

JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2007

FRANCE/Météo-France

1. Summary of highlights

- Implementation of the new supercomputer Nec SX8 : two 16 nodes machines, 8 processors per node.
- Enhanced resolution for global model
- New observations in data assimilation: Metop radiances and scatterometer winds, Metop and Cosmic GPS radio-occultation data

2. Equipment in use

- 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 Nec SX8 (128 processors, clustered in 16 nodes, with 128Gbytes 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	SHIP	SYNOP	TEMP	TEMP SHIP
4300	160000	40000	30	33000	1700	10000	59000	1300	17
PROFIL ER-US	PROFILER- EU	Sea wind	ERS URA	ERS UWA	ERS UWI	ASCAT	GEO RAD	GEO WIND	WAVEOB
700	2400	26000	250	250	350	28000	9000	7000	2000
HIRS	AMSU-A	AMSU- B/MHS	AIRS	IASI		GPS surf	GPS RO	SSMI	SSMIS
62000	50000	160000	24000	10000		700	1500	46000	45000

- 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. Forecasting 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 (4-15 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 ARPEGE physics and numerics are different from the IFS model.

Météo-France also runs a limited area model system called ALADIN, whose software is an extension of the ARPEGE/IFS library.

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, Morocco, Poland, Portugal, Romania, Slovakia, Slovenia, Tunisia, Turkey.

4.1 System run schedule and forecast ranges

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 forecasting system (4-15 days)

As mentioned above, it is the operational T799 IFS model of ECMWF and T399 Ensemble Prediction System for 4-5day and 6-7day forecast bulletins.

4.3 Short-range forecasting system (0-102 hrs)

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 $T \times C$ over the pole, and T / C at the antipode.

The present horizontal discretisation is T538 C2.4 having its grid pole in France (46.5N, 2.6E), leading to a horizontal resolution of the collocation grid of 15 km over France and 89km over New Zealand. The collocation grid (540x1080 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 60 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.

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

The ARPEGE 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 (T538C2.4) whereas the analyzed structures are produced at a lower resolution, in 2 loops T107C1 (25 iterations), T224C1 (30 iterations). 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, Atmospheric Motion Winds ((GOES 11 and 12, MTSAT 1R, Meteosat 9 and 7), AMSU-A, B and HIRS (from NOAA, Aqua and Metop satellites), scatterometer winds (Seawinds from Quikscat and ASCAT from Metop), MODIS winds (Aqua and Terra satellites), SSM/I (DMSP), AIRS (Aqua), European GPS zenithal total delays, GPS radio occultation data (COSMIC constellation, GRACE, GRAS on Metop), 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: T224 linear grid increments on a T538C2.4 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-Chebyshev 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 Relaxation of Sea Surface Temperature to NCEP SST analysis (1/12 degree grid) and sea-ice mask using SSM/I data (from DMSP F14).

4.3.1.2 Research performed in this field

The research in data assimilation is on extending the amount of assimilated data, mostly through the use of new satellite instruments such as MetOp and ADM/Aeolus; improving the observation treatment, notably through better modelling of IR radiances over clouds and microwave emissivities over land; improving surface analyses; and improving the data assimilation algorithms, with current focus on improving models of background error covariances, and sampling flow dependent analysis and forecast errors through the deployment of an ensemble data assimilation system. There is additional research on targeting observations and observing system experiments.

4.3.2 Model

4.3.2.1 In operation

basis equations: Primitive equations system

independent variables: horizontal wind vector, temperature, specific humidity and surface pressure, cloud water and ice, precipitating water and ice.

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: from 15 to 89 km, 900s time step.

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).

4.3.2.2 Research performed in this field

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Modelling research is on improving the model dynamical core through new discretisation options and tests of non-hydrostatic effects; and improving the model physical parametrisations (new convection scheme with better accounting of transport and microphysics; vertical diffusion scheme with prognostic turbulent kinetic energy incorporating a thermal-based shallow convection scheme; new tiling surface scheme with detailed physiography, representation of various ecosystems, towns, lakes, ocean fluxes etc). There is additional experiments in specific projects e.g. CLOUDNET, MAP-DPHASE, model validation with satellites and mast measurements.

4.3.3 Operationally available NWP products

The above-described numerical models feed an 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.

4.3.4 Operational techniques for application of NWP products

4.3.4.1 In operation

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)

4.3.4.2 Research performed in this field
[Summary of research and development efforts in the area]

4.3.5 Ensemble Prediction System

1. In operation

PEARP ensemble forecasting system (0-60 hours)

An ensemble prediction system has been run operationally at Météo-France once a day (at 18UTC) since June 2004 (Nicolau, 2002) and upgraded in January 2008 (Descamps and Labadie). The perturbations used in the ensemble are generated by the singular vectors method and bred modes from the previous PEARP run. Singular vectors are optimized at 12h with a low resolution over various areas including both hemispheres, the tropics, and an emphasis on the Western European area. 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 and 55 levels. Different products (Stamps, plumes, probabilistic charts) are provided to the forecasters.

4.3.5.2 Research performed in this field

Research is focusing on the optimisation of the ensemble size, resolution and perturbation method, including modifications to the singular method and better accounting for analysis error through bred modes and interaction with an assimilation ensemble method.

4.3.5.3 Operationally available EPS Products

Different products (Stamps, plumes, probabilistic charts) are provided to the forecasters.

4.3.6 Short-range Forecasting Systems (0-54 hrs)

ALADIN (0-54hours)

ALADIN is a limited area version of ARPEGE-IFS, to which it is identical 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. Several ALADIN systems run on various domains, among which ALADIN-France, ALADIN-Réunion (for tropical cyclone prediction on the Southwestern Indian Ocean) and others for assistance and defence tasks.

ALADIN-France 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 and 10-metre wind. 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 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 an incremental technique.

4.4 Nowcasting and Very Short-range Forecasting Systems (0-6 hrs)

4.4.1 Nowcasting system

4.4.1.1 In operation

Regarding observation, the 24-radars network is nearly fully dopplerized and equipped with a triple-PRF scheme; it provides VAD profiles on each Doppler radar; 5 dual polarization radars are installed; a cloud-to-ground lightning detection network based on Impact technology is in use, and the core ground observation network includes nearly 600 hundreds automated stations (measuring T, U, dd, ff)

On forecaster's workstations, state-of-the art functionalities and data acquisition allows to display and easily superimpose various data sources, both conventional and remotely-sensed data which refresh rate is basically 5 minutes.

Radar image extrapolation is operated both centrally and on forecaster's workstations, using the "2PiR" algorithm. Rain patterns move is diagnosed centrally every 5 minutes, and move fields are distributed to the workstations for interactive use, both for displaying rain trajectories and computing extrapolated images. A central extrapolation of the national radar composite has been put in operations in 2008, which is presently used for providing (on a part of French mainland territory) a commercial service announcing rain start up to one hour ahead, at the spatial scale of each French city/district.

Two object-oriented diagnostics for convective clouds/cells are run centrally and provided to the forecasters : the so-called Rapid Developing Thunderstorm product, developed in the context of Eumetsat's Satellite Application Facility for Nowcasting (SAF-NWC), tracks clouds, identifies those which are convective, and provides some descriptive attributes for their dynamics; it is run both over western Europe and tropical Africa; the CONO (Convection Nowcasting Objects) performs a similar task on radar images for describing convective cells from high reflectivity patterns. Both products also incorporates cloud-to-ground lightning data.

Three other products of the SAF-NWC are also operated, namely the Cloud Mask, Cloud Type, and "Cloud Top Temperature and Height" products

An optimal interpolation mesoscale analysis scheme, DiagPack, is operated hourly on a 10km grid; it does analyse surface parameters for providing 3D analyses and diagnostic parameters such as the CAPE.

A fog nowcasting system is operated for Roissy airport. It makes use of the 1D detailed physics COBEL model and of radiometric and mast measurements; its extension to Orly and Saint-Exupéry airports is underway

4.4.1.2 Research performed in this field

The SIGOONS system (Significant Weather Object Oriented Nowcasting system) is approaching the mature stage for thunderstorm nowcasting end-user products: based on the CONO objects (see above), it allows for issuing automated warnings (and amendments) through SMS (Short Message Service) and mail, and providing graphical product on the Web and on mobile phones; for the time being the products are purely automated and forecast horizon is limited to one hour; the development is going on regarding the addition of forecaster's expertise at the scale of organized convective systems, for lengthening this horizon up to 3 hours (in a less deterministic formulation)

Provision of thunderstorm nowcast to the aircrafts and ATC in an object-oriented way is being developed, including in the frame of the EU FLYSAFE project.

Fine scale 3D retrieval of 3D wind is under development, based on multiple Doppler data and the analytical MUSCAT method; its resolutions are 2km in the horizontal, 500m in the vertical and 15 minutes.

Precipitation typing using dual-polarization data is under tuning.

The Cloud Type product of the SAF-NWC is being improved for twilight conditions and for convective cloud identification. The RDT product is also being improved for this latter aspect (with more focus on medium to high top clouds) and for operations on other geostationary satellites.

A VarPack meso-scale analysis scheme has been derived from the variational analysis of the Arpege/Aladin/IFS suite, and tune in order to replace toward end 2008 the OI DiagPack scheme currently in operations

4.4.2 Models for Very Short-range Forecasting Systems

4.4.2.1 In operation

[information on models in operational use, as appropriate related to 4.4]

4.4.2.2 Research performed in this field

[Summary of research and development efforts in the area]

4.5 Specialized numerical predictions

[Specialized NP on sea waves, sea ice, tropical cyclones, pollution transport and dispersion, solar ultraviolet (UV) radiation and air quality forecasting etc.]

4.5.1 Assimilation of specific data, analysis and initialization (where applicable)

4.5.1.1 In operation

[information on the major data processing steps, where applicable]

4.5.1.2 Research performed in this field

[Summary of research and development efforts in the area]

4.5.2 Specific Models

4.5.2.1 In operation

Tropical cyclones forecast model

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 centres.

The ARPEGE-Tropiques model is the same as the metropolitan one, but with a uniform truncature T358L41 for the forecast (time step 1350s) . Sea surface pressure bogus data , produced by forecasters in La Réunion centre 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 France, 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	

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 Caribbean model, forecasting the waves up to 72 hours with 6 hour step, over Caribbean 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. VAG/GLOBAL VAG/REGIONAL and VAG/COASTAL are run with a long-cut-off and short cut-off

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.

Pollutant transport and dispersion forecast

At an international level, Météo-France Toulouse is a Regional Specialized Meteorological Center for the WMO and the International Atomic Energy Agency (IAEA) ; it has also the responsibility of Volcanic Ash Advisory Centre for the International Civil Aviation Organization (ICAO). In this context, it provides atmospheric transport model products for operational environmental emergency response related to nuclear accidents or radiological emergencies, and forecasts of plumes of volcanic ashes. In the framework of the French government emergency plan, Météo-France is also involved in case of chemical or nuclear releases. The

organization of Météo-France is based on a special crisis operations centre that studies the evolution of weather/pollution conditions and provides forecasts on the pollutant plume.

Until now, for the long-range dispersion forecast, Météo-France Toulouse uses two operational tools to assess impacts in case of an accidental release:

- an air mass trajectories software, describing the evolution of a neutrally buoyant particle in the wind field forecasted by the NWP (ARPEGE),
- an eulerian off-line dispersion model, MEDIA, solving an advection-diffusion equation for a passive scalar. MEDIA uses ARPEGE forecasts as meteorological forcing.

A next generation of model is currently implemented for operations, MOCAGE-Accident. Indeed, Météo-France has developed the 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 on air quality forecast). MOCAGE-Accident is a specific configuration which takes into account point sources and relevant sink processes: 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/>). The operational use is planned in 2008. In its backward version, MOCAGE-accident is also already used for backtracking exercises of the Comprehensive nuclear-Test-Ban Treaty Organization (CTBTO).

At local scale, the system PERLE focuses on the local description of the atmospheric pollutant cloud at local and regional scales, in the vicinity of the 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). PERLE is used only over the Metropolitan France in operations.

Meso-NH uses two nested grids 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 advanced 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.

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.

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 (Rhône, 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.

Air quality, sand dust and UV index 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). MOCAGE is also a central element of the contribution of Météo-France in EU and ESA funded “GMES Atmosphere” projects : GEMS (FP6), PROMOTE (GSE) and MACC (FP7). In these projects, Météo-France is involved in both global and European activities.

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. From June 2005, MOCAGE has been included in the supervised operational suite at Météo-France to ensure timely delivery of products. The current operational configuration is the following : 3 nested domains (globe, 2° resolution ; Europe, 0,5° resolution ; France, 0,1° resolution) ; 47 vertical levels up to 5 hPa ; meteorological forcings from the operational suites, ARPEGE and ALADIN. MOCAGE is run once daily to provide forecast for up to 96h in advance. In addition to chemical forecasts (O3, NO2, NO, SO2...), MOCAGE provides sand dust forecasts by taking into account dusts emissions from the two major source areas worldwide: Sahara and Saudi Arabia on the one hand, China on the other hand.

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.

4.5.2.2 Research performed in this field

[Summary of research and development efforts in the area]

4.5.3 Specific products operationally available

[brief description of variables which are outputs from the model integration]

4.6 Extended range forecasts (ERF) (10 days to 30 days)

4.6.1 Models

4.6.1.1 In operation

[information on Models and Ensemble System in operational use, as appropriate related to 4.6]

4.6.1.2 Research performed in this field

[Summary of research and development efforts in the area]

4.6.2 Operationally available NWP model and EPS ERF products

[brief description of variables which are outputs from the model integration]

4.7 Long range forecasts (LRF) (30 days up to two years)

4.7.1 In operation

A specific version of ARPEGE model, called ARPEGE-Climat is used 41 times a month to run a 6 month range forecast, starting from ECMWF assimilation. The SST forecast is based on the OPA 8.2 / Orca grid oceanic model, which is fully coupled with the atmospheric model. The 41 members of the ensemble sample both different atmospheric and oceanic initial conditions. The atmospheric conditions are given by the 8 last operational ECMWF analyses while 5 different oceanic states provided by the Mercator analysis are associated to each atmospheric states (+ the last available conditions). Coupling is performed using the Oasis coupler from Cerfacs. The hindcast was ran on the 1993-2003 period using 5 members. The operational suite is distributed between Toulouse (Oceanic analysis, Post-processing) and Reading (run of the models) and the results are made available to the Euro-Sip Multi-Model Ensemble, collaborative effort of ECMWF, Météo-France and UK Met Office. The atmospheric model is using mainly the same ARPEGE software as the short range forecast model, excepted some parameterizations (a full set of parameterization is implemented) and the resolution which corresponds to a triangular truncature T63 without stretching and it has 31 vertical levels like IFS model during ERA-15 (ECMWF reanalysis). The Oceanic model has a 2 degree resolution excepted in equatorial regions where the latitudinal resolution is increased (0.5 degrees). The vertical resolution corresponds to 31 levels (~10m close to the surface and ~500 m below 3000 m)

4.7.2 Research performed in this field

[Summary of research and development efforts in the area]

4.7.2 Operationally available EPS LRF products

Deterministic products : Ensemble mean as Indices and recalibrated Anomalies, Significance Test.

Probabilistic products : Ensemble Member frequency into the tercile categories, Ensemble Member frequency into « extreme » categories (above + σ and below - σ), Probabilistic forecast synthesis (most frequent category).

Parameters : Precipitation, Temperature at 2m and 850hPa, Geopotential Height at 500hPa, Mean Sea Level Pressure, SST, Niño plumes for Niño 4, Niño 3.4, Niño 3 and Niño 1+2 boxes, Global fields (2°5 by 2°5).

Toulouse is recognized as GPC for LRF (WMO-CBS – November 2006).

5. Verification of prognostic products

5.1 Scores of the operational ARPEGE model:

Against analyses

	24 hours			72 hours		
	NH	SH	TR	NH	SH	TR
Z500 RMSE	9.6	13.8		27.2	37	
W250 RMSEV	4.5	4.7	4.3	9.6	10.5	7.4
W850 RMSEV			2.8			4.2

NH : Northern Hemisphere

SH : Southern Hemisphere

TR : Tropics

Against observations

24 hours

	NA	EU	AS	AU/NZ	TR	NH	SH
Z500 RMSE	11.5	11.3	13.3	11.2	14.0	12.8	14.5

W250 RMSEV	6.7	6.0	6.0	6.0	5.7	6.1	6.5
W850 RMSEV	4.2	4.4	4.2	4.3	4.4	4.4	5.1

72 hours

	NA	EU	AS	AU/NZ	TR	NH	SH
Z500 RMSE	28.2	26.8	24.3	22.2	17.3	28.4	28.7
W250 RMSEV	11.4	10.4	9.5	9.5	7.7	10.3	10.3
W850 RMSEV	5.8	5.7	6.4	5.7	5.2	5.8	6.4

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

5.2 Research performed in this field
 [Summary of research and development efforts in the area]

6. Plans for the future (*next 4 years*)

6.1 Development of the GDPFS

6.1.1 Major changes expected for 2008

- New data management system based on Linux clusters.
- Enhanced use of satellite data (IASI and GRAS from Metop, higher radiances density...)
- New limited area model AROME, non hydrostatic spectral model.
- Implementation of a global 3D-VAR ensemble assimilation system.
- Radar Doppler wind assimilation in the ALADIN and AROME systems.
- Progressive retirement of the ARPEGE-Tropics configuration.
- New version of the coupling model for LRF, including better vertical resolution, better oceanic analysis, longer hindcast experience with 11 members in a consistent way with the new version of Euro-Sip namely "system 3". The range of forecast will be extended to 7 months.

6.1.2 [major changes in the Operational DPFS which are envisaged within the next 4 years]

6.2 Planned research Activities in NWP, Nowcasting and Long-range Forecasting

[Summary of planned research and development efforts in NWP, Nowcasting and LRF for the next 4 years]

6.2.1 Planned Research Activities in NWP

Assuming the operational implementation of AROME is done in 2008, as planned, several upgrades and developments are envisaged on all the operational NWP models for 2009, associated to an upgrade of the NEC computer. A significant increase of the horizontal ARPEGE resolution will be tried, keeping the stretching factor unchanged (2.4), aiming at a resolution close to 10 km at its maximum over France. For AROME, the increase of resolution is likely to be put mainly on the vertical resolution.

Research and studies on horizontal resolutions higher than 2.5km (around 1km) will be carried out with different configurations of AROME and also with the research model Meso-NH (Note: the current AROME physics package is a direct legacy of Meso-NH). One example is the plan to run AROME at 1km horizontal resolution over the Northern Alps in February 2009, as an experiment to support the ski world championship. For several years, AROME is likely to remain a genuine research tool for kilometric scales, in addition to its first role of operational NWP model. Some

research will be also carried out, in order to define how the NWP softwares should evolve towards the hectometric resolution in the vertical.

The research work on physical parameterizations will be carried out in the context of a strategy trying to insure the maximum interoperability between the different parameterization sets and the different models at different scales (and with different dynamical cores). One subset of this “physical work” will concern the so-called “simplified” or “linearized” parameterizations which are an essential ingredient of 4D-VAR and perhaps also ensemble prediction systems.

An important research aspect for the next few years is the development of a 4D-VAR option for LAM, in collaboration with several ALADIN and HIRLAM countries, although there is no planned date for replacing the current 3D-VAR operational schemes of ALADIN-France and AROME. All the variational assimilation schemes will be improved by algorithmic developments on the background error covariance matrix, and by more interaction with the ensemble assimilation system. Radar reflectivity data will not be assimilated in AROME before 2009. The general research work on observation utilization (in 4D or 3D-VAR) will include the ADM-AEOLUS wind observations, the new scatterometers, GPS or sounders when they come, as well as a better utilization of sounders, especially over land and over ice. Several research campaigns from Thorpex or the IPY (International Polar Year) will contribute to the validation and the use of these observations.

Also associated to some field-experiments (Thorpex, Medex), important research efforts will be devoted to the mechanisms of cyclogenesis, the Atlantic storm-tracks, the intense cyclogenesis and precipitations in the Mediterranean Sea, not only in a forecasting perspective, but also from a climate point of view.

6.2.2 Planned Research Activities in Nowcasting

The nowcasting work will progressively rely more and more on NWP models, as such models (like AROME) will be run at higher resolutions, more frequently and more rapidly. The capacity of these models to treat the convective cells at the right place and at the right time, in the assimilation and the very first hours of the model integration, is likely to remain an important research challenge for a few years. This research area will cover the model capacities (physics, dynamics), but also the question of the impact of several observing systems on the analysis and very short-term forecasts.

6.2.3 Planned Research Activities in Long-range Forecasting

These research activities are largely connected to the ones related to climate modelling, and they are carried out in a large European context (ECMWF-EUROSIP, ENSEMBLES). During the next few years, several statistical methods will be applied to the simulations performed in the ENSEMBLES project in order to exploit these simulations as much as possible.

6.2.4 Other research activities related to modelling

Hydrological models, atmospheric chemistry models, snow models are examples of applications which are normally downstream of NWP models, and which are now carried out routinely in Météo-France. The research work on these different applications involve more and more techniques or algorithms which were used so far only in NWP, for example data assimilation or ensemble techniques. The work on the chemistry model MOCAGE involves the assimilation of several measurements from satellite instruments. The researchers are more and more faced with the question of assimilating data in a system of coupled models.

7. References

[information on where more detailed descriptions of different components of the DPFS can be found]

(Indicate related Internet Web sites also)

Characteristics of the LRF Météo-France operational suite and its verifications corresponding to the WMO-SVS are made available through the Web site of the Lead-Centre for Verification at <http://www.bom.gov.au/wmo/lrfvs/>

