An Essay on the Eta Cumulus Convection (BMJ) Scheme

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1. History and mechanisms in place

It could well be that the various mechanisms in place in the Eta cumulus convection scheme can only be well understood if the history of the scheme is told in its chronological order. This will be done here. At NCEP, Janjic has implemented the Betts-Miller (BM) scheme in the Eta model in late eighties (Janjic 1990). Subsequent model tests revealed a problem of excessive precipitation over warm water. Janjic has modified the Betts Miller scheme so as to address the problem, as described in his 1994 paper. In doing so, he made numerous experiments with two cases: one in which heavy precipitation was justified, and another in which it was not. He managed to produce code which avoided doing excessive precipitation in the case in which it was not justified, while not damaging the case in which it was, a remarkable achievement. The actual work was done in 1990, but its description was published in 1994.

The Janjic (1994) BM scheme modifications contain two stratagems that act to reduce heavy precipitation. They both depend on “cloud efficiency”, a nondimensional parameter Janjic introduced, in the code denoted as EFI. EFI is proportional to the rate of change of the “environment”, or better cloud column "entropy" change, per unit precipitation produced. When for a given change of the environment precipitation produced is large, EFI will be small. The code limits EFI to be between 0.2 and 1.

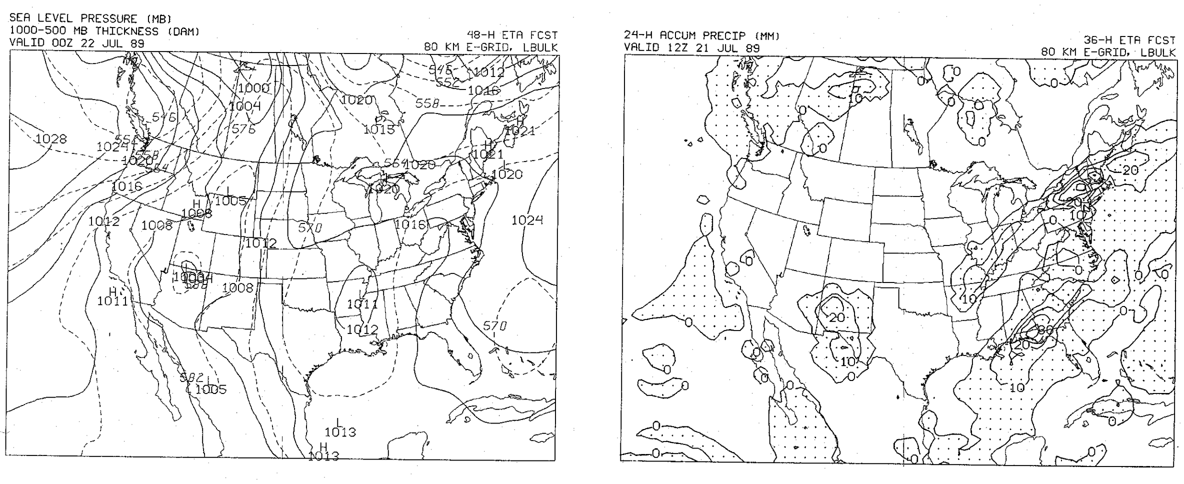
One of the stratagems affected as a result will be the choice of the preliminary humidity reference profiles. These profiles act to trigger convection, in the sense that the model column humidity at the time and place considered has to be greater than the reference one for convection to be possible. As opposed to fixed predetermined reference humidity profile of the original BM scheme, Janjic made the scheme choose its preliminary reference profile in between two sets, “fast” (or “dry”) and “slow” (“moist”), depending on the value of the parameter EFI. The fast profiles – defined by their values of DSPs (deficit of saturation pressure) – are multiplied by FSS (factor to obtain “slow” profiles over the sea) to obtain slow profiles. At the time FSS had a value of 0.6 (paper, page 933). When EFI is smaller (heavier precipitation) profiles chosen by the scheme will be closer to the slow profiles, that have smaller magnitudes of DSP values. With smaller DSP magnitudes, the preliminary reference humidity profiles are wetter, or, q_{ref} values are greater, and thus closer to saturation. Thus, a given column humidity profile, wetter than the reference in order to have convection, will be less different from the reference profile; and since the scheme has the change of specific humidity in an active convection time step proportional to the difference in specific humidities, Eq. (2.2) of the paper, the rate of precipitation will be smaller. Thereby the scheme is discouraging heavy convection.

It should be noted that in addition to column vs preliminary reference humidity profiles the scheme has other requirements for activating deep convection as well as mechanisms in place; for a comprehensive description see Baldwin et al. (2002). Among those, if all the requirements for deep convection are met, preliminary reference humidity and temperature profiles will be changed so that nudging toward the two results in conservation of column enthalpy. This ensures that heating via latent heat release in properly compensated by the removal of water vapor converted into precipitation.

The other stratagem discouraging heavy convection is the extension of the relaxation time, Eq. (3.6) of the paper. The chosen smallest scheme's relaxation time (TREL) is divided by a function of EFI ("FEFI") to obtain the relaxation time to be used. When EFI is smaller (heavier precipitation) relaxation time increases. As EFI is decreasing from 1 to 0.2, FEFI is prescribed to decrease linearly from 1 to 0.7. As a result, with the original (1994 paper) parameters, the relaxation time was permitted to increase from its smallest value of 3000 s, to 4285 s as EFI decreases to its minimum allowed value of 0.2. This also discourages heavy convection.

One should note that while both of these stratagems act to discourage heavy convection, there is an important difference between them. The former, affecting reference profiles, affects not only the amount of possible convection but also the scheme's convection "trigger function", requirements deciding if there is going to be convection at the considered column or not. The latter, extension of the relaxation time, affects only the amount of precipitation to be produced within the time step of active convection.

It was later discovered however that the Eta problem with excessive precipitation over warm water of the late eighties was not caused by the Betts-Miller convection scheme, but by a faulty scheme for the surface heat transport. The surface fluxes scheme in place at the time of the Janjic two cases experiments (Janjic 1990, p. 1435) was at times and places leading to unrealistically large values over relatively warm water. Once the surface fluxes scheme was replaced by the "lbulk" scheme of Mesinger (Mesinger and Lobocki 1991; see also Mesinger 2010), the case of Janjic (1994) with heavy spurious precipitation was rerun using the original Betts-Miller scheme, and no spurious heavy precipitation was obtained. This result is shown in the figure:



The left panel plot above, 48-h sea level pressure forecast, and the right panel, 24-h accumulated precipitation verifying at 36-h, correspond to the bottom right panel of Fig. 6, and the right panel of Fig. 7 of Janjic (1994). Verification plots are shown in Fig. 5 of the same paper. The skill of the two forecasts in this particular situation can be seen to be about the same. The spurious precipitation over warm water is removed to about the same degree in both, and the sea level pressure forecast above in the area of interest if anything verifies even a little better.

As it is, the modifications of the Betts-Miller scheme remained nevertheless in the NCEP Eta code, albeit compared to the published values with a reduced intensity of the first of the two described stratagems: FSS value of 0.85 was used and still is in what will be referred to as the "NCEP Eta code". Minimum relaxation time TREL on the other hand was decreased to 2500 s, making the relaxation time in between 2500 and 3570 s, depending on the value of EFI.

It is only fair to note that the suppression of heavy convection by the two mechanisms has been justified in Janjic (1994) of course not as "tuning" needed to avoid cases of spurious runaway convection, but by an idea that for low cloud efficiency convection should in a way step back and allow greater moistening of the column and eventually the onset of large scale precipitation. EFI was suggested to be a relevant nondimensional parameter that should govern the transition from one, convection regime, to another, in which large-scale precipitation dominates.

Note that introduction of a relevant nondimensional parameter such as EFI is an attractive feature of a description of a process for which no first principle equations are available. When the parameter is successfully chosen, an empirical determination of its value leads to a successful outcome – many examples for such a success are available in the turbulence theory. The highly successful Monin-Obukhov similarity theory is perhaps the best known. But we cannot have our cake and eat it too. The dimensional analysis similarity approach leads to equations with constants, or functions, to be determined empirically. What agrees with data/experiment, is what is correct, and no room is left any more for a choice of numbers to be referred to as "consistent" or as making "sense within the given physical model".

Another feature of the modified scheme, nowadays mostly referred to as the Betts-Miller-Janjic (BMJ) scheme, needs to be mentioned. It is the possibility to use different profiles over sea and over land. Originally Janjic (1994 paper) implemented his modifications over water ("sea") points only. Somewhat later, the scheme was implemented over land also (see the code in CUPARM, and in CUCNVC.F), but with humidity profiles over land drier than over the sea.

One can find some justification for making the trigger of the convection over land less demanding than over the sea in the idea that over land inhomogeneities of the surface including topography should facilitate the onset of convection compared to the situation with profiles etc the same but with inhomogeneities absent. However, even though there is an effort in the code to smooth the discontinuity in the reference profiles imposed, the operational Eta results at NCEP with different profiles kept showing visibly increased precipitation over coastal areas compared to areas just offshore. This was considered unrealistic, and at one point in the late nineties decision was made to run the scheme using reference profiles over land equal to those over the sea. This is achieved in the code by setting "unified convection with profiles as prescribed over the sea", UNIS=.true..

Another issue that has received attention is that with great regularity the NCEP Eta precipitation verified during the convection season would show a bias profile with the bias visibly decreasing for higher precipitation intensities. The bias values would be not much different from unity for low and medium precipitation intensities but would then gradually decrease, dropping to values on the order of only 0.5 or less at the high intensity end. This shape would dominate also full year plots. Examples of the plots of this shape can be seen at very many places. For examples from earlier times one can inspect plots in Mesinger (2000), and from more recent times one in Mesinger and Jovic (2004), and finally that of the lower panel of Fig. 3 in (Mesinger 2008).

With the heavy precipitation of an obvious special interest, this was a concern and at one point during a convection season at my suggestion a "parallel" run was set up at NCEP in which FSS had a value of 1.10. This can be referred to as "reversed profiles" experiment. The idea was to use the scheme's ability of choosing its reference profiles in a way opposite to the original intention, to encourage as opposed to discourage heavy convection. The results were just as expected, with the bias plot of the Eta approximately flat, without the usual decrease toward the heavy precipitation end.

Subsequently, I have run numerous experiments on a case of heavy convection which seemed to me might be typical of the Eta BMJ bias problem. In addition to "control", these experiments included a "neutral" scheme run (FSS=1, FEFI=1), reversed profiles (FSS=1.1), and a reversed relaxation time extension run (FEFI=2-FEFI). Both the reversed profiles and the reversed relaxation time extension runs visibly improved the result.

For implementation of the reversed profiles scheme it was however required that a physical rationale for the change be agreed upon by the relevant Mesoscale Branch people. My suggested rationale was not accepted by Brad Ferrier with explanations which perhaps can best be summarized by his having felt he needed more time to study the matter, and that missing heavy precipitation should more appropriately be produced by the cloud microphysics scheme. Brad Ferrier's e-mail is available on request.

This not having been achieved by the time of the ICTP 2005 workshop, at my suggestion we have in the Eta code that was distributed to participants and later put on the CPTEC Eta site changed the convection scheme so as to use FSS=1.10, and FEFI=1.

Experiments done subsequently by the CPTEC Sin Chan Chou's group, and by Marcelo Seluchi's group have however indicated that these ICTP 2005 values were in a way an overkill. Note that setting FEFI=1 not only disables the relaxation time extension feature, but that this also sets the value of the relaxation time at the low end of its NCEP range of 2500 to 3570 s. Resulting precipitation intensity will then be considerably greater than if for example the relaxation time in the middle of the NCEP range had been specified.

As a result, a number of sets of values of various parameters of the BMJ scheme can be found in various Eta codes, as will be listed in the following section.

2. Eta BMJ scheme parameters as found in various codes

a. NCEP ("standard") Eta code

This is the code that is the latest Eta code on Matt Pyle's NCEP "workstation Eta" site, and also the code that was used for NCEP North American Regional Reanalysis (NARR). The code can be found on the NARR DVD that was distributed with the March 2006 issue of the Bulletin of the AMS. This presumably is also the code that was (is?) downloadable from the COMET Eta site. The parameters used are:

unis=.true.
fss=0.85
dspbfs=-3875., dsp0fs=-5875., dsptfs=-1875.
trel=2500.
fefi=efmnt+slope*(efi-efimn)

b. ICTP 2005 Eta code
This code was distributed to participants of the ICTP 2005 RWPM (Regional Weather Predictability and Modeling) workshop, and is downloadable – with an upgrade that does not concern convection – from the CPTEC Eta site. The parameters used are:

unis=.true.
fss=1.10
dspbfs=-3875., dsp0fs=-5875., dsptfs=-1875.
trel=2500.
fefi=1.

c. Serra do Mar code
This code was arrived at within the CPTEC's Serra do Mar project, led by Sin Can Chou. Serra do Mar are coastal mountains in the area between Rio and Sao Paolo. Coming to the conclusion that the ICTP 2005 choices were resulting in too much precipitation, the parameters were changed back to their NCEP values, except for the fast profile dsps. They were chosen at the bottom and at the zero level drier than NCEP's, specifically:

unis=.true.
fss=0.85
dspbfs=-5000., dsp0fs=-7000., dsptfs=-1500.
trel=2500.
fefi=efmnt+slope*(efi-efimn)

Thus, with these values, both BMJ mechanisms for the suppression of heavy convection were restored. However, the problem of too much precipitation obtained with the ICTP 2005 code, presumably primarily due to the relaxation time having always been the shortest of the "standard" NCEP code range (fefi=1), was avoided.

d. CPTEC operational/ Marcelo Seluchi code
Following very comprehensive testing over the operational CPTEC Eta domain (most of South America), in an effort led by Marcelo Seluchi, CPTEC operational values were arrived at as follows:

unil=.false., unis=.false.
fsl=0.85, fss=1.00
dspbfl=-4500., dsp0fl=-5500., dsptfl=-2000.
dspbfs=-3875., dsp0fs=-5875., dsptfs=-1875.
trel=3250.
fefi=efmnt+slope*(efi-efimn)

3. Discussion

The choice of BMJ parameters for the ICTP 2005 code was made to address the bias seen in the performance of the NCEP BMJ code over the continental United States in quite a few convective seasons. As said above, month after month in spring and summer, and year after year, the Eta precipitation would show just a slightly increased bias for low precipitation intensities, then a gradually decreasing bias over the medium intensity categories, and finally a bias decreasing with intensity still more across the remaining highest categories ending with a bias of only on the order of 0.5 at the high intensity end of bias plots. Thus, this behavior is firmly established and strongly points to the two described mechanisms being responsible. Insufficient heavy rain running the NCEP BMJ scheme Eta in MCS cases over northern Argentina associated with South American Low Level Jet (SALLJ) situations was also demonstrated by Rozante and Cavalcanti (2008).

The ICTP 2005 parameters in which the first mechanism was reversed (fss=1.10), and the second switched off (fefi=1.) were chosen to correct for this intensity dependent bias. These choices were tested on experiments done with only one case, and according to later experiments at CPTEC were resulting in overall too much rain. In hindsight this can be understood by noting that with fast (dry) DSPs unchanged and the profiles reversed, the profiles actually used would always be at least as dry as the prescribed “dry” ones, and on average drier still. Thus, with the moisture trigger now being easier to achieve increased precipitation not only for the heavy intensity categories but for the light ones as well should have been expected and must have happened. To avoid this unnecessary bias increase for the light intensity categories when using the reversed profiles the prescribed “dry” DSPs should have been made “wetter” – smaller in absolute values – as this would have made satisfying the convection requirements harder, and thus the convection less frequent.

Another promising alternative is to keep the dry DSPs as in the NCEP code or similar, but to address its intense convection bias problem by switching off or reversing the “fefi mechanism” only. Note that DSPs together with fss determine the position of the range of trigger moisture profiles that the scheme can choose, affecting thus the frequency of convection. The fefi mechanism on the other hand does not affect the convection trigger, but only affects the amount of precipitation in a convection time step, depending on the tentative cloud efficiency, which in turn reflects the tentative precipitation intensity. Moving the available range of moisture profiles toward moister profiles will reduce the frequency of convection. This should occur because with reference profiles chosen to be on average moister less frequently the actual model moisture will be moister yet, which is a necessary condition for convection. For example, keeping dry DSPs as in the NCEP code but using fss=0.825 as opposed to 0.85 should reduce the frequency and thus also the light rain some. Note that the light rain tended to be slightly overdone in NCEP operational runs, see, e.g., plots in Mesinger (2008). Frequency being determined, the intensity depending on the tentative cloud efficiency can be affected by modifying fefi. In one of the experiments referred to above done on a single case I have used a “reversed” fefi by prescribing fefi=2-fefi. This increases the amount of precipitation for cases of intense convection. And finally, the total amount of precipitation per time step, in light as well as intense cases, can be affected by the choice of trel.

These were the options meant to be set as the “control” in the ICTP 2008 Eta code, along with trel=2500. However, inadvertently, the ICTP 2008 code has used

```
unis=.true.
fss=1.10
dspbfs=-3875., dsp0fs=-5875., dsptfs=-1875.
trel=2500.
fefi=2-[efmnt+slope*(efi-efimn)]
```

Thus, this is the same as the ICTP 2005 code, except for the "reversed" (as opposed to "neutral") fefi. These values are used in the CPTEC currently posted code.

In summary, with these values, because of the "reversed" dsps, heavy convection will be encouraged since with heavy convection the scheme will choose drier profiles, thus increasing the difference $q–q_{ref}$ and therefore also the decrease of q in the convection time step. However, since the range available for dsps is with fss>1 compared to "standard" NCEP code shifted toward the drier values, satisfying the convection trigger will be easier and more frequent convection steps should be expected. The "reversed" efi compared to the "standard" NCEP code will also encourage heavy convection, with the fefi changing from 1.3 for heavy tentative convection to 1 for light convection; making the relaxation time change from 1923 s to 2500 s, respectively.

Users are encouraged to make experiments with variations of some of these parameters. Thus, one might want to test if somewhat different trel values affect the total precipitation substantially. One might also want to test and if the “reversed” fefi chosen in the code does indeed reduce heavy convection while not visibly modifying the light convection, as suggested above.

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