Physics Introduction and Configurations in MPAS

Wei Wang
NCAR/MMM
MPAS-A Tutorials, 7 - 9 April 2025
Boulder Colorado
(with contributions from Fowler and Dudhia)

This material is based upon work supported by the National Center for Atmospheric Research, which is a major facility sponsored by the National Science Foundation under Cooperative Agreement No. 1852977.

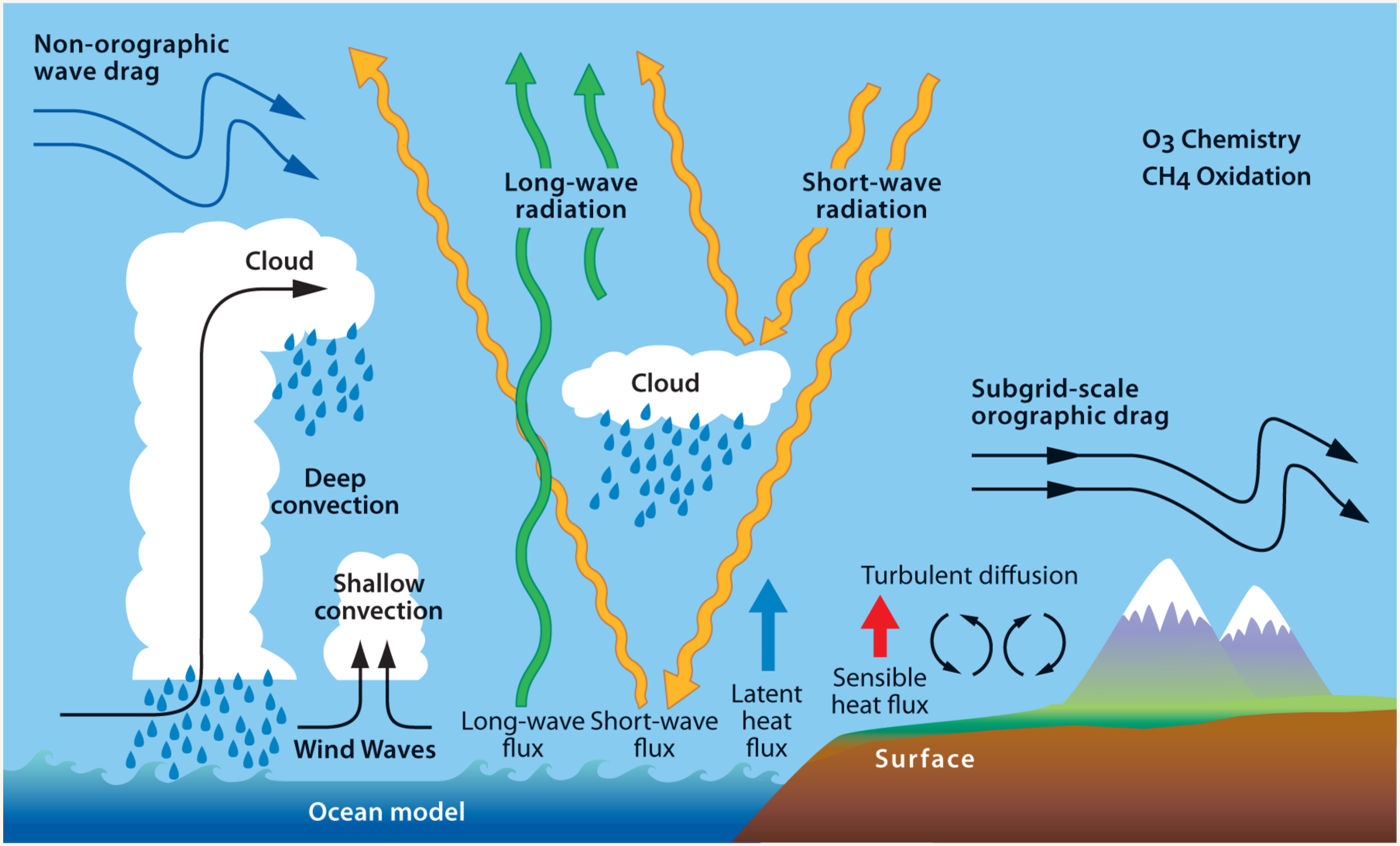
MPAS
Model for Prediction Across Scales

Outline

1) The atmospheric physics processes represented in the model and their interactions.
2) Physics options in MPAS and how to configure them.

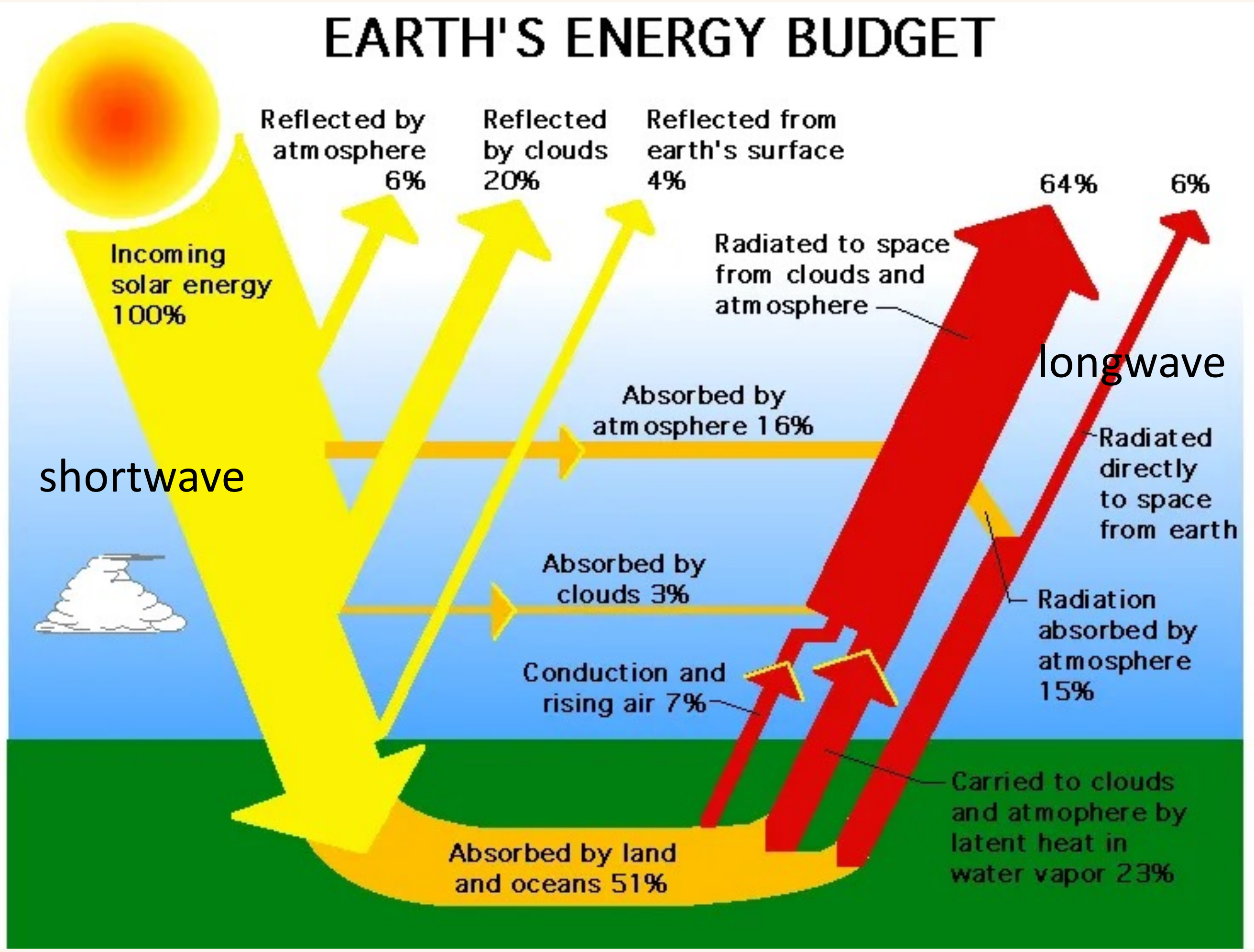
MPAS Model for Prediction Across Scales

Atmospheric Physical Processes



(From ECMWF)

Radiation Processes



(From UCAR/SCIED)

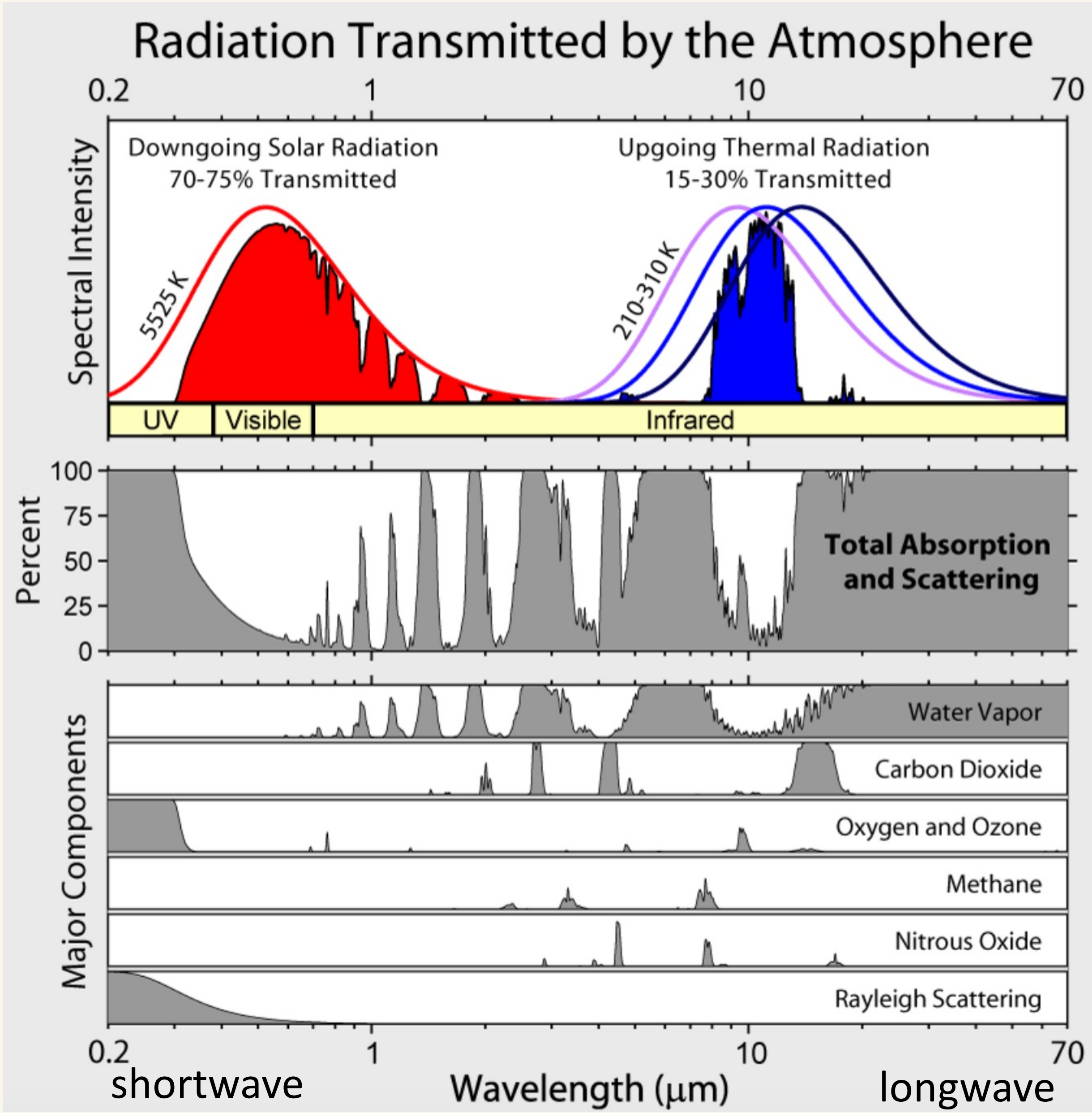
Shortwave: Coming from Sun

Longwave: emitting from surface

Both interact with atmospheric tracer gases, clouds, and aerosols via absorption, scattering and reflection. Ozone impacts on SW.

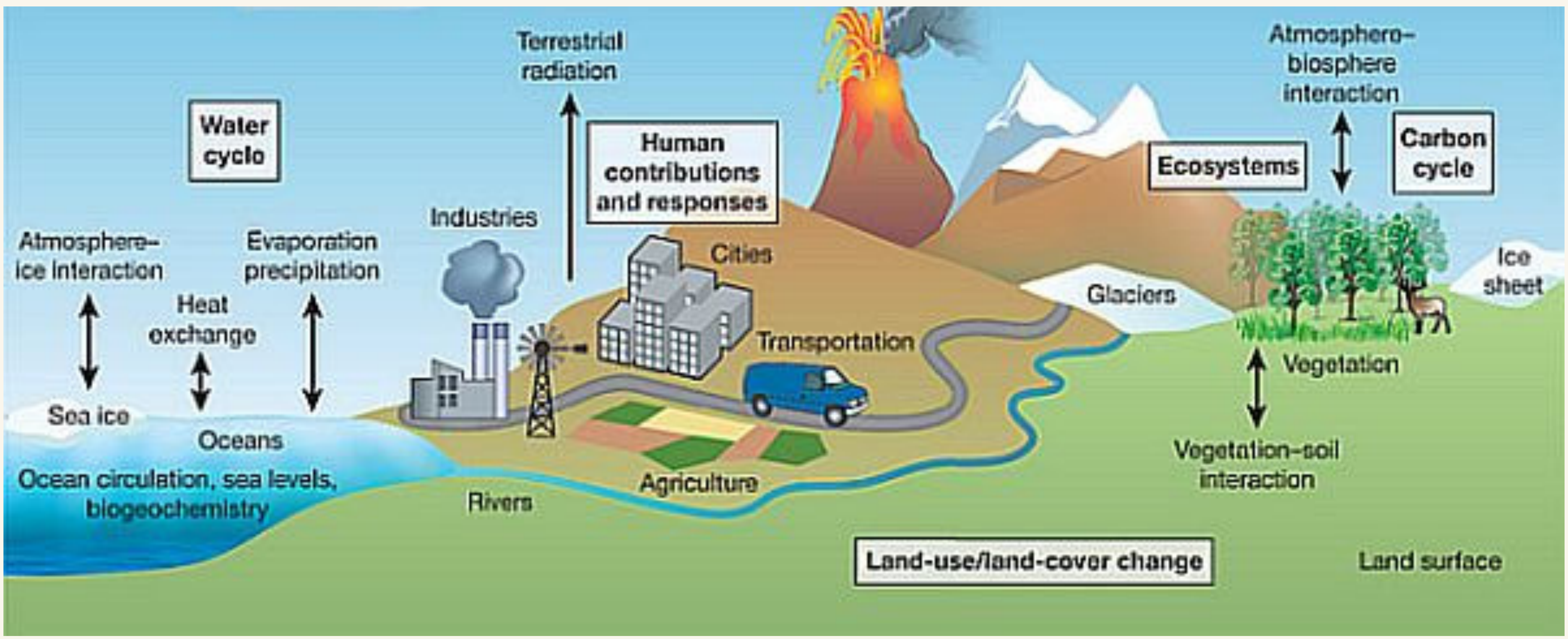
Predicts atmospheric warming (e.g. by absorption) or cooling, and radiation fluxes at the surface.

Radiation Processes



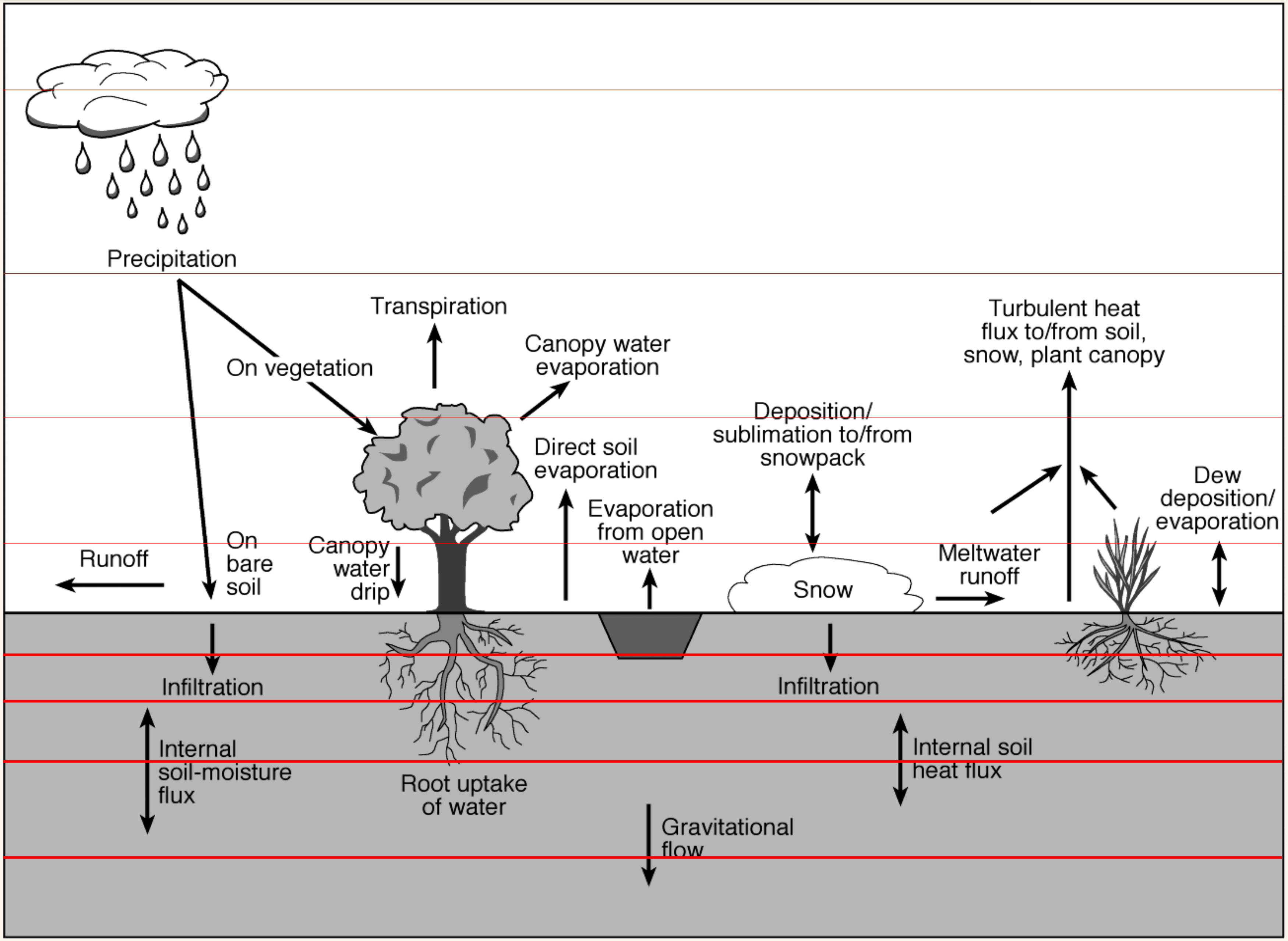
Land Processes

- Land surface physics is driven by radiational forcing and precipitation.
- It considers processes like heat and moisture transfer in the soil layers, vegetation effect, surface runoff and snow.
- Land physics predicts surface fluxes over land, urban areas, glacier and seaice.
- It diagnoses surface temperature, and water vapor variables.



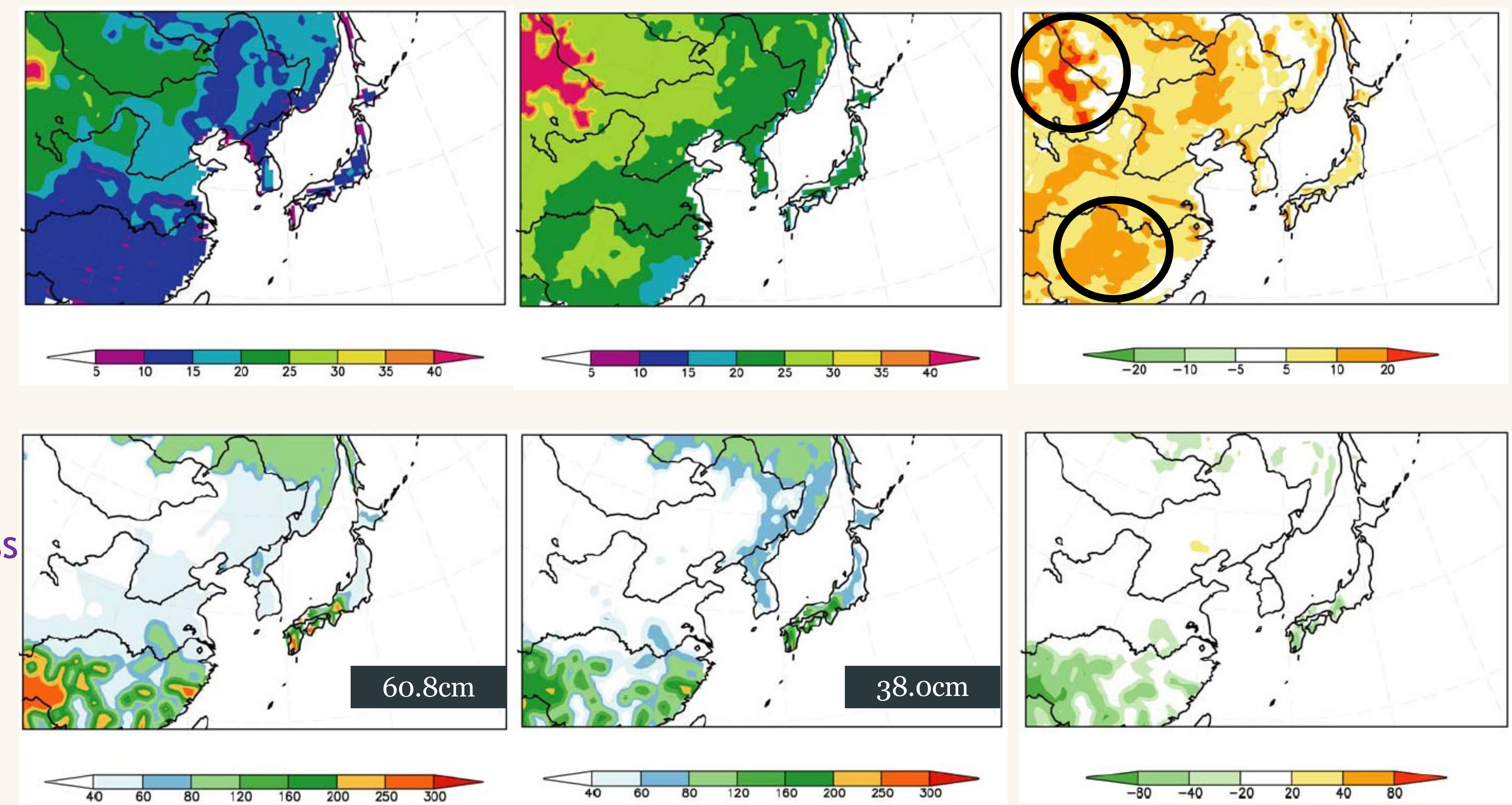
(From Moss et al. 2010)

Land Surface Processes



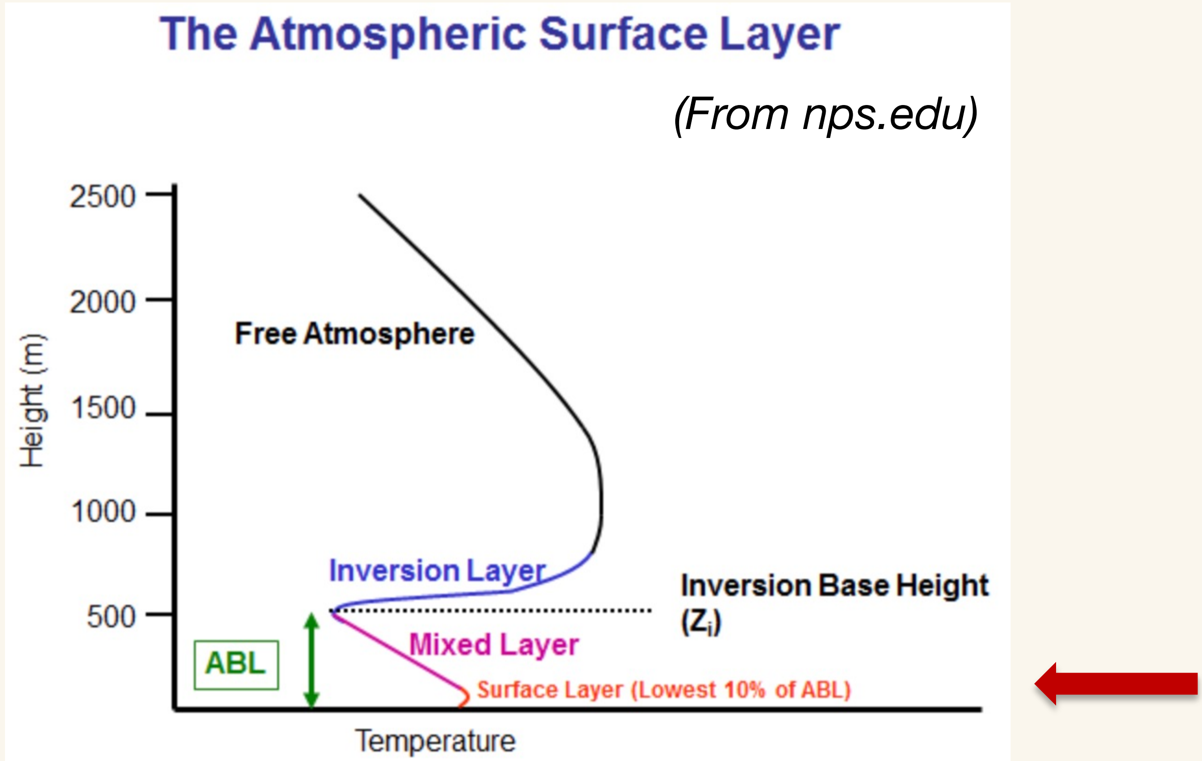
Uncertainties in Input Data

	Sib	USGS	USGS-Sib
Albedo			
Roughness length			



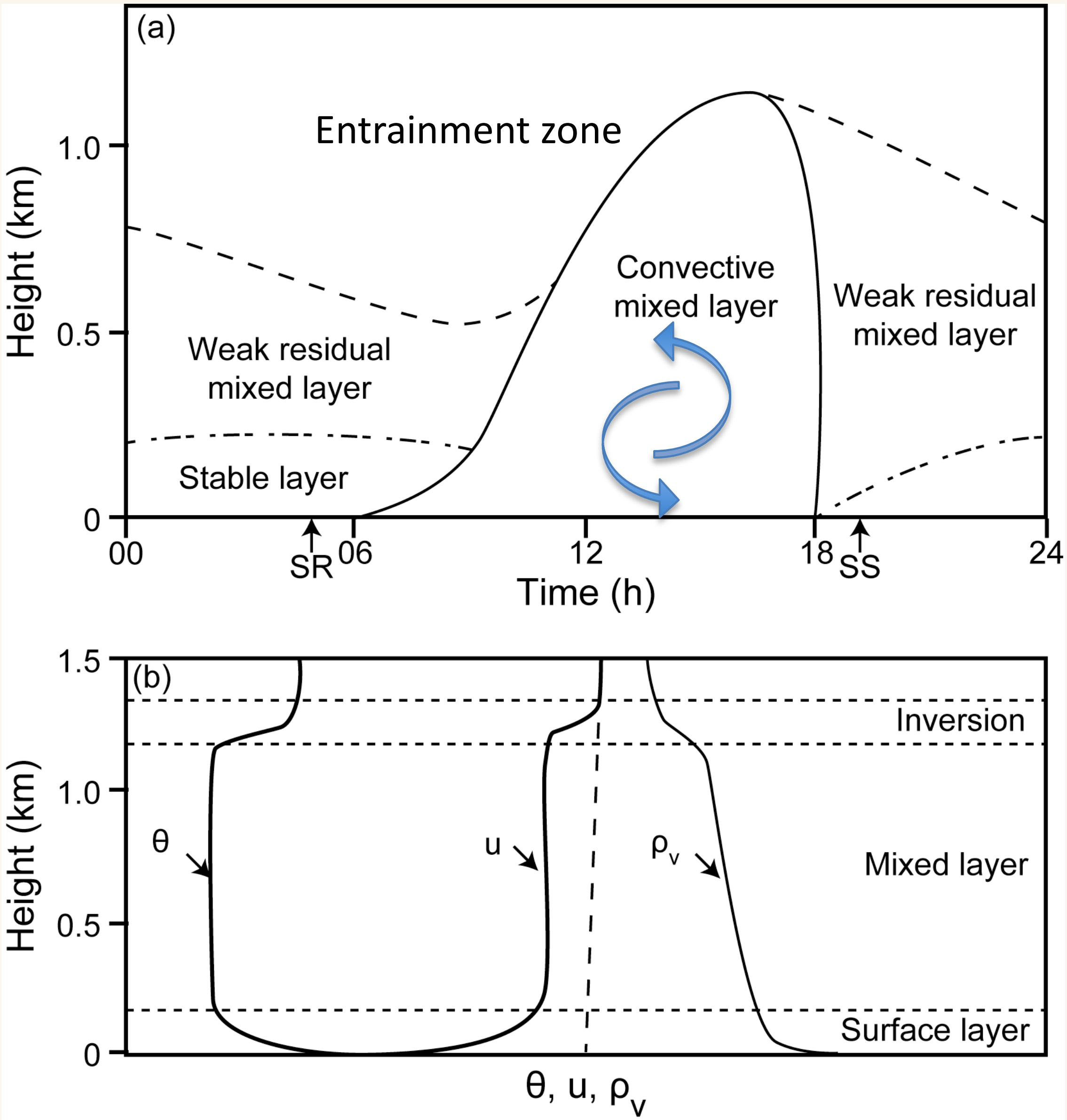
(From Songyou Hong)

Surface Layer Processes



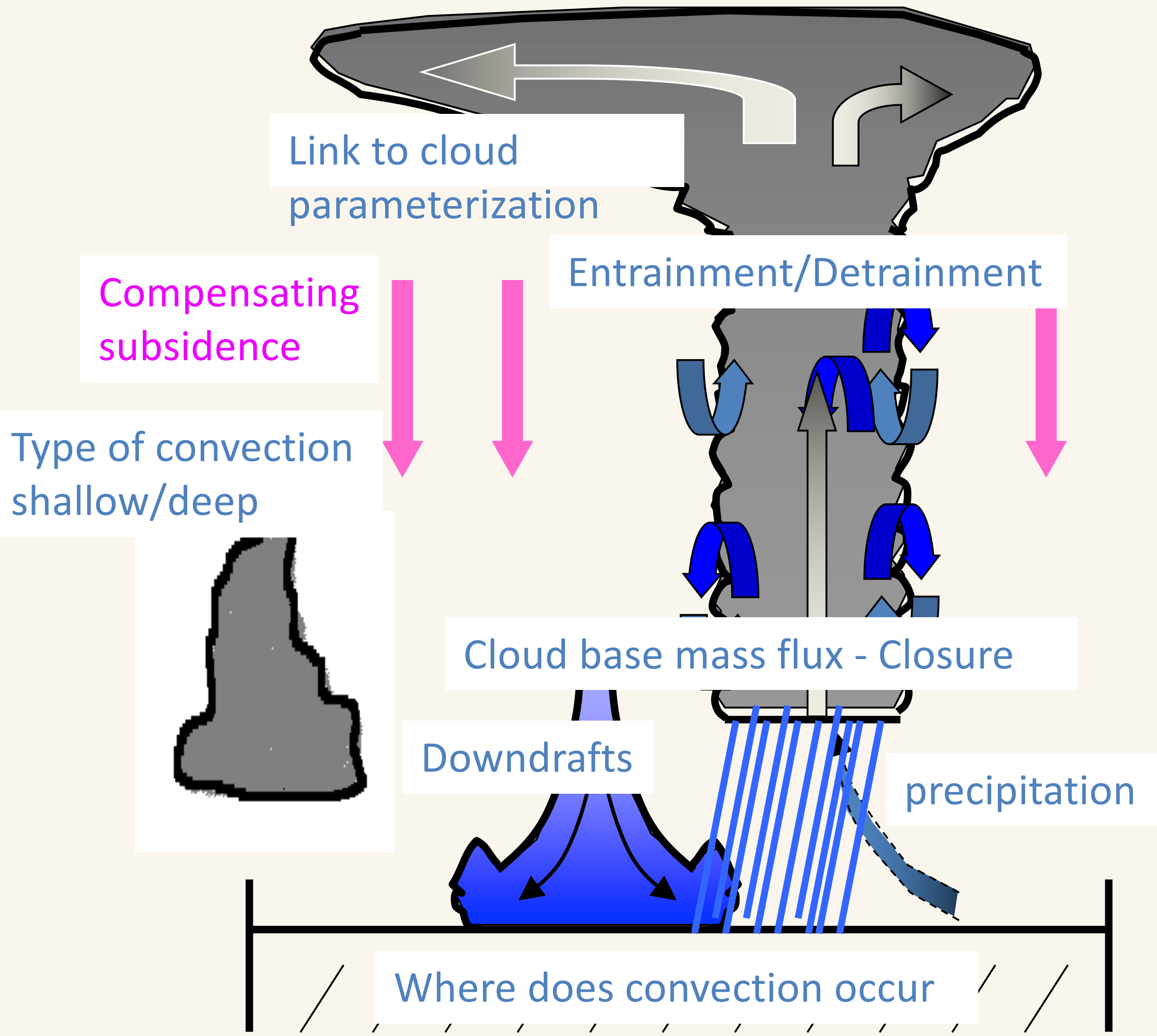
- Lowest 10 % of the PBL, where mechanical generated turbulence dominates.
- It is referred to as constant flux layer, where Monin-Obukhov similarity theory applies.
- It calculates the exchange coefficients of heat, moisture and momentum between land and atmosphere.

Planetary Boundary Layer 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: TKE, non-local, EDMF

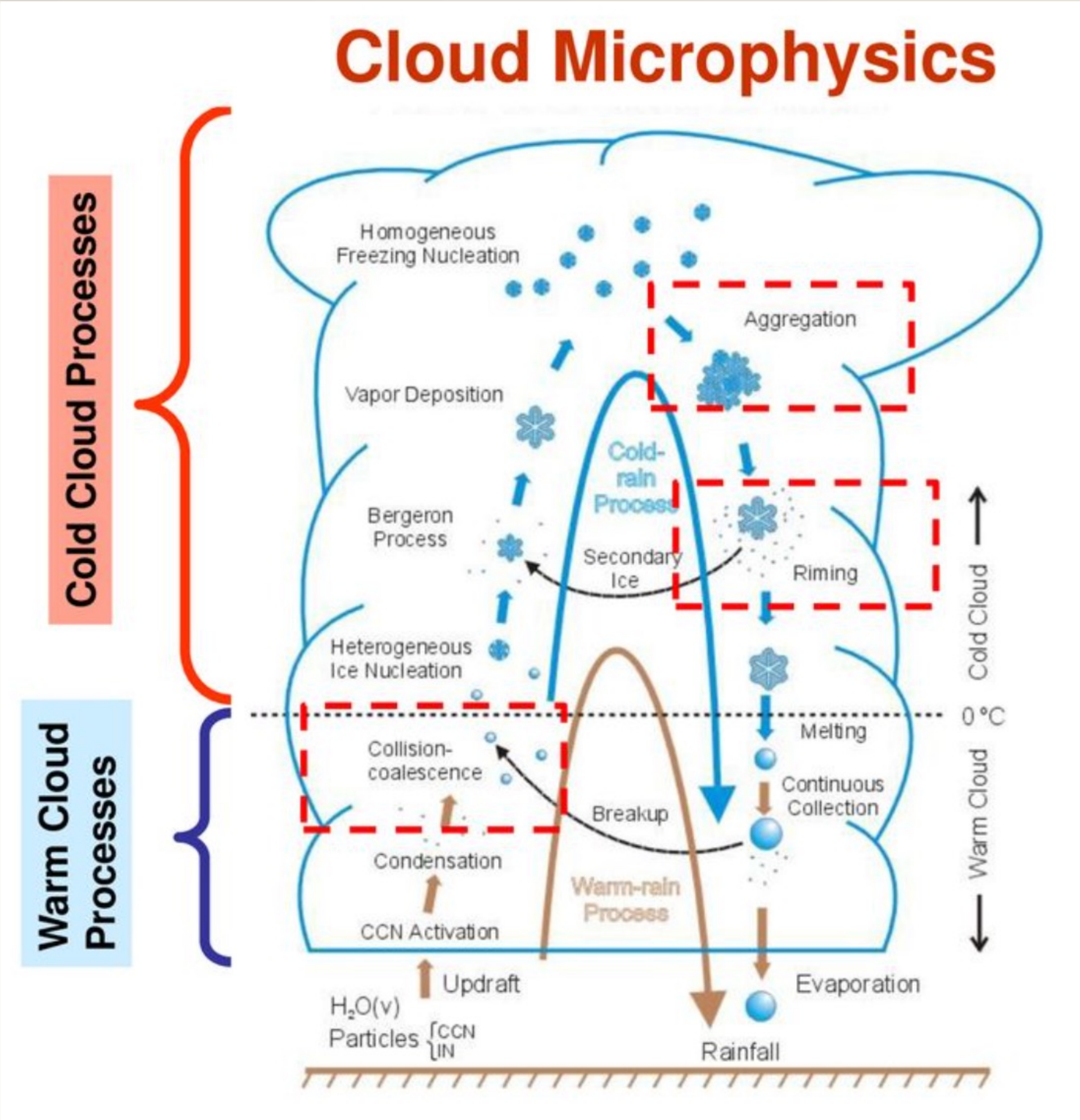
Cumulus Convection Processes



(From ECMWF)

- A convective or cumulus scheme parameterizes convective transport of heat and moisture and its effect on grid scale – warming and drying.
- Include 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 CPS in MPAS are mass-flux type. Some schemes consider momentum transport. Some are scale-aware.

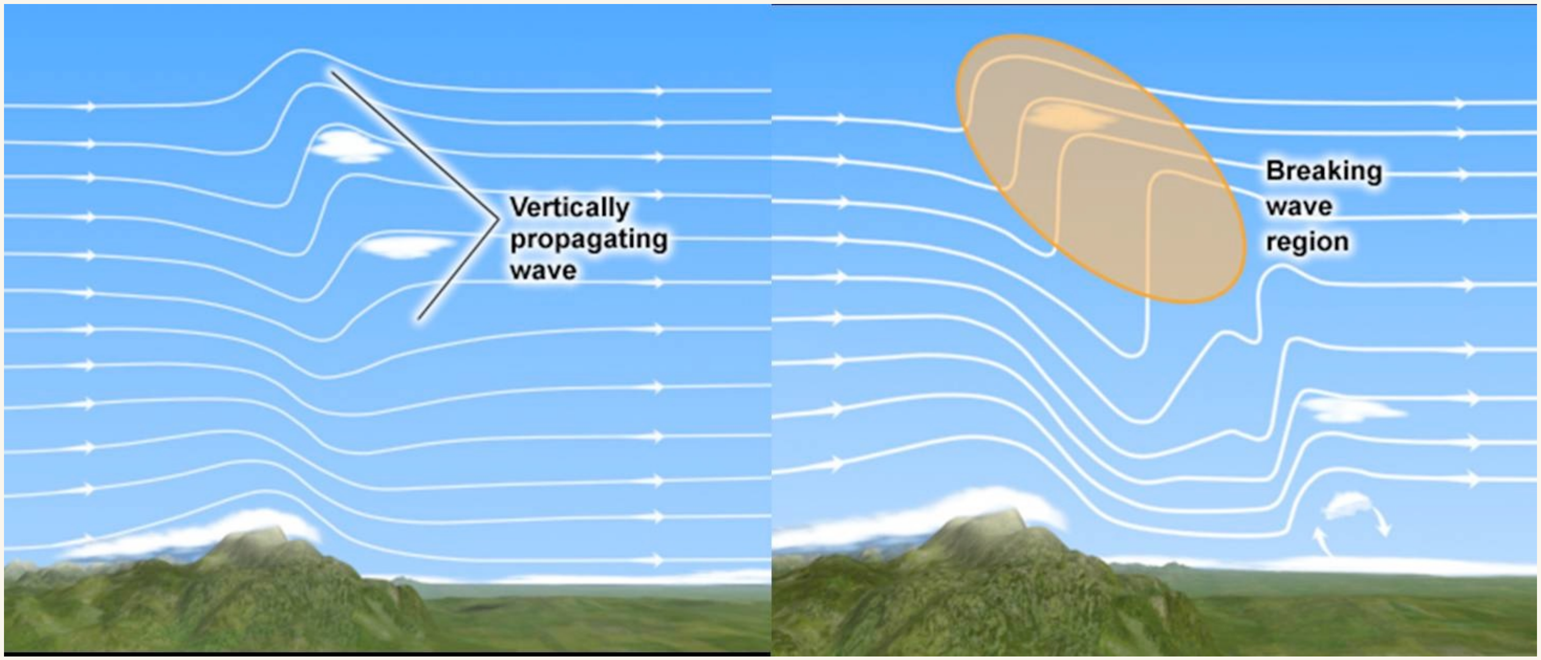
Microphysics



- Model detailed cloud physics. Considers processes like condensation, deposition, evaporation, collection, melting and freezing.
- Predict mass mixing ratio for cloud water/ice, rain/snow, graupel/hail.
- Have different complexity: single moment (like WSM6); partial double moment, (like Thompson scheme).
- Clouds interact with radiation.
- Contributes to mass loading in dynamics

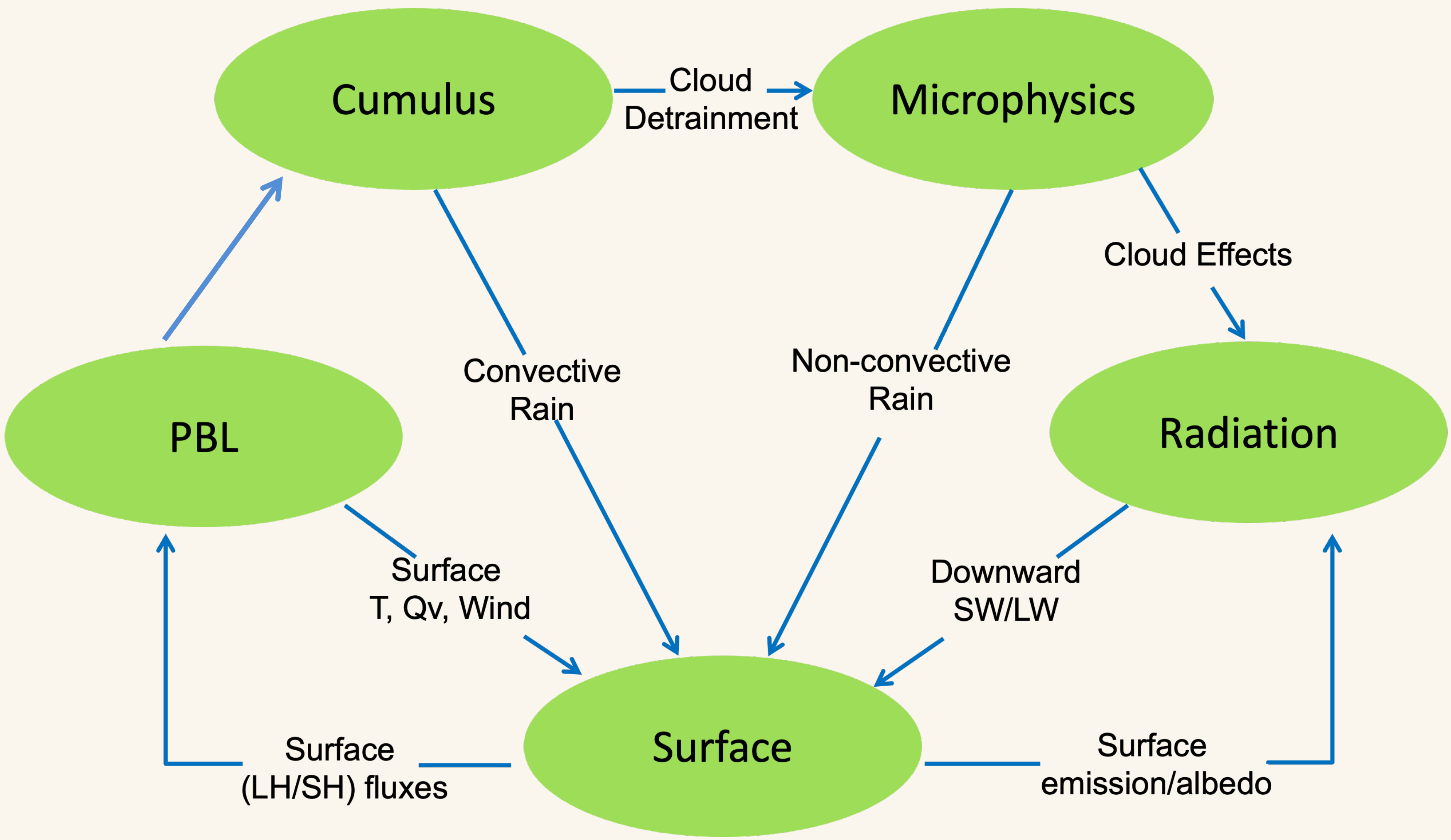
MPAS
Model for Prediction Across Scales

Orographic Gravity Wave Drag



Vertical propagating waves excited by the topography may break under certain atmospheric conditions and hence it needs to be represented in the model, especially when grid sizes are larger than 5 km. Low level flow blocking are also parameterized.

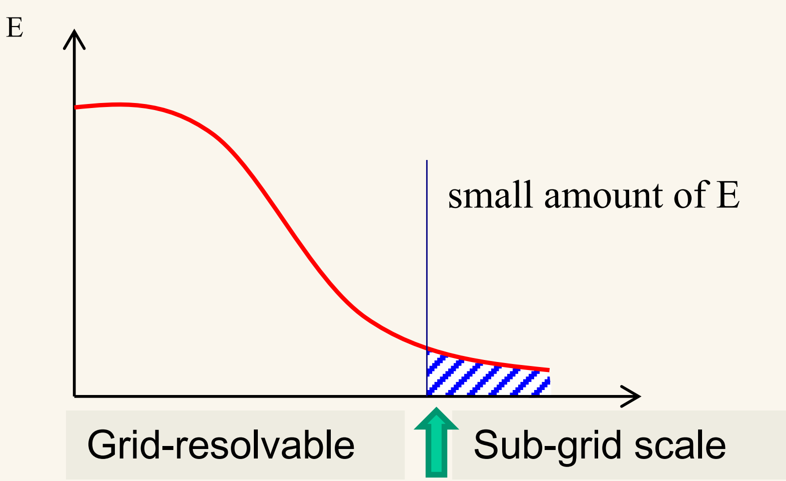
Direct Physics Interactions



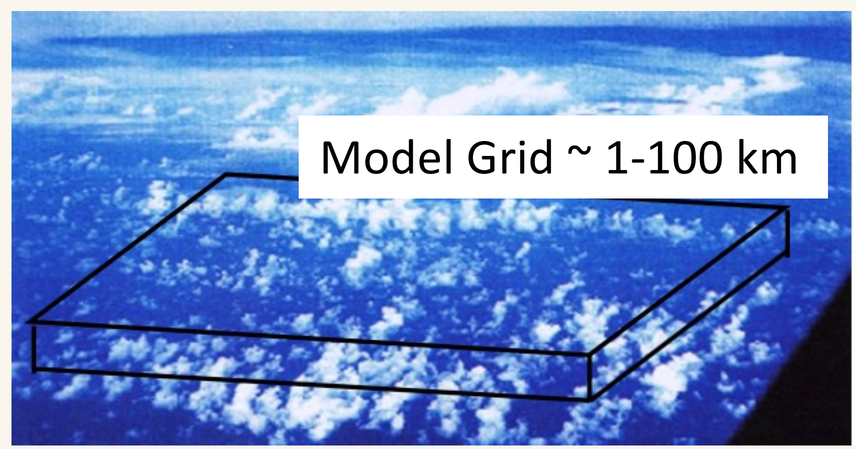
MPAS
Model for Prediction Across Scales

How is Physics Represented?

- Finite model resolution to represent continuous atmosphere.
- Physics is complex, and operate on subgrid scales.
- Must use explicit model variables (like u, v, p, T, Qv, etc.) to represent sub-grid processes.



Energy Perspective



Example: Subgrid Clouds

MPAS
Model for Prediction Across Scales

What does MPAS have in v8.2?

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-Fritcsh, Tiedtke
Ocean	1-D Ocean mixed layer
Orographic Gravity Wave Drag	Choi & Hong

* More options are coming.

MPAS
Model for Prediction Across Scales

Physics Options in MPAS v8.2

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’

Physics Specification in MPAS

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

MPAS
Model for Prediction Across Scales

How to Configure Physics?

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'
    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 B11 in the User's Guide

MPAS
Model for Prediction Across Scales

How to Configure Physics?

Example shown below is the ‘convection_permitting’ suite.

```
&physics
    config_physics_suite      = 'convection_permitting'
    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 B11 in the User’s Guide

MPAS Model for Prediction Across Scales

How to Configure Physics?

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

- Can replace one or more options in a suite:

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

Physics Specification in MPAS

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

- To turn any options off, set it to 'off': e.g.

```
config_convection_scheme = `off'
```

How to Configure Physics?

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 (config_radtlw_interval, config_radtsw_interval, config_o3climatology)

longer simulations (config_sst_update, config_sstdiurn_update, config_deepsoiltemp_update)

useful options (config_micro_re, config_ysu_pblmix)

See Chapter 6 and B11 in the User's Guide

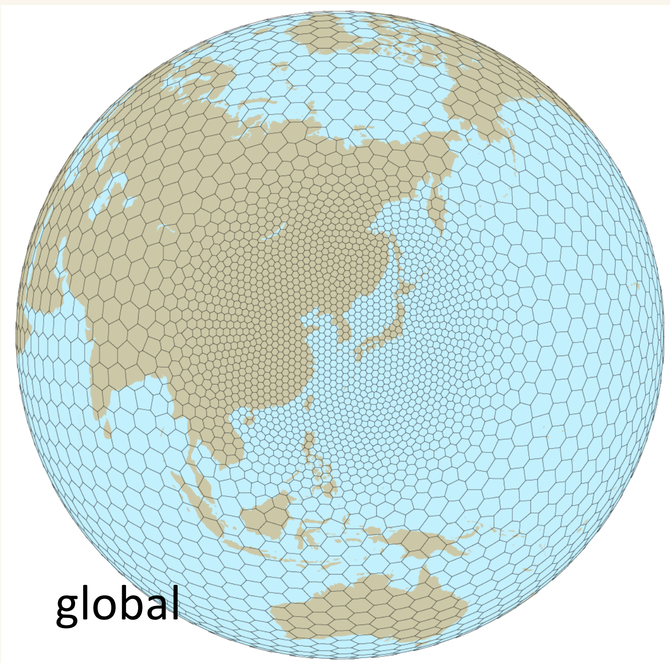
MPAS
Model for Prediction Across Scales

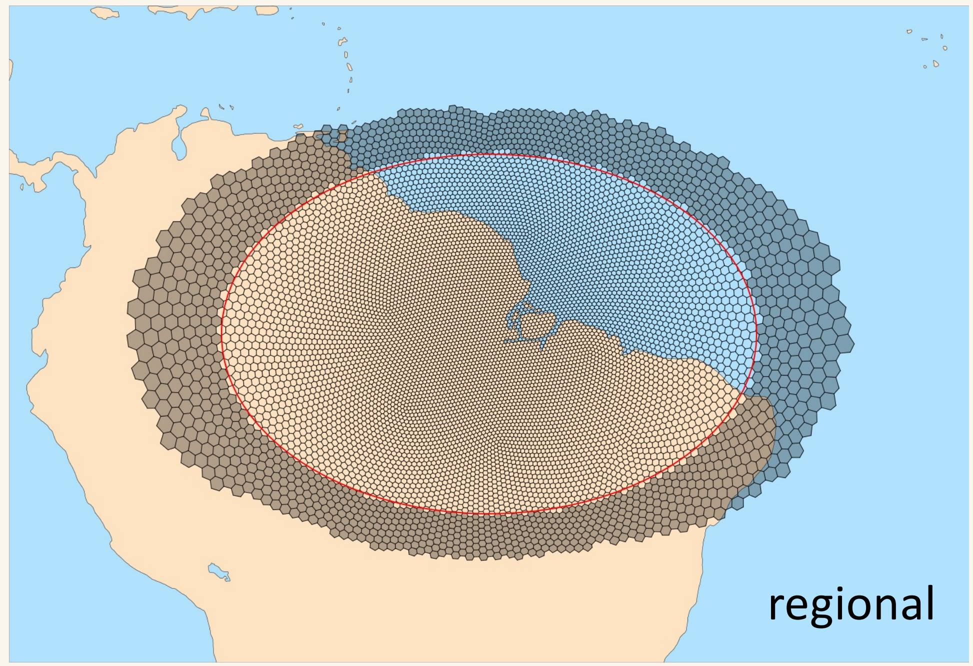
Physics Data Files in MPAS v8.2

File Name	What's for
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

Special Notes for Scale-Aware CPS

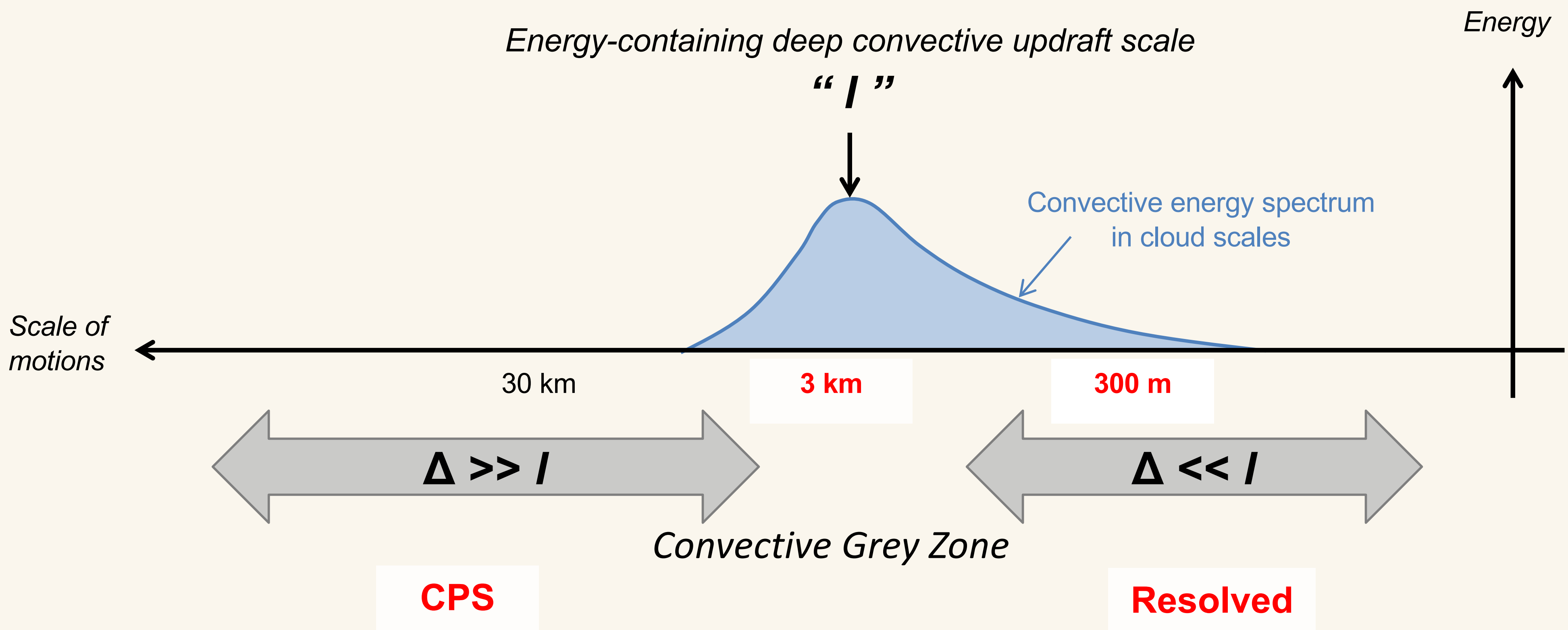
For variable resolution applications with mesh sizes ranging from mesoscale to cloud-permitting scale, we need to consider physics that is 'scale-aware'.





MPAS
Model for Prediction Across Scales

Special Notes for Scale-Aware CPS

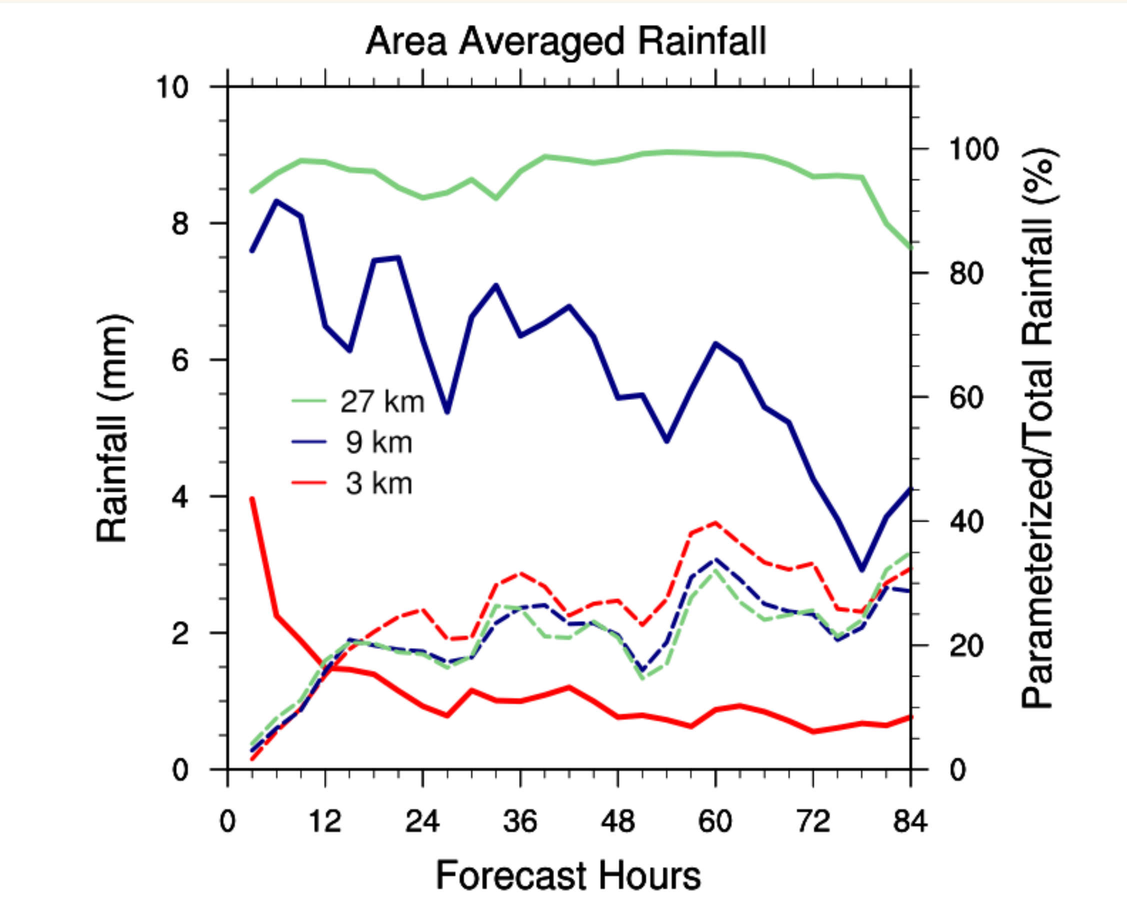


A schematic showing the energy spectrum in a horizontal plane as a function of model grid distance.

MPAS
Model for Prediction Across Scales

Special Notes for Scale-Aware CPS

For model mesh sizes above 1 km, the most relevant physics to consider ‘scale-aware’ is the cumulus parameterization



Solid lines: ratios; dashed: 3 hrly rainfall

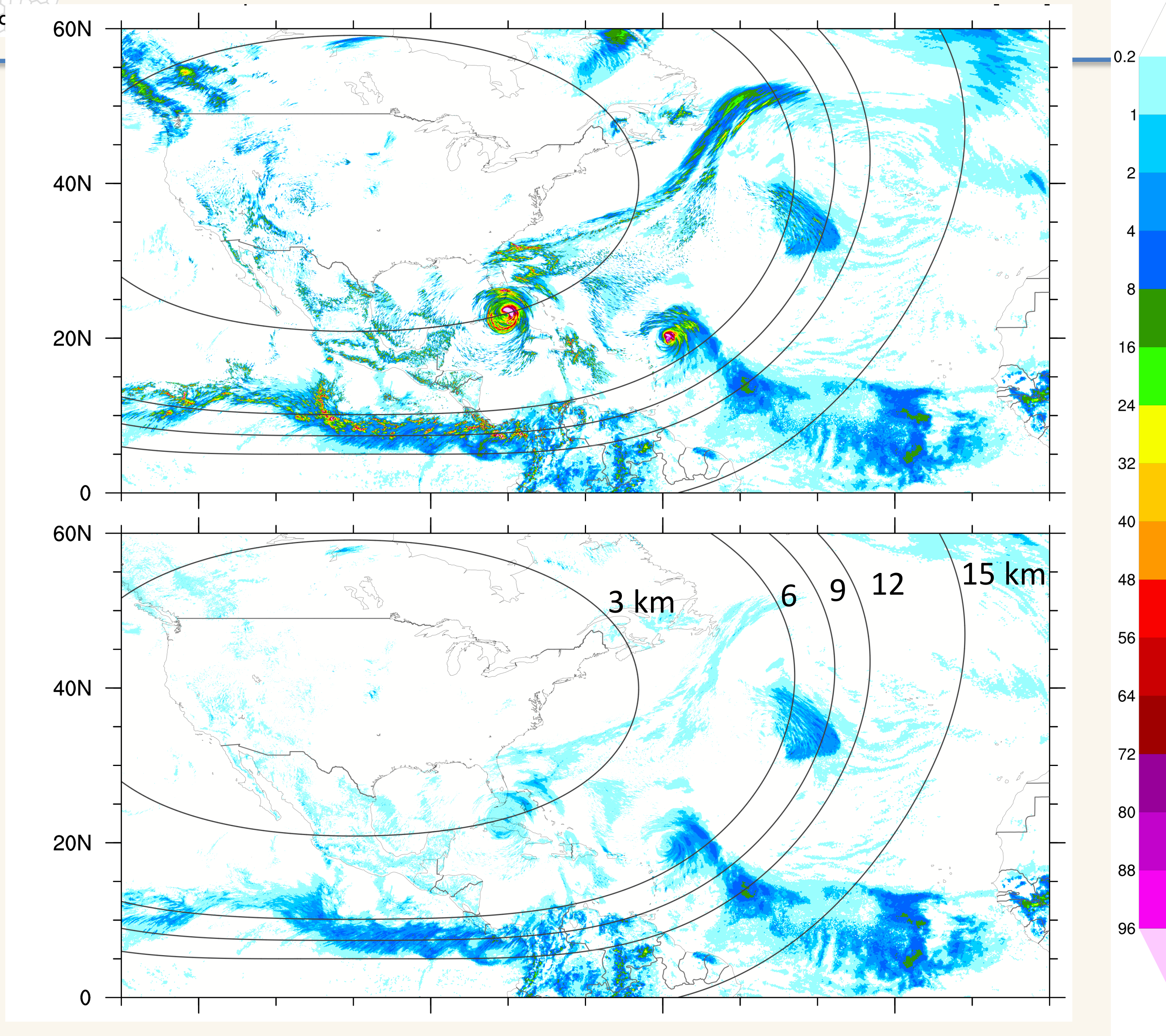
- The left plot shows hurricane Harvey simulations at 27, 9 and 3 km using WRF.
- The convective portion (solid lines) of the rainfall decreases as the grid size decreases from 27 km (green) to 3 km (red).

MPAS
Model for Prediction Across Sc

Simulation of Hurricane Irma with a 15-3 km Mesh

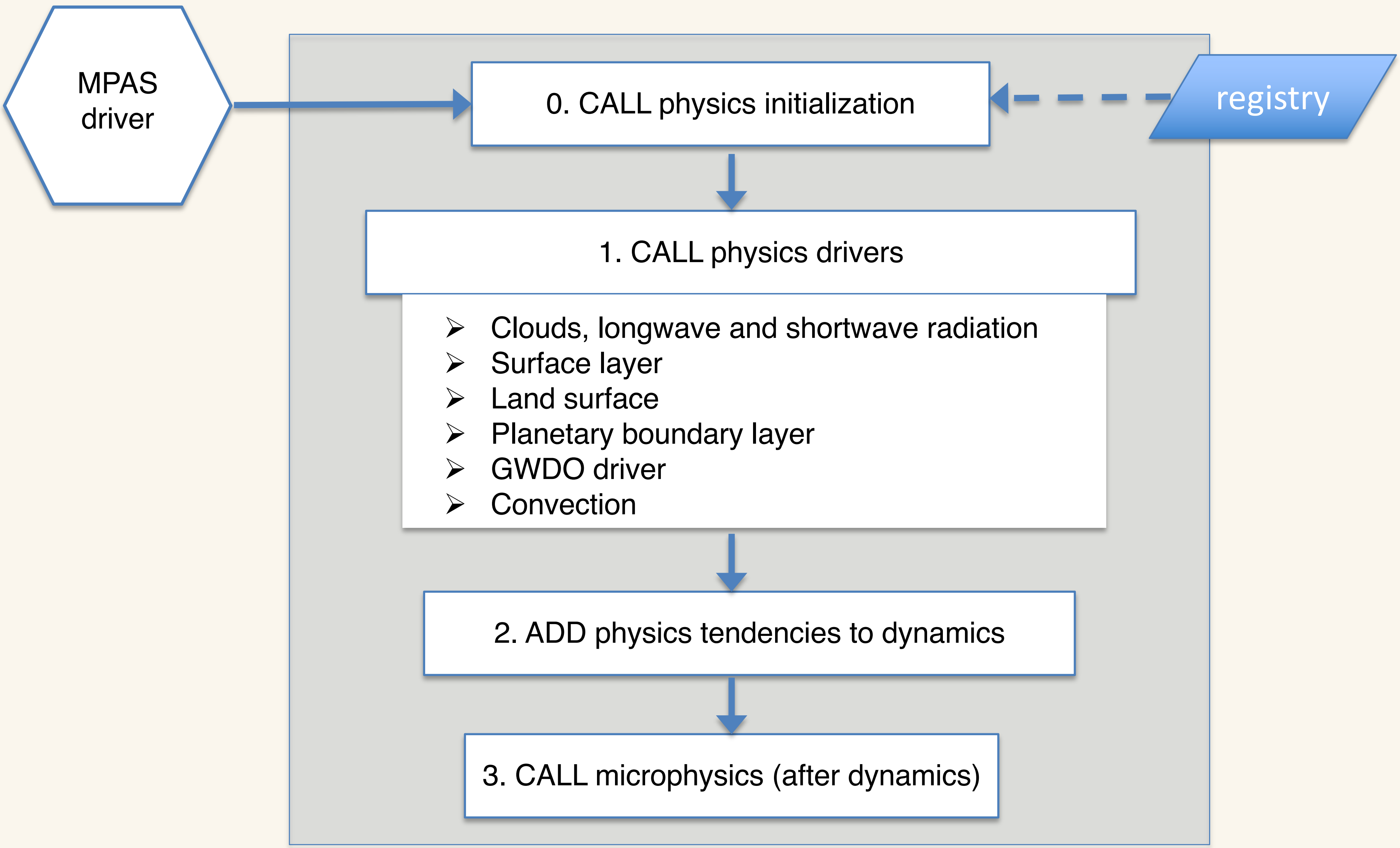
Total Rainfall

Convective Rainfall



MPAS
Model for Prediction Across Scales

MPAS Time Step



MPAS
Model for Prediction Across Scales

Physics Code Structure

MPAS-Model/src/core_atmosphere/physics/

```
Makefile
Registry_noahmp.xml
ccpp_kind_types.F
checkout_data_files.sh
mpas_atmphys_camrad_init.F
mpas_atmphys_constants.F
mpas_atmphys_control.F
mpas_atmphys_date_time.F
mpas_atmphys_driver.F
mpas_atmphys_driver_cloudiness.F
mpas_atmphys_driver_convection.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_init_microphysics.F
mpas_atmphys_initialize_real.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_todynamics.F
mpas_atmphys_update.F
mpas_atmphys_update_surface.F
mpas_atmphys_utilities.F
mpas_atmphys_vars.F
physics_noahmp/
physics_wrf/
physics_mmm/
```

access to data files (checkout_data_files.sh)

drivers for separate physics process (mpas_atmphys_driver*.F)

initialization of separate physics process (mpas_atmphys_camrad_init.F, mpas_atmphys_init.F, mpas_atmphys_init_microphysics.F, mpas_atmphys_initialize_real.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/)

Directory appears after compilation (physics_mmm/)

MPAS
Model for Prediction Across Scales

Summary

1) MPAS has most of the atmospheric and land surface physics.
2) More physics options will be available in MPAS and new development is expected to come from the community.
3) New physics coming into the repository is expected to be CCPP-compliant (CCPP: Common Community Physics Package).
4) Modeling physics is still very challenging, and improving model physics will improve model outcome.

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