WRF Physics Options

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WRF Physics

- Turbulence/Diffusion (diff_opt, km_opt)
- 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

Sub-grid eddy mixing effects on all fields

ARW only

diff_opt=1

- 2^{nd} order diffusion on model levels
  - Constant vertical coefficient (kvdif)
  - Or Use with PBL
- 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)

ARW only

diff_opt=2

- 2nd order horizontal diffusion
- Allows for terrain-following coordinate
- km_opt
  - 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)
- 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 ($=H/\rho c_p$)

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
- Idealized large-eddy resolving cases
  - km_opt=2 (tke scheme) is designed for hi-res eddy-resolving modeling
- Cloud-resolving modeling (smooth or no topography)
  - diff_opt=1; km_opt=2,3
- Complex topography
  - diff_opt=2 is more accurate for sloped coordinate surfaces, and prevents diffusion up/down valley sides
- Note: WRF can run with no diffusion, but especially not recommended with even-order advection

ARW only

diff_6th_opt

- 6th order horizontal diffusion on model levels
  - Used as a numerical filter for 2*dx noise
  - Suitable for idealized and real-data cases
- diff_6th_opt
  - 0: none (default)
  - 1: on
  - 2: on and prohibit up-gradient diffusion
- 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 in 2.2 release

ARW only

damp_opt=2

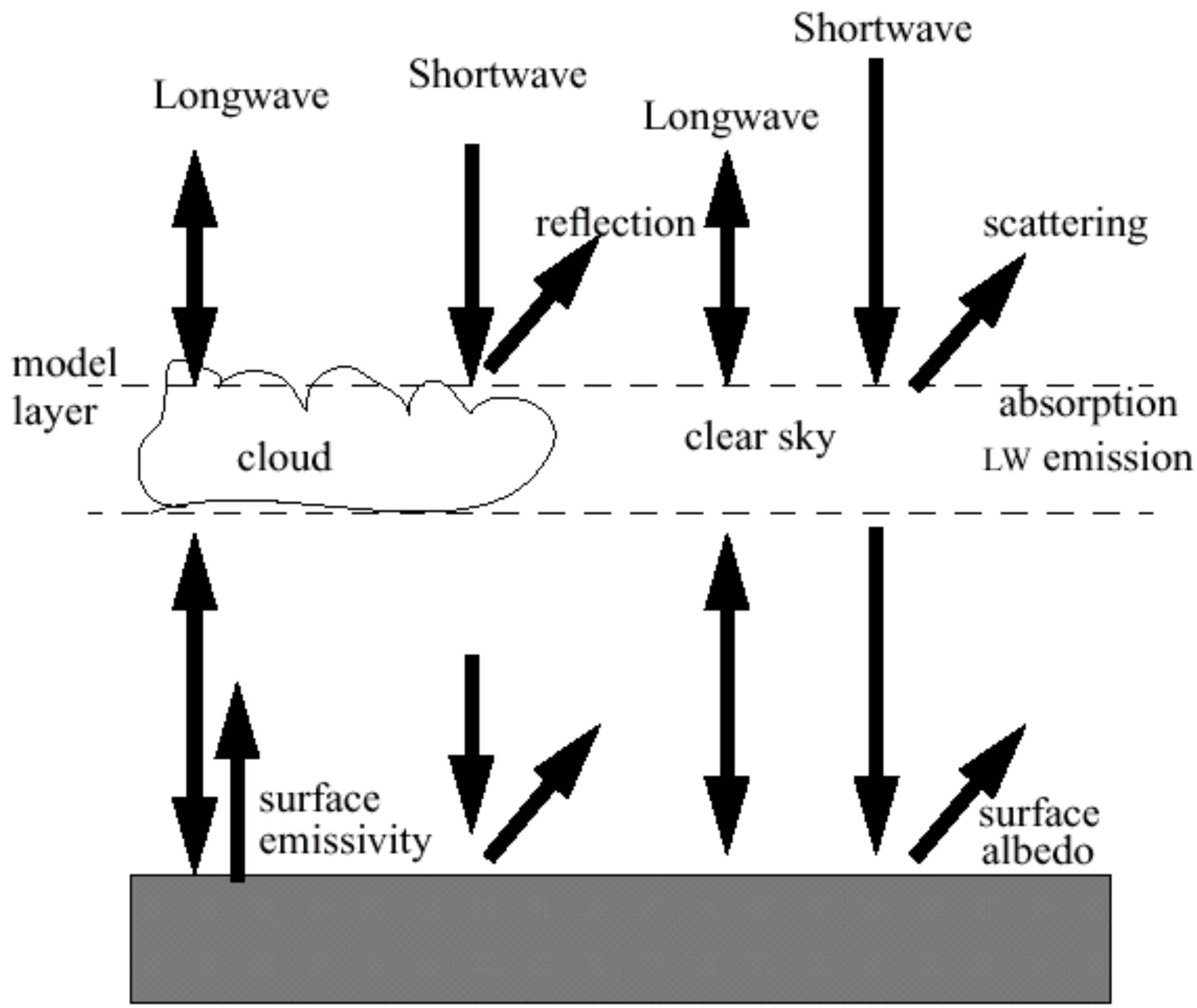
- Upper level relaxation towards 1-d profile
- Rayleigh (relaxation) layer
- Cosine function of height
- Uses additional parameters
  - zdamp: depth of damping layer
  - dampcoef: inverse time scale (s^{-1})
- Works for idealized cases only

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 clouds (1/0 fraction)
- Ozone/CO_2 from climatology

ARW only

ra_lw_physics=3

CAM3 scheme

- Spectral scheme
- 8 longwave bands
- Look-up table fit to accurate calculations
- Interacts with clouds (RH-based cloud fraction when RH<1)
- Can interact with trace gases and aerosols
- Ozone/CO_2 from climatology

ra_lw_physics=99

GFDL longwave scheme

- used in Eta/NMM
- Can only be called with Ferrier microphysics
  - Remove #define for use without Ferrier
- Spectral scheme from global model
- Also uses tables
- Interacts with clouds
- Ozone/CO_2 from climatology

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.
- Water vapor absorption
- Cloud albedo and absorption

ARW only

ra_sw_physics=2

Goddard shortwave

- Spectral method
- Interacts with clouds
- Ozone effects

ARW only

ra_sw_physics=3

CAM3 shortwave

- Spectral method (19 bands)
- Interacts with clouds
- Ozone effects
- Can interact with aerosols and trace gases
- Note: CAM schemes need some extra namelist items (see README.namelist)

ra_sw_physics=99

GFDL shortwave

- Used in Eta/NMM model
- Can only be used with Ferrier microphysics (see GFDL longwave)
- Ozone effects
- Interacts with clouds

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

NMM only

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

Surface schemes

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

ARW only

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

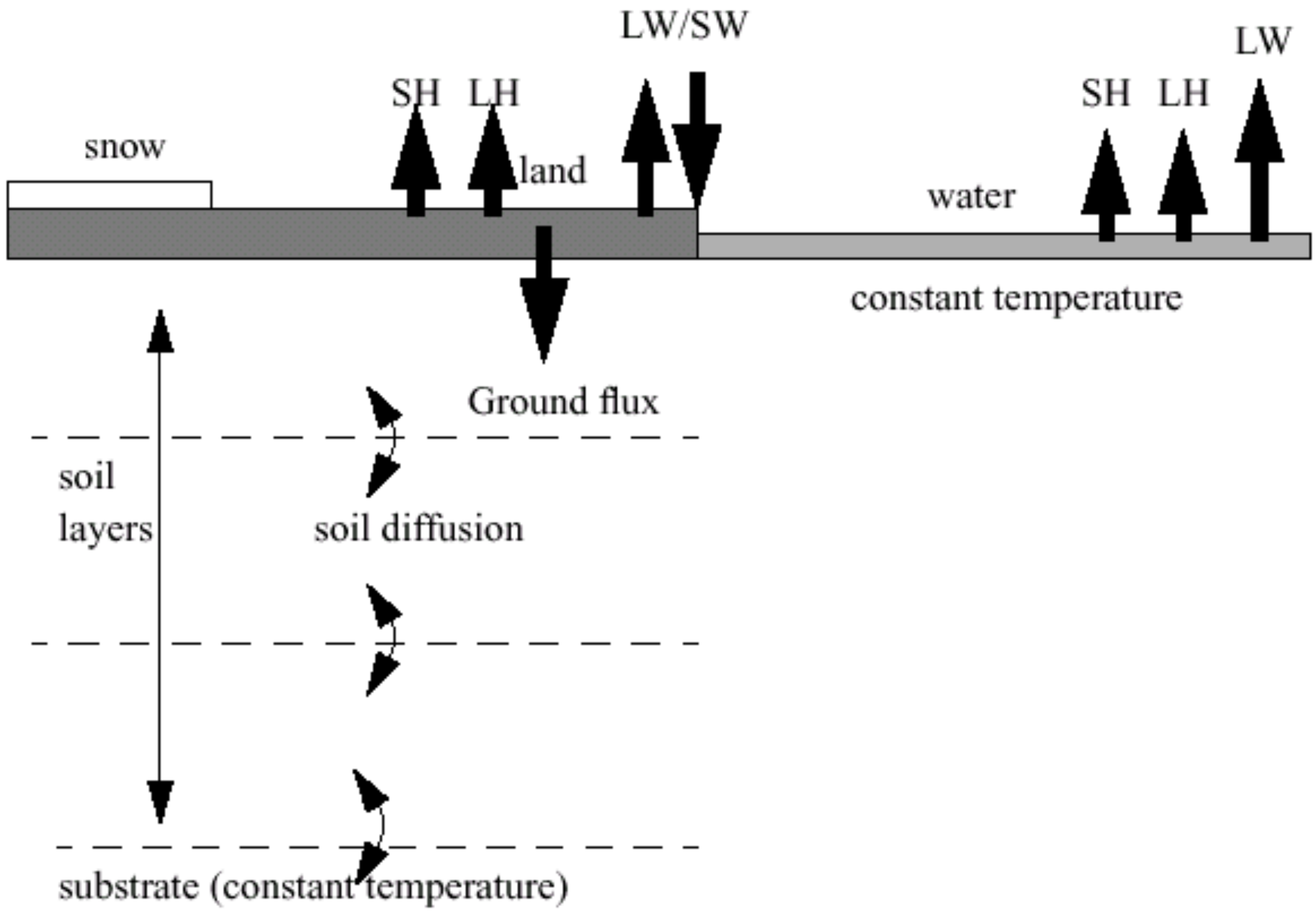
NMM only

sf_sfclay_physics=3

GFS Monin-Obukhov similarity theory

- For use with NMM-LSM
- Should be used with bl_pbl_physics=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 effect for water
- No soil moisture or snow-cover prediction
- Moisture availability based on land-use only
- Provides heat and moisture fluxes for PBL

ARW only

sf_surface_physics=2

Noah Land Surface Model

- 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)

NMM only

sf_surface_physics=99

NMM Land Surface Model (NCEP Noah)

- 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

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

LANDUSE.TBL

LANDUSE.TBL file (ascii) has land-use properties (vegetation, urban, water, etc.)

- 24 USGS categories 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
- Other tables (VEGPARM.TBL, etc.) are used by Noah
- RUC LSM has internal values

Initializing LSMs

- Noah and RUC LSM require additional fields for initialization
  - Soil temperature
  - Soil moisture
  - Snow liquid equivalent
- Best source is a consistent model-derived dataset
  - Eta/GFS/AGRMET/NNRP for Noah (although some have limited soil levels available)
  - RUC for RUC
- Optimally the resolution, land-use, soil texture, should match the data source model, otherwise there will be a spin-up issue

ARW only

sst_update=1

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

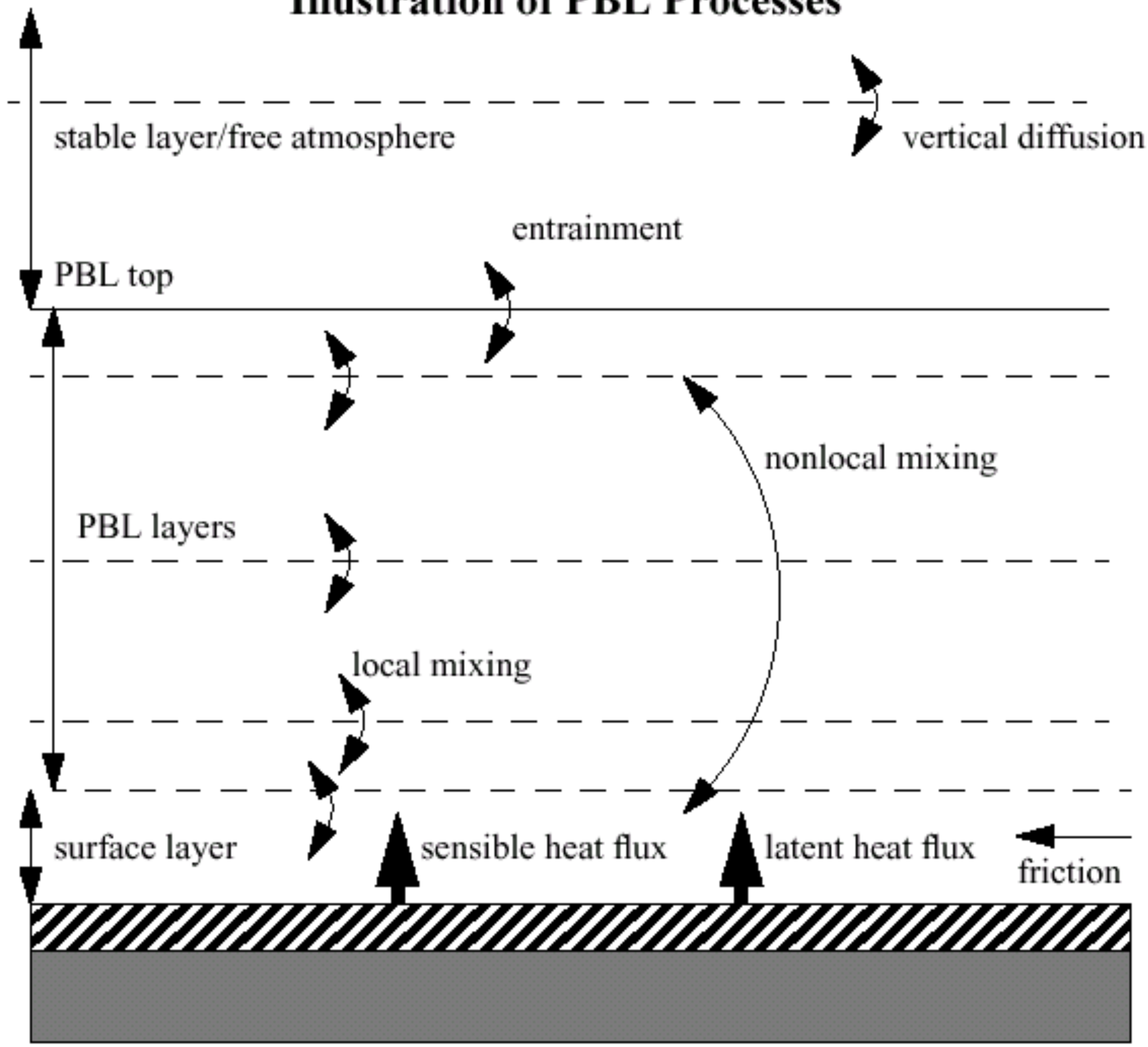
- For long-period simulations (a week or more)
- wrflowinp_d01 created by *real*
- Sea-ice
  - OK if sea-ice is constant with time
  - Cannot update sea-ice cover (yet)
  - Treat time-varying sea-ice as just cold water (no initial sea ice) if using sst_update
- Vegetation fraction update is included in file too

Planetary Boundary Layer

Boundary layer fluxes (heat, moisture, momentum)

Vertical diffusion

Illustration of PBL Processes



ARW only

bl_pbl_physics=1

YSU PBL scheme (Hong and Noh)

- 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

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

NMM only

bl_pbl_physics=3

GFS PBL

- 1st order Troen-Mahrt
- Closely related to MRF PBL
- Non-local-K vertical mixing in boundary layer and free atmosphere

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)

NMM only

nphs

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

PBL Scheme Options

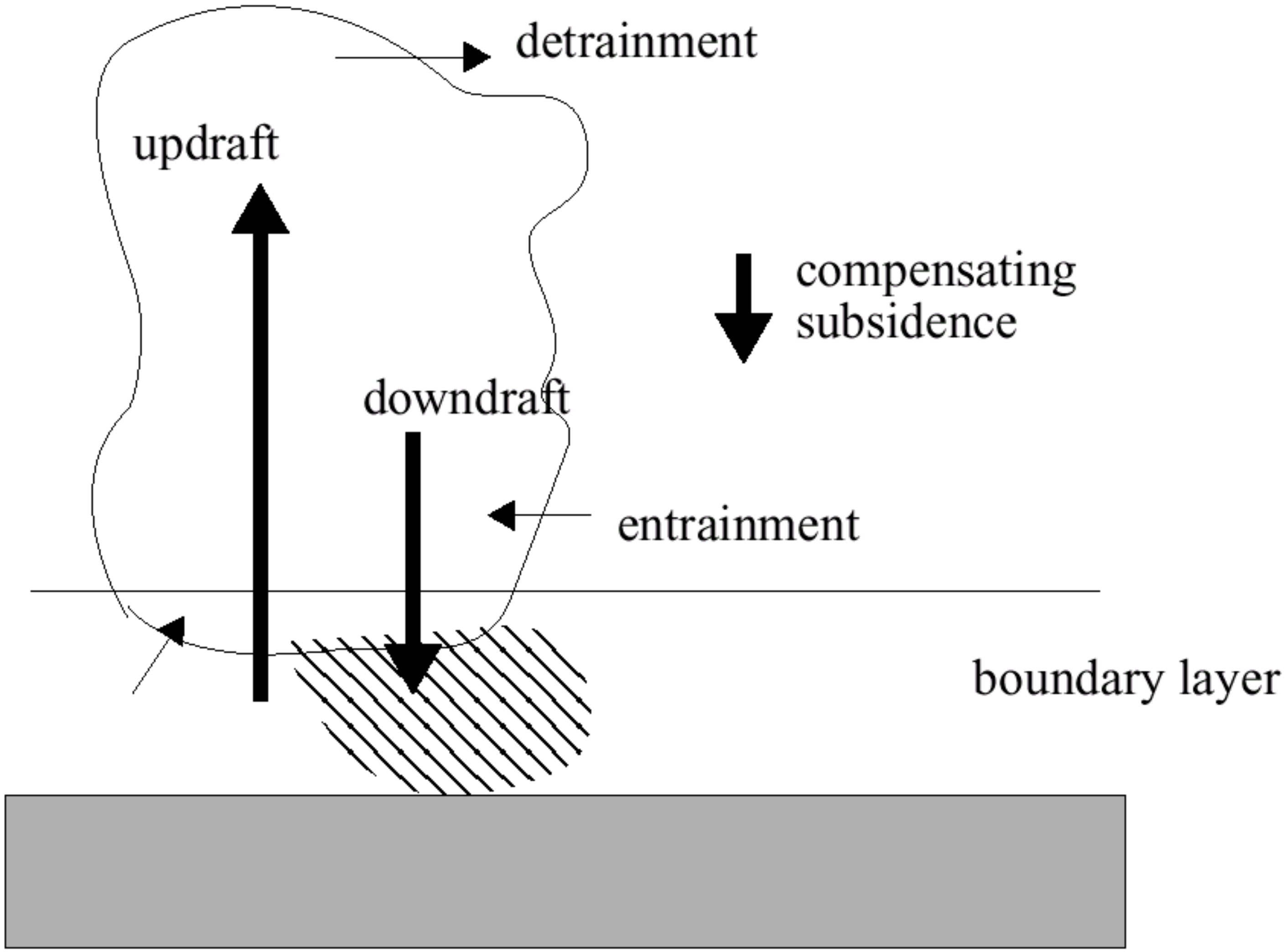
PBL schemes can be used for most grid sizes when surface fluxes are present

- Assumes that PBL eddies are not resolved
- At grid size dx << 1 km, this assumption breaks down
- With PBL scheme, lowest full level should be .99 or .995 (not too close to 1)
- Can use 3d tke diffusion, but, this is not yet coupled to the actual surface fluxes
- Currently 3d tke can only be used with constant specified surface fluxes

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 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 water and ice detrainment
- Clouds persist over convective time scale (not 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
- 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) - 3 cap strengths, 3 profiles
- Explicit updrafts/downdrafts
- Mean feedback of ensemble is applied
- Weights can be tuned (spatially, temporally) to optimize scheme (training)

NMM only

cu_physics=4

Simpified Arakawa-Schubert (SAS) GFS scheme

- Quasi-equilibrium scheme
- Related to Grell scheme in MM5
- Downdrafts and single, simple cloud

ARW only

cudt

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

NMM only

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 ?
  - 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

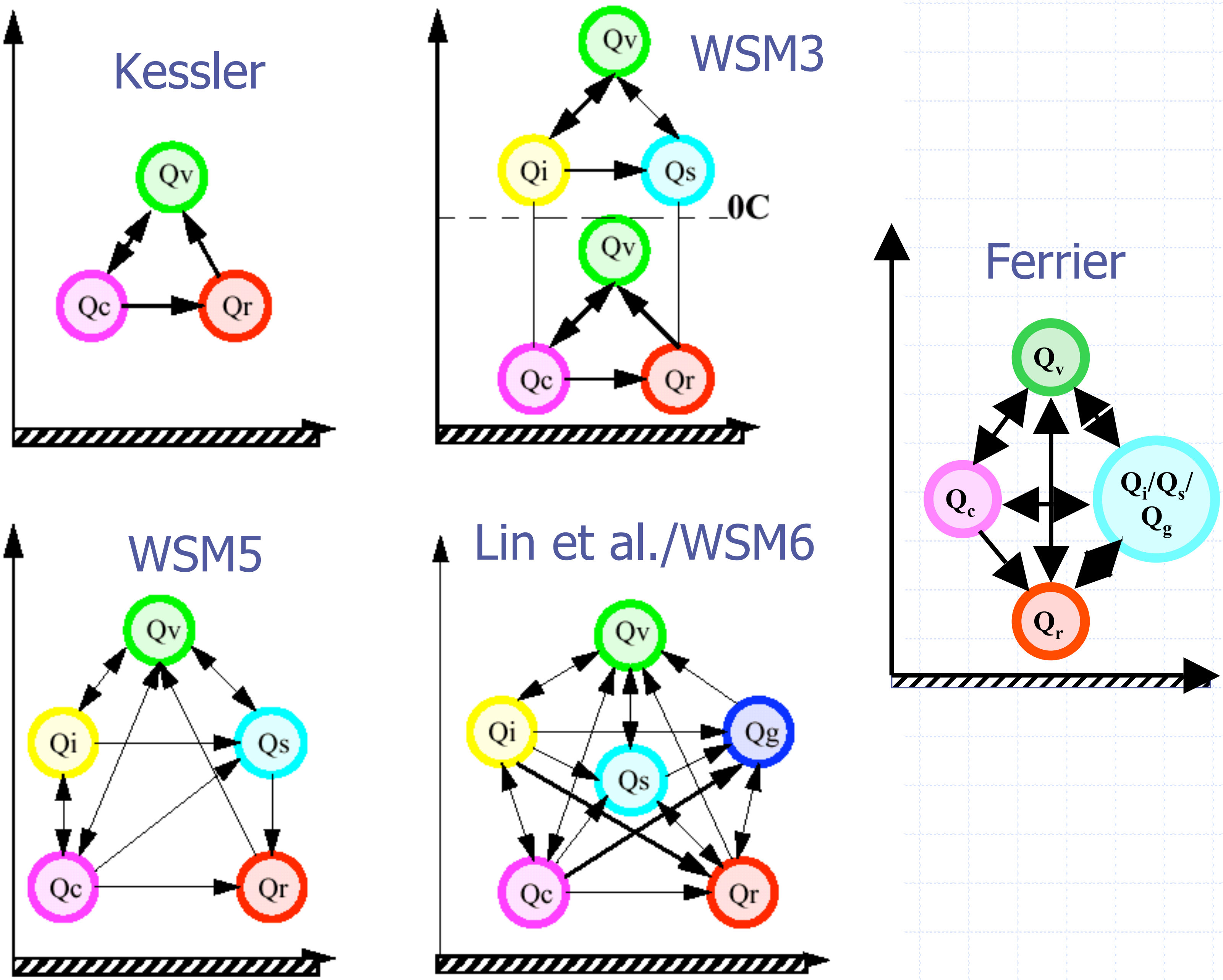
Microphysics

Atmospheric heat and moisture tendencies

Microphysical rates

Surface rainfall

Illustration of Microphysics Processes



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

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 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
- Modified accretion
- Time-split fall terms with melting

mp_physics=8

Thompson et al. graupel scheme

- From Thompson et al. (2006, WRF workshop)
- Newer version of Thompson et al. (2004) scheme
- Updated significantly for 2.2
- 6-class microphysics with graupel
- Ice number concentration also predicted (double-moment ice)
- Time-split fall terms

ARW only

mp_physics=98,99

NCEP3,NCEP5

- Old options from Version 1.3 still available for comparison
- Originally from Regional Spectral Model
- To be phased out later

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

NMM only

nphs

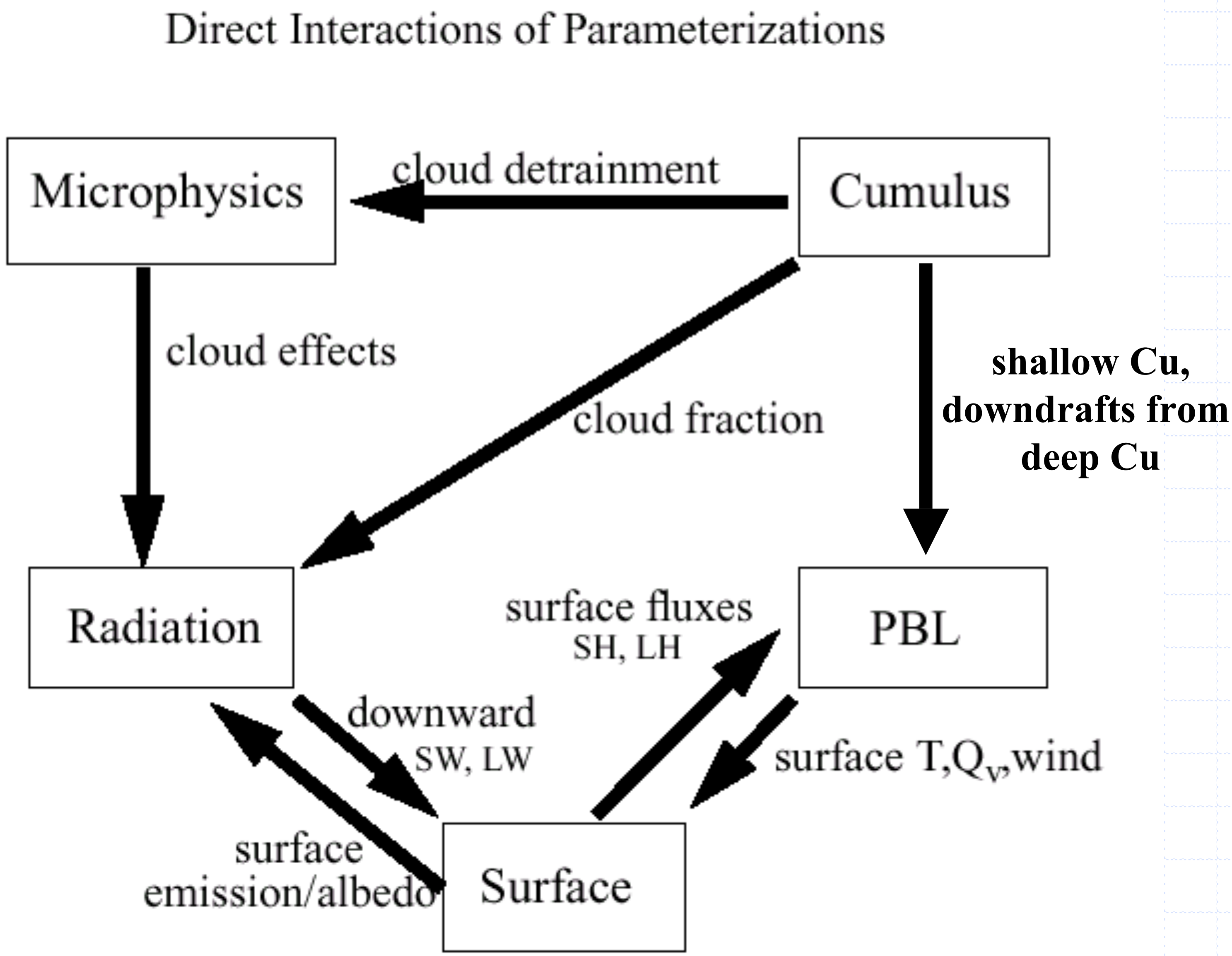
- Time steps between microphysics calls
- Same as parameter for turbulence/PBL/LSM
- Typical value is 10 for efficiency

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

Physics Interactions


Direct Interactions of Parameterizations
Microphysics
cloud detrainment
Cumulus
cloud effects
cloud fraction
shallow Cu, downdrafts from deep Cu
Radiation
surface fluxes SH, LH
PBL
downward SW, LW
surface T,Q$_v$,wind
surface emission/albedo
Surface

ARW only

FDDA

- Method of nudging model towards observations or analysis
- May be used for
  - Dynamical initialization (pre-forecast period)
  - Creating 4D meteorological datasets (e.g. for air quality model)
  - Boundary conditions (outer domain nudged towards analysis)

Method

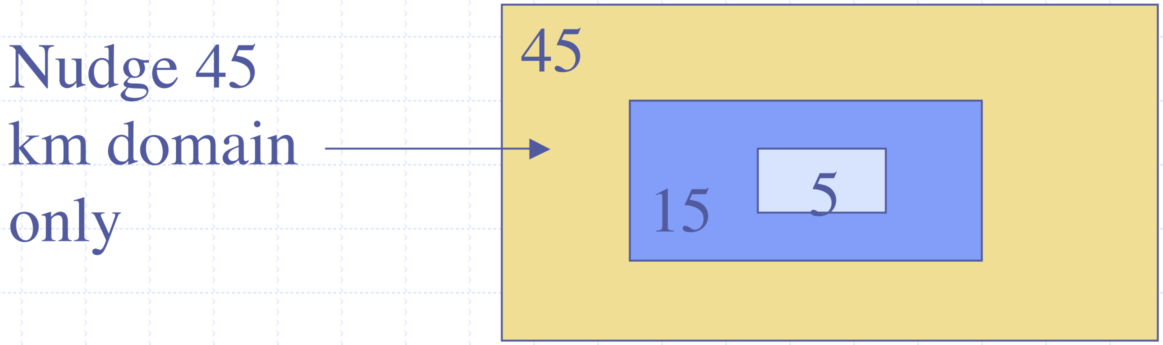
- Model is run with extra nudging terms for horizontal winds, temperature and water vapor
- In analysis nudging, these terms nudge point-by-point to a 3d space- and time-interpolated analysis field
- In obs-nudging, points near observations are nudged based on model error at obs site
- The nudging is a relaxation term with a user-defined time scale around an hour or more
- Nudging will work with nesting and restarts

Dynamic Initialization

- Model domains are nudged towards analysis in a pre-forecast period of 6-12 hours
- This has benefit of smooth start up at forecast time zero

Boundary Conditions

- Nudge an outer domain towards analysis through forecast
- This has benefit of providing smoother boundary conditions to domain of interest than if 15 km domain is the outer domain with interpolated-analysis boundary conditions



FDDA Methods

- Two Methods
  - Grid or analysis nudging (suitable for coarse resolution)
  - Observation or station nudging (suitable for fine-scale or asynoptic obs)
- Nudging can be applied to winds, temperature, and water vapor

Note: nudging terms are fake sources, so avoid FDDA use in dynamics or budget studies

Analysis Nudging

- Each grid-point is nudged towards a value that is time-interpolated from analyses

$$\frac{\partial p^* \alpha}{\partial t} = F(\alpha, \mathbf{x}, t) + G_\alpha \cdot W_\alpha \cdot \epsilon_\alpha(\mathbf{x}) \cdot p^*(\hat{\alpha}_0 - \alpha)$$

In WRF p* is mu

Analysis Nudging

$$\frac{\partial p^* \alpha}{\partial t} = F(\alpha, \mathbf{x}, t) + G_\alpha \cdot W_\alpha \cdot \epsilon_\alpha(\mathbf{x}) \cdot p^*(\hat{\alpha}_0 - \alpha)$$

- G is nudging inverse time scale
- W is vertical weight (upper air and surface)
- ε is a horizontal weight for obs density (not implemented yet)

Analysis Nudging

- 3d analysis nudging uses the WRF input fields at multiple times that are put in wrffdda file by program real
  - With low time-resolution analyses, it is recommended not to use 3d grid-nudging in the boundary layer, especially for temperature
- Surface (2d) analysis nudging not available yet

Analysis-Nudging namelist options

- Can choose frequency of nudging calculations
- Can choose nudging time scale for each variable
- Can choose which variables not to nudge in the PBL
- Can choose a model level for each variable below which nudging is turned off
- Can choose a ramping period over which nudging is turned off gradually

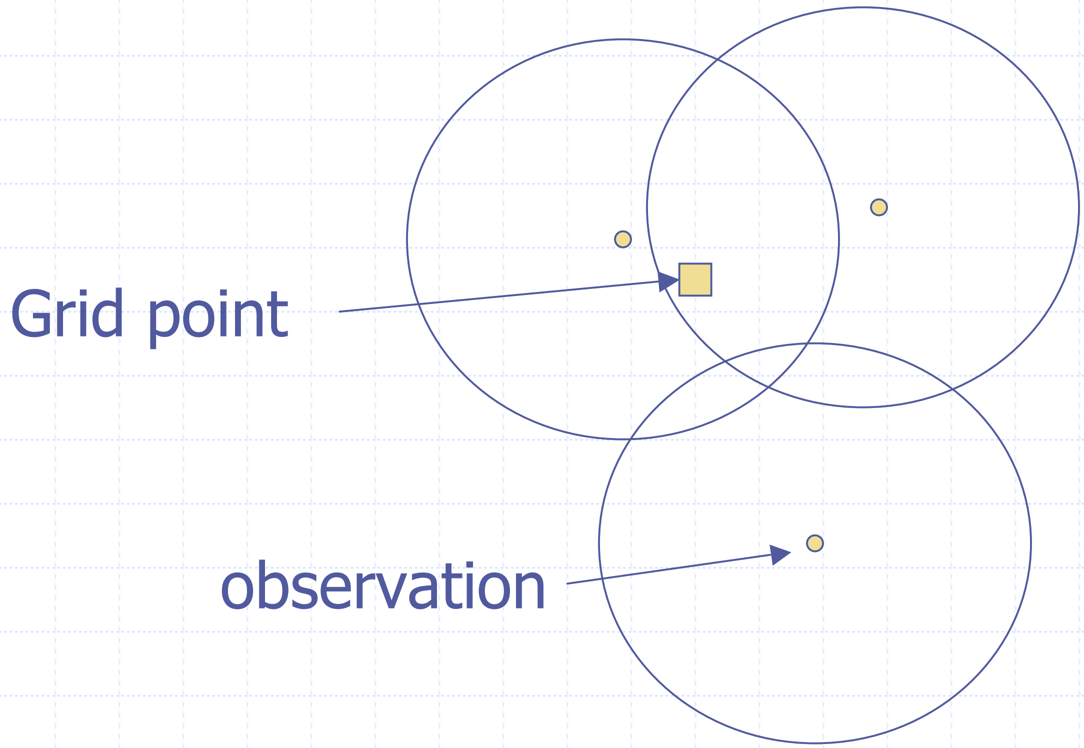
Obs Nudging

- Each grid point is nudged using a weighted average of differences from observations within a radius of influence and time window

$$\frac{\partial p^* \alpha}{\partial t} = F(\alpha, \mathbf{x}, t) + G_\alpha \cdot p^* \frac{\sum_{i=1}^{N} W_i^2(\mathbf{x}, t) \cdot \gamma_i \cdot (\alpha_o - \hat{\alpha})_i}{\sum_{i=1}^{N} W_i(\mathbf{x}, t)}$$

$$W(\mathbf{x}, t) = w_{xy} \cdot w_\sigma \cdot w_t$$

Obs Nudging



Obs Nudging

$$w_{xy} = \frac{R^2 - D^2}{R^2 + D^2} \qquad 0 \le D \le R$$

$$w_{xy} = 0 \qquad D > R,$$

- R is radius of influence
- D is distance from ob modified by elevation difference

Obs Nudging

$$w_t = 1 \qquad |t - t_0| < \tau/2$$

$$w_t = \frac{\tau - |t - t_0|}{\tau/2} \qquad \tau/2 \leq |t - t_0| \leq \tau$$

- τ is the specified time window for the obs
- This is a function that ramps up and down

Obs Nudging

- w_σ is the vertical weighting – usually the vertical influence is set small (0.005 sigma) so that data is only assimilated on its own sigma level
- obs input file is a special ascii file with obs sorted in chronological order
    - each record is the obs (u, v, T, Q) at a given model position and time

Obs-Nudging namelist options

- Can choose frequency of nudging calculations
- Can choose nudging time scale for each variable
- Can choose horizontal and vertical radius of influence
- Can choose time window
- Can choose a ramping period over which nudging is turned off gradually

FDDA Summary

- FDDA grid nudging is suitable for coarser grid sizes where analysis can be better than model-produced fields
- Obs nudging can be used to assimilate asynoptic or high-frequency observations
- Grid and obs nudging can be combined
- FDDA has fake sources and sinks and so should not be used on the domain of interest and in the time period of interest for scientific studies and simulations

Further plans

- Add 2d (surface) nudging and integrate with 3d nudging
- Integrate with analyses produced by WRF-Var

End