An introduction to SURFEX

SURFEX course

Program of the course

	09:30	09:45	10:00	10:30	11:00	11:30	12:00	14:00	14:30	15:00	15:30	16:00	16:30
Tuesday 12/03/2024	introduction	SURFEX general presentation *(Patrick Le Moigne)*		break	SURFEX installation and compilation -PART I *(Marie Minvielle)*		LUNCH	SURFEX installation and compilation - PART II *(MM)*	break	PGD and ECOCLIMAP *(MM)*			
Wednesday 13/03/2024	PREP *(MM)*		PGD and PREP exercises *(Antoine Verrelle and MM)*	break	PGD and PREP exercises *(AV and MM)*		LUNCH	ISBA presentation *(Aaron Boone)*	break	Practical exercises : ISBA *(AV and MM)*			
Thursday 14/03/2024	Town scheme : TEB *(Valéry Masson)*		break	Practical exercises : TEB *(AV and MM)*		Water scheme : FLAKE *(PLM)*	LUNCH	Practical exercises : FLAKE *(AV and MM)*	break	Practical exercises : ISBA *(AV and MM)*			
Friday 15/03/2024	Data assimilation in SURFEX *(Bertrand Bonan)*		break	Practical exercises *(AV and MM)*		Conclusion discussion evaluation	LUNCH						

Attestation of stage ?

Documentation for the course

Presentation and exercices :

http://www.cnrm.meteo.fr/surfex/spip.php?article423

Documentation : scientific documentation and user's guide (efficient research tool)export versions, bugfixes, etc. :

http://www.umr-cnrm.fr/surfex/

Outline

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

Main Principles

Let's begin, what is SURFEX ?

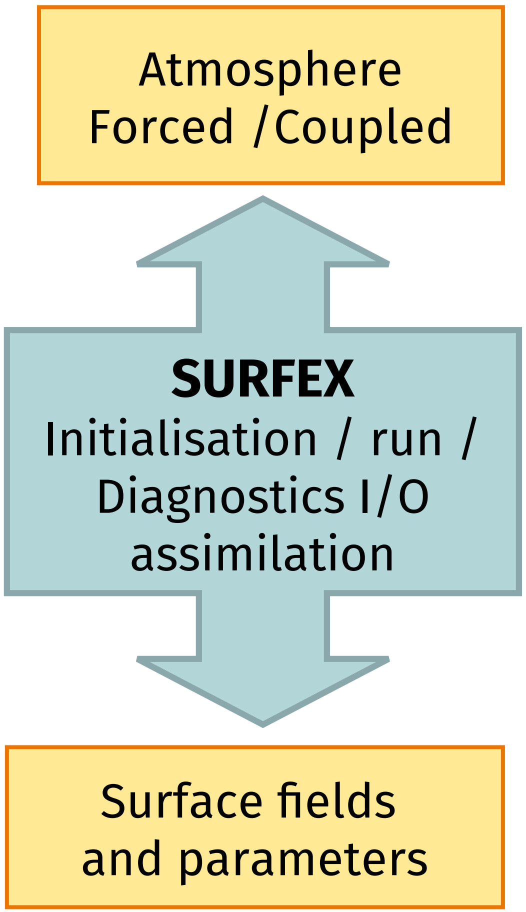
SURFEX means « surface externalisée »

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

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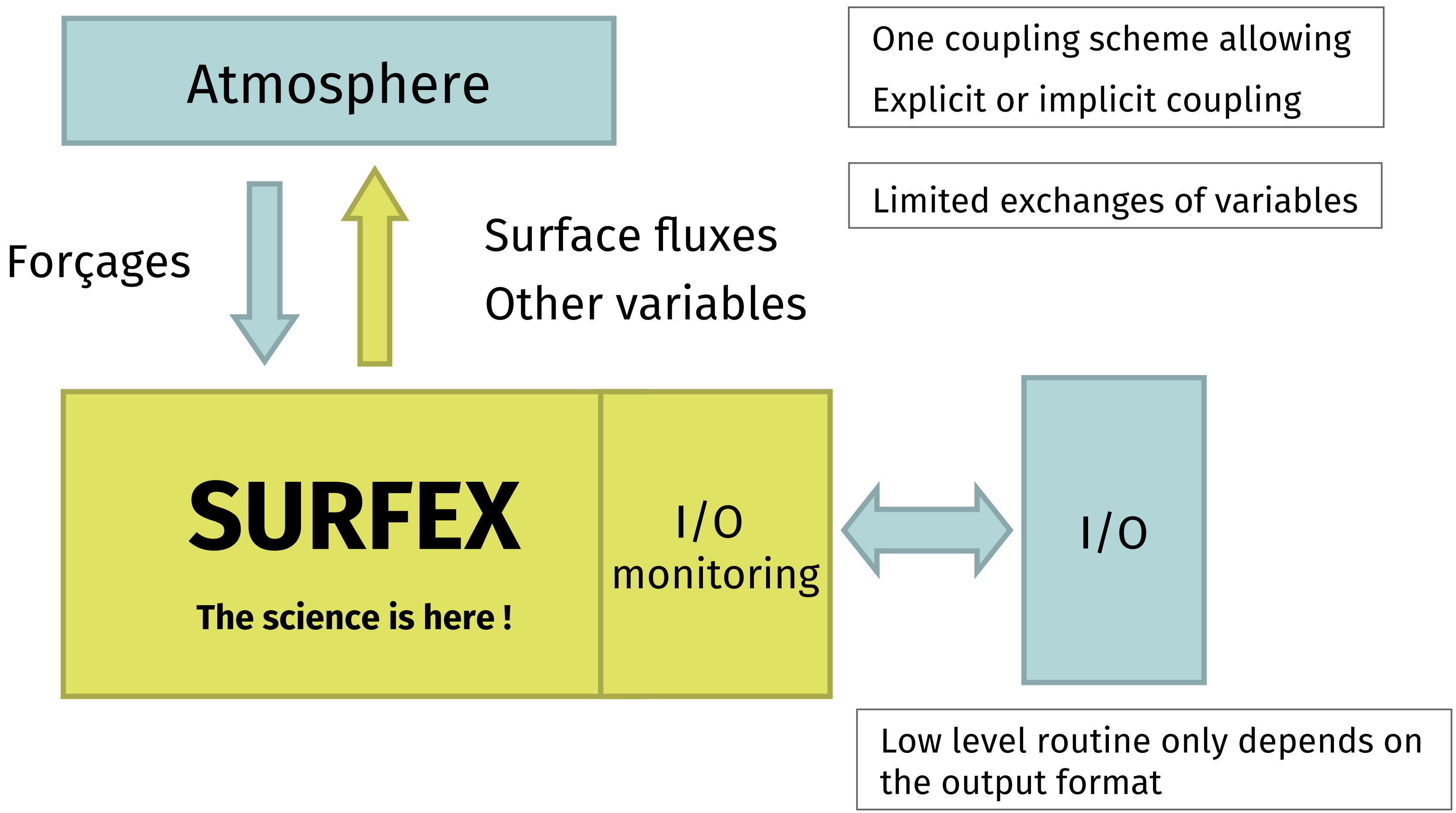
Coupling and interfaces



SURFEX : history

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

- Scales : 1 m ㅍ 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+V5.38)
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	
V8.0	2016	CY43t1		
V8.1	Feb 2018		V5.4.0	CM6 (CY37t2+V8 or V7.3)

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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-AROME
- ARPEGE (2015/2016)

Offline operational applications

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

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

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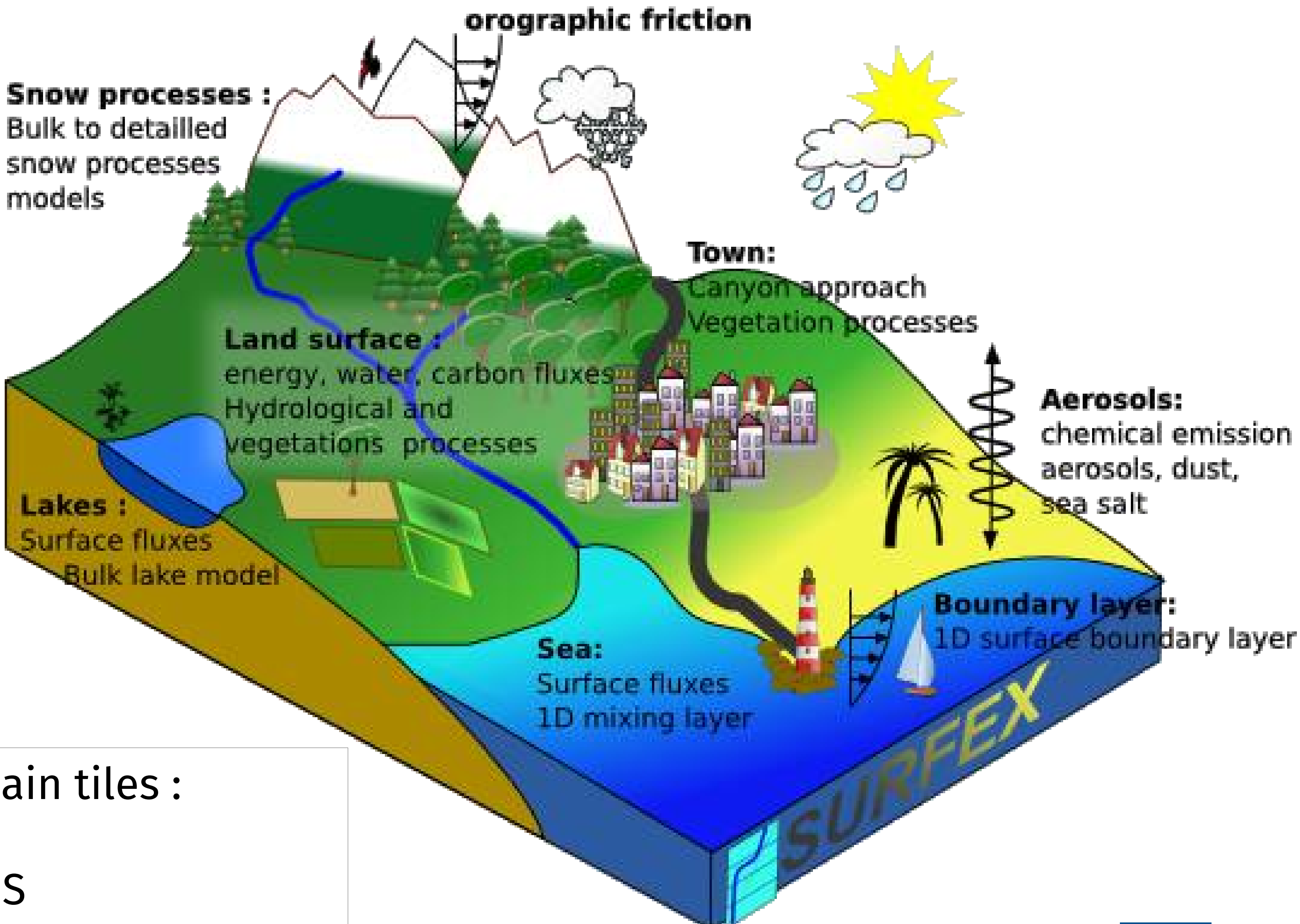
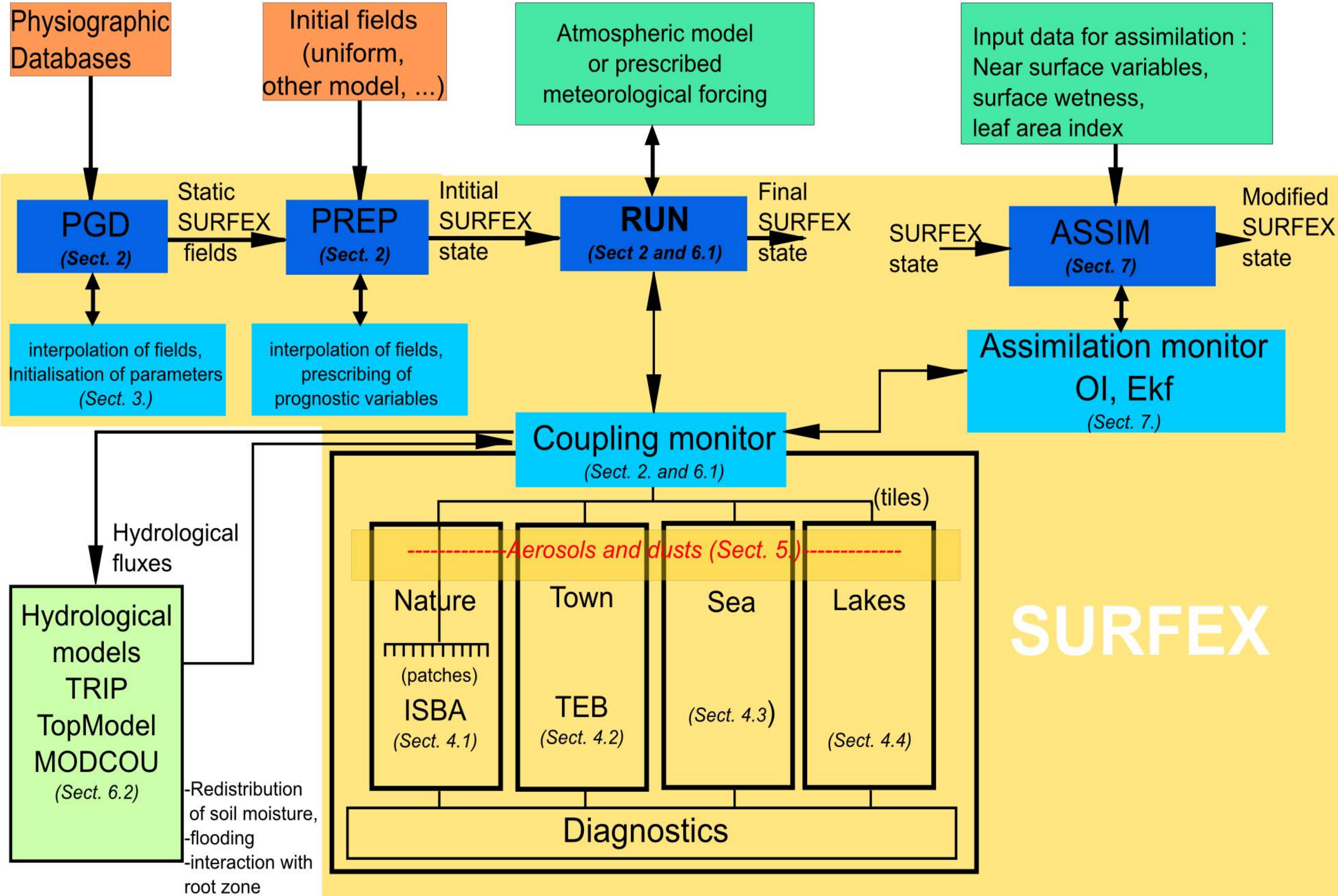


Four main tiles :

- SEA
- LAKES
- NATURE (natural surfaces)
- TOWN



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

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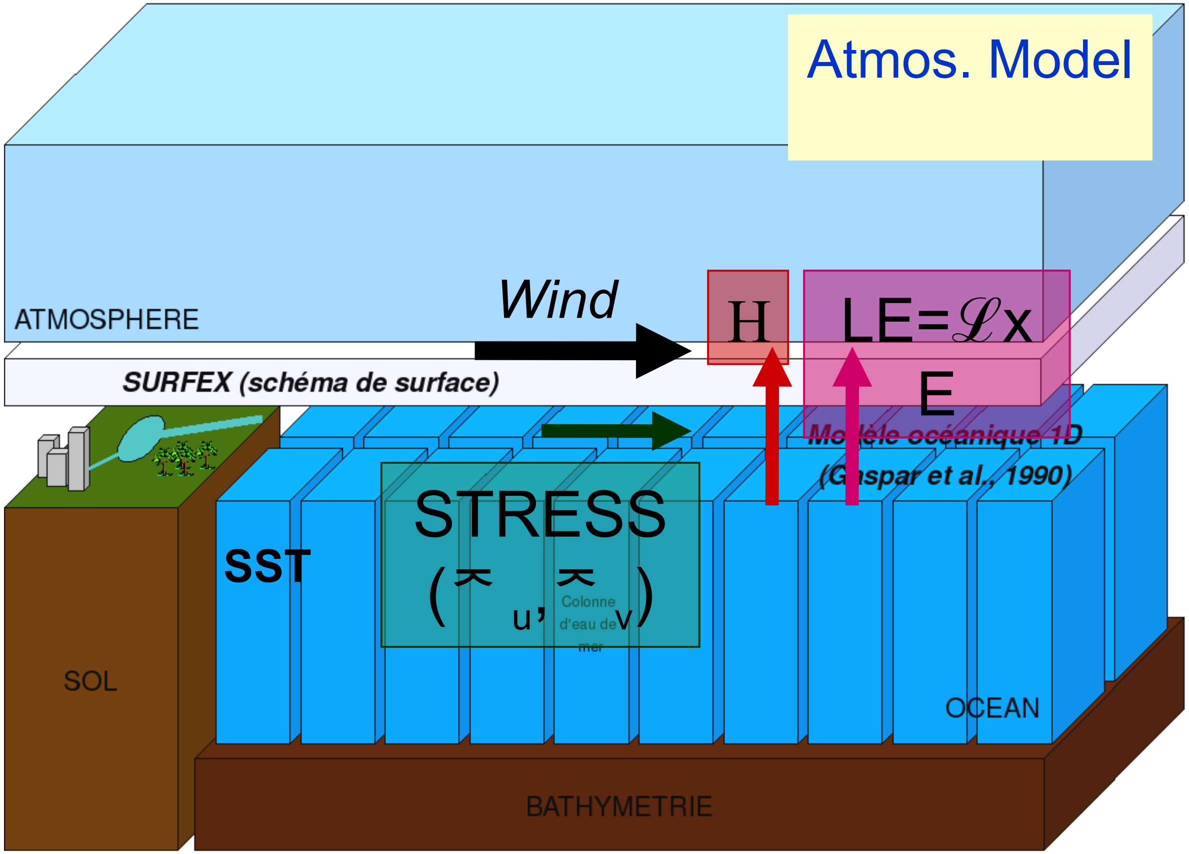
Sea / Ocean

- ECUME multi-campaign parametrisation (prescribed SST)

- 1D ocean mixing layer model Gaspar et al., 1990



Lakes : Flake model

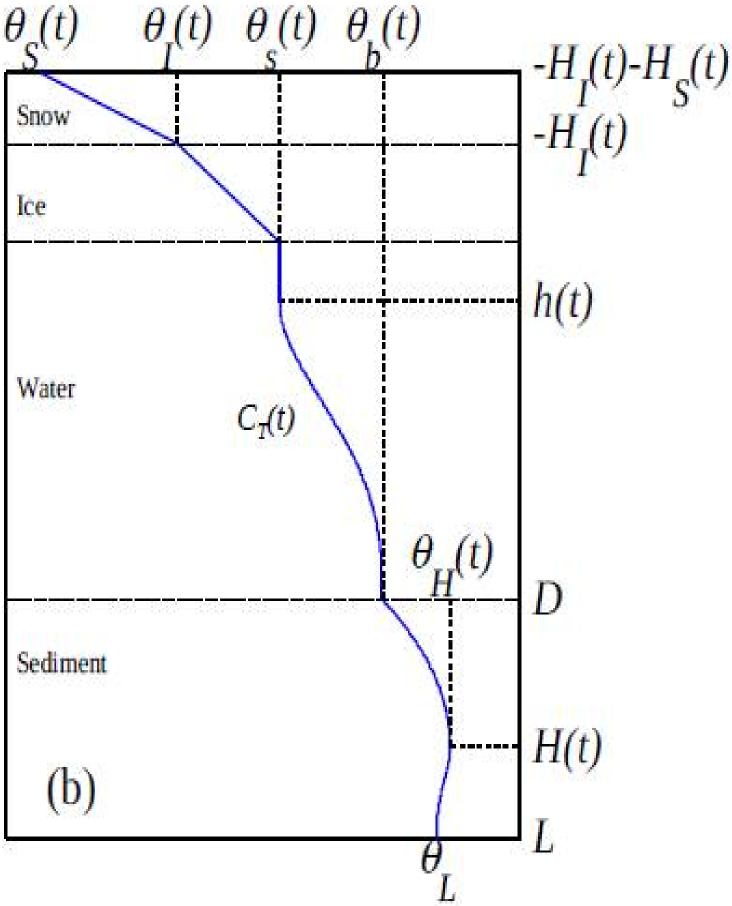
Simple model, based on assumed shape of the temperature profile

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.



http://www.flake.igb-berlin.de/

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)

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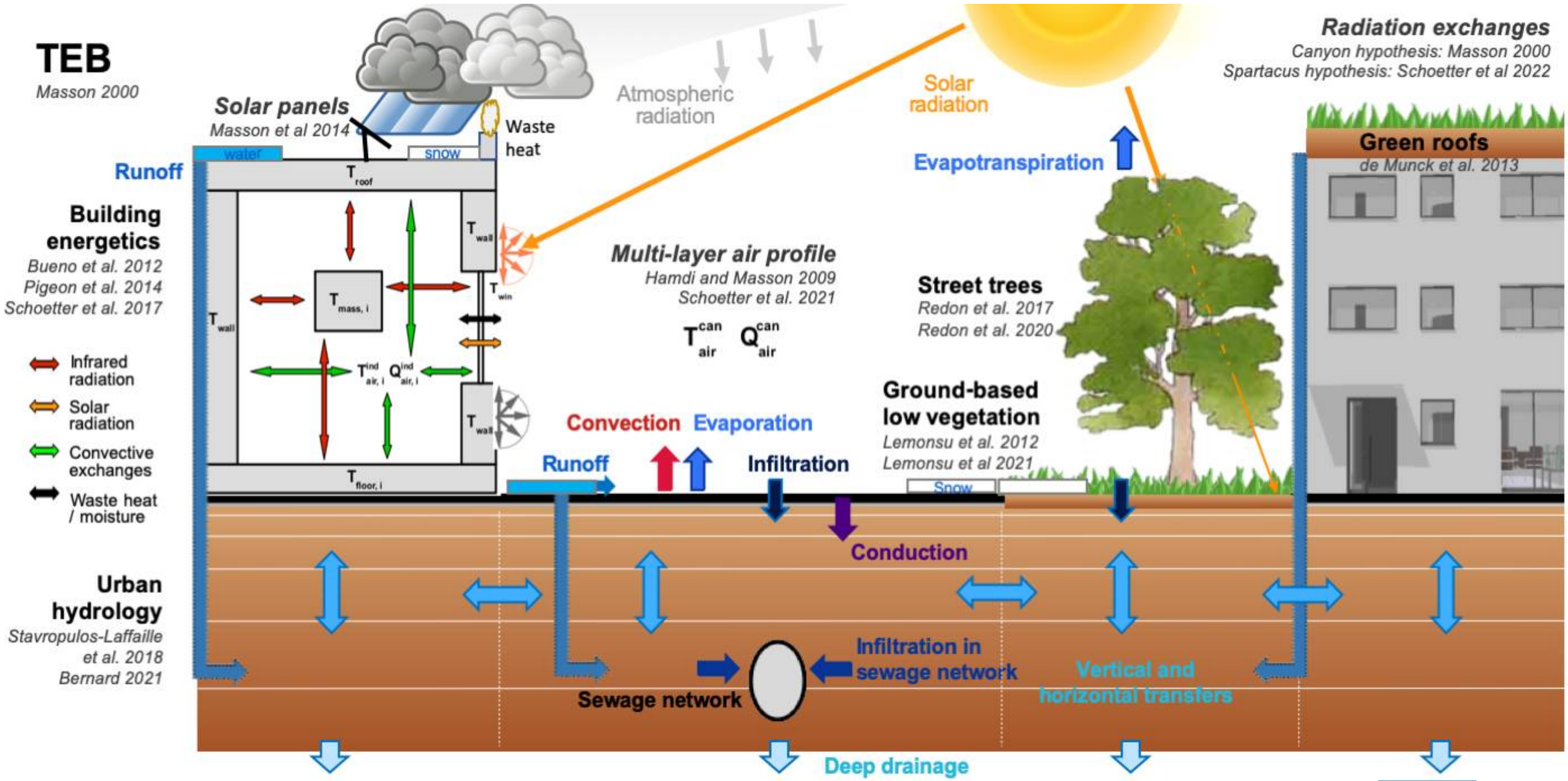
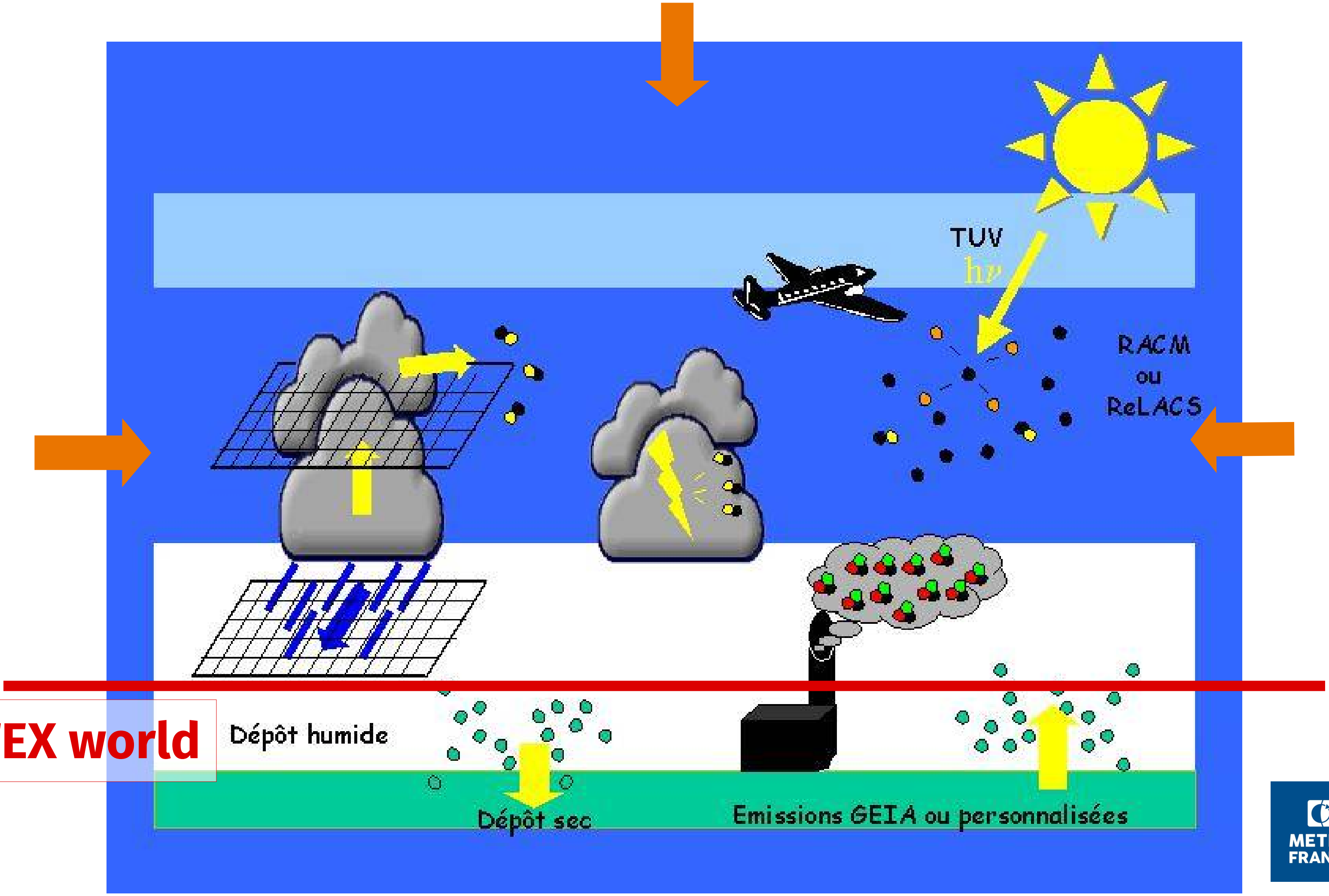
Town : TEB



TEB
Masson 2000
Solar panels
Masson et al 2014
water
snow
Waste heat
Atmospheric radiation
Solar radiation
Radiation exchanges
Canyon hypothesis: Masson 2000
Spartacus hypothesis: Schoetter et al 2022
Green roofs
de Munck et al. 2013
Runoff
Evapotranspiration
Building energetics
Bueno et al. 2012
Pigeon et al. 2014
Schoetter et al. 2017
Infrared radiation
Solar radiation
Convective exchanges
Waste heat / moisture
Multi-layer air profile
Hamdi and Masson 2009
Schoetter et al. 2021
Street trees
Redon et al. 2017
Redon et al. 2020
Ground-based low vegetation
Lemonsu et al. 2012
Lemonsu et al 2021
Convection
Evaporation
Runoff
Infiltration
Snow
Conduction
Urban hydrology
Stavropulos-Laffaille et al. 2018
Bernard 2021
Infiltration in sewage network
Vertical and horizontal transfers
Sewage network
Deep drainage

Chemical scheme

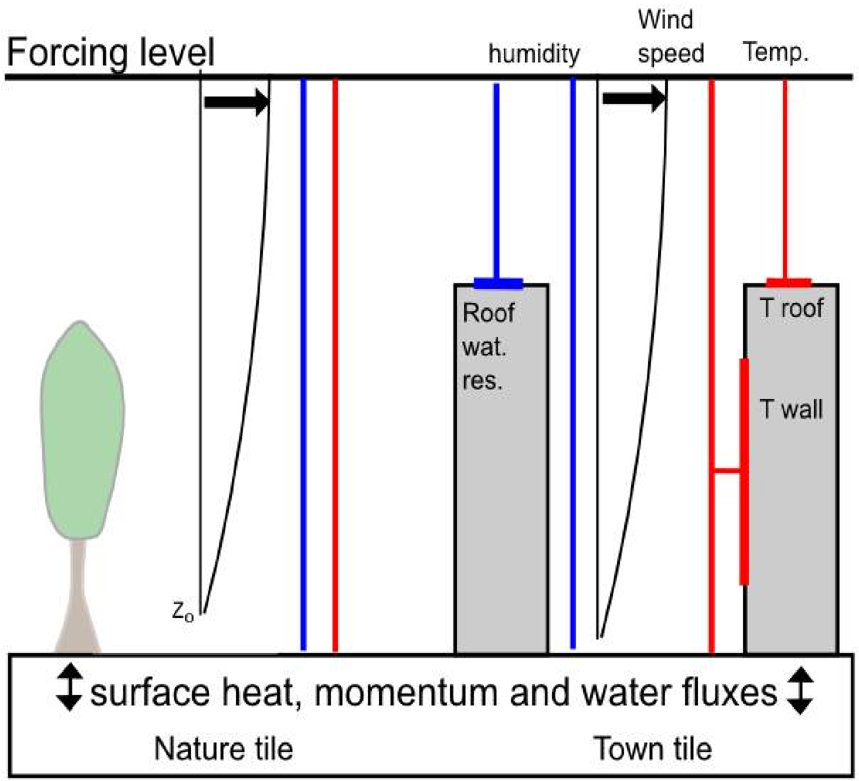
From local (dx=1 km) to synoptic scale (dx=50 km)
http://www.aero.obs-mip.fr/mesonh



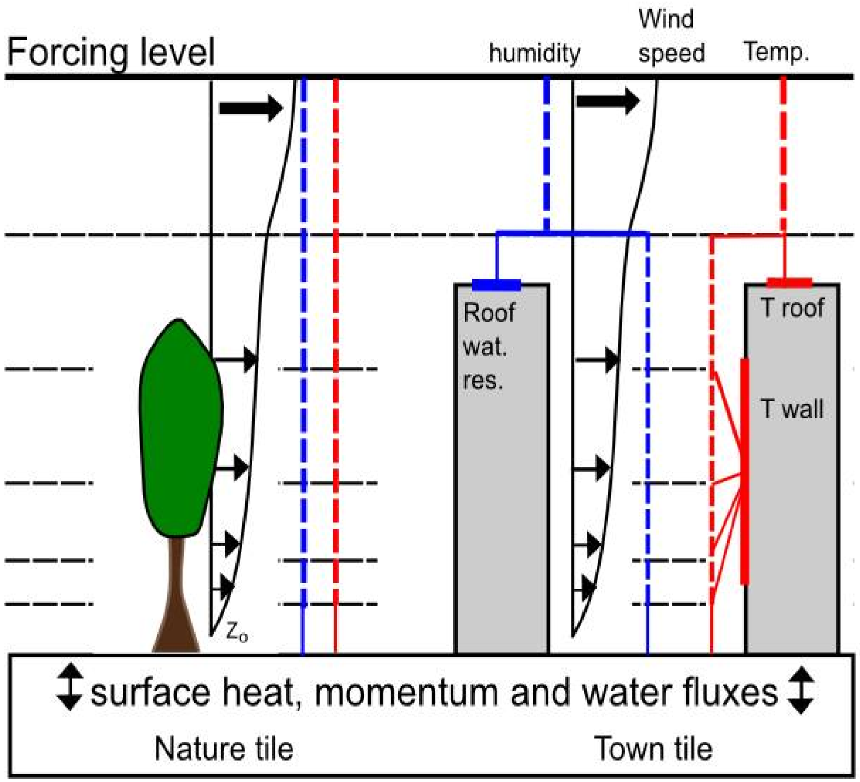
SURFEX world

The SBL model (Canopy)

without SBL model



with SBL model

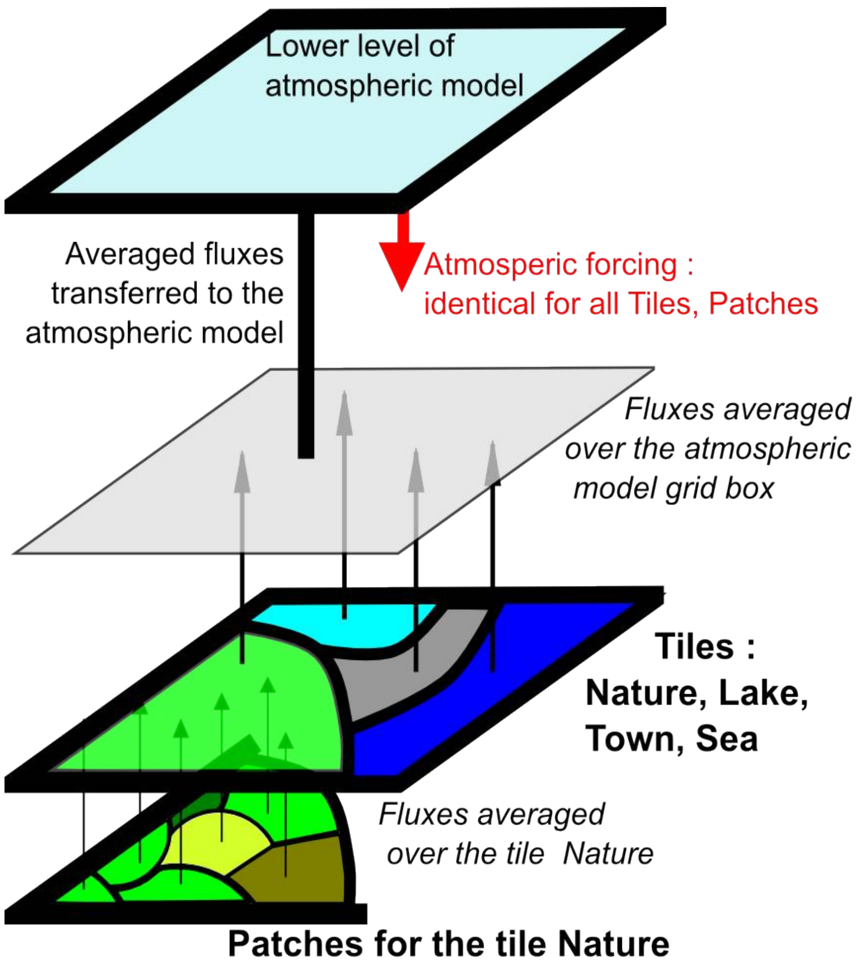


Describing the surface

How can we represent the surface heterogeneity in a grid ?

<u>Tiling approach :</u>

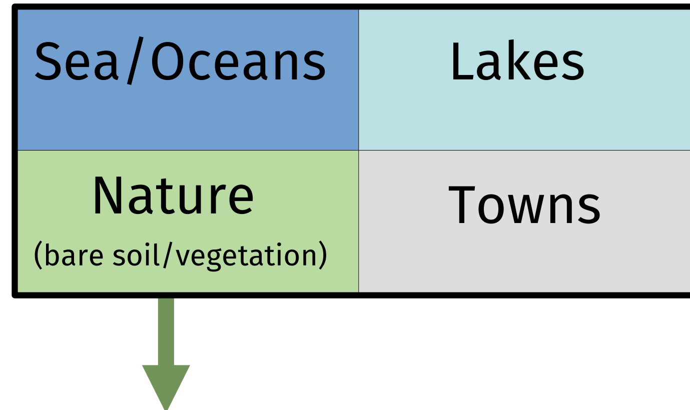
- Within a grid mesh, the surface is divided into several homogeneous component.
- Each component receives the same atmospheric forcing
- Each component calculates fluxes
- Fluxes are aggregated and returned to the atmosphere
- No horizontal transfert within the surface



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.



- The tile Nature is divided into 19 natural functional types

NO (no vegetation)	**C4** (summer crops)	**BOGR** (boreal grassland)
ROCK (bare rock)	**IRR** (irrigated crops)	**SHRB** (shrub)
SNOW (permanent snow and ice)	**GRAS** (grassland)	**TEBE** (temperate broadleaf evergreen)
TEBD (temperate boradleaf deciduous)	**TROG** (tropical grassland)	**TENE** (temperate needleleaf evergreen)
BONE (boreal needleleaf evergeen)	**PARK** (peat bogs, parks, gardens)	**BOBD** (boreal broadleaf deciduous)
TRBE (tropical broadleaf evergreen)	**TRBD** (tropical broadleaf deciduous)	**BOND** (boreal needleleaf deciduous)
C3 (winter crops)		

Aggregation of functional types is possible in ISBA

Number of patches chosen by user

	19	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	1
ROCK	2	2	2	1	1	1	1	1	1	1	1	1	1
SNOW	3	3	3	2	2	2	2	1	1	1	1	1	1
C3	7	7	7	6	5	4	4	3	3	3	3	1	1
C4	8	8	8	7	6	5	4	3	3	3	3	1	1
GRASS	10	10	10	9	8	7	6	5	5	3	3	1	1
BOGR	18	10	10	9	8	7	6	5	5	3	3	1	1
TROG	11	11	10	9	8	7	6	5	5	3	3	1	1
IRR	9	9	9	8	7	6	5	4	4	4	3	1	1
PARK	12	12	11	10	9	8	7	6	4	4	3	1	1
TEBD	4	4	4	3	3	3	3	2	2	2	2	2	1
TRBD	13	4	4	3	3	3	3	2	2	2	2	2	1
TEBE	14	4	4	3	3	3	3	2	2	2	2	2	1
BOBD	16	4	4	3	3	3	3	2	2	2	2	2	1
SHRB	19	4	4	3	3	3	3	2	2	2	2	2	1
TRBE	6	6	6	5	3	3	3	2	2	2	2	2	1
BONE	5	5	5	4	4	3	3	2	2	2	2	2	1
TENE	15	5	5	4	4	3	3	2	2	2	2	2	1
BOND	17	5	5	4	4	3	3	2	2	2	2	2	1

Physiographic parameters

<u>The surface needs several types of parameters</u> :

- 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
- - ...

<u>Solutions</u> :

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

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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)

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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)

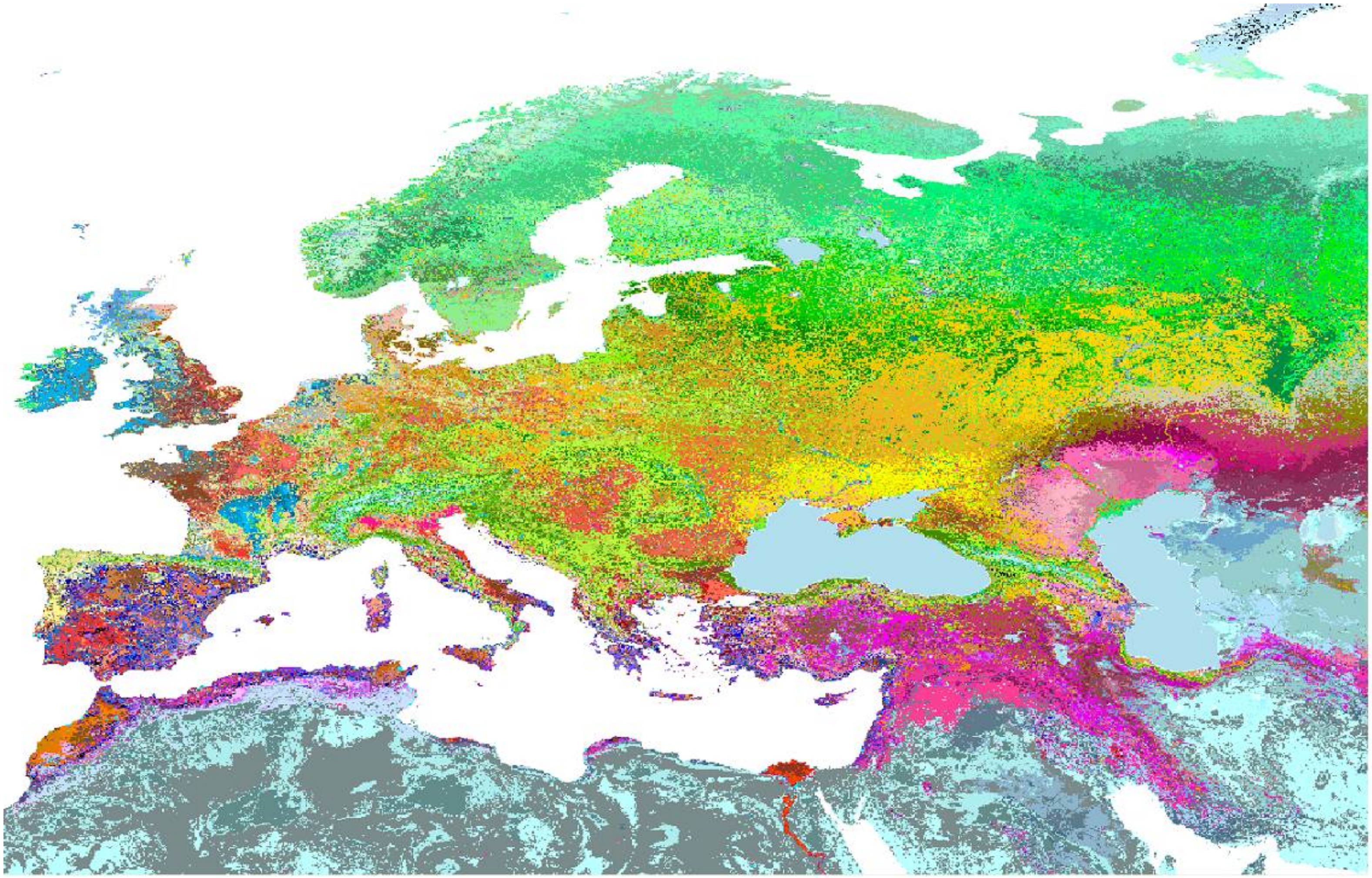
ECOCLIMAP I : global (215 covers)

ECOCLIMAP II Europe (273 covers)

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

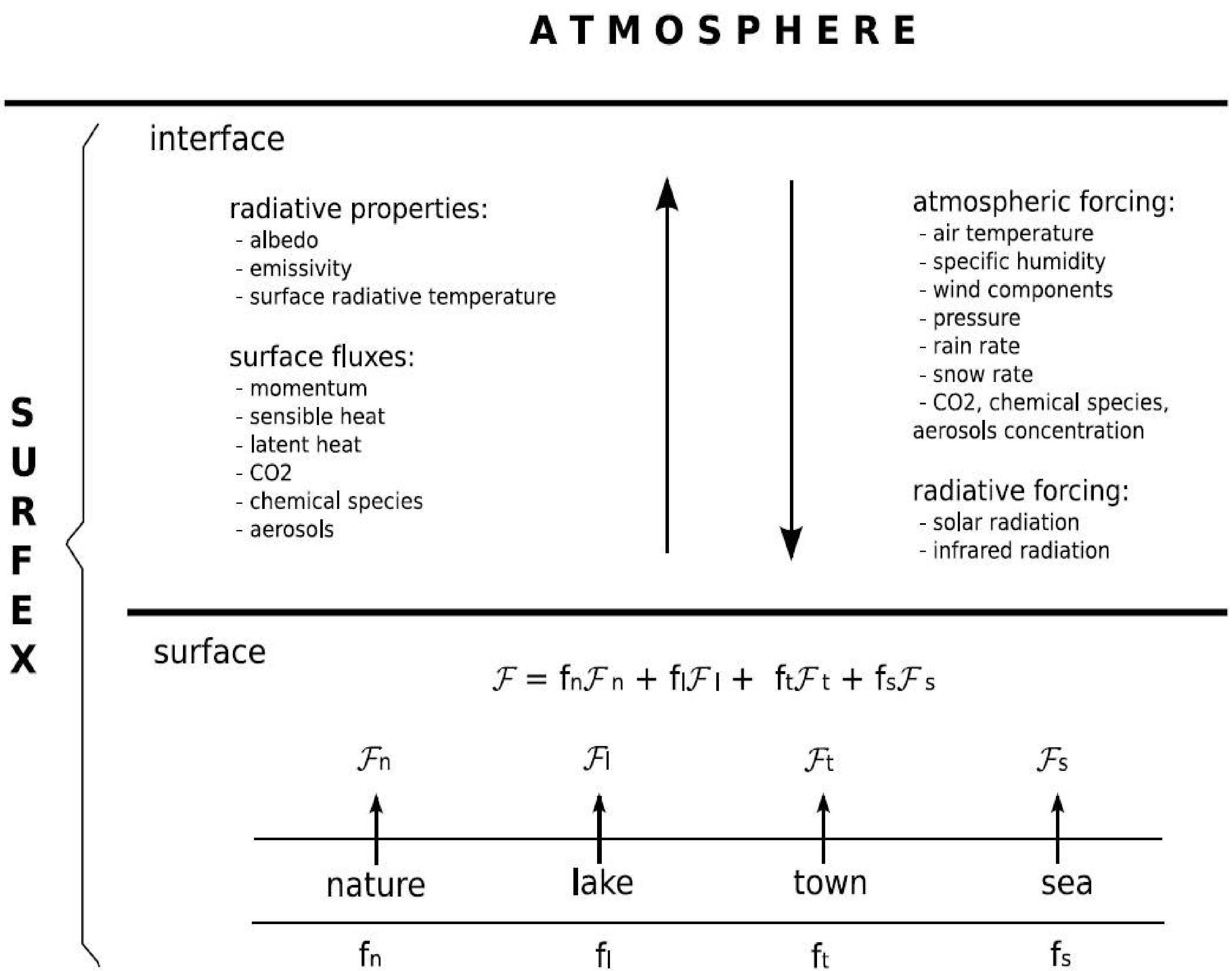
Constant surface parameters: visible / nir / uv albedos, minimum stomatal resistance…

ECOCLIMAP-II Europe



Interface with the atmosphere

Interface with the atmosphere



Coupling with the atmosphere

Explicit coupling (general case) :

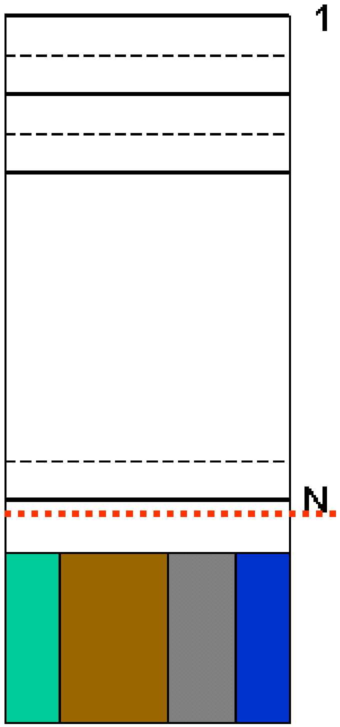
variables are provided at T (or T → T+DT)
Fluxes are returned averaged over T / T+DT

Offline : ASCII, binary, lfi, FA,
netcdf standardized interface

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

$$\begin{cases} H^+ = \rho C_p V_N^- C_H^- \left(\beta_S T_S^+ - \beta_N T_N^+\right) \\ \frac{C_s}{\Delta t}\left(T_S^+ - T_S^-\right) = R_n^+ - H^+ - LE^+ - G^+ \end{cases}$$

Upward sweep

Interface routines

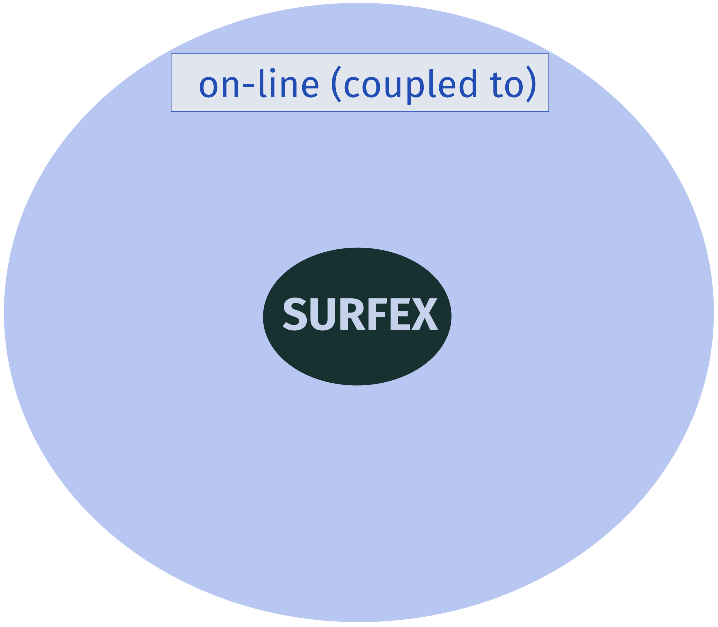
coupling_surf_atm : packing and call 4 main tiles

- 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

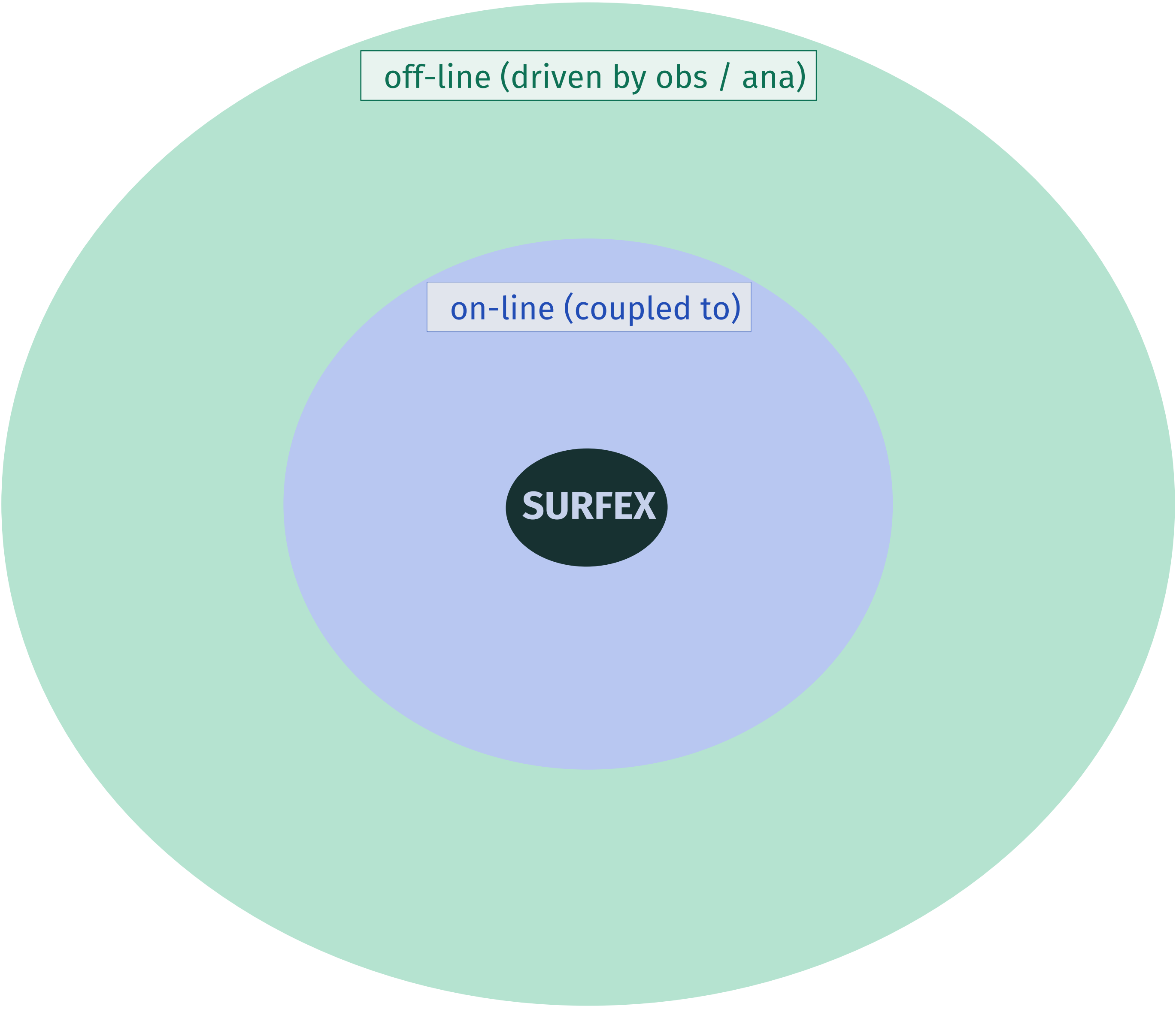
All coupling_xxx have the same arguments

SURFEX applications

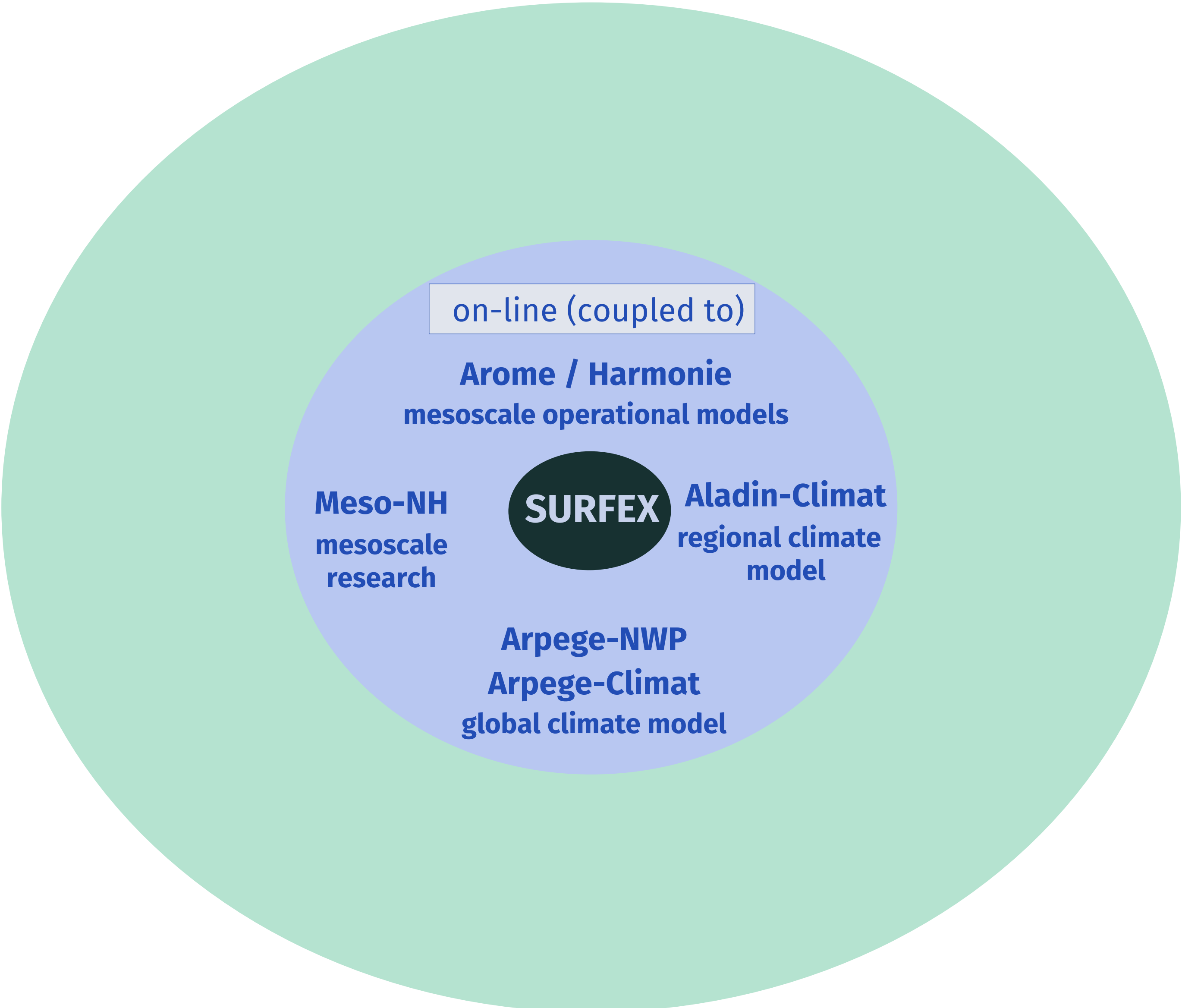
SURFEX applications



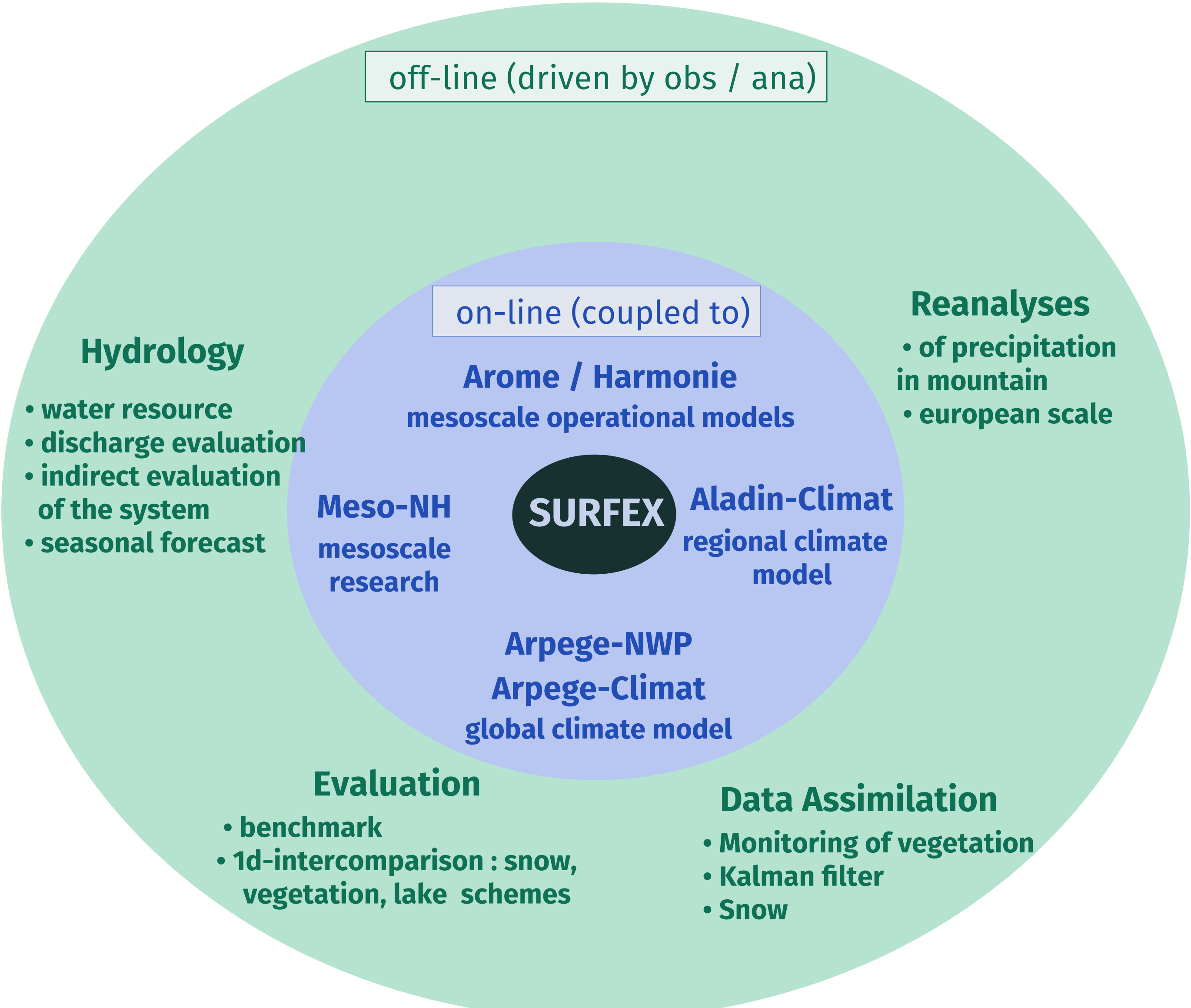
SURFEX applications



SURFEX applications



SURFEX applications



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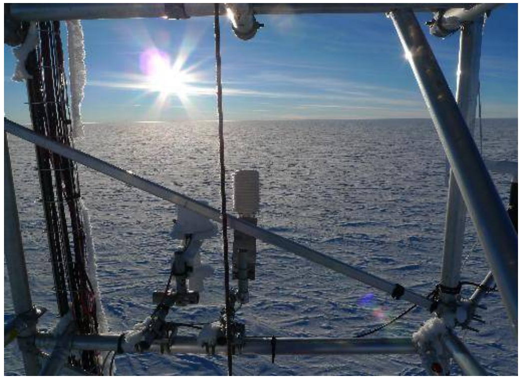
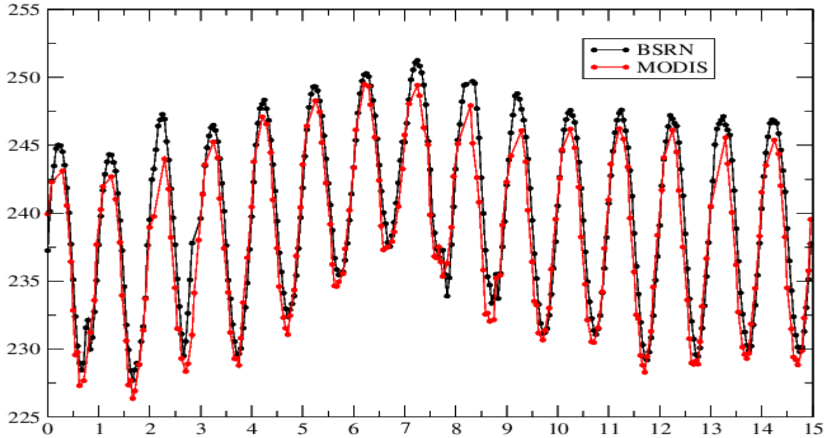
Inter-comparison of snow models: GABLS4 experiment

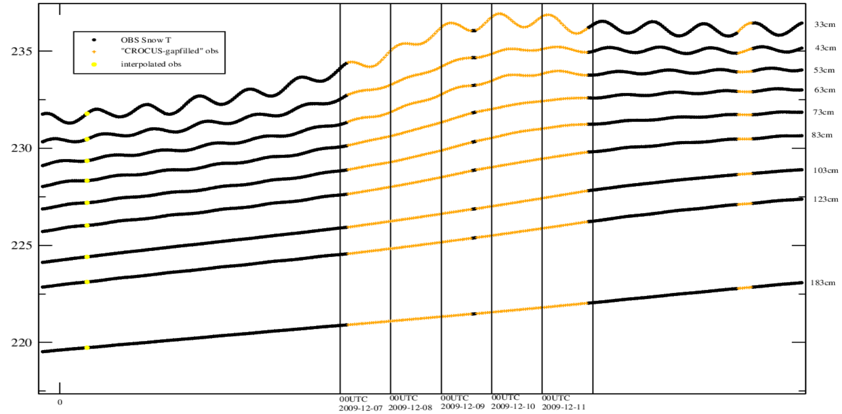
DomeC Antarctica



Surface temperature measurements

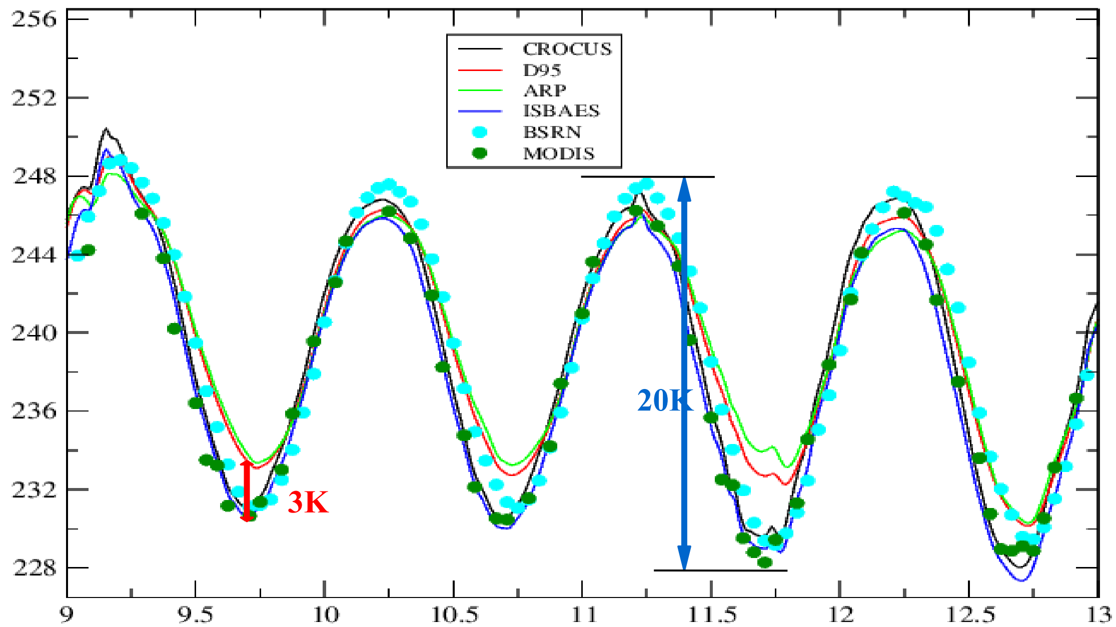


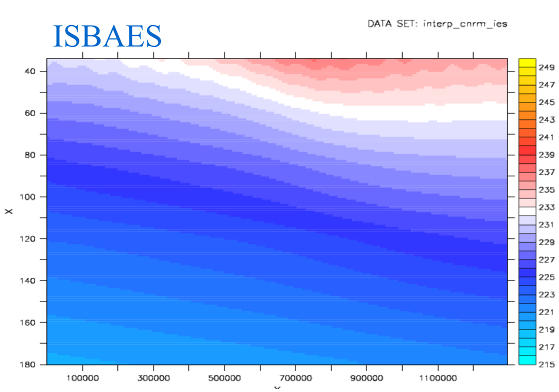
Snow temperature measurements

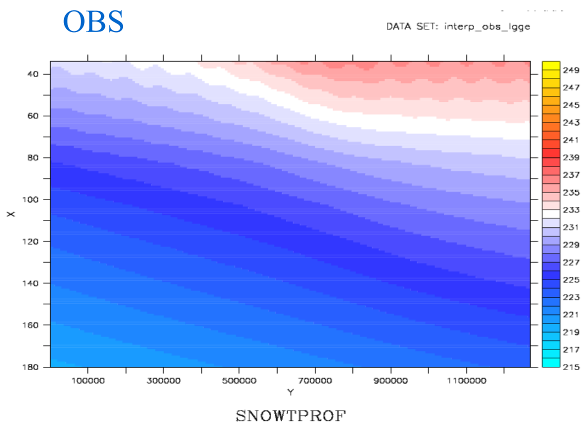


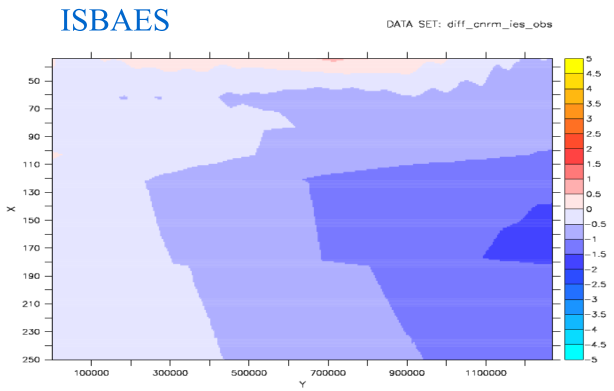
Inter-comparison of snow models: GABLS4 experiment

Simulated surface temperature







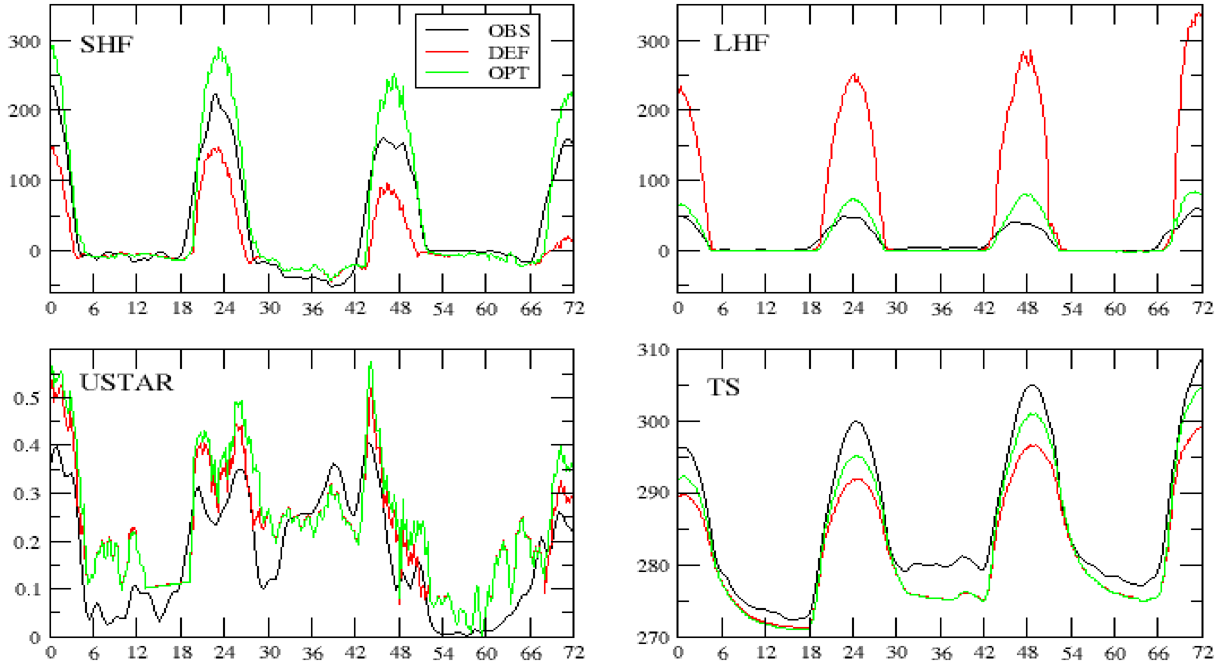


Inter-comparison of vegetation models: DICE experiment

American Great Plains

DEF

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



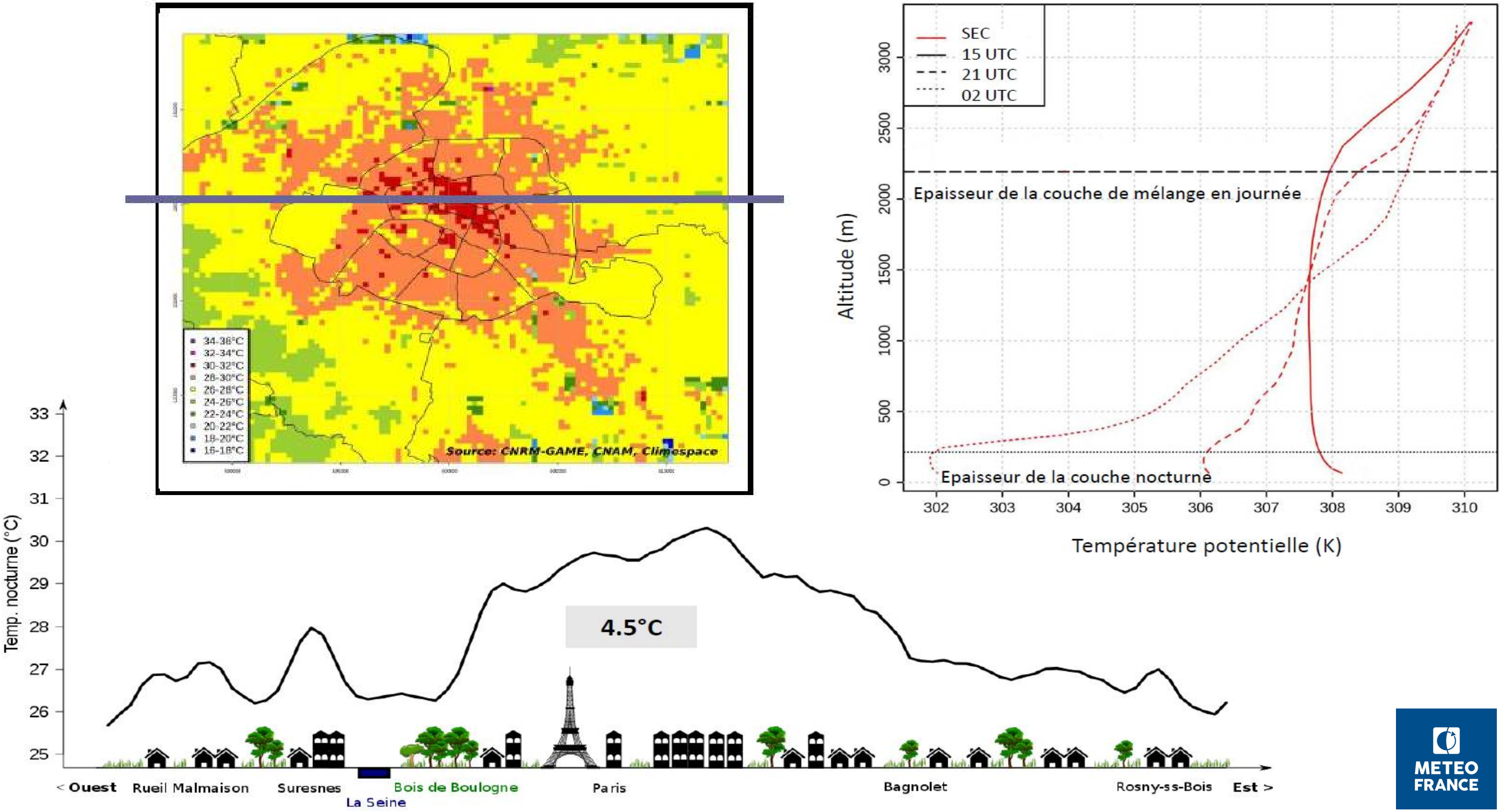
OPT

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



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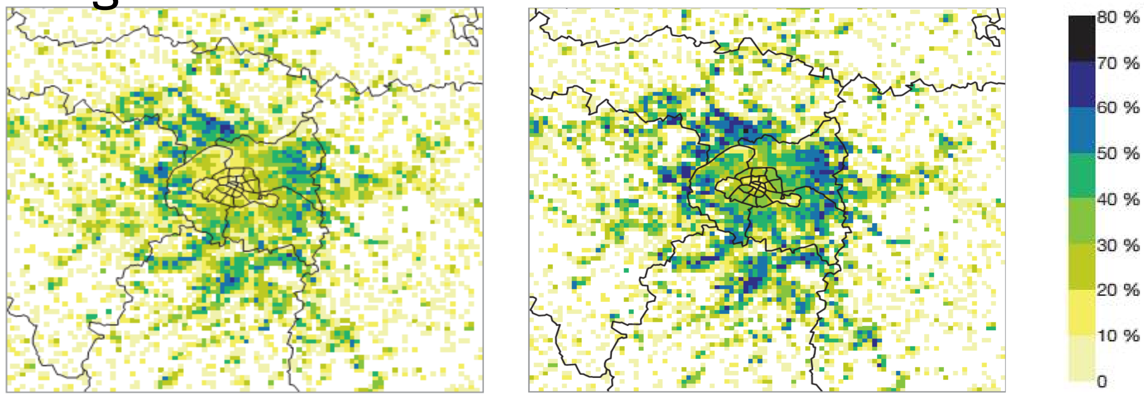
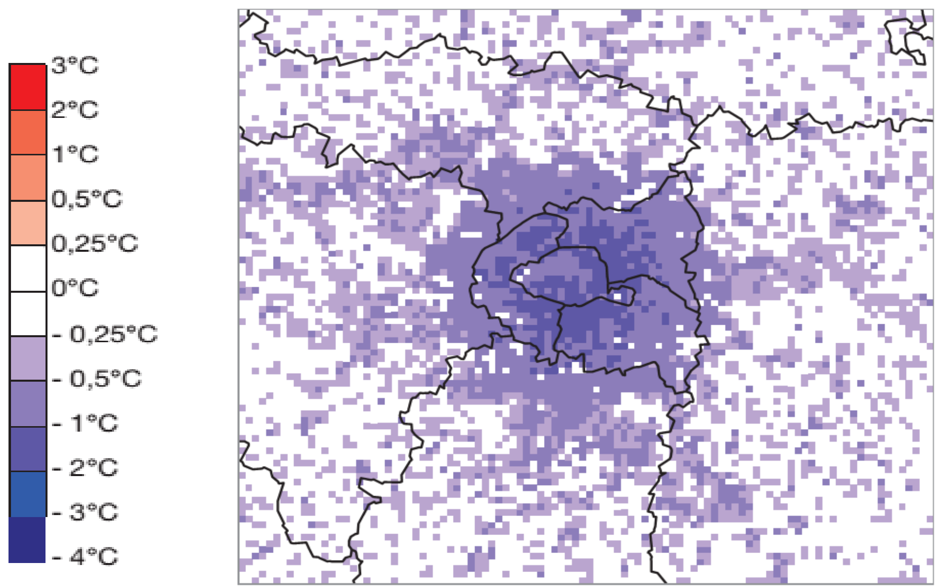
TEB model dedicated to urban areas

Urban planning scenario

Urban fraction



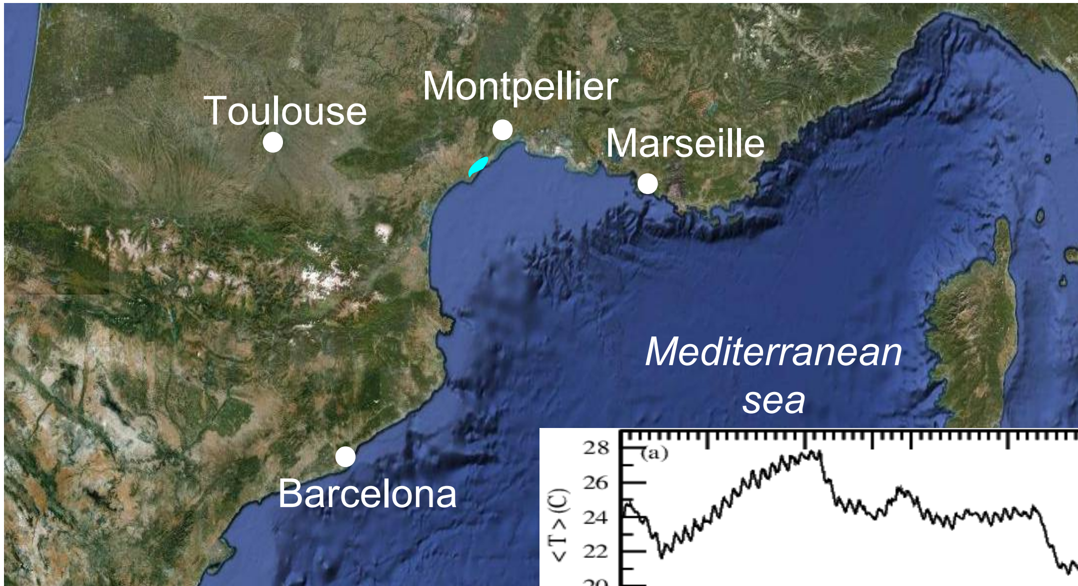
Street Temperature variation

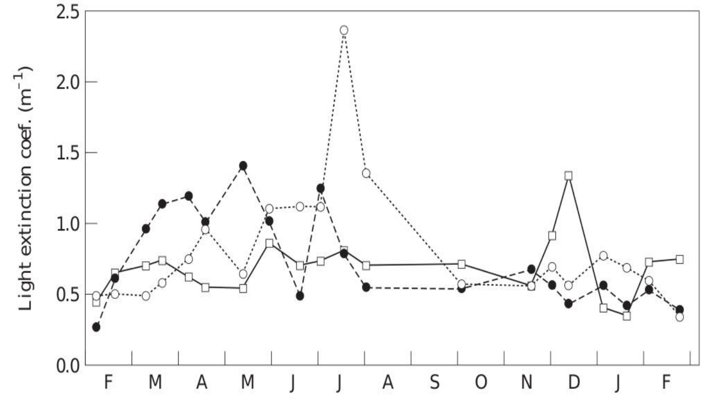


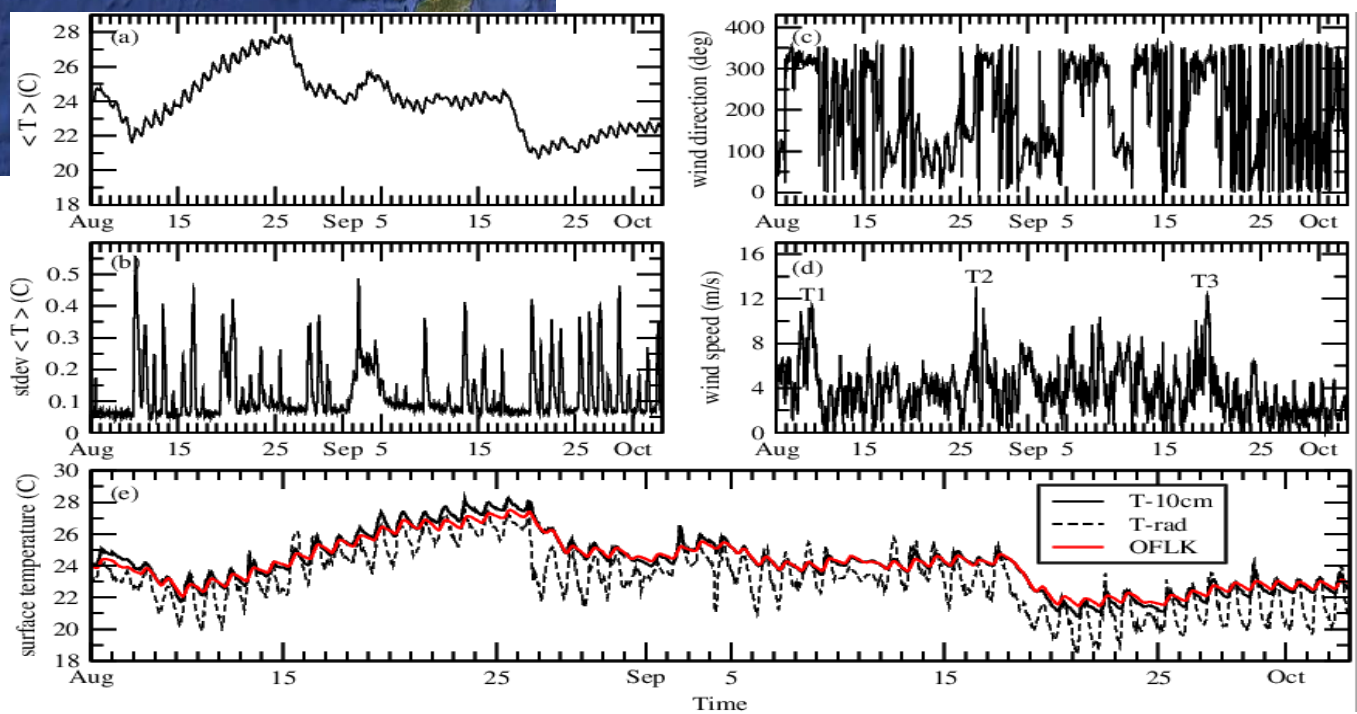
Source : C. de Munck

Evaluation of the lake model

Thau Lagoon in south France



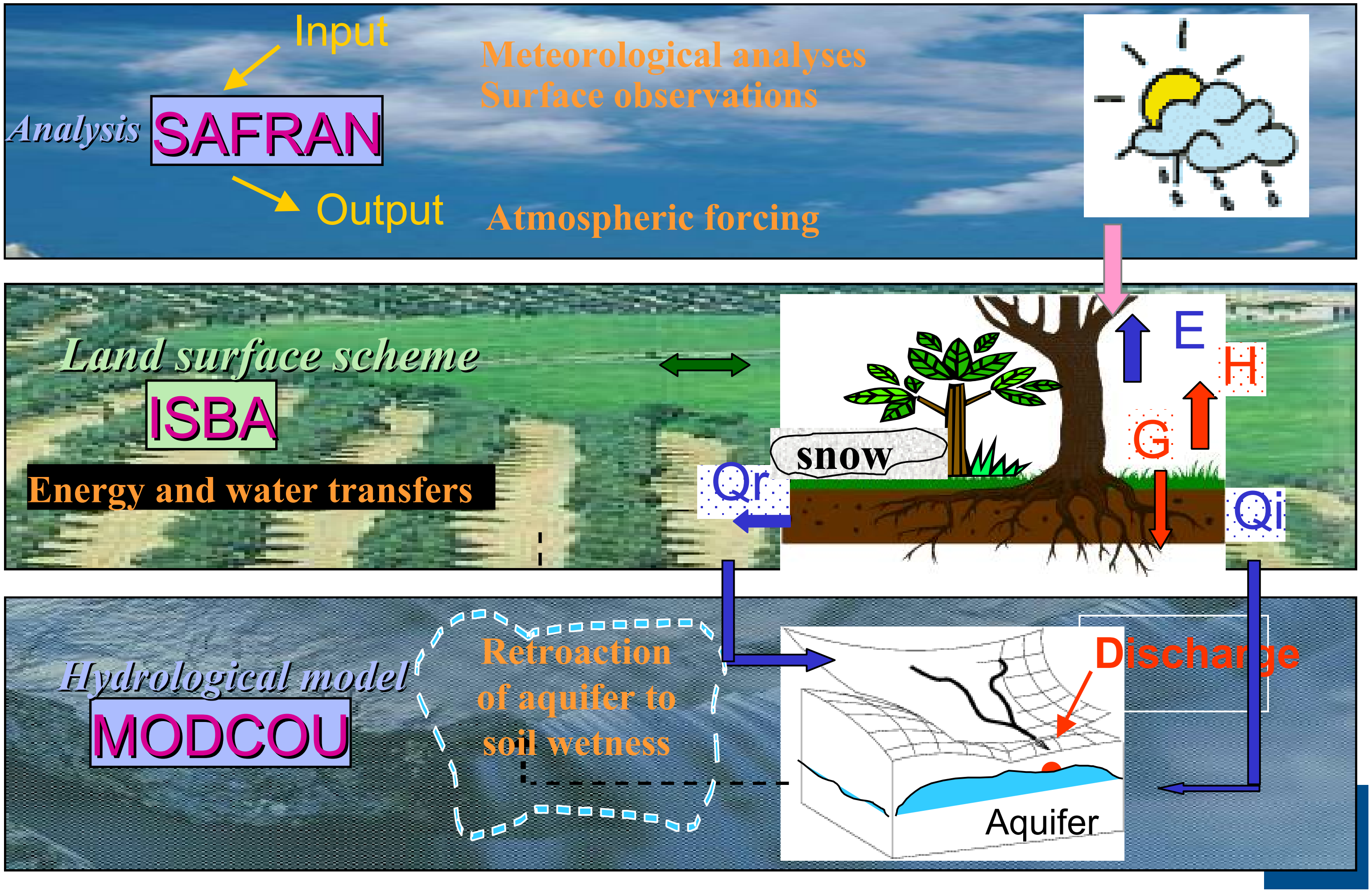




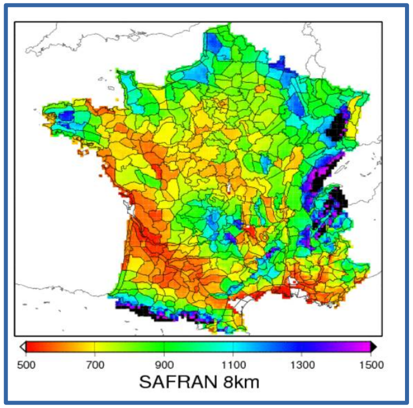
2,5 month field campaign

Depth=4m

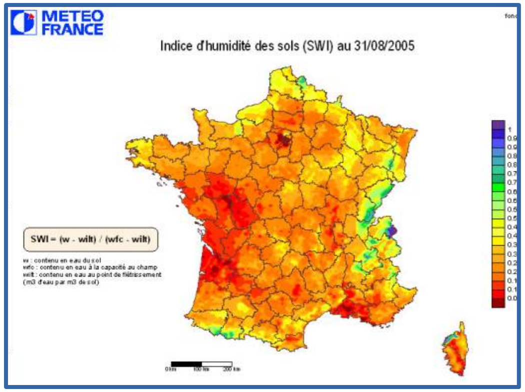
Hydrologic suite SIM



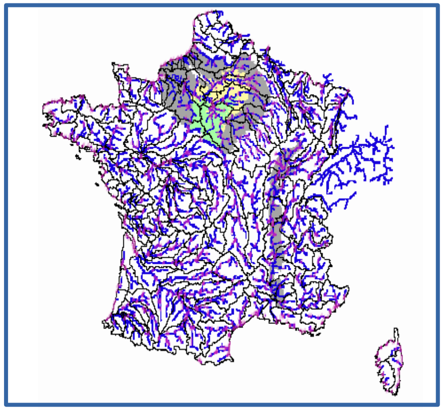
Hydrologic suite SIM



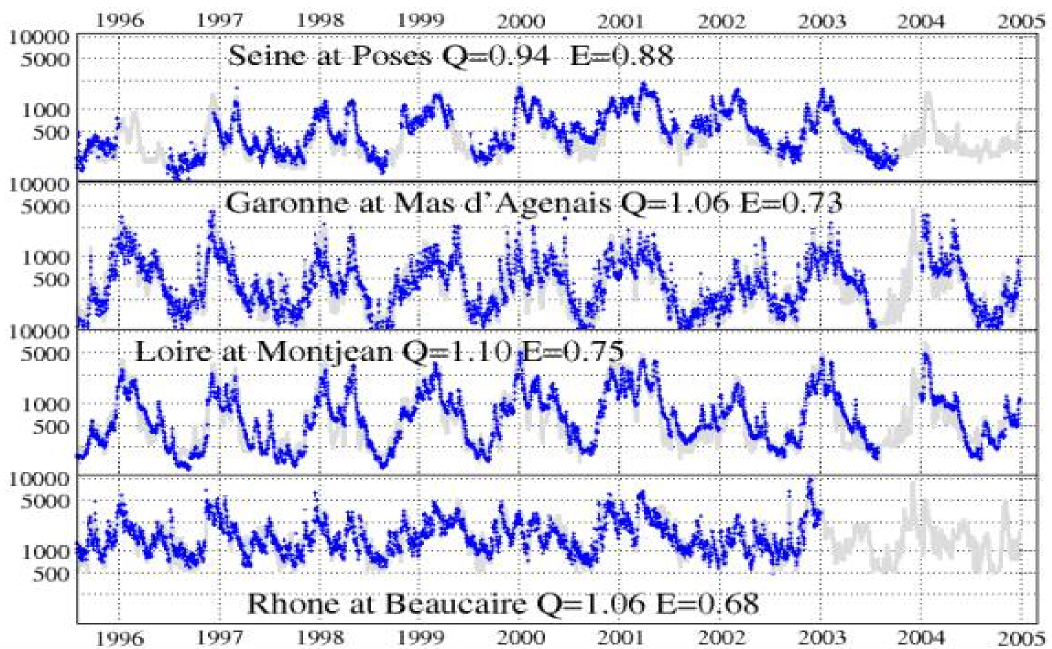
SAFRAN



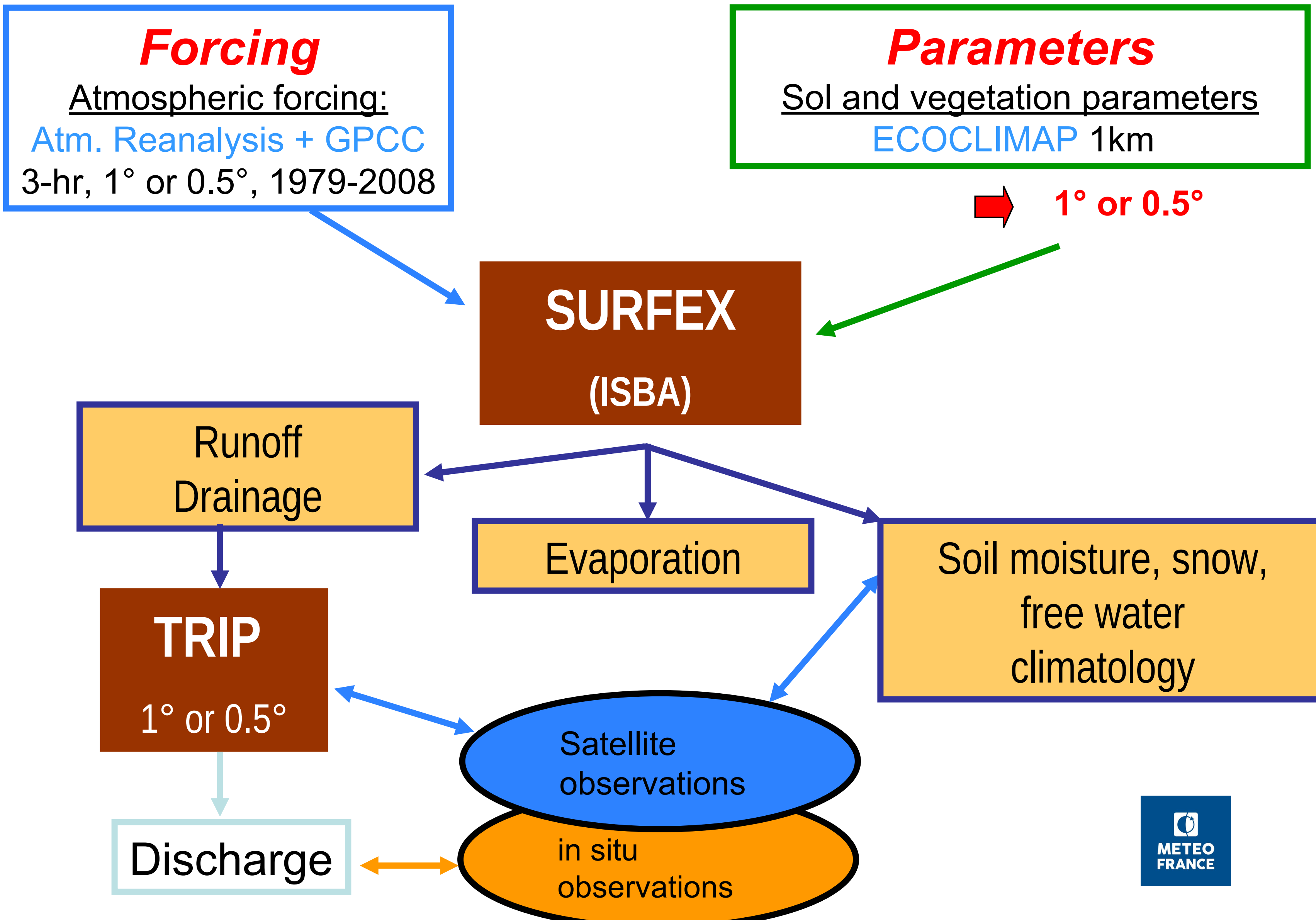
ISBA



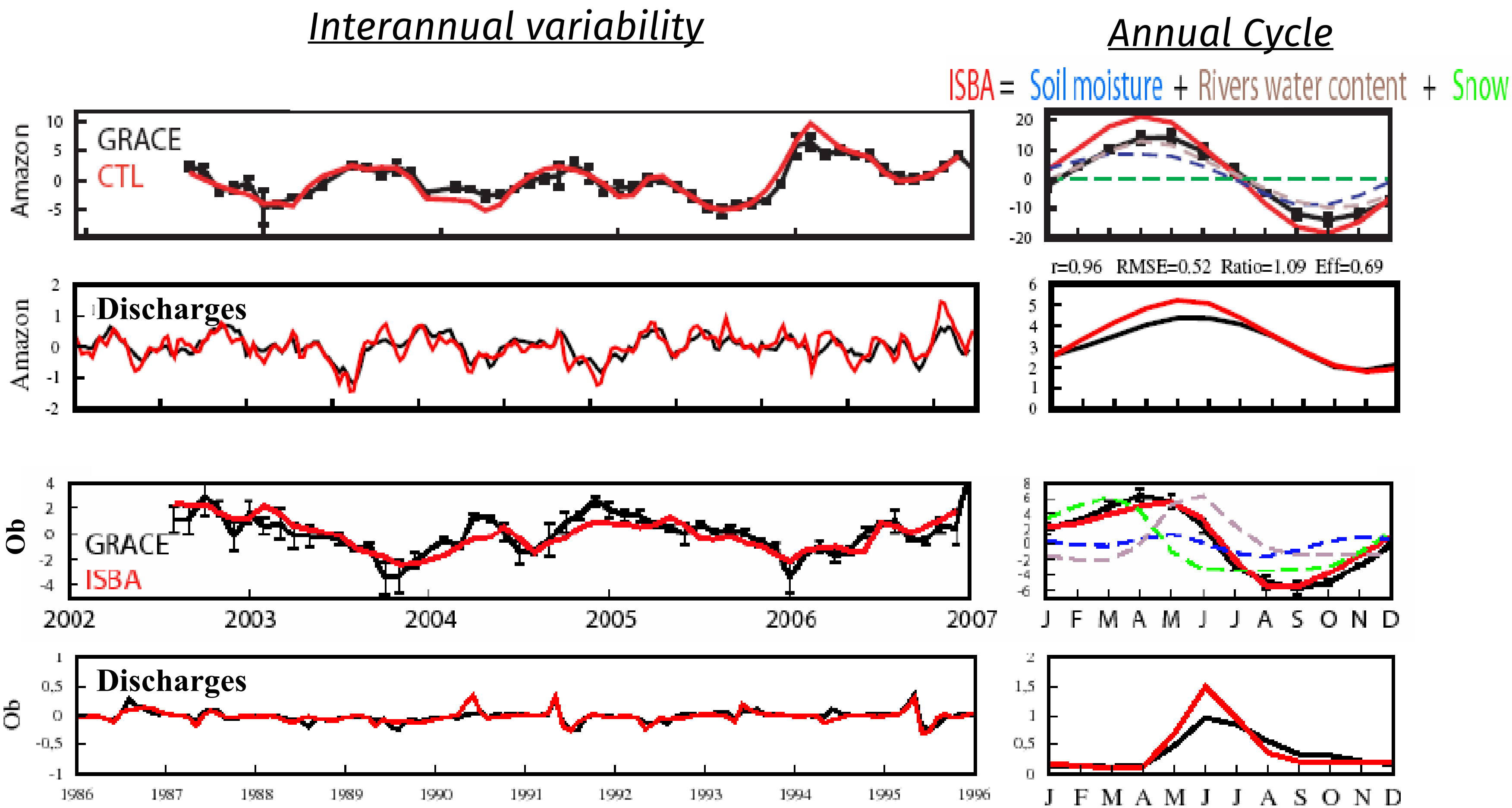
MODCOU



Hydrologic suite SURFEX-TRIP



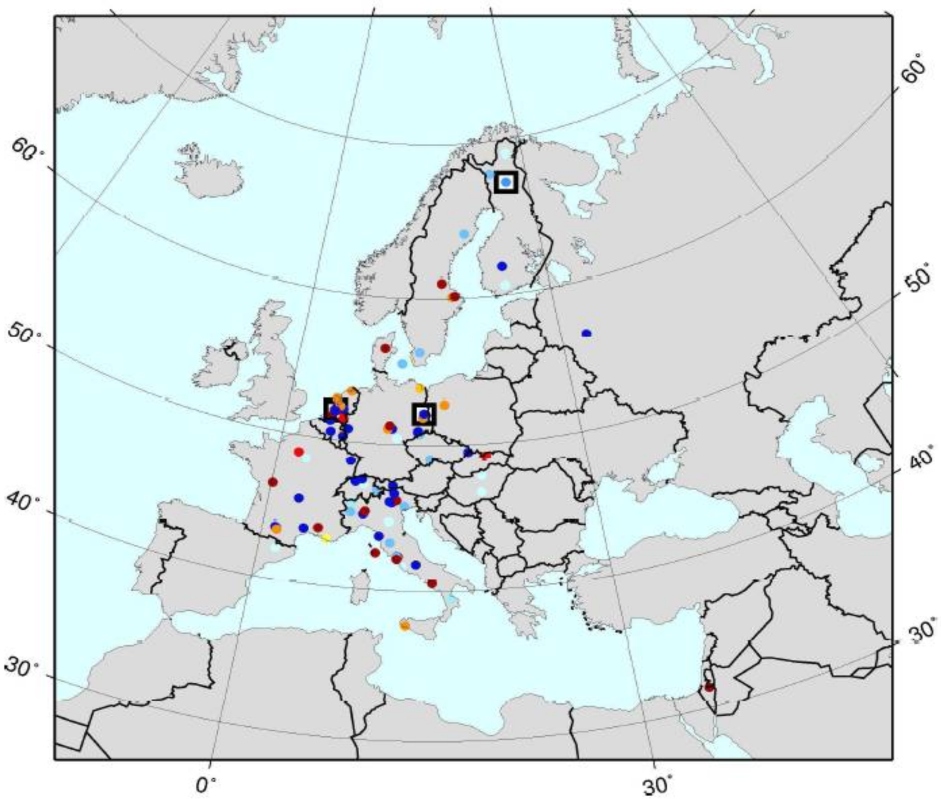
Hydrologic suite SURFEX-TRIP

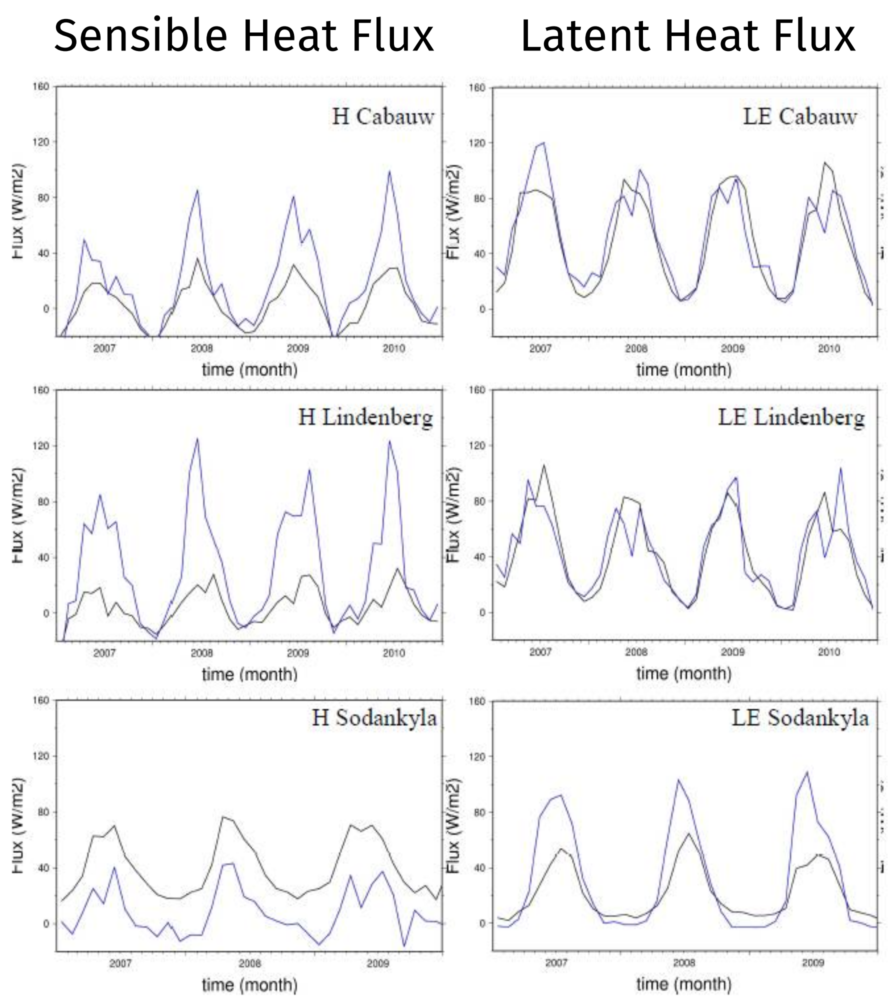


(Alkama et al. 2010, J. Hydrometeorology)

Continental surfaces reanalyses

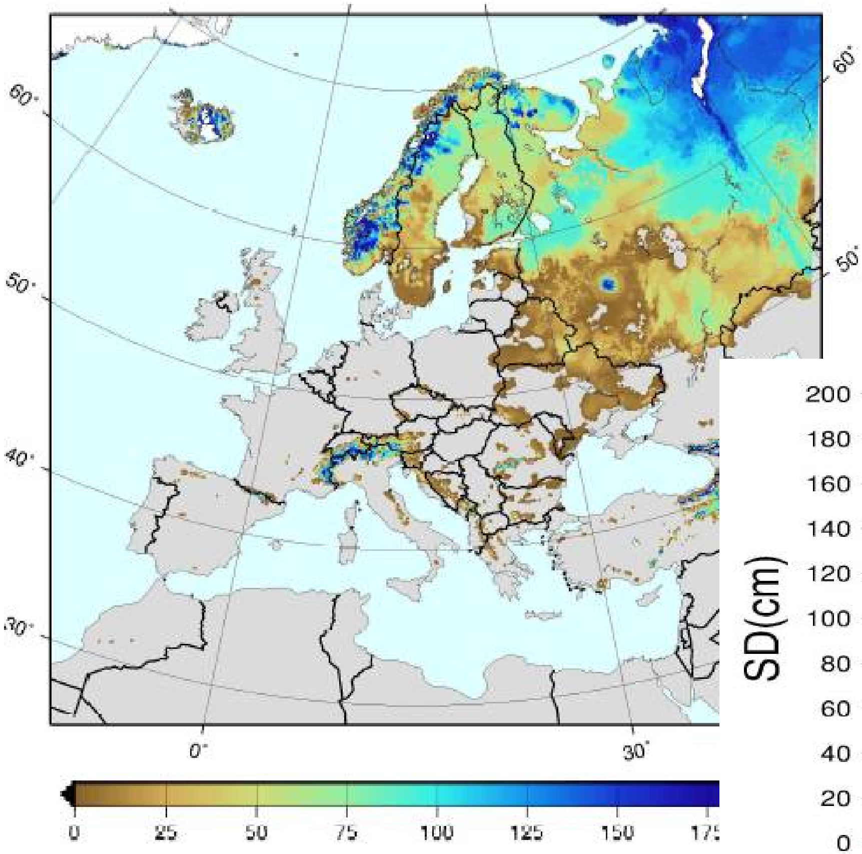
Sensible Heat Flux FLUXNET sites





Continental surfaces reanalyses

Snow Depth



Results at Sodankyla

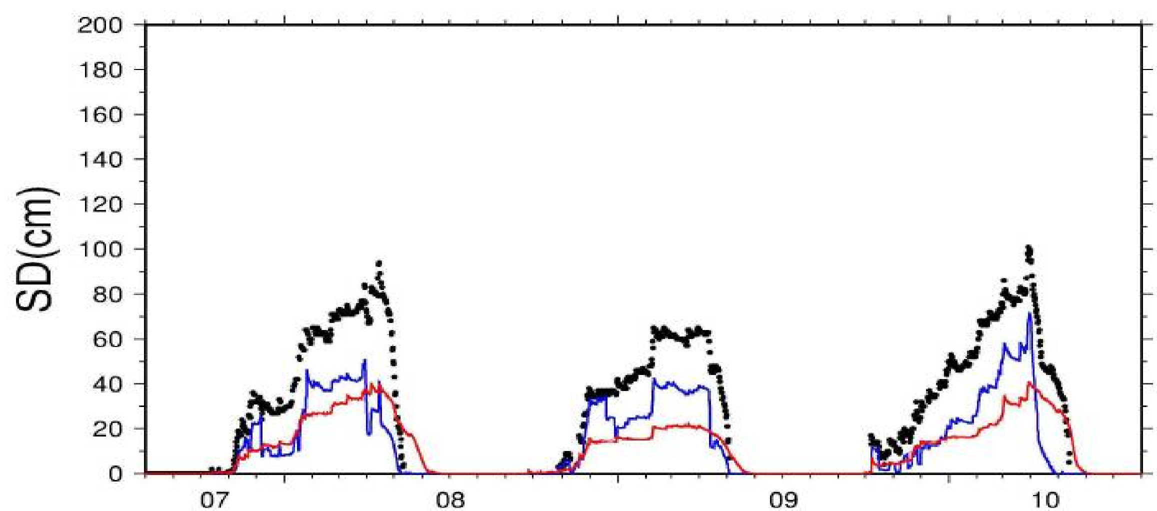
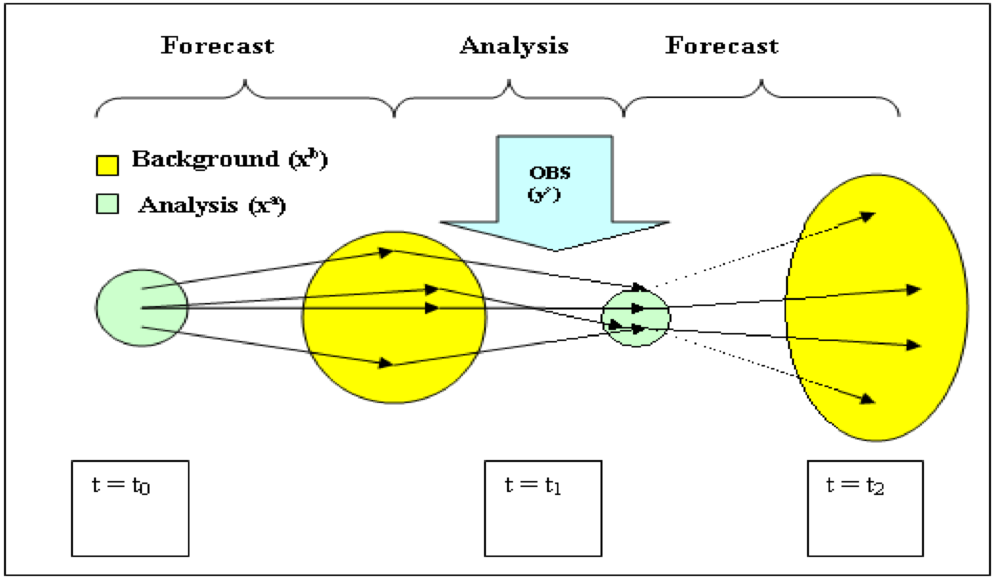


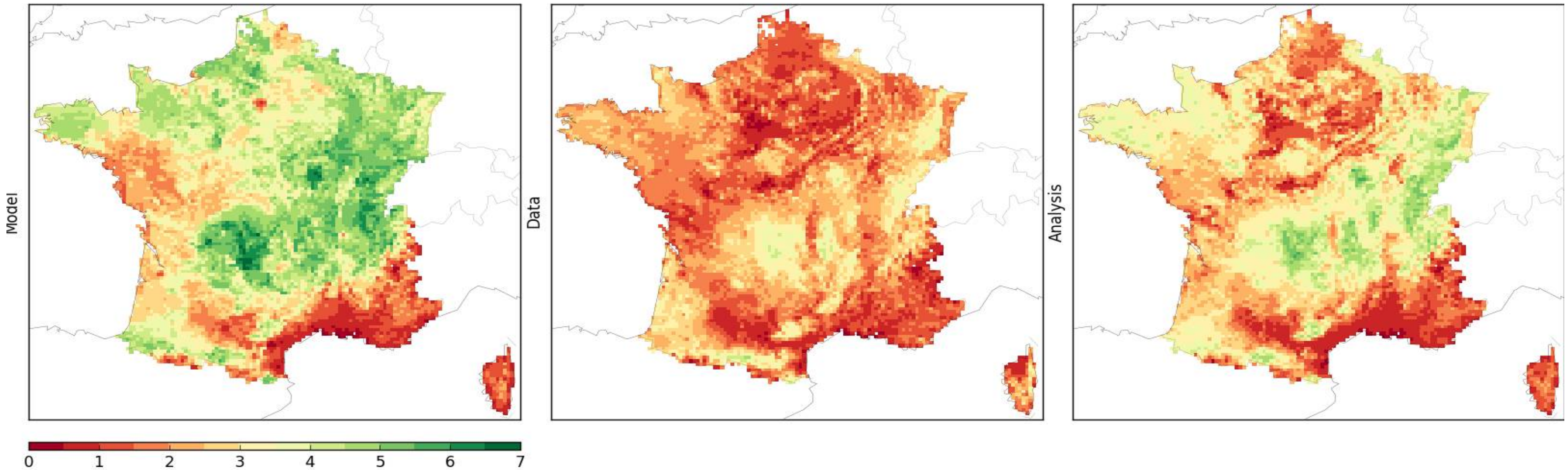
Figure : time series of snow depth (in cm) at the Sodankyla station during the period 2007-2010. The black dots represent the observations, the blue curve represents the simulation made by SURFEX driven by MESCAN and the red curve represents the simulation made by SURFEX driven by ERA-Interim.

Data Assimilation

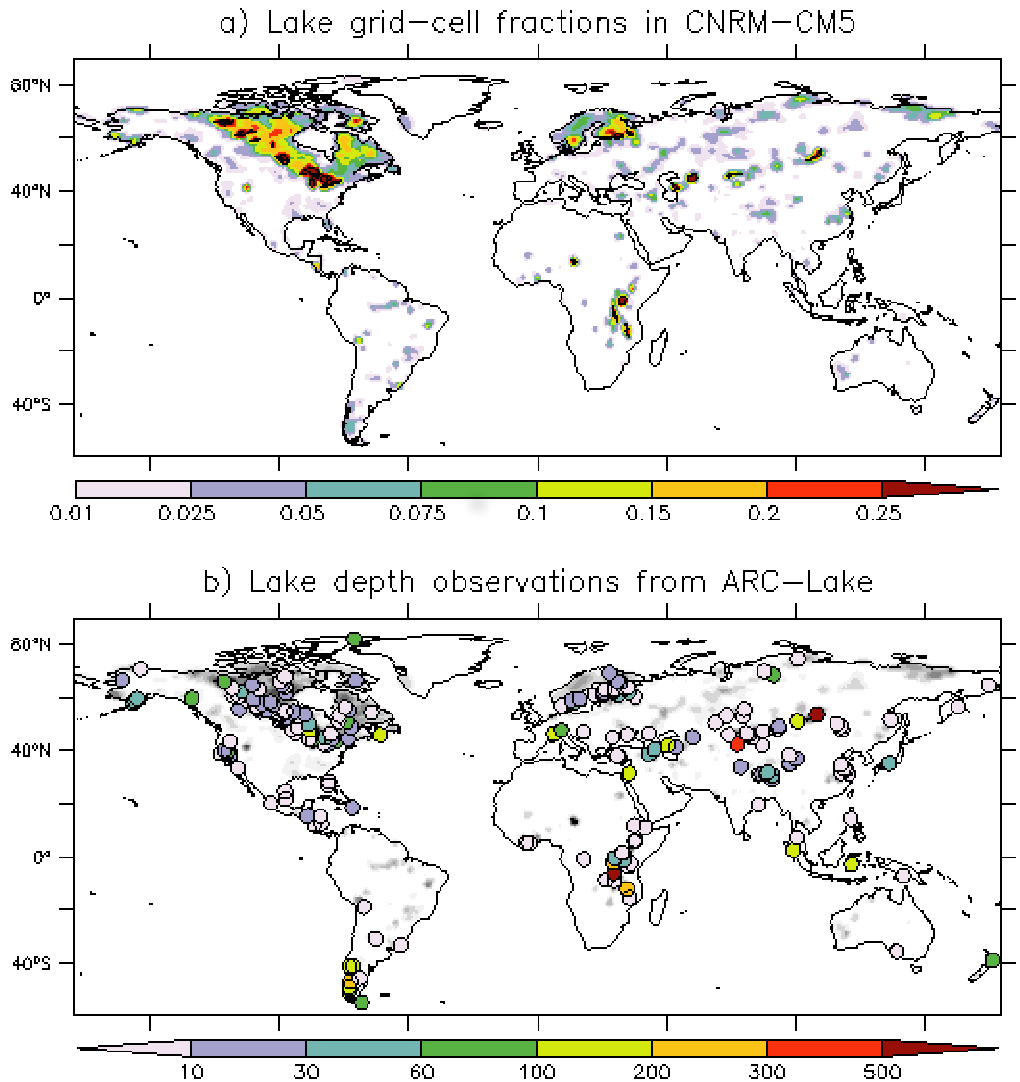
EnKF uses flow-dependent background-error covariance from ensemble spread (Research only)



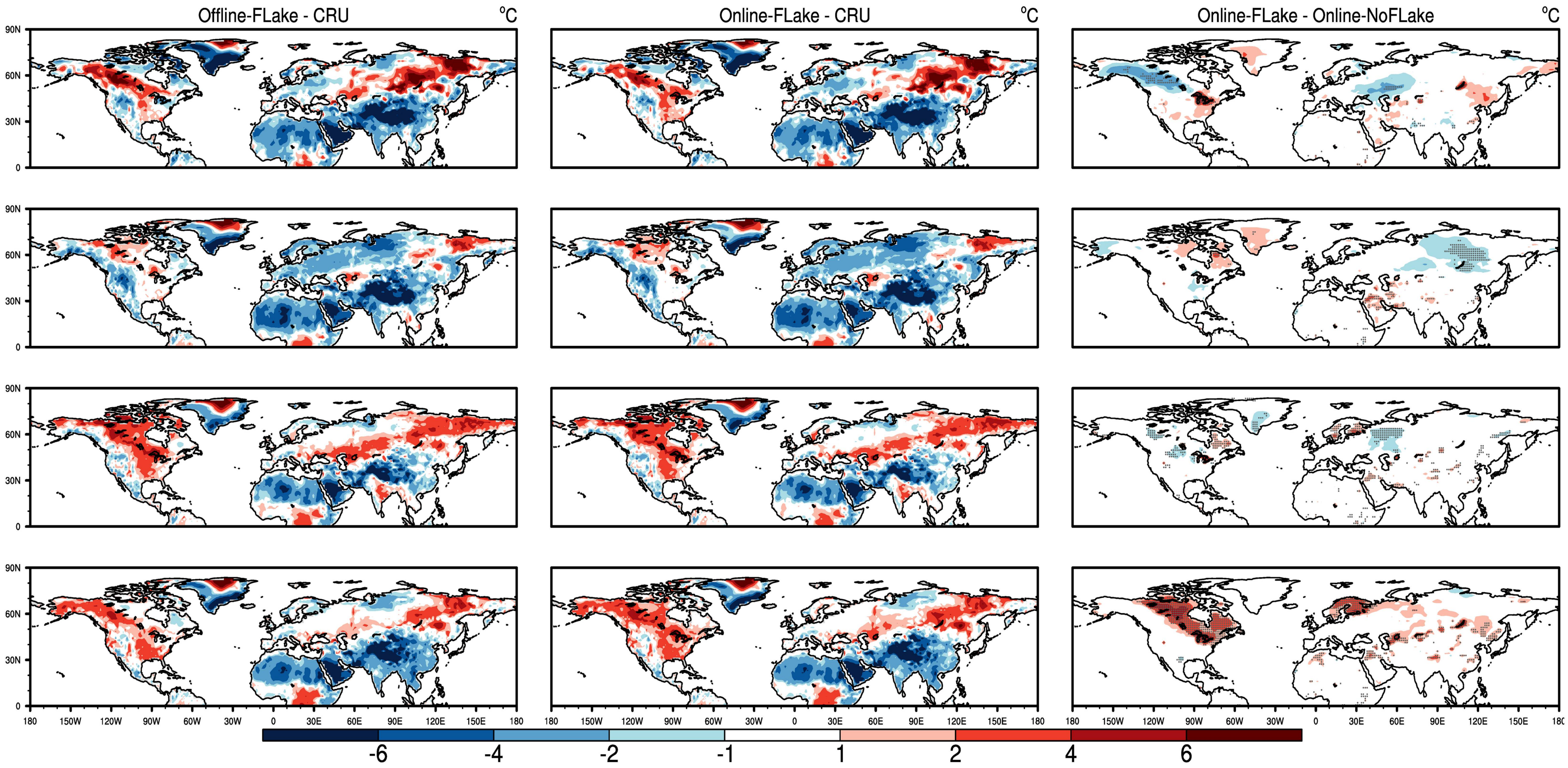
LAI -- September 2007



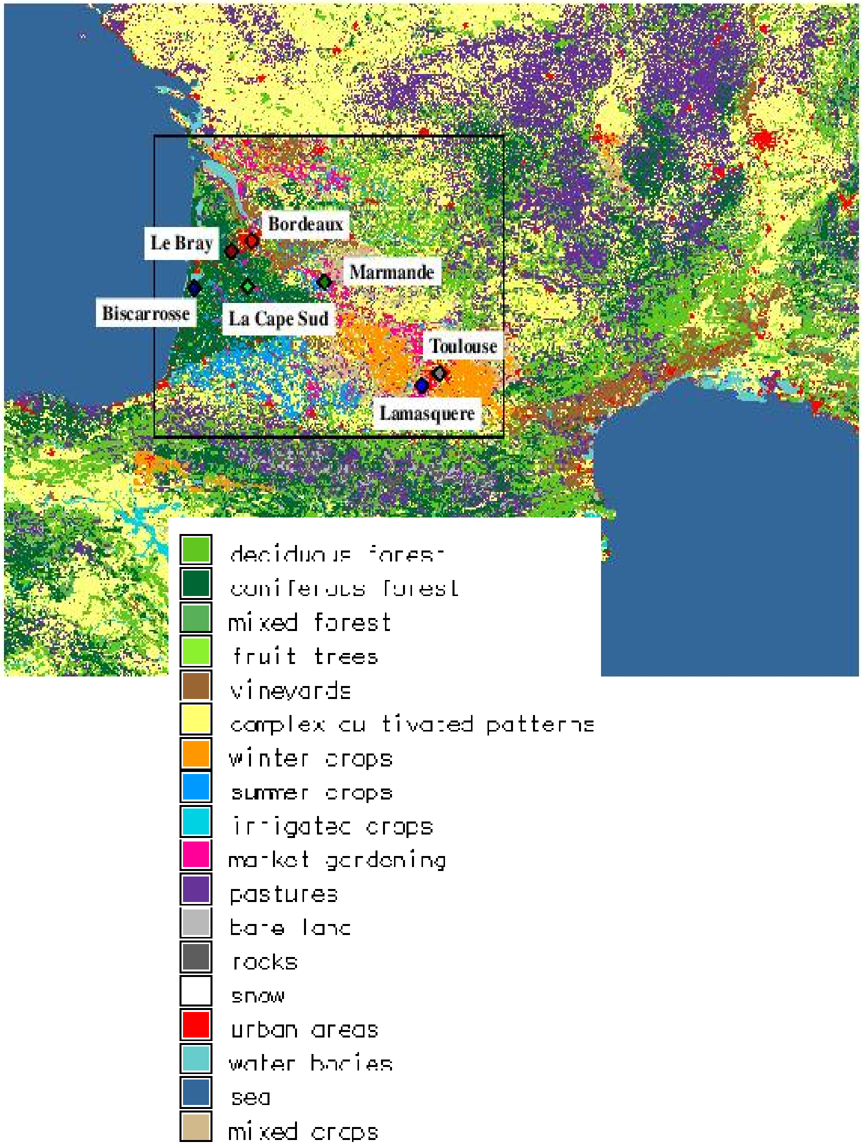
Lake model in Arpege-Climat

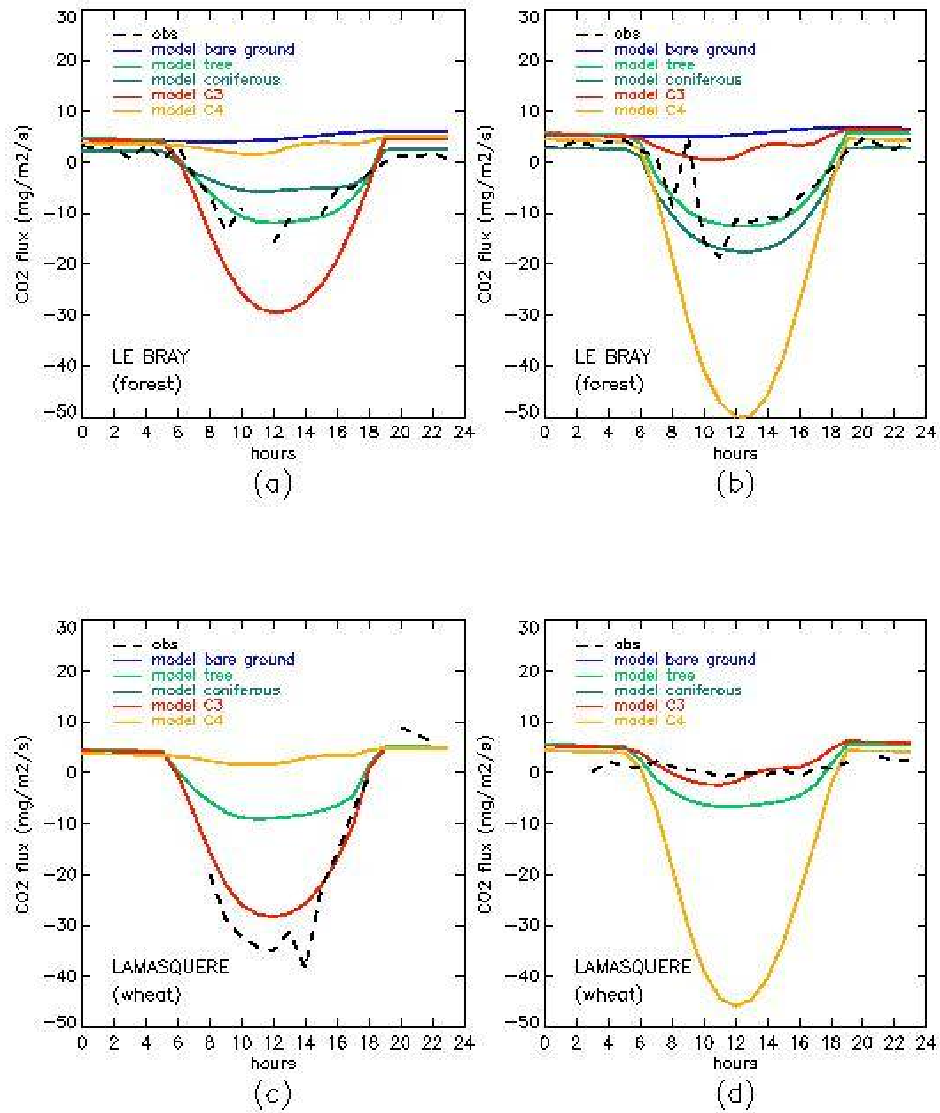


Lake model in Arpege-Climat

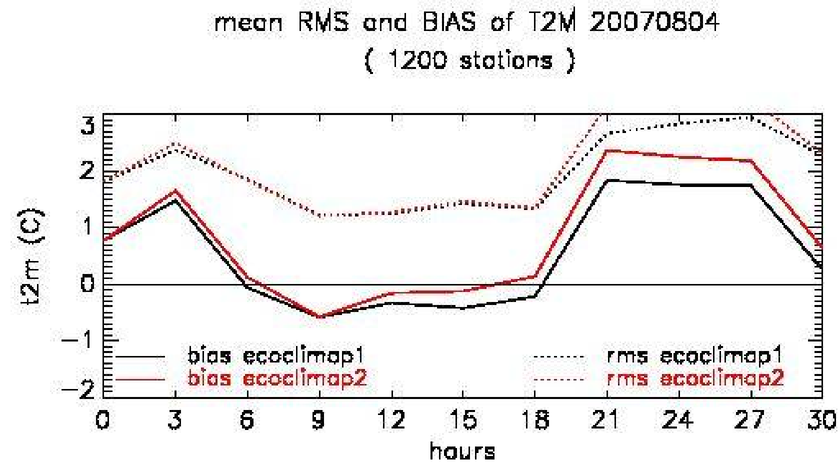


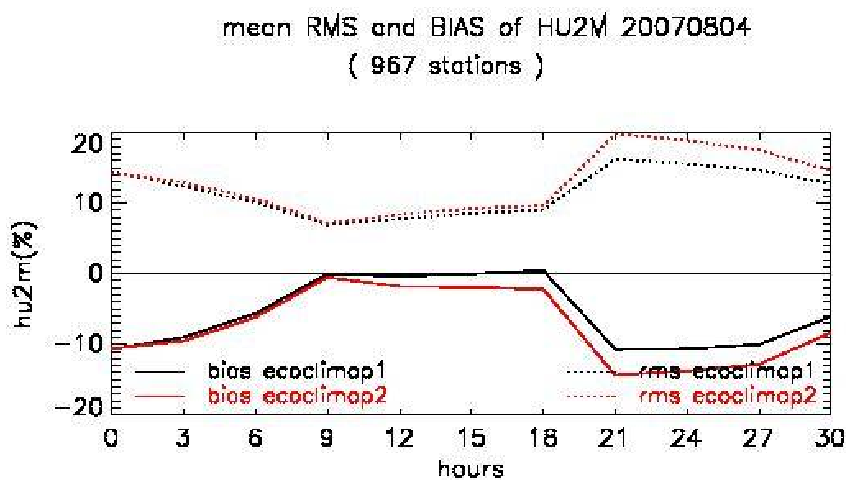
CarboEurope with Meso-NH





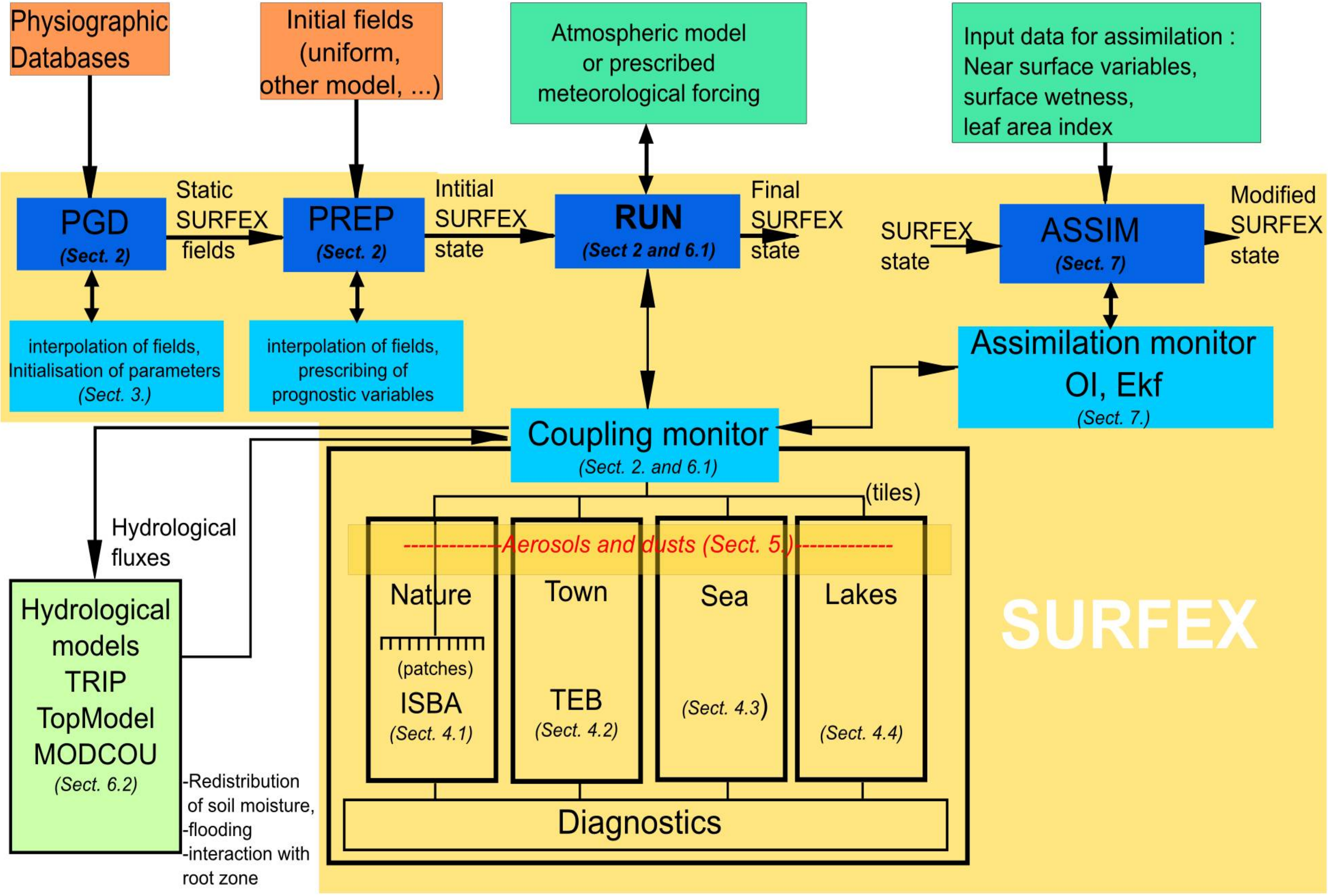
Comparison with AROME





More practical…
Running SURFEX

METEO
FRANCE



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

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** :

  Example 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

Initialisation of prognostics variables

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)

METEO FRANCE

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