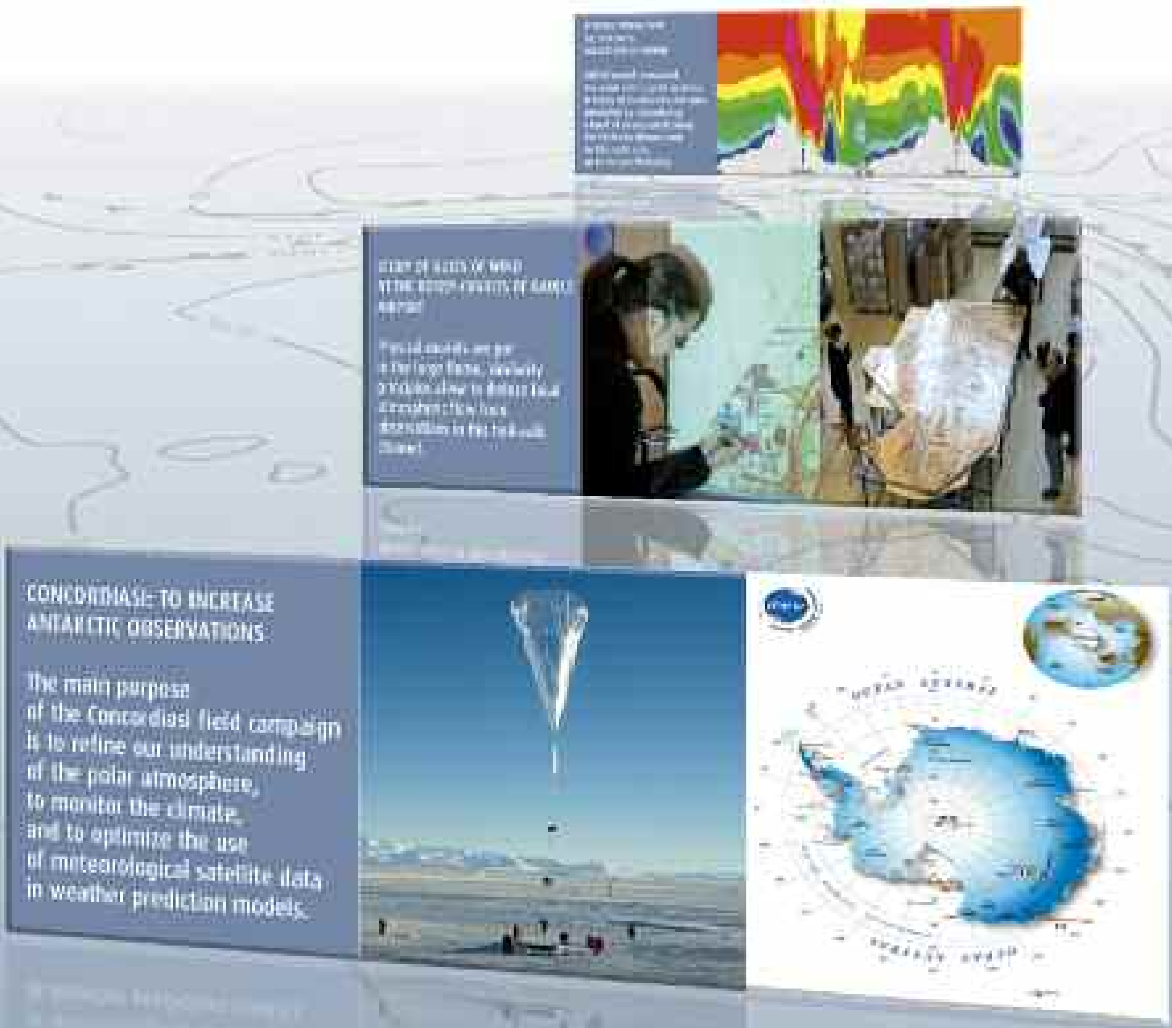
Research Report 2010



METEO FRANCE
Toujours un temps d'avance

Research Report 2010

Table of contents

Météo-France policy in matters of research aims foremost to guide the institution in carrying out its mission “to monitoring the atmosphere, the upper ocean and the snow cover, to anticipate and inform about their evolution”. Météo-France founding decree also stipulates that research activities must play a role in “the observation and understanding of the atmosphere and its interaction with the environment, human activities and climate”.

The prime objectives are thus:

• To insure that the laboratory masters the best techniques in the field of atmospheric, upper ocean and snow cover observations:

• To continuously improve tools used in the numerical prediction of the evolution of the environment at all scales (time and space), in climate simulations, bearing in mind intrinsic interactions.

Research activities are shared between the National Meteorological Research Centre (CNRM) and some other Météo-France departments.

CNRM is composed of a management board located partly in Toulouse and partly in Paris and of seven research departments: Meteorological Aviation Centre (CAM at Francazal, Toulouse), Snow Study Centre (CEN in Grenoble), Meteorological Marine Centre (CMM at Brest), Numerical Weather Prediction and Assimilation Department, Experimental & Instrumental Meteorology Department, Large Scale Meteorology and Climate Department, Mesoscale Meteorology Department (these last 4 departments are located on the Toulouse campus). The Network Studies and In house Knowledge Transfer and Common Personnel Department complete this framework.

The sharing of means with other research institutes led to the founding of three “mixed units” whose task force is increased from CNRS and universities scientists:

• The Atmospheric Meteorological Research Group (GAME) has formed a partnership with CNRS that includes the Toulouse four research departments and the Snow Study Centre of Grenoble.

• The French instrumented aeroplanes for research and environment Department (Safire) is a mixed unit between Météo France, CNRS and CNES.

• The atmosphere and Cyclone Laboratory (LACY) is an mixed unit between CNRS, the University of La Réunion and Météo-France.

In 2010, the collaboration with the Observatoire Midi-Pyrénées was strengthened to form a collegiate body composed of sciences of the Universe research laboratories in Toulouse under the supervising authorities of the University and CNRS. In 2011 Météo-France entered this partnership that also comprises IRD and CNES. GAME assessment periods will coincide with those of OMP.

Output by Météo-France research teams are apportioned between broad themes: computation source codes imparted to operational services or the scientific community for numerical prediction purposes; scientific publications printed in the most renown international journals on state-of-the-art scientific knowledge; data bases on observations made during field campaigns or numerical simulation findings, for scientists use for their own work; patents, mostly in the field of instrumentation, few at the moment but increasing every time; lastly, education and public relations, both important fields to recruit new blood and explain our work.

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Our work falls within a yearly "Research Programme". It encompasses some hundred or so activities derived essentially from internal requests from Météo-France own departments. The Direction of Production is amongst the chief one, as it daily assesses the quality of weather predictions and informs upstream departments about flaws that have been encountered by forecasters and quality control teams on numerical weather prediction. Work on numerical prediction as well as primary research depends on it, notably field campaigns essential to further understanding of ill defined processes within models, such as orography, cloud and aerosol microphysics, urban atmospheric chemistry ...
CNRM is involved in shaping Météo-France strategic road map in such fields as in civil aviation or with the Department of Defence. Some governmental bodies, such as the "Conseil Superieur de la Météorologie" or Météo-France Scientific Advisory Committee, whose members are not all from the institute, make recommendations that may influence the research programme. Lastly, international bodies such as the IPCC or the World Climate Research Programme promote ways on the type of research needed to mitigate climate issues facing us.
Within the collaborative framework with CNRS and universities, a four year rating and programming process is being implemented. It should enable to take into account the current scientific trends and not stray from the French scientific community, thus benefit from the synergy during field campaigns.
This 2010 Research Report is moulded according to its predecessors and aims to bring readers matter-of-fact information about progresses on some topics. This report is by no means exhaustive, but illustrates the richness and diversity of some themes being investigated in our laboratories.
I which you a pleasant read.

Philippe Bougeault,
Director of Research.
(Photo: Ph. Dos, Météo-France)

Weather forecasting models

Numerical weather prediction

On 6 April 2010, the new versions of the deterministic models Arome, Arpege and Aladin became operational. They benefit from finer resolutions and from more observations and have been developed along the second half of 2009. On 24 november 2010, the convection permitting Arome model horizontal domain was well enlarged and its surface variables benefited from their own specific analysis. Together with the considerable changes brought to the Arpege global ensemble prediction on 8 December 2009 and the change to an increased horizontal resolution on 13 December 2010, most of the commitments of the contract with the government resulting from the increased computational power brought by the computers leased from NEC are honored. The various panels of the figure show some actual forecasts from the various models of key 2010 weather events.

Even on these cases, there is room for improvement. No progress step means the end of forecast models evolutions. The following pages highlight various aspects of these continuous improvements, some on their way to reach operations, others preparing the future. Part of these activities are performed in close cooperation either with ECMWF, or with the countries of the Aladin and HIRLAM consortia.

Aside from the results presented hereafter, the beginning of work related to the replacement of the current computer by 2013-2014 must be briefly mentioned. A market survey suggests the likeliness of moving towards new architectures dominated by the parallelization of calculations. The first system to have been adapted is Arome and its surface scheme. Not all research topics have been illustrated here. A possible way to improve the initial conditions of that same Arome system could be to perform slightly adjusted analyses whether in the presence of a cloud or not. Progresses in the use of cloud-affected radiances should enable their operational use within the next few years. Preparations for the replacement of the deep convection parameterization of the hydrostatic models is continuing. The representation of error statistics should be refined with the introduction of a flow dependent error correlation length scale. Three new Aladin systems with their own data assimilation have been introduced within the operational suite. They cover three oversea areas where their output has begun to be examined.

1

▶

Real time forecast charts produced by several of the numerical weather prediction applications of Météo-France prior to remarkable 2010 cases.
(A) 3.5 days ahead forecast of what will turn out to be the southern Pacific tropical cyclone Oli by the then operational Arpege model.
(B) 2.5 days ahead 35 members Arpege ensemble prediction forecast of the 10 m wind gusts 75% quantile prior to the 28 february windstorm locate Charente and Vendée as threatened areas.
(C) Spatialized observed wind gusts and their Arpege and Arome forecast for 28 February 03 UTC. The improved wind gust diagnostic provides, with about a one day lead time, the proper order of magnitude, while extending the hit area too far south.
(D) 2.5 days ahead Arpege ensemble prediction of the 24 h accumulated rainfall 75% quantile prior to the 7 September heavy precipitation event provides reasonably well the extent and location of the precipitations (the leftmost sub-panel shows the observations from the Météo-France climatological division).
(E) 1 h accumulated rainfall as analyzed by the Antilope data fusion system and forecasted by Arpege and Arome. On the evening of 7 September, an intense precipitation line redevelops over the Gard area but it moves fast eastward. The wide domain Arome system locates this phase reasonably well, while the coupling model Arpege delays it.

Improvement of humidity analyses by observations

The quality of the initialization of humidity impacts the quality of predictions, especially of precipitations. An extensive effort has been made to improve data assimilation linked to atmospheric humidity in operational weather prediction systems. In the global model ARPEGE, the increase in the horizontal resolution has made it possible to use diurnal 2m humidity observations over land as they are implemented in Limited Area Models. Furthermore, bias corrections of humidity radiosonde data are now being implemented, using ECMWF developments in this field.

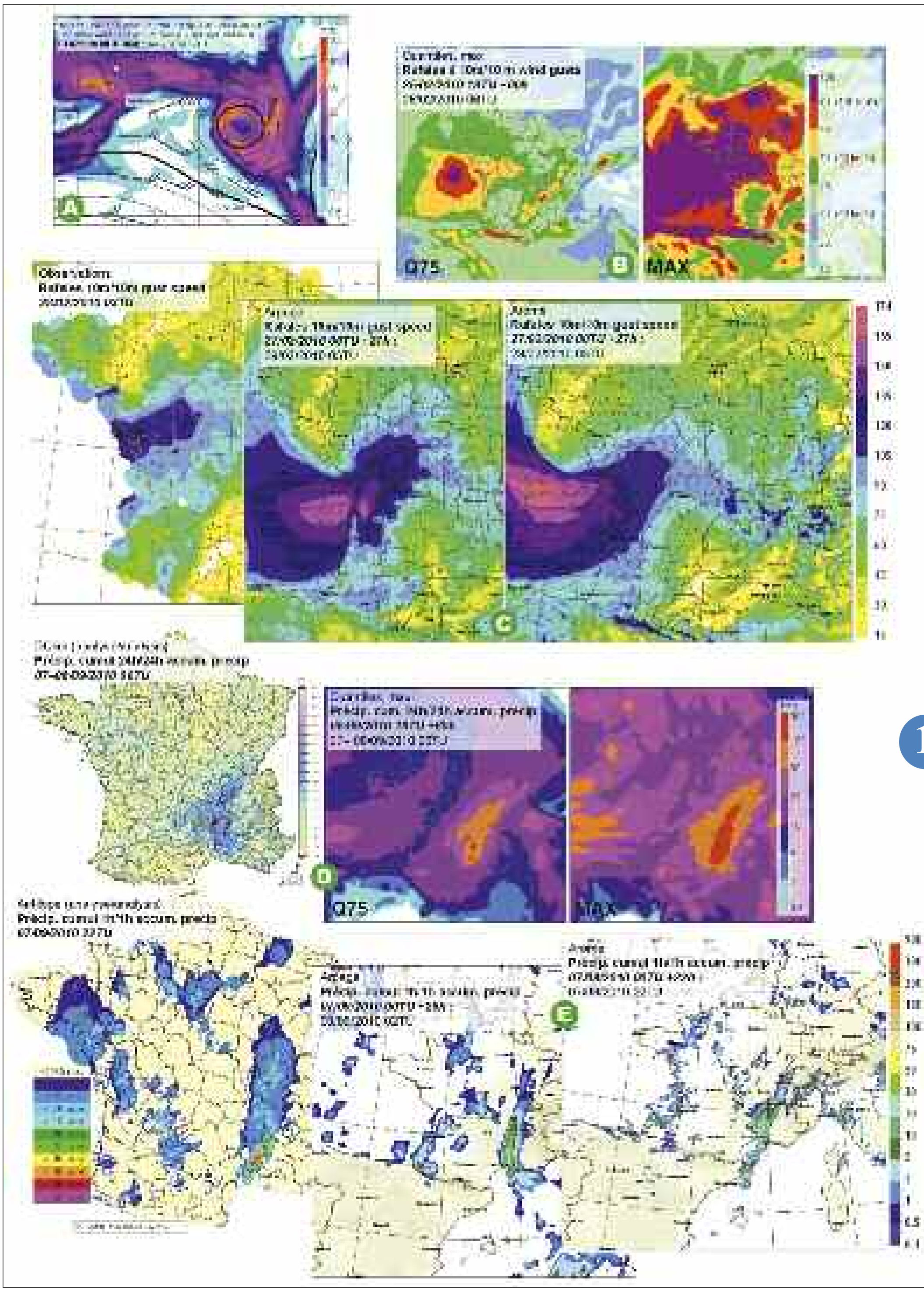
The operational implementation in 2008 of an innovative surface emissivity parametrization of microwave data over land, means that, it is now possible to assimilate low-peaking sounding channels of AMSU and MHS over land and over sea ice, which is a first-ever. Furthermore, data from the imager of the two latest American SSMIS satellites (Special Sensor Microwave Imager/Sounder) and from humidity sensitive channels of the IASI hyper spectral sounder are now assimilated in the system.

All the above mentioned developments are common to all operational models. This year, it has been possible to assimilate radar reflectivity data in the non hydrostatic AROME model. As can be seen in the figure, the assimilation of reflectivities improves precipitation detection scores for short range forecasts while, at the same time, retaining a good level of false alarm rate. This is the fruits of many years of collaborative research and development between CNRM and DSO which provides us with tailored quality controlled data.

2

▶

Comparison of forecast time-series to rain-gauges
On top, probability of detection (POD); bottom, false alarm rate (FAR) for short range cumulated precipitation forecasts between 00 h and 03 h (of the 8 assimilation cycles per day). Scores show the 1 mm/h precipitation threshold for the experiment with the assimilation of radar reflectivities (solid black line), and without the assimilation of radar reflectivities (solid green line), between the 11th and the 21st of December 2008 inclusive. The dashed black line corresponds to the number of observations below the threshold of 1 mm/h.



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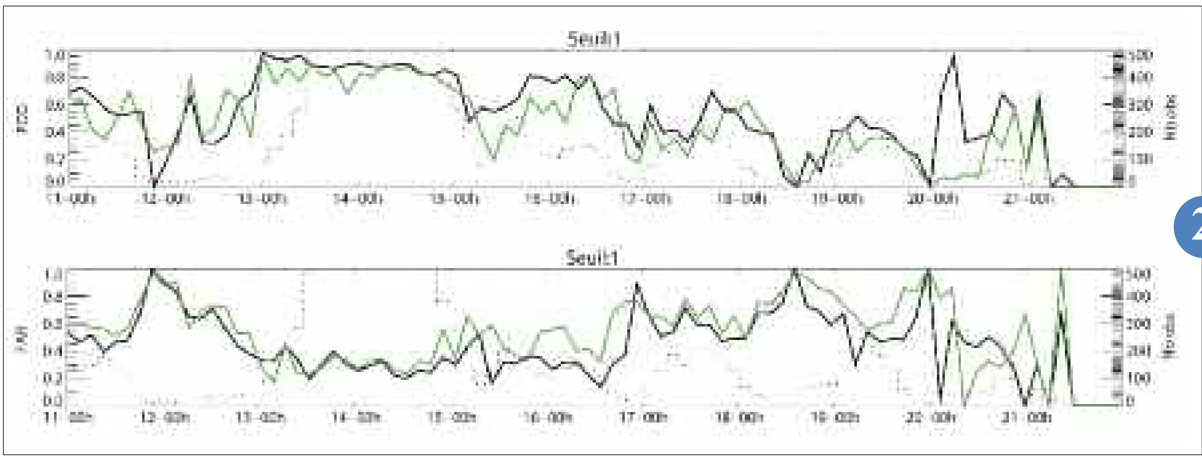

2

Background errors of the day for AROME

AROME-France operational data assimilation system uses background error covariances to filter and propagate observed information. The flow dependence of these covariances is currently neglected. In order to relax this static approach, geographically averaged covariances can be calculated daily using an AROME ensemble assimilation, which is coupled to the operational ARPEGE ensemble assimilation based on same principles.
These statistics depend on the meteorological phenomena encountered. Background error variances are smaller in anticyclonic situations, excepted for temperature and humidity in low troposphere, where the uncertainty due to the fog and low cloud events remains important.
In convective situations these variances are larger, representing the uncertainty associated to convective phenomena. Spatial correlation differences are illustrated by single observation experiments: analysis increment caused by a given departure between observation and background is more (resp. less) extended horizontally (resp. vertically) in an anticyclonic situation than in a convective one. Under the observation location, the impact on the wind field is also different: the cooling has a weak influence in the first case, whereas it generates a strong divergent circulation in the second.
Studies have shown a positive impact of these covariances of the day on the data assimilation system behaviour. Impact on forecast performances provided by this system has to be evaluated.

3

Estimation and representation of model error in ensemble data assimilation

Since July 2008, a global ensemble data assimilation system is run operationally at Météo-France. This enables flow-dependent forecast error variances to be produced. During the analysis step, this allows a larger weight to be given to observations in regions linked to storms for instance, where uncertainties are larger. This ensemble assimilation system is also used to initialize operational ensemble forecasts. However, the evolution of ensemble perturbations relies on a perfect model assumption, and resulting error variances are increased a posteriori, to account for contribution of model error to variances.
Studies are being conducted to estimate and represent model error contributions to the perturbation evolution more accurately. The ensemble spread is compared to departures between forecasts and observations, to derive model error estimates. This information is then used to amplify perturbations after each forecast step. Compared to the spread obtained when using a perfect model assumption, this inflation technique allows the ensemble spread to be increased by a factor 2.
The effective amplification of perturbations is particularly pronounced in low pressure systems (see figure). Moreover, new variance estimates have a positive impact on the forecast quality, in addition of being more consistent with observation-based estimates. It is thus considered to implement this approach operationally in the near future.

4

A surface analysis system for the AROME model

The numerical weather prediction model AROME at convective scale (2.5 km) has a dedicated atmospheric data assimilation system providing every 3 hours optimal corrections to short-range forecasts using specific mesoscale observations such as radar data. These corrections lead to an improved state of the atmosphere (analysis) from which new forecasts can be issued. The quality of fine scale forecasts also depends upon the land surface state (soil temperatures and moisture contents) since it strongly influences water and energy exchanges with the atmosphere. In its current operational configuration, the prognostic soil variables of AROME are interpolated from surface analyses produced by the global model ARPEGE. In order for AROME to have its own surface analysis system, a methodology based on the one currently used in the operational models ARPEGE and ALADIN has been set-up. Soil temperature and moisture contents are corrected using screen-level short-range forecasts errors of temperature and relative humidity. Figure 1 shows the soil wetness index produced on 1st October 2010 by the operational AROME suite (interpolation from the ARPEGE model) and by an experimental AROME suite (having its own surface analysis). Most dry and wet regions are rather consistent over the domain between the two maps. However, the interest of correcting AROME forecasts clearly shows up since small scale features are better resolved particularly over mountainous regions. Quantitative Precipitation Forecasts are systematically improved with the experimental AROME suite. This surface analysis system should become operational by the end of 2010. Future work concern the use of observations more directly informative about surface states (precipitation, micro-wave and infra-red radiances).

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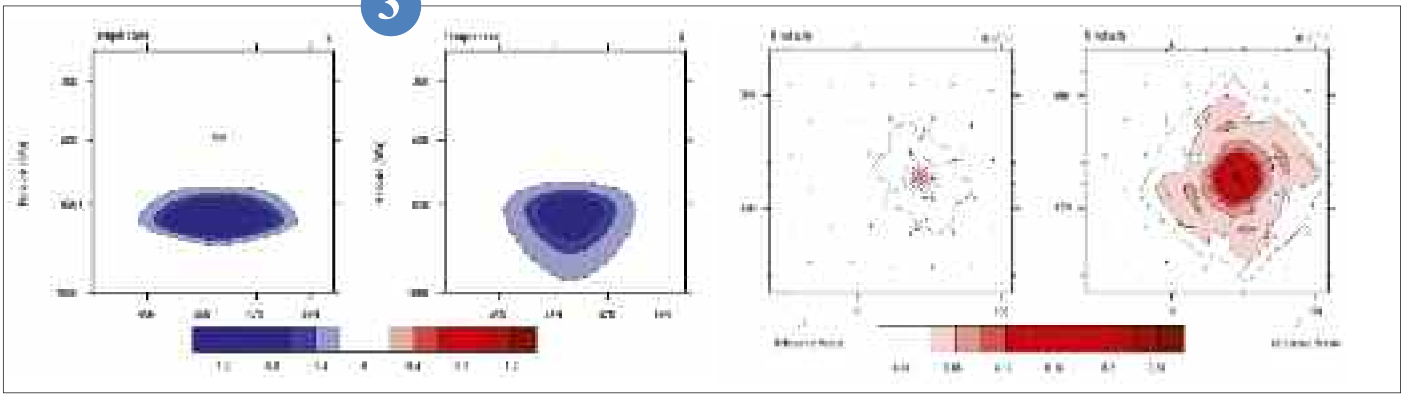
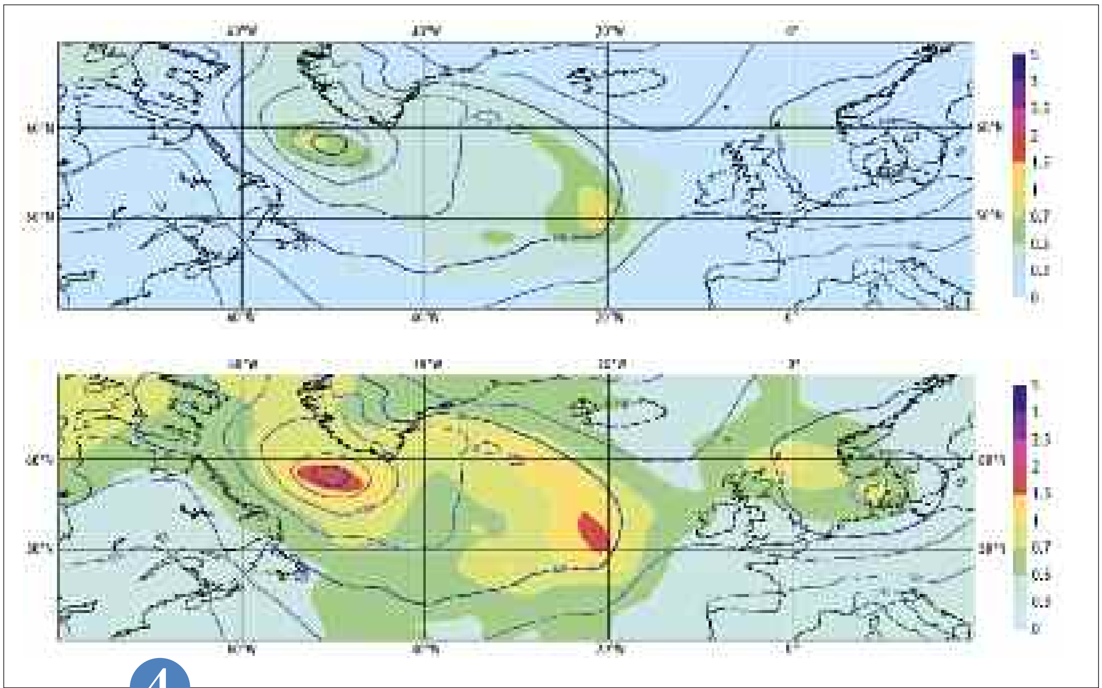


Analysis increment (difference between analysis and background) caused by a given innovation (difference between observation and background) of temperature at 850 hPa using background error covariances calculated for an anticyclonic (left) and a convective (right) situation : vertical cross section of temperature increment (top) and horizontal cross section at 950 hPa of wind increment (bottom).

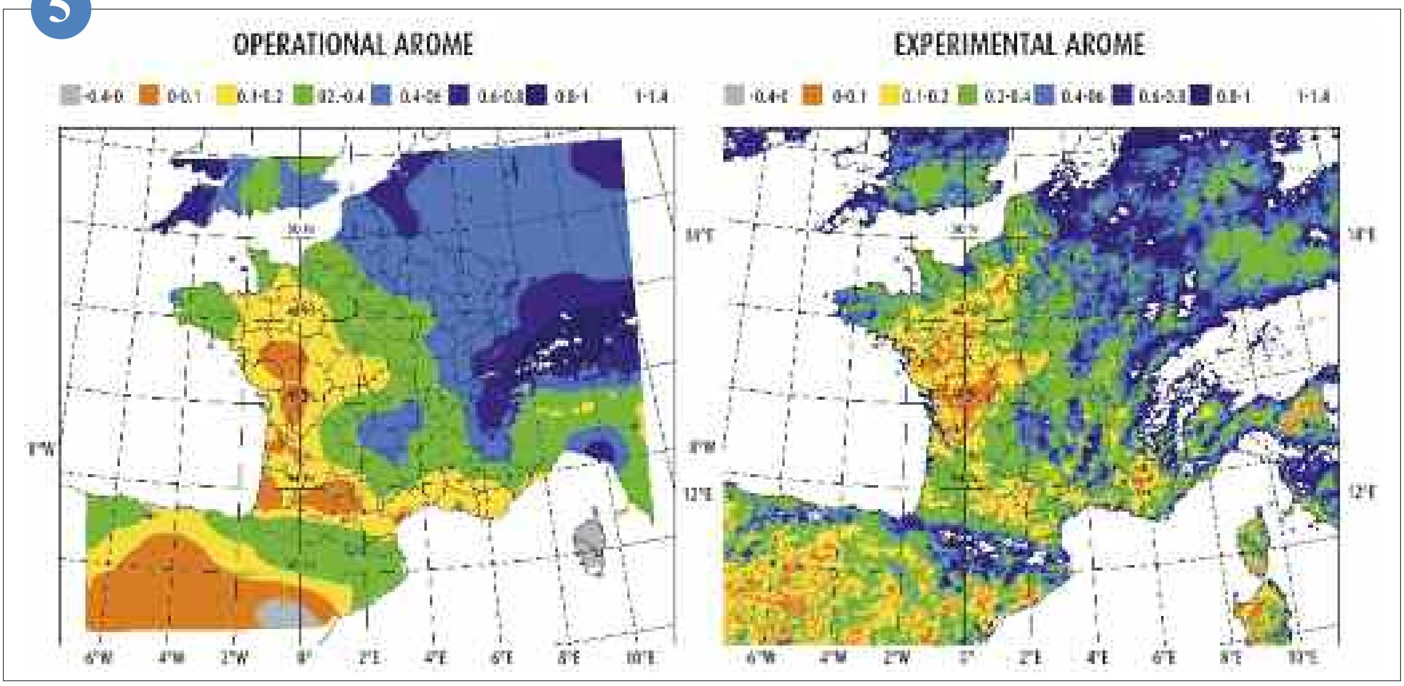


4

Amplitude of forecast perturbations for surface pressure (iso-colors, in hPa), derived from an ensemble assimilation system (a) based on a perfect model assumption, and (b) including a model error representation in the evolution of perturbations. The mean sea level pressure field is overlaid with blue isolines (iso-contours: 10 hPa).

Soil wetness index (negative values are associated with very dry soils. Values larger than one indicate moist soils evaporating at maximum rate) on 1st October 2010 from the operational AROME suite (soil moisture field interpolated from the one produced for the global scale model ARPEGE) and from an experimental AROME suite (having its own surface analysis system).

5



Improvements of clouds and microphysics in Arpege and Aladin

The representation of stratiform clouds, shallow convective clouds and associated precipitations is based in Arpege and Aladin models on the prognostic evolution of specific humidity for four classes of hydrometeors: cloud liquid water, cloud solid water, rain and snow. Microphysical processes related to precipitation such as autoconversion, collection, melting, evaporation, sublimation and sedimentation are described explicitly. Sedimentation is computed with a statistical algorithm suitable for “long” time steps (between 9 and 30 minutes) such as the ones used in operational weather forecasting Arpege and Aladin models.

This parameterization of microphysical processes has been improved to correct some deficiencies identified by forecasters. Non zero sedimentation speed, about several centimeters per second, is now taken into account for the liquid and solid cloud water. This modification decreases the cirrus cloud cover in a realistic way and the high sensitivity of the parameterization to the autoconversion threshold for the solid water phase. This change allows a revision of the snow fall speed (0.6 m/s to 1.5 m/s) and of the autoconversion thresholds with a slightly positive impact on the simulation of stratocumulus clouds.

Concerning the outlook, it is envisaged to use this prognostic microphysical scheme for the representation of deep convective clouds and possibly to improve some microphysical processes associated with the solid water phase.

6

Comparison of cloud products within IASI footprints for cloudy radiance assimilation

IASI data are now assimilated in clear conditions at many operational meteorological centres, providing good impact on forecast. However, more than 80% on the whole globe are covered by clouds and all the centres began to assimilate cloud-affected sounder data. The first step is to detect and characterize the clouds within the IASI spot and the main useful cloud parameters are the cloud top height and effective amount. A direct validation with in situ truth being difficult, one way of investigating the limitations of a particular methodology is to perform a careful inter-comparison of the results of different schemes. For this study, operational cloud schemes from CMC, CMS, CNRM, ECMWF, JMA, NOAA, UKMO and UNIBAS using various cloud retrieval methods were applied to a 12 hour global IASI acquisition. The figure show typical examples of cloud pressures comparisons. The agreement between all the schemes is always better for high clouds even for small cloud amount and for the lower layers for opaque and overcast situations. For low level clouds, the agreement decreases quickly with the cloud cover due to the schemes sensitivity to surface parameters errors. This problem is partially avoided when using co-registered AVHRR data. Standard deviations of differences are generally about 100-150hpa with biases less than 50hPa and correlations around 0.90. The occurrence of multi-cloud layers is about 70% in this study. For single overcast layers of thick clouds there is quite no incorrect detection of the data as clear by any of the schemes and the cloud characterization is also improved with correlations often larger than 0.95 what shows the importance of assimilation these data in priority.

7

New developments about statistical adjustments

For many years, Météo-France have been producing local forecasts by statistical adjustments (SA) which are based on the use of statistical models developed from archives of a predictand (locally observed variable) and predictors (explanatory variables from numerical models).

This year, three particular points were surveyed:

• The spatialization : new statistical adjustments using non local but spatialized predictand (gridded fields) have been developed for cloudiness (using satellite observations), precipitation (using ANTILOPE analysis) and wind speed at 10m (using VARPACK analysis).

• The probabilistic forecasts: forecasts are provided in the form of probabilistic distributions. The different probabilistic laws are defined from the distribution of observations (normal temperatures, log-normal precipitation and Weibull wind). Forecasts are given in in terms of expectation, quantiles or probabilities.

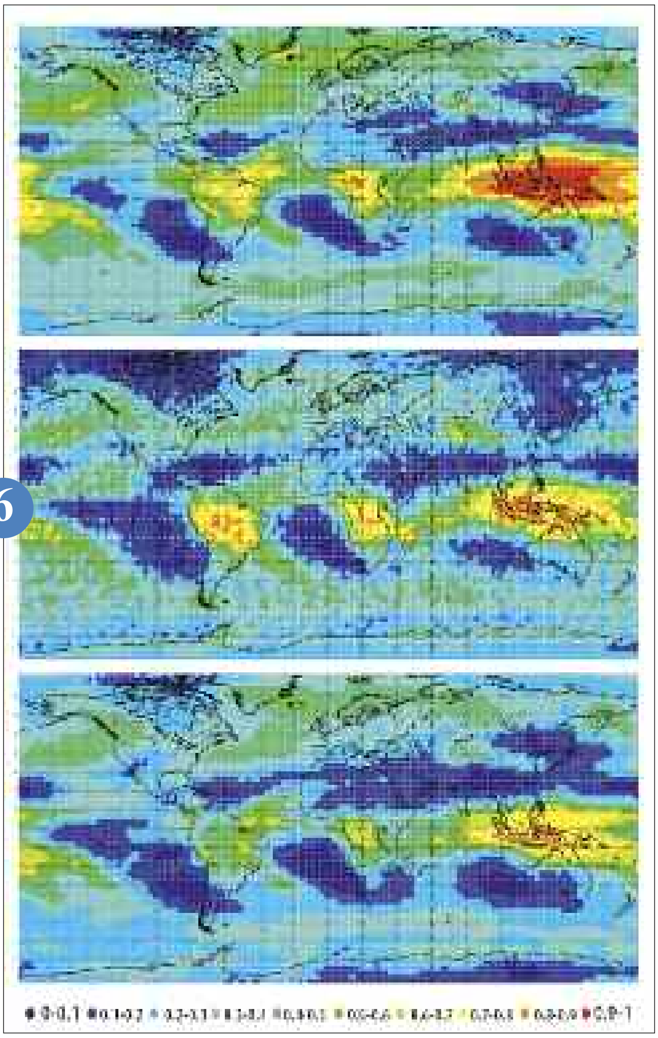
• New parameters : for the photovoltaic energy production, it is necessary to get reliable estimates of radiation. Studies have been undertaken to develop forecasts by SA for this parameter which presents a bimodal distribution, leading to interesting results over France, but more mitigated for the Island of La Reunion.

These developments will be operational in 2011. Further studies are planned for the generalization of probabilistic forecasts and the development of SA forecasts for ceilings for aeronautics.

8

high cloud cover simulated by the ARPEGE model averaged over December-January-February 2007/2008 with the old (top panel) and then new (lower panel) version of microphysics compared to the high cloud cover (product CALIPSO-GOCCP) derived from CALIPSO lidar observations (middle panel).

6



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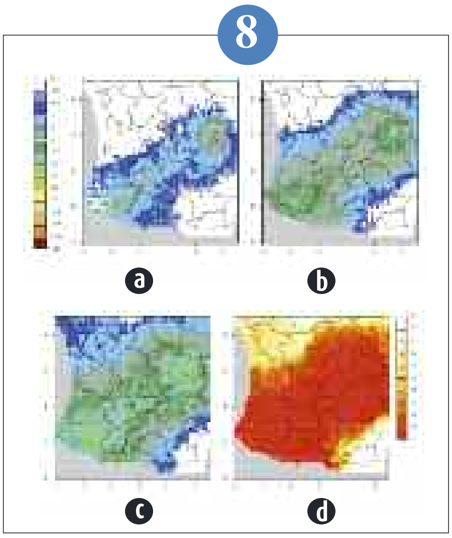
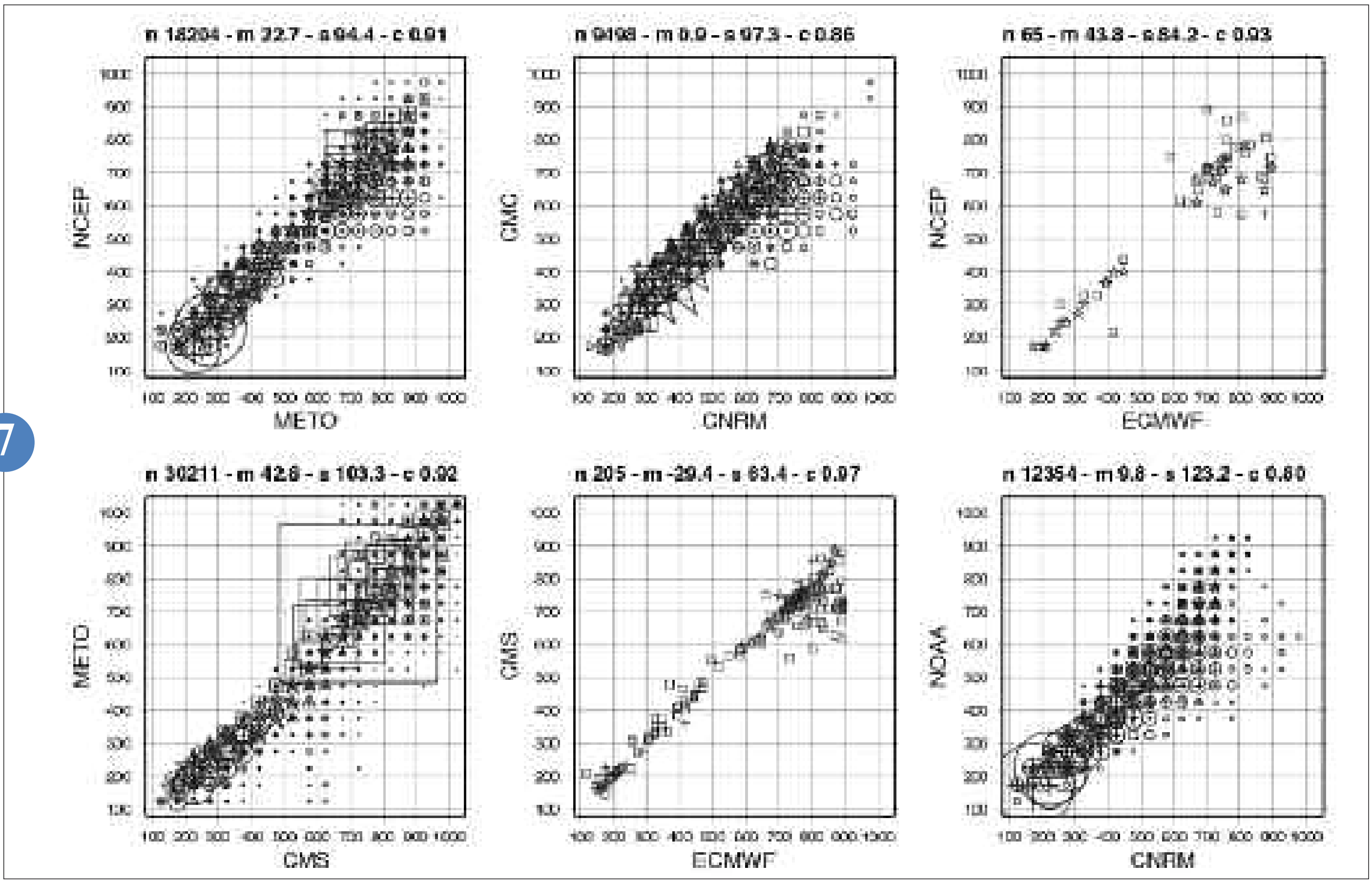


SA Spatialized probabilistic forecast of 3h accumulated precipitations (ARPEGE model, based on 20070212, 00UTC) :
a) Q10,
b) expectation,
c) Q90
and d) probability of occurrence.

Examples of bi-dimensional histograms and scatter plots for ECMWF.
Characters correspond to the retrieved cloud effective amount of the scheme in abscissa (0.1○ 0.3+ 0.5Δ 0.7★ 0.9□). The size of the characters indicates the distribution except for the graphs with ECMWF.

7



Research and developments about Arome model

Validation of AROME for Xynthia Pyrenees

Xynthia storm entered in the France through the Pyrenees the 27th of February 2010 in a south flux, inducing very strong winds over the Pyrénées-Atlantiques, the Hautes-Pyrénées and the Haute-Garonne. The strong winds were located not only on the peaks (238 km/h at "Pic du Midi"), but also in the valleys, as in Luchon where a human death occurred.
AROME model forecasted the event with a good accuracy in terms of localization and gust intensities by reproducing a band of strong winds along the Pyrénées downstream on the north side, up to the pre-Pyrénées. The model clearly shows trapped orographic waves (figure a), and their presence is confirmed by the Lannemezan lidar. These trapped waves, characterized by an energy propagating vertically and horizontally downstream, contribute to speed up low level winds (figure b), and are associated to non hydrostatic processes. Indeed, the AROME simulation in the hydrostatic version does not reproduce the trapped waves guide (figure c), and therefore the downstream low level winds are reduced (figure d), underestimating the storm winds.

9

Implementation and evaluation of an AROME model version covering the north-western Mediterranean for the preparation of HyMeX

As part of preparation for the HyMeX field campaign, a version of the AROME model covering the northwest of the Mediterranean is implemented. This model, called AROME_WMED covers a large area at a spatial resolution of 2.5 km extending from Portugal to Sicily and North Africa to the Alps. For the purposes of the AROME_WMED assimilation component, the variance-covariance matrix of the guess error was recalculated. The data flow is similar to the operational model AROME (France). In the context of the operational support to the HyMeX field campaign, AROME_WMED should run operationally during the Intensive Observation Periods (IOPs) planned in fall 2012 and spring 2013 to feed the HyMeX decision-making center and hence guide the deployment of instruments used specifically for these POIs (aircraft, balloons, etc.). In addition, AROME_WMED should help making progress on issues such as data assimilation, the physical parameterizations and process studies, focusing on its specific maritime domain.
In June 2010 a particularly violent rain-storm episode has affected the Var (83): on June 15, 2010, a maximum of 397 mm in 24 hours was observed in the central-eastern part of the department (Les Arcs). AROME operational forecasted about 100 mm/24 hr on the east of the department, while AROME_WMED forecasted a higher amount (205 mm/24 hr), but positioned it too far in the west of this department.

10

Improvement concerning boundary layer clouds in AROME model

The operational use of daily AROME forecasts has showed that, periodically, in wintry stable conditions, the model does not simulate cloud cover despite a significant relative humidity.
The statistical subgrid cloud scheme considers that, at the model mesh scale (2.5 km for AROME), moisture is not uniformly spread and, thus, it is possible to have cloud without having, on average, saturation, on condition that heterogeneity is great enough. The latter is represented by the mean of a variance, said to be subgrid, given by the turbulence scheme. To this first contribution, a nebulosity provided by the shallow convection scheme (cumulus, stratocumulus) is added.
Noted forecasting flaws indicate an underestimation of the subgrid variance that, presently, does not take enough into account mesoscale variability. A first improvement, with encouraging results (see figures), is found by adding a variability term allowing to simulate a partial cloud cover in high relative humidity areas (consistent with ongoing work at KNMI).
The improvement of statistical cloud scheme will be pursued by introducing a subgrid variance depending on orography (small cumulus on summits). In addition, to reduce the too "binary" aspect of the simulated nebulosity in cumulus and stratocumulus cases (cover either absent, or full, seldom partial), another entrainment formulation and a new cloud parametrisation will be evaluated in the shallow convection scheme.

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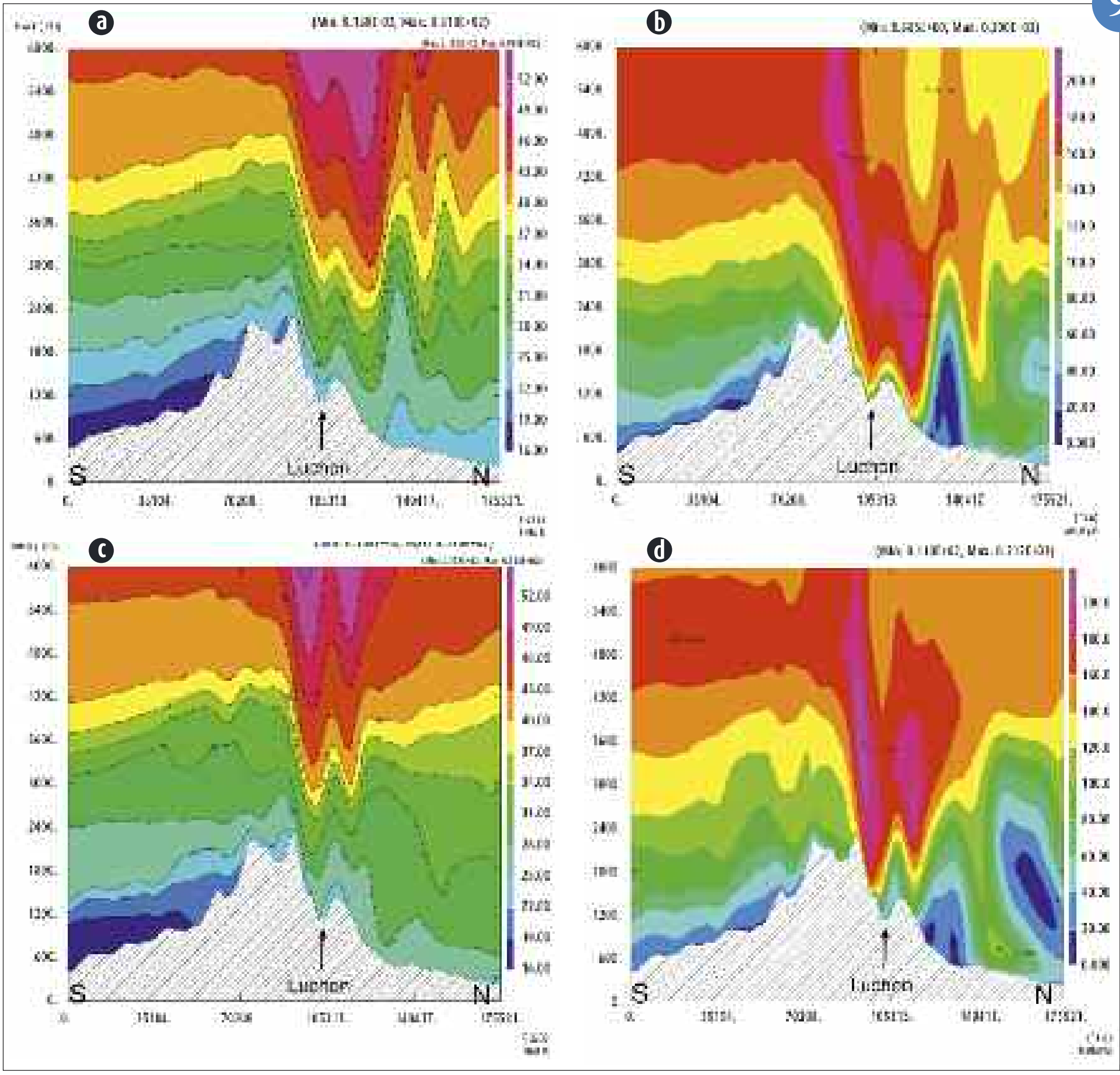
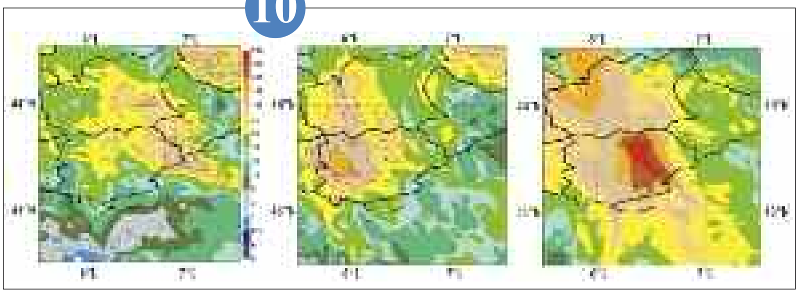


◀ Vertical cross section along the South-North axis the 27th of February 2010 at 21 UTC of:
a) Potential temperature simulated by AROME in the Non Hydrostatic version.
b) Wind intensity simulated by AROME in the Non Hydrostatic version.
c) Potential temperature simulated by AROME in the Hydrostatic version.
d) Wind intensity simulated by AROME in the Hydrostatic version.

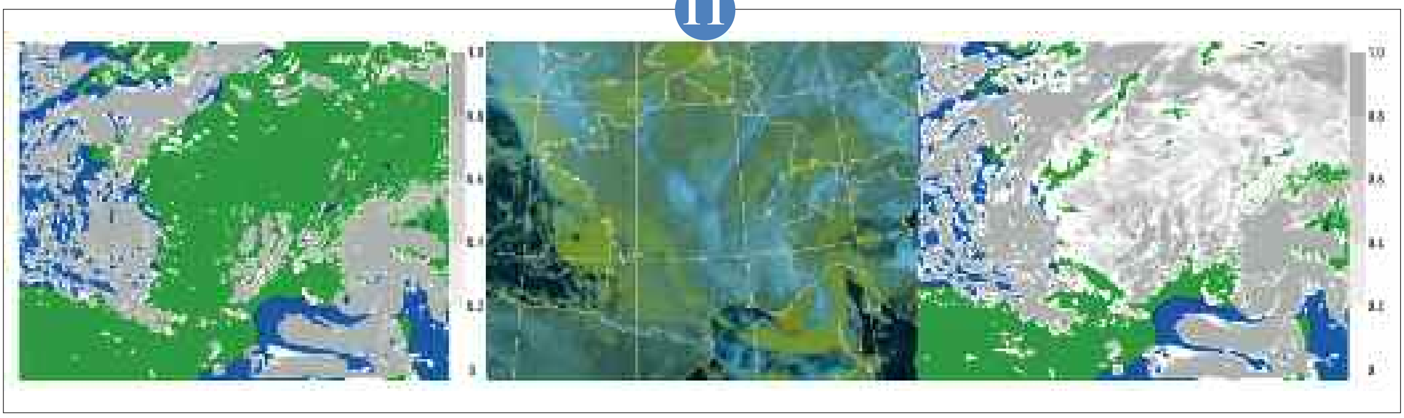
10



◀ Precipitation forecast over 24 hours on the Var (from 15/06/2010 to 16/06/2010 06 UTC 06 UTC) for AROME (left figure) and AROME_WMED (central figure); the Collobrières (Var) radar derived 24 hr-cumulated amount on the right figure.

Low-level nebulosity valid on 10th January 2010 at 06 UTC forecasted by AROME in operational version (left, low values in white, high values in grey) and by AROME with the new sub-grid variance term (right) to be compared to the colored composition (middle, low-level nebulosity in yellow). ▼

11



Non fully-elastic equations systems

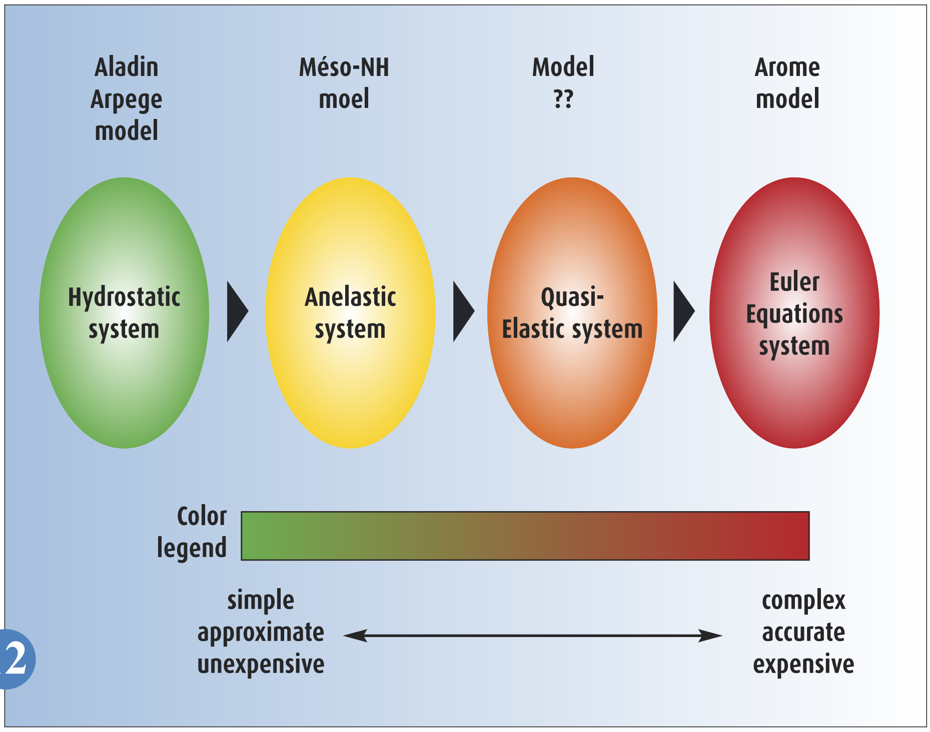
For the governing equations of the atmospheric fluid, the Euler Equations (EE) system, used for instance in the AROME model, is free of approximation but relatively difficult to implement with efficiency and robustness in NWP, at least in some configurations (large domains, or very high resolutions with very chaotic flows). In cooperation with ECMWF, GMAP team is currently studying the relevance of a new class of so-called "quasi-elastic" (QE) governing equations. In these systems, as in previous hydrostatic or anelastic systems, the elastic waves, difficult to handle efficiently, are completely filtered. In contrast, QE systems have a degree of accuracy almost as good as the EE system.
We have shown that QE systems could easily be used in the specific context of our NWP models ("mass" vertical coordinate, semi-implicit semi-Lagrangian time-schemes...). Then it has been established that these systems do not suffer of the theoretical limitations linked to hydrostatic or anelastic approximations (unappropriateness for large scales or high resolutions, strong distortion of the structure and propagation of baroclinic and barotropic waves...). QE systems are thus promising from the theoretical point on view, but the practical relevance for NWP is still to be demonstrated. Similarly to anelastic systems, the pressure field is obtained through a diagnostic equation, but this latter is quite more complex in QE systems, and might be difficult to solve accurately. A first prototype should be implemented next year.

12

Towards an AROME ensemble prediction system: assessment in a heavy precipitation event framework in Mediterranean region

South-eastern France is often subject to flash-floods generated by heavy precipitation events especially in autumn. Despite great realism of fine-scale forecasts from non-hydrostatic numerical atmospheric models, it is still necessary to assess and quantify the forecast uncertainty.
The aim of this study is to develop dedicated methods of generation of ensembles to quantify the convective-scale predictability of AROME forecasts. To take into consideration the sources of uncertainty impacting high-resolution forecasts, ensemble simulations are performed with the AROME model. The uncertainty at synoptic-scale on both initial and boundary conditions is given by the Météo-France's large-scale ensemble forecasting system PEARP (AROME-PEARP). Error on meso-scale initial state is represented from experiments assimilating randomly perturbed observations (AROME-PERTOBS). Another ensemble combines both previous sources of uncertainty (AROME-COMB).
Ensembles are evaluated over a one month-period encompassing heavy precipitation events. Calculated probabilistic scores (ROC) show a fair resolution and the ability of these forecast systems to discriminate between precipitation event occurrences and non-occurrences. Moreover, the meso-scale perturbations have their maximum impact at very short-range, whereas the influence of synoptic-scale uncertainty becomes significant beyond 12 h.
The uncertainty due to modelling errors for AROME will be also considered furthermore. This work is part of the French MEDUP project.

13



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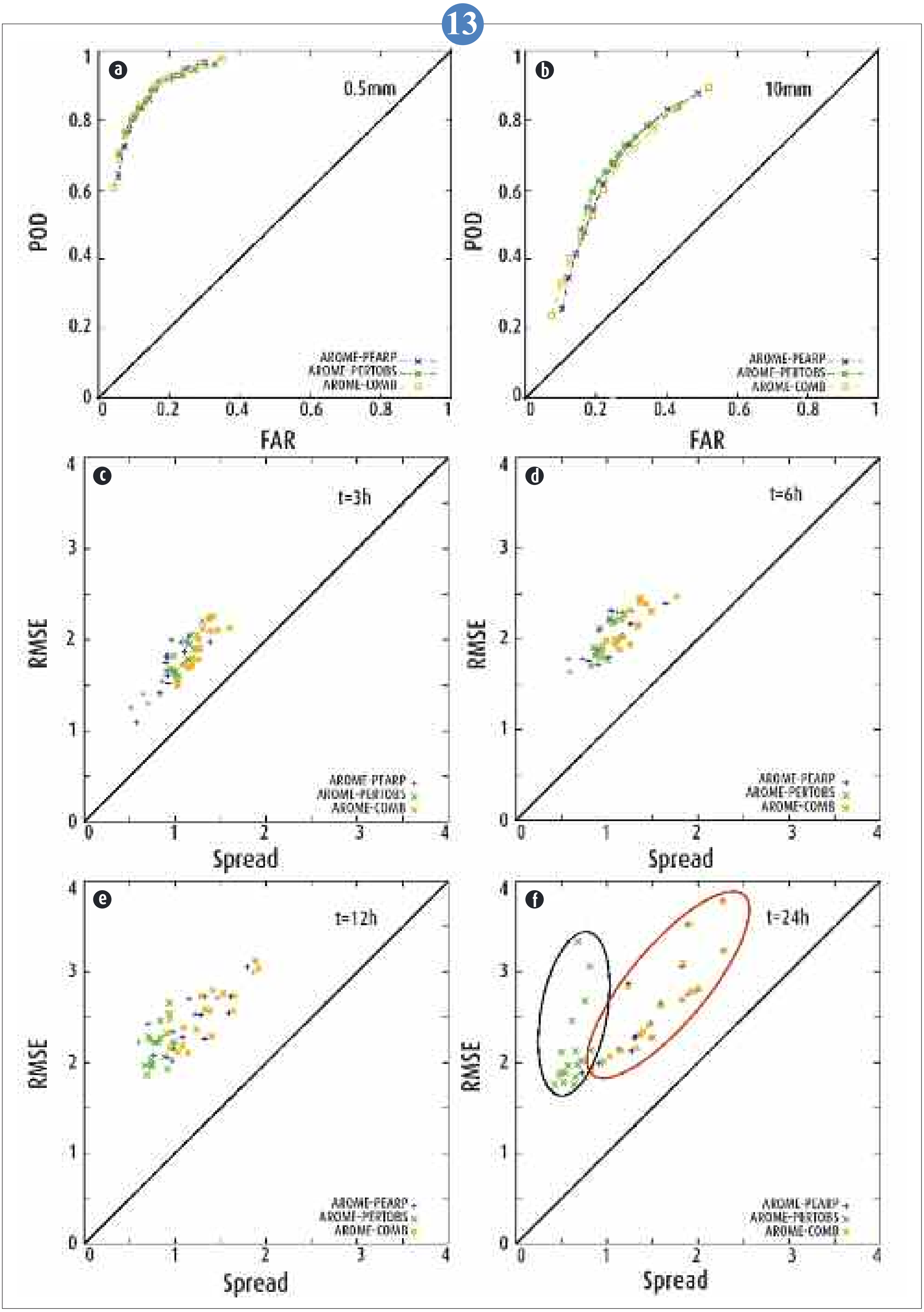

▲ ROC (Relative Operating Characteristics) scores calculated for the 24 h-accumulated rainfall and for thresholds of: a) rain- no rain 0.5 mm and b) 10 mm. Panels c), d), e) et f) stand for the root mean squared error as a function of the mean ensemble spread for wind at 925 hPa. The quality of a forecast system is estimated by the area under the ROC curve, the larger the area the better the quality (or resolution). Each symbol represents one day in the period.

Cyclone forecasting

A new algorithm for tracking tropical cyclones

For more than twenty years, the numerical prediction of tropical cyclones has been steadily improving. In order to assess and to compare the cyclone forecasts by such models, it is necessary to track automatically the cyclone systems in the successive forecast fields.
A first classical tracking algorithm consists in searching for a cyclone signature in the surface pressure field (at mean sea level). A local pressure minimum is indeed the most simple marker of a cyclonic system. However it appears that such a tracking method is not always reliable, in particular when the cyclone propagates over land, where the pressure field may be perturbed by the relief.
A new algorithm, that consists in detecting the cyclone signature both in altitude (geopotential on the isobaric level 700 hPa) and in the low-level wind field (on the isobaric level 925 hPa), improves tracking over and near land. The enclosed figure shows the gain of this new algorithm for two models forecasting the tropical storm Jade (2009). Moreover, this algorithm improves significantly the detection and the forecast tracks of cyclones at the beginning at at the end of their life.
Thanks to this new algorithm, it will be possible to set up reliable automatic tools for comparison of numerical models. Besides, some cyclone forecasting products, in particular issued from ensemble prediction, would be improved.

14

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Trajectory of the tropical storm Jade (2009) over Madagascar forecasted by the Météo-France models Arpege and Aladin. The tracks are computed either with the classical mean sea level pressure algorithm (Mslp, Arpege in light blue, Aladin in grey) or with the new algorithm (Arpege in dark blue, Aladin in black). The jumps of the Mslp tracks towards the western coast of Madagascar are unrealistic.

The effect of the orography of La Réunion Island on the track of cyclones moving nearby

La Réunion Island, located in the South-West Indian Ocean, is regularly hit by tropical storms. In 2002, the tropical cyclone Dina moved as closely as 50 km from the island, where it generated extreme winds, intense precipitations and many damages. Every year, some less intense depressions or moving further away, are responsible for intense precipitations in La Réunion Island (Diwa in 2006, Gamede in 2007, Gael in 2009). The topography of La Réunion is characteristic of a young volcanic island: its maximal diameter is 80 km and its orography is more than 3000 m high. In order to better predict cyclone tracks, the possible effect of such an orography on cyclone tracks has been studied.
The first part of the study consisted in making an inventory of every cyclone that have moved nearby La Réunion Island since 1981 and to assess their track deflection. It has thus been shown that the trajectories are influenced by the island up to a distance of 400 km. The study was then completed by some high-resolution idealized numerical simulations. The simulation of a cyclone without orography is used as a reference. In the other simulations, the relief of La Réunion Island is put at different distances from the reference track. The effect of the relief appears then as the difference between the simulated tracks and the reference track. The enclosed figure shows the significant effect of the relief on a cyclone moving at 100 km at the south of the island. A sensitivity study of the deviations to cyclone parameters will help to better understand the effects.
Ultimately, the objective is to build a conceptual model of the effect of the relief on the trajectories, in order to better predict the impacts of cyclones on La Réunion Island.

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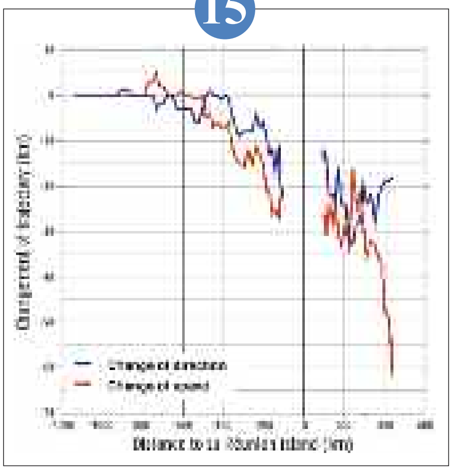


Difference of position of an idealized cyclone between a simulation without orography and a simulation with the relief of La Réunion Island, located 100 km at the north of the cyclone, along the trajectory. The relief has two effects: a deceleration along the track (red curve) and a deviation towards the south (blue curve). Both effects are maintained and amplify after the cyclone hits the island (point 0 in abscissa).

Research for aeronautics

SESAR

The European Union agreed on new rules in air traffic management systems in Europe to be implemented by 2020. SESAR (Single European Sky ATM Research) is a joint R & D air traffic control infrastructure modernisation programme, a unique public-private partnership in air traffic management. Preliminary studies showed that meteorology was a key factor, therefore a formal R & D meteorological road-map has been formalized in the "master plan" and the2008-2013 work plan.
Météo-France involvement in SESAR is not without consequences as it not only implies to improve our contribution to the French civil aviation authority over its airspace, but also as from 2012 for wider functional airspace blocks (FAB). Météo-France commitment to the programme imply that specific research must be undertaken.
Météo-France joining forces with DSNA and THALES on several projects, was successful in its invitation to tender to the SESAR programme. Projects that have been accepted deal with the observation and prediction of convection in the approach zone, wake vortex turbulence (WP12.2) and the prediction of aeroplane 4D trajectories (WP4.7). CNRM involvement is foremost, notably by the development of an AROME-aéroport model (scale 500m) by GMAP and new data merging algorithms by GMEI.
A new invitation to tender specifically for meteorology (WP11.2) was issued in July 2010. A "EUMETNET" consortium composed of 11 European meteorological services, Belgocontrol, Austrocontrol, DLR, NLR and Thalès gathered together to submit the tender. CNRM together with other departments of the institute (DSO, DSI, Dprévi) took part in submitting the tender. Météo-France involvement focuses mostly on the fruition of a "4Dweather-cube" executed by DSI and on the "sub-task" "TMA&En-route 4D-grid" by CNRM/GMEI.

Study of gusts at the Roissy-Charles de Gaulle airport : hydraulic and numerical simulations

During strong storms, air traffic may be totally blocked for Hours on Roissy-CDG airport. The reason is that, for winds exceeding 100 km/h, embarking and disembarking of passengers is forbidden by international rules. Though, since the reference measurements are near the runways, there might be zones protected by the terminals where a few operations could be securely maintained. In order to improve the meteorological service to civil aviation at Roissy-CDG, Météo-France decided to start a multi-support study to describe the wind at fine-scale on the airport. Numerical simulation is combined to hydraulic simulation and field measurements to obtain the most reliable and accurate representation of gusts on the airport, especially near the passengers walkways.

Physical models are put in the large flume of CNRM-GAME, similarity principles allow to deduce local atmospheric flow from observations in this hydraulic channel. By rotating the model we can change the direction of the simulated wind. Once the general flow is known on different areas of the airport, a more accurate model will be used to determine precisely the gusts near the walkways in a focus zone, including airplanes models.
A research project is associated to this applied study: it is indeed a rare opportunity to get laboratory experiments, numerical simulations and in situ measurements on a real atmospheric boundary layer. This will be an opportunity to apply innovative non-linear filtering techniques, in order to characterize temporal and spatial scales of the wind field over the airport. It will provide a unique dataset to discuss strengths and limitations of physical and numerical modeling nowadays.

1

The making of the large area model (left two), fine-scale velocity field (an embankment of a train TGV) (center), velocity measurement on a large area model (valley of Tarn in France-Verrière viaduct building site) (right).

1

Gusts over Roissy-CDG airport study: in situ measurements

The physics and numeric air flow simulations around Roissy Charles de Gaulle airport infrastructures will be validated with in situ measurements. Collaborating with Aéroports de Paris, CNRM has set up in July 2010 6 wind measurements systems for constitute a validating data set. Measurements are performed with ultrasonic anemometers in order to also estimate turbulence and vertical components of the wind. The measurements systems have been located on the roofs of mobile walkways or close to them on fixed stands like pylons. The first ones are equipped with GPS transmitters and angle to localize and to correct precisely the measurements according to the walkway position. Acquired each minute, measurements are transmitted to CNRM once a day. Measurements will be systematically compared with four standard aeronautical measurements performed on the two runways and who are not disturbed by the airport infrastructures. In case of strong wind, the acquisition is turned to a period of one second. This measurements will be used to validate numerical and physical turbulence estimation performed. Sensors were settled for one year, expecting get some relevant strong wind.

2

National low-level wind shear mosaic inside the precipitations from Doppler radars

The ability of detecting and quantifying low-level wind-shear at a high spatio-temporal resolution (5'–1 km²) is interesting for Météo-France departments in charge of aeronautical forecasting, now-casting and for those in charge of the evaluation of numerical weather prediction models. Wind shear is associated with numerous dangerous meteorological phenomena: gust fronts, convergence areas (conditioning the intensification of convection), mesocyclones areas that can attest the presence of tornadoes, like in Hautmont, 2008.

To get a spatialised information of low-level wind shear, we use the radial velocity data from the French Doppler radar network ARAMIS1. A previous work to improve the quality of radial velocity has been done. The wind shear algorithm search, for each pixel of the final mosaic, the maximum gradient of radial velocity in all directions (on an horizontal plane) for the different altitude levels available between 0 and 1500 meters above ground, and select the maximum value.

A first qualitative evaluation has been done on a few situations and gave promising results, in particular on a narrow cold front band (illustrated on images a and b). A first comparison with ground wind data (anemometers) has also been undertaken and exchanges are in progress with the future users to finalise the product specifications.

A real time demonstration of the national wind shear mosaic is planned for 2011. The integration of the wind shear information inside the thunderstorm identification product (OPIC2) is also considered.

3

The input of the research aircraft during the Eyjafjöll volcano eruption

On March 20th 2010, the Icelandic Eyjafjöll volcano erupted, throwing ashes into the atmosphere that forced many European countries to stop the air traffic.

Facing a very large and badly known phenomena, the research aircraft of Météo-France and the CNRS-INSU, operated by SAFIRE, have been urgently mobilized to perform observation missions.

A first instrumental configuration has been setup:

- A lidar, operated by the Laboratoire des Sciences du Climat et l'Environnement (LSCE), for remote sensing of the ash plume,
- Four microphysics sensors to measure the size and concentration of the particles between 0,1 µm to 300 µm.

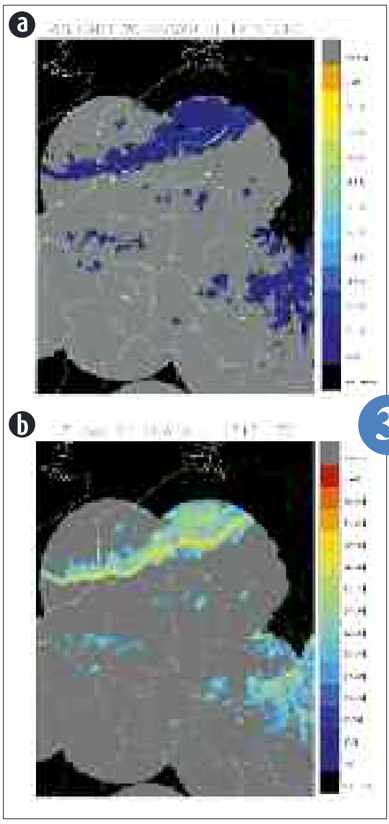
This instrument set has been later completed by an air inlet with physic-chemistry analyzers (filter analyses performed by INERIS and the Institut de Physique du Globe de Paris), as well as radiometers from the Laboratoire d'Optique Atmosphérique).

In total, the research aircraft ATR42 and Falcon20 flew almost 50 hours, in close cooperation with several laboratories specialized in the environment science. These flights have brought crucial information to help the decision to re-open the airways.

4

2

Anemometer on a mobile walkway at Charles de Gaulle Airport.



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a) Maximum of horizontal wind shear between 0 et 1500 m above ground (m/s/km), estimated inside precipitation areas from Doppler data coming from ARAMIS radar network. Zoom on the North of France, 29/08/2010 at 1715 UTC.
b) Radar reflectivity composite (dBZ): maximum value between 0 and 1500 m above ground. Zoom on the North of France, 29/08/2010 at 1715 UTC.

4

The Leosphere lidar on board the Falcon20. This lidar can make remote detection of aerosol layers (such as ash layers).

Studies of meteorological process

Researches on understanding and modeling of mesoscale phenomena and processes aim at improving their representation within NWP and climate systems of Météo-France. Along this line, the following advances have been made in 2010: First, concerning the surface modeling, a database of physiographic parameters for lakes has been developed for the surface model SURFEX; the representation of snow processes, including snow transport, has been improved; a parameterization of the effects of vegetation in towns have been introduced in the TEB town sub-model of SURFEX. Regarding the cloud parameterization, a new statistical distribution of the thermodynamical characteristics for the sub-grid boundary layer clouds has been issued from the analysis of several LES.
In 2010, process studies have continued to be carried out based on the rich AMMA 2006 field campaign dataset. Significant progresses have been made in the identification and understanding of the connections between large-scale circulation and the sub-seasonal variability of the African monsoon. Effects of surface heterogeneities on the atmospheric boundary layer development over Western African regions have been also further studied. CNRM is strongly involved in the preparation of the next multidisciplinary field campaign HyMeX dedicated to the hydrological cycle in the Mediterranean. The first version of the International Science Plan of HyMeX has been finalized this year. Several studies have also contributed to the design of the observation strategy for intense observation periods of HyMeX. Within the framework of the CAL/VAL of the SMOS satellite, successfully launched at the end of 2009, in situ soil moisture measurements have been performed over Southwestern France at the vertical of the CAROLS radiometer onboard the French SAFIRE/ATR42 aircraft. The SMOSREX and SMOSMANIA soil moisture observations have complemented these field campaign observations.

1

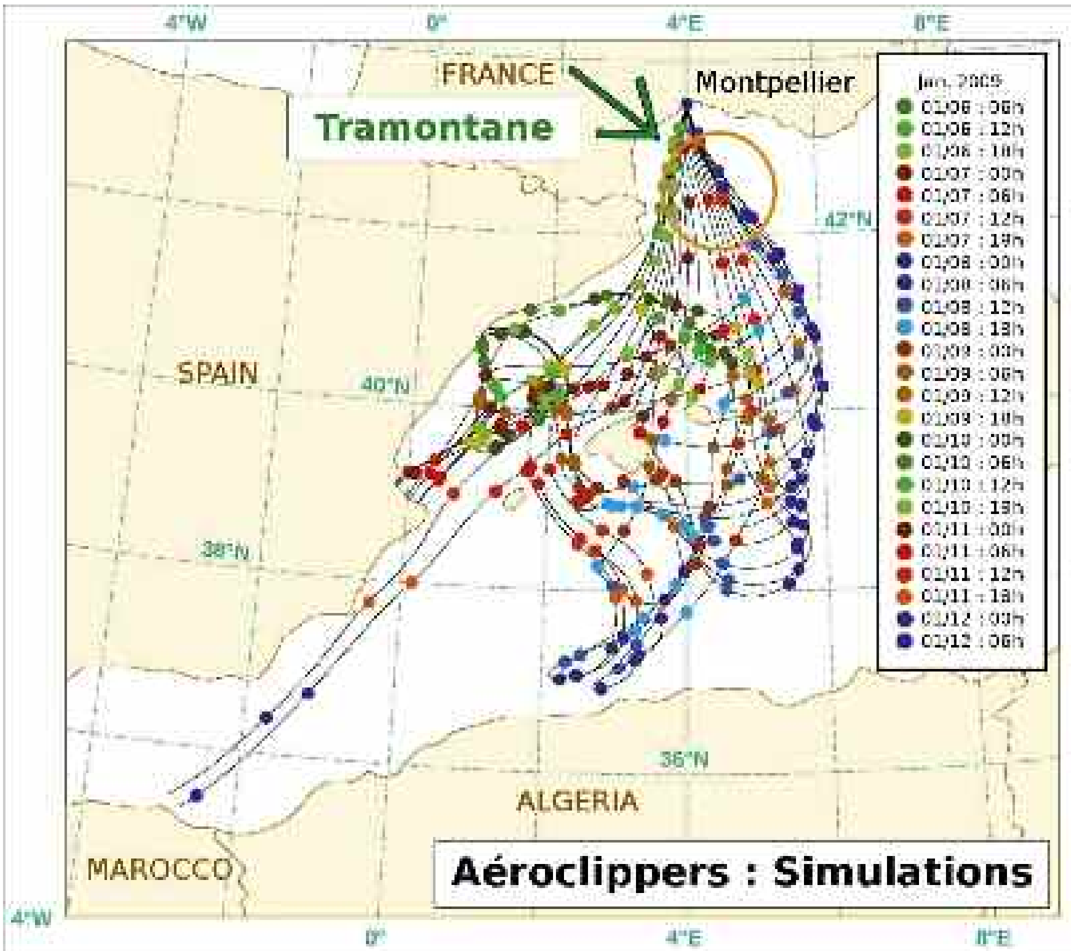
BAMED/HyMeX: Which launching sites for CNES low-level pressurized balloons?

The BAMED project prepares boundary layer balloons to be deployed during special observing periods (SOP) of HyMeX field campaign. The LMD and the CNRM are partners in this project.
Two types of balloons are being prepared at CNES.
The BLPBs are free pressurized balloons that drift along Lagrangian trajectories at about 900 hPa level, above the open sea. They collect measurements of temperature, humidity, pressure and wind that are transmitted in real-time. They will be launched upstream and prior to intense precipitation events (Cévennes) in France during the SOP in autumn. Preliminary studies have identified the island of Minorca as the best launch site.
Aéroclippers are tethered balloons towing a marine gondola. These platforms collect data to infer sea-surface fluxes; they are likely to be launched from the French coast on episodes of strong local winds during the Spring SOP. Indeed, Mistral and Tramontane are strongly linked to the occurrence of ocean deep convection in the Gulf of Lion. The determination of the launch sites in the Gulf continues at CNRM.
The deployment will require preparing the BLPBs and the Aéroclippers well in advance. To this end, we will prepare and use decision-making tools developed for adaptive observation. Thus, the value of the collected data should be maximized when used in weather numerical weather prediction models.

2

1

The CAROLS campaigns in 2009-2010: Observation of the soil moisture heterogeneities with in a SMOS pixel (blue circle), below the flight of the ATR42 (red lines) equipped with a similar radiometer type as the SMOS one. Soil moisture measurements, with probes shown in the bottom right panel, have been performed for three areas (yellow boxes) with different crops: from left to right, hillside crop, forest of Lahage, crop over the plain.



2

Simulated trajectories of Aéroclipper launched from a coastal site close to Montpellier during an episode with Tramontane wind from 6 to 7 of January 2009. We simulated the release of 25 Aéroclippers (one every 2 hours). Here, the trajectories are simulated with ECMWF analysis, but also simulated fine-scale trajectory with Meso-NH (AROME) may be used. Aéroclipper trajectories are interrupted when the platform reaches any coast. The region of interest for deep marine convection (encircled in orange on the picture) is very well sampled in this case.

Influence of uncertainties in the prediction of a network of adaptive observations

Adaptive observation aims at improving the quality of numerical weather prediction by means of small adjustments in some near future observing networks. The goal is to predict which change in the observing system will reduce at most the uncertainties in the forecasts. In practice, the uncertainties that are known when making the calculations are projected into the future. Although they have been identified, some sources of uncertainty are particularly difficult to model, especially when the NWP system is very complex.
Thanks to a simple (reduced dimension) meteorological model but equipped with full assimilation and ensemble forecast systems (to know model state uncertainties), we have been able to explore a new way of predicting the adjustment of an observing network. The novelty is an extended use of the ensemble-based approach, which is probabilistic rather than deterministic. In previous studies, we only accounted for the uncertainties contained in the error variances from the data assimilation. It has been shown that this ensemble-based approach performed better, on average, than the deterministic approach. It also showed that the relevance of uncertainties on the model state when adjusting the observations is crucial.
Although they have been obtained in a simple system (motivated by a too high computational cost in more complex systems), these results allow adaptive observation techniques to evolve toward a greater efficiency.

3

Sensing the stable atmospheric boundary layer in a stratified water flume

Understanding and prediction of stably stratified atmospheric boundary layers (SABL) is a longstanding challenge in the field of meteorology. In spite of previous studies, either from field experiments or by numerical simulations, there is no satisfactory parametrization of SABL which results in poor forecasting skills for winter and nocturnal conditions of weather prediction and climate numerical models. This issue is also closely linked to other environmental and societal challenges such as fog and air quality prediction, or wind engineering.
If the first laboratory experiments on stratified boundary layers have been done more than forty years ago, rapid progress of numerical modeling in the eighties and nineties put this approach in the shade. But since the beginning of the 2000s, increasing needs of numerical modelers for laboratory experiments data have renewed the interest in it.
The CNRM-GAME stratified water flume is a quasi-unique infrastructure specially designed to generate accurate and exhaustive datasets on flows similar to atmospheric ones under perfectly controlled conditions. It is thus a good extension of field experiments limited by the fact that data are scattered and conditions are not well controlled.
Experiments have been recently carried out in collaboration with D. Dobrovolschi (Romanian meteorological service) and G.-J. Steeneveld (Wageningen University). A well developed boundary layer has been observed, and results will bring new insights into understanding of SABL.

5

Convective initiation and surface heterogeneities

Daytime convection over land is a widespread phenomenon which involves couplings between surface and boundary-layer processes. However, the actual reasons why precisely convection occurs in one place or another or not at all are often unclear. In order to better understand the nature of these links, a statistical analysis of satellite products documenting both surface properties and convective initiations was carried out over the Sahel, in collaboration with the CEH (CM Taylor and colleagues), within the AMMA program.
Results from the 2006 monsoon are illustrated in the figure; they made use of collocated land surface temperature estimates from Land-SAF, AMSR-E top soil moisture, the ISIS convective systems tracking algorithm and meteorological analyses. For scales of 100 km x 100 km, they underline links between surface soil moisture and cloud base height but without any clear relationship to CAPE (upper panel a). On the other hand, the development of deep convective systems appears sensitive to soil moisture anomalies and land surface temperature anomalies (LSTA), with initiations being more numerous over drier and warmer surfaces (lower panel b). Explorations at finer spatial scale also reveal the importance of LSTA gradients at scales of a few tens of kilometres. Thus, a reliable modelling of convective triggering appears to involve the representation of interactions between surface and boundary layer processes occurring at the mesoscale.

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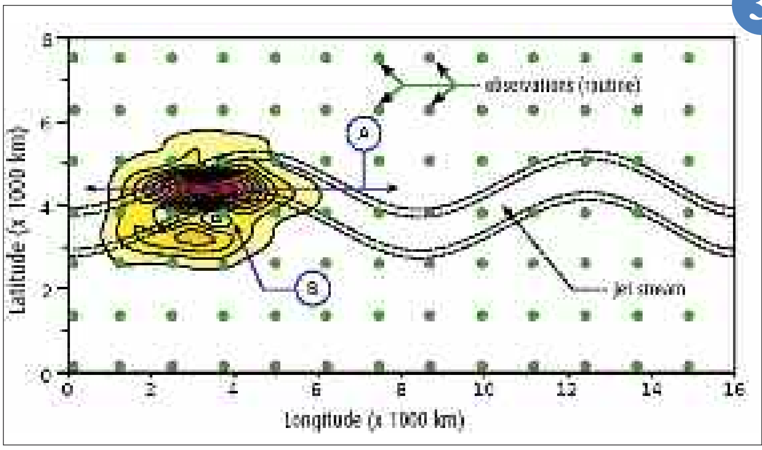
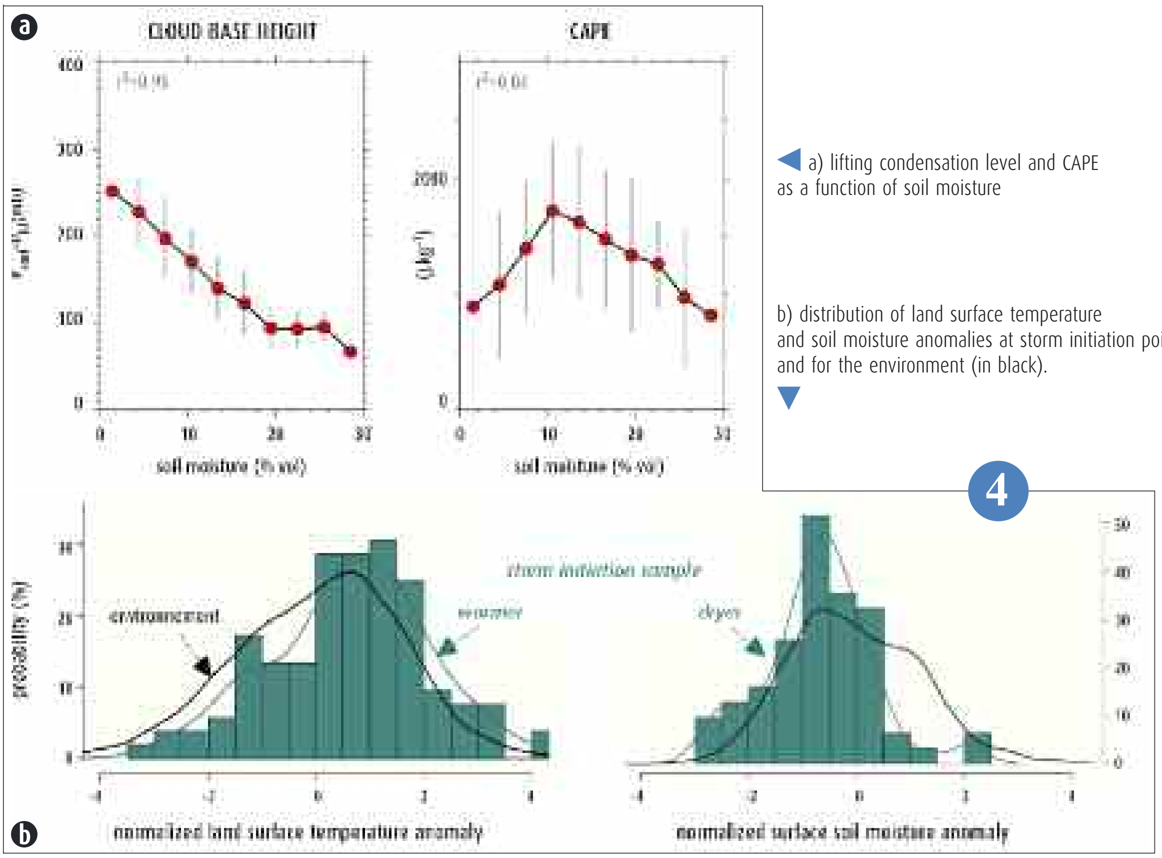


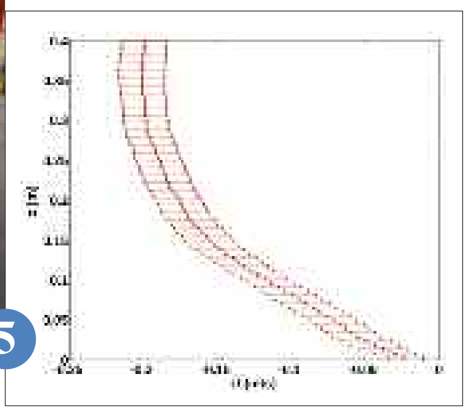
Average over the ensemble members of the sensitivity field accounting for the uncertainties related to the assimilation of routine observations (green dots on the diagram). This field shows "where" an additional observation will reduce the uncertainties in forecasts. This field is compact (with a limited geographical extension), but also locally modified (holes) by the presence of routine observations. It is assumed the routine observations will be present in the future when the observation network will be adjusted. In the present case, the adjustment consists in the addition of a single observation on each model level. The dotted wavy lines show the region of strong wind in lieu of jet stream in the simple model. The horizontal and vertical axes represent the extension in longitude and latitude of the model domain. The axis denoted "A" shows an elongated area of high values associated with high variances in the analyses. Instead, the "B" shows a zone of low amplitudes (hole) because it is well observed routinely.



a) lifting condensation level and CAPE as a function of soil moisture

b) distribution of land surface temperature and soil moisture anomalies at storm initiation points (in blue) and for the environment (in black).

Experimental set-up of the CNRM-GAME stratified water flume used for a study of a stable atmospheric boundary layer carried recently. A pulsed laser illuminated a vertical plane to precisely measure velocities, whereas 7 density probes recorded simultaneously vertical density profiles.



Mean horizontal velocity profile for a run with a speed of 21.2cm/s.

Surface parameters

Measuring soil moisture in meteorological stations: usefulness for the verification of operational models

Soil moisture is a key variable for land surface monitoring as it controls hydrological processes (runoff, evaporation from bare soil and transpiration from the vegetation cover) and impacts plant growth and carbon fluxes. At Météo-France, modelled surface soil moisture (SSM) data are obtained through the SIM (SAFRAN, ISBA, MODCOU) suite of models used operationally since 2003 to monitor the water resource in near real time at a national scale (with a 8×8 km resolution). Operational soil moisture products are also available from numerical weather prediction services such as Météo-France and ECMWF, with the ALADIN and IFS modelling platforms, respectively. In situ soil moisture observations are needed to evaluate soil moisture products derived from either modelling or remote sensing. The SMOSMANIA network is a long-term data acquisition effort of profile soil moisture observations in southern France. With this project, soil moisture profile measurements at 12 automated weather stations of Météo-France from the RADOME network, have been obtained since January 2007. The SSM measured in situ at 5 cm permits to evaluate the SSM simulated by SIM, ALADIN and IFS, together with SSM estimates derived from coarse-resolution (25 km) active microwave observations from the ASCAT scatterometer instrument (C-band, onboard METOP), issued by EUMETSAT. The ECMWF SSM estimates correlate better with the in situ observations than the Météo-France products. This may be due to the higher ability of the multi-layer land surface model used at ECMWF to represent the soil moisture profile. However, the SSM derived from SIM corresponds to a thin soil surface layer and presents good correlations with ASCAT SSM estimates for the very first centimetres of soil.

6

Land cover and biophysical parameters maps at the African continental scale: the ECOCLIMAP-II programme

The ECOCLIMAP programme includes a land cover classification and a database of surface parameters inferred from this classification based on look-up tables.

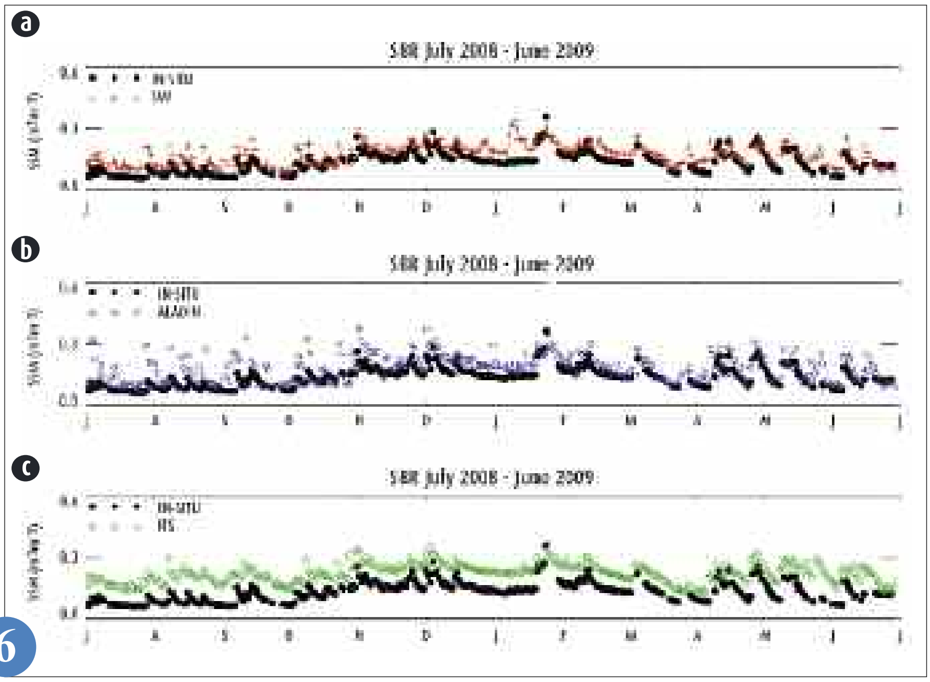
A new classification of the vegetation in functionally homogeneous ecosystems has been achieved at the African continental scale in the frame of the Ph.D. thesis of Armel Kaptué. A hybrid clustering approach was considered to upgrade the 1 km classification of African ecosystems based on an analysis of 8 years (2000 to 2007) of SPOT/VEGETATION NDVI (Normalized Difference Vegetation Index) data.

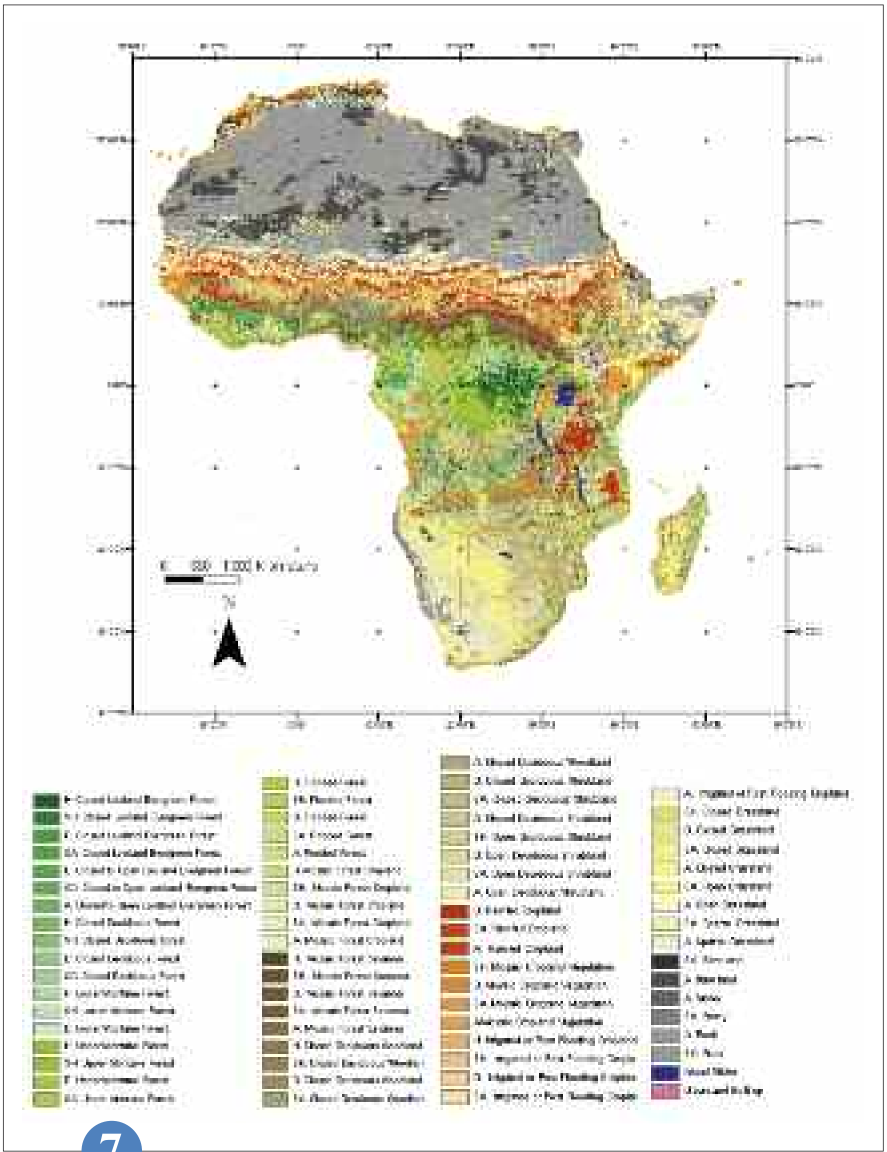
The African continent was first fragmented in 5 climate regions in using the Index of the Segmentation of Fourier Component (ISFC) as a new FFT-based segmentation index for splitting areas into equal-reasoning regions. Further, we applied a new hybrid clustering approach that captures gradients in terms of timing, duration, and intensity of the photosynthetic activity for the same ecosystem unit. It results a 1 km trimmed bioclimatic ecoregion map with 73 classes that is compliant with the Land Cover Classification System (LCCS) nomenclature. These classes are disaggregated in fractions of vegetation types from ISBA. The key biophysical parameters (leaf area index, albedo) issued from satellites programmes are made self-consistent through the classification product.

The suggested ISFC method makes the ecosystem identification and labelling easier, also yielding a consistent ecosystem mapping independently of the resolution (low, moderate or high) and of the remote sensing domain (optical or radar). The degree of generalization and automation of this method across time and space will support an update of the global ecosystems at a reasonable cost.

7

Comparison of in situ surface soil moisture at Sabres (SBR) with simulations provided by (from top to bottom): a) SIM, (b) ALADIN, (c) the ECMWF IFS. Adapted from Albergel et al. 2010.





7

New land cover classification ECOCLIMAP-II at 1km over Africa with 73 classes.

The vegetation in the TEB urban model

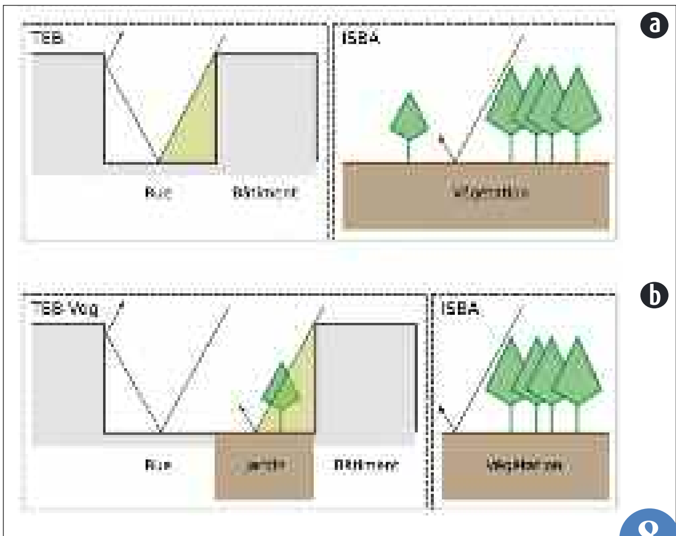
The TEB urban model, developed to represent the city in meteorological models (Meso-NH, AROME), deals only with the exchange of moisture, energy and momentum between the impervious surfaces – roads, roofs, walls – and the atmosphere. The vegetation is modelled independently by ISBA, without direct interaction with impervious surfaces. The fluxes are calculated separately by the two models and then aggregated, as well as the 2-meter air temperatures. This approach leads to problems of representativeness at very local scale, more particularly in residential areas where the vegetation is part of the urban landscape.

A "vegetated" version of TEB (TEB-Veg) has been developed to explicitly represent the vegetation within the urban canyon. The radiation budget includes the shadow effects of buildings on gardens. The surface exchanges for gardens are still modelled by ISBA, but forced by the atmospheric conditions determined by TEB inside the canyon. Conversely, the calculation of air temperature and humidity within the canyon takes into account the contributions of vegetation through the sensible and latent heat fluxes.

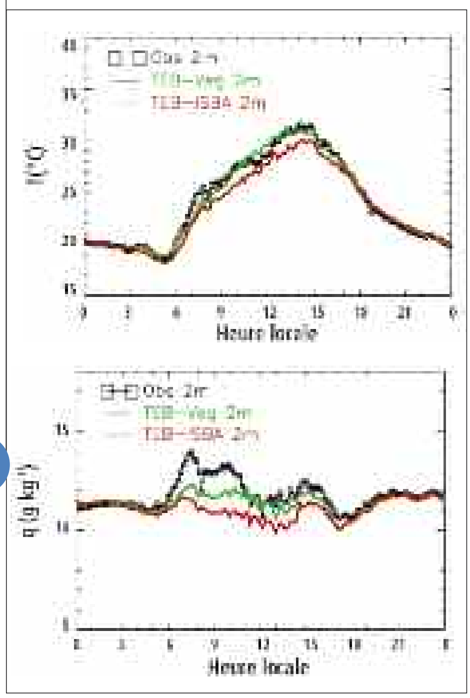
TEB-Veg was evaluated using microclimatic measurements collected in a courtyard surrounded by buildings, and compared with the TEB-ISBA approach without interaction. It appears that the explicit consideration of gardens in the urban model improves the urban microclimate modelling.

This new version of TEB is particularly interesting for impact studies of climate change at the city scale, and more specifically the evaluation of greening strategies of cities in order to improve the climatic comfort.

8



Comparison between (a) the TEB-ISBA approach without interaction between vegetation and impervious covers, and (b) the TEB-Veg approach that includes gardens inside urban canyons.



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Comparison between 2-meter air temperature (left) and humidity (right) recorded inside the instrumented courtyard, and simulated by both TEB-Veg and TEB-ISBA approaches.

Climate and climate change studies

Regarding the climate research group, one of the main originality of the year 2010 is an intensification of the research teams effort to participate in international intercomparison projects with high potential benefit, and this in different areas. In the field of large scale climate variability study, the most striking feature is the preparation and launching of the international intercomparison exercise CMIP5 (Coupled Model Intercomparison Project) to serve as the basis for the analysis of climate change that will appear in the next IPCC report (Assesment Report 5). These simulations are performed using a new version of the coupled climate system model CNRM-CM5 developed in collaboration with CERFACS and IPSL. This year also saw the launch of our participation in a new international simulation exercise that will serve as a basis for the next IPCC report in the field of climate regionalization (CORDEX), with the first simulations with enhanced resolution over the entire African continent. In the field of seasonal forecasting, the international project CHFP ("Historical Climate Forecasting Project") WCRP provides a framework for impact studies of a more detailed representation of the stratosphere on the predictability. Finally, another highlight is the realization of the first simulations with MOCAGE forced by ARPEGE-Climat in 1850 and the 2000s as part of the intercomparison exercise "Atmospheric Chemistry and Climate" that will be also analyzed in the next IPCC report, and the initial results appear promising.

1

Simulation of the 20th century climate with CNRM-CM5

The new global coupled climate model CNRM-CM5 is based on the ocean-atmosphere core formed by NEMO3.2 (IPSL, Paris)/ ARPEGE-Climat v5 (Météo-France). Surface-atmosphere exchanges, sea ice and river routing are represented by SURFEX v5, Gelato v5 and TRIP models. This new model has a horizontal resolution of about 150 km and was developed in collaboration with Cerfacs (Toulouse). This model will be used by CNRM-GAME to carry out a total of 8000 years of new simulations in the framework of the coupled model intercomparison project CMIP5. Participating to this project implies to simulate future climate according to different scenarios and to run ensembles of climate simulations for the 1850-2005 period. To simulate this recent past, it is necessary to take into account observations of volcanic eruptions, solar variability, greenhouse gases and atmospheric aerosols. Running ensembles of simulations allows to assess to what extent the modelled ensemble spread is compatible with observations. Several climate simulations have been already completed. They suggest the model has significantly improved compared to the previous version. In particular, the simulated global mean warming during the 20th century is now close to observations. This warming took place in two phases, first until the 1940s, then after the mid-1970s. The simulated interannual variability is also realistic. Part of this variability is internal to the climate system, and part of it is forced, like the impact of major volcanic eruptions. The observed and simulated short-lived, cooling impact of eruptions generally match quite well, except in the case of the Krakatoa (1883) eruption, due to a likely underestimation of the observed cooling.

2

Our participation in CORDEX

Up to now, the production of regional climate scenarios was carried out in the framework of national or European programs. For the next IPCC report, WMO decided to coordinate regional climate activities at global scale, proposing the CORDEX project. In this project, 12 domains are proposed over the globe for downscaling (50 km mesh) the standard IPCC scenarios (150 km mesh). The first domain to be downscaled is Africa. At Météo-France, we have two atmosphere models at disposal: ARPEGE with variable resolution and ALADIN with limited domain. In the first phase, the models are driven at their lateral boundaries by ERA-interim reanalyses (1989-2008). The aim is to evaluate the capacity to reproduce the regional climate. Figure 1 shows mean summer (JJA) precipitation in a 20-year simulation of ARPEGE, compared with observation. Despite a small underestimation, the rainfall distribution over the continent is satisfactorily reproduced. Similar features are found in a free ARPEGE simulation (not shown). We have also prepared a version of ALADIN over the Mediterranean domain, and carried out a 20-year simulation driven by ERA-interim. The next steps will be to drive these two regional models by our IPCC-AR5 scenario, and to investigate new domains like Europe or Central America/Carribean.

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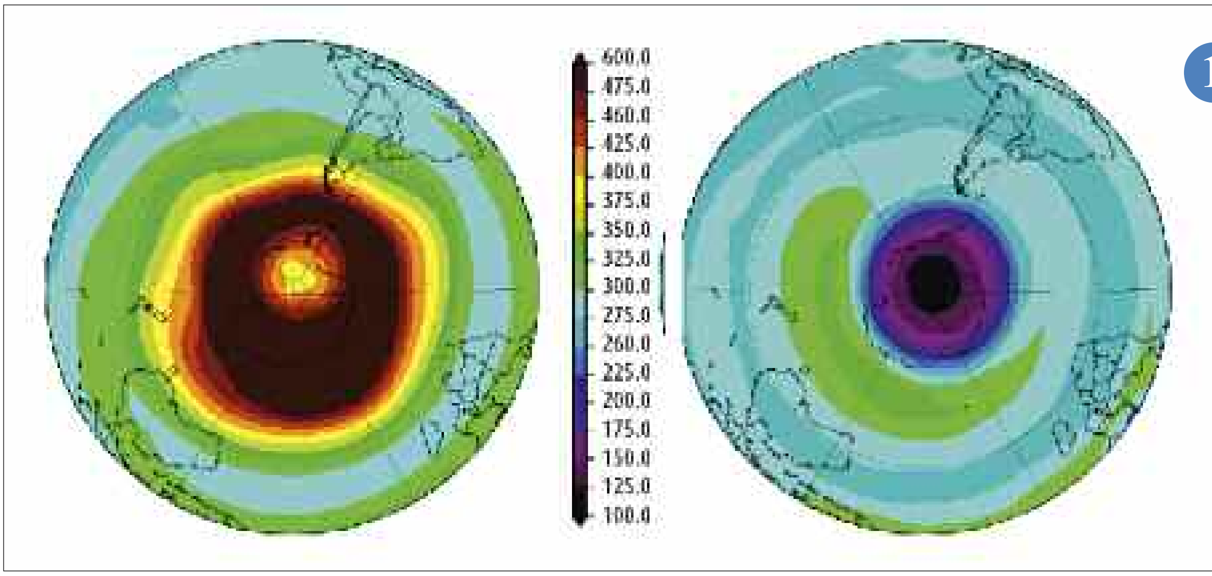

Total ozone content in the atmospheric column above the south pole in October, simulated by the MOCAGE model forced by ARPEGE-Climat for a representative year of 1850 (left) and a representative year of the 2000s (right). These experiments were conducted as part of the international intercomparison exercise “Atmospheric Chemistry and Climate”.

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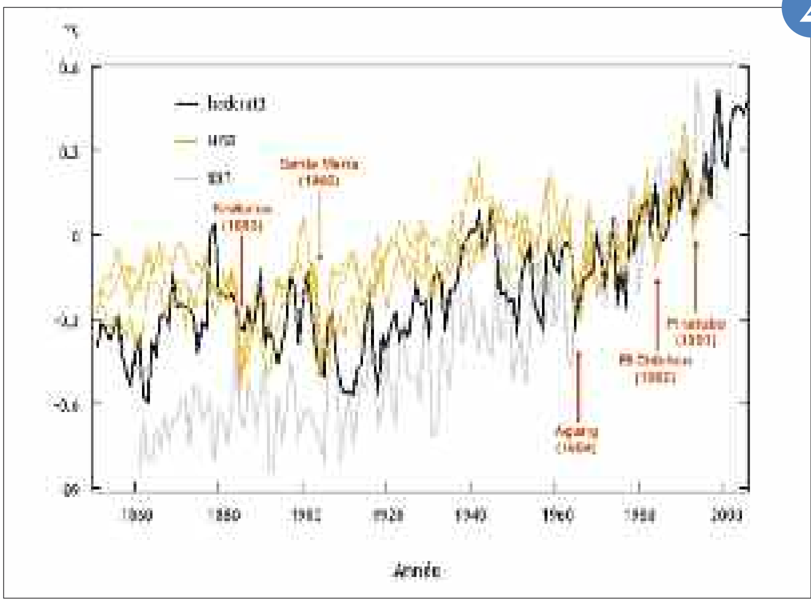

Global mean 2 m air temperature anomaly with respect to 1961-1990 (°C): simulated by CNRM-CM3 (in grey), 3-member ensemble simulation by CNRM-CM5, with natural and antropogenic forcings (in orange), and HadCRUT3 observations (in black). Major volcaniques eruptions are in red.

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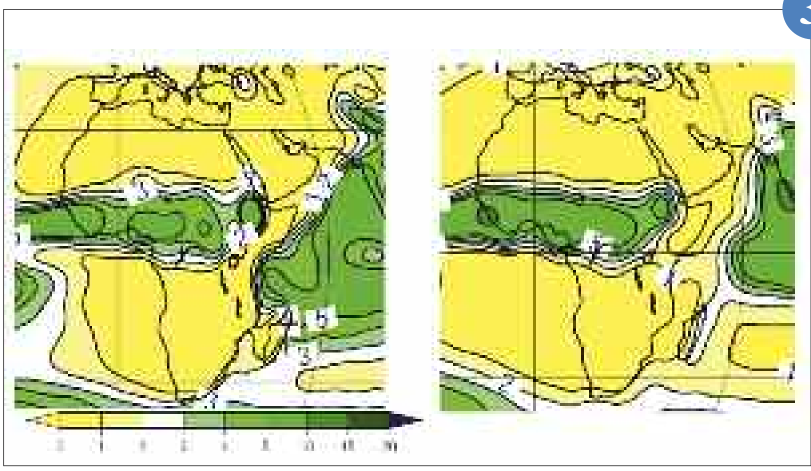

Mean precipitation (mm/day) in JJA as simulated by ARPEGE-climat at 50 km resolution driven by reanalyses (left) and according to observations (right).

Intraseasonal Variability of the West African monsoon: the role of mid-latitudes and of the Saharan Heat Low

Persistent dry periods during summer West African monsoon can lead to severe outcomes such as crop failure and food shortage in the Sahel. Conversely, prolonged wet periods can favour flood occurrence and yield low of life and property. The understanding and forecast of such events, especially those that occur at the intraseasonal timescale, are crucial to improve food management and disaster mitigation.
In the framework of the AMMA program, a particular attention has been devoted on this monsoon intraseasonal variability. At the 15-day timescale, several origins have been proposed, notably convectively-coupled equatorial waves. The Saharan heat low is also one of the major actors of the monsoon, which partly drives the moisture flow over the continent. Following the study of its intraseasonal variability, interactions between mid-latitudes and convection over West Africa have been highlighted. Extratropical intraseasonal Rossby waves induce anomalous cyclonic/anticyclonic circulations over the Mediterranean, which can be advected toward the Eastern Sahel. There, they modulate the heat low structure, the fluxes of moisture and dry air, and thus convection.
The existence of several independent mechanisms explaining intraseasonal convective fluctuations may leads to constructive or destructive interferences, and thus to a high spatial and temporal variability of the monsoon dry and wet spells. However, their relationship with the extratropical intraseasonal variability is an interesting source of predictability, and more skilful forecasts over the Sahel can be expected.

4

Conceptual model of interactions between mid-latitudes and convection over West Africa. Two levels are reported. Anomalous cyclonic/anticyclonic circulations at 700 hPa are indicated with dashed/solid circles. Low-level heat low ventilations and the monsoon flow are reported with blue arrows whose thickness indicates their strength. Note that there is a westward tilt between the wind anomalies near the surface and those at 700 hPa over the Mediterranean area, and an eastward tilt between the two over West Africa. The heat low (HL) position and extension are indicated with a solid contour, red-filled when it is anomalously strong, and blue-filled when it is anomalously weak. The subtropical westerly jet and the African easterly jet (AEJ) are indicated by a thick straight black arrow. The region from where equatorial Rossby waves emanate has been reported over the Indian Ocean. The scenario is the following: a Rossby wave propagates eastward over the Mediterranean, modulating the heat low ventilations. The Libyan one is first reduced (t0), leading to an intensified heat low (t0+5), and then reinforced (t0+8) leading to the heat low collapse (t0+12). At the same time, anomalous circulation near 700 hPa can be advected toward the Eastern Sahel, where they modulate the low-level moisture flow, and thus convection. These anomalies are then advected westward, likely by the African easterly jet.

Variability of hurricane activity

The last IPCC1 report (2007) could only emphasize the lack of knowledge of the scientific community concerning the evolution of tropical cyclone activity in a human-induced warming. At the very most, finest models suggest a decrease in tropical cyclones number associated with an increase of the intensity of the strongest systems.
From many years, we study hurricane activity with the help of the French ARPEGE/Climat model in a rotated/stretched configuration, i.e. for which the grid is modified in such a way that the pole of interest has the finest local resolution while the antipode's one has the coarsest. Past use of this configuration, in SST2 forced mode (SST calculated by a low resolution coupled model) emphasized the role of the SST anomaly structures more than intensity, in the response of hurricanes to warming.
More recently, we introduced the coupling with ocean in the rotated/stretched configuration. We thus allow interaction between high resolved hurricanes and ocean. Our knowledge of the sensitivity of hurricanes to man-induced warming should be increased in the future, by introducing a new degree of freedom in the system.
Coming works will focus on the comparison between forced and coupled pre-industrial simulations, before looking at the evolution of the hurricanes during XXth and XXIst centuries

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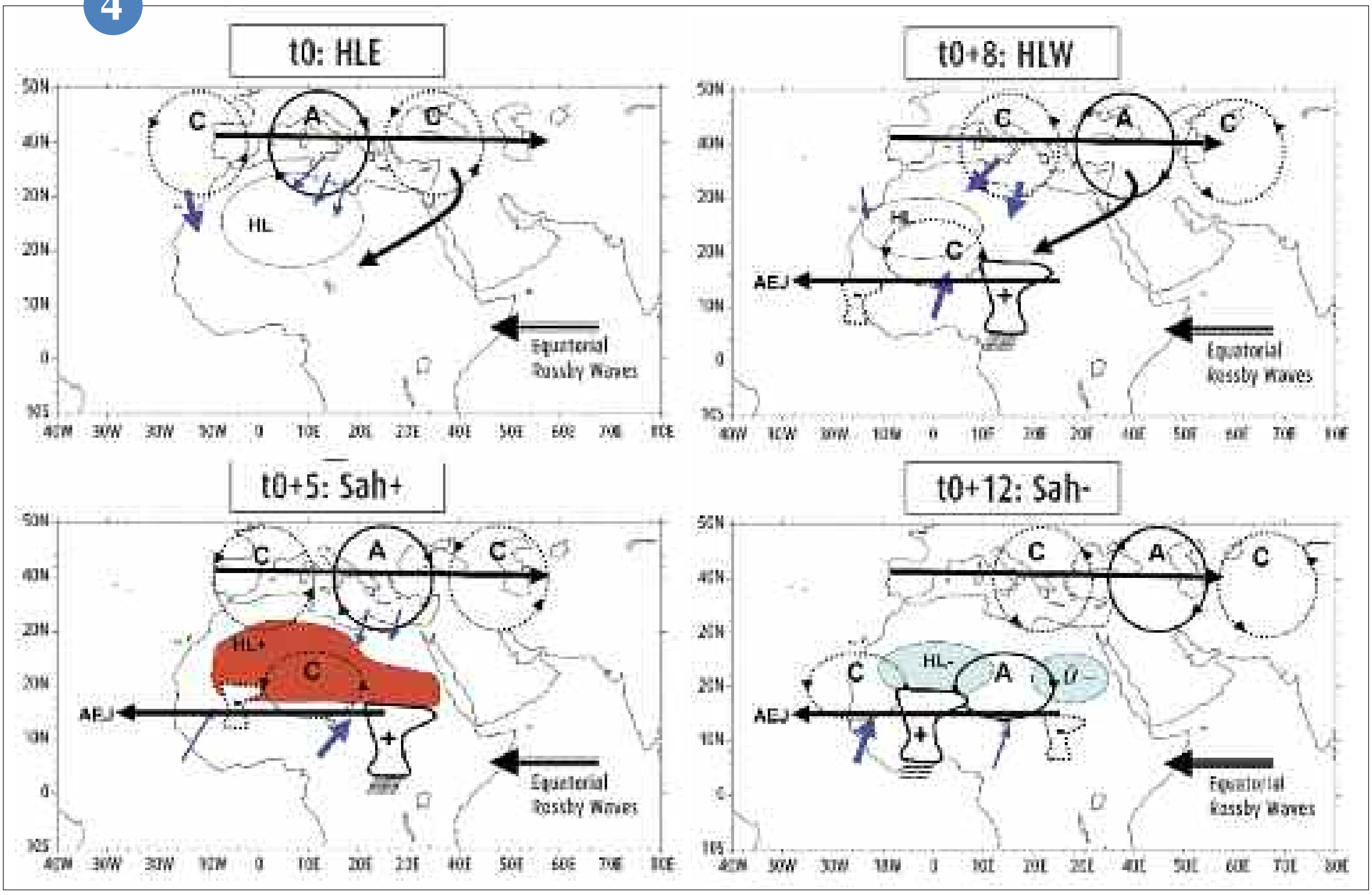

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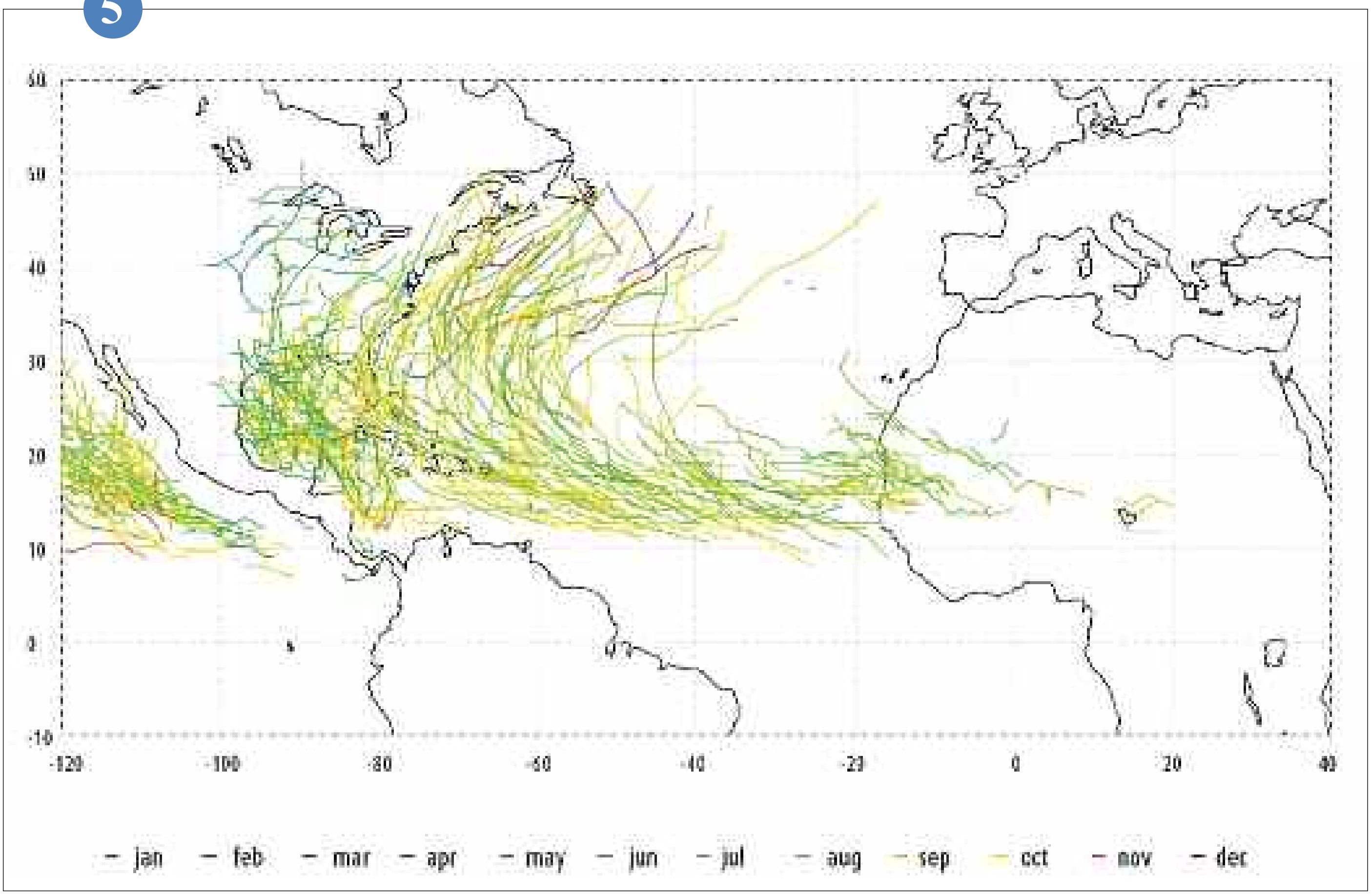
Detected tracks in the pre-industrial rotated/stretched ARPEGE simulation, coupled with the NEMO ocean model from IPSL3.

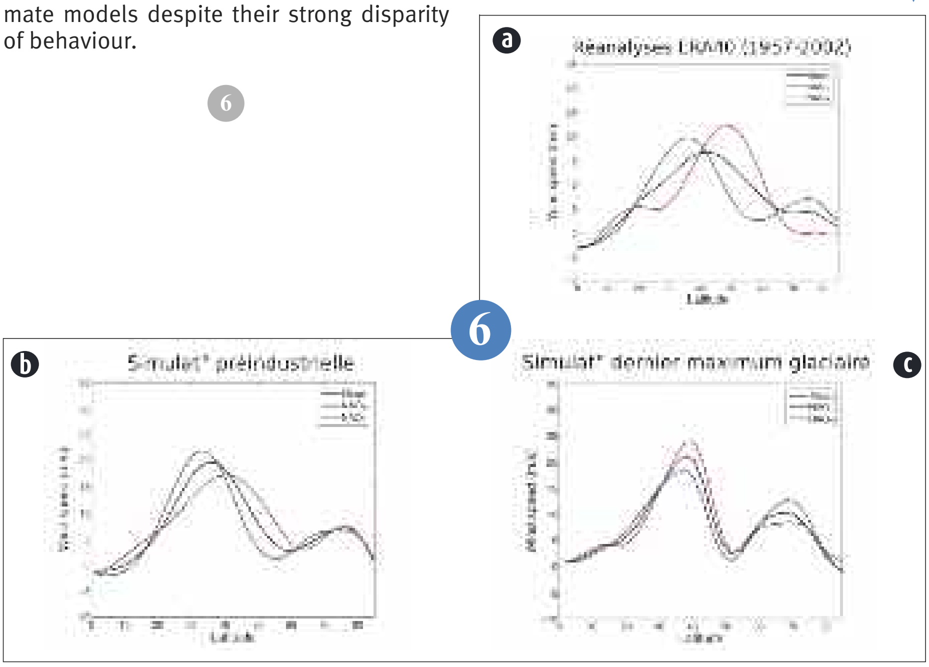


The North Atlantic Oscillation in present-day and last glacial maximum climate simulations

The North Atlantic Oscillation (NAO) is the major source of variability in the atmospheric circulation over the Atlantic that determines in large part the European weather and climate at different time scales (intraseasonal, interannual, interdecennal etc...). Nowdays, the NAO is characterized by strong latitudinal fluctuations of the Atlantic jet stream. The positive phase is related to a more northward position of the jet while the negative phase to a more southward position (cf. panel a).
The purpose of our study was to characterize the major source of variability in the atmospheric circulation during the last glacial maximum (also called NAO hereafter) using the full coupled atmosphere-ocean general circulation model ARPEGE. First, a simulation under preindustrial conditions has been performed (panel b). It shows that the model is able to reproduce the latitudinal fluctuations of the NAO as observed in reanalysis data. However, the fluctuations in the simulation have weaker amplitudes than in the observed NAO. The last glacial maximum NAO is quite different since it corresponds to acceleration-deceleration or extension-retraction of the Atlantic jet (panel c) and shows no latitudinal vacillation. A more detailed analysis made with the same model has revealed that the topography effect of the ice sheets and more precisely the high topography of the Laurentide ice sheet is mainly responsible for this change in the behaviour of the Atlantic jet stream via the storm-track eddy feedback.
Note finally that this property of the jet stream variability during the last glacial maximum has been obtained with other climate models despite their strong disparity of behaviour.

6

Representation of the major source of variability in the Atlantic atmospheric circulation (first EOF of the geopotential at 850 hPa for December, January and February) in (a) ERA40 reanalysis data for the period from 1957 to 2002, (b) the preindustrial simulation of ARPEGE and (c) the last glacial maximum simulation of ARPEGE. On each panel, each curve represents the zonal wind at 500 hPa averaged over the Atlantic domain (80°W-10°E) as function of latitude; in black, the climatological value; in red and blue lines, the values for the positive and negative phase, respectively.



Compared climate impacts of transportation modes

Transportation activities are growing fast since several decades and may impact the atmospheric composition and contribute to the climate change. European project QUANTIFY (coordinated by R. Sausen, DLR) provided the opportunity to evaluate and to compare for the first time the impacts of different transportation modes: road traffic, shipping and aviation.
The Atmosphere Ocean General Circulation Model CNRM-CM3.3 was run for transient simulations of the time period 1860-2100 while taking into account radiative forcings by water vapour, carbon dioxide CO_2, methane CH_4, ozone, and aerosols as well as forcings by condensation trails produced by aircraft and by CFC-12 and HFC-134a gases produced by car air conditioners.
Average surface temperature increase due to CO_2 emissions by road traffic, shipping, and aviation are 0.3, 0.1, and 0.1 degree during the 21st century respectively, that are to be compared to the 2.2 degree increase for the whole activity of scenario A1B of IPCC. Other exhausts than CO_2 show varied impacts: road traffic produces a temperature increase of 0.05 degree near 2050 that vanishes almost in 2100; shipping produces a temperature decrease of 0.1 degree in 2100 both from the SO_2 exhausts (negative radiative impact of aerosol sulphate produced) and from the NO_x exhausts (reduction of CH_4 lifetime); aviation produces a temperature increase of 0.15 degree in 2100. Total impact of emissions by aircraft in thus higher by a factor of 2.5 than their only CO_2 emissions.
QUANTIFY was aimed at a thorough evaluation of all climate impacts of transportation activities using global modelling of the earth system. However, many impacts could only be calculated using radiative forcings provided by partner research groups of the project. Results obtained are therefore innovative but efforts are continued to better model interactions between atmospheric circulation, chemistry and aerosol.

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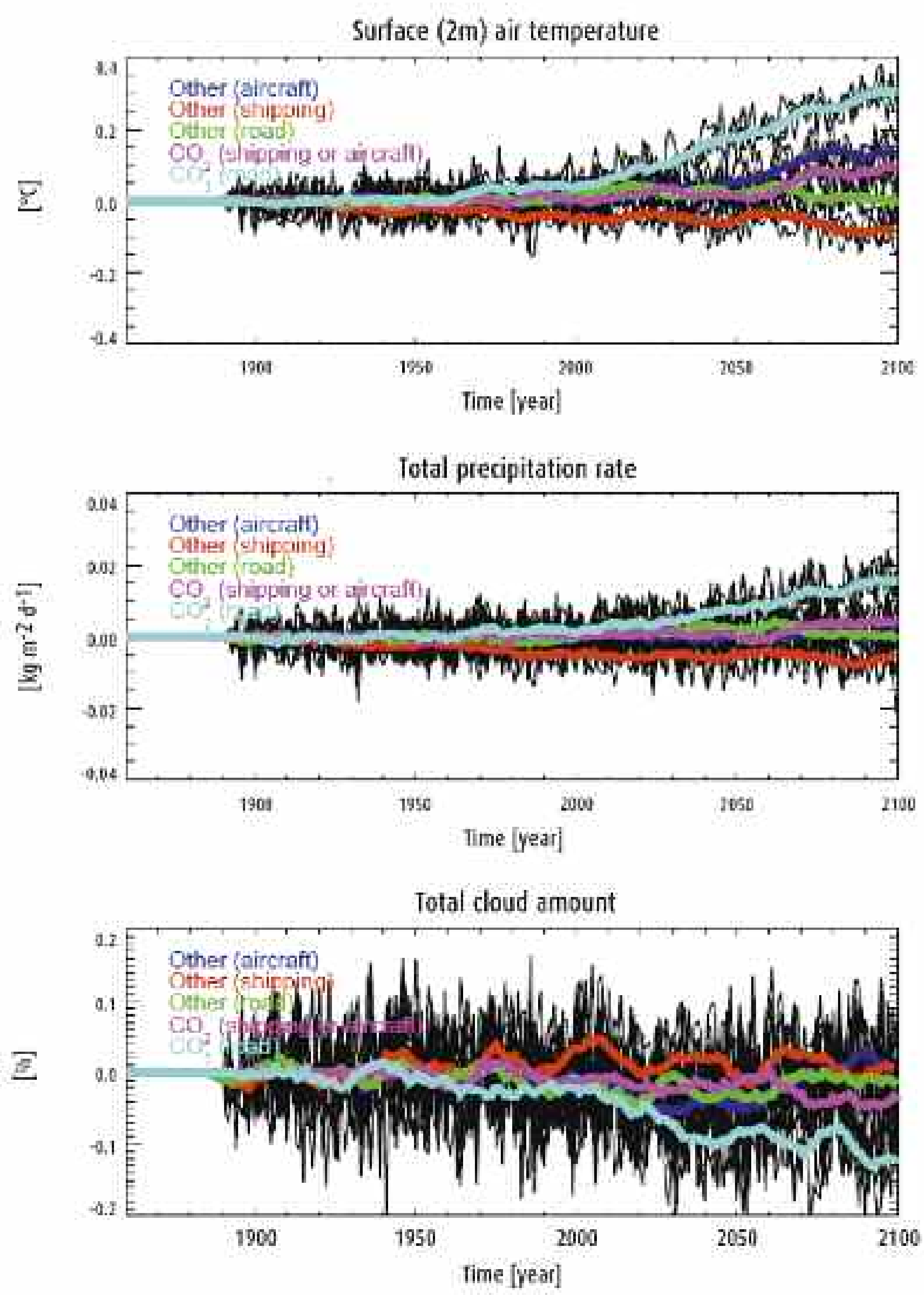


Time evolution of average surface temperature, precipitations, and cloudiness as a result of scenario A1B of IPCC (2006). Running time averages of impacts of CO_2 emissions are shown in light blue (road traffic), and purple (shipping or aircraft). Running time averages of impacts of non CO_2 emissions are shown in green (road traffic), red (shipping), and dark blue (aircraft).

Atmosphere and environment studies

Hydro-meteorology

Impact of the representation of the surface in climate impact studies

Increased atmospheric concentration of carbon dioxide has a direct effect on plant physiology: the assimilation of carbon is more efficient, reducing water losses through transpiration, but this effect may be offset by increase in leaf area, mechanically associated with increased transpiration. The surface scheme ISBA-A-gs is able to simulate these effects. Under the project Medup, this version was compared with the standard version of ISBA which does not take into account this effect. This study was conducted for the current climate and for the climate of the late twenty-first century on the French Mediterranean area using the climate scenario A2 CYPRIM.
For the current climate, vegetation (leaf area index) calculated by ISBA-A-gs was compared with estimates of the ECOCLIMAP 1 and 2 databases. In future climate, the vegetation development is faster in the spring, due to the increase in temperature, decrease in snow cover and increased concentration of carbon dioxide. This leads to increased evapotranspiration greater than in the case of unchanged vegetation, leading to a higher decrease of discharge in the area.
Taking into account the direct effect of carbon dioxide on plant physiology in studies of climate impact has so far been little studied. This effect can have a significant impact in some cases. These studies will be pursued to better understand the feedbacks that are involved in the soil-plant system.

1

X-band radar algorithms as part of the RHYTMME1 project

The RHYTMME project plans the installation of several X-band radars in the South-East of France during the period from 2010 to 2013, complementing an already installed radar on Mont Vial north of Nice. An ambitious R&D programme started in 2010 to make better use of X-band radar signals that are particularly affected by attenuation from precipitation. The R&D programme, which implies several post-doctoral researchers, recruited by the project, comprise many working lines:

– **Radar platform:** a central production platform of elaborated products (surface rainfall accumulation, reflectivity images,...) from raw polar radar data has been specified and is currently being developed. Thanks to this platform it will be possible to make demonstrations of specific products of the RYTHMME project (in particular surface rainfall accumulation in X-band). This platform also constitute a prototype for a new technical architecture for operational production.

– **Quantitative estimation of liquid and solid precipitation:** the work that has been carried out in 2010 consisted of adapting to X-band the polarimetric processing chain installed on ARAMIS2 radars. Adaptations have thus been done to the attenuation correction and hydrometeor classification blocks. In 2011, the work will go on and a real time demonstration of an X-band rain accumulation mosaic is planned for autumn.

– **Doppler:** a work was initiated in 2010 to solve velocity aliasing problems, particularly severe with the X-band, to make the radial velocities usable for the different applications (numerical weather prediction models in particular).

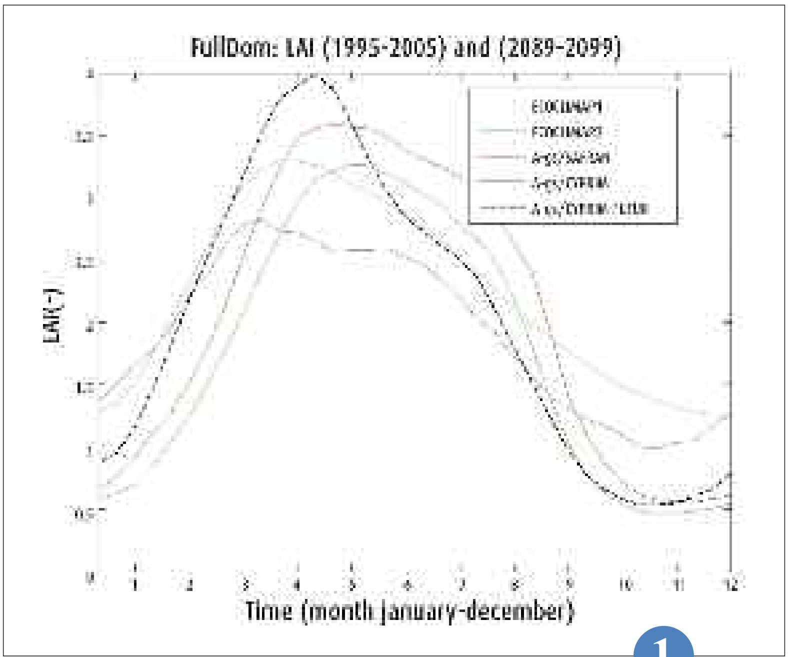
– **Restitution of the humidity field thanks to the radar refractivity technique:** a PhD work demonstrated that the measure is accessible with magnetron radars. A simulation based on MESO-NH3 revealed convection signatures in the refractivity field and specified the sampling conditions adapted to the frequency of X-band radars.

2

A precipitation estimation data base

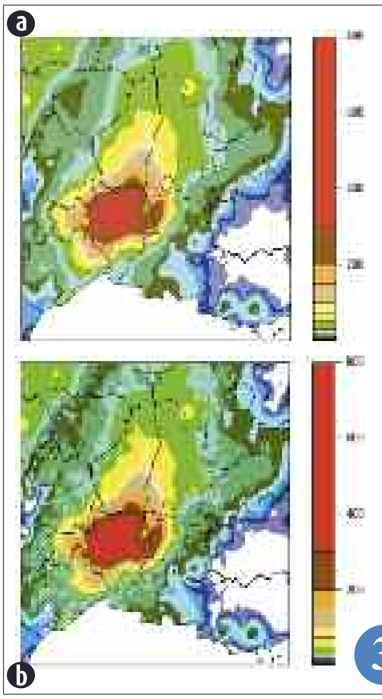
Météo-France is committed to delivering to hydrological community a database of the best surface precipitation accumulation estimation at hourly time step and 1 km² spatial resolution over a period of at least 10 years. This database aims at providing a common reference in order to for example test its value for hydrological models and calibrate them. The optimal use of different sources of archived information (radars, rain gauges, satellite data, ...) is sought.
The year 2010 has been dedicated to the specification of the radar correction procedures, radar-rain gauge calibration and merging at daily and hourly time steps for the period 1997-2006.
Archived radar data used are available on the radar areas every 5 minutes and squared kilometer. To take full advantage of this data, it was necessary to detect ground-clutter areas, remove clear-air echoes, correct the shielded sectors and apply an advection field between two consecutive radar images.
Then the daily gauges data are used to make the best use of both sources of information for assessing the precipitation field; daily gauges are also used where no (or too low) radar values are available. Finally, the temporal downscaling (from 24 to 1 hour) is performed using again information from radar and rain gauges which is less numerous at such an hourly time step.
Then the rain gauge data are used daily time step to make the best use of joint information on the rainfall field (ground radar) radar accumulations are missing or weak supplemented. Finally, the switch to hourly time step is performed again using information from radar and rain gauges at the much smaller time step.Haut du formulaire
Simple and robust methods have been favoured in order to respect the objective of delivery of a first version of the database by the end of 2011.

3



1

Comparison of the leaf area index simulated by ISBA-A-gs in different configurations on the Mediterranean part of France to the data of databases ECOCLIMAP 1 and 2.
A-gs/SAFRAN: simulation using the mesoscale meteorological analysis SAFRAN.
A-gs/CYPRIM: same with the climate scenario desaggregated for the current climate.
A-gs/CYPRIM FUTURE: same with the climate scenario desaggregated for the end of the century.



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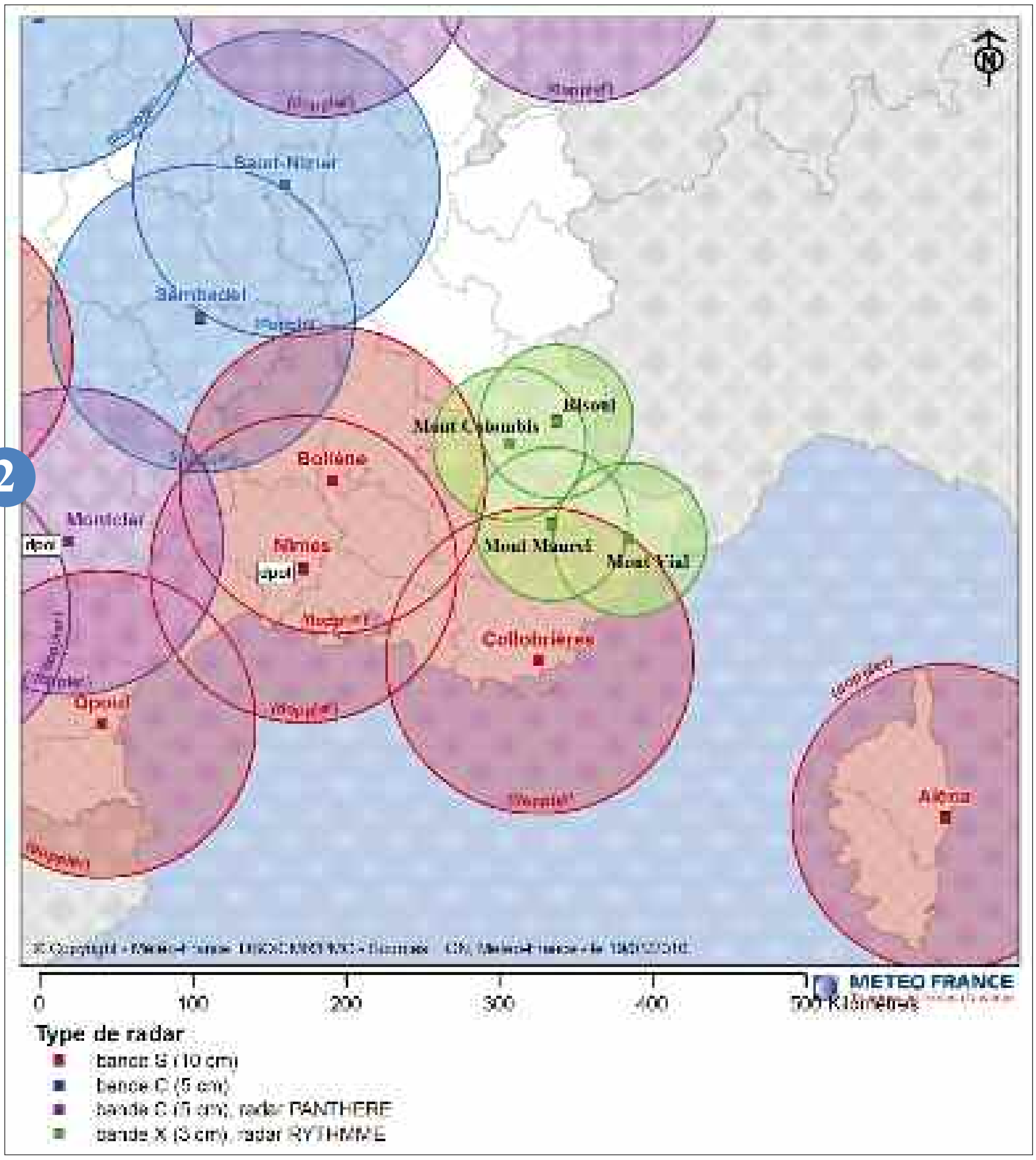
Rainfall estimation (in mm) for 8th of September 2009 on the Bollène radar area a) by kriging of rain gauges data alone, b) by merging of radar and rain gauges data.



2

Map showing the existing ARAMIS radars covering the south east of France and their respective 100 km range circle (red standing for S-band, blue for C-and, "Doppler" for equipped with Doppler capabilities and "dpol" for equipped with dual-polarisation) along with the four X-band Doppler, polarimetric radars of the RHYTMME Project (and their 60 km range circle). The locations of the two northernmost radars are still indicative.

Oceanography (modelling and instrumentation)

In 2010, CMM carried on its mission strewing oceans with observation buoys, thus contributing to internationally heighten thereputation of CNRM and Météo-France. Though the major part of its work consists in answering calls from operational observation, CMM play an important part in field campaigns of the scientific community.
In the framework of the European Programme ESURFMAR steered by CMM, a network of more than 100 drifting buoys are maintained over the North Atlantic ocean. Some thirty or so drifting buoys are put at sea in the Indian Ocean to monitor cyclones and better observations over a large southern region. Five open ocean anchored stations are moored in oceans, two in the Atlantic Ocean in cooperation with the UK MetOffice, two in the Mediterranean Sea and one in the French West Indies.
In the framework of Hymex, the Mediterranean Project gathers momentum and the use of the two anchored buoys to study the ocean-surface interface and the ocean mixed layer gradually intensify. CMM presence is vouched by its involvement in sea campaigns and the deployment and retrieval of drifting buoys. CMM contributes towards the validation of the SMOS satellite salinity data in the Bay of Biscay and the Amazon region, using drifting buoys.
A specific research action has started to better understand the waves impact on fluxes between ocean and atmosphere. This task is achieve by in situ data retrieval and data processing and their interactions with experimental parametrisation of numerical prediction systems.

4

Drifting buoy deployments to calibrate and validate SMOS measurements

Launched on November 2nd, 2009, satellite SMOS is theoretically able to measure the salinity at the surface of the oceans with a spatial resolution of 200 km x 200 km and an accuracy of 0,1 psu. In order to calibrate and validate the algorithms used to retrieve this parameter, in situ measurements are indispensable. As for the surface temperature, drifting buoys are the most suitable. These are actually carrying out their measurements closer to the surface than other instruments (shipborne thermosalinographs, Argo floats). During the last years, CMM widely contributed to the development of salinity buoys derived from the operational SVP-B drifter used to measure atmospheric pressure and sea surface temperature. These buoys have been used during various campaigns in the frame of GLOSCAL. In 2010, fourteen Metocean buoys, directly managed by CMM, were deployed during Ovide; Amandes and Carols campaings. In parallel, LOCEAN deployed as many buoys from Pacific Gyre.
CMM is responsible for the GTS transmission of the data for all these buoys. The validation of SMOS data started. Other buoys will be needed. They will also serve to validate the data from NASA satellite Aquarius which should be launched in 2011.

5

Scintillometry: a new tool to retrieve sensible heat fluxes over sea and lakes

Direct measurements of the sensible and latent heat fluxes over water (sea, lakes) are still challenging due to platform and instrumental constraints (platform motion, flow distortion, high frequency observations). In 2009, CNRM has been recording sensible heat fluxes over the Thau lagoon for a few months using an indirect method: scintillometry was providing measurements of the fluctuations of refraction index of the light along a 4800 m optical path. This fluctuation function is then converted into the temperature structure function, which, in turn, provides an assessment of the sensible heat flux. As a major advantage in such an aquatic environment, this method does not introduce any flow distortion and is independant on the platform motion, as the instruments can logically be installed on the coast. This Thau lagoon experiment being the first scintillometry operation over a lake, the validity of the method has been checked using a collocated eddy-covariance station. The processing strategy of the scintillometry data has been carefully adapted to the air-water conditions. The agreement between the sensible heat flux measured by scintillometry, estimated by eddy covariance and computed from a bulk method (using the reference COARE 3.0 software) is very good over the 4 months of measurements.

6

Sea temperature fluctuations as measured under the moored buoys

Within the HyMex perspective (as part of the Chantier Méditerranée), the CNRM is adding new sensors on the Gulf of Lions and Côte d'Azur moored buoys. These buoys has been providing for more than 10 years now observations of atmospheric parameters (pressure, temperature, humidity, and wind) and of the sea surface temperature. These measurements are then used (together with satellite observations) to constrain NWP models. To better monitor physical interactions between ocean and atmosphere in North Western Mediterranean, these two moored buoys should be equipped with rain gauges and radiation sensors right from the beginning of the HyMex Enhanced Observing Period (2011). Concerning hydrological observations, each buoy should be enhanced with a surface thermosalinograph, a wave recorder, and sea temperature soundings between the surface and 200 m deep. Such sensors (five) have already been installed under the Gulf of Lions buoy in the fall 2009. The first series of measurements shows clearly the deepening of the mixing layer under 200 m and a set of rapid temperature fluctuations around 100 m, likely due to internal waves. This chain of sensors will be completed in 2011 to include 20 temperature sensors under each of the Mediterranean buoys.

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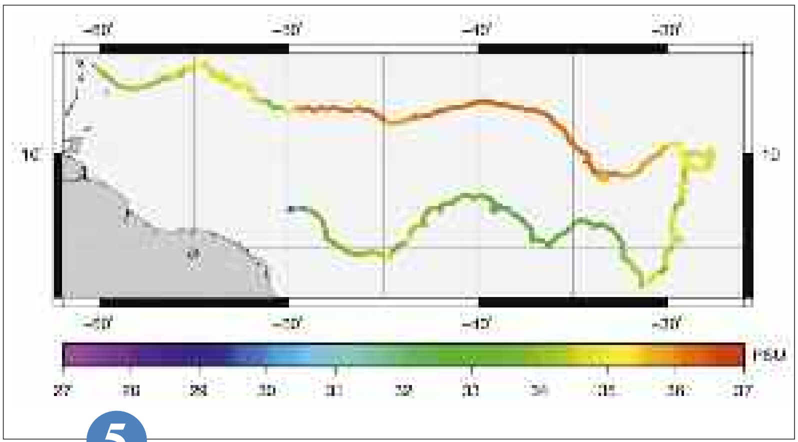
Renewal of the Lion Gulf buoy (March 2010).



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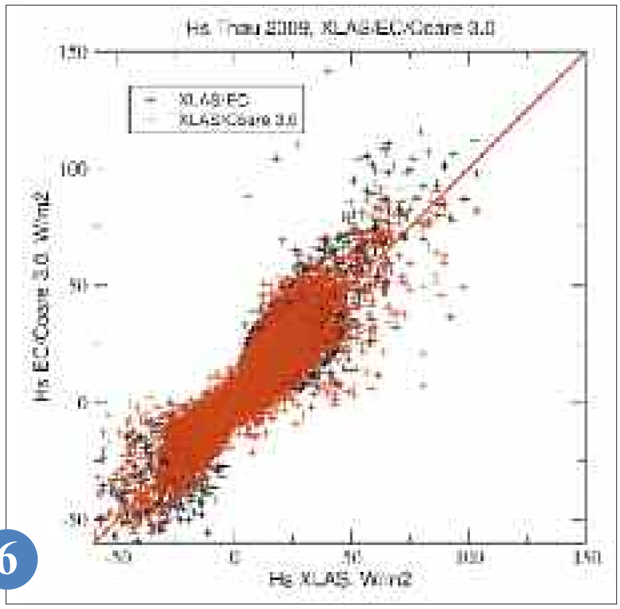
Sea Surface Salinity measurements (psu) from Metocean drifting buoy 72579 from August 2008 to October 2009.



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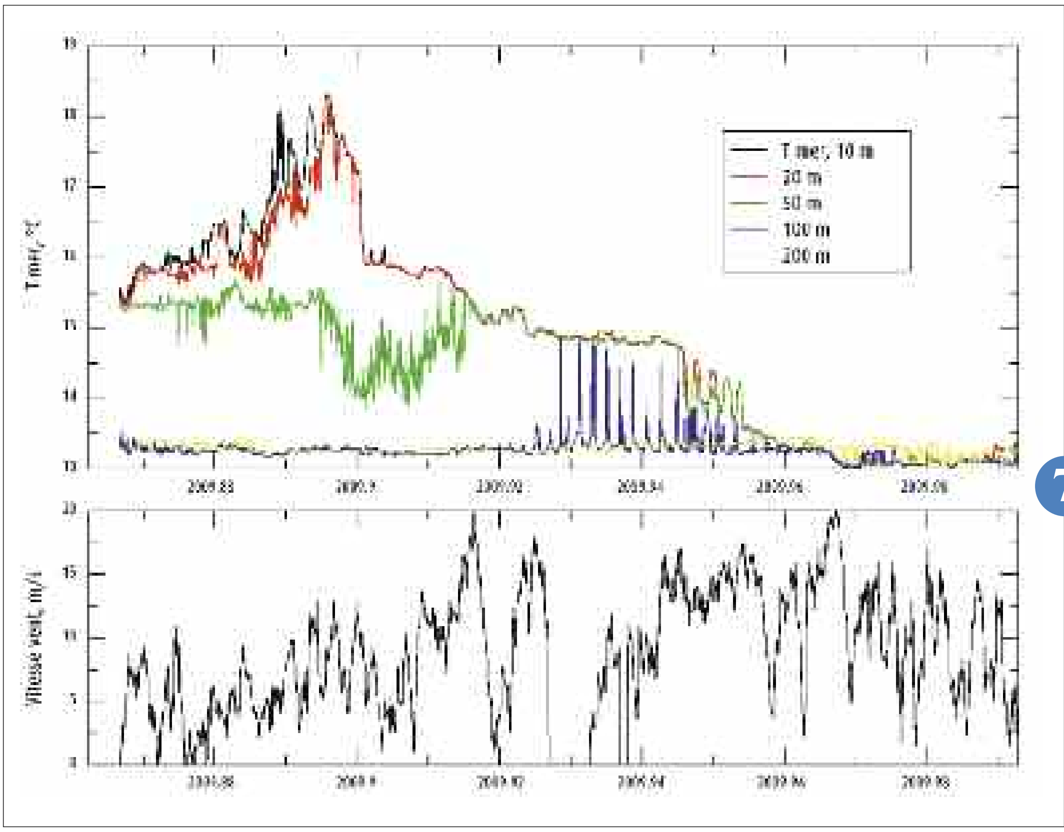
Comparison between sensible heat fluxes over the Thau lagoon, measured using the scintillometry method (X axis), the eddy-covariance method (black) and computed using the bulk algorithm (red).



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Sea temperature fluctuations under the Gulf of Lions buoy, end 2009 (10 to 200 m deep, top) in comparison with collocated wind velocity (bottom).

Measuring in situ rain rates at sea: rain gauges calibration

In the framework of HyMex, CNRM is reinforcing atmospheric and hydrological observations on the Mediterranean moored buoys. This includes rain rate recording. In situ measurements of precipitations at sea is still an issue, with uncertainties due to the platform motion, wind effects – frequently strong in open sea conditions, spray impact, and possibly breaking waves. Recently, instruments have been developped to better account for the two first effects. The CMM team of CNRM carried out a calibration campaign of 2 rain gauges by comparing them with the CDM 29 (Guipavas) rain gauge for several months. The more sophisticated rain gauge (Eigenbrodt) includes a built-in wind effects correction, the second one (Young) is suitable for measurements at sea but without hardware correction. These instruments, including the CDM 29 rain gauge, are based on different measurement principles: tipping buckets rain gauge, self-siphoning level mesurement rain gauge, and weighting rain gauge. Comparisons, on a fairly rainy period, show a very good agreement between the Eigenbrodt rain gauge and the reference. The Young instrument slightly underestimates the rain rate even in light wind conditions. This bias cancels if a software correction of the wind effects is added, and the agreement between the two instruments and the reference is then better than 0.1 mm/h (standard deviation). To continue with these tests under open sea conditions, both instruments will be installed on the Côte d'Azur moored buoy in early 2011.

8

Heat budgets from ARGO floats during the AMMA/EGEE campaigns (2005-2007)

The West African Monsoon depends on sea surface temperatures in the eastern equatorial Atlantic. For example, the negative temperature anomalies observed in spring 2005 during the emplacement of the Atlantic cold tongue, interacted strongly with the West African Monsoon. In this study, the mechanisms at the origin of such anomalies were investigated by using ARGO profiling floats.

These ARGO floats drift at a parking depth of 1500 m and record temperature and salinity profiles every ten days while ascending to the sea surface. If the number of profiles is high enough over a given area, the data can be used to compute heat budgets, thus allowing to describe the physical mechanisms at play in the oceanic top layers. The deployment of ARGO floats during the AMMA/EGEE campaigns in 2005, 2006 and 2007 increased considerably the total number of temperature profiles in this region of the Atlantic basin, thus allowing to establish a reliable heat budget during this period.

The results indicate that sea surface fluxes dominate the heat budget at seasonal and interannual timescales. Over the cold tongue region, the seasonal variation of the heat budget mainly follow the seasonal cycle of the surface heat fluxes. In this region, the net sea surface heat fluxes are positive all year long (i.e. the ocean gains heat from the atmosphere), even in spring, a period of strong cloudiness. Entrainment at the mixed layer base and advection play a minor role. Vertical mixing at the mixed layer base is an important source of cooling mainly in boreal spring. These results are in fairly good agreement with observations collected during the AMMA/EGEE campaigns. In the future it will be interesting to know if realistic numerical simulations are able to corroborate such findings.

9

Operational use of numerical weather prediction model outputs for correcting sea surface temperature calculation algorithms

The Centre de Météorologie Spatiale (CMS) in Lannion has produced operationally sea surface temperature (SST) fields from METOP, SEVIRI and GOES-EAST data. We use multispectral methods: SST is calculated by linear combination of the “window” IR brightness temperatures, with coefficients derived by regression from a database gathering surface temperatures and the corresponding brightness temperatures. These algorithms are accurate for atmospheric conditions close to the “average” atmosphere of the learning dataset, but they show errors in case of atypical atmospheres such as those met in the tropical Atlantic. We are thus using actual atmospheric profiles from numerical weather model forecasts (ECMWF) and RTTOV to calculate, on simulated brightness temperatures, the local error resulting from using an average algorithm (Le Borgne et al, 2010). This method is being implemented in operational conditions in CMS. Figure (a) shows the mean difference in August 2010 between the operational MSG derived SST fields and the Met Office fine scale SST analysis (OSTIA). Figure (b) shows the corresponding mean of our algorithm errors derived from ECMWF profiles. The calculated error, used as a correction term improves the accuracy of our SST fields (Figure c). We will apply this method to the geostationary satellite processing, then to the METOP chain.

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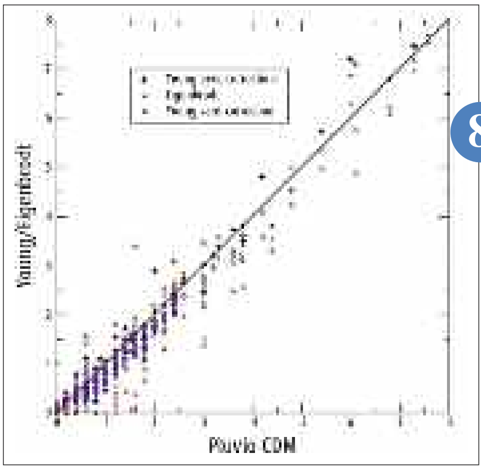

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Comparison between precipitation rates as measured by the CDM 29 rain gauge (reference), the Young rain gauge without (black) and with (blue) wind correction, and the Eigenbrodt rain gauge (red).

ARGO float (courtesy: IFREMER).

Contribution of the different terms of the mixed layer heat budget in the area 15°W-3°E; 1°N-4°S (region of the Atlantic cold tongue), for the period 2005-2007. The fluxes are in W.m^{-2}.

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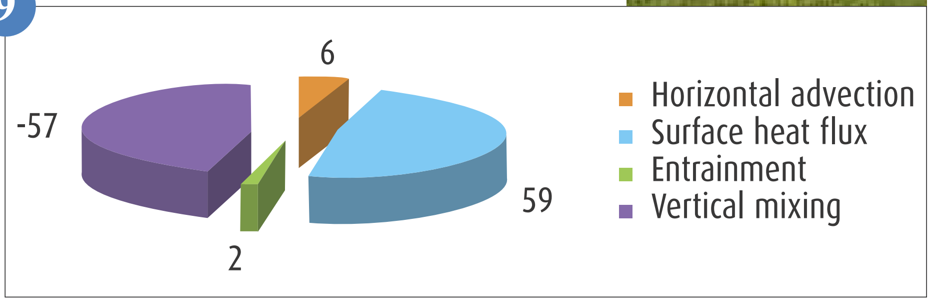

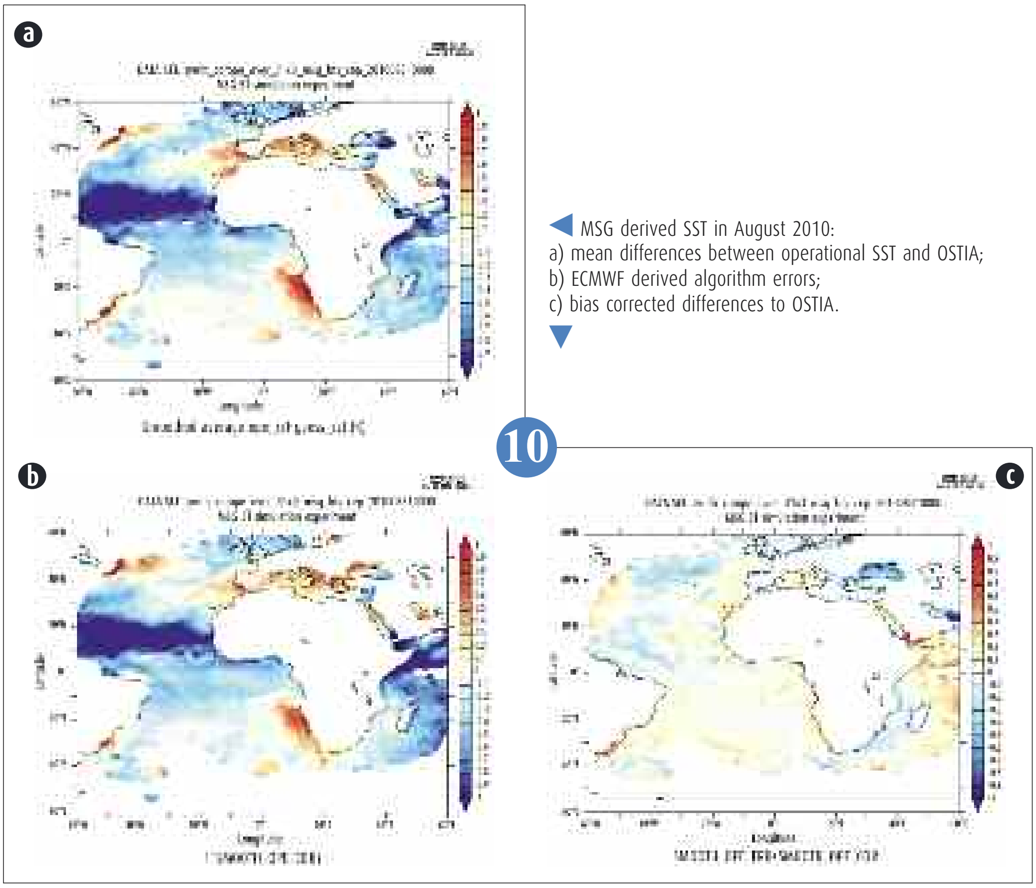

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MSG derived SST in August 2010:
a) mean differences between operational SST and OSTIA;
b) ECMWF derived algorithm errors;
c) bias corrected differences to OSTIA.

Contribution of high resolution ocean modeling in the drift prediction

High-resolution versions (1/36°) of the Mercator model were defined and tested on two areas of interest where the contribution of Mercator must be decisive for the drift prediction. The two areas are the Western Mediterranean Sea, and the equatorial Atlantic off the Congo and Angola. These two versions are embedded in the operating system PSY2 (3rd version), which has a resolution of the 12th degree over the Atlantic Ocean and the Mediterranean Sea.

The shift to a finer grid on the horizontal (1/12° -> 1/36°) goes with an intensification of the currents, since energy is distributed on smaller volumes. This fixes a speed bias in forecasts consistently present in 1/12°. Mesoscale structures (eddies, filaments, frontal structures, etc...) and generation conditions of these phenomena are best represented.

Data from an experiment in the Mediterranean sea, conducted in late 2007 as part of the European MERSEA project, and drift data buoys provided by TOTAL in offshore Angola, have been exploited. It is shown that the success of the results is strongly linked to a good description of the process of fine spatial and temporal scales involved in turbulent zone. For the area offshore Angola, a new representation of the river fluxes was developed. It has shown very positive results. Furthermore, the use of a high frequency forcing and better resolution showed a clear benefit on average results.

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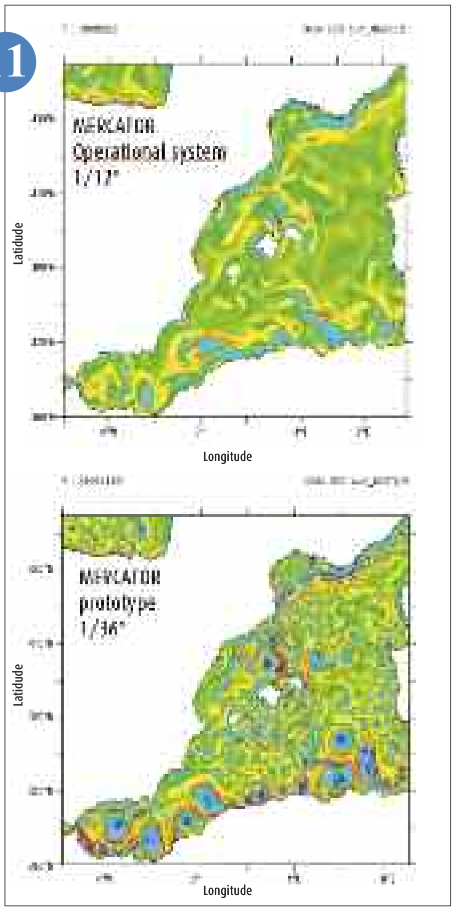

From Stéphane Law Chune (Mercator-Océan).

Satellite data assimilation in the new global wave model MFWAM

A 3rd generation wave model (MFWAM) resulting from a collaboration between Meteo-France, SHOM and IFREMER runs on the operational suite of Meteo-France since April 2009. The computer code was then upgraded in March 2010 to include new settings for a better estimate of the swell dissipation from the perspective of optimal use of satellite data in the model. The data assimilation modules developed with the support from CNES have recently been implemented and tested in the new wave model for an operational implementation in early 2011. The model will incorporate data from radar altimeter on board Jason-1, Envisat and Jason-2 satellites, and those derived from the Synthetic Aperture Radar ASAR on board ENVISAT satellite which will also provide information on the direction and wave period. Research will be conducted subsequently to prepare the integration of data from new sensors developed within the framework of the Franco-Indian space mission SARAL Altika and the Franco-Chinese space mission CFOSAT. The data should be be available in 2011 for the Altika instrument , and in 2014 for the SWIM instrument (CFOSAT).

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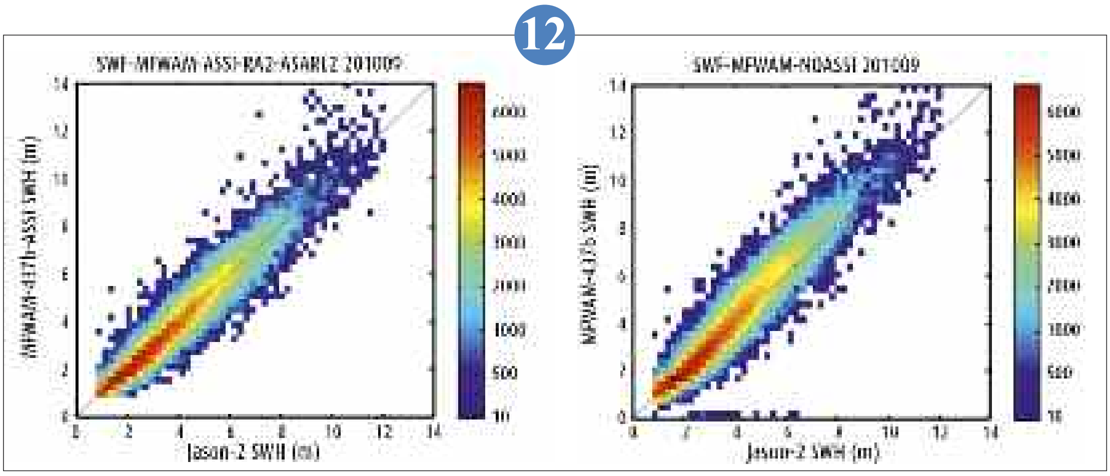


Scatter plots showing the density of model-observation data. Left panel for the MFWAM model with ENVISAT data assimilation (altimeter and SAR), right panel without assimilation. The validation data are from the Jason-2 stallite. Thanks to data assimilation the model relative error for septemner 2010 has been reduced from 15% to 12%.

Atmospheric chemistry and air quality

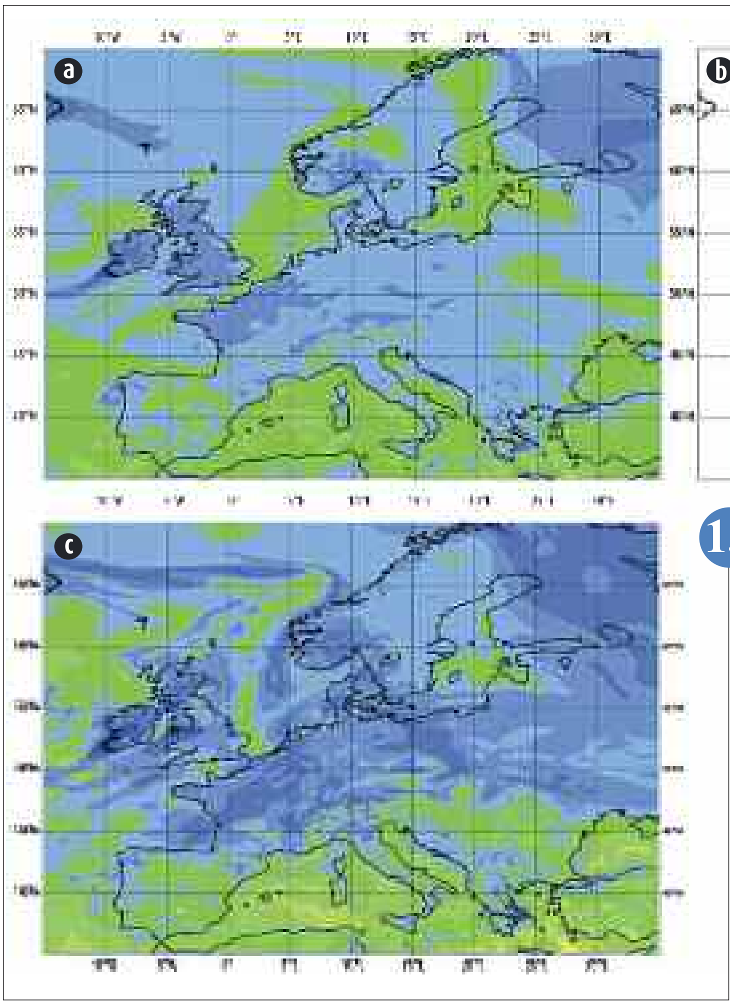
Contribution to « GMES Atmosphere » core service

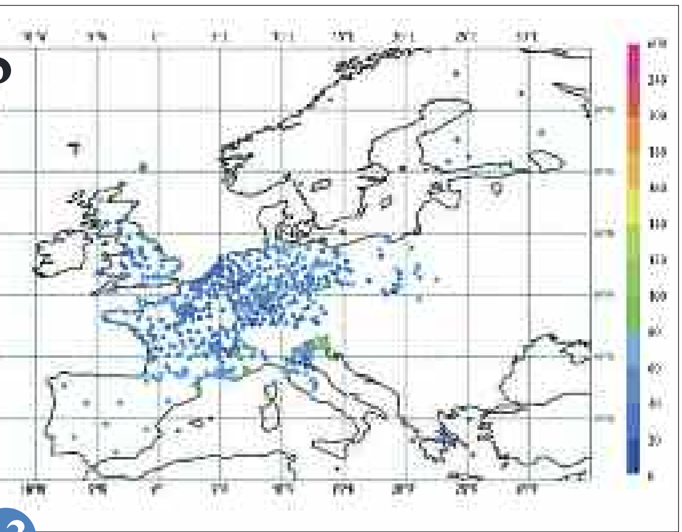
Météo-France, together with it partners from Prév'Air, INERIS, CNRS and ADEME, plays a pivotal role in the setting up of pre-operational air quality services in Europe within the GMES "Atmosphere" program lead by ECMWF.

Air quality forecasts up to +72 h are provided daily, using an ensemble of seven models among the most advanced in Europe. These ensemble forecasts are complemented with a range of verification skill scores against over a thousand sites distributed in Europe and, as a recent addition, with hourly surface analyses available daily for the day before. The provision of air quality analyses in quasi near-real-time constitutes an advance at the international level, confirming the level and maturity of the European teams involved in GMES. Following a research collaboration of several years with CERFACS, the analyses done with Météo-France's MOCAGE model rely on a 3dvar method implemented with the PALM coupling software. Currently, only surface ozone data are considered in the daily pre-operational production, but the list of assimilated data will progressively be extended to other surface observations, in particular nitrogen and sulphur dioxides, and to satellite retrievals.

Since 2010, Météo-France is responsible for providing ensemble and verification products via a new internet platform, which delivers the near-real-time regional products of GMES "Atmosphere". This platforms provides in particular data to the "Eye-On-Earth" system of the EEA, which informs European citizens with timely updates on the status of our environment. GMES pre-operational services thus progressively support information portals of the European Union. The next important step ahead is to succeed in the transition to fully operational services by 2015.

13





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Surface ozone forecasts (+12 h) done with the MOCAGE model for october 13th 2010 1200 UTC (a), observations for the same date (b) and corresponding 3dvar analysis (c).
For this date, assimilated observations tend to reduce ozone in the North of Europe and to increase levels in the South.

MOCAGE-accident now used in operations

Modelling the dispersion of atmospheric releases has long been an operational activity at Météo-France, in support of its core national and international responsibilities.
For example, as one of the 8 WMO RSMC worldwide for environmental emergencies, Météo-France has to provide IAEA with timely dispersion forecasts in case of a nuclear accident occurring anywhere in the world; Météo-France has also to deliver inverse modelling results used to infer the origin of anomalous radionuclide levels detected by CTBTO. An other major activity, as a VAAC for ICAO, is the monitoring and forecasting of the transport of ashes during volcanic eruptions, which present an hazard for aviation.
To fulfil these goals, the Mocage-accident model has been brought into operations at the beginning of 2010, replacing a previous tool now obsolete. Mocage-accident is a specific version of Météo-France's Mocage chemistry and transport model, adapted to the modelling of atmospheric dispersion and deposition of pollutants released from point sources, from regional to continental and global scales. In addition to account for additional processes (convection, scavenging in 3-D, sedimentation) and to use more recent and detailed parameterizations, Mocage-accident is operated at a higher resolution than its predecessor.
Beyond benefiting from several validation studies carried out with Mocage, Mocage-accident has also been specifically assessed by inter-comparison with other dispersion models and against measurements from field campaigns.

The use of Mocage-accident in operations at Météo-France is an important step. Others will follow in the future, as the tool will be subject to regular upgrades.

14

Mocage-accident simulations (left) and images deduced from MetOp/IASI measurements (right, data provided by LATMOS and Université Libre de Bruxelles) for the Eyjafjallajokull eruption on May 6th (top) and May 9th 2010 (down). Even if the comparison can only be limited due to the qualitative nature of the satellite images, this indicates that the successive positions of the ashes plume in Mocage-accident simulations are very realistic.

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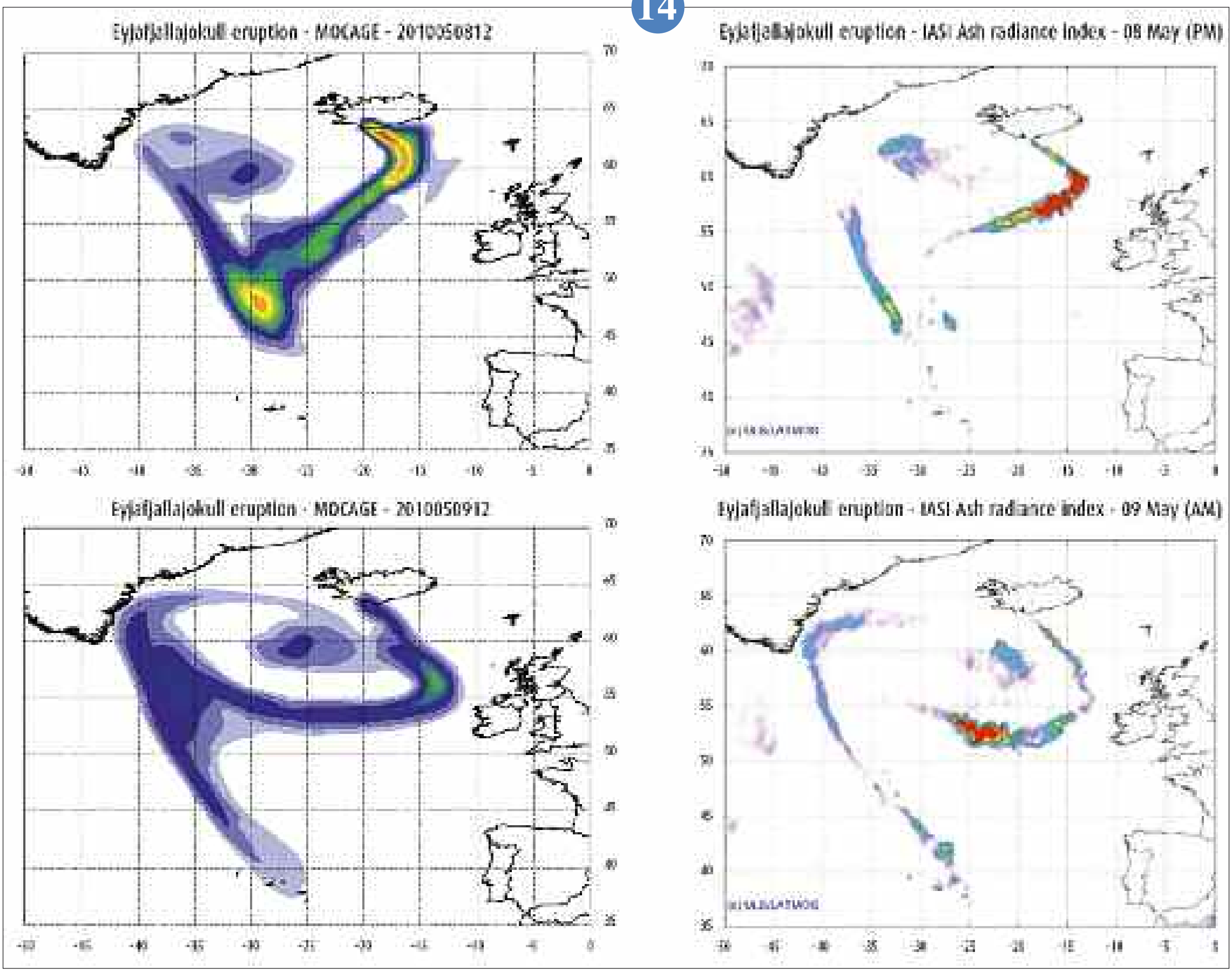

Avalanches and snow-cover studies

During the year 2010, CEN worked on many important projects using the Safran-Crocus-MEPRA (SCM) model suite: sensitivity tests and validation of the Pyrenean snow climatology using SCM models, building up an avalanche climatology based on data from the Cemagref Avalanche Permanent Survey and data simulated by the SCM suite, impact studies about climate change on the Alpine snow cover (SCAMPEI project).
Remote sensing data assimilation in a snow model was used to improve the Saint Sorlin glacier mass budget.
Glacierized and snow coverered surface areas modelling of a tropical high altitude watershed was seen through to completion.
Special emphasis was given regarding the modelling of the physical properties of snow: setting up of new measurements at the Col de Porte (thermal conduction, snow specific surface area), prototype developments for regular measurements, development of the Crocus code and its integration in Surfex. Alongside this work, the snow micro-structure is still under investigation, especially the characteristics of snow from 3D image analysis (such as the specific surface area or crystal orientation) and modelling of snow metamorphism. CEN also supported many operational prediction activities on avalanches risk forecasting such as testing a new Bulletin Estimate Avalanche risk and the intallation of automatic weather stations “Nivôse”.

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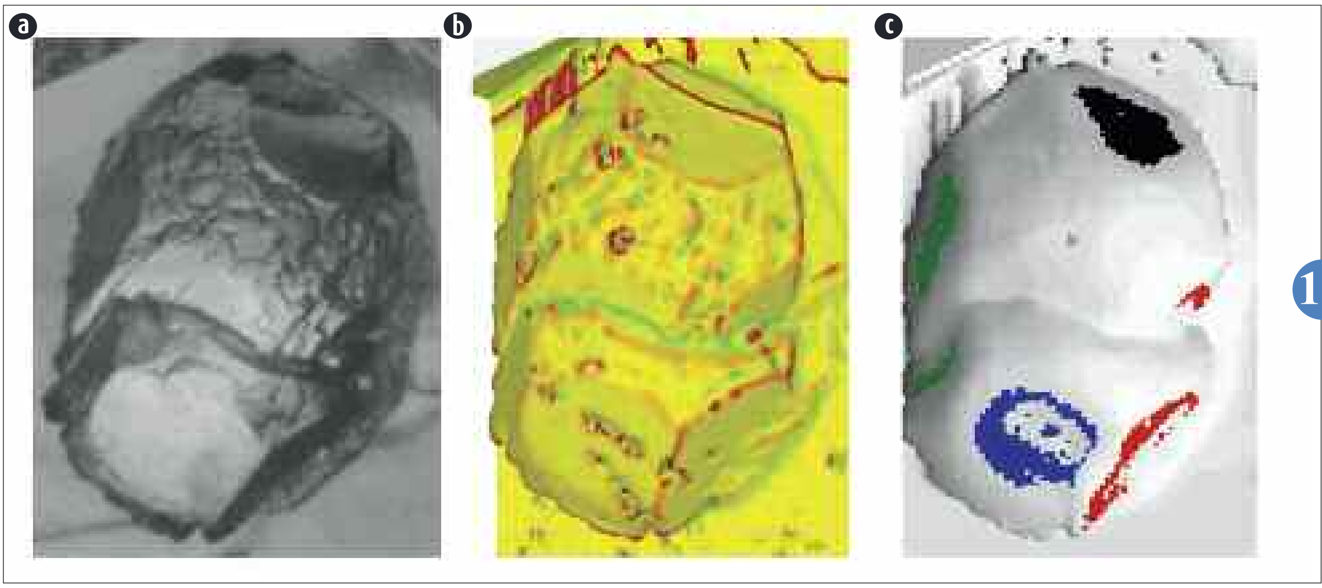

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▲ Detection of the orientation of a snow crystal from faces of attack 3D images observation under optic microscope of a face of attack obtained by sublimation (a) ; representation of the 3D volume after X ray tomography (b) ; automatic recognition of facets of the figure enabling to identify crystallographic axes of the analysed snow crystal (c) : the black facet corresponds to the basement face whereas the green, blue and red ones correspond to prismatic faces (collaboration CNE-LGGE-3SR).

Albedo data observations into snow model CROCUS, application to simulate temperate glacier spatialised mass balance

The albedo is a key parameter in the surface energy balance of temperate glacier. This variable is highly variable both in time and space. Remote-sensing is thus a suitable method to retrieve its spatial and temporal variations.

A method is developed to determine surface albedo on Saint Sorlin glacier (massif des Grandes Rousses, France) using MODIS data and.

Theses albedo maps are assimilated into the snow model CROCUS. A spatialised version of the model is developed to simulate the spatialised mass balance of the glacier. Input meteorological data comes from SAFRAN. The method is applied during five hydrological years showing a reasonable agreement between mass balance measurements and model estimates. The root mean square error is 0.5 m water equivalent over the five studied years.

The method is readily applicable to other temperate glaciers and allow improved quantification of physical processes involved in temperate glacier mass-balance towards a better understanding of complex interactions between albedo, surface energy balance and climate.

16

Distributed simulation of water production in the partially glacierized watershed Zongo (Bolivia, 4853-6014 m)

Andean glaciers, located in a key geographic location for the dynamics of the global climate, also provide indications on its variability. Their water production keeps up significant water flow during the dry season, of substantial importance for people leaving at the foothills of the mountains (both for drinking water supply and hydropower).

Prior to attempting to predict the future behavior of high-altitude Andean watersheds in connection with global climate change, it is necessary to understand its relationship to the current climate settings in terms of the snow and ice mass balance and river runoff. Following previous point-scale applications, the detailed snowpack models Crocus and ISBA-Crocus were used to carry out a distributed simulation of energy and mass-balance over the high-altitude, 63% glacierized Zongo watershed over a time period of 19 months. This project was undertaken through a collaborative effort supported by Météo-France (CNRM/CEN), IRD and LGGE, and makes use of field data acquired through the SOERE/GLACIOCLIM observatory.

The models were adapted to be run under the environmental conditions of a tropical glacier, and proved efficient to simulate the ephemeral snow cover of glacier moraines, the overall glacier mass-balance, and ultimately the total runoff of the outlet river. In addition, the snow hydrological budget of the high altitude watershed was investigated yielding new insights into the altitudinal and seasonal distribution of the contribution of moraine and glacierized areas to the water budget, and the high sensitivity of this ecosystem to moderate increases (+1°C) of air temperature. These preliminary sensitivity studies await confirmation through further investigations, which are in order.

17

In situ monitoring of the time evolution of the thermal conductivity of snow

The thermal conductivity characterizes the ability for a medium to transfer heat. Air and ice, the main constituents of snow, feature thermal conductivities on the order of 0.02 et 2.3 W/(m.K), respectively, so that heat transfer through ice is 100 times more efficient than through air. Therefore, heat transfer in snow proceeds mostly through at grain boundaries within the ice matrix. The thermal conductivity of snow thus depends on the geometric properties of the interconnected network of snow grains, which is called « microstructure ». These properties evolve over time owing to snow metamorphism, which depends on the temperature gradient in the snow, which in turn depends on the thermal conductivity of snow. This demonstrates the existence of a feedback loop involving the internal physical properties of the snowpack.

The thermal conductivity of snow can be measured using special probes inserted in the snowpack. The Snow Research Centre (belonging to CNRM-GAME; Météo-France/CNRS), together with colleagues from the Laboratoire de Glaciologie et Géophysique de l'Environnement (LGGE, CNRS – Université de Grenoble), has refined this method to monitor the time evolution of the thermal conductivity of snow using probes continuously embedded in the snowpack. The results show that the thermal conductivity of fresh snow is low, on the order of 0.05 W/m.K, confirming the good insulating properties of this medium. It then quickly increases over time, demonstrating how rapidly the physical properties of snow evolve through time. At first order, this increase is related to the compaction of the snow, which leads to increasing the density of bonds between snow grains. Modeling at the microscopic and macroscopic scale is currently undertaken to improve our understanding of such processes.

18

Analysis and forecasts of exceptional avalanche situations with the SCM chain: February 1999 in the Chamonix valley

Our understanding of extreme avalanche situations is often based on rare observations and thus incomplete. In an attempt to raise this difficulty, we used the numerical SAFRAN-CROCUS-MEPRA (SCM) procedure of avalanche hazard estimation to study the extreme events of February 1999 in the Chamonix valley.

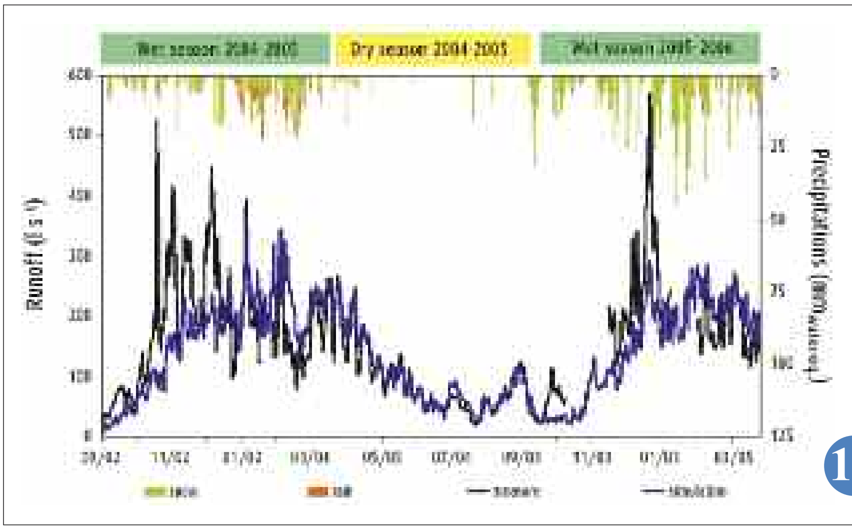
Sensitivity tests of the avalanche hazard to various snow and weather factors were performed. Moreover, the forecasts of the SCM chain, which has been implemented since 2005, were studied. A new index, describing the snowpack instability as a function of movable snow, as well as exposure, altitude and slope, was developed.

The exceptional snowpack instability in February 1999, which was primarily due to intense snowfalls, was significantly strengthened by accumulations of snow transported by wind. On contrary, layers of weak mechanical cohesion at the base of the snowpack probably did not participate to triggering of avalanches but may have contributed to increase their volumes. The SCM avalanche hazard are reliable and eased by the use of the instability index, which provides details on the magnitude, location and evolution of extreme instability.

This study suggests that the SCM models are adapted to the analysis and forecast of extreme avalanche hazard at the massif scale. Moreover, it underlines both the needs for modeling wind transport in an operational context and the benefit of the instability index.

19

Measured (black) and simulated (blue) daily water flow from the Zongo watershed (September 2004 – March 2006), along with daily liquid (orange) and solid (green) precipitation.



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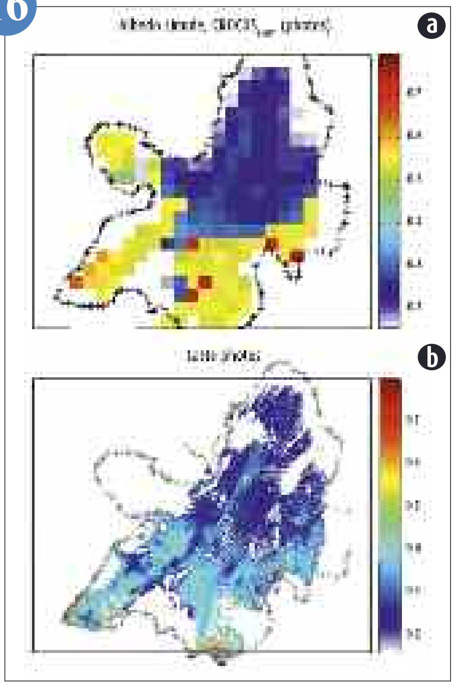
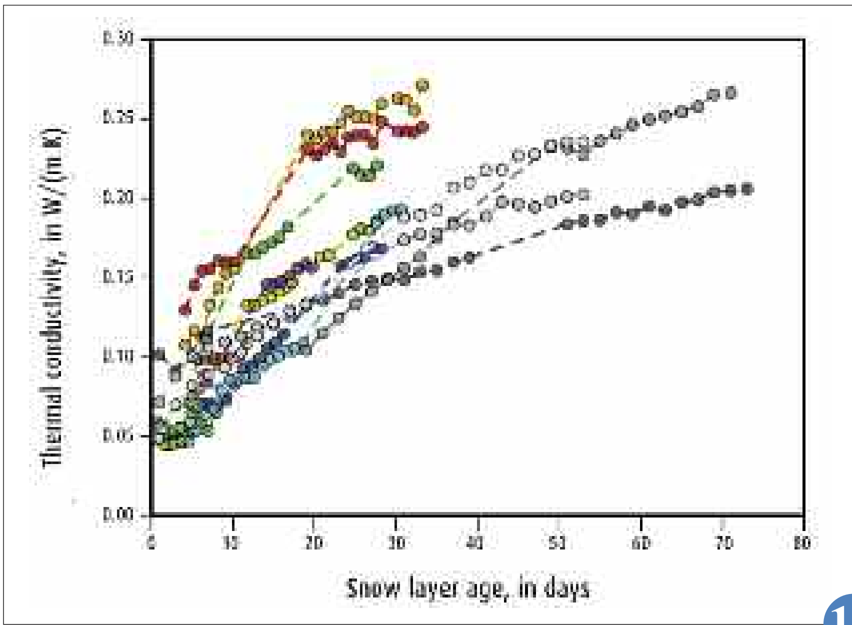


a) Albedo simulated by CROCUS_ASSIM using albedo data from terrestrial photographs (10 m spatial resolution).
b) Observed albedo map deduced from visible and near-infrared terrestrial photographs.
Both panels date is 2009 July 16th and represent Saint Sorlin glacier.



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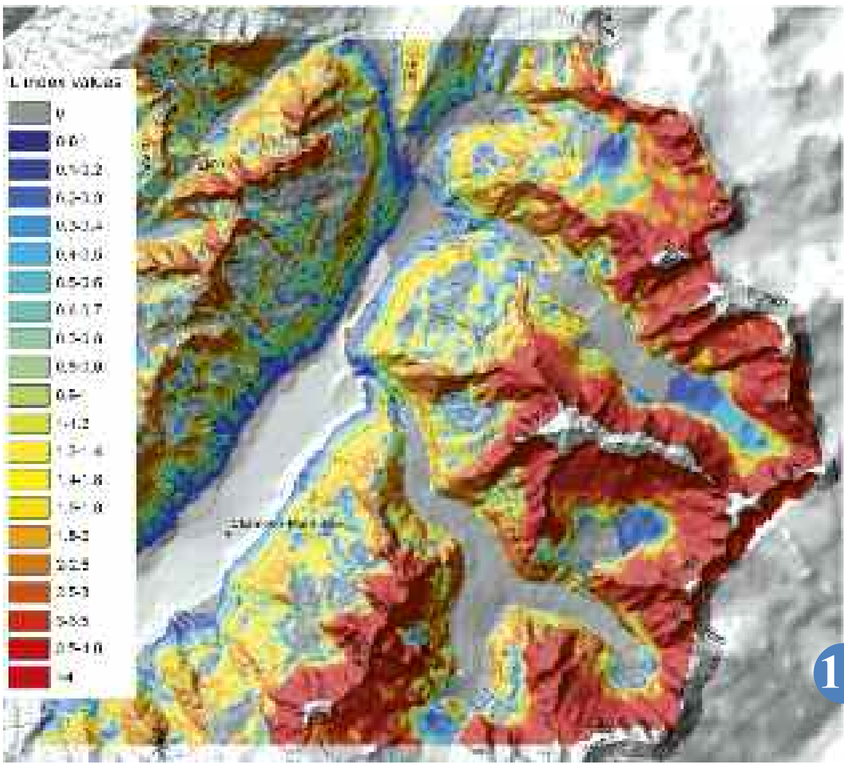
Time evolution of the thermal conductivity of snow, measured within the snowpack at two sites: Argentière (Mont Blanc range) in 2008-2009 (4 probes, greyscale) and Col de Porte (Chartreuse range, close to Grenoble) in 2009-2010 (8 probes, color).



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Map of the snow instability index on February 9 at 12 UTC in the Chamonix valley.

Instrumentation and experimental research

The intense pace of experimental studies in 2010 has mobilized the personnel and the observation facilities of the CNRM. The Concordiasi field experiment that has been conducted in Antarctica as part of the international polar year was coordinated by CNRM. Scientists contributed with their expertise and the operation of a radiosounding system at the Condordia site.
Airborne facilities were very active with 4 field experiments flown, two for cal/val of satellite instruments, and two projects dedicated to the boundary layer, aerosol pollution in Paris and infra-red propagation at the surface. The ATR-42 turboprop aircraft also contributed to the activities of the EUFAR European network with a trans-national access campaign for Portuguese researchers in the Madeira Island and a training course on atmospheric turbulence organised by the atmospheric and climate institute of Roma in Southern France.
Ground teams performed 9 field campaigns covering a large panel of scientific fields, cloud remote sensing, aerosol pollution and the SMOS satellite cal/val in conjunction with the airborne facilities, wind burst and fog at Charles-de-Gaulle airport, and the development of scintillometer techniques for turbulence measurements and electromagnetic propagation in the boundary layer.
Beyond these anticipated experimental research activities, CNRM played a key role during the volcanic ash crisis of April 2010. SAFIRE reconfigured the two aircraft over the week-end, the FA-20 for aerosol remote sensing, and the ATR-42 for in situ measurements. Each aircraft performed 5 research flights, which greatly contributed to the reopening of the French airspace.
Such a high level of field projects leaves little potential of instrumental developments, but still new techniques were been developed and tested for turbulence measurements on the tethered balloon and an autonomous system was completed for aerosol measurements at the ground.

Aircraft Instrumentation

The CAROLS campaign: validation of satellite measurements of soil moisture and ocean salinity

Following the successful launch of the SMOS satellite in November 2009, the ATR42 of Météo-France flew the CAROLS instrument for a 3 months campaign. The goal of the flights was to validate the measurements performed by the satellite: brightness temperature, soil moisture estimation and ocean salinity. CAROLS is a hyper-frequency radiometer (L band), developed by the LATMOS in cooperation with the Danish Technical University.
The ATR42 is operated by SAFIRE, joint group of Météo-France, the CNRS and the CNES, in charge of the French research aircraft.
After 3 test campaigns in 2007, 2008 and 2009 performed to validate the instrument quality and get a large data base above several ground sites (Biscay Bay, south-west of France, Valencia in Spain), the ATR42 was ready for the synchronized overpasses with the satellite. The aircraft and satellite data are then compared to validate the calibration and the quality of the space sensor.
The measurement campaign took place during 3 months (April to June 2010), from Toulouse, with one flight every three days in average. Despite few flights postponed because of the volcanic ashes episode that stopped the air traffic in Europe, the scientific objectives have been reached. A large database has been created and available to the partners: CESBIO, LATMOS, LOCEAN, Météo-France, INRA-Bordeaux, Université de Valence, CNES, ESA.
The campaign ended in November 2010 by 10 days of ocean overflight from Brest. For this purpose, the STORM radar has been mounted on the aircraft. This radar gives information on the sea aspect and the wave's height.

1

One of the 2 CAROLS antennas mounted on the rear flour opening of the ATR42.

1

Flight plans flown by the ATR42 above the Biscay Bay.

The Megha-Tropiques campaign: tropical clouds microphysics

The scientific campaign Megha-Tropiques aims at validating the eponymous satellite. This french-indian satellite will overfly the tropical region and continuously measure the moisture and microphysics state (water or ice) inside the clouds. These data are especially interesting during the monsoon season.
In order to prepare the future satellite validation, the SAFIRE Falcon20 was equipped with the RASTA radar developed by the LATMOS (Paris) and numerous microphysics sensors mounted under the wings (joint operation with the LaMP from Clermont-Ferrand)
Although the satellite was not launched in 2010, the measurements performed over the Niger have provided information about liquid or ice contents inside the thunderstorms clouds and validated the remote measurements from ground based radars. A large part of the flights could be flown in the vicinity of the 2 ground radars deployed close to Niamey.
The weather conditions have been really good during the whole month of August 2010 and the recorded data are very promising.
The aircraft and the instruments are now ready for the satellite validation campaign in summer 2011 to be held in the Indian Ocean.

2

The Piper, a light aircraft for measurements above the city

In 2010, the small twin-engine Piper-Aztec from SAFIRE came back to activity through two measurement campaigns above the cities of Paris and Nantes.
Less used by the scientific community since the arrival of the 2 large aircraft ATR42 and Falcon20 in the SAFIRE fleet in 2006, the Piper-Aztec has shown high capabilities for the measurements above the cities. Indeed, this small aircraft can be allowed to overfly the urban areas at low altitude. In addition, the exploitation cost is very low.
The Piper-Aztec is the oldest aircraft operated by SAFIRE, service unit of the CNRS, Météo-France and the CNES. This aircraft can fly cameras (hole inside the fuselage), chemistry analyzers (air inlets) or sensors under the wings.

MEGAPOLI
In January and February 2010, the Piper flew around Paris to study the aging of the pollutants pushed by the wind outside the Paris area.
Although the weather conditions were not as good as expected (anticyclonic conditions rarely present), the Piper has collected very interesting data.

FLUXSAP
In May 2010, the Piper-Aztec overflew the city of Nantes with an infrared camera. These building surface temperature measurements were complementary with several equipments placed on the ground or on the top of masts.
In 2010, the Piper-Aztec proved once again its benefit for the science. The airplane will fly its next campaign near Toulouse in July 2011 for air turbulence studies.

3

The strong European involvement of the French research aircraft

The airborne research is more and more managed at a European level (EUFAR project) ; SAFIRE, the French research aircraft operator, plays a major role in this European cooperation.
Indeed, SAFIRE operates 3 of the 30 research aircraft in Europe, especially one of the four jets (the Falcon 20) and one of the three large troposphere aircraft (the ATR42).
The ATR42 is very often requested by the European scientific community within the EUFAR project. This aircraft can fly many passengers (up to 9 places in the cabin) and an important scientific payload (2 tons). In 2010, it participated to a summer school that taught to 20 students airborne measurements from an aircraft. The ATR42 has also flown 2 campaigns above the island of Madeira for 2 Portuguese research teams (measurement of gravity and turbulence vortexes under the island wind).
Météo-France and its SAFIRE unit have initiated the transnational cooperation scheme. The objective is to facilitate access to the aircraft for scientists from countries that are not equipped while consolidating the SAFIRE team and finances.
This cooperation scheme is now leading to a multilateral agreement through the European project COPAL.

4

2

◀ Refueling of the Falcon20 in Niamey, NIGER.

3

◀ The air inlets of the Piper-Aztec.

European students in front of the ATR42 during the TETRAD summer school at Hyères, France. September 2010.

▼

4

In situ instrumentation – remote sensing
Concordiasi campaign

The genesis of Concordiasi

Concordiasi is a concatenation of the name of the Franco-Italian Concordia polar research station, located 1000 km in mainland Antarctica and of the acronym IASI (Infrared Atmospheric Sounding Interferometer), an instrument measuring temperature, humidity and the chemical composition of the atmosphere with an unprecedented precision. The idea to associate IASI data and measurements from radiosondes launched from the Concordia research station occurred during a meeting between scientists from Météo-France and from the Laboratory of Glaciology and Geophysical Environment. This led to the Concordiasi field campaign coordinated by Météo-France, strongly supported by CNES and for logistics issues by the French Polar Institute Paul-Emile Victor (IPEV).

The main purpose of the Concordiasi field campaign is to refine our understanding of the polar atmosphere, to monitor the climate, and to optimize the use of meteorological satellite data in weather prediction models. The Concordiasi project took a new dimension after the addition, besides normal radiosoundings, of pressurised stratospheric balloons developed by CNES (figure1). These 12 m diameter balloons filled with helium can fly at a constant 17 km altitude for several months with a 50 kg load of equipment. The whole measuring system is composed of 19 of these drifting balloons, launched from the Antarctic US McMurdo research station. Thirteen of these balloons carry each fifty dropsondes supplied by NCAR (National Center for Atmospheric Research, USA). They are remotely released by scientists in Toulouse. During the descent, each dropsonde measures the vertical profile of the atmosphere at so many different locations impossible to get by any other means.

Scientists from the Laboratoire de Météorologie Dynamique, universities from Wyoming, Colorado and Purdue, Indiana, got involved in the project. They have devised several atmospheric sensors able to measure movements in the upper atmosphere, to measure the chemical components of the atmosphere and monitor the Ozone so as to have a better insight into its depletion. These sensors are onboard 6 stratospheric balloons.

5

To increase Antarctic observations to improve weather predictions and to monitor climate change

Observations about Antarctica are scarce and far between. Over this 13 millions km² vast continent, observations come from 13 research stations, mainly located near the coast. This radiosounding coverage of Antarctica falls short of what is needed to precisely describe the Antarctic entire atmosphere (figure 6). On the other hand, polar orbiting satellites give, over the entire region, a tremendous amount of data.

To efficiently use satellite measurements, it is necessary to check their use against ground observations. The purpose of the Concordiasi field campaign is to generate additional radio sounding data besides those produced by operational research stations, over a set period of time and about areas inaccessible by any other means (inside the continent especially). It is thus possible to verify that data generated by the IASI sounder onboard the MetOp satellite are relevantly used to tune up the meteorological model, thanks to many measurements characteristic of the whole area. Should it be necessary, algorithms will be improved and introduced in new versions of weather prediction models that will also monitor climate change.

6

First results

During the early phase of the Concordiasi field campaign (polar Spring 2008 and 2009), in situ measurements were made at the Concordia research station, some 1000km inland, synchronised with the orbiting MetOp satellite. These measurements were compared to profiles of the atmosphere from Météo France prediction model. It was found that the model was lacking in accuracy in its simulation of the surface temperature at the Concordia research station. Conversely, the combination of IASI and the model showed a positive impact, the combined values being much closer to those made in situ by a French scientist from Météo France who was sent to Antarctica for that purpose (figures a & b). This justifies the use of IASI data to adjust the model in the very specific environment of the Concordia research station.

During the second phase, from September to November 2010, the tuning of the assimilation of IASI data will be extended to a much wider zone under diverse meteorological conditions. Figure c shows all the dropsonde measurements as from the beginning of the campaign.

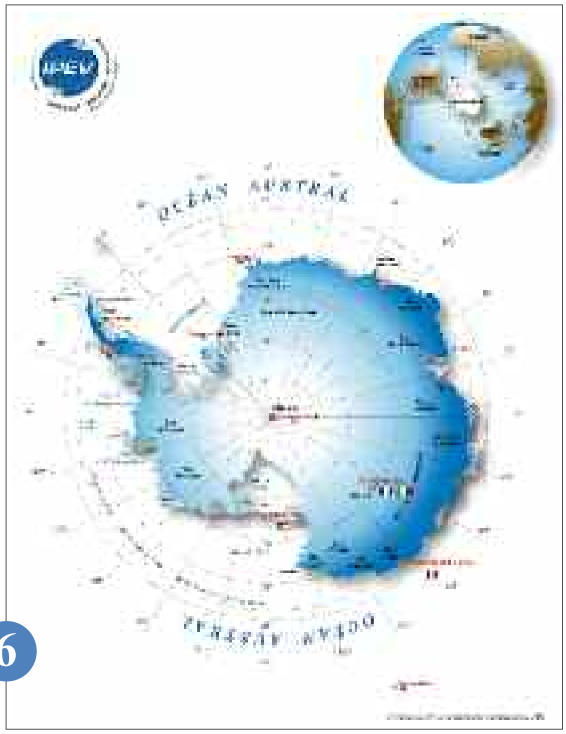
Two major criteria have been defined for releasing the dropsondes. The first one seeks to know whether the trajectory of the balloon crosses the path of the MetOp satellite (see figure d). The second one relates to the surveying of a relevant area, from a meteorological viewpoint, by balloons, meaning, able to provide additional observation data that will significantly improve predictions.

Besides dropsondes, many research stations were called for to make additional soundings: the French Dumont d'Urville research station, the Franco-Italian one of Concordia and the British one of Rothera.

7

5

Stratospheric balloons launched from the McMurdo research station, Philippe Cocquerez, CNES.



The Antarctica, map provided by the French Polar Institute IPEV.

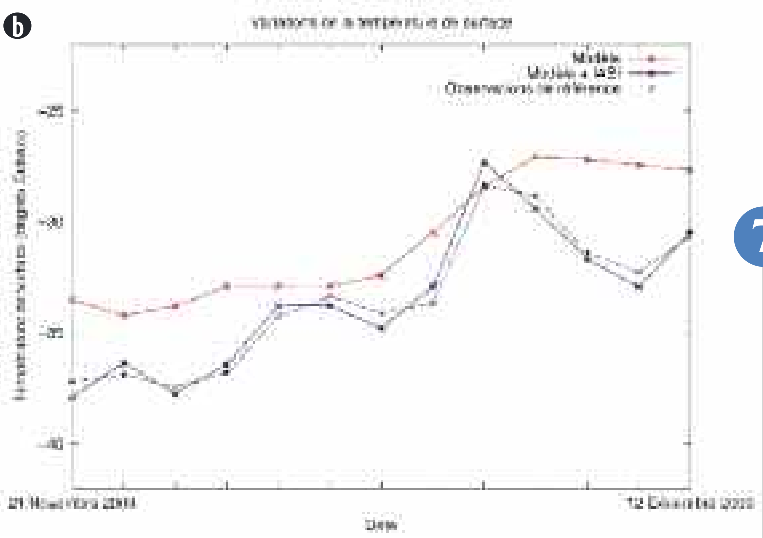
6

a

Olivier Traullé at work at Concordia.

Temporal series of surface temperature at Concordia. The model is drawn in red, with added IASI data in blue, in situ observations in black. In this figure, one can see a slight discrepancy between predictions from the model and data from in situ observations. Once the model is adjusted with IASI data, the combined estimations are much closer to those made in situ.

b



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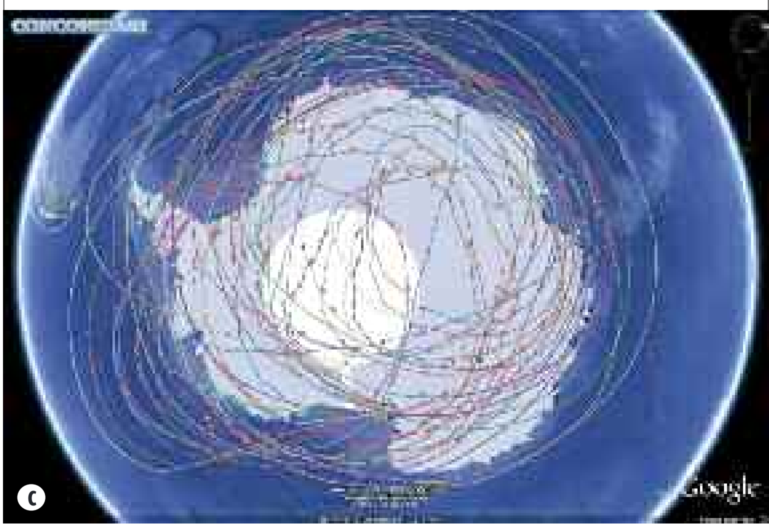

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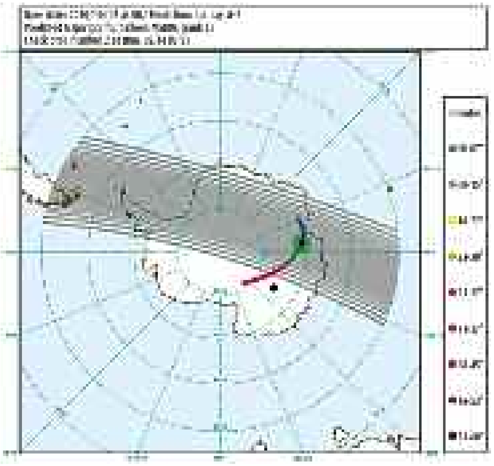

d

Predictions for the 8th of October 2010 of the swath of the MetOp satellite carrying IASI (grey zone) and of the position of one balloon (coloured line). The prediction of the trajectory of the balloon for the 8th of October is depicted by the coloured line. The optimal position to drop the sonde is depicted by a black triangle. Should the launch happen at 2:14 UTC, it shall be in phase with the satellite (given 7 minutes).

Location of the 275 dropsondes launched between the 23d of September and the 19th of October 2010.

Planning the operations using specific local predictions

The release of balloons depends on the frequent and potentially fierce surface wind in Antarctica. On site, scientists can rely on the US McMurdo research station for weather conditions, who has, at its disposal, observation data and information from several numerical systems. Furthermore, Météo-France provides weather forecasts for this specific event. Specifically adapted numerical models pooled to give a fine description of the atmosphere over the McMurdo region routinely run on the supercomputer in Toulouse. The first one is the global model ARPEGE, whose resolution in Antarctica is around 10 km, and which has been adapted from the operational global model. The second one is the AROME model which has a 2.5 km resolution and can make precise predictions about areas close to the McMurdo research station. It is very important to have at one disposal, a model with a good quality of the orography, so much vital for wind predictions. Forecasts are communicated twice a day: once in the morning in order to plan current operations and a second time in the evening to anticipate next day operations. Predictions were highly appreciated by the scientific staff, in particular during the launch of a balloon on the 11th of September (figure 8).

Acknowledgements: Concordiasi is an international project, currently supported by the following agencies: Météo-France, CNES, CNRS/INSU, NSF, NCAR, University of Wyoming, Purdue University, University of Colorado, the Alfred Wegener Institute, the Met Office and ECMWF. Concordiasi also benefits from logistic or financial support of the operational polar agencies IPEV, PNRA, USAP and BAS, and from BSRN measurements at Concordia. Concordiasi is part of the THORPEX-IPY cluster within the International Polar Year effort.

8

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

The MEGAPOLI project aims at giving a full, consistent and quantitative description of the impact of megacities on air quality, chemical composition of the troposphere and climate. The study of particulate pollution in the Ile-de-France is the focal point of the project, including organization of a large experimental campaign to better understand and quantify sources of particulate pollution. This region was chosen as study site because of its high load of pollution, strong contrast between its urban and rural areas, and the presence of a dense network of air quality monitoring. After the summer campaign which took place in July 2009, a winter campaign was held between mid-January and mid February 2010. Firstly, the team GMEI/MNPCA of CNRM-GAME has instrumented the experimental ground site of SIRTA: counters for particle, condensation nuclei, cloud and fog droplets, and analyzers for the size spectrum of particles and droplets. Then, the SAFIRE Piper Aztec joined the aerodrome of Cergy-Pontoise, where he stayed until mid-February. During the winter season, since the thickness of the boundary layer was lower, the air pollution events were most frequently observed at altitudes lower than in summer. The involvement of the instrumented Piper in a streamlined configuration for the measurement of aerosols (physico-chemical) and gases (O_3, NO_x) was considered sufficient for this campaign (although the ATR was used during the summer campaign). Partners particularly involved in the analysis of this phase are: CNRS (LSCE, LISA, LCP, LGGE, LaMP, LMD), MPI-C (Mainz), PSI (Zürich), INERIS, and Leosphere.

9

New Design of a turbulence measurement sonde for tethered ballonf

Turbulence measurements on the atmospheric boundary layer entire thickness is still difficult to perform. It is sometimes made with tall masts when the interest is the first hundreds of meters above ground level. Beyond, it becomes necessary to use airborne means who are very constraint by aeronautical rules and airborne flight characteristics, or remote sensing means. Tethered balloon inflated with helium is a good and easy to use way during short measurement field campaigns. This kind of small balloon is able to set a lightweight instrumentation between ground level and the top of the bounday layer. In 2010, CNRM began the design of an autonomous sonde of weight less than 2 Kg. The sonde is builded with an higth frequency acquisition system on a micro controller base, an ultrasonic anemometer and a motion, attitude and GPS pack. The motion pack allow to correct wind measurements disturbed by balloon and sonde motions. With a fast thermometer, the system will allow to estimate heat sensible flux to several levels. The first tests conducted in august 2010 at the Centre de Recherche Atmosphérique in Lannemezan allowed to confirm prototype flight characteristics and to constitute a data set for validate wind correction and data processing algorithms. Also, we will have a simple tool for turbulence estimation useful during boundary layer studies fields campaigns or for the validation of remote sensing instruments.

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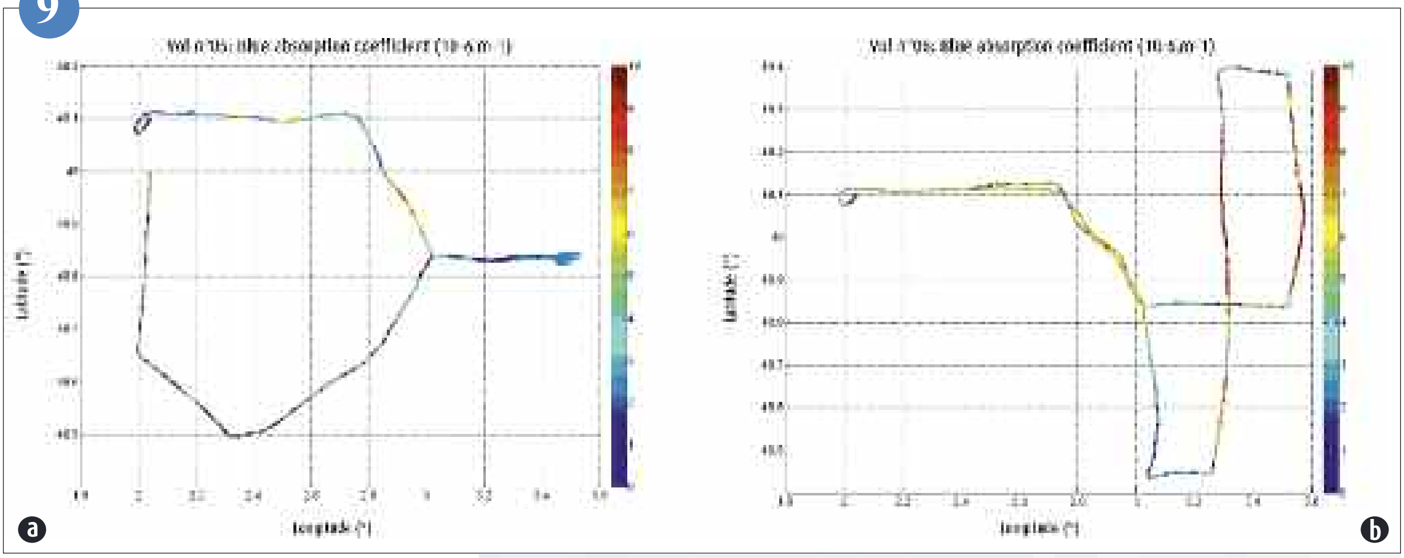
▲ AROME predictions for the 10 of September 2010, showing a favourable window (low wind) to launch a balloon for the following day at 3 UTC. Predictions of the model are in green, local observations in red. A strong variation of the wind speed, well reproduced by the model, can be noticed.

10

◀ Tethered balloon and turbulence measurement sonde during first tests. ▼

9



a

b

c

▲ Absorption coefficient of light by aerosol particles during the scientific flights of January 31, 2010,
a) in the morning around Paris,
b) in the afternoon in the east area of Paris.
The regional transport of absorbant particles to the east area of Paris can be clearly distinguished.
c) Members of the SAFIRE team involved in the MEGAPOLI winter campaign in front of the instrumented Piper Aztec. ▶

A campaign for the microphysics of precipitation in Toulouse (winter 2009-2010)

The CIDEX campaign is an experience that focuses on the multidisciplinary study of the microphysics of precipitation and risk prediction of aircraft icing.
The main objectives of this experiment are to test new calibration methods suited to polarimetric radar, to determine their ability to detect supercooled water, and better understand the dynamic and thermodynamic conditions for the emergence of the phenomenon of icing.
This project is based on exploiting the synergy between different types of instrumental radars implemented by CNRM/GAME and LaMP. The experimental apparatus consists of a set of research instruments (Micro Rain Radars, wind profilers UHF and VHF band radar X, disdrometer, rain gauge and radiosonde) was deployed for two months on four separate sites in the vicinity polarimetric radar operating at Toulouse.
Although the cumulative rainfall recorded in the Toulouse region during the winter of 2009-2010 were substantially below average, many interesting cases, including the snowstrom of March 8, 2010, have been sampled and are currently being analyzed. Studies conducted during CIDEX will grow further in the near future the Southern Alps with the installation for 18 months, part of the experimental device in the valley of the Var in the project RHYTMME.

11

11

Site CIDEX Castanet with wind profiler, X-band, Micro rain Radar...

Knowledge transfer and communication

The valorisation of research activities consists first of all of a large internal and external communication on the latest developments in meteorology, climate and environment studies.
Different meetings are yearly organised: the Atmospheric Modelisation workshop, which regroups participants of different Research Laboratories, was held in January on the sources of uncertainties in the modelisation and the R&D workshop, a propitious moment for scientific exchanges between all Météo-France's researchers, in June on the snow cover. Other meetings were specifically organised in 2010, such as a one day workshop on the climate change and the communication on uncertainties or the ICARE Conference on the Météopole campus in Toulouse.
In 2010, a complete review of the web site of the principal research unit – the CNRM-GAME – has begun. This important task was undertaken by the opening of a new site in a quite complete version and will be continued by the upgrades with available news. This will allow a better visibility of the research activities at Météo-France.
To go further than the communication, the valorisation towards the other departments of Météo-France consists of a transfer of research results to operational units, as a complement to the actions conducted by the other departments.
In 2010, the most important actions concerned new types of statistical adaptations of the numerical model output, a more generalized utilisation of ensemble forecasts and the implementation of facilities to undertake simulations with numerical models for case studies.

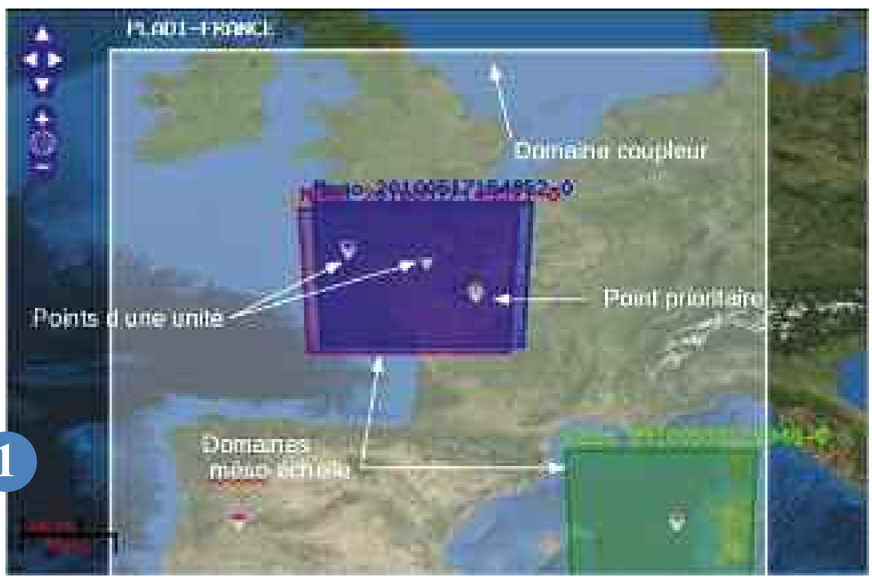
Dynamic Downscaling: End-User and Consulting Department tools

Mesoscale Modeling is currently undergoing a major change: the models are becoming end users tools. This mutation stimulates the development of ergonomic interfaces, extends the domains of application beyond meteorology, and multiplies opportunities for validation.
Jointly developed by BEC and CDMA, Armillaire has two goals: give a Human Machine Interface to manage all the complex tasks of dynamic downscaling experiments and offer of a set of pre-defined productions. Armillaire is based on configuration and launching experiments tool: OLIVE. Two types of experiments based on AROME have been defined: "real time" experiments (forced by IFS, ARPEGE or ALADIN) and "reanalysis" experiments (forced by ERA-40 or ERA-Interim re-analysis). Armillary has been deployed in December 2010 to help the CISMF, to respond to various requests of the French Army, for overseas theatres.

As Defense is not the only user of mesoscale data, BEC has developed tools and expertise in other various domains as: wind energy (selection of representative situations), hydrology (use of model-Top Model) etc... 2011 will be an opportunity to define dynamic downscaling services offered by BEC to support Météo-France Studies Departments.

1

Screenshot of Armillaire "theatres" page.



1

On the use of Ensemble Forecasts at the NFC and for short range Forecasts

The aim of the national project “Prévi-Prob” is to promote at the NFC the analysis of the uncertainty associated with the deterministic forecasts, by using the “Ensemble Forecasts” and the “Multi-Models” (Météo-France, ECMWF, Canada, USA) at day+2 and +3.
As part of “Prévi-Prob”, an experiment was organized in the Laboratory of Forecasting during the 2009-10 winter. The purpose was to finalize the methods already existing at the NFC, with a daily test of the available products and a possibility to create new ones (like the “smarties”). The involvement of the forecasters was important, with an input of the “Ensemble Forecasts” evaluated as “good” and the writing of a User-Guide.
This 2009-10 experiment is intended to be continued in 2010-11 at the NFC. Almost the same products and tools will be used, with however some updating or tuning, with a more systematic control of the daily outputs and with a possibility to test the uncertainty at day+1.

2

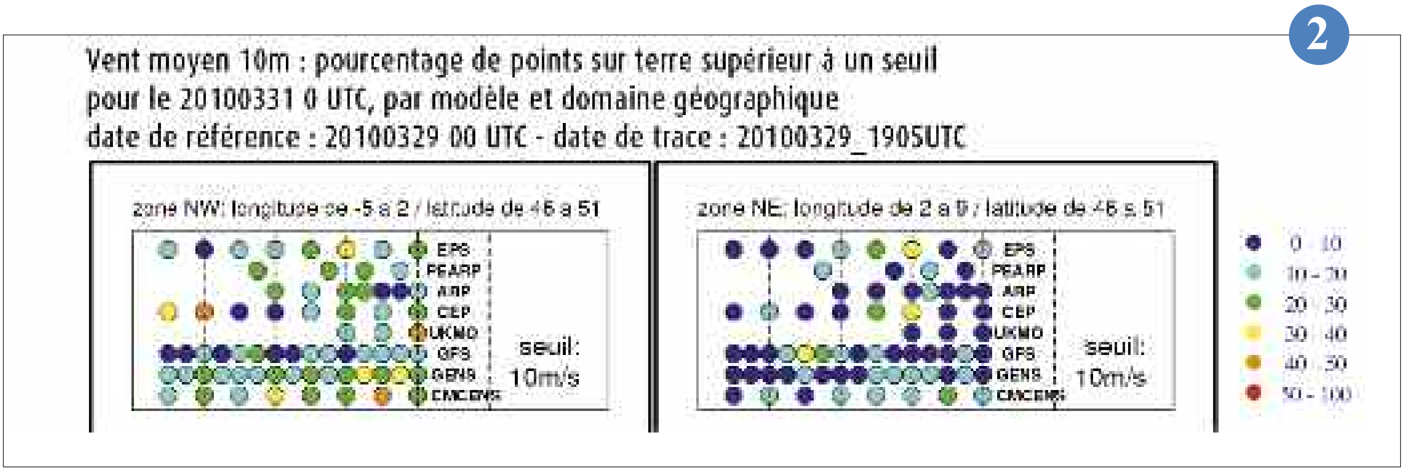
A new external website for CNRM-GAME

The CNRM external website has been completely re-designed in 2010. This action has been successfully achieved in December, since the new site opened before the end of the year. The main goals of this project were:
– to built an actual lab site, giving a better visibility to the research actions led by the Research Centre, in addition with the scientific information which are available on Meteo-France or CNRS websites,
– to allow easy and frequent article updates, by dispatching the writing activity among a large number of contributors, thanks to a new architecture based on a powerful content management tool,
– to give the opportunity to permanent or non-permanent staff to have their own personal page.
Several models for the future site have been evaluated during the 1st quarter of 2010. A solution based on SP/IP was finally chosen. The classification of the different research activities is mainly built on the organization of the last GAME report. A short presentation of the different project in which the CNRM is involved is available through several access : by scientific area, by financial sources, by CNRM-GAME’s role in the project. Moreover, the scientific publications of the lab, which are of course available on line, may be sorted thanks to different criteria, allowing an efficient access to the information.
The new website has been progressively filled during the autumn. Thanks to the strong motivation of the whole CNRM units, the site contents has been considered as rich enough to allow an official opening of the site in December 2010 (http://www.cnrm-game.fr/). Its contents will be extended in 2011, in order to cover all the different activities of the laboratory.

3

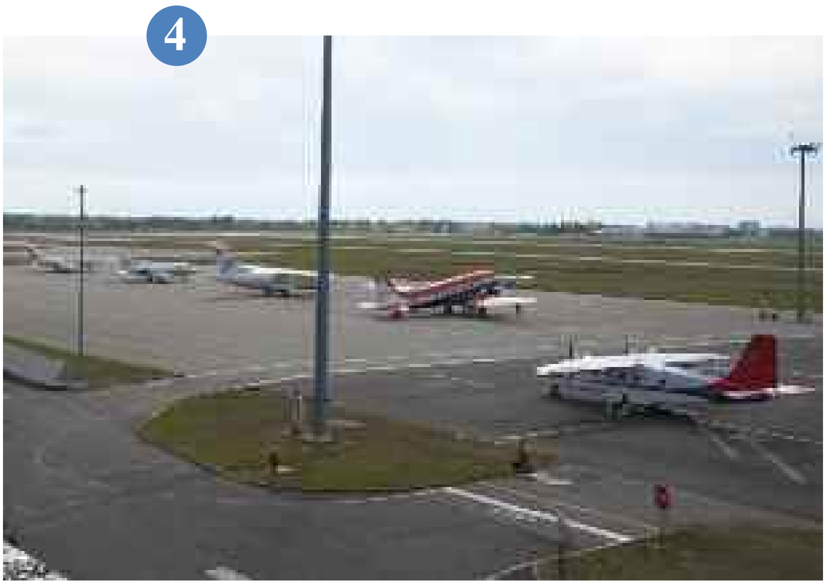
ICARE

Since its commencement in 2000, Météo-France acts as coordinator to the European Facility for Airborne Research in environmental and geoscience project (EUFAR). Within the 7th framework programme (2008-2012), EUFAR was allocated the sum of 8 M€ from the European Commission, to co-ordinate the activities of around twenty institutions and companies and provide access to some thirty or so instrumented research aeroplanes. EUFAR is engaged to improve the service by strengthening expertise through exchange of knowledge, development of standards and protocols, constitution of data bases, organization of training sessions for young scientists. Lastly, the consortium promotes three collaborative research activities on the implementation of new airborne instrumentation and state of the art softwares for hyper-spectral imagery observation. Initiated by EUFAR, the COPAL project (Community Heavy Payload and Long Distance Research Aircraft), commissioned by the European Commission, is a preparatory study within the Research Infrastuctures ESFRI roadmap.
The draft project COPAL, coordinated by Météo-France has the objective to providing a European heavy-payload long endurance instrumented aircraft (such as the C130 or Airbus 400M) which is quite lacking in the present European research fleet.
To celebrate EUFAR ten years existence, Météo-France together with CNRS, CNES, Toulouse-Blagnac Airport, RTRA-STAE, Airbus, the European IAGOS programme, Midi-Pyrénées Regional Council, the Haute-Garonne General Council, the Urban community of Greater Toulouse, Toulouse and Blagnac town halls, jointly organised an international conference on airborne instrumentation between the 25 and the 29th of October 2010. Over 200 international experts on airborne instrumentation, representatives from the European Community, from ESA and RTRA outlined their ideas on developing airborne measurement technologies, on scientific needs and new challenges facing research, on research infrastructure management in Europe and the United States of America, and short and mid-term perspectives in this field. All presentations are accessible on the network portal:
www.eufar.net/icare
Following the conference, a twelve research airplane inter-calibration campaign from the flying wing of the University of Karslruhe to USA NCAR C130 Hercule took place at Toulouse-Blagnac airfield. With the strong support from CCER, airplanes made 12 flights following requisite specific inter-calibration conditions such as several flight patrols. Twenty young European scientists were trained to data post-processing which are now quality controlled. Lastly, 60 participants from the field of airborne instrumentation and the aviation industry displayed products and know how in the airport business lounge.



▲ The coloured "smarties" associated with the risk to observe a grid points (1/4th of France) where the "10 m wind" exceeding some threshold values. The coloured scale gives the percent of grid points above the threshold. The more recent run (deterministic of ensemble) is on the right. One can analyse the stability of the forecasts by going to the left for a given model, to see all the previous runs (by step of 6h and with a vertical line for each day).

◀ The main page of the brand-new CNRM-GAME website.



◀ Research airplanes on Toulouse-Blagnac tarmac business airport.

Appendix

2010 Scientific papers list

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

Agusti-Panareda A., A. Beljaars, M. Ahlgrimm, G. Balsamo, O. Bock, R. Forbes, A. Ghelli, F. Guichard, M. Köhler, R. Meynadier and J.-J. Morcrette, 2010: The ECMWF re-analysis for the AMMA observational campaign. Volume: 136. Issue: 651. Pages: 1457-1472 – Quart. J. Royal Meteorological Society. Doi: 10.1002/qj.662 .

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Glossary

Organisms and Laboratories

Organisms

ADEME Agence de l'Environnement et de la Maîtrise de l'Energie
AIEA Agence Internationale de l'Energie Atomique
ANR Agence Nationale de la Recherche
BEC Bureau d'Etudes et de Consultance
CDM Centre Départemental de la Météorologie
CDMA Cellule de développement Météo-Air
CEH Centre for Ecology and Hydrology
CEN Centre d'Etudes de la Neige
CEPMMT Centre Européen pour les Prévisions Météorologiques à Moyen Terme
CERFACS Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique
CMM Centre de Météorologie Marine
CMRS Centre Météorologique Régional Spécialisé
CMS Centre de Météorologie Spatiale
CNES Centre National d'Études Spatiales
CNP Centre National de Prévision
EEA Agence Environnementale Européenne
ESA European Space Agency
EUFAR EUropean Facility for Airborne Research
EUMETNET EUropean METeorological NETwork
ICARE International Conference on Airborne Research for the Environment
IFREMER Institut Francais de Recherche pour l'Exploitation de la MER
INERIS Institut National de l'Environnement et des Risques
INSU Institut National des Sciences de l'Univers
IPEV Institut Paul Emile Victor
IRD Institut de Recherche pour le Développement
JMA Japan Meteorological Agency
MetOffice United Kingdom Meteorological Office
MPI Max Planck Institut
NASA National Aeronautics and Space Administration
NCAR National Center for Atmospheric Research
NEC Nippon Electric Company
NOAA National Ocean and Atmosphere Administration
OACI Organisation de l'Aviation Civile Internationale
OMM Organisation Météorologique Mondiale
RTRA-STAE Réseau Thématique de Recherche Avancée – Sciences et Technologies pour l'Aéronautique et l'Espace
SHOM Service Hydrographique et Océanographique de la Marine
UKMO United Kingdom Meteorological Office
VAAC Volcanic Ash Advisory Centre

Laboratories or R&D units

CESBIO Centre d'Etudes Spatiales de la BIOsphère
CNRM Centre National de Recherches Météorologiques
CNRM-GAME Groupe d'études de l'Atmosphère MÉtéorologique
CNRS Centre National de Recherches Scientifiques
DSO Direction des Systèmes d'Observation (Météo-France)
GAME Groupe d'Etude de l'Atmosphère Météorologique
IPSL Institut Pierre Simon Laplace
LAMP Laboratoire de Météorologie Physique
LATMOS Laboratoire ATmosphères, Milieux, Observations Spatiales
LCP Laboratoire Chimie et Procédés
LGGE Laboratoire de Glaciologie et de Géophysique de l'Environnement
LMD Laboratoire de Météorologie Dynamique
LOCEAN Laboratoire d'Océanographie et du Climat : Expérimentations et Approches Numériques
LSCE Laboratoire des Sciences du Climat et de l'Environnement
SAFIRE Service des Avions Français Instrumentés pour la Recherche en Environnement

National or international programs or projects

BAMED BAlloons in the MEDiterranean
CHFP Climate Historical Forecasting Project
CIDEX Calibration and Icing Detection EXperiment
CMIP Coupled Model Intercomparaison Project
CYPRIM projet Cyclogénèse et précipitations intenses dans la zone méditerranéenne
ESURFMAR Eumetnet SURFace MARine programme
GLOSCAL GLobal Ocean Surface salinity CALibration and validation
HyMeX Hydrological cYcle in the Mediterranean EXperiment
MEPRA Modèle Expert de Prévision du Risque d'Avalanche (modélisation)
MERCATOR-OCEAN Programme coopératif d'océanographie opérationnelle
METOP METeorological Operational Polar satellites
PNRA Programma Nazionale di Recerche in Antartide
QUANTIFY Programme QUANTIFYing the climate impact of global and European transport systems
RHYTMME Risques HYdro-météorologiques en Territoires de Montagnes et MEditerranéens
SMOS Soil Moisture and Ocean Salinity
THORPEX THe Observing system Research and Predictability EXperiment
USAP United States Antarctic Program
WCRP World Climate Research Programme

Campaigns

AMMA Analyse Multidisciplinaire de la Mousson Africaine
CORDEX COordinated Regional climate Downscaling EXperiment
MEGAPOLI Megacities : Emissions, urban, regional and Global Atmospheric POLlution and climate effects, and Integrated tools for assessment and mitigation
SMOSREX Surface MOnitoring of the Soil Reservoir EXperiment

Other acronyms

ALADIN Aire Limitée Adaptation Dynamique et développement InterNational
AMSR Advanced Microwave Scanning Radiometer
AMSU Advanced Microwave Sounding Unit
ANTILOPE ANalyse par spaTIaLisation hOraire des PrEcipitations
ARAMIS Application Radar A la Météorologie Infra-Synoptique
ARGO Array for Real time Geostrophic Oceanography
AROME Application de la Recherche à l'Opérationnel à Méso-Échelle
AROME-COMB AROME - COMBinaison
AROME-PERTOBS AROME (OBServations PERTurbées aléatoirement)
ARPEGE Action de Recherche Petite Échelle Grande Échelle
AS Adaptations Statistiques
ASAR Advanced Synthetic Arperture Radar
ASCAT Advanced SCATterometer
AVHRR Advanced Very High Resolution Radiometer
BAS British Antarctic Survey
BPCL Ballon Pressurisé de Couche Limite
CALIPSO Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations
CAPE Convective Available Potential Energy
CAROLS Combined Airborne Radio-instruments for Ocean and Land Studies
CFOSAT Chinese-French SATellite
CISMF Centre Inter-armées de Soutien Météorologique aux Forces
CLAS Couches Limites Atmosphériques Stables
CMC Cellule Météorologique de Crise
CNRM-CM5 Version 5 du Modèle de Climat du CNRM
COPAL COmmunity heavy-PAyload Long endurance instrumented aircraft for tropospheric research in environmental and geo-sciences
CROCUS Modèle de simulation numérique du manteau neigeux développé par Météo-France
DP Direction de la Production
DPrévi Direction de la Prévision
DSI Direction des Systèmes d'Information (Météo-France)
DSNA Direction des Services de la Navigation Aérienne
ECMWF European Centre for Medium-range Weather Forecasts
ECOCLIMAP Base de données de paramètres de surface
EGEE Etude du golfe de GuinEE
ENVISAT ENVIronmental SATellite
ERA Re-Analysis
FAB Fonctionnal Aerospace Block
FAR Fausse AleRte
GELATO Global Experimental Leads and ice for ATmosphere and Ocean
GIEC Groupe Intergouvernemental d'experts sur l'Evolution du Climat

GMAP Groupe de Modélisation et d'Assimilation pour la Prévision
GMEI Groupe de Météorologie Expérimentale et Instrumentale
GMES Global Monitoring for Environment and Security
GPS Global Positionning System
HIRLAM HIgh Resolution Limited Area Model
HSS Measurement of improvement of the forecast
IAGOS In-service Aircraft for Global Observing System
IASI Interféromètre Atmosphérique de Sondage Infrarouge
IFS Integrated Forecasting System
ISBA Interaction between Soil, Biosphere and Atmosphere
ISFC Indice de Segmentation de la Composante de Fourier
ISIS Algorithme de suivi automatique des systèmes identifiés à partir de l'imagerie infra-rouge de Météosat
Land-SAF LAND Satellite Application Facilities
LCCS Land Cover Classification System
LES Large Eddy Simulation model
LISA LIdar SAtellite
MEDUP MEDiterranean intense events : Uncertainties and Propagation on environment
Megha-Tropiques Satellite franco-indien dédié à l'étude du cycle de l'eau et des échanges d'énergie dans la zone tropicale
MERSEA Marine EnviRonment and Security for the European Area
MESO-NH Modèle à MESO-échelle Non Hydrostatisque
MFWAM Météo-France WAve Model
MHS Microwave Humidity Sounder
MNPCA Microphysique des Nuages et de Physico-Chimie de l'Atmosphère
MOCAGE MOdélisation de la Chimie Atmosphérique de Grande Echelle (modélisation)
MODCOU MODèle hydrologique COUplé surface-souterrain.
MODIS MODerate-resolution Imaging Spectro-radiometer (instrument)
MRR Micro Rain Radars
NAO North Atlantic Oscillation
NEMO Nucleus for European Modelling of Ocean
NSF Norges StandardiseringsForbund
OPIC Objets pour la Prévision Immédiate de la Convection
OSTIA Operational Sea surface Temperature and sea Ice Analysis
OTICE Organisation du Traité d'Interdiction Complète des Essais nucléaires
PALM Projet d'Assimilation par Logiciel Multi-méthodes
PEARP Prévision d'Ensemble ARPège
PNT Prévision Numérique du Temps
POD PrObabilité de Détection
POI Période d'Observation Intensive
Prev'Air Plateforme nationale de la qualité de l'air
Prévi-Prob Projet sur les Prévisions Pobabilistes
PSI Pollutant Standard Index
RADOME Réseau d'Acquisition de Données d'Observations Météorologiques Etendu
ROC Relative Operating Characteristic curve
SAFRAN Système d'Analyse Fournissant des Renseignements Atmosphériques à la Neige
SESAR Single European Sky ATM Research
SEVIRI Spinning Enhanced Visible and Infra-Red Imager
SFRI Système Français de Recherche et d'Innovation
SIM SAFRAN ISBA MODCOU
SIRTA Site Instrumental de Recherche par Télédétection Atmosphérique
SMOSMANIA Soil Moisture Observing System – Meteorological Automatic Network Integrated Application
SMT Système Mondial de Télécommunications
SOERE/GLACIOCLIM Système d'Observation et d'Expérimentation sur le long terme pour la Recherche en Environnement : "Les GLACIers, un Observatoire du CLIMat".
SOP Special Observing Period
SSMIS Special Sensor Microwave Imager/Sounder
SURFEX SURFace EXternalisée
SVP Surface Velocity Program
SWIM Surface Wave Investigation and Monitoring
TEB Town Energy Budget
TRIP Total Runoff Integrating Pathways
TSM Températures de Surface de la Mer
UHF Ultra-Haute Fréquence
UNIBAS Modèle de précipitations
VARPACK Current tool for diagnostic analysis in Meteo-France
VHF Very High Frequency

CNRM: Management structure

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SAFIRE: French group of Aircraft Equipped for Environmental Research

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