Multiphasic equations for a NWP system

CNRM/GMME/Méso-NH

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Clouds in NWP models

SCOOP

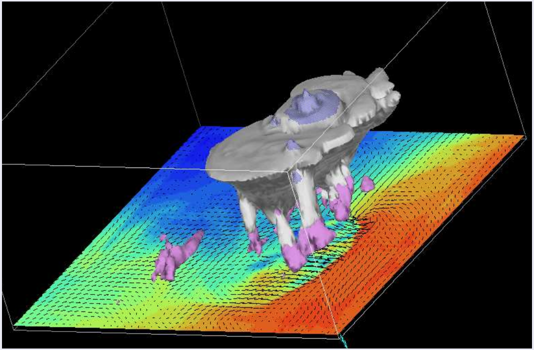
There was NO cloud in ALADIN !

Clouds in NWP models

SCOOP

There was NO cloud in ALADIN !

But now,
we compute
clouds with
AROME...



Please, don't kill me yet

I explain ...

Clouds in NWP models

Large scale physics

For « large scale » model, we usually suppose that a diagnostic representation of condensates is enough.

- We use diagnostic formulation from the mean water vapor content to diagnose cloud fraction for the radiation
- As the condensates (cloud and rain) are not pronostic, they are not directly known by the dynamics : no advection, no inertia, no weight of condensates

Cloud scale physics

In order to solve explicitly clouds formation and life cycle, we need a NH-dynamics, but also a finer resolution of microphysics processes.

- Explicit evolution equations for condensates (multiphasic system)
- Interaction between condensates and the dynamics

Large scale physics / cloud scale physics in practice

Water phase changes in a « large scale » physics

- cond/evap with the pseudo-adiabatic hypothesis (no consensed phase in the atmosphere, precipitations are known only through their consequences on T and q_v)
- equations for gaseous species only
- $$\frac{\partial \rho_v}{\partial t} = \frac{\partial P}{\partial z}$$

Water phase changes in a cloud scale physics

- parametrisation of detailled microphysical processes (but there may still be problem with unresolved clouds)
- equations for gases and condensates
- $$\frac{\partial \rho_v}{\partial t} = -\frac{\partial(\rho_c + \rho_r)}{\partial z} + \frac{\partial P}{\partial z}$$

our worry

To have a consistant set of equations with hypotheses and approximations « under control » and valid for pseudo-adiabatic or multiphasic, ($\delta m = 0$ or $\delta m = 1$), hydrostatic or non-hydrostatic **NWP** model.

Warnings

It is a « burning » subject with recent references only

Questions

Variables in a multiphasic atmospheric parcel

- Which ρ ?
- Which p and T ?
- Which wind ? What velocities should we manipulate ?
- Advection of what by what ?

How can we treat condensates ?

- As individuals wih their own evolution laws ?
- As continuous components of a mixture ?

Our current choices

A continuum of droplets and drops

$$\rho_c = \frac{m_c}{V_{gaz}} \quad \rho_r = \frac{m_r}{V_{gaz}}$$

$$\rho = \sum_k \rho_k$$

Local equilibrium hypothesis

$$T = T_c = T_r = T_{gaz}$$

$$\vec{v} = \vec{v}_c = \vec{v}_r = \vec{v}_{gaz}$$

Barycentric formulation

$$\rho w = \sum_k \rho_k w_k$$

State equation

An equation for perfect gaz only

$$p = p_a + e = \rho_a R_a T + \rho_v R_v T$$

or

$$p = \rho R_h T$$

with $R_h = q_a R_a + q_v Rv$ and $q_a = \rho_a/\rho$, $q_v = \rho_v/\rho$

Total mass conservation

Budget of mass in a geometric volum V

$$\frac{\partial m}{\partial t} = \frac{\partial \left(\int_V \rho dv \right)}{\partial t} = - \int_S \sum_k (\rho_k \vec{u}_k . \vec{n}) dS + \int_V \sum_k \dot{\rho}_k dv$$

No mass source

$$\sum_k \dot{\rho}_k = 0$$

Eulerian form of the multiphasic continuity equation

$$\frac{\partial \rho}{\partial t} = \mathrm{div}(\rho \vec{u})$$

An alternative : dry air conservation (Bannon, 2002)

Budget of dry air in a geometric volum V

$$\frac{\partial m_a}{\partial t} = \frac{\partial \left(\int_V \rho_a dv \right)}{\partial t} = -\int_S \rho_a \vec{u}_a . \vec{n} dS + \int_V \dot{\rho}_a dv$$

No dry air source

$$\dot{\rho}_a = 0$$

Eulerian form of the dry air continuity equation

$$\frac{\partial \rho_a}{\partial t} = \mathrm{div}(\rho_a \vec{u_a})$$

Budget equation for local variables

Budget for a geometric volume V

$$\frac{\partial \int_V \sum_k (\rho_k \psi_k)\, dv}{\partial t} = -\int_S \sum_k (\rho_k \psi_k \vec{u}_k . \vec{n})\, ds + \int_V \sum_k \dot{S}_k dv$$

Local form of the budget equation

$$\frac{\partial (\rho \psi)}{\partial t} = -\mathrm{div}[\sum_k (\rho_k \psi_k \vec{u}_k)] + \sum_k \dot{S}_k$$

Advection term

Barycentric advection

$$\rho \frac{\partial (\psi)}{\partial t} + \rho \vec{u}.\vec{\mathrm{grad}}(\psi) = \underbrace{-\frac{\partial [\sum_k (\rho_k \psi_k \tilde{w}_k)]}{\partial z}}_{(+)} + \sum_k \dot{S}_k$$

with $\psi = \sum_k q_k \psi_k$ and $\sum_k (\rho_k \tilde{w}_k) = 0$

Alternative : Dry air advection (Bannon, 2002)

$$\rho_a \frac{\partial (\psi)}{\partial t} + \rho_a \vec{u}_a.\vec{\mathrm{grad}}(\psi) = \underbrace{-\frac{\partial [\sum_k (\rho_k \psi_k \breve{w}_k)]}{\partial z}}_{(+)} + \sum_k \dot{S}_k$$

with $\psi = \sum_k r_k \psi_k$ but $\sum_k (\rho_k \breve{w}_k) \neq 0$

Terms (+) are usually not computed in current NWP models but a degenerated form , consistent with the pseudo-adiabatic and hydrostatic hypotheses of such a term exists in the thermodynamic equation of ARPEGE/ALADIN.

Turbulent / organised diffusive terms

Budget equation for mean variables

$$\frac{\partial(\overline{\rho}\widehat{\psi})}{\partial t} = -\mathrm{div}(\overline{\rho}\widehat{\psi}\widehat{\vec{u}}) - \mathrm{div}(\overline{\rho\psi''\vec{u}''}) - \frac{\partial[\sum_k \overline{\rho}\widehat{q}_k\widehat{\psi}_k\widehat{\tilde{w}}_k]}{\partial z} - \frac{\partial[\sum_k \widehat{q}_k\overline{\rho\psi_k''\tilde{w}_k''}]}{\partial z} - \frac{\partial[\sum_k \widehat{\psi}_k\overline{\rho q_k''\tilde{w}_k''}]}{\partial z} - \frac{\partial[\sum_k \widehat{\tilde{w}}_k\overline{\rho q_k''\psi_k''}]}{\partial z} - \frac{\partial[\sum_k \overline{\rho q_k''\psi_k''\tilde{w}_k''}]}{\partial z} + \sum_k \overline{\dot{S}_k}$$

Simplified form

$$\overline{\rho}\frac{\partial(\widehat{\psi})}{\partial t} + \underbrace{\overline{\rho}\widehat{\vec{u}}.\vec{\mathrm{grad}}(\widehat{\psi})}_{-\ advection} = -\underbrace{\mathrm{div}(\overline{\rho\psi''\vec{u}''})}_{turbulent} - \underbrace{\frac{\partial[\sum_k \overline{\rho}\widehat{q}_k\widehat{\psi}_k\widehat{\tilde{w}}_k]}{\partial z}}_{organised} + \sum_k \overline{\dot{S}}_k$$

Multiphasic equations for ALARO and AROME — hydro — non-hydro —

Hydro

Horizontal momentum

No formal change (but with total ρ)

Vertical momentum

No formal change (but with total ρ)

Thermodynamics

A $(+)$ term :

$$-\frac{\partial\left[\sum_k\left(\overline{\rho}{c_p}_k\widehat{q_k}\widehat{T}\widehat{\tilde{w}_k}\right)\right]}{\partial z}$$

Non-hydro

Horizontal momentum

No formal change

Vertical momentum

A $(+)$ term :

$$-\frac{\partial\left(\sum_k\overline{\rho}\widehat{q}_k\widehat{\tilde{w}}_k\widehat{\tilde{w}}_k\right)}{\partial z}$$

thermodynamics

A new form of energy : the Organised Diffusive Kinetic Energy

$$\rho\tilde{e}_c=\sum_k\left(\frac{\rho_k}{2}\tilde{w}_k^2\right)$$

Current status and perspectives

- A draft reference paper available (z-coordinate, multiphasic hydro/non-hydro or pseudo-adiabatic/hydro)
- Add the equations in mass-based coordinate for hydro/non-hydro, pseudo-adiabatic/multiphasic cases (P. Bénard)
- Check our approach with multiphasic system specialists (CERFACS, Toulouse University)
- Check the consistency of the code with the reference equations
- And correct the (main) inconsistencies, at least for impact evaluation