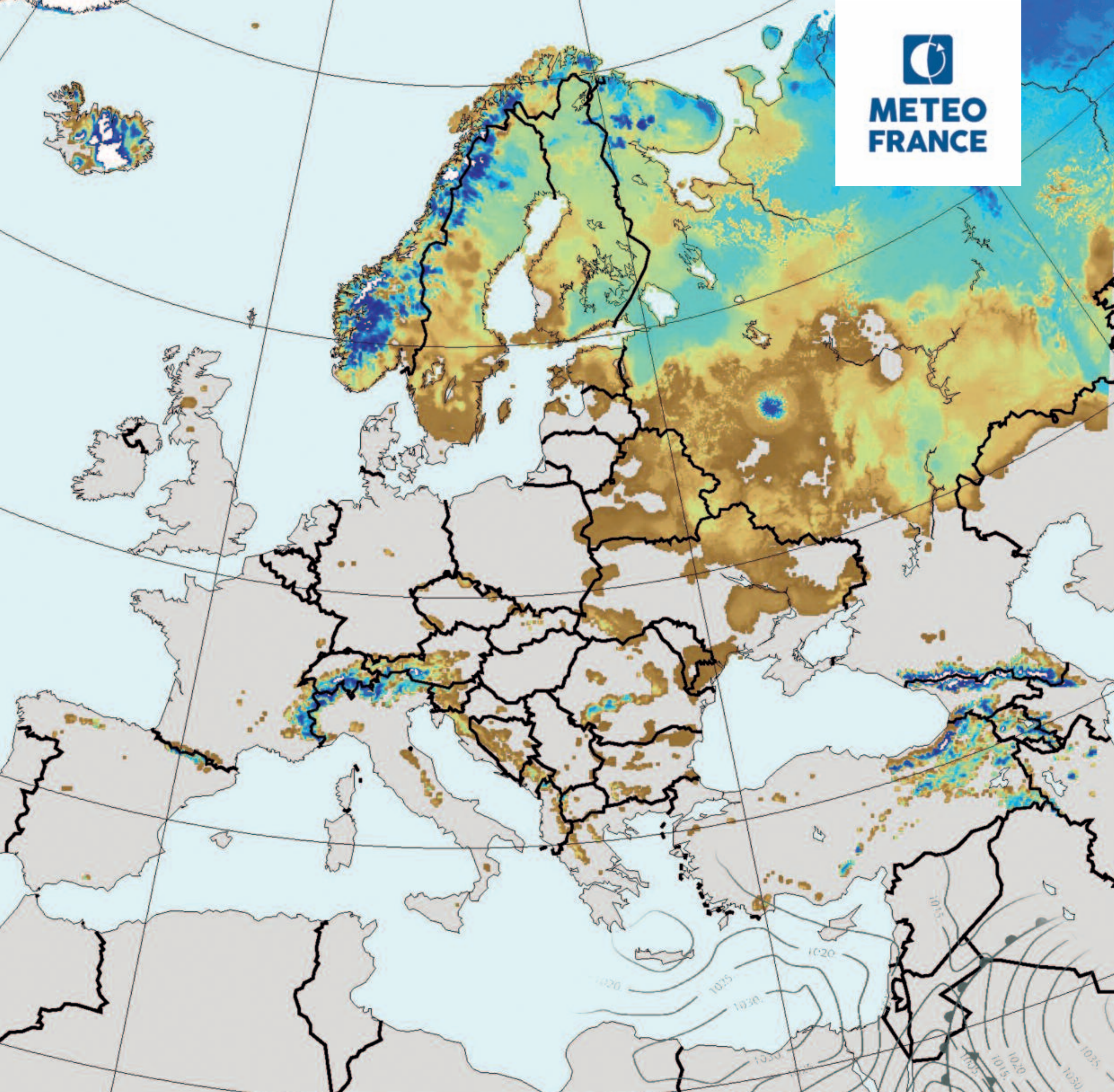

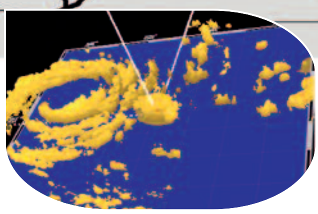

Research **Report**

2014

Research Report 2014

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Research has a special place in Météo-France, boosting innovation in domains such as observations, numerical weather prediction or climate prediction. It is instrumental for improving constantly the quality of operational products and bringing new answers to the expectations of society and civil authorities.

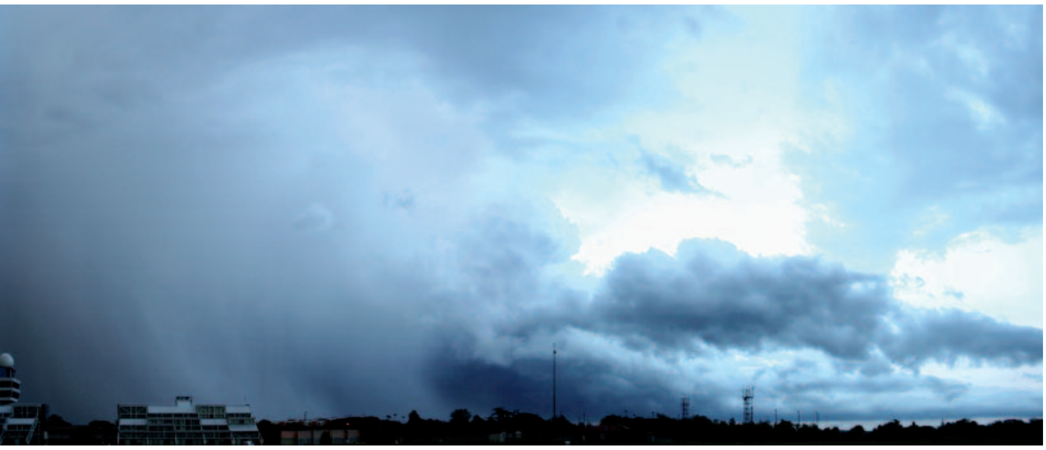
Research objectives are listed in the Science Strategy for 2013-2020, and are organized along seven main directions:

- Continuing the convergence between weather and climate models
- Improving the representation of physical processes and coupling
- Increasing regularly the resolution of all forecasting systems
- Generalizing the use of ensemble methods
- Developing the expertise on operational observing systems
- Assessing the impacts of mankind on climate
- Exploring the predictability of climate from sub-seasonal to decadal time scales.

This report presents some salient results obtained in 2014. I shall stress in particular the development of the future numerical prediction systems that will make good use of the enhanced computing resources of Météo-France. Data from field experiments conducted in recent years, such as AMMA and HYMEX, are being actively analyzed for new research and validation of the prediction systems, such as the new AROME ensemble forecasting system. The study of basic microphysical processes feeds improvements in forecasting extreme events, such as hail or tropical cyclones. Our fine scale atmospheric model AROME is now being used for climate projections, opening a new avenue to investigate the impact of climate change on extreme precipitation risks in the Mediterranean region – a question of importance often posed by local civil authorities. Finally, improving the measurement systems also occupies a good part of our resources.

In 2014 an independent evaluation of our main research laboratory, the GAME, was conducted by the Haut Conseil pour l'Evaluation de la Recherche et de l'Enseignement Supérieur. This confirmed the high quality of our research activities and our leadership at the national level. I will not resist citing the global conclusion of HCERES report:

"The GAME plays a specific role in the French national research landscape. As a research laboratory of Météo-



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France, its role is to develop the research activity necessary for the operational forecasting missions. As a Mixed Research Unit of CNRS, it has demonstrated a major role in the academic research community. The GAME fulfills this dual mission in a remarkable way. It is a leading contributor, at international level, to the development of numerical weather prediction systems. It also conducts upstream research on weather and climate processes on a large variety of space and time scales. In total, the GAME conducts a wide spectrum research, aiming to develop a competency in most aspects of meteorology, climate and air quality. Its international impact is strong in several flagship domains, as outlined in the detailed report. The GAME is a structure of Excellency. Their staffs have demonstrated during the evaluation a strong commitment to the objectives of the laboratory and a great confidence in management."

Philippe Bougeault
Director, Centre National de Recherches Météorologiques

Numerical weather prediction

An important background activity of the numerical weather prediction (NWP) group is to integrate within a single source code the changes proposed by the scientists from the European weather services gathered in the ALADIN and HIRLAM consortia, by the scientists from ECMWF as well as by its own members. This activity enables to distribute developments. Although quite heavy, it contributes to allow Météo-France to benefit from a state-of-the-art numerical weather prediction system with fewer resources than comparable services. These cooperations create the context within which various research actions from the group are undertaken with a view to prepare the mid- and longer-term future. ECMWF has taken several initiatives that result in reorganizing the code or in partial but important rewriting of it, to which the group contributes both scientifically and technically. Thus, a new data assimilation algorithm has made its first steps. It is based on using large size ensembles. It is also written in a new way, with an object oriented language. Keeping with data assimilation, a PhD thesis has brought a rigorous theoretical framework to the statistical estimate of forecast error covariances and to their localization in space, which is necessary to these new approaches of data assimilation. The very first tests of a dynamical core of the Météo-France models, very different from the current one have occurred, in the case when the parallelization of the current core would be found insufficient at the future resolutions of AROME. In this perspective, experiments with resolutions from 500m to 50m are performed over a mountainous area in order to identify possible difficulties. A framework has been set up in order to try to make progress in fog forecasting, thanks to a very fine 3D spatial resolution near the ground.

On the side of shorter-term actions, porting the whole of the NWP suite to the new Bull-Intel computer has been completed in January. This change of computer corresponds to giving-up vector processor technology, a change that has been prepared since 2010. Achieving good technical performances with the operational codes now depend on their ability to allow computations to be run in parallel. Porting the NWP suite was also the first step towards setting up new, improved versions of the various NWP applications. The following articles highlight some of the characteristics of these new versions or examples of the progress that they enable.

The end of 2013 and the beginning of 2014 have seen a series of windstorms rushing over France. All these events have been properly anticipated. Considerable progress has been achieved since the quite similar 1989—1990 winter season. The behaviour of the global ARPEGE suite during this recent winter, as measured by several scores, is in itself a result that deserves to be cited. The reference score on mass distribution has slightly improved during the heart of this period, as well as the new accumulated precipitation scores, a behaviour never seen so far, as such situations have always led to degrade, at best, such scores. This sequence of events therefore appears to validate on one hand the availability of a so far unseen number of observation data due to the presence in space of three hyper-spectral infrared sounders, all of them used by ARPEGE and AROME and, on the other hand, it also validates close to eight years of pioneering work on associating an ensemble of data assimilation to the reference 4D-Var assimilation of ARPEGE.

Modelling

Preparation of the 2015 version of the global forecasting system ARPEGE

A new version of the ARPEGE global forecasting system is enabled by the new computer system of Météo-France with significant changes, while remaining consistent with the priority given to the various versions of AROME systems in the new sharing of computer time.
The horizontal resolution is improved, from 60 to 36 km over Southern Pacific and from 10 to 7.5 km over Western Europe. The analysis increment resolution is refined from 62 to 50 km. The vertical resolution is also finer: 105 levels instead of 70.
Background error covariances used in the 4D-Var analysis are better sampled thanks to the implementation of a 25 members ensemble data assimilation, as shown in another article. Initialization, temporal resolution of the assimilation window and bias correction of satellite observations are also improved.
The number of observations grows significantly, with a doubling of the density of satellite observations in the analysis and the assimilation of new observations. Taking a single example, ARPEGE now uses microwave sounding channel data of SAPHIR on Megha-Tropiques.
This new version of ARPEGE improves synoptic scores, as well as precipitation scores over France to a lesser extent, precipitation scores that are one of the key points of this system. The figure illustrates the behaviour of this version during one of the southern France heavy precipitation events that occurred during fall 2014. Note that the forecast shown has also been performed in real time.

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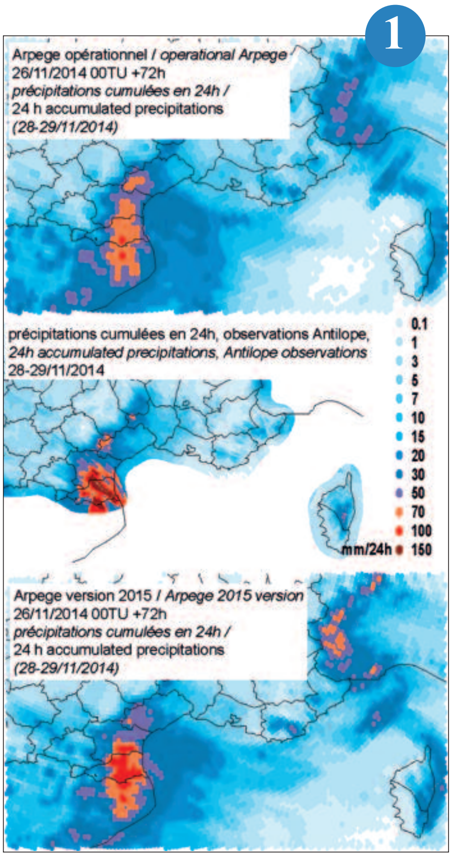
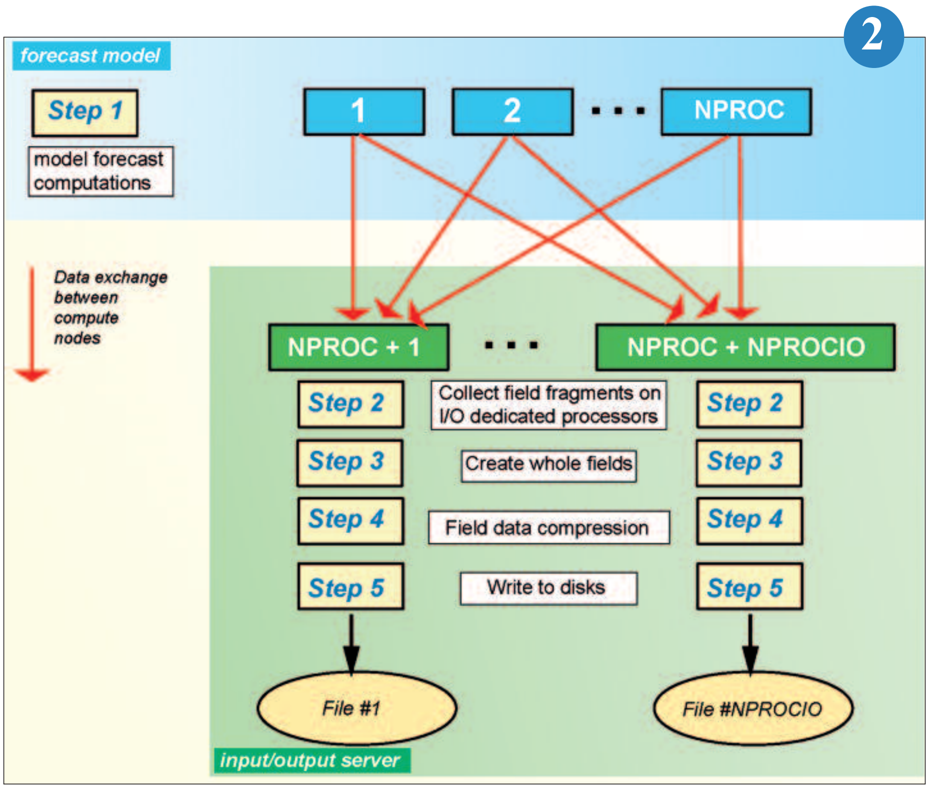


24h accumulated precipitations (in mm) for November 29th 2014: Antilope analysis (middle), 72h ARPEGE forecast with the operational version (top) and with the new configuration summarized in the article and that will become operational early 2015 (bottom).



Schematic of the input/output (I/O) server now included in the Météo-France operational models running on a parallel computer having many cores.

Optimizing weather forecast models: using an IO server

The new high performance computing system used by Météo-France since 2013 is made up of two scalar clusters manufactured by BULL. Each cluster runs one thousand dual Intel Ivy bridge processor nodes, for a grand total of 20000 scalar cores per cluster. In order to adapt to this new architecture, the input/output (IO) subsystem of operational numerical weather prediction models has been rewritten and now relies on distributed and asynchronous techniques.
This new scheme, commonly called "IO server" involves the following steps, as described on the figure:
• asynchronous sending of two dimensional field fragments produced by model tasks to dedicated IO processors, while model integration goes on
• gathering of field fragments in order to recreate whole fields
• compression of whole fields by IO processors
• writing compressed fields (one file per IO processor)
This approach proved to be necessary in order to fulfil operational time constraints on AROME running at a resolution of 1.3 km.
The implementation of this new system was complicated, because a piece of data which was so far contained in a single file is now scattered among several files. New commands for manipulating these sets of files have been created and replaced where needed all usual commands for copying, moving, deleting files, etc...

Several divisions of Météo-France contributed to the implementation of this new IO scheme which is used in operations since July 2014. Reading input files using this IO server should be possible in the future, and will improve the model performance, in particular for lateral boundary conditions of AROME.

2

Stochastic methods for modelling of sub-grid processes

At the present time, refining model resolution requires to improve both the understanding and the modelling of meso-scale physical processes (from few dozen meters to kilometre). The grids of current operational models are too large to represent these phenomena, which are thus called “sub-grid” phenomena. To fill this gap, parameterizations are used to model sub-grid processes. The idea is to model sub-grid turbulence using particle systems instead of a parameterization.
The first experiences have shown the high potential of this technic. Thanks to the particles which evolve at fine scale while being coherent with the model, the method opens access to the processes variability inside the models grid cells. In the near future, the particle method may be applied to fine scale turbulence modelling on a limited area (an airport for instance), and may also contribute to develop more realistic sub-grid parameterizations.

3

Impact of Atmosphere-Ocean coupling on Tropical Cyclone forecast

The heat contained in the upper ocean layers is the main source of energy for mature tropical cyclones (TC). The evolution of TC intensity is thus strongly driven by surface heat content of the ocean, which is a parameter that also changes considerably during the passage of a cyclone.
A first study aiming to assess the impact of atmosphere-ocean coupling on hurricane forecasting was conducted from the model ALADIN-Réunion. Thanks to a fruitful collaboration between the TC research unit of Meteo-France (CRC) and MERCATOR a processing chain was set up to supply ocean fields required by the model in real-time. Most systems observed during hurricane seasons 2012-2013 and 2013-2014 have been simulated by activating the 1D oceanic coupling available in the SURFEX module. The results have shown that the coupling could have a significant (and generally quite positive) impact on hurricane forecasting. In particular, it was shown that the ocean-atmosphere coupling could both limit the over-intensification phenomena commonly observed in the most intense systems and improve, sometimes significantly, predicted trajectories.
This study was then extended to the AROME model, which was used in a 3DVAR configuration mode coupled with a 1D ocean mixed layer model. This “research” configuration was used to assess the impact of oceanic coupling on the forecasting of tropical cyclones Bejisa (Dec2013-Jan2014) and Hellen (March-April2014). The figure “a” shows the impact of both oceanic coupling and data assimilation on analyzed maximum winds during TC Bejisa. The figure “b” shows the forecast error (bias and STD) for an ensemble of 7 model predictions as a function of forecast lead-time. Over-intensification clearly disappears when ocean coupling is activated.

4

1.3 km resolution AROME: final adjustments

During the first half of the year, final adjustments were made to the new version of the 1.3 km horizontal resolution AROME model enabled by the new computer procurement. The 90-level vertical resolution that was set in 2013 has a lowest level at 5 m, the top being below the stratopause. Regarding the dynamical core of the model, the options that ensure a numerical stability for time steps as long as 60s have been validated. Great care was paid to the numerical diffusion and to the semi-Lagrangian advection scheme which benefits from a new formulation that limits the over-estimation of density currents below convective cells. Lowering the bottom level to 5 m from the present 10 m, simplified the interface between the SURFEX surface model and the atmosphere thus eliminating having to use its operational surface boundary layer module. Indeed, a level so near the ground limits occurrences of the atmosphere-surface decoupling which lead to too cold nightly temperatures.
Some significant work on the output fields has also been achieved namely a new engine to produce these fields, a new output domain, surface files more frequently produced, a vertical resolution increase of some output fields, and the addition of some new ones. One such new diagnostic is the turbulent energy dissipation rate useful to air traffic management to estimate how long it will take the atmosphere to return to a stable state in the wake of an aircraft.
An AROME-1.3 km suite is running in real-time and evaluated since the end of June 2014. Scores and case studies confirm a decided improvement of precipitation forecasts, including, as illustrated in the figure, a reduction of the positive bias, which was particularly pronounced between 12 and 18 TU (occurrence of the maximum of convective precipitation). One can also see a marked improvement of the behaviour of the model during the Cévenol episodes of this autumn, in agreement with such scores.

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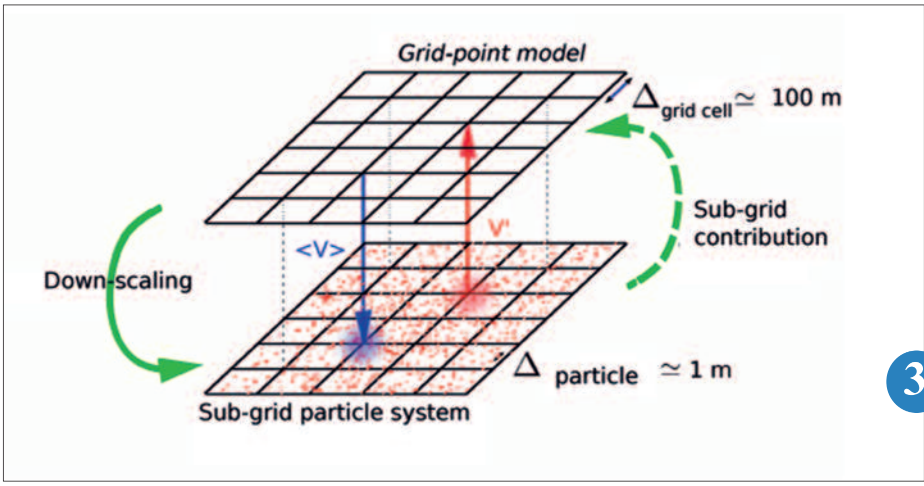
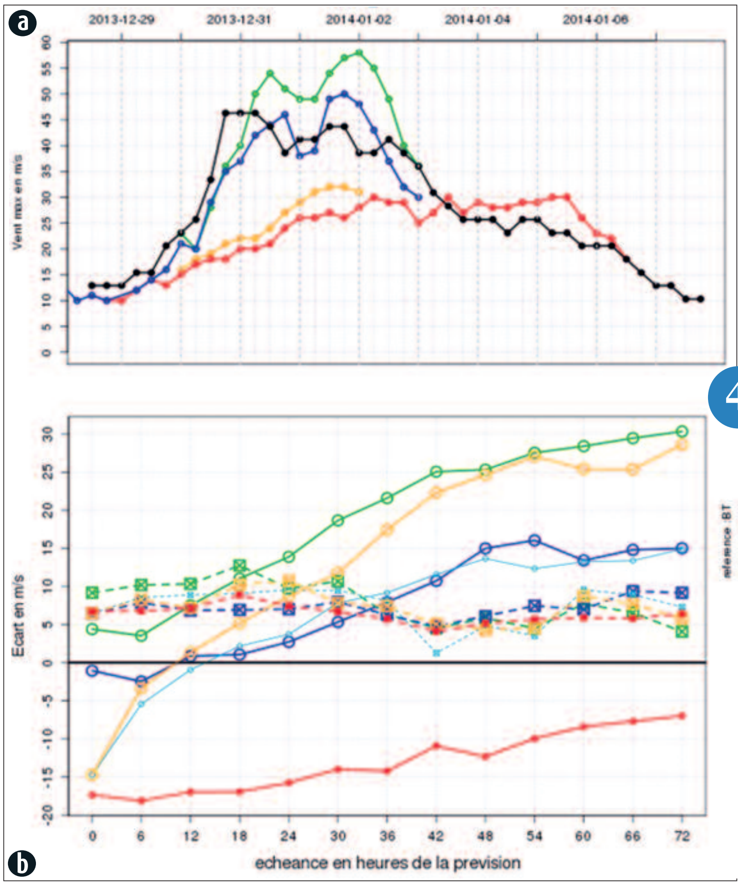


3

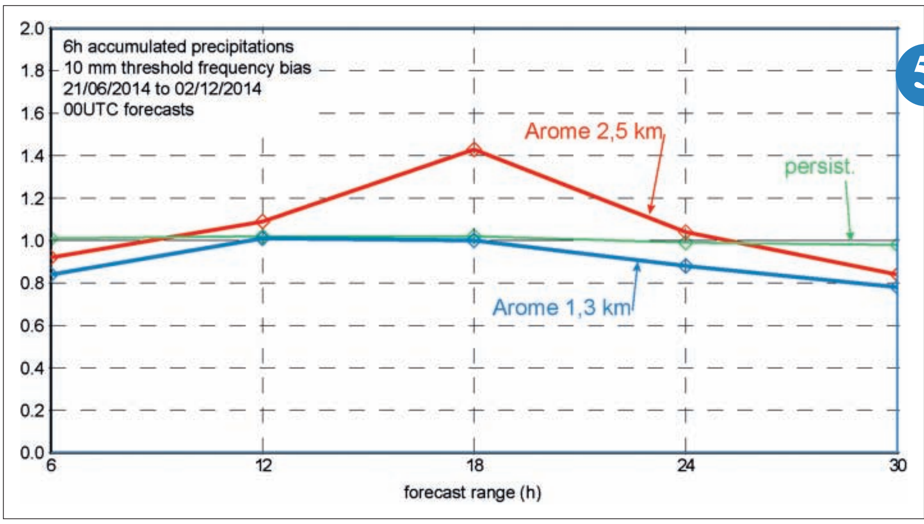
The grid point model forces the sub-grid particle system with averaged quantities, noted <V>. It is the down-scaling step. Then the particles evolve following the local dynamics and give back the sub-grid contribution, V'.



4

Maximum observed (black) and analyzed winds during Bejisa for different model configurations: IFS (red), AROME with no assimilation and no coupling (orange), AROME with assimilation and no coupling (green) and AROME with assimilation and OA coupling (blue).

As in Fig a, but for mean bias (solid lines) and STD (dashed lines) as a function of forecast lead-time.



5

Frequency biases of 6 hourly accumulated precipitation forecasts above given thresholds, 10 mm/6h in this case, against forecast range between 21 June and 2 December 2014. Forecasts are started from 00UTC. Red curve: operational AROME (2.5 km resolution); blue curve: new 1.3 km AROME; green curve: persistence forecast.

Assimilation

An hourly 3D Var data assimilation cycle for AROME

Observations are until now incorporated into the AROME data assimilation system every 3 hours. Hourly assimilation of observations is now possible and it allows to benefit from all the frequent observations available such as radar data, which is very informative at the AROME model horizontal scales (1.3 km). Thus, observations in the assimilation window [H-30 min, H+30 min[are combined to a 1 h range forecast initialized with the previous analysis, to provide a new analysed model state at H. This analysis is used as initial conditions in a new 1 h range forecast, itself used as a background to assimilate the observations at H+1, thereby forming an hourly continuous assimilation cycle of observations.
In the operational context, long range forecasts (up to 42 h) produced every 3 h, using the analysis valid at H, also wait for the lateral boundary conditions provided by the global model ARPEGE forecast of the same analysis time. Thus, these forecasts are also able to benefit from the analysed information at H+1, using a special algorithm, the Incremental Analysis Update, in order to add parts of the analysis increment obtained at H+1 at each model integration time step during the time interval [H+30 min; H+1 h 30[.
This configuration of the AROME-France system allows better performances, especially during meteorological situations sensitive to initial conditions, such as convective phenomena. This configuration, currently in test phase, should become operational at the beginning of 2015.

6

Improved representation of forecast error dynamics using an increased size for ensemble data assimilation

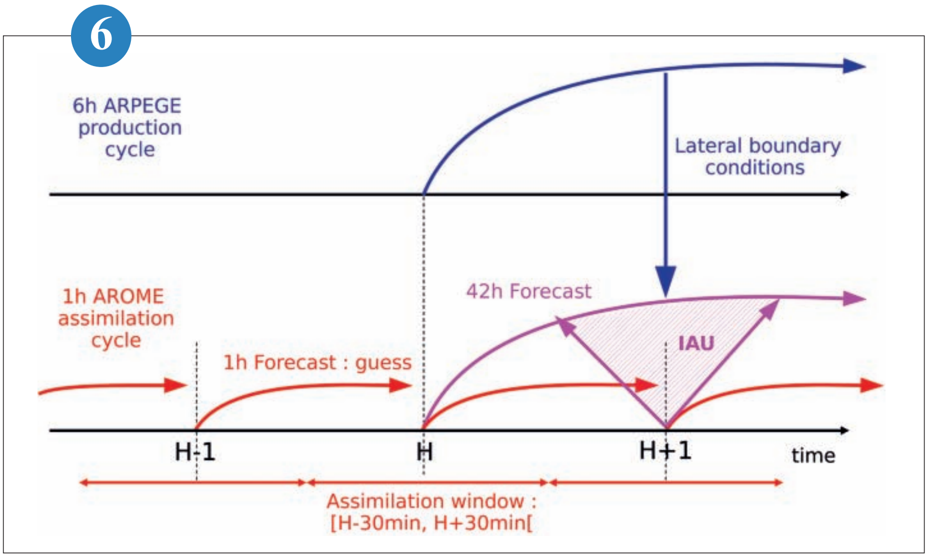
Assimilation of observations in numerical prediction models such as ARPEGE relies on accurate description of spatial correlations of forecast errors, as these allow observations to be spatialized. The estimation of these correlations is currently based on an ensemble data assimilation system containing 6 perturbed members and a temporal average over the 4 most recent days. This provides about one hundred forecasts in order to estimate correlations, which are recomputed once a day.
A new version of the ARPEGE ensemble assimilation has been developed, based on 25 members, a temporal average reduced to one day and a half (instead of 4 days), and an update of correlations every 6 hours (instead of 24 hours).
The figure illustrates that a more frequent update of correlations enables to account for the geographical variations of horizontal correlations length scales, estimated 15 November 2013 at 06UTC and at 12UTC respectively. One can observe in particular that these length scales evolve significantly over 6 hours in this area, which is linked, among other things, to the displacement of low pressure systems.
Impact studies indicate that this improved representation of correlations, associated to the increase of ensemble size, allows improved forecast quality. This new version of the ensemble assimilation also allows the 35 members of the ARPEGE ensemble prediction system to be better initialized, by providing 25 independent initial perturbations.
These evolutions will be part of the version of the ARPEGE system which will be made operational in 2015.

7

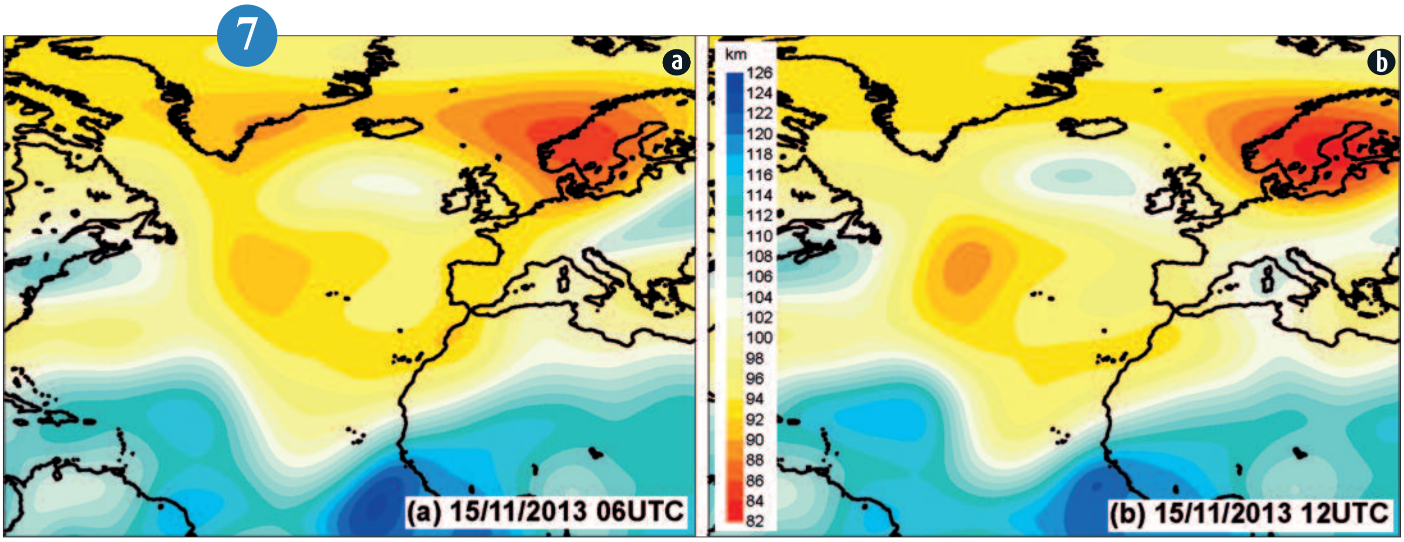
Increasing the density of IASI observations in overseas ALADIN models

IASI is an infrared hyperspectral sounder on board the polar orbiting European satellites Metop-A and Metop-B. It provides very precise atmospheric soundings with indirect measures of temperature and humidity profiles, within a 12 km pixel at nadir.
Following the very positive impact of assimilating high density IASI data in the AROME-France system, efforts have been directed towards the 4 oversea numerical weather prediction ALADIN systems (Southern Indian Ocean around La Réunion Island, Carabean and Guyana in the Western Atlantic, Polynesia and New-Caledonia in the Southern Pacific). The density of IASI observations used in these four data assimilation systems has been increased from 125 km to 70 km. All pixels are now proposed to the selection, instead of 1 out of 8 previously, so as to allow for the most relevant choice of pixel to assimilate. As a result, there is about 3.6 times more information from IASI used in these systems.
The impact on tropical cyclone forecast has been evaluated during the appropriate seasons in the Southern Indian and Western Atlantic domains. Forecast quality has been improved, especially that of low level wind and humidity fields, up to 24-48 forecast range as well as that of upper-tropospheric winds. The impact is neutral, on average, on the forecast of trajectory and amplitude of tropical cyclones. Such a high density of IASI data opens the way towards assimilating could properties, improving the realisticness of tropical weather systems in the oversea data assimilation and forecast suites.

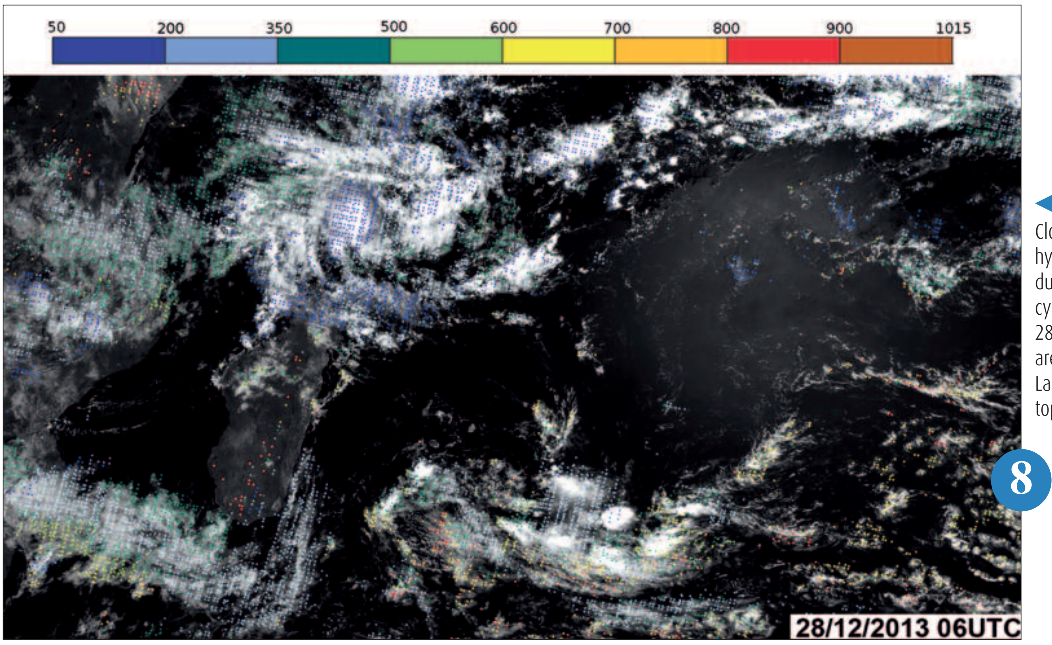
8



Schematic showing the new hourly continuous data assimilation cycle of the AROME-France system (red), for one hour H with incremental analysis update of the next analysis (magenta), (valid for H=00, 06, 12 and 18UTC) and for the production cycle of its host model ARPEGE (blue).



Horizontal length scales of forecast correlations errors of wind near 300 hPa (9.2 km height, colour shading, in km), estimated 15 November 2013 at 06UTC (a) and at 12UTC (b). The length scale of a local correlation function is a measure of its spatial extension..



Cloud top pressure derived from IASI hyperspectral sounder data, during the development phase of tropical cyclone Bejisa in the Indian Ocean, 28 December 2013 06UTC, over the limited area hydrostatic model ALADIN centred over La Réunion Island. Colour scale of cloud top pressure in hPa.

Impact of a new initial perturbation method for the ensemble prediction

The representation of initial uncertainty is an essential aspect of ensemble prediction, with a large impact on forecast performance at early ranges.
Two approaches are commonly used to design perturbed initial states for a limited area, convective scale ensemble forecast system:
Downscaling of perturbations from a global coarser ensemble prediction. This method is simple and almost cost-free, but it is not able to represent initial uncertainties at small scales.
Ensemble data assimilation. This method is more costly but it samples the uncertainty at all scales resolved by the model.
Experiments performed with the AROME ensemble prediction indicate a significant benefit from ensemble assimilation in the first hours of forecast, which supports the idea that it is necessary to represent the uncertainty at all scales from the initial time.
In this context, the possibility to produce cheaper fine-scale initial perturbations has been examined. The method proposed generates initial perturbations from random draws from the AROME forecast error covariances matrix. Such an approach then provides balanced flow-independent perturbations.
A first evaluation shows that these perturbations lead to a statistically significant improvement over the downscaled perturbations. This is related to the very-short spin-up of random perturbations that quickly get organized into dynamically flow-dependent structures close to those provided by an ensemble assimilation.
Hence, until an ensemble assimilation has been made available for operational use, the random perturbation method can be a viable alternative for initializing a convective-scale ensemble prediction.

9

Tools and methods of knoweldge transfer

Using HyMeX data to verify forecasts

The development of numerical weather forecasts systems requires abundant meteorological data to study the relationship between system upgrades and forecast improvements. Here, HyMeX surface data have been used in AROME high-resolution ensemble prediction studies. The aim is for this system to be operational in 2016. During autumn 2012, the collection of HyMeX observations has led to a threefold increase in usable data density for temperature, humidity, wind speed and precipitation, including heavy rain. The reprocessed, quality controlled data has been used to upgrade the representation of surface uncertainties in the model, and to better understand the relationship between surface, initial and lateral boundary condition errors.
The result is an effective ensemble prediction system for short (~1-day) ranges over France and its neighbourhood. The effort now focuses on radar observations and intense phenomena that require multiyear datasets.

10

Towards a calibrated extreme event prediction

Numerical weather prediction systems are subject to systematic errors that calibration (also called Model Output Statistics) can partly correct. All the statistical models that can be applied use a learning sample. Large sample size leads to more reliable results. However, one year is the largest homogeneous training data set one can afford due to constant improvement of the numerical prediction system. Though such a short data set is useful for the calibration of recurrent phenomena, it is useless for the prediction of extremes such as the most extreme windstorms.
Therefore the climate of the current version of the ARPEGE model has been computed. A simplified version of the ensemble prediction system based on initial conditions provided by the ERA-Interim 30 years re-analysis. An attempt was made to calibrate the probabilistic wind gust forecast related to the 50 most intense windstorms that affected France during the same period of time.
For each event, this calibration is based on the distance between the cumulative density function of climate and that of the forecast of the same event. The present approach emphasizes the tails of the two distributions. This calibration does improve significantly the detection of the strongest wind gusts. Moreover, the degradation with the forecast range appears weak.

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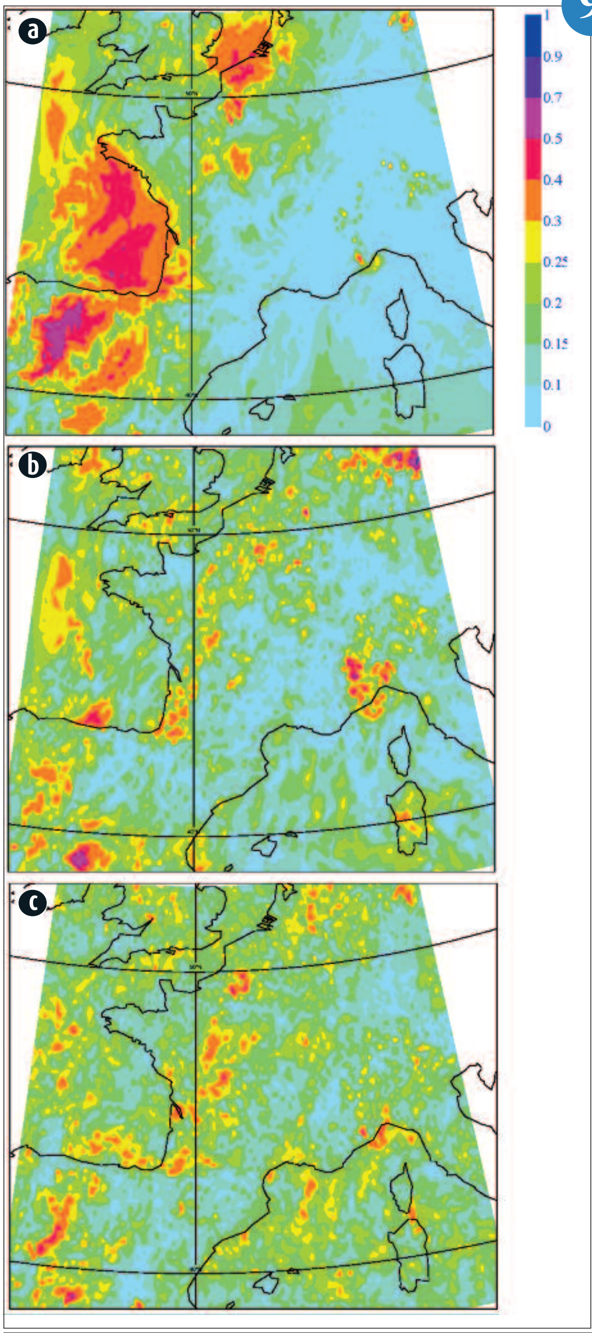
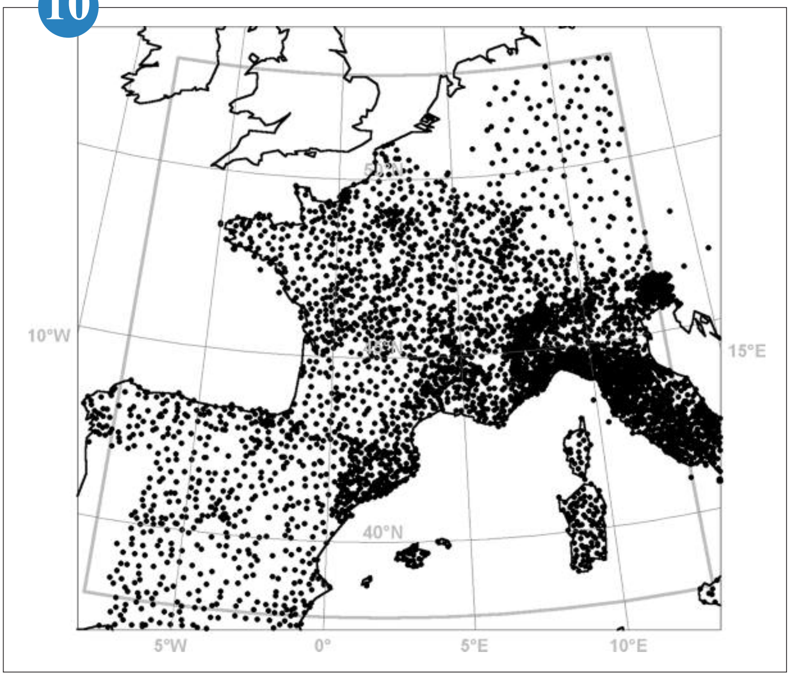


Spread of 1h-forecasts from the AROME ensemble prediction system, of 850hPa temperature valid on 8 June 2014 at 22UTC. The ensemble prediction is initialized with: (a) downscaled perturbations from the ARPEGE ensemble prediction (PEARP), (b) an AROME ensemble data assimilation and (c) random perturbations from the AROME forecast-error covariances. Random perturbations quickly lead to an ensemble spread close to that provided by the ensemble assimilation, whereas it requires about 9 to 12h for the PEARP perturbations to develop realistic small-scale structures.

10



Precipitation observing network used for ensemble prediction studies during HyMeX (autumn 2012)

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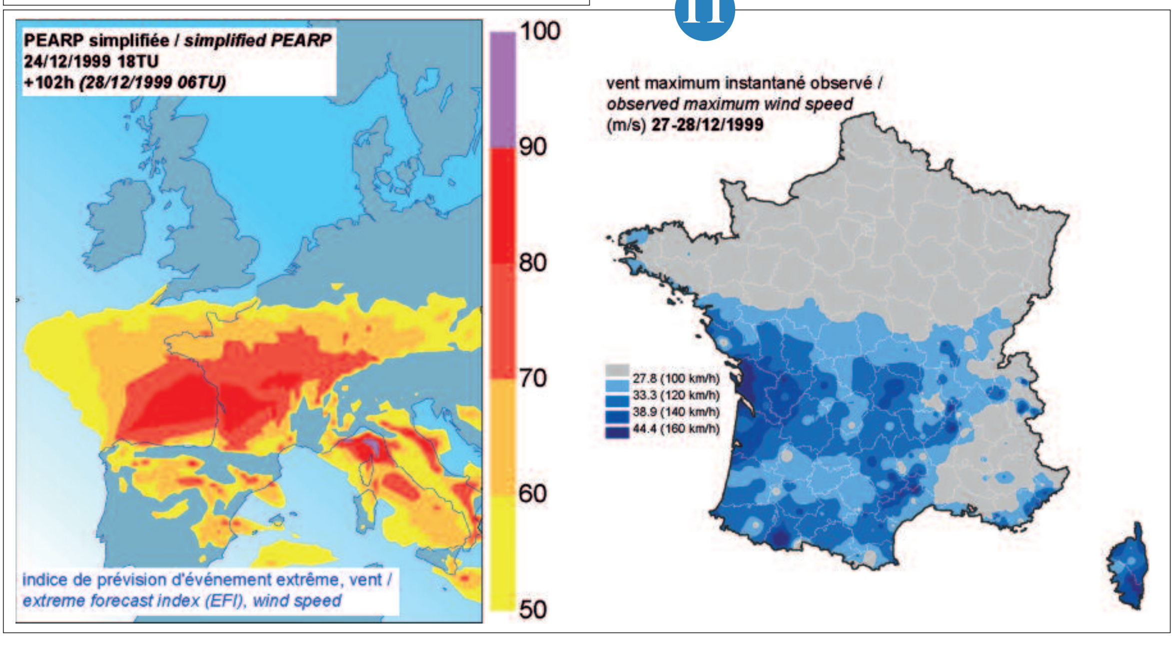

102 hours range probabilistic prediction of the 27 December 1999 storm (Martin). Left panel: the shaded areas show the departure of the ensemble forecast from the climate distribution. Right panel: gridded 10 m maximum wind gusts observations during 27 and 28 December 1999, provided by the Direction of Climatology.

The MISVA project: towards forecasting applications

The African monsoon is modulated by dry and wet spells lasting from a few days up to weeks. Their impact on Sahelian societies is often dramatic: a dry spell can reduce the food security, whereas intense and long-lasting precipitations can cause important floods. The understanding and the improvement of the forecast of such events represent major events for their warning and the attenuation of their impact.
Owing to a better understanding of this variability acquired during the international AMMA project, we developed in collaboration with Senegal and the OMP a web site MISVA (http://misva.sedoo.fr/), to monitor and forecast the intra-seasonal variability over Africa. It works in real time all during the monsoon season (June to September) since 2011. This site proposes diagnostics from the synoptic to the intra-seasonal scales which are now operationally used by Senegalese and French forecasters. In spite of a poor skill of present models to forecast precipitation over West Africa, the use of MISVA diagnostics based on more pertinent variables such as the monsoon equivalent depth (Figure a) or the barotropic component of the flow (Figure b) allows the anticipation of dry and wet spells, and flood risks a few days to a week in advance.
This fruitful collaboration between researchers and forecasters allows us testing our theories and rising new scientific issues to treat. An important outcome of MISVA is also the improving of the forecasting method and its illustration through a set a well-documented case study that contributed to the international project of the West African forecaster's Handbook to be published in 2015.

12

Validation of ice clouds infrared parameterisation in RTTOV using the A-Train

Infrared satellite data assimilation for NWP model does not currently allow to take into account NWP model cloud variables. To reach this objective it is necessary first to validate the radiative transfer model that simulates the infrared radiances from cloud optical properties parameterisation based on these NWP model cloud variables.
The CMS participates for many years in the development of the fast radiative transfer model RTTOV for the assimilation of infrared and microwave radiances in NWP models. For ice clouds, RTTOV provides different parameterisations depending on ice crystals size and shape. Recently, a new single parameterisation of ice clouds optical properties has been implemented in RTTOV. This single parameterisation is based on a database that contains various shapes and a new particle size distribution.
To validate this parameterization, we compared infrared radiances simulated from retrieved ice water content profiles based on collocated observations from active instruments onboard the A-Train constellation (the radar CPR onboard CloudSat and the Lidar CALIOP onboard CALIPSO) and observations from the infrared radiometer IIR also onboard CALIPSO. The Figure shows histograms of the differences in brightness temperature between IIR observations and RTTOV simulations for the current and the new ice cloud infrared parameterisation. The better performance of the new parameterisation is shown with a more symmetrical distribution, a bias closer to zero and a lower standard deviation.
Studies undertaken by Météo-France for the assimilation of infrared cloudy radiances can right now benefit from this new ice cloud infrared parameterisation.

13

Benefit of prognostic hail for storm prediction

Hailstorm is an intense and local phenomenon that occurs at sub-kilometric scales. Forecasting hailstorms is a real challenge that becomes achievable with a numerical weather prediction (NWP) model that has fine enough spatial resolution.
The hailstorm of June 23, 2014, which produced flash floods and severe damages over the west of Toulouse (115 mm in 2 hours over Colomiers), was simulated with the Meso-NH model at 500 m horizontal resolution, with a focus on the parameterization of cloud microphysics. The explicit representation of hail in the current microphysical scheme of Meso-NH/AROME models, in addition to rimed species already present as aggregates and graupel, significantly improves the amount of precipitation at the ground, and structures a stronger and more realistic convective line (Figure). The presence of hail reinforces the low-level dynamics of the convective system, by increasing downdrafts due to hail melting and rain evaporation, making the cold pool stronger and deeper. The location of the convective cells and their characteristics, such as the total mass of hail, the number of hailstone and their kinetic energy, present a good degree of realism that has been evaluated with ANELFA hail pads. These diagnostics, that are not available with the current microphysical scheme of AROME, would be potentially interesting for agriculture professionals for instance.
The study underlines the importance of a detailed microphysical scheme in fine resolution NWP models such as AROME.

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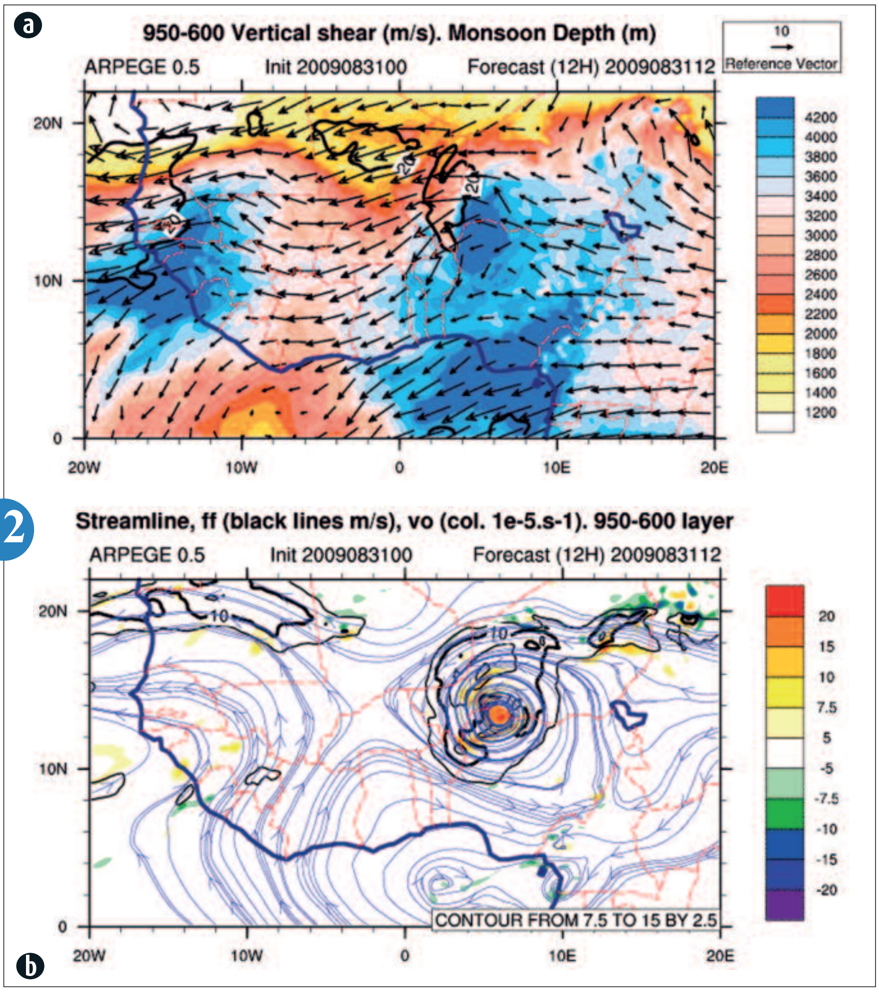
Example of MISVA diagnostics for African Easterly Waves for the Ouagadougou 2009 flood case (18 h before the event). (a) The equivalent monsoon depth visualizes the monsoon bursts (blue areas) on the eastern side of troughs, whereas the shear vector in the 950-600 hPa provides the propagation direction of convective systems and their degree of organization. (b) The barotropic circulation allows detecting the most intense Easterly Waves when the mean circulation in the 950-600 hPa layer is closed, cyclonic (red spots) and intense (black isolines of intensity). When both criteria (a) and (b) are met and strong, the synoptic situation is favourable for floods.

12



Histogram of the brightness temperature differences between IIR observations and RTTOV simulations. A total of 26791 ice cloud profiles were selected over the globe during two weeks. Ice cloud visible optical depths are between 0.03 and 4 and cloud layer pressures are situated between 440 and 50 hPa. Current infrared ice cloud parameterisations are represented in green, blue, purple and cyan. The new infrared ice cloud parameterisation is represented in red. Mean and standard values of each distribution are given in the legend.

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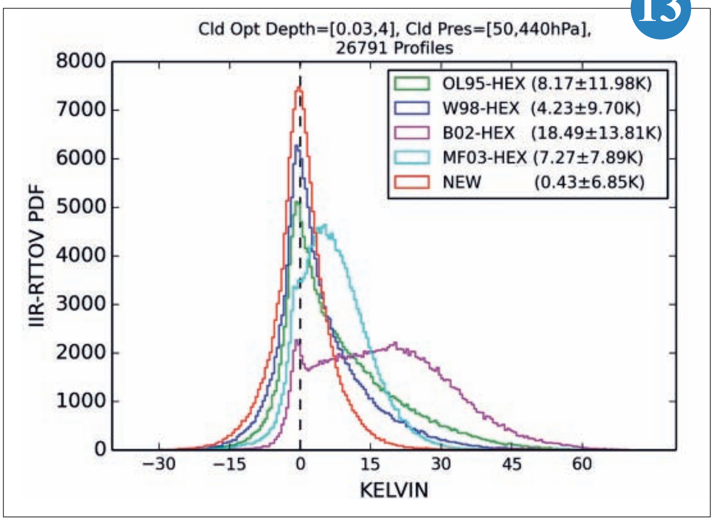

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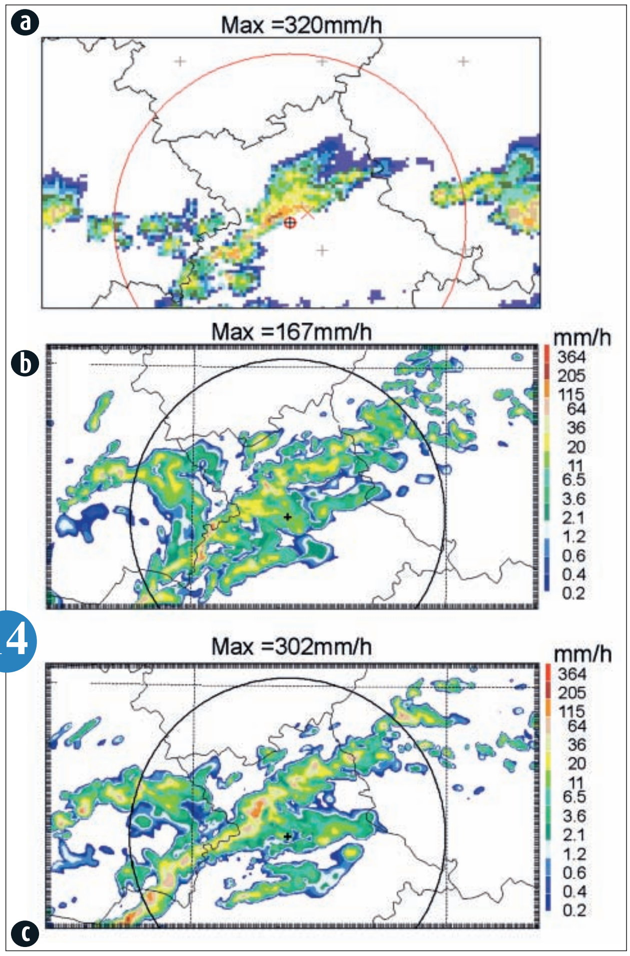


Ground precipitation rate (in mm/h) the 23th of June 2014 at 17:15UTC (a) observed by Toulouse radar, simulated by Meso-NH with the microphysical scheme (b) without explicit hail and (c) with explicit hail. The circle has a 50 km radius around Toulouse radar.

Study of process

Scientists at CNRM-GAME actively work toward understanding physical processes upstream to the applications. A better knowledge of the intimate mechanisms that govern meteorological phenomena, as well as their continuously improved representation in numerical models, are critical for the operational groups involved in risk management or climate adaptation.
The researchers address various compartments of the Earth system, ranging from microphysics to planetary scale features. The reader could be struck by the variety of spatial and temporal scales, from the smallest ones to the entire planet, or from few seconds to the longer tempos of climate variability.
Observations, field campaigns and experiments feed scientific knowledge. Numerical models, covering this large range of scales, are the vital analysis tools. Scientists take full advantage of all the resources offered by numerical systems. They can carry "surgical" experiments to deconstruct and understand processes. They can slightly modify conditions of reconstructed past events to create monster events, aiming to raise awareness on risks and inviting to work on reducing vulnerabilities.
In 2014, emphasis has been put on storms, both from a meteorological and a climatological perspective. Understanding the dynamics of severe weather, but also the interplay with planetary climatic oscillations governing their low frequency variability are some of the scientific objectives of such research works. The final target is always the transfer to forecasting and risk reduction. This also provides the rationale for the compilation and reconstruction of past storms, with the idea that knowing the past will help us to understand our present and foresee the future.
Last but not least, the reader will appreciate the list of world class fluid mechanism works carried on in the hydraulic tank. Since the early 80's, this infrastructure has heavily served fundamental sciences as well as weather related applications. It is now stopped after decades of virtuous service. This closure opens a new page for process studies at CNRM-GAME!

1

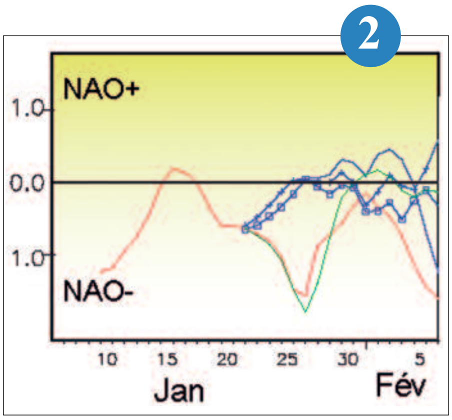
Understanding

Impact of the stratosphere onto the troposphere

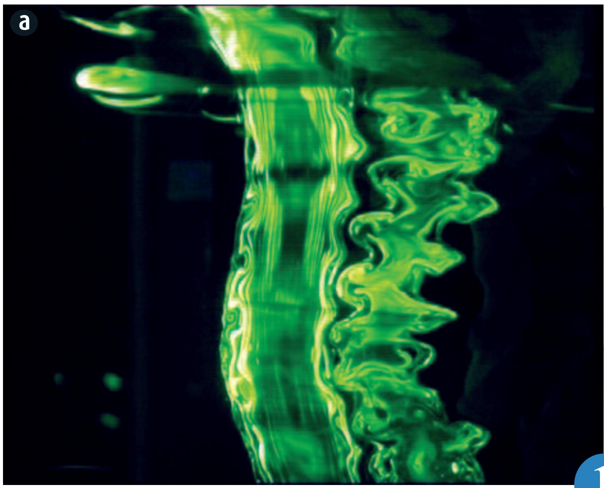
Polar vortex variability as well as the North-Atlantic upper-tropospheric jet stream variability are well represented by different phases of the Northern hemisphere Annular Mode (NAM) and the North-Atlantic Oscillation (NAO). A positive NAO-phase leads to moist and mild winter over Northern Europe whereas a negative phase shifts the jet stream southward leading to more precipitations of Southern Europe and the Mediterranean basin. Negative (respectively positive) NAM-phase is characterized by a weak (respectively strong) polar vortex. The influence of the stratosphere onto the troposphere is subject to debates during the last decade.
The January to February 2010 period, characterized by a transition from a long-lasting positive to a negative phase of the NAO is illustrative of this kind of relationship. "Numerical surgery" applied to initial-condition stratospheric Potential Vorticity followed by forecasts tells us that the removal of the polar vortex (actually the removal of its Potential Vorticity) makes the transition toward the negative NAO phase easier.

However, that may not be the only mechanism. Another series of experiments, illustrated by the figure, shows that the synoptic-scale activity over the Pacific also plays an important role: reducing it, still using numerical surgery, prevents the NAO phase transition. This is because during its later non-linear decay phase, a mid-latitude cyclone reaching the Atlantic modifies the NAO through the way it gives part of its kinetic energy back to its environment.

2

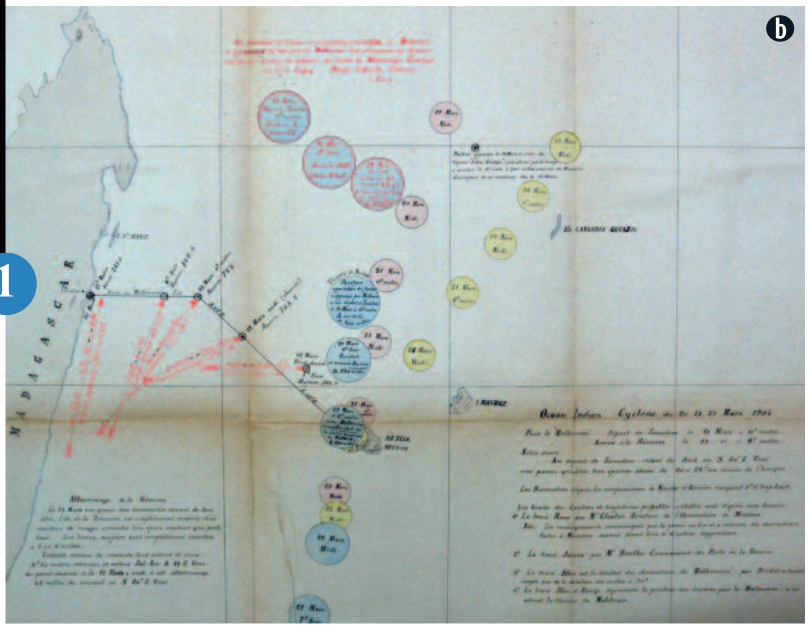


Sensitivity of the NAO phase to the synoptic activity over the Pacific. The event of interest if the transition from NAO+ to NAO- that occurs end of January 2010 (the red curve displays the observed index proved by ARPEGE analyses). The green curve shows that the forecast starting on the 22th January 2010 is skilful. The blue curves indicate that the decaying of the index is hindered by the cancellation of the synoptic activity onto the Pacific (the 3 curves stand for experiments based on 3 different analyses, an ARPEGE analysis using a 2 hour observation window, another ARPEGE analysis using a 8 hour observation window and the ERA-Interim one).



(a): Instability of a pair of cyclonic and anticyclonic vortices in a rotating and stratified fluid Anticyclonic vortex (to the right) is unstable to small scale perturbation contrary to the cyclonic vortex (to the left). The flow is visualized using a fluorescent dye. (Copyright Météo-France/GMEI/SPEA - P. Billant)

1



(b): Map of the 20-21-22 March 1904 cyclone around La Réunion island. From the meteorological archives currently being restored thanks to Foundation BNP Paribas sponsorship © Archives nationales/Météo-France.

Influence of low-frequency modes of variability in the Northeast Pacific on the North Atlantic Oscillation via the downstream propagation of synoptic waves

The North Atlantic Oscillation (NAO) represents the dominant atmospheric circulation in winter over the North Atlantic. It corresponds to a variation of the North Atlantic jet with latitude: the North Atlantic jet is shifted poleward during the positive NAO phase (NAO+) guiding more storms over the western part of Europe. During the negative NAO phase (NAO-), the North Atlantic jet is shifted equatorward, leading to a drier weather over the western part of Europe. Thus, the understanding of the mechanism influencing the changes of the NAO is a key question in order to characterise and predict the weather during the winter season.

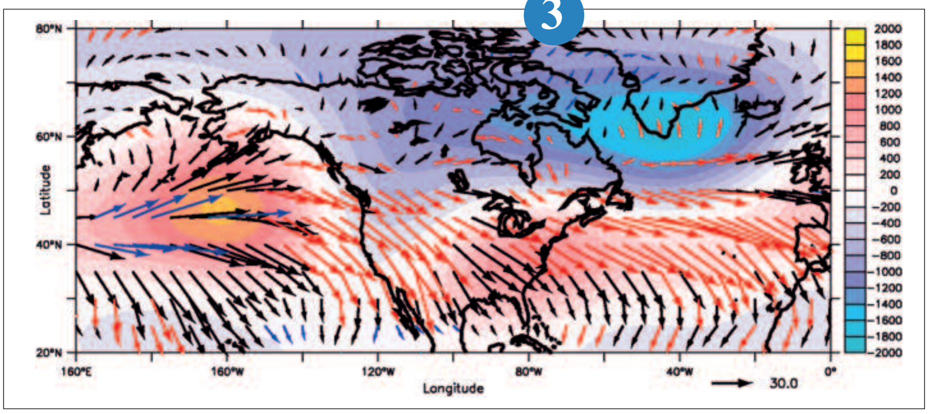
One key ingredient influencing the NAO is the existence of a low-frequency, planetary-scale geopotential anomaly located over the northeast Pacific-North American area. This anomaly modifies the propagation of Rossby waves over North America and downstream, influencing the NAO via the subsequent breaking of these waves over the North Atlantic. A positive anomaly (ridge) over the northeast Pacific modifies the tilt of eddies composing these waves in a southwest/northeast direction which favours the NAO+, whereas a negative anomaly (thalweg) induces a north/south tilt favouring the NAO-.

This mechanism can explain the link between the NAO and low-frequency modes of variability in the Pacific, like El Niño-Southern Oscillation (ENSO) or the Pacific-North American tele-connection (PNA). Indeed, the low-frequency atmospheric anomaly in the North Pacific associated to these two modes of variability modifies the downstream propagation of Rossby waves in the same way (see figure).

3

Monthly composite of the association of negative PNA and positive NAO phases (20 months). The shading corresponds to the low-frequency geopotential anomaly, arrows represent the E vector (see scale at bottom in $m^2 s^{-2}$) at 300 hPa (about 15 km high) for the months of November to December between 1957 and 2002 (ERA40 reanalysis). E vectors oriented toward the equator indicates that eddies composing the synoptic Rossby waves show a southwest/northeast tilt, eastward-oriented E vectors indicates a north/south tilt and E vectors oriented poleward indicates a northwest/southeast tilt. Red arrows indicate that E vectors are significantly oriented toward the equator (70% confidence threshold), whereas blue arrows indicate that E vectors are significantly oriented toward the pole, with the same confidence threshold.

3



Explicit aerosol-clouds interactions in the microphysical scheme LIMA

Atmospheric aerosols affect the cloud microstructure through their ability to nucleate droplets or ice crystals. They are also involved in complex processes and in many feedbacks impacting both the cloud physics and the cloud dynamics.
The 2-moment microphysical scheme LIMA was developed in Meso-NH to explicitly represent aerosol-clouds interactions at convective scale. Thus, LIMA includes a detailed, 3D prognostic representation of aerosols accounting for the diversity of aerosol chemical compositions (and therefore nucleating abilities), sizes and concentrations.
LIMA is based on the ICE3 scheme, which is operational in AROME. The same hydrometeors classes are considered (cloud droplets, rain drops, ice crystals, snow, graupel, and optionally hail). To provide a better representation of the cloud microstructure and aerosol impacts, LIMA also has three additional prognostic variables for the number concentrations of cloud droplets, rain drops and ice crystals.
To initialize aerosols for LIMA, the MACC analyses performed at the ECMWF are used. The coupling strategy enables the use of LIMA with a realistic aerosol population. Figure a) shows, for a case of heavy convective rainfall observed during HyMeX, the benefit of using such a realistic aerosol population.
LIMA should become the new reference microphysical scheme in Météo-France for cloud processes and aerosol-clouds interactions studies. LIMA will be transferred to the AROME model to improve the cloud representation in the operational numerical weather prediction system.

4

Vertical profile of fog droplet size distribution measurements

Fog life cycle results from the nonlinear interactions of competing processes (radiative cooling, turbulence, microphysics) and vertical profile measurements of thermodynamical and microphysical properties are needed to better understand such relationships and to validate numerical simulations.
An airborne Cloud Droplet Spectrometer (CDP) from Droplet Measurement Technology (Boulder, CO) that provides cloud droplet size distribution over 2-50 µm in diameter, has been adapted in order to be operated under a tethered balloon. This device has been deployed with a tethersonde that provides meteorological parameters during a field campaign carried out at Magescq (Landes) in the south-west of France during winter 2013/14.
To validate vertical profiles collected with the tethered balloon, a forest fire tower has been equipped at 3 altitude levels (8, 24 and 42 m) with instruments providing droplet size distribution measurements (Fast-FSSP, CDP and Fog Monitor) as well as direct measurements of liquid water content (PVM-100) and visibility (DF20).
During the night of 5-6 March 2014, a complete fog life cycle event was sampled from the formation to the dissipation stage. These measurements show that liquid water content and microphysical properties (droplet size and number concentration) follow different time evolution depending on the altitude level. Analysis of size distributions also reveals typical features of quasi-adiabatic droplet growth at the top of the fog layer.

6

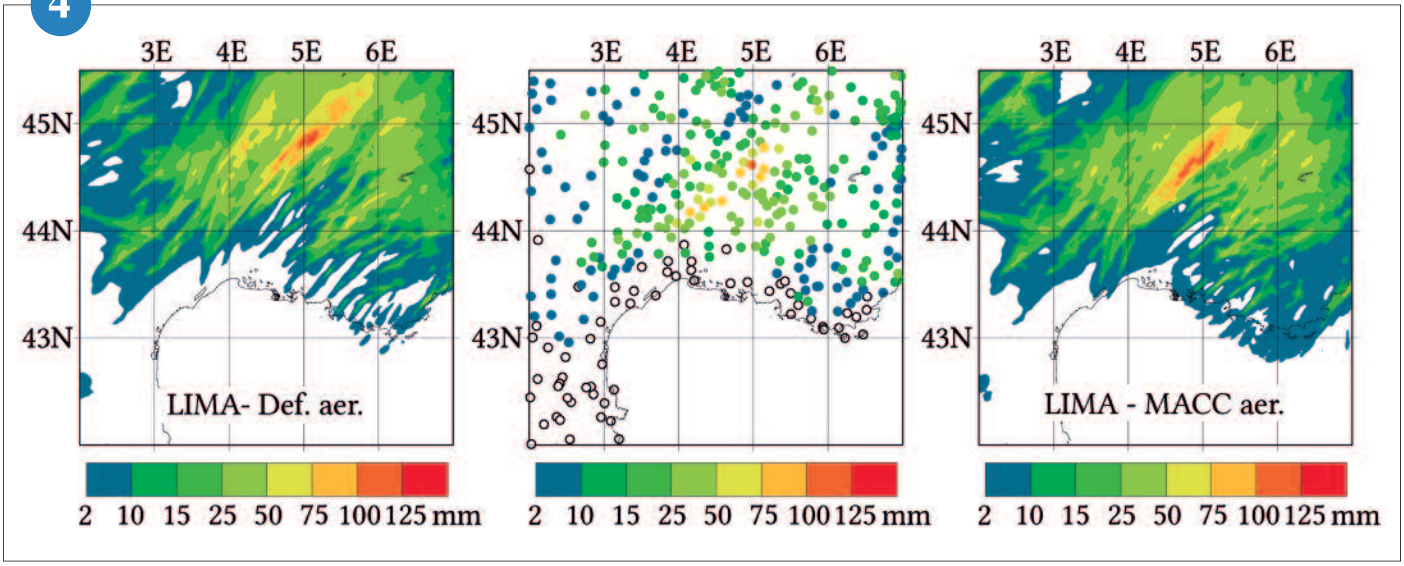
Convective gusts in the Sahel

Soil aeolian erosion is an intermittent process, observed during strong wind events. In the Sahel, the strongest surface winds correspond to gusts associated with storms and squall lines (Figure a); these convective events are indeed responsible for a large part of aeolian erosion. The comparison of surface wind speed data acquired at several Sahelian sites with those from meteorological reanalyses such as ERA-Interim, NCEP-CFSR or MERRA shows that the latter miss convective gusts. These gusts indeed correspond to subgrid processes and are not well represented with current parameterizations (Largeron et al. 2015). Thus, surface wind speed provided by reanalyses, even though they are often used as input for soil erosion models, are not well adapted in the Sahel.
In order to advance on this issue, we design and introduce a parameterization of surface wind speed distribution during convective events. This parameterization builds on a statistical analysis of surface winds provided by CASCADE simulations performed over West Africa. The simulations are run over several weeks during the monsoon, with a finer spatial grid allowing an explicit representation of convective events. Figure b shows an example of wind speed distributions during convective periods built from CASCADE simulations and obtained with a parameterization which, for now, takes into account precipitation rates. If relevant, we plan to further incorporate the influence of a few other driving variables such as wind shear and convective indexes.

5

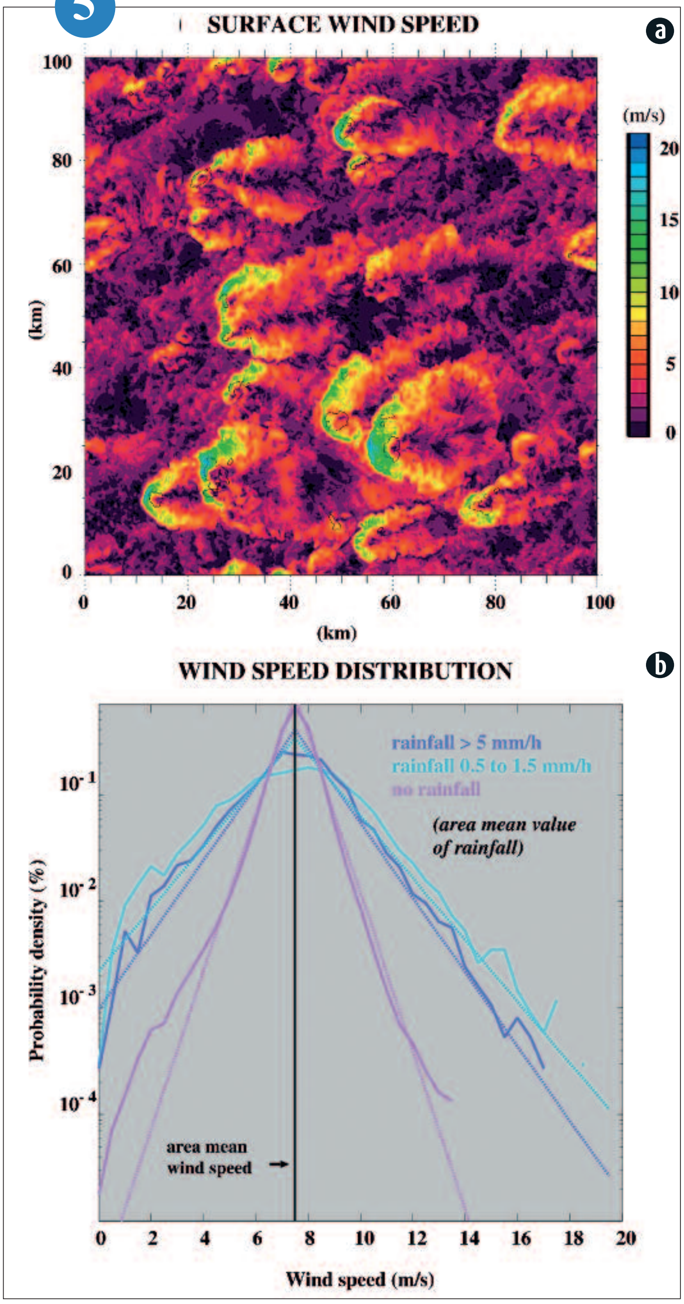
Surface wind speed: (a) horizontal cross section during a convective storm simulated with the MesoNH Large Eddy Simulation (LES, horizontal grid size of 100 m x 100 m); (b) for a given value of mean wind speed (solid black line), comparison of the distributions of wind speed for different ranges of precipitation (colours) in CASCADE simulations (dotted lines) and with the parameterization estimate (solid lines) – mean values are considered over horizontal areas of 70 km x 70 km.

4



12-h accumulated rainfall, 12UTC 24 sept. 2012.
Meso-NH simulations using default (left)
or MACC (right) aerosol initialization, and observations (centre).

5



6

Instruments deployed under the tethered balloon:
modified CDP (top) and tethersonde (bottom).

Impact of the cloud microphysics on the development and life cyclone of a tropical cyclone

Faced with the cyclone threat, the main issue is to forecast both the track, the intensity and the main consequences of a cyclone passing next to inhabited regions. During the last years, the track forecasting has been largely improved, but the intensity and associated hazards forecasting remains a major scientific issue.
The potential impact of the cloud microphysics on cyclone modeling is analyzed through high resolution numerical simulations of an idealized tropical cyclone performed with the research model Meso-NH. The reference simulation uses the microphysical scheme ICE3, also put into the numerical weather prediction model AROME. The mass of liquid (cloud water, rain) and ice (crystals, snow, graupel) particles is predicted. If the ice phase is excluded, the cyclone accelerates and is deflected toward the pole (Figure a). If the graupel fall-speed is reduced, the minimum sea level pressure, a marker of the cyclone intensity, is up to10 hPa higher than in the reference simulation (Figure b). The microphysics hypotheses impact the phase changes inside the cloud and thus the latent heating budget, which modify the air buoyancy, and the radial and tangential cyclonic circulations.
This preliminary study shows the significant impact of the microphysics on the numerical representation of tropical cyclones. Simulations of cyclones Dumile (2013) and Bejisa (2014) will be performed with a microphysics scheme that predict both the mass and number of cloud particles, and coupled to an aerosol concentration budget, sources of cloud particles. Thus, the aerosols-clouds interactions will be analyzed.

7

The CNRM-GAME large stratified water flume at the heart of research on topographic internal waves in Europe

Cutting-edge studies have been conducted by the CNRM-GAME water flume team for thirty years in various fields such as pollutant dispersion and high resolution wind mapping over complex site, wakes in stratified flows, or stratified turbulence.
Since 2007, the main focus of the team has been research activities on internal gravity waves generated over the sea floor by tides or at the earth surface by winds.
Due to the temporal and spatial scales involved, data field measurements are difficult and explicit numerical modeling is only possible for very small domain. This is why laboratory work is such an important tool to investigate the complex phenomena associated with these waves. One important condition is to be able to generate stratified flows at high Reynolds number in the laboratory, the CNRM-GAME water flume is precisely one of the very few facilities in the world with this capacity. Most notable works, each a world first, are listed below.
2007: experiments on turbulent eddies downwind mountains (rotors) with Hannover university.
2008: 3D visualizations of lee-waves breaking with IMFT.
2009: simultaneous measurement of wave field and drag over a mountain with University College London.
2011-2012: experiments on the different mechanisms of interaction of a ridge with the bottom of the oceanic mixed layer with OMP/LA.
2013: experiments on internal waves effect in a stable boundary layer with Wageningen University.
2014: experimental falsification of internal-tide-generation paradigm with NIOZ, experiments on supercritical internal tides over complex topography with Stockholm University, experiments on rotors in a valley and downwind a double mountain with Innsbruck and Vienna University, NCAR and the national weather services of Island and Croatia.

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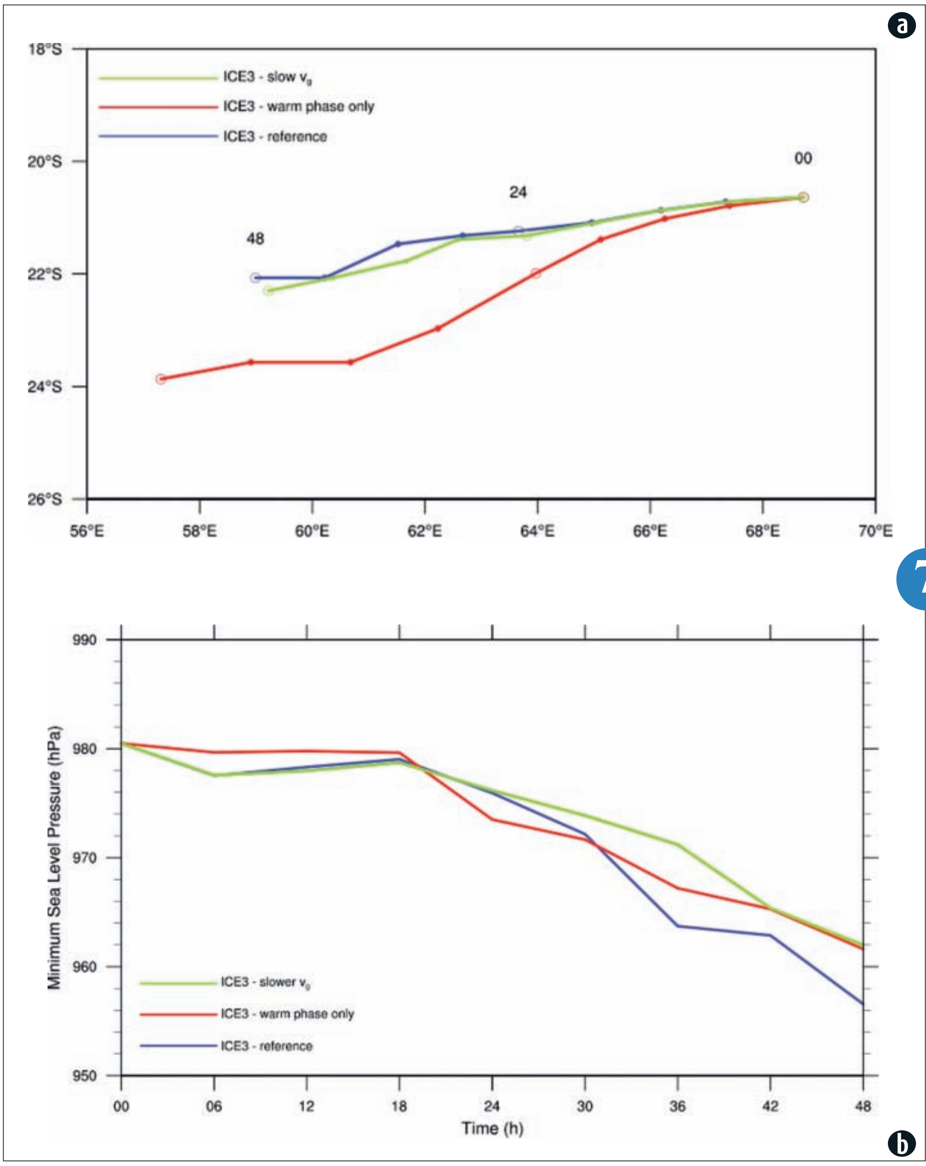

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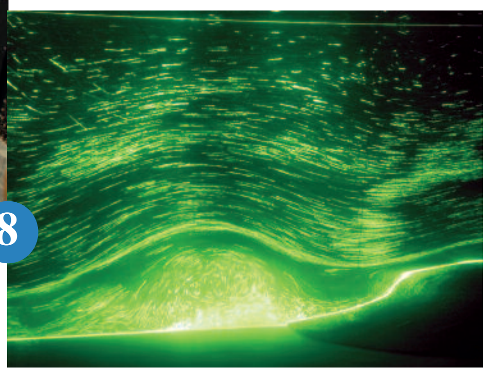
(a): 48-h track of an idealized tropical cyclone simulated by Meso-NH at 2 km horizontal resolution. The blue, red and green lines shows the cyclone tracks using the microphysics schemes ICE3, ICE3 without the ice phase, and ICE3 with slower graupel fall-speed, respectively.

(b): Temporal evolution during 48 hours of the minimum sea level pressure (hPa) for an idealized tropical cyclone simulated by Meso-NH. The blue, red and green lines shows the cyclone tracks using the microphysics schemes ICE3, ICE3 without the ice phase, and ICE3 with slower graupel fall-speed, respectively.

8

The CNRM-GAME large stratified water flume.

Rotor (side view, perpendicular to the flow) under the first crest of the wave downstream of a mountain. Visualization is obtained by particles illuminated by a vertical laser plane sheet. Reynolds number of the flow is larger than 20000.



To focus on the storms in the past

Past storms simulations with downscaling starting from a large-scale re-analysis

The purpose of the IncREO project is to better anticipate and plan which measures should be taken whenever a natural disaster happens, based on Earth observations.
In this context, Météo-France (CNRM-GAME et Marine Forecast) together with the Bulgarian National Institute of Meteorology and Hydrology, investigated waves and surges resulting from past storms over the French and Bulgarian coasts. Thirty events between 1924 and 2012 have been selected.
Wave and storm-surge models are forced by the low level atmospheric states. To get the best possible forcing, numerical weather forecasts of these past events were produced using ECMWF reanalyses. They are considered to provide the best memory of past weather. A downscaling is, nonetheless, needed to properly resolve intense cyclogenesis at mid-latitudes.
Two types of downscaling have been used. The first one, quite straightforward, includes an interpolation of the re-analysis followed by a finer-mesh weather forecast. Wave and storm-surge simulation results are better than those using direct re-analysis data as forcing. The second procedure takes into account small scale data from forecasts from the previous 6h runs and combines them to the large-scale re-analysis data from the ECMWF re-analysis. This second method yields the deepest and best reproduced storms.
These methods could be applied to other surge and flood cases so as to better understand and prevent these events.

9

Characterization of the historic storms in France

The ANTHEMIS action coordinated by the Direction de la Climatologie aims at characterizing storms having affected French territory during the last decades. Various complementary methods were followed: wind gust data, geostrophical wind estimation and atmospheric reanalysis. The final goal is to give complete diagnoses on these climatic extremes thanks to a web site open to the public in 2015. This site will integrate information on the historic storms of the last 200 years, knowledge of their dynamic and description of their climatic variability, trends and future evolution.
In 2014, a study was led on a high-resolution original set data over France (hourly and 2,5 square km). These data come from a statistical process including wind gust observations, geographical parameters and data of the operational model AROME, since 2009 in a continuous way but replayed in an event mode for more than 500 storms days between 1980 and 2009.
The study has experimented a new method of storm characterization for identification, spatial extension, duration and severity of the phenomena. At the end, 146 events experienced during the last 35 years such as Lothar and Martin in December, 1999 or Xynthia in 2010 were qualified. The method has been defined to be applicable in real time and will give in 2015 new tools for climate monitoring of these extreme events.

10

Story of storms, real or imagined

The Vimers 1 project intended to better foresee the risk of sea submersions on the Brittany coasts, through a partnership between Météo-France, the SHOM and the CEREMA. It has just been completed in autumn 2014. For this project, meteorological situations of nearly twelve storms have been carefully described thanks to ancient documents relating to the 1891/1950 period (meteorological reports of that time, barograms…). Each of these former events, which must not be forgotten, has been the purpose of an about ten pages report which gives a very accurate picture of the path and the strength of the storm.
For more well-known events, belonging to a representative sample built with more recent storms (1979/2014), the waves and sea surges have been modelled again. During these simulations, the combination of the storm with a spring tide peak has been tested.
For the final part of the project, storms which have never happened but which are physically credible have been focussed on to learn about the consequences. For that purpose, the simulations of the ARPEGE's Ensemble Forecasts (PEARP) have been used. Indeed, some of the perturbed forecasts may suggest a much stronger phenomenon than the real one, with a quite different track. Thus, in the case of the storm Xynthia (28/02/2010), more considerable waves and sea surges could have occurred at some places of the Breton coastline. In the same way, imaginary violent western winds in the Channel have been able to induce extreme waves and sea surges inside the St-Malo Gulf. But, no return periods have been assigned yet to the bound water levels. That is one of the aims of the project Vimers 2 which is being programmed at the end of this year 2014 with a wider partnership.

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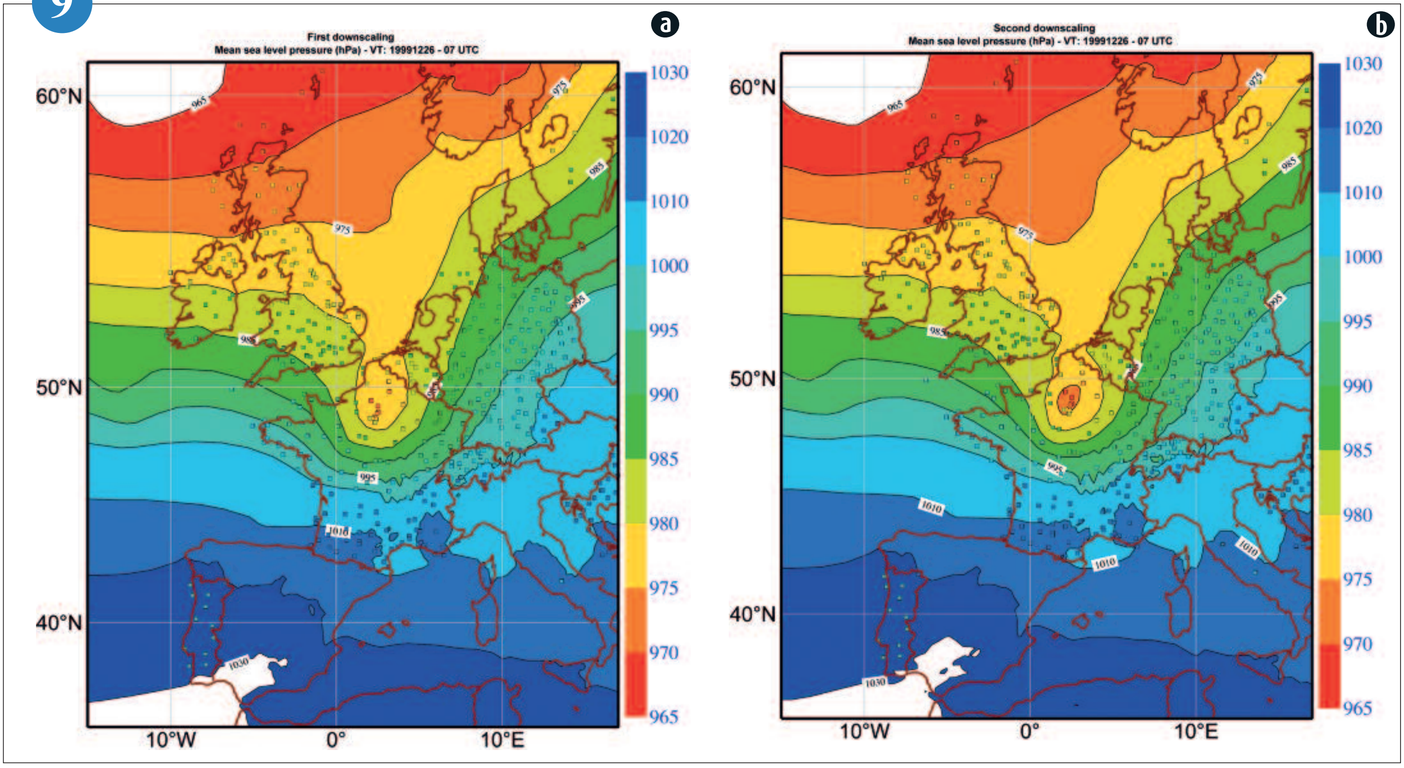

Mean sea level pressure (shaded, hPa) for the first (a) and second (b) downscaling method on 26/12/1999 at 07UTC. Observations (hPa) are superimposed and represented by coloured squares.

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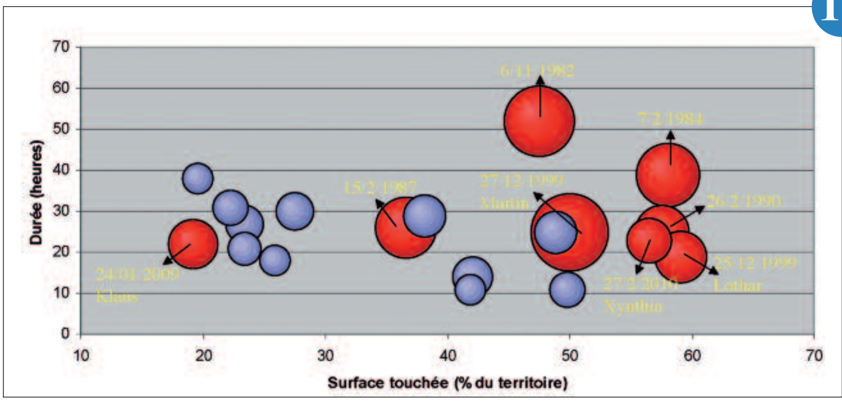
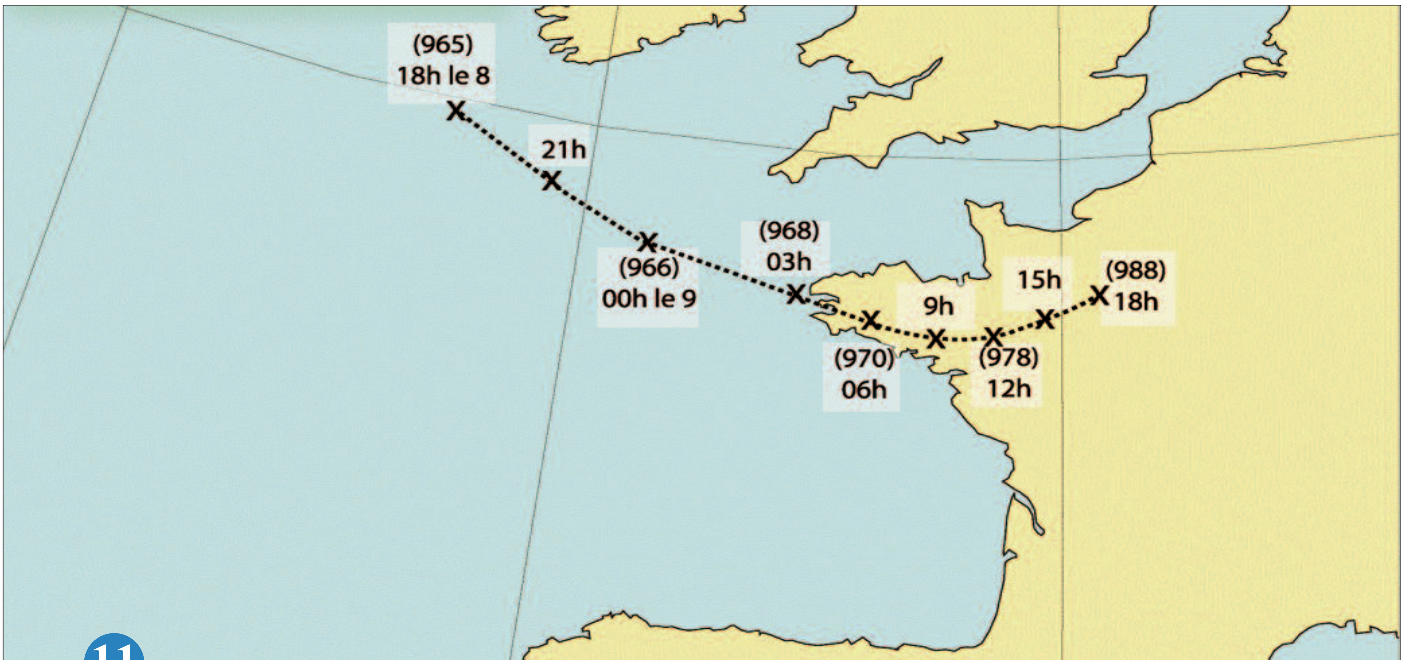


Characterization of the major storms experienced in French Territory over the period 1980-2013 according to the percentage of area affected (abscissas), duration in hours (orderly) and severity with Lamb indices (size of bubbles).
In red, the strongest 8 storms with their date and possible name.



11

Path and levels of the depression, observed on the 8th and 9th of January 1924, after the appraisal of reports and data of those days.

Re-run of past storm events with regard to surge modelling

The participation of the Météo-France marine forecast service to Vimers1 project consisted in running its surge present operational model with wind and pressure forcing data which aimed to represent at best weather conditions encountered in some selected past storm events. These forcing data were issued from the ALADIN atmospheric model which had previously been run in a downscaling mode coupled with ERA-INTERIM reanalyses.

Figure "a" shows both time curves of model and "observed" surge at Brest location during the "25 February 1989" storm event. We can notice a great resemblance between these two curves, even if in this case the model overestimates the "observed" surge by 5 to 10 centimeters (with here a 71 cm maximal model surge versus a 63 cm maximal "observed" one).

The maximum "observed" and model surge values at the first represented high tide, occurring on the morning of February 25, are both around sixty centimeters, and lead to a 7.11 m total sea level value, which is 0.82 m under the local Highest Astronomical Tide level (HAT) and so doesn't represent by itself a flooding threat.

Figure "b" shows the equivalent graph obtained on the same storm event, that is to say with a calculation using exactly the same wind and pressure forcing data, but having delayed time by 278 hours to bring the surge highest pike into coincidence with the much larger high sea tide of 9 March 2009 in the morning (here with 116 tide coefficient value, HAT level corresponding to a 120 value). The model surge value at this high tide now reaches 68 cm, which, when added to the 7.66 m of astronomical tide high sea level, leads to a 8.34 m total sea level value, this time exceeding HAT level by 0.41 m.

So we can see how a same storm, according to whether its maximum surge pike occurs or doesn't occur exactly at the same time than a very high "astronomical" tide, can lead to very different flooding risks, even if maximum surge is significant but not exceptional at all.

For this event and this place (Brest), we also verified that non-linear interaction between "astronomical" tide and "atmospheric" surge was rather weak, that is not generally the case for most Channel and North Sea locations, by example.

12

Tropical cyclone rapid intensification in the southwest Indian Ocean: climatology

A climatological study has been carried out in close collaboration with the RSMC in La Reunion, in charge of the cyclonic surveillance over the southwest Indian Ocean. The aim is to position our tropical basin on the international stage by highlighting its own characteristics; characteristics that have already been defined in two other basins. The 177 tropical systems analysed over the 1999-2014 period fall into 3 categories: 39 depressions, 64 storms and 74 cyclones (maximum intensity stage reached throughout their life time). A definition for rapid intensification (RI) is proposed as a 24-hour intensity change exceeding 13.9 m/s, a threshold corresponding to the 95th percentile of all 24-h over-water intensity changes of tropical systems over the southwest Indian Ocean. This value is lower than the official threshold of 15.4 m/s established over the North Atlantic with the same method.

The frequency distribution of 24-h intensity change stratified by tropical cyclone intensity is shown in figure. It indicates that RI (extreme right-hand side of the graph) is more likely to occur for storms since the latter are further away from their maximum potential intensity (MPI) than hurricanes and, thus, have the potential to intensify faster. Conversely, there is a higher likelihood for hurricanes to decay rapidly (left-hand side of the graph) due to their comparatively high initial intensities but also due to their southern positions that induce (i) more chance to land and (ii) reduced oceanic heat content.

It is also shown that 36.2% of all tropical systems (resp. 75.7% of all tropical cyclones) underwent RI at least once during their lifetime. Finally, the study identified the privileged areas for rapid intensification in the basin, for each category of systems (depressions, storms, cyclones).

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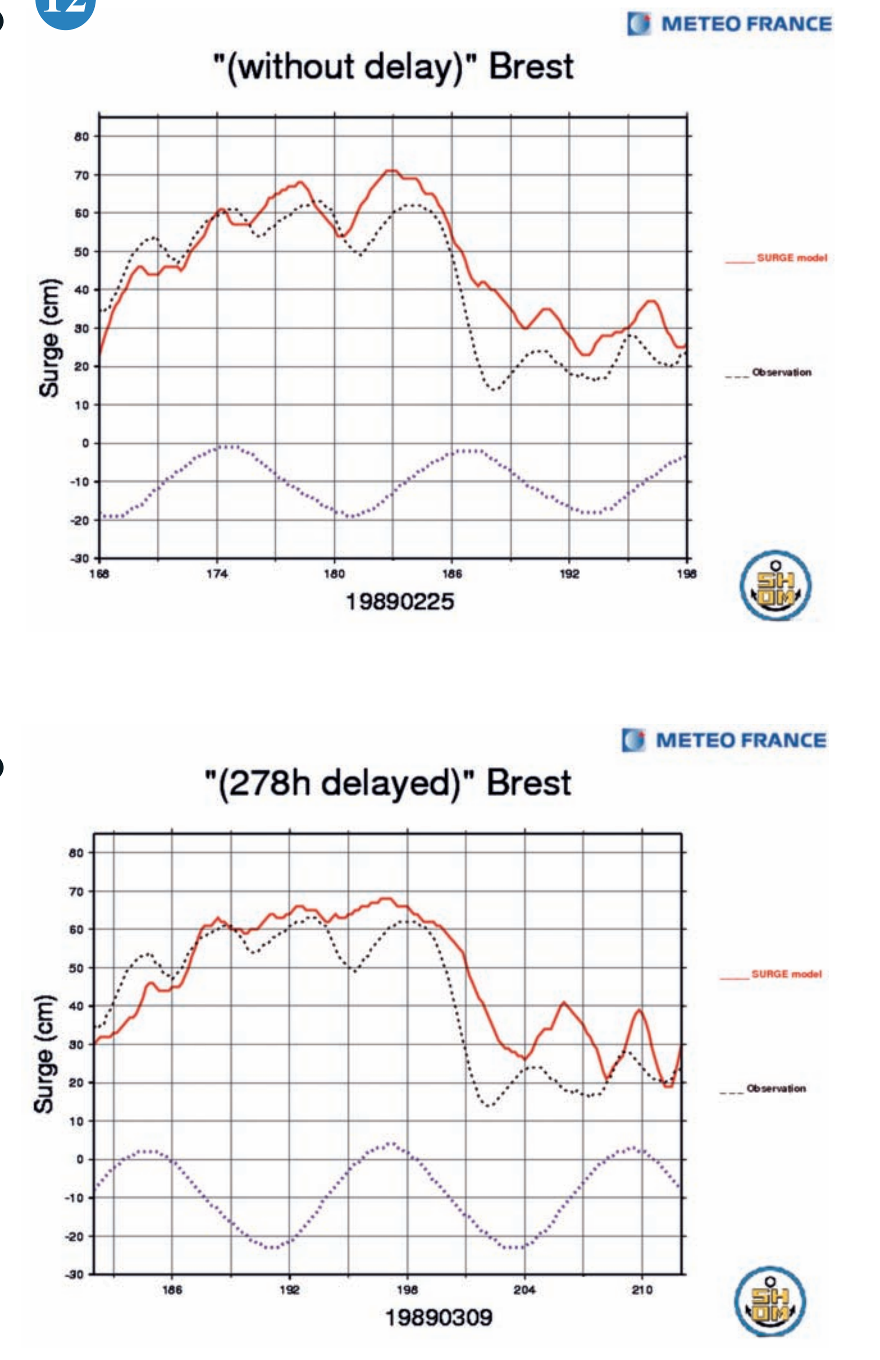

(a)): Time surge curves at Brest location during the “25 February 1989” storm event: storm surge simulated by model is visible on the solid red line curve, to be compared with the « observed » one which can be seen on the thin black dashed curve; the purple dotted curve at the bottom of the graph represents the tide in reduced size, just to indicate when occur low and high tides.

(b): Time surge curves at Brest location when the “25 February 1989” weather conditions are delayed by 278 hours to bring the main surge pike into coincidence with a very high tide pike at March 9, 1989: in such a case, maximum total sea level is obtained by adding the maximum model surge of the red curve to the maximum tide value of the purple dotted line curve at same time (reduced for convenience on graph).

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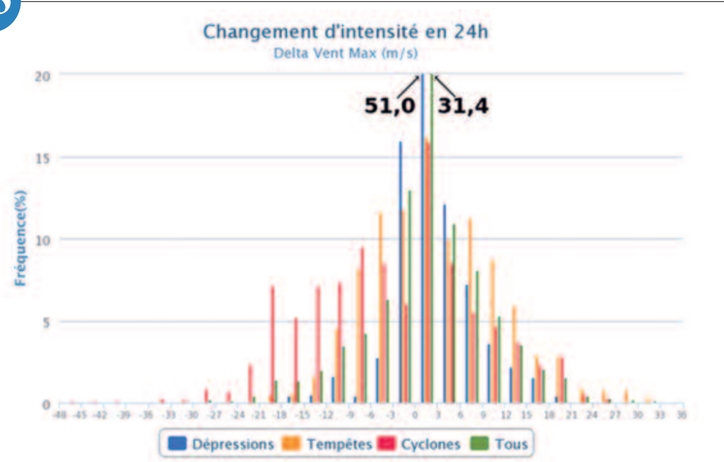


Frequency distribution of 24-h intensity change (V24) stratified by tropical system initial intensity. Distributions are provided for tropical depressions (Vmax < 17 m/s), tropical storms (17 m/s ≤Vmax ≤34 m/s), tropical cyclones (Vmax > 34 m/s) and all tropical systems.

Climate

Through the year 2014, we pursued the analyses of climate simulations performed within the context of the CMIP5 international project. These include a study of the respective role of the physical and dynamical processes on the future increase of day to day and diurnal variability in summer and in Europe. This year is also a year of transition to the new configurations of the climate models that will be used in the upcoming international exercises. A first continuous simulation of 6-month duration over south-eastern France with AROME shows the ability of the model to simulate the most intense rains at climatic scales. But before the achievement of this work, some studies also focused on climate variability and the ability of existing configurations of models to simulate, to interpret, or even to forecast this variability. This is particularly the case for a study conducted in collaboration with IPSL and recently published, showing the possibility to forecast the natural variations of the phytoplankton primary productivity up to 2 to 5 years in advance. Another study has allowed improving the representation of surface processes linked to the carbon cycle over the Amazon rainforest. Regarding the seasonal forecasting, a study explored the influence of the size of the forecast ensembles on the scores for different variables. On the other side, the seasonal forecast research field has extended both towards the smaller scale and, downstream, towards the applications of forecasts, including in a climate service context.
Research and development in the field of climatology focused on collection of data designed to feed the reconstruction of climate during the 20th century prepared by ECMWF. A new dataset of homogenized temperature, much more complete than the previous one, was produced over the period 1950-2013. Its analysis allows us to conclude to the detection of climate change in metropolitan France, not only on average but also at the local level throughout the territory. In the field of climate production in France, the application of a new method of estimation of precipitation extremes on a regional scale, reveals to be superior to the methods used so far.

Modelling Climate and climate change

Evolution of European summer temperatures in the CMIP5 generation of climate projections

Europe is warming, particularly in summer. By 2100, the amplitude of the summer warming is estimated between 0.1 and 8°C according to CMIP5 projections (Figure).
This important uncertainty results from (i) the choice of the socio-economic scenario (RCP), (ii) the choice of the climate model and, to a lesser extent, (iii) the internal variability, an intrinsic feature of the climate system which can be estimated through ensemble simulations. Together with this mean warming, future projections suggest an increase in both day-to-day and diurnal variations of European summer temperatures, albeit again with large uncertainties linked to the scenario, the model and the internal variability. Interestingly, contrarily to the mean warming, the increase in variability is specific to European summers, as no such a trend systematically arises in other regions and/or seasons. The mean warming and, more marginally, the increase in temperature variability contribute to make heat waves more frequent, more intense, longer lasting and more extended spatially.
Reducing the uncertainties associated with these trends thus constitutes a crucial issue, particularly for impact studies. The research conducted at GMGEC has allowed to quantify how, for a given scenario, the mean warming and variability increase are modulated by the response of the North-Atlantic atmospheric dynamics, and the reduction in both the cloudiness and soil moisture in Europe. Current studies focus on establishing links between simulated future changes and model skills in representing the present-day climate, in order to constrain climate projections by observations.

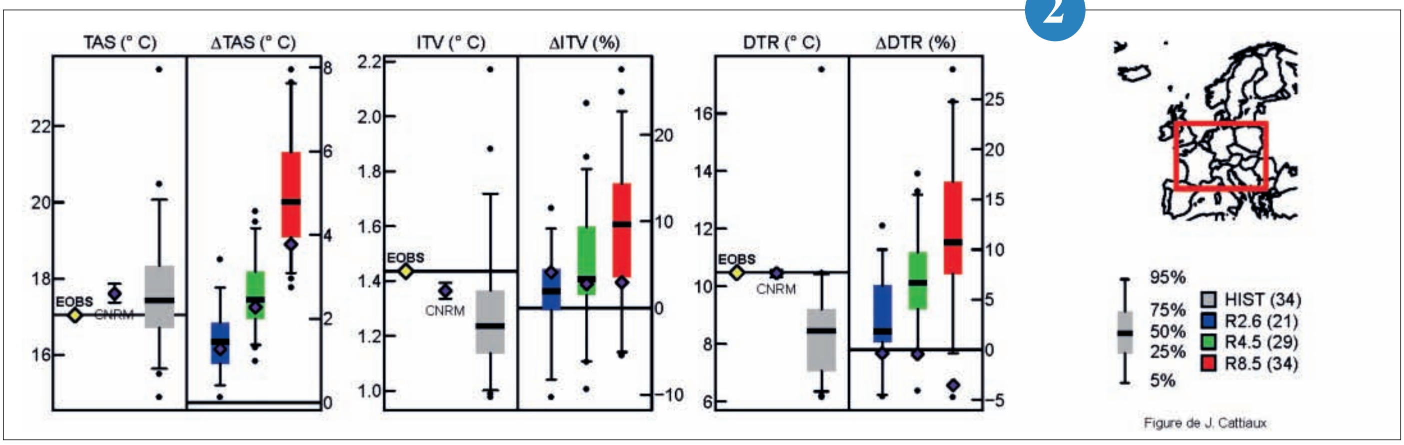
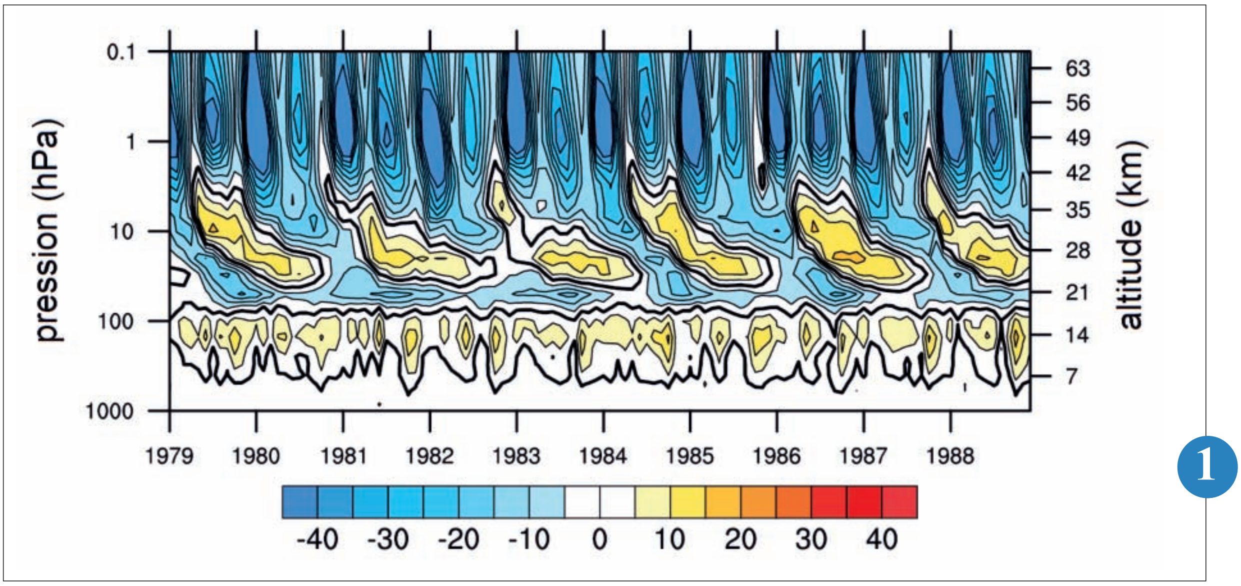


Figure de J. Cattiaux



Time-height section of the mean zonal wind simulated over the equator (5S-5N) by the ARPEGE-Climat T63 91-level model, including the parameterization of non-orographic gravity waves, and forced by ERA-Interim. The figure shows the ability of the model to simulate the Quasi-Biennal Oscillation (QBO).

First attempt to simulate climate with AROME

Evaluating climate impacts of anthropogenic warming requires a spatial resolution finer than that of today IPCC models. With ARPEGE variable resolution model and then ALADIN model, Météo-France has tried to satisfy this demand since the mid-1990s. We have progressively reduced our grid size to 50 km, 25 km and 12 km, according to the increasing capacity of computers. We have described with some success regional characteristics of the French or European climates, and their possible evolution due to global change. However, these models represent the phenomenon of convection, which produces intense rainfall, through various empirical relations of increasing complexity named physical parameterizations. The so-called "Cevenol episodes" are coarsely represented (lift of moist air over the mountains under the thrust of large-scale circulation).

The AROME model, used since a few years at Météo-France for short-range prediction has, with its 2.5 km horizontal resolution and its non-hydrostatic equations the capacity to represent quantitatively the convection phenomenon. This is illustrated by the figure with a continuous simulation (not a sequence of short predictions) of July to December 1994. ALADIN, driven by the observed large scale over the Mediterranean basin, drives in turn AROME on South-East France. We have sorted the most intense rain days. Among the 10 selected with ALADIN, 9 are strong rain days for both models. One can see that if ALADIN captures coarsely high precipitation areas, AROME produces locally heavier precipitation. The perspective is to validate the model over the last 20 years and to downscale an IPCC scenario.

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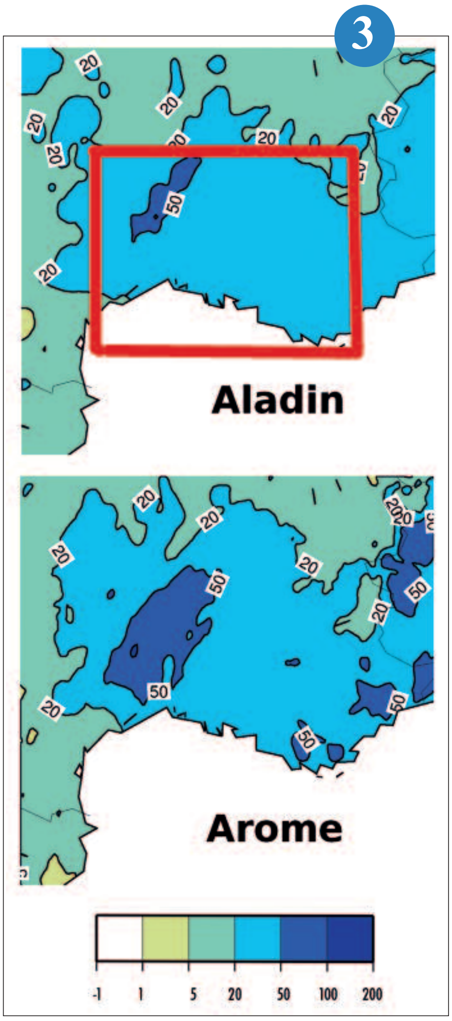

Mean precipitation of the rainiest 10 days of July-December 1994. The selection criterion is mean precipitation inside the red rectangle: ALADIN model (left panel) and AROME model (right panel)

Mean and variability of European summer temperatures. Left: mean air surface temperature (TAS). Middle: inter-diurnal (day-to-day) temperature variability (ITV). Right: diurnal temperature range (DTR). For each panel are plotted the values estimated over the period 1979-2008 (observations in yellow, range of the CNRM-CM5 model in purple, and gray boxplot for the CMIP5 ensemble), and the differences between 2070-2099 and 1979-2008 for three climate scenarios (blue, green and red boxplots for the CMIP5 ensemble for respectively RCP2.6, RCP4.5 and RCP8.5, with the CNRM-CM5 in purple). Changes in variability are expressed in percentages relative to present-day values. The region of interest, the boxplot signification and the number of models used in each ensemble are indicated in the caption.

Assessing potential to predict natural fluctuations of the marine production of phytoplankton in the tropical Pacific

The tropical Pacific hosts the largest world fisheries that supply the world with several hundred million tons of fish commercially exploited. In this region, fishes catches varies substantially from one year to another, responding to climate oscillations such as the El Niño/La Niña. During La Niña phase, the equatorial upwelling strengthens, bringing nutrient-rich deep waters at surface enhancing the phytoplankton growth. The production of the phytoplankton, called the net primary productivity (NPP), is at the base of the marine trophic food web, supporting stock of living marine resources. During El Niño phase, nutrient-depleted surface waters reduce the NPP, inducing trophic pressure on some fish stocks. This stress induced by the natural variability acts concomitantly to that due to human foraging on marine ecosystem. Although interesting, few works have truly investigate the capability to predict natural variation of NPP considering that the ability to predict El Niño phenomenon is limited to 6 months to 1 year.

Here, we investigate the ability of an Earth system model to perform predictions of tropical Pacific NPP variations observed by satellite since 1997. Results suggest a predictive skill for NPP of 3 years, which is higher than that of sea surface temperature (1 year). These results open novel perspectives to the development of science-based management approaches to marine resources relying on integrated physical-biogeochemical forecasting systems.

4

Representation of carbon and water exchange between the Amazon forest and the atmosphere

The Amazon rainforest plays a crucial role in the global climate system regulating the regional water and carbon cycles. The forest recycles about 25 to 35 % of the precipitation and stores about 10 % of the global above ground biomass. The Amazon biome is currently a sink of carbon absorbing more carbon than it releases but this sink was strongly reduced during the major droughts of 2005 and 2010. The climate simulations for the last IPCC report show an increased consensus for a longer and more intense dry season in the Amazon at the end of the 21st century. This would reduce the Amazon sink of carbon and hence amplify the greenhouse effect.

In this context, it is necessary for a climate model to correctly represent the processes governing the water and carbon exchanges in the Amazon. We evaluated the CNRM-GAME land surface model, ISBA-CC, before its use in the climate model CNRM-CM6. The comparison with the measurements from five « FLUXNET » towers and the results from two artificial drying experiments in the Amazon and Guiana led us to modify the parameterization of evapotranspiration, respiration and the vegetation sensitivity to drought. The model was then tested over the whole Amazon basin using river discharge data, reconstructed evapotranspiration and carbon assimilation fluxes, and remotely sensed total water storage variations and chlorophyll fluorescence data. Finally, the sensitivity of the ISBA-CC parameterisations to future climate change was explored in order to prepare its use within the climate model CNRM-CM6.

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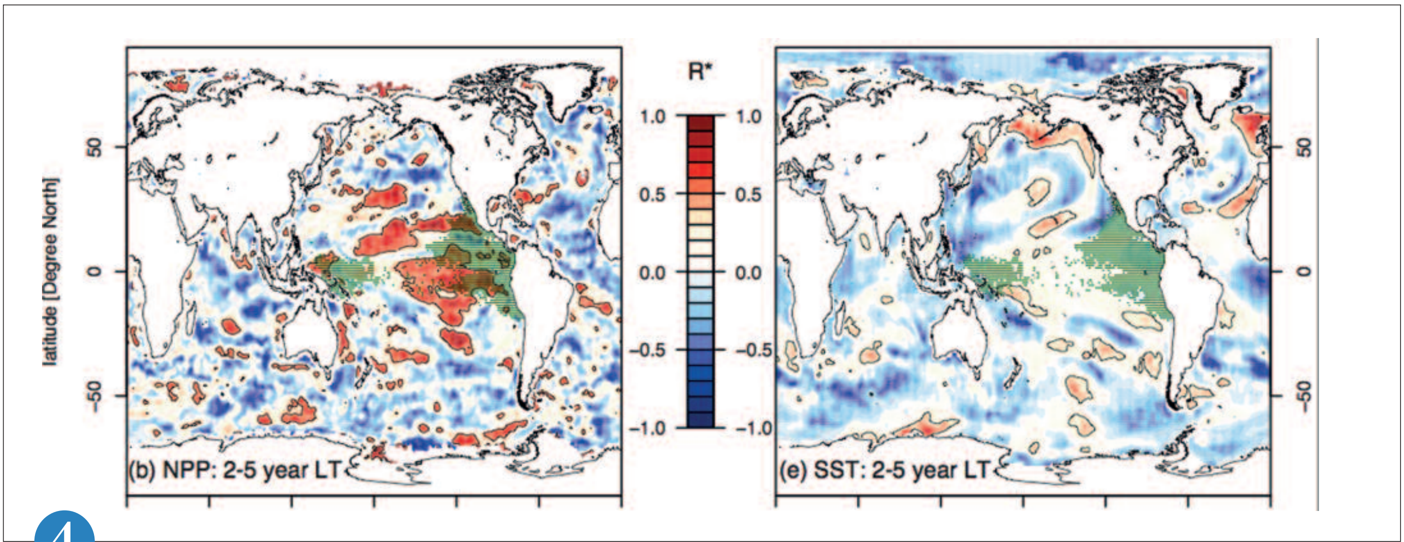

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Comparison of the predictive skill at 2-to-5 years in reproducing observed variations in annual mean net primary productivity (NPP) and sea surface temperature (SST) measure in terms of correlation with observed yearly mean anomalies of primary productivity of Eppley-VGPM and VGPM average and Reynolds and HadISST average for sea surface temperature. Fishing areas over Jan. 1991-Dec. 2011 within the low-latitude Pacific Ocean (30°S-30°N) are indicated as green-hatched regions.

Sunrise over the French Guyana rainforest and monthly mean latent heat from 2001 to 2004: observed (black; Goulden et al., 2004) and simulated with the ISBA_CC control version (red) and modified version (green) for the Tapajos, km83 site (Brazil).

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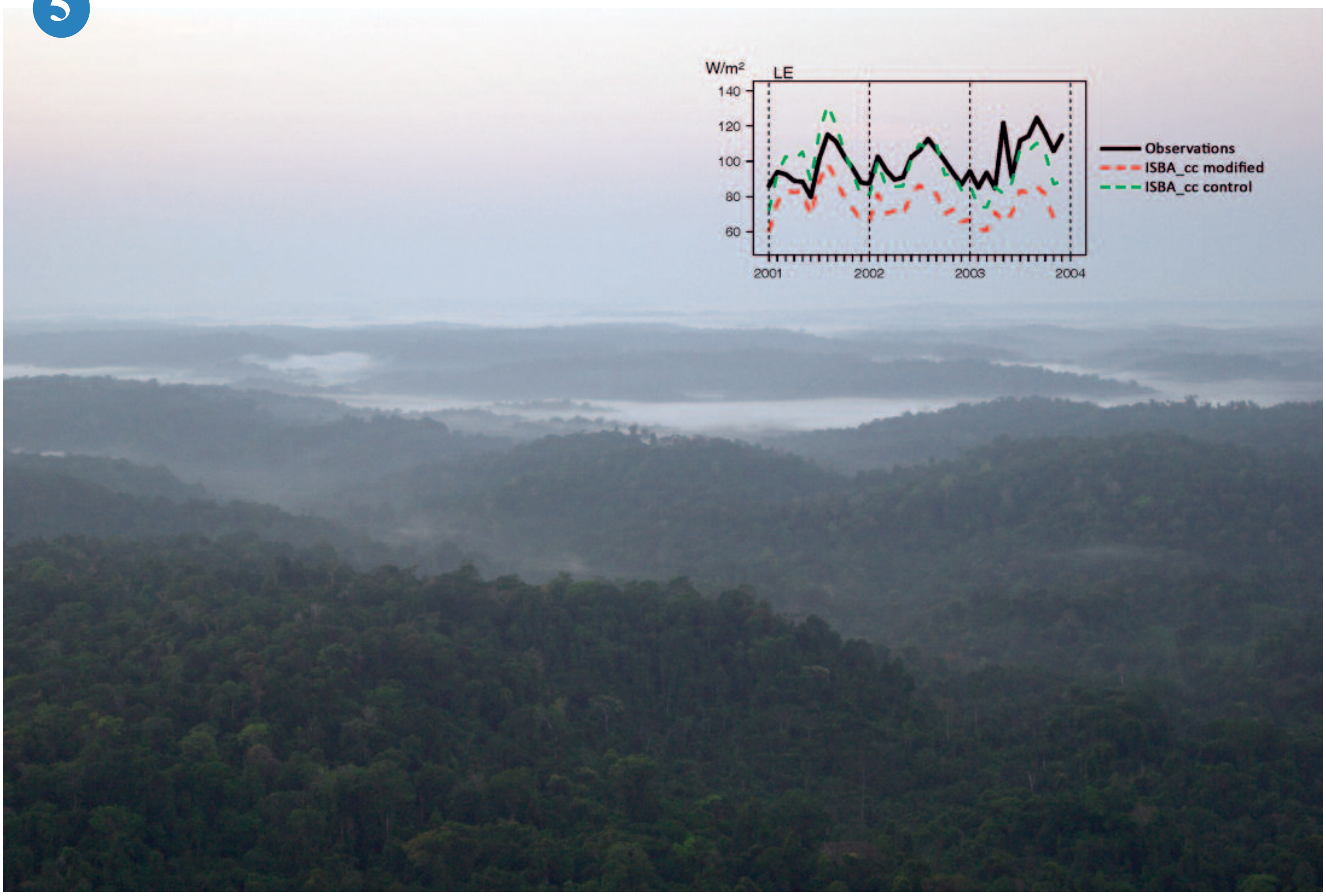


Seasonal and climate forecasts

Seasonal prediction: using very large ensembles

The probabilistic aspect of a meteorological forecast increases with the forecast range. A few month ahead, it is impossible to rely on one single model integration, as good as it is. Equiprobable scenarios are constructed, under the implicit assumption that the truth will be one realization of the probability law described by the forecast sample. The question of the sample size, limited by computation resources is an open question.
In the 2000s (e.g. ENSEMBLES European project) one considered a 10-member size as a good compromise. In the real time forecasts of EUROSIP, this size is 51 for actual forecasts, but 10 to 15 for hindcasts. The increasing capacity of multi-node computers and the possibility to explore more situations by adding stochastic perturbations in the equations led us to produce, for the last 34 years, ensembles of 215 members with Météo-France model. By randomly selecting many subsamples of a given size, one can estimate the gain in score, but also in accuracy, when the ensemble size is increased. The figure shows scores for tropical precipitation (PT), northern hemisphere 500 hPa geopotential height (ZHN) and North Atlantic Oscillation index (NAO). The behavior is different for the 3 predictands. PT scores are robust and stabilize with 20 members. ZHN scores stabilize near 50 members and are accurate enough to permit model intercomparison. NAO scores seem to stabilize near 50 members, but one can notice that the upper quantile decreases with size and that with 100 members the scores have a weak statistical accuracy.

6

Statistical downscaling for seasonal forecasting over Europe

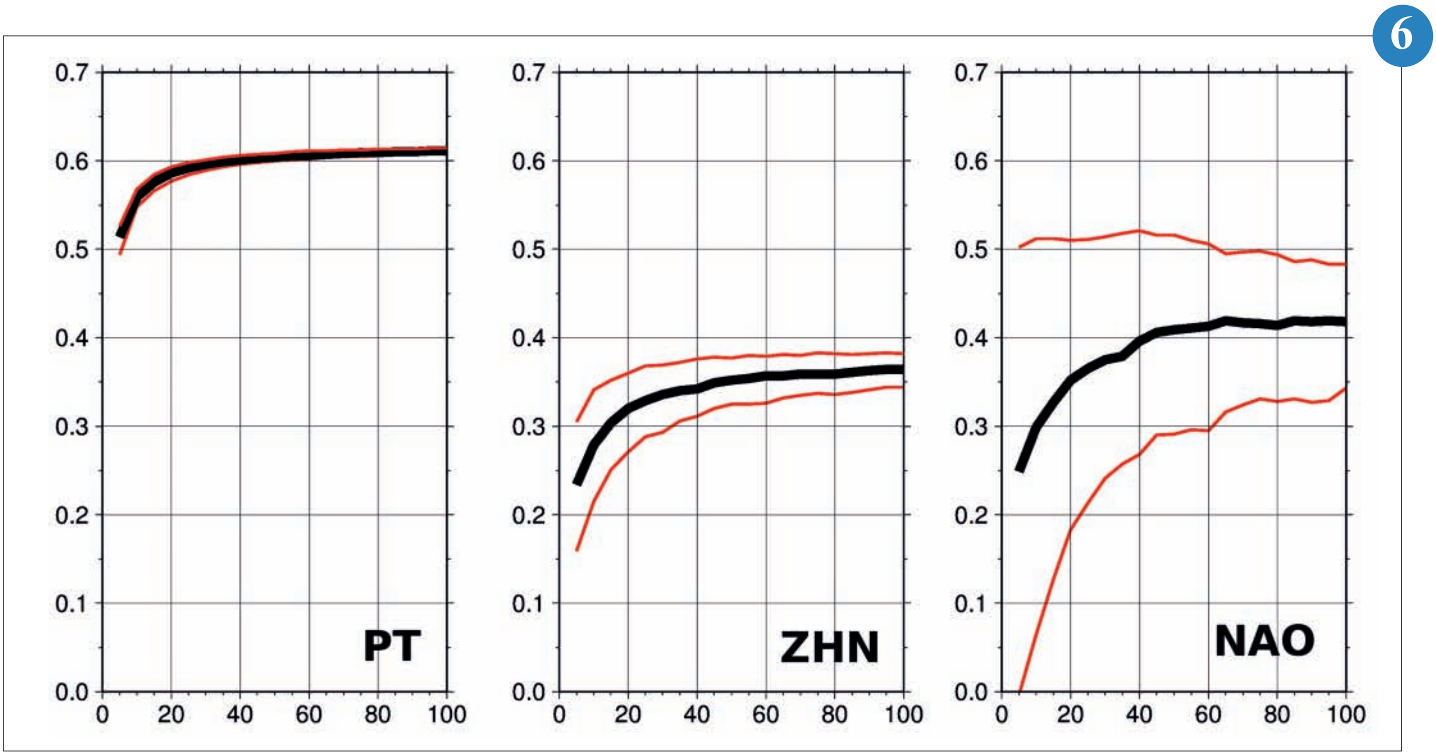
Despite constant progress in modelling, which benefits also to climate change modelling, the seasonal forecasting scores remain modest: seasonal predictability in mid-latitudes is indeed limited.
Over Europe, whether in terms of temperatures or precipitations, current models provide a very limited added value compared to purely climatological information. Moreover, if we consider the low resolution (about 150 km on average), we easily understand the difficulty to develop applications.
That's the reason why we have to develop downscaling of seasonal forecasts. This approach is close to statistical adaptations made for short or medium range forecast, or to the regionalization of climate change scenarios. Their objectives are to provide better resolution data, taking the best from large scale information, and to be climatologically consistent.
A simple 8km-downscaling method has been developed for hydrological forecast over France as part of EUPORIAS project (cf. EUPORIAS article). The Climatology Department of Meteo-France, in collaboration with GMME team of CNRM, has tested other methods, based on weather regimes. This approach tries to use the large scale information present in seasonal forecasts (what is really "viewed" by model) to translate it in fine scale impacts, knowing the links between large scale circulation and local climate. The results for the winter season are encouraging and open operational perspectives.

7

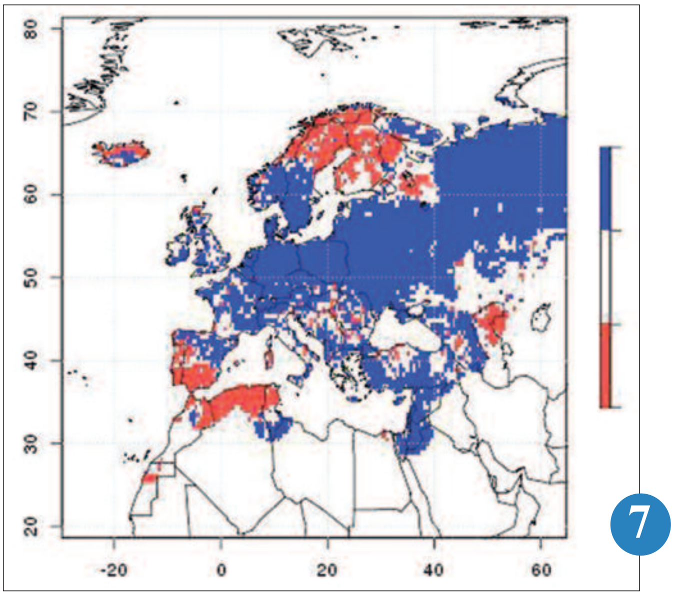
Application of seasonal forecasting to agriculture and evaluation over France

In 2014, a Ph. D. study (Nicolas Canal) in partnership with Météo-France and Arvalis-Institut du Végétal ended. The objective was to evaluate how the use of seasonal weather forecasting to force a wheat growth model in France could predict the evolution of agrometeorological variables of that culture.
Seasonal forecasts produced during the European project ENSEMBLES for the period 1981-2005 were used as inputs to the crop model Panoramix from Arvalis – Institut du Végétal. The analyses focused on the prediction of the main phenological stages, water balance and cumulative temperature. It has been demonstrated that a set of seasonal forecasting scenarios gives better estimates of the variables than using a climatological method commonly used in agronomy. The best predictions are generally obtained in the north of France. Finally, the predictability is extended using an ensemble approach in comparison to a restricted approach using only the median of the scenarios provided by the forecasting system.
In parallel, statistical forecasting methods based on indicators from the land surface model ISBA-A-gs and satellite observations of vegetation were assessed. The ISBA-A-gs model has been able to represent the variability of cereal and fodder productions. The potential of the prediction of the end of their growth cycle from soil moisture simulated by the model and the satellite LAI is generally greater for grasslands that for crops.

8

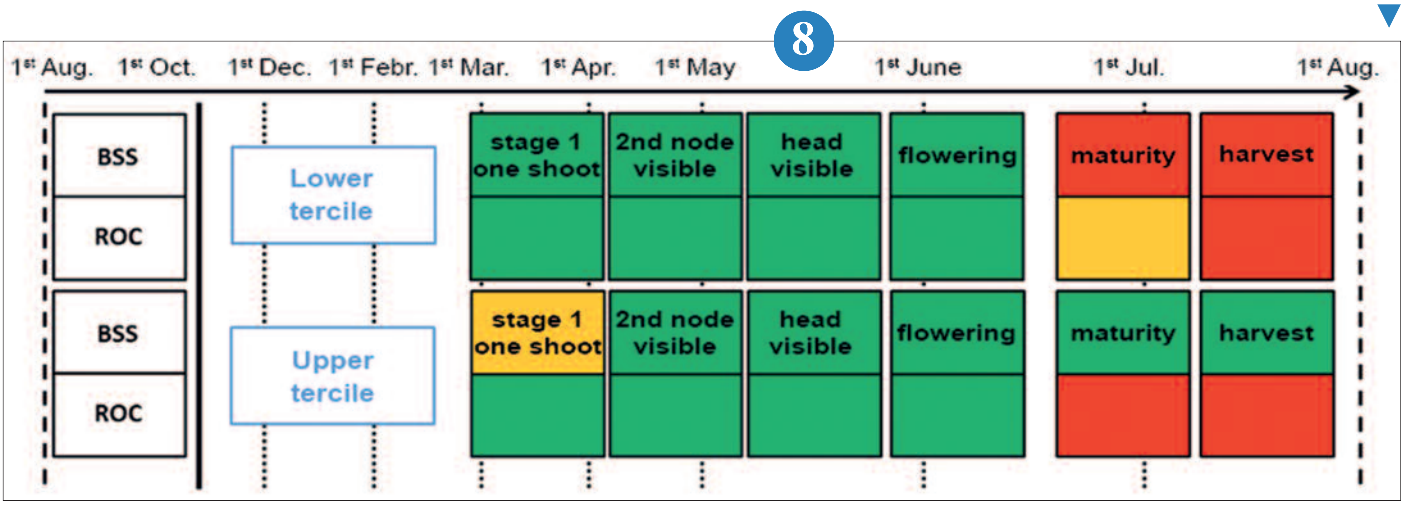


▲ Hindcasts for 1979-2013 winter seasons: correlation scores (left hand to right hand side) for tropical precipitation (PT), 30°N-90°N 500 hPa height (ZHN) and North Atlantic Oscillation index (NAO). The ensemble size is in abscissa. Black curve for median, red curves for 5% and 95% quantiles



▲ December-January-February score for 2 meters temperature, lower tercile. In blue (red) downscaling is significantly better (worse) than ARPEGE. In white, no significant difference.

Comparative evaluation of an ensemble forecast of the wheat crop development stages computed with seasonal weather forecasts and climatic prediction. Lower and upper tercile thresholds are evaluated according to two kinds of scores: Brier Skill Score (BSS) and the Receiver Operator Characteristics (ROC). A green rectangle indicates that the computation with seasonal forecasts gives a better score than the computation with climate predictions. An orange rectangle shows no significant differences between both approaches. A red rectangle indicates that the use of climatic predictions gives a better score. ▼



Seasonal Forecast and Climate Services: the EUPORIAS project

Seasonal forecast is being to take its place in the landscape of Climate Services. Indeed, it appears more and more as the first necessary step to adapt to future climate variability.
In this context, Météo-France is partner of an European project dedicated to Climate Services: the EUPORIAS project (http://www.euporias.eu). This project is complementary to the SPECS project which itself is more Climate modelling oriented (including their improvement).
The main objectives of EUPORIAS are:
• To develop and provide a robust and reliable impact forecasting system for some specific case studies (carefully selected).
• To establish and document the key deficit of knowledge and vulnerabilities from important application sectors (e.g.: water, energy, tourism, health, transport, agriculture), and the associated specific users' needs as well.
• To develop a protocol of shared knowledge necessary to the promotion of the use of these new products (including the uptake of uncertainty).
• To establish and document the current value of Climate Services in Europe.
In this framework, Météo-France is especially focus over France on the water resource domain and the energy domain as well. We continue the developments done on the Seasonal Hydrological Forecasts through a collaborative effort with specific stakeholders which are volunteers to help us on this project. In addition to EDF, quite obvious partner, we will work with some basin agency which are representative of different stakes; the Etablissement Public Seine Grands Lacs (Seine river basin) and the SMEAG (Adour-Garonne river basin).
Specific products based on the river flow forecasts have been developed for the corresponding rivers. A calibration work taking benefit of the data used in the decision making processes has been performed. As a conclusion a quantile/quantile correction has been selected. Then a specific protocol has been developed and proposed to our stakeholders in order to assess the impact of the use of the information shaped to their decision making processes. It looks like a Placebo protocol with 2 set of forecasts. One corresponds to the seasonal forecast while the other is the Placebo. These forecasts will be used for decision in a « blind-like » manner, if possible using the entire hindcast period (30 years).
All this work should lead to the evaluation of the usefulness of such information, and beyond, to the operationalisation of such forecasting suite, with a strong demand for the water resource domain, the energy or agriculture domains as well, and the associated climate services.

9

Diagnosis and detection of climate change

A new reference dataset to analyse of the evolution of temperature in France since the 1950s

Instrumental observations cannot be used directly to study climate evolution. The measurement conditions (relocation, instrumentations and other) change over time, and these changes can cause inhomogeneities (artificial shifts) of the same magnitude as the climate change signal: for example, inhomogeneity in a temperature series may reach 1 °C, that is similar to the increase of temperature in France during the 20th century. Homogenization is a statistical procedure that has been developed for detection and correction of these inhomogeneities in observed data series, to keep only climate signal information.
In 2013, a new dataset of monthly homogeneous series of temperature beginning in the 1950s has been produced by Météo-France. It provides an unprecedented coverage of the metropolitan territory with 228 minimum and 251 maximum temperature series of high quality. Monthly homogenized series for temperature are also available for 3 French overseas departments. From 1959 to 2009, the mean warming over France (+0.3 °C per decade) is mainly explained by spring and summer temperatures increase. It is greater than the one experienced over the 20th century (+0.1 °C per decade), due to an acceleration of the warming since the 1970s.
These homogenized series will be regularly updated, in order to provide an up to date diagnosis. In addition, a first set of homogenized series for precipitation will be available by the end of 2014.

10

Estimating climate change at the local scale

The temperature dataset presented in the previous article is highly relevant to quantify the observed warming at the local scale, and to draw the map of recent warming over the country.
Various statistical methods are available to quantify the mean temperature change, and associated uncertainty. A simple and widely used method consists in fitting a linear trend to the observations, and assuming internal variability to be a white noise in time. Work undertaken to evaluate this approach shows that using a linear trend is reasonable for the variable and time period under study. However, there is evidence that the climate variability presents some memory effect, although limited. Taking into account this memory effect enlarges confidence intervals from about 20%.
Results suggest that the mean temperature over France has warmed by around 1.5°C +/- 0.5°C from 1959 to 2009. This result is also relevant in term of climate change detection. As 0°C lies outside the estimated confidence interval, the observations are not consistent with internal variability only, and we can really talk about climate change. The figures show that this result is still true for each individual temperature series. This indicates that the warming is now detectable at the local scale, over all mainland France.

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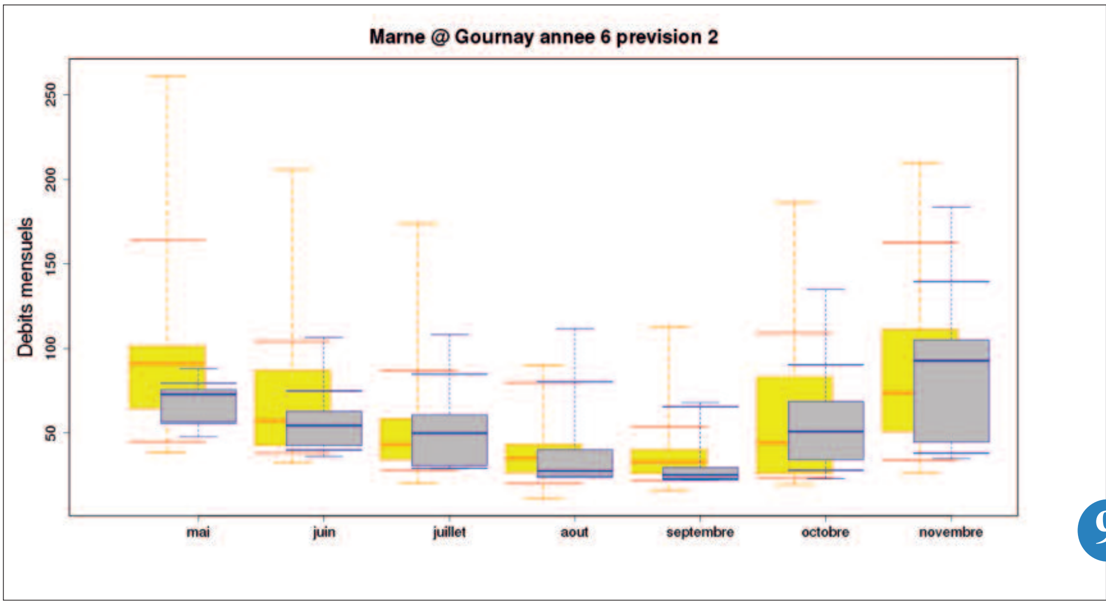

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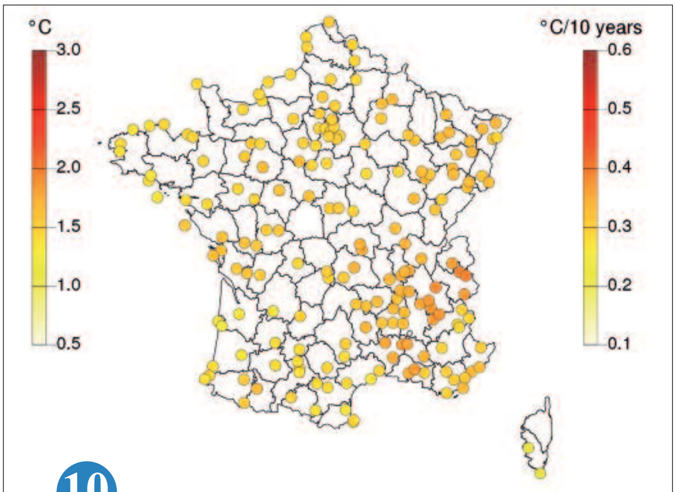
◀
River flow forecasts (monthly means) at Gournay (Seine basin)
In yellow, the 1979-2007 climatology of observed river flow, in blue the forecasts for 2007 summer season.
Boxes represent the inter-quartile range, whiskers represent min/max, and thick lines represent the median.



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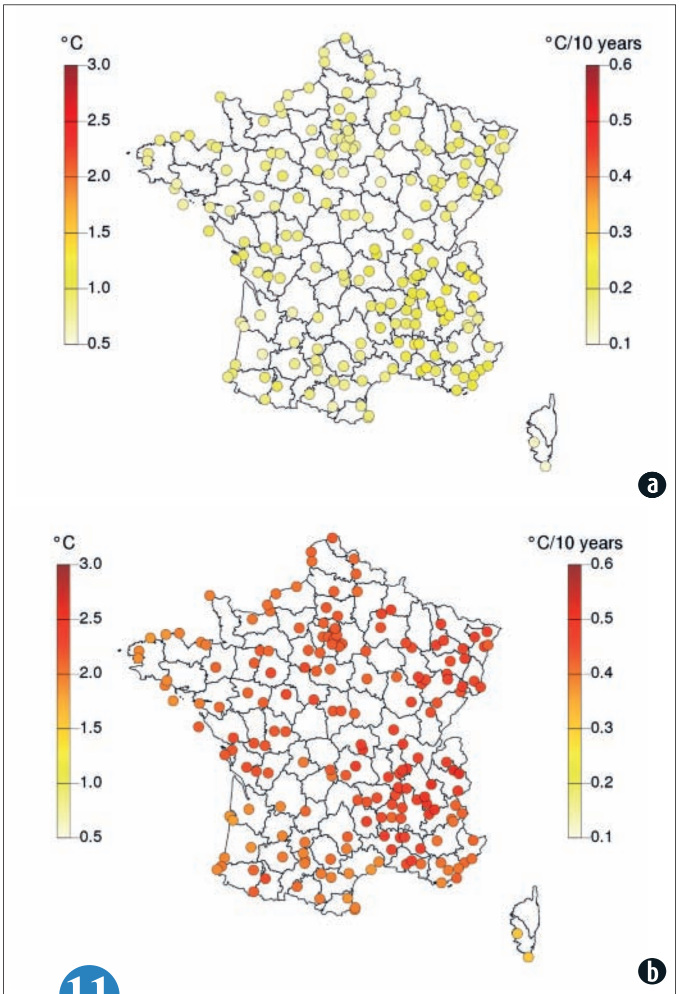
▲
Increase (in °C, left scale) and trend (°C per decade, right scale) of mean temperature computed from homogenized series over the 1959-2009 period.
Black circles indicate significant trend.



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▲
Lower (a) and upper (b) bounds of the 95% confidence interval associated with the previous map: mean temperature change (in °C, left scale) and trend (in °C per decade, right scale) deduced from homogenised series over the 1959-2009 period.

Estimation of rainfall extremes based on regional methods

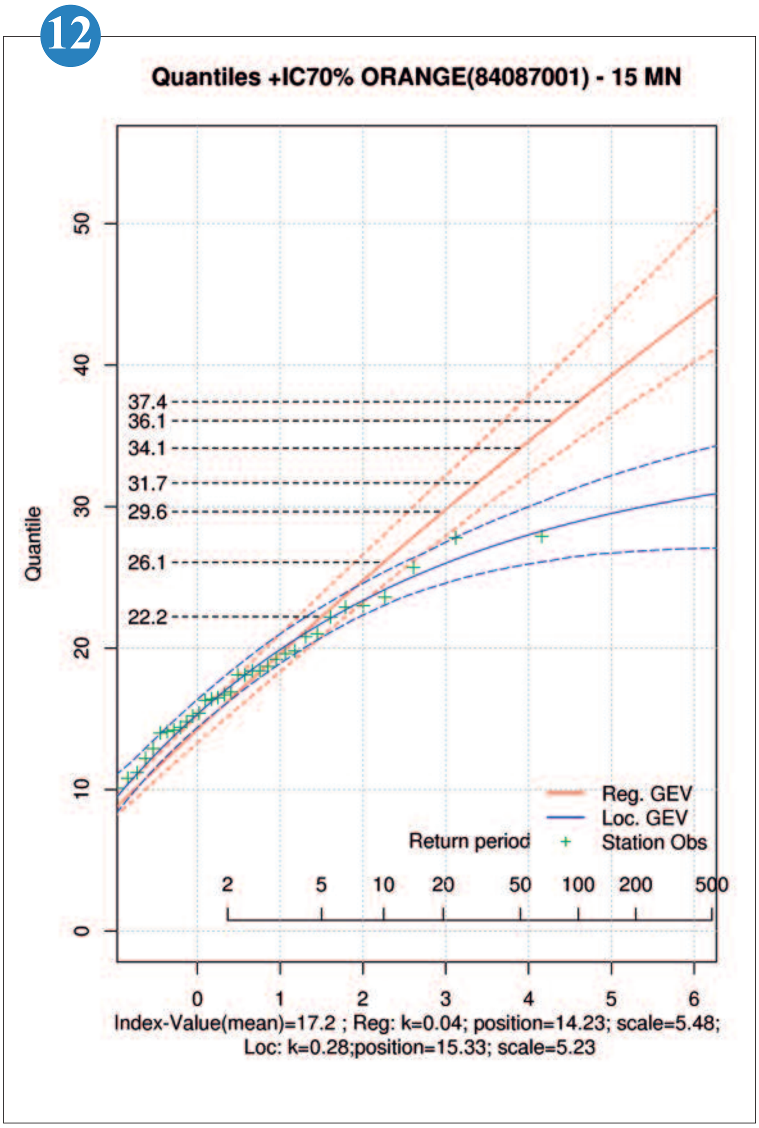
Météo-France produces a climatological estimation of rainfall extremes from measurements made in all French and overseas stations with 6 minutes to 10 days timesteps. The method used up to now is based on the theory of extreme values laws (Coles, 2001) applied at local series which have been selected with length and quality series criteria.
The ANR Extraflow project, which is an intercomparison of extreme values of rainfall and flow rate estimation project, makes clear the regional approach is much better, in terms of accuracy and robustness.
In the context of a research partnership, the climatology department has initiated the transcoding of the estimation of extreme rainfall regional method based on daily timestep, which has been developed by the Hydro Science laboratory in Montpellier (Neppel and Carreau), as well as the development of its hourly and daily time-step upgrade.
The regional approach purpose is to improve the data of a given measurement site with all the series available in an area of around 50km radius, which fulfil different homogeneity tests. The independent regional sample on which are calculated the return periods, is composed by all the rainfall events that occurred in the neighbourhood, rescaled by an index value related with their own measurement site. This method was applied in 2014 during a student training course, over grand Lyon area and over part of Cevennes Mountains.
The benefit of regional methods is to reduce the sampling variability by increasing the observations amount. They also improve the reliability on the resulting quantiles by expanding the area.

12

Recovery of upper air data in the framework of the FP7 ERA-CLIM 2 project

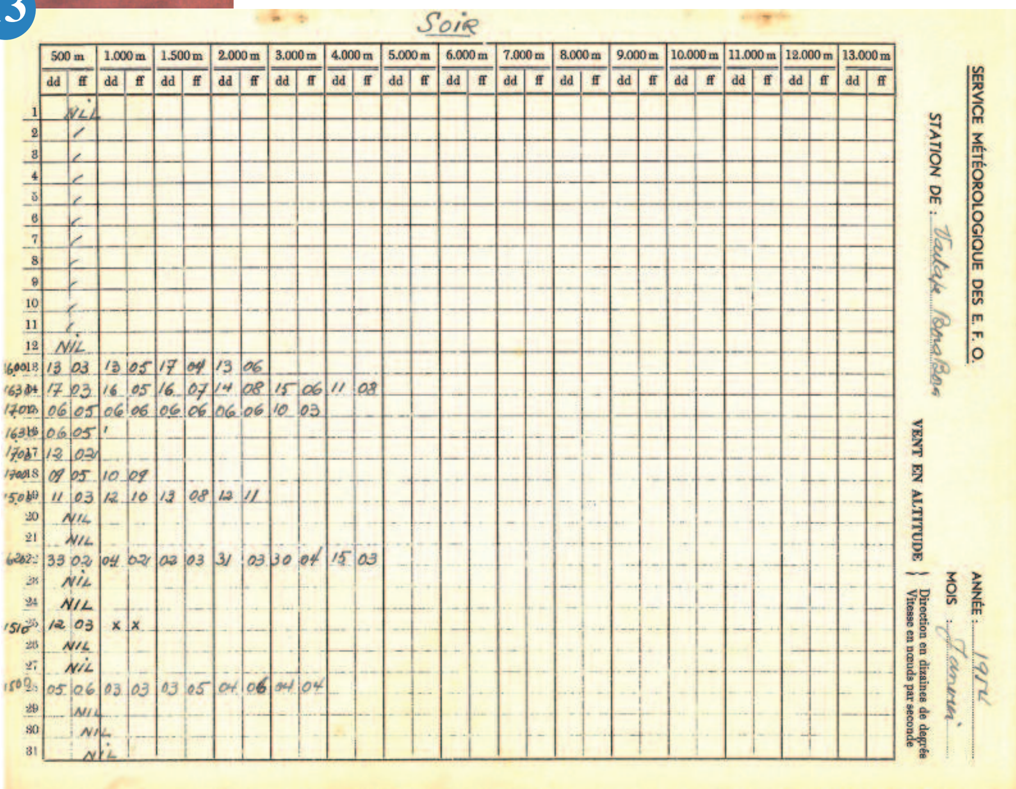
Météo-France has been involved in the European FP7 ERA-CLIM2 project for the period 2014-2016, continuing and expanding the climate date rescue efforts started in the FP7 ERA-CLIM1. ERA-CLIM2, coordinated by ECMWF, aims to prepare input data and assimilation systems for a new global coupled ocean-atmosphere reanalysis of the twentieth century.
Météo-France is engaged in activities of recovering, inventorying, imaging and digitising pre-1957 historical upper air data, integral parts of the Météo-France Data Rescue action. French contribution has been essential due to the availability of a huge amount of historical meteorological observations stored at the French climate archives for France mainland, overseas territories and former colonies.
15 long-term series of upper wind data (direction and speed) back to 1920 and 5 radiosonde long-term series back to 1937 (pressure, temperature and humidity) have been identified for France mainland in the framework of ERA-CLIM1.
Météo-France contribution to ERA-CLIM2 has been focusing on French tropics and polar stations: 22 long-term series of upper air wind have been catalogued. Series for overseas French territories cover the period back to 1936 whereas series for Southern and Antarctic French lands can be extended back to 1950. 1.4 million of upper wind data have been already integrated to the Météo-France national climate databank at the end of 2014. The inventoried, digitized and quality controlled long-term series have been delivered to ECMWF in order to be assimilated by the future reanalyses.

13



Frequency distribution of "GEV regional", "GEV local" and extreme rainfall observed at the time-step15MN in the Orange station.

Launch of radiosonde balloon in Mururoa Atoll in the 1980's



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VENT EN ALTITUDE

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Upper air wind records for Vaïtape (Bora Bora), January 1954

Chemistry, aerosols and air quality

The year 2014 was marked by the work of operational implementation, at the direction of the production of Météo-France, of the European air quality ensemble forecast chain developed at CNRM in the context of the MACC project. This year, significant progresses have also been made in taking into account aerosols, both in the air quality forecasting model, and in the models used for climate variability studies at the global and regional scales. Concerning the MOCAGE chemistry-transport model, a new chemical cycle was introduced to study the effect of volcanic halogens at a global scale, tested on the case of an Etna volcano eruption. Other developments, to take into account secondary inorganic aerosols and their feedbacks on the gas chemistry, were introduced in this model.
Concerning the global and regional climate models, a prognostic aerosol scheme was introduced showing the ability of the two models to reproduce the main spatial and temporal structures of aerosol optical depths. On the observational component, a key element is the restitution of the aerosol optical depths over long periods thanks to the MSG geostationary satellite data processing. Furthermore, an airborne campaign named CHemCallnt was conducted, allowing an inter-comparison of embedded instruments of chemical measurements with corresponding equipment installed at ground level.

1

3D atmospheric modelling of the halogen species from volcanoes

The impact of halogen species on atmospheric chemistry remains a major source of uncertainty, in particular in relation to the stratospheric ozone cycle. Volcanoes can contribute to the budget of these species but the processes that are responsible for the concentrations of the different volcanic gases are not well known. Halides (HCl and HBr) are directly emitted by the volcanoes, but because of their high solubility, they can be removed from the atmosphere by rainfall. In contrast, the bromine monoxide (BrO), which is less soluble, is often detected within volcanic plumes and then transported on large distances.
In order to study the effect of volcanic halogens at the global scale, the 3-D numerical global model MOCAGE was recently adapted to represent the chemical cycle producing BrO. This is a first study with a 3D global model because all the previous modelling studies were realised in one dimension, at local scale. For the case of the eruption of Mount Etna on the 10th of May 2008, MOCAGE produces a realistic plume of SO_2 and BrO. The volcanic plume's location the 11th of May 2008 is slightly shifted westwards because of uncertainties in the height of the plume (cf. figure). This first study showed the importance of the emission information, such as the vertical extension of the plume, the gas composition and the quantities emitted. Simulations with a regional or a global resolution gives quantities of BrO that are very close. On this basis, a future step will be to study on longer time scales the global influence of the whole volcanic halogens on the atmosphere.

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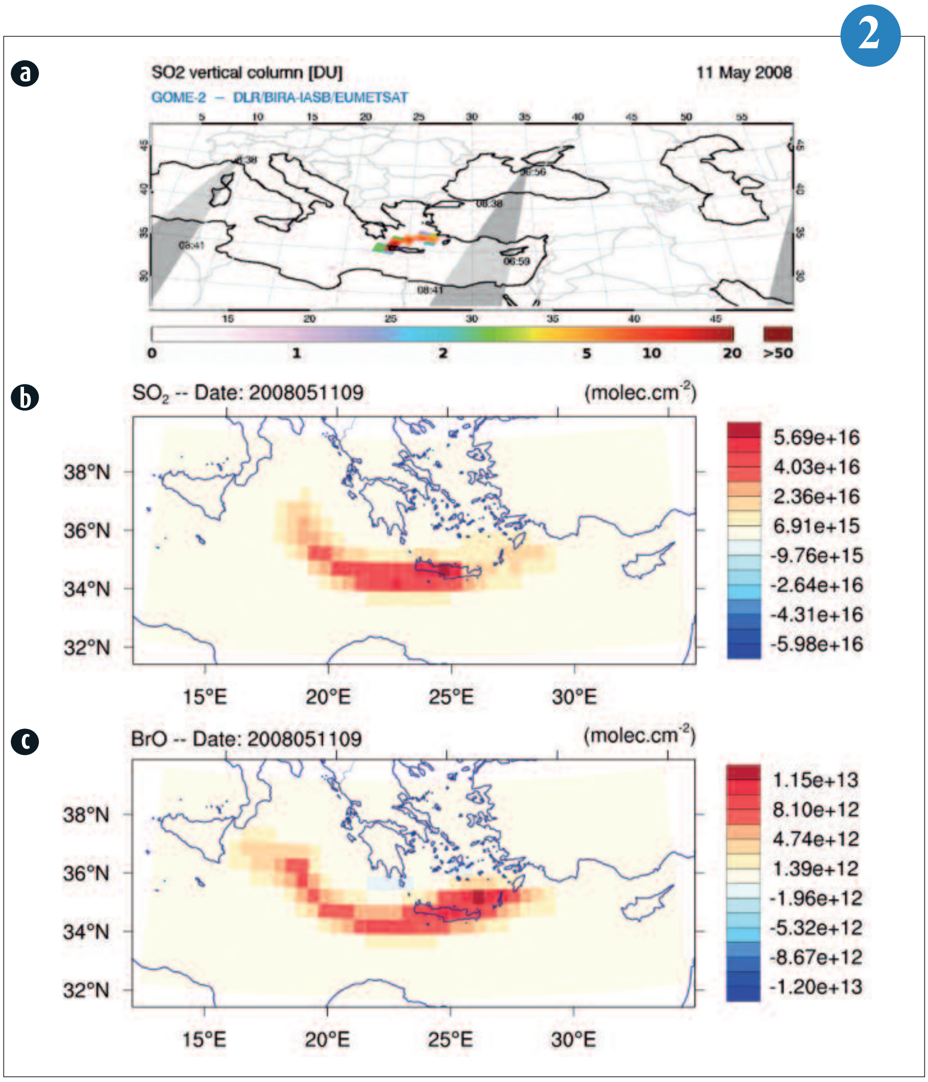

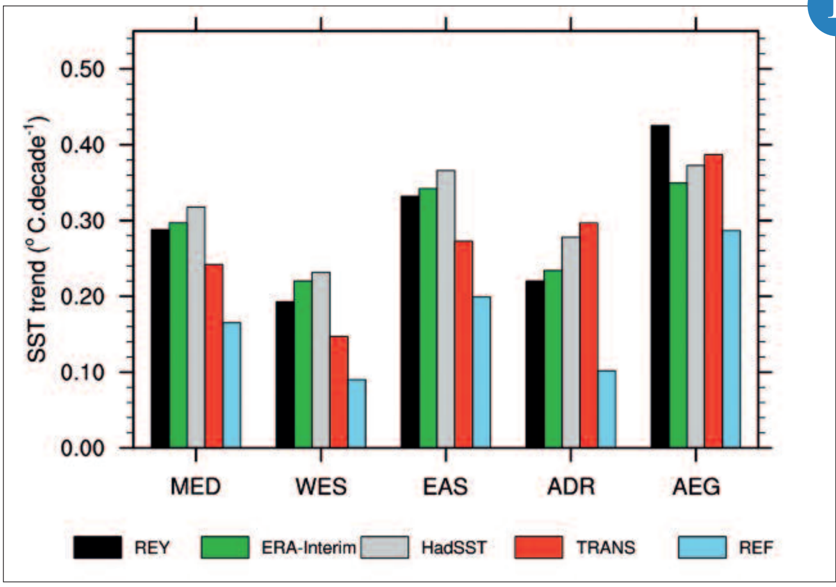

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Two simulations, TRANS and REF, have been performed with the regional climate system model CNRM-RCSM on the Mediterranean area, respectively, with and without time-varying aerosol optical depths over the period 1982–2012. The figure shows an evaluation of Mediterranean sea surface temperature trends in °C decade-1 over the period, averaged over different domains (MED = Mediterranean Sea, WES = Western basin, EAS = Eastern basin, ADR = Adriatic Sea, and AEG = Aegean Sea) for the observations (REY for Reynolds et al. reanalysis, ERA-Interim ECMWF reanalysis, and HadSST Hadley Center dataset) and the REF and TRANS simulations.

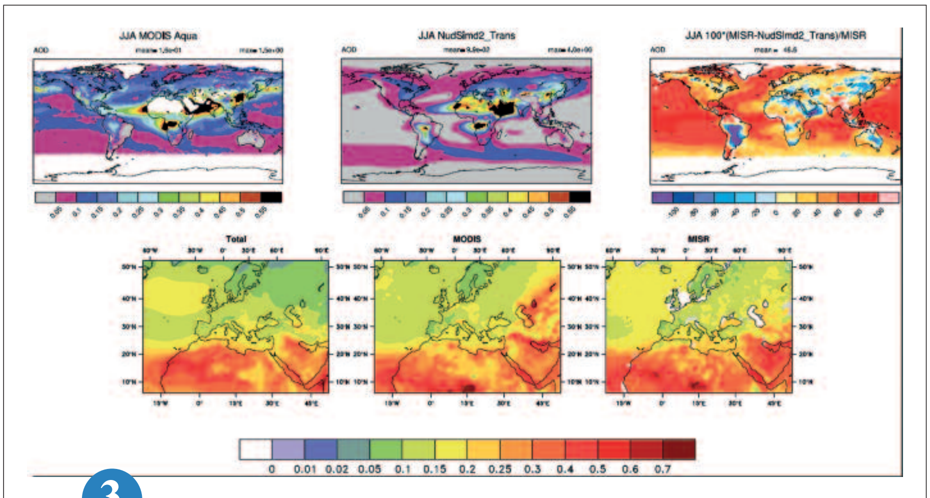
Prognostic aerosols in the CNRM climate models

In its Fifth Assessment Report, IPCC has underlined the importance of aerosols within the climate system, as well as associated uncertainties still due to their modeling. In this framework, a prognostic aerosol scheme has been introduced in the global and regional CNRM climate models, up to now aerosols have been prescribed with monthly aerosol optical depth climatologies.

This scheme, derived from the one used in the ECMWF numerical weather forecast model, simulates the physical evolution (emission, natural aerosol uplift, transport, dry and wet deposition, sedimentation) of the main tropospheric aerosols (black carbon, organic matter, sulfate, desert dust and sea salt). The evaluation of this scheme has been realized in parallel at the global and regional (over a broad Mediterranean area) scales, based on climate simulations carried out respectively with CNRM-CM and CNRM-RCSM, which share the same computer code. The simulated aerosol optical depths have been compared to the ones observed by different satellite instruments (see Figure), to reference climatologies, and also to ground-based observations from the AERONET network.

This evaluation shows the ability of both models to reproduce the main patterns of the spatial and temporal variability of aerosol optical depth. The few deficiencies identified could be corrected by improving the sea-salt emission processes and the representation of the sulfur cycle generating sulfate aerosols. This modeling work, which will be extended with an evaluation of the prognostic aerosol radiative effects at the global scale, is a step in the preparation of the CNRM-CM model to the next IPCC exercise.

3



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Maps representing the contribution of the volcanic plume emitted from Mount Etna on the 11th May 2008 around 9h UTC. (a): Observations of SO_2 by the GOME2 satellite. These are oblique columns. (b): Volcanic plume of SO_2 modelled by MOCAGE, using a regional resolution (0.5°× 0.5°), and obtained by difference between a simulation with and without eruption. These are tropospheric columns. (c): Same as (b) but for BrO.

1st line: total aerosol optical depth (JJA 2003-2012) for satellite data (MODIS/Aqua), the CNRM-CM simulation, and their relative difference.
2nd line: total aerosol optical depth (2003-2012) for the CNRM-RCSM simulation, and satellite data (MODIS/Aqua and MISR).

Introduction of secondary inorganic aerosols into the CTM MOCAGE: towards a better modelling of particulate matter pollution event in France

Atmospheric aerosols have a major impact on various environmental issues: visibility reduction, influence on weather and climate, and health impacts. Secondary inorganic aerosols correspond to aerosols formed in the atmosphere from gaseous precursors. These aerosols are composed of acids and salts of sulfate, nitrate, and ammonium. They are formed from sulphure dioxide, nitrous oxides and ammonia. These aerosols are important as they contribute on average to 30% of the total mass of particulate matter having a diameter below 2.5 microns (PM2.5).

The model MOCAGE developed at CNRM is a chemistry transport model used for daily air quality forecast in the framework of the program Prev'Air. Recently new developments allowing the formation of secondary inorganic aerosols and their impacts on the gaseous chemistry have been implemented into the model MOCAGE.

The figure represents annual mean concentration of secondary inorganic aerosols simulated for the year 2010 in Europe with the model MOCAGE. The sulfates are essentially present over Eastern Europe while nitrates mostly over Benelux and the Po Valley. The ammonium concentrations are weaker but present all over the continent.

These developments will be used for operational air quality forecasts run at Météo-France over France and Europe. They will also be used for scientific studies concerning for example the aerosol budget in the Mediterranean area.

4

Aerosol detection by MSG geostationary satellite

A new aerosol optical depth (AOD) product is delivered in near real time by the ICARE Data and Services Centre to the scientific community. The AERUS-GEO (Aerosol and surface albEdo Retrieval Using a directional Splitting method - application to GEOstationary data) product is derived from observations from the Meteosat Second Generation (MSG) geostationary satellite covering Europe, Africa, and part of Asia and South America. The retrieval method exploits the directional information contained in the series of 96 MSG observations per day of the Earth's disk to derive a daily averaged AOD. The performances of this product are similar to those of other widely used satellite-derived AOD: MODIS DT (Dark Target), MODIS DB (Deep Blue) or MISR. It is important to note here that AERUS-GEO provided more than 10 times more AOD estimates than MISR (twice to three time more than MODIS DT and DB), which may help it provide more robust AOD estimates for long time ranges. Figure 1 illustrates the satisfactory performances of the proposed AOD product over all types of surfaces, contrary to MODIS-based AOD products.

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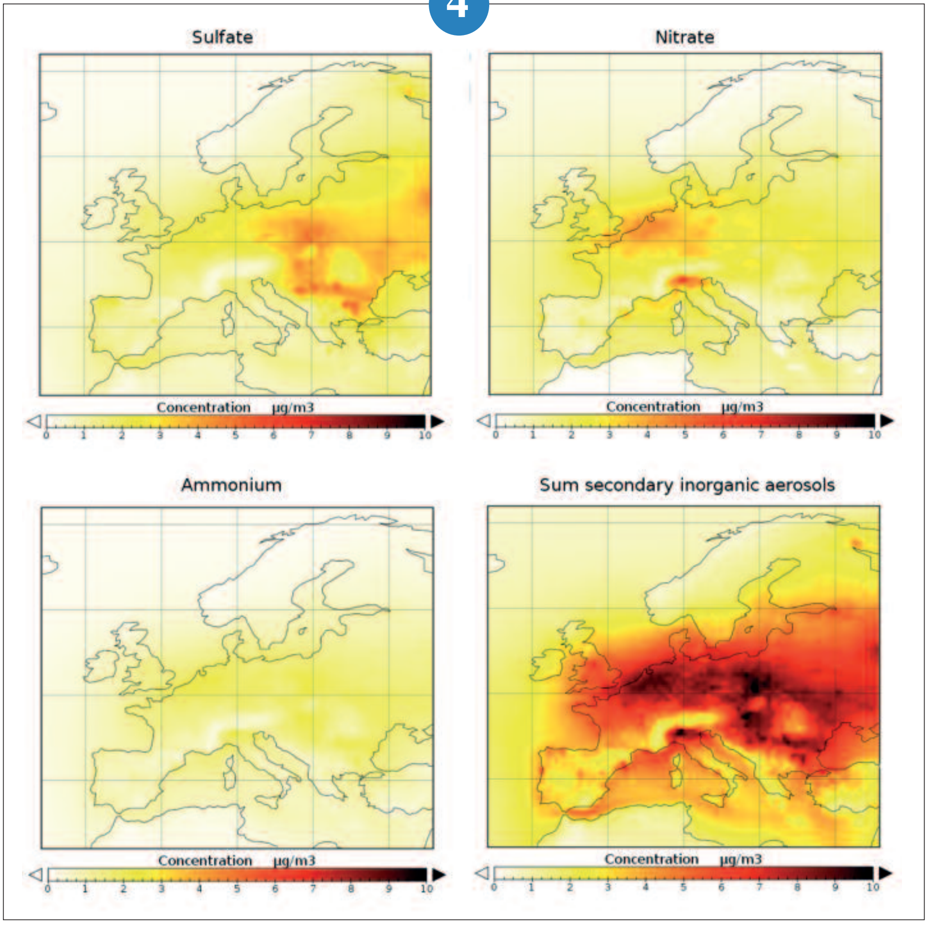
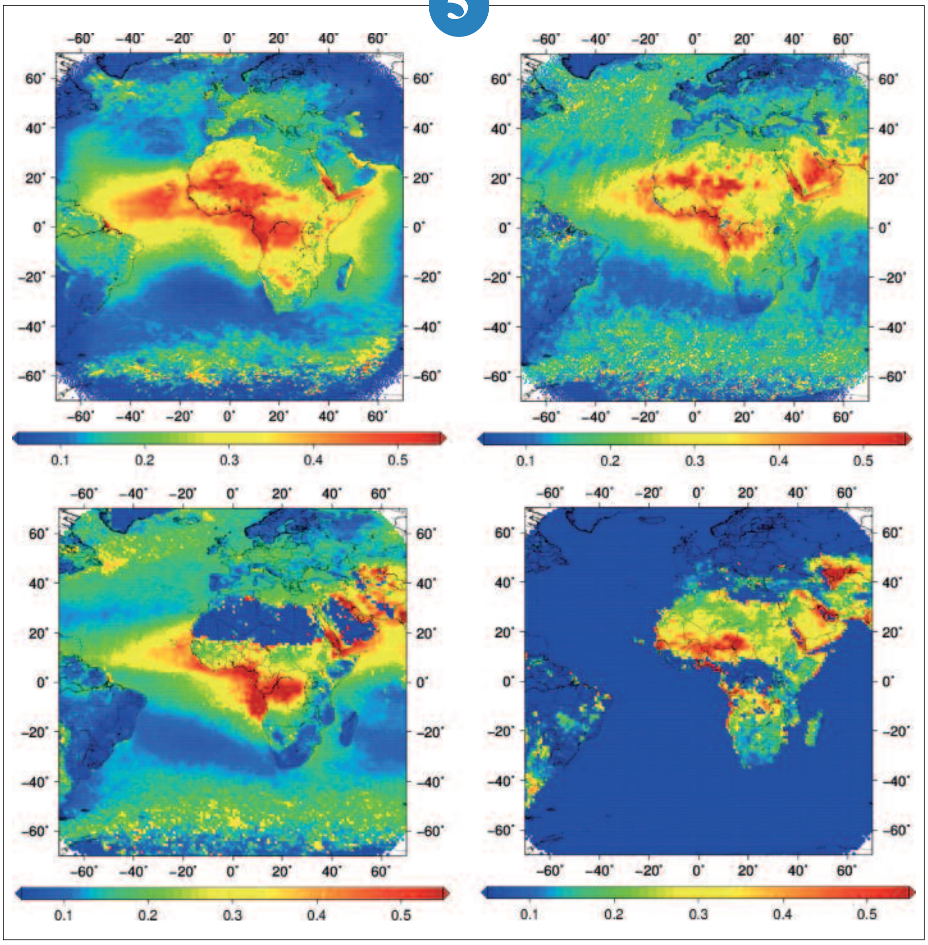


2010 annual mean of secondary inorganic aerosols and its different components (sulfate, nitrate and ammonium) computed using the chemistry transport model MOCAGE over Europe.

5



Mean AOD from December 1st 2012 to November 30th 2013: AERUS-GEO (top-left), MISR (top-right), MODIS DT (bottom-left), and MODIS DB (bottom-right).

Towards MACC project operational phase

MACC project is part of the European COPERNICUS program. It is dedicated to the monitoring of the atmosphere around the globe, with a particular focus on Europe. Météo-France is in charge since 2010 of the 4-days forecasts and analysis of the air quality across Europe. This relies on an ensemble approach combining seven regional numerical models. Météo-France is also tasked with providing the output products to the public. Moving toward a full operational system has been the challenge of this year.
This is a four steps process. Since July 2014, the MOCAGE-MACC forecast system, forced with ECMWF IFS meteorology, has been run on Météo-France operational supercomputer. In December 2014, the MOCAGE analysis system will be integrated in the Meteo-France's operational computing suite. Progressively, the collect of the seven individual models outputs, the databases storage, the ensemble computation, the display on a website of the graphical products and the distribution of all the outputs to the end users, will received a pre-operational status. This will be achieved by the end of the 2014 year. The last step will be to activate the full operational service. Finally, a significant work has been done to design the website for the products display: The graphical user interface of the site was demonstrated, for the project evaluation in September. The definition of the "numerical data download service" metadata, complies to the INSPIRE standard (ISO 19115). The service architecture is based on an OpenWIS solution.
The current system is therefore a sound demonstration of the system planned for the Copernicus Atmosphere Service operational phase. Consistently, Meteo-France will respond to the invitation to tender for the atmosphere service, to be launched in early 2015.

6

CHemCalInt: Campaign of calibration and inter-comparison of airborne national community chemistry instrumentation in gas phase

The exploration of the chemical composition of the atmosphere by airborne means remains today indispensable because it allows a description of horizontal and vertical levels of the pollutant gradients. However, it remains complex because of the extreme operating-conditions.
In order to ensure the consistency of the measurements and their performances, an airborne campaign named ChemCalInt was completed in May 2014 with the ATR operated by SAFIRE and the contributions of many French laboratories (LISA/IPSL, LaMP, LiPhy, LPC2E, LSCE and Mines Douai). On board, an instrumental configuration combining different techniques of optical, spectroscopic measurements and chemiluminescence of the main atmospheric photo-oxidants (ozone, CO, NO, NO_2, NOy) and greenhouse effect gases (CH_4, CO_2, H_2O) have been installed. These facilities were developed by laboratories (e.g. MONA for the measurement of NO_2 NO and NOy, MOZART for the measurement of CO and ozone and SPIRIT for the measurement of CO and NO_2). Others are either are well-known trade analyzers, or being tested (e.g., SARA, PICARRO). They could be inter-compared also with equipment installed in the surface observatories that were overflown.
Now, the scientific community has a set of consistent airborne chemistry sensors, which will be a major asset for future campaigns.

7

6

"Visualization website" and "data download service" homepages (as developed within the framework of the MACC project).

a

7

The experimental instrumentation setup inside the ATR (Copyright Estelle Tanniou)

b

SAFIRE ATR42 seen from Atmosphere Research Centre (CRA) in Lannemezan during an inter-comparison flight between airborne and ground instrumentations. Copyright Solène Derrien (LA)

Continental surfaces

During the past year, most of researches were dedicated to prepare a new version of the surface modelling platform SURFEX that will integrate major scientific advances in the natural surfaces model ISBA for about the representation of the soil, the snow and a better representation of the energy balance at the interface between soil (bare or snowy)-vegetation-atmosphere, as well as the representation of new processes into the town model TEB, with the consideration of the irrigation and the solar panels for example. This new version should be distributed in 2015 as licensed CeCILL-C free software.
SURFEX is used coupled with the Météo-France climate and numerical weather prediction models, but also in off-line mode driven by meteorological analyses or forecasts. As instance, in 2014, within the framework of the European project EURO4M, a SURFEX simulation driven by the MESCAN regional analyses over Europe was produced over a 3-y period. This activity will be pursued by the succeeding project UERA to produce a continental surfaces reanalysis over a long period. SURFEX, and in particular the hydrological model ISBA-TOP dedicated to Mediterranean flash-floods, is also used to evaluate (with SCHAPI) discharge forecasts driven by ensemble precipitation forecasts from the AROME model, in preparation of the arrival of an ensemble prediction system based on AROME in the operational Météo-France numerical weather prediction suite.
As regard the use and elaboration of satellite products to characterize the continental surfaces, new algorithms for albedo and radiation products were designed, in particular to take advantage of the new satellite PROBA-V (as a replacement of SPOT-VGT) and future Sentinel satellites (Figure).

1

Fine scale re-analysis of surface variables over Europe. EURO4M Project

An increasing number of users need to know the evolution of surface variables (soil and surface parameters) at fine scale (less than 10 km) over long periods (several decades). The European EURO4M project is a contribution to this overall effort for the establishment of such data sets.
Météo-France has worked in collaboration with the Swedish Meteorological Service to develop a new meteorological analysis of near-surface variables based on the expertise developed in both services system for many years. Météo-France has validated this system in France, and then implemented it across Europe to produce all the necessary data to feed the SURFEX model: surface temperature, wind, humidity near the surface, solar and infrared radiation, precipitation. SURFEX could produce many surface fields (temperature, soil moisture, snow cover, ...) over Europe to resolve 5.5 km from 2007 to 2010 (figure). The data were validated by comparison with snow depth observations and fluxes in different stations.
The goal for the coming years is to continue this re-analysis activity by producing fields over 50 years (this is the purpose of the European UERRA project), to improve the quality and the number of products and prepare to contribute to future initiatives of the European COPERNICUS program in this area.

2

CHROME Project: an ensemble hydrological forecast for a better anticipation of flash floods

CHROME project aims to enhance early flood warning and hydrological prediction in a Mediterranean context for three neighbouring "cevenol" catchments: Gardon, Ardèche and Cèze (500 to 2000 km²).
It is led jointly by the SCHAPI and Météo-France and is based on four distinct hydrological distributed models forced by an ensemble precipitation forecast provided by AROME.
The rainfall ensemble is generated by a perturbation method in localisation and intensity designed by the GMME/MICADO team from the CNRM.
The hydro-meteorological chain provides an ensemble discharge forecast up to 30 hours ahead, at an hourly time-step.
In 2013, the real-time modelling chain was set up and multi-models graphs were developed.
In 2014, the benefit of a hydrological multi-model approach to represent hydrological uncertainties was confirmed with the re-run of 13 past events using ANTILOPE rainfall as input. The results of this analysis show that each hydrological model brings information to the ensemble and that the mean of the ensemble is particularly efficient.
The operational benefit of this new forecast system was assessed by the regional hydrological service. It proved the contribution of CHROME for the establishing of flood warning as well as for the prediction of quantitative discharges.
The real-time chain was re-activated at the beginning of October 2014. It allowed the production of simulations for the floods that effectively occurred during this month.
A complementary assessment will be carried out in 2015 based on the confrontation of the hydrological ensemble forecast and the observed discharges of past events.

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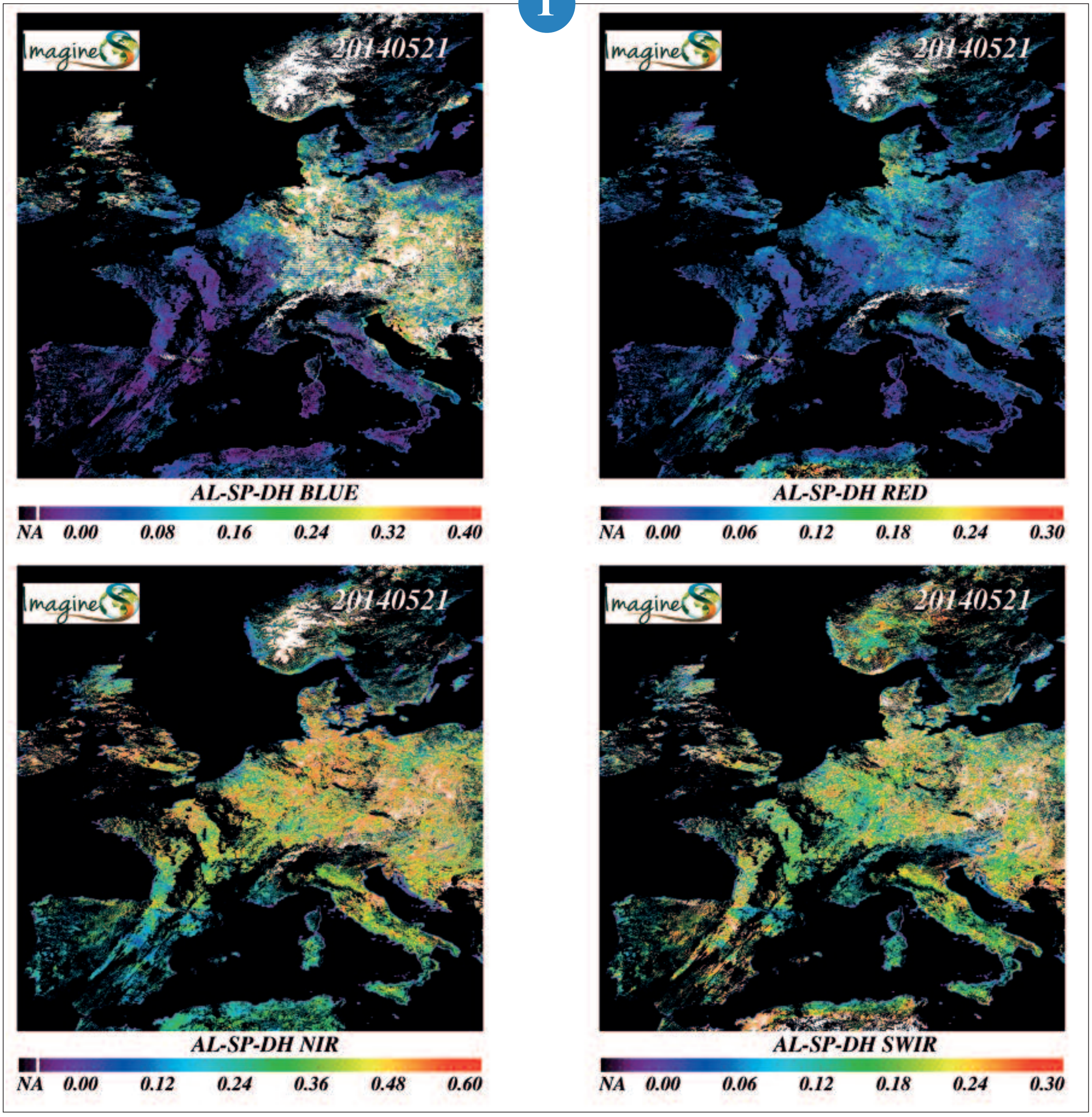

Hemispherical directional spectral albedo products at 300 m resolution based on the PROBA-V polar satellite data (21 May 2014)

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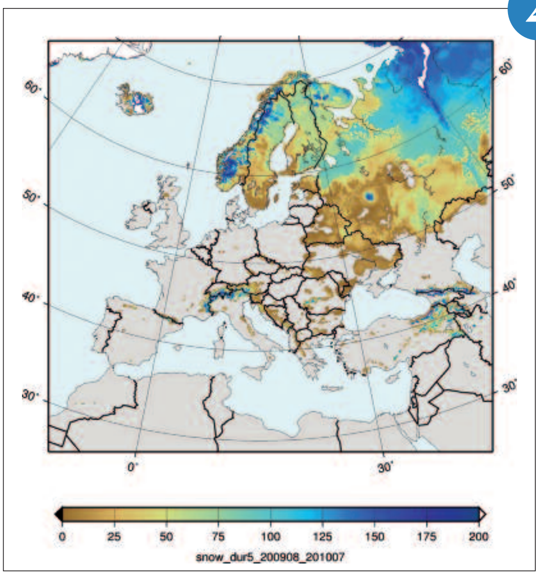
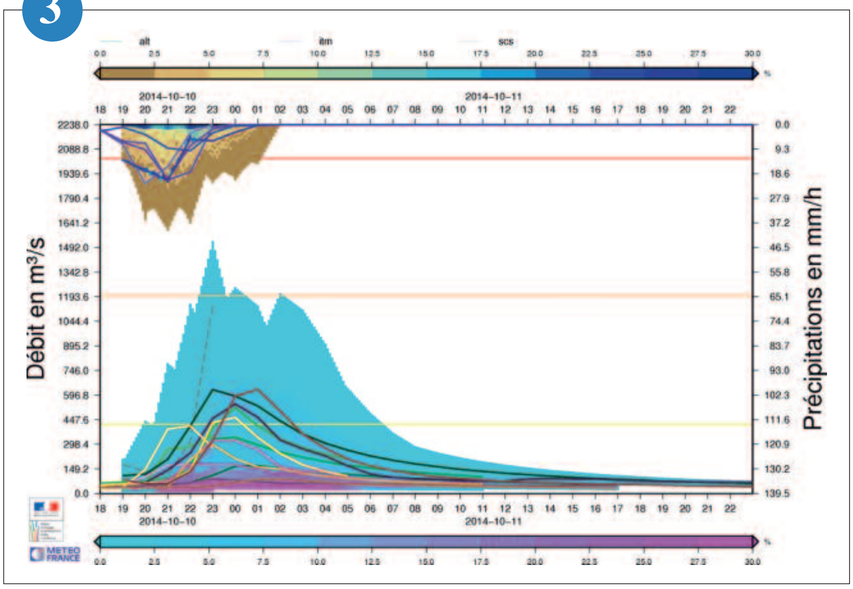


Snow cover duration (in days), simulated by SURFEX for the winter 2009/2010 (number of days where the simulated depth is higher or equal to 5 cm)

Discharge and precipitation density plot – Real time results for the 10th October 2014 at Anduze on the Gardon River.

3



Evaluation of improved explicit multilayer soil and snow schemes in SURFEX

Realistic modeling of the snowpack and energy transfers in the soil-snow continuum at high latitudes of the northern hemisphere is known as important for seasonal forecasting and climate projections. It therefore appeared crucial to improve soil (DF: sol DiFfusion) and snow (ES: Explicit Snow) schemes present in the SURFEX land surface model of the CNRM and to evaluate their ability to simulate these processes. For the soil, a discretization with 14 layers over 12m depths was adopted. Hydrodynamic and thermal soils properties have been refined accounting for the amount of organic carbon presents in the soil (SOC: Soil Organique Carbone). For the snowpack, a discretization using 12 layers was preferred to the old version using only three layers. Representation of some snow key processes as its viscosity, its compaction due to wind, its age and its albedo on the visible and near infrared spectra were improved by importing and simplifying parameterizations from the Crocus detailed snow scheme of the CEN.

The validation was performed over Siberia where there is a dense dataset of snow depth (186 stations) and soil temperature (119 stations) in areas without vegetation. 3 simulations forced by the ERA-Interim reanalysis were performed over the 1979-1993 period. Results show that the physic of the snowpack is of prime importance to simulate realistic soils temperatures in winter while the good representation of summer temperatures is related to the consideration of soil organic carbon. These new schemes will be evaluated in the climate model CNRM soon.

4

Impact of climate change on agro-systems and forests

The implementation of adaptation strategies of agriculture to climate change is conditioned by the knowledge of impacts and of the associated uncertainties. In the framework of the ORACLE ANR project, CNRM has produced 150-yr (1950-2100) simulations over France of the biomass of various vegetation types (straw cereals, grasslands, broadleaf and coniferous forests) and of the soil water content associated to each of these vegetation types.

Thirteen climatic simulations from the 4th IPCC assessment report, disaggregated at a spatial resolution of 8 km by 8 km, were used to drive the ISBA-A-gs soil-plant model, over 191 grid-cells representing the main French agricultural and forest regions. Statistical methods were used to quantify the impact of climate change and the agreement between climate models between near future (NF) (2020-2049), far future (FF) (2070-2099) and a reference past period (1970-1999).

Everywhere in France, the duration of dry (wet) periods increases (decreases), up (down) to + (-) 30d/yr in NF conditions. For all the vegetation types, leaf onset and the annual maximum LAI occur earlier. On the other hand, large regional discrepancies are simulated for the senescence period (e.g. earlier in western and southern France for broadleaf forests, later in eastern France) for both NF and FF. The length of the growing period is often more uncertain in FF than in NF in relation to differences in climate models. These simulations will be extended to the Euro-Mediterranean area and coupled with a hydrologic model. The new IPCC simulations will be used to complete this work.

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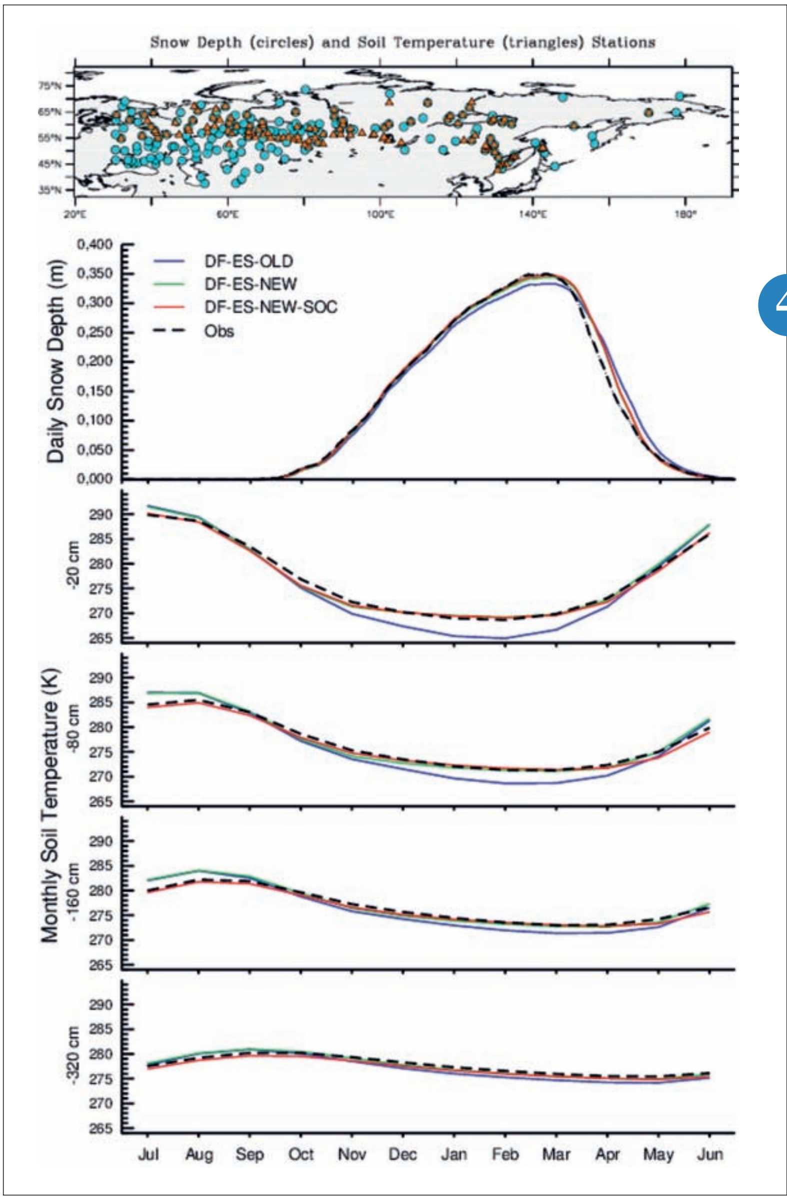

Spatial distribution of Siberian snow height (cyan circle) and soil temperatures (orange triangles) measurements, and comparison of observed and simulated climatological seasonal cycles.
Seasonal cycles of daily snow height and monthly temperatures are obtained by averaging all stations over the period 1979-1993.
Soil temperatures are observed at −20, -80, -160 and −320 cm depth.
Observations (Obs) are shown in black, the old version of the model (DF-ES-OLD) in blue, the new version (DF-ES-NEW) in green, and the inclusion of soil organic carbon (DF-ES-NEW-SOC) in red.

Differences in leaf offset dates for broadleaf forests as simulated by ISBA-A-gs, (left) in near future conditions and (right) in far future conditions. The size of symbols is proportional to the number of climate models associated to a significant impact. Triangles indicate that at least one climate model triggers an impact different from the others.

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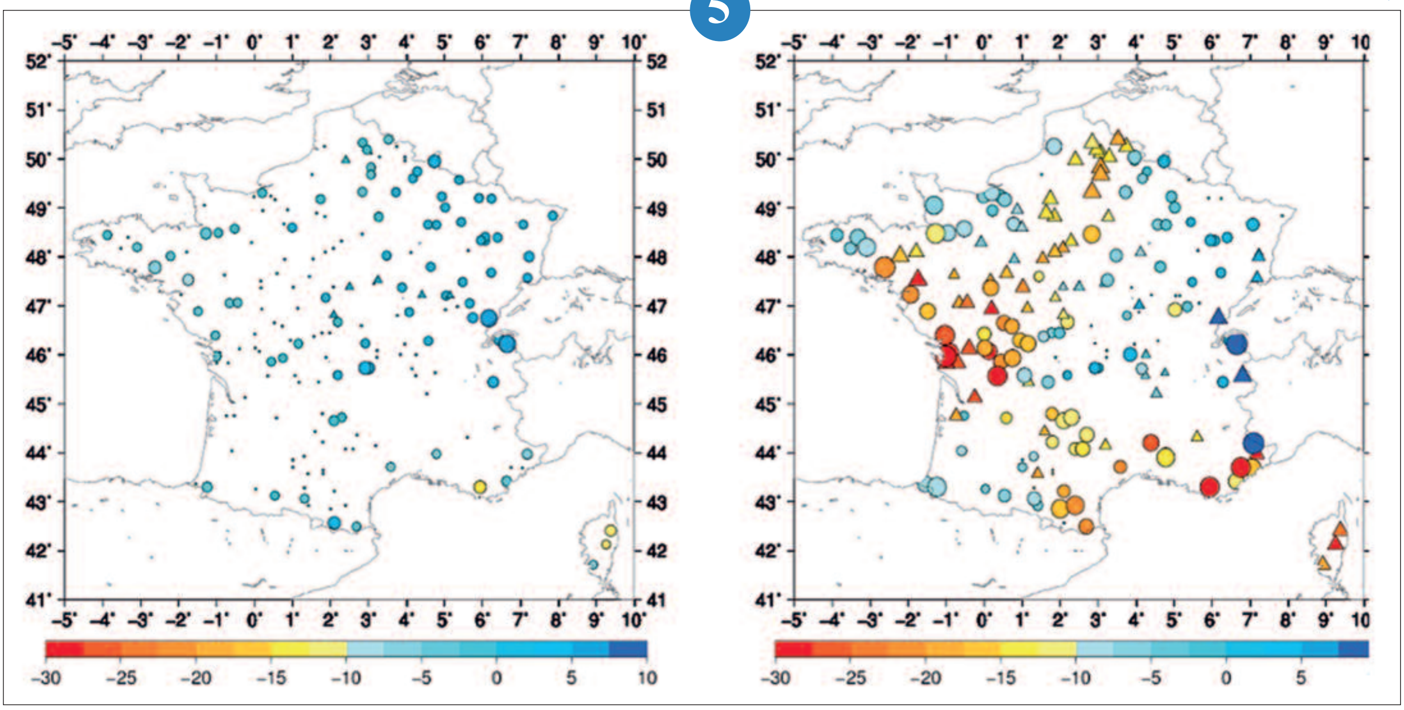

Snow

Research on the snowpack and avalanches across several scientific fields, such as snow-atmosphere interactions, the study of the physical properties of snow and remote sensing of snow cover, for which the contributions of this chapter show some progress made this year. The first snowpack simulations at high resolution powered by AROME have been performed, showing in particular their contribution to characterize the snowpack spatial variability. An initial study of ensemble forecasts of avalanche risk based on ARPEGE ensemble forecasts (PEARP) demonstrated the superiority of this approach over a deterministic calculation for terms up to 4 days. The work carried out in recent years on the use of MODIS imagery to characterize the surface properties of the snowpack found an original application through the identification of the Greenland darkening related to pollution of surface snow by atmospheric aerosols.
Innovative work has also been done on the link between micro and macro scales on the properties of the snowpack: homogenization techniques have been applied to the transport of heat and mass in the snow, opening the way for improved parameterizations of snow models used to predict risk of avalanche and simulation of snow-atmosphere interactions. During this year, a significant effort was made to build the operational SAFRAN- SURFEX Mepra tool, the results of which are used by Météo-France avalanche forecasters since the end of 2014. Finally, one can notice the CEN participation to the Solid Precipitation Inter-comparison Experiment (SPICE) led by WMO.

1

Homogenization of heat and mass transport in dry snow: from the microscopic to the macroscopic description of involved phenomena

Once deposited on the ground, snow forms a complex porous medium that mainly consists of air and ice, and whose microstructure is constantly changing as a result of the physical conditions imposed by its environment. These micro-structural changes of the snow strongly impact the temporal evolution of its macroscopic properties and should be taken into account for an accurate snowpack modeling.
We conducted a theoretical study based on the homogenization method of multiple scale expansions to obtain a macroscopic description of the heat and vapor transport in dry snow from the physical phenomena occurring at micro-scale (heat conduction, vapor diffusion, forced convection and phase changes). The resulting macroscopic model is described by two coupled diffusion equations, each of them involving a source term which accounts for the phase change at the pore scale. The accuracy and robustness of the model were illustrated by 2D numerical simulations. In addition, this approach allows for computing the related effective properties (tensors of thermal conductivity, diffusion, etc.) from 3D microstructures obtained by tomography. The derivation of the macroscopic model also confirmed that the effective vapor diffusion coefficient is not enhanced in snow compared to that in air.
The multi-scale approach offers new perspectives for snowpack modeling since it provides the macroscopic description of a homogeneous layer of snow, directly from the physics and snow structure that are known at micro-scale.

2

Schematic of the approach used in this study: the macroscopic description and the effective properties are derived from the physics and the morphology of snow, known at micro-scale.
(a) and (b) Physical description of the heat and mass transport at micro and macro-scale.
(c) Tomographic image of a snow sample.
(d) Numerical estimations of the effective vapor diffusion coefficient computed from tomographic images. The vertical tip of the "T-shapes" and the horizontal bars represent the vertical and horizontal components of the normalized diffusion tensor. The results show a clear dependence on the density and a significant anisotropy for certain types of snow. The whole study was conducted in collaboration with the 3SR laboratory.

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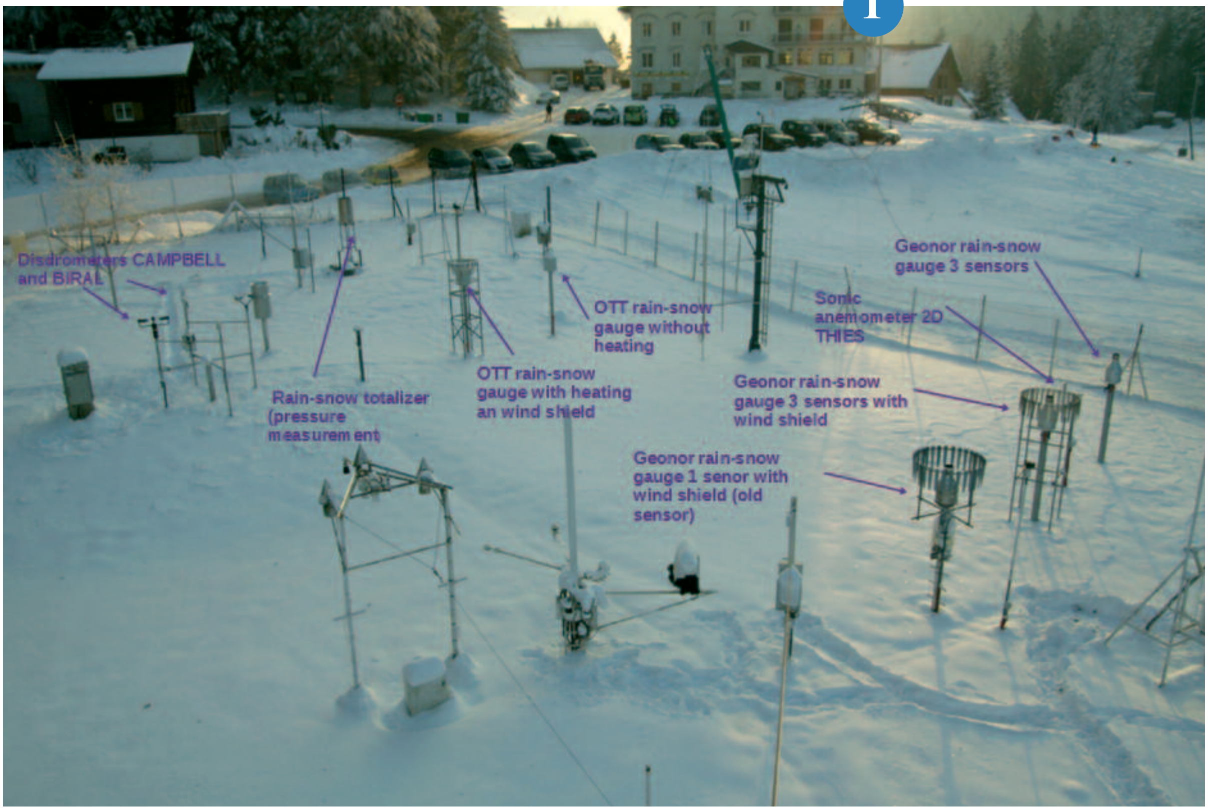
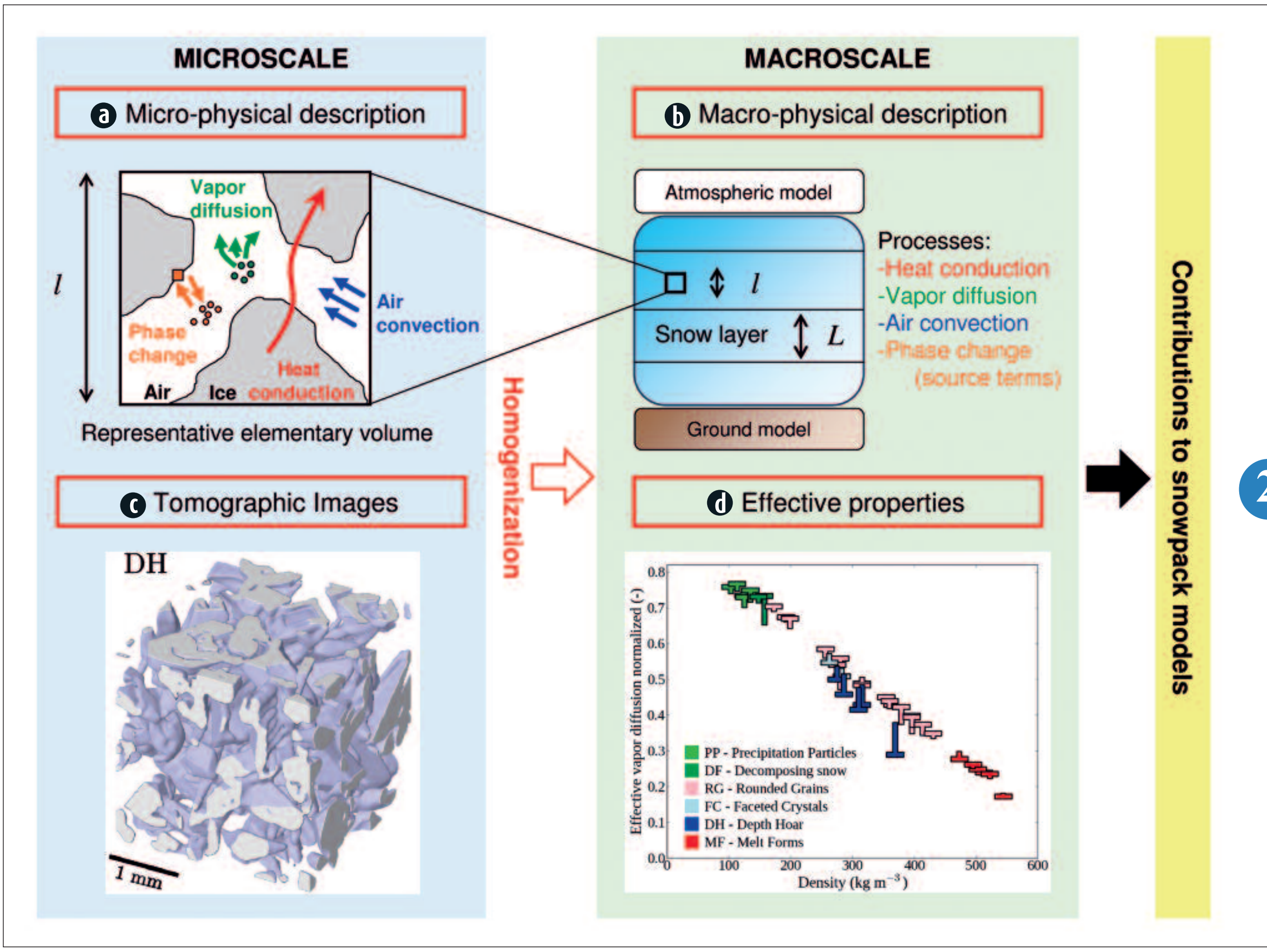


Measurement site of the Col de Porte (1320 m in the Chartreuse Mountains).
The captions show the various sensors that measure precipitation,
which include those specifically installed for SPICE (Geonor gauges with 3 sensors).



2

Ensemble forecasting of snow cover and avalanche hazard

The prediction of avalanche hazard results from an analysis of current snow conditions, the upcoming meteorological conditions and their combined impact on the future state of the snowpack. The S2M chain of numerical models is used in avalanche forecast units in France to estimate present and future avalanche hazard over areas assumed to be meteorologically homogeneous (massifs), primarily as a function of altitude.

The input provided until now to S2M in terms of meteorological forecast comes from the deterministic numerical weather prediction model ARPEGE with a lead-time of 2 days. The uncertainty associated with meteorological prediction is not accounted for although the high sensitivity of the snowpack to meteorological conditions and numerous threshold effects make its prediction challenging. A first ensemble forecasting system of snow cover and avalanche hazard was set up using the 35 members of the ARPEGE ensemble meteorological forecasting to feed S2M.

A posteriori ensemble forecasts were generated and evaluated in the French Alps for the winter 2013-2014. Forecasts over the Pyrenees during the exceptional winter and spring 2012-2013 were also carried out. Results indicate that accounting for the uncertainty in meteorological forecast improves significantly the skill and the usefulness of the modelling chain, regardless of the prediction lead time. The predictability of snowpack conditions using the ensemble forecast technique remains good at a 4 day lead time. This will allow, in the future, building probabilistic estimates of simulated avalanche hazard level in support of operational avalanche hazard forecasting activities.

3

Contribution of snow impurities to Greenland's darkening since 2009

Solar energy absorbed by the snow on the ground depends on its reflective properties (also termed albedo), which depend mostly on near surface snow characteristics (often referred to as "snow grain size") and on the amount of light-absorbing impurities.

The analysis of data collected by satellites monitoring Greenland albedo has revealed that, since 2009, surface snow in the springtime and in summertime is darker than before. That Greenland becomes darker in the summertime has been identified in the past as one element of a positive feedback loop of the climate system: along with atmospheric warming, near surface snow temperature increases, which induces enhanced grain growth. In turn, this increase in snow grain size drives snow albedo reduction and thus an increase of solar light absorption which amplifies the initial warming.

Recent research (Dumont et al., Nature Geosci. 2014) carried out at CNRM-GAME (CEN and GMGEC), in collaboration with LGGE, focuses on the change occurring in springtime, and has demonstrated that springtime darkening could be linked to increasing amounts of light-absorbing impurities in snow. Satellite data further indicate that such impurities feature a distinct colour, and cannot be attributed to black carbon deposition, but possible to mineral dust which could be transported from snow-free areas.

Numerical simulations show that this springtime darkening has potentially contributed significantly to the recent acceleration of Greenland melt. Potential further increases of the deposition rate of light-absorbing impurities should be taken into account for future projections of the impact of climate change on the state of the Greenland ice sheet, and its impact on sea level rise.

This work was supported by ANR Jeune Chercheur MONISNOW, ANR NEEM and EU FP7 COMBINE.

4

Towards a new chain of models for snowpack simulations, AROME-SURFEX/Crocus

The evolution of snowpack physical and mechanical properties is driven by the weather conditions. Therefore, the spatial variability of these conditions in mountainous terrain must be taken into account to forecast snowpack conditions and avalanche hazard.

The meteorological analysis and forecast system SAFRAN currently provides meteorological parameters at various elevations to the snowpack model, SURFEX/Crocus, for geographical areas assumed to be meteorologically homogeneous ("massif", typical size 800 km²). Under this assumption, this system cannot fully capture the spatial variability of snowpack conditions within each massif which limits the spatial resolution of avalanche hazard forecasts. An alternative to SAFRAN forecasts is offered by the NWP system AROME. The quality of AROME forecasts in alpine terrain has been estimated good enough to drive SURFEX/Crocus. Snowpack simulations have been carried out for 5 winters (from August 2009 to July 2014) with a 2.5 km-grid spacing over the French Alps. Results were compared with snow depth measurements and outputs from a simulation using forcing from the SAFRAN reanalysis (Fig.). The snowpack variability within each massif is better represented by AROME-SURFEX/Crocus, especially for massifs located along the border between France and Italy. However, this new chain tends to overestimate snow depth over the Northern Alps.

The chain AROME-SURFEX/Crocus will benefit from the next version of AROME at 1.3-km grid spacing available in early 2015. Downscaling methods will be then used to drive sub-kilometre snowpack simulations over the French mountains.

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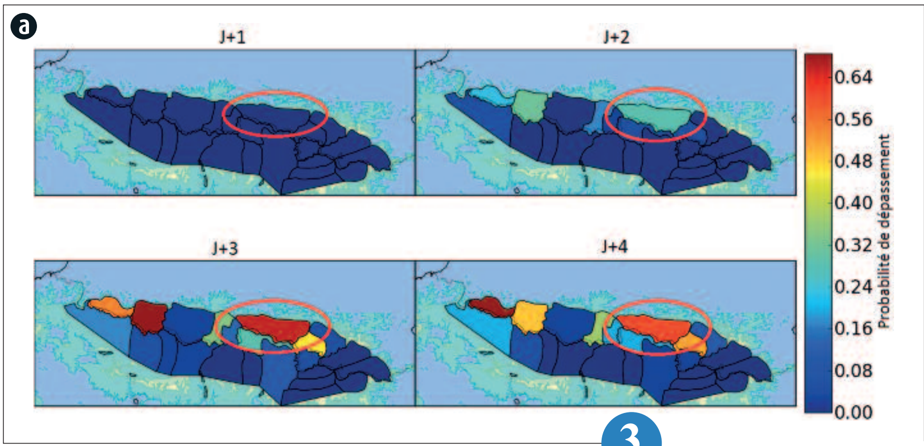

Forecast of the PEARP-S2M ensemble forecasting system from the 01-13-2013 with a 4 day prediction lead time in terms of Natural Hazard Index (NHI) of avalanches at the massif scale (index ranging from 0 to 8).
The Pyrenees maps (a) provide forecasts of exceedance probabilities of the threshold 3 for NHI and for lead times D+1, D+2, D+3 and D+4. High probabilities of important avalanche events are forecast for many French massifs, especially at a 3 days lead time. During that day, numerous big avalanches indeed occurred, resulting in road breaks and important damages.

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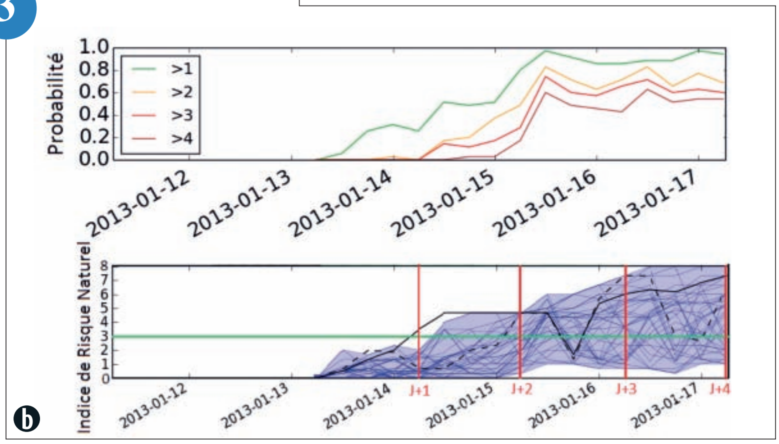

Figure (b) gives more details for the Couserans massif with the forecast evolution of exceedance probabilities for different thresholds (top) and the spread of the 35 forecast members in terms of NHI (bottom). The number of forecast members over a given threshold explains the computed probabilities. The dispersion between members increases with lead time, as expected for any ensemble forecasting method. Dash black line represents the deterministic forecast and solid black line is the reference (a posteriori reanalysed NHI).

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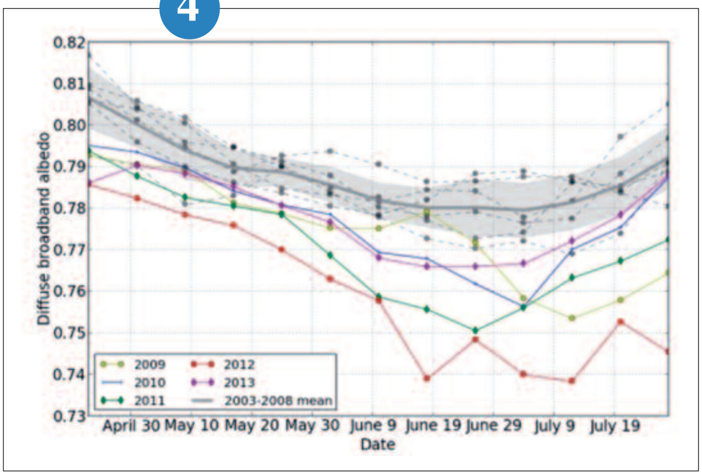
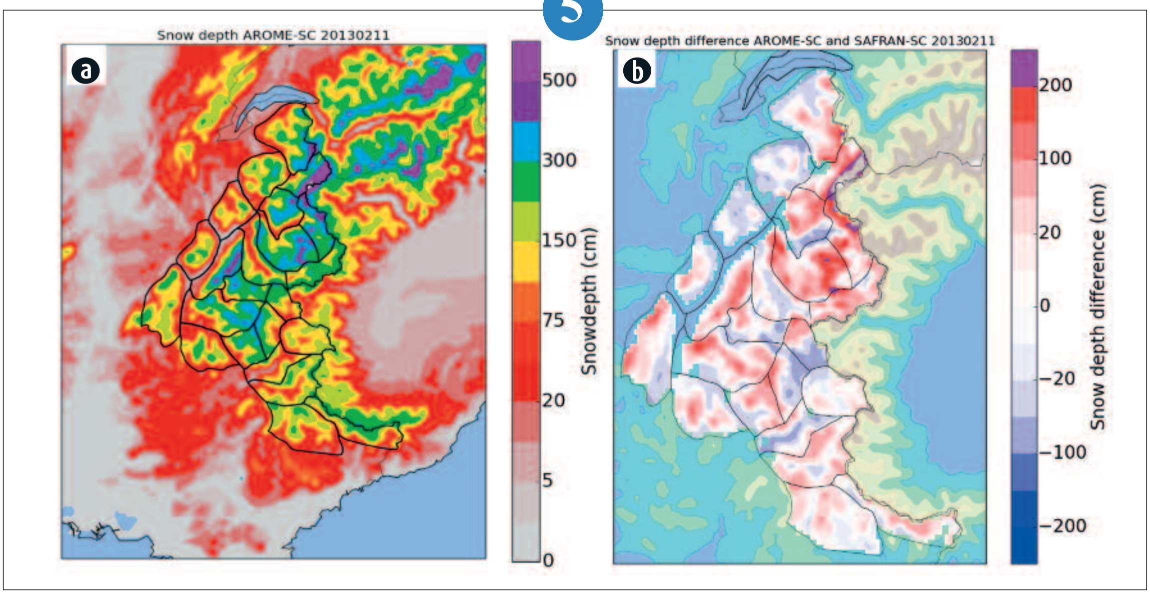


Time evolution of snow albedo as seen by the satellites since 2003 for high elevation locations (above 2000 m altitude) on the Greenland ice sheet. Since 2008-2009, a decrease of albedo has been observed. In summertime, it is attributed to enhanced grain growth along with temperature increase. In the springtime, this study has shown that it is related to a higher concentration of light-absorbing impurities in near surface snow.

5

(a) Snow depth (cm) simulated by the chain AROME-SURFEX/Crocus on 2013/02/11 and (b) snow depth difference (cm) between AROME-SURFEX/Crocus and SAFRAN-SURFEX/Crocus for the same day.



Oceanography

Observations at sea for needs of Météo-France and scientific community (support to research, participation to the inter-agencies program CORIOLIS) are sustainable at Centre de Météorologie Marine (CMM). As such, CMM maintains three moored buoys, plus two in cooperation with UK MetOffice. It manages and distributes information from about 150 drifting buoys: 100 in the North Atlantic for the E-SURFMAR account (operational service of EUMETNET), the others in Tropical Atlantic and the Indian Ocean.
Part of the research activities is dedicated to improving the marine observation for meteorology, via software or instrumental development, and participation in national and international research programs.
Research activities on ocean-atmosphere interactions concern the influence of the ocean on the atmospheric boundary layer (especially the influence of sea conditions on the turbulent flow) and improved parameterization of the turbulent fluxes in models Numerical Weather Prediction (NWP).
This year 2014 has been marked by the analysis and control of data and especially those HyMeX additional sensors installed on the occasion on Mediterranean moored buoys. Sea state impact on simulation of a intense precipitating event with fine scale simulations by Meso NH uses these data of SOP1 HyMeX, as part of a thesis in production in CMM.

1

Wave impact on the turbulent fluxes in HyMeX in situ observations

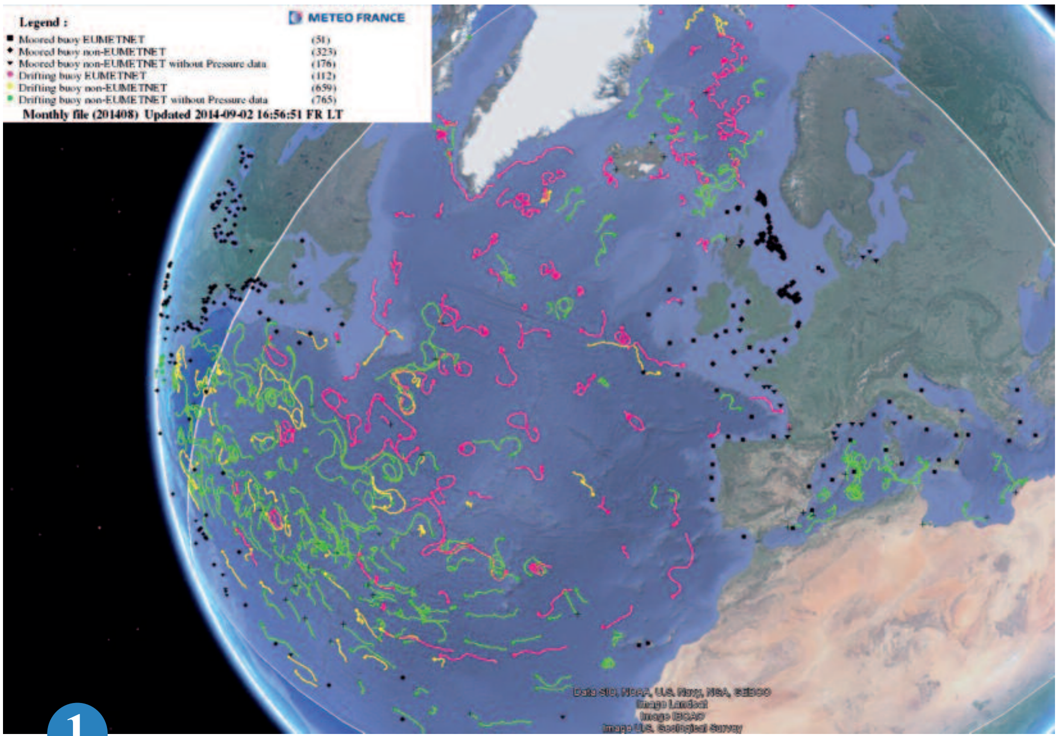
During the HyMeX SOP1, several intensive observing periods took place at sea, with simultaneous observations of the turbulent fluxes at the air-sea interface and of the sea state. High frequency fluxes measurement were processed using the eddy-covariance (most straightforward) and inertial dissipative methods thanks to a software developed jointly by the IPSL and the MIO-IRPHE. This processing includes numerous corrections and quality checks and provides momentum, sensible heat and latent heat fluxes, all of them being proportional to the wind stress. The wind stress is a direct function of the sea surface roughness z0, in meters, and of the surface wind speed. It corresponds to the friction of the wind on the sea surface, therefore to the transfer of mechanical energy to the sea resulting in the wave field formation and in the corresponding slowing down of the wind.
Since the 1990's, several studies based on in situ datasets and on laboratory measurements have shown that, for a given wind speed, the surface roughness depends in a rather straightforward way on the wave age (or on its inverse). These observations were confirmed by modelling studies of the physics of the interface. The wave age corresponds to the state of development of the wind sea and is defined as the ratio of the wave speed by the wind stress. For a given wind speed, more rapid waves correspond to higher wave ages. The sea surface roughness is higher for a younger sea (also a more steep sea) than for an older sea, and this is exactly what is observed on the HyMeX measurements in the Mediterranean Sea.

2

Impact of the sea-state on the simulation of a heavy precipitating event (HyMeX, IOP 16a)

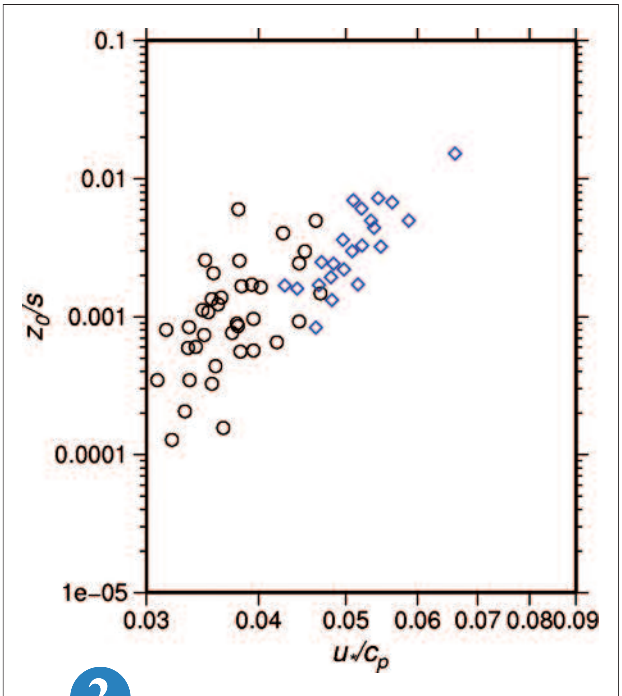
We took advantage of the simulation of a heavy precipitating event (HPE) which took place during the HyMeX IOP 16a by using the high-resolution non-hydrostatic model MesoNH to perform a sensibility study on the impact of the sea state on the turbulent fluxes. Through the sea surface roughness, the wind waves influence the wind stress and the low-level atmospheric turbulent fluxes (momentum, sensible heat and latent heat fluxes). In turn, they likely impact the wind field and the evolution of the low-level flow at the origin of the HPE.
Quantifying this impact is the objective of this case study of the IOP 16a, which is well documented within the HyMeX framework (numerous in situ observations, several hindcasts) and which resulted in more than 100 m rain accumulation and in two casualties in Toulon. The event is simulated for a time period of 36 h with a horizontal resolution of 2.5 km and the very same configuration except for taking into account the wave influence on the turbulent fluxes. In the first case (NOWAV), waves are not accounted for. In the second case (WAM), the surface roughness is a function of the wave age, which is an output of the analyses of the Météo-France wave model MF-WAM for the simulation period. The comparison of the momentum flux at the sea surface (figure, 26/10/12 at 14:00 UT) shows clearly the wave impact on the low level flow heading towards the French south-east coasts from the north-west of Sardinia, and corresponding to the mesoscale convective systems feeding the HPE. An increase of 100% of the momentum flux results here in a slowing down of the surface wind field of about 30%.

3



1

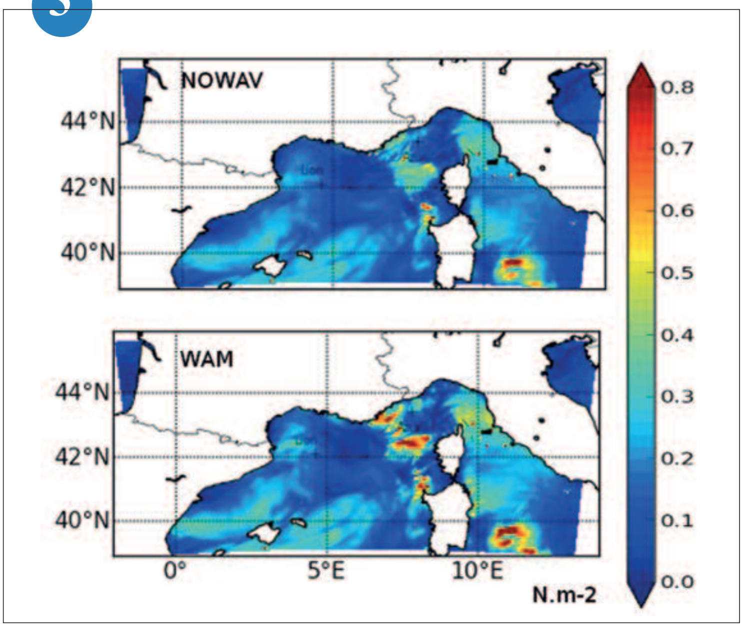
Positions and trajectories of buoys in the North Atlantic for the month of August 2014



2

Dimensionless roughness of the sea surface (s is the standard deviation of the wave height) as a function of the inverse of the wave age u^*/c_p. Observations corresponding to pure wind waves are in blue, those corresponding to intermediate sea state (with a swell component) are in black.

3



Comparison of the momentum flux (N m^{-2}) as simulated on the 26/10/2014 at 14:00UT during the HyMeX IOP 16a, with no wave effect (NOWAV, top) and with the effect of waves from the MF-WAM model analysis (WAM, bottom).

Use HYCOM3D currents to calculate the drift at sea

Since 2012, the marine forecast service of Météo-France and the SHOM work in partnership to improve the simulation of drift in marine environment. Thus, the drift model MOTHY operated by the forecasters from the CNP has been interfaced with the current provided by the SHOM operational systems (HYCOM3D model).
MOTHY models surface currents in response to wind, pressure and tidal currents. Two solutions were then selected. The first mode (mode 1) uses the HYCOM Ocean currents modeled as a "background" current to be added to MOTHY. This allows to take into account the permanent circulation and signature of additional processes internal to the ocean (like eg. 3D turbulence) that is deprived MOTHY. The second mode (mode 2) directly uses the entire oceanic signal from HYCOM to calculate the drift. The validation strategy is to reproduce the trajectories of drifters observed in the Bay of Biscay (MOUTON 2012 campaigns, SHOM).
The Lagrangian diagnostics implemented show that the HYCOM total current gives encouraging results for drift forecasting, especially for trajectories submitted to tidal currents. Some bias relative to wind currents were nevertheless highlighted, suggesting adjustments to investigate soon.

4

Ocean mixed layer study during the two HyMeX Special Observing Periods

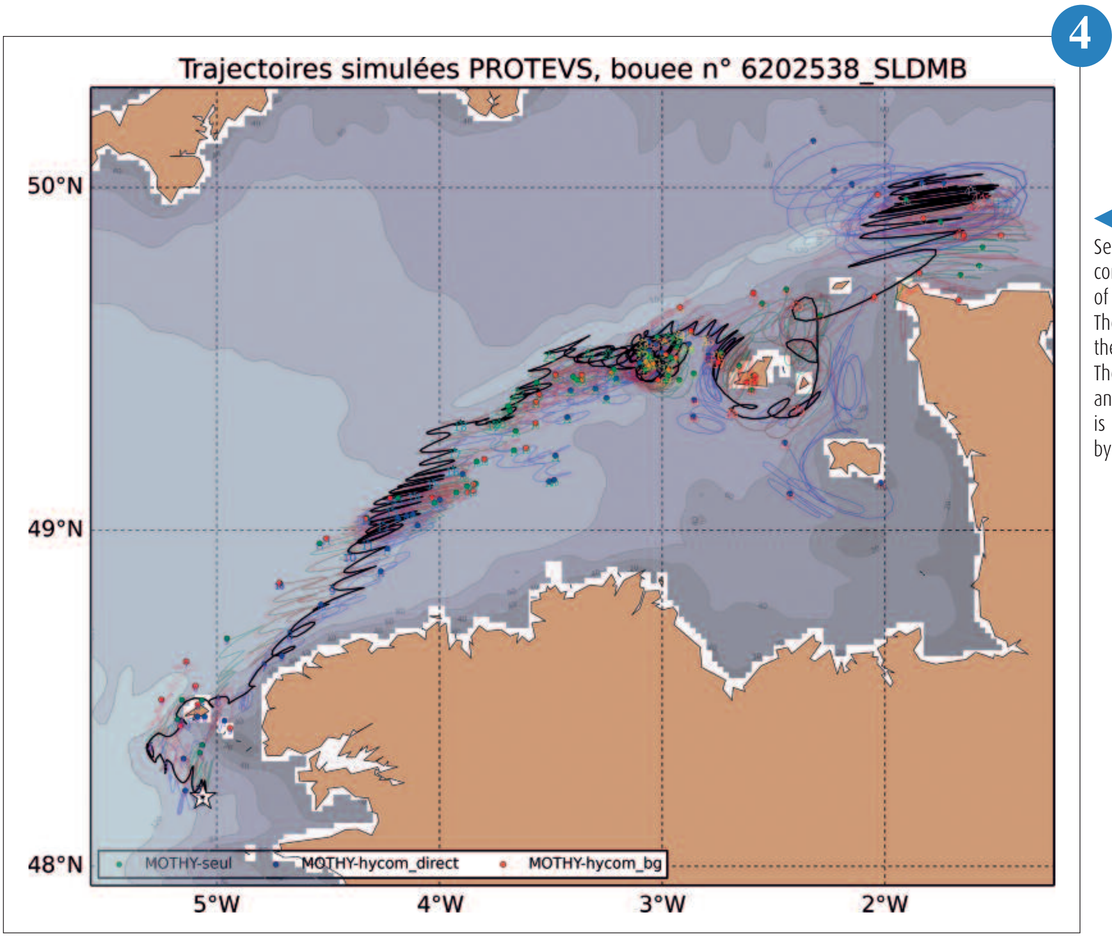
Air-sea interactions play a major role during the intense meteorological events that frequently occur in the Mediterranean region. The ocean mixed layer, directly interacting with the atmospheric low levels, has small-scale, immediate and intense responses under these events. The two field-campaigns (SOPs) of the HyMeX program constitute an unprecedented dataset, which allows the evaluation of mesoscale ocean simulations in the western Mediterranean Sea.
Driven in surface by the high-resolution and short-term (0-24 h) forecasts of the AROME-WMED system, the NEMO-WMED36 ocean model (~2.5 km-resolution) is able to represent fine scale ocean structures and their rapid variations. During SOP1 in autumn 2012, the rapid succession of intense evaporation and precipitation strongly constrains the salinity, the stratification and thus the ocean mixed layer depth (Figure a). The numerical simulation permits to better understand the processes involved in the ocean response. It notably highlights the important role of the local dynamics and vertical stratification on the mixed layer tendencies. SOP2, in February-March 2013, is characterized by dense water formation in the Gulf of Lion, highly controlled by strong and cold wind events (Mistral and Tramontane). The ocean model represents well the ocean deep convection and the transport of the new dense water ($\geq$ 29.11 kg/m^3) to the basin bottom and south-eastwards, in particular thanks to very fine scale structures (with sizes $\leq$ 50 km, Figure b).
In the following step, the air-sea coupled system AROME-NEMO over the western Mediterranean region (WMED) will be used to represent, identify and better understand the coupled processes involved in intense meteorological events.

5

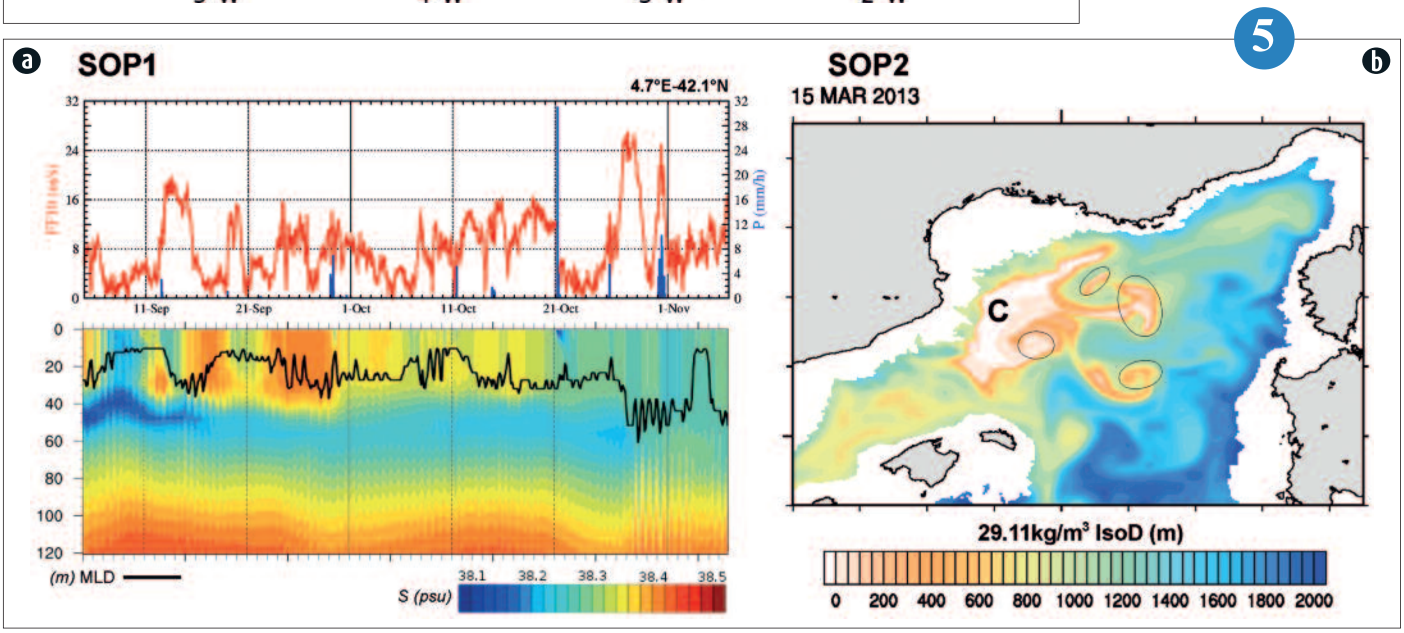
A new version of the waves model

The waves model of Météo-France, MFWAM, is derived from the WAM code, as for the European Centre of Medium range Weather Forecast, and has used for several years a physic developed in collaboration with IFREMER and SHOM.
On the 23rd April 2014, the global MFWAM was the first to assimilate operationally the waves heights provided by the 3 altimeters currently aboard satellites: Jason-2, Saral and Cryosat-2. The MFWAM model appears so as one of the most precise in the monthly intercomparison of global waves models operated by weather centres, according to the JCOMM (cf. Figure). In November 2014, a new version of the MFWAM model has been installed in the operational suit, benefiting by the developments done in the framework of the MyWave European project. The changes focus on an improved bathymetry, a better masking of islands, a new propagating scheme, improvements in the physics and an adjustment of the non-linear interactions. The validation of this new version with altimeter data has showed a global improvement of the normalised standard deviation of waves heights by 5%. This new version allows also to reduce the strong bias of the waves heights in the southern hemisphere and to improve the surface wind drag.
Next year, this MFWAM model will be used to force coastal waves models, able to reproduce the complex waves physics in very shallow water.

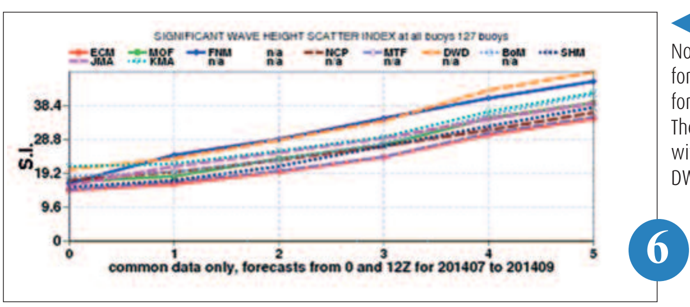
6



Set of trajectories predicted by models compared to the actual trajectory of a buoy from the experiment. The simulated trajectories are in color, the one observed in black. The buoy's trajectory starts with a star and a new simulation of three-day is started each day by following its path.



NEMO-WMED36 simulation: (a) 10m-wind speed (m/s) and precipitation (mm/h) in the AROME-WMED forecast during SOP1 at 4.7°E-42.1°N (top panel). Salinity profile (colour, psu) and ocean mixed layer depth (MLD, black contours, m) time-series (bottom panel). (b) Depth of the =29.11kg/m³ isopycnal surface (IsoD, m), the 15th March 2013. "C" indicates the deep convection area. Eddies of the "new" dense water formed are indicated with ellipses.



Normalised standard deviation of the significant height of waves (in %) for various global waves models, in comparison with 127 buoys measurements, for the period July-September 2014, for different forecast ranges.
The MFWAM model is indicated by MTF (Météo France) and its results are plotted with a mauve dashed line, together with other weather centres (CEP, MetOffice, FNMOC, NCEP, DWD...), according to the inter-comparison of the JCOMM (OMM/COI).

Wave modelling under extreme conditions

The waves generated by severe storms or cyclones can cause large damages at the coasts. The case of cyclone Bejisa in the beginning of January 2014 has induced several red warning bulletins of waves/ submersion. This cyclone has a fast and explosive intensification with winds increasing from 32 to 95 knots in one day (starting from 29 to 30 December 2013). The trajectory of the cyclone Bejisa passed westerly of La Réunion island generating waves with significant wave heights greater than 10 meters (see figure a). The winds at the ocean surface from the atmospheric model ALADIN-Réunion were underestimated. Consequently, the wave model MFWAM gives weaker significant wave heights than those provided by the altimeter SARAL passing in the cyclone zone, as illustrated in figure b. It is clear that the benefit of the assimilation of the altimeter wave data to correct such wind forcing misfitting, is crucial for the cyclonic season (see also figure b).

January 2014 has been a very intense in terms of severe storms propagating high waves to the French Atlantic coasts. Several awareness bulletins of waves/submersion have been issued by the forecasters. The wave model MFWAM has predicted accurately the wave parameters for these stormy events. The figure c shows the good fit of significant wave heights from the wave model MFWAM and the buoy Brittany managed by Météo-France.

7

An ensemble forecasting system for coastal storm surges

The Estimation of the variability of water levels has become an important issue for the VVS (Operational coastal flood warning) set up since the Xynthia storm in October 2011. It is within the framework of the HOMONIM project which aims to improve the prediction capabilities of coastal flooding that an ensemble forecasting system for storm surges was developed.

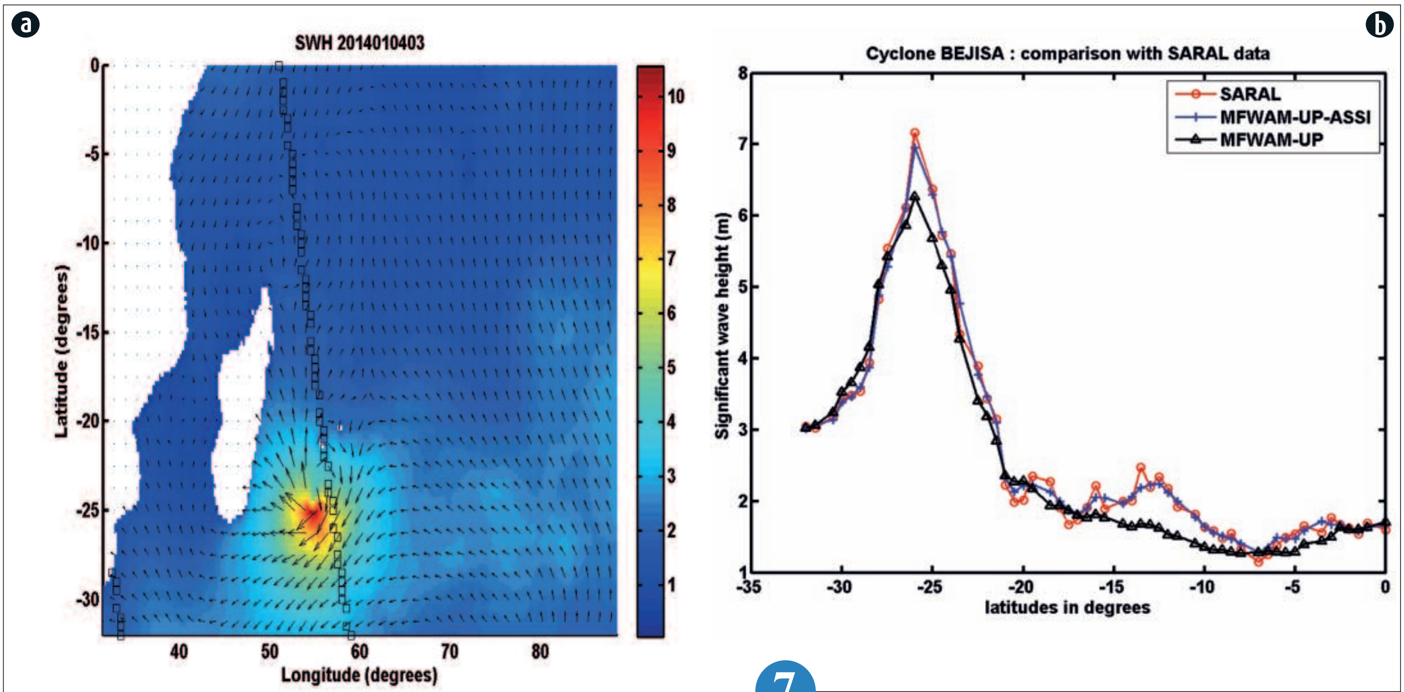
For that purpose, atmospheric quantities (surface wind and sea-level pressure fields) of the ensemble forecasting system of Météo-France (PEARP), which gives 35 scenarios, are used to drive a storm surges model. The simulation gives a surge evaluation to nearly 50 French coastal locations.

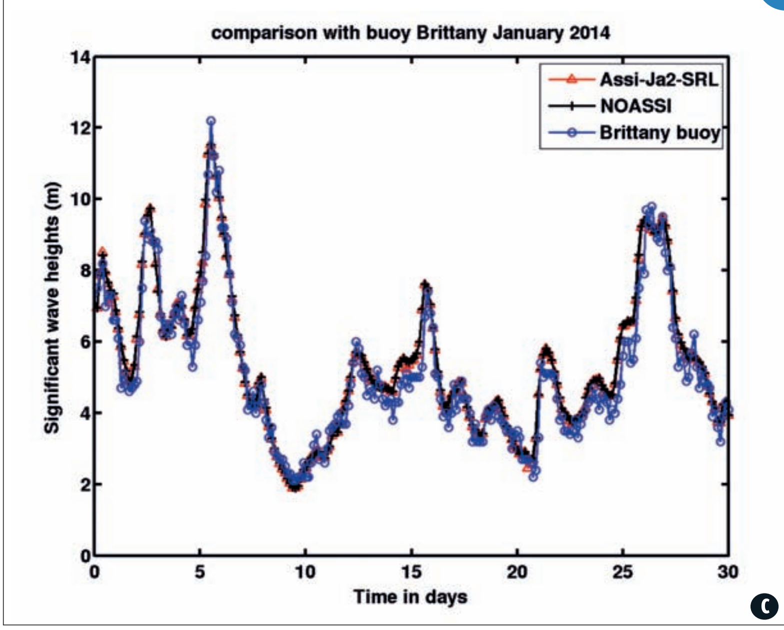
A website displays results (see figure) for each locations with time series but also with risks maps of going beyond the HAT (Highest astronomical tide), calculated on each location given upper-quartile values of water level model output.

This new visualization tool should give a better idea of uncertainties on model surges to marine forecasters analyzing spread in values given by the members of ensemble forecasts.

Several studies were started: Comparison between the new surge model HYCOM2D with the old one of Météo-France, Choice of atmospheric forcing (PEARP vs Ensemble prediction system of the CEPMMT), and comparison with deterministic model results. A statistical evaluation of this ensemble forecasting system will be developed to better estimate model bias on certain location. This storm surge ensemble system will be operational on 2015.

8



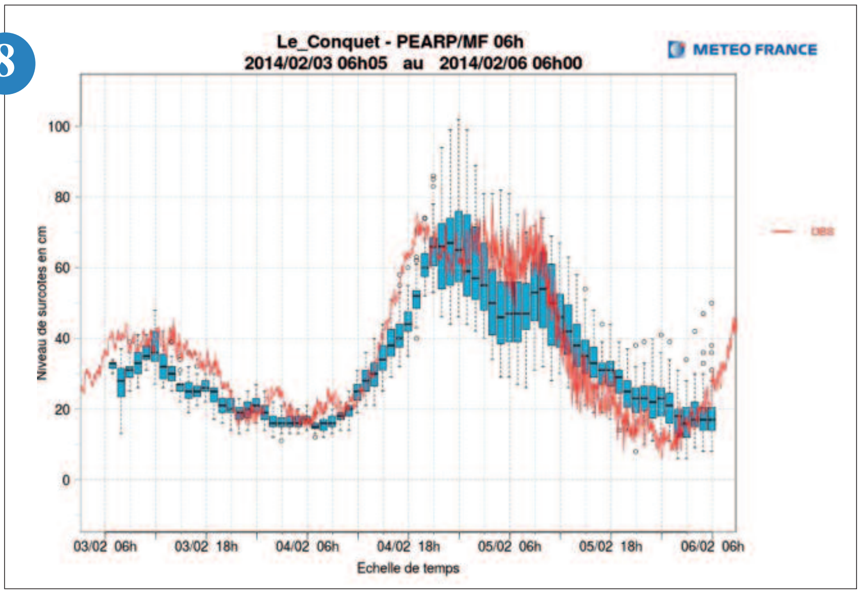


7

(a): Snapshot of significant wave heights from the new wave model MFWAM on 4 January 2014 at 3:00 (UTC). The squares stand for the orbit track locations of the satellite SARAL/Altika.
(b): Variation of significant wave heights at the orbit track of SARAL/Altika on 4 January 2014 at 3:00 (UTC). Red, blue and black colours indicate the wave heights from SARAL/Altika and the new model MFWAM with and without assimilation, respectively.

(c): Time series of significant wave heights during January 2014. Blue, red and black curves stand for wave heights from the buoy Brittany, the model MFWAM with and without assimilation of altimeter wave data, respectively.

8



Time series of storm surges ensemble forecast for Le Conquet during the Petra storm on February 4, 2014. Use of PEARP atmospheric forcing and the old storm surges model of Météo-France (MF). Surge observations are showed on red line, and the ensemble forecast has given with boxplot. NB: Graphical summary of a numerical data sample through five statistics: median, lower quartile, upper quartile, and some indication of more extreme upper and lower values, and outliers (circle). The blue box representing all the members between the lower quartile (Probability 25%) and the upper quartile (Prob. 75%), the median (Prob. 50%), the extreme give the minimum and maximum values and outliers (circle).

Observation engineering, campaigns and products

The year 2014 has been very busy for the SAFIRE unit. Operating aircrafts for environmental research on behalf of Météo-France, CNRS and CNES, the unit has contributed several experimental campaigns in the frame of CHARMEX, a program dedicated to air quality in the Mediterranean basin, and HAIC with the ultimate aim to improve the safety of civil aviation and the participation of major stakeholders like EASA, FAA, Boeing and Airbus.
The improvement of processing techniques for operational observation data has been the object of several studies. One of them had the objective to retrieve 3D reflectivity fields from the observations of the two meteorological radars of the Reunion Island. It had to take into account the specificities of the local meteorology. The possibility was investigated to extend to the maritime domain the application of CARIBOU, an hourly analysis of low-level visibility for the benefit the French Navy.
New instrumental techniques have been developed. A gondola for turbulence measurement under a tethered balloon has been validated. It should become a standard technique for turbulence studies in the future. A campaign was carried out for testing new sensors developed by the GSMA research laboratory for air chemistry measurements. It took advantage of the capacity of the double-balloon sounding technique to enable the recovery of the scientific payload after the flights.
Observation techniques are used in the frame of science programs. In 2014 was carried out the third and last part of EUREQUA, a program dedicated to the environmental quality of highly urbanized city areas. One of its specific aspects was its multidisciplinary character with the participation of sociologists. A study was also conducted in the frame of the TROPICO program. Based on the analysis of satellite data, its aim was to study the impact of convection on the variability of the water vapor content in the high-troposphere, low-stratosphere region of the atmosphere.

1

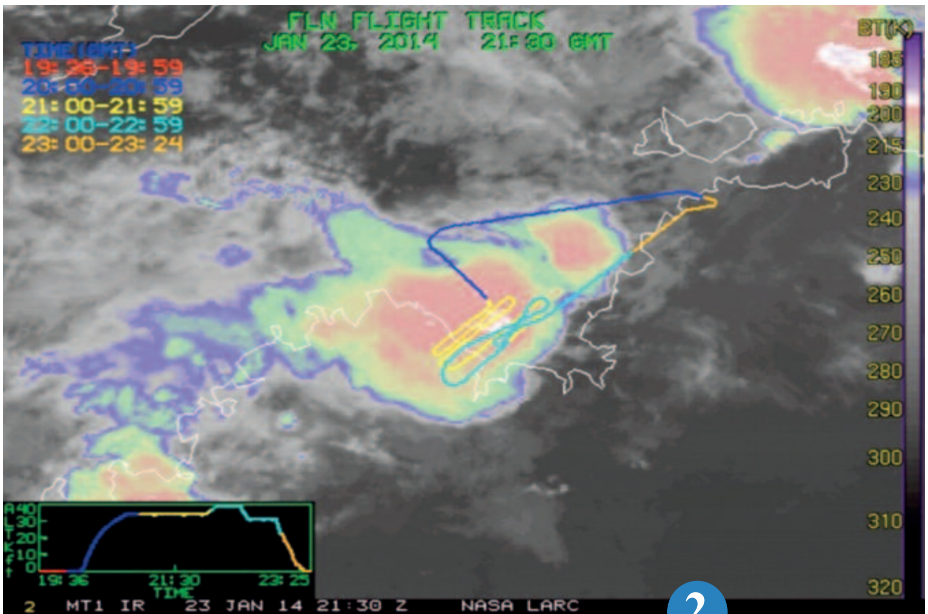
HAIC/High IWC: A study of high-altitude ice crystals to enhance aviation safety

Since early 1990s, incidents with reactors have been observed at high altitude and low temperature. Although classing icing is already taken into account in aircraft certifications measurements anomalies in temperature and aerodynamic velocity have been also reported. Thus, dedicated study of the properties of the crystals of ice and of super cooled water droplets in the atmosphere turns to be of prime importance regarding aviation safety. HAIC & High IWC projects are funded by European Union, EASA and FAA and coordinated by Airbus and NASA. It aims to contribute to a revision of aviation standards defining high-altitude atmosphere, to study the properties of high ice-density zones in the convective clouds and to contribute to the technological developments of instruments for detection and avoidance of these dangerous areas.
From January to March 2014, an experimental airborne campaign based in Darwin (North of the Australia) involved the Falcon 20 operated by SAFIRE, with the expertise of French laboratories LaMP/OPGC and LATMOS/IPSL. The Falcon 20 was equipped with 95GHz radars to study the properties within convective clouds areas with high concentration of ice crystals and many innovative in-situ probes to study microphysical processes that occur in these areas.

After more than 70 hours flying, the analysis of the data will allow a better understanding of formation of ice crystals and thus to improve the detection and avoidance of areas where these phenomena occur. However, other flights are planned year next to contribute to the evolution of standards for the certification of aircrafts and their equipment.

2

Falcon 20 flight track during a scientific mission on the West of Darwin, Australia
(flight performed on 23/01/2014).
(Source NASA LARC by INSU)



2

1

Instrumental set-up deployed at Cap Corse during 3 years (until July 2014) in the frame of the research programme CHARMEX-MISTRALS.

GLAM: An experiment to measure the chemical constituents over the Mediterranean Basin

Inside the vast CHARMEX-MISTRALS project, the GLAM experiment (Gradient in Longitude of Atmospheric constituents above the Mediterranean basin) aims to describe with a high resolution the distribution of pollutants over the Mediterranean Basin along an East-West axis, including vertical profiles. SAFIRE provided its Falcon 20 for 5 days of measurements between Francazal (France) and Larnaca (Cyprus) by measuring along the track at altitudes of 5 000 m (one way) and 9 000 m (return), and vertical soundings from 12 000 m to less than 100 m above the sea. From 6 au 10 August 2014, a crew of 7 persons flew for more than 24 hours of scientific data collection. This experiment is for SAFIRE a very original issue for it has been made without any ground-based support neither for scientific instrumentation nor data processing. Even though measurements went without any problem, its feedback is a precious mean to enhance our service offer, in order to answer any similar demand in the future.

3

a

3

(a): The Falcon 20 has a long take-off because unusually heavy, due to the particularity of the mission. (Copyright SAFIRE/ J.-C. Canonici)

b

(b): Early briefing just before take-off at Francazal.(Copyright SAFIRE/J.-C. Canonici)

EUREQUA measurements campaigns

The EUREQUA project raises the issue of definition and evaluation of the environmental quality of neighbourhoods. The approach is to integrate and cross observable data characterizing the physical environment and people's perceptions of their living quality.
A key step of the project is the experimental phase, based on three field campaigns in Marseille, Paris and Toulouse. More particularly, the Toulouse study area is the Borlongue-Papus-Tabar neighbourhood that is surrounded by the ring road and the Seysses Road, and is subject to noise and air pollution nuisances. From January to June 2014, meteorological data (temperature, wind, humidity) were continuously collected to characterize the spatial and temporal variability of microclimate. Scientists have also beaten the pavement for 3 successive days in January, April and June to make mobile measurements of microclimate, air quality, and noise (Figure a). Finally, during "commented walks", the inhabitants completed a social survey (simultaneously to measurements) about their feeling in terms of sound, air-quality, and thermal comfort. In our discipline, the first data crosses show that people are able to perceive some variations in apparent temperature, in the study area, which are consistent with what is measured (Figure b). But the concept of climate comfort is much more subjective.
This data set should help us to provide a multi-criteria assessment of the environmental quality. It can then be applied to requalification scenarios for neighbourhoods, which will be studied by numerical modelling exercises. Ultimately, a good practice guide will be written to the urban planners.

4

High resolution greenhouse gas vertical profile measurements with light free balloons

CNRM and GSMA collaborate to achieve greenhouse gas measurements method between surface and troposphere. GSMA designed a new light-weighted, accurate, sensor called AMULSE "Atmospheric Measurements by Ultra-Light SpEctrometer", to measure greenhouse gas (carbon dioxide, methane...). This sensor is flying under two CNRM light balloon: the first is carrier and is separated at a preset height or by an order; the second is slowing the payload fall, when the first balloon is separated. The instrumentation is retrieved in the field by GPS tracking performed with a commercial radiosonde. The forecast track of the flight is conducted from a wind profile (measured or predicted by AROME and ARPEGE models) and adjusts the drop zone and preposition the instrumentation recovery team.

A field campaign was carried out in the region of Reims in the fall 2014 with 17 flights, all completed successfully and with a single instrument. 12 flights exceeded 7 km altitude. This campaign helped us to qualify the AMULSE sensor at these altitudes, to clarify the flight and recovery methods.Later, this method will achieve regular and frequent soundings for process studies or satellite validation.

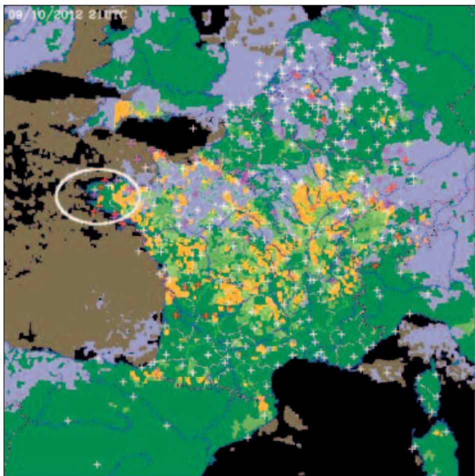
5

Extension of CARIBOU on the maritime area

CARIBOU product provides an hourly analysis of a probable occurrence of fog or mist over metropolitan France. The decision algorithm combines the MSG cloudy classification, the French radar rainfall (PANTHERE) and hourly fields from the surface analysis VARPACK (humidity and the strength of the wind). Following an evaluation whereby it was found that the first version was less efficient on sea, therefore the algorithm was adapted accordingly.
First of all, the contribution of each parameter was studied on the maritime area and the radar rainfall was found to be unnecessary. However, some other parameters were introduced. The difference between the dew-point temperature and the sea surface temperature, combined with the MSG cloudy classification appears to be determinant. Other variables such as tendencies where also studied but proved to have no effects. Thresholds allowing to exclude any risk of mist or fog were adjusted, based on scores. In particular, the related risk threshold for the humidity was redefined.

From the end of the year until the early 2015, the product is being evaluated by the end users. When completed, if the product is considered satisfactory, the new version of CARIBOU, adapted to the maritime area, will be deployed.

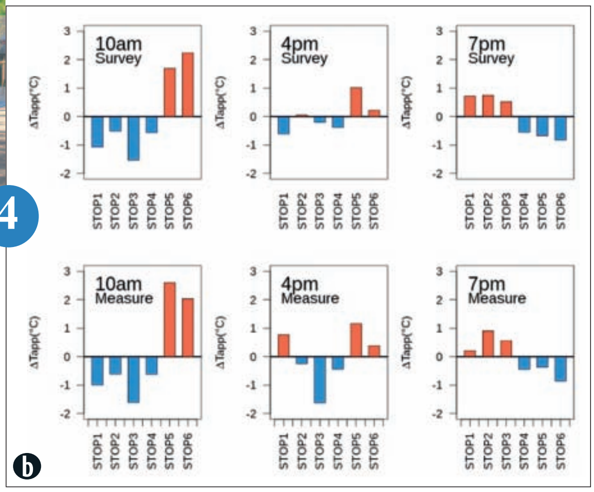
6



a Analyse CARIBOU V1.3 opérationnel du 09/10/2012, 21UTC

(a): Left: Example of mobile measurements collected in Toulouse neighbourhood (here is the temperature anomaly, on June 18th 2014 9am).
Right: picture of surveyed people (top) and measurement systems (bottom).

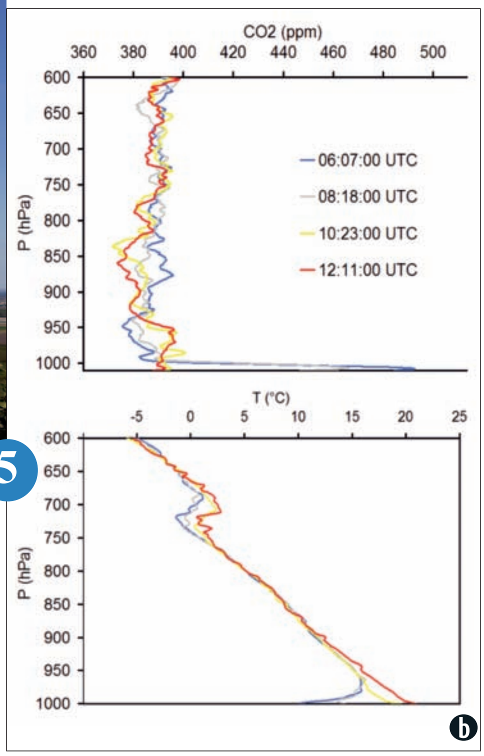
4



(b): Difference compared to the mean value in apparent temperature estimated by surveyed people at each stop point of the walk (top) and in thermal comfort indices computed using mobile measurements recorded simultaneously (bottom).
Results for the commented walks performed in Toulouse in summer at 10am, 4pm, and 7pm.

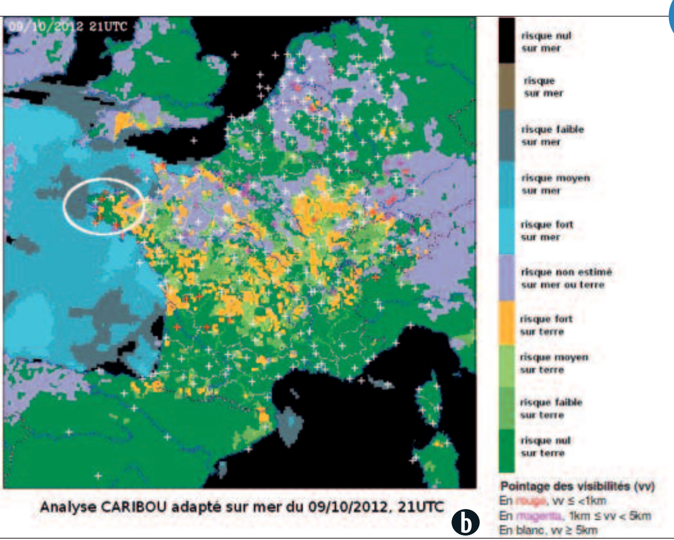
(a): Preparation of an AMULSE flight. Copyright Lilian Joly (GSMA)

5



(b): Carbon dioxide and temperature profiles measured during 4 consecutive flights made the 2014, 1st October in Saint Hilaire le Grand (51).

6



Comparison between the operational version of CARIBOU (a) and the modified version of CARIBOU on maritime area (b)
The reported observations on Breton coasts prove the occurrence of mist and fog: the operational product doesn't detect any risk while the modified product suggests a risk from low to high.

Water Vapor Budget at the Tropical Tropopause

The upper troposphere-lower tropical stratosphere (TTL) is a key region of the atmosphere where water vapor (H_2O) injected from the troposphere to the stratosphere influences the radiative balance of the earth and consequently the climate.
In the framework of the ANR TRO-pico that considers the H_2O budget in the TTL at different scales (from local to global), a study (Carminati et al., 2014) was mainly focused on the role of deep convection on variability of H_2O in the TTL in the whole tropics from space-borne measurements. Observations of H_2O, ice cloud and temperature performed by the Microwave Limb Sounder (MLS) space-borne sensor aboard the Aura platform, were analyzed between 2005 and 2012 in the tropics as well as smaller areas of South America, Africa, etc. An approach consisting in analyzing the difference between daytime and nighttime measurements helped to highlight the effects of continental convection compared to the oceanic convection (Figure a), and the influence of the hemisphere and the season.
The results demonstrate that the continental convection is largely responsible for the variability of H_2O in the TTL by injecting ice crystals which, following their sublimation, hydrate this region of the atmosphere. This phenomenon is observed on average up to the lower stratosphere during convective seasons and is more pronounced in the Southern Hemisphere (Figure b). The analysis now focuses on smaller areas of South America (southern Brazil vs. Amazon) using space-borne measurements, field campaign made of balloon launches, model outputs and assimilation.

7

Turbulence measurement under tether-balloon

Inside the atmosphere, the atmospheric boundary layer (ABL) requires continuous monitoring as this is the layer that undergoes primarily the influence of anthropogenic activities. Turbulent processes of ABL contribute the most to transfers of energy and matter between the surface and the atmosphere. It is in this context that the observation on the vertical turbulent parameters presents an interest. The probe shown in Figure “a” was built to measure under tether-balloon, thermodynamic parameters at very high frequency (10Hz) for the first few hundred meters of the atmosphere. The probe developed by the team GMEI/4M is an innovative tool and complementary at others measures made on mast and by research aircraft during experimental campaign dedicated to the ABL.
During the field campaign of the BLLAST (Boundary Layer Late Afternoon and Sunset Transition) project, this probe was implemented. Three years after the field campaign, the data from this probe have contributed to three project components: (i) study the evolution in the late afternoon of the turbulent structure of the CLA, (ii) evaluate the numerical weather prediction models and (iii) validate the measurement of the Doppler lidar turbulence. Figure “b” shows the second item with the representation of the temporal evolution of the turbulent kinetic energy (TKE), one of the characteristic parameter of the turbulence, at 4 different altitudes obtained with various observations (top) and simulated (low) by the French numerical weather prediction model AROME for 2 consecutive days.
Ongoing projects concerning this probe focus on the possibility to estimate vertical profile of the dissipation rate of TKE and also to add a fast humidly sensor.

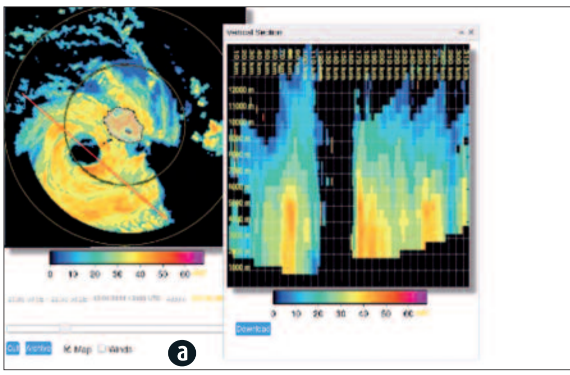
8

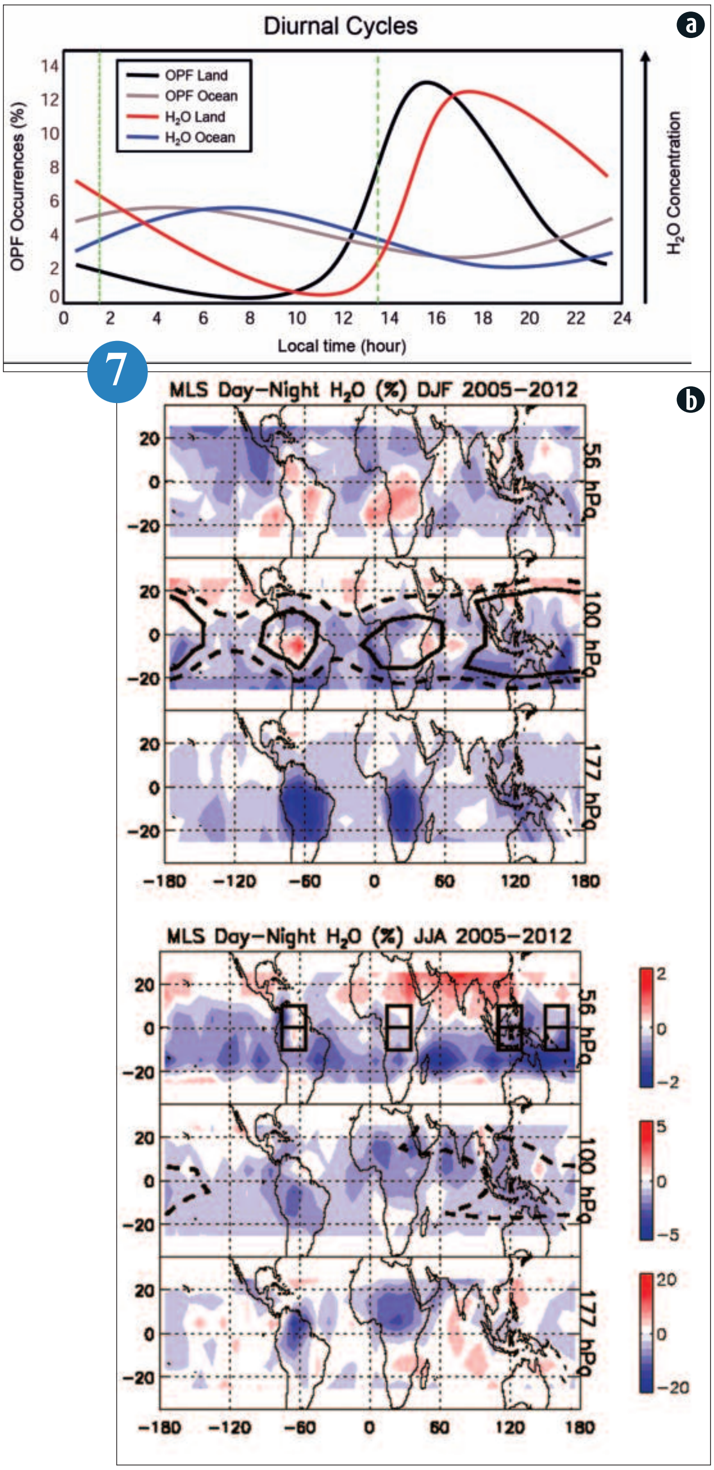
Exploiting radar data for tropical cyclone study: the R2-3D chain

R2-3D (Radar Réunion - 3 Dimensions) is a processing chain allowing to analyze reflectivity data collected by the two Doppler radars operated by Météo-France in Reunion Island (Colorado radar located north of the island, and Piton Villers located center-east of the island).
This new chain, developed by the Tropical Cyclone Research Unit (CRC) of Météo-France, automatically unpacks and processes radar data archived on the BDM (Weather Database) to create a 3-D composite of reflectivity Colorado and Piton-Villers radar observations. Outputs are provided to the end user through in an interactive, web-based, visualization tool allowing to display reflectivity data in 3-dimensions.
3-D precipitation fields are calculated from raw PPIs of radar reflectivity over an area of 400 km x 400 km x 15 km, with horizontal resolution of 1km and 500m along the vertical. The calculation method is based upon a combination of Cressman and vertical interpolation schemes, which are particularly well suited to process radar data collected in tropical cyclones. The quality of the final product is assessed every hour through using an ensemble of image comparison and pattern recognition methods.
Eventually the 3D images are vectorised at each horizontal level in a universal, lightweight geographic file format (GeoJSON) and are stored in a PostGIS database to allow for exploitation with other tools and GIS standards. The perspectives at short and medium terms are the ability to remotely display numerical model simulation outputs (mainly Meso-NH and AROME), such as wind, precipitation and pressure fields, in an interactive and user-friendly way.

9

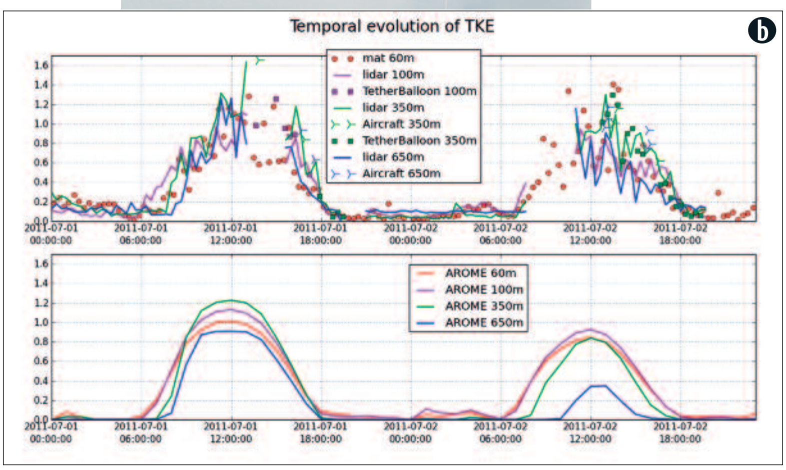
(a): R2-3D vertical cross-section of radar reflectivity in tropical cyclone BEJISA (2 Jan. 2014)
(b): Interactive 3D view of BEJISA reflectivities (only reflectivities higher than 35 dbZ are shown)

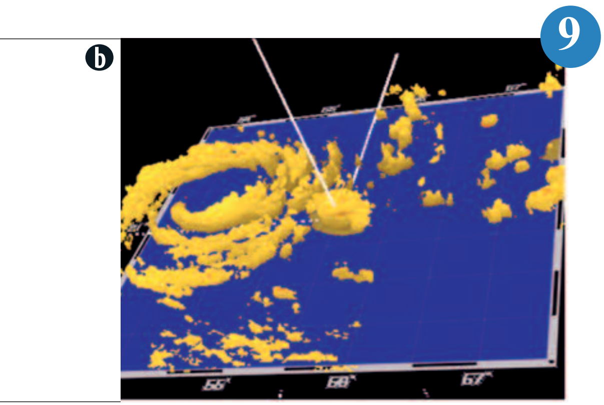




(a): Schematic representation of the diurnal cycle of convection in the upper troposphere (UT) above land (black solid line) and above ocean (grey solid curve) with the expected H_2O diurnal cycle in the UT above land (red solid line) and above ocean (blue solid curve). The green dotted lines represent the MLS satellite sampling local time.
(b): (Left, from top to bottom)
Mean relative difference between the daytime (13:30 Local Time, LT) and night-time (01:30 LT) MLS H2O measurements for December, January and February for 8 years (2005–2012) in the 25°N–25°S latitude band at 56, 100 and 177 hPa. The 192 (black solid line) and 195 K (black dashed line) temperature contours are represented at 100 hPa.
(Right)
Like as left but for June, July and August. The eight black boxes at 56 hPa represent the eight areas of study; namely, northern and southern tropical America, Africa, the maritime continent and western Pacific.

(a): The turbulence probe was built around a sonic anemometer and a coupled inertial-GPS motion sensor.
(b): Temporal evolution of turbulent kinetic energy ([m^2s^{-2}]) observed (high) and simulated (low) during two days of BLLAST experiment for 4 different altitudes.





Research and aeronautics

Research aircraft for meteorology, meteorological research in support to aviation
An instrumented aircraft is a unique exploration tool for sampling the atmosphere in-situ, follow weather phenomena while they are advected and analyse their evolution. Météo-France, in partnership with CNRS and CNES, operates 3 research aircraft in the framework of the "Unité Mixte" SAFIRE. Since 2000, Météo-France coordinates the European infrastructure network EUFAR of research aircraft for the environment and after 13 years of European Commission support, the objective of the consortium is to constitute a legal sustainable structure.
Météo-France also contributes actively to the definition of the new MET services to aviation within the framework of the R&D SESAR programme of the Single European Sky Initiative. After gathering user requirements, we are now testing the acceptability of these new services by the users and refining their content in large scale demonstration projects and validation exercises that constitute the last step before deployment.

1

Research aircraft for meteorology, meteorological research in support to aviation

1

Constituting a sustainable legal structure for EUFAR

The European Facility of Airborne Research (EUFAR) is a network and project, dedicated to supporting airborne environmental research by improving access to research infrastructures most suited to the needs of researchers across Europe, providing professional support and training, and enabling the sharing of expertise and harmonisation of research practices.
Since its creation in 2000, EUFAR has developed significantly in terms of its activities, size of network and budget. Following 3 previous contracts, the current project, EUFAR2 (2014-2018), has a budget of €6m funded by the European Commission, and facilitates Transnational Access to 18 research aircraft and 3 remote-sensing instruments through the 12 European-based operators who are part of EUFAR's current 24-partner consortium. The CNRM has been responsible for the overall coordination of the EUFAR projects, with the exception of the current project, whose coordination is shared with the Met Office.

A main focus of the current project is the establishment of a sustainable legal structure for EUFAR. This is critical to ensuring the continuity of EUFAR and securing, at the least, partial financial independence from the European Commission who has been funding the project since its start. After carefully examining different legal forms relevant for EUFAR, the arguments are strongly in favour of establishing an International non-profit Association under the Belgian law (AISBL). Together with the implementation of an Open Access scheme by means of resource-sharing to support the mobility of personnel across countries envisaged in 2016, such a sustainable structure would contribute substantially toward broadening the user base of existing airborne research facilities in Europe and mobilising additional resources for this end. In essence, this would cement EUFAR's position as the key portal for airborne research in Europe.

2

Contributions Météo-France to SESAR

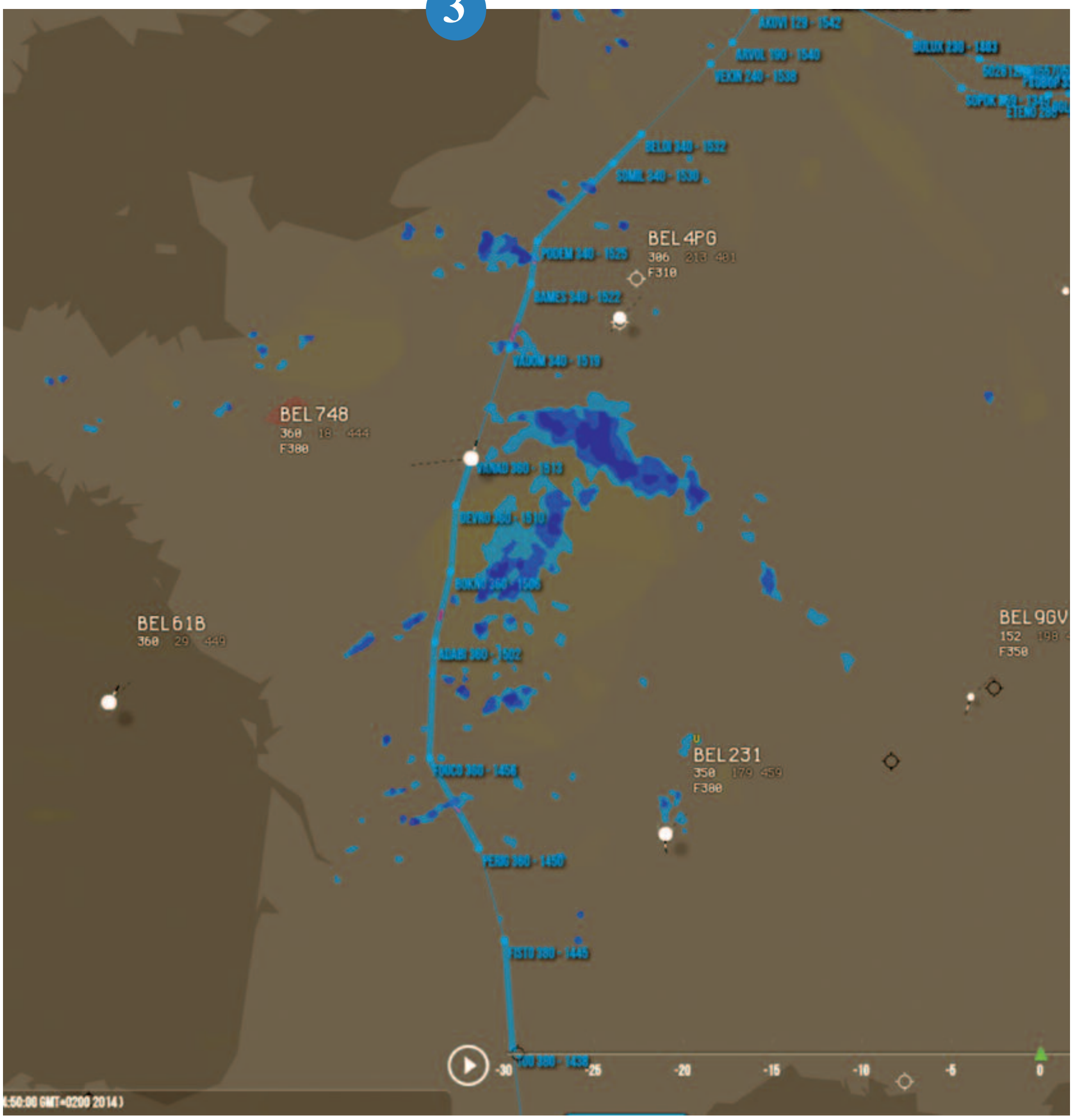
Besides European harmonization of the MET services to aviation with our German and British colleagues from DWD and the UKMO which constitutes the core of our contribution to SESAR in the WP11.2 project, two innovative services have been tested and their acceptability by the users has been evaluated.
The first one addresses the issue of MET forecast uncertainty integration in ATM decision support tools relying on ensemble MET forecast to mitigate the significant spatial and temporal variability of the uncertainty, in particular during adverse weather conditions. This activity is part of the upstream research project IMET "Investigation of the Optimal Approach for Future Trajectory Prediction Systems to Use METeorological Uncertainty Information" in collaboration with NLR for the ground segment and a SESAR validation project with the SABRE industry that develops trajectory prediction applications for the airlines.
The second one is focused on convection hazards for aviation for which the vertical dimension is crucial to pilots and controllers. As part of the TOPMET project, an innovative service for the observation of convection (ASPOC-3D) in support to tactical decision has been tested. Convection was very active in France in 2014 so that numerous interesting case studies have been performed to explore the most effective ways of using such information at the ground and on board. Further tests, extended to short term planning in support to the flow manager with innovative convection nowcasting services will be performed in 2015 as part of the TOPLINK project.

3

2

(a): Instrumentation in the BAe-146 research aircraft, operated by FAAM based in the UK, available for transnational access under the current EUFAR2 framework.
(b): Jean-Louis Brenguier, founder of the EUFAR network & former coordinator of previous EUFAR projects, next to a pod mounted on the ATR-42 operated by SAFIRE.

3



MET information (ASPOC3D) superimposed to aircraft trajectory and ATM (Air Traffic Management) information - Pilot position.
Copyright ©TOPMET 2014

Drones for the atmospheric research: the eyes in the sky

The current drone technology and their ability to fly unattended give interesting new possibilities for research in atmospheric sciences. Started in 2012, the project VOLTIGE aims at developing fleets of ultralight drones (‹2kg) for the study of the three-dimensional structure of fog. The project is conducted in collaboration with ENAC (provision of drones and their autonomous flight systems) and ENM (involvement of students). CNRM develops the scientific payloads (sensors and their acquisition systems). Tests have already been carried out on a helicopter base of the French army (Landes) and near Lannemezan where the University of Toulouse operates a site instrumented for atmospheric research. The final campaign shall take place in the fall of 2015.
Another parallel project called SKYSCANNER is supported by the regional agency RTRA-STAE. There again scientific observations are targeted with a fleet of drones, but the target this time is clouds. The project is conducted in collaboration with ENAC and Sup' Aero. CNRM shall define the observation strategy. The other partners have the objective to make it possible.
Last but not least, a big European project aimed at studying the impact on climate change of the interactions between aerosols and clouds has recently started. Called BACCHUS, it involves drones. Two major campaigns are planned for 2015. CNRM will operate drones equipped with sensors for the characterization of the thermodynamic state and the aerosol content of the atmosphere.
Ultralight drones are easy to operate and cheap. They are thus very good tools for introducing students to the experimental meteorology.

4

New meteorological information allows for optimised flight trajectories

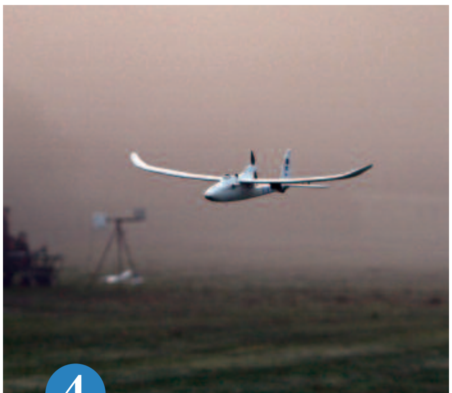
Météo-France, together with its European partners, has studied since November 2013 the use of a new generation of meteorological services for aviation. Thanks to the new meteorological services, pilots, flight dispatchers, and air traffic controllers will be able to share in real time a continuous overview of most weather events that could potentially impact the safety, efficiency, or even simply the comfort of the flight (lightning, convection, icing, turbulence, wind...) and their evolution in short and medium-term thanks to Ensemble forecasts up to 24 hours (refresh rate of 5 min for the first 3 hours and of 1 hour beyond). In turn, pilots will be able to better anticipate and handle such phenomena, and optimise their trajectory accordingly from take-off to landing.
Under the framework of SESAR, the technology pillar of the Single European Sky (SES) initiative, these new services underwent testing under real flight conditions in July and August 2014 as part of the demonstration programme called TOPMET. TOPMET involves experts from 4 European countries: Thales (project coordinator), Brussels Airlines, DSNA and 3 members of EUMETNET EIG: Météo-France, DWD and MET Office.
The TOPMET trials have validated the prerequisites of this new Collaborative Decision Making process, enabling the identification of the most relevant MET information for the various stakeholders, and providing guidance on how such information can be processed to better support the decisions of each stakeholder.

A new SESAR demonstration project, called TOPLINK, will take over from TOPMET in 2015, involving a larger panel of institutional and industrial partners: Thales, Airbus, Aéroport de Paris, DSNA, Croatia Control, Austro Control, Air France, Brussels Airlines, Air Corsica, Météo-France, Finnish Meteorological Institute and DWD. The observation will be supplemented with an immediate Ensemble forecast of convection risk over a period of 3 hours. New satellite communication systems between the ground and the cockpit will be deployed, enabling the transfer of updated meteorological information during the flight with the aim of better forecast of flight and arrival times, enhanced safety and improved comfort of the crew and passengers.

5

TOPMET pilot application.

5



4

The landing of the drone during a flight in a fog.

Appendix

2014 Scientific papers list

Papers published in peer-reviewed journals (impact factor > 1)

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Glossary

Organismes et Laboratoires

Organismes

ADEME	Agence de l'Environnement et de la Maîtrise de l'Energie
AIEA	Agence Internationale de l'Energie Atomique
ANELFA	Association Nationale d'Etude et de Lutte contre les Fléaux Atmosphériques (Association to Suppress Atmospheric Plagues)
ANR	Agence Nationale de la Recherche
BEC	Bureau d'Etudes et de Consultance
CDM	Centre Départemental de la Météorologie
CDMA	Cellule de développement Météo-Air
CEH	Centre for Ecology and Hydrology
CEMAGREF	CEntre national du Machinisme Agricole, du Génie Rural, des Eaux et Forêts (Institut national de Recherche en Sciences et Technologies pour l'Environnement et l'Agriculture)
CEN	Centre d'Etudes de la Neige
CEPMMT	Centre Européen pour les Prévisions Météorologiques à Moyen Terme
CERFACS	Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique
CMM	Centre de Météorologie Marine
CMRS	Centre Météorologique Régional Spécialisé
CMS	Centre de Météorologie Spatiale
CNES	Centre National d'Études Spatiales
CNP	Centre National de Prévision
DGA	Délégation générale pour l'armement
DGPR	Direction Générale de la Prévention des Risques
EALAT	Ecole de l'Aviation Légère de l'Armée de Terre
EASA	European Aviation Safety Agency
EEA	Agence Environnementale Européenne
ESA	European Space Agency
ETNA	Division Ecoulements Torrentiels, Neige et Avalanches du CEMAGREF
EUFAR	EUropean Facility for Airborne Research in Environmental and Geo-sciences
EUMETNET	EUropean METeorological NETwork
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAA	US Federal Aviation Agency
FAAM	Facility for Airborne Atmospheric Measurements (Royaume-Uni)
ICARE	International Conference on Airborne Research for the Environment
IFREMER	Institut Francais de Recherche pour l'Exploitation de la MER
INERIS	Institut National de l'Environnement et des Risques
INRIA	Institut National de Recherche en Informatique et en Automatique
INSU	Institut National des Sciences de l'Univers
IPEV	Institut Paul Emile Victor
IRD	Institut de Recherche pour le Développement
IRSTEA	Institut national de Recherche en Sciences et Technologies pour l'Environnement et l'Agriculture (anciennement CEMAGREF)
JMA	Japan Meteorological Agency
MEDDTL	Ministère de l'Ecologie, du Développement Durable, des Transports et du Logement
MERCATOR-OCEAN	Société Civile Française d'océanographie opérationnelle
MetOffice	United Kingdom Meteorological Office
MPI	Max Planck Institut
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NEC	Nippon Electric Company
NOAA	National Ocean and Atmosphere Administration
OACI	Organisation de l'Aviation Civile Internationale
OMM	Organisation Météorologique Mondiale
OMP	Observatoire Midi-Pyrénées
RSMC	Regional Specialized Meteorological Centre
RTRA-STAE	Réseau Thématique de Recherche Avancée - Sciences et Technologies pour l'Aéronautique et l'Espace
SCHAPI	French national hydrological service
SHOM	Hydrodynamic and Oceanic service of the French national Marine
SMHI	Swedish Meteorological and Hydrological Institute
UKMO	United Kingdom Meteorological Office
VAAC	Volcanic Ash Advisory Centre

Laboratories or R&D units

3SR	Laboratoire Sols – Solides – Structures – Rhéologie, UJF Grenoble/CNRS/Grenoble INP
CEREA	Centre d'Enseignement et de Recherche en Environnement Atmosphérique
CESBIO	Centre d'Etudes Spatiales de la BIOsphère
CNRM	Centre National de Recherches Météorologiques
CNRM-GAME	Groupe d'études de l'Atmosphère MÉtéorologique
CNRS	Centre National de Recherches Scientifiques
CRA	Centre de Recherches Atmosphériques
DSO	Direction des Systèmes d'Observation (Météo-France)
GAME	Groupe d'Etude de l'Atmosphère Météorologique
GSMA	Groupe de spectrométrie moléculaire et atmosphérique, UMR 7331 CNRS Université de Reims Champagne Ardennes
IFSTTAR	Institut Français des Sciences et Technologies des Transports, de l'Aménagement et des Réseaux
IGN	Institut Géographique National
IPSL	Institut Pierre Simon Laplace
LaMP	Laboratoire de Météorologie Physique
LATMOS	Laboratoire ATmosphères, Milieux, Observations Spatiales
LAVUE	Laboratoire Architecture, Ville, Urbanisme, Environnement
LCP	Laboratoire Chimie et Procédés
LEGI	Laboratoire des écoulements physiques et industriels
LGGE	Laboratoire de Glaciologie et de Géophysique de l'Environnement
LHSV	Laboratoire d'Hydraulique Saint-Venant
LIRIS	Laboratoire d'InfoRmatique en Image et Systèmes d'information
LISST	Laboratoire Interdisciplinaire Solidarités, Sociétés, Territoires
LMD	Laboratoire de Météorologie Dynamique
LOCEAN	Laboratoire d'Océanographie et du Climat : Expérimentations et Approches Numériques
LPCEE	Laboratoire de Physique et Chimie de l'Environnement et de l'Espace
LPED	Laboratoire Population Environnement Développement
LRA	Laboratoire de Recherche en Architecture
LSCE	Laboratoire des Sciences du Climat et de l'Environnement
SAFIRE	French group of Aircraft Equipped for Environmental Research - Unit of the CNRS, Meteo-France and the CNES which operates the 3 French research aircraft

National or international programs or projects

BACCHUS	Impact of Biogenic versus Anthropogenic emissions on Clouds and Climate: towards a Holistic UnderStanding
BAMED	BAlloons in the MEDiterranean
CHFP	Climate Historical Forecasting Project
CHROME	Coupling Hydro-meteorological Regional Multi-Ensemble
CIDEX	Calibration and Icing Detection EXperiment
CMIP	Coupled Model Intercomparaison Project
COPERNICUS	European Earth observation system http://www.copernicus.eu/pages-principales/services/climate-change/

CYPRIM	projet Cyclogénèse et précipitations intenses dans la zone méditerranéenne
ERA-CLIM	European Reanalysis of Global Climate Observations
ESURFMAR	Eumetnet SURFace MARine programme
EUREQUA	Evaluation mUltidisciplinaire et Requalification Environnementale des QUArtiers, projet financé par l'Agence Nationale pour la Recherche, ANR-2011-VILD-006. Partenaires : GAME, IFSTTAR, CEREA, LISST, LAVUE, LPED.
EURO4M	European reanalysis and observations for monitoring http://www.euro4m.eu/
GHRSST	International Group for High Resolution SST
GLOSCAL	GLobal Ocean Surface salinity CALibration and validation
HOMONIM	Historique Observation MOdélisation des Niveaux Marins
HyMeX	Hydrological cYcle in the Mediterranean EXperiment
IncREO	Increasing Resilience through Earth Observation
LEFE	programme national « Les Enveloppes Fluides et l'Environnement »
MACC	Monitoring Atmospheric Composition and Climate
METOP	METeorological Operational Polar satellites
PNRA	Programma Nazionale di Recerche in Antartide
QUANTIFY	Programme QUANTIFYing the climate impact of global and European transport systems
RHYTMME	Risques HYdro-météorologiques en Territoires de Montagnes et MEditerranéens
SCAMPEI	Scénarios Climatiques Adaptés aux Montagnes : Phénomènes extrêmes, Enneigement et Incertitudes - projet de l'ANR coordonné par le CNRM
SMOS	Soil Moisture and Ocean Salinity
Suomi-NPP	US program for meteorological polar orbiting satellites
THORPEX	THe Observing system Research and Predictability EXperiment
UERRA	Uncertainties in Ensembles of Regional Re-Analyses
USAP	United States Antarctic Program
VOLTIGE	Vecteur d'Observation de La Troposphère pour l'Investigation et la Gestion de l'Environnement
WCRP	World Climate Research Programme

Campaigns

AMMA	Analyses Multidisciplinaires de la Mousson Africaine
CORDEX	COordinated Regional climate Downscaling EXperiment
EUREQUA	Evaluation mUltidisciplinaire et Requalification Environnemental des QUArtiers
HAIC	High Altitude and Ice Crystals (www.haic.eu)
MEGAPOLI	Megacities : Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation
SMOSREX	Surface MOnitoring of the Soil Reservoir EXperiment

Other acronyms

AIRS	Atmospheric Infrared Sounder
ALADIN	Aire Limitée Adaptation Dynamique et développement InterNational
AMSR	Advanced Microwave Scanning Radiometer
AMSU	Advanced Microwave Sounding Unit
AMSU-A	Advanced Microwave Sounding Unit-A
AMSU-B	Advanced Microwave Sounding Unit-B
ANASYG	ANAlyse Synoptique Graphique
ANTILOPE	ANalyse par spaTIaLisation hOraire des PrEcipitations
ARAMIS	Application Radar A la Météorologie Infra-Synoptique
ARGO	Array for Real time Geostrophic Oceanography
AROME	Application of Research to Operations at Mesoscale
AROME-COMB	AROME - COMBinaison
AROME-PERTOBS	AROME (OBServations PERTurbées aléatoirement)
AROME-WMED	AROME configuration over the Western Mediterranean region
ARPEGE	Action de Recherche Petite Échelle Grande Échelle
AS	Adaptations Statistiques
ASAR	Advanced Synthetic Arperture Radar
ASCAT	Advanced SCATterometer
ASTEX	Atlantic Stratocumulus Transition EXperiment
ATM	Air Traffic Management
ATMS	Advanced Technology Microwave Sounder
AVHRR	Advanced Very High Resolution Radiometer
BAS	British Antarctic Survey
BLPB	Boundary Layer Pressurized Balloon
BPCL	Ballon Pressurisé de Couche Limite
CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization
CALIPSO	Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CANARI	Code d'Analyse Nécessaire à ARPEGE pour ses Rejets et son Initialisation
CAPE	Convective Available Potential Energy
CAPRICORNE	CAractéristiques PRIncipales de la COuveRture NuageusE
CARIBOU	Cartographie de l'Analyse du RIsque de Brume et de brOUillard
CAROLS	Combined Airborne Radio-instruments for Ocean and Land Studies
Cb	Cumulonimbus
CFMIP	Cloud Feedback Intercomparison Project
CFOSAT	Chinese-French SATellite
ChArMEx	Chemistry-Aerosol Mediterranean Experiment
CISMF	Centre Inter-armées de Soutien Météorologique aux Forces
CLAS	Couches Limites Atmosphériques Stables
CMC	Cellule Météorologique de Crise
CMIP5	5th phase of the Coupled Model Inter-comparison Project
CNRM-CM5	Version 5 du Modèle de Climat du CNRM
CNRM-RCSM	Regional Climate System Model
COP	Objectives and Performance Contract
COPAL	COmmunity heavy-PAyload Long endurance instrumented aircraft for tropospheric research in environmental and geo-sciences
CPR	Cloud Profiling Radar
CrIS	Cross-track Infra-Red Sounder
CROCUS	Modèle de simulation numérique du manteau neigeux développé par Météo-France.
DCT	Diffraction Contrast Tomography
DEM	Discrete Element Method
DMT	Dropplet Measurement Technologies
DP	Direction de la Production
DPrévi	Direction de la Prévision
DSI	Direction des Systèmes d'Information (Météo-France)
DSNA	Direction des Services de la Navigation Aérienne
ECMWF	European Centre for Medium-range Weather Forecasts
ECOCLIMAP	Base de données de paramètres de surface
EGEE	Etude du golfe de GuinEE
ENVISAT	ENVIronmental SATellite
ERA	European Re-Analysis
ESRF	European Synchrotron Radiation Facility
EUCLIPSE	European Union Cloud Intercomparison, Process Study & Evaluation
FAB	Fonctionnal Aerospace Block
FABEC	Functional Airspace Block Europe Central
FAR	Fausse AleRte
FSO	Forecast Sensitivity to Observations
GELATO	Global Experimental Leads and ice for ATmosphere and Ocean
GEV	Generalized extreme value (GEV) distribution
GIEC	Groupe Intergouvernemental d'experts sur l'Evolution du Climat
GMAP	Groupe de Modélisation et d'Assimilation pour la Prévision
GMEI	Experimental and Instrumental Meteorology Group
GMES	Global Monitoring for Environment and Security
GPP	Gross Primary Production
GPS	Global Positionning System
High IWC	High Ice Water Content
HIRLAM	HIgh Resolution Limited Area Model
HISCRTM	HIgh Spectral resolution Cloudy-sky Radiative Transfer Model
HSS	Measurement of improvement of the forecast
HYCOM	HYbrid Coordinate Ocean Model
IAGOS	In-service Aircraft for Global Observing System
IASI	Infrared Atmospheric Sounding Interferometer
IAU	Incremental analysis update
IFS	Integrated Forecasting System
IIR	Infrared Imaging Radiometer
ISBA	Interactions Soil Biosphere Atmosphere
ISBA-A-gs	Interactions Soil-Biosphere-Atmosphere model, including photosynthesis and vegetation growth
ISBA - ES	Numerical model developped at CNRM to represent soil-vegetation evolution, with a refined snow pack tretament
ISFC	Indice de Segmentation de la Composante de Fourier
ISIS	Algorithme de suivi automatique des systèmes identifiés à partir de l'imagerie infra-rouge de Météosat
LAI	Leaf Area Index
Land-SAF	LAND Satellite Application Facilities
LCCS	Land Cover Classification System

LES	Large Eddy Simulation model
LISA	LIdar SAtellite
MEDUP	MEDiterranean intense events : Uncertainties and Propagation on environment
Megha-Tropiques	Satellite fanco-indien dédié à l'étude du cycle de l'eau et des échanges d'énergie dans la zone tropicale
MEPRA	Modèle Expert de Prévision du Risque d'Avalanche (modélisation)
MERSEA	Marine EnviRonment and Security for the European Area
MESCAN	Combinaison de MESAN (nom du système suédois) et de CANARI
MESO-NH	Modèle à MESO-échelle Non Hydrostatisque
MFWAM	Météo-France WAve Model
MHS	Microwave Humidity Sounder
MISR	Multi-angle Imaging SpectroRadiometer
MNPCA	Microphysique des Nuages et de Physico-Chimie de l'Atmosphère
MOCAGE	MOdélisation de la Chimie Atmosphérique de Grande Echelle (modélisation)
MODCOU	MODèle hydrologique COUplé surface-souterrain.
MODIS	MODerate-resolution Imaging Spectro-radiometer (instrument)
MoMa	Méthodes Mathématiques pour le couplage modèles et données dans les systèmes non-linéaires stochastiques à grand nombre de degrés de liberté
MOTHY	French Oil Spill drift Model
MRR	Micro Rain Radars
MSG	METEOSAT Second Generation
NAO	North Atlantic Oscillation
NEMO	Nucleus for European Modelling of Ocean
NEMO-WMED36	NEMO configuration of the Western Mediterranean Sea
NSF	Norges StandardiseringsForbund
NWP	Numerical Weather Prediction
OPIC	Objets pour la Prévision Immédiate de la Convection
ORACLE	Opportunités et Risques pour les Agro-ecosystèmes et les forêts en réponse aux changements CLimatiquE, socio-économiques et politiques en France
ORCHIDEE	ORganizing Carbon and Hydrology in Dynamic EcosystEms
OSCAT	OCEANSAT-2 Scatterometer
OSTIA	Operational Sea surface Temperature sea Ice Analysis
OTICE	Organisation du Traité d'Interdiction Complète des Essais nucléaires
PALM	Projet d'Assimilation par Logiciel Multi-méthodes
PEARP	Prévision d'Ensemble ARPège
PI	Prévision Immédiate
PN	Prévision Numérique
POD	PrObabilité de Détection
POI	Période d'Observation Intensive
PRESYG	PREvision Synoptique Graphique
Prev'Air	Plateforme nationale de la qualité de l'air
PREVIBOSS	PREvisibilité à courte échéance de la variabilité de la VIsibilité dans le cycle de vie du Brouillard, à partir de données d'Observation Sol et Satellite
Prévi-Prob	Projet sur les prévisions probabilistes
PSI	Pollutant Standard Index
PSR	Plan Submersions Rapides
PVM	Particulate Volume Monitor
PVs	Moist-air Potential Vorticity
RADOME	Réseau d'Acquisition de Données d'Observations Météorologiques Etendu
RCP8.5	8.5 W/m² Representative Concentration Pathway corresponding to a 8.5 W/m² radiative forcing at the end of the 21st century compared to preindustrial climate
RHI	Range Height Indicator (coupe verticale)
ROC	Relative Operating Characteristic curve
RTTOV	Radiative Transfer for TOVS
SAFNWP	Satellite Application Facility for Numerical Weather Prediction
SAF OSI	Satellite Application Facility for Ocean and Sea Ice
SAFRAN	Système d'Analyse Fournissant des Renseignements Atmosphériques pour la Neige - Set of reconstructed data from observations over France for 1958 to present at high horizontal, vertical and temporal resolution
SAPHIR	Sondeur Atmosphérique du Profil d'Humidité Intertropicale par Radiométrie
SARA	Spectroscopy by Amplified Resonant Absorption
SATOB	Satellite Observation
SCM	Single-Column Model
SESAR	Single European Sky ATM Research
SEVIRI	Spinning Enhanced Visible and Infra-Red Imager
SFRI	Système Français de Recherche et d'Innovation
S2M	SAFRAN - SURFEX/ISBA-Crocus – MEPRA
SIM	SAFRAN ISBA MODCOU
SIRTA	Site Instrumental de Recherche par Télédétection Atmosphérique
SMOSMANIA	Soil Moisture Observing System – Meteorological Automatic Network Integrated Application
SMT	Système Mondial de Télécommunications
SOERE/GLACIOCLIM	Système d'Observation et d'Expérimentation sur le long terme pour la Recherche en Environnement : "Les GLACIers, un Observatoire du CLIMat".
SOP	Special Observing Period
SPIRIT	SPectromètre Infra-Rouge In situ Toute altitude
SSMI/S	Special Sounder Microwave Imager/Sounder
SURFEX	code de SURFace Externalisé (externalized land surface parameterization)
SVP	Surface Velocity Program
SWI	Soil Wetness Index
SWIM	Surface Wave Investigation and Monitoring
SYMPOSIUM	SYstème Météorologique de Prévision Orienté Services, Intéressant des Usagers Multiples - split of French territory into climate heterogeneous areas, the size of which is to 10 to 30 km
TCU	Towering Cumulus
TEB	Town Energy Budget
TRIP	Total Runoff Integrating Pathways
TSM	Températures de Surface de la Mer
UHF	Ultra-Haute Fréquence
UNIBAS	Modèle de précipitations
VARPACK	Current tool for diagnostic analysis in Meteo-France
VHF	Very High Frequency
WWLLN	World Wide Lightning Location Network

CNRM: Management structure

31.12.2014

Head: **Philippe Bougeault**

Deputy Head - Toulouse: **Marc Pontaud**
Scientific deputy Head - Toulouse: **Philippe Dandin**
Deputy Head - Saint-Mandé: **Jacques Parent de Chatelet**

SAFIRE: French group of Aircraft Equipped for Environmental Research

METEOROLOGICAL AVIATION CENTRE — CAM - Toulouse
Centre Head: **Jean-Christophe Canonici**

SNOW RESEARCH CENTRE — CEN - Grenoble
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Centre Head: **Jean Rolland**

MODELLING FOR ASSIMILATION AND FORECASTING GROUP — GMAP - Toulouse
Group Head: **Alain Joly**

EXPERIMENTAL AND INSTRUMENTAL METEOROLOGY GROUP — GMEI - Toulouse
Group Head: **Alain Dabas**

CLIMATE AND LARGE SCALE MODELLING GROUP — GMGEC - Toulouse
Group Head: **Serge Planton**

MESO-SCALE MODELLING GROUP — GMME - Toulouse
Group Head: **Véronique Ducrocq**

INTERNAL KNOWLEDGE TRANSFERS GROUP — RETIC - Toulouse
Group Head: **Dominique Giard**

GENERAL SERVICES — SC/Toulouse
Head: **Marc Pontaud**

Nota:
The GAME is the Joint Research Unit between Météo-France and CNRS. Groups on deep blue are fully included in GAME; groups on light blue are partially included in GAME.

SAFIRE is a joint unit between Météo-France, CNRS and CNES.

Météo-France
73, avenue de Paris
94165 Saint-Mandé Cedex
Phone: +33 (0) 1 77 94 77 94
Fax: + 33 (0) 1 77 94 70 05
www.meteofrance.com

Centre National
de Recherches Météorologiques
Groupe d'étude
de l'Atmosphère Météorologique
42, avenue Gaspard Coriolis
31057 Toulouse Cedex 1 France
Phone: +33 (0) 5 61 07 93 70
Fax: + 33 (0) 5 60 07 96 00
http://www.cnrm-game.fr
Mail: contact@cnrm.meteo.fr

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