I have been investigating how the bug found by Carey Friedman in the MERRA wet deposition and convection routines affects Hg simulation using the GEOS-FP met fields. Carey found that the tracer mass passed from the atmosphere to the ocean was less than the deposited mass archived in the wet deposition diagnostics. For Carey's POP simulation, this discrepancy was 44% for convective wet deposition and 3% for large scale wet deposition, for one year of run time.

I am using the v9-02 code, running the 4x5 global domain for the month of June 2013. My findings are as follows:

1) For the bug in the WASHOUT_ONLY routine (WETSCAV_MOD):
Carey has identified that the bug is caused by the following condition (in bod) which prevents washout at a particular level:

```
IF ( IT_IS_NAN( WASHFRAC ) ) THEN
   CYCLE
ELSEIF ( WASHFRAC < 1D-3 ) THEN
   CYCLE
ENDIF
```

I have tested the model with (i) the current (above) setting, (ii) with the setting changed to: `WASHFRAC < 1D-20`, and (iii) without any condition for `WASHFRAC`. A comparison of the mass of Hg2+HgP passed from the air to the ocean, and the mass wet deposited, for a 1-month simulation, is below:

Condition	Mass passed to ocean	Mass wet deposited
(i)	209 Mg	276 Mg
(ii)	276 Mg	277 Mg
(iii)	246 Mg	246 Mg

I think that any condition requiring that the `WASHFRAC > 0` for washout to occur, prevents the partial resuspension of the dissolved mass falling from above, and leads to an overestimate in the wet deposited mass. I recommend that a condition on `WASHFRAC` should be removed. If this leads to negative values of DSTT, we should add a few lines (example below) to restrict DSTT to a minimum of 0.

```
IF ( DSTT(NN,L,I,J) + WETLOSS < 0d0 ) THEN
     WETLOSS        = -DSTT(NN,L,I,J)
     DSTT(NN,L,I,J) = 0d0
ENDIF
```

For the Hg2 and HgP, large scale wet deposition is dominant loss mechanism (>90%), and this bug has a large effect on the Hg simulation. The effect, of course, is not restricted only to the Hg/POP simulations.

The discrepancy in the mass passed to the ocean and mass wet deposited arises because the condition on WASHFRAC causes intermediate layers to be skipped in the computation of DSTT (see code below). DSTT, as currently coded, needs to be updated at each level as we move down from the vertical grid.

```
        IF ( F_RAINOUT > 0d0 ) THEN
          DSTT(NN,L,I,J) = DSTT(NN,L,  I,J) + WETLOSS
        ELSE
          DSTT(NN,L,I,J) = DSTT(NN,L+1,I,J) + WETLOSS
        ENDIF
```

2) For the bug in the DO_MERRA_CONVECTION routine (CONVECTION_MOD):
I think, the bug here is very similar to the bug above. The following piece of code prevents the archiving of deposited mass in the wet deposition diagnostic, but is recorded in the mass that is passed from the air to the ocean. Since mass can be gained (lost from the deposited fraction) in a level during washout due to partial resuspension of the mass falling from above, the wet deposition diagnostic was overestimated. I propose that the if condition (in red) be deleted from the following code that archives wet deposition diagnostic after washout:

```
  IF ( OPTIONS%USE_DIAG38 .and. F(K,IC) > 0d0 ) THEN
       DIAG38(K,IC) = DIAG38(K,IC)
     &                        + ( T0 * AREA_M2 / TCVV_DNS )
```

Here, F is the fraction of tracer scavenged in convective updrafts, and is not related to washout. In GEOS-FP convection does not always start in the first level. A comparison of the mass of Hg2+HgP passed from the air to the ocean, and the mass wet deposited, for a 1-month simulation, is below:

Condition	Mass passed to ocean	Mass wet deposited
Current code	23.3 Mg	23.6 Mg
After above fix	23.3 Mg	23.3 Mg

For the other two bugs, I propose the following fix;

```
old:        ! Archive T0 for use in the next section
            T0_SUM   = T0_SUM + T0

new:        ! Pass T0_SUM in units of kg tracer/m2/timestep
            T0_SUM   = T0_SUM + T0 / TCVV * SDT
.....................................................................
.........
      IF ( AER == .TRUE. ) THEN

            !-----------------------------------------------------
-----
            ! Washout of aerosol tracers
            ! This is modeled as a kinetic process
            !-----------------------------------------------------
-----
            ! Define ALPHA, the fraction of raindrops that
            ! re-evaporate when falling from (I,J,L+1) to (I,J,L)
            ALPHA    = ( REEVAPCN(K) * AD(K) )/ ( PDOWN(K+1)   *
AREA_M2 * 10d0 )

           ! ALPHA2 is the fraction of the rained-out aerosols
           ! that gets resuspended in grid box (I,J,L)
            ALPHA2   = 0.5d0 * ALPHA

           ! GAINED is the rained out aerosol coming down from
           ! grid box (I,J,L+1) that will evaporate and re-enter
           ! the atmosphere in the gas phase in grid box (I,J,L).
           GAINED   = T0_SUM * ALPHA2

           ! Amount of aerosol lost to washout in grid box
old:       WETLOSS = Q(K,IC) * WASHFRAC - GAINED
new:       WETLOSS = Q(K,IC) * BMASS(K) / TCVV * WASHFRAC -
GAINED

           ! LOST is the rained out aerosol coming down from
           ! grid box (I,J,L+1) that will remain in the liquid
           ! phase in grid box (I,J,L) and will NOT re-evaporate.
           LOST     = T0_SUM - GAINED

new:      ! Update tracer concentration
new:      Q(K,IC) = Q(K,IC) - WETLOSS * TCVV / BMASS(K)

           ! Update T0_SUM, the total amount of scavenged
           ! tracer that will be passed to the grid box below
           T0_SUM = T0_SUM + WETLOSS

        ELSE

           !------------------------------------------------------
----
```

```
            ! Washout of non-aerosol tracers
            ! This is modeled as an equilibrium process
            !-----------------------------------------------------
----
            ! MASS_NOWASH is the amount of non-aerosol tracer in
            ! grid box (I,J,L) that is NOT available for washout.
            MASS_NOWASH = ( 1d0 - F_WASHOUT ) * Q(K,IC)

            ! MASS_WASH is the total amount of non-aerosol tracer
            ! that is available for washout in grid box (I,J,L).
            ! It consists of the mass in the precipitating
            ! part of box (I,J,L), plus the previously rained-out
            ! tracer coming down from grid box (I,J,L+1).
            ! (Eq. 15, Jacob et al, 2000).
old:        MASS_WASH    = ( F_WASHOUT * Q(K,IC) ) + T0_SUM
new:        MASS_WASH    = ( F_WASHOUT * Q(K,IC) ) * BMASS(K) /
TCVV + T0_SUM

            ! WETLOSS is the amount of tracer mass in
            ! grid box (I,J,L) that is lost to washout.
            ! (Eq. 16, Jacob et al, 2000)
            WETLOSS      = MASS_WASH * WASHFRAC - T0_SUM

            ! The tracer left in grid box (I,J,L) is what was
            ! in originally in the non-precipitating fraction
            ! of the box, plus MASS_WASH, less WETLOSS.
old:        Q(K,IC)      = Q(K,IC) - WETLOSS
new:        Q(K,IC)      = Q(K,IC) - WETLOSS * TCVV / BMASS(K)

            ! Updated T0_SUM, the total scavenged tracer
            ! that will be passed to the grid box below
            T0_SUM       = T0_SUM + WETLOSS

         ENDIF
        !---------------------------------------------------------
---
        !  N D 3 8   D i a g n o s t i c
        !
        !---------------------------------------------------------
---
        IF ( OPTIONS%USE_DIAG38 .and. F(K,IC) > 0d0 ) THEN
old:        DIAG38(K,IC) = DIAG38(K,IC) + ( WETLOSS * AREA_M2 /
TCVV_DNS )
new:        DIAG38(K,IC) = DIAG38(K,IC) + ( WETLOSS * AREA_M2 /
NDT )

        ENDIF

    !==============================================================
=====
    ! (5)  M e r c u r y   O c e a n   M o d e l   A r c h i v a l
    !==============================================================
=====
```

```
   !--------------------------------------
   ! Hg2
   !--------------------------------------
   IF ( IS_Hg .and. IS_Hg2( IC ) ) THEN

     ! Wet scavenged Hg(II) in [kg/s]
old:  WET_Hg2 = ( TO_SUM * AREA_M2 / TCVV_DNS )

     ! Convert [kg/s] to [kg]
old:  WET_Hg2 = WET_Hg2 * NDT

new: ! Wet scavenged Hg(II) in [kg]
new:  WET_Hg2 = ( TO_SUM * AREA_M2 )

     ! Pass to "ocean_mercury_mod.f"
     CALL ADD_Hg2_WD      ( I, J, IC, WET_Hg2 )
     CALL ADD_Hg2_SNOWPACK( I, J, IC, WET_Hg2, State_Met )
   ENDIF

    !--------------------------------------
    ! HgP
    !--------------------------------------
     IF ( IS_Hg .and. IS_HgP( IC ) ) THEN
old:   ! Wet scavenged Hg(P) in [kg/s]
old:   WET_HgP = ( TO_SUM * AREA_M2 / TCVV_DNS )

old:   ! Convert [kg/s] to [kg]
old:   WET_HgP = WET_HgP * NDT

new:   ! Wet scavenged Hg(P) in [kg]
new:   WET_HgP = ( TO_SUM * AREA_M2 )

        ! Pass to "ocean_mercury_mod.f"
        CALL ADD_HgP_WD      ( I, J, IC, WET_HgP )
        CALL ADD_Hg2_SNOWPACK( I, J, IC, WET_HgP, State_Met )
      ENDIF
```