The Common Community Physics Package (CCPP): bridging the gap between research and operations to improve U.S. numerical weather prediction capabilities

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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 by enabling the community to participate in the development and testing.

https://ufscommunity.org/index.html
Infrastructure for development of model 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 existing schemes adding new schemes or transferring them between models
- Physics suite construct (vetted combination of schemes) is important, but the CCPP must enable easy interchange of schemes within a suite
- Scientific documentation generated from inline doxygen markup and metadata
The CCPP within the model system

- ccpp-framework/auto-generated caps replace traditional physics drivers
- glue code between physics in drivers needs to become interstitial schemes
Key features of the CCPP

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

```xml
<suite name="GFS_v15p2">
  ...
  <group name="radiation">
    ...
  </group>
  <group name="physics">
    ...
    <!-- Surface iteration loop -->
    <subcycle loop="2">
      ...
      <scheme>lsm_noah</scheme>
      ...
    </subcycle>
    ...
  </group>
  ...
</suite>
```
Writing a CCPP-compliant parameterization is easy

module myscheme
    implicit none
    contains
    subroutine myscheme_init()
    end subroutine myscheme_init

!> \section arg_table_myscheme_run Argument Table
!! \htmlinclude myscheme_run.html
!!
subroutine myscheme_run(ni, psfc, errmsg, errflg)
    integer, intent(in) :: ni
    real, intent(inout) :: psfc(:)
    character(len=*), intent(out) :: errmsg
    integer, intent(out) :: errflg
    ...
end subroutine myscheme_run

subroutine myscheme_finalize()
end subroutine
end module myscheme

[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

[psfc]
  standard_name = surface_air_pressure
  long_name = air pressure at surface
  units = Pa
  dimensions = (horizontal_dimension)
  type = real
  intent = inout
  optional = F
  ...

myscheme.F90

myscheme.meta
Metadata is used for scientific documentation

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) [2096], most of the key elements have been simplified/improved. This code at this stage bears little to no similarity to the original Lin NP in nature; therefore, it is best to be called GFDL microphysics (GFDL MP). More...

Detailed Description

Author
Shin-Jenn Lin, Jinglong Zhou

The module contains the GFSL cloud microphysics (Chen and Lin [2013]). The module is paired with GFSL In-Core Fast Saturation Adjustment Module, which performs the “test” processes.

The subroutine executes the full GFSL cloud microphysics.

Argument Table

<table>
<thead>
<tr>
<th>local_name</th>
<th>standard_name</th>
<th>long_name</th>
<th>units</th>
<th>type</th>
<th>dimensions</th>
<th>kind</th>
<th>intent</th>
<th>optional</th>
</tr>
</thead>
<tbody>
<tr>
<td>layer</td>
<td>vertical_dimension</td>
<td>number of vertical levels</td>
<td>count</td>
<td>integer</td>
<td></td>
<td></td>
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<td>False</td>
</tr>
<tr>
<td>m</td>
<td>horizontal_layer_extent</td>
<td>horizontal layer extent</td>
<td>count</td>
<td>integer</td>
<td></td>
<td></td>
<td>False</td>
<td>False</td>
</tr>
<tr>
<td>i_m</td>
<td>gravitational_acceleration</td>
<td>gravitational acceleration</td>
<td>m/s</td>
<td>real</td>
<td></td>
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<td>False</td>
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<tr>
<td>lon_frt</td>
<td>ratio of vapor to dry air gas constant minus one</td>
<td>ideal gas constant for dry air</td>
<td>real</td>
<td>True</td>
<td>False</td>
<td>kind phys</td>
<td>False</td>
<td>False</td>
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<tr>
<td>sm_d</td>
<td>gas_constant_dry_air</td>
<td>ideal gas constant for dry air</td>
<td>1-j, 1, m-1</td>
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<td></td>
<td></td>
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<td>False</td>
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<tr>
<td>hand</td>
<td>land_area_fraction_lr_microphysics</td>
<td>land area fraction used in microphysics schemes</td>
<td>frac</td>
<td>integer</td>
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<td>kind phys</td>
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<tr>
<td>carea</td>
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<tr>
<td>rmcol</td>
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<tr>
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<td>water vapor specific humidity updated by physics</td>
<td>kg kg-1</td>
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<td>Horizontal dimension</td>
<td>kind phys</td>
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<tr>
<td>pslw_vapor(condensed_water_morning_ratio_updated_by_physics)</td>
<td>condensed water morning ratio updated by physics</td>
<td>kg kg-1</td>
<td>real</td>
<td>Horizontal dimension</td>
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<td>kg kg-1</td>
<td>real</td>
<td>Horizontal dimension</td>
<td>kind phys</td>
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<td>pswr_rain(condensed_water_morning_ratio_updated_by_physics)</td>
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<tr>
<td>prsn_rain(condensed_water_morning_ratio_updated_by_physics)</td>
<td>condensed rain snow morning ratio updated by physics</td>
<td>kg kg-1</td>
<td>real</td>
<td>Horizontal dimension</td>
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<tr>
<td>prsn_gruslo_gauss_update_by_physics</td>
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<td>kg kg-1</td>
<td>real</td>
<td>Horizontal dimension</td>
<td>kind phys</td>
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<td></td>
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<tr>
<td>prsn_gruslo_gauss_update_by_physics</td>
<td>condensed rain snow morning ratio updated by physics</td>
<td>kg kg-1</td>
<td>real</td>
<td>Horizontal dimension</td>
<td>kind phys</td>
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<tr>
<td>prsn_gruslo_gauss_update_by_physics</td>
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<tr>
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<td>Horizontal dimension</td>
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<td>False</td>
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</tr>
</tbody>
</table>

https://dtcenter.org/gmtb/users/ccpp
CCPP provides options for performance and flexibility

- CCPP uses a multi-suite static build to maintain the required performance for operations
  - Compile options for the UFS (and DTC’s Single Column Model SCM): SUITES="abc,xyz,..."
  - Filters unused schemes and variables, and auto-generates Fortran caps for each of the suites

- CCPP supports automatic unit conversions to expedite development and transition

- Parallelization in CCPP: limited support for MPI, full support for OpenMP (see bonus slides)
CCPP is part of the authoritative UFS code repository

- Merged into the authoritative UFS Weather Model code repository in July 2019
- CCPP physics are bit-for-bit identical with existing physics with reproducibility compiler flags
- Scheduled for operational implementation in the GFS/GEFS 2024
- Part of the UFS Medium-Range Weather App public release in March 2020
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 to provide information on
  - 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)
- Automatic variable allocation for variables used by physics only
- Compare metadata to actual Fortran code
- Improved build system and code generator

*SIMA: System for Integrated Modeling-Atmosphere
A bounty of low- (and higher-)hanging fruit

The existing CCPP framework capabilities and the NCAR contributions provide opportunities for development:

- Automatic array transformations \((i,j,k)\) to \((i,k)\), \((k,i)\) to …
- Calculation of derived variables (pot. temp. from temp. & geopotential)
- Detect logical flaws in suites (read variable that has not been written to)
- Automated saving of physics scheme state for restarts
- Extended diagnostic output capabilities from schemes
- Creation of CCPP or NUOPC cap for physics, run either inline or as a separate component (required for UFS)
- Generation of optimized caps to dispatch physics on CPUs, GPUs, … (required for next-generation HPCs)
- …
## CCPP Public Releases

<table>
<thead>
<tr>
<th>V</th>
<th>Date</th>
<th>Physics</th>
<th>Host</th>
</tr>
</thead>
<tbody>
<tr>
<td>v1</td>
<td>2018 Apr</td>
<td>GFS v14 operational</td>
<td>SCM</td>
</tr>
<tr>
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<td>GFS v14 operational updated</td>
<td>SCM</td>
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<tr>
<td></td>
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<td>GFDL microphysics</td>
<td>UFS WM for developers</td>
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<tr>
<td>v2</td>
<td>2018 Aug</td>
<td>GFS v15 operational</td>
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<td>Developmental schemes/suites</td>
<td>UFS WM for developers</td>
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<tr>
<td>v3</td>
<td>2019 Jul</td>
<td>GFS v15 operational</td>
<td>SCM</td>
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<td>v4</td>
<td>2020 Mar</td>
<td>GFS v15 operational</td>
<td>SCM</td>
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<td>Developmental schemes/suites</td>
<td>UFS WM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(incl GFS v16 developmental)</td>
<td>UFS MRW</td>
</tr>
</tbody>
</table>

CCPP v4: [https://dtcenter.org/ccpp](https://dtcenter.org/ccpp)
- Helpdesk: [gmtb-help@ucar.edu](mailto:gmtb-help@ucar.edu)
- UFS Users’ Support Forums: [https://forums.ufscommunity.org](https://forums.ufscommunity.org)

SCM – CCPP Single Column Model
UFS WM – UFS Weather Model
UFS MRW – UFS Medium-Range Weather App
## CCPP v4 supported suites

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<th>Operational</th>
<th>Experimental</th>
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<tbody>
<tr>
<td><strong>Microphysics</strong></td>
<td>GFS_v15p2</td>
<td>csawmg*</td>
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<tr>
<td></td>
<td>GFS_v16beta</td>
<td>GSD_v1*</td>
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<tr>
<td><strong>Boundary Layer</strong></td>
<td>GFDL</td>
<td>M-G3</td>
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<td></td>
<td>K-EDMF</td>
<td>Thompson</td>
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<td><strong>Surface Layer</strong></td>
<td>K-EDMF</td>
<td>saMYNN</td>
</tr>
<tr>
<td></td>
<td>GFS</td>
<td>GFS</td>
</tr>
<tr>
<td><strong>Deep convection</strong></td>
<td>SAS</td>
<td>Chikira-Sugiyama</td>
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<td>SAS</td>
<td>Grell-Freitas</td>
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<td><strong>Shallow Convection</strong></td>
<td>SAS</td>
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<td></td>
<td>SAS</td>
<td>MYNN and GF</td>
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<tr>
<td><strong>Radiation</strong></td>
<td>RRTMG</td>
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<td><strong>Gravity Wave Drag</strong></td>
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<td>uGWP</td>
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<td></td>
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<td><strong>Land Surface</strong></td>
<td>Noah</td>
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<td>Noah</td>
<td>RUC</td>
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<td><strong>Ozone</strong></td>
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<td><strong>H₂O</strong></td>
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<td>NRL</td>
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<tr>
<td></td>
<td>NRL</td>
<td>NRL</td>
</tr>
</tbody>
</table>

Additional parameterizations and suites are under-development. * with SCM only
Collaboration with NRL NEPTUNE

- CCPP has been implemented in NEPTUNE by NRL team
- Experiments with NEPTUNE have been conducted with various physics suites

**Total precipitation**
(explicit + parameterized)
for 60-h forecast (mm/h)

Suite 4 improves drizzle bias

Courtesy of
Matus Martini (Devine)
Alex Reinecke, Jim Doyle (NRL)
One framework to rule them all (and accelerate R2O)

CCPP framework

MICM
NCAR

NOAA physics
NCAR physics
CCPP physics
common physics
user physics

your physics here

your model here

UFS
NOAA

CESM
NCAR

MPAS
NCAR

WRF
NCAR

NEPTUNE
NRL
Bonus slides
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
## Parameterizations in ccpp-physics master

<table>
<thead>
<tr>
<th>Category</th>
<th>Implementation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microphysics</td>
<td>Zhao-Carr, GFDL (incl. sat adj in dycore), MG2-3, <strong>Thompson, F-A</strong></td>
</tr>
<tr>
<td>PBL</td>
<td>K-EDMF, TKE-EDMF, moist TKE-EDMF, <strong>YSU, saYSU, MYJ</strong></td>
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<tr>
<td>Surface Layer</td>
<td>GFS, <strong>MYNN, MYJ</strong></td>
</tr>
<tr>
<td>Deep Convection</td>
<td>saSAS, Chikira-Sugiyama, <strong>GF, Tiedtke</strong></td>
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<tr>
<td>Shallow Convection</td>
<td>EDMF, <strong>GF, Tiedtke</strong></td>
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<td>PBL and Shal Convection</td>
<td>SHOC, <strong>MYNN</strong></td>
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<tr>
<td>Radiation</td>
<td>RRTMG</td>
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<tr>
<td>Gravity Wave Drag</td>
<td>GFS orographic, GFS convective, uGWD, <strong>RAP/HRRR drag suite</strong></td>
</tr>
<tr>
<td>Land Surface</td>
<td>Noah, Noah-MP, <strong>RUC</strong></td>
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<tr>
<td>Ocean</td>
<td>Simple GFS ocean</td>
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<tr>
<td>Sea Ice</td>
<td>Simple GFS sea ice</td>
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<td>Ozone</td>
<td>2006 NRL, 2015 NRL</td>
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<td>H$_2$O</td>
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