Physics
and Physics Configurations in MPAS

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(with contributions from Fowler and Dudhia)

NCAR

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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.

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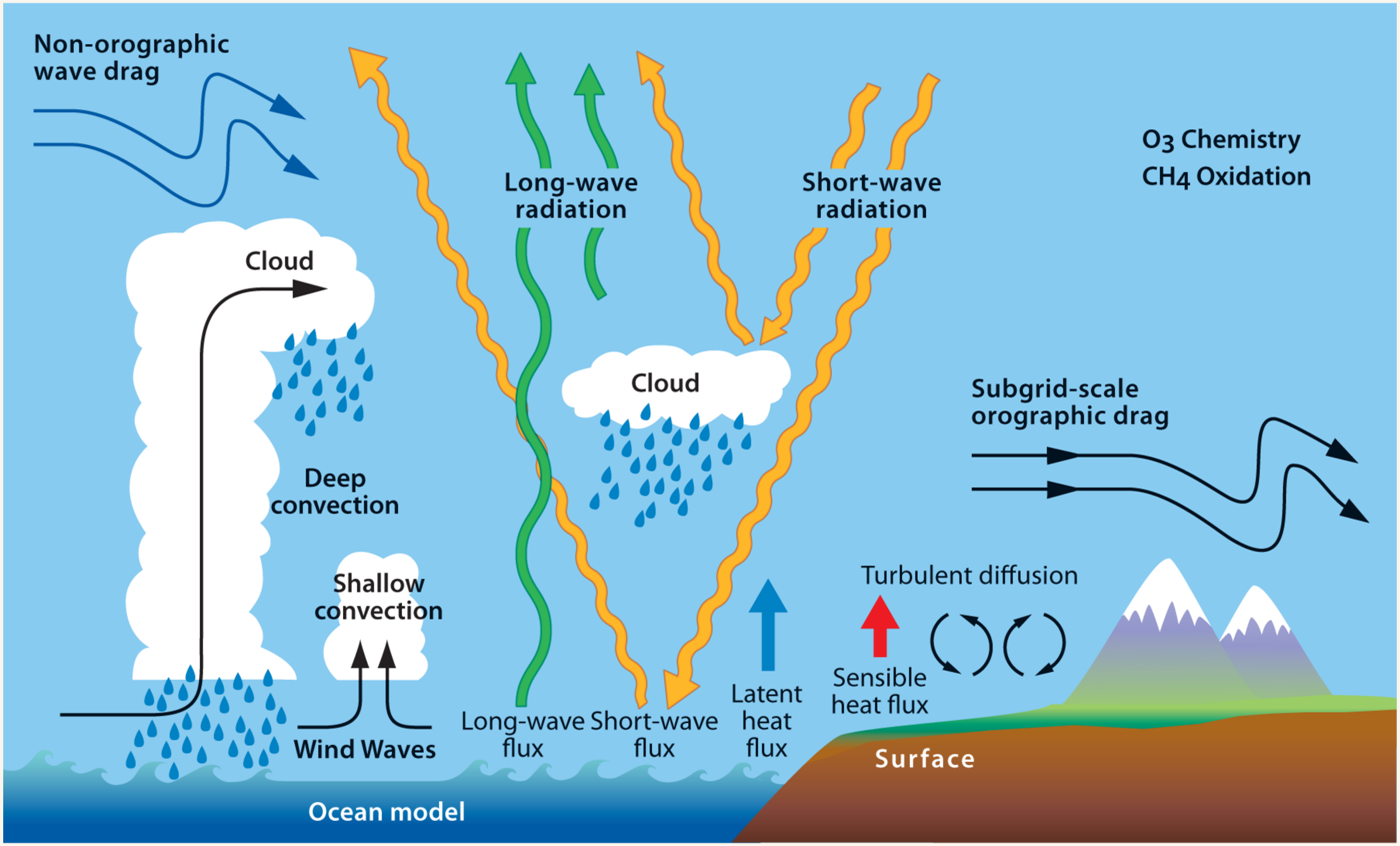
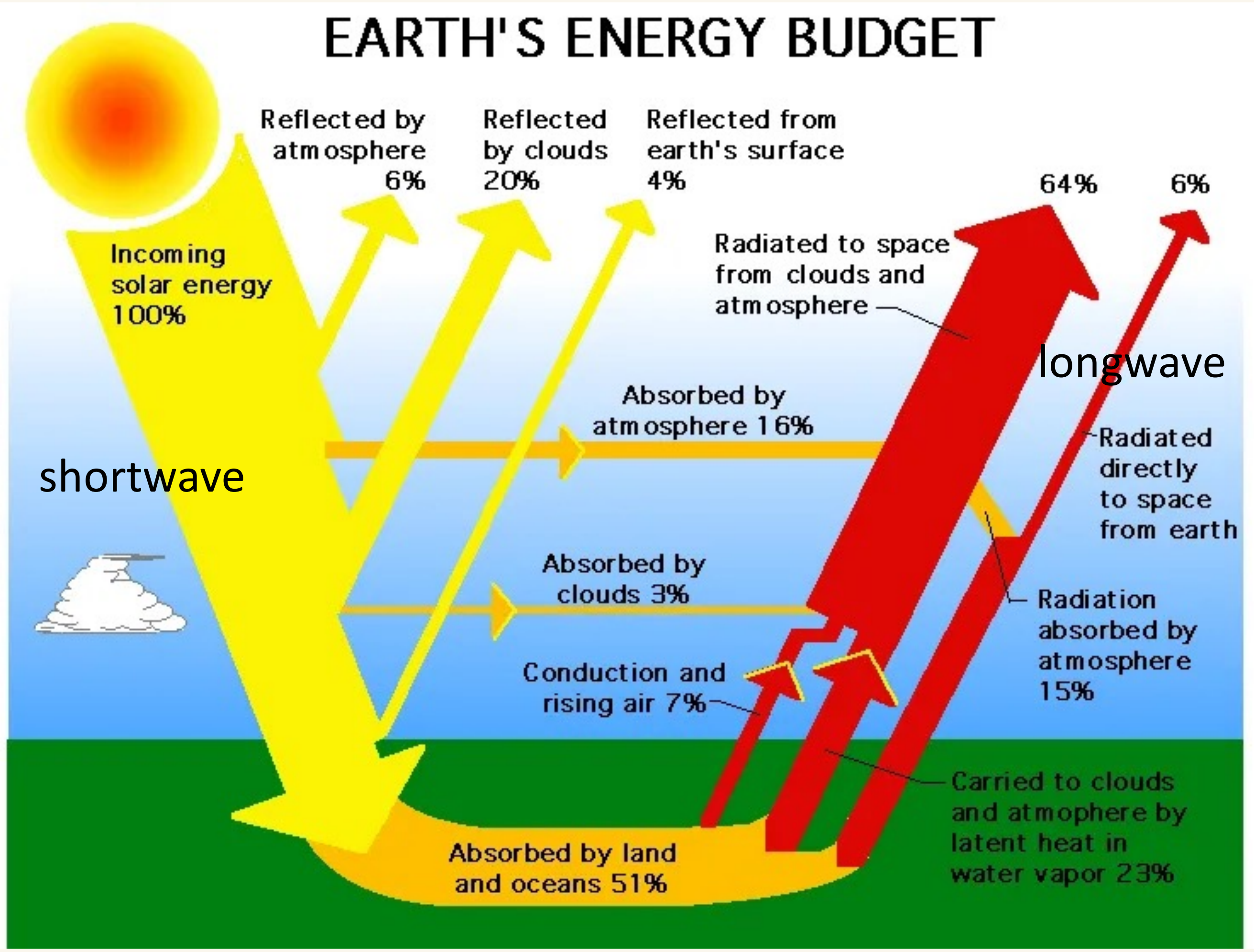
Atmospheric Physical Processes



(From ECMWF)

Radiation Processes



(From UCAR/SCIED)

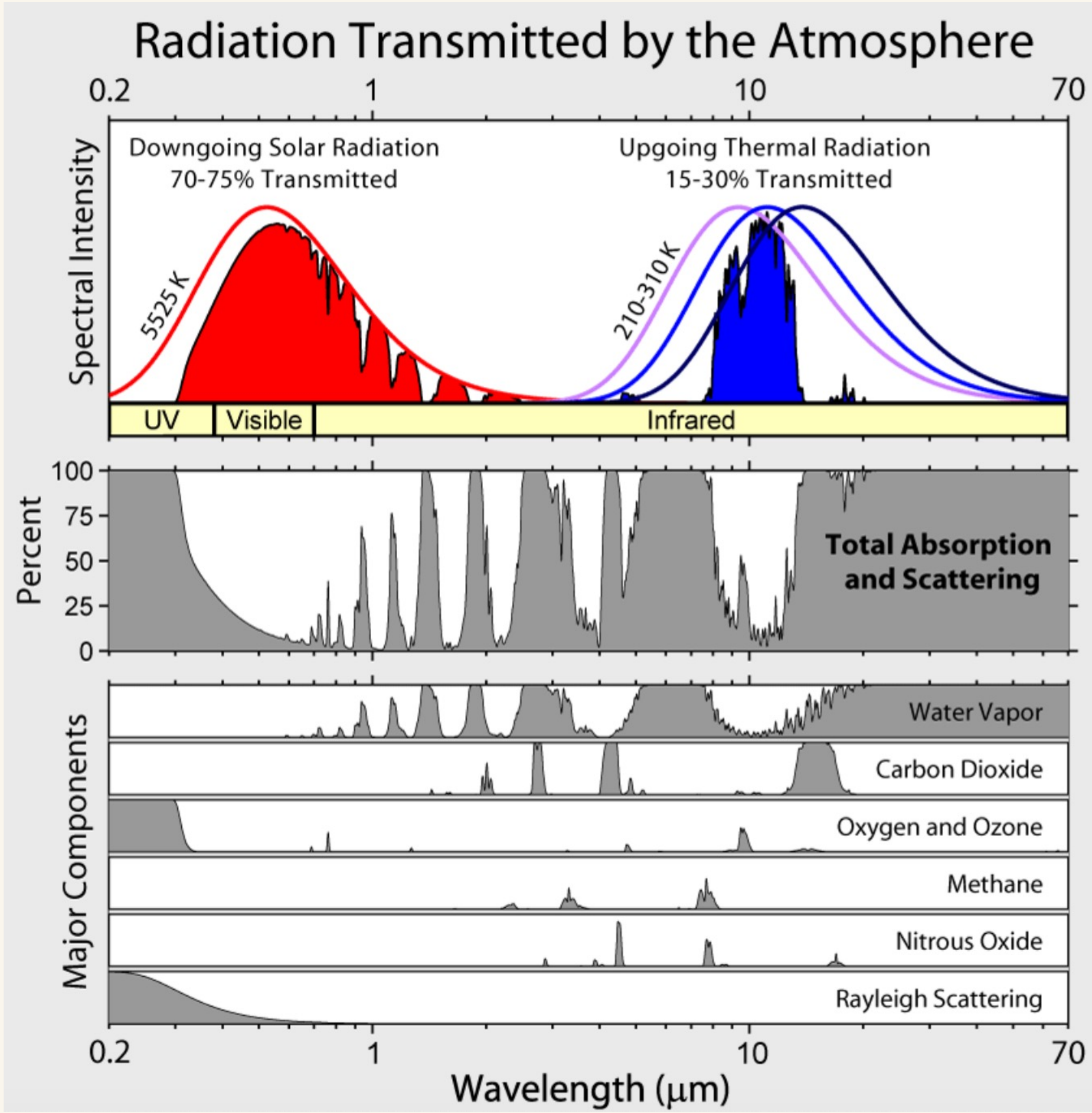
Shortwave: Coming from Sun

Longwave: emitting from surface

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

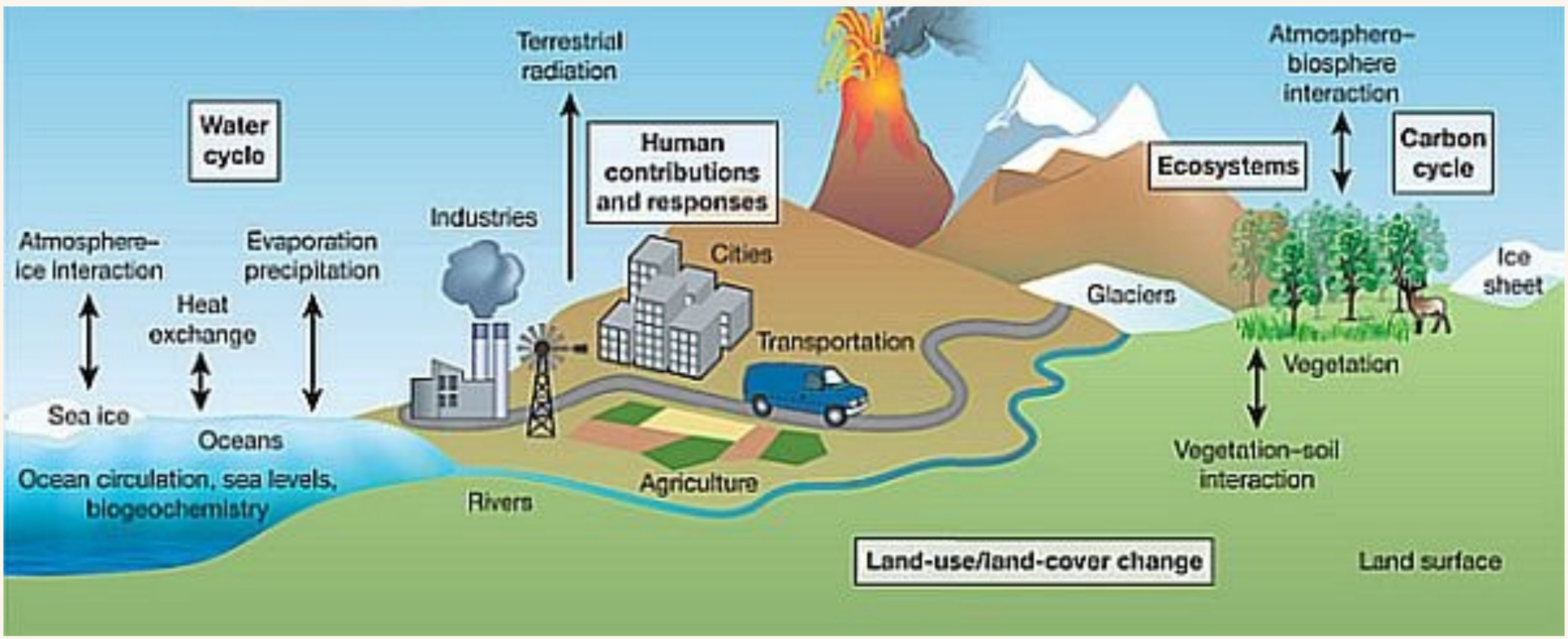
Predicts atmospheric warming (e.g. by absorption) or cooling, and radiation fluxes at the surface.

Radiation Processes



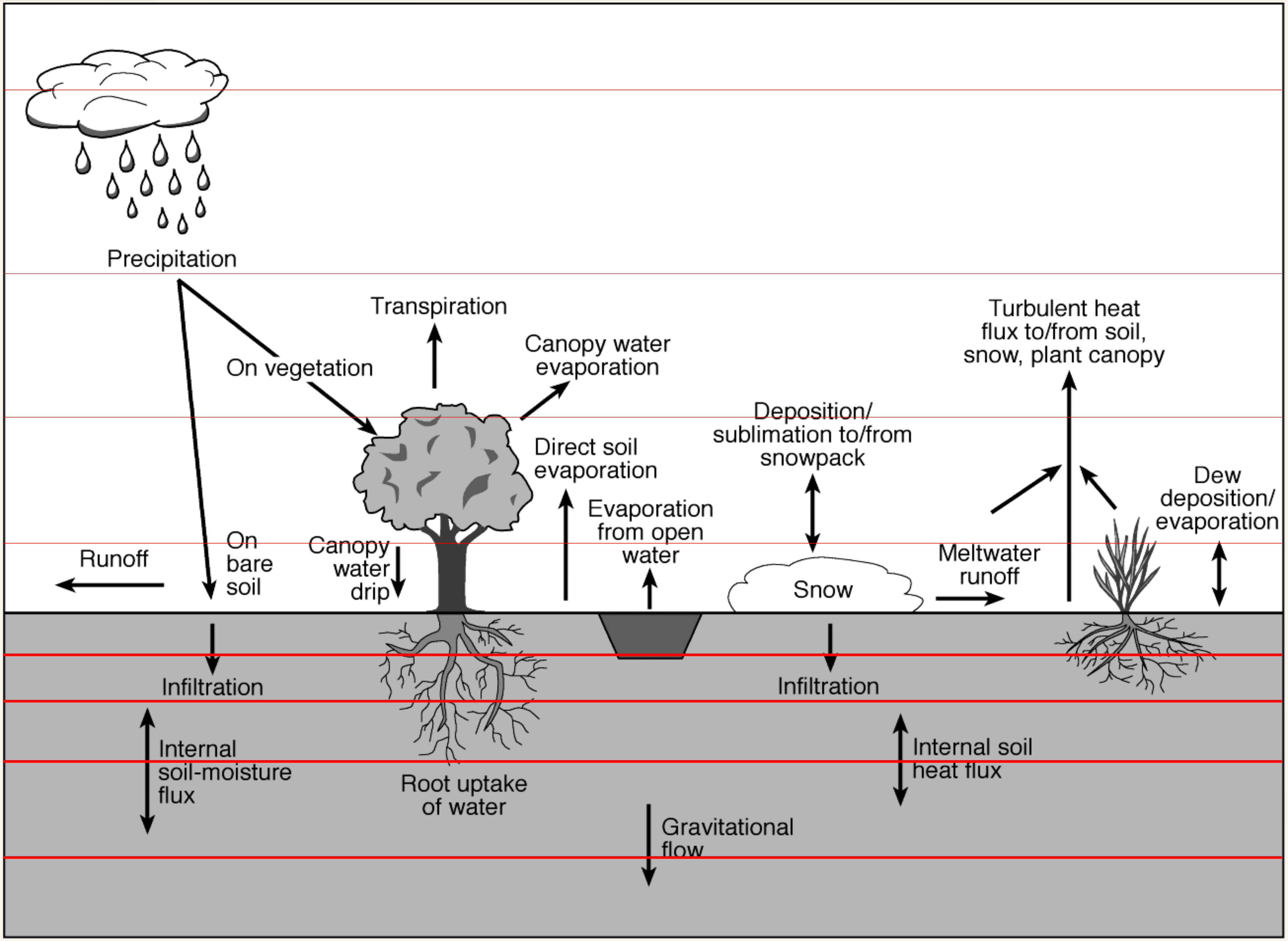
Land and Surface Layer Processes

- Land surface physics considers processes like heat and moisture transfer in the soil layers, vegetation effect, surface runoff and snow.
- Land physics predicts surface fluxes, surface T and Q over land, urban areas, glacier and seaice.
- It represents coupling between land and atmosphere, driven by surface energy budget and water fluxes.



(From Moss et al. 2010)

Land Surface Processes



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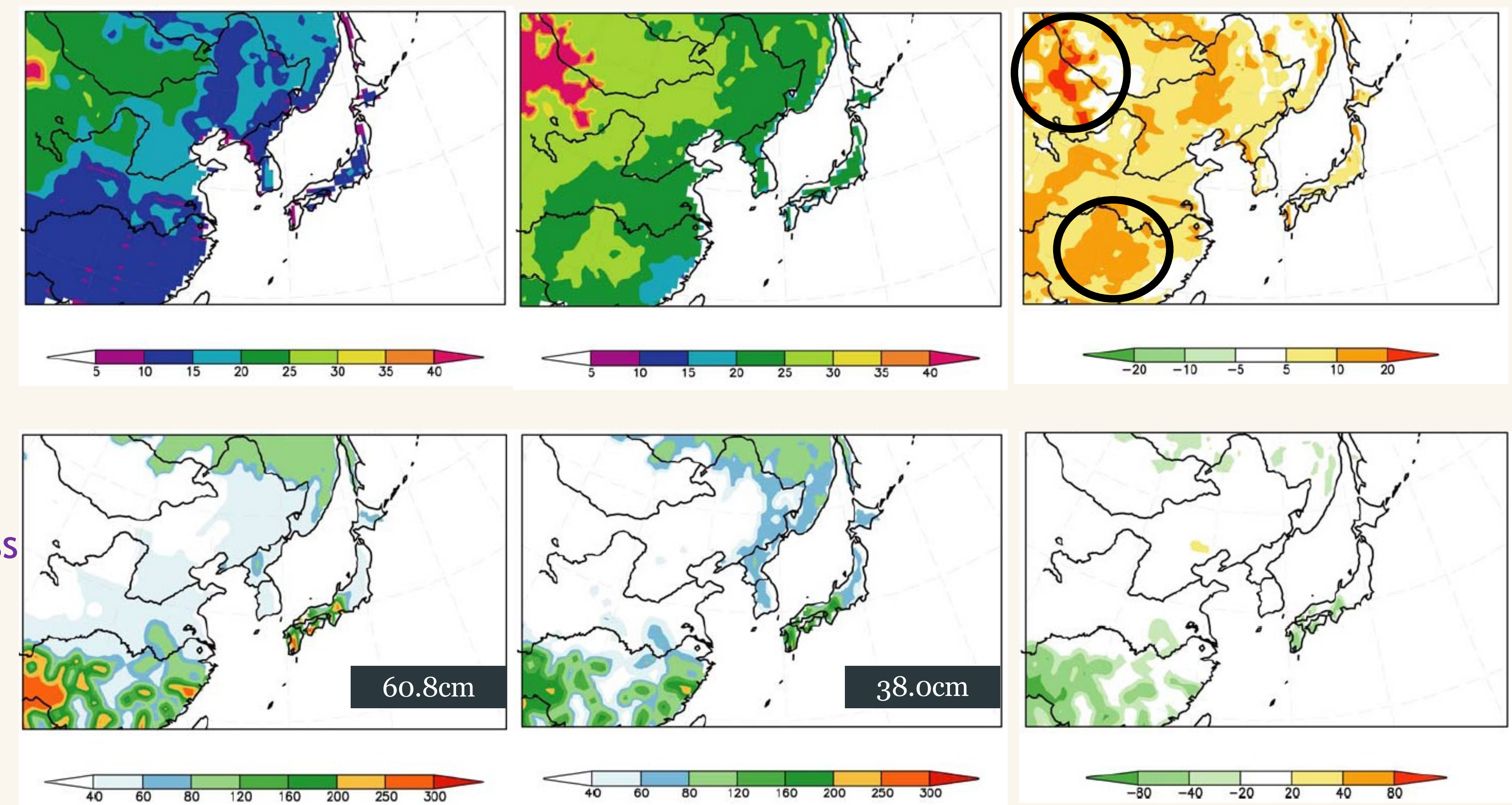
Uncertainties in Input Data

Sib | USGS | USGS-Sib

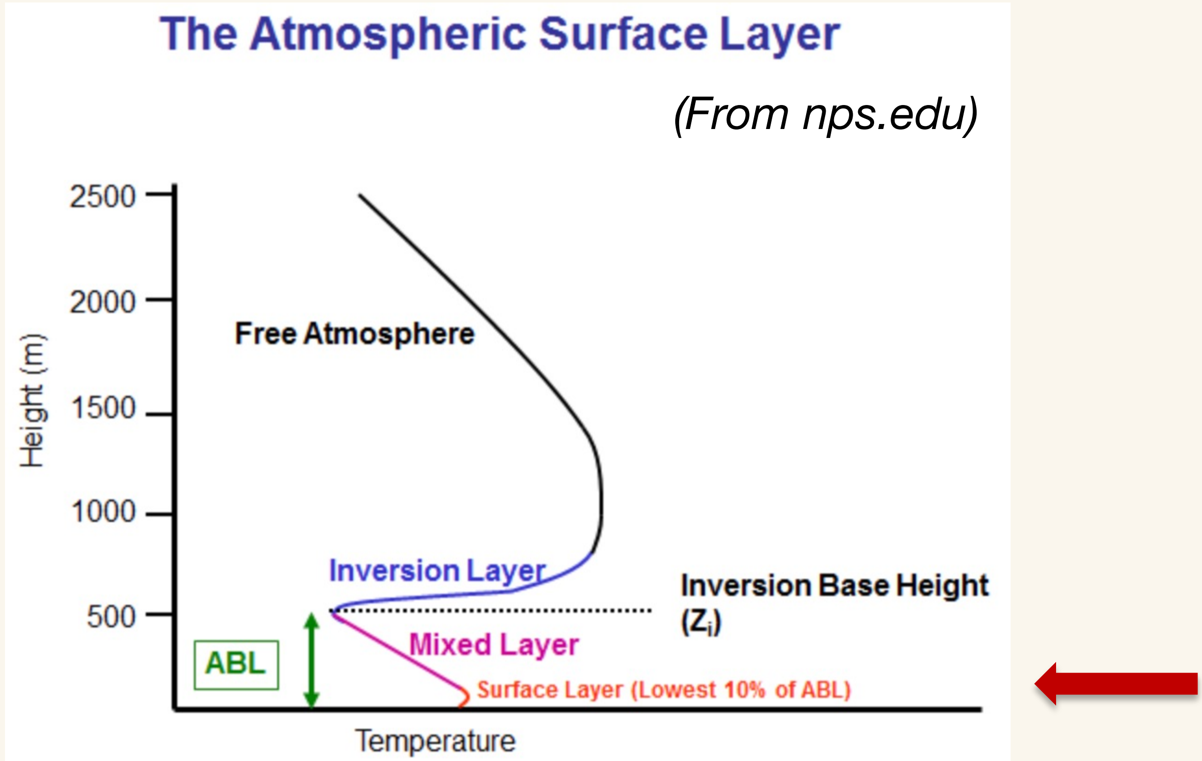
Albedo

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.
- The theory is used to determine exchange coefficients of heat, moisture and momentum between land and atmosphere.

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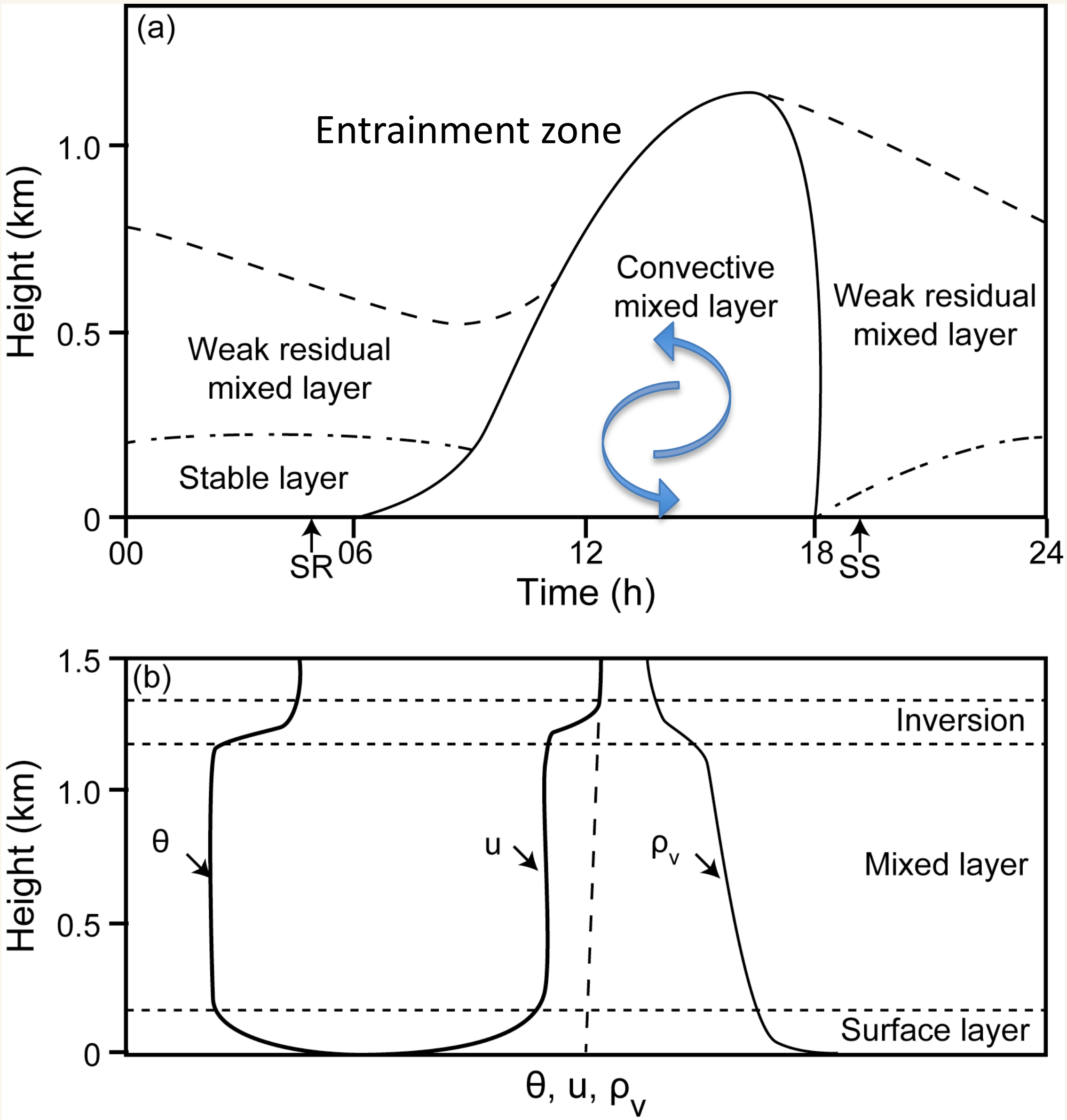
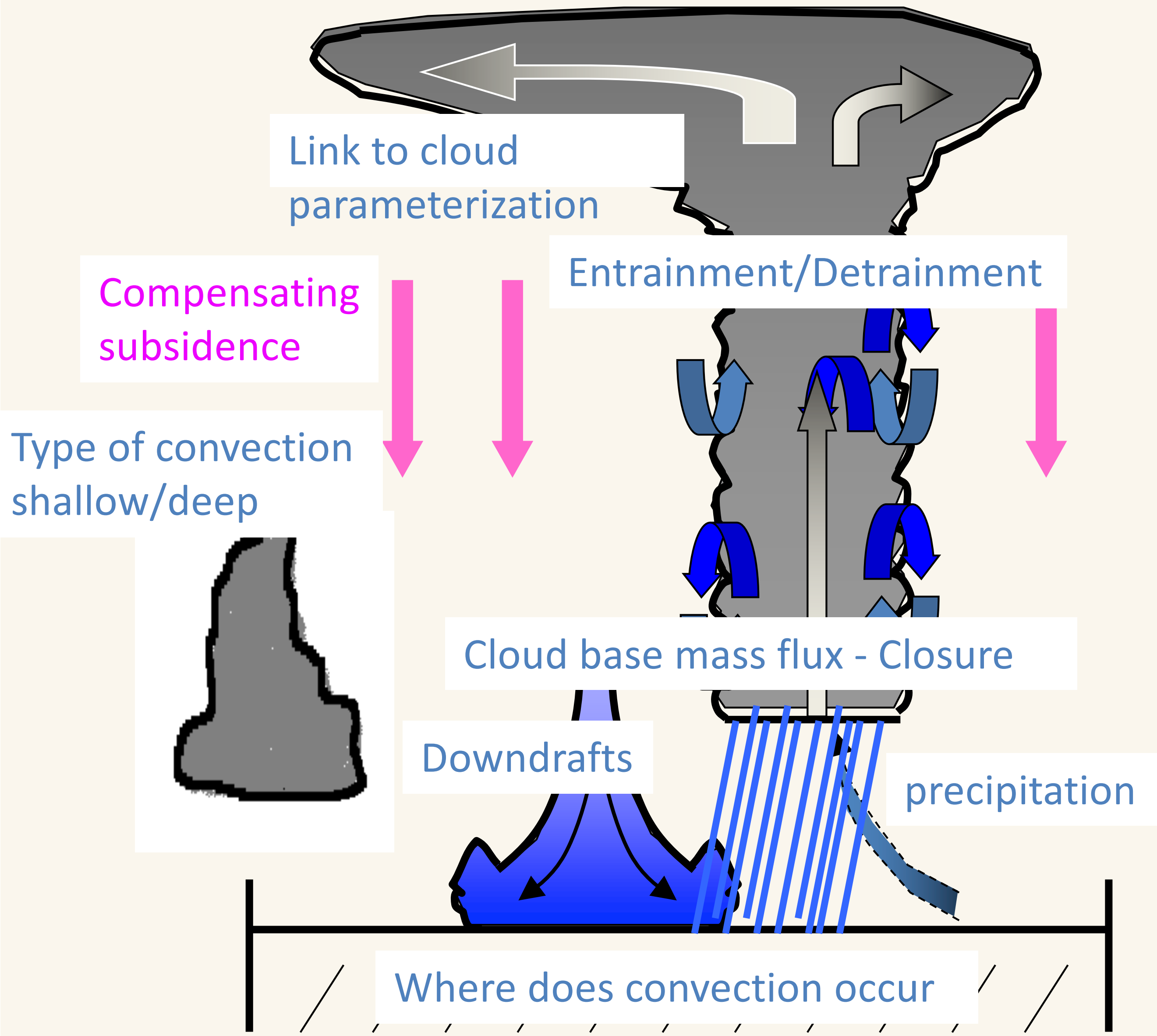
Planetary Boundary Layer Processes



- 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

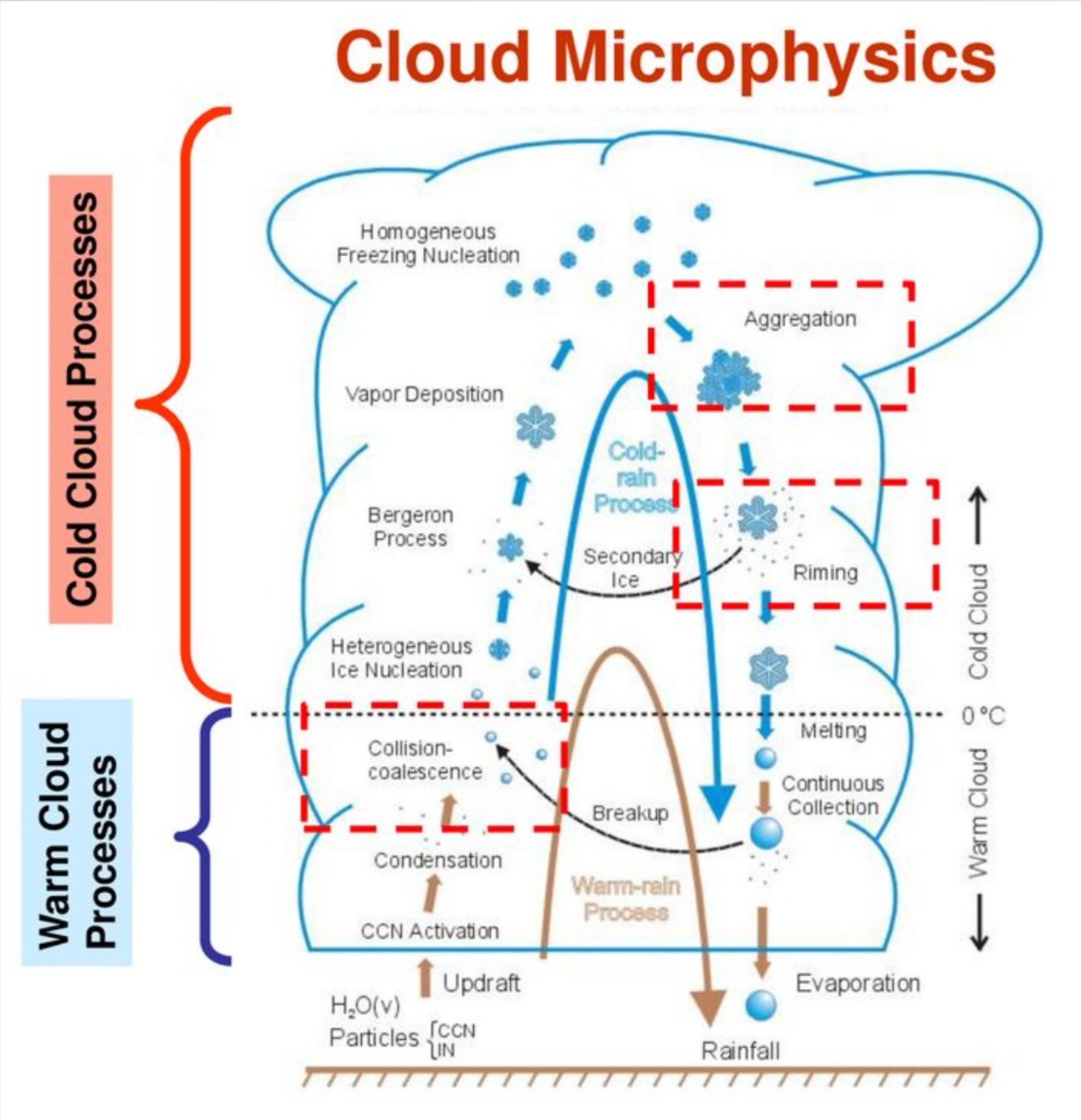
Cumulus Convection Processes



(From ECMWF)

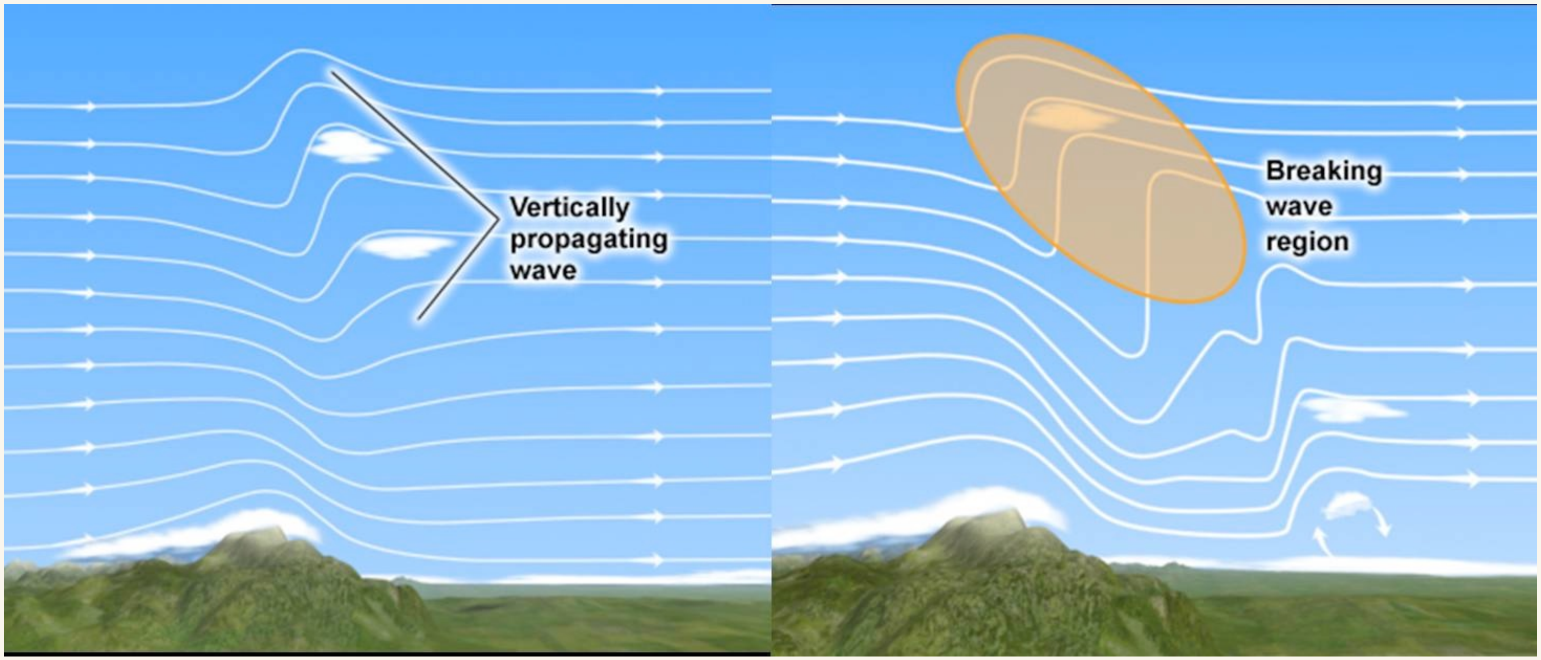
- A convective or cumulus scheme parameterizes convective transport of heat and moisture and its effect on grid scale – warming and drying.
- Include both deep and shallow convection.
- A scheme needs to determine where and when convection occurs and how strong it is.
- Cloud species can be detrained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

Microphysics



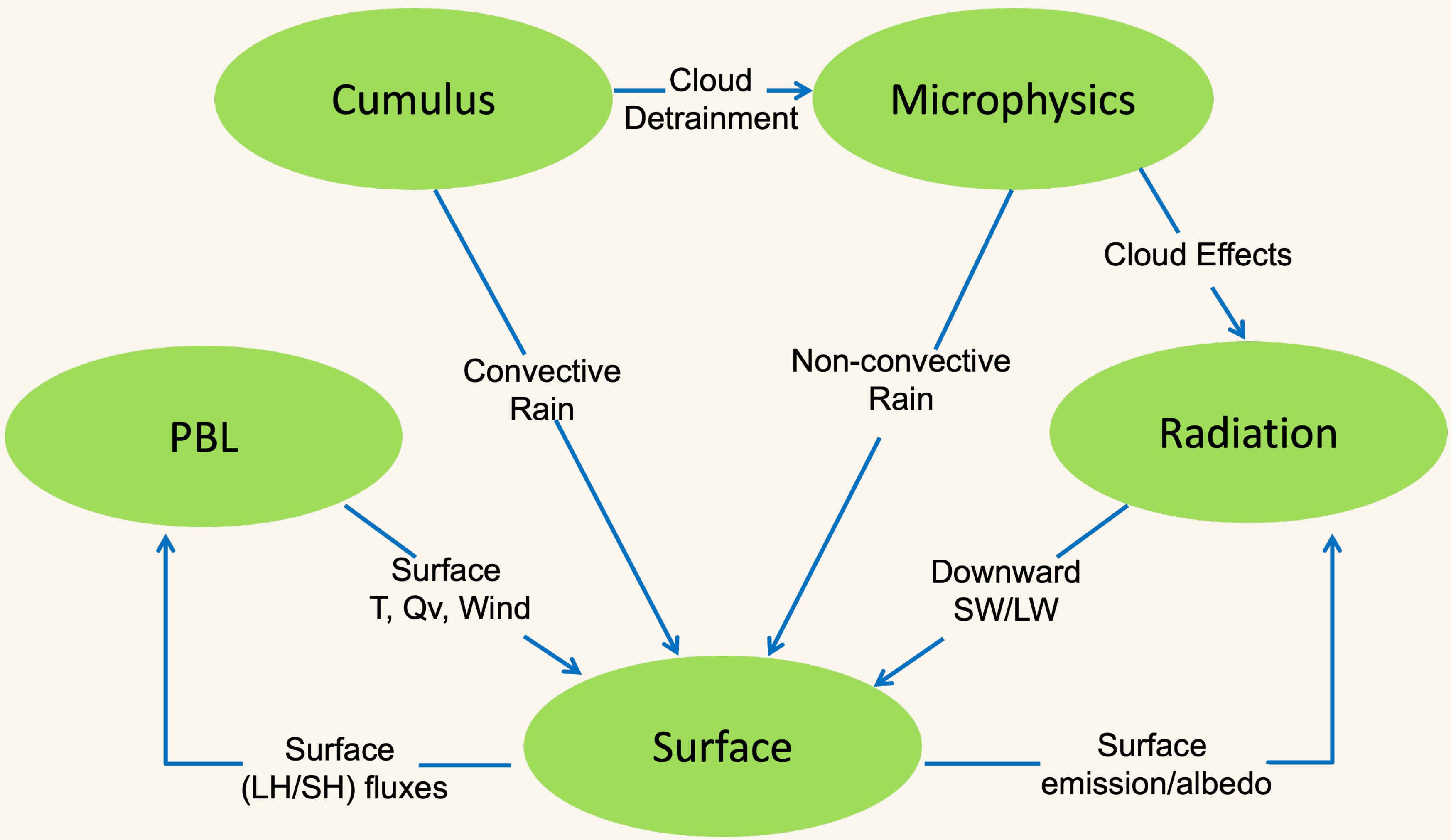
- Model detailed cloud physics. Considers processes like condensation, deposition, evaporation, collection, melting and freezing.
- Predict cloud water/ice, rain/snow, graupel/hail.
- Have different complexity: single moment (like WSM6) which only predicts mass mixing ratios; partial double moment, like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

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



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What does MPAS have in v8.0.1?

Physics	Options
Radiation	RRTMG, CAM
Surface Layer	MM5, Revised MM5, MYNN
Land Surface	Noah
PBL	YSU, MYNN
Microphysics	Kessler, WSM6, Thompson
Convection	New Tiedtke, Grell-Freitas, Kain-Fritcsh, Tiedtke
Ocean	1-D Ocean mixed layer
Orographic Gravity Wave Drag	Choi & Hong

* More options are coming.

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Physics Options in MPAS v8.0.1

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	‘noah’
config_pbl_scheme	‘bl_ysu’, ‘bl_mynn’
config_microp_scheme	‘mp_kessler’, ‘mp_wsm6’, ‘mp_thompson’
config_convection_scheme	'cu_ntiedtke’, ‘cu_grell_freitas’, ‘cu_kain-fritcsh’, ‘cu_tiedtke’
config_oml1d	true
config_gwdo_scheme	‘bl_ysu_gwdo’

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Physics Specification in MPAS

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

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How to Configure Physics?

Example shown 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'
    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

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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.

```
&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_mynn'
/
```

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Physics Specification in MPAS

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:

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

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
/
```

radiation related (config_radtlw_interval, config_radtsw_interval, config_o3climatology)

longer simulations (config_sst_update, config_sstdiurn_update, config_deepsoiltemp_update)

See Chapter 6 and B11 in the User's Guide

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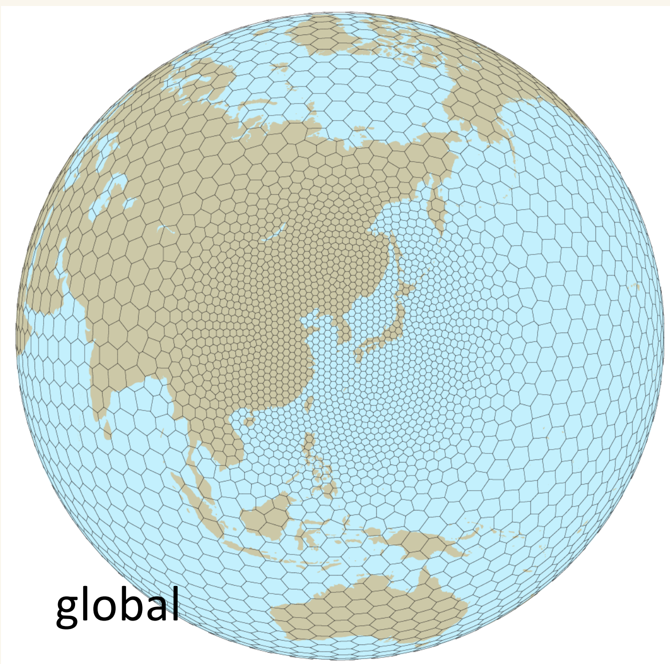
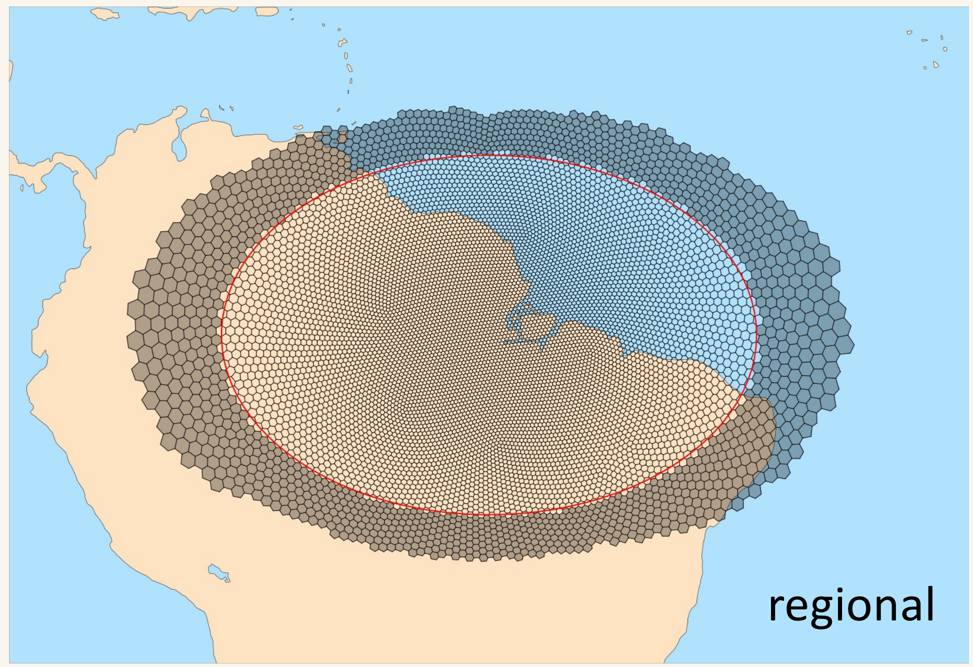
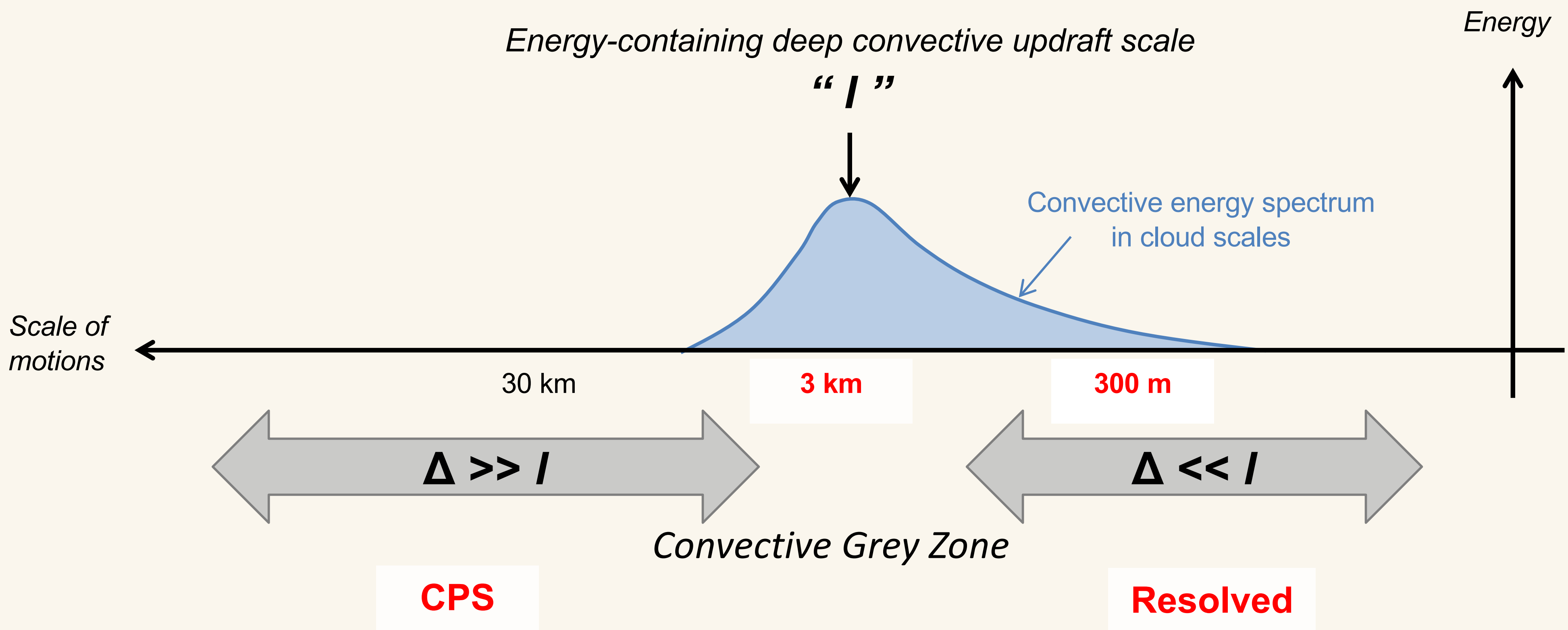
Special Notes for Scale-Aware CPS

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





Special Notes for Scale-Aware CPS



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

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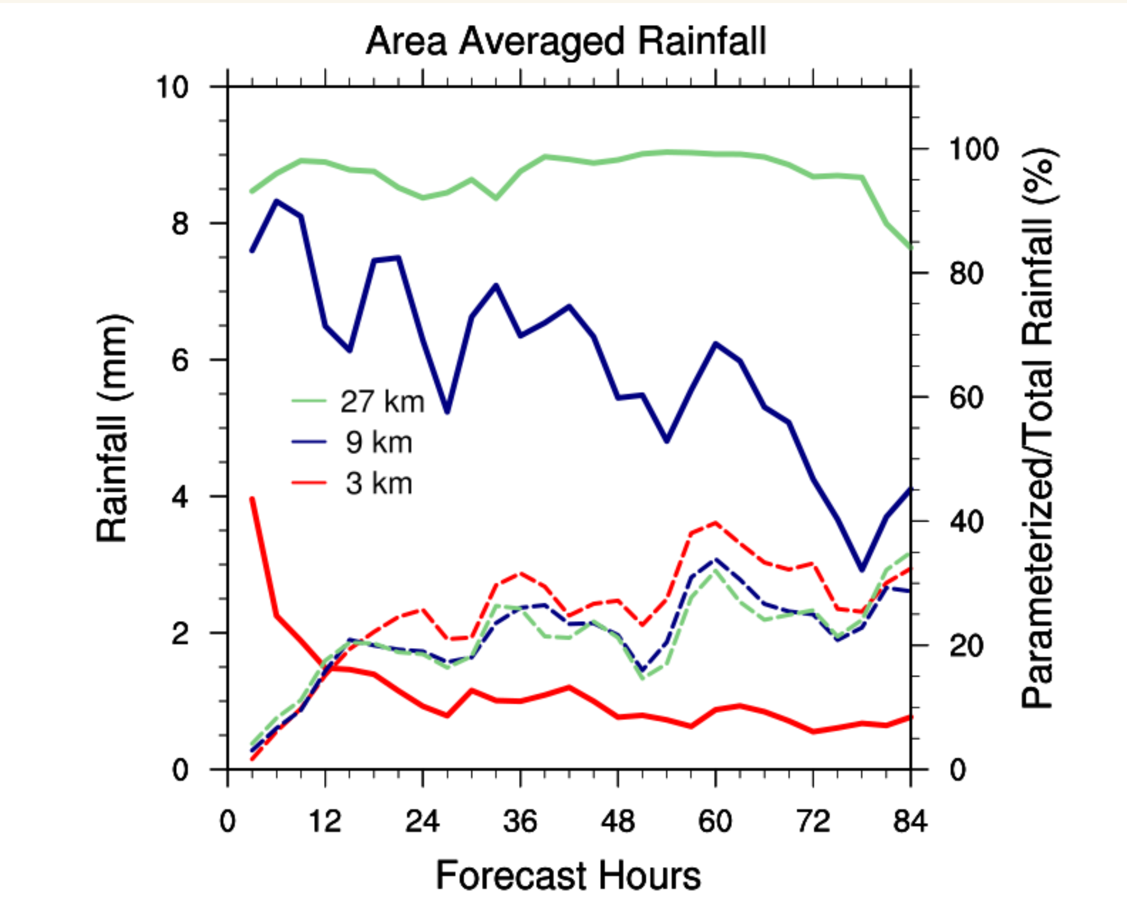
Special Notes for Scale-Aware CPS

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 with WRF
- The convective portion of the rainfall decreases as the grid size decreases from 27 km (green) to 3 km (red)

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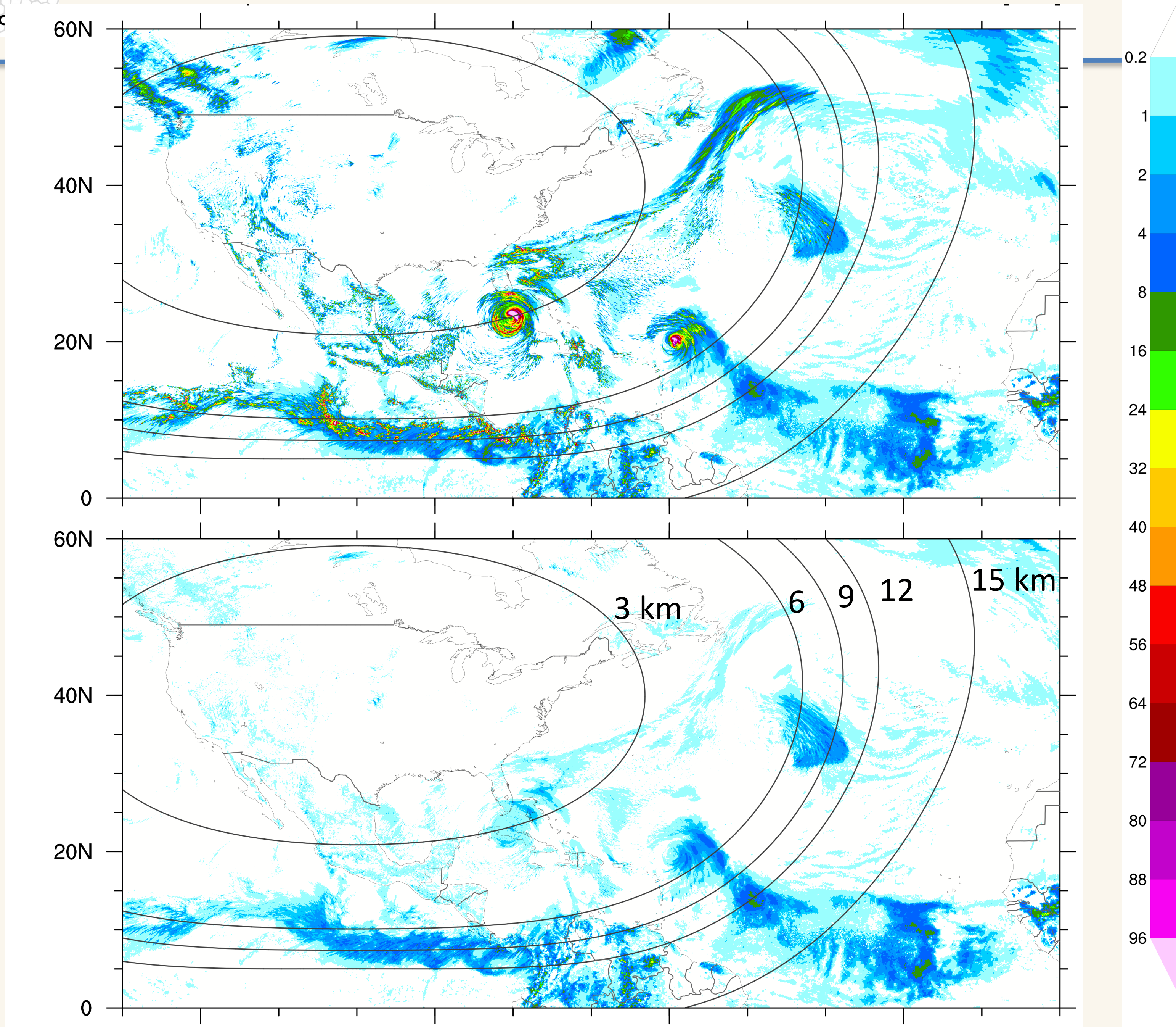
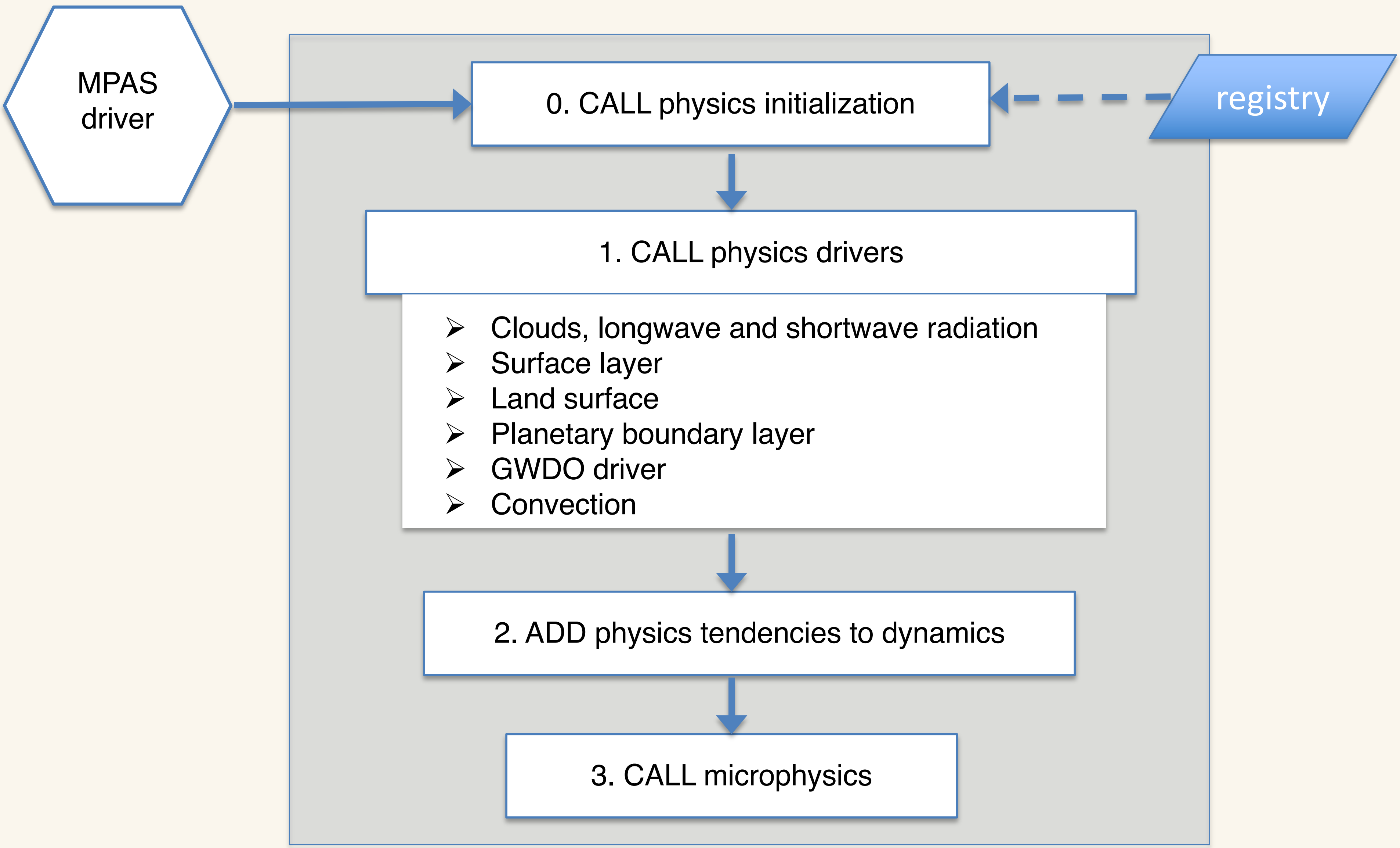
Simulation of Hurricane Irma with a 15-3 km Mesh

Total
Rainfall

Convective
Rainfall



MPAS Time Step



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Physics Code Structure

MPAS-Model/src/core_atmosphere/physics/

```
ccpp_kinds.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_shared.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_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_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_mmm/
physics_wrf/
```

access to data files: checkout_data_files.sh

initialization of separate physics process: mpas_atmphys_camrad_init.F, mpas_atmphys_init.F, mpas_atmphys_initialize_real.F, mpas_atmphys_init_microphysics.F, mpas_atmphys_lsm_noahinit.F, mpas_atmphys_rrtmg_lwinit.F, mpas_atmphys_rrtmg_swinit.F

drivers for separate physics process: mpas_atmphys_driver_cloudiness.F through mpas_atmphys_driver_sfclayer.F

physics modules: physics_mmm/, physics_wrf/

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Summary

1) MPAS has most of the atmospheric and land surface physics.
2) It is not too hard to add a new physics – follow the examples of existing physics.
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