MPAS
Model for Prediction Across Scales

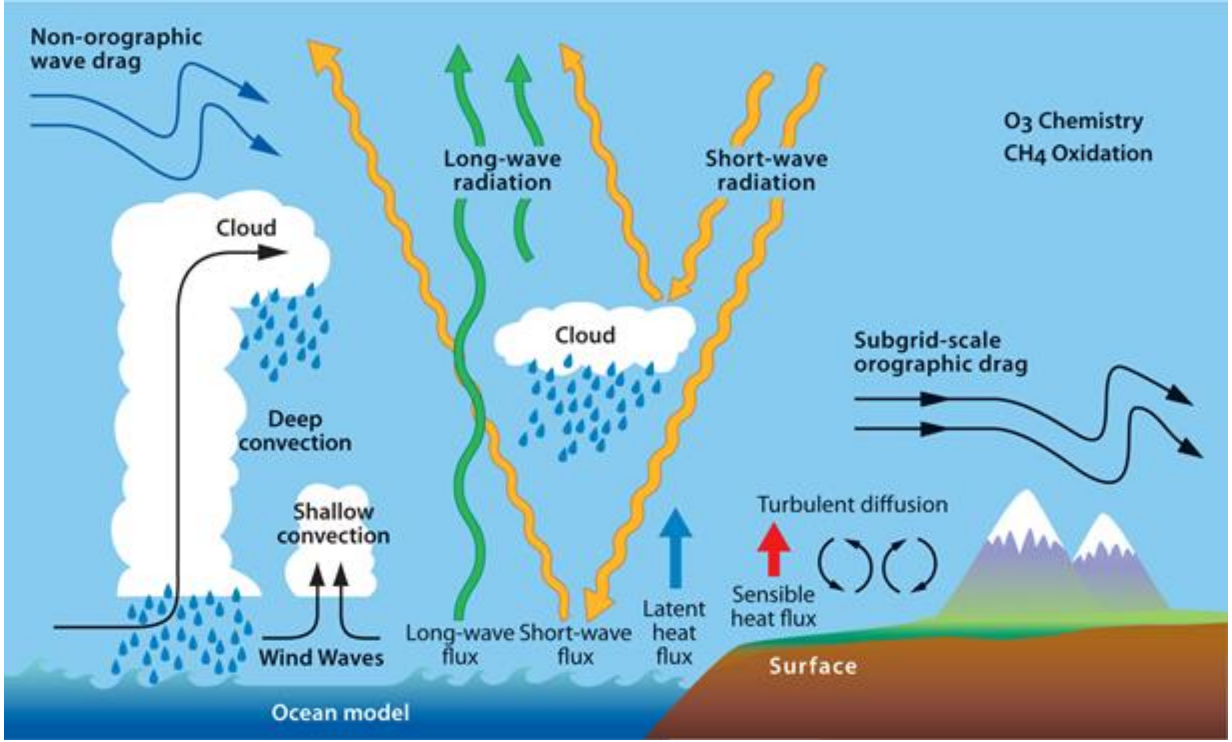
# Physics and Physics Configuration in MPAS

May Wong, Laura Fowler, Wei Wang and Jimy Dudhia

*NSF NCAR Microscale and Mesoscale Meteorology Laboratory*

MPAS-A Tutorial 2025

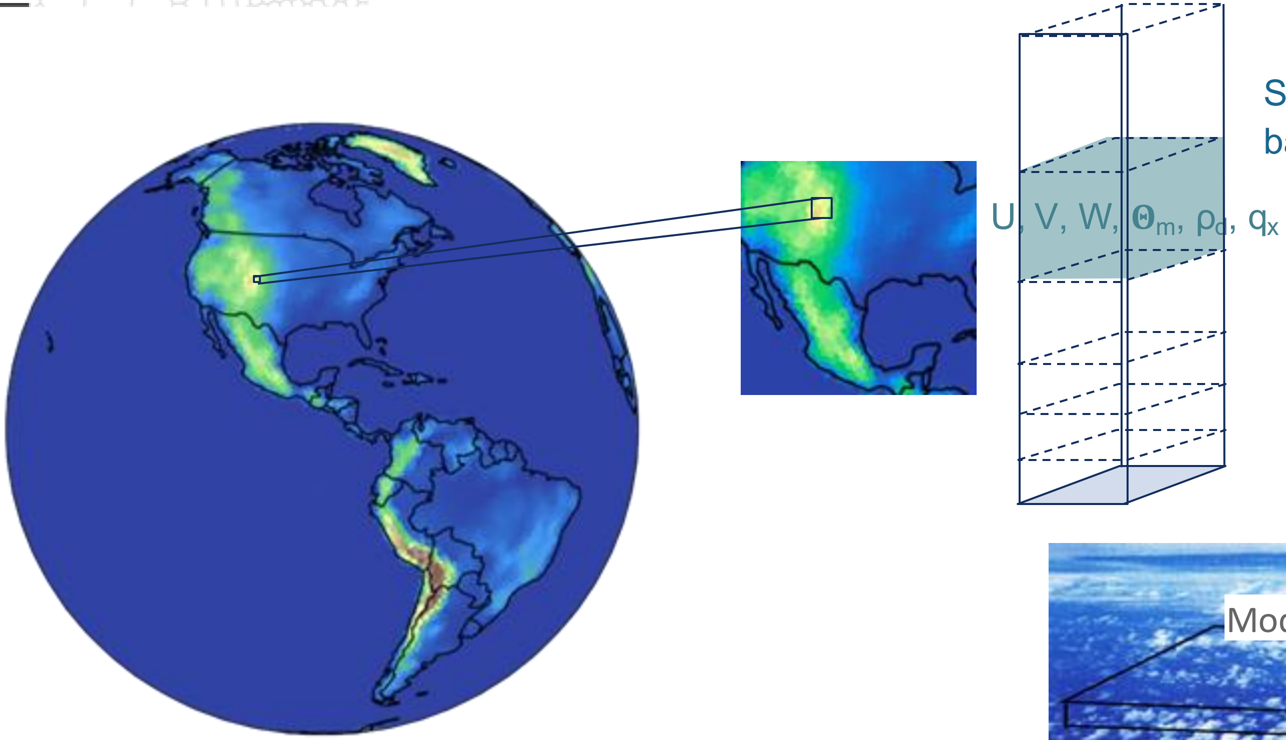
# Atmospheric Physical Processes




*(From ECMWF)*

MPAS
Model for Prediction Across Scales

# How are these physical processes represented?

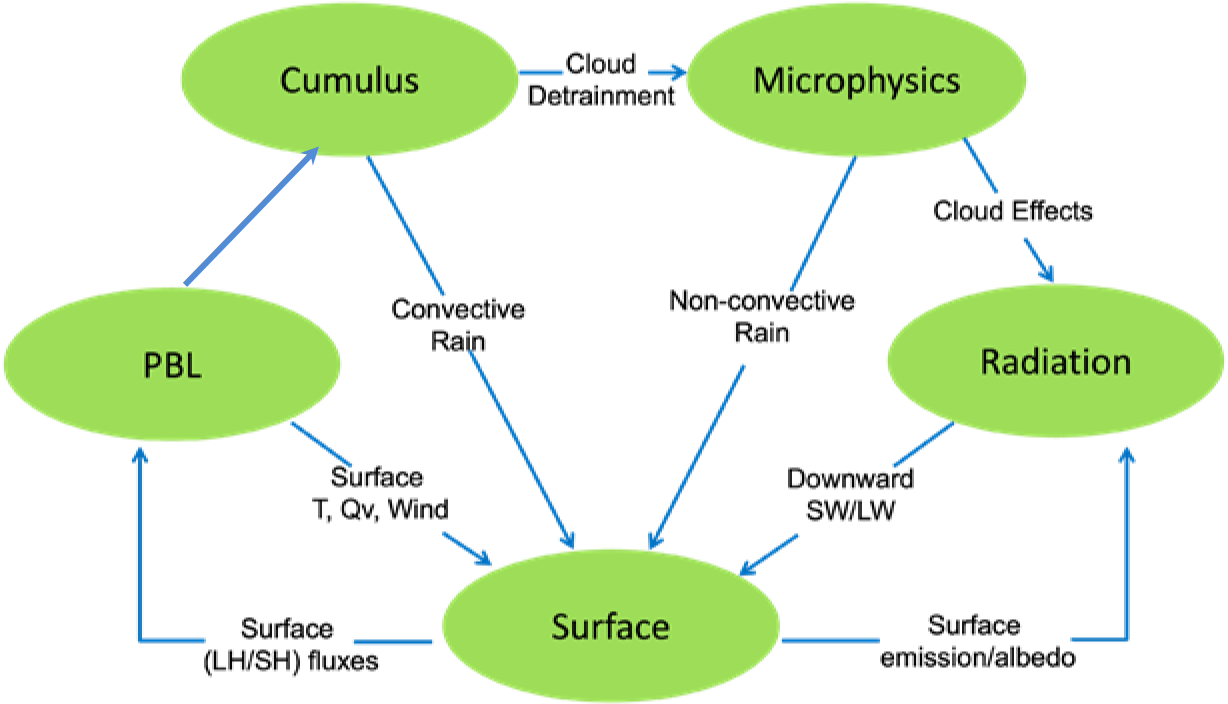



Subgrid-scale representations are based on typical prognostic variables:

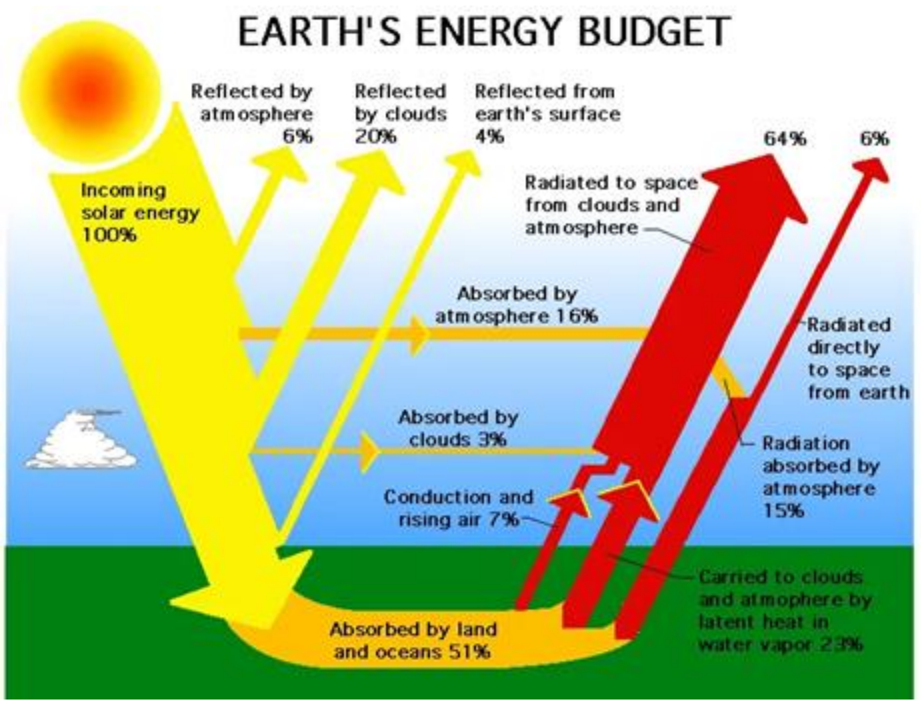
- Horizontal winds
- Vertical wind
- Temperature
- Density
- Water species


Example: subgrid clouds

# 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.

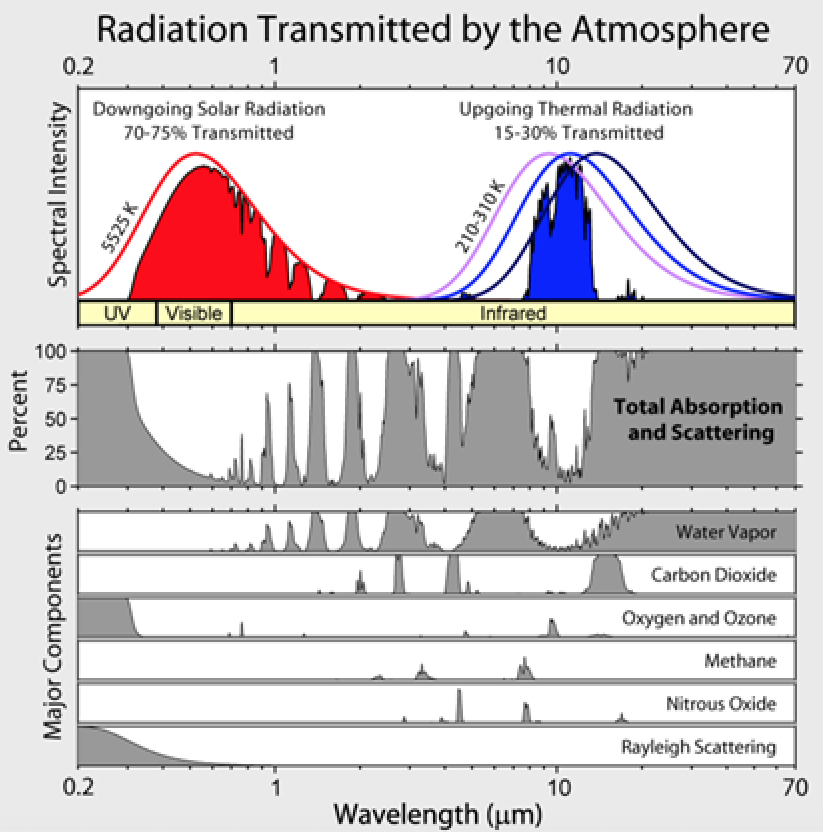
# Radiative Processes

**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

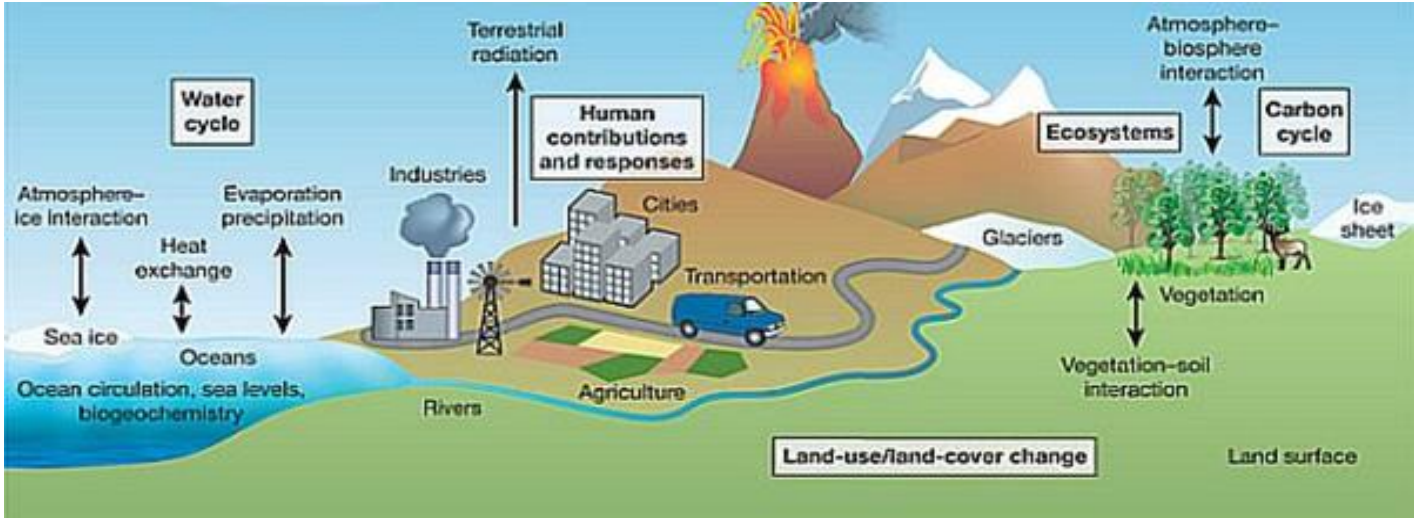
Surface emissivity based on land-type

Downward surface flux for land energy budget

IR cooling at cloud tops and warming at cloud base

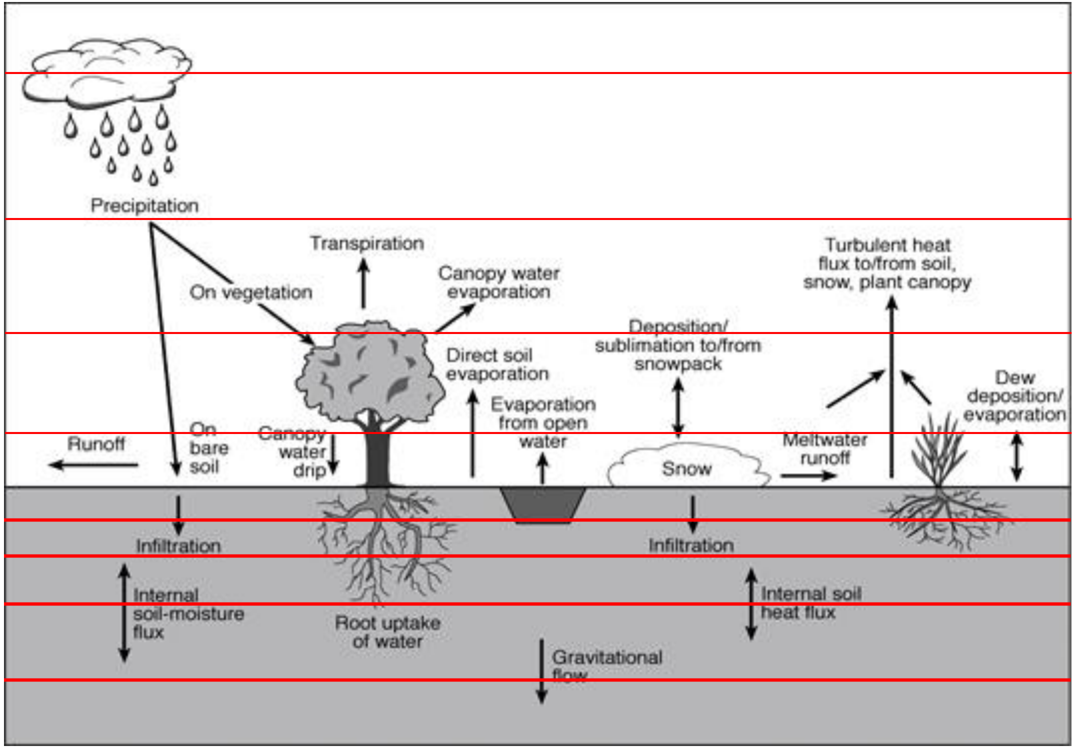
# Land Surface Processes

- 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.
- It diagnoses surface temperature and water vapor mixing ratio.




(From Moss et al. 2010)

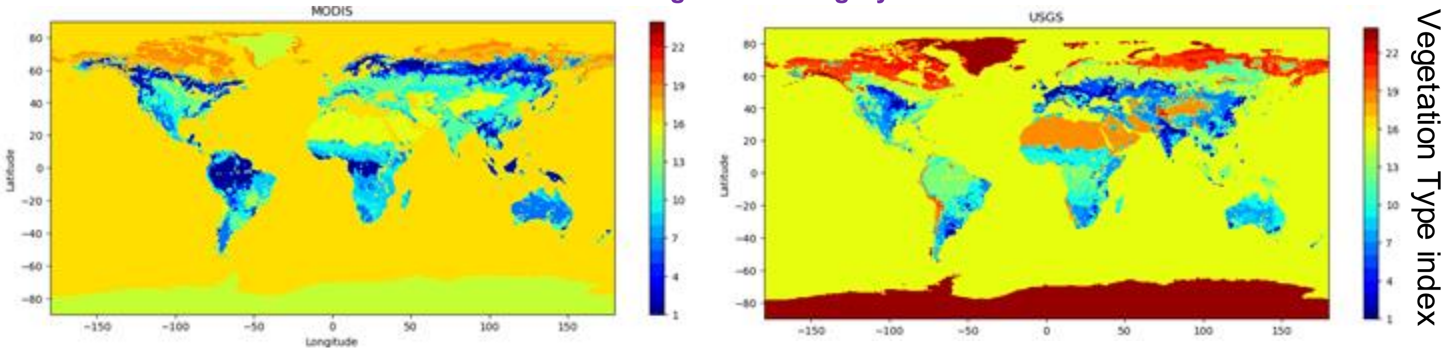
# Land Surface Processes



# Input Data

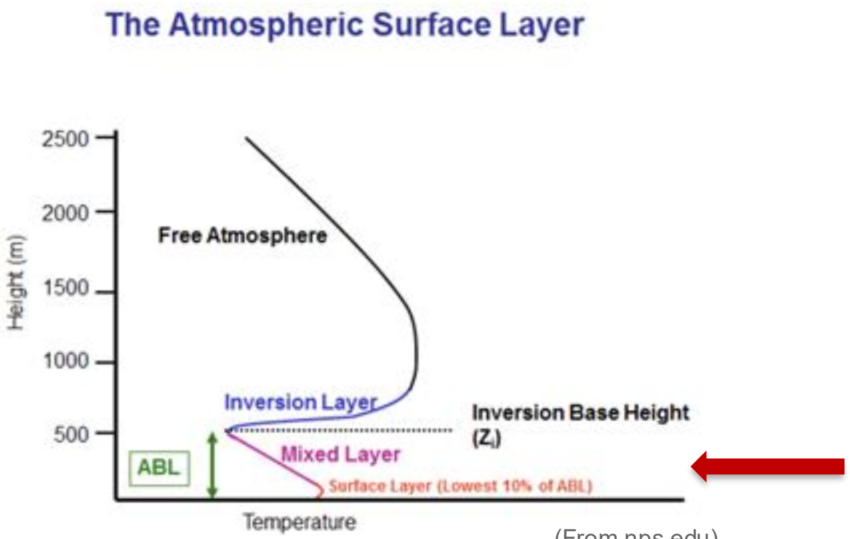
**MODIS** | **USGS**

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

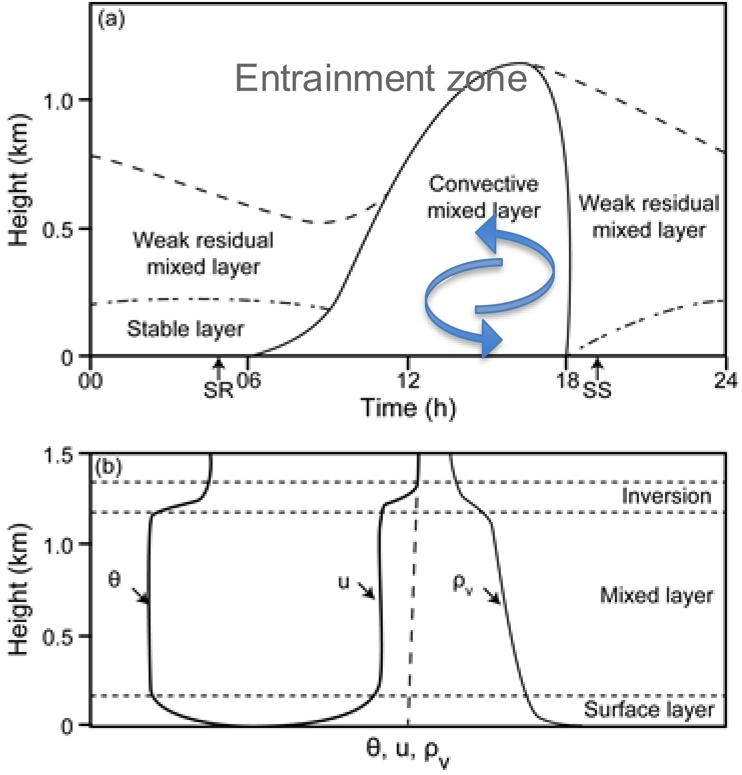
# Surface Layer Processes




(From nps.edu)

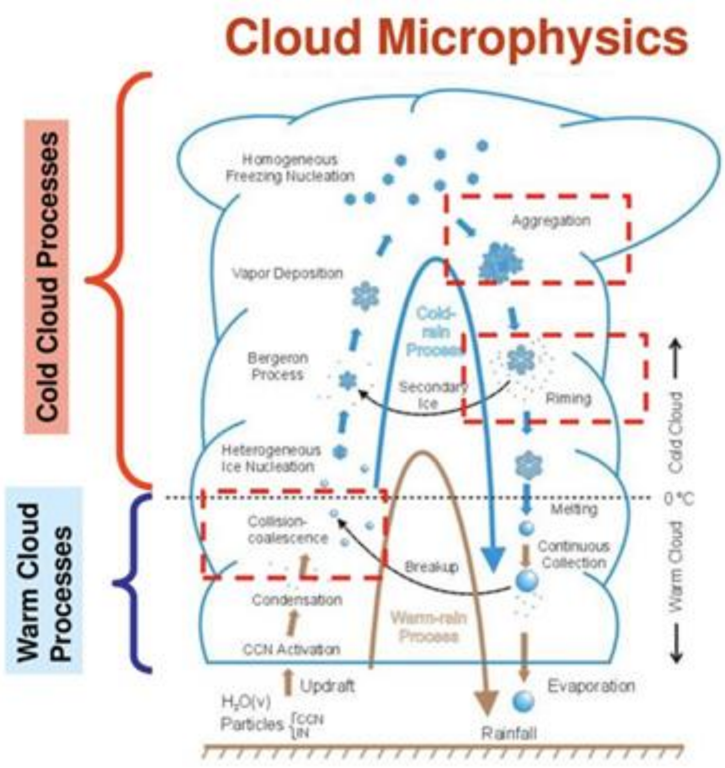
- Lowest 10% of the PBL, where turbulence generated by shear and convective heat transfer dominates.
- Approximated as a constant flux layer, where Monin-Obukhov similarity theory applies.
- The surface layer scheme calculates the exchange coefficients of heat, moisture and momentum between land and atmosphere, which are needed by the land surface model.

# Planetary Boundary Layer (PBL) Processes



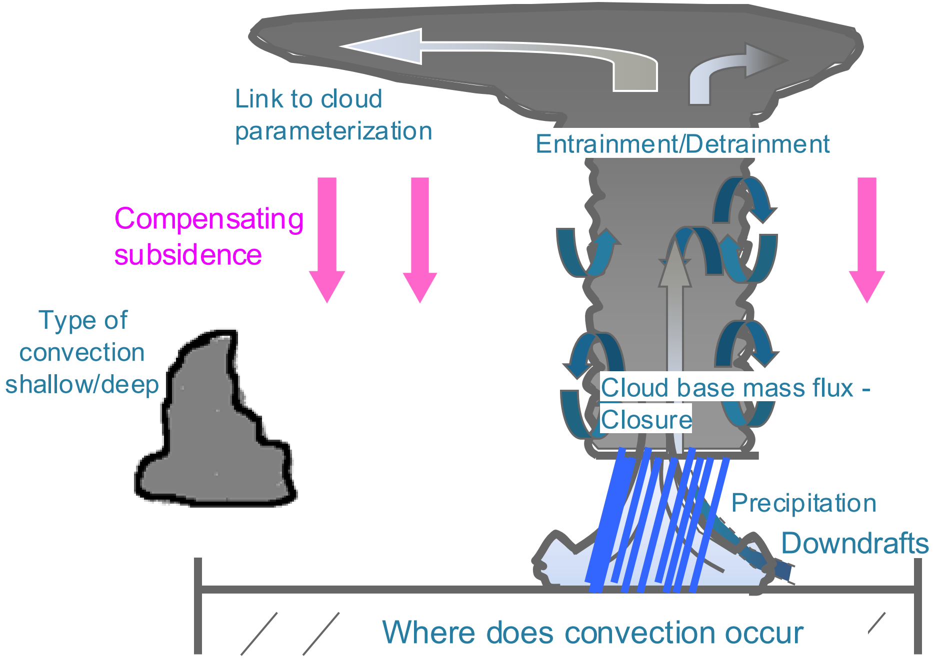

- A PBL scheme parameterizes the vertical transport of momentum, heat and water vapor fluxes due to turbulent eddy diffusion.
- It distributes surface fluxes with boundary layer eddies, and grows PBL by entrainment.
- Daytime boundary layer: unstable, convective, well mixed in 1-3 km
- Nighttime boundary 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)

# Microphysics




- Model detailed cloud physics. Considers latent heating processes like condensation, deposition, evaporation, collection, melting and freezing
- Typical types of hydrometeors: cloud water, cloud ice, rain, snow, graupel (and hail).
- 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

# Cumulus Convection Processes



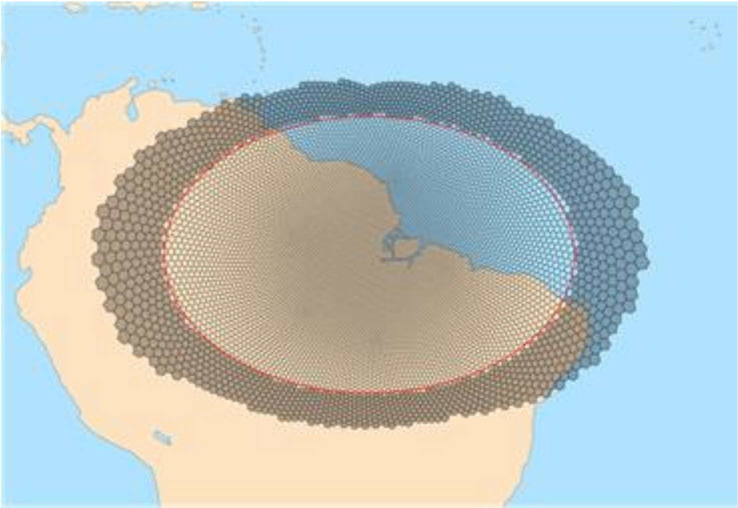

*(From ECMWF)*

- 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.

# Special Note on Scale-Aware Convection Schemes

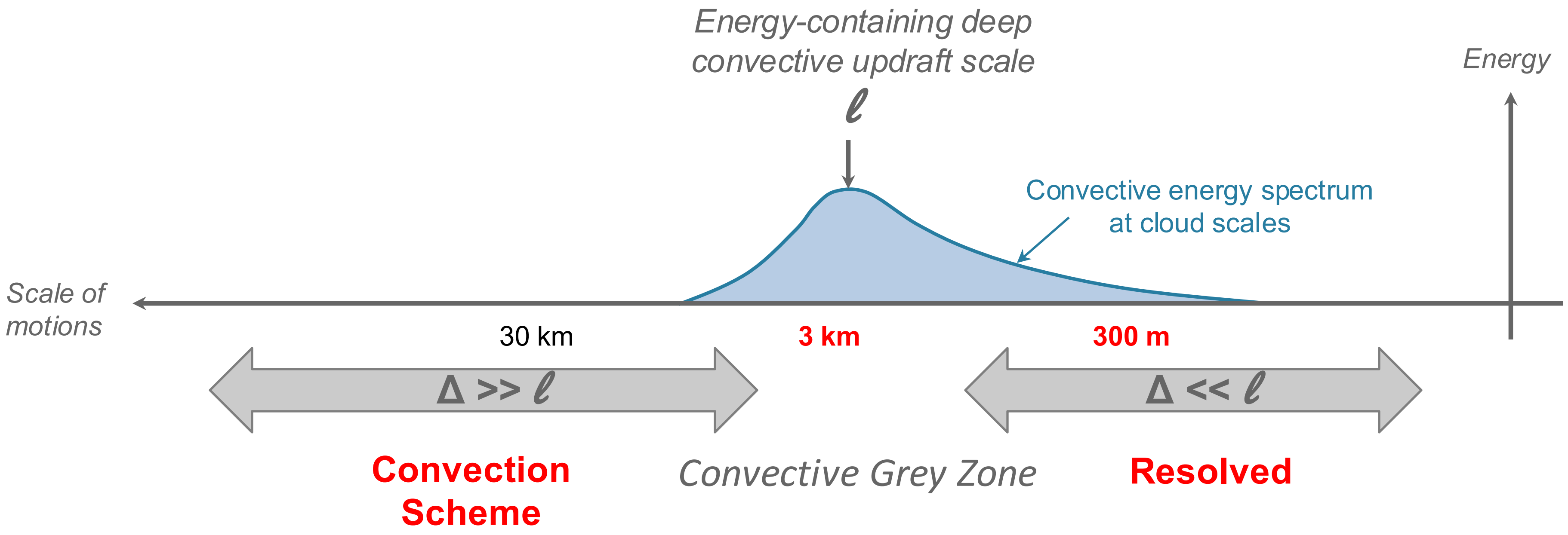
For variable-resolution applications with mesh spacings ranging from mesoscale to cloud-permitting scale, we need to consider using physics that are ‘scale-aware’.

global



regional

# Special Note on Scale-Aware Convection Schemes

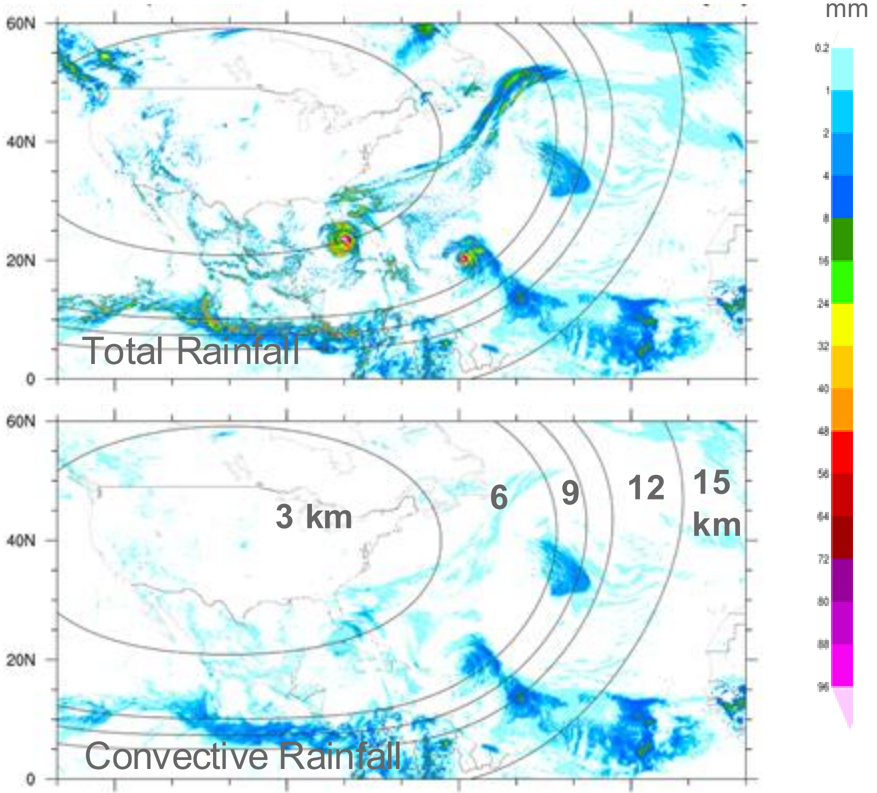



A schematic showing the energy spectrum in the horizontal plane.

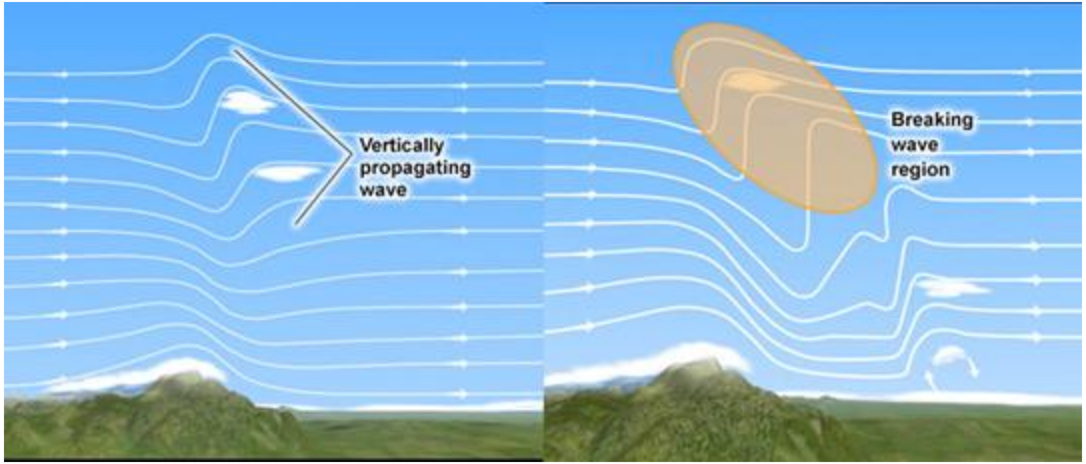
# Special Note on Scale-Aware Convection Schemes

- 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



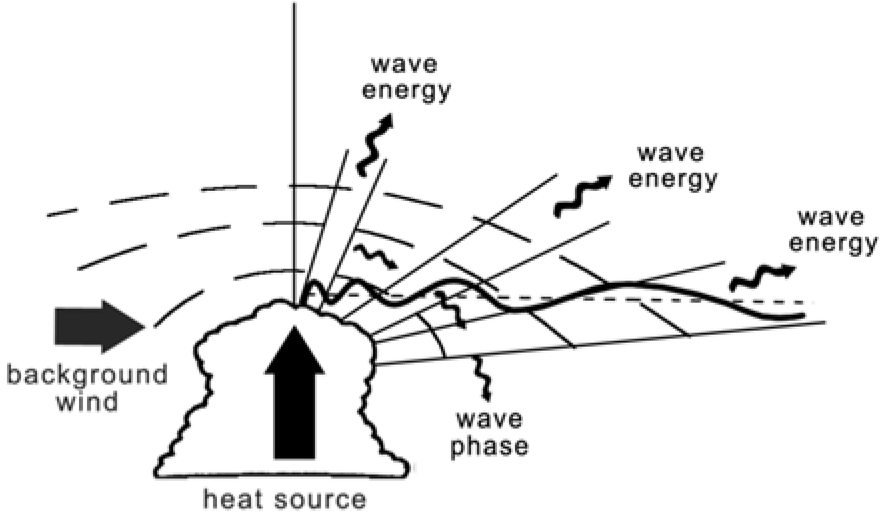
# Orographic Gravity Wave Drag




- 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.

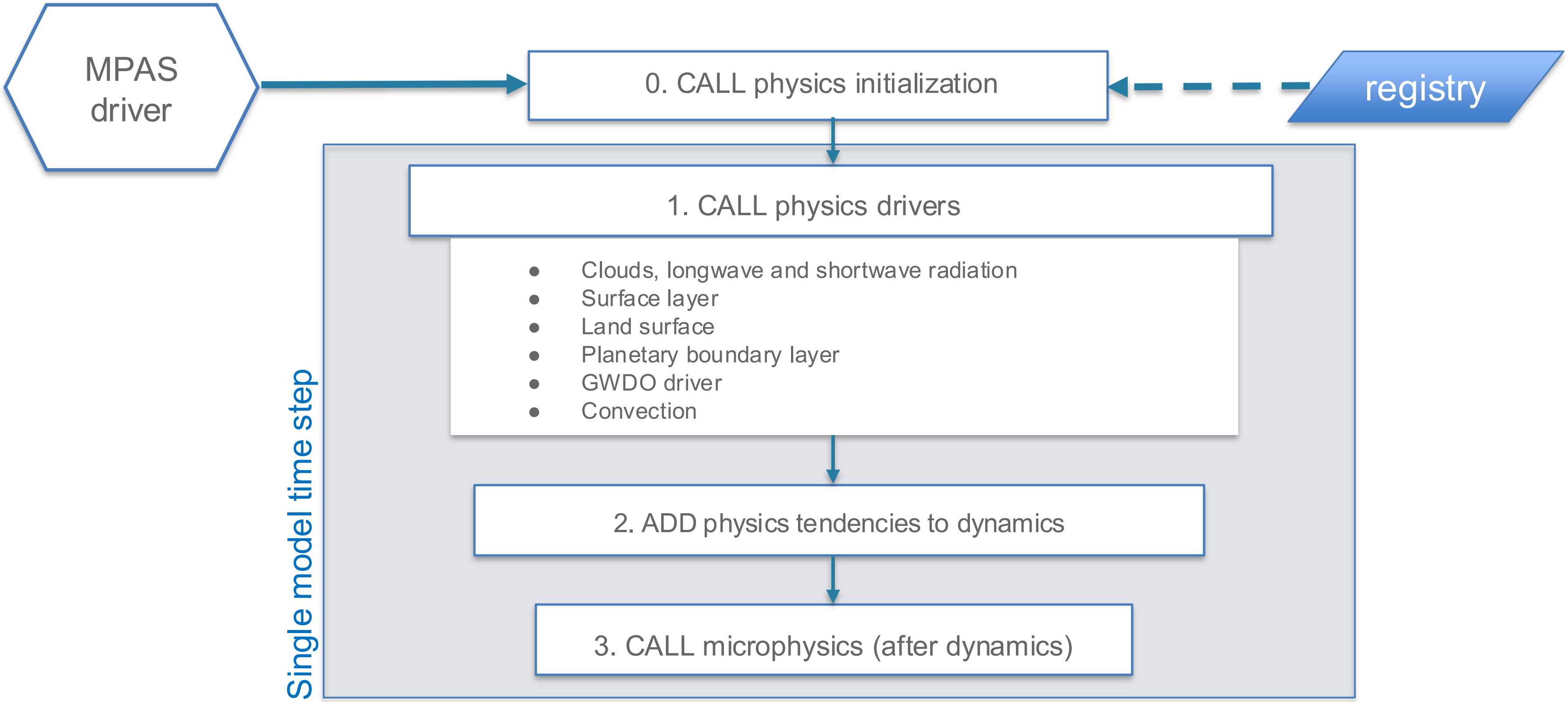
# Nonstationary Gravity Wave Drag




*(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.

# Coupling of physics with dynamics in MPAS-A



# 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<br>config_radt_sw_scheme | ’RRTMG’, ‘CAM’<br>‘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’ ,<br>‘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 |

MPAS
Model for Prediction Across Scales

# 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

MPAS
Model for Prediction Across Scales

# 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'
```

MPAS
Model for Prediction Across Scales

# 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<br>CAM_AEROPT_DATA.DBL | CAM radiation |
| RRTMG_LW_DATA<br>RRTMG_SW_DATA<br>OZONE_DAT.TBL<br>OZONE_LAT.TBL<br>OZONE_PLEV.TBL | RRTMG radiation |
| CCN_ACTIVATE_DATA<br>MP_THOMPSON_freezeH2O_DATA.DBL<br>MP_THOMPSON_QIautQS_DATA.DBL<br>MP_THOMPSON_QRacrQG_DATA.DBL<br>MP_THOMPSON_QRacrQS_DATA.DBL | Thompson Microphysics<br>created by ***build_tables*** |
| GENPARM.TBL<br>LANDUSE.TBL<br>SOILPARM.TBL<br>VEGPARM.TBL | Noah LSM |
| NoahmpTable.TBL | NoahMP LSM |

MPAS
Model for Prediction Across Scales

# Physics Code Structure in V8.3.1

MPAS-Model/src/core_atmosphere/physics/

```
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
```

access to data files (checkout_data_files.sh)

drivers for different physics schemes (mpas_atmphys_driver_convection.F through mpas_atmphys_driver_sfclayer.F)

initialization of different physics schemes (mpas_atmphys_camrad_init.F, mpas_atmphys_initialize_real.F, mpas_atmphys_init_microphysics.F, mpas_atmphys_lsm_noahinit.F, mpas_atmphys_lsm_noahmpinit.F, mpas_atmphys_rrtmg_lwinit.F, mpas_atmphys_rrtmg_swinit.F)

physics modules (physics_noahmp/, physics_wrf/)

directories appear after compilation (physics_mmm/, physics_noaa/UGWP)

# 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
```

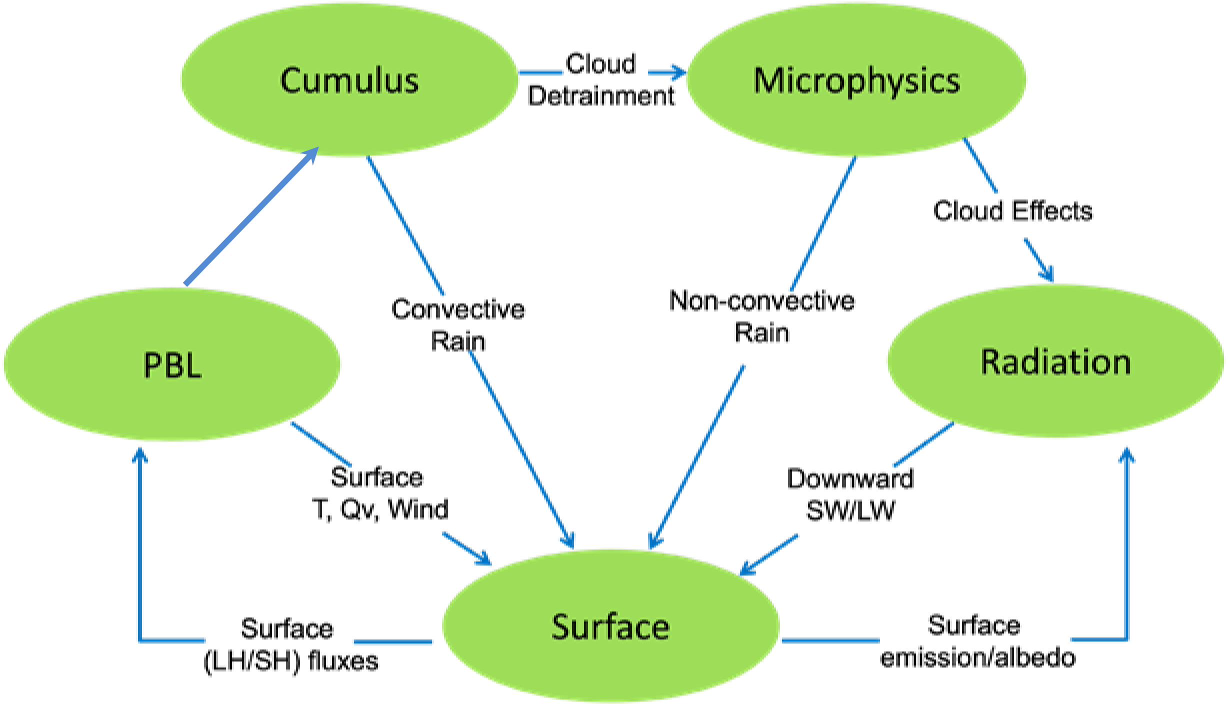
MPAS
Model for Prediction Across Scales

# 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-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.