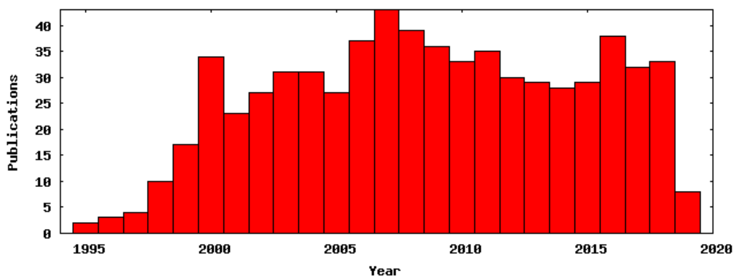
Meso-NH
mesoscale non-hydrostatic model

METEO FRANCE

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

+ LACy, CERFACS, LOPS (Brest), SPE (Corsica) ...

http://mesonh.aero.obs-mip.fr/mesonh54



514 articles
145 thesis

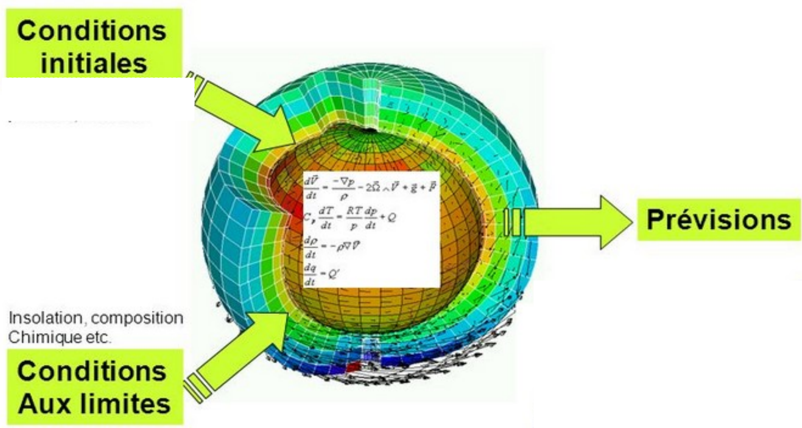
<u>References</u> : *Lafore et al., 1998 – Lac et al., 2018, GMD*

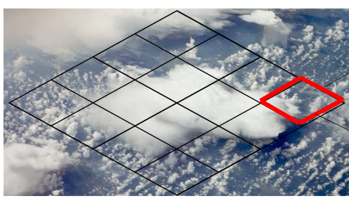
Plan

1. **Introduction (a few illustrations)**
2. **Dynamics**
3. **Physics (without SURFEX)**
4. **A few words about on-line couplings : electricity, fire, chemistry/aerosols ...**

What is an atmospheric model ?

It predicts the atmospheric state evolution represented with a spatio-temporal discretization

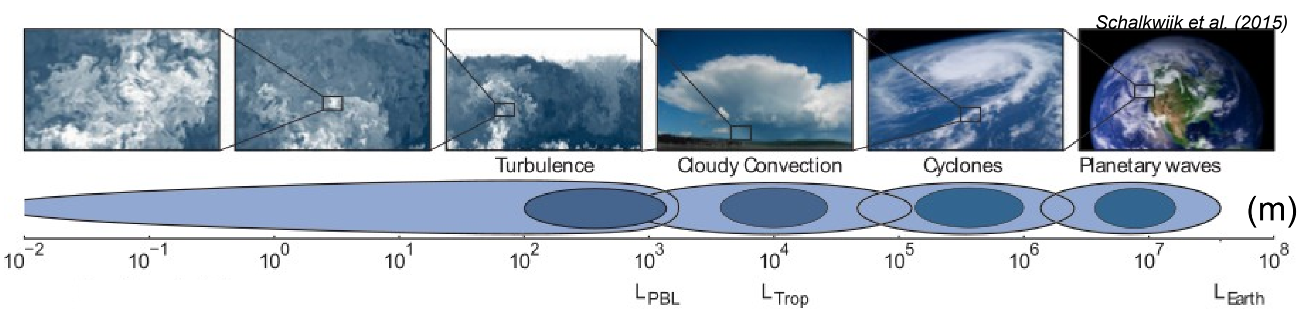




Resolved processes : **dynamical** core

Subgrid processes : **physical** parametrizations

Space and time scales



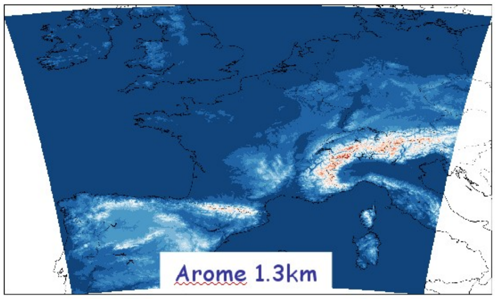
« Direct Numerical »« Large-Eddy Simulation » « Cloud System Resolving model »

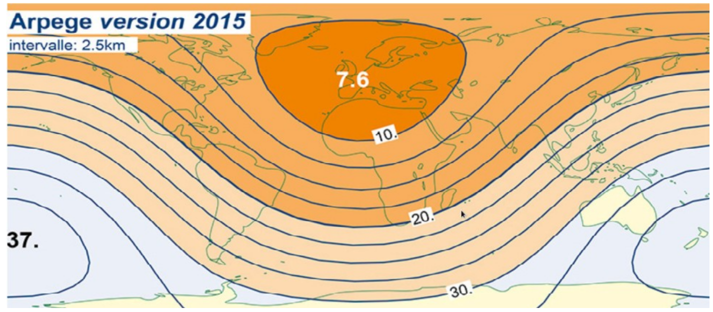
(DNS) (LES) (CSRM)

Méso-NH

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).**

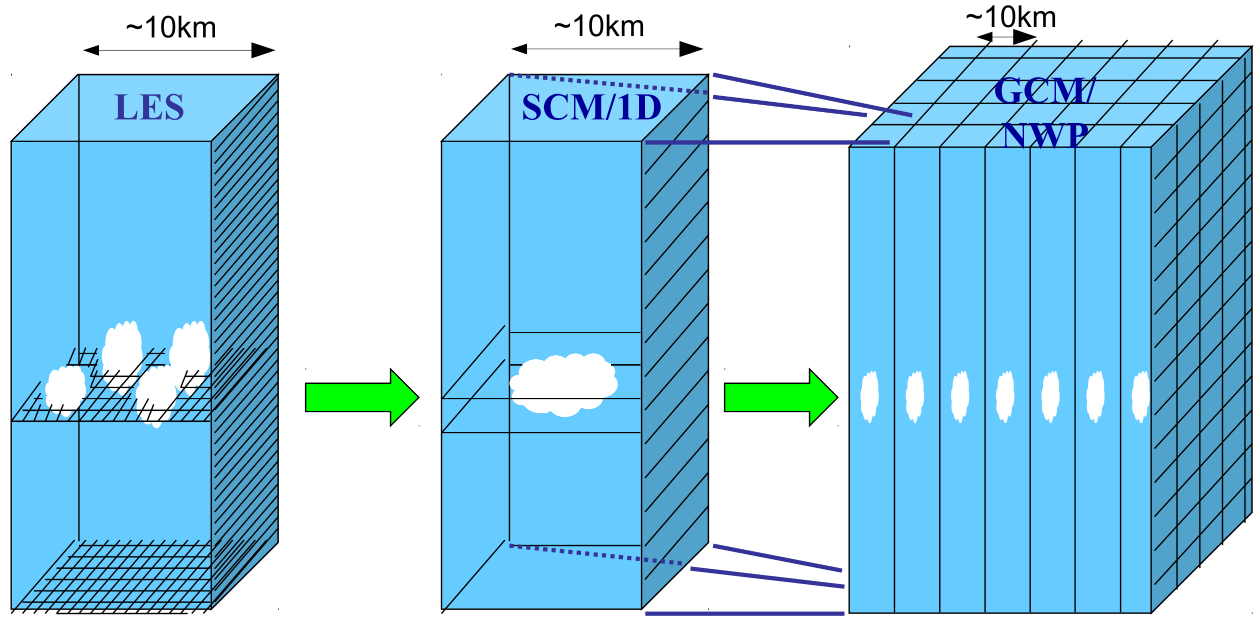
LAM

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

Why do we need a high resolution 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

METHODOLOGY to improve PARAMETRIZATIONS



LES : Subgrid Kinetic Energy < 20 % Total Kinetic Energy
Dx depends on the motions : ~100m for convection, ~ 1m for stable boundary layer

The mean and the PDF fields of the LES constitute the reference for the 1D and 3D NWP fields

Meso-NH : The same set-up in 1D and LES (initial conditions , flux, large scale forcings)

Meso-NH mesoscale non-hydrostatic model

Main characteristics

DYNAMICS

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

PHYSICS

- ✗ Coupled with the externalized surface model SURFEX (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

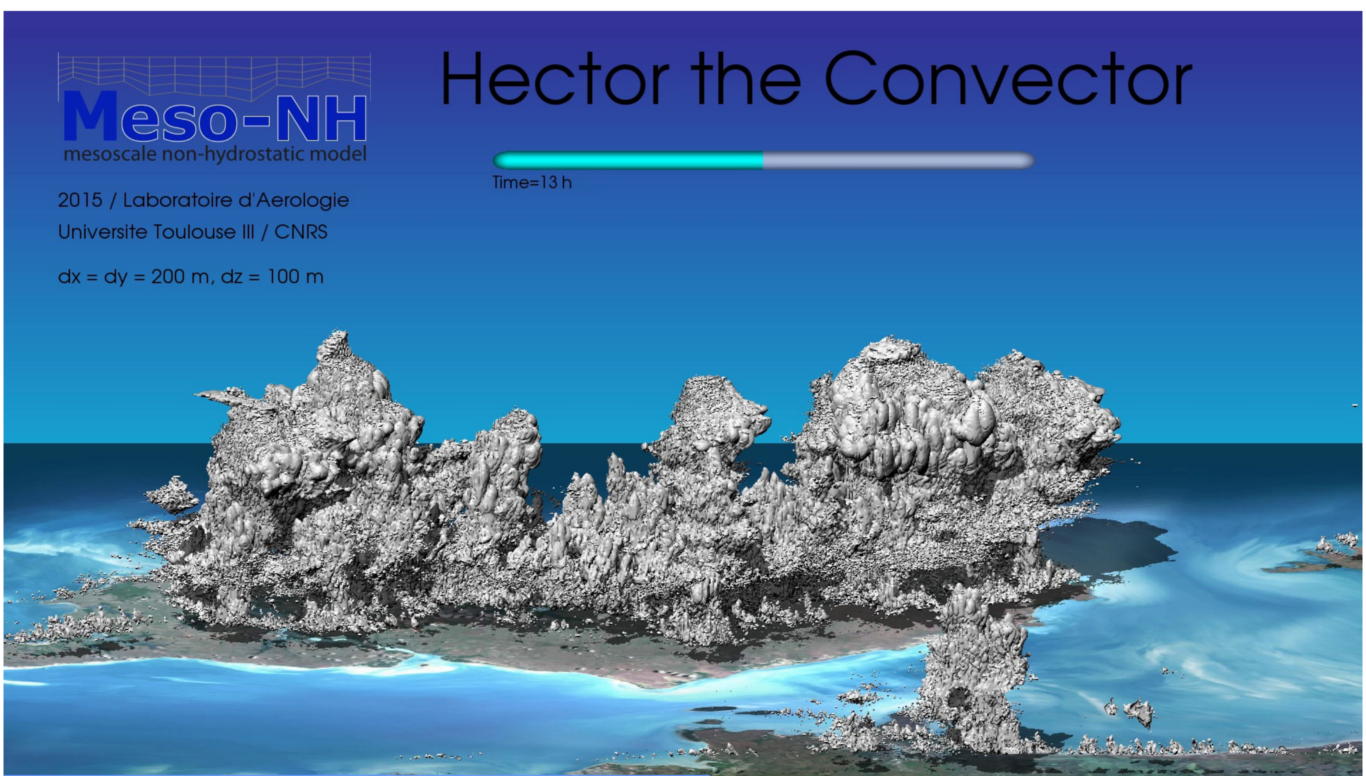
- ✗ The physics of AROME comes from Meso-NH (1D version)

Meso-NH
mesoscale non-hydrostatic model

General view

- ✗ **Real cases** (from ECMWF, ARPEGE, AROME, GFS analyses or forecasts)
- ✗ **Ideal cases** ≠ unrealistic cases
  - Academic cases (validation of the dynamics)
  - Basic studies (Diurnal cycle …) : Cloud Resolving Model (CRM)
  - To reproduce an observed reality (via forcings)
    (intercomparison : GCSS, EUROCS …)
- ✗ Simulations **3D, 2D, 1D** – Real cases only in 3D

- ✗ From a simple to a sophisticated physics
- ✗ Different numerical schemes : from accurate and expensive to cheaper
- ✗ A set of **diagnostics** (budgets, profilers, trajectories …)
- ✗ Parallelized and vectorized
- ✗ A broad range of hardware system for the research community : CRAY, IBM, BULL, cluster of PC … towards GPU
- ✗ Adapted to **large grids**
- ✗ No operational objective.



- 2560 x 2048 x 256, 1.34 billion gridpoints
  Δx=100 m and Δz=40 - 100 m : **1st Giga-LES**
- 10-h simulation on IBM BlueGene-Q
  8 million CPU h, 16 kcores, 20 Tb data
- Initial field from Darwin sounding

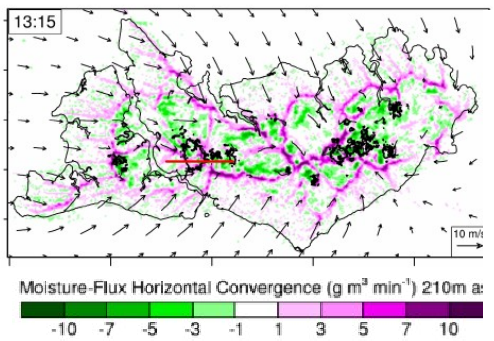
A storm that grew daily during pre-monsoon on the Tiwi Islands north of Darwin

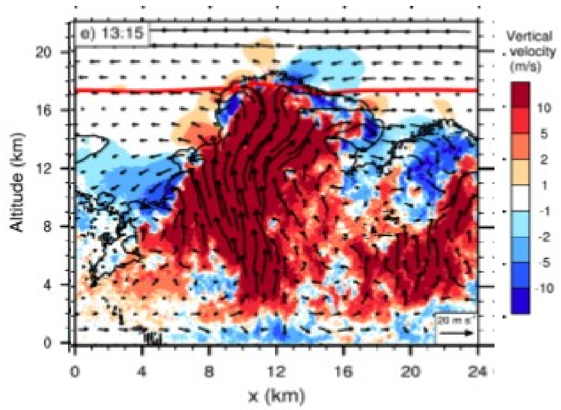
Dauhut et al., Atmos. Sci. Lett. 2015

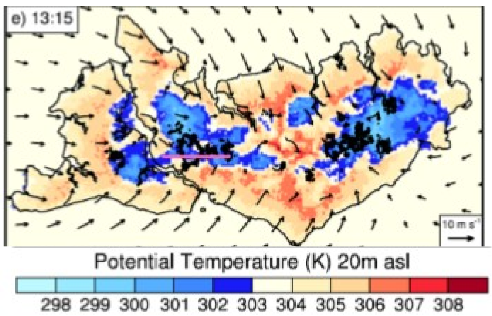
Video on https://youtu.be/xjPumywGaAU

Formation of the tallest updrafts

13:15 Very Deep Convection







- Humidity convergence lines advected inland by the sea breeze
- Cold pools pushed the convergence lines inland
- Tallest updrafts reached 18km and inhibited the other updrafts by detraining subsiding air

Convergence intensified by cold pools

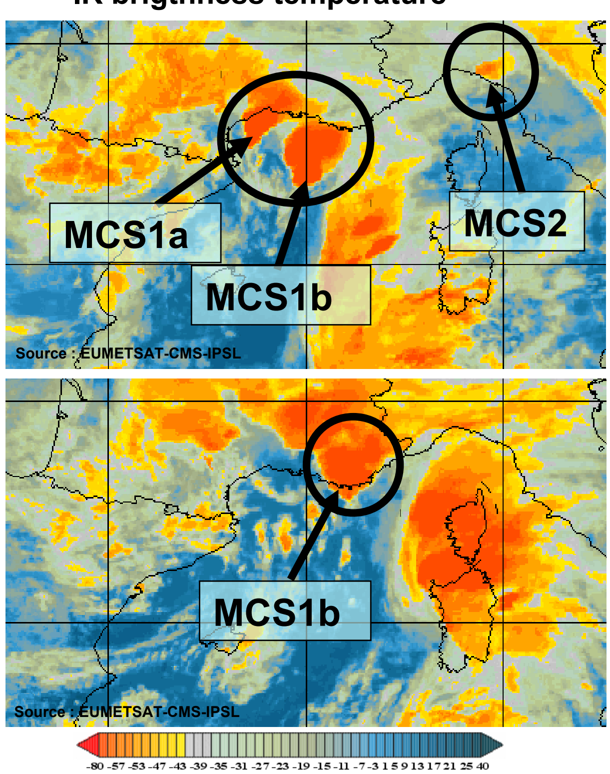
Diagnostics to study key physical processes

POI16 HYMEX : Observed convective systems

Nuissier et Civiate, 2013

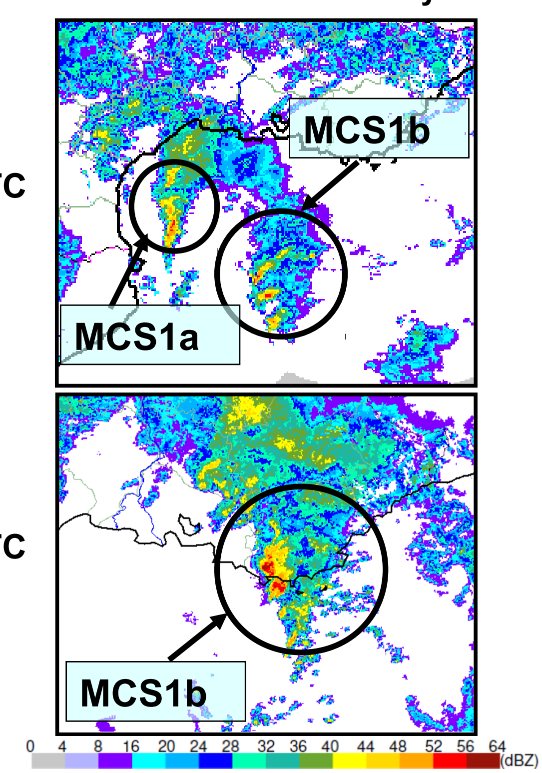
IR brigthness temperature

Observed radar reflectivity



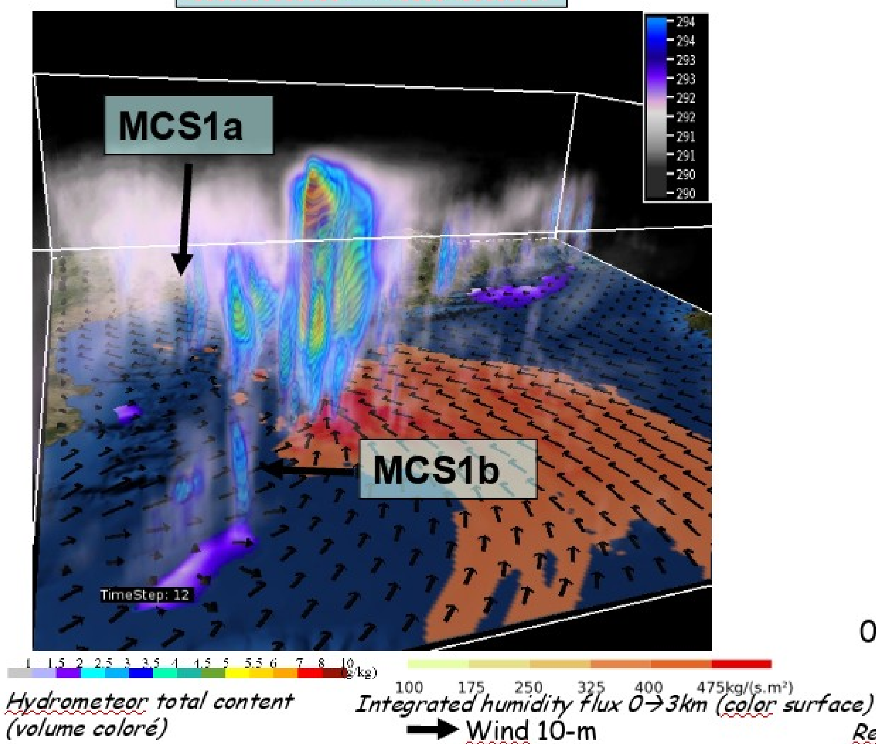
08 UTC

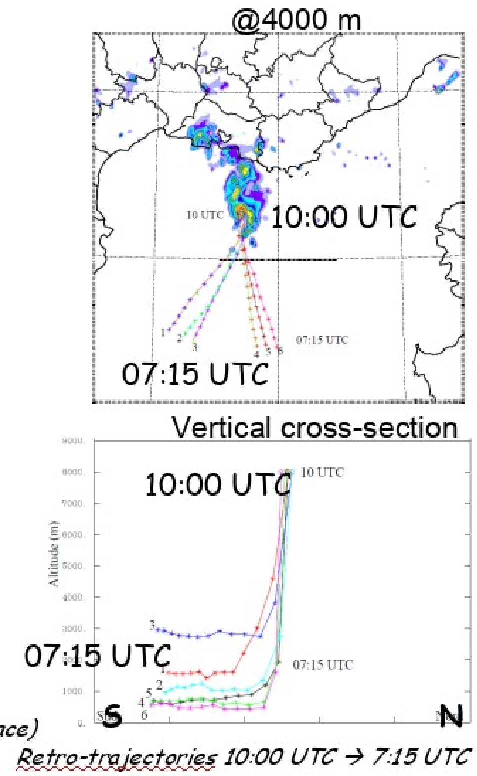
13 UTC



Diagnostics to study key physical processes

Vizualisation 3D with VAPOR



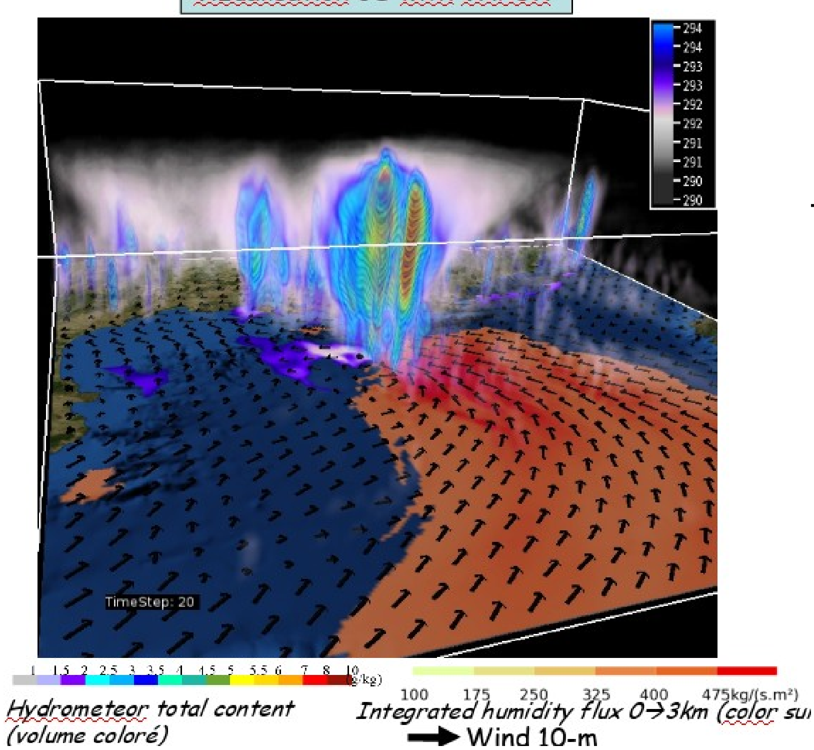


- Humidity advection and low-level convergence !

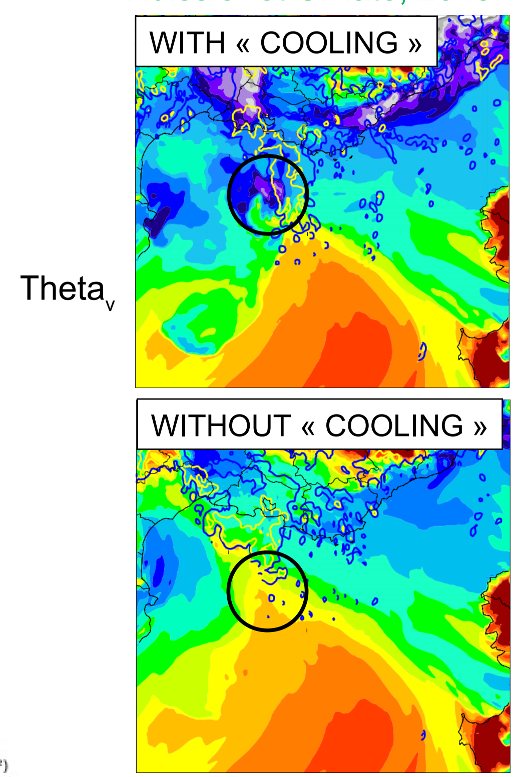
Nuissier et Civiate, 2013

Key physical processes

Vizualisation 3D with VAPOR



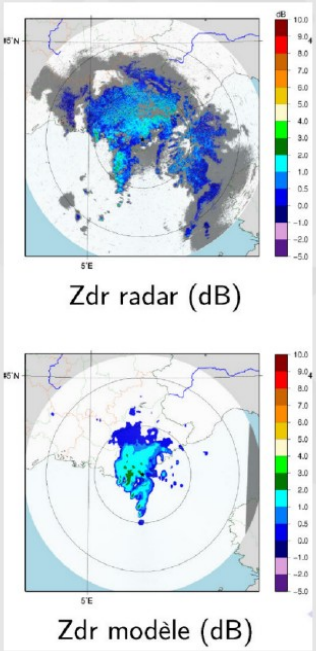
Nuissier et Civiate, 2013

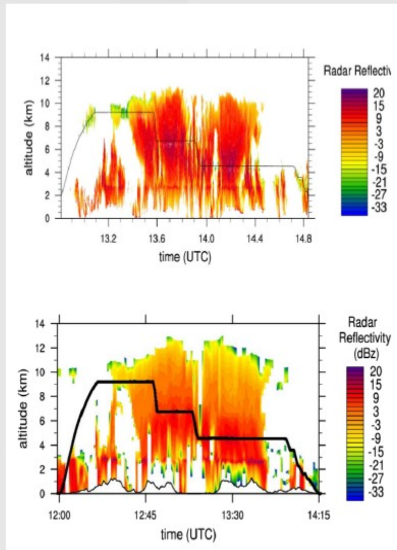


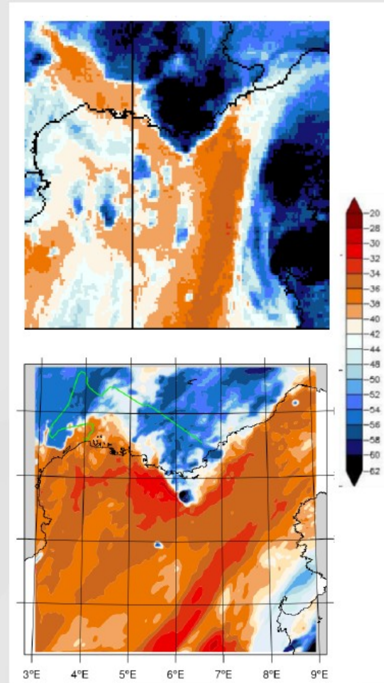
- Lifting on the leading edge of the cold pool
- MCS1b quickly advected to the north without cooling

Observation operators to compare

- Polarimetric radar
- Airborne obs.
- Satellite



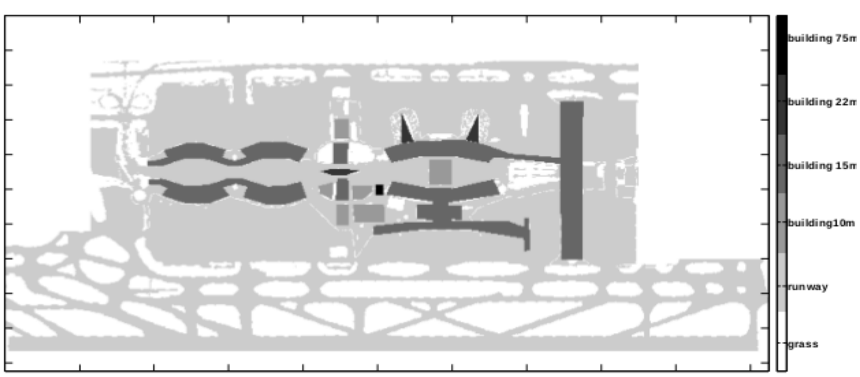




CNRM-GAME

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

Database from Aéroports de Paris
Surface elements have been built



3000×1000 ×135
Δx=1.5m
Δz=1m
Flat terrain
Building drag effect

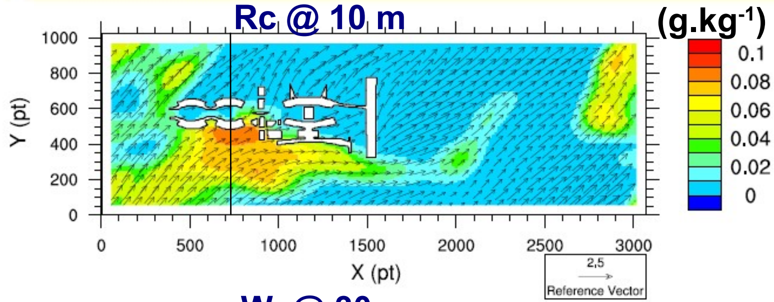
Bergot et al., 2015, QJRMS

CNRM-GAME

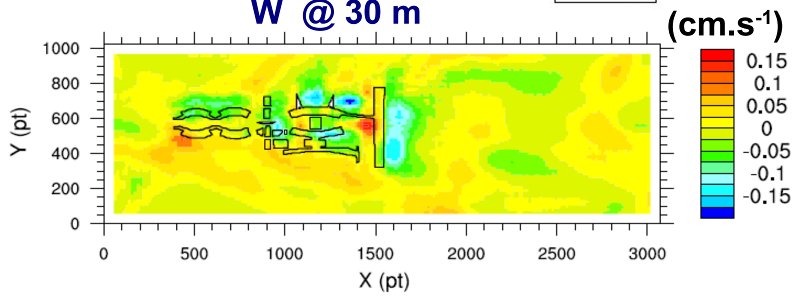
23h15 UTC

Development of the fog

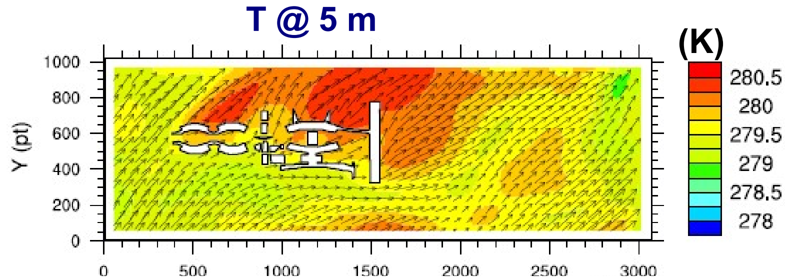
DRAG



Very heterogeneous fog formation (~1.5 h)
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

Scalability

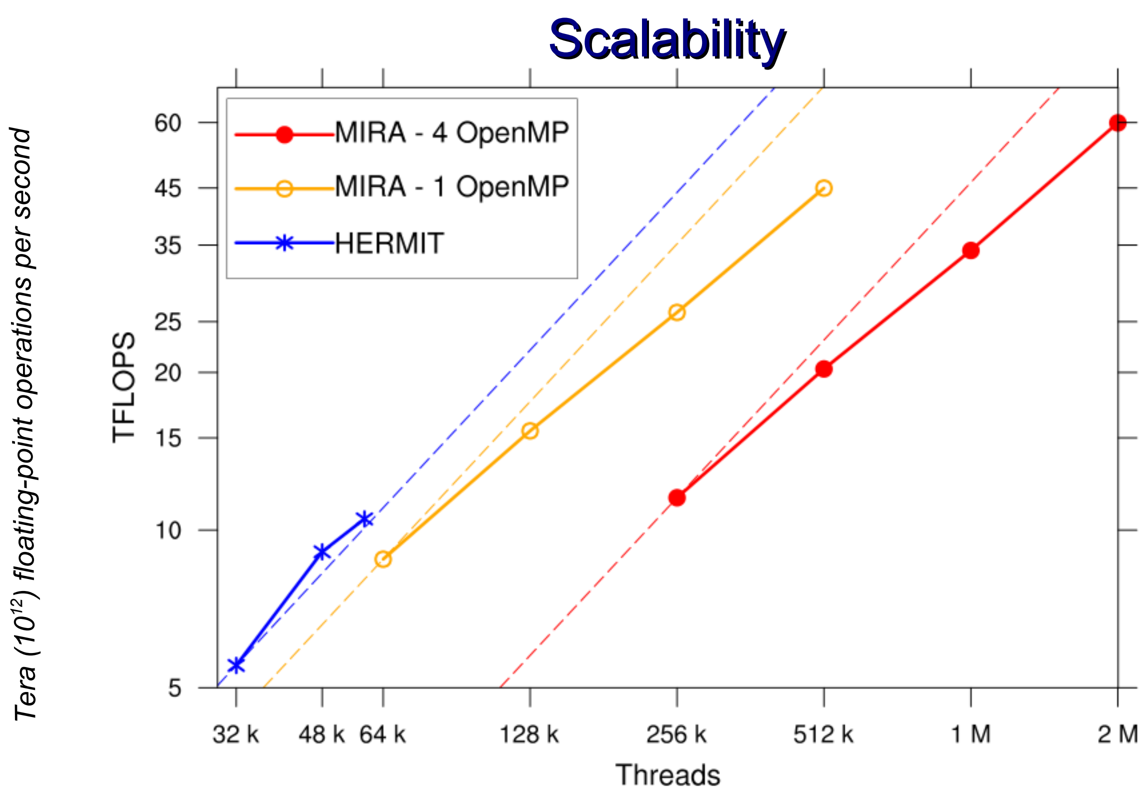


Figure 1. Performance of Meso-NH in scalability. Average sustained power (expressed in TFLOPS) depending on the number of threads obtained by Meso-NH for a grid of 4096 × 4096 × 1024 points (17 billion points) on two machines (HERMIT, a Cray XE6 in Germany and MIRA, a IBM Blue Gene/Q in the USA using either one or four OpenMP tasks per core). The dashed lines show the optimal speedup.

TFLOPS gradually increases with the number of threads while remaining close to the optimal speedup

2. Dynamics

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

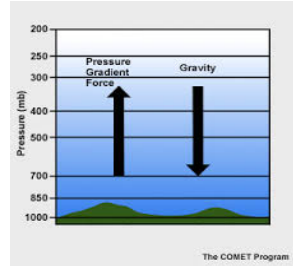
Dépends on :
- **Hypothesis** : Non-hydrostatism ; anelastic
- **Horizontal Geometry** : Coupling, Embedded models
- **Vertical coordinates** : Upper boundary limit
- **Orography characteristics** (average and envelop orography)
- **Numerical methods** : Grid points; Explicit ; Eulerian
- **Model variables**;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

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
- The hydrostatism 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)

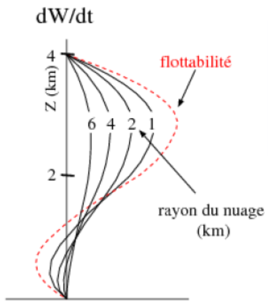
$$\begin{aligned} u &= 0 + \tilde{u} \\ v &= 0 + \tilde{v} \\ w &= 0 + \tilde{w} \\ T &= T_{ref} + \tilde{T} \\ p &= p_{ref} + \tilde{p} \\ \rho &= \rho_{ref} + \tilde{\rho} \end{aligned}$$

- 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 :

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

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**

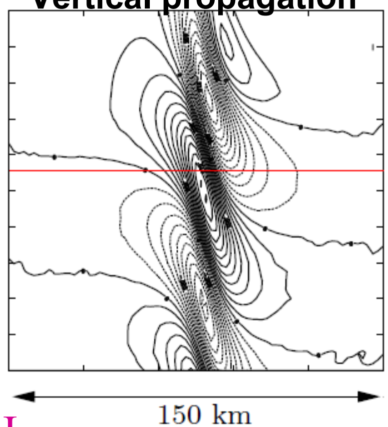
Orographic waves, H and NH waves

$N = 0,01 \mathrm{s}^{-1}$
$U = 10 \mathrm{\ m.s}^{-1}$
H=hauteur montagne=10 m

→ $(NH)/U << 1$: cas linéaire

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

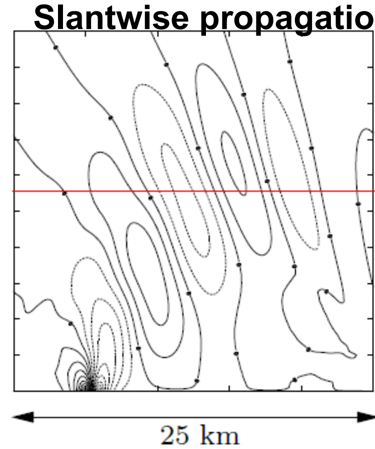
Vertical propagation



L>> H

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

Slantwise propagation

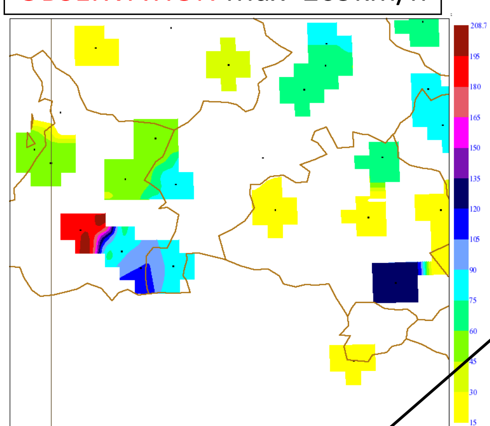


L~H

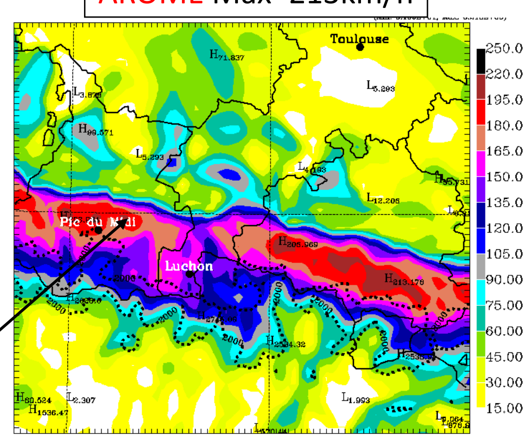
L=largeur montagne=665 m
$(NL)/U << 1$: non hydrostatique

Fine-scale simulations of Xynthia winds

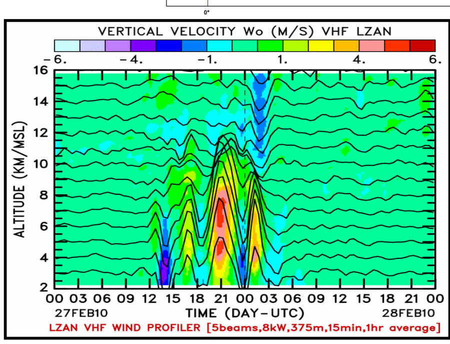
OBSERVATION Max=209km/h



AROME Max=213km/h



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

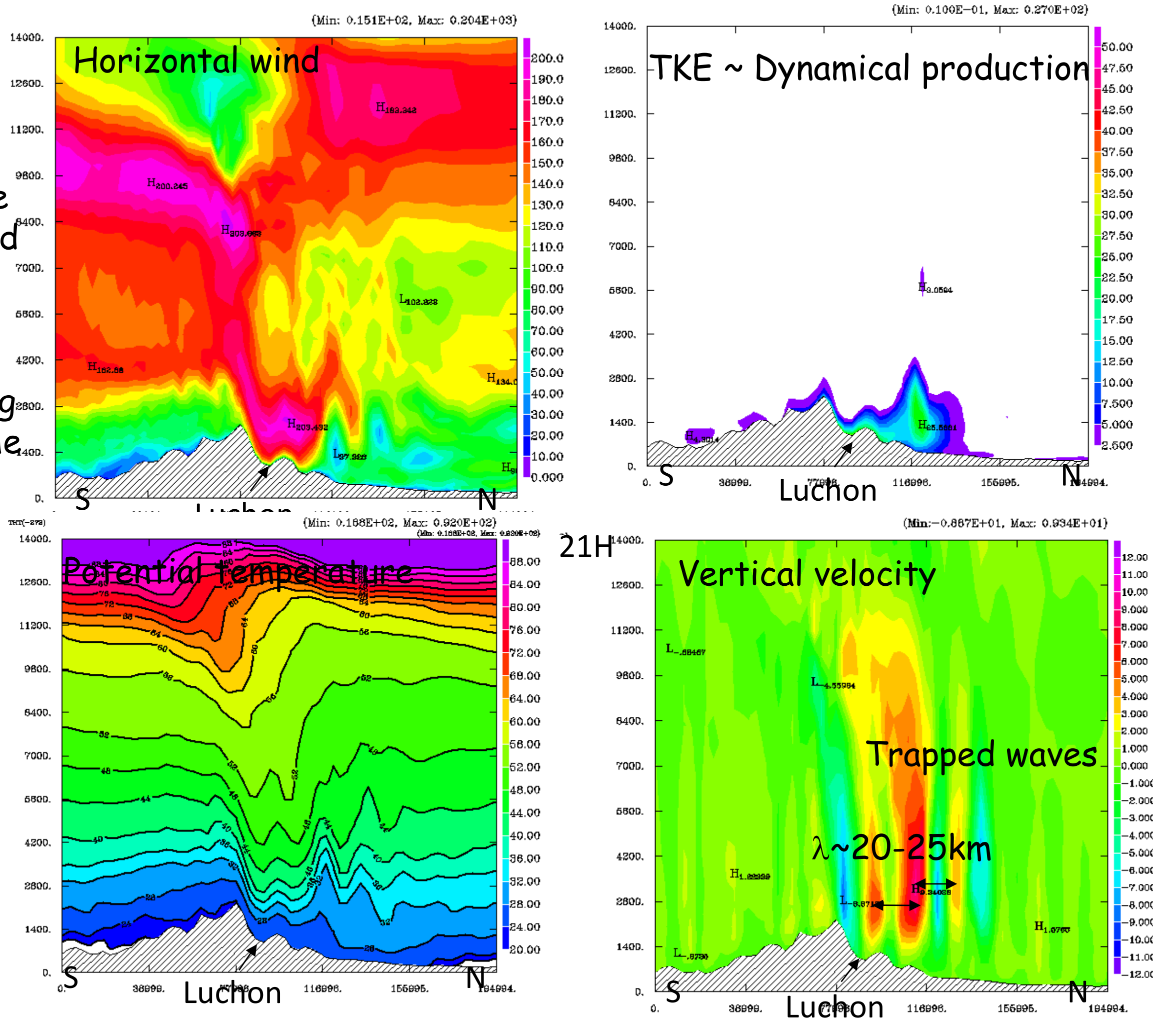


Lannemezan wind profiler shows a structure of trapped gravity waves

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

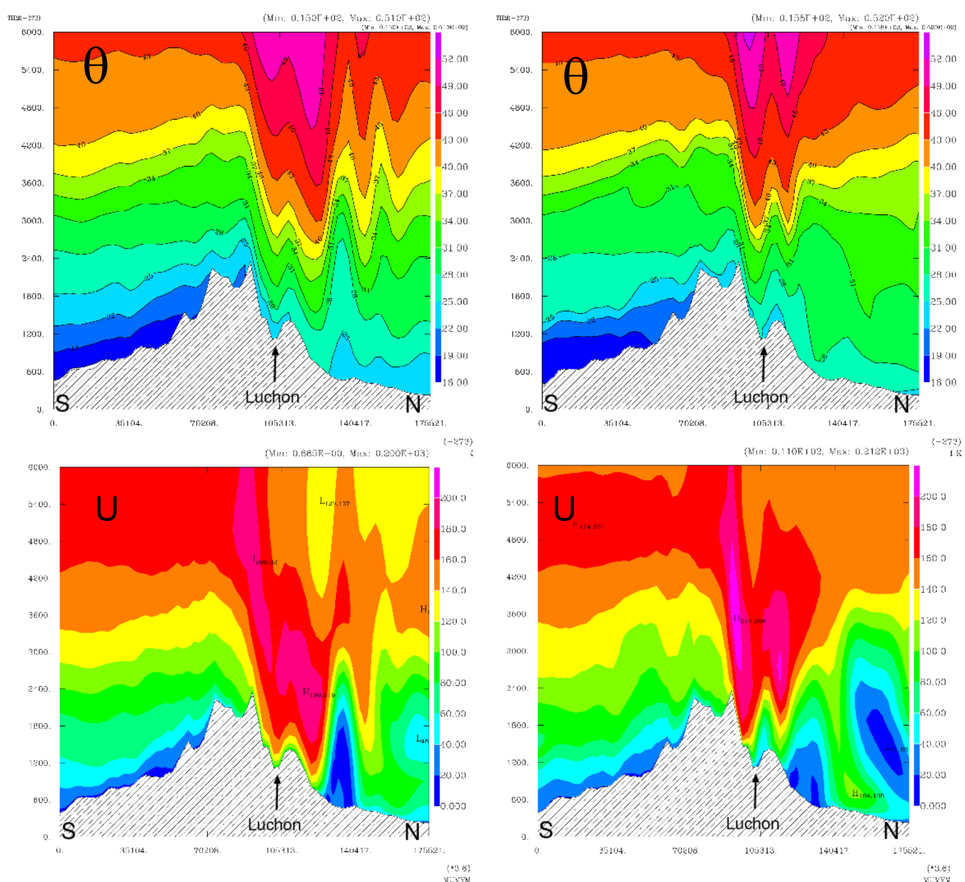
Meso-NH : same forecast than AROME

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



Non-Hydrostatic Hydrostatic

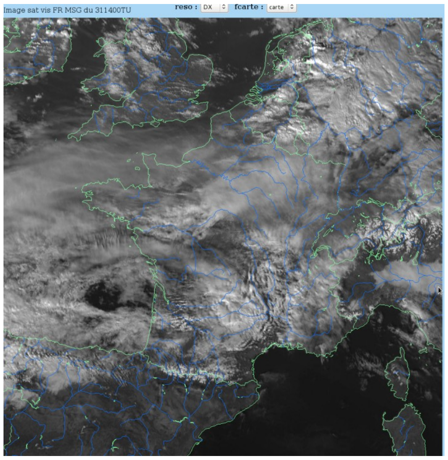
AROME



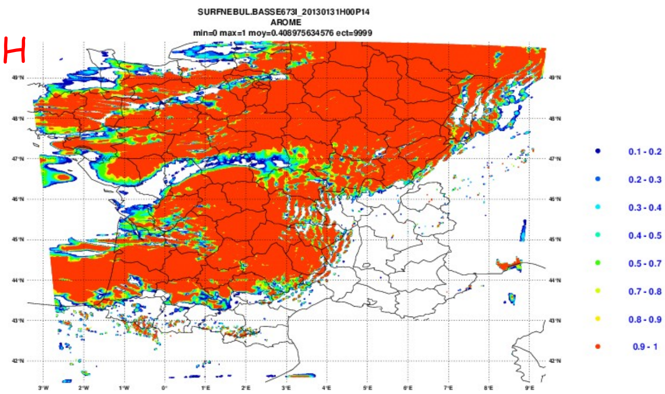
H : Trapping and low level winds are weakened

Non-Hydrostatic vs. Hydrostatic

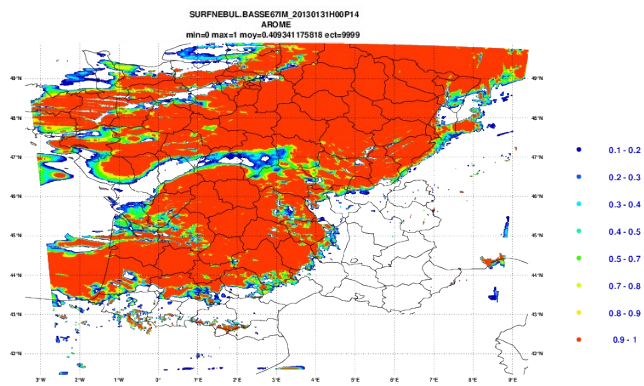
31 Janv. 2013



AROME
1.3km NH



AROME
1.3km H



Elastic processes

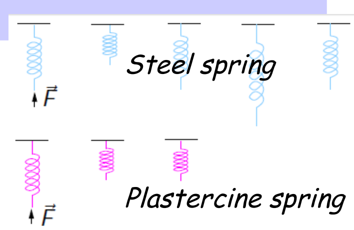
We know that air is compressible

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**

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



Filtering of elastic processes

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

$\tilde{p}$ becomes a diagnostic variable

Except for buoyancy

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	Modèle hydrostatique
w est une variable pronostique (Méso-NH, Aladin-NH/Arome)	w est une variable diagnostique (Arpège/IFS, Aladin)

Modèle « fully compressible »	Modèle anélastique
$\tilde{p}$ est également pronostique (Aladin-NH/Arome)	$\tilde{p}$ est diagnostique (Méso-NH)

Numerical methods to control acoustic waves

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 : Anelastic 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%) → For LES with steep slopes, orography needs to be smoothed.

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

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, Ra is the gas constant of dry air, and Cp is the specific heat capacity at a constant pressure of dry air. This equation is often known as Poisson's equation.

$T=\pi.\theta$ where π is the Exner function

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 a specie is expressed as a ratio of specie mass, per kilogram of dry air, in any given parcel of air : $r_j=m_j/m_d=\rho_j/\rho_d$

$$r_j(kg/kg)=\frac{q_j}{1-q_t}$$

q_j is the specific humidity (in kg/kg), per kilogram of total air
q_t is the total specific humidity : $q_t=q_v+q_c+q_r+q_i+q_s+q_g$

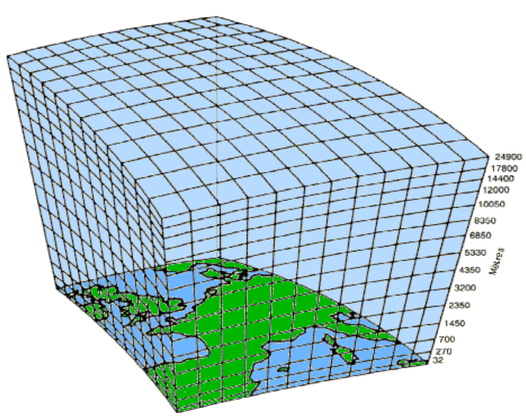
As there is conservation of dry air mass :
=> Conservation of a mass of a given species = conservation of its mixing ratio

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 concentrations, or others

Coordinates system



Vertical coordinates

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

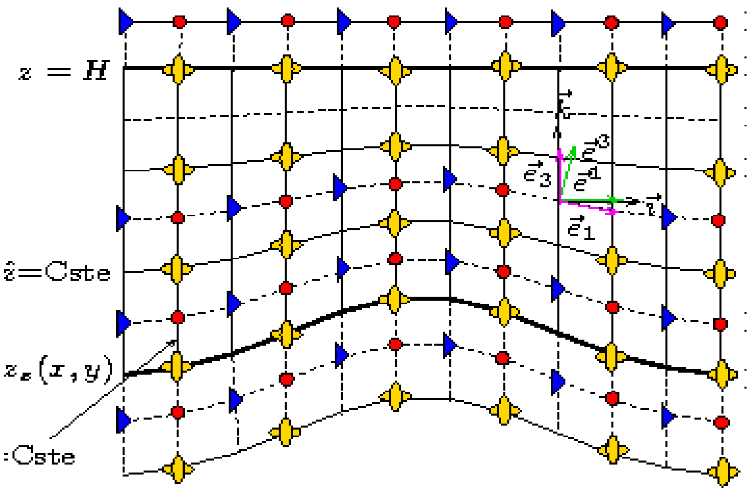
$$\hat{z}(k) = \frac{z(i,j,k) - z_s(i,j)}{H - z_s(i,j)} H$$

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



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

Vertical coordinates

-**Sleve** coordinate: in the presence of steep orograph, the small scale features decrease rapidly with height limiting steep slopes to the lowermost few kilometers

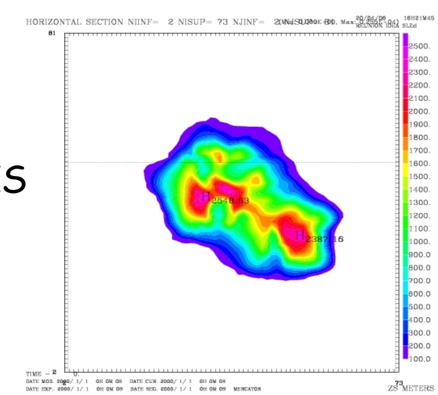
$$z(i,j,k) = \hat{z} + z_{S1} \times \frac{\sinh[(H - \hat{z}(k))/s_1]}{\sinh[H/s_1]} + z_{S2} \times \frac{\sinh[(H - \hat{z}(k))/s_2]}{\sinh[H/s_2]}$$

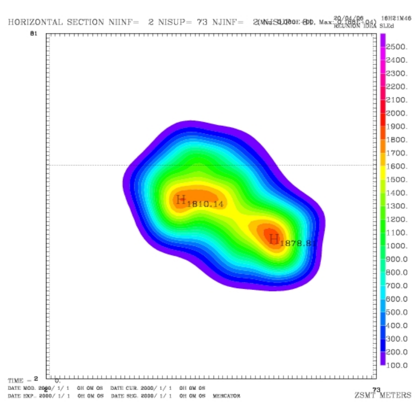
Large scale contribution of the smooth orography   Small scale contribution

ZS=ZS1 +ZS2 = ZSMT + (ZS-ZSMT)

Reunion test case

ZS





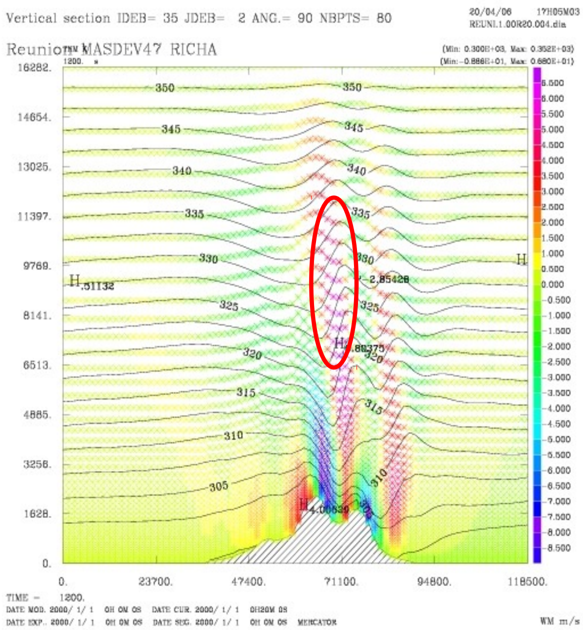
ZS1

(average on 9 points)

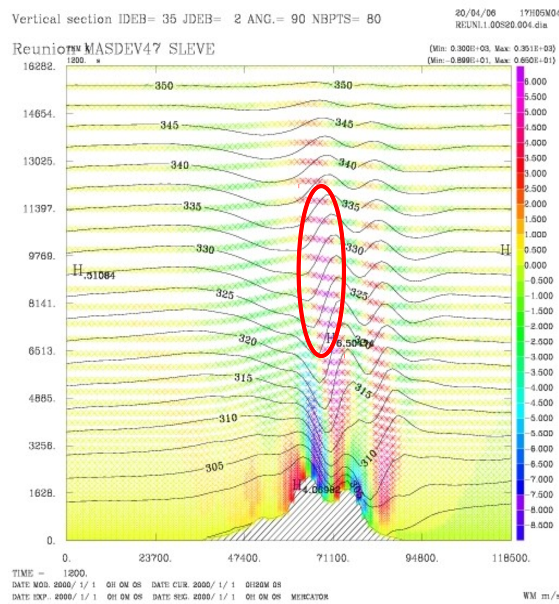
Reunion test case

WM
THM

GC



SLEVE



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 $\widehat{x}_0, \widehat{y}_0$

→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)

Coordinates system

-Physical space : x, y, z – Transformed space $\hat{x}, \hat{y}, \hat{z}$

- Metric coefficients

$$\begin{aligned}
\hat{d}_{xx} &= \frac{\partial x}{\partial \hat{x}} = \frac{r}{am} \\
\hat{d}_{yy} &= \frac{\partial y}{\partial \hat{y}} = \frac{r}{am} \\
\hat{d}_{zz} &= \frac{\partial z}{\partial \hat{z}} = 1 - \frac{z_s}{H} \\
\hat{d}_{zx} &= \frac{\partial z}{\partial \hat{x}} = \frac{\partial z_s}{\partial \hat{x}}(1 - \frac{\hat{z}}{H}) \\
\hat{d}_{zy} &= \frac{\partial z}{\partial \hat{y}} = \frac{\partial z_s}{\partial \hat{y}}(1 - \frac{\hat{z}}{H})
\end{aligned}$$

r=distance to the earth center
a=earth radius

- Jacobian = ratio of the volumes in the transformed and physical spaces

$$\hat{J} = \hat{d}_{xx}\hat{d}_{yy}\hat{d}_{zz} = (\frac{r}{am})^2(1 - \frac{z_S}{H})$$

- Prognostic variables are multiplied by $\hat{\rho} = \hat{J}\rho_{ref}$ (RHODJ)
and are $\hat{\rho}u, \hat{\rho}v, \hat{\rho}w, \hat{\rho}\theta, \hat{\rho}r_*$, and $\hat{\rho}s_*$

ρ_{ref} = dry density of the reference state

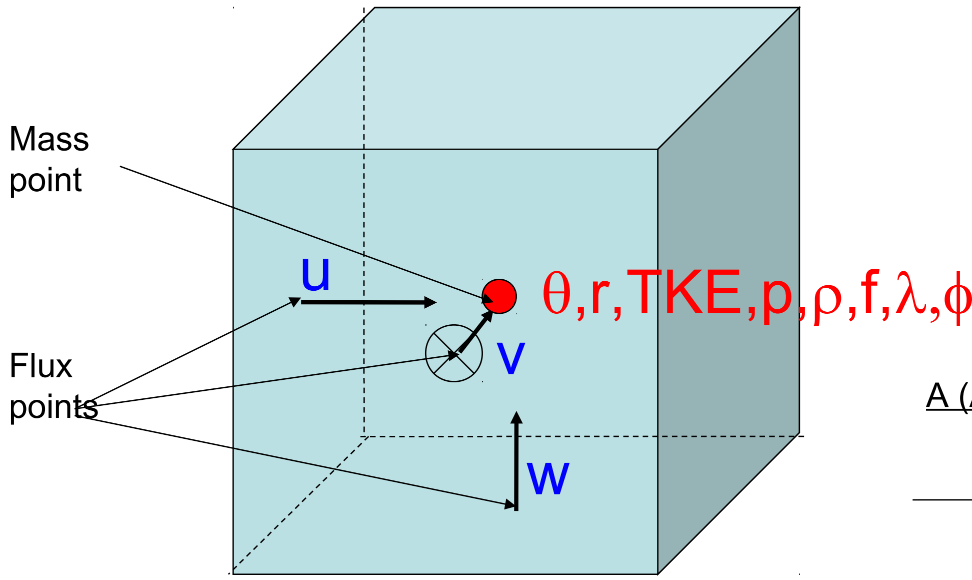
If z<< a is considered, **thin shell** hypothesis (possibility for ideal cases)

Spatial discretization

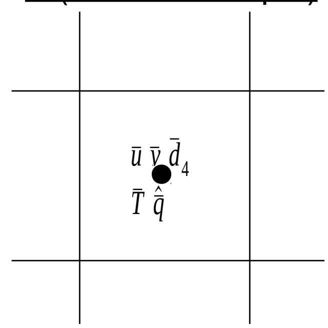
Meso-NH
mesoscale non-hydrostatic model

Spatial discretization

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

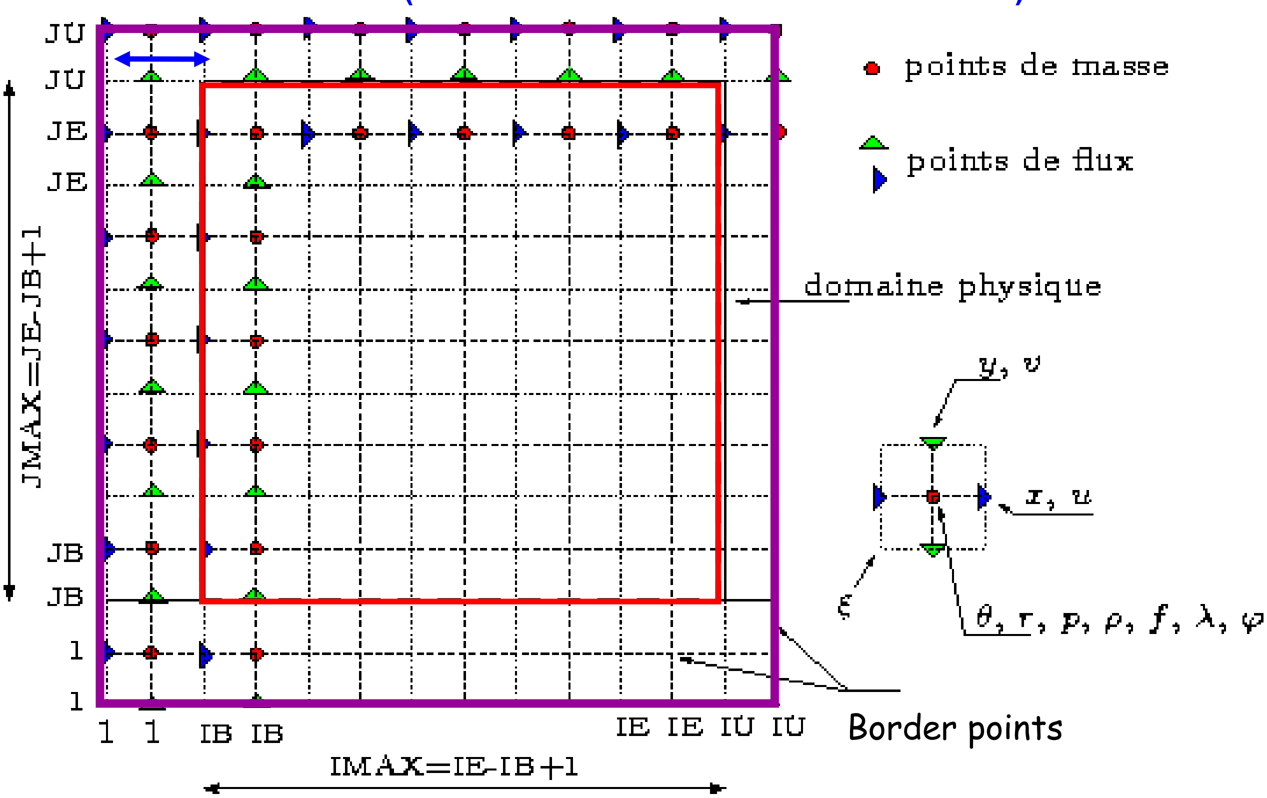


A (Arome example)



Horizontal discretization

JPHEXT (=1 or 3 if 5th order advection scheme)



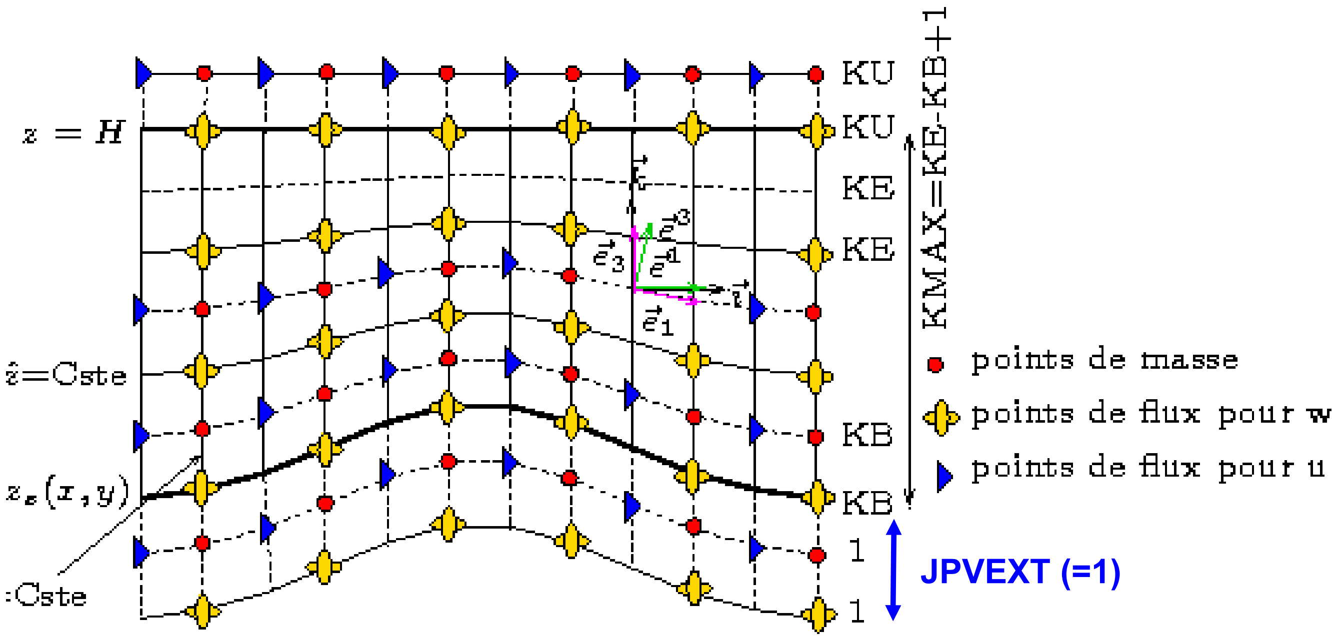
IB = 1+HEXT
JB = 1+HEXT

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

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

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

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

Scalar variables transport (θ,r,tracers) :

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

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

Finite volume method

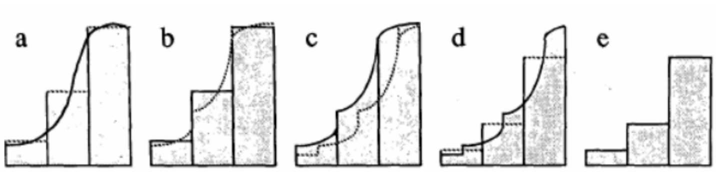


FIG. 5. Schematic illustration of the piecewise parabolic advection procedure. (a) From the initial distribution (solid curve), zone averages (dotted lines) are computed analytically. (This step is performed only at the beginning of the computations.) (b) Using the zone averages (solid lines), a parabola (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

Time splitting introduced to follow CFL <1
evolving during the run as a function of CFL (LSPLIT_CFL=T)

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

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

(U^c,V^c,W^c) : advector field = contravariant = wind orthogonal to the coordinate lines

1. **4th order centred scheme (CEN4TH)** :

- with Leap-Frog and a come-back to FIT (CTEMP_ADV_SCHEME='LEFR')

  Numerical diffusion necessary + Asselin temporal filter $u_{n+1}=u_{n-1}+2\Delta t\, f(u_n)$

  Accurate but not efficient (small time steps)

- with Runge -Kutta RKC4 (CTEMP_ADV_SCHEME='RKC4')

  Accurate and more efficient

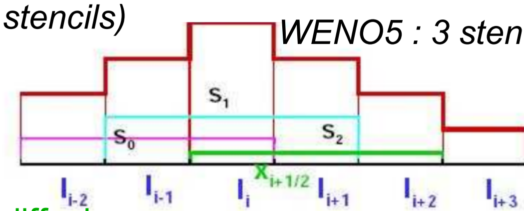
$$\begin{aligned} u_n^{(1)} &= u_n \\ u_n^{(k)} &= u_n + \Delta t \sum_{i=1}^{k-1} a_{k,i}\, f\left(t_n + c_i \Delta t, u_n^{(i)}\right) \\ u_{n+1} &= u_n + \Delta t \sum_{k=1}^{s} b_k\, f\left(t_n + c_k \Delta t, u_n^{(k)}\right) \end{aligned}$$

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 : 3 stencils

WENO5

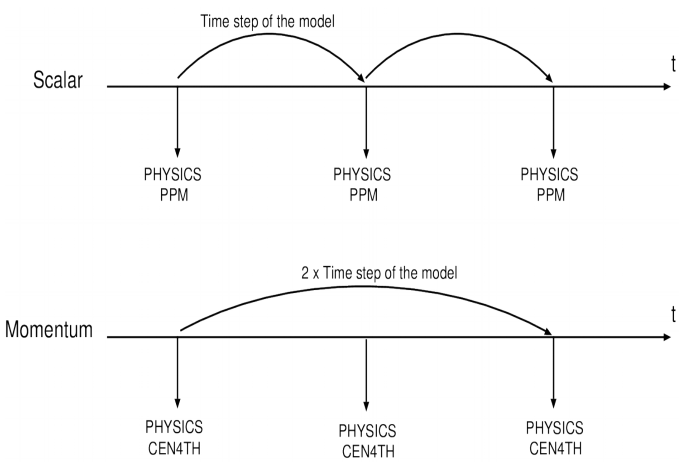


Conservative and non-oscillatory

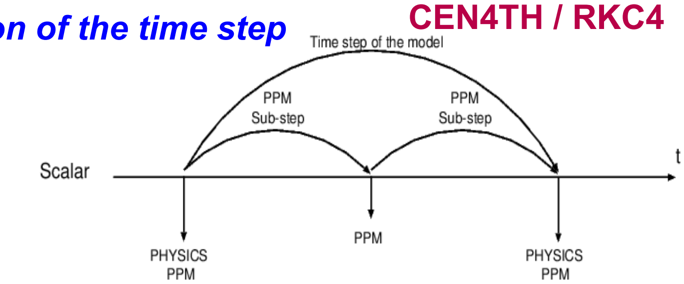
Efficient (long time steps). WENO3 very diffusive

Optimization of the time step

CEN4TH / LF

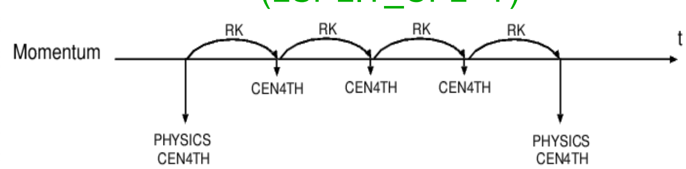


CEN4TH / RKC4

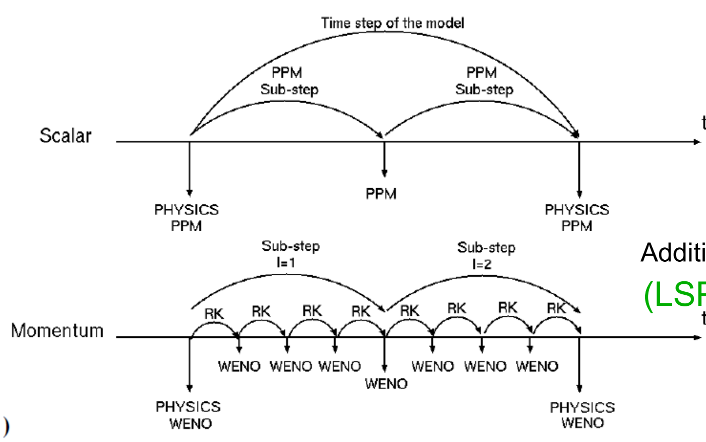


Δt of the model has increased

(LSPLIT_CFL=T)



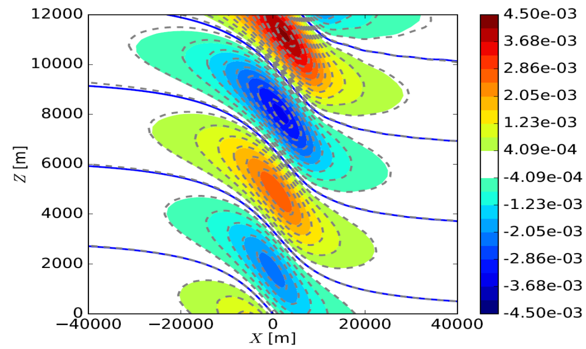
WENO5 / RKC4



Additional time-splitting

(LSPLIT_CFL=T)

Hydrostatic orographic wave

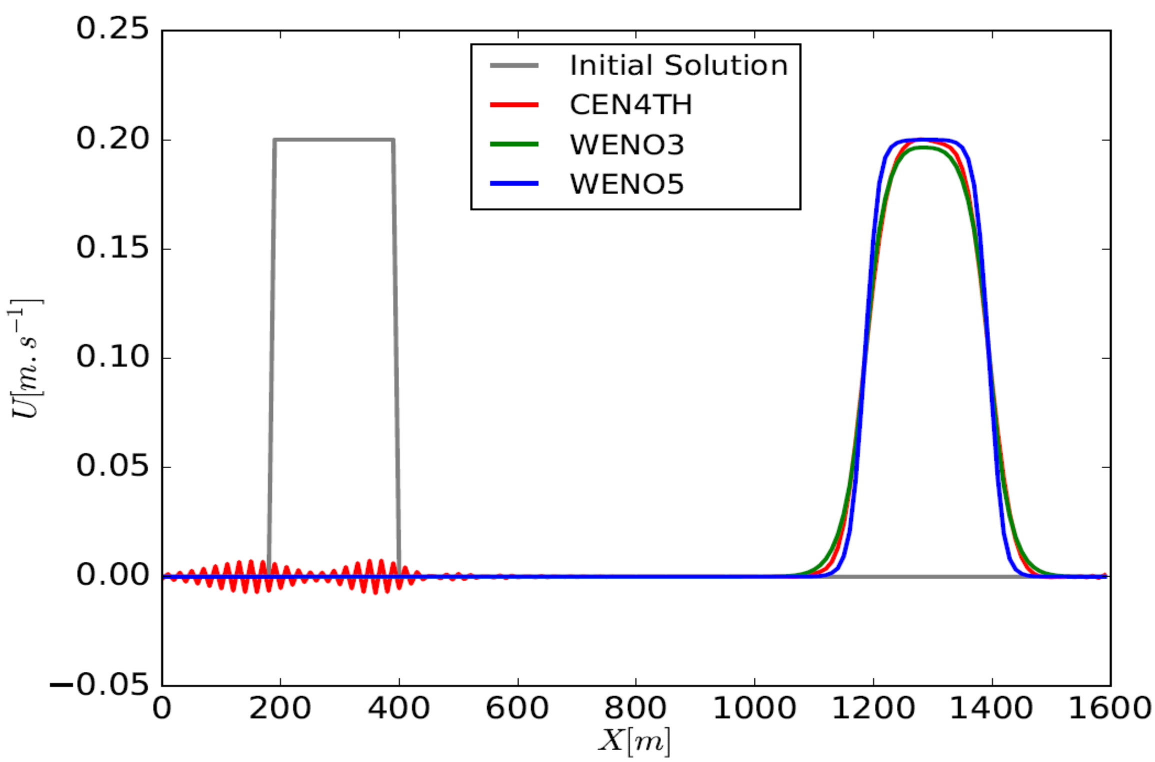


CFL max :

	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

Lunet et al., 2017

Linear advection after 1000 s



CEN4TH : Finite difference scheme : 2Δx spurious waves
→ Numerical diffusion necessary

Spectrum tool
Numerical diffusion

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

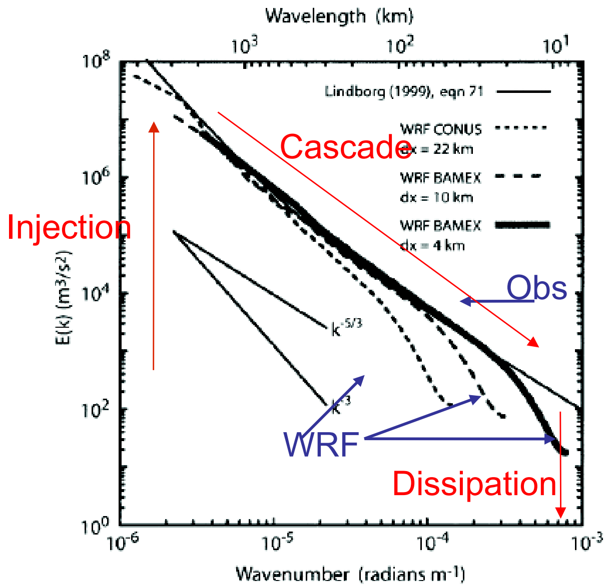
EXSEG1.nam : NAM_DYN LNUMDIFU
LNUMDIFTH

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

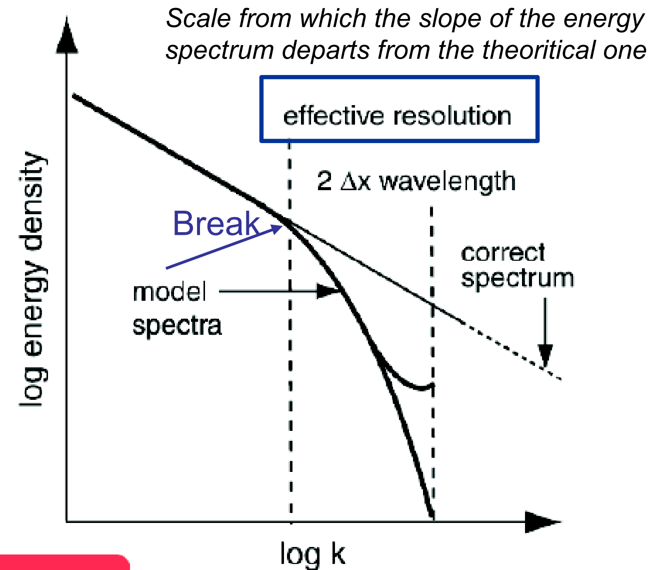
With CMET_ADV_SCHEME= « PPM_xx » LNUMDIFTH=F

Energy spectra

Program SPECTRE



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



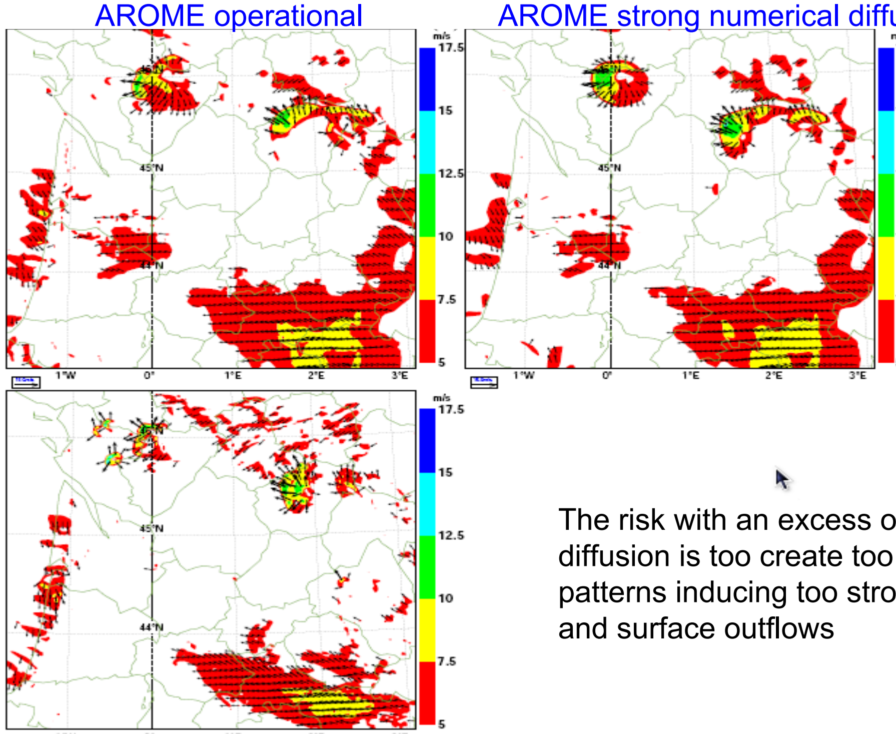
Example for WRF : effective resolution = 7Δx : e.g. 17km for Δx=2.5km

28/04/10

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

AROME operational AROME strong numerical diffusion

Δx=2.5km



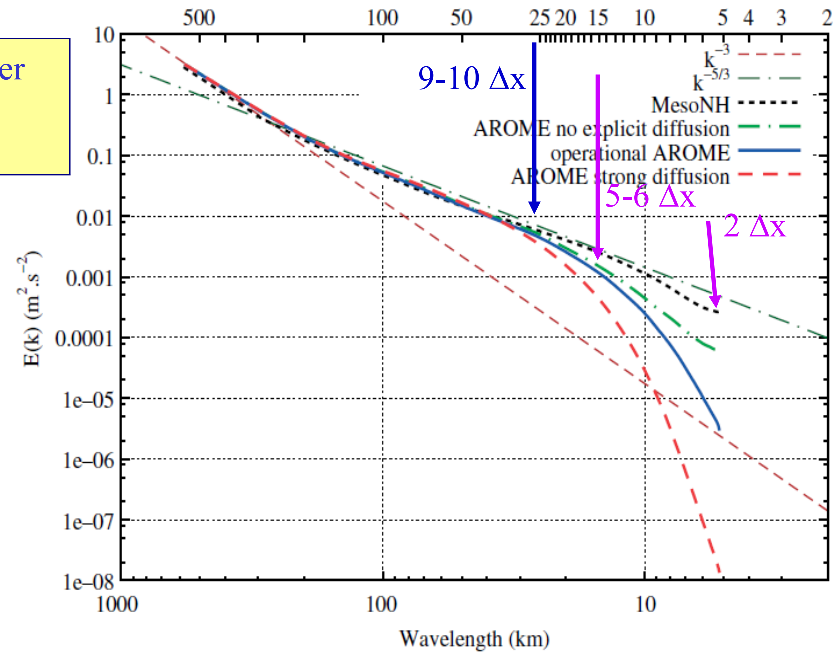
Méso-NH

The risk with an excess of numerical diffusion is too create too large scale patterns inducing too strong cooling and surface outflows

4 – KE spectra

Comparison between AROME and MesoNH (case: April 2007)

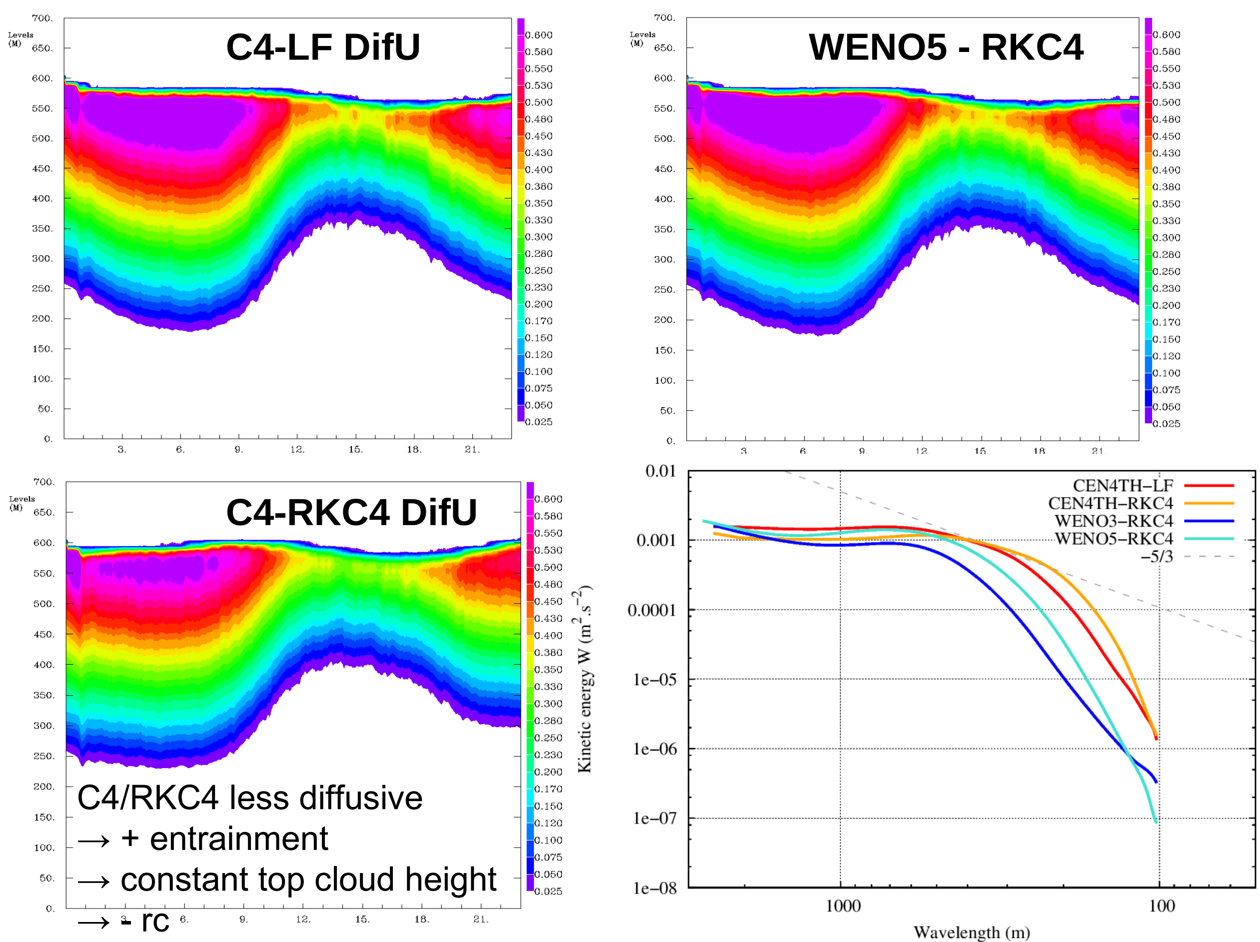
KE spectra (U,V) averaged over the free troposphere (3-9km) between 13 and 17 UTC



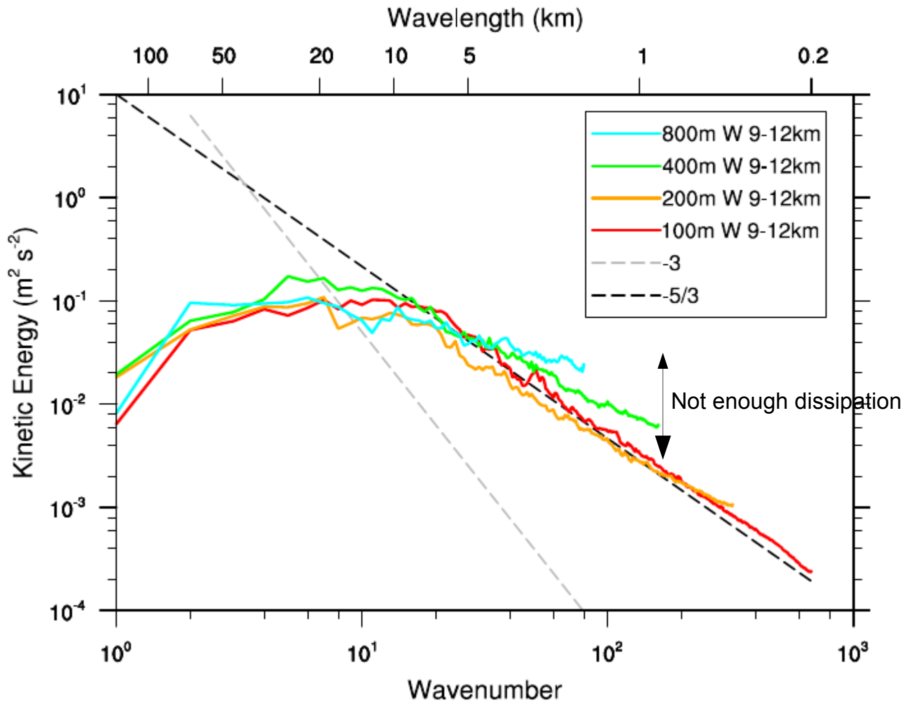
→ Effective resolution:

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

Cas FIRE : LES (Δx=50m)



Hector the convector : Spectrum of vertical velocity

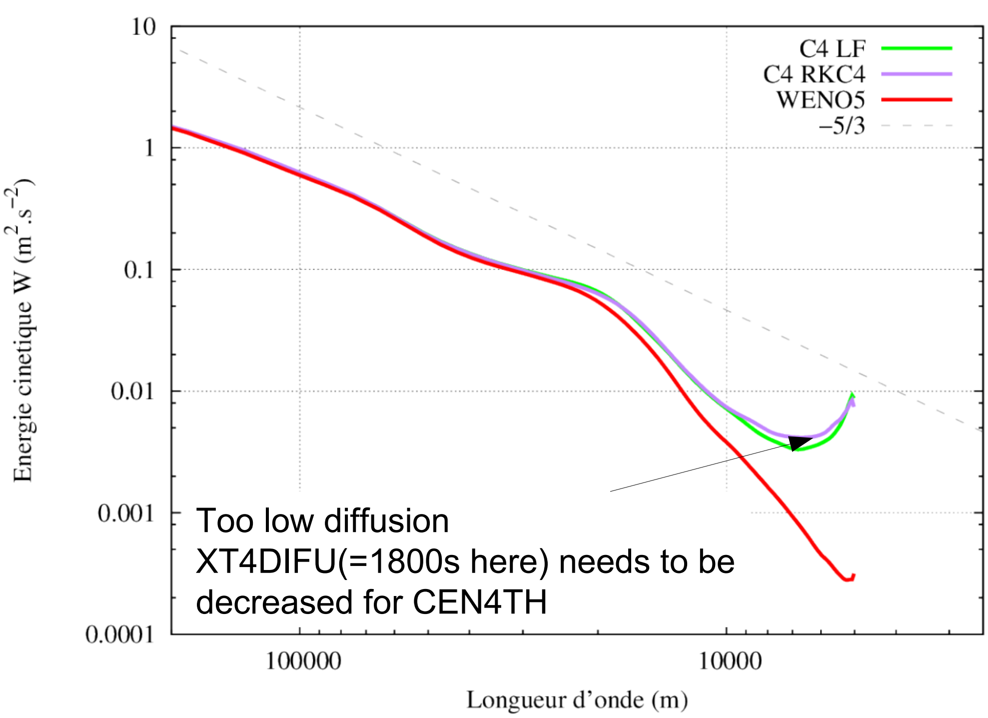


13:00

A grid spacing of Δx=200 m or 100 m is required to reproduce the -5/3 theorical slope and to converge : necessary resolution for a LES of convection

KE spectra

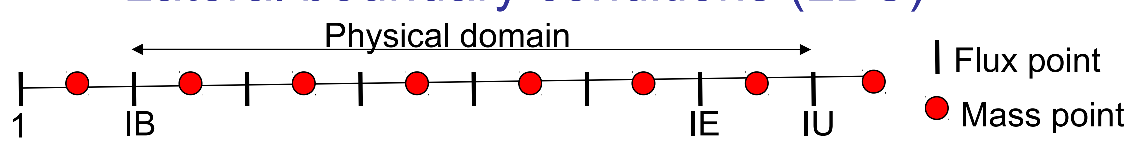
Also a good way to tune numerical diffusion



Lateral boundary conditions

Meso-NH
mesoscale non-hydrostatic model

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 .

→ Not advisable

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

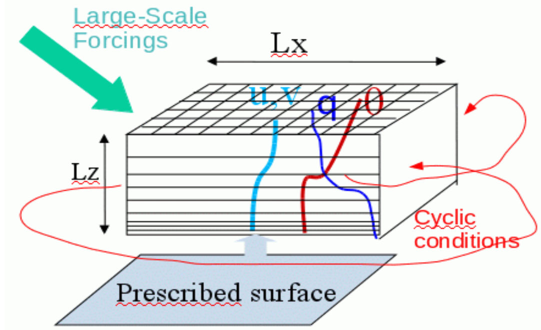
- Top absorbing layer (NAM_DYN et NAM_DYNn LVE_RELAX,XALKTOP, XALZBOT) to prevent spurious reflection : Rayleigh damping towards LS fields

→ Most of the time necessary

- In real cases : Initialization and coupling from the LS models : ARPEGE, ALADIN, ECMWF, AROME. GFS since version 5.4.

Initial conditions

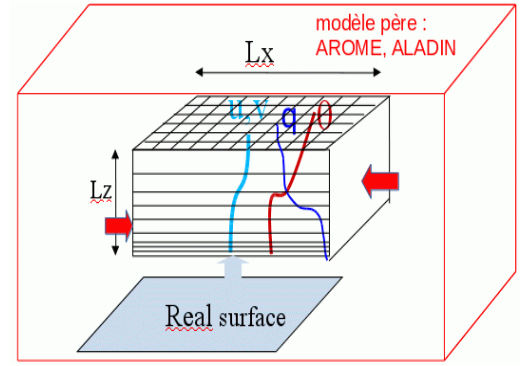
Idealized case



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

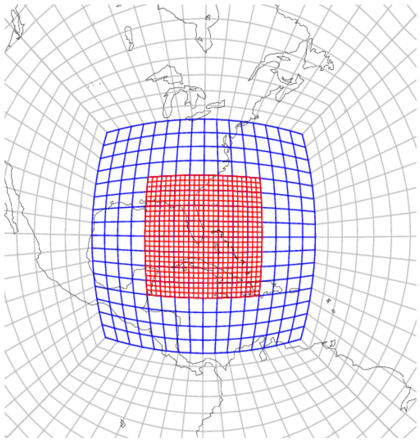
- Same initial and forcing conditions for all the points
- LBC : If CYCLIC : No orography

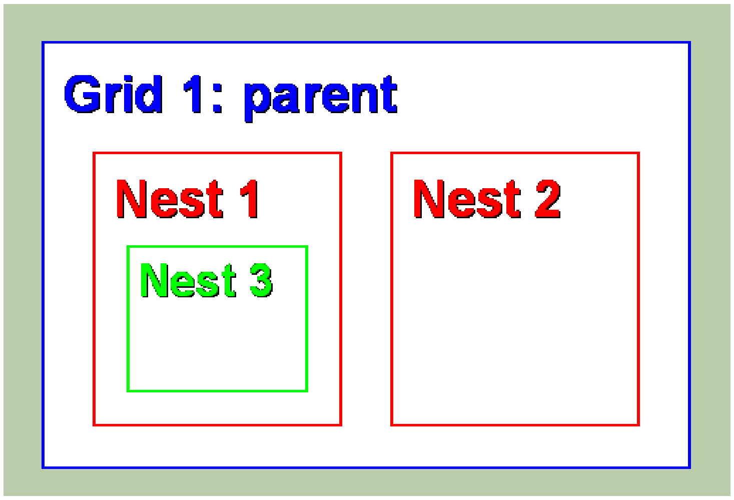
Real case



Input :
- Initial and coupling conditions on the whole domain from a LS model for the atmosphere and the surface -
Coupling conditions : interpolated in time between 2 coupling times

Grid nesting





Grid-nesting

Every time step of the father :

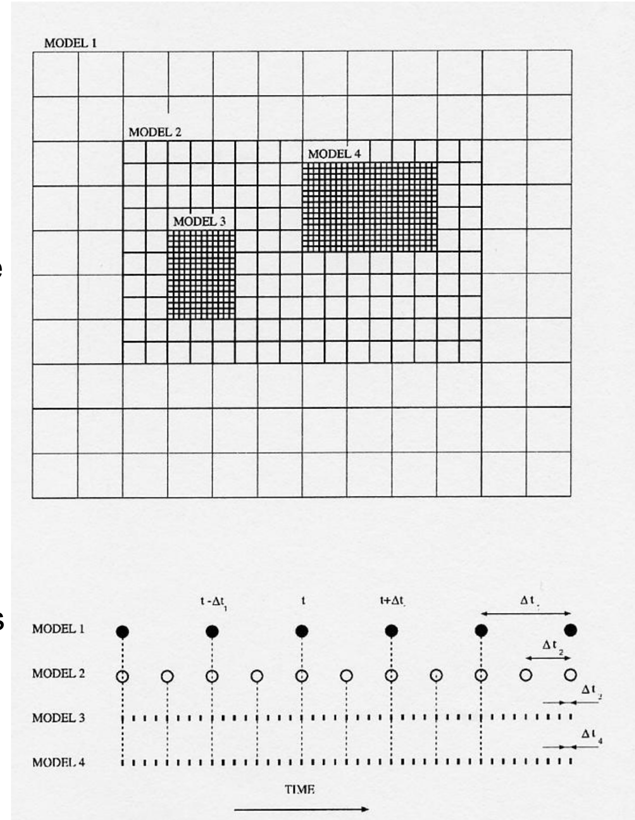
The father gives the LBC to the son by interpolation

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)

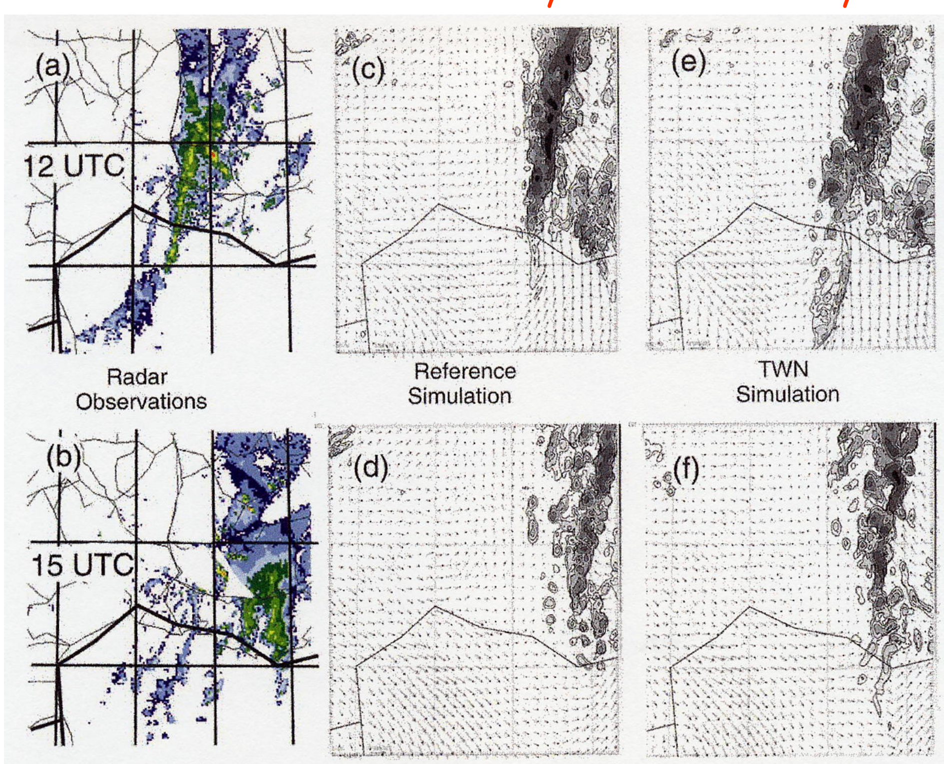


Vaison-la-Romaine : 22 september 1992

One-way Two-way

3 nested grids : 40/10/2.5km

Instantaneous precipitations 2.5km



Stein et al., 2000

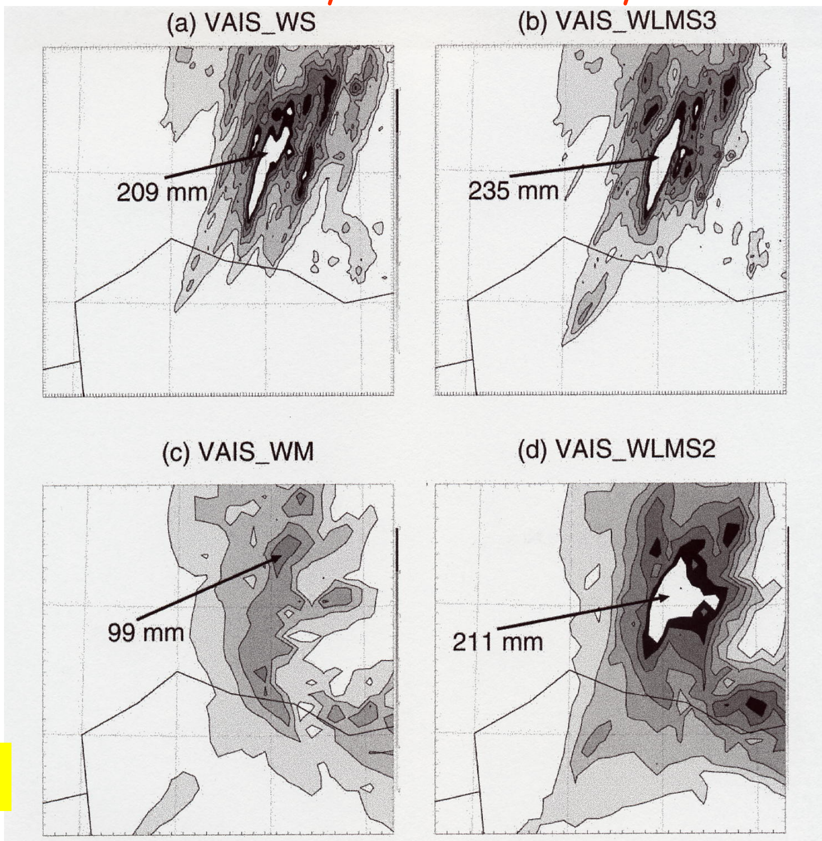
Vaison-la-Romaine : 22 september 1992

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

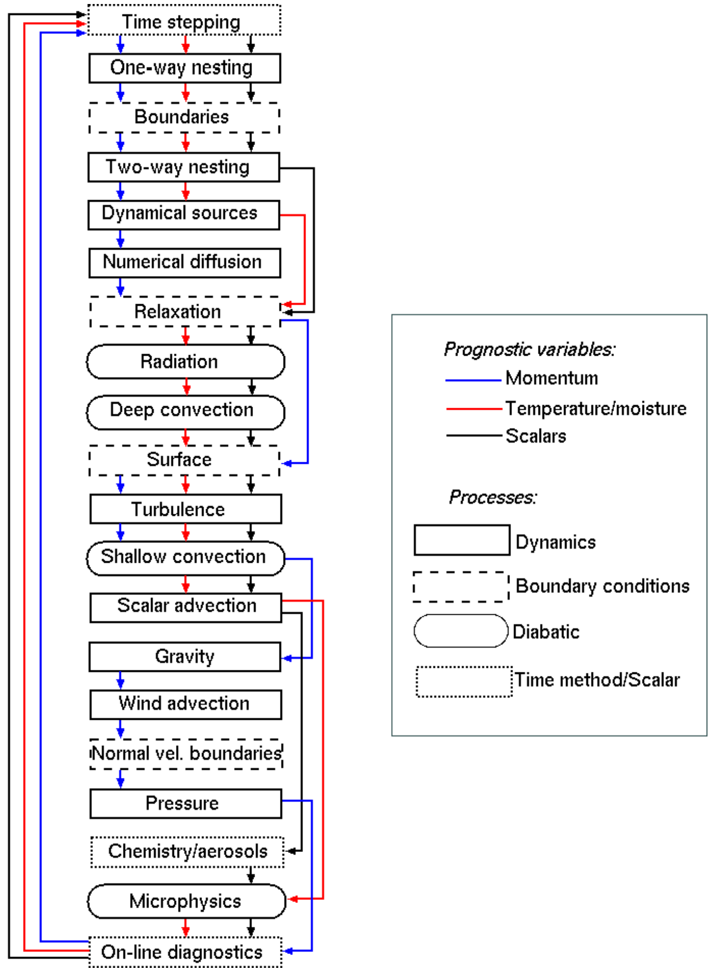
1980's 1990's 2000's

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 6-8**	**For 2.5km**	**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**

60s(15s):WENO
15s : CEN4th-RKC4
6s : CEN4TH-LF

Organization of the time step

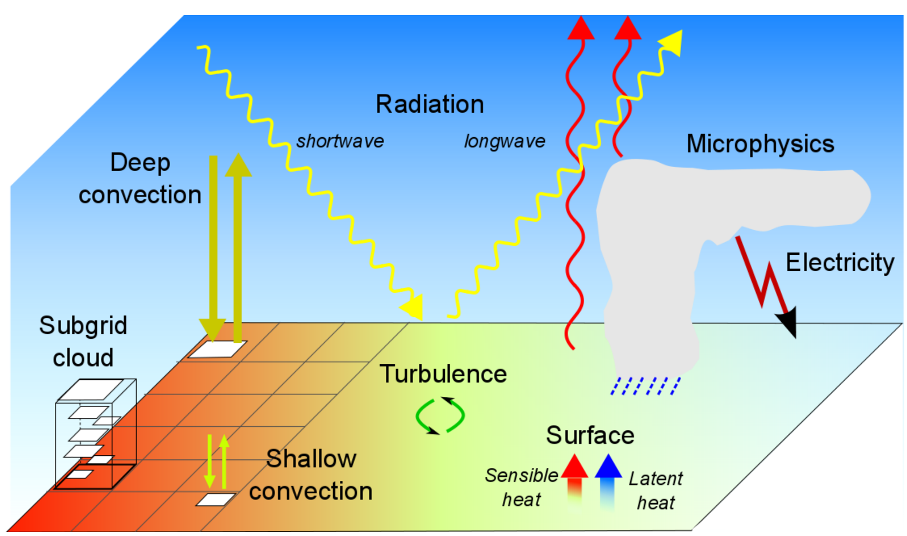
Parallel splitting approach :
All process tendencies are computed from the same model state and then the sum of the tendencies is used to step forward



Physics

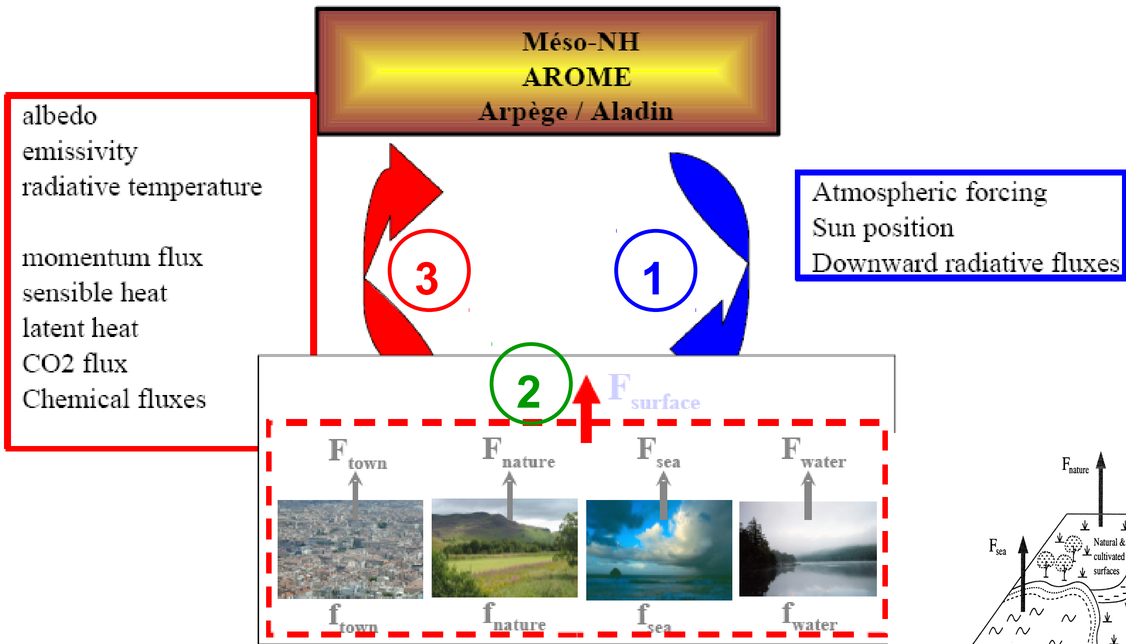
PHYSICS : Part of the model that deals with diabatic processes, water state changes, subgrid processes, surface interaction.

- SURFACE (externalized)
- TURBULENCE
- CONVECTION
- MICROPHYSIC
- RADIATION
- CHEMISTRY



The SURFEX (SURface Externalized) land surface scheme

Exchanges of flux and atmospheric forcing at each time step



see P. Le Moigne's presentation

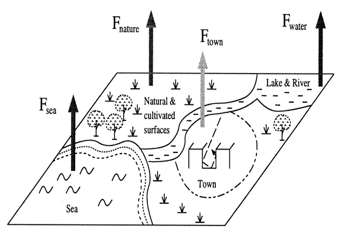
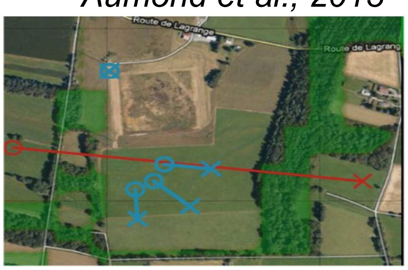


Figure 15.1: Partitioning of the MESO-NH grid box, and corresponding turbulent fluxes. F stands either for M (momentum flux), H (sensible heat flux), LE (latent heat flux), $S^{\uparrow}$ (the reflected solar radiation) or $L^{\uparrow}$ (the upward longwave radiation).

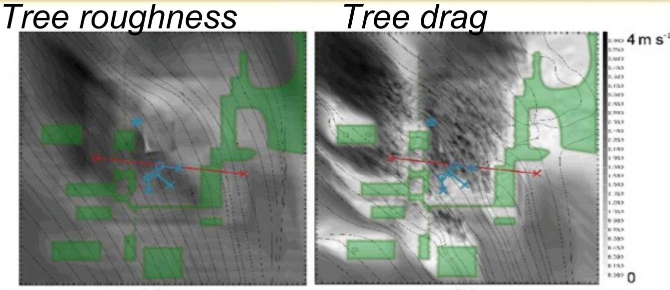
CNRM-GAME

Surface heterogeneities with LES

Aumond et al., 2013

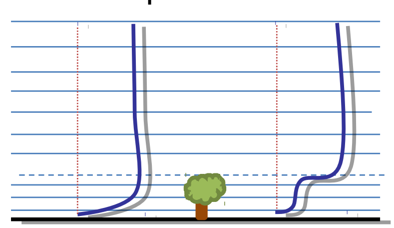


Tree roughness *Tree drag*



1. Roughness length with TEB/ISBA :

2. Drag force with presence of buildings/trees :



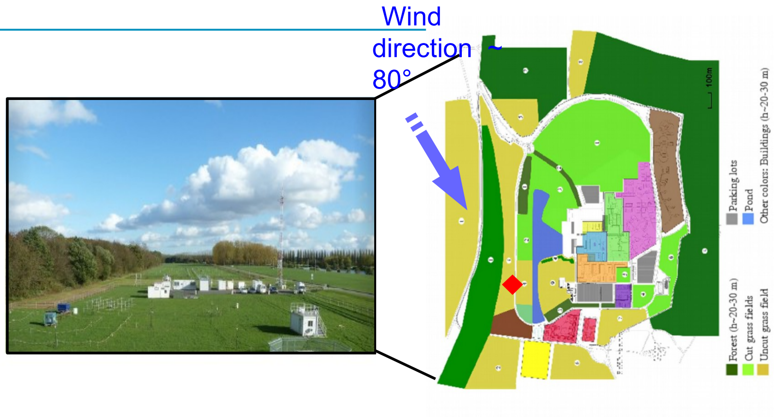
$$\frac{\partial U}{\partial t} = F_u - \underline{C_d A_f(z) U (U^2 + V^2)^{0,5}}$$

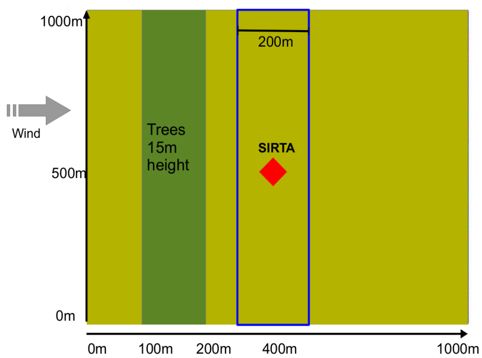
$$\frac{\partial e}{\partial t} = F_e - \underline{C_d A_f(z) e}$$

A_f= Canopy area density
Building not porous

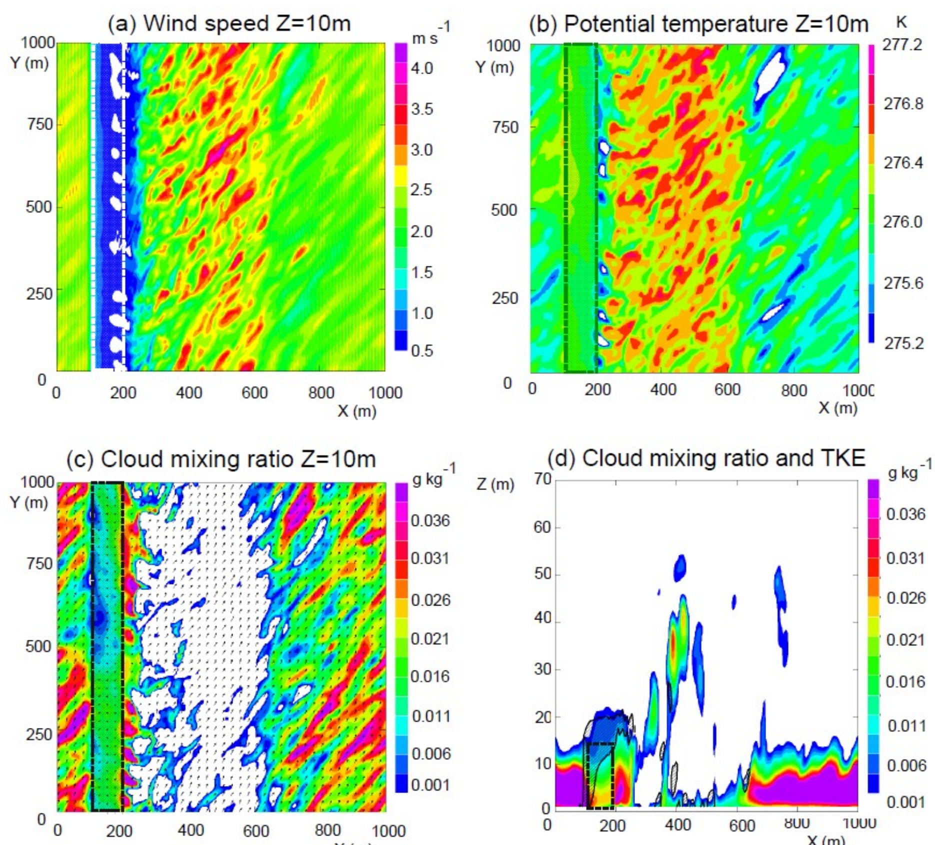
Becomes necessary at very fine vertical resolution

Fog at SIRTA : impact of trees (Mazoyer et al., 2017, ACP)





Fog at SIRTA : impact of trees (Mazoyer et al., 2017, ACP)



Subgrid transport

Prognostic variables represent a mean state on the mesh grid.

Resolution of a model -> subgrid processes are filtered
Parametrization to close the Reynolds system

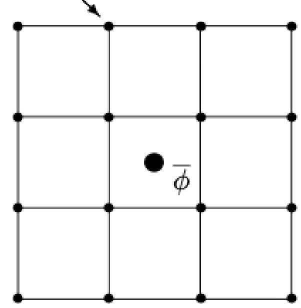
Subgrid transport

Prognostic variables represent a mean state on the mesh grid.

Resolution of a model -> subgrid processes are filtered
Parametrization to close the Reynolds system

Formalisme de Reynolds

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



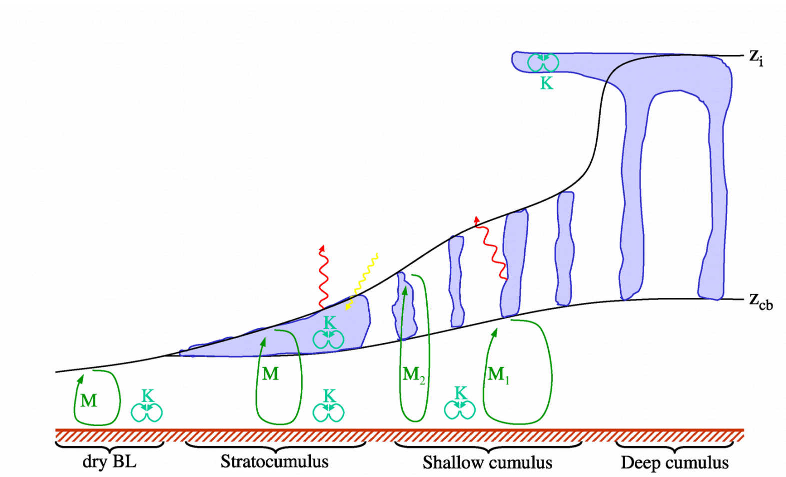
$$\left(\frac{\partial \phi}{\partial t}\right)_{adv} = -u_i \frac{\partial \phi}{\partial x_i}$$ Resolved

Subgrid

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

Transport of ϕ by subgrid fluctuations : Parametrization

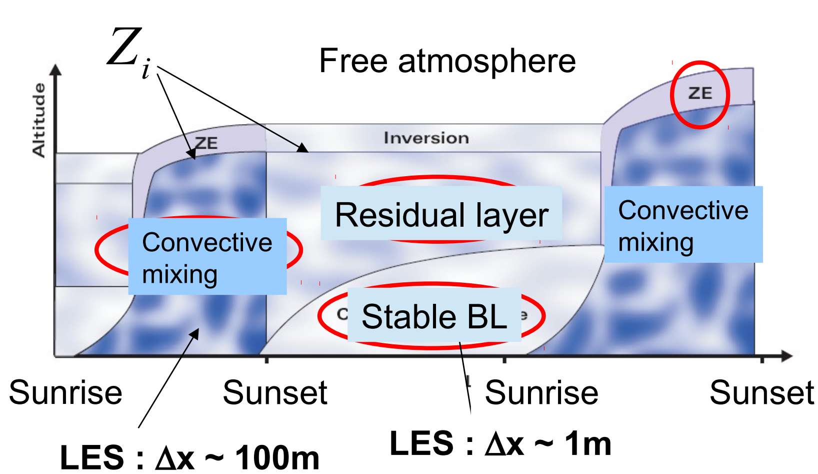
SUBGRID TRANSPORT



- 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)

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

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

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

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

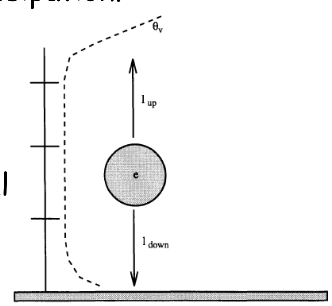
-> K method with

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

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'**)

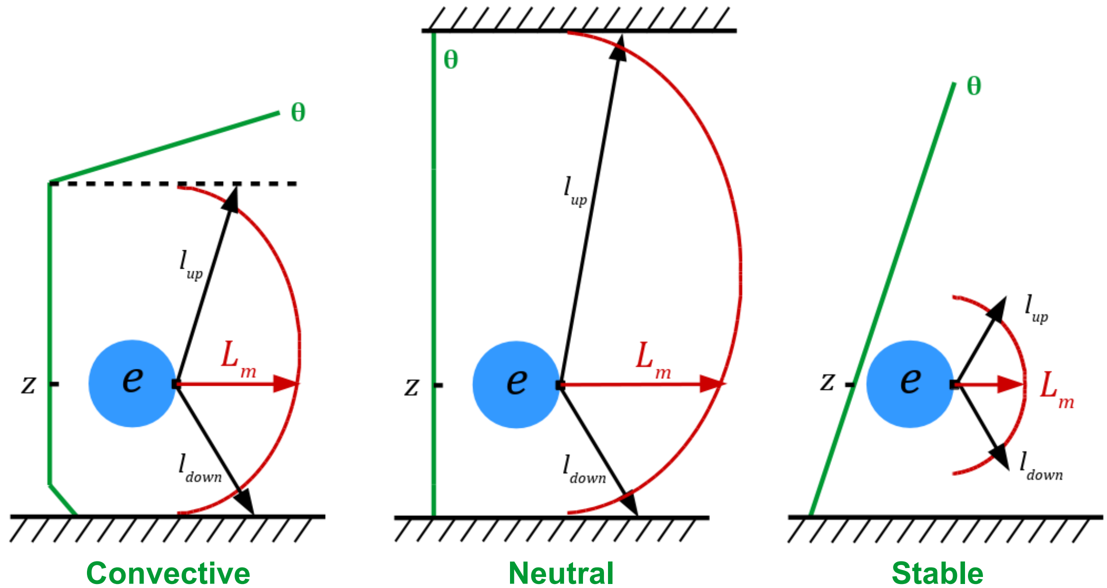
LES (inertial subrange) : (Δx.Δy.Δz)1/3 and Deardorf mixing length (**CTURBLEN='DEAR'** or CTURBLEN='DELT')

Mixing length BL89

Bougeault and Lacarrere (1989)

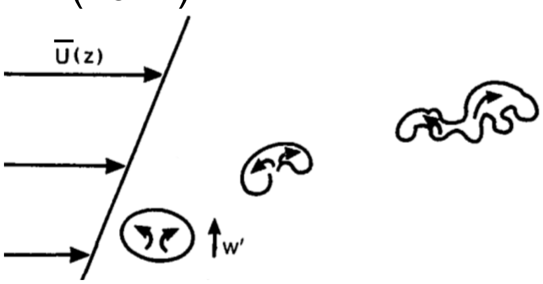
$$\int_{z}^{z+l_{up}} \beta\left[\theta(z') - \theta(z)\right] dz' = e(z)$$

$$\int_{z-l_{down}}^{z} \beta\left[\theta(z) - \theta(z')\right] dz' = e(z)$$



Problem : BL89 not physical in neutral condition, overestimated in stable

Possible solution ? Wind shear : Rodier and Masson (2017) : RM17



$$S = \sqrt{\left(\frac{\partial \overline{U}}{\partial z}\right)^2 + \left(\frac{\partial \overline{V}}{\partial z}\right)^2}$$

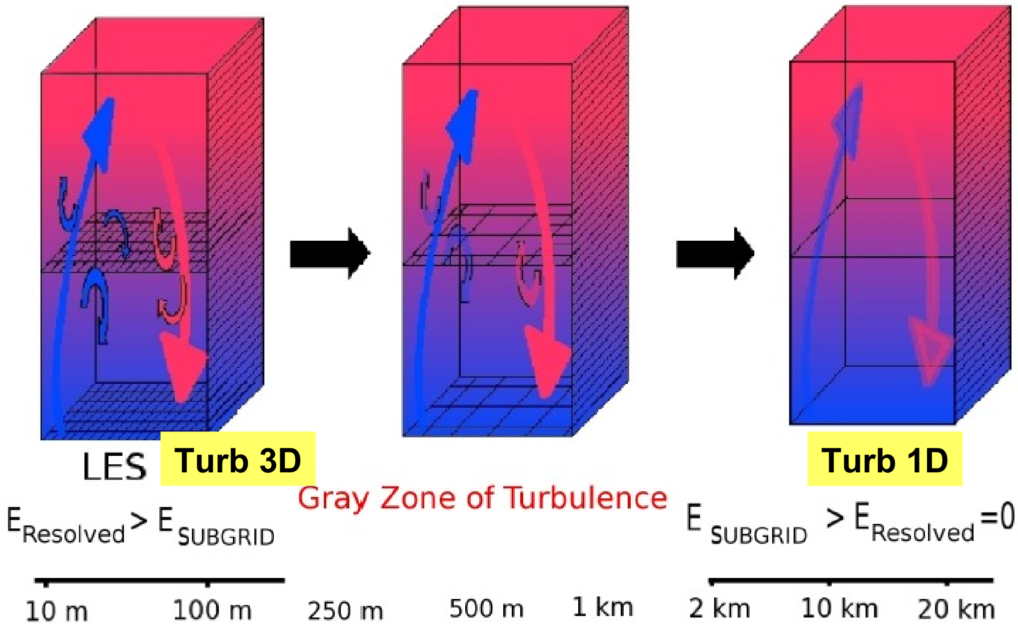
$$L_m = C\frac{\sqrt{e}}{S}$$

New formulation :

$$\int_{z}^{z+l_{up}} \left[\beta(\theta(z') - \theta(z)) + C_0\sqrt{e}S(z')\right] dz' = e(z)$$

$$\int_{z-l_{down}}^{z} \left[\underbrace{\beta(\theta(z) - \theta(z'))}_{\text{Buoyancy}} + \underbrace{C_0\sqrt{e}S(z')}_{\text{Shear}}\right] dz' = e(z)$$

Turbulence 3D versus 1D



Whole turbulence scheme

Honnert et Masson, 2014

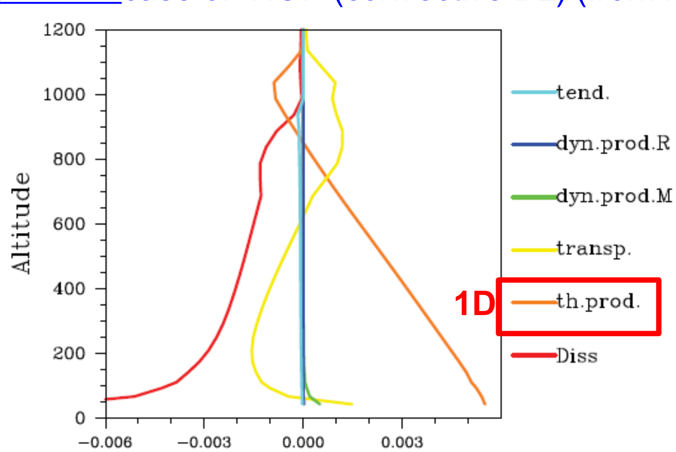
Horizontal gradients in the turbulent equations are neglected except for the transport of TKE

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

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

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

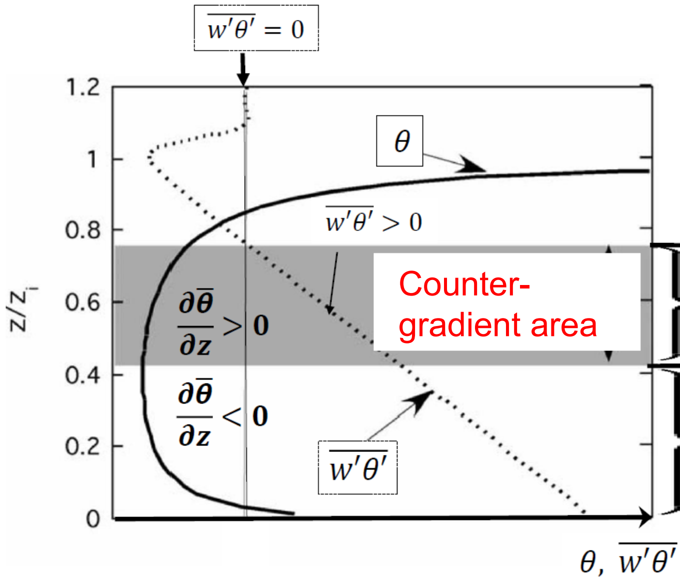
BUDGET of TKE : case of IHOP (convective BL) (from Honnert, 2012)



Mesoscale (Δx=8km)

Limit of the K method for a convective boundary layer

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



Observé	modèle
$\frac{\partial\bar\theta}{\partial z}\overline{w'\theta'}_l > 0$	$\cancel{\overline{w'\theta'} = -K\frac{\partial\bar\theta}{\partial z}}$
$\frac{\partial\bar\theta}{\partial z}\overline{w'\theta'}_l < 0$	$\overline{w'\theta'} = -K\frac{\partial\bar\theta}{\partial z}$ ✓ 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)

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

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

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

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

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

Turbulence
Small Eddies
Local Effect

Shallow convection
Thermals
(coherent structures)
Non local transport

EDKF scheme (PMMC09)

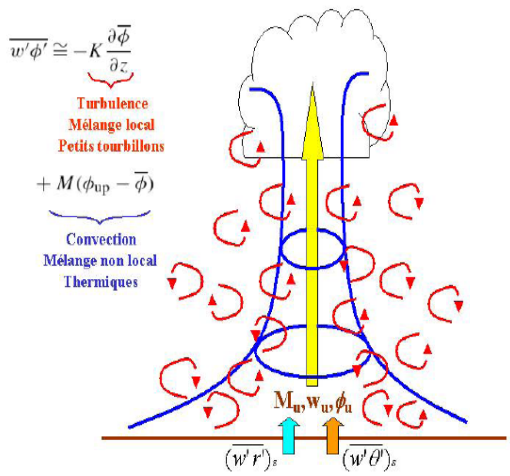
1. Pergaud J., Masson V., Malardel S. and Couvreux F. (2009) A parameterization of dry thermals and shallow cumuli for mesoscale numerical weather prediction. *Boun. Layer Meteor.* 132 :93-106.

- **Necessary until Δx ~1km – 500m**

EDKF : A parametrization for dry and cloudy convective boundary layers

PMMC09 [1] (ou EDKF)

- The scheme is diagnostic (no memory of the convective activity from the previous Δt)
- Two equation (mass flux and vertical velocity) resolved from the bottom to the top
- Closure with the initialization of mass flux from the surface as a function of buoyancy



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

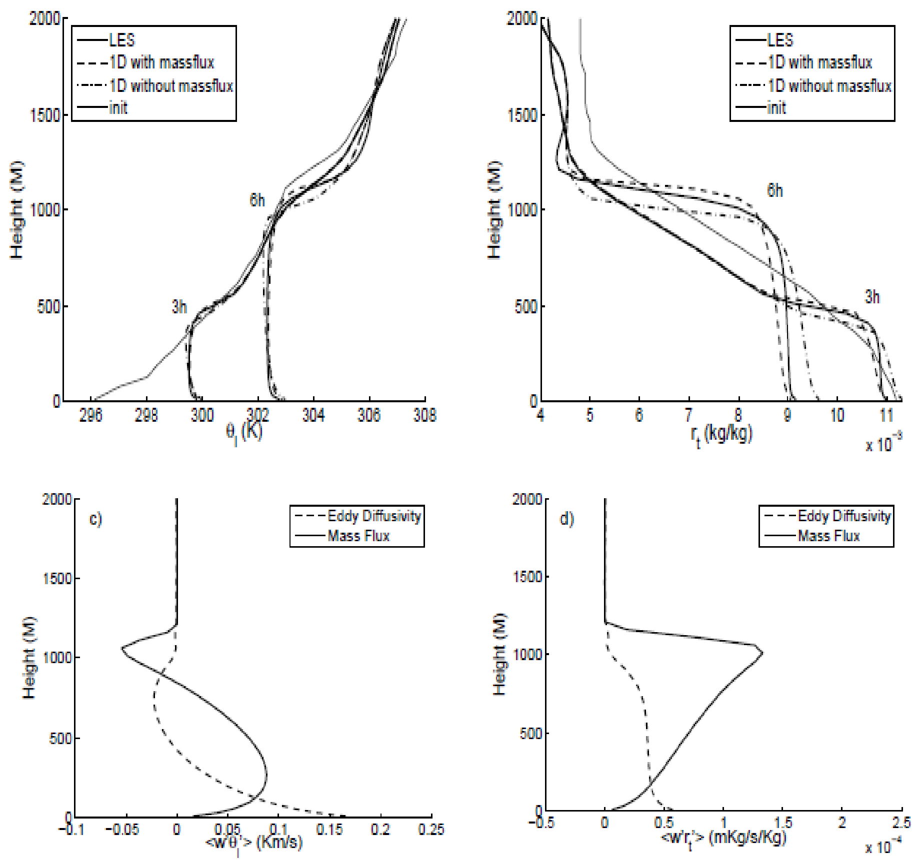
Dry convective boundary layer : IHOP (Pergaud et al., 2009)

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)

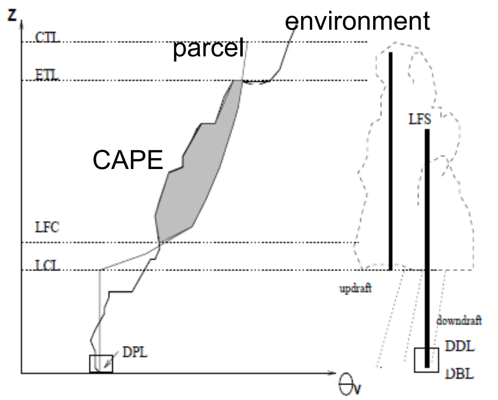
Mass-flux in the upper part (non local)



DEEP CONVECTION

Necessary for Δx > 5km. But not below where 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

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

~ : environment

- : mean horizontal

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

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

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,

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

Deep convection produces 2D convective precipitation at the ground (PRCONV,PACCONV) to add to the explicit precipitation (from the microphysics : INPRT, ACPRT)

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

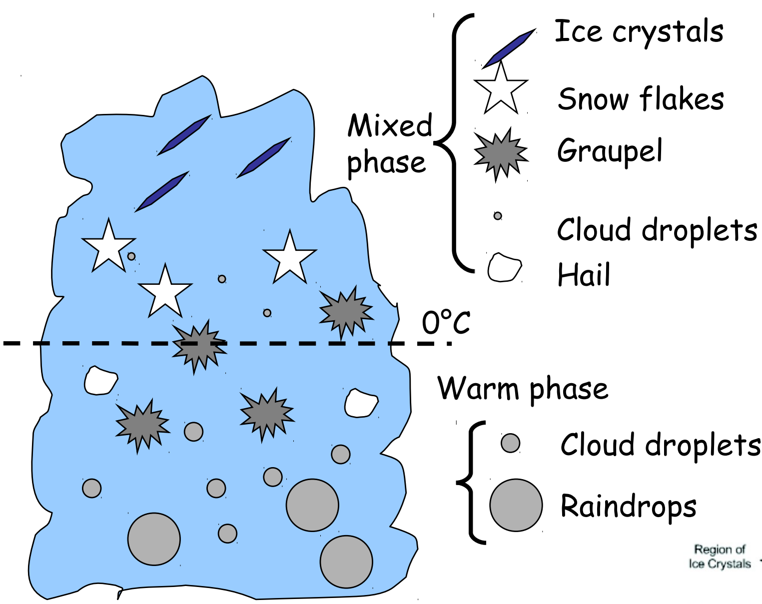
Basic assumptions :

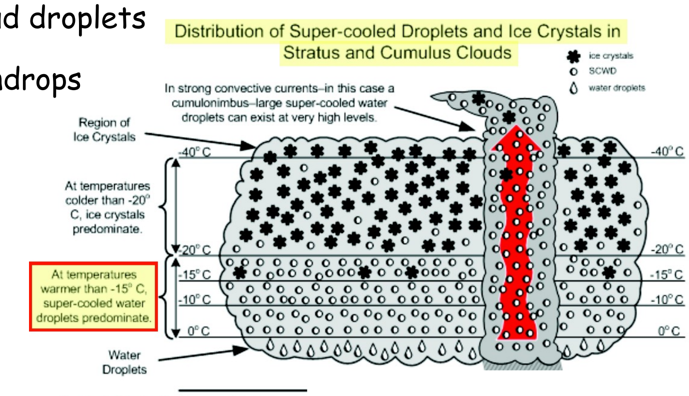
1. The various types of hydrometeors are simplified to a few categories, e.g., cloud droplets, raindrops, cloud ice, snow, graupel, hail : BULK ↔BIN

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

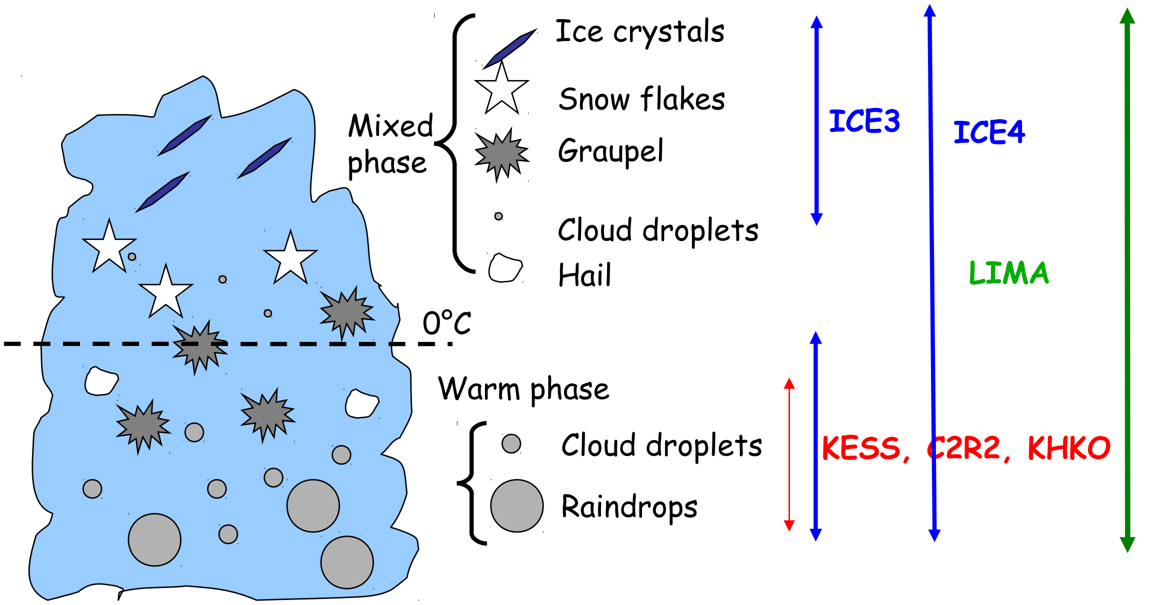




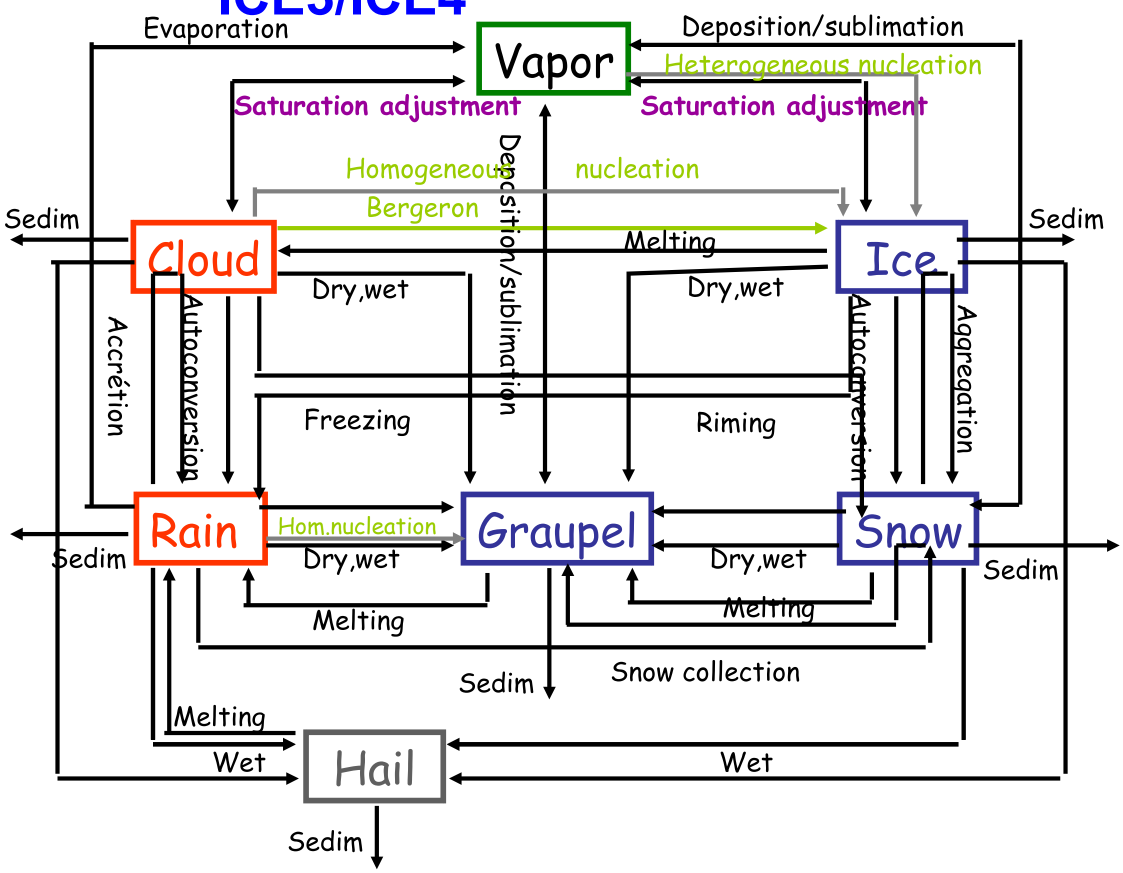
MICROPHYSICS

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



ICE3/ICE4



Caniaux, 1993 – Pinty and Jabouille, 1998

Particle size distributions

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

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

N is the total concentration

Precipitating species : **$N = C\lambda^{x}$**

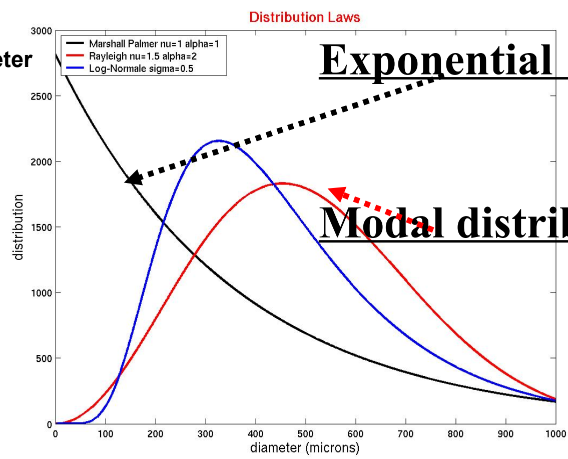
For clouds, N imposed **(Nc=300/cm3 on land, 100/cm3 on sea)**

λ is the slope parameter deduced from the mixing ratio

1-moment scheme

(α, ν) are free shape parameters (Marshall-Palmer law: $\alpha=\nu=1$)

Intercept parameter



<u>Exponential decay</u> : rain, snow, graupel

<u>Modal distribution</u> : droplets, cloud ice

Microphysical characteristics

Very useful p-moment formula

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

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

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

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

Microphysical characteristics

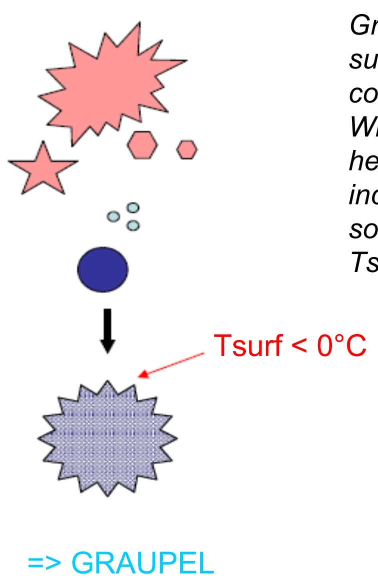
- **Mass-Size relationship: $m=aD^{b}$**
- **Fall speed-Size relationship: $v=cD^{d} \cdot (\rho_{00}/\rho_{a})^{0.4}$**

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

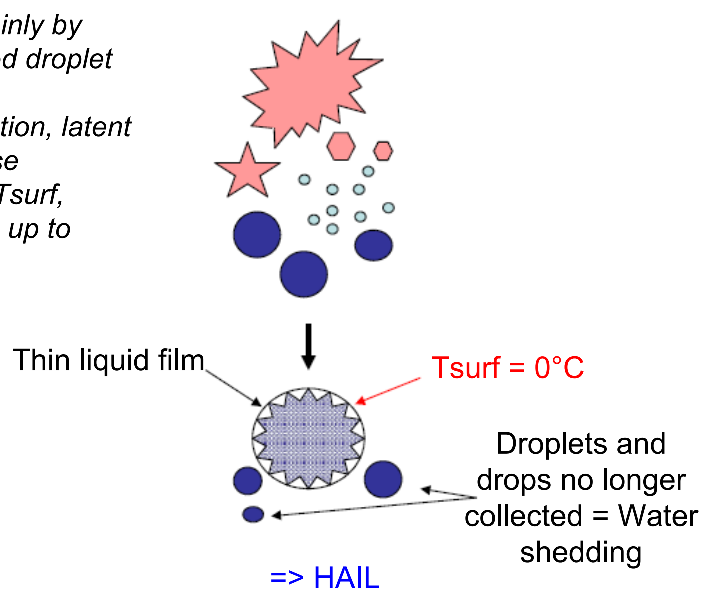
Hail formation

DRY GROWTH



Growth mainly by supercooled droplet collection.
With collection, latent heat release increases Tsurf, sometimes up to Tsurf=0°C

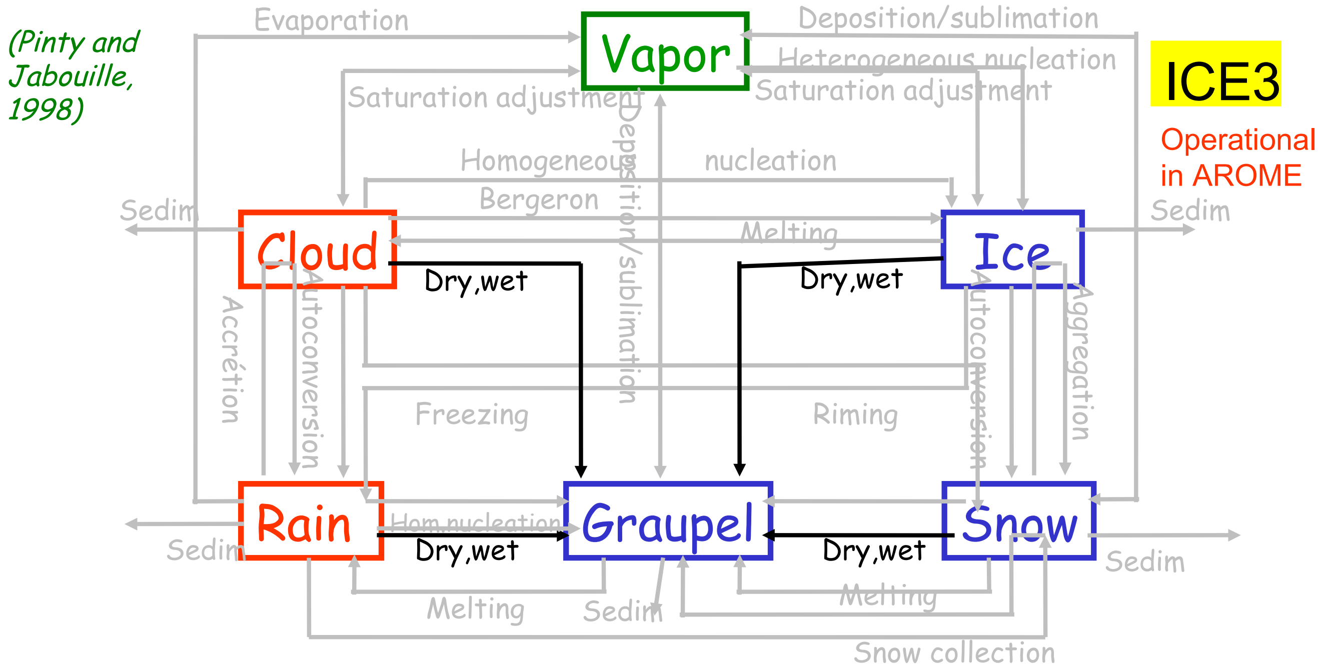
WET GROWTH



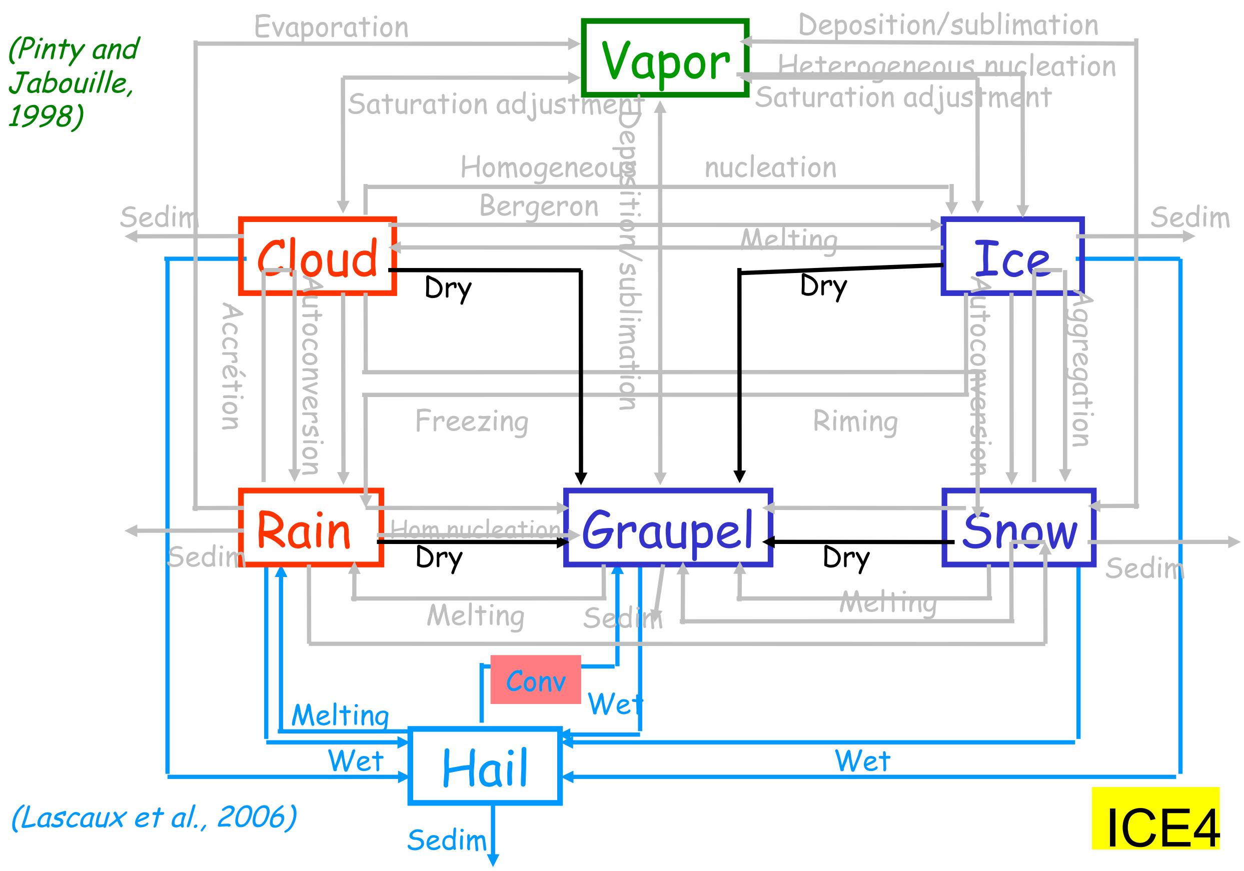
ICE3 : Dry and wet growth lead to graupel
ICE4 : Wet growth leads to hail

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

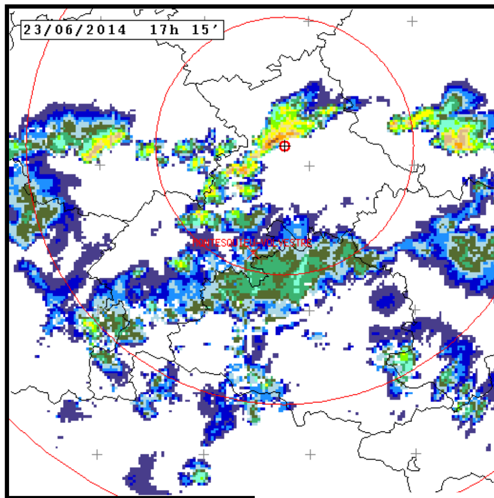
Méso-NH and AROME : ICE3 1-moment scheme



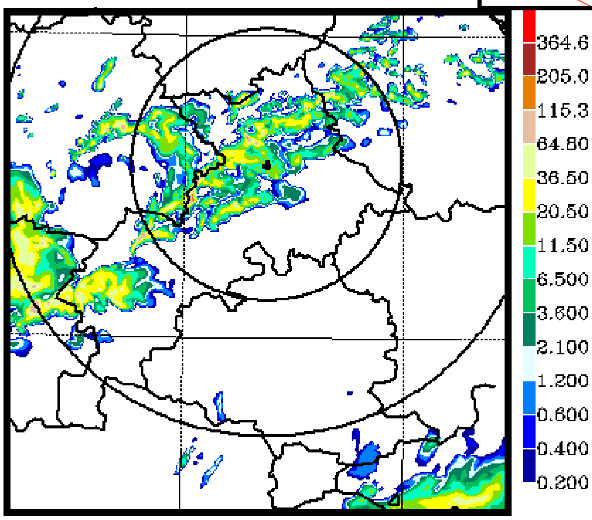
Méso-NH and AROME : ICE4 1-moment scheme



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

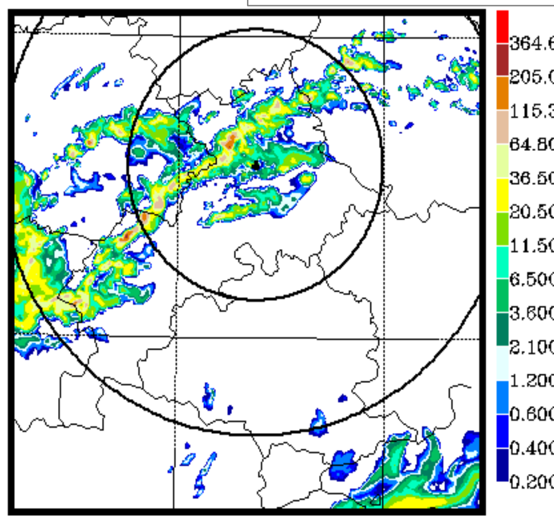


ICE3 Δx=500m



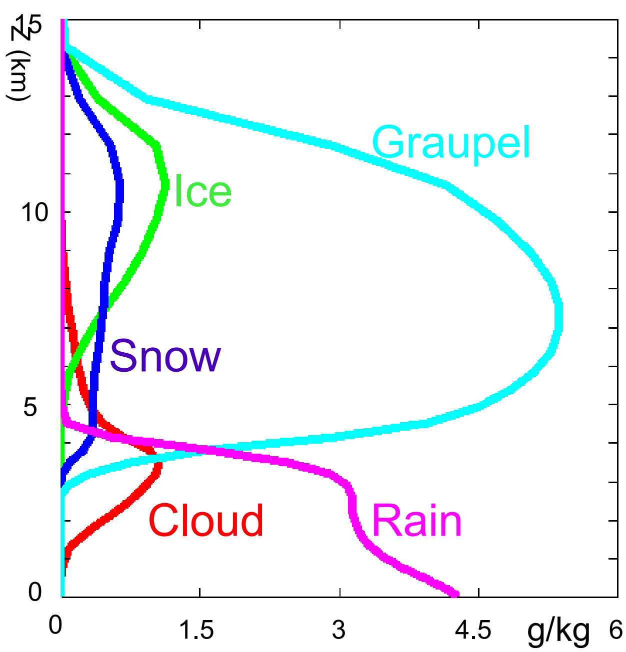
ICE4

Stronger precipitation

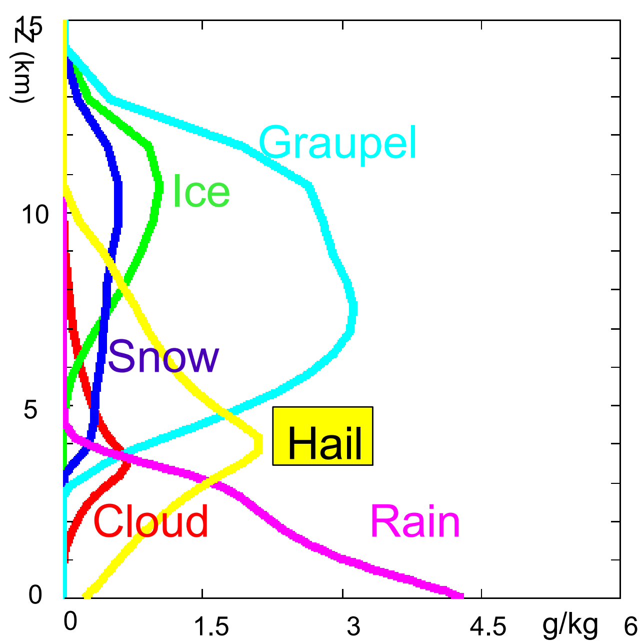


Hydrometeor budget

ICE3

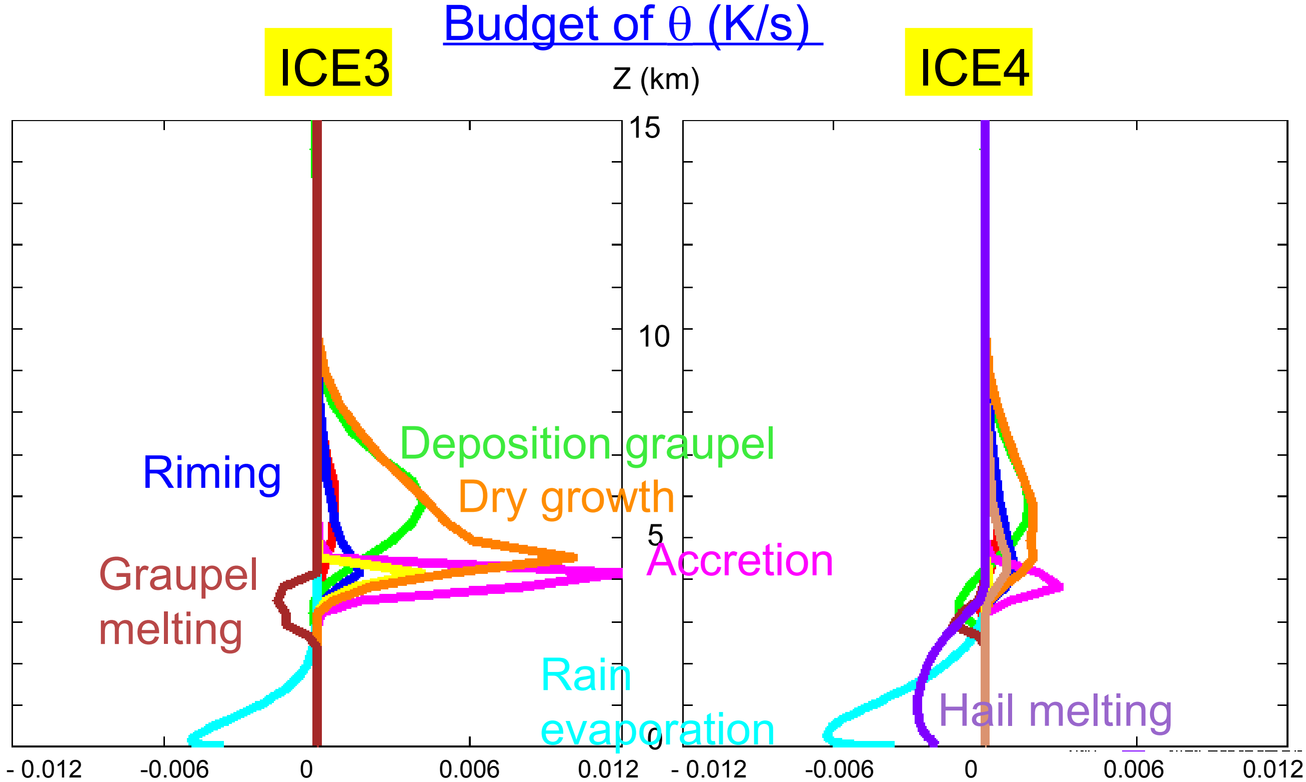


ICE4



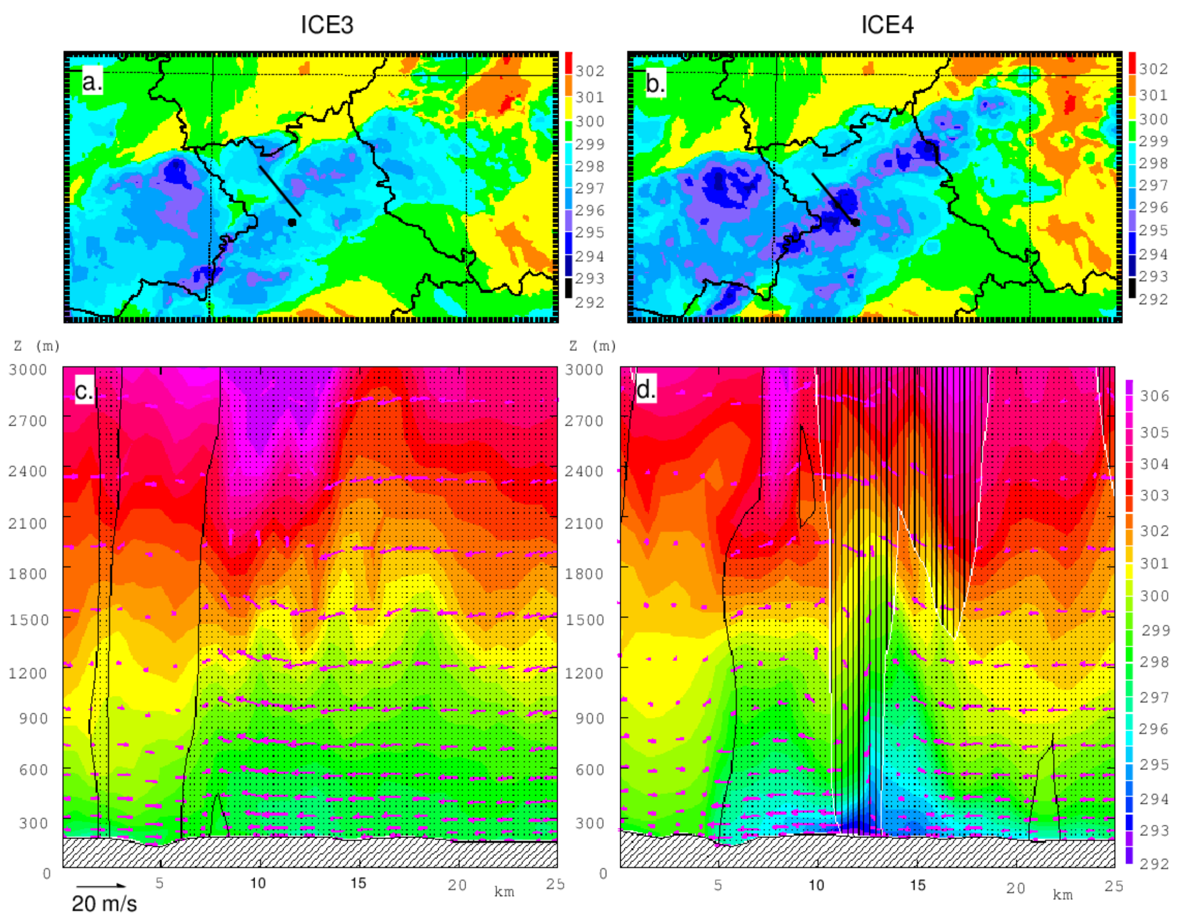
1-hour mean mixing ratios over area where ground precipitation rate > 100 mm/h

Budget of θ (K/s)



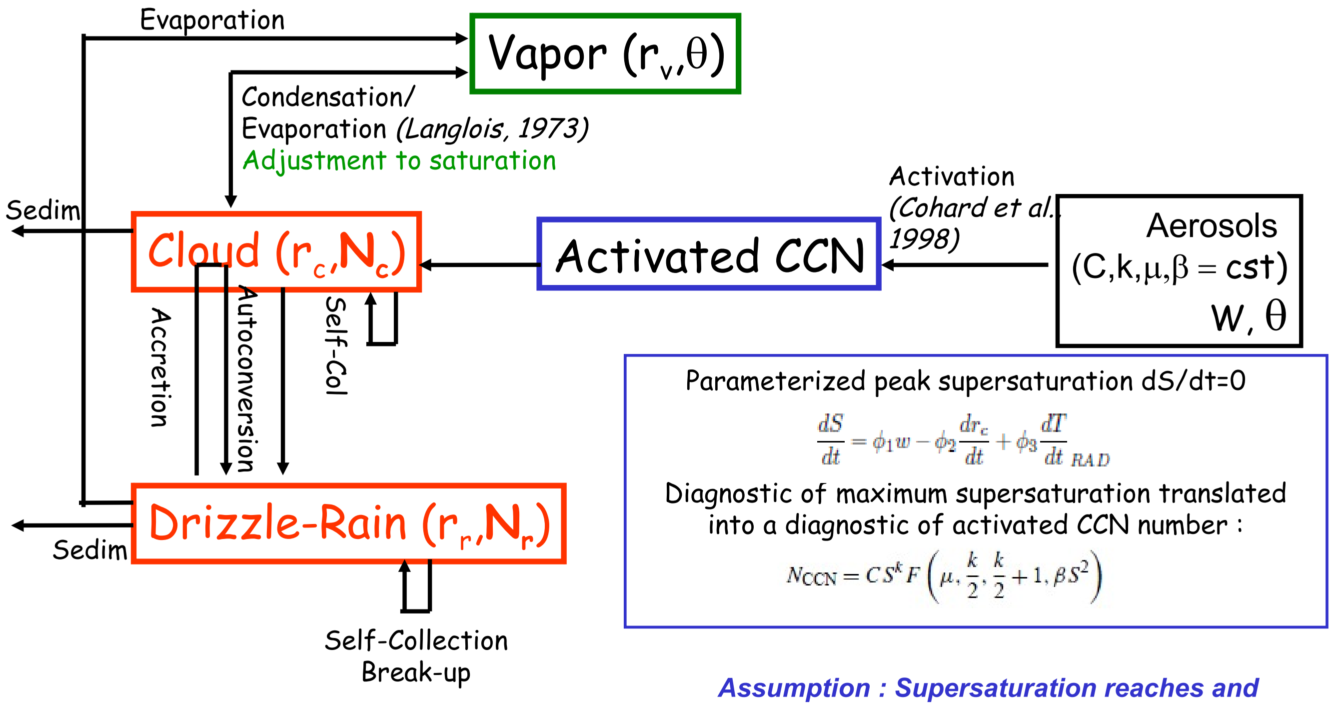
ICE3 : Heating in the mid-troposphere due to dry growth and deposition on graupel and accretion on droplets

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



Meso-NH : Warm 2-moment microphysical schemes

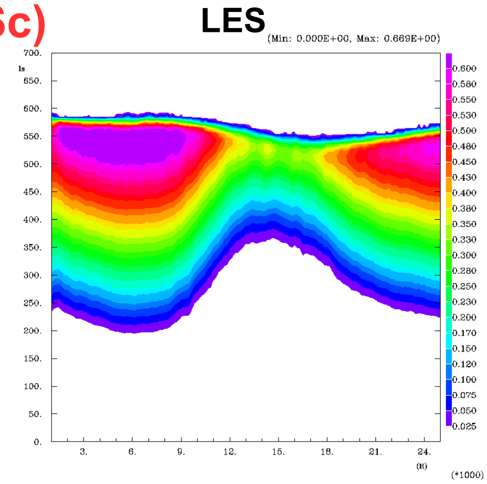
Cohard and Pinty, 1998 for Cu ; Geoffroy et al., 2008 for Sc-St



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

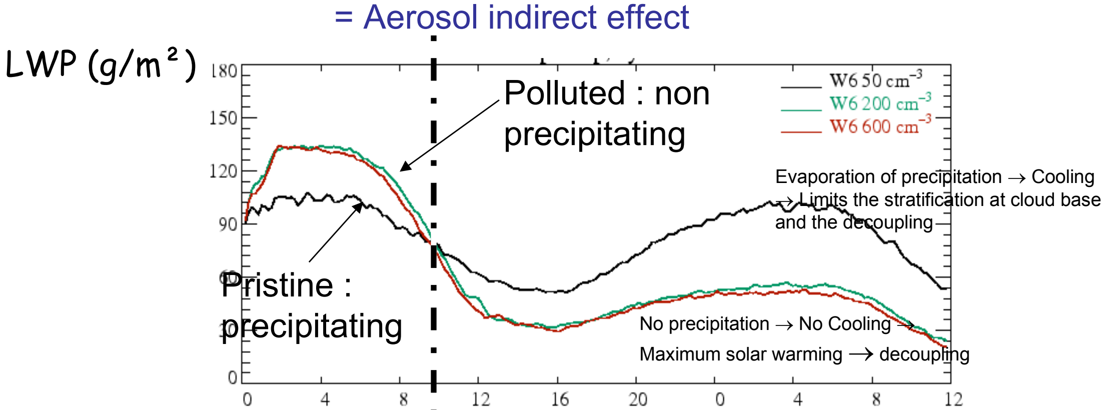
FIRE (Sc)

LES



Δx=Δy= 50m, Δz=10m
T=36h

LES study : Impact of the pollution on the stratocumulus diurnal cycle
= Aerosol indirect effect

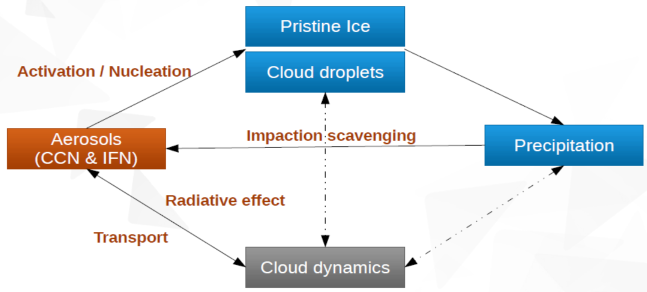


Sandu, I., 2007

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

Free aerosols – Activated
N_{free} N_{act}

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

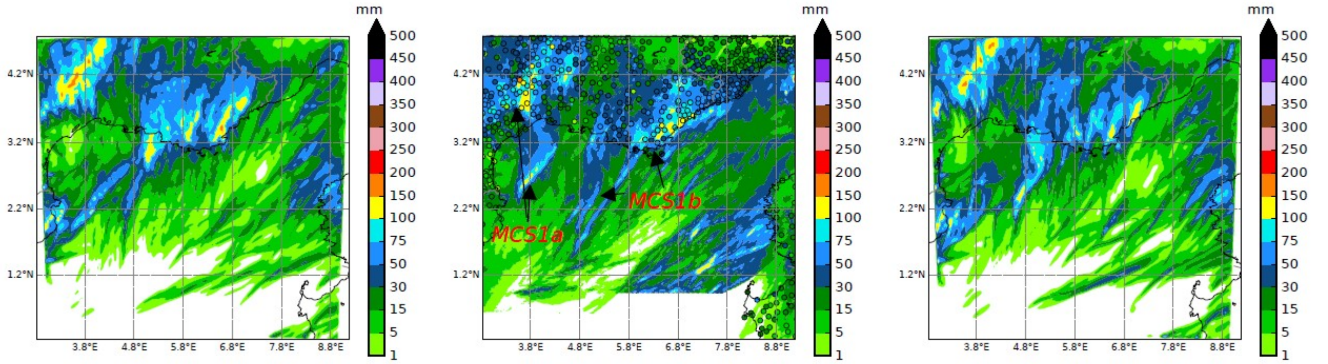
- Complete microphysical scheme derived from ICE3
  - Explicit deposition of water vapour on ice crystals
  - Improved pristine ice ⟶ snow conversion
- Aerosol treatment
  - Transport by the resolved flow and turbulence
  - CCN activation (Cohard and Pinty, 2000) ⟶ cloud droplets
  - IFN nucleation (Phillips 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)

Supersaturation over ice

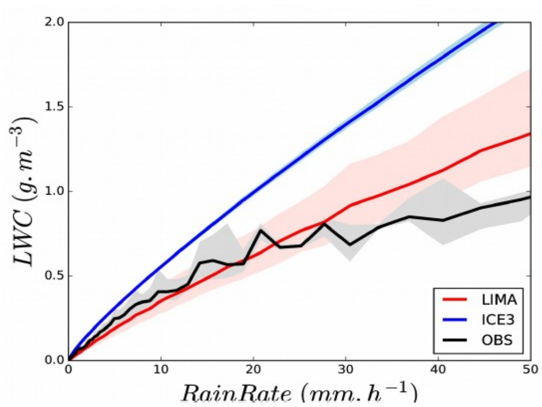
- Vié *et al.*, 2015: LIMA (v1.0): a two-moment microphysical scheme driven by a multimodal population of cloud condensation and ice freezing nuclei, GMDD, doi:10.5194/gmdd-8-7767-2015.

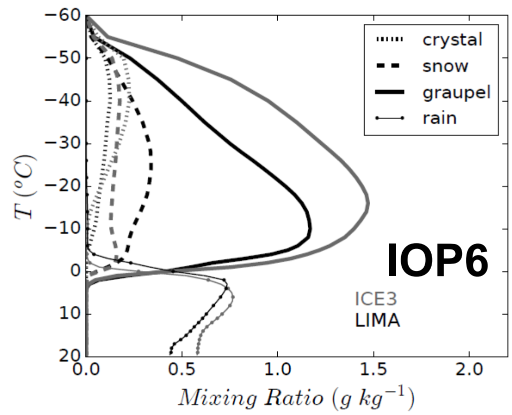
Application to HYMEX : IOP16

Taufour et al., 2018



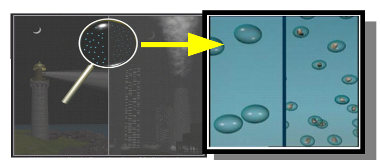
(a) ICE3 (b) Observations (c) LIMA

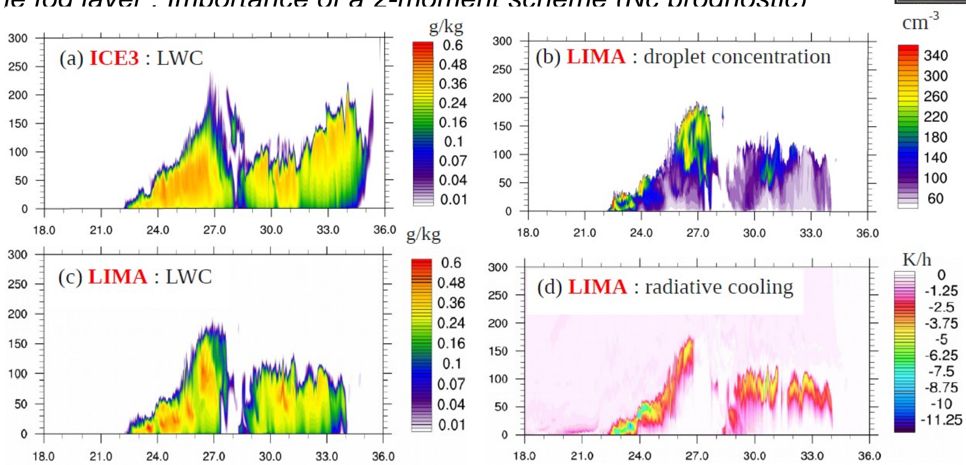




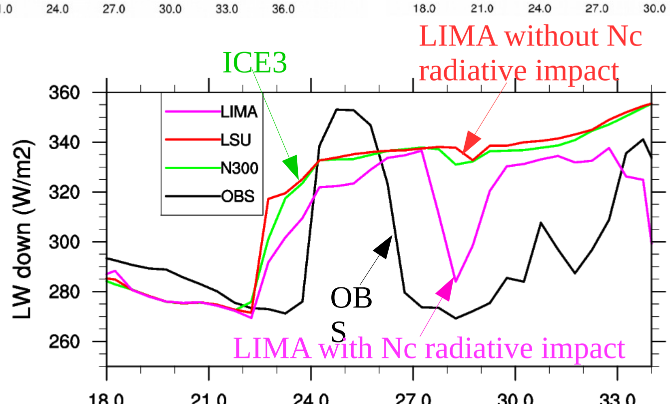
Impact on Fog (Léo Ducongé PhD)

For the same water amount, a fog can be optically thin (few big droplets) or thick (a lot of small droplets) → impact the development of the fog layer : Importance of a 2-moment scheme (Nc prognostic)





LIMA : realistic vertical variability



LIMA : impact on fog if cloud optical properties take into account Nc (Re,τ,g,SSA)

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 :

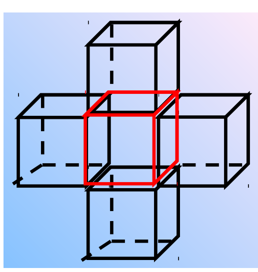
- « All or nothing » adjustment : Cloud fraction = 0 or 1

- Subgrid adjustment : Cloud fraction (between 0 and 1) computed from the subgrid variability given by the turbulence or/and the shallow convection, through a PDF

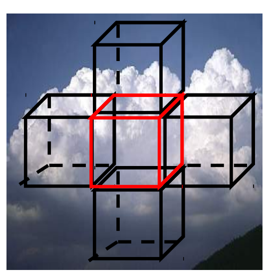
CLOUD SCHEME

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

Correct only for resolved clouds



OR



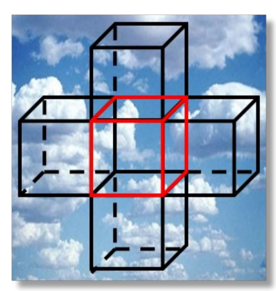
a/ *No saturated case*
$\Rightarrow$ **Clear sky** $\bar{r}_c = 0$

b/ *Fully saturated*
$\Rightarrow$ **Fully cloudy** $\bar{r}_c = \bar{r}_t - r_{sat}(\bar{T})$

➔ **Subgrid condensation scheme**

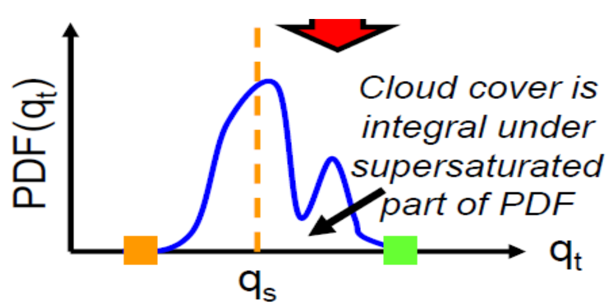
Correct for all cloud types

(resolved and subgrid)



$$C = \int_{q_s}^{\infty} PDF(q_t)\,dq_t$$

$$q_c = \int_{q_s}^{\infty} (q_t - q_s)\,PDF(q_t)\,dq_t$$

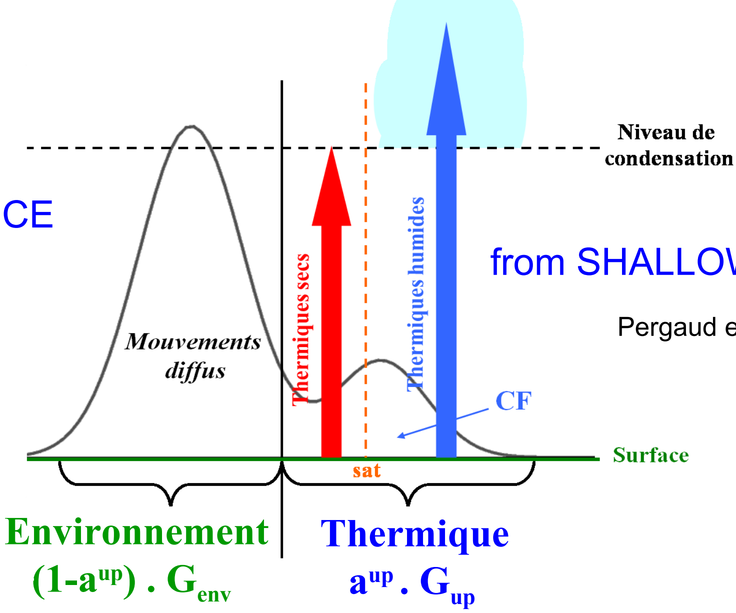


Cloud fraction of DEEP CLOUDS

PDF according to Chaboureau and Bechtlod 2002

Cloud fraction of CLOUD BOUNDARY LAYER

from TURBULENCE



from SHALLOW CONVECTION

Pergaud et al., 2009

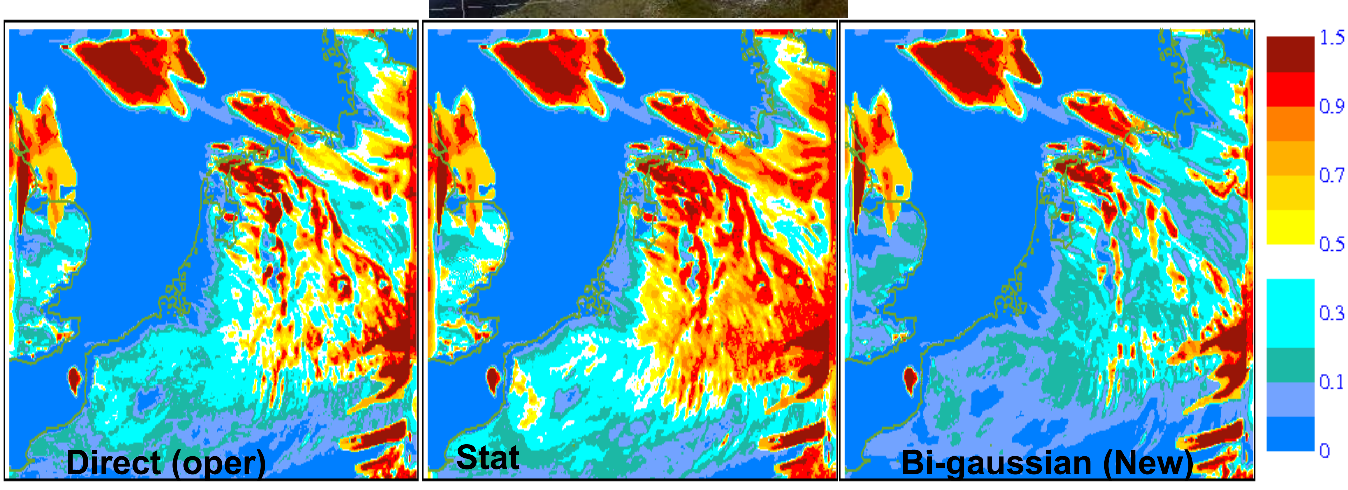
Combination of Gaussian (stratocumulus) and exponential (cumulus) distribution functions depending on turbulent fluxes. (Bougeault, 82) / (Bechtold, 95)

Cloud fraction very important for the radiation scheme

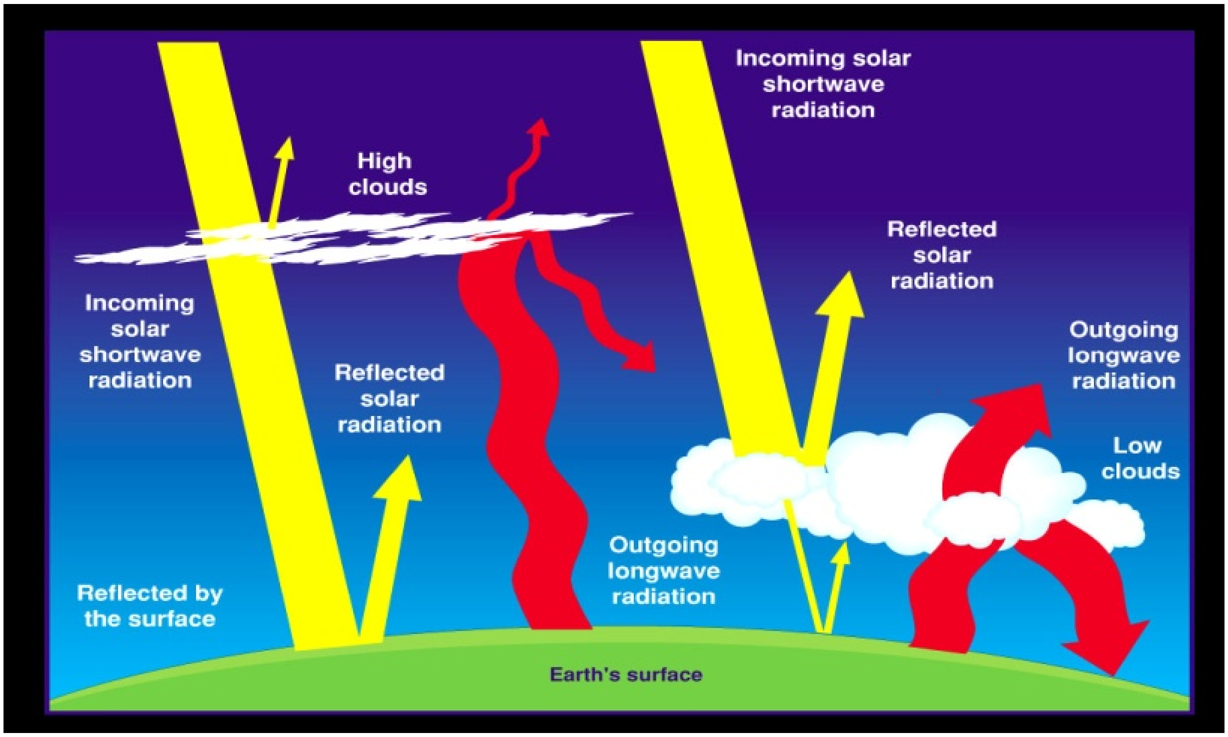
Improvement of the cloud scheme

(9 April 2010 at 12h)

From S.Riette

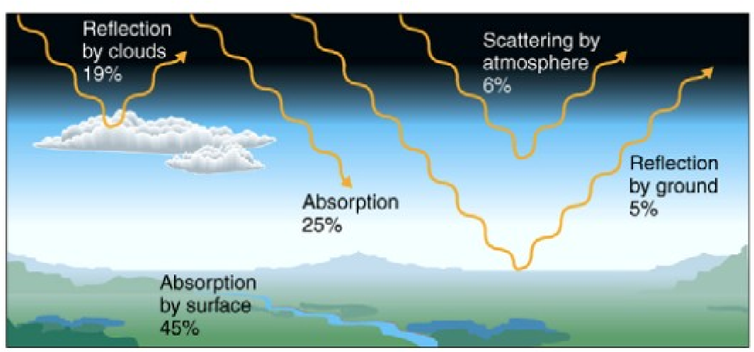


Radiation

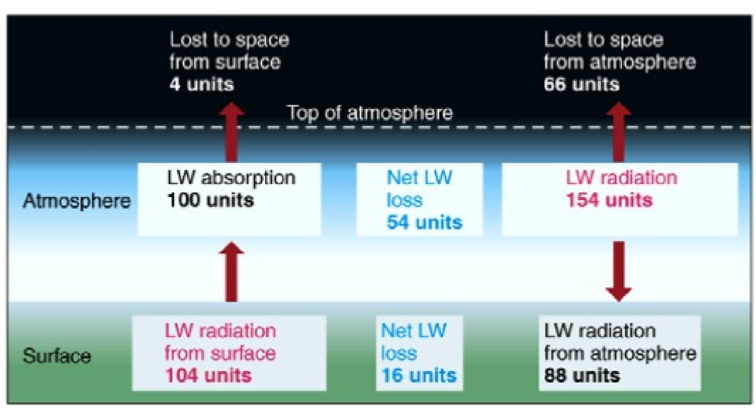


Radiation

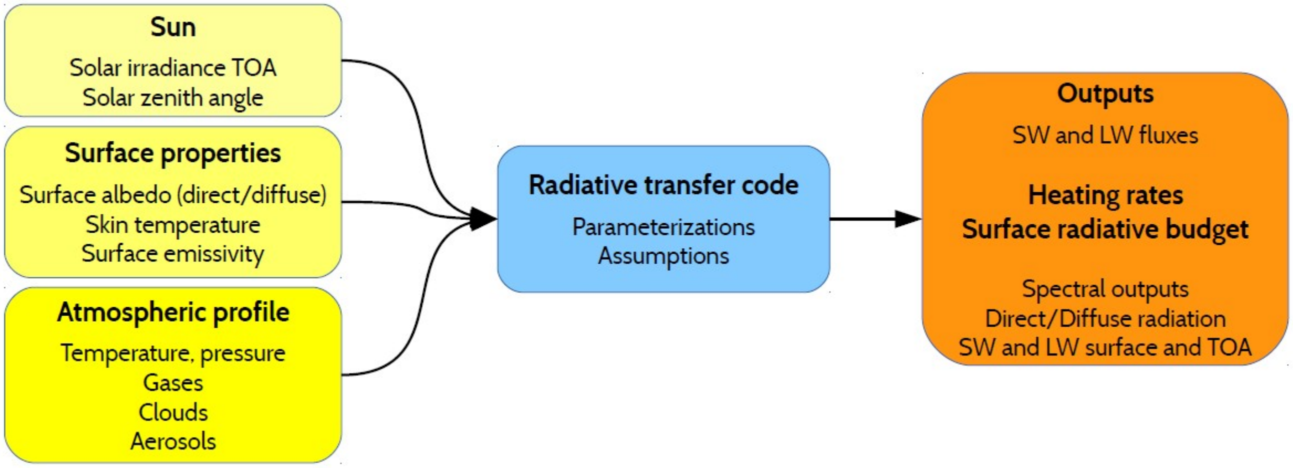
SWnet=SW ↓– SW↑



LWnet=LW ↓– LW↑



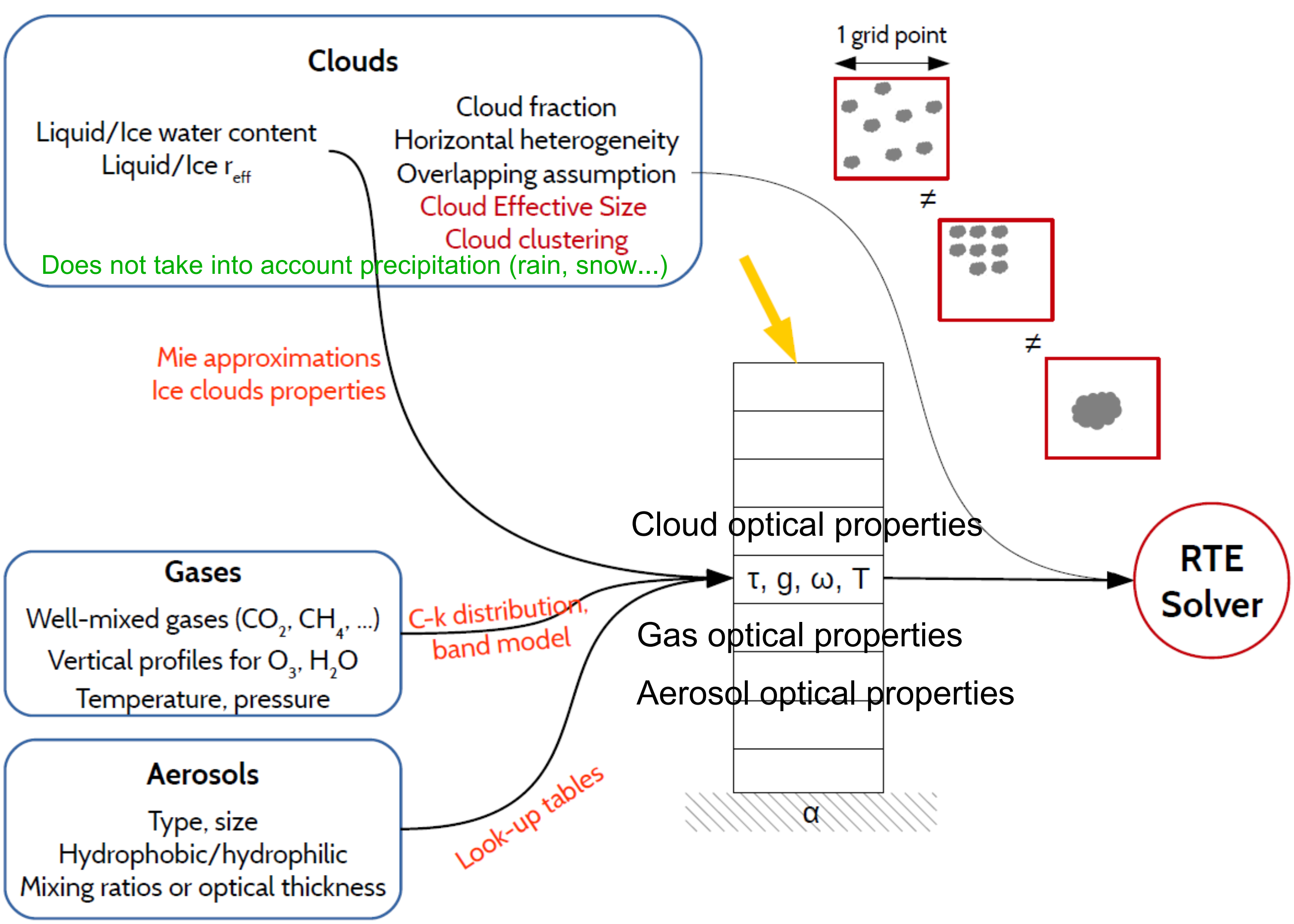
What does an atmospheric radiative transfer code do ?

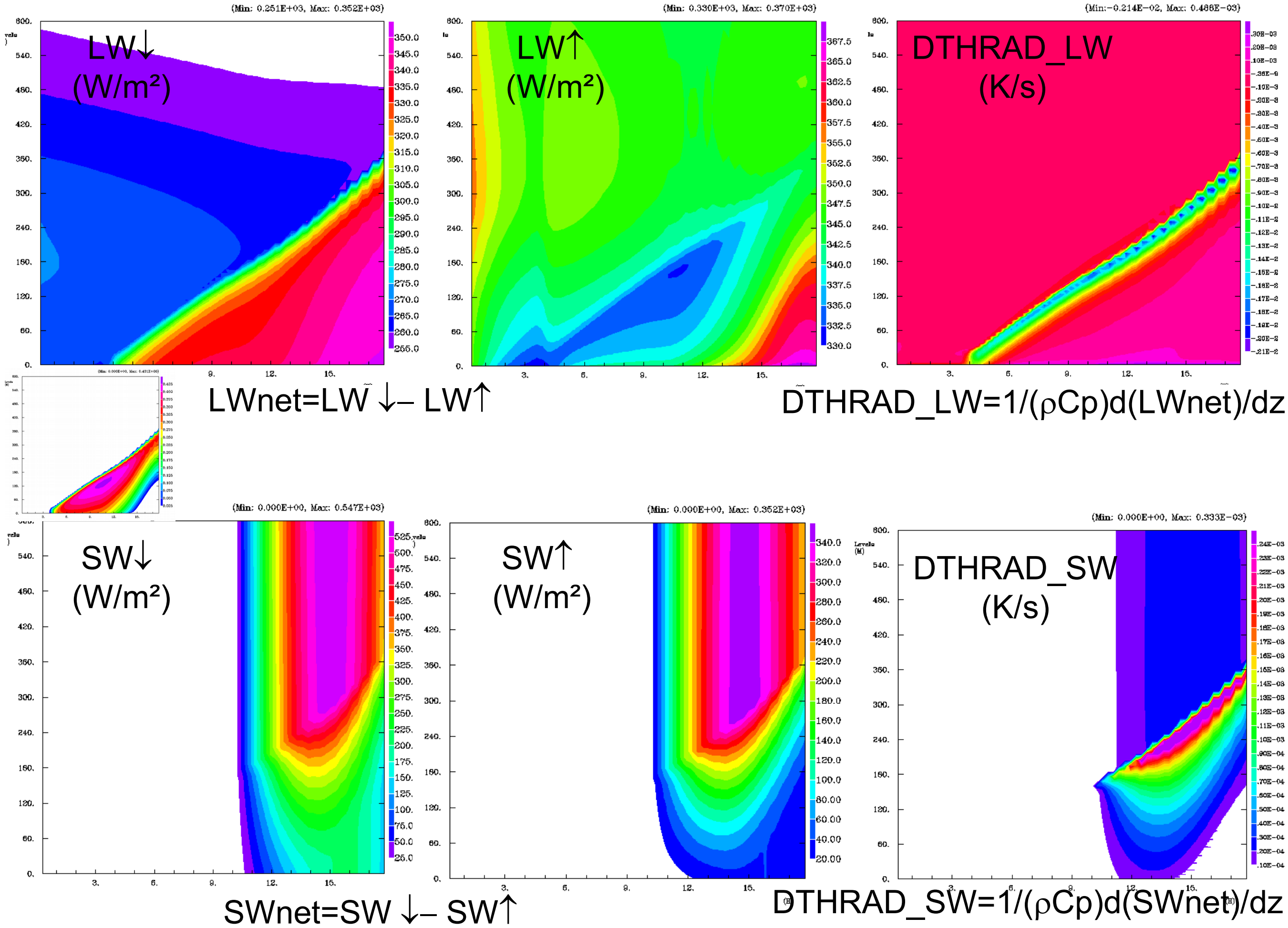


- LW: Emission and absorption of telluric and atmospheric radiation :
  - LW scheme: 9 spectral bands
  - RRTM scheme : 16 spectral bands
- SW : Reflexion, diffusion and absorption of solar radiation :
  - SW scheme: 1 single : 6 spectral bands
  - SRTM (ecRad) : 14 bands

- 2 radiation codes : ECMW or ecRad (Hogan and Bozzo, 2016)
- 1D scheme : parallel plan assumption. But with ecRad, possibility of 3D parametrization with SPARTACUS
- Expensive cost -> called at a lower frequency than Δt.

What does an atmospheric radiative transfer code do ?





Links between parametrizations

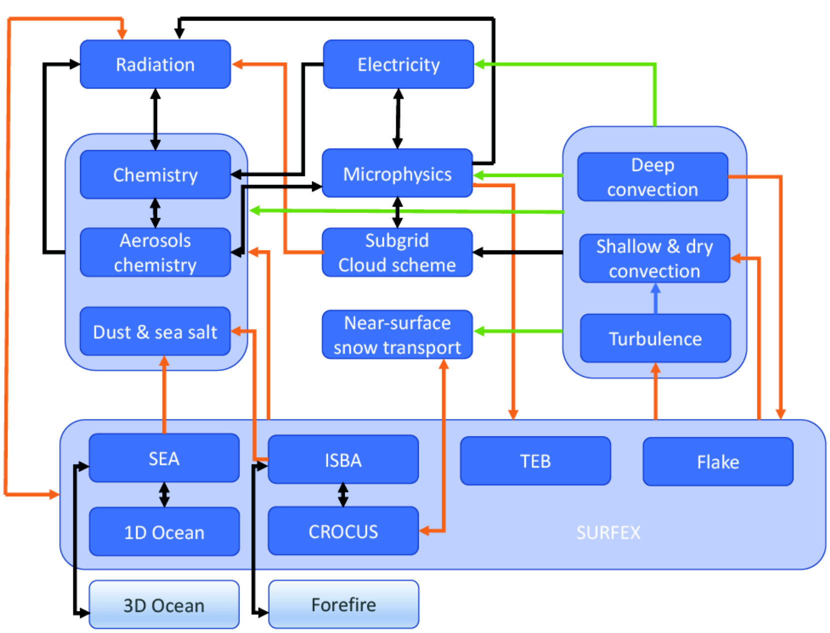


Figure 6. Physical and chemical schemes and the one-way or two-way links between them. Black arrows represent the direct interaction between schemes, orange arrows the indirect interaction through fluxes or cloud fraction, and green arrows the subgrid transport of prognostic variables.

Plan

1. Introduction (a few illustrations)
2. Dynamics
3. Physics (without SURFEX)
4. **A few words about on-line couplings : electricity, fire, chemistry/aerosols ...**

Meso-NH
mesoscale non-hydrostatic model

Explicit electrical scheme in Meso-NH

Pinty and Barthe

Electrical scheme of MesoNH

3 CRM (Mansell et al., 2002; Barthe et Pinty, 2007; Fierro et al., 2013) with a complete explicit 3D electrical scheme.

- Prognostic equation for the charge density of each hydrometeor.

Source terms : turbulence, charging mechanism rates, sedimentation, charge neutralization by lightning flashes

- Charge separation mainly driven by non inductive charging mechanism

- Then charges can be exchanged between the different hydrometeor species during the microphysical processes

- Also equations for positive and negative ion concentrations

- Electric field computation

- Ligthning flashes and neutralization of charges

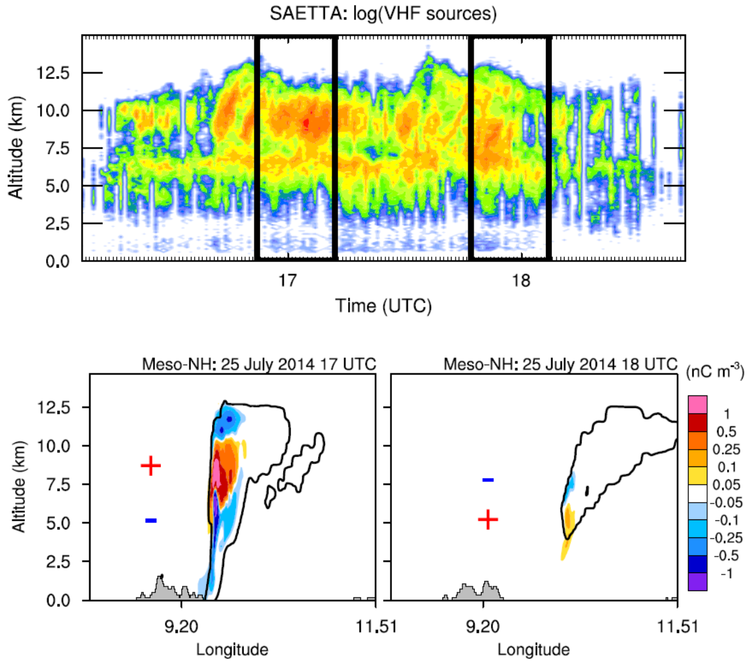
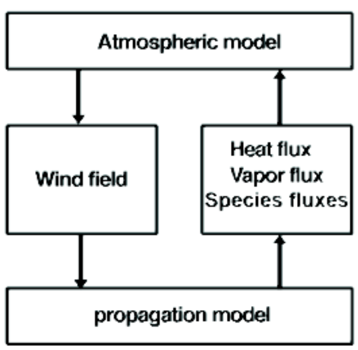


Figure 13. Comparison between the SAETTA data and the Meso-NH simulation for the case of the 25 July 2014 event over Corsica. Time series of the vertical profiles of the SAETTA VHF sources (top) and MesoNH cross-sections of the total charge density (nC m^{-3}; colors) corresponding to the windows of the SAETTA profiles with a direct cell (left) of "normal" polarity and an indirect cell (right) of "reverse" polarity. The cloudy area is shown with a black isoline.

Coupling with a fire propagation model ForeFIRE



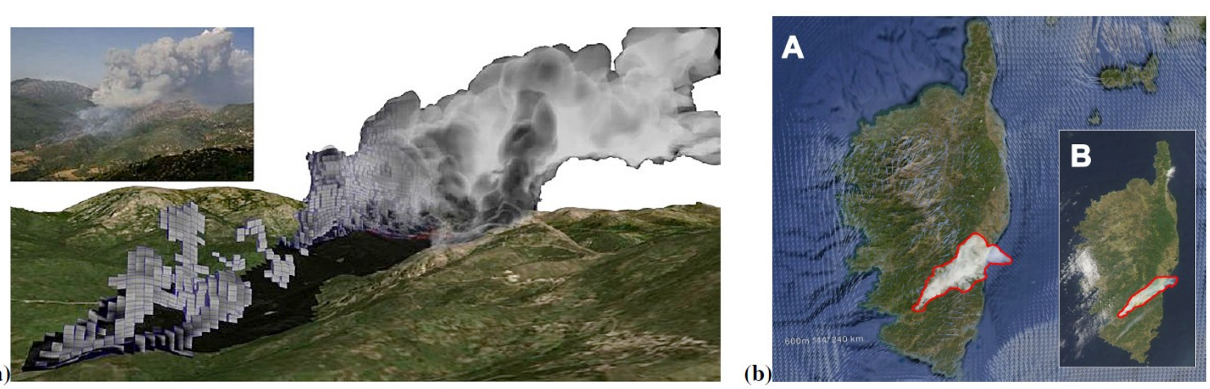
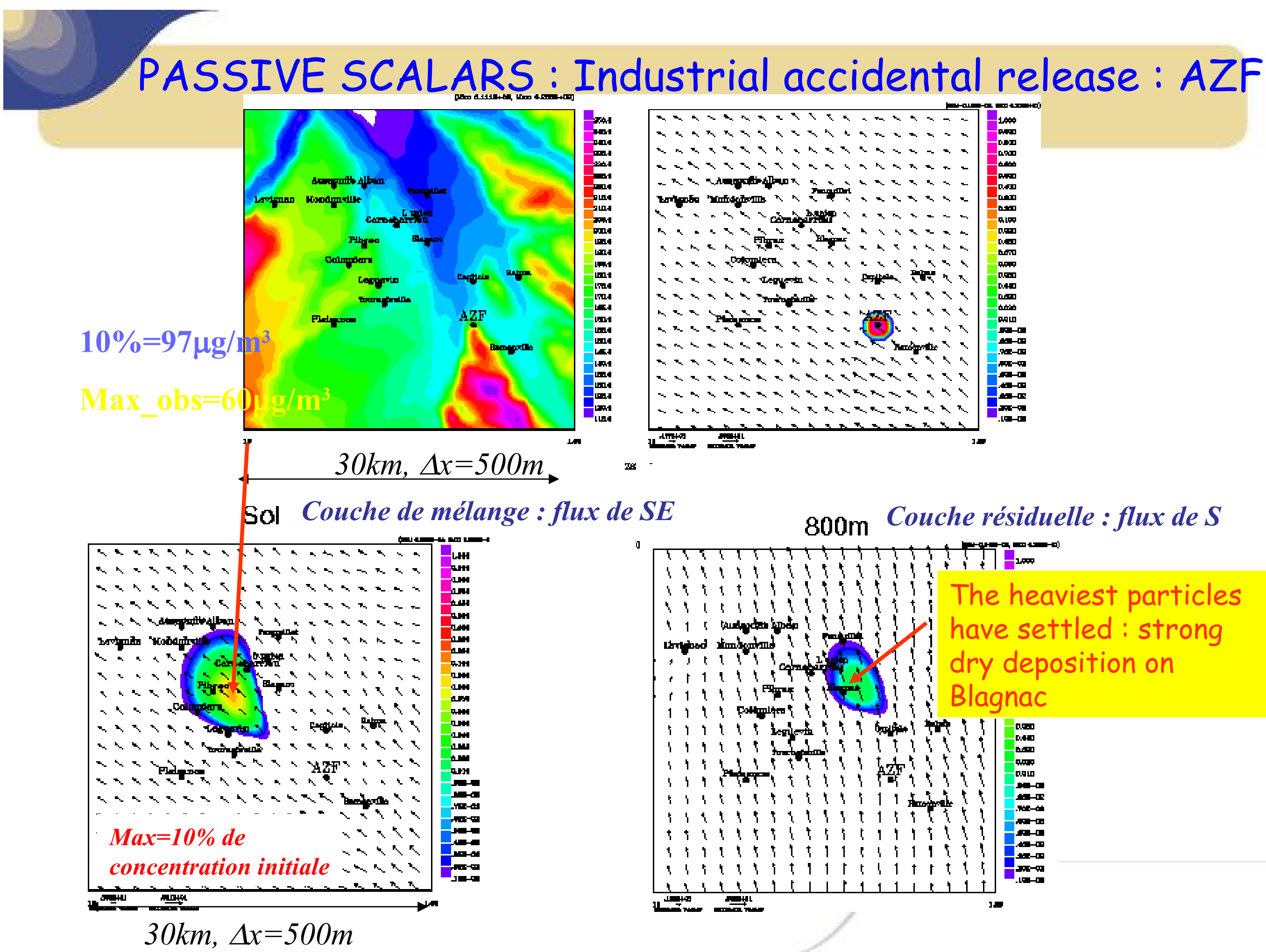
(a) (b)


Figure 12. Simulated smoke tracer on 23 July 2009 (a) in the 50 m resolution domain compared to the plume's photograph (at the top left) and (b) in the 600 m resolution domain highlighted in red (A) at 15:00 UTC compared to the MODIS image (B) of Corsica at 14:50 UTC.

On-line Chemistry & Aerosols

- Passive tracers
- Gazeous chemistry
- Aerosols
- Dusts
- Sea salts
- Aqueous chemistry

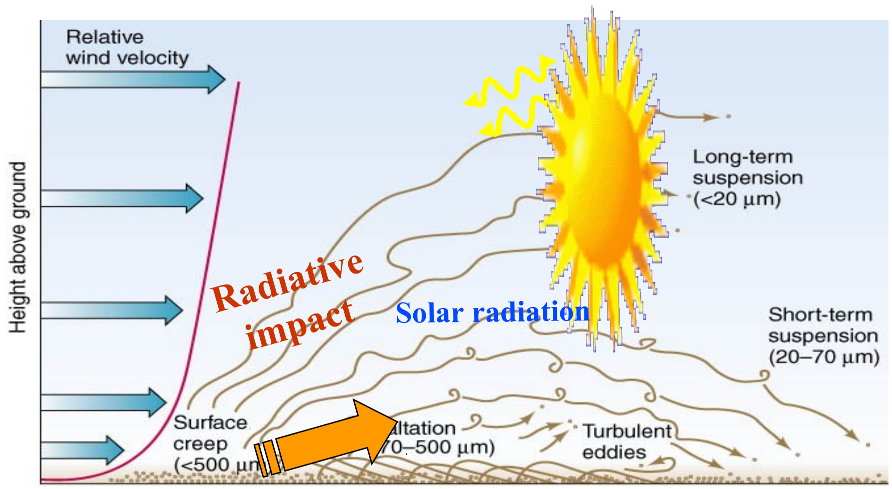


Dust parametrization in MesoNH/SURFEX

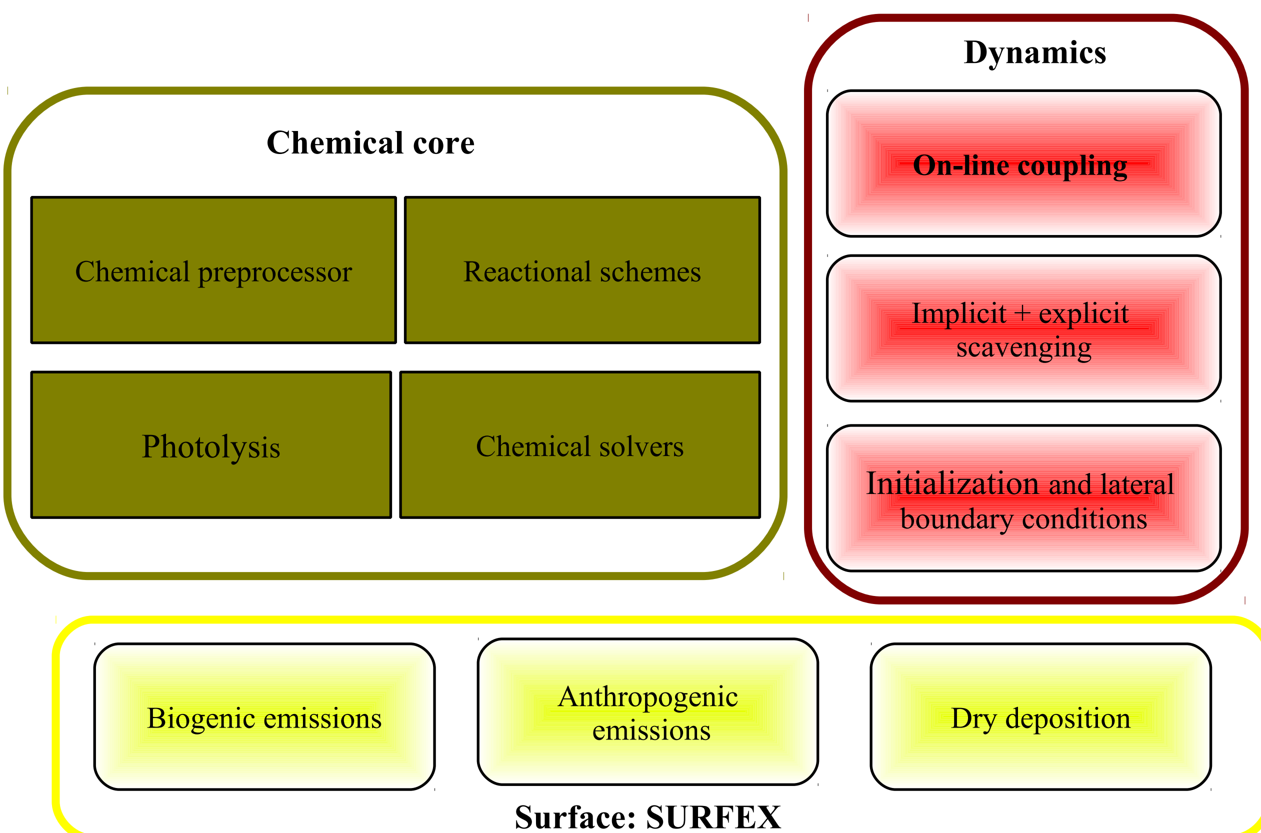
(Grini et al, 2006, Tulet et al, 2005)

Only 3 additive prognostic variables

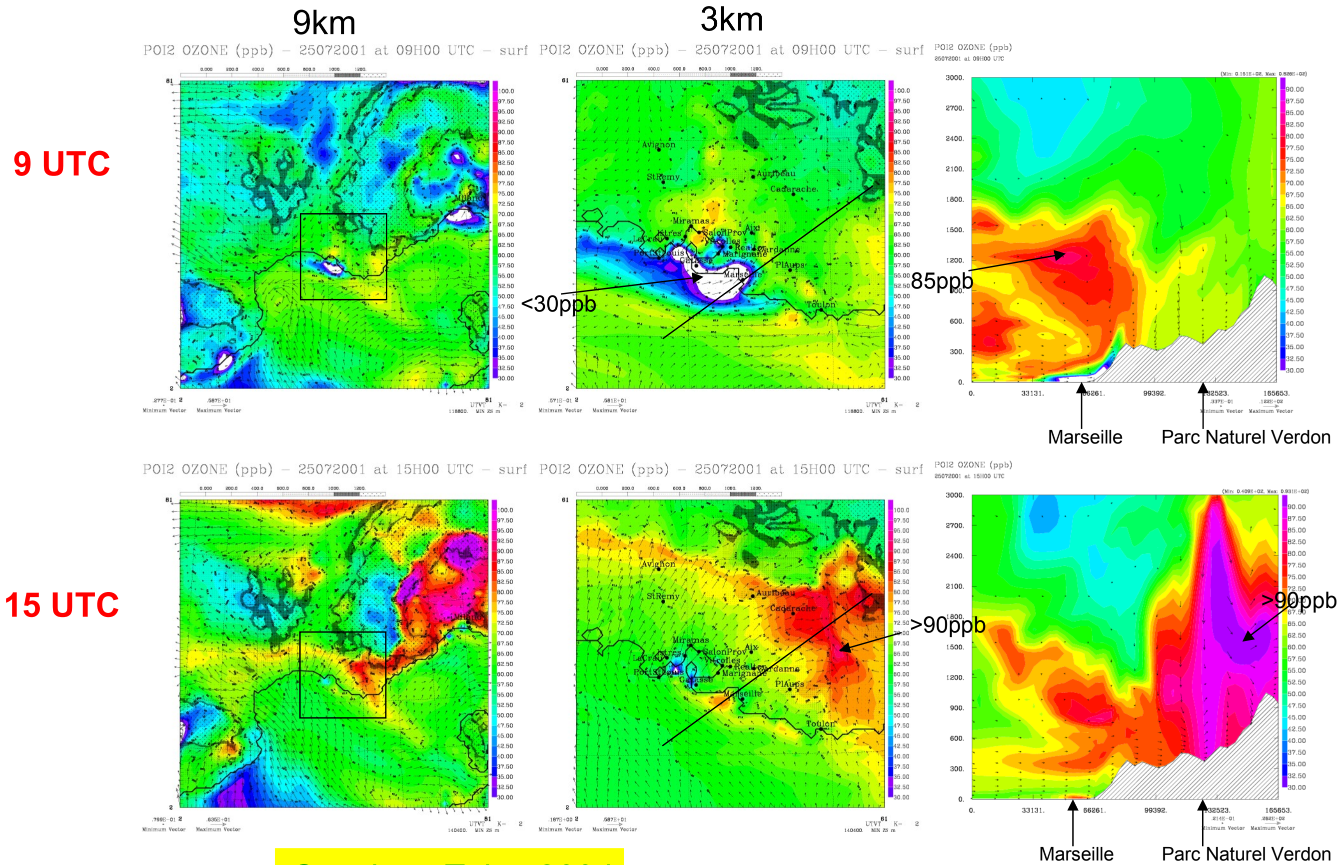
No chemistry



Gazeous chemistry



OZONE le 25 Juin 2001



Cousin et Tulet, 2004

Aerosol chemistry

Scheme = ORILAM

Coeur aérosol: MesoNH / AROME

- Coagulation / nucléation (V. Crassier)
- Schéma réactionnels précurseurs SOA (P. Tulet)
- Équilibres thermodynamiques (V. Crassier, P. Tulet)
- Solveurs SOA (P. Tulet, A. Grini)

Surface: SURFEX

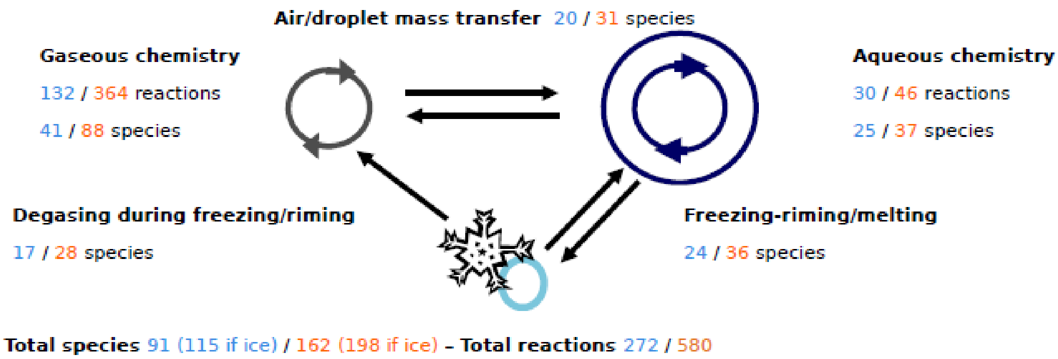
- Emissions aérosols désertiques, sels (A. Grini, M. Mohktari P. Tulet)
- Dépôt sec (P. Tulet)

Atmosphère: MesonH, AROME, ALADIN

- Sédimentation (P. Tulet)
- Lessivage aérosol implicite/explicite (P. Tulet, N. Begue)
- Activation CCN (J. Rangonio,P. Tulet, M. Leriche)
- Propriétés optiques et Couplage radiatif (B. Aouizerats, A. Grini)

Cloud chemistry module

- ReLACS-AQ or ReLACS2-AQ mechanism
- Air/droplet mass transfer for cloud and rain
- Cloud microphysical mass transfer of chemical species for mixed phase cloud (collision/coalescence, freezing and riming, melting, hydrometeors sedimentation)
- Computing pH as a diagnostic by solving the electro-neutrality equation
- Solving the chemical system using the Rosenbrock family solver



An introduction to **SURFEX**

Program of the course

METEO FRANCE
Toujours un temps d'avance

Ecole Nationale de la Météorologie

Formation Permanente

Stage : SURFEX course

08 Feb 2016 - 10 Feb 2016

room : C057

	09h00	10h00	10h30	10h45 – 12h15		14h00	14h30	15h00	15h30	16h00 – 17h00
Monday 8. Feb. 2016					LUNCH	Genereal presentation of SURFEX (PLM)		SURFEX applications (PLM)	Break	SURFEX Installation (SF & PLM)
Tuesday 9. Feb. 2016	ECOCLIMAP and PGD (SF)	PREP (PLM)	Break	Practical exercise PGD-PREP (SF & PLM)	LUNCH	Nature scheme : ISBA (PLM)	Town scheme (SF)	Lakes and Oceans (PLM)	Break	Practical exercice : ISBA, TEB, FLake (SF & PLM)
Wednesday 10. Feb. 2016	Programming exercise (SF & PLM)		Break	Programming exercise and continuation of practical exercise (SF & PLM)	LUNCH	Finalization of practical and programming exercises (SF & PLM)			Break	Conclusion and Evaluation of the course (SF & PLM)

Responsable de la session : P. Le Moigne (PLM), S. Faroux (SF) (CNRM)

Semaine du 08/02/2016 au 10/02/2016

Attestation of stage ?

Documentation for the course :

Presentation and exercices :
http://www.cnrm.meteo.fr/surfex/spip.php?article36

Documentation : scientific documentation and user's guide (efficient research tool)export versions, bugfixes, etc. :
http://www.cnrm.meteo.fr/surfex-lab/

Two different web sites are used for SURFEX :

Internet : http://www.cnrm.meteo.fr/surfex/

Filtered on IP address : http://www.cnrm.meteo.fr/surfex-lab/

- Provide sufex-support@meteo.fr your IP address (if outside Meteo-France)

Outline

- **Introduction – main principles**
- **Physics**
- **Description of the surface (tiles – patches – databases)**
- **Interface with the atmosphere**
- **Running SURFEX**

Main Principles

Let's begin, what is SURFEX ?

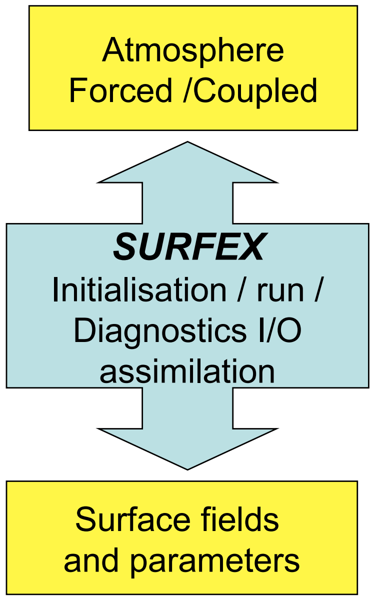
SURFEX means « surface externalisée »

SURFEX is a code that represents the surface processes.

SURFEX is « externalized », this means that the code can be used inside a meteorological or climate model, or in stand alone (offline) mode.

SURFEX has a modular structure and can include new parameterizations or schemes.

Why do we need externalized surface codes ?



- **The aim of a surface code is to simulate the fluxes between the surface and the atmosphere : energy, water, carbon, dust, snow, chemical species…**
- **The surface code needs to simulate processes « below » or « inside » the surface to provide this fluxes.**
- **Surface codes are improved and validated offline, many works on surface processes are done by people not belonging to the meteorological or climatological communities.**
- **The use of the same code for coupled and offline application is mandatory in order to ensure the consistency between the two applications.**
- **Need to <u>externalize</u> the surface code of the atmospheric model. I.e. clearly separate them from other part of the code in order to run them in stand alone mode**

cnrs

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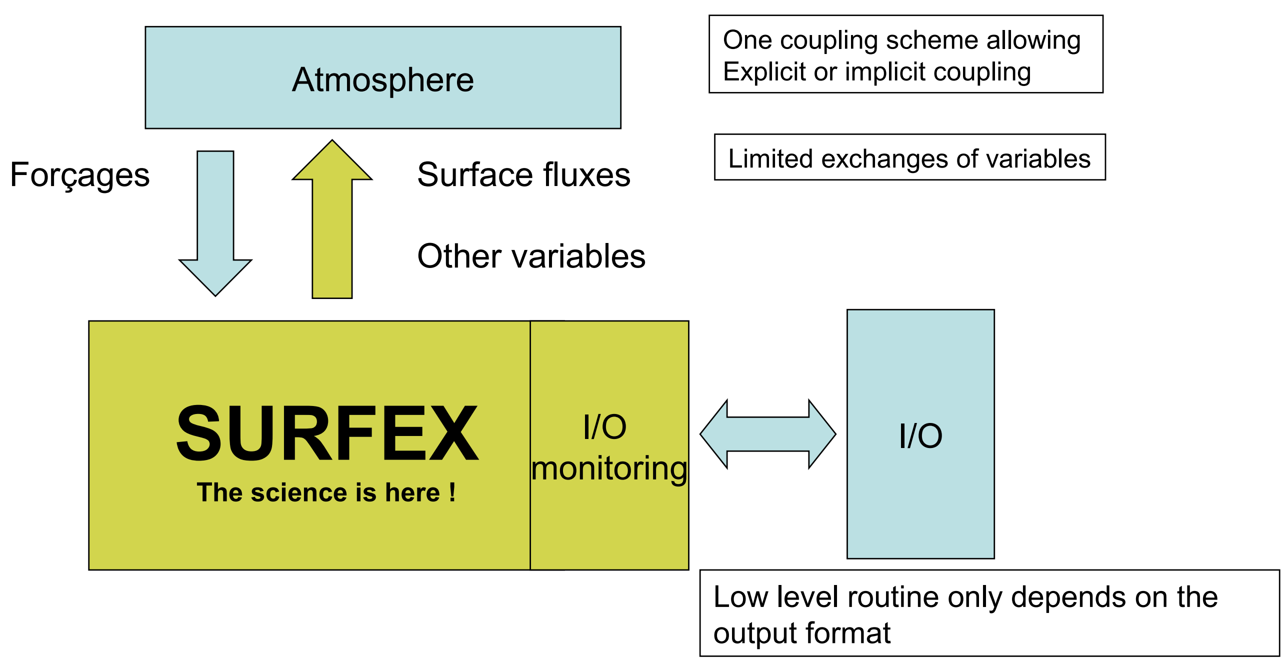
Coupling and interfaces



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SURFEX : history

~2000 : Initial decision : building of SURFEX on the base of the existing ISBA/TEB codes

Scales : 1 m ➔ 300 km

Use : numerical weather forecast, climate runs, monitoring, reanalysis, process studies.

2005 : V1 : Méso-NH, AROME
2008 : coupling with TRIP
2009 : Extended Kalman filter
2009 : FLake
2010 : coupling with Top-Model
2010 : CNRM-CM5.1
2010/2011 : ALADIN, assimilation (OI) for ALADIN et AROME
2011 : Surfex Scientific committee : CNRM (GMAP, GMGEC, GMME), Méso-NH, ALADIN, HIRLAM.
2011 : CROCUS
2012 : SODA (Surfex offline data assimilation)
2013 : TEB/BEM (building energy model)
2015 : ISBA/MEB, use of OASIS for coupling with hydrology and ocean models

Versions and correspondence with atmospheric models versions

SFX	release	NWP	MNH	CNRM-CM
V1	2005			
V4.8	2008	CY35t2	V4.8	
V5.8	2009	CY36t1		CM5 (CY32+V5.8)
V6	2010	CY37t1		
V7.1	2011		V4.9	
V7.2	Feb 2012	CY38t1		
V7.2.1	Jan 2013	CY39t1		
V7.3	Feb. 2013	CY40t1	V4.10	
V8	2016			CM6(CY37t2+V8 or V7.3**)

- v6+ (V6.0+ GMAP optimisations)
- ** CY40t1 and CNRM-CM6 contains additional developments

Coupled and operational applications based on SURFEX

Atmospheric models :

Mesoscale model Meso-nh

Climate research : ARPEGE – ALADIN

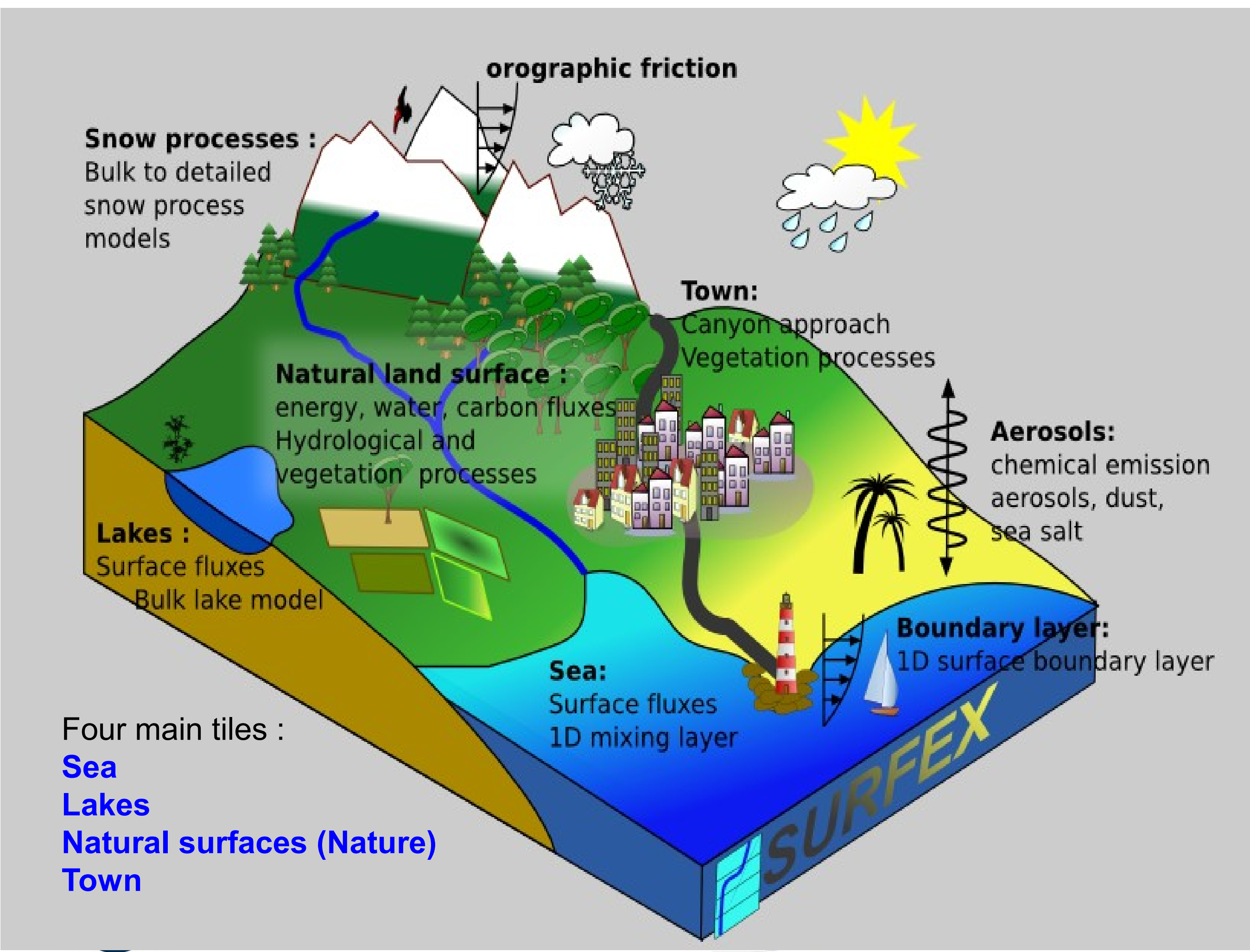
Numerical weather prediction :

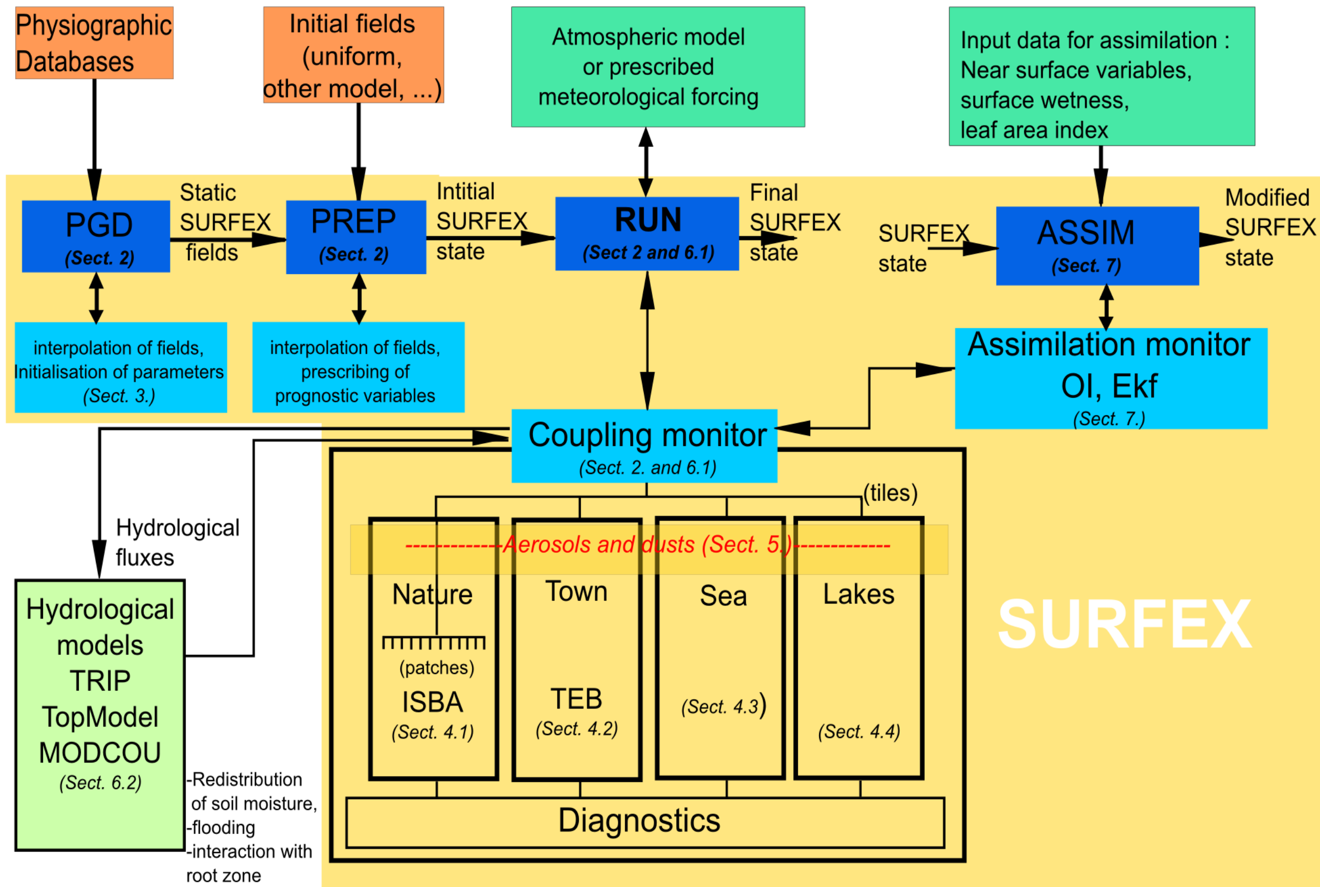
- AROME (2008)
- ALADIN (2010)
- Soil analysis (OI_MAIN) 2011
- ALARO
- HARMONIE
- ARPEGE (2015/2016)

Offline operational applications

Snow and avalanches : Safran-Surfex-Mepra (2014)

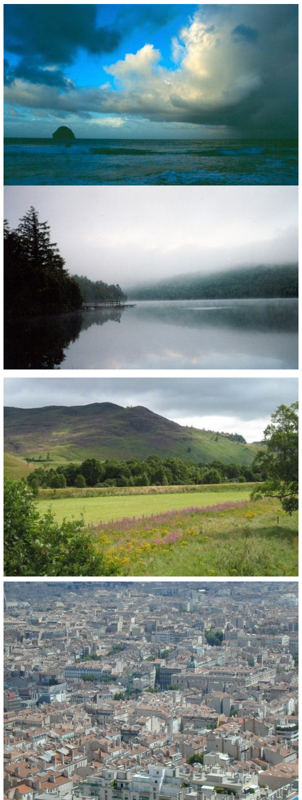
Hydrology : Safran-Surfex-Modcou (2015/2016)




Physiographic Databases
Initial fields (uniform, other model, ...)
Atmospheric model or prescribed meteorological forcing
Input data for assimilation : Near surface variables, surface wetness, leaf area index
PGD (Sect. 2)
Static SURFEX fields
PREP (Sect. 2)
Intitial SURFEX state
RUN (Sect 2 and 6.1)
Final SURFEX state
SURFEX state
ASSIM (Sect. 7)
Modified SURFEX state
interpolation of fields, Initialisation of parameters (Sect. 3.)
interpolation of fields, prescribing of prognostic variables
Assimilation monitor OI, Ekf (Sect. 7.)
Coupling monitor (Sect. 2. and 6.1)
(tiles)
Hydrological fluxes
------------Aerosols and dusts (Sect. 5)------------
Nature
(patches)
ISBA (Sect. 4.1)
Town
TEB (Sect. 4.2)
Sea
(Sect. 4.3)
Lakes
(Sect. 4.4)
SURFEX
Hydrological models TRIP TopModel MODCOU (Sect. 6.2)
-Redistribution of soil moisture,
-flooding
-interaction with root zone
Diagnostics

Physics

Physical schemes



Sea and oceans :
Prescribed SST, Charnock formula
Mondon and Redelsperger
ECUME (multicampaign parametrisation)
1D ocean model

Lakes :
Prescribed surface temperatures, Charnock formula
FLake

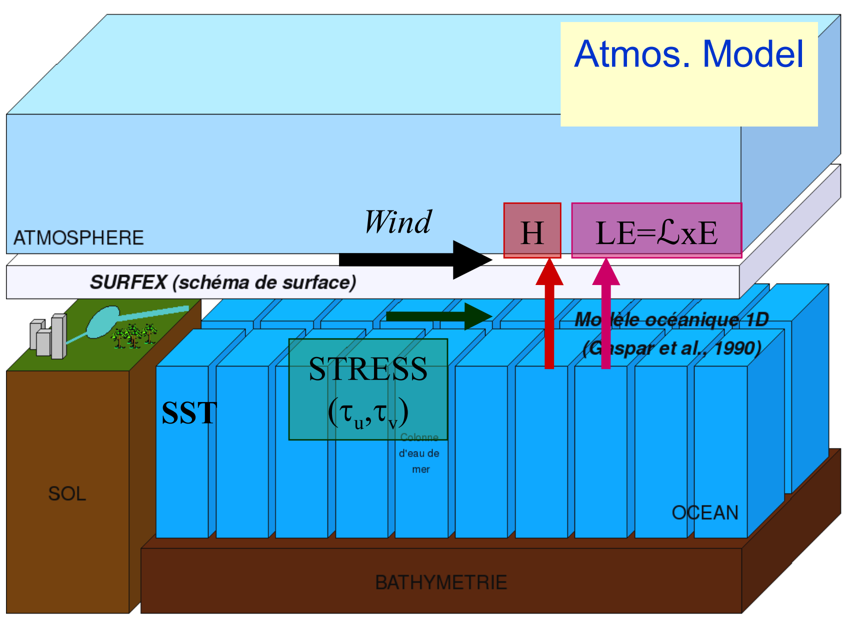
Sol/Vegetation : ISBA
(Interaction Soil Biosphere Atmosphere)

Town : TEB (Town Energy Balance)
Canyon Approach,
Detailed radiatif scheme
Heat storage in buildings

METEO FRANCE
Toujours un temps d'avance

SEA / OCEAN

- **ECUME multi-campaign parametrisation (prescribed SST)**
- **1D ocean mixing layer model Gaspar et al., 1990**



METEO FRANCE
Toujours un temps d'avance

Lakes : Flake model

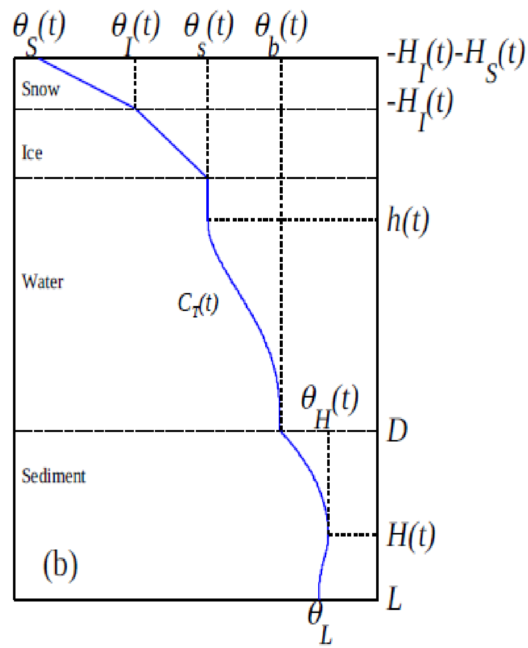
Simple model, based on assumed shape of the temperature profile

Snow/Ice :

- **the ice depth,**
- **the temperature at the ice upper surface,**
- **the snow depth, and the temperature at the snow upper surface.**

Water / Sediments

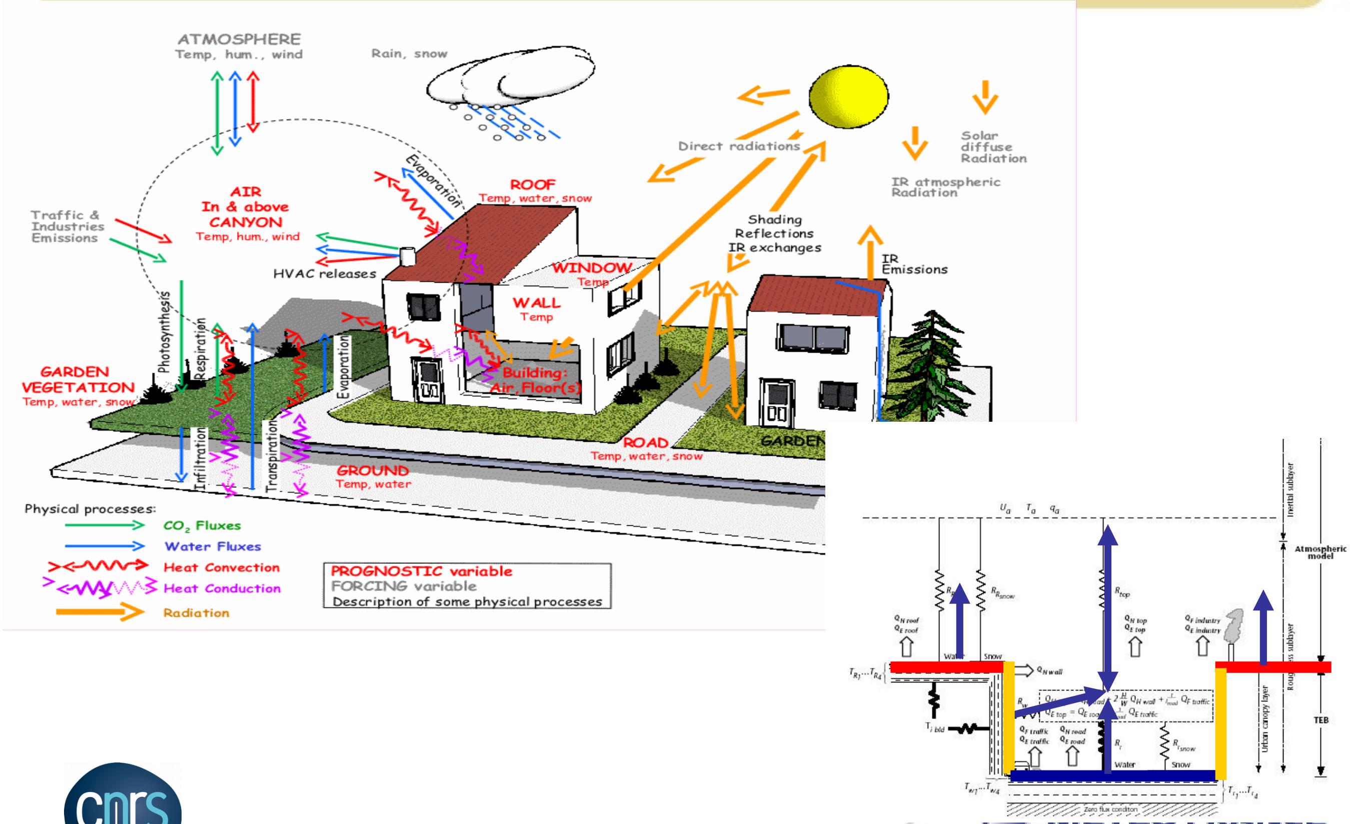
- **the surface temperature,**
- **the bottom temperature,**
- **the mixed-layer depth,**
- **the shape factor with respect to the temperature profile in the thermocline,**
- **the depth within bottom sediments penetrated by the thermal wave, and**
- **the temperature at that depth.**



ISBA main physical options

ISBA	Soil	Force restore : 2 temperature, 2 or 3 layers for water, icing Diffusion : multilayer (temperature, water, icing)
	Vegetation	Noilhan et Planton 89 (~Jarvis) A-gs (photosynthesis and CO2 fluxes) A-gs and interactive vegetation Slow carbon processes (wood and roots)
	Hydrology	No subgrid process Subgrid surface runoff Subgrid drainage Flooding and coupling with TRIP
	Snow	1 layer, albedo, density variable (ARP/Climat, Douville 95) 1 layer, albedo, density variable (ARP/ALD, Bazile) Multilayer (3, or…) albedo, density, liquid water content (Boone and Etchevers 2000)

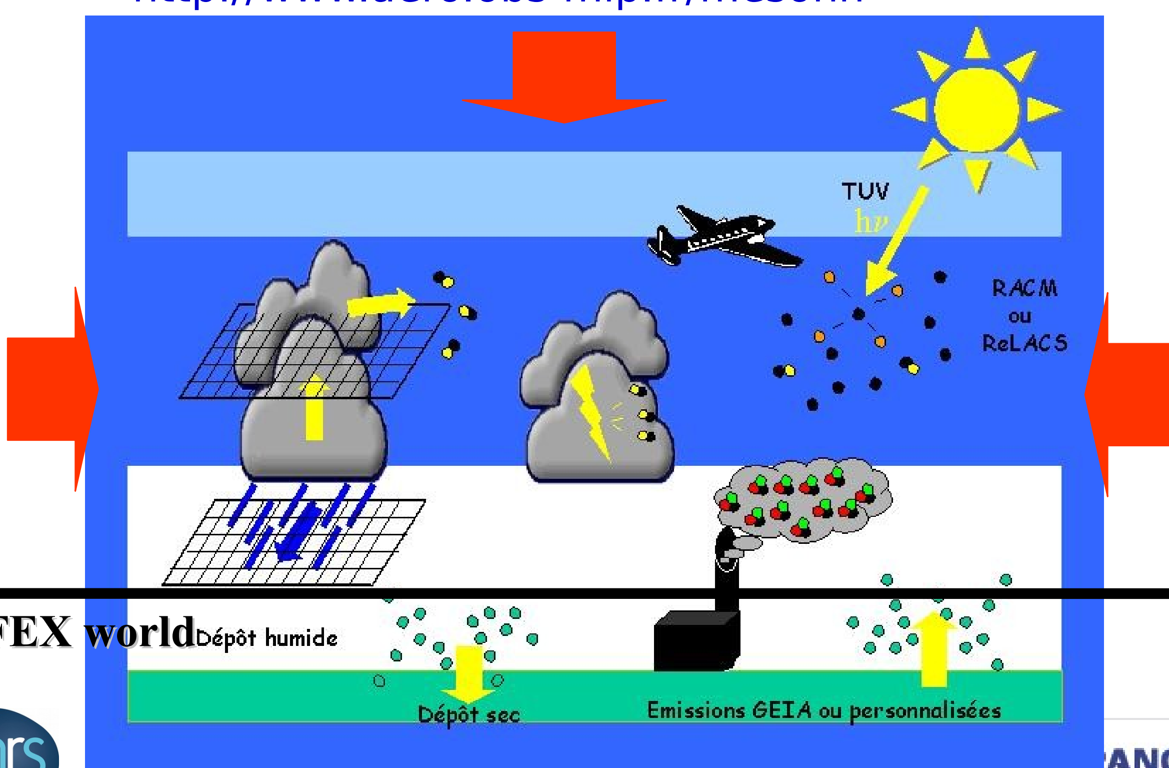
TEB



Toujours un temps d'avance

Chemical scheme
From local (dx=1 km) to synoptic scale (dx=50 km)

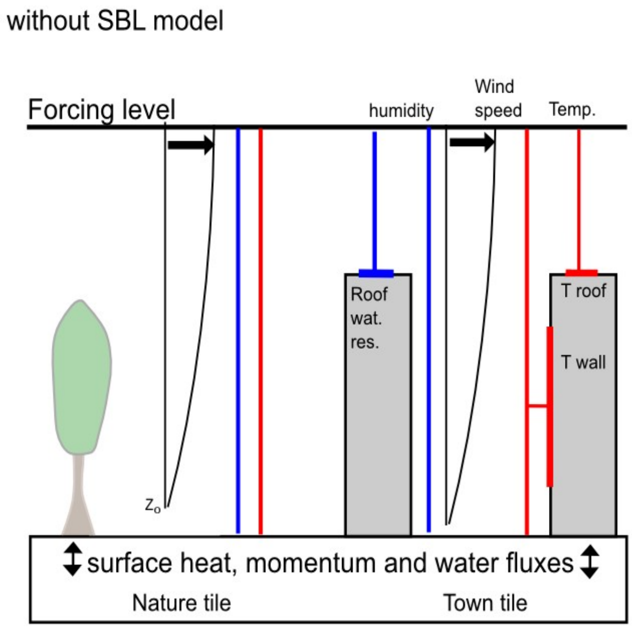
http://www.aero.obs-mip.fr/mesonh



SURFEX world

Toujours un temps d'avance

The SBL model (Canopy)

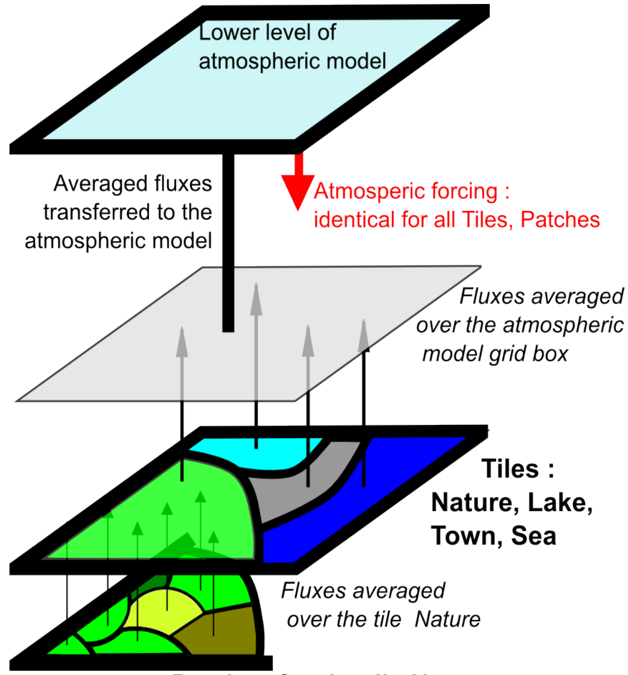


Describing the surface

How can we represent the surface heterogeneity in a grid ?

Tiling approach :

- **Within a grid mesh, the surface is divided into several homogeneous component.**
- **Each component receives the same atmospheric forcing**
- **Each component calculates fluxes**
- **Fluxes are aggregated and returned to the atmosphere**
- **No horizontal transfert within the surface**



SURFEX tiling and coupling with an atmospheric model

Tiling in SURFEX :

- **The surface is divide into**

  4 main Tiles, which are treated by different models.

Sea/Oceans	Lakes
Nature (bare soil/ vegetation)	Towns

NO no vegetation	C3 (C3 crops)
ROCK (bare rock)	C4 (C4 crops)
SNOW (snow and ice)	IRR (irrigated crops)
TREE (deciduous broadleaved forest)	GRAS (temperate /C3 grassland)
CONI (evergreen needleleaved forest)	TROG (tropical /C4 grassland)
EVER (evergreen broadleaved forest)	PARK (wetlands)

- **The tile Nature is divi into 12 (or 19) patches or natural functional types**

Aggregation of functional types is possible in ISBA

Total number of patchs chosen by user

	12	11	10	9	8	7	6	5	4	3	2	1
NO	1	1	1	1	1	1	1	1	1	1	1	1
ROCK	2	2	1	1	1	1	1	1	1	1	1	1
SNOW	3	3	2	2	2	2	1	1	1	1	1	1
TREE	4	4	3	3	3	3	2	2	2	2	2	1
CONI	5	5	4	4	3	3	2	2	2	2	2	1
EVER	6	6	5	3	3	3	2	2	2	2	2	1
C3	7	7	6	5	4	4	3	3	3	3	1	1
C4	8	8	7	6	5	4	3	3	3	3	1	1
IRR	9	9	8	7	6	5	4	4	4	3	1	1
GRAS	10	10	9	8	7	6	5	5	3	3	1	1
TROG	11	10	9	8	7	6	5	5	3	3	1	1
PARK	12	11	10	9	8	7	6	4	4	3	1	1

Physiographic parameters

The surface needs several types of parameters :

Orography

Type of the surface (tile) and vegetation types (patches) for « Nature »

- ISBA : Albedo, leaf area index, soil texture, …
- FLAKE : lake depth, extinction coefficient …
- SEA Bathymetry
- …

Solutions :

- **Prescribe the model parameters using a namelist (simple offline runs).**

Physiographic parameters

Solutions :

- **Databases :**
  - Land cover database ECOCLIMAP
  - Topography (e.g. Gtopo30 at 1 km or SRTM for higher resolution, from which the mean grid-cell altitude and sub-grid topography parameters are derived).
  - Soil properties (clay and sand proportions, organic matters) derived from FAO or HWSD databases.
  - Lake depth and optical water properties (Kourzeneva et al., 2011)
  - Ocean Bathymetry (e.g. Etopo2 from Smith and Sandwell (1997))
- **Ad hoc parameter list (specific cases)**

ECOCLIMAP :
A global database of surface parameters

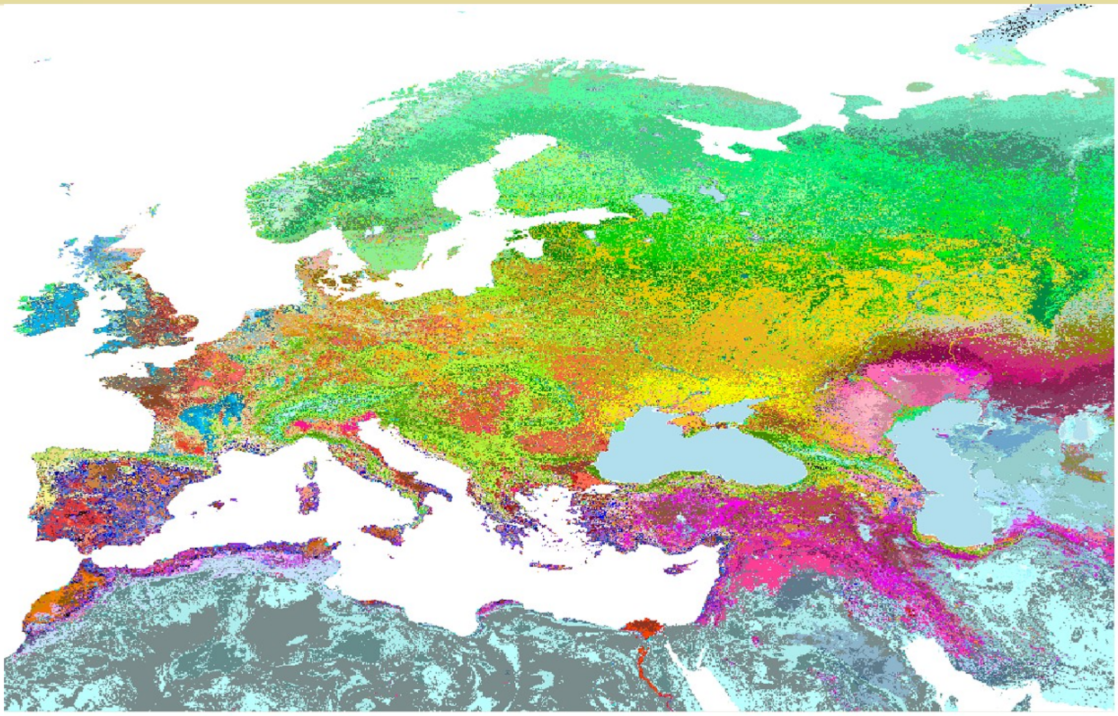
A land cover map at 1 km resolution in latlon projection
Fully coupled to SURFEX, or available separately)

ECOCLIMAP I : global (215 covers)
ECOCLIMAP II Europe (273 covers)

10-day period surface parameters: LAI, fraction of vegetation veg, roughness length, emissivity, fraction of greeness.

Constant surface parameters: visible / nir / uv albedos, minimum stomatal resistance…

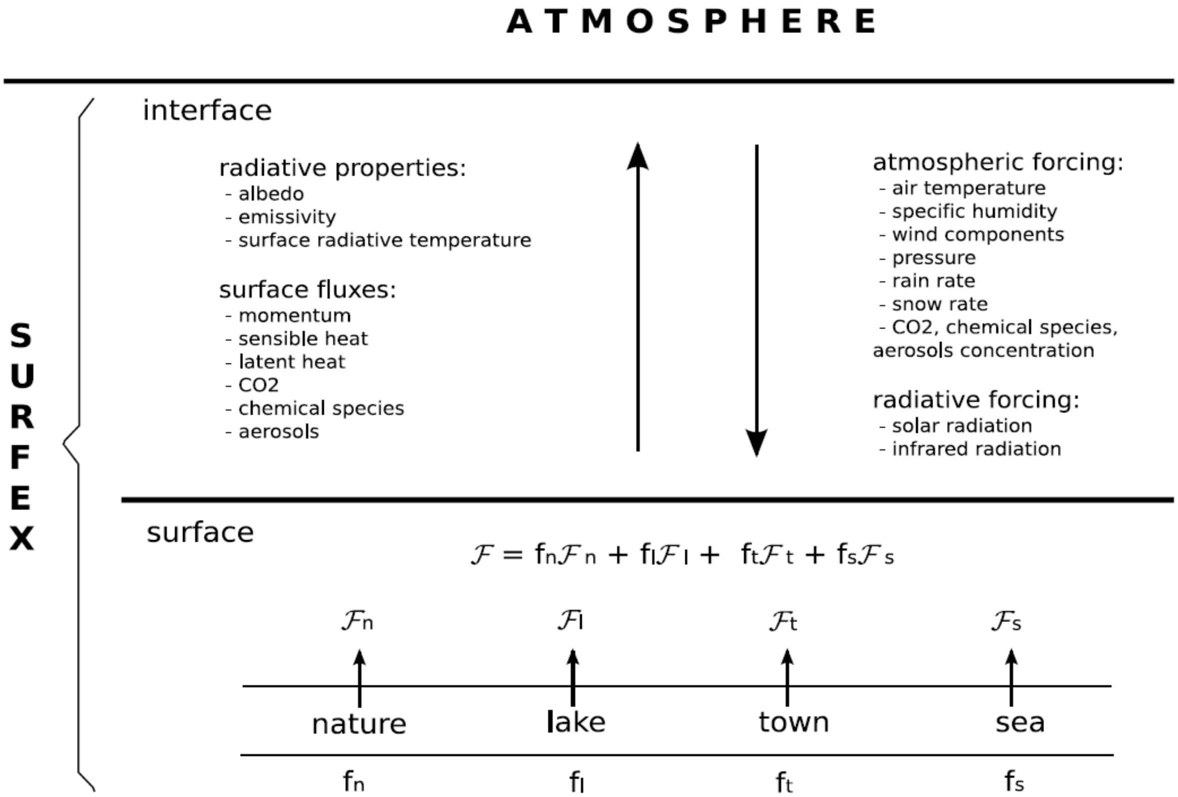
ECOCLIMAP-II Europe



ECOCLIMAPII domain

Interface with the atmosphere

Interface with the atmosphere



Coupling with the atmosphere :

Explicit coupling (general case) :

variables are provided at T (or T → T+DT)
Fluxes are returned averaged over T / T+DT

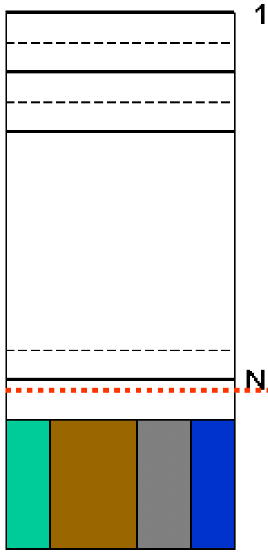
Offline : ASCII, binary, lfi, FA,
netcdf standardized interface
(ALMA, Polcher et al., 1998)

http://web.lmd.jussieu.fr/~polcher/ALMA/

Coupled mode : call coupling_surf_atm(variables…)

implicit coupling

In case of long time step to avoid instabilities in the coupling with the atmosphere. The surface is called in the middle of the vertical diffusion loop (Best et al., 2004).



Vertical diffusion
$$\begin{cases} X \equiv u, v, \theta, q \\ X_i^+ - X_i^- = -\omega_{i,i}\left(X_{i+1}^+ - X_i^+\right) + \omega_{i-1,i}\left(X_i^+ - X_{i-1}^+\right) \\ F_{X,0} = 0 \end{cases}$$

Downward sweep
$$\begin{cases} X_i^+ = A_{X,i}^- X_{i+1}^+ + B_{X,i} \\ A_{X,i} = f\left(\omega_{i-1,i}, \omega_{i,i}, A_{X,i-1}\right) \\ B_{X,i} = f\left(\omega_{i-1,i}, \omega_{i,i}, B_{X,i-1}, X_{X,i-1}\right) \end{cases}$$

Lower atmospheric level
$$X_N^+ = A_{X,N}^- F_{X,S}^+ + B_{X,N}^-$$

Surface Ts + Fluxes on each tiles, Average fluxes
$$\begin{cases} H^+ = \rho C_p V_N^- C_H^- \left(\beta_S T_S^+ - \beta_N T_N^+\right) \\ \dfrac{C_s}{\Delta t}\left(T_S^+ - T_S^-\right) = R_n^+ - H^+ - LE^+ - G^+ \end{cases}$$

Upward sweep

Interface routines

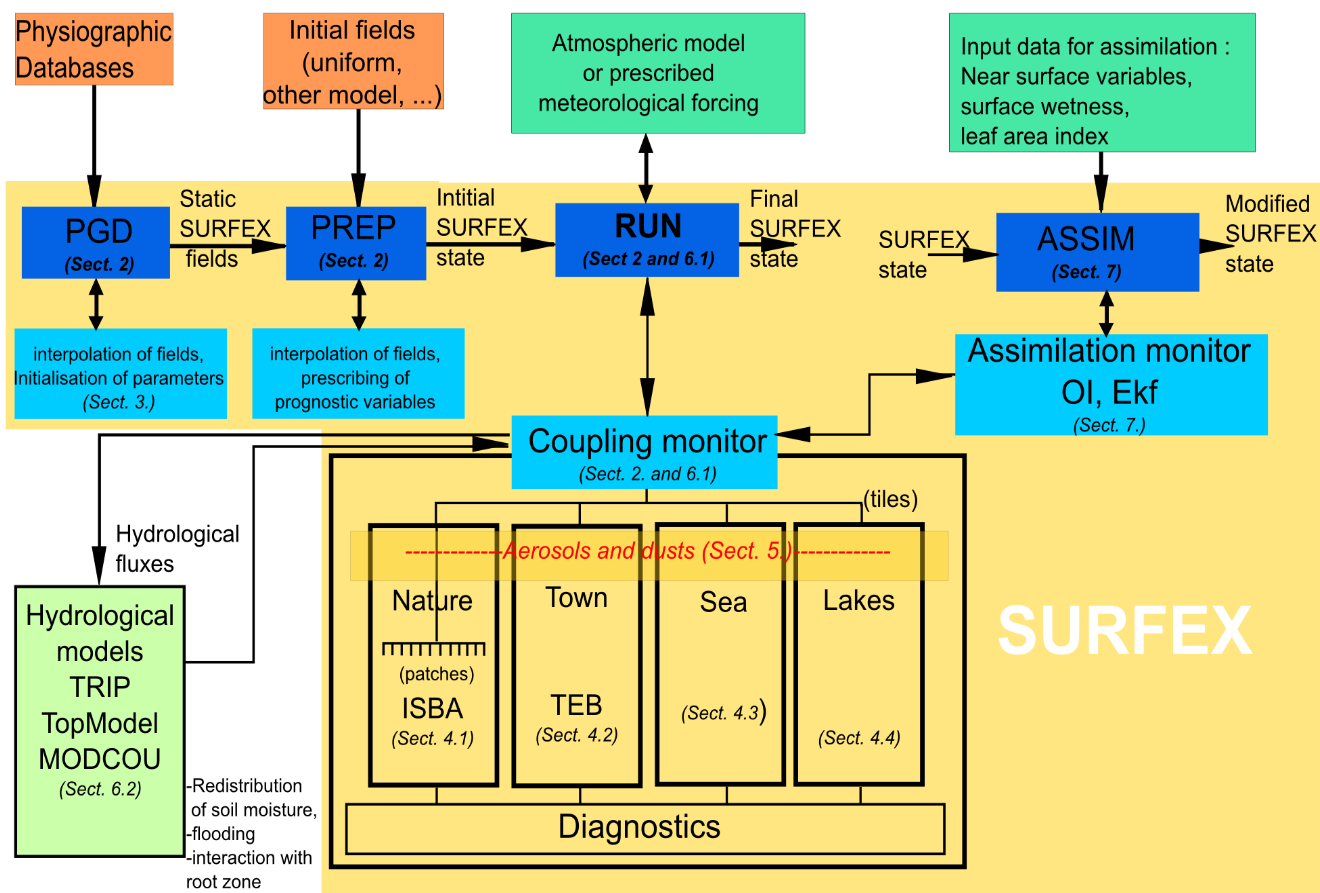
coupling_surf_atm : **packing and call 4 main tiles**

- **coupling_naturen** : **call of the chosen scheme for the tile**
- **coupling_isba_svatn** : **choice of method of coupling**
- **coupling_isba_orographyn** : **subgrid_orography**
- **coupling_isba_canopy** : **boundary layer**
- **coupling_isban** : **divide in patches, interactive vegetation , flood, dusts**

Isba : **energy and water fluxes**

All coupling_xxx have the same arguments

More practical …
Running SURFEX



Running SURFEX

PGD : Physiography
•Choice of surface schemes
•Grid
•physiography

↓

PREP : initialisation of prognostics variables

↓

RUN mode : atmospheric model, offline, ASSIM, DIAG
run and diagnostics
(need atmospheric forcing)

PGD

Surface schemes :

Ex for NATURE : NONE, FLUX, TSZ0, ISBA (and options for ISBA)

Grid :

- **Gaussian, conformal projection, LONLAT reg, IGN (French Lambert projection), NONE (namelist)**
- **A part of the grid of an already existing file**
- **Can be given in fortran argument (ignore namelists)**

Physiography :

- **Covers : ECOLIMAP or uniform**
- **Orography (GTOPO30, other files, uniform)**
- **Sand and Clay fractions (FAO, other file, uniform)**

PREP

Date of all surface schemes

File to read, or uniform variables (namelist)

RUN (offline) prognostic variables

OPTIONS for RUN :

General : general options for surface atmosphere
By scheme : options for run (e.g. : subgrid hydrology)

Run : need a PGD file, a PREP file and an atmospheric forcing

DIAG

Inside « RUN » or autonomously using a surface file and an « instantaneous » forcing.

Defined by namelist (various options)

diagnostics aggregated over all the surface, or by tiles, or by patches (nature)

ASSIM

OI_MAIN :

Soil analysis based on Optimal interpolation (Giard and Bazile, 2000, Monthly weather review)

Input : T2m, RH2m

VARASSIM :

Soil analysis based on EKF (Mahfouf et al., 2009, JGR)

Input : T2m, RH2m, wg (satellite) and/or LAI (ISBA-A-gs)

SODA (SURFEX offline data assimilation) :

New driver for OI and varassim

surfex course

Octobre 2012

S. Faroux, P. Le Moigne, E. Martin

CNRM / GMME

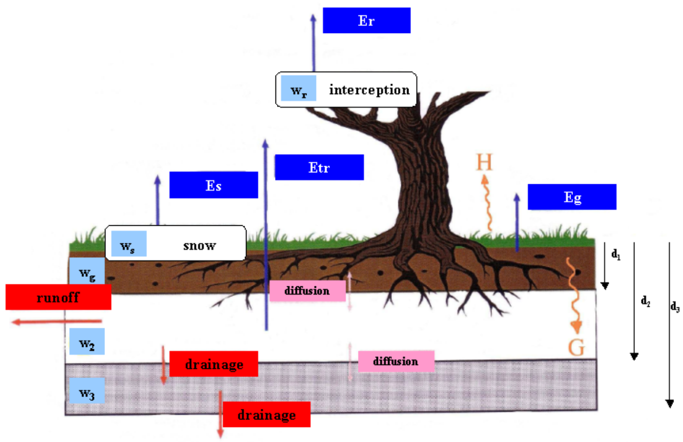
PREP

To initialize prognostic variables of models, namely : ISBA (nature), TEB (town), FLAKE et WATFLX (lakes) ou SEAFLX (sea/ocean)

$$\frac{\partial X}{\partial t} = \cdots \leftarrow \quad X(t=0)$$

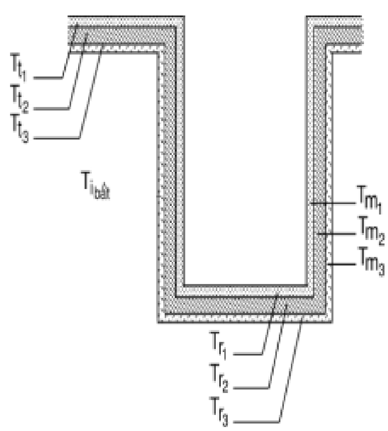
ISBA variables

- vertical profiles of T, w_l et w_i
- interception reservoir water content
- snow water equivalent, albedo, ...



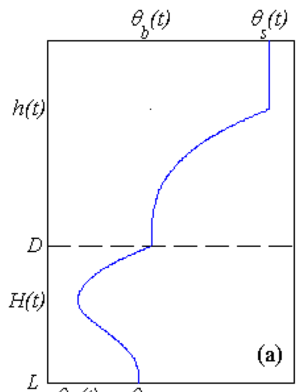
TEB variables

- roof, walls and road temperatures
- roof water content
- road water content



FLAKE variables

- surface temperature
- mixing layer depth
- lake deep temperature
- mean water temperature
- shape of profile



INITIALISATION : PREP
LAKES AND OCEANS
THE SBL MODEL
AEROSOLS

tool functionality
prognostic variables
initialization
principle
namelist
practical exercise

WATFLX/SEAFLX variables

- surface temperature

kept constant during the run

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CMO1D variables

- surface temperature
- salinity
- current
- turbulent kinetic energy

initialization

uniform initialization

values at z=0 meters height

initialization from a file

atmospheric or ocean model type :
ECMWF, ARPEGE, ALADIN, Meso-NH, MOCAGE, MERCATOR
lat lon value type :
only for some fields (T and w_l of ISBA)

principle

Isba variables

- reading of atmospheric fields
- projection on a detailed soil grid (20 layers)
- horizontal interpolations on the fine grid
- vertical interpolations on the target grid
- back to model variables

example

To initialize all prognostic variables from an ECMWF grib file, except Isba temperature and humidity profiles from external files :

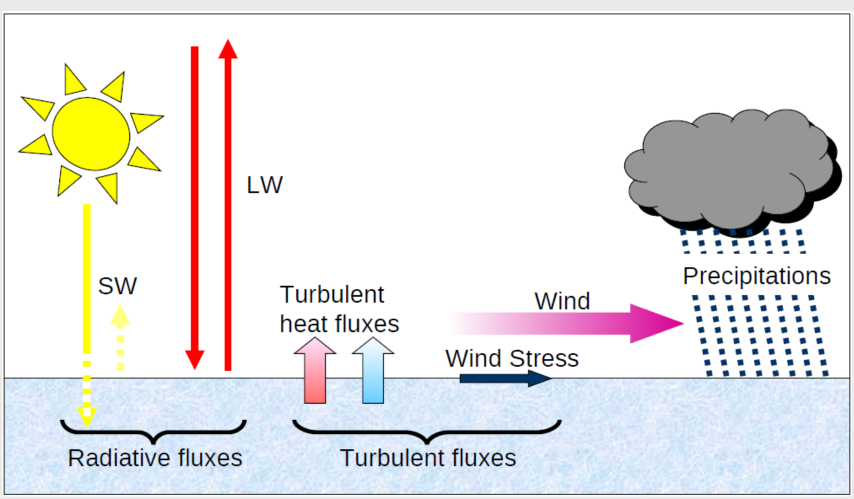
```
&NAM_PREP_SURF_ATM
CFILE='ecmwf.OD.20050526.18',CFILETYPE='GRIB ' /

&NAM_PREP_TEB
CFILE_TEB ='ecmwf.OD.20050526.18',CTYPE='GRIB ' /

&NAM_PREP_SEAFLUX
CFILE_SEAFLX='ecmwf.OD.20050526.18',CTYPE='GRIB ' /

&NAM_PREP_WATFLUX
CFILE_WATFLX='ecmwf.OD.20050526.18',CTYPE='GRIB ' /

&NAM_PREP_ISBA
CFILE_ISBA ='ecmwf.OD.20050526.18',CTYPE='GRIB ' ,
CFILE_HUG_SURF = 'SWI1_SIM_2005052618_ALL' ,
CFILE_HUG_ROOT = 'SWI2_SIM_2005052618_ALL' ,
CFILE_HUG_DEEP = 'SWI3_SIM_2005052618_ALL' ,
CFILE_TG_SURF = 'TG1_SIM_2005052618_ALL' ,
CFILE_TG_ROOT = 'TG2_SIM_2005052618_ALL' ,
CFILE_TG_DEEP = 'TG3_SIM_2005052618_ALL' ,
CTYPE_HUG = 'ASCLLV', CTYPE_TG = 'ASCLLV' /
```

practical exercise

subject available on training course web page

Lakes/Oceans

air-water exchanges



surface fluxes

Bulk method

surface turbulent fluxes are related to gradients of meteorological variables by a set of exchange coefficients that depend on the atmosphere stratification :

$$Q_{mom} = \rho \cdot \overline{w'U'} \qquad Q_{sen} = \rho \cdot C_p \cdot \overline{w'\theta'} \qquad Q_{lat} = \rho \cdot L_v \cdot \overline{w'q'}$$

$$\overline{w'\eta'} = -C_\eta \cdot \Delta U \cdot \Delta \eta$$

surface fluxes

kinematic fluxes

kinematic fluxes can be expressed through the caracteristic scales u_*, θ_* and q_* as follows :

$$\overline{w'U'} = -{u_*}^2 = -C_D \cdot (\Delta U)^2$$

$$\overline{w'\theta'} = -u_* \cdot \theta_* = -C_H \cdot \Delta U \cdot \Delta \theta$$

$$\overline{w'q'} = -u_* \cdot q_* = -C_E \cdot \Delta U \cdot \Delta q$$

exchange coefficients

the goal is equivalent to calculating C_D, C_H and C_E coefficients to know surface fluxes

direct approch

- from atmosphere stability (R_I), one deduces C_D for a given z_0 of 10^{-3}
- then u_* and Q_{mom}
- Charnock approach gives : $z_0 = 0.015\frac{{u_*}^2}{g}$
- one can then deduce C_H et C_E
- and finally Q_{sen} and Q_{lat} knowing the water surface temperature, maintained constant during the run

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FLake lake model

exchange coefficients

iterative approch

based on the iterative computation of u_*, θ_* and q_*

ECUME on sea/ocean

neutral exchange coefficients are calibrated according to the 10m wind speed measured during field campaigns (Pomme, Equalant, Albatros, ...)

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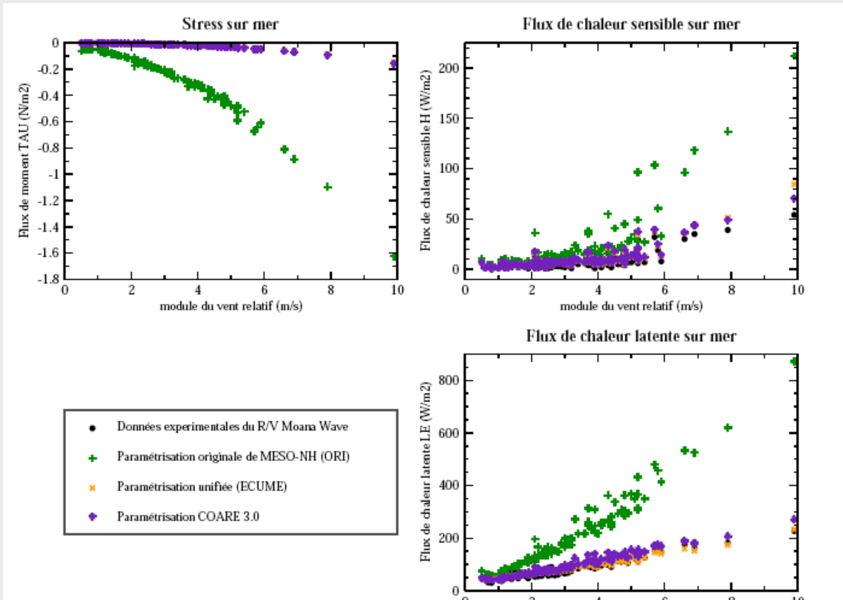
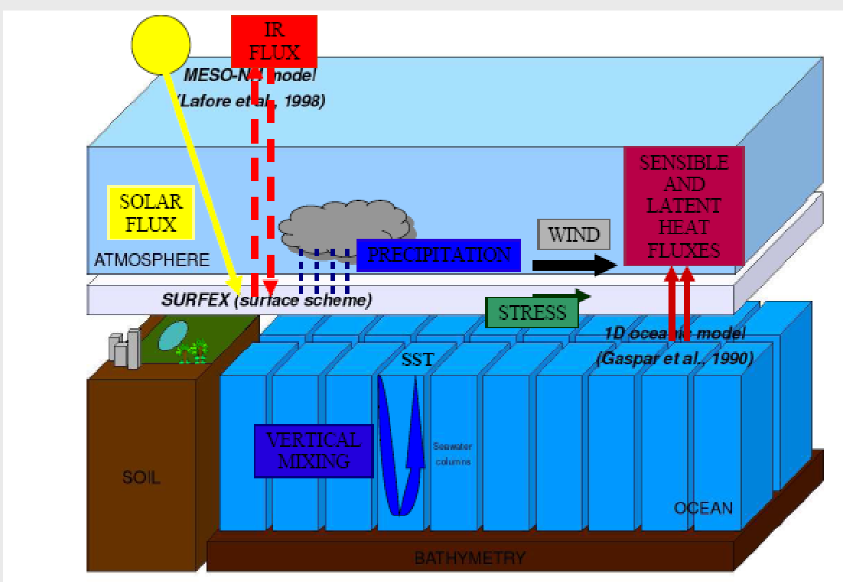
ECUME

impact on fluxes



sea/oceans

1D-Ocean Mixed Layer model



model equations (1)

a variable is decomposed into mean + fluctuation

$$\alpha = \bar{\alpha} + \alpha' \quad ; \quad \textit{temperature } T, \ \textit{salinity } S, \ \textit{currant } \vec{u}, \textit{TKE } e$$

equations

$$\frac{\partial T}{\partial t} = \frac{F_{sol}}{\rho_0 C_p}\frac{\partial I(z)}{\partial z} - \frac{\partial \overline{w'T'}}{\partial z}$$

$$\frac{\partial S}{\partial t} = -\frac{\partial \overline{w'S'}}{\partial z}$$

$$\frac{\partial u}{\partial t} = fv - \frac{\partial \overline{w'u'}}{\partial z}$$

$$\frac{\partial v}{\partial t} = -fu - \frac{\partial \overline{w'v'}}{\partial z}$$

upper boundary condition

$$\overline{w'T'}(0) = -(Q_{sen} + Q_{lat} + F_{IR})/(\rho_0 C_p)$$

$$\overline{w'S'}(0) = (P - Evap)/(\rho_0 C_p)$$

$$\overline{w'u'}(0) = -\tau_u/(\rho_0 C_p)$$

$$\overline{w'v'}(0) = -\tau_v/(\rho_0 C_p)$$

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model equations (2)

system closure

$$\overline{w'T'} = -K \cdot \frac{\partial \overline{T}}{\partial z}$$

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

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

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

diffusivity coefficient

$$K = c_k \cdot l_k \cdot \overline{e}^{1/2}$$

turbulent kinetic energy : $e = \frac{1}{2}(u'^2 + v'^2 + w'^2)$

$$\frac{\partial \overline{e}}{\partial t} = -\frac{\partial}{\partial z}\left(\overline{w'e} + \frac{1}{\rho_0}\overline{w'p'}\right) - \left(\overline{w'u'}\frac{\partial \overline{u}}{\partial z} + \overline{w'v'}\frac{\partial \overline{v}}{\partial z}\right) + \overline{b'w'} - \epsilon$$

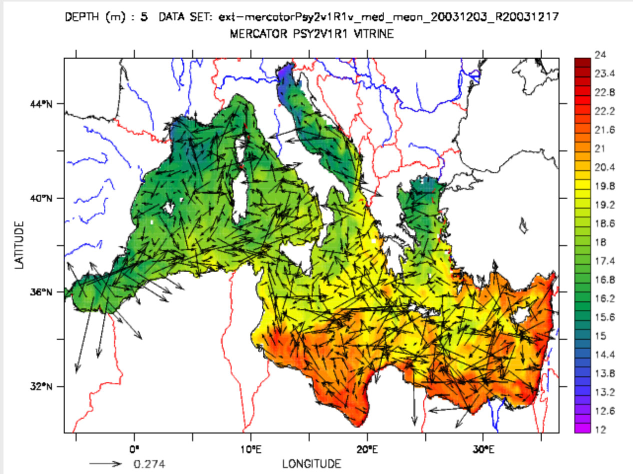
$$-\frac{\partial}{\partial z}\left(\overline{w'e} + \frac{1}{\rho_0}\overline{w'p'}\right) = -K_e \cdot \frac{\partial \overline{e}}{\partial z}$$

$$K_e = c_\epsilon \cdot l_\epsilon \cdot \overline{e}^{1/2}$$

$$b = \frac{g}{\rho_0}(\rho - \rho_0) \qquad \rho = \rho(T, S)$$

$$\epsilon = c_\epsilon \cdot l_\epsilon \cdot \overline{e}^{3/2}$$

temperature initialization



temperature (degC) and current (m/s)

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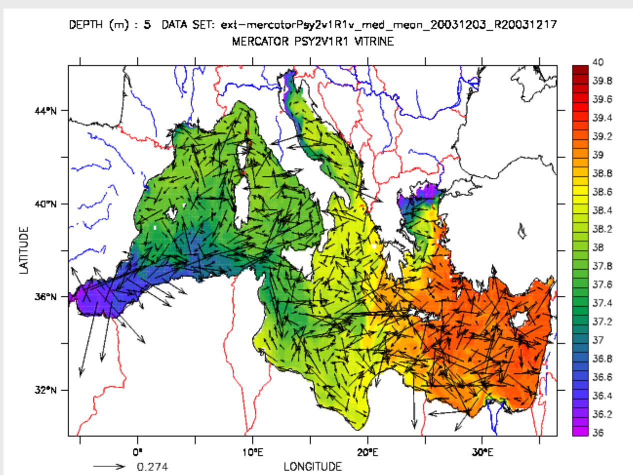
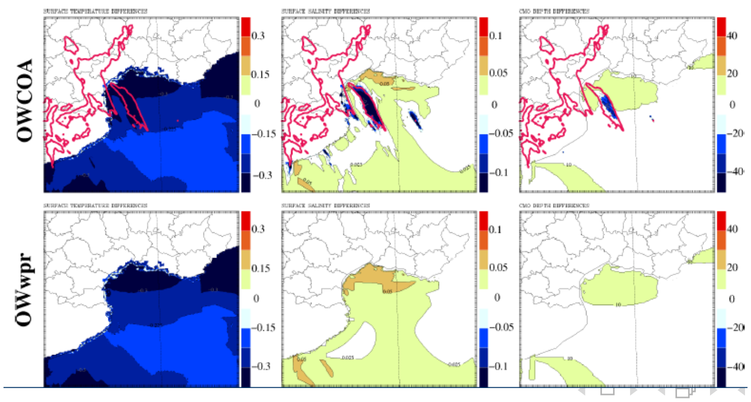
salinity initialization



salinity (degC) and current (m/s)

response to heavy rainfall : Aude November, 12, 1999 at 21TU

- freshwater supply
- decrease of salinity
- increase of stratification
- lower temperature



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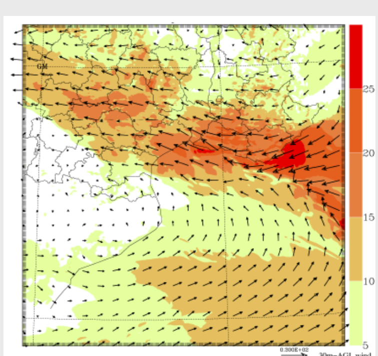
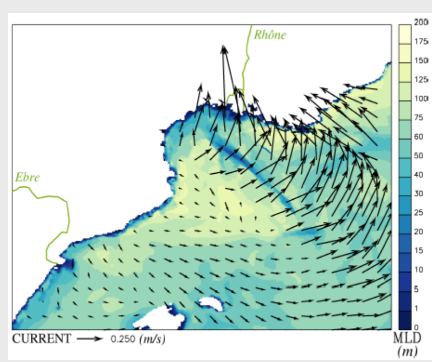
response to a strong jet

Hérault case : Decembre, 4, 2003 at 00TU

- eastern wind (Rhône delta)
- creation of a surface current
- potential perturbation of the river runoff

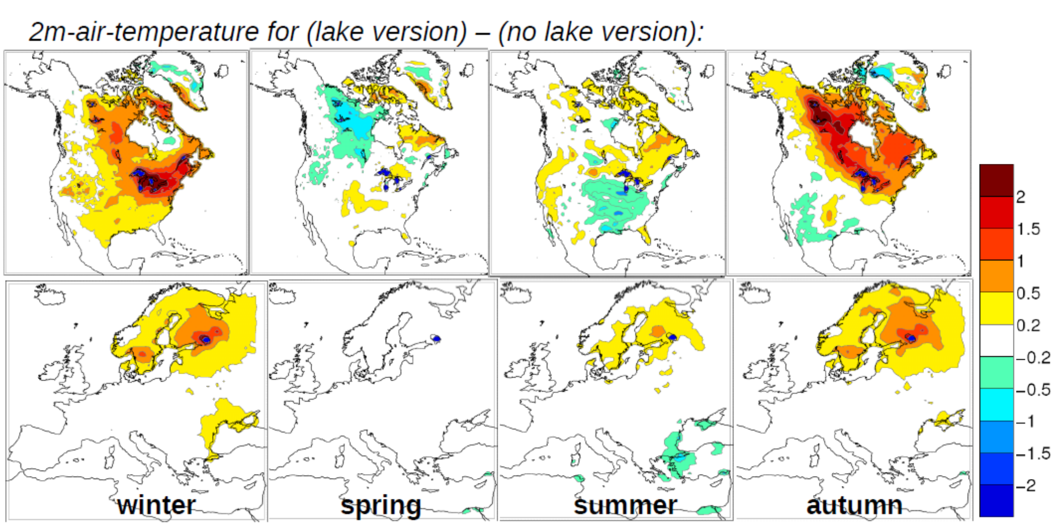




Why focus on lakes ?

- a lake can affect the boundary layer structure and therefore the sensible weather
- it depends on its size, shape and on the meteorological situation
- lake coverage is large in boreal regions or in the american Great lakes region (for example)

impact in a climate model

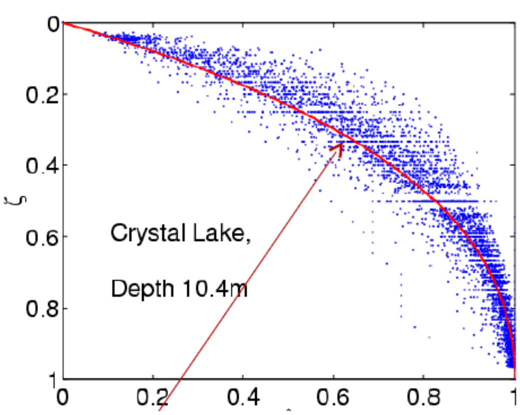


- 3D-models are detailed but too expensive (CPU)
- multi-layer 1D-models : expensive
- one-layer 1D-model : big errors (never stratified)
- FLake : 2-layers 1D-model
  - vertical profile is parameterized
  - low CPU cost
  - realistic physics

"self-similarity" concept

temperature profile in the thermocline can be parameterized by a universal function of the depth (adimentionned), 4th order polynomial

$$\Phi(\zeta) = \frac{\theta_s(t) - \theta(z,t)}{\Delta\theta(t)} \quad ; \quad \zeta = \frac{z - h(t)}{\Delta h(t)}$$

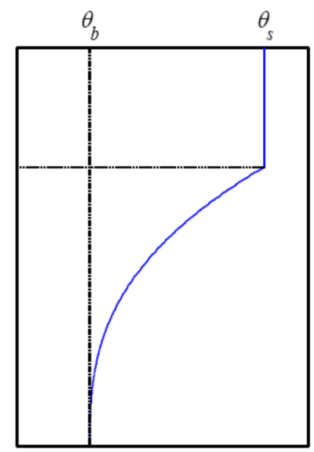


$\theta(z,t) = \theta_s(t)$ *in the mixed layer*

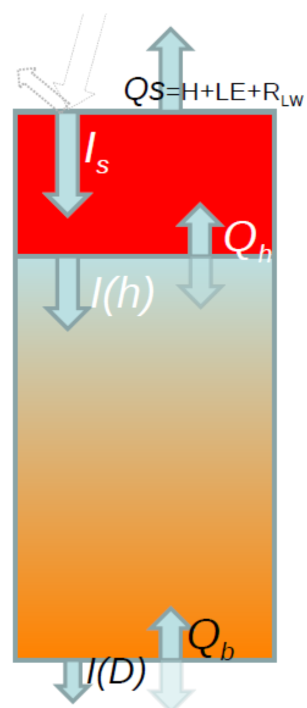
$\theta(z,t) = \theta_s(t) - (\theta_s(t) - \theta_b(t))\Phi(\zeta)$ *in the thermocline*

- temperatures θ_s, θ_b
- thickness of the mixed layer h
- $C_T = \int_0^1 \Phi(\zeta) d\zeta$
- mean temperature $\overline{\theta}$

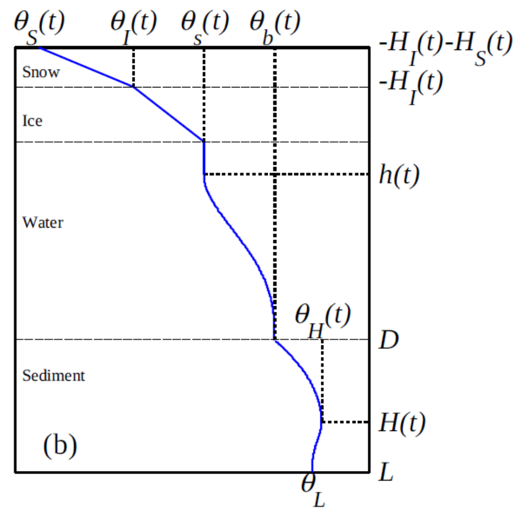
$$\overline{\theta} = \theta_s - C_T(1 - \frac{h}{D})(\theta_s - \theta_b)$$



- conservation of the total energy :
  $\rho_w c_w D \frac{d\overline{\theta}}{dt} = Q_s - Q_b + I_s - I(D)$
- conservation of the mixed layer
  $\rho_w c_w h \frac{d\theta_s}{dt} = Q_s - Q_h + I_s - I(h)$
- h evolution : computed by accounting for convective and stable regimes
- C_T evolution : computed by a relaxation equation with caracteristic time being proportionnal to $(D-h)^2$



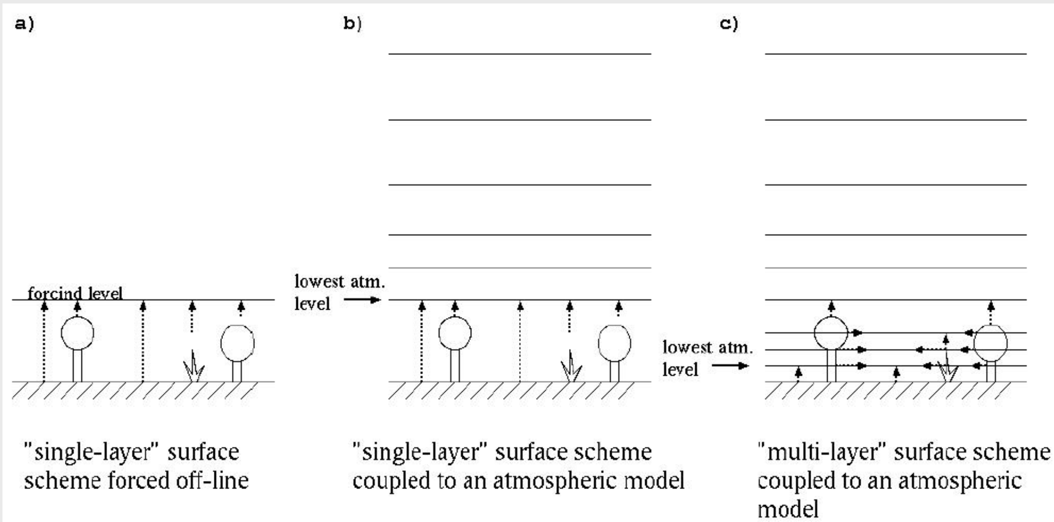
- sediments module
- surface freezing
- snow on ice



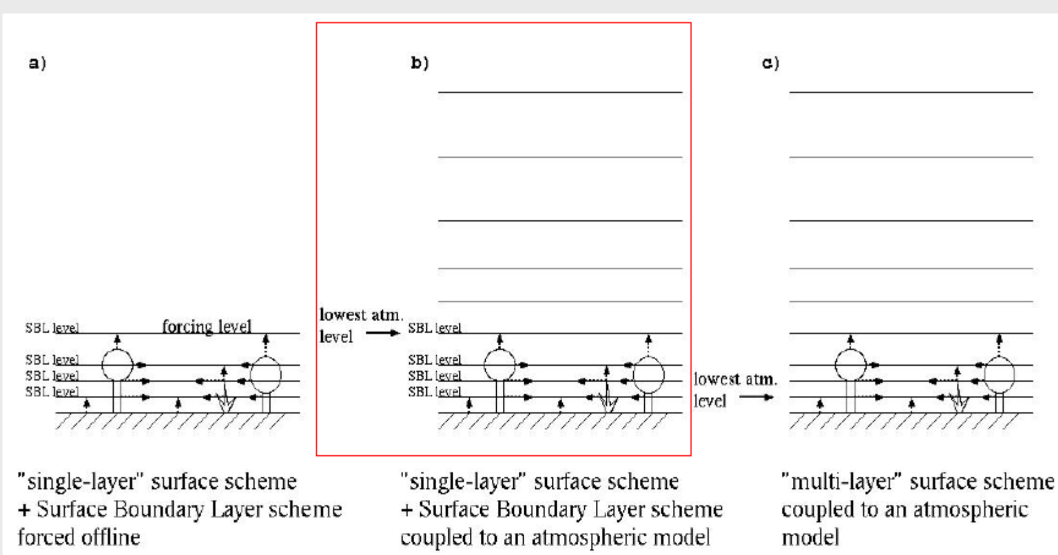
SBL : a surface boundary layer model for urban areas

- in atmospheric models, urban schemes are multi-layers or single-layer
- single-layer schemes are generally efficient
- multi-layers schemes better describe the air in the canyon. But their implementation rely very complex.
- SBL scheme is efficient and easy to implement

the different schemes



SBL scheme



SBL assumptions

That of a classical surface boundary layer :

- mean wind direction does not vary in the surface layer
- turbulent transport and advection of TKE are small as compared as the others terms
- constant flux layer above the canopy
- large scale forcing are uniform with height

principle of SBL

- takes into account the effects of obstacles in the grid cell : large-scale forcing, introduction of a drag force (deceleration of streamflow), heating/cooling, drying/moistening and small-scale TKE production.

$$\frac{\partial U}{\partial t} = \frac{\partial U}{\partial t}(z_a) + Turb(U) + Drag(U)$$

$$\frac{\partial \theta}{\partial t} = \frac{\partial \theta}{\partial t}(z_a) + Turb(\theta) + \frac{\partial \theta}{\partial t}$$

$$\frac{\partial q}{\partial t} = \frac{\partial q}{\partial t}(z_a) + Turb(q) + \frac{\partial q}{\partial t}$$

$$\frac{\partial ECT}{\partial t} = Prod\_Dyn + Prod\_Therm + Dissip + \frac{\partial ECT}{\partial t}$$

Boundary conditions are determined by the forcing layer and the suafec turbulent fluxes computed by Surfex

activation

- activation during PREP step :

```
&NAM_PREP_ISBA
        LISBA_CANOPY = T /
&NAM_PREP_TEB
        LTEB_CANOPY = T /
&NAM_PREP_WATFLUX
        LWAT_SBL = T /
&NAM_PREP_SEAFLUX
        LSEA_SBL = T /
```

- the model output is U, θ, q, TKE for the 6 extra-layers

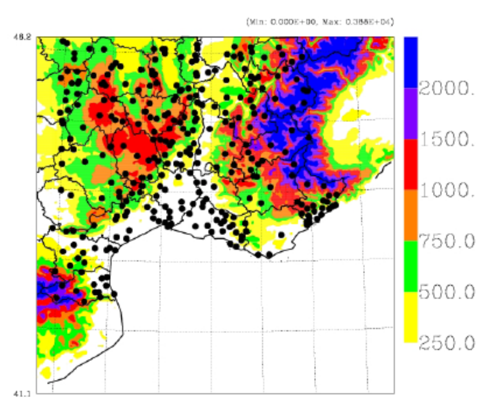
- T_{2m} is forecasted by the model and isn't diagnostic anymore
- surface fluxes are modified

validation of SBL in Arome

Use of SBL scheme above vegetation

Arome simulations

- south-east of France
- lower atm. 17m
- 5 extra-layers



validation of SBL with Arome

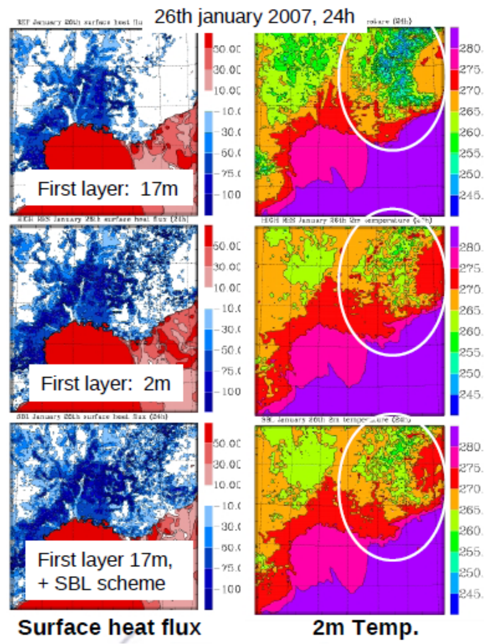
Masson and Seity, 2009, JAMC, 48, 7, 1377-1397

simulations Arome

- lower atm. layer 17m + veg. scheme
- lower atm. layer 2m + veg. scheme
- lower atm. layer 17m + veg. scheme + SBL

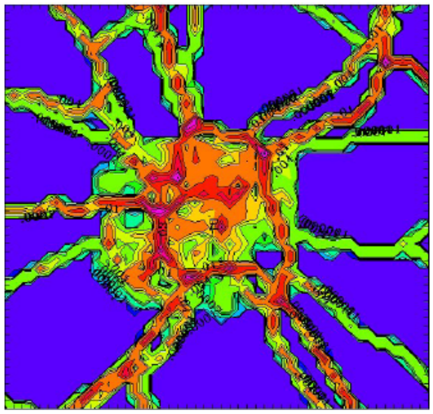
SBL is as good as high resolution

- better coupling sfc/atm at night
- sensible heat fluxes more negatives
- coherent temperature fields



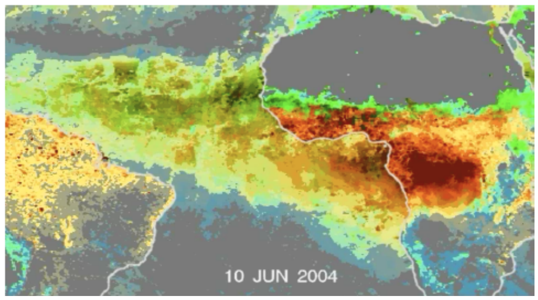
anthropic chemical emission

- independent of meteorological conditions : traffic, industrial activity
- emission cadastre : NOx fluxes over Toulouse



aerosols natural emission

- depends on meteorological conditions and surface properties
- desert aerosols, sea salt, biogenic fluxes

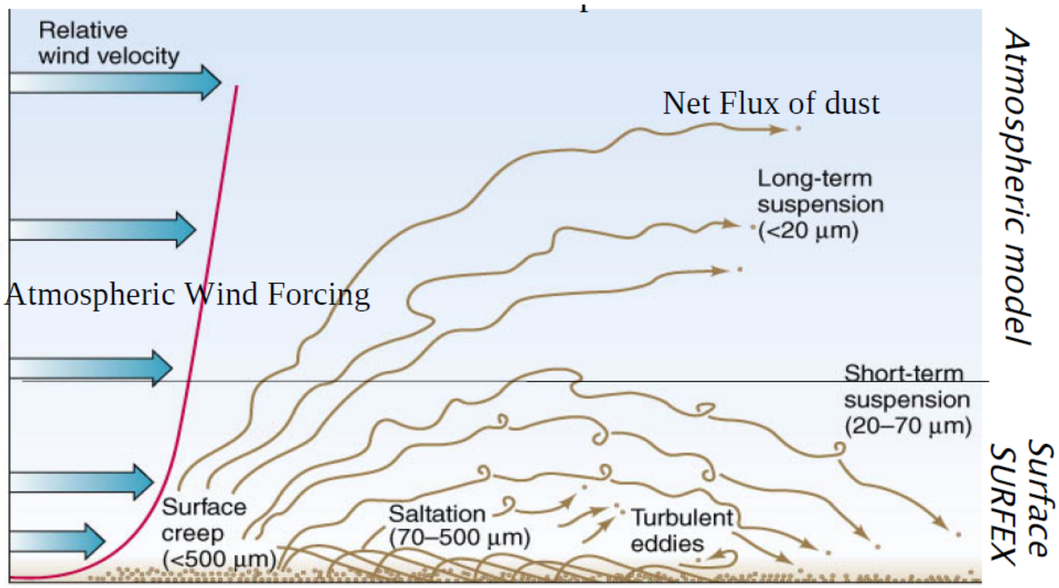


dust observed by MODIS

dust production

- threshold $u_* = 0.2m/s$
- saltation : horizontal mouvement of particules in a turbulent layer close to the surface
- sandblasting : bombardment of surface aggregates by particles in saltation and production of fines particules : desert aerosols

schematic diagram



DEAD model

modelling dust emissions

- computation of dry soil erosion threshold ${u_*}^d$ (fct of ρ, D, particules) Marticorena and Bergametti, 1995
- accounting for soil humidity :

$$w < w' \; : \; {u_*}^w = {u_*}^d$$

$$w > w' \; : \; {u_*}^w = {u_*}^d \cdot \left(1 + 1.21(w - w')^{0.68}\right)^{1/2}$$

w' depends on soil texture (%argile) Fecan et al., 1999

DEAD model

modelling dust emissions

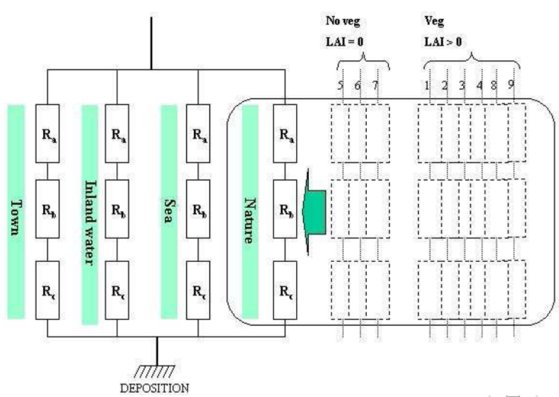
- impact of roughness on ${u_*}^d$ Marticorena and Bergametti, 1995
- computation of the surface horizontal flux F_h : White, 1979
- computation of the dust vertical flux F_v :
  $F_v = \alpha \cdot F_h$ α depends on %argile

dry deposition

- parameterization of dry deposition for gaz and aerosols at surface by turbulent transfer
- gaz caracteristics to know : solubility, molecular mass
- parameterization of deposition with the deposition speed $v_d = -\frac{F_c}{c(z)}$

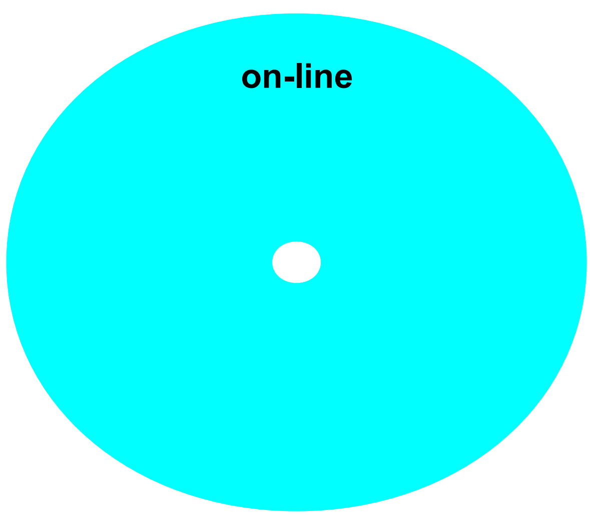
$$v_d = (R_a + R_b + R_c)^{-1}$$

R_a : aerodynamical resistance, R_b : quasi-laminar resistance et R_c surface resistance

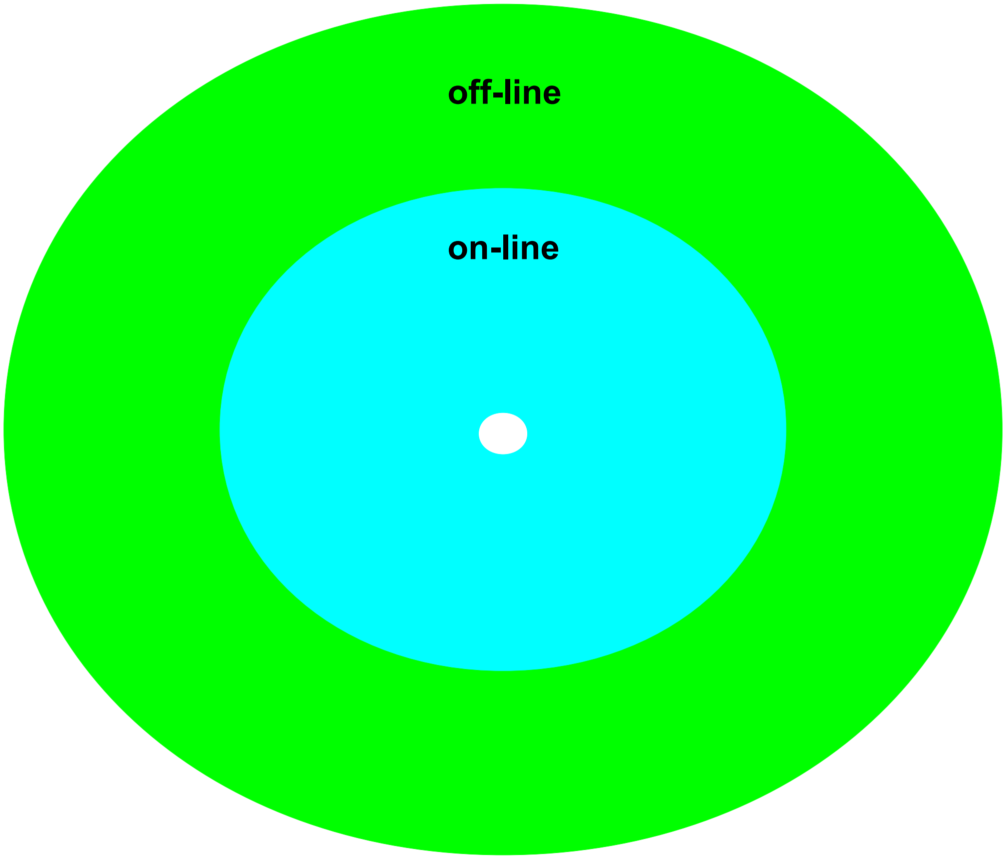


SURFEX applications

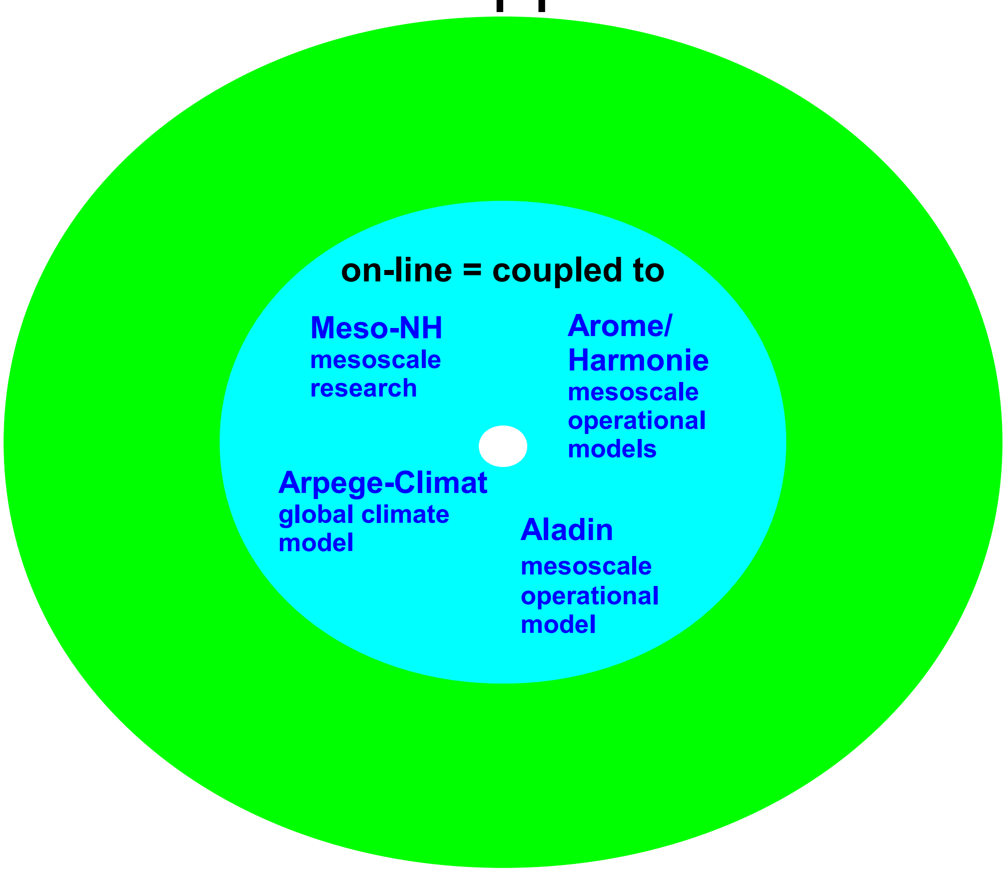
SURFEX applications



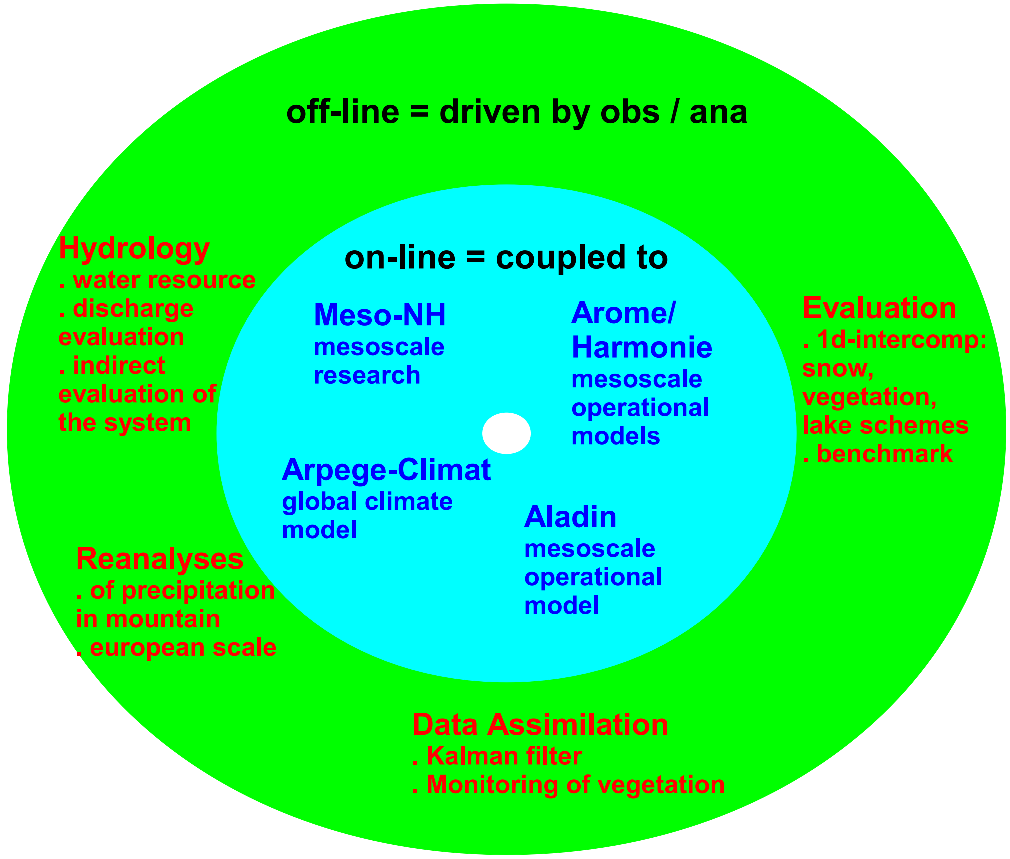
SURFEX applications



SURFEX applications

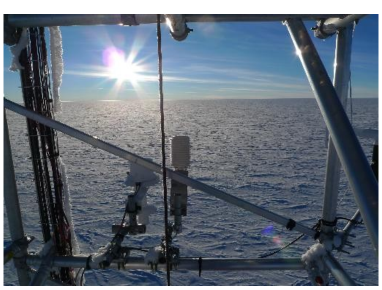


SURFEX applications

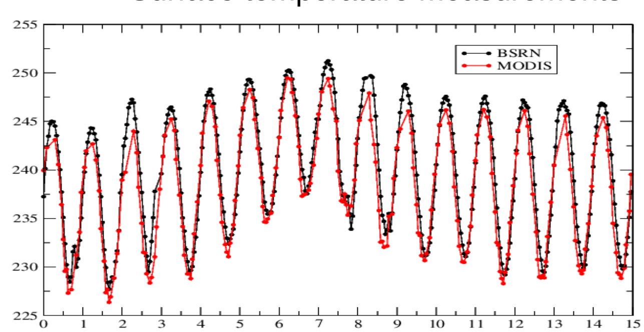


Inter-comparison of snow models: GABLS4 experiment

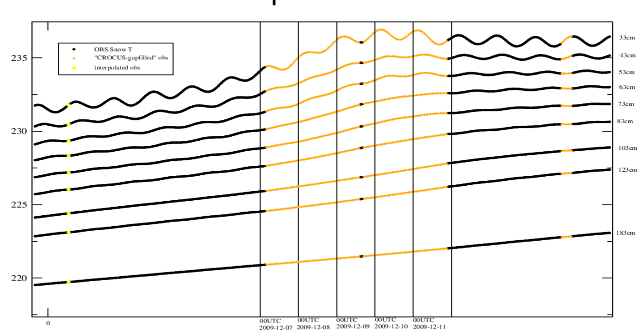
DomeC Antarctica



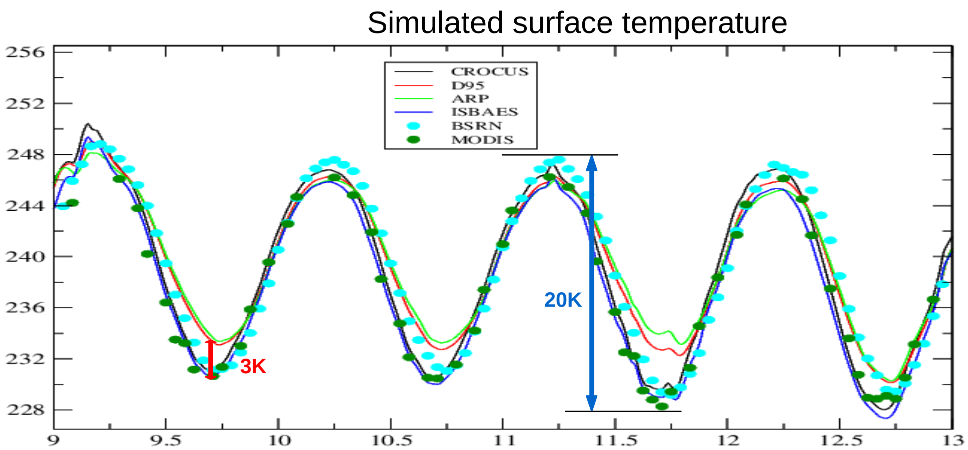
Surface temperature measurements

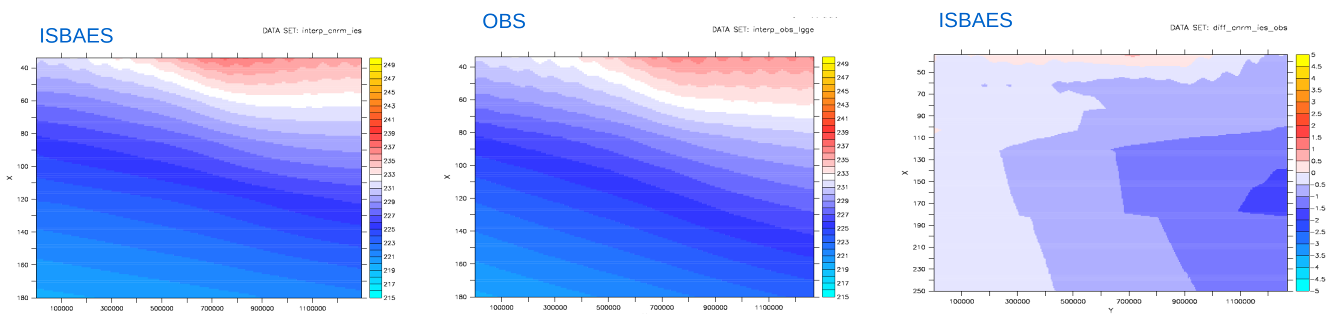


Snow temperature measurements



Inter-comparison of snow models: GABLS4 experiment

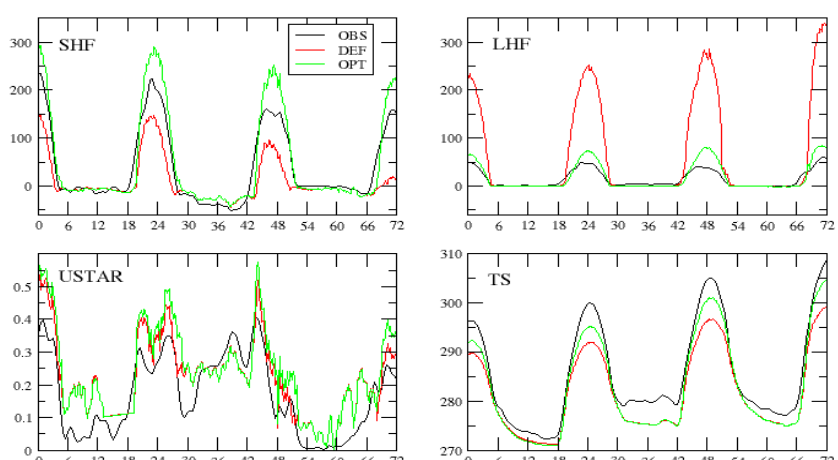




Inter-comparison of vegetation models: DICE experiment

American Great Plains

DEF crops and grassland
veg fraction = 0.81
root depth=1.5m
total depth=2.0m
initial SWI = 0.60

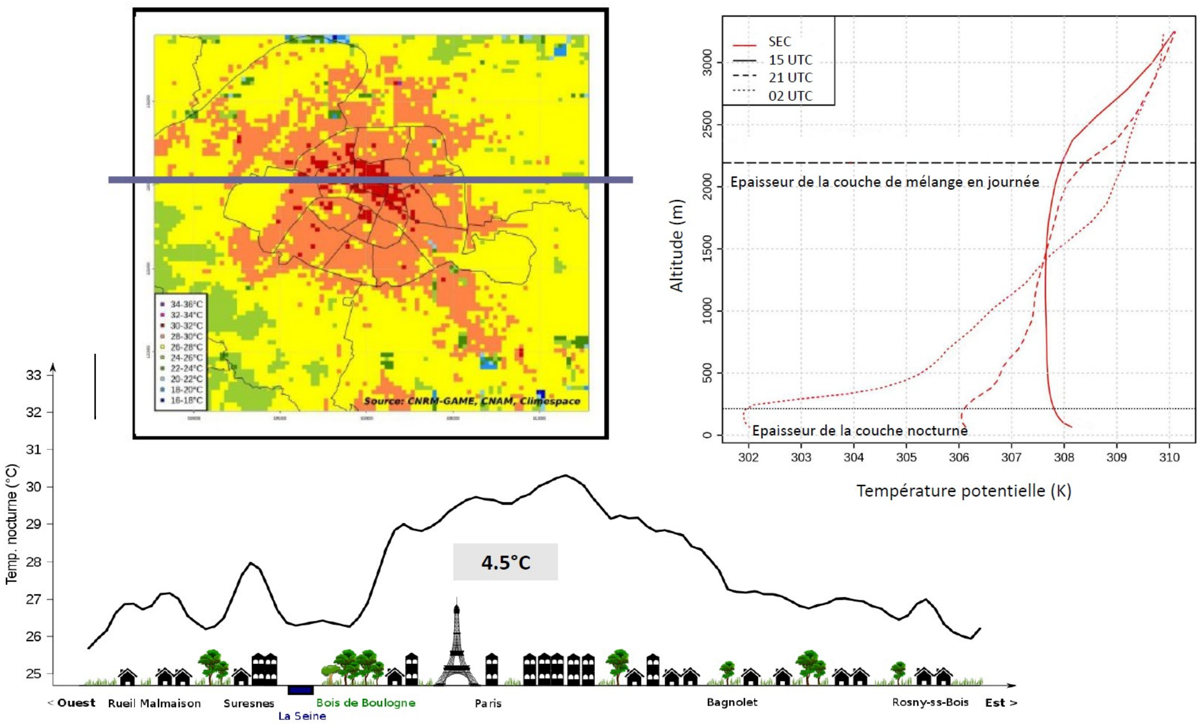


OPT grassland
veg fraction = 0.95
root depth=0.4m
total depth=0.6m
initial SWI = 0.26

TEB model dedicated to urban areas

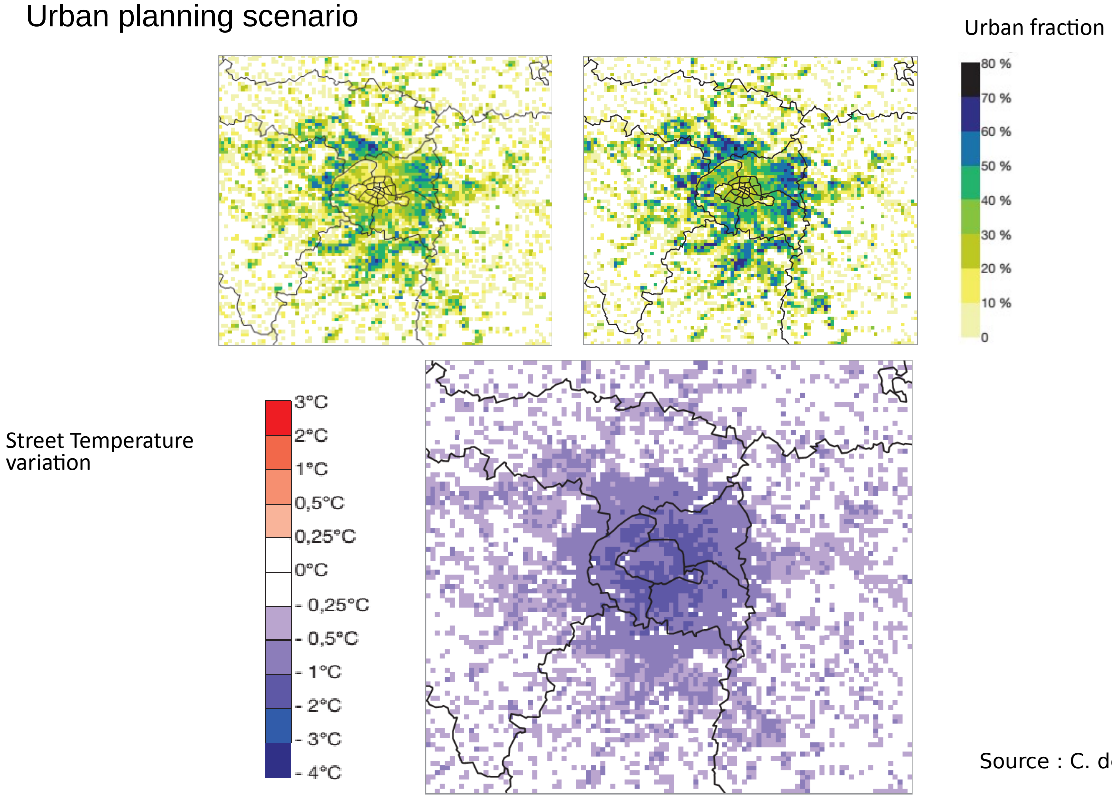
Urban Heat Island

Impact on PBL



TEB model dedicated to urban areas

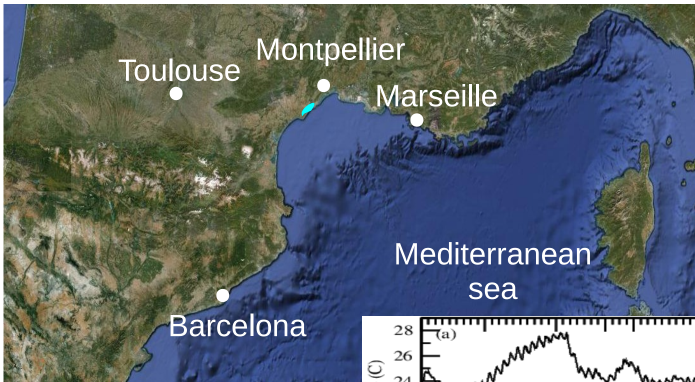
Urban planning scenario

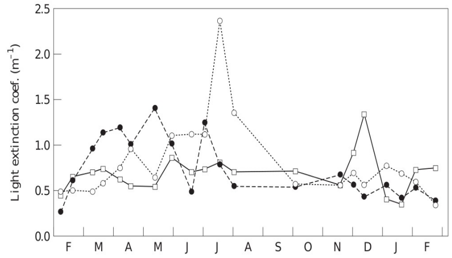


Source : C. de Munck

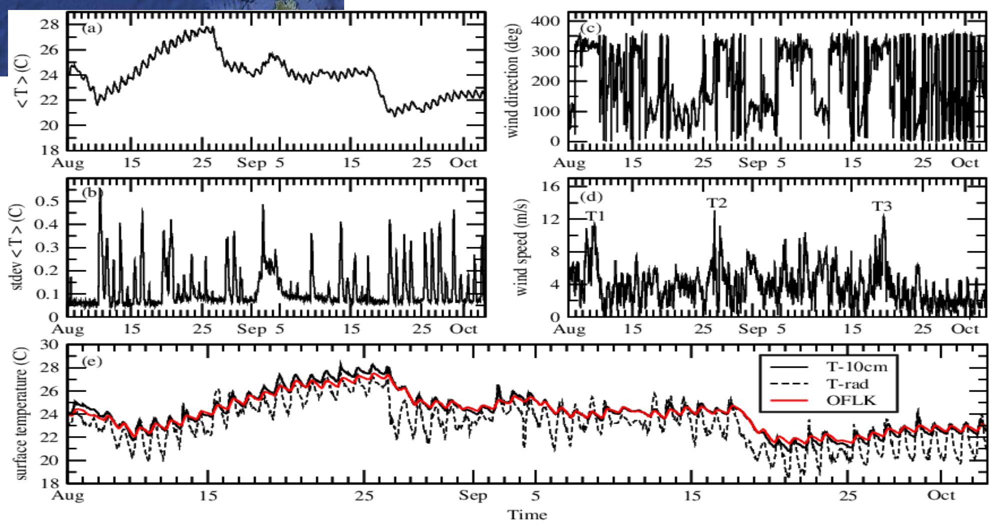
Evaluation of the lake model

Thau Lagoon in south France

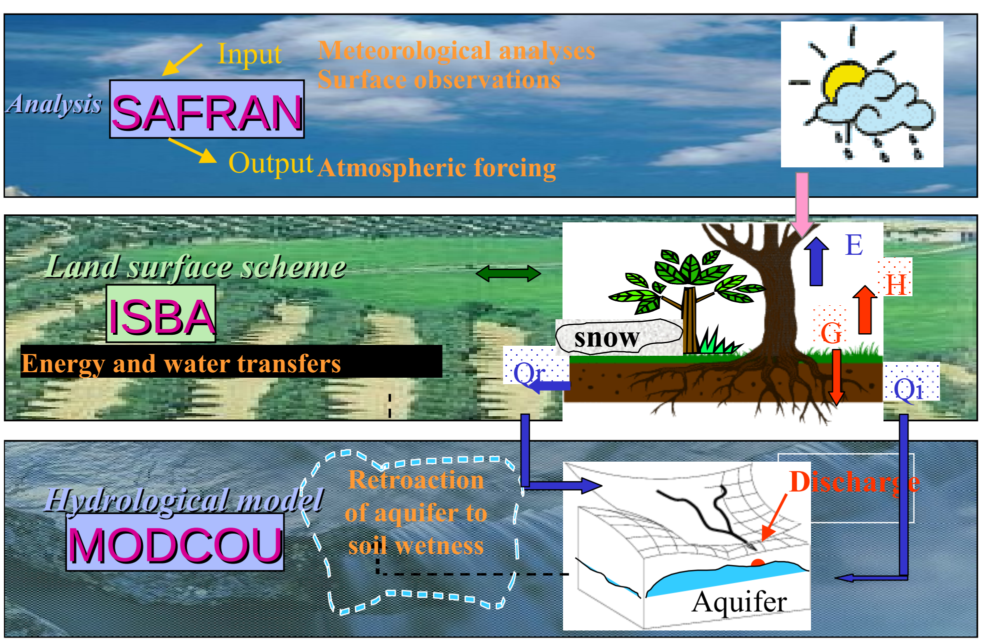




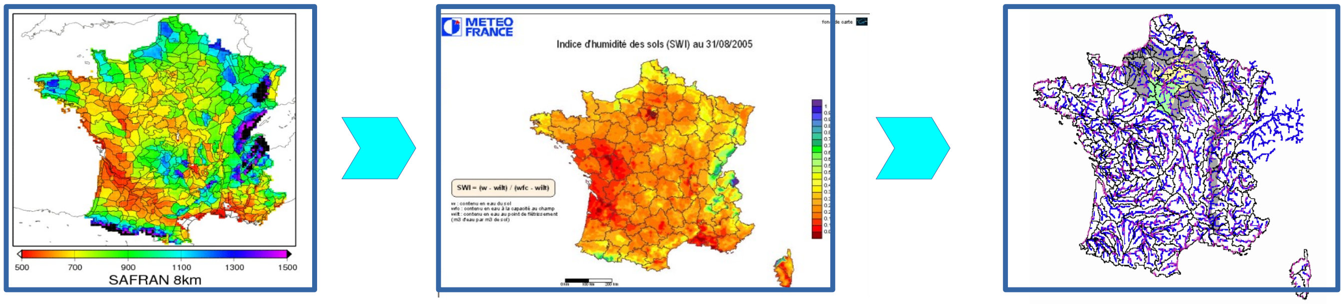
2,5 month field campaign
Depth=4m



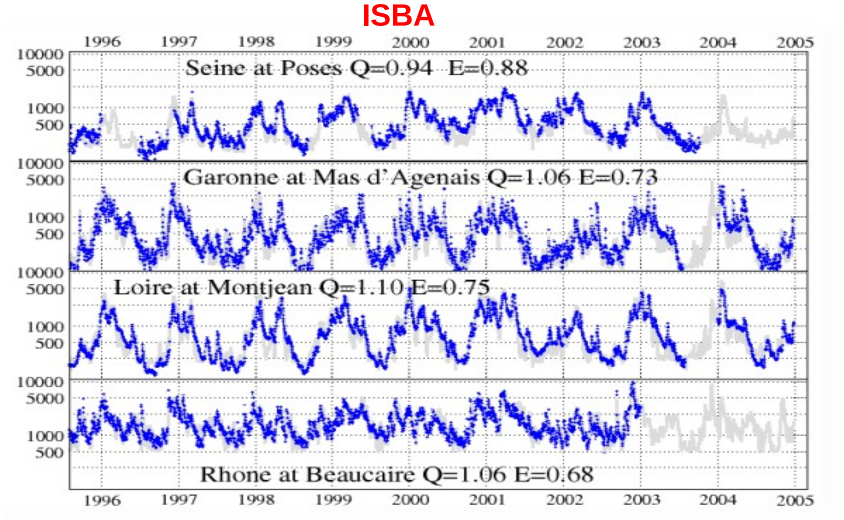
Hydrologic suite SIM



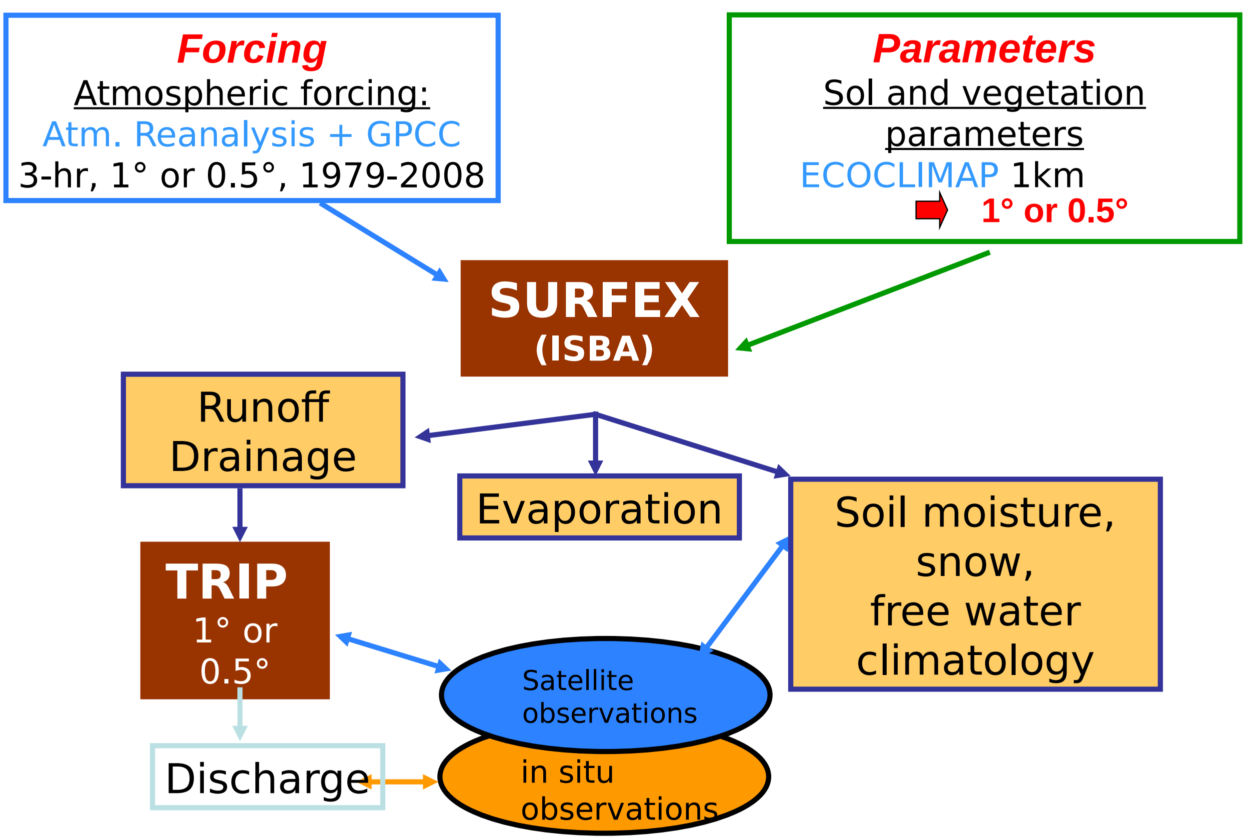
Hydrologic suite SIM



SAFRAN ISBA MODCOU

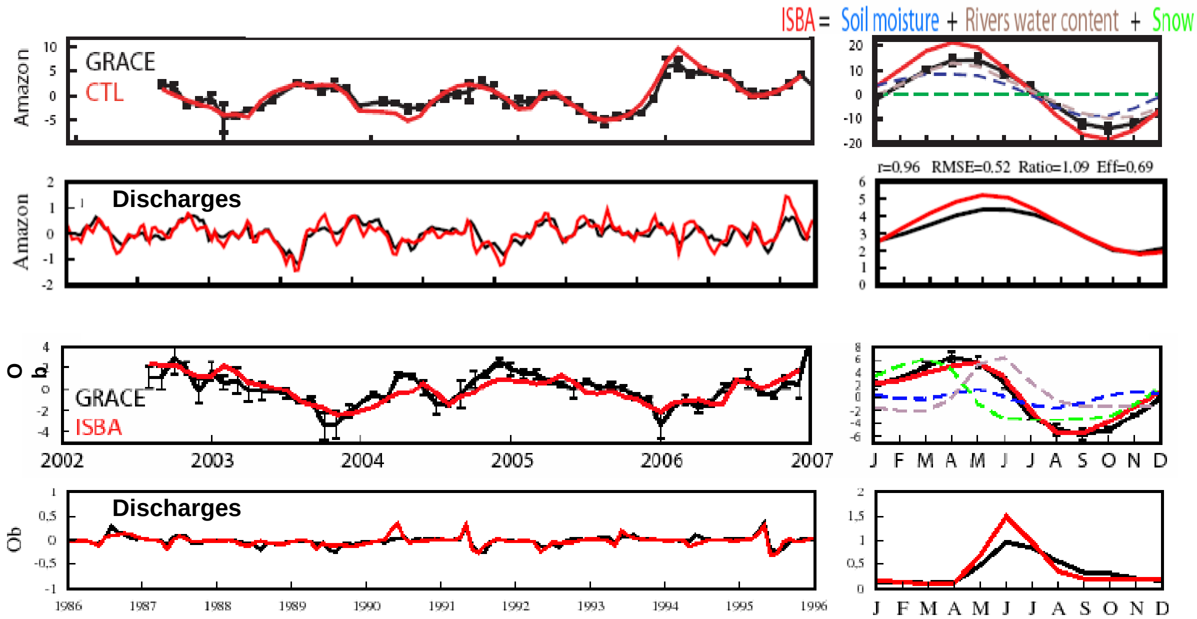


Hydrologic suite SURFEX-TRIP



Hydrologic suite SURFEX-TRIP

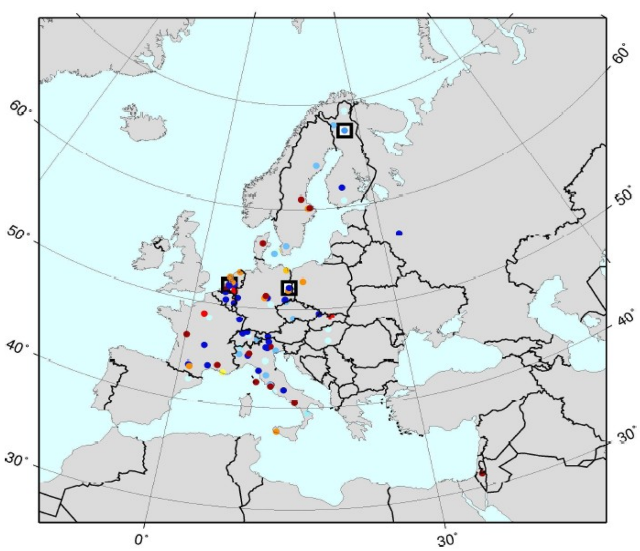
Interannual variability — *Annual*

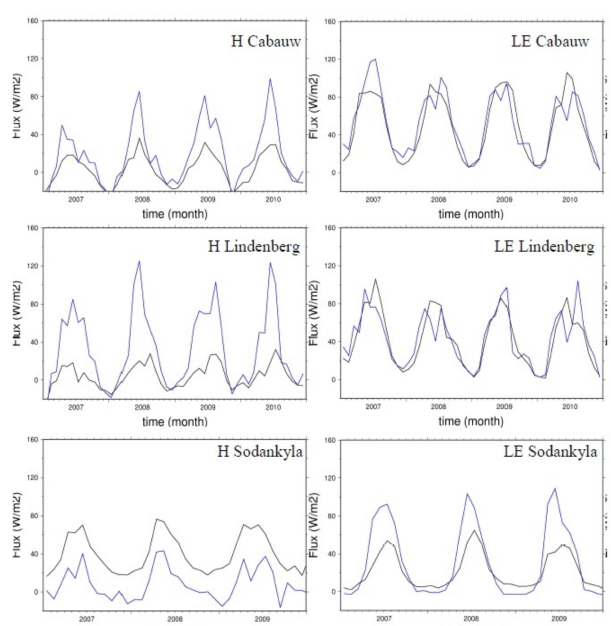


(Alkama et al. 2010, J. Hydrometeorology)

Continental surfaces reanalyses

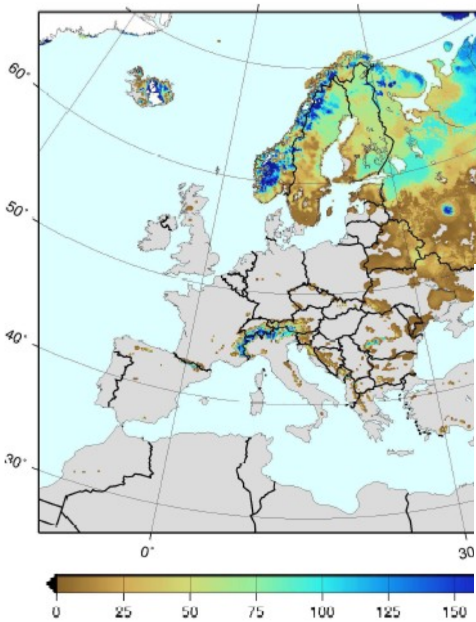
Sensible Heat Flux FLUXNET sites





Continental surfaces reanalyses

Snow Depth



Results at Sodankyla

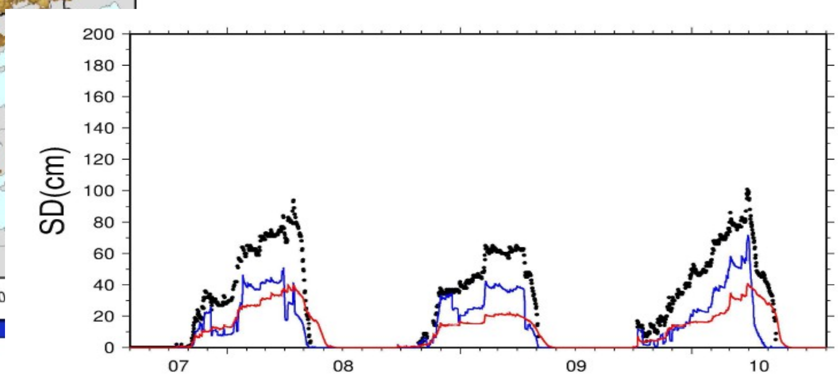
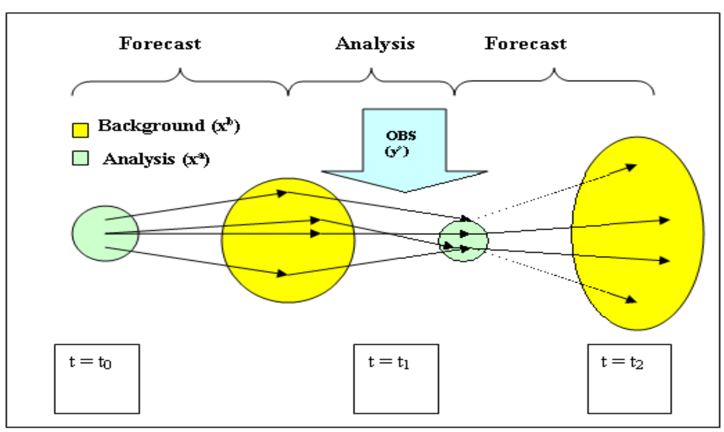


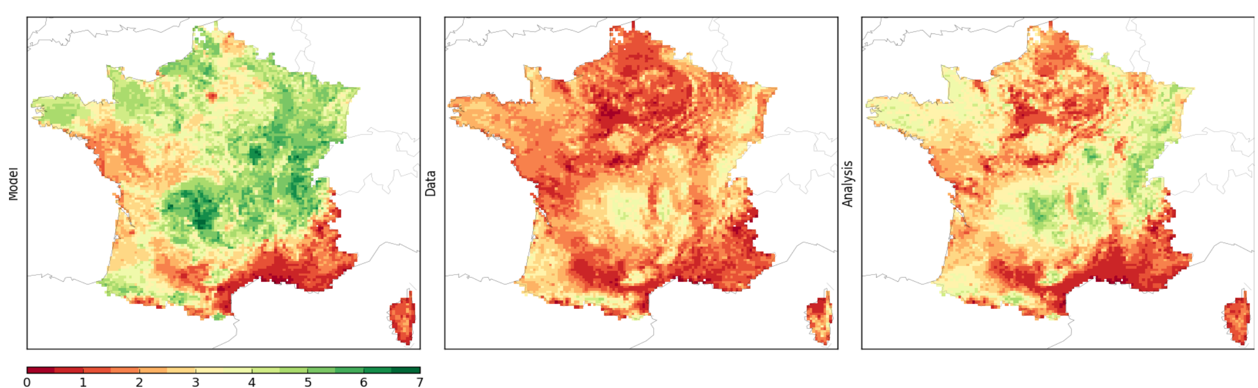
Figure : time series of snow depth (in cm) at the Sodankyla station during the period 2007-2010. The black dots represent the observations, the blue curve represents the simulation made by SURFEX driven by MESCAN and the red curve represents the simulation made by SURFEX driven by ERA-Interim.

Data assimilation

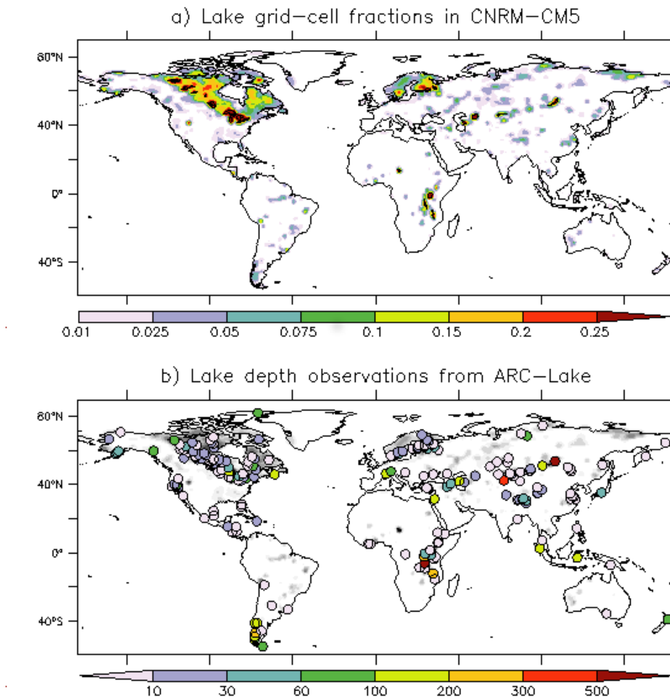
EnKF uses flow-dependent background-error covariance from ensemble spread (Research only)



LAI -- September 2007

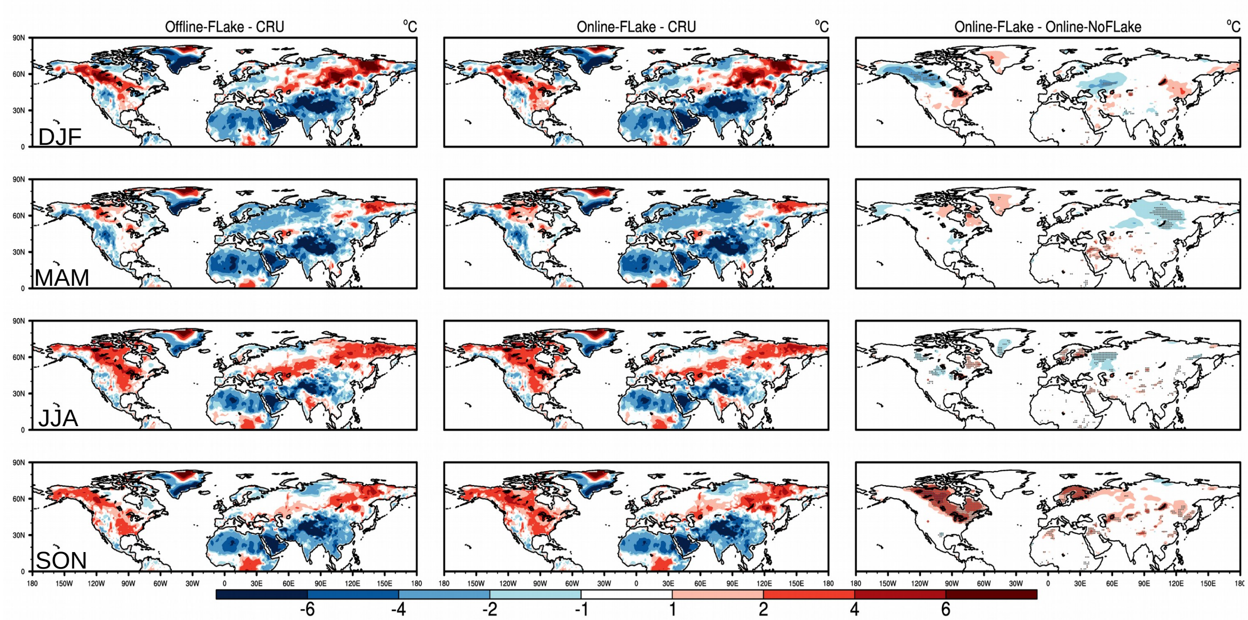


Lake model in Arpege-Climat

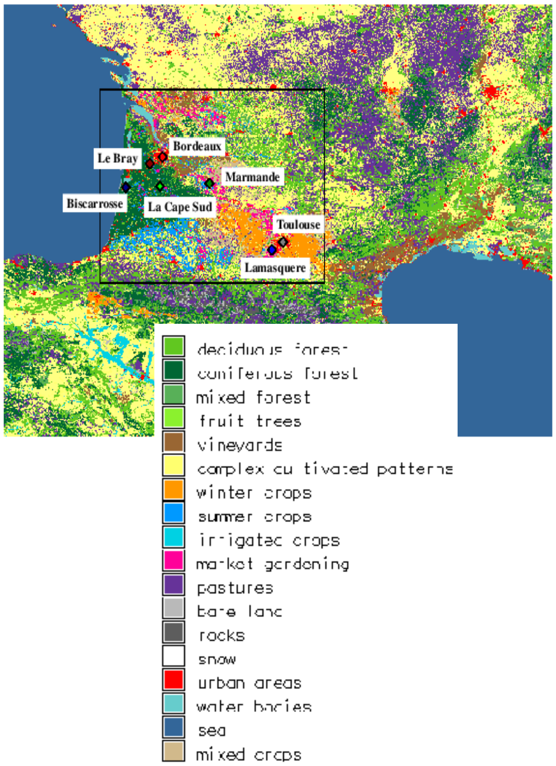


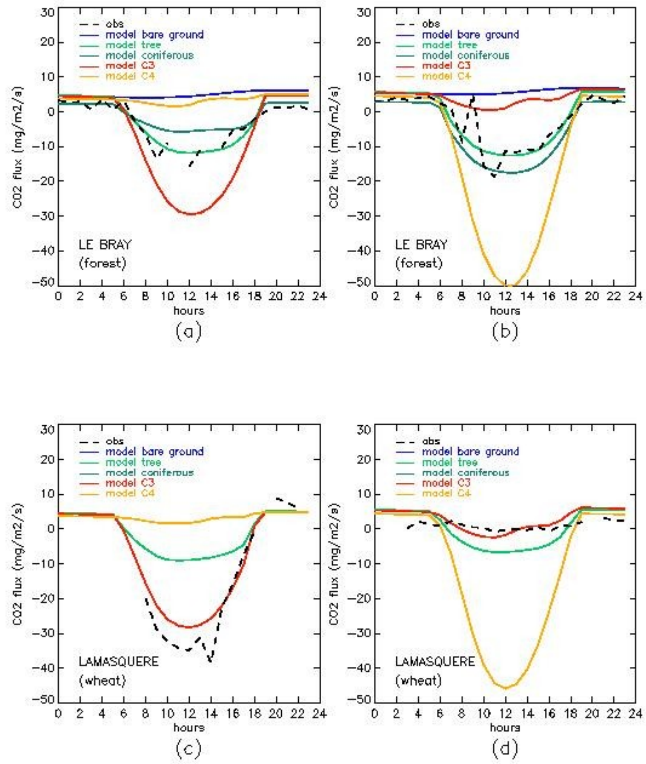
Lake model in Arpege-Climat

Maximum 2m-temperature

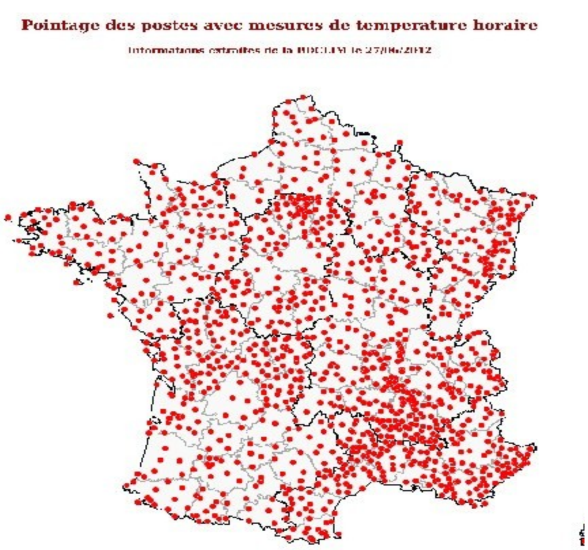


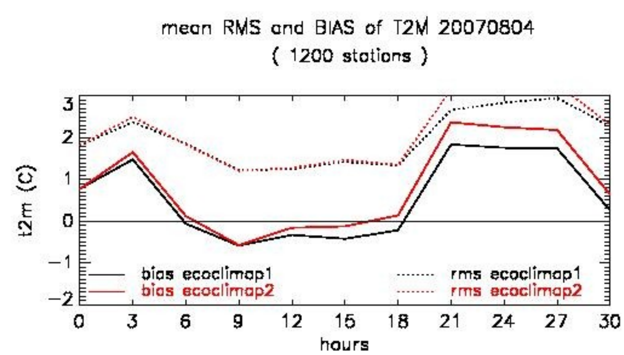
CarboEurope with Meso-NH

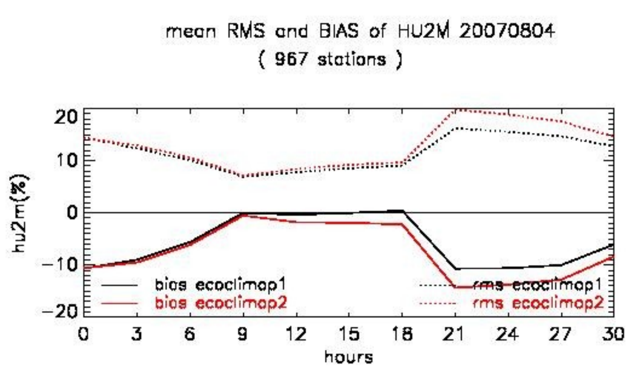




Comparison with Arome







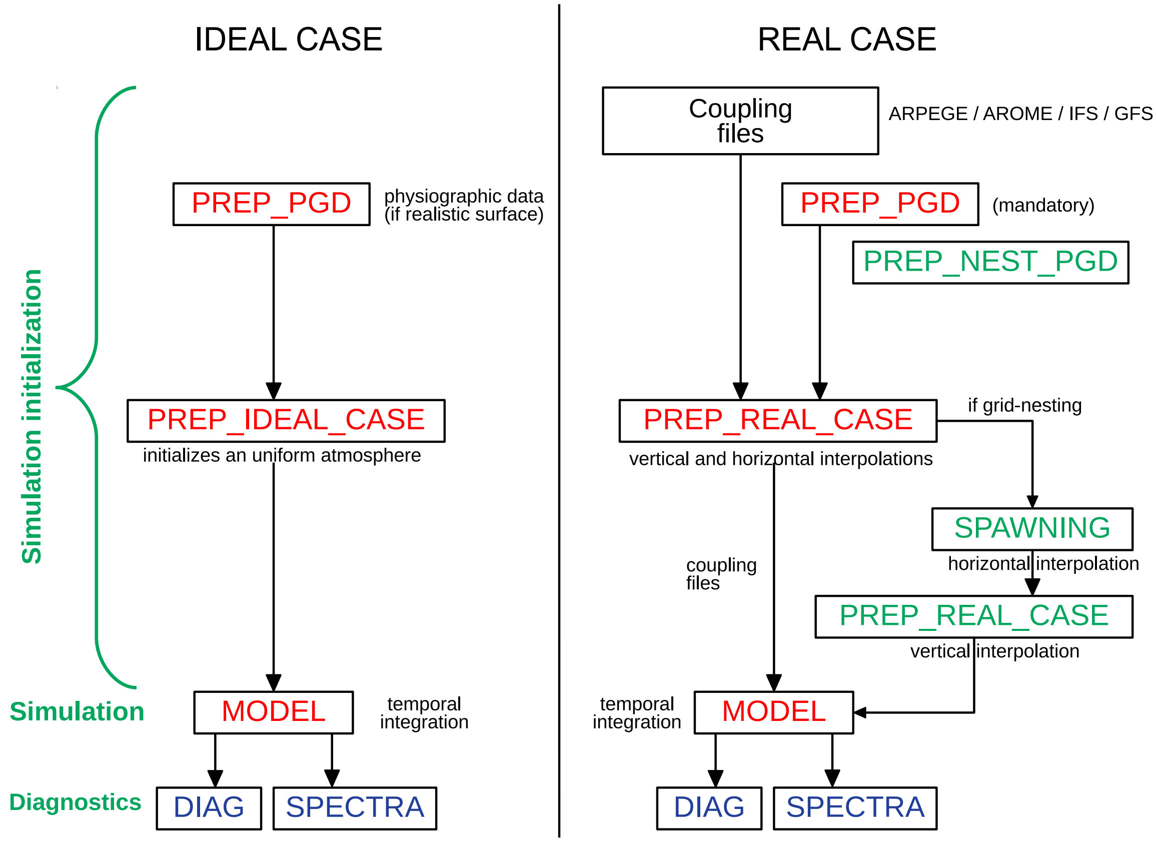
MesoNH environment

MesoNH Tutorial Class 11-14 February 2019

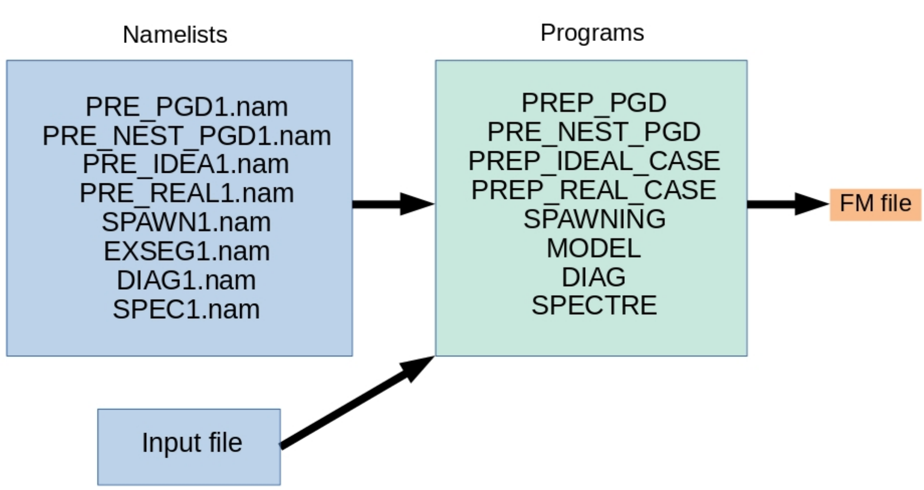
MESONH simulation = succession of elementary steps

Elementary steps :

1. Preparation of physiographic file (PGD)
   - PREP_PGD
   - PREP_NEST_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



Namelists

Definition

- Input file for each program
- Use : set the parameters of the program
- Specific format

Format (Méso-NH)

- Name is fixed (except the number if grid-nesting)
- Avoid tabulating
- Contains sub-namelists (groups)
- Groups start by **&NAM_** and end with \
- If a group is not mentionned ⇒ default values

Lists of groups and options : **user's guide** (Méso-NH + SURFEX)

Namelists : example

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

&NAM_LUNITn   CINIFILE = "GABL4.1.ECH13.001",
              CINIFILEPGD='GABL4.1.ECH00.001PGD' /

&NAM_CONFn LUSERV=F/

&NAM_DYNn XTSTEP=0.75,XT4DIFU = 100. /

&NAM_ADVn  CUVW_ADV_SCHEME = "WENO_K",NWENO_ORDER=4,CTEMP_SCHEME='RKC4',
           CMET_ADV_SCHEME = "PPM_01", CSV_ADV_SCHEME = "PPM_01",/

&NAM_PARAMn  CTURB='TKEL', CRAD='NONE', CCLOUD='NONE', CSCONV='NONE',
             CDCONV='NONE'  /

&NAM_LBCn    CLBCX = 2*"CYCL", CLBCY = 2*"CYCL",
             XCPHASE = 10.0 /

&NAM_TURBn XIMPL=1., CTURBLEN='DEAR', CTURBDIM='3DIM',
           LTURB_FLX=T, LTURB_DIAG=T, LSUBG_COND=F,
           XKEMIN=1E-10,
           LSIGMAS=F, LSIG_CONV=F, LRMC01=T /

&NAM_CONF CCONF="RESTA", CEQNSYS ='DUR', LFLAT=T,
          NMODEL=1, NVERB=6, CEXP="GABL4", CSEG="ECH14",
          LFORCING=T, CSPLIT   = 'BSPLITTING',
          NHALO=1, JPHEXT=1 /

&NAM_CONFZ MPI_BUFFER_SIZE=800 /
```

Meso-NH files

MesoNH files

NC (Netcdf)

format highly recommended

lfi

historical format

2 types of output files :

- synchronous
- diachronics

with 2 parts :

- .des : descriptive ascii file (namelists used)
- .lfi or .nc : data + metadata

Synchronous or diachronic ?

Synchronous file

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

In the simulation, a synchronous file allows to (re)start the model in several segments (**RESTART**)

Segments

A MESONH simulation can be divided in 1 or several **SEGMENTS**.

Why ?

- subdivide jobs (computing time limit $\Rightarrow$ supercomputer)
  - example : Instead of 1 segment of 24 hours, we can do 4 segments of 6 hours
- have a different number of domain in the segments
  - example : we can have a first segment of 6 hours with 1 domain and a second segment of 12 hours with 2 nested-domains

Synchronous or diachronic ?

Diachronic file ≈ time series

- contains some chosen variables (flux, tendency, mean) stored at **differents times** during simulation in a part of the domain
- activation of "on-line" diagnostics
- file name ends by .00**0**

Available variables (refer to *Diagnostics* presentation)

- Budgets
- LES
- Aircrafts and balloons
- Stations and profilers

Examples of output files from the run

6 hours run with outputs every 2 hours

1 segment (no RESTART)

Synchronous files
CTRL0.1.SEG01.001
CTRL0.1.SEG01.002
CTRL0.1.SEG01.003

Diachronic file
CTRL0.1.SEG01.000

3 segments (RESTART)

1st segment
CTRL0.1.SEG01.000
CTRL0.1.SEG01.001

2nd segment
CTRL0.1.SEG02.000
CTRL0.1.SEG02.001

3rd segment
CTRL0.1.SEG03.000
CTRL0.1.SEG03.001

Highly-frequent and smaller output

On demand smaller output files (optional, since version 5.4)

- The user selects a few variables only $\Rightarrow$ smaller files
- Use : huge domain and/or very frequent output (ex : 3D animation)
- Restart not possible from these outputs
- Possible available variables : same as in synchronous files

Documentation

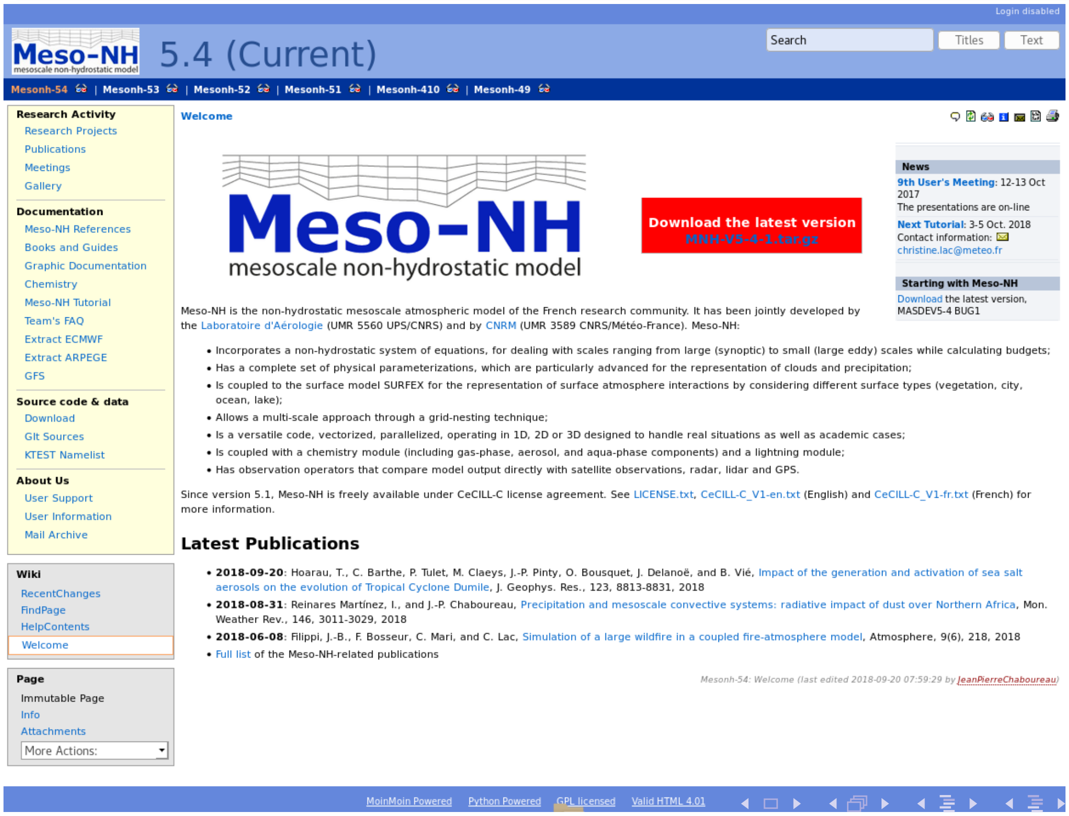
MesoNH Tutorial Class 11-14 February 2019

Informations pool

- The website
- The scientific doc
- The user's guide
- The support team
- in

The website

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



The website : Research Activity

- Publications list (with URL)
- Meetings : every 2 years for the user's meeting (presentations are online)
- Some videos and illustrations in a gallery

The website : Documentation

- Specific Meso-NH references (by topic)
- Scientific docs (by topic + SURFEX)
- User's guide (Méso-NH + SURFEX)
- Misc. doc
  (parallelization, Lagrangian analysis, Forefire, reproductibility)
- Docs on graphical tools (ncl, python, visIt, vapor)
- Guide for simulations with chemistry
- This tutorial : exercices (with solutions) and the presentations
- Guide for GIT and Meso-NH setup on several machines
- Guide for extracting IFS, ARPEGE, AROME and GFS files

The website : Code & Data

- Downloading the code and data (PACK + physiographic files)
- GIT sources
- Sample of simulations examples (KTEST)

The support team

Support at LA			
Jean-Pierre CHABOUREAU	Scientific coordination	0561332750	jean-pierre.chaboureau@aero.obs-mip.fr
Juan ESCOBAR	Web, Vecto Parallel, Optimisation, GENCI interface	0561332749	juan.escobar@aero.obs-mip.fr
Didier GAZEN	IO, Parallel Development	0561332749	didier.gazen@aero.obs-mip.fr
Maud LERICHE	Chemistry	0561332755	maud.leriche@aero.obs-mip.fr
Philippe WAUTELET	Big data	0561332745	philippe.wautelet@aero.obs-mip.fr
Support at CNRM			
Christine LAC	Parameterization development and general code management	0561079842	christine.lac@meteo.fr
Quentin RODIER	Tool management, model coupling	0561079315	quentin.rodier@meteo.fr
Jeanine PAYART	UNIX Procedures Meso-NH administration at CNRM	0561079487	jeanine.payart@meteo.fr
Support at LACy			
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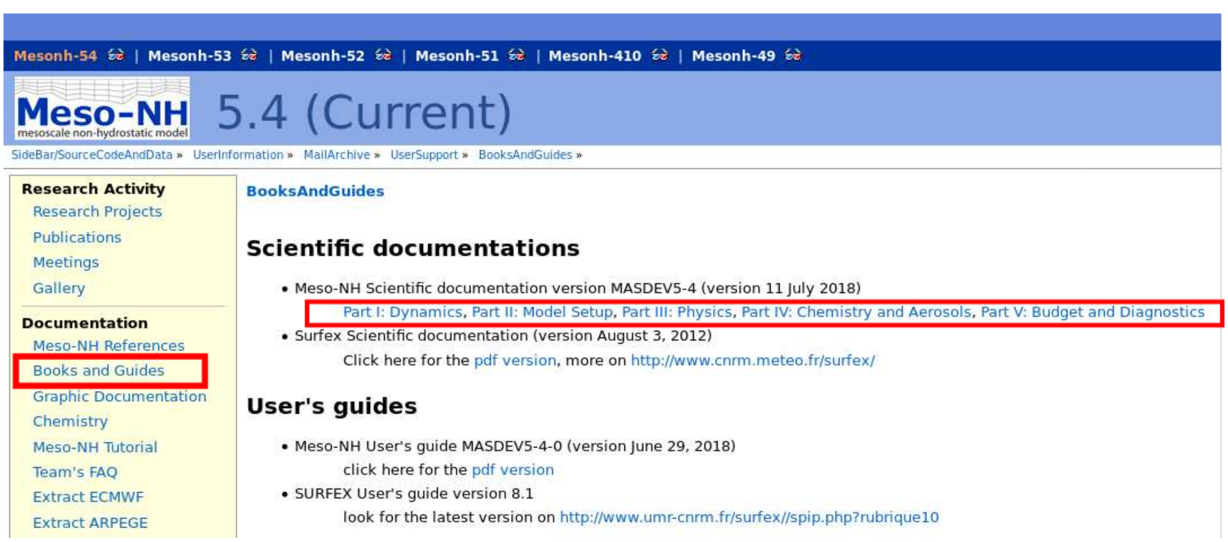
Support mailing list

mesonhsupport@obs-mip.fr

The scientific doc


Mesonh-54 | Mesonh-53 | Mesonh-52 | Mesonh-51 | Mesonh-410 | Mesonh-49

Meso-NH mesoscale non-hydrostatic model 5.4 (Current)

SideBar/SourceCodeAndData » UserInformation » MailArchive » UserSupport » BooksAndGuides »

Research Activity
- Research Projects
- Publications
- Meetings
- Gallery

Documentation
- Meso-NH References
- Books and Guides
- Graphic Documentation
- Chemistry
- Meso-NH Tutorial
- Team's FAQ
- Extract ECMWF
- Extract ARPEGE

BooksAndGuides

Scientific documentations

- Meso-NH Scientific documentation version MASDEV5-4 (version 11 July 2018)
  Part I: Dynamics, Part II: Model Setup, Part III: Physics, Part IV: Chemistry and Aerosols, Part V: Budget and Diagnostics
- Surfex Scientific documentation (version August 3, 2012)
  Click here for the pdf version, more on http://www.cnrm.meteo.fr/surfex/

User's guides

- Meso-NH User's guide MASDEV5-4-0 (version June 29, 2018)
  click here for the pdf version
- SURFEX User's guide version 8.1
  look for the latest version on http://www.umr-cnrm.fr/surfex//spip.php?rubrique10

The Meso-NH Atmospheric Simulation System:

Scientific Documentation

Part I: Dynamics

The Meso-NH Atmospheric Simulation System:

Scientific Documentation

Part II: Model Setup

The Meso-NH Atmospheric Simulation System: Scientific Documentation

Part III: Physics

The Meso-NH Atmospheric Simulation System: Scientific Documentation

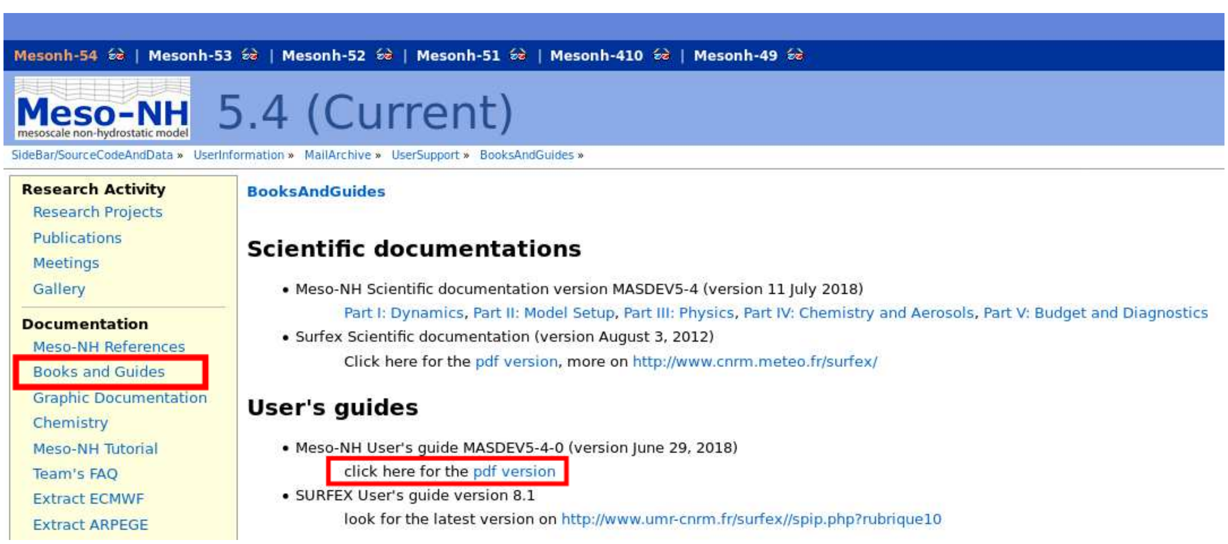
Part IV: Chemistry and Aerosols

The Meso-NH Atmospheric Simulation System:

Scientific Documentation

Part V: Budget and Diagnostics

The user's guide



The user's guide

The user's guide

The user's guide : namelist sub-groups

9.2.33 Namelist NAM_DYNn (parameters for the dynamics of model n)

Fortran name	Fortran type	default value
XTSTEP	real	60.
CPRESOPT	4 characters	'CRESI'
NITR	integer	4
LITRADJ	logical	TRUE
XRELAX	real	1.
LHORELAX_UVWTH	logical	FALSE
LHORELAX_RV	logical	FALSE
LHORELAX_RC	logical	FALSE
LHORELAX_RR	logical	FALSE
LHORELAX_RI	logical	FALSE
LHORELAX_RS	logical	FALSE
LHORELAX_RG	logical	FALSE
LHORELAX_RH	logical	FALSE
LHORELAX_TKE	logical	FALSE
LHORELAX_SV	array logical	FALSE
LHORELAX_SVC2R2	logical	FALSE
LHORELAX_SVC1R3	logical	FALSE
LHORELAX_SVLG	logical	FALSE
LHORELAX_SVCHEM	logical	FALSE
LHORELAX_SVDST	logical	FALSE
LHORELAX_SVPP	logical	FALSE
LHORELAX_SVAER	logical	FALSE
LVE_RELAX	logical	FALSE
LVE_RELAX_GRD	logical	FALSE
NRIMX	integer	1
NRIMY	integer	1
XRIMKMAX	real	$1/(100*60.)$
XT4DIFU	real	1800.
XT4DIFTH	real	1800.
XT4DIFSV	real	1800.

It contains the specific dynamic parameters for the modesimulation.texl n. They are included in the module MODD_DYNn.

- XTSTEP : Time step in seconds. If the model is not the DAD model, XTSTEP is not taken into account but NDTRATIO in NAM_NESTING.
- CPRESOPT : Pressure solver option. 3 choices are implemented in MESONH for the moment (see the Scientific documentation for more details) :

The user's guide : variables names

The user's guide : variables names

Name	Dim	Meaning	Unit
ACPRC	[D]	Accumulated Cloud Precipitation Rain Rate	mm
ACPRG	[D]	Accumulated Precipitation Graupel Rate	mm
ACPRH	[D]	Accumulated Precipitation Hail Rate	mm
ACPRR	[D]	Accumulated Precipitation Rain Rate	mm
ACPRS	[D]	Accumulated Precipitation Snow Rate	mm
ACPRT	[D]	Total Accumulated Precipitation Rate	mm
AZIM	[2D]	azimuth	rad
CG_RATE	[2D]	CloudGround lightning Rate	/s
CG_TOTAL_NB	[2D]	CloudGround lightning Number	-
CLDFR	[2D]	Cloud fraction	
CLEARCOL_TM1	[2D]	Trace of cloud	-
DIR_ALB	[2D]	Direct albedo	-
DIRFLASWD	[2D]	Direct Downward Long Waves on flat surface	W/m^2
DIRSRFSWD	[2D]	Direct Downward Long Waves	W/m^2
DSVCONVxxx	[3D]	Convective tendency for scalar variable	/s
DSVCONV_LINOX	[3D]	Convective tendency for linox	/s
DRCCONV	[2D]	Convective R_c tendency	/s
DRICONV	[2D]	Convective R_i tendency	/s
DRVCONV	[2D]	Convective R_v tendency	/s
DTHCONV	[2D]	Convective heating/cooling rate	K/s
DTHRAD	[2D]	Radiative heating/cooling rate	K/s

The user's guide : variables names

Name	Dim	Meaning	Unit
PRSCONV	[2D]	Convective instantaneous Precipitation Rate for Snow	mm/h
RCT	[3D]	Cloud mixing Ratio at t time	kg/kg
RGT	[3D]	Graupel mixing Ratio at t time	kg/kg
RHODREF	[3D]	Dry density for reference state with orography	kg/m^3
RHOREFZ	[1D]	rhodz for reference state without orography	kg/m^3
RHT	[3D]	Hail mixing Ratio at t time	kg/kg
RIT	[3D]	Ice mixing Ratio at t time	kg/kg
RRT	[3D]	Rain mixing Ratio at t time	kg/kg
RST	[3D]	Snow mixing Ratio at t time	kg/kg
RVFRC	[1D]	$(\partial r_v/\partial t)_{frc}$ forcing vapor mixing ratio	kg/kg
RVT	[3D]	Vapor mixing Ratio at t time	kg/kg
SCA_ALB	[2D]	Scattered albedo	-
SCAFLASWD	[2D]	Scattered Downward Long Waves on flat surface	W/m^2
SVTnnn	[3D]	User or passive scalar variables at t time	kg/kg
TENDRVFRC	[1D]	$(\partial r_v/\partial t)_{frc}$	/s
TENDTHFRC	[1D]	$(\partial \theta/\partial t)_{frc}$	K/s
THFRC	[1D]	θ_{frc} forcing potential temperature	K
THT	[3D]	potential temperature at t time	K
THVREF	[3D]	Thetav for reference state with orography	K
THVREFZ	[1D]	thetavz for reference state without orography	K
TKET	[3D]	Turbulent Kinetic Energy at t time	m^2/s^2
TSRAD	[2D]	Radiative Surface Temperature	K
UFRC	[1D]	zonal component of horizontal forcing wind	m/s
UT	[3D]	horizontal component U of wind at t time	m/s
VFRC	[1D]	meridian component of horizontal forcing wind	m/s
VT	[3D]	horizontal component V of wind at t time	m/s
WFRC	[D]	vertical forcing wind	m/s
WT	[3D]	vertical wind at t time	m/s
ZENITH	[2D]	zenith	rad
ZS	[2D]	orography	m
ZSMT	[2D]	smoothed orography for SLEVE vertical coordinate	m

The SURFEX doc

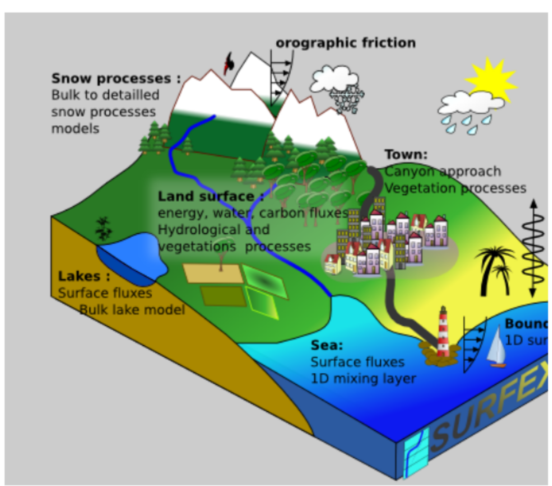
http://www.umr-cnrm.fr/surfex/
SURFEX tutorial : once a year (february)

Links

Contents

- General presentation
- Coordination
- Get the code and browser
- Scientific documentation
- Technical documentation
- Versions documentation
- User's guide
- Physiographic maps
- Various tools
- The STRATO tests base
- Training courses
- Contact us
- Useful links
- Forum
- WORKSHOP

Welcome to the SURFEX Home Page



SURFEX (Surface Externalisée, in French) is a surface modelling platform developed by Météo-France in cooperation with the scientific community.

SURFEX is composed of various physical models for natural land surface, urbanized areas, lakes and oceans. It also simulates chemistry and aerosols surface processes and can be used for assimilation of surface and near surface variables.

Graphical tools
&
Files manipulation

MesoNH Tutorial Class 11-14 February 2019

MesoNH files

NC (Netcdf)

highly recommended format

lfi

historical format

2 types of output files :

- synchronous
- diachronics

with 2 parts :

- .des : descriptive ascii file (namelists used)
- .lfi or .nc : data + metadata

Examples of NetCDF output from a MesoNH simulation

6 hours run with outputs every 2 hours

1 segment (no RESTART)

Synchronous files
`CTRL0.1.SEG01.001.nc`
`CTRL0.1.SEG01.002.nc`
`CTRL0.1.SEG01.003.nc`

Diachronic file
`CTRL0.1.SEG01.000.nc`

3 segments (RESTART)

1st segment
`CTRL0.1.SEG01.000.nc`
`CTRL0.1.SEG01.001.nc`

2nd segment
`CTRL0.1.SEG02.000.nc`
`CTRL0.1.SEG02.001.nc`

3rd segment
`CTRL0.1.SEG03.000.nc`
`CTRL0.1.SEG03.001.nc`

Some useful commands for data printing

All the data

ncdump file.nc

Variables name + metadata

ncdump -h file.nc

Data from specific variables only

ncdump -v var1 var2 file.nc

Data of coordinates/dimensions

ncdump -c file.nc

Example : ncdump -h file.nc

```
netcdf NOADV.1.RUN01.001 {
dimensions:
        ni = 12 ;
        nj = 12 ;
        ni_u = 12 ;
        nj_u = 12 ;
        ni_v = 12 ;
        nj_v = 12 ;
        level = 112 ;
        level_w = 112 ;
        time = UNLIMITED ; // (1 currently)
        size3 = 3 ;
        char16 = 16 ;
        char32 = 32 ;
        size4 = 4 ;
        size2 = 2 ;
        size6 = 6 ;
variables:
        int MNHVERSION(size3) ;
                MNHVERSION:long_name = "MesoNH version" ;
                MNHVERSION:_FillValue = -2147483647 ;
                MNHVERSION:valid_min = -2147483646 ;
                MNHVERSION:valid_max = 2147483647 ;
        int MASDEV ;
                MASDEV:long_name = "MesoNH version (without bugfix)" ;
        int BUGFIX ;
                BUGFIX:long_name = "MesoNH bugfix number" ;
        char BIBUSER(char16) ;
                BIBUSER:long_name = "MesoNH: user binary library" ;
        char PROGRAM(char16) ;
                PROGRAM:long_name = "MesoNH family: used program" ;
        char STORAGE_TYPE(char16) ;
                STORAGE_TYPE:long_name = "STORAGE_TYPE" ;
                STORAGE_TYPE:comment = "Storage type for the information written in the FM files" ;
```

Example : ncdump -h file.nc

```
                COUPLING:comment = "Logical for coupling file";
        double UT(time, level, nj_u, ni_u) ;
                UT:standard_name = "x_wind" ;
                UT:long_name = "UT" ;
                UT:units = "m s-1" ;
                UT:grid = 2 ;
                UT:comment = "X_Y_Z_U component of wind" ;
                UT:_FillValue = 9.96920996838687e+36 ;
                UT:valid_min = -1.e+36 ;
                UT:valid_max = 1.e+36 ;
        double VT(time, level, nj_v, ni_v) ;
                VT:standard_name = "y_wind" ;
                VT:long_name = "VT" ;
                VT:units = "m s-1" ;
                VT:grid = 3 ;
                VT:comment = "X_Y_Z_V component of wind" ;
                VT:_FillValue = 9.96920996838687e+36 ;
                VT:valid_min = -1.e+36 ;
                VT:valid_max = 1.e+36 ;
        double WT(time, level_w, nj, ni) ;
                WT:standard_name = "upward_air_velocity" ;
                WT:long_name = "WT" ;
                WT:units = "m s-1" ;
                WT:grid = 4 ;
                WT:comment = "X_Y_Z_vertical wind" ;
                WT:_FillValue = 9.96920996838687e+36 ;
                WT:valid_min = -1.e+36 ;
                WT:valid_max = 1.e+36 ;
        double THT(time, level, nj, ni) ;
                THT:standard_name = "air_potential_temperature" ;
                THT:long_name = "THT" ;
                THT:units = "K" ;
```

NCO commands

nco.sourceforge.net

- **ncap2** netCDF Arithmetic Processor
- **ncatted** netCDF ATTribute EDitor
- **ncbo** netCDF Binary Operator (addition, multiplication, etc)
- **nces** netCDF Ensemble Statistics
- **ncecat** netCDF Ensemble conCATenator
- **ncks** netCDF Kitchen Sink
- **ncrename** netCDF RENAMEer
- **ncwa** netCDF Weighted Averager
- **ncpdq** netCDF Permute Dimensions Quickly, Pack Data Quietly
- **ncflint** netCDF FiLe INTerpolator

NCO commands : some examples

ncbo --op_typ=add file1.nc file2.nc file3.nc

file3 = file1 + file2 (same variables)

ncbo --op_typ=mlt file1.nc file2.nc file3.nc

file3 = file1 * file2 (same variables)

ncecat file1.nc file2.nc file3.nc file4.nc file.nc

concatenate variables from files 1 to 4 in file.nc (add a dimension)

ncks -a -A in.nc out.nc

write all the variables from in.nc in out.nc

NCO commands : some examples

ncwa in.nc out.nc

write the mean of the variables (on all the dimensions) from in.nc in out.nc

nces file[1-4].nc out.nc

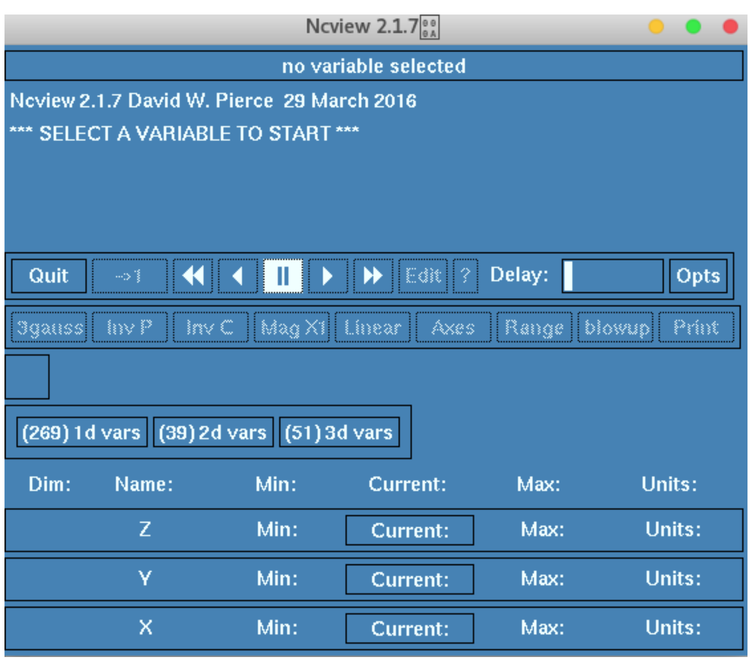
write the mean of the variables of file[1 to 4].nc in out.nc

ncrename -v p,pressure file.nc

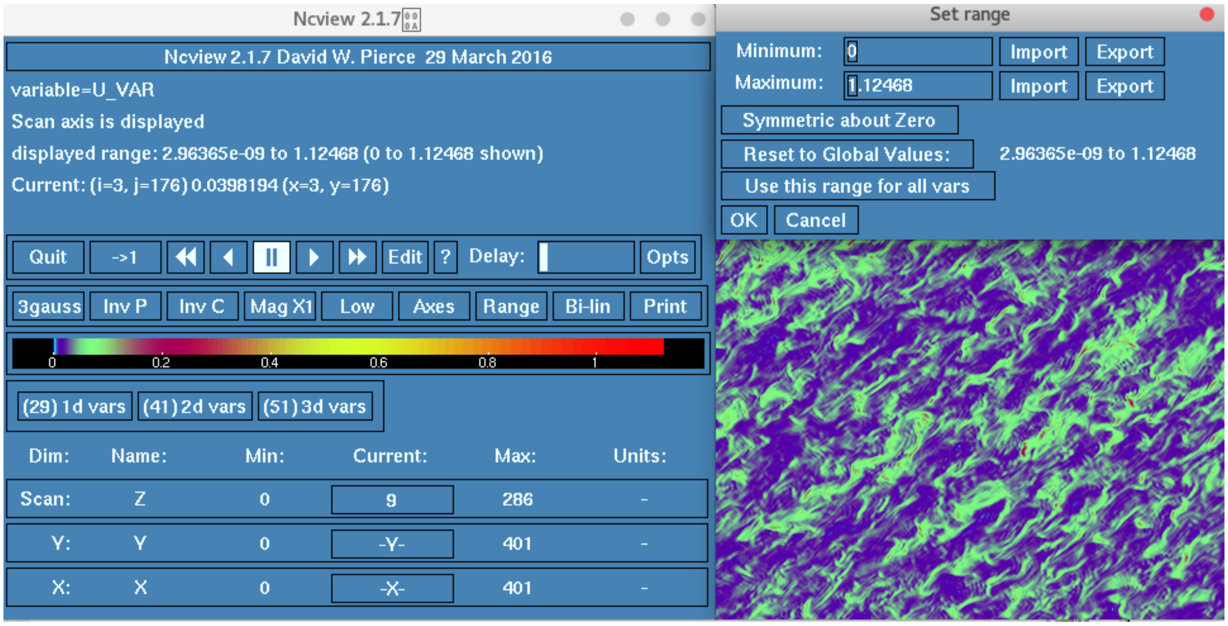
rename the variable p to pressure in file.nc

Quick data visualization : ncview

ncview file.nc

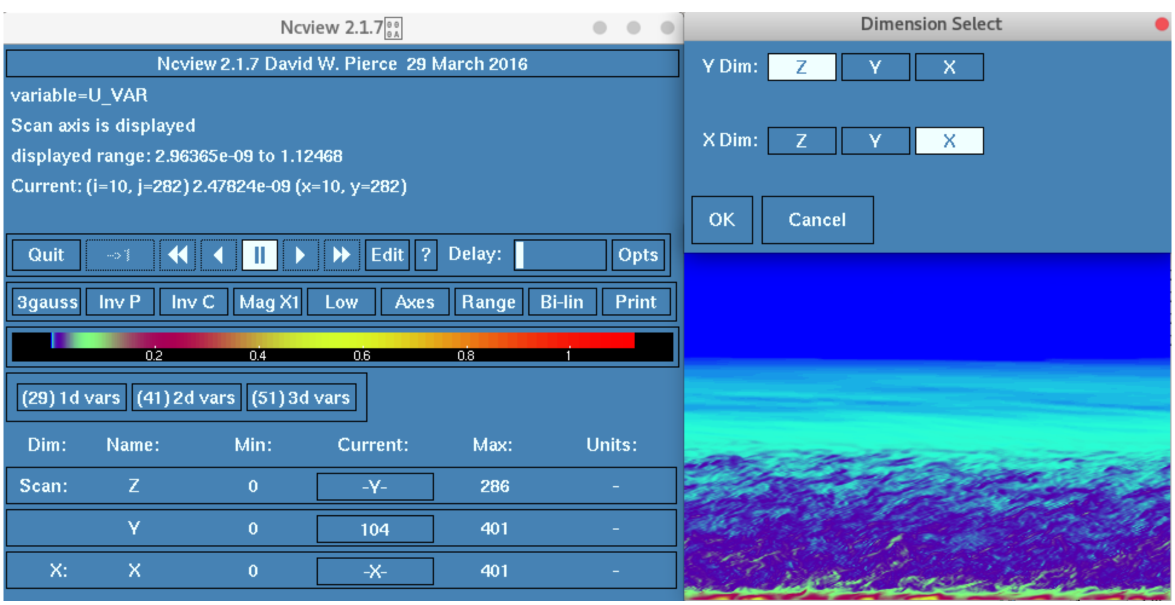


Quick data visualization : ncview



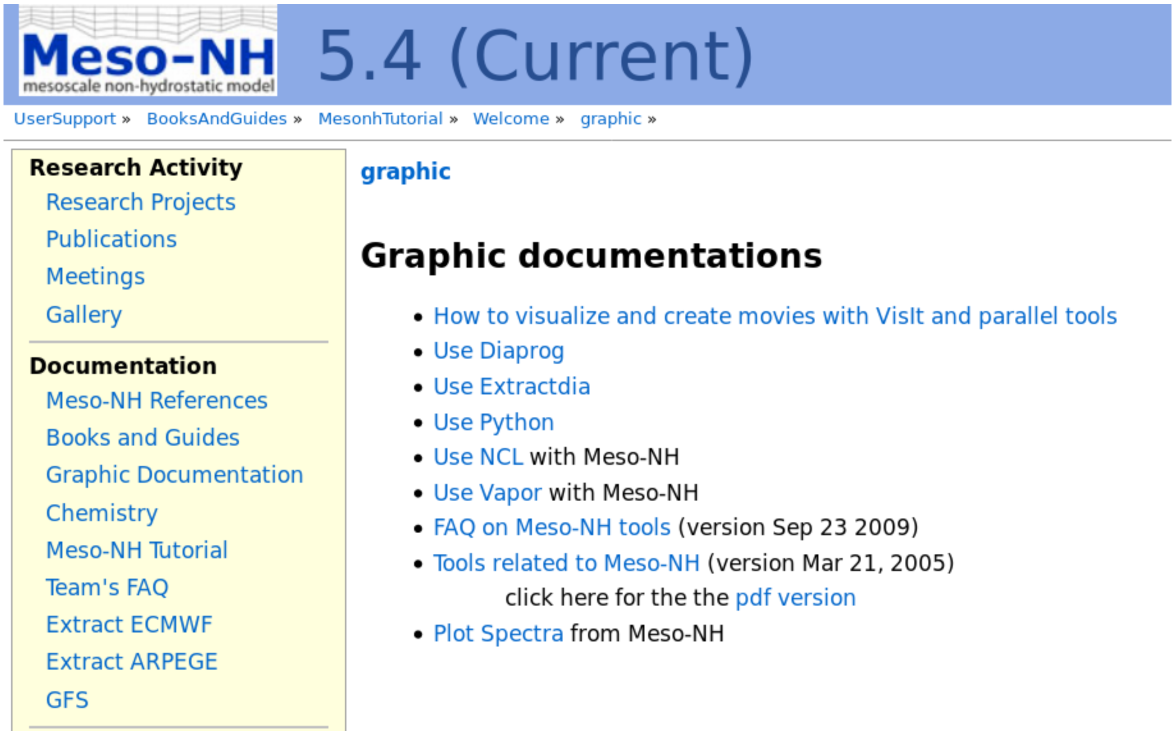
Coupe horizontale de la variance u'^2

Quick data visualization : ncview



Vertical cross-section of u'^2

Graphical tools : online documentation



Meso-NH mesoscale non-hydrostatic model 5.4 (Current)

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- GFS

graphic

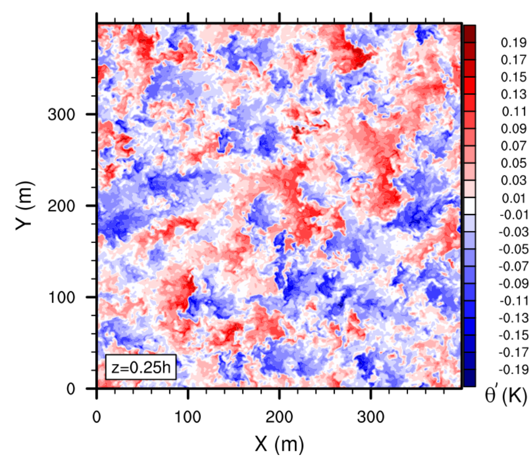
Graphic documentations

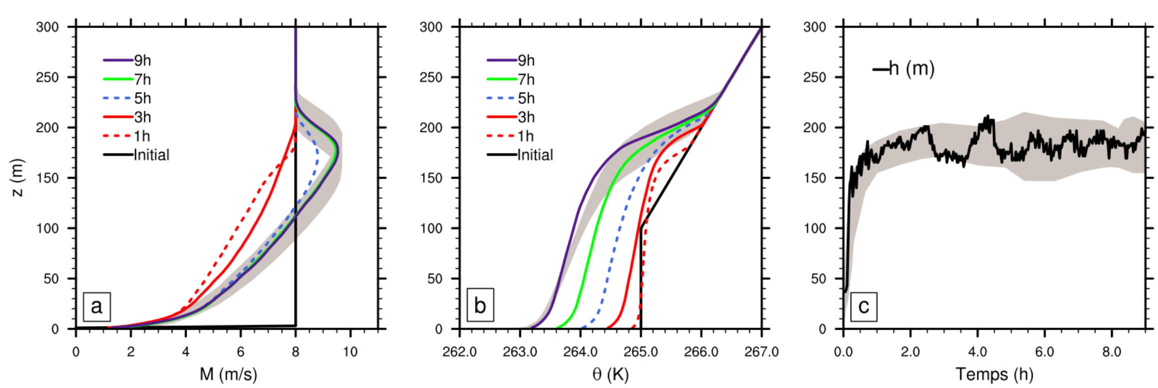
- How to visualize and create movies with VisIt and parallel tools
- Use Diaprog
- Use Extractdia
- Use Python
- Use NCL with Meso-NH
- Use Vapor with Meso-NH
- FAQ on Meso-NH tools (version Sep 23 2009)
- Tools related to Meso-NH (version Mar 21, 2005)
  click here for the the pdf version
- Plot Spectra from Meso-NH

Tool : NCL

http ://www.ncl.ucar.edu

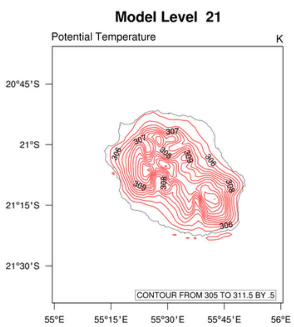
hundreds of examples

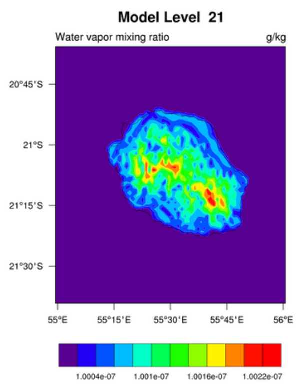


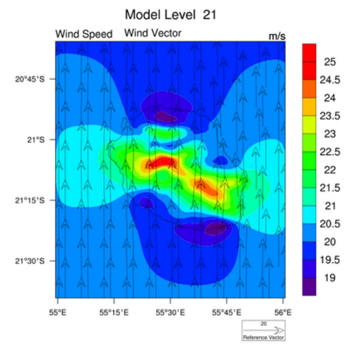


NCL : example with MesoNH

KTEST of la Réunion (script available online)







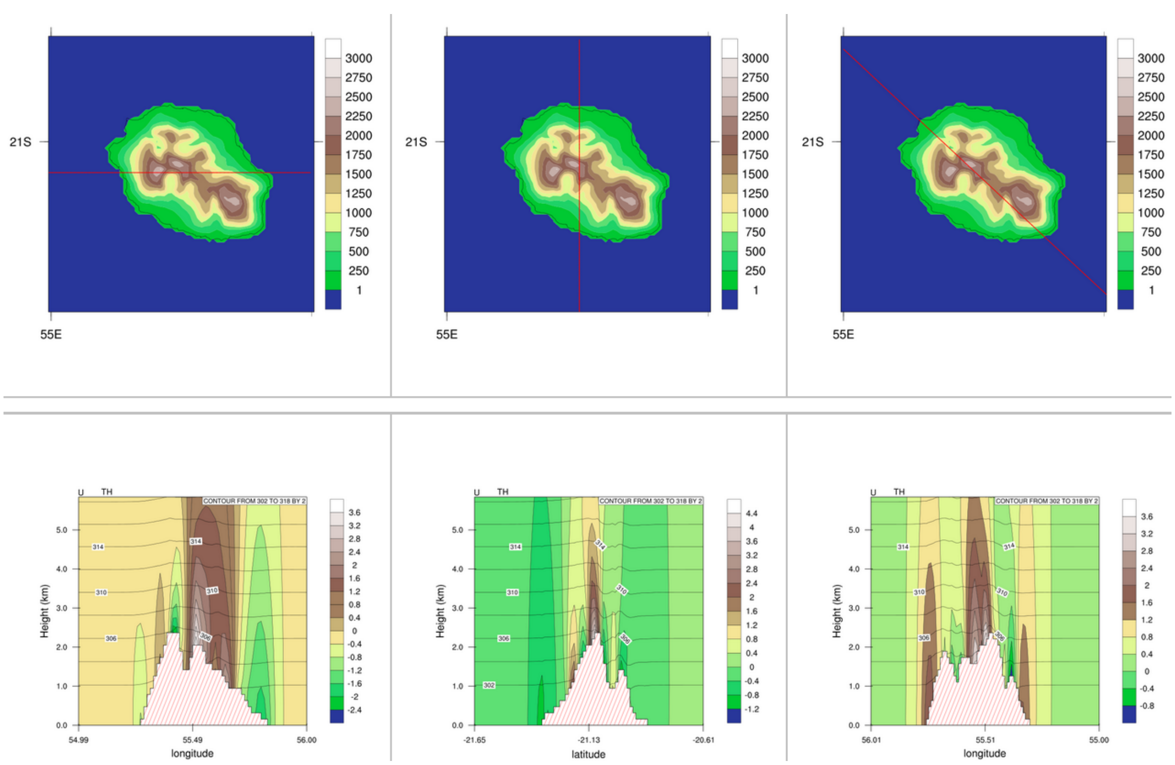
NCL : example with MesoNH

```
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_code.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/csm/gsn_csm.ncl"
load "$NCARG_ROOT/lib/ncarg/nclscripts/wrf/WRFUserARW.ncl"

;==============================================================;
;  Example of script to plot field on model levels from MESONH
;  netcdf4 file generated with version 5.2
;==============================================================;

begin

;================================================;
; Open file
;================================================;
; The MESONH input file.
; ----------------------
  mnh_file="REUNI.1.00A20.004.nc4"
  a = addfile(mnh_file,"r")

;=================================================;
; Open the workstation and choose colormap
; For paper quality plot do not use type ncgm or eps
; Use ps or pdf or x11 (for debugging)
;=================================================;
  type = "png"
  wks = gsn_open_wks(type,"plt_ModelLevels")
  gsn_define_colormap(wks,"rainbow+gray")
```

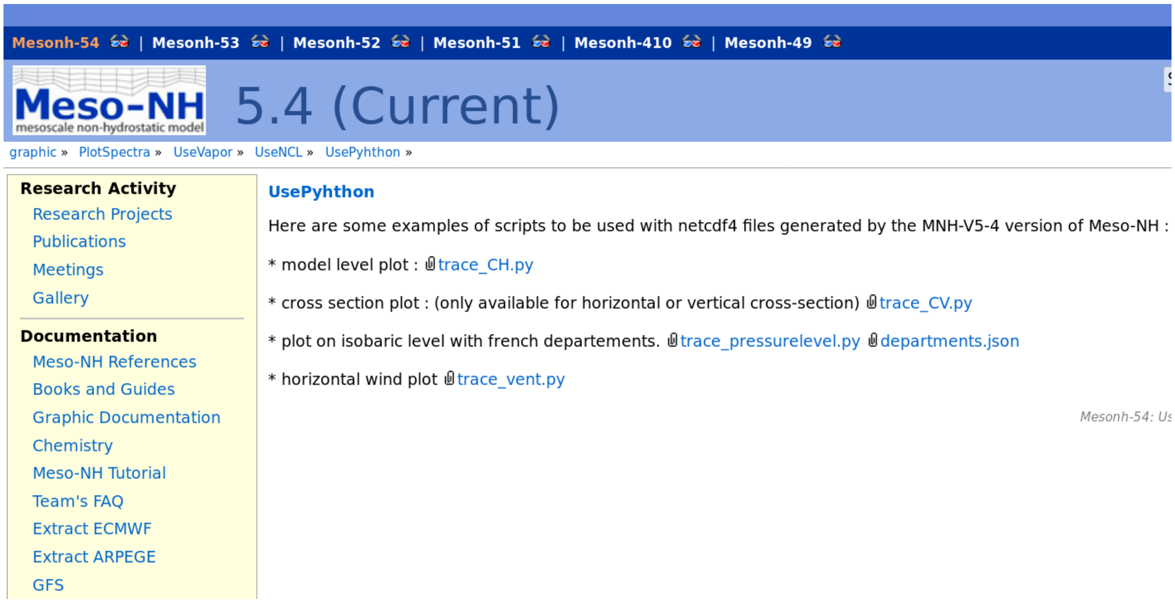
NCL : example with MesoNH

```
;=================================================;
; Get informations on variable sizes
; dims are dims-2 to remove non-physical values
;=================================================;
  mdims = getfilevardimsizes(a,"THT") ; get dimension sizes
  nd = dimsizes(mdims)
  imax=mdims(nd-1)-2
  jmax=mdims(nd-2)-2
  kmax=mdims(nd-3)-2

;=================================================;
; Read the variables we need
;=================================================;
  lat2d = a->LAT(1:jmax,1:imax)
  lat2d@units="degrees_north"
  lon2d = a->LON(1:jmax,1:imax)
  lon2d@units="degrees_east"

  th  = a->THT(1:kmax,1:jmax,1:imax)   ; theta
  th@long_name="Potential Temperature"
  th@units = "K"
  th@lat2d=lat2d
  th@lon2d=lon2d
```

NCL : example with MesoNH



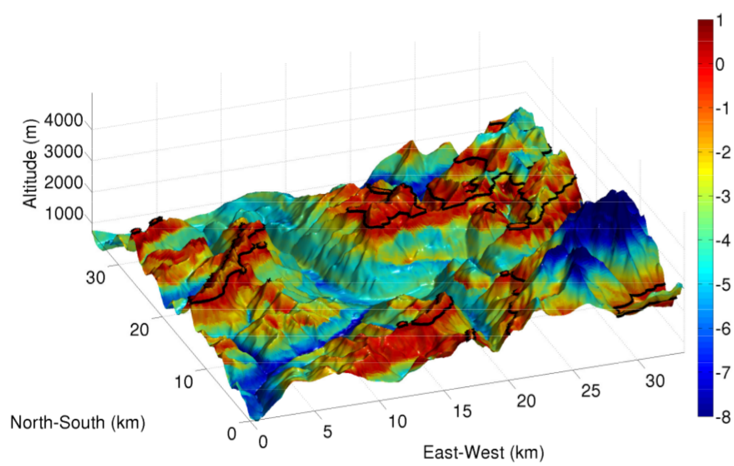
Tool : python



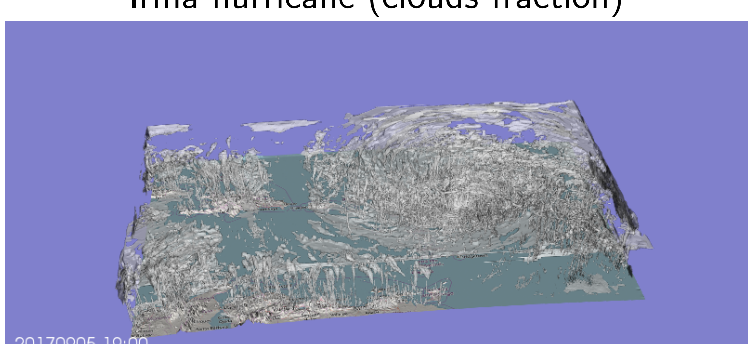
Some python scripts are available online
(ex : vertical and horizontal cross-sections ; skewT diagram)

Tool : python

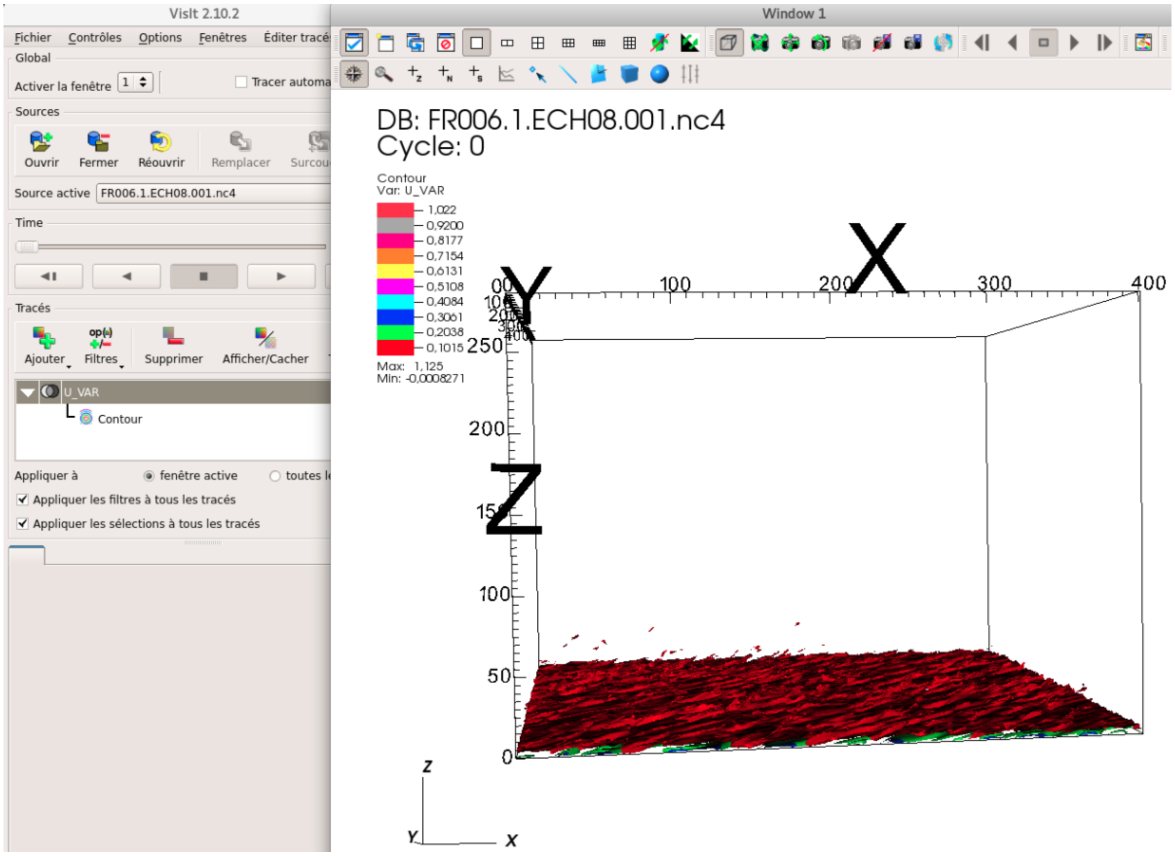
Arve valley in the Alps (temperature)



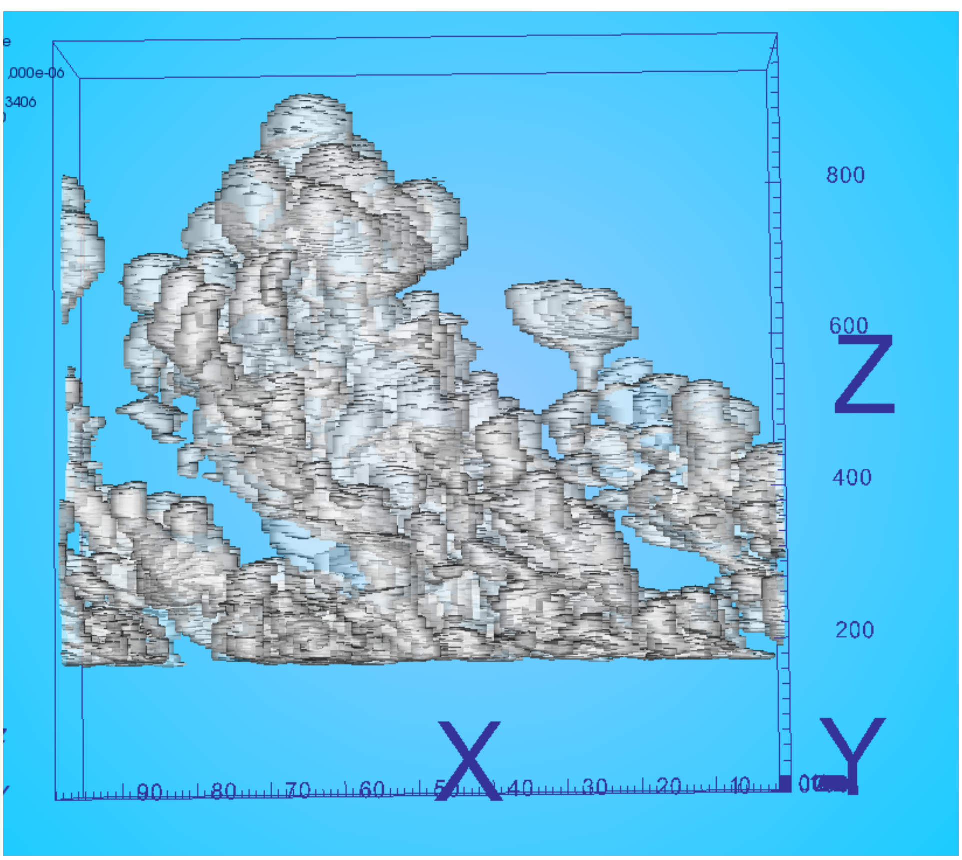
Irma hurricane (clouds fraction)

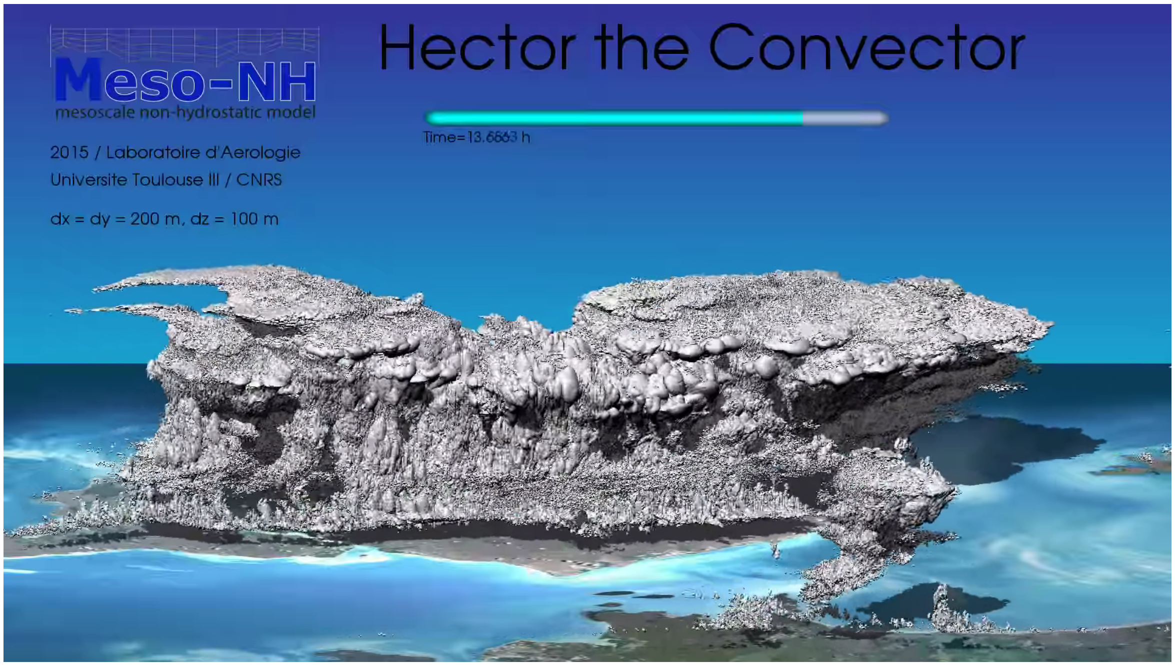


Tool : visit



Tool : visit




Hector the Convector
Meso-NH
mesoscale non-hydrostatic model
Time=13.6663 h
2015 / Laboratoire d'Aerologie
Universite Toulouse III / CNRS
dx = dy = 200 m, dz = 100 m

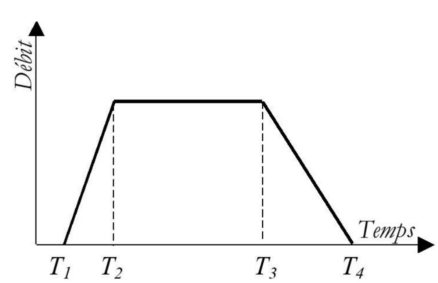
Diagnostics

MesoNH Tutorial Class 11-14 February 2019

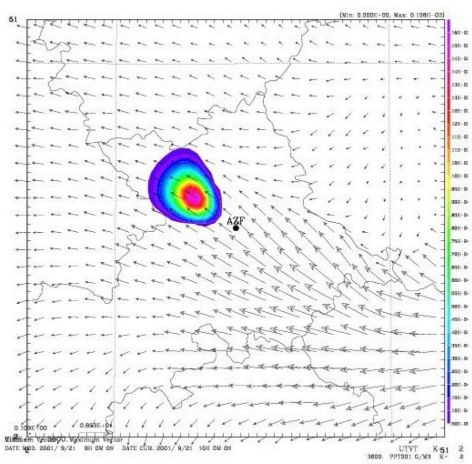
Passiv pollutants

You can initialize passive pollutants, they will be advected and transported (by the turbulence scheme and convection (optional) during the simulation)
Ponctual release at the ground or in altitude of a pollutant mass with 3 stages for the emission rate. There are no deposition nor scavenging.

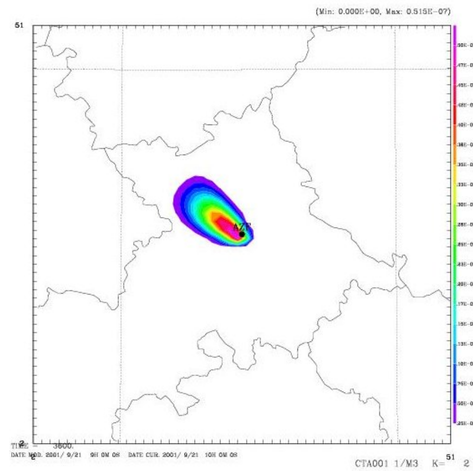
```
&NAM_PASPOL
LPASPOL = T ,
NRELEASE = 1 ,
CPPINIT(1) = "1PT" ,
XPPLAT(1) = 43.567 ,
XPPLON(1) = 1.439 ,
XPPBOT(1) = 10.0 ,
XPPTOP(1) = 500.0 ,
XPPMASS(1) = 10000000. ,
CPPT1(1) = "20010921090000",
CPPT2(1) = "20010921090000",
CPPT3(1) = "20010921091500",
CPPT4(1) = "20010921091500" /
```



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



Concentration (g/m3) at 10h



Atmospheric coefficient transfer at 10h : integral and normalized concentration

Lagrangian trajectory

They are 3 special passive scalars because they are initialized with the spatial coordinates at the initial time. They 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://mesonh.aero.obs-mip.fr/`
section "`Books and Guides`",
Lagrangian Analyses' Documentation (Gheusi et Stein, mai 2005).

Lagrangian trajectory

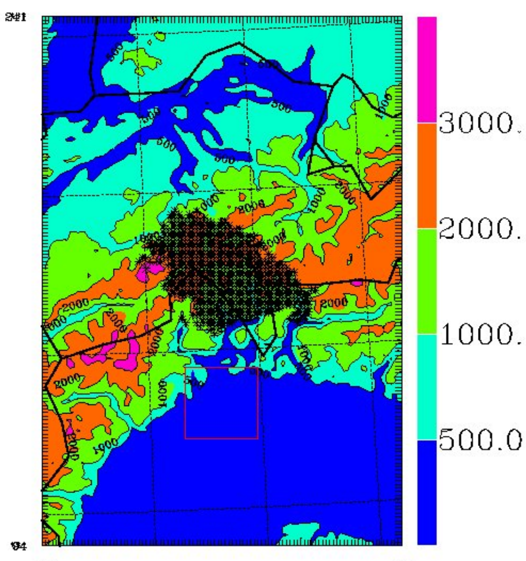
Namelists

- **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 desactivate the turbulent transport
- **EXSEGn.nam**
  - `&NAM_PARAM_KAFRn` : `LCHTRANS=T` to activate the convective transport.

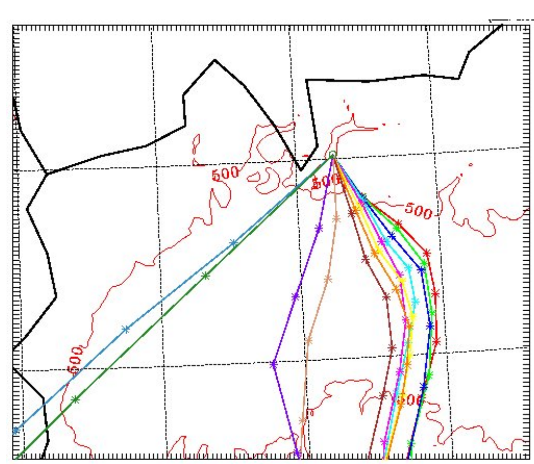
Output fields

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

Lagrangian trajectory

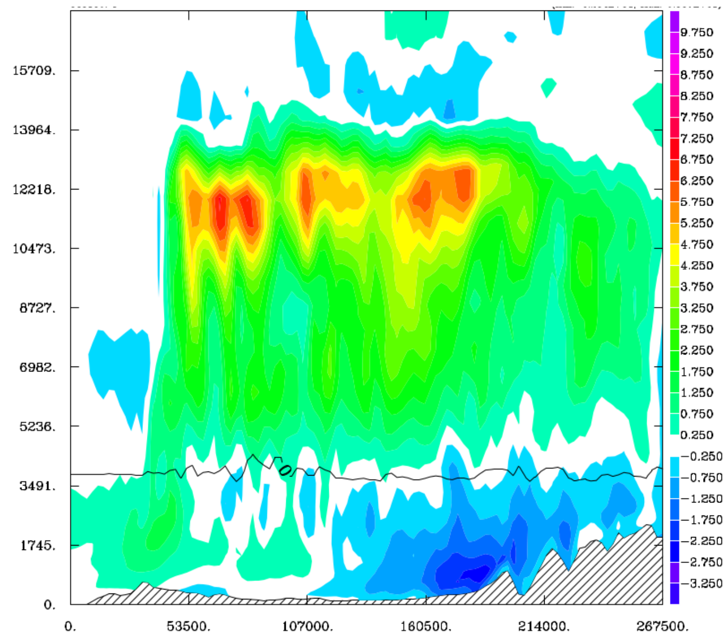


Plumes



Back-trajectories

Lagrangian trajectory



Vertical cross-section along an organized convection line, showing the net vertical displacement $\Delta z = z - z_0$ of the Lagrangian parcels over 30 min (color areas, Δz in km). The quasi-horizontal line is the 0°C-isotherm

Temporal series

You can store prognostic variables during the simulation.

Three types of series :

- **(t)** : horizontally and vertically averaged values (in a box to be specified by its indexes 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

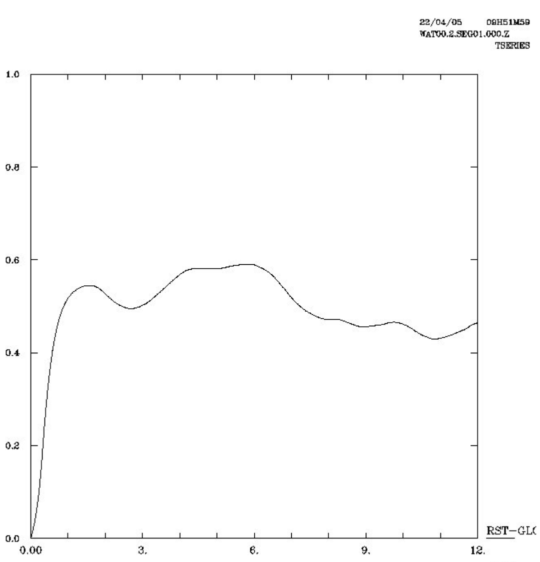
To do it :

- 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`.

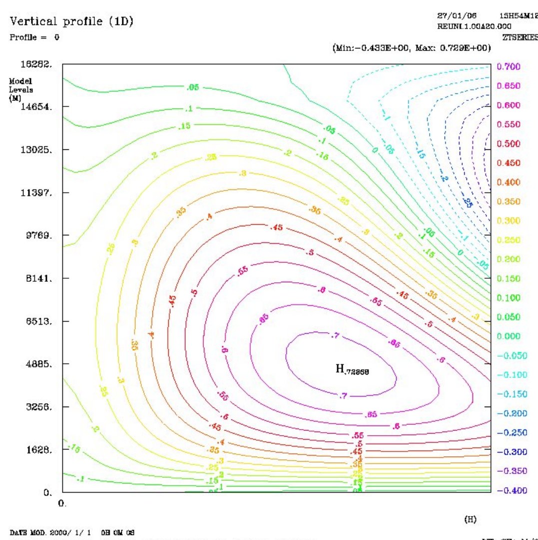
Outputs

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

Temporal series



snow mixing ratio (t)



vertical velocity (z,t) averaged above sea mask

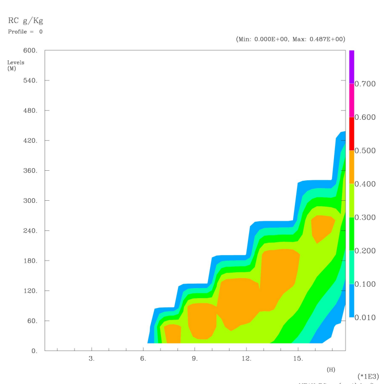
Writing of turbulent diagnostics (mainly used by Large Eddy Simulations) :

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

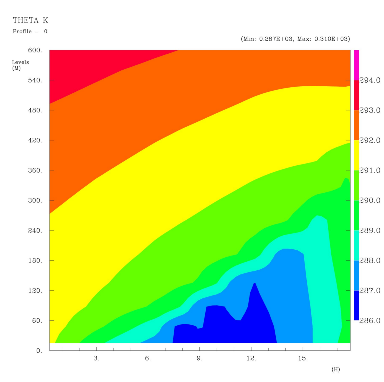
To do it :

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

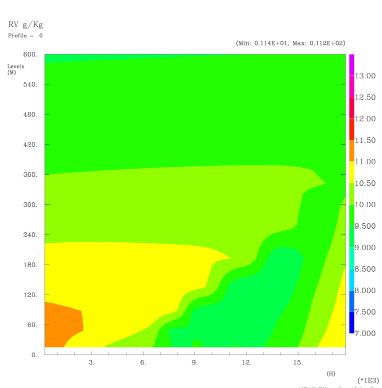
Data are in the diachronic file CEXP.n.CSEG.**000**



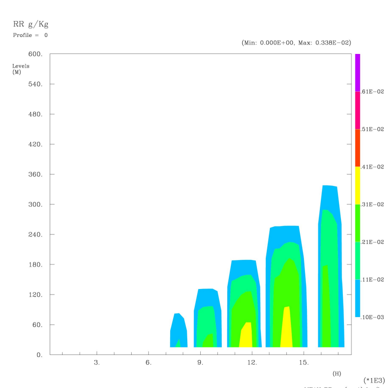
MEAN_RC



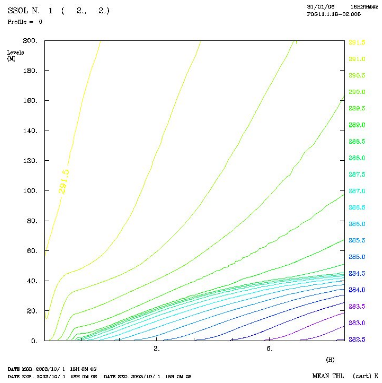
MEAN_TH



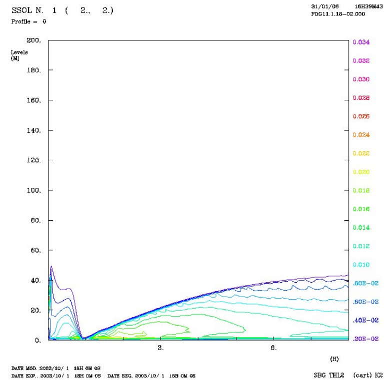
MEAN_RV



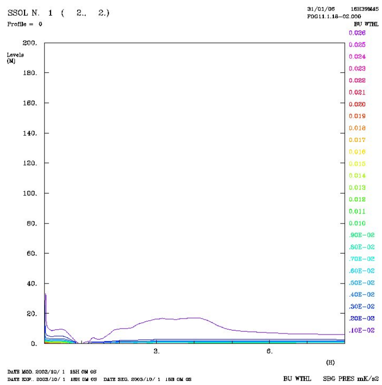
MEAN_RR



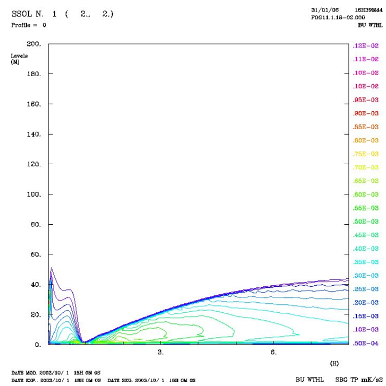
moyenne : $<\theta_l>$



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



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



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

LES Diagnostics

All available variables are in appendix C of the user's guide

C.3 LES averaged fields (LLES_MEAN=TRUE)

field	notation in the diachronic file	dim.	if	comments
$<u>$	MEAN_U	z,t,p		
$<v>$	MEAN_V	z,t,p		
$<w>$	MEAN_W	z,t,p		
$<p>$	MEAN_PRE	z,t,p		
$<\rho>$	MEAN_RHO	z,t,p		
$<\theta>$	MEAN_TH	z,t,p		dimension 'p' is equal to the number of masks when this dimension is not present, the computation is made only on the cartesian mask.
$<\theta_l>$	MEAN_THL	z,t,p	r_c	
$<\theta_v>$	MEAN_THV	z,t,p	r_v	
$<r_v>$	MEAN_RV	z,t,p	r_v	
$<r_c>$	MEAN_RC	z,t,p	r_c	
$<r_r>$	MEAN_RR	z,t,p	r_r	
$<r_i>$	MEAN_RI	z,t,p	r_i	
$<r_s>$	MEAN_RS	z,t,p	r_s	
$<r_g>$	MEAN_RG	z,t,p	r_g	
$<r_h>$	MEAN_RH	z,t,p	r_h	
$<s_v>$	MEAN_SV	z,t,p,n	s_v	
$<\sqrt{\overline{u}^2+\overline{v}^2}>$	MEAN_WIND	z,t,p		different from $\sqrt{<\overline{u}>^2+<\overline{v}>^2}$!
$<\overline{\rho}\max(\overline{w},<w>)>$	MEAN_MSFX	z,t,p		mean upward mass flux

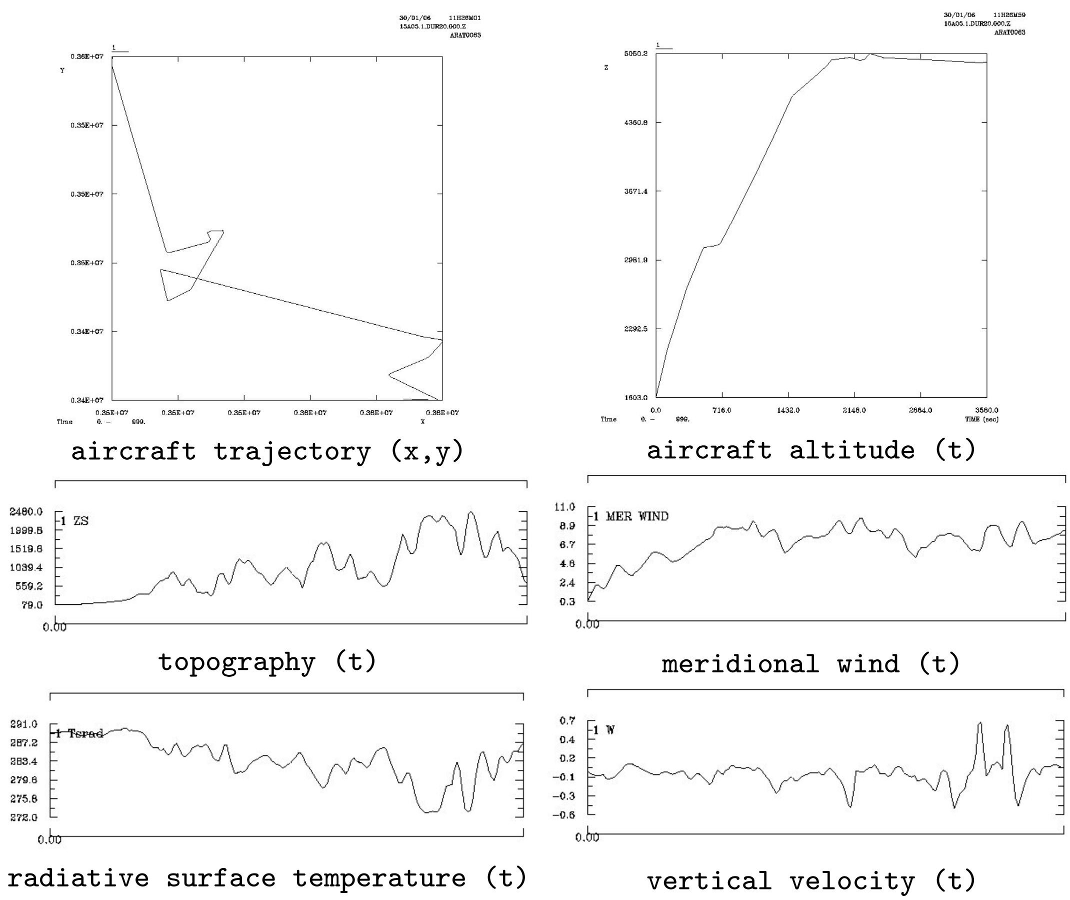
You can store the prognostic fields along aircraft (30 max.) and balloon trajectories (9 max.) during the simulation.

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 define the aircraft trajectory.

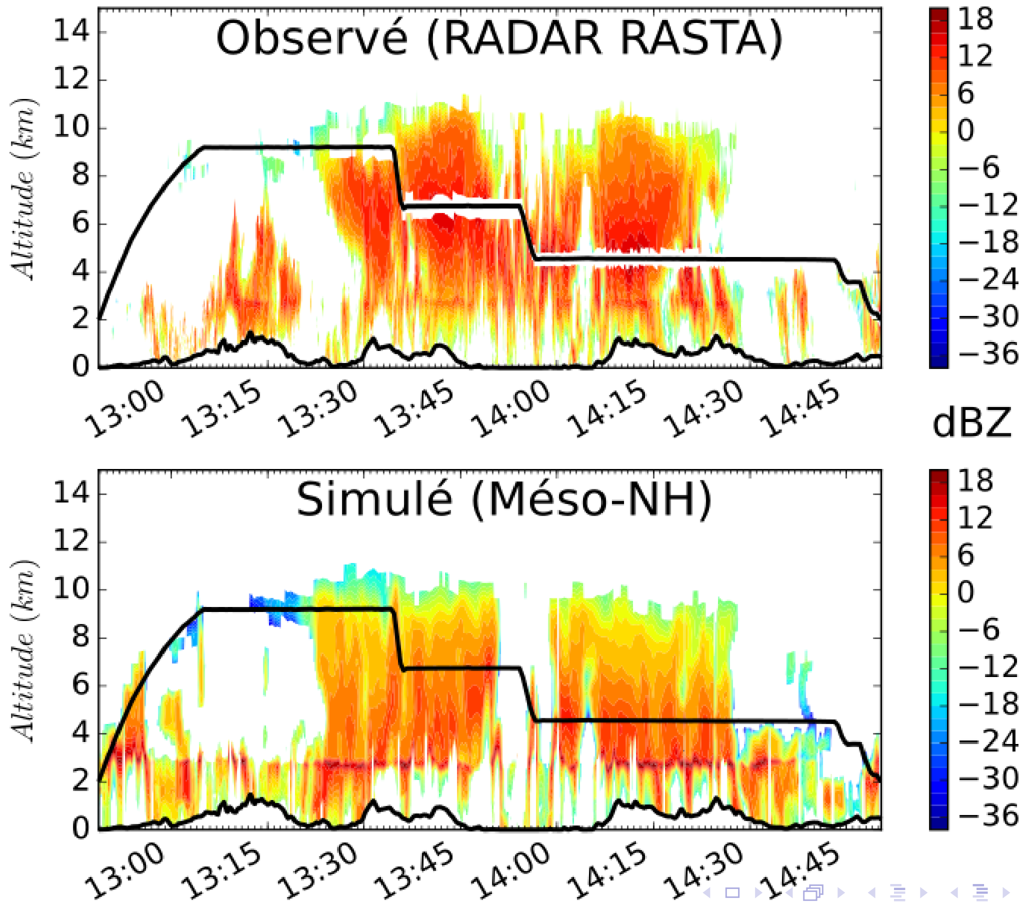
Note :

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



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

Aircraft



Stations, profilers

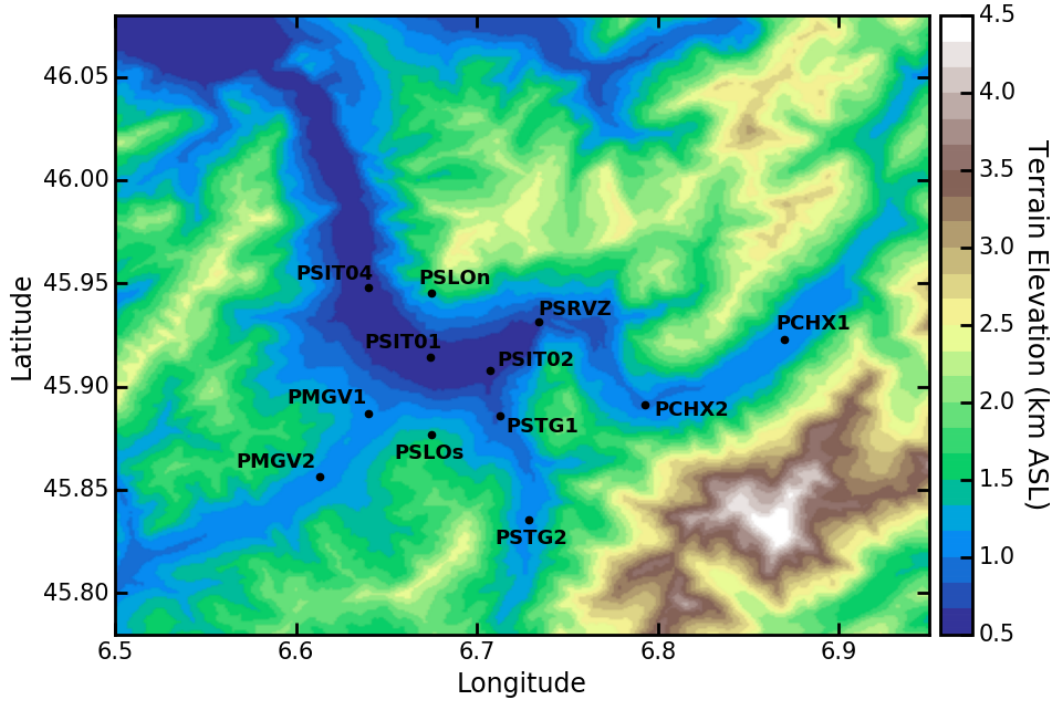
You can store prognostic fields and surface diagnostics at the profilers or stations locations during the simulation.

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).

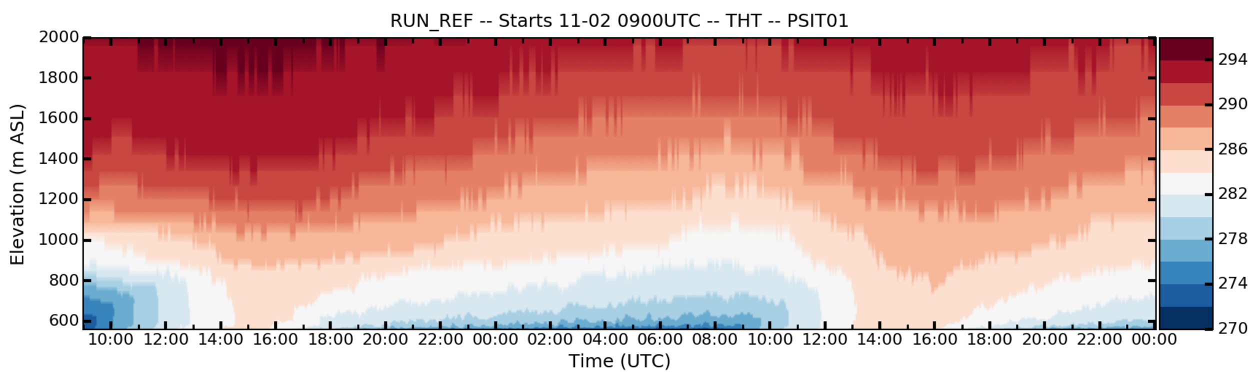
Data are stored in the diachronic file CEXP.n.CSEG.**000**

Stations, profilers



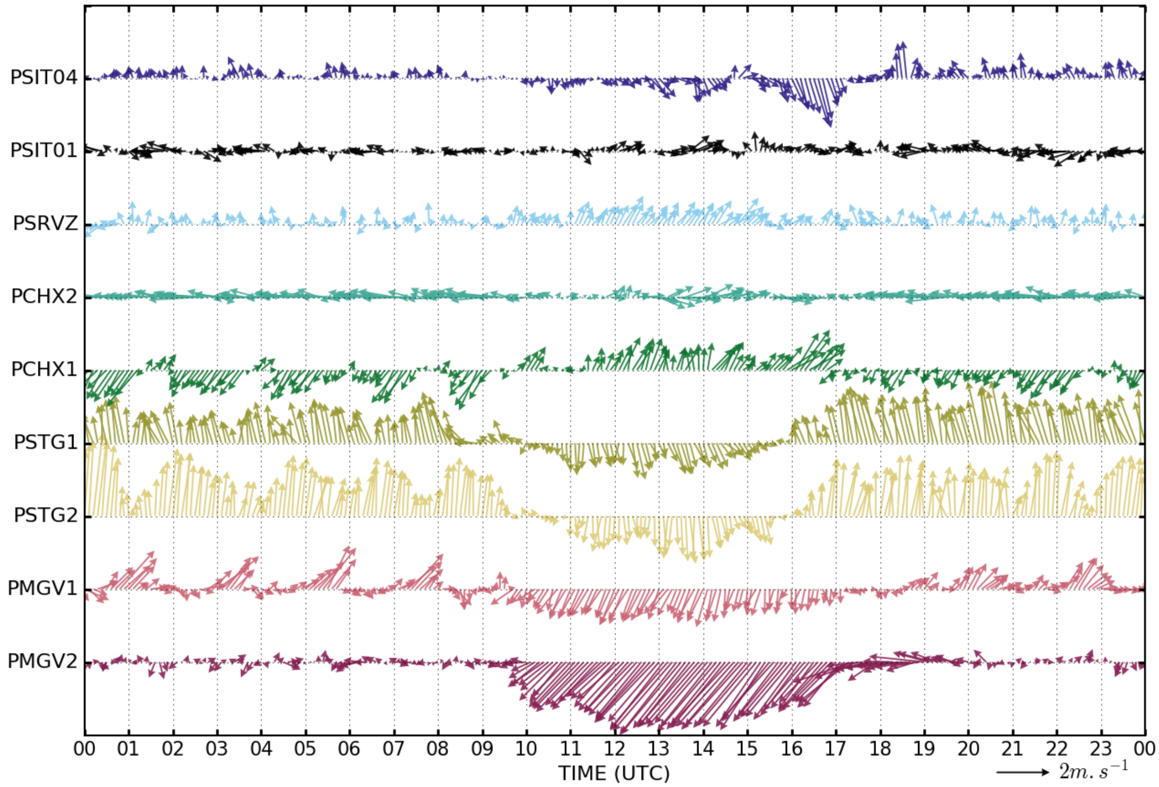
The Arve valley (Alpes, France)

Stations, profilers



Potential Temperature (z,t) at profileur PSIT01

Stations, profilers



Evolution of the wind at all stations

Budgets

You can store during the simulation the different source terms of the equation of every prognostic 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 to the 3 directions,
- optional temporal average to 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,` *zonal wind*

`&NAM_BU_RV,` *meridional wind*

`&NAM_BU_RW,` *vertical wind*

`&NAM_BU_RTH,` *potential temperature*

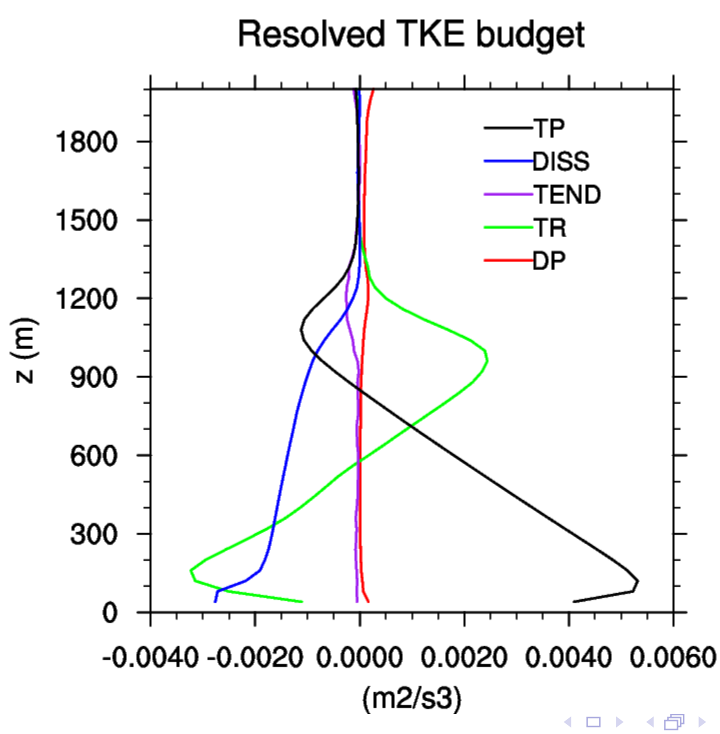
`&NAM_BU_RRV,` *water vapor*

`&NAM_BU_RRR,` *rain water*, etc

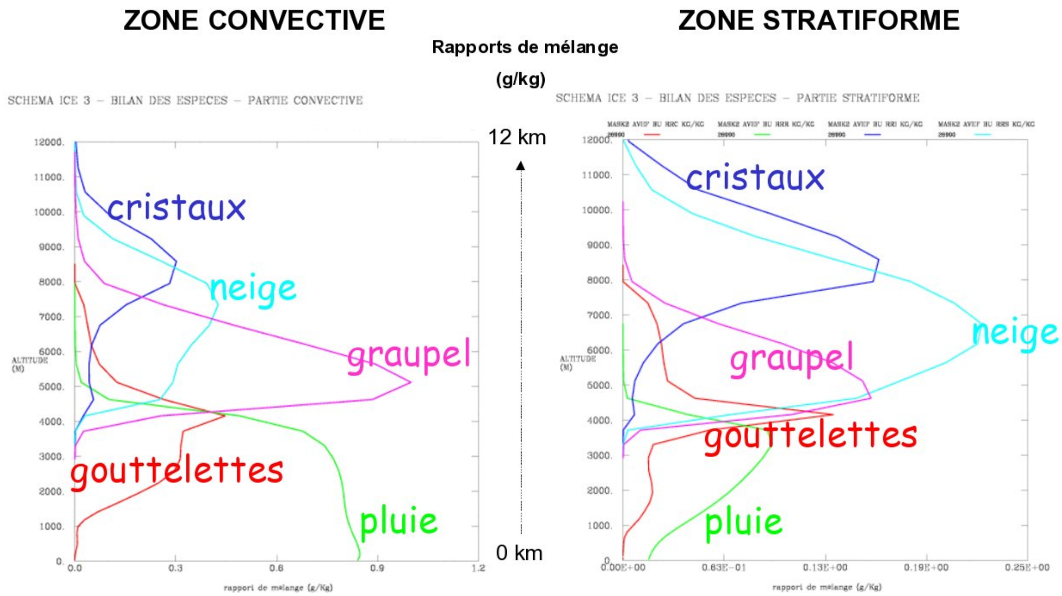
Data are in the diachronic file CEXP.n.CSEG.**000**

Budgets

$$\frac{DTKE}{Dt} = TP + TR + DISS + DP$$

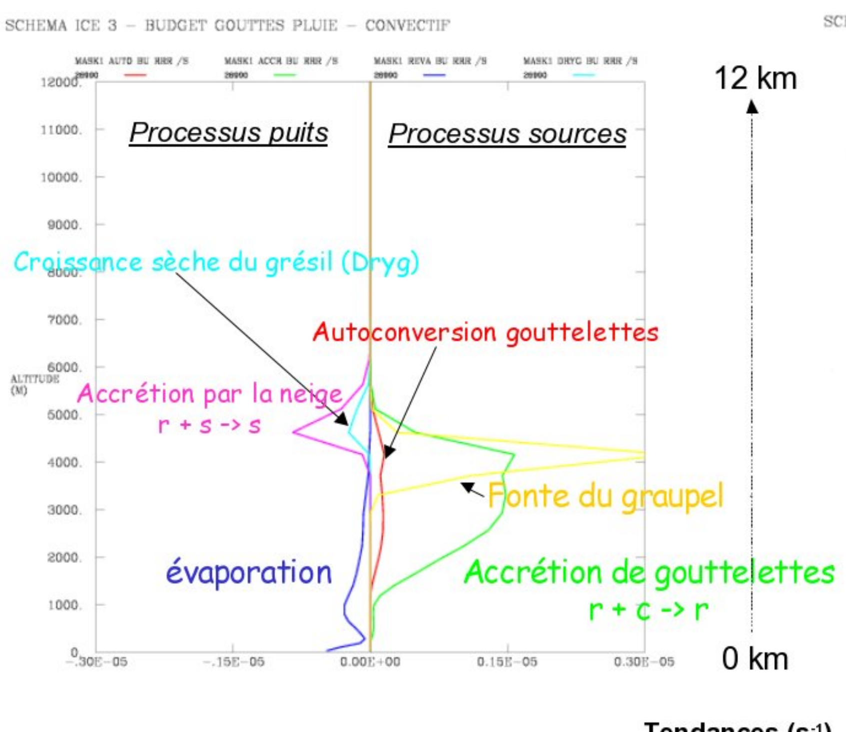


Budgets



Budgets

$$\frac{Dr_r}{Dt} = DRYG + ACC\_SNOW + ACC\_DROP + EVAP + MELT + CONV$$



Program DIAG

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

- variables derived from prognostic 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

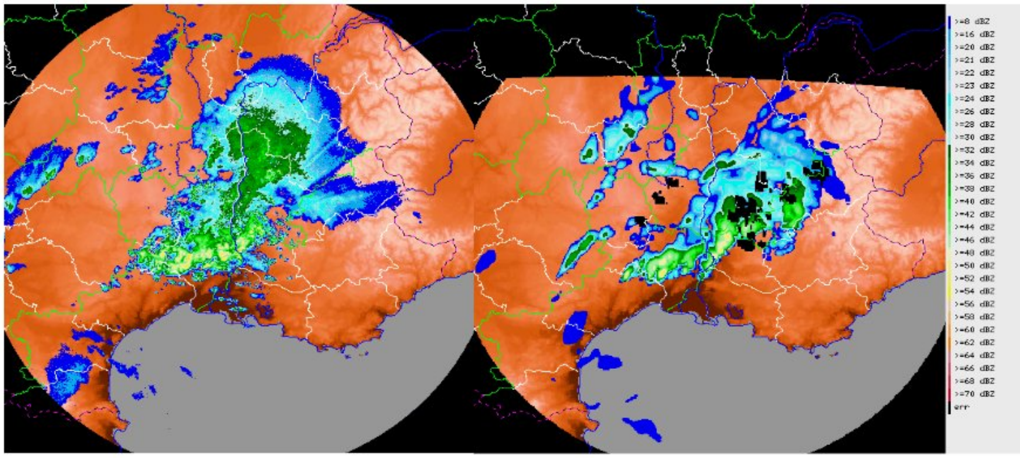
Example of DIAG1.nam :

```
 &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 /
```

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

Radar simulator

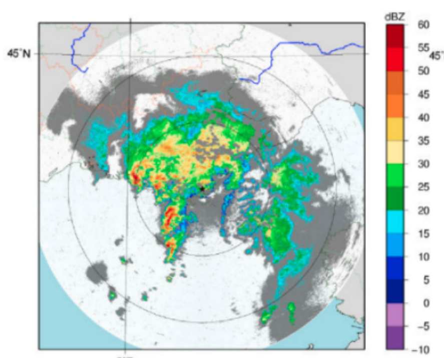


Réflectivités observées *Réflectivités simulées avec Méso-NH*

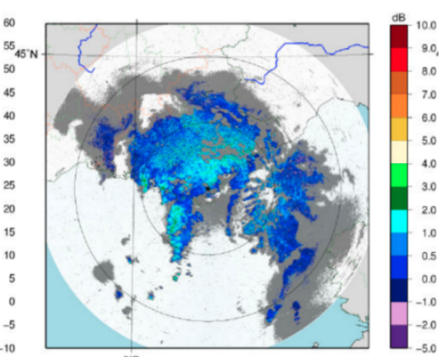
(radar de Bollène le 8 sep. 2002 à 21 UTC, élévation=1,2°)

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

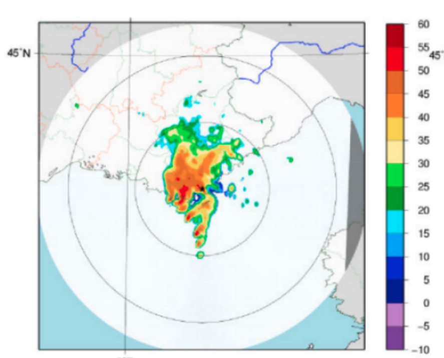
Polarimetric radar simulator, elevation = 1.4°



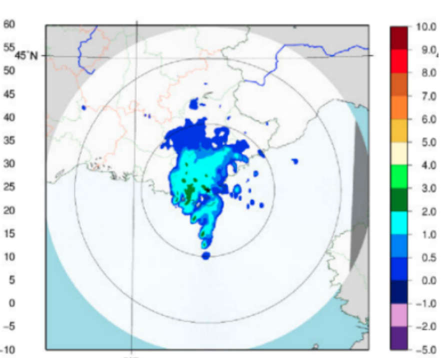
Zhh radar (dBZ)



Zdr radar (dB)

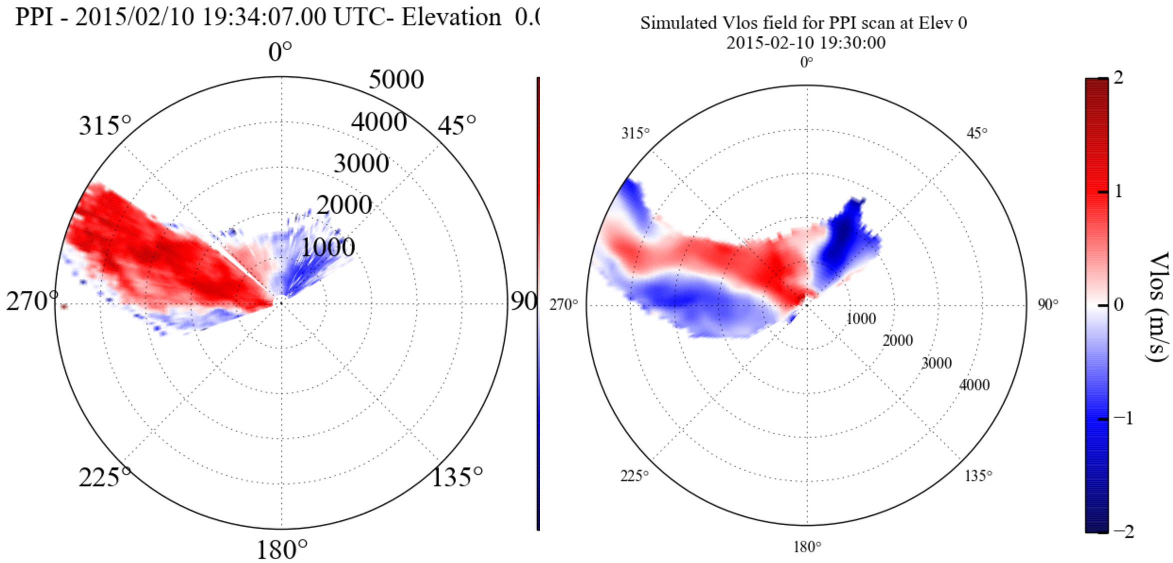


Zhh modèle (dBZ)



Zdr modèle (dB)

Radar simulator

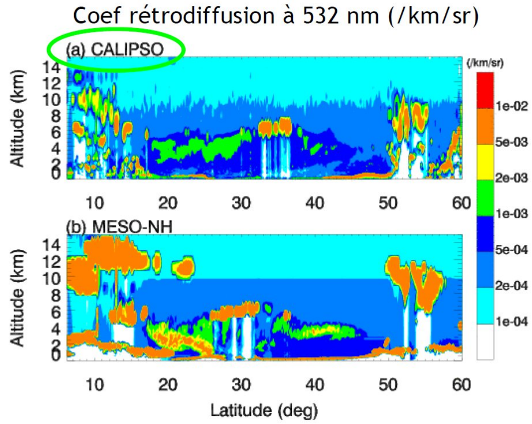


Observed radial velocity

Simulated radial velocity

Lidar simulator

Coef rétrodiffusion à 532 nm (/km/sr)

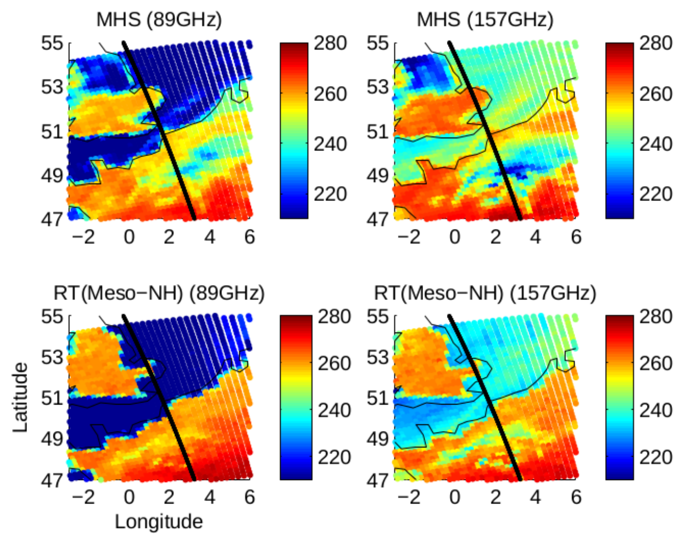


Chaboureau et al , QJRMS 2011

In &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

Satellite images simulator (brightness temperature)



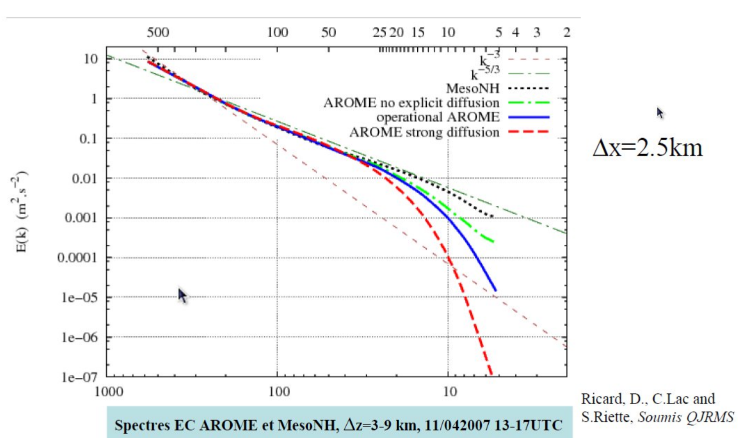
In &NAM_DIAG :

- CRAD_SAT= type of satellite
- Water vapor or IR channel
- with/without subgrid condensation scheme taken into account
- Highly recommended to use RTTOV (see the doc)

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'/
```



Notions of Fortran 90 and coding norms
Parallelization
Adaptation to large grids

Meso-NH training course

Coding norms : To clarify the reading of the code, to facilitate the integration of a new code

• FORTRAN 90 : Style : Free format (up to 132 characters per line !): no blank line, each row begins at the 1st column. Continuation character = &. Capital letters (small letters only for the comments). Comment character = !
Block Structures : DO/END DO ; IF / ELSE/ END IF; WHERE / ELSE WHERE / END WHERE ; CASE / SELECT / END CASE

• MODULES : Units of compilation
- Structure : MODULE name_module
déclarations …
END MODULE name_module
- Use in an other subroutine : USE nom_module

- MODD_ : Variables declaration : *ex : modd_ref.f90 common to all the nested models, modd_fieldn.f90 only for the model. 2D or 3D variables (i,j, :) only in modd_xxxn.f90.*
- MODN_ : Namelists declaration : *ex : modn_conf.f90*
- MODE_ : Functions : *ex : mode_thermo.f90*
- MODI_ : Module included the routine interface (dummy arguments) : ex: modi_advecuvw.f90 in advecuvw.f90 : Checking at the call that arguments are correct

For the USE MODD, the command ONLY is encouraged : USE MODD_xx, ONLY : VAR

• VARIABLES DECLARATION : 3 types

- Global : In all the routines using the MODD
- Dummy arguments :

```
REAL, DIMENSION(:,:,:),   INTENT(INOUT)    :: PUT, PVT, PWT ! Wind at t
```

- Local : Known only in the routine

– Préfixage des variables : norme DOCTOR

type status	INTEGER	REAL	LOGICAL	CHARACTER	TYPE
global or MODULE	N	X	L (not LP)	C	T (not TP,TS,TZ)
dummy arguments	K	P (not PP)	O	H	TP
local variables	I (not IS)	Z (not ZS)	G (not GS)	Y (not YS,YP)	TZ
loop control	J (not JP)	-	-	-	-

- Necessary to declare all the variables : IMPLICIT NONE

• ARRAY treatment

DYNAMICAL ALLOCATION :

REAL, DIMENSION(:,:), **ALLOCATABLE** :: ZZS
ALLOCATE (ZZS(IIU,IJU))
IF (**ALLOCATED** (ZZS)) …
DEALLOCATE (ZZS)

MATRICE TREATMENT :

ex : `ZVMOD( :, :) = SQRT(ZU( :, :)**2 + ZV( :, :)**2)`

• DISCRET OPERATORS :

- MEAN computation : Shuman operator (USE MODI_SHUMAN) :

ex: MZM -> $\overline{\alpha}^{z}$ for α localized at the mass point

DZF -> $\dfrac{\partial\alpha}{\partial z}$ for α localized at the flux point

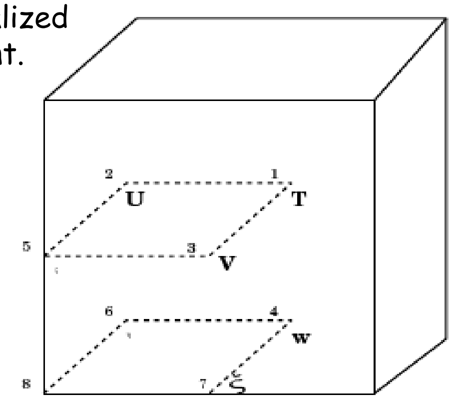
Principle :

- 1st letter : D for finite Difference operator, M for Mean
- 2nd letter : X for direction x, Y and Z
- 3rd letter : M for a field localized at the mass point, F for a field localized at the flux point

- GRADIANTS computation : (USE MODI_GRADIENT_M) :

ex : GX_M_U : Gradiant along X of a variable localized at a mass point with a result at the x-flux (U) point.

shuman.f90

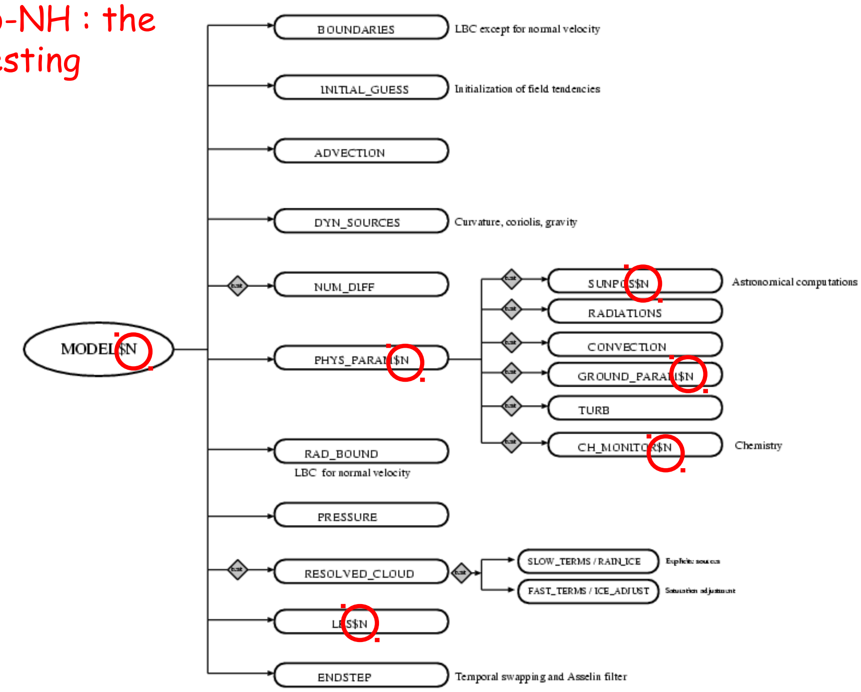



```
!     ####################
      MODULE MODI_ADVECUVW
!     ####################
!
INTERFACE
!
      SUBROUTINE ADVECUVW ( PUT,   PVT,   PWT,                       &
                            PRUCT, PRVCT, PRWCT,                     &
                            PRUS,  PRVS,  PRWS                       )
!
!
REAL, DIMENSION(:,:,:),   INTENT(IN)    :: PUT, PVT, PWT ! Wind at t
!
REAL, DIMENSION(:,:,:),   INTENT(IN)    :: PRUCT     ! contravariant
REAL, DIMENSION(:,:,:),   INTENT(IN)    :: PRVCT     !  components
REAL, DIMENSION(:,:,:),   INTENT(IN)    :: PRWCT     ! of momentum
!
REAL, DIMENSION(:,:,:),   INTENT(INOUT) :: PRUS, PRVS, PRWS ! Sources of Momentum
!
END SUBROUTINE ADVECUVW
!
END INTERFACE
!
END MODULE MODI_ADVECUVW
!
!
!
!     ###########################################################
      SUBROUTINE ADVECUVW ( PUT,   PVT,   PWT,                       &
                            PRUCT, PRVCT, PRWCT,                     &
                            PRUS,  PRVS,  PRWS                       )
!     ###########################################################
!
!!****  *ADVECUVW * - routine to compute the advection terms of momentum
!!
!!    PURPOSE
!!    -------
!!      The purpose of this routine is to compute the three advection terms
!!    of each component of the momentum, written in flux form.
!!      The advection velocity is taken as the contravariant form of
!!    the momentum for extension to non-cartesian geometry and
!!    conformal projection cases. The different sources terms are stored for
!!    the budget computations.
```

```
!!    AUTHOR
!!    ------
!!          J.-P. Pinty      * Laboratoire d'Aerologie*
!!          J.-P. Lafore     * Meteo France *
!!
!!    MODIFICATIONS
!!    -------------
!!      Original    06/07/94
!!      Corrections 06/09/94 (J.-P. Lafore)
!!                  02/11/94 (J.Stein)   extrapolation under the ground
!!                  16/03/95 (J.Stein)   remove R from the historical variables
!!                  01/04/95 (Ph. Hereil J. Nicolau) add the budget computation
!!                  16/10/95 (J. Stein)     change the budget calls
!!                  19/12/96 (J.-P. Pinty)  update the budget calls
!!                  07/11/02 (V. Masson)    update the budget calls
!!
!-------------------------------------------------------------------------------
!
!*       0.    DECLARATIONS
!              ------------
!
USE MODD_BUDGET
!
USE MODI_SHUMAN
USE MODI_BUDGET
!
IMPLICIT NONE
!
!*       0.1   Declarations of dummy arguments :
!
REAL, DIMENSION(:,:,:),   INTENT(IN)    :: PUT, PVT, PWT ! Wind at t
!
REAL, DIMENSION(:,:,:),   INTENT(IN)    :: PRUCT     ! contravariant
REAL, DIMENSION(:,:,:),   INTENT(IN)    :: PRVCT     !  components
REAL, DIMENSION(:,:,:),   INTENT(IN)    :: PRWCT     ! of momentum
!
REAL, DIMENSION(:,:,:),   INTENT(INOUT) :: PRUS, PRVS, PRWS ! Sources of Momentum
!
!
!
!-------------------------------------------------------------------------------
```

```
!*       1.     COMPUTES THE ADVECTIVE TENDANCIES
!                     --------------------------------
!
PRUS(:,:,:) = PRUS(:,:,:)                                 &
             -DXM( MXF(PRUCT(:,:,:))*MXF(PUT(:,:,:)) )
IF (LBUDGET_U)  CALL BUDGET (PRUS,1,'ADVX_BU_RU')
!
PRUS(:,:,:) = PRUS(:,:,:)                                 &
             -DYF( MXM(PRVCT(:,:,:))*MYM(PUT(:,:,:)) )
IF (LBUDGET_U)  CALL BUDGET (PRUS,1,'ADVY_BU_RU')
!
PRUS(:,:,:) = PRUS(:,:,:)                                 &
             -DZF( MXM(PRWCT(:,:,:))*MZM(PUT(:,:,:)) )
IF (LBUDGET_U)  CALL BUDGET (PRUS,1,'ADVZ_BU_RU')
!
!
PRVS(:,:,:) = PRVS(:,:,:)                                 &
             -DXF( MYM(PRUCT(:,:,:))*MXM(PVT(:,:,:)) )
IF (LBUDGET_V)  CALL BUDGET (PRVS,2,'ADVX_BU_RV')
!
PRVS(:,:,:) = PRVS(:,:,:)                                 &
             -DYM( MYF(PRVCT(:,:,:))*MYF(PVT(:,:,:)) )
IF (LBUDGET_V)  CALL BUDGET (PRVS,2,'ADVY_BU_RV')
!
PRVS(:,:,:) = PRVS(:,:,:)                                 &
             -DZF( MYM(PRWCT(:,:,:))*MZM(PVT(:,:,:)) )
IF (LBUDGET_V)  CALL BUDGET (PRVS,2,'ADVZ_BU_RV')
!
!
PRWS(:,:,:) = PRWS(:,:,:)                                 &
             -DXF( MZM(PRUCT(:,:,:))*MXM(PWT(:,:,:)) )
IF (LBUDGET_W)  CALL BUDGET (PRWS,3,'ADVX_BU_RW')
!
PRWS(:,:,:) = PRWS(:,:,:)                                 &
             -DYF( MZM(PRVCT(:,:,:))*MYM(PWT(:,:,:)) )
IF (LBUDGET_W)  CALL BUDGET (PRWS,3,'ADVY_BU_RW')
!
PRWS(:,:,:) = PRWS(:,:,:)                                 &
             -DZM( MZF(PRWCT(:,:,:))*MZF(PWT(:,:,:)) )
IF (LBUDGET_W)  CALL BUDGET (PRWS,3,'ADVZ_BU_RW')
!
!-------------------------------------------------------------------------------
!
END SUBROUTINE ADVECUVW
```

A specificity of Meso-NH : the _n relative to grid-nesting



- Routines without _n : can't use modules with _n. Variables relative to the horizontal domain (i,j) must be introduced by dummy arguments.

-> MODD without _n cannot include variables relative to the horizontal domain (i,j)

-> Variables of high-level routines in the model must be included in MODD while those of low-level routines must be included with dummy arguments.

RULES

- If a subroutine *yyy.f90* calls a function or a subroutine *aaa* and is the only one to call it, *aaa* can be called by *yyy.f90* after a CONTAINS.
If another subroutine *zzz.f90* needs *aaa*, then *aaa.f90* must be created to avoid duplication code.

- To help the developers, a namelist NAM_BLANK exists associated to a MODN_BLANK and a MODD_BLANK with different types of variables ready to be used : you have only to declare MODD_BLANK in your routine :

XDUMMY1...8, NDUMMY1...8, LDUMMY1...8, CDUMMY1...8
in EXSEG1.nam i.e. : &NAM_BLANK XDUMMY1=100., CDUMMY1='TRAINING' /

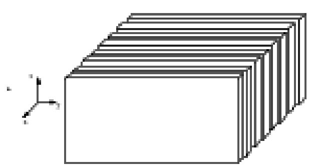
A FEW RULES for REPRODUCIBILITY
(result independent of the number of processors)

To avoid transformed functions :
ALL, ANY, COUNT, MAXVAL, MINVAL, SUM, MINLOC, MAXLOC : local application

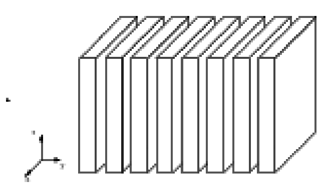
To avoid anticipated exit of a loop :
EXIT, CYCLE and RETURN, GOTO

General view : Replace
« if the process has converged for every points, we stop » (EXIT, CYCLE, RETURN)
By
« we compute on all the points where the process has not yet converged » (WHERE)

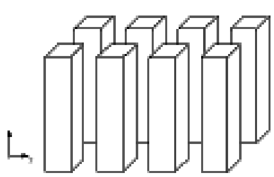
PARALLELIZATION : 3 types of decomposition
Related to computer performance



CSPLIT = 'YSPLITTING' : by default
Adapted to Vector machines



CSPLIT = 'XSPLITTING' : adapted to
Vector machines



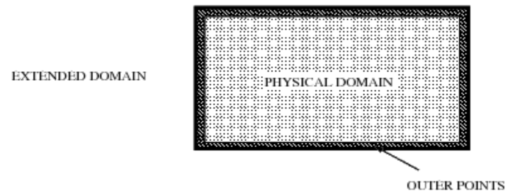
CSPLIT = 'BSPLITTING' : on scalar machines with
a lot of processors

PARALLELIZATION

To deal with LBC, the model arrays are over-dimensioned by one grid point :

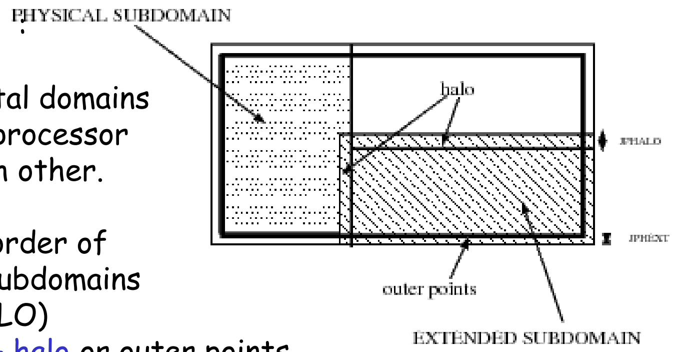
- Physical domain : inner area where the physical calculations are valid

- Extended domain : the arrays are defined on the whole domain included the outer points



Width of the additional area : **JPVEXT=1, JPHEXT = 1 (JPHEXT=3 for WENO5 in CYCL)**

Horizontal decomposition for parallelization :



The physical domain is splitted into horizontal domains
Each subdomain is allocated on a different processor
The physical subdomains do not overlap each other.

Finite differences require data along the border of adjacent physical subdomains -> Extended subdomains
The overlap area = the Halo (Width = JPHALO)
Extended subdomain = physical subdomain + halo or outer points
Until now JPHALO=1. With WENO5, JPHALO=3.

A variable is local when it refers to the subdomain and its value differs for each processor
A variable is global when it refers to the whole domain. Some variables are suffixed by _ll
e.g. NIMAX_ll for the physical domain and NIMAX for the physical subdomain

PARALLELIZATION (documentation available on the web site)

All the steps parallelized in Méso-NH :

PGD, NEST_PGD, PREP_IDEAL, PREP_REAL, SPAWNING, RUN, DIAG

mpirun **-np ${MPI_TASKS_TOTAL} -ppn ${MPI_TASKS_PER_NODE}**

Just an exception : SPECTRE

mpirun **-np 1 -ppn 1**

- pour PREP_IDEAL_CASE & MESONH

  &NAM_DYNn_PRE CPRESOPT= 'ZRESI' /

- que pour PREP_REAL_CASE

  &NAM_REAL_CONF CPRESOPT= 'ZRESI' /

- que pour MESONH

  &NAM_DYNn CPRESOPT= 'ZRESI' /

Nbre processeurs max = DimX . DimY

Problème Mémoire fréquent lors de la montée en résolution

1ère erreur fréquente : Mémoire insuffisante

Utiliser le résultat de la commande sacct -o :
RSSMax ou MaxRSS : Mémoire utilisée sur le nœud le plus consommateur

Doit être inférieur à 64 GB sur beaufix/prolix par ex.

Si supérieur, diminuer le nombre de processeurs par nœud.

Problème Mémoire fréquent lors de la montée en résolution

2ème message d'erreur fréquent , Problème de Mémoire pour les buffers MPI , genre :

An error occurred in MPI_Bsend …

MPI_ERR_BUFFER: invalid buffer pointer ...

- Diagnostique : pas assez de mémoire pour écrire/lire en entier un champs 3D sur le processeur 0 qui est chargé de faire les I/O
- Solution : augmenter le buffer prévu, 40 MB par défaut, via la variable prévue à cet effet dans la namelist NAM_CONFZ (tous les programmes la lisent) , ici 100 MB :

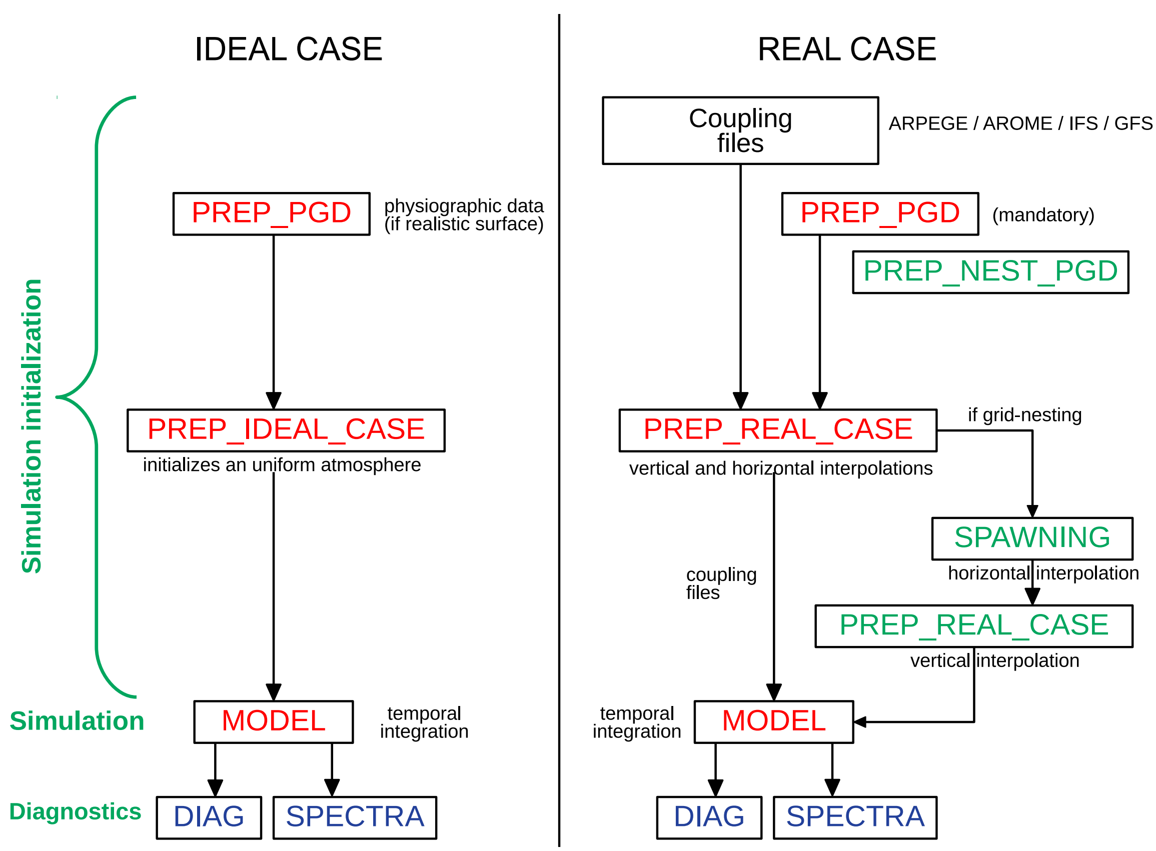
&NAM_CONFZ MPI_BUFFER_SIZE=100 /

MPI_BUFFER_SIZE recommandé = 2 fois la taille d'un champ 3D en Mo = NX*NY*NZ*8 / 1000000

Max = 2000 (2 Go)

Ideal case

MesoNH Tutorial Class 11-14 February 2019



Interests

- theorical study :
  from initial idealised fields
  in 1D,2D,3D configuration
  in cartesian geometry or conformal projection
- tests of validation

How does it work ?

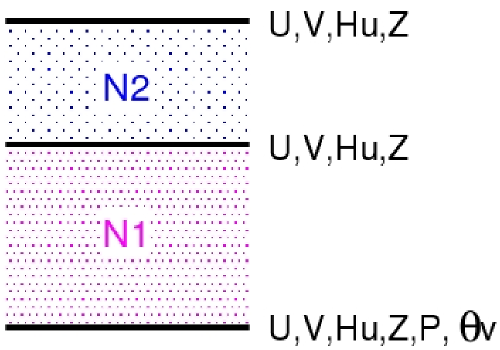
The user

1. specifies an uniform atmosphere from a profile
2. can add a perturbation
3. initializes the surface fields : idealised or realistic

Uniform state

Vertical profile defined by :

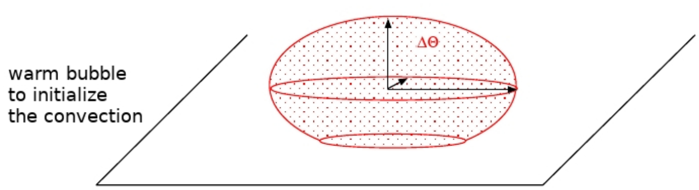
- some layers with constant Brunt-Väisälä frequency, wind and humidity at the interfaces : CIDEAL='CSTN'



- or data from a radio-sounding : CIDEAL='RSOU'

Analytical perturbations

- on thermodynamic fields



- on potential temperature : white noise for LES simulations
- on non-divergent components of the wind

namelist &NAM_PERT_PRE
to modify according to the user's needs : routine set_perturb.f90

Forcing terms

1D chronological serie to impose a large-scale environment :

- constant translation of the domain, geostrophic forcing (u_{frc},v_{frc})
- vertical transport : w_{frc}
- horizontal transport : $\left.\frac{\partial\theta}{\partial x}\right|_{frc}$, $\left.\frac{\partial\theta}{\partial y}\right|_{frc}$, $\left.\frac{\partial r_v}{\partial x}\right|_{frc}$, $\left.\frac{\partial r_v}{\partial y}\right|_{frc}$
- newtonian force : u_{frc}, v_{frc}, θ_{frc}, r_{vfrc}
- tendency : $\left.\frac{\partial\theta}{\partial t}\right|_{frc}$, $\left.\frac{\partial r_v}{\partial t}\right|_{frc}$, $\left.\frac{\partial u}{\partial t}\right|_{frc}$, $\left.\frac{\partial v}{\partial t}\right|_{frc}$

Surface fields

- Orography (namelist &NAM_CONF_PRE) :
  - idealised : flat (CZS='FLAT'), sinusoidal (CZS='SINE') or bell-shaped (CZS='BELL')
  - real : discretised (CZS='DATA') or read in a MesoNH PGD file
- Physiographic data (land-sea mask, type of cover SST, LAI, lay, sand...)
  - idealised : uniform
  - realistic : MesoNH PGD
- Prognostic fields (ground temperatures `TG_SURF`, `_ROOT _DEEP`, water contents `WG_SURF`, `_ROOT _DEEP`)
  - idealised : uniform
  - realistic : from a file from an operational model or from a MesoNH file

PREP_IDEAL_CASE

PREP_IDEAL_CASE

- computation of the horizontal grid (cartesian or conformal) and vertical one
- interpolation of the atmospheric fields with respect to :
  - hydrostatic balance
  - possible geostrophic balance
  - correction of u, v, w by the pressure solver

  to verify the ground condition and the anelastic constraint
- computation of the profiles of the reference state (anelastic approximation)
- writing in a NetCDF file of all the fields necessary for a simulation (prognostic : u, v, w, θ, r_v diagnostic P, surface fields)

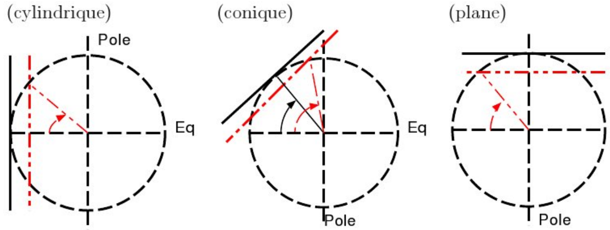
Choice of the horizontal grid

- number of points : $\boxed{\texttt{IMAX} = 2^p * 3^q * 5^r,\ \texttt{JMAX} = 2^s * 3^t * 5^u}$
- meshes : `DELTAX`, `DELTAY` (in meters)

1 2 3 4 5 6 8 9 10 12 15 16 18 20 24 25 27 30 32 36 40 45 48 50 54 60
64 72 75 80 81 90 96 100 108 120 125 128 135 144 150 160 162 180 192
200 216 225 240 243 250 256 270 288 300 320 324 360 375 384 400 405
432 450 480 486 500 512 540 576 600 625 640 648 675 720 729 750 768
800 810 864 900 960 972 1000 1024 1080 1125 1152 1200 1215 1250
1280 1296 1350 1440 1458 1500 1536 1600 1620 1728 1800 1875 1920
1944 2000 2025 2048 2160 2187 2250 2304 2400 2430 2500 2560 2592
2700 2880 2916 3000 3072 3125 3200 3240 3375 3456 3600 3645 3750
3840 3888 4000 4050 4096 4320 4374 4500 4608 4800 4860 5000 5120
5184 5400 5625 5760 5832 6000 6075 6144 6250 6400 6480 6561 6750
6912 7200 7290 7500 7680 7776 8000 8100 8192 8640 8748 9000 9216
9375 9600 9720 10000 10125 10240 10368 10800 10935 11250 11520
11664 12000 12150 12288 12500 etc

- Domain geometry
  - a **cartesian geometry** (`LCARTESIAN=T`) : Earth sphericity isn't take in account (for small scale phenomena),
  - **conformal projection**.

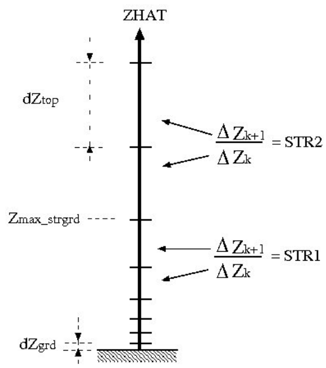
	Mercator	Lambert Conforme	Stéréographique Polaire
	(cylindrique)	(conique)	(plane)



	XRPK=0	0<XRPK<1	XRPK=1
		(-1<XRPK<0)	(XRPK=-1)
tangent	(XLAT0=0)	(0<XLAT0<90)	(XLAT0=90)
sécant	(0<XLAT0<90)	(0<XLAT0<90)	(0<XLAT0<90)
domaines :	lat. tropicales	lat. tempérées	lat. polaires

Choice of the vertical grid

number of points : KMAX
discretisation :



- manual : list of levels ZHAT(1), ZHAT(2),..., ZHAT(NKMAX)
- or analytical (logarithmic with z) : Computation of ZHAT from :

  _ ΔZ at ground (ZDZGRD)
  _ ΔZ at top (ZDZTOP)
  _ STRetching ($0 \leq \Delta Z^{k+1}/\Delta Z^{k} < 10\%$) :
  $ZSTRGRD$ for $z \in [0, ZZMAX\_STRGRD]$
  $ZSTRTOP$ for $z > ZZMAX\_STRGRD$

Vertical grid

A program is available on the website (Miscellaneous section)

```
&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
```

```
 Enter nb of levels KMAX and the level ZMAX_STRGRD:
30 2500
 Enter mesh size at groud and at the top:ZGRD, ZTOP
60 700
  Enter low- and high- level stretching: SGRD, STOP:
9 7
 altitude           3  :   60.0000000     -    60.0000000
 altitude           4  :   125.400002     -    65.4000015
 altitude           5  :   196.686005     -    71.2860031
 altitude           6  :   274.387756     -    77.7017517
 altitude           7  :   359.082672     -    84.6949158
 altitude           8  :   451.400146     -    92.3174744
 altitude           9  :   552.026184     -    100.626038
 altitude          10  :   661.708557     -    109.682373
 altitude          11  :   781.262329     -    119.553772
 altitude          12  :   911.575928     -    130.313599
 altitude          13  :   1053.61780     -    142.041870
 altitude          14  :   1208.44348     -    154.825684
 altitude          15  :   1377.20349     -    168.760010
 altitude          16  :   1561.15186     -    183.948364
 altitude          17  :   1761.65552     -    200.503662
 altitude          18  :   1980.20447     -    218.548950
 altitude          19  :   2218.42285     -    238.218384
```

```
&NAM_DIMn_PRE NIMAX=30, NJMAX=30 /     number of points in i and j

&NAM_CONF_PRE LCARTESIAN=.TRUE.,       cartesian geometry
              CEQNSYS='LHE',           choice of equation system
              CZS='BELL',              choice of orography
              CIDEAL='CSTN',           type of initialisation of the atmosphere
              LPERTURB=.T. /           add perturbation

&NAM_GRIDH_PRE XDELTAX=4 .E3, XDELTAY=4.E3,   mesh in X and Y
               XHMAX=1000., XAX=10.E3, XAY=10.E3   define
               NIZS=16, NJZS=16/                   the bell

&NAM_VER_GRID NKMAX=24,                number of vertical levels
              ZDZGRD=500., ZDZTOP=500. /   ΔZ at top and at ground

&NAM_PERT_PRE CPERT_KIND='TH',         type of perturbation
              XAMPLITH=1.5,            max amplitude for θ
              XCENTERZ=1500.,          height for Δθmax
size of perturbation XRADX=10.E3,XRADY=10.E3, XRADZ=600. /
```



```
&NAM_LUNITn CINIFILE='BILAN.1' /       name of output file

&NAM_LBCn_PRE CLBCX = 2*"OPEN",
              CLBCY = 2*"OPEN" /       lateral boundary conditions

&NAM_VPROF_PRE CTYPELOC='IJGRID',      variables to defined the profile
               NILOC=10, NJLOC=10,     localisation of vertical profile
               LGEOSBAL=.FALSE. /      no geostrophic balance

CSTN
2000 01 01 0.        date
2                    number of levels
285.                 θv at ground
100000.              P at ground
0. 20000.            height at all levels
10. 10.              zonal wind component at all levels
0. 0.                meridian wind component at all levels
0. 0.                relative humidity at all levels
0.01                 Brünt-Vaisala frequency at all layers
```

MODEL

EXSEG1.nam

```
&NAM_LUNITn CINIFILE = "BILAN.1" /initial file

&NAM_DYNn XTSTEP = 40.,   time step (s)
          CPRESOPT = "CRESI", LITRADJ = T,pressure solver
horizontal LHORELAX_UVWTH = T, LHORELAX_RV = T,
relaxation NRIMX = 6, NRIMY = 6, XRIMKMAX = 0.0005,
          LVE_RELAX = T,vertical relaxation
          /

&NAM_ADVn CUVW_ADV_SCHEME = "WENO_K" ,advection scheme for U,V
          NWENO_ORDER=5 , CTEMP_SCHEME='RK53'
          CMET_ADV_SCHEME = "PPM_01", /for θ,r,TKE

&NAM_PARAMn CCLOUD = "ICE3",CTURB = "TKEL",
             microphysic    turbulence
            CDCONV = "KAFR",CSCONV = "NONE",
             deep convection  shallow convection
            CRAD = "ECMW" /radiative scheme
```

```
&NAM_PARAM_KAFRn XDTCONV = 300., NICE = 1,
parameters for convection KAFR  LDIAGCONV = F /

&NAM_PARAM_RADn XDTRAD = 1800., XDTRAD_CLONLY = 900.,
parameters for radiative scheme LCLEAR_SKY = F /

&NAM_TURBn CTURBDIM = "1DIM", CTURBLEN = "BL89",
turbulence      LSUBG_COND = F,
parameters      LTURB_FLX = F, LTURB_DIAG = F /

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

&NAM_CONF CCONF = "START", configuration START or RESTA
          CEQNSYS = "LHE", Equation system
          NMODEL = 1, NVERB = 5,  number of models / verbosity
          CEXP = "CTRL0", CSEG = "SEG01",
          LLG = T /

&NAM_DYN XSEGLEN = 10800., segment length (s)
         XASSELIN = 0.2, LCORIO = T,
         XALKTOP = 0.001, XALZBOT = 14000. /
          parameters for vertical relaxation
```

```
&NAM_BACKUP XBAK_TIME(1,1) = 3600,  output files
            XBAK_TIME(1,2) = 7200, XBAK_TIME(1,3) = 10800/

&NAM_BUDGET CBUTYPE='CART', XBULEN=600., XBUWRI=1800.
 parameters     NBUIL=50, NBUIH=60, NBUJL=50,
 for           NBUJH=65, NBUKL=2, NBUKH=10,
 BUDGET         LBU_KCP=F, LBU_ICP=T, LBU_JCP=T /

&NAM_BU_RTH LBU_RTH=T, NADVXTH=1, NADVYTH=2, NADVZTH=2,
budget for θ    NREVATH=1, NCONDTH=2 /

&NAM_CONFIO LCDF4=T LLFIOUT=T LLFIREAD=F /IO netcdf/FM

&NAM_LES / LES diagnostics

&NAM_SERIES / temporal series

&NAM_BLANK /
```

Name of output file

Output files from the run are named :

CEXP.NMODEL.CSEG.00n

CEXP et CSEG must have EXACTLY 5 characters

Example :

CTRL0.1.SEG01.001
CTRL0.1.SEG01.002
CTRL0.1.SEG01.003

synchronous files

all the variables at a given time

CTRL0.1.SEG01.000

time-series files

temporal series, budget....

Simulations with SURFEX

PRE_IDEA1.nam :

With an input PGD file

```
&NAM_GRn_PRE CSURF='EXTE' /

&NAM_REAL_PGD CPGD_FILE = 'REUNION_PGD_1km5',
              LREAD_ZS= T, LREAD_GROUND_PARAM= T /

&NAM_LUNITn CINIFILE = 'REUNION_IDEA',
            CINIFILEPGD = 'REUNION_PGD_1km5' /
```

Without an input PGD file : 2 files in output(initial + PGD)

```
&NAM_GRn_PRE CSURF='EXTE' /

&NAM_LUNITn CINIFILE = 'REUNION_IDEA',
            CINIFILEPGD = 'REUNION_PGD_1km5' /
```

EXSEG1.nam :

```
&NAM_LUNITn CINIFILE = "BILAN.1" /
```

initial file

```
            CINIFILEPGD = "REUNION_PGD_1km5" /
```

PGD file associated to the initial file

Training Course : Ideal case

MesoNH Tutorial Class 3-5 October 2018

Presentation

Objectives :

- run an ideal case
- discover and modify namelists

For each simulation :

- create a new directory
- modify namelists to change the name of the outputs files

Preparation

cd /utemp/MNH-V5-4-1/MY_RUN/KTEST
mkdir TP_CAS_IDEAL
cd TP_CAS_IDEAL
tar xvf ∼rodierq/tp_ideal_makefile.tar
cd SIMULATION1
If it is not already done :
. /utemp/MNH-V5-4-1/conf/profile_mesonh-LXgfortran-MNH-V5-4-1-MPIVIDE-DEBUG

Simulation 1

1. Modify the namelists to have :
   - a square domain with 24 points with a mesh of 1 km
   - a time step of 16s
   - 1 hour of simulation
   - 4 output files (at 1200s, 1800s, 2400s and 3600s)
2. Run the simulation (PREP_IDEAL_CASE + MESONH)
3. Visualize the results
   - with ncl : plot_KW78.ncl
   - Convert files with conv2dia and plot with diaprog (example of directives in dir.KW78)

Simulation 2

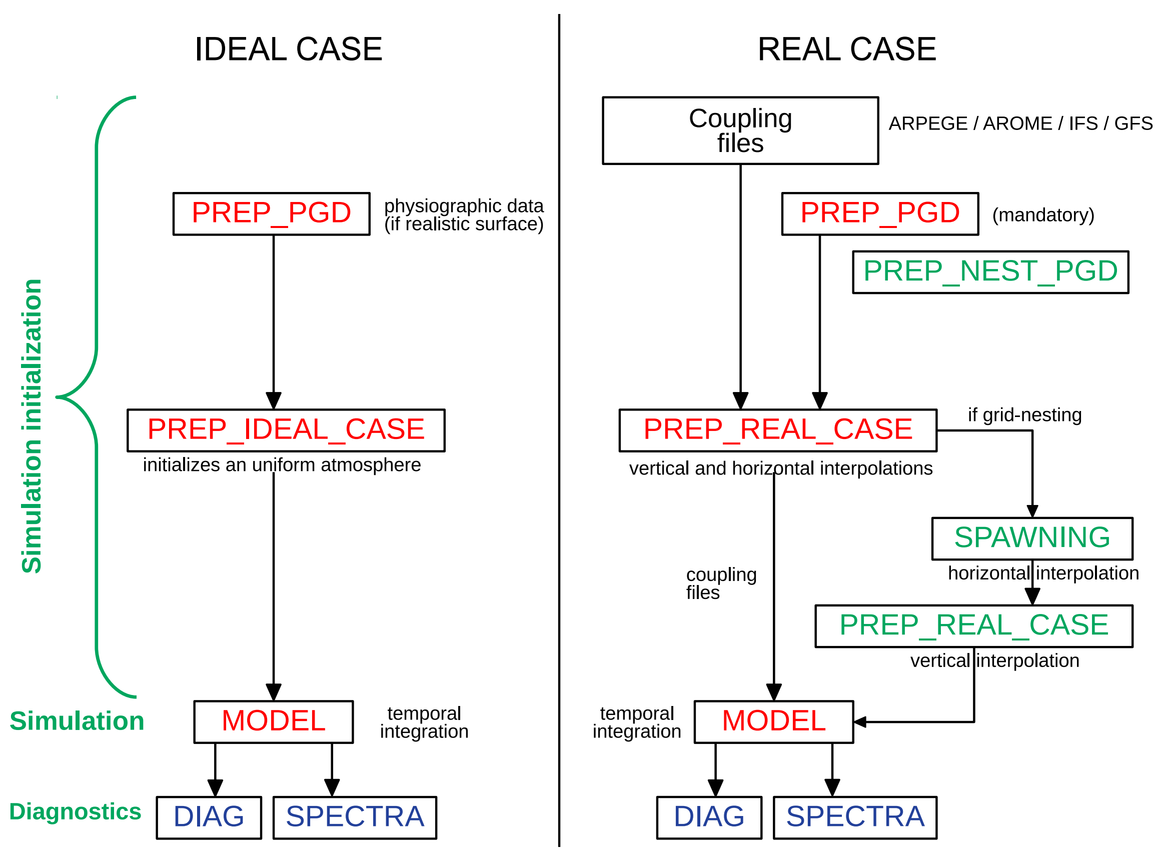
1. From the namelists created for the **simulation 1**, modify the namelists to add orography with this features :
   - a bell orography
   - in the center of the domain
   - with a heigth of 2000m
   - and a width of 2000m in x and y
2. Run the simulation
3. Compare with the simulation 1

Simulation 3

1. From the namelists created for the **simulation 1**, modify the namelists to remove the perturbation in θ
2. Run the simulation
3. Compare with the simulation 1

Real case

MesoNH Tutorial Class 11-14 February 2019



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'/surface cover database
&NAM_ZS YZS='gtopo30'/orography database
&NAM_ISBA YCLAY='clay_fao',YSAND='sand_fao'/clay and sand fractions
```

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

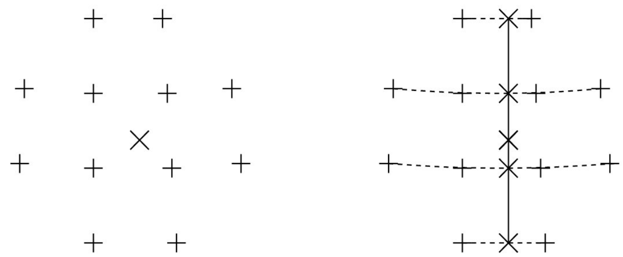
Atmospherical fields

Atmospherical data are issued from :

- model forecasts (GRIB) :
  - ECMWF : **extractecmwf**
  - ARPEGE, ALADIN, AROME, AROME-OM : **extractarpege** / **extrarome**
  - GFS
  - MOCAGE
  - 2018 : new centralized tool with EPyGrAM
- other MesoNH simulation

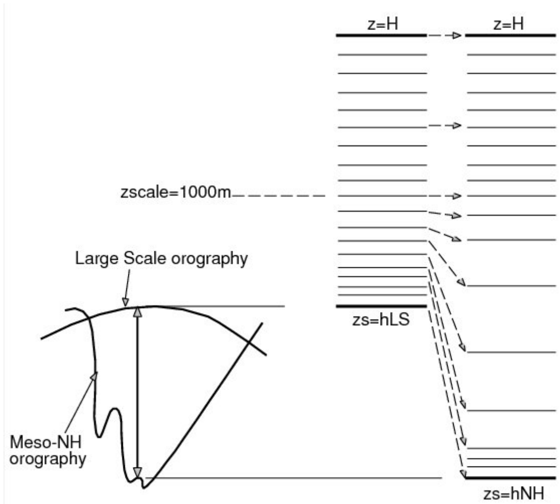
PREP_REAL_CASE

- Horizontal interpolation
  for GRIB files (IFS, ARPEGE, ALADIN, AROME or 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'

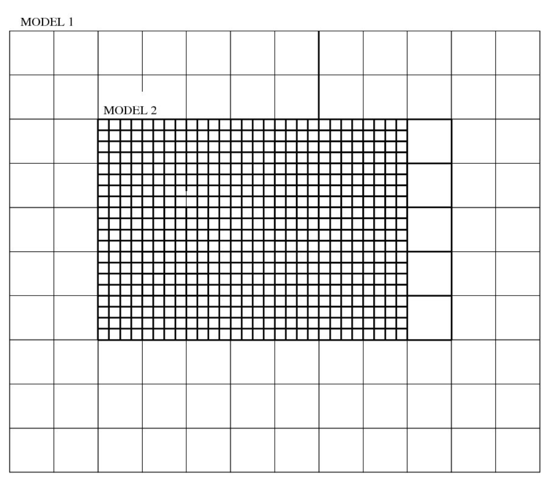
entre hLS et zscale

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
```

two-domain simulation



2 domains simulation : Grid-nesting

We need :

- a PGD file for every model
- All the PGDs must have the same averaged orography over their common area :
  PREP_NEST_PGD (the mean of orography for a SON file in the overlapping domain of its DAD file must be equal to the orography of the dad file at its resolution).

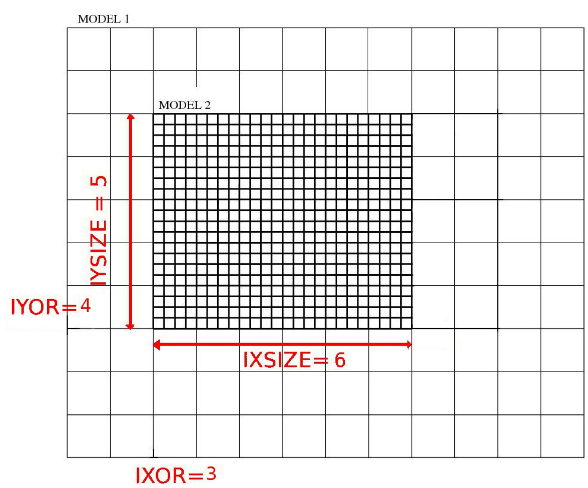
ALL PGD FILES MUST BE MADE AND "NESTED" BEFORE THE SIMULATION

- prepare initial 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',
   YINIFILETYPE='MESONH'
/
```




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

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

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 the initial 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
```

The SPAWNING stage must be followed by **PREP_REAL_CASE** if the domain is not flat

PREP_REAL_CASE

PRE_REAL1.nam :

```
&NAM_FILE_NAMES
      HATMFILE ='28JANVIER_21H.spa04', input file (spawned file)
      HATMFILETYPE='MESONH',
      HPGDFILE ='PGD_SON.neste1',
      CINIFILE ='28JAN21H_MODEL_2' /output name of prep_real_case
&NAM_REAL_CONF NVERB=5 /
&NAM_VER_GRID YZGRID_TYPE='SAMEGR' /
&NAM_PREP_SURF_ATM          namelist from SURFEX
       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 namelists ended by **n** are taken into 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", start/restart simulation
          NMODEL = 2, number of [father + son(s)] models
          CEXP = "CTRL0", CSEG = "SEG01" /

          name of the outputs = CEXP.Nmodel.CSEG.00(n)

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

```
&NAM_NESTING NDAD(2) = 1, 1 is the father of the son number 2
             NDTRATIO(2) = 4, ratio of the timestep for the son number 2
             XWAY(2) = 2. 1 = one-way; 2 = two-way interactions /

&NAM_BACKUP XBAK_TIME(1,1)=100/

&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" /
```

Training Course : Real case

MesoNH Tutorial Class 11-14 February 2019

Presentation

Objectives :

- run a MESONH simulation in real case
- understand the different steps with 1 or 2 models
- discover and modify the namelists

Please :
Modify only what is asked in the namelists

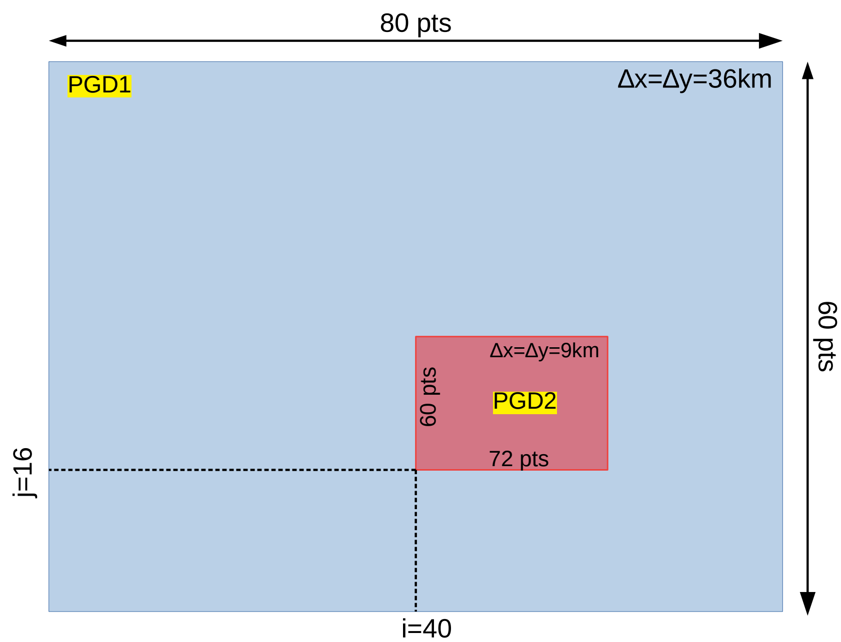
Preparation

cd /utemp/MNH-V5-4-1/MY_RUN/KTEST
mkdir TP_CAS_REEL
cd TP_CAS_REEL
tar xvf ~rodierq/tp_real_makefile.tar
You have now subdirectories numbered in the order of the steps requested. In each subdirectory, you will find the namelists to modify the files and the scripts named run_...
export PREP_PGD_FILES=rodierq/PGD
If it is not already done :
. /utemp/MNH-V5-4-1/conf/profile_mesonh-LXgfortran-MNH-V5-4-1-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 x-direction and 60 in y-direction
   - 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 x-direction and 60 in y-direction (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

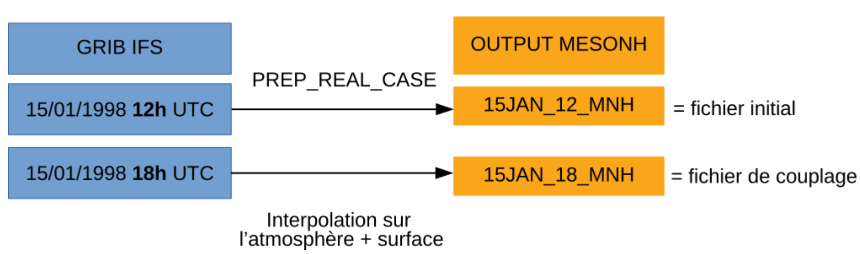
Creation of all the PGD files



Preparation of coupling files

The extraction of GRIB files is already done with extractecmwf. The files 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 namelist in order to have :
   - 1 domain
   - 1 hour of simulation
   - 4 output files (every 15 minutes)
   - a time step of 120 s
   - the output files must be named : **16J36.1.SEG01.00n**
2. Run the MESONH simulation

Segment 2

1. In the directory `005_run1`, modify the namelist in order to restart the simulation for 1 hour. The output files must be named : **16J36.1.SEG02.00n**
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 namelist) to make the horizontal interpolation from the dad's domain to the child's domain at 14h (end of segment 2)
2. In the directory 007_preal, modify the namelist 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 namelist in order to have :
   - 2 domains
   - 1 hour of simulation
   - 2 output files (every 30 minutes) for each domain
   - a time step of 120 seconds for the father and a ratio of 4 for the son
   - two-way interaction
   - the output files must be named : **16J36.1.SEG03.00n**
4. Run the MESONH simulation
5. In the directory 009_diag, run the step DIAG on the files you want