ALARO Generic equations and their concrete code translations

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Sadržaj

1 Introduction

2 Model equations

2.1 Momentum equation - wind components (u and v)

The conservation of motion gives the change of wind vector as a result of Coriolis force, pressure gradient and parameterized processes as turbulent and convective transport as well as grawity wave drag.

$$\frac{d\vec{V}}{dt} = -f\vec{k} \times \vec{V} - \vec{\nabla}\phi - RT\vec{\nabla}\ln p - g\frac{\partial}{\partial p}\left(J_{\vec{V}}^{turb} + J_{\vec{V}}^{qwd} + J_{\vec{V}}^{cnv}\right) \tag{1}$$

where

ϕ is the geopotentiel,

$J_{\vec{V}}^{turb}$ momentum flux due to turbulent vertical diffusion,

$J_{\vec{V}}^{qwd}$ momentum flux due to gravity wave drag and

$J_{\vec{V}}^{cnv}$ momentum flux due to deep convective transport.

2.2 Temperature (T)

The atmosphere is considered as an ideal gas in local thermodynamic equilibrium. The conservation of heat gives change of temperature due to vertical motion and many parameterized processes.

$$\frac{dT}{dt} = \frac{RT}{c_p}\frac{\omega}{p} + \left(\frac{\partial T}{\partial t}\right)_{phy} \tag{2}$$

where $\left(\frac{\partial T}{\partial t}\right)_{phy}$ represents contribution to temperature evolution due to physical parameterizations. But physical parameterizations give fluxes of dry static energy or enthalpy.

$$h = c_pT + \phi + \frac{u^2 + v^2}{2} + \mathrm{TKE}$$

where $c_p = c_{pd} + (c_{pv} - c_{pd})q_v + (c_l - c_{pd})(q_l + q_r) + (c_i - c_{pd})(q_i + q_s)$,

c_p is the specific heat of moist air,

c_{pd} the dry air specific heat,

c_{pv} the water vapour specific heat,

c_l the liquid water specific heat,

c_i the solid water specific heat,

$E_k = \frac{u^2+v^2}{2}$ the kinetic energy,

TKE the turbulent kinetic energy,

q_x the mass ratios of the various species.

the temperature tendency due to parameterized processes $\left(\frac{\partial T}{\partial t}\right)_{phy}$ is computed through

$$\left(\frac{\partial h}{\partial t}\right)_{phy} = -g\frac{\partial}{\partial p}\Big({J_h}^{sol} + {J_h}^{ther} + {J_h}^{turb} + {J_h}^{cnv} + (c_l - c_{pd})P_lT + (c_i - c_{pd})P_iT$$

$$+\delta_m(\hat{c} - c_{pd})(P_l + P_i)T - L_v({J_{q_v}}^{ccl} + {J_{q_v}}^{scl} - {J_{q_v}}^{pel}) - L_s({J_{q_v}}^{cci} + {J_{q_v}}^{scn} - {J_{q_v}}^{pen})\Big) \quad (3)$$

where

${J_h}^{sol}$ is enthalpy flux due to shortwave radiation,

${J_h}^{ther}$ is enthalpy flux due to longwave radiation,

${J_h}^{turb}$ is dry static energy flux due to turbulent diffusion,

${J_h}^{cnv}$ is dry static energy flux due to convective transport,

$(c_l - c_{pd})P_lT$ is dry static energy flux due to liquid precipitation flux,

$(c_i - c_{pd})P_iT$ is dry static energy flux due to solid precipitation flux,

$(\hat{c} - c_{pd})(P_l + P_i)T$ is compensating dry static energy flux of non-precipitating species,

$L_v{J_{q_v}}^{ccl}$ is dry static energy flux due to convective condensation of liquid water,

$L_v{J_{q_v}}^{scl}$ is dry static energy flux due to stratiform condensation of liquid water,

$L_v{J_{q_v}}^{pel}$ is dry static energy flux due to evaporation of liquid precipitation,

$L_s {J_{q_v}}^{cci}$ is dry static energy flux due to convective condensation of cloud ice,

$L_s {J_{q_v}}^{scn}$ is dry static energy flux due to stratiform condensation of cloud ice,

$L_s {J_{q_v}}^{pen}$ is dry static energy flux due to evaporation of solid precipitation,

New value of temperature is computed using the new value of enthalpy:

$$T^{t+\Delta t} = \frac{h^{t+\Delta t} - E_k^{t+\Delta t} - \mathrm{TKE}^{t+\Delta t} - \phi}{c_p} \tag{4}$$

2.3 Specific humidity (q_v)

$$\frac{dq_v}{dt} = -g\frac{\partial}{\partial p}\Big({J_{q_v}}^{turb} + {J_{q_v}}^{cnv} + {J_{q_v}}^{ccl} + {J_{q_v}}^{cci} + {J_{q_v}}^{scl} + {J_{q_v}}^{scn} + {J_{q_v}}^{neg}$$

$$-{J_{q_v}}^{pel} - {J_{q_v}}^{pen} + \delta_m \frac{q_v(P_l + P_i)}{1 - q_r - q_s}\Big) \tag{5}$$

where

${J_{q_v}}^{turb}$ specific humidity flux due to turbulent vertical diffusion,

${J_{q_v}}^{cnv}$ specific humidity flux due to convective transport,

${J_{q_v}}^{ccl}$ specific humidity flux due to convective condensation of liquid water,

${J_{q_v}}^{cci}$ specific humidity flux due to convective condensation of cloud ice,

${J_{q_v}}^{scl}$ specific humidity flux due to stratiform condensation of liquid water,

${J_{q_v}}^{scn}$ specific humidity flux due to stratiform condensation of cloud ice,

${J_{q_v}}^{neg}$ specific humidity flux to correct for negative values,

${J_{q_v}}^{pel}$ specific humidity flux due to evaporation of liquid precipitation,

${J_{q_v}}^{pen}$ specific humidity flux due to evaporation of solid precipitation and

$\delta_m \frac{q_v(P_l+P_i)}{1-q_r-q_s}$ term if $\delta_m = 1$ accounts for the change of the mass of the atmosphere due to precipitation/evaporation budget.

2.4 Cloud liquid water (q_l)

$$\frac{dq_l}{dt} = -g\frac{\partial}{\partial p}\left(J_{q_l}{}^{turb} + J_{q_l}{}^{cnv} + J_{q_l}{}^{neg} + J_{q_l}{}^{asl} - J_{q_v}{}^{scl} - J_{q_v}{}^{ccl} + \delta_m\frac{q_l(P_l + P_i)}{1 - q_r - q_s}\right) \tag{6}$$

where

$J_{q_l}{}^{turb}$ cloud liquid water flux due to turbulent vertical diffusion,

$J_{q_l}{}^{cnv}$ cloud liquid water flux due to convective transport,

$J_{q_l}{}^{neg}$ cloud liquid water flux to correct for negative values,

$J_{q_l}{}^{asl}$ cloud liquid water flux due to autoconversion to rain,

$J_{q_v}{}^{scl}$ specific humidity flux due to stratiform condensation of liquid water,

$J_{q_v}{}^{ccl}$ specific humidity flux due to convective condensation of liquid water,

$\delta_m \frac{q_l(P_l+P_i)}{1-q_r-q_s}$ term if $\delta_m = 1$ accounts for the change of the mass of the atmosphere due to precipitation/evaporation budget.

2.5 Cloud ice (q_i)

$$\frac{dq_i}{dt} = -g\frac{\partial}{\partial p}\left(J_{q_i}{}^{turb} + J_{q_i}{}^{cnv} + J_{q_i}{}^{neg} + J_{q_i}{}^{asn} - J_{q_v}{}^{scn} - J_{q_v}{}^{ccn} + \delta_m\frac{q_i(P_l + P_i)}{1 - q_r - q_s}\right) \tag{7}$$

where

$J_{q_i}{}^{turb}$ cloud ice flux due to turbulent vertical diffusion,

$J_{q_i}{}^{cnv}$ cloud ice flux due to convective transport,

$J_{q_i}{}^{neg}$ cloud ice flux to correct for negative values,

$J_{q_i}{}^{asn}$ cloud ice flux due to autoconversion to snow,

$J_{q_v}{}^{scl}$ specific humidity flux due to stratiform condensation of cloud ice,

$J_{q_v}{}^{ccl}$ specific humidity flux due to convective condensation of cloud ice,

$\delta_m \frac{q_i(P_l+P_i)}{1-q_r-q_s}$ term if $\delta_m = 1$ accounts for the change of the mass of the atmosphere due to precipitation/evaporation budget.

2.6 Rain (q_r)

$$\frac{dq_r}{dt} = -g\frac{\partial}{\partial p}\left(J_{q_v}{}^{pel} + J_{q_r}{}^{neg} + P_l - J_{q_l}{}^{asl}\right) \quad (8)$$

where

$J_{q_v}{}^{pel}$ specific humidity flux due to evaporation of liquid precipitation,

$J_{q_r}{}^{neg}$ rain flux to correct for negative values,

P_l rain flux due to convective and stratiform liquid precipitation fluxes and

$J_{q_l}{}^{asl}$ cloud liquid water flux due to autoconversion to rain.

2.7 Snow (q_s)

$$\frac{dq_s}{dt} = -g\frac{\partial}{\partial p}(J_{q_v}{}^{pen} + J_{q_s}{}^{neg} + P_i - J_{q_i}{}^{asn}) \quad (9)$$

where

$J_{q_v}{}^{pen}$ specific humidity flux due to evaporation of solid precipitation,

$J_{q_s}{}^{neg}$ snow flux to correct for negative values,

P_i snow flux due to convective and stratiform solid precipitation fluxes and

$J_{q_i}{}^{asn}$ cloud ice flux due to autoconversion to snow.

3 Fluxes

3.1 Convective fluxes

Fluxes of model variables due to deep convection are PDIFCQ ($J_{q_v}{}^{cnv}$), PDIFCQI ($J_{q_i}{}^{cnv}$), PDIFCQL ($J_{q_l}{}^{cnv}$), PDIFCS ($J_s{}^{cnv}$), PSTRCU ($J_u{}^{cnv}$) and PSTRCV ($J_v{}^{cnv}$).

When prognostic convection (3MT) is activated, these fluxes are computed by prognostic updraft computations in ACCVUD, updated by convective diffusion and downdraft contribution after ACMODO. Otherwise, these fluxes computed in ACCVIMP.

3.2 Turbulent diffusion fluxes

Fluxes of model variables due to turbulent vertical diffusion are PDIFTQ (${J_{q_v}}^{turb}$), PDIFTQI (${J_{q_i}}^{turb}$), PDIFTQL (${J_{q_l}}^{turb}$), PDIFTS (${J_s}^{turb}$), PFPTKE (J_{TKE}^{turb}), PSTRTU (${J_u}^{turb}$) and PSTRTV (${J_v}^{turb}$).

They are computed in ACDIFUS, and used afterwards to update temporary local values of model variables as well as to compute moisture convergence PCVGQ.

3.3 Condensation, evaporation and autoconversion fluxes

Fluxes of model variables due to condensation, evaporation and autoconversion are PFCCQL (${J_{q_v}}^{ccl}$), PFCCQN (${J_{q_v}}^{ccn}$), PFCSQL (${J_{q_v}}^{scl}$), PFCSQN (${J_{q_v}}^{scn}$), PFESL (${J_{q_v}}^{pel}$), PFESN (${J_{q_v}}^{pen}$), PFASL (${J_{q_v}}^{asl}$), PFASN (${J_{q_v}}^{asn}$), PFPLCL (P_l^{cnv}), PFPLCN (P_i^{cnv}), PFPLSL (P_l^{str}) and PFPLSN (P_i^{str}).

When prognostic convection (LCVPRO), prognostic downdraft (LCDDPRO) and 3MT (L3MT) are activated, convective condensation fluxes, PFCCQL (${J_{q_v}}^{ccl}$) and PFCCQN (${J_{q_v}}^{ccn}$), and convective precipitation fluxes PFPLCL (P_l^{cnv}) and PFPLCN (P_i^{cnv}), are computed by prognostic updraft computations in ACCVUD, used to update temporary local values of model variables. Otherwise, these fluxes computed in ACCVIMP.

When prognostic stratiform precipitation scheme (LSTRAPRO) or 3MT (L3MT) is activated, stratiform condensation fluxes, PFCSQL (${J_{q_v}}^{scl}$), PF-CSQN (${J_{q_v}}^{scn}$), and stratiform precipitation fluxes, PFPLSL (P_l^{str}) and PF-PLSN (P_i^{str}), are computed by prognostic resolved precipitation computations in ACCDEV, completed by APLMPHYS for prognostic convection (L3MT) and used to update temporary local values of model variables. Otherwise, these fluxes computed in ACPLUIE.

Evaporation and autoconversion fluxes are

- liquid precipitation generation term computed in ACCDEV completed by APLMPHYS for prognostic convection from cloud liquid water if prognostic condensates are activated, from water vapour otherwise in ACPLIUE subroutine (in APLPAR and MF_PHYS subroutines it is PFPFPL, in CPTEND_NEW subroutine it is PFASL and represents ${J_{q_v}}^{asl}$),

- solid precipitation generation term computed in ACCDEV completed by APLMPHYS for prognostic convection from cloud ice if prognostic condensates are activated, from water vapour otherwise in ACPLIUE subroutine (in APLPAR and MF_PHYS subroutines it is PFPFPN, in CPTEND_NEW subroutine it is PFASN and represents ${J_{q_v}}^{asn}$),

- evaporation of precipitation terms for liquid (PFPEVPL in APLPAR and MF_PHYS subroutines, PFESL (${J_{q_v}}^{pel}$) in CPTEND_NEW) and solid (PFPEVPN in APLPAR and MF_PHYS subroutines, PFESN (${J_{q_v}}^{pen}$) in CPTEND_NEW) are computed in ACCDEV completed by APLMPHYS if prognostic condensates and prognostic convection are activated, otherwise it is a product of ACPLIUE.

3.4 Negative correction

It is necessary to correct possible occurences of negative values of moist species. These fluxes are computed for water vapour PFCQNG (${J_{q_v}}^{neg}$, PFCQVNG in aplpar), cloud liquid water PFCQLNG (${J_{q_r}}^{neg}$), cloud ice PFCQING (${J_{q_r}}^{neg}$), rain PFCQRNG (${J_{q_r}}^{neg}$) and snow PFCQSNG ${J_{q_s}}^{neg}$. They are computed only if prognostic condensates are used, of course, under switches LCONDWT, L3MT and LSTRAPRO in APLPAR subroutine: in the beginning, after turbulent vertical diffusion computations of ACDIFUS, after porgnostic updraft computations of ACCVUD and after prognostic downdraft of ACMODO.