Meso-NH

mesoscale non-hydrostatic model

A **research** model, jointly developped by CNRM(Meteo-France/CNRS) and Laboratoire d'Aérologie (CNRS/UPS)

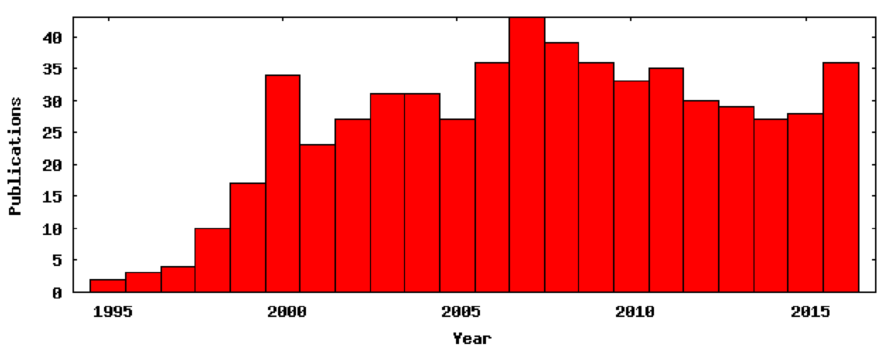
http://mesonh.aero.obs-mip.fr/mesonh52

Steering Committee : LA, CNRM, CERFACS, LPO (Brest), Univ.EVORA, SPE (Corsica)

cnrs Observatoire Midi-Pyrénées METEO FRANCE

Access :
Open source since April 2014

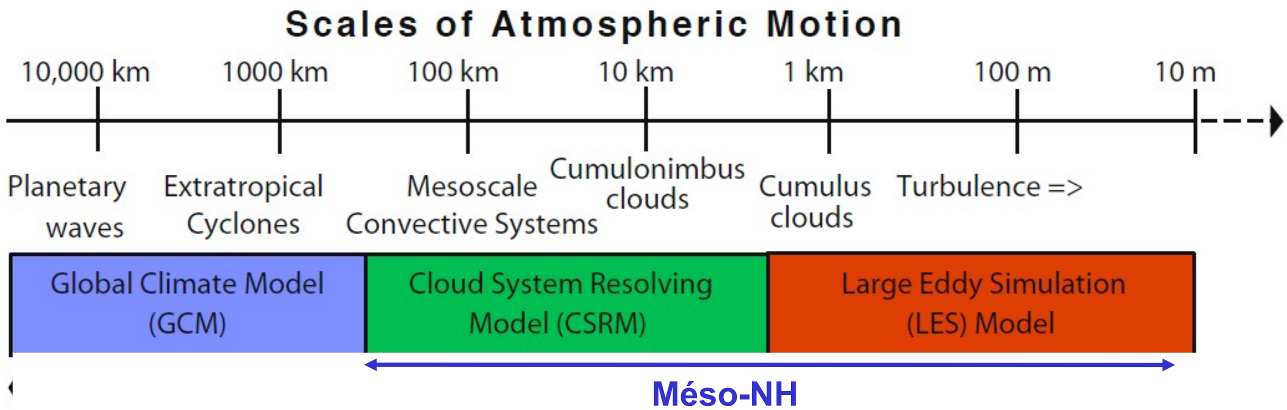
Publications



130 PhD, 451 papers

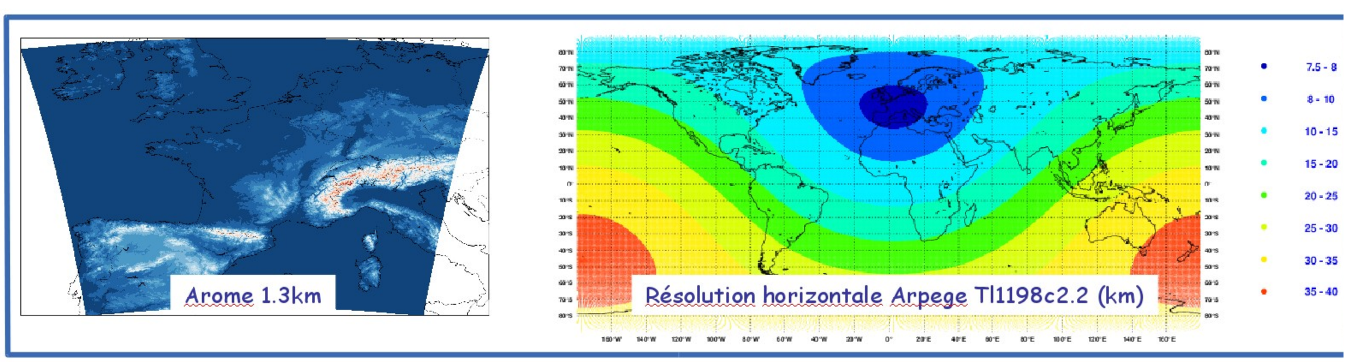
http://mesonh.aero.obs-mip.fr/cgi-bin/mesonh/publi.pl?art=on&phd=on

Space and time scales

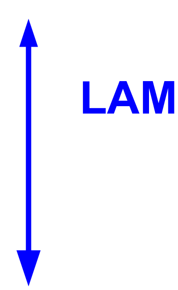


Different meteorological models at Meteo-France

- **Global Climate Model (GCM) : ARPEGE Climat**
- **NWP at synoptic scale : ECMWF, ARPEGE (Δx=7.5km on France)**



- **NWP at meso-β scale : AROME (2008) (Δx=1.3km)**
- **Research model for synoptic to meso-γ scale : Méso-NH (Δx=50km to cm).**



Other equivalent meso-scale models elsewhere : WRF, RAMS, LM, UM …

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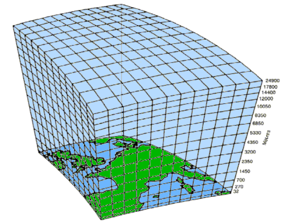
Main characteristics



✗ A broad range of resolution from synoptic scales (Dx~10km), meso-scale (Dx~1km) to Large Eddy Simulation (Dx~100m to 1cm)
✗ Non hydrostatic anelastic model
✗ Eulerian explicit grid-point model with 4th or 5th transport schemes
✗ Grid-nesting

✗ Coupled with the externalized surface model SUFEX (vegetation, town, lake, sea)
✗ Turbulence 1D (meso-scale) or 3D → **Large Eddy Simulations (LES)**
✗ Microphysics 1-moment or 2-moment
✗ Shallow and deep convection schemes
✗ ECMWF radiation
✗ Chemistry, Aerosols and Dusts
✗ Electricity scheme

✗ Physics of AROME comes from Meso-NH

Why do we need a research model like Meso-NH ?

- To improve parameterizations for Large Scale models : fine resolution simulations allow to resolve the main coherent patterns and inform on fine scale variability.
- To help the evaluation and the improvement of NWP models like AROME (High resolution capability, Grid Nesting)
- To better understand the physics (e.g. cloud processes), to characterize local effects : meso-scale to large eddy simulations
- To carry out impact studies and use the model as a laboratory
- To develop Diagnostics : budgets, LES diagnostics ; observation simulators : satellite, radar, lidar, scintillometer, to validate the model and to develop new data assimilation
- To develop new couplings (e.g. Electricity, Hydrology …) and applications (astronomy …). Most recent applications : Fire propagation, Pollen dispersion, aircraft contrails, acoustic … : A tool for faisability studies

PLAN

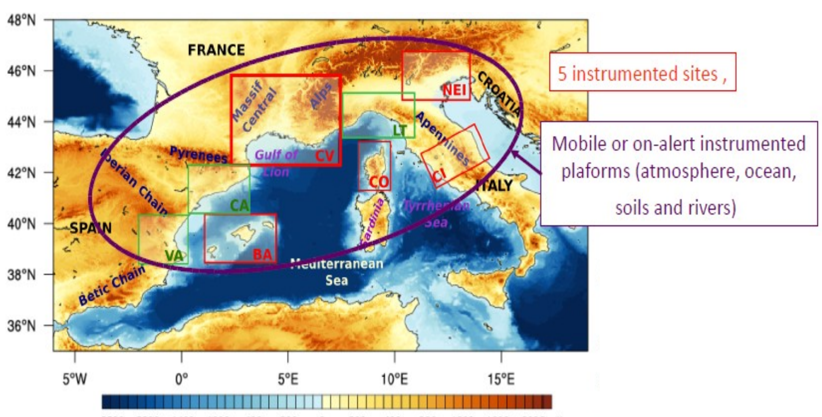
1 . A few focus on the current topics

- ✗ Deep convection – Heavy precipitation
- ✗ Fog
- ✗ Dust
- ✗ Microphysics – Aerosol impacts
- ✗ Coupling : exemple of Fire propagation

2 . Important next future developments

- ✗ Immersed Boundary Method (IBM)
- ✗ Turbulence in clouds
- ✗ Stable turbulence

1. a DEEP CONVECTION – HEAVY PRECIPITATION



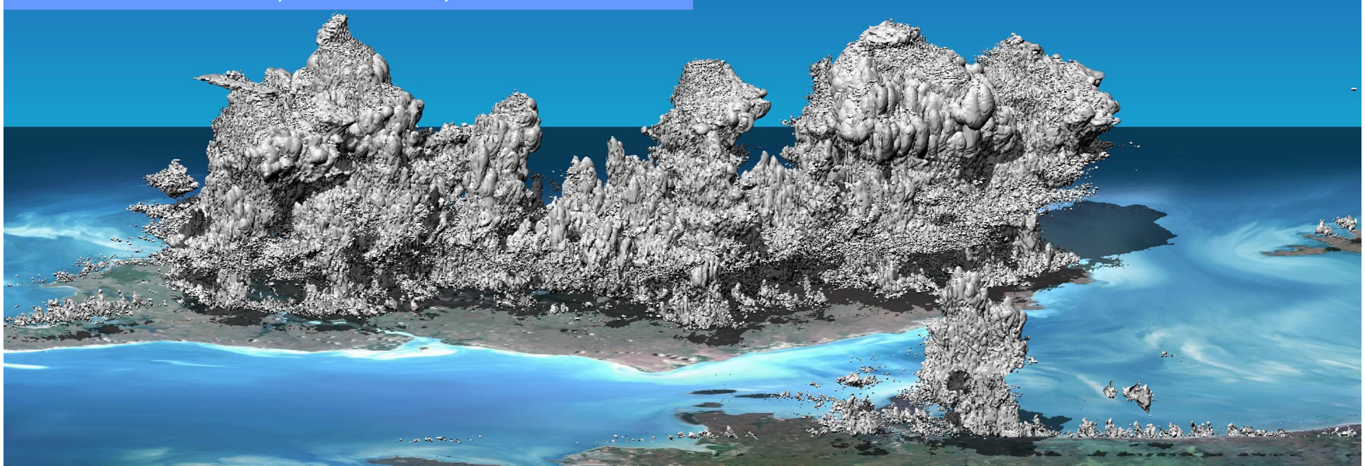
Among the more recent studies with Meso-NH :
Duffourg et al., 2016
Augros et al., 2016

In Madeira island, Couto et al. (2016 a and b)

DEEP CONVECTION : Analysis of updrafts in a Giga-LES

Hector the Convector

- 2560 x 2048 x 256, 1.34 billion gridpoints
  Δx=100 m and Δz=40 – 100 m
- 10-h simulation on IBM BlueGene-Q
  8 million CPU h, 16 kcores, 20 Tb data

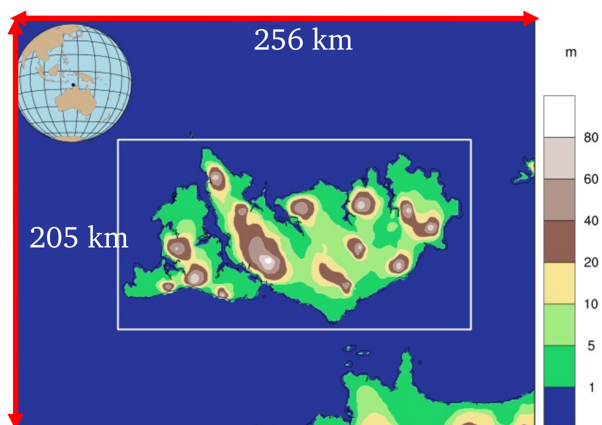


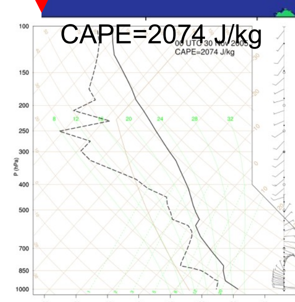
Video on https://youtu.be/xjPumywGaAU

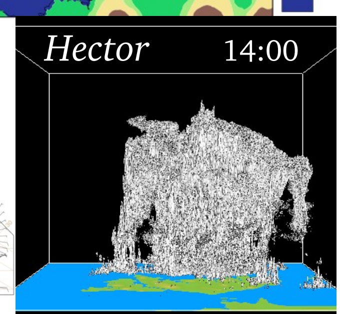
Meso-NH set-up

mesoscale non-hydrostatic model

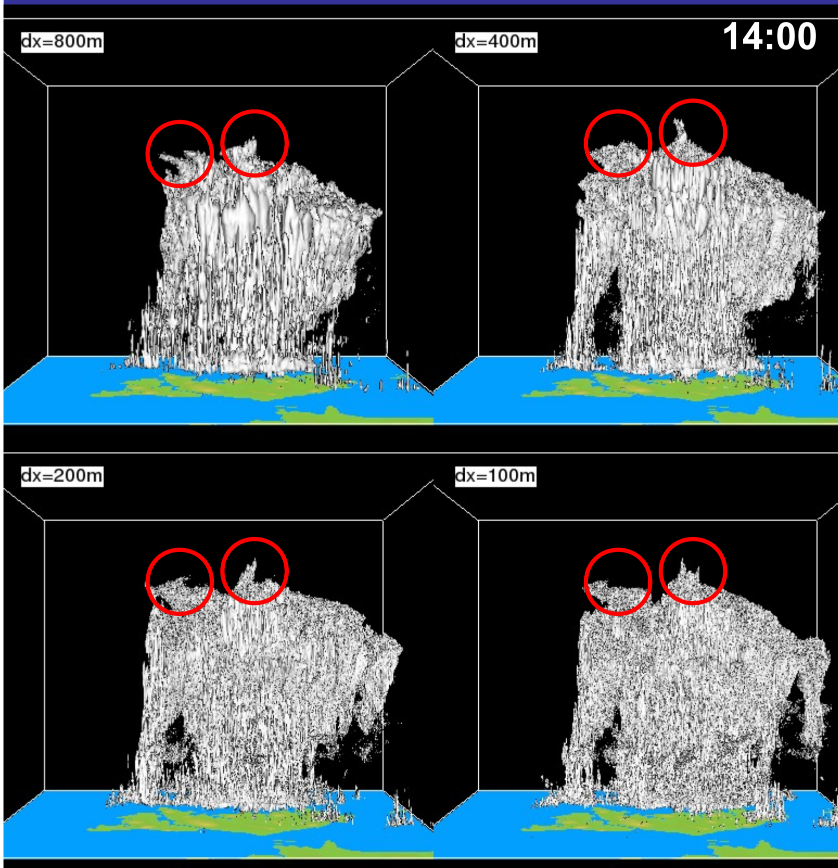
- The first Giga-LES of *Hector the Convector*
- 2560 x 2048 x 256, 1.34 billion gridpoints
  Δx=100 m and Δz=40 – 100 m
- 10-h simulation on IBM BlueGene-Q
  8 million CPU h, 16 kcores, 20 Tb data
- Initial field from Darwin sounding taken at 00 UTC 30 November 2005 (0930 LST)
- Open boundary conditions
- 3D turbulence, mixed-phase microphysics, SURFEX surface scheme (sea, land)
- Sensitivity experiments with
  Δx=1600, 800, 400, and 200 m
  over the same domain and with the same parameterizations

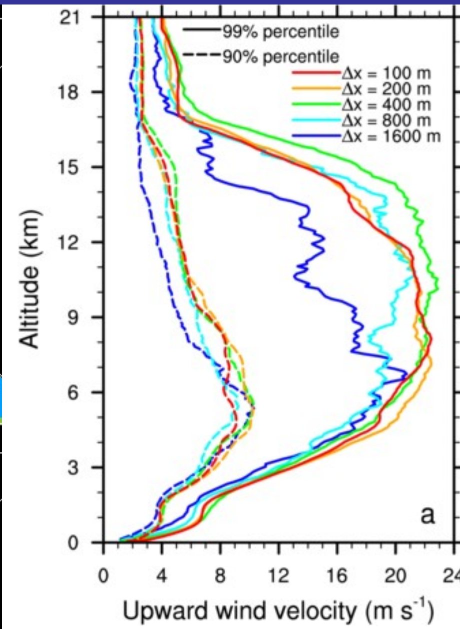






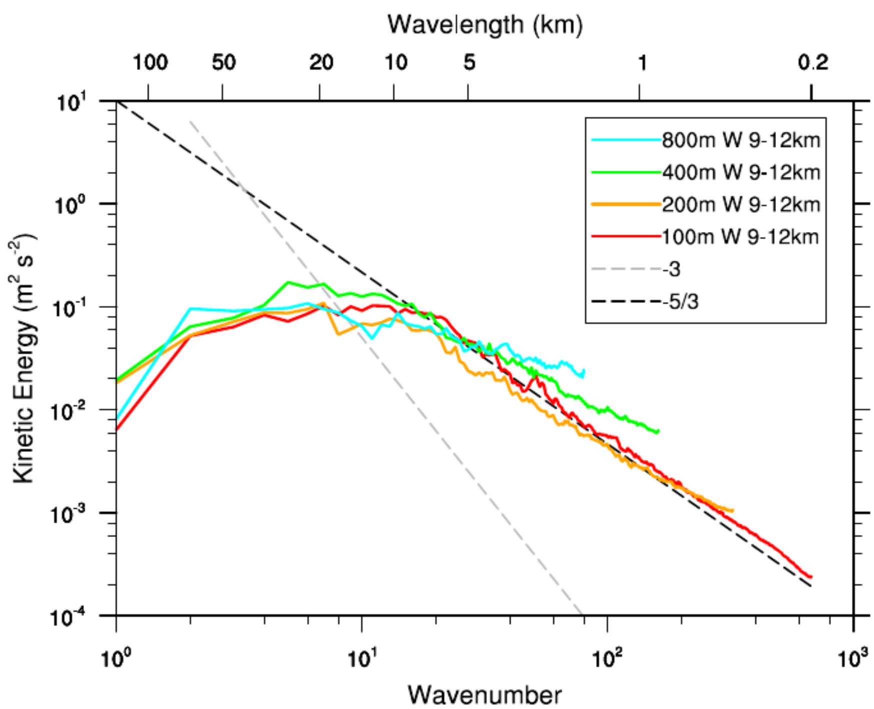
Sensitivity to grid spacing





The vertical velocity for the most rapid updrafts generally decreases with reduced resolution

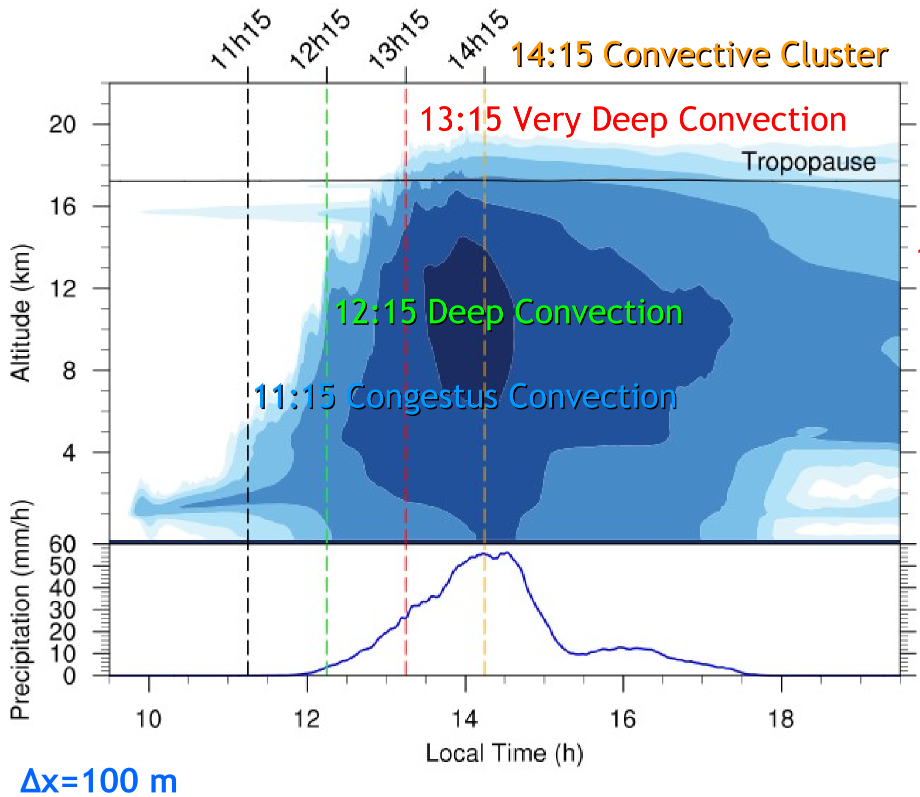
Spectrum of vertical velocity

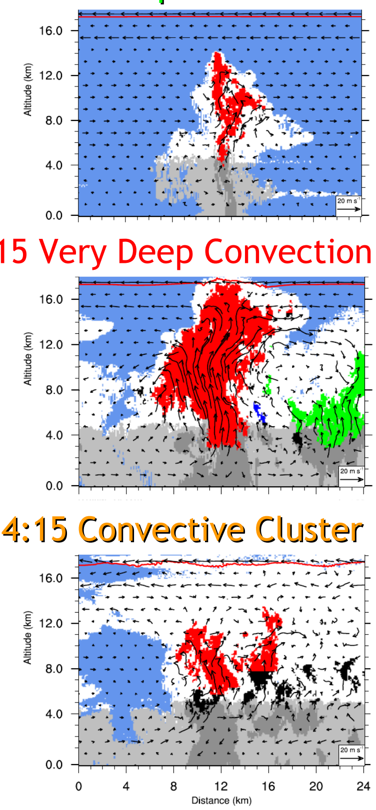


13:00

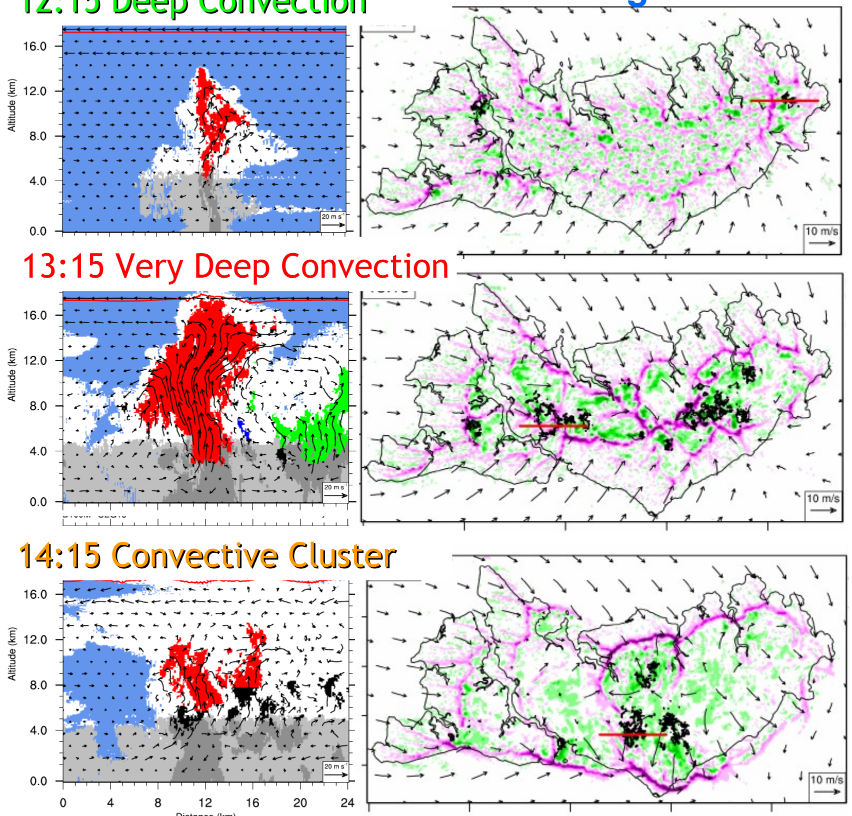
A grid spacing of Δx=200 m or 100 m is required for a reliable estimate of the hydration of the stratosphere

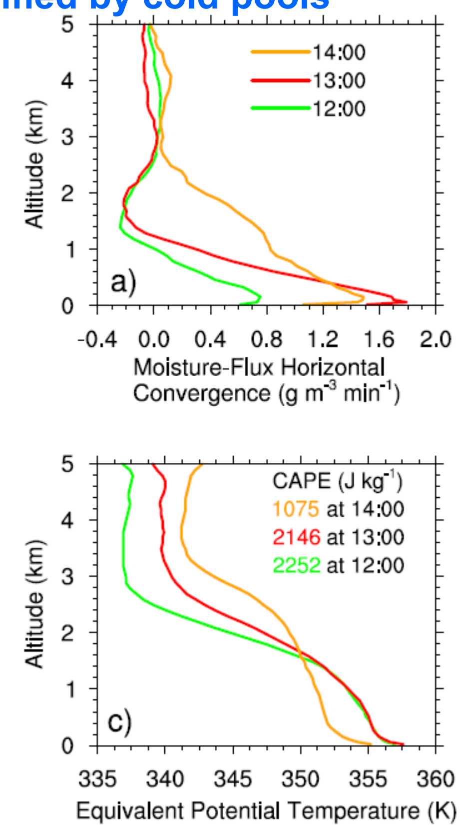
Gradual growth of Hector



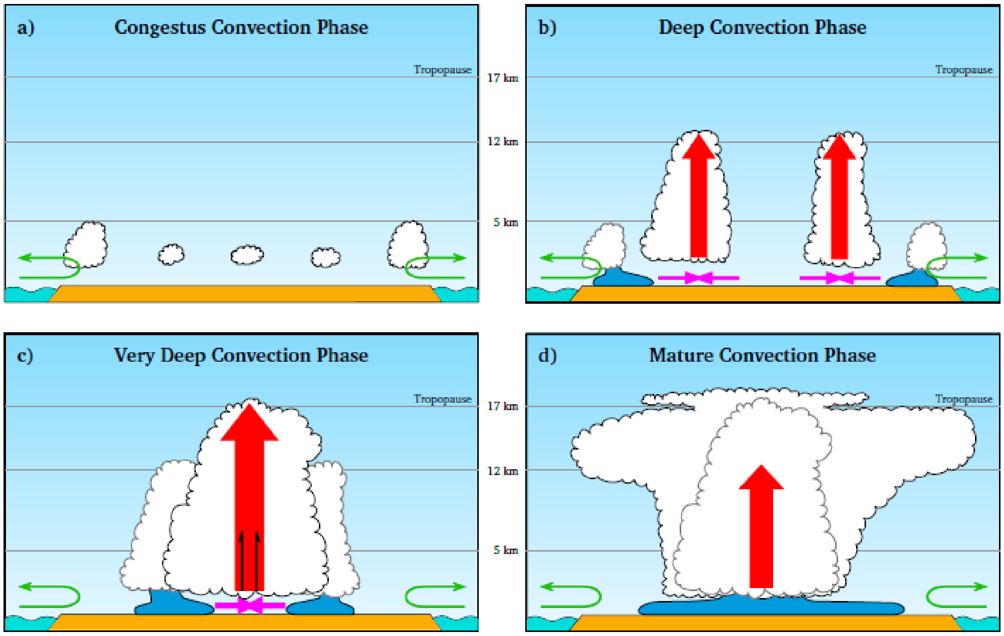


Formation of the tallest updrafts





Successive phases of convection



Dauhut et al., J. Atmos. Sci., 2016

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1. b FOG

Effects of small-scale surface heterogeneities on radiation fog :

1. Buildings : LES at Paris CDG airport
2. Trees : LES at the SIRTA site

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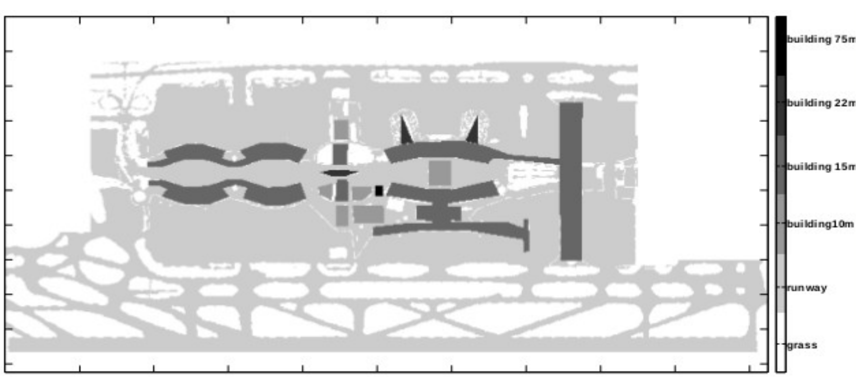
CNRM-GAME

Effects of small-scale surface heterogeneities on radiation fog : LES at Paris CDG airport

Database from Aéroports de Paris
Surface elements have been built



$3000 \times 1000 \times 135$
$\Delta x = 1.5m$
$\Delta z = 1m$
Flat terrain
Building drag effect

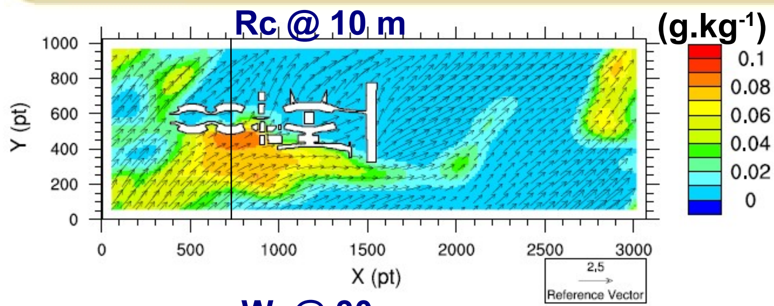
Bergot et al., 2015, QJRMS

CNRM-GAME

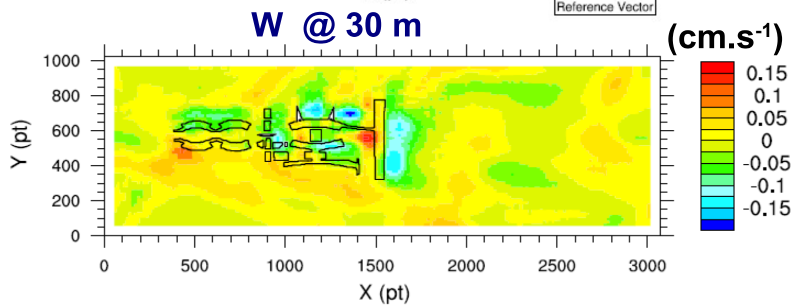
23h15 UTC

Development of the fog

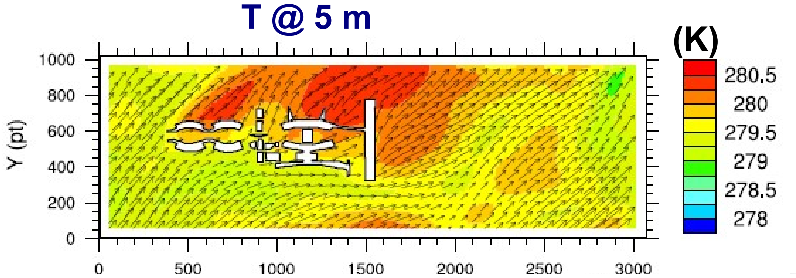
DRAG



Very heterogeneous fog formation (~1.5 h) : 30 min more than BLD
No fog downstream



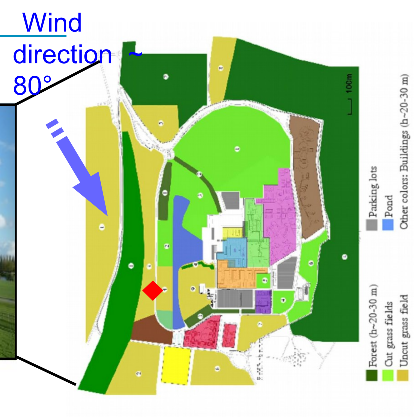
Ascendance (0.1cm.s^{-1}) upstream and subsidence (-0.1cm.s^{-1}) downstream

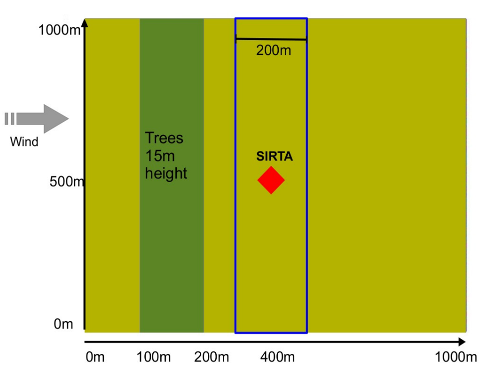


Heating (1K) downstream due to subsidence (adding to anthopogenic heating) delays fog formation

Fog at SIRTA : impact of dynamics on microphysics

(Mazoyer et al., 2016, ACPD)





– Δx=5m
– Δz=1m
- Flat terrain
- Tree drag effect
-2-moment microphysics

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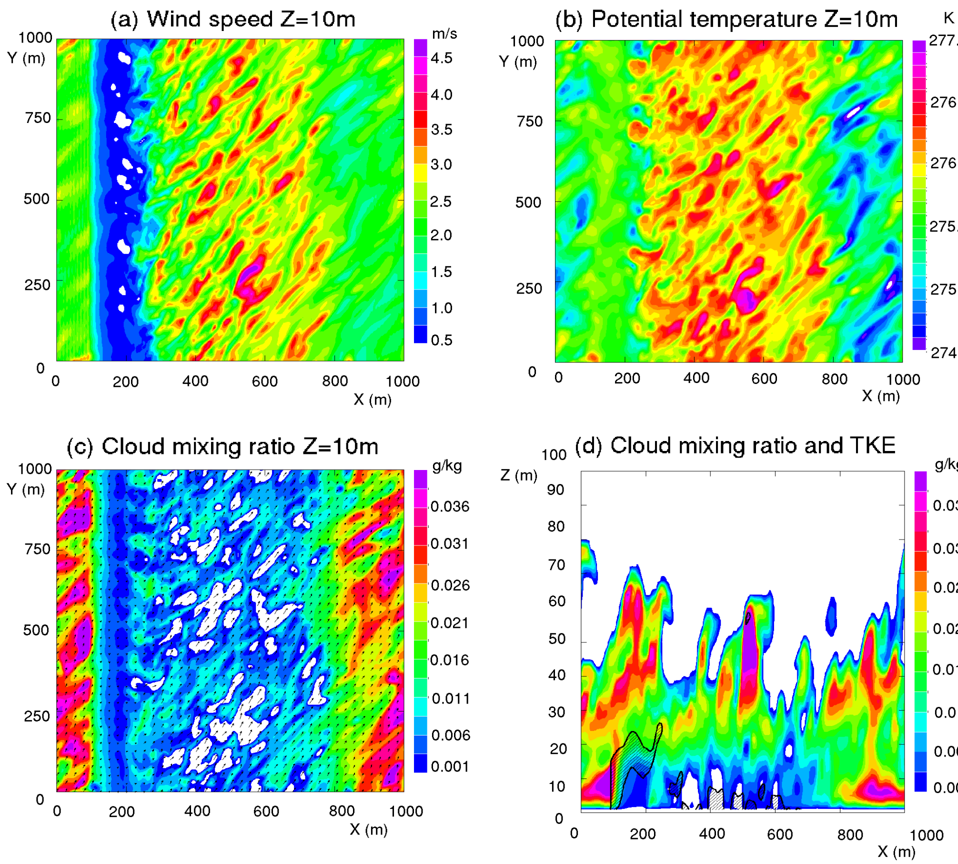
Impact of trees



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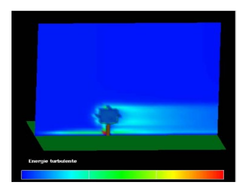
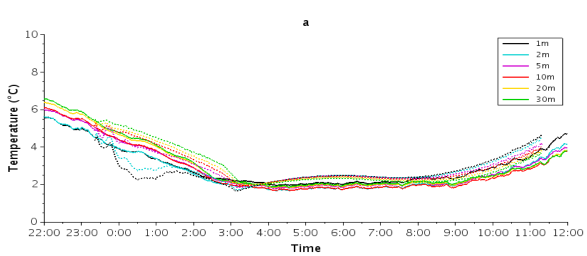
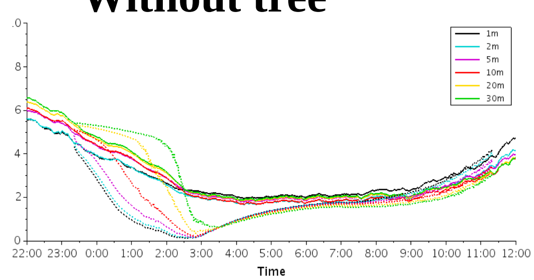
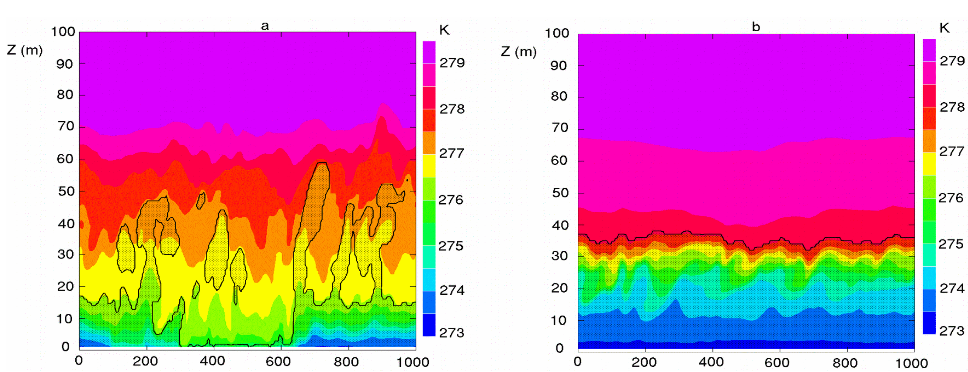
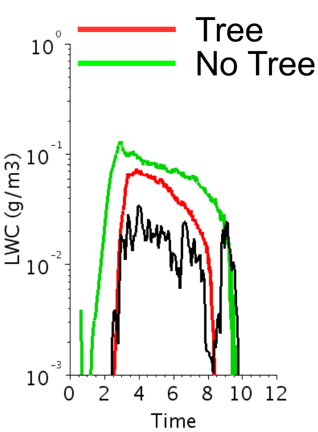


With trees **Without tree**





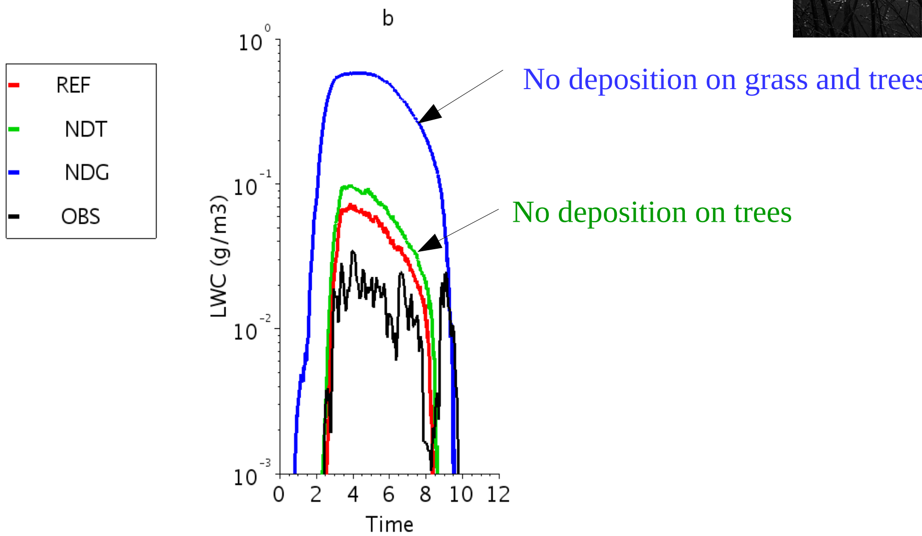




Fog formation

LWC overestimated

Impact of deposition on vegetation



Deposition and dynamical effect of trees essential to reproduce the microphysics of the LES

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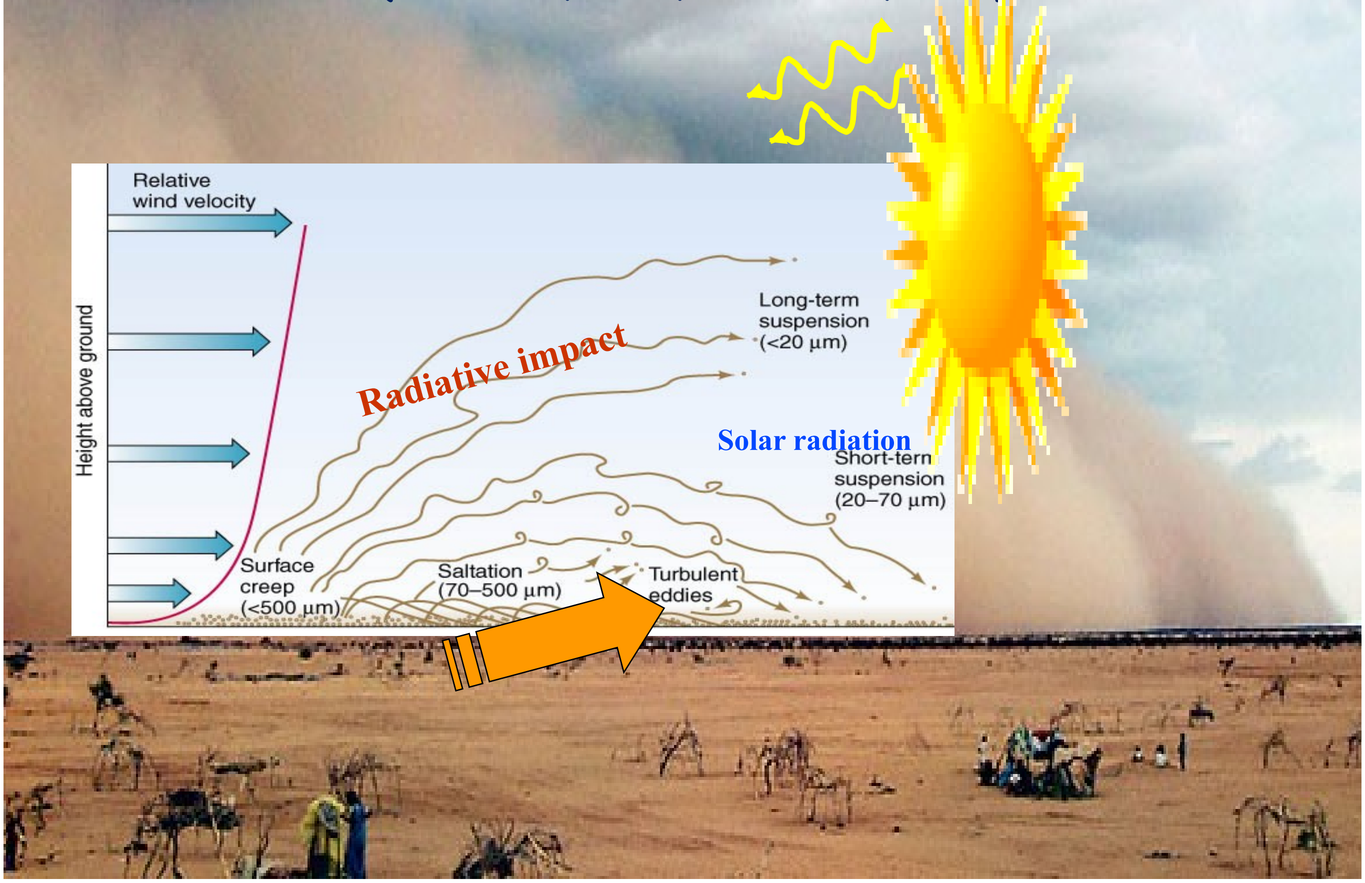
- ✗ **Dust**
- ✗ **Microphysics – Aerosol impacts**
- ✗ Coupling : exemple of Fire propagation

2 . Important next future developments

- ✗ Immersed Boundary Method (IBM)
- ✗ Turbulence in clouds
- ✗ Stable turbulence

Dust parametrization in MesoNH/SURFEX
(Grini et al, 2006, Tulet et al, 2005)



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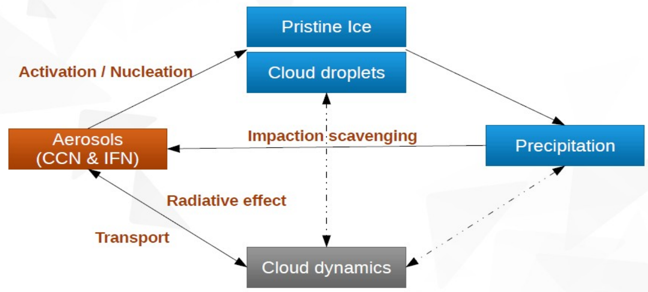
The 2-moment microphysical scheme LIMA

LIMA : Liquid Ice Multiple Aerosols

Complex aerosols – clouds – precipitations interactions



- 2-moment, mixed-phase microphysical scheme in Meso-NH

Droplets	Drops	Ice	Snow	Graupel	Hail
r_c N_c	r_r N_r	r_i N_i	r_s	r_g	r_h

r: mass mixing ratio (kg.kg^{-1}) N: number conc. (#.kg^{-1})

- Prognostic evolution of a realistic aerosol population
  - Multimodal (lognormal psd), 3D externally mixed aerosols
  - Distinction between several types of CCN / IN / coated IN
  - MACC analyses provide realistic aerosol populations

- Complete microphysical scheme derived from ICE3
  - Explicit deposition of water vapour on ice crystals
  - Improved pristine ice → snow conversion
- Aerosol treatment
  - Transport by the resolved flow and turbulence
  - CCN activation (Cohard and Pinty, 2000) → cloud droplets
  - IFN nucleation (Phillips et al. 2008, 2013) → ice crystals
  - Below-cloud aerosol washing-out by rain (Berthet et al. 2010)
- Aerosol radiative impact
  - Interface with the radiation scheme for aerosols by Aouizerats et al. (2010)

- Vié *et al.*, 2015: LIMA (v1.0): a two-moment microphysical scheme driven by a multimodal population of cloud condensation and ice freezing nuclei, GMDD, doi:10.5194/gmdd-8-7767-2015.

Application to a squall-line :

In-cloud depletion+transport

$N_{CCNfree}$+Nc

$N_{IFNfree}$+Ni

Below cloud scavenging

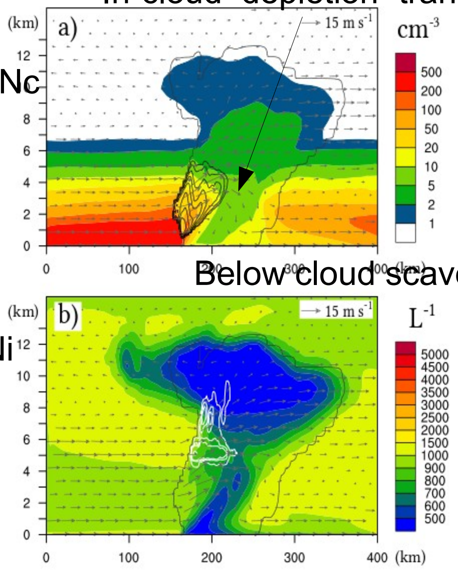


Figure 5. Squall line characteristics of the REF experiment. **(a)** Free CCN (colours) and cloud droplet (black contours, same scale as free CCN) number concentrations (cm^{-3}), **(b)** free IFN (colours) and cloud ice (white contours at 0.01, 0.05, 0.1, 0.5, 1 and 5) number concentrations (L^{-1}). A single cloud contour (in grey at 10^{-6} kg kg^{-1}) and the wind (vertical wind speed multiplied by 10) are superimposed.

Vié et al., 2015

Supersaturation over ice

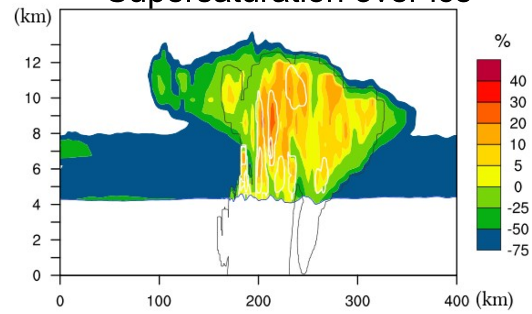
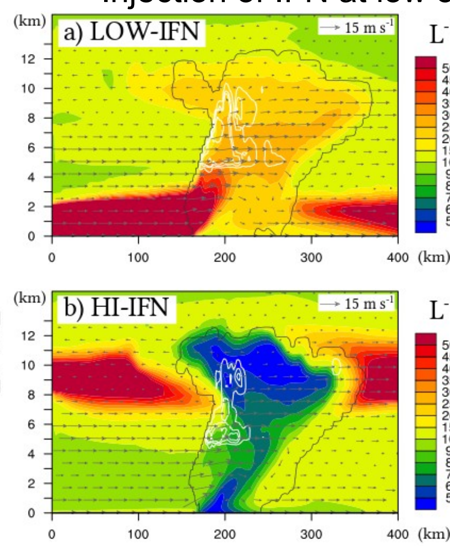


Figure 6. Instantaneous supersaturation over ice (colours, %) and pristine ice concentration (white contours at 10^{-3} and 0.1 L^{-1}) with cloud contour at 10^{-6} kg kg^{-1} (grey contour) and 0 °C isotherm (blue contour), for the REF simulation of the squall line after 7 h.

Injection of IFN at low or high level



Feeds the convective system

Loss by entrainment

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FIRE propagation

Goal

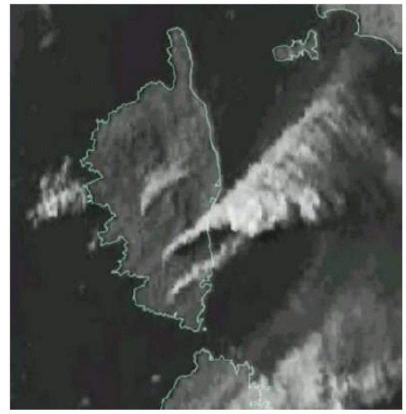
- Wildland fires impact the life of people and cause damages
- Better modeling for managing fire fighting

Modeling wildland fire is challenging

- Multi-physics, multi-scale problem : combustion, emissions, radiation/fluid dynamics, atmospheric physics
- A necessary 2-way interaction between the fire and the atmosphere

Extreme values for the atmospheric model

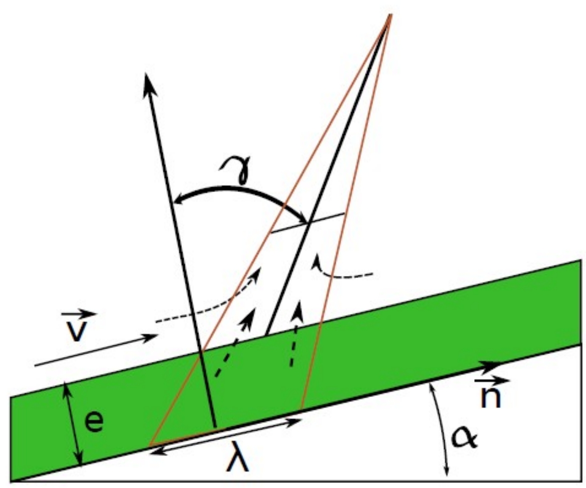
- High resolution around fire (meter),
- Upward radiative fluxes 100 times larger ($Ts \sim 1000K$),
- Upward sensible heat fluxes 1000 times larger (up to 1000 $KW.m^{-2}$)



Meso-NH coupled with FOREFIRE

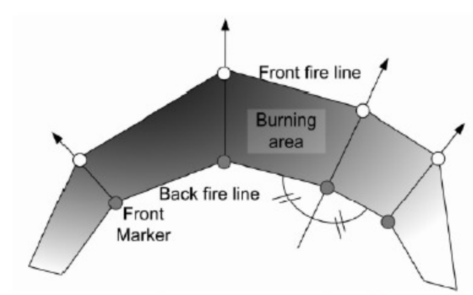
Front dynamics

- GPL licence,
- Flame : Balbi et al. (2007),
- Front velocity (Rate of spread - ROS),
- Firefront acting as a tilted radiant panel, heating vegetation and vaporizing water content,
- Wind and slope effects with a vector method,
- Fuel characteristics



Front tracking

- Asynchronous front tracking method : Filippi et al. (2009)
- Active nodes,
- Dynamic addition and removal of markers



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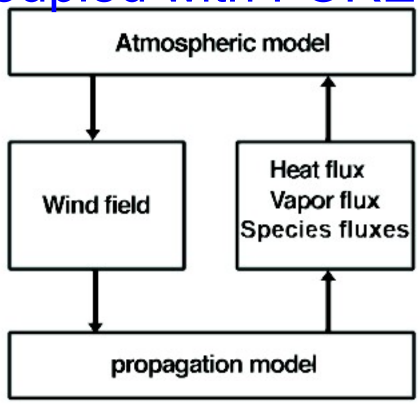
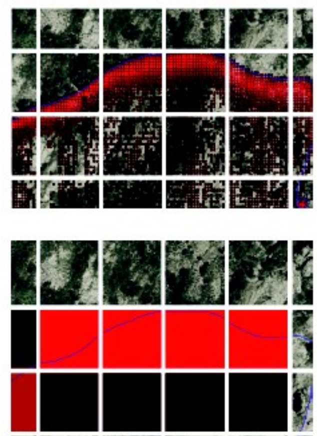


- Only a portion of the atmospheric cell is burning : burning ratio

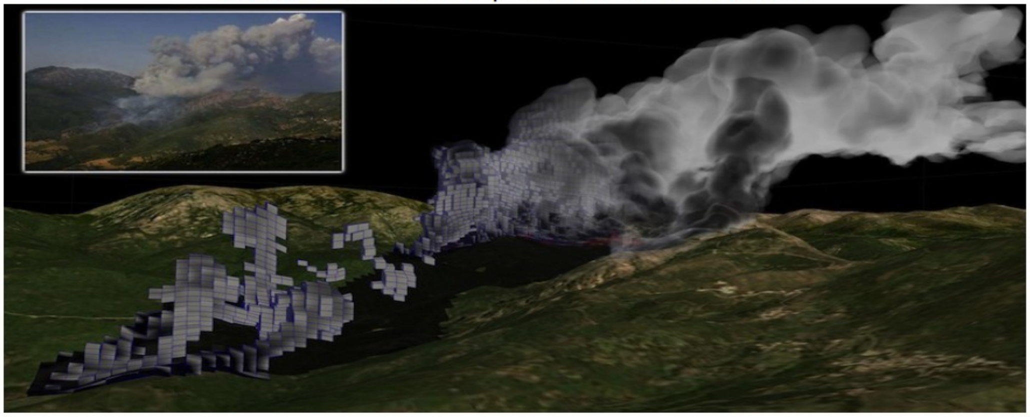


Large Wildfire

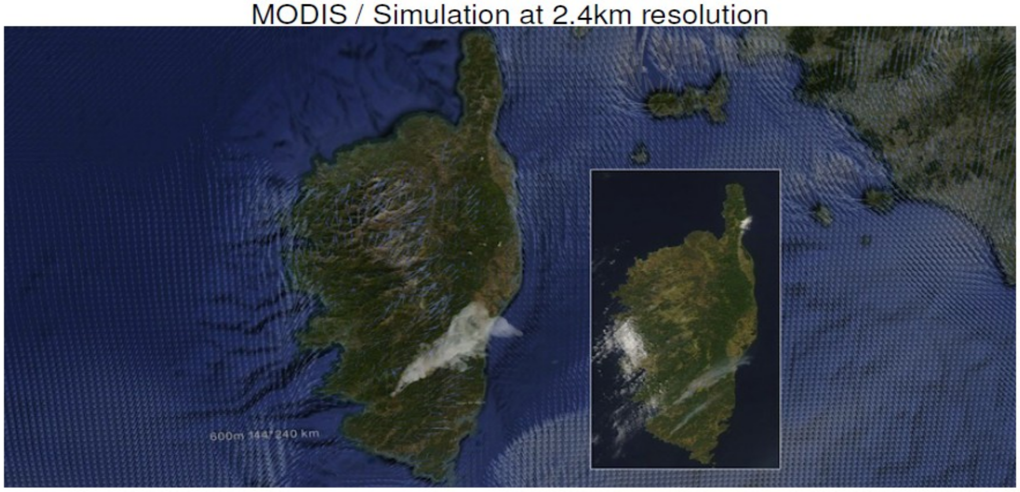
Valle Male Fire

- 2009 July 23 : 3000 ha total, 2000 ha the first afternoon,
- 2 other major fires the same day,
- Mediterranean maquis and pine forests,
- Extreme weather,
- Simulation on the first 8 hours, without fire fighting actions,
- 2.4km/600m/200m/50m nested atmospheric resolution,
- Meteorological initialization : ALADIN ($\Delta x = 10km$)
- 0.1 / 10m front resolution,
- Parallel supercomputing,
- Fuel data from National Forest Inventory (IFN).

Observed/simulated plume at 50m resolution



MODIS / Simulation at 2.4km resolution



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Dispersion of pollutants above complex surfaces : the IBM method

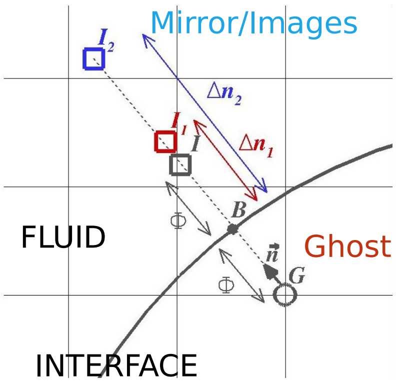
F.Auguste, D.Cariolle, O.Thouron
CERFACS : **C**entre **E**uropéen de **R**echerche et de **F**ormation **A**vancée en **C**alcul **S**cientifique

→ Objective

- Modeling the interactions between the atmospheric flow and heterogeneous terrain, from the resolved scale of buildings/mountains to atmospheric meso-scale
- Limited options in MesoNH : structured-grid models, boundary fitted method

Immersed boundary method (IBM) in MesoNH

Formulating the impact of the topography as a local modification of conservation laws in the model



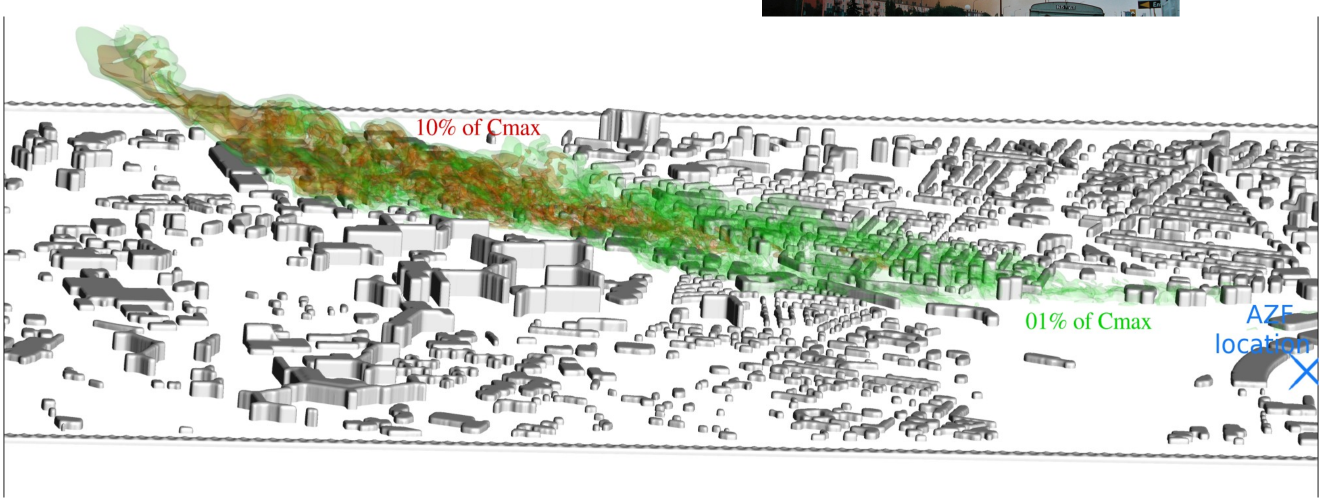
→ STEPS

- Solid-fluid interface detection (level-set function)
- Recovery of the fluid information (interpolation)
- Ghost value computation
  - Interpolation in the direction normal to the interface
  - Satisfaction of the boundary condition at the interface

Dispersion of pollutants above complex surfaces : the IBM method

Application to AZF (Toulouse, Sept.2011)

Explosion and NO_2 dispersion (Toulouse, Sept. 2001)



Meso-NH
mesoscale non-hydrostatic model

PLAN

1 . A few focus on the current topics

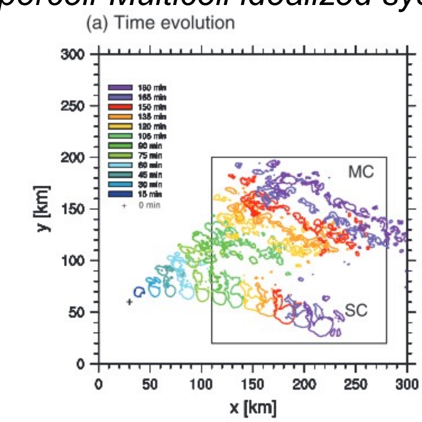
- ✗ Deep convection – Heavy precipitation
- ✗ Fog
- ✗ Dust
- ✗ Microphysics – Aerosol impacts
- ✗ Coupling : exemple of Fire propagation

2 . Important next future developments

- ✗ Immersed Boundary Method (IBM)
- ✗ **Turbulence in clouds**
- ✗ Stable turbulence

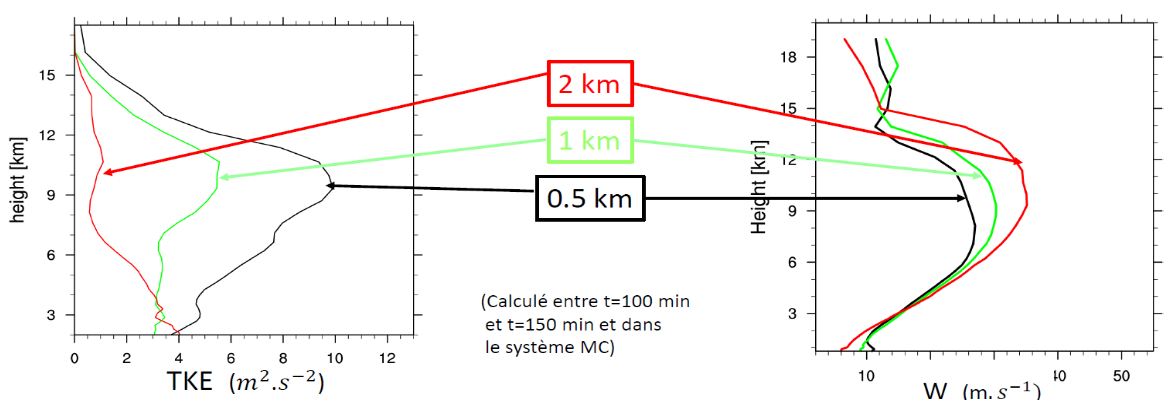
Turbulence inside convective clouds

Supercell-Multicell idealized system



At kilometric scales, TKE increases with resolution : not correct

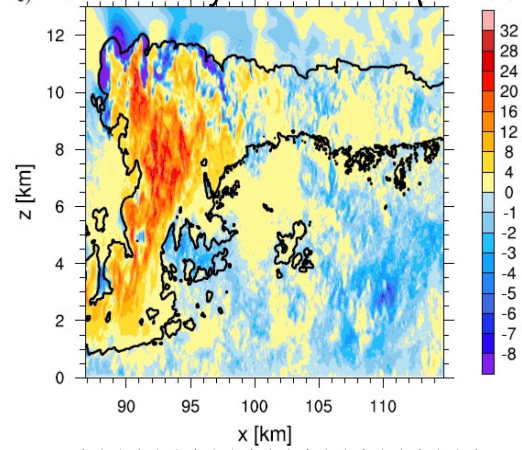
Insufficient turbulence in clouds



Verrelle et al., 2015, QJRMS

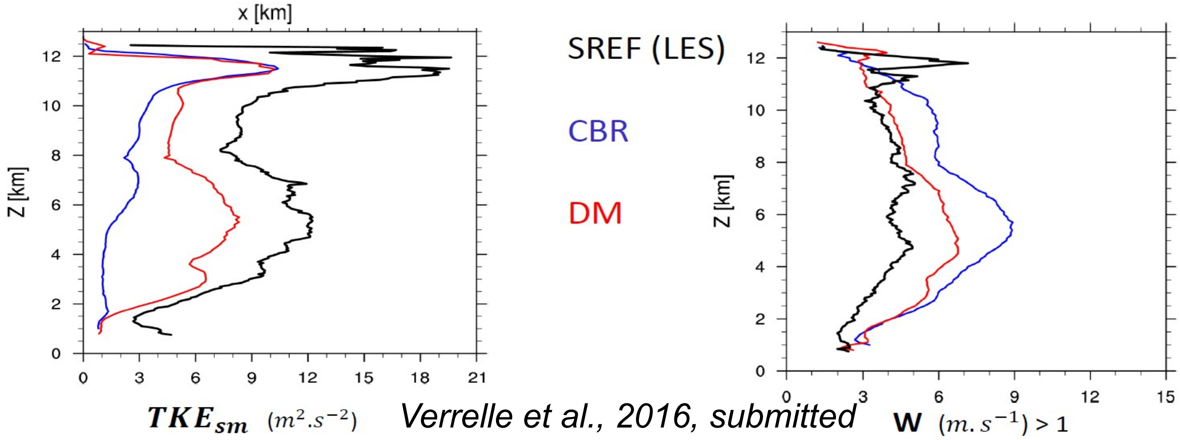
Turbulence inside convective clouds

Vertical velocity from a LES (Δx=50m)



New formulation of the thermodynamical turbulent fluxes inside clouds based on horizontal gradients

Next step : to increase turbulence by entrainment at the cloud edges



Verrelle et al., 2016, submitted

Meso-NH
mesoscale non-hydrostatic model

PLAN

1 . A few focus on the current topics

- ✗ Deep convection – Heavy precipitation
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2 . Important next future developments

- ✗ Immersed Boundary Method (IBM)
- ✗ Turbulence in clouds
- ✗ **Stable turbulence**

Dynamics

Part of the model to describe the evolution of a laminar fluid (no turbulence), without heat exchange (adiabatic).

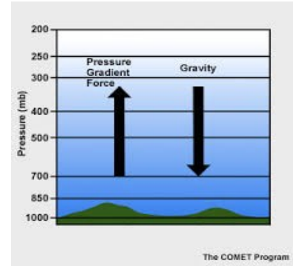
Dépends on :
- **Hypothesis** : Non-hydrostatism ; anelastic
- **Horizontal Geometry** : Coupling, Embedded models
- **Vertical coordinates** : Superior boundary limit
- **Orography characteristics** (average and envelop orography)
- **Numerical methods** : Grid points; Explicit ; Eulerian
- **Model variables**;
- **Dynamical sources** : Coriolis, gravité …

Non-hydrostatism / Anelastic

What is the hydrostatism ?

Non hydrostatic equation of the vertical motion

$$\frac{Dw}{Dt} = -\frac{1}{\rho}\frac{\partial p}{\partial z} - g$$



If H << L we can neglect the vertical acceleration compared to the vertical component of the pressure force : that is the **hydrostatic approximation**

- Pressure at a point is represented by the mass of the above air column
- W is not equal to 0 or constant, but it is diagnosed
- Filters acoustic waves

To represent correctly the processes at convective scale, it is necessary to keep the complete equation of the vertical motion (**non hydrostatism**)

Perturbations from a reference state

In practice, we often write the non hydrostatic equations by decomposing the variables as the sum of a **reference rest state (hydrostatic)** and the difference with this reference state (noted ~ here)

$$\begin{aligned} u &= 0 + \tilde{u} \\ v &= 0 + \tilde{v} \\ w &= 0 + \tilde{w} \\ T &= T_{ref} + \tilde{T} \\ p &= p_{ref} + \tilde{p} \\ \rho &= \rho_{ref} + \tilde{\rho} \end{aligned}$$

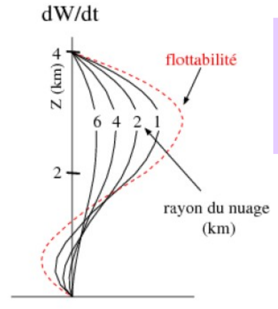
- The reference rest state has no meteorological interest
- Perturbations to this state represent meteorological phenomena

At the first order, the equation of the vertical motion becomes :

$$\frac{Dw}{Dt} = \underbrace{-\frac{1}{\rho_{ref}}\frac{\partial \tilde{p}}{\partial z}}_{\text{Pressure term}} \underbrace{-\frac{g}{\rho_{ref}}\tilde{\rho}}_{\text{Buoyancy}}$$

Pressure term Buoyancy

Validity of the non hydrostatism



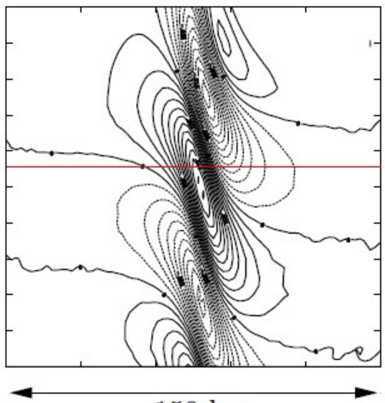
Exemple analytique de Yau, 79

The non hydrostatic effects become important for horizontal scales less than 10 km → **Convection, gravity waves**

Orographic waves, H and NH waves

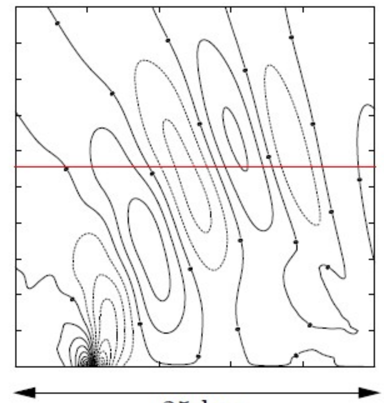
$N = 0,01 s^{-1}$
$U = 10$ m.s^{-1}
H=hauteur montagne=10 m → $(NH)/U << 1$: cas linéaire

L = Width of the mountain
H = Height of the mountain



L>> H

L=largeur montagne=10 km
$(NL)/U >> 1$: hydrostatique

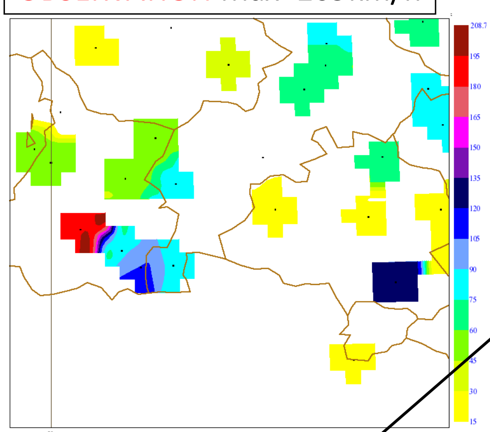


L~H

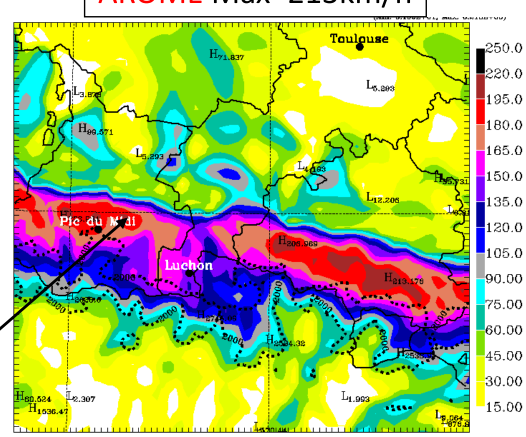
L=largeur montagne=665 m
$(NL)/U << 1$: non hydrostatique

Fine-scale simulations of Xynthia winds

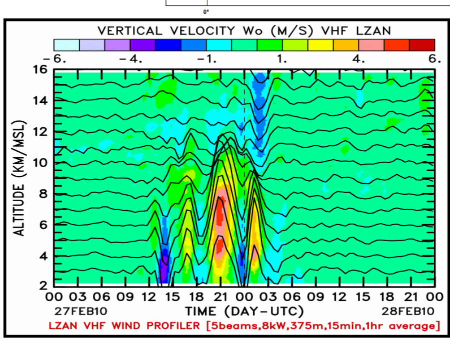
OBSERVATION Max=209km/h



AROME Max=213km/h



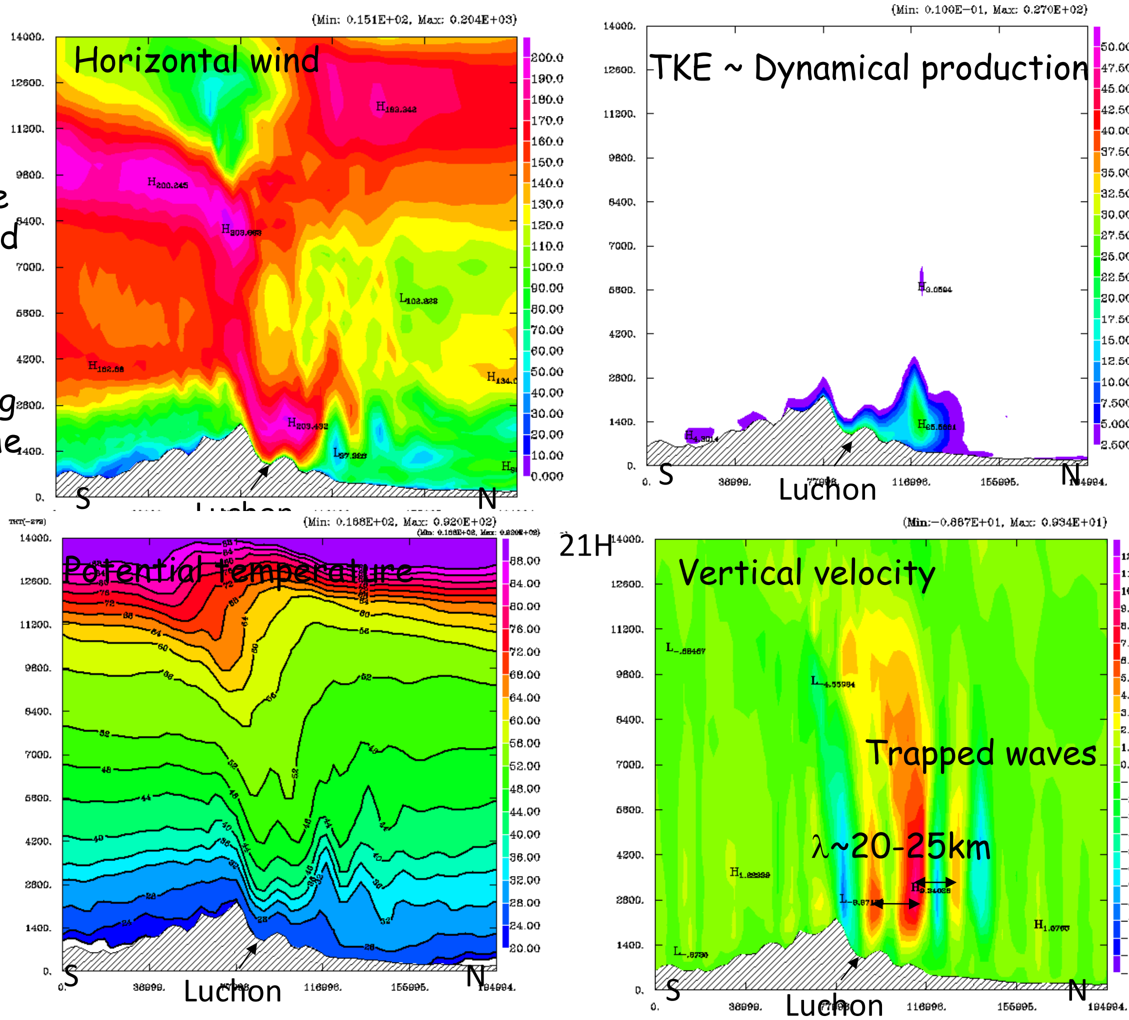
10m gust wind (km/h) 28 Feb. 2010 at 21 UTC



Lannemezan wind profiler shows a structure of trapped gravity waves

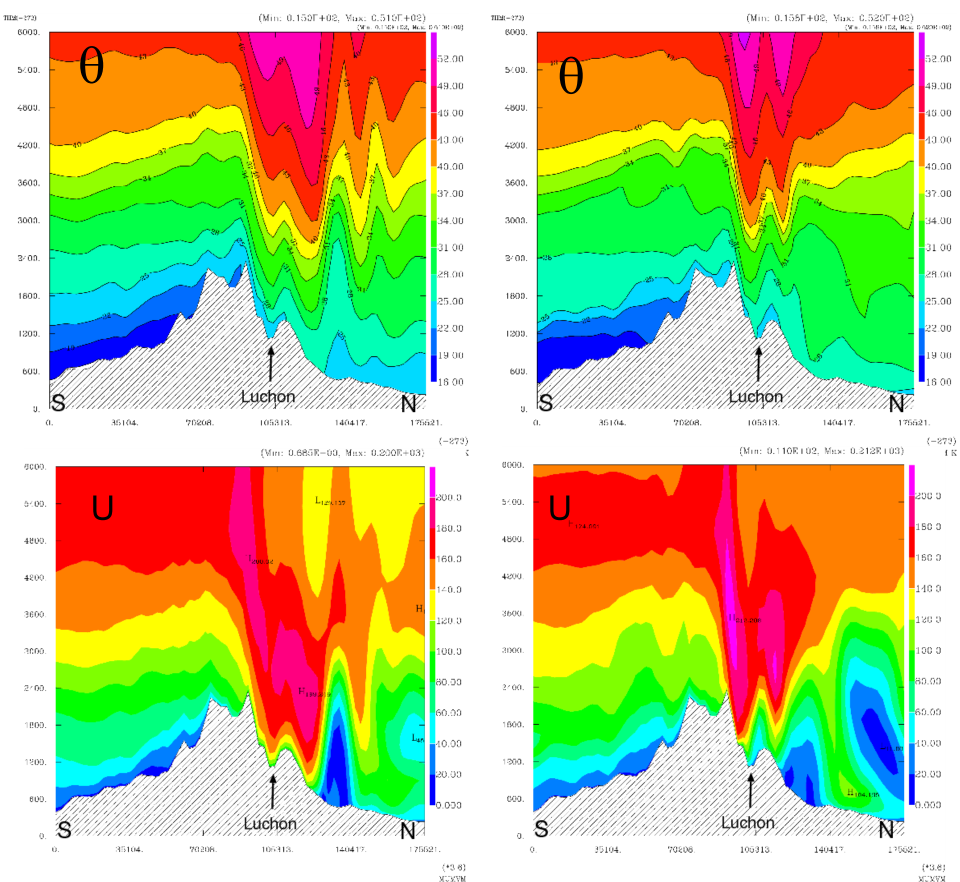
Good forecast on the Pyrenees with AROME, with a band of strong winds on the north of the Pyrenees in the South wind

AROME : Structure of trapped gravity waves inducing the strong wind in the North valleys



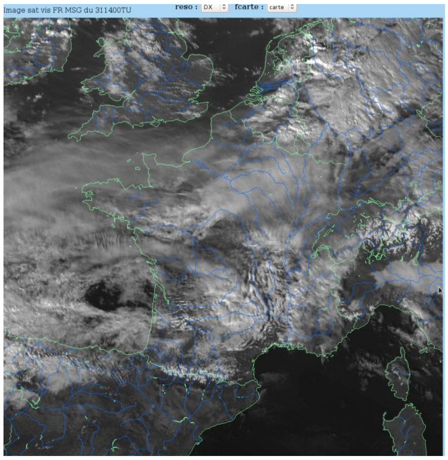
Non-Hydrostatic Hydrostatic

AROME

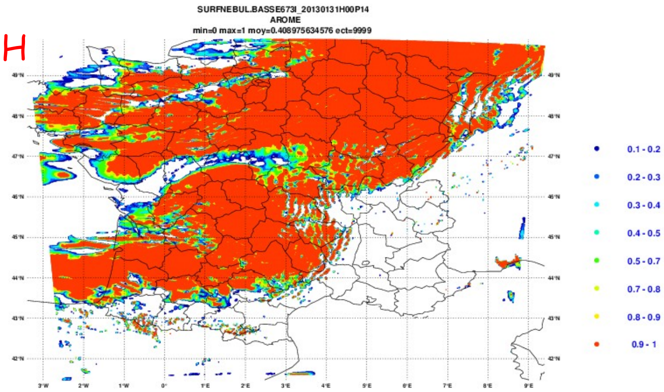


Non-Hydrostatic vs. Hydrostatic

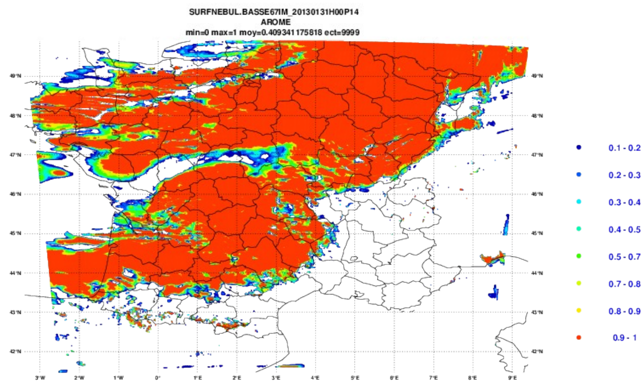
31 Janv. 2013



AROME 1.3km NH



AROME 1.3km H



Elastic processes

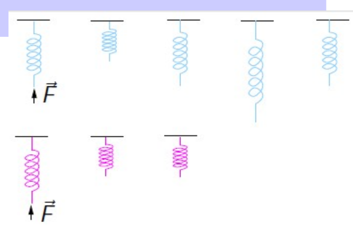
We know that air is compressible

Elastic processes correspond to a rapid response of the volume taken by an air mass submitted to pressure perturbations. Elasticity explains sound propagation in the atmosphere : Sound waves : very little energy and meteorologically unimportant. But severe limitation on Δt as $\Delta t <= \Delta x/Cs$ (CFL)

Volumic mass equation

The equation of the volume taken by an air mass is given by the Navier-Stokes system : **Continuity equation**

$$\frac{D\rho}{Dt} = -\frac{\rho}{V}\frac{DV}{Dt} = -\rho \mathrm{div}(\vec{u})$$



Filtering of elastic processes

Anelastic : $\mathrm{div}(\rho_{ref}\vec{u}) = 0$ $\qquad \frac{\partial \tilde{\rho}}{\partial t} = 0 \qquad \tilde{\rho} < \rho_{REF}$

$\tilde{p}$ becomes a diagnostic variable

By modifying the continuity equation, we can get out the volumic mass evolution associated to the air elasticity : it is not described in the continuity equation anymore : we **filter the acoustic waves**

Compressible + anélastique = pseudo-compressible

Modèle non hydrostatique

w est une variable pronostique (Méso-NH, Aladin-NH/Arome)

Modèle hydrostatique

w est une variable diagnostique (Arpège/IFS, Aladin)

Modèle « fully compressible »

$\tilde{p}$ est également pronostique (Aladin-NH/Arome)

Numerical methods control acoustic waves

Modèle anélastique

$\tilde{p}$ est diagnostique (Méso-NH)

In idealized cases with Meso-NH :
possibility to use ***Boussinesq* approximation** : density variations are neglected (ρ_{ref}~cste) except for the buoyancy term : *incompressibility* : adapted to boundary layer studies (ρ varies less than 10%), but not in most of the cases

Anelastic – Pressure solver

- 3 different versions of the equation system : Anélastic modified, Lipps et Hemler, Durran

- Anelastic constraint + Momentum conservation equation = **Pressure problem resolution**

An elliptic equation is solved by the **pressure solver**, allowing to diagnose the pressure perturbation.

The solver cost increases linearly with the points number on the horizontal and on the vertical : Between 25% and 50% of the total numerical cost.

Steeper the slopes, higher the iteration number. No convergence for very strong slopes (> 60%).

Anorther constraint associated to the elliptic equation : we need to know the solution on the whole domain : implies **communication between processors**, that impacts the scalability

Prognostic variables

Meso-NH
mesoscale non-hydrostatic model

Prognostic variables

- Prognostic = Memory of the previous time step :

Wind (u,v,w), Potential temperature θ, mixing ratio of hydrométéors (r_v,r_c,r_r,r_i,r_g,r_s), Turbulent Kinetic Energy, tracers :

- **θ :** The potential temperature of a parcel of fluid at pressure P is the temperature that the parcel would acquire if adiabatically brought to a standard reference pressure P0, usually 1000hPa.

$$\theta = T\left(\frac{P_0}{P}\right)^{R_a/C_p}$$

where T is the current absolute temperature (in K) of the parcel, R is the gas constant of air, and cp is the specific heat capacity at a constant pressure. This equation is often known as Poisson's equation.

θ conserved during an adiabatic transform in a dry atmosphere (vertical motions are often associated to adiabatic transforms) : Vertical variations of θ, on the contrary to T, don't take into account P variations:

$$\frac{\partial T}{\partial z} = -9.8°/1000\,m \Leftrightarrow \frac{\partial \theta}{\partial z} = 0$$

θ evolution equation = Diabatic effects (radiation …) + Phase changes effects

Variables

Mixing ratio (of vapor) is expressed as a ratio of water vapor mass, per kilogram of dry air, in any given parcel of air

$$r\left(kg/kg\right)=\frac{q}{1-q}$$ q=specific humidity (en kg/m3) : q=ρdref.r

There is conservation of dry air mass

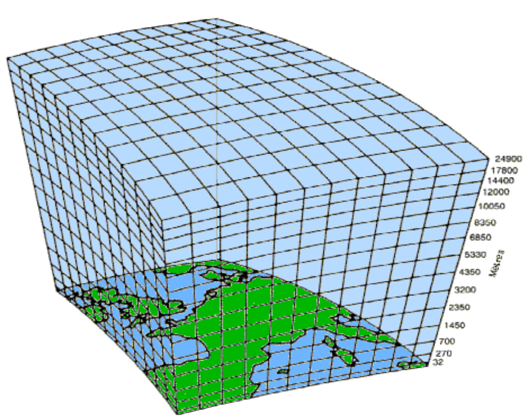
=> Conservation of a mass of a given species = conservation of its mixing ratio

Turbulent kinetic energy is the mean kinetic energy per unit mass associated with eddies in turbulent flow. Physically, the turbulence kinetic energy is characterised by measured root-mean-square (RMS) velocity fluctuations

$$TKE=\frac{1}{2}\left(\overline{u'^2}+\overline{v'^2}+\overline{w'^2}\right)$$

Tracers : passive or chemical

Coordinates system



Meso-NH
mesoscale non-hydrostatic model

Vertical coordinates

- **Following terrain** Vertical coordinate of **Gal-Chen et Sommerville** :

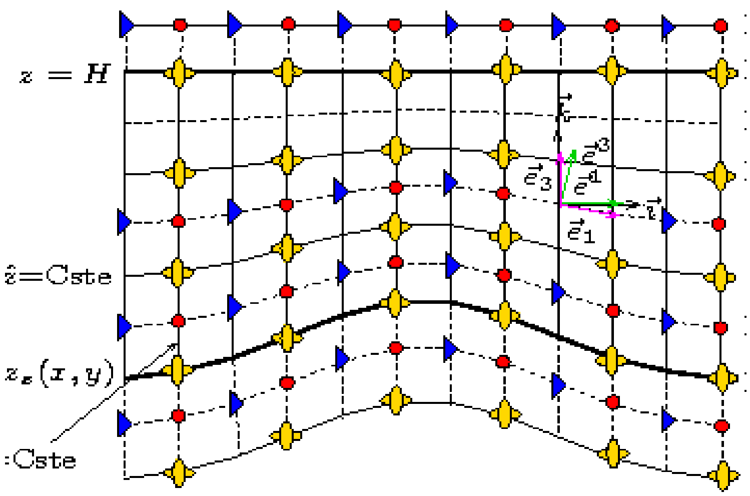
$$\hat{z}(k) = \frac{z(i,j,k) - z_s(i,j)}{H - z_s(i,j)} H$$

z = height of the model level, z_s = Orography

$$z = z_s \rightarrow \hat{z} = 0, \quad z = H \rightarrow \hat{z} = H$$

$$z(i,j,k) = \hat{z}(k) \frac{(H - ZS(i,j))}{H} + ZS(i,j)$$

Linear decrease of the orography



$$z(i,j,k) = XZZ : flux\ pt$$
$$\hat{z}(k) = XZHAT : flux\ pt$$

Horizontal coordinates

- 3 types of **conformal projection** to take into account the Earth roundness : Polar stereographic, Lambert or Mercator (always for **real cases**)

Projection defined by :
- Conicity parameter *K* (noted XRPK) : K=0 Mercator, K=1 Stereo, 0<K<1 Lambert
- the earth radius *a*
- reference longitude λ_0 and latitude ϕ_0 : *recommended* XRPK=sin(ϕ_0)
- angle of rotation β
- coordinates of the pole in projection $\hat{x}_0, \hat{y}_0$

→Map scale factor **m**= Ratio of distances on the projection surface to distances on the sphere

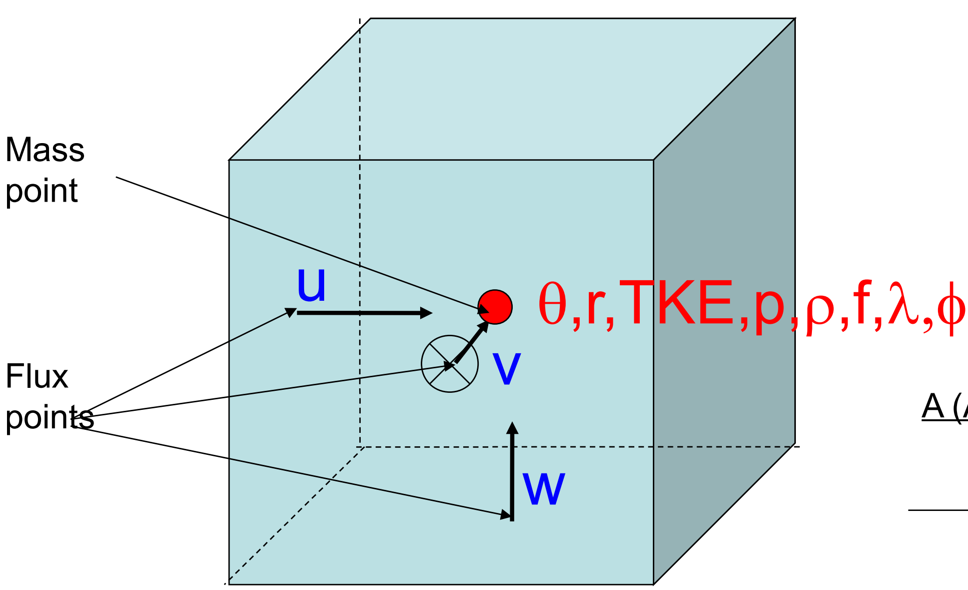
$$m = \left(\frac{\cos\varphi_0}{\cos\varphi}\right)^{1-K} \left(\frac{1+\sin\varphi_0}{1+\sin\varphi}\right)^{K}$$

→ Possibility to degenerate to **cartesian coordinates** when the Earth roundness can be neglected : m=1 (only for **ideal** cases) (~ tangent plan approximation)

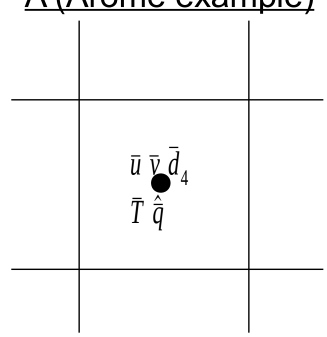
Spatial discretization

Spatial discretization

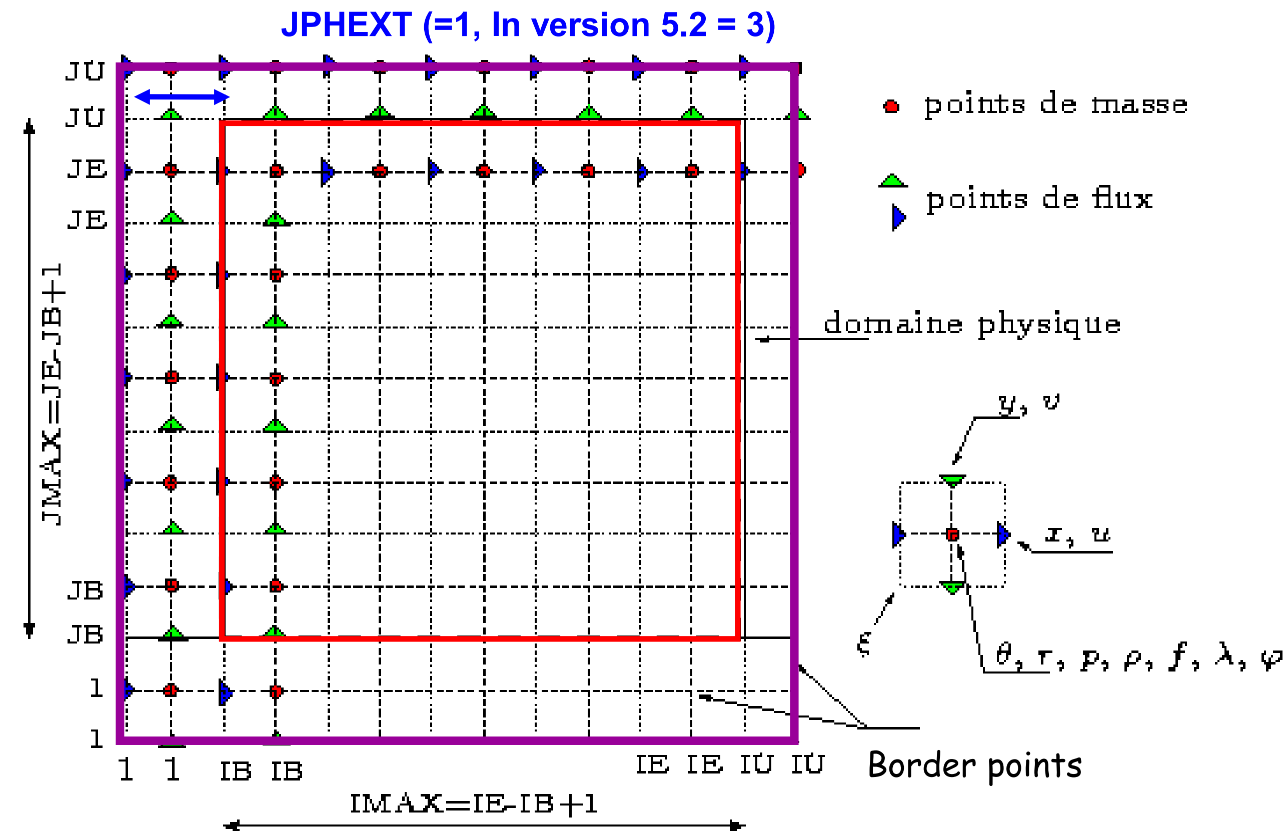
- Localization on the C grid of Arakawa (filtering of 2Δx waves)



A (Arome example)



Horizontal discretization



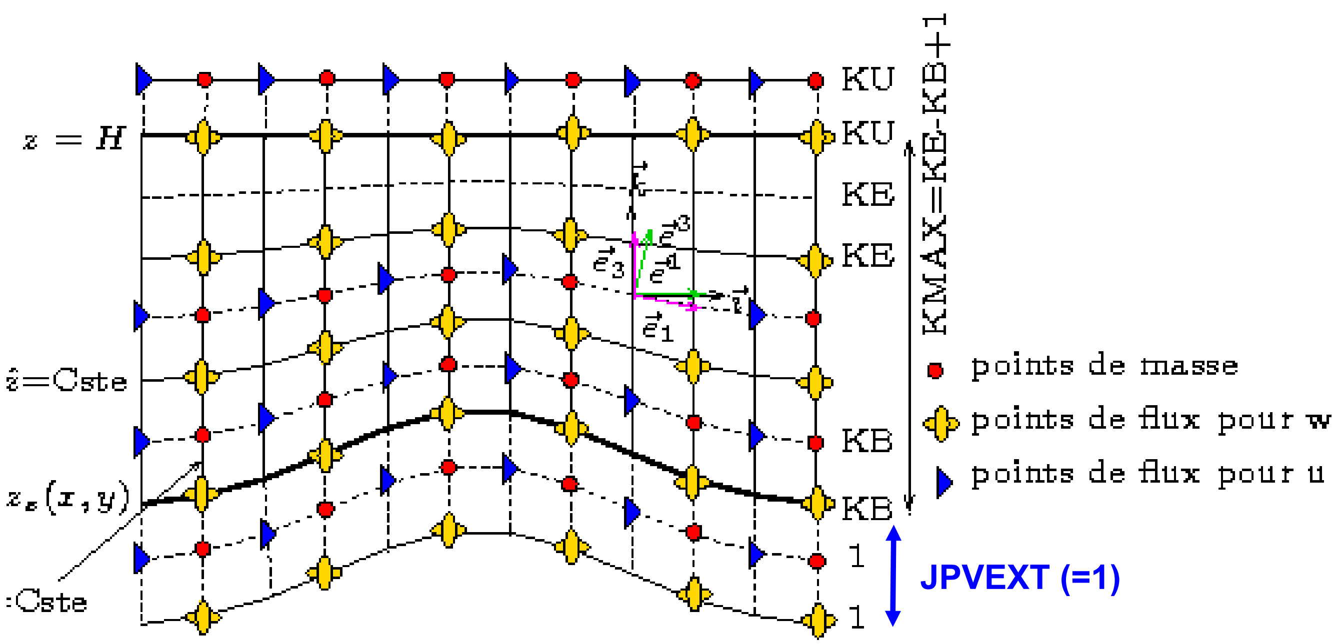
IB = 1+HEXT
JB = 1+HEXT

IE = IB+IMAX -1
JE = JB+JMAX -1

IU = IE+HEXT = IMAX + 2 HEXT
JU = JE+HEXT = JMAX + 2 HEXT

Vertical discretization

Gal Chen et Sommerville vertical coordinate $\hat{z} = \frac{z - z_s}{H - z_s} H$



Numerical schemes

Transport schemes (resolved transport)

Eulerian scheme, explicit, vertical coordinate following the terrain, flux formulation for the advection equation

$$\frac{\partial}{\partial t}(\rho\phi) = -\frac{\partial}{\partial x}(\rho U\phi) - \frac{\partial}{\partial y}(\rho V\phi) - \frac{\partial}{\partial z}(\rho W\phi)$$

Temporal discretization FIT : $(\rho\phi)_i^{t+\Delta t} = (\rho\phi)_i^t - \mathcal{F}_{x,i}(\phi^t)$

- C grid : → 2 transport schemes :
  - For meteorological and scalar variables
  - For wind components

Scalar variables transport (θ,r,tracers) :

PPM scheme (3[th] order, Colella and Woodward, 1984) (CMET_ADV_SCHEME and CSV_ADV_SCHEME = PPM_00 or PPM_01)

$$\mathcal{F}_{x,i}(\phi^t) = \frac{\Delta t}{\Delta x_i}\left[(\rho U)_{i+1/2} f(\phi^t)_{i+1/2} - (\rho U)_{i-1/2} f(\phi^t)_{i-1/2}\right]$$

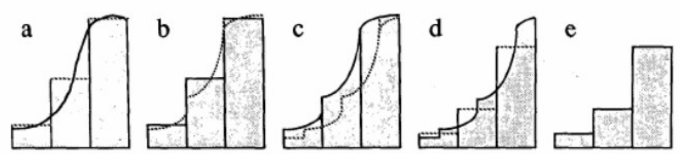


FIG. 5. Schematic illustration of the piecewise parabolic advection procedure. (a) From the initial distribution (solid curve), zone averages (dotted lines) are computed analytically. (This step is performed only at the beginning of the computations.) (b) Using the zone averages (solid lines), a parabola (dotted) is constructed within each zone. (c) The piecewise parabolic distribution is shown before (solid) and after (dotted) advection toward the right at a Courant number of approximately 0.5. (d) After advection, each parabola is integrated analytically to determine the new zone average (dotted). (e) The new zone averages are shown at the end of the time step (the beginning of the next time step). Adapted from van Leer (1977).

PPM conservative by construction, stable for Cr<1 +

monotonicity properties (so positive definite) with PPM_01

Transport of the wind by itself (CUVW_ADV_SCHEME) associated to the temporal scheme for wind advection (CTEMP_ADV_SCHEME)

$$\frac{\partial}{\partial t}(\tilde{\rho} u) = -\frac{\partial}{\partial x}(\tilde{\rho} U^c\, u) - \frac{\partial}{\partial y}(\tilde{\rho} V^c\, u) - \frac{\partial}{\partial z}(\tilde{\rho} W^c\, u)$$

1. **4th order centred scheme (CEN4TH)** : (CTEMP_ADV_SCHEME='LEFR')

- with Leap-Frog and a come-back to FIT

  Numerical diffusion necessary + Asselin temporal filter

  Accurate but not efficient (small time steps)

- with Runge -Kutta RKC4 **(Version 5.3)**

  (CTEMP_ADV_SCHEME='RKC4')

  Accurate and more efficient

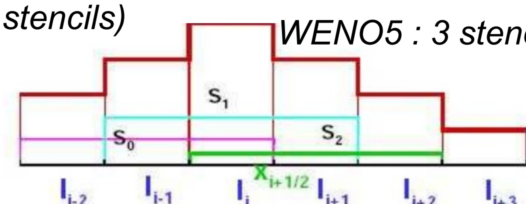
$$\begin{aligned} u_n^{(1)} &= u_n \\ u_n^{(k)} &= u_n + \Delta t \sum_{i=1}^{k-1} a_{k,i}\, f\left(t_n + c_i \Delta t, u_n^{(i)}\right) \\ u_{n+1} &= u_n + \Delta t \sum_{k=1}^{s} b_k\, f\left(t_n + c_k \Delta t, u_n^{(k)}\right) \end{aligned}$$

2. **WENO schemes** (Weighted Essentially Non Oscillating, Liu et al.(1994)) : WENO3 and WENO5 associated to RK53

   Linear combination of polynomial curves using stencils of r width (nb of meshes in a stencil) (WENO3 : 2 stencils)

   WENO5 : Version 5.2

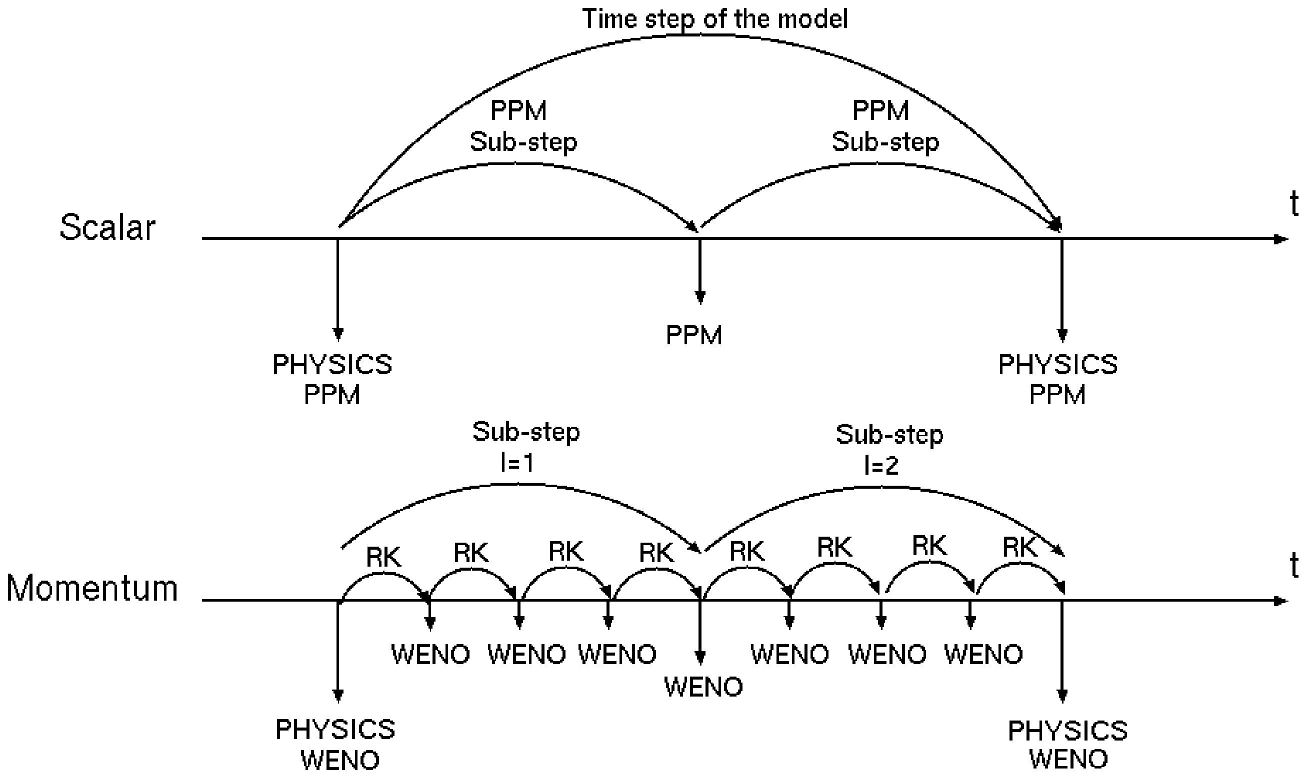
WENO5 : 3 stencils



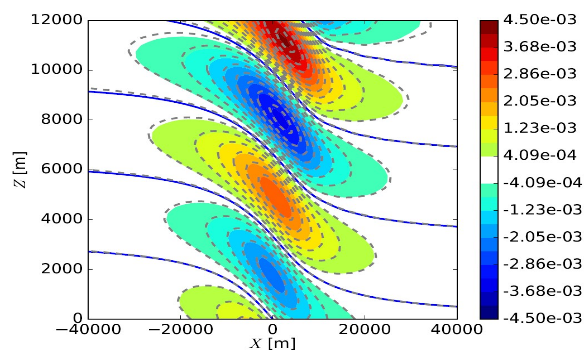
Conservative and non-oscillatory

Efficient (long time steps). WENO3 very diffusive

Optimization of the time step

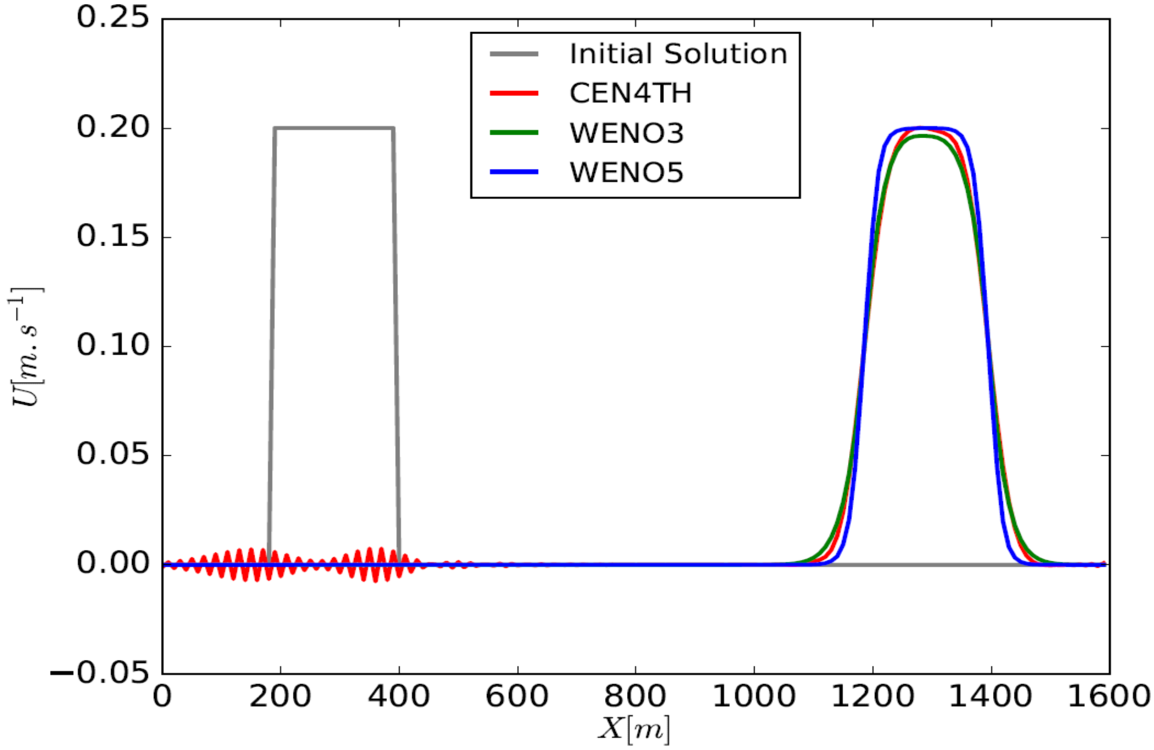


Hydrostatic orographic wave



CFL max :

	LF	RK53	RKC4
CEN4TH	0.4		1.7
WENO5 splitting=1		1.4	1.4
WENO5 splitting=2		1.8	1.8
WENO3 splitting=1		1.3	1.3
WENO3 splitting=2		2.5	2.4



Linear advection after 1000 s

Numerical diffusion
Spectrum tool

Meso-NH
mesoscale non-hydrostatic model

Numerical diffusion

Numerical damping to avoid energy accumulation for the shortest waves (around 2Δx) :

- Numerical diffusion : 4th order operator applied to the fluctuations of the prognostic variables (departure from the LS variables) (**XT4DIFF**)

Needed for dissipation : unavoidable BUT to use with moderation : otherwise will affect the accuracy and the effective resolution

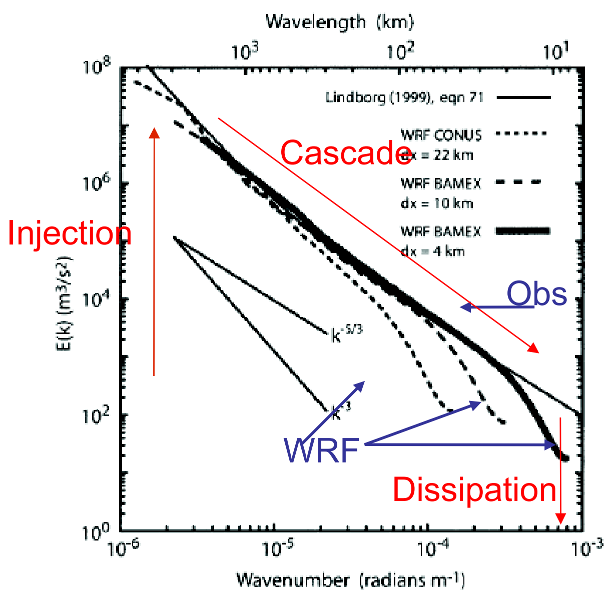
EXSEG1.nam : NAM_DYN LNUMDIFU
LNUMDIFTH

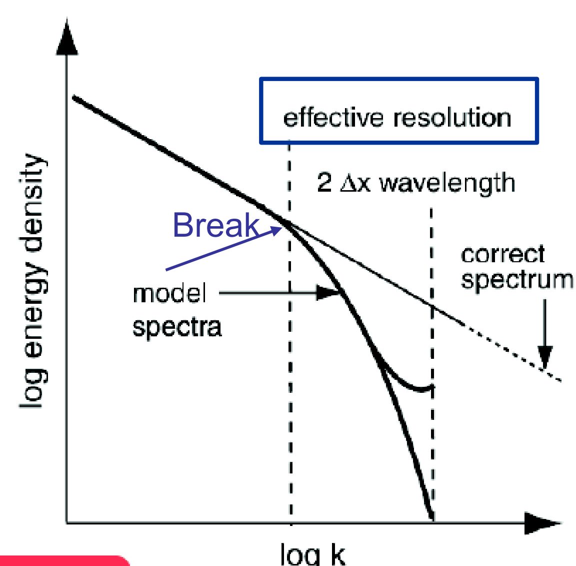
With CUVW_ADV_SCHEME= « CEN4TH » put LNUMDIFU=T
With CUVW_ADV_SCHEME= « WENO_K » put LNUMDIFU=F

With CMET_ADV_SCHEME= « PPM_xx » LNUMDIFTH=F

Energy spectra

Program SPECTRE





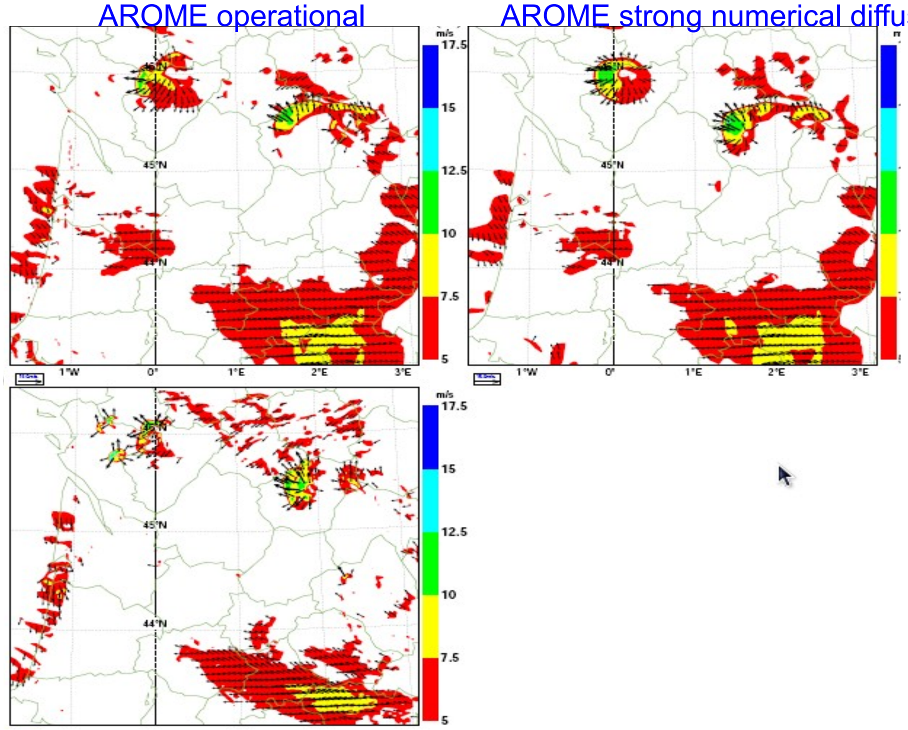
Spectre : prévisions avec le modèle WRF (Skamarock, 2004)

Example for WRF : effective resolution = 7Δx : e.g. 17km for Δx=2.5km

Isolated convective cells (11 april 2008) – Ricard et al., 2012, QJRMS

AROME operational | AROME strong numerical diffusion

Δx=2.5km

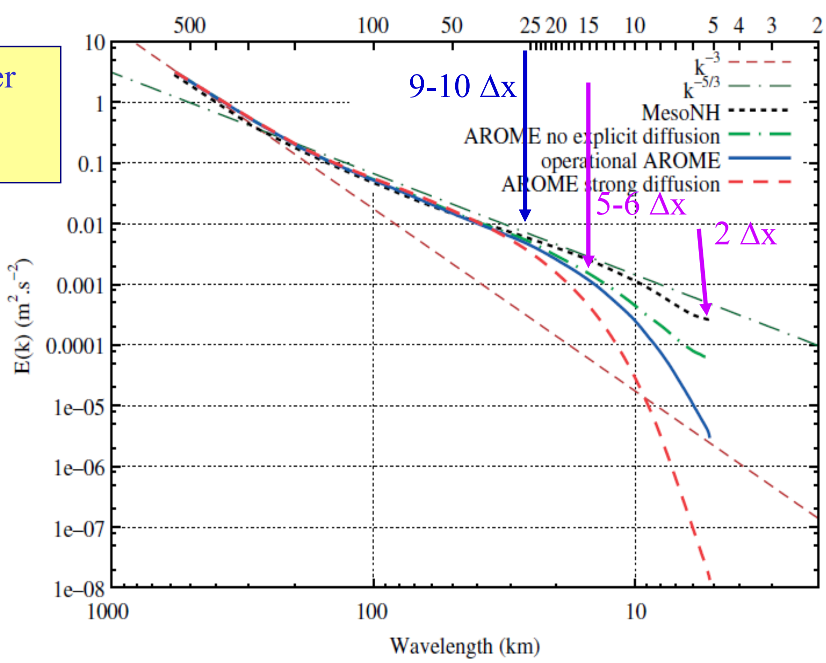


Méso-NH

4 – KE spectra

Comparison between AROME and MesoNH (case: April 2007)

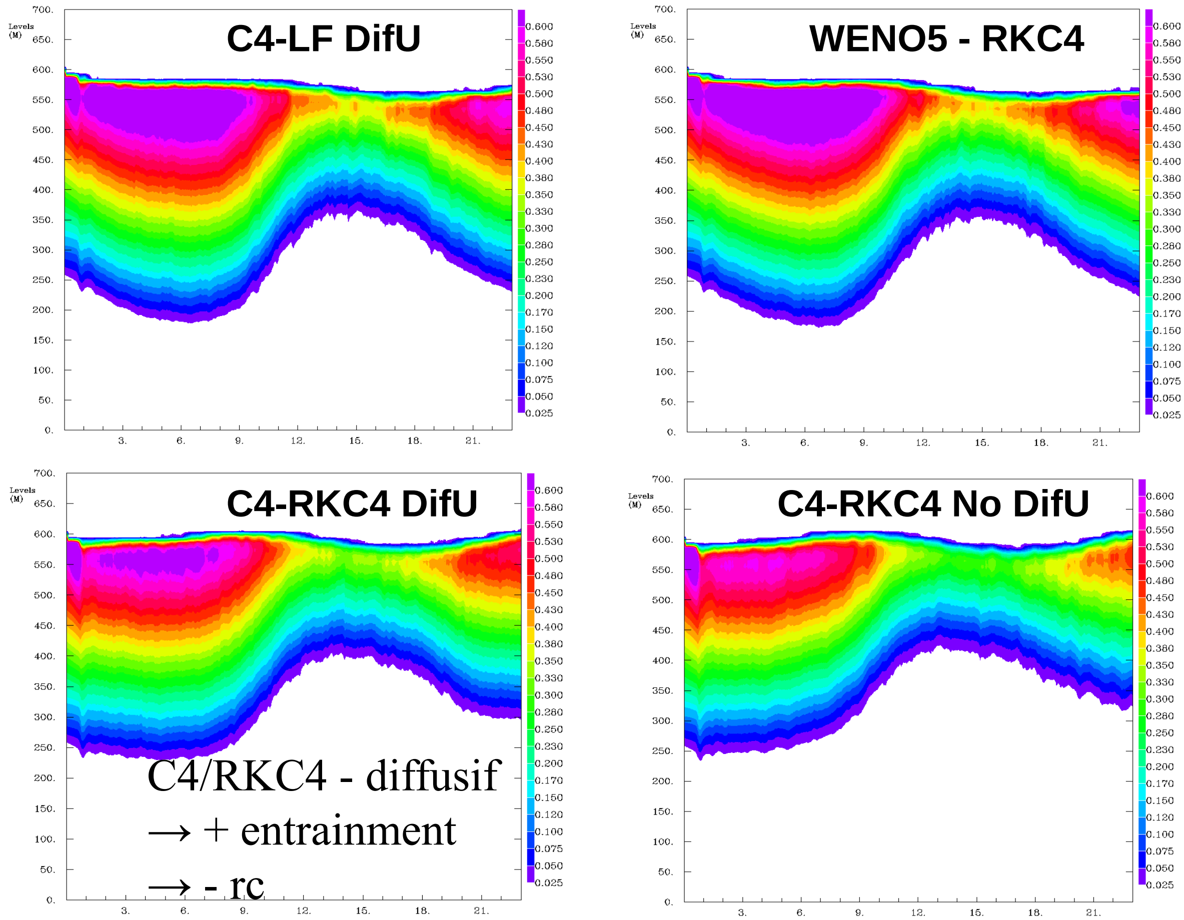
KE spectra (U,V) averaged over the free troposphere (3-9km) between 13 and 17 UTC

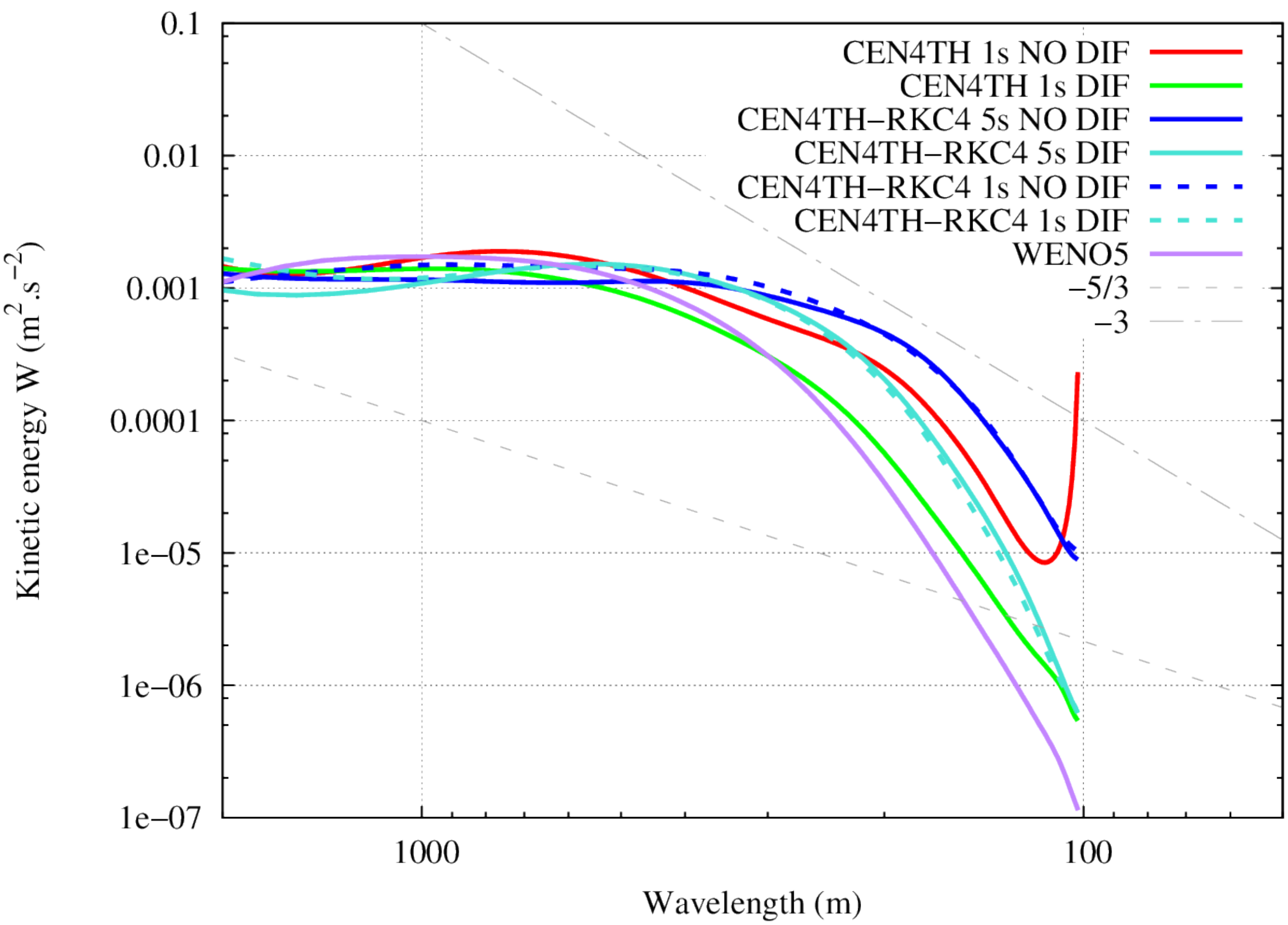


→ Effective resolution:

- MesoNH with CEN4TH : ~14 km ~ 5-6 Δx
- AROME: ~ 24 km ~9-10 Δx, variance loss more important

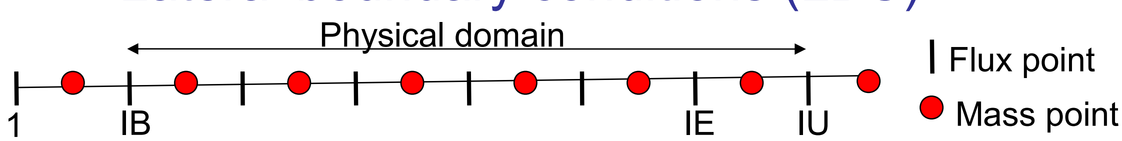
Cas FIRE : LES (Dx=50m)





Lateral boundary conditions

Lateral boundary conditions (LBC)



There are 3 types of LBC :

- **CYCLIC (for both sides)** :
  $\varphi(IB)=\varphi(IU)\ \ et\ \ \varphi(1)=\varphi(IE)$
- **RIGID WALL** : $\varphi(1)=\varphi(IB)\ \ et\ \ \varphi(IU)=\varphi(IE)$
  $u(IB)=u(IE)=0$

Conservation of the mass (without sedimentation)

- **OPEN : wave-radiative** (systematic in real case) :
  - *Scalaires and tangential velocity components* :
    - Outflow (given by the sign of Un): Extrapolation from the interior
    - Inflow : Interpolation between inside value and LS value
  - *Normal velocities (inflow and outflow):*

Non conservation of the mass

K=XCARPKMAX

$$\frac{\partial u_n}{\partial t} = \left(\frac{\partial u_n}{\partial t}\right)_{LB} - C^*\left(\frac{\partial u_n}{\partial x} - \left(\frac{\partial u_n}{\partial x}\right)_{LB}\right) - K\ (u_n - u_{nLB}), \qquad (5.4)$$

where the subscript LB stands for large-scale value of the field, C^* denotes the phase speed of the perturbation field $u_n - (u_n)_{LB}$, and K is the inverse of a damping time. The large scale gradient $(\partial u_n/\partial x)_{LB}$ and the time evolution $(\partial u_n/\partial t)_{LB}$ are specified by the coupling model. For idealized simulations including no larger-scale effects, they are of course set to zero.

Boundary conditions

- Lateral « sponge » : only for the father model, to slowly incorporate inward propagating LS waves (NAM_DYNn LHORELAX_xx, NRIMX, NRIMY, XRIMKMAX) (structure of « hippodrome ») : Rayleigh damping towards LS fields

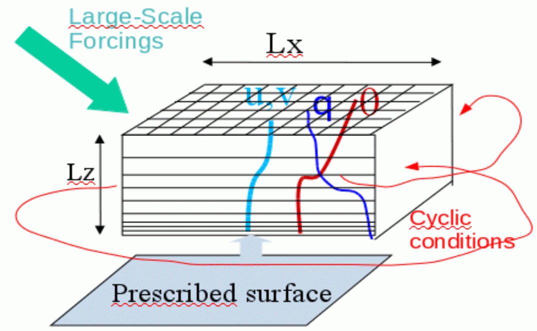
- The top and the bottom boundaries : slip conditions without friction (w=0)

- Top absorbing layer (NAM_DYN et NAM_DYNn LVE_RELAX,XALKTOP, XALZBOT) to prevent spurious reflection : Rayleigh damping towards LS fields

- In real cases : Initialization and coupling from the LS models : ARPEGE, ALADIN, ECMWF, AROME. Soon GFS (version 5.3)

Initial conditions

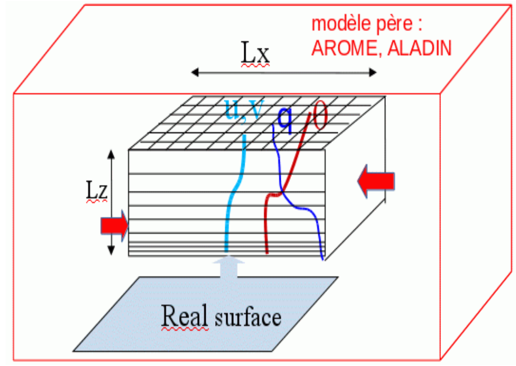
Idealized case



Input :
- U, V, T, HU initial profile
- Ug, Vg, T, HU forcing profile
- Prescribed surface

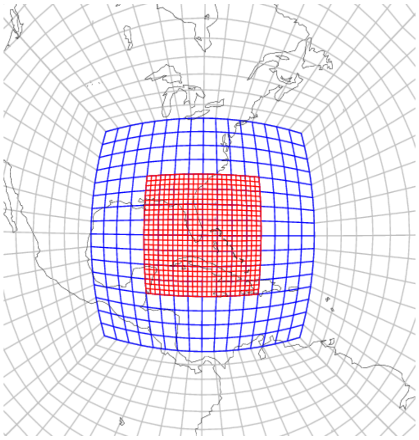
- Same initial and forcing conditions for all the points
- LBC : No orography, no horizontal gradient

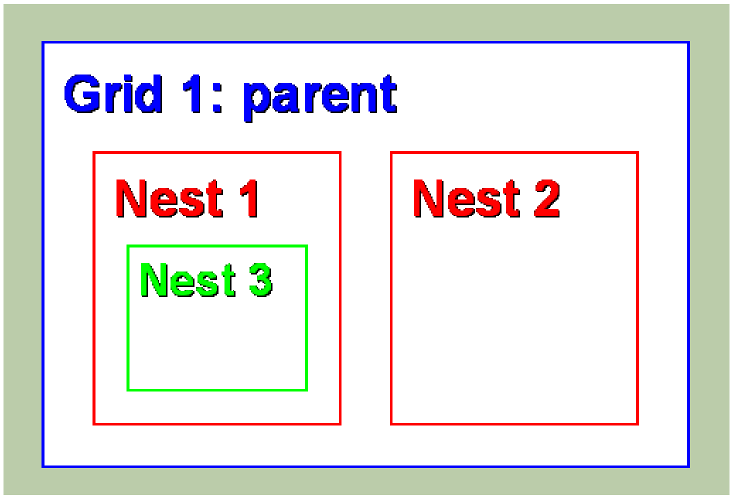
Real case



Input :
- Initial and coupling conditions on the whole domain from a LS model for the atmosphere and the surface

Grid nesting





Grid-nesting

Every time step of the father :

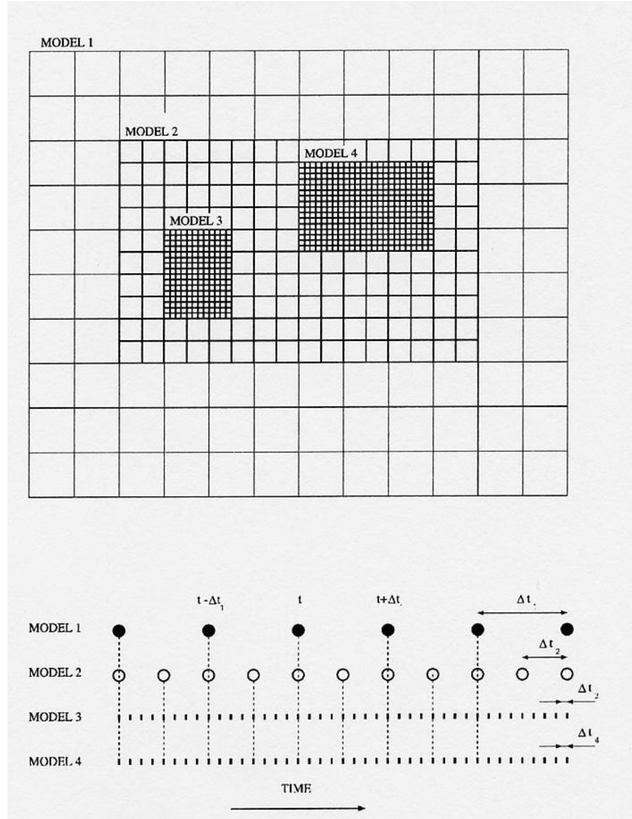
The father gives the LBC to the son by interpolation

One-way (XWAY=1) : The son doesn't influence the father : only father waves are allowed to enter and affect the son model

Two-way (XWAY=2) : Waves resolved by the son model can also affect the father model (all the 3D variables excepted TKE + 2D fields) on the common area : variables of the father are relaxed towards the son in the entire overlapping domain

Constraints :

- Integer Ratio between horizontal resolutions and between time steps
- The same vertical grid
- Only open BC for the son (no cyclic)



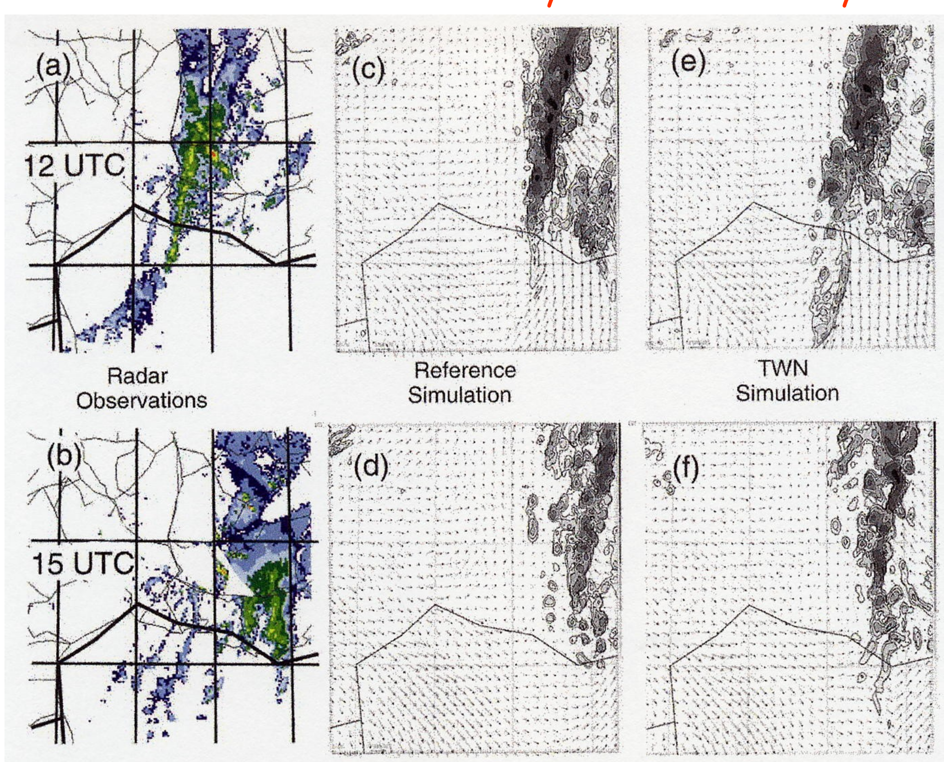
Vaison-la-Romaine : 22 september 1992

3 nested grids : 40/10/2.5km

Instantaneous precipitations 2.5km

One-way

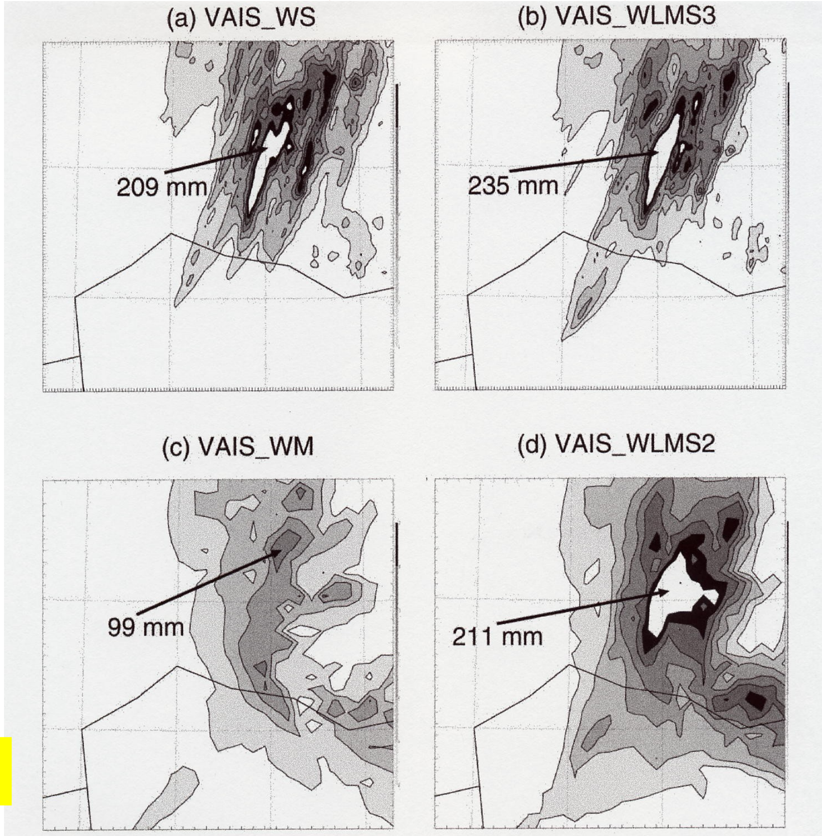
Two-way



Stein et al., 2000

Vaison-la-Romaine : 22 september 1992

One-way Two-way



2.5 km

Cumulated precipitations for 9h (Obs=300mm in 6h)

10km

Stein et al., 2000

EXSEG1.nam : NAM_NESTING XWAY(2)= NDTRATIO(2)=

DYNAMICS

	1980's		1990's			2000's			
Models	**MM5 PSU/NCAR**	**RAMS**	**MC2 UQM**	**ARPS U.Okl.**	**Meso-NH MF/LA**	**WRF NCAR/MMM**	**LM COSMO**	**UM UKMO**	**AROME MF**
Higher Resolution	**LES**	**LES**	**2km**	**LES**	**LES**	**LES**	**LES**	**1km**	**2.5km Up to 1km**
Hypothesis	NH Anelas	NH Anelas	NH Full compres	NH Full compres	NH Anelas	NH Full compres	NH Full compres	NH Full compres	NH Full compres
Spectral/ grid point	Grid	Grid	Spectral	Grid	Grid	Grid	Grid	Spectral	Spectral
Grid (Arakawa)	C	C	C	C	C	C	C	C	A
Advection scheme	Euler.	Euler.	SL	Euler.	Euler.	Euler.	Euler.	SL	SL
Temporal scheme	Explicit LF	Explicit LF	SI	Explicit LF	Explicit LF	Explicit Split	Explicit Split	SI	SI
Time step	**For 2.5km 8s**	**For 2.5km 8s**	**For 2.5km 60s**	**For 2.5km 6-8s**	**For 2.5km** **60s(15s):WENO 6s : CEN4TH-LF**	**For 2.5km 15s**	**For 2.5km 15s**	**For 2.5km 60s**	**For 2.5km 60s**
Nesting	**2 way**	**2 way**	**1 way**	**2 way**	**2 way**	**2 way**	**2 way**	**1 way**	**1 way**

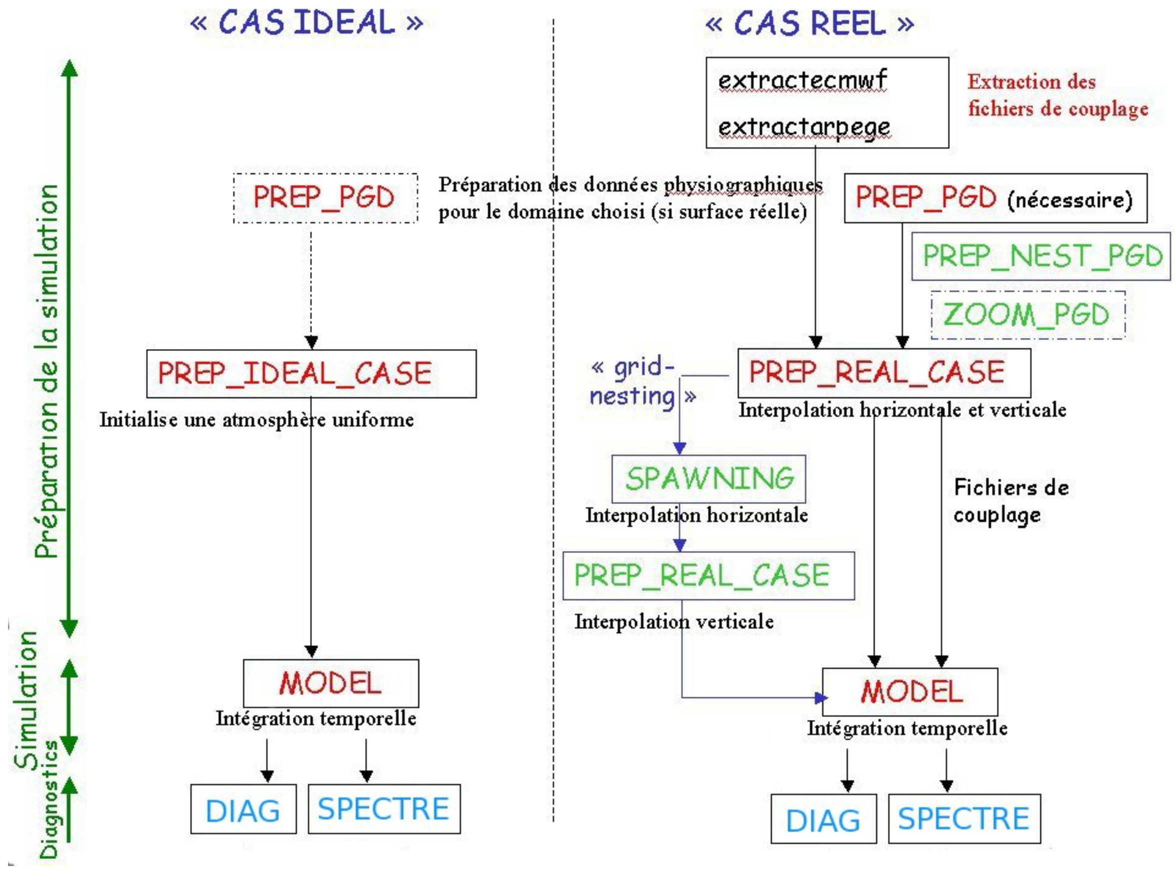
MesoNH environment

MesoNH Tutorial Class 3 - 5 Oct 2016

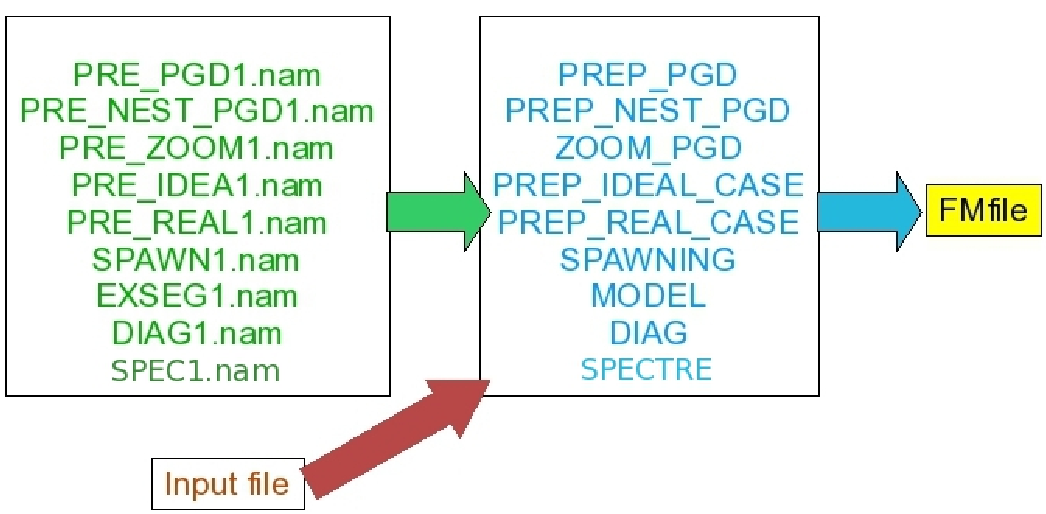
MESONH simulation = succession of elementary steps

Elementary steps :

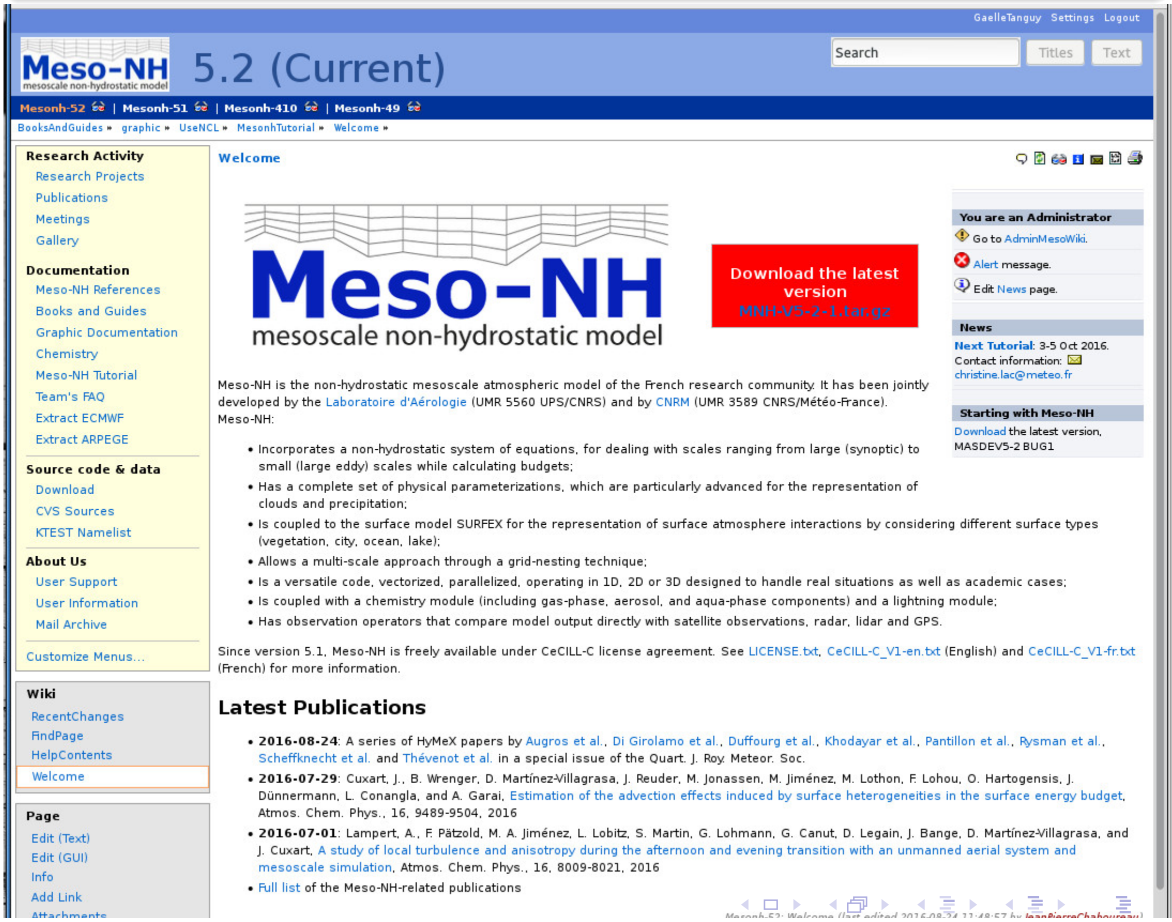
1. Preparation of physiographic file (PGD)
   - PREP_PGD
   - PREP_NEST_PGD
   - ZOOM_PGD
2. Preparation of the simulation
   - PREP_IDEAL_CASE
   - PREP_REAL_CASE
   - SPAWNING
3. Run
   - MODEL or MESONH
4. Diagnostics
   - DIAG
   - SPECTRE



Program and Namelists



http://mesonh.aero.obs-mip.fr/mesonh



Meso-NH files

MesoNH files

FM (File Manager)

storage format of data for I/o in the different program of MESONH

2 sorts of FM files :

- synchronous
- diachronics

with 2 parts :

- .des
- .lfi

Synchronous or diachronic ?

Synchronous file

- contains all the variables that describe atmosphere **at a given time** on the whole domain
- allows communication between the differents programs
- domain dimensions and time are identical for all the fields

a synchronous file could be converted in a diachronic file with : conv2dia

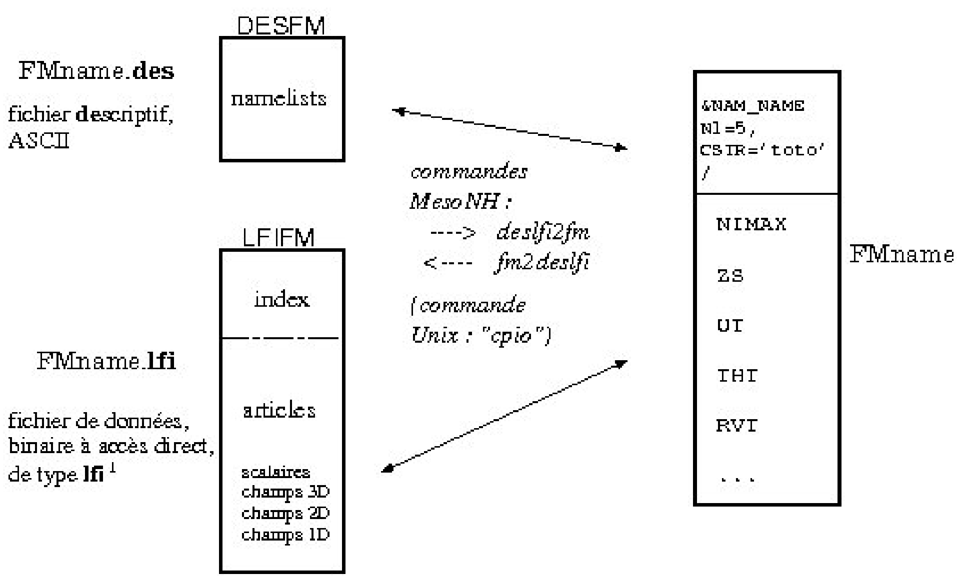
Synchronous or diachronic ?

Diachronic file

- contain some choosen variables (flux, tendancy, mean) stored at **differents times** during simulation in a part of the domain
- it is written by activation of "on-line" diagnostics : .000
- Every field is documented by 6 articles, which specify spatial domain, time, mask and processus

Diachronic format is the one who is used by MESONH tools (diaprog, extractdia, obs2mesonh, mesonh2obs...)

.des and .lfi parts



fm2deslfi fmname ⇒ fmname.des fmname.lfi
deslfi2fm fmname ⇒ fmname

Rq : in PGD files, .des part is empty

Fields' names

2D variables
ZS : [2D] orography (m) INPRR : [2D] instantaneous precipitations (mm/h) ACPRR : [2D] accumulated precipitations (m) PRCONV : [2D] instantaneous convective precipitations (mm/h) PACCONV : [2D] accumulated convective precipitations (m)
Pronostic dynamic variables
UT, VT : [3D] horizontal components of wind (m/s) WT : [3D] vertical component of wind (m/s) PABST : [3D] pression (Pa) THT : [3D] potential temperature (K) RVT : [3D] mixing ratio of vapor (kg/kg) RCT : [3D] mixing ratio of cloud water (kg/kg) RRT : [3D] mixing ratio of rain water (kg/kg) RIT : [3D] mixing ratio of ice (kg/kg) RST : [3D] mixing ratio of snow (kg/kg) RGT : [3D] mixing ratio of graupel (kg/kg) RHT : [3D] mixing ratio of hail (kg/kg) TKET : [3D] turbulent kinetic energy (m^2/s^2)

Fields' names

Large Scale variables
LSUM, LSVM, LSWM, LSTHM, LSRVM : [3D] (time-dependant if coupling files provided)
Physical schemes
DTHRAD : [3D] radiative tendancy for TH (K/s) DTHCONV : [3D] convective tendancy for TH (K/s) TSRAD : [2D] surface radiative temperature (K)

after DIAG, see fields' names in MesoNH user's guide (chap 10.2)

- fmmore fmname ⇒ return the list of articles present in the file + fmname.des
- lfiz fmname.lfi ⇒ fmname.Z.lfi : compressed file
- unlfiz fmname.Z.lfi ⇒ fmname.lfi : uncompressed file
- conv2dia⇒ convert a synchronous file in diachronic file
- diaprog ⇒ graphic software
- extractdia⇒ convert into netcdf, ascii...
- obs2mesonh⇒ to put observations on MESONH grid
- mesonh2obs⇒ to extract MESONH data on an observation grid

Mesonh Tools

MesoNH Tutorial Class 3 - 5 Oct 2016

How to get directly netcdf output file ?

- **for MNH-V5-2-0 and after :** A namelist too add in all the namelist file :

```
&NAM_CONFIO
  LCDF4=T
  LLFIOUT=T
  LLFIREAD=F  /
```

In output : one file .nc4

- versions 4-10 et 5-1
  - **before any compilation :** you have to set `MNH_NCWRIT` variable

```
export MNH_NCWRIT=MNH_NCWRIT
./configure
. ../conf/profile_mesonh
make
```

  - **in namelist :** (for each MESONH step)
    add namelist `&NAM_NCOUT LNETCDF=.TRUE. /`
    For DIAG, you can only have the netcdf
    file : `&NAM_NCOUT LNETCDF=.TRUE.  LLFIFM=.FALSE /`
  - The netcdf files have the same name as the lfi file but with the extension : .nc
    - *sf1.nc and *sf2.nc : surface fields
    - *ser.nc : series fields
    - *phy.ncf : fields written by phys_param.f90

Tools to convert lfi in netcdf

- extractdia : allows to extract fields from a diachronic file, on the whole domain or on a part of it, to interpole them (horizontal and/or vertical grid)(cases KCDL ZCDL and PCDL)
  use : see after
  output : file.nc
- lfi2cdf : conversion of the synchronus file in netcdf file
  use : lfi2cdf file
  output : file.cdf

Use of conv2dia

conv2dia allows to convert synchronus file into diachronic file

```
conv2dia
ENTER NUMBER OF INPUT FM FILES
ENTER FM FILE NAME
ENTER DIACHRONIC FILE NAME
DO YOU WANT TO COARSER RESOLUTION along X ? (y/n)
       Enter the ratio IX (1 point on IX points kept)
DO YOU WANT TO COARSER RESOLUTION ALONG Y ? (y/n)
       Enter the ratio IX (1 point on IX points kept)
DELETION OF PARAMETERS AT TIME t-dt ? (enter 1)
DELETION OF PARAMETERS AT TIME t    ? (enter 2)
NO DELETION                         ? (enter 0)
  Do you want to ELIM or to SELECT parameters ? (E/S)
```

All the directives are stored in a text file named : **dirconv**

extractdia

extractdia allows to extract fields from a diachronic file, on the whole domain or on a part of it, to interpole them (horizontal and/or vertical grid) and to write them in some other given format : diachronic, netcdf, grib, ascii, free format

```
DIAC  diachronic
LLHV  lon/lat/alt/val              IJHV    I/J/alt/val
llhv  lat/lon/alt/val              jihv    J/I/alt/val
LLZV  lon/lat/Z level/val          IJZV    I/J/Z/val
llzv  lat/lon/Z level/val          jizv    J/I/Z/val
LLPV  lon/lat/Pressure level/val   IJPV    I/J/P/val
llpv  lat/lon/Pressure level/val   ijpv    J/I/P/val
KCDL  netcdf with the model's levels
ZCDL  netcdf in Z levels           ZGRB   grib in Z levels
PCDL  netcdf in Pressure levels    PGRB   grib in P levels
FREE  free format defined by the user (FORTRAN)
```

all the directives are stored in a text file named : **dirextract**

extractdia

```
- Name of the diachro file (without .lfi) ?
- type of the output file
- Prints (0/1/2/3) ?
 - ZOOM ? (the questions are different for all the output format)
- List of these levels ? (only for Z or P interpolation)
- LALO/CONF ?
- Name of the group in upper case (13 characters max.)
```

- ASCII file begin with 3 heading lines
- For netcdf format, you must begin with the field with the largest dimension (3D before 2D)

obs2mesonh

obs2mesonh allows to replace observations on a MesoNH grid.

- The ouput file has diachronic FM format : it can be used as input for diaprog
- The input files are :
  - one or several ASCII files, each of it contains the values if one type of observation
  - a diachronic file whose grids will be used to replace previous observation values

all the directives are stored in a text file named : **dirobs2mnh**

obs2mesonh

```
- Name of the diachro file to read the grid ?
- Prints ( 0/1/2/3)
- Name of the output file ?

- Format of the input observation file:
  LL=   n lines Lon,Lat,val
  ll=   n lines lat,lon,val
  DLL=  date (YYYYMMDDHHMISS) then n lines Lon,Lat,val
  Dll=  date (YYYYMMDDHHMISS) then n lines lat,lon,val
  LLa=  n lines Lon,Lat,alt(m),val
  lla=  n lines lat,lon,alt(m),val
  DLLa= date (YYYYMMDDHHMISS) then n lines Lon,Lat,alt(m),val
  Dlla= date (YYYYMMDDHHMISS) then n lines lat,lon,alt(m),val
 (END to stop)?

- Name of the input observation file ?
- Name of the new field to be created ?
(if the first letter is:
  W: the field is localised at vertical flux points, otherwise at mass points
  U: the field (U-component for zonal) will be converted to MesoNH wind compone
     the V-component must be provided immediately after
- Unit of the new field ?
- Profil of the new field (3D/2D/1D)?
```

mesonh2obs

mesonh2obs allows to interpolate MesoNH fields at given points

- Output file is an ASCII file
- The input files are :
  - an ASCII file indicated the position of the points
  - a diachronic file with fields to interpolate at previous points

all the directives are stored in a text file named : **dirmnh2obs**

mesonh2obs

```
- Format of the output file:
  (and of the input observation file
   with positions)
  Lon-Lat-Height(MNH)-Value= LLHV
  lat-lon-height(MNH)-value= llhv
  Lon-Lat-Z(m)-Value       = LLZV
  lat-lon-Z(m)-value       = llzv
  Lon-Lat-P(hPa)-Value     = LLPV
  lat-lon-P(hPa)-value     = llpv

- Name of the file which contains
  the localisation of the obs ?
- Prints 0/1/2/3
- Name of the diachro file ?
- Name of the group in upper case ?
```

Example of directives

llhv
obscoordlatlon
1
MAP_IOP3d.Z
THT
T2M
THETAE
END
END

diaprog

diaprog graphical tools to treat diachronic file

- diaprog stores images in a file named `gmeta`.
  - to visualise images : `idt gmeta`

You have to rename it before use diaprog again

all the directives are stored in a text file named : **dir.date :hh :mm**

Directives

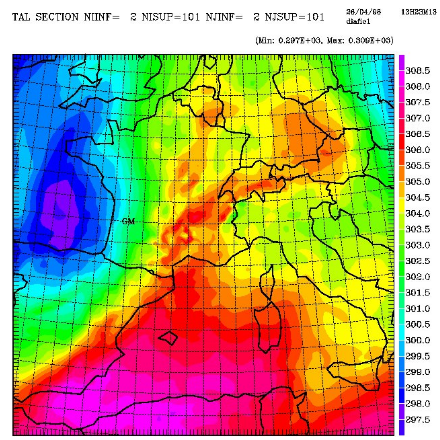
- 80 characters maximum
  - & : characters to continue on a second line
- they are composed by keywords between "_ _"
- respect a strict syntax
- converted in upper case except :
  - file name
  - process name
- fortran character !

General directives

- Open a file
  - _FILE_'filename'
  - _FILE2_"filename2"
- open a graphic window : VISU
- Directives to scan file
  - print groups : print all the group names in the file
  - print *groupname* dim proc time : print informations for the group "groupname"
  - print filecur : print the name of the current file
- To superpose fields _ON_

horizontal section (chapter 3)

- **_K_** : on an model level
- **_PR_** : on an isobaric level
- **_Z_** : on an altitude level
- **_TK_** : on an isentropic level
- **_EV_** : on an potential vorticity level
- **_SV3_** : on any level

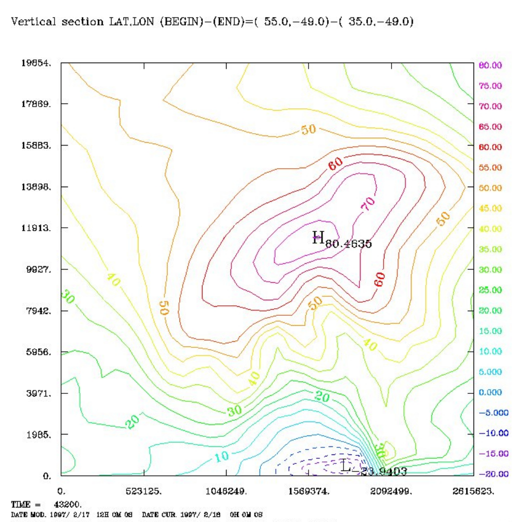


THT_Z_3000

Vertical section : _CV_ (chapter 4)

defined by 4 different ways :

- Origin + angle + number of points
  - grid index
  - conformal coordinate
- Extremity
  - grid index
  - conformal coordinate
  - geogrpahic coordinate



VTT_CV_

Horizontal profile (chapter 5)

- parallell to the axes (NIINF-NISUP / NJINF-NJSUP)
- other orientation (intersection of a horizontal section and a vertical one)

Vertical profile : _PV_ (chapter 6)

- defined by a vertical section and localisation of the profile : PROFILE=

Radio-sounding : _RS_ (chapter 7)

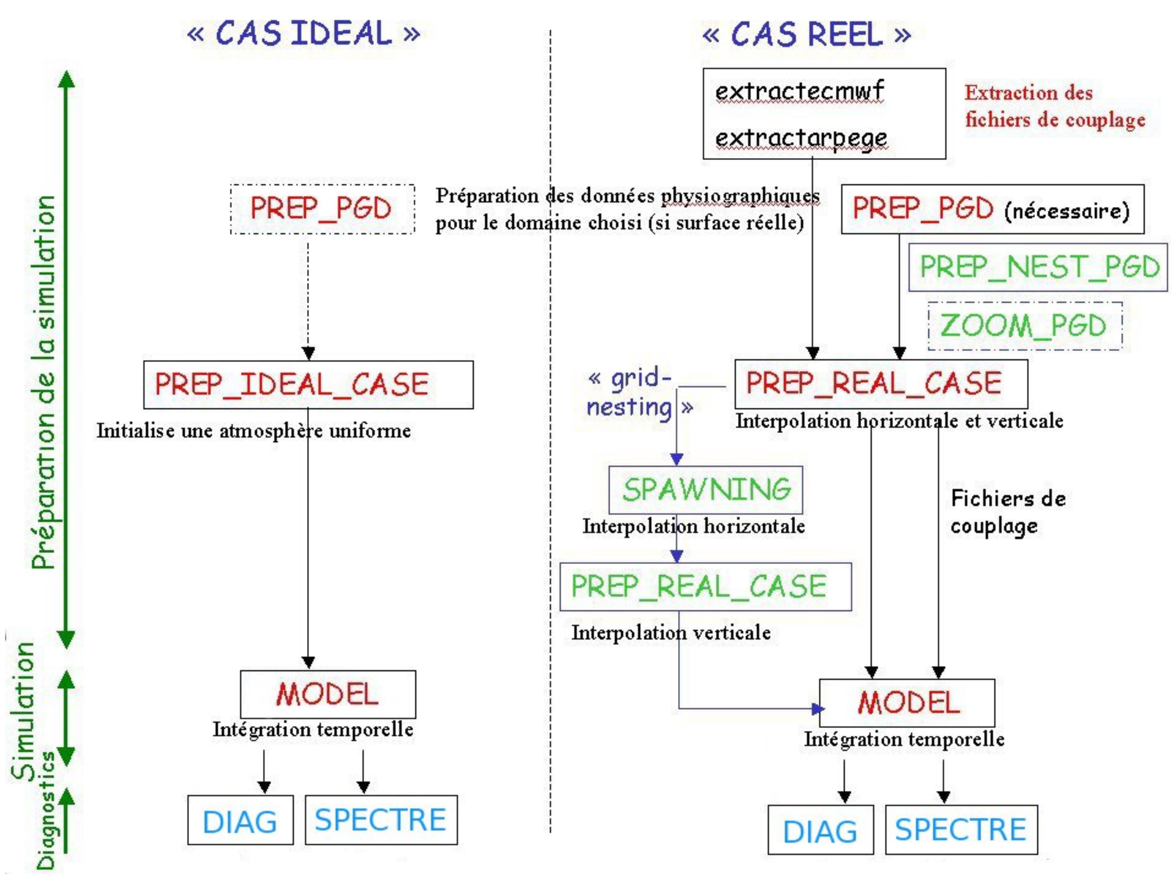
- NIRS= NJRS= ou XIRS= XJRS=

Operations on fields (chapter 9)

- sum or multiplication by a constant value
- sum or difference between 2 fields _MINUS_ _PLUS_
- multiplication or division of a field by an other *expr1= /expr1=

Real case

MesoNH Tutorial Class 3 - 5 Oct 2016



One-domain simulation

Creation of PGD file

Program PREP_PGD

interpolation on horizontal grid of input fields
Output PGD : FM file with projection, domain and 2D fields

45 input files for :

- orography
- cover
- sand fraction
- clay fraction

Namelist PRE_PGD1.nam

```
&NAM_PGDFILE CPGDFILE='PGD_DAD' /PGD file name

&NAM_CONF_PROJ XLAT0=37., XLON0=5.1, lat/lon reference
      cone factor  XRPK=0.58, XBETA=0 /rotation angle

&NAM_CONF_PROJ_GRID XLATCEN=38., XLONCEN=5., center lat/lon
                    NIMAX=12, NJMAX=10, number of points in I and J
                    XDX=2000., XDY=2000. /ΔX and ΔY

&NAM_PGD_SCHEMES CNATURE='ISBA', CSEA='SEAFLX',
surface schemes     CWATER='WATFLX', CTOWN='TEB' /

&NAM_COVER YCOVER='ecoclimats_v2', YFILETYPE='DIRECT' /
&NAM_ZS YZS='gtopo30', YFILETYPE='DIRECT' /
&NAM_ISBA YCLAY='clay_fao', YCLAYFILETYPE='DIRECT' ,
          YSAND='sand_fao', YSANDFILETYPE='DIRECT' /

&NAM_CH_EMIS_PGD /
&NAM_DUMMY_PGD /
```

NIMAX and NJMAX must be equal to $2^n\ 3^m\ 5^p$

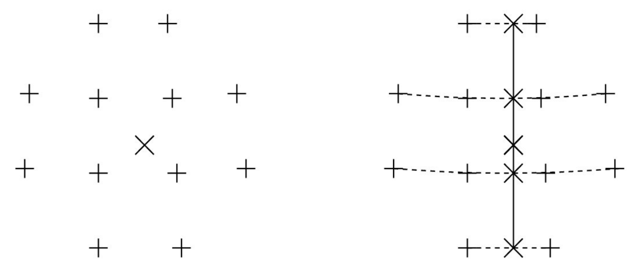
Atmospherical fields

Atmospherical data are issued from :

- model forecasts (GRIB) :
  - CEPMMT : **extractecmwf**
  - ARPEGE, ALADIN, AROME, MOCAGE : **extractarpege**
- on other MESONH simulation (low resolution simulation)

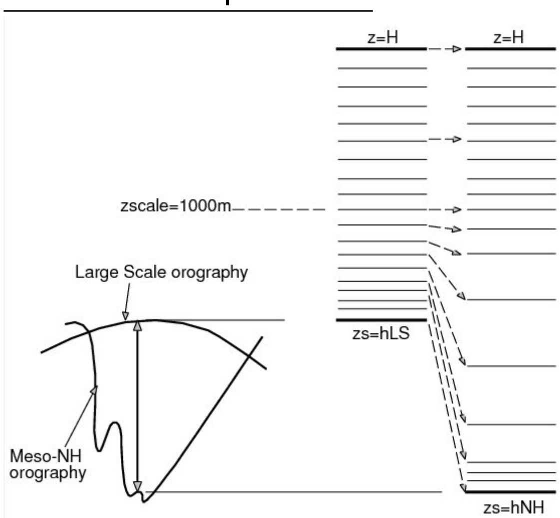
PREP_REAL_CASE

- Horizontal interpolation
  for GRIB files (CEPMMT,ARPEGE, ALADIN, AROME ou MOCAGE) : interpolation (U,V,T,q,Ps, 2D fields) on PGD grid from the nearest 12 points.



PREP_REAL_CASE

- Vertical interpolation



déplacement vertical selon la fonction 'shift'

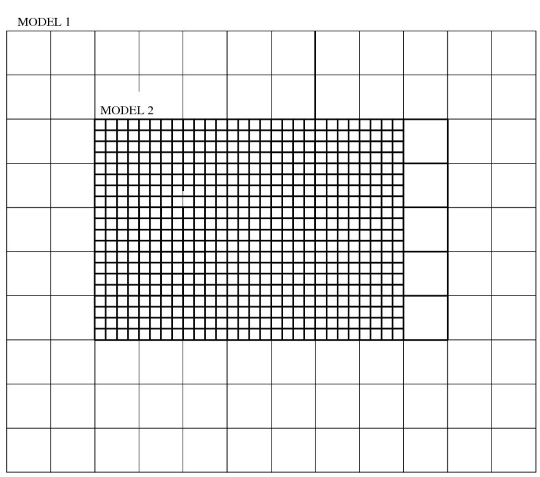
entre hLS et zscale

Namelist PRE_REAL1.nam

It must be made for initial file and all coupling files

```
&NAM_FILE_NAMES
     HATMFILE ='aladin.FC.20110128.21' ,atmospherical file
     HATMFILETYPE='GRIBEX',type of atmospherical file
     HPGDFILE ='PGD_DAD' ,PGD file name
     CINIFILE='28JANVIER_21H' /name of output file

&NAM_VER_GRID NKMAX=30,number of points in Z
              YZGRID_TYPE='FUNCTN',FUNCTN or MANUAL
              ZDZGRD=60., ZDZTOP=700.,ΔZ at ground/at top
              ZZMAX_STRGRD=2500., Height for streching change
              ZSTRGRD=9.,ZSTRTOP=7. /streching at ground/at top

&NAM_BLANK /
```

two-domain simulation



2 domains simulation : Grid-nesting

We need :

- a PGD file for every models
- All the PGDs must satisfy condition on orography : PREP_NEST_PGD (the mean of orogrpahy for a SON file in a domain corresponding to the grid mesh of its DAD file must be equal to the orography of the dad file in this mesh)

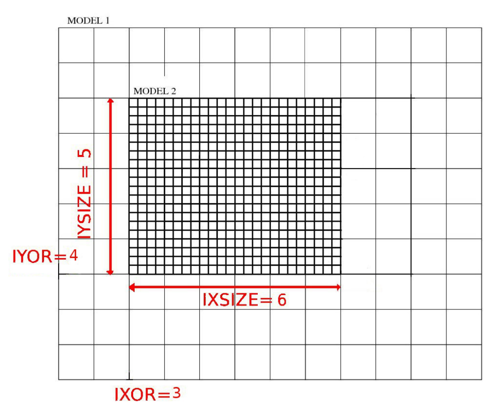
ALL PGD FILES MUST BE MADE AND "NESTED" BEFORE THE SIMULATION

- prepare inital file for the son's domain(s)
  - SPAWNING : horizontal interpolation of 3D fields from dad's model to son's model
  - PREP_REAL_CASE :vertical interpolation from DAD to SON
- a file EXSEGn.nam for every domain

son's PGD : PREP_PGD

- PRE_PGD1.nam :

```
&NAM_PGDFILE
   CPGDFILE='PGD_SON' /

&NAM_CONF_PROJ /

&NAM_CONF_PROJ_GRID /

&NAM_PGD_GRID
   YINIFILE='PGD_PERE',
   YFILETYPE='MESONH' /
```




```
&NAM_INIFILE_CONF_PROJ IXOR=3, IYOR=4,
                       IXSIZE=6, IYSIZE=5,
                       IDXRATIO=4, IDYRATIO=4 /

&NAM_COVER YCOVER='ecoclimats_v2', YFILETYPE='DIRECT' /
&NAM_ZS YZS='gtopo30', YFILETYPE='DIRECT' /
&NAM_ISBA YCLAY='clay_fao', YCLAYFILETYPE='DIRECT' ,
          YSAND='sand_fao', YSANDFILETYPE='DIRECT' /
```

PREP_NEST_PGD


```
&NAM_PGD1 YPGD1= 'PGD_DAD' /DAD PGD file
&NAM_PGD2 YPGD2= 'PGD_SON' , IDAD = 1 /
                     First SON PGD file / number of the DAD file
&NAM_PGD3 /
...
&NAM_PGD8 /
&NAM_NEST_PGD YNEST= 'e1' /string of 2 characters to be added to the PGD file names
to define the corresponding output PGD file names
```

SPAWNING

```
&NAM_GRID2_SPA /
&NAM_LUNIT2_SPA CINIFILE = '28JANVIER_21H' ,
               name of initial FM file
                CINIFILEPGD = 'PGD_DAD.neste1',
               PGD file associated to CINIFILE
                YDOMAIN = 'PGD_SON.neste1',
               PGD file name (output domain)
                YSPANBR = '04' /
               number to generate output file name : .spa04
&NAM_BLANK /
```

The SPAWNING stage must be followed by **PREP_REAL_CASE**

PREP_REAL_CASE

PRE_REAL1.nam :

```
&NAM_FILE_NAMES
     HATMFILE ='28JANVIER_21H.spa04',
     HATMFILETYPE='MESONH',
     HPGDFILE ='PGD_SON.neste1',
     CINIFILE ='28JAN21H_MODEL_2' /

&NAM_REAL_CONF NVERB=5 /

&NAM_VER_GRID YZGRID_TYPE='SAMEGR' /

&NAM_PREP_SURF_ATM
      CFILE = '28JANVIER_21H',
      CFILETYPE = 'MESONH' ,
      CFILEPGD="PGD_PERE.neste1",
      CFILEPGDTYPE = 'MESONH' /
```

Namelist

Principe

One namelist EXSEG**n**.nam for each model

Model 1 (dad) : EXSEG1.nam

Namelist ended by **n** are relative to model 1
Other namelists are common for all models

Modele 2 (son) : EXSEG2.nam

There is only an initial file (no coupling file)
Only namelist ended by **n** are taken in account

file EXSEG1.nam

```
&NAM_LUNITn CINIFILE = "28JANVIER_21H",
            CINIFILEPGD = "PGD_PERE.neste1"/
            CCPLFILE(1) = "29JANVIER_00H"/

&NAM_DYNn XTSTEP = 60., CPRESOPT = "CRESI",
          NITR=8,LHORELAX_UVWTH = T,
          LHORELAX_RV = T, LVE_RELAX = T,
          NRIMX = 5, NRIMY = 5, XRIMKMAX = 0.0083 /

&NAM_ADVn CUVW_ADV_SCHEME = "WENO_K",
          NWENO_ORDER=5 CTEMP_SCHEME='RK53',
          CMET_ADV_SCHEME = "PPM_01" /

&NAM_PARAMn CTURB = "TKEL", CRAD = "ECMW",
            CSCONV = "KAFR", CDCONV = "KAFR",
            CCLOUD = "KESS"/
```

```
&NAM_PARAM_RADn XDTRAD = 3600.,
                XDTRAD_CLONLY = 3600.,
                NRAD_COLNBR = 400 /

&NAM_PARAM_KAFRn XDTCONV = 300., NICE = 1,
                 LREFRESH_ALL = T, LDOWN = T /

&NAM_LBCn CLBCX = 2*"OPEN", CLBCY = 2*"OPEN" /

&NAM_TURBn CTURBLEN = "BL89",
           CTURBDIM = "1DIM",
           LSUBG_COND = F /

&NAM_CONF CCONF = "START", NMODEL = 2,
          NVERB = 5,
          CEXP = "CTRL0", CSEG = "SEG01" /

&NAM_DYN XSEGLEN = 400., LCORIO = T,
         XALKTOP = 0.001, XALZBOT = 14500. /
```

```
&NAM_NESTING NDAD(2) = 1,
             NDTRATIO(2) = 4,
             XWAY(2) = 2. /

&NAM_FMOUT XFMOUT(1,1) = 100., XFMOUT(1,2) = 200.,
           XFMOUT(1,3) = 300., XFMOUT(1,4) = 400.,
           XFMOUT(2,1) = 100., XFMOUT(2,2) = 200.,
           XFMOUT(2,3) = 300., XFMOUT(2,4) = 400. /

&NAM_CONFIO LCDF4=T LLFIOUT=T LLFIREAD=F /
&NAM_ISBAn CSCOND = "NP89", CALBEDO = "DRY",
           CC1DRY = 'DEF', CSOILFRZ = 'DEF',
           CDIFSFCOND = 'DEF', CSNOWRES= 'DEF' /

&NAM_SGH_ISBAn CRUNOFF = "WSAT"/

&NAM_SEAFLUXn CSEA_ALB="UNIF" /
```

file EXSEG2.nam

```
&NAM_LUNITn CINIFILE = "28JAN21H_MODEL_2"/
            CINIFILEPGD = "PGD_FILS.neste1"/

&NAM_DYNn CPRESOPT = "CRESI",
         LHORELAX_UVWTH = F, LHORELAX_RV = F,
         LHORELAX_RC= F, LHORELAX_RR= F,
         LHORELAX_RS= F, LHORELAX_RI= F,
         LHORELAX_RG= F, LHORELAX_TKE= F,
         LVE_RELAX = T,NITR=8,
         NRIMX = 0, NRIMY = 0 /

&NAM_ADVn CUVW_ADV_SCHEME = "WENO_K",
          CMET_ADV_SCHEME = "PPM_01" /

&NAM_PARAMn CTURB = "TKEL", CRAD = "ECMW",
            CSCONV = "KAFR", CDCONV = "KAFR",
            CCLOUD = "KESS"/
```

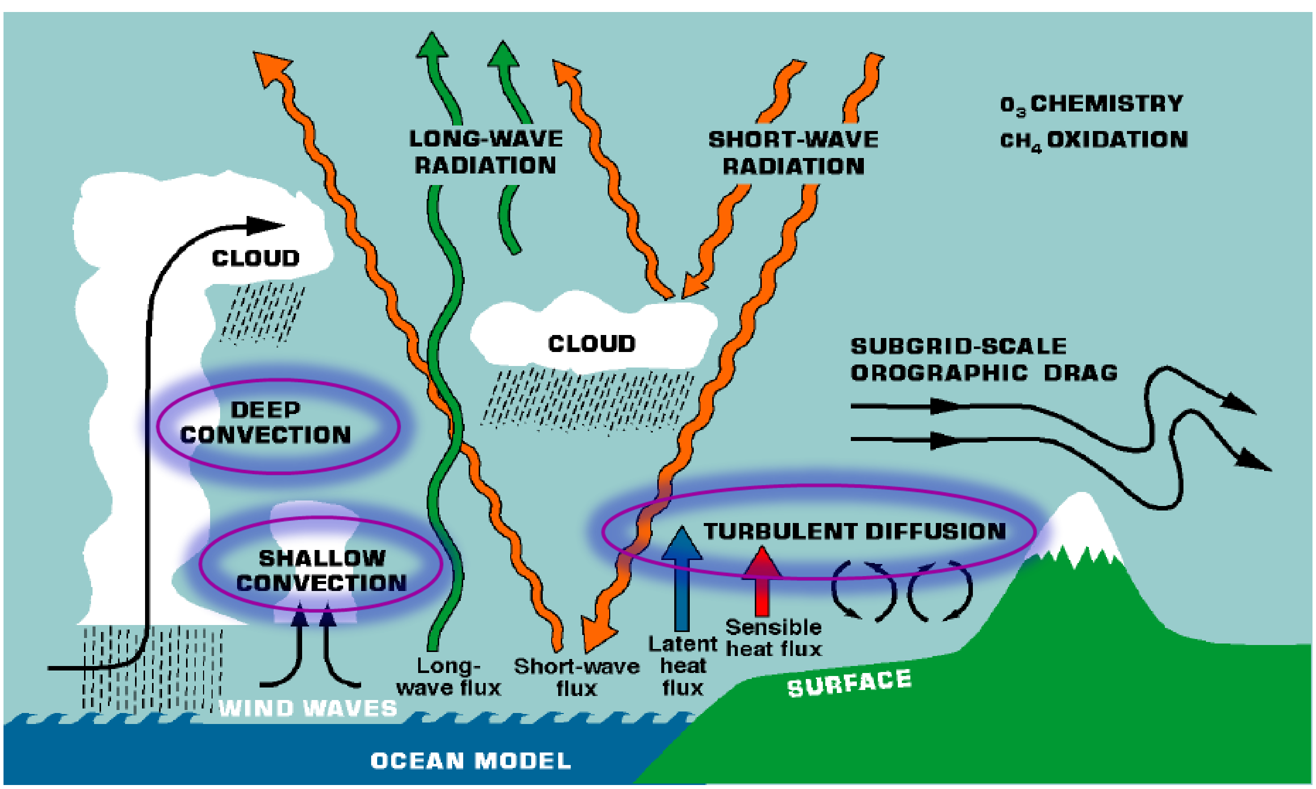
```
&NAM_PARAM_RADn XDTRAD = 1800.,
                XDTRAD_CLONLY = 1800.,
                LCLEAR_SKY = F, NRAD_COLNBR = 400 /

&NAM_PARAM_KAFRn XDTCONV = 300., NICE = 1,
                 LREFRESH_ALL = T, LDOWN = T /

&NAM_LBCn CLBCX = 2*"OPEN", CLBCY = 2*"OPEN",
          XCPHASE = 20. /

&NAM_TURBn XIMPL = 1., CTURBLEN = "BL89",
           CTURBDIM = "1DIM",
           LSUBG_COND = F /

&NAM_ISBAn CSCOND = "NP89", CALBEDO = "DRY",
          CC1DRY = 'DEF', CSOILFRZ = 'DEF',
          CDIFSFCOND = 'DEF', CSNOWRES= 'DEF'/

&NAM_SGH_ISBAn CRUNOFF = "WSAT"/

&NAM_SEAFLUXn CSEA_ALB="UNIF" /
```

PHYSICS

PHYSICS : Part of the model that deals with diabatic processes, water state changes, subgrid processes, surface interaction.

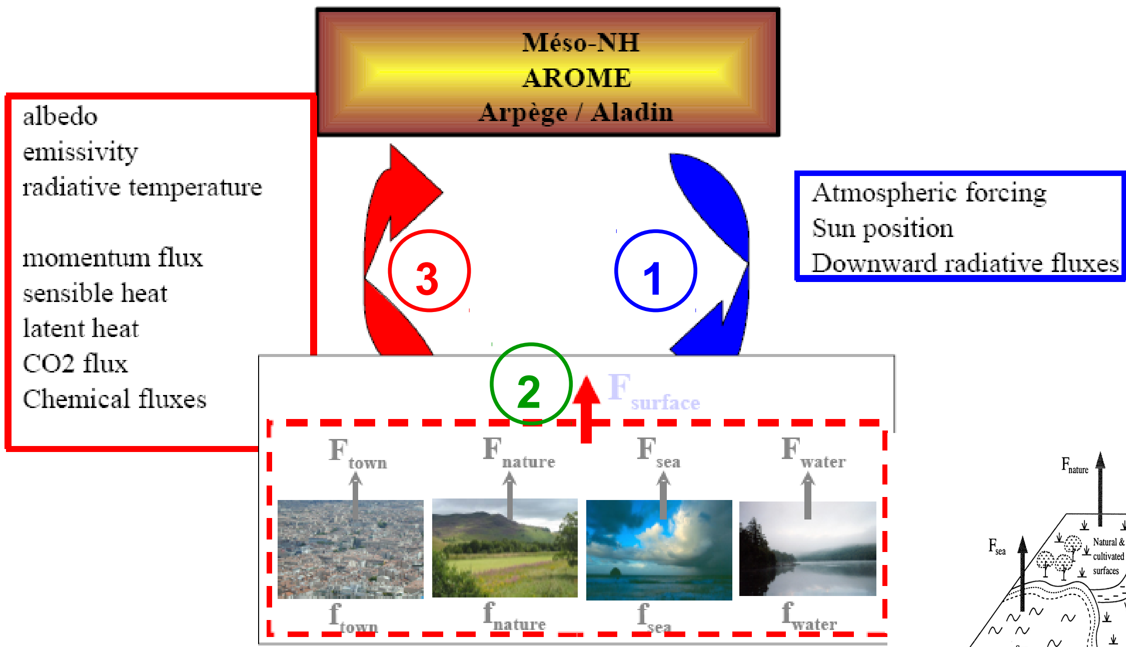
- MICROPHYSICS
- CONVECTION
- TURBULENCE
- RADIATION
- SURFACE (externalised)
- CHEMISTRY

Processes that need to be parametrized



The SURFEX (SURface Externalized) land surface scheme

Exchanges of flux and atmospheric forcing at each time step



see Rui's presentation

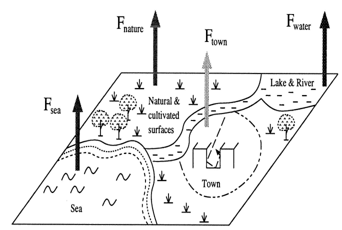
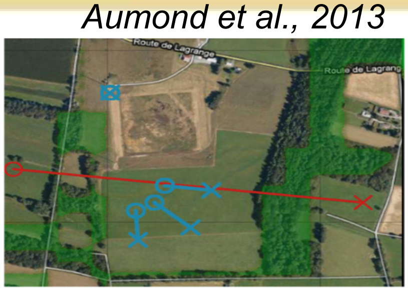


Figure 15.1: Partitioning of the MESO-NH grid box, and corresponding turbulent fluxes. F stands either for M (momentum flux), H (sensible heat flux), LE (latent heat flux), $S^{\uparrow}$ (the reflected solar radiation) or $L^{\uparrow}$ (the upward longwave radiation).

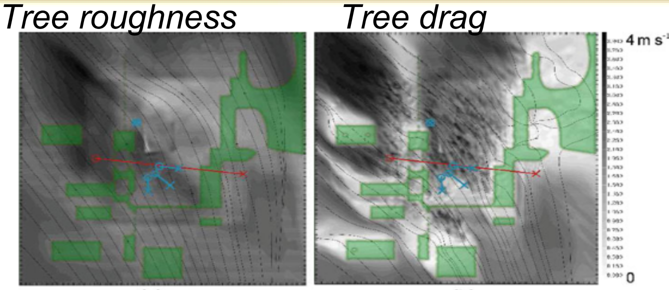
CNRM-GAME

Surface heterogeneities with LES

Aumond et al., 2013

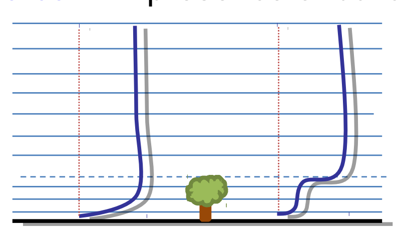


Tree roughness *Tree drag*



1. Roughness length with TEB/ISBA :

2. Drag force with presence of buildings/trees :



$$\frac{\partial U}{\partial t} = F_u - C_d A_f(z) U (U^2 + V^2)^{0,5}$$

$$\frac{\partial e}{\partial t} = F_e - C_d A_f(z) e$$

A_f= Canopy area density
Building not porous

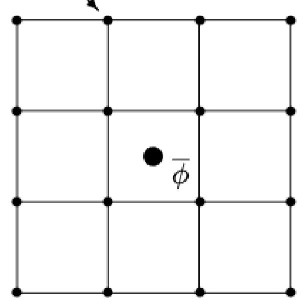
Becomes necessary at very fine vertical resolution

Subgrid transport

Prognostic variables represent a mean state on the mesh grid.

Formalisme de Reynolds

$\phi = \overline{\phi} + \phi'$ $\qquad \overline{\phi'} = 0$



$$\left(\frac{\partial \phi}{\partial t}\right)_{adv} = -u_i \frac{\partial \phi}{\partial x_i}$$

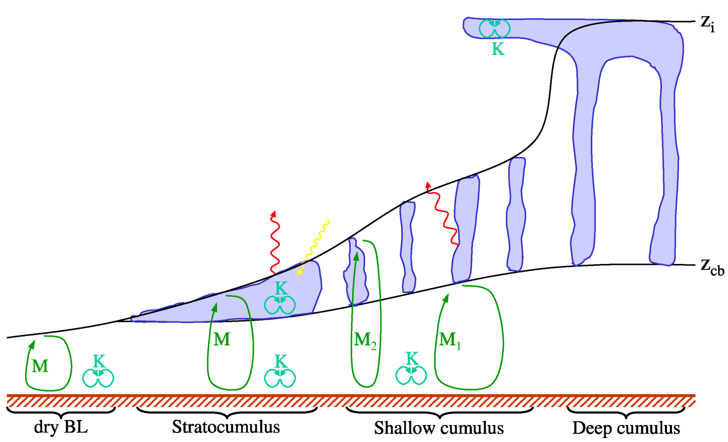
Resolution of a model -> subgrid processes are filtered

Parametrization to close the Reynolds system

$$\left(\frac{\partial \overline{\phi}}{\partial t}\right)_{adv} = -\overline{u_i}\frac{\partial \overline{\phi}}{\partial x_i} - \frac{\partial \overline{u_i'\phi'}}{\partial x_i}$$

Transport of ϕ by subgrid fluctuations : Parametrization

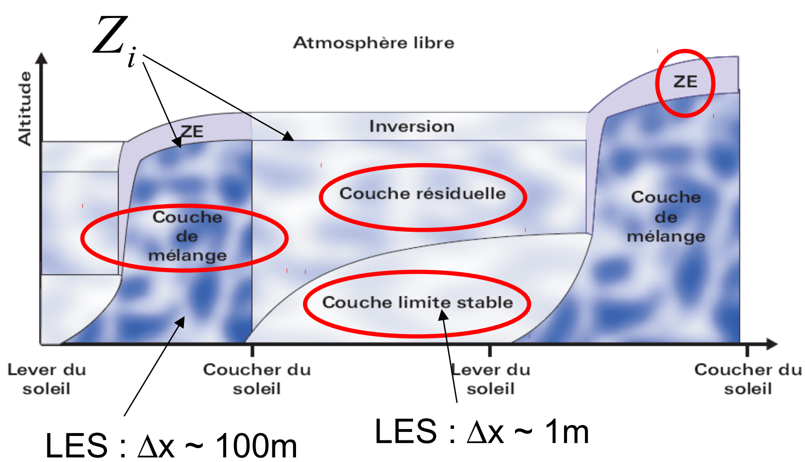
SUBGRID TRANSPORT



- Homogeneous small eddies → Turbulence
- Higher vertical extension, with or without cloud → Shallow convection
- Deep vertical extension of clouds, with precipitation → Deep convection

TURBULENCE

- TURBULENCE=SUBGRID TRANSPORT by small eddies
- TURBULENCE = Parametrization of the mean effect of the transport of momentum, sensible heat (enthalpy) and latent heat (no précipitating water) by small subgrid eddies considered homogeneous and isotropic .
- Turbulence is mainly active in the Boundary Layer, but not only . At the surface, turbulent fluxes are computed in the surface model (SURFEX).



TURBULENCE

Same turbulence scheme for mesoscale and LES modes : Cuxart et al. (2000), Redelsperger and Sommeria (1981). Local scheme. Second-order moments are diagnosed (12) :

$u'_i = u_i - \overline{u_i}$

$$\overline{u'_i\theta'} = -\frac{2}{3}\frac{L}{C_s}e^{\frac{1}{2}}\frac{\partial\overline{\theta}}{\partial x_i}\phi_i,$$

$$\overline{u'_i r'_v} = -\frac{2}{3}\frac{L}{C_h}e^{\frac{1}{2}}\frac{\partial\overline{r_v}}{\partial x_i}\psi_i,$$

Stability functions (inverse turbulent Prandtl and Schmidt numbers)

$$\overline{u'_i u'_j} = \frac{2}{3}\delta_{ij}\,e - \frac{4}{15}\frac{L}{C_m}e^{\frac{1}{2}}\left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3}\delta_{ij}\frac{\partial u_m}{\partial x_m}\right),$$

$$\overline{\theta' r'_v} = C_2 L^2\left(\frac{\partial\overline{\theta}}{\partial x_m}\frac{\partial\overline{r_v}}{\partial x_m}\right)(\phi_m + \psi_m),$$

$$\overline{\theta'^2} = C_1 L^2\left(\frac{\partial\overline{\theta}}{\partial x_m}\frac{\partial\overline{\theta}}{\partial x_m}\right)\phi_m,$$

$$\overline{r'^2_v} = C_1 L^2\left(\frac{\partial\overline{r_v}}{\partial x_m}\frac{\partial\overline{r_v}}{\partial x_m}\right)\psi_m.$$

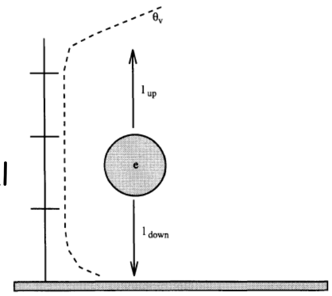
-> K method with

$$\overline{w'\theta'} = -K\frac{\partial\theta}{\partial z}$$

$K = c\,L\,e^{1/2}$

TURBULENCE

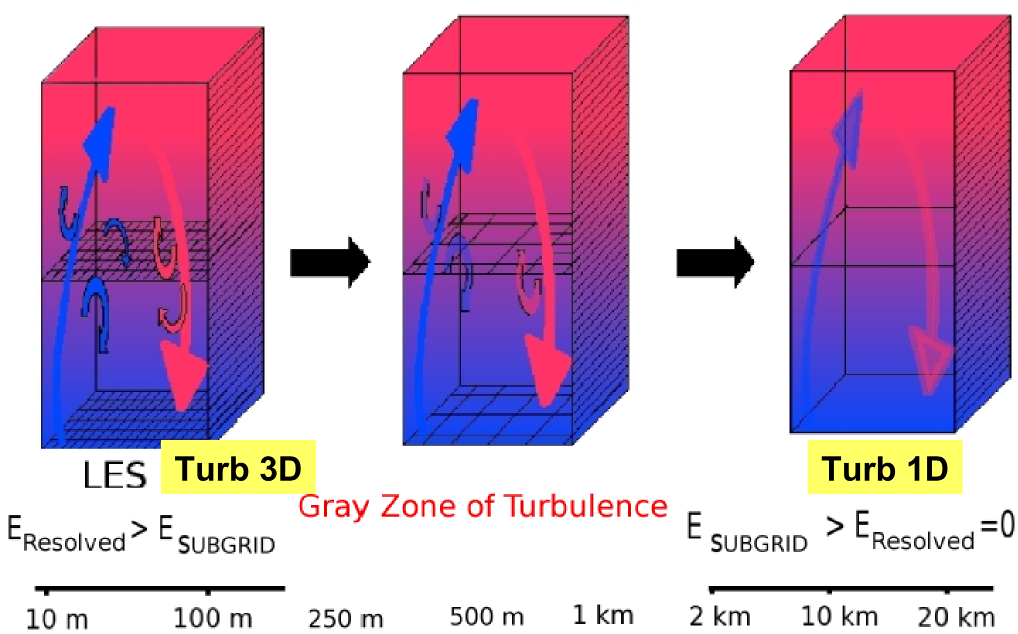
L is the **mixing length** that allows to close the system = Size of the most energetic eddies that feed the energy cascade towards the dissipation.



Different possibilities to parametrize L (**CTURBLEN**) :

- **meso-scale** : BL89 : The distance a parcel of air having the initial TKE of the level can travel upwards (l_{up}) and downwards (l_{down}) before being stopped by buoyancy effects : $L=f(l_{up},l_{down})$ (**CTURBLEN='BL89'**)

LES (inertial subrange) : $(\Delta x.\Delta y.\Delta z)1/3$ and Deardorf mixing length (**CTURBLEN='DEAR'** or CTURBLEN='DELT')



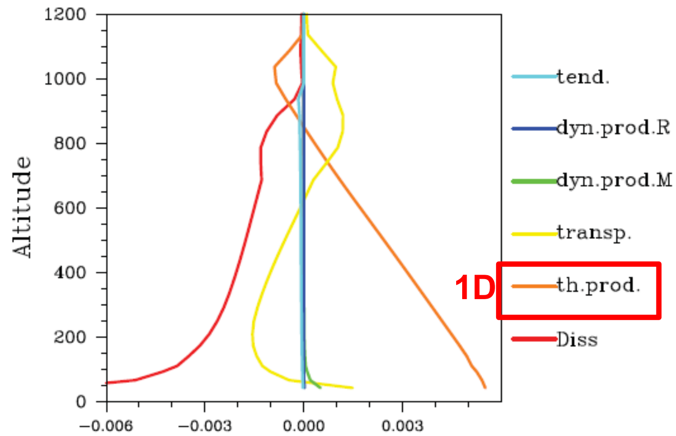
Horizontal gradients in the turbulent equations are neglected except for the transport of TKE

Prognostic TKE : $e=\frac{1}{2}\left(u'^2+v'^2+w'^2\right)$

$$\frac{\partial TKE}{\partial t} = advection + \underbrace{prod.dyn.\ (DP)}_{\overline{u'_i u'_j}\frac{\partial \overline{U}_i}{\partial x_j}}^{\text{3D}} + \underbrace{prod.therm.\ (TP)}_{\frac{g}{\theta_{vref}}\left(E_\theta \overline{w'\theta'_l} + E_r \overline{w'r'_{np}}\right)}^{\text{1D}} + transport + dissipation$$

$$(r_{np} = r_c + r_i + r_v)$$

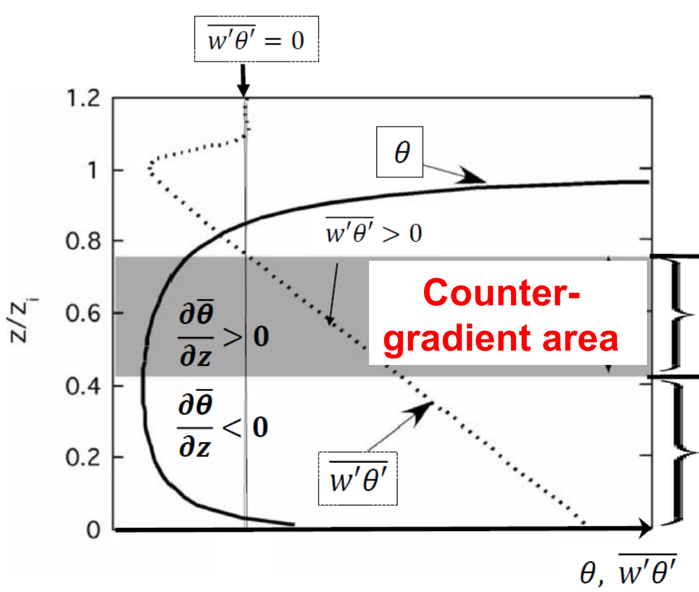
BUDGET of TKE : case of IHOP (convective BL) (from Honnert, 2012)



Mesoscale (Δx=8km)

Limit of the K method for a convective boundary layer

$$\overline{w'\theta'} = -K\frac{\partial \theta}{\partial z}$$



	Observé	modèle
	$\frac{\partial\overline{\theta}}{\partial z}\overline{w'\theta'}_l > 0$	~~$\overline{w'\theta'} = -K\frac{\partial\overline{\theta}}{\partial z}$~~
	$\frac{\partial\overline{\theta}}{\partial z}\overline{w'\theta'}_l < 0$	$\overline{w'\theta'} = -K\frac{\partial\overline{\theta}}{\partial z}$ ✓ O.K.

SHALLOW CONVECTION

- Historical approach : K-theory or eddy-diffusivity
  : good small eddy closure but problem in the countergradient zone of the convective BL (Stull, 1988)

$$\overline{w'\phi'} \cong -K\frac{\partial\overline{\phi}}{\partial z}$$

- Counter gradient Term (Deardorff, 1972) :
  ν : effect of the non local transport

$$\overline{w'\theta'} = -K'\left(\frac{\partial\overline{\theta}}{\partial z} - \gamma c\right)$$

- Based on the EDMF scheme (Soares et al,2004) : Mass-flux approach

$$\overline{w'\phi'} = -K\left(\frac{\partial\overline{\phi}}{\partial z}\right) + \frac{M_u}{\rho}(\phi_u - \overline{\phi})$$

Turbulence
Small Eddies
Local Effect

Shallow convection
Thermals
(coherent structures)
Non local transport

EDKF scheme (PMMC09)

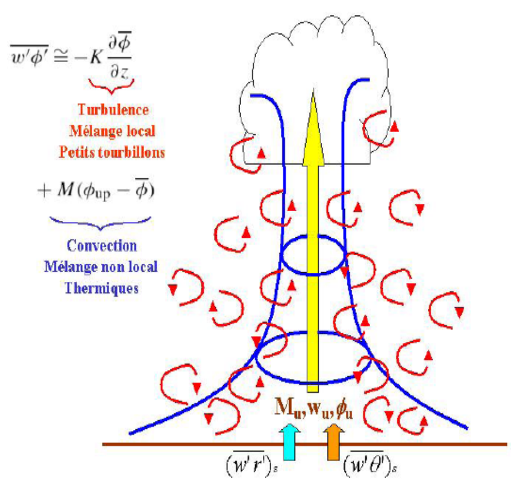
1. Pergaud J., Masson V., Malardel S. and Couvreux F. (2009) A parameterization of dry thermals and shallow cumuli for mesoscale numerical weather prediction. *Boun. Layer Meteor.* 132 :93-106.

- **Necessary until Δx ~1km – 500m**

EDKF : A parametrization for dry and cloudy convective boundary layers

PMMC09[1](ou EDKF)

- - Diagnostic scheme : no memory of the convective activity from the previous time step
- - 1 equation for the mass flux + 1 equation for the vertical velocity
- - Initialization of the mass flux at the bottom of the model as a function of the surface buoyancy flux

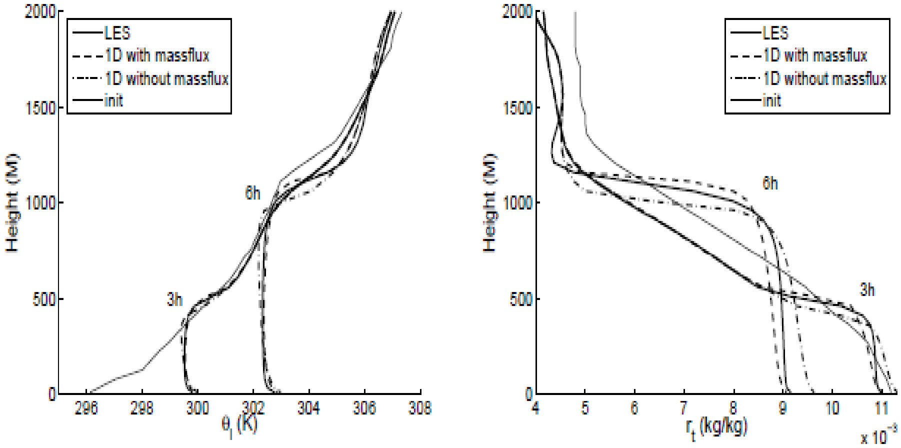


$$\begin{cases} w_u\dfrac{\partial w_u}{\partial z} = aB_u - b\epsilon w_u^2 \\ \dfrac{1}{M}\dfrac{\partial M}{\partial z} = (\epsilon - \delta) \\ M_0 = C_{M_0}\rho\left(\dfrac{g}{\theta_{vref}}\overline{w'\theta'_{vs}}L_{up}\right)^{\frac{1}{3}} \end{cases}$$

Dry convective boundary layer : IHOP (Pergaud et al., 2009)

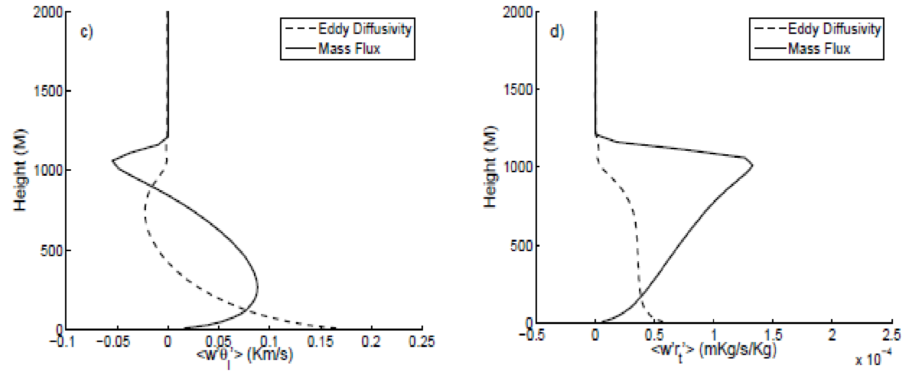
Without mass-flux :

- Insufficient top-entrainment -> too low inversion
- BL too cold and too moist



Eddy-diffusivity in the low part of the BL (local)

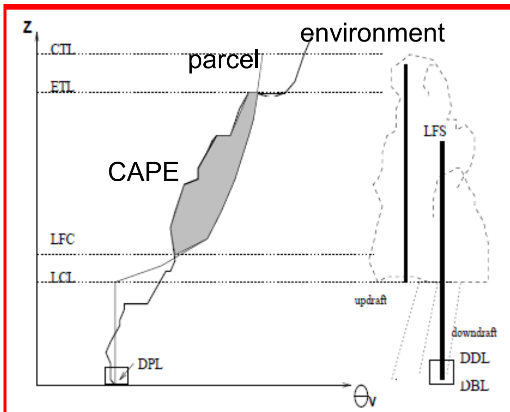
Mass-flux in the upper part (non local)



DEEP CONVECTION

Necessary for Δx > 5km. Below it is explicitly resolved.

Mass flux scheme : Kain-Fritsch-Bechtold (KFB) (Bechtold et al., 2005)



LCL = Lifting condensation level
DPL = Departure level
CTL = Cloud top level
LFC = Level of free convection (positive buoyancy)
ETL = Equilibrium temperature level (zero buoyancy)
LFS = Level of free sink
DBL = Downdraft base level

$$\left.\frac{\partial\overline{\Psi}}{\partial t}\right|_{\rm conv} = \frac{\partial(\overline{w'\Psi'})}{\partial z}$$

$$\approx \frac{1}{\overline{\rho}A}\frac{\partial}{\partial z}\left[M^u(\Psi^u-\overline{\Psi})+M^d(\Psi^d-\overline{\Psi})+\tilde{M}(\tilde{\Psi}-\overline{\Psi})\right]$$

$$\approx \frac{1}{\overline{\rho}A}\frac{\partial}{\partial z}\left[M^u\Psi^u+M^d\Psi^d-(M^u+M^d)\overline{\Psi}\right],$$

~ : environment

- : mean horizontal

where Ψ is a conserved variable, $M=\overline{\rho}wA$ is the mass flux (kg s^{-1}), w the vertical velocity, and $A=A^u+A^d+\tilde{A}$ denotes the horizontal domain (grid size). O

$$\frac{\partial}{\partial z}(M^u\Psi^u)=\epsilon^u\overline{\Psi}-\delta^u\Psi^u; \qquad \frac{\partial}{\partial z}(M^d\Psi^d)=\epsilon^d\overline{\Psi}-\delta^d\Psi^d$$

entrainment ϵ and detrainment δ,

$$\left.\frac{\partial\overline{\Psi}}{\partial t}\right|_{\rm conv} = \frac{1}{\overline{\rho}A}\left[\frac{\partial}{\partial z}([M^u+M^d]\overline{\Psi})-[\epsilon^u+\epsilon^d]\overline{\Psi}+\delta^u\Psi^u+\delta^d\Psi^d\right]$$

Microphysics and cloud scheme

Microphysics and cloud scheme

Motivation : Cloud microphysical schemes have to describe the formation, growth and sedimentation of water particles (hydrometeors).
They provide the latent heating rates for the dynamics.

For NWP : important for quantitative precipitation forecasts
For climate : radiative impact and aerosol-cloud-radiation interactions

Basic assumptions :

1. The various types of hydrometeors are simplified to a few categories, e.g., cloud droplets, raindrops, cloud ice, snow, graupel, hail : BULK ↔BIN

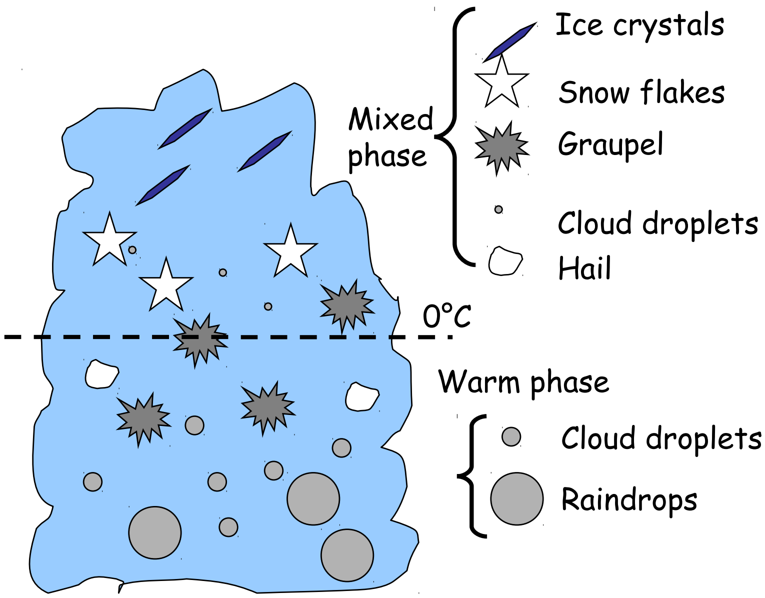
2. We assume thermodynamic equilibrium between cloud droplets and water vapor. Therefore the condensation/evaporation of cloud droplets can be treated diagnostically, i.e., by the so-called saturation adjustment.

Meso-NH
mesoscale non-hydrostatic model

MICROPHYSICS

Concentrations : * 1-moment scheme $N_i = C\lambda_i^x, i = \{r,s,g,h\}$

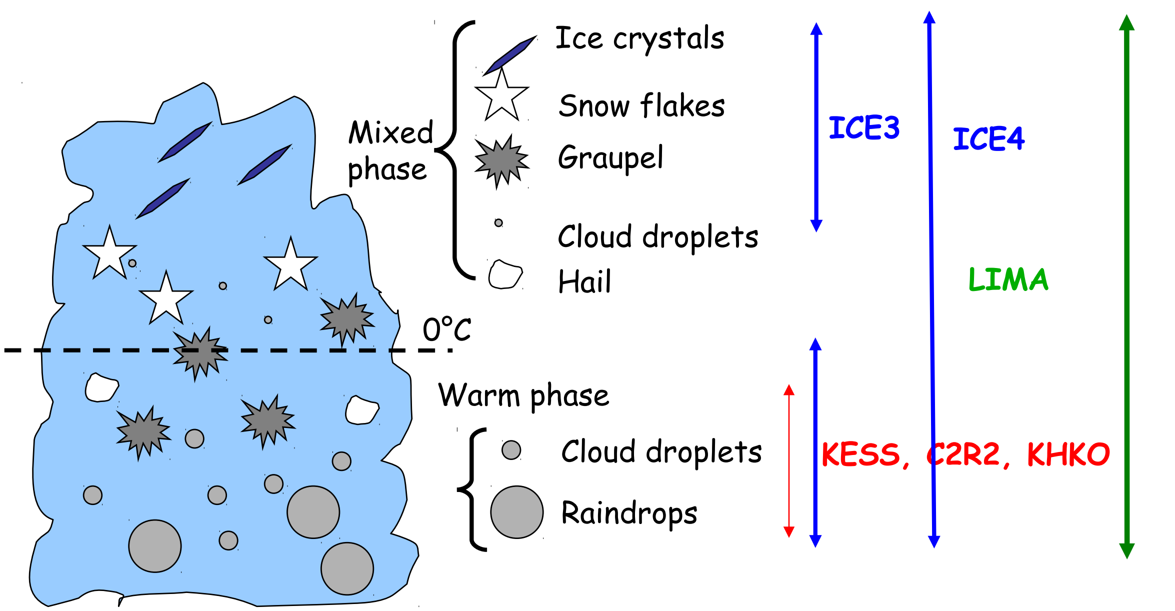
* 2-moment scheme : Integration of $\partial N_i / \partial t$



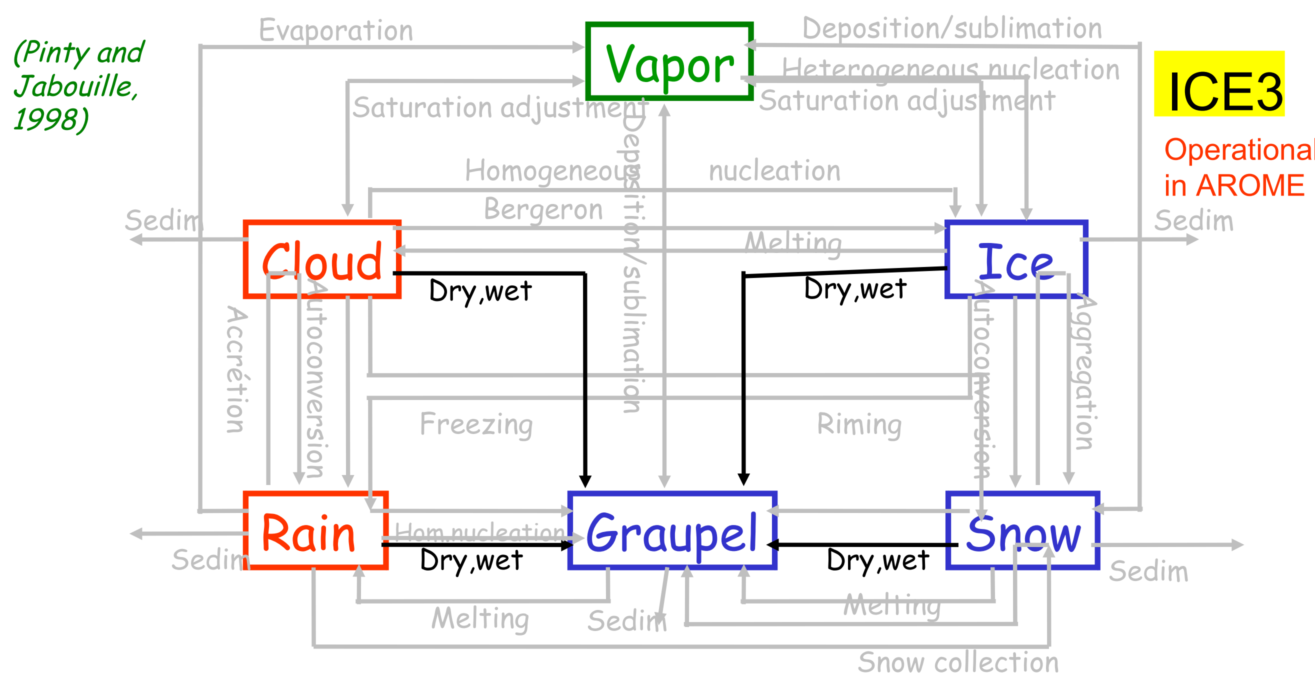
MICROPHYSICS

Concentrations : * 1-moment scheme $N_i = C\lambda_i^x, i = \{r,s,g,h\}$ KESS ICE3, ICE4

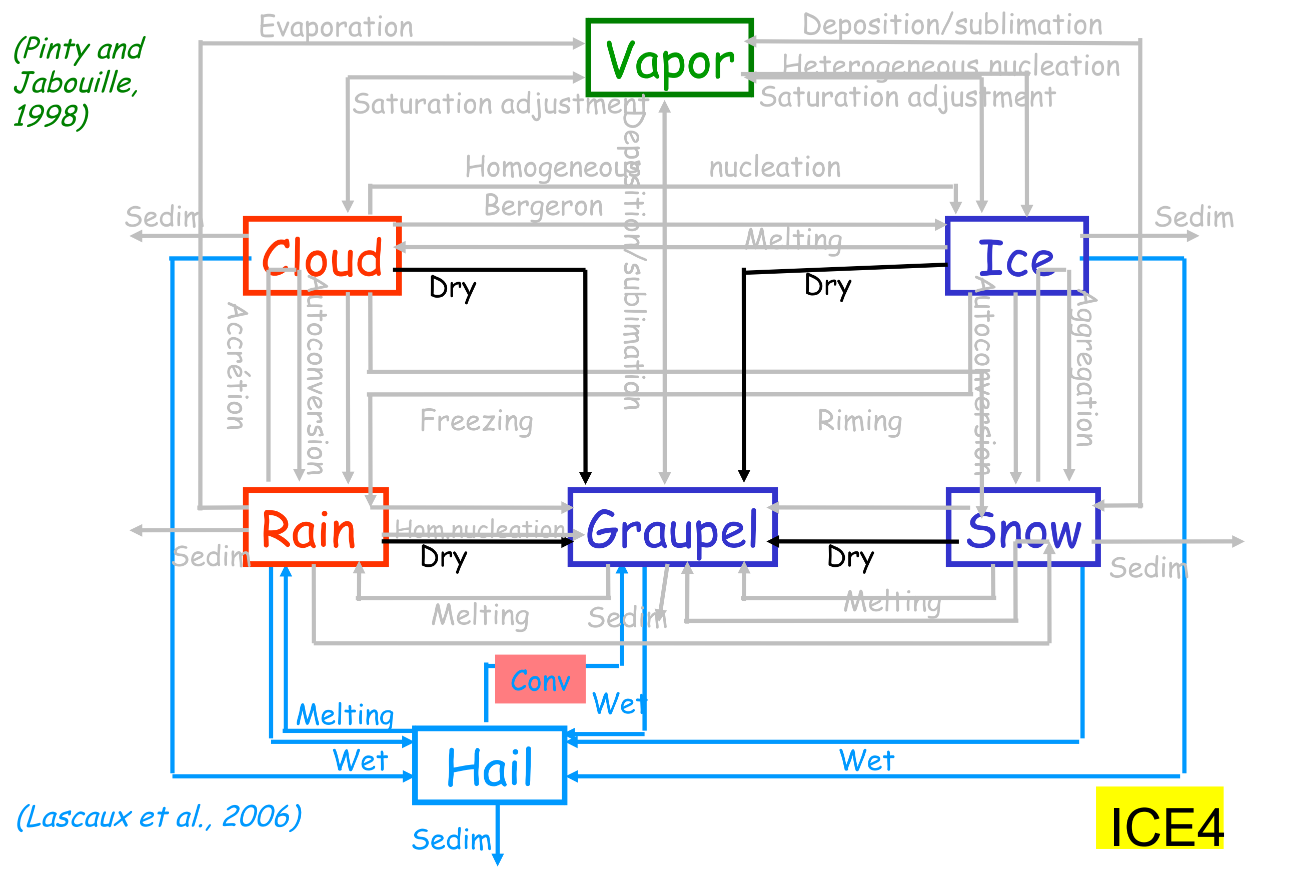
* 2-moment scheme : Integration of $\partial N_i / \partial t$ C2R2, KHKO, LIMA



Méso-NH and AROME : ICE3 1-moment scheme



Méso-NH and AROME : ICE4 1-moment scheme

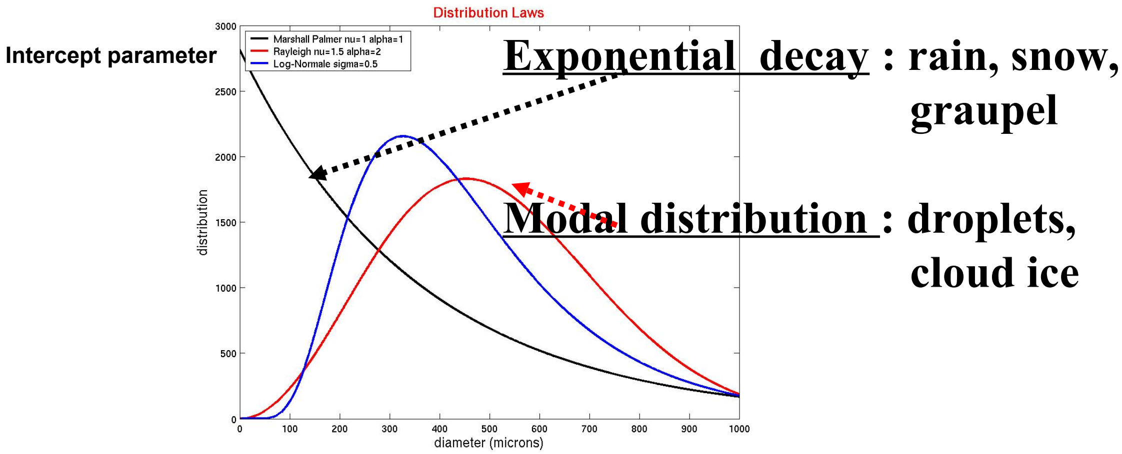


Particle size distributions

- **Size distribution (n(D)): Generalized Gamma law**

$$n(D)\,\mathrm{dD} = N g(D)\,\mathrm{dD} = N \frac{\alpha}{\Gamma(\nu)} \lambda^{\alpha\nu} D^{\alpha\nu-1} \exp\left(-(\lambda D)^{\alpha}\right)\mathrm{dD}$$

N is the total concentration
Precipitating species : $N = C\lambda^{x}$
For clouds, N imposed (Nc=300/cm3 on land, 100/cm3 on sea)
λ is the slope parameter deduced from the mixing ratio
(α, ν) are free shape parameters (Marshall-Palmer law: $\alpha=\nu=1$)



Microphysical characteristics

Very useful p-moment formula

$$M(p) = \int_0^{\infty} D^p n(D)\,\mathrm{dD} = \frac{\Gamma(\nu + p/\alpha)}{\Gamma(\nu)} \frac{1}{\lambda^p} = N G(p) \frac{1}{\lambda^p}$$

M(0)=Concentration
M(1)=Mean diameter
M(3)=Mean volume

The content of any specy : $\rho_d r = \int_0^{\infty} m(D) n(D)\,dD = a N M(b)$

The slope parameter depends on the content : $\lambda = \left(\frac{\rho_d r}{a C G(b)}\right)^{\frac{1}{x-b}}$

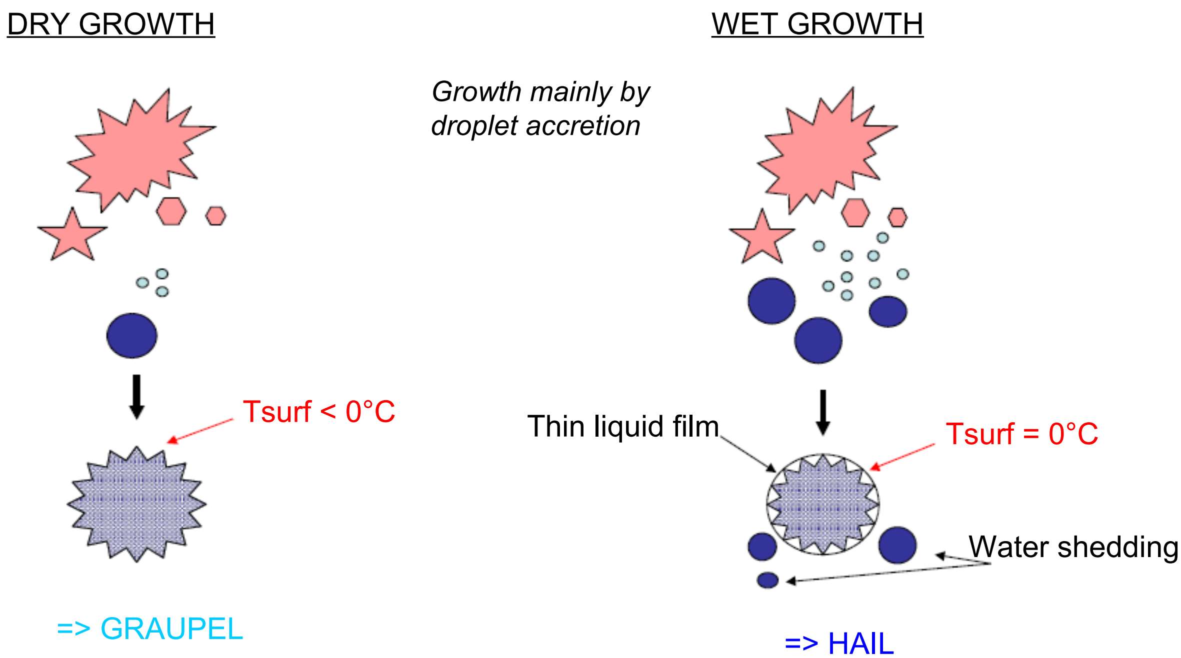
Microphysical characteristics

- **Mass-Size relationship:** $m=aD^b$
- **Fall speed-Size relationship:** $v=cD^d \cdot (\rho_{00}/\rho_a)^{0.4}$

Category → Parameters		Cloud water	Rain water	Cloud ice	Snowflake Aggregate	Graupel	Hail
mass	a	524	524	0.82	0.02	19.6	470
	b	3	3	2.5	1.9	2.8	3.0
speed	c	3.2e7	842	800	5.1	124	207
	d	2	0.8	1.00	0.27	0.66	0.64

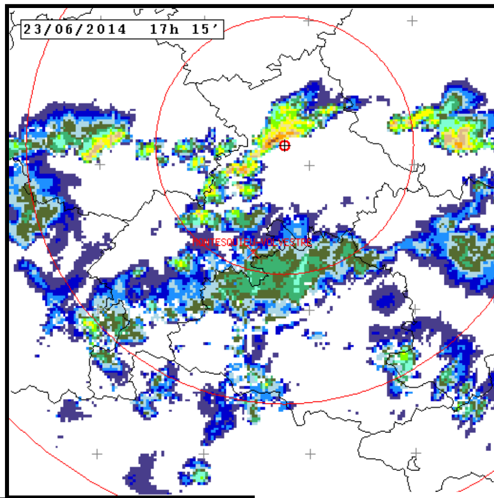
The **a, b, c** and **d** coefficients (MKS units) are adjusted from ground or *in situ* measurements

Hail formation



Shedding important source of new raindrops (Wisner et al., 1972).
New raindrops may serve as new hailstone embryos (Rasmussen and Heymsfield, 1987).

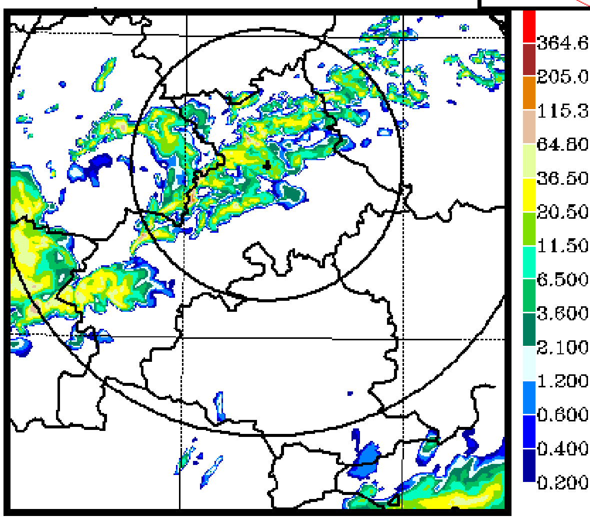
Instantaneous
Precipitation rate (mm/h)
Toulouse radar
17h15 TU

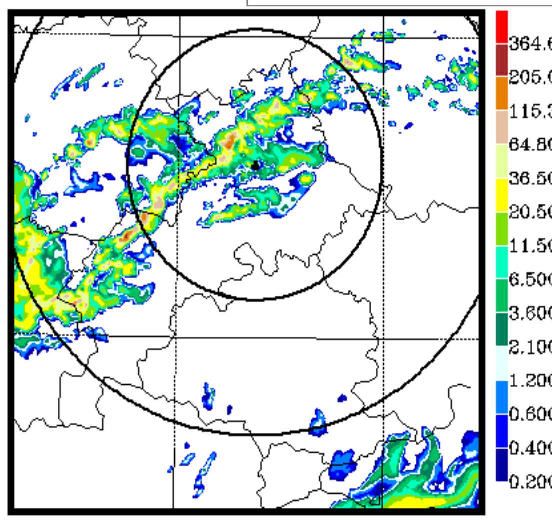


ICE3 Δx=500m

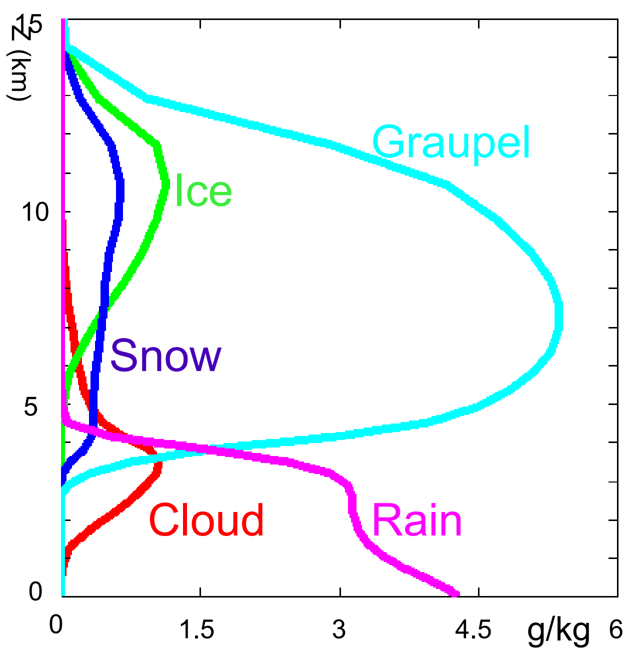
ICE4

Stronger precipitation

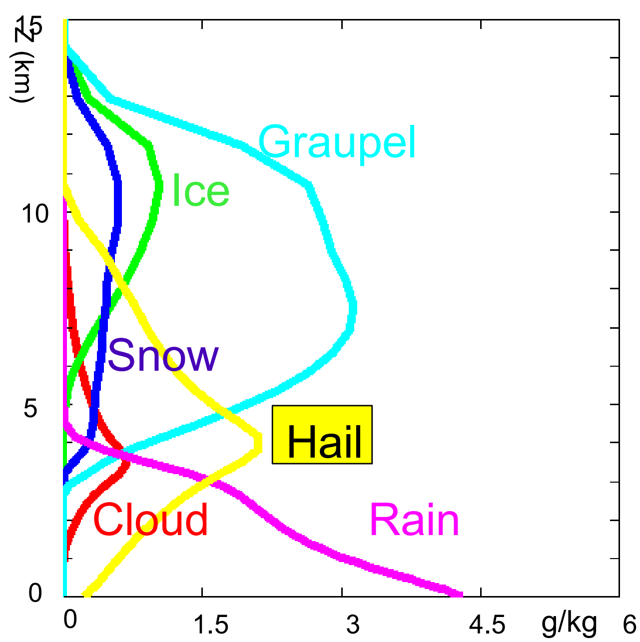




ICE3

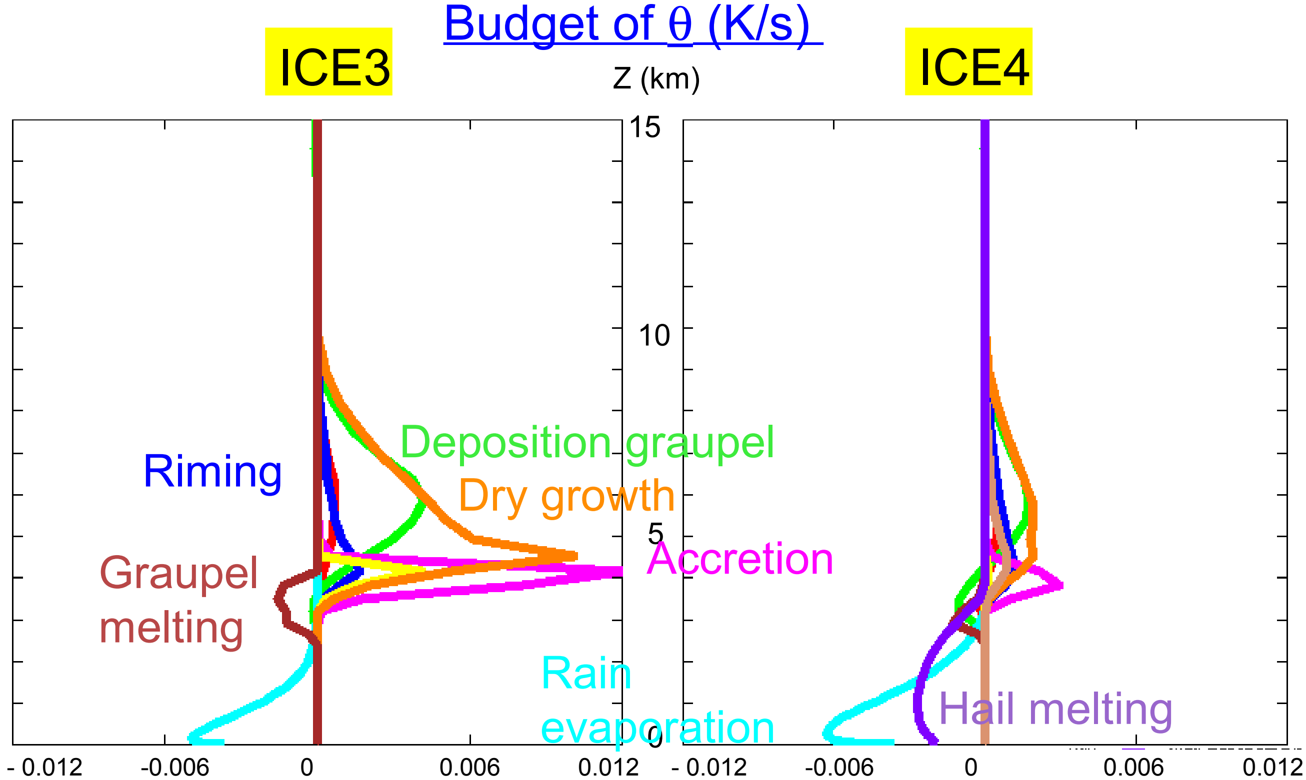


ICE4



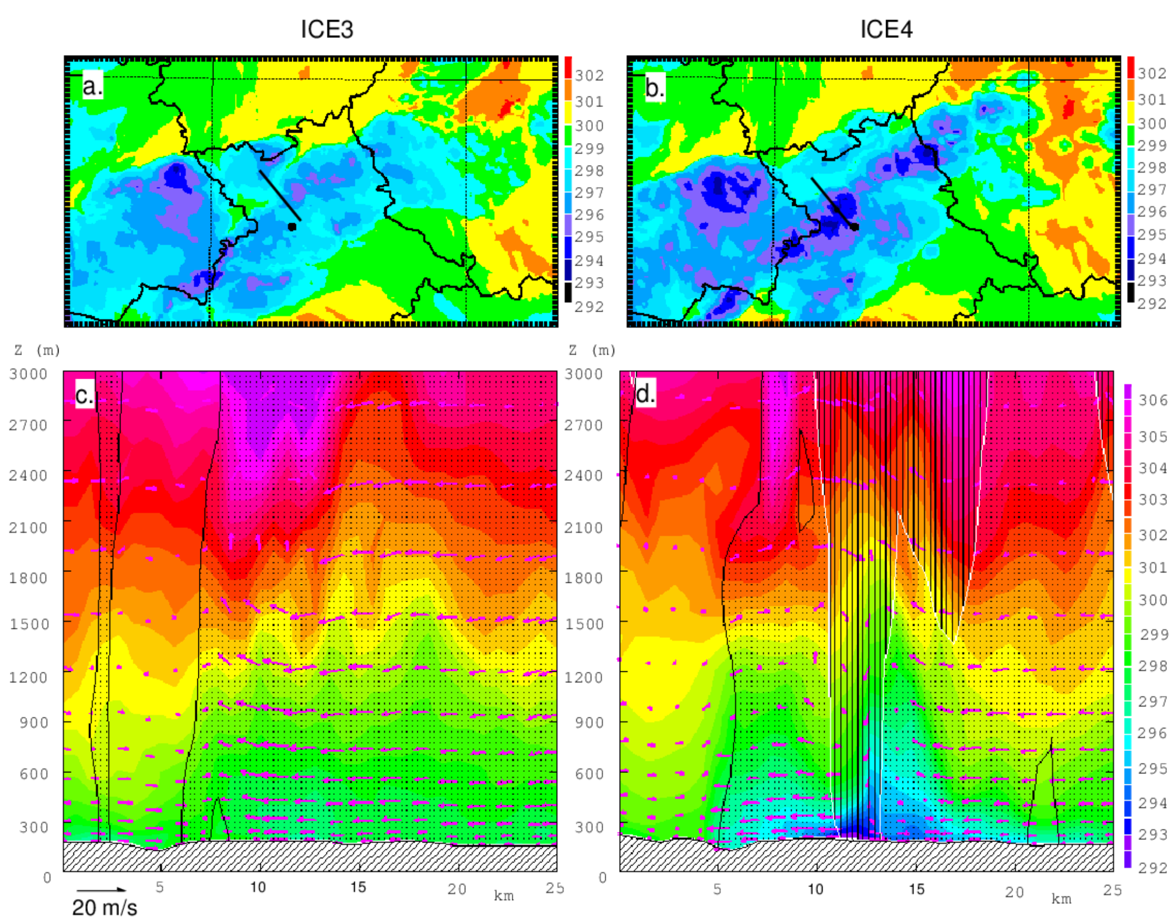
1-hour mean mixing ratios over area where ground precipitation rate > 100 mm/h

Budget of θ (K/s)



ICE3 : Heating in the mid-troposphere due to dry growth and deposition on graupel and accretion on droplets

ICE4 : Cold pool stronger and deeper due to hail melting and stronger evaporation rate.
Low level convective dynamics reinforced.



MICROPHYSICS

FAST MICROPHYSICS : Adjustment to saturation

At the end of the Δt, the guesses of r_v, r_c, r_i et θ à $t+\Delta t$ are adjusted consistently to satisfy strict saturation criterium : any deficit or excess of vapor is compensated or absorbed by cloud species : Essential as it produces the cloud and ice amounts and defines the temperature

$\rightarrow$ 2 possibilities :

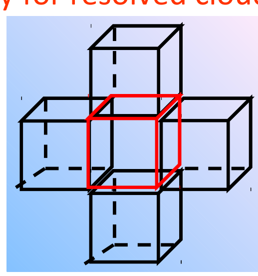
- « All or nothing » adjustment

- Subgrid adjustment : Cloud fraction computed from the subgrid variability given by the turbulence or/and the shallow convection, through a PDF

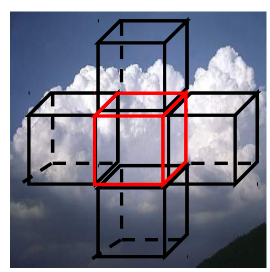
CLOUD SCHEME

➔ **« All or nothing» method (Mean saturation)**

Correct only for resolved clouds



OR



a/ *No saturated case*

$\Rightarrow$ **Clear sky** $\overline{r_c}=0$

b/ *Fully saturated*

$\Rightarrow$ **Fully cloudy** $\overline{r_c}=\overline{r_t}-r_{sat}(\overline{T})$

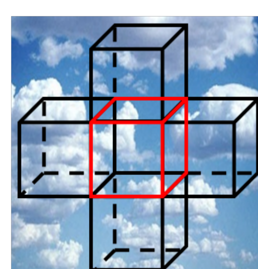
➔ **Subgrid condensation scheme**

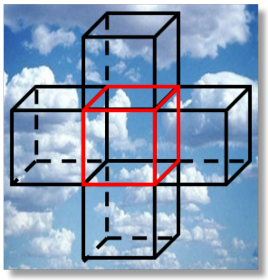
Correct for all cloud types (resolved and subgrid)

c/ *Partially saturated* : 0<CF<1

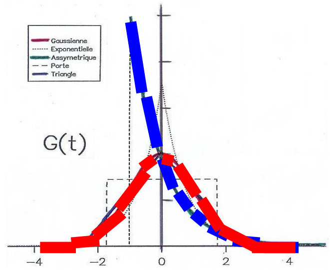
$\overline{r_c}$ «**diluted in the mesh** »: $\overline{r_c}=\overline{r_t-r_{sat}(T)}$

Necessity to parametrize $r_t-r_{sat}(T)$, given by the subgrid fluctuations (turbulence, convection) $\Rightarrow$ Statistical representation





CLOUD SCHEME from TURBULENCE

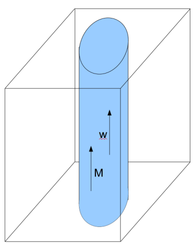


Combination of Gaussian (stratocumulus) and exponential (cumulus) distribution functions depending on turbulent fluxes.
(Bougeault, 82) / (Bechtold, 95)

CLOUD SCHEME from SHALLOW CONVECTION

« DIRECT » (oper)

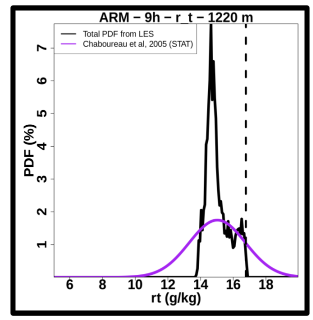
CF and Rc/Ri are diagnosed directly from updraft variables.
(Pergaud et al, 2009)



$$CF = \alpha \times \frac{M}{\rho w}$$

« STAT »

A variance is diagnosed from updraft variables, added to the turbulence one and applied to an uni-modal PDF (Chaboureau et al, 2005)

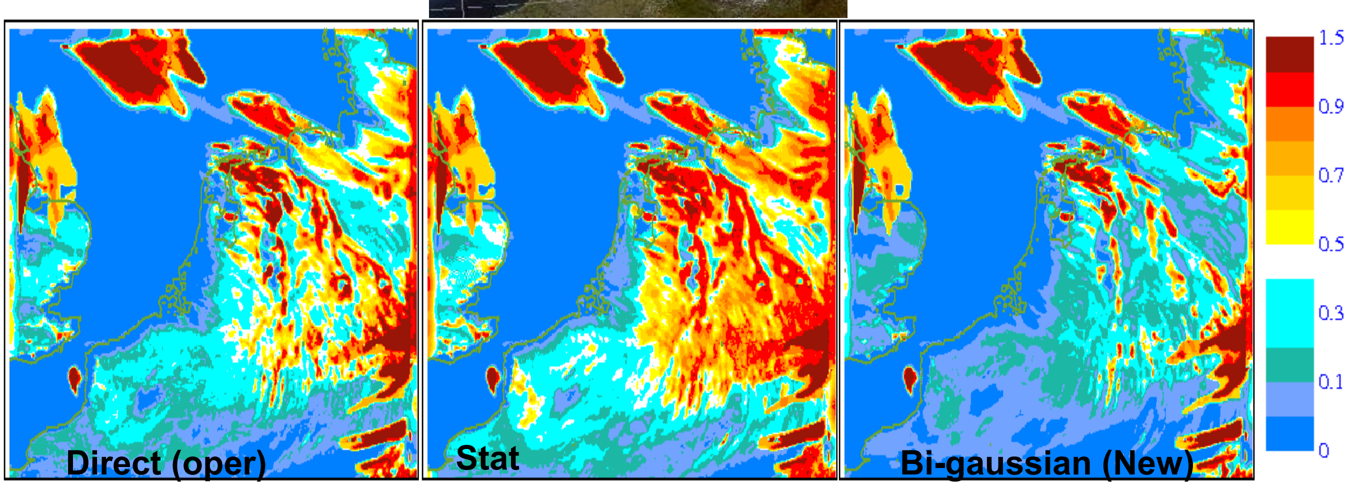


Improvement of the cloud scheme

(9 April 2010 at 12h)

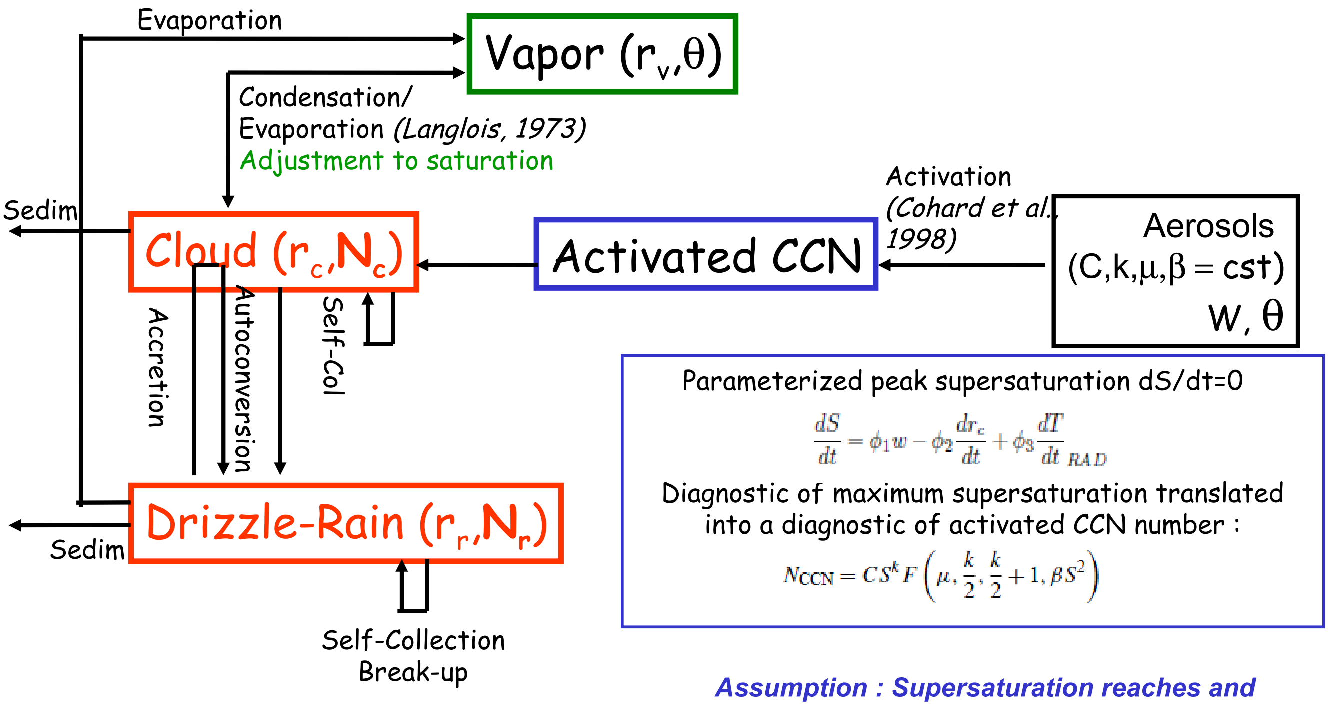
From S.Riette

On-going evaluation with soundings and satellite products

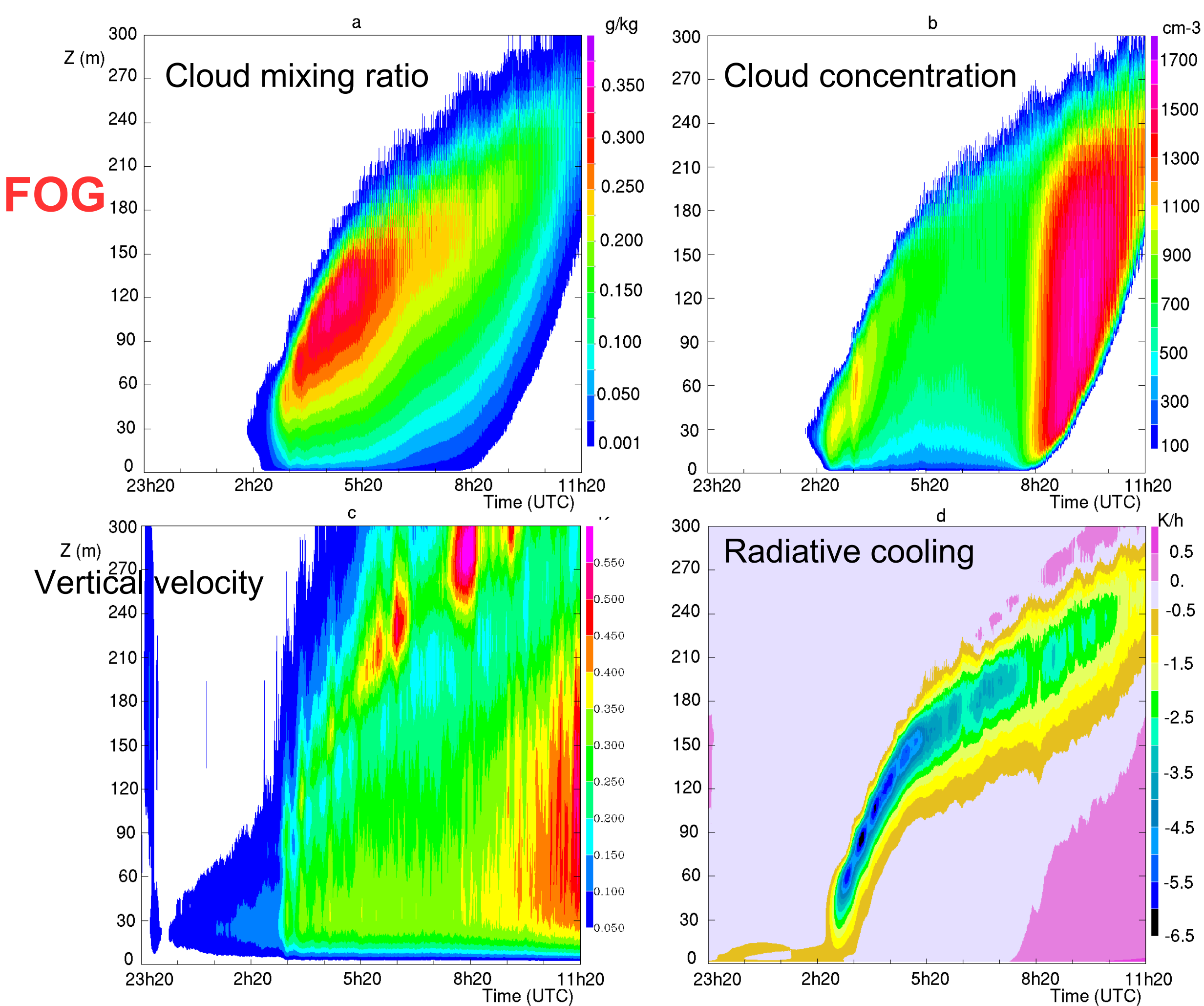


Meso-NH : Warm 2-moment microphysical schemes

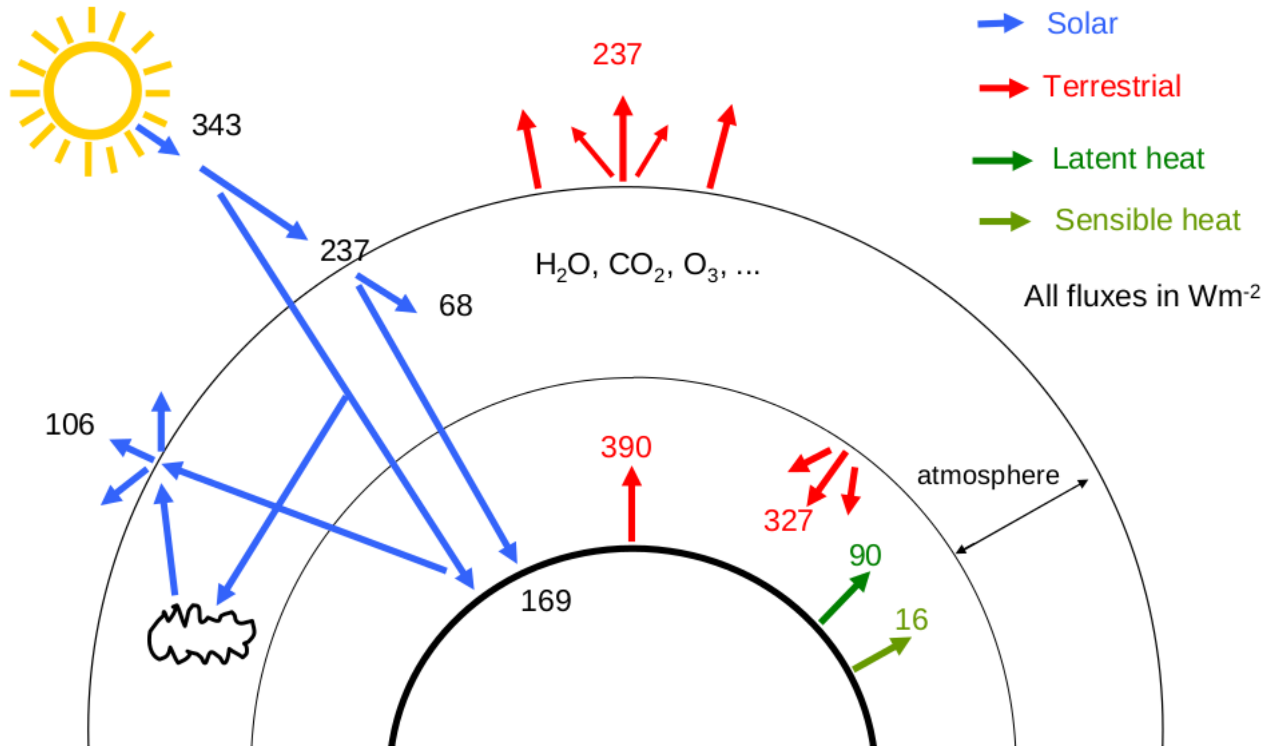
Cohard and Pinty, 1998 for Cu ; Geoffroy et al., 2008 for Sc-St



Assumption : Supersaturation reaches and passes its maximum within a time step

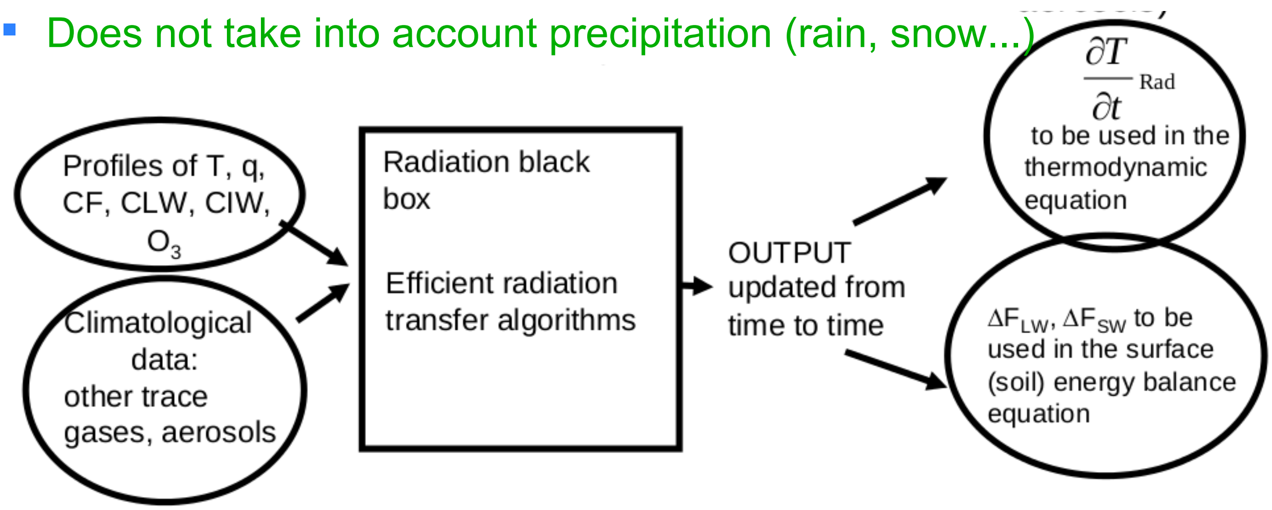


Radiation



Coupling with the **transfer radiative code of ECMWF** to take into account microphysics/dynamics/radiation interactions

- « **Column** » model of radiative transfer $$\frac{\partial T}{\partial t} = \frac{g}{C_{ph}} \frac{\partial F_{SW/LW}}{\partial p}$$
- Input : θ, rv, rc, ri, N (Cloud fraction) profiles. Output : θ tendency computed from SW and LW fluxes, upwards and downwards.
- Does not take into account precipitation (rain, snow...)

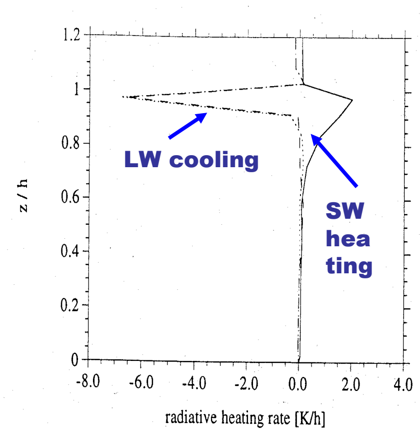


RADIATION

Radiative fluxes :

- LW: Emission and absorption of telluric and atmospheric radiation :
  - LW scheme: 9 spectral bands
  - RRTM scheme : 16 spectral bands : better representation of the different absorption windows
- SW : Reflexion, diffusion and absorption of solar radiation :
  SW scheme: 1 single : 6 spectral bands

For a Sc during the day



RADIATION

- Radiative fluxes, optical properties and emissivity depend on the atmospheric constituant : gaz (H_2O, CO_2, O_3), aérosols (6 esp.), cloud droplets :

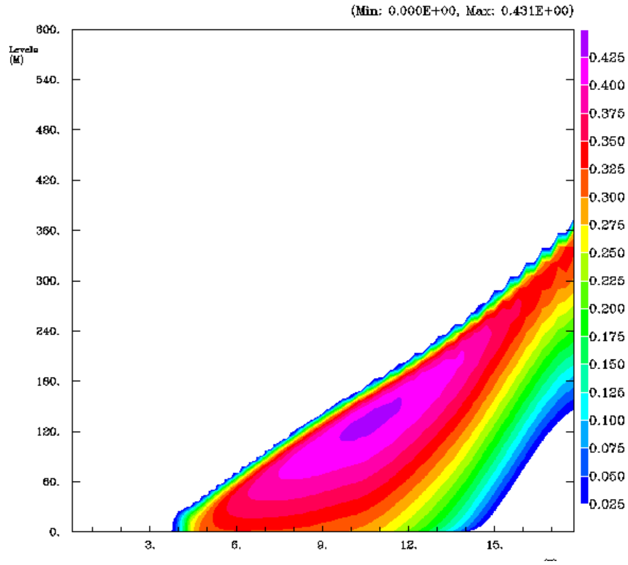
  Between Meso-NH and ECMWF radiation, interface of parametrizations to calculate effective radius of drops and droplets, optical properties for SW (optical thickness, SSA, Asymetrie factor)

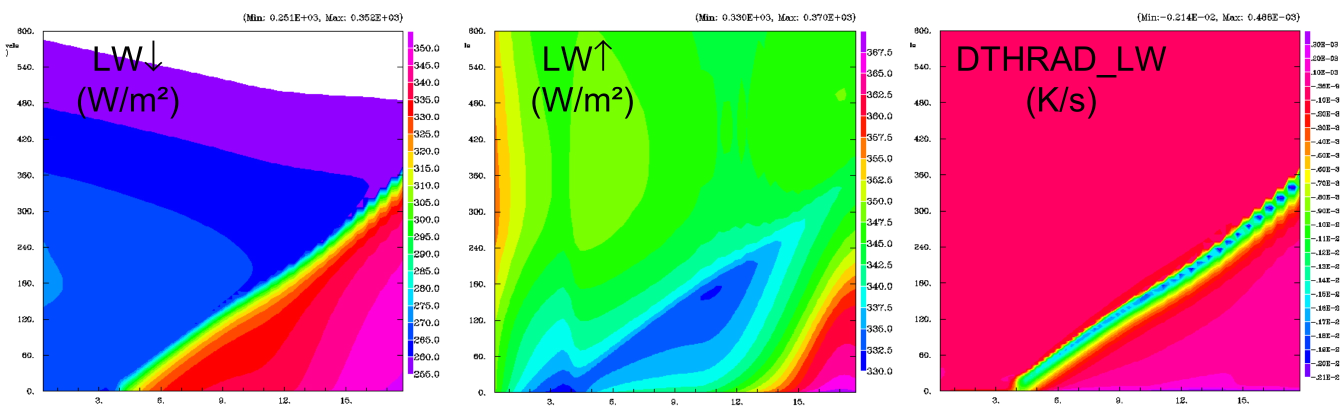
  and emissivity for LW : depends on the microphysical scheme (1-moment or 2-moment)

- Expensive cost, so called at a lower frequency than Δt.

Example of a 1D fog case

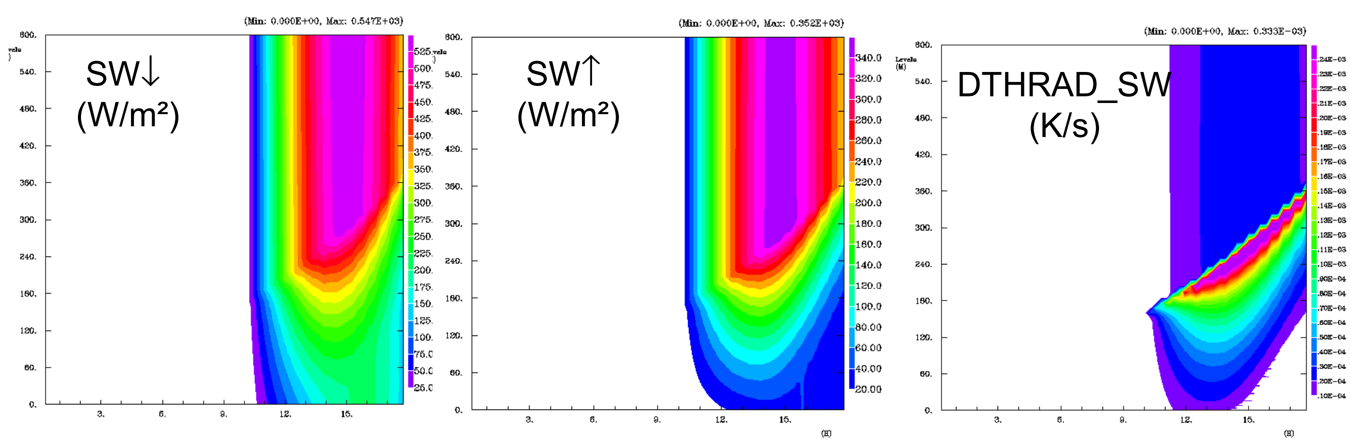
Rc (g/kg)





LWnet=LW ↓– LW↑

DTHRAD_LW=1/(ρCp)d(LWnet)/dz



SWnet=SW ↓– SW↑

DTHRAD_SW=1/(ρCp)d(SWnet)/dz

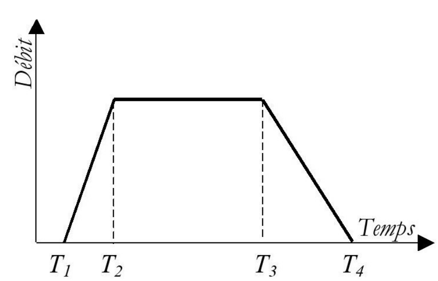
Diagnostics

MesoNH Tutorial Class 3 - 5 Oct 2016

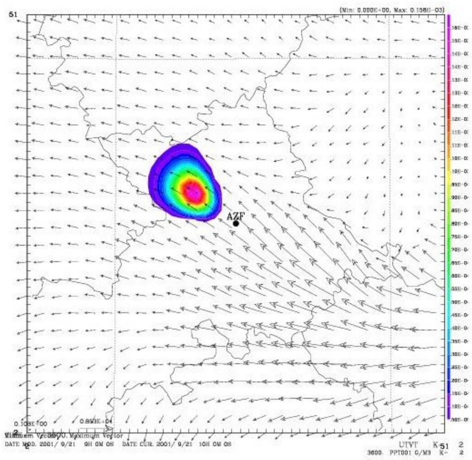
passiv pollutants

You can initialize passive pollutants, they will be advected and transported (by the turbulence scheme and convection (optional) one during the simulation)
Ponctual release at ground or in altitude of a pollutant mass with 3 stages for the flow. There are not deposition nor "lessivage"

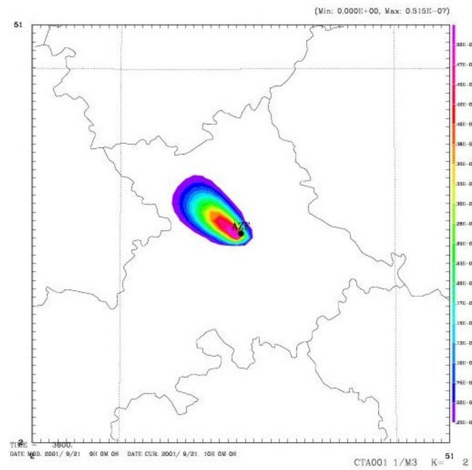
```
&NAM_PASPOL
LPASPOL = T ,
NRELEASE = 1 ,
CPPINIT(1) = "1PT" ,
XPPLAT(1) = 43.567 ,
XPPLON(1) = 1.439 ,
XPPBOT(1) = 10.0 ,
XPPTOP(1) = 500.0 ,
XPPMASS(1) = 10000000. ,
CPPT1(1) = "20010921090000",
CPPT2(1) = "20010921090000",
CPPT3(1) = "20010921091500",
CPPT4(1) = "20010921091500" /
```



Ex : AZF on 21/09/2001 : 10 tonnes released from 9h to 9h15 on 500m



Concentration (g/m3) at 10h



Coefficient de transfert atmosphérique à 10h : Concentration intégrée et normalisée

Lagrangian trajectory

They are 3 special passive scalars, because they are initialized with the spatial coordinates at the initial time, which are advected and transported during the simulation. They allow to plot fields on an iso-“initial altitude”, trajectories (‘parcel plumes’) and back-trajectories, WITHOUT specifying the positions of the particules at the beginning of the simulation.

Documentation

`http://www.aero.obs-mip.fr/mesonh/index2.html`
section ‘`Books and Guides`’,
Lagrangian Analyses’ Documentation (Gheusi et Stein, mai 2005).

Lagrangian trajectory

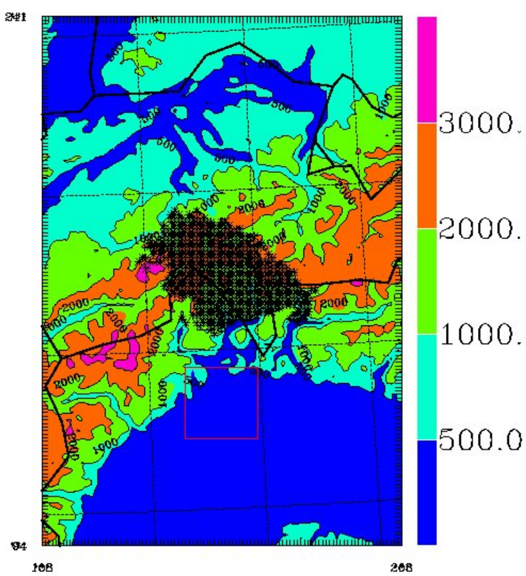
Namelists

- **EXSEG1.nam** in `&NAM_CONF`
  - **LLG=T** : to select the tracers
  - `LINIT_LG =T` : to reinit the valued at the beginning of each segment
  - `LNOMIXLG=T` : to suppress the turbulent transport
- **EXSEGn.nam**
  - `&NAM_PARAM_KAFRn` : `LCHTRANS=T` to activate the convective transport.

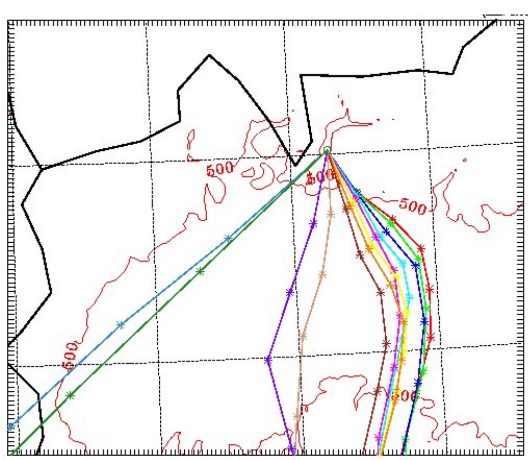
Output fields

`LGXT,LGYT,LGZT`
of the synchronous files CEXP.n.CSEG.00**n** (n>0)

Lagrangian trajectory



Plumes



Back-trajectories

Temporal series

You can store pronostic variables during the simulation.

Three types of series are available :

- (t) : horizontally and vertically averaged values (in a box to be specified by its indexess Imin,Imax,Jmin,Jmax,Kmin,Kmax),
- (z,t) : horizontally averaged values (in an area to be specified by its indexes I,J)
- (x,t) : values at a given level K (or averaged between 2 levels) horizontallly added along y (in a slice to be specified by Jmin,Jmax).

Note :

You can code other types of storage by modifying the routines themselves (`ini_seriesn.f90`, `seriesn.f90`, `write_seriesn.f90`)

Temporal series

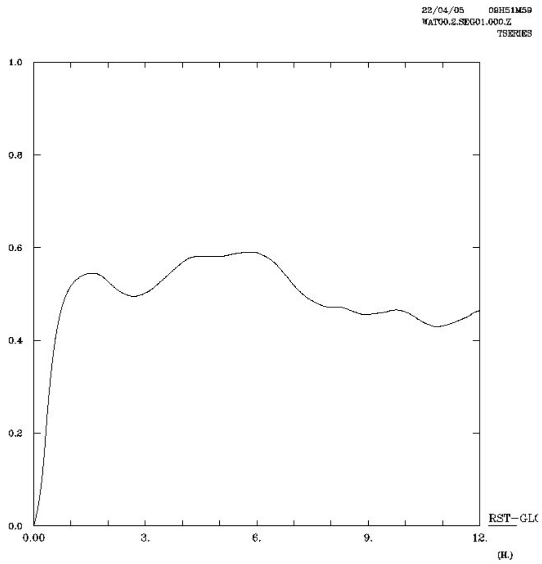
To do it :

- EXSEG1.nam : select the series with `LSERIES=T` in `&NAM_SERIES`
- EXSEGn.nam : specify the averaging areas, the slices, the levels and the storage frequency in `&NAM_SERIESn`.

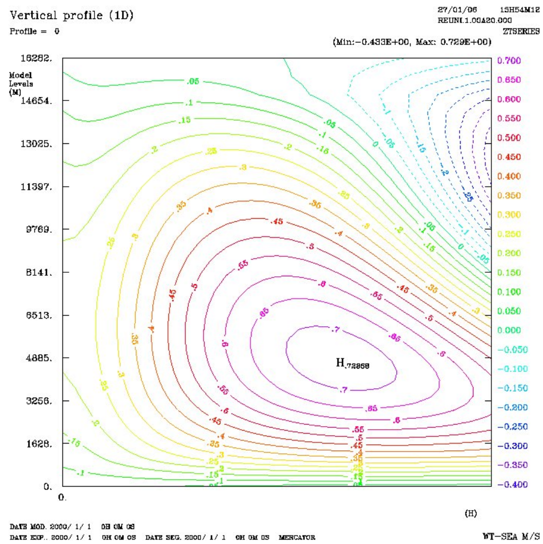
Variables de sorties

Data are in the**TSERIES, ZTSERIES, XTSERIESnn** fields of the diachronic file CEXP.n.CSEG.**000**

Temporal series



TSERIES_P_PROC7_FT1_



ZTSERIES_P_PROC3_PVT_

LES Diagnostics

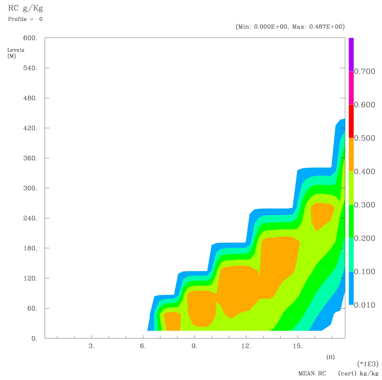
Writing of turbulent diagnostics (mainly used by Large Eddy Simulations) :

- temporal evolution of vertical profils,
- temporal average and/or normalisation of vertical profils.

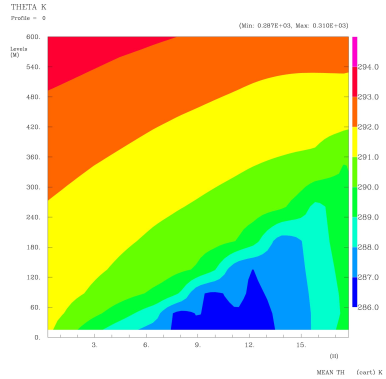
To do it :

In file EXSEG1.nam, define the characteristics of the budgets in the namelist **&NAM_LES**

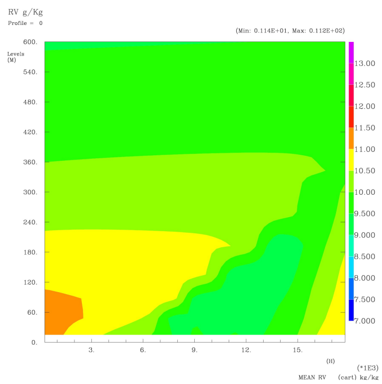
Data are in the diachronic file CEXP.n.CSEG.**000**



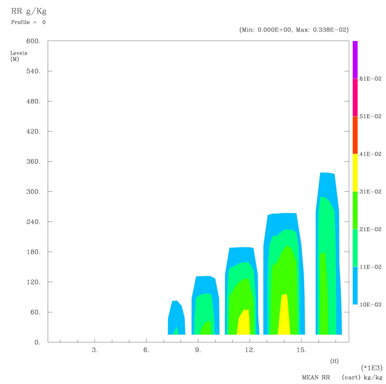
MEAN_RC



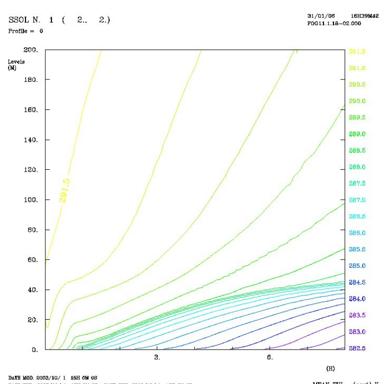
MEAN_TH



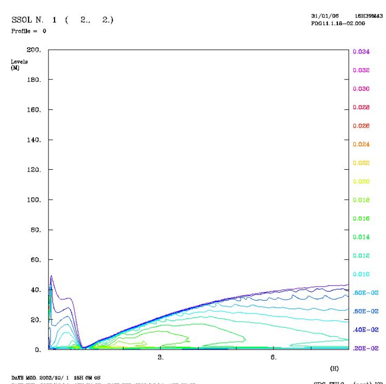
MEAN_RV



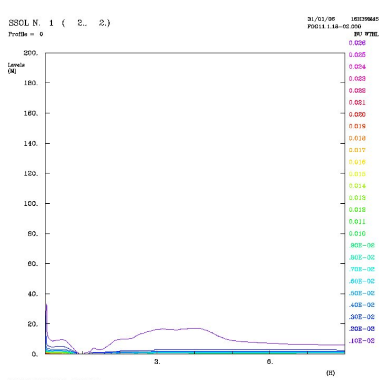
MEAN_RR



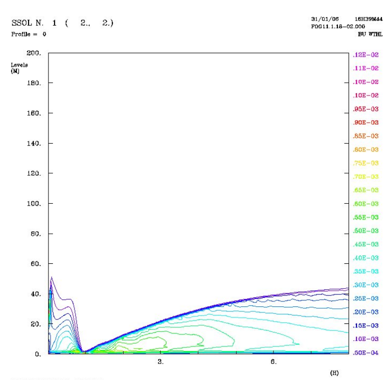
moyenne : $< \theta_l >$
MEAN_THL_PVT_



covariance : $< \overline{\theta_l'^2} >$
SBG_THL2_PVT_



bilan : $\left(\frac{\partial < \overline{w'\theta_l'} >}{\partial t} \right)_{pres}$
BU_WTHL_P_3_PVT_



bilan : $\left(\frac{\partial < \overline{w'\theta_l'} >}{\partial t} \right)_{therm.prod.}$
BU_WTHL_P_4_PVT_

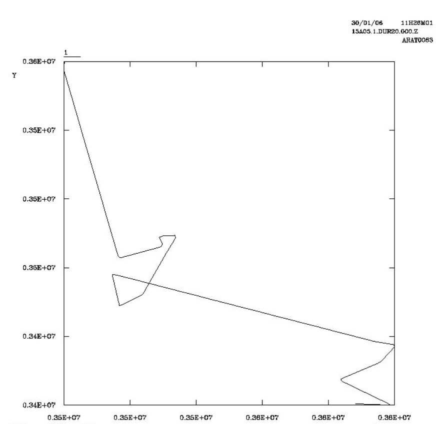
You can store the pronostic fields along aircraft (until 30) and balloon trajectories (until 9) during the simulation.

To do it

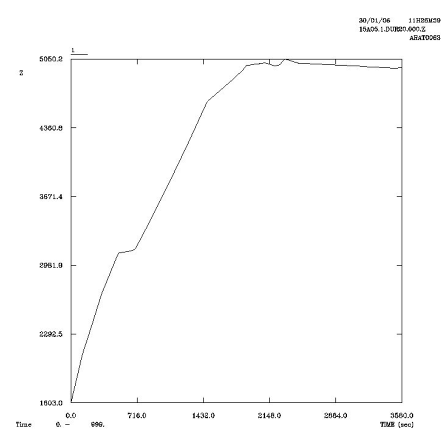
The **ini_balloon.f90** routine allows to define the initial position of the balloons (iso-density type, constant volume or radio-sounding) which will be advected.
The **ini_aircraft.f90** routine allows to defile the aircraft trajectory.

Note :

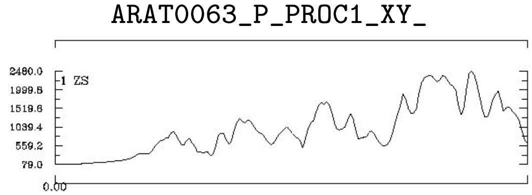
The DIAG program allows to compute trajectories from the synchronous file with stationnary fields(`LAIRCRAFT_BALLOON` in `&NAM_DIAG` de DIAG1.nam).



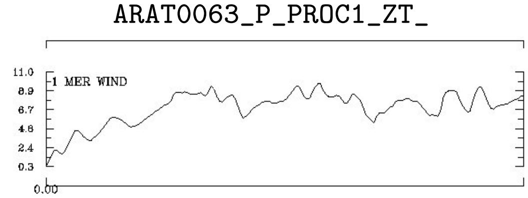
ARAT0063_P_PROC1_XY_



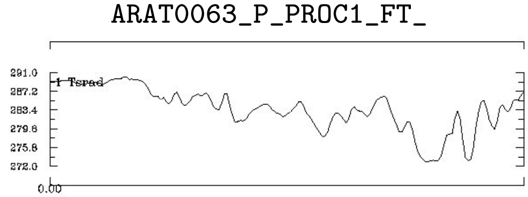
ARAT0063_P_PROC1_ZT_



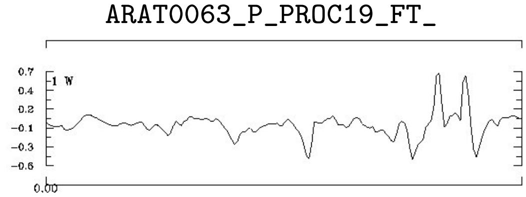
ARAT0063_P_PROC1_FT_



ARAT0063_P_PROC19_FT_



ARAT0063_P_PROC6_FT_



ARAT0063_P_PROC7_FT_

Data are in the diachronic file CEXP.n.CSEG.**000**

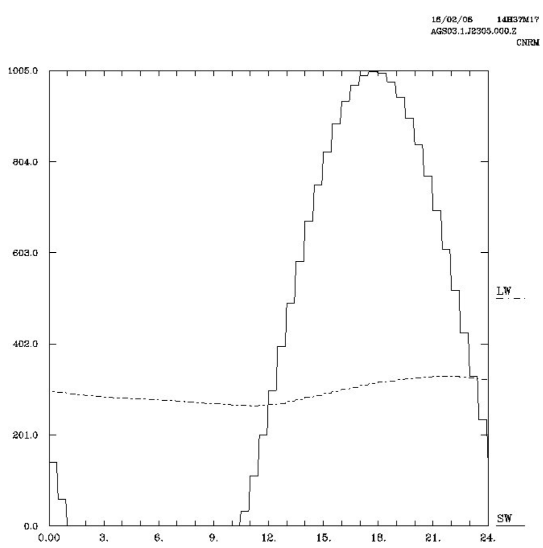
Stations, profilers

You can store pronostic fields and surface diagnostics at the localisation of stations or profilers during the simulation.

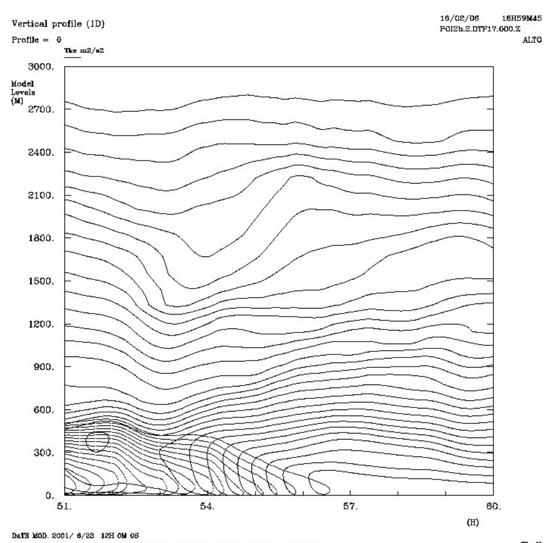
To do it

The **ini_stationn.f90** routine allows to set the position of the stations (latitude, longitude and altitude).
The **ini_profilern.f90** routine allows to set the position of the profilers (latitude, longitude).

Stations, profilers




```
print groups
print CNRM proc
CNRM_P_17_FT1__ON_CNRM_P_18_FT1_
```




```
ALTO_P_1_PVT__T_time1_to_time543_ON_
ALTO_P_11_PVT__T_time1_to_time543
```

Data are stored in the diachronic file CEXP.n.CSEG.**000**

Budgets

You can store during the simulation the differents source terms of the equation of every pronostic variable (u,v,w,θ,mixing ratio,TKE) :

- on a part of the simulation domain defined by
  - a box (Imin,Imax,Jmin,Jmax,Kmin,Kmax) : `CBUTYPE='CART'`
  - some areas selected according a criteria (ex : `WHERE XUM >0.`) evaluated at each timestep : `CBUTYPE='MASK'`
- optional spatial average in the 3 directions,
- optional temporal average on a specified duration.

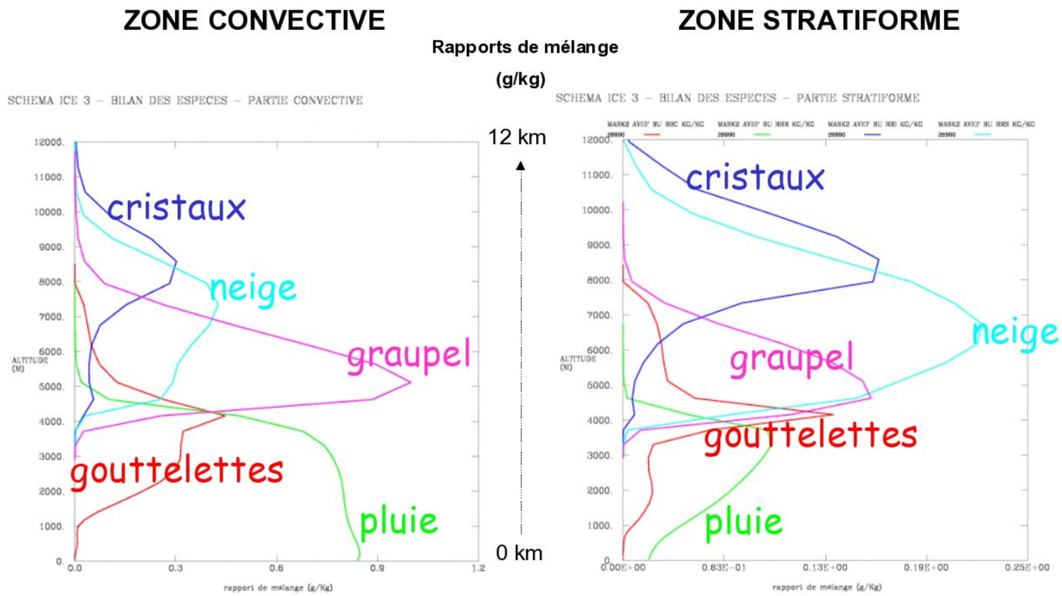
Budgets

To do it :

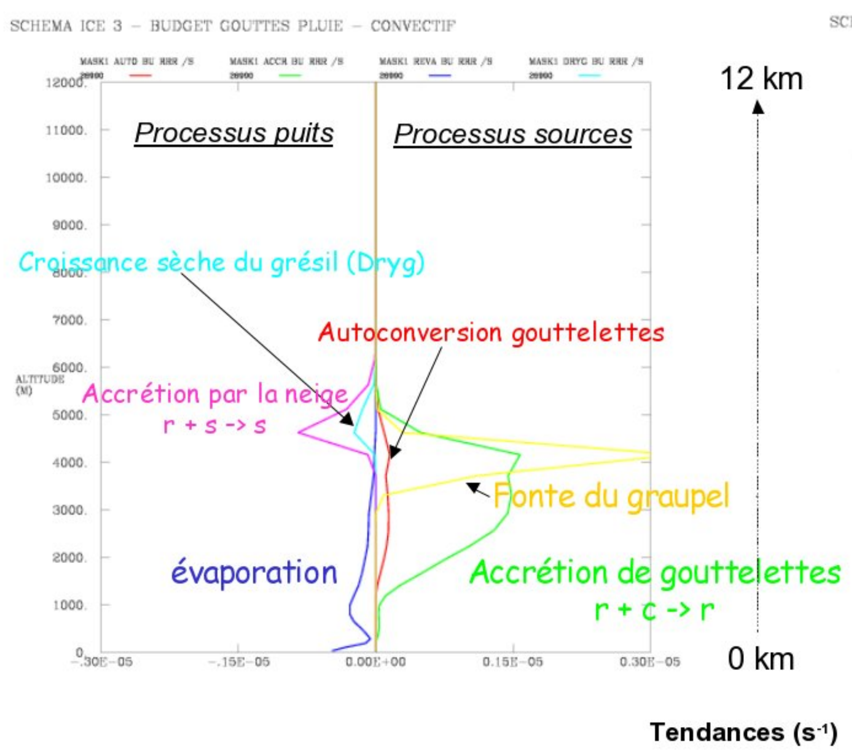
In file `EXSEG1.nam`, define the characteristics of the budgets in the namelist **&NAM_BUDGET**
In files `EXSEGn.nam`, choose the terms to be stored in the namelists
`&NAM_BU_RU,`
`&NAM_BU_RV,`
`&NAM_BU_RW,`
`&NAM_BU_RTH, etc.`

Data are in the diachronic file CEXP.n.CSEG.**000**

Budgets



Budgets



Program DIAG

It allows to compute a large number of diagnoctic quantitites from a synchronous file :

- variables derived from pronostic ones (vorticities, 'moist' temperatures, integrated mixing ratios),
- to compare to radar data
- diagnostics from physical parametrisations : convection, radiation and turbulence schemes,
- diagnostics of the externalized surface scheme,
- Lagrangian trajectories with several start points

See the whole list of diagnostic at chapter 10 of "the Meso–NH user's guide" (book3).

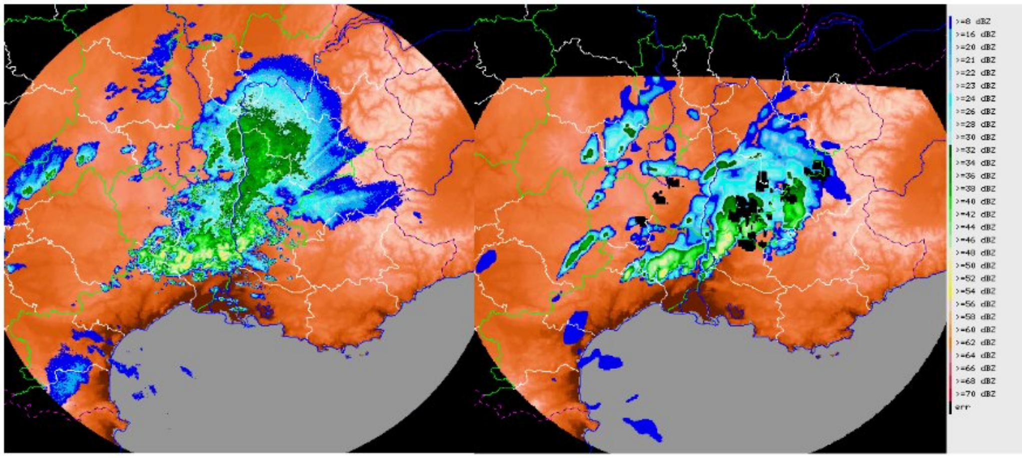
Program DIAG

Example of DIAG1.nam :

```
 &NAM_DIAG
CISO='TKPREV',
LVAR_RS=T,
LVAR_MRW=T,
NCONV_KF=1, NCAPE=1,
LTPZH=F,
LMOIST_V=F,
LMOIST_E=T,
LMSLP=T,
LTHW=T,
LCLD_COV=T,
LRADAR=F,
LDIAG(:)=.FALSE. /
```

```
 &NAM_DIAG_FILE
YINIFILE(1)= "16JT0.1.09A12.001" ,
YINIFILEPGD(1)= "FILE_PGD" ,
YSUFFIX = "dg" /

&NAM_KAFR_PARAMn /
&NAM_RAD_PARAMn /
&NAM_DIAG_SURFn
N2M=2 LSURF_BUDGET=T /
&NAM_DIAG_ISBAn
LPGD=F LSURF_EVAP_BUDGET=T /
```

Radar simulator



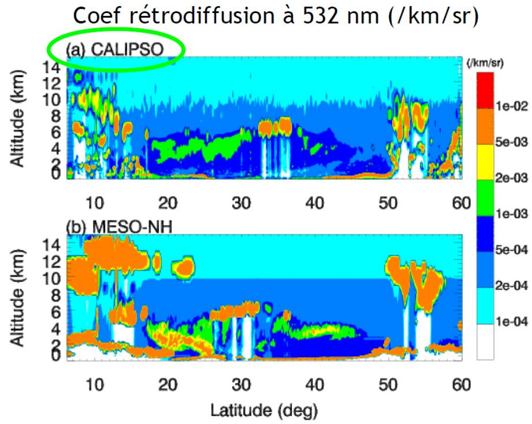
Réflectivités observées *Réflectivités simulées avec Méso-NH*

(radar de Bollène le 8 sep. 2002 à 21 UTC, élévation=1,2°)

- LRADAR=T
- you have to specify the version : NVERSION_RAD= 1 or 2

Lidar simulator

Coef rétrodiffusion à 532 nm (/km/sr)



Chaboureau et al , QJRMS 2011

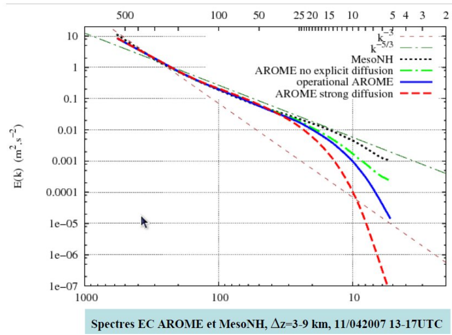
Dans &NAM_DIAG / :

- LLIDAR=T
- CVIEW_LIDAR= : lidar point of vew 'NADIR' or 'ZENIT'
- XALT_LIDAR=0 : altitude of lidar in meters
- XWVL_LIDAR=0.532E-6 : wavelength of lidar in meters

Program SPECTRE

Example SPEC1.nam :

```
&NAM_SPECTRE
LSPECTRE_U=.TRUE.,
LSPECTRE_V=.TRUE.,
LSPECTRE_W=.TRUE.,
LSPECTRE_TH=.TRUE.,
LSPECTRE_RV=.TRUE.,
LSPECTRE_LSU=.FALSE.,
LSPECTRE_LSV=.FALSE.,
LSPECTRE_LSW=.FALSE.,
LSPECTRE_LSTH=.FALSE.,
LSPECTRE_LSRV=.FALSE.,
LSMOOTH=.TRUE./
&NAM_ZOOM_SPECTRE
LZOOM=.FALSE.,
NXDEB=10,
NYDEB=20,
NITOT=20,
NJTOT=30/
&NAM_DOMAIN_AROME /

&NAM_SPECTRE_FILE
        YINIFILE(1) = "16JAN.1.12B18.001",
        CTYPEFILE='MESONH'/
```



Δx=2.5km

Ricard, D., C.Lac and S.Riette, *Soumis QJRMS*

Training Course : Real case

MesoNH Tutorial Class 3-5 Oct 2016

Presentation

Aim :

- do a MESONH simulation in real case
- understand the different steps for 1 and 2 models
- discover and modify namelists

NB :
You have to modify in the namelists file only what is asked and the name of the files which have all been modified

Preparation

cd /utemp/MNH-V5-2-1/MY_RUN/KTEST
mkdir TP_CAS_REEL
cd TP_CAS_REEL
tar xvf ~delautierg/tp_real_makefile.tar
You have now subdirectories numbered in the order of the step asked. In each subdirectory, you will find the namelists to modify files and the script run_...
export PREP_PGD_FILES=~delautierg/mesonh/PGD
If it isn't done :
. /utemp/MNH-V5-2-1/conf/profile_mesonh-LXgfortranI4-MNH-V5-2-1-MPIVIDE-DEBUG

Creation of all the PDG files

1. In the directory 001_pgd1, run the step PREP_PGD to create the dad's PGD file named **PGD_36km** with :
   - a domain with 80 points in i and 60 in j
   - a mesh of 36 km in x and y
2. In the directory 002_pgd2, run the step PREP_PGD to create the son's PGD file named **PGD_9km** with :
   - a domain with 72 points in i and 60 in j (number of points for the son's domain)
   - a mesh of 9 km in x and y
   - which start at point i=40,j=16 from dad's domain
3. In the directory 003_nest, make PREP_NEST_PGD

Preparation of coupling files

The extractions of GRIB files have allready been made with extractarpege and are in the directory 004_ecmwf2lfi

1. in the directory 004_ecmwf2lfi run the step PREP_REAL_CASE to make the inital file for dad's domain from the atmospheric file **ecmwf.EI.19980115.12** named **15JAN_12_MNH**
2. run the step PREP_REAL_CASE to make the coupling file for dad's domain from the atmospheric file **ecmwf.EI.19980115.18** named **15JAN_18_MNH**

Segment 1

We will now run the simulation with only one domain between 12h and 13h with a coupling file at 18h.

1. In the directory 005_run1, modify the file of namelists in order to have :
   - 1 domain
   - 1 hour of simulation
   - 4 out put files (every 15 minutes)
   - a time step of 120 s
   - the output files must be named : **16J36.1.00A12.00n**
2. Run the MESONH simulation

Segment 2

1. In the directory 005_run1, modify the file of namelists in order to restart the simulation for 1 hour. The output files must be named : **16J36.1.00A13.00n**
2. Run the MESONH simulation

Segment 3

We will now run a simulation with the 2 domains between 14h and 15h.
We first create the initial file for son's domain.

1. In the directory 006_spa_mod1_mod2, run the step SPAWNING (modify the file of namelists) to make the horizontal interoplation from the dad's domain to the child's domain at 14h (end of segment 2)
2. In the directory 007_preal, modify the file of namelists in order to create the son's initial file named **15JAN_14_MNH2** (vertical interpolation after SPAWNING)

Segment 3

3. In the directory 008_run2, modify the file of namelists in order to have :
   - 2 domains
   - 1 hour of simulation
   - 2 output files (every 30 minutes) for each domain
   - a time step of 120 secondes for the father and a ratio of 4 for the son
   - two-way interaction
   - the output files must be named : **16J36.1.12B18.00n**
4. Run the MESONH simulation
5. In the directory 009_diag, run the step DIAG on the files you want