Common Community Physics Package (CCPP) update: enabling atmospheric physics development for research and operations

Dom Heinzeller[1,3,4,6]

acknowledging the Developmental Testbed Center (DTC) CCPP developer team

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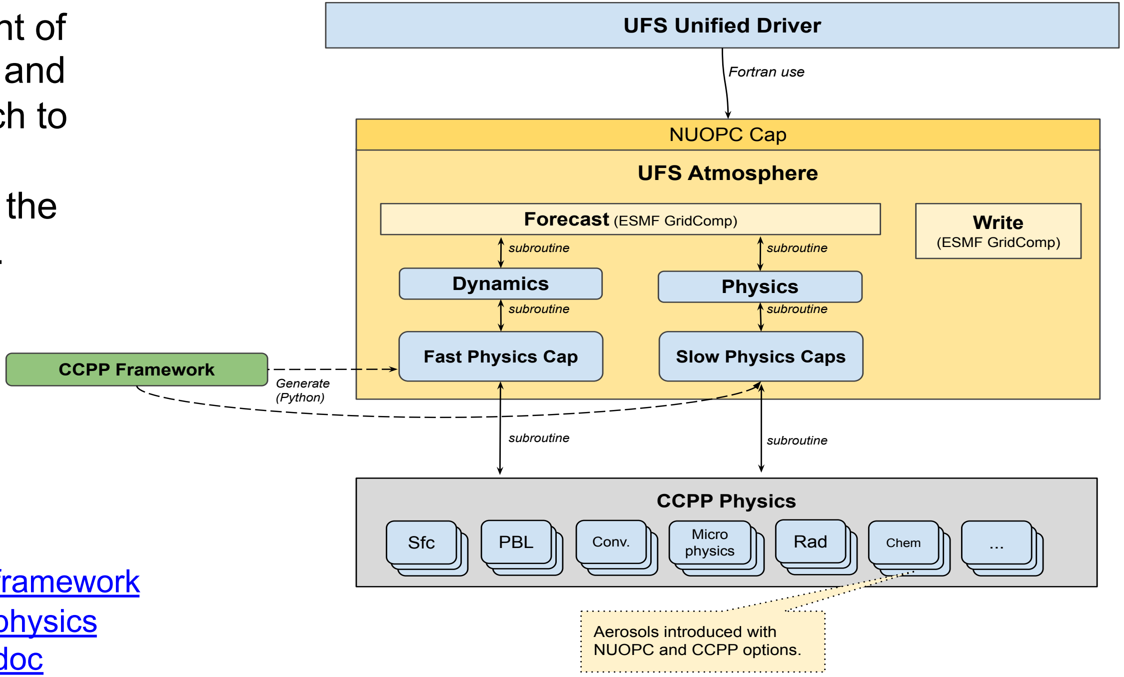
Developmental Testbed Center

The beginning (2017): UFS infrastructure for atmospheric physics

& chemical

… facilitate the improvement of physical parameterizations and their transition from research to operations by enabling the community to participate in the development and testing …

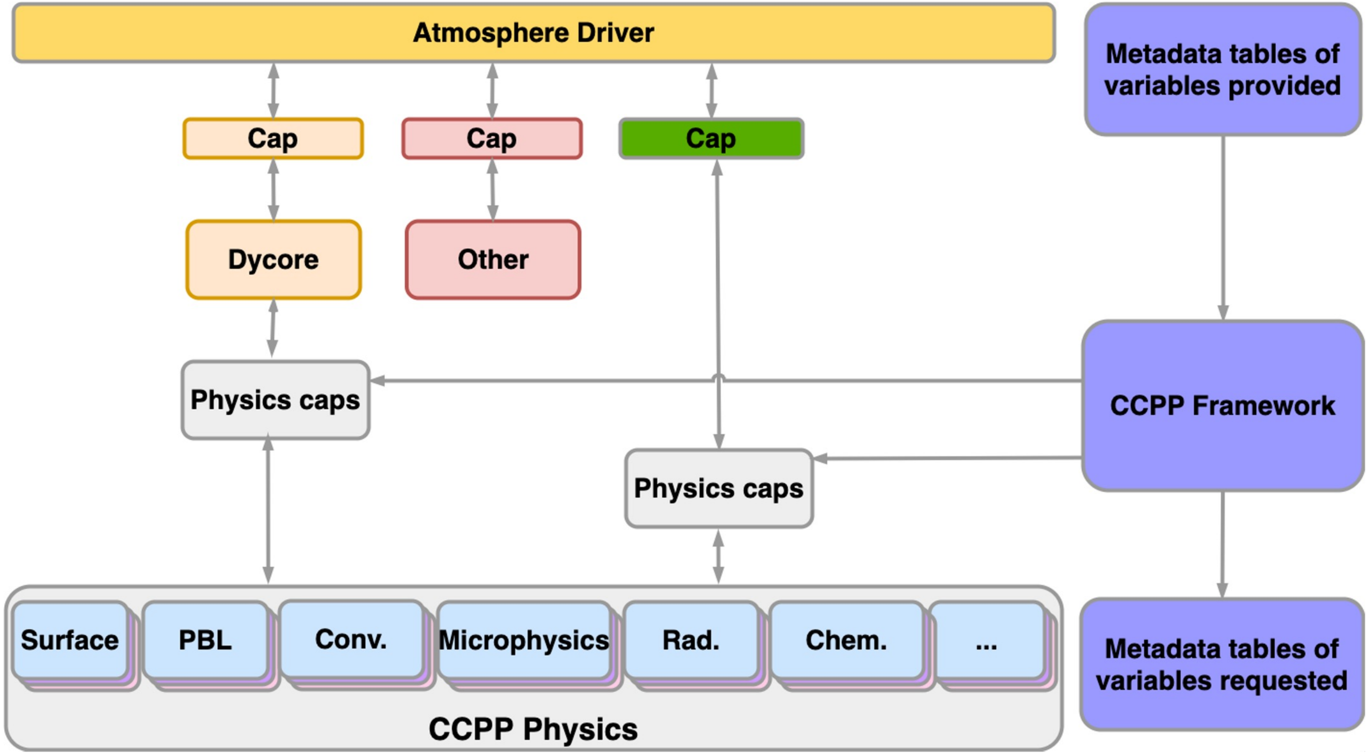


Common Community Physics Package (CCPP)

https://github.com/NCAR/ccpp-framework
https://github.com/NCAR/ccpp-physics
https://github.com/NCAR/ccpp-doc

Image courtesy: Rocky Dunlap

CCPP relies on documented interfaces (metadata)



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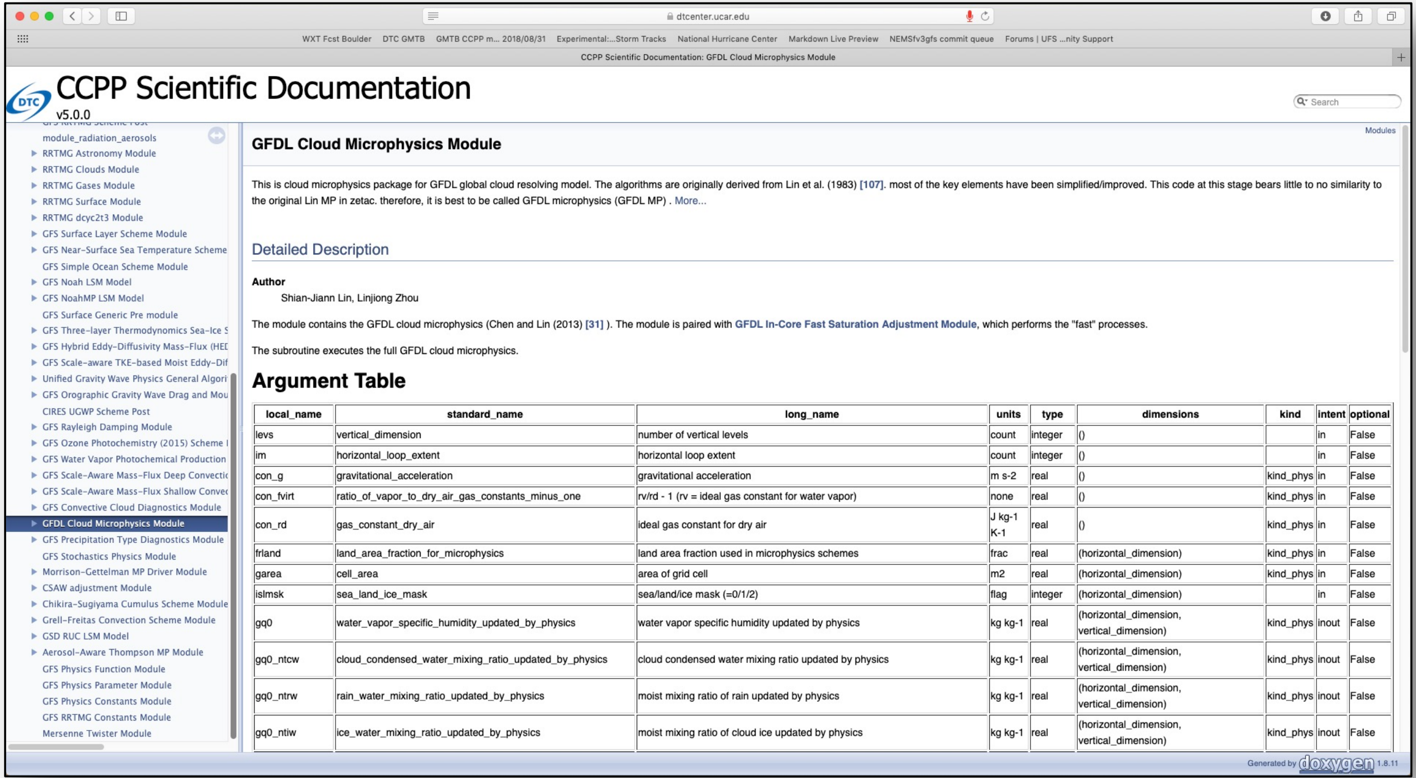
Metadata is also used to generate scientific documentation



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WXT Fcst Boulder DTC GMTB GMTB CCPP m... 2018/08/31 Experimental:...Storm Tracks National Hurricane Center Markdown Live Preview NEMSfv3gfs commit queue Forums | UFS ...nity Support

CCPP Scientific Documentation: GFDL Cloud Microphysics Module

CCPP Scientific Documentation
v5.0.0

Search

module_radiation_aerosols
RRTMG Astronomy Module
RRTMG Clouds Module
RRTMG Gases Module
RRTMG Surface Module
RRTMG dcyc2t3 Module
GFS Surface Layer Scheme Module
GFS Near-Surface Sea Temperature Scheme
GFS Simple Ocean Scheme Module
GFS Noah LSM Model
GFS NoahMP LSM Model
GFS Surface Generic Pre module
GFS Three-layer Thermodynomics Sea-Ice S
GFS Hybrid Eddy-Diffusivity Mass-Flux (HEI
GFS Scale-aware TKE-based Moist Eddy-Dif
Unified Gravity Wave Physics General Algori
GFS Orographic Gravity Wave Drag and Mou
CIRES UGWP Scheme Post
GFS Rayleigh Damping Module
GFS Ozone Photochemistry (2015) Scheme I
GFS Water Vapor Photochemical Production
GFS Scale-Aware Mass-Flux Deep Convectio
GFS Scale-Aware Mass-Flux Shallow Convec
GFS Convective Cloud Diagnostics Module
GFDL Cloud Microphysics Module
GFS Precipitation Type Diagnostics Module
GFS Stochastics Physics Module
Morrison-Gettelman MP Driver Module
CSAW adjustment Module
Chikira-Sugiyama Cumulus Scheme Module
Grell-Freitas Convection Scheme Module
GSD RUC LSM Model
Aerosol-Aware Thompson MP Module
GFS Physics Function Module
GFS Physics Parameter Module
GFS Physics Constants Module
GFS RRTMG Constants Module
Mersenne Twister Module

Modules

GFDL Cloud Microphysics Module

This is cloud microphysics package for GFDL global cloud resolving model. The algorithms are originally derived from Lin et al. (1983) [107]. 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) [31]). The module is paired with **GFDL In-Core Fast Saturation Adjustment Module**, which performs the "fast" processes.

The subroutine executes the full GFDL cloud microphysics.

Argument Table

local_name	standard_name	long_name	units	type	dimensions	kind	intent	optional
levs	vertical_dimension	number of vertical levels	count	integer	()		in	False
im	horizontal_loop_extent	horizontal loop extent	count	integer	()		in	False
con_g	gravitational_acceleration	gravitational acceleration	m s-2	real	()	kind_phys	in	False
con_fvirt	ratio_of_vapor_to_dry_air_gas_constants_minus_one	rv/rd - 1 (rv = ideal gas constant for water vapor)	none	real	()	kind_phys	in	False
con_rd	gas_constant_dry_air	ideal gas constant for dry air	J kg-1 K-1	real	()	kind_phys	in	False
frland	land_area_fraction_for_microphysics	land area fraction used in microphysics schemes	frac	real	(horizontal_dimension)	kind_phys	in	False
garea	cell_area	area of grid cell	m2	real	(horizontal_dimension)	kind_phys	in	False
islmsk	sea_land_ice_mask	sea/land/ice mask (=0/1/2)	flag	integer	(horizontal_dimension)		in	False
gq0	water_vapor_specific_humidity_updated_by_physics	water vapor specific humidity updated by physics	kg kg-1	real	(horizontal_dimension, vertical_dimension)	kind_phys	inout	False
gq0_ntcw	cloud_condensed_water_mixing_ratio_updated_by_physics	cloud condensed water mixing ratio updated by physics	kg kg-1	real	(horizontal_dimension, vertical_dimension)	kind_phys	inout	False
gq0_ntrw	rain_water_mixing_ratio_updated_by_physics	moist mixing ratio of rain updated by physics	kg kg-1	real	(horizontal_dimension, vertical_dimension)	kind_phys	inout	False
gq0_ntiw	ice_water_mixing_ratio_updated_by_physics	moist mixing ratio of cloud ice updated by physics	kg kg-1	real	(horizontal_dimension, vertical_dimension)	kind_phys	inout	False

Generated by doxygen 1.8.11

https://dtcenter.ucar.edu/GMTB/v5.0.0/sci_doc

Developmental Testbed Center

CCPP uses XML suite definition files at build time

```xml
<?xml version="1.0" encoding="UTF-8"?>

<suite name="FV3_GFS_v16" version="1">
  <group name="fast_physics">
    <subcycle loop="1">
      <scheme>fv_sat_adj</scheme>
    </subcycle>
  </group>
  <group name="time_vary">
    <subcycle loop="1">
      <scheme>GFS_time_vary_pre</scheme>
      <scheme>GFS_rrtmg_setup</scheme>
      <scheme>GFS_rad_time_vary</scheme>
      <scheme>GFS_phys_time_vary</scheme>
    </subcycle>
  </group>
  <group name="radiation">
    <subcycle loop="1">
      <scheme>GFS_suite_interstitial_rad_reset</scheme>
      <scheme>GFS_rrtmg_pre</scheme>
      <scheme>GFS_radiation_surface</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>
    </subcycle>
  </group>
  ...
```

```xml
...
<group name="physics">
    <subcycle loop="1">
      <scheme>GFS_suite_interstitial_phys_reset</scheme>
      <scheme>GFS_suite_stateout_reset</scheme>
      <scheme>get_prs_fv3</scheme>
      <scheme>GFS_suite_interstitial_1</scheme>
      <scheme>GFS_surface_generic_pre</scheme>
      <scheme>GFS_surface_composites_pre</scheme>
      <scheme>dcyc2t3</scheme>
      <scheme>GFS_surface_composites_inter</scheme>
      <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>lsm_noah</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>
      <scheme>sfc_diag</scheme>
      <scheme>sfc_diag_post</scheme>
      <scheme>GFS_surface_generic_post</scheme>
      <scheme>GFS_PBL_generic_pre</scheme>
      <scheme>satmedmfvdifq</scheme>
      ...
```

```xml
      ...
      <scheme>GFS_PBL_generic_post</scheme>
      <scheme>GFS_GWD_generic_pre</scheme>
      <scheme>cires_ugwp</scheme>
      <scheme>cires_ugwp_post</scheme>
      <scheme>GFS_GWD_generic_post</scheme>
      <scheme>GFS_suite_stateout_update</scheme>
      <scheme>ozphys_2015</scheme>
      <scheme>h2ophys</scheme>
      <scheme>get_phi_fv3</scheme>
      <scheme>GFS_suite_interstitial_3</scheme>
      <scheme>GFS_DCNV_generic_pre</scheme>
      <scheme>samfdeepcnv</scheme>
      <scheme>GFS_DCNV_generic_post</scheme>
      <scheme>GFS_SCNV_generic_pre</scheme>
      <scheme>samfshalcnv</scheme>
      <scheme>GFS_SCNV_generic_post</scheme>
      <scheme>GFS_suite_interstitial_4</scheme>
      <scheme>cnvc90</scheme>
      <scheme>GFS_MP_generic_pre</scheme>
      <scheme>gfdl_cloud_microphys</scheme>
      <scheme>GFS_MP_generic_post</scheme>
      <scheme>maximum_hourly_diagnostics</scheme>
    </subcycle>
  </group>
  <group name="stochastics">
    <subcycle loop="1">
      <scheme>GFS_stochastics</scheme>
      <scheme>phys_tend</scheme>
    </subcycle>
  </group>
</suite>
```

Developmental Testbed Center

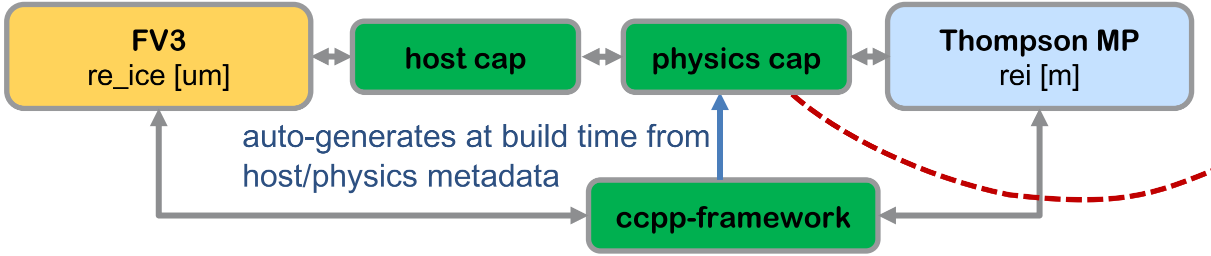
CCPP provides options for performance and flexibility

- CCPP uses a multi-suite build to maintain the required performance for operations
  - Compile options for the UFS (and the CCPP Single Column Model (SCM))

```
cmake … -DCCPP_SUITES="abc,xyz,…"
```

  - Filters unused schemes and variables, auto-generates Fortran caps for each suite
  - No branching (if-then-else, ...) inside the suite caps for improved performance

- CCPP supports automatic unit conversions to expedite development and transition




```
allocate(tmp1, source=re_ice)
tmp1=1.0E-6*re_ice
call thompson_mp(rei=tmp1,...)
re_ice=1.0E+6*tmp1
deallocate(tmp1)
```

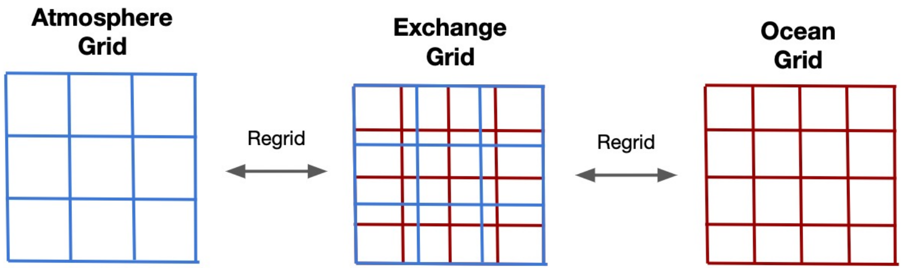
Active development: single precision physics, Xgrid

A single-precision build of all physics used in the UFS was recently contributed by the Naval Research Lab in collaboration with DTC and NOAA-EMC.

- Further research is needed into which processes need to be double precision in these and other physics. Talking to experts at ECMWF to learn more!

The ESMF team recently contributed the exchange grid capability to the UFS in collaboration with DTC and NOAA-ENC.

- CMEPS was modified to act as a CCPP host model to perform atmosphere-ocean flux computation



Five CCPP releases so far – v6 coming soon!

V	Date	Physics	Host
v1	2018 Apr	GFS v14 operational	SCM
v2	2018 Aug	GFS v14 operational updated GFDL microphysics	SCM UFS WM for developers
v3	2019 Jul	GFS v15 operational Developmental schemes/suites	SCM UFS WM for developers
v4	2020 Mar	GFS v15 operational Developmental schemes/suites	SCM UFS WM / UFS MRW 1.0
v5	2020 Nov	GFS v15 operational Developmental schemes/suites	SCM UFS WM / UFS SRW 1.0 / MRW 1.1
V6	2022 Jun	GFS v16 operational Developmental schemes/suites	SCM UFS WM / UFS SRW 2.0

- Scientific/Tech Docs, Users Guide, FAQ: https://dtcenter.org/ccpp
- CCPP Support Forum: https://dtcenter.org/forum/ccpp-user-support
- UFS Users' Support Forums: https://forums.ufscommunity.org
- GitHub discussions: https://github.com/NCAR/ccpp-framework/discussions (same for physics)

SCM – CCPP Single Column Model
UFS WM – UFS Weather Model
MRW/SRW – Medium/Short-Range Weather

Parameterizations in CCPP authoritative main branch

Microphysics	Zhao-Carr, GFDL, MG2-3, Thompson, Ferrier-Aligo, NSSL
PBL	K-EDMF, TKE-EDMF, moist TKE-EDMF, YSU, saYSU, MYJ
Surface Layer	GFS, MYNN, MYJ
Deep Convection	oldSAS, saSAS, RAS, Chikira-Sugiyama, GF, Tiedtke
Shallow Convection	oldSAS, saSAS, RAS, GF, Tiedtke
PBL and Shal Convection	SHOC, MYNN
Radiation	RRTMG, RRTMGP
Gravity Wave Drag	GFS orographic, GFS convective, uGWD, RAP/HRRR drag suite
Land Surface	Noah, Noah-MP, RUC
Ocean / Lake	Simple GFS ocean, Flake
Sea Ice	Simple GFS sea ice, RUC
Ozone	2006 NRL, 2015 NRL
H_2O	NRL

Implementation
- DTC
- NOAA GSL
- NOAA PSL
- NOAA NSSL
- OU
- NOAA EMC

CCPP v6 Supported Suites – release June 2022

Type	Operational	Developmental				
Suites	GFS_v16	GFSv17_p8	RAP	RRFS_v1beta	WoFS	HRRR
UFS regional SRW	✅			✅	✅	✅
SCM	✅	✅	✅	✅	✅	✅
Microp	GFDL	Thomp	Thomp	Thomp	NSSL	Thomp
PBL	TKE EDMF	TKE EDMF	MYNN	MYNN	MYNN	MYNN
Sfc lay	GFS	GFS	GFS	MYNN	MYNN	MYNN
Deep cu	saSAS	saSAS + CA	Grell-Freitas	N/A	N/A	N/A
Shal cu	saMF	saMF	Grell-Freitas	N/A	N/A	N/A
Radiation	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG	RRTMG
GWP	cires_ugwp	unified_ugwp	drag_suite	cires_ugwp	cires_ugwp	drag_suite
LSM	Noah	NoahMP	RUC	NoahMP	Noah	RUC

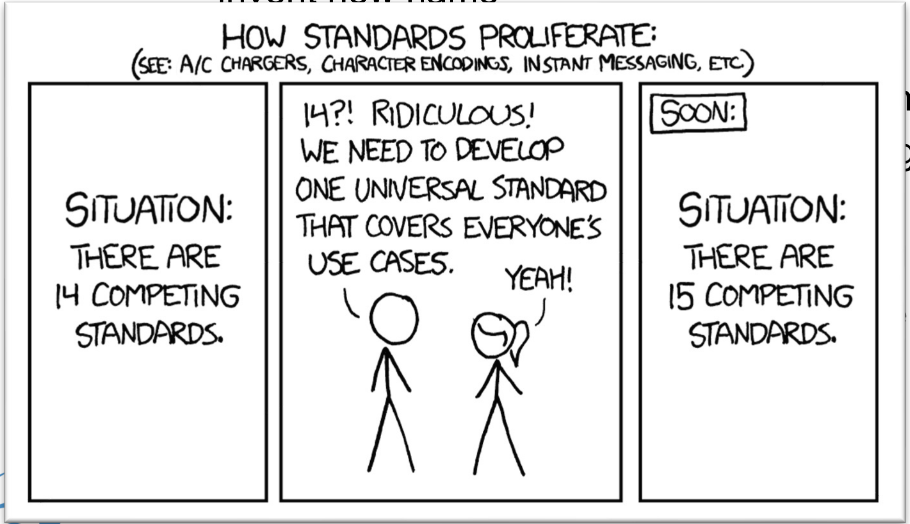
CCPP Standard Names: Rules and Dictionary

- Standard names are a key aspect of the CCPP since they are used to communicate variables between the host model and the physics
- Whenever possible, use CF convention
- If standard name not available in CF convention, invent new name

nes

g names

house



CCPP Standard Names

This document contains information about the rules used to create Standard Names for use with the Common Community Physics Package (CCPP). It describes the

- CCPP Standard Name rules
- Standard Name qualifiers
- Other common standard name components
- Acronyms, abbreviations, and aliases
- Units

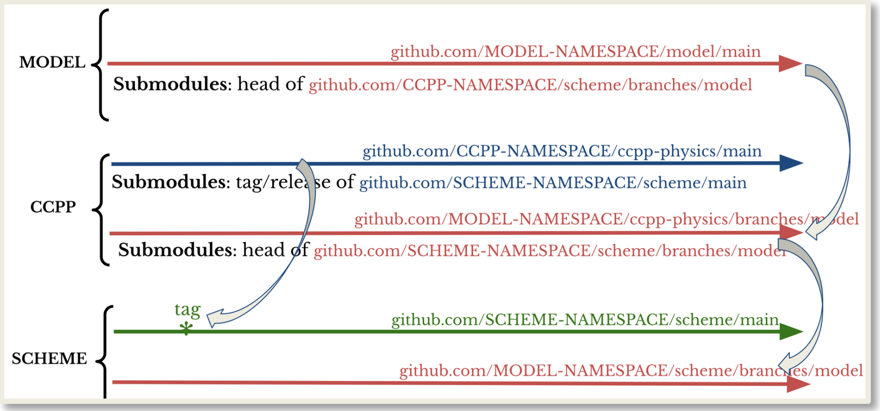
CCPP Standard Name Rules

1. Standard names should be identical to those from the latest version of the Climate and Forecast (CF) metadata conventions unless an appropriate name does not exist in that standard.
2. When a standard name doesn't exist in the CF conventions,

https://github.com/ESCOMP/CCPPStandardNames

Code management for shared physics and chemistry

- Multi-institutional team: DTC, NRL, NOAA, and NCAR
- What do we want this collaborative effort to look like?
- Various common interests, such as
  - Parameterizations for some processes
  - Collaborations with broader community
- Topics addressed so far
  - Code repository structure
  - Standardization of scheme names
  - Responsibilities for PR reviews
  - Best practices for interoperability
  - Dictionary of standard names
- Currently: an authoritative CCPP Physics repo for SCM/ UFS/NEPTUNE (DTC), and a NCAR repository for of CCPP-compliant physics being shared among WRF, MPAS, and CM1 (see [Fowler, L., 2022](), starts at 1h38 min into video).

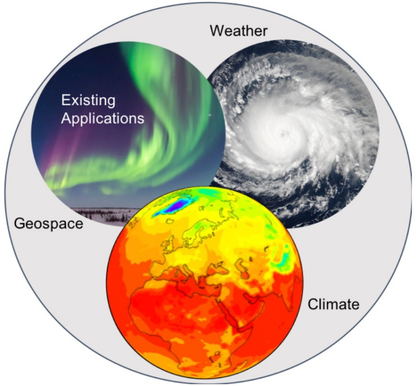


NOAA-NCAR Memorandum of Agreement (2019)

In 2019, NOAA and NCAR agreed to jointly develop the CCPP framework as a single system to communicate between models and physics.

NCAR contributions to the CCPP framework (within SIMA*):

- Augmented metadata standard (already adopted in the UFS)
- Automatic variable allocation for variables used by physics only
- Compare metadata to actual Fortran code
- Improved build system and code generator
- Advancements for chemistry (constituents, …)
- …

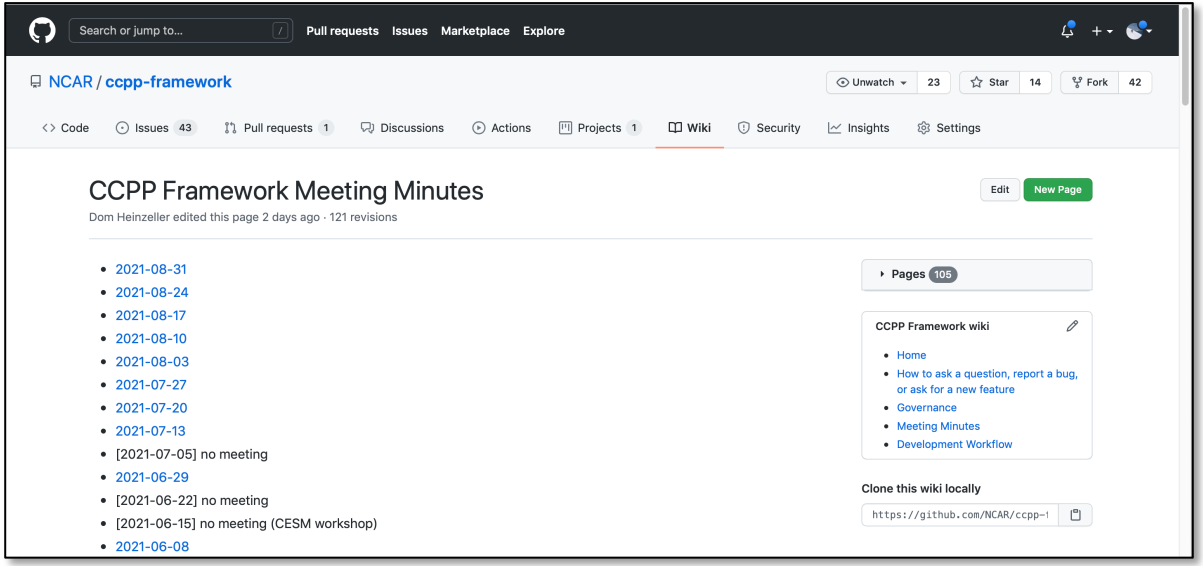


Original timeline: Transition to next-generation framework in 2021 – then delayed to 2022 – then came the SIMA review.

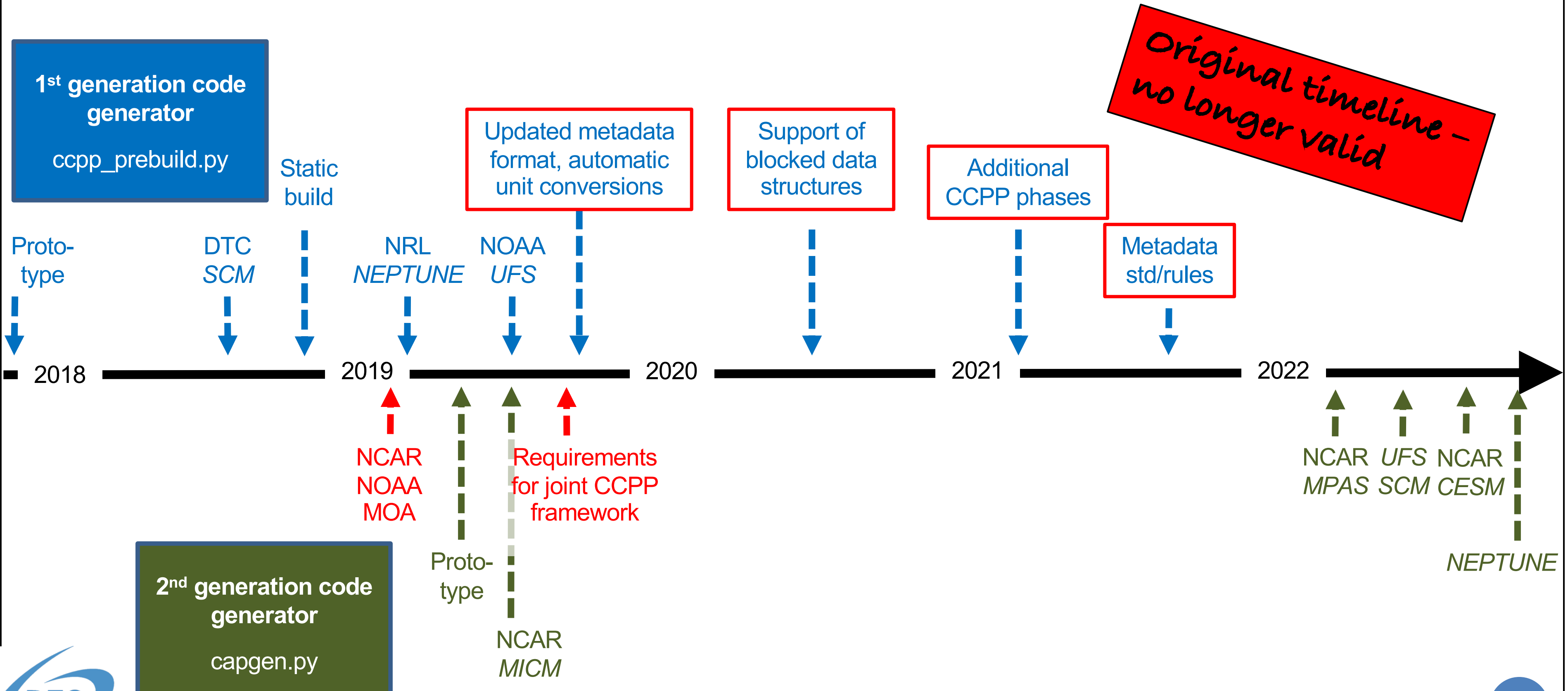
*SIMA: System for Integrated Modeling-Atmosphere

Framework development and code management

- Developing a process for joint code management and testing of CCPP framework
- Currently limited to participants of CCPP framework developer meetings (NOAA, NCAR)
- In the future, all organizations using CCPP in their models must be involved
- These efforts have been put on hold as we await the outcome of the SIMA review



Converging towards a common CCPP framework



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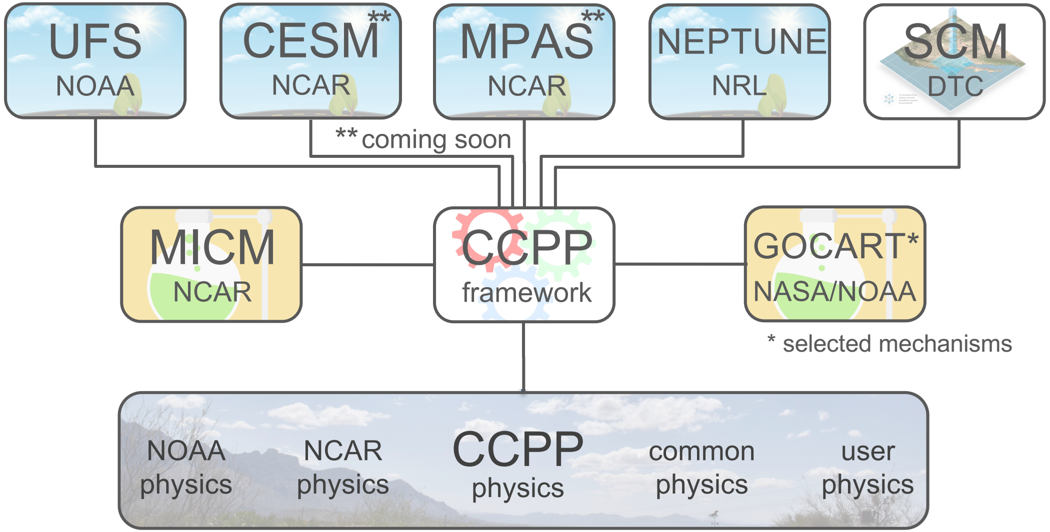
Transition to Operations

- CCPP selected as the framework for atmospheric physics (and possibly chemistry) in the UFS
- Included in UFS Medium-/Short-Range Weather, Subseasonal-to-Seasonal, Hurricane Apps
- Scheduled for operational implementation in the GFS/GEFS in 2024
- On track for operational use with the Rapid Refresh Forecast System (RRFS) and the Hurricane Analysis and Forecast System (HAFS) starting 2023

Without CCPP	UFS Operational		Implementations		With CCPP
2019	2020	2021	2022	2023	2024
GFS v15		GFS v16	WCOSS moratorium		GFS v17
	GEFS v12				GEFS v13
				HAFS v1	HAFS v2
				RRFS v1	RRFS v2

adapted from Tallapragada (2021)

Take home messages

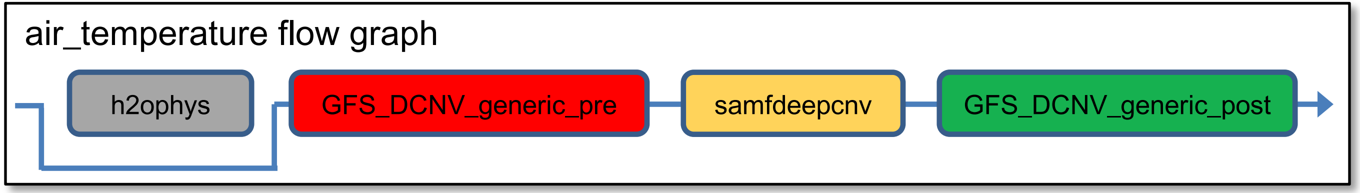


- The Common Community Physics Package lowers the bar for adding new physics or transferring them between models, and facilitates development and testing of innovations
- The CCPP metadata and code generator provide ample opportunities for development
- Prototypes exist for running aerosol chemistry in CCPP, inline with the physics
- The future of CCPP at NCAR depends on the outcomes of the SIMA review.

Additional material

Opportunities for future development

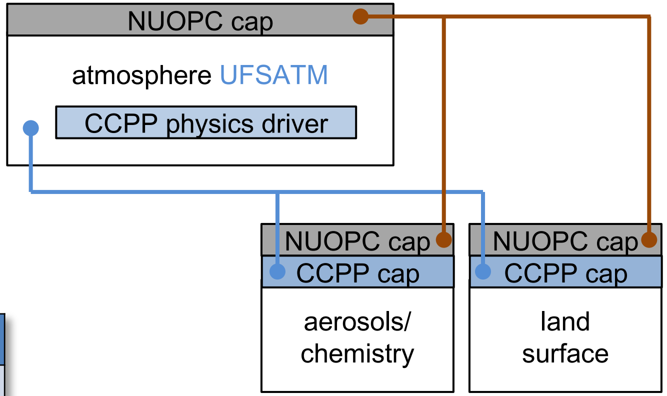
- Automatic array transformations: (i,k,j) to (i,k) to (k,i) to … - also vertical flipping
- Calculation of derived variables: pot. temp. from temp. & geopotential, …
- Visualization of how variables travel through a physics suite

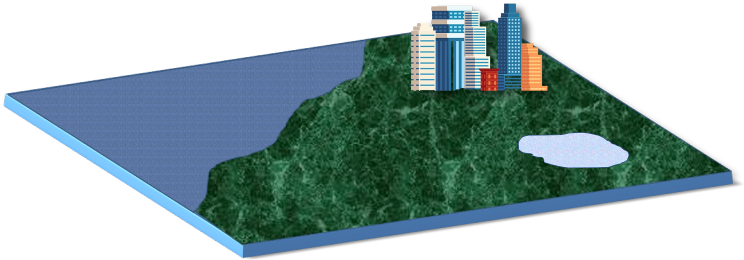


- Error handling including traceback information to replace existing error message/flag
- Specification of time-split vs process-split processes in suite definition file
- Logic to handle schemes that update the state in place or that return tendencies
- Extended diagnostic output capabilities from schemes (beyond tendencies)
- Improved handling of constituent arrays and properties (especially for chemistry)
- Automated saving of physics scheme state for restarts

Opportunities for future development (cont'd)

- Creation of CCPP or NUOPC cap for physics, run inline or as a separate component (required for UFS)
- Generation of optimized caps to dispatch physics on CPUs, GPUs, … (required for next-generation HPCs)
- Capability to decompose and recombine grid columns into different surface types for selected physics





Col	Surface type
1	Composite

split

Col*	Surface type
1	Ocean
2	Land
3	Lake
4	Urban

Surface physics

combine