Overview of WRF Physics
Microphysics

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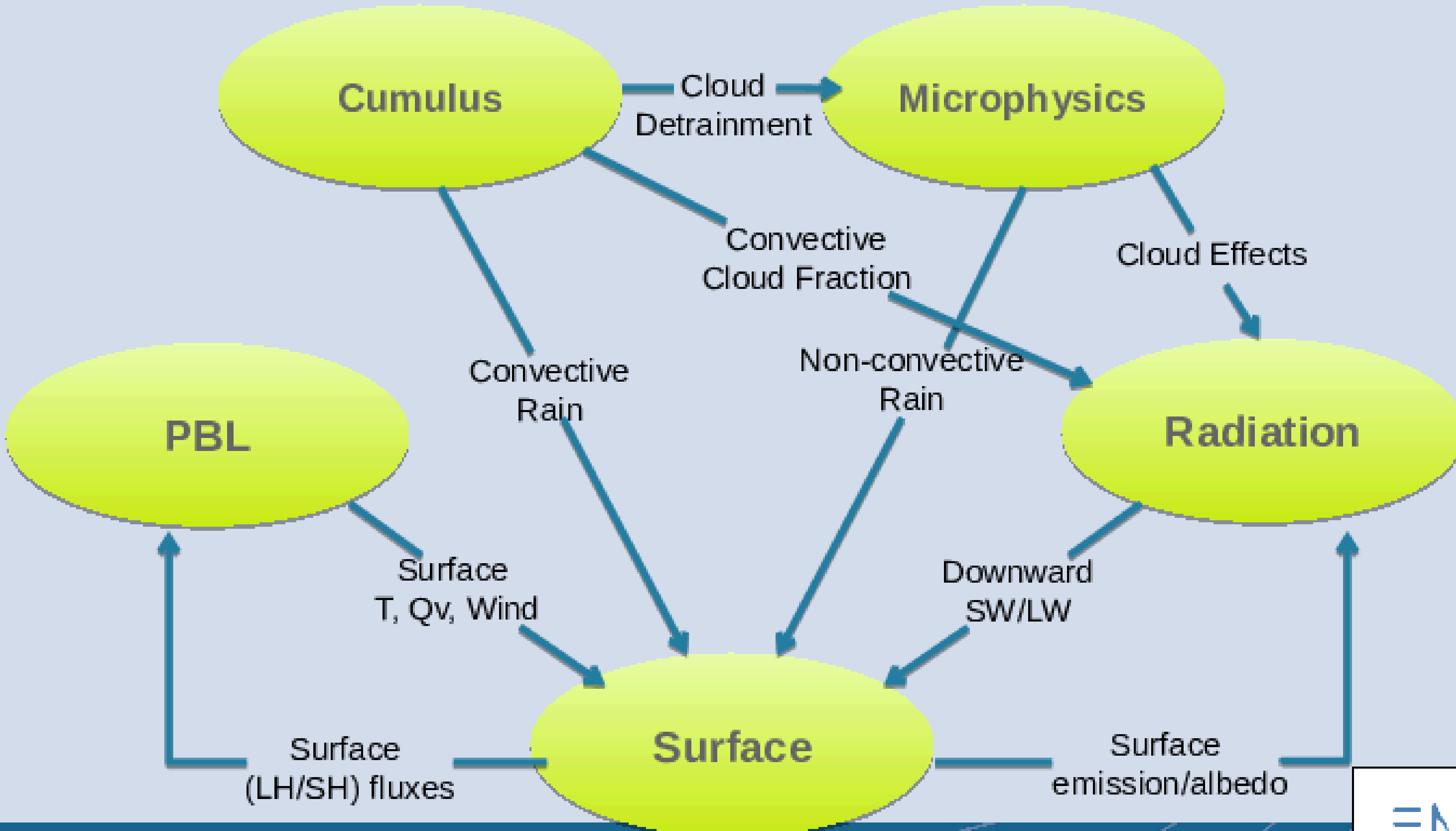
WRF Physics

- 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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Microphysics

Provides

Atmospheric heat and moisture tendencies

Microphysical rates

Surface resolved-scale rainfall

Resolved clouds

- Formed by radiative, dynamical or convective processes
- Model only considers grid-scale average so will not resolve fine-scale structures

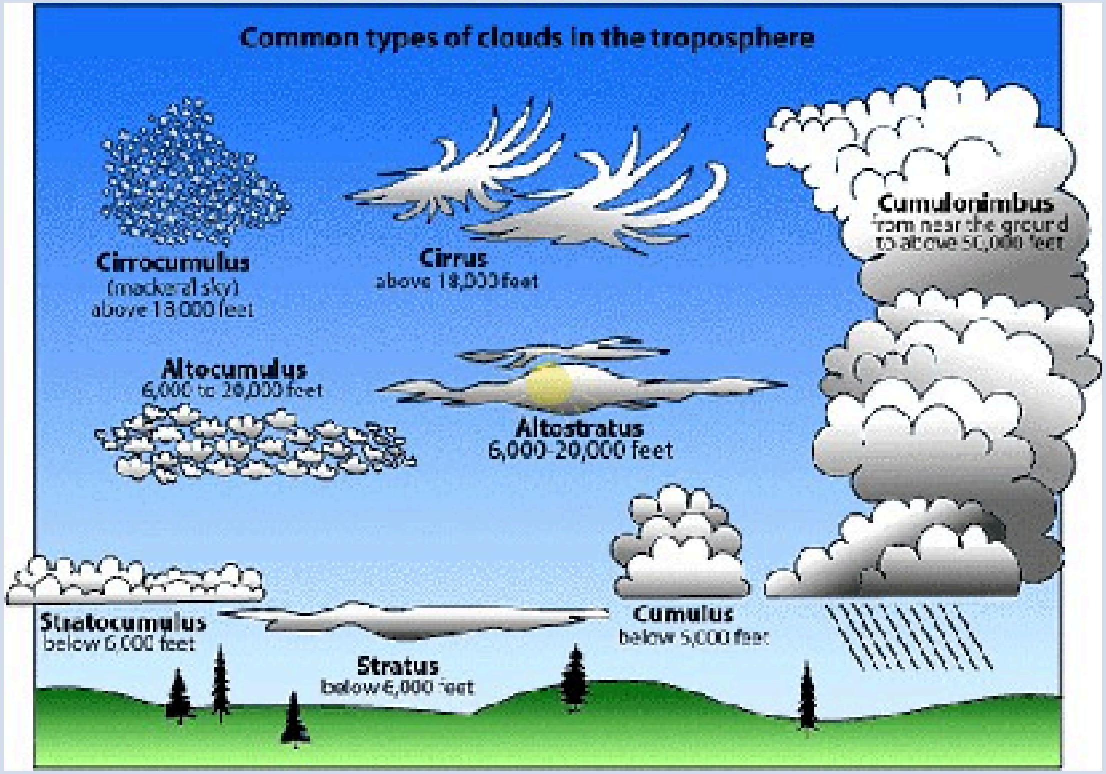
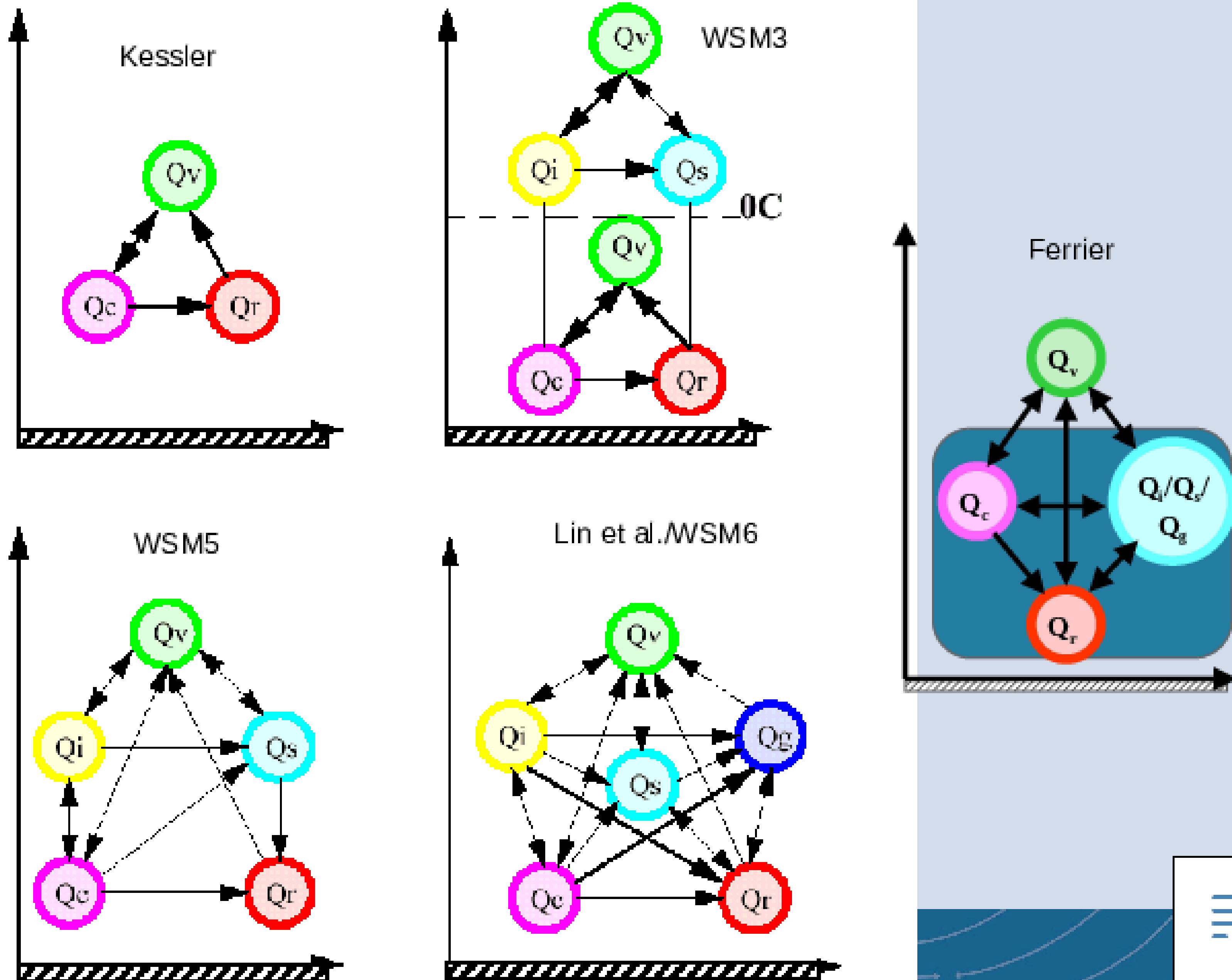


Illustration of Microphysics Processes



WRF Microphysics Options (mp_physics)

- Range of levels of sophistication
  - Warm rain (i.e. no ice, 3 arrays) – Kessler (idealized)
  - Simple ice (3 arrays) – WSM3
  - Mesoscale (5 arrays, no graupel) – WSM5
  - Cloud-scale single-moment (6 arrays, graupel) – WSM6, Lin, Goddard, SBU, Eta-Ferrier
  - Double-moment (8-13 arrays) – Thompson, Morrison, Milbrandt-Yau, WDM5, WDM6
  - Double-moment + shape/density prediction – NSSL, P3, ISHMAEL
  - Spectral Bin (120-240 arrays)

Microphysics schemes

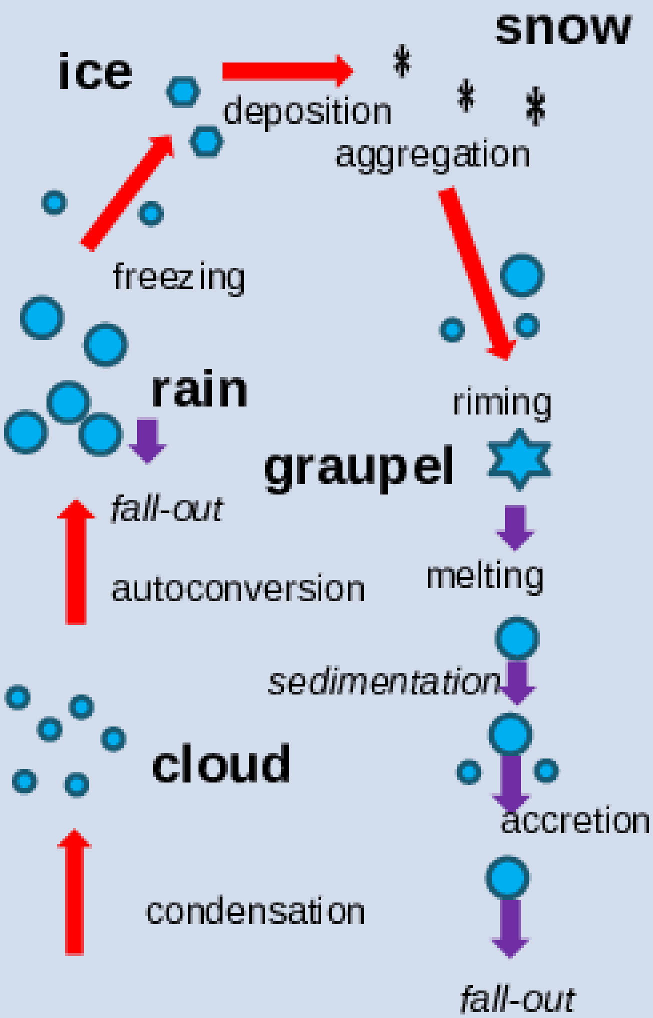
mp_physics	Scheme	Reference	Added
1	Kessler	Kessler (1969)	2000
2	Lin (Purdue)	Lin, Farley and Orville (1983, JCAM)	2000
3	WSM3	Hong, Dudhia and Chen (2004, MWR)	2004
4	WSM5	Hong, Dudhia and Chen (2004, MWR)	2004
5	Eta (Ferrier)	Rogers, Black, Ferrier et al. (2001)	2000
6	WSM6	Hong and Lim (2006, JKMS)	2004
7	Goddard	Tao, Simpson and McCumber (1989, MWR)	2008
8	Thompson (+old)	Thompson et al. (2008, MWR)	2009
9	Milbrandt 2-mom	Milbrandt and Yau (2005, JAS)	2010
10	Morrison 2-mom	Morrison et al. (2009, MWR)	2008
11	CESM 1.0	Morrison and Gettelman (2008, JC)	2013
13	SBU-Ylin	Lin and Colle (2011, MWR)	2011
14	WDM5	Lim and Hong (2010, MWR)	2009
16	WDM6	Lim and Hong (2010, MWR)	2009
17	NSSL 2-mom	Mansell, Ziegler and Bruning (2010, JAS)	[illegible]
18	NSSL 2-mom + ccn	Mansell, Ziegler and Bruning (2010, JAS)	[illegible]

Microphysics schemes

mp_physics	Scheme	Reference	Added
19	NSSL 7-class	Mansell, Ziegler and Bruning (2010, JAS)	2013
21	NSSL 6-class	Gilmore, Straka and Rasmussen (2004, MWR)	2013
22	NSSL 6-class 2-mom	Mansell, Ziegler and Bruning (2010, JAS)	2015
24	WSM7	Bae, Hong and Tao (2018, APJAS)	2019
26	WDM7	Bae, Hong and Tao (2018, APJAS)	2019
28	Thompson aero	Thompson and Eidhammer (2014, JAS)	2014
30	SBM fast	Khain, Lynn and Dudhia (2010, JAS)	2014
32	SBM full	Khain et al. (2004, JAS)	2014
50	P3	Morrison and Milbrandt (2015, JAS)	2017
51	P3-nc	Morrison and Milbrandt (2015, JAS)	2017
52	P3-2nd	Morrison and Milbrandt (2015, JAS)	2018
55	ISHMAEL	Jensen et al. (2017, JAS)	2019

Microphysics Processes

- Latent heat release from
  - Condensation, evaporation, deposition, sublimation, freezing, melting
- Particle types
  - Cloud water, rain drops, ice crystals, snow, graupel/hail
    - Total mass contributes to liquid loading in *dynamics*
- Processes
  - Aggregation, accretion, autoconversion (growth), riming, sedimentation (fall term)
  - Water and ice saturation differ

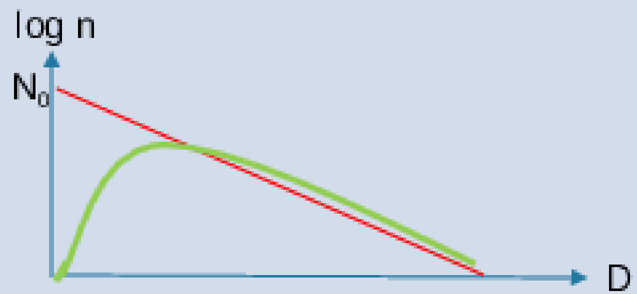


Particle Formation

- Cloud droplets (10s of microns) condense from vapor at water saturation
  - Cloud condensation nuclei fixed or variable (specified or chemistry)
- Rain (~mm diameter) forms from cloud droplet growth
- Ice crystals (10s of microns) form from freezing of droplets or deposition on nuclei
  - Ice nuclei assumed or explicit (dust particles)
- Snow (100s of microns) forms from growth of ice crystals at ice supersaturation and their aggregation
- Graupel/hail (mm to cm) form and grow from mixed-phase interactions between water and ice particles
- Precipitating particles are typically assigned to an observationally based **size distribution**

Size Distribution

- Log-normal (red), n is number per size range, D is diameter
  - $n(D)\,dD = N_0 \exp(-\lambda D)\,dD$



- Gamma (green) with exponent α
  - $n(D)\,dD = N_0 D^{\alpha} \exp(-\lambda D)\,dD$
- Mass and fall speed depend on D
  - $M = \pi \rho_r D^3$
  - $V = a D^b$
- Gamma function is integrated to relate mixing ratio Q_r to λ
  - $/ \rho\ Q_r)^{1/4}$ for log-normal distribution
  - where ρ_r is rain density and ρ is air density
- Integration also gives a mass-weighted fall speed
  - $V_t = a\,[\,\Gamma(4+b)/6\,]\,\lambda^{-b}$

Microphysics: Single and Double Moment Schemes

- Single-moment schemes have one prediction equation for mass (kg/kg) per species (Qr, Qs, etc.) with particle size distribution being derived from fixed parameters (e.g. N_0)
- Double-moment (DM) schemes add a prediction equation for number concentration (#/kg) per DM species (Nr, Ns, etc.)
  - DM schemes may only be double-moment for a few species
  - DM schemes allow for additional processes such as size-sorting during fall-out and aerosol (CCN) effects

Spectral Bin Schemes

- Hebrew University of Jerusalem (Khain and Lynn scheme)
- Size distribution resolved by doubling mass bins (typically 32 for each particle type)
- Many added advected arrays (*expensive*)
  - Options have 4x32 (fast scheme) or 8x32 (full scheme) arrays
- Version 4.3 has a new fast bin scheme

Microphysics: Fall terms

- Microphysics schemes handle fall terms for particles (usually everything except cloud water has a fall term)
  - Rain ~5 m/s
  - Graupel ~ 2 m/2
  - Hail 5-10 m/s
  - Snow ~1-2 m/s
  - Ice crystals ~0.5 m/s
- For long time-steps (such as mesoscale applications dt ~ 60 s, Vt= 5 m/s), drops may fall more than a grid level in a time-step
- This requires either splitting the microphysics time-step (most schemes) or lagrangian numerical methods (WSM and WDM schemes) to keep the scheme numerically stable

Particle Densities and Shapes

- Some schemes allow variable densities especially for riming rather than discrete densities for snow, graupel and hail
  - WSM6/WDM6 schemes simply combine snow and graupel for purposes of computing fallspeed – rimed fraction is qg/(qs+qg)
  - NSSL schemes compute volume of graupel as a density variable
  - P3 computes growth by riming and deposition to compute density for ice/snow/graupel combined particles
- New ISHMAEL scheme predicts density and aspect ratio (shape)
- HUJI full spectral bin scheme has separate ice crystal habits (plates, columns, dendrites)

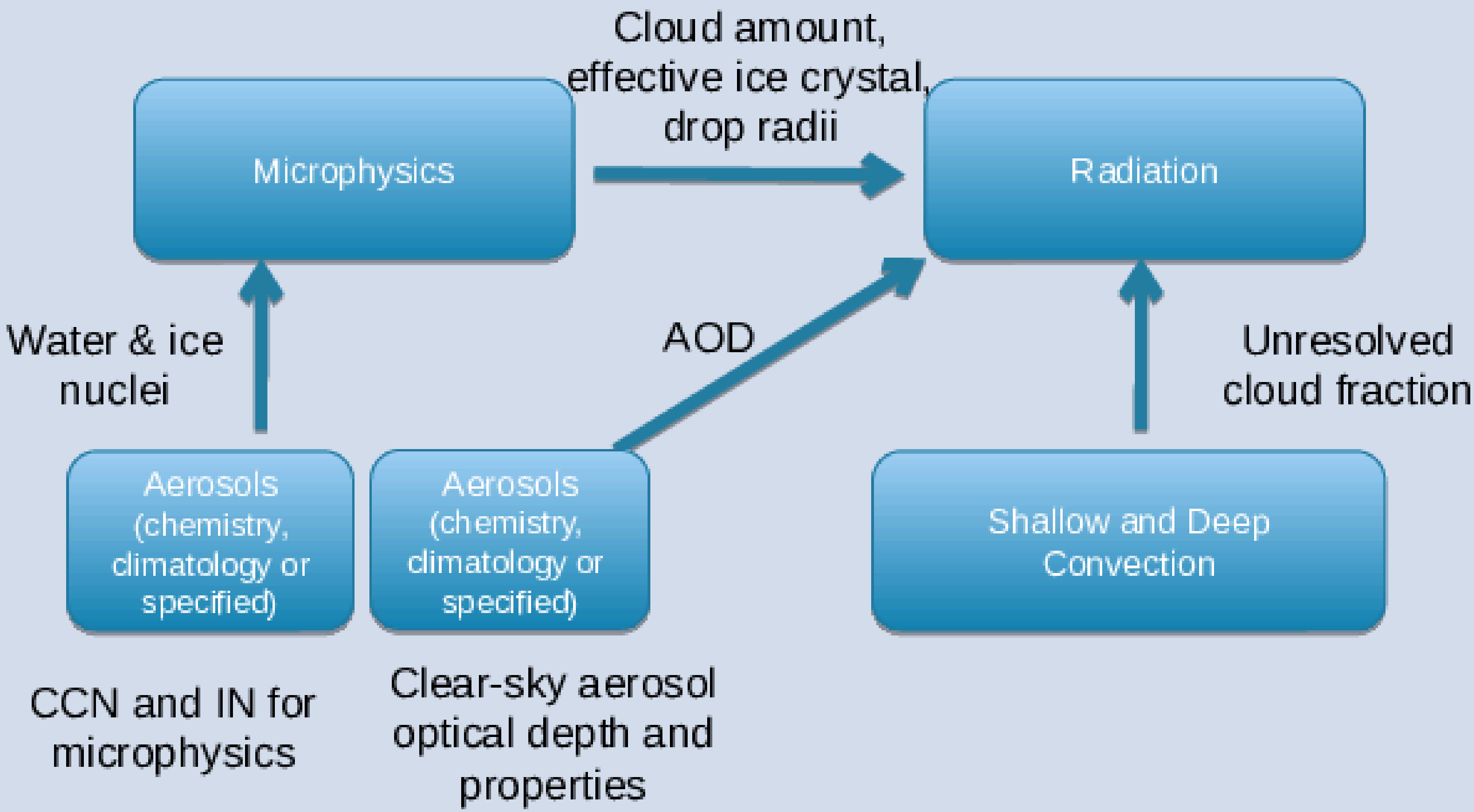
Interaction with Aerosols

- WRF-Chem can provide aerosols to some options (Lin, Morrison, CESM MG)
- WDM, one NSSL option, and Spectral Bin schemes can advect idealized CCNs which affect cloud droplet number
- Thompson “aerosol-aware” scheme can use its own aerosols (water and ice nuclei) initialized from climatology, advected
  - Since V4.0 also can do dust emission (*dust_emis=1*)
- Morrison aerosol version in V4.0 interacts with climatological aerosols

Interaction with Radiation

- Several schemes now pass their own ice, snow, cloud-water particle sizes to RRTMG radiation
  - Thompson, WSM, WDM, NSSL 2-mom schemes
  - This represents so-called indirect effect on radiation due to drop size variation
  - Other schemes do not and radiation uses internal assumptions about particle sizes

Cloud-Aerosol-Radiation Interaction



Note: aerosols not always unified (CCN and AOD may come from different sources)

Microphysics schemes

* Advects only total condensate   Nn= CCN number

mp_physics	Scheme	Cores	Mass Variables	Number Variables
1	Kessler	ARW	Qc Qr	
2	Lin (Purdue)	ARW (Chem)	Qc Qr Qi Qs Qg	
3	WSM3	ARW	Qc Qr	
4	WSM5	ARW NMM	Qc Qr Qi Qs	
5	Eta (Ferrier)	ARW NMM	Qc Qr Qs (Qt*)	
6	WSM6	ARW NMM	Qc Qr Qi Qs Qg	
7	Goddard 4-ice	ARW	Qc Qr Qi Qs Qg Qh	
8	Thompson	ARW NMM	Qc Qr Qi Qs Qg	Ni Nr
9	Milbrandt 2-mom	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr Ni Ns Ng Nh
10, 40	Morrison 2-mom	ARW (Chem)	Qc Qr Qi Qs Qg	Nr Ni Ns Ng
11	CESM 1.0	ARW (Chem)	Qc Qr Qi Qs	Nc Nr Ni Ns
13	SBU-YLin	ARW	Qc Qr Qi Qs	
14	WDM5	ARW	Qc Qr Qi Qs	Nn Nc Nr
16	WDM6	ARW	Qc Qr Qi Qs Qg	Nn Nc Nr

Microphysics schemes

mp_physics	Scheme	Cores	Mass Variables	Number Variables
17	NSSL 2-mom	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr Ni Ns Ng Nh
18	NSSL2-mom+ccn	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr Ni Ns Ng Nh Nn
19	NSSL 7-class	ARW	Qc Qr Qi Qs Qg Qh	VOLg
21	NSSL 6-class	ARW	Qc Qr Qi Qs Qg	
22	NSSL 6-class 2-mom	ARW	Qc Qr Qi Qs Qg	Nn Nc Nr Ni Ns Ng VOLg
24	WSM7	ARW	Qc Qr Qi Qs Qg Qh	
26	WDM7	ARW	Qc Qr Qi Qs Qg Qh	Nc Nr
28	Thompson aero	ARW	Qc Qr Qi Qs Qg	Nc Ni Nr Nn Nni

- Nn = CCN number
- VOLg = graupel volume

Microphysics schemes

mp_physics	Scheme	Cores	Mass Variables	Number Variables
30	HUJI fast SBM	ARW	Qc Qr Qi Qs Qg	Nn Nc Nr Ni Ns Ng
32	HUJI full SBM	ARW	Qc Qr Qic Qip Qid Qs Qg Qh (outputs aggregated from bins)	Nn Nc Nr Nic Nip Nid Ns Ng Nh
50	P3	ARW	Qc Qr Qi	Nr Ni Ri Bi
51	P3-nc	ARW	Qc Qr Qi	Nc Nr Ni Ri Bi
52	P3-2nd	ARW	Qc Qr Qi2	Nc Nr Ni Ni2 Ri Ri2 Bi Bi2
55	ISHMAEL	ARW	Qc Qr Qi Qi2 Qi3	Nr Ni Ni2 Ni3 Vi Vi2 Vi3 Ai Ai2 Ai3

- Nn = CCN number
- Ri = rimed ice mass   Bi = rimed ice volume
- Vi = volume   Ai = vol*aspect ratio

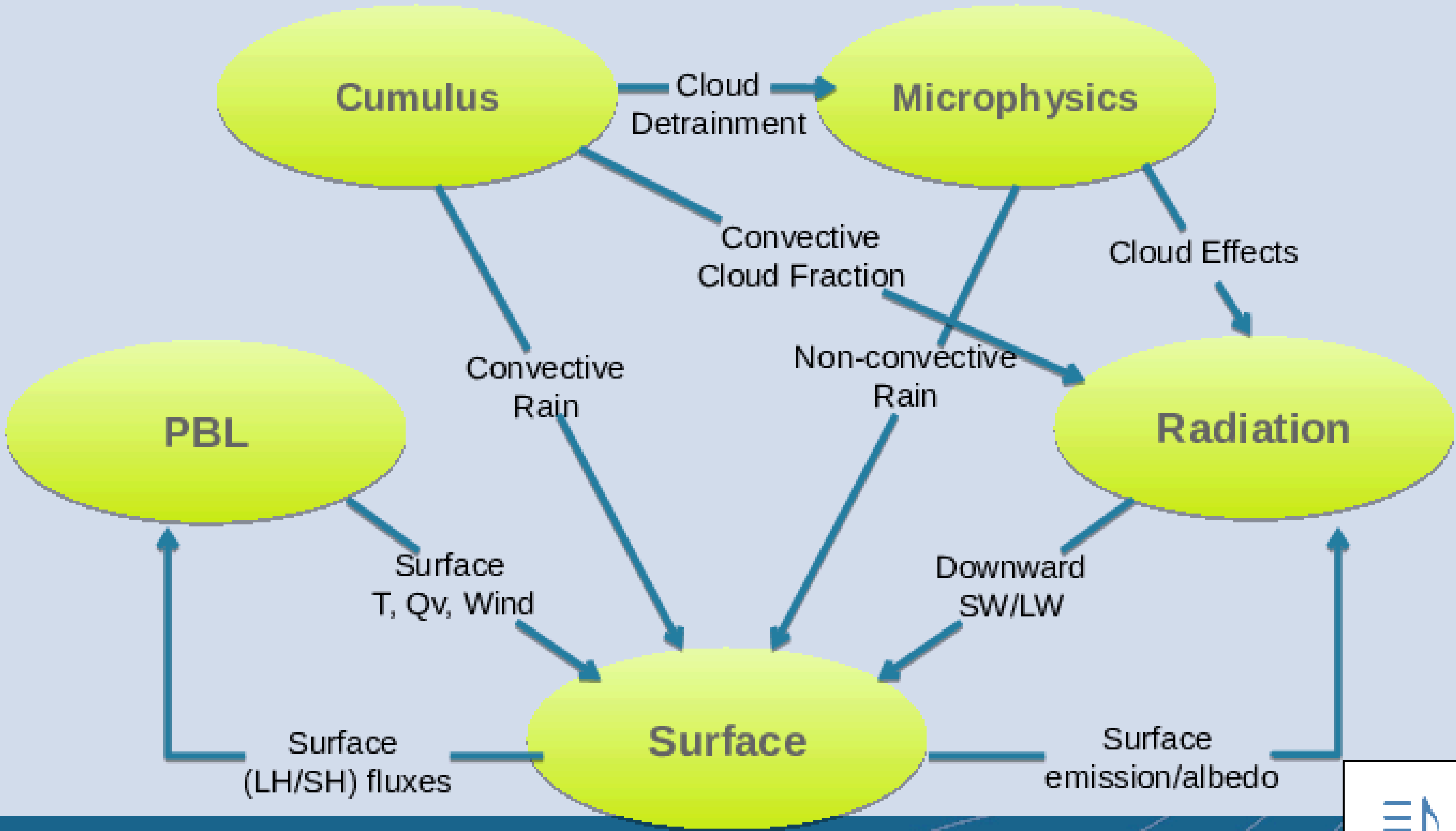
Microphysics Options: Recommendations

- Probably not necessary to use a graupel scheme for dx > 10 km
  - Updrafts producing graupel not resolved
  - Cheaper scheme may give similar results
- When resolving individual updrafts, graupel scheme should be used
- All domains use same option

Rainfall Output

- Cumulus and microphysics can be run at the same time
- ARW outputs rainfall accumulations since simulation start time (0 hr) in mm
- RAINC comes from cumulus scheme
- RAINNC comes from microphysics scheme
- Total is RAINC+RAINNC
  - Despite name this is **total** surface precipitation
  - RAINNCV is time-step value
  - SNOWNC/SNOWNCV are **snow sub-set** of RAINC/RAINNCV (also GRAUPELNC, etc.)
  - Note *bucket_mm* option mentioned earlier for longer simulations

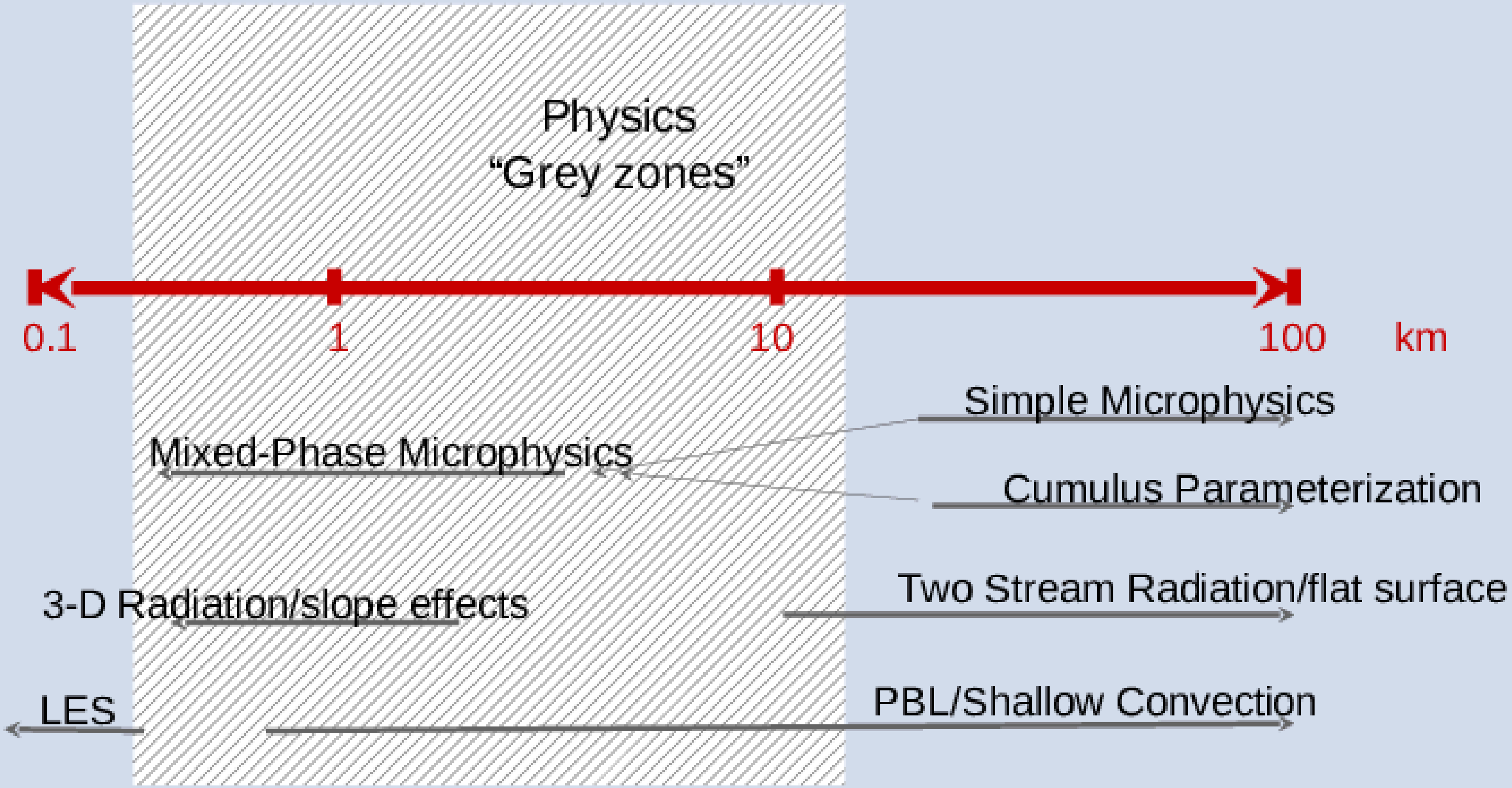
Direct Interactions of Parameterizations



Microphysics Summary

- Resolved Clouds
- Options
  - Warm rain to complex and spectral bin
- Microphysics Processes
  - Latent heat, particle types, processes
  - Particle formation, size distribution
  - Single and double-moment schemes, Spectral bin schemes
  - Fall terms
  - Particle densities and shapes
- Interaction with aerosols
- Interaction with radiation
- Rainfall output

Physics in Multiscale NWP Model

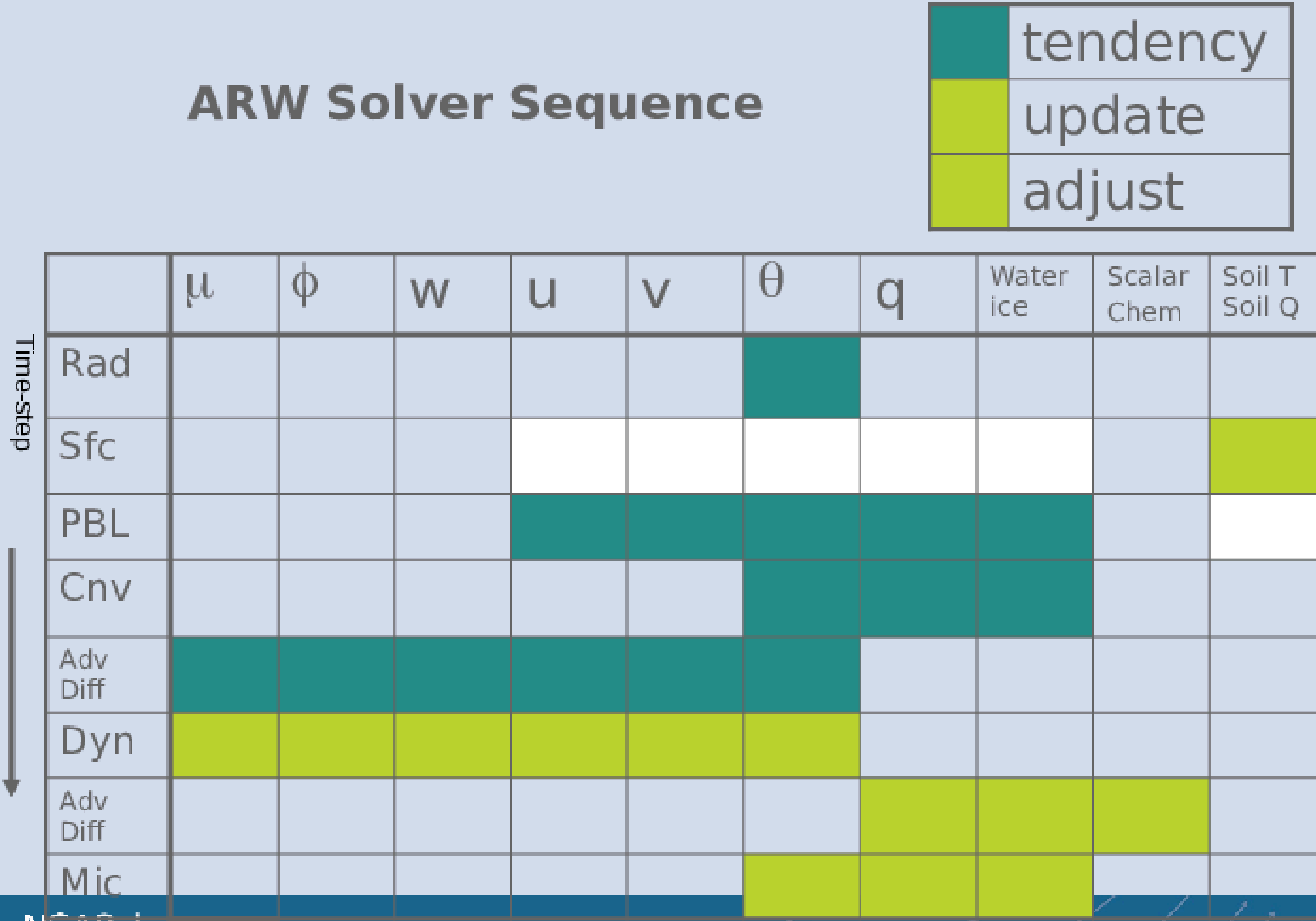


Solver Calling Sequence

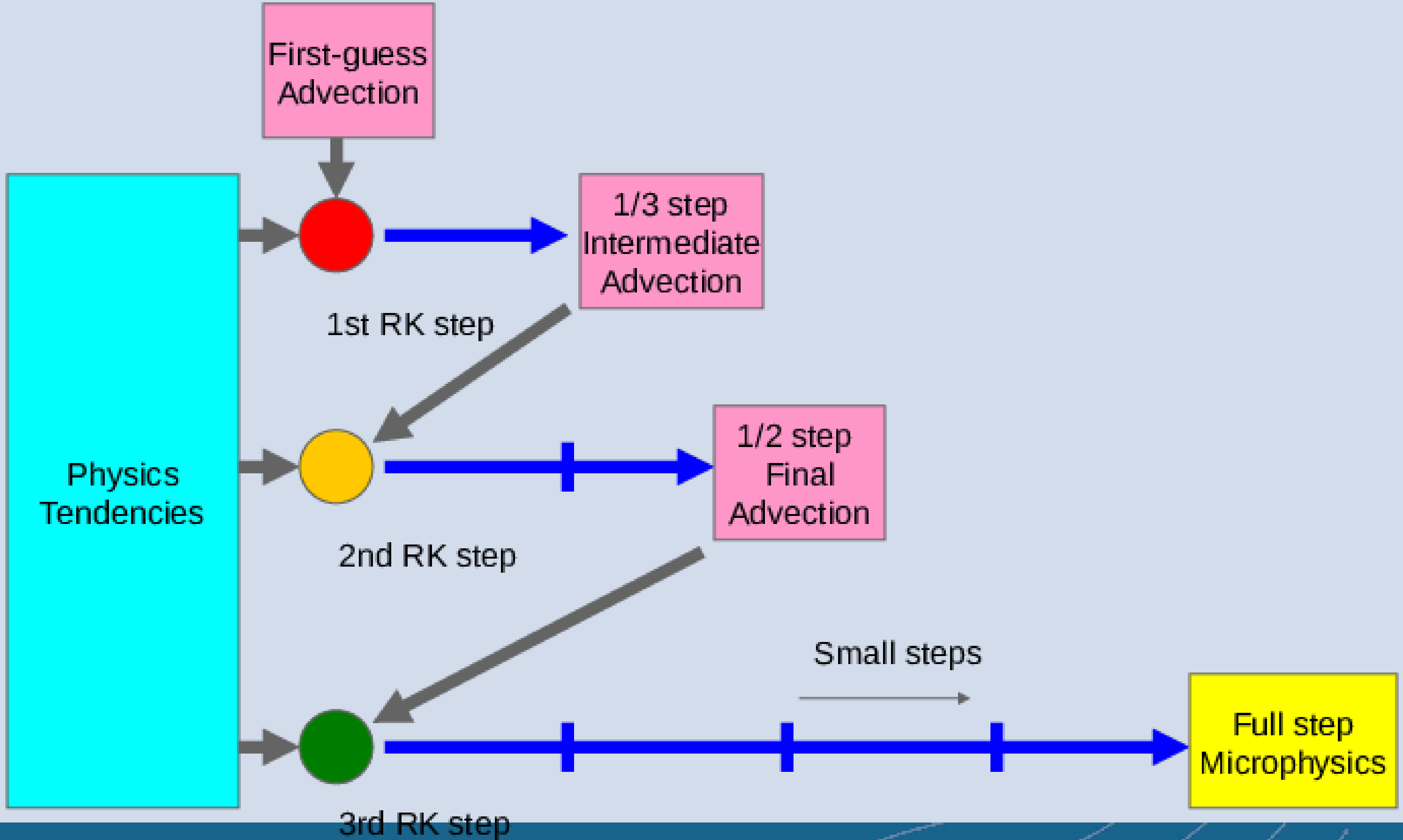
Call to solver advances one domain by one model time-step

- 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,…