MPAS
Model for Prediction Across Scales

Physics and Physics Configuration in MPAS

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MPAS-A Tutorial 2026

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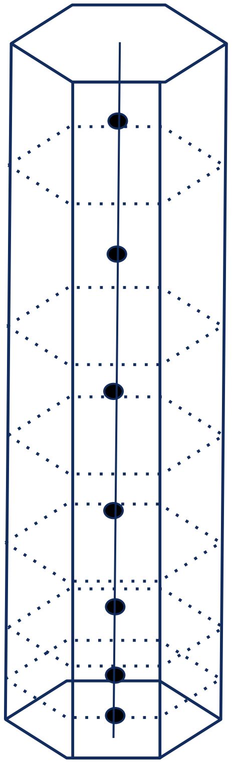
Physics Parameterizations

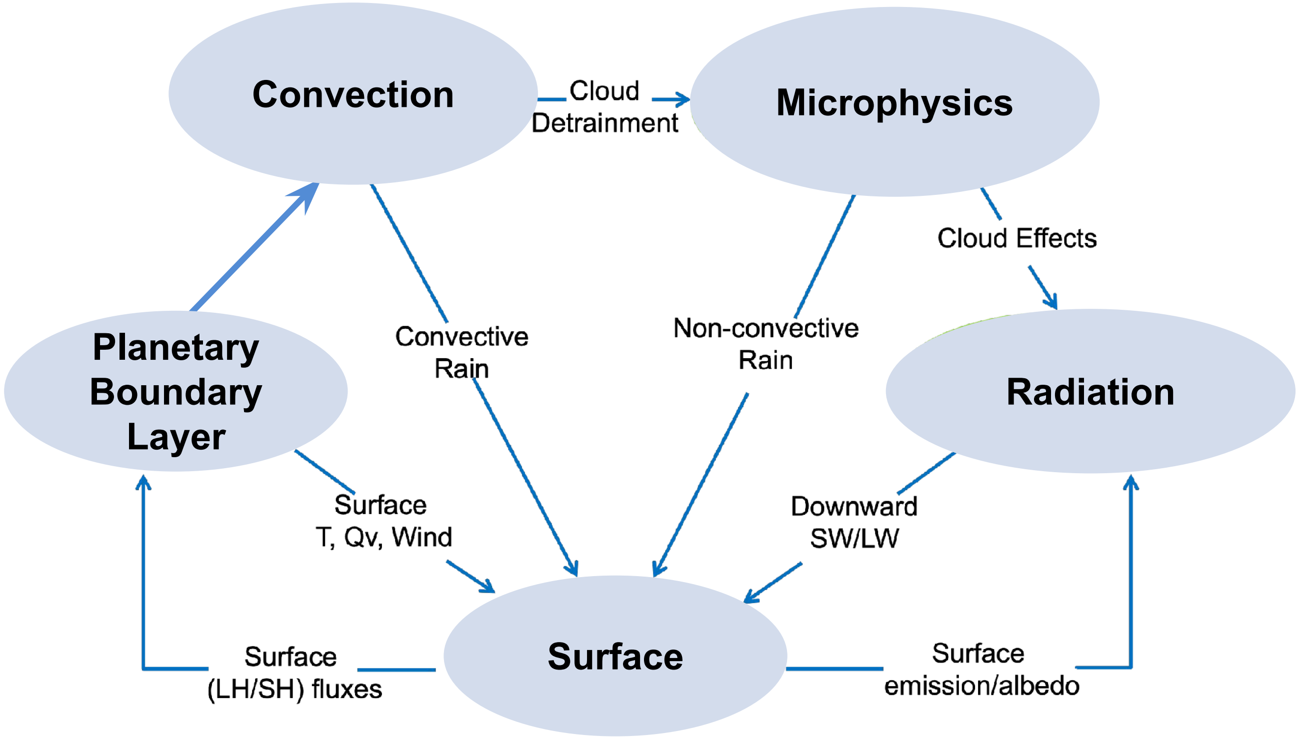
Parameterizations are used to describe the mean effect of subgrid-scale physical processes that feedback onto the model state in each cell volume.

Subgrid-scale representations typically depend on the prognostic variables:

- Horizontal winds
- Vertical wind
- Potential temperature
- Density
- Water species



Model Physics



Coupling of physics with dynamics in MPAS-A

MPAS driver

CALL physics initialization

registry

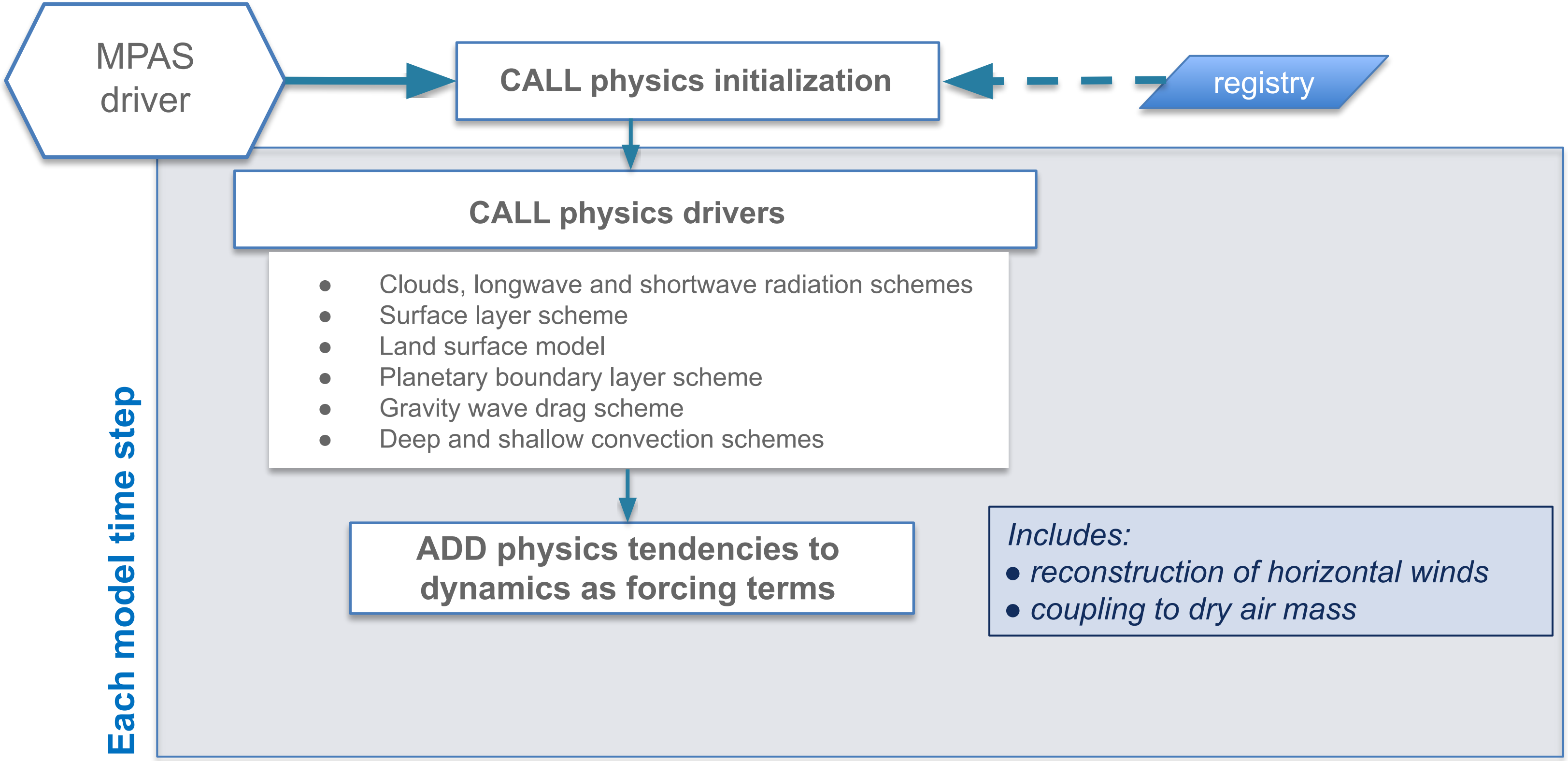
Each model time step

CALL physics drivers

- Clouds, longwave and shortwave radiation schemes
- Surface layer scheme
- Land surface model
- Planetary boundary layer scheme
- Gravity wave drag scheme
- Deep and shallow convection schemes

MPAS uses a process-split physics approximation, so all parameterizations have the same input state (time-level t).

Coupling of physics with dynamics in MPAS-A



Coupling of physics with dynamics in MPAS-A

MPAS driver → **CALL physics initialization** ← registry

Each model time step

CALL physics drivers

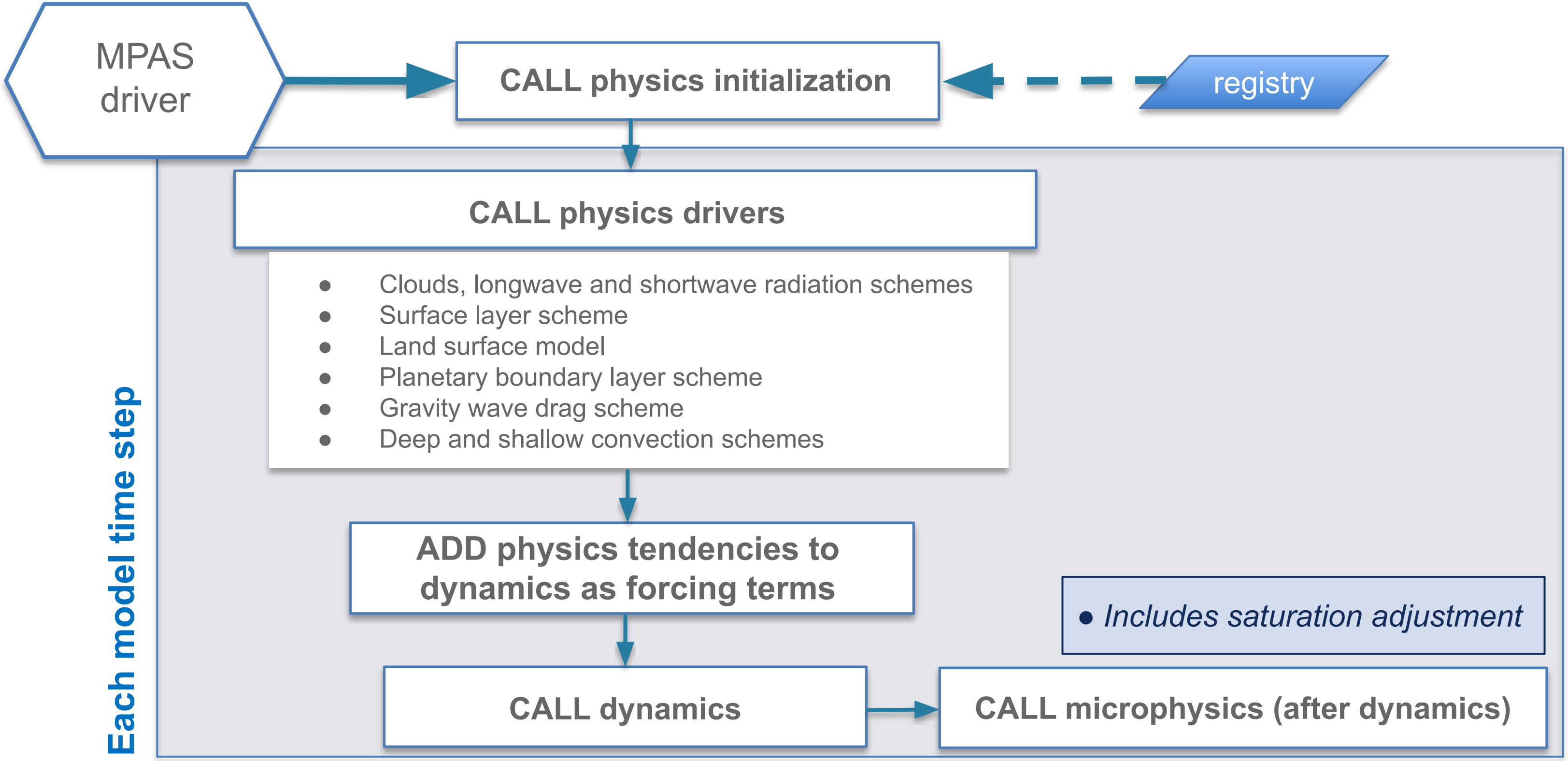
- Clouds, longwave and shortwave radiation schemes
- Surface layer scheme
- Land surface model
- Planetary boundary layer scheme
- Gravity wave drag scheme
- Deep and shallow convection schemes

ADD physics tendencies to dynamics as forcing terms

CALL dynamics

- *Dynamics split steps / RK time-stepping*
- *Scalar transport*

Coupling of physics with dynamics in MPAS-A



Convection schemes

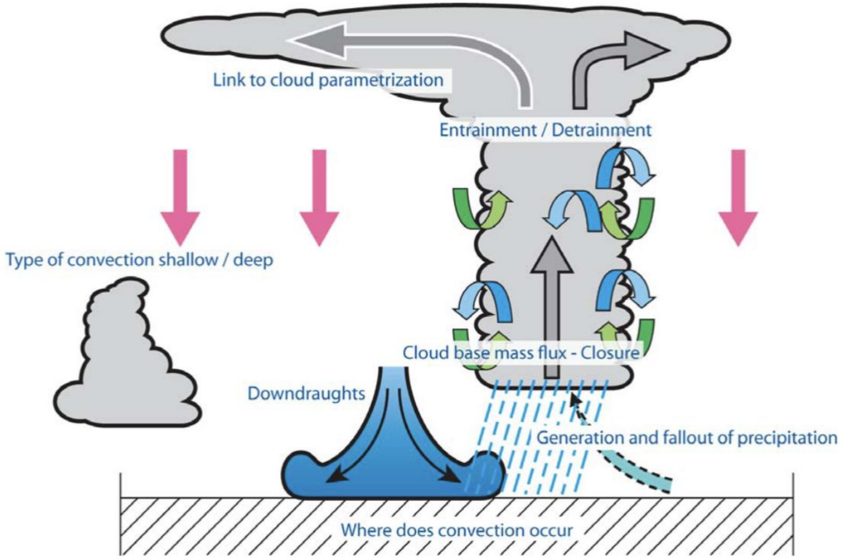


Figure 3. Schematic of a bulk convection scheme with a shallow and deep entraining/detraining cloudy ascending plume, and downdraught region. Further represented features are trigger of convection, environmental subsidence, microphysics and precipitation, and detrainment of cloud mass in anvils.

From Bechtold 2008: Seminar on Parameterization of Subgrid Physical Processes

- A convection or cumulus scheme parameterizes the ensemble effect of convective transport of heat, moisture (and momentum) on the grid scale

- Particularly important at mesh spacing, Δ > 10 km, when updrafts are too small to be explicitly resolved

- At Δ < 4 km, numerous studies have shown that simulations are more realistic when the convection scheme is turned off.

- Available schemes:
  - Grell-Freitas (scale-aware)
  - New Tiedtke (scale-aware)
  - Kain-Fritsch
  - Tiedtke

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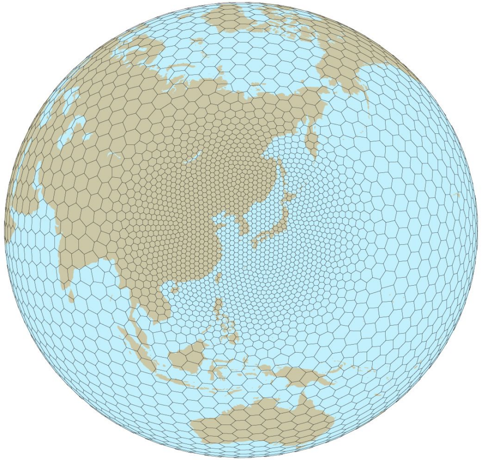
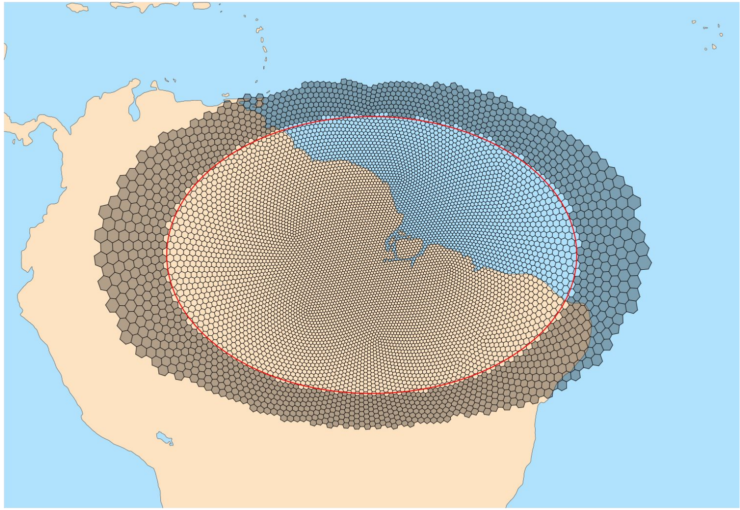
Scale-aware convection schemes

For variable-resolution applications with mesh spacings ranging from mesoscale to cloud-permitting scales, scale-aware schemes need to be used.



global



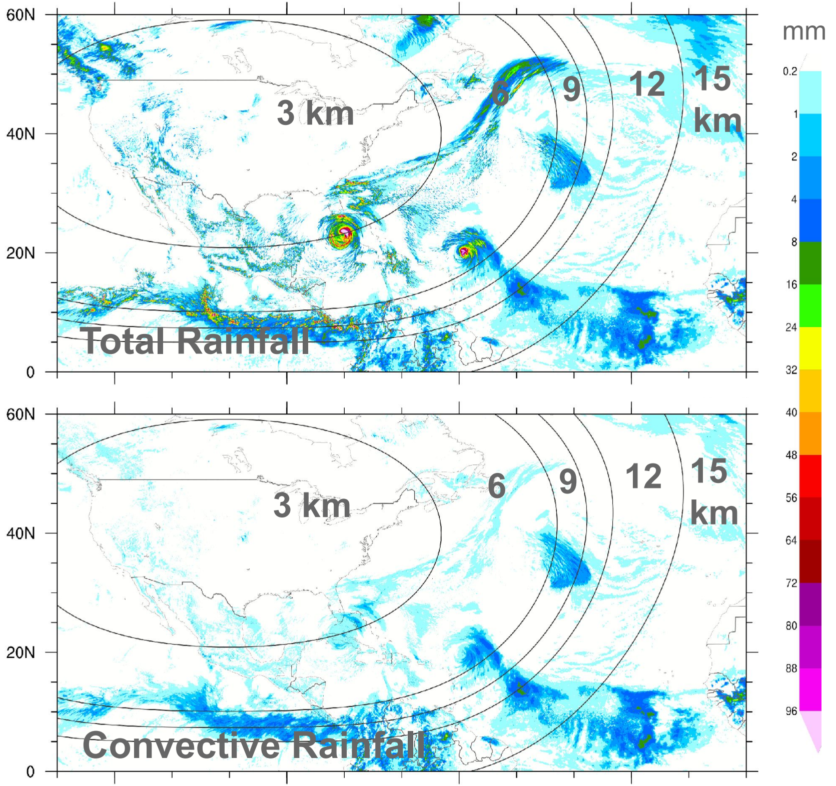
regional

Scale-aware convection schemes

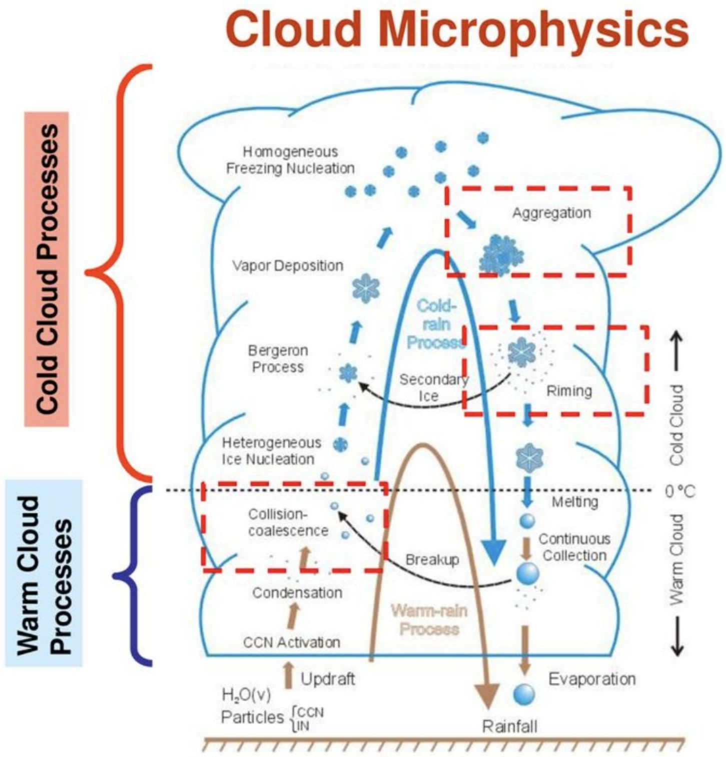
- ‘Scale-awareness’ starts at $\Delta \leq \sim 15$ km

- One way to determine how active the scale-aware scheme is by examining the rainfall produced by the convection scheme.

Simulation of Hurricane Irma with a 15-3 km mesh



Bulk Microphysics Schemes



- Detailed cloud microphysical processes, such as condensation, deposition, evaporation, collection, melting, freezing, sedimentation, etc. Contributes to mass loading in dynamics
- Prognostic hydrometeors: cloud water, cloud ice, rain, snow, and graupel (and hail)
- Clouds interact with radiation
- Available schemes:
  - Kessler (single moment)
  - WSM6 (single moment)
  - Aerosol-aware Thompson (partial double moment)

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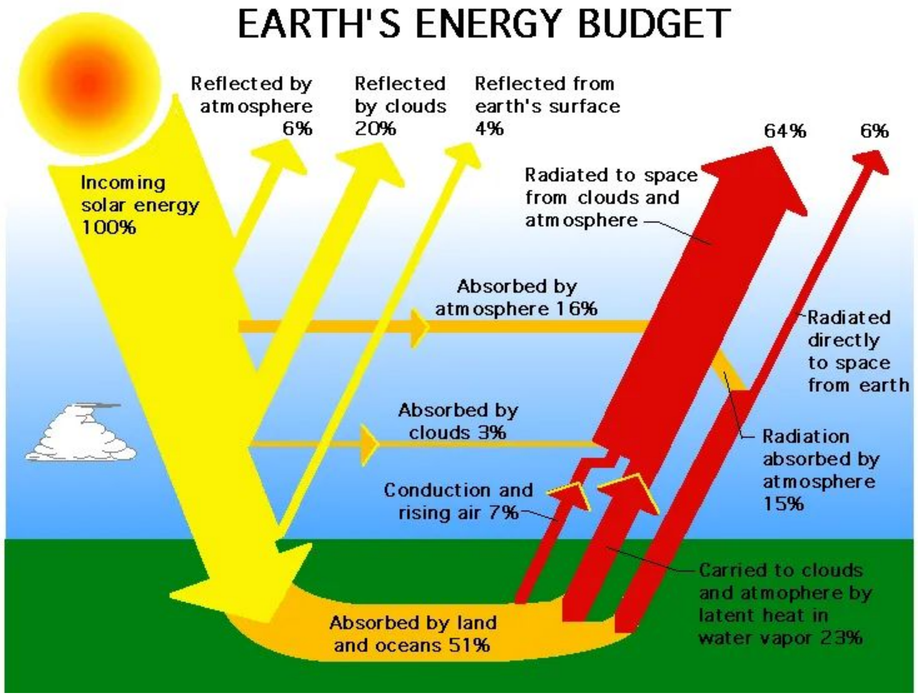
Radiation schemes



(From UCAR/SCIED, adapted from an illustration by J.T. Kiehl and K.E. Trensberth)

Radiation schemes predict atmospheric warming (e.g. by absorption) or cooling in a vertical column, and also compute the surface radiative fluxes.

Shortwave Radiation: Clear-sky and cloudy fluxes, annual and diurnal solar cycles, important term in the surface energy balance

Longwave Radiation: Clear-sky and cloudy fluxes, IR emission from layers, surface emissivity based on land-type, downward surface flux for land energy budget, IR cooling at cloud tops and warming at cloud base

Available schemes:

- CAM Shortwave and Longwave
- RRTMG Shortwave and Longwave

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Radiation schemes

Monthly ozone climatology (else: fixed vertical profile is used)

```
config_o3climatology = true
```

Effective radii of cloud-water, cloud ice and snow from microphysics

```
config_microp_re = false
```
(default)

Horizontal cloud fraction

```
config_radt_cld_scheme = suite
(possible_values="`suite’, `cld_fraction',`cld_incidence')
```

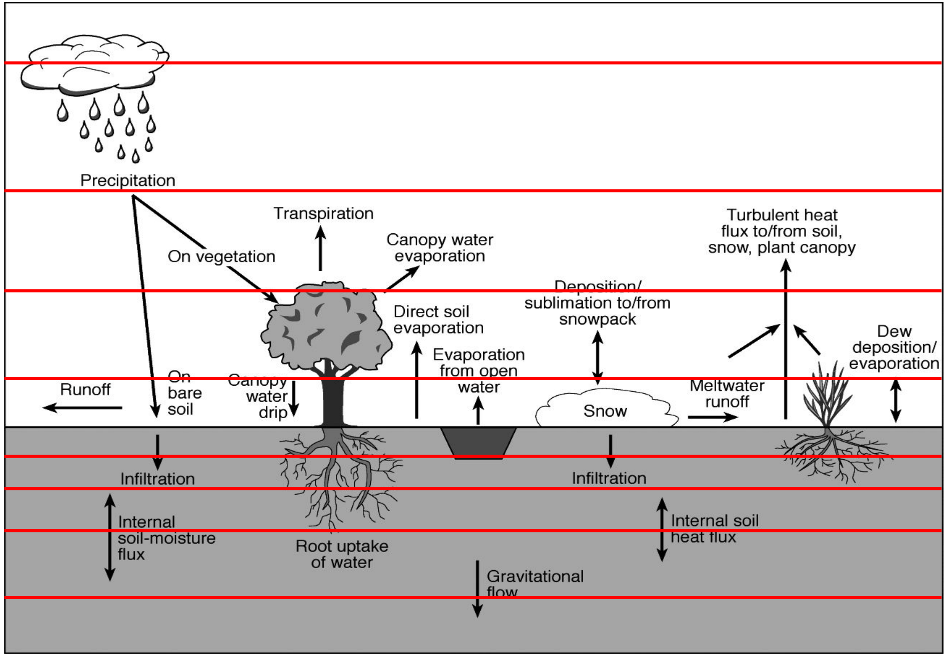
Cloud overlap assumptions and decorrelation lengths

```
config_radt_cld_overlap = maximum_random
(possible_values="`none',`random',`maximum_random',`maximum',`exponential',`'exponential_random'")

config_radt_cld_dcorrlen = constant
(possible_values="`constant',`latitude_varying'")
```

Land Surface Models

- A land surface model (LSM) considers processes of heat and moisture transfer in the soil layers, vegetation effect, surface runoff and snow.
- Predicts surface fluxes over land, urban areas, glacier and sea ice. Compute diagnostics for surface temperature and water vapor mixing ratio
- Available LSMs:
  - Noah
  - Noah-MP (v5.0.1)



MPAS Model for Prediction Across Scales

Using Noah-MP LSM

Noah-MP v5.0.1 has been added to MPAS-A since v8.2.0 (with fixes in more recent releases).

- Features dynamic vegetation model, multi-layer snowpack model, schemes for groundwater hydrology
- Requires new static fields: soil composition and texture (`soilcomp`, `soilcl1`, `soilcl2`, `soilcl3`, `soilcl4`)

In namelist.init_atmosphere, when creating static files and init files:

```
config_noahmp_static = true (default value)
```

For backward-compatibility of **older** static files (generated using init_atmosphere_model pre-v8.2.0)

If you're **not** using Noah-MP, set the following in namelist.init_atmosphere when creating init.nc:

```
config_noahmp_static = false
```

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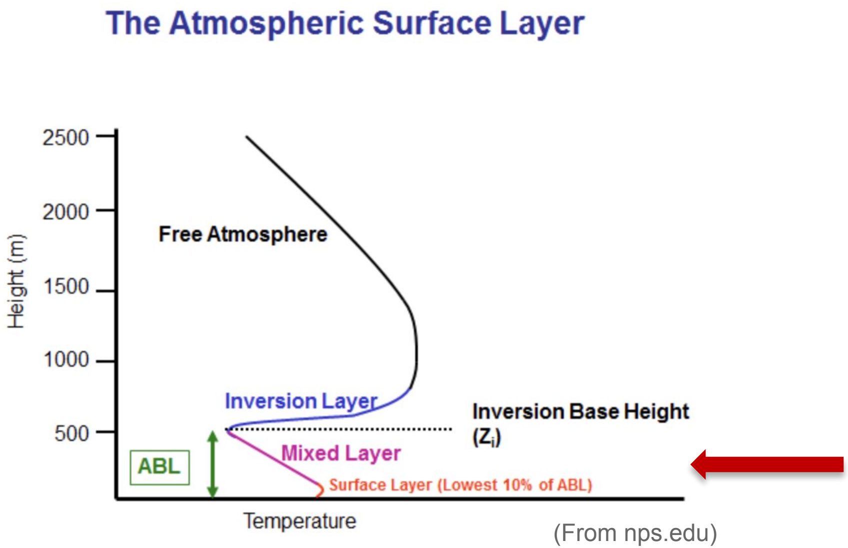
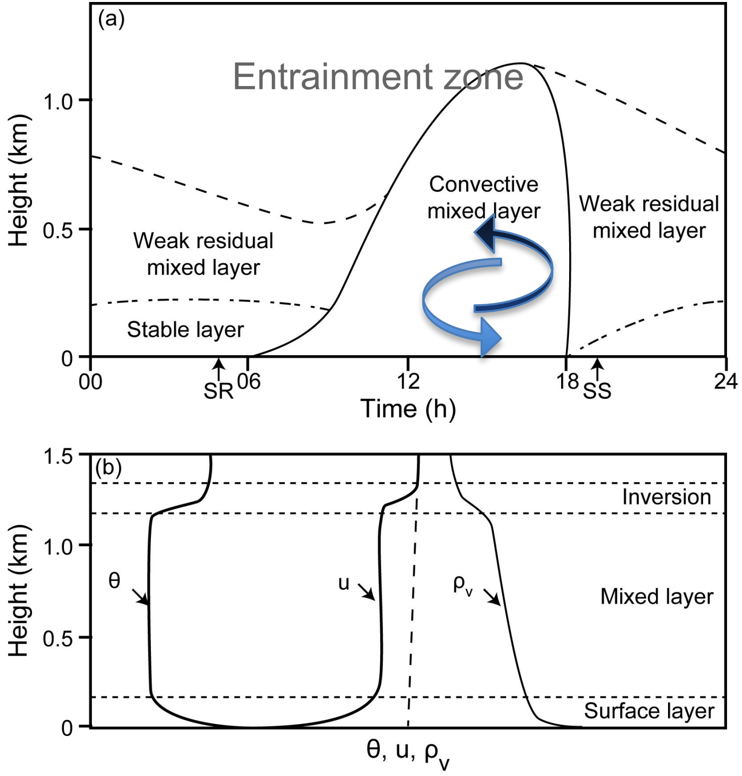
Surface Layer Schemes



(From nps.edu)

- The surface layer scheme calculates the exchange coefficients of heat, moisture and momentum between land and atmosphere, which are needed by the land surface model.
- Lowest 10% of the PBL, where turbulence generated by shear and convective heat transfer dominates. Approximated as a constant flux layer, where Monin-Obukhov similarity theory applies.
- Diagnostics for 2-m temperature, water-vapor mixing ratio, and 10-m winds
- Available schemes:
    - Revised MM5
    - MYNN
- Usually paired with a specific PBL scheme

Planetary Boundary Layer (PBL) Schemes

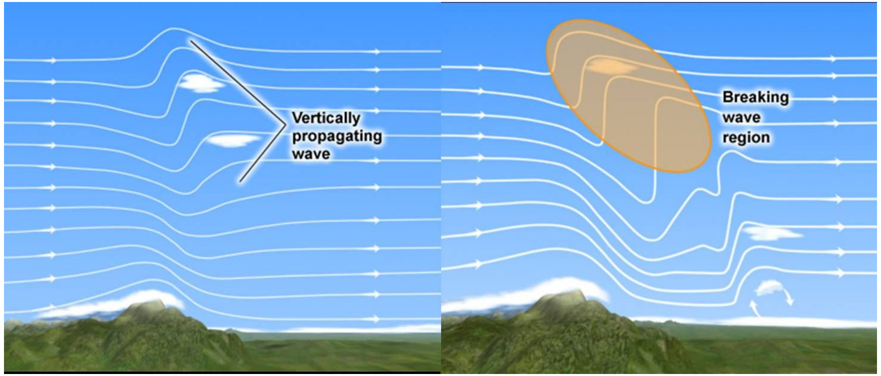


- A PBL scheme parameterizes the vertical transport of momentum, heat and water vapor fluxes within the PBL and represents turbulent mixing above the BL.
- Types: local (e.g., MYNN), non-local (e.g. YSU and mass-flux schemes, such as MYNN-EDMF)
- Available schemes:
  - MYNN
  - YSU
- Radiation-driven mixing:

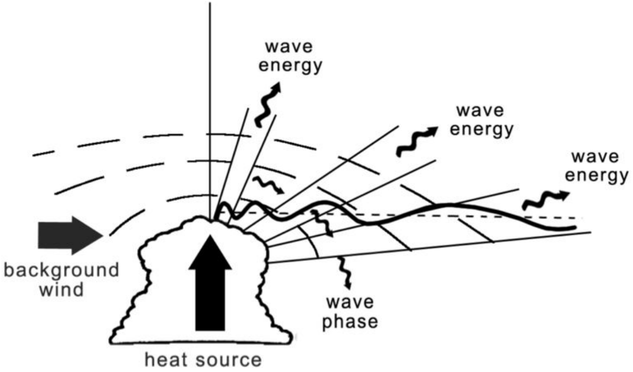
```
config_ysu_pblmix = true (default = false)
config_mynn_topdown = 1 (default = 0)
```

Gravity Wave Drag Schemes

Stationary sources



Non-stationary sources



(From Young-Joon Kim et al. 2003; Hooke, 1986)

- Represent the subgrid-scale effect of vertically propagating waves excited by the **topography** or dynamically induced by **other non-orographic sources** such as convection, frontogenesis and shear zones

- Wave-breaking occurs under certain atmospheric conditions and exert a drag on the atmospheric flow. This needs to be represented in the model, especially when the mesh spacing is larger than 5 km. Low-level flow blocking effects are also parameterized.

Gravity Wave Drag Schemes

- Available schemes
  - YSU Orographic GWD scheme (orographic sources only)
  - NOAA Unified GWP (UGWP) scheme (includes orographic and non-stationary sources)

- Notes on UGWP scheme (`config_gwdo_scheme = 'bl_ugwp_gwdo'`)
  - Need to pre-process with two new static input directories:
    - topo_ugwp_30s
    - topo_ugwp_2.5m

    In namelist.init_atmosphere:

    ```
    config_native_gwd_gsl_static = true
    ```

    In namelist.atmosphere:

    `config_ngw_scheme = true` (default value: false)
    `config_ugwp_diags = true`
    `config_knob_ugwp_tauamp = 0.13E-3` (default value; may be beneficial to increase when Δ > 10 km)

  - To use the UGWP non-stationary gravity wave drag scheme, requires additional input file:
    Lookup table `ugwp_limb_tau.nc`

Physics Schemes in MPAS-A

Physics	Options
Radiation	RRTMG, CAM
Surface Layer	MM5, Revised MM5, MYNN
Land Surface	Noah, NoahMP
PBL	YSU (non-local), MYNN (TKE, EDMF)
Microphysics	Kessler (warm rain), WSM6 (single moment), Thompson, Thompson+aerosol (partially double moment; as in WRF v4.1.4)
Convection	New Tiedtke, Grell-Freitas, Kain-Fritsch, Tiedtke
Ocean	1-D Ocean mixed layer
Gravity Wave Drag	GWDO (Choi & Hong), Unified Gravity Wave Physics (includes option for non-stationary gravity wave drag)

underlined: identical to those in the latest WRF release

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Corresponding Physics Options in MPAS-A

Physics	Options
config_radt_lw_scheme config_radt_sw_scheme	’RRTMG’, ‘CAM’ ‘RRTMG’, ‘CAM’
config_sfclayer_scheme	‘sf_monin_obukhov’, ‘sf_monin_obukhov_rev’, ‘sf_mynn’
config_lsm_scheme	‘sf_noah’, ‘sf_noahmp’
config_pbl_scheme	‘bl_ysu’, ‘bl_mynn’
config_microp_scheme	‘mp_kessler’, ‘mp_wsm6’, ‘mp_thompson’ , ‘mp_thompson_aerosols’
config_convection_scheme	'cu_ntiedtke’, ‘cu_grell_freitas’, ‘cu_kain_fritcsh’, ‘cu_tiedtke’
config_oml1d	true or false
config_gwdo_scheme	‘bl_ysu_gwdo’, ‘bl_ugwp_gwdo'

Physics Specification using Suites

Physics Suites	Physics Schemes
'mesoscale_reference' **Tropical storms and convection**	RRTMG, Xu-Randall cloud fraction, Noah LSM, YSU GWDO, YSU PBL, Revised MM5 sfc layer, new Tiedtke, WSM6
'convection_permitting' **Mid-latitude convective weather**	RRTMG, Xu-Randall cloud fraction, Noah LSM, YSU GWDO, MYNN PBL, MYNN sfc layer, Grell-Freitas, Thompson

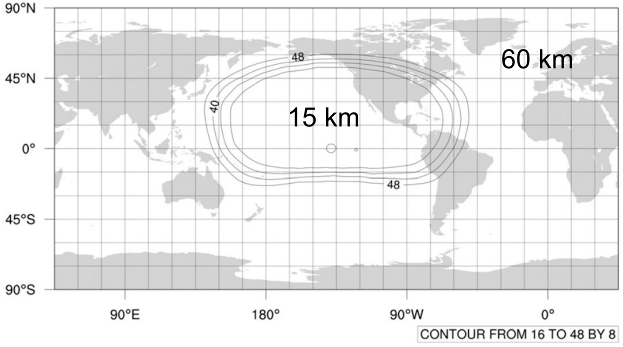

FIG. 1. Centroid spacing for variable-resolution MPAS mesh. Contour interval is 8 km.

Figure from Davis et al. (2016)

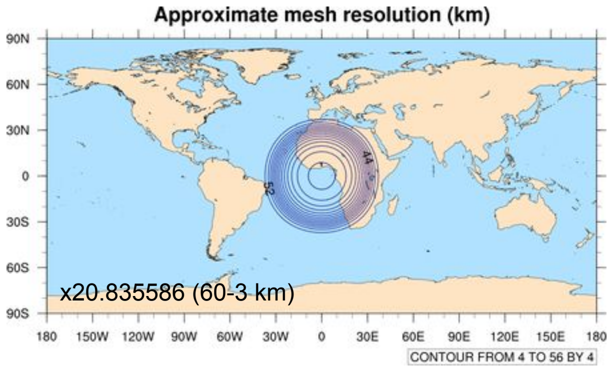

Figure from MPAS webpage

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Configuring physics options

Physics is configured by using namelist record &physics. It can be defined as a suite, or individual options, or combination of both. Example shown below is the 'mesoscale_reference' suite:

```
&physics
    config_physics_suite      = 'mesoscale_reference'
/
```

```
&physics
    config_convection_scheme = 'cu_ntiedtke'
    config_microp_scheme     = 'mp_wsm6'
    config_pbl_scheme        = 'bl_ysu'
    config_sfclayer_scheme   = 'sf_monin_obukhov_rev'
    config_lsm_scheme        = 'sf_noah'
    config_radt_lw_scheme    = 'rrtmg_lw'
    config_radt_sw_scheme    = 'rrtmg_sw'
    config_radt_cld_scheme   = 'cld_fraction'
    config_gwdo_scheme       = 'bl_ysu_gwdo'
/
```

Configuring physics options

Physics is configured by using namelist record &physics. It can be defined as a suite, or individual options, or combination of both. Example shown below is the ‘convection_permitting’ suite:

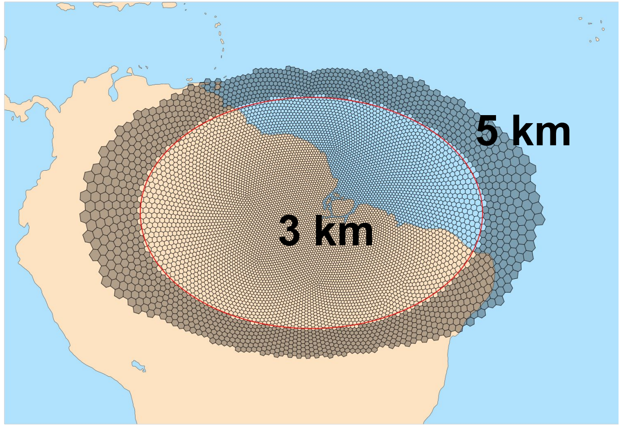
```
&physics
    config_physics_suite      = 'convection_permitting'
/
```

```
&physics
    config_convection_scheme = 'cu_grell_freitas'
    config_microp_scheme     = 'mp_thompson'
    config_pbl_scheme        = 'bl_mynn'
    config_sfclayer_scheme   = 'sf_mynn'
    config_lsm_scheme        = 'sf_noah'
    config_radt_lw_scheme    = 'rrtmg_lw'
    config_radt_sw_scheme    = 'rrtmg_sw'
    config_radt_cld_scheme   = 'cld_fraction'
    config_gwdo_scheme       = 'bl_ysu_gwdo'
/
```

Configuring physics options

To turn any options off, set it to ‘off’: e.g.

```
config_physics_suite      = 'convection_permitting'
config_convection_scheme = 'off'
```



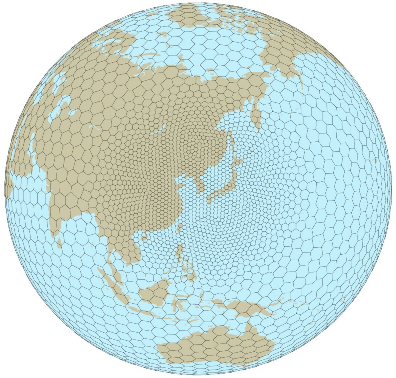
Example: regional convection-permitting simulation to be compared with other model configurations (e.g, in WRF)

Configuring physics options

Can replace one or more options in a suite:

```
config_physics_suite      = 'convection_permitting'
config_lsm_scheme         = 'sf_noahmp'
```

(reminder: default in this physics suite: `'sf_noah'`)



global variable-resolution

Example: Comparison of physics options

Configuring physics options

Also consider the following – these have corresponding options in WRF:

```
&physics
    config_radtlw_interval = '00:15:00'
    config_radtsw_interval = '00:15:00'
    config_o3climatology = true
    config_sfc_albedo = true
    config_sfc_snowalbedo = true
    config_sst_update = false
    config_sstdiurn_update = false
    config_deepsoiltemp_update = false
    config_micro_re = true
    config_ysu_pblmix = true
/
```

radiation related

longer simulations

useful options (default: false)

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Physics Data Files in MPAS

File Name	Needed by
CAM_ABS_DATA.DBL CAM_AEROPT_DATA.DBL	CAM radiation
RRTMG_LW_DATA RRTMG_SW_DATA OZONE_DAT.TBL OZONE_LAT.TBL OZONE_PLEV.TBL	RRTMG radiation
GENPARM.TBL LANDUSE.TBL SOILPARM.TBL VEGPARM.TBL	Noah LSM
NoahmpTable.TBL	NoahMP LSM
CCN_ACTIVATE_DATA MP_THOMPSON_freezeH2O_DATA.DBL MP_THOMPSON_QIautQS_DATA.DBL MP_THOMPSON_QRacrQG_DATA.DBL MP_THOMPSON_QRacrQS_DATA.DBL	Thompson Microphysics created by ***build_tables***

Physics Data Files in MPAS

> When you first download MPAS:

```
cmake  CMakeLists.txt  docs  INSTALL  LICENSE  Makefile  README.md  setup_mpas.csh  setup_mpas.sh  src  testing_and_setup
```

> After compiling atmosphere_model:

```
atmosphere_model      GENPARM.TBL           OZONE_PLEV.TBL                    stream_list.atmosphere.diag_ugwp
build_tables          INSTALL               README.md                         stream_list.atmosphere.output
CAM_ABS_DATA.DBL      LANDUSE.TBL           RRTMG_LW_DATA                     stream_list.atmosphere.surface
CAM_AEROPT_DATA.DBL   LICENSE               RRTMG_LW_DATA.DBL                 streams.atmosphere
CCN_ACTIVATE_DATA     Makefile              RRTMG_SW_DATA                     testing_and_setup
cmake                 namelist.atmosphere   RRTMG_SW_DATA.DBL                 VEGPARM.TBL
CMakeLists.txt        NoahmpTable.TBL       SOILPARM.TBL
default_inputs        OZONE_DAT.TBL         src
docs                  OZONE_LAT.TBL         stream_list.atmosphere.diagnostics
```

> If using the Thompson microphysics, run ./build_tables:

```
MP_THOMPSON_freezeH2O_DATA.DBL  MP_THOMPSON_QIautQS_DATA.DBL  MP_THOMPSON_QRacrQG_DATA.DBL  MP_THOMPSON_QRacrQS_DATA.DBL
```

Physics Code Structure

MPAS-Model/src/core_atmosphere/physics/

access to data files

drivers for different physics schemes

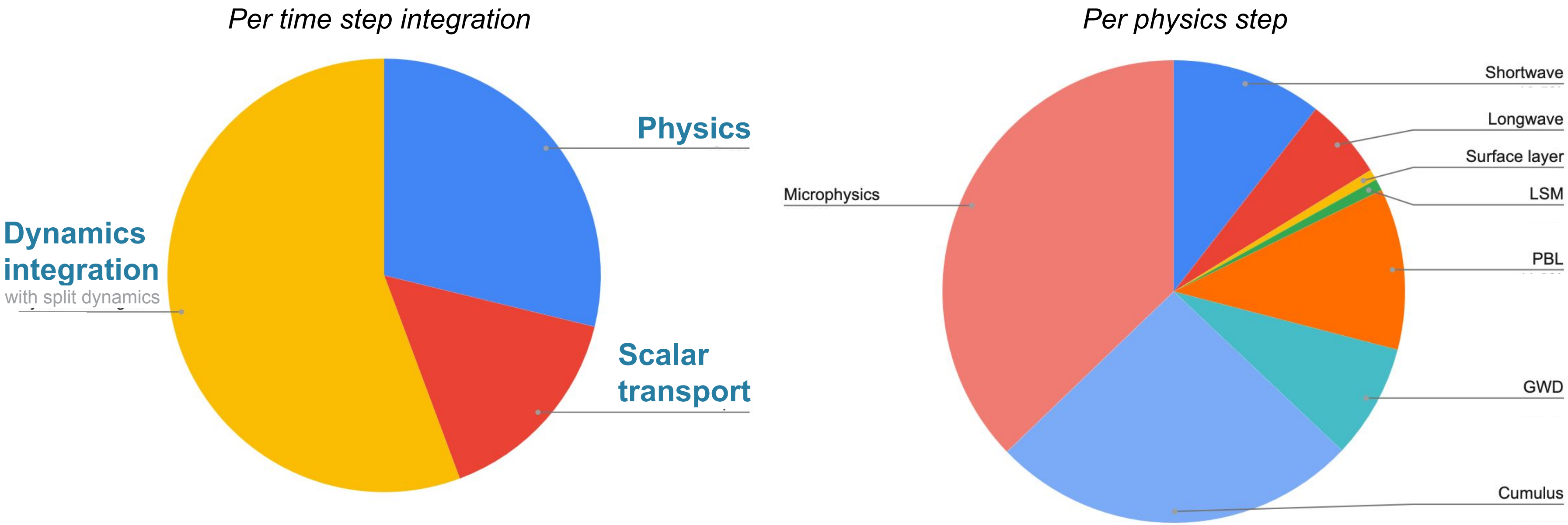
```
ccpp_kind_types.F
checkout_data_files.sh
Makefile
mpas_atmphys_camrad_init.F
mpas_atmphys_constants.F
mpas_atmphys_control.F
mpas_atmphys_date_time.F
mpas_atmphys_driver_cloudiness.F
mpas_atmphys_driver_convection.F
mpas_atmphys_driver.F
mpas_atmphys_driver_gwdo.F
mpas_atmphys_driver_lsm.F
mpas_atmphys_driver_lsm_noahmp.F
mpas_atmphys_driver_microphysics.F
mpas_atmphys_driver_oml.F
mpas_atmphys_driver_pbl.F
mpas_atmphys_driver_radiation_lw.F
mpas_atmphys_driver_radiation_sw.F
mpas_atmphys_driver_seaice.F
mpas_atmphys_driver_sfclayer.F
mpas_atmphys_finalize.F
mpas_atmphys_functions.F
mpas_atmphys_init.F
mpas_atmphys_initialize_real.F
mpas_atmphys_init_microphysics.F
mpas_atmphys_interface.F
mpas_atmphys_landuse.F
mpas_atmphys_lsm_noahinit.F
mpas_atmphys_lsm_noahmpfinalize.F
mpas_atmphys_lsm_noahmpinit.F
mpas_atmphys_lsm_shared.F
mpas_atmphys_manager.F
mpas_atmphys_o3climatology.F
mpas_atmphys_packages.F
mpas_atmphys_rrtmg_lwinit.F
mpas_atmphys_rrtmg_swinit.F
mpas_atmphys_sfc_diagnostics.F
mpas_atmphys_todynamics.F
mpas_atmphys_update.F
mpas_atmphys_update_surface.F
mpas_atmphys_utilities.F
mpas_atmphys_vars.F
physics_noahmp/
physics_wrf/
Registry_noahmp.xml
physics_mmm/
physics_noaa/UGWP
```

initialization of different physics schemes

physics modules

directories appear after compilation

Physics computational cost estimates



You can make these pie charts yourself! See the end of the `log.atmosphere.0000.out` file.

Physics computational cost estimates

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log.atmosphere.0000.out

```
************************************************************
   Finished running the atmosphere core
************************************************************

 Timer information:
    Globals are computed across all threads and processors

 Columns:
    total time: Global max of accumulated time spent in timer
    calls: Total number of times this timer was started / stopped.
    min: Global min of time spent in a single start / stop
    max: Global max of time spent in a single start / stop
    avg: Global max of average time spent in a single start / stop
    pct_tot: Percent of the timer at level 1
    pct_par: Percent of the parent timer (one level up)
    par_eff: Parallel efficiency, global average total time / global max total time


   timer_name                                    total       calls        min            max            avg        pct_tot    pct_par     par_eff
 1 total time                                  134.23737       1      134.22641      134.23737      134.22977    100.00       0.00        1.00
 2  initialize                                   7.23004       1        7.19965        7.23004        7.20398      5.39       5.39        1.00
    [ ... ]
 2  time integration                            88.12379     720        0.07422        0.33574        0.12206     65.65      65.65        1.00
 3   physics driver                             32.06623     720        0.00339        0.23973        0.02964     23.89      36.39        0.67
    [ ... ]
 3   physics_get_tend                           12.24263     720        0.00055        0.15910        0.00573      9.12      13.89        0.34
    [ ... ]
 3   atm_advance_scalars_mono                    3.93824     720        0.00354        0.01047        0.00478      2.93       4.47        0.87
 3   microphysics                                7.72630     720        0.00499        0.04717        0.00894      5.76       8.77        0.83
 4    mp_wsm6                                    6.80256     720        0.00374        0.01431        0.00762      5.07      88.04        0.81
```

Physics computational cost estimates

log.atmosphere.0000.out

```
 *************************************************************
    Finished running the atmosphere core
 *************************************************************

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     calls: Total number of times this timer was started / stopped.
     min: Global min of time spent in a single start / stop
     max: Global max of time spent in a single start / stop
     avg: Global max of average time spent in a single start / stop
     pct_tot: Percent of the timer at level 1
     pct_par: Percent of the parent timer (one level up)
     par_eff: Parallel efficiency, global average total time / global max total time
```

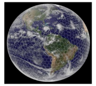
	timer_name	total	calls	min	max	avg	pct_tot	pct_par	par_eff
1	total time	149.84329	1	149.83255	149.84329	149.83759	100.00	0.00	1.00
2	initialize	8.99379	1	8.98116	8.99379	8.98554	6.00	6.00	1.00
	[...]								
2	time integration	102.07790	720	0.09291	0.34305	0.14143	68.12	68.12	1.00
3	physics driver	32.70108	720	0.00345	0.23641	0.03004	21.82	32.04	0.66
	[...]								
3	physics_get_tend	12.62386	720	0.00059	0.14702	0.00595	8.42	12.37	0.34
	[...]								
3	atm_advance_scalars_mono	5.22112	720	0.00531	0.01178	0.00658	3.48	5.11	0.91
3	microphysics	18.14388	720	0.00379	0.09364	0.01750	12.11	17.77	0.69
4	mp_thompson	17.14138	720	0.00287	0.03900	0.01631	11.44	94.47	0.68

Additional Resources

For references to various physics schemes and detailed physics talks:

1. https://www2.mmm.ucar.edu/wrf/users/physics/phys_references.html
2. https://www2.mmm.ucar.edu/wrf/users/tutorial/tutorial.html

Chapter 6 and Appendix B.12 in the User's Guide



MPAS Atmosphere

Appendix B: Model Namelist Options

Documentation
- Overview of MPAS-A
- Users' Guide
  - Foreword
  - 1. MPAS Overview
  - 2. Quick Start Guide
  - 3. Building MPAS
  - 4. Preparing Meshes
  - Configuring I/O
  - 6. Physics Suites
  - Running MPAS-A
  - 8. Model Options
  - 9. Visualization
  - App.A: Init. Namelist
  - App.B: Model Namelist

B.12 physics

input_soil_data (character)

Units	
Description	Input soil use classification *(hidden by default)*
Possible Values	

input_soil_temperature_lab (integer)

Units	
Description	Days over which the deep soil temperature is computed using skin temperature *(hidden by default)*
Possible Values	Positive integers *(default: 140)*

num_soil_layers (integer)

Units	
Description	Number of soil layers in Noah land surface scheme *(hidden by default)*
Possible Values	Positive integers; for Noah LSM, must be set to 4 *(default: 4)*

months (integer)

Units	
Description	Number of months per year *(hidden by default)*
Possible Values	Positive integer values; DO NOT CHANGE *(default: 12)*

src/core_atmosphere/Registry.xml

```xml
<nml_option name="config_bucket_update" type="character" default_value="none"
     units="-"
     description="time interval between updates of accumulated rain and radiation diagnostics"
     possible_values="`DD_HH:MM:SS' or `none'"/>

<nml_option name="config_physics_suite" type="character" default_value="mesoscale_reference" in_defaults="true"
     units="-"
     description="Choice of physics suite"
     possible_values="`mesoscale_reference',`convection_permitting',`none'"/>

<nml_option name="config_microp_scheme" type="character" default_value="suite" in_defaults="false"
     units="-"
     description="configuration for cloud microphysics schemes"
     possible_values="`suite',`mp_wsm6',`mp_thompson',`mp_thompson_aerosols', `mp_kessler',`off'"/>

<nml_option name="config_convection_scheme" type="character" default_value="suite" in_defaults="false"
     units="-"
     description="configuration for convection schemes"
     possible_values="`suite',`cu_kain_fritsch',`cu_tiedtke',`cu_ntiedtke',`cu_grell_freitas',`off'"/>

<nml_option name="config_lsm_scheme" type="character" default_value="suite" in_defaults="false"
     units="-"
     description="configuration for land-surface schemes"
     possible_values="`suite',`sf_noah',`sf_noahmp`, `off'"/>

<nml_option name="config_pbl_scheme" type="character" default_value="suite" in_defaults="false"
     units="-"
     description="configuration for planetary boundary layer schemes"
     possible_values="`suite',`bl_ysu',`bl_mynn',`off'"/>

<nml_option name="config_gwdo_scheme" type="character" default_value="suite" in_defaults="false"
     units="-"
     description="configuration of gravity wave drag over orography"
     possible_values="`suite',`bl_ysu_gwdo',`bl_ugwp_gwdo',`off'"/>

<nml_option name="config_ngw_scheme" type="logical" default_value="false" in_defaults="false"
     units="-"
     description="logical for non-stationary gravity wave drag scheme"
     possible_values=".true. or .false."/>

<nml_option name="config_knob_ugwp_tauamp" type="real" default_value="0.13e-3" in_defaults="false"
     units="-"
     description="non-stationary gravity wave drag absolute momentum flux at launch level"
     possible_values="Non-negative real values"/>
```

We expect more physics options to become available in MPAS-A along with new developments contributed from the community.