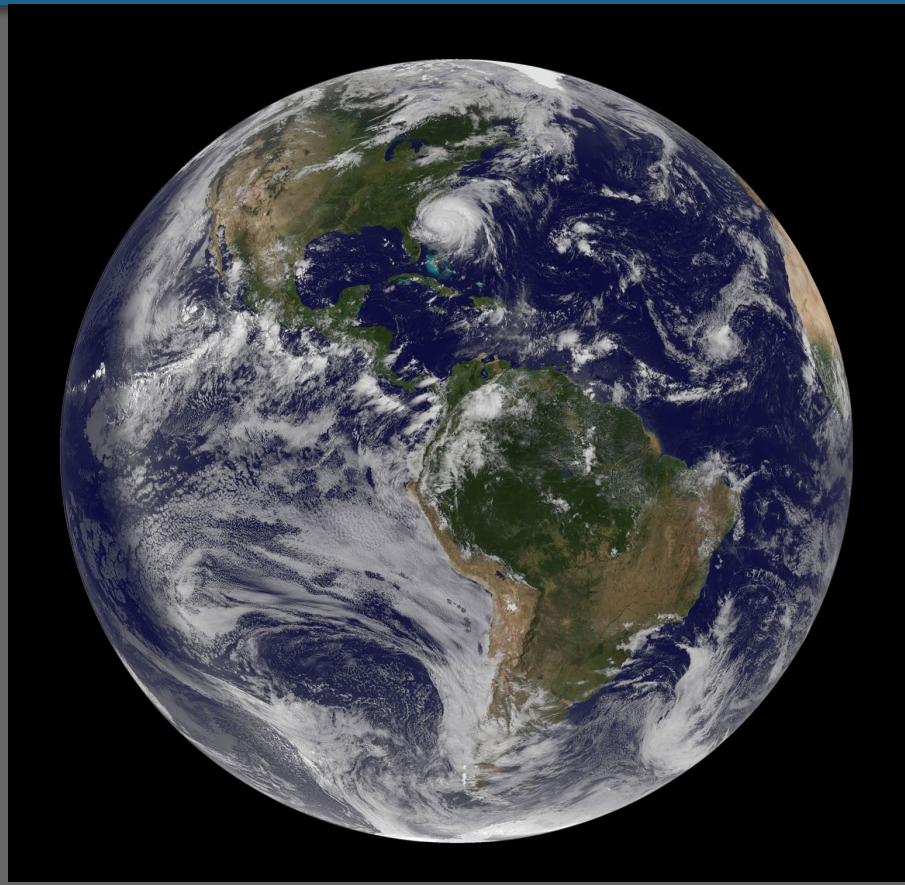
ESMF Progress Update and Roadmap

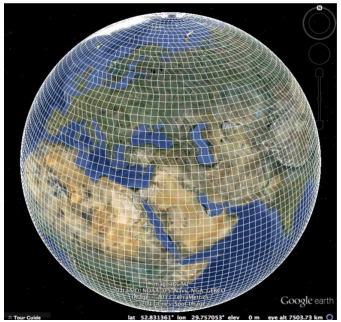


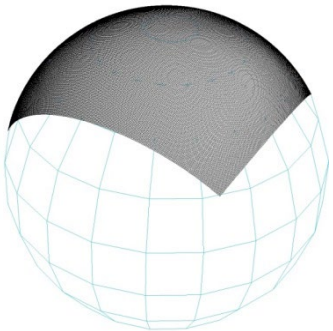
Ann Tsay

June 10, 2025

Agenda

- Overview of ESMF
- Select List of changes from 8.6.1 - 8.8.1 relevant to CESM
- Up-coming 8.9.0 changes
- Roadmap
- Team
- Q&A



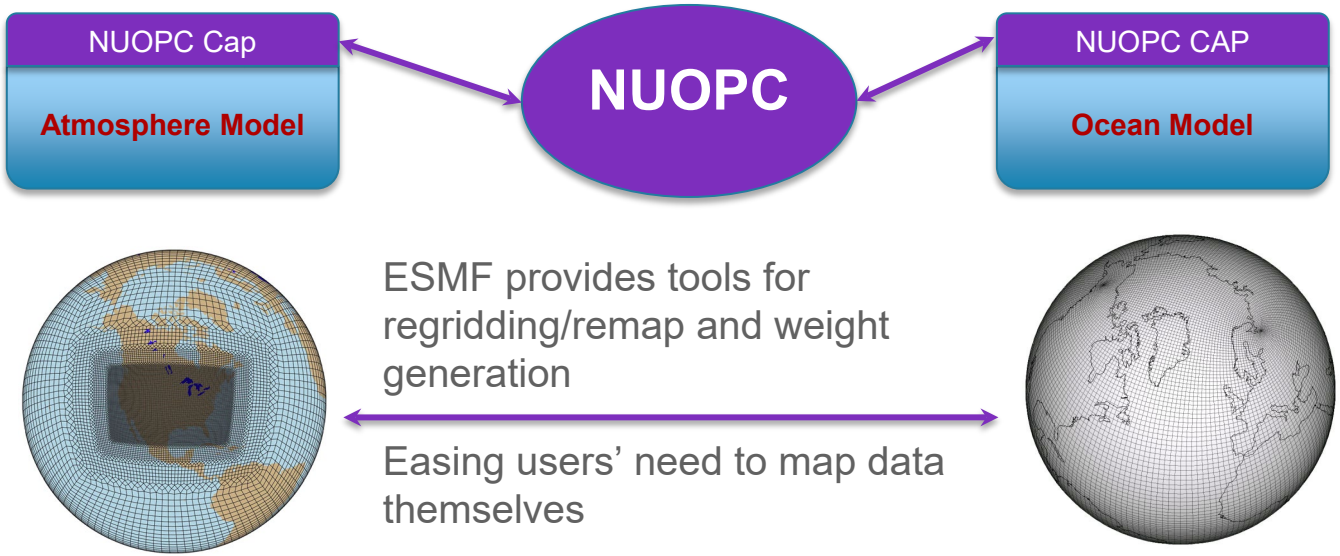


ESMF Overview

The **E**arth **S**ystem **M**odeling **F**ramework (ESMF) is a **high performance parallel software infrastructure** used in coupled Earth science applications.

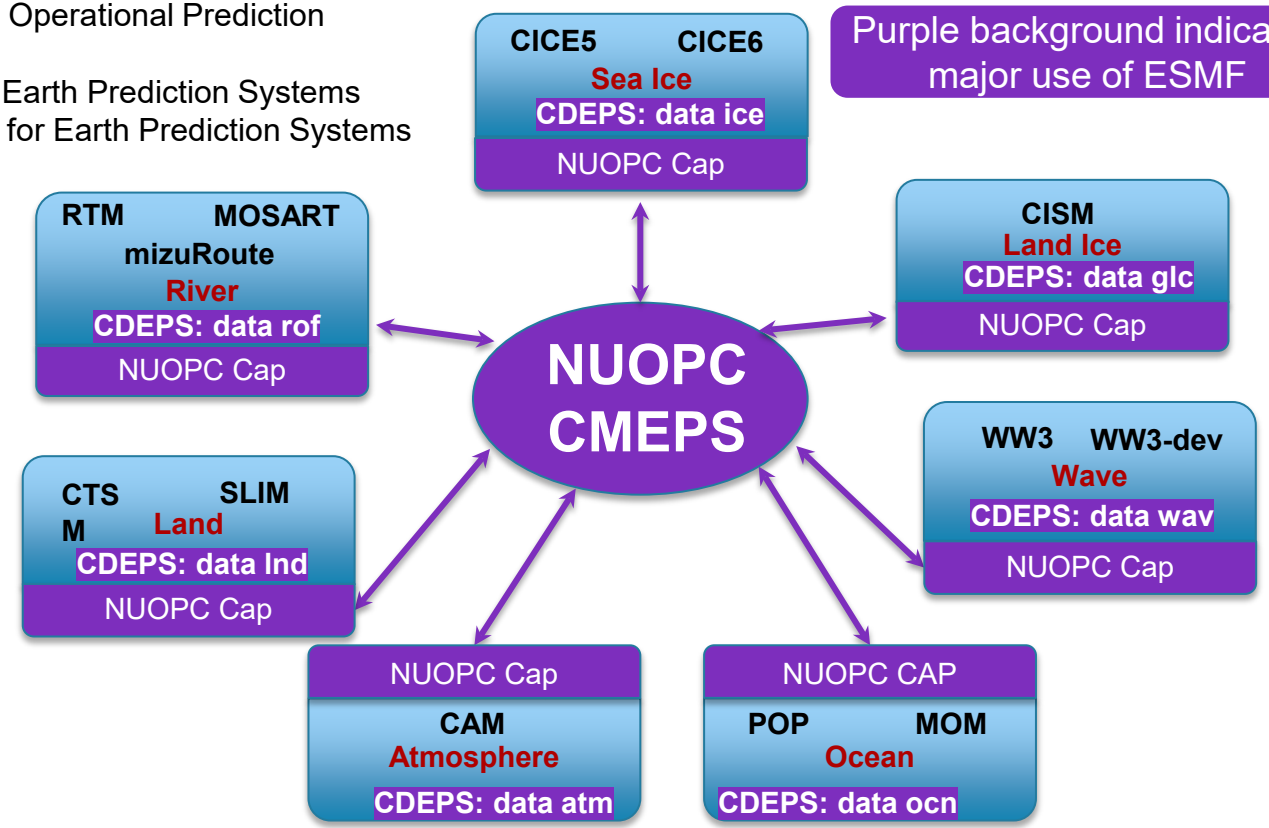
Focuses on
- Interoperability
- Reusability
- Regridding
- Performance

NUOPC: ESMF's National Unified Operational Prediction Capability layer



Use of ESMF in Community Earth System Model

NUOPC: ESMF's National Unified Operational Prediction Capability layer
CMEPS: Community Mediator for Earth Prediction Systems
CDEPS: Community Data Models for Earth Prediction Systems



Selected List of Changes

8.6.1

- ESMF config class which handles files nuopc.runconfig (used in CESM) has been made more robust and able to handle new usages.

Update to ESMFMESH unstructured mesh file format to dynamically connect indexing to an attribute of a variable

8.7.0

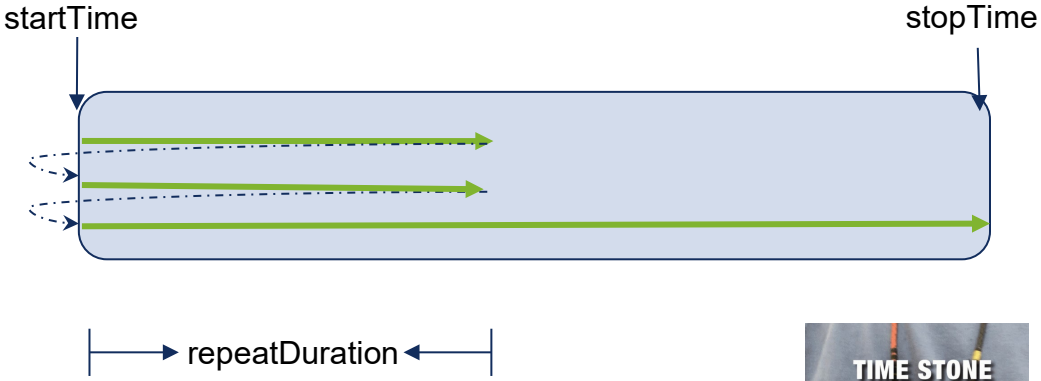
- New repeat capability in ESMF Clock, which may be useful in spinning up a model
- Performance Optimization
  - Redist/Regrid routeHandle calculation was improved for some cases -> For NASA, this decrease the routeHandle calculation time by a factor of 20.
  - Reduces the memory requirement for applications that have a large number of Arrays or Fields and run on large numbers of PETs.
- The NUOPC Connection Options now support remapMethod “conserve_2nd” and extrapMethod “nearest_d”

Repeated Clock Capability

NASA requested: Historical data set looping to spin up the model until it gets to a stable/equilibrium state and then we can progress with simulation.

This could provide an alternative for CESM's current mechanism for spinup and handling of data streams.

- Set a repeatDuration
- When current time reaches startTime+repeatDuration, it will go back to startTime
- User stops the looping so it proceed with model (future feature is to add repeatCount as internal stop condition)



Selected List of Changes

8.6.1

- ESMF config class which handles files nuopc.runconfig (used in CESM) has been made more robust and able to handle new usages.

Update to ESMFMESH unstructured mesh file format to dynamically connect indexing to an attribute of a variable

8.7.0

- New repeat capability in ESMF Clock, which may be useful in spinning up a model
- Performance Optimization
  - Redist/Regrid routeHandle calculation was improved for some cases -> For NASA, this decreases the routeHandle calculation time by a factor of 20.
  - Reduces the memory requirement for applications that have a large number of Arrays or Fields and run on large numbers of PETs.
- The NUOPC Connection Options now support remapMethod “conserve_2nd” and extrapMethod “nearest_d”

Remap/Regrid Methods Recap

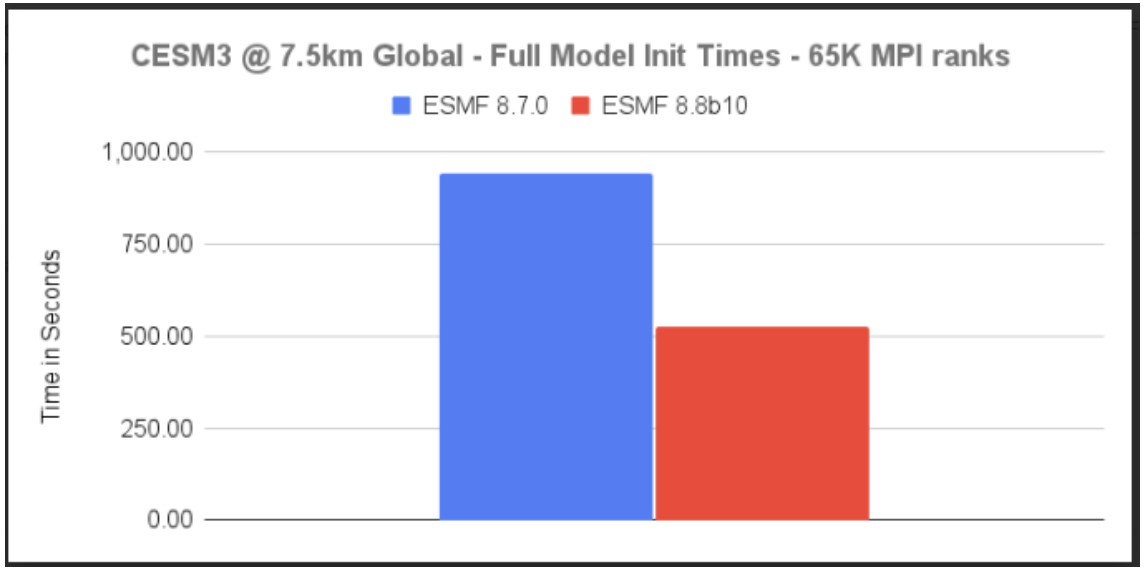
Name	Pros	Cons	Typical Uses
Bilinear	Smooth	Non-conservative	Interpolation of state variables (e.g. temp.)
Patch	Very smooth including derivatives	Values can go outside src range, Non-conservative	Interpolation of state variables where you want them to be very smooth (e.g. wind stress)
Conserve	Preserves integral over an area for values between src and dst	Can be blocky with a coarser src than dst	Interpolation of fluxes or other quantities in cases where you need the total amount to be preserved
Conserve 2nd	Preserves integral over an area for values between src and dst	Values can go outside src range	Interpolation of fluxes or other quantities in cases where you need the total amount to be preserved, but want a smoother result than the above
Nearest SToD	Exactly copies existing values, dst point doesn't need to be within src grid	Not smooth, Non-conservative	Interpolation of values that you don't want blended (e.g. land type), extrapolation
Nearest DToS	Preserves sum of values between src and dst, dst point doesn't need to be within src grid	Not smooth, Non-conservative	Discharging river run off into a body of water

Selected List of Changes

8.8.0

- Performance Optimization: state_reconcile function improvement
- Second Order Remapping on XGrid accuracy improvement -> XGrid is now the default for Atm-ocean flux calculation in CESM.

Improvement in Model Initialization Time

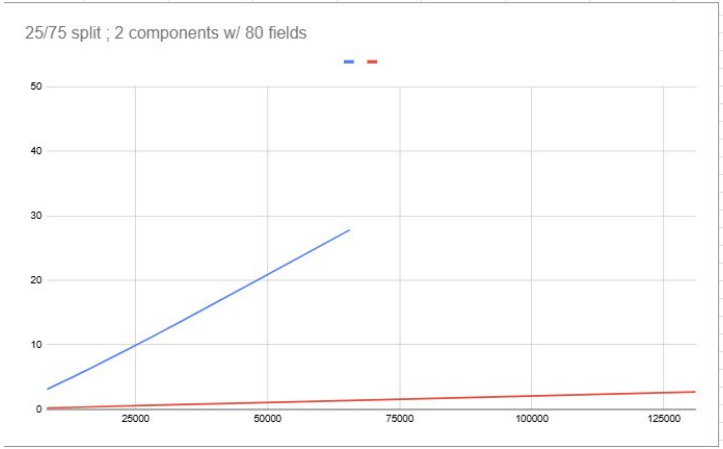


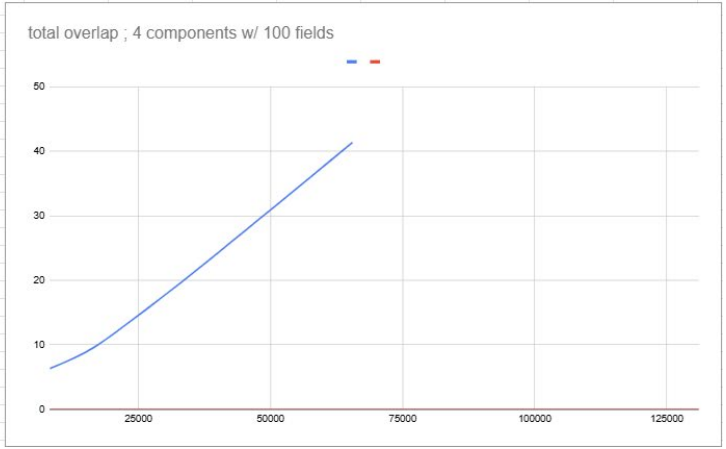
Verion 8.8.0: Performance Optimization

8.8.0

- Performance Optimization: state_reconcile function improvement
- Second Order Remapping on XGrid accuracy improvement -> XGrid is now the default for Atm-ocean flux calculation in CESM.

The old version (blue) was growing quadratically, whereas new version (red) is growing at a much slower pace (almost flat)



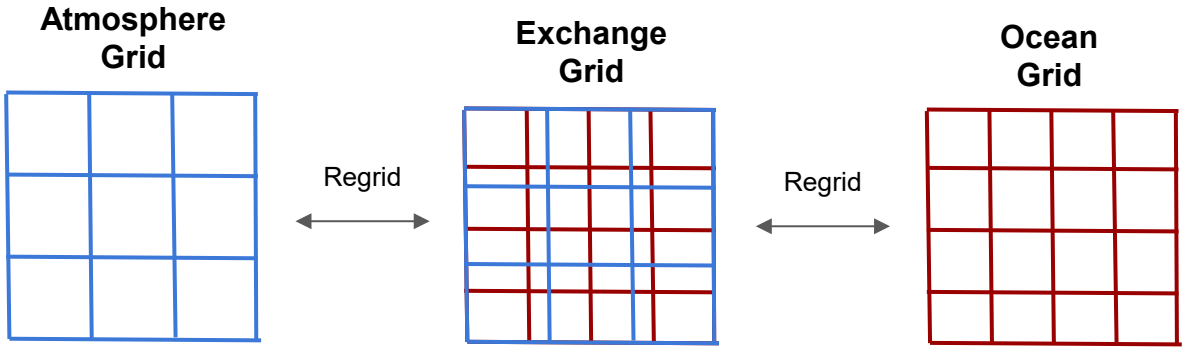


Version 8.8.0: XGrid

8.8.0

- Performance Optimization: Improve model initialization time (state_reconcile)
- Second Order Remapping on XGrid accuracy improvement -> XGrid is now the default for Atm-ocean flux calculation in CESM.

The exchange grid is the set of intersecting cells formed from the union of all vertices in two (or more) parent grids.



Benefits to CESM:

- Calculations are always done at the highest resolution.
- User is not forced to choose between which grid to compute on.

Balaji, V., Anderson, J., Held, I., Winton, M., Durachta, J., Malyshev, S., & Stouffer, R. (2006). The Exchange Grid: A mechanism for data exchange between Earth System components on independent grids. https://extranet.gfdl.noaa.gov/~vb/pdf/xgridpaper.pdf

Up-coming 8.9.0 release

Target Release Date: by early July.

Potential Relevant Features to CESM:

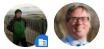
Nearest Neighbor reproducibility fix when numbers of processors changes

- New ESMF Runtime Debugging Feature
  - ESMF_RUNTIME_ABORT_LOGMSG_TYPES and ESMF_RUNTIME_ABORT_ACTION
  - Abort directly after logging ESMF_LOGMSG_ERROR, ESMF_LOGMSG_WARNING, etc. to ESMF PET logs
  - Multiple abort control options: MPI_ABORT or SIGABRT (SIGABRT is capable of core dump from the abort location)
- Broadened the complexity of meshes handled by ESMF regridding
- ESMPy: vectorRegrid flag and multiple DE data
- Build ESMF Documentation from Forks

Future Features Roadmap

Planning for a Change Review Board this summer to help prioritize features from internal and external stakeholders.

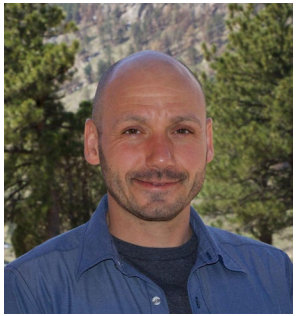
Some potential relevant future improvements for CESM:

- Additional efficiency improvements (time/mem): StateReconcile, Regrid Wgt. Calc.
-  Signal Alarm
- Ability to write meshes and convert various grid formats to ESMF mesh
-  Reading shape file (GIS format) into Mesh
- Regridding Tool improvements to help CESM community. Including:
  - Adding support for CESM grid formats to the ESMF_Regrid command line regridding tool
  - Improving performance by adding support for regrid weight reuse in ESMF_Regrid/ESMPy
- Attaching metadata to ESMF objects and exchanging metadata through NUOPC connectors.
- Multi-language support (i.e. add features in ESMPy and C API, etc)
- Field merging, smoothing, and blending (useful for runoff mapping)
- And others…

ESMF Team

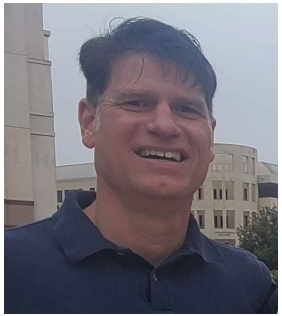
Always ready to answer community questions via esmf_support@ucar.edu or Github Discussion board.

Bob **Oehmke**



Dan **Rosen**

Bill **Sacks**



Gerhard **Theurich***

Ann **Tsay**

Ufuk **Turuncoglu**

The ESMF Core Team is primarily housed within NCAR's CGD Lab, Boulder, Colorado.

*Gerhard is part of Navy Research Lab (NRL), and in California.