WRF Physics

1. Turbulence/Diffusion (diff_opt, km_opt)
2. Radiation
   1) Longwave (ra_lw_physics)
   2) Shortwave (ra_sw_physics)
3. Surface
   1) Surface layer (sf_sfclay_physics)
   2) Land/water surface (sf_surface_physics)
4. PBL (bl_physics)
5. Cumulus parameterization (cu_physics)
6. Microphysics (mp_physics)

&physics

- Seven major physics categories:
  1. **ra_lw_physics: 0,1,3,99.**
  2. **ra_sw_physics: 0,1,2,3,99.**
  3. **sf_sfclay_physics: 0,1,2,3,7**
  4. **sf_surface_physics: 0,1,2,3,99** (set before running **real** or **ideal**, need to match with **num_soil_layers** variable)**.**
  5. **bl_pbl_physics: 0,1,2,99.**
  6. **cu_physics: 0,1,2,3,99.**
  7. **mp_physics: 0,1,2,3,4,5,6,8,10.**

Turbulence/Diffusion

- Sub-grid eddy mixing effects on all fields.
- diff_opt=1: 2nd order diffusion on model levels Constant vertical coefficient (kvdif) or use with PBL. For theta, only perturbation from base state is diffused. Horizontal diffusion acts along model levels. Simpler numerical method with only neighboring points on the same model level.
- diff_opt=2: 2nd order horizontal diffusion. Allows for terrain-following coordinate. Horizontal diffusion acts along model levels. Numerical method includes vertical correction term using more grid points. mix_full_fields=.true.: vertical diffusion acts on full (not perturbation) fields (recommended, but default = .false.). Explicit large-eddy simulation (LES) PBL in real-data cases (V3) or idealized cases
    - sf_sfclay_physics (only option 1 currently) and
    - sf_surface_physics (choose non-zero option)
        - bl_pbl_physics = 0
        - isfflx = 1 (drag and heat flux from physics) OR
        - isfflx = 2 (drag from physics, heat flux from tke_heat_flux)
        - km_opt = 2 or 3

Exchange Coefficient

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

$$H = \rho c_p C_{hs} \Delta\theta$$

It is related to the roughness length and u_* by

$$C_{hs} = \frac{k u_*}{\ln\left(\frac{z}{z_0}\right) - \psi_h}$$

Surface Fluxes

- Heat, moisture and momentum

$$H = \rho c_p u_* \theta_* \qquad E = \rho u_* q_* \qquad \tau = \rho u_* u_*$$

$$u_* = \frac{kV_r}{\ln(z_r / z_0) - \psi_m} \qquad \theta_* = \frac{k\Delta\theta}{\ln(z_r / z_{0h}) - \psi_h} \qquad q_* = \frac{k\Delta q}{\ln(z_r / z_{0q}) - \psi_h}$$

Subscript r is reference level (lowest model level, or 2 m or 10 m) z0 are the roughness lengths

Turbulence/Diffusion

- km_opt

  1: constant (khdif and kvdif used)

  2: 1.5-order TKE prediction (not recommended with diff_opt=1)

  3: Smagorinsky (deformation/stability based K) (not recommended with diff_opt=1)

  4: 2D Smagorinsky (deformation based on horizontal wind for horizontal diffusion only).

Diffusion Option Choice

- Real-data case with PBL physics on
  Best is diff_opt=1, km_opt=4
  This complements vertical diffusion done by PBL scheme
- High-resolution real-data cases (~100 m grid)
  No PBL
  diff_opt=2; km_opt=2,3 (tke or Smagorinsky scheme)
- Idealized cloud-resolving modeling (smooth or no topography)
  diff_opt=2; km_opt=2,3
- Complex topography with no PBL scheme
  diff_opt=2 is more accurate for sloped coordinate surfaces, and prevents diffusion up/down valley sides
- Note: WRF can run with no diffusion (diff_opt=0).

diff_6th_opt

- 6th order optional added horizontal diffusion on model levels
  - Used as a numerical filter for 2*dx noise
  - Suitable for idealized and real-data cases
  - Affects all advected variables including scalars
- diff_6th_opt
  - 0: none (default)
  - 1: on (can produce negative water)
  - 2: on and prohibit up-gradient diffusion (better for water conservation)
- diff_6th_factor
  - Non-dimensional strength (typical value 0.12, 1.0 corresponds to complete removal of 2*dx wave in a timestep).

damp_opt=1

- Upper level diffusive layer
- Enhanced horizontal diffusion at top
- Also enhanced vertical diffusion at top for diff_opt=2
- Cosine function of height
- Uses additional parameters

  zdamp: depth of damping layer

  dampcoef: nondimensional maximum magnitude of damping

damp_opt=2

- Upper level relaxation towards 1-d profile
- Rayleigh (relaxation) layer
- Cosine function of height
- Uses additional parameters

  zdamp: depth of damping layer

  dampcoef: inverse time scale (s-1)
- Works for idealized cases only

damp_opt=3

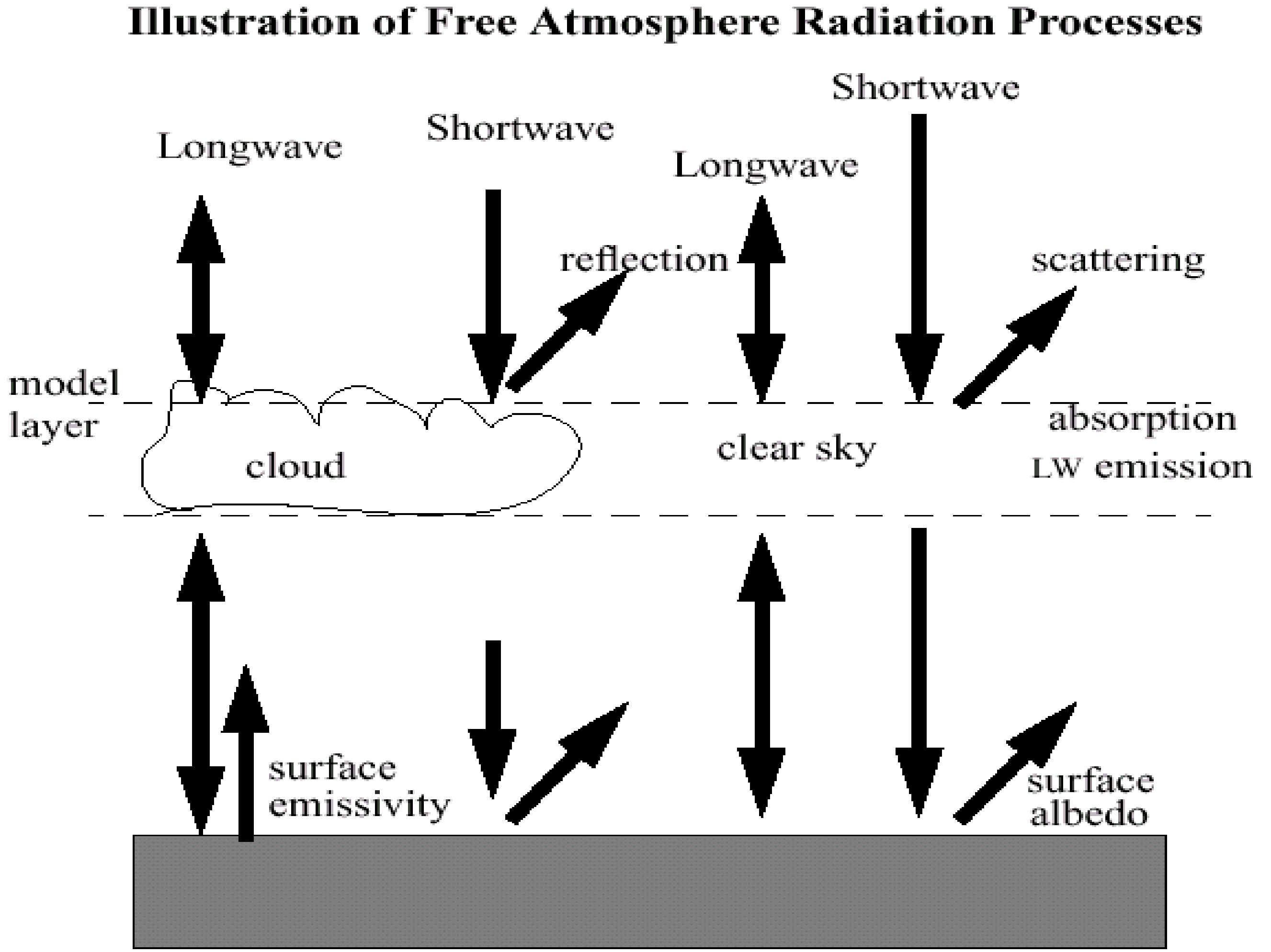
- “W-Rayleigh” (relaxation) layer
- Upper level relaxation towards zero vertical motion
- Cosine function of height
- Uses additional parameters

  zdamp: depth of damping layer

  dampcoef: inverse time scale (s-1)
- Works for idealized and real-data cases
- Applied in small time-steps (dampcoef=0.2 is stable)

Radiation

- Atmospheric temperature tendency.
- Surface radiative fluxes.



Radiation

- ra_lw_physics=1

  RRTM scheme: spectral scheme, K-distribution, look-up table fit to accurate calculations, Interacts with clouds (1/0 fraction), ozone profile specified, CO2 constant (well-mixed).

- ra_lw_physics=3

  CAM3 scheme: spectral scheme, 8 longwave bands, look-up table fit to accurate calculations, interacts with clouds, can interact with trace gases and aerosols, ozone profile function of month & latitude, CO2 fixed constant.

Radiation

- ra_lw_physics=99

  GFDL longwave scheme: used in Eta/NMM, default code is used with Ferrier microphysics, spectral scheme from global model, also uses tables Interacts with clouds (cloud fraction), ozone profile based on season and latitude, CO_2 fixed.
- ra_sw_physics=1

  MM5 shortwave (Dudhia): simple downward calculation, clear-sky scattering, water vapor absorption, cloud albedo and absorption, version 3 has slope_rad and topo_shading switches (0,1) to turn on slope and shading effects in this radiation option only.

Radiation

- ra_sw_physics=2

  Goddard shortwave: spectral method, interacts with clouds, ozone profile (tropical, summer/winter, mid-lat, polar), CO_2 fixed.

- ra_sw_physics=3

  CAM3 shortwave: spectral method (19 bands), interacts with clouds, ozone/CO_2 profile as in CAM longwave, can interact with aerosols.

Radiation

- ra_sw_physics=99

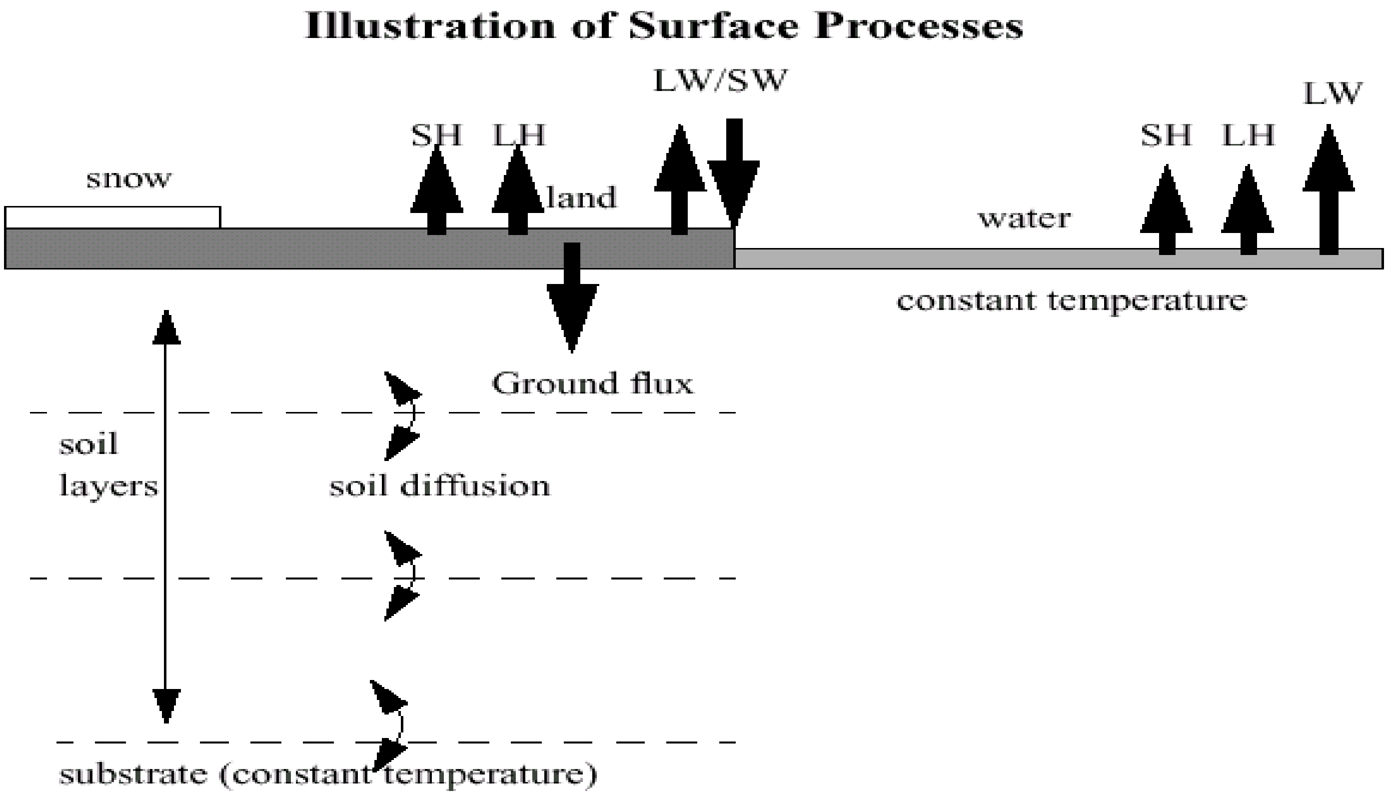
  GFDL shortwave: used in Eta/NMM model, default code is used with Ferrier microphysics (see GFDL longwave), ozone/ CO_2 profile as in GFDL longwave, interacts with clouds (and cloud fraction).
- Radt

  Radiation time-step recommendation, radiation is too expensive to call every step, frequency should resolve cloud-cover changes with time radt=1 minute per km grid size is about right (e.g. radt=10 for dx=10 km), each domain can have its own value but recommend using same value on all 2-way nests.
- nrads/nradl

  Radiation time-step recommendation: number of fundamental steps per radiation call; operational setting should be 3600/dt; Higher resolution could be used, e.g. 1800/dt; recommend same value for all nested domains.

Surface schemes

- Surface layer of atmosphere diagnostics (exchange/transfer coefficients)
- Land Surface: Soil temperature/moisture/snow prediction/sea-ice temperature.
- Heat, moisture and momentum.



Roughness Lengths

- 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.

sf_sfclay_physics=1

- Monin-Obukhov similarity theory
- Taken from standard relations used in

MM5 MRF PBL

- Provides exchange coefficients to surface (land) scheme
- Should be used with bl_pbl_physics=1 or 99

sf_sfclay_physics=2

- Monin-Obukhov similarity theory
- Modifications due to Janjic
- Taken from standard relations used in NMM model, including Zilitinkevich thermal roughness length.
- Should be used with bl_pbl_physics=2

sf_sfclay_physics=3

- GFS Monin-Obukhov similarity theory
- For use with NMM-LSM
- Should be used with bl_pbl_physics=3

sf_sfclay_physics=7

- Pleim-Xiu surface layer (EPA)
- For use with PX LSM and ACM PBL
- Should be used with sf_surface_physics=7
  and bl_pbl_physics=7
- New in Version 3

sf_surface_physics=2

- Noah Land Surface Model (Unified ARW/NMM version in Version 3)
- Vegetation effects included
- Predicts soil temperature and soil moisture in four layers
- Predicts snow cover and canopy moisture
- Handles fractional snow cover and frozen soil
- Diagnoses skin temp and uses emissivity
- Provides heat and moisture fluxes for PBL
- 2.2 has Urban Canopy Model option (ucmcall=1, ARW only).

sf_surface_physics=3

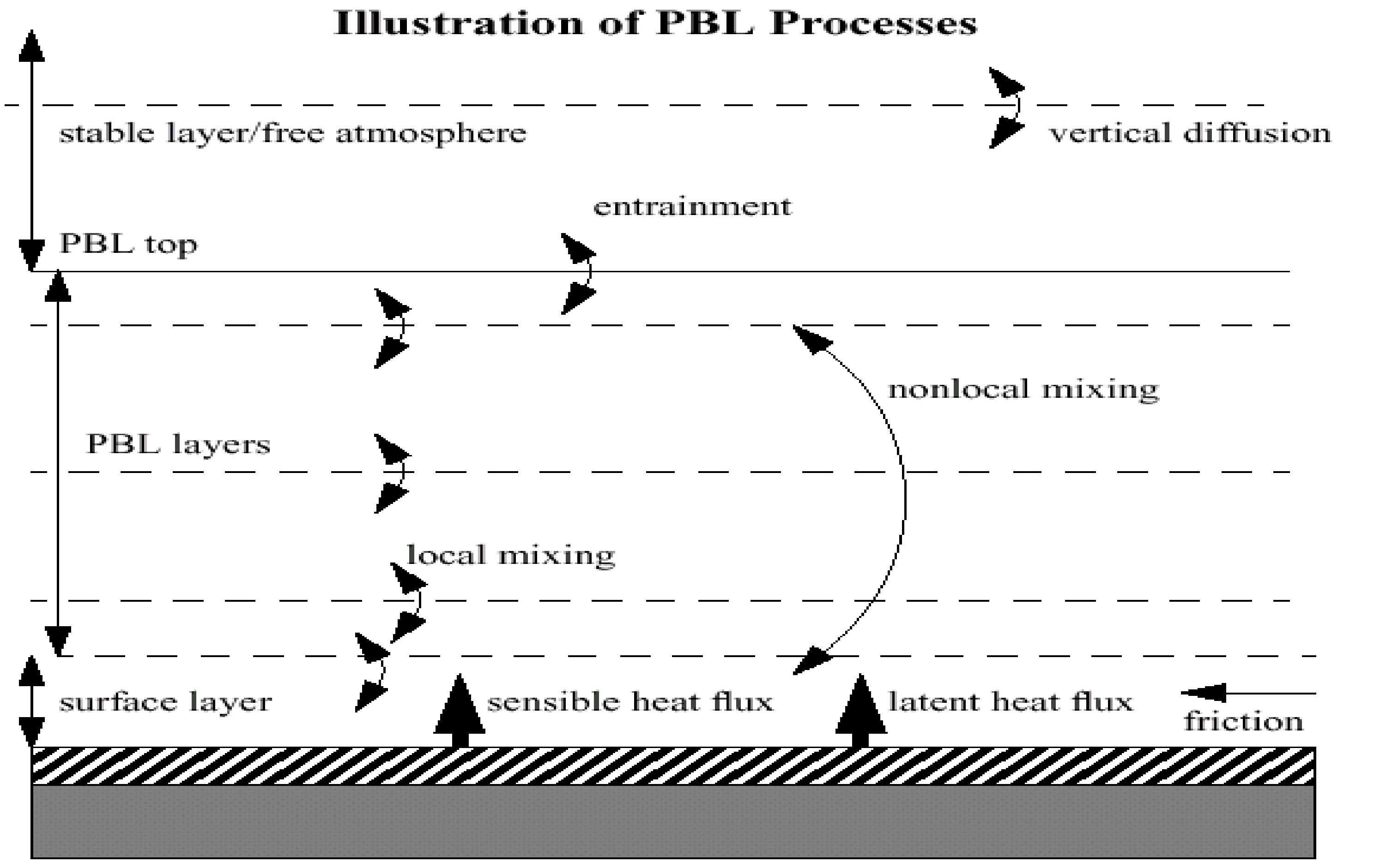
- RUC Land Surface Model (Smirnova)
- Vegetation effects included
- Predicts soil temperature and soil moisture in six layers
- Multi-layer snow model
- Provides heat and moisture fluxes for PBL

sf_surface_physics=7

- Pleim-Xiu Land Surface Model (EPA)
- New in Version 3
- Vegetation effects included
- Predicts soil temperature and soil moisture in two layers
- Simple snow-cover model
- Provides heat and moisture fluxes for PBL

Planetary Boundary Layer

- Boundary layer fluxes (heat, moisture, momentum)
- Vertical diffusion



bl_pbl_physics=1

- YSU PBL scheme (Hong, Noh and Dudhia 2006)
- Parabolic non-local-K mixing in dry convective boundary layer
- Troen-Mahrt countergradient term (non-local flux)
- Depth of PBL determined from thermal profile
- Explicit treatment of entrainment
- Vertical diffusion depends on Ri in free atmosphere
- New stable surface BL mixing using bulk Ri
- Available for NMM in Version 3

bl_pbl_physics=2

- Mellor-Yamada-Janjic (Eta/NMM) PBL
- 1.5-order, level 2.5, TKE prediction
- Local TKE-based vertical mixing in boundary layer and free atmosphere
- TKE_MYJ is advected by NMM, not by
- ARW (yet)

bl_pbl_physics=99

- MRF PBL scheme (Hong and Pan 1996)
- Non-local-K mixing in dry convective boundary layer
- Depth of PBL determined from critical Ri number
- Vertical diffusion depends on Ri in free atmosphere

bldt

- Minutes between boundary layer/LSM calls
- Typical value is 0 (every step)
- ARW only

nphs

- Time steps between PBL/turbulence/LSM calls
- Typical value is 10 for efficiency
- Also used for microphysics

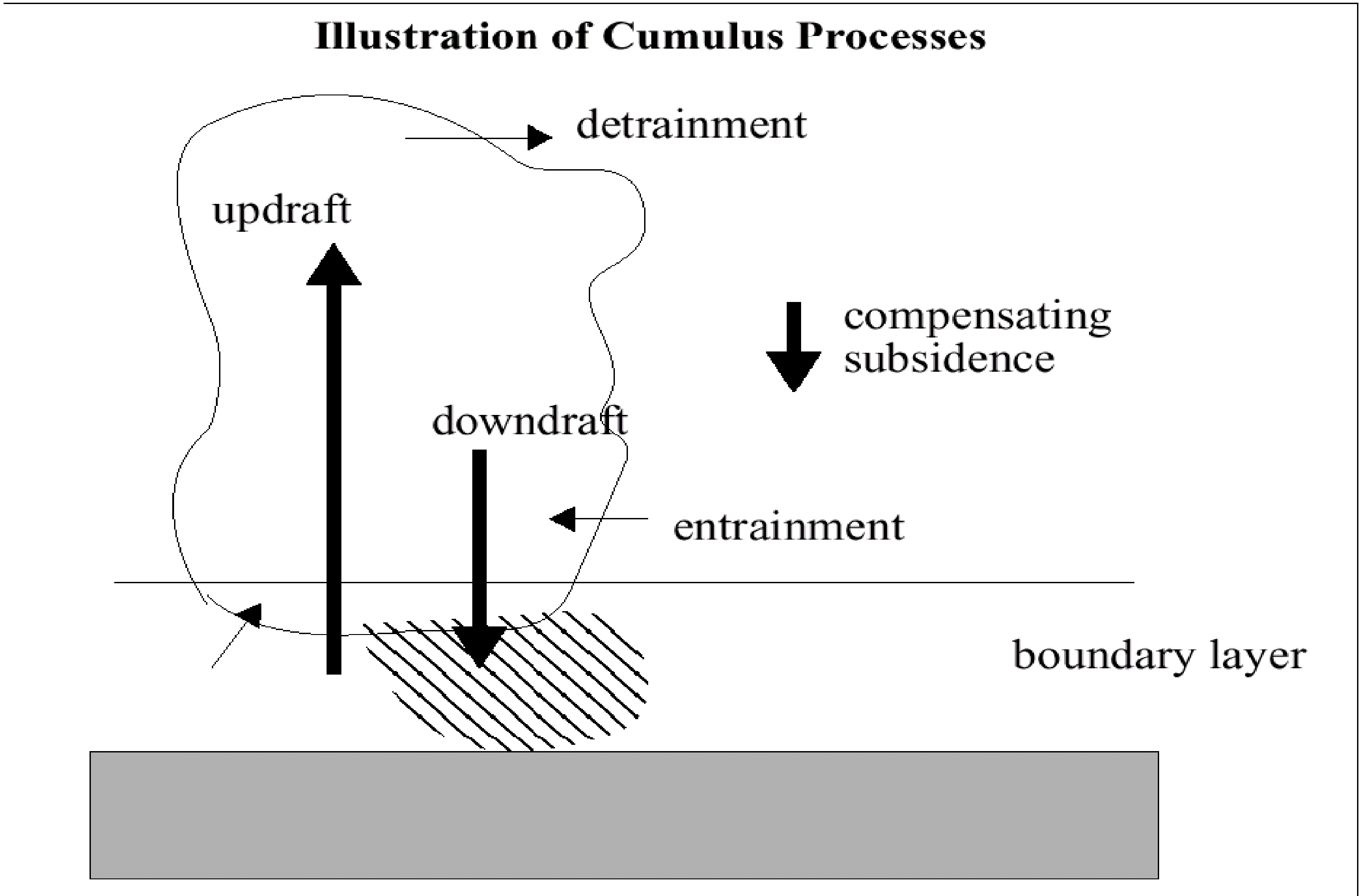
PBL Scheme Options

- PBL schemes can be used for most grid sizes when surface fluxes are present
- With PBL scheme, lowest full level should be .99 or .995 (not too close to 1)
- Assumes that PBL eddies are not resolved
- At grid size dx << 1 km, this assumption breaks down
- Can use 3d diffusion instead of a PBL scheme in Version 3 (coupled to surface physics)

  Works best when dx and dz are comparable

Cumulus Parameterization

- Atmospheric heat and moisture/cloud tendencies, surface rainfall



cu_physics=1

- New Kain-Fritsch
- As in MM5 and Eta/NMM test version
- Includes shallow convection (no downdrafts)
- Low-level vertical motion in trigger function
- CAPE removal time scale closure
- Mass flux type with updrafts and downdrafts, entrainment and detrainment
- Includes clour, rain, ice, snow detrainment
- Clouds persist over convective time scale (recalculated every convective step in NMM)

cu_physics=2

- Betts-Miller-Janjic
- As in NMM model (Janjic 1994)
- Adjustment type scheme
- Deep and shallow profiles
- BM saturated profile modified by cloud efficiency, so post-convective profile can be unsaturated in BMJ
- No explicit updraft or downdraft
- No cloud detrainment
- Scheme changed significantly since V2.1

cu_physics=3

- Grell-Devenyi Ensemble
- Multiple-closure (e.g. CAPE removal, quasi-equilibrium) - 16 mass flux closures
- Multi-parameter (e.g maximum cap, precipitation efficiency) - e.g. 3 cap strengths, 3 mass flux profiles
- Explicit updrafts/downdrafts
- Includes cloud and ice detrainment
- Mean feedback of ensemble is applied
- Weights can be tuned (spatially, temporally) to optimize scheme (training)

cu_physics=4

- Simpified Arakawa-Schubert (SAS) GFS scheme
- Quasi-equilibrium scheme
- Related to Grell scheme in MM5
- Includes cloud and ice detrainment
- Downdrafts and single, simple cloud

cu_physics=5

- Grell-3d
- Smaller ensemble than GD
- Explicit updrafts/downdrafts
- Includes cloud and ice detrainment
- Subsidence is spread to neighboring columns
- This makes it more suitable for < 10 km grid size than other options
- Mean feedback of ensemble is applied
- Weights can be tuned (spatially, temporally) to optimize scheme (training)

cudt

- Time steps between cumulus scheme calls
- Typical value is 5 minutes.

ncnvc

- Time steps between cumulus parameterization calls
- Typically 10 - same as NPHS

Cumulus scheme

- Recommendations about use

  For dx ≥ 10 km: probably need cumulus scheme

  For dx ≤ 3 km: probably do not need scheme

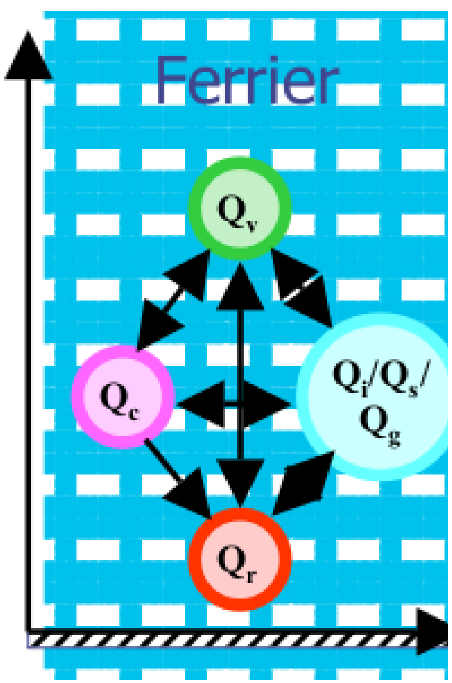
  However, there are cases where the earlier triggering of convection by cumulus schemes help
- For dx=3-10 km, scale separation is a question

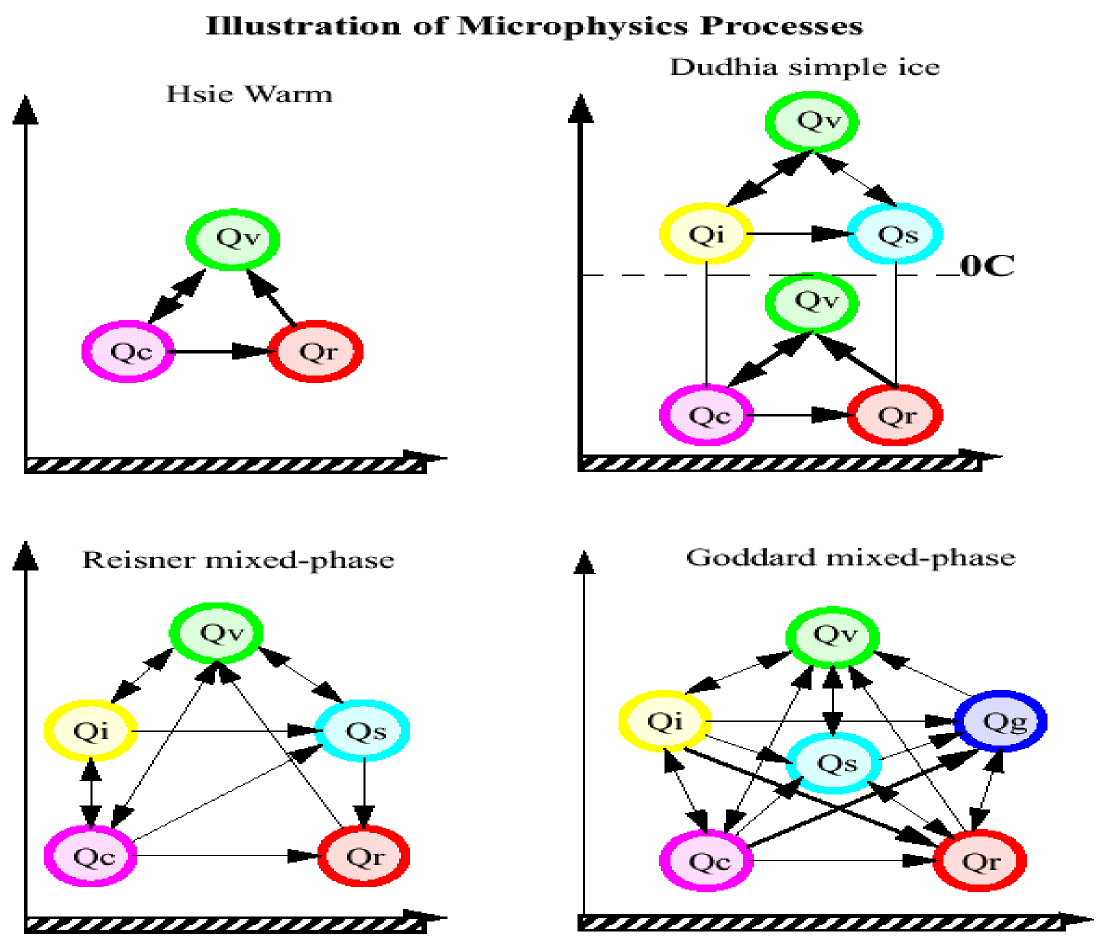
  No schemes are specifically designed with this range of scales in mind
- Issues with 2-way nesting when physics differs across nest boundaries (seen in precip field on parent domain)

  best to use same physics in both domains or 1-way nesting

Microphysics

- Atmospheric heat and moisture tendencies
- Microphysical rates
- Surface rainfall





mp_physics=1

- Kessler scheme
- Warm rain – no ice
- Idealized microphysics
- Time-split rainfall

mp_physics=2

- Purdue Lin et al. scheme
- 5-class microphysics including graupel
- Includes ice sedimentation and timesplit fall terms

mp_physics=3

- WSM 3-class scheme
- From Hong, Dudhia and Chen (2004)
- Replaces NCEP3 scheme
- 3-class microphysics with ice
- Ice processes below 0 deg C
- Ice number is function of ice content
- Ice sedimentation and time-split fall terms

mp_physics=4

- WSM 5-class scheme
- Also from Hong, Dudhia and Chen (2004)
- Replaces NCEP5 scheme
- 5-class microphysics with ice
- Supercooled water and snow melt
- Ice sedimentation and time-split fall terms

mp_physics=5

- Ferrier (current NAM) scheme
- Designed for efficiency
  - Advection only of total condensate and vapor
  - Diagnostic cloud water, rain, & ice (cloud ice, snow/graupel) from storage arrays – assumes fractions of water & ice within the column are fixed during advection
- Supercooled liquid water & ice melt
- Variable density for precipitation ice (snow/graupel/sleet) – “rime factor”

mp_physics=6

- WSM 6-class scheme
- From Hong and Lim (2006, JKMS)
- 6-class microphysics with graupel
- Ice number concentration as in WSM3 and WSM5
- New combined snow/graupel fall speed
- Time-split fall terms with melting

mp_physics=7

- Goddard 6-class scheme
- From Tao et al.
- 6-class microphysics with graupel
- Based on Lin et al. with modifications for ice/water saturation
- gsfcgce_hail switch for hail/graupel properties
  gsfcgce_2ice switch for removing graupel or snow processes
- Time-split fall terms with melting

mp_physics=8

- Thompson et al. graupel scheme
- From Thompson et al.
- Newer version of Thompson et al. (2004) scheme
- 6-class microphysics with graupel
- Ice number concentration also predicted (double-moment ice)
- Time-split fall terms

mp_physics=10

- Morrison 2-moment scheme
- New in Version 3.0
- 6-class microphysics with graupel
- Number concentrations also predicted for ice, snow, rain, and graupel (double-moment)
- Time-split fall terms

no_mp_heating=1

- Turn off heating effect of microphysics

  Zeroes out the temperature tendency

  Equivalent to no latent heat

  Other microphysics processes not affected

mp_zero_out

- Microphysics switch (also mp_zero_out_thresh)

  1: all values less than threshold set to zero (except vapor)

  2: as 1 but vapor also limited ≥ 0
- This option will not conserve total water
- Not needed when using positive definite advection
- NMM: Recommend mp_zero_out=0

nphs

- Time steps between microphysics calls
- Same as parameter for turbulence/PBL/LSM
- Typical value is 10 for efficiency

Microphysics Options

- Recommendations about choice
- 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
- WRF 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

  - RAINNCV is time-step value

  - SNOWNC/SNOWNCV are snow sub-set of RAINC/RAINNCV (also GRAUPELNC, etc.)

Physics Interactions