Technical Report on the Global Data Processing and Forecast System

Météo-France 2006 status

1. SUMMARY OF HIGHLIGHTS

- Improvements to model physics (more sophisticated IR radiation, boundary layer mixing, prognostic treatment of cloud and precipitation processes)
- Algorithmic improvements to the ALADIN assimilation system
- Higher model top and change of vertical resolution from 41 to 46 levels
- Improved use of some existing observing systems (AIRS, Modis winds, Meteosat radiances, SSM/I)
- New scheduling for 00UTC short cut-off production
- ALADIN-Réunion LAM model with a 3DVAR assimilation

2. EQUIPMENT IN USE AT THE CENTRE

- Information commutators on GTS are the TRANSMET computers (2 Dell PowerEdge6850, operating with Linux RHEL AS 4 and RDBMS Postgres).
- the management of the forecasting system (control of the data in input of NWP models, post processing, production of charts with the NWP output) is made on a HP RP4440 computer running Oracle RDBMS, US-Navy originating NEONS meteorological data management system, and PV-WAVE graphical software; one HP K580 is used as file server, one HP D370 workstation is devoted to the system monitoring, which is based on DCE. The whole system (production machine + file server + monitoring workstation), called DIAPASON, is doubled for backup.
- NWP operational models are running on a FUJITSU VPP5000 (31 processors, 21 with 8 Gbytes memory each, the others with 4Gbytes memory each)
- Dissemination of forecast and observation products (from GTS included), in particular to the French weather stations, is made through satellite communication (RETIM2000 system).

3. DATA AND PRODUCTS FROM GTS IN USE

Average number of messages, by day:

AIREP	ACARS	AMDAR	BATHY	BUOY	PILOT	SATEM	SATOB	SHIP	SYNOP	TEMP	TEMPSHIP
4300	160000	30000	40	35000	1700	32000	450000	8600	56000	1300	17
HIRS	AMSU-A	AMSU-B	Sea wind	ERS URA	ERS UWA	ERS UWI	PROFILER-US	PROFILER-EU	GEO RAD	GEO WIND	SSMI
62000	49000	152000	26000	250	250	350	700	2000	9000	10000	46000

GRID from EXETER : 2876
GRID from WASHINGTON : 525
GRIB aero 1.25 from EXETER : 18816
GRIB 2.5 from EXETER : 9552
GRIB ECMWF : 1776
Fac-simile products:
- aeronautical charts from Exeter 476 and ECMWF 110 (T4 code)

4. FORECAST SYSTEM

The operational forecast system at Météo-France is based on several configurations of one single code, ARPEGE/IFS, which uses extra software to run the limited area model ALADIN.
The ARPEGE/IFS library has been developed jointly by Météo-France and ECMWF. ARPEGE is its usual name in Toulouse and IFS the one used in Reading):

IFS (Integrated Forecast System) is the ECMWF global model for medium range forecasts (4-7 days)

ARPEGE (Action de Recherche Petite Echelle Grande Echelle) is the Météo-France variable mesh global model run in Toulouse for short range predictions (1-4 days)

The ALADIN library has been developed jointly by Météo-France and the national meteorological or hydro meteorological services of the following countries: Algeria, Austria, Belgium, Bulgaria, Croatia, Czech Republic, Hungary, Moldova, Morocco, Poland, Portugal, Romania, Slovakia, Slovenia, Tunisia.

4.1. System run Schedule

The operational forecast system at Météo-France is based on ARPEGE and ALADIN, using the following rules :
. an assimilation (long cut-off) analysis is performed before each short cut-off analysis.
. the product's availability is :
initialised analysis (P0) cut-off+30'
ARPEGE forecast 10' every 24H range
ALADIN-France ARPEGE+10'
Stretched configuration

HH	0000 UTC		0600 UTC	1200 UTC	1800 UTC
long cut-off	0810 UTC		1250 UTC	2010 UTC	0050 UTC
short cut-off	1H10	2H10	3H	1H50	3H
ARPEGE range	54H	102H	72H	84H	60H
end of ARPEGE	0150 UTC	0340 UTC	1010 UTC	1500 UTC	2210 UTC
ALADIN range	54H	54H	48H	42H	36H

4.2. Medium range (4-10 days) forecast system

As mentioned above, it is the operational T511 IFS model of ECMWF and T255 Ensemble Prediction System for 4-5day and 6-7day forecast bulletins.

4.3. Short range forecast system

4.3.1. <u>The ARPEGE forecast model (0-102 hours)</u>

ARPEGE/IFS is a common Météo-France / ECMWF development as explained above. It is a tunable system based on a global spectral model that can be used for several applications: data assimilation, short-range prediction, medium-range prediction, climate research, and predictability studies.

Its ARPEGE-France configuration uses Schmidt's transformation to define a geographically variable resolution, with maximum resolution over mainland France, a minimum resolution near New Zealand, and a smoothly varying resolution in between (Courtier and Geleyn 1988). T being the nominal truncation and C the "stretching factor", the local truncation of the model is T x C over the pole, and T / C at the antipode.

The present horizontal discretisation is T358 C2.4 having its grid pole in France (46.5N, 2.6E), leading to a horizontal resolution of the colocation grid of 23 km over France and 133km over New Zealand. The collocation grid (358x720 points) is Gaussian linear, with a local mesh size equivalent to the resolution implied by the local spectral truncation.

The vertical discretisation is a hybrid mass-based coordinate with 46 levels, following Simmons and Burridge (1981) with an increased resolution in the low atmosphere. The first level is at 5 Pa, and the lowest one at 17m above the ground.

4.3.2. <u>Assimilation, objective analysis and initialization</u>

The assimilation runs with a 6 hour cycle. The objective analysis is performed with a multi-incremental 4D variational scheme: i.e. the departure obs-guess is computed at full resolution (T358C2.4) whereas the analyzed structures are produced at a lower resolution, in 2 loops T107C1, T149C1. It is therefore assumed that the small scales (not corrected by the analysis) are forced by the (analyzed) large scales in the subsequent forecast.

assimilated data: SYNOP, SHIP, BUOY, BATHY, TEMP, TEMPSHIP and PILOT (part A, B, C and D), profilers, AIREP, AMDAR, ACARS, SATOB, AMSU-A, B and HIRS (from NOAA and Aqua satellites), Quikscat ambiguous winds, MODIS winds (Aqua and Terra satellites), SSM/I (DMSP), AIRS (Aqua), European GPS zenithal total delays, with observation time in [H-3h,H+3h]
assimilation cycle: 6 hour cycle.
analysis method: Multivariate four dimensional variational analysis
analysed variables: Wind, temperature and specific humidity on model levels, plus surface pressure.
first guess: A 6-hour forecast of ARPEGE in normal operations
cover: Global cover.
horizontal resolution: T149 linear grid increments on a T358C2.4 background
vertical resolution: as in the ARPEGE forecast model, see above

initialization: weak DFI constraint in the variational cost function and incremental digital filter initialization (ie filtering analysis increments fields) using a Dolph-Chebishev filter with a stop-band edge period of 5h .
surface: analysis of superficial and mean soil temperature (resp moisture) from forecast errors on 2m temperature (resp. relative humidity)relaxation towards climatology for snow and mean soil temperature and moisture initialization of Sea Surface Temperature and ice concentration using NOAA data

Model
basis equations: Primitive equations system
independent variables: horizontal wind vector, temperature, specific humidity and surface pressure.
dependent variables: Vertical velocity and density
numerical technique: Spectral two-time-level semi-lagrangian model and temporal discretization using semi-implicit scheme
integration domain: global
orography, gravity wave drag: The orography of this model is computed on the ARPEGE forecast model collocation grid from the GTOPT030 database using a variational technique that strongly reduces the noise associated to Gibbs waves (see Bouteloup, 1995). The gravity wave drag takes in account subgrid anisotropy, blocking and mid-tropospheric effects.
horizontal diffusion: Implicit in spectral space and incorporating an orography dependent correction for temperature
vertical diffusion: Scheme linked to PBL (see next point)
planetary boundary layer: ECMWF method (Louis et al. 1981) with several enhancements in the stable case
resolution, time step: As in the ARPEGE forecast model, see above. The time step is 16 minutes.
Earth surface: An improved version of the ISBA (Interaction Soil Biosphere Atmosphere) scheme is used, including an explicit parameterization of soil freezing. Six prognostic variables are handled by ISBA: surface temperature, mean soil temperature, interception water content (water on the leaves), superficial soil water content (first centimeter), total liquid soil water content, total frozen soil water content. A very simple parameterization of snow cover is added with albedo ageing. Soil characteristics (texture, depth) are point-dependent. Vegetation characteristics are point- and month-dependent.
radiation: A version of the 2-band Fouquart-Morcrette radiation scheme in the visible wavelengths, the 16-band RRTM scheme in the infrared.
subgrid convection: Mass-flux scheme (Bougeault 1985) enhanced with

i. the Gregory-Kershaw treatment of momentum transport by cumulus,
ii. a treatment of the moist adiabatic computation consistent with "i",
iii. a downdraft parameterisation,
iv. Vertically variable entrainment and detrainment rates,
v. a parameterisation of the selective effect of entrainment leading to a warmer upper part of the single cloud ascent.

explicit microphysics: Prognostic scheme derived from Lopez (2002), handling evolution and 3D advection of water vapor, cloud liquid water and ice, precipitating rain and snow. The cloud cover is diagnosed according to Xu and Randall (1996).

4.3.3. PEARP ensemble forecasting system (0-60 hours)

An ensemble prediction system is running operationally at Météo-France once a day (at 18UTC) since June 2004 (Nicolau, 2002). The perturbations used in the ensemble are generated by the singular vectors method. Singular vectors are optimized at 12h with a low resolution (TL95) over a limited area including the Western Europe and the northern part of the Atlantic Ocean. By this way, perturbations are efficient in area of interest. Because of heavy computational cost, the ensemble is limited to 11 members (10 perturbed + 1 control) but uses the operational version of the ARPEGE model with a spectral truncation of TL358 with a stretching coefficient of 2.4. Different products (Stamps, plumes, probabilistic charts) are provided to the forecasters.

4.3.4. ALADIN (0-54hours)

ALADIN is a limited area version of ARPEGE-IFS, to which it is identicial except for the horizontal discretisation (spectral biFourier on a doubly periodic rectangle, mapped to the sphere by a conformal Lambert transform) and the lateral boundary coupling to ARPEGE every 3 hours.

ALADIN has its own data assimilation, based on 3DVAR. Data used are the same as ARPEGE, plus SEVIRI radiances processed by CMS/Lannion, and SYNOP observations of 2-metre

temperature and humidity. The use of additional humidity data improves convective precipitation forecasts in accordance with Ducrocq et al (2002). The SEVIRI radiances are used as 5 clear-sky channels, with an air mass-dependent bias correction The ALADIN surface prognostic variables are reset to the interpolated ARPEGE surface analysis every 6 hours.
The operational version is semi-lagrangian (time step 7min), with a 300x300 collocation grid the on Lambert projection domain (54°95N/33°66N,-11°18W/19°64E), leading to an equivalent finite difference resolution of roughly 9km.

The vertical resolution is the same as in the operational ARPEGE model described above. The digital filter initialization uses a Dolph-Chebyshev filter with a stop-band edge period of 3h and a backward-forward scheme.

4.3.5. <u>NWP Products</u>

The above-described numerical models feed a analysis and forecast database, with the following characteristics:
different horizontal domains for different horizontal resolution (from the global domain with a 2.5° and 1.5° mesh to the "France" domain with a 0.1° mesh)
vertical levels are the standard pressure levels
independence, from the creating model, of the format of the database products.

The meteorological fields stored in this database are:
- at all levels: geopotential, temperature, humidity, wind (including vertical velocity)
- at screen level: pressure, temperature, humidity, heat and radiation fluxes, snow and water content
- at sea surface level: reduced pressure
- some data at particular levels: 500 hPa absolute vorticity, high medium and low cloudness, iso 0° and iso -10°, tropopause, 3D cloud fields, etc...

ARPEGE produces boundary conditions for the ALADIN applications run in Austria, Bulgaria, Croatia, Czech Republic, Hungary, Morocco, Poland, Portugal, Romania, Slovakia, Slovenia, Tunisia, while ALADIN-France provides boundary conditions for ALADIN-Belgium.

4.3.6. <u>Operational use of NWP products</u>

Mainly on screen (especially SYNERGIE workstation and PC software) or on paper, hundreds of charts...

4.4. Specialized forecasts

4.4.1. <u>Tropical cyclones forecast model</u>

A specific version of ARPEGE, called ARPEGE-Tropiques, has been implemented for more detailed forecasts over tropical areas, and sent to the SYNERGIE software in French oversea regional centers.
The ARPEGE-Tropiques model is the same as the metropolitan one, but with a uniform truncature T358L41 for the forecast (time step 1350s) , and T107C1L41 for the 4DVAR analysis.
Sea surface pressure bogus data , produced by forecasters in La Réunion center are incorporated in the assimilation to get a more precise location of cyclones. These bogus data are transmitted on the GTS in BUFR.
The models are run twice a day based on 00UTC and 12UTC, up to 72 h , with a 3.50 hour cut-off.
A regional model ALADIN-Réunion has been added to operational suite, coupled with ARPEGE Tropiques, with its own data assimilation.

Uniform configuration

HH	0000 UTC	0600 UTC	1200 UTC	1800 UTC
long cut-off	1010 UTC	1515 UTC	2330 UTC	0340 UTC
short cut-off	3H50		3H50	
ARPEGE range	72H		72H	
end of ARPEGE	0550 UTC		1730 UTC	
ALADIN range	54H		54H	

4.4.2. <u>Local weather elements</u>

Millions of local forecasts of weather parameters are produced daily through statistical adaptation of NWP output. Main methods are multiple linear regression (MLR) and discriminant analysis (DA). MOS (model output statistics) is preferred to PP (perfect prognosis), but a pseudo-PP (equations computed over the first 24h then applied to the other steps) method is used to ensemble systems. Kalman filter (KF) is applied when relevant. Ensemble distributions are calibrated before computing probabilities.

Two new models (and their LAM version) are now produced:

CTPINI (LAM version: ALADIN-CTPINI): a model ran by the forecaster with an initial state slightly modified by the potential vorticity inversion method.

PACOURT (LAM version: PLAD0): a model based on a 3DVAR-FGAT data assimilation process in order to provide a quick outlook to the forecaster.

Model	Domain	Parameter	Nb of sites	Basis	From	To	By	Type
ARPEGE CTPini PAcourt	France	2m Temperature+ daily extremes	2588	00, 06, 12, 18	+3	+96,+72, +84, +60	3h	MLR+KF
		2m Humidity + daily extremes	1038	00, 06, 12, 18	+3	+96,+42, +72, +30	3h	MLR+KF
		Dew point temperature	982	00, 06, 12, 18	+3	+96,+42, +72, +30	3h	MLR
		Total Cloud Cover	139	00, 12	+3	+96, +72	3h	MLR+KF
		Total Cloud Cover (categories 0, 0-2, 1-2, 3-4, 3-5, 5-6, 5-7, 6-8, 7-8, 8)	150	00, 06, 12, 18	+3	+96,+42, +72, +30	3h	DA
		10m Wind speed	731	00, 06, 12, 18	+3	+96,+42, +72, +30	3h	MLR+KF
		10m Wind direction	713	00, 06, 12, 18	+3	+96,+42, +72, +30	3h	MLR+KF
		Visibility, probabilities (thresholds 800, 1000, 1500, 3000 and 5000m)	16	12		+18		DA
		Wind gusts, probabilities (thresholds 28 to 78kt by 5kt)	648	00, 06, 12, 18	+3	+96,+42, +72, +30	3h	DA
ALADIN AL-CTPini AL-court	France	10m Wind speed	719	00, 06, 12, 18	+3	+48,+42, +36, +30	3h	MLR
		10m Wind direction	713	00, 06, 12, 18	+3	+48,+42, +36, +30	3h	MLR
PEARP	France	2m Temperature+ daily extremes, individual runs	1206	18	+3	+60	3h	MLR (Pseudo-PP) to Ind. Memb., KF to Ens. Mean
		10m Wind speed, individual runs	586	18	+3	+60	3h	MLR to Ind. Memb., (Pseudo-PP)Calibration (Rank diagrams)
		24h precipitations, individual runs	1150	18	+30	+54	24h	Calibration (Rank diagrams)
IFS	World	2m Temperature+ daily extremes	6010	00, 12	+6	+180	3h	MLR+KF

	France	2m Temperature+ daily extremes	2588	00, 12	+12	+180	3h	MLR+KF
		2m Humidity + daily extremes	1156	00, 12	+12	+180	3h	MLR+KF
		Total Cloud Cover (categories 0, 0-2, 1-2, 3-4, 3-5, 5-6, 5-7, 6-8, 7-8, 8)	150	00, 12	+12	+180	3h	DA
		10m Wind speed	811	00, 12	+12	+180	3h	RLM
		10m Wind direction	788	00, 12	+12	+180	3h	RLM
EPS	World	2m Temperature+ daily extremes, individual runs	3338	00, 12	+6	+360	3h	MLR (Pseudo-PP) to Ind. Memb.
	France	2m Temperature+ daily extremes, individual runs	1206	00, 12	+6	+360	3h	MLR Pseudo-PP) to Ind. Memb., KF to Ens. Mean
		10m Wind speed, individual runs and probabilities	586	00, 12	+12	+240	6	MLR Pseudo-PP) to Ind. Memb. Calibration (Rank diagrams)

4.4.3. Marine forecasts

Wave hindcast and forecasting system

Five models run operationally in France for determining the sea conditions:

A global wave model , computing the waves over all the oceans up to 102 hour forecast, from the wind outputs of large scale fields derived from the global atmospheric models ARPEGE

Type:	coupled discrete deep water
Integration domain:	Global
Grid:	regular grid; resolution: 1°
Frequency resolution:	12 frequency components, logarithmically spaced from 0.04 Hz to 0.3 Hz
Direction resolution:	18 equally-spaced direction components
Integration scheme:	time step = 900s
Boundary forcing:	winds at 10m level from ARPEGE, updated every 6 hours
Surface classification:	sea ice deduced from ARPEGE SST
Assimilation:	4 analyses/day using significant wave heights from Jason and Envisat altimeters

Another global wave model , computing the waves over all the oceans up to 72 hour forecast, from the wind outputs of large scale fields derived from the global atmospheric models ARPEGE/TROPIQUE

Type:	coupled discrete deep water
Integration domain:	Global
Grid:	regular grid; resolution: 1°
Frequency resolution:	12 frequency components, logarithmically spaced from 0.04 Hz to 0.3 Hz
Direction resolution:	18 equally-spaced direction components
Integration scheme:	time step = 900s
Boundary forcing:	winds at 10m level from ARPEGE/TROPIQUE, updated every 6 hours
Surface classification:	sea ice deduced from ARPEGE SST
Assimilation:	4 analyses/day using significant wave heights from Jason and Envisat altimeters

A regional model, forecasting the waves up to 54 hours with 3 hour step, over the European Seas (Atlantic, Mediterrean , Baltic, North Sea, Black sea, ...) , from the wind outputs of small scale fields derived from ARPEGE.

Type:	Coupled discrete shallow water
Domain:	European Seas : 67N-30N-12W-42E
Grid:	regular grid; resolution: 0°25
Frequency resolution:	12 frequency components, logarithmically spaced from 0.04 Hz to 0.3 Hz
Direction resolution:	18 equally-spaced direction components
Timestep:	300s
Boundary forcing:	winds at 10m level from ARPEGE, updated every 3 hours.

A coastal model, forecasting the waves up to 54 hours with 3 hour step, over the French continental shelf, from the wind outputs of small scale fields derived from ALADIN.

Type:	Coupled discrete shallow water
Domain:	French Seas (Metropolitan France only): 57N-35N-11W-17E
Grid:	regular grid; resolution: 0°1
Frequency resolution:	12 frequency components, logarithmically spaced from 0.04 Hz to 0.3 Hz
Direction resolution:	18 equally-spaced direction components
Timestep:	150s
Boundary forcing:	winds at 10m level from ALADIN, updated every 3 hours.

A Carabbean model, forecasting the waves up to 72 hours with 6 hour step, over Carrabean sea, nested in the global VAG/TROPIQUE model, from the wind outputs of ARPEGE TROPIQUES.

Type:	Coupled discrete shallow water
Domain:	French Seas (Metropolitan France only): 20N-8N-71W-58E
Grid:	regular grid; resolution: 0°1
Frequency resolution:	12 frequency components, logarithmically spaced from 0.04 Hz to 0.3 Hz
Direction resolution:	18 equally-spaced direction components
Timestep:	150s
Boundary forcing:	winds at 10m level from ARPEGE/TROPIQUES, updated every 6 hours.

These models are available on 00UTC, 06UTC, 12UTC and 18UTC runs, except for VAG/TROPIQUE and VAG/Carrabean, available only on 00UTC and 12UTC.

Operational simulations of the oceanic circulation in tropical Atlantic

The oceanic primitive equation model OPA7, developed by CNRS/LODYC, has been run operationally every month, using all the surface fluxes produced by the operational ARPEGE model. Its main characteristics are 17 horizontal levels in z coordinate with a realistic bathymetry, and a 1/3 degree horizontal resolution. Systematics comparisons have been performed with bathythermic observations sent through the GTS, and against sea surface temperatures from ERS data (ATSR).

Storm surge model

A depth-averaged, numerical storm-surge model has been developed and configured to provide storm-surges forecasts along coastlines of France. Two versions of this model, one for overseas territories to forecast tropical cyclones storm surges and one for metropolitan French coastline.

Overseas domain: Atmospheric fields are inferred from an analytical-empirical cyclone model which require only cyclone position, intensity and size. The model has been operated since 1994 in the French Antilles, 1995 in New Caledonia, 1997 in the French Polynesia and 1998 in La Reunion. The model can be used in two different ways. In real-time mode as a tropical cyclone is approaching an island or in climatological mode: a cyclone climatology is used to prepare a data base of pre-computed surges. Due to the low accuracy of tropical cyclone trajectory forecasts, the second mode seems to be, at present time, the best way to use the model.
The grid mesh is fixed for each domain and varies from 150 m to 1850 m.

Metropolitan domain: Atmospheric fields are taken from atmospheric numerical models: IFS (ECMWF), ARPEGE and ALADIN (Météo-France). The system has been operated since October 1999 for the Channel and Bay of Biscay, March 2002 for the Mediterranean Sea and November

2002 for the North Sea.
48 hours forecast are produced on a 5' grid mesh.

Drift model (oil spills, containers, Search & Rescue)

Météo-France is in charge of spill drift predictions within the spill response plan POLMAR-MER in case of a threat for the French coastline. At an international level, Météo-France can intervene within the Marine Pollution Emergency Response Support System (MPERSS) for the high seas. Météo-France is Area Meteorological Coordinator for METAREA II and III west, and supporting service for METAREA I, III east, VII B and VIII C.
Météo-France developed a drift model named MOTHY (Modèle Océanique de Transport d'HYdrocarbures). MOTHY is an integrated system that includes hydrodynamic coastal ocean modelling (2D+1D) and atmospheric forcing from ARPEGE or IFS models. The hydrodynamic coastal ocean is linked to an oil spill model, where oil slick is considered as a distribution of independent droplets. These droplets move with shear current, turbulent diffusion and buoyancy. The system has been operated since 1994 and can be used for oil spills or drifting objects. New developments, exercises and training are jointly conducted with CEDRE (Centre de documentation de recherche et d'expérimentations sur les pollutions accidentelles des eaux). MOTHY correctly predicted the drift of the oil during Erika (December 1999) and Prestige (2002-2003) in the Bay of Biscay.
The domain is global with a better accuracy on specific areas, including French seas.
Forecasts are produced up to 5 days on fixed grid from 150 m to 9 km.

4.4.4. Pollutant transport and dispersion forecast

At an international level, Meteo-France Toulouse has been designated as a regional specialized meteorological centre (RSMC) with activity specialization on the provision of atmospheric transport model products for environmental emergency response. This provision is related to nuclear accidents, or radiological emergencies, and plumes of volcanic ashes for ICCA. In the framework of the French government emergency plan, Meteo-France is also involved for chemical or nuclear releases. The operational organization of Météo-France, for facing atmospheric pollution accidents, is based on a special crisis meteorological cell (CMC) that studies the evolution of weather/pollution conditions and provides forecasts on the pollutant plume.

Up till now, for the long-range dispersion forecast, Meteo-France Toulouse uses two operational tools to track the plume following an accidental release: an air mass trajectories software, describing the evolution of a neutrally buoyant particle in the wind field forecasted by the NWP, and an eulerian off-line dispersion model, MEDIA, solving an advection-diffusion equation for a passive scalar. A next generation of model is currently evaluated, MOCAGE-Accident. Indeed, Meteo-France has developed a global three-dimensional Chemical Transport Model, MOCAGE, dedicated to the numerical simulation of the interactions between dynamical, physical and chemical processes in the lower stratosphere and in the troposphere (see section 7.4.7). MOCAGE-Accident is used in the specific way of a ponctual emission, with the set of sinks, as dry deposition, scavenging of soluble gases by convective and stratiform rain, and fallout. MOCAGE-Accident participates in the intercomparison exercise ENSEMBLE (http://ensemble.ei.jrc.it/) and operational implementation is planned in 2007.

At local scale, the system PERLE focuses on the local description of the atmospheric pollutant cloud at regional and local scale, in the vicinity of the affected site of radionuclide or chemical release. It is based on a meso-scale non hydrostatic model for meteorological fields, Meso-NH (Lafore et al., 1998), coupled to a lagrangian particle model for the dispersion (currently the SPRAY software developed by Aria Technologies).
Meso-NH uses two nested models for emergency response, with a first domain covering 240km*240km area (8-km resolution) and a second domain covering 60km*60km area (2-km resolution), and two-way interactions between them. The initial and boundary conditions of the larger domain are defined by ALADIN. With advanced physical subgrid parametrizations (turbulence, convection …), Meso-NH is more satisfactory than diagnostic models, based on the principle of conservation of mass, that are commonly used for dispersion modelling. The lagrangian particle formulation allows a description of the pollutant cloud in the vicinity of the release during the first critical few hours, without gaussian assumptions commonly used at this scale.

4.4.5. Snow and avalanches

For several years, applications related to snow and avalanches in Grenoble have used the ensemble of models “SAFRAN / CROCUS /MEPRA”. SAFRAN is an analysis system working at the scale of one mountain system (massif). The system has also been exported to various foreign countries.

Since the end of 2001, this new analysis system has been run operationally. It allows the use of surface observations with a 1hour frequency. It is used in forecast mode over the Alps and the Pyrenees, with precipitation fields from ALADIN/France as input.

4.4.6. Hydrology

The analysis code SAFRAN (Durand et al., 1993) is also used in the hydrological application SIM (Safran-Isba-Modcou) developed by the research branch of Météo-France. The SIM system is made of 3 different components. SAFRAN is used to provide an analysis of the atmospheric forcing based on the various screen-level observations and guesses from the 00UTC, 06UTC,12UTC, 18UTC ARPEGE analysis. The water and energy budgets are computed by the surface scheme ISBA and MODCOU is a distributed hydrological model that computes the evolution of the aquifers and the river flow. The SIM system after being validated over 3 large basins (Rhone, Garonne and Seine) has been extended over France with a fixed grid of 8 km. This large-scale hydrological model is currently operational at Météo-France.
Based on the same framework, another real time application is addressing the problem of road surface temperature. This application called SIR (Safran-Isba Route) is also operational over France. Using atmospheric forcing from ARPEGE forecast, the SAFRAN code provides atmospheric fields to the Isba scheme applied in this case in diffusion mode. The model SIR is available on 00UTC and 06 UTC runs and provides 48 hours forecast of road surface temperature.

4.4.7. Air quality forecast

MOCAGE multi-scale Chemistry and Transport Model was developed at Météo-France for both research and operational applications in the field of environmental modelling (Peuch et al., 1999). MOCAGE is the last of a series of numerical atmospheric chemistry models developed at Météo-France, which has had expertise recognized at the international level since the early eighties. MOCAGE is built on the basis of the REPROBUS CTM (Lefèvre et al., 1994) ; however, at variance REPROBUS, which only accounted for the stratosphere, MOCAGE considers simultaneously the troposphere and stratosphere at the planetary scale. In addition, it is possible within MOCAGE to zoom down to the regional scale over limited-area sub-domains, the model providing its own time-dependent chemical boundary conditions. The computational structure of MOCAGE is flexible and allows to adapt and contribute to a wide range of scientific questions : “chemical weather” forecasts (Dufour et al., 2004), global scale tropospheric chemistry and chemical data assimilation (Cathala et al., 2003) or coupled chemistry-climate scenarios.
Depending upon applications, MOCAGE can run in both on-line, coupled to a general circulation model for climate studies for instance, or off-line modes, forced by archived meteorological analyses or forecasts. The off-line configuration uses Météo-France ARPEGE and ALADIN or ECMWF/IFS operational Numerical Weather Prediction products. The dynamical forcings (hydrostatic winds, temperature, humidity and pressure) feed the advection scheme, as well as the physical and chemical parameterizations ; they are generally available every 3 hours, and are linearly interpolated to yield hourly values, which is the time-step for advection ; smaller time-steps are used for physical processes and chemistry, but the meteorological variables are kept constant over each hour. MOCAGE is based upon a semi-lagrangian advection scheme, using a cubic polynomial interpolation in all three directions. At the expense of a specific mass conservation correction (applied every time-step), the semi-lagrangian formulation allows to treat simultaneously a large number of tracers, typically of the order of one hundred or more. This configuration for advection was already used successfully within REPROBUS, in the context of runs of several years (WMO, 1998).
At Météo-France, MOCAGE has been run daily since 2002 to provide air quality forecasts. During the 2003 August heat wave, it provided 3-day ozone forecasting over Europe showing that ozone peak events overlap a large part of France and of Western Europe. Such pollution events enhanced the mortality due to the heat wave effect by few percents. In 2004, Météo-France has joined the partnership consortium “Prév’Air” in charge of the pollution monitoring for France, lead by the Ministry of Environment. During the same period, MOCAGE also provides UV index forecasting. The forecasting of ultraviolet (UV) radiation at the surface is really the result of forecasts of stratospheric ozone, clouds, aerosols, surface albedo and elevation. From June 2005, MOCAGE has been included in the supervised operational suite at Météo-France to ensure timely delivery of products.

4.5. Long range forecasts (3 months)

A specific version of ARPEGE model , called ARPEGE-Climat is used 9 times a month to run 120 to 129 days forecasts, starting from ECMWF assimilation. The SST forecast is based on an auto regresssive statistical scheme on grid points, which is run once on the first day of the series. The seasonal forecasting system is using mainly the same ARPEGE software as the short range forecast model, except the following points:

resolution, time step: This version of the ARPEGE model has a triangular truncature T63 without stretching. The collocation grid has 128x64 points with a reduction near the poles; it has 31 vertical levels like IFS model during ERA-15 (ECMWF reanalysis). The time step is 1800 seconds.

radiation: Fouquart Morcrette scheme (1995)

clouds, vertical diffusion, stratified precipitations: Ricard Royer statistical scheme (1993).

5. VERIFICATION OF FORECASTS

Scores of the operational ARPEGE model:

Against analyses

	24 hours			72 hours			
	NH	SH	TR		NH	SH	TR
Z500 RMSE	10.2	14.7			29.4	39.7	
W250 RMSEV	4.7	4.9	4.6		10.0	11.0	7.6
W850 RMSEV			2.8				4.3

NH : Northern Hemisphere SH : Southern Hemisphere TR : Tropics

Against observations

24 hours

	NA	EU	AS	AU/NZ	TR	NH	SH
Z500 RMSE	11.5	10.9	14.0	12.6	14.9	12.8	15.8
W250 RMSEV	6.8	5.9	6.4	6.2	5.8	6.3	6.4
W850 RMSEV	4.2	4.4	4.4	4.3	4.5	4.4	5.0

72 hours

	NA	EU	AS	AU/NZ	TR	NH	SH
Z500 RMSE	29.6	26.6	28.8	23.9	17.3	30.7	30.8
W250 RMSEV	11.6	10.4	10.3	9.7	7.8	10.8	10.4
W850 RMSEV	5.9	5.7	6.2	5.7	5.3	6.1	6.3

NA : North America EU : Europe AS : Asia AU/NZ : Australia / New Zealand
NH : Northern Hemisphere SH : Southern Hemisphere TR : Tropics

Recall:
Météo-France draws up a quarterly bulletin of “verification of the numerical products used for meteorological forecasting" (in French) which can be obtained by writing to:

Météo-France
DPrévi/COMPAS
42, av. Coriolis
F-31057 TOULOUSE Cedex 1
FRANCE

6. FUTURE PLANS

6.1. Major changes expected for 2007

- Implementation of the new supercomputer Nec SX8
- Enhanced resolution for global models (see below)
- New observations in data assimilation: Metop radiances and scatterometer winds, Metop and Cosmic GPS radio-occultation data.

6.2. Research activities in NWP

The focus in on parallel enhancement of the ARPEGE/ALADIN models (with an increase in ARPEGE resolution to T538C2.4L60, i.e. 15km resolution over Western Europe), their 4DVar and 3DVar assimilation schemes (including new satellite data such as GPS occultation and IASI radiances, and an upgrade to the 4DVar increment resolution), and the AROME model and data assimilation system (real time experimental coverage of the whole mainland teritory at 2.5km horizontal resolution, 3DVar data assimilation including Doppler radar radial winds). Complementary activities are diverse and include upgrades to the physical parametrisations (shallow convection, boundary layer turbulence, surface model, subgrid deep convection), to the data assimilation algorithms (ensemble data assimilation, flow-dependent structure functions, improved humidity analysis), to the data usage (microwave radiances over land, use of radar reflectivities, cloudy IR radiances, etc.), to ensemble forecasting, and studies on synoptic storm dynamics, observing systems, assimilation of meteorological objects, numerical nowcasting.

6.2.1. Development of the ARPEGE and ALADIN operational systems

The basic design of the ARPEGE system will be kept unchanged, although some research and development work is expected in all the scientific areas. After an important retuning of the stretching factor from 3.5 to 2.4, performed in June 2003, the stretching factor is likely to be kept to 2.4 for a few years; the horizontal resolution will be increased (probably to T538 at the end of 2007) after the migration of the system to the NEC computer. Current indications show that one may reach a T800/C2.4 resolution around 2010; the 4D-VAR minimisation could then be performed at T250 (this last figure is the one driving the analysis increment resolution). T800 would mean about 10km resolution over France and 60km at its antipode. For 2007, the resolution changes will be probably a move from 46 to 60 or 70 levels in the vertical. Algorithmic developments in 4D-VAR (minimisation, structure functions) will be made in order to have an assimilation system better adapted to the variable resolution. As the assimilation is currently the more expensive part of the ARPEGE system, for both the main stretched run and the uniform run called “ARPEGE-TROPIQUE”, the two assimilation suites are likely to converge into a single assimilation system. In addition to the algorithmic developments already mentioned, the main research in data assimilation concerns the use of new observing systems. Following the launch of the Metop satellite in October 2006, a lot of assimilation efforts in 2007 will be devoted to the use of its micro-wave and HIRS instruments, as well as the use of the new instruments (IASI, GRAS producing GPS data). The work on the assimilation of all GPS data (including COSMIC) will continue. The research and development work goes on also to prepare the launch of ADM-AEOLUS now planned in 2009.

With respect to the ARPEGE physical parameterizations, improvements are expected on processes like the ones treating the clouds and hydrometeors (with the new variables introduced in 2006), also with the introduction of a TKE (Turbulent Kinetic Energy), the orography effects and the surface processes (which will appear in a modular form, external to the rest of the code).

The ARPEGE ensemble prediction system (called PEARP) has not received any development of its own during the last 2 or 3 years, except the developments of the deterministic model which were systematically imported to the PEARP. In 2007, an important evolution of the performance of the system (as ensemble) will start. Then the system will probably move towards an ensemble where the scatter is higher and not limited to Europe.

The ALADIN/France model has been upgraded to 46 levels (following ARPEGE) in 2006. In the near future it will follow ARPEGE to 60 or 70 levels and for most of the parameterisation schemes. No horizontal resolution change is planned for ALADIN/France. The ALADIN/France 3D-VAR (which went into operations in July 2005) will be improved and retuned on several aspects, especially the use of high resolution observations over France. This task is also an important step for the preparation of the AROME assimilation which will be operational in 2008.

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6.2.2. Development of the mesoscale system AROME

The first and main aim of the AROME project is to have an operational NWP model over France which will be run at a horizontal resolution of 2.5 km, which is about 4 times better than the current ALADIN/France. Such a mesoscale system will be based on three major components:

- a non-hydrostatic (NH) dynamical core based on the NH version already existing in the ALADIN software;
- a physical package which is to a large extent imported from the research NH model of Météo-France called Meso-NH;
- a 3D-VAR data assimilation system which is very similar to the one operational in ALADIN/France, adapted to the kilometric horizontal resolution, and to the observations which are relevant for this type of scale.

AROME is not intended to be only an operational model, it will be also a research tool (used inside and outside Météo-France). This implies some specific research activities which may or may not lead to an operational use in forecasting mode. An example is the development of an AROME module of atmospheric chemistry (air quality); another one is the modelling of the upper ocean boundary layer, which may be important when the weather is driven by strong precipitation coming from the seas around France.

2007 will be dedicated to:

- running an AROME prototype on the NEC computer, with an area covering France;
- testing, tuning and validating the system, especially the physical parameterizations which are relevant for accurate forecasts of meteorological events such as fog, thunderstorms, precipitation, wind-gusts;
- implementing the AROME data assimilation on the same area, together with the use of new high resolution observing systems.

6.2.3. Other related activities

Climate versions of ARPEGE and ALADIN are also used in Météo-France for climate studies and seasonal forecasting. Then, several developments in the area of physical parameterizations are actually beneficial both for NWP and climate studies.

The code collaboration with ECMWF on the ARPEGE/IFS system will continue; it is particularly important for developing the software and the observation operators which will be needed for assimilating the ADM-AEOLUS winds in 2009. This specific observing system is treated through a special project between ESA, ECMWF and Meteo-France.

ALADIN/France is only one operational model among 12 or 15 different others run in different European and African countries, on different areas. In the context of this wide international collaboration, the “ALARO” project has been launched in order to provide an improved version of ALADIN, with computing requirements which are not as big as the AROME requirements. ALARO will then “smooth out’ to some extent the “sudden transition” between ALADIN and AROME. ALARO will have a physical parameterization package which will be improved with respect to the current ARPEGE and ALADIN physics; it will be also more flexible and adapted to horizontal resolutions between the “AROME 2km” and the “ALADIN 10km”.

By choosing for the future a non-hydrostatic dynamical core identical to ALADIN-NH and to AROME, the HIRLAM consortium has got its developments closer to the ALADIN ones. A code collaboration has then been initiated (agreement signed in 2005) and is getting stronger also in the areas of data assimilation and physical parameterizations.

Developments in hydrology modelling, snow modelling and soil modelling will be pursued, especially in the context of the so-called EUMETSAT SAF (Satellite Application Facilities); the interactions of hydrology and land surfaces with NWP becomes more and more important when atmospheric models are progressing and their resolution is increasing. In the same way NWP models will become more and more sensitive to accurate ocean products (Meteo-France leads the ocean SAF). The links between the weather models and the atmospheric chemistry models will also become more and more important. In relation with the European “GEMS” project, research and developments will be carried out in Meteo-France on the assimilation of chemical species in the atmosphere, and on the proper interfaces between chemical assimilations on one side, and NWP assimilation on the other side.

2006 was the peak of the AMMA campaign (dedicated to the African Monsoon) where many NWP tools were used over Africa, including the Meteo-France operational ones. The investigation on the African physical processes, and their predictability will go on in 2007 and onwards. Another campaign, focused on the Mediterranean sea (atmospheric, hydrological, oceanographical processes) is in preparation for 2010 or 2011. It will be also an opportunity for testing several NWP aspects closely related to hydrology and oceanography (the main theme of the campaign will be the hydrological cycle).

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