Thompson Microphysics Updates in the Unified Forecast System

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The Thompson microphysics scheme was evaluated in the Unified Forecast System (UFS) for medium-range weather application in both atmosphere-only and fully coupled atmosphere-ocean-ice-wave system configurations. Initial tests based on the Global Forecast System (GFS) version 16 configuration showed that the Thompson microphysics scheme became unstable with a typical GFS time step. A temperature tendency limiter associated with the scheme was previously used to improve the stability in another forecasting system. But the limiter violated energy conservation because it limited the temperature tendency to a certain value when it exceeded a threshold. An inner-loop time-splitting approach and a new semi-Lagrangian sedimentation scheme for rain and graupel were implemented in the scheme to alleviate this numerical instability problem. The inner-loop divided the physical time step into a few smaller ones when Thompson microphysics was called. After each small step, the variables were updated. The inner-loop increased the stability by avoiding production of large tendencies from fast processes due to a large time step. Because the inner-loop method needed to run the whole microphysics multiple times it was time consuming. The computational cost increased by about 24% in an inner-loop experiment compared with a control, a version of GFSv16 with C768 and 127L resolutions and 144-hour forecast length. The semi-Lagrangian sedimentation method of rain and graupel was based on the work by Juang and Hong (2009). The method was first implemented in the WRF Single Microphysics (WSM) series. The method conserves mass and is positive definite. Two updates were made. One update (by Dr. Juang) was to fix an interpolation bug which caused a mass conservation issue after sedimentation happens. The other (by Dr. Hong) was updating the terminal velocities of falling hydrometeors at each small step when more than one sub-time steps (in the physical time step) were needed to satisfy the deformation CFL condition. It was the second update that stabilized the scheme. The computational cost of the semi-Lagrangian sedimentation method increased by about 14% compared with the same control experiment.

To reduce biases of radiative fluxes at the surface and at the top of the atmosphere, the conversions from cloud ice to snow and from snow to graupel in the scheme were modified along with the ice falling velocity. A few other parameters related to the ice formation process were also adjusted to help improve radiative fluxes, including the threshold value of maximum ice number concentration and super-saturation requirement in ice nucleation. The convective cloud condensate was included in the calculations of cloud cover and radiative transfer. Both coupled and uncoupled experiments were conducted to examine the impacts of these changes on global and regional forecast skill at different temporal and spatial scales. Figure 1 and Figure 2 illustrate the impacts of a few changes on the out-going longwave radiation (OLR) at the top of the atmosphere and the downward shortwave (DSW) radiative flux at the surface in two global forecast-only experiments (cp8f11 and cp8tb3) with C768 horizontal resolution and L127 vertical resolution. Both cp8f11 and cp8tb3 have 18 cases (every 5 days from December 03 2020 to February 26 2021). In the two experiments, the cp8f11 is the control based on a version of the GFS.v17 prototype. The cp8tb3 added a few changes to cp8f11, i.e. an increase of the maximum threshold value from 250 L^{-1} to 1000 L^{-1} and a decrease of the

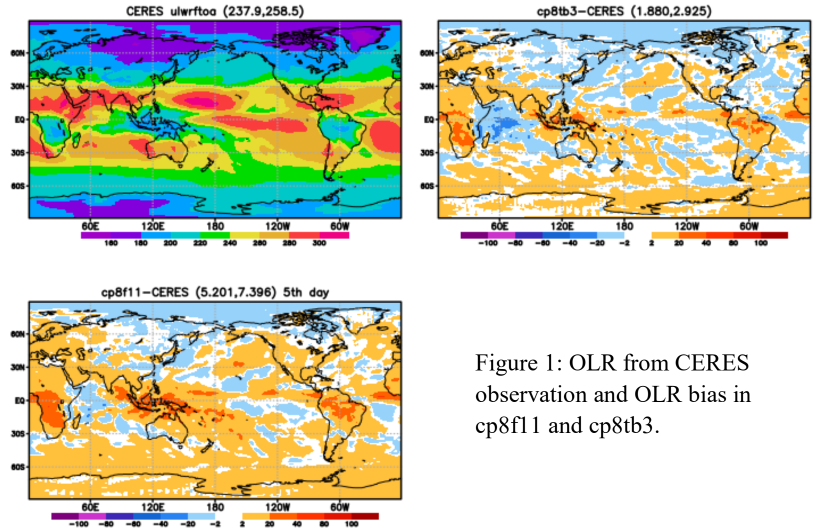

Figure 1: OLR from CERES observation and OLR bias in cp8f11 and cp8tb3.

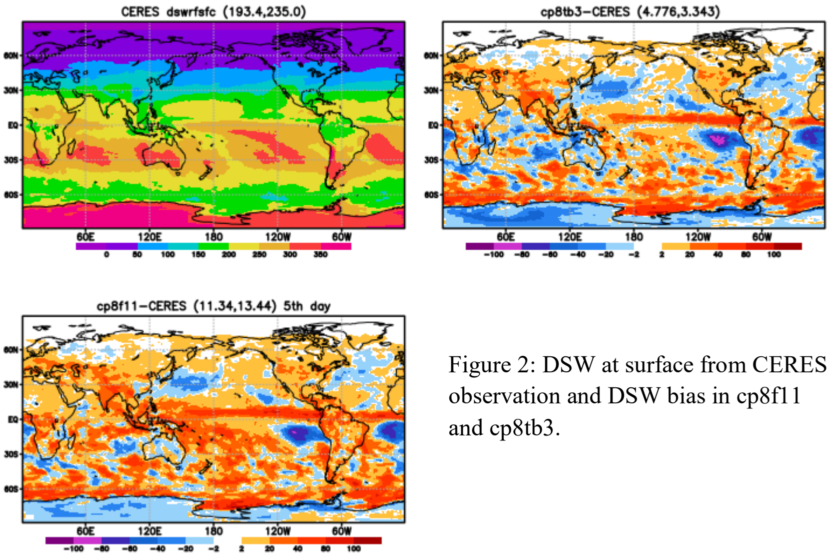

Figure 2: DSW at surface from CERES observation and DSW bias in cp8f11 and cp8tb3.

super-saturation requirement from %125 to 115% with respect to ice. In cp8tb3, the cloud number concentration over the ocean is reduced to 75 cm^{-3} from 100 cm^{-3}. Convective cloud condensate was used in the radiative flux calculation in cp8tb3. Figure 1 shows that compared with CERES observed OLR, the bias in the cp8tb3 experiment is reduced over the globe. The contribution of this reduction is mainly from the increase of ice at high altitudes. As illustrated in Figure 2, the DSW flux bias at the surface is reduced over the tropical region and over the southern ocean; however, the bias is increased over the south east Pacific ocean off the coast.

References

Juang, H.-M.H., Hong, S.-Y.: Forward semi-lagrangian advection with mass conservation and positive definiteness for falling hydrometeors. Mon. Weather Rev. **138**, 1778–1791 (2010)