PHYSICS-DYNAMICS INTERFACE

Plan of the lecture

- Physics in the NWP model – the notion of parameterizations and concepts;
- Flux form formulation – property of conservation;
- Basic hypothesis and system of equations for moist physics;
- Example of the realization – thermodynamic basis for the ALARO microphysics;
- Link to the deep moist convection parameterization

What are parameterisations, how to define their ensemble? (1/3)

- Two ***open*** limits: with ***the resolved dynamics*** and with the ***yet too sophisticated processes*** => no single definition.
- Traps:
  - wrong perception of cause and consequence;
  - wrong perception of model-dependency;
  - lost search for super-conservative variables.
- Misleading definitions:
  - terms treated in a ‘statistical’ sense;
  - non-linear terms;
  - balance with dynamical tendencies (‘on demand’ parameterisation misleading dream).

What are parameterisations, how to define their ensemble? (2/3)

- Diabatism (non conservation of energy, angular momentum or moisture in the Lagrangian sense)
  - but which energy (example of latent heat)?
  - some purely adiabatic effects must be parametrised (e.g. impact of stagnant cold air on the upper flow).
- Irreversibility (no correct back-integration in time)
  - some phenomenon are reversible at one scale and irreversible at another one.
  - difficult partition (e.g. condensation vs. precipitation).
- Sub-grid scale choice
  - radiation and phase changes are basically grid-scale;
  - surface forcing is always sub-grid-scale.

What are parameterisations, how to define their ensemble? (3/3)

- A practical way out of all these vicious circles:
  - have a global look at the ***cycles***;
  - search conservation laws (Green-Ostrogradsky trick);
  - treat and discretise “unknown terms” on a case to case basis:
    - statistical approach for purely non-linear problems;
    - complex algorithmic for phase changes;
    - attention focused on feed-back loops;
    - numerical analysis for irreversibility, stiffness and non-linear instability;
    - avoid the problem of parameterisation (or modelling) inside the parameterisation.
- Ultimately, verify scale-independency as well as consistency (even after discretisation).
- A parameterization is intended to produce correctly the average impact of the process within each grid-box.

Processes treated in NWP models (most frequently parameterized ones)

- Turbulent fluxes (between the surface and the lowest model level and between two model levels);
- Orographic mountain drag/lift;
- Soil processes;
- Cloudiness;
- Stratiform (grid-box scale) precipitation;
- Convection (moist deep; i.e. with precipitation);
- Radiation

- Parameterization schemes generate tendencies, which impact the dynamical core variables (pressure, temperature, wind) and other prognostic variables (moisture species, TKE, …)

Interactions and feed-back loops

= quantities

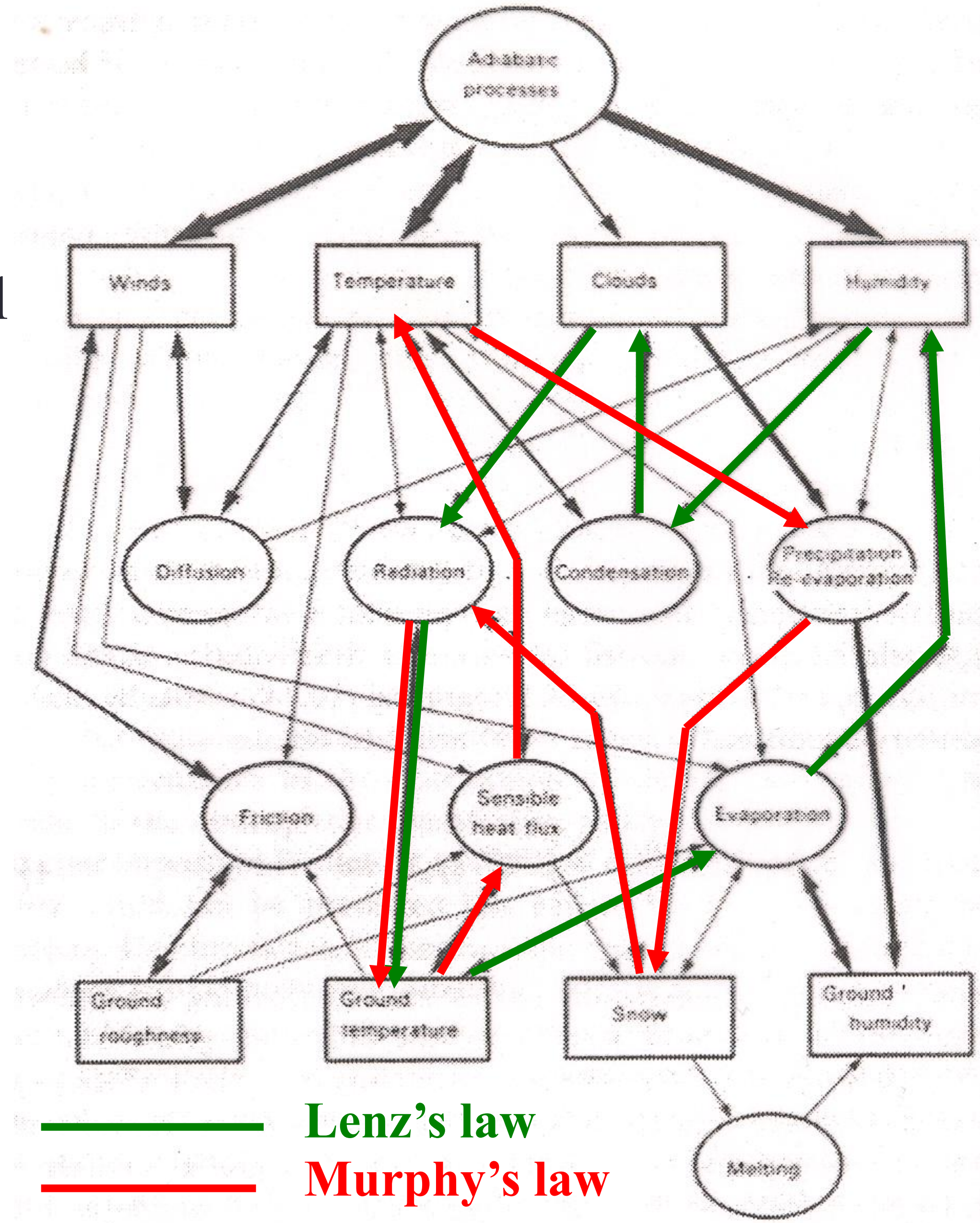
= processes

= impact or control

Every closed loop of arrows represent a feed-back process

Negative feed-back loop, the effect counteracts the cause

Positive feed-back loop, the effect amplifies the cause



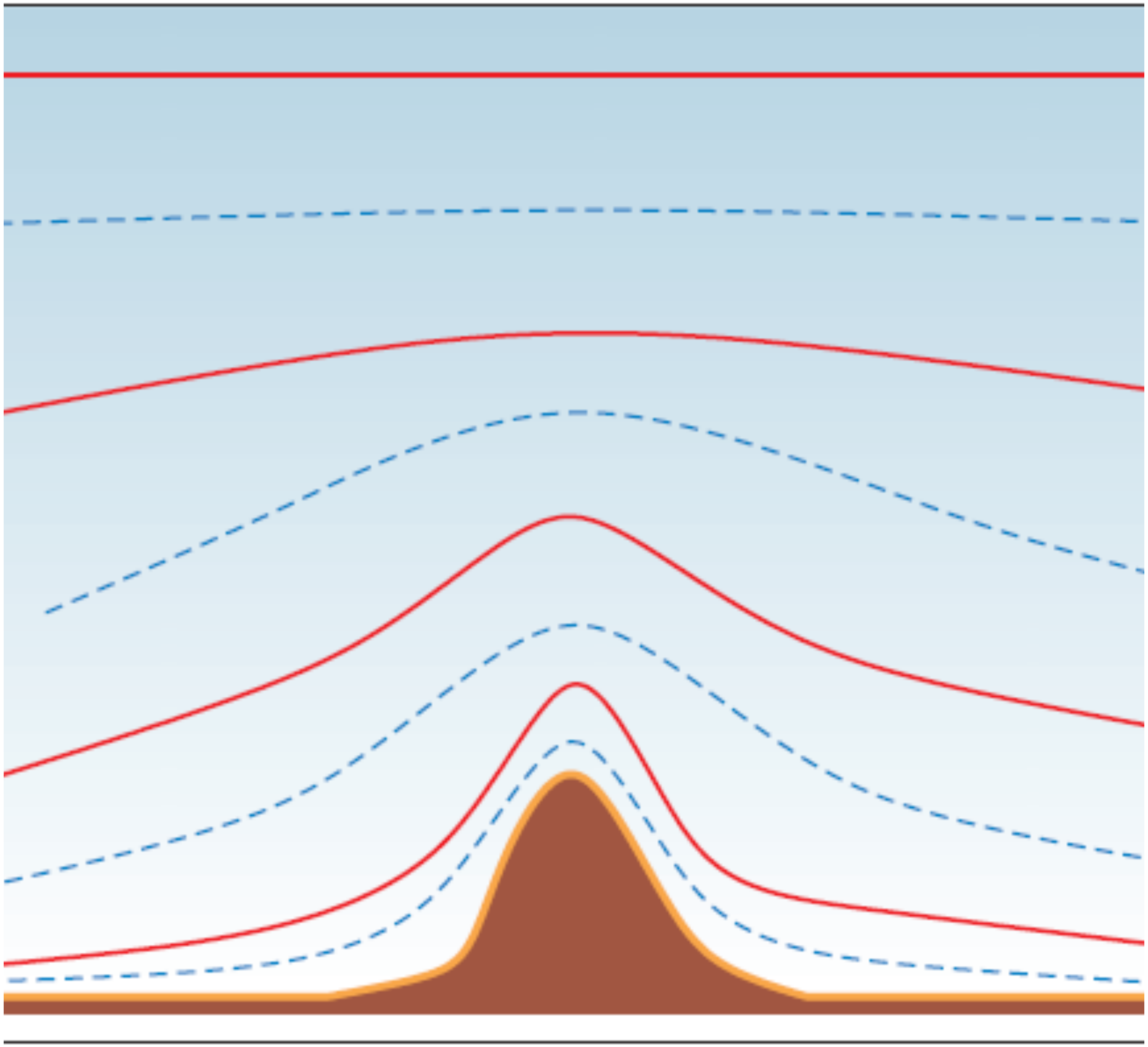
Flux form to treat the physics tendencies

In NWP the physics is 1D – we treat the vertical column.

Given the respective horizontal and vertical resolution ratios, grid-boxes are still very flat – together with the nature of the processes it gives a good justification to work with the vertical fluxes.

Fluxes are defined at the layer interfaces – red lines. Their divergence gives the tendency in the layer – dashed blue lines.

Conservation is ensured.



Flux form interfacing (1/2)

- Flux transport, on the basis of the equations

$$\frac{}{t} = g.\frac{(F\ )}{p} \qquad\qquad F\ = \frac{}{.w\ .}$$

- Examples
  - Energy

$$(\ ) = \frac{J}{kg} \qquad (F\ ) = \frac{kg}{m^3}.\frac{m}{s}.\frac{J}{kg} = \frac{J}{m^2.s} = \frac{W}{m^2}$$

  - Species

$$(\ ) = [1] \qquad (F\ ) = \frac{kg}{m^3}.\frac{m}{s}.[1] = \frac{kg}{m^2.s}$$

  - Momentum

$$(\ ) = \frac{m}{s} \qquad (F\ ) = \frac{kg}{m^3}.\frac{m}{s}.\frac{m}{s} = \frac{kg}{m.s^2} = [Pa]!!$$

Flux form interfacing (2/2)

- Energy conversion, example of potential to kinetic
  - Locally

$$\frac{R.\quad .T}{p} = \frac{J}{kg.K} \cdot \frac{Pa}{s} \cdot \frac{K}{Pa} = \frac{W}{kg}$$

  - Integrally

$$\frac{R.\quad .T}{p} \cdot \frac{dp}{g} = \frac{W}{kg} \cdot \frac{kg}{m^2} = \frac{W}{m^2}$$

Vertical integrand

of course !

Green-Ostrogradsky

Simplifying hypothesis (1/3)

- In order to get the governing ***diabatic*** equations, i.e. including the source terms from the physics, we need to apply some simplifying hypothesis.
- Here the goal is to obtain a set of consistent simplifications in order to have a useful view of the atmospheric thermodynamics.
- ‘Useful’ means here:
  - Can be converted into tractable equations;
  - Can give a conservative view of the conversions (Green-Ostrogradsky again);
  - Can be put in relation with existing measurements.

Simplifying hypothesis (2/3)

Main hypotheses:

- How the atmospheric mass vary with the hydrological cycle:
    1. Conservation of the total mass: all types of precipitation leaving the atmosphere have a counter-flux of dry air. Prevailing choice in NWP.
    2. Mass changes are controlled by the precipitation-evaporation budget at the surface. There is no compensation by dry air. This option has consequences on the continuity equation => pressure tendency and vertical velocity depend on the surface precipitation flux.
- All gases obey Boyle-Mariotte's and Dalton's laws

  => state equation is tractable.
- Condensed phases have a zero volume

  => avoids the non-compressibility problem for associated portion of the atmospheric content.

Simplifying hypothesis (3/3)

- All specific heat values are temperature independent

  => linear dependency of latent heats on temperature. Clausius-Clapeyron equation can be analytically integrated and yield rather accurate values of saturation pressures

- Atmosphere is in permanent thermodynamic equilibrium

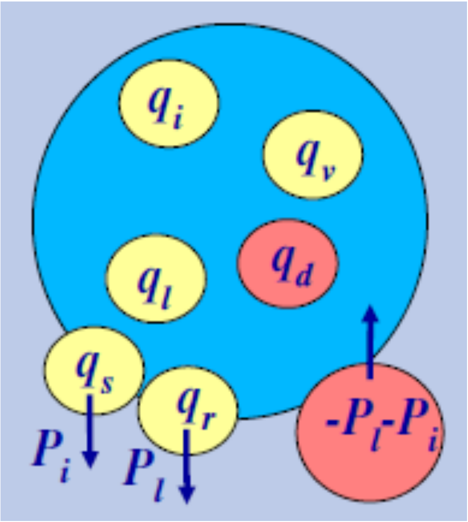
  => derivation of enthalpy budgets, flux-divergence form of tendencies;

Link to a microphysical scheme

- Considered species:
  1. Dry air: q_d
  2. Water vapour: q_v
  3. Cloud (suspended) liquid water: q_l
  4. Cloud (suspended) ice: q_i
  5. Rain (falling pericipitation): q_r
  6. Snow (any solid falling precipitation): q_s

$$q_d + q_v + q_l + q_i + q_r + q_s = 1$$

We shall retain the option of conserving the total mass of the atmosphere



Thermodynamic basis for equations

All phase changes pass by vapor phase – thermodynamically equivalent and easy budget interface.

Graupel and hail can be treated as sub-classes of snow.

Pseudo- fluxes:

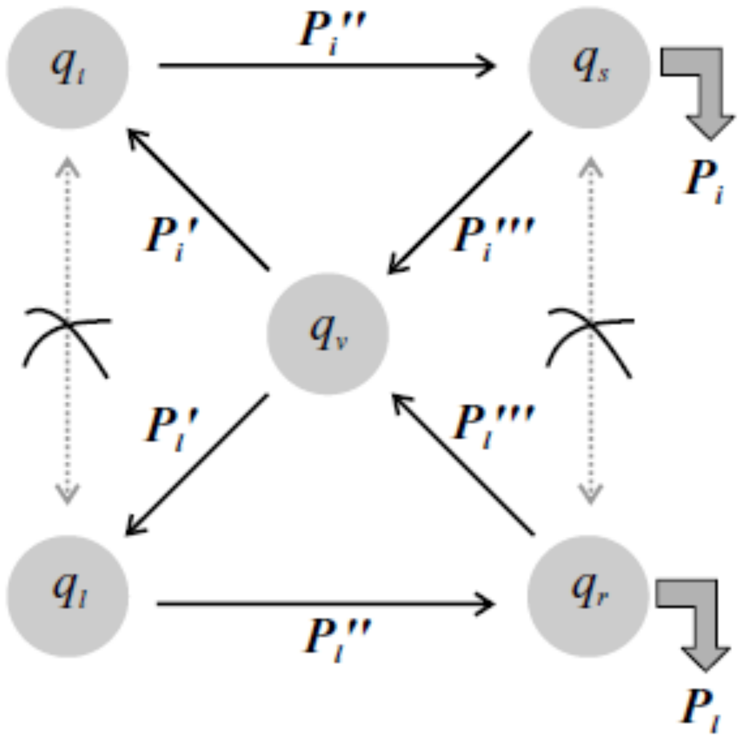
Condensation $P'_{(l/i)}$

Autoconversion $P''_{(l/i)}$

Evaporation $P'''_{(l/i)}$

Precipitation fluxes:

Liquid and solid: $P_{(l/i)}$



Evolution of temperature – enthalpy budget

$$\frac{\partial}{\partial t}(c_p T) = -g\frac{\partial}{\partial p}\left[\begin{array}{c}(c_l - c_{pd})P_l T + (c_i - c_{pd})P_i T \\ -(\hat{c} - c_{pd})(P_l + P_i)T \\ +J_s + J_{rad} \\ -L_l(T_0)\left(P'_l - P'''_l\right) - L_i(T_0)(P'_i - P_i''') \end{array}\right]$$

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

$$\hat{c} = \frac{c_{pd}q_d + c_{pv}q_v + c_l q_l + c_i q_i}{1 - q_r - q_s}$$

$$L_{l/i}(T) = L_{l/i}(T_0) + (c_{pv} - c_{l/i})T$$

Derivation is based on entropy equation, here is the compact result.
The sum of all terms in the bracket above gives the total enthalpy flux.
Red term exists in fully mass weighted framework only.

Evolution of species

$$\frac{dq_v}{dt} = g\frac{\partial}{\partial p}\left[P_l''' + P_i''' - P_l' - P_i' + \frac{q_v(P_l + P_i)}{1 - q_r - q_s} - J_{q_v}\right]$$

$$\frac{dq_l}{dt} = g\frac{\partial}{\partial p}\left[P_l' - P_l'' + \frac{q_l(P_l + P_i)}{1 - q_r - q_s} - J_{q_l}\right]$$

$$\frac{dq_i}{dt} = g\frac{\partial}{\partial p}\left[P_i' - P_i'' + \frac{q_l(P_l + P_i)}{1 - q_r - q_s} - J_{q_i}\right]$$

$$\frac{dq_r}{dt} = g\frac{\partial}{\partial p}\left[P_l'' - P_l''' - P_l\right]$$

$$\frac{dq_s}{dt} = g\frac{\partial}{\partial p}\left[P_i'' - P_i''' - P_i\right]$$

Derivation is based on the conservation.
Red terms exists in fully mass weighted framework only.

Further requirements on the microphysics scheme (ALARO example)

Challenges to construct the microphysics for NWP:

- Use of flux-conservative thermodynamic equations and well defined interface;
- Possibility of using relatively long time-steps (numerics and sedimentation problem => statistical sedimentation);
- Possibility of unified treatment for stratiform and convective clouds (sub-grid-scale geometry of clouds and precipitation) – Grey zone challenge of moist deep convection but not only;
- Modularity (ready to test options in the same environment otherwise).

Sub-grid geometry of clouds and precipitation

As conclusion for Lesson

Probably more than 90% of erroneous scientific statements about the modelled behaviour of the atmosphere come from methodological errors!