schemes
  - Positive model bias feature: VER-91 scheme





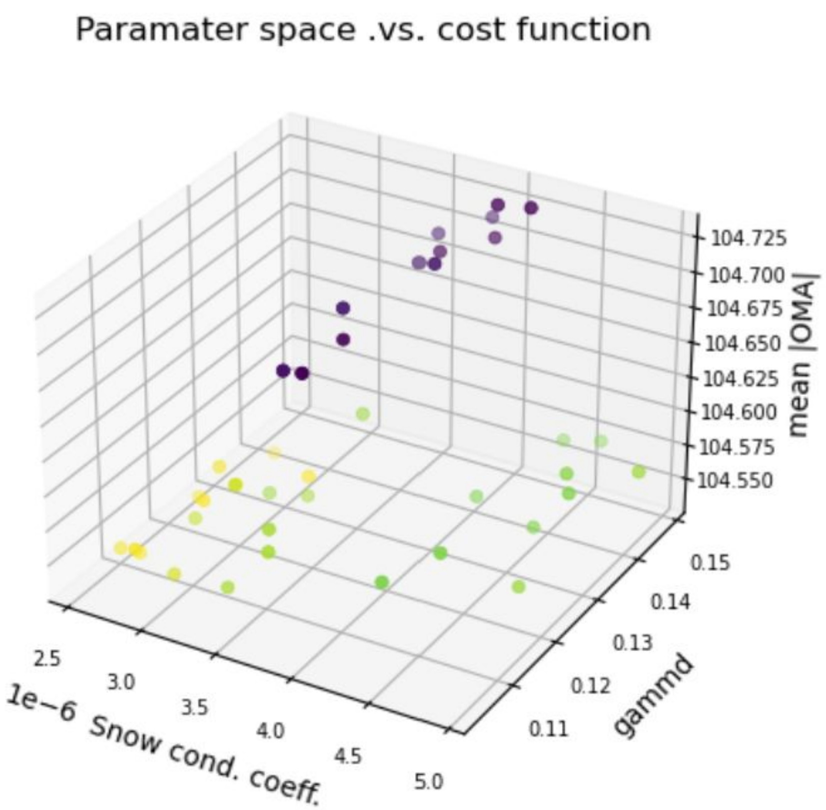
WIDE. OPEN. SCIENCE.

Sensitivity analysis code structure: Sobol method

- **Use of HofX experiment statistics generated with selected parameter space**

```
from SALib.sample import saltelli
from SALib.analyze import sobol
def cost_function(X):
    ...
    oma = hofx_stats(expath)
    result[i] = oma
    ...
if __name__ == '__main__':
  problem = { 'num_vars': 2,
    'names': ['snowcon', 'gammd'],
    'bounds': [[2.5e-6, 5.0e-6],
               [1.0e-1, 1.5e-1]]}
  param_values = saltelli.sample(problem,10)
  Y  = cost_function(param_values)
  Si = sobol.analyze(problem, Y)
```

Parameter	S1	S1_conf	ST	ST_conf
snowcon	0.889140	0.834094	0.907900	0.653783
gammd	-0.024089	0.051513	0.001362	0.002892



Next Steps: as part of future UFS Land DA release activities

- Identify python-based parametrization impact analysis options and analyze feasibility to integrate with DA workflow system to effectively manage extensive experiment scopes for longer time scale analysis
- Add additional observation options: in-situ and remote sensing
- Build unified build environment consistent with UFS Weather model structure
- Maintain continuous code change integration and evaluation approaches and tools
- Coordination of JEDI and UFS App development to support and enhance NOAA operational GDAS land DA features through R2O and O2R transition processes

THANK YOU

More information about UFS Weather and land DA features: Jong.Kim@noaa.gov
https://github.com/ufs-community/land-DA_workflow

AGU23