2019 Joint WRF/MPAS Users' Workshop, 06/13/2019

The Common Community Physics Package CCPP: Unifying physics across NOAA and NCAR models using a common software framework

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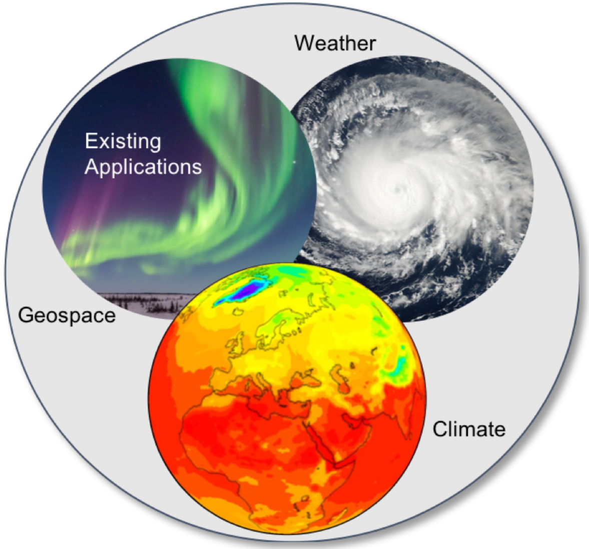
DTC Developmental Testbed Center

NCAR's SIMA

The System for Integrated Modeling of the Atmosphere (SIMA)

- is designed to reproduce a majority of the existing weather and climate prediction capability in a unified system
- will provide global nonhydrostatic coupled earth-system modeling capabilities for weather and climate applications
- encompasses the **creation of a framework for sharing physics** between NCAR's flagship models



https://wiki.ucar.edu/display/singletrack/Singletrack+Atmospheric+Model+Unification+Project+Home
https://wiki.ucar.edu/display/SIMA/System+for+Integrated+Modeling+of+the+Atmosphere+Home

NOAA's Unified Forecasting System

The Unified Forecast System (UFS)

- is a community-based, coupled comprehensive earth system modeling system
- is designed to provide numerical guidance for applications in the forecast suite of NOAA's National Centers for Environmental Prediction (NCEP)
- spans local to global domains and predictive time scales from hours to years
- provides the foundation for closing the gap between ECMWF and NCEP

One cornerstone of the UFS is to **facilitate the improvement of physical parameterizations** and their transition from research to operations (DTC/GMTB).

https://ufscommunity.org/index.html

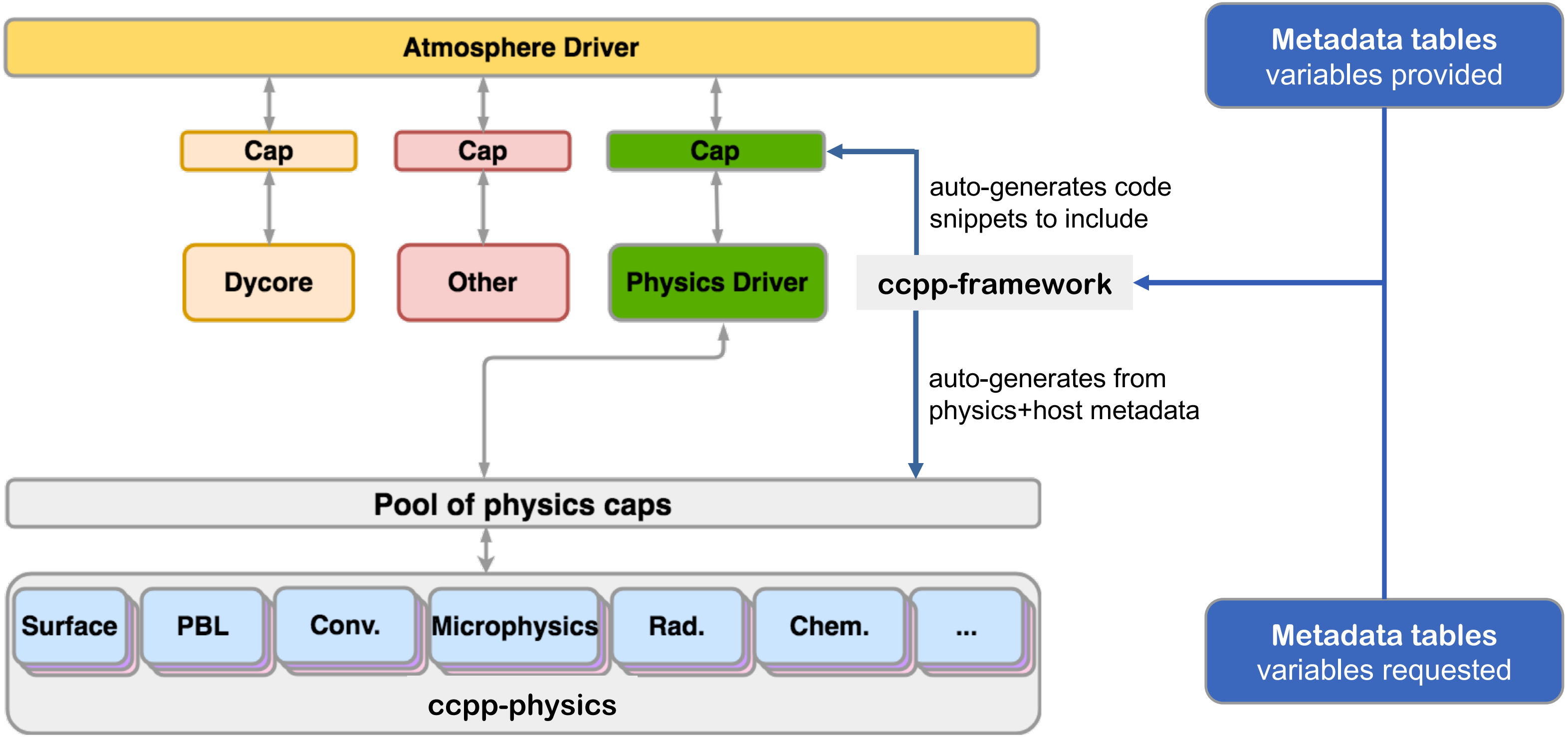
Infrastructure for development of model physics

The Common Community Physics Package (CCPP) consists of an infrastructure component, **ccpp-framework,** and a collection of compliant physics suites, **ccpp-physics**.

Driving principles:

- Readily available and well supported: open source, on GitHub, accepting external contributions (review/approval process)
- Model-agnostic to enable collaboration and accelerate innovations
- Documented interfaces (metadata) facilitate using/enhancing existing schemes, adding new schemes or transfer them between models
- Inline documentation using doxygen for scientific doc (incl. metadata)
- Physics suite construct is important, but the CCPP must enable easy interchange of schemes within a suite (need for interstitial/glue code)

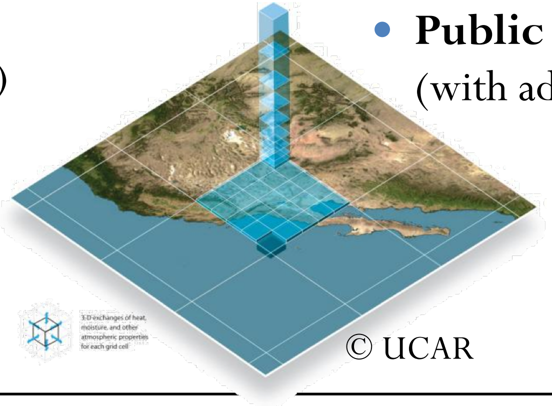
The CCPP within the model system



CCPP key features and releases

- **Suite configuration**: suite definition file (XML)
- **Grouping**: schemes can be called in groups with other computations in between (e.g. dycore, coupling)
- **Ordering**: user-defined order of execution of schemes (may require changing interstitial code)
- **Subcycling/iterations**: schemes can be called at higher frequency than others/dynamics

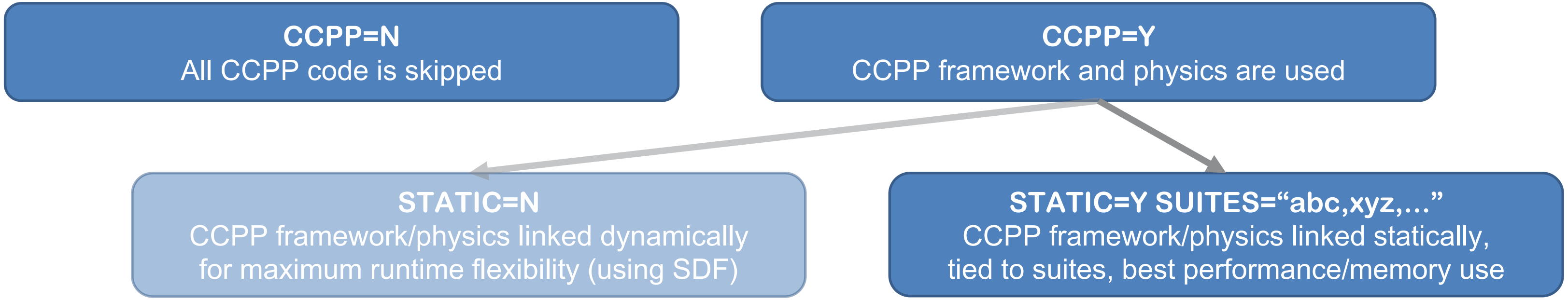
- **First release** of CCPP with GMTB Single Column Model in April 2018 (GFS physics)
- **Second release** in July 2018 with GMTB SCM (with GFDL microphysics)
- **Third release** in June 2019 with GMTB SCM (with CPT and RAP/HRRR physics), internal release for FV3 developers
- **Public release** with FV3 later this year (with additional physics and features)


3-D exchanges of heat, moisture, and other atmospheric properties for each grid cell

© UCAR

CCPP provides options for performance and flexibility

CCPP can be built in different ways to prioritize flexibility or performance (example: FV3)



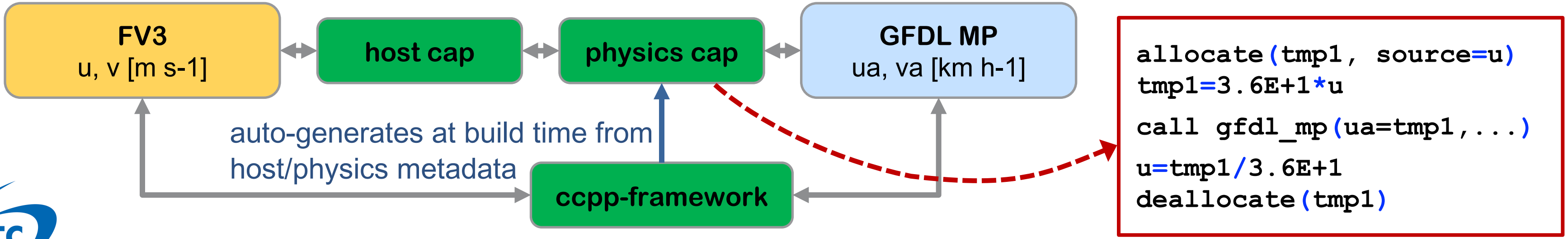
CCPP=N
All CCPP code is skipped

CCPP=Y
CCPP framework and physics are used

STATIC=N
CCPP framework/physics linked dynamically
for maximum runtime flexibility (using SDF)

STATIC=Y SUITES="abc,xyz,…"
CCPP framework/physics linked statically,
tied to suites, best performance/memory use

CCPP supports automatic unit conversions to expedite development and transition



FV3
u, v [m s-1]

host cap

physics cap

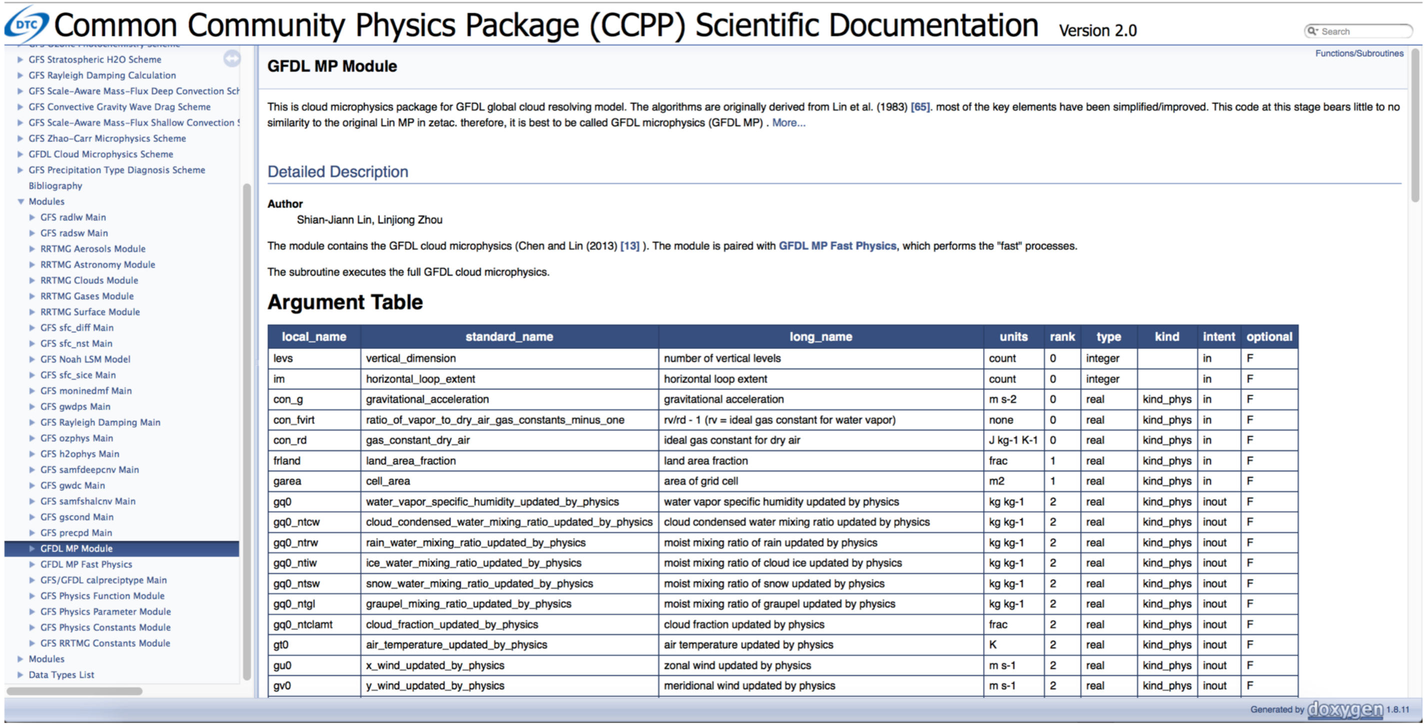
GFDL MP
ua, va [km h-1]

auto-generates at build time from
host/physics metadata

ccpp-framework

```
allocate(tmp1, source=u)
tmp1=3.6E+1*u
call gfdl_mp(ua=tmp1,...)
u=tmp1/3.6E+1
deallocate(tmp1)
```

Metadata is used for scientific documentation



Common Community Physics Package (CCPP) Scientific Documentation Version 2.0

- GFS Stratospheric H2O Scheme
- GFS Rayleigh Damping Calculation
- GFS Scale-Aware Mass-Flux Deep Convection Sch
- GFS Convective Gravity Wave Drag Scheme
- GFS Scale-Aware Mass-Flux Shallow Convection S
- GFS Zhao-Carr Microphysics Scheme
- GFDL Cloud Microphysics Scheme
- GFS Precipitation Type Diagnosis Scheme
- Bibliography
- Modules
  - GFS radlw Main
  - GFS radsw Main
  - RRTMG Aerosols Module
  - RRTMG Astronomy Module
  - RRTMG Clouds Module
  - RRTMG Gases Module
  - RRTMG Surface Module
  - GFS sfc_diff Main
  - GFS sfc_nst Main
  - GFS Noah LSM Model
  - GFS sfc_sice Main
  - GFS moninedmf Main
  - GFS gwdps Main
  - GFS Rayleigh Damping Main
  - GFS ozphys Main
  - GFS h2ophys Main
  - GFS samfdeepcnv Main
  - GFS gwdc Main
  - GFS samfshalcnv Main
  - GFS gscond Main
  - GFS precpd Main
  - GFDL MP Module
  - GFDL MP Fast Physics
  - GFS/GFDL calpreciptype Main
  - GFS Physics Function Module
  - GFS Physics Parameter Module
  - GFS Physics Constants Module
  - GFS RRTMG Constants Module
- Modules
- Data Types List

Functions/Subroutines

GFDL MP Module

This is cloud microphysics package for GFDL global cloud resolving model. The algorithms are originally derived from Lin et al. (1983) [65]. most of the key elements have been simplified/improved. This code at this stage bears little to no similarity to the original Lin MP in zetac. therefore, it is best to be called GFDL microphysics (GFDL MP) . More...

Detailed Description

Author

Shian-Jiann Lin, Linjiong Zhou

The module contains the GFDL cloud microphysics (Chen and Lin (2013) [13]). The module is paired with **GFDL MP Fast Physics**, which performs the "fast" processes.

The subroutine executes the full GFDL cloud microphysics.

Argument Table

local_name	standard_name	long_name	units	rank	type	kind	intent	optional
levs	vertical_dimension	number of vertical levels	count	0	integer		in	F
im	horizontal_loop_extent	horizontal loop extent	count	0	integer		in	F
con_g	gravitational_acceleration	gravitational acceleration	m s-2	0	real	kind_phys	in	F
con_fvirt	ratio_of_vapor_to_dry_air_gas_constants_minus_one	rv/rd - 1 (rv = ideal gas constant for water vapor)	none	0	real	kind_phys	in	F
con_rd	gas_constant_dry_air	ideal gas constant for dry air	J kg-1 K-1	0	real	kind_phys	in	F
frland	land_area_fraction	land area fraction	frac	1	real	kind_phys	in	F
garea	cell_area	area of grid cell	m2	1	real	kind_phys	in	F
gq0	water_vapor_specific_humidity_updated_by_physics	water vapor specific humidity updated by physics	kg kg-1	2	real	kind_phys	inout	F
gq0_ntcw	cloud_condensed_water_mixing_ratio_updated_by_physics	cloud condensed water mixing ratio updated by physics	kg kg-1	2	real	kind_phys	inout	F
gq0_ntrw	rain_water_mixing_ratio_updated_by_physics	moist mixing ratio of rain updated by physics	kg kg-1	2	real	kind_phys	inout	F
gq0_ntiw	ice_water_mixing_ratio_updated_by_physics	moist mixing ratio of cloud ice updated by physics	kg kg-1	2	real	kind_phys	inout	F
gq0_ntsw	snow_water_mixing_ratio_updated_by_physics	moist mixing ratio of snow updated by physics	kg kg-1	2	real	kind_phys	inout	F
gq0_ntgl	graupel_mixing_ratio_updated_by_physics	moist mixing ratio of graupel updated by physics	kg kg-1	2	real	kind_phys	inout	F
gq0_ntclamt	cloud_fraction_updated_by_physics	cloud fraction updated by physics	frac	2	real	kind_phys	inout	F
gt0	air_temperature_updated_by_physics	air temperature updated by physics	K	2	real	kind_phys	inout	F
gu0	x_wind_updated_by_physics	zonal wind updated by physics	m s-1	2	real	kind_phys	inout	F
gv0	y_wind_updated_by_physics	meridional wind updated by physics	m s-1	2	real	kind_phys	inout	F

Generated by doxygen 1.8.11

https://dtcenter.org/gmtb/users/ccpp

Parallelization in CCPP: limited MPI, full threading

Overarching paradigms

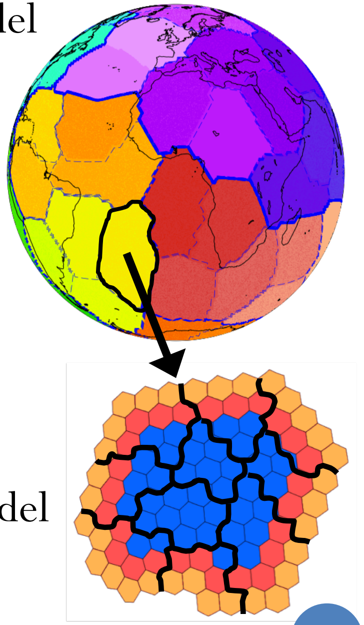
- physics are column-based, no communication during time integration in physics
- physics initialization/finalization are independent of threading strategy of the model

MPI

- MPI communication only allowed in the physics initialization/finalization
- use MPI communicator provided by host model, not `MPI_COMM_WORLD`

OpenMP

- time integration (but not init./final.) can be called by multiple threads
- threading inside physics is allowed, use # OpenMP threads provided by host model



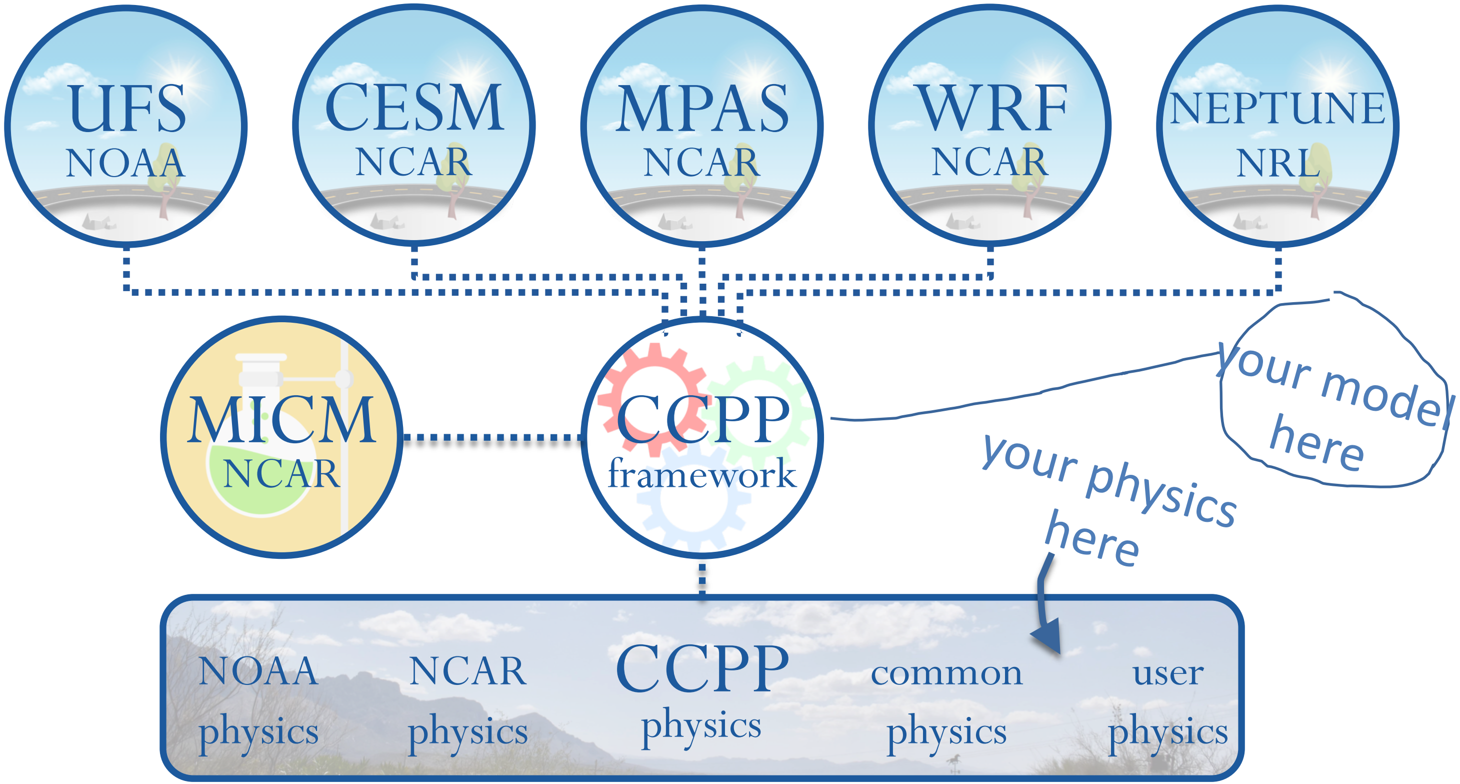
NOAA–NCAR cooperation: to boldly go where …

In 2018, NOAA and NCAR signed a memorandum to jointly develop the CCPP framework as a single system to communicate between models and physics.

Additional requirements and nice-to-have features for framework

- metadata needs to be augmented to provide
  - coordinate variables and vertical direction
  - dimensions and index ordering of arrays
  - state variables, tendencies, persistent variables
  - tracers and what to do with them (e.g. advection)
- compare metadata to actual Fortran code
- improved build system, code generation, variable allocation

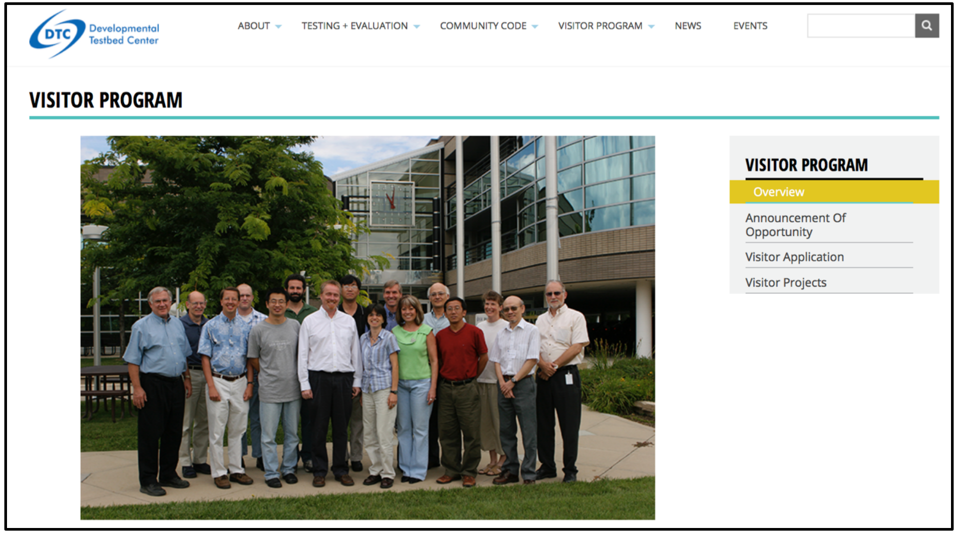
Please join the show!



We can even pay you - the DTC visitor program

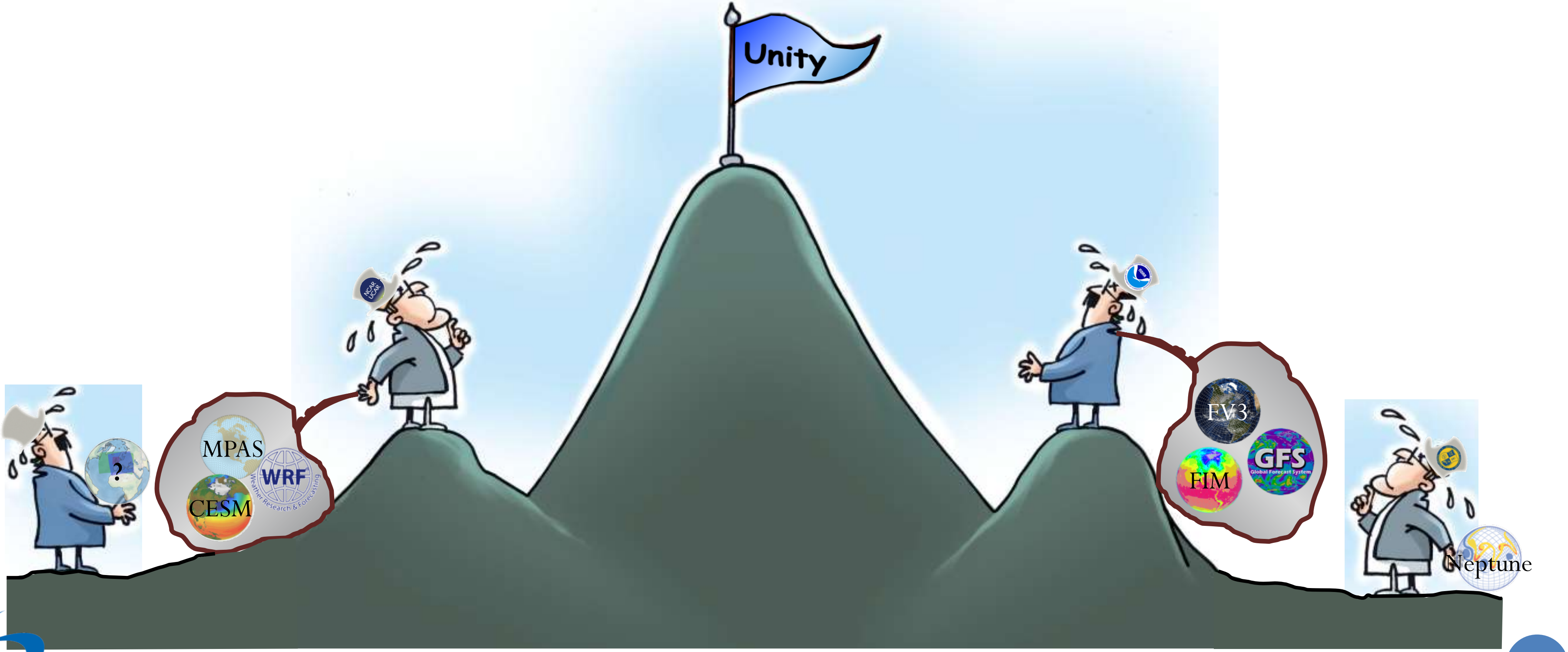
The DTC visitor program is currently accepting proposals

- adding cases to GMTB's Single Column Model
- contributing process-based diagnostics to testbed
- adding, assessing and improving parameterizations in CCPP
- see website for more information



https://dtcenter.org/visitor-program

Model unification efforts at NOAA, NCAR and beyond



Bonus material

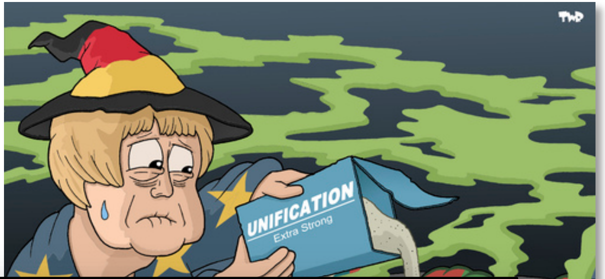
Model unification - omnipresent and misunderstood

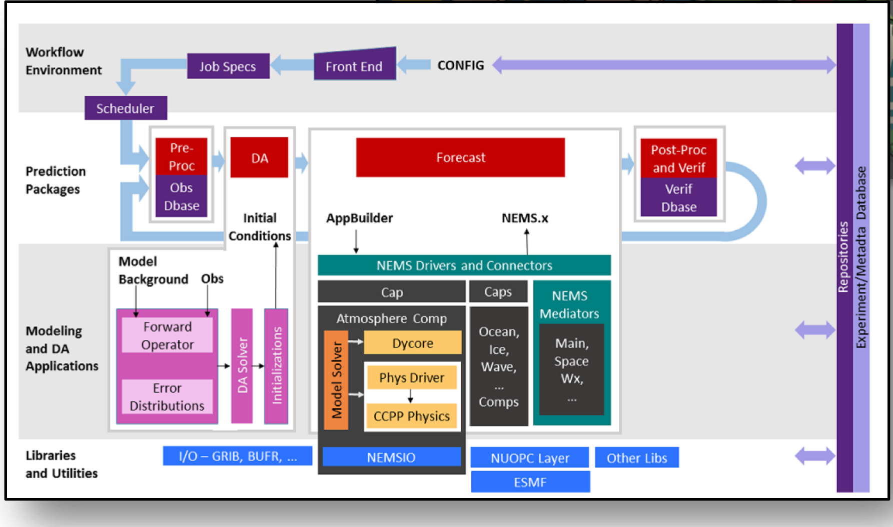
Unification has become a buzz word, but it is often misunderstood.

In atmospheric sciences, unification does **not** imply a single model and set of physics that everyone has to use.

Unification refers to creating a system of earth model components that can be exchanged and combined easily …

- to foster collaborations and facilitate research and development
- to accelerate transitions from research to operations and vice versa
- to avoid duplication of efforts and repetition of mistkaes





Workflow Environment

Job Specs

Front End

CONFIG

Scheduler

Prediction Packages

Pre-Proc

Obs Dbase

DA

Initial Conditions

Forecast

AppBuilder

NEMS.x

Post-Proc and Verif

Verif Dbase

Modeling and DA Applications

Model Background

Obs

Forward Operator

Error Distributions

DA Solver

Initializations

NEMS Drivers and Connectors

Cap

Caps

NEMS Mediators

Atmosphere Comp

Model Solver

Dycore

Phys Driver

CCPP Physics

Ocean, Ice, Wave, … Comps

Main, Space Wx, …

Libraries and Utilities

I/O – GRIB, BUFR, …

NEMSIO

NUOPC Layer

ESMF

Other Libs

Repositories

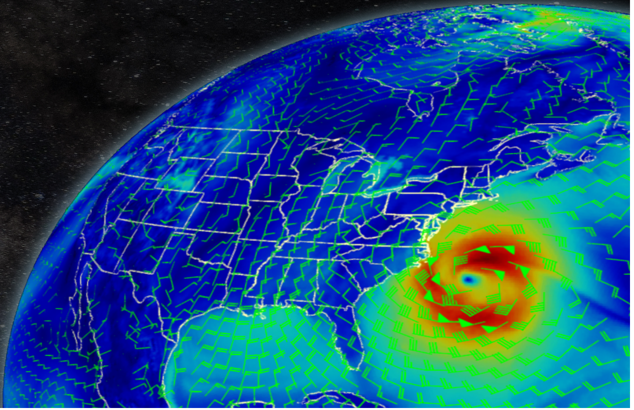
Experiment/Metadata Database

The Global Model Test Bed (GMTB)

Area within the Developmental Testbed Center (DTC) created to accelerate transition of physics developments by the community onto NOAA's Unified Forecast System

Approach:

- infrastructure for development of parameterizations/suites
- development of a hierarchical physics testbed
- assessment of physics innovations



See also Poster 27, L. Bernardet, Facilitating development of physical parameterizations for NOAA's Unified Forecast System

http://www2.mmm.ucar.edu/wrf/users/workshops/WS2019/short_abstracts/p27.html

Key features of the CCPP

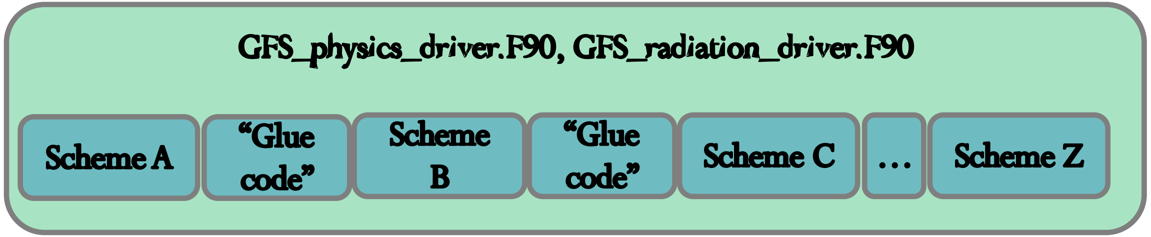
- **Runtime configuration**: suite definition file (XML)
- **Grouping**: schemes can be called in groups with other computations in between (e.g. dycore, coupling)
- **Ordering**: user-defined order of execution of schemes (may require changing interstitial code)
- **Subcycling/iterations**: schemes can be called at higher frequency than others/dynamics

```
<suite name="GFS_2017">
...
  <group name="radiation">
 🔵 <scheme>GFS_rrtmg_pre</scheme>
 🟢 <scheme>rrtmg_sw_pre</scheme>
 🔴 <scheme>rrtmg_sw</scheme>
 🟢 <scheme>rrtmg_sw_post</scheme>
 🟢 <scheme>rrtmg_lw_pre</scheme>
 🔴 <scheme>rrtmg_lw</scheme>
 🟢 <scheme>rrtmg_lw_post</scheme>
 🔵 <scheme>GFS_rrtmg_post</scheme>
  </group>
...
</suite>
```

🔵 suite interstitial 🟢 scheme interstitial 🔴 scheme

Interstitial code

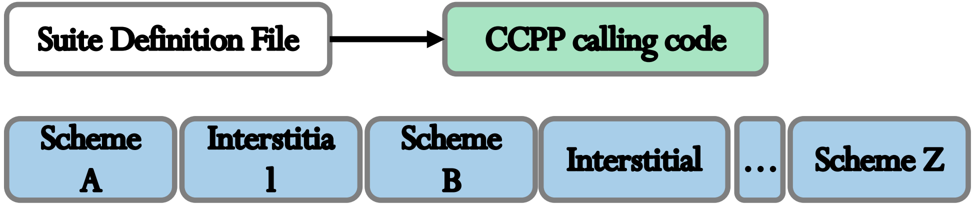
- “Suite-drivers” are called in current infrastructure (e.g. FV3):



GFS_physics_driver.F90, GFS_radiation_driver.F90

Scheme A | “Glue code” | Scheme B | “Glue code” | Scheme C | … | Scheme Z

- Suite Definition File instructs CCPP infrastructure to call individual schemes; “interstitial” code within suite drivers ➔ interstitial schemes



Suite Definition File → CCPP calling code

Scheme A | Interstitial 1 | Scheme B | Interstitial | … | Scheme Z

Current and new metadata standard in CCPP

Current, inline

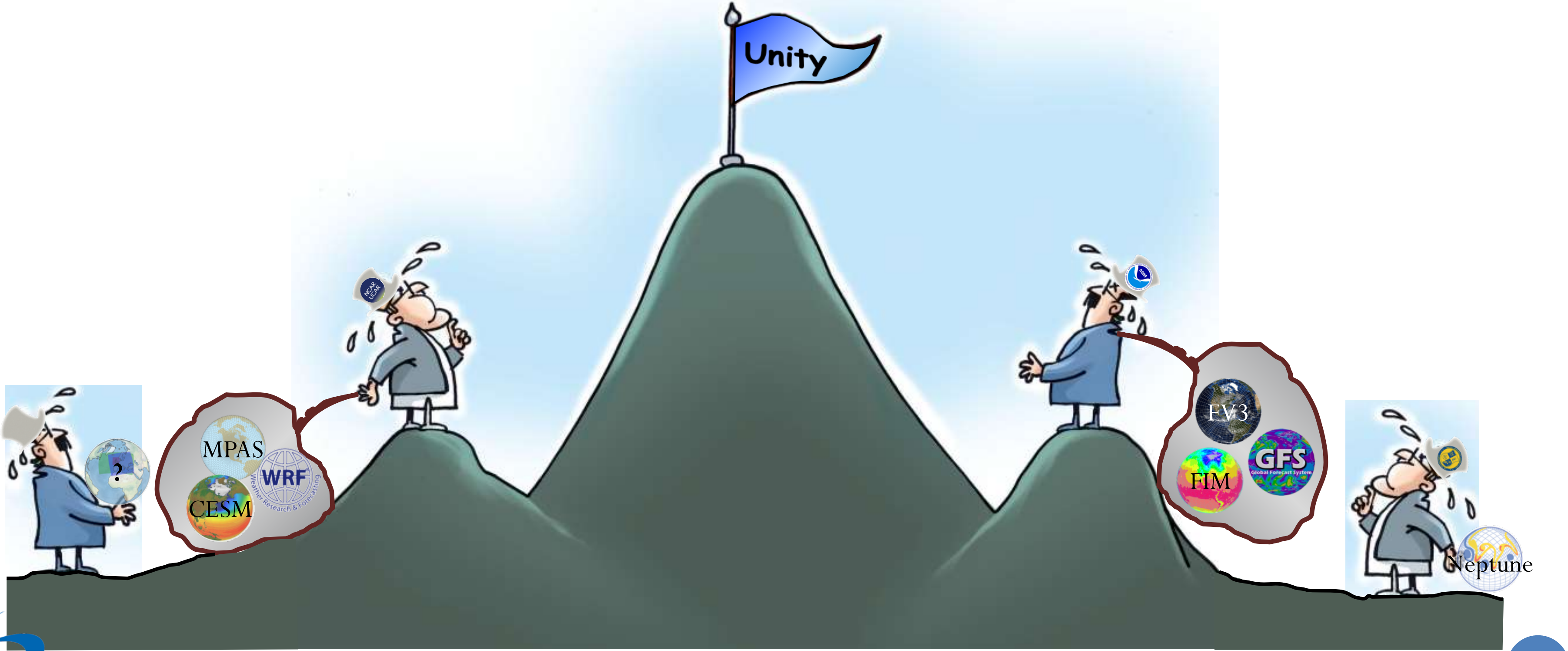
```
!> \section arg_table_myscheme_run Argument Table
!!| local_name | standard_name | long_name     | units | rank | type        | kind  | intent | optional |
!!|------------|---------------|---------------|-------|------|-------------|-------|--------|----------|
!!| ni         | horizontal_dimension | ...    | count |    0 | integer     |       | in     | F        |
!!| prs        | air_pressure  | air pressure| Pa    |    1 | real        | kind=8| inout  | F        |
!!| errmsg     | error_message | CCPP errmsg | none  |    0 | character   | len=* | out    | F        |
!!| errflg     | error_flag    | CCPP errflg | flag  |    0 | integer     |       | out    | F        |
!!
  subroutine myscheme_run (ni, prs, errmsg, errflg)
```

New, separate file

```
!> \section arg_table_myscheme_run Argument Table
!! \htmlinclude ozphys_run.html
!!
  subroutine myscheme_run (ni, prs, errmsg, errflg)
```

```
[ccpp-arg-table]
  name = myscheme_run
  type = scheme
[ni]
  standard_name = horizontal_dimension
  long_name = horizontal dimension
  units = count
  dimensions = ()
  type = integer
  intent = in
  optional = F
...
```

Model unification efforts at NOAA, NCAR and beyond


Unity
?
MPAS
WRF
Weather Research & Forecasting
CESM
NCAR UCAR
FV3
GFS
Global Forecast System
FIM
Neptune