MPAS
Model for Prediction Across Scales

Physics and Physics Configuration in MPAS

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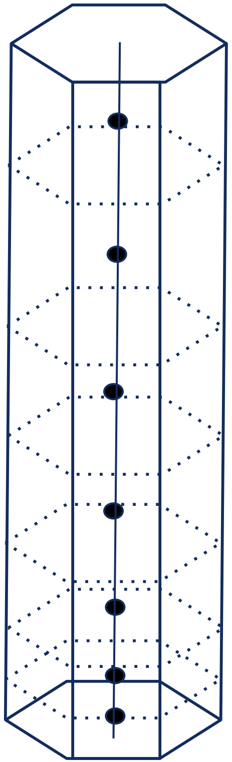
MPAS-A Tutorial 2026

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



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Coupling of physics with dynamics in MPAS-A

MPAS driver

0. CALL physics initialization

registry

Each model time step

1. 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).

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- Deep and shallow convection schemes

2. ADD physics tendencies to dynamics as forcing terms

Includes:
- *reconstruction of horizontal winds*
- *coupling to dry air mass*

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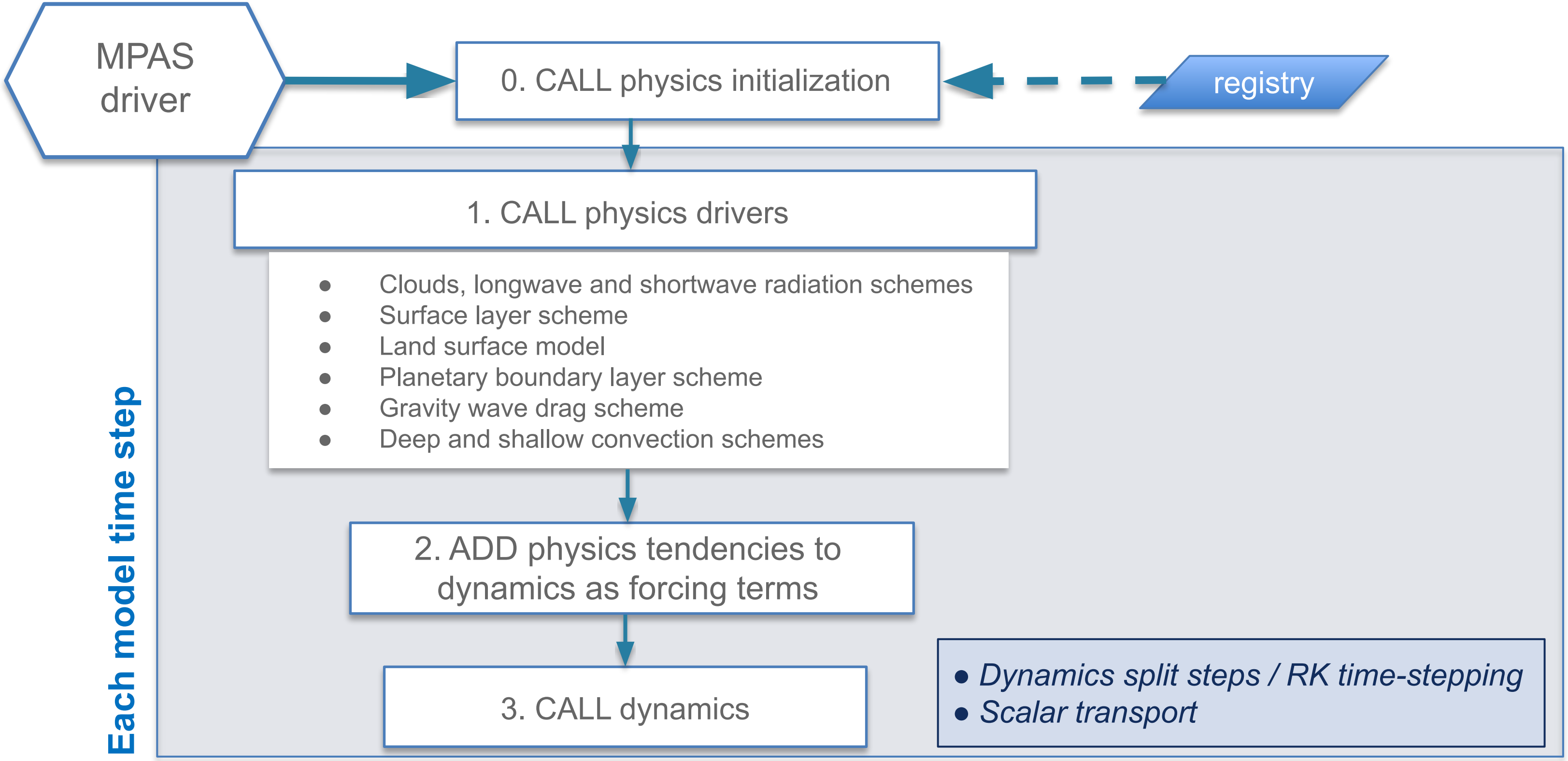
Coupling of physics with dynamics in MPAS-A



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- Deep and shallow convection schemes

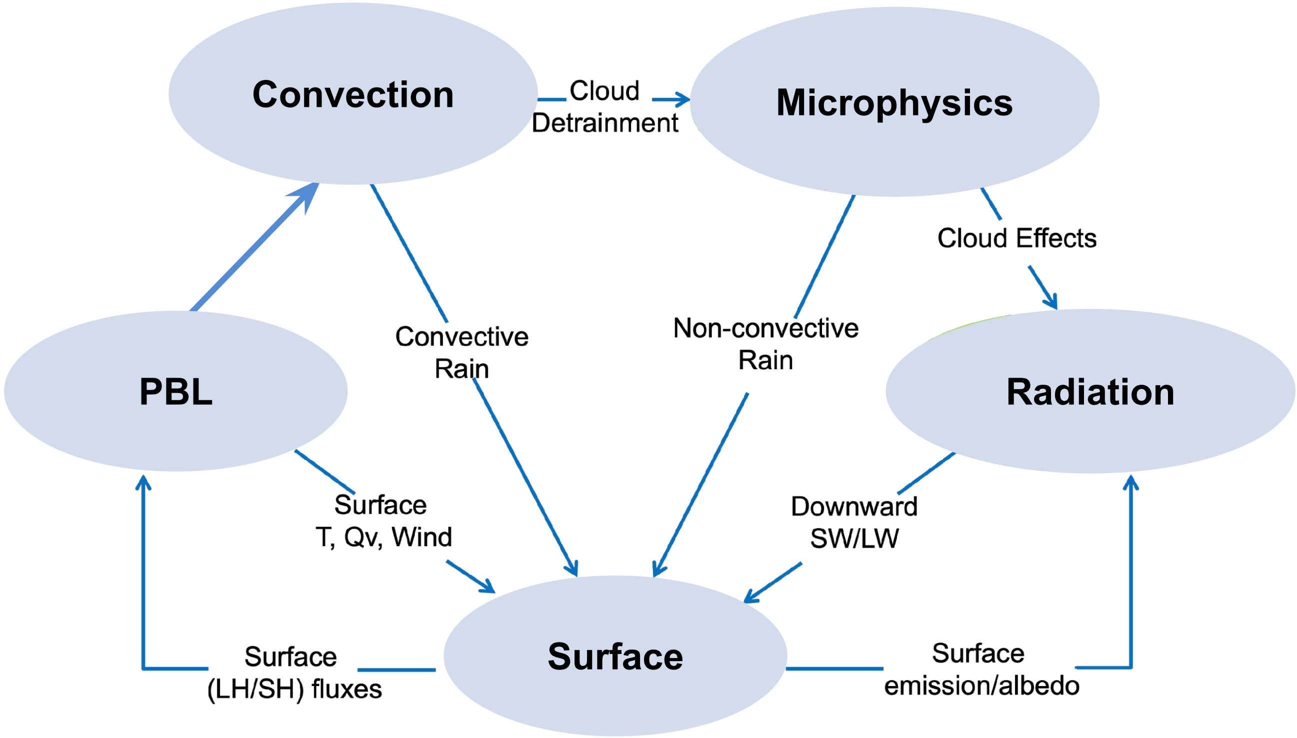
2. ADD physics tendencies to dynamics as forcing terms

3. CALL dynamics

4. CALL microphysics (after dynamics)

- *Includes saturation adjustment*

Direct Interactions among Model Physics



Convection schemes

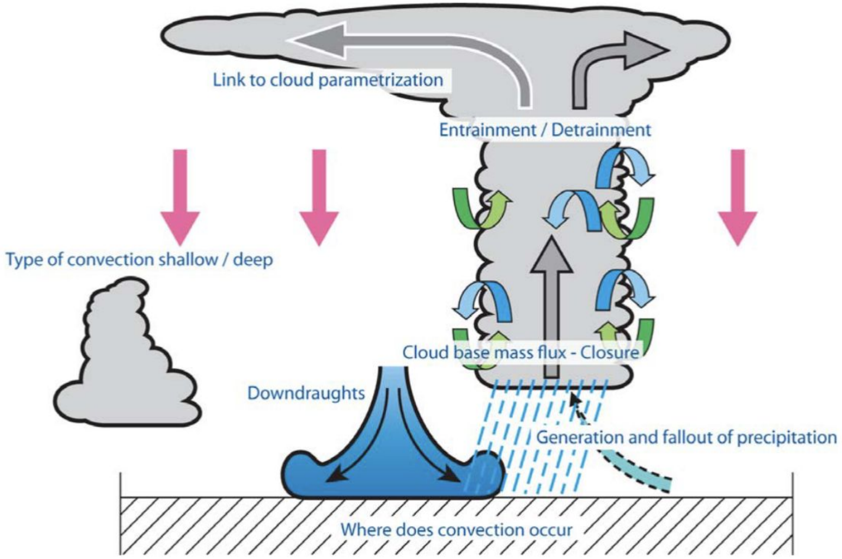


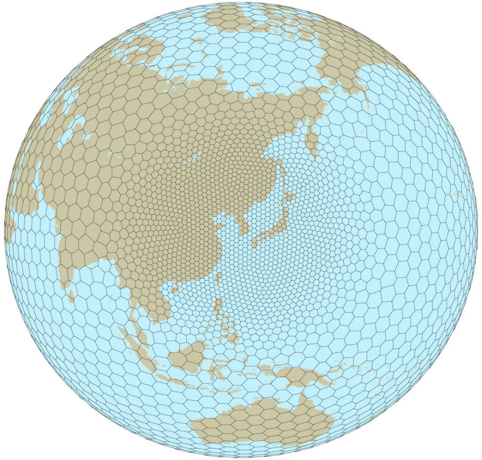
Figure 3. Schematic of a bulk convection scheme with a shallow and deep entraining/detraining cloudy ascending plume, and downdraught region. Further represented features are trigger of convection, environmental subsidence, microphysics and precipitation, and detrainment of cloud mass in anvils.

From Bechtold 2008: Seminar on Parameterization of Subgrid Physical Processes

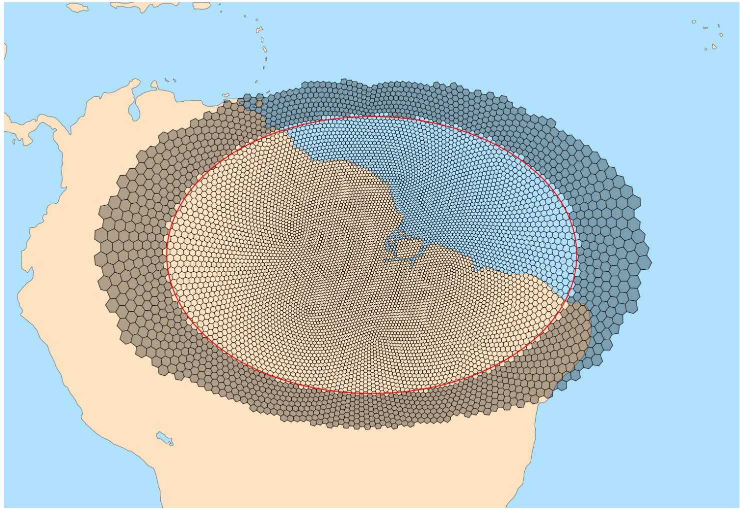
- A convection or cumulus scheme parameterizes the ensemble effect of convective transport of heat, moisture (and momentum) on the grid scale
- Particularly important at mesh spacing, Δ > 10 km, when updrafts are too small to be explicitly resolved
- At Δ < 4 km, numerous studies have shown that simulations are more realistic when the convection scheme is turned off.
- Available schemes:
  - Grell-Freitas (scale-aware)
  - Kain-Fritsch
  - New Tiedtke (scale-aware)
  - Tiedtke

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

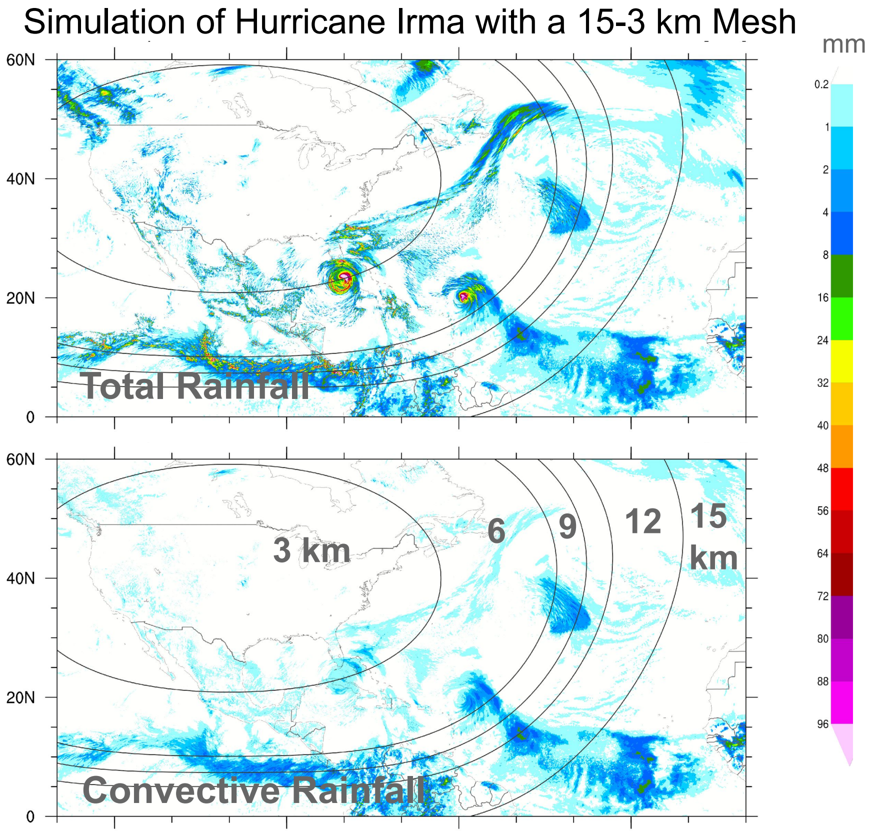


regional

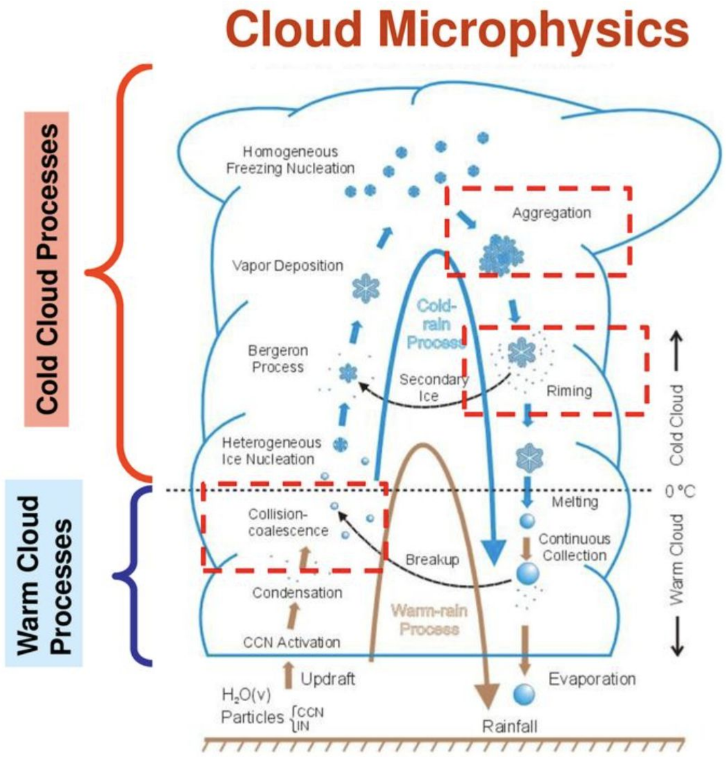
Scale-aware convection schemes

- ‘Scale-awareness’ is noticeable starting from ~15 km mesh spacing

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



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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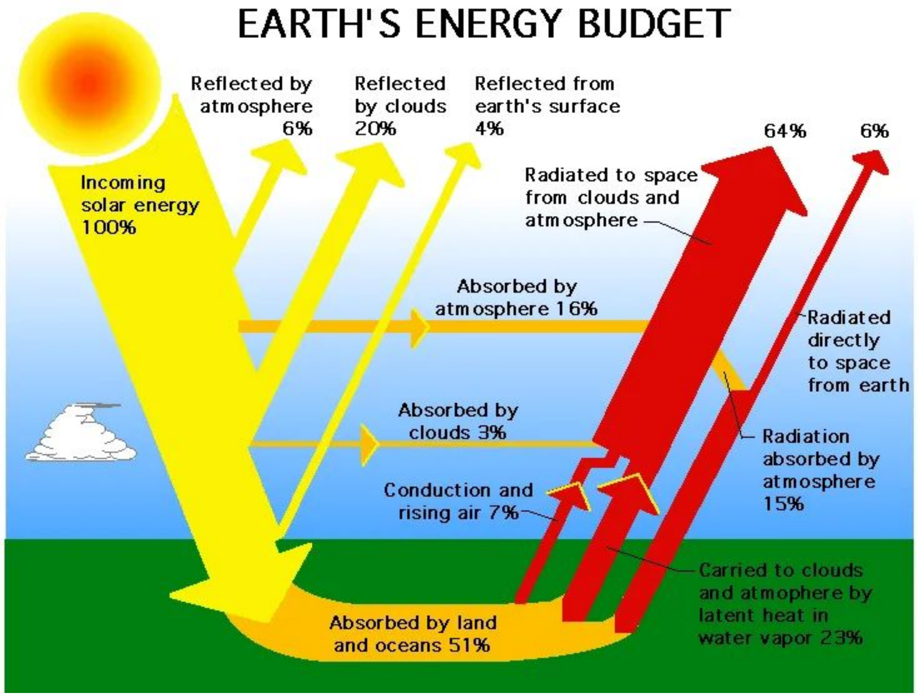
Radiation schemes



(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

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
```

Horizontal cloud fraction

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

Cloud overlap assumptions and decorrelation lengths

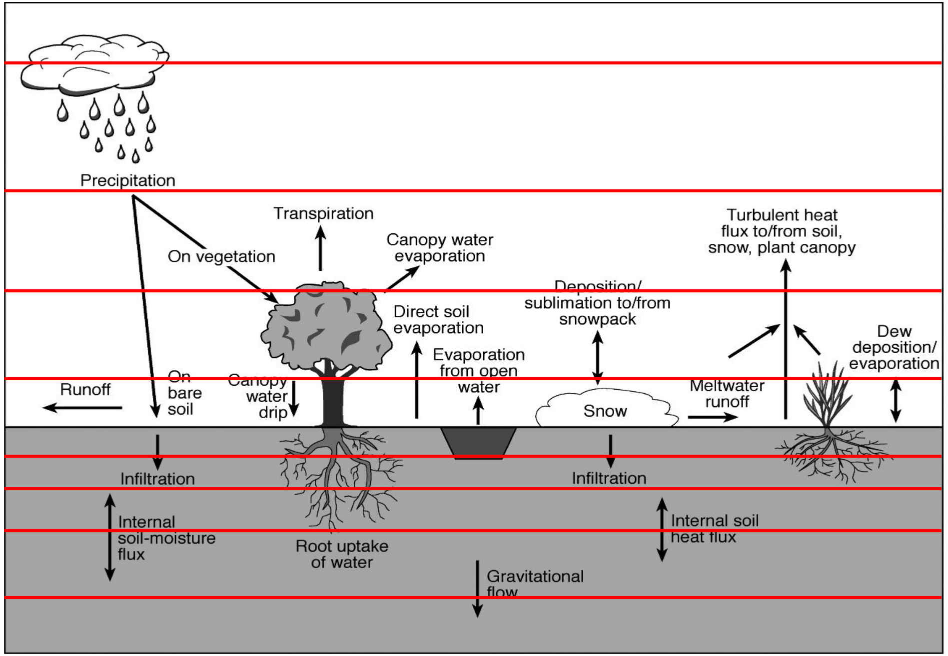
- New options in V8.3.0: exponential and exponential_random cloud overlap assumptions

```
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)



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Land Surface Models

Default options are underlined.

Options in `namelist.init_atmosphere`

Types of static data:

- 3 land use datasets: USGS 30'', <u>MODIS 30''</u>, and MODIS 15''
- 2 soil category databases: <u>STATSGO</u>, or BNU 30'' (Beijing Normal University)
- 2 topography datasets: GTOPO30 (30'') or <u>GMTED2010</u>
- 2 climatological monthly datasets for vegetation fraction, surface albedo, and snow albedo datasets from either <u>MODIS</u> or NCEP
- Options to supersample static data for real-data simulations with $\Delta < 1$ km:
  - `config_30s_supersample_factor` (for terrain, soilcat, monthly climatologies)
  - `config_supersample_factor` (for surface and snow albedo)
  - `config_lu_supersample_factor` (for land use data)

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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:

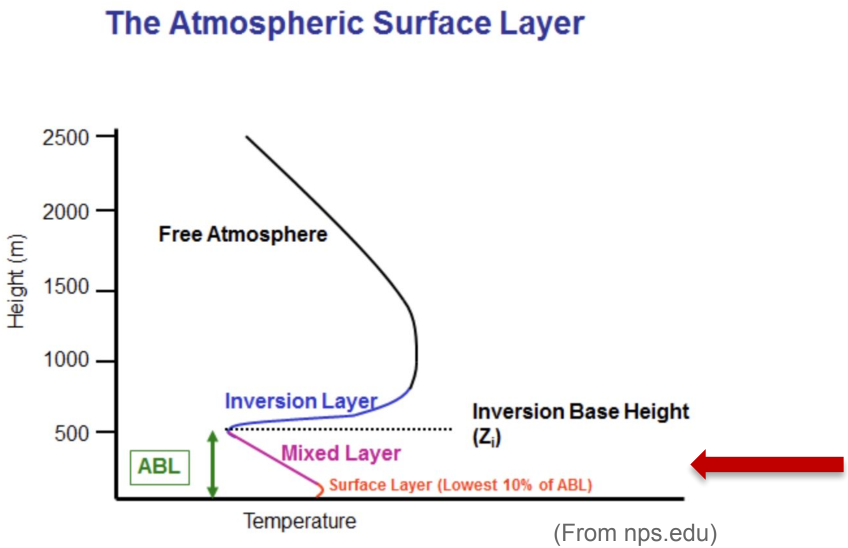
```
config_noahmp_static = true (default value)
```

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
```

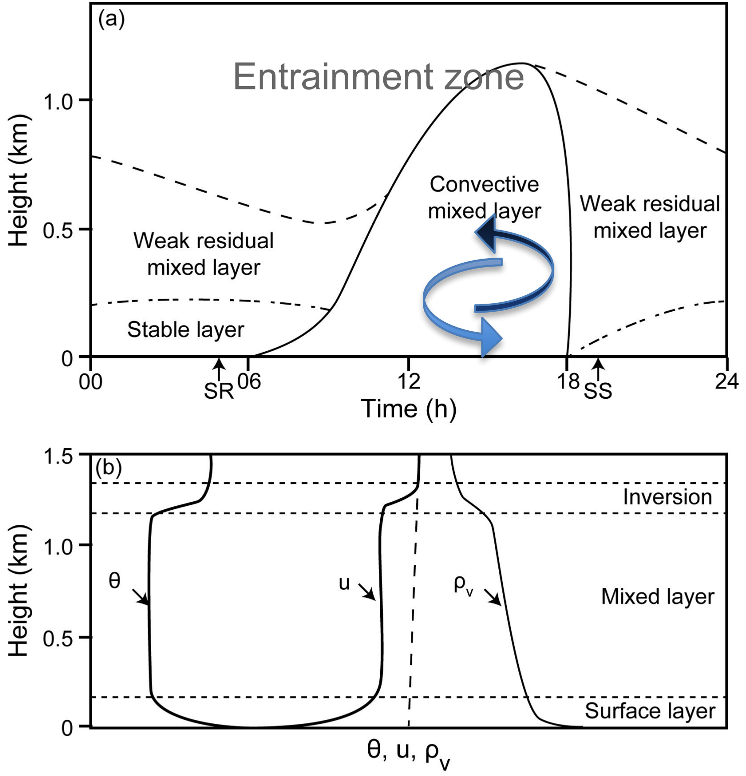
Surface Layer Schemes



(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

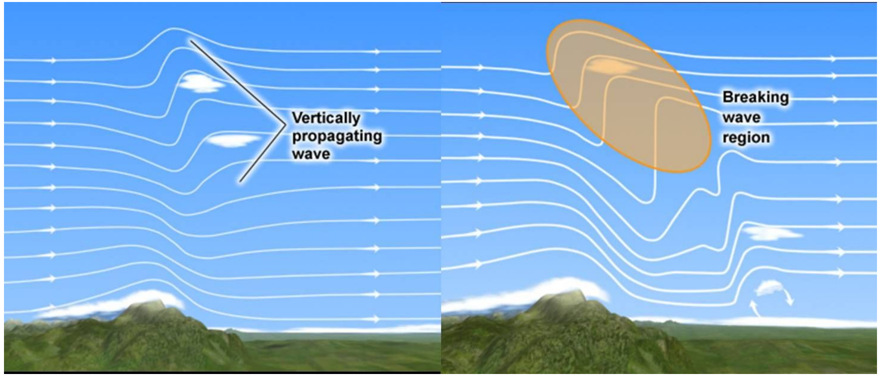


- A PBL scheme parameterizes the vertical transport of momentum, heat and water vapor fluxes within the PBL and represents turbulent mixing above the BL.
- Types: local (e.g., MYNN), non-local (e.g. YSU and mass-flux schemes, such as MYNN-EDMF)
- Available schemes:
  - MYNN
  - YSU
- Radiation-driven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

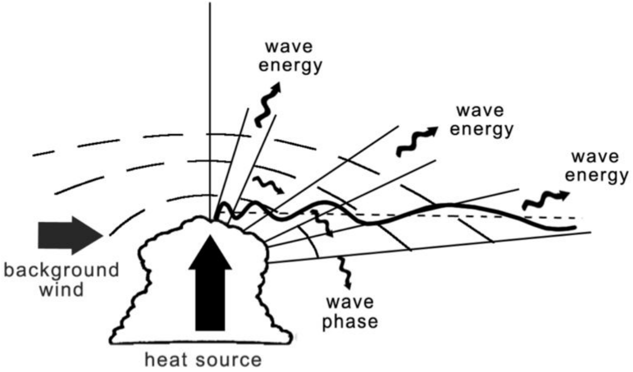
```
config_ysu_pblmix = true (default = false)
config_mynn_topdown = 1 (default = 0)
```

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
    config_ugwp_diags = true
    ```

  - To use the UGWP <u>non-stationary</u> gravity wave drag scheme, requires additional input file:

    Lookup table `ugwp_limb_tau.nc`

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Physics Schemes in MPAS-A V8.3.1

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 v8.3.1

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'

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Physics Specification using Suites

Physics Suites	Options
'mesoscale_reference'	RRTMG, Xu-Randall cloud fraction, Noah LSM, YSU PBL, Revised MM5 sfc layer, new Tiedtke, WSM6, GWDO
'convection_permitting'	RRTMG, Xu-Randall cloud fraction, Noah LSM, MYNN PBL, MYNN sfc layer, Grell-Freitas, Thompson, 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 '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'
/
```

See Chapter 6 and Appendix B.11 in the User's Guide

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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 ‘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'
/
```

See Chapter 6 and Appendix B.11 in the User’s Guide

Configuring physics options

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

```
config_convection_scheme = 'off'
```

Can replace one or more options in a suite:

```
config_physics_suite       = ‘convection_permitting'
config_convection_scheme = 'cu_ntiedtke'
```

Configuring physics options

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Along with these physics options, also consider the following – all 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

See Chapter 6 and Appendix B.11 in the User's Guide

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Physics Data Files in MPAS v8.3.1

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
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***
GENPARM.TBL LANDUSE.TBL SOILPARM.TBL VEGPARM.TBL	Noah LSM
NoahmpTable.TBL	NoahMP LSM

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Physics Code Structure in V8.3.1

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
```

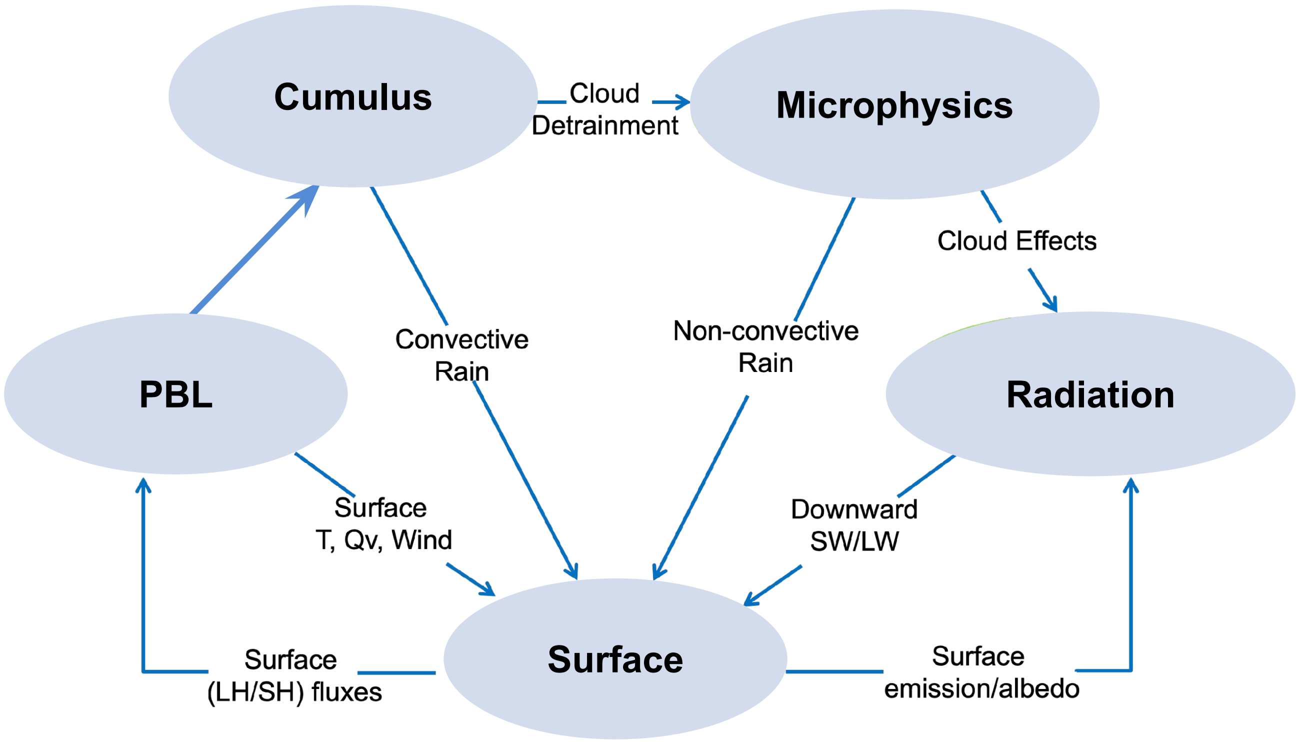
```
mpas_atmphys_initialize_real.F
mpas_atmphys_init_microphysics.F
mpas_atmphys_interface.F
mpas_atmphys_landuse.F
mpas_atmphys_lsm_noahinit.F
mpas_atmphys_lsm_noahmpfinalize.F
mpas_atmphys_lsm_noahmpinit.F
mpas_atmphys_lsm_shared.F
mpas_atmphys_manager.F
mpas_atmphys_o3climatology.F
mpas_atmphys_packages.F
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

MPAS-A Physics



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

See Chapter 6 and Appendix B.11 in the User's Guide

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