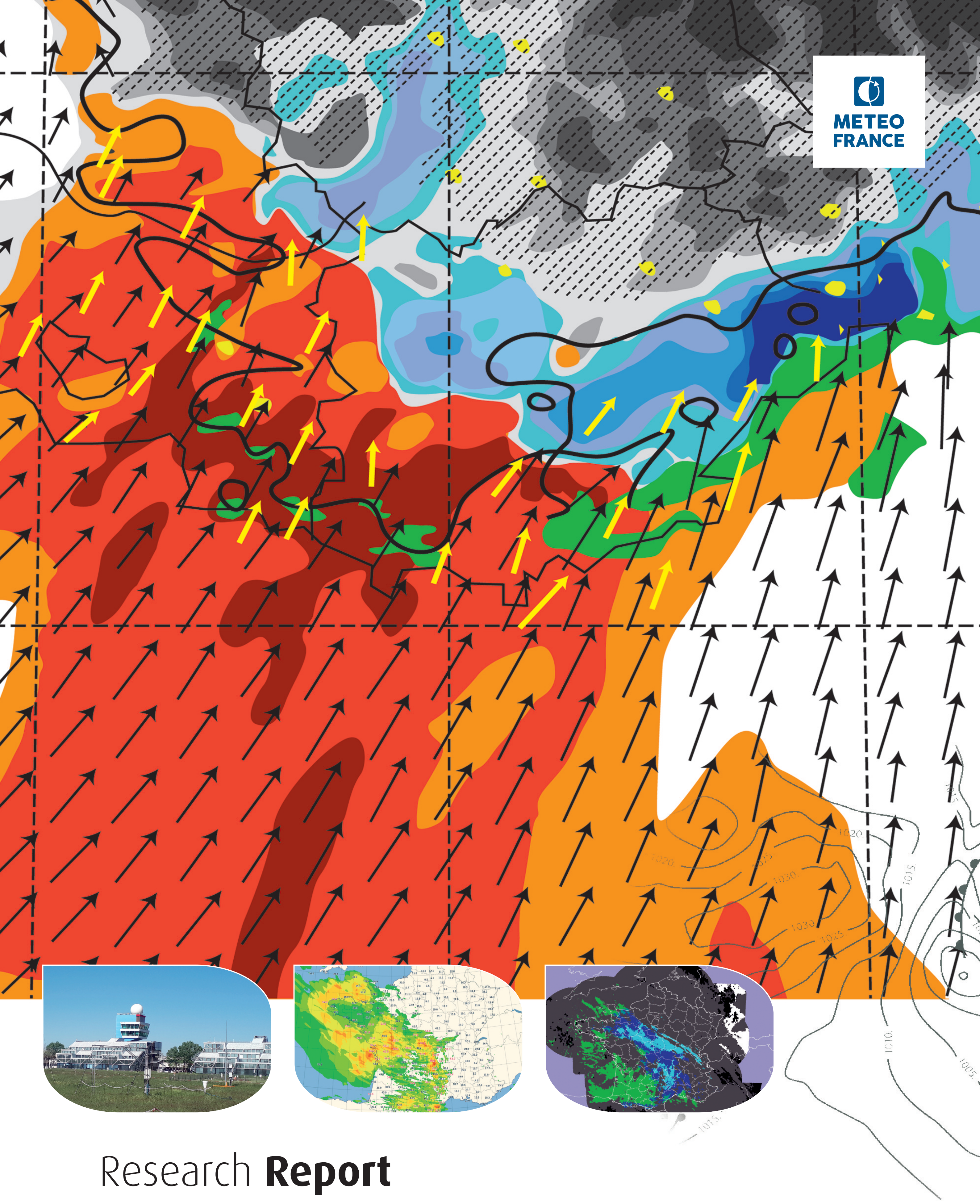

METEO FRANCE

Research **Report** 2016

Research Report 2016

Table of contents

Research activities at Météo-France connect with all the other departments of the meteorological service. They are a primary key to innovation for observation, numerical weather forecast and climate. Thanks to its research department, Météo-France is able to increase the quality of its deliverables and meets the continuously evolving requirements and needs of its customers.

2016 is a turning point regarding Météo-France mid-term plans. The 2012-2016 Contrat d'Objectifs et de Performance (COP) came to an end and meanwhile the next plan was prepared for the 2017-2021 period. All the objectives assigned to CNRM have been achieved, and namely the launch of the ensemble run with the non-hydrostatic limited area model AROME.

International cooperation is in the meteorological world's DNA. This is true for numerical modelling, satellite operations, collaborative projects and services. ECMWF stands as a key partner for Météo-France, working jointly on the global Arpege/IFS numerical suite. When regional modelling is considered, the striking feature is to be seen in the will of the Aladin and Hirlam consortia to merge around 2020 – In the meantime, both groups are reinforcing the various fields of collaboration. Météo-France is also actively working with Eumetsat and the European Space Agency, with an heavy agenda at short and mid-terms: ADM Aeolus to be soon launched, MTG and EPS-SG being actively prepared. These missions will carry new sensors and enable the provision of improved services. Serving is indeed the final aim of meteorological services. In that latter field too, cooperation is at work at the European level, namely within the Copernicus framework in which Météo-France is quite active.

At the national level, Météo-France stands as a key partner fully involved in the academic and research agenda. Links are strong with CNRS – joint research units are operated together, like CNRM or LACy – and Allenvi, the alliance of French agencies dealing with environmental issues. Connections with Universities are equally important, namely through Observatories in Toulouse (OMP), Grenoble (OSUG) and hopefully soon La Réunion (OSUR). Météo-France also co-invests in the data management facilities currently being set up by French agencies (Aeris, Theia...), as well as the research infrastructures (Actris-Fr, Climeri-Fr...) that connect with the European landscape. Noticeably, Météo-France offers a full access to the observations made by its operational network, hence reinforces the interaction between research and operational worlds.

In 2016, Météo-France HPC power has been up-graded to reach 2x2.5 Pflops. This was critical for the operational launch of the Arome ensemble. High Performance Computing is of paramount importance for meteorology. Works on scalability and numeric suited to the coming architectures have logically started to make the best use of future computer systems.

This report provides a full overview of the main research works carried on at CNRM and LACy, as well as in other departments at Météo-France. Heavy rainfall, fog, cyclones are strong operational drivers for research on micro-physics, stable layers or meso-scale

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ocean-atmosphere coupling. Activities start with on field campaigns were CNRM deploys innovative drones and miniaturized instruments focused on aerosols. Amongst the important achievements in 2016, one must notice the new multi-scale convection scheme, which should be deployed both for numerical weather forecast and for climate studies. It is also worth noting the availability of limited area Arome versions for each French overseas territory, which marks an end to a decade of efforts in meso-scale modelling.

Data assimilation is critical for numerical weather forecast. Météo-France heavily involves on a meso-scale ensemble assimilation system. This strategy aims at dealing with the temporal dimension and coping with the strong non-linearities of the assimilation process at meso-scale.

Impacts also catch the interest of Météo-France scientists. Avalanche forecast is quickly evolving towards high resolution and makes the best use of available micro-wave and visible satellite missions. At sea, forecasts also critically rely on satellite observations. One should mention the Copernicus Sentinel-3, Sentinel-1A, Sentinel-1B, but also the Chinese-French CFOSAT missions amongst the main on-going or achieved efforts in data assimilation for sea state. Another example comes from the air quality and pollution domain which has been enriched with new allergenic species thanks to the Copernicus programme. Here too, satellites missions and data assimilation are essential tools for meteorologists!

Météo-France research activities also deal with long term forecast and climate studies. CNRM scientists have been involved during COP21 in the evaluation of the INDCs (Intended Nationally Determined Contributions) and kept later on working on emission with other French groups. They also prepare the next CMIP-6 exercise, setting up a new version, CNRM-CM6, of the climate model and an Earth system version including the carbon cycle, CNRM-ES. Climate change impact on air composition is one of the effects studied at CNRM, which has obvious interest for air quality and health. The link between climate and weather is explored at seasonal and sub-seasonal time scales, using the CNRM-CM6 climate model in a seamless approach.

A wider perspective could be drawn. This is the role of few prospective works initiated in 2016, e.g. regarding connected objects or the valorisation of ensemble forecasts. Infrastructures are also a primary concern: The preparation of the renewing of the French high altitude research aircraft also received attention in 2016, hopefully with a positive answer in 2017.

The reader will enjoy the next pages where the rich activity deployed by Météo-France in various research domains is presented in details. 2016 marks the end of the previous mid-term plan and the start of a new one, covering 2016-2020 as far as CNRS is concerned, and 2017-2021 for Météo-France. Hopefully will the quality of Météo-France's research be kept at a high level, at least the same level at which my predecessor Philippe Bougeault has brought it. I sincerely thank him for such an achievement and for having paved the way for the future with a strong strategy.

Marc Pontaud
Director of Research, Météo-France,
Director, Centre National de Recherches Météorologiques (CNRM)

Numerical weather prediction

The following pages contain short articles illustrating key achievements in line with the longer term numerical weather prediction (NWP) scientific strategy of Météo-France, as published for example in 2013. The use of future observing systems, or even their design, such as the ADM-Aeolus lidar or the possibility of geostationary microwave soundings recall that no progress in the quality of finer scale weather forecast can be achieved without a commensurate increase in the time-space density and diversity of reliable observations. A better use of radar data available in the AROME domain is another much needed progress area. One key mid-term goal of the NWP and data assimilation (DA) research group is to improve the use of the too sparse information currently available for the various western European AROME forecasts (nowcast AROME-PI, ensemble PE AROME and deterministic AROME) through the introduction and use of an AROME ensemble data assimilation, and preliminary results are becoming available. Improving the realisticness of the model atmosphere is obviously another key area. Some recent results relating to turbulence parameterization are shown, in critical areas such as improving the representation of stable layers, which also is one aspect of improving low cloud and low visibility forecasts. Several recent comparisons of global atmospheric model dynamical cores, that part of the models handling the dynamics of the atmospheric waves spectrum, performed on some of the most recent computers available in the USA, involving the ECMWF IFS core which is also the basis of both the ARPEGE and AROME numerical schemes, confirm that this family of cores, thanks to the "long" time steps that they enable to use in operations, remain the most efficient ones in terms of "time to solution", the main criterion for operational weather forecast. However, this is achieved at the cost of disputable scalability properties of those cores. If larger computing power continues to be derived from increasing parallelism in computations, it may reach a point where even the time to solution is weakened with respect to "short" time step, better scalable, algorithms. Although nobody has, at the moment, any idea whether this situation may actually turn up or when, the NWP research group has laid down a ground-base for a fall-back numerical scheme solving the current fully-elastic mass coordinate AROME equations set in case the current one becomes demonstrably inefficient. The following articles also illustrate how the impact of observations on forecasts is assessed. They furthermore show that the research department of Météo-France actively contributes to preparing for one of the key ambitions of the new Objectives and Performances Contract between Météo-France and the Government, namely the extensive use of ensemble forecasts as well as the design of innovative services based on ensembles.

Beside these studies aiming longer term progress, the NWP and DA research group has been heavily involved in preparing new versions of the NWP integrated code, shared with ECMWF and the ALADIN and HIRLAM limited area NWP consortia. In this area, it must be remembered that this code is undergoing a dramatic modernization step. Although initially driven by the will to renew the DA control framework, the re-engineering effort leads to ease shared memory parallelization and better modularization. In full line with the previous Objectives and Performances Contract, a set of 5 IFS-coupled overseas 90 levels, 2.5 horizontal resolution AROME dynamical adaptation systems have become operational. A further key achievement has been to complete the setup within the Météo-France operational suite of the first generation AROME ensemble forecast system. All these new derivations of AROME are introduced using the new, object-oriented Vortex scripting system. The year has ended with the installation, as an experimental suite in the operational environment, of improved versions of the ARPEGE and AROME-F data assimilation and deterministic forecast systems. A special effort has been dedicated to the former one, by solving the decade-long awaiting of implementing the Météo-France SURFEX surface model, already used for example both in AROME and the climate version of ARPEGE. Another key change in ARPEGE is to represent all forms of convection with the new generation PCMT scheme. This scheme introduces, thanks to a dedicated set of new historical variables, actual convection life-cycles that naturally and physically solve a number of long-known drawbacks of classical, single-time step, convection schemes. An unusual one-year long experiment of this new ARPEGE version has been achieved, partly thanks to the new computing system that became available during the year, but also thanks to the dedication of the scientists of the group. The results indicate very good progress of the ARPEGE system, which will add to the confirmation that ARPEGE provides the earliest and best 00-UTC 24h forecasts over Europe. These new versions will be completed with their ensemble counterparts early in 2017 and will become operational during spring 2017.

1

Modelling and data assimilation

Physical consequences of measurement of the Lewis number

The aim of this study is to use the CNRM Météopole-Flux database in order to validate or invalidate some of the assumptions retained in the turbulence models. The turbulent Lewis number is the ratio of the Prandtl and Schmidt numbers and it is thus the ratio of the exchange coefficients for heat and humidity. This ratio is set to unity in all atmospheric models of the turbulence, this leading to several simplifications. In particular, the atmospheric variable on which the turbulence is acting so far is only an approximate version of the moist-air entropy.
It is shown that the Lewis number is varying with space and time, depending on the local

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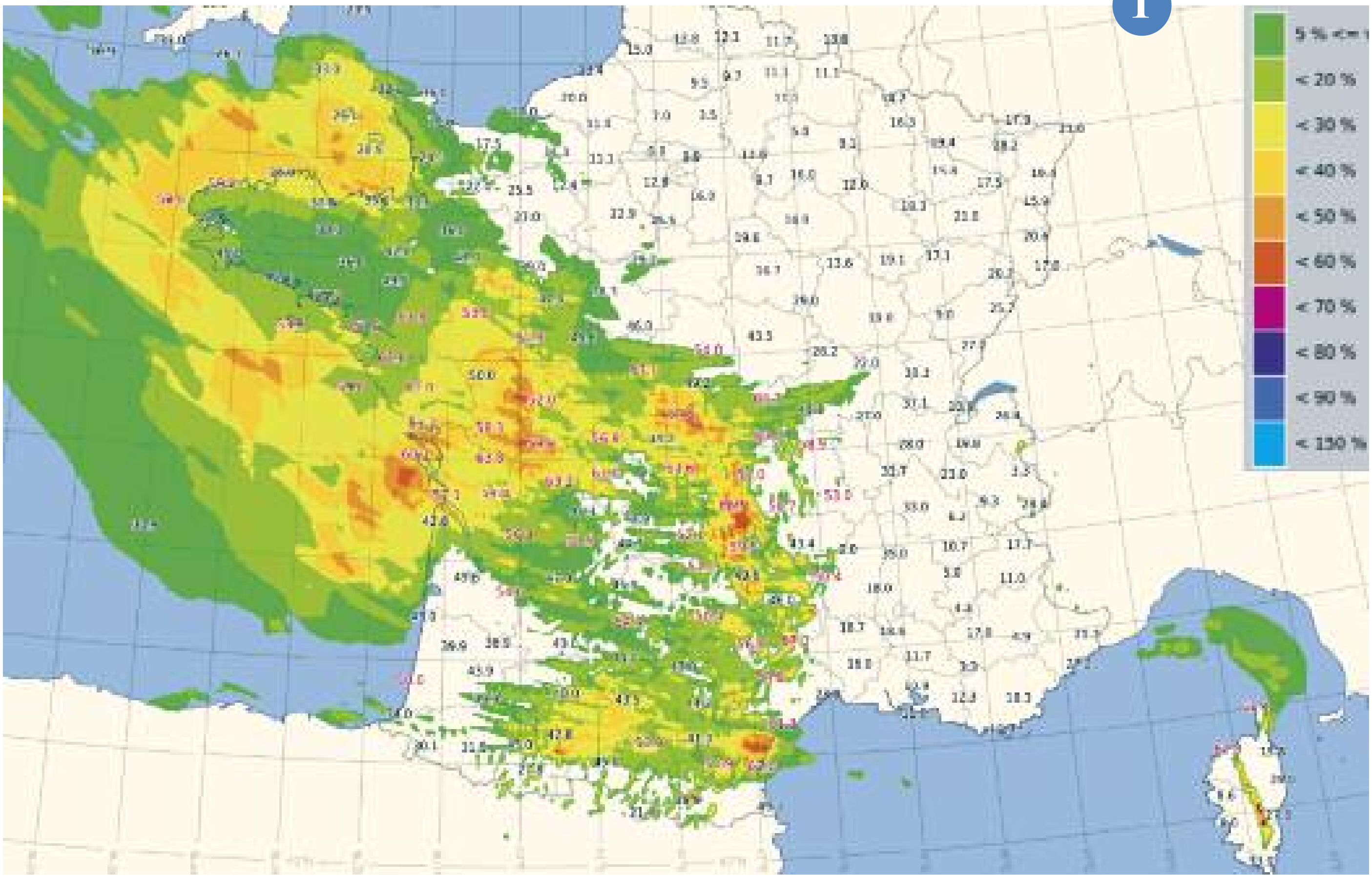

The probability of a maximum wind gustiness exceeding 50 knots obtained with the AROME Ensemble Prediction System at 15h lead time for the 6th of March 2017 at 12h UTC during the winter storm Zeus over France are plotted in a range of colours. The observations of maximum wind gustiness are also pointed on the map.

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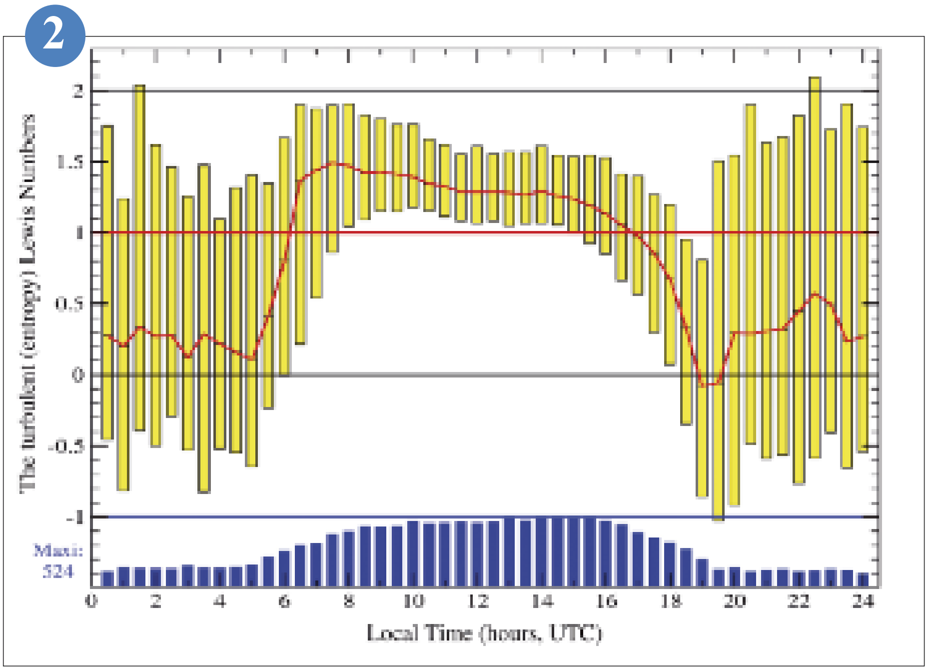

The diurnal cycle of the moist-air entropy Lewis number at Toulouse in two-year average, with the hours (UTC) in abscissas.

thermodynamic conditions. The diurnal cycle of the Lewis number is depicted in the figure for a period 2014-2016 and with the universal time in abscissas. Only the best quality observations are retained (from 100 to more than 500 observations for each 30mn interval, in blue). The yellow boxes represents the interquartile range (midspread) and the red piecewise linear curve connects the median values. Values are clearly above the unity between 8 and 15 UTC and they decrease below the unity at night. These results obtained with the Météopole-Flux measurements are mostly confirmed by the Cabauw mast in the Netherlands, by the campaigns used to build the ECUME bulk surface scheme over the oceans, and also by LES outputs considered as numerical laboratories.
All these observational databases will be compared with new parameterisations of turbulence where the Lewis number is not set to unity and where a more realistic value of the moist-air entropy is considered. Possible improvements are expected when and where the Lewis number is different from unity, and therefore depending on location and time of day.

2

GABLS4: an inter-comparison case to study the stable boundary layers

The GABLS4 inter-comparison, launched in summer 2014, aims to study the physical parameterizations of numerical weather and climate models in case of very stable boundary layer, and the interactions of the surface boundary layer with a homogeneous surface with a low conductivity such as snow on a flat topography (web site: http://www.umr-cnrm.fr/aladin/meshtml/GABLS4/GABLS4.html). This inter-comparison follows on the initiative started in the mid-2000 with a simple and idealized case done in 2004, followed by two other more complex cases ended in 2011 and 2014. This fourth project, supported by the international community during an ECMWF workshop, is organized in collaboration with LGGE and takes advantage of temperature, wind, humidity and turbulent fluxes observations available as several heights from a 45-m tower located at the observation site of Dome C on the Antarctic Plateau.
The inter-comparison consists of 3 inter-comparisons: land-snow model (LSM), Single Column Model (SCM), Large Eddy Simulation (LES) with two protocols for the last two: one real case with time variable forcings and radiation to allow comparison with observations and possibly LES, one idealized case with constant forcings, without radiation and moisture to make easier LES simulations.
Eventually, about 20 research teams are contributing to GABLS4. First results highlight a very large spread of surface sensible heat fluxes simulated by the models and an overestimation of the height of the low level jet even despite a very fine prescribed vertical resolution (see figure). Characterizing uncertainties in LES models (used to evaluate SCM), in very strong stable conditions, will be an objective for 2017.

3

Towards a Horizontally Explicit Vertically Implicit (HEVI) class of time schemes for the fully compressible dynamical system of AROME model

The use non-hydrostatic fully compressible modelling system for numerical weather prediction (NWP) raises many challenging questions, among which the choice of the time discretization scheme. It is commonly acknowledged that the ideal time marching algorithms to integrate the fully compressible system should both overcome the stability constraint imposed on time-step by the fast propagating waves, and be scalable enough for efficiently computing on massively parallel computer machine. The assumed poor scalability property of Semi-implicit (SI) time schemes, currently favoured in NWP, is quite a drawback as they require global communications to solve a three-dimensional elliptic problem.
Because it is considered as the best compromise between stability, accuracy and scalability the properties of various classes of HEVI schemes have been deeply explored within GMAP team. This class of time discretization eliminates all the problems linked to the implicit treatment of horizontal forcings by coupling explicit methods for the horizontal propagation of fast waves to an implicit treatment of vertically propagating elastic disturbances. The limitation in time-steps compared to SI schemes would be compensated by a much more economical algorithm per time-step.
Although, it has not been firmly established yet that the efficiency of such HEVI schemes could compete with SI schemes in an operational context, some idealized test-cases seem to highlight the predictive skills and the accuracy of HEVI schemes.

4

Towards the assimilation of dual-polarization radar observations in high resolution NWP models

The dual-polarization (DPOL) technique provides unprecedented information about the microphysical characteristics of precipitating clouds and helps improve the quality of radar observations. The aim of this work is to evaluate the potential of these observations for the initialization of convective-scale NWP models.
Assimilation experiments of DPOL observations have been conducted with AROME model and its 3D-VAR assimilation system. The assimilation method that was used is derived from the operational assimilation method for radar reflectivities. Pseudo-observations of relative humidity are first retrieved from observed reflectivity (Zhh) or specific differential phase (Kdp) profiles, through a unidimensional Bayesian inversion. The humidity profiles are then assimilated in the AROME 3D-VAR system.
Different assimilation experiments were conducted for two convective cases. The impact of attenuation correction was evaluated by comparing two experiments using reflectivity only, without (ZNocorr) or with (Z) attenuation correction. In experiment Z, higher humidity pseudo-observations were retrieved in regions affected by strong attenuation, which led to a better humidity enhancement in the convective regions in the analysis. The impact of Kdp was tested by using this variable only to retrieve the humidity pseudo-observations (experiment ZK). The benefit of Kdp was evidenced when Zhh is affected by partial beam blockage: in this case, ZK experiment enabled a better humidity enhancement in the convective regions in the analysis.
Globally, experiment ZNocorr, Z, ZK obtained similar scores in terms of precipitation forecasts but a larger number of cases will be examined in the future in order to better assess the benefit of DPOL observations.

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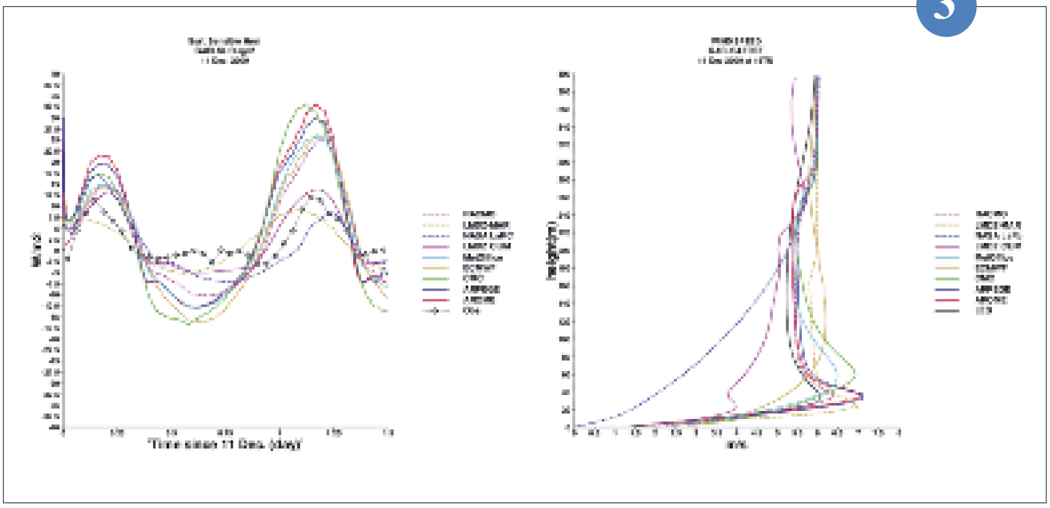

Single Column Models simulations (in color)
Left: Sensible surface heat fluxes in W/m²; observed fluxes (dotted line).
Right: Wind speed profile in m/s at 18 UTC; LES reference simulation (black line).

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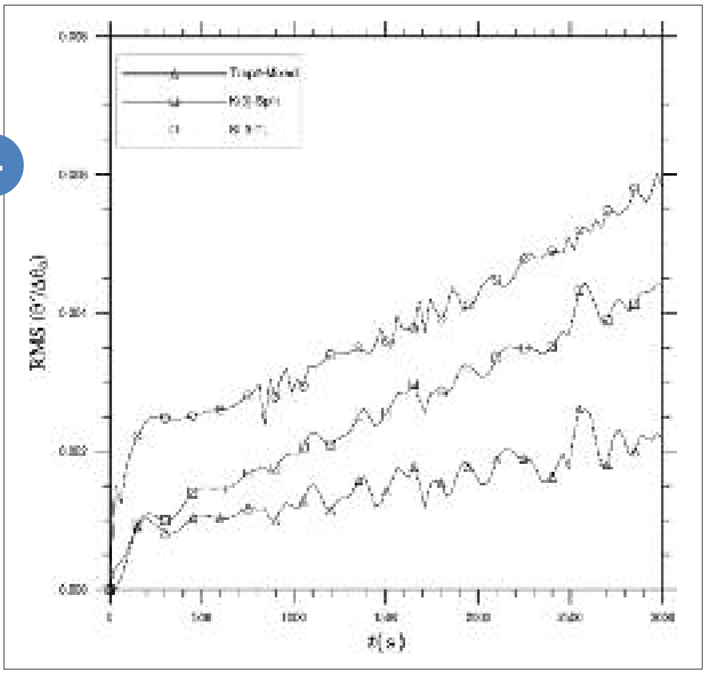

Normalized RMS errors in potential temperature for the non-hydrostatic horizontal wave propagation test-case, comparing SI, time-split HEVI, and Mixed Trap2(2,3,2) HEVI numerical solutions with the analytical solution.

Pseudo-observations of relative humidity (squares) retrieved by Z (a) and ZK (b) experiments, overlaid on analysed relative humidity fields after assimilation of the corresponding pseudo-observations. Altitude around 1600 m. 06 UTC 24/09/2012. Black lines indicate 35 dBZ reflectivity contours. Range rings show distances of 50 and 100 km from the Nîmes radar. In the white hatched area in (a), the closest radar observations of this altitude level are affected by a partial beam blockage over 10%.

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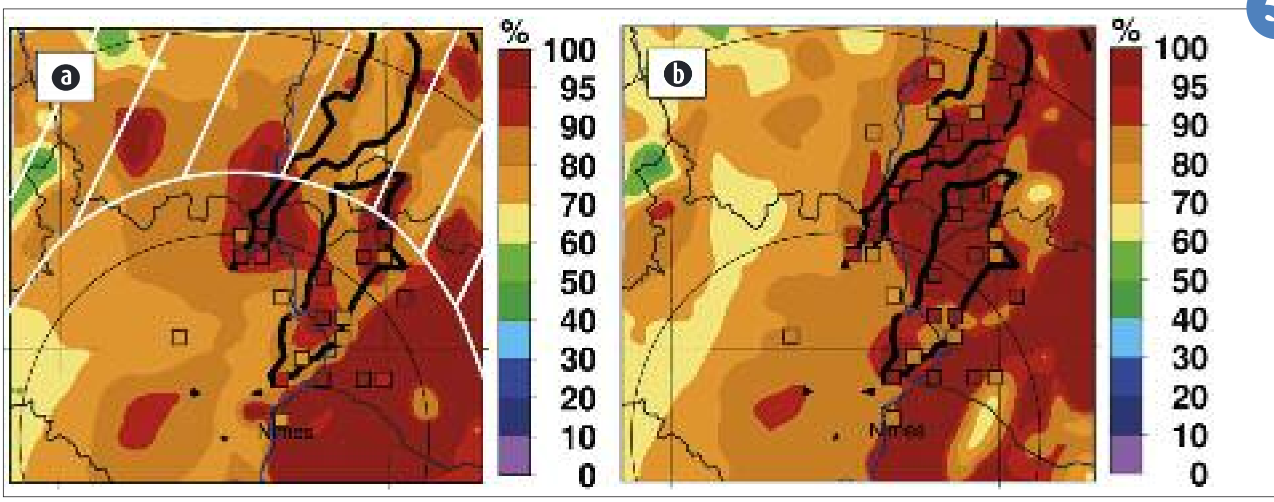

Potential impact of a microwave sounder onboard a geostationary satellite for AROME Forecasts

Observing the Earth in the microwave spectrum from the geostationary orbit has generated interest for several decades. Such a mission would add the high observation rate offered by a geostationary orbit to the sounding capability of the present observing system.
Recent technological advances may overcome the limitations that originally prevented from developing such an instrument. It would provide frequent observations informative on water vapor, temperature and hydrometeors in the atmosphere. Nevertheless, the foreseen radiometric precision of such an instrumental concept is likely to be degraded with respect the one of current microwave sounders onboard low Earth orbiting satellites. In collaboration with the European Space Agency, experiments have been conducted at CNRM in order to evaluate the potential benefit of such an instrument on Météo-France numerical weather prediction systems.
As no real observations were available, fully simulated but realistic experiments known as OSSE (Observing System Simulation Experiments) have been performed. In this simulated framework, the impact of such an instrument's radiometric precision on AROME France forecasts has been studied. The figure shows a meteorological scene observed with (a) an instrument as precise as current sounders in orbit, (b) an instrument with degraded radiometric precision. Results of these OSSE have shown that observations from such a future microwave geo-sounder should be characterized by a good radiometric precision if it aims at complementing the current dense observing system, which will be soon enhanced by the new generation of European geostationary satellites.

6

Impact of marine observations on weather predictions

EUMETNET has funded studies to quantify the importance of sea surface observations (vessels and buoys) on the quality of weather forecasts. CNRM participated and implemented the linear approach FSOi based on the sensitivity of forecasts to observations in ARPÈGE over a period of 21 months (July 2013 to April 2015), focusing on the 24-hours forecast error on Europe and Eastern Atlantic.
Most of moored buoys are not considered in the study because the focus was on the impact of mobile stations. Pressure and wind observations are assimilated and diagnosed with the FSOi. Various aspects of the impact have been studied: its dependence on latitude, on weather regimes and its relation to the density of observations. The distribution of the impact between buoys, vessels (VOS) with automatic measurements or human measurements as well as contributions by parameter are examined.
Most drifting buoys do not measure wind but their surface pressure measurements are considered to have better quality than those from VOS. Hence, the impact of the buoys largely dominates the impact of VOS. But ships and buoys are complementary in their Coastal / High-Seas distribution. Indeed, the data from VOS are very numerous near the coasts along shipping routes. Buoys are very well distributed throughout the North Atlantic basin, except in the South of the domain and in the Mediterranean. Thus, on a large Gascogne coastal zone, a unit observation from a vessel contributes 10 times less than a buoy observation, but the highest density of the VOS produced a cumulative impact which reaches up to 50% of the impact of buoys.

7

AEOLUS: the wind lidar mission of the European Space Agency soon in orbit

AEOLUS is the second core mission of the Earth Explorer programme of the European Space Agency. Launched in the late 90s, the programme should make a decisive step at the end of 2017 with the launch of the first wind lidar ever in space.
On a sun-synchronous, 7-day repeat cycle orbit, the lidar will measure the zonal component of the wind from the ground up to the lower stratosphere with a vertical resolution from 250m (in the boundary layer) up to 2km (in the lower stratosphere) and a horizontal resolution of 90km. The data recorded on board will be transmitted to the ground via the Svalbard acquisition station and will be available less than 1.5 hour in Europe. They will be distributed to all the meteorological services that intend to assimilate them. With two detection channels, this high-spectral resolution lidar will also measure the optical properties of the aerosols and cloud particles without any a priori assumption about their nature.
Studies are currently being conducted on their assimilation with air quality models such as MOCAGE at Météo-France. The CNRM has played an active role in the development of algorithms for the calibration, the retrieval of aerosol and wind products, and will be mobilized in 2018 when the first real data will be available. This will be the time for checking the good behaviour of the algorithms and updating them whenever needed.

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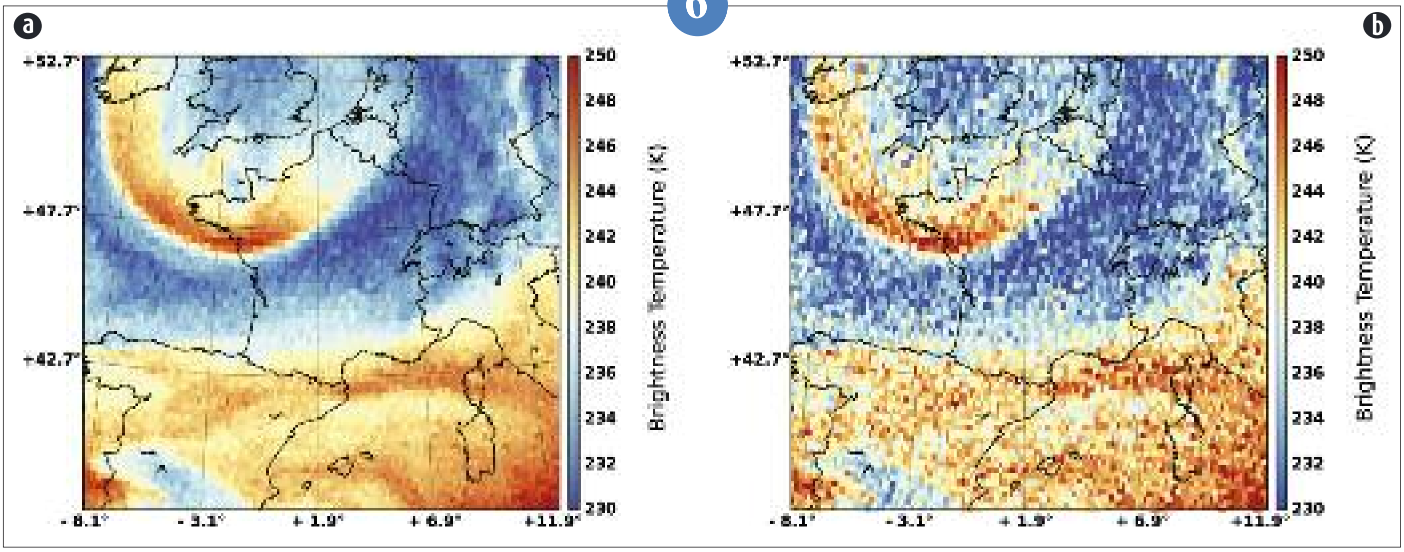
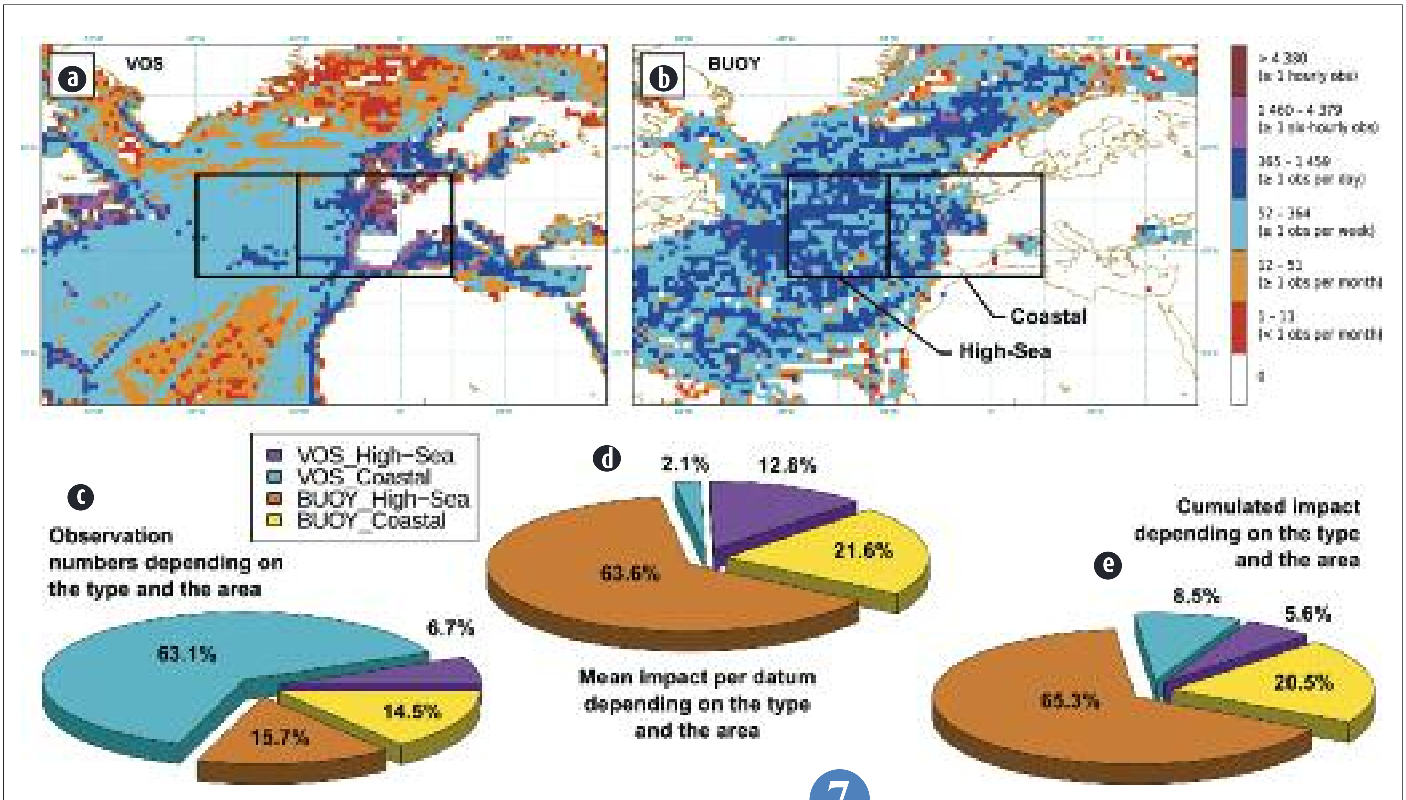


Simulated Brightness Temperatures at 183.31 +/- 0.2 GHz (water vapor absorption band) over the AROME domain for July 2nd 2015 at 12h UTC for an instrument (a) as precise as current radiometers onboard low Earth orbiting satellites, (b) with degraded radiometric precision.



7

Geographical distribution of observations from VOS (a) and buoys (b) for the whole sample
The black rectangles show the delimitation of the "High-Seas" and "Coastal" zones used in the diagrams (c, d and e) of relative contributions in number (c) in impact per unit observation (d) or accumulated impact (e) from Buoy and VOS measurements.

8

Artist view of the AEOLUS satellite pointing its laser beam down towards the atmosphere.

Ensemble forecasting

Hydro-meteorological ensemble forecasting of Mediterranean flash-floods

Mediterranean flash-floods, which often cause havoc and loss of life, are frequent in the fall season. They are due to heavy precipitation events (HPE) that affect fast responding watersheds. It remains a challenge to properly forecast Mediterranean rainfall location and intensity as well as the hydrological reaction of the Mediterranean catchments.
An hydro-meteorological integrated approach is developed at CNRM to forecast the discharge of fast-responding rivers: quantitative precipitation forecasts (QPF) from the atmospheric model AROME, whose kilometric resolution suits for HPE forecast, are used to drive the ISBA-TOP system, which is dedicated to flash-floods simulation.
Uncertainty affects this forecasting chain at several levels. The QPF used to drive ISBA-TOP are the major source of uncertainty. Using rainfall scenarii from AROME-EPS, the ensemble prediction system based on AROME allows to manage it. But the knowledge of initial soil moisture is also uncertain and the hydrological model itself is affected by uncertainty. The sensitivity of ISBA-TOP model to its parameters and initial soil moisture is thus investigated. Discharge simulations with ISBA-TOP are found sensitive to three hydro-dynamical parameters. This sensitivity depends on initial soil moisture conditions. Perturbation methods varying the three sensitive parameters and initial soil moisture allow to build an ensemble-based version of the ISBA-TOP system. A HEPS that takes the uncertainty at the three levels into account can thus be designed using AROME-EPS QPFs to drive the ISBA-TOP ensemble-based version.
The skill of this HEPS is still to be assessed. A low bias found on the AROME-EPS rainfall forecasts has to be corrected first.

9

Forecasting ground-satellite interruption

The frequencies used to transmit data from high resolution Earth-Observation satellite to Earth (from 2 to 14 GHz) are now saturated and can no longer meet the users requirements in terms of flow rate. Higher frequencies since they are associated with wider bandwidths offer new opportunities. Future Earth-Observation satellites will then use frequencies from 18 to 53 GHz. However sensitivity to tropospheric phenomena becomes critical as frequency increases. Significant signal attenuation is then expected especially when heavy precipitation occurs. To circumvent this problem new methodologies using weather forecast must be developed to allow acceptable availability. A statistical model predicting the rain attenuation knowing the predicted precipitation probability using the ensemble prediction system PEARP is developed (see the figure). The learning sample is one year of transmission data from a low-orbit satellite to a ground station located in Toulouse. It is then possible to adapt the link using the predicted propagation conditions. Using our sample, it is possible to see an improvement of the flow rate of about 30% with respect to the situation when nothing is known about the weather conditions.

10

An Extreme Forecast Index (EFI) for extreme events based on ensemble forecasting

Ensemble forecasting is dedicated to sample probabilist density function of atmospheric variables. Post-processing is a key issue to make ensemble forecasting useful for end users. For example, it is rather simple to compute the probability for an extreme event to occur. It is achieved by computing the ratio of members for which the corresponding atmospheric variable exceeds a given value. As deterministic models, ensembles suffer from systematic errors. For instance, the way an ensemble forecasting system can reproduce climatological extreme events frequencies must be assessed. We have created a reference dataset (reforecast) based on systematic hindcasts of a simplified version of our ensemble system, for a period of 30 years. Then, we can compare current ensemble forecasts to the climatology of past forecasts. For the case of extreme events, we implement the Extreme Forecast Index (EFI) that aims at comparing one current ensemble forecast density distribution to the reforecast distribution. EFI has been validated for 50 cases of intense wind gust for France over the last 30 years (Boisserie et al. 2016). EFI is also implemented for studying Mediterranean heavy precipitations events. An experimental product has been recently made available for forecasters to consider EFI (see figure). A second indicator is shown, Shift Of Tails (SOT), based on distribution comparisons above high quantiles 90 % or 95 % of climate and daily ensemble prediction.

11

Development of an ensemble of data assimilations for AROME and PEARO

Numerical Weather Prediction at kilometric scale is targeting high impact meteorological events such as fog, convective storms, and wind gusts, using the AROME system at Météo-France. An ensemble of data assimilations based on AROME is under development. It will provide AROME with flow-dependent error statistics, while also being used to initialize the ensemble prediction system.
This ensemble of assimilations and predictions is built from a variational scheme, where observations are explicitly perturbed. This allows a good representation of the error cycling in our system; yet this is quite costly from a computational viewpoint. The GMAP has recently developed a version of AROME at reduced spatial resolution (3,8 km) to limit the numerical cost of the ensemble.
Other perturbations will be applied, for instance the sea surface temperature is different for every member. The dispersion of the ensemble is improved through a new inflation scheme that compares the spread with the skill of the ensemble mean. With this ensemble, the error statistics can be calculated online, describing the spatio-temporal evolution of the uncertainty (Figure). Because the ensemble is limited in size – currently to 25 members, these statistics are affected by sampling noise. Sophisticated filtering algorithms have been designed to alleviate this problem.
Experiments aim at quantifying the impact of this ensemble on the AROME and PEARO systems over long periods, with operations planned for 2018.

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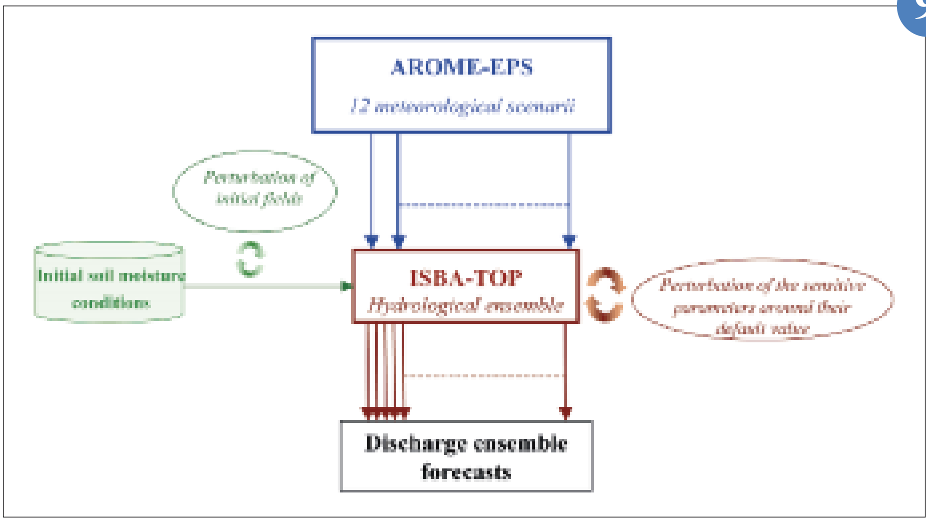

Scheme of the hydro-meteorological ensemble prediction system (HEPS) based on the ISBA-TOP model. Uncertainty affects this system at three stages: meteorological forecasts (in blue), hydrological modeling (in red) and soil moisture state (in green). The HEPS takes uncertainty at those three levels into account.

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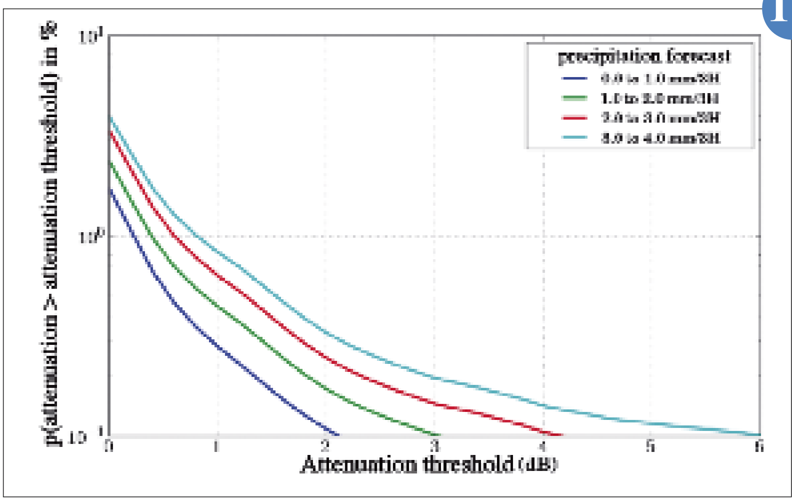

Probability that the attenuation is larger than a given threshold for different thresholds (x-axis) and different precipitation rates predicted using ARPEGE.

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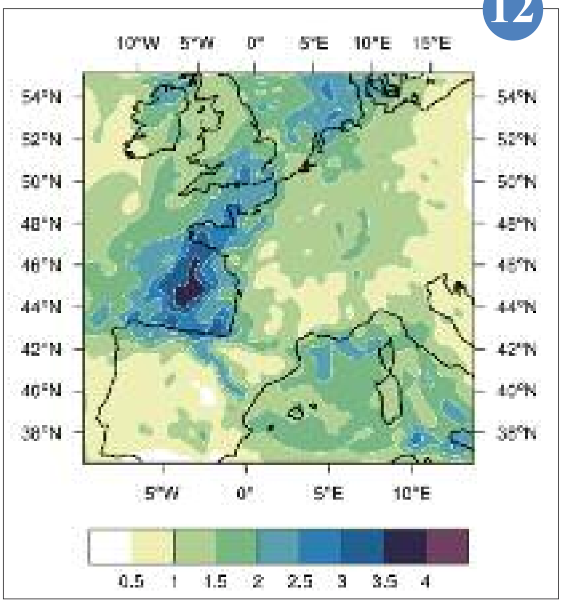
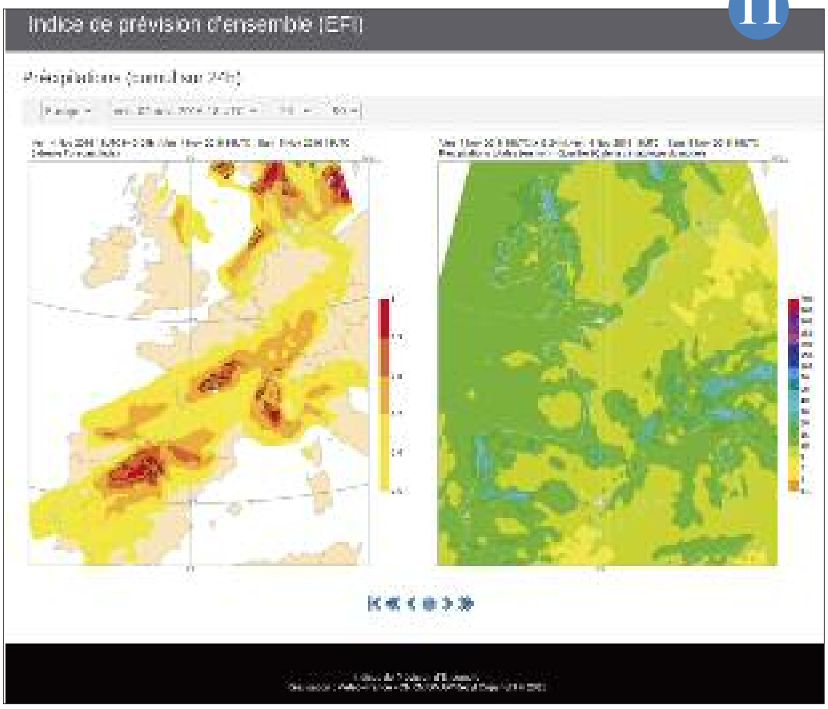


Standard deviation of the error in wind (m/s) for a 3h range forecast, as estimated from the ensemble of AROME data assimilations, valid on June 23th 2016 15 UTC, at the top of the boundary layer. The strong uncertainty is linked with the developments of convective activity over the North West of France.

Experimental EFI display page
Shadings: EFI values; black contours: SOT.

11



Process studies

Researches on process knowledge aim at a better understanding of weather systems and surface-atmosphere interactions in order to improve high-impact weather forecasting and to advance physical process modelling of the numerical weather prediction (NWP) and climate models. Several examples of process studies performed in 2016 are hereby presented for tropical cyclones over Indian Ocean and for heavy precipitation in Mediterranean regions and over West Africa.
The methodologies involve field campaign observations and very high-resolution modelling, from few meters to few kilometers horizontal resolution. The following highlights of 2016 show how the observations from the BLLAST field campaign in summer 2011 and from the HyMeX field campaign in autumn 2012 have been employed to evaluate and further improve the physical modelling of turbulence and microphysics for the AROME NWP model. Pioneered real-case very-high resolution simulations with 100m-150m grid meshes were also performed for two types of high-impact weather situations: a fog period during the LANFEX field campaign (Fig.) and two heavy precipitation events during HyMeX. These simulations will be first verified against field campaign observations and then will served as reference both for studying the role of the fine scale terrain patterns on the fog formation and precipitation and for improving the physical parameterizations of the Météo-France NWP and climate models.

1

Boundary-layer turbulent processes represented by Meteo-France numerical weather prediction models during the BLLAST campaign

The BLLAST (Boundary-Layer Late Afternoon Sunset Turbulence) campaign aimed at studying the transition from daytime to nighttime conditions and acquired many boundary-layer observations. We use those observations to evaluate both Meteo-France Numerical Weather Prediction models, AROME the limited area model and ARPEGE the global one.
We analyzed the representation of the temperature and moisture vertical profiles as well as the time evolution of surface variables and energetic budget. We highlighted some biases such as the overestimation of the sensible heat fluxes for the grid point with high vegetation in ARPEGE and the overestimation of the latent heat fluxes in AROME. AROME better reproduces the boundary-layer vertical structure both due to the finer vertical resolution as well as the better depiction of orography-induced circulation. Special attention was paid to the evaluation of the turbulent kinetic energy that quantifies the intensity of turbulence.
The figure shows the time-evolution of the turbulent kinetic energy observed (mast, aircraft, lidar and tethered balloon) and simulated at various vertical heights. Both models reproduce the order of magnitude. AROME underestimate this variable at 8m but better reproduce the day to day as well as the diurnal variability.
This works allows to identify biases in the reproduction of boundary-layer processes in particular the turbulence intensity thanks to the BLLAST data.

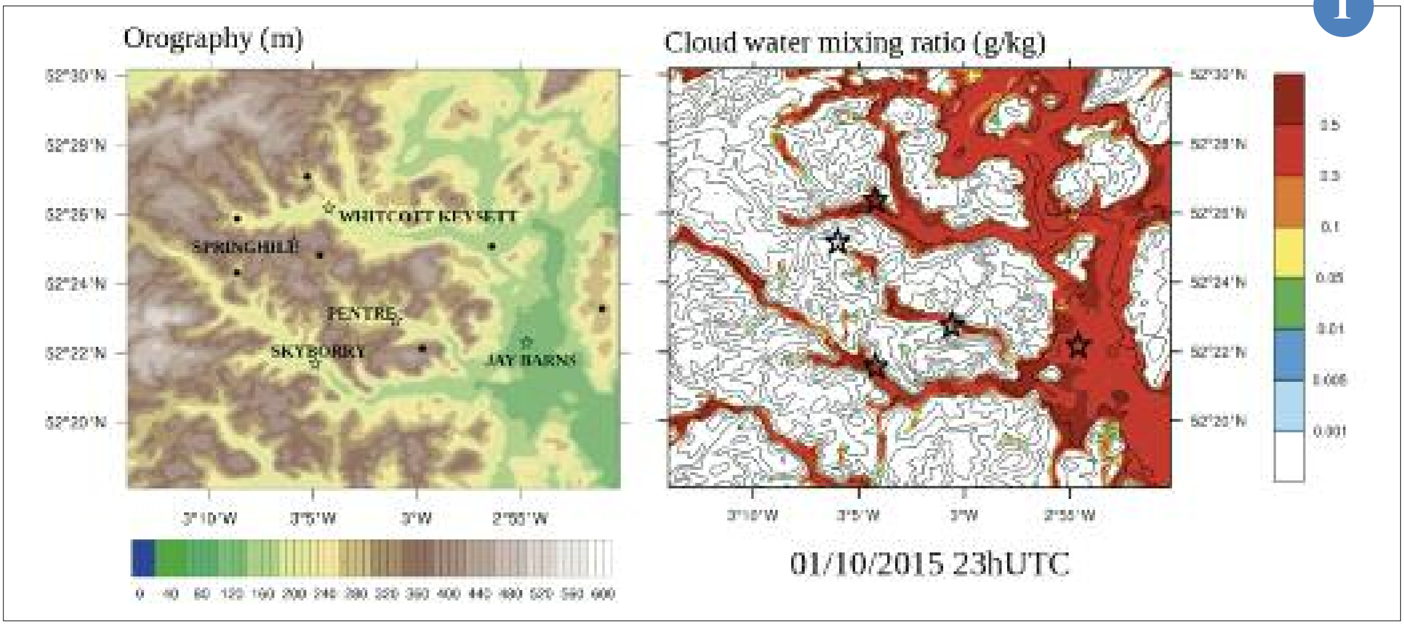
2

Evaluation of the 2-moment microphysical scheme LIMA, in Meso-NH and AROME

Atmospheric aerosols affect the cloud microstructure through their ability to nucleate droplets or ice crystals.
The 2-moment microphysical scheme LIMA explicitly represents aerosol-clouds interactions at convective scale. Its clouds and precipitations representation is under evaluation in Meso-NH using detailed microphysical observations from the HyMeX campaign. The synergistic use of different observation types (disdrometers, polarimetric radars, airborne in-situ probes, etc.) provides a precise description of the cloud composition and precipitations.
The comparison to these observations reveals that LIMA represents the observed variability in cloud and precipitation characteristics much better than the 1-moment scheme ICE3, used operationally in AROME (Fig.). It also helps to identify the shortcomings of LIMA (such as the overestimation of mean rain drops diameters) and ways to improve the scheme (releasing one constraint on the particle size distribution).
LIMA was also implemented in the AROME model, and tested for two 1-month periods, using an homogeneous aerosol population. First results from this statistical evaluation show a positive bias for heavy precipitation on the one hand, and a large impact of the aerosol concentration on small precipitation occurrence and amounts.
The added value of LIMA is its ability to represent a realistic aerosol population. Therefore, a method to initialize the aerosols from MACC analyses or MOCAGE forecasts was implemented and is under evaluation, both for process studies and in view of the future use of LIMA in the operational model.

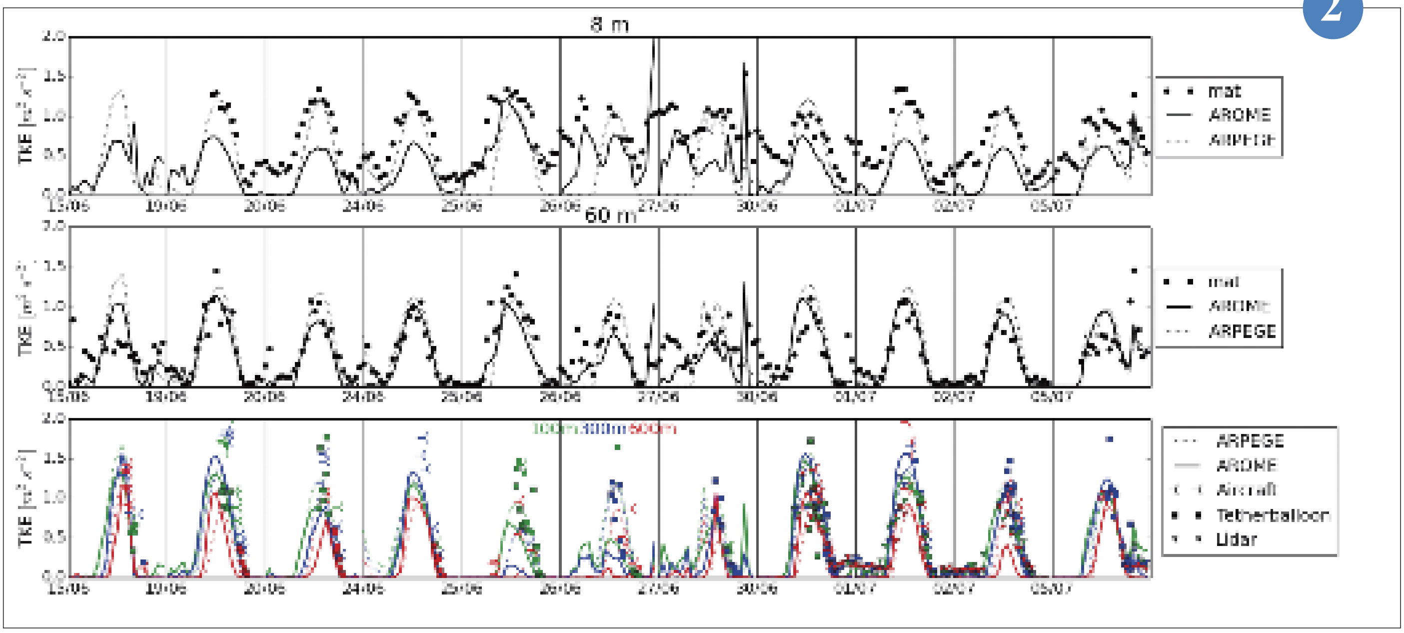
3

1



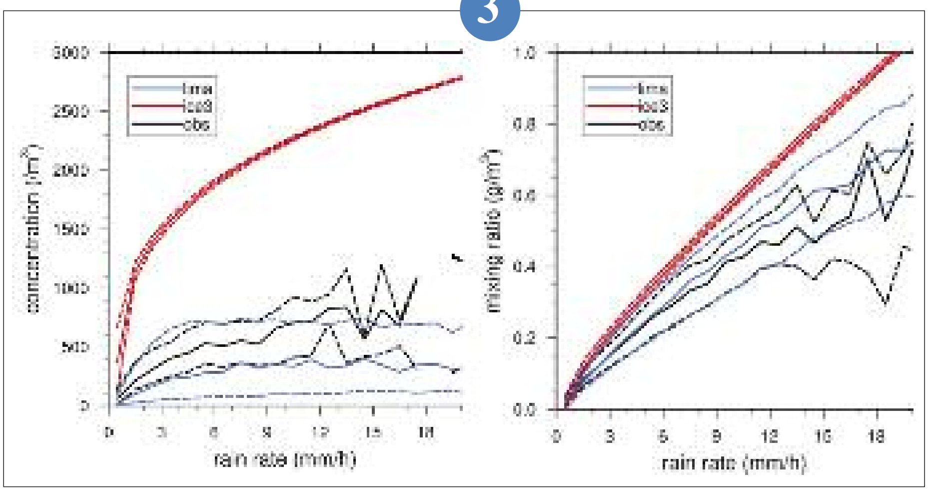
Meso-NH simulation at 100m horizontal resolution for a fog situation during the LANFEX field campaign over a UK hilly area
Left panel: Model orography; Right panel: Cloud water mixing ratio (colour scale) superimposed to the orography (isolines). The very high resolution allows to simulate the fog which mostly forms in the narrow mountain valleys and over plains as observed.

2



Temporal evolution of turbulent kinetic energy at 8m (top panel), 60m (middle panel) and 100m, 300m or 500m (bottom panel) observed by surface station, mast, aircraft, doppler lidar or tethered balloon or simulated by AROME and ARPEGE for the different intensive observing period of the BLLAST field campaign.

3



Mean (plain line) and quartiles (dashes) of rain drops concentration (left) and mixing ratio (right) as a function of rain rate, for HyMeX IOP16 (26/10/2012). LIMA (blue) is closer to the disdrometers observations (black) and represents their variability better than ICE3 (red).

Analysis of the extreme rain event of Ouagadougou on 1st September 2009

Africa is repeatedly affected by high-impact weather with devastating consequences for local communities. A key question is to understand what determines the predictability of these events. For that aim, the THORPEX program of WMO selected for the West Africa the extreme rain event that occurred in Burkina Faso on September 1st 2009 with 263 mm recorded at Ouagadougou leading to displaced people, deaths and material damage.
In collaboration with forecasters of Senegal (ANACIM) we performed a detailed multi-scale analysis of this extreme event that occurred within a 20-days period, with the passage of a train de of 3 African easterly waves combined with a strong and large wet anomaly initiated over Eastern Africa. The amplification of these waves resulted in the breaking of the second one and in the formation of a moist vortex forcing intense precipitations. Contrary to squall lines – the dominant type of precipitating system over Sahel – this system is not associated with density currents and propagates slowly allowing strong precipitation accumulation (Figure). At larger scales we noticed interactions between several equatorial waves (Kelvin, Rossby and mixed Rossby-Gravity) contributing to the occurrence of this extreme event.
This study has been completed by high-resolution AROME simulations to study the formation and propagation of the moist vortex and its interactions with the convective activity. Also a statistical analysis has been performed on a set of extreme rain events observed over Western Sahel, confirming some results drawn from the case study of the Ouagadougou event.

4

Mediterranean heavy precipitation: moisture structures and convective processes (HyMeX IOP13 case study)

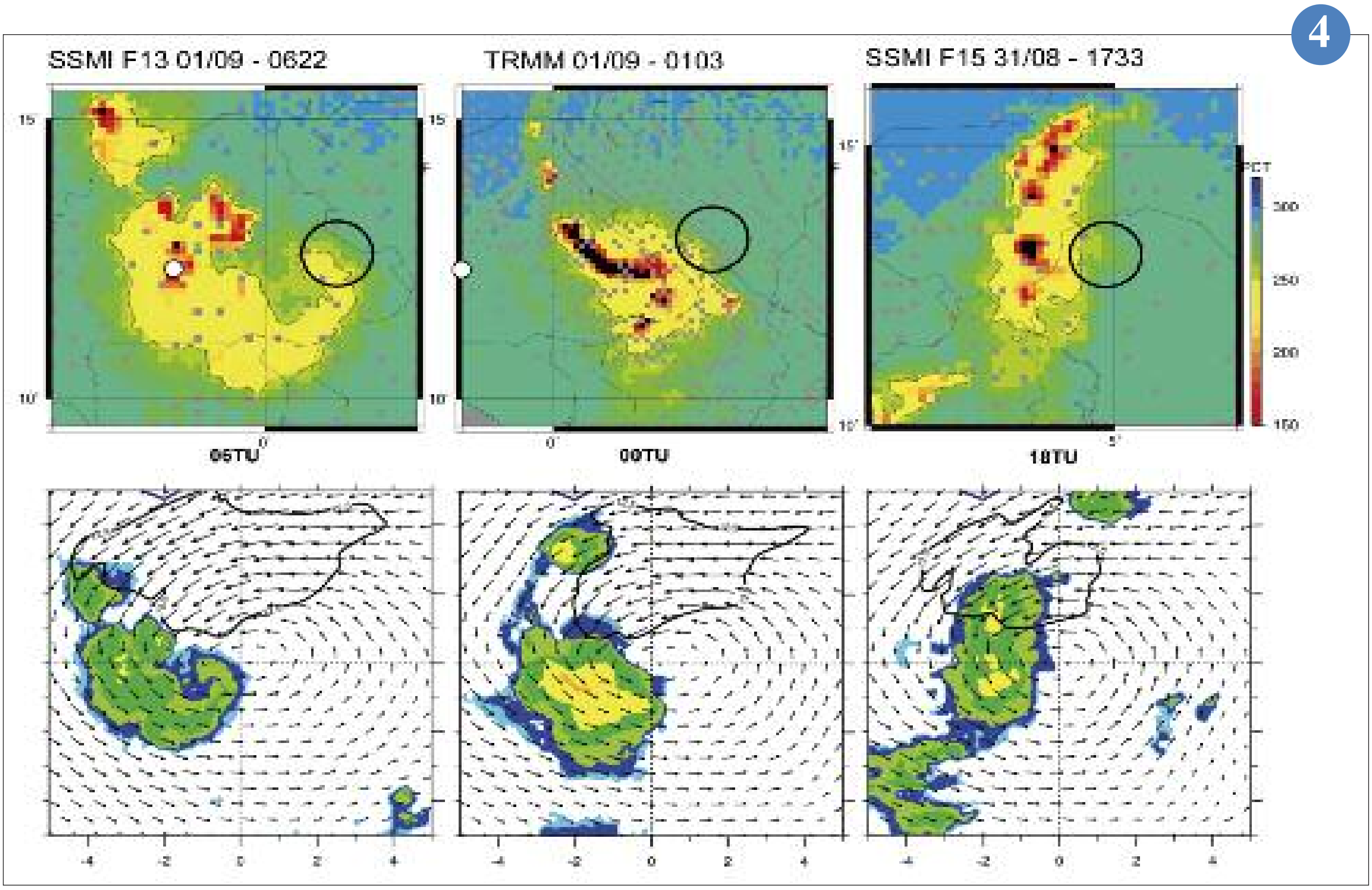
Mediterranean regions are regularly affected by heavy precipitation events. During such events, large rainfall accumulations (often more than 100mm in 12h) fall on small river catchments and cause devastating flash floods. The forecasts for these high-impact events thus need to be highly accurate both in time and space. This requests that the convective processes involved are well known and that they are realistically represented in the numerical models.
In the autumn 2012, during the first Special Observation Period (SOP1) of the experimental campaign HyMeX, various instruments were deployed to observe closely the Mediterranean heavy precipitating systems and their environment. On 14/10/2012 (IOP13), a low-level jet is leading towards the French coast a marine warm and moist air mass topped with dry air (4-7 g/kg above the boundary layer and 1-2 g/kg above 2500m). Convection is triggered over the foothills and shifts slowly towards the coast and the sea.
Numerical simulations of this event were performed with the research model Meso-NH at 2,5km horizontal resolution. HyMeX observations show that the simulated precipitating systems and the convective processes involved are realistic. A part of the precipitation is evaporated in the dry layer. The evaporative cooling is channelled in the valleys and flows progressively towards the coast shifting the convective ascents from the bottom of the valleys to the sea. A similar reversal of the surface winds in the valleys associated to a pronounced cooling appears both in the simulation and in the observations.
Quasi-LES simulations of this event are ongoing to study the organisation and the fine-scale dynamical, turbulent and microphysical processes of the convective systems.

5

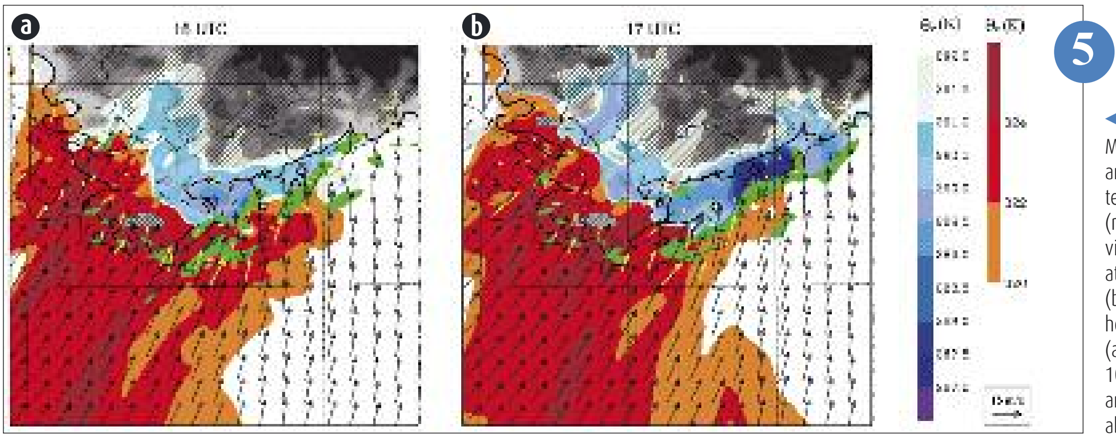
Impact of orography of Reunion Island on the trajectory of cyclones

Numerous studies have shown that orography can significantly influence the trajectory and intensity of tropical cyclones in the vicinity of small-to-large islands. Because of its large size, steep terrain and position, the case of Taiwan Island has been particularly studied, but smaller islands such as Reunion Island may also have a significant influence on the trajectory of tropical cyclones (e.g. Bejisa in 2014 or Dina in 2002).
The analysis of "best-track" data from RSMC-cyclones Reunion Island over the period 1981-2015 showed that tropical cyclones passing within a distance of ~ 200 km of Reunion Island are more often subject to track and speed modifications than more distant systems. To confirm these results, 15 idealized numerical simulations were carried out using the research model Meso-NH (no island, flat island, variable terrain height / distance to the island). Results of these simulations confirm those of the climatological analysis and show that the area of influence of Reunion Island is maximized at a distance more or less equals to twice the radius of maximum wind of the system (distance between the center of the tropical cyclone and the point where maximum wind is observed). The effect of the island is reflected in particular by a phenomenon of aspiration (change of trajectory together with acceleration towards the island) associated with a decrease of intensity as the tropical cyclone approaches the island. After moving away from the island, the system resumes to its initial trajectory and gradually re-intensifies.
This work should allow forecasters to anticipate more precisely sudden track changes of tropical cyclones evolving in the vicinity of small mountainous islands such as Reunion Island.

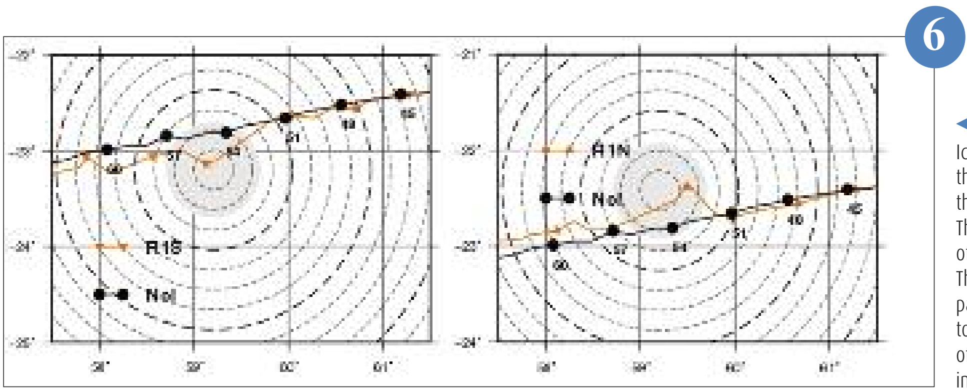
6



Evolution of the precipitation structure associated with the moist vortex.
Upper row: Satellite snapshots of the Polarized Corrected Temperature (PCT in °K) in the vortex vicinity indicated by the black circle. Light precipitation (1-3 mm/h) are delimited by PCT > 255 K (green shading), while convective precipitations (10-12 mm/h) correspond to PCT < 225 K (warm shading). Lower row: GSMAP accumulated rain over 1 hr (colour in mm) and of the mean wind vector field over the 950-600 hPa layer as analysed by ARPEGE. The 10° square domain centre corresponds to the mean vortex centre. Heavy black contour outline the core of wind speed higher than 12.5 m s^{-1}.
On 31 August at 18UTC (right side), the linear structure corresponds to a squall line system, 6h later its wrapping by the cyclonic circulation is under-way (centre) resulting on 1st September at 06UTC (left side) in a spiral structure over Ouagadougou (white dot) and in a vortex intensification.



Meso-NH simulation (a) 16 UTC and (b) 17 UTC: equivalent potential temperature at 925 hPa (red colour scale, K) virtual potential temperature at first model level (blue colour scale, K), horizontal wind at 925 hPa (arrows, simulation in black, 10-m observations in yellow) and vertical motions at 500 m above 0.5 m/s (green areas).



Idealized Meso-NH simulations showing the trajectory modification of a cyclone passing nearby the Reunion Island
The black curve represents the theoretical trajectory of the system in the absence of island.
The orange curves show the trajectory of a system passing at a distance of one radius of maximum wind to the north (left panel) and to the south (right panel) of La Reunion. The location of the island is shown in gray.

Climate

In 2016, the global mean temperature was 1.1 °C above the preindustrial level and warmest on record since the beginning of the instrumental period. Polar regions were particularly warm, with sea ice shrinking to unprecedented low levels. The central aim of the Paris agreement (COP 21) is to keep the global temperature rise well below 2 °C, and to pursue efforts to contain it to 1.5 °C. According to current knowledge, this objective implies a massive reduction of greenhouse gases emissions and, if this fails, the use of geo-engineering techniques, which need to be assessed.
Concerning observation, Météo-France has continued to rescue ancient climatological data, increasing the length of the related time-series. Longer, homogenised time-series allow to better disentangle variability and climate change by directly analysing the data itself or by assimilating the data in reanalyses, which provide a consistent picture of the state of the climate system. This year, a new reference solar radiation dataset for metropolitan France since the 1930's has been defined, while for the French overseas territories, the rescue of sea-level pressure, temperature, humidity and wind data has continued.
Concerning climate modelling, the development of the 6th version of the ARPEGE-Climate has come to an end. This model includes a brand new representation of atmospheric physics also used in the numerical weather prediction version of ARPEGE, and has been integrated in the global coupled climate model CNRM-CM6. CNRM-CM6 will be operated to perform simulations for CMIP6 (Coupled Model Inter-comparison Project phase 6). This exercise will provide future climate projections under several scenarios to the scientific community. It will also allow to better understand model errors and the climate response to external forcings (greenhouse gases, aerosols, volcanic eruptions and solar variability). For the time being, the reference database of multi-model climate simulations is CMIP5. Last year original analyses looking at storm-track changes and the sinuosity of the North Hemisphere mid-latitudes jet were applied to these simulations.
In parallel, Météo-France aims at widening the offer of climate services with new products. Some of them are elaborated from Météo-France's operational seasonal forecasts, which are constantly improved through research. In 2016, work was done in order to better take into account model imperfections and improve the initialisation of the forecast system. Last year, two prototypes of climate services have been developed. The first prototype aims for a better seasonal management of water resources up to three months in advance, and the second one provides a diagnostic on the frequency of weather regimes in the North Atlantic in seasonal forecasts. Other activities related to wind and solar energies were carried out to assess the balance between supply and demand a few days in advance, for the upcoming season or for the next decades.

1

Studies of climate

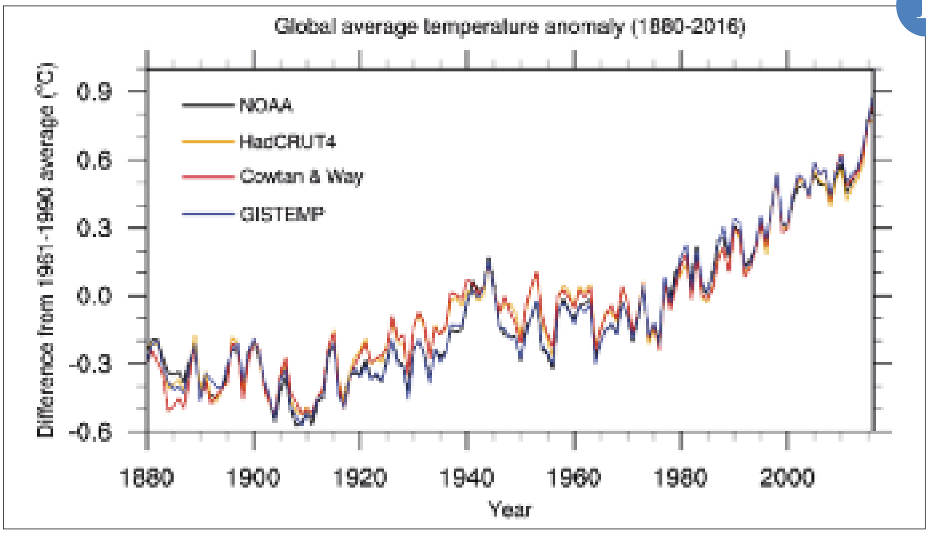
Development and evaluation of ARPEGE-Climat version 6

The atmospheric general circulation model, ARPEGE-Climat, is a central component of the CNRM climate model. At the end of 2016, version 6 of this atmospheric model, coupled with ocean and ice models, was finalized. It will serve as a basis for the CNRM contribution to the Coupled Model Inter-comparison Project CMIP-6.
This version includes many developments that have been made over the last 5 to 10 years and have involved the various units of CNRM: the new convection scheme, coupled with detailed cloud microphysics, continuously treats deep and shallow convection; the new turbulence scheme improves the representation of the boundary layer; the new land surface scheme describes the processes related to ground-waters and floodplains; and the new non-orographic gravity waves scheme allows for the inclusion of sources related to deep convection and frontogenesis. The final adjustments focused on the model energy balance and the reduction of the most significant biases (high tropical clouds and extreme orographic rainfall).
Compared to the previous version implemented in CMIP-5, the model simulates, for example, a significantly more realistic distribution of tropical rainfall (with an excellent simulation of the Asian summer monsoon, see illustration) and of cumulus on tropical oceans and stratocumulus on the eastern subtropical oceans. The representation of the stratosphere is also greatly improved, with the first realistic simulation of the Quasi-Biennial Oscillation in the equatorial stratosphere.

2

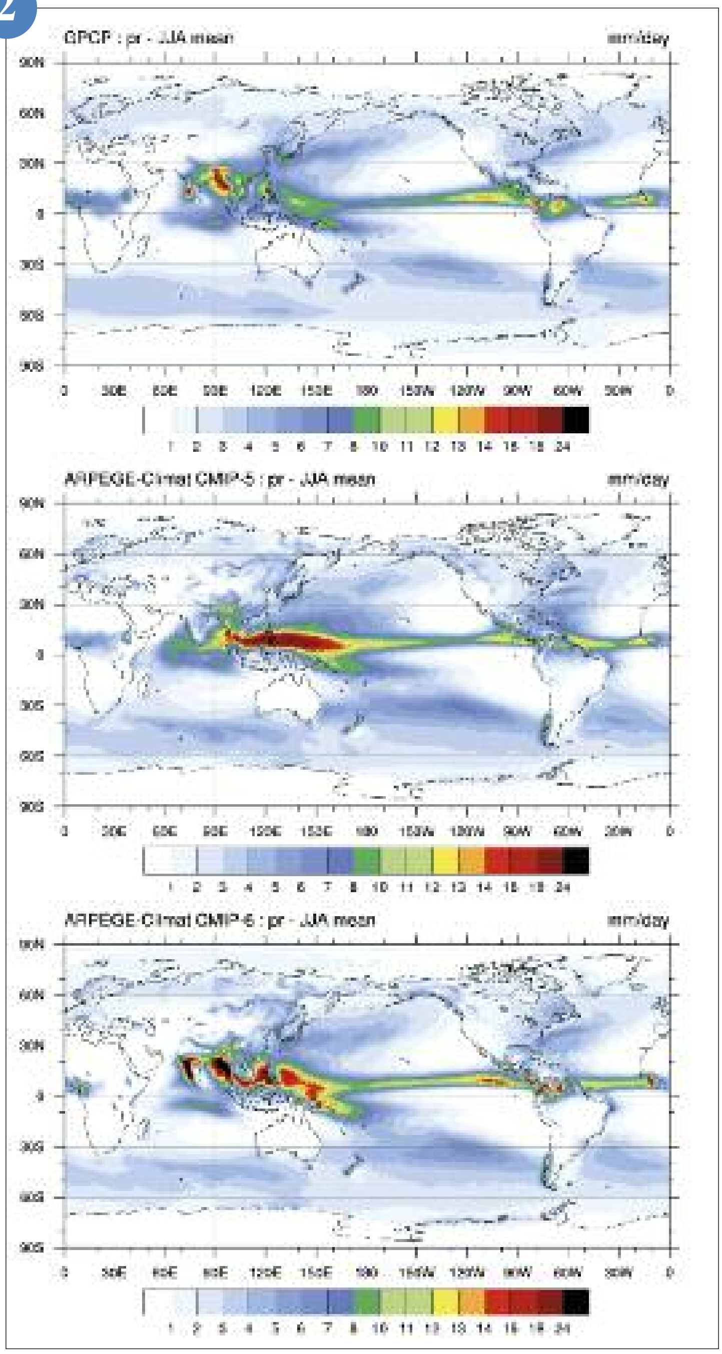
A new reference dataset to analyse of the evolution of sunshine in France since the 1930s

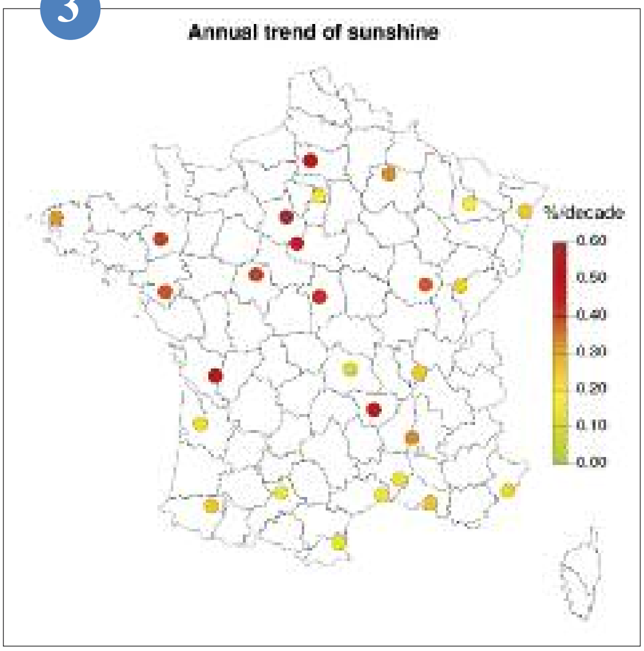
The analysis of climatic changes is performed using long reference series. Homogenization is a statistical procedure which allows to constitute a monthly series corrected for breaks due to relocation of measurement points, changes in their environment, changes in sensors or observers, etc. After the construction of new sets of monthly temperatures and precipitation series, Météo-France has just updated the set of long homogenized series of sunshine for metropolitan France.
The previous dataset involved 18 series over the period 1931-2000. Following a major work of Climate Data Rescue, imaging, digitization and data insertion, the number of homogenized series has been increased to 27. This new homogenization action has also benefited from the evolution of Homer software.
This dataset of 27 homogenized series of sunshine over the period 1931-2014 shows an upward trend in the duration of annual sunshine throughout the territory over the



Global annual average near-surface temperature anomalies from four datasets: NOAA, HadCRUT4, Cowtan & Way (2014) and GISTEMP, with reference to the 1961-1990 period.

1979-2008 JJA averaged precipitation (mm/day) for (top) GPCP product, and (middle) ARPEGE-Climat version CMIP-5 and (bottom) ARPEGE-Climat version CMIP-6 simulations performed with prescribed observed sea surface temperatures.





Evolution of the sunshine, trend 1931-2014 (in% per decade) computed from the homogenized series.

period 1931-2014. The calculated trends range from 0.1% to 0.6% per decade but show mostly non-significant positive trend. A large north-western quarter of France ranging from Cognac to Beauvais comprises almost all of the highest values. This upward trend is significant throughout the country in autumn and winter. On the other hand, the spring and summer series show no significant trend.

The new set of homogenized series is coherent with the results obtained previously. The data used and the method having been improved, it becomes the new reference set to analyze the evolution of sunshine on France.

Data Rescue activities for Global Climate Reanalysis

Demand by Research for historical climate data as input to climate reanalysis has been increased with specific needs in term of type, temporal frequency, period of the parameters. Sub-daily pressure, temperature, humidity, surface wind and upper wind observations going back to the middle of the 19th century are expected by the scientific community. One scientific challenge consists to target the recovery of meteorological data from isolated areas (polar and tropical regions), for which international databanks are the poorest.

To meet this demand, climate data rescue activities have been undertaken by Météo-France for many years. They involve searching, organizing and cataloguing physical archives, imaging physical records, keying of data, data quality controlling and making climate data and metadata available.

In 2016, the action has been focused on French overseas territories thanks to recovering of a part of Météo-France holdings kept at the French National Archives. Weather reports of hospitals in Saint-Pierre and Miquelon, New Caledonia, French West Indies and Reunion Island have been imaged and surface climate data have been digitised over the period 1861-1932. In addition, historical records of Météo-France professional stations have enabled upper air data in Guadeloupe, French Guyana and Reunion Island after 1945 to be recovered.

The exceptional heritage of Météo-France Climate archives, with several linear kilometres of historical climate records, allows us to envisage further progress.

4

Climatological study of spatial and temporal variability of precipitation in Reunion Island

A study, based upon the use of rain-gauge data and ERA-INTERIM re-analyzes over the period 1979-2015 (37 years), is carried out to identify the various regimes of precipitation in Reunion Island according to the properties of prevailing winds. Results of this climatological analysis showed that three main climatological seasons could be identified: the rainy season (JFMA, southern summer), characterized by weak tradewinds and tradewinds inversion height of ~ 3000m, the dry season (MJJAS, austral winter) characterized by stronger tradewinds and lower inversion level (2000m) and a transition season (OND), characterized by moderate tradewinds and intermediate inversion height (2500m).

A weather regime analysis was carried out for each of these 3 seasons in order to study more precisely the spatial and temporal variability of precipitation inferred from rainfall data analysis. The links between weather regimes and rainfall were highlighted by statistical methods (principal and canonical component analyzes). Between 4 and 5 classes were identified for each of the 3 seasons (5 for the austral summer, 4 for both the austral winter and the transition season).

Using weather regime analysis and tradewinds inversion criterion should ultimately improve radar quantitative precipitation estimates through developing Z-R relationships adapted to seasons and weather conditions. This study is part of the interdisciplinary project ERO-VEG (erosion-vegetation, funded by Ministry of Outremer) which aims to better understand the impact of precipitation on erosion at the scale of Reunion Island.

5

Diurnal cycle and dominant winds in New Caledonia

Within the Pluvar project involving Météo France/Météo New Caledonia and regional partners (IRD Noumea, University of French Polynesia, University of the South Pacific, University of Auckland, NIWA) and funded by the Pacific Fund, researchers have identified a peculiar characteristics of the diurnal cycle over New Caledonia. The diurnal cycle of rainfall is stronger and more continental, i.e. with a maximum in late afternoon, on the leeward coast of New Caledonia. The intensity of land-sea breezes varies with that of precipitation: a strong sea breeze occurs in the afternoon on the leeward coast, creates ascending motion there and favours moist, deep convection.

This phenomenon is true in the mean, with dominant winds coming from East/South-East, but also when the dominant wind changes following the weather regime, as the figure shows: in the mean, the diurnal cycle is small on the East coast and large on the West coast; in the southerly weather regime, the sea breeze is damped on the West coast and better established on the East coast.

Using a high-resolution model, the scientists have been able to show that this sensitivity results from various factors. First, the dominant wind can allow deep convection to happen all day on the windward coast by bringing humid air that condenses while going up the slopes of the central mountain range, and this limits the diurnal cycle. Second, the cumulated sea breeze and dominant wind on the windward coast allows the atmospheric flow to pass the range in the afternoon and to humidify the troposphere above the leeward coast, reinforcing convection there. The researchers still need to better quantify the contributions of the different mechanisms and to investigate their potential effects on extreme meteorological events.

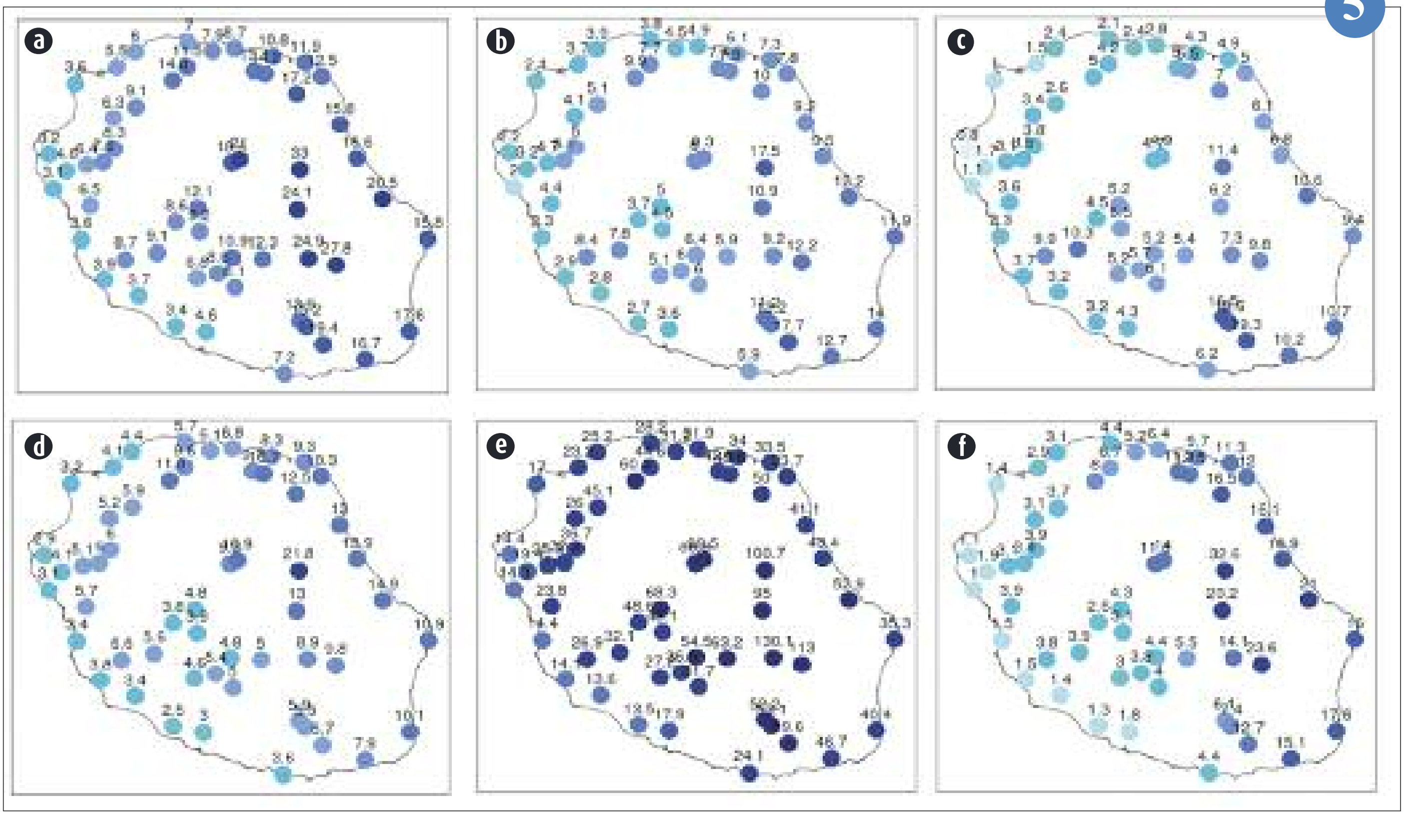
6

4

Instrument enclosure at Saint-Pierre hospital (Saint-Pierre and Miquelon) in 1902.

(a) average daily precipitation in Reunion Island over the period January-February-March-April (JFMA), calculated from a climatological rainfall series of 37 years (54 raingauges stations); (b-f) daily mean for the 5 identified weather regimes: (b) low pressure area; (c) ridge; (d) low-pressure system; (e) trade-winds ; (f) neutral.

5



Surface wind anomaly (arrows) in the afternoon (14h-17h) (with respect to the daily mean), and its intensity (shadings) in the mean (a) and in the southerly regime (b) during the warm season (November-April), as simulated by a high-resolution model.

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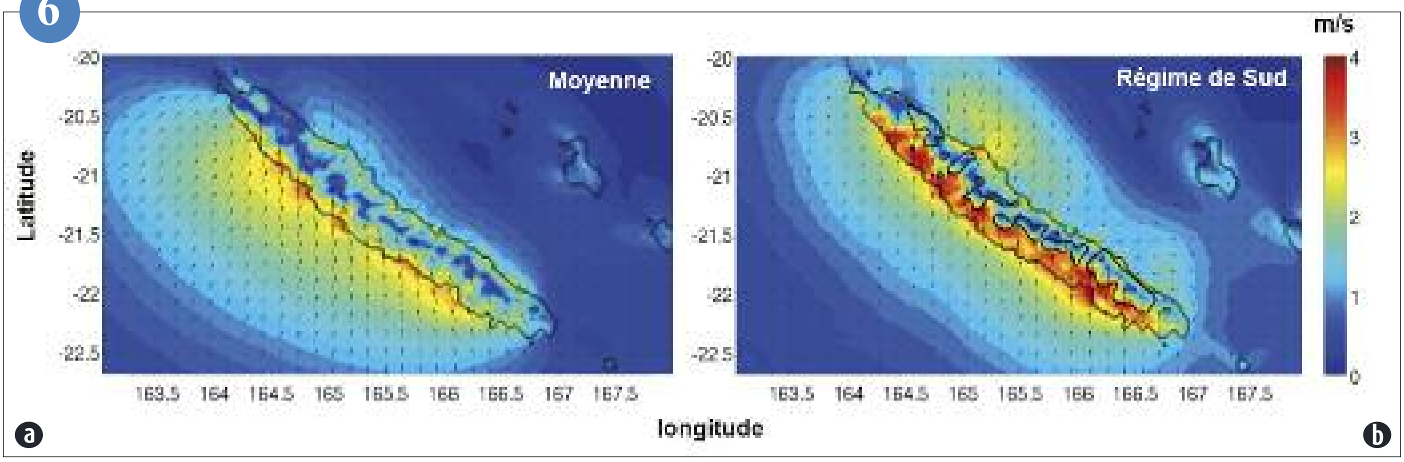

Climate change

Measurements and perception of microclimate at neighbourhood scale

The Bordelongue-Papus-Tabar neighbourhood (Toulouse, France) has been studied for the interdisciplinary project EUREQUA. Commented walks took place at 10h, 16h, 19h for 3 days of January, April and June 2014. At 6 stop points, meteorological, acoustics and pollution measurements have been combined with surveys about perception of various environmental dimensions by inhabitants. The database includes 162 measurement points and 186 respondents.
The microclimatic data indicate a spatial and temporal variability. For the wind, the seasonal trends are less pronounced than for air temperature or humidity, but noticeable differences are observed between stop points, that are some places are more exposed than others (Fig. a).
A multiple linear regression displays that wind perception (according to levels "very calm", "calm", "windy", "very windy") is correlated with mean wind speed and standard deviation recorded at stop point during the duration of the survey (Fig. b), and is negatively correlated with mean radiant temperature. The wind speed for which the perception is changing from calm to windy is stronger during summer than during winter, which indicates people are less sensitive to wind when weather is less cold. The heat evaluation (from "very cold" to "very hot") is correlated with mean radiant temperature during summer, and not air temperature. During winter, no correlation is found. Finally, the assessment of climatic comfort is not linked with measured variables or climatic dimensions questioned by the surveys. It is strongly correlated with general evaluation of places, of acoustic quality, and air quality, so that it seems to be involved in a more integrative evaluation of environmental quality.

7

Sinuosity of the mid-latitude atmospheric flow in a warming world

Is the Northern atmospheric jet stream becoming wavier, and if yes, is it the fingerprint of climate change? The question has been heartily debated over the past few years, especially after a spate of intense wintertime blockings in Europe and North America. Some studies mentioned a potential link with the decline in Arctic sea ice extent, since the polar amplification can affect the mid-latitude flow through changes in the equator-to-pole temperature gradient.
In the present study we have characterized the flow sinuosity through an original metric based on the length of 500mb geopotential height iso-contours (figure). This approach is similar to the quantification of river meandering in geomorphology. First, we checked the consistency with other classical metrics (NAO index, blocking frequency), and then we have investigated both recent trends in sinuosity and projected changes in the CMIP5 model ensemble.
Over the recent period we find a slight increase in sinuosity, albeit with a weak signal-to-noise ratio. Future projections are more robust and indicate a generalized decrease in sinuosity in a warmer climate. Associated uncertainties are partially explained by model discrepancies in their equator-to-pole temperature gradient response; in particular models with a weaker polar amplification exhibit a stronger decrease in sinuosity.
Future work will focus on the understanding of the recent sinuosity increase (internal variability? transient response?) and on constraining future projections.

8

Constraining the long-term climate response to stratospheric sulfate aerosols injection by the short-term volcanic climate response

Rising greenhouse gas emissions are leading to global warming and climate change, which will have multiple impacts on ecosystems and human society. Geoengineering methods like solar radiation management (SRM) by stratospheric sulfate aerosols injection (SAI) aim at mitigating symptoms of climate change, reducing the global mean temperature. So far, Earth System Models (ESMs) are useful tools to assess impacts of geoengineering methods on climate. However, coordinated simulations performed with the Geoengineering Model Intercomparison Project (GeoMIP) have shown that climate cooling in response to a continuous injection of 5Tg of SO_2 per year under RCP4.5 future projection (the so-called G4 experiment) differs substantially between one model to each other.
Employing volcanic eruptions as an analog of stratospheric aerosols injection, a statistical relationship emerges between the long-term cooling in response to reduced clear-sky surface down-welling shortwave radiation (SWcs), and the short-term cooling related to the change in SWcs induced by the major volcanic eruptions observed over the historical period (1850-2005). This relationship explains almost 80% of the multi-model spread. Combined with contemporary observations of the latest volcanic eruptions (satellite observations and model reanalysis), this relationship provides a tight constraint on the climate impacts of SRM-SAI.
Compared with the range between ESMs ensemble (0.32 to 0.86 K per $W.m^{-2}$), the estimated constrained value (0.37 K per $W.m^{-2}$) represents much higher confidence ways to assess the impacts of SRM-SAI on climate, especially on hydrological and carbon cycles feedbacks.

9

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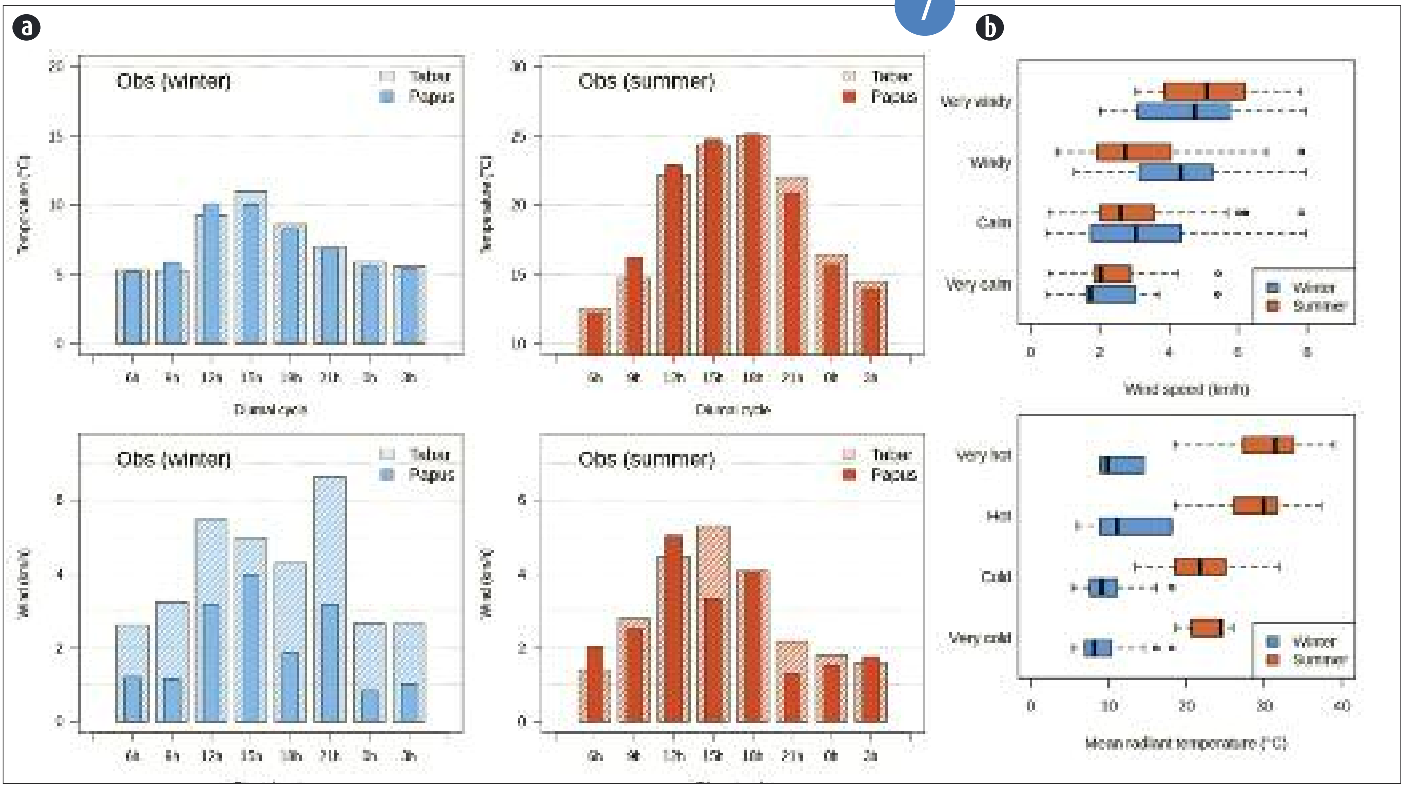
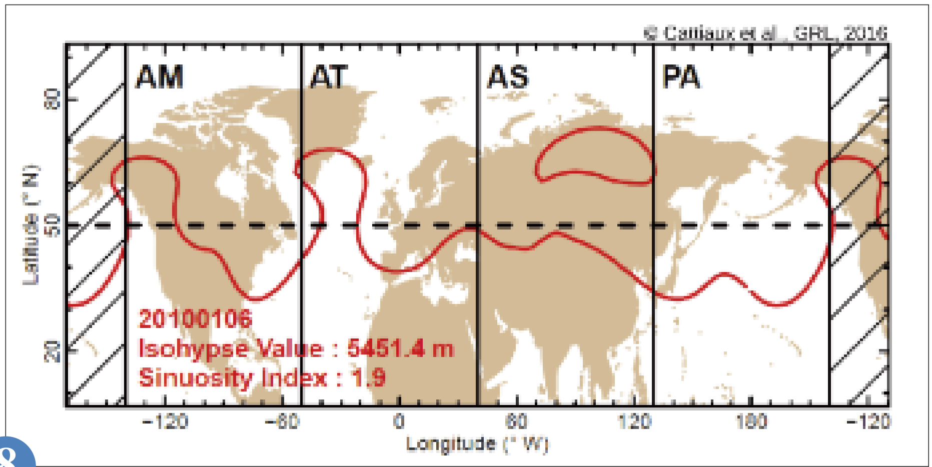


(a) : Comparison between temperatures and wind speeds measured during winter and summer at two stop points (Tabar and Papus) of the studied neighborhood.
(b) : Comparison (for all points) between evaluation of wind by the surveys and wind speed measurements (top), and between evaluation of heat by the surveys and mean radiant temperature measurements (bottom).



8

Example of sinuosity computation for January 6, 2010
Iso-contour (red) of 500mb geopotential height whose value (5451.6 m) corresponds to the field mean over 30–70°N. The sinuosity is defined as the ration between the length of this isohypse and the length of the « straight line » at equivalent latitude (50°N).
For this given day, the particularly high sinuosity (1.9) is due to two ridges in North America and Europe and a cut-off high in Asia.

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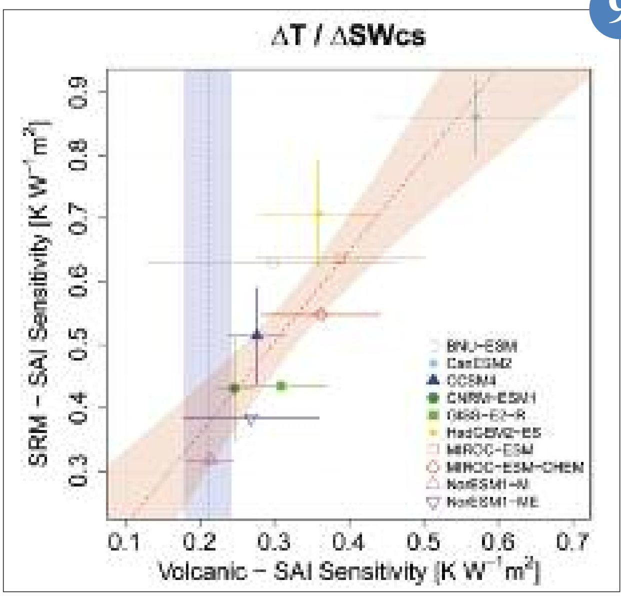

Changes in continental air surface temperature normalized by the clear-sky surface down-welling shortwave radiation (ΔT/ΔSWcs) in response to injection of stratospheric sulfate aerosols. X-axis represents the amplitude of ΔT/ΔSWcs in the context of observed and simulated major volcanic eruptions from 1850 to 2005; Y-axis indicates solely the amplitude of ΔT/ΔSWcs in response to long-term solar radiation management as simulated by CMIP5/GeoMIP Earth System models. A linear regression through an ensemble of 10 models is represented by the red dashed line, while the blue dashed line refers to the observational constraint. The 95% confidence intervals are represented with red and blue colored areas, and with continuous lines for each model.

Inter-annual variability of the Atlantic Cold Tongue

Each spring, Equatorial Atlantic sea surface temperatures fall by more than 4°C, favouring the West African Monsoon development. The amplitude of this cooling depends on the year and partly pre-conditions the monsoon intensity. Mechanisms at play on inter-annual time scales are not well known. These have been studied through a heat budget analysis of the ocean upper layers using the NEMO ocean model over the period 1982-2008.
It has been shown that the model is able to realistically represent the mechanisms of the seasonal spring cooling. Such a validation has been performed using PIRATA buoys data as well as several analysis and reanalysis ocean products.
Spring cooling has then been classified so as to determine years of relatively strong and weak cooling. This classification allowed to make a composite climatological study of these events.
Compositing the different terms of the upper ocean heat budget has shown that strong spring cooling are associated to an intensification of the oceanic turbulent mixing at the base of the mixed layer often generated by wind anomalies on the Atlantic western equatorial basin. Surface heat fluxes tend to compensate for the temperature anomalies dynamically generated. Weak and strong cooling are shown to be relatively symmetric except during summer since strong cooling tend to decline quickly whereas weak cooling tend to last longer due to relatively cold horizontal advection.

10

Storm-tracks trends during the 20th century

The 20th century windstorm variability is studied in the frame of a project funded by SCOR, a French reinsurance company and Météo-France. A tracking method developed at CNRM is applied to identify the cyclone trajectories within the new 20th century reanalysis ERA20C provided by ECMWF. The cyclone dataset reveals a huge multi-decadal variability with a significant increase of the strong mid-latitude cyclones between 1936 and 1980 whereas before 1936 and after 1980 no significant trend is identified. This result is put into perspective with the main planetary scale modes of variability in order to assess the windstorm variability. The 1936-1980 period is characterized by a increase of the sea ice extent and polar cooling. The consequence is an increase of the North-South thermal gradient balanced with an increase of the upper-level jets, consistent with an increase of the mid-latitude cyclones leading to windstorms. Before 1936 and after 1980 the polar warming associated with a decrease of the sea ice extent show less clear responses in terms of temperature gradient, upper-level winds and windstorm activity. The most recent period shows a decrease of the windstorm activity of North-western Europe. Although ERA20C has a limited resolution and increasing amount of assimilated observations along the century, the multi-decadal windstorm variability estimation seems reliable.

11

Climate services development for the energy sector

CLIM4ENERGY COPERNICUS project, led by CEA, aims at providing climate services to the energy sector.
Among these services, Météo-France develops, in close cooperation with the French electricity transmission system operator, RTE, a set of indicators of the adequacy between demand and electricity production.
This supply-demand balance is dependent on the meteorological conditions for two reasons. On the one hand, the production of intermittent renewable energies (solar and wind) is directly dependent on wind and radiation conditions. On the other hand, the electricity consumption of some European countries, as e.g. France, is touched by very strong positive anomalies in case of a cold peak.
All along a six month specification phase with RTE, several indicators were tested and compared with observations. The aim of these indicators is to assess the electricity production from intermittent renewable energies (solar and wind) as well as the electricity consumption anomalies linked with the meteorological context. Daily weather regimes have been determined in order to better recognize and anticipate meteorological event unfavourable to supply-demand balance.
These indicators are being computed on a set of EUROCORDEX unbiased (by IPSL) climate projections for more than 30 European countries in order to assess their potential changes with 2030 and 2050 horizons for two greenhouse gases emission scenarios (RCP4,5, RCP8.5). They will also be computed and evaluated for seasonal forecasts.

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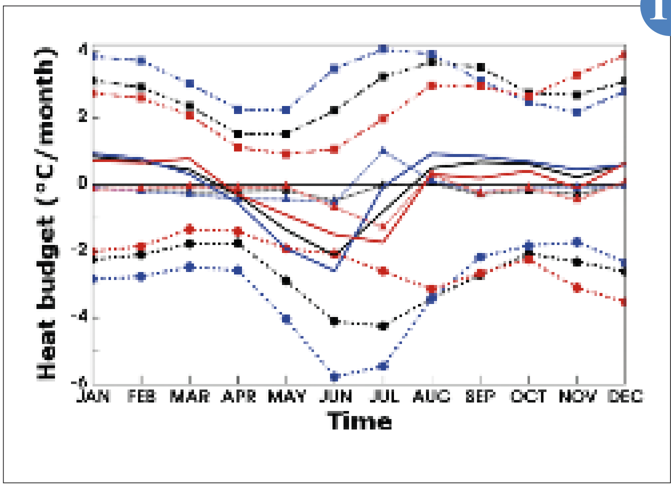

Seasonal cycle of the upper ocean heat budget over the domain 15°W-6°W, 4°S-1°N.
Black lines represent the mean over the period 1982-2008,
blue lines years with strong cooling (1983, 1992, 1997, 2004, 2005)
and red lines years with weak cooling (1988, 1991, 1995, 1996, 1999).
Solid lines stand for temperature tendencies, dashed lines and dots markers:
the vertical mixing contribution,
dashed lines and squared markers: the surface heat fluxes contribution,
and dotted lines with triangle: the horizontal advection contribution.

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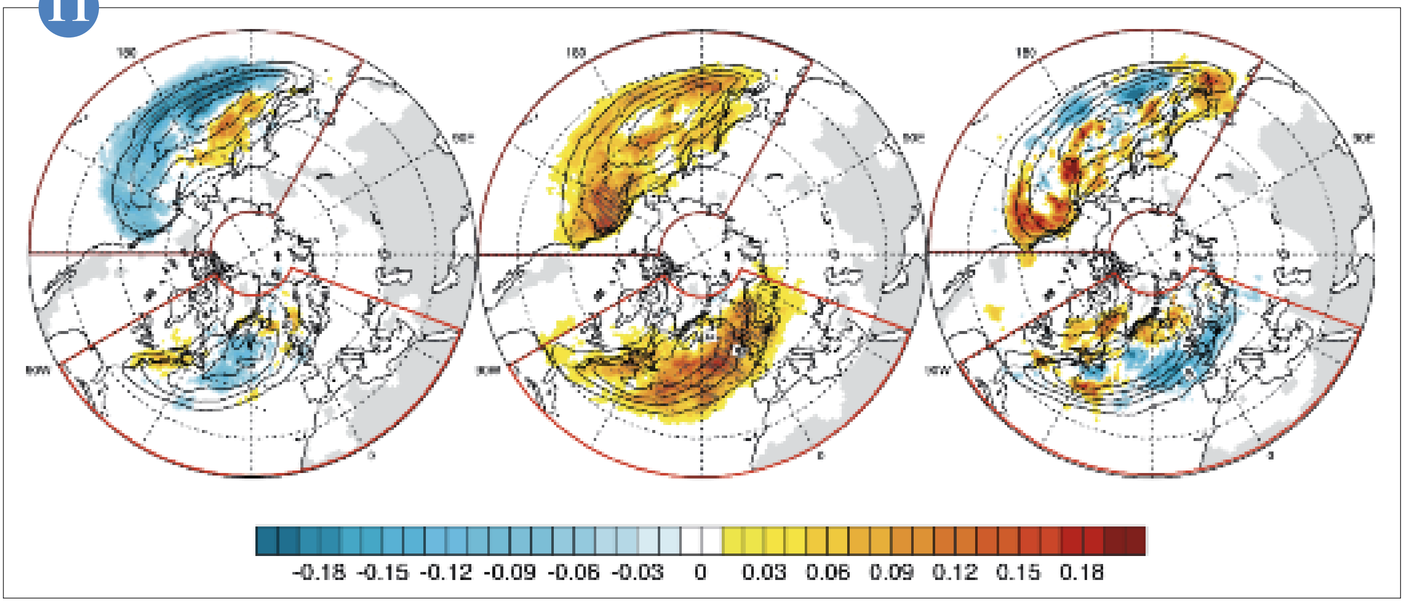

Winter storm density (black solid lines) and trends (shading)
From left to right: 1900-1936, 1936-1980 and 1980-2009.

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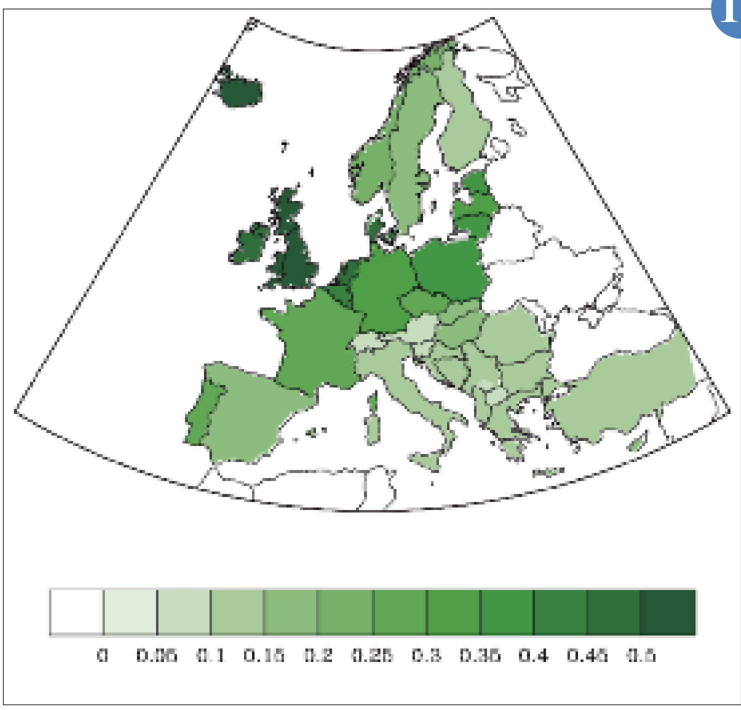

Winter mean wind capacity factor - Mean of 10 EuroCordex models ensemble for 2030 time-slice.

Seasonal forecast

Development of Seasonal Forecast Multi-Model products

In the frame of the Copernicus Climate Change Service (C3S), Météo-France has been selected by the ECMWF (C3S operator) to contribute to the future European Multi Modele Seasonal Forecast, both to provide data from the Arpege model but also to support the development of Multi-Model products

The project takes place from January 2016 to March 2018 with a first phase of Proof of concept, followed by a pre-operational one.

The Météo-France contribution for the development of Seasonal Forecast products will concern 4 domains:

- The operational assessment of new products with the NMS users in the context of our responsibility of Regional Climate Centre for Long Range Forecast over Europe
- The specification of general circulation products : weather regimes and variability modes (see Figure)
- The development of statistical post treatments on Seasonal Forecast: quantile mapping and regression based on weather regimes
- The conception of extreme probability products for storms, heat waves, cold spells or droughts.

A first work on the variability modes over North Atlantic and Europe area has allowed to identify four main patterns: North Atlantic Oscillation (NAO), East Atlantic (EA), Blocking (Bl) and Pacific North American (PNA), according to the Barnston and Livezey.method. These patterns have been calculated and evaluated over the Hindcast of Arpege Seasonal Forecast System 5 (1991-2014) and implemented for a real time using in a Forecast mode.

Original 2D representations have been defined for the operational needs (See Figure).

These products will be used in 2017 both for Climate Monitoring and Seasonal Forecasting.

13

Addressing model inadequacies in seasonal forecasts

In the field of seasonal predictions, taking into account uncertainties arising from initial conditions, but also from the coupled model (numerical approximations, sub-grid scale parametrizations), is of the utmost importance. In the framework of the SPECS European project (2012-2016), CNRM studied a group of methods consisting in introducing stochastic perturbations in the coupled seasonal forecasting system, so as to sample the possible impact of model imperfections on the forecast. In-run perturbations-corrections of the atmospheric component ARPEGE dynamics, consisting in subtracting estimations of model errors estimated in retrospective forecasts from the model prognostic variables, were shown to improve the model bias over mid-latitudes (Fig.) and model skill, although to a smaller extent. These perturbations can also be used to generate ensemble spread by applying different corrections to each forecast ensemble member. This method called stochastic dynamics is now used operationally in the seasonal forecasting system.

A second approach, the SPPT method developed at ECMWF, perturbs the physical parametrization tendencies of the atmospheric model using multiplicative coefficients auto-correlated in space and time. The approach helps increase the ensemble spread, but has contrasted impacts in terms of scores according to the region and variable of interest.

Future efforts will focus on the combination of these two techniques in the ARPEGE model, and the assessment of the impact of similar perturbations in the ocean component of the coupled seasonal forecasting system.

14

Progresses in seasonal forecasting from SPECS project

The SPECS European project has just finished in October 2016. For four years it has involved the main European actors in seasonal forecasting. Contrary to the preceding projects like DEMETER or ENSEMBLES it did not consist in building a hind-cast database with multi-model ensembles. Its target was to improve predictability on scientific bases and to increase the usefulness of the forecasts through a coupling with another European project named EUPORIAS.

There are many ways to attempt to improve a numerical forecast, in particular by sophisticating the ocean soil or atmosphere model. In this project, we needed to compare the results of different models, so we restricted to:

- land soil initial state
- sea-ice initial state
- horizontal resolution
- including a realistic stratosphere
- taking into account model inadequacy

The results show that evaluating an individual source of potential improvement leads to an increase of some scores and a decrease of some others. The most robust improvement comes from soil moisture and sea-ice initialization in May. Taking into account all sources of improvement at a time maintains the different score increases and removes the score decreases. The new Météo-France forecast system (Eurosip system 5) operational since July 2016 includes all modifications listed above. The figure shows the ENSO forecast scores for system 4 and system 5.

15

A climate service experiment for the water resource management over the Seine and the Garonne basin

In the frame of the FP7/EUPORIAS project, Météo-France has developed a prototype of climate service for the seasonal water resource management (http://riff.euporias.eu/en).

This service has been built in close relation with two main stakeholders (Seine Grands Lacs and Syndicat Mixte d'Etudes et d'Aménagement de la Garonne), involved in the definition of tailored products adapted to their needs and in the assessment of the value of the prototype for the decision making (redo of 29 past years).

This year, a real time experiment has been driven from a new hydrological and seasonal system, including the Surfex-Modcou model available over France forced by the Arpege Seasonal Forecast System 5.

Two quantile-mapping adjustments have also been implemented on the output of the seasonal forecast (with the reanalysis Safran as the reference for the observations) and on the river flows simulated by Surfex-Modcou (with observations coming from natural river flows provided by the water resource managers).

For the operational needs, river flows probabilistic forecasts have been provided on 4 stations of interest for the users (three on the Garonne basin and one on the Seine Basin) based on the May initialisation of Seasonal Forecast, covering the period from June to October. These forecasts have been presented in the strategic committees of the stakeholders, by comparison with the climatology and forecasts based on historical simulations.

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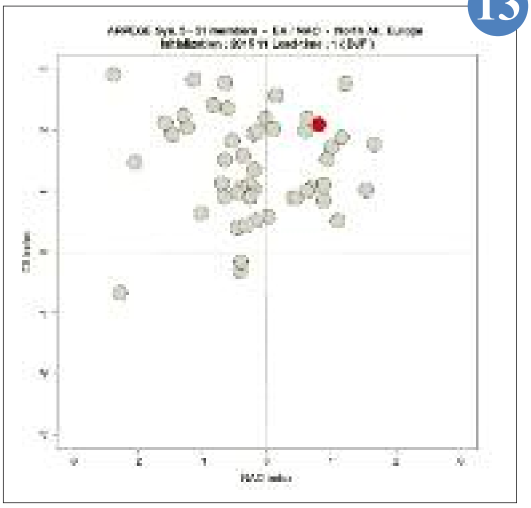

Seasonal Forecast of the variability mode Est Atlantic (EA) and North Atlantic Oscillation (NAO) for the quarterly DJF from the 51 members of the Arpege system 5 with the initialization of November 2015 (grey points) compared with the observation (red point).

Mean 500 hPa geopotential bias (m) in winter (December to February) in three sets of seasonal predictions with CNRM-CM initialized in November 1979 to 2012: REF (without stochastic perturbations), SMM (monthly mean corrections-perturbations) and S5D (five-day sequences of corrections-perturbations). Corrections are estimated during the other years of the retrospective forecast period. Reference is ERA-Interim.

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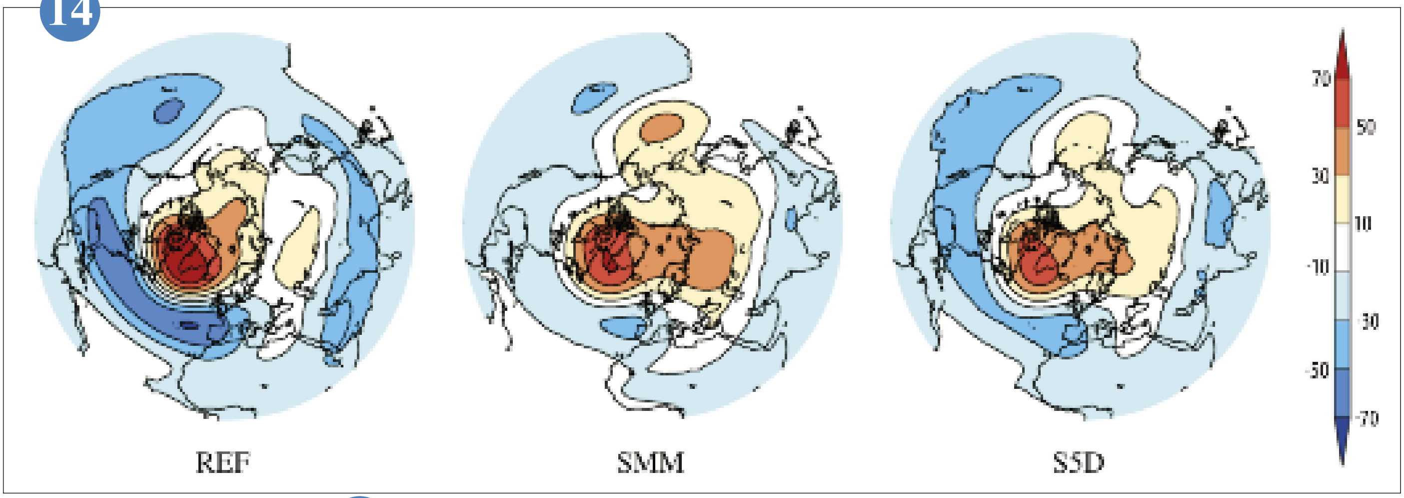

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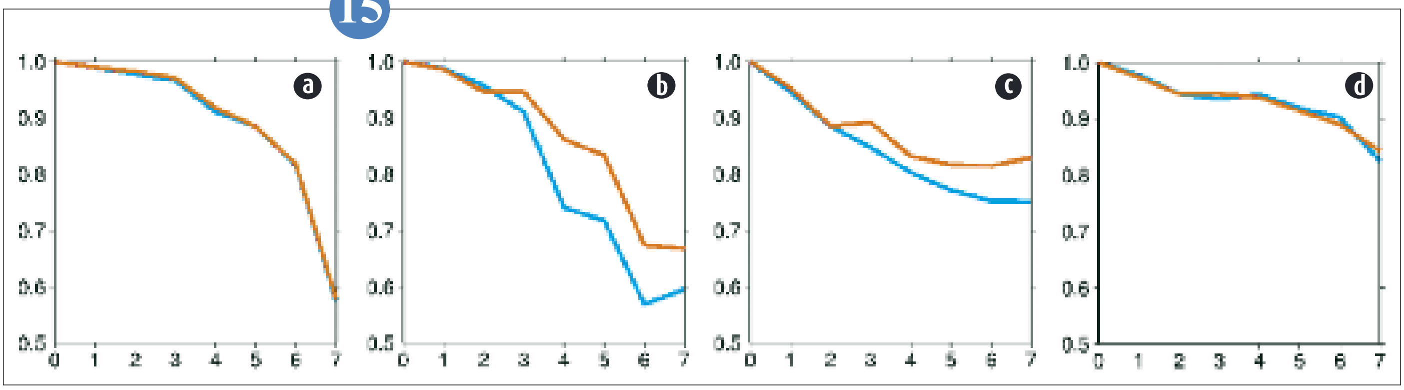
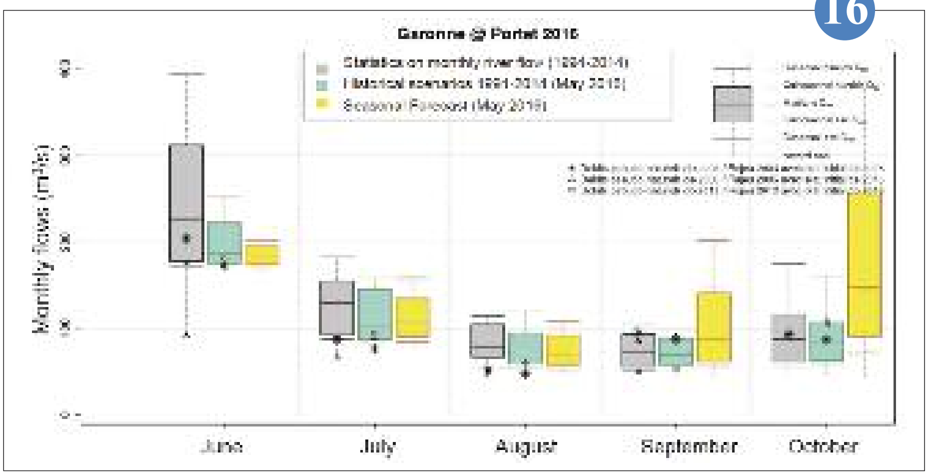


Correlation of monthly surface temperature of central equatorial Pacific ocean (Nino 3.4 area) as a function of forecast lag (month) for November (a) February (b) May (c) and August (d) starting situations; previous Météo-France forecast system (blue line) against new system (red line).

Probabilistic representation of monthly river flow seasonal forecasts at the "Portet sur Garonne" station (near Toulouse) for the summer 2016 from the May initialization. The climatology of the river flows is represented in the grey boxplot; historical simulations from the May 2016 initial state are in the green one and seasonal forecasts in the yellow one.

16



Atmospheric composition: aerosols, microphysics and chemistry

The understanding and modelling of atmospheric composition (chemical species and aerosols) and its feedbacks with the atmosphere is essential for several reasons. In the lower atmosphere, atmospheric composition itself, or air quality is a health issue. The presence of aerosol particles, for example those originating from volcanic eruptions can interfere with air traffic. In terms of meteorology and climate, aerosols reduce surface solar radiation, which results in cooling the Earth's surface. Some of them are also condensation nuclei and affect cloud properties. A reactive gas such as ozone affects air quality when present in the lower atmosphere, is a greenhouse gas in the troposphere and filters UV radiation in the low stratosphere.

Concerning observation, a big airborne measurement campaign using the ATR-42 aircraft operated by the SAFIRE unit, focused on aerosol, radiation and cloud measurements took place in West Africa. In parallel, tests have shown that instrumented drones allow to estimate marine aerosol sources, which are still poorly represented in climate, meteorological and air quality models.

The modelling of aerosols with MOCAGE makes continuous progress thanks to observation and provides a comprehensive and consistent picture of processes at play (emissions, chemical production and destruction, deposition and import-export) on a given domain and time-span. In some cases, this knowledge allows to inform decision making concerning for example the control of the emissions of air pollutants. Also, the implementation of interactive aerosols in ARPEGE-Climat has allowed to produce global aerosol climatologies from emissions for the coupled climate model CNRM-CM6. Finally, the assimilation of chemical species in MOCAGE has been improved. This year, the added value of assimilating measurements from the future Sentinel-5P platform has been demonstrated for CO, using OSSEs (Observing System Simulation Experiments).

1

Seasonal variation of the aerosols over the Mediterranean basin

The Mediterranean basin is a region with important climatic and sanitary issues. Aerosols play a role in sanitary impact with highly polluted area, and in climatic impact with effect on radiation and clouds. It seems then important to understand the aerosol life-cycle in this region.

MOCAGE is a chemistry-transport model developed at CNRM, which allows the simulation of gaseous and particulate concentrations. Using this model, we simulate the year 2013 in order to study the aerosol budget over the Mediterranean basin on the domain presented in the figure (f). We showed that all the aerosols presented here are exported out of the domain, sometimes in high quantity such as 40% of black carbon aerosols.

The figure presents, on a monthly basis, the budget for: sea salt (a), desert dust (b), black carbon (c), primary organic carbon (d) and secondary inorganic aerosols (e). The different curves represent the emission or chemical production in green, the sum of deposition terms in blue , the chemical loss in red, the import/export term in purple (negative if export) and the burden in brown. We observe a strong seasonality for desert dust with an intense activity in spring and summer. Other aerosols present an annual cycle as sea salt and black carbon. We showed that the anomaly in summer for primary organic carbon was due to large import of air mass strongly polluted by biomass burning from the North American continent.

This study allows us to illustrate the range of aerosol related phenomenon in the Mediterranean basin and is a key step forward the understanding of the aerosol life-cycle.

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Desert dust outbreak in Southern France (Montpellier) after a storm in Sahara
Copyright: Laurent Garcelon / Infoclimat

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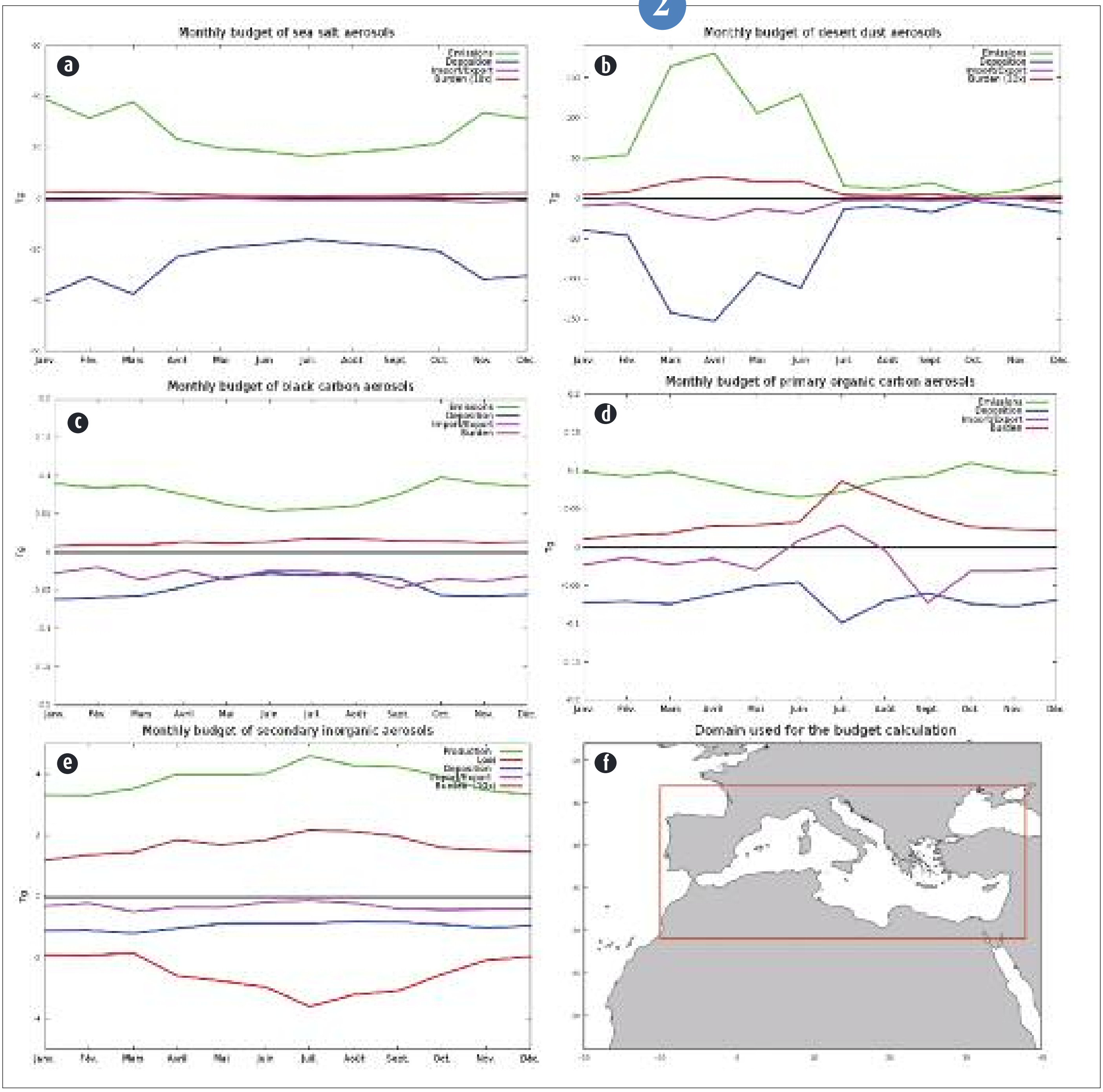

Will the satellite instrument Sentinel-5P be capable of measuring pollution in the lowermost tropospheric layers?

The capabilities of satellite instruments for sensing the lower troposphere have improved recently, and opened the way for monitoring and better understanding of atmospheric pollution processes. The future satellite Sentinel-5P (S-5P) of the Copernicus program is a Low Earth Orbit platform that will aim at providing global daily measurements of atmospheric pollutants (such as CO), climate related trace gases and aerosols, at relatively high spatial resolution (from below 8 km to below 50 km).
A method to objectively determine the added value of future satellite observations is that of Observing System Simulation Experiments (OSSEs) commonly based on data assimilation. The satellite observations are simulated from a model state (nature run) using the instrument characteristics and are assimilated to another model (control run) in order to evaluate the benefits obtained in the analysis (assimilation run).
Our study focusses on carbon monoxide (CO), which remains challenging to measure at the surface. CO has lifetime sufficiently long to provide information on the transport pathways of atmospheric pollutants. The OSSE was conducted over Europe for summer 2003, which was extremely hot and favourable to accumulation of pollutants in the boundary layer. The OSSE was conducted with the MOCAGE model. The results indicate that the simulated S-5P measurements benefit to monitor surface CO. In general, the largest benefit occurs over land in remote regions where CO sources are sparse. Future work will consist in evaluating the added value of other future satellites for air quality monitoring.

3

Atmospheric pollution in West Africa: measurements of aerosols physico-chemical properties during the DACCIWA airborne campaign

In the framework of the Dynamics-Aerosol-Chemistry-Cloud Interactions in West Africa (DACCIWA) project, an unprecedented field campaign took place in summer 2016 in West Africa. The ATR-42 research aircraft operated by SAFIRE performed twenty flights to sample the local air pollution from maritime traffic and coastal megacities (Abidjan, Accra, Lomé), as well as regional pollution from Southern Hemisphere biomass burning and Saharan desert dust.
The GMEI group from CNRM, and in particular the MNPCA team, played a driving role in the project by operating the aerosol sampling inlet on-board the ATR-42 and by installing a large set of instruments: particle and cloud condensation nuclei counters, particle size distribution and light extinction analysers and an analyser that measures black carbon properties (concentration, size distribution, mixing state). The first results show very high concentrations of black carbon both in urban plumes and background conditions (Figure a), which could be due to continuous open burning in open landfills and emissions from old high-polluting vehicles.
Aircraft observations also show that biomass burning and mineral dust plumes are mainly present in the altitude range of 1.5-6 km. During such events, the extinction coefficient increases up to 250 Mm^{-1} (Figure b), which highlights their significant impact on the vertical distribution of optical properties in the region.
The data treatment of the full dataset is ongoing to develop parameterizations of aerosol–radiation–cloud interactions and improve the representation of aerosols in climate and air quality models.

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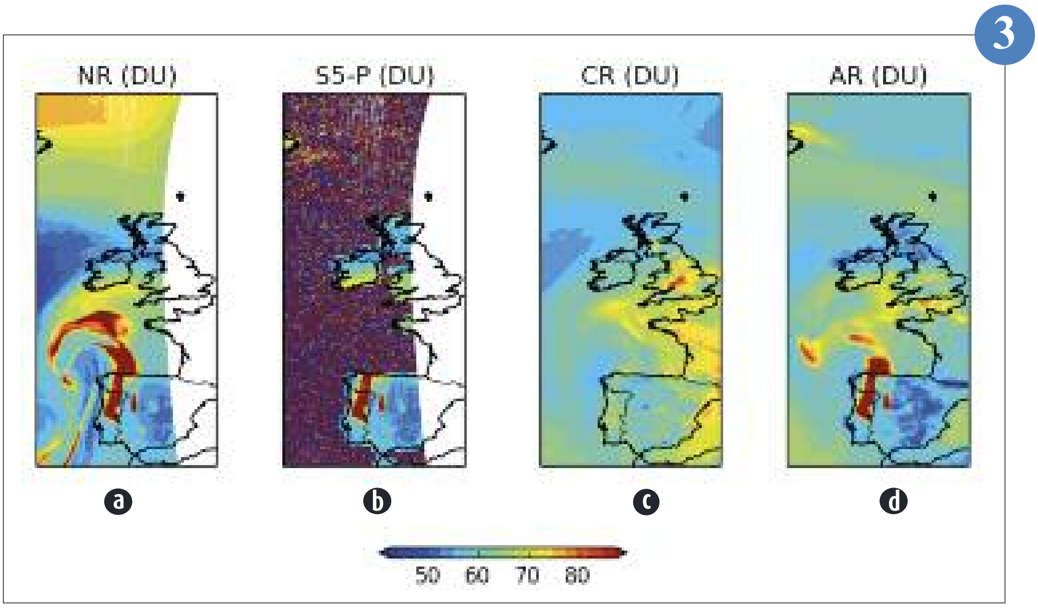
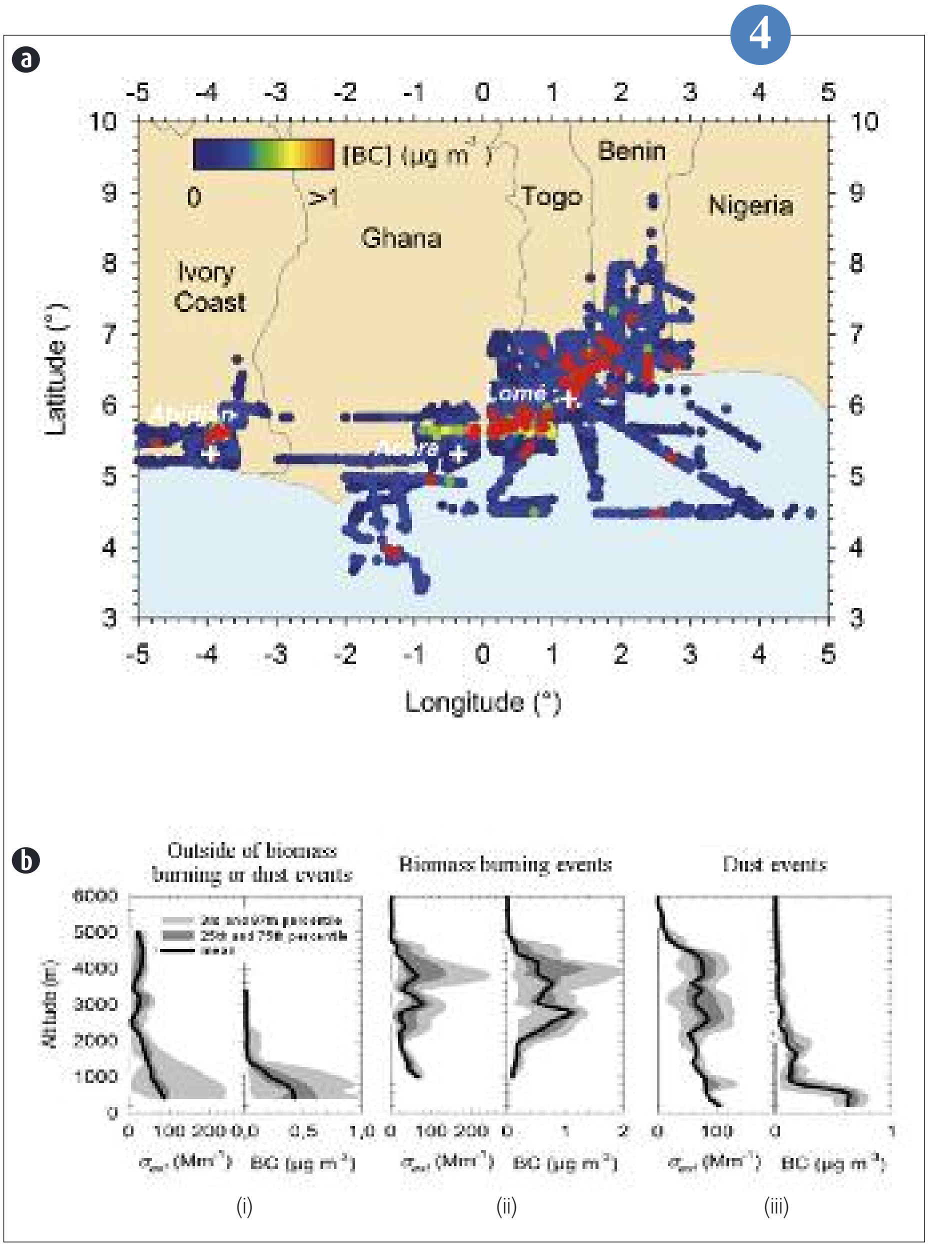


CO total column at 14:15 UTC on 4 August 2003, Dobson units, DU, during a forest fire event in Portugal
a: Nature Run;
b: simulated S-5P observations;
c: Control Run;
d: Assimilation Run. Red/blue colours indicate relatively high/low values of the CO total column.
From Abida et al, 2016.



a : Spatial distribution of black carbon concentration measured with the SP2 on-board the ATR-42 during DACCIWA.

b : Vertical distributions of extinction coefficient (left) and black carbon concentration (right) outside of biomass burning or dust event (i), during biomass burning events from Southern Hemisphere (ii) and during dust events from Saharan and Sudan deserts (iii). The mean values obtained during the campaign are shown with black lines and the 3rd, 25th, 75th and 97th percentiles are shown in grey shaded areas.

Measurement of the energy fluxes and aerosols over oceans with large-scale UAV: the MIRIAD project

The National Centre for Meteorological Research at Météo-France is leading a new project to study the atmosphere at the interface of Earth's surface using instrumented drones. The project is titled MIRIAD (Système de Mesures scIentifiques de flux de suRface en mIlieu mAritime embarqué sur Drone). It is conducted in partnership with the Laboratoire d'Aérologie of the Midi-Pyrénées Observatory and AJS, Inc. (a private company based in the Toulouse region and a member of the Aerospace Valley, specialized in the development and construction of mid-size, long-range UAVs). The project is funded by the Occitanie region and the European Union.

The ocean is one of the key regions needing in-situ measurements of energy flux and aerosols in order to improve climate models [e.g., Pierce and Adams, 2006, Pringle et al. 2010]. The relative importance of energy fluxes and sources of aerosols at the air-sea interface (i.e., wave breaking, whitecap cover) remain important unresolved issues.

However, in spite of the important role of aerosols and surface energy fluxes, the ability to conduct measure within ten meters of the ocean surface is technically very difficult. Indeed, observations using instruments fixed on research vessels are often affected by the interactions between the vessel's structure and the air flow. In addition, the spatial scale of sampling, using oceanographic research vessels, is limited to its transect at relatively slow speeds. The use of UAVs will enable to study the diurnal evolution of surface energy and aerosol fluxes at the regional level. The Boreal drone, developed by AJS Inc., have a 4 m wingspan and can fly for 10 hours, travel 1,000 km, and carry 5 kg of instrumentation. The Boréal UAV will be equipped with altimetric radars in order to conduct autonomous flights at very low altitude above the sea (to less than 10 m under favourable conditions).

In order to achieve the scientific and technical objectives, the success of the project depends on the expertise of each partner – the development of the scientific payloads to measure the energy fluxes and aerosols (Laboratoire d'Aérologie and CNRM), and adapt the navigation system of a drone for low-altitude flights (AJS Inc.). In 2016, the altimetric radars were successfully integrated and tested along the coast of Aquitaine at Monthalivet. The radar altimetry also measured the sea surface state, which is one of the key parameters in estimating marine aerosol fluxes. In another series of flights in late 2016, vertical profiles of aerosol show a strong gradient at the ocean surface related to the production of aerosols in the surf zone – clearly illustrating the need for low-level flights at the air-sea interface.

Once equipped with sensors to measure surface energy and aerosol fluxes, the Boréal UAV will allow the acquisition of essential data to improve our climate models. At the end of the project (December 2018), the Boréal UAVs will be transferred to SAFIRE as part of the French national infrastructure for conducting airborne research.

5

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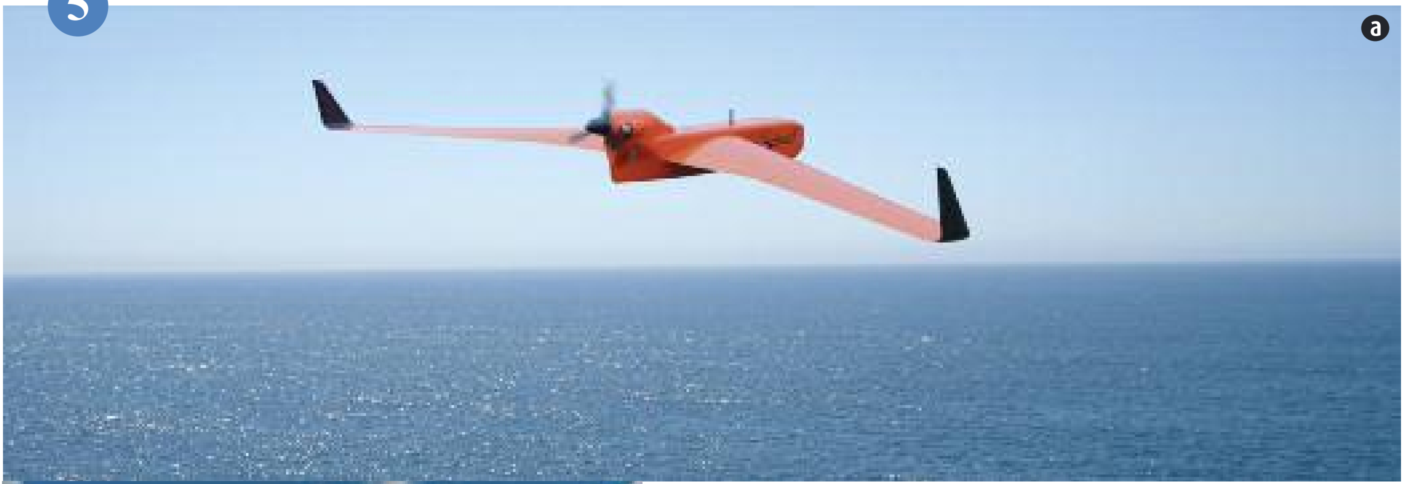

a : Boreal UAV developed by AJS Inc., during flight.
Copyright "© AJS"

b : Delivery of the Boreal UAV in CNRM.
Copyright "© Christophe Ciais - Météo France"

c : Project team MIRIAD in front of the Boreal UAV: (from left to right) Fabien Pollina (AJS), Marc Pollina (AJS), Greg Roberts (CNRM/GMEI/MNPCA), Sébastien Barrau (CNRM/GMEI), Michel Gavart (AJS), Frédéric Murguet (CNRM/GMEI/MNPCA).
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Snow and land surface hydrology

Météo-France performs research activities addressing all components of the water cycle on the surface of the Earth, including in particular land surfaces, which play a major role for meteorology and climate, and their impacts. The various states of water at the Earth surface (liquid, snow, ice) must be considered comprehensively, due to the fact that many processes are intertwined.
Météo-France operations in snow science and land surface hydrology, including all activities relevant for snow conditions in mountain terrain (in particular avalanche hazard), encompass a wide range of domains. This includes academic knowledge about key physical processes, surface and remotely sensed observations, data processing, numerical modelling across various time and space scales. All of these approaches are needed to understand snowpack and land surface behaviour and predict their evolution. Research in these domains naturally addresses this broad disciplinary diversity, most often in combination, with mutually beneficial interactions.
Main research efforts in snow science and land surface hydrology are devoted to enhancing basic knowledge about snow processes, which govern transformations taking place within the snowpack and control its physical and mechanical behaviour, as well as processes involving ground and the vegetation. Numerical modelling activities benefit from theoretical advances, and have seen several progresses in recent years. This concerns in particular increasing the spatial resolution over which numerical models operate, a better characterization of model errors, and better linkages between models predicted variables and satellite observations. All of these developments are required to prepare future model chains operating also in mountain areas, with increased spatial resolution, ensemble framework and satellite data assimilation.
One of the main achievements of the year 2016 is the completion of the international Solid Precipitation Inter-Comparison Project (under the auspices of the World Meteorological Organization). The main goal of the project was to assess the performance of various types of solid precipitation sensors, but also depth and mass of snow on the ground. This is particularly difficult with currently existing instruments especially under mountainous, windy conditions. Snow scientists from Météo-France, in collaboration with the local research community in Grenoble, have contributed to this research effort, through intensive observation campaigns at the experimental site Col de Porte, and contribution to data analysis and finalization of the final report. This report will hopefully be used by operational and research network managers in order to increase the quantification of observation errors, and favour observation methods which minimize them.

1

Super-cooled precipitations and ice layer formation on the snowpack surface in the Pyrenees

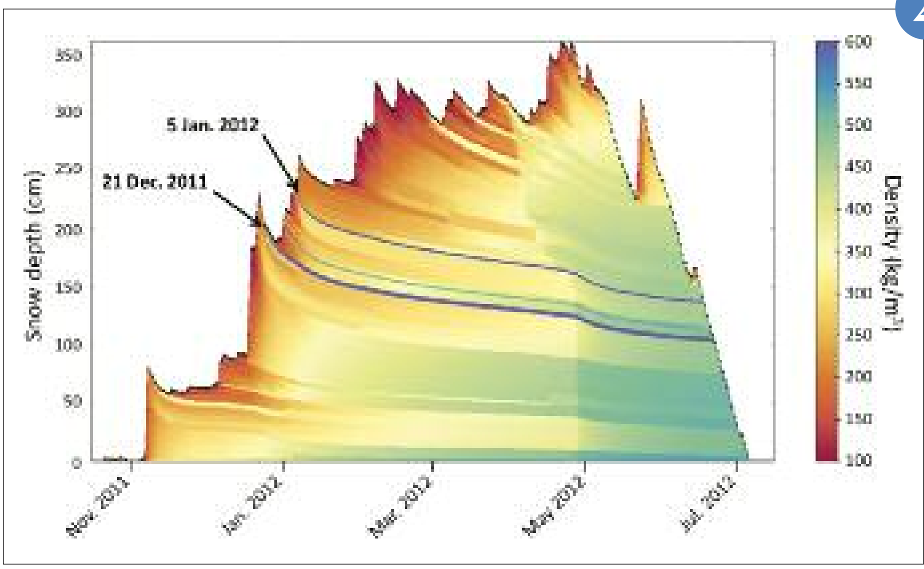
Freezing precipitations are made of super-cooled liquid water drops, which freeze upon contact with an object. This phenomenon is sometimes observed in mountains where it may lead to the formation of a pure ice layer on the snow surface. It occurs in general at least once a year in the Pyrenees, and makes mountain travel dangerous (9 fatalities in January 2012).
A recent project aimed at assessing the ability of the Numerical Weather Prediction system AROME to forecast such events in the Pyrenees. A diagnostic was proposed, combining the liquid cloud water content and the screen temperature forecast by AROME. It has been applied to AROME daily forecasts during five successive winter seasons, from 2010 to 2015, and compared to observed events reported on websites of the back-country skiing communities. The diagnostic shows good skills with 71 % to 75 % of detections, and 16 % to 32 % of false alarms. A focus on the event of January 2012 shows that the model captures well the location of regions affected by the ice layer formation.
Moreover, ice formation on the snow surface can be simulated with the detailed snowpack model Crocus, driven by the meteorological fields of AROME, modified according to the diagnostic. To this end, a specific scheme has been developed in Crocus to represent pure ice formation due to the solidification of super-cooled water on contact with the snow surface. With this scheme, the model can properly simulate the formation and evolution of ice layers during the winter (Fig.).
Beyond the prevention of accidents due to the surface ice layer, this can potentially improve avalanche hazard forecasting since the presence of the ice layer can influence the snowpack stability during several weeks after its formation.

2

1

Overview of the instrumental plot of the experimental site at Col de Porte, including sensors deployed for the WMO-SPICE project.

2



Evolution of the snowpack density during winter 2011/2012, at 2370 m in the massif of Haute-Bigorre (Pyrenees), simulated by Crocus, driven by AROME forecasts including the freezing precipitation diagnostic. Both ice layers observed during the season (21 December and 5 January) are correctly reproduced (arrows) and correspond to high density layers.

Avalanche debris detection using high resolution SAR images from Sentinel-1

Remote sensing of avalanche debris in mountain areas offers new opportunities to improve our understanding of avalanche activity and to evaluate the physical models of avalanche hazard forecasts. The location of avalanche debris and the estimation of their sizes are of great interest for studies dealing with the stability of the snowpack, and also for studying the variability of natural avalanche activity, which could be related to climate change. In addition, time series of avalanche events, with relevant time and space resolutions, would be highly relevant to better identify avalanche risk zones and periods. Such time series would complement some other existing database mostly based on visual observations, for instance: Enquête Permanente sur les Avalanches (EPA) database, Sensitive Avalanche Paths (SSA), and the CLPA database (Localization Map of Avalanche Phenomena).
Sentinel-1 satellites offer a unique tool to monitor some properties of the snowpack using a C-band Synthetic Aperture Radar (SAR) with a high spatial resolution (20m) and with a revisit frequency of 6 days over the French mountain massifs. We use a change detection algorithm to isolate avalanche debris-like features based on the backscatter contrast between avalanche debris and the surrounding undisturbed snowpack. The debris detection is based on major changes in the backscatter coefficients due to changes in snow properties following the avalanche event (height, density, roughness, ...), with the medium around the avalanche remaining almost unchanged.
Our algorithm has been successfully tested in the French Alps and Pyrenees (see the attached figure with a mapping of avalanche deposits near Aragnouet in the Pyrenees in March 2015) and has been designed for an automatic use which will make an operational implementation possible in the near future. Moreover, an avalanche event mapping database will be constructed since the winter of 2014-2015. Such a database would be a considerable asset to allow a return of experiences on the “Vigilance” situations of Météo-France (red / orange) and more generally to assess past situations.

3

CellDyM: a room temperature operating cryogenic cell for the dynamic monitoring of snow metamorphism by time-lapse X-ray micro-tomography

Once deposited on the ground, snow forms a complex porous medium that mainly consists of air and ice, and whose microstructure is constantly changing as a result of the physical conditions imposed by its environment. These micro-structural changes, known as snow metamorphism, strongly impact the temporal evolution of its physical properties and should be taken into account for an accurate snowpack modeling.
To better understand the physics at stake in snow metamorphism, we developed approaches to monitor the microstructure evolution in three dimensions (3D), and to compare these morphological evolutions to the ones obtained by numerical simulation. On the experimental side, we thus designed a cryogenic cell that precisely maintains the thermal conditions of a sample while it is scanned by X-ray tomography, a non-destructive technique adapted to the 3D imaging of materials.
Based on a thermo-electrical regulation and a vacuum insulation system, the cell, named CellDyM (cryogenic Cell for the Dynamic Monitoring of snow metamorphism), can directly operate at room temperature. It, therefore, does not require the usage of a tomographic scanner specifically installed in a cold room. It is, thus, adaptable to all kind of scanners including those of the ESRF (European Synchrotron Radiation Facility, located in Grenoble), which offers significant advantages in terms of imaging techniques, resolution, and acquisition speed.
The first results obtained are very satisfactory and open new opportunities for the study of snow metamorphism. This device may also be used for other topics such as snow micromechanics or the study of snow impurities.

4

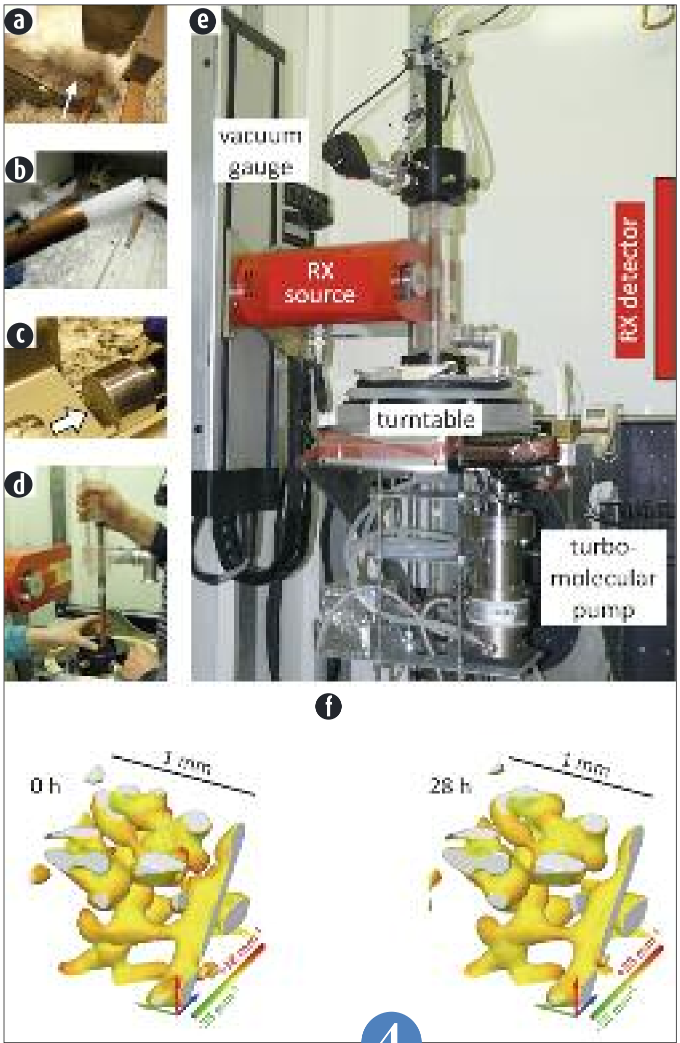
Optical reflectance assimilation to improve snowpack simulations

The physical properties of the snow cover in mountainous areas are highly variable both in time and space. Point measurements thus fail to depict this variability while satellite data are more appropriate for its monitoring. Current snowpack modeling does not include any snow observation so that modeling errors accumulate during the snow season due to the snowpack “memory”. The assimilation of satellite data in snow simulations is a promising way to improve snow numerical simulations throughout the snow season.
One of the main error sources for snowpack modeling is due to uncertainties of the meteorological forcings. This uncertainty can be better accounted for by performing ensemble snowpack simulations. The accuracy of the ensemble simulations can be improved by assimilating satellite data using for example particles filter. The filter selects the simulations “closest” to the satellite date and improves snow simulation accuracy.
The selection of assimilated observation data is crucial. A recent study has shown that assimilating optical reflectances (visible and near-infrared) from multispectral imagers such as MODIS (MODerate resolution Imaging Spectrometer) significantly improves point-scale snow water equivalent and snow height simulated by the detailed snow model Crocus (Figure). Such optical reflectances are available daily (in cloud-free conditions) at a spatial resolution of a few hundred meters, adequate for mountain topography. The impact of assimilation now needs to be investigated for wider geographical areas.

5

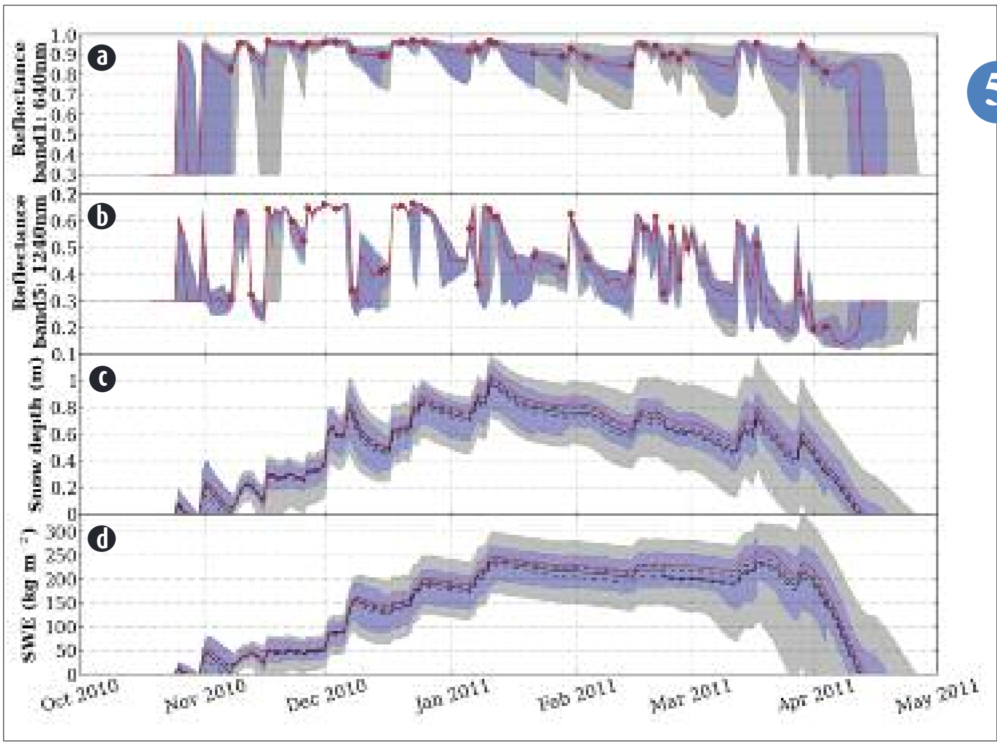
3

Avalanche debris, in green, identified using a couple of Sentinel-1A SAR images (images of 22/02/2015 and 06/03/2015) superimposed with that of EPA observations near Aragnouet in the French Pyrenees.



Experimental setup (left) and results for an experiment of isothermal metamorphism (right):
(a) Snow coring into a snow layer;
(b-c) Core insertion of the snow cylinder into its aluminum sample holder;
(d) Installation of the sample into the CellDyM cryogenic cell;
(e) Overview of the cell installed in the tomographic cabin of the 3SR lab (RX-solutions).
(f) A sub-volume of the snow sample undergoing a 28 h long isothermal metamorphism at -7°C.
The color map indicates the mean curvature scale, where convexities, flat shapes, and concavities are shown in red, yellow, and green, respectively. As in every sintering phenomenon, concavities grow at the expense of convexities, generating a smoother microstructure. The smallest details of the images are about 7.8 µm.

4



5

Evolution of the ensemble snowpack simulations over the 2010/2011 season:
(a) and (b) reflectance at 640 and 1240 nm (first and fifth MODIS band, respectively), (c) snow depth, and (d) snow water equivalent.
The blue shadings represent the envelopes of the ensemble assimilating MODIS-like reflectances, and the grey shading the envelopes of the ensemble without assimilation.
The red lines represent the control simulation (synthetic truth). In graph (a) and (b), the red dots show the assimilated observations.
In both (c) and (d), the black solid line shows the 50 % quantiles (median of the ensemble), and the black dotted lines, the 33 and 67 % quantiles for the ensemble with assimilation.

Evolution of the hydro-meteorological modelling chain: from SIM to SIM2

The hydro-meteorological modelling suite SIM (SAFRAN-ISBA-MODCOU) has been used for several years at DCSC for operational production. Recently, different improvements have been developed by the CNRM. The physics used for soil modelling has evolved, from a « force restore » approach with 3 soil layers, towards a « diffusion » version using 14 soil layers. Moreover, the sub-grid variability of the topography was taken into account through the development of a « mountain » treatment chain, which takes into account several altitude levels within a grid point. Finally, the SUREX tool (containing the ISBA model code) is now used.
These new developments have been integrated in the new operational chain SIM2, and SIM2 is being used for production since September 2016. This new SIM2 chain was first validated by the CNRM, and this was extended by an assessment of the impacts of the model evolutions on the operational/real time hydro-meteorological products. The evolution of the soil modelling, as well as the use of the « mountain » chain, leads to significant differences in the values of the parameters used in operational products, particularly the soil wetness index (SWI). A document describing the impacts on the products due to the evolution towards the SIM2 model chain is available for all the end users.
The evolution towards SIM2 is still going on for Météo-France partners (such as SCAHPI) and for research projects involving SIM such as ensemble mid-term hydrological forecasts, seasonal hydrological forecasts, and the AQUI-FR project.

6

Remotely sensed observations and model data fusion for monitoring the terrestrial water cycle

Dynamic integration of observations can improve the representation of land surface processes by models. Particularly, remotely sensed observations have the advantage of being globally available with high temporal frequency. Many observations, linked with the hydrological cycle and vegetation, are (or will be) available with improved spatial and temporal resolutions. Data assimilation techniques make it possible to integrate them into large scale Land Surface Models (LSMs) in a way that is fully consistent with their representation of surface processes. LSMs coupled with river routing systems lead to a better monitoring of the terrestrial water cycle.
A Land Data Assimilation System (LDAS) has been set up within the SURFEX modelling platform. The LDAS is able to ingest information from satellite-derived surface soil moisture (SSM) and Leaf Area Index (LAI) observations to constrain the Total Runoff Integrating Pathways (C-TRIP) continental hydrological system. Analysis impact of bio-geophysical variables within SURFEX is reflected on terrestrial water cycle variables (e.g. river flow) through a daily, interactive coupling between SURFEX and CTRIP. Figure below represents analysis impact on LAI over the Euro-Mediterranean area. Analysis is closer to the observations than the model (no assimilation). An impact study on river discharge representation by CTRIP over 1980-2010 using more than 100 gauging stations shows the added value of the analysis. Interpretation of this result is however hampered by the lack of representation in SURFEX of processes related to human activities (such as agricultural practices, presence of reservoir dams). A next step in SURFEX realism is the representation of irrigation and agricultural practices.

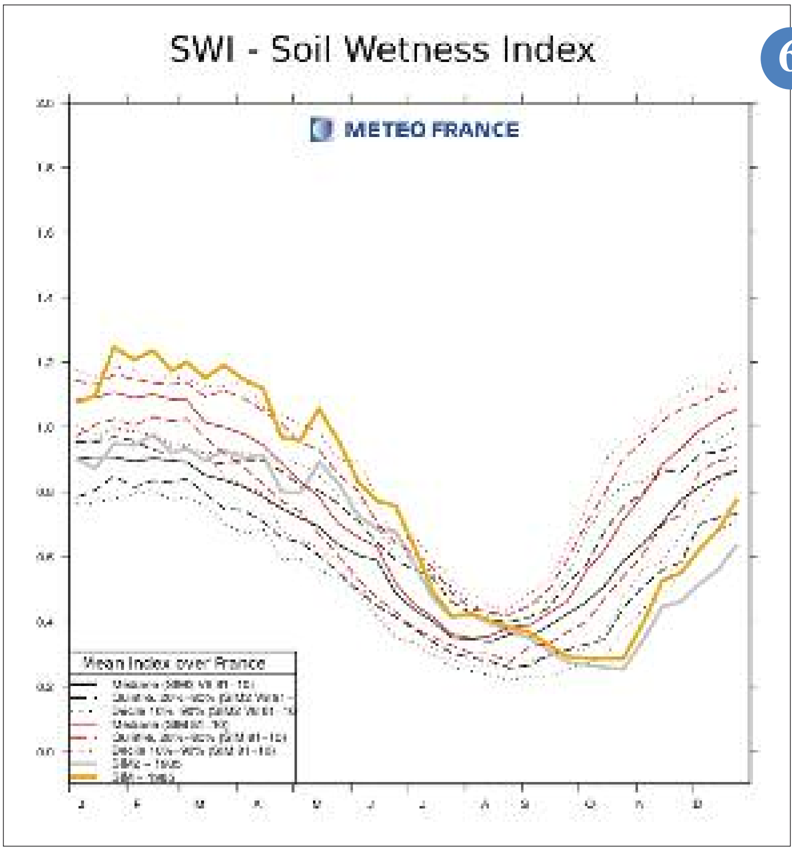
7

Impact of improved modelling of forest evapotranspiration and its partitioning on simulated river discharge

The current version of the land surface model ISBA, which represents the natural continental component of the Météo-France SURFEX platform, models the superficial soil and overlying vegetation as a single composite layer using averaged physical properties. A new option, ISBA-MEB (Multi-Energy-Balance), explicitly accounts for each of these two surfaces, which permits a more realistic explicit representation of key processes such as below canopy shading, ground-canopy radiative exchanges, snow interception by the vegetation, and forest litter.
Detailed evaluations of this new development using local scale observational data have shown that the representation of the surface energy budget is improved for a large range of climates and forest types. In particular, the amplitude of the soil conduction flux is significantly reduced leading to increased sensible heat flux which is in better agreement with observations. The Météo-France hydro-meteorological modelling chain SIM, which models the hydrological state variables and river discharge over all of France, serves as an important research tool for evaluating new surface model developments at the regional scale for multi-decadal timescales. ISBA-MEB has been found to improve the discharge simulation at nearly all of the available measurement stations (fig.), and improved bare-soil evaporation has been identified as the main reason. The new improved explicit representation of forests leads to a lower annual cycle of this flux which systematically improves simulated discharge throughout the year (decreased runoff production in winter and increases in summer).

8

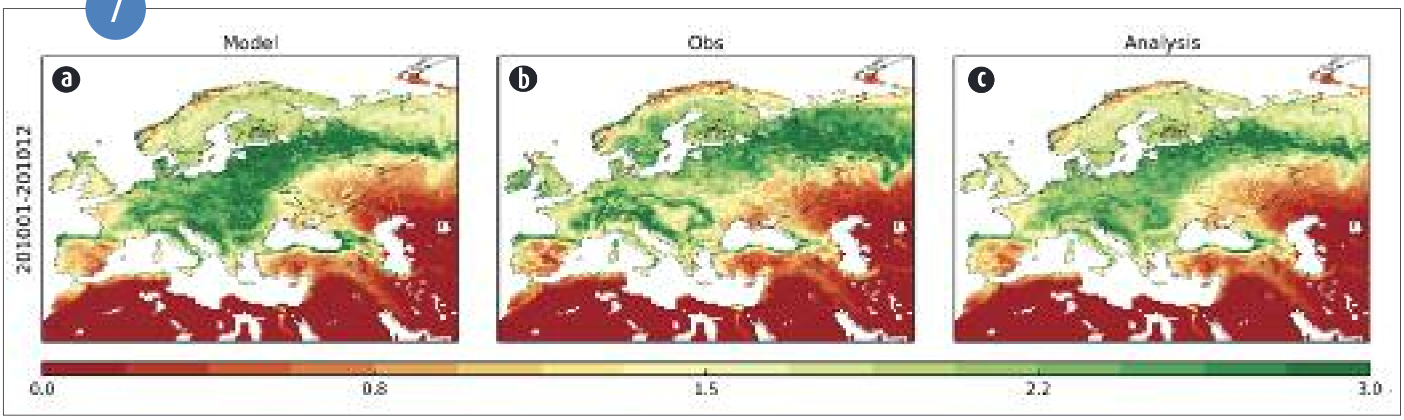
6



Comparison between the 10 day SWI climatology (1981-2010) from SIM and SIM2, and evolution of the 10 day SWI for the year 1985
The values of the parameter itself are different between SIM and SIM2 due to the modeling improvements, however the inter-annual variations are similar, and for a particular year, the comparison to the climatology shows identical patterns.

Leaf Area Index (m^2m^{-2}):
(a) model simulations (no assimilation),
(b) remotely sensed observations,
(c) analysis after assimilation (i.e. of b).
Values are averaged over 2010.

7



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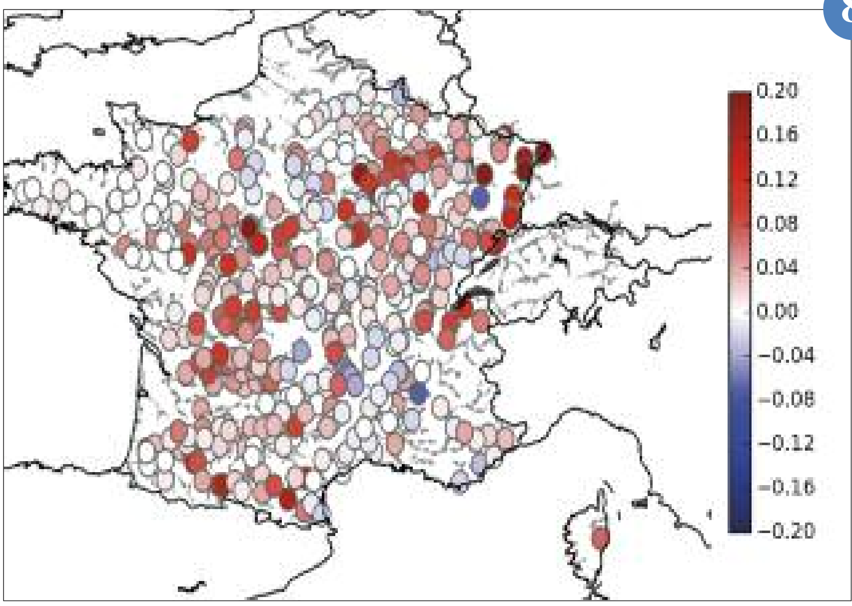


Nash criteria difference, which is classically used to evaluate the quality of modeled river discharge,
between the new model option for forests and the default
Stations with negative values of Nash for both simulations are not shown. 68 % of the Nash values are now greater than 0.5 (threshold good score) compared to 63 %
using the original model.

Oceanography

Understanding the key processes that govern the "Earth System" – the meaning of these words reveals how closely tangled the atmosphere and the other Earth compartments are –, is the primary objective for scientists at CNRM. Improving the knowledge of the mechanisms, that govern meteorological and coupled phenomena, as well as their representation in numerical models, is critical for downstream applications and services. For risk management, security, climate adaptation or economy, continuous advances transferred to operations drive progress for users. This is especially true in the various fields of marine activities, on high sea or in coastal areas.
Oceans and marine meteorology, since meteorological services were created, are one of the great priorities of meteorological research. Together with oceanographers, meteorologists and climatologists study air-sea exchanges and couplings at various scales. Deep convection or atmosphere-waves-currents interactions are various phenomena under investigation. Oceanic features also become interesting for short term prediction of striking events, at stake along our coasts, in metropolitan and overseas France.
Météo-France's research is also being much applied and targets the improvement of key applications. The reader will discover how our teams improve the Search and Rescue tools. It is probably useless to stress that such SAR services are delivered almost every day in real time by marine forecasters, for real emergency cases over the seven seas...

1

New operational coastal model for wave forecasting in West Indies and Guyana

Since the end of 2015, the follow on of the project HOMONIM aims to improve the storm surge and waves forecasting in coastal areas of the French overseas. The project is conducted by Météo-France and SHOM and supported by the French ministry of Ecology (MEEM). The main outcome of the first part of the project HOMONIM is the implementation of in operations a high resolution coastal wave model WaveWatch 3 (WW3) for the metropolitan coasts in March 2015.
Numerical studies on bathymetry data and testing of several meshes have been performed with the coastal model WW3 for the West Indies and Guyana coastal domain. The validation of the coastal model has been performed for a long period and on extreme events happened recently. The coastal model WW3 for the West Indies and Guyana has been implemented in operations since December 2016. Integrated wave parameters are provided with a resolution of 200 m at the coasts. The model has an irregular grid that matches accurately with the islands coastlines. The coastal model WW3 is driven by analysed winds from the Arome-OM atmospheric system dedicated to the French territories with a resolution of 2.5km. The wave spectra at the boundaries are provided by the regional wave model of Météo-France MFWAM with a resolution of 10km.
For shallow water processes the coastal model WW3 improves the waves refraction, wave breaking induced by the bathymetry, and the bottom friction dissipation term. For the future developments particular attention will be considered in terms of wave/currents interactions and moving muddy bottom for the Guyana coastal area. Finally the project will support the deployment of coastal WW3 with unstructured grid for Mayotte and Reunion Islands.

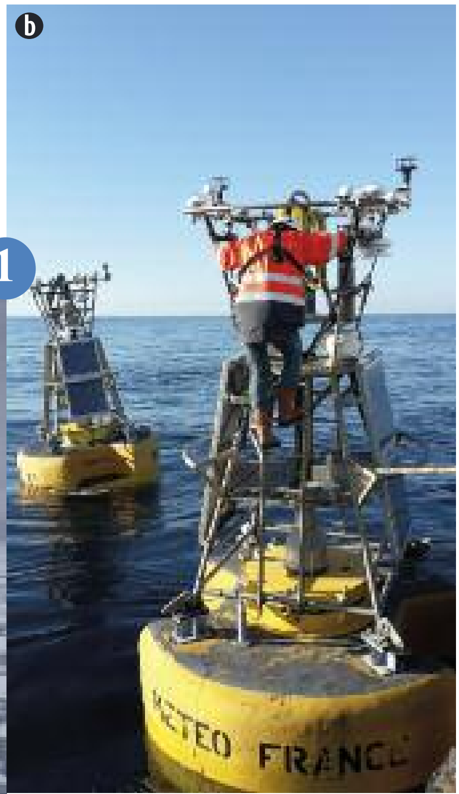
2

Use of currents and sea levels by the coastal wave model

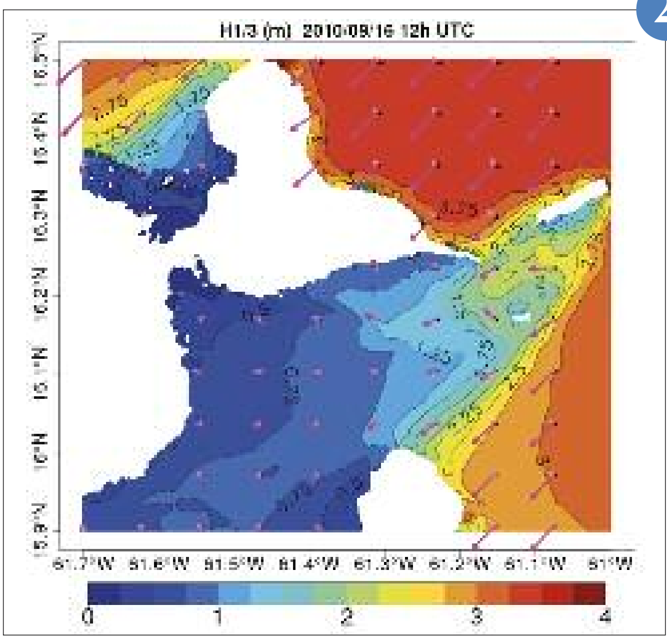
In the framework of the HOMONIM project, managed by Météo-France and SHOM, with the support of DGPR and DGSCGC, a coastal wave model (WW3) was developed, and then installed in the operational suit at Météo-France in June 2015. The mesh size of this model gets up to 200 m on the French coast.
At the end of 2016, a new version of this model, developed with SHOM, uses, on the Atlantic/Chanel area, the currents and the sea levels computed by the Hycom2D model, developed also by the HOMONIM project. These new forcings allow the wave model to describe more precisely the coastal area, namely when the tides are important and the water depth weak. The foreshores are so better represented (areas becoming alternatively earth or sea depending on the phases of the tides) and the waves physics take advantage of the more accurate bathymetry. Moreover, the use of the oceanic currents improves the computations, both for the wave heights and their periods. Waves measurements were realized in March 2016, at the head of the Bay of Mont St. Michel, in a foreshore, when the sea state was moderate. The figure shows the WW3 simulation improvement when the sea level, and then the currents, are taken into account, in comparison with the measurements off the beach of Hirel.
This coastal waves model enhancing is a first step to the complete coupling between waves and storm surges models, which will be tested and validated in the coming months, with a prototype on the Pertuis Charentais (HOMONIM project).

3

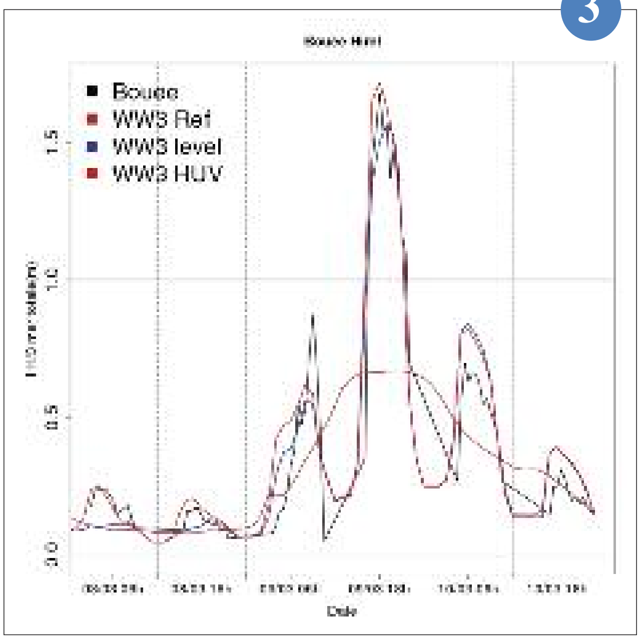
The research vessel "Akademic Treshnikov" in the sea ice of the southern ocean on 2016 during the international Antarctic circumnavigation expedition (ACE) of the Swiss Polar Institute. Météo-France collaborate with the University of Melbourne for testing the radar WAMOS in order to investigate interactions between waves, currents and ice.
Copyright: Alessandro Toffoli / University of Melbourne.



(b) : The new buoy ODAS12 just moored near the old one ODAS11 in December 2016 at the "Côte d'Azur" permanent observing position in the Mediterranean sea.



Significant wave height of the total sea (in meters) of WW3 on 16 September 2010 at 12:00 (UTC) in Guadeloupe
Red arrows describe the direction of swell generated by hurricane Igor (4th category) moving at 600 km north-east.



Comparison between the measurements (« Bouee », black line) and the simulations of the significative waves height by WW3, without oceanic forcing (« Ref », brown line), with the sea level (« level », blue line) and with the sea level and the currents (« HUV », red line). The event occurs from the 8th to the 10th of March 2016, the measurements being done off the beach of Hirel, at the head of the Bay of Mont St. Michel, by Dinard-EPHE.

Wave modelling for Copernicus services (global and regional)

The ocean waves play a crucial role in the exchanges of momentum and heat fluxes and gases transfer at the ocean-atmosphere interface. In the framework of the operational Copernicus services (Copernicus Marine Environment Monitoring Service: CMEMS), Météo-France (DirOP/MAR) will provide the wave products of the wave model MFWAM for the global scale with a grid size of 20 km. The global model is driven by ECMWF winds and uses the assimilation of altimeters data. The model MFWAM is also used for the regional domain Iberian Biscay and Ireland (IBI) with a grid size of 10 km with a collaboration of Puertos Del Estado, AEMET, CESGA and Marine Institute.
The launch of the Copernicus services dedicated to waves is scheduled for April 2017. In the version V3 of the operational system CMEMS-IBI, the wave model MFWAM is coupled to the ocean circulation model NEMO. Three coupling processes have been implemented and investigated. The first process concerns the Stokes-Coriolis forcing, which uses the Stokes drift computed by the wave model. The second process consists in taking into account the momentum stress driven by the waves to ocean, and finally the third process uses the turbulence induced by wave breaking and injected in the ocean mixed layer.
The first results on the coupling show significant impact on key parameters, which are sea surface temperature, surface currents, salinity and the ocean mixed layer. The validation phase of the coupling between the ocean and waves for a long period 2014/2015 is undergoing and aims to adjust and improve the physical parametrisations used in the models.

4

Taking into account jibing to improve MOTHY drift system

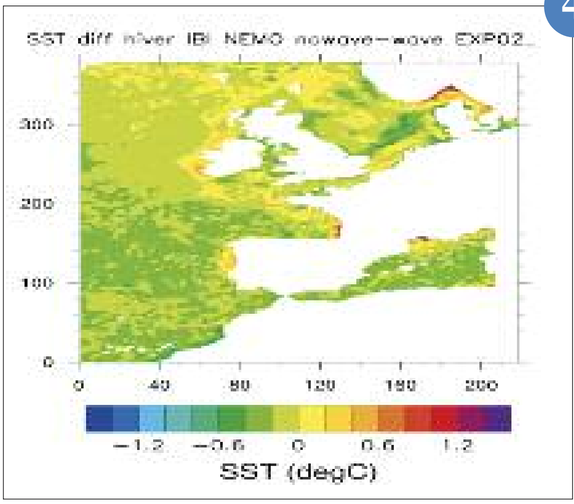
As part of its national and international responsibilities, Météo-France operates the MOTHY drift prediction system for oil slicks or floating objects. The system is activated over 800 times a year for actual spills or search and rescue operations. The search for objects or people constitutes 80% of applications.
Small differences in the initial orientation of an object relative to the wind can lead to drift to the right or left of the wind direction, with the same probability. These two positions are not stable. The object can jibe, namely, change tack downwind. The frequency of these changes is an important element for modeling search areas. Without jibe, the initial probability distribution will rapidly separate into two areas of high probability depending on whether the object has a left or right track. If the object jibes, the probability distribution will over time fill in the central area between the two dominant search areas. The more frequent the jibing, the more central the distribution will be.
The dynamics of jibing is poorly understood, but estimated jibing frequency has been determined from observations. These random jibes are now taken into account in the drift calculations.

5

Studying ocean deep convection in the Mediterranean Sea: the HyMeX winter 2012-2013 case

Ocean deep convection is a fundamental phenomenon for physical oceanography. It is a key element of the thermohaline circulation and a key area for exchanges between the surface and deep ocean. In order to improve the knowledge and modelling of this phenomenon, HyMeX, MerMex and MOOSE programs have collected an unprecedented amount of observations in the northwestern Mediterranean Sea during the year 2012-2013.
In particular, observations of this golden case allow to continuously monitor the ocean mixed layer chronology (Figure a, black). Convection reaches intermediate depths in late January; it reaches the bottom of the water column in February and again in mid-March, before the definitive restratification. They also allow to quantify for the first time the dense water volume seasonal variations (Figure b, black) and to estimate an annual deep convection rate of 1.3-2.3 Sv (1Sv=10^6 m^3/s) and a restratification rate of 0.8 Sv.
For a comparison, Figures a and b display results from two initialized ensemble simulations by randomly perturbing mesoscale structures from the initial conditions deduced from August 2012 observations. Only the red ensemble resolves ocean mesoscale with a 2km-resolution zoom. Numerical simulations succeed to reproduce the successive phases of the phenomenon (Figure a) as well as the dense water volume seasonal variations (Figure b) despite a low underestimation of the maximum convection magnitude. The explicit representation of mesoscale increases the realism of deep convection geography (not shown), it decreases its magnitude (Figure a) and it increases the restratification rate (Figure b).

6

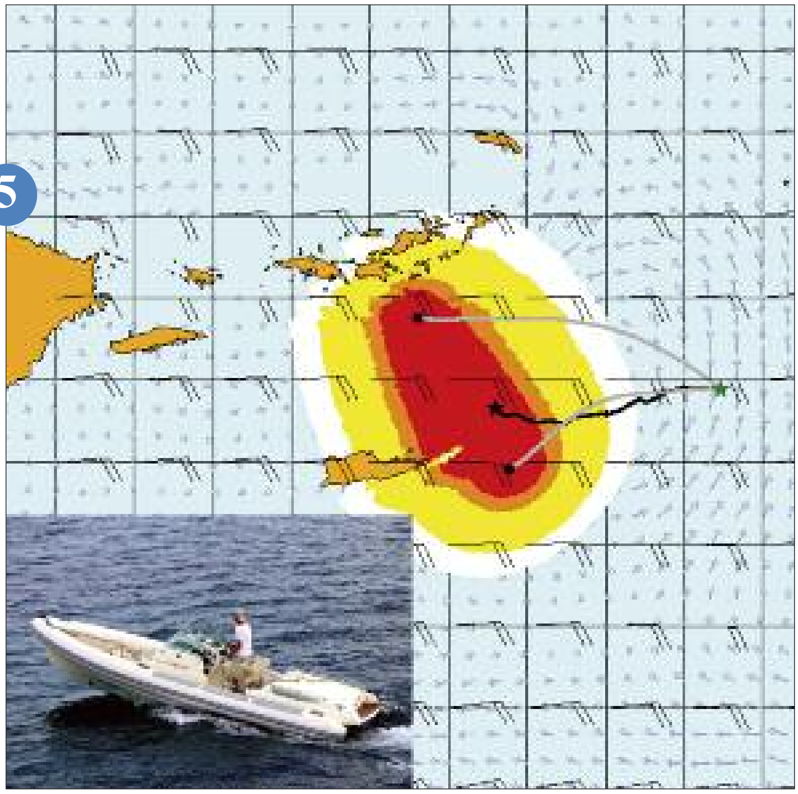


4

Difference of mean sea surface temperature (in °C) between runs of NEMO-IBI uncoupled and coupled (Stokes-Coriolis forcing and ocean side stress from MFWAM) with the waves for the winter season of 2014 on IBI domain. Positive values of difference stand for cooling of the ocean surface induced by the waves.

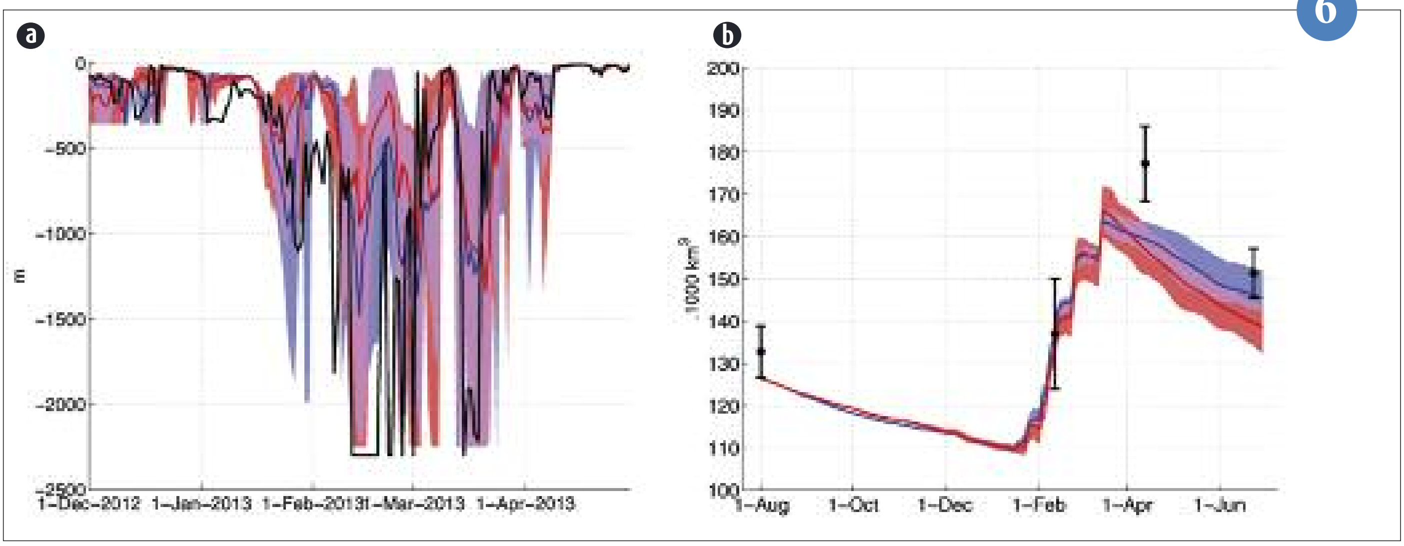
5

Probabilistic drift forecast of an inflatable boat near Virgin Islands, Caribbean Sea. The probability of presence of the boat 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 green star indicates the position of loss of the boat. The black star indicates the position where the boat was found 60 hours later.



Daily time-series (a) of the mixed layer depth (in meters) at LION station (42.1°N,4.7°E) from December 1st 2012 to May 1st 2013 and (b) of the dense water volume (in thousands of km^3) in the northwestern Mediterranean Sea (potential density anomaly larger than 29.11kg/m^3) from August 1st 2012 to July 1st 2013. Observations are in black; the 10-member Mediterranean NEMO ensemble simulation (6km resolution) is in blue and the twin ensemble at 2km resolution over the northwestern Mediterranean is in red.

6



Observation engineering, campaigns and products

There are more and more connected objects acquiring data potentially interesting for weather forecast. The amount of data could become huge and revolutionize operational observation. To keep up with the technological innovation, Météo-France started this year an experiment. It consists in acquiring temperature measurements made on board connected vehicles. It is a first step towards a system alerting drivers of bad road conditions ahead.
Column integrated amounts of water vapor can be derived from GPS receivers. The technique was developed in the 90s and has reached a high level of maturity. It is now possible to derive the information sufficiently rapidly that it can be assimilated by models. A program was started in 2016 that aims at deploying a network of GPS receivers in the Indian Ocean for improving the forecast of tropical cyclones.
Data fusion is still developing and spreading. Combining radar and rain rate observations the ANTILOPE product is now available overseas while maps of precipitation type (rain, snow, ice...) are now computed in real time.
Observation plays a key role in atmospheric research. It provides long series of measured parameters against which the quality of a model can be tested – as the Météopôle-Flux station in Toulouse does for surface exchanges – or give details on the processes governing weather phenomena like fog for instance, thus allowing their representation of numerical models.

1

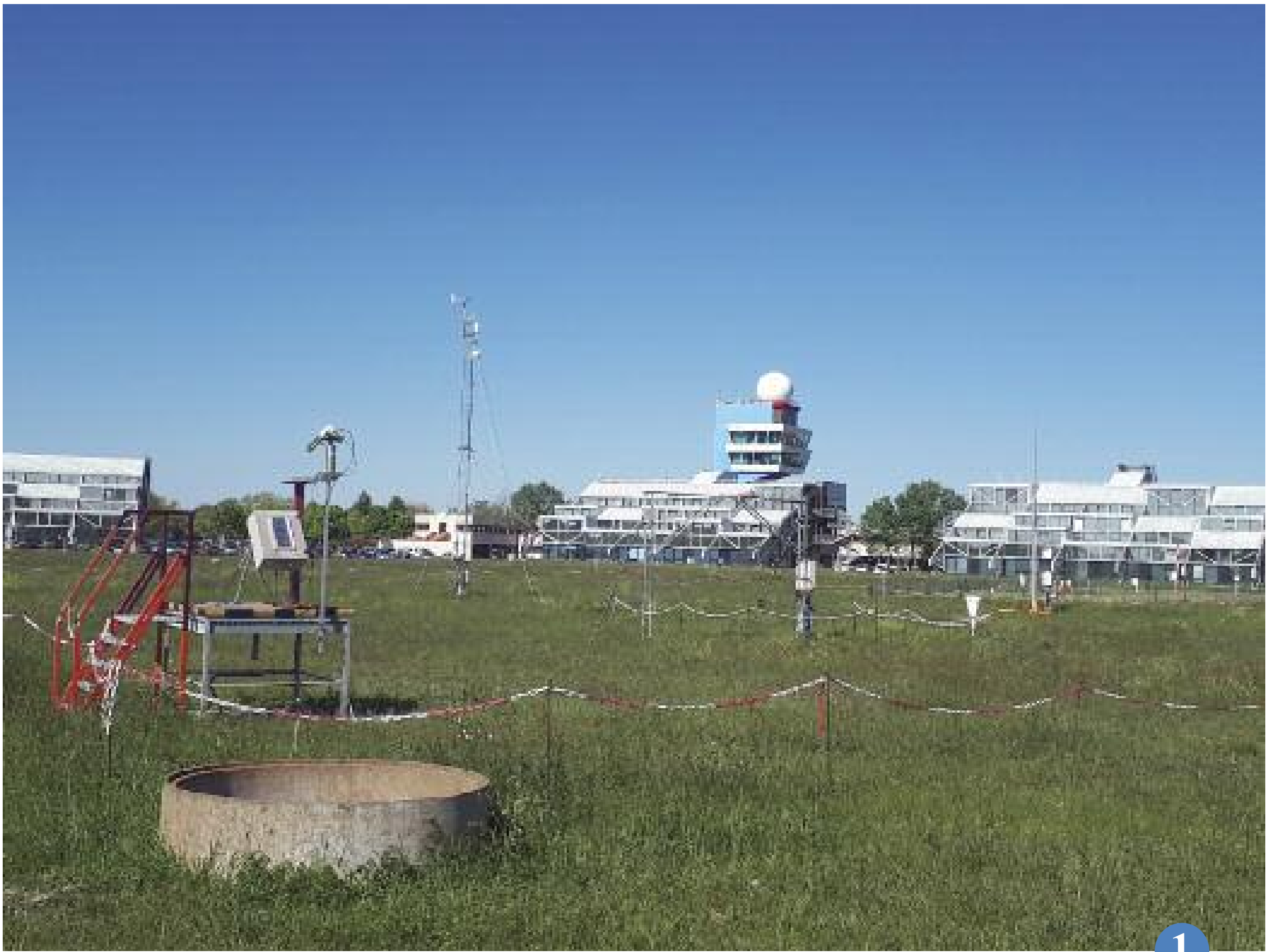
Vertical profile of fog microphysics experiments

Fog has a significant impact on human activities in particular with respect to air transport operations. To improve fog simulation and forecast the CNRM conducted two field campaigns during fall 2015 and 2016 in collaboration with IRSN (Institut de Radioprotection et de Sûreté Nucléaire). Realized at the Observatoire Pérenne de l'Environnement (OPE) of ANDRA (Agence Nationale pour la gestion des Déchets Radio-Actifs) located in the East of France (250 km from Paris) in a deep rural area, an innovative instrumental set-up was deployed to gain insights on the following objectives:

- to document typical features of the vertical profiles of fog microphysical properties (droplet size and number concentration, liquid water content and visibility) in order to constrain and validate numerical simulations;
- to assess the impact on fog forecast of the assimilation of humidity and temperature profiles retrieved from a ground-based microwave radiometer into the AROME NWP model;
- to evaluate the amount of fog water deposition on plants by turbulent mixing which is a substantial sink of water at the surface, not yet taken into account in NWP model.

Numerous instruments were installed on a mast at different altitude levels (2, 10, 50 and 120 m). During intensive observation periods in situ vertical profiles up to 500 m height above the ground were performed with a tethered balloon. Ultra-light (650 g) remotely piloted aircraft systems were used to characterize the boundary layer properties evolution in complement to radiosonde measurements.
These data are currently analysed to investigate the variability of the different parameters along the vertical into the whole fog layer during the fog life cycle. A few events of fog formation by stratus lowering which are very difficult to forecast, have been sampled during the campaign.

2



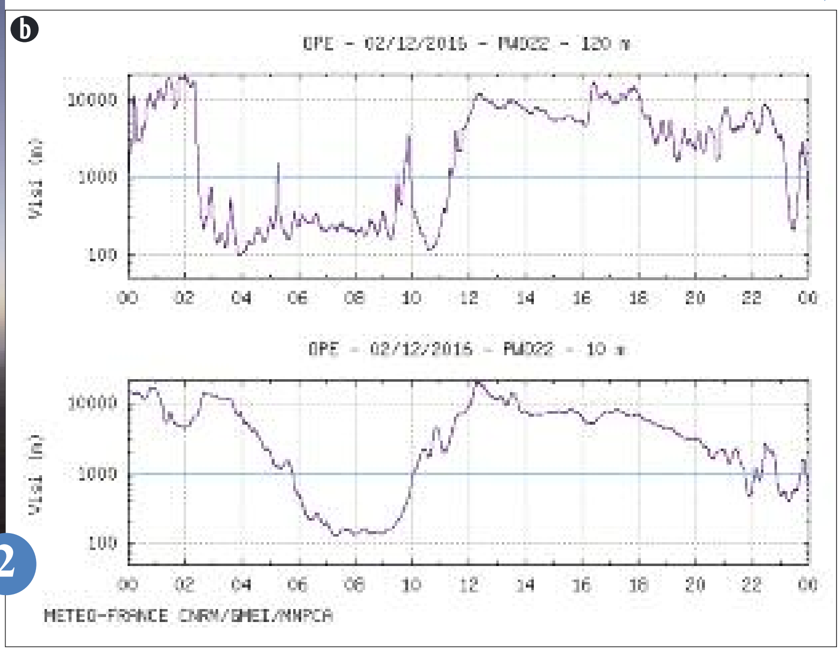
1

Météopole-Flux area.

2

(a) : Radiosonde launch in the early morning.

(b) : Times series of the visibility as measured by the two PWD22 installed on the mast for the 2 Dec. 2016 stratus lowering case. They show that the top of the mast at 120 m height is in the cloud (visibility < 1000 m) at 2h30 while the fog reaches the ground just before 6h.



Météopole-Flux: measuring surface–atmosphere exchanges, and encouraging scientific exchanges

The Météopole-Flux station is specifically designed to measure, in addition to usual meteorological parameters, the surface-atmosphere exchanges of heat, water vapour and CO_2. Notably, high-rate measurements (20 samples per second) of 3D wind, temperature, humidity and CO_2 concentration allow to compute the turbulent vertical fluxes of energy and CO_2, using the eddy covariance method. Soil moisture and temperature are measured down to two meters, which is rarely seen on comparable stations.
The GMEI group installed this station in 2012 at the experimental field of Météopole, in Toulouse, to support the work of the GMME group on soil-vegetation-atmosphere transfer schemes. A homogeneous dataset, covering the 2012-2016 period, and taking into account the latest instrument calibrations, has recently been released.
Use of this station rapidly expanded beyond the initiators. It is now used by GMAP to validate parametrisations of the models, and to study enthalpy of moist air. Radiative measurements have been added (a photometer of the AERONET network, and photosynthetically active radiation). It is a reference station for urban climate studies and it supported a test campaign of soil moisture retrieval from reflected GPS signal.
The interest of this station is recognized beyond Météo-France: in 2017, it will be integrated in the ACTRIS-France research infrastructure, and will become an associated site to the ICOS network.

3

The 2016/2017 connected vehicles experimentation

An experimental campaign devoted to connected vehicles is conducted in partnership with the Continental private company.
A first experiment with 1 vehicle was done during the 2015/2016 winter to study the technical relevance of the connected system (dongle + phone) and to qualify preliminarily the quality of measurement of an easily exploitable parameter: the air temperature. The comparison (Fig. a) with spatialized observations of temperature showed that the temperature measured from the vehicle was relatively satisfactory (mean error of -0.7 °C and root mean square error of 1.1 °C). Moreover, it has been shown that in a mountainous area it was possible to observe a vertical temperature profile from the vehicle measurement (Fig. b), with an expected add-value for the detection of temperature inversion, observation of the rain-snow transition.
A larger scale campaign (200 vehicles including 100 company car of Météo-France distributed over the whole French territory) is in progress for the winter 2016/2017, in order to create a database and also to study the relevance of forecasting alerts on the itinerary (1h) broadcasted within the vehicle concerning the risks of phenomena impacting the safety (freezing rain, snow, hail ...).
The analysis of the results of this campaign will extend the approach to the exploitation of other parameters from the vehicle which are more difficult to exploit than temperature (wipers for precipitation, ESP for surface condition, beams for visibility ...). The final aim of this project is to obtain an on-board forecast/warning system integrating in real time the data from other vehicles.

4

HYDRE

HYDRE is a software whose purpose is to determine ground precipitation type: rain, freezing rain, snow, hail, ...
It has been developed during the last two years in order to help forecasters to better handle critical winter phenomena as well as hail occurrence in metropolitan France.
It makes use of various sources of information: weather radar and satellite, ground observation networks and AROME NWP forecasts.
The method used to determine winter precipitation types is inspired by algorithms already implemented in Canada or United States; it relies on the structure of the vertical profile of temperature, which is derived from the latest AROME NWP forecasts.
As for hail occurrence and size (small, medium or large) determination, it is done exclusively by using weather radar data (polarimetry and reflectivity).
An experimentation by forecasters has been conducted from January to October 2016, which has made it possible to validate the algorithms and to refine the settings of this first version.
This product is going to be in operational use by the end of 2016, providing information every 5 minutes. In the future, it will benefits from advances in radar measurements and numerical forecasting.

5

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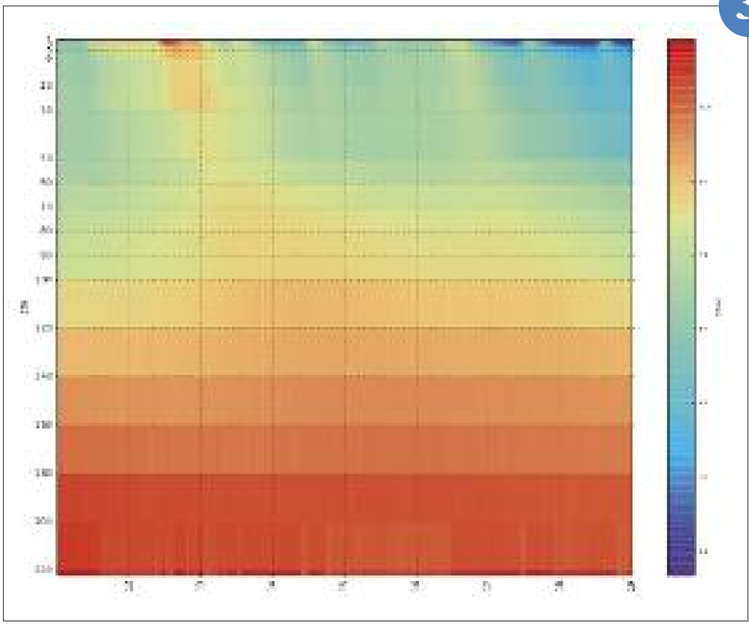
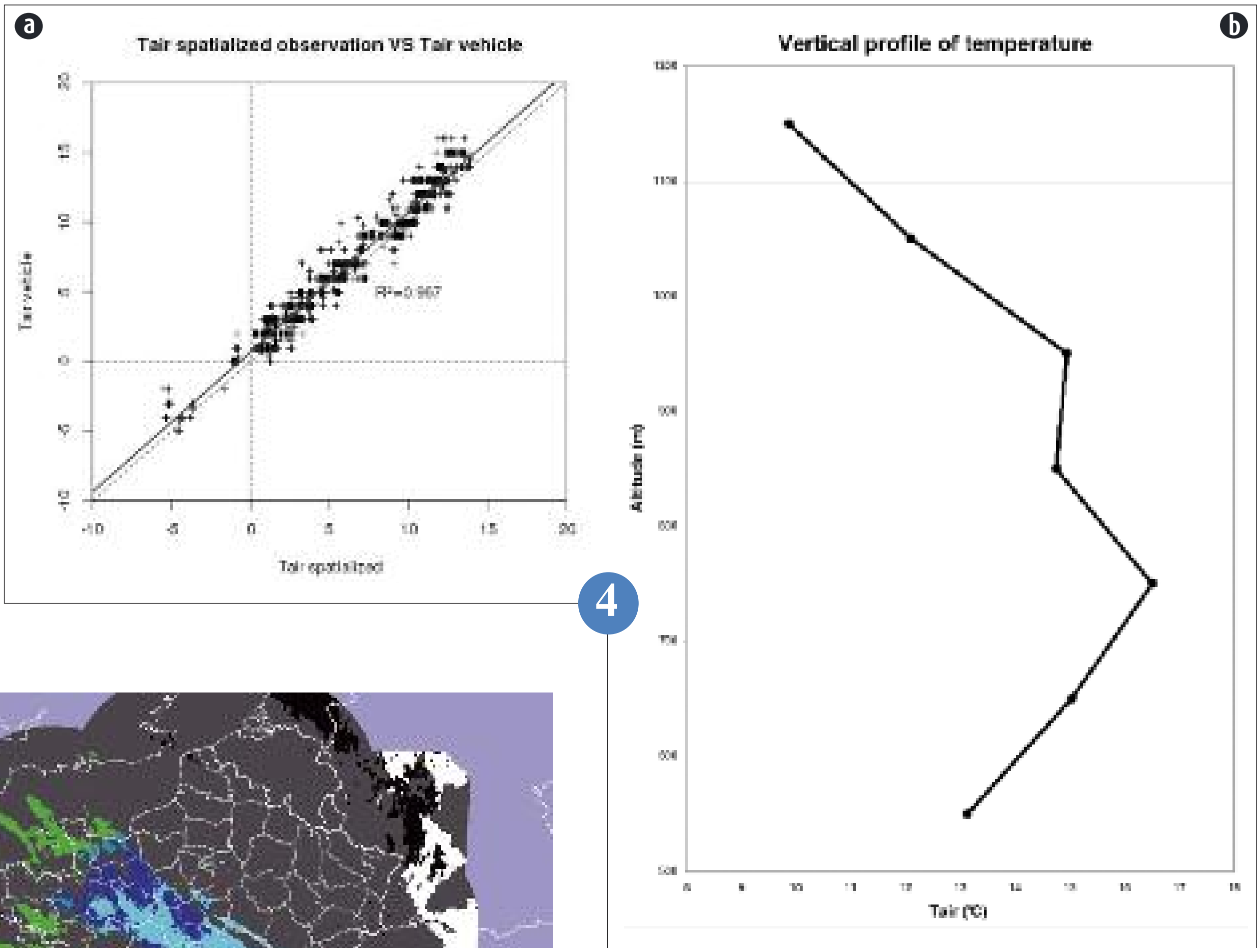


Time-depth cross-section of soil temperature between January 11th and 18th, clearly showing the downward propagation of temperature waves.

(a) : Comparison of air temperature measured by the vehicle with an operational product of spatialized temperature observations (1km resolution, 5 minutes frequency) during the 2015/2016 winter.
(b) : Example of vertical profile of temperature reconstituted from vehicle measurement (road journey within the Alps).

4



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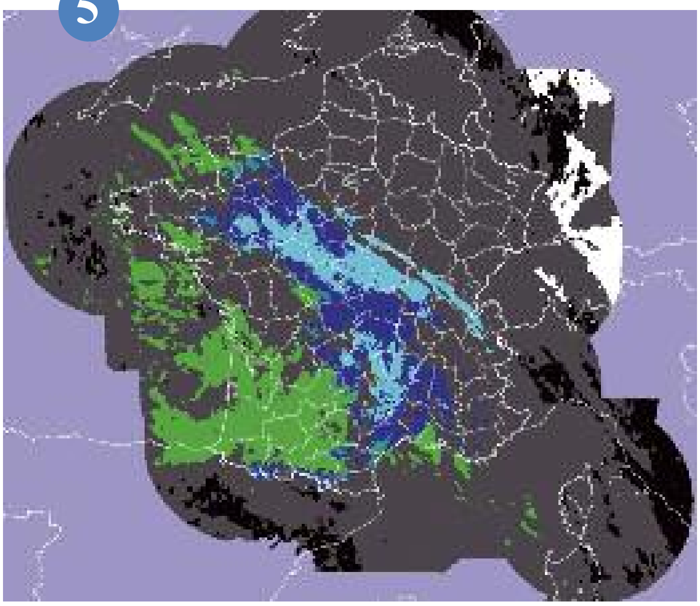


HYDRE ground precipitation type, 18/01/2016 11.00 TU. It shows rain (in green), snow (in blue) and rain and snow mixed (turquoise).
Sky blue colour indicates that falling snow will lie on the ground, white colour indicates snow lying on the ground seen by satellite.

Merging data for overseas territories

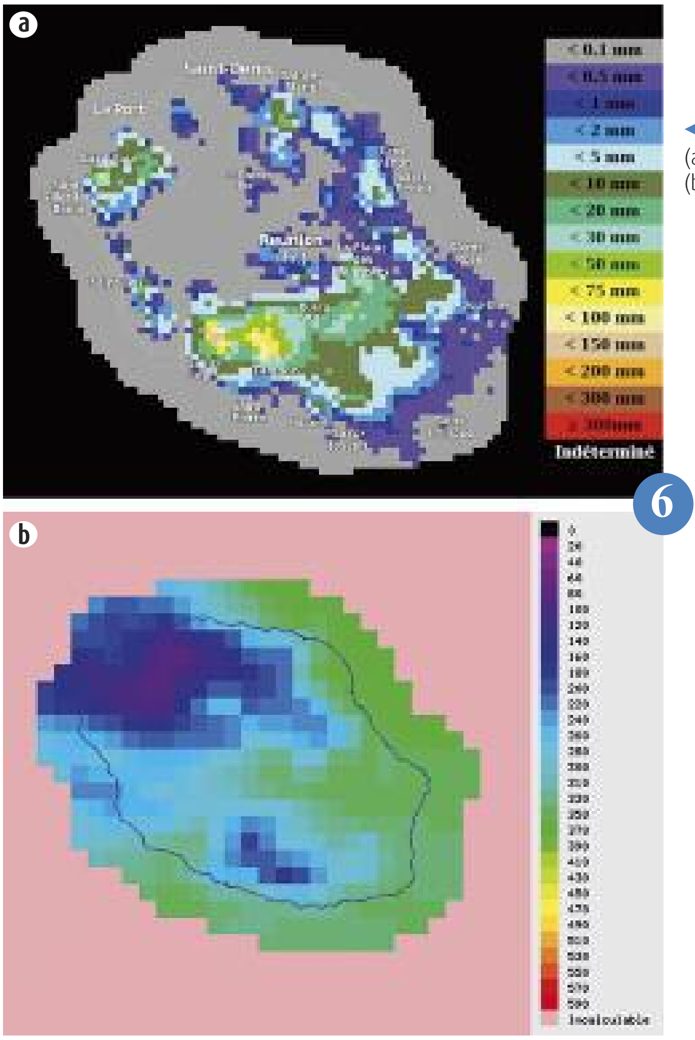
Observation products merging data from various sources have been produced for overseas territories.
ANTILOPE is an hourly analysis of precipitation, merging radar and rain gauge data. It was initially developed for metropolitan France. Using radar images, precipitation is split into a stratiform part and a convective part. The hourly accumulation associated with these two parts is estimated using a spatialization method (kriging with external drift) making it possible to correct radar data with rain gauge data. The end result is the sum of the two estimates (convective and stratiform parts). This method has been adapted for Reunion Island (Indian Ocean), where it is now operationally produced. Evaluations are underway for Martinique and Guadeloupe (French West Indies) and New Caledonia (Pacific Ocean).
Furthermore, a spatial analysis of global solar radiation has been developed especially for overseas territories. The method consists in spatializing in situ measurements (inverse of distance), using a radiation draft. Ideally, this draft is produced from SSI satellite images. If those data are not available, the draft is evaluated from cloud classification and maximum radiation at the top of the atmosphere. Hourly and daily global solar radiation accumulations are produced on Reunion Island, Martinique and New Caledonia.
Adapting the spatial analysis of global solar radiation to metropolitan France is now considered.

6

Deployment and development (for meteorology) of a network of GPS stations in the Southwest Indian Ocean (SWIO) basin

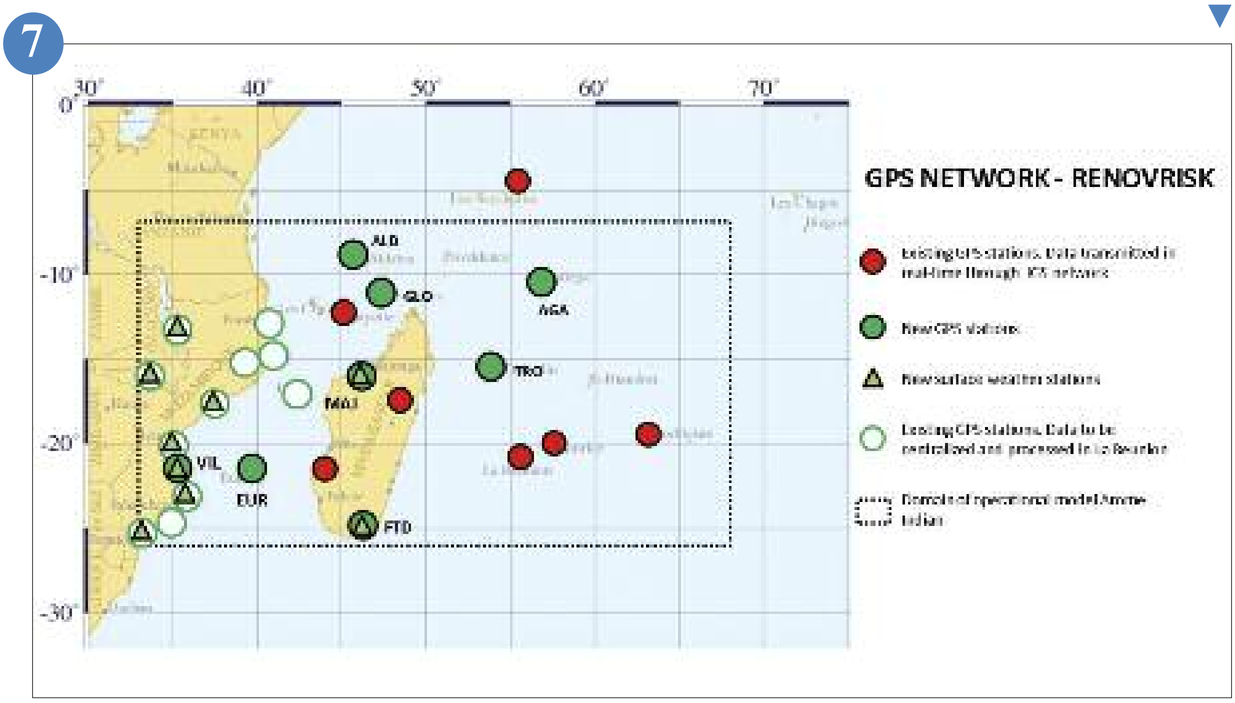
Tropical cyclones develop and evolve predominantly over the oceans, where conventional direct observations are usually very sparse. The Southwest Indian Ocean (SWIO) basin, in spite of its intense cyclonic activity – it is the second most active basin in the world after the western Pacific basin - is the least instrumented of the seven cyclonic basins of the planet.
In order to adapt to new needs in weather research, particularly in terms of numerical modeling and climate monitoring, Laboratoire de l'Atmosphère et des Cyclones (LACy) has launched an ambitious project aiming at increasing the number of experimental sites measuring atmospheric humidity in the SWIO basin. As part of this project, new ground-based GPS stations will be deployed in Madagascar, Seychelles, Mauritius, Mozambique and Eparses Islands of Glorieuses, Tromelin, Juan and Europa within the next two years. Observations collected by these new sensors, as well as by ~ 15 existing GPS stations currently used for research in geodynamics, will be concentrated at Observatoire de Physique de l'Atmosphère de La Réunion (OPAR) to be processed and distributed to main research and operational Regional weather centers.
These data, which may be ultimately assimilated into the new model Arome Indian Ocean, will allow to evaluate the realism of tropical cyclone model simulations and forecasts, to better understand atmospheric processes involved in cyclogenesis and rapid intensification, as well as to monitor climate change, via the analysis of the integrated water vapor content over the long term. This project, which is a perfect example of transdisciplinary collaboration, is part of the research program ReNovRisk (Innovative and Integrated Research on Natural Risks), funded by the French State, the Region of Reunion Island and the European Union.

7



(a) : ANTILOPE (Reunion Island, 25/10/2016 11 UTC).
(b) : Spatialization of global solar radiation (Reunion Island, 18/10/2016 10 UTC).

Overview of the GPS network operated in the frame of the ReNovRisk program. The red circles show GPS stations whose data (integrated water vapor content, zenithal delay) are processed and transmitted in real time; The white circles show existing stations whose data will be centralized in Reunion for processing and distribution from 2017 on; The green circles and triangles indicate the new GPS and weather stations to be installed in 2017 as part of the program. The domain of the Arome Indian model is also indicated.



Research and aeronautics

Within the framework of the R&D SESAR programme of the Single European Sky initiative, Météo-France actively contributed in 2016 to the last activities of the first programme part, providing some of the new services prototypes as well as skill and expertise, which allow successful demonstration exercises. Météo-France is now led up to contribute to the deployment of these new MET services, including the SWIM-compliant platform to access weather information at the European level. Further research on weather phenomena impacting aviation has been conducted through activities on high altitude ice crystals, condensation trails or convection. In 2016, several flight campaigns were also operated, for instance over Africa or the North Atlantic Ocean, involving research aircrafts from the EUFAR network. A success in aviation serving research in meteorology!

1

Planes in support to meteorological research

Technology Transfer within EUFAR - the unique network of airborne research for the environment in Europe

Technology transfer, a new and challenging activity, was adopted by EUFAR in its current contract funded under the EU's 7th framework programme (2014-2018). Led by EUFAR partner ONERA, this activity seeks to support the transfer of technology between experts in airborne measurements and industry by creating a framework and enabling environment for exchange and development of private-public partnerships with the aim of upgrading airborne research instruments, methods and software into innovative and useful products within the lifetime of the project and beyond.
Although not an EU requirement, EUFAR took on this activity following the EU's strong emphasis on investing more and better in research and innovation to enhance Europe's international competiveness and innovation capacity. Moreover, focusing on transforming research results into marketable products/services will have various socio-economic impacts, such as responding to major environmental and societal challenges from climate change and pollution to creating economic growth. This would also provide industry with new channels to access state-of-the-art technology and guarantee continued public funding for research. Furthermore, the EU has made it mandatory for projects, requesting funding under the H2020 programme and beyond, to have a strong element of technology transfer, regardless of scientific field.
Despite much anticipation at the start of the EUFAR contract, the activity took much longer than expected to take off and continues to face a number of setbacks particularly related to the novelty of the task and difficulty in motivating scientists to get on-board. To date, a guide has been developed showcasing strategies to introduce technologies in potential markets. One workshop has taken place involving EUFAR scientists to share best practices on knowledge transfer, IPR management, R&D contracts, etc. and facilitate subsequent interaction with industry. Furthermore, 12 innovative breakthroughs developed by scientific labs within the EUFAR community have been selected, which will be presented to industry representatives through a special workshop to begin the scientist/industry conversation with the hope of paying the way for a successful partnership or two before the end of the project.

2

DACCIWA: a better understanding of pollution impacts in West Africa

The DACCIWA project, funded by the European Union, focuses on relations between meteorology, climate and air pollution in West Africa, from Ivory Coast to Nigeria. For the first time scientists are able to fully study the impacts of natural and anthropogenic emissions (emitted by human activities) on the atmosphere of this region and to assess their impact on human and ecosystem health, through a field campaign in June and July 2016.
The ATR 42 operated by the French airborne environment research service named SAFIRE (CNRS / Météo-France / CNES) is one of three research aircraft that have worked in a coordinated way over the countries of the Gulf of Guinea, in addition to many ground equipment. Based in Lomé, Togo, it carried more than two tons of in situ measuring instruments (including 3 different mass spectrometers) and remote sensing. The ATR 42 performed more than 80 hours of scientific flights and thanks to the expertise of the laboratories of LaMP / OPGC, CNRM, LISA, LATMOS and LSCE (all three from IPSL), numerous data sets were gathered.
This airborne campaign documented the chemical composition of the atmosphere upstream and downstream of pollution sources and its impact on cloud properties. It also provided information on regional sources of pollution such as biomass fires or desert dusts. Scientist will now analyze these data in order to propose an instructive scheme of the interaction between atmospheric chemistry, aerosols, low cloud formation and dissipation, energy budget and precipitation in order to improve weather, climate and air quality models.

3

Meteorological research and aeronautics.

1

2

Exhibition of the ALIDS probe awarded a prize during the Normandy AeroEspace Tech Day, Rouen, France, 24 November 2015. ALIDS is one of 12 technologies selected to be presented to industry under EUFAR's technology transfer activity.
From left to right - Pascal Lemaître (IRSN), ALIDS lead scientist Emmanuel Porcheron (IRSN), EUFAR project coordinator Élisabeth Gérard (Météo-France) and Marc Brunel (CORIA).

3

(a) : The airborne laboratory ATR 42 before a flight, Lomé, Togo.
Copyright: Arnaud MANSAT / CNRS ULISSE

(b) : Checking of ATR 42 airborne instruments during the warmup before a flight.
Copyright: Arnaud MANSAT / CNRS ULISSE

EPATAN-NEAREX: a Franco-Norwegian contribution to the NAWDEX campaign in Iceland

The NAWDEX experiment (North Atlantic Waveguide Downstream and impact Experiment) took place from mid-September to mid-October 2016. It is the most important international campaign dedicated to the study of atmospheric perturbations in the North Atlantic that has been organized since nearly 20 years, with the FASTEX campaign in 1997. NAWDEX studies the small scale thermosdynamical processes inside these perturbations, particularly inside the "warm-air conveyor belts" which are not necessarily well described in the models, leading to uncertainties in the short- and medium-range weather forecasts.
The French airborne component has participated from 28th September to 17th October 2016, when the Safire Falcon 20, based in Iceland at Keflavik Airport, performed 14 flights for the benefit of French (LATMOS, LA, LaMP, LMD et Météo-France) and Norwegian (Norwegian met, Univ. Bergen, Univ. Oslo) scientific teams. DLR from Germany was engaging 2 aircraft, one Falcon 20 and one Gulfstream 5 "HALO" in the NAWDEX campaign. The British BAE146 from FAAM also participated to a coordinated flight with French and German aircraft, preparing forthcoming space missions (on MetOp – Eumetsat). Measurements made during flights of the SAFIRE F20 were aiming to deal with the goals of two projects. On one side, EPATAN, funded by ESA and CNES, is preparing the "Earthcare" space mission (clouds and aerosol radiative forcing), and ADM-Aeolus (atmospheric dynamics), notably by providing a unique dataset of active teledetection measurements with the instruments RASTA (radar 95 GHz) and LNG (LIDAR 355 nm). On the other side, the project NEAREX that was selected by EUFAR and led by a Norwegian team, aims at a better understanding of air masses called "atmospheric rivers", which transport heat and moisture from subtropical areas to higher latitudes and may cause intense precipitations over lands. Releasing of dropsondes completed the dataset by in-situ measurements, which were directly sent to the global telecommunication system (GTS).
As a synergy with the NAWDEX campaign, a wide set of clouds and mid-latitude typical situations have been sampled. Comparisons can also be made with measurements of similar instruments on-board other participating aircraft.
Thanks to the excellent reliability of aircraft and instruments, as well as involvement of people, the French team could perform the whole program of flights, even during severe conditions.

4

Airborne adaptation of a humidity measuring instrument

The sensor used to measure a fast humidity measurement (Lyman α) can no longer be maintained. The challenge is to replace it with a newer sensor with the least possible certification in the shortest time to participate in the DACCIWA campaign during the summer of 2016.
In order to minimize the certification phase, in particular avoiding test flights, we chose to keep the Lyman α envelope and replace the internal detection electronics with electronics from a sensor sold by Campbell: the KH20.
Both instruments are based on measuring the absorption of a specific ultraviolet line. These two wavelengths are absorbed in a similar way by water vapor, which implies that the optical paths will be of the same order of magnitude.
The operation consists of a mechanical adaptation of the transmitter / receiver of the KH20 with parts designed at SAFIRE in the Lyman envelope. At the same time, the certification phase is being conducted. This is reduced but necessary due to the installation of a new instrument.
Then, numerous tests are carried out, both on the ground and in flight to ensure the quality of the measurements and the absence of disturbance induced by this new instrument. The tests show that the measurement contains information up to 10Hz. Currently, it is necessary to fix the optical path before each flight in order to avoid saturation of the signal. At DACCIWA the instrument flew over 100 hours with satisfaction.
In the future it is planned to install a stepper motor controlled from the cabin in order to vary the distance of the optical path in order to adapt to all the situations encountered in flight by widening the measuring range of the instrument.

5

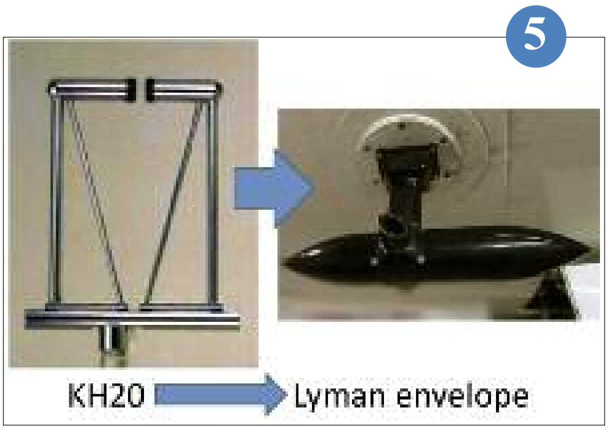
Meteorological research in support to aviation

Météo-France contributions to SESAR

Year 2016 is the closure of the first part of the SESAR program. Solution prototypes that were developed and verified within the project dedicated to meteorology, i.e. project WP11.2 were also involved in some validation exercises run by some of the ATM projects, and in large scale demonstration exercises such as TOPLINK or the SWIM Global Demo, with good success. Météo-France SESAR teams were deeply involved in these exercises in collaboration with our historical partners in WP11.2, especially Thalès, the FMI, the DWD and the UK Met Office.
Météo-France SESAR teams contributed to the EUMETNET workshop in May 2016 which aim was to inform all EIG members on activities performed during the WP11.2 project of SESAR. At last, the Closure Event in June 2016 was another good opportunity to demonstrate the MET solutions developed in WP11.2, grouped under the concept for 4DWxCube, and to assess their maturity level. As a consequence, the WP11.2 team was pleased to note that the SESAR JU included in the technical communication media, named the SESAR Solutions Catalogue (http://www.sesarju.eu/solutions), the MET solution called "MET Information Exchange" under number #35. This solution is now in the pipeline for delivery. MET information exchange will be deployed as part of initial SWIM, in accordance with the Pilot Common Project.
The three proposals for deployment submitted by EUMETNET partners within the framework of the EU resolution called Pilot Common Project (PCP) and the INEA CEF 2015 call for deployment, and finalised early 2016 have been successfully selected and awarded for cofounding (50%). These projects started in October 2016 with a first phase for the detailing of the work plan in each project. The final objective is to deploy three services: the European Weather Radar Composite of 2D/3D Convection Information Service; 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 SWIM-compliant European MET Information Exchange service (portal) named MET-GATE on which users expectations are strong and which is led by Météo-France.

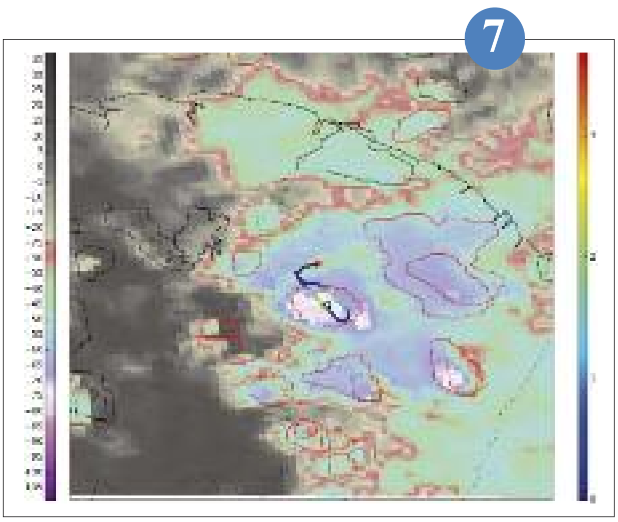
6

On the tarmac of Keflavik airport, the Safire-Falcon20 (foreground) near the DLR-Gulfstream HALO (middle) and – Falcon 20 (background).



KH20 metamorphosis.

(a) : Cover of the SESAR Solutions Catalogue.
(b) : Solution 'MET Information Exchange' in the SESAR Solutions Catalogue.



Satellite image of 25/May/2015 above Cayenne in infrared 10.8μm channel (temperature scale in °C on the left) with cloudy cells (in red the convective ones) and IWC flight (scale on the right, in g/m³).

The use of RDT in the HAIC project

The European FP7 HAIC 2012-2017 project aims at characterizing specific environmental conditions in the vicinity of convective clouds that can lead to aeronautical events linked to high-altitude mixed phase and glaciated icing.

RDT is software developed by Météo-France in the framework of NWCSAF. RDT detects, tracks and characterizes convective systems.

In the framework of the HAIC project, the RDT has been operated by Météo-France and provided over the different field's campaign on an operational basis through dedicated processing chains. The RDT was operated for various satellites and domains: MTSAT for the first HAIC campaign (Darwin, 2014), MSG for the second one (Cayenne, 2015) and Himawari-8 and Meteosat 7 for the last one (Darwin/La Réunion, 2016).

First objective was to target the convective areas for the research planes. Thus RDT was used by forecasters of each campaign for the ground meteorological support. RDT outputs were also adapted to be up-linked to the research planes thanks to the Planet system developed by Atmosphere Company (2015 and 2016 campaigns). This development allowed to enhance for the pilots the vision of surrounding convective areas.

Second objective was to study with the field campaigns data how far RDT can be used to detect high IWC areas. Qualitative and quantitative studies provided reasonably good results, especially in terms of probability of detection. In the figure one can see high IWC value inside a convective cell. RDT reached the level 5 of TRL procedure used in the HAIC project to assess the degree of maturity of a technology.

Considering the good performances of RDT, the last NWCSAF release of the product (v2016) includes an attribute describing IWC risk inside each cell.

Acknowledgement:
This project has received funding from the European Union's FP7 in research, technological development and demonstration under grant agreement n°ACP2-GA-2012-314314.

TOPLINK (SESAR): opening the way to new collaborative system of information sharing for aviation

Among the European demonstration projects of the SESAR 1 programme (2009-2016), in which Météo-France actively participated and contributed, the TOPLINK project was a reference and allowed to test and validate a new collaborative system of information sharing, especially meteorological information, dedicated to Air Navigation Services Providers, airports, airlines and general aviation.
After 75 days of operations, during the summer 2016, with Paris Charles de Gaulle airport and French, Croatian and Austrian air traffic control, 81 days of operation with the airline partners (Brussels Airlines, Air France, Hop! and Air Corsica), 84 test flights with pilots and 15,000 flights managed by the ground staff of these same airlines, the contribution and benefits of this new system have been assessed and validated on a large scale.
The TOPLINK project was able to demonstrate that the use of a such system could significantly improve operational performance and support the stakeholders 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.
The TOPLINK project was the right place for the validation of new MET services taking into account the aviation users' perspective. All MET services used during this demonstration exercise have been developed in accordance with SWIM concepts and are now available on the MET-GATE portal, led by Météo-France and EUMETNET members.

TOPLINK partners: Thales, Airbus, Météo-France, 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
https://www.youtube.com/watch?v=e79iIBP0W5Y

8

SESAR SWIM GLOBAL DEMO 2016: a global demonstration of the TOPLINK system and MET-GATE prototype, led by Météo-France

The SESAR SWIM GLOBAL DEMONSTRATION, which took place in 2016 in Rome (8 and 9 June), is an event bringing together more than a hundred ATM stakeholders and about forty world organizations, with the goal to showcase the global interoperability capabilities of system-wide information management (SWIM) and in relation to the ICAO GANP/ASBU's and the European ATM Master Plan.
System-wide information management (SWIM) is about sharing the right aeronautical and meteorological information with the right ATM stakeholders at the right time. This innovative concept represents a seismic shift in how information management is done in ATM. This change is critical to efficiently handle the expected increase in global air traffic in the coming years.
As part of this event, the TOPLINK system and the Eumetnet 4DWeatherCube MET-GATE* prototype, led by Météo-France, have been extended from Europe to the United States, Brazil, Africa, Europe, the Middle East and Australia and carried out full-scale exercises on simulated flights in order to demonstrate their ability to function on a global scale. The resulting added-value is demonstrated for different user profiles such as Airlines (Brussels Airlines, TAP Portugal and Qantas), ANSPs (Vienna ACC), or Airports (Paris CDG).

(*) Developed within the framework of SESAR, the prototype 4DWeatherCube MET-GATE of Eumetnet, led by Météo France, with the support of MET Office, the DWD (Deutscher Wetterdienst) and THALES, is a portal of single access to Meteorological information for aviation.

For more information:
http://www.sesarju.eu/newsroom/events/sesar-swim-global-demonstration

10

What progress in forecasting contrails?

Condensation trail (contrail) forecasting is of major interest for defense applications, particulary for stealth military aircrafts. Forecasts currently used in France have not changed over the last fifteen years. On request of the DGA, looking for a short-term improvement of these forecasts, Météo-France and CERFACS performed a state of the art review, in France and abroad, in both civil and defense fields. Analysis among the existing solutions was then conducted to determine which could benefit defense applications.
Most current operational solutions are still based on the 1953 Schmidt Appleman criterion, which was upgraded in 1996. An improvement would be to add the possibility of parametrize the aircraft characteristics (e.g. contrails factor): this work resulted in the specification of a more complete algorithm.
Furthermore, the scientific community is working on more complex models which won't become operational before several years.
Recommendations for further studies and implementation of measurement campaigns were given to DGA that might consider requesting and funding them.
Finally, as the contrails contribute to the greenhouse effect, their forecast could become capital for air traffic in a few years.

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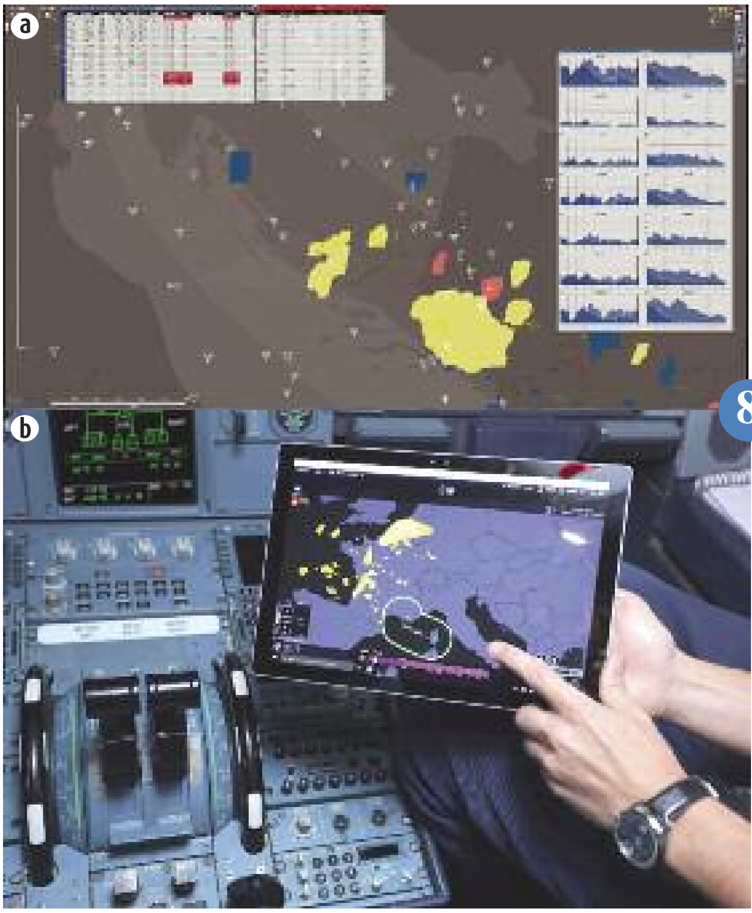

(a) : Meteorological information (convection) displayed on a touchpad by pilots during the flight (Copyright SESAR-TOPLINK-2016).
(b) : Meteorological information displayed on the ANSPs FMP position (Copyright SESAR-TOPLINK-2016).

9

Contrails.

10

The MET-GATE prototype has been tested in global scale trials during the SESAR SWIM GLOBAL DEMO in Rome from 8 to 9 June 2016.
Participation of Météo-France, MET Office et DWD.

Appendix

2016 Scientific papers list

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

Artinyan, E., Vincendon B., Kroumova K, Nedkov N, Tsarev P., Balabanova S., Koshinchanov G,: Flood forecasting and alert system for Arda River basin. Journal of Hydrology, Volume: 541, Special Issue: SI, Pages: 457-470, Part: A, Doi 10.1016/j.jhydrol. 2016.02.059. Published: OCT 2016.

Arbogast P., O. Pannekoucke, L. Raynaud, R. Lalanne and E. Mémin: Object-oriented processing of CRM precipitation forecasts by stochastic filtering. Quarterly Journal of the Royal Meteorological Society, Volume: 142, Issue: 700, Pages: 2827-2838, Part: PT A, Published: OCT 2016.

Augros, C., O. Caumont, V. Ducrocq, N. Gaussiat, P. Tabary, 2016: Comparisons between S, C, and X band polarimetric radar observations and convective-scale simulations of HyMeX first special observing period, Quaterly journal of the Royal Meteorological Society, Volume: 142, Special Issue: SI, Supplement: 1, Pages: 347-362, Doi: 10.1002/qj.2572. Published: AUG 2016.

Avanzi, F., C. De Michele, S. Morin, C. M. Carmagnola, A. Ghezzi and Y. Lejeune, 2016: Model complexity and data requirements in snow hydrology: seeking a balance in practical applications. Hydrological Processes, Doi: 10.1002/hyp.10782, Published: FEB 2016.

Azaïs J.-M., and A. Ribes, 2015: Multivariate spline analysis for multiplicative models: Estimation, testing and application to climate change. Journal of Multivariate Analysis, Volume: 144, Pages: 38-53, Doi: 10.1016/j.jmva.2015.09.026. Published: FEB 2016.

Batté, L. And M. Déqué, 2016: Randomly correcting model errors in the ARPEGE-Climate v6.1 component of CNRM-CM: applications for seasonal forecasts. Geoscientific Model Development, Volume: 9, Issue: 6, Pages: 2055-2076, Doi: 10.5194/gmd-9-2055-2016. Published: 2016.

Bazin, L., A. Landais, V. Masson-Delmotte, C. Ritz, G. Picard, E. Capron, J. Jouzel, M. Dumont, M. Leuenberger and F. Prié, 2016: Phase relationships between orbital forcing and the composition of air trapped in Antarctic ice cores. Climate of the Past, Volume: 12, Pages: 729-748, Doi: 10.5194/cp-12-729-2016, Published: MAR 2016.

Beck, J., F. Bouttier, L. Wiegand, C. Gebhardt, C. Eagle, N. Roberts: Development and verification of two convection-allowiing multi-model ensembles over Western Europe. Quaterly Journal of the Royal Meteorological Society, Volume: 142, Issue: 700, Pages: 2808-2826, Part: PT A, Doi: 10.1002/qj.2870. Published: OCT 2016.

Bergot T., 2016: Large-eddy simulation of the dissipation of radiation fog. Quarterly journal of the royal meteorological society, Volume: 142, Issue: 695, Pages: 1029-1040, Part: B, Doi: 10.1002/qj.2706 Published: JAN 2016.

Berthou, S., Mailler, S., Drobinski, P., Arsouze, T., Bastin, S., Béranger, K., Flaounas, E., Lebeaupin Brossier, C., Somot, S. and Stéfanon, M. (2016), Influence of submonthly air–sea coupling on heavy precipitation events in the Western Mediterranean basin. Quaterly Journal of the Royal Meteorological Society, Volume: 142, Special Issue: SI, Supplement: 1, Pages: 453-471, Doi: 10.1002/ qj.2717. Published: AUG 2016.

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Glossary

Organisms and Laboratories

Organisms

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
EU European Union
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
MEEM Ministère de l'Environnement, de l'Energie et de la Mer
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
NIWA National Institute for Water and the Atmosphere (New-Zeland)
NOAA National Ocean and Atmosphere Administration
OACI Organisation de l'Aviation Civile Internationale
OMM Organisation Météorologique Mondiale
OMP Observatoire Midi-Pyrénées
ONERA French Aerospace Lab
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
WMO World Meteorological Organization

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
GeoMIP Geoengineering Model Intercomparison Project
GHRSST International Group for High Resolution SST
GLOSCAL GLobal Ocean Surface salinity CALibration and validation
H2020 Framework Programme for Research and Innovation (2014-2020)
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
PLUVAR Variabilité sub-saisonnière des pluies sur les iles du Pacifique Sud
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
ALIDS Airborne Laser Interferometric Drop Sizer
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
CTRIP CNRM-Total Routing Integrated Pathway
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
ECUME Exchange Coefficients from Unified Multi-campaings Estimates
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
FSOi Forecast Sensitivity to Observations-based impact
GABLS4 Gewex Atmospheric Boundary Layer Study
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 Modelling and Assimilation for Forecasting Group
GMEI Experimental and Instrumental Meteorology Group

GMES	Global Monitoring for Environment and Security
GMME	Meso-Scale Modelling Group
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
IOP	Intensive Observation Period
IPR	Intellectual Property Rights
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
IWC	Ice Water Content
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
NWCSAF	Satellite Application Facility for Nowcasting
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
PEARO	Prévision d'Ensemble AROME
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)
RDT	Rapidly Developing Thunderstorm
RHI	Range Height Indicator (coupe verticale)
ROC	Relative Operating Characteristic curve
RTTOV	Radiative Transfer for TOVS
SAFNWP	Satellite Application Facility for Numerical Weather Prediction
SAF OSI	Satellite Application Facility for Ocean and Sea Ice
SAFRAN	Système d'Analyse Fournissant des Renseignements Atmosphériques pour la Neige - Set of reconstructed data from observations over France for 1958 to present at high horizontal, vertical and temporal resolution
SAPHIR	Sondeur Atmosphérique du Profil d'Humidité Intertropicale par Radiométrie
SARA	Spectroscopy by Amplified Resonant Absorption
SATOB	Satellite Observation
SCM	Single-Column Model
SESAR	Single European Sky ATM Research
SEVIRI	Spinning Enhanced Visible and Infra-Red Imager
SFRI	Système Français de Recherche et d'Innovation
S2M	SAFRAN - SURFEX/ISBA-Crocus – MEPRA
SIM	SAFRAN ISBA MODCOU
SIRTA	Site Instrumental de Recherche par Télédétection Atmosphérique
SMOSMANIA	Soil Moisture Observing System – Meteorological Automatic Network Integrated Application
SMT	Système Mondial de Télécommunications
SOERE/GLACIOCLIM	Système d'Observation et d'Expérimentation sur le long terme pour la Recherche en Environnement : "Les GLACIers, un Observatoire du CLIMat".
SOP	Special Observing Period
SPC	Service de Prévision des Crues (Flooding Forecasting Service)
SPIRIT	SPectromètre Infra-Rouge In situ Toute altitude
SPPT	Stochastically Perturbed Parametrization Tendencies
SSI	Solar Surface Irradiance
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
TRL	Technology Readiness Level
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
VOS	Voluntary Observing Ships
WWLLN	World Wide Lightning Location Network

CNRM : Management structure

31.12.2016

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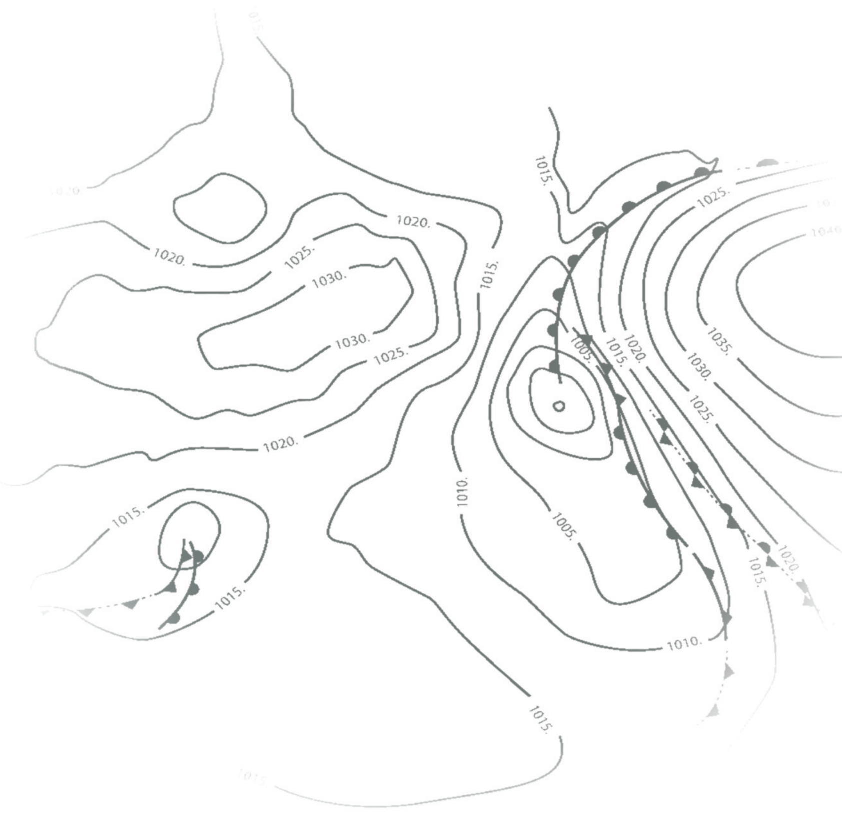

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