Noah-MP Component Model

Noah-MP Land Surface Model Tutorial: Model Physics, Code Structures, and Simulation Exercises

***Ufuk Turuncoglu*[1] & *Michael Barlage*[2]**
(1) NCAR/CGD/CSEG/ESMF
(2) NOAA EMC/UFS Land Working Group Co-lead

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Outline

- Introduction
  - General information about UFS Weather Model and land coupling
    - CCPP Physics (sub-grid scale parametrizations)
    - Coupling infrastructure in general
    - Details of land component (Noah-MP) and coupling
- Hand zone session
  - Running data atmosphere forced configuration using Docker container

Project Goals and Objectives

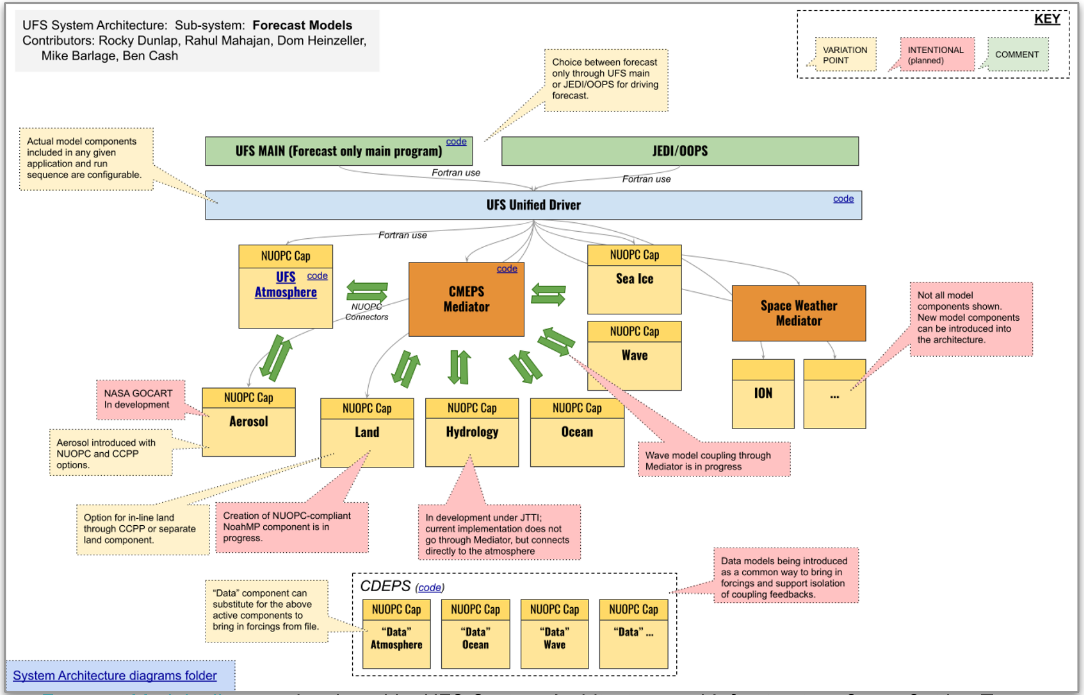
- The project will deliver **new land modeling infrastructure** software that enables running component-based land surface models (LSMs) within the UFS.

Project Title: "Advancing Land Modeling Infrastructure in the UFS for Hierarchical Model Development"
PIs: Ufuk Turuncoglu (old PIs Rocky Dunlap and Mariana Vertenstein)
EMC Collaborator: Mike Barlage
Funded by FY21 Joint Technology Transfer Initiative (JTTI) Program - **July 2024**

Obj 1	The Noah-MP parameterization will be "wrapped" as a NUOPC-based model component, and will be demonstrated to run as an independent component under the UFS Driver in different configurations.
Obj 2	The Noah-MP component will be configured to run "one-way coupled" with atmospheric forcings provided by the Community Data Models for Earth Prediction Systems (CDEPS).
Obj 3	The Noah-MP component will be configured to run "two-way coupled" to the active atmosphere model through the Community Mediator for Earth Prediction Systems (CMEPS).

NOAA's Unified Forecast System

- The UFS is a community-based, coupled, comprehensive Earth modeling system.



Forecast Models diagram developed by UFS System Architecture and Infrastructure Cross-Cutting Team.

It uses ESMF library for coupling.

UFS configurations:

UFS GFS:
FV3ATM-MOM6-CICE6-WW3-GOCART-CMEPS

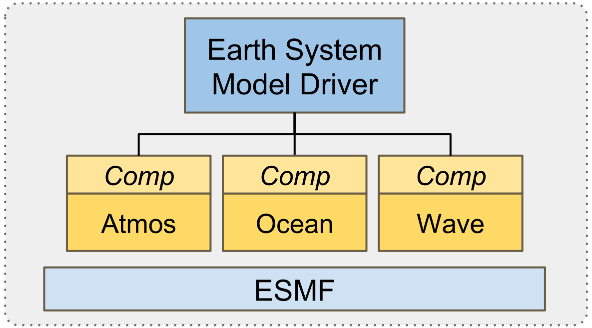
UFS Hurricane (HAFS):
FV3ATM-HYCOM-WW3-CMEPS

UFS RRFS:
FV3ATM+Hydrology+Fire

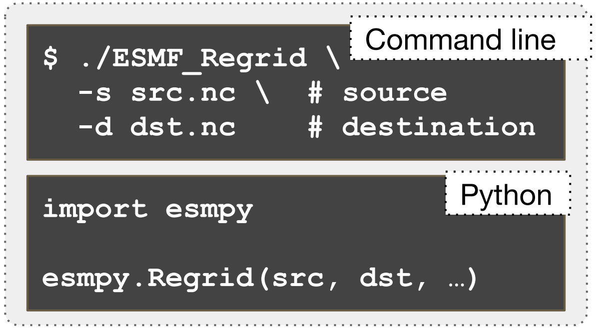
UFS Coastal (under development):
ADCIRC, FVCOM, ROMS, SCHISM

ESMF

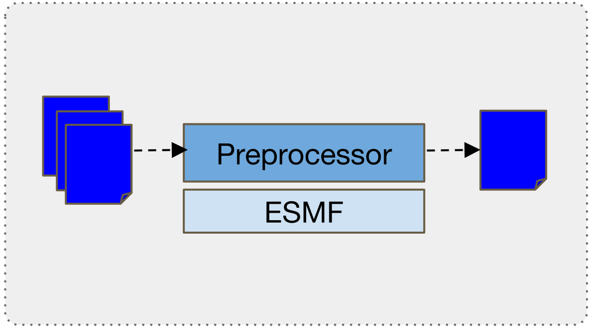
- The **E**arth **S**ystem **M**odeling **F**ramework (ESMF) is parallelizable high-performance software infrastructure used in coupled Earth science applications.
- It is open source software: https://github.com/esmf-org/esmf
- Different ways to use ESMF?



Coupling infrastructure
in a modeling system
(includes the NUOPC Layer)



Offline tool for grid remapping** and **interpolation weight generation
(command line and Python)



Library** used to construct custom tools, such as **preprocessor coprocessing** and **postprocessor

NUOPC Layer

- The **N**ational **U**nified **O**perational **P**rediction **C**apability (NUOPC) is a software layer on top of ESMF that provides "out of the box" capabilities for constructing coupled models.
- Noah-MP under UFS Weather Model is one of the such components

Driver

Driver

A Driver has one or more child components and is responsible for coordinating their initialization sequence and driving them through a customizable run sequence.

Connector → **Connector** ←

Connector

A Connector performs standard communication operations, in parallel, between other components, such as grid remapping and redistribution of data. Connectors have a built-in field matching algorithm based on standard names.

Model

Model

A Model "cap" wraps a geophysical model code with standard initialization and run methods so it can be plugged into a Driver.

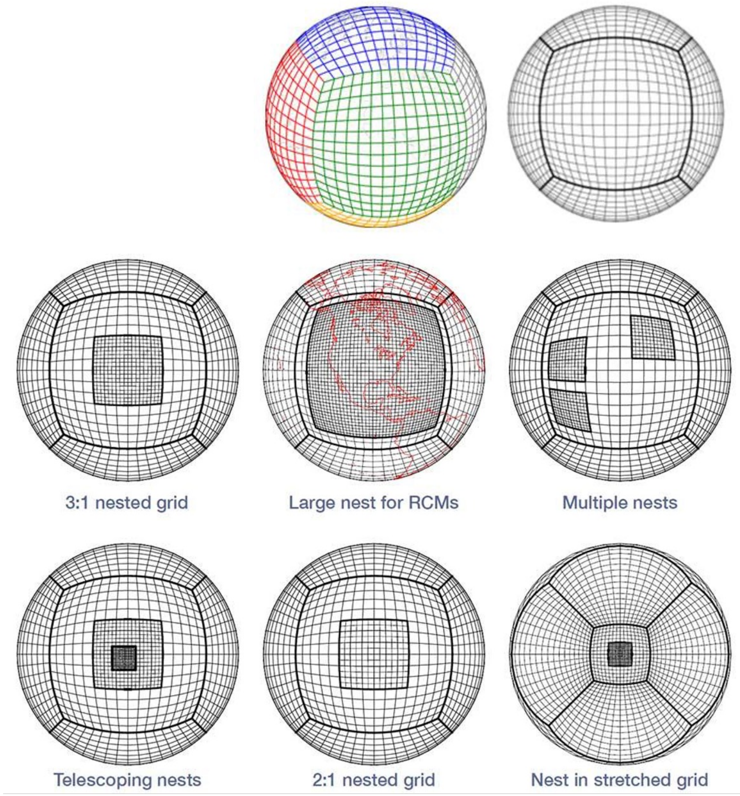
Mediator

Mediator

A Mediator contains custom coupling code such as flux calculations, accumulation/averaging, and merging of fields among several components.

FV3ATM - Atmospheric Component of NOAA’s UFS

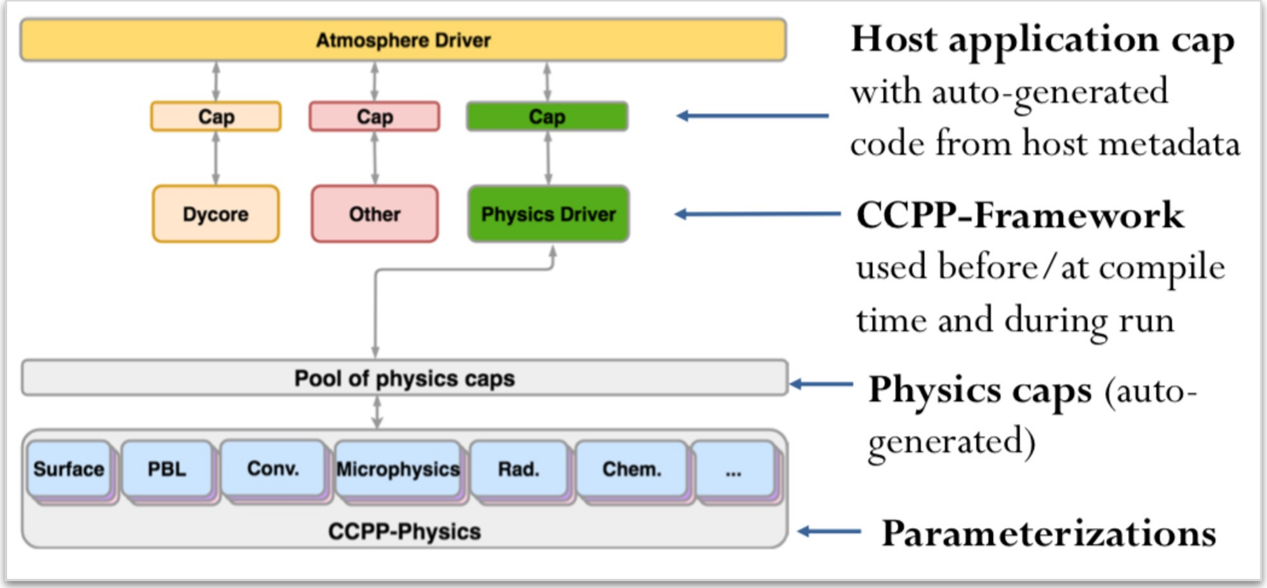
- Sub-components of FV3ATM
  - FV3: Finite-Volume Cubed-Sphere Dynamical Core
  - The Common Community Physics Package (CCPP)
    - Framework and Physics
    - Defines sub-grid scale parametrizations
  - UFS stochastic physics
  - Async I/O
  - Coupling interface (ESMF/NUOPC)
- We will use C96 (~1deg.) resolution of global configuration in this short course



https://www.gfdl.noaa.gov/fv3/fv3-grids/

CCPP - The Common Community Physics Package

- There are two distinct parts to the CCPP: a library of physical parameterizations (CCPP-Physics) that conforms to selected standards and an infrastructure (CCPP-Framework) that enables connecting the physics to a host model.



Noah-MP - Land Component of NOAA's UFS

- The component model uses old version of code (same one found in FV3ATM CCPP Physics)
- Since Noah-MP does not provide capability to run standalone. It requires a driver layer such as HRLDAS or CCPP/Physics Driver.

ESMF/NUOPC cap

NOAHMP-interface/noahmp/drivers/nuopc/
"cap" files

CCPP/Physics Driver

NOAHMP-interface/noahmp/drivers/ccpp/
noahmpdrv.F90

Noah-MP Model

NOAHMP-interface/noahmp/src
module_sf_noahmp_glacier.F90
module_sf_noahmplsm.F90

NUOPC "cap" layer
1) provides functionality to interact with other components
2) domain creation
3) multi-tile I/O
4) namelist support
…

driver layer
1) prepares variables for model
2) loops through 1d grid points

model layer
1) model functionality

Code Structure

```
.
├── cmake
│   ├── FindESMF.cmake
│   └── FindNetCDF.cmake
├── CMakeLists.txt
├── drivers
│   ├── ccpp
│   │   ├── funcphys.f90
│   │   ├── machine.F
│   │   ├── namelist_soilveg.f
│   │   ├── noahmpdrv.F90
│   │   ├── noahmpdrv.meta
│   │   ├── noahmp_tables.f90
│   │   ├── physcons.F90
│   │   ├── set_soilveg.f
│   │   ├── sfc_diff.f
│   │   └── update.sh
│   ├── nuopc
│   │   ├── docs
│   │   │   ├── Makefile
│   │   │   ├── README.md
│   │   │   └── source
│   │   │       ├── BuildingAndRunning.rst
│   │   │       ├── ComponentTesting.rst
│   │   │       ├── conf.py
│   │   │       ├── DriverAndCoupling.rst
│   │   │       ├── index.rst
│   │   │       └── references.bib
│   │   ├── lnd_comp_domain.F90
│   │   ├── lnd_comp_driver.F90
│   │   ├── lnd_comp_import_export.F90
│   │   ├── lnd_comp_io.F90
│   │   ├── lnd_comp_kind.F90
│   │   ├── lnd_comp_nuopc.F90
│   │   ├── lnd_comp_shr.F90
│   │   └── lnd_comp_types.F90
│   └── wrf
│       └── module_sf_noahmpdrv.F
```

Build system for standalone model and creates *libnoahmp.a*.

CCPP Physics related files.

ESMF/NUOPC cap files and documentation source (Sphinx)

Files for testing (DATM+LND) with GitHub action - nuopc-comp-testing

Parameter tables

Model code

```
├── .git
├── .github
│   └── workflows
│       ├── data
│       │   ├── C96.initial.tile1.nc
│       │   ├── C96.initial.tile2.nc
│       │   ├── C96.initial.tile3.nc
│       │   ├── C96.initial.tile4.nc
│       │   ├── C96.initial.tile5.nc
│       │   ├── C96.initial.tile6.nc
│       ├── datm_noahmp.yaml
│       └── tests
│           ├── test_datm_lnd
│           │   ├── datm.yaml
│           │   └── lnd.yaml
│           └── test_datm_lnd.yaml
├── parameters
│   ├── GENPARM.TBL
│   ├── MPTABLE.TBL
│   └── SOILPARM.TBL
├── README.md
├── src
│   ├── module_sf_noahmp_glacier.F90
│   └── module_sf_noahmplsm.F90
```

Import Fields for DATM+LND

- Noah-MP can be forced with data atmosphere: GSWP3 or ERA5

Import

Std. Name	Alias	Unit	Receiver
Sa_z	inst_height_lowest	m	lnd
Sa_tbot	inst_temp_height_lowest	K	lnd
Sa_pslv	inst_pres_height_surface	Pa	lnd
Sa_pbot	inst_pres_height_lowest	Pa	lnd
Sa_shum	inst_spec_humid_height_lowest	kg kg-1	lnd
Sa_u	inst_zonal_wind_height_lowest	m s-1	lnd
Sa_v	inst_merid_wind_height_lowest	m s-1	lnd
Sa_wspd	inst_wind_speed_height_lowest	m s-1	lnd
Faxa_swdn	mean_down_sw_flx	W m-2	lnd
Faxa_lwdn	mean_down_lw_flx	W m-2	lnd
Faxa_rain	mean_prec_rate	kg m-2 s-1	lnd

- There is no any limitation to use other data atmosphere modes supported by CDEPS such as CFSR, GFS, CFS etc.
- The default interpolation type is defined in CMEPS mediator. In this case, *1st Order Conservative interpolation* is used for active model coupling and *1st Order Conservative (with nearest-neighbour)* for coupling with data components.

Import/Export Fields for FV3ATM+LND

- Note: side-by-side configuration does not send fields to FV3ATM (*cpllnd2atm = .false.*)

Import

Std. Name	Alias	Unit	Receiver
Sa_z	inst_height_lowest	m	lnd
Sa_ta	inst_temp_height_lowest_from_phys	K	lnd
Sa_pslv	inst_pres_height_surface	Pa	lnd
Sa_qa	inst_spec_humid_height_lowest_from_phys	kg kg-1	lnd
Sa_ua	inst_zonal_wind_height_lowest_from_phys	m s-1	lnd
Sa_va	inst_merid_wind_height_lowest_from_phys	m s-1	lnd
Faxa_swdn	mean_down_sw_flx	W m-2	lnd
Faxa_lwdn	mean_down_lw_flx	W m-2	lnd
Faxa_swnet	mean_net_sw_flx	W m-2	lnd
Faxa_rain	mean_prec_rate	kg m-2 s-1	lnd
Sa_prsl	inst_pres_height_lowest_from_phys	Pa	lnd
vfrac		0-1	lnd
Faxa_snow	mean_fprec_rate	kg m-2 s-1	lnd
Faxa_rainc	mean_prec_rate_conv	kg m-2 s-1	lnd
Sa_tskn	inst_temp_height_surface	K	lnd
Sa_exner	inst_exner_function_height_lowest	0-1	lnd
Sa_ustar	surface_friction_velocity	m s-1	lnd
zorl		cm	lnd

Export

Std. Name	Alias	Unit	Receiver
Sl_lfrac	land_fraction	0-1	mediator
Fall_lat	mean_laten_heat_flx_lnd	kg kg-1 m s-1	atm
Fall_sen	mean_sensi_heat_flx_lnd	K m s-1	atm
Fall_evap	mean_potential_laten_heat_flx_lnd	W m-2	atm
Fall_gflx	mean_upward_heat_flux_lnd	W m-2	atm
Fall_roff	mean_runoff_rate_lnd	kg m-2 s-1	atm
Fall_soff	mean_subsurface_runoff_rate_lnd	kg m-2 s-1	atm
Sl_sfrac	mean_snow_area_fraction_lnd	0-1	atm
Sl_tref	inst_temp_height2m_lnd	K	atm
Sl_qref	inst_spec_humid_height2m_lnd	kg kg-1	atm
Sl_q	inst_spec_humid_lnd	kg kg-1	atm
Sl_cmm	inst_drag_wind_speed_for_momentum	m s-1	atm
Sl_chh	inst_drag_mass_flux_for_heat_and_moisture	kg m-2 s-1	atm
Sl_zvfun	inst_func_of_roughness_length_and_vfrac	0-1	atm

Namelist Options

- Noah-MP configuration parameters: *ufs.configure* and in *LND_attributes::* group

Option	Description	Possible Values
mosaic_file	The path and name of the mosaic grid file	any, INPUT/C96_mosaic.nc
input_dir	The directory that stores initial conditions, static information and grid related files	any
ic_type	Indicates the source of the initial conditions (custom - C96.initial.tile[1-6].nc and sfc - sfc_data.tile[1-6].nc)	custom, sfc (default)
layout	Defines decompositions in each direction on each tile (i.e. 3:8 for C96).	any number pair separated with double column
num_soil_levels	Number of soil levels used by NoahMP Land Model	any number
forcing_height	Height of the atmospheric forcing in meters. Used to overwrite component provided one.	any number
soil_level_thickness	Thickness of the soil levels. Needs to be consistent with num_soil_levels	Any list of number separated with double column
soil_level_nodes	Depths of the node points for each soil level.Needs to be consistent with num_soil_levels	Any list of number separated with double column
dynamic_vegetation_option	Options for dynamic vegetation	1 (off), 2 (on)
canopy_stomatal_resistance_option	Canopy stomatal resistance	1 (ball-berry), 2 (jarvis)
soil_wetness_option	Options for soil moisture factor for stomatal resistance	1 (noah), 2 (clm), 3 (ssib)
runoff_option	Options for runoff and groundwater	1 (simgm), 2 (simtop), 3 (schaake96), 4 (bats)
surface_exchange_option	Options for surface layer drag coefficient (ch and cm)	1 (m-o),2 (chen97)
supercooled_soilwater_option	Options for supercooled liquid water	1(ny06), 2 (koren99)
frozen_soil_adjust_option	Options for frozen soil permeability	1 (ny06), 2 (koren99)
radiative_transfer_option	Options for radiation transfer	1 (gap=f(3d,cosz), 2 (gap=0), 3 (gap=1-fveg)
snow_albedo_option	Options for snow surface albedo	1 (bats), 2 (class)
precip_partition_option	Options for rainfall & snowfall	1 (jordan91), 2 (bats), 3 (noah)
soil_temp_lower_bdy_option	Options for lower boundary of soil temperature	1 (zero-flux), 2 (noah)
soil_temp_time_scheme_option	Options for surface resistance	1->sakaguchi/zeng; 2->seller; 3->mod sellers; 4->1+snow
glacier_option	Options for glacier treatment (fixed to 2 in noahmpdrv)	(1->phase change; 2->simple)
output_freq	Options for output frequency in seconds	any number
restart_freq	Options for restatr frequency in seconds (negative for disabling)	any number
do_mynnedmf	Option for MYNN-EDMF (default is false)	true or false
do_mynnsfclay	Option for MYNN surface layer scheme (default is false)	true or false
soil_type_category	Option for soil type	0 (Zobler - 9 category), 1 (STATSGO - 19 category), 2 (STAS-RUC - 19 category)
veg_type_category	Option for source of vegetation data	0 (USGS), 1 (IGBP), 2 (UMD), 3 (NLCD40), 4 (USGS-RUC), 5 (MODI-RUC)
initial_emiss	Option for initial surface lw emissivity in fraction (default value is 0.95)	any number between 0-1
initial_albedo	Option for initial mean surface albedo (value is default 0.2)	any number between 0-1
has_export	Option to enable export fields (default value is true)	true or false
calc_snet	Option to calculate shortwave radiation internally (default value is false)	true or false

Additional configuration options in FV3 side:

input.nml and *gfs_physics_nml* section

cpllnd - atm->lnd

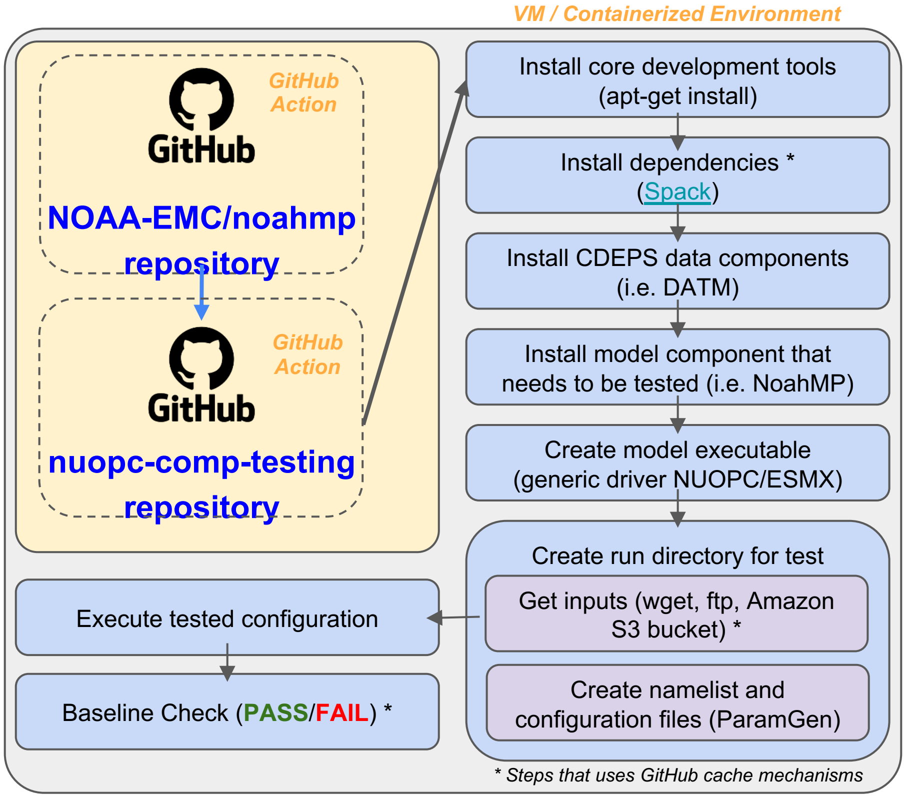
cpllnd2atm - lnd->atm

CI/CD Testing

It runs very simple DATM+Noah-MP configuration in every push or PR to Noah-MP repository

Low-resolution GSWP3 forced C96 (~1°global) land configuration

Check results against the baseline to find possible and unexpected baseline changes



https://github.com/esmf-org/nuopc-comp-testing

Limitations

- Only tested with global cubed-sphere grid
  - *grid_spec.nc* and *oro_data.tile*.nc* files are used to define the global domain, mask information and land fraction.
  - It requires additional work to support regional domains
    - single tile regional FV3 configurations
    - Regular lat-lon grids (global and regional) can be also supported by reading in ESMF mesh file but this requires additional development and testing
- I/O layer also needs to be extended to work with other grids and configurations
  - Current implementation uses ESMF for I/O (based on PIO2 library)
- Need to develop a set of tools to generate input files that store static information and initial conditions for other grid types and regional applications

Supported Configurations

- *DATM+LND* (incl. restart capability)
  - Tested with GSWP3 and ERA5 forcing provided by CDEPS data component
  - The model can be forced with different focings using CDEPS
    - The model can be even forced with cyclic data
- *FV3ATM+LND side-by-side* configuration (no feedback from land to atmosphere)
  - FV3ATM/CCPP/Noah-MP also runs
  - Aims to validate the results coming from component model using CCPP version
- *FV3ATM+LND fully coupled* (incl. restart capability)
  - Fully active atmosphere coupled two-way with land component
  - Supports also running land component in higher resolution such as C384 (~0.25°global)

CCPP Suite File and Run Sequence

FV3/ccpp/suites/suite_FV3_GFS_v17_p8.xml

```
      <scheme>GFS_suite_interstitial_2</scheme>
    </subcycle>
    <!-- Surface iteration loop -->
    <subcycle loop="2">
      <scheme>sfc_diff</scheme>
      <scheme>GFS_surface_loop_control_part1</scheme>
      <scheme>sfc_nst_pre</scheme>
      <scheme>sfc_nst</scheme>
      <scheme>sfc_nst_post</scheme>
      <scheme>noahmpdrv</scheme>
      <scheme>sfc_land</scheme>
      <scheme>sfc_sice</scheme>
      <scheme>GFS_surface_loop_control_part2</scheme>
    </subcycle>
    <!-- End of surface iteration loop -->
    <subcycle loop="1">
      <scheme>GFS_surface_composites_post</scheme>
```

skips if cplInd2atm = .true. (sfc_nst_post)

runs if cplInd2atm = .true. (noahmpdrv)

merges fluxes for fractional grid (GFS_surface_composites_post)

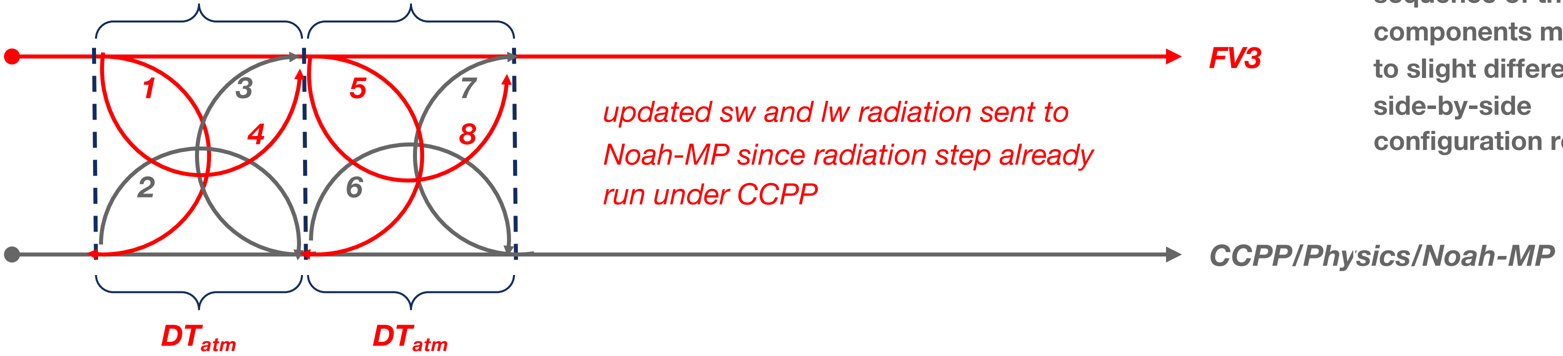
ufs.configure

```
# cold
runSeq::
@3600
   MED med_phases_prep_atm
   MED -> ATM :remapMethod=redist
   ATM
   ATM -> MED :remapMethod=redist
   MED med_phases_post_atm
   MED med_phases_prep_lnd
   MED -> LND :remapMethod=redist
   LND
   LND -> MED :remapMethod=redist
   MED med_phases_post_lnd
   MED med_phases_restart_write
   MED med_phases_history_write
@
::
```

coupling interval in sec (@3600)

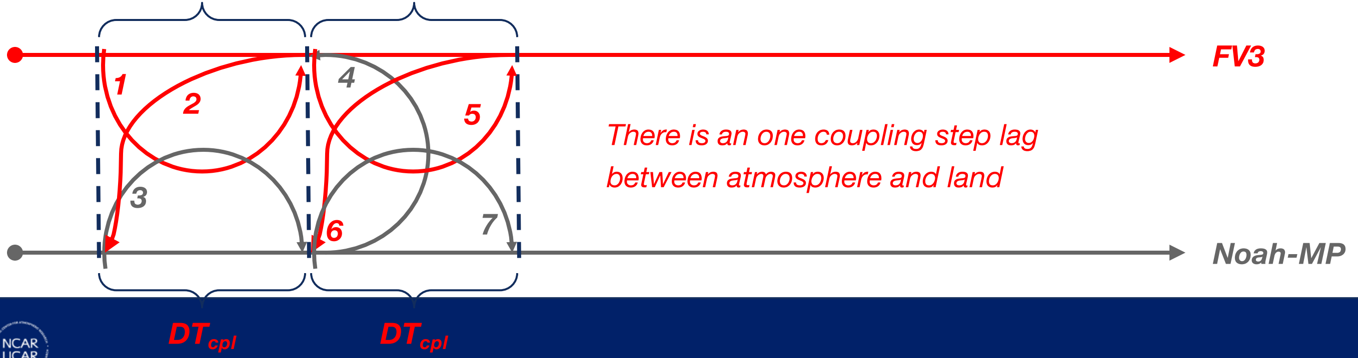
Run Sequence: CCPP vs. Component

- Standalone atmosphere with CCPP/Physics Noah-MP



The difference in run sequence of the components might lead to slight difference in the side-by-side configuration results.

- Coupled atmosphere-land configuration with component Noah-MP



The only way to mimic FV3/CCPP way, is splitting the CCPP suite run phases, and allow calling component model just after radiation step.

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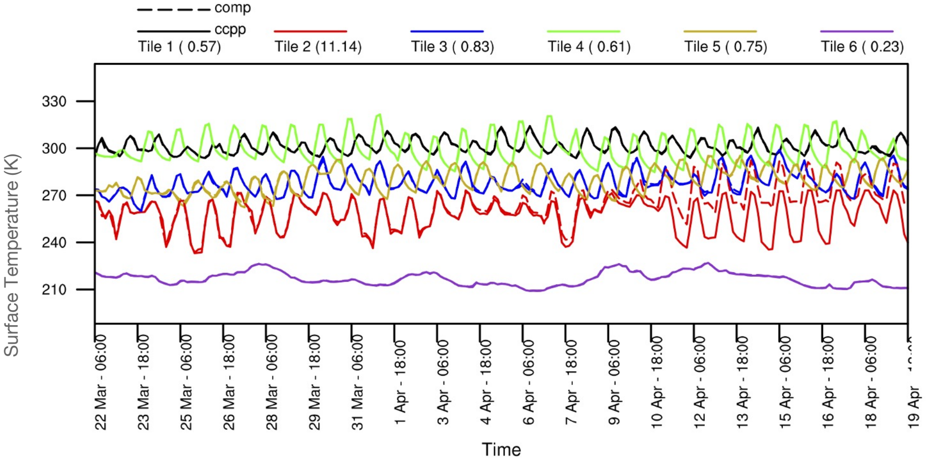
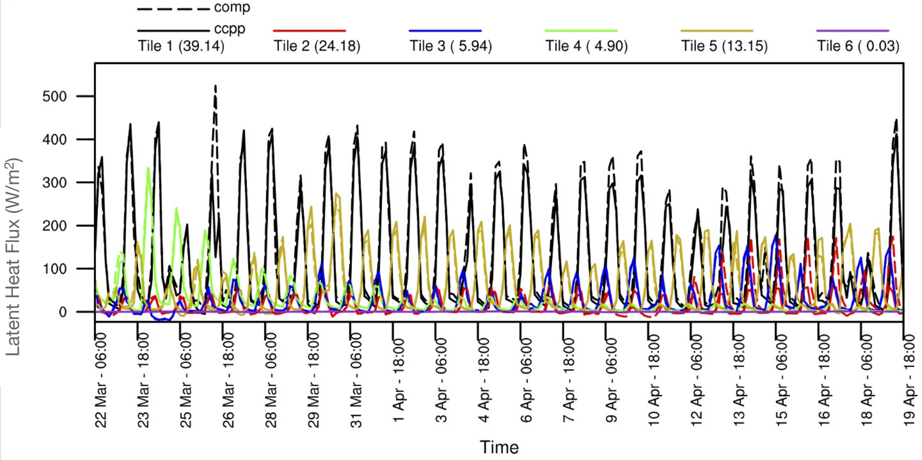
Validation

- A set of 30 days run was performed with different configurations of the model
- Side-by-side comparison (*control_p8_atmlnd_sbs* - sfcf* vs. land output)

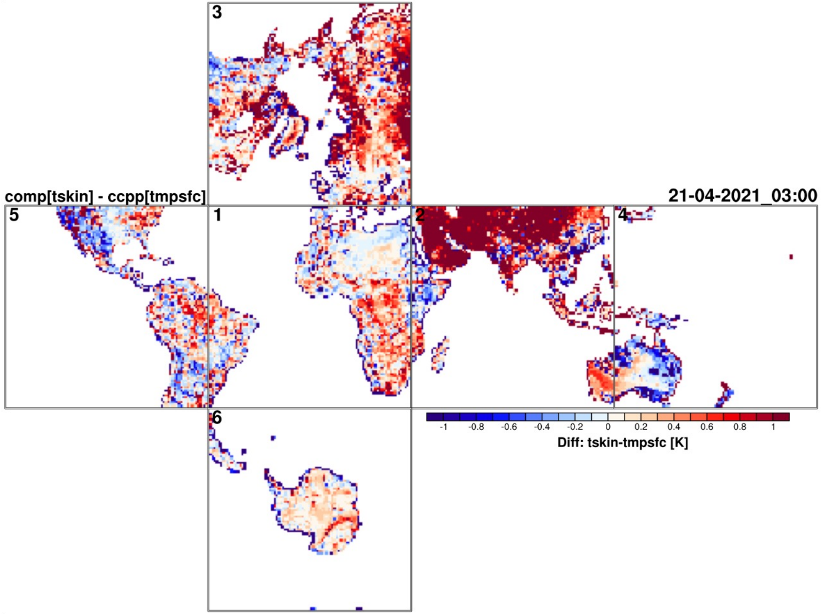


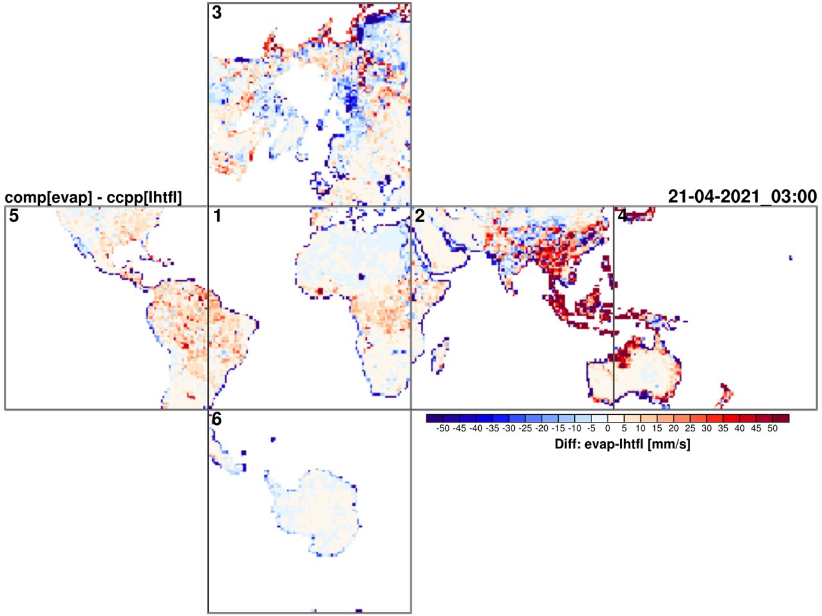


- The component version of the Noah-MP is able to reproduces the results of FV3/CCPP version. The solution start to diverge after couple of weeks (see tile 2 results)

Validation

- Difference after 30-days for *control_p8_atmlnd_sbs*

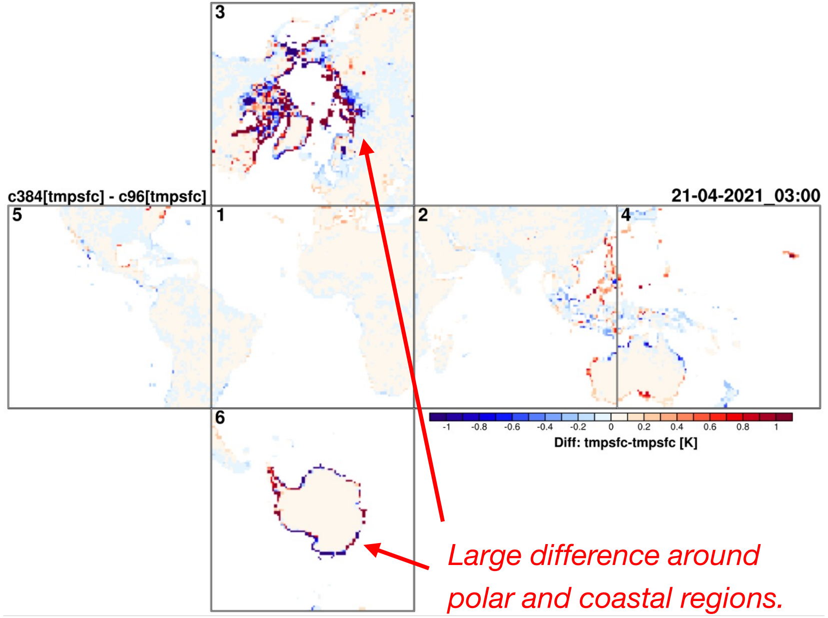


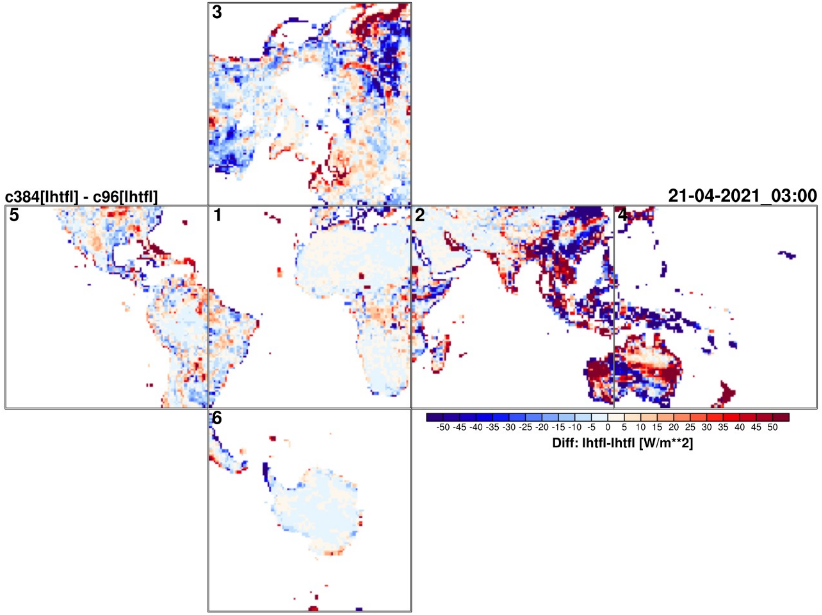


- Since the solution diverges, the difference between component model and CCPP version is relatively large at the end of the simulation (after 30 days).

Higher resolution land component?

- The fully coupled configuration - *control_p8_atmlnd* is also run with two resolution.
- Following figure compares FV3ATM output of two runs after 30 days of simulation





Hands-on

- Content:
  - https://github.com/uturuncoglu/tutorials/blob/main/AMS24_Tutorial_UFS_Noah-MP.ipynb