Clouds in GEM and calculation of cloud cover variables

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1. Objectives

In spring 2009 (March 12th), we implemented some changes to the GEM15 forecast system. Among others, we now use the radiative transfer scheme cccmarad rather than newrad. Several changes to the preprocessing of clouds before their use by the radiative transfer scheme were made as well as changes to the scheme itself. This document provides information about the clouds (condensate and cloud fraction) produced by the different schems as well as as the "recipes" used to calculate the total cloud fraction and the liquid and solid condensate required by the radiative transfer scheme. In particular we describe the set of diagnostic variables useful for cloud verification. The information contained in this document applies to physics library 4.7 ans subsequent versions.

2. Definitions

Explicit clouds: clouds resulting from microphysical processes (e.g. condensation due to supersaturation); typically stratiform-type clouds for low resolution models or cirrus "detrained" from deep convection. These clouds are advected.
Implicit clouds: cumuliform clouds resulting from diagnostic calculations. These clouds are not advected, since they are considered to have a very short lifetime.

3. Production of Clouds by the Model Physics

The parameterizations of shallow convection, deep convection and the boundary layer as well as the explicit condensation parameterization can (depending on the option chosen) produce tendencies (RATES OF CHANGE) of explicit (i.e. advected) clouds or implicit (sub-grid scale) clouds. Table 1 below shows which scheme produces which type of cloud along with the output variable names used to examine the condensate or the cloud fraction.

Fundamentally the only way to determine what clouds have been produced by the model is to examine these variables.

Scheme	Explicit Clouds		Implicit Clouds	
	Condensate	Cloud fraction	Condensate	Cloud fraction
Stratiform (Sundqvist, Milbrandt-Yau)	d(qcplus);ON=CQ and others for KY and MY	f(fxp); ON=NS F(fxp)=1 for MY and KYf		
Deep convection (Kain-Fritsch)	f(qtde);ON=qtde		f(qsdi);ON=qsdi f(qldi);ON=qldi	f(fdc);ON=CK
Shallow convection (ktrsnt)			f(qssc);ON=qssc f(qlsc);ON=qlsc	f(fsc);ON=fsc
Boundary layer (Moist TKE)			f(qtbl);ON=qtbl	f(fbl);ON=NC

Table 1: Variable names for each scheme

4. Preparation of Clouds for the Radiative Transfer

Since the cloud fraction as well as the implicit clouds are not advected, the radiative transfer (the first physical parameterization to act at each timestep) uses the complete set of variables from the preceding timestep (tmoins).
The radiative transfer scheme needs values of total cloud fraction, total liquid condensate and total solid condensate. These fields are prepared in two steps.

1. Preparation of the "total cloud"
At the end of *phy_exe.ftn*, the subroutine *prep_cw.ftn* (prepare cloud water) is called. Its function is to amalgamate the implicit and explicit clouds to produce a total condensate (grid scale) as well as a total cloud fraction. The total condensate is then the sum of all the explicit and implicit contributions.

When the Sundqvist scheme is used (consun1), the total condensate appears in the variable f(LWC) and the liquid-solid partition is done only in the second step described below. In this case, the field f(IWC) must be equal to zero.

When schemes of the type MixPhase, KY or MY are used, the liquid condensate as well as the total solid condensate are calculated in this first step.

The total cloud fraction is calculated under the hypothesis of random overlap, i.e. f(ftot) = 1 – (1-fxp)*(1-fsc)*(1-fdc). This variable takes values between 0 and 1. As a result, **f(ftot), f(LWC) and f(IWC)** are the variables representative of the "total cloud". One must remember, however, that the values of f(LWC) and f(IWC) vary depending on which microphysical scheme is used.

2. Preparation for the radiative transfer

At the beginning of *phy_exe.ftn*, the subroutine *prep_cw_rad2.ftn* (prepare cloud water for radiation) is called. Its role is to: i) impose minimum values of cloud fraction and condensate and guarantee coherence between the two variables; if one of them is zero, the other is also set equal to zero; ii) impose a maximum value of total condensate; and iii) if necessary, partition the total condensate into liquid and solid.

Operation i) does not depend on the radiative or microphysical scheme used. Operation iii) is not necessary when the microphysical scheme used is MixPhase, Kong-Yau or Milbrandt-Yau. For the other microphysical schemes such as consun1 the partition is done with the formula of Rockel et al. (1991) (frac = .0059+.9941*exp[-0.003102*Temp^2]) if the **newrad** radiative transfer scheme is used, or with the formular of Boudala et al. (2004) (frac = twc^(0.141)*exp(0.037*(tcel)) if the **cccmarad** scheme is used. Figure 1 shows the mean global profiles of LWC and IWC (black curve for the Rockel partition, red for the Boudala partition). The Boudala partition results in a higher ice fraction. It is important to note that the choice of partition formula affects the total optical thickness of the clouds since the two phases of water have different optical properties.

Operation ii) is done only for the **newrad** scheme and only for microphysical schemes like Sundqvist and other simpler schemes (istcond .le. 4). *In the new radiative transfer scheme, this operation is not done*. Therefore, this scheme sees more condensate which results in a greater optical thickness or emissivity of the clouds. This has resulted in improvements in the tropospheric temperature bias, particularly in the tropics.

The maximum of total condensate is calculated in the subroutine liqwc which is called by *prep_cw_rad2.ftn*. It is approximately equal to 25% of the adiabatic value obtained if a saturated parcel rises from the surface. Figure 2 presents mean global profiles of LWC and IWC if the maximum is imposed (black curve) and if it is not (red curve). The effect of the maximum is roughly to divide the condensate by 2. This means that the clouds produced by the set of cloud production parameterizations and the clouds seen by the radiative transfer **can be very different when the newrad scheme is used**. With cccmarad, the differences are much smaller. Furthermore, as already mentioned, the change in parameterization for the partition of total condensate between liquid and solid will also affect the clouds' optical thickness and therefore their emissivity.

5. The Diagnostic Variable NT

NT is defined in the dictionary as "total cloud cover". With respect to radiative transfer, the can mean two things: **real** total cloud cover or **effective** total cloud cover. Our NT is an **effective** total cloud cover ("effective" in the sense that ftot, the cloud fraction, is weighted by [1-τ], where τ is the cloud transmittance in the atmospheric IR window around 10μm. In the presence of a cloud (with a cloud fraction of 100%) that is optically thin at a given level, the *real* total cloud cover would be equal to 1 while the *effective* cloud cover would be less than 1. This difference is clearly seen in comparing Figures 3 and 4, which show respectively the real and effective cloud cover, for the same cloud field.

It is important to note that to calculate either the real or the effective NT, one must make an assumption about the arrangement of clouds in the vertical. The "overlap" hypothesis called "maximum-random" is used. In it, the overlap is a maximum when the cloud layers are connected and random when they are separated by clear sky.

The diagnostic variable NT has several uses:
1. as a clear/cloudy sky mask;
2. to see where the model has produced clouds;
3. to forecasts cloudiness (e.g. in the web page "Sky conditions for astronomy";
4. as a UMOS predictor for cloud cover;
5. as a UMOS predictor for surface temperature;
6. as a UMOS predictor for PoPs;
7. as a field to compare with 10.7µ satellite imagery; and
8. to verify model clouds against various observation types, from human observations to various satellite products.

The variable NT as currently calculated is perhaps not an optimal tool for each of these uses. Ideally one would understand clearly each use and then develop variables better adapted to each use. For example, for items 1, 2 and 8 (human observation) It would be better to use the true cloud cover.

6. Effective cloud cover following the implementation of cccmarad in GEM15 and in the Strato

In section 5 we saw that our NT is effective and so depends on the total optical thickness of the clouds as seen by the radiation scheme. In section 4 it was pointed out that we have changed the cloud pre-processing done before applying the radiation scheme (e.g. no maximum for the condensate, and liquid-solid partition). Furthermore, the cloud optical properties are different in the cccmarad package. As a result, even if the clouds produced by the models have not changed much, the effective cloud cover (NT) obtained through the newrad scheme can be significantly different from the NT obtained with cccmarad.

Figure 5 shows the NT obtained from the operational GEM-15 model (using newrad). This figure can be compared to Figure 4 which shows the effective cloud cover calculated by the new system (cccmarad). It is clear that the effective cloud cover from cccmarad is larger in the Arctic.

Figure 6 shows the mean difference (over 40 winter cases) between the effective cloud cover of the operational GEM-15 (with GPS-RO) and the version of GEM-15 that was proposed in September 2008 (with cccmarad). There are significant differences (~15-20%) in the Arctic. In summer a similar signal at such a large scale is not observed.

7. New cloud cover variables with the physics package 4.7

Given that over the years several applications have been developed that use the variable NT as a "substitute" for the cloud cover, efforts have been made to create a variable that resembles as closely as possible the NT that was obtained through the newrad scheme. To this end, the "recipe" used in newrad (cloud filtering, liquid-solid partition, optical properties) was imported and used to calculate in ccmarad an NT comparable to the old NT.

We also created a set of variables that are coherent with the cloud coverage as seen by cccmarad. These new variables are:

ecc : effective cloud cover (cccmarad)
eccl: effective low cloud cover (cccmarad) [surface to sigma=0.7]
eccm: effective mid cloud clover (cccmarad) [sigma=0.7 to sigma=0.4]
ecch : effective high cloud cover (cccmarad) [above sigma=0.4]
tcc: true cloud cover

The variable tcc is not a function of the optical thickness of the clouds. It represents more directly the cloud fraction produced by the model.

NB These new variables as well as the old NT exist only starting from version 4.7 of the physics library.

7. Conclusion

One must realize that the effective cloud cover (NT or ecc) is not a cloud fraction. This must be taken into account when comparisons of this variable are made with human observations or satellite imagery. As mentioned above, NT as currently calculated is perhaps not the optimum variable for each of the uses to which it is put; each use might be better served with an improved variable designed for it. Furthermore a more systematic verification of clouds from station observations as well as from satellite-related tools (e.g "simulator") would be useful.