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Supplement of

Surface deposition of marine fog and its treatment in the Weather Research and Forecasting (WRF) model

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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 qccurr(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 ust (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,

\[
 vdfg(i,j) = ust(i,j) * \frac{karman}{\text{LOG}(1+z1/z0c)}. \quad (A1)
\]

In WRF the lowest grid cell centre (mass point) is at z1= 0.5*dz8w(i,kts,j). The friction velocity, ust 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 ust is an input variable in module_bl_mynn. It is an in/out variable in module_sf_sfclayrev and other places.

A direct approach in module_bl_mynn: An alternative approach would be to still leave gravitational settling in the Thompson microphysics code, 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

\[
 a(k)= 0! \quad \text{This is not used anyway}
\]
\[
 b(k)= 1. + \text{dtz(k)} \left( \frac{\text{khdz(k+1)/rho(k)+ depvel}}{\text{0.5*dtz(k)} \ast \text{s_aw(k+1)}} \right)
\]
\[
 c(k)= -\text{dtz(k)} \left( \frac{\text{khdz(k+1)/rho(k)}}{\text{0.5*dtz(k)} \ast \text{s_aw(k+1)}} \right)
\]
\[
 d(k)= \text{sqc(k)} + \text{qcd(k)} \ast \text{delt} - \text{dtz(k)} \ast \text{s_awqc(k+1)} + \text{det_sqc(k)} \ast \text{delt}
\]

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 ust and with a roughness length for cloud droplets z0c serving as a tuning parameter (see Eq. A1). ust is a known quantity within module_bl_mynn and in that module z1 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, 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 $v_{dfg}$ 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 $v_{dfg}$ in module_sf_fogdes is replaced by

$$v_{dfg}(i,j) = \frac{ust(i,j) \times \text{karman}}{\log(1+0.5 \times dz_8w(i,kts,j)/z_0c)}$$

$ust$ and $\text{karman}$ 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

$$depvel = \frac{ust \times vk}{\log(1.0+0.5 \times dz(kts)/z_0c)}$$

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 $z_0c$ namelist.physics l 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,

```fortran
! 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.

| Physics                          | Scheme                                           | Namelist option        |
|----------------------------------|--------------------------------------------------|------------------------|
| Microphysics                    | Thompson scheme                                 | mp_physics = 8         |
| PBL                              | MYNN scheme                                      | bl_pblPhysics = 5      |
| Longwave radiation Shortwave radiation | Goddard shortwave and longwave schemes             | ra_lw_physics = 5      |
| Surface layer physics            | MYNN scheme                                      | sf_sfclayPhysics = 5   |
| Land surface model option        | Unified Noah land surface scheme                 | sf_surfacePhysics = 2  |

$z_0c$ 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,
um_metgrid_soil_levels = 4,
eta_levels=1,0.999550329,0.999064684,0.998540576,0.998017048,0.997485468,0.996937911,
0.946049303,0.942206555,0.938157835,0.933895342,0.929411201,0.924697471,0.919746169,0.914549282,0.
0.9098788,0.90338667,0.897404939,0.891145657,0.884600951,0.877763042,0.870624266,0.863177094,0.855
414162,0.847328292,0.838912519,0.830160115,0.821064616,0.811619851,0.801819962,0.791659437,0.78113
3134,0.770236304,0.758964624,0.747314215,0.735281673,0.722864089,0.710059077,0.696864792,0.6832799
57,0.669303878,0.654936469,0.64017266,0.62503447,0.609494844,0.593573958,0.577270971,0.560589754
,0.543534887,0.52611617,0.508325952,0.490184573,0.471694881,0.452864977,0.433703668,0.414220448,0.3
94425497,0.374329663,0.353944449,0.333281996,0.312355063,0.291177007,0.269761575,0.248123788,0.22
6278095,0.20424016,0.182025921,0.15965174,0.137134364,0.114490891,0.091738729,0.068895558,0.045979
29,0.023008022,0.
dx = 30000, 10000, 3333.33,
dy = 30000, 10000, 3333.33,
grid_id = 1, 2, 3,
pARENT_id = 0, 1, 2,
i_PARENT_start = 1, 40, 30,
j_PARENT_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_sfcclay_physics = 5, 5, -1,
sf_surface_physics = -1, -1, -1,
radi = 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.,
dampcoef = 0.2, 0.2, 0.2
khdif = 0, 0, 0,
kvdif = 0, 0, 0,
on_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

&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
pio_form_restart = 2
io_form_input = 2
pio_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_top_requested = 5000,
e_vert = 101,
eta_levels=1.0,0.999550329,0.999064684,0.998540576,0.997975378,0.99736332,0.996710487,0.996004811,0.995246067
0.994430874,0.993555682,0.992616776,0.991610268,0.990532098,0.989378024,0.988143627,0.986824303,0.985415265
0.98391154,0.982307967,0.9805992,0.978779705,0.976843763,0.97485468,0.97259873,0.96993791,0.964049303
0.952206555,0.938157835,0.933895342,0.929411201,0.924697471,0.919746169,0.914549282,0.909098788,0.90386678
0.897404939,0.891145657,0.884600951,0.877763042,0.870624266,0.863177094,0.855414162,0.847328292,0.838912519
0.830160115,0.821064616,0.811619851,0.801819962,0.791659437,0.78113134,0.770236304,0.758964624,0.747314215
0.735281673,0.722864089,0.710059077,0.696864792,0.683279957,0.669303878,0.654936469,0.640178266,0.625030447
0.609494844,0.593573958,0.577270971,0.560589754,0.543534878,0.526116167,0.508325952,0.490184573,0.471694881
0.452864977,0.433703668,0.414220448,0.394425497,0.374329663,0.353944449,0.333281996,0.312355063,0.291177007
0.269761757,0.248123788,0.226278095,0.20424016,0.182025921,0.15965174,0.137134364,0.114490891,0.091738729
0.068895558,0.04597929,0.023008022,0

dx = 4000,
dy = 4000,
ztop = 12000.,
&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,
    km opt = 4,
    diff 6th opt = 0,
    diff 6th factor = 0.12,
    base temp = 290,
    damp opt = 3,
    zdamp = 5000.,
    dampcoef = 0.2,
    khdif = 400,
    kvdif = 100,
    non hydrostatic = .true.,
    pert coriolis = .true.,
    mix full fields = .true.,
/
&bdy_control
  periodic_x = .true.,
  symmetric_x = .false.,
  symmetric_xe = .false.,
  open_x = .false.,
  open_xe = .false.,
  periodic_y = .true.,
  symmetric_y = .false.,
  symmetric_ye = .false.,
  open_y = .false.,
  open_ye = .false.,
/

&namelist_quilt
  nio_tasks_per_group = 0,
  nio_groups = 1,
/

input_sounding

|   |      |      |   |   |   |
|---|------|------|---|---|---|
| 0 | 15.2135 | 1.684739 | 300 | 0 | 100000 |
| 0 | 0 | 0 | 300 | 0 | 0 |
| 14.36386 | 15.66428 | 1.734882 | 300.0574554 | 0 |
| 39.51661 | 16.46412 | 1.795376 | 300.1580664 | 0 |
| 68.32745 | 16.91014 | 1.821371 | 300.2733098 | 0 |
| 104.4252 | 17.33809 | 1.834659 | 300.4177008 | 0 |
| 147.903 | 17.6819 | 1.836351 | 300.591612 | 0 |
| 195.1703 | 17.95195 | 1.828004 | 300.7806812 | 0 |
| 246.326 | 18.13941 | 1.816244 | 300.985304 | 0 |
| 305.0642 | 18.34531 | 1.79469 | 301.2202568 | 0 |
| 371.5457 | 18.59395 | 1.757789 | 301.4861828 | 0 |
| 445.8617 | 18.94404 | 1.687326 | 301.7834468 | 0 |
| 528.2252 | 19.27828 | 1.604498 | 302.1129008 | 0 |
| 622.5799 | 19.60619 | 1.510228 | 302.4903196 | 0 |
| 729.2806 | 19.82945 | 1.437 | 302.9171224 | 0 |
| 840.8768 | 19.99547 | 1.367795 | 303.3635072 | 0 |
| 1086.145 | 20.18544 | 1.245873 | 304.34458 | 0 |
| 1475.502 | 20.11891 | 1.138823 | 305.902008 | 0 |
| 1879.58 | 19.61444 | 1.19511 | 307.51832 | 0 |
| 2299.135 | 19.99515 | 0.9100478 | 309.19654 | 0 |
| 2903.724 | 19.80644 | 0.882338 | 311.614896 | 0 |
| 3675.125 | 20.07976 | 0.4701067 | 314.7005 | 0 |
| 4424.906 | 20.15394 | 0.217673 | 317.699624 | 0 |
| 5150.854 | 20.15331 | 0.1040568 | 320.603416 | 0 |
| 5851.01 | 20.13972 | 0.05413042 | 323.40404 | 0 |
| 6523.846 | 20.12534 | 0.02823016 | 326.095384 | 0 |
| 7167.809 | 20.11333 | 0.0145569 | 328.671236 | 0 |
| 7781.478 | 20.10371 | 0.007098135 | 331.125912 | 0 |
| 8364.123 | 20.09343 | 0.001647223 | 333.456492 | 0 |
| 8916.062 | 20.08292 | -0.002034351 | 335.664248 | 0 |
9437.159  20.07114  -0.004490612  337.748636  0
9918.392  20.06209  -0.005408974  339.673568  0
10351.67  20.05387  -0.005584579  341.40668  0
10739.01  20.04557  -0.005253968  342.95604  0
11083.74  20.03736  -0.004549216  344.33496  0
11389.16  20.02689  -0.003294062  345.55664  0
11658.5  20.01003  -0.000894236  346.634  0
11895.04  19.99507  0.001371083  347.58016  0
12131.58  20  0  348.52632  0

**Input_soil**

| Soil Depth | Soil Water Content | Soil Water Content |
|-----------|--------------------|--------------------|
| 0.000000  | 300.00000000      | 300.00000000      |
| 0.050000  | 300.00000000      | 1.00000           |
| 0.250000  | 300.00000000      | 1.00000           |
| 0.700000  | 300.00000000      | 1.00000           |
| 1.500000  | 300.00000000      | 1.00000           |

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).

Notes prepared by L Cheng, Z Chen, and Y. Chen. Aug 2021.