A History of Modifications to SUBROUTINE CONVECT

by
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The following represents modifications to the convection scheme as it was originally described in Emanuel, K.A., 1991, *J. Atmos. Sci.*, **48**, 2313-2335.

MODIFICATIONS INCORPORATED IN VERSION 1.1

1. The fractional areas, SIG(I), are now calculated in a completely different way. They are adjusted in such a way that the minimum buoyancy in the cloud layer below level I is kept nearly constant. The fractional areas are adjusted downward whenever the minimum buoyancy below level I is less than a critical, positive value, and upward when the minimum buoyancy exceeds this value (DTCRIT). The mass fluxes in entrained air updrafts are also corrected accordingly. In some sense, SIG(I) may be thought of as the frequency of updraft penetration to level I within a time step and over a grid box. Also, a term whose magnitude is governed by BETA acts to relax SIG(I) slowly back to its mean value over I.

2. The variable W0(I) is now a smoothed value of the vertical velocity of an undiluted updraft to level I.

3. The calculation of the precipitation-driven downdraft specific humidity, RP(I), is now being done using upwind differencing, and the advection of RP(I) and buoyancy, B(I), is now also done by upwind differences. As a result, the scheme no longer applies a smoother to RP(I).

4. It was discovered that a floating point divide error occurred once in a blue moon in subroutine TLIFT when two terms exactly cancel. This has been fixed to give the correct answer in this event.

The effect of these changes, particularly the first two, is to give a somewhat smoother time evolution of convective forcing, and to slightly favor shallow convection compared to Version 1.0. This results in a slightly moister lower troposphere under many conditions. The problem whose fix is discussed in 4.) above gave a floating point divide error once after about 10**6 time steps.

MODIFICATIONS INCORPORATED IN VERSION 1.21

The main point of the modifications made here has been to further clean up the energy conservation of the scheme. All of the thermodynamics, including those of the dry adiabatic adjustment, have been rephrased so that liquid water static energy, rather than liquid water potential temperature, is conserved in the adjustment. This accounts for the heat generated when kinetic energy is dissipated. Also, the heat generated when rain falls at terminal velocity has been included in this version...this does make a small but noticeable difference in the energy balance. Also, the partitioning of the undiluted updraft mass fluxes into the various mixed air drafts has been altered slightly to be more consistent with the description provided in Emanuel, *J. Atmos. Sci.*, 1991. The average user will not notice much difference between this version and the previous version 1.1.

MODIFICATIONS INCORPORATED IN VERSION 1.23

The nature of the computation of sigma has been slightly altered to give smoother evolution of the mass fluxes. The parameter BETA damps the evolution of sigma; the magnitude of the damping is proportional to 1 - BETA. Various small alterations have been made to improve the matching between the convective fluxes and boundary layer processes. In particular, the formulation of CONVECT provides little or no justification for producing variations with height of the forcing of static energy or water content BELOW CLOUD BASE. Thus the tendencies of these two quantities are now homogenized below cloud base. Also, the dry adiabatic adjustment should now not be bypassed even if the calling model has a boundary layer scheme; the user can, however, prevent CONVECT from returning altered values of T and R by setting NOPT to 0 near the beginning of the subroutine. The unsaturated downdraft mass flux, MP, is now forced to decrease linearly to zero between cloud base and the surface. This prevents noise resulting from large values of MP near the surface and produces smoother tendencies below cloud base. Also, a small amount of inertia is added to MP to prevent rapid changes in this quantity when the static stability changes abruptly. Finally, detrainment near cloud top is now interpolated so as to represent detrainment exactly at the level of neutral buoyancy, rather than at the first level above the LNB as in previous versions. This prevents unrealistic cooling due to overshooting. The average user should find little difference between this and the previous version of the scheme.

MODIFICATIONS INCORPORATED IN VERSION 1.25

The unsaturated downdraft calculation has been simplified by eliminating the nonhydrostatic calculation and simply placing a lower bound on the dry static stability used in the hydrostatic computation. This is done purely for numerical simplicity. A small error was discovered in the way the detrainment level is moved as described in Version 1.23 above, and likewise, in the homogenization of the subcloud layer forcing...these errors resulted in slight nonconservation of water. These have been fixed. A few very minor changes have been made in order to further reduce high frequency fluctuations. Finally, the subroutine TLIFT has been replaced by a more accurate scheme, with a very small price in computational speed.

MODIFICATIONS INCORPORATED IN VERSION 1.26

Two modest changes and one minor change have been made to Version 1.15, as well has a few "housekeeping" changes that do not affect the results but clean up the code a bit. Perhaps the most important change is in the dry convective adjustment that is performed prior to the moist convection. In all earlier versions of CONVECT, dry adiabatic adjustment was performed over all contiguous levels whose potential temperature is less than that of the reference level. (The scheme iterates through all reference levels, from the top down.) This was a "liberal" adjustment, in that it tended to adjust through too great a depth, resulting in boundary layers that were too deep and had jumps of potential temperature across their tops that could be large. This was noticeable at very high vertical resolutions. In this version, the adjustment is performed on all contiguous grid points whose potential temperature is lower than the pressure-weighted mean potential temperature of the reference level and the points in question. This results in boundary layers with minimal jumps of potential temperature across their tops. The main effect of this change is to reduce the sometimes large differences between results at high and at low vertical resolutions. Starting with this version, the saturation specific humidity is altered during dry adiabatic adjustment; the altered value is not passed back to the calling program unless the user asks it (and temperature and specific humidity) to be. The lack of adjustment of saturation specific humidity in previous versions was an oversight; but the effects of this change are negligible since it is only a diagnostic quantity with limited significance in the boundary layer. The adjustment of the fractional areas of undiluted updrafts has been changed to reflect the faster response of shallower clouds to changing large-scale conditions. Specifically, the adjustment time scale, rather than being constant with height, is now the time scale of an undiluted parcel to ascend to a given altitude. The effect of this change is to slightly enhance shallow cloud activity and produce a slightly moister lower troposphere under most circumstances in which deep and shallow convection co-exist. Finally, the re-normalization of the entrained air mass fluxes has been slightly refined and cleaned up. This has very minimal influence on the output of the scheme.

MODIFICATIONS INCORPORATED IN VERSION 2.00

The major change here is the check for moist convection originating from levels above the surface. In this version, CONVECT searches upward from the surface for air that is unstable to upward displacement. It allows convection only from the FIRST level that it encounters unstable air, except that it skips to the top of mixed layers. Thus, CONVECT can now represent moist convection originating from air above the boundary layer, but only when the boundary layer is not also unstable. This should handle most cases of elevated convection, such as occur in frontal zones.

The new parameter PPMIN is the minimum pressure below which CONVECT does not check for convective origin levels. Thus if PPMIN=600, convection is assumed to originate somewhere in the layer between the surface and 600 mb.

The other change is to allow for the specification of the gravitational acceleration, G. Formerly, it was set at 10.0 m/s**2.

MODIFICATIONS INCORPORATED IN VERSION 2.01

1. If the specific humidity exceeds its saturation value, it is set to the saturation value within the routine; this adjustment is not passed back to the calling program.

2. The maximum value SIG(I) is allowed to have has been increased to 0.2.

3. The downdraft mass flux decreases linearly between the actual surface and a pressure level equal to 0.949 times the surface pressure. (Before, the mass flux was decreasing linearly between 1000 mb and 949 mb; this caused problems where the surface pressure was somewhat less than 1000 mb.)

MODIFICATIONS INCORPORATED IN VERSION 2.02

1. The user no longer has the option of preventing CONVECT from passing back arrays of temperature and mixing ratio altered by dry adiabatic adjustment, as this may produce inconsistencies.

2. The default value of ALPHA is changed from 1.0 to 0.1; this was found to produce smoother integrations at low temperatures.

3. If the dry adiabatic adjustment produces supersaturation, the excess water is condensed out and added to the convective precipitation, and the latent heat is added to the relevant layer(s). This replaces modification (1) in Version 2.01.

4. Convection is assumed to originate at the lowest level for which a lifted parcel is unstable. (Formerly, convection could not originate at the base of adiabatic layers.)

5. The lifted condensation level may now occur within dry adiabatic layers.

6. Very rarely, the parcel temperature within subroutine TLIFT falls close to -243.5 C, causing the calculation of ES to blow up. A protection has now been added to prevent this. (It happened, apparently, when parcels were lifted to extremely low pressure.)

7. It was discovered that the variable CLW is undefined below the parcel origin level, when the latter occurs at I>1, but it is called in do loop 400. Many compilers won't notice, because these undefined values get multiplied by zero, but some complain. The problem has been fixed by defining CLW at all levels in subroutine TLIFT.

MODIFICATIONS INCORPORATED IN VERSION 2.03

The method of relaxing the cloud mass fluxes toward their statistical equilibrium values has been modified somewhat in order to achieve a smoother evolution of convection. The values of ALPHA and BETA have been modified accordingly.

THE WORK ARRAY W0 HAS BEEN DROPPED AND SHOULD NO LONGER BE INCLUDED IN THE CALL TO CONVECT.

MODIFICATIONS INCORPORATED IN VERSION 3.00

This version contains extensive revisions to earlier versions of the convection scheme. In addition to some important changes in the code, as described below, **the parameters of the scheme have been extensively optimized using data from TOGA-COARE,** as described in detail in Emanuel and Zivkovic-Rothman (*J. Atmos. Sci*., 1999).

The code changes are as follows:

1. A surface layer has been added to the dry adiabatic adjustment part of the routine. This as elevated temperature and specific humidity in comparison to the interior mixed layer.

2. The precipitation efficiencies are now modeled after a Kessler-type scheme with a temperature-dependent autoconversion threshold.

3. The storage array SIG has been replaced by a scalar, the cloud base mass flux (CBMF). CBMF is regulated by a measure of the negative area between the lifted condensation level and the level of free convection in the sounding.

4. The rate of mixing M(I) of undiluted air from cloud base with its environment is now determined through a buoyancy-based formulation, so that the rate of change of mass flux with height is strongly related to parcel buoyancy. This is completely different from the previous formulation, in which the variation was determined through the adjustment of SIG(I) based on a global quasi-equilibrium hypothesis. In the process of optimizing the scheme using TOGA-COARE data, this was found to produce better results than the previous formulation.

5. The effect of the ice phase has been modeled here by specifying temperature-dependent fall speeds and coefficients of evaporation of precipitation. Although the latent heat of fusion is not included, the temperature-dependence of the latent heat of vaporization has been carried down to temperatures below freezing, crudely mimicking the effect of latent heat of fusion. The temperature dependence of the fall speed has a particularly large effect on the humidity adjustment by the scheme.

6. The scheme now yields, through its call statement, magnitudes of temperature, moisture and velocity perturbations characterizing the unsaturated downdraft near the surface, for use in coupling convective fluxes to surface fluxes, as described in Emanuel and Zivkovic-Rothman (1999).

MODIFICATIONS INCORPORATED IN VERSION 3.10

1. The mixing formulation has been modified to add the effect of a constant fractional mixing rate to the existing buoyancy-dependent mixing.

2. There has been some minor re-tuning of a few parameters based on corrections to the TOGA-COARE data set owing to problems with the humidity measurements produced by the rawindsondes.

MODIFICATIONS INCORPORATED IN VERSION 3.20

1. The fractional area covered by surface outflow, SIGMD, has been dropped from the formulation of the downdraft fluctuations for use in coupling to surface fluxes.

2. Further re-tuning of parameters based on new refinements of the TOGA-COARE data.

3. The possibility of convective penetration of thin stable layers has been accounted for.

4. An error in the definition of the downdraft velocity scale, WD, has been fixed.

5. Interpolation of cloud top to the actual level of neutral buoyancy has been dropped.

6. The saturation value over ice is used where appropriate in TLIFT.

MODIFICATIONS INCORPORATED IN VERSION 4.1

1. The counter, NCOUNT, is no longer used. Instead, when the convective mass flux relaxes to zero, the routine is skipped.

2. The fall speed of snow is now assumed to be a constant pressure velocity rather than a constant actual velocity.

3. Slight refinements of parameters based on refinements of TOGA-COARE IFA data.

4. Correction of small errors in surface layer scheme

5. Requirement that ambient air between parcel origin level and cloud base have dry adiabatic lapse rate has been dropped.

6. EP(I) and SIGP(I) now defined between bottom level and parcel origin level. This may have caused problems with certain compilers before.

7. Refinements to definition of negative area in sounding, used in adjustment of CBMF.

8. Small but inconsistent term dropped from temperature adjustment by unsaturated downdraft.

9. Re-insertion of interpolation of tendencies near INB.

10. Dropped homogenization of tendencies below cloud base.

11. Small constant correction to temperature tendencies to guarantee enthalpy conservation.

MODIFICATIONS INCORPORATED IN VERSION 4.2

1. Convection origin level now the level whose lifted parcel is *most* unstable, rather than the *first* level with unstable air.

2. Upper limit on level from which air may convect has been removed.

3. Redefined INB as level where CAPE=0 rather than level of neutral buoyancy. This permits overshooting, which is deemed crucial for the accurate representation of trade cumuli. Mixing formulation altered between level of neutral buoyancy and INB.

4. Artificial limitation on magnitude of mass fluxes, so as not to violate CFL, eliminated.

5. Slight refinement of a few parameters based on TOGA-COARE data.

6. Dry adiabatic adjustment produces constant virtual potential temperature, rather than constant potential temperature.

MODIFICATIONS INCORPORATED IN VERSION 4.3

1. Opportunity to bypass dry adiabatic adjustment included. This was found to be important to do for models that have boundary layer schemes.

2. Opportunity to define minimum level from which convection may originate included. This is important in models with extremely fine resolution in boundary layer…minimum level from which convection may originate should be defined well within mixed layer (as opposed to surface layer).

3. Tendencies of momentum and passive tracers included with this version of the scheme. The passive tracers are convected assuming no real sources and sinks; momentum fluxes are calculated according to the method of Gregory and . This is equivalent to multiplying by a constant coefficient the tendencies calculated assuming no momentum sources in convective drafts.

4. Certain coding modifications were made only to insure that no indeterminates show up in compilation.

5. A lower limit was placed on lifted parcel temperatures to prevent blowing up in certain cases with very low surface temperatures.

MODIFICATION INCORPORATED IN VERSION 4.3a

1. A bug was fixed in the calculation of the level INB of vanishing CAPE.

MODIFCATIONS INCORPORATED IN VERSION 4.3b

1. A fix was made to handle the rare circumstance that the level of minimum moist static energy lies below MINORIG. Thanks to William Ingram for suggesting this.

2. In previous versions of 4.3, convection was not permitted if the level of minimum moist static energy lies at or above 400 mb. This was preventing moist convection over Tibet in some cases and was thus removed. Thanks to William Ingram for pointing this out.

3. The maximum precipitation efficiency was lowered from 1.0 to 0.999 to better handle the interface with high cloud parameterizations, following the suggestion of Sandrine Bony.

4. The effective value of the coefficient DAMP is now scaled by the time step, following the suggestion of Sandrine Bony.

5. A bug was found in the calculation of the mixing fractions. *This has an important effect on the simulation of shallow convective clouds*. Thanks to Olivier Pauluis for finding and correcting this.

MODIFCATIONS INCORPORATED IN VERSION 4.3c

The calculation of the entrainment rate was modified according to a suggestion by Dr. Melinda Peng of the Navy Research Laboratory. Specifically, the entrainment is now proportional to the undilute buoyancy itself, rather than to the vertical gradient of undilute buoyancy.

For the purposes of calculating the density temperature of undilute lifted parcels, the adiabatic water loading is retained over the whole displacement. This reduces the warm bias noted in the upper troposphere in tests using the TOGA COARE IFA data.

The value of the heat capacity of liquid water was reduced from its true value of 4190 J/Kg/K to an artificially low value of 2500 J/Kg/K. This is found to further reduce the warm bias noted in the preceding paragraph.