WRF Physics Options

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WRF Physics

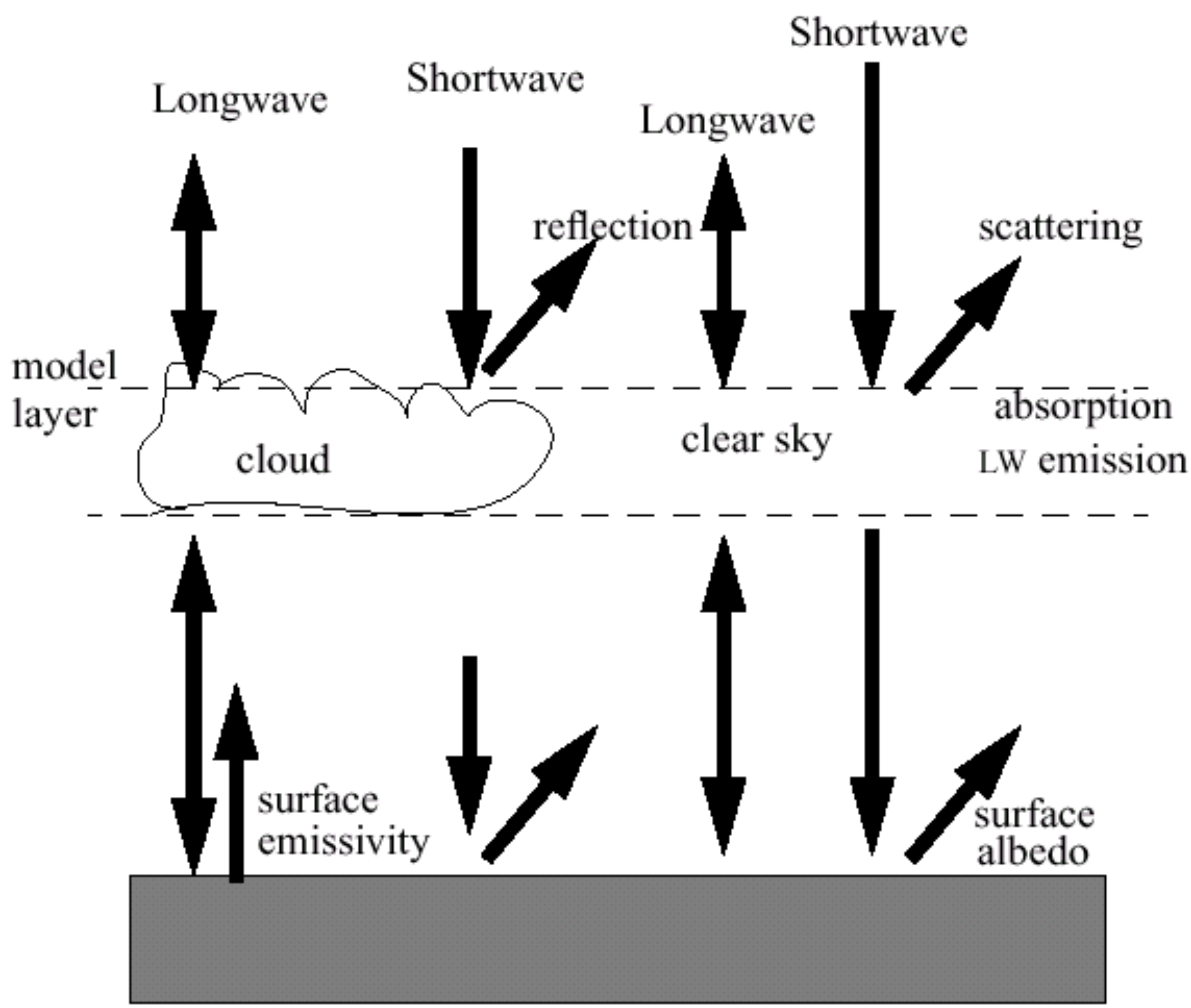
- Radiation
  - Longwave (ra_lw_physics)
  - Shortwave (ra_sw_physics)
- Surface
  - Surface layer (sf_sfclay_physics)
  - Land/water surface (sf_surface_physics)
- PBL (bl_physics)
- Cumulus parameterization (cu_physics)
- Microphysics (mp_physics)
- Turbulence/Diffusion (diff_opt, km_opt)

Radiation

Atmospheric temperature tendency

Surface radiative fluxes

Illustration of Free Atmosphere Radiation Processes



ra_lw_physics=1

RRTM scheme

- Spectral scheme
- K-distribution
- Look-up table fit to accurate calculations
- Interacts with resolved clouds
- Ozone profile specified
- CO2 constant (well-mixed)

ARW only

ra_lw_physics=3

CAM3 scheme

- Spectral scheme
- 8 longwave bands
- Look-up table fit to accurate calculations
- Interacts with cloud fractions
- Can interact with trace gases and aerosols
- Ozone profile function of month, latitude
- CO2 changes based on year (since V3.1)
- Top-of-atmosphere (TOA) and surface diagnostics for climate

ARW only

ra_lw_physics=4

RRTMG longwave scheme (Since V3.1)

- Spectral scheme 16 longwave bands (K-distribution)
- Look-up table fit to accurate calculations
- Interacts with cloud fractions (MCICA, Monte Carlo Independent Cloud Approximation random overlap method)
- Ozone profile specified
- CO2 and trace gases specified
- WRF-Chem optical depth
- TOA and surface diagnostics for climate

ARW only

ra_lw_physics=5

New Goddard longwave scheme (Since V3.3)

- Spectral scheme
- 10 longwave bands
- Look-up table fit to accurate calculations
- Interacts with cloud fractions
- Can interact with trace gases and aerosols
- Ozone profile specified
- CO2 and trace gases specified
- TOA and surface diagnostics for climate

ARW only

ra_lw_physics=31

Held-Suarez relaxation term

- For Held-Suarez global idealized test
- Relaxation towards latitude and pressure-dependent temperature function
- Simple code - can be used as basis for other simplified radiation schemes, e.g relaxation or constant cooling functions

ra_lw_physics=99

GFDL longwave scheme

- used in Eta/NMM
- Default code is used with Ferrier microphysics
  - Remove #define to compile for use without Ferrier
- Spectral scheme from global model
- Also uses tables
- Interacts with clouds (cloud fraction)
- Ozone profile based on season, latitude
- CO_2 fixed
- ra_lw_physics=98 (nearly identical) for HWRF

ra_sw_physics=1

MM5 shortwave (Dudhia)

- Simple downward calculation
- Clear-sky scattering
  - swrad_scat tuning parameter
    - 1.0 = 10% scattered, 0.5=5%, etc.
  - WRF-Chem aerosol effect (PM2.5)
- Water vapor absorption
- Cloud albedo and absorption
- No ozone effect (model top below 50 hPa OK)

ARW only

ra_sw_physics=2

Goddard shortwave

- Spectral method
- Interacts with resolved clouds
- Ozone profile (tropical, summer/winter, mid-lat, polar)
- CO_2 fixed
- WRF-Chem optical depths

ARW only

ra_sw_physics=3

CAM3 shortwave

- Spectral method (19 bands)
- Interacts with cloud fractions
- Ozone/CO2 profile as in CAM longwave
- Can interact with aerosols and trace gases
- TOA and surface diagnostics for climate
- Note: CAM schemes need some extra namelist items (see README.namelist)

ARW only

ra_sw_physics=4

RRTMG shortwave (Since V3.1)

- Spectral method (14 bands)
- Interacts with cloud fractions (MCICA method)
- Ozone/CO_2 profile as in RRTMG longwave
- Trace gases specified
- WRF-Chem optical depths
- TOA and surface diagnostics for climate

ARW only

ra_sw_physics=5

New Goddard shortwave scheme (Since V3.3)

- Spectral scheme
- 11 shortwave bands
- Look-up table fit to accurate calculations
- Interacts with cloud fractions
- Ozone profile specified
- CO2 and trace gases specified
- TOA and surface diagnostics for climate

ra_sw_physics=99

GFDL shortwave

- Used in Eta/NMM model
- Default code is used with Ferrier microphysics (see GFDL longwave)
- Ozone/CO2 profile as in GFDL longwave
- Interacts with clouds (and cloud fraction)
- ra_lw_physics=98 (nearly identical) for HWRF

Slope effects on shortwave

- In V3.2 available for all shortwave options
- Represents effect of slope on surface solar flux accounting for diffuse/direct effects
- slope_rad=1: activates slope effects - may be useful for complex topography and grid lengths < 2 km.
- topo_shading=1: shading of neighboring grids by mountains - may be useful for grid lengths < 1 km.

ARW only

radt

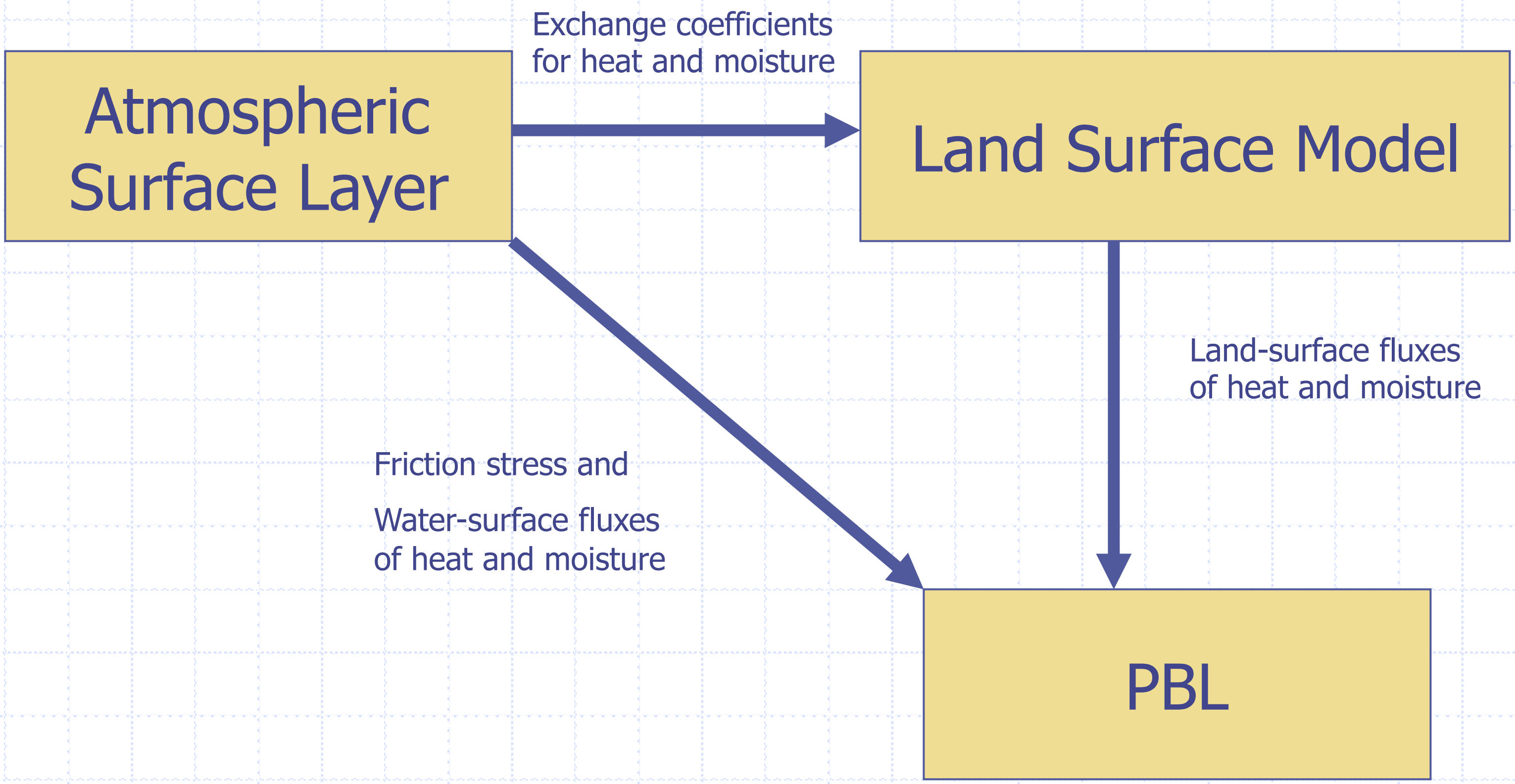
Radiation time-step recommendation

- 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

Surface schemes

- Surface layer of atmosphere diagnostics (exchange/transfer coeffs)
- Land Surface: Soil temperature / moisture /snow prediction /sea-ice temperature

Surface Physics Components



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)

z_0 are the roughness lengths

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

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

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

sf_sfclay_physics=1

Monin-Obukhov similarity theory

- Taken from standard relations used in MM5 MRF PBL
- Provides exchange coefficients to surface (land) scheme
- iz0tlnd thermal roughness length options for land points (0: Original Carlson-Boland, 1: Chen-Zhang)
  - Chen and Zhang (2009, JGR) modifies Zilitinkevich method with vegetation height
- 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
- iz0tlnd thermal roughness length options for land points (0: Original Zilitinkevich, 1: Chen-Zhang)
- Can be used with bl_pbl_physics=2, 9

sf_sfclay_physics=4

QNSE Monin-Obukhov similarity theory (New in V3.1)

- For use with QNSE-PBL
- Should be used with bl_pbl_physics=4
- Very similar to MYJ SFC
- New stability functions

ARW only

sf_sfclay_physics=5

MYNN Monin-Obukhov similarity theory (New in V3.1)

- For use with MYNN-PBL
- Should be used with bl_pbl_physics=5

ARW only

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

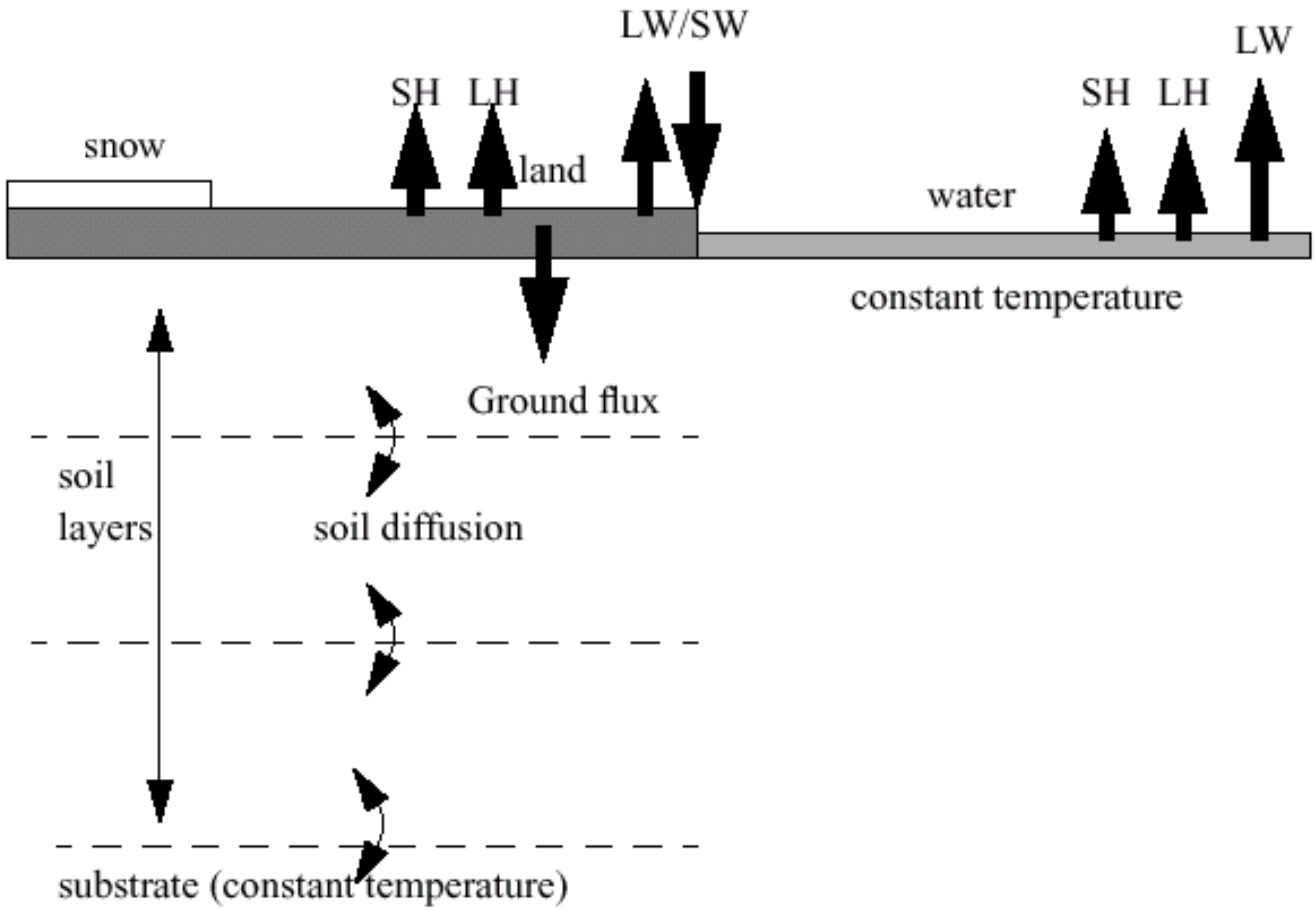
ARW only

sf_sfclay_physics=10

TEMF surface layer (Angevine et al.)

- For use with TEMF PBL
  - Should be used with bl_pbl_physics=10
- New in Version 3.3

Illustration of Surface Processes



ARW only

sf_surface_physics=1

5-layer thermal diffusion model from MM5

- Predict ground temp and soil temps
- Thermal properties depend on land use
- No soil moisture or snow-cover prediction
- Moisture availability based on land-use only
- Provides heat and moisture fluxes for PBL

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 and diagnoses skin temperature
- Predicts snow cover and canopy moisture
- Handles fractional snow cover and frozen soil
- New time-varying snow albedo (in V3.1)
- Provides heat and moisture fluxes for PBL
- Noah has 2 Urban Canopy Model options (sf_urban_physics, ARW only)

sf_urban_physics=1

Urban Canopy Model (UCM, Kusaka et al.)

- Sub-grid wall, roof, and road effects on radiation and fluxes
- Anthropogenic heat source can be specified
- Can use low, medium and high density urban categories

sf_urban_physics=2

Building Environment Parameterization (BEP, Martilli et al.)

- Sub-grid wall, roof, and road effects on radiation and fluxes
- Can be used with MYJ PBL or BouLac PBL to represent buildings higher than lowest model levels (Multi-layer urban model)
- Needs additional sub-grid building fractional area information

sf_urban_physics=3

Building Energy Model (BEM, Martilli and Salamanca)

- Includes anthropogenic building effects (heating, air-conditioning) in addition to BEP
- Can be used with MYJ PBL or BouLac PBL to represent buildings higher than lowest model levels (Multi-layer urban model)
- Needs additional sub-grid building fractional area information

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

ARW only

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

VEGPARM.TBL

Text (ASCII) file that has vegetation properties for Noah and RUC LSMs (separate sections in this table)

- 24 USGS categories or 20 MODIS categories (new) from 30" global dataset
- Each type is assigned min/max value of
  - Albedo
  - Leaf Area Index
  - Emissivity
  - Roughness length
- Other vegetation properties (stomatal resistance etc.)
- From 3.1, monthly vegetation fraction determines seasonal cycle between min and max values in Noah
- There is also a SOILPARM.TBL for soil properties in Noah and RUC

LANDUSE.TBL

Text (ASCII) file that has land-use properties for 5-layer slab model (vegetation, urban, water, etc.)

- From Version 3.1 Noah LSM does not use this table
- 24 USGS categories or 20 MODIS categories (new) from 30” global dataset
- Each type is assigned summer/winter value
  - Albedo
  - Emissivity
  - Roughness length
- Other table properties (thermal inertia, moisture availability, snow albedo effect) are used by 5-layer model
- Also note
  - Other tables (VEGPARM.TBL, etc.) are used by Noah
  - RUC LSM uses same table files after Version 3

Initializing LSMs

- Noah and RUC LSM 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)

Initializing LSMs

- There are consistent model-derived datasets for Noah and RUC LSMs
  - Eta/GFS/AGRMET/NNRP for Noah (although some have limited soil levels available)
  - RUC for RUC
- But, resolution of mesoscale land-use means there will be inconsistency in elevation, soil type and vegetation
- This leads to spin-up as adjustments occur in soil temperature and moisture
- This spin-up can only be avoided by running offline model on the same grid (e.g. HRLDAS for Noah)
- Cycling land state between forecasts also helps, but may propagate errors (e.g in rainfall effect on soil moisture)

ARW only

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 since Version 3.0
- 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

- New in V3.1
- 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 later)
- No-leap-year compilation option for CCSM-driven runs

ARW only

Hurricane Options

- Ocean Mixed Layer Model (omlcall=1)
  - 1-d slab ocean mixed layer (specified initial depth)
  - Includes wind-driven ocean mixing for SST cooling feedback
- 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)

Fractional Sea Ice

- fractional_seaice=1 - with input sea-ice fraction data can partition land/water fluxes within a grid box
- Since Version 3.1

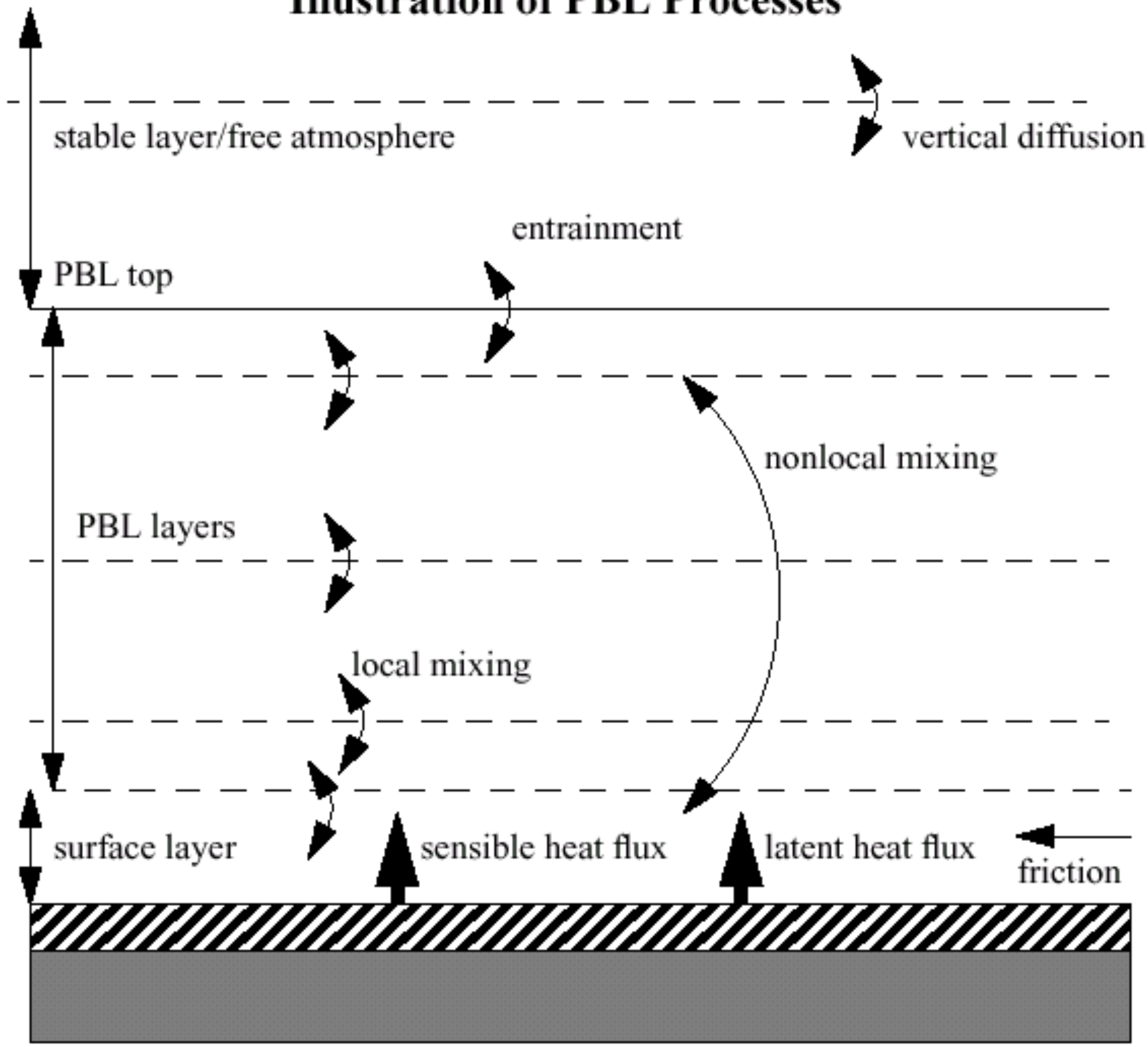
Planetary Boundary Layer

Boundary layer fluxes (heat, moisture, momentum)

Vertical diffusion

$$\frac{\partial}{\partial z} K_v \frac{\partial}{\partial z} \theta$$

Illustration of PBL Processes



bl_pbl_physics=1

YSU PBL scheme (Hong, Noh and Dudhia 2006)

- Parabolic K profile mixing in dry convective boundary layer
- Troen-Mahrt countergradient flux (non-local)

$$\frac{\partial}{\partial z}(K_v \frac{\partial}{\partial z}\theta + \Gamma)$$

- 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

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=4

QNSE (Quasi-Normal Scale Elimination) PBL from Galperin and Sukoriansky

- 1.5-order, level 2.5, TKE prediction
- Local TKE-based vertical mixing in boundary layer and free atmosphere
- New theory for stably stratified case
- Mixing length follows MYJ, TKE production simplified from MYJ

bl_pbl_physics=5 and 6

MYNN (Nakanishi and Niino) PBL

- (5)1.5-order, level 2.5, TKE prediction, OR
- (6)2nd-order, level 3, TKE, θ'^2,q'^2 and $\theta' q'$ prediction
- Local TKE-based vertical mixing in boundary layer and free atmosphere
- Since V3.1
- TKE advected since V3.3 (output name: QKE)

ARW only

bl_pbl_physics=7

Asymmetrical Convective Model, Version 2 (ACM2) PBL (Pleim and Chang)

- Blackadar-type thermal mixing upwards from surface layer
- Local mixing downwards
- PBL height from critical bulk Richardson number

ARW only

bl_pbl_physics=8

BouLac PBL (Bougeault and Lacarrère)

- TKE prediction scheme
- Designed to work with multi-layer urban model (BEP)
- Since V3.1

ARW only

bl_pbl_physics=9

CAM UW PBL (Bretherton and Park, U. Washington)

- TKE prediction scheme
- From current CESM climate model physics
- Use with sf_sfclay_physics=2
- New in V3.3

ARW only

bl_pbl_physics=10

Total Energy - Mass Flux (TEMF) PBL (Angevine et al.)

- Total Turbulent Energy (kinetic + potential) prediction scheme
- Includes mass-flux shallow convection
- New in V3.3

ARW only

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

ARW only

bldt

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

PBL Scheme Options

PBL schemes can be used for most grid sizes when surface fluxes are present

- With ACM2, GFS and MRF PBL schemes, lowest full level should be .99 or .995 not too close to 1 (YSU can now handle thin layers)
- TKE schemes can use thinner surface layers
- 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

ARW only

Large Eddy Simulation

- Explicit large-eddy simulation (LES) available for real-data cases (V3) or idealized cases
- For dx <~200 meters (dx~dz), horizontal and vertical mixing should be unified in the turbulence/diffusion parameterization
  - bl_pbl_physics = 0 (activates vertical diffusion routines)
    - isfflx = 0 (idealized drag and heat flux from namelist)
    - isfflx = 1 (drag and heat flux from physics)
      - sf_sfclay_physics=1
      - sf_surface_physics (choose non-zero option)
    - isfflx = 2 (drag from physics, heat flux from tke_heat_flux)
      - sf_sfclay_physics=1
  - diff_opt=2, km_opt = 2 or 3
  - mix_isotropic=1 (if dx and dz are of same order)

Gravity Wave Drag (gwd_opt=1 for ARW, 2 for NMM)

- ARW scheme from Hong et al. New in V3.1
- Accounts for orographic gravity wave effect on momentum profile
- Extra sub-grid orographic information comes from geogrid
- Probably needed only if all below apply
  - dx > 10 km
  - Simulations longer than 5 days
  - Domains including mountains

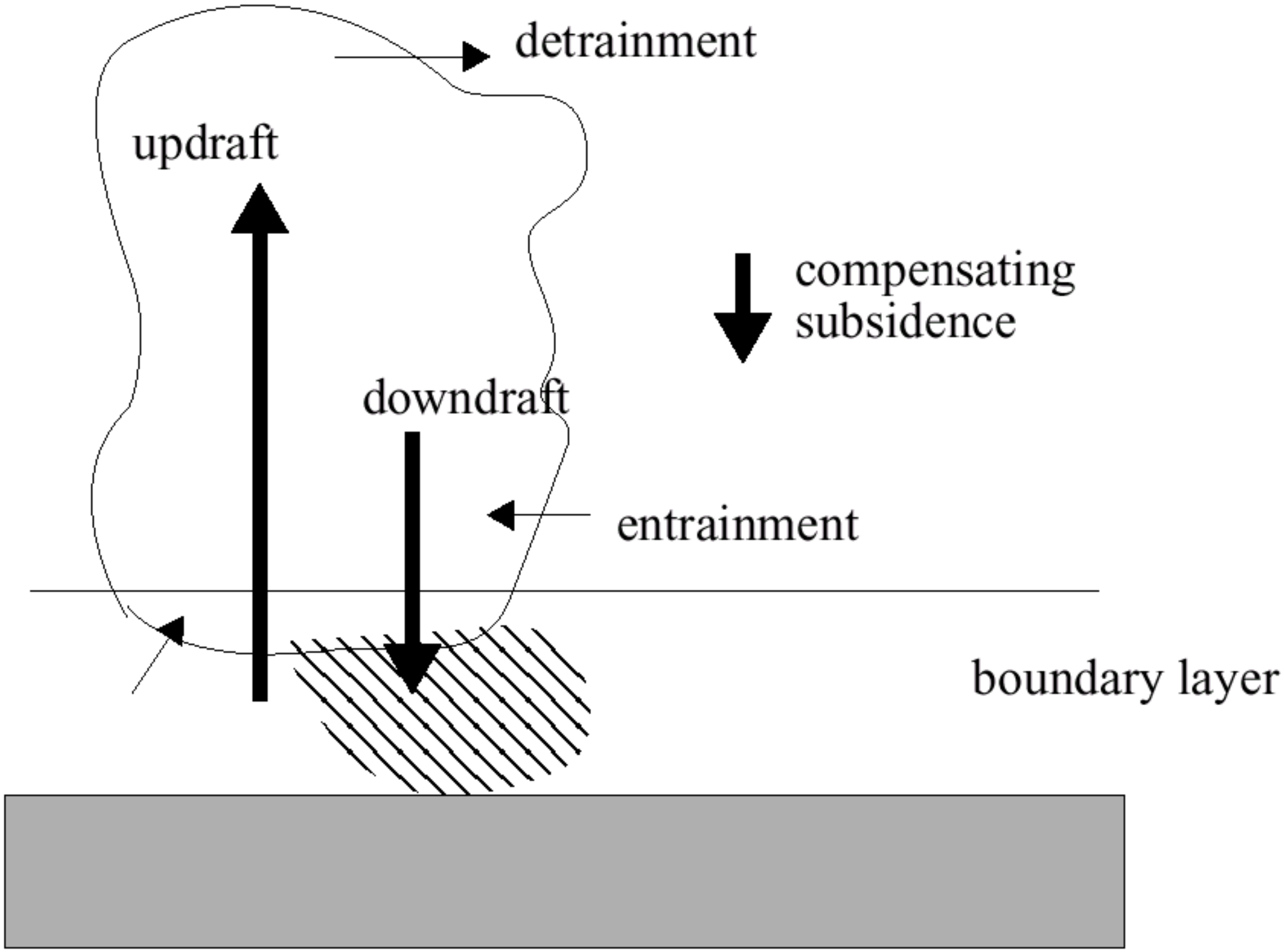
Wind Farm Parameterization

- From A. Fitch (U. of Bergen, Norway)
- To be used with MYNN PBL
- Represents effect of specified turbines on wind and TKE in lower boundary-layer
- See README.windturbine file in WRF tar file for set-up information

Cumulus Parameterization

- Atmospheric heat and moisture/ cloud tendencies
- Surface rainfall

Illustration of Cumulus Processes



cu_physics=1

New Kain-Fritsch

- As in MM5 and Eta/NMM ensemble 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 cloud, rain, ice, snow detrainment
- Clouds persist over convective time scale (recalculated every convective step in NMM)
- Old KF is option 99

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 (CAPE removal, quasi-equilibrium, moisture convergence, cloud-base ascent) - 16 mass flux closures
- Multi-parameter (maximum cap, precipitation efficiency) - e.g. 3 cap strengths, 3 efficiencies
- 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) scheme

- Quasi-equilibrium scheme
- Related to Grell scheme in MM5
- Includes cloud and ice detrainment
- Downdrafts and single, simple cloud
- Shallow convective mixing in ARW only
- Part of HWRF physics in NMM
- Momentum transport in NMM only

cu_physics=5

Grell-3d

- As GD, but slightly different ensemble
- Includes cloud and ice detrainment
- Subsidence is spread to neighboring columns
  - This makes it more suitable for < 10 km grid size than other options
  - cugd_avgdx=1 (default), 3(spread subsidence)
- ishallow=1 option for shallow convection
- Mean feedback of ensemble is applied
- Weights can be tuned (spatially, temporally) to optimize scheme (training)

cu_physics=6

Tiedtke scheme (U. Hawaii version)

- Mass-flux scheme
- CAPE-removal time scale closure
- Includes cloud and ice detrainment
- Includes shallow convection
- Includes momentum transport
- New in V3.3

cu_physics=7

CAM Zhang-McFarlane scheme

- Mass-flux scheme
- CAPE-removal time-scale closure
- From current CESM climate model physics
- Includes cloud and ice detrainment
- Includes momentum transport
- New in V3.3

cu_physics=14

- New Simpified Arakawa-Schubert (NSAS) scheme
- Quasi-equilibrium scheme
- Updated from SAS for current NCEP GFS global model
- Includes cloud and ice detrainment
- Downdrafts and single, simple cloud
- New mass-flux type shallow convection (changed from SAS)
- Momentum transport
- New in V3.3

ARW only

shcu_physics=2

CAM UW shallow convection (Bretherton and Park, U. Washington)

- To be used with a TKE PBL scheme and a deep scheme with no shallow convection (e.g. CESM Zhang-McFarlane)
- From current CESM climate model physics
- New shallow convection driver in V3.3
- Other options such as Grell ishallow to be moved here in the future

ARW only

cudt

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

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

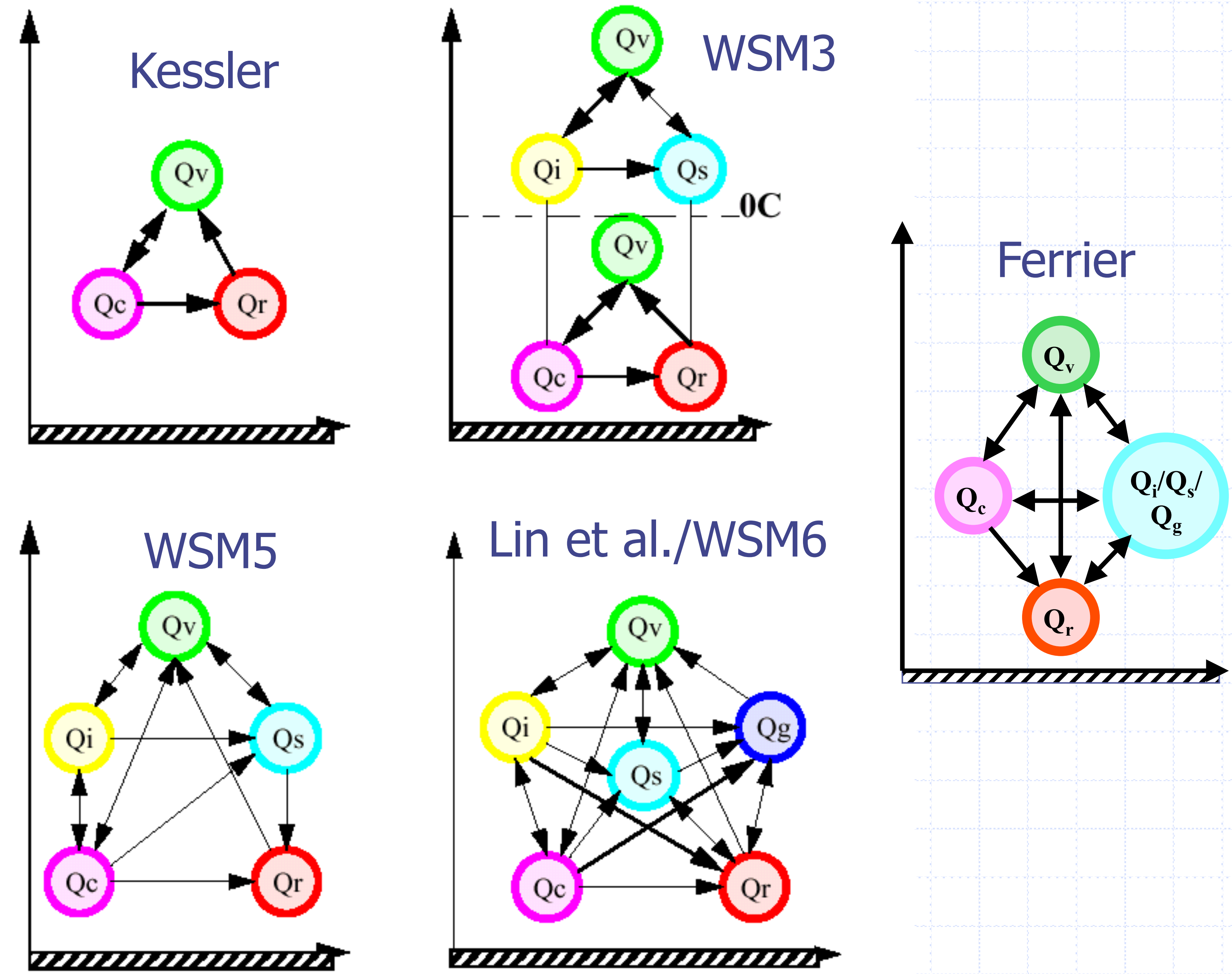
Microphysics

Atmospheric heat and moisture tendencies

Microphysical rates

Surface rainfall

Illustration of Microphysics Processes



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 diagnostic
- Double-moment schemes add a prediction equation for number concentration (#/kg) per double-moment species (Nr, Ns, etc.)
- Double-moment schemes may only be double-moment for a few species
- Double-moment schemes allow for additional processes such as size-sorting during fall-out and sometimes aerosol effects on clouds

Microphysics: Fall terms

- Microphysics schemes handle fall terms for particles (usually everything except cloud water has a fall term)
- 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 splitting the time-step or lagrangian numerical methods to keep the scheme numerically stable

ARW only

mp_physics=1

Kessler scheme

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

ARW only

mp_physics=2

Purdue Lin et al. scheme

- 5-class microphysics including graupel
- Includes ice sedimentation and time-split fall terms
- Can be used with WRF-Chem aerosols

ARW only

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
- Semi-lagrangian fall terms in V3.2

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
- Semi-lagrangian fall terms in V3.2

ARW only

mp_physics=14

WDM 5-class scheme

- Version of WSM5 that is double-moment for warm rain processes
- 5-class microphysics with ice
- CCN, and number concentrations of cloud and rain also predicted

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=85 (nearly identical) for HWRF

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
- Semi-lagrangian fall terms

ARW only

mp_physics=16

WDM 6-class scheme

- Version of WSM6 that is double-moment for warm rain processes
- 6-class microphysics with graupel
- CCN, and number concentrations of cloud and rain also predicted

ARW only

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

New Thompson et al. scheme in V3.1

- Replacement of Thompson et al. (2007) scheme that was option 8 in V3.0
- 6-class microphysics with graupel
- Ice and rain number concentrations also predicted (double-moment ice)
- Time-split fall terms

ARW only

mp_physics=9

Milbrandt-Yau 2-moment scheme

- New in Version 3.2
- 7-class microphysics with separate graupel and hail
- Number concentrations predicted for all six water/ice species (double-moment) - 12 variables
- Time-split fall terms

ARW only

mp_physics=10

Morrison 2-moment scheme

- Since Version 3.0
- 6-class microphysics with graupel
- Number concentrations also predicted for ice, snow, rain, and graupel (double-moment)
- Time-split fall terms
- Can be used with WRF-Chem aerosols (V3.3)

mp_physics=13

Stonybrook University (Y. Lin, SBU) scheme

- From Lin and Colle (2010)
- Was option 8 in Version 3.0
- 5-class microphysics (no graupel)
- Riming intensity factor for mixed-phase
- Time-split fall terms
- New in V3.3

ARW only

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
  - Since Version 3.0

ARW only

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
- Note: this option will not conserve total water
- Not needed when using positive definite advection
- NMM: Recommend mp_zero_out=0

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

ARW only

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

ARW only

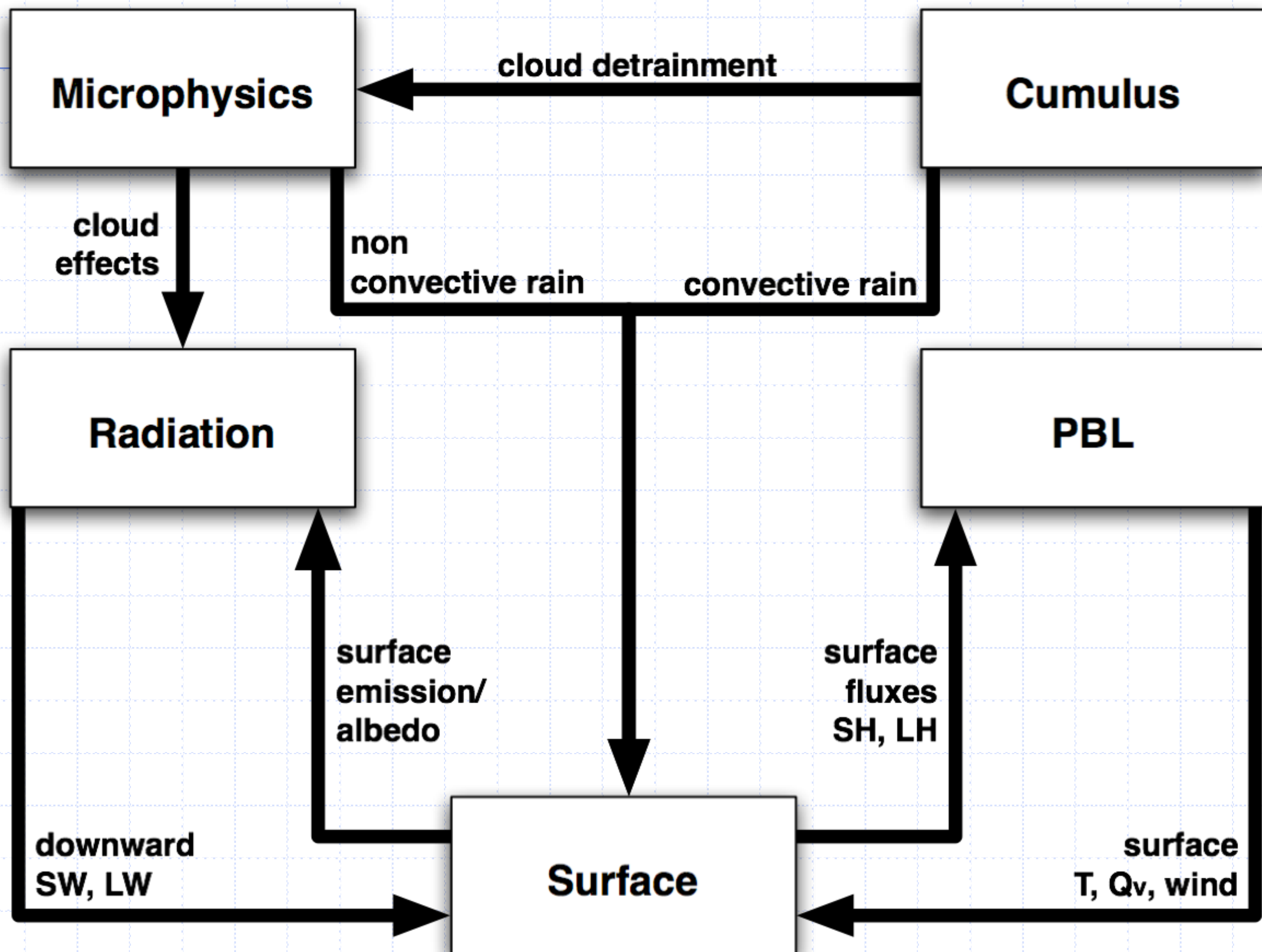
Rainfall Output

Options for "buckets"

- prec_acc_dt (minutes) - accumulates separate prec_acc_c, prec_acc_nc, snow_acc_nc in each time window (we recommend prec_acc_dt is equal to the wrf output frequency to avoid confusion)
- bucket_mm - separates RAIN(N)C into RAIN(N)C and I_RAIN(N)C to allow accuracy with large totals such as in multi-year accumulations
  - Rain = I_RAIN(N)C*bucket_mm + RAIN(N)C
  - bucket_mm = 100 mm is a reasonable bucket value
  - bucket_J also for CAM and RRTMG radiation budget terms (1.e9 J/m^2 recommended)

Physics Interactions

Direct Interactions of Parameterizations



Turbulence/Diffusion

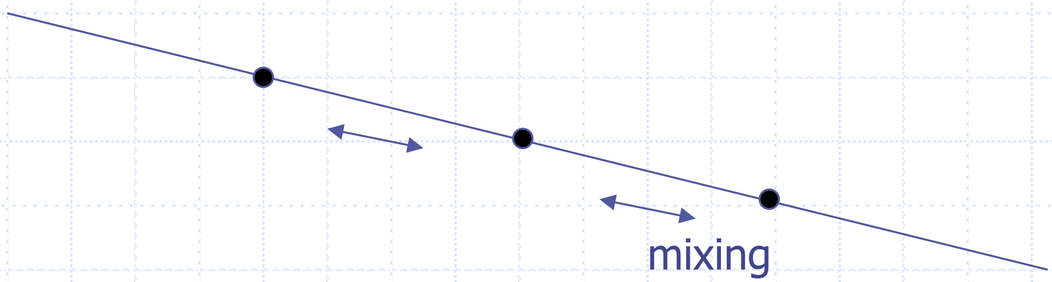
Sub-grid eddy mixing effects on all fields, e.g. $\frac{\partial}{\partial x} K_h \frac{\partial}{\partial x}\theta + \frac{\partial}{\partial y} K_h \frac{\partial}{\partial y}\theta + \frac{\partial}{\partial z} K_v \frac{\partial}{\partial z}\theta$

ARW only

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
- km_opt selects method to compute K
  - 1: constant (khdif and kvdif used)
  - 4: 2D Smagorinsky (deformation based on horizontal wind for horizontal diffusion only)

Difference between diff_opt 1 and 2

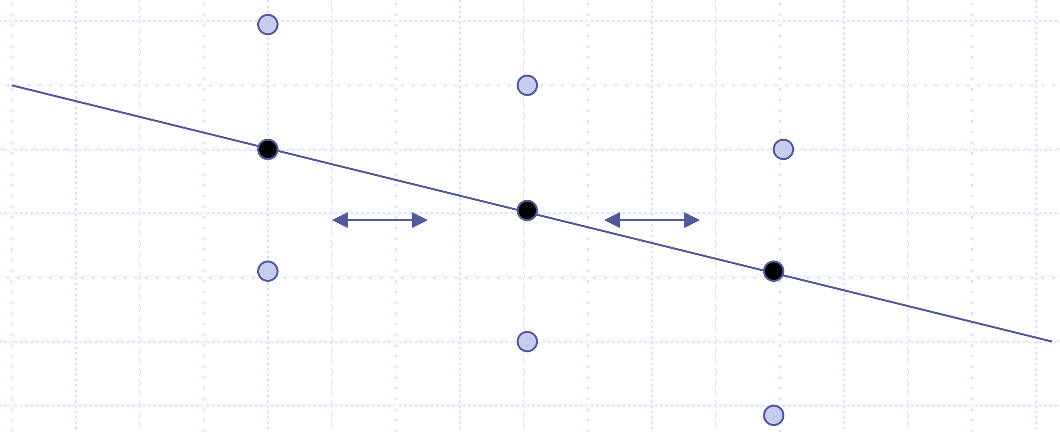


diff_opt=1

Horizontal diffusion acts along model levels

Simpler numerical method with only neighboring points on the same model level

Difference between diff_opt 1 and 2



diff_opt=2
Horizontal diffusion acts on horizontal gradients
Numerical method includes vertical correction term using more grid points

ARW only

diff_opt=2

- 2nd order horizontal diffusion
- Allows for terrain-following coordinate
- km_opt selects method to compute K
  - 1: constant (khdif and kvdif used)
  - 2: 1.5-order TKE prediction
  - 3: Smagorinsky (deformation/stability based K)
  - 4: 2D Smagorinsky (deformation based on horizontal wind for horizontal diffusion only)

ARW only

diff_opt=2 (continued)

- mix_full_fields=.true.: vertical diffusion acts on full (not perturbation) fields (recommended, but default = .false.)
- mix_isotropic=1: same length scale used for horizontal and vertical diffusion (for dx≈dz)
- Idealized constant surface fluxes can be added in diff_opt=2 using namelist (dynamics section). Not available for diff_opt=1.
  - tke_drag_coefficient (C_D)
  - tke_heat_flux ($=H/\rho c_p$)
  - Must use isfflx=0 to use these switches

ARW only

diff_opt=2 (continued)

- Explicit large-eddy simulation (LES) PBL in real-data cases (V3) or idealized cases
  - bl_pbl_physics = 0
    - isfflx = 0 (idealized drag and heat flux from namelist)
    - isfflx = 1 (drag and heat flux from physics)
      - sf_sfclay_physics=1
      - sf_surface_physics (choose non-zero option)
    - isfflx = 2 (drag from physics, heat flux from tke_heat_flux)
      - sf_sfclay_physics=1
  - km_opt = 2 or 3
  - mix_isotropic=1 (if dx and dz are of same order)
- Not available for diff_opt=1.

ARW only

sfs_opt

- Sub-filter-scale stress model for LES applications impacting momentum mixing (Kosovic, Mirocha)
  - sfs_opt=0 (default) off
  - sfs_opt=1 Nonlinear Backscatter and Anisotropy (NBA) option 1: using diagnostic stress terms (km_opt=2,3)
  - sfs_opt=2 NBA option 2: using tke-based stress terms (km_opt=2 only)
  - Also m_opt=1 for added outputs of SGS stresses

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)

ARW only

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 time-step)

ARW only

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
- Works for idealized cases and real-data since 2.2 release

ARW only

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

ARW only

damp_opt=3

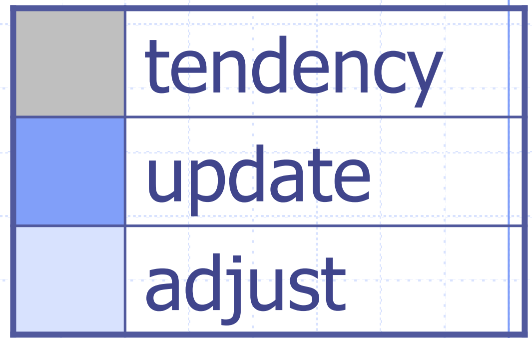
- "W-Rayleigh" (relaxation) layer
- Upper level relaxation towards zero vertical motion
- Cosine function of height
- Uses additional parameters
  - zdamp: depth of damping layer
  - dampcoef: inverse time scale (s^{-1})
- Works for idealized and real-data cases
- Applied in small time-steps (dampcoef=0.2 is stable)

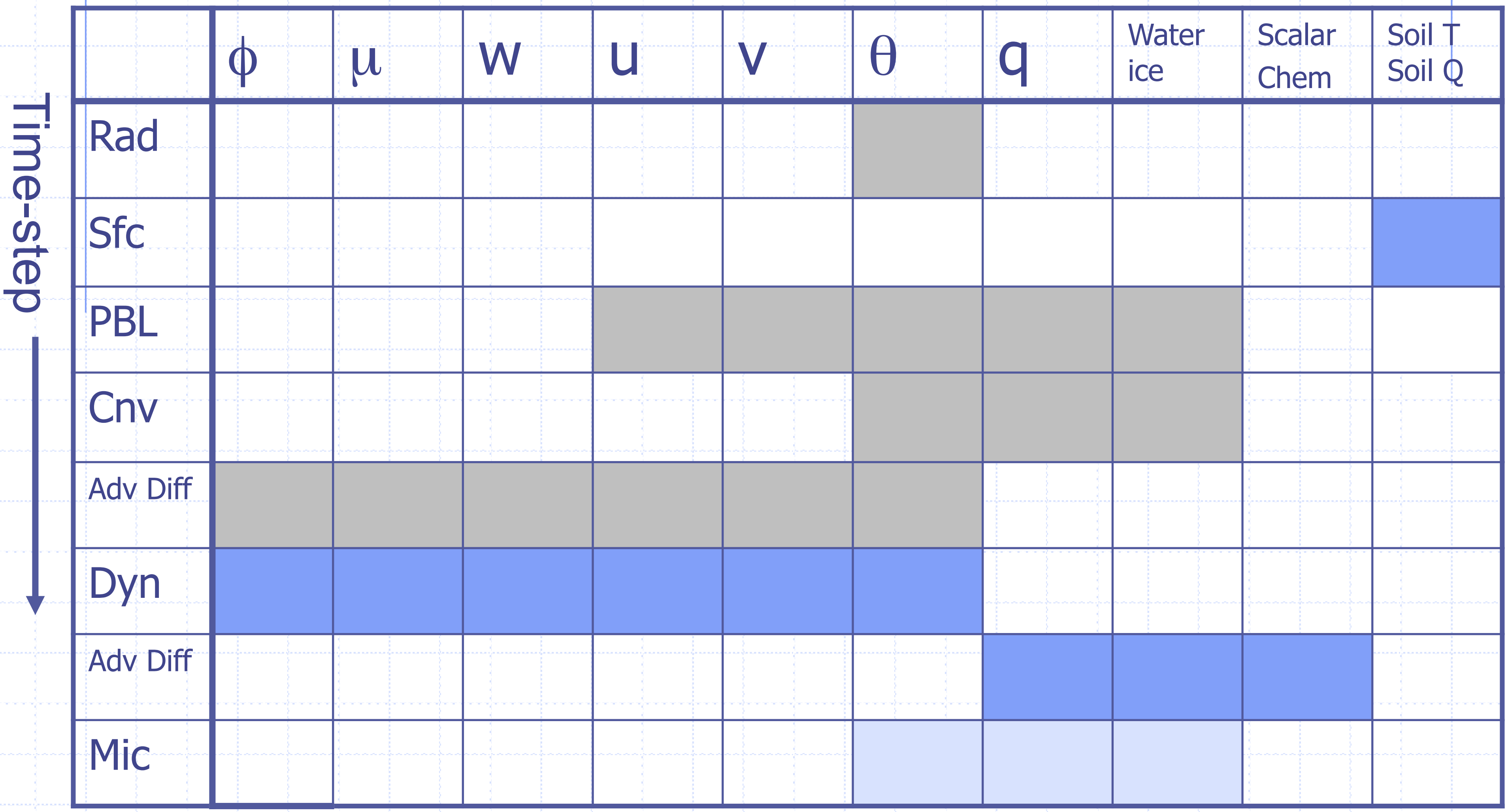
Solver Calling Sequence (ARW example)

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

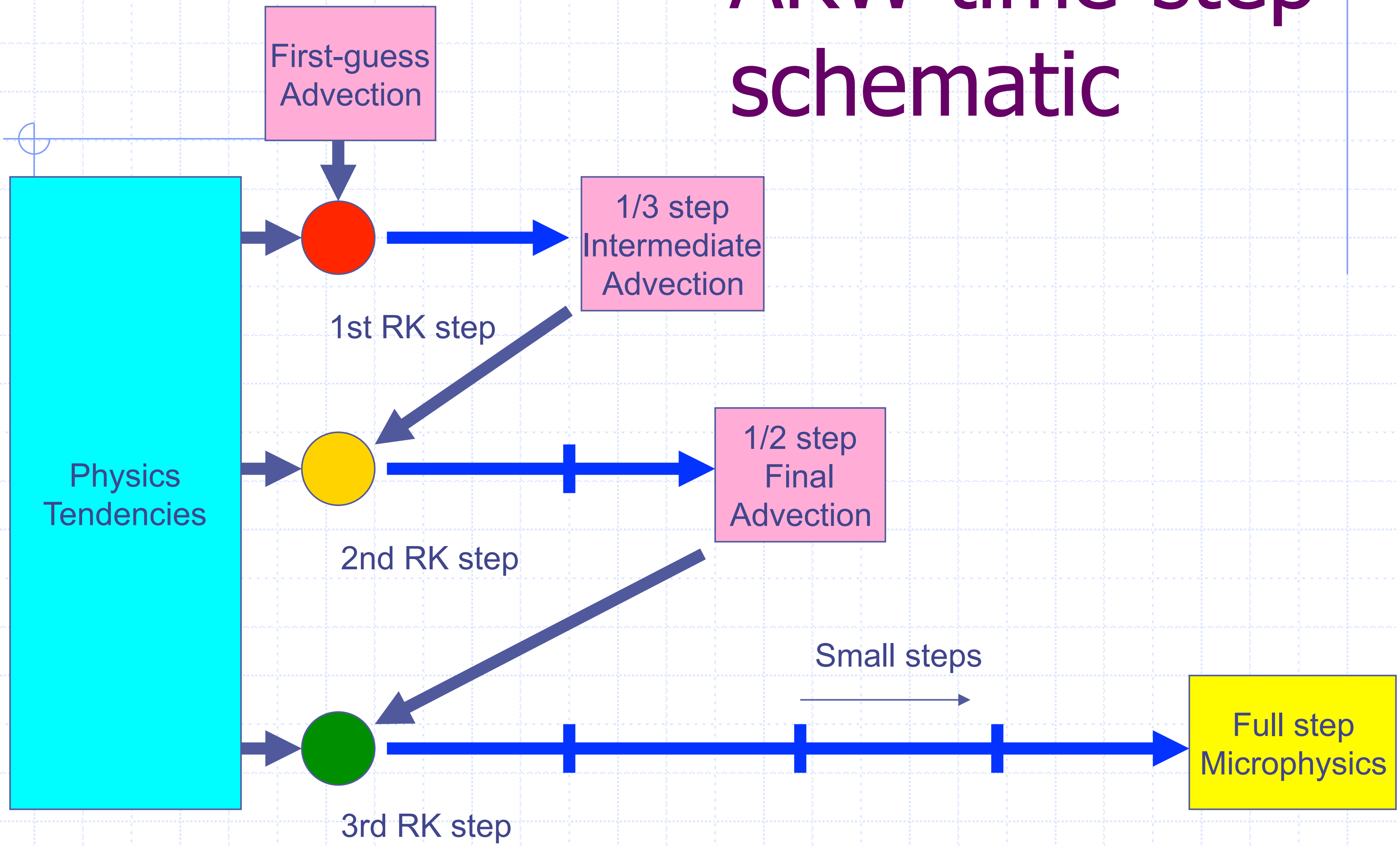
- Physics tendencies
  - Radiation, surface, land-state update, PBL, cumulus, grid-fdda, obs-fdda
- Dynamics tendencies
  - Diffusion, advection, dynamics terms (for 3d momentum, theta, geopotential, surface pressure)
- Acoustic steps
  - Update 3d momentum, theta, surface pressure, height
- Scalar dynamics 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

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

Summary of Boundary Layer, Microphysics and Cumulus Options

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NCAR/MMM

PBL schemes in V3.3

bl_pbl_ physics	Scheme	Reference	Added
1	YSU	Hong, Noh and Dudhia (2006, MWR)	2004
2	MYJ	Janjic (1994, MWR)	2000
3	GFS	Hong and Pan (1996, MWR)	2005
4	QNSE	Sukoriansky, Galperin and Perov (2005, BLM)	2009
5	MYNN2	Nakanishi and Niino (2006, BLM)	2009
6	MYNN3	Nakanishi and Niino (2006, BLM)	2009
7	ACM2	Pleim (2007, JAMC)	2008
8	BouLac	Bougeault and Lacarrere (1989, MWR)	2009
9	UW	Bretherton and Park (2009, JC)	2011
10	TEMF	Angevine, Jiang and Mauritsen (2010, MWR)	2011
99	MRF	Hong and Pan (1996, MWR)	2000

PBL schemes in V3.3

3.3 changes

bl_pbl_ physics	Scheme	Cores	sf_sfclay_ physics	Prognostic variables	Diagnostic variables	Cloud mixing
1	YSU	ARW NMM	1		exch_h	QC,QI
2	MYJ	ARW NMM	2	TKE_PBL	EL_PBL, exch_h	QC,QI
3	GFS(hwrf)	NMM	3			QC,QI
4	QNSE	ARW NMM	4	TKE_PBL	EL_PBL, exch_h, exch_m	QC,QI
5	MYNN2	ARW	1,2,5	QKE	Tsq, Qsq, Cov, exch_h, exch_m	QC
6	MYNN3	ARW	1,2,5	QKE, Tsq, Qsq, Cov	exch_h, exch_m	QC
7	ACM2	ARW	1,7			QC,QI
8	BouLac	ARW	1,2	TKE_PBL	EL_PBL, exch_h, exch_m	QC
9	UW	ARW	2	TKE_PBL	exch_h, exch_m	QC
10	TEMF	ARW	10	TE_TEMF	*_temf	QC, QI
99	MRF	ARW NMM	1			QC,QI

LES schemes

- Unified horizontal and vertical mixing (for dx~dz).

Typically needed for dx<~200 m. Also use mix_isotropic=1.

bl_pbl_physics	diff_opt	km_opt	Scheme	Cores	sf_sfclay_physics	isfflx	Prognostic variables
0	2	2	tke	ARW	0,1,2	0,1,2	tke
0	2	3	3d Smagorinsky	ARW	0,1,2	0,1,2	

Namelist isfflx controls surface flux methods

isfflx	sf_sfclay_physics	Heat flux	Drag	Real/Ideal
0	0	From namelist tke_heat_flux	From namelist tke_drag_coefficient	Ideal
1	1,2	From LSM/sfclay physics (HFX, QFX)	From sfclay physics (UST)	Real
2	1,2	From namelist tke_heat_flux	From sfclay physics (UST)	Ideal

Microphysics schemes in V3.3

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	Hong and Pan (1996, MWR)	2008
13	SBU-Ylin	Lin and Colle (2011, MWR)	2011
14	WDM5	Lim and Hong (2010,...)	2009
16	WDM6	Lim and Hong (2010,...)	2009

* Advects only total condensate ** Nn= CCN number

Microphysics schemes in V3.3

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	ARW	Qc Qr Qi Qs Qg	
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	Morrison 2-mom	ARW (Chem)	Qc Qr Qi Qs Qg	Nr Ni Ns Ng
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

Cumulus schemes in V3.3

mp_physics	Scheme	Reference	Added
1	Kain-Fritsch	Kain (2004, JAM)	2000
2	Betts-Miller-Janjic	Janjic (1994, MWR; 2000, JAS)	2002
3	Grell-Devenyi	Grell and Devenyi (2002, GRL)	2002
4	Simplified Arakawa-Schubert	Grell et al. (1994, MM5 NCAR Tech Note)	2002/ 2011
5	Grell-3	Grell and Devenyi (2002, GRL)	2008
6	Tiedtke	Tiedtke (1989, MWR), Zhang, Wang and Hamilton (2011, MWR)	2011
7	Zhang-McFarlane	Zhang and McFarlane (1995, AO)	2011
14	New SAS	Han and Pan (2010,…)	2011
99	Old Kain-Fritsch	Kain and Fritsch (1990, JAS; 1993 Meteo. Monogr.)	2000

Cumulus schemes in V3.3

cu_physics	Scheme	Cores	Moisture Tendencies	Momentum Tendencies	Shallow Convection
1	Kain-Fritsch Eta	ARW NMM	Qc Qr Qi Qs	no	yes
2	Betts-Miller-Janjic	ARW NMM	-	no	yes
3	Grell-Devenyi	ARW	Qc Qi	no	no
4	Simplified Arakawa-Schubert	ARW NMM	Qc Qi	yes (NMM)	yes (ARW)
5	Grell-3	ARW	Qc Qi	no	yes
6	Tiedtke	ARW	Qc Qi	yes	yes
7	Zhang-McFarlane	ARW	Qc Qi	yes	no
14	New SAS	ARW	Qc Qi	yes	yes
99	Old Kain-Fritsch	ARW	Qc Qr Qi Qs	no	no