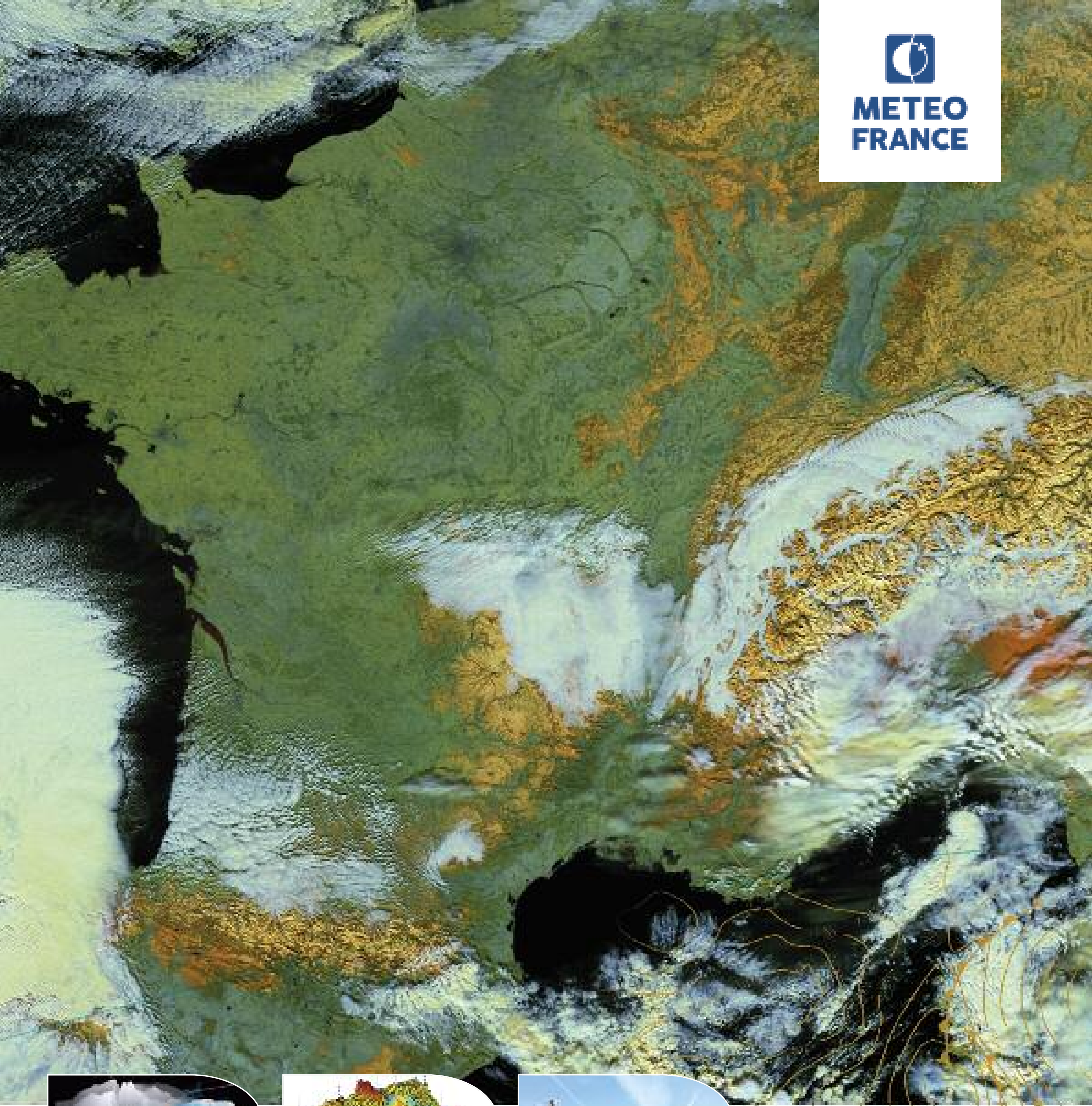

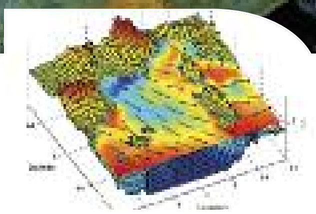


Research **Report** 2015

Research Report 2015

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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 essential for improving constantly the quality of our 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.

The main result for 2015 was the operational implementation of several upgrades of our weather prediction systems, as planned in our 2012-2016 Contract with the Government. The convective scale prediction system AROME is now operated at a horizontal resolution of 1.3km, twice the previous resolution. The vertical resolution was also improved, going from 60 to 90 levels. These changes have improved the realism of the atmospheric simulations and are very well received by our forecasters. The data assimilation cycle of AROME remains a sequential-variational 3D algorithm, but the frequency of the analyses has increased from 8 to 24 times per day, thereby tripling the number of data actually used for the forecasts. Concerning observations, more microwave satellite data, surface data, radiosondes, and above all more radar data are used. Another important development is the initial operational implementation of a new suite producing an analysis and a short forecast (6h) every hour, with exactly the same configuration as the AROME system. This is called the "Nowcasting-AROME", and is the first of the new systems that will be produced according to the Contract with the Government. The high resolution and ensemble version of the global prediction system ARPEGE have been also significantly upgraded.

In the domain of Climate, our scientists have heavily engaged in 2015 in activities around the Paris-Climat

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conference (COP21), with several large scientific conferences and multiple public presentations. Several interesting new results regarding detection-attribution of extreme events and Earth System processes have been published.
Important agreements with the organizations designated by the European Commission to run the Copernicus Services have been signed. Due to the quality of its research activities, Météo-France is thereby consolidating its role as a key actor of the four Copernicus Services (Atmosphere, Marine, Climate, Land).
Regarding upstream research, an important achievement was the field campaign in the valley of Passy (Alps), to study the characteristics of the winter stable atmospheric boundary layer, which has a strong impact on air quality.
Regarding research infrastructures, consultation is in progress with our partners to identify the best strategy to replace the Falcon-20 research airplane, coming soon to the end of its life. A complete evaluation of various scenarios will be presented to funding organizations in 2016. The creation of an "Association Internationale Sans But Lucratif" grouping the main European operators of research airplanes will be effective in 2016. The development of unmanned airborne systems for environmental research is also actively pursued.
In 2015, we introduced several important changes in the Centre National de Recherches Météorologiques. Many activities have been transferred to other services of Météo-France, and the research center will from now on concentrate on its research mission. The cooperation agreement with CNRS, the main French science agency, has been renewed, and our common unit will from 2016 be called simply "CNRM".
This is the last foreword I sign as Director of Research. I take pleasure in thanking my colleagues of Météo-France who have helped me for this mission since 2009, and I wish best of luck to my successor, Marc Pontaud.

Philippe Bougeault
Director, Centre National de Recherches Météorologiques

Numerical weather prediction and data assimilations

A significant part of the numerical weather prediction (NWP) deliverables committed by the contract between Météo-France and government has become operationally available. They are not only available to the production departments of Météo-France, but, as a result of the public data policy implemented soon after these upgrades, they are also directly available to all, through several open visualization sites on the Internet or even as numerical data. Most of the existing NWP applications have undergone very significant changes, in two steps, in April and in December 2015.

The convective-permitting scale AROME system is now running with a horizontal resolution of 1.3 km, namely a halving relative to the previous version. Vertical resolution has also been increased, with a change from 60 to 90 levels combined to concentrating them further in the lower atmosphere. Such changes improve the realisticness of the model atmosphere, enable more processes and new scales to be handled explicitly. However, improving forecasts is a somewhat different question, it also requires that the link between the actual atmosphere and the model initial state be improved as well. Two of the most significant changes in this area are a move towards a more continuous data assimilation process and a change in the spatial density of radar data used in the assimilation. The AROME variational data assimilation cycle remains a 3D sequential process, but the frequency of the analyses steps has been increased from 8 to 24 per day, thus potentially trebling the number of data used. On the observation side, more satellite microwave data, much more surface and radio-sounding data are used. But a change implemented in December has to be singled out, the radar data spatial density has been increased up to fourfold, the spatial thinning having been changed from 16 km to 8 km. At the same time, two effects of the radiation-orography interaction have been introduced into AROME. Downward radiative fluxes from the atmosphere are now modulated by the local surface slope, and the direct solar flux at a given point is now intercepted by a realistic horizon or skyline, namely any distant mountainous other point in the sun direction. This is a noticeable change insofar as this kind of very local effect was, up to now, considered to be typical of what human forecasters could account for, knowing they were tuning a forecast for an area on this or that side of a valley. The figure illustrates capabilities but also limitations of how the AROME system performs in real extreme situations. Another important achievement, shared with the Nowcasting operations team and several operations departments, has been the introduction in the operational suite of an hourly analysis plus 6h short-range AROME forecast, with the same 1.3 km configuration. This is called AROME-PI (for “nowcasting AROME”) and it is the first of the new systems that are to be introduced as part of the current contract. This introduction has been achieved using a completely new scripting framework, based on the Python language. This technical development is meant to ease the transition from experimental to operational frameworks.

Both the ensemble and deterministic versions of the variable resolution global system ARPEGE have also been seriously upgraded. It is not possible to go into details, the main highlights are improved vertical and horizontal resolutions (the ensemble reaches 10 km horizontal resolution over Europe), novel use of satellite data, such as world first assimilation of microwave SAPHIR observations from the Indian-French Megha-Tropic platform. Another key change has been to increase the size of the pioneering 4D variational ensemble data assimilation from 6 to 25 members, that provides weather-dependent background error statistics to the reference 4D variational assimilation. This also benefits the ARPEGE ensemble, which is also the first global operational system to use a new representation of atmospheric convection further described below.

All these visible changes are grounded into the less visible but nonetheless vital continuous evolution of the underlying NWP computer code. This code is shared and co-developed with ECMWF as well as with many European and North-African national weather services. This international cooperation is both exemplar and essential in order to all participants to benefit from a state of the art NWP highly integrated and yet versatile system with limited resources.

Along these operational and technical activities, the NWP group has also achieved research goals. Some of these are illustrated below. To mention a few others, prototypes of new data assimilation algorithms have been built and are now experimented with. They still belong to the variational family, but they are much more heavily based on ensembles. On the side of physical processes, the international study of the new GABLS 4 Concordia stable boundary layer framework has been launched. The important impact of vertical resolution in the ability to simulate 4D fog life-cycle has been documented. Two Horizon 2020 European projects are beginning, one involving a mesoscale surface reanalysis, another one focused on adapting codes and core algorithms to future computing architectures. In that latter area, two new core numerical schemes are being tested or designed: an alternative “horizontally explicit vertically implicit” scheme for AROME, should the current spectral method become unaffordable and a high-precision but non-spectral scheme for a global model.

1

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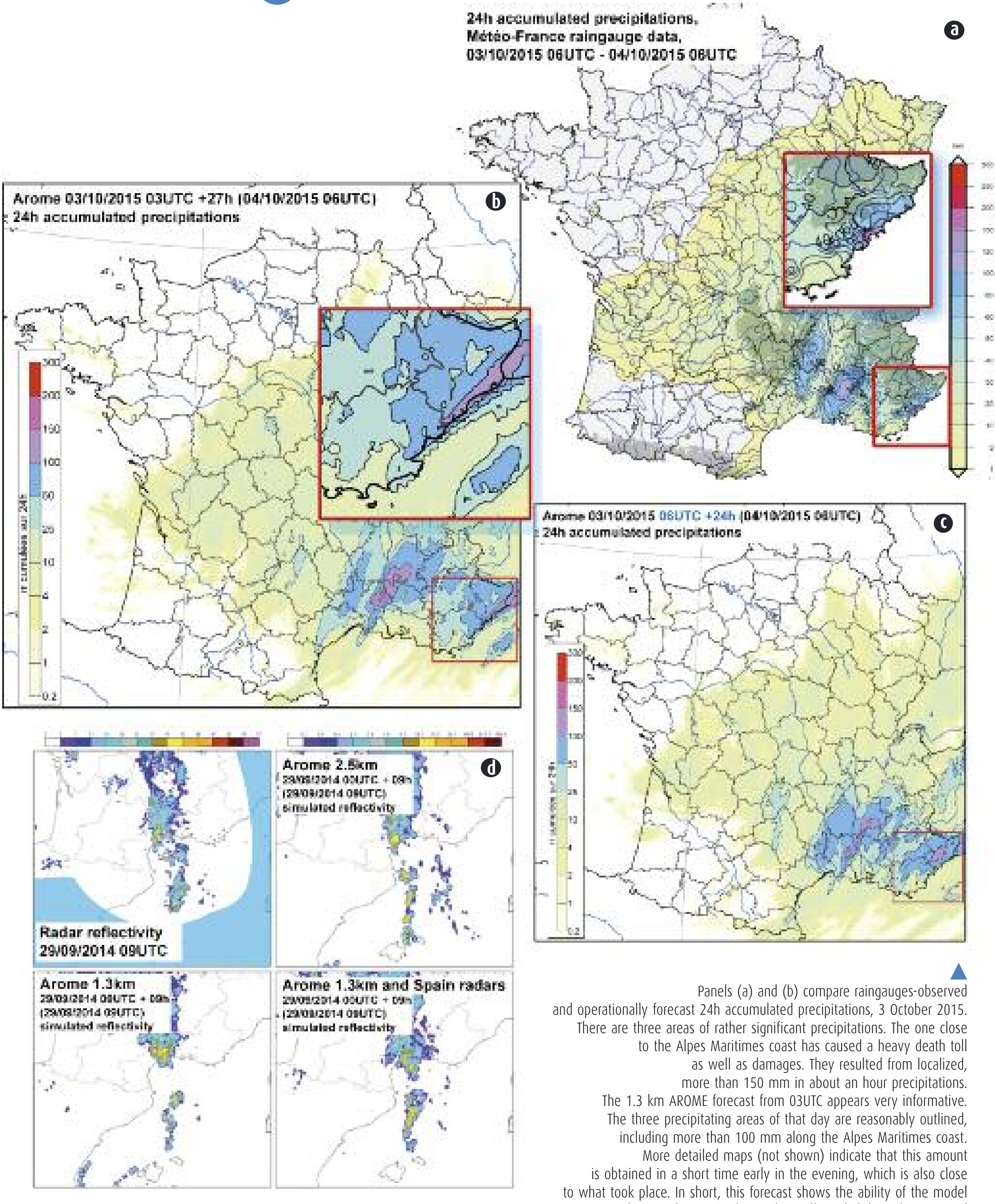

Panels (a) and (b) compare raingauges-observed and operationally forecast 24h accumulated precipitations, 3 October 2015. There are three areas of rather significant precipitations. The one close to the Alpes Maritimes coast has caused a heavy death toll as well as damages. They resulted from localized, more than 150 mm in about an hour precipitations. The 1.3 km AROME forecast from 03UTC appears very informative. The three precipitating areas of that day are reasonably outlined, including more than 100 mm along the Alpes Maritimes coast. More detailed maps (not shown) indicate that this amount is obtained in a short time early in the evening, which is also close to what took place. In short, this forecast shows the ability of the model to represent the actual event with a realistic albeit slightly underestimated intensity. However, this forecast appeared to be the best only after the fact: it was not so easy to use in real time, because it is part of a series that is not fully consistent in time as shown by panel (c), the 06UTC forecast. One explanation is the likely low predictability of that precipitating system but highlighted by an insufficient control of AROME by observations, especially over the Mediterranean. This is further illustrated by panel (d), on a different case of September 2014, when the Montpellier area has been flooded. The best representation of the cloud system near the coast and over the Mediterranean area combines the higher spatial resolution and the use of extra radar data from Spain. These data have been especially provided by the Spanish weather service for this case study, but they are not available operationally for the time being.

Development of a convective-scale ensemble prediction system

In 2016, the increase of computing resources will be used to put into operation a new numerical weather prediction system: the AROME Ensemble Prediction (called PEARO). The configuration of this system, currently developed at CNRM, uses 12 perturbed forecasts of the AROME-France model with a 2,5km horizontal resolution and 90 vertical levels, coupled with the ARPEGE ensemble prediction system (PEARP). Each member is perturbed in order to represent the main sources of uncertainty, including the error on initial conditions, surface conditions, lateral boundary conditions and the model. The PEARO system will run twice a day, at 09 and 21 UTC, to provide forecasts up to a 45h range.
Objective verifications of PEARO, performed over several months of simulation, indicate a significant improvement over PEARP, especially regarding precipitation and 10-meter wind speed. The PEARO system has also been used and evaluated by forecasters during two forecast exercises in October 2014 and June 2015.
The preparation to the future operational utilisation of PEARO has continued during fall 2015, during which a pre-operational run of PEARO has been run in near real time once per day, in order to organize weekly training sessions on recent past events. These exercises offered the possibility to examine the behaviour of PEARO on a wide range of situations, among which several cases of strong winds, fog and heavy precipitation. They also contributed to more accurately define work methods, as well as relevant parameters and diagnoses, and appropriate visualisation tools necessary to fully make use of ensemble forecasts.

2

A new convection scheme for numerical weather and climate prediction of showers and storms

A new convection scheme called PCMT (Prognostic Clouds, Microphysics and Transport) has been developed. More sophistication was introduced in microphysics; the scheme takes into account dry layers below condensation level, improving the convective triggering, with positive impact on convective diurnal cycle prediction. The scheme can be run with physical options, such as the choice of convective closure (intensity) or lateral cloud entrainment, to serve as a research test-bed for new ideas in modelling convection. This scheme is part of the NWP (Numerical Weather Prediction) and GCM (Global Climate Model) ARPEGE model.

3

Ensemble Prediction for Mediterranean flash floods

Very fast and devastating floods often affect the Mediterranean, especially in the fall season. Those so-called “flash-floods” are caused by heavy rainfall events both location and intensity of which are difficult to forecast. Moreover the modelling of Mediterranean rivers discharge also suffers from uncertainty due to highly non linear reactions.
A hydro-meteorological integrated approach is developed at CNRM for flash floods modelling and forecasting purposes. The ISBA-TOP coupled system is designed for fast response river simulations. The use of quantitative precipitation forecasts from the kilometric-scale atmospheric model AROME to drive ISBA-TOP allows Mediterranean rivers discharges forecasting.
But uncertainty still affects those models outputs even if they are continuously improved. The uncertainty on rainfall forecasts can be sampled thanks to the AROME Ensemble Prediction System and its about ten of rainfall scenarios with the same probability. Each scenario is modified introducing a perturbation based on climatology of rainfall forecasts errors. The obtained ensemble, which has more members that the original AROME EPS, is used to drive ISBA-TOP so as to produce a discharge ensemble forecast.
The current works aim at considering other sources of uncertainty: the uncomplete knowledge of initial soil moisture and the hydrological modelling. The hydro-dynamical parameters of the ISBA-TOP system that has a high impact on discharge simulations has been identified and it has been proved that their impact depends also on the initial soil moisture.
The next step is to consider those three sources of uncertainty together so as to build a complete hydro-meteorological ensemble prediction system.

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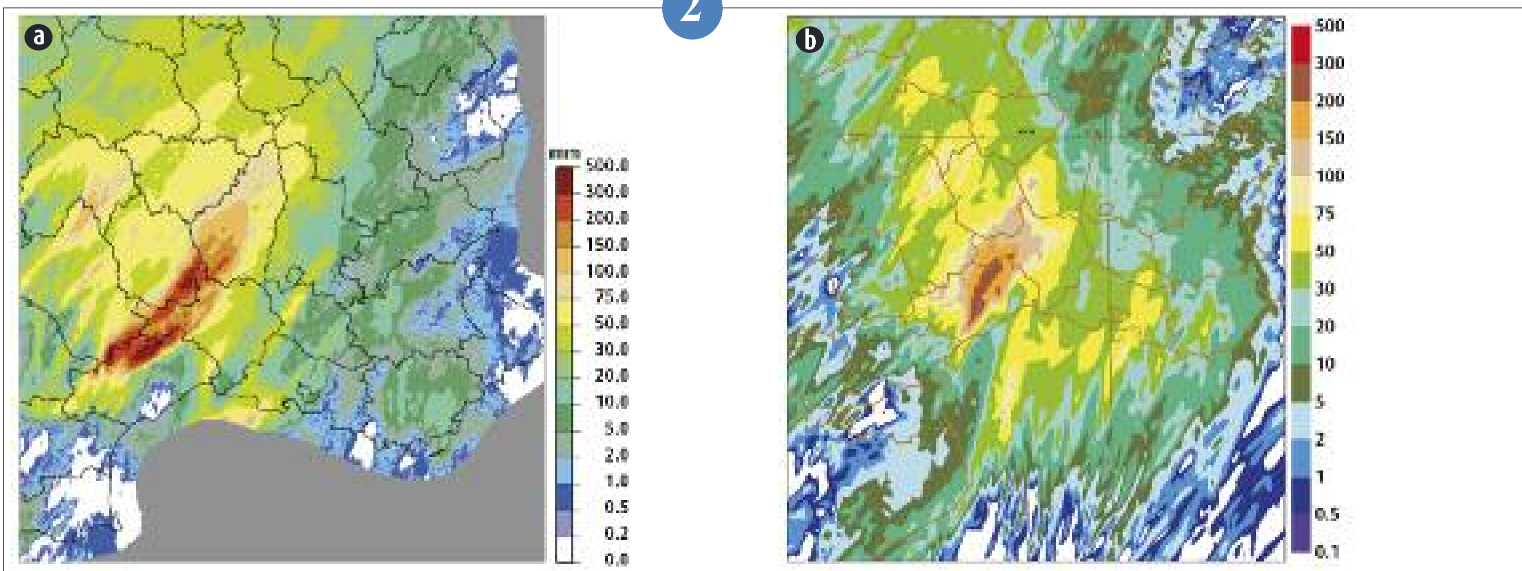
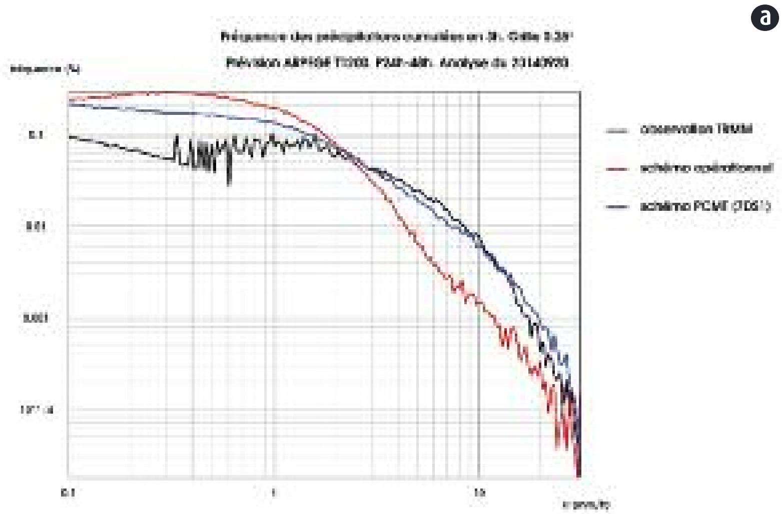
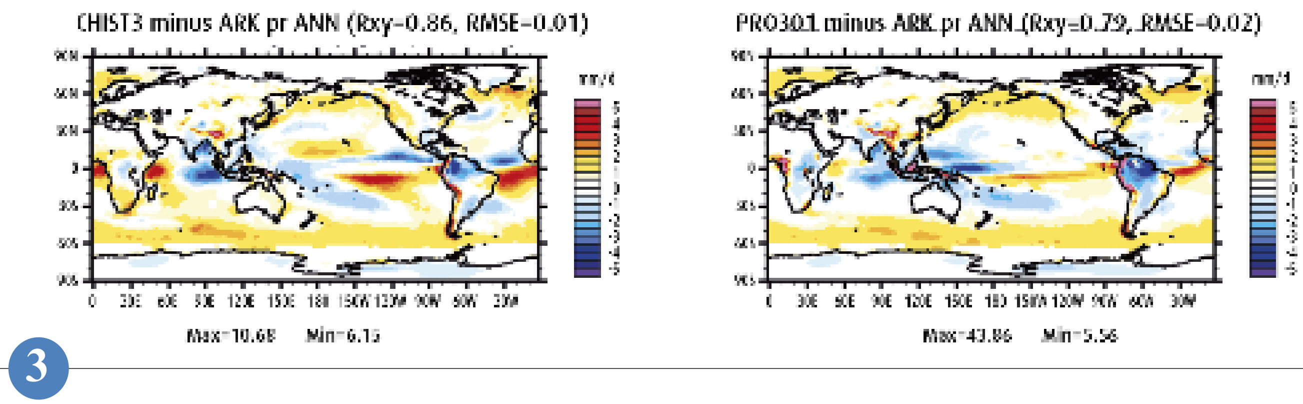


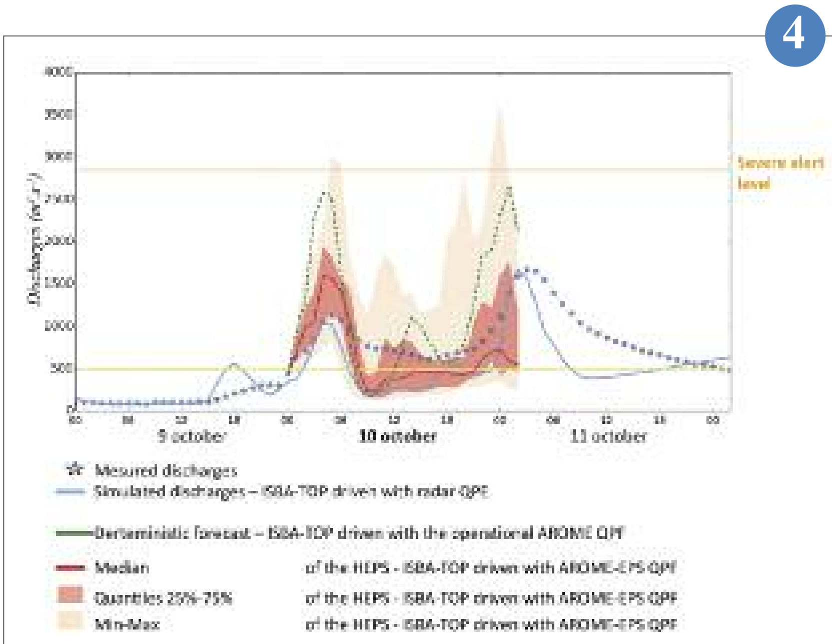


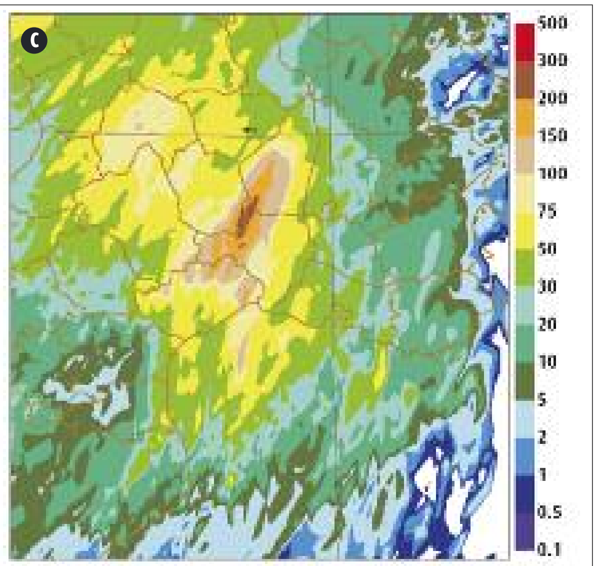
Comparison of observed and predicted PDFs of precipitation
The observed PDF over the area 60°S-60°N, 180°W-180°E, from drizzle (0.1 mm/h) to heavy rain (> 10 mm/h), can be compared to predicted precipitation PDFs: the new scheme (blue) prediction is more realistic than that of the control scheme (red): less light precipitation, more heavy precipitation, thus closer to observed PDF.

Annual precipitation biases, as simulated by the ARPEGE-Climate model, using old physics (above) and PCMT physics (below)
Biases are computed with respect to Xie and Arkin (1997) climatology.
The spatial extent of positive biases, around ITCZ (Inter Tropical Convergence Zone) is significantly reduced in using the PCMT scheme.



Ensemble forecasts of the Ardèche river discharge at Vallon Pont d'Arc valid for 10 October 2014 obtained with ISBA-TOP driven by AROME rainfall forecast (dashed green line) and by AROME EPS forecasts (shaded areas). The discharge forecasts can be compared to discharge observations (stars) and to discharge simulation obtained driving ISBA-TOP with rainfall observations (solid blue line).
The "severe alert threshold" for this river (from the operational hydrological service) is indicated as an orange line.





24h-accumulated precipitation, valid on 13 September 2015 at 03 UTC:
(a) observations, (b) AROME deterministic forecast from 12 September at 00 UTC
and (c) quantile 90% of the AROME ensemble prediction system from 11 September at 21 UTC.

Some AROME models for the oversea territories

Faced with extreme meteorological events, counties and overseas territorial collectivities must have at their disposal the very best weather predictions possible to ensure the safety of the people and of properties.
For many years now, Numerical Weather Prediction systems are dedicated to tropical areas. 2015 saw a major improvement with the use of the AROME model.
The most obvious gain comes from the increase in the vertical resolution from 8 to 2.5 km which better renders the complex orography of the volcanic island (see figures) and locally related effects. AROME, as a model, can explicitly solve the formation of the biggest convective clouds which signally improves forecasts of heavy precipitations, a common occurrence in these regions. Tropical Cyclone prediction also benefits from the increase in both horizontal and vertical resolutions, and also of better physical parametrisations.
For every forecast, these AROME models for oversea use as initial conditions the analysis of the ECMWF model. For the future, to improve these initial conditions, some of these models could use the own data assimilation cycles with the addition of local radars. The coupling ocean/atmosphere may be another way of improvement, which enables modelling their mutual interactions during a forecast. Modelling the ocean cooling in the cyclone wake and its retroaction on the atmosphere would thus be possible.

5

Radar assimilation at higher density in the AROME model at convective scale

Through the resolution increase of the AROME model, additional smaller scale meteorological features can be simulated, and also progressively analyzed. The updated version of the AROME model with a 1.3 km horizontal resolution allows to consider the assimilation of radar data at higher density. However, the assimilation of radar observations in the AROME model at 2.5 km resolution showed that their horizontal density can not be less than 15 km, in order to avoid observation error correlations induced by the differences between the scales of real precipitating features and the resolved model scales.
In agreement with a number of diagnostics of the assimilation system, it became possible to consider a radar density at 8 km after tuning some parameters from the reflectivity inversion and also the observation error of radial Doppler winds.

The clear positive impact of the radar high-density has been shown, in particular by an improvement of the precipitating forecast scores up to 18 hours. Such improvement of the score « BSS » for the 6-hour accumulation, computed against the quantitative precipitation estimation ANTILOPE is displayed in Figure a.
The triggering of some convective cells, hardly simulated with the AROME system at 2.5 km resolution, have been described with this new configuration. It is illustrated by a convective case on the 19th September 2014 over the Mediterranean (Figure b) associated to the development of a strong super-cell that reached the city of Toulon the following morning. With the high-density radar data, the convection is triggered at the correct location, even if the model fails to reproduce both the observed extent and intensity.

6

6

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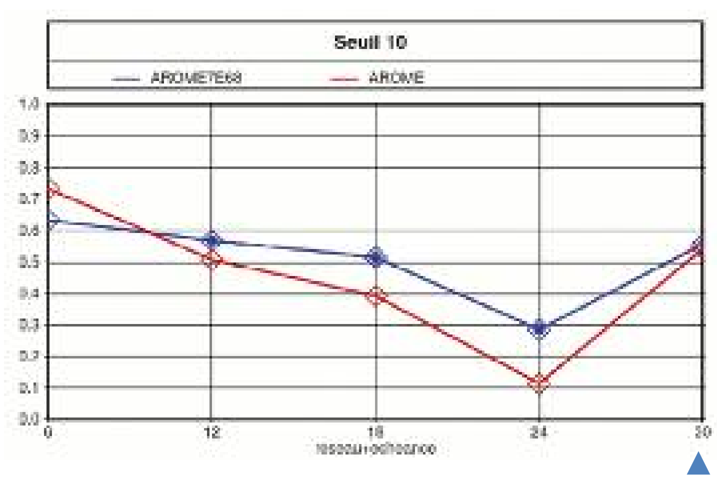
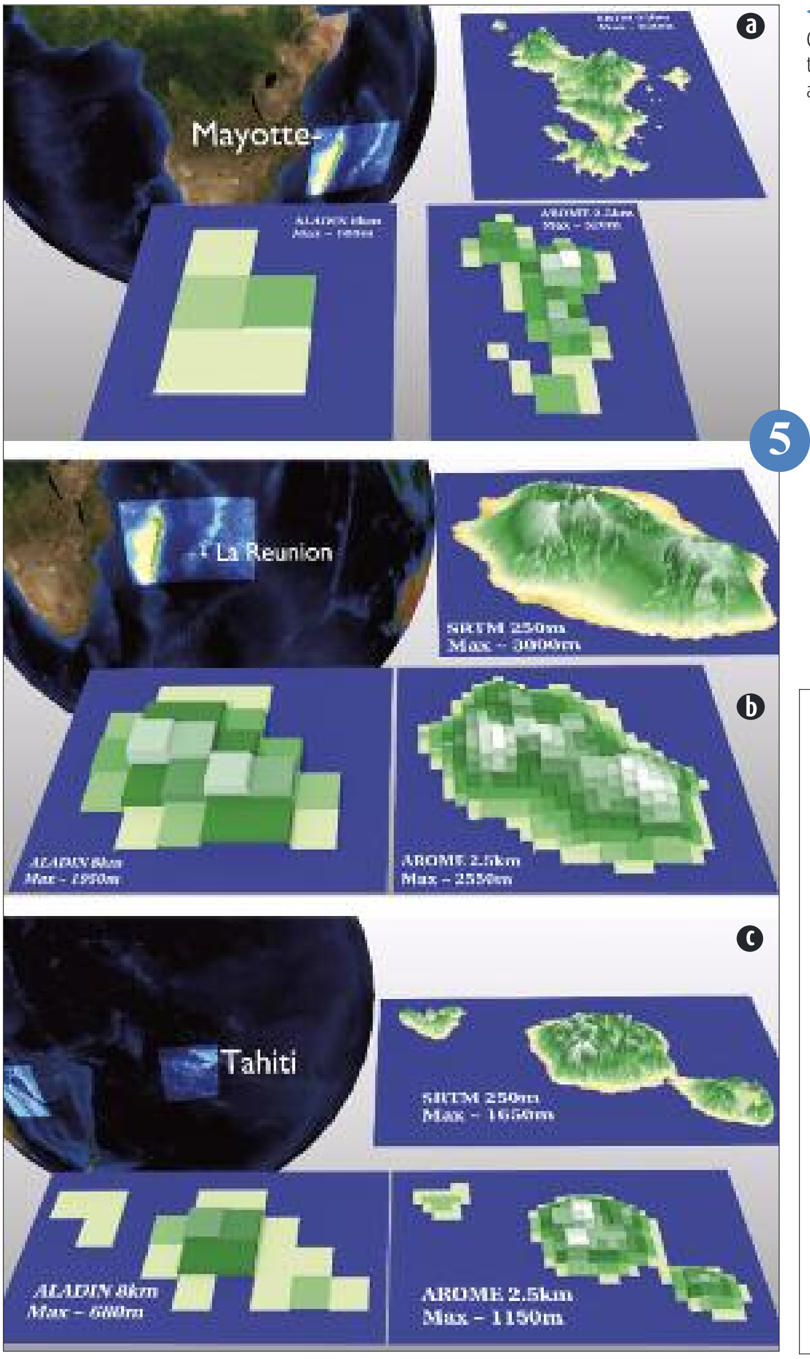


Over 5 forecast ranges (6h to 30h) « Regional Brier Skill Scores », probabilistic scores for the 6-hour precipitating accumulation (RR6) for the AROME reference (red) and the experiment with radar data at high-density (blue) over the time period between the 4th July and the 6th August 2015. The score is shown here for the threshold 10 mm. Higher scores reflect improved forecast skill. The BSS takes into account a 52 km neighbourhood.

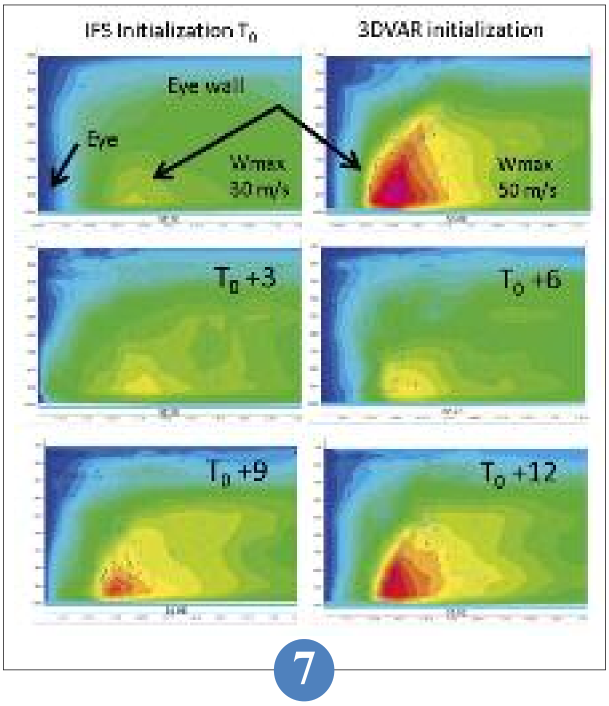
Over the South-East of France on the 19th September 2014 :radar composite (left) at 07h TU, and simulated radar reflectivity at 700 hPa from the cycled 1-hour AROME forecasts at the valid time 0700 UTC, for the reference (middle) and for an experiment with radar data at high-density (right).

b



Comparison of the orography between Mayotte (a), the Island of La Réunion (b) and Tahiti (c) from the ALADIN (8km) and AROME (2.5km) models and measured by SRTM (250m).

Azimuthal mean of AROME Indian analyzed (top) and forecasted (middle, bottom) wind speed within tropical cyclone Bejisa. The AROME 3D-VAR analysis allows to reduce from nearly 12 hours the time required to reconstruct the structure of the cyclone (spin-up) when the model is initialized from a ECMWF analysis.



Benefits of data assimilation for high resolution tropical cyclone forecasting

The prototype version of model AROME “Indian” developed conjointly by the Tropical Cyclone Research Division (CRC) and National Center for Meteorological Research (CNRM) of Météo-France is considered as the laboratory of the four AROME models (Indian, New Caledonia, French West Indies and Guiana, Polynesia) which will soon be deployed for operational forecasting in French oversea territories. Over the last few years, many studies have been performed at CRC in order to evaluate the impact of data assimilation for tropical cyclone forecasting. To do so the 3D-VAR assimilation scheme of the model AROME-France has been implemented in AROME Indian, and tested on numerous cases of tropical cyclones that recently formed in the southwest Indian Ocean basin (Dumile, Bejisa, Hellen, Bansi ...).
Results of these studies show that data assimilation generally has a very positive impact on the performance of the model in cyclonic conditions. Compared to a conventional initialization from ECMWF model analysis, the 3D-VAR analysis of AROME Indian provides more realistic forecasts of rainfall and winds, but also allows to greatly reduce the spin-up of the model (Fig.). However the use of 3DVAR analysis seems to have little impact on forecasted trajectory, which appears to be essentially driven by the coupling model.

7

Exploring the use of space-borne radars for forecasting systems' validation over Tropical Overseas territories

The GPM Core Observatory satellite is a joined American/Japanese mission (NASA/JAXA) dedicated to the observation of precipitation over the globe. The core payload is composed by two microwave instruments, amongst which, the precipitation radar DPR. With two frequencies at 13.6 and 35.5GHz, the DPR provides information on the hydrometeors content within the clouds. This instrument is of particular interest over regions of the globe that are not or poorly covered by ground-based radars, like open oceans.
Within the framework of the development of Météo-France's next generation forecasting system dedicated to the Tropics, characterizing the AROME capability to model tropical convection is a key exercise. The DPR onboard the GPM Core satellite is a very relevant source of information to assess the realism of clouds three dimensional structures of AROME forecasts for Overseas territories where indeed the ground-based radars only cover a small fraction of the model domains.
A first set of comparisons has been performed between DPR observations and AROME forecasts over the Indian Ocean during the 2015 cyclonic season. The figure shows cyclone Bansi that occurred in January 2015: (a) and (c) figures show Bansi as observed by Meteosat in the thermal Infrared domain and by the DPR radar at 35.5GHz; (b) and (d) figures show a corresponding forecast of AROME Indian Ocean, in the observation space. In particular, a comparison of the two cross-sections ((c) and (d)) highlights the high degree of agreement that can be found between observations and AROME forecasts regarding the three dimensional structures of clouds. This kind of comparison may be useful in order to assess the forecasts of AROME future versions, and in particular of its microphysics scheme.

8

Impact of vertical resolution on the formation processes of a fog situation on Roissy airport

For an optimum management of large airports such as Roissy Charles De Gaulle, the prediction of fog is paramount.
This study aims to estimate the impact of the vertical resolution of the AROME model on the life cycle of a radiation fog case. Numerical predictions using several vertical resolutions were tested with the meso-scale model AROME over a horizontal domain centred on Roissy CDG airport. Three vertical resolutions were tested with the same horizontal resolution as in the operational AROME model (1.3km), viz 60 levels, 90 levels as in the current operational model and 156 levels with the first level at one meter. A significant impact of the vertical resolution on the fog life cycle can be seen on the figure. Do not focus on numerical values of visibility which were computed with the Kunkel formula but at the fog onset. In the 156 levels simulation fog onset is two hours earlier than the operational 90 levels forecast.
In the context of operating a high capacity airport this information is very important. A study on several cases corroborates this result for fog detected by the model. However, the sole increment of the vertical resolution does not suffice to improve the number of no detection or false alarm. Thereafter, the study will be devoted to find an algorithmic solution to reconcile a high vertical resolution with operational numerical stability constraints.

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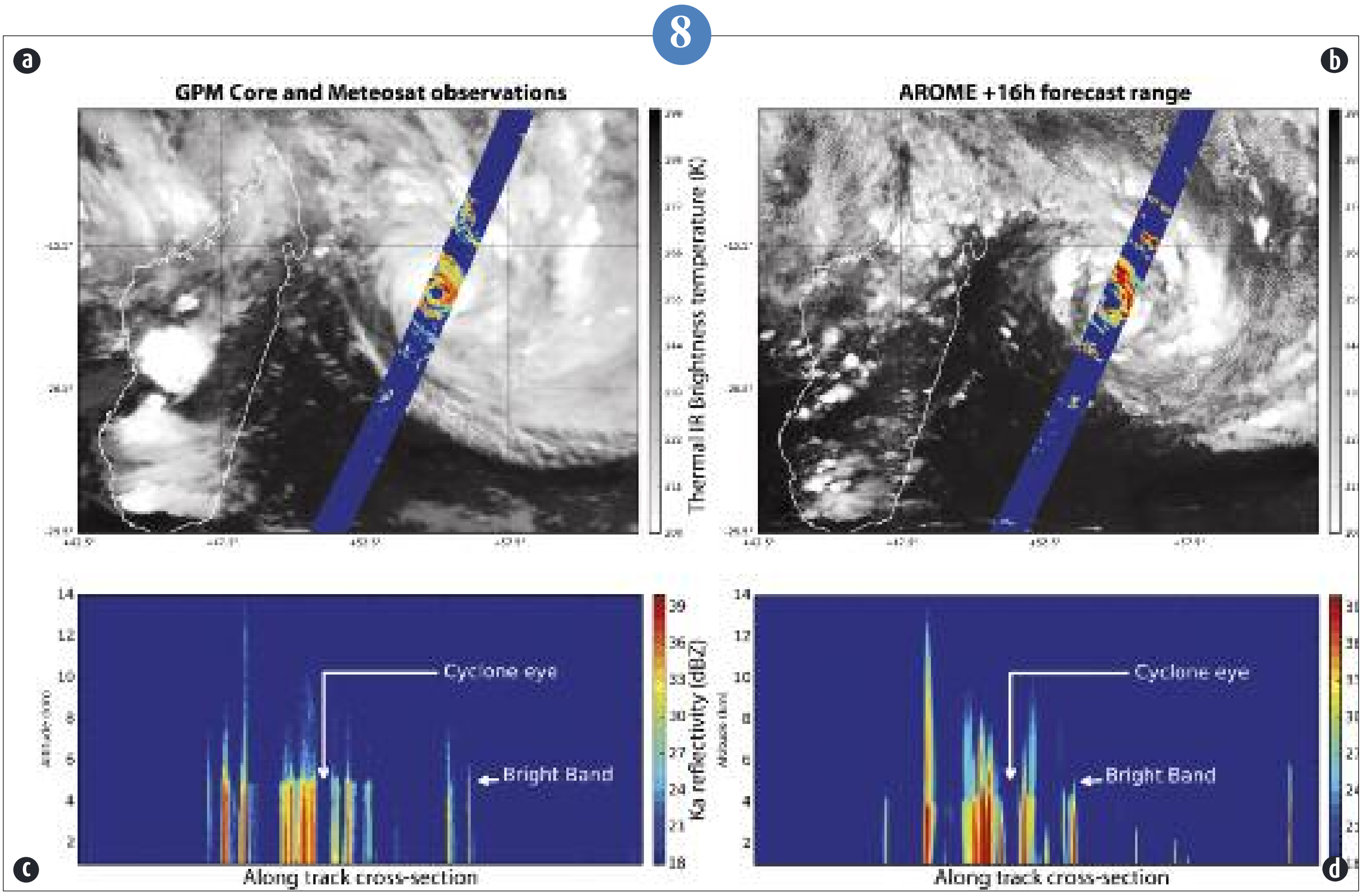
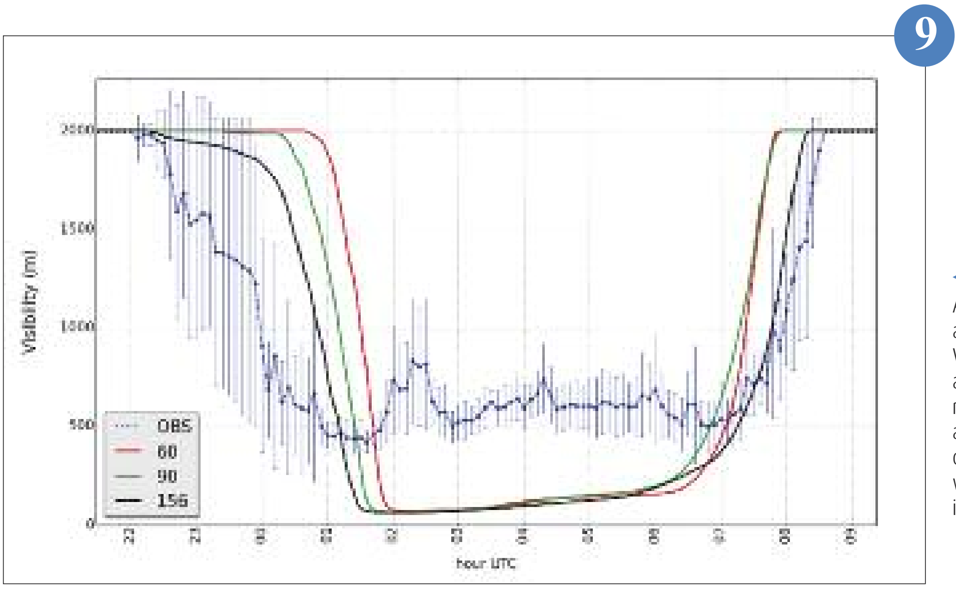


(a) Cyclone Bansi observed on January 11th 2015 at 11h00 UTC by Meteosat in the thermal infrared domain (brightness temperatures in black and white) and by the DPR 35.5GHz radar and for an elevation of 3km above ground (radar reflectivities in colors, same color bar as (c) and (d) figures).
(b) Same as (a) but for an AROME forecast initialized at 00h00 UTC on January 11th.
(c) DPR cross-section in the middle of the DPR swath shown on (a).
(d) Same as (c) but for the same AROME forecast as represented on (b).



Average and standard deviation of measured visibility at Roissy airport on October 22, 2012 (blue). Visibility computed by the AROME model at a 1.3km horizontal resolution with several vertical resolutions (60 levels in red, 90 levels in green and 156 levels in black) Do not focus on numerical values of visibility which were computed with the Kunkel formula but at the fog onset in the 156 levels simulation, which is close to observations.

Study of process

Process studies carried out at CNRM, aim at advancing the understanding and modeling of meteorological phenomena and their interaction with continental or marine surfaces. This chapter illustrates some advances obtained in 2015 about tropical and mid-latitude convective precipitation systems, mid-latitude storms, and continental surfaces.
A major highlight of the past year is the mid-term review of the international research program HyMeX, dedicated to the water cycle in Mediterranean and co-coordinated by Météo-France. A first series of studies using the numerous data collected during the two field campaigns have been synthesized and published, including about fifteen papers with CNRM co-authorship in HyMeX-dedicated issues of international scientific journals. The studies on heavy precipitation events observed during the first HyMeX field campaign on 2012 allow to advance the understanding of the processes involved in the triggering and development of heavy precipitation in northwestern Mediterranean. The modifications of the low-level winds by the Mediterranean coastal mountains are a key ingredient. Even though it depends on the specific local topography, common characteristics have been identified for all the studied cases. Besides orographic lifting of the low-level moist and unstable flow impinging the mountains, other ingredients are often involved: i) wind convergence line, most often over the sea, due to the forcing of the surrounding mountains on the low-level flow or synoptic forcing; ii) a low-level cold pool, mainly due to the evaporation of the rainfall beneath the cloud; iii) the channeling and deviation of the low-level flow by the mountains.

1

Evaluation of the turbulence parameterization in deep convective clouds

Few studies have evaluated the turbulence parameterization inside convective clouds in atmospheric models at kilometre scale. Yet, turbulence can be strong inside cumulus and cumulonimbus and can have an impact on the structure and dynamics of these clouds.
A Large-Eddy Simulation (LES) of deep convection with 50-m grid spacing using simplified atmospheric conditions has been performed with the research Meso-NH model.
This LES is used as a reference simulation to characterize the turbulent fluxes within the convective clouds at hectometre and kilometre scales. Thus, turbulent structures, called counter-gradient structures, have been identified, indicative of a non-local turbulence.

The evaluation of the turbulence scheme, currently used in the Meso-NH and AROME models, shows that the thermal production of turbulence (Figure b) and consequently the turbulent kinetic energy are widely underestimated in the clouds at these scales. In particular, the counter-gradient structures of the vertical turbulent fluxes are not reproduced because the current formulation is not suitable. An alternative formulation, based on horizontal gradients, can better represent these turbulent structures and the thermal production with an increase of the turbulent kinetic energy and lower vertical velocities in convective clouds. Indeed, the latter are too often overestimated inside deep convective clouds by models using a kilometre resolution.

In the next future, we plan to evaluate and to improve this new parameterization using simulations of real cases of deep convection that occurred over the Mediterranean area during the two-month HyMeX field campaign.

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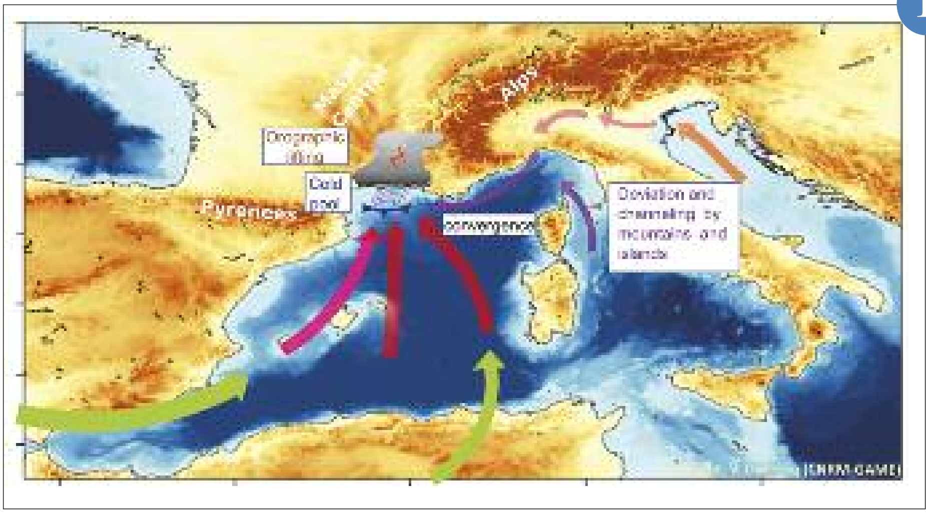

Conceptual model for low-level atmospheric circulation and triggering mechanisms associated with Mediterranean heavy precipitation events.

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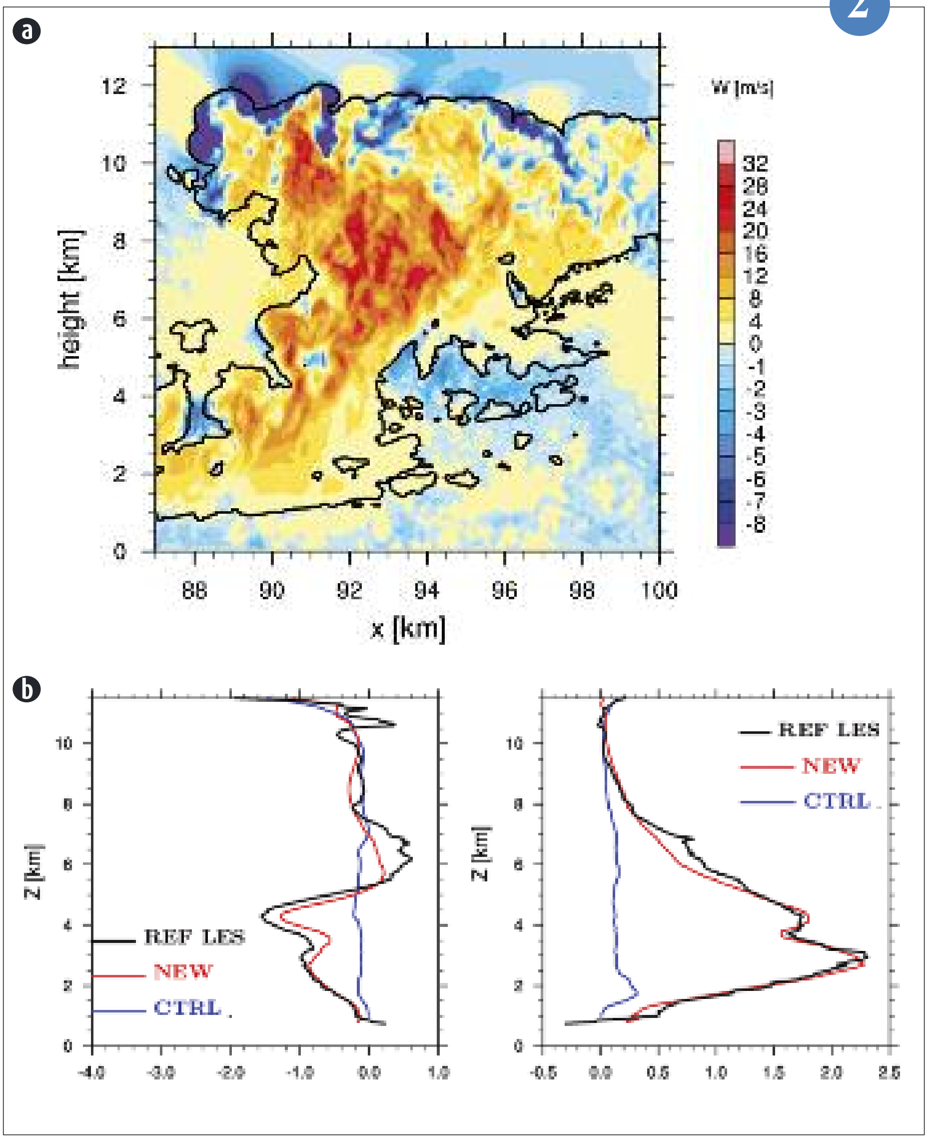

(a): Vertical cross section inside a cumulonimbus for the reference simulation (LES using 50-m grid spacing): cloud contour (in black line) and vertical velocities ($m.s^{-1}$, shading).
(b): Vertical profiles averaged inside the convective clouds of vertical heat flux (left, $m.s^{-1}.K$) and non precipitating total water (right, $m.s^{-1}.g.kg^{-1}$) contributing to the thermal production of turbulence for simulations using 1-km horizontal grid-spacing with the current scheme (CTRL in blue line) and with the modified scheme (NEW in red line). They are compared to turbulent fluxes of the reference simulation (REF LES in black line) filtered at the same kilometre resolution.

Evolution of the storm-tracks in the 20th century

The evolution of the number of extra-tropical cyclones as well as the location of the storm-tracks has been studied among the scientific community during the last years. The release of a new ECMWF reanalysis (observation-based) data covering the period 1900-2010 allows us to study the evolution of storms homogeneously during the last century.
We applied a tracking algorithm (Ayrault, 1998), for the period 1900-2010 and we computed the annual number of tracked storms. The figure shows the annual number of storms for the North Hemisphere in blue and for the Atlantic region (120W-60E 20N-90N) in red. We can see an increase in the number of storms on period 1900-1920 (not significant in the Atlantic region) and 1970-1990 followed by a decrease after the 90's. While these last two trends may be related with the Arctic Oscillation, the increase observed in the beginning of the century is much more difficult to explain. When looking at other regions like the "Pacific" (120E-120W 20N-90N) and the "Asia" (60E-120E 20N-90N), this trend in the early century is also observed. Similarly, for all regions the number of long (and consequently intense) storms presents common features with the former results.
We can therefore conclude that whereas the trend over the Atlantic (red straight line) is not significant those over the other basins (Asia, Pacific) show a clear increase in the number of storms during the last decades. The trend observed in the beginning of the century in all regions might be attributed to the lack of available observations for this period.

3

Systematic errors estimation of forecasting depression trajectory with retrospective forecasts

Weather forecasting relies mostly on calibrated numerical weather model outputs. The hope is to correct systematic biases and to moderate over- or under-dispersion of ensemble prediction systems. However, an effective calibration, including extreme events, requires very long training samples.
Having this in mind we set up a retrospective forecasting system based on ECMWF reanalysis. We have thus forecasts on a 30 years period obtained with the latest version of models used in the ensemble prediction system. It is possible to characterize systematic errors of phenomena such as mid-latitude low-pressure systems. The focus here is the displacement systematic errors of depressions forecasted by the models. A systematic identification of most intense depressions was performed. A method of optical flow has enabled, on every event, to characterize the displacement error. 500 events corresponding to the highest errors were analysed using composites. In particular it is shown that the depressions moving eastward too quickly are significantly different than depressions moving too slowly. The depressions moving too slowly are also the depressions with the most underestimated amplitudes in the forecast. We find a well-known result: the eastward propagation is slowed by the lack of vorticity induced by the latent heat release in front of the system. In the case of depressions moving too quickly we find that they are not deep enough in the forecast. Again the moist processes are in question. In this second case the evaporation in the upper troposphere is supposed to produce an anticyclone, which in some configurations recently studied at CNRM, are able to induce a headwind in the lower layers and thus slow the progression of the depression.
This mode of analysis of systematic errors will be extended and improved in the future. We bet it will be a factor in improving numerical models.

5

Strong winds in the storms, reality of "sting jets"

The mid-latitude storms result of baroclinic interaction mechanism. One can thus explain the presence of strong winds rotating around the depression in the opposite clockwise direction. However, this mechanism does not explain the highest wind gusts generally organized into coherent spatial mesoscale structures.
The southern edge of mature stage depressions (see figure) is a particularly good region for very strong winds. It is characterized by low static stability, strong horizontal temperature gradients, proximity of cloud structures, but above all by the presence of atmospheric air parcels with long and complex history: they originate generally from the warm sector and undergo strong updrafts while they go around the depression. When they are located west of the depression in the upper troposphere they undergo severe subsidence reinforced by the diabatic cooling due to evaporation of clouds and frontolysis. These mesoscale structures, called "sting jets" were mainly studied in real cases of recent storms. The identification of a "sting jet" in an idealized storm as in the figure is considered to be more difficult. The establishment of idealized simulations helped to highlight the high sensitivity of the intensity of strong winds to the depression in which strong winds are formed: a growing depression south side of the jet has a very strong "sting jet" while the growing depression remaining in cold air does not have such structures.

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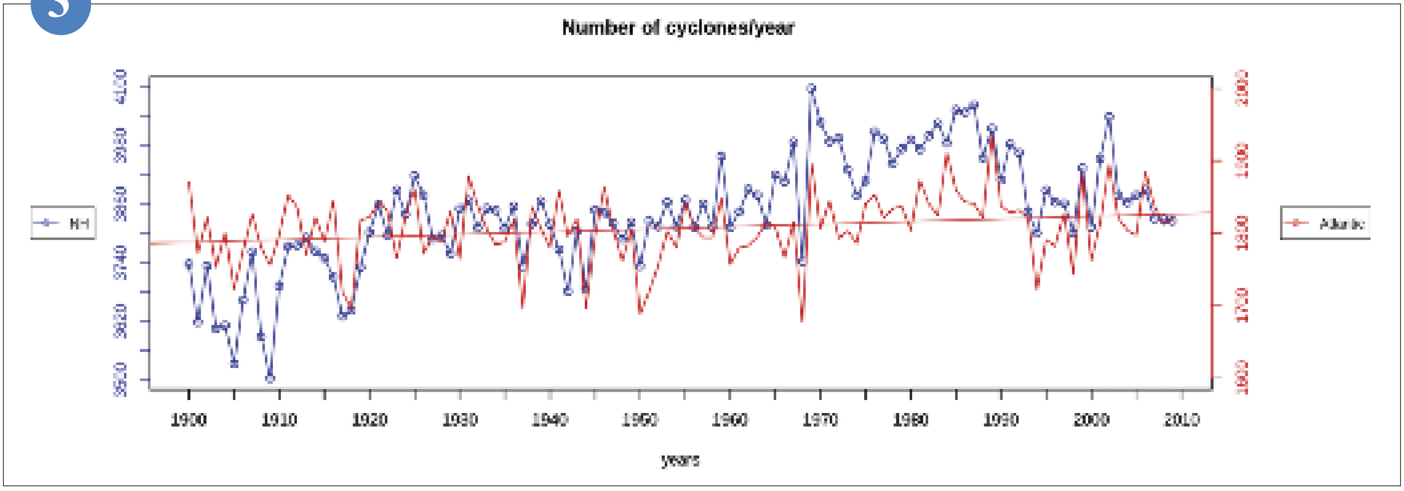

Evolution of the number of depressions for the northern hemisphere (in blue) and the North Atlantic/Europe Basin (in red) The straight line materializes the average trend for the century on the second domain.

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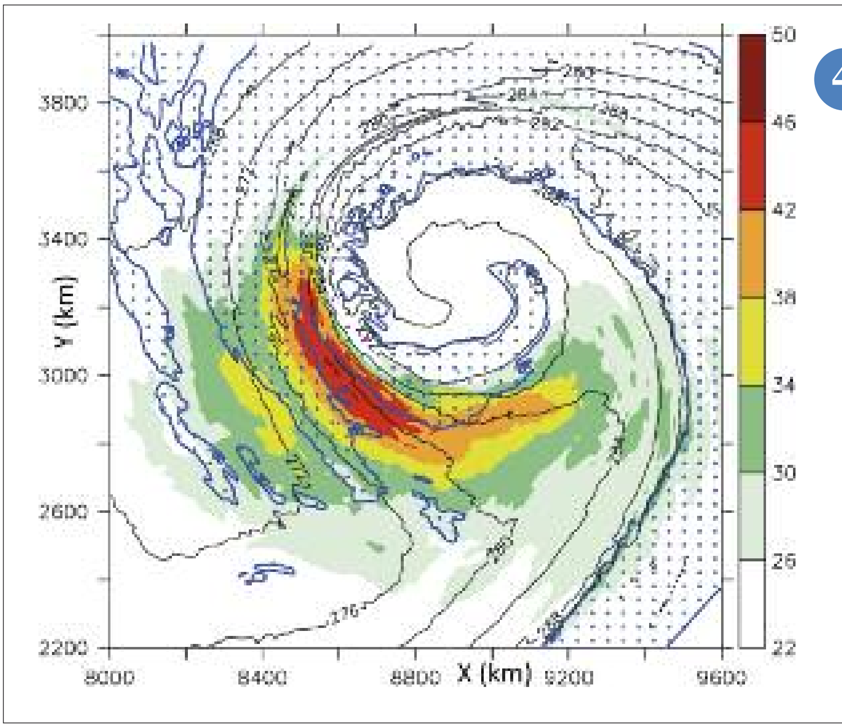

Extract of a Meso-NH simulation at 4 km horizontal resolution and 200 m vertical resolution in the lower troposphere on a 1600 x 1700 km geographical domain centered on the depression after 4 days of simulation. Color ranges: wind speed (in m/s), potential temperature in black and thin contours (K), relative humidity greater than 80% (spotted area) at 1.7 km height.

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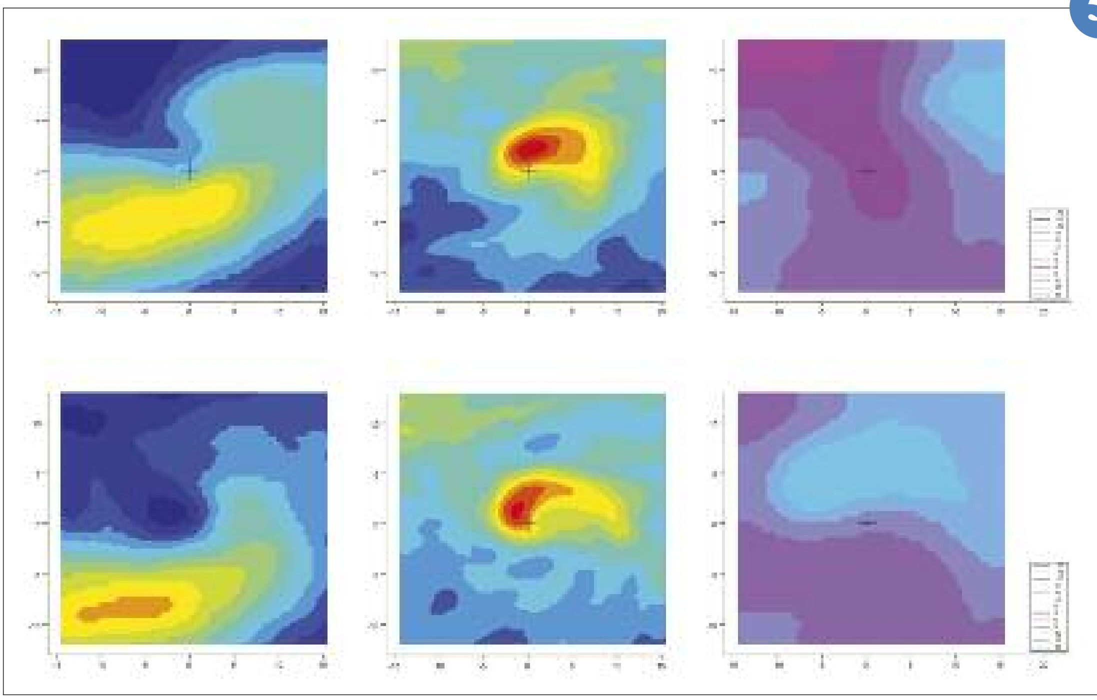


Composites in the referential of the depression of systems with the highest position errors in the east-west direction The area shown is marked in degrees of latitude and longitude brought back at latitude 45°. Above: composite of depressions moving too slowly. Below: composite of depressions moving too quickly. From left to right: wind speed at 300 hPa, humidity at 700 hPa, geopotential error at 300 hPa due to diabatisme.

New drought indices from the assimilation of satellite data

The current agricultural drought indicators produced by Meteo-France are derived from digital simulations of soil moisture produced by the SURFEX modelling platform. In the framework of the IMAGINES European project, a research was conducted in order to assess the impact on the monitoring of agricultural droughts of the integration of satellite data into SURFEX.
A data assimilation system was implemented to this end. It provides simulations of the biomass and leaf area index of straw cereals and grasslands over France. It is shown that these simulations can be improved through the assimilation of satellite products distributed in near-real-time by the Copernicus Global Land service (**http://land.copernicus.eu/global/**).
Reference in situ observations of the agricultural yields show that using satellite data, a significant correlation between the maximum annual above-ground biomass simulated by SURFEX and the agricultural yield at the scale of administrative units (départements) can be achieved. Without satellite data, very low correlations are observed. It is also shown that new 10-day drought indicators, complementary to soil moisture, can be derived from the leaf area index and from the above-ground biomass of vegetation. The Puy-de-Dôme example is shown in the following Figure as this administrative unit contains both straw cereals and grasslands. These demonstration drought monitoring products for the 2008-2013 period are freely available on the project web site (http://fp7-imagines.eu/) for 45 administrative units for cereals and for 48 administrative units for grasslands.

6

Towards a new typology of environments favouring Mediterranean heavy precipitating events

Autumn Mediterranean heavy precipitating events (HPEs) are extreme natural phenomena of major societal impacts. Spatially larger than a simple thunderstorm, they are associated with typical synoptic forcing atmospheric circulations. We propose a new characterization of these circulations combining variables that represent a large part of the atmospheric processes involved in HPES. We assess their ability to distinguish the different impact zones of the HPEs (Eastern Pyrénees, the Cévennes, Gard plain, ..., see inset figure).
By an original method of multivariate classification based on the ERA-Interim reanalysis (ECMWF) an eight-class score describes the average variability of the Mediterranean autumn atmospheric circulations. Three of them discriminate well most of the 90 notable events observed between 1989 and 2010. Incidentally, this shows the importance of these events in the Mediterranean climate. In addition, by comparing the patterns of the HPEs only with the patterns associated with the three classes prone to HPES, specific atmospheric ingredients occur for several impact areas. Class C1 corresponds to a rapid southern south over the Mediterranean basin. The Cévennes are affected when intense high level circulation combines with a warm sea surface, while the Pyrénees Orientales (PO) is impacted when Rossby wave train cyclonic breaking directs wind south-easterly. The Gard plain and Hérault are impacted when the large scale flow becomes more stationary. C2 class, the blocking high over Central Europe promotes the Hérault and the Cevennes. In class C7, Rossby wave-breaking to the West combined with the blocking to the East produces HPES in the Hérault and the PO areas. The robustness of the classification methodology allows to consider the study of these environments in climate change simulations.

7

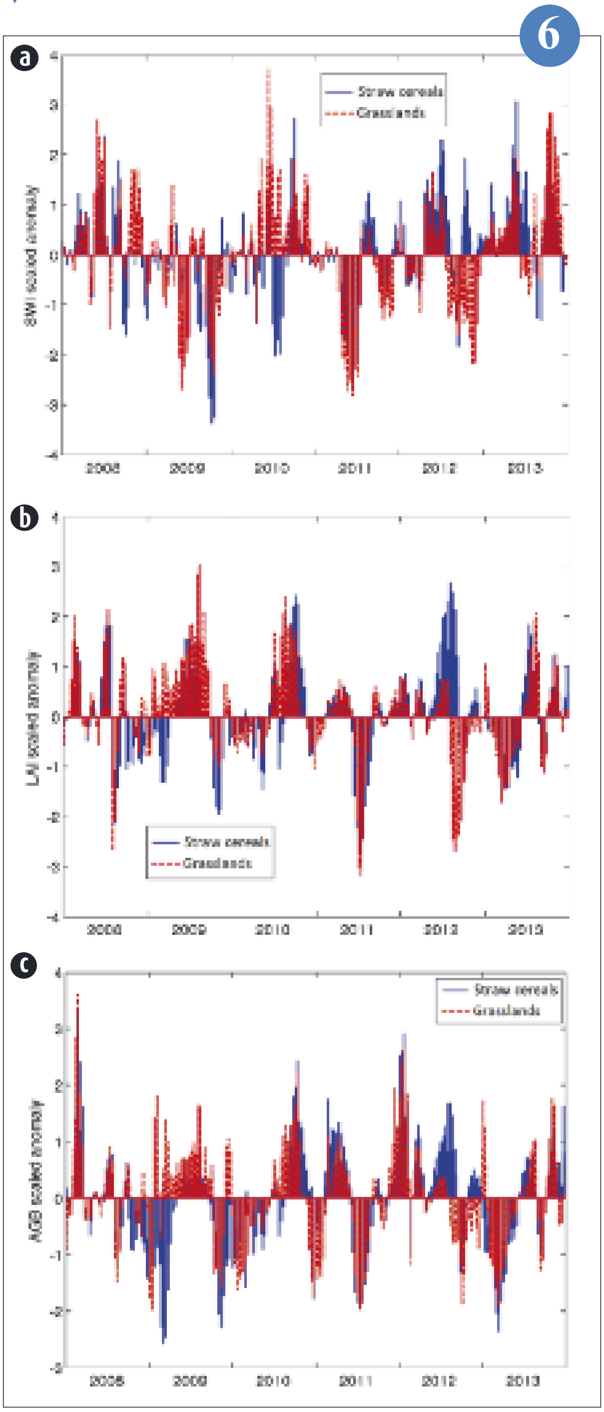
The use of satellite data for improving regional scale hydrological modelling

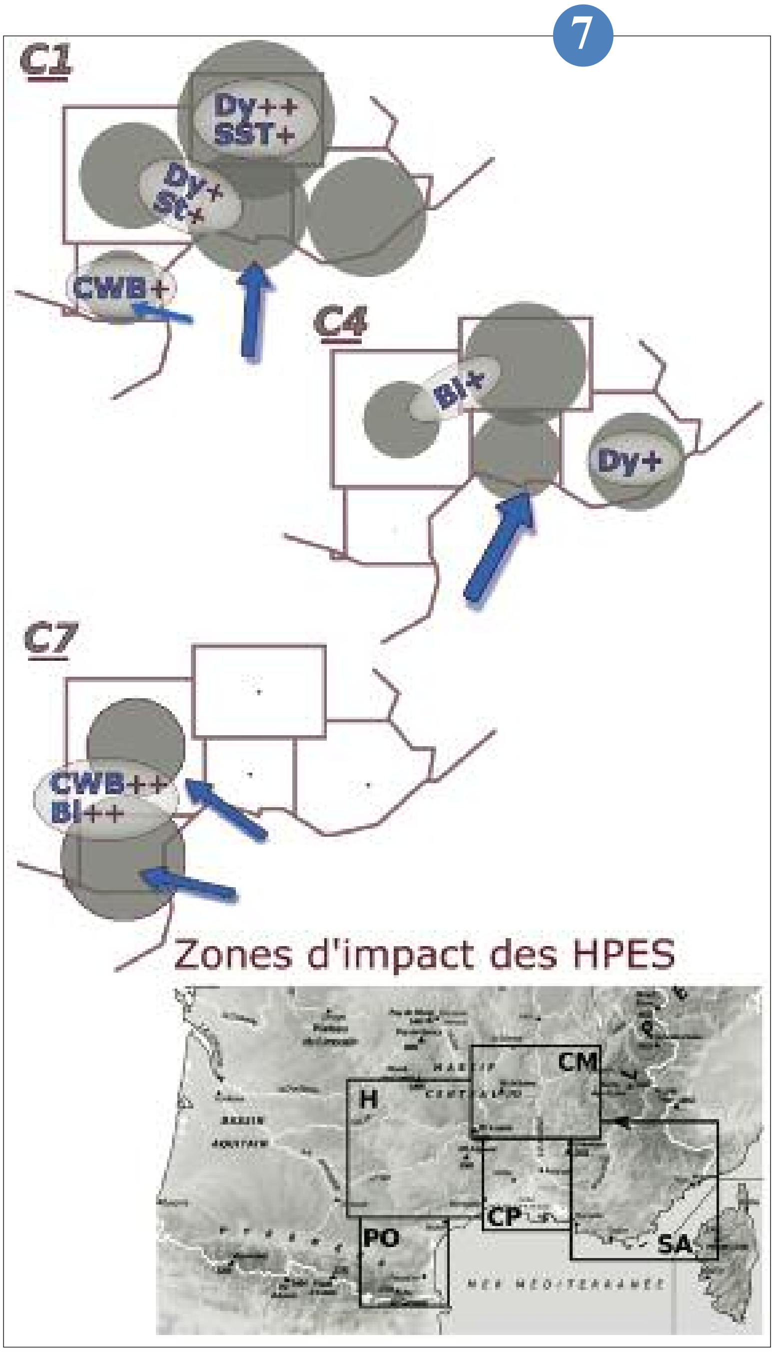
joint CNES-NASA satellite SWOT (Surface Water and Ocean Topography), with a launch tentatively slated for 2020, will observe heights for rivers wider than 50 m with 5 revisits over France per each orbit repeat period of approximately 21 days. These data will be used both to evaluate hydro-meteorological models and to improve the monitoring of water resources from regional to global scales. The operational hydro-meteorological model chain SAFRAN-ISBA-MODCOU (SIM), developed at Météo-France, is used to simulate the spatial and temporal evolution of water flow over the continents. The Garonne basin, located in southwestern France, has been selected for the current study. SIM is capable of simulating water heights every three hours for entire hydrographic network of the Garonne, with an average root mean square error between 40 and 50 cm at the outlet of the river (Fig. a). This error is satisfactory, and also shows the potential of SWOT to improve the model since the satellite measurement error is approximately 10 cm for a surface of about 1 km² (for a river section which is 10 km long and 100m wide).
It is shown that data assimilation of synthetic SWOT observations can be used to improve the main river routing parameter of MODCOU: the roughness coefficient Kstr. Several tests have been done which result in a convergence of the value of ***Kstr*** to within an acceptable error tolerance of the « true » value. This has a direct effect on the river flow simulation since it is very sensitive to this parameter (Fig. b and c). Future work will focus on using more realistic SWOT errors in the assimilation scheme. Indeed, the measurement error sources are numerous (instrument defects, view angle, observed surface, atmospheric state, etc.) and are directly related to the quality of the satellite measurements. In addition to being a feasibility study for SWOT, this work will help to improve the modeling of the water cycle over France. It is planned that the tools and methods developed within the context of this study will be tested for other basins in the world.

8

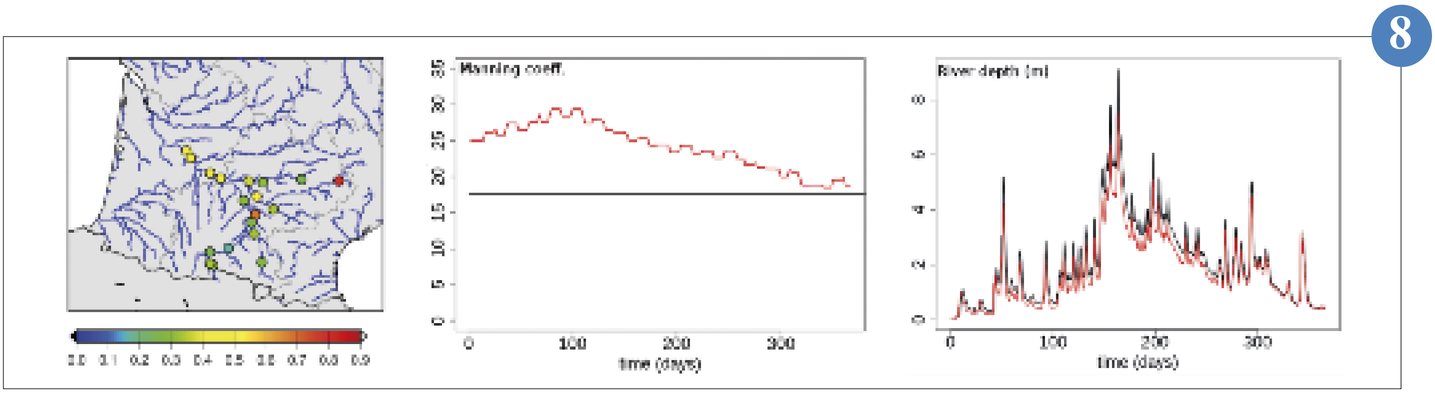
(a): Daily root mean square error of water height for 19 gauging stations: the study period is from Aug. 1, 1995 to July 31, 2006.
(b) and (c): Time evolution of the water height and the roughness coefficient, ***Kstr***, at Bergerac (Dordogne river), over the period from Aug. 1, 1995 to July 31, 2006 (panel b). The red curves represent the analysis states of ***Kstr*** and water height, and the black curves correspond to reality which is the solution to attain (panel c). By assimilating SWOT synthetic data, the ***Kstr*** approaches the reality as time progresses, and therefore the water heights, which depend on ***Kstr***, also approach the reality.
The difference between the assimilated water height and the «truth» becomes less than 10 cm after approximately 10 months of assimilation

10-daily scaled anomalies from 2008 to 2013 of (a) soil wetness index, (b) leaf area index, (c) above ground biomass for Puy-de-Dôme at two locations for straw cereals and grasslands (blue and red lines, respectively), in units of standard deviation.





Atmospheric ingredients fostering HPEs by impact area according to 3 distinctive classes, C1, C4, C7 of the classification in eight classes.
The blue arrows indicate the direction of the flow in lower layers. The surface of the grey circles is proportional to the number of HPE by area. "CWB" indicates the presence of a cyclonic breaking in western area. "Dy" specifies that the barocliny associated with the south jet has high amplitude. "SST" reminds that the sea surface temperature is higher. "Bl" indicates that a ridge of high pressure is present over Central Europe. "St": large-scale structures are stationary. Impact areas: H: Hérault, PO: Pyrénées Orientales, CM: Cévennes, CP: Gard plain, SA: Southern Alps.



Role of rain evaporation, water recycling and atmospheric circulation on the African monsoon

The rainfall over West Africa is the net result of:

• the moisture brought over land by the large-scale atmospheric circulation (Fig. a) in a layer confined between 1000 hPa and 700 hPa (*transport*),

• the capability of storms to convert atmospheric humidity into precipitation reaching the surface (*storm efficiency*),

• the surface evaporation occurring in response to rainfall, which can feed new storms with moisture (*water recycling*).

Although this suggests a simple view of what a monsoon is, current weather-forecast and climate models struggle to represent the correct positioning and intensity of the observed rainfall in Africa, which underscores a continued lack of understanding of the monsoon system.

A simplified numerical model has therefore been developed, assuming the West African monsoon can be reduced to a large-scale meridional-vertical breeze circulation, in which the effects of the three key processes – transport, storm efficiency and water recycling are represented. Their effects are modulated directly in the model by using a set of parameters ranging from 0, when the mechanism is totally removed, to a value of 1 for which it is fully active. Considering the model results (Fig. b), the transport by the low level monsoon winds (Fig. iii) is found to be the leading factor in determining the location/intensity of rainfall, associated with a large displacement of the rainfall maximum and a drastic reduction of its meridional extent. The storm efficiency (Fig. i) and the water recycling (Fig. ii), although less significant than the atmospheric transport, are not negligible since they both modulate the amount of surface rainfall as well as the positioning of the rainfall maximum.

Although the magnitude of the water recycling and storm efficiency are difficult to observe, this framework provides a better understanding of their relative significance compared to the atmospheric transport. More broadly, it gives a range of responses of the monsoon system to a variation of these processes, which can a useful step in an evaluation/improvement perspective of climate models, in which these processes are also at play.

9

Composite analysis of Tropical Mesoscale Convective Systems life cycle

Mesoscale Convective Systems are the main source of precipitation and cold cloudiness in the Tropics (Houze 2004). Convective systems can be decomposed in several sub-regions (convective updraft, precipitating stratiform region and non-precipitating stratiform region or anvil) involving themselves different physical processes that evolve over the life cycle. The documentation of the evolution of these physical properties is a major challenge if one wants to be able to represent convective systems and their associated impact in models of different scale.

In order to do so, a composite multi-satellite approach was implemented (Bouniol et al 2015). The ability of geostationary satellites to monitor changes in cloud cover during the life cycle of convective systems via tracking algorithm is used (Fiolleau et al 2013) defining systems trajectories. The intersection of these trajectories with tracks of non-geostationary satellites (A-Train in this study) documents the physical properties within these systems at each stage of the life cycle. This methodology is illustrated in figure.

Evolution of microphysical properties, microphysical and radiative has been documented in three geographic regions corresponding to contrasting environments: the continental western Africa and the Atlantic Ocean for the summer season and the Indian Ocean during the winter season. A particular life cycle exists for Continental convective systems with a more intense convection at the beginning of the life cycle. Dense and large hydrometeors are then found at high altitude up to the cirriform region. Oceanic systems show less variability in their life cycle, suggesting a less intense deep convection but active throughout the life of the system.

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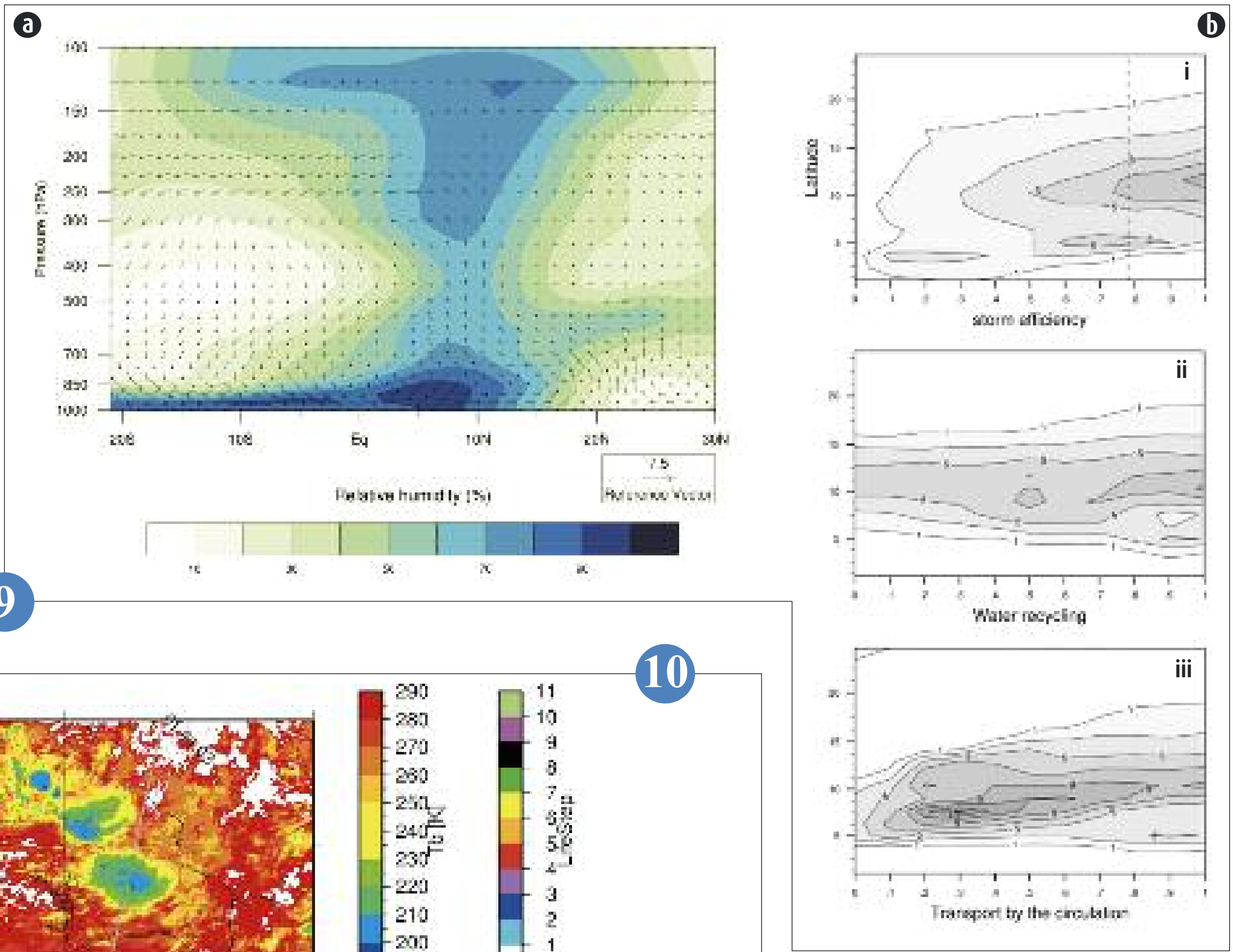

(a): Example of summer-mean meridional-vertical circulation (arrows m/s) and relative humidity (%) on average over West Africa (10W-10E) from the Era Interim reanalysis.
(b): Summer-mean meridional profiles of rainfall (mm/d) obtained by modulating the storm efficiency (i), the water recycling (ii) and the humidity transport by the atmospheric circulation (iii) in the simplified model.

10

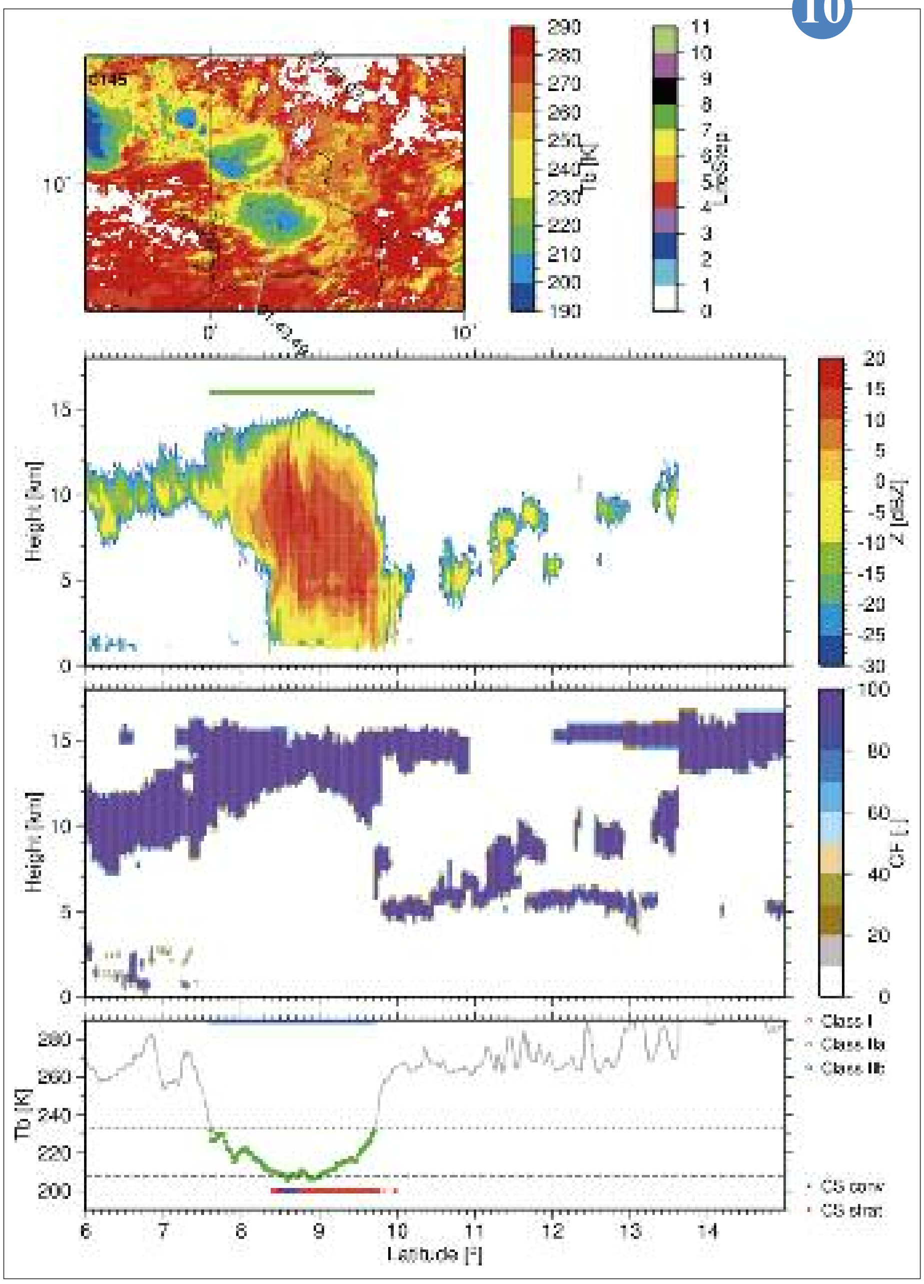

Illustration the multi-instrumental sampling of a convective system in West Africa
The first panel represents the MSG brightness temperature at 10.5 µm. Gray line is the ground track of the A-Train. At this time the system is in the 6th phase of its life cycle (yellow segment superimposed on the system).
The second panel is the reflectivity in DBZ measured by the radar onboard CloudSat. The third panel is the cloud cover observed by the lidar onboard CALIPSO.
The fourth panel is the brightness temperature measured by MSG extracted along the track of the A-Train with superimposed the step of the life cycle and the status of the profile: convective and stratiform.

Climate

During year 2015, the first climate simulations preparing our participation to the CMIP6 international project, were performed with a new version of the climatic system model CNRM-CM6 and a first version of the "Earth system" model CNRM-ESM1. In parallel, studies of climate variability, in particular on the role of the tropical Pacific ocean on the global warming, were led. In the field of climate regionalization, the first studies of the impact of the future climate change on heavy precipitation events in the southeast of France took advantage of the excellent capacity of the AROME model to simulate these events. The description of extremes in the climate projections has to lean on the finest possible diagnostics, qualified from observed data. A new diagnostic of heat waves so allows to specify the expected worsening of this risk on the metropolitan territory. The translation of this risk inside cities and adaptation measures that might ensue, were topics of a large scale international symposium organized by the CNRM. The projections of extreme climatic events were also used as a basis of a study of the evolution of the associated risks.

In the field of climate prediction, the year was marked by the public delivery of the first ensembles of predictions with a 2-month time range in the frame of the S2S international project. In addition, two applications of the seasonal forecasts to regional scales knew an important development. This concerns the Arctic sea-ice prediction which benefits from a multi-model approach and a seasonal hydrological forecast in France which turns out a potential decision making tool for water management.

Other developments concerned the improvement of databases and diagnostics allowing the characterization of observed climate variations. Works so led to generate a new set of homogenized precipitation series, to improve the temperature treatment in the Safran reanalysis, to commit new developments of the spatialization tool Aurelhy or still to specify the determination of the intensity of tropical cyclones. Beyond the treatment of climate variables, the use of the ISBA model allows now to reach original diagnostics of the impacts of climate change on the vegetation cycle in metropolitan France.

1

Modelling Climate and climate change

CNRM-CM6 and CNRM-ESM2, new models for CMIP6

The CMIP6 international project has been designed in order to answer three broad questions:

• How does the Earth System respond to various forcings, such as greenhouse gases?

• What are the origins and consequences of systematic model biases?

• How can we assess future climate changes given climate variability, predictability and uncertainties in scenarios?

In 2016, some of the modelling groups wishing to contribute to CMIP6 will launch their first simulations, contributing to the scientific basis of the next IPCC assessment report.

CNRM will participate significantly to this effort in collaboration with CERFACS (Toulouse) and LGGE (Grenoble). To this end, the new climate system model CNRM-CM6 is currently being developed. CNRM-CM6 will include the Arpège-Climat v6 atmospheric model and its new prognostic physics, the Surfex v8 surface model, the latest version of the Nemo ocean model (v3.6) coupled with Gelato 6 sea ice model, and the river routing scheme TRIP v2. The couplings within this system are managed by the new coupler OASIS-MCT3 developed at CERFACS. The model will be operated at low resolution (CNRM-CM6-LR) and high resolution (CNRM-CM6-HR). In CNRM-CM6-LR, the atmospheric and oceanic components will have horizontal resolutions of about 150 km and 1° respectively. Resolutions will be about 50 km and 0.25° in CNRM-CM6-HR. CNRM-CM6 will be the physical core of CNRM-ESM2 Earth System model, which will include a representation of the global carbon cycle, stratospheric chemistry and tropospheric aerosols. Several multi-decadal simulations have been performed with a preliminary version of CNRM-CM6, showing that the mean model biases are reduced compared with CMIP5 simulations run with CNRM-CM5.

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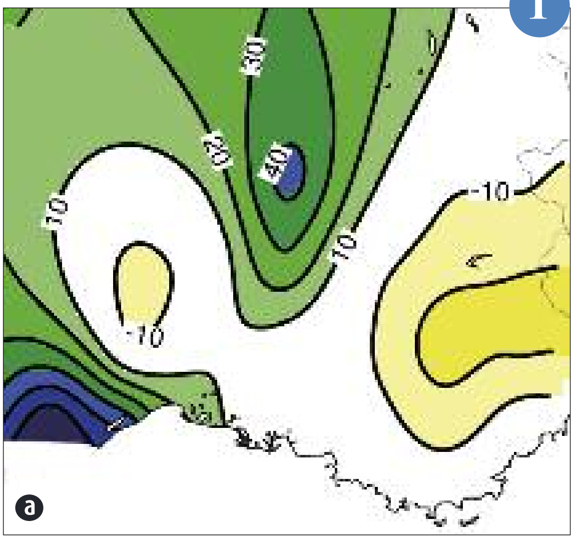
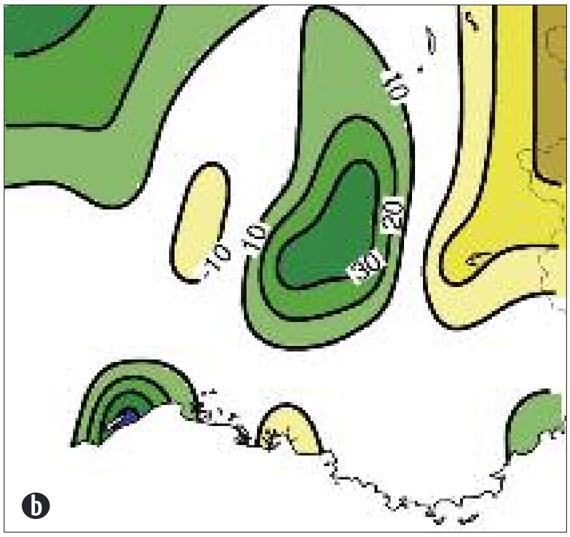
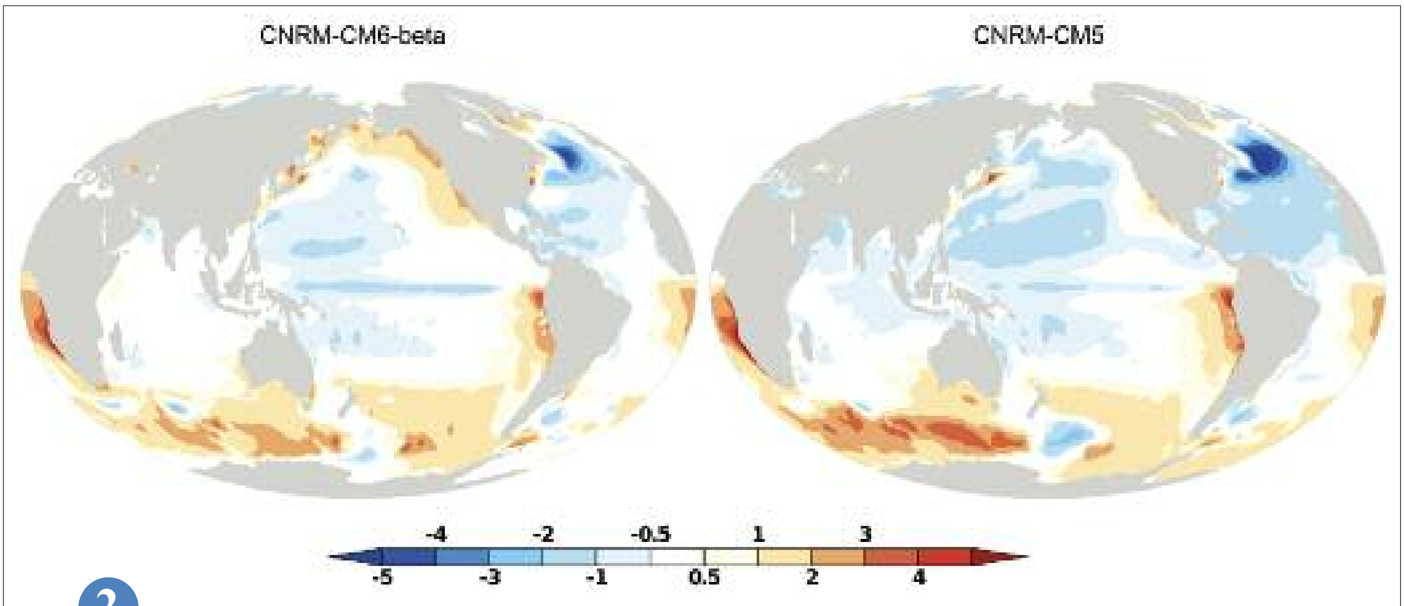


Evolution of extreme precipitation in the southeast of France (quantile 0.999 in mm/day) between the 1989-2000 and the 2089-2100 periods, calculated with the ALADIN-Climat model with a resolution of 12 km (a) and with the AROME model with a resolution of 2.5 km (b) for the RCP8.5 emission scenario.





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Difference (model minus observations) between the simulated near-surface air temperature in climate experiments with perpetual 1990 forcing and HadSST climatology for 1980-1999: preliminary version of CNRM-CM6 (left) and CNRM-CM5 (right).).

Multi-decadal modulation of global warming by the tropical Pacific variability

According to the latest IPCC report, and in spite of increasing atmospheric concentrations of greenhouse gases, the rate of global warming has been smaller over the recent 1998–2012 period than over the second half of the 20th century. This global warming “hiatus” might be however explained by the natural climate variability and a year 1998 marked by a major El Niño event in the tropical Pacific. This hypothesis seems to be supported by the fact that the ensemble mean derived from the CMIP5 historical simulations does not show a slowdown of global warming. Beyond the El Niño phenomenon, the Pacific Ocean shows a strong multi-decadal variability associated with fluctuations of the dominant winds. The main reason for the hiatus could be the recent intensification of the trade winds in the tropical Pacific which could have increased the subsurface ocean heat uptake through an enhanced overturning ocean circulation.

For testing this hypothesis, the CNRM-GAME scientists have achieved two ensembles of coupled ocean-atmosphere simulations focused on the 1979-2012 period and differing by their experimental design. The first technique consists in driving the evolution of the monthly mean sea surface temperature anomalies over the tropical Pacific, the second one in driving the upper ocean dynamics (through the application of the observed wind stress) in order to warrant realistic heat fluxes between the atmosphere and the upper ocean within the same domain. Compared to the control experiment only driven by the observed natural and anthropogenic radiative forcings, both ensembles show a significant slowdown of global warming. The magnitude of this slowdown is however sensitive to the experimental design. It is less pronounced but shows a more realistic geographical pattern when using the wind stress overriding technique.

This result confirms the key role of the upper tropical Pacific ocean dynamics in the multi-decadal modulation of the global ocean heat uptake. It implies that the global atmospheric warming should accelerate over the next few decades, unless it is inhibited by a major volcanic eruption.

3

A tropical cyclone rapid intensification index to aid prediction over the southwest Indian Ocean

In close collaboration with RSMC La Reunion, in charge of the cyclonic surveillance over the southwest Indian Ocean, the climatological study initiated in 2014 was completed in 2015 to provide forecasters with statistical tools to improve the prediction of tropical cyclone (TC) intensity change.

Over the 1999-2014 period of study, rapid intensification (RI) for oceanic tropical systems was statistically defined as a 24-hour intensity change of the maximum surface winds exceeding 15.4m/s. This is equivalent to the official threshold determined for the North Atlantic from 1-minute mean winds while we use 10-min mean winds following the WMO recommendation. An analysis of the dynamic and thermodynamic environmental fields (in a 200-800-km region surrounding the storm center) using ERA-Interim data revealed six potential RI predictors (Fig.). For each of them, statistically significant differences are found to exist between the means of the RI and non-RI samples at the 99.9% level using a two-sided t test. RI predictors are: TC intensity change during the previous 12h (DVMXM12), a high upper-level divergence (DIV200), a weak 850-200-hPa vertical wind shear (SHR), a high sea surface temperature in a 200-km radius surrounding the storm center (SST), a weak upper-level cyclonic potential vorticity (on the 350-K isentrope, PV350), and a strong relative eddy-angular momentum convergence at upper levels (REFC).

A statistical-dynamical tool for estimating the probability of RI was developed using best multilinear regression of the most relevant environmental RI predictors over the basin and will be tested over the next cyclonic seasons.

4

Improvement of temperature re-analysis coming from SAFRAN using extreme temperatures observations (national project EXTREMOSCOPE)

Due to the evolution of the hourly temperature observations’ network over France in the 1990’s (development of local networks), surface temperature re-analysis systems using those data have some temporal heterogeneities which prevent to use them for climatological studies.

To address this problem we used daily extreme temperatures observations because they are less affected by the quick evolution of the observations network. We set and assessed two methods to deduce, for an observation station, pseudo-observations of hourly temperatures from daily extreme temperatures. The method finally selected (producing unbiased pseudo-observations) uses hourly observations from neighboring stations as extra information.

Those pseudo-observations, used in addition to usual hourly observations, allow us to reduce the gap in the number of hourly data provided to re-analysis systems between the beginning and the end of the re-analysis period. Impact studies had been carried out with the analysis system SAFRAN from 1958 to 2010.

Temperature anomalies coming from this new system are compared to those obtained from a national thermal index (calculated with data from 30 stations over France) and from homogenised series. It shows a reduction of heterogeneities with respect to an analysis using only usual hourly observations, however some of them remain.

The complete validation of those new re-analysed temperatures to produce operational national and regional thermal indexes is still ongoing. From now those data are already used to evaluate the spatial variability of heat waves in the framework of the national project EXTREMOSCPE.

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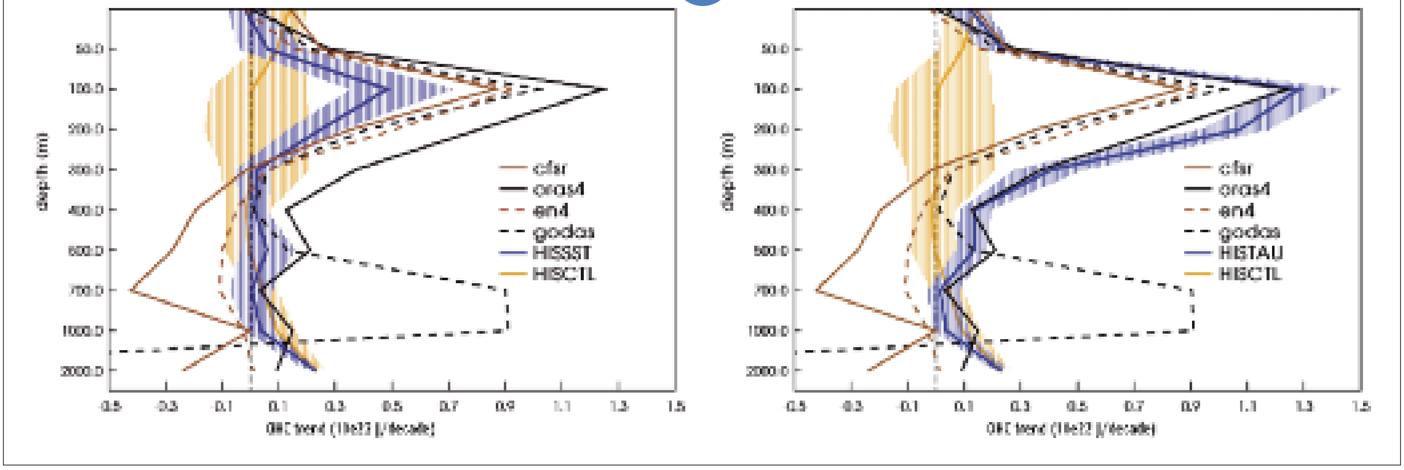
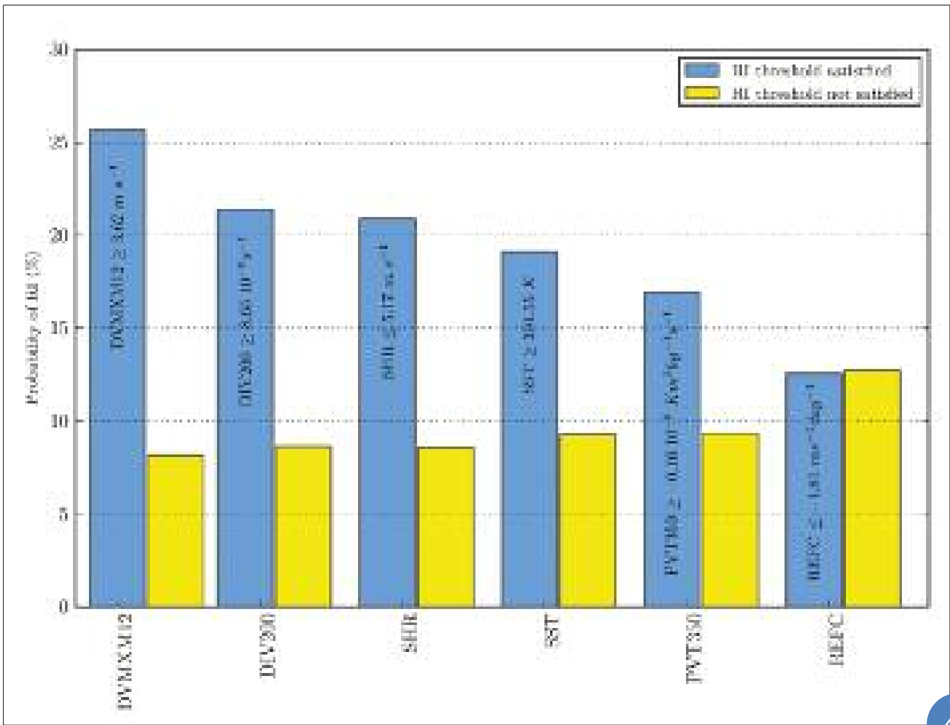


(a) et (b): Vertical profiles (as a function of depth in m on the y-axis) of 1998-2012 linear trends in the west tropical Pacific (20°S-20°N, west of 200°E) heat content (in 1022J/dec) in four global ocean reanalysis datasets (ORAS4 being the most reliable) and in three ensemble experiments: HISCTL (control experiment with a free tropical Pacific variability), HISSST (left-hand side only, perturbed experiment with tropical Pacific daily sea surface temperatures relaxed towards the observed monthly mean anomalies), and HISTAU (right-hand side only, perturbed experiment with tropical Pacific daily surface wind stress overridden by observations). Ensemble mean linear trend profiles are shown as thick lines while shading extends over the range of all ensemble members.



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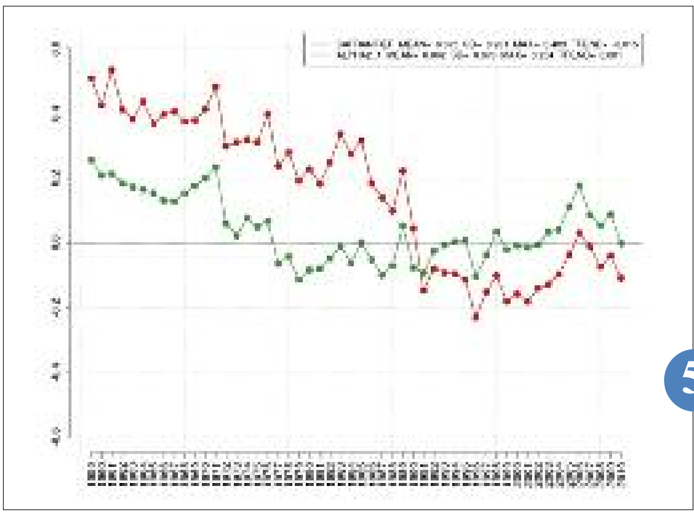
The probability of rapid intensification (RI) when the specified RI predictors (X-axis) were satisfied (blue) or not (yellow) The RI thresholds of each predictor are also presented. To illustrate, RI occurred 25% of the time when DVMXM12 was above the 3.6m/s threshold.



5

Differences of annual anomalies for minimum temperature coming from SAFRAN Reference in red (using only usual hourly observations) and SAFRAN ALPHA2_1 in green (using additional pseudo-observations) with respect to anomalies coming from the national thermal index

Seasonal and climate forecasts

Sub-seasonal prediction: Summer 2015

Météo-France provides weather forecasts up to three days and seasonal forecasts for two to six months, the range in between being assigned to ECMWF. The WMO project s2s (sub-seasonal to seasonal) offers on line monthly forecasts in quasi-real time.
CNRM decided to participate in this exercise, by providing on 1st of each month forecasts up to month two. A series of reforecasts covers 1993-2014, and 51-member ensembles are issued each month since May 2015. These forecasts are produced with the same model as our system 5 of operational seasonal forecasting. Figures "a" and "b" show forecasts starting respectively at June 1st and July 1st for mean daily temperature over France. Those two months (particularly July) have undergone above normal temperatures. The chronology of the model is not highly accurate, even during the first days. The model does not compete with ARPEGE-AROME short-range weather forecasts. The plume of individual forecasts stays mainly above 1993-2014 climate normals. One can observe that the increase in temperature late June, which reaches a maximum on July 1st, is anticipated by the June 1st forecast. The perspectives are to use a sufficient number of reforecasts to assess, through prediction scores, the capability and limits of a seasonal forecast model to predict a realistic chronology of large-scale phenomena.

6

Arctic sea ice predictability: a multi-model approach

The Arctic sea ice cover is a major component of the global climate system. It may also be an important source of climate seasonal predictability. A capacity to predict the sea ice cover a few months in advance could benefit to seasonal forecasting capabilities in the high latitudes and beyond.
In this study, we compare 5-month predictions of the Arctic sea ice extent with CNRM-CM5.1 and EC-Earthv2.3 global coupled models. Predictions are initialized on 1 May every year between 1990 and 2008.
Despite sizeable biases, skill scores for the predictions of sea ice extent anomalies are significantly high in both models, in the Arctic Ocean as well as in sub-regions such as the Barents and Kara Seas.
For some lead times, the multi-model predictions resulting from the combination of the predictions of the two models are better than those of each individual model. Regarding sea ice spatial distribution, multi-model predictions are often more realistic than those of individual models, due to bias compensation. Thus, multi-model predictions could be of use for some Arctic Ocean users.
The multi-model approach is a promising framework for future development and qualification of Arctic seasonal forecasting systems. Focusing on sub-regional predictions seems also more relevant for understanding the mechanisms of variability and predictability of the coupled ocean-sea ice-atmosphere system, and highlighting possible linkages between high and mid-latitudes.

7

An application of seasonal forecast to water resource management in France

Seasonal forecasts applications are very rare over Europe, despite clear expectations. Of course, because of the low level of predictability, but also because of the difficulty to interface complex probabilistic information with potential users' tools.
One of the main objectives of the European project EUPORIAS (2012-2016) is precisely to encourage the climate community to interact with stakeholders, and to assess, through specific and well-documented case studies, the benefit of seasonal forecasts on decision making processes.
In this context, the prototype proposed by Météo-France aims to provide to water resource managers tailored information, that could help them to anticipate the coming season. It is based on a hydrological forecasting chain, built on seasonal forecasts (from ARPEGE model) and on a SVAT model (SAFRAN-ISBA-MODCOU). In particular, this chain delivers probabilistic river flow forecasts over France. EPTB Seine-Grands Lacs, responsible for the management of 4 large reservoirs in the upper Seine catchment, has collaborated intensively to this work.
The usefulness assessment of seasonal forecasts has been led on one catchment, for May 1 initial conditions, to anticipate the summer season. 29 decisions have been "replayed", in a blind test with 2 sets of forecast (seasonal forecast on one hand, and on the other hand with a placebo where the hydrological chain is forced by some scenarios taken from climatology), and "without forecast" (knowledge of dam level and hydrological conditions on May 1). This experiment seems to show that the hydrological chain helps to better manage the first months of the dry season.

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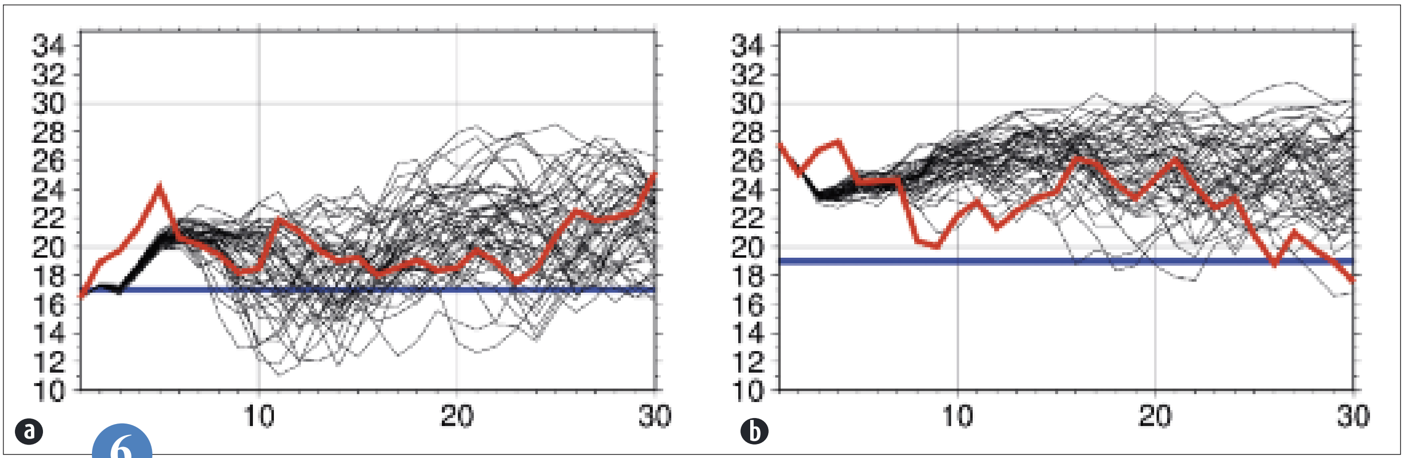

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Forecast (black thin line) and observed (red thick line) daily temperature over France in June 2015 (a) and July (b). The blue straight line is monthly mean of the last 22 years.

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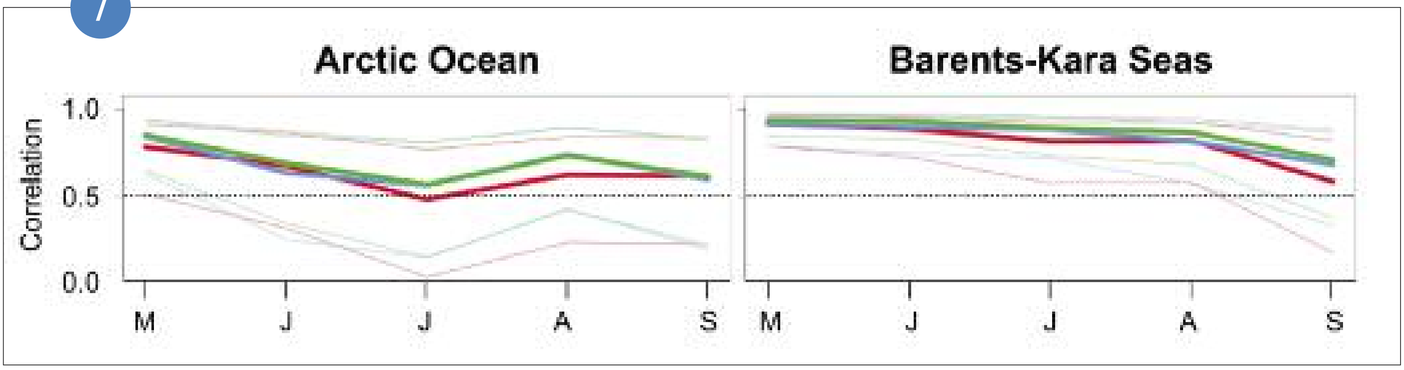

Correlation coefficients, as a function of the prediction lead time (start date : May 1), between the observed sea ice extent (source: NSIDC) and the sea ice extent predicted by the models in the Arctic Ocean (left) and the Barents-Kara Sea (right). Red: EC-Earthv2.3. Blue: CNRM-CM5.1. Green: combination of the two models. Thin lines show the confidence interval of the correlation (thick lines).

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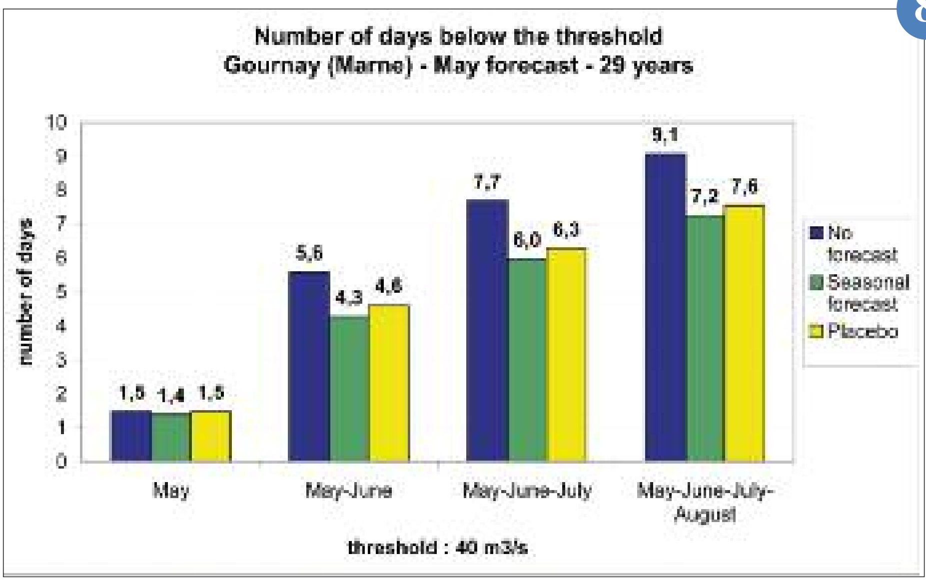

Results over 29 decisions made on May 1st, without any forecast (in blue), with seasonal forecasts (in green) and with the placebo (in yellow). A perfect decision would lead to "zero day below the threshold". These assessments rely on the 1st forecast month (May), the first two forecast months (May and June), the first three forecast months (May to July) and the first four forecast months (May to August).

Diagnosis and detection of climate change

The 9th International Conference on Urban Climate

How to prevent cities from becoming furnaces because of global warming?
Almost 600 researchers of 60 countries have interacted and exchanged on the results of their scientific studies on this topic. Météo-France organized in Toulouse this summer, from the 20th to the 24th of July, the 9thInternational Conference on Urban Climate (ICUC9). This conference takes place every 3 years and gathers all the scientific community on urban climate. It is organised under the aegis of the International Association for Urban Climate (IAUC). Since its first edition in 1989, this is the first time France hosted this international scientific event. As always, due to the urban problems in these countries, Asians formed the largest delegation.
This conference helped to increase knowledge on urban climate on the basis of observation and modelling. A workshop on “Local Climate Zones” brought together 200 participants. This approach aims to map the cities as homogeneous areas in terms of typology and urban microclimate (which was verified by measurement campaigns, such as in Nancy or in Colombo, Sri Lanka). This type of mapping, generalized to all cities of the world, will provide a common framework for the scientific community for future work in urban climate.
This edition also focused on the adaptation of cities to climate change. For example, Australian scientists that are specialists in urban vegetation and alternative methods of city water management, recommend planting trees in town. Other studies conducted in China highlight the interest of preserving undeveloped green axes to ventilate the city. Studies at Météo-France show, by modelling, that greening a part of the available spaces on the ground, such as parking lots and sidewalks, would reduce the temperature by a few degrees during a heat wave.

9

Characterization of heat waves in current and future climate (EXTREMOSCOPE project)

A new method for heat waves analysis at regional scale has been defined within the framework of the EXTREMOSCOPE project, funded by French Ecology Ministry (MEDDE). Diverted from the operational tool for national climate monitoring, the identification of the events is assumed by using different percentiles from average temperature series. Each heat wave can be defined in terms of duration but also maximum of intensity and severity. This method has been assessed with national and regional temperature indices, and applied in current climate with a new dataset coming from Safran reanalysis, aggregated into a local scale in France (95 departments). In the same way, heat waves analysis was projected in future climate with a Regional Climate Model (Aladin Climat) and three different scenarios RCP 2.6, RCP4.5 et RCP8.5.
An inventory of past heat waves at regional scale since 1958 has been achieved and allows to build an original climatology, highlighting different typologies in France according to Mediterranean regions (more intense and more severe waves) or North Eastern area (more numerous waves). In particular, this approach has been used to qualify heat waves experimented during summer 2015 in France.
In future climate, Aladin Climat projections with all RCP used, agrees on an accentuation of heat waves during the twenty-first century in number of events, duration and severity with an intensity strongly dependant on the scenario RCP considered (see Figure).
This work will be pursued in the next months taking account uncertainties linked to climate models considering Eurocordex ensemble.

10

A reference dataset for the analysis of the evolution of rainfall amount in France since the 1950s

Analyzing climate changes from meteorological measurements requires climatological series whose values are comparable over time. Many events are likely to introduce inhomogeneity in the series (due to relocation of measurement station, changes in their environment, changes of sensor...). Homogenization is a statistical process to detect and correct heterogenities related to these changes, in order to keep only the climate signal.
In 2014, Météo-France has achieved the homogenization of a set of monthly series for precipitation covering metropolitan France since the 1950s. Météo-France now has more than 200 monthly homogenized series of temperature and 1100 for precipitation allowing to provide a diagnosis at the regional level. Homogenized series are also available on some overseas territories.
Over the period 1959-2009, the analysis indicates mostly an increase in annual rainfall amount in the northern part of the country and a decrease in the southern regions. This contrast between the North and the South is observed during summer and especially during winter. However, excepted in some regions in the East of France or close to the Mediterranean Sea, annual trends are generally not significant and sensitive to the studied period.
The ClimatHD (http://www.meteofrance.fr/climat-passe-et-futur/climathd) application relies on these homogenized series in its section on the past climate. The homogenized series will be regularly updated, in order to provide an up to date diagnosis.

11

9

Participants to the '9th International Conference on Urban Climate' in Toulouse
All extended abstracts, posters and slides of the oral presentations are available on the website of the conference: http://www.meteo.fr/icuc9

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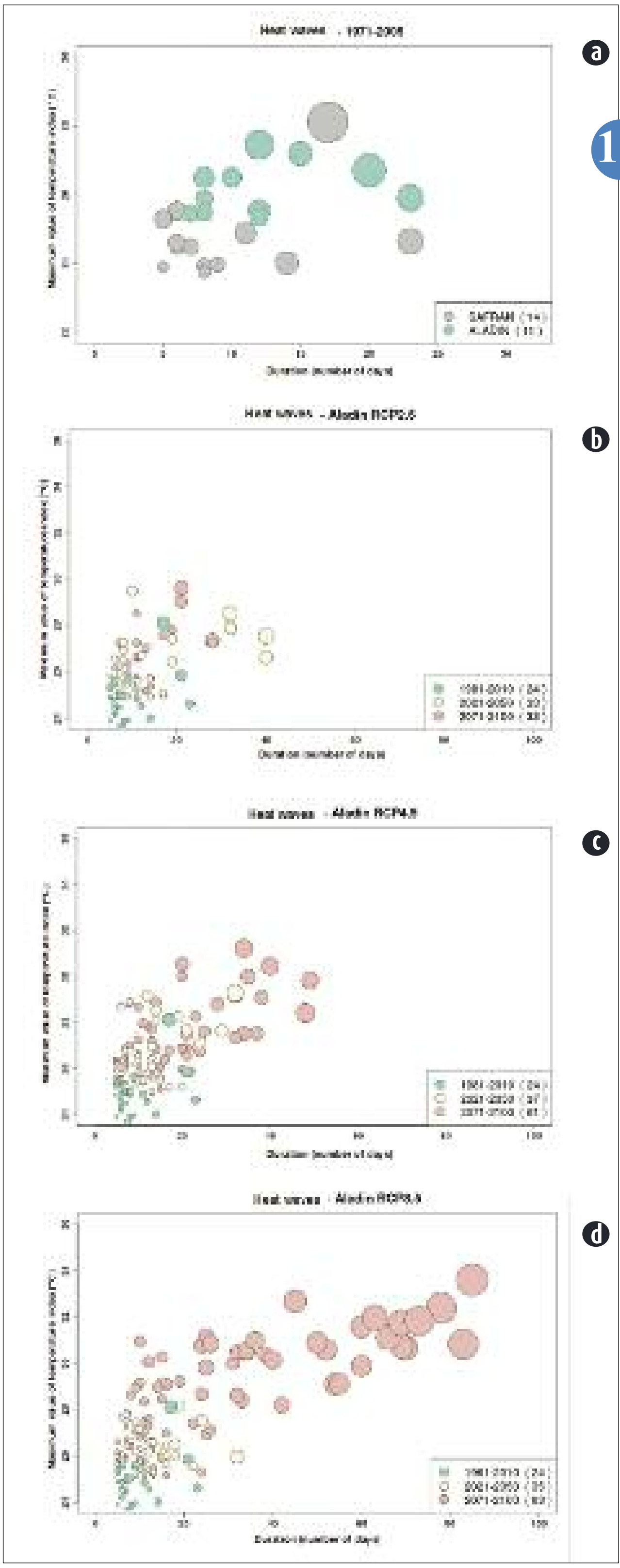

Representation of the projected evolution of heat wave in France with climate model ALADIN in terms of duration (X axes), maximum of intensity (Y axes) and severity (size of bubbles):
(a): comparison historical run and Safran re-analysis over the period 1971-2005;
(b): projection with RCP 2.6 (in green, current period 1981-2010, in yellow, mid-century 2021-2050, in red, end of century 2071-2100);
(c): idem with RCP4.5;
(d): idem with RCP 8.5.

Evolution of annual rainfall amount for the period 1959-2009, estimated from the homogenised series.

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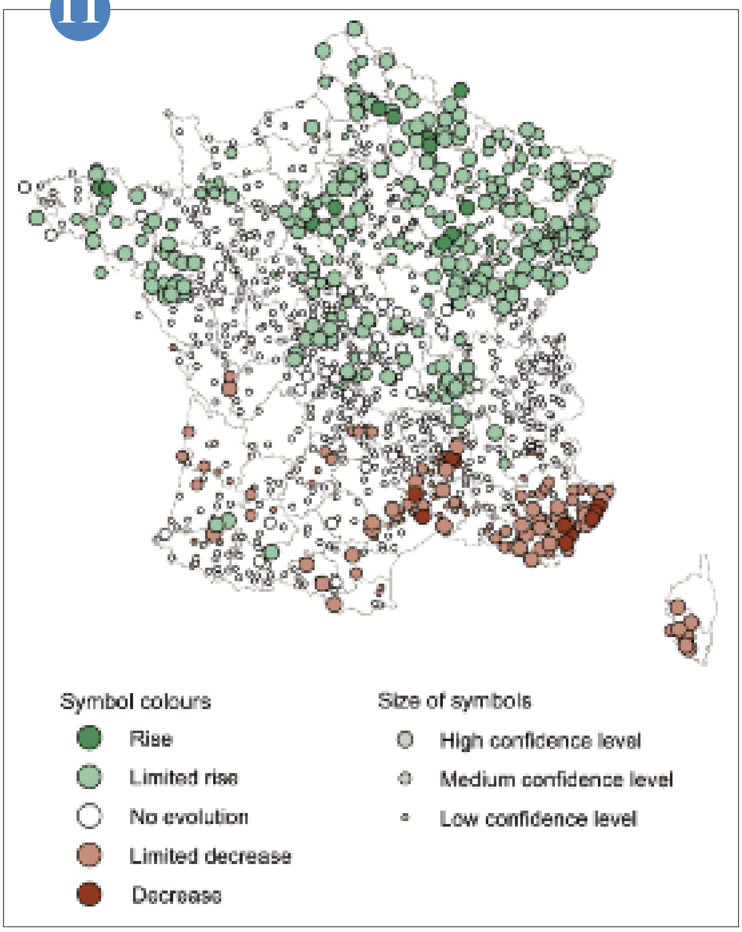

AURELHY evolution

Météo-France developed in the 1980s (Bénichou & Le Breton, 1987) an innovative spatialization method, AURELHY (Analyse Utilisant le RELief pour l'HYdrométéorologie), which uses the climatological normals at the observation network stations and the statistical relationship with orography on climatological scales. This tool, used by Météo-France/DCSC for the production of spatialized climatological normals on France (Canellas et al, 2014), had undergone little evolution since its creation, though spatialization of meteorological parameters has been a very active field of research.
Météo-France/DCSC has therefore initiated in 2014 a pluri-annual action to upgrade AURELHY, both on the technical and methodological plans. The first year has been devoted to the technical evolution of the software, which has been converted to a more modern and evolutive language (R), and to the simultaneous introduction of various new options in the code. The work has been continued in 2015 with the completion of a set of sensitivity experiments designed to optimize the implementation of the method (spatial resolution, statistical method of predictors' selection, kriging parameters, ...) and to explore possible evolutions (introduction of new predictors, combination of several spatial scales, use of weather type classifications, etc). A last aspect of this work, currently undergoing, is the improvement of the input data used by AURELHY (filling gaps in observed data, inclusion of other sources of data, ...).
The aim of this action is to provide a new operational version of AURELHY in 2016, usable for a large range of applications.

12

Modelling the financial impact of climate change on catastrophe losses

In 2015, Météo-France performed long-term climate modelling to support the work of the French Reinsurance Company (CCR) that aims at assessing the financial impact of climate change on natural disaster compensation scheme, following a medium IPCC scenario.
To allow a comparison between insured losses under the current climate (2010) and their equivalent in 2050, Météo-France Meteorological Services Direction ran two climate simulations of 200 years with the help of CNRM and DCSC.
These simulations of ARPEGE-Climat model offer a multitude of plausible and consistent meteorological situations under a given greenhouse gases concentration assumption. Results are stored at about 20km resolution, at a hourly time step and debiaised with SAFRAN or ERA-Interim reanalysis. Debiaised data is introduced in the land surface model ISBA to generate soil water indices.
CCR impact models, fed with these climate simulations output, addressed flood, drought and storm surge.
The conclusion is that natural disaster losses due to climate events in mainland France should double in 2050.
This increase is mainly due to the evolution of insured values and their spatial distribution. It represents more than three quarters of the total increase.
Climate change will also have, in terms of events intensity and frequency, an impact that explains 20% of the increase.
The results of this work were presented during the meeting "The challenges of natural disaster insurance against the future climate", organized by CCR, at the COP21 Climate Summit.

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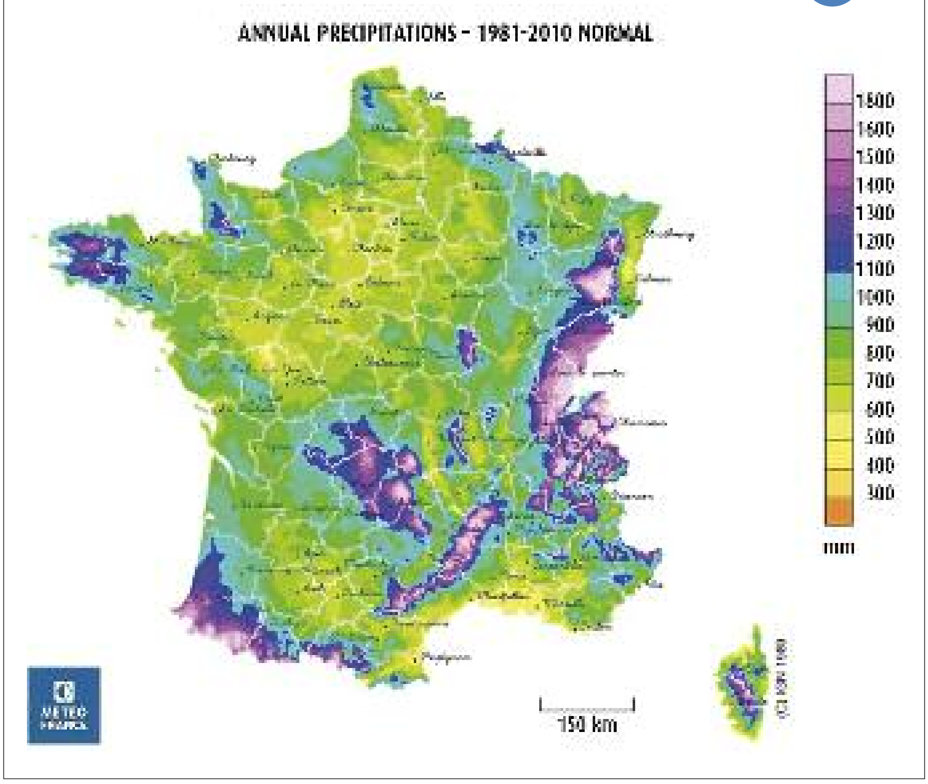
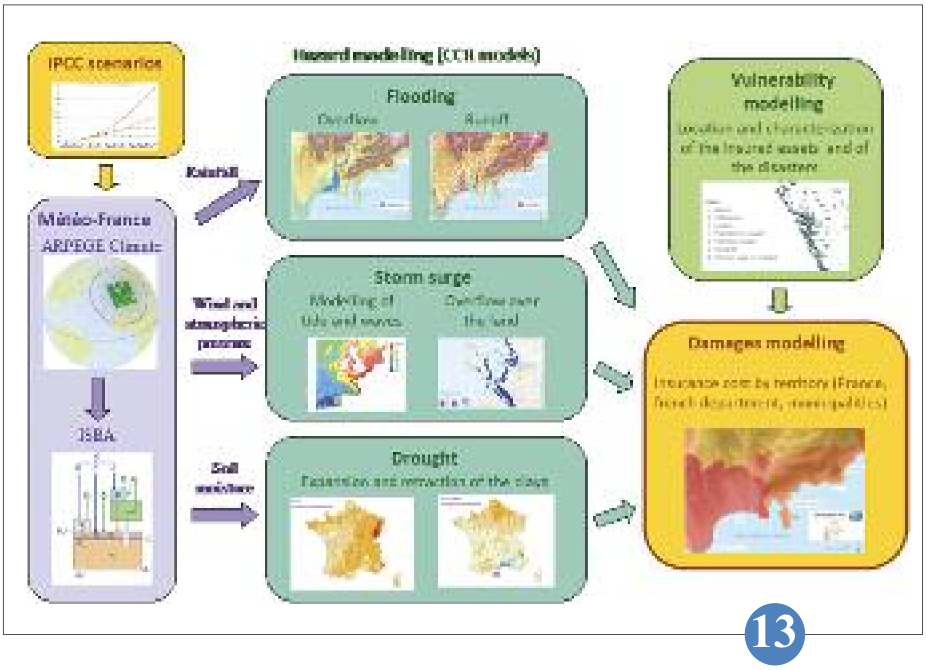


AURELHY normal of annual precipitations (mm) above France for the 1981-2010 period.

Modelling chain of damages due to natural disasters (source: CCR).



Impact of climate change on the vegetation cycle over France

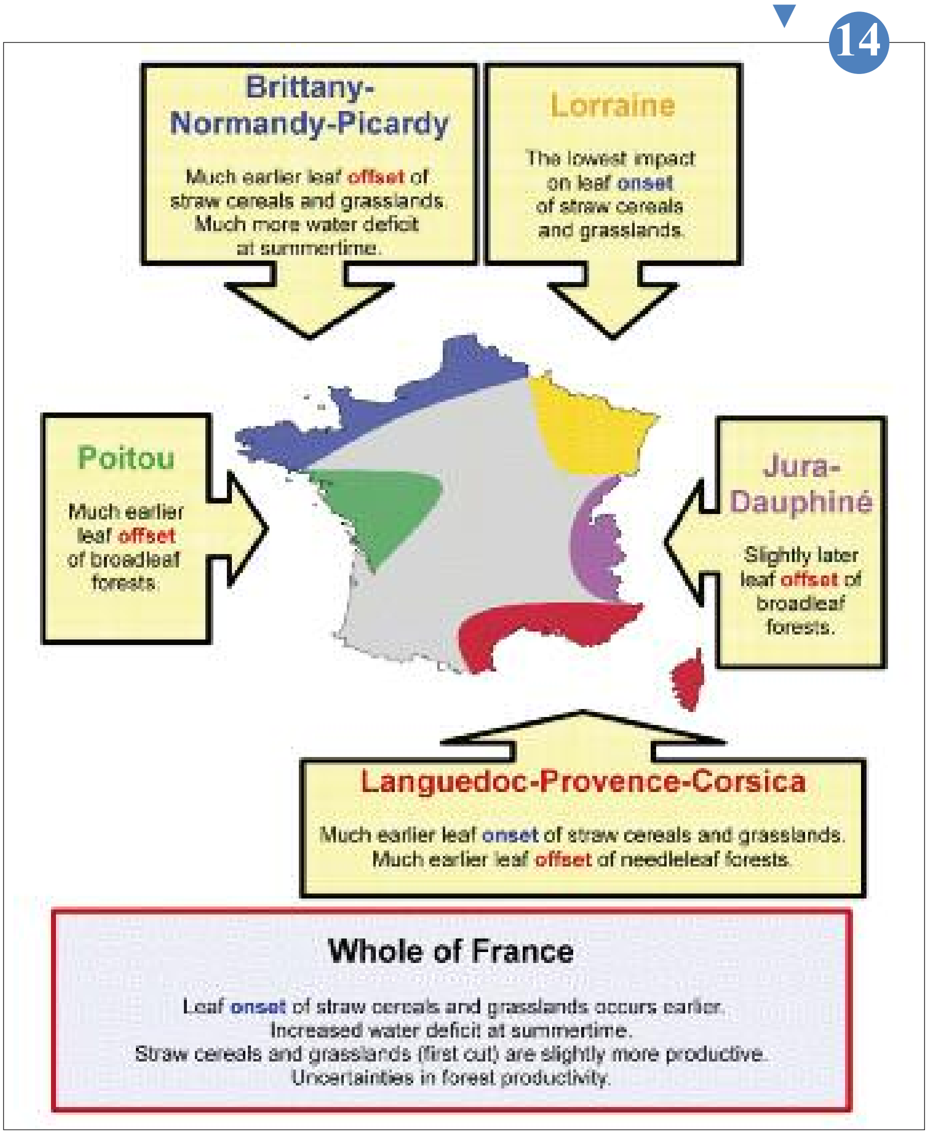
Climate is traditionally characterized by atmospheric variables such as air temperature. In the context of climate change it is important to consider, also, terrestrial variables more directly linked to life, such as the above-ground biomass of vegetation or soil moisture.

The ISBA (Interactions between Soil, Biosphere and Atmosphere) model is used in atmospheric and hydrological models of Meteo-France to simulate the water and energy fluxes on a sub-hourly basis. This model also provides simulations of photosynthesis, plant growth, and carbon storage into soils. An ensemble of eleven downscaled climatic simulations was used to characterize consistent future trends.

First, an earlier leaf onset is simulated for all the vegetation types, everywhere in France. The CO_2 effect triggers a slight increase in the productivity of grasslands (first cut) and of straw cereals. On the other hand, the forest productivity displays high uncertainties as it is very sensitive to the use of a given climate model. Other trends present regional characteristics. In the Brittany-Normandy-Picardy area, ISBA simulates a much earlier leaf offset than today for all the vegetation types, in relation to a more pronounced summer drought. In the Poitou region, forest defoliation would occur much earlier than today. Conversely, the model simulates a slightly later leaf offset of broadleaf forests in the Vosges, Jura, and Dauphiné mountainous areas. Finally, a much earlier leaf onset is simulated for low vegetation in the Mediterranean area.

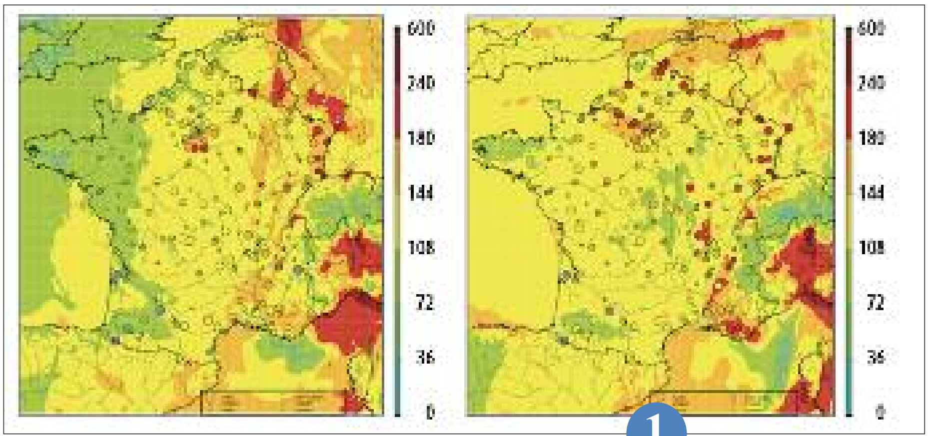
13

Main trends in France on the phenology and on the biomass production simulated by the ISBA model related to climate change in the 21st century, based on an ensemble of climatic simulations.



Chemistry, aerosols and air quality

At the end of the European project MACC, Météo-France was retained, through a response to a call of opportunity of the Copernicus Atmosphere program, to coordinate and operate an activity of operational production of air quality multi-model forecasts over Europe. Within the framework of the development of this system, we realized first evaluation studies of the robustness of the scores of performance of the multi-model ensemble in the forecast of ozone pollution episodes. Within the framework of the researches led on volcanic plumes, a new tool of survey and visualization of the plumes was developed allowing to bring a precious help to the realization of measurement campaigns. A striking fact of year 2015 also concerned the validation of the representation of the secondary inorganic aerosols in the chemistry-transport model MOCAGE, both at regional and global scales. In particular, the PM10 forecasts over France using this new model version show a net improvement, as well over long periods as for aerosol pollution events. In addition, the processing and analysis of the data of the GLAM campaign led within the framework of the international project CHARMEX, allowed to document the variability of the chemical constituents and aerosol particles over the Mediterranean Basin.



1

Daily maximal concentrations of surface ozone (µgm^{-3}) forecasted by the new version of the MOCAGE model including the secondary inorganic aerosols. The forecasts correspond to the pollution episode occurring the 2 (left) and 3 (right) of July 2015. The associated observations appear in coloured circles at the locations of the measurement stations.

1

Evaluation of the robustness of ensemble methods for air quality

The Copernicus Atmosphere Monitoring Service for air quality aims at providing analyses and forecasts of the main pollutants over Europe: from 25°W to 45°E and from 30°N to 70°N.

Based on the outputs from 7 individual models, a multi-model ensemble has been developed during the MACC-II research project, in order to produce the best possible outputs. The MACC-II ensemble is currently based upon a median value approach: for each time-step and for each grid-point of the domain, the ensemble model value is simply defined as the median value of all the individual model outputs at this point.

The sensitivity of the ensemble performance to the number of models that are used is assessed during an ozone pollution episode over Europe (from 9th to 15th of June 2014). The median ensembles 'MEDIAN 7', 'MEDIAN 5', 'MEDIAN 3', based respectively on 7, 5 and 3 models, and '1BEST', which is the best model during the ozone peak time, are compared with regards to surface observations over Europe. The results (Figure) confirm that the complete ensemble (MEDIAN 7) performs generally better than the best model (1BEST). When only five models (MEDIAN 5) are used, all scores show slight differences with the MEDIAN 7. Going to only three models (MEDIAN 3) leads to statistical indicators degraded but performance is generally better than the best model. This indicates that using an ensemble of models, even if reduced, is more useful than using a single model of very good quality. This also shows that with 5 models available, the ensemble is still robust compared to observations.

Although robust and reliable, the median approach may be outperformed by more refined methods, which are under investigation.

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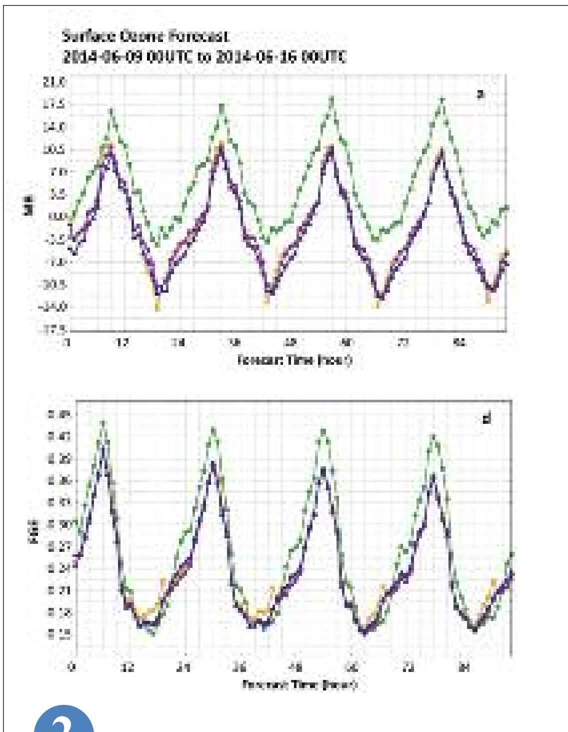
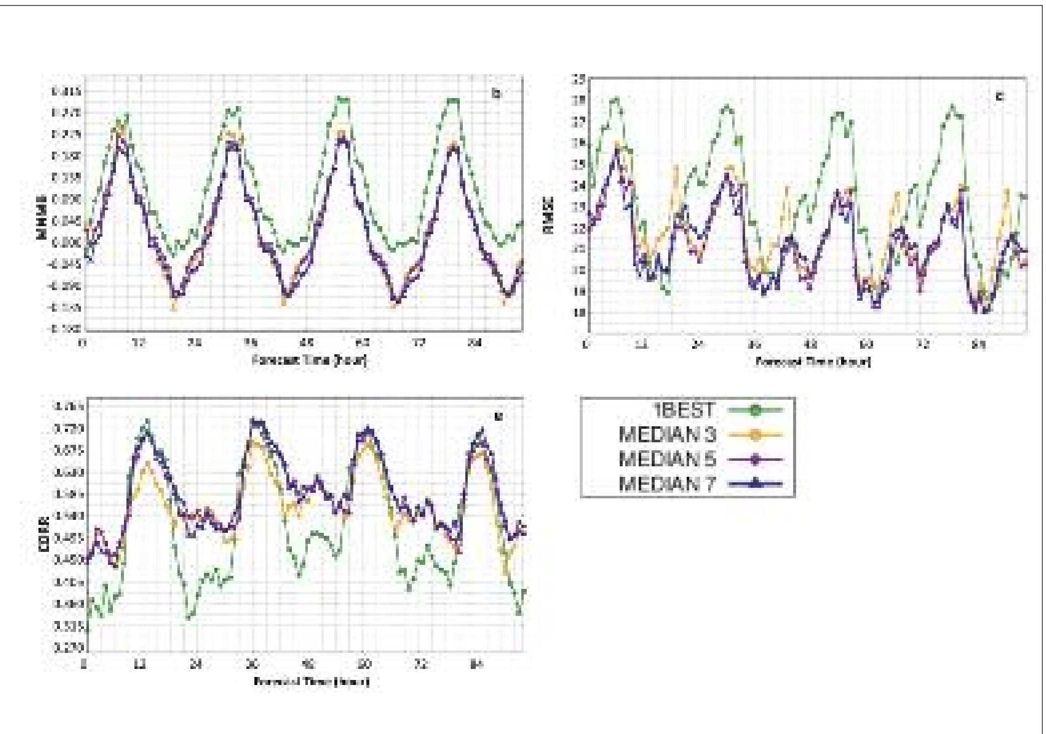


2

Website for Copernicus atmosphere regional products.

Statistical indicators for ozone as a function of the forecast time (in hour): MEDIAN 7, MEDIAN 5, MEDIAN 3 and 1BEST (see text for their definition) compared to the hourly surface station measurements available for the period from the 9th to the 15th of June 2014 over the MACC-II European domain. (a) Mean Bias in g.m^{3}, (b) Modified Normalized Mean Bias, (c) Root-Mean-Square Error in g.m^{3}, (d) Forecast Gross Error and (e) Correlation.



Copernicus Atmosphere Regional Production

Copernicus services are developed in the continuity of the GMES program (Global Monitoring for Environment and Security) supervised by European Space Agency and European Union. In particular, the implementation of the atmosphere services program has been delegated to European Centre for Medium-Range Weather Forecasts (ECMWF) by the European Union.

After competitive bidding, Météo-France will lead the CAMS50 services for a three year contract. CAMS50 project is related to the operational regional production of a multi-model ensemble (air quality models: forecasts, analyses and re analyses), based upon the heritage of MACC research projects. Météo-France ensures the following services and responsibilities:

- provision of data and products
- reliability of the system
- evolutions regarding users needs

Nine subcontractors are involved in this project:

- INERIS provides steering role for the re-analysis productions, and brings the outputs of its CHIMERE model
- Five other institutes European provide the outputs of their models, MetNorway (EMEP), RIUUK (EURAD IM), KNMI, TNO (Lotos-Euros), SMHI (MATCH), FMI(SILAM) to join those of the model MOCAGE of Météo-France and CHIMERE, cited above
- Three countries were integrated into the proposal, in order to prepare an extension of the number of models contributed to the ensemble: UKMO (AQUM), Aarhus University (DEHM) and WUT (GEM QA).

Within MF, the collaboration of many departments (DSM, DSI, CNRM, DCT) and the specific hiring of personnel were required to offer this service with a budget of several million euros. The main objective of this project is to deliver fully operational data and products to users. However it also includes a development aspect for improving the system, and it will interact with other projects of the Copernicus atmosphere program, regarding users' needs, evolutions or validations of the products.

3

Assimilation of Lidar Aerosol products in the MOCAGE model: towards improving the vertical distribution

The assimilation of aerosols is a relatively new field compared to that of the reactive gases. Even if the number of unknowns relating to aerosol is larger than that of gases, the assimilation of aerosols nevertheless improves their distribution in the model.
In CNRM-GAME, the assimilation of aerosols is implemented in the chemistry-transport model MOCAGE since 2014 and allows to assimilate two types of aerosol data: 1) integrated atmospheric column such as the Aerosol Optical Depth, 2) or aerosol profiles from lidar measurements with different configurations (from the ground, from satellite platforms or from aircraft measurements).
Assimilation of lidar profiles of CALIOP measurements onboard the CALIPSO satellite during the summer 2012 was undertaken in terms of extinction coefficient. This period corresponds to the airborne campaign TRAQA-2012 and coincides with a desert dust transport event from Africa over the Mediterranean.
Figure (a) shows the aircraft trajectory with respect to its altitude corresponding to 29 June 2012 between 10:00 and 15:00. Figure (b) shows the aerosol concentration time-series of both model outputs and assimilated product compared to in-situ measurements made by the aircraft. Clearly the assimilation of CALIOP observations significantly improves the penny-underestimation of the aerosol concentration predicted by the model especially in high altitudes. Figure (c) shows a vertical cross-section of the aerosol concentration given by the MOCAGE model compared to that resulting from the CALIOP assimilated product. The improvement of the free model run by the assimilation of lidar profiles is evident both in terms of quantity and in terms of aerosol vertical distribution.

4

The Gradient in Longitude of Atmospheric constituents above the Mediterranean basin (GLAM) airborne campaign

In the framework of the Chemistry-Aerosol Mediterranean Experiment (CHARMEX) programme, the *Gradient in Longitude of Atmospheric constituents above the Mediterranean basin* (GLAM) airborne campaign has been set up to investigate the variability of constituents (pollutants and greenhouse gases) and aerosols between the West and the East of the Mediterranean Basin in summer 2014.
Aboard the SAFIRE Falcon 20 aircraft, several instruments measured aerosols, humidity and chemical compounds such as ozone (O_3), carbon monoxide (CO), methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). The campaign took place from 6 to 10 August 2014 from Toulouse (France) to Larnaca (Cyprus) via Menorca (Spain), Lampedusa (Italy) and Heraklion (Crete) at 5000 m altitude and the backward transect at 9000 m altitude.
Along an East-West axis or along the vertical, we analysed different processes:
1 – Intercontinental transport: biomass burning from Northern America, desert dust from Sahara and O3-depleted maritime boundary layer air masses from the Arabian Sea impacted the upper tropospheric Mediterranean Basin after 10-15 days of transport.
2 – Subsidence: vertical stratification of the atmosphere has helped quantifying the vertical descent over the central-Eastern Mediterranean Basin.
3 – Pollution: in the maritime boundary layer off the Cyprus and the Lampedusa coasts, episodes of highly polluted air masses were measured but could not be attributed neither to long-range transport of pollutants nor to local inland pollution.
We are now investigating the possibilities of a new airborne summertime campaign to evaluate the link between the Eastern Mediterranean Basin and Asia, particularly the Arabian Sea/peninsula and the Indian subcontinent.

6

FLEXFIRE: Production and 3D visualization tool of volcanic plumes via Internet

In the frame of ANR (Research National Agency) research project STRAP (Transdisciplinary Synergy Responding to volcanic plumes Hazards), the Tropical Cyclone Research Division of Météo-France in La Réunion and the "troposphere" team of the Laboratory of Atmosphere and Cyclones (LACy) have developed the web tool FLEXFIRE, which allows both to run the atmospheric diffusion model FLEXPART used to monitor sulfur plumes from volcanic eruptions, and to view the results in interactive 3D. Although the model runs in Toulouse and visualization products are created in La Reunion, the whole production chain and 3D display is controlled by a simple internet browser. The entire production (3D and simulation files) shall not exceed thirty minutes.
This ability to remotely control the FLEXPART model was particularly useful during the recent eruptions of the Piton de la Fournaise volcano. Indeed, engineers and researchers were able to launch the model and visualize simulation outputs from anywhere, allowing to adjust at all times the flight plans of ULM performing in-situ measurements in volcanic plumes.

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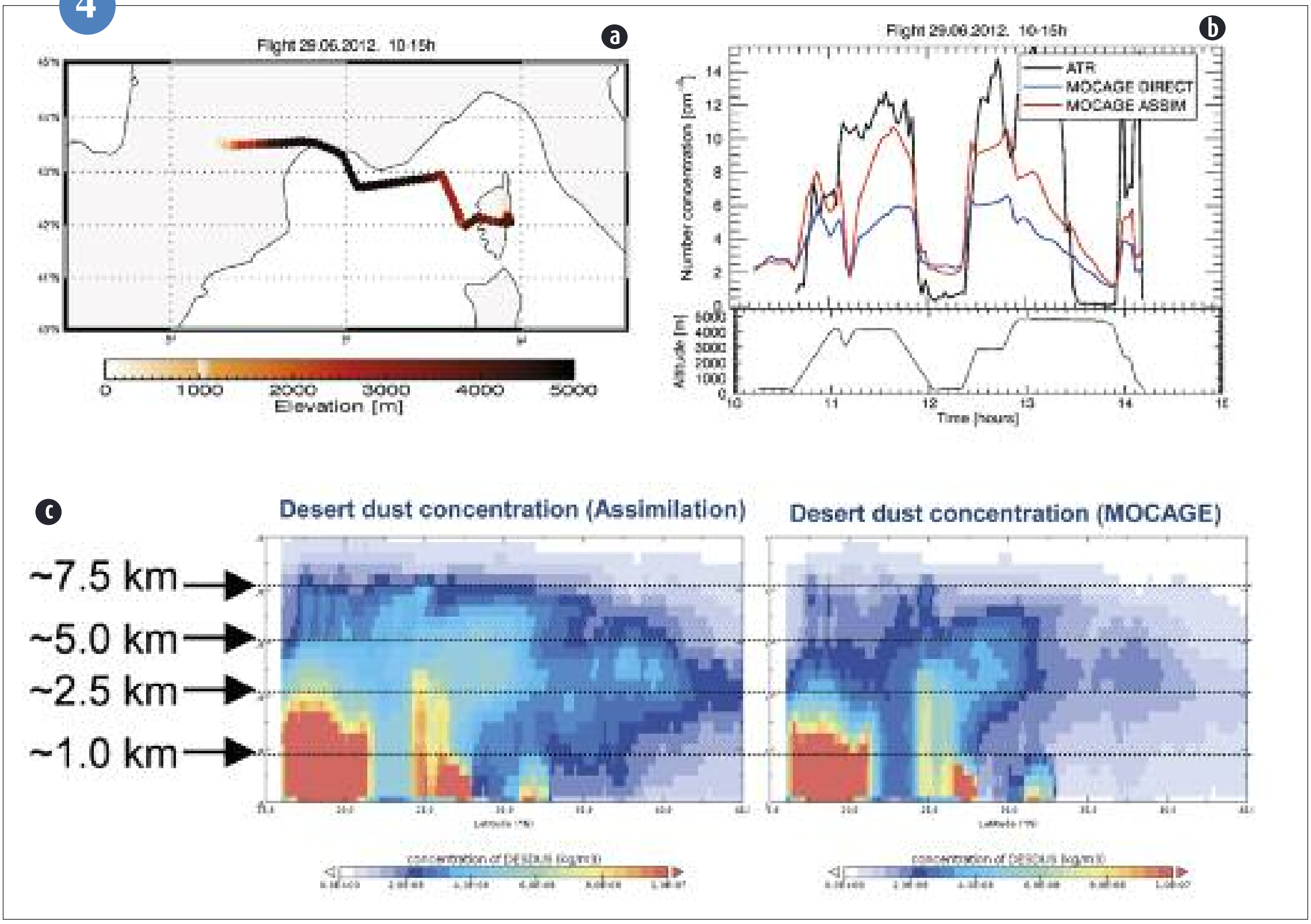
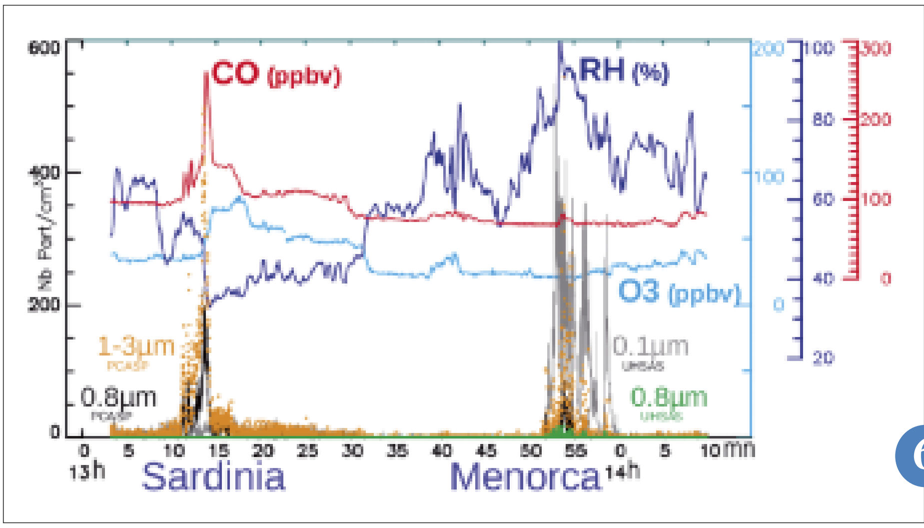


(a): The aircraft trajectory with respect to its altitude corresponding to 29 June 2012 between 10:00 and 15:00.
(b): Time-series of aerosol concentration given by the MOCAGE model, the CALIOP assimilated product and the in-situ aircraft measurements.
(c): The vertical cross section of the aerosol concentration given by the MOCAGE model compared to that resulting from the CALIOP assimilated product.

5

Interactive web interface used for 3D visualization of FLEXPART model outputs.



6

Time evolution of the aerosols and pollutants measured during GLAM on 10 August 2014 at 9 km altitude showing elevated aerosol loadings above Sardinia and Menorca together with high pollutants (O_3 and CO) over Sardinia (biomass burning) and low pollutants over Menorca (Saharan dust).

Snow

Snow science covers intrinsically a wide range of spatial scales, spanning the microscopic scale where transformation processes occur steadily, to the scale of mountain ranges which is relevant for weather and avalanche hazard forecasting. The macroscopic scale, or snowpack scale, corresponds to what can be visually observed in the field, and features a significant heterogeneity due to a variety of natural phenomena. Terrestrial laser scanning provides means to describe in detail the time evolution of the heterogeneity of the snow cover, able to provide constrains for numerical models designed to represent the processes responsible for this variability. At a larger scale, radar observations can increasingly be used, in combination with traditional surface observations, high-resolution numerical weather prediction models (such as AROME) and snowpack models, to provide increasingly accurate representation the snow conditions in a given mountain range.
On a different note, in order to address challenges induced by the impact of climate change on the socio-economy of snow tourism, efforts are underway to better understand the impact of snow management practices (grooming and snowmaking) on the behaviour of snow on the ground and better assess its climate vulnerability. Last, significant emphasis is placed on research at the microscopic scale, to better understand the physical and mechanical behaviour of snow, which is needed to provide new insights into processes driving avalanche hazard level and the evolution of snow. This requires the development of dedicated tools to obtain and specifically process the large amount of information representing the geometry of snow at the micrometre scale.
Snow research at Météo-France also spans a wide range of time scales. A few hours are sufficient to witness significant changes in snowpack state (due to snow accumulation, wetting, wind-induced erosion etc.). In contrast, the study of past and future climate conditions and their impact on the state of the mountain snowpack cover several decades, but in fact they rely on models which describe the time evolution of snow at the sub-daily scale, which is needed to properly account for the many non-linear processes governing the evolution of snow.

1

Microstructure-based modelling of snow mechanics

Characterizing the mechanical properties of snow and its evolution is a major challenge for avalanche forecasting. There is not a unique snow material but numerous snow types distinguished by the shape, the size and the spatial arrangement of their ice particles, which is called “microstructure”. The mechanical properties of snow are tied to this microstructure. However, because of the wide range of microstructural patterns and the difficulty in conducting mechanical tests on this fragile and heterogeneous material, the relationship between microstructure and mechanical properties is still poorly understood.
To decipher this link, we built, in collaboration with Irstea Grenoble, a mechanical model based on the three-dimensional microstructure of snow obtained by X-ray micro-tomography. The main idea is to numerically reproduce mechanical experiments by considering snow simply as a structure of ice. The difficulty of this approach is the processing of the large amount of data obtained by tomography at high resolution (10µm). For loadings involving small local deformations such as the elastic behaviour (Fig. a), the strategy is to use a fine description of the structure but a simple constitutive law for ice. For loadings involving complex structural re-arrangements such as the penetration of an object (Fig. b), the degrees of freedom of the structure are constrained to inter-granular deformations.

This method overcomes the difficulty of conducting real experiments on fragile snow types and enables to apply different and controlled loadings on the same sample. The accomplished progress helps to improve our knowledge of the material, in particular concerning its mechanical behaviour and the means to characterize it.

2

Two different strategies of microstructure-based mechanical modelling:
(a): Elastic stress distribution in a snow sample subjected to isostatic compression, modelled with finite elements;
(b): Grain re-arrangements during a cone penetration test, modelled with discrete elements.

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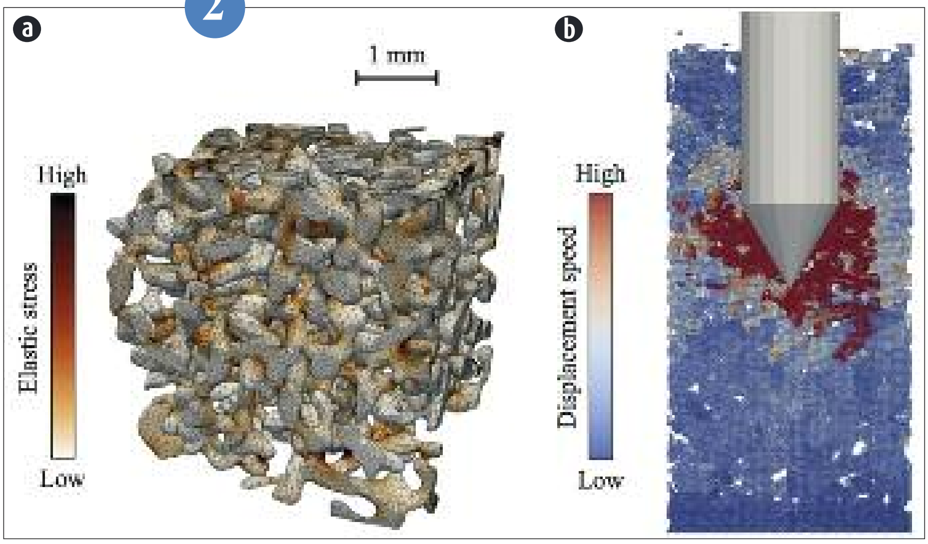

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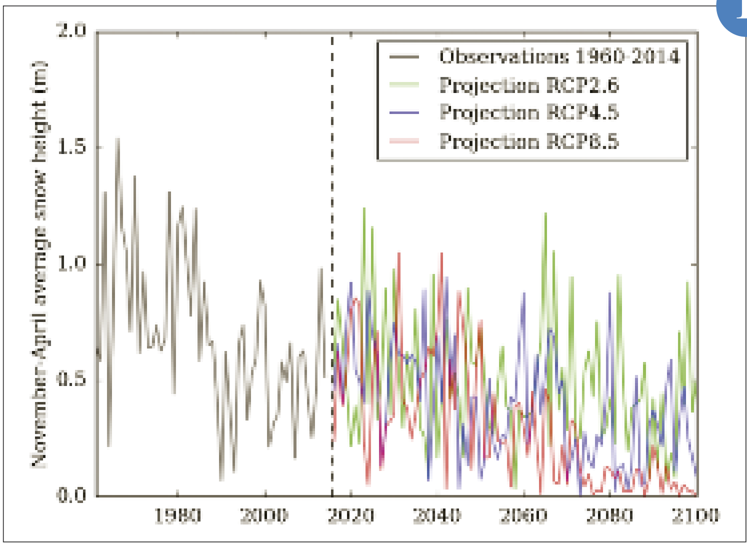

Overview of snow observations since 1960 to 2014 at the Col de Porte site (Chartreuse mountain range near Grenoble, 1325 m altitude) and climate projections into the 21st century according to the RCP 2.6, 4.5 and 8.5 scenarios.
Climate projections were carried out using the snowpack model Crocus driven by corrected output of the regional climate model ALADIN, in turn driven by the global climate model ARPEGE in the IPCC AR5 configuration.
Observations and projections feature significant year-to-year variability, superimposed on a steadily decreasing trend regardless of the climate scenario considered.

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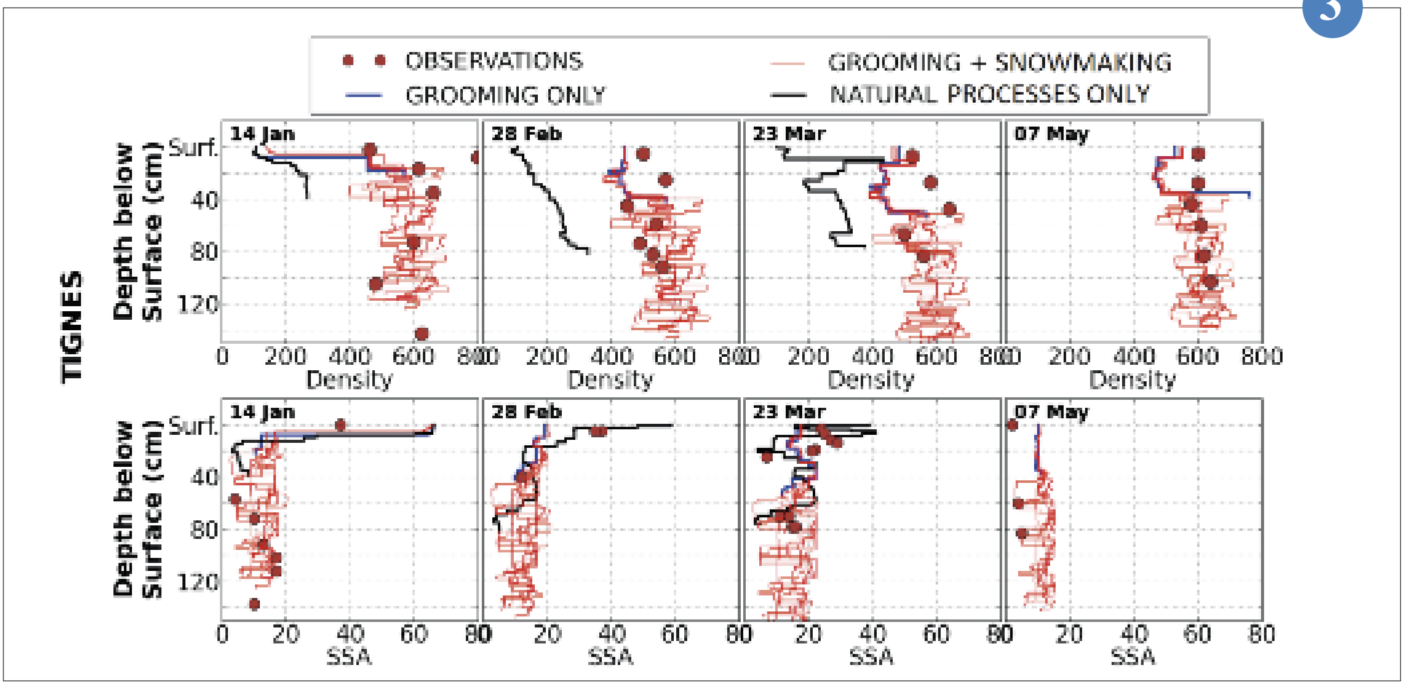

Impact of snow management on density (top line, kg m^{-3}) and snow microstructure (specific surface area: SSA, bottom line, m^2 kg^{-1}) of the top 150cm of the snowpack in Tignes (2015 winter season). In-situ observations (dots) are shown with simulations for natural snow conditions (black), groomed natural snow (blue) and groomed + machine-made snow (red, ensemble of simulations).

Integration of snow management processes in a detailed snowpack model

ow on ski slopes is a key socio-economic and environmental issue in mountain regions. Indeed, winter sports industry has become a very competitive global market and the increasing attention paid to climate change aroused the interest from both policy makers and ski lift operators to increase the level of understanding of the processes at play. In addition, most investigations of the climate vulnerability of the ski industry have been based on natural snow conditions even though snow management processes induce significant change to the physical state and behavior of the snowpack so that snow on ski slopes is markedly different than natural snow conditions in their surroundings.

In order to address snow conditions on ski slopes we have explicitly integrated comprehensive grooming and snowmaking approaches into the detailed multi-layer snowpack model Crocus. The implementation of grooming represents its impact on snow properties (densification, modification of the snow microstructure). The production of snow is carried out with respect to the ongoing meteorological conditions and specified rules, consistently with professional practices, and accounts for the fact that artificial snow has peculiar physical properties, different from freshly fallen natural snow. In-situ observations were carried out in four French Alps resorts during the 2014-2015 winter season spanning a wide range of snow management strategies and meteorological conditions. The model proved to provide significantly more realistic simulations of the snow properties on ski slopes with respect to these observations (Figure) than simulations of natural snow only.

The implementation of snow management in Crocus appears as a major step to better assess the evolution of snow conditions in ski resorts under past, present and future climate conditions. This work is carried out in close collaboration with Irstea Grenoble and in relationship with winter tourism stakeholders.

3

Monitoring of seasonal snowpack variability at an high-altitude alpine site and its evolution

In mountainous area, the spatial variability of snow depth depends strongly on the elevation and aspect of the slopes and their exposure to the wind, with a large impact on the avalanche hazard.
In order to better quantify the influence of wind-induced snow transport on this variability, a Terrestrial Laser Scanner (TLS) has been deployed during winters 2013-2014 and 2014-2015 around the experimental site of Col du Lac Blanc (2720 m a.s.l, Grandes Rousses range, French Alps). Blowing snow events often occur at this site. TLS allows to acquire three-dimensional point clouds of the snow-covered surface at high resolution over a surface covering approximately 25 ha with a range up to 800 m. Specific post-processing treatments are then applied to retrieve a Digital Elevation Model (DEM) of the snow-covered surface. Using the DEM of the snow-free terrain, snow depths are computed by difference between the two DEMs. The figure shows an example of maps of snow depth around Col du Lac Blanc at three dates of winter 2014-2015. It illustrates the high spatial variability of the snow cover at this site. Two areas where snow accumulates during blowing snow events are identified at the Northern and Southern sides of the site where snow depths are locally higher than 5 meters (Figure). Over these two winters, 13 snow depth maps have been realized.
This work, done in collaboration with Irstea Grenoble, provides a database of snow depth maps which is used to evaluate the numerical models of wind-induced snow transport and its effect, developed by Météo-France researchers.

4

Meteorological analysis in mountainous area, impact of radar observations

Daily precipitation analyses are necessary to model the evolution of the state of snowpack, which is done over French mountain regions using the snowpack model Crocus. The meteorological analysis scheme SAFRAN provides surface analyses of appropriate meteorological parameters (temperature, humidity, precipitation...) which govern energy and water budget of the snowpack, at massif scale (a massif is assumed to be a homogeneous area of about 500 km² or greater).
The main motivations of the present development is to build a precipitation analysis system called ODYC (Outil 1D-Var pour l'analYse des PreCipitations en zones de montagnes) having a quality similar to SAFRAN but that can also be easily adapted to provide precipitation analyses at smaller spatial scales. The ODYC system is able to use both conventional and remote sensing data (meteorological radar) which provide direct or indirect estimates of precipitation with background information from short-range forecasts of the AROME model.

The ODYC performances were evaluated over two years (2012-2014) and its impact on the quality of snow depth simulations was examined using the snowpack model Crocus driven by ODYC meteorological forcing data. The figure shows the evolution of snow depth simulated using Crocus at the Isola observation station (located in the Mercantour massif, altitude of 1860m) using meteorological forcings from SAFRAN and from ODYC with various configurations (with or without the use of radar observations in the analysis, with or without using radar-derived hourly distribution of precipitation). The impact of radar observations is of particular interest for large rainfall or snowfall accumulation events, which can play a key role for accurate avalanche hazard forecasts.

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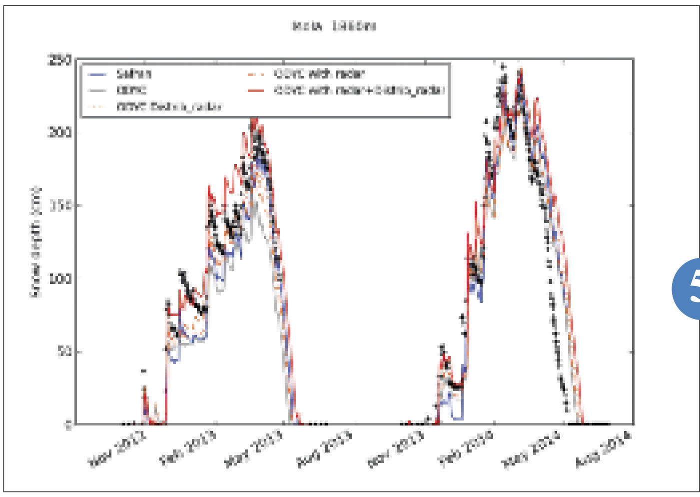

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Snow height simulations with Crocus model, forced by various precipitation analyses over two years from August 2012 to August 2014 at Isola observation station (altitude of 1860 m) The black crosses represent the observations, and the various simulations with SAFRAN and ODYC are plotted ("ODYC": baseline experiment, "ODYC Distrib_radar": hourly distribution based on hourly radar accumulations, "ODYC with radar": analysis using daily radar accumulations, "ODYC with radar + Distrib_radar": analysis using daily radar accumulations and hourly distribution based on hourly radar accumulations).

A daytime snow RGB composite for Suomi-NPP/VIIRS

RGB composite imagery is a robust and fast processing technique for satellite observations to provide near-real time synthesized weather information to forecasters and media. The technique consists in superposing three images resulting from a linear combination of multi-spectral observations and corresponding to red, blue and green.
A new algorithm for the detection of snow during daytime has been recently developed for the Suomi-NPP/VIIRS instruments. The algorithm uses the VIIRS band centred at 2.25 µm channel to enhance snow detection and the band centred at 1.24 µm to highlight the temporal variability of the snow cover. To differentiate snow from clouds, snow has been chosen to be coloured from yellow to red. In that way snow can be distinguished through thin clouds.
The Figure (a) shows a general overview of the daytime snow RGB composite product over France and some parts of Europe on the 7th February 2015 at 12:52 UTC. Snow-covered surfaces are well isolated from clouds and are noticeable in yellow shades over most of mountains massif but also over many areas of Eastern France and Germany. Furthermore, smaller areas covered by snow such as in Normandy and in Picardy are perceptible. Lastly, a red area is also seen in Lombardy. The colour difference is explained by a lower reflectance of the snow in the blue and green pseudo-channels due to melting. The Figure (b) shows the South-Eastern part of France on the 7th March 2015 at 12:27 UTC. Snow-covered areas such as over the "Massif Central" (on top left) are seen through cirrus clouds. The product is available at the spatial resolution of 750 m but might be refined to 375 m.

6

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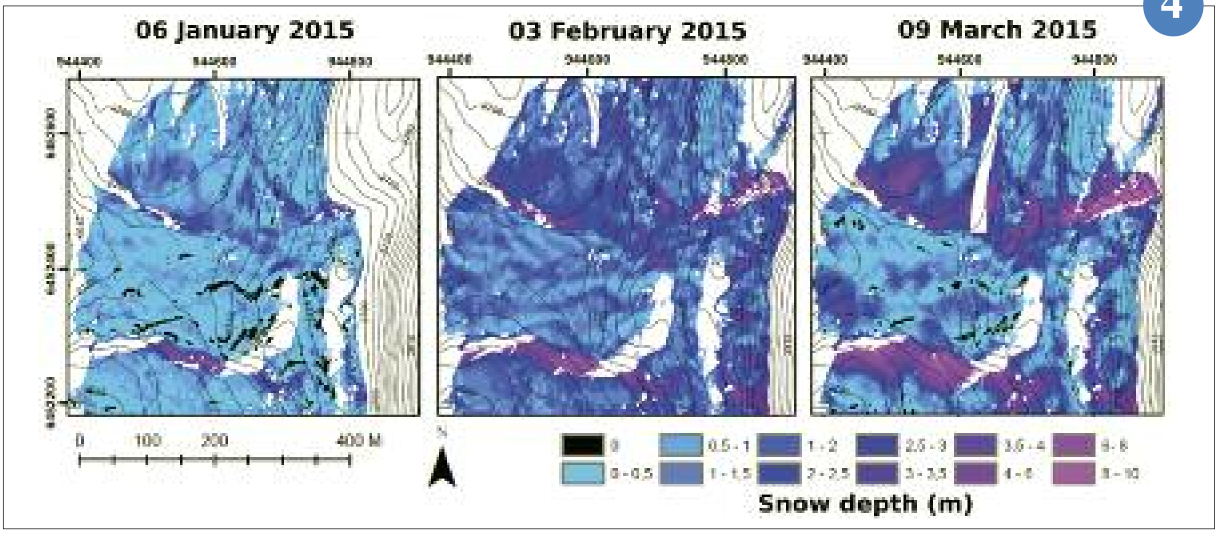
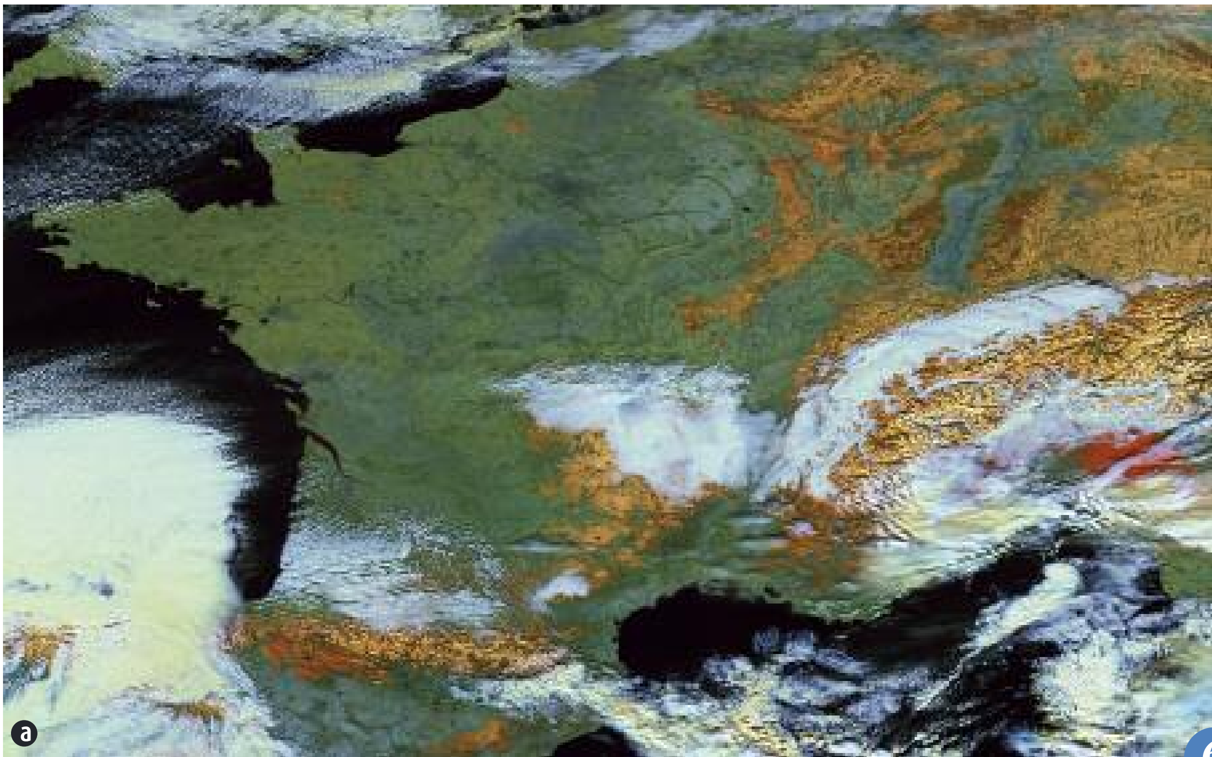


Map of snow depth (m) around Col du Lac Blanc for 3 dates of the winter 2014-2015.



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(a) Daytime snow RGB product over France and some parts of Europe on the 7th February 2015 at 12:52 UTC
Snow-covered surfaces are represented in yellow, orange and red.

(b) Daytime snow RGB product over the South-Eastern part of France on the 7th March 2015 at 12:27 UTC
Snow-covered areas such as over the “Massif Central” (on top left) are seen through cirrus clouds.

Oceanography

Research activities on ocean-atmosphere interactions study the influence of the ocean on the atmospheric boundary layer (especially the influence of sea conditions on the turbulent fluxes) and improved parameterization of the turbulent fluxes in models Numerical Weather Prediction (NWP).

Maritime observation activities at CMM are sustained for the medium to long term. This includes the maintenance of three moored buoys, plus two in cooperation with the UK Met Office. In addition, the CMM maintains a network of more than 100 drifting buoys in the North Atlantic (including the Arctic Ocean) on behalf of E-SURFMAR (an operational service of EUMETNET), and more than 30 drifting buoys in the Indian Ocean, and the CMM monitors and disseminates the observations.

The highlights of 2015 are:

- the development, integration, and first deployment at sea of a new automatic weather station for moored buoys called “MERCURY Bouée”,
- the beginning of operations related to the AtlantOS project, the AtlantOS consortium having assigned drifting buoys activities to E-SURFMAR: deployment of an array of 15 drifting buoys in the south of the North Atlantic, development of a drifting buoy with a salinity sensor, assessment of a drifting buoy fitted with temperature profiling chain,
- the ongoing study of the impact of sea state on the simulation of a precipitating intense event with fine scale simulations by Meso-NH using the data of Special Observation Period 1 (SOP1) of HyMeX,
- the ongoing activities on calibration, maintaining services and deployments of HyMeX sensors, each time one of the Mediterranean buoys is visited, then recovering, processing and data transmitting,
- the ongoing management activities of the E-SURFMAR operational service.

Composite picture of buoys deployments: moored buoys, drifting buoys (SVP-B, Marisondes).

1

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

A heavy precipitating event (HPE) occurring during the HyMeX IOP16a was simulated using the high-resolution, non-hydrostatic model Meso-NH in order to investigate the sensitivity of this type of events to the sea state, through the sea surface roughness. A change of surface roughness has an impact on the wind stress and surface atmospheric turbulent fluxes (momentum, sensible and latent heat fluxes).

Two identical high-resolution simulations (2.5 km) were performed; the only difference concerns the representation of the sea state: without wave effects (NOWAV) or with the surface roughness depending on the wave age, which is computed using the outputs of the Météo-France wave model (WAM). The comparison of the friction velocity and of the surface wind speed obtained in these two simulations (Figures “a” and “b”, 26/10/2012, 08 UTC) shows a clear impact of the waves on the low-level flow on the Gulf of Lion, feeding the mesoscale convective systems which are responsible for the heavy precipitations. The increase of the friction velocity due to the waves results in a decrease of the surface wind speed up to 3 m/s.

Concerning the 24h rainfall cumulative amounts (Figure “c”), this slowdown induces changes in both the maximum amount and the location of the peak of precipitations in the Var region, which moves toward the coast in better agreement with the rain gauges observations. The scores of the precipitation forecasts significantly improve when the sea state is accounted for by the model, leading to possible benefits for numerical weather prediction.

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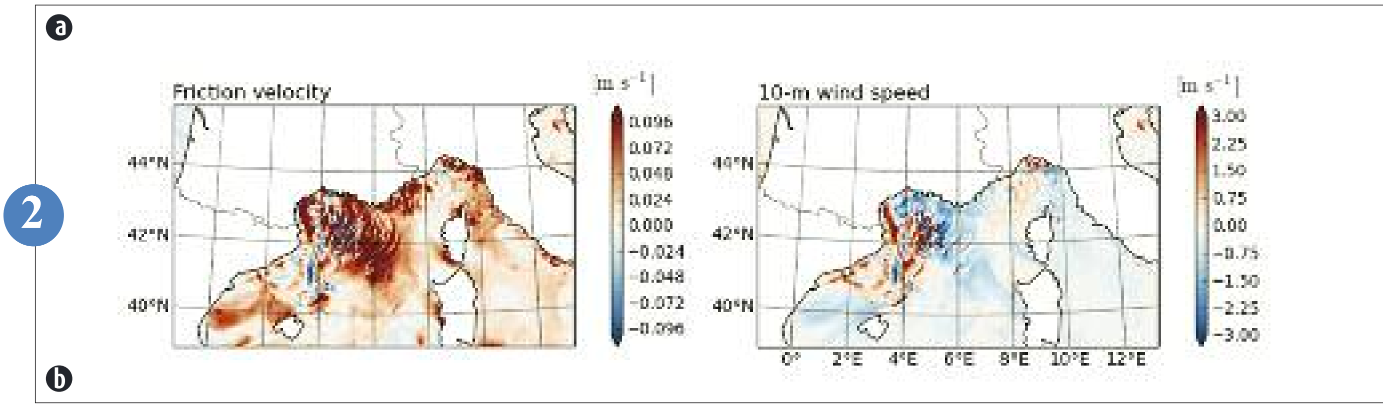


Towards an enhanced understanding of energy and water exchanges thanks to Météo-France moored buoys

In the Mediterranean Sea, Météo-France moored buoys have been measuring atmospheric parameters (pressure, temperature, humidity, and wind) and oceanographic parameters (sea surface temperature and swell) since 1999.

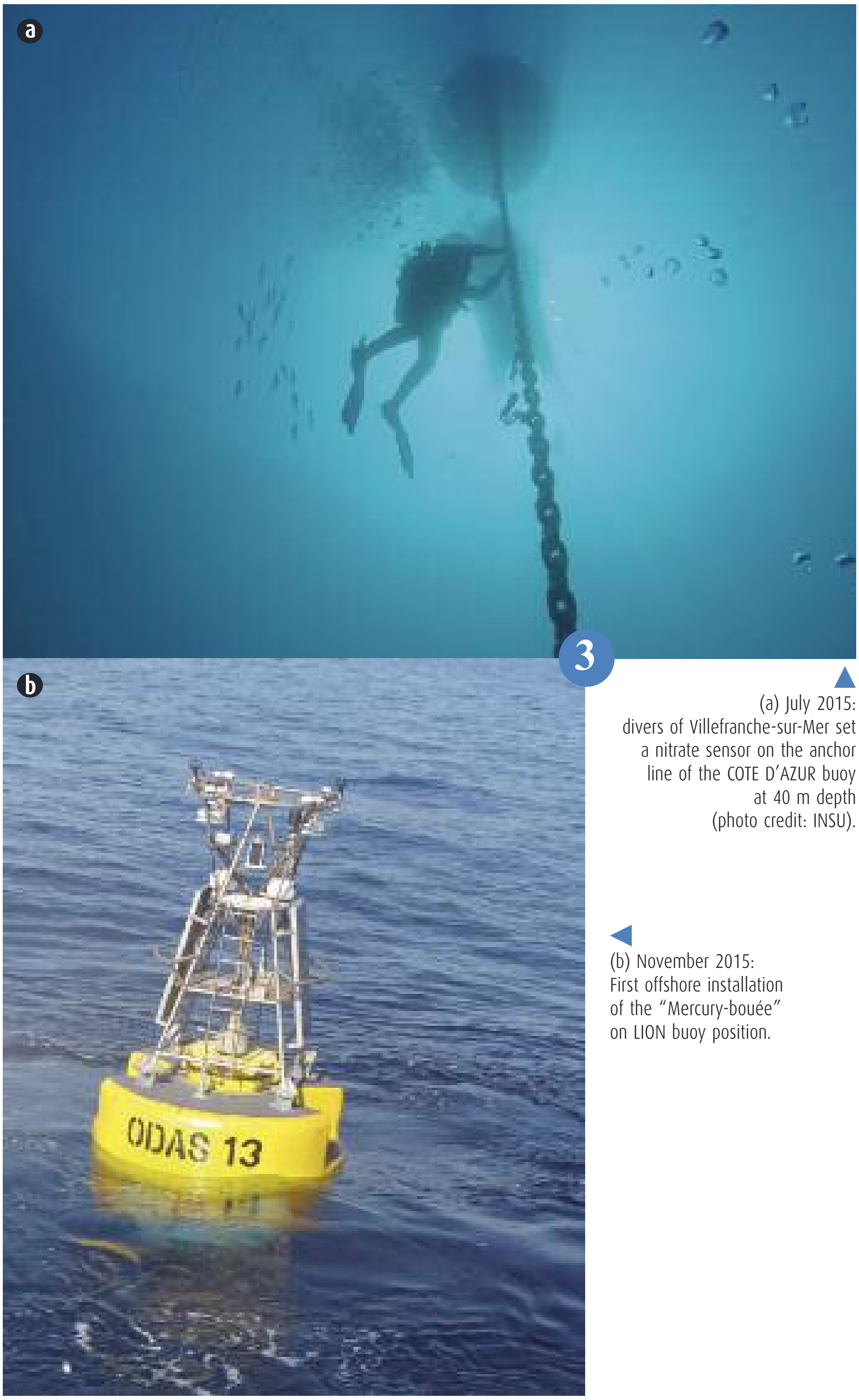
Since 2010, the measurements also include solar and infra-red radiative flux, precipitation, and sea surface salinity. A specific data acquisition system, developed at CNRM/CMM, has enabled to collect these data between 2010 and 2015. Effective November 2015, the buoy LION is now equipped with a new automated station « Mercury-bouée », featuring a novel data transmission system.

In addition, the mooring lines host subsurface sensors, from the surface down to 260 m depth: 20 autonomous registering temperature and pressure sensors, and 2 sea salinity and temperature sensors.

Over the summer of 2015, divers from INSU (Villefranche-sur-Mer) have added an instrument at 40 m depth to monitor the nitrate contents in sea water.

Adding sensors to a mooring line is a difficult task. One must aim to preserve the line itself, as well the sensors attached to it. The deployment of a mooring chain, which endures harsher conditions than a cable, is hence more complex. Before any implantation of additional sensor, the CMM assesses the efficiency of the attachment device for at least 6 months.

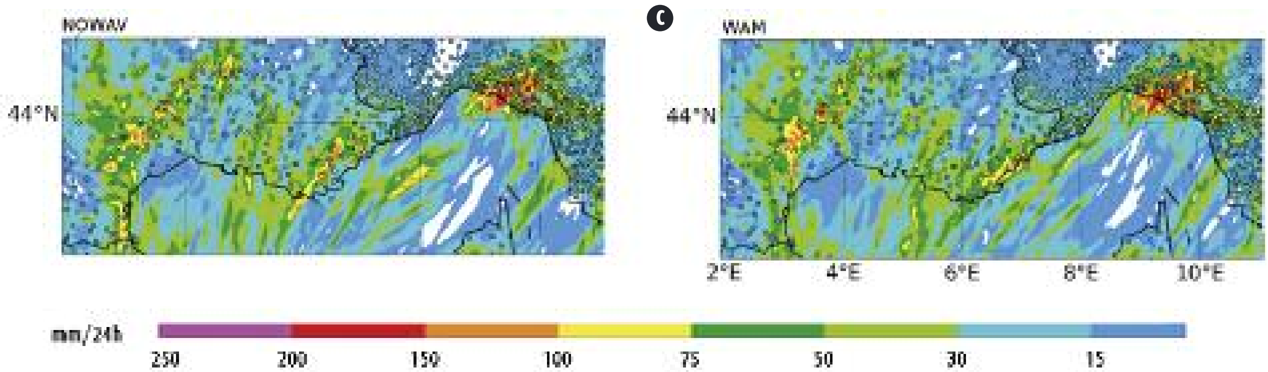
3



(a) July 2015: divers of Villefranche-sur-Mer set a nitrate sensor on the anchor line of the COTE D'AZUR buoy at 40 m depth (photo credit: INSU).

(b) November 2015: First offshore installation of the "Mercury-bouée" on LION buoy position.

Difference between WAM and NOWAV simulations at 08 UTC for (a) the friction velocity (m/s) and (b) the 10-m wind speed (m/s).
24-h accumulated rainfall (mm) on 27 October 2012 at 00 UTC from NOWAV (top), and WAM (bottom).
Coloured bullets are for the 24-h cumulative rainfall from rain gauge observations.



Surface fluxes and heat and water budget closure: application to the North-West Mediterranean

The problem of heat and water budget closure in the ocean is an important subject in operational and research oceanography. The problem is that many errors affect surface heat and water fluxes as output of bulk algorithms. In bulk algorithms, errors are associated with physical approximations, with the choice of numerous constants or pseudo-constants and with time and space resolution of the input data. In addition, bulk algorithms suffer from large uncertainties for low and high winds.
An original method was developed to overcome these uncertainties. It consists to adjust turbulent fluxes and precipitation so that they are consistent with the evolution of heat and salt contents deduced directly from in-situ observations. The method was successfully applied during one year to the north-western Mediterranean Basin, thanks to the large dataset collected during MOOSE 2012, MOOSE 2013, DEWEX 2012, DEWEX 2013 and the wintertime 2013 HYMEX campaigns.

The method is based on: (1) the simulation of temperature and salinity profiles averaged over an area of 300x300 km² between Corsica and the Balearic Islands, by using a column model; (2) optimizing coefficients assigned to the surface fluxes and some model parameters. The optimization requires a genetic algorithm to perform numerous (about 50.000) simulations and find the cost function which minimizes the adjustable parameters. At the end of the minimization process, the adjusted fluxes allow to simulate the average sea surface temperature and salinity with errors less than 0.02 °C (or 0.08%) and 0.01 psu (or 0.02%) respectively over one year. The adjusted fluxes are used as reference for assessing fluxes of numerical weather prediction models and other flux dataset, often used to force ocean models.

4

New operational model for coastal wave forecasting

The HOMONIM project started on 2012 is research collaboration between Météo-France and SHOM supported by the French ministry of Ecology (MEDDE). The project aims to improve the storm surge and waves forecasting in coastal areas. Since March 2015, a high resolution coastal wave model WaveWatch 3 (WW3) has been operationally implemented. The model has an irregular grid that matches well the distorted coastlines. Mean wave parameters are provided with a resolution of 200 m at the French coasts (Atlantic Ocean, British channel and the Mediterranean Sea). The model WW3 is driven by winds from the atmospheric model ARPEGE and the wave spectra at the boundaries are provided by the regional wave model of Météo-France MFWAM with a resolution of 10 km.
Tests of different dissipation source terms have been performed on storm cases and 1-year long run. The mean wave parameters have been validated thanks to altimeters wave data and buoys data provided by CEREMA. The operational version of the coastal model WW3 uses the same source terms as the model MFWAM in deep water. However for shallow water processes the model WW3 improves the wave refraction and breaking induced by the bathymetry, and also the bottom friction dissipation term.
The follow-on of the project consist in implementing the coastal model WW3 at French territories such as West Indies, Guyana and La Réunion. The impact of using surface currents and the sea level update from the surge model will be also investigated.

5

Assimilation of altimeters data in regional MFWAM

The assimilation of altimeters data corrects the model errors in a very efficient way, and consequently to issue a highly reliable marine security bulletins. The next launch of Sentinel-3A and Jason-3 satellites will further increase the data density of several ocean basins. Since November 1, 2015 the regional models MFWAM (grid size 10 km) of Météo-France uses the assimilation of altimeters data in operations. This upgrade improves the sea state forecast in particular for extreme events such as waves generated by storms and cyclones. For example, during the last cyclonic season in the Indian Ocean, it has been shown that the assimilation of altimeter data reduced by roughly 10% the root mean square errors of the significant wave height. The figure shows the difference of significant wave heights with and without assimilation for the cyclone BANSI.

6

Improvement of MOTHY drift system with new objects

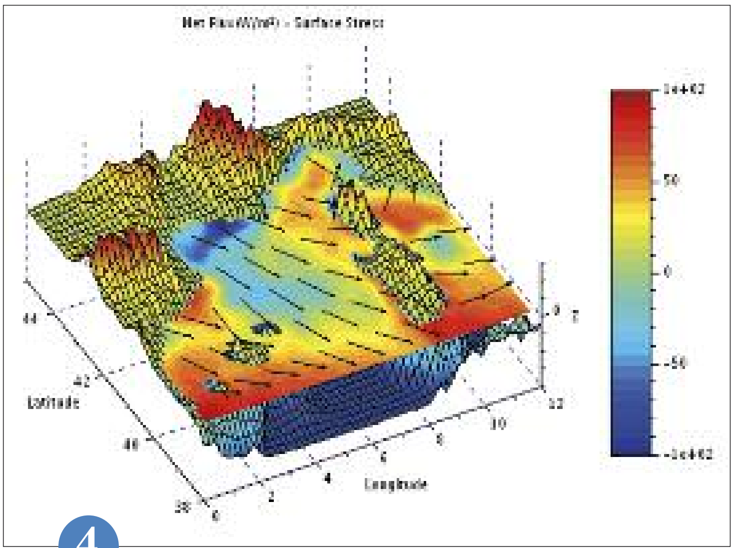
As part of its national and international responsibilities, Météo-France operates the MOTHY drift prediction system for oil slicks or floating objects. The system is activated over 700 times a year for actual spills or search and rescue operations. The search for objects or people constitutes 80% of applications.
The initial data base was established by the US Coast Guard Service from experiments at sea. It is gradually enriched by the results of experiments conducted at sea by specialized agencies or by feedback provided by the Centres Régionaux Opérationnels de Surveillance et de Sauvetage (CROSS) or the Maritime Rescue Coordination Center (MRCC).
15 new objects were incorporated in 2015. They are personal water craft (standup paddle, jet ski), yachts and fishing vessels, some of them used in specific regions such as the Polynesian fishing boat poti marara. There are also large vessels 250 m long in loaded or in ballast conditions. Finally some special objects (oil barrel, floating mine) complete the list.
Furthermore, the graphics rendering has been improved to allow easier reading of research areas.

7

Help to better forecast the marine submersions with the HOMONIM project

Launched in 2013 in the framework of the PSR and with the support of the DGPR, the HOMONIM project, leaded by Météo-France and SHOM, ends its first phase in 2015. It namely allows to improve the modelling of the sea level and of the coastal waves, with the set up of two new models in the operational suit of Météo-France: a storm surge model in 2014 and then a waves model in 2015 with configurations covering the metropolitan shore where the resolution reached respectively 1 km and 200 m. In 2015, a second phase of this project has been decided (2015-2019), with the financing of the DGPR and the DGSCGC, in order to continue the improvements of the tools helping to manage the marine submersions.
Thus, the storm surge and the waves models will be configured for the overseas territories to provide operational forecasts on their shore with a resolution at least as fine as for the metropolitan shore. Moreover, an ensemble prediction for the storm surge will be set up for the metropolitan France to allow the

Surface net heat fluxes (colour) and wind-stress (arrows) on the North-Western Mediterranean for the period August 2012- August 2013. This is the first time that mesoscale ocean surface fluxes allow to close heat and water budgets over the basin. On average, the net heat flux is negative over the field of action of the Mistral and Tramontane winds and contrasts with positive values outside.



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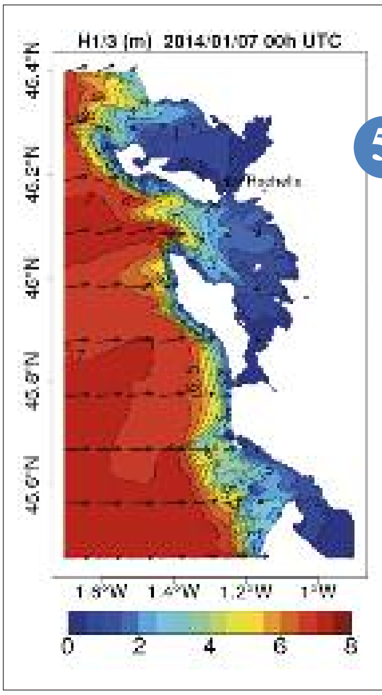

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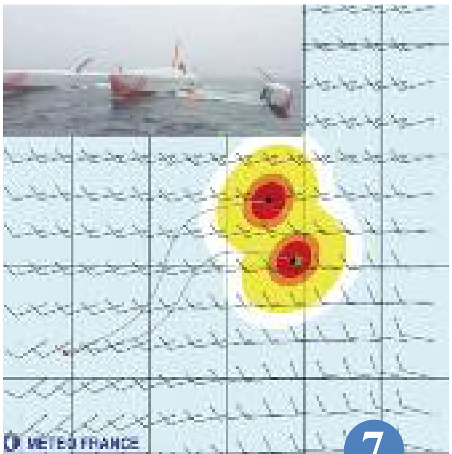
Significant wave height of the total sea state (m) of WW3 the 07/01/2014 at 00h UT
Red arrows represent the swell direction.
The height variations come in part from the wave breaking and energy dissipation due to refraction and sea bottom.

Probabilistic drift forecast of upside down trimaran in the Bay of Biscay
The probability of presence of trimaran is: 50% red; 67% red and orange; 95% red, orange and yellow; 99% by adding white.
Black dots are deterministic forecasts with two assumptions on initial orientation to the wind.
The red star indicates the position of capsizing.
The green star gives the location where the trimaran was found after 26 hours.



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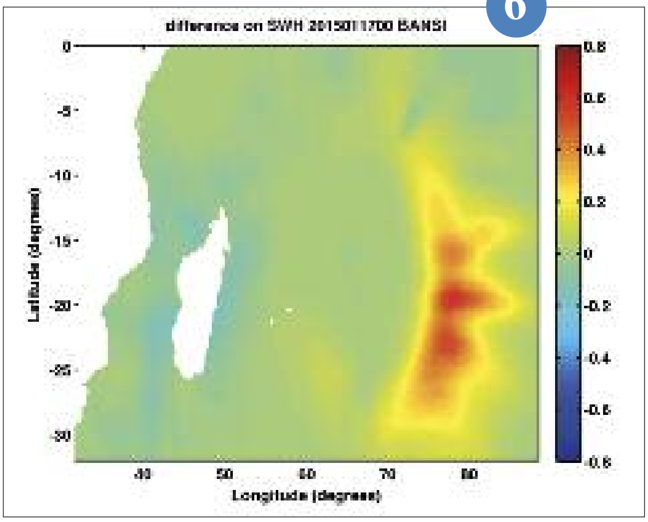

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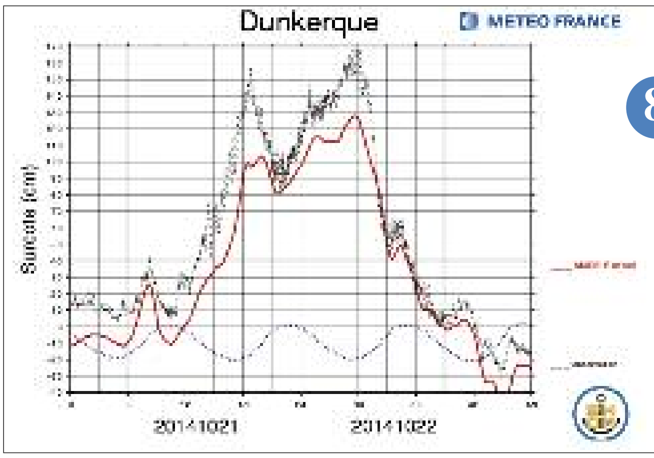
Difference of significant wave heights from the model MFWAM-Réunion with and without assimilation for the cyclone BANSI on 17 January 2015 at 0:00 UTC.

Storm surge (cm) computed by Hycom2D, at Dunkerque, during the 21rst and 22nd of October 2014. The surge measurement (from the tide gauge of SHOM) is indicated by the dotted black line, and the modelled surge by a red line. The curve in the lower part of the graph represents the tides and allows to identify the time of high and low tides. The model error is so between 10 and 15 cm at the high tides (most critical for the submersion) and between 40 and 50 cm during the 2 peaks of storm surge. This shows the ability of the current model to reproduce the chronology of the storm surge but also the improvements the HOMONIM project will have to bring to better forecast its amplitude.



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forecasters to estimate the uncertainties of the forecasts and to help them to anticipate the extreme events. Finally, the potential of the high resolution (about 30 m) will be studied on a reduced area with stakes, by coupling the sea level model and the waves model.
A special attention will be paid to the optimal use of these models by the actors contributing to the management of the marine submersions: Meteo-France forecasters in charge of the wave-flooding warning map, and others (RDI, SPC).

8

Observation engineering, campaigns and products

Instrumented aircrafts are a key element of observation systems deployed for atmospheric research. Started several years ago, the European program EUFAR has worked to improve the access to these infrastructures to the scientists, in particular those who have no such facility at home. The program was renewed in 2014 for a 4 year extension with the ambitious goal to create a permanent association. The observation capacities of instrumented aircrafts are improved by technical developments like the use of GNSS receivers to characterize the observation of soil moisture) or instruments like the sea-state radar KuROS built to test future space missions. The know-how of SAFIRE and research teams contributed the large international program HAIC aimed at improving aviation security.
The use of Unattended Arial Vehicules (UAVs) in atmospheric research has been under consideration for several years. They offer the possibility to make observation at lower costs and/or in volumes inaccessible to manned aircrafts. Their payload is however much more limited. This limit can be however at least partially resolved by flying together several UAVs bearing complementary instruments. The possibility to do so was validated in the frame of the VOLTIGE program.
The observation of the atmosphere with sensors deployed at ground has also been the object of new developments. New techniques have been studied for improving the quality of the data provided by the radars of the operational network. The merits of different techniques for the filtering of ground echoes were assessed. X-band radars are complementing longer range C or S band radars in mountainous regions, but they suffer from a stronger attenuation. The possibility to correct for it was studied. In the research domain, one goal is to make observations of the lowest layer of the atmosphere at high space and time resolutions (as illustrated by the Passy 2015 campaign). This calls for the development of new observation techniques. An example is the application to Doppler lidar measurements of non-linear filtering techniques that allows the measurement turbulence parameters. It is presently the object of a technology transfer.

1

The Passy-2015 field experiment: wintertime atmospheric dynamics and air quality in a narrow alpine valley

Wintertime anticyclonic conditions are often associated to high levels of pollution in urbanized or industrialized area, particularly in mountainous terrain.
The Arve river valley is very sensitive to this phenomenon, in particular close to the city of Passy (Haute-Savoie), 20 km down valley past Chamonix. The area has indeed one of the worst air qualities in France.
Besides air quality monitoring, as managed by the local air quality agency Air Rhône-Alpes or the project DECOMBIO led by LGGE, it is crucial to improve our understanding of atmospheric dynamics within the valley under these wintertime conditions in order to know how it drives pollutants dispersion.
This is one of the reasons why the Passy-2015 field experiment was carried out in this area during the winter 2014-2015. Many instruments (wind, temperature and water vapor profilers, scanning lidars, instrumented towers...) were deployed on a main site and four satellite sites. In February 2015, during two intensive observation periods, high frequency radiosondes, a tethered balloon, a UAV and a sodar were added.
Several years of collaborative work by scientists and engineers from Air Rhône-Alpes, CNRM-GAME, LEGI, LGGE, LTHE and NCAS (UK) will follow this field experiment led by CNRM-GAME and funded by ADEME (LEFE/INSU project coordinated by LEGI) and METEO FRANCE.
It will contribute to improve weather (low temperature, road icing, fog...) and air quality predictions in this kind of valley and more generally at wintertime and in mountainous terrain.

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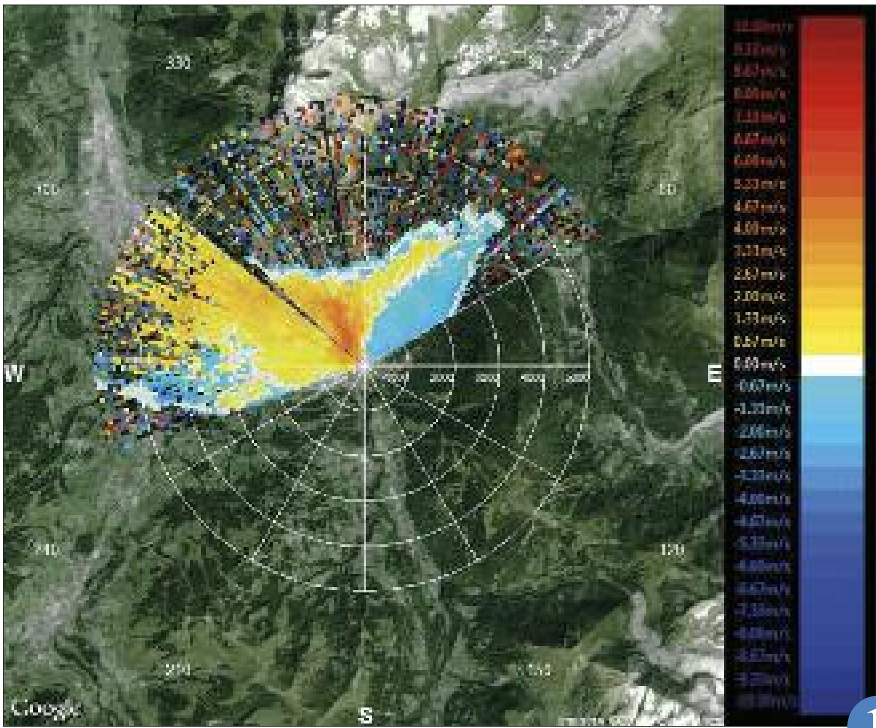


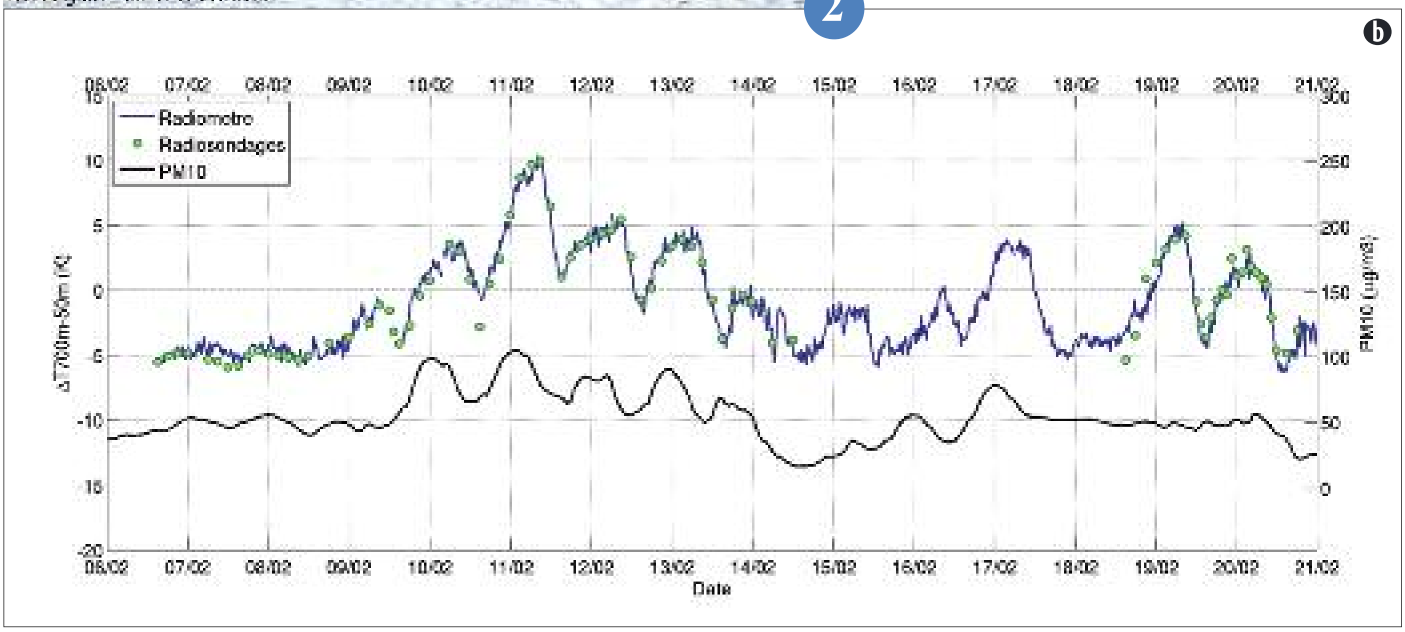
Radial wind velocities (in m/s) measured by the scanning Doppler lidar WLS200S on the 11th of January, 2015, at 19:45UTC in the Arve valley in Haute-Savoie, France, during the Passy-2015 campaign. Radial winds are the component of the wind in the direction of the line-of-sight of the lidar. The instrument was located at the center of the figure at scanning at a fixed elevation angle of 4°. A positive radial velocity means the wind is blowing away from the lidar (and vice-versa for negative velocities). In the East, a sharp wind shear is visible with positive radial velocities to the North and negative radial velocities to the south. They indicate the wind is blowing down the valley on the south side of the valley, due to cold, dense air coming from Chamonix above.

1

(a) 10-m instrumented tower, ground station and fog microphysics station being installed on the main field experiment site, Mont Blanc can be seen in the background.

(b) 12h-averaged concentrations of particles with a diameter of 10 micrometers or less (PM10, black curve) in February 2015 and atmospheric stability in the valley estimated from radiosondes (green dots) and from the main site microwave radiometer (blue curve).

2



Tropospheric Observing System for the Investigation and Management of the Environment (VOLTIGE)

Over the past decade, the scientific community has embraced the use of autonomous RPAS (remotely piloted aircraft system) as tools to improve observations of atmospheric phenomena. To this end, the VOLTIGE (Vecteurs d'Observation de La Troposphere pour l'Investigation et la Gestion de l'Environnement) program developed an observing system to study the life cycle of fog with multiple ultra-light RPAS.

Four science-oriented platforms were developed: solar fluxes, turbulence, cloud measurements and real-time video. Each platform was also equipped with meteorological sensors. Over 160 flights and more than 35 flight hours have been conducted as part of the VOLTIGE project.

The four aircraft flew simultaneously and the sensor measurements were used by the autopilot to adapt its flight based on given atmo-spheric conditions. A few flights were conducted during dissipating fog events, but it general we found it difficult to coordinate the forecasting of fog events with the limited time-window allowed by airspace restrictions. Nonetheless, vertical profiles from the VOLTIGE flights have been compared to Météo France forecast models, and the results suggest that forecast models may be improved using high resolution and frequent in-situ measurements.

The Basse Couche Campaign (BAC+) was initiated as a collaborative agreement with the military's flight school (French Army Light Aviation; EALAT) to conduct regular UAS flights in the Landes – a region known for its fog. BAC+ provides a first-step towards deploying small RPAS in an operational network at Météo France. In addition, the École Nationale de la Météorologie now includes the development and sensors integration of RPAS as part of its academic curriculum.

The project was financed by the Agence Nationale de la Recherche and labeled by Aerospace Valley.

3

Local turbulent atmosphere reconstruction system: a patent and an industrial transfer

For several years, reconstruction systems for local turbulent atmosphere have been developed at CNRM. These systems provide real-time three-dimensional numerical images of the atmospheric boundary layer in a volume probed by sensors. These reconstruction systems are useful for research applications as they capture the characteristics of the dynamics in the first layers of the atmosphere at the rate of several seconds. They also can be deployed on industrial or other sensitive sites (wind farms, airport platforms, large events ...) in order to obtain high speed quantifications of the turbulence parameters such as the turbulent kinetic energy, turbulent intensity, gust distribution, etc.... Coupled to a lidar, these reconstruction systems provide real-time estimations of these parameters every 4 or 5 seconds, with spatial resolutions from 20m to 40m depending on the instrument. In 2015, the developments on local reconstruction systems have reached a good level of maturity. A technology transfer was decided. It will start in 2016 with the aim to deliver a pre-industrial prototype in 2017. We hope to reach an operational system in the near term. At the same time, some parts of the reconstruction system are subject of a patent. The patent will be applied during 2016.

4

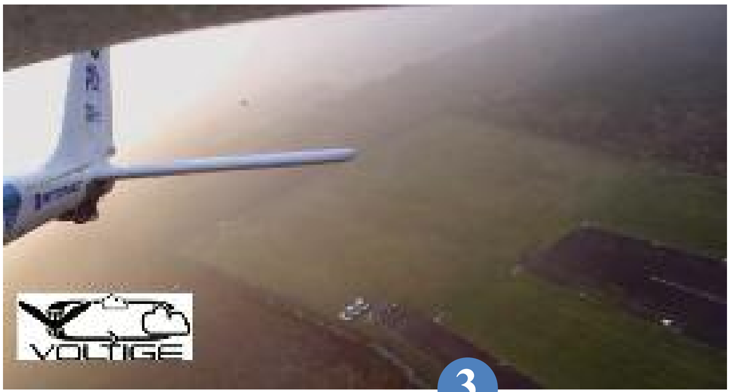
Rainfall measurements over the Alps from Météo-France new X band radars

Météo-France launched in 2012, in partnership with the DGPR, the PUMA project to extend the coverage of the ARAMIS radar network. Four polarimetric X-band Doppler radars were installed at Mont Maurel, Mont Colombis, Vars ski resort in the Southern Alps and at Moucherotte peak near Grenoble. During the qualification phase that led to the integration of the radar QPE products into the operational national radar composite, local forecasters involved in the trials have consistently reported improvements in the estimation of the rainfall, such as during the episode of August 23, 2015, with the hourly accumulation calculated over the Hautes-Alpes being more accurate using the trial composite then using the operational one (Fig. a and b).

However, X-band radars are affected by attenuation. The current processing chain that takes advantage of the polarimetric capabilities of the radars to correct for the attenuation in the rain, cannot account correctly for the attenuation due to the melting layer. The altitude difference between Vars radar site (2580m) and Mont Colombis radar site (1757m) was used to unveil the problem. Figure c shows the reflectivities measured by the two radars in a vertical plane which contains them. The iso-zero is at 2200m, 400m above the Colombis and 400m below the Vars radar. The reflectivities measured by Colombis radar are as much as 10 dB lower than those measured by Vars radar at the same location due to the attenuation suffered by the radar signal at the crossing of the melting layer.

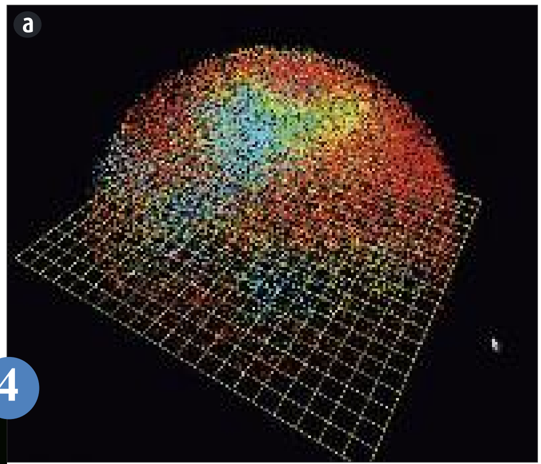
5

QPE composite products, without (a) and with (b) X band radars, compared to gauges, during August 23, 2015 episode.
(c) Average reflectivities observed by Colombis and Vars radars, in the same vertical plane, between 19:00 and 23: 55, during the episode of August 23, 2015
The black vertical line is equidistant from the two radars.



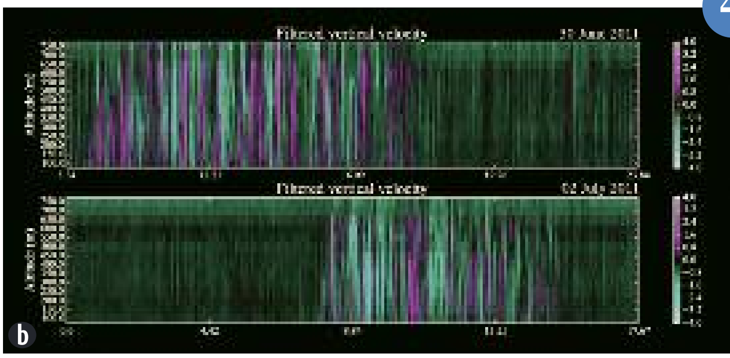
3

View of dissipating fog during a VOLTIGE flight in the Landes.

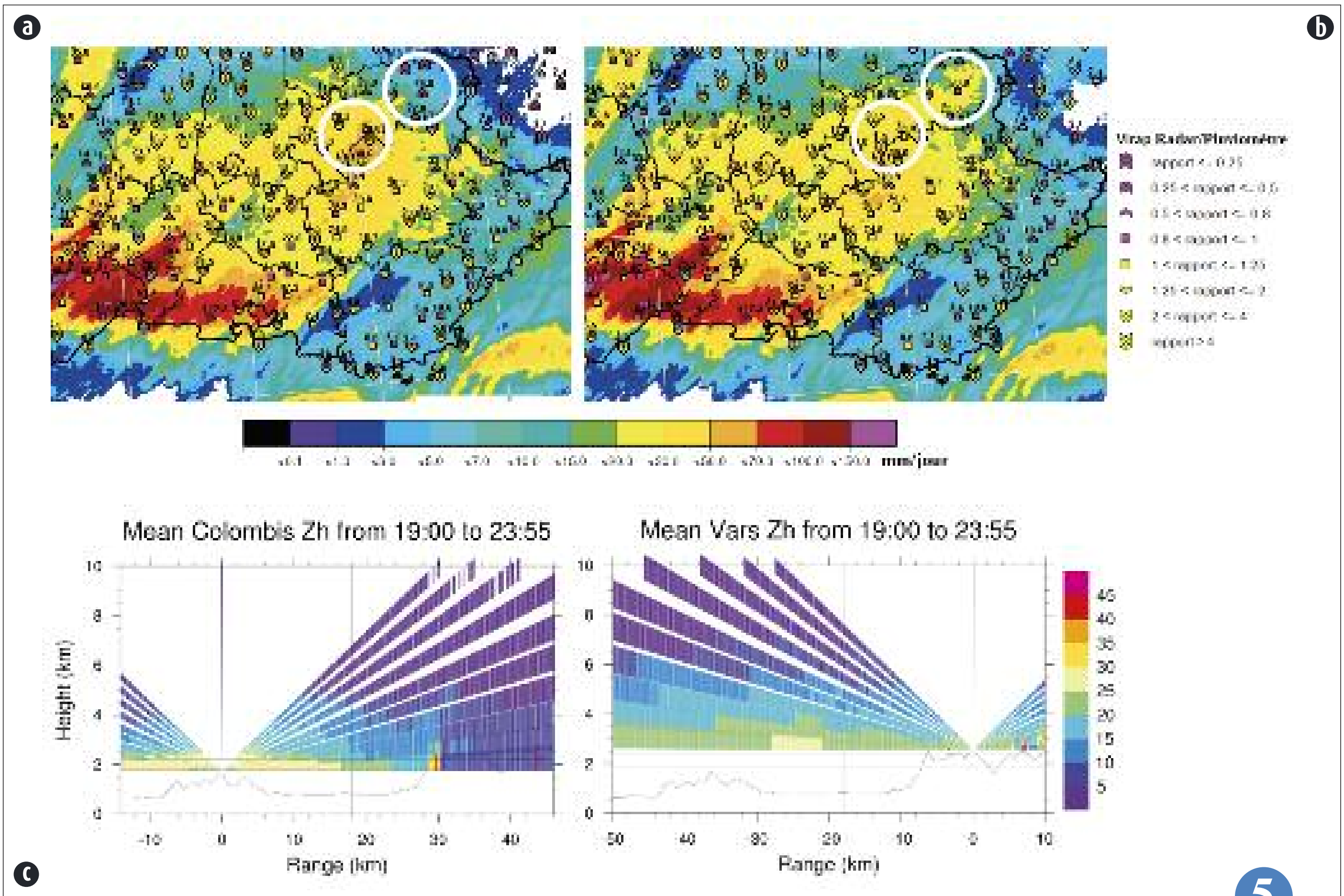


(a) The reconstruction system uses a representation of the local atmosphere using numerical particles. These particles carry with them the dynamical turbulence parameters. Nonlinear filtering methods are used to learn the correct characteristics according to the observations.

4



(b) From the reconstructed atmosphere, it is possible to draw high frequency profiles of turbulence parameters, with confidence intervals. Vertical velocity profiles are presented. They have been computed using measurements of a Leosphere vertical lidar during the BLLAST experiment campaign in Lannemezan (France) on 30 June and 2 July 2011.



5

Towards a clutter filtering solution adapted to Météo-France radars transmission mode

At Météo-France, a triple-PRT (Pulse Repetition Time) transmission mode is used by the radars of the ARAMIS network to provide unambiguous radial winds up to ± 60m/s while maintaining a maximum range of 250 km. However, the irregular sampling that results from this particular transmission mode does not allow the use of conventional spectral methods to filter ground clutter. The quality of the Doppler velocity depends on the dealiasing method used, the PRF (Pulse Repetition Frequency) values and the intensity of the clutter.
Before considering the implementation of a clutter filter, a first step is to optimize the dealiasing method and to select the best triplet. A study was conducted to compare two methods, a fist one called "subtractive" which is currently used on the radars of the network and another one called "brutal". The performances of each of the methods were evaluated from simulated data by calculating the successful dealiasing rate for different triplets of PRF and different values of SCR (Signal to Clutter Ratio). The simulations were made for the C-band radars. For each simulation, the Doppler velocity of the target is randomly set between ±60m/s. Figures a and b show the dealiasing rates obtained for two values of SCR and for each of the methods as a function of the PRF values used in the simulation, one of the values being set at 500 Hz. The performances of each method are very sensitive to the choice of the triplet used and even more so in the presence of clutter. The "brutal" approach gives the best results; the triplet used operationally for the "subtractive" method is not optimal.

6

HAIC / High IWC: Study of ice crystals at high-altitudes to enhance aviation safety

The knowledge of the properties of ice-crystals and of super-cooled droplets in the atmosphere is a critical challenge for aviation safety. HAIC & High IWC projects, funded by the European Union, EASA and FAA, coordinated by Airbus and NASA aim to review aviation standards defining the high-altitude atmosphere, to study the properties of areas with a high-rate of ice inside convective clouds. They also contribute to the technological development of instruments able to detect and to avoid these dangerous areas.
After the first flights made by SAFIRE in the North of Australia from January to March 2014, a new experimental airborne campaign has been performed in May 2015 in French Guyana with the Falcon 20, and two other Canadian and American research aircraft. Still equipped with a set of instruments dedicated to the characterisation of the properties of ice crystals, the Falcon 20 performed more than 100 flight hours in areas with high concentration of microcrystals from convective tropical clouds.
The work of the French expert laboratories LaMP/OPGC and LATMOS/IPSL as well as NASA is ongoing. The analysis of these measurements will allow a better understanding of this phenomenon. It has already been discovered that there is a high variability of the size distribution of crystals in areas with a heavy concentration of ice - i.e. high concentration of small crystals and low concentration of bigger crystals. Furthermore, based on the collected data, it will be possible to define new standards to represent the atmosphere at high altitude and so, to enhance detection and avoidance of areas where these phenomena are located.

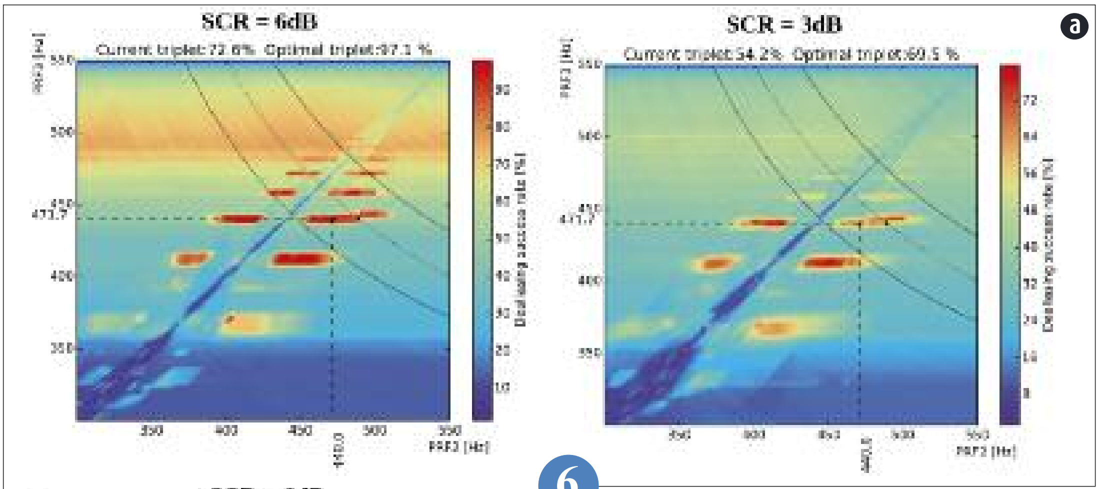
7

GLORI campaigns

Global navigation satellite system (GNSS) reflectometry has recently emerged as a promising remote sensing tool for the retrieval of several geophysical parameters characterizing continental land surfaces (soil moisture, vegetation water content, biomass). When GNSS-reflected signals are recorded and processed by an airborne receiver, they can be interpreted in the form of delay correlation waveforms or delay Doppler maps (DDMs).
In 2013, a new polarimetric GNSS-R system, referred to as the GLORI receiver, is developed by CESBIO. This system was installed on SAFIRE French ATR42 research aircraft. Following initial laboratory qualifications, two airborne campaigns involving 9 flights were carried out in 2014 and 2015 in the South West of France, over various types of land cover, including agricultural fields and forest. The 2014 campaign demonstrated the viability of the instrument's concept and certified GLORI for use in the SAFIRE ATR-42 research aircraft. In the case of the 2015 campaign, four different test sites were selected for the acquisition of GLORI data over land. Flights were coordinated with in situ ground truth campaigns. Various in situ measurements were made on these sites (vegetation biomass, roughness, soil moisture, and leaf area index), in order to validate the GLORI data, to improve the direct bi-static models, and finally to optimise the inversion algorithms.

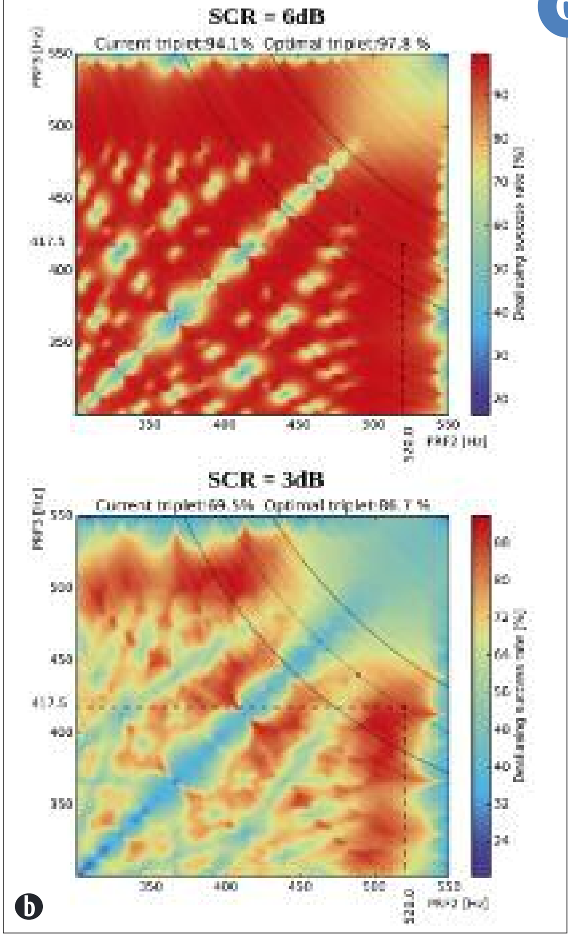
8

a

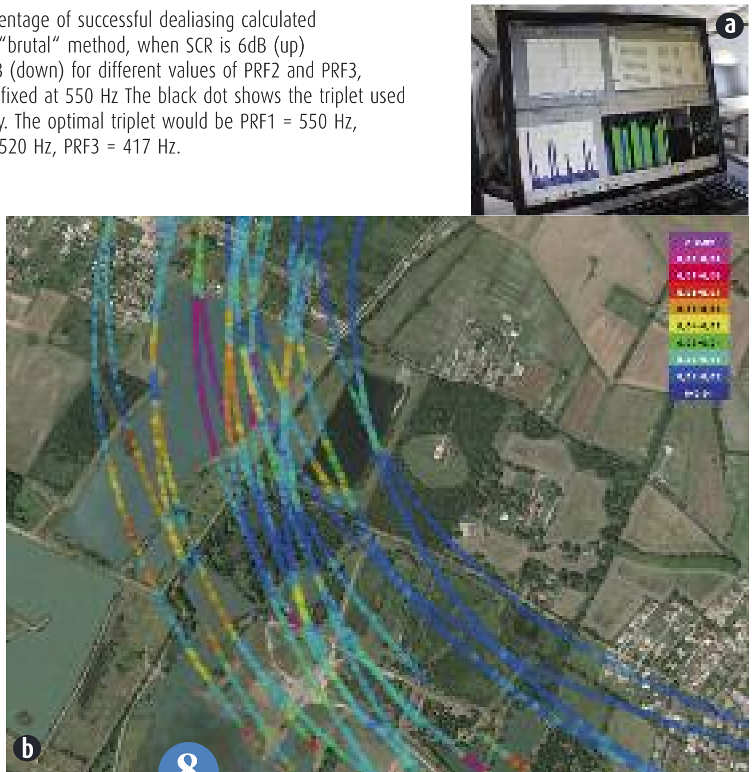


6

(a) Percentage of successful dealiasing calculated for the “subtractive” method, when SCR is 6dB (left) and 3dB (right) for different values of PRF2 and PRF3, PRF1 is fixed at 550 Hz The black dot shows the triplet used currently. The optimal triplet would be PRF1 = 550 Hz, 471 Hz = PRF2, PRF3 = 440 Hz.



(b) Percentage of successful dealiasing calculated for the “brutal” method, when SCR is 6dB (up) and 3dB (down) for different values of PRF2 and PRF3, PRF1 is fixed at 550 Hz The black dot shows the triplet used currently. The optimal triplet would be PRF1 = 550 Hz, PRF2 = 520 Hz, PRF3 = 417 Hz.



8

(a) Detection of GPS satellites.
(b) GPS signal reflected by the continental surfaces.

7

(a) Pre-flight preparation of the SAFIRE Falcon 20 at Cayenne, French Guyana.
(b) HAIC HIWC international teams in front of the SAFIRE Falcon 20 during the French Guyana field experiment.

Observing the sea state by a radar on board the SAFIRE ATR42

Observing and modelling sea-state remain major issues as well for marine forecast (security of goods and people) as for the progress of science on ocean/atmosphere coupled system.

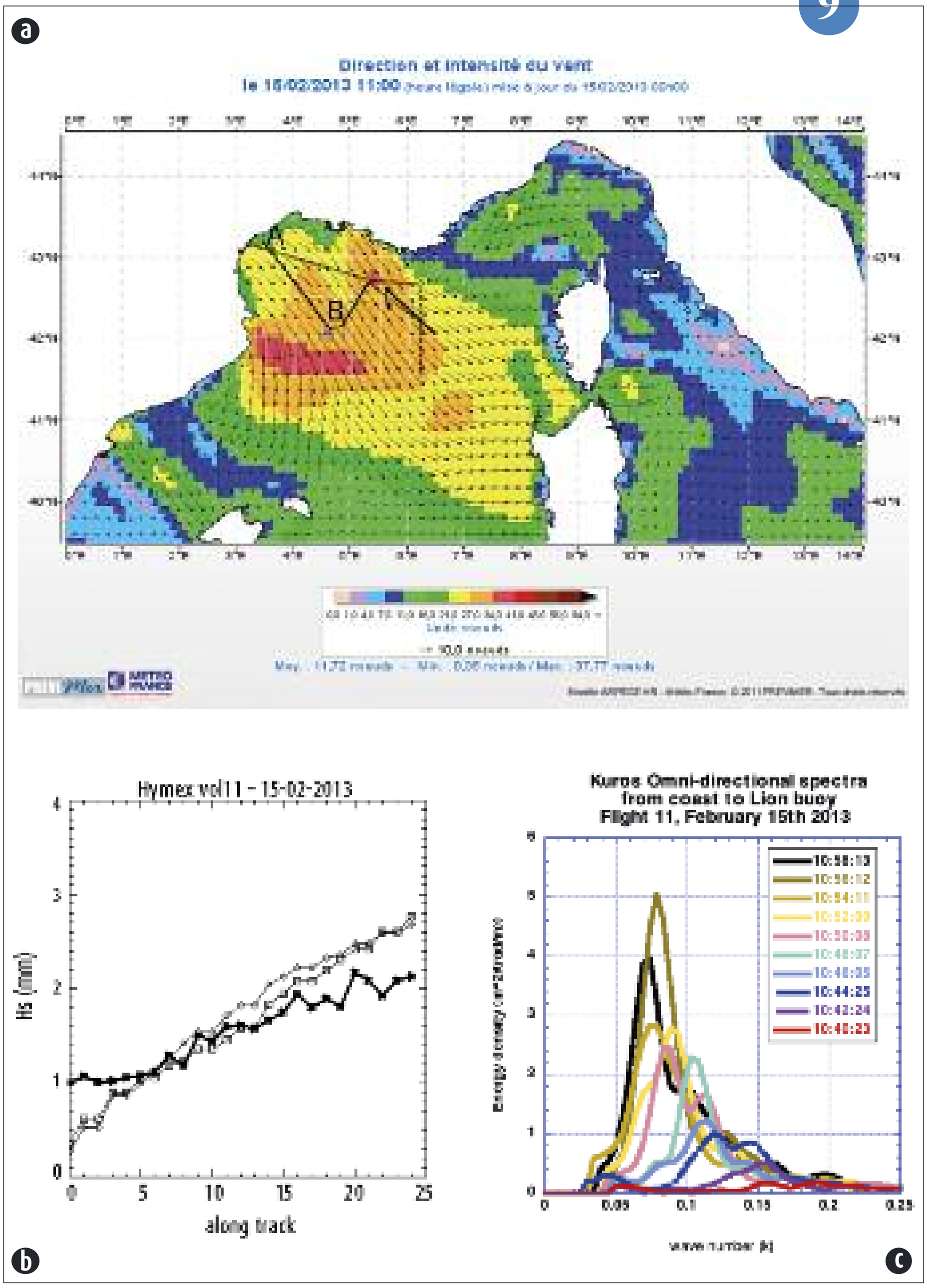
For many years, Météo-France is developing collaboration with the CNRS/LATMOS using the airborne facilities of SAFIRE. A radar named KuROS has been designed by LATMOS in 2012 in order to be installed on-board the ATR42. There are many goals to it:

- preparation of the space mission CFOSAT, dedicated to the global observation of ocean surface winds and waves by radar,
- study of the wind and wave fields, of the wind/waves and wind/current coupling, and validation of the MFWAM Météo-France numerical wave forecast model,
- upstream work about the surface current measurement by radar.

These activities are also based on collaboration between the marine and oceanographic department of Météo-France and the CNRS/LATMOS. Since 2013, KuROS has been operated on the ATR42 at many times. Data sets in sea-state in conditions of strong sea-state (Mistral and Tramontane winds) have been collected during fifteen flights performed as part of the HYMEX campaign in winter 2013 over the Gulf of Lion (Mediterranean Sea). Situations of strong wave/current interactions were encountered during seven flights over the Iroise Sea carried out during oceanographic campaigns PROTEVS (SHOM, 2013), and BBWAVES (October 2015). All of these campaigns permitted to harvest interesting data, which are being analysed. The radar data and associated data processing methods were validated in 2014 (Caudal et al, 2014). Work combining observation of wave spectra by KuROS and MFWAM wave prediction model outputs is under progress (figures a, b, c). Beyond the ongoing analysis, which will serve the goals mentioned above, the project is to complete the dataset by new flights over the Iroise Sea in 2016 before an implementation of KuROS over the Bay of Biscaye during the validation period of the CFOSAT satellite after its launch in 2018.

9

9



(a) Wind field (model ARPEGE) on 15 February 2013 during one of the KuROS flights of the HYMEX campaign.
Black: acquisition points of KuROS data along the path of the ATR-42, during levels at 2000 m (closed symbols), and 3000 m (opened symbols). Axis A-B: corresponds to the results illustrated in the figures b et c.
Red point in B: position of the wind/waves buoy.
(b) Significant height of waves along the axis A-B of the figure above, on 15 February 2013.
Bold line results from the radar KuROS (LATMOS processing). Thin line: model MFWAM at the nearest grid-points.
(c) Omni-directional spectra of the waves versus the wave number from the KuROS observations acquired along the axis A-B of the figure above.

EUFAR the unique portal for airborne research in Europe

Created in 2000 and supported by the EU Framework Programmes since then, EUFAR was born out of the necessity to create a central network and access point for the airborne research community in Europe. With the aim to support researchers by granting them access to research infrastructures, not accessible in their home countries, EUFAR also provides technical support and training in the field of airborne research for the environmental and geo-sciences.
Today, EUFAR2 (2014-2018) coordinates and facilitates transnational access to 18 instrumented aircraft and 3 remote-sensing instruments through the 13 operators who are part of EUFAR's current 24-partner European consortium. In addition, the current project supports networking and research activities focused on providing an enabling environment for and promoting airborne research.
With the launch of a brand new website (www.eufar.net) in mid-November 2015, EUFAR aims to improve user experience on the website, which serves as a source of information and a hub where users are able to collaborate, learn, share expertise and best practices, and apply for transnational access, and education and training funded opportunities within the network. With its newly designed eye-catching interface, the website offers easy navigation, and user friendly functionalities. New features also include a section on news and airborne research stories to keep users up-to-date on EUFAR's activities, a career section, photo galleries, and much more. By elaborating new solutions for the web portal, EUFAR continues to serve as an interactive and dynamic platform bringing together experts, early-stage researchers, operators, data users, industry and other stakeholders in the airborne research community.

10

(a) Snapshot of new EUFAR website homepage.
(b) Snapshot of EUFAR webpage with sections dedicated to news, airborne research stories and publications.

Research and aeronautics

Meteorological research in support to aviation

In 2015, Météo-France actively contributes to the development of the new MET services to aviation within the framework of the R&D SESAR programme of the Single European Sky initiative. With the objective of testing the acceptability of these new services by the users, Météo-France assists in the preparation of validation exercises and of large scale demonstration projects, the most important one being TOPLINK. Météo-France also leads the prototype development of the unique platform to access weather information at the European level, the EUMETNET 4DWeatherCube MET-GATE and does the promotion of the state of the art collaborative weather information services on a European scale with success.

1

TOPLINK: collaborative system of information sharing to optimize the pass of aircraft

Météo-France, who is actively involved in the SESAR programme (technological element of the Single European Sky), is currently developing , in collaboration with its European partners, a new system of sharing timely meteorological and aeronautical information, simultaneously among air traffic controllers, ground staff and pilots.
This shared information will optimise the response to unforeseen events resulting in timely adjustments to the flight plan. This system will support those involved in flight management, ensuring that even during risky events (severe convection to be avoided for example), the flight path is optimized permanently, from taking-off to landing, guaranteeing passenger safety and comfort.

Tested by Brussels Airlines in the summer of 2014 with a prototype version (TOPMET demonstration project), the system evolves and will be tested in a new version under real flight conditions from early 2016 as part of the TOPLINK European project. The aim will be to deepen the development of the concept and accelerate its expected deployment within the next two years. Météo-France is currently working with 13 other partners, who are part of the SESAR network: Thales, Airbus, Finnish Meteorological Institute, DWD, Paris Airport, ENAC, DSNA, Croatia Crontrol, Austro Control, Brussels Airlines, Air France, Hop! and Air Corsica.
For more information:
www.sesarju.eu/node/2100

2

Probabilistic thunderstorm prediction for air traffic management

Intense convection can impact aviation through loss of visibility, up- and downdrafts, turbulence, icing, lightning, hail, gusts, and so on. Thunderstorm events can reduce airspace capacity with impacts on the economy, safety and environmental impact of aviation. Due to their usually low predictability, the focus is on improving their forecasts at scales of a few tens of kilometres and typical ranges from 3 to 30 hours. Their key features are intensity, vertical extension and probability of occurrence, which can only be represented by kilometric-resolution numerical ensemble prediction systems such as AROME-France-EPS, a system that will be operational at Météo-France in 2016.
Specific research is needed to extract useful information from the ensemble. For instance, a radar-based verification technique has been developed. Some filtering is used to ensure compatibility between the modelled and observed 3D reflectivities. Significant convective cells are identified using the echo-top (cloud top height) diagnostic. Probabilistic data visualization accounts for the user sensitivity to forecast errors, such as his/her tolerance to false alarms. In applications such as aircraft trajectory planning, this processing facilitates the use of meteorological information among many other constraints. Objective scores prove that this approach is superior to both deterministic forecasts and lower-resolution ensembles.

4

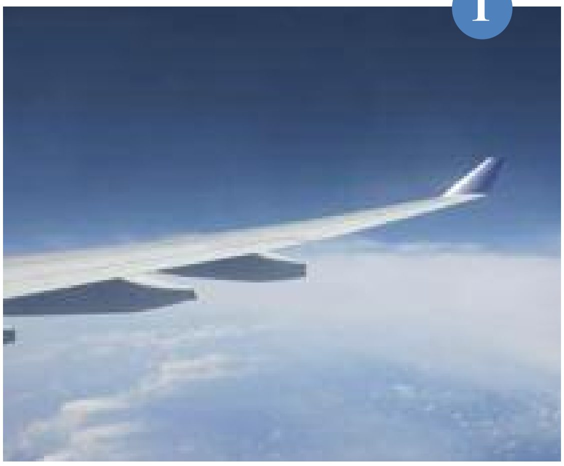
Météo-France in SESAR

In collaboration with our German and British colleagues from the DWD and the UKMO, Météo-France has actively contributed to the final phase of the development of the prototypes for new harmonized and consolidated MET services at a European scale for observation and forecast of the weather phenomena that could potentially impact the safety and efficiency of flights and air traffic management: convection, icing, turbulence. According to roles and responsibilities sharing between EUMETNET partners, we have also contributed to or performed the verification of some of those new services.
In this context, the state of the art achieved in 2015 has allowed us to prepare proposals for deployment within the framework of the EU resolution called Pilot Common Project (PCP) and the INEA CEF 2015 call for deployment. Three proposals for deployment have been finalized in coordination with our EUMETNET colleagues: the European Weather Radar Composite of Convection Information Service which aims at providing the users with 2D and 3D information on convection observation (convective cloud position, convection intensity, cloud top) over a large part of Europe; the European Harmonised Forecasts of Adverse Weather which would provide consolidated and harmonised forecast of icing, turbulence and convection over the western part of Europe, and the European MET Information Exchange (MET-GATE) which would be led by Météo-France.
Météo-France has also assisted in the preparation of validation exercises and of large scale demonstration projects, such as TOPLINK. All MET services used during this demonstration exercise have been developed in accordance with SWIM concepts (SWIM-compliant formats such as XML, web-services such as WCS, WMS …) and are now available on the MET-GATE portal. The TOPLINK demonstration exercise execution in spring 2016 will be the right place for the validation of our new MET services taking into account the aviation users' perspective.

3

Meteorological research in support to aviation.

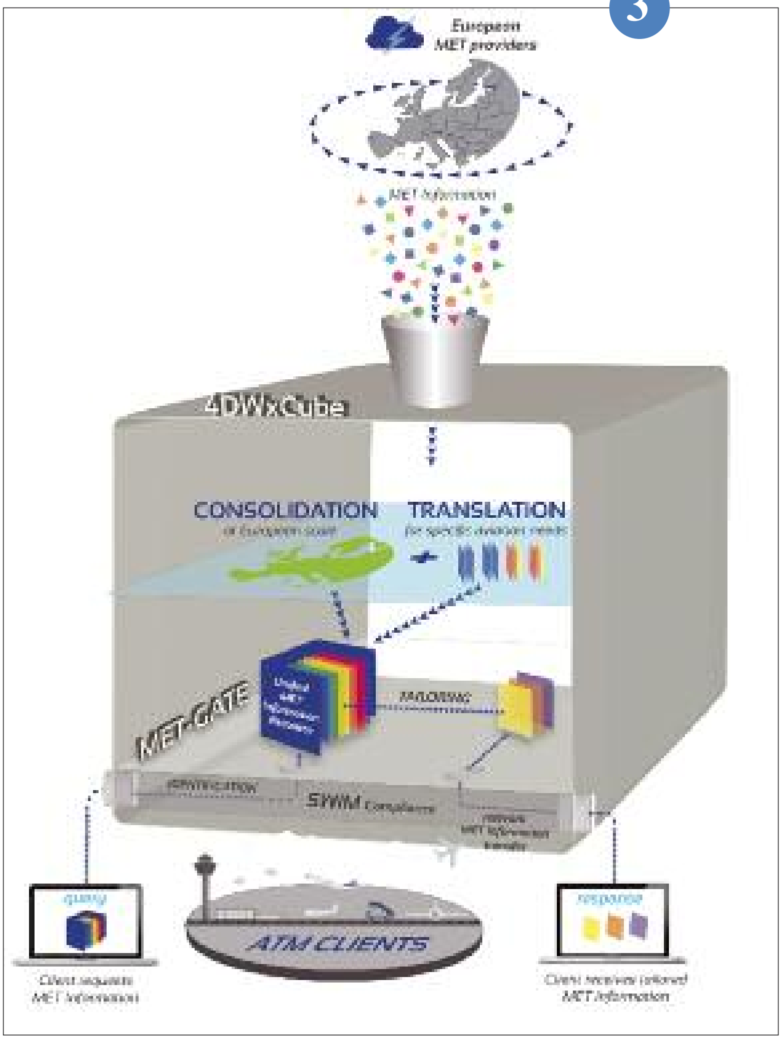
1



2

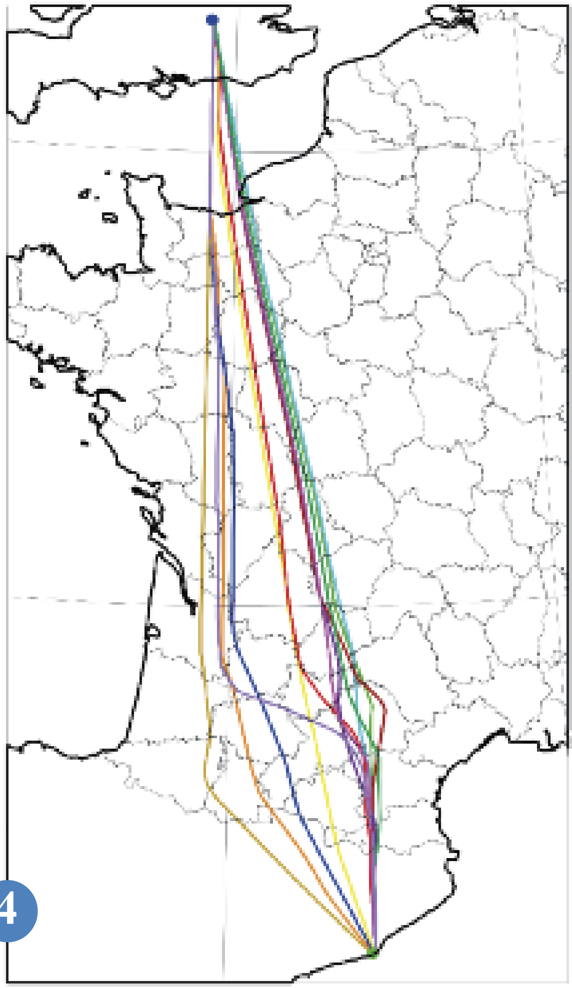
Meteorological information visible on a touchpad by pilots during the flight
Copyright SESAR-TOPMET.

3



EUMETNET 4DWxCube MET-GATE schema.

Optimal trajectories for a flight from Barcelona to London
on 22 June 2014, 18h UTC,
according to the weather forecasts 24h ahead
Each trajectory accounts for uncertainties on wind and convection,
as there were thunderstorms in southwestern France.
Twelve equally likely meteorological scenarios are plotted.
This kind of information can be useful to air traffic management
because it integrates probabilistic information about flight timing,
fuel consumption, and aircraft safety.



4

IMET project 2015

The IMET project aimed to investigate and provide recommendations on how to use the uncertainty information from Ensemble Prediction Systems (EPSs) to optimize trajectory prediction. The 30-month project assessed the level of sensitivity of several key aircraft trajectory parameters to meteorological forecast uncertainty.
One parameter that is impacted by weather forecasts is the amount of fuel needed for a flight. For long-haul flights, a contingency fuel is calculated which takes into account possible additional en-route fuel consumption caused by weather, routing changes or ATM restrictions. Many airlines determine its actual value using a single deterministic weather forecast, a trajectory predictor (TP), and by comparing predicted weather conditions with previously experienced meteorological conditions for the same route.
In the IMET approach, each ensemble member is used by the TP to compute the amount of contingency fuel. The resulting set of predicted fuel values provides the information to estimate the uncertainty of the contingency fuel due to weather (see plot). By translating weather uncertainty to fuel uncertainty in this way allows for more effective decision making.
When applied, the IMET approach could bring positive benefits in terms of cost reduction by quantifying the integrated trajectory uncertainty parameters due to weather and thus leading to a reduction in contingency fuel.
The results of the project have being taken up by the SESAR industrial research project on flight planning (SESAR WP11.1)

5

EUMETNET 4DWeatherCube MET-GATE, project led by Météo-France, winner of the Best-in-Class SESAR SWIM MASTER CLASS 2015

The sharing of timely information, between all stakeholders of a flight using interoperable services, is the heart of the future European Air Traffic Management System developed under the SESAR programme!
System Wide Information Management (SWIM), a high-level concept a few years ago, is now becoming a reality thanks to the development of prototypes and cutting edge solutions in all fields of Air Traffic Management (ATM). This breakthrough has been particularly driven by the SESAR SWIM MASTER CLASS (SMC) - an annual competition involving 20 projects organized by EUROCONTROL over the span of four years.
Designed as a unique platform to access weather information at the European level, the EUMETNET 4DWeatherCube MET-GATE prototype, led by Météo-France with the support of the MET Office, the DWD and THALES, received the highest award of SESAR SWIM MASTER CLASS in the "services" category in 2015.
This offers a significant opportunity to promote the state of the art collaborative weather information services on a European scale.
Following the example of Alticode, THALES, Airbus Defense & Space and IDS, many ATM stakeholders have expressed their keen interest in the 4DWeatherCube MET-GATE prototype, which currently provides eight SWIM compliance services. The objective, in the coming years, will be to develop, a fully operational 4DWeatherCube MET-GATE system integrated in SESAR's activities.

6

6

EUMETNET 4DWeatherCube MET-GATE, winner of the Best-in-Class SESAR SWIM MASTER CLASS 2015, the "services" category.

5

TP / Cost	T^1	T^2	. . .	T^m
Weather 1	t_{11}	t_{21}	. . .	t_{m1}
Weather 2	t_{12}	t_{22}	. . .	t_{m2}
⋮	⋮	⋮	⋱	⋮
Weather n	t_{1n}	t_{2n}	. . .	t_{mn}
PDF				

Estimation of the uncertainty of the contingency fuel due to weather

Appendix

2015 Scientific papers list

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

Adloff, F., S. Somot, F. Sevault, G. Jorda, R. Aznar, M. Déqué, M. Herrmann, M. Marcos, C. Dubois, E. Padorno, E. Alvarez-Fanjul, D. Gomis, 2015: Mediterranean Sea response to climate change in an ensemble of twenty first century scenarios. Climate Dynamics, Volume: 45, Issue: 9-10, Pages: 2775-2802, Doi: 10.1007/s00382-015-2507-3. Published: NOV 2015.

Andrello, M., D. Mouillot, S. Somot, W. Thuiller, and S. Manel, 2014: Additive effects of climate change on connectivity among marine protected areas and larval supply to fished areas. Diversity and Distributions, Volume: 21, Issue: 2, Pages: 139-150, Doi: 10.1111/ddi.12250. Published: FEB 2015.

Astier, N., M. Plu, and C. Claud, 2015: Associations between tropical cyclone activity in the Southwest Indian Ocean and El Niño Southern Oscillation. Atmospheric Science Letters, Volume: 16, Issue: 4, Pages: 506-511, Doi: 10.1002/asl.589. Published: OCT-DEC 2015.

Auger, L., O. Dupont, S. Hagelin, P. Brousseau and P. Brovelli: AROME–NWC: a new now-casting tool based on an operational mesoscale forecasting system. Quarterly Journal of the Royal Meteorological Society, Volume: 141, Issue : 690, Pages : 1603-1611, Part: A, Doi: 10.1002/qj.2463. Published: JUL 2015.

Balmaseda, M.A., F. Hernandez, A. Storto, M.D. Palmer, O. Alves, L. Shi, G.C. Smith, T. Toyoda, M. Valdivieso, B. Barnier, D. Behringer, T. Boyer, Y-S. Chang, G.A. Chepurin, N. Ferry, G. Forget, Y. Fujii, S. Good, S. Guinehut, K. Haines, Y. Ishikawa, S.,Keeley, A. Köhl, T. Lee, M.J. Martin, S. Masina, S. Masuda, B. Meyssignac, K. Mogensen, L. Parent, K.A. Peterson, Y.M. Tang, Y. Yin, G. Vernieres, X. Wang, J. Waters, R. Wedd, O. Wang, Y. Xue, M. Chevallier, J-F. Lemieux, F. Dupont, T. Kuragano, M. Kamachi, T. Awaji, Caltabiano, K. Wilmer-Becker, and F. Gaillard, 2015: The Ocean Reanalyses Intercomparison Project (ORA-IP). Journal of Operational Oceanography, Volume: 8, Special Issue: SI, Supplement: 1, Pages: S80-S97, Doi: 10.1080/1755876X.2015.1022329. Published: 2015.

Bari, D.; Bergot, T.; El Khlifi, M., 2015: Numerical study of a coastal fog event over Casablanca, Morocco. Quaterly journal of the Royal Meteorological Society, Volume: 141, Issue: 690, Pages: 1894-1905, Part: A, Doi: 10.1002/qj.2494. Published: JUL 2015.

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Glossary

Organismes and Laboratories

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 (Head Office of the Hazard Prevention)
DGSCGC	Direction générale de la Sécurité Civile et de la Gestion de Crise (Head Office of the Civil Security and of the Crisis Management)
EALAT	Ecole de l'Aviation Légère de l'Armée de Terre
EASA	European Aviation Safety Agency
EEA	Agence Environnementale Européenne
ENAC	Ecole Nationale de l'Aviation Civile
ENM	Ecole Nationale de la Météorologie
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)
FMI	Finnish Meteorological Institute
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)
JAXA	Japan Aerospace eXploration Agency
JMA	Japan Meteorological Agency
KNMI-TNO	Royal Netherlands Meteorological Institute and Netherlands Organization for Applied Scientific Research
MEDDE	Ministère de l’Ecologie, du Développement Durable et de l'Energie
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	Service Hydrographique et Océanographique de la Marine (Marine Hydrographical and Oceanographical Service)
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
RIU Rhenish Institute for environmental research at the University of Cologne
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
WUT Warsaw University of Technology (Politechnika Warszawska)

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
EUFAR2 2nd EUFAR project under FP7 and 4th since 2000
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/
FP7 7th Framework Programme for Research
GHRSST International Group for High Resolution SST
GLOSCAL GLobal Ocean Surface salinity CALibration and validation
HOMONIM Historique Observation MOdélisation des Niveaux Marins (History, Observation, Modelisation of Sea Level)
HyMeX Hydrological cYcle in the Mediterranean EXperiment
IMAGINES Implementing Multi-scale Agricultural Indicators Exploiting Sentinels
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
BSS Probabilistic score « Brier Skill Score »
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.
DCSC Direction de la Climatologie et des Services Climatiques
DCT Diffraction Contrast Tomography
DEM Discrete Element Method
DMT Dropplet Measurement Technologies
DP Direction de la Production
DPR Dual frequency Precipitation Radar
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
GNSS-R Global Navigation by Satellite System - Reflectometry
GPM Global Precipitation Measurement
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
ISBA-TOP Coupling between the surface scheme ISBA and a « mediterranean » version of the hydrological TOPMODEL model
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
PDO Pacific Decadal Oscillation
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 (Rapid Submersion Plan)
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
RDI Référent Départemental Inondation (Flooding Departmental Reference)
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 horizon tal, 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
SPC Service de Prévision des Crues (Flooding Forecasting Service)
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

31.12.2015

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Deputy Head - Toulouse: **Marc Pontaud**
Scientific deputy Head - Toulouse: **Philippe Dandin**
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SAFIRE: French group of Aircraft Equipped for Environmental Research

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SNOW RESEARCH CENTRE — CEN - Grenoble
Centre Head: **Samuel Morin**

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MODELLING FOR ASSIMILATION AND FORECASTING GROUP — GMAP - Toulouse
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EXPERIMENTAL AND INSTRUMENTAL METEOROLOGY GROUP — GMEI - Toulouse
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CLIMATE AND LARGE SCALE MODELLING GROUP — GMGEC - Toulouse
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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.

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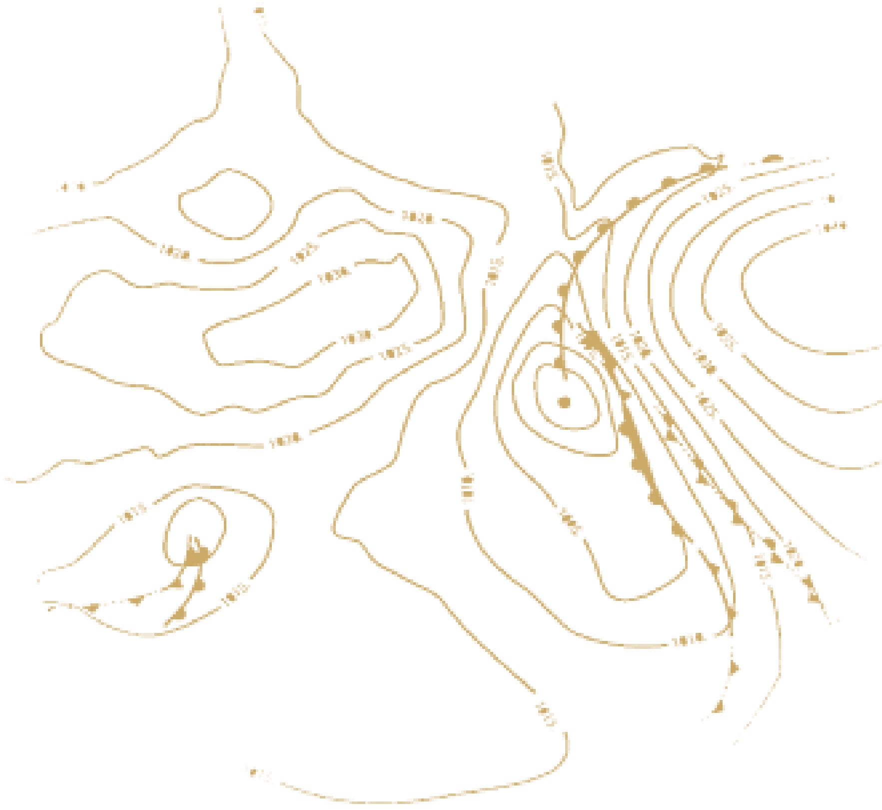

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