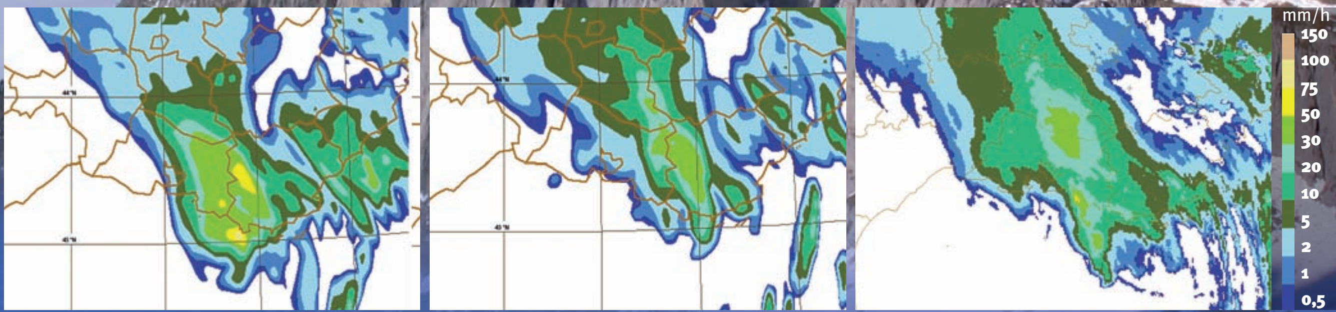

Operational Arome

New Arome version in test

Radar observation

Research Report

2009

METEO FRANCE
Toujours un temps d'avance

Research Report 2009

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When I became Director of Research in the spring of 2009, I found a Centre National de Recherches Météorologiques quite different from the one I had left six years before. The Research environment in France is evolving fast: Universities are the new places of power, the “Agence Nationale pour la Recherche” has been introduced as the main funding mechanism and, generally speaking, support can be obtained from multiple sources for research on adaptation to Climate Change. There are also urgent requirements from the aeronautical and Defence sectors, and these requirements drive the research agenda to some extent. As far as laboratories are concerned, we now have three joint units with CNRS (CNRM-GAME, SAFIRE, and LACy). The first one has reached a respectable size and now includes a “Laboratory Committee”. A description of the research process has also been introduced into the Météo-France quality management system.

Clearly, our modern society demands much of meteorological research. It also offers new opportunities, but these tend to come randomly. We need strict working methods in order to keep essential strategic directions in our world of contracts and deliverables. I would like to take the opportunity to thank my predecessors, Daniel Cariolle and Eric Brun, for having developed a robust governing structure that allows Météo-France research to be steered safely.

The results of 2009 are a clear testimony to the excellence of their work: in Numerical Weather Prediction, new configurations have been developed for our forecasting systems ARPEGE, ALADIN and AROME, which will ensure both optimal use of the new computing resources and clear progress in forecast quality. The use of satellite data is advancing fast. The cooperation of Météo-France with CNES, EUMETSAT and ESA has never been so intense. We are engaged in Earth Observation projects such as IASI, SMOS, AEOLUS, CoreH2O, PREMIER, POGEQA, and several Satellite Application Facilities. In the field of Climate, a new version of our Earth-System model has been prepared to guarantee our contributions to the upcoming 5th IPCC report. Consultations with IPSL have started to share a larger part of the Earth System modelling infrastructure. Research has largely contributed to the growing offer of Météo-France regarding adaptation to Climate Change. We are engaged in many projects with users in the fields of hydrology, town planning, and agriculture. The exploitation of the observations collected during the international AMMA programme is currently delivering many publications, and an international conference held in Ouagadougou last July attracted 500 scientists representing many nations and disciplines. Finally the preparation of the HYMEX programme on the water budget and intense rainfall over the Mediterranean area and its integration in the larger work on the habitability of the Mediterranean Basin has made regular progress.

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Philippe Bougeault, Director of Research at Meteo-France, speaking live from Toulouse Meteopole for France 3 TV during the Researchers' night 2009, on September 25th.

Weather forecasting models

The research on numerical weather prediction aims to produce better weather forecasts and also new tools, thanks to numerical atmospheric modelling systems, with configurations that can be adapted to several applications: global scale ARPEGE, ALADIN and AROME for local/regional fine predictions, and an ENSEMBLE prediction system of assimilation and prediction for probabilistic forecasts.

In 2009, the physics parametrization of the global model ARPEGE was updated with the introduction of a prognostic turbulence scheme, a new representation of shallow convection and the introduction of ocean/atmosphere interactions, which greatly improved the modelling of the lower layers. Some progress has been made regarding the use of satellite radiances by a better assimilation of Metop/IASI and Aqua/AIRS data through research on cloudy radiances. All this work has largely helped to improve the ARPEGE forecasts, as verified by forecast scores and by studies of the 24th January 2009 storm. It was also of some benefit to ALADIN and AROME, which, moreover, have been given a new local surface assimilation scheme (surface soil and sea level temperature).

The next step was to adapt software to the new, more powerful NEC SX9 supercomputer. This led to an increased resolution of numerical systems as well as new scientific improvements such as the assimilation of radar reflectivity in AROME using an original technique of Bayesian inversion of precipitation observations, which makes Météo-France one of the leading centres in the world for radar assimilation. Some improvements have been achieved concerning wind gust products, which are essential during storms, and satellite image simulations. These new versions of ARPEGE, ALADIN and AROME will be operational in early 2010.

At the same time, the ensemble prediction system is making headway so as to give the best short range probabilistic information possible over mainland France.

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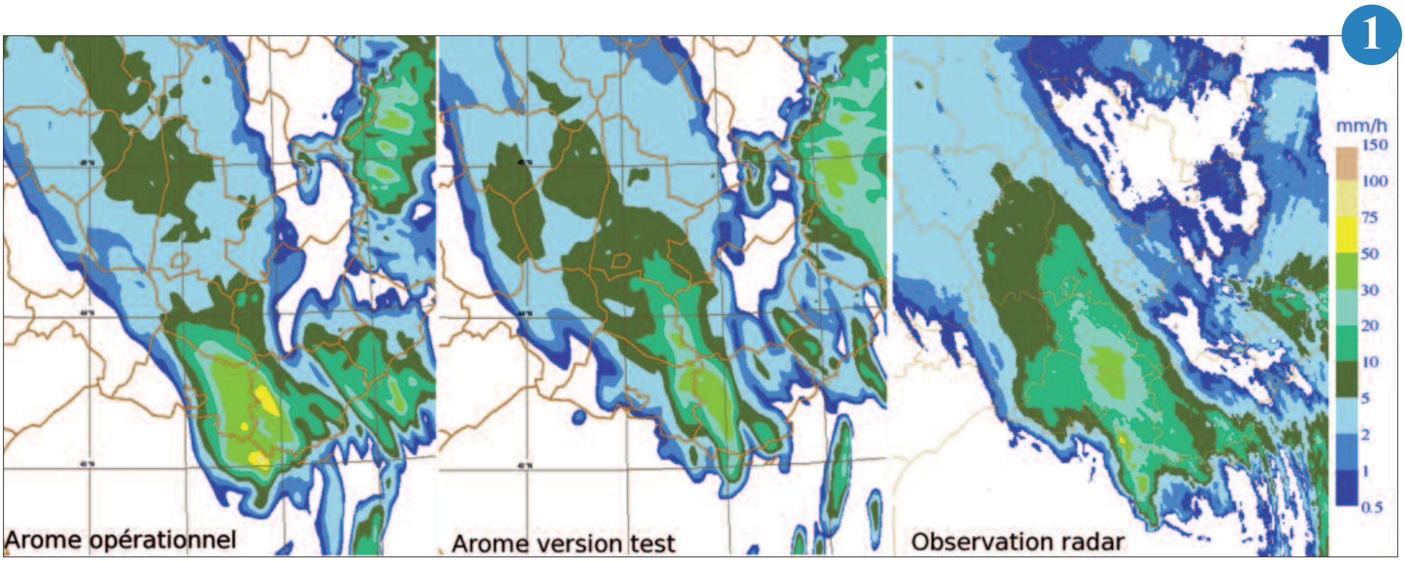

▲ AROME local adaptation of the preoperational ARPEGE predicted situation of 16th September 2009 at 6:00UTC for a 30h forecast, total 1-hour surface precipitation (mm) and instant cloudiness (grey shades for low, medium and high cover).

Upstream numerical prediction research focuses on several scientific topics such as: (1) data assimilation techniques with an emphasis on the modelling of error structures, (2) studies of storms and heavy precipitation events in relation with large scale atmospheric dynamics, (3) greater use of satellite data in cloudy and/or rainy conditions over land, and (4) increased efficiency of high resolution models. These fields of research are advancing in collaboration with the French and international scientific community and are part of worldwide research projects involving many labs and agencies, such as Hymex, AMMA, Concordiasi, Thorpex-Tnawdex, SESAR, and the Seventh Framework Programme, and are in line with the requirements of the Ministry of Defence.

This research work is complemented by cooperation within Europe, with the ECMWF, ALADIN and HIRLAM communities, and allows the concerted development of numerical prediction on a shared basis.

Synoptic numerical weather prediction

New pre-operational versions of the ARPEGE and AROME models

The extension of the supercomputer (NEC/SX9) has permitted a major evolution of the ARPEGE and AROME models used for operational weather forecasting at Météo-France. The initialization of the global model, ARPEGE, which is based on the 4D-VAR assimilation, significantly improved with the increase in the resolution of the analysis increments (60 km instead of 90 km) and in the horizontal density of the assimilated satellite observations, and with the assimilation of new IASI (water vapour and surface) and AMSU-B (low troposphere humidity over land) channels. The characterization of the background and observation error statistics benefits from evolutions in the ensemble assimilation, in particular the use of the 4D-Var algorithm. The spatial resolution of the ARPEGE model has been increased with the use of 70 vertical levels and a horizontal mesh varying from 10 km over France to 60 km at the antipodes. This configuration allows direct coupling with the meso-scale model AROME and simplifies the operational suite and its use by the forecasters.
The radar reflectivities of the French ARAMIS network are assimilated in the AROME 3D-Var analysis. This has been made possible thanks to many development and research activities on the pre-processing and the assimilation of these observations. The vertical resolution of the AROME model has been increased, in particular in the planetary boundary layer, with nearly twice the previous number of vertical levels. The new AROME release is built with 27 levels in the first 3 000 metres. The representation of physical processes is improved for the calculation of the convective updraft in the shallow convection scheme and by taking into account the sedimentation of cloud droplets, which are important for simulating fog.

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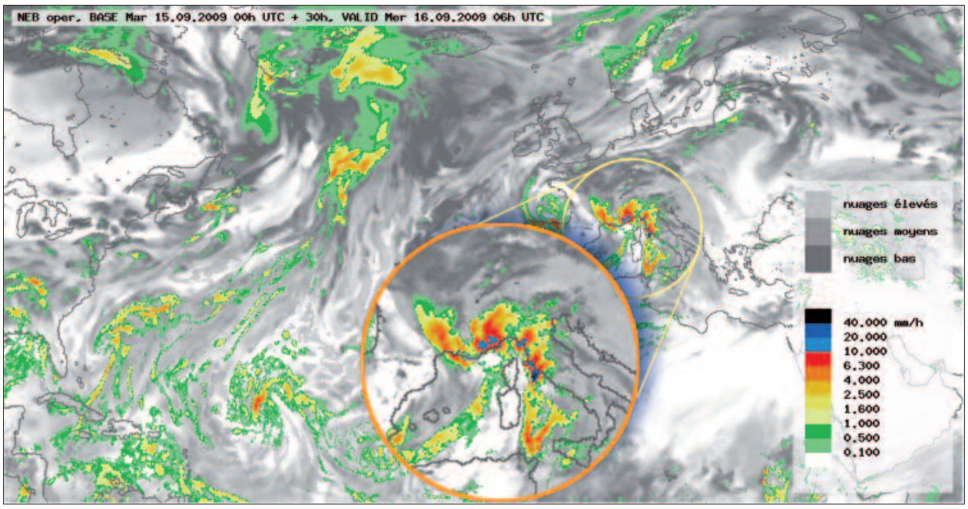

2 Surface precipitation cumulated over 1 hour (in mm) and low, medium and high instantaneous cloudiness (grey colours) for a 30h forecast valid on 16th September 2009 at 6 UTC made with the pre-operational version of the ARPEGE model.

Towards operational use of the Aladin model for overseas areas

Météo-France is planning to implement regional NWP systems for its overseas dominions. The target configuration is an Aladin 3DVAR assimilation, very similar to the one used for Réunion Island. Thus, New Caledonia, Polynesia, and the West Indies and French Guyana will be able to take advantage of Aladin outputs with 8 km resolution and 70 vertical levels for the short-term forecasts over their areas.
In 2009, tests were performed with a dynamic adaptation from "70-level Arpège". They allowed the model domains for the Pacific to be carefully selected. They validated the use of the surface scheme SURFEX and demonstrated the improvements for the tropics due to the new physical parameterizations, which have been operational in our models since February 2009. The figure shows a forecast of heavy rain over the New Caledonia area.
Given the performance of global models in the tropics, IFS, with its resolution of around 16 km since the beginning of 2010, has been chosen as the coupling system. The use of IFS will require asynchronous coupling because of production time constraints. The coupling of the surface will be still done with Arpège.
The implementation of data assimilation in the overseas Aladin configurations will require the installation of a simplified procedure in order to define customised configurations. For each area, the background covariance error matrix will have to be calculated. The aim is to automate this calculation, which is necessary for the 3DVAR assimilation.
Evaluation of Aladin overseas models coupled with IFS and including assimilation should begin during spring 2010 and the operational implementation is planned for early 2011.

3

Estimating forecast uncertainties: PEARP, the Météo-France state of the art ensemble forecast

PEARP (for Prévision d'Ensemble ARPEGE) is Météo-France's global and mesoscale ensemble prediction system for Europe. This ensemble is especially tuned for short range predictions.
In 2009, significant changes were implemented and tested within PEARP. They aimed to better quantify the sources of uncertainty inherent in any weather forecast. PEARP will be coupled with the Météo-France ensemble assimilation system in order to better estimate the initial uncertainty. Moreover, using several different physical packages will allow a kind of model error to be represented. Finally, a significant increase in the size of the ensemble (from 11 to 35 members) should improve forecasting of relatively infrequent events. A first evaluation shows that these modifications have a positive impact in terms of all the probabilistic scores computed so far.
This new version of PEARP was brought into operation in December 2009 and will be tested by French forecasters during the following winter. Other evolutions, such as an increase in the horizontal resolution from 15 to 10 km over France, are expected in 2010. PEARP and EPS from ECMWF are the main sources of information about the uncertainties of short- and medium-range weather forecasts, whose more extensive use is the main objective of the PREVIPROB project.

4

Toward an operational probabilistic forecast suite

The PREVIPROB project was initiated in early 2009 for a period of three years. It aims to install a suite of probabilistic forecasts from the short to the medium range. In order to achieve this objective, tools will be developed for ensemble prediction systems.
Firstly, coupling applications (hydrological model, surges model, marine or environmental pollution tracking, etc.) will be implemented on ensemble prediction systems, including PEARP, developed and maintained by CNRM. It will then be possible to produce probabilistic forecasts for the detection and monitoring of specific risks (floods, forest fires, pollution) by modelling the uncertainties associated with these forecasts.
Secondly, post-processing will provide optimal forecast probability density functions for both ensemble prediction systems and single models. This post-processing is based on statistical techniques using probability laws tailored to each parameter (normal distribution for temperature, gamma distribution for rainfall, Weibull distribution for wind speed).
Finally, studies oriented towards aid in decision-making will use probabilistic forecasts to analyze the needs of the end-user by cost and loss models.
The project involves the development of visualization products, a methodology for using probabilistic forecasts, checks and training and will finally lead to the implementation of a probabilistic forecasts suite.

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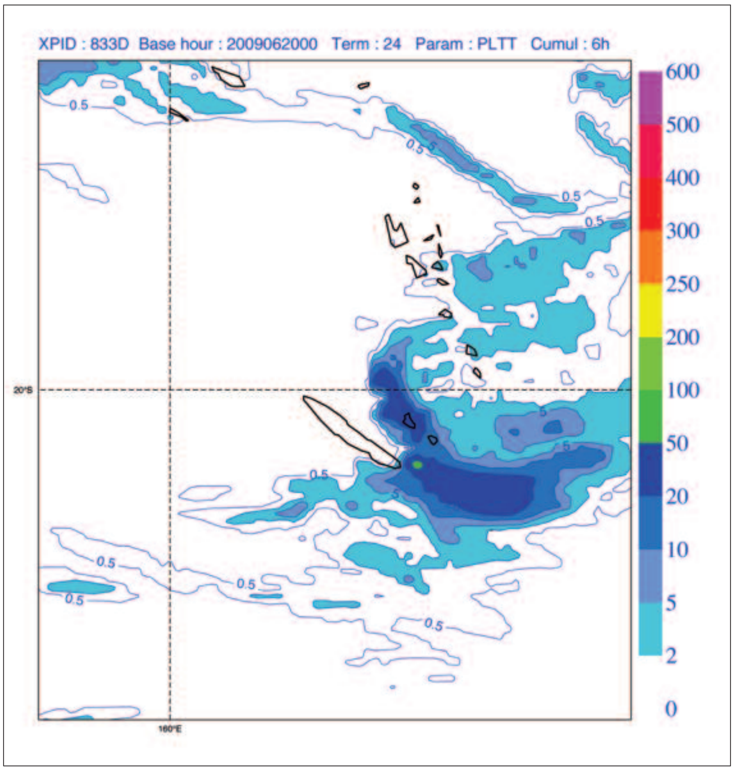
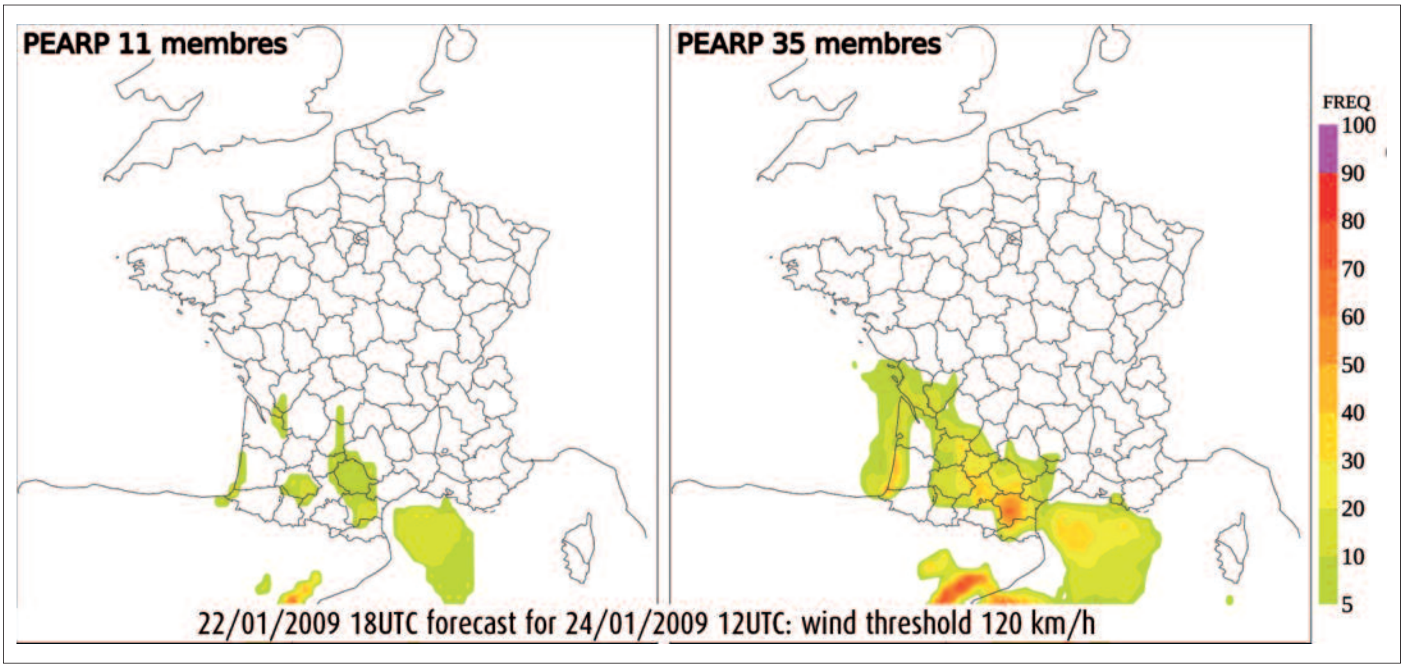


6 hours of cumulated precipitation of an Aladin 24-hour forecast on June 21st 2009 over the New-Caledonia domain.



Case of January 24th, 2009. We are focusing on strong wind gusts for the beginning of the afternoon. The left panel presents probabilities of gusts exceeding the 120 km/h threshold in operational PEARP. The right panel presents the same parameter for the new version of PEARP that is described in the main text. The new version provides a better prediction of the event with higher frequencies that are better located.

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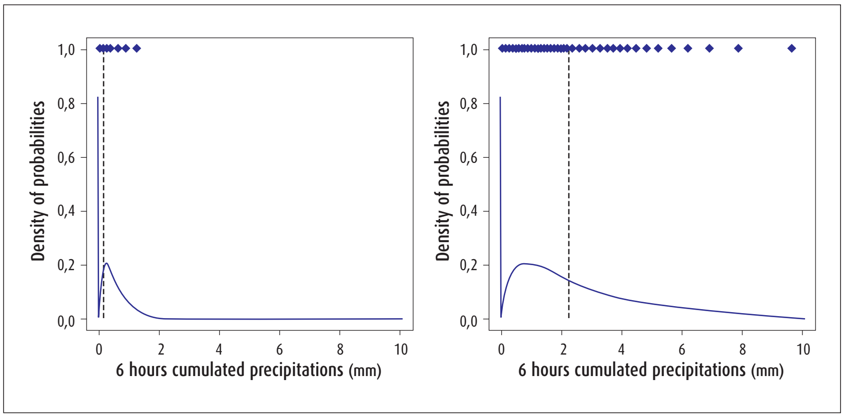

Discrete and continuous probability density function for forecast precipitation. Forecast on 09/02/2006 at 12:00 for Bordeaux, step 48h (non-precipitation case) on the left. Forecast on 01/03/2006 at 12:00 for Bordeaux, step 48h (precipitation case) on the right.

Data assimilation

Implementation of an ensemble 4D-Var assimilation

Data assimilation is based on a statistical characterization of forecast errors. The expected amplitudes of these errors (described by variances), which depend on the weather situation, need to be specified.
In this context, an ensemble using six perturbed assimilations is running operationally. The spread of such an ensemble allows the space and time dynamics of forecast errors to be estimated. Moreover, a 4D version of this ensemble assimilation is being tested and should simulate errors of the 4D-Var system better.
This is illustrated by figures a and b, which correspond to a severe storm case over France on 24th January 2009. The geographical distribution of variances is more realistic in the 4D version (figure a) than in the 3D version (figure b), with a maximum that is more pronounced and better located over France, in accordance with the strong uncertainty associated with this kind of intense weather system.
The superiority of the ensemble 4D assimilation has been confirmed by comparisons with departures between forecasts and observations, and by studies of the impact of variances provided by the ensemble on the forecast quality. The associated increase in computation cost is moderate, and compatible with the ongoing computation power increase.
It is planned to extend the use of departures between forecasts and observations to estimate the contributions of model errors (to be distinguished from errors induced by initial conditions). This will enable this error component, which is poorly known at present, to be estimated objectively.

6

Assimilation of radar reflectivities in the AROME model

Through studies of precipitating systems, the assimilation of the volume radar reflectivities from the national ARAMIS network into the AROME model has given a better description of qualitative and quantitative precipitation short-term forecasts, especially for cases of good vertical sampling of the atmosphere.
Relative humidity profiles from radar reflectivities are firstly retrieved and then assimilated. The method has the main advantage of using vertical information provided by the volume radars that are the most useful. As both rainy and non-rainy observations are used, either precipitations are produced or the model dries. Figure a shows the impact of assimilating reflectivities from high altitudes (rain does not reach the ground) on a relative humidity analysis. The propagation of the information is consistent with the observed spatial scales. Since the end of 2008, the reflectivity assimilation has been systematically evaluated by means of a radar product optimized for the Arome model (Doppler winds and reflectivities). The data from the 24 radars of the network will be assimilated but neither the very low reflectivities from the lower troposphere (echoes which may be unidentified anomalous beam propagation) nor the lowest elevations affected by high values of topographical beam blockage will be assimilated.
Daily evaluations of this assimilation have shown positive results in a pre-operational context. In particular, a positive impact has been found for very-short-range precipitation forecast scores. Fig. b shows positive scores for 6-hour accumulated precipitation forecasts against rain gauges, for between 3-hour and 9-hour forecasts, when the reflectivities are assimilated (REFL) against CTRL (reflectivities are not used). Improvement is also observed in forecast scores for other parameters (such as wind) over long periods.

7

Impact of hyperspectral infrared sounders in Numerical Weather Prediction

IASI and AIRS, respectively onboard the European MetOp and the US Aqua polar orbiting satellites, are hyperspectral infrared sounders which provide thousands of channels in each profile. They have been in operational use in the global model ARPEGE and the limited-area model ALADIN since 2006 for AIRS and 2008 for IASI.
As infrared spectra are affected by the presence of clouds, their detection and characterization are of prime importance. Firstly, only clear channels were assimilated. To take the cloud effects into account, an algorithm is used to retrieve a cloud-top pressure and an effective emissivity in each pixel, which are then fed into the system to assimilate cloud-affected channels. This has been evaluated for AIRS spectra and led to an increase in the amount of data used and also to a positive impact on forecasts. Similar developments are in progress for IASI.
In the global model, ARPEGE, assimilating 4 times more data, from 1 every 250 km in operations to 1 every 125 km, has shown a positive impact on forecasts for all variables (e.g. the wind or the geopotential) and at all ranges, and especially in the Southern Hemisphere. IASI and AIRS data have also been assimilated at high density in the convective scale model AROME. Despite rather poor temporal coverage of the domain, they had a positive impact for upper air and surface fields in all time ranges up to 30h. The prediction of precipitation, which is a key point for AROME, has also been improved.
The next steps will mainly consist of characterizing land surface properties to enhance the assimilation of infrared sounders over land for all models.

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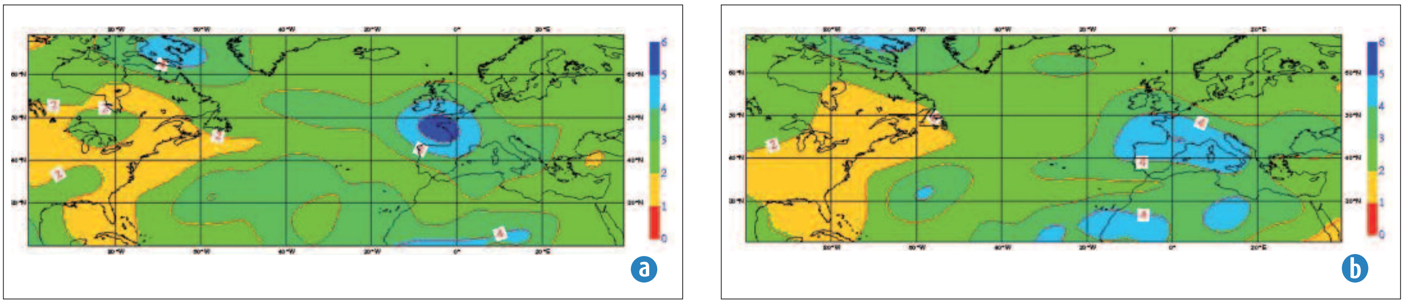

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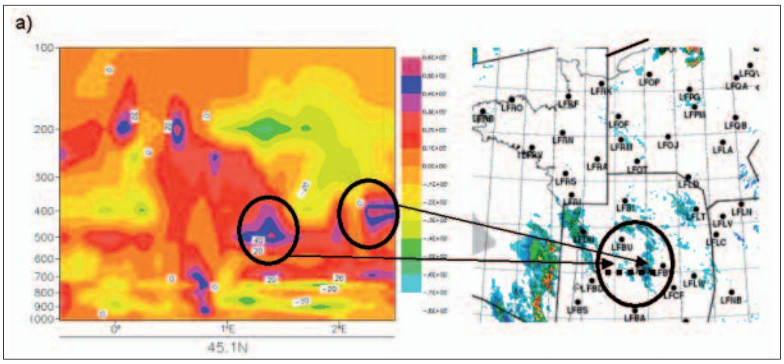
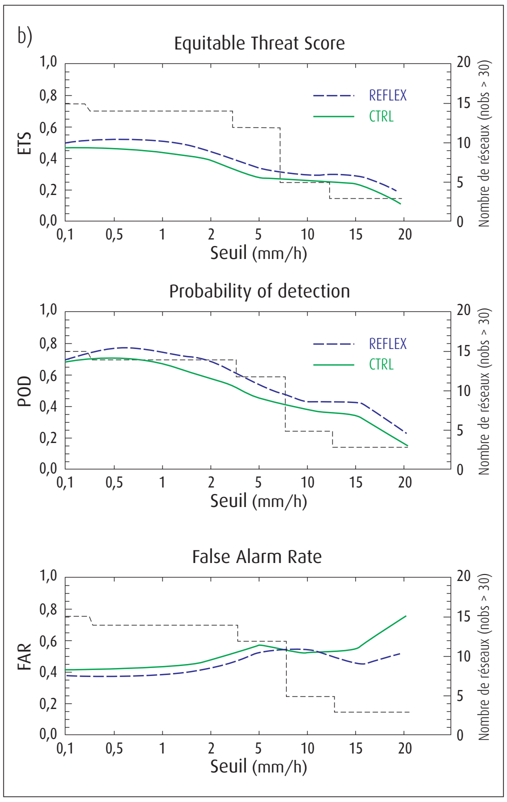
Maps of standard deviations of forecast errors of zonal wind (unit: ms-1) around 500 hPa on 24th January 2009 estimated with two different versions of ensemble assimilation. (**a**): standard deviations given by an ensemble 4D assimilation; (**b**): standard deviations given by an ensemble 3D assimilation.



a - Left, vertical cross-section (corresponding to the dashed line on the radar composite map right) from a relative humidity difference between an experiment with assimilation of radar reflectivities and an experiment in which reflectivity was not assimilated.

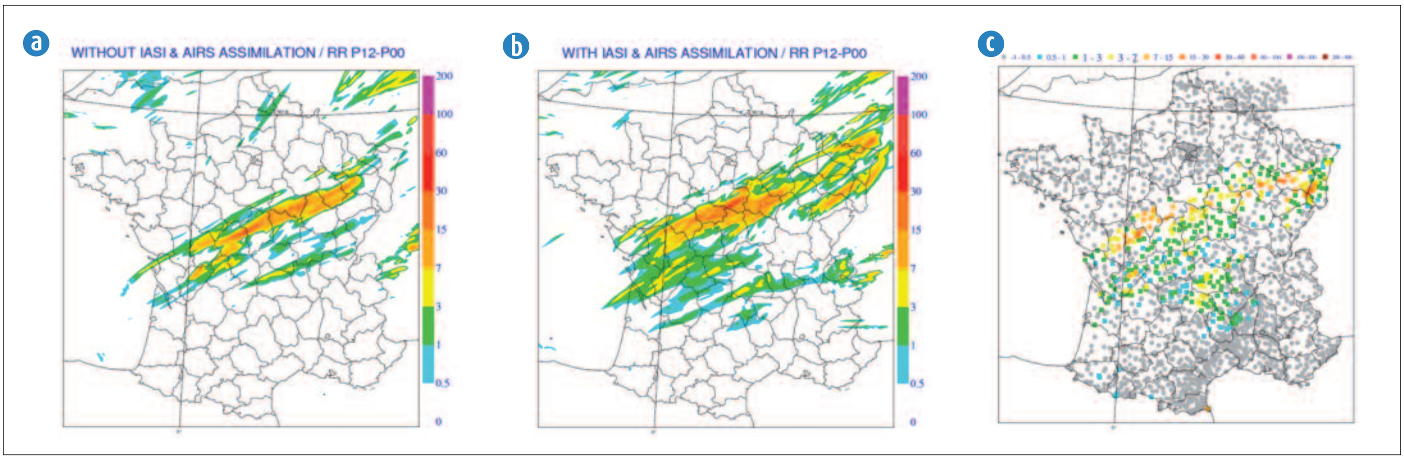


b - From top to bottom, averages of Equitable Threat Scores (ETS), Probability of detection (POD) and False Alarm Rate (FAR) for 6-hour precipitation forecasts against rain gauges, between 3-h and 9h forecasts (at 00 and 12 UTC from 15 April to 23 April 2009 00h), versus threshold (mm/h) for CTRL (green line) and REFL (black dashed line). The thin dashed line represents the number of forecasts taken into account in the calculations, i.e. for which the number of observations above the threshold exceeds 30.

7

8

12h precipitation accumulation as forecast by AROME with no assimilation of AIRS or IASI data (**a**), and with assimilation of AIRS & IASI data (**b**), to be compared with rain gauge measurements (**c**), for the period between 00 and 12 UTC on 21st May 2009.



Validation of the humidity profiles retrieved with IASI from the Jaivex campaign

The fluctuations of humidity profiles are at present poorly evaluated through the assimilation of satellite data. The JAIVEX campaign, which took place during the validation phase of the METOP satellite, provided a high-quality set of IASI observations co-registered with several dropsondes.
The marine clear situations (25 observations) enabled the retrieval of humidity profiles to be improved. We set the 178 channels used by ECMWF as the reference (case A in the figure), together with their two matrices of errors of observations and background. We estimated the impact of a more accurate matrix of observation errors and a dynamic selection of 150 channels from the set of 366 channels selected before the launch of the satellite and broadcast on the GTS (case B), and from a subset of 1700 channels sensitive to temperature and to water vapour only (case C). The improvement in the retrieved profiles can be assessed by the better coherence with the profile of the dropsonde, the observed residuals – calculated smaller on the whole spectrum, a larger contribution of information coming from IASI in the retrieval and a finer vertical resolution.
The figure shows results for a clear situation close to a cloud layer (29/04/2007). The strong fluctuation in humidity is very badly represented by the forecast. The reference conditions do not allow the forecast to be left: the fluctuations are not retrieved by the inversion and little information comes from IASI. Experiments B and C significantly improve the retrieved profile and the contribution of IASI in the inversion.
This work will continue with the treatment of cases over land and by increasing the number of vertical pressure levels.

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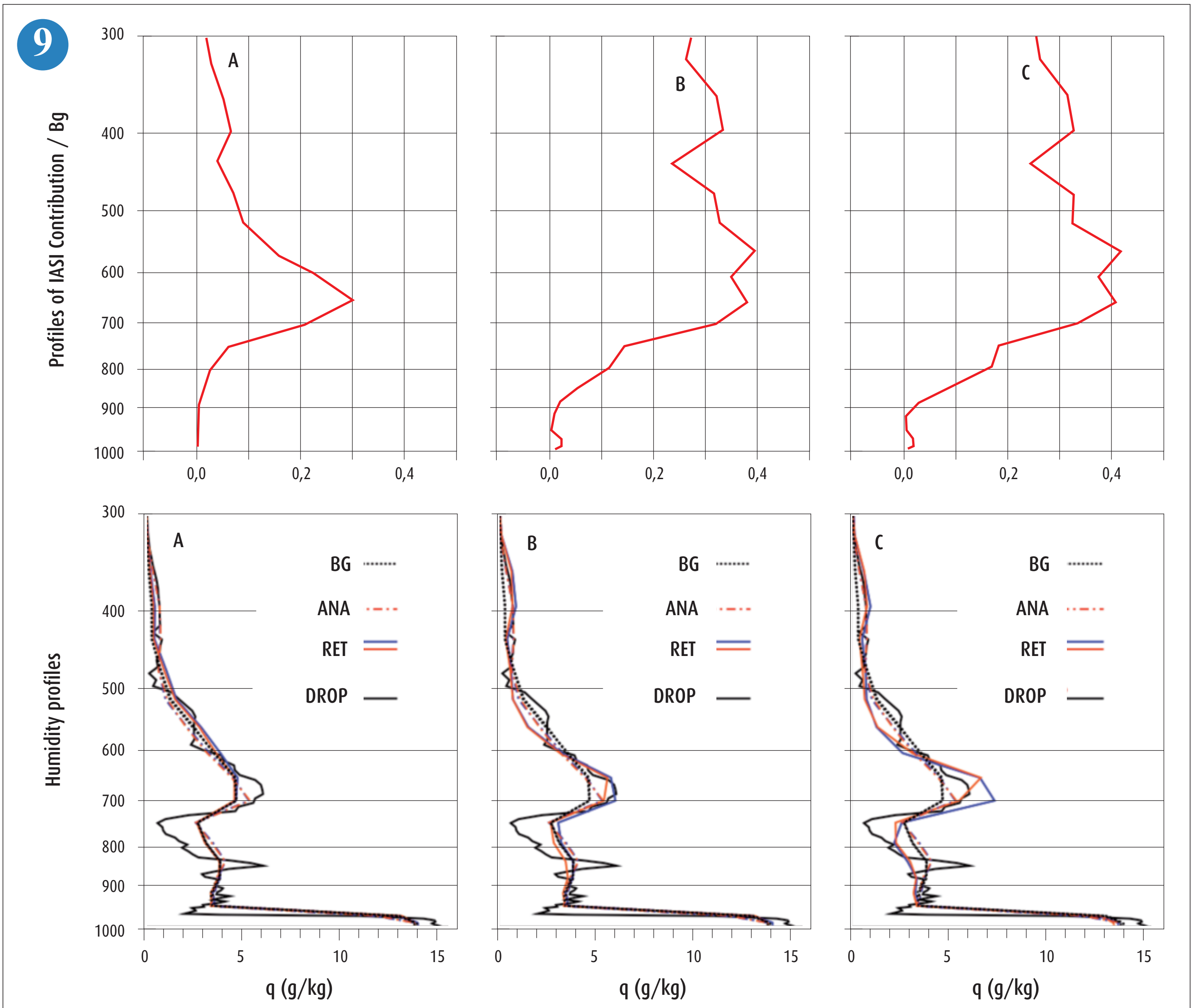

Part of the information provided by IASI (upper figures) with regard to forecast onto the pressure levels of RTTOV and corresponding humidity profiles (bottom figures). The black curve shows the profile of the dropsonde, the continuous curves the profiles retrieved from 2 IASI spots at 14km (red) and 26km (blue) and 10 minutes from the dropsonde launch. The fine dotted curve corresponds to the forecast (1Dvar initialization) and the bold dotted curve shows the closest analysis.

Cyclone forecasting

Analysis of the interaction of tropical cyclone Ivan (2008) with the ocean

Tropical cyclones extract most of their energy from the upper layers of the ocean. Cyclone intensification is only possible if the surface temperature of the ocean is higher than 26°C to at least 30 feet below the surface. Firstly, cyclone winds extract energy from the ocean through surface fluxes and this, in turn, intensifies the cyclone winds. However, they also generate some dynamic effects on the upper layers of the ocean, which may modify the sea surface temperature (SST). Thus, the interactions are particularly complex. Moreover, a better understanding of the mechanisms between cyclones and the ocean is crucial to the improvement of cyclone intensity forecasts.

The figure below shows the study of tropical cyclone Ivan (South-West Indian Ocean, 2008) and its interactions with the ocean as it moves from a region of cool SST to warm SST. Two simulations from times t=0 and t=96h were conducted with the high-resolution Meso-NH model. The first simulation (forced) had a fixed SST field at the surface. The second simulation (coupled) allowed the SST to evolve with time through a coupling of Meso-NH with an oceanic model that was able to simulate the evolution of water columns. It may be observed that the cyclone was less intensified by the coupled simulation than by the forced one, which overrated the intensification level. A more detailed study analysed the physical processes responsible for the differences between the two simulations.

In the future, this type of coupled models will be implemented for the operational prediction of tropical cyclones.

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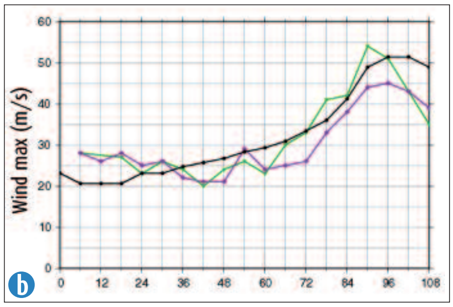
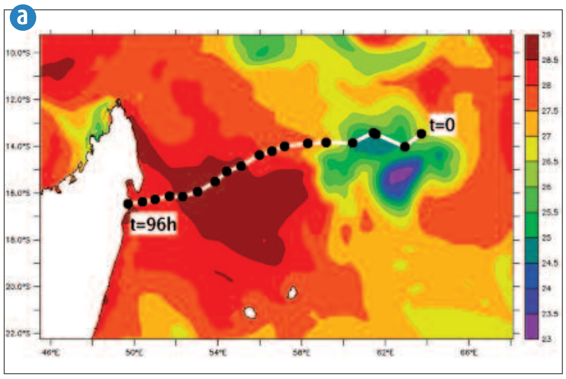


b - evolution of the intensity of Ivan (maximum wind at 10m) analysed (reference in black), by the forced simulation (green) and by the coupled simulation (purple).



10

a - track of the cyclone Ivan between the two times of the simulations (t=0 and t=96h), on a map showing the initial sea surface temperature.

Skill of the Aladin-Reunion model on the case of tropical cyclone Gael (2009)

Aladin-Reunion is a limited-area model that covers the South-West Indian Ocean with a 10-km grid mesh. This operational model is continually being adapted to improve the forecasting of the tracks and the intensities of tropical cyclones.

In 2009, some of the physical parametrizations of Aladin-Reunion were modified, with, in particular, the use of a new parametrization of the air-sea fluxes. The main interest of this model is its ability to correctly represent the structure of cyclones, which global models cannot do. In terms of track prediction, its skills are reasonably good, and sometimes excellent. Thus, in February 2009, the tropical cyclone Gael passed 400 km North of Réunion Island before swerving southward round the island. All the Aladin-Reunion forecasts from 4th February onward (see figure) show this swerve and the forecasted tracks are very close to the real track. However, other models foresaw this inward movement either closer to Madagascar or as a straight track. However, in terms of intensity forecasts, Aladin-Reunion generated too great a deepening of the cyclone.

The model will continue to evolve with an increase in horizontal (8 km) and vertical resolution soon.

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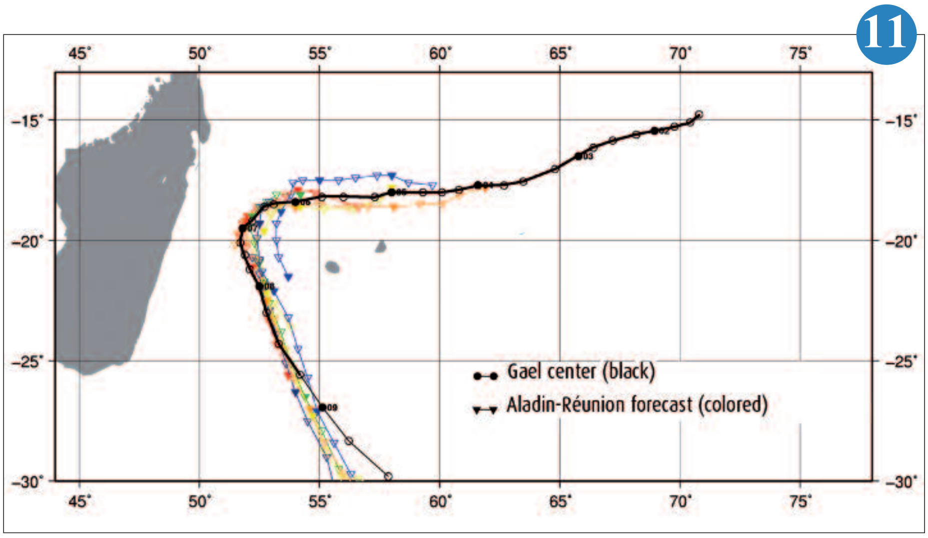

Tracks of Gael: analysed (black), and forecast by several simulations of Aladin-Reunion at different initial times (one colour per initial time).

Nowcasting

The ARISP project

The Airports of Paris (ADP) and Météo-France's Paris Office of Studies and Climatology (BEC) have agreed on the necessity to develop a new runway temperature forecasting system, called ARISP (AROME-ISBA-Piste). The basic principle of such a model is not new for Météo-France: a meteorological model (ARPEGE), interpolated both spatially and temporally by means of appropriate software (SAFRAN), provides meteorological inputs for the Interface-Sol-Biosphère-Atmosphère (ISBA) model which, knowing both the atmospheric forcings and the physical properties of the ground column below, is able to compute the evolution of its temperature and humidity profiles. This scheme is used operationally by SIR (SAFRAN-ISBA-ROUTE), a road temperature forecasting system.
A new feature in the system currently being developed by BEC is the use of forecast parameters from the new operational model AROME instead of from SAFRAN. The fine mesh of AROME (horizontal resolution: 2.5 km) is expected to serve this fine scale application better. Moreover, the original microphysics of AROME and its ability to represent realistic clouds improve its forecasts of infra-red and visible radiation, and these ingredients of radiative transfer are a major component of the soil temperature. Preliminary results comparing ARISP and SIR for a winter's day cycle are shown in the figure on the next page.
Other features are also being added, such as original ISBA tuning (individualized for each runway profile) and the use of meteorological observations to initialize the forecasts.
The first tests of this system will take place during winter 2009-2010 for Roissy Charles-De-Gaulle airport and during the following winter for Orly airport.

12

Characterization of the cloud cover from satellite imagery in the SAFNWC

The Satellite Application Facility in support of Nowcasting (SAFNWC) is part of the EUMETSAT ground segment. It provides users with a software package for extracting products useful for nowcasting purposes from the MSG-SEVIRI derived products. The part of the software dedicated to cloud product retrieval (cloud types, cloud top height) was developed in 2009.
Many improvements have been made. The major change concerns low level clouds. The twilight detection of fog or low stratus has been greatly improved using a combination of temporal analysis and image processing techniques. Furthermore, low stratus clouds can easily be mistaken for mid-level clouds; this confusion has been reduced by the use of the 8.7µm infrared channel. This visualisation is especially important to forecasters but also for automatic applications using SAFNWC cloud types, such as fog risk mapping, or SEVIRI radiance assimilation in the fine mesh model AROME. Additionally, the use of the High Resolution Visible (HRV) channel has led to improved daytime identification of sub-pixel cumulus clouds.
Although the SAFNWC/MSG software was designed for MSG SEVIRI data applications, Météo-France, LMD and ICARE have adapted it to retrieve cloud products from other geostationary satellite imagery (GOES 10-11-12, MTSAT-1). The modified software is now operational at the ICARE centre to support to the Megha-Tropique mission.

13

Detection and tracking of storm cells in the service of aviation

The FLYSAFE project has defined and tested a weather information system contributing to the flight safety of all aircraft. This system gives real-time information to pilots about the position and the trend of the following weather hazards: thunderstorms, icing and turbulence in clear sky conditions.
The thunderstorm hazard system was developed jointly by Météo-France and the German Aerospace Centre. The underlying idea is to complement the thunderstorm description from the onboard radar by adding ground weather information. In order to reduce the data flow and to facilitate the integration of hazards into onboard systems, the thunderstorm representation has been simplified so that the pilots and/or the onboard data fusion process receive the minimum useful information. The thunderstorm hazard is depicted by two volumes. The first volume is defined by the radar imagery and gives a picture of risk of heavy rain, hail and lightning. The second volume is defined by the satellite imagery. It particularly characterizes the top of systems, including the risk of severe turbulence for commercial aviation.
The weather information system for thunderstorm hazards has been tested in a flight simulator configuration but also in flight conditions by two research aircraft. The complementary nature of ground information and airborne radar data has been confirmed, in particular by completing the convective information outside the angular coverage of the airborne radar and also in cases of beam attenuation by heavy rain. The combined system can also warn pilots of a convection triggering area before it is detected by the onboard sensor.

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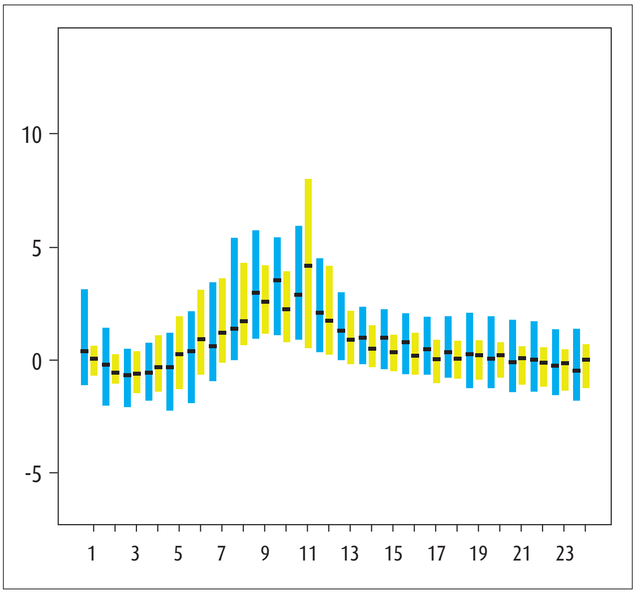

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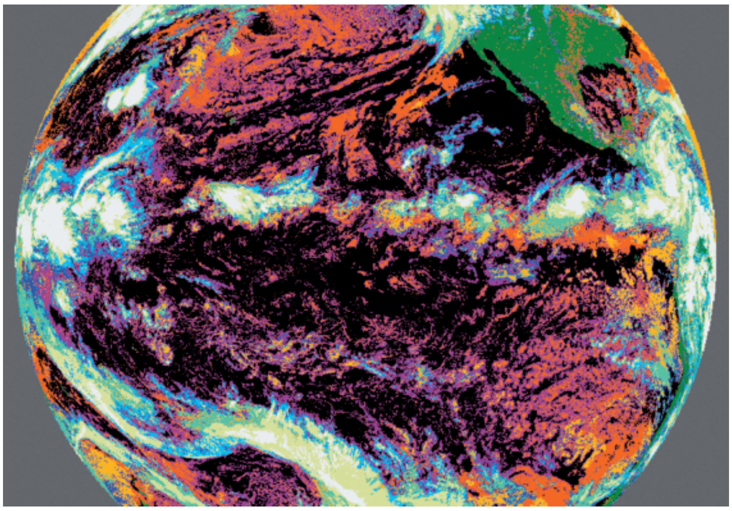
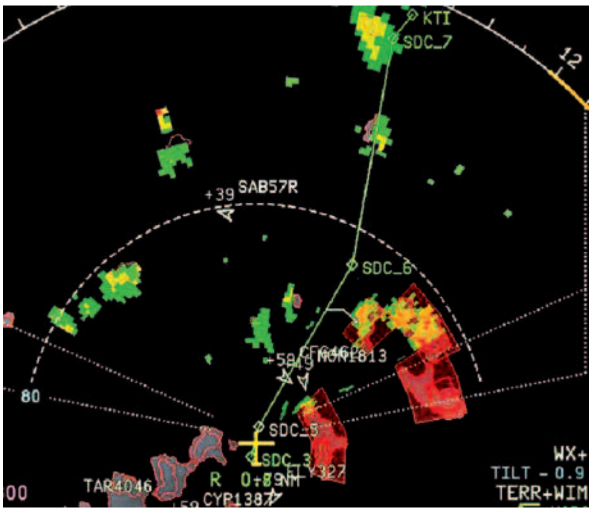
Comparison, during a day's cycle, of the departures between forecast temperatures and in situ observations for two systems: ARISP (using an experimental version of AROME, in yellow) and SIR (in blue). The bottom point of each bar is the Q25 percentile, the point in the middle is the median and the upper point is the Q75 percentile. Data were collected during winter 2007-2008.



13

Examples of cloud type retrieved from GOES-11 geostationary satellites over the Pacific Ocean in support of the Megha-Tropique mission.



14

Superimposition of the airborne radar image (Raster), thunderstorm hazard volumes from the ground weather information system (Polygons), hazard boxes from the onboard data fusion process (Red Boxes), and safe trajectory proposed by the onboard computer (Green Line)

Studies of meteorological process

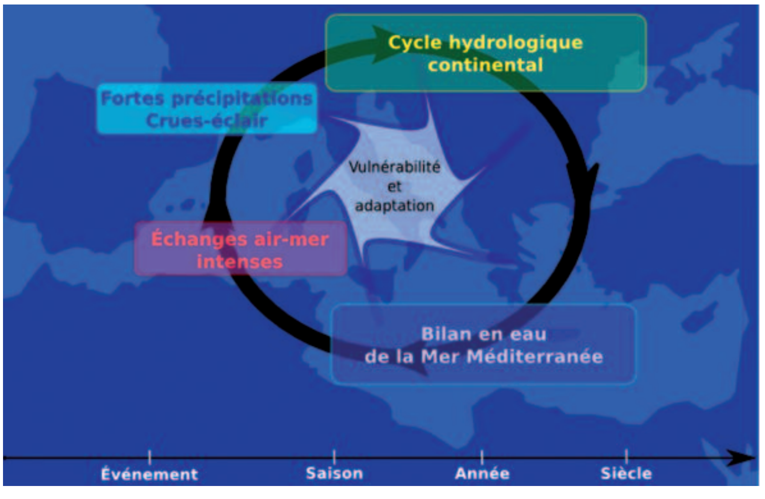
From the small to the synoptic scale

The finality of understanding and modelling meso-scale processes and phenomena is to improve the numerical weather prediction and climate prediction models at Météo-France. Meso-scale research covers deep convection, micro physics processes of cloudy and precipitating systems, the study of convective and stable boundary layers including fog and ocean-atmosphere interface processes considering many different kind of surfaces (natural, urban, lake, ocean), and also mainland hydrology.

At the end of 2008, the new meso-scale model AROME was implemented operationally over France as a result of the successful convergence of the Meso-NH/AROME physics parametrizations and the fruitful assimilation of new data into the model (GPS, radar). The development and the validation of a new shallow convection scheme (called EDKF), first in meso-NH and then in AROME, has enabled to correct some early shortcomings of organized wind structures in AROME. Upstream research has also taken place to pave the way for mid-term kilometric and sub-kilometric scale numerical weather predictions. In this area, work has been initiated to merge PEARP Ensemble predictions with AROME Ensemble assimilation on severe rainfall events in order to develop a methodology for an ensemble prediction with the AROME model at the kilometric scale. These efforts are combined with other studies to define an Ensemble prediction of rapid floods using the ISBA-TOPMODEL hydro-meteorological system. Weak and strong points of the sub-kilometric AROME and meso-NH models have been analyzed in order to prepare the use of these models at such resolutions in an operational context as well as for research. At these scales, it is difficult to describe the mechanisms behind the turbulence since we are faced with a “grey area”. Set against LES simulations, a preliminary study has shown the flaws of the current parametrizations of the turbulence in meso-NH. The studies of fog, of sound propagation or to improve cloud parametrization are resorting more and more frequently to these LES.

Field campaigns and the exploitation of the data collected are two other aspects of meso-scale research. Data analysis from the 2006 AMMA field campaign has continued in 2009. The analyses of data from the COPS field campaigns (assimilation of GPS and radar data using AROME), and of those from the Carboeurope campaign in the South West of France, using the simulation of the whole 2005 field campaign, showed good behaviour for the simulation of CO_2 fluxes and concentrations with the ISBA-A-Gs scheme. Throughout 2009, several research teams have taken part in the SNORTEX measurement campaign on the remote sensing of snow covered forests, and in the CAROLS campaign on the estimation of soil superficial moisture with a view to the launch of SMOS. Lastly, a sustained effort has been necessary to coordinate and plan the HyMeX experiment programme on Mediterranean water cycle management (see figure). Preliminary studies are being undertaken to define the implementation of the HyMeX programme, such as a version of AROME that can assimilate data of the western Mediterranean basin, and real or idealized study cases of intense rainy events for the northwest Mediterranean basin.

1



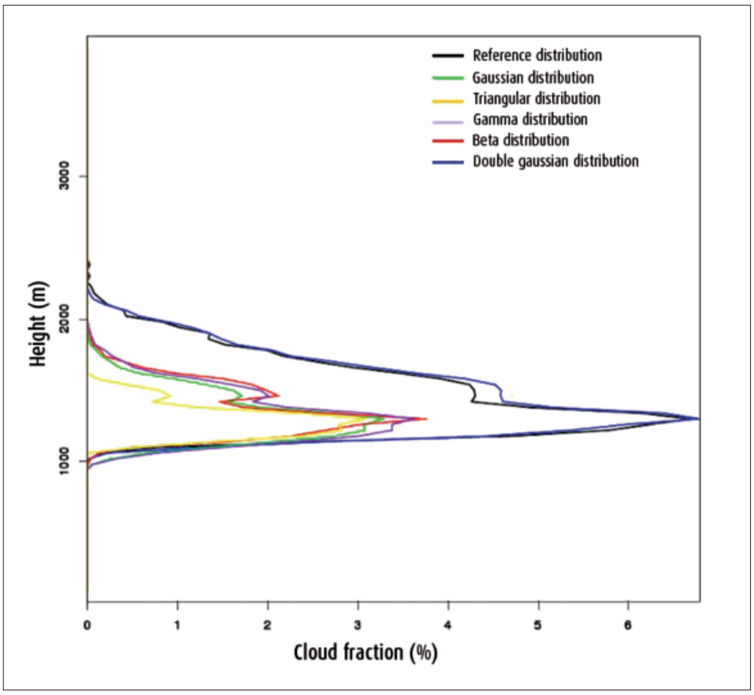
1

The 5 major HyMeX research themes deal with prediction improvements and preventive actions against intense Mediterranean events (intense rain, rapid flood, storms, drought), and assessment of the local impact of climate changes, especially on the Mediterranean thermohaline circulation.

Improvement of the cloud scheme in the AROME model

Even at the horizontal resolution of AROME (2.5 km), there are still subgrid clouds that an "all or nothing" method, assuming that a model grid is either totally cloudy or completely clear, fails to represent. Therefore, it is necessary to consider a subgrid cloud scheme which describes the cloud variability inside a model grid box, based on a statistical distribution which should be valid for all cloud types.
Large Eddy Simulations (LES), with a resolution of the order of 100 m, were carried out with the Méso-NH model to estimate these subgrid fluctuations by considering the whole LES domain as a single grid box of the mesoscale model (5 km). The reference distribution deduced from LES data appears bounded, flexible and sometimes asymmetric and shows a second mode. For cumulus clouds, this second mode corresponds to the water feed from the surface associated with the triggering of shallow convection whereas, for stratocumulus clouds, it shows the entrainment of dry air from the free troposphere drying out the cloud layer. The theoretical unimodal distributions classically used by atmospheric models do not consider this second mode and underestimate the cloud fields. The hypothesis of a unimodal distribution used at large scale is no longer valid at mesoscale resolution.
The future objective is to determine a bimodal distribution, built as a linear combination of two Gaussian distributions. A method to define their parameters from the model variables will be designed in order to be able to implement such bimodal distribution in the Méso-NH and AROME subgrid cloud schemes.

2



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Vertical profiles of the cloud fraction for the reference distribution (LES) (black), the double Gaussian distribution (blue) and different theoretical unimodal distributions for a shallow cumulus case.
Only the double Gaussian distribution is able to fit the reference distribution.

A study of severe convective events with the output of fine mesh Météo-France models

The aim of the Forecast Laboratory is to prepare and validate possible new tools for operational forecasting purposes. In this context, after the damage caused by the F4-tornado in the region of Haumont in the North of France (on 3rd August 2008), it was decided to supplement the existing set of tools with the U.S.A.'s severe convection indices. They are now computed on a daily basis and for the whole Météo-France suite of models (ARPEGE, ALADIN and AROME, reaching 15, 10 and 2.5 km of horizontal resolution, respectively).

The STP (Significant Tornado Parameter) is used in the U.S.A. to quantify the risk of appearance of tornados. It is a complex formula (see figure): a product of 4 non-dimensional terms, with normalization factors leading to a threshold of 1 or so, with an increasing probability of tornados.

The STP values depicted in the figure were computed from ALADIN and AROME outputs and for the Haumont region at 20 and 21 UTC (just before and after the tornado), corresponding to 2h and 3h forecasts from the 18 UTC analysis. Clearly, the signal is stronger and better located for the higher resolution model AROME than for ALADIN, with significant values up to 0.8 in (a) and greater than 1.2 in (b).

The encouraging results obtained for this Haumont case led us to compute the STP indices daily over France throughout the summer of 2009 and for the three models running at Météo-France. Results are not so encouraging as for the Haumont case, with numerous false alarms and non-detections. Thus, this first attempt to use the STP indices will be followed by tests of additional products in 2010 (modifications of the non-dimensional terms, new input data such as the turbulent kinetic energy, etc.)

3

Climatology of fine mesh wind in the low layers for foreign locations

In order to establish a fine mesh wind climatology, several suitably long series of wind measurements are usually necessary. Obviously, such series are not available world-wide (e.g. oceans, deserts, mountains). The research programme that SHOM and Météo-France have jointly set up for 3 years aims to develop a method to establish high resolution wind climatology in areas where wind measurements are rare.

The methodology follows the pattern of the CNRM B95 action on metropolitan France but is now used for 3 areas that are very different in terms of climate: the Gulf of Guinea, the northern Indian Ocean and the Eastern Mediterranean basin.

Recent progress in modelling has provided high resolution models that take climatic phenomena (such as convection, breeze) and relief into account in a more realistic way. However, due to computing limits, it is not yet possible to run these non-hydrostatic models over a long period of time to produce a reference climate. Consequently, a weather type method has been used. From the ERA40 re-analyses, parameters have been defined to differentiate the various weather types and classify them (class 4 for the Gulf of Guinea, 7 for the Indian Ocean, 10 for the Eastern Mediterranean). The statistical analysis of 23 years of re-analyses (1979/2001) made it possible to specify a hundred dates that represent the climates of these areas.

The next step will be to carry out high resolution simulations for each zone of interest on these hundred dates, in order to rebuild the wind climatology of each area. To this end, it is planned to have series of interlocked simulations starting from the ERA 40 low resolution re-analysis, followed by ALADIN model simulations (30 and 10 km resolution), and ending with the 2.5 km resolution AROME model.

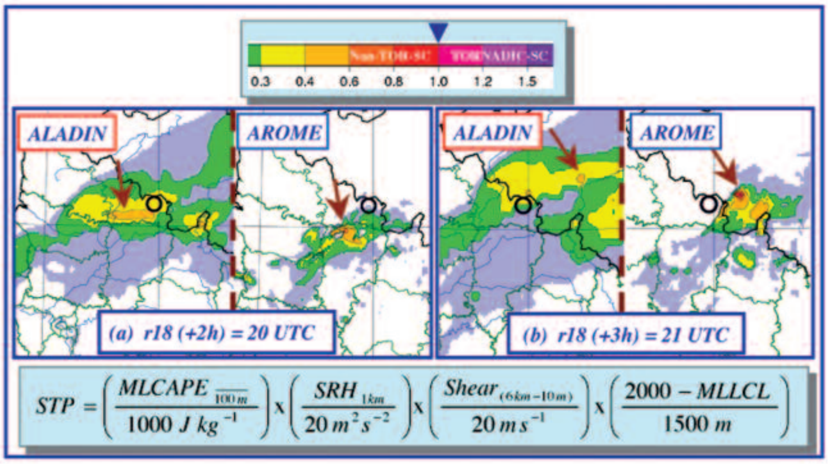
4

Evolution of a low-level cyclone into a storm in the absence of an upper-level precursor

Before reaching the French coasts, the two European storms of Christmas 1999 were low-level cyclones with moderate amplitude travelling across the Atlantic. They quickly deepened during their interaction with the upper-level large-scale jet. For the second storm, this interaction was favoured by the presence of an upper-level precursor, which was not the case for the first one. If, in a numerical simulation, the upper level disturbance is removed from the second storm, this storm simply disappears. This suggests that, in the absence of an upper-level precursor, some dynamic properties of a low-level cyclone are crucial for its future evolution.

In order to identify these parameters, numerical sensitivity experiments were performed using the French operational model ARPEGE. The initial low of the first storm was replaced by an idealized one for which various characteristics could be modified, such as its horizontal shape or position. Two factors favour the strong deepening of the idealized low, as shown by the figure: the case of weak stretching and a position closer to the upper-level jet (figure). It is quite surprising that a change as slight as 1.5 degrees in its position is enough to entirely modify the scenario.

5



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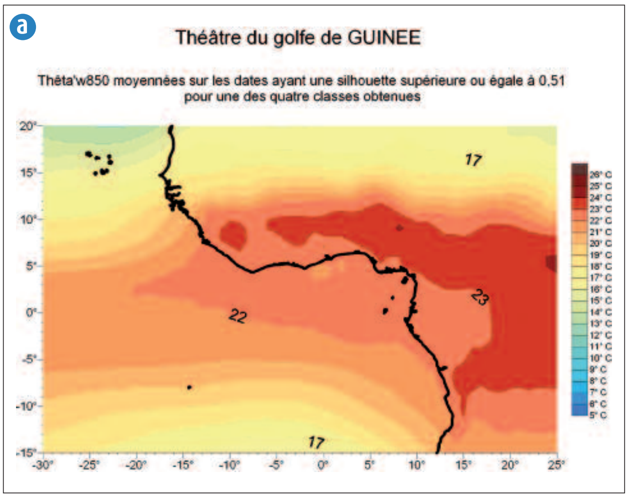
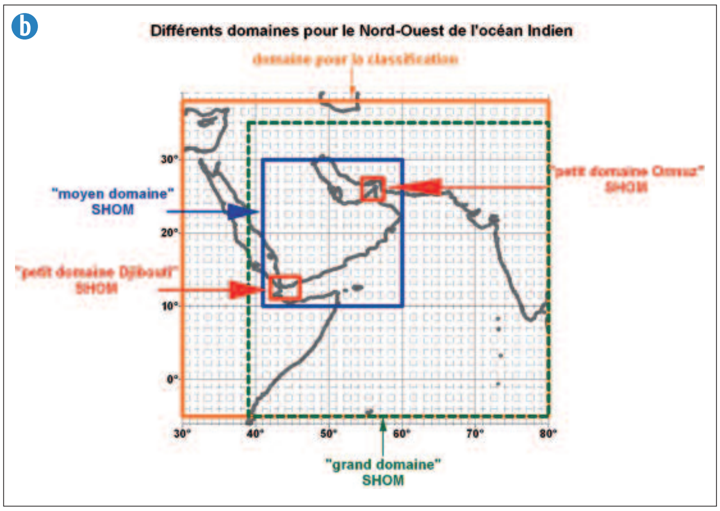
Map of the STP for 3rd August 2008 for the ALADIN and AROME models. The black circle represents the region of Haumont.
(a) 2 h forecast (just before the tornado);
(b) 3 h forecast (just after).



a - θ'W at 850 hPa for a class defined over the Gulf of Guinea.



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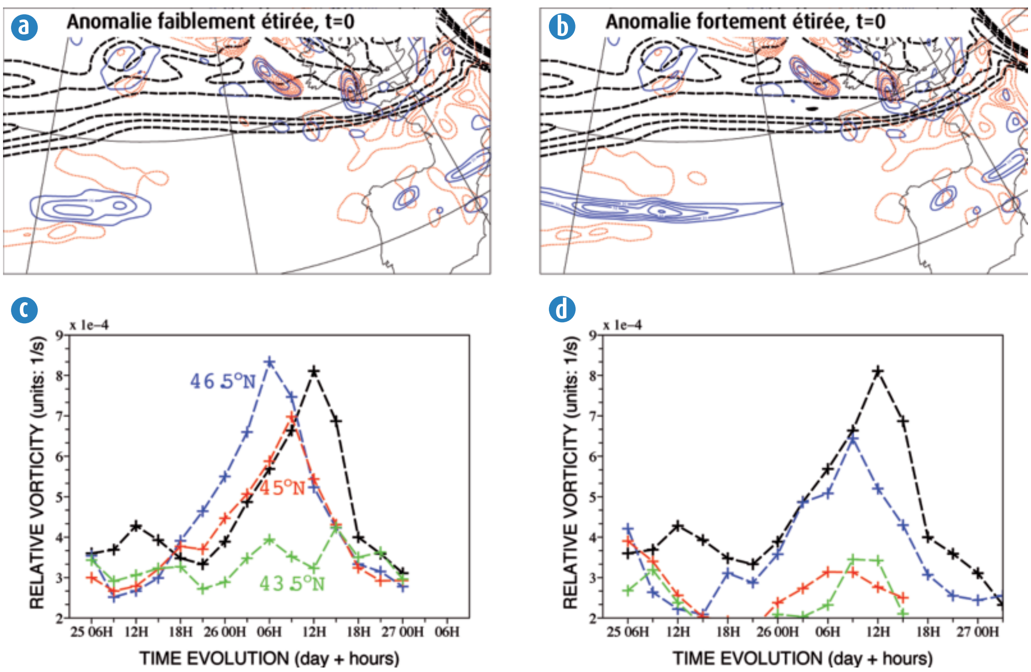
b - Fields of the interlocked models and fields for classification of weather types.



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Upper panels present two different initial conditions where the initial low of the first storm has been replaced by an idealized one at 06 UTC 25 December 1999. The relative vorticity at 850 hPa (blue contours; interval: 8 10^{-5} s^{-1}), and at 300 hPa (black contours, interval: 5 10^{-5} s^{-1}), and the vertical velocity at 600 hPa (red contours, interval: 0.4 $Pa.s^{-1}$) are represented for
(a) a weakly stretched anomaly and
(b) a strongly stretched anomaly centred at 36W, 45N
(c) evolution of the relative vorticity maximum at 850 hPa for an anomaly centred at 46.5N (blue), 45N (red), and 43.5N (green)
(d) same as (c) but for a strongly stretched anomaly. The black curve corresponds to the forecast of the real storm starting on the same date.

Fog studies

Fog modelling

Accurate modelling of the life cycle of a fog layer is always a great challenge. However, fog can have important societal impact (e.g. transportation or pollution), and it is necessary to improve the knowledge on the physical mechanism driving a fog layer. Currently, our research focuses on the determination of the initial conditions, on the impact of aerosols, and on the very fine scale circulation inside a fog layer.

As for other meteorological forecasting systems, improving the quality of the forecast is very dependent on the initial conditions. An ensemble Kalman filter and a particle filter assimilation scheme have been developed in the Cobel-Isba numerical forecasting system. Cobel-Isba is a local numerical fog prediction system used operationally at three airports in France : Paris-CdG, Paris-Orly and Lyon. These two new assimilation methods have improved the quality of fog forecasting at local scale.

Some research is also in progress on the microphysical parameterization, in order to take the specificity of the fog granulometric spectra into account. This work is carried out with data coming from the Paris-Fog and Toulouse-Fog field experiments. The results show a non-trivial dependence between the number of aerosol particles and fog. In a very polluted atmosphere, it is very difficult to form dense fog. Haze, however, is very frequent.

Strong horizontal and vertical gradients exist inside fog layers. Fine resolution is necessary to accurately represent the interactions among the physical processes but, unfortunately, such a resolution is not yet possible for operational forecasts. Nevertheless, simulations carried out with Meso-Nh at a horizontal resolution of 5 m and a vertical resolution of 1 m, allow the heterogeneities inside a fog layer to be studied at small scale.

This research will lead to the development of new physical parameterizations and, consequently, to improved fog forecasting.

6

Fog monitoring at Roissy airport with an acoustic remote sensor

In the framework of a national programme aiming to improve fog forecasting at airports, an experiment has been carried out to test the potential of an acoustic remote sensor – the sodar – to provide operational observations of the phenomenon. The theory leads us to think that a sodar, which detects turbulent temperature heterogeneities, should be able to detect the top of fog layers in real time.

However, as no thorough testing has been carried out yet, it was decided to undertake some experiments to check this capacity. A sodar was purchased in early 2008 and deployed at Roissy airport in June 2008. After a few weeks of operations, it became clear that the sodar was able to work properly despite significant ambient noise.

The experiment took place during the winter of 2008-2009. During four months, a team from CNRM operated a tethered balloon system at Roissy each time fog was either forecast or observed. The tethered balloon measured the vertical profile of temperature and humidity once every hour in the first few hundred metres of the atmosphere. About 10 fog events were thus observed.

The results clearly confirm the ability of the sodar to detect and precisely locate the top of the fog layer in real time, which appears as a peak in the signal strength (reflectivity). They show that the sodar provides some additional information to correct the fog height analysis made by the fog forecasting system (COBEL). It now remains to assess the impact of that information on forecasting skills.

7

Spatialization of low visibilities to improve mist and fog detection in CARIBOU

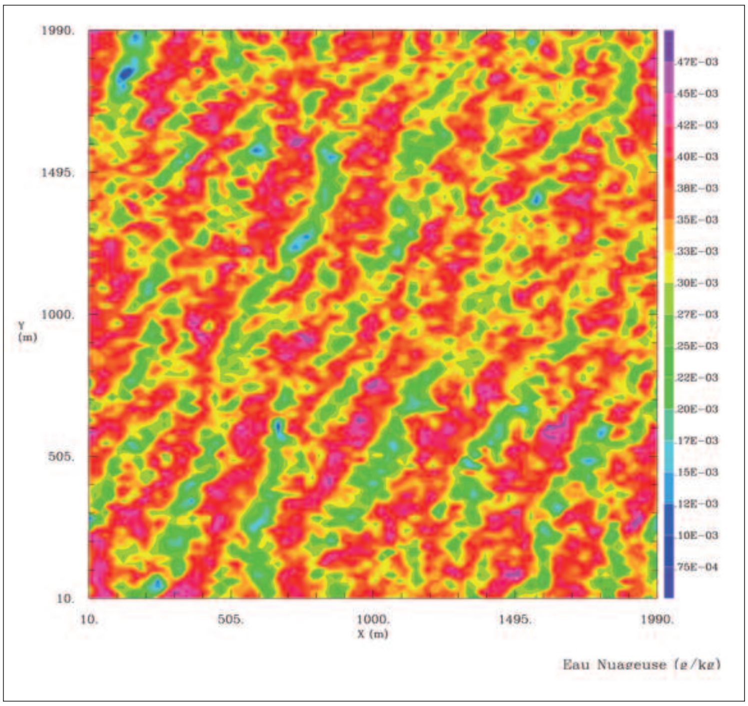
The CARIBOU analysis has been providing spatialized information about mist and fog risks for metropolitan France since June 2007. CARIBOU detects the phenomenon but does not forecast it. Moreover, analyses do not give visibility values and they are not systematically available throughout the domain.

A new method has been developed to correct these drawbacks. It is based on the spatialization of visibility values observed in situ by means of a multiple linear regression involving meteorological and geographical predictors. This interpolation of residuals improves results as it gives a better correspondence with observations of visibility and therefore an indication of the expected visibility over the whole domain.

Then, merging those spatialized visibilities with the current CARIBOU analysis allows us to take into account the quantitative information about visibility reductions and the qualitative information about the risk of mist or fog occurrence. Thus, it becomes possible, for example, to produce maps which match the probability of observing visibility values lower than a given threshold (200, 600, 1000 or 5000 m).

Results are encouraging so far. However, new developments have yet to be validated before this new version of CARIBOU can be implemented operationally. The foremost goal is to satisfy the request of the SYMPOSIUM-2 project (by supplying probability distributions of visibility values) and also to take better account of the characteristics of the visibility observations used.

8



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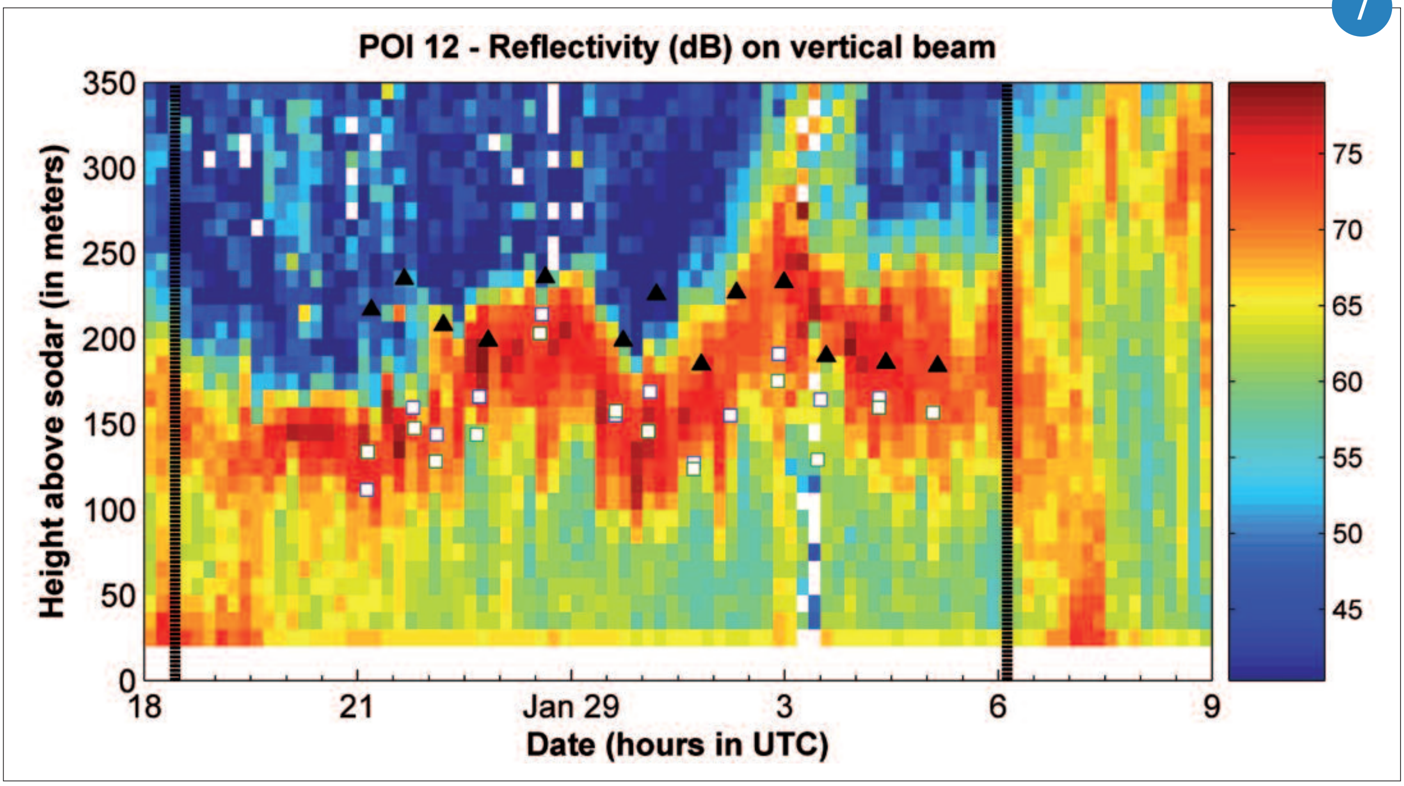
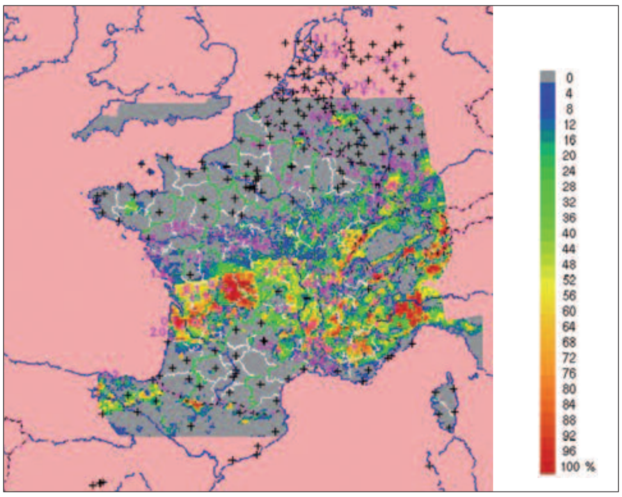
Horizontal cross section in a fog layer.
The liquid cloud water inside the fog layer comes from a numerical simulation at very fine scale (5 m in the horizontal and 1 m in the vertical).
The linear structures inside the fog layer can be seen clearly.

Colour coded plot of the sodar signal strength (the reflectivity) versus time (x-axis) and height above the ground (y-axis).
The colour code is shown on the right. The white squares indicate the fog layer top as revealed by the tethered balloon.
The black triangles show the maximum height reached by the balloon. The vertical bars indicate the beginning and the end of the fog event. The good correlation between the white squares and the line of high acoustic reflectivity in altitude demonstrates the operational ability of the sodar to monitor the top of the fog layer.

7





8

Probability of observing visibility values less than 1000 m – 09/17/2009 05 UTC (in %).

Work around the AMMA programme

Launched in Niamey in February 2002, AMMA is an international programme to improve our knowledge of the West African Monsoon (WAM) and its variability, with emphasis on daily-to-interannual timescales including climate change but also its impacts on natural and cultivated resources, and diseases. AMMA is also working to improve observation networks, weather and climate predictions and their applications (early warning systems for resources and diseases). AMMA has a keen interest in fundamental scientific issues and societal needs.
During the 3rd AMMA Conference which took place in Ougadougou in July 2009, the main achievements were presented to 500 researchers of all disciplines. Key features of the monsoon are now better understood, such as the Saharan heat low, interactions between surface and atmosphere, cold tongue mechanisms and their role in the monsoon onset. Prediction models, together with remote sensing data, estimate water budgets and sources over the region better. In collaboration with major numerical weather prediction centres, short term forecasts have been improved thanks to the assimilation of bias corrected radiosoundings and microwave radiances on the continent. The study of IPCC climatic scenarios shows that it is over the AMMA region that models differ most. The poor representation of remote connections between tropical regions raises many issues not only for this part of Africa but also for surrounding areas. Achievements have also been made on the links between climate and diseases (meningitis, malaria, rift valley fever), water resources, and farming production, with the first maps of advice for sowing, and also on the atmospheric pollution in major African towns.
Moreover, the AMMA phase II plan was also discussed during debates and meetings at Ouagadoudou. The programme will further develop its research on interactions between society, environment and climate and on the improvement of prediction systems and their applications.

1

Assimilation of surface sensitive microwave observations in the framework of AMMA

Observations from the AMSU-A & AMSU-B instruments provide relevant information about the vertical structure of temperature and humidity. The assimilation of these observations is still far from optimal in the models. Observations containing a considerable amount information on incoming signals from the surface are usually rejected from the assimilation because of an inappropriate description of the land emissivity. In July 2008, the use of AMSU-A and -B at Météo-France made substantial progress with the operational implementation of a new land emissivity parametrization. Since this change, strategies have been explored to assimilate surface sensitive observations for the first time ever. Studies were undertaken to assimilate observations sensitive to the atmospheric boundary layer over land. In addition to a control experiment, a two-month experiment was run during the summer 2006. Unlike the first one, the second experiment assimilated low level temperature and humidity observations from AMSU over land.

Assimilating these observations had major consequences on key parameters of the water cycle. An important change was noted in the analysed atmospheric fields and in the precipitation forecasts over the Tropics. Our experiment emphasized that the atmosphere was becoming more humid in India, South America and in West Africa while it was drying over Arabia and North-East Africa. The humidity change not only concerns the surface but also many levels of the atmosphere, up to 500 hPa. The humidity change was successfully evaluated using independent GPS data. The changes resulted in a better-organized African monsoon with a stronger ITCZ. Forecast errors were significantly reduced over the Tropics, leading to significant forecast improvements at higher latitudes in the 48h to 72h range.

2

Convective development within daytime drying boundary layers

Prior to the monsoon onset, daytime Sahelian convective boundary layers show generic features, which were particularly well captured by a suite of instruments on July 10th 2006. They include:
– significant growth of the mixed layer. On July 10th, its top matched the variations of the lifting condensation level until mid-afternoon (cyan curve in central upper panel), consistently with cloud base heights estimated with the colocated ceilometer (red dots),
– well defined boundary layer organizations, evolving from morning rolls (MIT radar reflectivity, upper left panel) to afternoon cells and then, in some places, to deeper isolated convective elements. This was the case on July 10th (upper middle panel, time series of vertically pointing cloud radar reflectivities): a deep convective cell developed within the field of view of the MIT radar and generated an almost circular convective outflow (upper right panel) spreading through the lowest levels where the wind speed was fairly low. However, sounding data did not show an increase in CAPE or a decrease in the level of free convection in the daytime-drying boundary layer (lower panel).
The features that were observed differed from the usual view that daytime convection over land should be related to a daytime CAPE increase. Further studies need to be undertaken since this situation seems difficult to model and its parametrization has been largely overlooked during recent years.

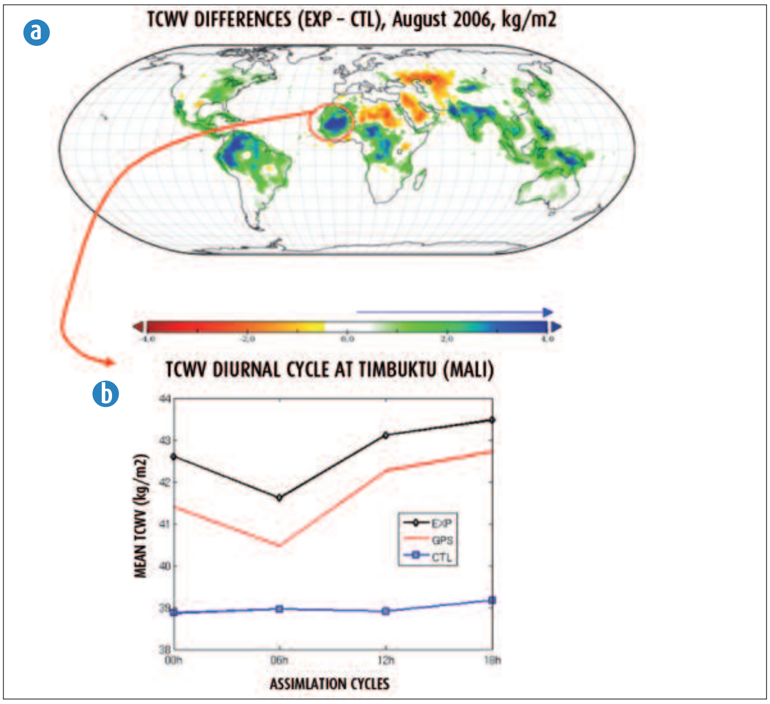
3

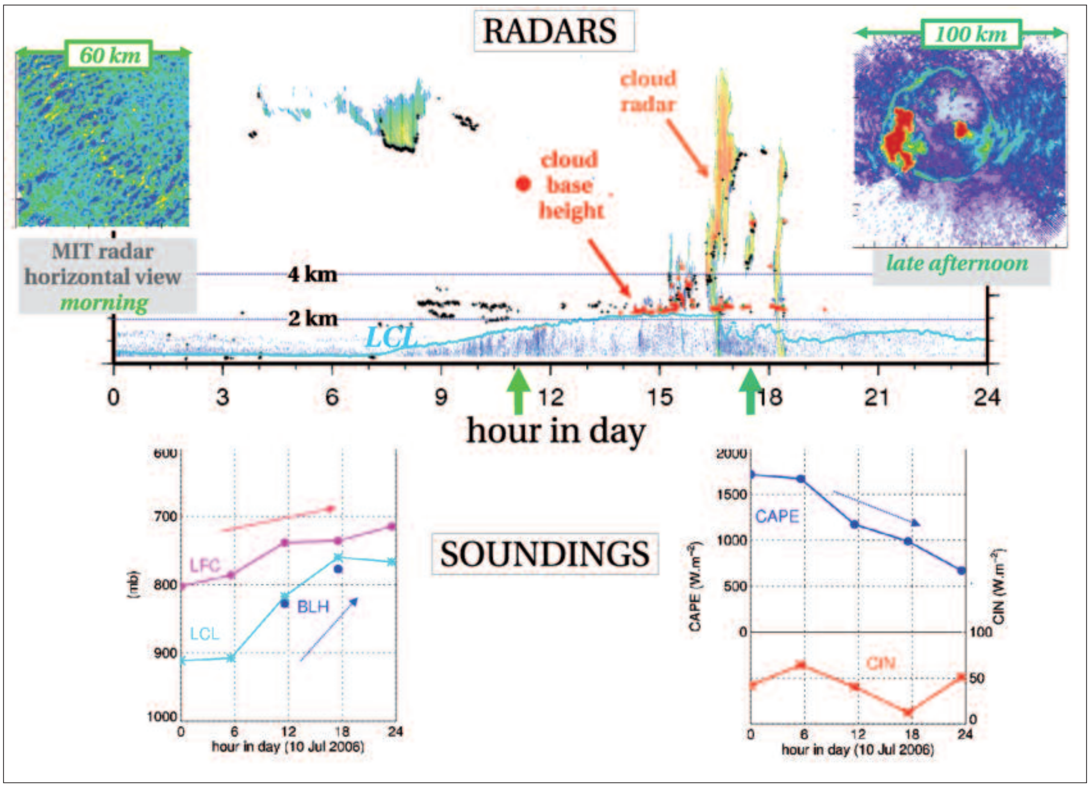
Some of the participants at the 3d AMMA conference, Ouagadougou, July 2009.

1

(a) Mean Total Column Water Vapour (TCWV) differences (experiment minus control) during August 2006. Negative (positive) values indicate that the control assimilation is more moist (dry) than the experiment.
(b) Diurnal cycle of TCWV near TIMBUKTU (MALI) estimated using GPS measurements and using analyses from CTL and from EXP assimilation experiments. Statistics are for 45 days (from 01/08/2006 to 14/09/2006).

2





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View of a daytime convective development from MIT and cloud radars (top panel), the soundings labelled LCL, LFC and BLH represent the lifting condensation level, the level of free convection and the boundary layer height respectively (bottom panel).

The African Monsoon Multidisciplinary Analyses (AMMA) Land surface Model Intercomparison Project: current status and perspectives

A high priority of AMMA is to better understand and model the influence of the spatial and temporal variability of surface processes on the African monsoon. This is being addressed through a multi-scale modelling approach using an ensemble of land surface models (LSMs) which rely on dedicated satellite-based and land surface parameter products, and data from the AMMA observational field campaign. The international coordination of the land surface modelling activities is supported by the AMMA Land surface Model Intercomparison Project (ALMIP).
In the recently completed ALMIP Phase I, a dozen different groups from the international community performed multi-year simulations (2002-2007) over West Africa. The LSMs were able to produce spatial and temporal soil moisture patterns consistent with the remotely sensed brightness temperature. At the grid scale, ALMIP surface sensible heat flux estimates had the same basic response to the wet season as seen in aggregated fluxes from local scale observational sites (see figure). The LSM simulations are currently being used extensively for hydrological modelling, regional scale water budget estimates, mesoscale atmospheric case studies (initialization and evaluation), and the evaluation of regional and global scale atmospheric models.
In the next ALMIP Phase, LSMs will be evaluated using observational data from the three heavily instrumented super site “squares” of the AMMA-CATCH observing system, which cover a north-south transect encompassing a large eco-climatic gradient.

4

Cold Tongue and African Monsoon

Although it is well known that the African monsoon depends strongly on energy gradients between the Gulf of Guinea and West Africa, our knowledge on the formation of the tongue of cold water (or Cold Tongue: CT) and its interactions with the monsoon is far more limited. That is why one goal of the AMMA (2006) experiment was to study the tropical Atlantic upper-layers and their impacts on the monsoon.
Each year from May to August, the Sea Surface Temperature (SST) south of the equator drops by 6 to 8°C with the strengthening of south-easterly trade winds in the southern hemisphere; this is the CT event.
Explanations of the processes that generate the CT are based either on the Ekman pumping theory or on the propagation of Kelvin waves along the equator. However, these schemes are too simplified; they do not consider the equatorial current system which is formed by the westward surface current (the South Equatorial Current: SEC) and the eastward sub-surface current (the Equatorial Under Current: EUC).
Vertical motion in the ocean can be inferred from the geostrophic balance. Geostrophy at the equator links the vertical shear of zonal current to the concavity of the pressure field. When winds break or disturb this connexion, the fluid tends to restore the geostrophic balance by readjusting the pressure field through a vertical velocity. This conceptual scheme is shown in figure a. In May, when the trade winds are strengthening, the SEC and the vertical shear of zonal current intensify. Then the pressure field adjusts to the new current system through an upwelling which carries deep cold water towards the surface. An illustration of this adjustment in a 3D ocean model is shown in figure b. The equatorial upwelling is thus an indirect oceanic response to the surface wind and not a direct response of the Ekman pumping.
This understanding of CT behaviour is entirely new and suggests that the biases of climate models (reversed zonal SST gradients at the equator; EUC unrealistic or absent) may be due to a poor representation of this adjustment mechanism.

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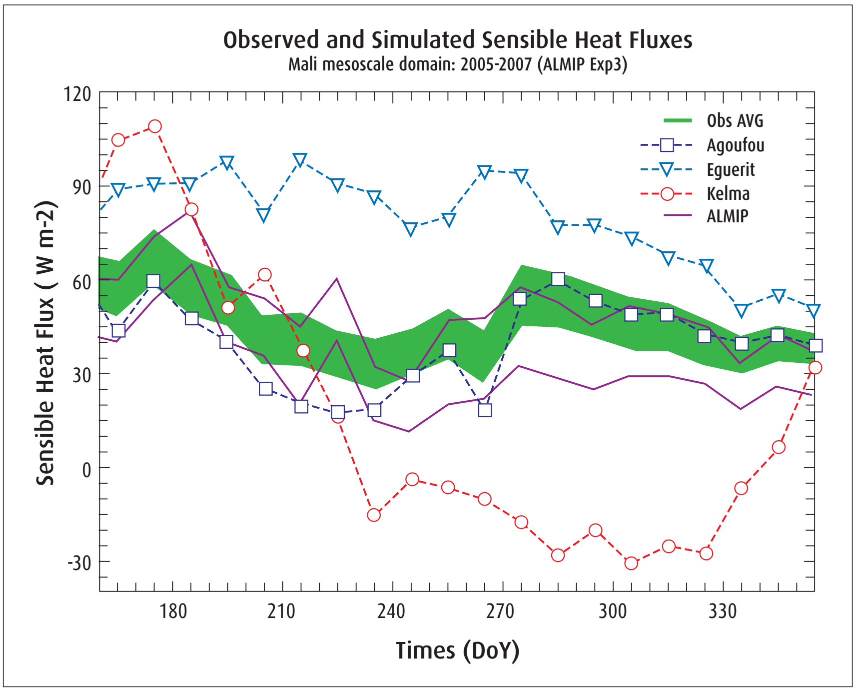

The three-year average (2005-2007) observed sensible heat flux for the three local sites within the Mali super-site are indicated by the non-filled symbols, and the shaded green area corresponds to the spread of the spatially aggregated fluxes (representing the 60x60 km2 meso-scale domain). The dashed curves enclose the spread (1 standard deviation) of the ALMIP multi-model average.

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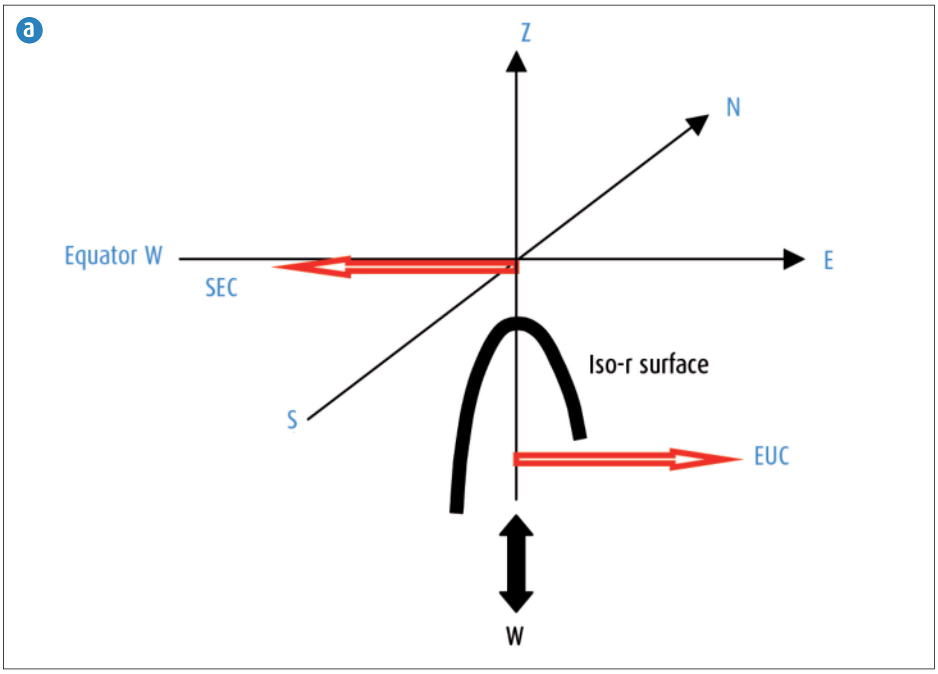
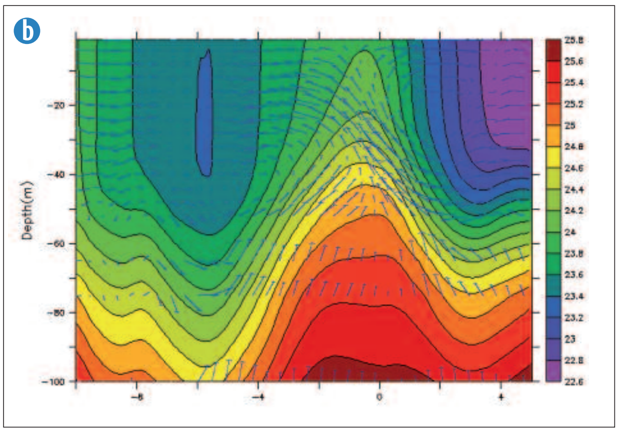


a - Conceptual scheme of the zonal current system at the equator (red arrows), the westward south equatorial current (SEC) at the surface and the eastward equatorial under-current (EUC). The vertical velocity W tends to adjust the concavity of the iso-pressure/density to the vertical shear of zonal current.



b - Meridian vertical section between latitudes 10S and 5N of the current vector (v: meridian velocity; w: vertical velocity) superimposed on the density (colour field). The equatorial zonal currents system (Latitude=0) is perpendicular to the section. The equatorial convergence restores the concavity of the density/pressure field at all times and sustains the vertical shear of the zonal current. The realism of the equatorial under-current depends closely on this convergence.

Climate and climate change studies

At Meteo-France, research on climate modelling mostly focuses on the impact of human activities on climate and on atmospheric chemistry, climate regionalization, long-term predictability and ocean-atmosphere interaction studies. These issues are of prime importance to Météo France as can be understood from the main orientations of the 2009-2011 objective goals. Among the six orientations, one explicitly mentions the will to meet the challenge brought by climate changes, and their impact and consequences on the environment and economic activities.

In 2009, in the field of large scale climate variability, several simulations were carried out to analyze the remote connections between tropical and extra-tropical regions. Some of the findings show that, even though the correction of tropical biases has little or no overall effect on extra-tropical biases, the situation is different for some specific cases in special weather conditions. The year 2003 was investigated in depth.

Regarding possible large-scale climate evolution, the CNRM-CM5 model that will be used to make IPCC simulations has reached its final development stage and is currently being evaluated. This model will have twice the resolution obtained previously. It will also innovate with the addition of a new radiative code developed by ECMWF and will include the SURFEX module, which makes it possible to integrate the latest developments on the representation of land surfaces into the climate model. One of the main advances of the early simulations is a great improvement in Arctic sea ice simulations, thanks to a better representation of atmospheric dynamics.

Within the framework of the "Cyclone & Climate" project of the French National Research Agency («Agence Nationale de la Recherche»), some ARPEGE-Climat forced experiments have been carried out on anomalous sea surface temperatures retrieved from the simulations of 15 IPCC models. The forced model gives a fairly good representation of the dispersion of cyclogenesis responses to climate changes, which goes to show the importance of simulating sea surface temperatures.

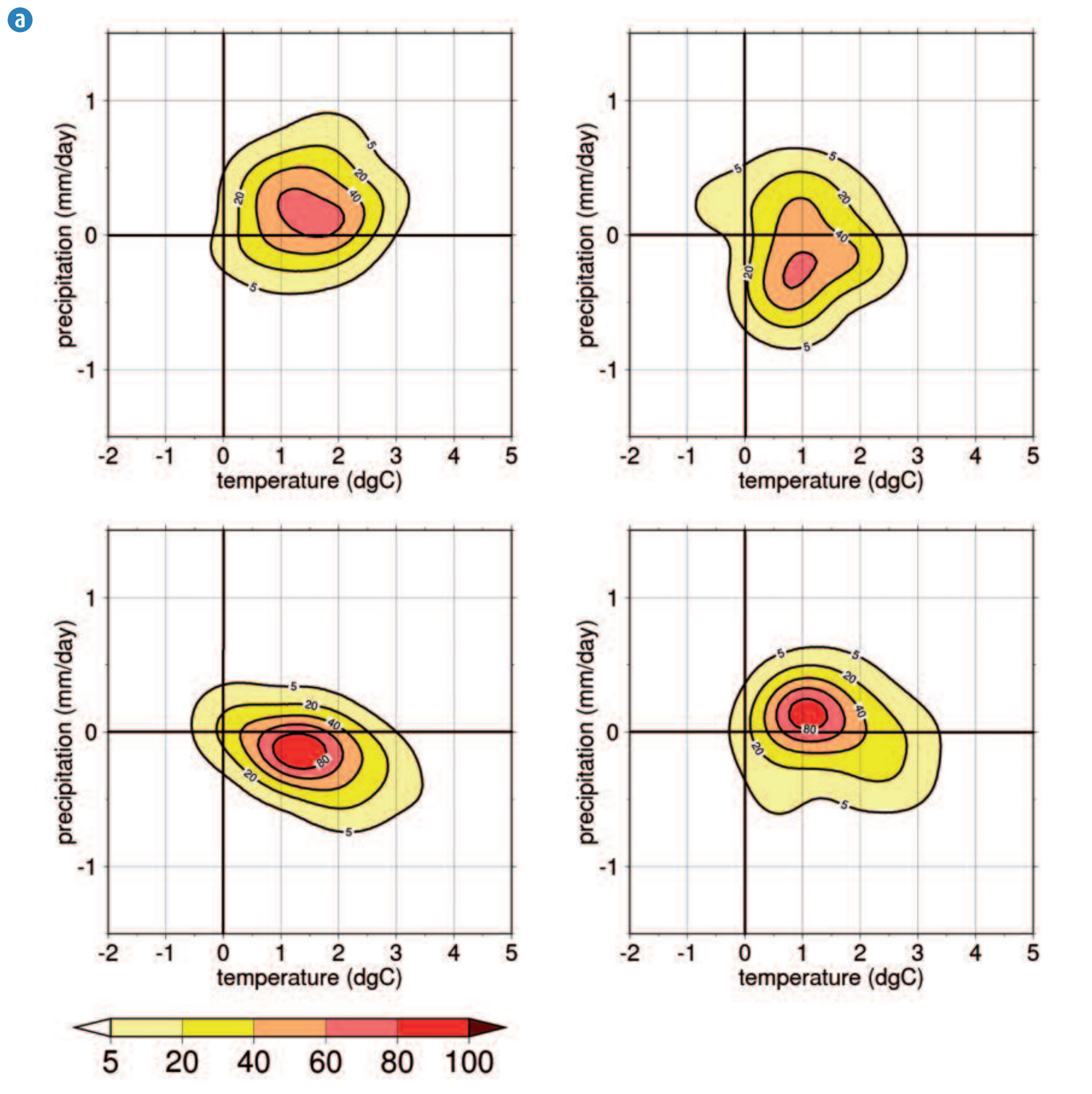
In the field of climate regionalization, results from the European ENSEMBLES project have given an estimate of the probability of climate changes (temperature and precipitations) for European capital cities (Fig.a). Other fields of study deal with climate uncertainties and their sources, water and heat fluxes in the Mediterranean basin and weather regimes in Europe. New Aladin-Climat and ARPEGE-Climat simulations have been carried out, among them, a global 50 km resolution simulation and also variable-resolution simulations, for which the pole is located at various positions of the globe, which have been found to be quite valuable. Within the framework of the ANR-SCAMPEI project, 12km resolution climate change scenarios over France have been implemented to study the impact of climate changes on mountainous regions. In 2009, new high-resolution numerical tools were implemented in the latest twin ALADIN-Climat/NEMOMED8 model for the Mediterranean basin.

In the area of climate change detection and attribution, studies based on the latest statistical methods have been extended to precipitation over France. They reveal signs of a modification of the spatial distribution of yearly mean precipitation. Furthermore, a new regional scale methodology for allocating climate changes has been developed and successfully tested on academic cases.

In the field of seasonal prediction, coupled or non-coupled simulations have shown that predictability scores are not sensitive to the version of ARPEGE-Climat physics parametrizations as similar scores are obtained whether version 4 or version 5 is used. Furthermore, a version of the ARPEGE-Climat model with the pole centred on the Mediterranean Sea, coupled with a global ocean model, has been brought in to make seasonal prediction simulations at a higher resolution over West Africa.

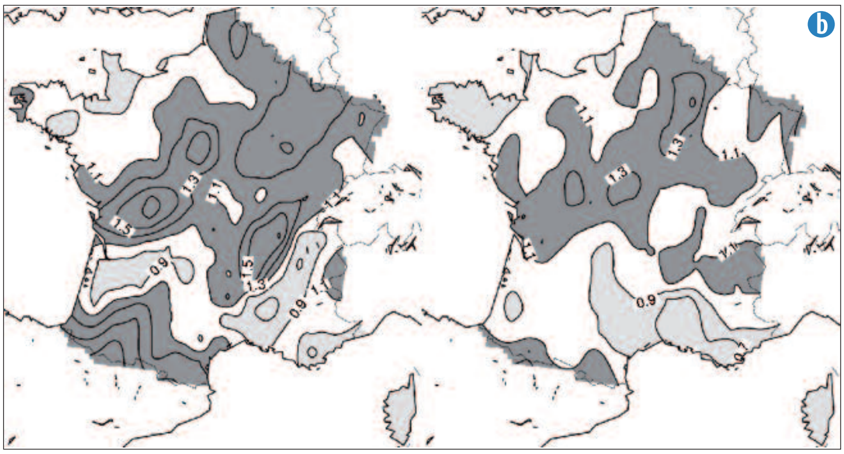
In the area of chemistry-climate interactions, CNRM took part, for the first time, in an international CCMVal comparison exercise dedicated to the next "Ozone Assessment" report. The first findings show that the model of stratospheric climatology is no better or worse than other models for the south hemisphere (Fig.b) on average, but they also point out some flaws, such as the absence of the Quasi-Biennial Oscillation. The chemical behaviour of the model called CNRM-ACM (ARPEGE coupled with MOCAGE) agrees with that of most other models.

1



a - Joint probability distributions of temperature (in degrees) and precipitation (in mm/day) variations for Paris for 2021-2050 relative to 1961-1990 following the A1B emission scenario. These distributions are built from a balance of 16 climate model results (with resolutions of around 25 km) for winter and spring (top, from left to right), and for summer and autumn (bottom, from left to right).

1



b - Ratio between the 99.9% quantile of the 1960-2000 summer rainfall simulated by ALADIN-Climat forced by ERA40 reanalysis, and that of the SAFRAN observation analysis. ALADIN-Climat has a 50-km resolution (left panel), and a 12-km resolution (right panel); SAFRAN reanalysis has an 8-km resolution.

Climate change studies

Characterizing urban trends in long climate series: the example of Vienna (Austria) temperature series

Long instrumental climate records are the basis of climate research. However, these series are usually affected by artificial shifts due to changes in the measurement conditions (relocations, instrumentation and other changes). As artificial shifts often have the same magnitude as the climate signal, such as long-term variations, trends or cycles, a direct analysis of the raw data series can lead to wrong conclusions about climate change. These abrupt changes can be detected and corrected using classical statistical homogenization procedures but more gradual changes, caused by urbanization for example, may also alter the series.
UBRIS, a new correction model, has been developed to handle the problem of gradual changes in the series. UBRIS is able to separate artificial urban and natural climatic trends: it proposes significance tests for the artificial trends, which, used together with correction of abrupt shifts, allows artificial urban trends to be removed if the user so desires.
In collaboration with ZAMG, UBRIS is being tested on 13 Vienna (central, suburban and rural) temperature series. We have shown that urban trends affect only suburban series. The order of magnitude of these additional trends is +0.05 to +0.1°C per decade. Central series, for which the environment was already urban when the records started, do not exhibit significant urban trends. Taking into account the possible presence of gradual artificial changes caused by urbanization, UBRIS proposes an improved estimation of climate change in observed instrumental temperature series.

2

Toward the 5th IPCC report

Contributing to the next IPCC report, to be issued in 2013, requires new simulations of past and future climates to be run in early 2010. To this end, a new global coupled climate model, CNRM-CM5 has been developed in collaboration with Cerfacs.
This model is based on the coupling of the most recent versions of NEMO ocean and ARPEGE-Climate atmospheric general circulation models. CNRM-CM5 has a horizontal resolution of about 1° in longitude / latitude, to be compared with the 2° resolution of the current version of CNRM-CM. The sea ice and river routing components of CNRM-CM5 are respectively GELATO and TRIP. A new radiation scheme has been included in ARPEGE. Moreover, continental processes and ocean-atmosphere energy exchanges are now represented by the new SURFEX platform. The representation of some forcing factors that contribute to the shaping of climate change and variability has been improved. In particular, the simulated climate impacts of sulphate aerosols and volcanic eruptions have been confronted with observations. Lessons learned from this comparison have allowed the representation of these processes to be improved in CNRM-CM5.
Many test-simulations have already been run with CNRM-CM5, suggesting that several aspects of the climate simulations produced by this new model are clearly improved. In particular, the representation of sea ice in the Arctic is more realistic due, among other reasons, to much better simulated atmospheric dynamics. The El Niño phenomenon and its impact on the African monsoon are also better simulated.

3

A climate scenario at high resolution over the globe

Since computers have been used to try to solve numerical equations of the atmosphere, the choice of a horizontal resolution has been a crucial question. A better outline of seas and mountains leads to a better representation of weather and climate.
By choosing ARPEGE in the early 1990s, Météo-France acquired a numerical tool that favoured the resolution of a certain area of the globe in order to take best advantage of the available computer power. During the last few years, we have carried out a series of numerical simulations of the 1950-2100 period using IPCC scenarios for the ocean evolution and downscaling atmospheric variables. In these experiments, the resolution varies between 50 km in the target area and 300 km at the antipodes. In most cases, the target area is Europe, but two scenarios focus on North America and one on the Far East. Nevertheless, many other areas are not yet covered at high resolution.
The recent acquisition of the NEC-SX9 computer by Météo-France and its large availability during the first weeks after its implementation allowed us to perform an experiment that was huge in terms of computer resources: 150 years simulated with a uniform 50-km resolution over the globe. The figure shows the model response during winter and summer for temperatures by the end of the 21st century.

4

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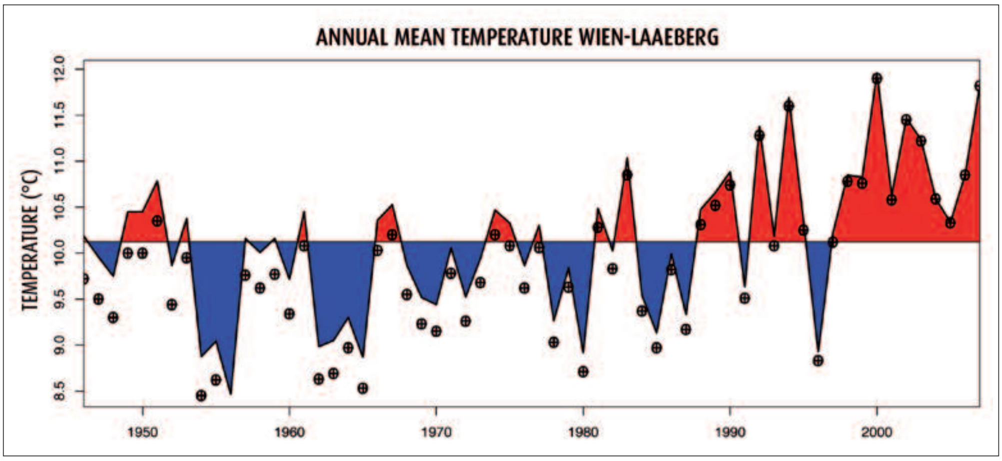
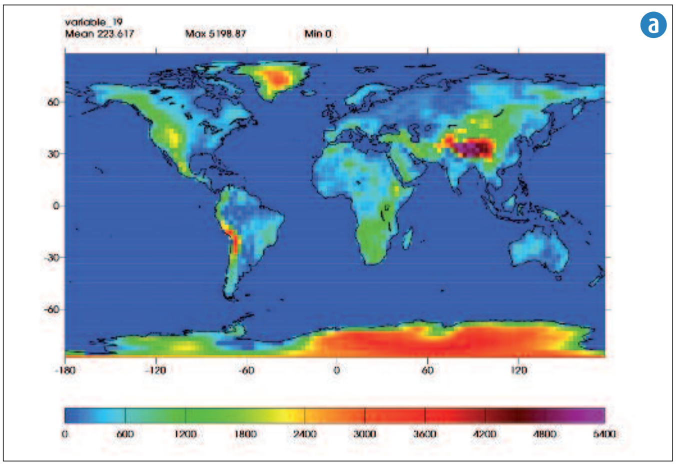


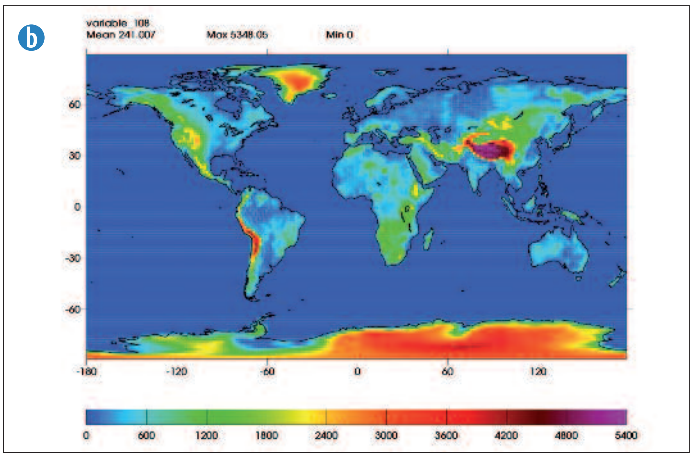
◀ Evolution of annual mean temperatures of Vienna-Laaerberg suburban series, after correction of abrupt changes (Å) and elimination of artificial trends by means of UBRIS (solid line).

3



◀ a - Orography representation in the previous CNRM-CM version.

▼ b - Orography representation in the new CNRM-CM version.



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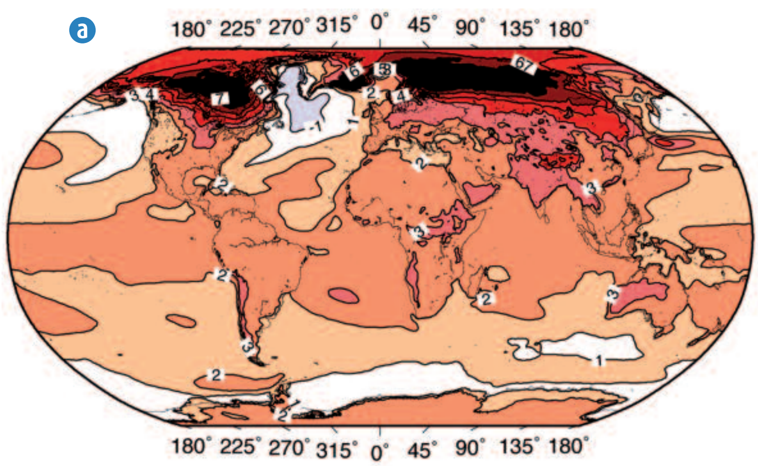
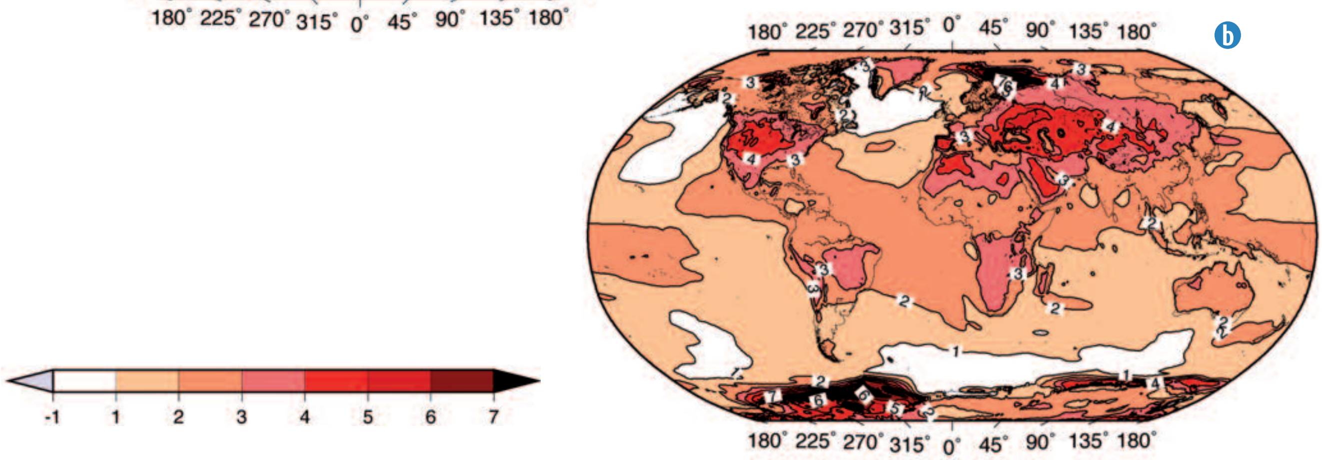


Mean temperature difference between 2071-2100 and 1961-1990 for boreal winter (a) and summer (b); contour interval 1 K.



Statistical detection of climate change

One key issue when studying human influence on climate is to properly assess the climate change signs that can be observed. In order to perform such an evaluation, the IPCC has introduced the concept of climate change detection, which involves separating climate change signals from natural internal climate variability.
The work done by Météo France in the field of detection has firstly concerned the statistical tools. Suitable methods for climate change detection at the regional scale have been introduced in order to extend the analysis performed at the global scale. These methods were then applied to temperature and precipitation homogenised datasets covering France. Significant changes were highlighted on annual and seasonal mean temperatures. The global temperature increase was again found but, above all, these studies identified the spatial pattern of current climate changes. This pattern is "robust" from a statistical point of view and, in consequence, could be studied from a physical point of view or compared with the patterns provided by climate model simulations. By studying annual precipitation, some significant changes have also been highlighted over the 1900-2006 period, although the sign of the change depends on the location. Additional results have been obtained over the Mediterranean area, in the context of the European project CIRCE.
In order to improve the description of current climate changes, a wide range of additional applications of these methods can now be considered, in particular to other climate variables.

5

Regional climate change: probabilistic approach in ENSEMBLES project

One of the innovative features of the European project ENSEMBLES, which ended in 2009, was the delivery of probability laws for regional scenarios. For the years 2021-2050, the climate change response over Europe is, indeed, rather uncertain.
In this project, 14 regional models, including our ALADIN model, were used to produce an ensemble of possible scenarios at 25-km resolution over Europe. Some regional models were driven by several global models, leading to 17 simulations. In contrast to the previous European project PRUDENCE, it was decided that each model would receive a different weight. For this purpose, all regional models were driven by observations during the 1961-2000 period. For six types of diagnostics, each model received a mark evaluating the degree of similarity with observations. These marks were aggregated to produce a weight for each regional model. Then, each simulation received a probability proportional to the weight of the regional model. A probability law for the climate change response was calculated, based on three factors: the probability of each simulation, the internal variability of each model, and the possibility of intermediate models which were not in our sample.
The figure on page 27 shows the mean multimodel answer for each season, and the figure on page 31 shows the bivariate probability density function for temperature and precipitation in Paris for summer and winter periods.

6

Evaluating the impact of different modes of transport on the climate

Emissions by transport systems (land surface, shipping, and aviation) into the atmosphere are geographically widespread and occur at various altitudes. They are made up of carbon dioxide and a large variety of gases (ozone precursors) and aerosols (soot, sulphates). With sustainable development in mind, the EU financed the QUANTIFY research project, which aims to assess how much impact the various modes of transport have on climate change.
CNRM participated in this effort with specific runs of its coupled atmosphere-ocean circulation model. In addition to the radiative forcing by non-reactive greenhouse gases, the model was parametrized so as to produce realistic amounts of reactive gases, clouds, and particles that also contributed to the radiative forcing. The parametrization of chemical processes was validated using coupled runs of the Chemistry and Transport Model MOCAGE and of the Global Circulation Model Arpège-Climat.
6 transient runs from 1860 to 2100 were performed and compared, thus showing the impacts of CO_2 and other emissions, together with the impacts of different transport modes. By 2100 and for all modes taken together, CO_2 emission will have increased the surface temperature by 0.6°C. For the standard scenario studied, the contribution of aviation is about 0.2 degree and no transport mode dominates. Other emissions have a lesser impact, which depends very much on the mode of transport. Aviation emissions contribute to heating (production of ozone and of contrails that contribute to the greenhouse effect) whereas shipping produces cooling (additional reflection of sunlight by aerosol and cloud droplets, and a significant reduction of the methane life time). In conclusion, the non-CO_2 impact of transports in general appears to be limited, but this result only holds true for constant road traffic with improving exhaust quality.
This work helps to improve our understanding of the interactions between atmospheric chemistry and climate. Regional climate change has to be studied further to check if modification patterns could be related to specific modes of transport.

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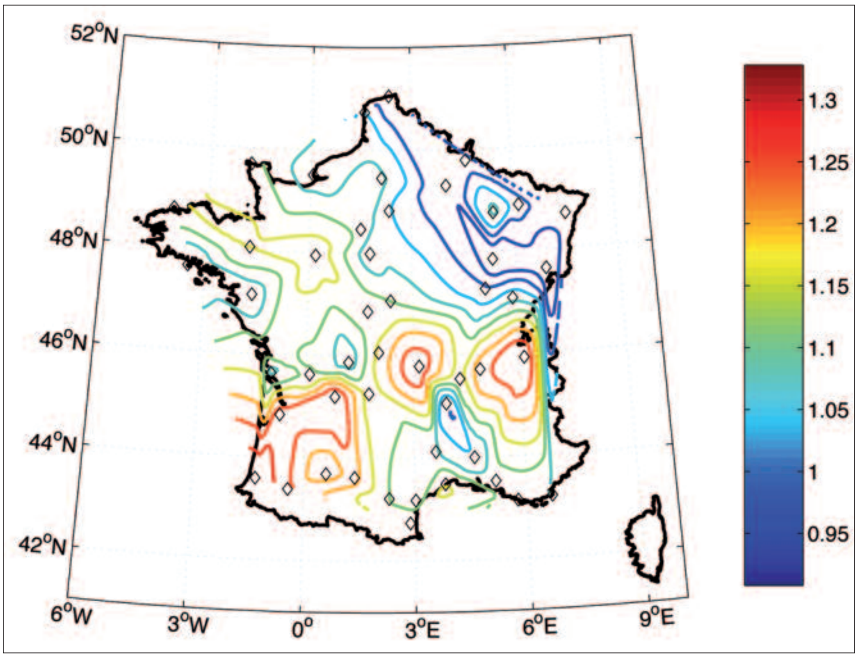

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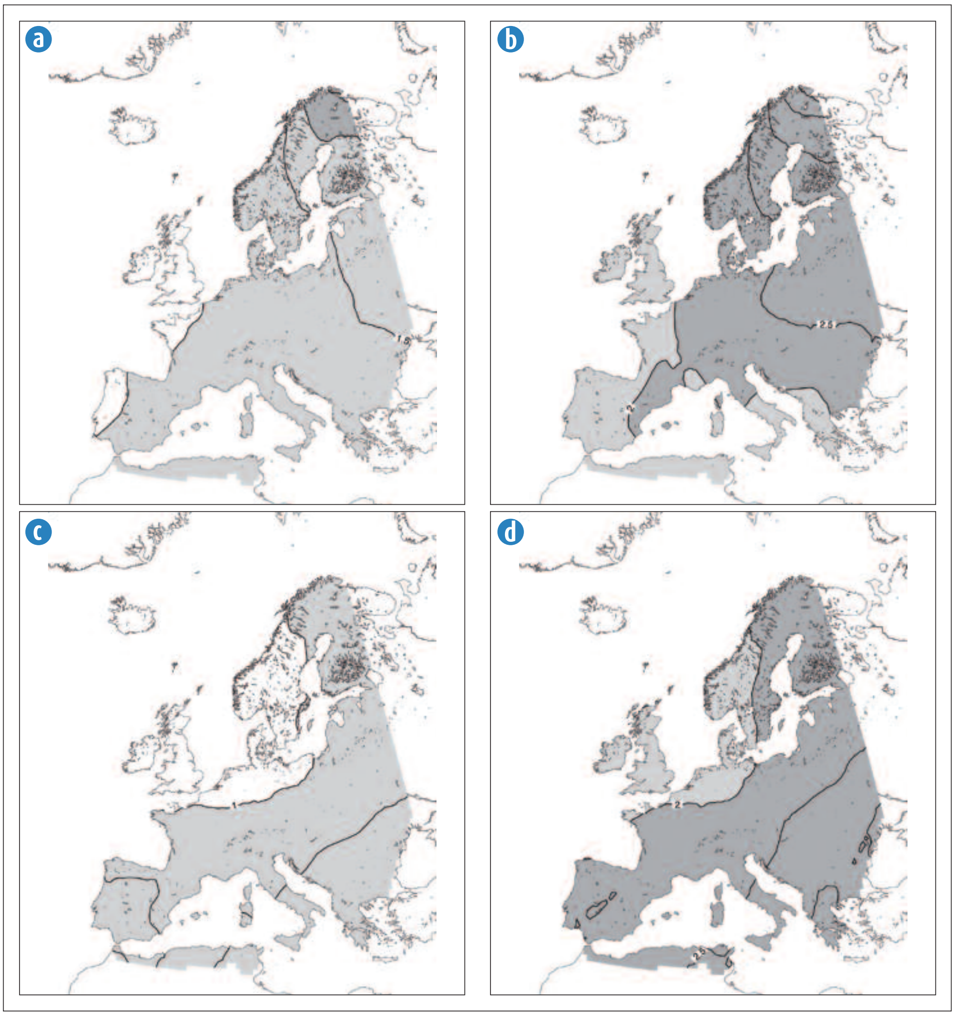
Spatial distribution of annual mean temperature change between 1900 and 2006 as estimated by a detection method (°C).



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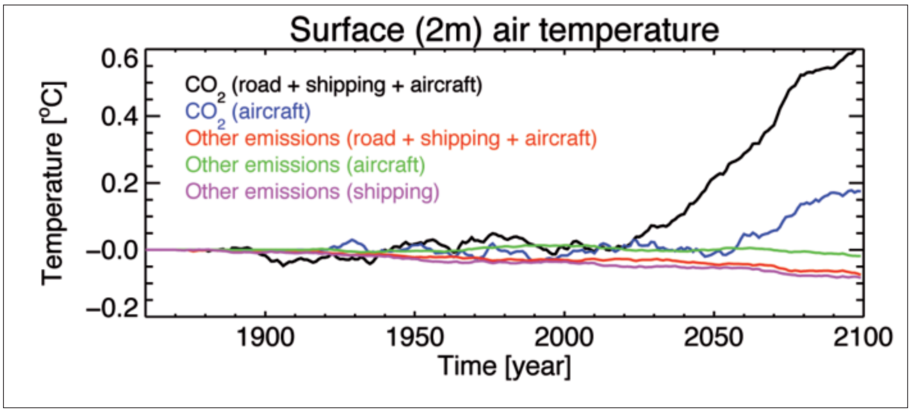
Mean response of ENSEMBLES multi-model (17 regional climate models) for winter (a,b) and summer (c,d) temperatures in 2021-2050 with respect to 1961-1990; lower (a,c) and upper (b,d) boundaries of a 99% confidence interval; contour interval 0.5°C.

7

Average temperature change until 2100 for the IPCC emission scenario SRES-A1, with separate contributions of CO_2 and other constituents, for different modes of transport (road traffic, aviation, shipping).



Impacts of climate change and adaptation strategies

Climatic trends over the last 50 years in the French Pyrenees: evidence of warming in the early 1980s and its impact on snow depth

Because of the insufficient amount of directly observed long-term snow data, the Safran-Crocus model chain has been used for retrospective snow and weather climate analyses in the French Pyrenees from 1958 to 2008.
The main task was to retrieve all the available weather data since 1958 for the entire Pyrenees (French or Spanish) to provide optimum data to the Safran variational analysis scheme. 50 years of Safran-Crocus runs were conducted for 10 massifs of the French Pyrenees and Andorra. The results showed a very good correlation for air temperature and persistent problems on the precipitation and snow depth (problems of snow measurements in mountains and snow drifts). These limits being known, a climatology of weather and snow was drawn up using the simulated data. The West/East gradient was quantified, with annual precipitation twice as marked in the west (>2000 mm) as in the East (<1000 mm) and warmer temperatures in the East (about 6°C at 1800m) than in the West (about 5°C). Irrespective of altitude, the snow depths were significantly higher in the West than in the East.
As an overall trend, the annual mean air temperature rose by about 1°C. However, variations were great depending on altitudes and regions. A common feature for all regions was a rupture around 1981. Precipitation trends were rather mixed, with a large year-to-year variability making it hard to see clear tendencies. At low and mid elevation, trends in snow depth evolution were mainly negative. This study will continue, integrating the Spanish Pyrenees for the European FluxPyr project.

8

Characterizing droughts in France (1958-2008) with the SAFRAN-ISBA-MODCOU hydro-meteorological suite

Droughts can have impacts on various socio-economic sectors (water supply, irrigation, hydropower, etc.) that are based on specific components of the land surface hydrological cycle. Water resource monitoring thus requires indices related to meteorological, agricultural, and hydrological droughts. This study proposes a retrospective analysis of such droughts in France with the SAFRAN-ISBA-MODCOU (SIM) suite, used to build a hydro-meteorological reanalysis at high spatial and temporal resolution over the period 1958-2008.
Meteorological droughts are characterized by the Standardized Precipitation Index on different time scales. Agricultural and hydrological droughts are identified by applying a similar standardizing method with respect to the local climate, for soil moisture and stream flow respectively. Such an approach provides a consistent way of assessing the propagation of droughts through the land surface hydrological cycle, by considering indices derived from water contents in each component of the cycle.
Drought event statistics over the 50-year period — number of events, duration, severity and magnitude — were derived locally in order to highlight regional differences at multiple time scales and at multiple levels of the hydrological cycle. Spatial-temporal characteristics of drought events were then compared with past events on the national scale, from multi-year precipitation deficits (1989-1990) to short hot and dry periods (2003). This multilevel drought climatology will serve as a basis for assessing the impacts of climate change on droughts in France.

9

Evaluation of climate change impact on forest fires

Forest fires are a significant risk in France. Météo-France has been requested to study the long-term trend in terms of fire danger at national level.
This study is based on Fire Weather Index calculation. Fire weather indices provide efficient guidance tools for the prevention, early warning and surveillance of forest fires. The indices are based only on meteorological input data. This kind of product can also be used for climatological purposes. Fire frequency and fire severity are difficult to assess using Civil Protection databases only. Databases which give access to past fire event data (size, duration, place, etc.) are usually incomplete and inhomogeneous. Moreover, this approach mainly identifies the anthropogenic effect (due to changes in human activities and soil occupation) rather than climate change impacts. Trends in fire danger can be studied through FWI reanalysis over a long period. In order to assess a long-term trend, FWI has been recomputed over a 50-year period by Météo-France. The Safran model has been used to derive a 50-year hydrometeorological reanalysis, running from 1958 to 2008. This database has been used as an input to the operational FWI module run by Météo-France in close collaboration with the Civil Protection organization.
First results are based on the comparison of 1961-1980 with 1989-2008. The comparison between the two study periods shows an overall increase of FWI in France (+22% between 1961-1989 and 1989-2008, or +24% for the summer period only). This increase in FWI is statistically significant in the south of France. The increase in average daily FWI during summer is locally very strong. It may reach 20 for some areas, like the Herault region and the South of Corsica. Trends are also very clear in terms of total number of days with FWI above a threshold. In many French regions, the annual number of days with FWI> 20 shows an increase from 10 to 50 days locally. The surface of the metropolitan area concerned by at least one day each year with FWI> 20 also doubled between the 1961-1980 period and the 1989-2008 period.
Thus, these results suggest an increase in the length of the fire season and an extension of the regions affected by forest fires.

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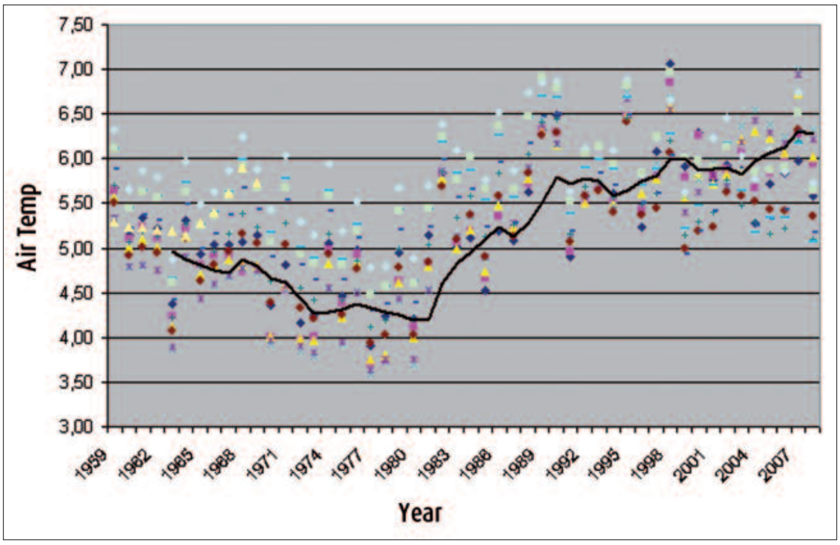

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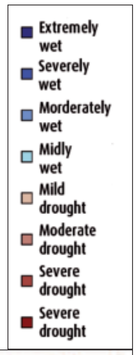
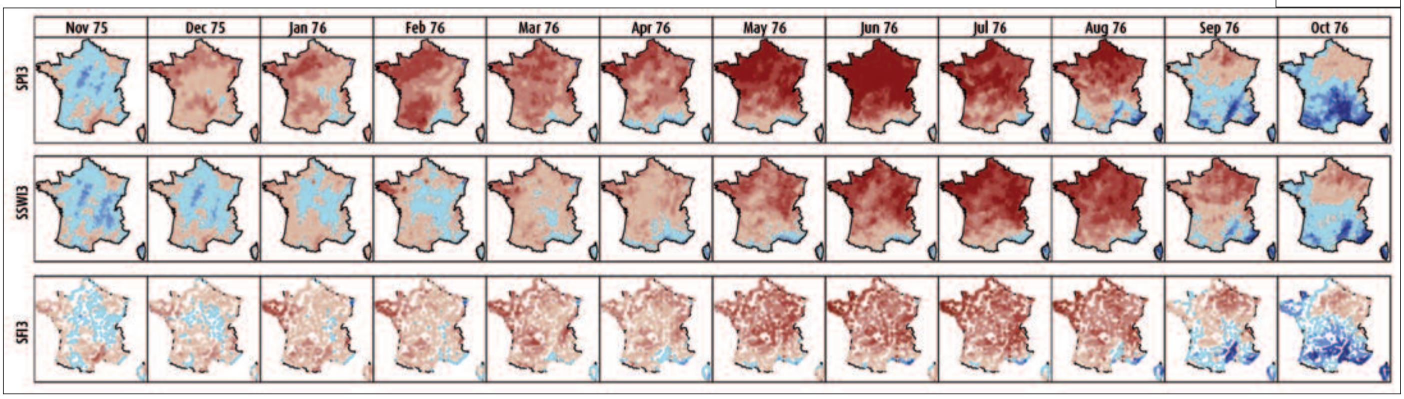
Mean annual air temperature at 1800 m from Safran (1958-2007) over the 10 French Pyrenees mountain massifs and Andorra, with a mean mobile trend over 5 years.





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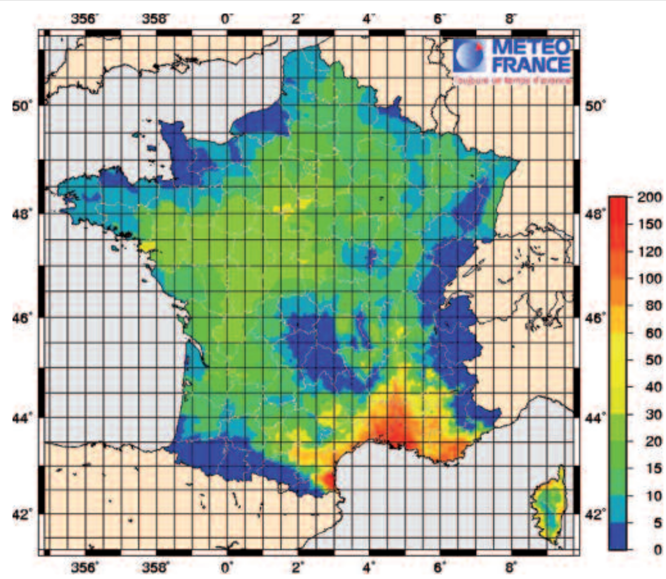
Evolution of the 1976 drought with indices based on 3-month deficits of precipitation (top), soil moisture (middle) and river stream flow (bottom).



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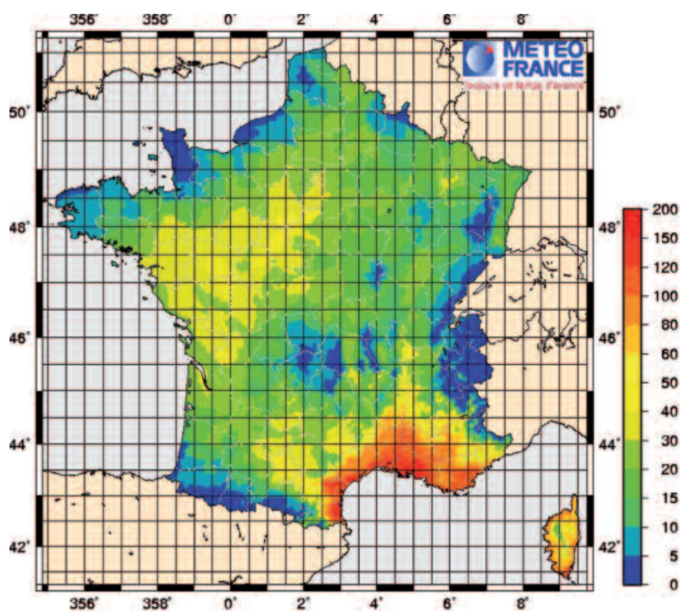

Annual number of days with FWI > 20 for 1961-1980 (left) and 1989-2008 (right).
The probability of a fire is very low when FWI < 20

A terrestrial carbon flux climatology over France

Vegetation and soil exchange energy, water, and carbon with the atmosphere. These fluxes are linked to soil moisture and to vegetation biomass. It is important to have a good knowledge of the seasonal and inter-annual variability of these parameters to assess the effects of climate change.
The ISBA-A-gs model describes the evolution of these variables, according to weather and climate events (e.g. droughts). Simulations at high resolution (8 km) were conducted over France for the period 1994-2006, using the ECOCLIMAP2 vegetation map and atmospheric variables from the SAFRAN climatology. The analysis of these simulations helped to better characterize the impact of the 2003 heat wave on soil moisture and on the leaf area index of the vegetation. The drought affected mainly south-eastern France and parts of northern France. The simulations show, however, that the anomalies in soil moisture and in leaf area index present different spatial structures. In particular, in July 2003, an unusual vegetation dieback mainly affected the Midi-Pyrenees region, the Rhone and the Saone valleys, the Limagne, the Forez plain, and coastal areas of Corsica. The vegetation dieback was less widespread than the abnormal drying of soils. In some regions, such as the Ardennes or the north of the Alps, the vegetation grew even better despite a drier soil. These differences were somewhat mitigated for August.
This result illustrates the complementary nature of these two variables, which may present a contrasting response to climatic events.

11

Climate change impact on French forest evolution

Global climate may deeply affect the flora diversity during the course of the 21st century but our ability to forecast these changes is rather poor. The goal of the QDiv project led by Paul Leadley (Ecologie, Systématique et Evolution, CNRS/Université Paris Sud) is to develop quantitative estimates of changes in the spatial distribution and diversity of plants in France that could occur due to changes in climate and atmospheric CO2 concentration. This work is based on a combination of observations, field experiments and mathematical models (statistical models or process-based models representing photosynthesis). Comparisons between observations, experiments and model predictions will improve the level of confidence in our predictions and generate a stronger consensus regarding the risks from climate change and rising CO2 levels.
CNRM and CERFACS provide each participant with high-resolution 21st century climate simulations over France. CNRM also uses the dynamic ecosystem model IBIS to simulate forested ecosystems. For the 20th century, the model simulates mixed forests with broadleaf deciduous and coniferous trees over most of France (Figure a) except around the Mediterranean Sea where broadleaf evergreen trees (like Holm Oak) and evergreen shrubs dominate. This reflects the natural vegetation in France. According to the model, by the end of the 21st century, broadleaf and coniferous forests will be limited to mountain regions and north-eastern France (Figure b) while Mediterranean trees and shrubs will be able to colonize the entire South-West.
Participants are now comparing results from the models to understand their differences to deduce robust predictions that will be tested against field experiments and presented to decision makers.

12

The “Grand Pari”: for an adaptation of the Paris region to climate changes

Météo-France was involved in the Descartes group, coordinated by the architect Yves Lion, to study the “Grand Pari de l’Agglomération Parisienne”, an initiative directed by the Ministry of Culture. Ten consortia (each including town planners, architects, researchers, engineers, etc.) made multidisciplinary studies and proposed broad overviews of how the Paris agglomeration should evolve until the year 2030.
All the consortia proposed to obtain a greener urban area in one way or another (in order to mitigate the global warming by CO2 recapture) but we, in addition, quantified the impact on the urban micro-climate of an evolution scenario (for the year 2030) for Paris and its suburbs (including the surrounding countryside). This scenario, built by other members of the Descartes consortium, is based on a 40% extension of forests (the new forests being exploited for timber and heating), extended water reservoirs and a switch in agricultural practices from cereals to garden produce. In addition, new reflecting paints are assumed to be used in the suburban part of the agglomeration. By integrating these scenarios into the MesoNH atmospheric research model, we showed (figure a) that, during heat waves, the Urban Heat Island temperature would decrease by 3°C in suburban areas and by 2°C in Paris itself (although no modifications were proposed inside the historical part of Paris).
The Descartes team has shown that it is possible to make realistic improvements over the whole of an existing city (Paris) and its suburbs, with favourable impacts on economics, leisure and greenhouse gas emissions, as well as on the local urban climate.

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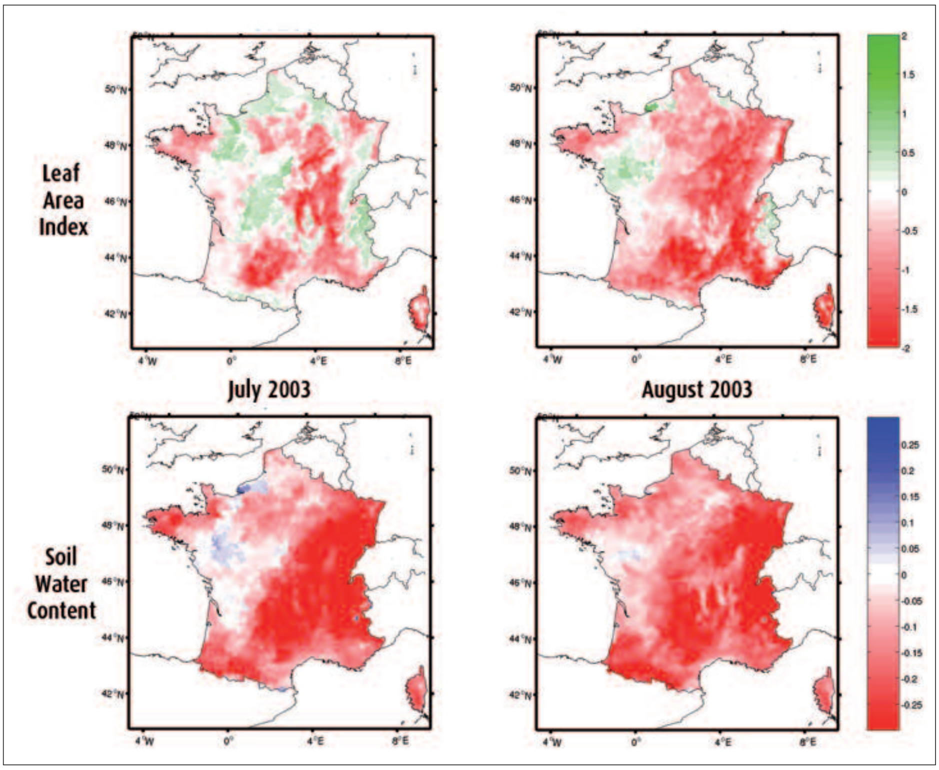

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Impact on vegetation of the 2003 drought, as simulated by the ISBA-A-gs model: anomalies for July 2003 (left) and for August 2003 (right) of leaf area index (top) and soil water content (bottom). A 12-year reference climatology (1994-2006) was used. The red colour represents a decrease of the variable considered in 2003 compared to the 1994-2006 average.

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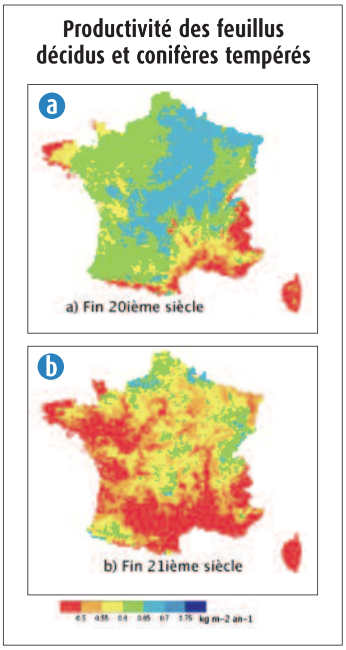

Net primary productivity of broadleaf deciduous and coniferous trees simulated by the dynamic ecosystem model IBIS a) at the end of the 20th century and b) at the end of the 21st century.

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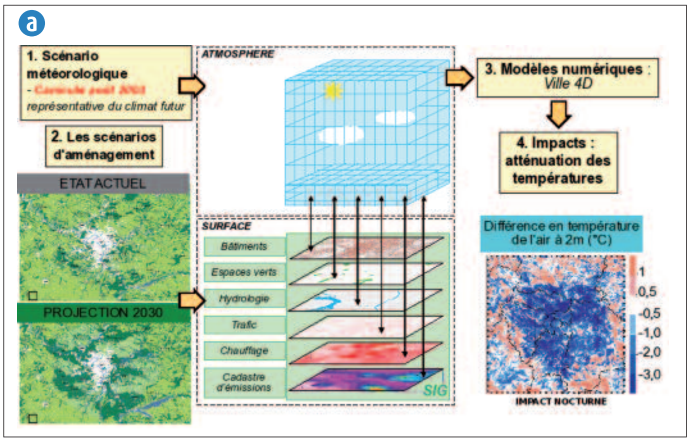
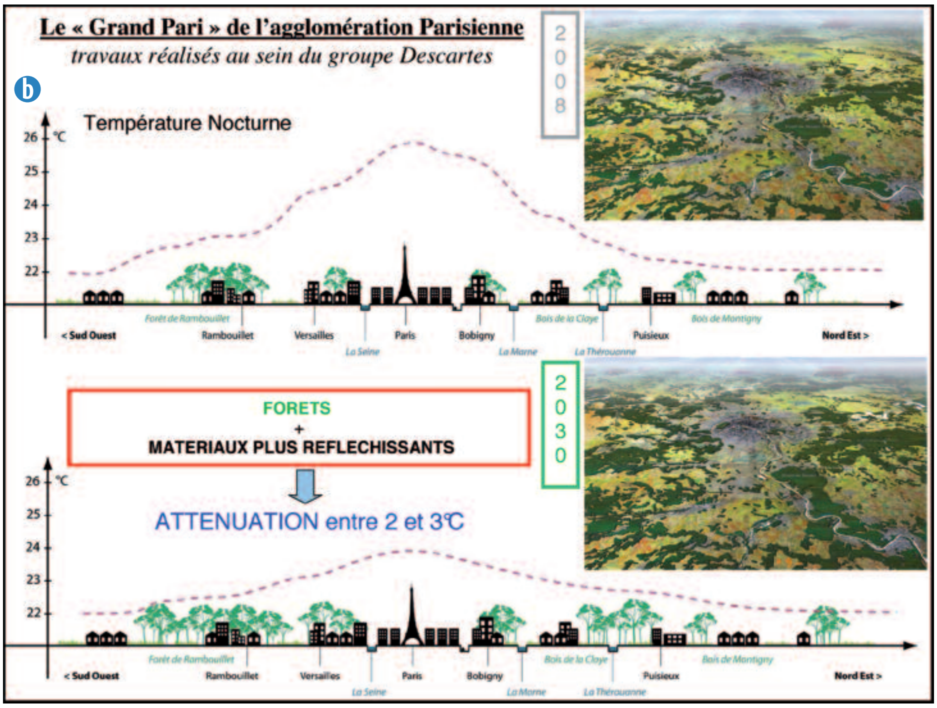


a - Methodology developed for the "Grand Pari" study.

b - The evaluated urban evolution would lead to a mitigation of temperatures of 2 to 3°C if a meteorological event like the heat wave of summer 2003 would reoccurred.



Atmosphere and environment studies

In 2009, numerous research activities were conducted in the areas of hydrometeorology, oceanography, snow cover, and chemical modelling. One of the major events of last year was the progress in discharge ensemble forecasts. Also noteworthy was the major Megapoli campaign, which aims to better understand the impacts of megacities on air quality.

Hydro-meteorology

Hydro-meteorological ensemble forecasting of heavy precipitation events in the Mediterranean region

South-eastern France is often subject to flash-floods generated by heavy precipitation events, especially in autumn. The forecasting of such events is affected by several uncertainties. The aim of this study is to define those uncertainties and their propagation from a meteorological forecast to a hydrological response. A hydro-meteorological ensemble approach has been designed and results are presented here for a quasi-stationary convective system case with high amounts of rainfall.

Taking account of fine-scale atmospheric uncertainty requires a specific ensemble prediction approach, which is why the AROME model is used. The uncertainty at synoptic-scale on both initial and boundary conditions is given by the eleven members of Meteo-France's large-scale ensemble forecasting system PEARP. Meso-scale data assimilation is also performed in AROME in order to be closer to the observations. Finally, the resulting AROME forecasts are used to drive the hydrological ISBA-TOPMODEL system to characterise the uncertainty on discharge forecasts.

The AROME rainfall fields show a significant variability of the simulated precipitation with respect to observations, both in intensity and location. Most of the hydrological forecasts underestimate the discharge but this ensemble approach has pointed out a possible flood of the Gardon river at Boucoiran, in contrast to the simulation using the deterministic AROME forecast.

The uncertainty due to initial conditions and modelling errors both for AROME and ISBA-TOPMODEL will be studied further in the framework of the French MEDUP project.

1

Impact of a streamflow assimilation system on ensemble streamflow predictions

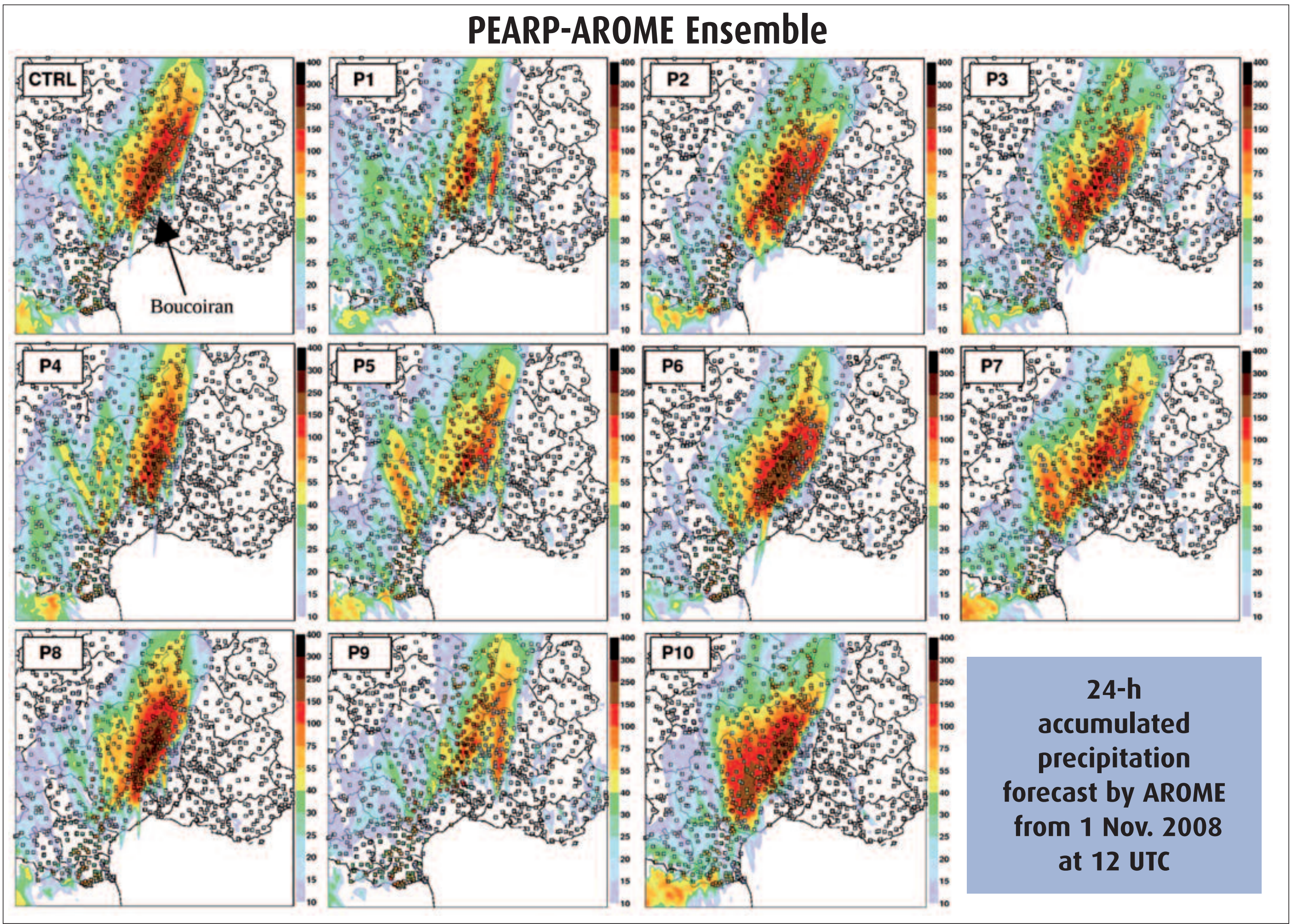
Several years ago, the hydro-meteorological SAFRAN-ISBA-MODCOU (SIM) suite was developed at Météo-France. SIM simulates surface hydrological balances and streamflows over all France (900 stations). An ensemble streamflow prediction system was built on this suite, using the ECMWF meteorological ensemble predictions (EPS) at a 10-day range. This ensemble streamflow prediction system showed its usefulness for alerts and pre-alerts.

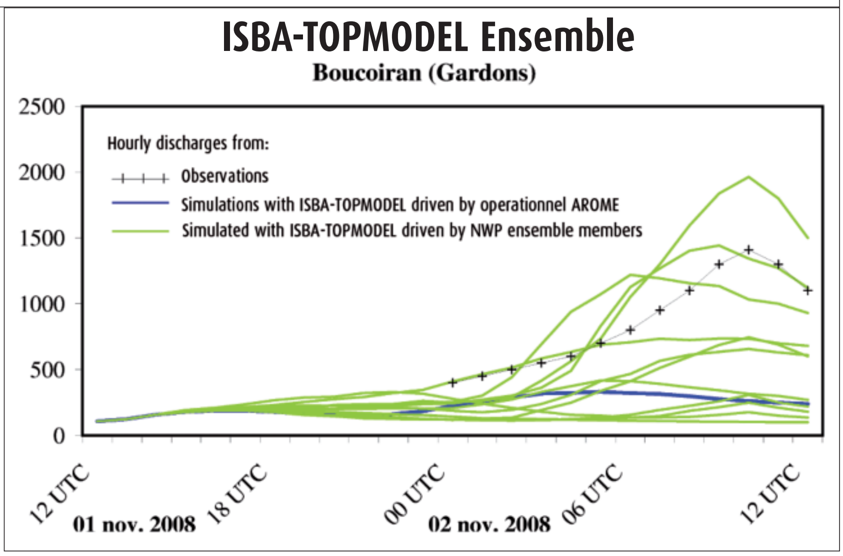
However, imperfections in the models and atmospheric forcing can lead to important events being missed. That is why a past discharge assimilation system was built from the Cerfacs tool PALM and implemented. It aims to provide initial states of better quality to the ensemble streamflow forecasts, the idea being to modify the SIM soil moisture in order to bring the simulated streamflows closer to the observed ones. Moreover, an improvement of the physics of the model was tested.

The ensemble streamflow forecasts initialized by the assimilated initial states were compared to the source ones for an 18-month period. This comparison showed a clear decrease in the error for the whole time range, which was due to the assimilation system itself for the first days and, then, to the improvement of the physics of the model. The ensemble scores were improved as were the scores used by the forecasters, which means that these forecasts will be easier for the Flood Prediction Services to use.

An operational implementation of the assimilation system is expected in the near future.

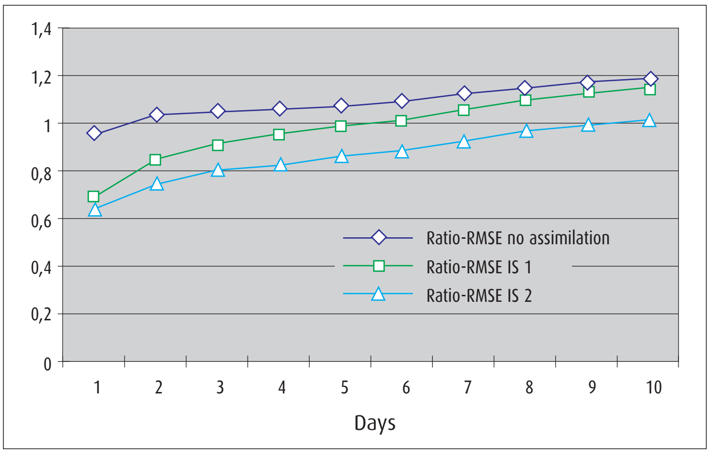
2





Hydro-meteorological ensemble simulations performed with the fine-scale atmospheric AROME model (left) driving the hydrological model ISBA-TOPMODEL (right). The simulated discharges (m3.s-1) are estimated at Boucoiran for the Gardon watershed. Accumulated rainfall rain-gauge observations are represented with squares. The hydrological simulation using a deterministic AROME forecast as input is the blue line and observations are represented with crosses.

1



2

Ratio-RMSE (standardized root mean square error) for the mean of the ensemble averaged for 148 stations from 10 March 2005 to 30 September 2006. The ensemble streamflow predictions without assimilation (blue), the ensemble streamflow predictions using the streamflow assimilation (green) (IS1), and the ensemble streamflow predictions using the streamflow assimilation and the improved physics (light blue) (IS2).

Oceanography (modelling and instrumentation)

In the field of oceanography, the CNRM is responsible for the development of drifting and fixed buoys that will enable interactions between ocean and atmosphere to be taken into account. We are helping to improve measurements on SVP buoys, and studying new data transmission systems, like Iridium. In 2008/2009, the participation in CAROLS and AMANDES campaigns helped to make ocean surface salinity measurements more reliable. Contributions to SMOS data validation are being made in the framework of the GLOSCAL programme.
The Eumetnet Council has given Meteo-France the responsibility for the EUCOS marine surface observation programme (E-Surfmar) until the end of 2011. The CMM team (which is one of the CNRM departments) is in charge of carrying out this action. This also leads the number of observations made by boats to be increased through the development of simple automatic stations (MINOS, BAROS) and the optimization of transmission costs (data compression, use of Iridium technology for transmission).
Participation in the management council of the PREVIMER project also allows us to evaluate the needs in coastal oceanography. On this subject, studies for a dedicated observation site started in 2009. The site will be developed in cooperation with many other partners.

3

SVP-BS drifting buoy (barometer and salinity).

3

The Marisonde "NG" drifting buoy, a tool for campaigns at sea

The Marisonde GT drifting buoys were built in the early 90's. They transmitted their data and were located through the Argos system. They measured wind speed, wind direction, atmospheric pressure and sea temperature at depths down to 200 meters. The technical solutions to have longer bathythermal chains showed their limits (limits due to the number of conducting wires and to the weight of cables). In order to increase the number of sensors, it was deemed necessary to develop an electronic device able to process a new type of bathythermal chain.
The idea is to dialogue, by "bus", with different sensors which are regularly spaced along the chain. The electronic board of the new generation of Marisonde was built to interface four buses. The sensors of the bathythermal chain are alternated on two buses in order to be able to obtain a temperature profile even if one bus fails.
The upgrade to the Marisonde New Generation (NG) fleet started in 2007 and is still in progress. About fifteen buoys will be deployed at sea during campaigns for sea-air interaction studies. The 300 metres long bathythermal chain is built with 16 temperature sensors and 4 hydrostatic pressure sensors on two buses.

4

Diurnal warming in the Arctic Ocean observed by satellite radiometry

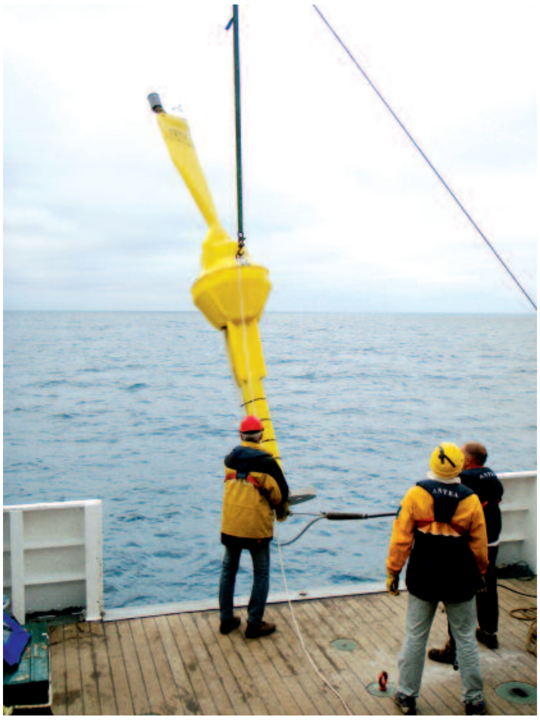
In the framework of the OSI SAF (EUMETSAT Ocean and Sea Ice Satellite Application Facility), Meteo-France's Satellite Meteorological Centre (CMS) has been producing 1-km-resolution sea surface temperature (SST) maps derived from METOP data since 2007. These maps are extensively validated, particularly in problematic areas such as the Arctic Ocean.
During the summer of 2008, the CMS operational team in charge of validating the OSI SAF products observed warm spots in the Arctic similar to those usually observed at mid latitudes in calm wind and high insolation conditions. To study this problem, an intensive observation experiment was organized in collaboration with our colleagues at the Norwegian Meteorological Office (Oslo) and at the University of Southampton. All satellite SST data from various sensors (AVHRR, MODIS, AMSRE,...) available during the summer of 2008 were gathered over a common grid to study the daily SST cycles (figure a). Diurnal warming is considered as significant if a daily amplitude of 1K is recorded by at least 3 sensors. These cycles are confirmed by the analysis of METOP SST patterns and the coincident METOP/ASCAT wind fields (figure c). This experiment revealed significant warm spots as far as 80°N (figure a).
Besides the meteorological and oceanographic implications of such phenomena, it is necessary to take these warm spots into account in the use of satellite SSTs. As they are superficial and transient, they must be removed if the aim is to construct coherent "foundation" temperature fields (below the diurnal thermocline).

5

A new dissipation term in the Meteo-France global wave model

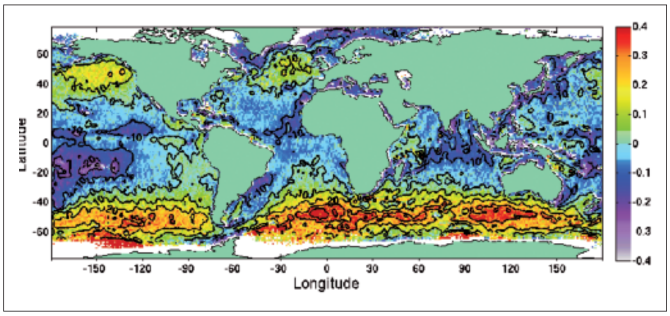
Thanks to a collaboration with SHOM and IFREMER, a new 3rd generation wave model (MFWAM) has been in use in the operational suite of Météo-France since April 2009. This model is an adaptation of the ECMWF wave model ECWAM with new formulations to take wave dissipation into account better. Although advances in numerical modelling and assimilation techniques associated with the use of data from many space-based sensors have improved the accuracy of surface wind analyses and forecasts at global and regional scale in recent years, some serious errors still persisted, especially in the tropics. Studies initially performed at Météo-France showed that these problems came from the dissipation term, and changes were proposed to improve it. Since then, the scientific community has been hard at work to better understand and parametrize wave dissipation mechanisms using the most recent advances, thanks to the joint efforts of SHOM, IFREMER and Météo-France in connection with the use of remote sensing data from CNES and ESA.
The new swell dissipation uses a threshold mechanism rather than the average wave steepness. This also leads to better wave growth. Adjustments still need to be made in order to reduce the residual biases, e.g. as encountered in the southern seas.

6



4

Deployment of Marisonde NG by RV Antea (Copyright Denis Dousse/Locean) for sea temperatures at depth during GOGASMOS in 2009 in the Bay of Biscay.

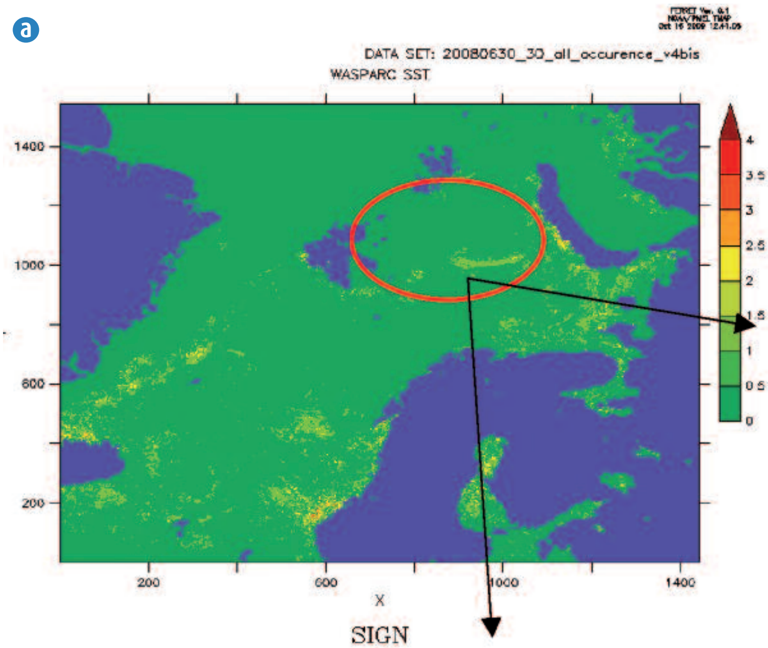


6

Map showing the mean difference between the significant wave height from the MFWAM wave, over a one-year period, and those measured by Jason, Envisat and GFO altimeters.

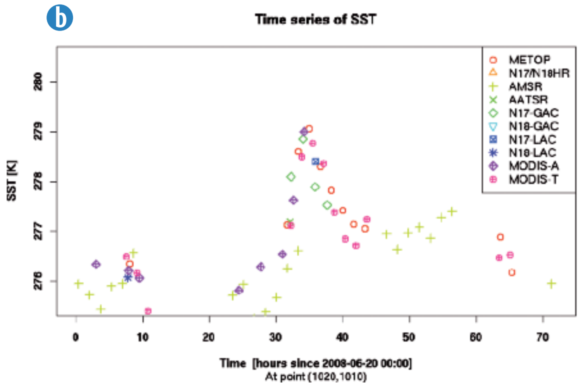
5

a



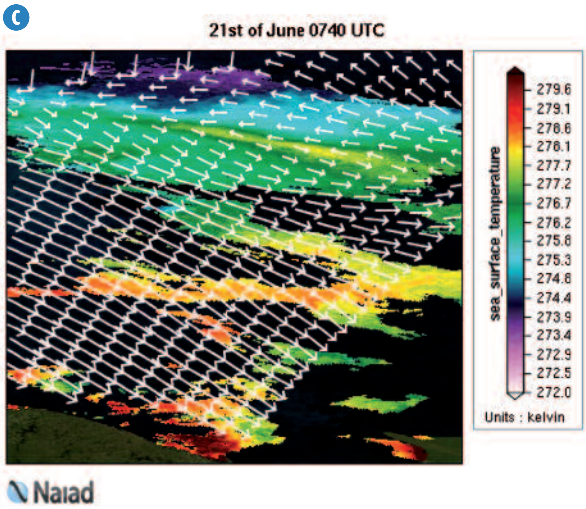
a - Number of significant diurnal cases in Arctic in June 2008.

b



b - Observation of such a case by several captors, on June 21st 2008, between Novaïa Zemlia and Spitzberg.

c



c - the same warm spot observed by METOP, with the corresponding ASCAT wind field superimposed.

Atmospheric chemistry and air quality

Ensemble air quality forecasting over Europe

Since June 2009, research activities have been carried out on ensemble air quality forecasting over Europe in the framework of the FP7 project MACC. The approach is based on 7 pre-operational models, including the two French ones CHIMERE (INERIS and CNRS) and MOCAGE (Météo-France), which are jointly operated in the context of the Prév'Air operational platform and partnership. Work focuses on primary gaseous pollutants, like ozone, secondary ones, like nitrogen dioxide, and on particulate matter.
Forecast skill is observed to be remarkably stable up to 72h: air quality forecasts for the same day are statistically equivalent to the those for two days ahead, for all pollutants considered. The degradation in the skill of meteorological forecasts thus has less impact than the synoptic situation itself, the time of day, the emission of pollutants or the specificities of each air quality model. This confirms the choice of a multi-model-based ensemble rather than an ensemble based on a single air quality model driven by an ensemble of perturbed meteorological forecasts. The spread in the multi-model ensemble depends on the pollutant considered. It is rather small for species that are primarily linked to dynamics (all MACC air quality models rely on IFS/ECMWF forecasts) and emissions, like nitrogen oxides. In contrast, it is large for ozone, for which chemistry and transport modelling specificities prevail.
Although the ensemble forecast by the "median" model (median value of the 7 models at each time and place) is generally among the best forecasts compared to individual models, we find a strong interest in building up differentially weighted ensembles, based upon the skill evaluated for the day before. We observe that the models that perform best in one area on one day have statistically higher chances of providing good forecasts for the day after.

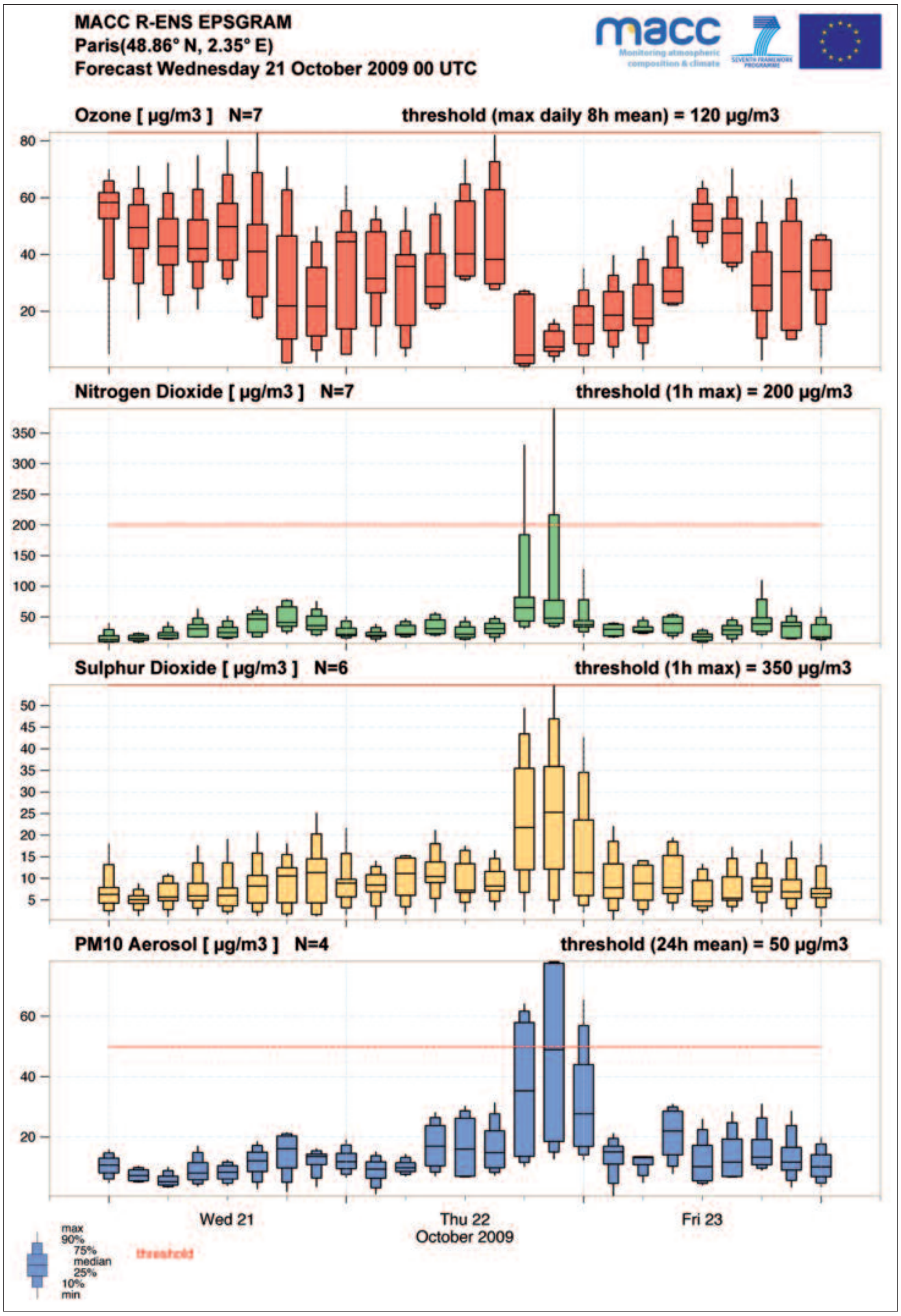
7

Impact of megacities on atmospheric pollution at regional scale: the MEGAPOLI experiment

The MEGAPOLI project brings together leading European research groups, state-of-the-art measurement systems and key players from developing countries to investigate the interactions among megacities, air quality and climate. The general objective is to better quantify primary and secondary aerosol sources in a large urban area and in its plume. Particular attention is paid to the build-up of the secondary organic aerosol and its relation to precursor gases.
Within the MEGAPOLI project, CNRM-GAME participated in an intensive measurement campaign which was carried out in the Paris region during July 2009 to examine the evolution of the aerosol and gas-aerosol interactions in the urban outflow of Paris. The Paris area was chosen because of its long established air quality monitoring (AIRPARIF).
The SAFIRE ATR42 performed 11 successful scientific flights (43 flight hours) during the field campaign. Each flight followed the same scenario: circles around Paris to document initial conditions in all directions, then legs moving away from Paris and in the downwind area to study the evolution of the pollution plume. The aircraft instrumentation was composed of aerosol analysers (3 of them were Mass Spectrometers) and air chemistry analysers (Ozone, CO, VOCs, etc.). These instruments, specific to this experiment, completed the basic aircraft measurements of pressure, temperature, humidity, position, and turbulence.
In addition to measurements made by the ATR42, many others were made from the ground and from 3 mobile labs (vans). 2 days were dedicated to an inter-calibration exercise between aircraft and mobile labs. For this purpose, the instrumented vans parked close to the aircraft at Pontoise-Cormeilles airport.
Pollution conditions during the campaign were fairly light, but with several days of stronger photochemical activity within the agglomeration and the plume. Thus, even for clean cases, the pollution plume was still well defined at more than 100 km downwind of Paris. Measurement data are currently being processed by the partners. The second part of the campaign took place in winter, from mid-January to mid-February 2010.

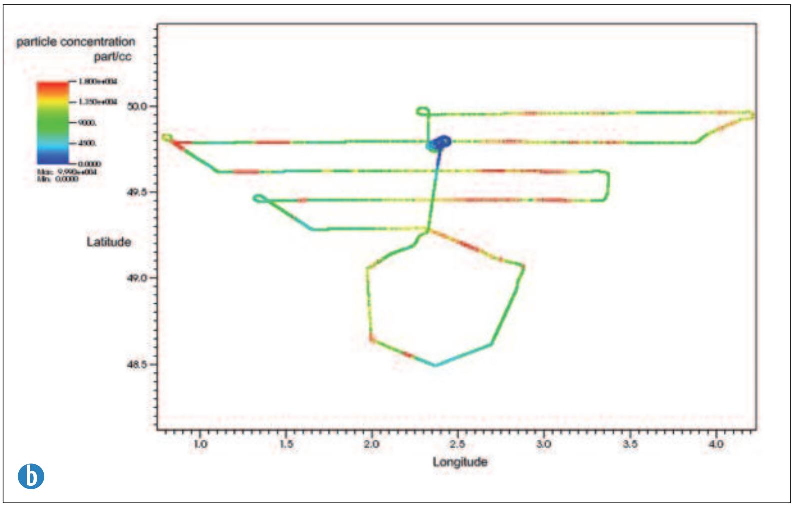
8

a - Some members of the CNRM and SAFIRE teams involved in the Megapoli campaign.



EPSgram (forecast including the spread of the multi-model ensemble) for the main pollutants over the Paris area and for the base date: 21/10/2009 00h. These diagrams are currently computed daily by ECMWF but the task is being transferred to Météo-France, who holds this responsibility within the MACC project.

7



b - Aerosol particle concentration during the scientific flight of July 21st, 2009 in the sector north of Paris (MEGAPOLI flight n° 32).
The pollution plume in the North-north-eastern area can be clearly identified.

c - Intercalibration exercice with the ATR42 and the 3 instrumented vans.

8

Avalanches and snow-cover studies

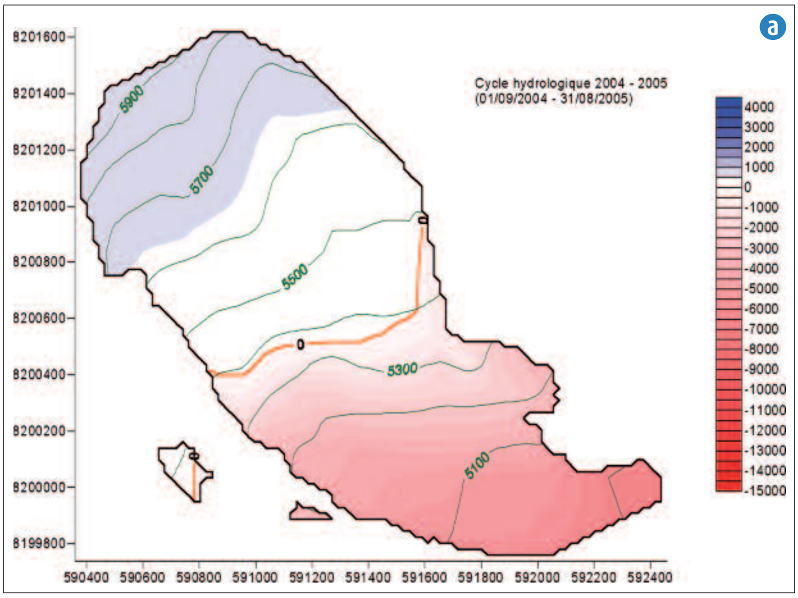
In the area of snow studies, many research activities are conducted at Meteo-France: measurements and modelling of snow cover and its interaction with the atmosphere, meteorological analysis in the mountains, snow transportation by wind, snow physical properties and their modifications, mechanical properties of snow cover and specific instrumentation.
Among the numerous 2009 results, work on snow transportation by wind is noteworthy, with a first study of transferring results to the forecasting services. A great effort has continued on micro-scale snow observation and modelling in order to document the main physical processes at this scale and to link them with the macroscopic properties of snow cover.
Work has also been conducted at larger scale, like glaciology modelling for a high altitude watershed in a tropical area, or snow-meteorology climatology of French mountains for the last 50 years. The study on the assimilation of remote sensing data in a snow model has been pursued, with encouraging initial results at “Col de Porte”. A significant effort has also been made for snow observation instrumentation, with the major action of renewing the “St Martin d’Heres” cold room.
In 2010, these research activities will go on, and new studies will be initiated, e.g. the modelling of snow transportation by wind with the Meso-NH model, the regionalisation of climatic scenarios in mountain areas (SCAMPEI project), the installation of new measurement systems for snow cover parameters (like heat conductivity or snow specific surface area) involving the development of new sensors. Microstructural models will be improved, drawing benefit from experiments performed in a cold room. Results from the SCM suite during the last 50 years will be compared to actual avalanche observations, in order to build a climatology for snow cover stability.
The effort made in instrumentation will be continued, particularly by contributing to the “Col des Montets” road survey, thanks to a seismic sensor and our involvement in the OPTIMISM project (optimisation of snow-meteorology sensors in polar conditions).

9

Impact of water vapour exchanges on snow settling: 3D modelling and experimental validation from tomographic images

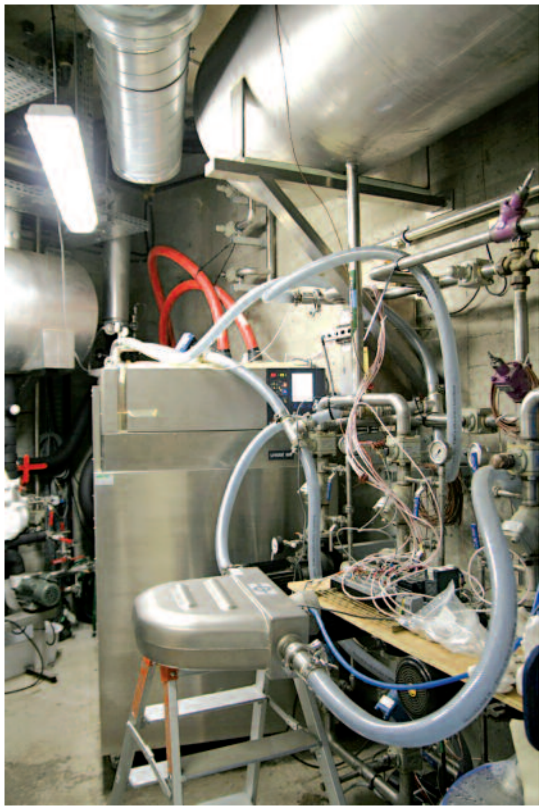
Snow is a complex material that transforms with time. When dry snow is placed in isothermal conditions, its metamorphism (i.e. its structural changes) leads to a marked densification.
We address here the mechanisms driving this densification and their relative roles: does settling result only from the action of the weight of the layers above (a mechanical effect) or can it also be partly explained by water vapour exchanges in the porous space of the ice matrix (an essentially thermodynamic effect)?
A previous study has already shown that accounting for thermodynamics alone could lead to disconnections between grains at the beginning of the metamorphism. Thus, the idea was to develop this model by adding simple mechanical laws in order to reorganize disconnected grains.
Simulations have been compared to images obtained by X-ray microtomography performed in a cold room (SLF, Davos, Switzerland). The same snow sample was studied during the whole experiment, allowing a very fine qualitative analysis of runs and in particular enabling identified grains to be followed.
The numerical model thus developed is able to reproduce the observed evolution of Specific Surface Area (ratio of air/ice interfacial area to ice mass) and partly explains the rapid densification observed. It is a promising tool for studying isothermal dry snow metamorphism and its impact on settling.

10

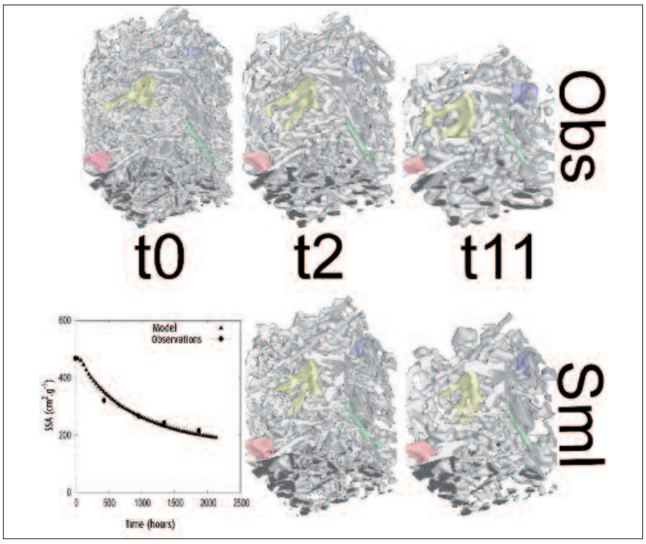


a - Annual mass balance of Zongo glacier calculated with the Crocus model from 1/9/2004 to 31/08/2005 (in water equivalent mm). Blue parts correspond to glacier accumulation areas, red parts to ablation areas.

9



b - New cold production system for the cold room laboratory. This ice-thermostat was installed during a first stage of performance evaluation for specific instrumentation, which aims to check some parameters, on input and output hydraulic circuits.



Dry snow sample placed in isothermal conditions (-8°C).
Three stages are plotted both for observation (Obs) and simulation (Sml): initial stage (t0), after 2 weeks (t2) and after 11 weeks (t11) of metamorphism.
Grains have been coloured to help settling and shape evolution to be followed; simulations and observations compare well.
The graph shows the time evolution of simulated (triangles) and observed (circles) Specific Surface Area.

10

Instrumentation

The purpose of instrumental and experimental research is to develop new tools, to implement different measurement systems and also to analyse data collected during important scientific field campaigns. 2009 was rich and fruitful with participation in no less than a dozen such campaigns.
Among the large amount of work carried out during the year, the development of a multi-column gauge for the direct recovery of water by condensation, successfully tested during the Megapoli campaign, is particularly noteworthy. However, most projects require very high technology ground, airborne or space instrumentation (radar, lidar, radiometers, etc.). Whenever the lab is involved, it develops techniques to retrieve physical parameters and to analyse them in a multi-instrumental environment. These fields of study will lead to a system for remote sensing of the vertical profiles of atmospheric parameters. Wide-ranging work has been achieved to prepare the AEOLUS space mission. New non-linear screening methods have been developed and two new techniques have been validated: the SODAR to measure the height of fog layers and the scintillometer to measure the latent heat fluxes calculated on a kilometric basis.
In the area of thematic research, several major results have been published in scientific reviews. For a study conducted with the Laboratoire d'Aérologie, combining physical simulation and numeric modelling, experiments were conducted on internal waves in the ocean. Within the framework of the European HYDRALAB programme, the international scientific community has brought in some fresh results on atmospheric internal waves.
Experimental studies on aerosols and clouds have been carried out in the framework of the SCMS, EUCAARI, CAPITOUL, AMMA, Toulouse or Paris Fog, and MILAGRO campaigns. The findings have been used as a basis for the numerical modelling of processes on aerosols, cloud microphysics and cloud dynamics of the boundary layer.

1

Airborne instrumentation

SAFIRE is a joint department between CNRS, Météo France and CNES which manages and operates three French planes equipped for and dedicated to environmental research.
In 2009, besides taking part in the MEGAPOLI and CAROLS field campaigns among others, SAFIRE was involved in four major themes: the renewal of the collective agreement linking the three operators, the strengthening of the technical competence of flight meteorologists, the building of plans for the future as the Francazal airfield is due to close very soon, and the restarting of Falcon 20 activities.
Drawn up in 2005 with a lifetime of 4 years, the collective agreement for SAFIRE ended in 2009. During this 4-year period, the relevance of the terms of the contract was indisputable and it has therefore been extended to a further 4-year period from 01/01/2009.
As two bigger planes (Falcon 20 & ATR42) joined the fleet in 2006, it was found necessary to train the new crew members in the field of meteorology and to harmonize skills. At the beginning of 2009, after theoretical and practical training, 5 crew members were awarded their flight meteorologist's licence. This theoretical training lasted for 18 days, while practical training (on the ground and in the air) lasted for a whole month.
Since 2003, SAFIRE has been housed on the Francazal airfield. In July 2008, the decision was taken to close the airfield by the end of 2010. Consequently, SAFIRE and CNRM directors worked together to find a solution so that the activities of the SAFIRE department could continue. The new site must be equipped with a hangar for the 3 planes and 700 m² of offices and laboratories. The collegial management strongly wished the SAFIRE department to stay in Toulouse area, not only because Météo France and CNES are located there but also because Toulouse is home to an Advance Research Cluster (Sciences & Technologies for Space & Aeronautics). Several solutions are being investigated for relocation in 2010 to Blagnac airport. Nevertheless, it is still possible that the Francazal airfield may remain an airport. In this case, SAFIRE would certainly choose this option, provided conditions were satisfactory.
Finally, in order to operate the Falcon 20 previously managed by IGN, CNRS has decided that, from now on, SAFIRE will exploit the plane directly and has recruited a registered pilot and a registered flight engineer who will come and strengthen the SAFIRE teams. The next Falcon 20 flights are scheduled for mid 2010.

2

CAROLS campaign: airborne measurement of soil humidity and ocean salinity

The objective of CAROLS flights is to validate the instrument of the same name, a passive radiometer and its associated algorithms, which measure the soil moisture and the ocean salinity. An equivalent radiometer (with a synthetic aperture antenna) is onboard the SMOS satellite which was launched on 2nd November 2009. The flight tests performed up to now have been dedicated to the preparation of the future satellite validation campaign.

Following the first tests that took place in late 2007 and October 2008 on the Météo-France ATR42, a one-month campaign was carried out in May 2009. Half of the CAROLS flights were flown with a combination of instruments: CAROLS radiometer and RASTA radar. The complementary radar measurements gave an indication of the sea surface conditions: wind and wave height.

The flight campaign was very productive for the development and improvement of the instruments. The SAFIRE and CETP teams (in charge of the CAROLS instrument) are now ready for the next ATR42 flight (April-June 2010), which will allow the first comparisons with the satellite data.

3

1

◀ Some of the instruments
(for example the sodar) installed at Roissy
during the campaign aimed
at improving fog measurements,
during the 1st quarter of 2009.

▲ **a** - The Falcon 20 in the air.
It is equipped with instruments under wing
for microphysics measurements (droplets & dust).

2

▶ **b** - The Toulouse-Francazal hangar used by SAFIRE since 2003. Might this equipment still be used in the future?

3

One of the 2 CAROLS antennas, mounted in the rear opening of the ATR42.

On-site instrumentation and remote sensing

Development of an airborne miniaturized multi-column CCN counter (mmA-CCNC)

One of the largest uncertainties in our understanding of climate change concerns the impact of aerosol particles on the formation of clouds, the subsequent indirect radiative forcing, and the precipitation formation processes. Cloud condensation nuclei (CCN) are the subset of aerosols that serve as cloud droplet embryos. Measurements of CCN are thus fundamental to link cloud microphysics and aerosol physics and chemistry.
A cylindrical, continuous-flow, thermal gradient diffusion chamber was developed by Roberts and Nenes in 2005 for measuring CCN concentration at a given supersaturation. Supersaturation is a function of the flow rate and of the temperature gradient in the column of the instrument and, as the flow is continuous, it allows for fast sampling (1 Hz).
Cooperative work between CNRM and SIO (Scripps Institute of Oceanography, San Diego, USA) was set up to further develop a CCN instrument dedicated to airborne experiments, which would perform fast measurements of CCN concentrations at multiple supersaturations (between 0.07% and 2%), using miniaturized multi-columns and fast sampling.
The components for the mini-CCN instruments were constructed at SIO and were assembled, tested and calibrated at CNRM. The instrument has been reduced in size and weight without compromising its performance, as attested by the calibration. In addition, the software in the miniature CCN has been tested to retrieve high-resolution supersaturation spectra.
A miniaturized single-column CCN instrument operated successfully onboard the SAFIRE ATR42 research aircraft during the MEGAPOLI experimental campaign in July 2009. The new miniaturized multi-column CCN instrument is available at CNRM since the end of 2009.

4

Wind lidar experiment at Nice airport

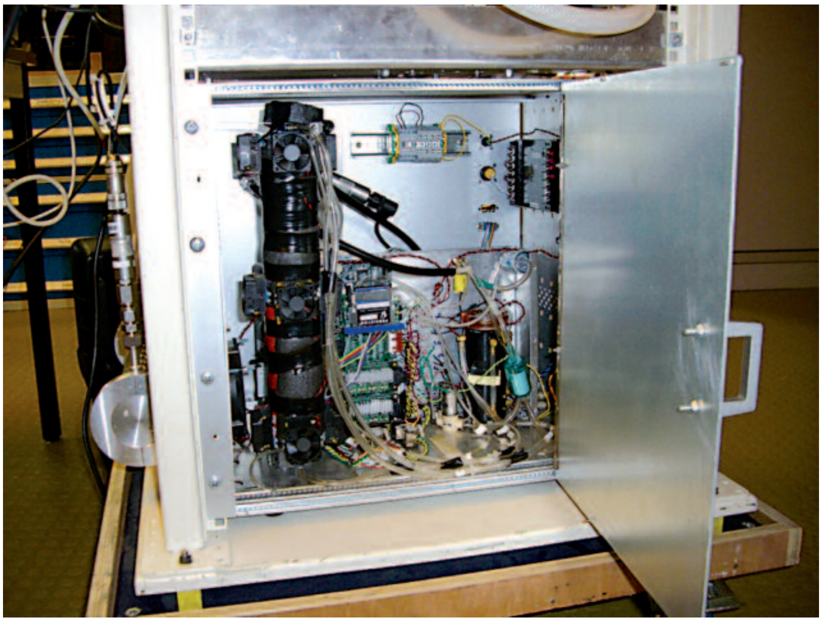
Clear air wind-shear is a frequent feature observed on the glide slope at Nice airport. Since new wind lidars, easier to install, have recently become available, DSO and CNRM decided to test them there in order to:
a) verify on-site the performance of a lidar in the actual atmospheric conditions in Nice.
b) evaluate its wind-shear detection ability on the glide slopes.
c) gather a high-resolution, if possible 3D, dataset, in order to describe the wind field close to the airport. This dataset will be used to improve the fine-mesh numerical weather model description of wind-shears.
The campaign took place from March to May 2009. It included the installation of a Lockheed Martin Coherent Technologies wind lidar close to Nice airport runways. The expected clear air range of this instrument is 10 km. It scans 360° in azimuth, at different elevation angles.
The experimentation was undertaken in liaison with the Civil Aviation Authority and four wind-shear cases were observed.
The first results indicate that the lidar is well suited to the detection of wind patterns. From the data collected and the aeronautical user's requirements, the specification of a wind-shear observation system in Nice is in progress. In the field of numerical weather prediction, the lidar winds have begun to be used as a reference for the simulations of the high resolution Meso-NH model on some specific cases.

5

Toward a significant improvement of the wind measurements from meteorological Doppler radars

At the end of 2009, the ARAMIS network was entirely equipped with Doppler radars. The Doppler information (radial velocity PPIs) of the 24 radars is assimilated operationally by the AROME model. It is also used to calculate the wind profiles above the radars and to rebuild the 3-D wind field in areas where radars overlap, in presence of precipitation. These overlapping areas are large in the French network because of the density of the network but also thanks to an innovative and patented Doppler technique that allows radial velocity measurements to be made without ambiguity over a range of more than 250 km. The 3D national fields of reflectivity and wind (15 minutes x 2.5 km) will be introduced operationally in 2010.
Studies were carried out in September 2008 to improve the quality of the Doppler measurements and reduce the rate of de-aliasing errors. Such errors are particularly visible on cases with strong convection or clear air. This is why, until now, it was recommended that users apply a median filter of 5x5 km^2 on the 1 km^2 resolution radial velocity images.
Tests at increased PRFs (Pulse Repetition Frequency) with Nyquist extended velocity (VNE) reduced from 60 to roughly 45 m/s have been performed on all the types of radars in the network (S-band radars, old and recent C-band radars). The Nyquist velocity is the maximum velocity that can be measured without ambiguity for a given Doppler scheme. These tests clearly demonstrated a reduction in the rate of measurement errors. For example, the rate changed from 16.7% to 2.5% between the current mode and the proposed new mode on a convective case observed by the Nimes S-Band radar. On the C-band radars, the proposed scheme is associated with a Nyquist velocity of 44 m/s. An algorithm was therefore developed to de-alias the high velocities (beyond this value). This algorithm uses the advection field. It was tested on many situations (storm, tornado, etc.) and proved satisfactory.
These modifications will progressively become operational in 2010. This will enable the use of the radial velocities with their original resolution (1 km^2). This is particularly important to detect small scale phenomena like windshear lines, convergence, and tornadoes. A national low-level windshear mosaic will be produced in real time for demonstration in summer 2010.

6



Airborne miniaturized CCN chamber installed aboard the SAFIRE ATR42 during MEGAPOLI.

4

Lidar observation of a wind-shear east of Nice.

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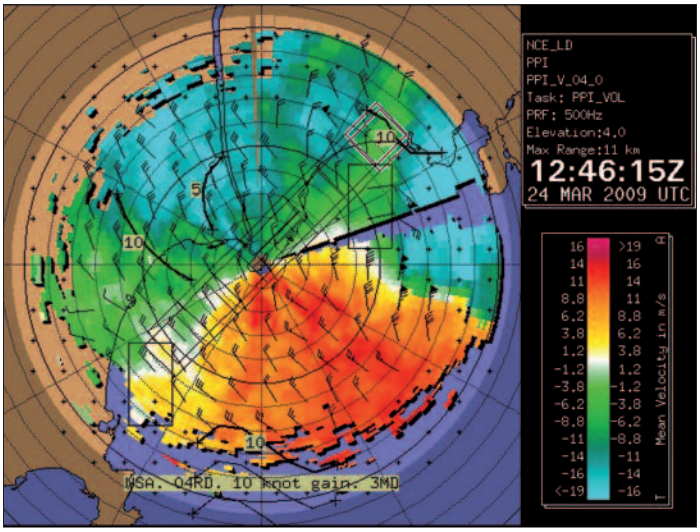

Radial velocity images with the current mode (left) and the proposed new mode (right). Nimes radar 15/07/2009 at 00 UTC, elevation 2.4°. Current mode: PRF1=290 Hz, VNE=58 m/s, Test mode: PRF1=500 Hz, VNE=50 m/s.

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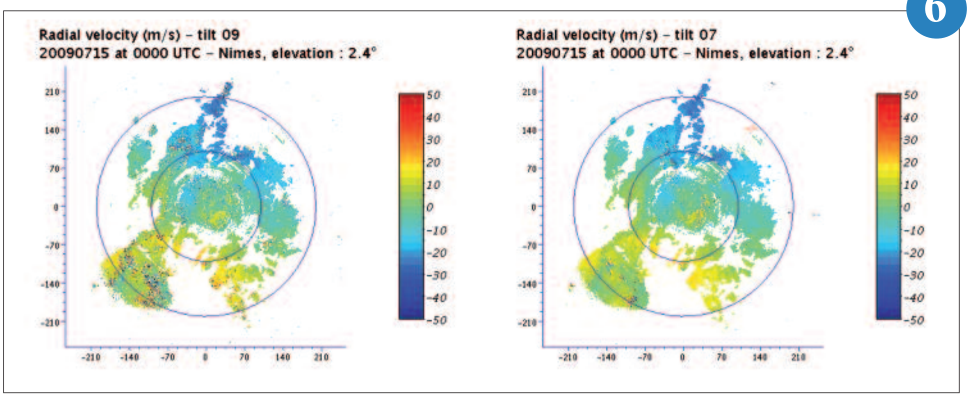

Toward operational use of polarimetric radar

A new technology called “dual-polarization” has been gradually introduced into the French ARAMIS radar network since 2004. In October 2009, 10 of the 24 metropolitan radars were dual-polarized. Data provided by these radars are much more numerous than those from conventional radars. They allow, for example, bright band detection, correction for the attenuation due to precipitation, and hydrometeor classification (light rain, heavy rain, dry snow, wet snow, hail, ...).
One difficulty of using dual-polarization data is that they have to be very carefully calibrated because algorithms are very sensitive to measurement errors. Considerable work has been undertaken in liaison with the maintenance team to develop robust indicators for real-time monitoring of polarimetric data quality.
Currently, data provided by the 10 dual-polarization French radars are processed in real-time. This processing suite includes correction for calibration biases, identification of non-meteorological echoes (ground clutter, insects, birds, etc.), bright band detection, correction for attenuation due to precipitation, and hydrometeor classification. A first version of this processing chain will become operational in the first half of 2010. At the same time, studies will continue on quantitative precipitation estimates, hail detection, rain/snow delineation at ground level and supercooled water detection. This processing chain will be further adapted to X-band radars in the framework of the RHYTMME project.

7

Evaluation of scintillometry sensible heat flux measurements on the Thau lagoon

Measurements of sensible and latent heat flux between liquid surfaces (lake, oceans, lagoon) and the atmosphere are still difficult to make because of infrastructure constraints (ship, buoy) and instrumentation limits.
Two techniques are used: a direct one with high frequency measurements of wind, temperature and humidity, in which fluxes are estimated using eddy correlation and an indirect one, so called “bulk” technique, with slow meteorological measurements by robust sensors, but relying on a parametrization. More recently, some methods based on light wave scintillation in presence of a sensible heat flux have been developed.
In 2009, the CNRM conducted a field campaign on the Thau lagoon to collect a data set for the validation of this technique. Several devices were used for surface/atmosphere flux measurements, such as meteorological stations, an eddy correlation system, and a Kipp and Zonen scintillometer with a 4.8-kilometre optical path length. A large data set has been collected to validate the scintillometer technique, and it is expected that continuous long-term measurements will be done. A new field campaign will be conducted in French Brittany during the winter of 2009-2010 in a coastal zone, for further validation.

8

CNRM-GAME stratified water flume and European research in meteorology

The scales involved in a number of phenomena are such that their observation in the atmosphere is difficult and their numerical modelling possible only for very limited areas. Laboratory experiments are thus a useful tool for their study, especially in a facility such as the CNRM-GAME stratified water flume. This instrument, unique in Europe, reproduces well controlled density-stratified flows particularly relevant for research in meteorology.
That is the reason why CNRM-GAME forms part of the European network of large hydraulic laboratory installations of the HYDRALAB-III project, supported by the European Commission in the Sixth Framework Programme. Three teams of researchers visited the physical simulation laboratory in this context, in order to gain new insights for their work through experiments funded by the EU.
D. Etling and C. Knigge, of the University of Hanover, were the first to take advantage of this project to carry out the first laboratory experiments on rotors that form downwind of mountains. These rotors are a danger to aircraft, and this work helped to clarify their formation mechanism.
The second team was composed of two mathematicians from University College London, E.R. Johnson and G. Esler. Laboratory validation of their work is important for its application to the representation of the drag exerted by mountains on the atmosphere in numerical models.
Finally, D. Dobrovolschi of the Romanian Meteorological Service and G.-J. Steeneveld of Wageningen University looked at vertical transport in a stable atmospheric boundary layer, to reduce the uncertainty attached to their representation in models.

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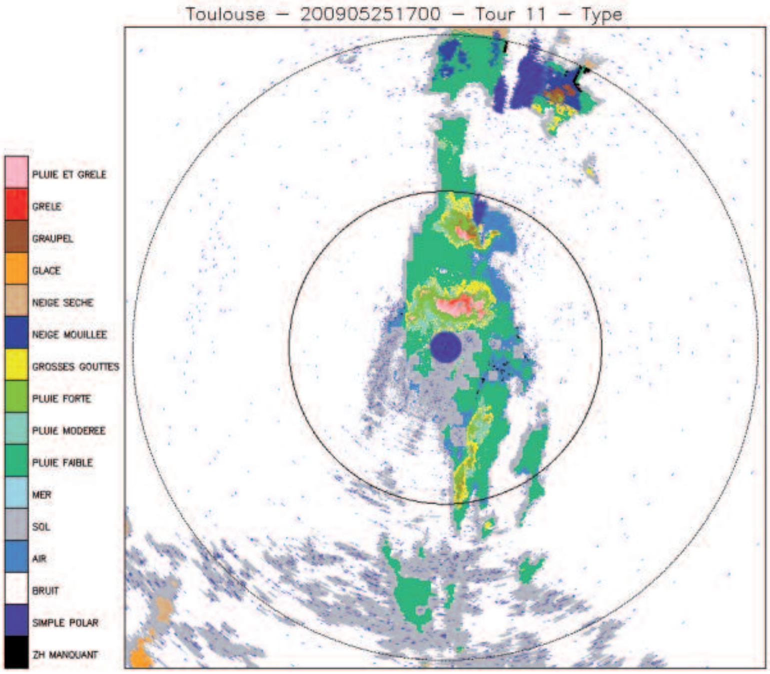
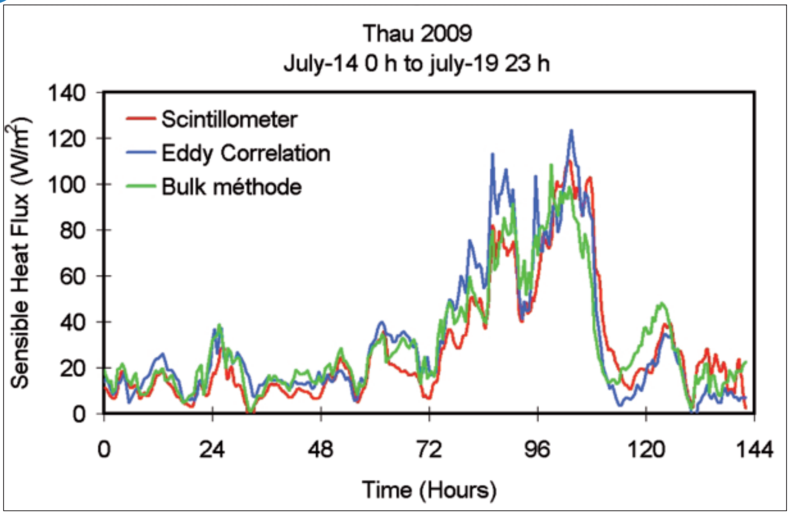


Results of the hydrometeor classification algorithm for the Toulouse radar at 1.5° elevation at 17.00 UTC on 25th May 2009.
Black circles are 50 km and 100 km away from the radar.
Grey areas are for ground clutter.

8

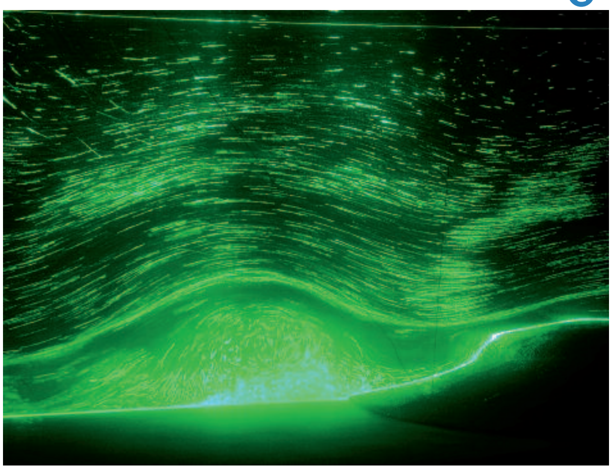


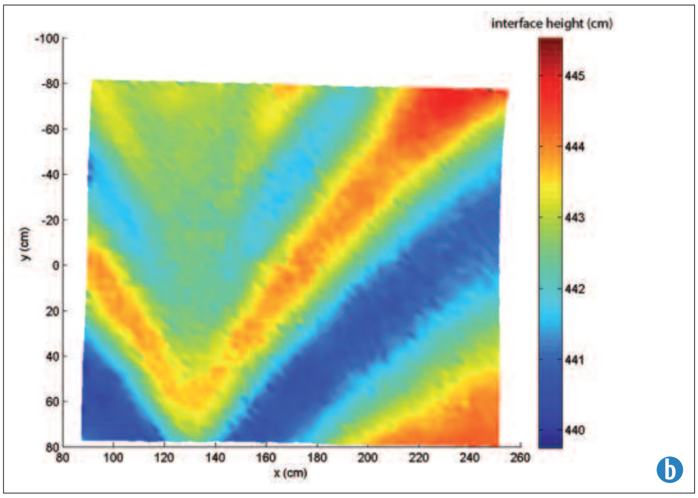
▲ **a** - Time series of sensible heat flux measured with "bulk","eddy correlation" and "scintillometer" methods on the Thau lagoon from July 14th to July 19th 2009.

▲ **b** - Scintillometer emitter installed in the north of the Thau lagoon.
The arrow indicates the scintillometer receiver location on the opposite shore.

9

▼ **a** -Laboratory experiment demonstrating the formation of a rotor under the first crest of the wave downstream of a mountain. Visualization (side view, perpendicular to the flow) is obtained here by particles illuminated by a vertical laser plane sheet.
The Reynolds number is larger than 20000.





▲ **b** - Internal waves generated at a density interface displayed by a stereoscopic technique (collaboration with Institute of Fluid Mechanics of Toulouse, courtesy of E. Cid). This technique measures interface height, shifted vertically by the waves that form behind the mountain (at bottom left). These waves are responsible for a significant portion of the drag exerted by mountains on the atmosphere.

Coordination and communication

Most, but not all, of Meteo France's research is carried out by CNRM. The Network of Studies and Internal Knowledge Transfers (RETIC department) is in charge of coordinating research and this is mostly done through the procedure of drawing up a non-CNRM research programme, and also through frequent meetings such as the yearly R&D Workshop, a propitious moment for scientific exchanges between all Météo France's researchers.
Another of RETIC's missions is to enhance the transfer of research results to operational units, as a complement to the actions conducted by the other departments. This task is manifold, it can consist of connecting experts, making documents available, catering for training courses in liaison with the National School of Meteorology (ENM) or even setting up whole programmes for departments' specific needs. RETIC also participates in the implementation and the development of the latest operational applications and their upgrades following research findings.
In 2009, the major undertakings of RETIC were to help implementation of an "innovation structure" at DSO, to define a way for CNRM and the Climatology Department to work together so as to make climate simulation data available and to define solutions to respond to the requests for impact studies. Other important actions were the contributions to implementing facilities compiling requests for model output, whether for forecasting or test cases, to writing an inter-department working group mandate that plans out the evolution of various components of the operational suite, so that the organisation installed during autumn 2007 can be perpetuated.
Another CNRM objective is to develop external communication, particularly on the latest developments in meteorology, climate and environment studies. Thus, many beacon actions took place in 2009: let us not forget the huge success of the second "Researchers' night", that has held on the Météopole campus, the finalisation of the AMMA field campaign film, African monsoon press conferences, interviews for the mass media given by our team of experts (e.g. TV/radio programmes during the Copenhagen conference, or for the 10th anniversary of the 1999 storms).

1

a - Participants at the R&D workshop, organized by RETIC in June 2009 (copyright P. Pichard, Météo-France).

1

b - Serge Planton
giving an interview to the French TV channel TF1 during a special programme about climate.

c - Interview of JP Lafore (CNRM/GMME) by B. Petit (CNRM/PAD) for the preparation of Météo-France film on the AMMA campaign.

Researchers' night: 1500 visitors captivated by the Meteopole campus

Météo-France, with its partners Cerfacs and CNRS, participated in Researchers' night, in association with the European Community, on September 25th 2009. This action aims to lead to direct contact between researchers and the general public, on scientific, technical and cultural aspects.
1500 visitors were received at the Meteopole campus on a splendid autumn evening. They had the opportunity to discover many outside experiments (night radiosoundings with real-time display of results, tethered balloon, lidar and telemeter presentation, instrumented bicycle, ...), to attend a wide range of conferences, to visit the stratified water flume ...
The direct dialog between scientists and visitors might take place behind new or renovated scale models (ST radar, SMOS satellite, oceanic circulation model, ...), or inside exhibition stands, where the main research results were described with panels, slides or short films. Direct links were established between the Conference Centre and Computer Room twice during the evening, allowing the public to discover the NEC supercomputer configuration and to get answers to their numerous questions on the computer power used for research activities. Cultural interludes were also scheduled from time to time (choral songs, painting or picture exhibits), in order to give an original and festive touch to this event.
So many visitors wanted to come and attend this evening that reservations had to be closed several days before 25/09. Important regional political figures (the President of the Midi-Pyrenees Region, for example) spent several hours on our site, and seemed to be delighted by their discoveries. France 3 national TV also chose the Meteo-France event to illustrate the European Researchers' night during its evening news. Ph Bougeault, Director of Research at Météo-France, participated in the live national TV programme. Then, A. Barelli, Regional Head of CNRS teams, was interviewed for this regional session of the news.
Many messages of acknowledgement were received after this event, proving that the evening was a great success, interesting many people. Recent progress in numerical weather prediction, improvements of our understanding of climate evolution, new atmospheric or environmental projects are a prime subject of concern for a broad public. Consequently, researchers have to present their results to visitors from time to time. Thus, the CNRM-GAME will continue its communication efforts in the coming years.

2

Communication around the AMMA programme

The 3rd International AMMA conference in Ouagadougou was the occasion for many fruitful exchanges. A "café des sciences" was organized around the theme "Women and Science" and the exhibition "Sous la mousson, des Hommes…" was presented in several places in town. Finally, three films were shown to the conference participants, in particular the motion picture "Au Coeur de la Mousson Africaine" made by Météo-France.
The Press was invited to two press conferences, one in Ouagadougou and the other at the CNRS headquarters in Paris. AFP, Le Monde and Libération, among others, were present to learn about key results of the programme exhibited in Ouagadougou and more than 30 articles were published following the press conference.
The semester which followed the field campaign in Ouagadougou gave rise to awareness actions, such as "Researchers' night" at Météo France's campus, to promote sciences for a wide audience. AMMA was present during the arts and sciences festival "La Novela", in Toulouse, under the theme: "travel notebook / research notebook". During the exhibition, when pictures, observation instruments, etc. were on display, Météo-France's motion picture "Au Coeur de la Mousson Africaine" was shown. The exhibition and films about AMMA toured France and also went to Mali, Senegal, Niger, Burkina Faso and Benin. Now, AMMA is concentrating its efforts on developing a communication network in west Africa to increase the spread of scientific information produced by the programme.

3

2

a - Some of the instruments installed for Researchers' night 2009 (tethered balloon, scintillometer, ...) Photo : Ph Dos, Météo-France.

2

◀ **b** - Philippe Bougeault (Director of Research) and Martin Malvy (President of Midi-Pyrenees Region) attend a conference in the crowded amphitheatre of CIC. Photo : Ph Dos, Météo-France.

▶ **c** - Armelle Barelli, CNRS Regional Head, during his interview live from the Meteopole campus, for France 3 Sud TV. (Photo : P. Pichard, Météo-France)

3

A. Sonneville (CNRM) welcomes P. Cohen, Mayor of Toulouse, and C. Guien, in charge of innovation for the City of Toulouse, under the AMMA tent installed during the Novella in October 2009, inside a garden in central Toulouse.

Appendix

2009 Scientific papers list

Papers published in Rank "a" journals (impact factor > 1)

Agustí-Panareda A., D. Vasiljevic, A. Beljaars, O. Bock, F. Guichard, M. Nuret, A. Garcia Mendez, E. Andersson, P. Bechtold, A. Fink, H. Hersbach, J-P. Lafore, J.-B. Ngamini, D. J. Parker, J-L. Redelsperger and A. M. Tompkins, 2009, Radiosonde humidity bias correction over the West African region for the special AMMA reanalysis at ECMWF, QJRMS, Volume 135 Issue 640, p 595-617. Doi : 10.1002/qj.396.

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Glossary

Organisms and Laboratories

Organisms

AIRPARIF	Surveillance de la qualité de l'air en Ile-de-France
ANR	National Agency of the Research
CERFACS	Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique
ECMWF	European Centre for Medium-Range Weather Forecasts
ESA	European Space Agency
EUMETNET	European METeorological NETwork
EUMETSAT	EUropean organisation for the exploitation of METerological SATellites
IFREMER	Institut Français de Recherche pour l'Exploitation de la MER
IGN	Institut Géographique National
RTRA STAE	Réseau Thématique de Recherche Avancé – Sciences et Technologies de l'Aéronautique et de l'Espace
SHOM	Service Hydrographique et Océanographique de la Marine
WMO	World Meteorological Organization

Laboratories or R&D units

CETMEF	Centre d'Etudes Techniques Maritimes et Fluviales
CETP	Centre d'Étude des environnements Terrestre et Planétaire
CNRM	Centre National de Recherche Météorologique
DSO	Direction des Systèmes d'Observation
GAME	Groupe d'étude de l'Atmosphère Météorologique
ICARE	Institut de Combustion, Aérothermique, Réactivité & Environnement
IPSL	Institut Pierre Simon Laplace – institut de recherche en sciences de l'environnement
LACy	Laboratoire de l'Atmosphère et des Cyclones
LMD	Laboratoire de Météorologie Dynamique
MIT	Massachusetts Institute of Technology
UMS-SAFIRE	Joint Service Unit - French Group of Aircraft Equipped for Environmental Research
SIO	Scripps Institute of Oceanography, San Diego, USA
ZAMG	Zentralanstalt für Meteorologie und Geodynamik, Austria

National or international programs or projects

ALMIP	AMMA Land Surface Inter-comparaison Project
CIRCE	Climate change and impact research : mediterranean environment (6e PCRD)
CarboEurope	Campaign of Study of the atmospheric carbon in Europe
CONCORDIASI	Validation de l'assimilation de IASI adaptée à l'Antarctique à l'aide de mesures in situ
ENSEMBLES	Ensemble-based predictions of climate changes and their impacts (6e PCRD)
EUCOS	EUmetnet Composit Observing System
E-Surfmar	Program of oceanic observation of surface
FluxPyr	European project on flows of energy in the Pyrénées
FLYSAFE	Airborne Integrated Systems For Safety Improvement, Flight Hazard Protection And All. Weather Operations
GARP	Global Atmospheric Research Programme
GLOSCAL	Global Ocean Salinity Calibration and Validation
IPCC	Intergouvernemental Panel on Climate Change(GIEC)
HYDRALAB	Integrating European Hydraulic research Infrastructure
HyMeX	Hydrological cycle in the Mediterranean Experiment
MEDUP	Forecast and projection in climate scenario of mediterranean intense events : uncertainties and Propagation on environment
METOP	METeorological Operationnal Polar satellites
POGEQA	Plateforme d'Observation GEostationnaire pour la mesure de la Qualité de l'Air (projet RTRA STAE)
PRUDENCE	Prediction of Regional scenarios and Uncertainties for Defining EuropeaN Climate change risks and Effects
QUANTIFY	QUANTIFYing the climate impact of global and European transport systems (6e PCRD)
RHYTMME	Risques HYdrométéorologiques en Territoires de Montagne et Méditerranéens
SAF	Satellite Application Facility
SAFNWC	Satellite Application Facility in support to NoWCasting
SCAMPEI	Scénarios Climatiques Adaptés aux zones de Montagne : Phénomènes extrêmes, Enneigement et Incertitudes
SESAR	Single European Sky ATM Research Programme
SMOS	Soil Moisture Observing System
THORPEX	THe Observing Research and Predictability Experiment (programme mondial du GARP sous l'égide de l'OMM)

Campaigns

AMMA	African Monsoon Multidisciplinary Analyses
AMANDES	Expérience au large de l'Amazone
CAPITOUL	Campagne expérimentale de météorologie urbaine sur Toulouse
COPS	Convective and Orographically-induced Precipitation Study
EUCAARI	European intergrated projection aerosol cloud climate air quality
JAIVEX	Joint Airborne IASI Validation EXperiment
MEGAPOLI	Study of the pollution in megacities
PARIS-FOG	Campaign of measures for the study of the life cycle of the fog (Palaiseau 2006)
SCMS	Small Cumulus Microphysics Study
ToulouseFog	Campaign of fog measurements around Toulouse

Other acronyms

4D-Var	Assimilation variationnelle quadridimensionnelle
AEOLUS	Satellite d'observation de la dynamique de l'atmosphère terrestre
AIRS	Atmospheric Infrared Sensor
ALADIN	Aire Limitée, Adaptation dynamique, Développement InterNational
AMSR-E	Advanced Microwave Scanning Radiometer for EOS (Earth Observing System)
AMSU	Advanced Microwave Sensor Unit
AMSU-B	Advanced Microwave Sounding Unit – B
AQUA	Satellite du Earth observing system de la NASA
ARAMIS	Application RAdar à la Météorologie Infra-Synoptique
ARISP	ARome ISba Piste : Système de prévision de température des pistes
AROME	Application de la Recherche à l'Opérationnel à Méso-Echelle
ARPEGE	Applications de la Recherche Petite Echelle Grande Echelle
ASAR	Advanced Synthetic Aperture Radar
ASCAT	Advanced SCATterometer
ATR	Avion de Transport Régional
BAROS	Station automatic of ship
BLH	Boundary Layer Heat
CAPE	Convective Available Potential Energy
CARIBOU	Mist and fog risk analysis mapping
CAROLS	Cooperative Airbone Radiometer for Ocean and Land Studies
CCMVal	Chemistry-Climate Model Validation
CCN	Cloud Condensation Nuclei
CNRM-CM5	CNRM's climate model, version 5
COBEL	Code de Brouillard à l'Echelle Locale
CoReH2O	Cold Regions Hydrology High-resolution Observatory
COV	Composés Organiques Volatile
CROCUS	Model of evolution of the snow-covered coat
Doppler	RAdio Detection And Ranging
ECOCLIMAP	Base de données de paramètres de surface
EDKF	Eddy-Diffusivity-Kain-Fritsch
ENVISAT	ENVIronmental SATellite
EPS	Ensemble Prediction System
ERA40	ECMWF reanalysis (on 40 years)
ESC	Equatorial Sub-Current
FP	Framework Program
FWI	Fire Weather Index
GELATO	Modèle d'évolution de la banquise développé au CNRM
GFO	Geosat Follow On
GLOSCAL	Global Ocean Salinity Calibration and Validation
GOES	Geostationary weather satellite
GPS	Global Positioning System
IASI	Interféromètre Atmosphérique de Sondage Infrarouge
IBIS	Integrated Blosphére Simulator
IFS	Integrated Forecasting System
IPY	International Polar year
ISBA	Interaction between Soil, Biosphere and Atmosphere
ITCZ	Intertropical Convergence Zone

LAI Leaf Area Index
LCL Lifting Condensation Level
LES Large Eddy Simulation
LFC Level of Free Convection
LSM Land Surface Model
MACC Monitoring Atmospheric Composition and Climate
Megha-Tropiques Satellite franco-indien dédié à l'étude du cycle de l'eau et des échanges d'énergie dans la zone tropicale
MESO-NH Modèle numérique à MESO-échelle Non-Hydrostatique
MFWAM Météo-France Wave Model
MILAGRO Megacity Initiative: Local and Global Research Observations
MINOS Station météorologique automatique embarquée sur navire
MOCAGE MOdèle de Chimie Atmosphérique à Grande Echelle
MODCOU MODèle hydrologique COUplé surface-souterrain
MODIS MODerate resolution Imaging Spectroradiometer
MSG Meteosat Seconde Génération
NEMOMED8 Version Régionale Méditerranée du Modèle Océanique version 8
Nox Oxyde d'Azote
OPTIMISM Optimisation de capteurs nivo-météorologiques en conditions polaires
OSI Ocean and Sea Ice
PALM Coupleur dynamique de codes parallèles développé par le CERFACS
PEARP Prévision d'Ensemble ARPège
PREMIER PRocess Exploration through Measurements of Infrared and millimetre-wave Emitted Radiation
PREVIMER Observations et prévisions de l'état et de la qualité des eaux côtières
PREVIPROB PREVIsion PROBabilité
PRFs Fréquence de récurrence des tirs radars
Qdiv Quantifying the effects of global environmental change on terrestrial plant Diversity
RASTA Radar Aéroporté et Sol de Télédétection Atmosphérique
SAFRAN Système d'Analyse Fournissant des Renseignements Atmosphériques à la Neige
SCM Safran Crocus Mepra
SEC South Equatorial Current
SEVIRI Spinning Enhanced Visible and Infrared Imager
SIM Safran-Isba-Modcou
SIR Safran-prévision/Isba-Route
SPOT Satellite Pour l'Observation de la Terre
SRES Special Report on Emission Scenarios
SST Sea Surface Temperature
STP Significant Tornado Parameter
SURFEX SURFace EXternalisée
SVAT Sol Vegetation Atmospheric
SX9 NEC supercomputer (used at Météo-France)
SYMPOSIUM Forecast weather system dedicated to multiple users services
TCW Tongue of Cold Water
TEB Town Energy Balance
TNAWDEX THORPEX North Atlantic Waveguide and DownstreamImpacts Experiment
TOPMODEL TOPography based hydrological MODEL
TRIP Total Runoff Integrating Pathway
UBRIS Urban Bias Removed of Instrumental Series
UTC Universal Time Coordinated (TU)
VNE Nyquist extended velocity

CNRM : Management structure

31.12.2009

Head: **Philippe Bougeault**

Deputy Head - Toulouse: **Joël Poitevin**
Scientific Deputy Head - Toulouse: **Marc Pontaud**
Deputy Head - Paris: **Pascale Delécluse**

SAFIRE : French Group of Aircraft Equipped for Environmental Research

METEOROLOGICAL AVIATION CENTRE — CAM - Toulouse
Centre head: **Lior Perez**

SNOW RESEARCH CENTRE — CEN - Grenoble
Centre head: **Pierre Etchevers**

MARINE METEOROLOGY CENTRE — CMM - Brest
Centre head: **Jean Rolland**

Modelling for assimilation and forecasting groupe — GMAP - Toulouse
Group head: **François Bouttier**

Experimental and instrumental meteorology group — GMEI - Toulouse
Group head: **Jean-Louis Brenguier**

Climate and large scale modelling group — GMGEC - Toulouse
Group head: **Serge Planton**

Meso-scale modelling group — GMME - Toulouse
Group head: **Véronique Ducrocq**

Internal Knowledge transfers group — RETIC - Toulouse
Group head: **Christine Dreveton**

General services — Paris & Toulouse
Head: **Joël Poitevin**

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

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

Since the end of 2008, the forecasters have been using the AROME numerical model.
A new version of this model, able to assimilate radar data, was built in 2009 and, among other benefits, will bring improvements in the localisation of precipitation.

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Research Report

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