Cheng, L., Chen, Z. and Chen,Y.,

Centre for Research in Earth and Space Science, Lassonde School of Engineering, York University, Toronto, Ontario, M3J 1P3, Canada

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 (z_{0c}) as the tuning parameter, maybe starting with z_{0c} = 0.01 (m). The deposition velocity would then be,

vdfg(i,j) = ust(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, 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 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

```
a(k)= 0 !  This is not used anyway
b(k)=1.+ dtz(k)*(khdz(k+1)/rho(k)+ depvel)- 0.5*dtz(k)*s_aw(k+1)
c(k)=  -dtz(k)*khdz(k+1)/rho(k)          - 0.5*dtz(k)*s_aw(k+1)
d(k)= sqc(k) + qcd(k)*delt - dtz(k)*s_awqc(k+1)+ det_sqc(k)*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 z_{0c} 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 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) = ust(i,j)*karman/LOG(1+0.5*dz8w(i,kts,j)/z0c)
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 = ust*vk/LOG(1.0+0.5*dz(kts)/z0c)
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, z0c 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 z0c 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

```
! 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:

```
! 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.

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

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=1,0.999550329,0.999064684,0.998540576,0.997975378,0.99736632,0.996710487,0.996004811,0.9
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
6,0.970277302,0.967814724,0.965204392,0.962439528,0.959513195,0.956418307,0.953147628,0.949693791,
0.946049303,0.942206555,0.938157835,0.933895342,0.929411201,0.924697471,0.919746169,0.914549282,0.
909098788,0.90338667,0.897404939,0.891145657,0.884600951,0.877763042,0.870624266,0.863177094,0.855
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
57,0.669303878,0.654936469,0.640178266,0.625030447,0.609494844,0.593573958,0.577270971,0.560589754
,0.543534878,0.526111617,0.508325952,0.490184573,0.471694881,0.452864977,0.433703668,0.414220448,0.
394425497,0.374329663,0.353944449,0.333281996,0.312355063,0.291177007,0.269761757,0.248123788,0.22
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_sfclay_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.,
 dampcoef                            = 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

```
&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_top_requested                   = 5000,
 e_vert                            = 101,
eta_levels=1,0.999550329,0.999064684,0.998540576,0.997975378,0.99736632,0.996710487,0.996004811,0.9
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
```

```
6,0.970277302,0.967814724,0.965204392,0.962439528,0.959513195,0.956418307,0.953147628,0.949693791,
0.946049303,0.942206555,0.938157835,0.933895342,0.929411201,0.924697471,0.919746169,0.914549282,0.
909098788,0.90338667,0.897404939,0.891145657,0.884600951,0.877763042,0.870624266,0.863177094,0.855
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
57,0.669303878,0.654936469,0.640178266,0.625030447,0.609494844,0.593573958,0.577270971,0.560589754
,0.543534878,0.526111617,0.508325952,0.490184573,0.471694881,0.452864977,0.433703668,0.414220448,0.
394425497,0.374329663,0.353944449,0.333281996,0.312355063,0.291177007,0.269761757,0.248123788,0.22
6278095,0.20424016,0.182025921,0.15965174,0.137134364,0.114490891,0.091738729,0.068895558,0.045979
29,0.023008022,0
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_xs                        = .false.,
 symmetric_xe                        = .false.,
 open_xs                             = .false.,
 open_xe                             = .false.,
 periodic_y                          = .true.,
 symmetric_ys                        = .false.,
 symmetric_ye                        = .false.,
 open_ys                             = .false.,
 open_ye                             = .false.,
 /

&namelist_quilt
 nio_tasks_per_group = 0,
 nio_groups = 1,
 /
```

input_sounding

0	15.21353	1.684739	300	0	100000
0	0	0	300	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

0.0000000	300.0000000	300.0000000
0.0500000	300.0000000	1.00000
0.2500000	300.0000000	1.00000
0.7000000	300.0000000	1.00000
1.5000000	300.0000000	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).