Overview of WRF Physics
Surface Physics

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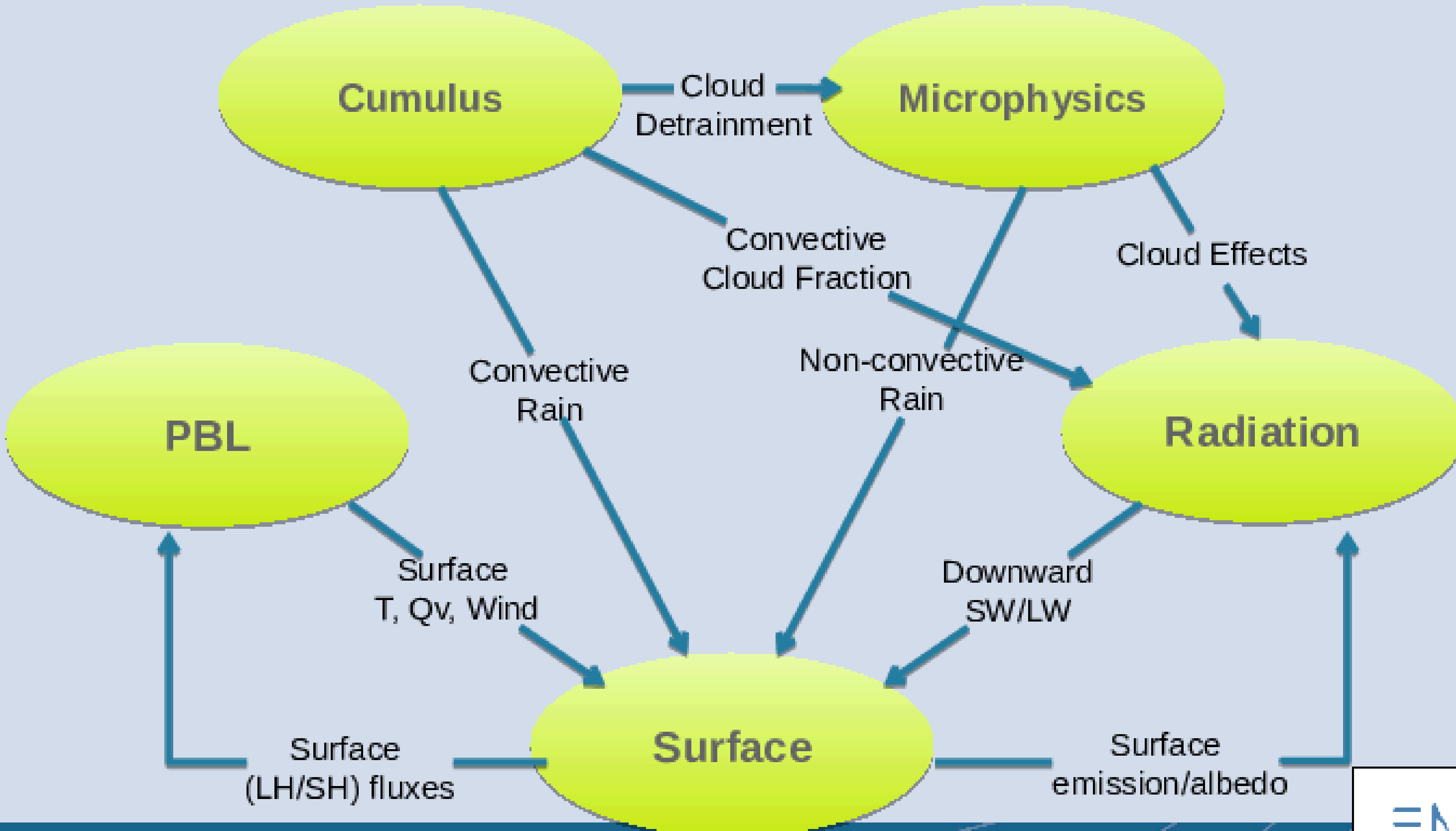
WRF Physics

- Radiation
  - Longwave (ra_lw_physics)
  - Shortwave (ra_sw_physics)
- **Surface**
  - **Surface layer (sf_sfclay_physics)**
  - **Land/water surface (sf_surface_physics)**
- PBL (bl_pbl_physics)
- Turbulence/Diffusion (diff_opt, km_opt)
- Cumulus parameterization (cu_physics)
- Microphysics (mp_physics)

Direct Interactions of Parameterizations



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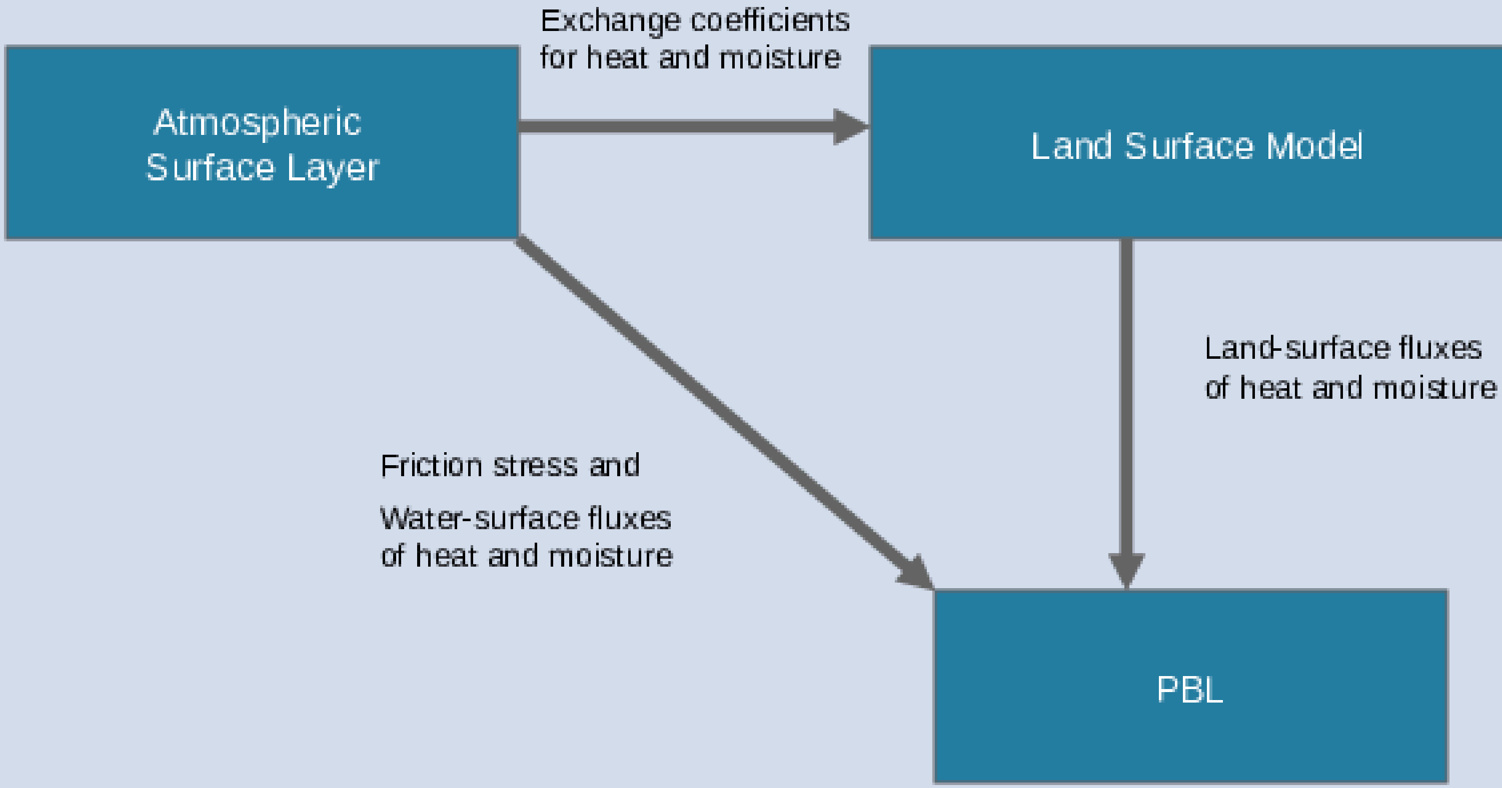
Surface schemes

Surface layer of atmosphere diagnostics (exchange/transfer coeffs)

Land Surface: Soil temperature /moisture /snow prediction /sea-ice temperature

Surface Physics Components

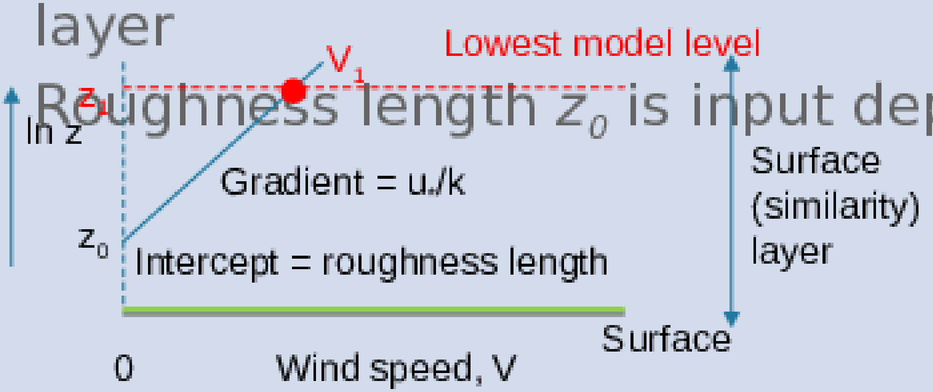


WRF Surface Layer Options (sf_sfclay_physics)

- Use similarity theory to determine exchange coefficients and diagnostics of 2m T and q and 10 m winds
- Provide exchange coefficient to land-surface models
- Provide friction velocity to PBL scheme
- Provide surface fluxes over water points
- Schemes have variations in stability functions, roughness lengths

Surface Layer

- Constant flux layer is about 0.1 x PBL height (~100 m)
- Lowest model level is within this layer (typically 10-50 m)
- Therefore lowest level variables can be used to derive surface fluxes via **similarity theory**
- Example, heat flux
- In similarity theory u_* and θ_* are constant in surface layer
- Roughness length z_0 is input dependent on surface



Neutral case:

$dV/d(\ln z) = u^* / k$

so

$u_* = kV_1 / \ln(z_1/z_0)$

k = 0.4 (von Karman constant)

Roughness Lengths (z_0)

- Roughness lengths are a measure of the “initial” length scale of surface eddies, and generally differ for velocity and scalars
- Roughness length depends on land-use type
- Some schemes use smaller roughness length for heat than for momentum
- For water points roughness length is a function of surface wind speed

Surface Fluxes

- Heat, moisture and momentum

Ψ *(z/L)* is the stability function where z/L is related to surface Ri
Subscript *r* is reference level (lowest model level, or 2 m or 10 m)
Δ refers to difference between surface and reference level value
z_0 are the roughness lengths
k is the von Karman constant (0.4)

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Stability Functions (ψ)

- ψ (*z/L*) modify the log profile
  - Zero for neutral conditions
  - Positive for unstable
  - Negative for stable
  - Look-up table function
- *L* is Monin-Obukhov length
- Note: *z/L* depends on ψ via u_* and θ_* so formula is implicit
- *z/L* is obtained from Ri_b via iteration in revised MM5 surface layer scheme (Jimenez et al.,

$$\frac{z}{L} = k\frac{g}{\theta_a} z \frac{\theta_*}{u_*^2}$$

$$\mathrm{Ri}_b = \frac{g}{\theta_a} z \frac{\theta_{va} - \theta_{vg}}{U^2},$$

$$\mathrm{Ri}_b = \frac{z}{L} \frac{\ln\left(\frac{z}{z_0}\right) - \psi_h\left(\frac{z}{L}\right)}{\left[\ln\left(\frac{z}{z_0}\right) - \psi_m\left(\frac{z}{L}\right)\right]^2},$$

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Stability Functions

- Jimenez et al. 2012 (Revised MM5 similarity theory)
- Ψ_m shown, Ψ_h similar
- Thick grey solid and dashed lines
- Unstable conditions (left)
- Stable conditions (right)

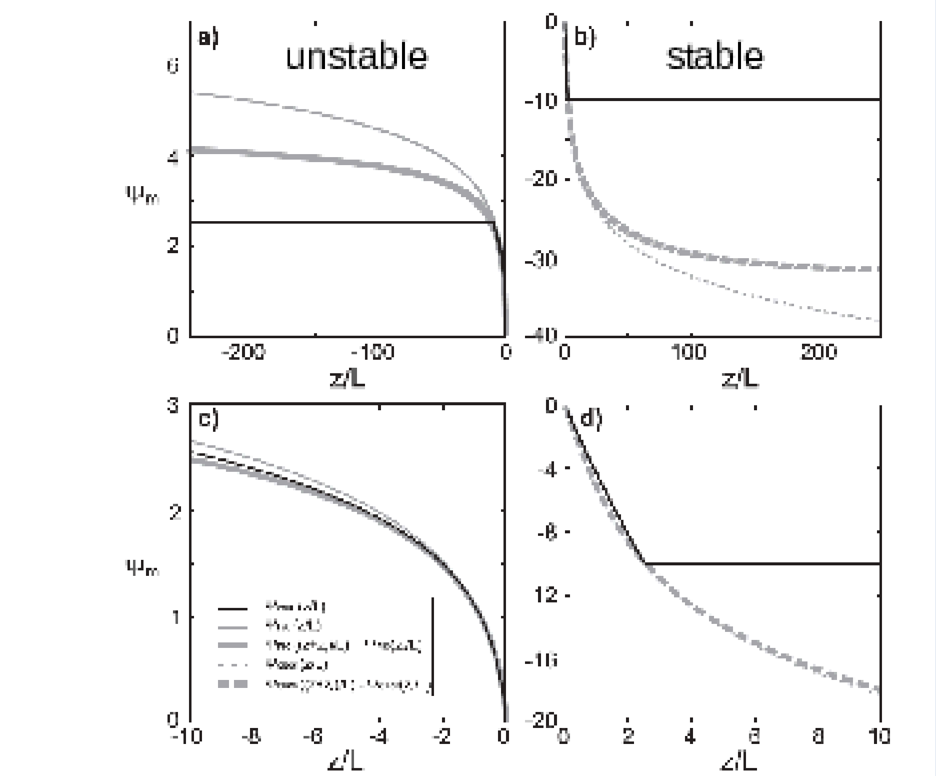

FIG. 3. Integrated similarity functions for momentum associated with (a) unstable and (b) stable conditions. (c),(d) The shape of the corrections near-neutral conditions. Ψ_{WRF} (black lines) is the integrated similarity function for momentum used in the old surface layer formulation, whereas ψ_{P96} is the one used in the new formulation (thin grey lines). The integrated similarity functions including the extra term (thick grey lines) are calculated for $z = 28$ m and $z_0 = 0.15$ m.

Exchange Coefficient

- C_{hs} is the exchange coefficient for heat, defined such that

It is the ratio of surface θ flux $(w'\theta')_s$ to θ difference (units of velocity) required by the land model and is related to the roughness length, stability function and u* by

Hurricane Options

- Ocean Mixed Layer Model (sf_ocean_physics=1)
  - 1-d slab ocean mixed layer (specified initial depth)
  - Includes wind-driven ocean mixing for SST cooling feedback
- 3d PWP ocean (Price et al.) (sf_ocean_physics=2)
  - 3-d multi-layer (~100) ocean, salinity effects
  - Fixed depth
- Alternative surface-layer options for high-wind ocean surface (isftcflx=1,2)
  - Use with sf_sfclay_physics=1
  - Modifies Charnock relation to give less surface friction at high winds (lower Cd)
  - Modifies surface enthalpy (Ck, heat/moisture) either with constant z0q (isftcflx=1), Garratt formulation (option 2)

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Fractional Sea Ice

- fractional_seaice=1 - with input sea-ice fraction data can partition land/water fluxes within a grid box
- Can be used with nearly all surface-layer schemes

WRF Land-Surface Model Options (sf_surface_physics)

- Simple 5-layer soil model
  - No vegetation or snow cover prediction, just thermal diffusion in soil layers
- Noah LSM, NoahMP, RUC LSM, PX LSM, CLM4, SSiB land-surface models
  - Sophisticated vegetation model and snow cover prediction

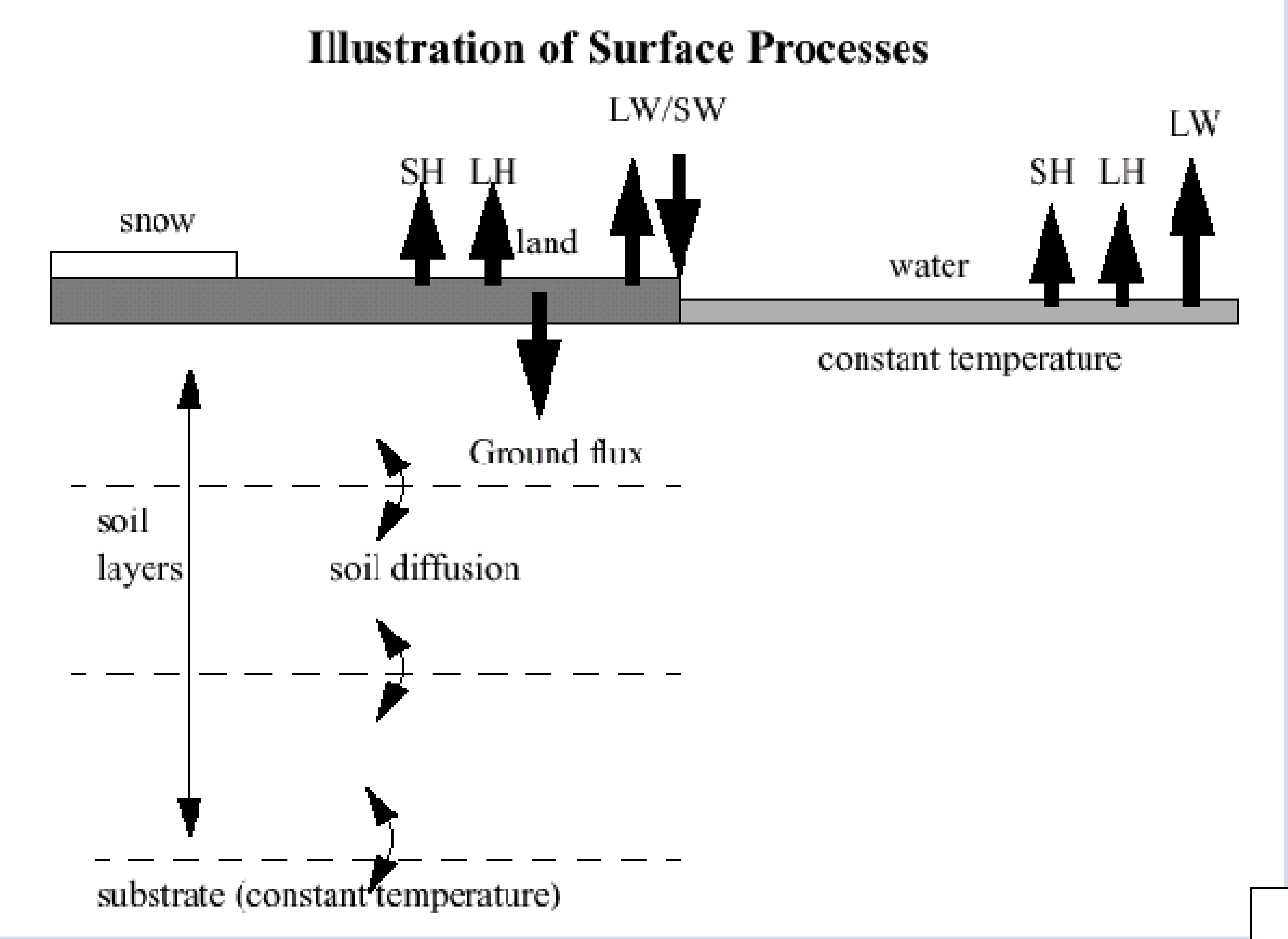
Illustration of Surface Processes
LW/SW
LW
SH
LH
SH
LH
snow
land
water
constant temperature
Ground flux
soil
layers
soil diffusion
substrate (constant temperature)

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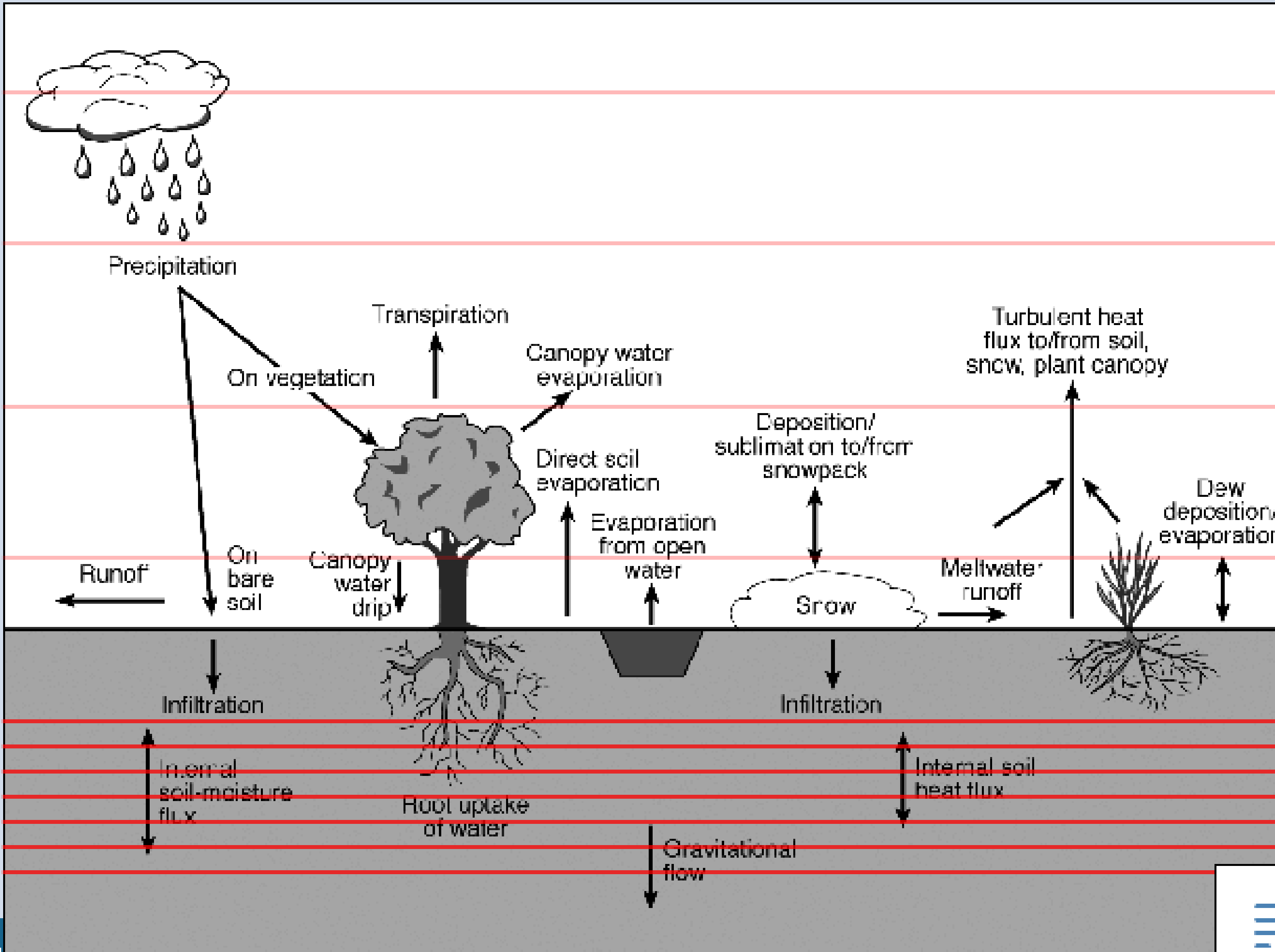
Land-Surface Model Processes



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Land-Surface Model

- Driven by surface energy and water fluxes
- Predicts soil temperature and soil moisture in layers (4 for Noah and NoahMP, 9 for RUC, 2 for PX and 3 for SSiB, 10 for CLM4)
- Predicts snow water equivalent on ground. May be in layers (NoahMP, RUC, SSiB,CLM4)
- May predict canopy moisture only (Noah, RUC) or temperature only (SSiB) or both (NoahMP, CLM4)

Land Surface Models

sf_surface_physics	Scheme	Reference
1	5-layer slab	Dudhia (1996)
2	Noah	Chen and Dudhia (MWR, 2001)
3	RUC	Benjamin et al. (MWR, 2004)
4	Noah-MP	Niu et al. (JGR, 2011), Yang et al. (JGR, 2011)
5	CLM4	Lawrence et al. (JAMES, 2011)
7	Pleim-Xiu	Pleim and Xiu (1995, 2003, JAM)
8	Simple SiB	Xue et al. (JClim, 1991)

Land Surface Models

sf_surface_physics	Scheme	Soil Temperature Layers	Soil Moisture Layers	Snow Layers
1	5-layer slab	5	0	0
2	Noah	4	4	1
3	RUC	6	6	1/2
4	Noah-MP	4	4	3
5	CLM4	10	10	5
7	Pleim-Xiu	2	2	1
8	Simple SiB	2	3	4

Vegetation and Soil

- Processes include evapotranspiration, root zone and leaf effects
- Vegetation fraction varies seasonally
- Considers vegetation categories (e.g. cropland, forest types, etc.)
- Considers soil categories (e.g. sandy, clay, etc.) for drainage and thermal conductivity

Snow Cover

- LSMs include fractional snow cover and predict snow water equivalent development based on precipitation, sublimation, melting and run-off
  - Single-layer snow (Noah, PX)
  - Multi-layer snow (RUC, NoahMP, SSiB,CLM4)
  - 5-layer option has no snow prediction
- Frozen soil water also predicted (Noah, NoahMP, RUC,CLM4)

Urban Effects

- Urban category in LSM is usually adequate for larger-scale studies
- Or can use an urban model (sf_urban_physics) with Noah and NoahMP LSMs
  - Urban Canopy Model
  - Building Environment Parameterization (multi-layer model)
  - Building Energy Model (adds heating/AC to BEP)
  - NUDAPT detailed map data for 40+ US cities

LSM Tables

- Properties can be changed in text files (tables)
- VEGPARM.TBL used by Noah and RUC for vegetation category properties
  - Albedo, roughness length, emissivity, vegetation properties
- MPTABLE.TBL used by NoahMP
- SOILPARM.TBL used by Noah and RUC for soil properties
- LANDUSE.TBL used by 5-layer model
- URBPARM.TBL used by urban models

Initializing LSMs

All LSMs (except slab option) require additional fields for initialization

- Soil temperature
- Soil moisture
- Snow liquid equivalent

- These are in the Grib files, but are not from observations
- They come from “offline” models driven by observations (rainfall, radiation, surface temperature, humidity wind) – part of operational analysis or reanalysis system

Initializing LSMs

- There are consistent model-derived datasets for Noah and RUC LSMs that match the levels in WRF
  - Eta/GFS/AGRMET/NNRP for Noah (although some older datasets have limited soil levels available)
  - RUC for RUC (just North America, limited availability)
- ECMWF/ERA soil analyses can be used and *real.exe* interpolates to WRF soil levels
- But, resolution of mesoscale land-use means there will be inconsistency in elevation, soil type and vegetation
- The only adjustment for soil temperature (done in real.exe) is for elevation differences between the original elevation and model elevation (SOILHGT used)

Initializing LSMs

- Inconsistency leads to spin-up as adjustments occur in soil temperature and moisture at the beginning of the simulation
- This spin-up can only be avoided by running offline model on the same grid (e.g. HRLDAS for Noah) – may take months to spin up soil moisture
- Cycling land state between forecasts also helps, but may propagate errors (e.g in rainfall effect on soil moisture)

Sub-grid Mosaic

- Default behavior is one dominant vegetation and soil type per grid cell
- Noah (sf_surface_mosaic) and RUC (mosaic_lu and mosaic_soil) allow multiple categories within a grid cell
- PX averages properties of sub-grid categories

Sea-Surface Update (sst_update=1)

Reads lower boundary file periodically to update the sea-surface temperature (otherwise it is fixed with time)

- For long-period simulations (a week or more)
- wrflowinp_d0*n* created by *real*
- Sea-ice can be updated
- Vegetation fraction update is included
  - Allows seasonal change in albedo, emissivity, roughness length in Noah LSM
- usemonalb=.true. to use monthly albedo input

Regional Climate Options

- *tmn_update=1* - updates deep-soil temperature for multi-year future-climate runs
- *sst_skin=1* - adds diurnal cycle to sea-surface temperature
- *bucket_mm and bucket_J* - a more accurate way to accumulate water and energy for long-run budgets (see next)
- *output_diagnostics=1* – ability to output max/min/mean/std of surface fields in a specified period (e.g. daily)

Accumulation Budgets

- Some outputs fields are accumulated from simulation start
- These include rainfall totals (mm or kg/m^2) RAINC, RAINNC, and radiation totals (J/m^2), ACLWUPT, ACSWDNB, etc.
- Averages over any period can use just the output at the end minus beginning and dividing by the interval
- But for **regional climate** simulations (months), 32-bit accuracy makes adding small time-step values to accumulated totals inaccurate since only about 7 significant figures are stored.
- We use *bucket_mm* and *bucket_J* to carry total in Integer and Remainder parts, e.g.
- Total rain = *RAINC* + *I_RAINC**bucket_mm*
- Default bucket value is typical monthly accumulation
  - *bucket_mm*=100 mm and *bucket_J*=10^9 Joules

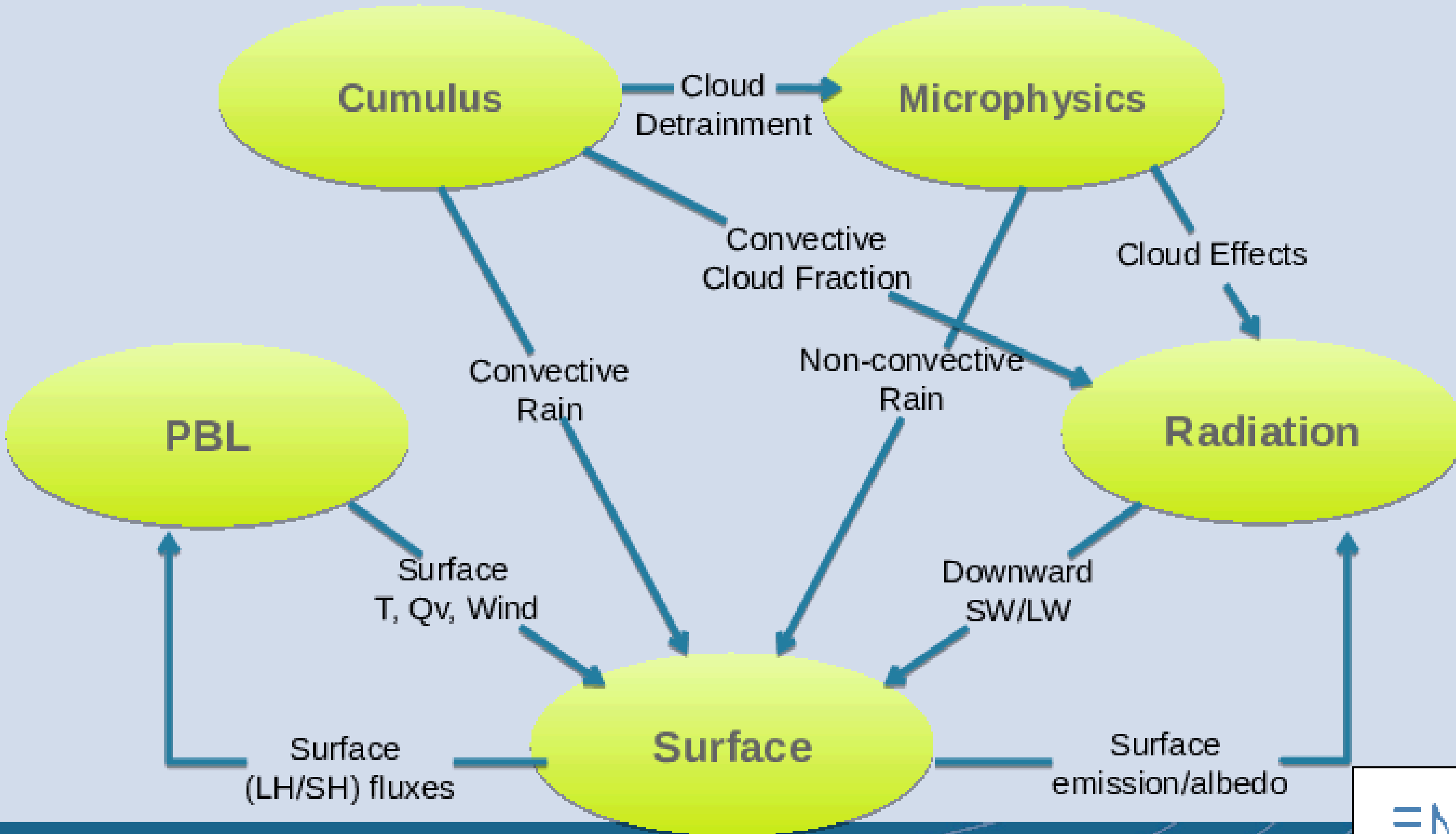
Lake Model

- 10-layer lake model from CLM (sf_lake_physics=1)
- We have global bathymetry data for most large lakes (added from geogrid)
- Also can predict lake ice
- Can be used with any LSM
- WPS preprocessing allows diurnal averaging methods to initialize lake temperatures where not resolved by SST analysis (TAVGSFC)

WRF-Hydro

- Coupling to hydrological model available
- Streamflow prediction, etc.
- Sub-grid tiling to ~100 m grid
- Requires special initialization for hydrological datasets

Direct Interactions of Parameterizations



Surface Physics Summary

- Surface Layer
  - Roughness lengths, surface fluxes, stability function, exchange coefficient, hurricane options, fractional sea ice,
- Land Surface Model
  - Vegetation, soil, snow cover, urban effects, LSM tables, initializing LSMs, sub-grid mosaic
- Regional Climate options
  - sst_update switch, accumulation budgets, lake model
- WRF-Hydro

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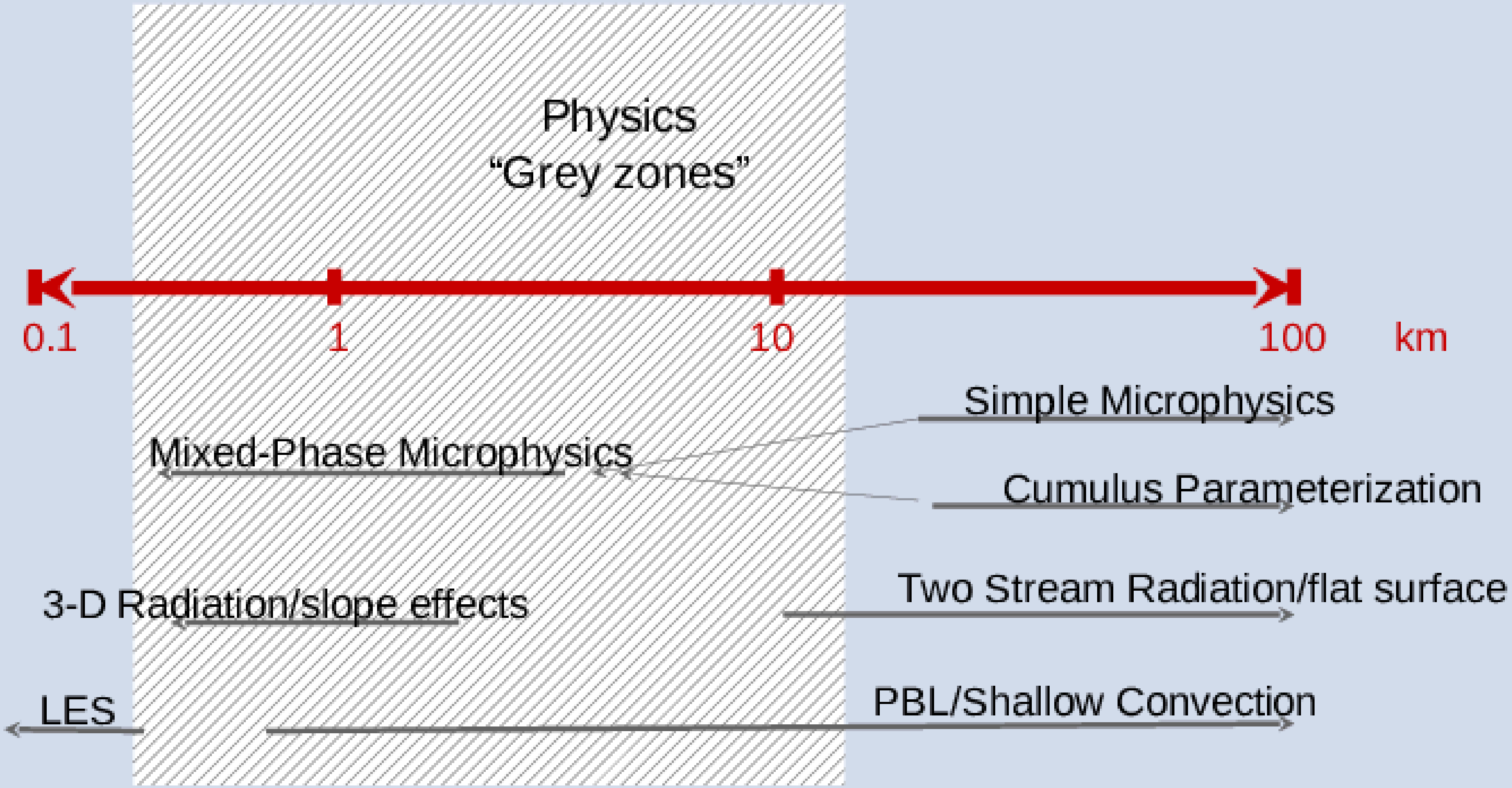
Physics in Multiscale NWP Model

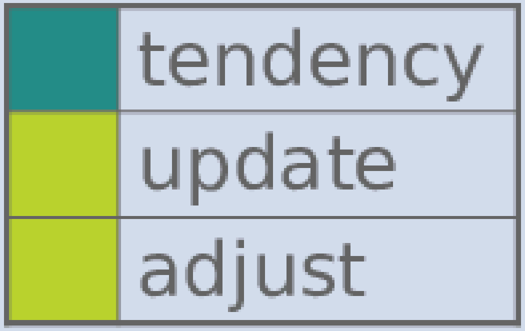


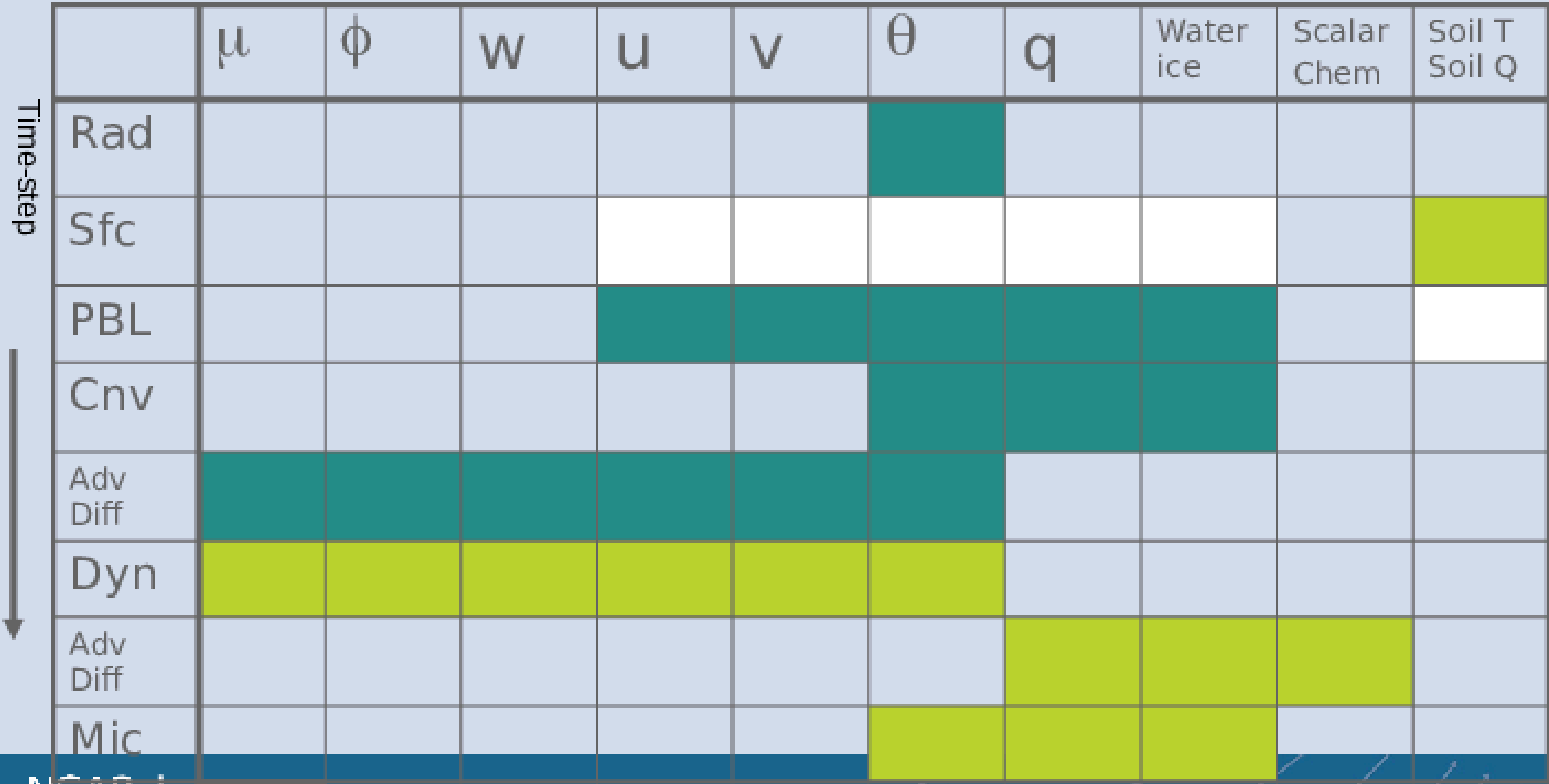
Solver Calling Sequence

Call to solver advances one domain by one model time-step

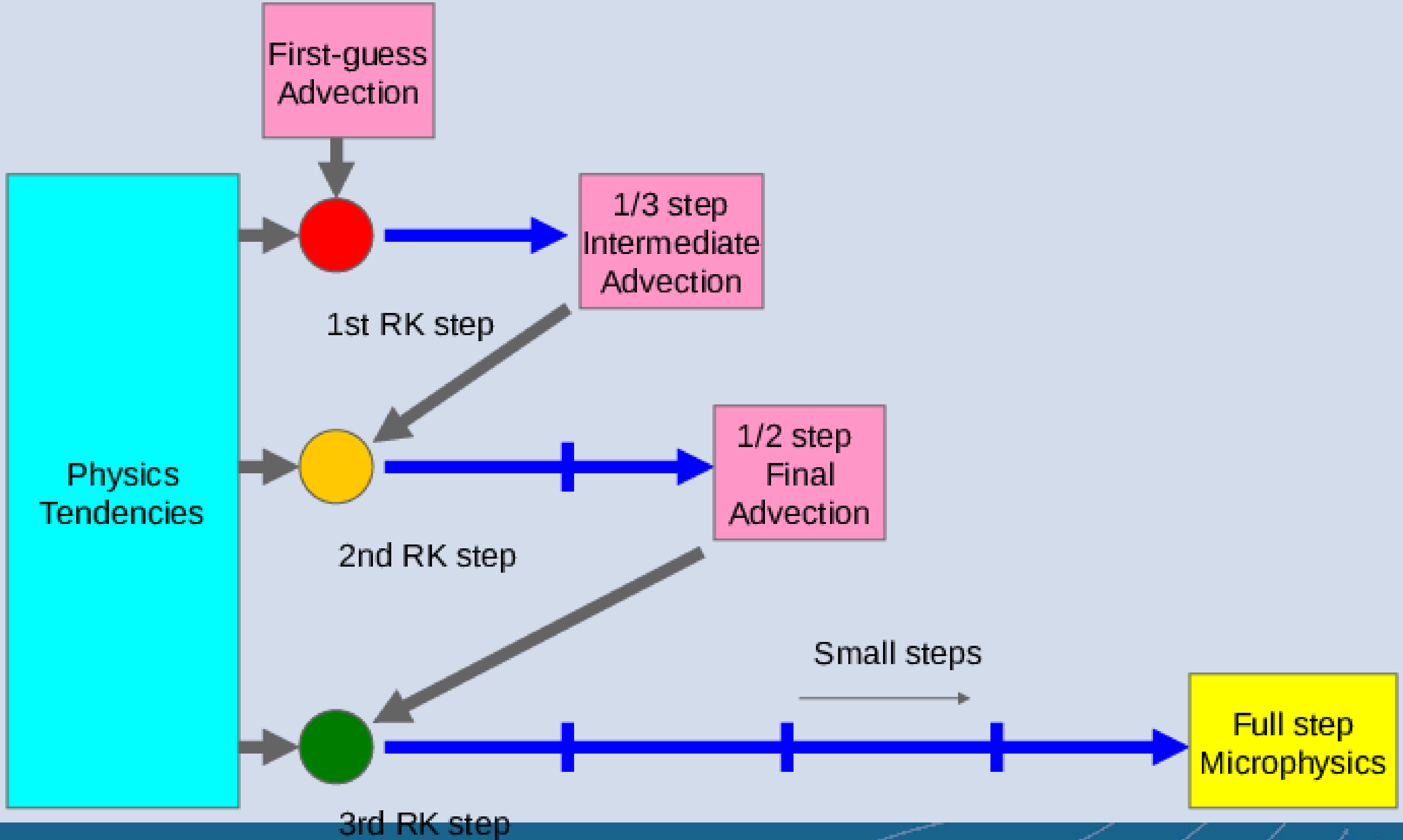
- Physics tendencies
  - Radiation, surface, land-state update, PBL, cumulus, grid-fdda, obs-fdda
- Dynamics tendencies
  - Diffusion, advection, dynamics terms (for 3d momentum, theta, geopotential, surface pressure)
- Acoustic steps
  - Update 3d momentum, theta, surface pressure, height
- Scalar dynamics tendencies and update
  - Advection, diffusion of moist (qv,qc, etc.), scalar, tracer, tke, (and chemistry) variables
- Microphysics update

ARW Solver Sequence





ARW time-step schematic



&physics (namelist.input)

Seven major physics categories:

- **mp_physics**: 0,1,2,3,…
- **ra_lw_physics**: 0,1,3,…
- **ra_sw_physics**: 0,1,2,3,…
- **sf_sfclay_physics**: 0,1,2, …
- **sf_surface_physics**: 0,1,2,3,… (set before running **real** or **ideal**, need to match with **num_soil_layers** variable)
  - **sf_urban_physics**: 0, 1, 2, 3
- **bl_pbl_physics**: 0,1,2,…
- **cu_physics**: 0,1,2,3,…

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