Supplementary material related to 
Surface deposition of marine fog and its treatment in the WRF model

by Peter A. Taylor, Zheqi Chen, Li Chen1, Soudeh Afsharian, Wensong Weng, George A. Isaac, Terry W. Bullock and Yongsheng Chen.

WRF Coding notes

A "Katata like" approach with module_bl_mynn and module_sf_fogdes: A quick fix to increase deposition of Qc to a water surface with module_bl_mynn could be to modify the WRF implementation of the Katata scheme in module_sf_fogdes to allow an extra land use category "water" with a more appropriate estimate of vdfg, the deposition velocity (m/s) of fog mixing ratio (Qc, kg/kg). There is however an additional complication in that module_bl_fogdes deals with gravitational settling of fog droplets through the air column as well as to the surface. However, as explained in a note posted at https://repository.library.noaa.gov/view/noaa/19837, that process is also dealt with in the microphysics module_mp_thompson. It should not be double counted. The Thompson microphysics code removes cloud droplets from the lowest level with its settling velocity sed_n(k) and relationships like nc(k) = MAX(10., nc(k) + (sed_n(k+1)-sed_n(k)) *odzq*DT).

Therefore we have left sedimentation through the air column, and sedimentation to the surface via simple droplet settling, as being treated by the Thompson microphysics code, although in some test cases we can set that settling velocity, vtck(k)=0. We can still use the option grav_settling = 2 in module_bl_mynn, BUT with the parameter gno set to 0 in module_bl_fogdes so that there is no settling through the air column while it remains active at the surface, just because that was the way it was coded in bl_fogdes.

One could set a deposition velocity vdfg(I,j) within module_sf_fogdes based on the lowest grid level wind speed, as discussed in section 3 above, or on the surface friction velocity. Then the turbulent flux of cloud droplets to the water surface from the lowest model level (called gfluxm for compatibility with existing code, even though not gravitational) could be represented (in module_bl_fogdes) as gfluxm=grav_settling2*qc_curr(i,k,j)*vdfg(i,j). The parameter grav_settling2 = 1 if grav_settling = 2 and qc_curr(i,k,j) is the Qc value at the current grid point, which has k = kts (normally = 1). This is the normal use of bl_mynn, but with module_sf_fogdes adjusted to provide vdfg values.

These could be defined by vdfg(i,j) = vtune * wspd(i,j) with vtune as a tuning option. This approach matches the WRF Katata code in module_sf_fogdes which has access to the lowest grid level wind speed (wspd) although vtune should be dependent on the lowest grid level. Our preferred approach is to use ustar (=ust(i,j)) as the velocity scale rather than wspd and a cloud droplet roughness length (z0c) as the tuning parameter, maybe starting with z0c = 0.01 (m). The deposition velocity would then be,

\[ vdfg(i,j) = ustar(i,j) * karman / \log(1+z1/z0c). \]  

(A1)

In WRF the lowest grid cell centre (mass point) is at z1 = 0.5*dz8w(i,kts,j). The friction velocity, ustar and the karman constant (0.4) are used or computed in other modules and need to be made accessible to module_sf_fogdes. Note that ustar is an input variable in module_bl_mynn. It is an in/out variable in module_sf_sfcldrev and other places.

A direct approach in module_bl_mynn: An alternative approach would be to still leave gravitational settling in the Thompson microphysics module, set grav_settling = 0 in module_bl_mynn, and then, vdfg(i,j) defined in
module_sf_fogdes, the settling of the cloud droplets through the air column and at the surface defined in module_bl_fogdes, are all turned to 0. When the tridiagonal matrices are being set up for cloud water, represent the downward flux of cloud water at the lower boundary by vdfg(i,j)*qc(1) so that for k = kts = 1 the code lines read

\[
\begin{align*}
    a(k) &= 0 \quad ! \text{This is not used anyway} \\
    b(k) &= 1. + dtz(k) \cdot (khdz(k+1)/\rho(k) + \text{depvel}) - 0.5 \cdot dtz(k) \cdot s_{aw}(k+1) \\
    c(k) &= -dtz(k) \cdot khdz(k+1)/\rho(k) - 0.5 \cdot dtz(k) \cdot s_{aw}(k+1) \\
    d(k) &= sqc(k) + qcd(k) \cdot \text{delt} - dtz(k) \cdot s_{awqc}(k+1) + \text{det_sqc}(k) \cdot \text{delt}
\end{align*}
\]

where depvel is used instead of vdfg to distinguish from vdfg defined in module_sf_fogdes. As with the Katata scheme extension depvel could be defined in terms of the friction velocity \( \text{ust} \) and with a roughness length for cloud droplets \( z_0c \) serving as a tuning parameter (see Eq. A1). \( \text{ust} \) is a known quantity within module_bl_mynn and in that module \( z_1 \) can be set = 0.5 \* dz(1). The \( s_{aw} \), \( s_{awc} \) and \( s_{awqc} \) terms are associated with mass flux and convective plume mixing, \( \text{det_sqc} \) is a "detrainment term" and \( qcd \) is a counter-gradient term. All should be = 0 at the lowest level but are left to minimize code changes.

**Code changes:** The additional deposition velocity vdfg defined in terms of ust and \( z_0c \) (Eq. A1), are implemented to module_sf_fogdes or module_bl_mynn.

i) For the "Katata like" approach, Katata’s vdfg in module_sf_fogdes is replaced by vdfg(i,j) = \( \text{ust}(i,j) \cdot \text{karman} / \log(1 + 0.5 \cdot \text{dz}(k)/z_0c) \) ust and karman need to be made accessible to the SUBROUTINE sf_fogdes.

ii) For the direct approach, in module_bl_mynn, the deposition velocity, depvel is given by depvel = \( \text{ust} \cdot \text{vk} / \log(1.0 + 0.5 \cdot \text{dz}(k)/z_0c) \) and is added to term \( b(k) \) in the tridiagonal matrices for the cloud water (Eq. A2). 

flqc is removed from term \( d(k) \) in the matrices for both approaches.

To make \( z_0c \) a namelist.input parameter, \( z_0c \) is added in Registry.EM_COMMON

rconfig real z0c namelist.physics 1 0.01 h "z0c" "roughness length for cloud droplets, default is 0.01"

The \( z_0c \) is added to the relevant subroutines, and also where the subroutines are called. The following modules, module_bl_mynn, module_sf_fogdes, module_pbl_driver, module_surface_driver, module_first_rk_step_part1 and Registry.EM_COMMON, are modified. The codes for these modules are posted separately, module_bl_mynn.F_KatataLike and module_bl_mynn.F_Direct are the codes of the module_bl_mynn for the "Katata like" approach and direct approach respectively.

**SCM study:** The following code changes are done for the SCM study. In module_initialize_scm_xy.F, the following code from line 321 to 330

```fortran
! this is adopted from Wayne Angevine's GABLS case
grid%znw(1) = 1.0
zrwa(kde) = exp((kde-1)/40.)
zwa(kde) = grid%ztop
DO k=2, kde-1
    zrwa(k) = exp((k-1)/40.)
zwa(k) = (zrwa(k)-1.) * grid%ztop/(zrwa(kde)-1.)
grid%znw(k) = 1. - (zwa(k) / zwa(kde))
ENDDO
grid%znw(kde) = 0.
```

are replaced with the following:

```fortran
! Read config instead
```
DO k=1, kde
    grid%znw(k) = model_config_rec%eta_levels(k)
ENDDO

It can allow the model to use user-specified eta levels in the namelist.

In module_first_rk_step_part1.F, the following code are inserted on line 163, after rk_step=1,

! Decrease TSK
IF (ANY(grid%tsk.GE.282)) THEN
    grid%tsk = grid%tsk-3*(grid%dt)/3600
ENDIF

It can force the skin temperature (TSK) to decrease, for our SCM study.

3D WRF namelist.input

The following is a namelist.input file for a 3D WRF simulation. The WRF codes are modified with “Katata like” approach. It is a two-way simulation with two nested domains. The horizontal resolutions are 30 km and 10 km for the parent and nested domains respectively. 101 vertical levels with increasing spacing between levels are used. The physics schemes are listed in the table below.

<table>
<thead>
<tr>
<th>Physics</th>
<th>Scheme</th>
<th>Namelist option</th>
</tr>
</thead>
<tbody>
<tr>
<td>Microphysics</td>
<td>Thompson scheme</td>
<td>mp_physics = 8</td>
</tr>
<tr>
<td>PBL</td>
<td>MYNN scheme</td>
<td>bl_pbl_physics = 5</td>
</tr>
<tr>
<td>Longwave radiation</td>
<td>Goddard shortwave and longwave schemes</td>
<td>ra_lw_physics = 5</td>
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<tr>
<td>Shortwave radiation</td>
<td></td>
<td>ra_lw_physics = 5</td>
</tr>
<tr>
<td>Surface layer physics</td>
<td>MYNN scheme</td>
<td>sf_sfclay_physics = 5</td>
</tr>
<tr>
<td>Land surface model option</td>
<td>Unified Noah land surface scheme</td>
<td>sf_surface_physics = 2</td>
</tr>
</tbody>
</table>

z0c can be set to be different values for sensitivity test. Here grav_settling = 2, 2, 0. To work with WRF code modified with direct approach, one should set grav_settling = 0, 0, 0.

namelist.input

&time_control
    run_days   = 0,
    run_hours  = 36,
    start_year = 2018, 2018, 2000,
    start_month= 07, 07, 01,
    start_day  = 01, 01, 24,
    start_hour = 12, 12, 12,
    end_year   = 2018, 2018, 2000,
    end_month  = 07, 07, 01,
    end_day    = 03, 03, 25,
    end_hour   = 00, 00, 12,
    interval_seconds = 21600
    input_from_file  = .true.,.true.,.true.,
history_interval = 60, 60, 60,
frames_per_outfile = 1, 1, 1000,
restart = .false.,
restart_interval = 360,
io_form_history = 2
io_form_restart = 2
io_form_input = 2
io_form_boundary = 2
/

&domains

time_step = 30,
time_step_fract_num = 0,
time_step_fract_den = 1,
max_dom = 2,
e_we = 120, 181, 94,
e_sn = 100, 181, 91,
e_vert = 101, 101, 33,
p_top_requested = 5000,
num_metgrid_levels = 32,
num_metgrid_soil_levels = 4,
eta_levels = 1.0, 0.999550329, 0.99904684, 0.998540576, 0.997975378, 0.99736632, 0.996710487, 0.99600481, 0.99526676, 0.994610268, 0.993953676, 0.97684376, 0.97478546, 0.97259873, 0.956417628, 0.949693791, 0.946049303, 0.942206555, 0.938157835, 0.93395342, 0.92941201, 0.924697471, 0.919746169, 0.914549282, 0.90909788, 0.90338667, 0.897404939, 0.891145657, 0.884600951, 0.877763042, 0.870624266, 0.863177094, 0.8554162, 0.847328292, 0.838912519, 0.830160115, 0.821064616, 0.811619851, 0.801819962, 0.791659437, 0.7811339437, 0.770236304, 0.758964624, 0.747314215, 0.735281673, 0.722864089, 0.710059077, 0.696864792, 0.683279957, 0.669303878, 0.654936469, 0.640178266, 0.625030447, 0.609498444, 0.593573958, 0.577270971, 0.560589754, 0.543534878, 0.526111617, 0.508325952, 0.490184573, 0.471694881, 0.452864977, 0.433703668, 0.414204448, 0.394425497, 0.374329663, 0.353944449, 0.333281996, 0.312355063, 0.291177007, 0.269761757, 0.248123788, 0.22678095, 0.20424016, 0.182025921, 0.15965174, 0.137134364, 0.114490891, 0.091738729, 0.068895558, 0.04597929, 0.02300822, 0.01,

dx = 30000, 10000, 3333.33,
dy = 30000, 10000, 3333.33,
grid_id = 1, 2, 3,
prompt_id = 0, 1, 2,
grid_start = 1, 40, 30,
grid_start = 1, 30, 30,
parent_grid_ratio = 1, 3, 3,
parent_time_step_ratio = 1, 3, 3,
feedback = 1,
smooth_option = 0
/

&physics

physics_suite = 'CONUS'
mp_physics = 8, 8, -1,
cu_physics = -1, -1, 0,
ra_lw_physics = 5, 5, -1,
ra_sw_physics = 5, 5, -1,
bl_pbl_physics = 5, 5, -1,
bl_mynn_mixlength = 2,
sf_sclay_physics = 5, 5, -1,
sf_surface_physics = -1, -1, -1,
radt = 30, 30, 30,
bldt = 0, 0, 0,
cudt = 5, 5, 5,
icloud = 1,
num_land_cat = 21,
sf_urban_physics = 0, 0, 0,
grav_settling = 2, 2, 0,
z0c = 0.01,
/

&fdda
/

&dynamics
hybrid_opt = 0,
w_damping = 0,
diff_opt = 1, 1, 1,
km_opt = 4, 4, 4,
diff_6th_opt = 0, 0, 0,
diff_6th_factor = 0.12, 0.12, 0.12,
base_temp = 290.
damp_opt = 0,
zdamp = 5000., 5000., 5000.,
dampcoeff = 0.2, 0.2, 0.2
khdif = 0, 0, 0,
kvdif = 0, 0, 0,
non_hydrostatic = .true., .true., .true.,
moist_adv_opt = 1, 1, 1,
scalar_adv_opt = 1, 1, 1,
gwd_opt = 1,
/

&bdy_control
spec_bdy_width = 5,
spec_zone = 1,
relax_zone = 4,
specified = .true., .false., .false.,
nested = .false., .true., .true.,
/

&grib2
/

&namelist_quilt
nio_tasks_per_group = 0,
nio_groups = 1,
SCM input files
The following files are required for a SCM simulation.

**namelist.input**

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&time_control
  run_days       = 4,
  run_hours      = 0,
  run_minutes    = 0,
  run_seconds    = 0,
  start_year     = 2018,
  start_month    = 08,
  start_day      = 15,
  start_hour     = 00,
  start_minute   = 00,
  start_second   = 00,
  end_year       = 2018,
  end_month      = 08,
  end_day        = 19,
  end_hour       = 00,
  end_minute     = 00,
  end_second     = 00,
  history_interval = 60,
  frames_per_outfile = 10000,
  restart        = .false.,
  restart_interval = 100000,
  io_form_history = 2
  io_form_restart = 2
  io_form_input   = 2
  io_form_boundary = 2
  auxinput3_inname = "force_ideal.nc"
  auxinput3_interval_h = 240
  io_form_auxinput3 = 2
/

&domains
  time_step      = 60,
  time_step_fract_num = 0,
  time_step_fract_den = 1,
  max_dom        = 1,
  s_we           = 1,
  e_we           = 3,
  s_sn           = 1,
  e_sn           = 3,
  s_vert         = 1,
  p_topRequested = 5000,
  e_vert         = 101,
eta_levels=1.0,0.999550329,0.999064684,0.998540576,0.997975378,0.99736632,0.996710487,0.9960411,0.9
95246067,0.994430874,0.993555682,0.992616776,0.991610268,0.990532098,0.989378024,0.988143627,0.986
824303,0.985415265,0.98391154,0.982307967,0.9805992,0.978779705,0.976843763,0.974785468,0.97259873
```
dx = 4000, 
&scm
  scm_force = 0
  scm_force_dx = 1000.
  num_force_layers = 8
  scm_lu_index = 16
  scm_isltyp = 14
  scm_lat = 43.93
  scm_lon = -60.01
  scm_th_adv = .false.
  scm_wind_adv = .false.
  scm_qv_adv = .false.
  scm_ql_adv = .false.
  scm_vert_adv = .false.
  scm_force_ql_largescale = .false.
  scm_force_wind_largescale = .false.
/ 
&physics
  mp_physics = 8,
  ra_lw_physics = 0,
  ra_sw_physics = 0,
  cldovrlp = 4,
  radt = 30,
  sf_sfclay_physics = 1,
  sf_surface_physics = 2,
  bl_pbl_physics = 1,
  bldt = 0,
  cu_physics = 6,
  cudt = 5,
  num_soil_layers = 4,
  grav_settling = 0,
  z0c = 0.01
/ 
&dynamics
  hybrid_opt = 2,
  w_damping = 0,
diff_opt = 1,
k_m_opt = 4,
diff_6th_opt = 0,
diff_6th_factor = 0.12,
base_temp = 290,
damp_opt = 3,
z_damp = 5000.,
dampcoef = 0.2,
k_hdif = 400,
k_vdif = 100,
non_hydrostatic = .true.,
pert_coriolis = .true.,
mix_full_fields = .true.,

&bdy_control
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symmetric_xs = .false.,
symmetric_xe = .false.,
open_xs = .false.,
open_xe = .false.,
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symmetric_ye = .false.,
open_ys = .false.,
open_ye = .false.,

&namelist_quilt
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nio_groups = 1,

input_sounding

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<tr>
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<th>Temp (K)</th>
<th>Temperature Gradient (K/m)</th>
<th>Pressure (hPa)</th>
<th>Probe Number</th>
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<td>303.3635072</td>
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</tr>
</tbody>
</table>
In addition, the user should edit the script make_scm_forcing.ncl. On line 37, change the time to the starting time of the simulation, in our case, 
initTime = "2018-08-15_00:00:00"; need to be in WRF format

then run the script using NCL (NCAR Command Language).