Improving convection simulation on the „gray-scale" resolutions in WRF

Convection processes in WRF are generally handled by explicitly resolving equations on very fine grid resolutions like < 1km, or using cumulus parametrization schemes on coarse resolutions like > 10km. The resolution range inbetween two mentioned scales has always been problematic and considered as a „gray scale" resolution range where explicit resolving is not fully capable of producing correctly simulated updrafts and at the same time traditional cumulus schemes were not optimized to work on those scales (i.e. working together with partially resolved convection by explicit equations).

Things where changed dramatically with latest WRF versions with inclusion of different scale-aware cumulus schemes, like Multi-scale KF, Grell-Freitas or KIAPS SAS schemes. Those schemes use different approach to try to „help" explicit convection routines to work better on scales where convection process is not fully resolved as explained above.

However, depending on exact model setup, geographical area of interest, and other particular case situation, those schemes may or might not ideally complement explicit convection resolving. In this short review, we show how we can tune KIAPS SAS (KSAS) scheme to engage less or more into convection simulation process, depending on particular case requirement.

To put in simple terms, in KSAS scheme [1], parameter that decides how actively it is going to engage in simulating convection processes, depending on actual grid resolution used, is called **sigma**. This parameter is calculated as:

$$\sigma = 1 - \frac{1}{\pi}\left\{\arctan\left(\sigma_{con}\left(\Delta x - \Delta 1\right)\right) + \frac{\pi}{2}\right\}$$

and

$$\sigma_{con} = \frac{\tan(0.4\,\pi)}{\Delta 1 - \Delta 2}$$

where Δx is the horizontal grid size (m) of a model, Δ1 and Δ2 are the values for determining the shape of the curve and are set to 5000 and 1000 m, respectively.

Further, if grid size is less than 5000m, additional modification to sigma function is applied:

$$\sigma = \sigma - 0.01684\,\frac{\Delta x}{1000} + 0.0842$$

If we plot sigma function against range of grid distances, we get S-shaped curve like shown in Figure 1.

1 https://journals.ametsoc.org/doi/10.1175/MWR-D-16-0034.1

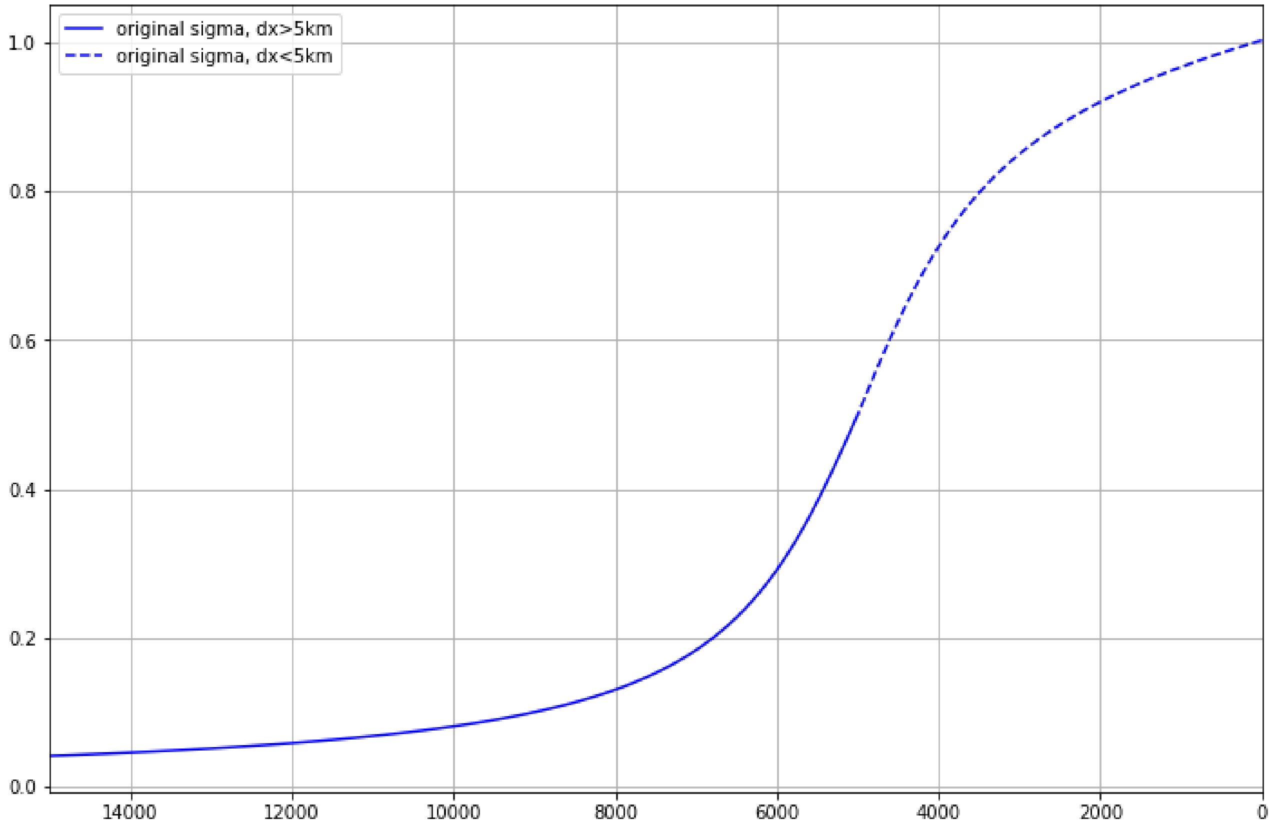

Figure 1: Original sigma function in KSAS scheme

From Figure 1, we can see that on coarse grids, sigma function gets low values (up to 0), whereas on fine grids it gets high values (up to 1). We can think of this value as a cumulus scheme damper function. When sigma value is low, scheme is not damped and is allowed to engage fully into convection simulation, and when sigma value is high, it is strongly damped and does not contribute to simulation much, leaving convection handling to explicit resolving equations. Within „gray zone" betwen ~10 and ~1 kilometer of horizontal grid size, sigma function gradually changes and allows partial contribution of cu scheme to the overall convection simulation.

The goal of modification is to make sigma function adjustible. Ideally, the overall shape of the curve should not be modified much, and values outside gray zone should not be changed also. What we can simply do in order to achieve that goal is to introduce new parameter $ksas_{coeff}$ like this:

$$\sigma = 1 - \frac{1}{\pi}\left\{\arctan\left(\sigma_{con}\left(ksas_{coeff}\,\Delta x - \Delta 1\right)\right) + \frac{\pi}{2}\right\}$$

Depending on $ksas_{coeff}$ value, the sigma function is modified as shown in Figure 2. Three modified sigma functions are shown as example, for value of $ksas_{coeff}$ 0.75, 1.2 and 1.6, respectively.

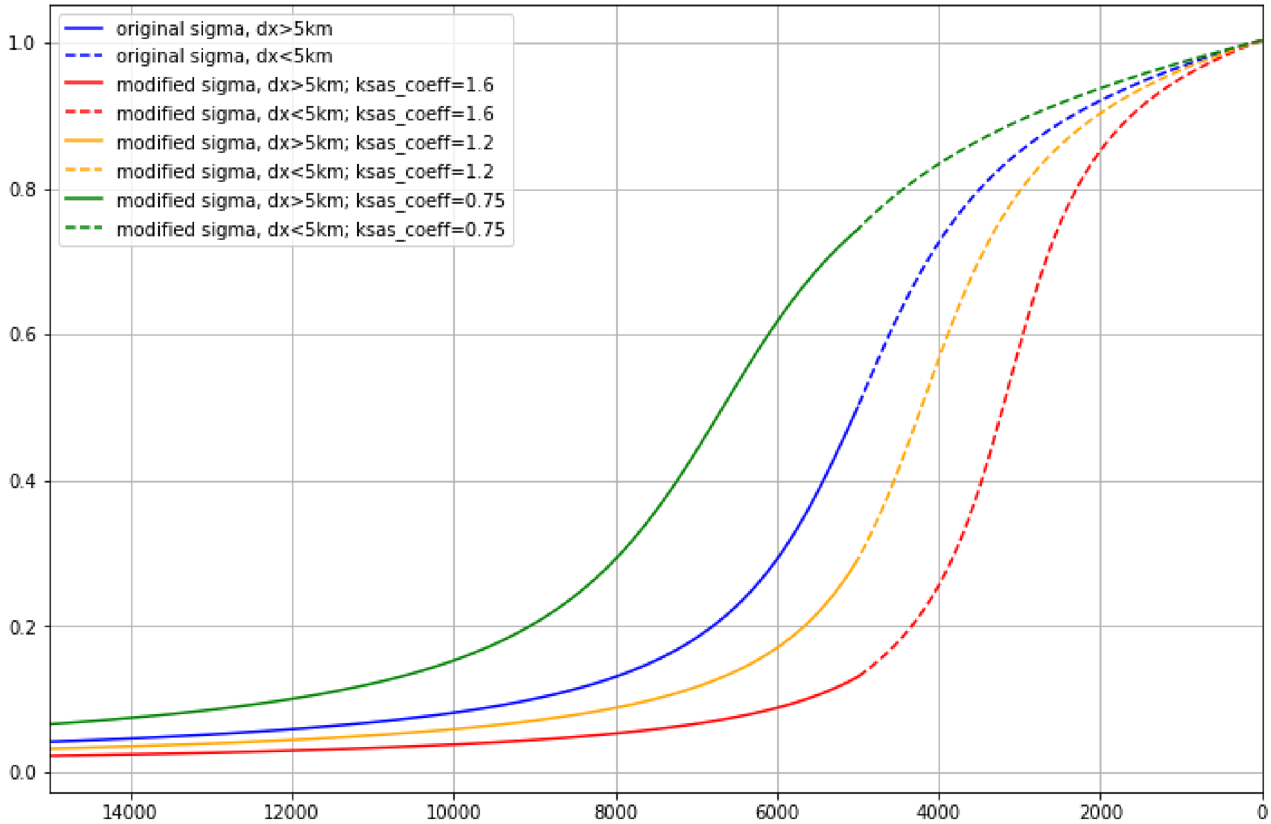

Figure 2: Examples of modifiaction of sigma function in KSAS cumulus scheme, for three different ksas_coeff values (0.75, 1.2 and 1.6), along with original sigma function

Modified sigma functions with $ksas_{coeff}$ value less than 1 results in more damping of cumulus scheme and consenquently, less active behaviour in simulations. In real world scenario this will most probably result in less convection simulated over „gray-zone" grid resolutions. Increasing $ksas_{coeff}$ value over 1 results in stronger activation of cumulus scheme, making it behave more similar like non scale-aware type of scheme over „grey-zone" grid resolution range. This might help if original KSAS scheme does not activate strongly enough, in which case, when convection is weakly triggered, it might be completely missed by either cu scheme and explicit equations.

It should be noted, that proposed modification does not alter much scheme behaviour outside of „gray-zone" resolution range much, as shown on Figure 2.

Described KSAS sigma function tuning is currently evaluated in operational MeteoAdriatic ARW model on the grid resolution of 3.5 kilometers, with results of testing available at http://meteoadriatic.net/WRF-ARW-4km-karte