Physics and Physics Configuration in MPAS

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MPAS-A Tutorial 2025

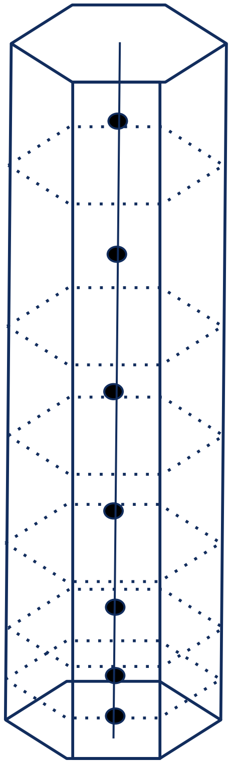
MPAS
Model for Prediction Across Scales

Physics Parameterizations

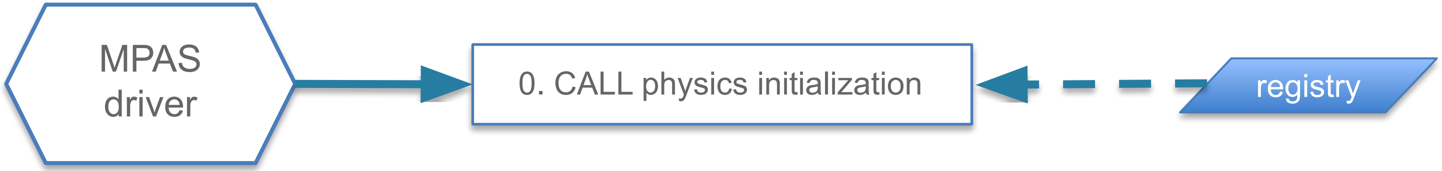
Parameterizations are used to describe the mean effect of subgrid-scale physical processes that feedback onto the model state in each cell volume.

Subgrid-scale representations typically depend on the prognostic variables:

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



Coupling of physics with dynamics in MPAS-A



- read and interpolate gridded lat-lon monthly-mean ozone climatology onto the MPAS mesh
- read input land use category
- read input tables needed for the land surface scheme
- read input tables needed for the long-wave and short-wave radiation schemes
- read input tables for the cloud microphysics schemes
- other initializations

Coupling of physics with dynamics in MPAS-A

MPAS driver

0. CALL physics initialization

registry

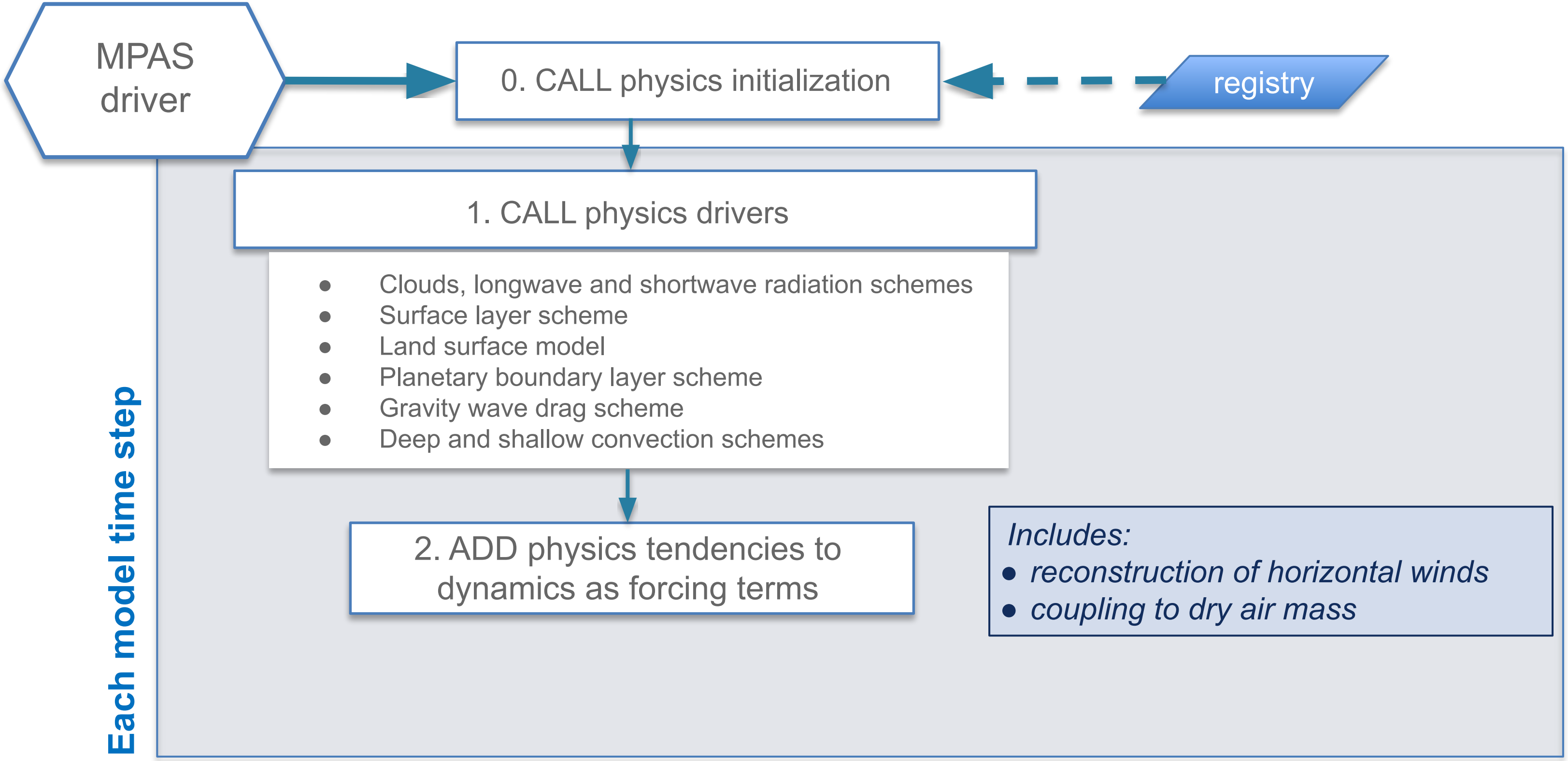
Each model time step

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).

Coupling of physics with dynamics in MPAS-A



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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

2. ADD physics tendencies to dynamics as forcing terms

3. CALL dynamics

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

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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

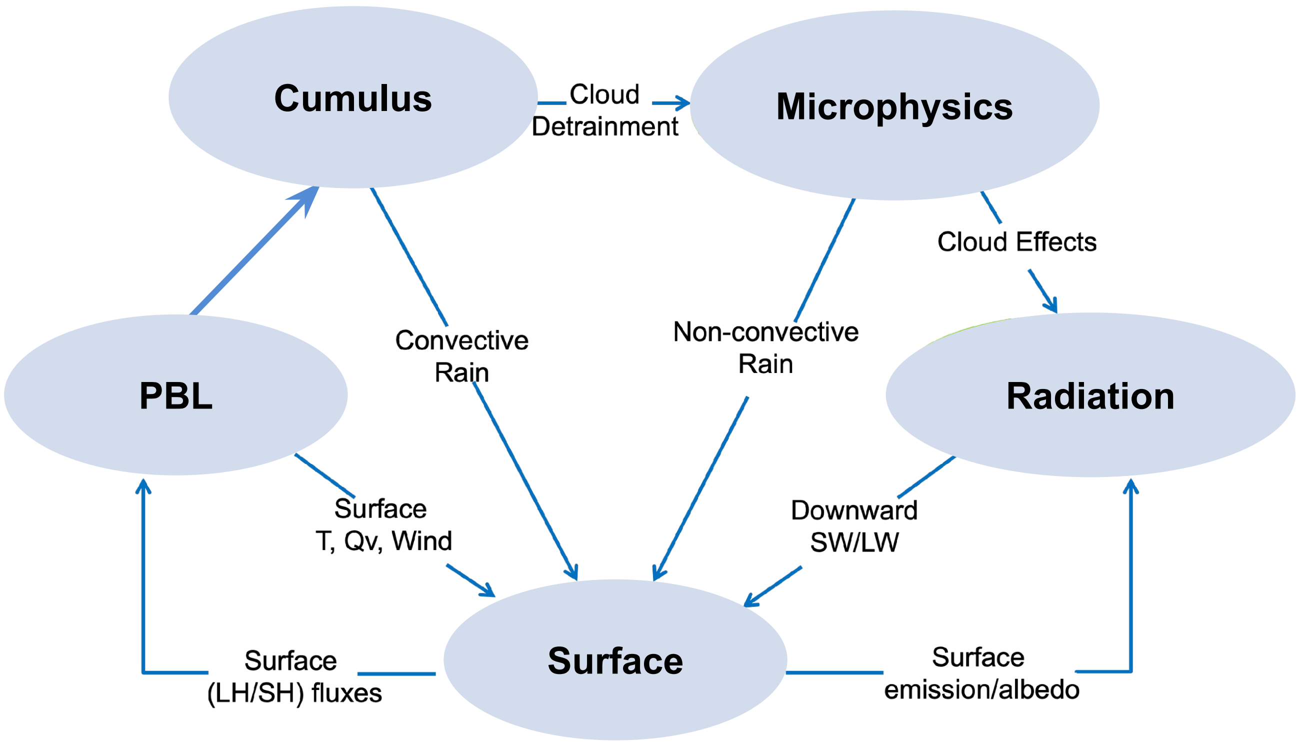
2. ADD physics tendencies to dynamics as forcing terms

3. CALL dynamics

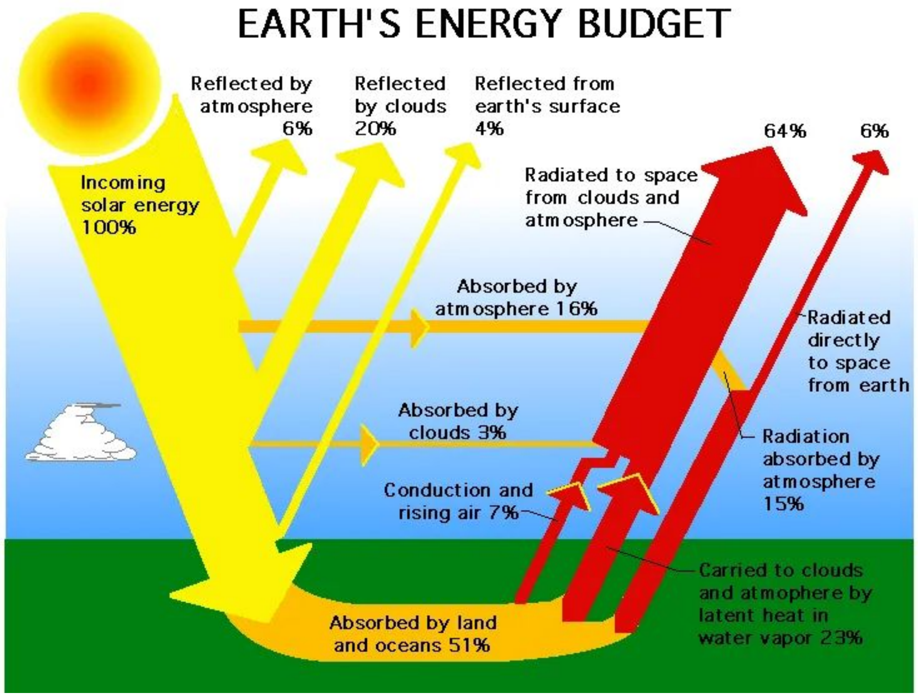
4. CALL microphysics (after dynamics)

- *Includes saturation adjustment*

Direct Interactions among Model Physics



Radiative Processes



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

Important heat exchange mechanisms in the atmosphere: absorption, scattering and reflection of both short- and longwave radiation by atmospheric constituents like trace gases, clouds, and aerosols.

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

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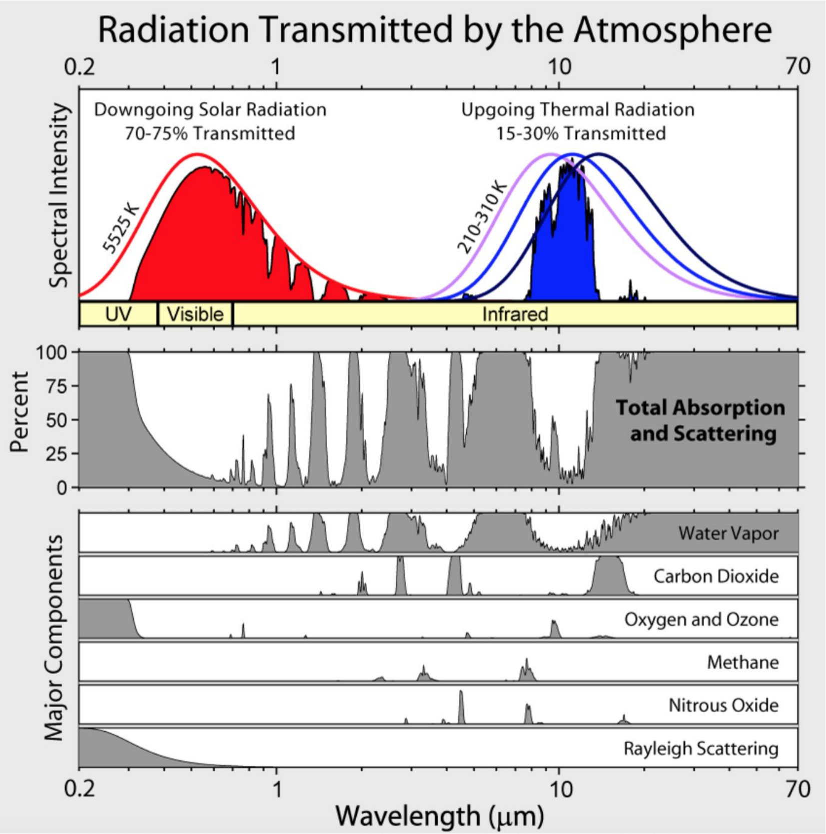
Radiative Processes

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

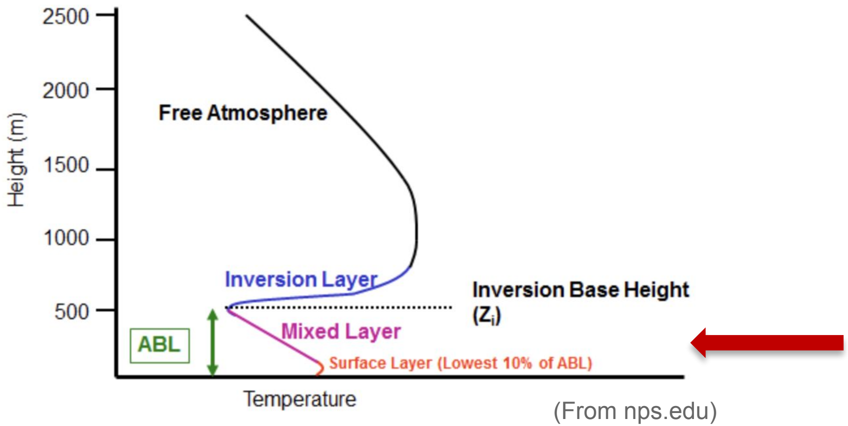
Surface emissivity based on land-type

Downward surface flux for land energy budget

IR cooling at cloud tops and warming at cloud base

Surface Layer Processes

The Atmospheric Surface Layer



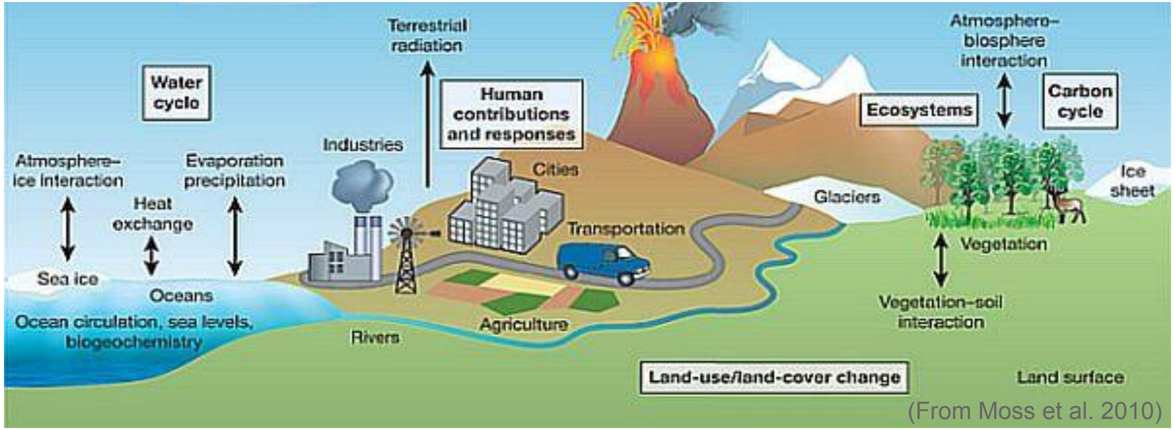
(From nps.edu)

- 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.
- 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.
- Diagnostics for 2-m temperature, water-vapor mixing ratio, and 10-m winds

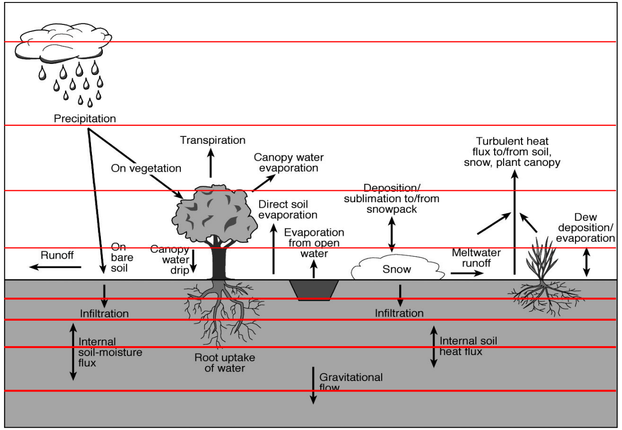
Model for Prediction Across Scales

Land Surface Processes

- Land surface physics are driven by radiative forcing and precipitation.
- A land surface model (LSM) considers processes like 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.
- Diagnostics for surface temperature and water vapor mixing ratio



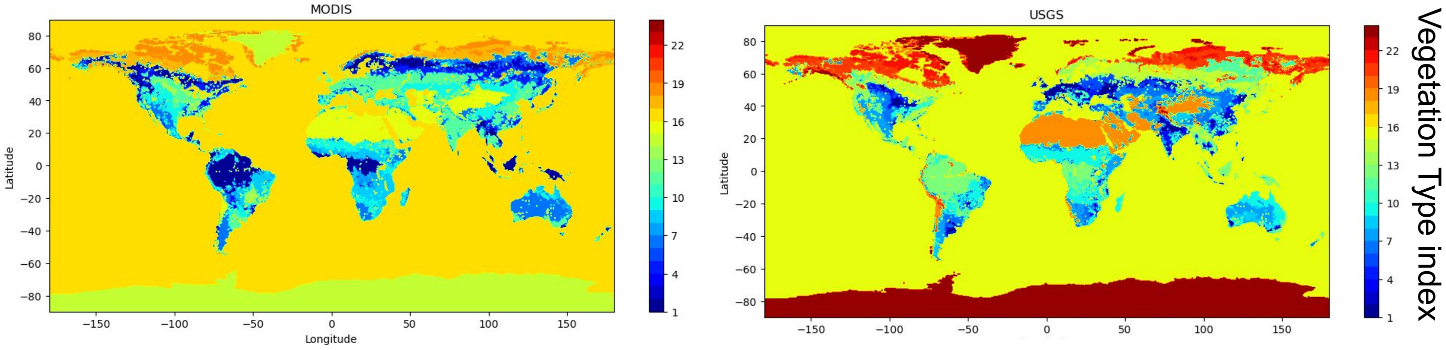
(From Moss et al. 2010)



Input Data

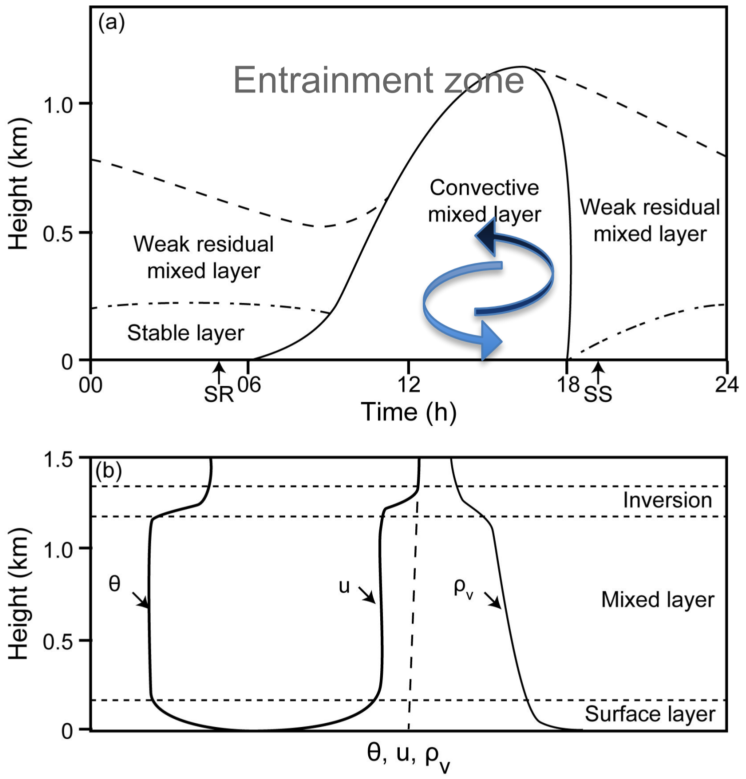
MODIS | **USGS**

Dominant vegetation category



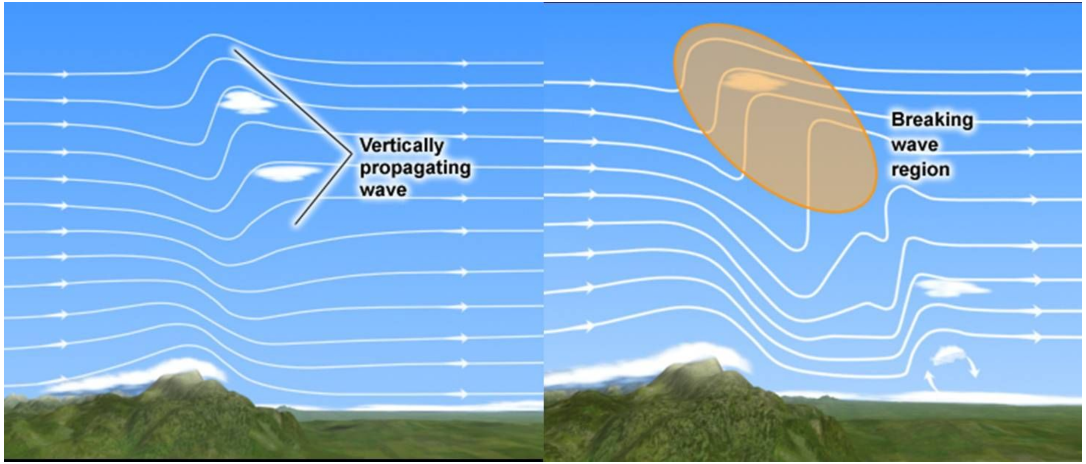
- Land use datasets: USGS (30 s), MODIS (30 s) and MODIS (15 s)
- Soil category databases: STATSGO or BNU (Beijing Normal University; 30 s)
- Types of topography datasets: GTOPO30 (30 s) or GMTED2010
- Climatological monthly vegetation fraction, surface albedo, and snow albedo datasets from MODIS or NCEP

Planetary Boundary Layer (PBL) Processes



- A PBL scheme parameterizes the vertical transport of momentum, heat and water vapor fluxes due to turbulent eddy diffusion.
- It distributes surface fluxes with boundary layer eddies, and grows PBL by entrainment.
- Daytime boundary layer: unstable, convective, well mixed in 1-3 km
- Nighttime boundary layer: usually stable, shallow, and mixing may be driven by shear.
- Types: local (e.g., MYNN), non-local (e.g. YSU and mass-flux schemes, such as MYNN-EDMF)

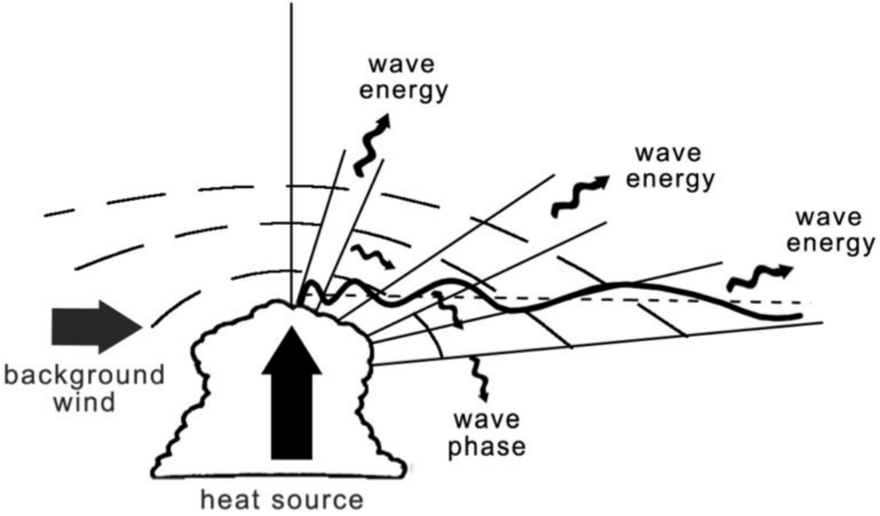
Orographic Gravity Wave Drag



- Vertically propagating waves excited by the topography may break under certain atmospheric conditions and exert a drag on the atmospheric flow. This needs to be represented in the model, especially when grid sizes are larger than 5 km.

- Low-level flow blocking effects are also parameterized.

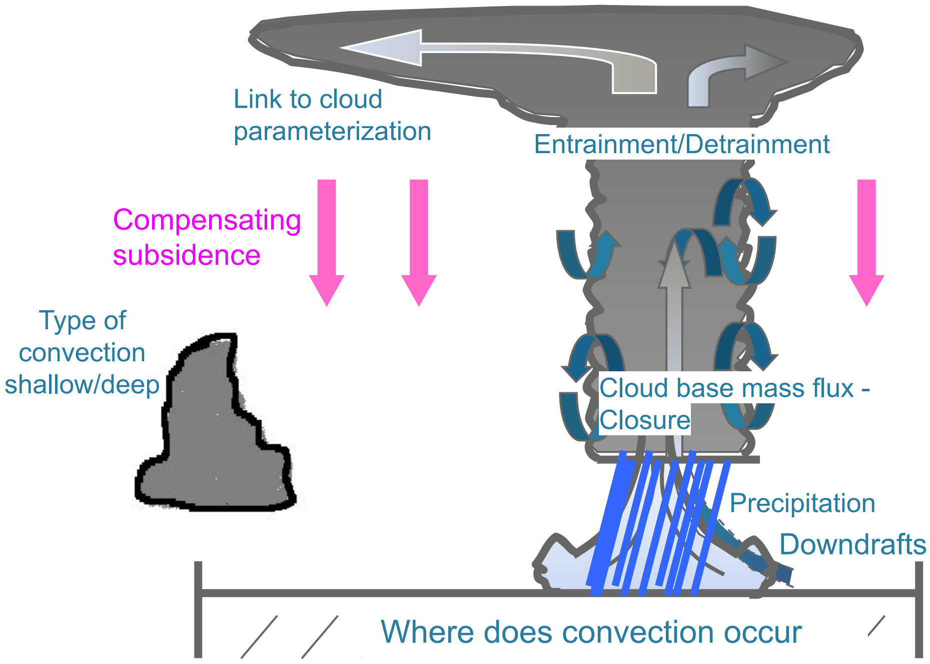
Nonstationary Gravity Wave Drag



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

Other non-orographic gravity waves dynamically induced by convection, frontogenesis and shear zones can also propagate vertically. Similar to orographic gravity waves, when wave breaking occurs, the impacts of the wave breaking and dissipation (drag) on the large-scale flow needs to be parameterized.

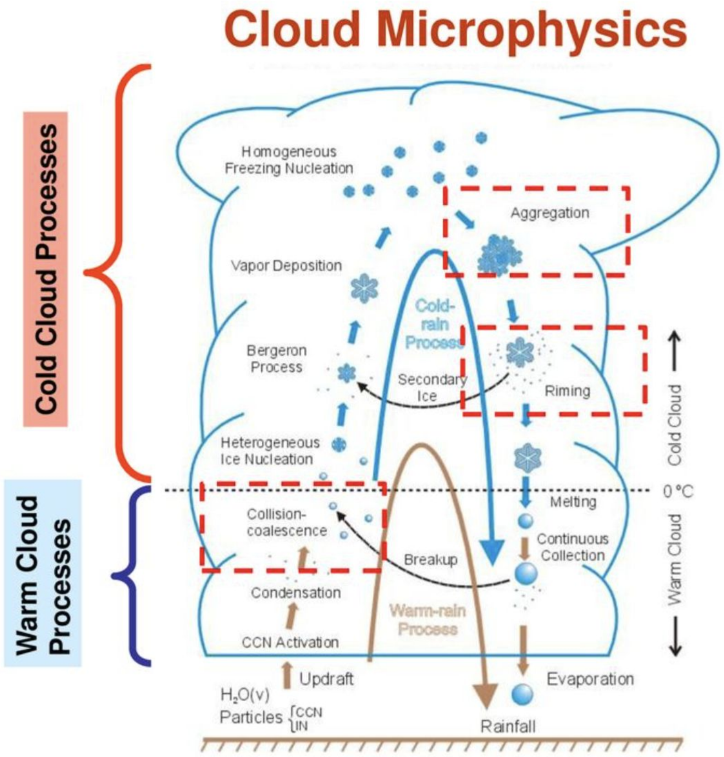
Cumulus Convection Processes



(From ECMWF)

- A convection or cumulus scheme parameterizes the convective transport of heat and moisture at the subgrid-scale and its warming/drying effect on the grid scale
- Includes both deep and shallow convection
- A scheme needs to determine where and when convection occurs and how strong it is.
- Cloud species can be detrained to grid scale.
- All cumulus schemes currently in MPAS are mass-flux type. Some schemes consider momentum transport. Some are scale-aware.

Microphysics



- Model detailed cloud physics. Considers latent heating processes like condensation, deposition, evaporation, collection, melting and freezing
- Hydrometeors: cloud water, cloud ice, rain water, snow, and graupel
- Also considers sedimentation
- Scheme complexity: single moment (like WSM6); partial double moment (like Thompson scheme).
- Clouds interact with radiation.
- Contributes to mass loading in dynamics

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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)
Convection	New Tiedtke, Grell-Freitas, Kain-Fritsch, Tiedtke
Ocean	1-D Ocean mixed layer
Gravity Wave Drag	GWDO (Choi & Hong), Unified Gravity Wave Drag (includes option for non-stationary gravity wave drag)

underlined: identical to those in the latest WRF release

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'

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

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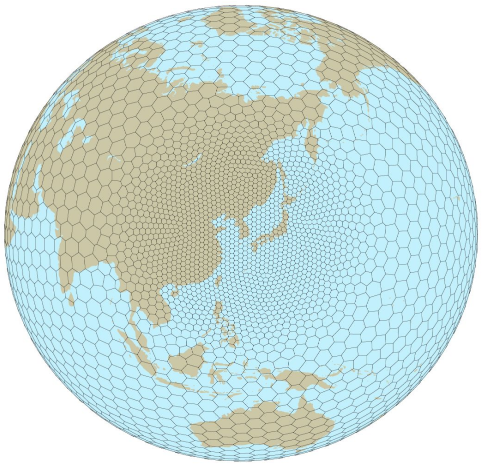
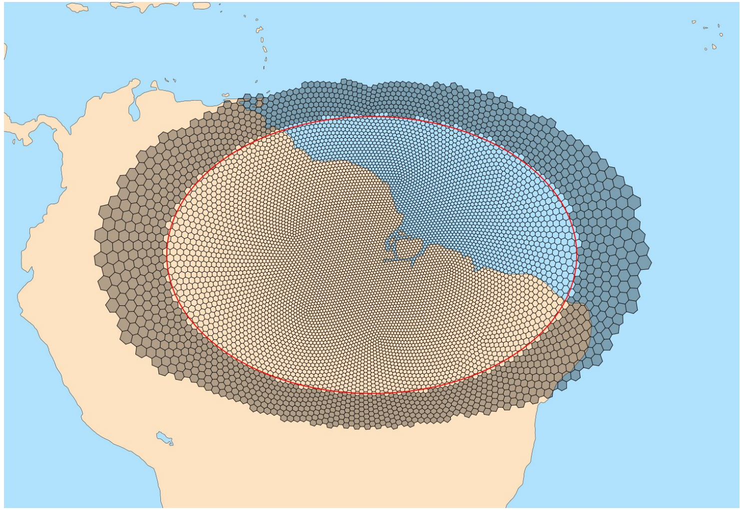
Special Note on Scale-Aware Convection Schemes

For variable-resolution applications with mesh spacings ranging from mesoscale to cloud-permitting scale, we need to consider using physics that are ‘scale-aware’.

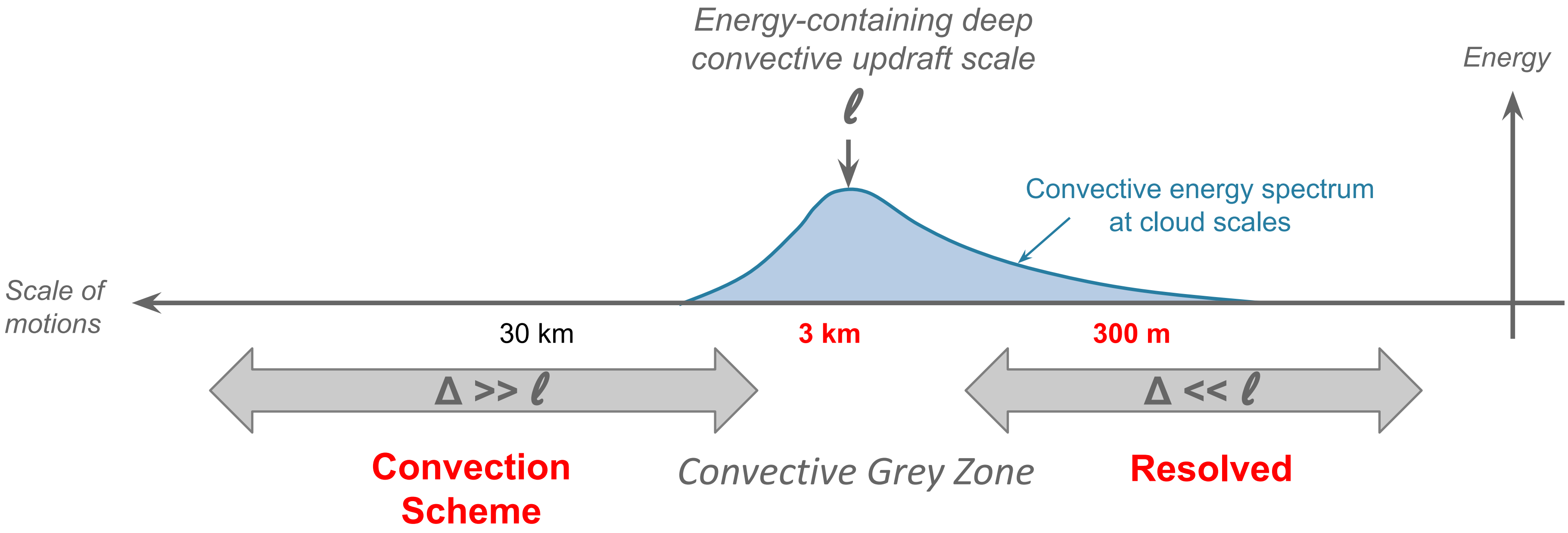


global



regional

Special Note on Scale-Aware Convection Schemes



A schematic showing the energy spectrum in the horizontal plane.

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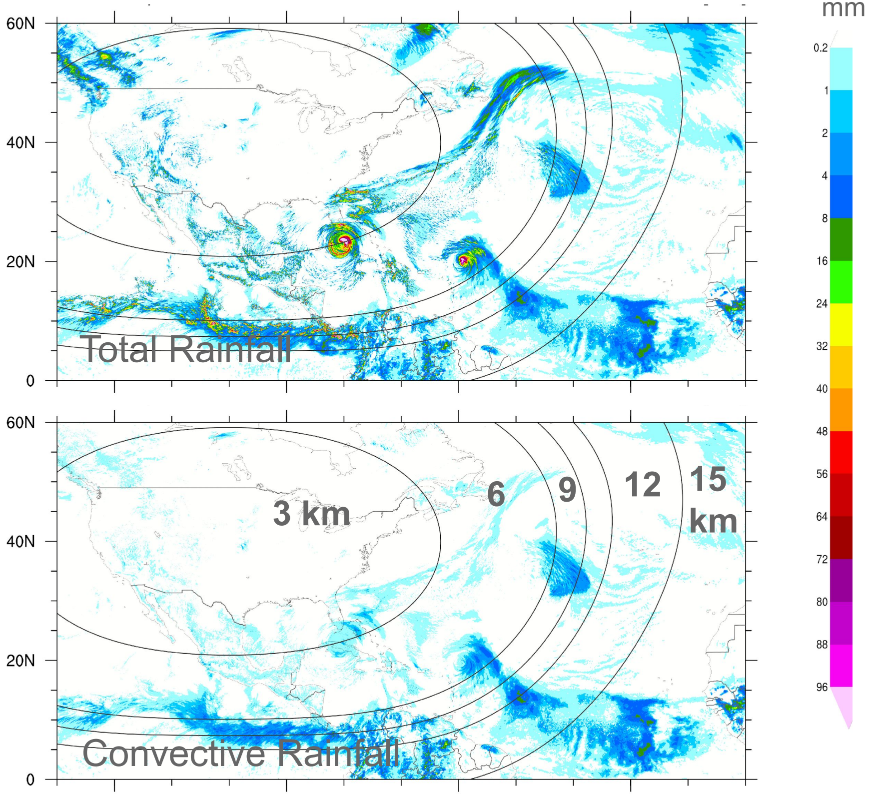
Special Note on Scale-Aware Convection Schemes

- For most variable-resolution applications with finest mesh spacing > 1 km
- ‘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.

Simulation of Hurricane Irma with a 15-3 km Mesh



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

Configuring physics options

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

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

Can replace one or more options in a suite:

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

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Configuring physics options

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

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

```
config_convection_scheme = 'off'
```

Configuring physics options

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

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

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

Physics Code Structure in V8.3.1

MPAS-Model/src/core_atmosphere/physics/physics_wrf

```
bl_mynn_post.F
bl_mynn_pre.F
cu_ntiedtke_post.F
cu_ntiedtke_pre.F
libmassv.F
LICENSE
Makefile
module_bep_bem_helper.F
module_bl_gwdo.F
module_bl_mynn.F
module_bl_ugwp_gwdo.F
module_bl_ysu.F
module_cam_error_function.F
module_cam_shr_kind_mod.F
module_cam_support.F
module_cu_gf.mpas.F
module_cu_kfeta.F
module_cu_ntiedtke.F
module_cu_tiedtke.F
module_mp_kessler.F
module_mp_radar.F
module_mp_thompson_aerosols.F
module_mp_thompson_cldfra3.F
module_mp_thompson.F
module_mp_wsm6.F
module_ra_cam.F
module_ra_cam_support.F
module_ra_rrtmg_lw.F
module_ra_rrtmg_sw_aerosols.F
module_ra_rrtmg_sw.F
module_ra_rrtmg_vinterp.F
module_sf_bem.F
module_sf_bep_bem.F
module_sf_bep.F
module_sf_mynn.F
module_sf_noahdrv.F
module_sf_noahlsm.F
module_sf_noahlsm_glacial_only.F
module_sf_noah_seaice_drv.F
module_sf_noah_seaice.F
module_sf_oml.F
module_sf_sfcdiags.F
module_sf_sfclay.F
module_sf_sfclayrev.F
module_sf_urban.F
sf_mynn_pre.F
sf_sfclayrev_pre.F
```

Physics Code Structure in V8.3.1

MPAS-Model/src/core_atmosphere/physics/physics_mmm

```
bl_gwdo.F90                  bl_ysu.mod                  mp_radar.F90              mynn_shared.o
bl_gwdo.mod                  bl_ysu.o                    mp_radar.mod              README.md
bl_gwdo.o                    cu_ntiedtke_common.mod      mp_radar.o                sf_mynn.F90
bl_mynn_common.mod           cu_ntiedtke.F90             mp_wsm6_effectRad.F90     sf_mynn.mod
bl_mynn.F90                  cu_ntiedtke.mod             mp_wsm6_effectrad.mod     sf_mynn.o
bl_mynn.mod                  cu_ntiedtke.o               mp_wsm6_effectRad.o       sf_sfclayrev.F90
bl_mynn.o                    LICENSE                     mp_wsm6.F90               sf_sfclayrev.mod
bl_mynn_subroutines.F90      Makefile.mpas               mp_wsm6.mod               sf_sfclayrev.o
bl_mynn_subroutines.mod      module_libmassv.F90         mp_wsm6.o
bl_mynn_subroutines.o        module_libmassv.mod         mynn_shared.F90
bl_ysu.F90                   module_libmassv.o           mynn_shared.mod
```

MPAS
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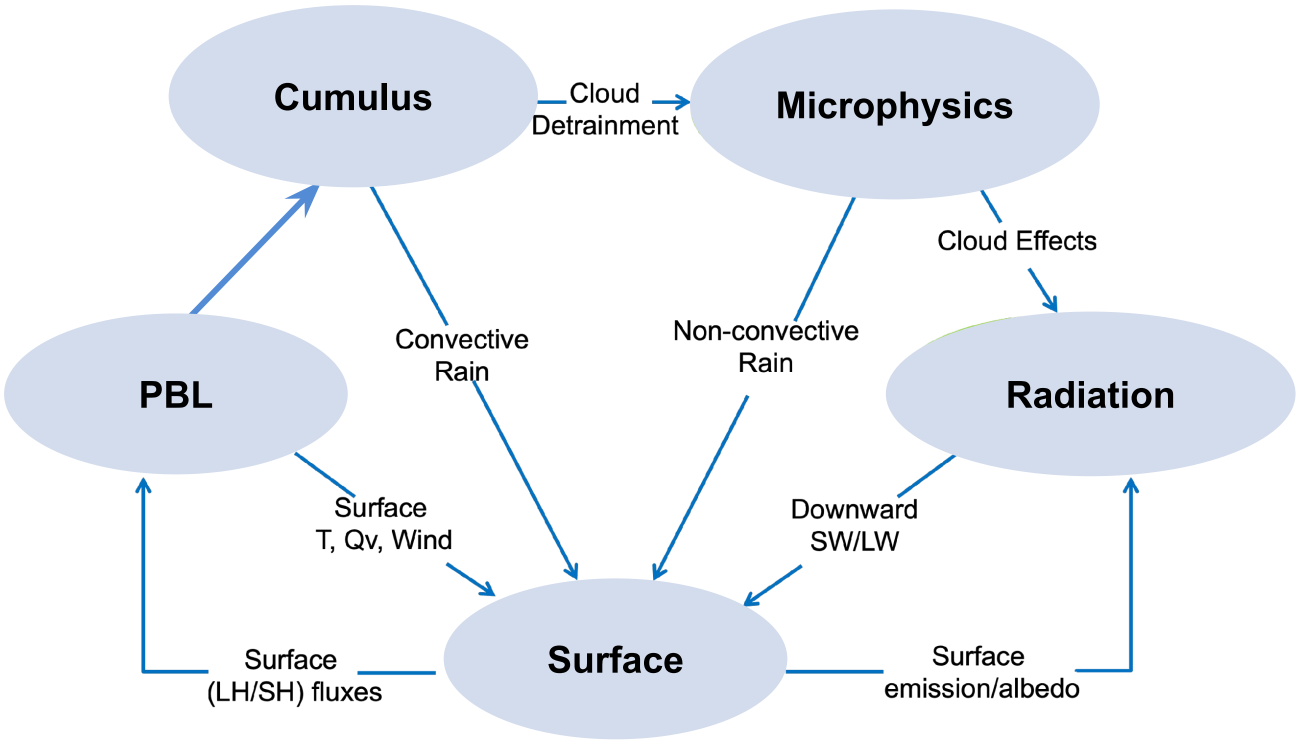
MPAS-A Physics



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.