JOINT WMO TECHNICAL PROGRESS REPORT ON THE GLOBAL DATA PROCESSING AND FORECASTING SYSTEM AND NUMERICAL WEATHER PREDICTION RESEARCH ACTIVITIES FOR 2017

Météo-France

1. Summary of highlights

A new version of operational NWP systems « CY42_op2 » became operational on 5th December 2017.

The main scientific modifications in the global systems are the followings: Use of the surface model SURFEX (Masson et al. 2013), resolution increase for the computation of background error variances and normalisation of variances induced by wavelet modelling of correlations in ARPEGE-EDA, assimilation of water vapour channels of GMI on GPM and MWHS2 on FY3-C, higher density of IASI and GEORAD observations. assimilation of window SEVIRI channels over sea, 5 new channels (ozone) for IASI, new physics in ARPEGE EPS

The same modifications related to observations have been implemented in the assimilation of regional systems. The other main modifications in regional systems are: New version of IAU (Incremental Analysis Update), new cloud optical properties, new autoconversion threshold for transformation of cloud droplets into rain, Ocean mixing layer scheme in Arome-Overseas sytems.

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 Linux cluster running Oracle RDBMS, US-Navy originating NEONS meteorological data management system, and PV-WAVE graphical software. The file servers are doubled for backup.
- NWP operational models are running on a BULL B710 DLC (1800 nodes of 40 processors). A similar configuration, dedicated to research is also used for backup.
- Dissemination of forecast and observation products (from GTS included), in particular to the French weather stations, is made through satellite communication (Eumetcast 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	
21000	**490000**	**80000**	**0**	**40000**	**200**	**18000**	**90000**	**1200**	**40**	
PROFILER-US	PROFILER-EU+VAD	PROFILER-CN	PROFILER-AUS	PROFILER-JP	ASCAT	GEORAD	GEOWIND	SSMI/S	HIRS	
0	**1600**	**0**	**0**	**460**	**70000**	**360000**	**180000**	**43000**	**0**	
AMSU-A	AMSU-B+MHS	SAPHIR	AIRS	IASI	CRIS	GPS sol	GPS sat	ATMS	MWHS2	GMI
220000	**140000**	**45000**	**36000**	**230000**	**55000**	**70000**	**220000**	**60000**	**40000**	**18000**

4. Forecasting system

The operational forecast system at Météo-France is based on several configurations of one single code, ARPEGE/IFS. Although Arpege and IFS are both global models, limited area configurations have been developed within the same framework, that can be summarized by the code names Arome for a non-hydrostatic version with dedicated parameterizations.

The ARPEGE/IFS libraries have been developed jointly by Météo-France, ECMWF and several NMS gathered in the Aladin, and more recently Hirlam, consortium. 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).

.

AROME (Application de la Recherche à l'Opérationnel à Mesoéchelle) combines a non-hydrostatic kernel and framework developed with the Aladin NWP consortium with physical parameterizations and surface representation developed by the French atmospheric research community within the Meso-NH project.

.

Météo-France belongs to the ALADIN consortium which integrates 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. A large part of the cooperation is designed to share the improvements for the dynamical core and the physical packages used by AROME and ARPEGE. There is also a growing collaboration with the HIRLAM consortium as well on AROME.

4.1 System run schedule and forecast ranges

The operational forecast system at Météo-France is based on ARPEGE, AROME using the following rules:

. ARPEGE, hydrostatic global system, provides boundary conditions for the AROME forecast at the same analysis time as well as to several instances of AROME, some performing dynamical adaptation only. One key feature of ARPEGE is its variable horizontal resolution. ARPEGE derives forecasts from a 4D-Var data assimilation with 6h windows for the assimilation cycle and shorter windows for the production cycle. An ensemble data assimilation of 6 members provides time and space varying first guess error statistics to the main 4D-Var assimilation.

ARPEGE is also used in ensemble mode, PEARP (Prévision d'ensemble ARPEGE). This ensemble has 35 members, it is run 4 times a day : from the 18UTC and 06UTC ARPEGE analyses up to 108h and 90h respectively and from the 0 and 12 UTC ARPEGE analysis up to 48 h. PEARP also makes use of the geometric transform of ARPEGE, so that it is both a global ensemble prediction system specifically tuned for the short-range and a mesoscale one in the Europe-North Atlantic area.

AROME-France is run at 0, 3, 6, 12 and 18 UTC up to 48h. It has its own 3D-Var data assimilation cycle, with a 1-h period and time window.

AROME-OM is run at 0 6 12 and 18 UTC up to 42h for 5 overseas different areas ; boundary and initial conditions are provided by ECMWF-IFS and AROME-France.

. long cut-off ARPEGE analyses are performed after some shorter cut-off analyses. This is currently not done for Arome because the model is run late after nominal analyses times, so that most observations are available.

. at 00UTC, the ARPEGE analysis and forecast is run twice, in order to provide early products based on very short cutoff analyses. In order to run the 00UTC Arome forecast about 1h earlier than at other synoptic times, its boundary conditions are provided by this early Arpege run.

. the typical global product availability is :

initialised analyses (P0)   cut-off time+45' forecasts 24h simulated every 10’ wall-clock time

Furthermore, a number of limited area forecasts are performed using IFS-provided lateral boundary conditions. Namely, there are 5 AROME models cover the 4 overseas areas: Caribbean and Guyana, La Réunion, New Caledonia and Polynesia. There is also an AROME model which performs a dynamical adaptation of IFS over Europe (same domain as AROME-FRANCE but with an horizontal resolution of 2.5 km instead of 1,3 for AROME-FRANCE) twice a day.

All times are UTC in the table below.

UTC valid times	0000		0600	1200	1800
long cut-off	0800		1255	2005	0115
short cut-off	0115	0215	0900	1350	2100
ARPEGE range (h)	60	102	72	114	60
end of ARPEGE	0209	0335	1011	1504	2207
PEARP range		48	90	48	108
AROME range (h)	48	45	42	48	42
end of AROME	0235	-	1100	1550	2300
AROME-Indien	42		42	42	42
AROME-Antilles	42		42	42	42
AROME-Guyane	42		42	42	42
AROME-Caledonie	42		42	42	42
AROME-Polynesie	42		42	42	36
AROME-EPS	15 (21 UTC)		45 (3 UTC)	51 (9 UTC)	45 (15 UTC)
AROME-PI	Forecasts available at H + 30 mn every hour H				

4.2 Medium range forecasting system (4-10 days)

The operational ECMWF T639L Ensemble Prediction System (EPS) is used from day 4 to day 9 for forecast bulletins. The forecasters also have a look at the medium range NCEP and CMC ensembles.

As mentioned in 4.3.4, statistical post-processing is produced with the ECMWF EPS until day 14.

Wave Ensemble Prediction System from ECMWF is used to anticipate risks of dangerous wave events.

4.3 Short-range forecasting system (0-72 hrs)

The short-range forecasting system run at Météo-France comprises three main systems (data assimilations and forecast models): ARPEGE, AROME and several instances of ALADIN. ARPEGE is a hydrostatic global system. AROME is a non-hydrostatic LAM system with 1.3km horizontal resolution and a domain centered over mainland France. ALADIN is a hydrostatic LAM system with 8km horizontal resolution with several instances, among which ALADIN-Réunion (over SW Indian Ocean), 3 other tropical ALADIN covering the Carribean and Guyana,

ARPEGE, ALADIN and AROME use the same software, called ARPEGE/IFS, which is a common development between Météo-France, ECMWF and the ALADIN and HIRLAM consortia of national (hydro-)meteorological services. ARPEGE/IFS is a versatile system originally based on a global spectral model and 4DVar data assimilation, it can be used for several applications: limited area modeling, 4DVar and 3DVar data assimilation, short-range prediction, medium-range prediction, climate research, ensemble prediction and ensemble data assimilation.

The ARPEGE system uses Schmidt's transformation to define a geographically variable resolution, with maximum resolution over mainland France (which is the stretching pole), 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 stretching pole, and T / C at the antipode; the local horizontal numerical resolution (in km) is 20000 / T x C at the stretching pole, and 20000 / T / C at the antipode

As of April 2015, the horizontal ARPEGE configuration is T1198 C2.2 with a stretching pole over France (46.5N, 2.6E), leading to a horizontal resolution of the collocation grid of 7.5 km over France and 36 km in the SW Pacific. The collocation grid (2400x1200 points) is Gaussian linear with reduction at the poles, the mesh size is everywhere close to the resolution implied by the local spectral truncation. The ensemble version of ARPEGE uses a reduced truncation T798 C2.4, so its resolution is 10 km over France and about 60 km in the SW Pacific. The AROME-France resolution is 1.3 km on a conformal tangent Lambert projection. Its oversea versions have 2,5 km of resolution together with AROME-IFS and AROME-EPS over Europe.

The vertical ARPEGE and AROME discretisations use a hybrid terrain-following, mass-based coordinate, following Simmons and Burridge (1981) with an increased resolution in the low atmosphere. ARPEGE use 105 levels, the lowest level is at 10 m above the ground. AROME uses 90 levels leading to a higher resolution in the troposphere and a lower resolution in the stratosphere as ARPEGE. The ensemble version of ARPEGE has 90 levels.
For further details about the model domains and vertical resolution, see http://www.cnrm.meteo.fr/gmap/

4.3.1 Data assimilation, objective analysis and initialization

4.3.1.1 In operation

The ARPEGE assimilation runs with a 6 hours cycle. The objective analysis is performed with a multi-incremental 4D variational (4DVar) scheme with first guess error statistics provided by 6-members ensemble: the departure obs-guess is computed at full resolution whereas the analyzed structures are produced at a lower resolution and with no stretching, by 2 minimization loops of increasing resolutions. It is therefore assumed that the small scales (not corrected by the analysis) are forced by the (analyzed) large scales in the subsequent forecast. The 25-members ensemble uses only one minimization loop at the reduced truncation T149 in the 4DVAR assimilation. And its dispersion is maintained by randomly perturbing observations. The AROME assimilation runs a 1 hour cycle with 3DVar at full model resolution.

assimilated data: ARPEGE uses SYNOP, SHIP, BUOY, BATHY, TEMP, TEMPSHIP, TEMPDROP and PILOT (part A, B, C and D), profilers, AIREP, AMDAR, ACARS, Atmospheric Motion Winds (GOES, MTSAT, Meteosat), AMSU-A, B or MHS and HIRS (from NOAA, Aqua and Metop satellites), ATMS and CRIS (Suomi-NPP), Meteosat clear sky radiances, scatterometer winds (Seawinds from Quikscat and ASCAT from Metop, Rapidscat), MODIS winds (Aqua and Terra satellites), SSMIS (from DMSP), Megha-Tropiques, IASI (from Metop), AIRS (from Aqua), European GPS zenithal total delays, GPS radio occultation data from several sources). ALADIN uses the same data types except that Meteosat/SEVIRI radiances are used directly. AROME uses the same data as ARPEGE except that it also uses radar reflectivities and doppler winds, and additional SYNOP and ACARS information, as well as radiances at higher spatial resolution whenever possible.

assimilation cycle: ARPEGE uses a 6 hours cycle and AROME uses a 1-hour cycle.

analysis method: ARPEGE uses the so-called “mixed” 4Dvar and ensemble approach. AROME uses 3DVar.

analysed variables: Horizontal wind, temperature and specific humidity on model levels, plus surface pressure.

first guess: A 6-hour forecast of ARPEGE (or a 1-hour forecast of AROME, respectively) in normal operations

coverage: ARPEGE is global. AROME is regional.

horizontal resolution: As of April 2015, the effective ARPEGE 4DVar increment resolution is T399c1. The assimilation ensemble increment resolution is T149C1. The ARPEGE background, and the AROME analyses, are used at the full resolution of the forecast model.

vertical resolution: as in the forecast models

initialization: in ARPEGE, weak digital filter constraint in the 4DVar variational cost function. In AROME, incremental analysis update.

surface: analysis of superficial and deep soil temperature and water content from observations of 2m temperature and humidity. Sea surface temperature is analyzed using SST reports and NCEP and OSTIA SST analyses. Sea-ice cover is based on OSI-SAF sea-ice products. Snow cover is not analyzed (it is relaxed towards climatology).

4.3.1.2 Research performed in this field

The research in data assimilation focuses on extending the amount of assimilated data, mostly through the use of new satellite instruments such as Suomi NPP, MetOp, ADM/Aeolus. There is research on improving the observation treatment, notably through better modelling of IR radiances over clouds and land, of microwave radiances over land, ice or in rainy areas, of radar processes. The improvement of data assimilation algorithms follows several directions e.g. improving models of background error covariances, sampling flow dependent analysis and forecast errors through the enhancement of an ensemble data assimilation system, radar processing, assimilation of surface variables. There is interest in new observing technologies such as X-band radars, lidars, and new radar-derived information. On-going activities are done to prepare the assimilation of wind measurements from the first spaceborne Doppler lidar Aeolus, radiances from instruments on-board future METOP-SG and MTG satellites.

4.3.2 Model

4.3.2.1 In operation

basis equations:
Primitive equations system in ARPEGE, compressible non-hydrostatic in AROME.

independent variables:
horizontal wind vector, temperature, specific humidity and surface pressure, cloud water and ice, precipitating water and ice, turbulent kinetic energy. Plus graupel, vertical velocity and hydrostatic pressure departure for AROME.

numerical technique:
Two-time-level semi-lagrangian spectral semi-implicit time-stepping and horizontal discretization scheme, vertical finite element discretization in ARPEGE , vertical finite differences in AROME.

integration domain:
global in ARPEGE, regional in ALADIN and AROME.

orography, gravity wave drag:
The orography of this model is computed on the forecast model collocation grid from the GTOPO030 database for ARPEGE and GMTED for AROME using a variational technique that controls the noise associated to Gibbs waves (see Bouteloup, 1995). The gravity wave drag in ARPEGE takes into account subgrid anisotropy, blocking and mid-tropospheric effects.

horizontal diffusion:

Implicit in spectral space and incorporating an orography dependent correction for temperature. AROME includes an additional gridpoint numerical diffusion, SLHD, which is associated with the semi-lagrangian advection scheme only for the condensed water variables.

vertical diffusion:

see next item

planetary boundary layer:

the PBL vertical diffusion is implemented as a CBR prognostic turbulent kinetic energy scheme that models the effect of subgrid eddies, plus a shallow convection scheme (KFB/EDKF) that simulates the mixing effect of subgrid non-precipitating convection.

resolution, time step:

see the resolutions above. The ARPEGE, ALADIN and AROME timesteps are 360s, 450s and 50s, respectively.

Earth surface:

ARPEGE and AROME use the SURFEX scheme which comprises four prognostic surface tiles (for soil/vegetation, sea/sea ice, lakes, towns), a snow scheme, a surface layer interpolator (Canopy), and the Ecoclimap physiographic database. SURFEX manages several dozens of prognostic variables. The exchanges of energy and water between the continuum ground-vegetation-snow and the atmosphere are represented with the ISBA-3L scheme, the snow scheme D95 and a ground frost scheme for the ground water

radiation:

A version of the 6-band Fouquart-Morcrette radiation scheme in the visible wavelengths, the 16-band RRTM scheme in the infrared.

subgrid convection:

The shallow convection scheme is documented in the PBL section. Deep convection is parameterized in ARPEGE only, as a Mass-flux scheme (Bougeault 1985) enhanced with

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

explicit microphysics:

ARPEGE uses a 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 Smith (1990).

AROME uses the ICE3 prognostic scheme to handle the same species plus graupel and the related processes. All models use statistical sedimentation numerical schemes for precipitation.

For more up-to-date details see http://www.cnrm.meteo.fr/gmap/

4.3.2.2 Research performed in this field

The NWP research programme combines the need (1) to improve the forecast performance for all systems, both in average (scores) terms, and for the provision of early warnings of high impact weather including storms, severe convection, floods, traffic hazards, to (2) to mix short-term developments with longer-term research, (2) to deliver new services according to user demand, scientific and technological opportunities. Many topics are addressed through cooperation with other labs and institutes.

Some research on short-range NWP deals with the modelling of mid-latitude cyclogeneses and tropical cyclones, including research to understand the underlying mechanisms. Specific research is also carried out on the mechanisms of intense Mediterranean cyclogeneses. This research is often carried out in the context of (existing or planned) campaigns (Hymex) or international projects (Nawdex). There is a continuous research effort on improving both the dynamics and the physics of all of NWP models (hydrostatic and non-hydrostatic dynamics). There is also a continuous effort aiming at improving the sets of physical parameterizations used operationally at all scales. A subset of this activity is dedicated to the so-called SURFEX system which treats the modeling of the Earth surface and its interactions with the atmosphere.

Future research priorities will include various aspects of the dynamics, the physics, the interactions between the two, and, for the longer term, developments needed for going to even higher horizontal resolutions and to massively parallel computer architectures. The research model Meso-NH is used as a research tool for very high resolution numerical experiments.

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 0.5° mesh to the "France" domain with a 0.01° mesh)
- vertical levels are standard pressure levels, height levels, plus others (e.g. isentropic)
- independence, from the originating model, of the format of the database products.

The meteorological fields stored in this database include:
- at upper levels: geopotential height, temperature, humidity, wind (including vertical velocity), cloud and precipitation variables, TKE
- at ground level: pressure, temperature, humidity, heat and radiation fluxes, snow and water content, etc
- at sea surface level: reduced pressure, QNH
- some data at particular levels: 500 hPa absolute vorticity, high medium and low cloudiness, iso 0° and iso -10°, tropopause, 3D cloud fields, potential vorticity, 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 (with a rank diagrams method) before computing probabilities.

ARPEGE	France	2m Temperature+ daily extremes	2781	00, 06, 12, 18	+3	+102,+72, +114,+60	3h	MLR+KF
		2m Humidity + daily extremes	1269	00, 06, 12, 18	+3	+102,+72, +84,+60	3h	MLR+KF
		Dew point temperature	982	00, 06, 12, 18	+3	+102,+72, +84,+60	3h	MLR
		Total Cloud Cover	164	00, 06, 12, 18	+3	+96,+42,+72,+30	3h	MLR+KF
		Total Cloud Cover	152	00, 06, 12, 18	+3	+102,+72, +84,+60	3h	DA

		10m Wind speed	861	00, 06, 12, 18	+3	+102,+72, +84,+60	3h	MLR
		10m Wind direction	822	00, 06, 12, 18	+3	+102,+72, +84,+60	3h	MLR
		Visibility, probabilities	125	00, 06, 12, 18	+3	+45	3h	DA
		Wind gusts, probabilities	648	00, 06, 12, 18	+3	+96,+42, +72, +30	3h	DA
	France +Réunion Island	Sunshine radiation	263+34	00, 06, 12, 18	+3	+102,+72, +84,+60	3	MLR+Calibration+KF
	Global	Total Cloud Cover	250000 gridpoints	00, 06 12, 18		+60 +60 +60 +60	3H	Random forest
PEARP	France	2m Temperature+ daily extremes, individual runs	2761	06, 18	+3	+72, +108	3h	MLR to Ind. Memb., KF to Ens. Mean
		10m Wind speed, individual runs	860	06, 18	+3	+72, +108	3h	MLR to Ind. Memb.,Calibration
		06h precipitations, individual runs	2295	06,18	+6	+102	6h	Calibration
IFS	World	2m Temperature+ daily extremes	7128	00, 12	+1,	+180	1h,	MLR+KF
	France	2m Temperature+ daily extremes	2781	00, 12	+3	+180	3h	MLR+KF
		2m Humidity + daily extremes	1269	00, 12	+6	+180	3h	MLR+KF
		Total Cloud Cover	152	00, 12	+6	+180	3h	DA
		10m Wind speed	861	00, 12	+6	+180	3h	RLM
		10m Wind direction	822	00, 12	+6	+180	3h	RLM
	France +Réunion Island	Sunshine radiation	263+34	00, 12	+3	+180	3h	RLM+Calibration+Kf
Mixed ARPEGE +IFS	France	2m Temperature+ daily extremes	2781	00, 06, 12, 18	+3	+102,+72, +84,+60	3h	MLR+KF
Mixed ARPEGE +IFS	World	2m Temperature+ daily extremes	4367	00,06,09,12,18,21	+1	+102,+96, +69,+84,+78,+57	1h	MLR+KF
EPS	World	2m Temperature+ daily extremes, individual runs	3338	00, 12	+3	+360	3h	MLR to Ind. Memb.
	France	2m Temperature+ daily extremes, individual runs	2761	00, 12	+3	+360	3h	MLR to Ind. Memb., KF to Ens. Mean
		10m Wind speed, individual runs and probabilities	792	00, 12	+6	+240	3h/6h	MLR to Ind. Memb. Calibration
		2m Humidity + daily extremes	1156	00, 12	+3	+240	3h	MLR +KF to Ind. Memb.

Monthly Forecast	France	2m Temperature+ daily extremes, individual runs	1056	00	+2	D+31	3h	MLR to Ind. Memb
Monthly Forecast	World	2m Temperature+ daily extremes, individual runs	7128	00	+3	D+31	3h	MLR to Ind. Memb
AROME	Europe	2m Temperature+ daily extremes	1169	00 06 12 18	+3	+48 +45 +42 +48 +42	1H	Gradient boosting + simple filtering+spatialisation on 0,01° grid
AROME	France	2m Humidity + daily extremes	1000	00 06 12 18	+3	+42 +39 +36 +42 +39	1H	Gradient boosting + filtering

4.3.4.2 Research performed in this field

The pre-operationnal tests are run for the following statistical post-processings

ARPEGE	France	2m Temperature+ daily extremes	1169	00 06 12 18	+3	+102,+72, +114,+60	3H	Random Forest+ simple filtering
ARPEGE	France	Windspeed Windgusts	50000 gridpoints	00 06 12 18	+3	+102,+72, +114,+60	1H	Random forest
Mixed ARPEGE+ AROME+ CEP	Europe	2m Temperature+ daily extremes	2000	00 06 12 18	+3	+102,+72, +114,+60	3H	Expert aggregation+spatialization
PEARP	Germany	Windspeed Windgusts	50000 gridpoints	00 06 12 18	+3	+90+90	3H	Quantile Random forest
PEARP	Europe	2m Temperature	2000	06 18	+3	+90+90	3H	Quantile Random forest + spatialization

Additionally, post-treated temperatures are spatialized on a 0.01x0.01 resolution grid over France by means of a multiresolution B-Spline analysis coupled with a linear model taking into account topography.

4.3.5 Ensemble Prediction System

4.3.5.1 In operation

An ensemble assimilation system runs operationally at Météo-France since July 2008. It features 25 4DVar data assimilation cycles using a uniform resolution version of ARPEGE, these assimilations are perturbed by applying random noise to the assimilated observations. The ensemble assimilation system provides initial perturbation information to the ensemble systems, and background error statistics to the ARPEGE and AROME data assimilation systems.

An ensemble prediction system, PEARP, runs operationally at Météo-France twice a day (at 06 and 18UTC). The perturbations used in the ensemble are generated from the ARPEGE data assimilation ensemble with additional perturbations provided by singular vectors. Singular vectors are optimised over 18h or 24h at T95 horizontal resolution over various areas including both hemispheres, the tropics, and an emphasis on the Western European area. The tropical areas target active tropical cyclogenesis zones (they vary with sesaons). The norm is a “total” energy in the extratropics and kinetic energy in the tropics. Forecast error is currently represented by using 10 physical packages that are randomly attributed to members at the beginning of each run. The ensemble features 35 members with a slightly modified version of the base ARPEGE model, aside from the changing physics (lower resolution than the deterministic ARPEGE system: T798C2.4L90). Different products (Stamps, plumes, probabilistic charts and others) are provided to the forecasters, mostly through a dedicated intranet site rather than within their worskstations.

A second ensemble prediction system, AROME-PE, runs operationally at Météo-France four times a day (at 3, 9, 15 and 21 UTC). This ensemble contains 12 perturbated members which use 12 different initial conditions coming from a hierarchical selection among the 35 PEARP members designed to maximize the dispersion of a selection of parameters. The selected members are also used to provide the lateral boundary conditions for the AROME-EPS members. Supplementary initial perturbations are added o surface parameters and stochastic physical physics perturbate the model at each time step of the forecast. Classical products (quantiles, probabilities, …) are available on the forecaster’s workstation. A neighborhood treatment is also applied to the ensemble in order to increase local probabilities.

4.3.5.2 Research performed in this field

Research on the PEARP ensemble is on the representation of model error and on forecast calibration with limited use of reforecast. The use of a larger “stretching” in order to bring horizontal resolution over Europe at the same range as the deterministic version is also a topic of active current research.
Research on the assimilation ensembles includes work on the representation of model error, computational improvements through 4DVar preconditioning, the interface with the background error models, and the application to limited area models. The feasibility of extending the hybrid approach by using ensemble members directly in the variational analysis is under consideration (so-called En-Var technique).
Research at convective scales aims to evaluate the performance of AROME ensembles for Mediterranean flood warnings (Hymex project), to develop a future operational convective-permitting scale ensemble, and to investigate predictability issues related to very short ranges (nowcasting) and precipitation fields. Also, research is active to design an ensemble of assimilation for a convection-permitting ensemble and which leads to an operational implementation in June 2018.

4.3.5.3 Operationally available EPS Products

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

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

4.4.1 Nowcasting system

4.4.1.1 In operation

Radar image extrapolation is operated both centrally and on forecaster’s workstations, using the “2PiR” algorithm. Rain patterns are 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 ¾ of French mainland territory) a commercial service announcing rain start up to one hour ahead, at the spatial scale of each French city/district.

In order to qualify in real time the severity of the observed rains, the product Aiga-Pluvio takes into account

- Radar rain depth composite accumulated on different depth at kilometric scale
- Return period of precipitation for different depths.

Based on this product, an Intense Rains Warning service on the scale of cities is already available and strictly meant for institutional use. Warnings are sent by mail, SMS and vocal messages to the mayors.

Two object-oriented diagnostics for convective clouds/cells are run centrally and provided to the forecasters and other end-users: the first one, RDT (Rapidly Developing Thunderstorm product) is based on satellite data, the second one is based on radar data. The RDT has been developed in the framework of Eumetsat's Satellite Application Facility for Nowcasting (SAF-NWC). RDT software tracks clouds, identifies those that are convective, and provides some descriptive attributes of their dynamics. An overshooting top detection is also performed by RDT. Since the version v2016, RDT also provides 1 hour extrapolations of convective cells. MSG data are used both in FDSS (Full Disk Scan Service) and RSS (Rapid Scan Service). In order to cover French oversea territories and also to provide new services to aviation, RDT is now produced on globe by Météo-France with 5 satellites. NWP data can be used to elaborate instability masks, improving the detection of warm systems by RDT, lightning data if available can optimize the Yes/No convection diagnosis and enrich the description of the cell. The product is operational in Eumetsat sense. A new product, Convection Initiation has been developped in the framework of SAF-NWC, the objective is to estimate the probability for a pixel to become a thunderstorm.

The CONO (Convection Nowcasting Objects) performs a similar task on composite reflectivity radar images for describing convective cells from high reflectivity patterns. Both products also incorporate lightning data.

A special version of CONO dedicated to aeronautical use has been developed. CONO and RDT contain some descriptors adapted for their use for aeronautical activities: overshooting top characteristics (RDT), cloud top altitude expressed in Flight Level (CONO and RDT), its trend (CONO and RDT), two outlines to better represent the convective systems (RDT), four reflectivity outlines to represent severity of convection (CONO), high Ice Water Content hazard (RDT). Special output files are also developed to facilitate the uplink from the ground to airplanes . Some of these activities have been developed in the framework of SESAR project. In Sesar Deployment project, partners develop a harmonized (seamless) forecast of several parameters.

In the SIGOONS system (Significant Weather Object Oriented Nowcasting system) CONO generated convective cells are further qualified regarding gust, rainfall intensity and risk of hail, using various sources, and extrapolated. This allows providing to professional customers an operational thunderstorm risk warning service, up to one hour ahead, through SMS (Short Message Service) and web site graphics.

AROME-NWC, the French nowcasting NWP model, has been in operation since March 2016 (see part 4.4.2). It has been designed for the forecasters issues and also as way of improving existing nowcasting products.

4.4.1.2 Research performed in this field

Research on nowcasting systems relies on blending NWP fields and extrapolation data on nowcasting scale.The aim is to take the best of each method to have the most relevant information without break whithin the 0-3h forecast interval.

Several approaches have been investigated. The method, developed since June 2016, rests on a so-called "sequential aggregation of predictors" method. This method aims to blend two predictors (in our case the extrapolation of QPE by 2PIR and AROME-NWC) so as to get a linear compound of products close or better than the best of any of them. A first merged version between QPE extrapolation and numerical prediction of rainfall has been produced since December 2016.

The use of such fields to feed thunderstorm's nowcasting products is a way to deliver nowcasting information beyond the first hour of forecast and to optimize the transition between extrapolation and NWP forecast.

Fine scale 3D retrieval of 3D wind for the whole mainland territory is under operational testing, based on multiple Doppler data and the analytical MUSCAT method; its resolutions are 2.5 km in the horizontal, 500m in the vertical and 15 minutes.

Precipitation typing using dual-polarization data and windshear mosaic using Doppler data are under tuning. Windshear mosaic is used to improve estimation of gusts under thunderstorm.

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) .

.

4.4.2 Models for Very Short-range Forecasting Systems

4.4.2.1 In operation

AROME-NWC nowcasting NWP model has been in operation since March 2016.

This system is built around a configuration of the existing mesoscale and limited area model AROME-FR. Both models share the same characteristics such as domain, physics and dynamics, 3DVar data assimilation system, spatial scale (1.3km), ARPEGE coupling model…

Nowcasting's constraints lead to a compromise between the amount of new observation in the analysis process and computational time. Thus, the observation time window of AROME-NWC is narrower, hence assimilates fewer observations, than AROME-FR's one.

AROME-NWC is performed every hour. Its 3D-var assimilation system starts with an analysis from the last available AROME-FR forecast valid at analysis time (the guess) and observations from 10min before to 10min after analysis time.

AROME NWC is mainly designed for surface condition forecasting (rainfall, snow, fog, gusts, humidity and cloudiness). Its main characteristics are :

- High frequency of forecast (hourly refreshed)
- High spatial and temporal resolution: 1.3 km mesh and for a given forecast, forecast fields are produced every 15 minutes
- Maximum forecast range of 6 hours

- The forecast parameters are available within 30 minutes after the latest observations.

Synthetic diagnosis are computed from the AROME Nowcasting forecasts concerning convection, fog, winter conditions like snow or freezing rain.

An assessment of AROME-Nowcasting's forecasts vs AROME-FR forecasts available at the same time confirms the positive impact of the one hour refresh cycle up to 2-3 hours range although its assimilates less observations (Auger et al. 2015). More recent scores of the current operational versions of these two models show similar conclusions.

For operational use of hourly refreshed forecasts, a dashboard has been created and tailored to meet forecaster's expectations.

This dashboard aims to warn forecasters when some fields exceed fixed thresholds and to help them to visualise relevant maps. It also enables to visualise several available forecasts for a given hour

4.4.2.2 Research performed in this field

The ability of such models to properly handle convective cells, both in a frequent assimilation cycle and during the very first hours of model integration, remains an important research challenge. The new needs of air traffic control management and optimization provide the initial incentive for this research, but there are others such as improving weather crisis management at local scale.

In addition to AROME-FR improvements that will benefit AROME-NWC, other avenues are being explored,

AROME-NWC is not run in cycle and does not use its own predictions for future predictions (too short cut-off). Research performed in this field aims to work on AROME-NWC's assimilation system in order to make a better use of observations and AROME-NWC's former runs informations.

4.5 Specialized numerical predictions

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 (as appropriate related to 4.5)

4.5.2.1 In operation

Marine forecasts

<u>Wave hindcast and forecasting system</u>

For determining the sea states on high seas, nine models run operationally in France :

A global wave model (MFWAM-GLOB-ARPEGE) computing the waves over all the oceans up to 114 hours forecast, from the wind outputs of large scale fields derived from the global atmospheric models ARPEGE

Type:	wave model
Integration domain:	Global
Grid:	regular grid; resolution: 0.2°
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Integration scheme:	time step = 600s
Boundary forcing:	winds at 10m level from ARPEGE, updated every 3 hours Surface classification: sea ice deduced from ARPEGE SST
Assimilation:	4 assimilations/day using significant wave heights from Jason 2, Jason 3, Saral, Cryosat2 and Sentinel-3A altimeters and soon, the SAR data from Sentinel1 (waves spectra) and the altimeter data from Sentinel 3B

Another global wave model (MFWAM-GLOB-ECMWF) computing the waves over all the oceans up to 120 hours forecast, from the wind outputs of large scale fields derived from the global atmospheric models IFS (ECMWF)

Type:	wave model
Integration domain:	Global
Grid:	regular grid; resolution: 0.1°
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Integration scheme:	time step = 240s
Boundary forcing:	winds at 10m level from IFS (ECMWF), updated every 3 hours Surface classification: sea ice mask from ECMWF, surface currents from CMEMS-MFC global ocean system.
Assimilation:	4 assimilations/day using significant wave heights from Jason 2, Jason 3, Saral and Cryosat-2, Sentinel-3A altimeters and soon, the SAR data from Sentinel1 (waves spectra) and the altimeter data from Sentinel 3 B

A regional model (MFWAM-REG-ARPEGE) forecasting the waves up to 114 hours with 3 hours step, over a vast area centered on Europe (North Atlantic, Mediterranean Sea, Baltic, North Sea and Black Sea, ...), from the wind outputs of small scale fields (1/10°) derived from ARPEGE and nested in the MFWAM-GLOB-ARPEGE wave model.

Type:	nested wave model
Domain:	European Seas : 80N-10S-100W-100E
Grid:	regular grid; resolution: 0°1
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	300s
Boundary forcing:	winds at 10m level from ARPEGE, updated every 3.

Another regional model (MFWAM-REG-ECMWF) forecasting the waves up to 120 hours with 3 hours step, over a vast area centered on Europe (North Atlantic, Mediterranean Sea, Baltic, North Sea and Black Sea, ...), from the wind of IFS (1/8°) and nested in the MFWAM-GLOB-ECMWF wave model.

Type:	Nested wave model
Domain:	European Seas : 80N-10S-100W-100E
Grid:	regular grid; resolution: 0°1
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	300s
Boundary forcing:	winds at 10m level from ECMWF, updated every 3 hours.

A Caribbean model (MFWAM-CARIBBEAN-AROME), forecasting the waves up to 42 hours with 3 hours step, over Caribbean sea extending to the Guyana coast, nested in the MFWAM-GLOB-ECMWF model, from the wind outputs of AROME-Antilles/Guyane (1/40°) and of IFS from ECMWF (1/8°).

Type:	Nested wave model
Domain:	28N-5S-75W-45W
Grid:	regular grid; resolution: 0°1
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	300s
Boundary forcing:	winds at 10m level from AROME-Antilles/Guyane, updated every 3 hours.

A Indian Ocean model (MFWAM-INDIAN OCEAN-AROME), forecasting the waves up to 42 hours with 3 hours step, over part of the Indian Ocean (centered on La Réunion Island), nested in the MFWAM-GLOB-ECMWF model, from the wind outputs of Arome-Indian Ocean (1/40°) and of IFS from ECMWF (1/8°)

Type:	Nested wave model
Domain:	0S-32S-31.5E-88.5E
Grid:	regular grid; resolution: 0°1
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	300s
Boundary forcing:	winds at 10m level from Arome-Indian Ocean, updated every 6 hours.

A Polynesian model (MFWAM-POLYNESIAN-AROME), forecasting the waves up to 42 hours with 3 hours step, over Polynesia, nested in the MFWAM-GLOB-ECMWF model, from the wind outputs of Arome-Polynesia and of IFS from ECMWF (1/8°).

Type:	Nested wave model
Domain:	1S-31S-196E-232E
Grid:	regular grid; resolution: 0°1
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	300s
Boundary forcing:	winds at 10m level from Arome-Polynesia, updated every 3 hours.

A New Caledonia model (MFWAM-New-Caledonia-AROME), forecasting the waves up to 42 hours with 3 hours step, over New Caledonia sea, nested in the MFWAM-GLOB-ECMWF model, from the wind outputs of Arome-New-Caledonia and of IFS from ECMWF (1/8°).

Type:	Nested wave model
Domain:	10S-30S-156E-174E
Grid:	regular grid; resolution: 0°1
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	300s
Boundary forcing:	winds at 10m level from Arome-New-Caledonia, updated every 3 hours.

A local model (MFWAM-France-AROME), forecasting the waves up to 30 hours with 1 hour step, over France, nested in the MFWAM-REG-ARPEGE model, from the wind outputs of AROME-France.

Type:	Nested wave model
Domain:	38N-53N-8W-12E
Grid:	regular grid; resolution: 0°025
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	60s
Boundary forcing:	winds at 10m level from AROME-France, updated every hour.

These 9 models are available at 00UTC, 06UTC, 12UTC and 18UTC runs.
MFWAM-GLOB-ARPEGE and MFWAM-REG-ARPEGE are run with a long-cut-off and short cut-off at 00 UTC.
Since March 2015 (but 2017 for overseas territories), five other models have been implemented to detail the sea state near the coast of France with different atmospheric forcings. These models

are based on the WW3 code with an unstructured grid and a minimum mesh size of 200 meters on the coast :

A coastal model 1 (WW3-France-ARPEGE), forecasting the waves up to 72 hours with 1 hour step (for the 36 first hours, 3h step after), over West and North France, nested in the MFWAM-REG-ARPEGE model, from the wind outputs of ARPEGE (1/10°).

Type:	Nested wave model
Domain:	french Atlantic, Channel and North Sea coasts
Grid:	irregular grid; resolution: up to 200 m on the coast
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	10s
Boundary forcing:	winds at 10m level from ARPEGE, updated every 3 hours.

A coastal model 2 (WW3-France-ECMWF), forecasting the waves up to 72 hours with 1 hour step (for the 36 first hours, 3h step after), over West and North France, nested in the MFWAM-REG-ECMWF model, from the wind outputs of IFS/ECMWF (1/8°).

Type:	Nested wave model
Domain:	french Atlantic, Channel and North Sea coasts
Grid:	irregular grid; resolution: up to 200 m on the coast
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	10s
Boundary forcing:	winds at 10m level from IFS/ECMWF, updated every 3 hours, surface currents and sea level from HYCOM-2D (storm surge model).

A coastal model 3 (WW3-France-ARPEGE), forecasting the waves up to 72 hours with 1 hour step (for the 36 first hours, 3h step after), over South France, nested in the MFWAM-REG-ARPEGE model, from the wind outputs of ARPEGE (1/10°).

Type:	Nested wave model
Domain:	french Mediterranean Sea coasts
Grid:	irregular grid; resolution: up to 200 m on the coast
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	10s
Boundary forcing:	winds at 10m level from ARPEGE, updated every 3 hours, surface currents and sea level from HYCOM-2D (storm surge model).

A coastal model 4 (WW3-France-AROME), forecasting the waves up to 42 hours with 1 hour step (for the 36 first hours, 3h step after), over South France, nested in the MFWAM-France-AROME model, from the wind outputs of AROME (1/40°).

Type:	Nested wave model
Domain:	french Mediterranean Sea coasts
Grid:	irregular grid; resolution: up to 200 m on the coast
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	10s
Boundary forcing:	winds at 10m level from AROME, updated every 3 hours.

A coastal caribbean and guyanese model (WW3-AG-AROME), forecasting the waves up to 42 hours with 3 hours step, over West Indies and french Guyana, nested in the MFWAM-

CARIBBEAN-AROME model, from the wind outputs of AROME-Antilles/Guyane (1/40°) and of IFS from ECMWF (1/8°).

Type:	Nested wave model
Domain:	french coasts of West Indies and Guyana
Grid:	irregular grid; resolution: up to 200 m
Frequency resolution:	30 frequency components, logarithmically spaced from 0.035 Hz to 0.555 Hz
Direction resolution:	24 equally-spaced direction components
Timestep:	10s
Boundary forcing:	winds at 10m level from AROME, updated every 3 hours.

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 (Hycom2D since January 2014, proprietary model before) has been configured to compute storm-surges forecasts along coastlines of metropolitan France (2 domains : Atlantic to North Sea and Mediterranean Sea), of SW Indian Ocean and of West Indies and French Guyana. The grid mesh size is around 1 kilometer at the coast (curvilinear grid) except for Channel (500 m), SW Indian Ocean (3 km) and French Guyana (2 km).

Metropolitan domain: Atmospheric fields are taken from atmospheric numerical models: IFS (ECMWF), ARPEGE and AROME (Météo-France). The system (based on a proprietary model until 2014) 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. The model is now run 13 times per day (for the 2 configurations describing the metropolitan domain): 4 times with Arpege forcings (10 m winds and surface pressure), 5 times with Arome forcings and 4 times with IFS forcings.
Up to 120 hours forecast are produced on a 1/24° grid mesh for the two domains : Mediterranean Sea and NE Atlantic Ocean (Bay of Biscay, Channel and North Sea). Storm surge and total sea level forecasts for about 120 locations along the French coast are also provided up to 120 h (every 10 minutes).

Overseas domain: for the Hycom2D model, the atmospheric forcing is AROME, completed by IFS to cover the whole 2 domains of Hycom2D (SW Indian Ocean and West Indies to French Guyana). These 2 models run 4 times per day to produce 42h forecasts.The storm surge and the total sea level are available at around 60 locations for each of the 2 configurations.

Another system, based on a proprietary storm surge model, can be used for overseas domains and in case of tropical cyclones :
atmospheric fields are inferred from an analytical-empirical cyclone model which requires 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.

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, AROME 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. For the Search And Rescue, an object drift model has been developed with 2 versions : a leeway one (for 73 object types) and a container one (every rectangular object) and a leeway one (for 73 object types). The last version has been operational since 1999.
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 the international level, Météo-France Toulouse has been designated as a Regional Specialized Meteorological Center (RSMC) by WMO for the provision of atmospheric transport model outputs in case of an environmental emergency response(nuclear and non-nuclear). In particular, RSMC Toulouse can be requested for support by the International Atomic Energy Agency (IAEA) in case of nuclear accidents or radiological emergencies, and by the Comprehensive nuclear-Test-Ban Treaty Organization (CTBTO) in case of detection of anomalous radionuclides levels. Forecasts of transport and deposition from the Atmospheric Transport Model (ATM) are provided in the first case, while backtracking modeling is performed in the second case. Météo-France Toulouse has also the responsibility of being a Volcanic Ash Advisory Centre (VAAC) for the International Civil Aviation Organization (ICAO). In this context, it provides forecasts of plumes of volcanic ashes at different flight levels. 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 center that considers jointly the evolution of weather and pollution conditions, and provides forecasts of the pollutant plume.

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 trajectory tool computes simple lagrangian trajectories. Three neutrally buoyant particles are released in the atmosphere at a geographic location defined by the user and at three fixed vertical levels: 950, 850 and 700 hPa, corresponding to about 500, 1500 and 3000 m above sea level in standard atmosphere. The particles are only subjected to the action of the large-scale wind; no other physical or atmospheric process is taken into account. The 3-D wind field is provided by the global NWP models ARPEGE from Météo-France or IFS from ECMWF (choice of the user) sampled at 0.5° resolution and on 15 vertical pressure levels, from 1000 to 100 hPa. The tool provides a quick estimate of the expected trajectory of air parcels originating from the planetary boundary layer at the location of interest.
- a dispersion model, MOCAGE-accident, based upon the MOCAGE three-dimensional chemistry and transport model developed by Météo-France for 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 version of MOCAGE specifically adapted for the transport and diffusion of accidental release from the regional to the global scale. Currently, only dynamical and physical processes are taken into account, excluding chemistry.

  MOCAGE-accident is based upon a semi-lagrangian advection scheme (Williamson and

Rasch, 1989). Concerning parameterized transport, turbulent mixing is treated following (Louis, 1979), as in the NWP suite ARPEGE, and transport by convection is based on a mass flux scheme (Bechtold et al., 2001). Dry deposition is accounted for simply, using fixed deposition velocities. Wet deposition is treated with a detailed scheme which takes into account a convective sink following (Mari, 2000) and a stratiform sink following (Liu, 2001). If needed (radionuclide), a radioactive decay is considered. Sedimentation is simply treated with a settling velocity which depends on the size and density of the particle.

MOCAGE-accident runs in off-line mode, using Météo-France ARPEGE or ECMWF/IFS operational NWP products as dynamical forcings. It can be run for an emission taking place everywhere over the globe. In the operational configuration, it can have a 0.1° (ARPEGE) or 0,125° (ECMWF) resolution domain around the emission source and a 0.5° global horizontal resolution and 47 hybrid (?,P) levels from the surface up to 5 hPa, with approximately 7 levels in the planetary boundary layer, 20 in the free troposphere and 20 in the stratosphere. Three types of pollutants can be considered: passive tracers, radionuclides and volcanic ashes.

MOCAGE-accident can be run in "inverse" mode in order to provide information on the origin of an air-mass arriving at a given point in space and time. This configuration, used to perform backtracking simulations in the context of CTBTO requests, takes only into account semi-lagrangian backwards advection and eddy diffusion (auto-adjoint process).

For local and regional scale dispersion forecast, Météo-France uses the system PERLE which is based on the combination of a meso-scale non hydrostatic model, which provides meteorological fields, and a lagrangian particle dispersion model (LPDM, from the Colorado State University), the formulation of which allows the description, during the first critical few hours, of the atmospheric pollutant cloud in the vicinity of a radionuclide or chemical release, without gaussian assumptions.

For the standard PERLE version, which is run over Metropolitan France in operations, the meso-scale meteorological fields considered are either AROME operational forecasts or specifically produced forecasts by the Meso-NH model (Lafore et al., 1998). In the case Meso-NH is considered, it uses two nested grids for emergency response, with a first domain covering 500km*500km area (4-km resolution) and a second domain covering 100km*100km area (1-km resolution), and two-way interactions between them; the initial and boundary conditions of the larger domain are defined by ARPEGE. In 2011, a "global" version of PERLE has been developed and can be used for any limited area domain over the globe, by considering IFS fields for both initial and boundary conditions of Meso-NH.

Air quality, sand dust and UV index forecast

MOCAGE 3D 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 in to higher horizontal resolutions 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. There are over 45 publications in the international peer-reviewed literature presenting MOCAGE results.

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 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 pollution monitoring and forecasting 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. By end of 2016, MOCAGE has been updated in order to refine the global domain ,the current operational configuration is the following : 3 nested domains (globe, 1° resolution ; Europe, 0,5° resolution ; France, 0,1° resolution) ; 47 vertical levels up to 5 hPa ; meteorological forcings from the operational suites, ARPEGE and AROME. 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: Africa and Middle East on the one hand, China on the other hand. Other aerosols taken into account are: sea salt, black carbon and other Particulate Matter (PM). Since 2015, MOCAGE code has been taking into account the formation of inorganic aerosols through the ISORROPIA module, thus improving the PM forecasts during pollution episodes.

MOCAGE is also a central element of the contribution of Météo-France to the Regional Air Quality Production of the Copernicus Atmosphere Monitoring Service "CAMS50". For this operational service, MOCAGE runs daily to provide air quality forecasts and analyses over Europe. The current operational configuration is the following : A global domain (globe, 2° resolution) and a regional domain (Europe wide : 30°N - 70°N, 25°W - 45°E); 47 vertical levels up to 5 hPa ; meteorological forcings from the operational suites, IFS and chemical forcings from the CAMS C-IFS global production, MOCAGE-CAMS provides daily forecasts for up to 96h in advance and analyses of the previous day for 10 species : ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2), carbon monoxide (CO), particulate matters below 10 mm (PM10) and below 2.5 mm (PM2.5), nitrogen monoxide (NO), ammonia (NH3), peroxyacetyl-nitrates (PANs), non-methane Volatile Organic Compounds (NMVOC) and birch, olive, ragweed and grass pollen (during season). MOCAGE CAMS is also operated in that context to produce interim and validated reanalyses (Reanalyses for the previous Year and for the Year-2).

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 AROME-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 (Rhone, Garonne and Seine) has been extended over France with a fixed grid of 8 km.
A new version of SIM suite, named SIM2 has been implemented in 2017 with improvements of the soil water processes.
The hydrological model SIM2 is currently operational at Météo-France in analysis mode over France and in forecast mode at medium range with input coming from EPS and for seasonal forecast with input coming from MF Syst 6. **Road Weather**

Météo-France uses a specific model (ISBA-Route) for road surface conditions forecasting. This road model is operationnaly used to provide forecast (1km scale, 96 hour range, 4 runs/day at 0, 6, 12 and 18 UTC) of road surface conditions in France (road surface temperature, water and ice height on road). The input atmospheric forcing is elaborated from forecasters expertized atmospheric fields. A new system is currently under development, in following months the ISBA-Route road model will be directly used with the ensemble AROME-EPS atmospheric forecast (2.5 km, 12 members) to elaborate probalistic products dedicated to road managers.

4.5.2.2 Research performed in this field

Research and Development activities for tropical cyclone numerical prediction are conducted by the Météo-France team in La Réunion (South-West Indian Ocean) in collaboration with Toulouse. Research work is also conducted for using the non-hydrostatic 2.5 km Arome model for cyclone prediction with the implementation of an 1D ocean model initialized with Mercator operational products. The sensitivity of intensity forecasts to different parameters is under investigation, and a 3D-Var configuration is under development for research purpose.

For applications related to hydrology, snow and atmospheric chemistry, Météo-France uses specific models like SIM (Safran, Isba, Modcou, - hydrology), Mocage (chemistry and pollution). These models are generally younger than the NWP model ARPEGE. Moreover they require this NWP model for their coupling. The research covers at least three aspects: (i) Propagation and management of the uncertainty in the overall chain which covers both the NWP and the specific model; (ii) Development, validation or tuning of the specific processes (run-off; reactive gas, etc…); (iii) Assimilation of specific observations, including, for chemistry observations, studies helping the definition of future satellite missions.

On-going research and development activities for MOCAGE are mainly focussed on:

- refining the resolution of MOCAGE at 2.5 km over France and interfacing a new anthropogenic emission inventory at 1 km resolution,
- implementing a limited-area 0.2°-resolution domain for MOCAGE-Accident,
- preparing for the assimilation of aerosol observations coming from ground-based lidars (E-PROFILE from EUMETNET), and satellite lidars (CALIPSO, ADM-Aeolus and EarthCare) and imagers defiling and geostationary satellites,
- assessing the benefit of using the MOCAGE gas and aerosol profiles as an input of the radiative transfer modules of ARPEGE.
- Proposing new outputs according to users needs (VAAC and CMRS)

On-going research and development activities for PERLE are mainly focussed on:

- updating the lagrangian particle dispersion model in PERLE
- implementing a new version that consider higher vertical levels

- implementing a new version that enlarge the current domain to a bigger one : 500 km * 500 km
-

4.5.3 Specific products operationally available

Monthly forecast bulletins are based on ECMWF monthly forecast products. Statistical post-processing of 2m-temperature is performed with the ECMWF monthly forecast system output up to day 32.

4.5.4 Operational techniques for application of specialized numerical prediction products *(MOS, PPM, KF, Expert Systems, etc..)* (as appropriate related to 4.5)

4.5.4.1 In operation

Météo-France operates the Regional Air Quality Production of CAMS over Europe (Marécal et al, 2015). The daily forecasts and analyses of seven operational models that are operated in Europe (CHIMERE from INERIS, EMEP from Met. Norway, EURAD-IM from RIUUK, MATCH from SMHI, MOCAGE from Meteo-France and SILAM from FMI) are received at Météo-France, and then processed to deliver ENSEMBLE fields. The ENSEMBLE is presently based on the median value of the seven models.

Statistical post-processing is performed for the MOCAGE ozone forecasts : linear MOS + kriging with external drift to spatialize the corrections at the O3 stations.

4.5.4.2 Research performed in this field

4.5.5 Probabilistic predictions (where applicable)

4.5.5.1 In operation

The Regional Air Quality Production of CAMS over Europe delivers EPSgrams at the location of the 41 European capitals, providing an estimate of the uncertainty of the air quality forecasts at these locations.

4.5.5.2 Research performed in this field

4.5.5.3 Operationally available probabilistic prediction products

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

4.6.1 In operation

4.6.2 Research performed in this field

With the same system 5 as in LRF (see below) we produce 32-day forecasts on a weekly basis in quasi-real time. This is our contribution to the international S2S project, led by ECMWF. The hindcast period starts in 1993. Most research is devoted to the predictability of rainfall over Nouvelle-Calédonie (a South Pacific island).

4.6.3 Operationally available EPS products

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

4.7.1 In operation

Météo-France produces operational seasonal forecasts with its system 5. System 5 has been integrated in the multi-model EUROSIP in June 2016 and is currently the new operational version for seasonal forecast. System 5 is described by a technical documentation available at
http://www.cnrm.meteo.fr/IMG/pdf/system5-technical.pdf

A detailed algorithmic description of the atmosphere model ARPEGE can be found at:
http://www.cnrm.meteo.fr/gmgec/arpege-climat/ARPCLI-V5.1/index.html
The sea-ice model GELATO is described at:
http://www.cnrm.meteo.fr/spip.php?rubrique225
The ocean model NEMO is described at
http://www.nemo-ocean.eu/

Issue frequency:	Monthly
Temporal resolution:	[averages, accumulations or frequencies over 1-month or 3-months (seasons)]
Spatial resolution:	[0.75° x 0.75°]
Spatial coverage:	*[Global]*
Lead time:	[Any lead time between 0 and 4 months for seasons, between 0 and 6 for months]
Output types:	[graphical images http://elaboration.seasonal.meteo.fr]
Verification as per WMO SVSLRF	*(a) location of verification : http://elaboration.seasonal.meteo.fr/fr/content/scores-arpege-sys5 ; (b) if the verification is completed on at least 15 years hindcasts: Y; (c) other than ensemble size, if the prediction system is used in operations identical to that used in hindcast verification :Y*

Since April 2018, another operational system has started, in the framework of the European Copernicus program. This new system 6 is based on a version of the model close to the climate model used in the CMIP6 international experiment.
System 6 is described by a technical documentation available at
http://www.umr-cnrm.fr/IMG/pdf/system6-technical.pdf
This new system includes a higher horizontal resolution in the atmosphere and a higher vertical resolution in the ocean. The physical parameterizations of the atmosphere component have been widely renewed (see 2017 report).

System 5 should stop with the end of EUROSIP in late 2018.

4.7.2 Research performed in this field

In the preparation of the next systems, we have investigated a few potential improvements. The next major upgrade will be the 0.25° resolution ocean model (NEMO). The definite evaluation of this upgrade requires a new ocean reanalysis 1993-2016 available in late 2018. We have investigated the role of a higher vertical resolution in the atmosphere, leading to a better prediction of the stratospheric polar vortex in the northern hemisphere, but to little impact in the troposphere. We have driven the atmosphere with monthly reconstructed aerosols, instead of climatological ones in our operational system. This has only local impacts. Promising results on near surface summer temperature predictability have been found with the improvement of soil moisture, either by driving the soil model SURFEX with reanalyses, or by correcting in line model precipitation. The probabilistic predictability of near surface summer temperature in South Europe can be additionally improved by introducing the higher resolution (12 km) limited area model ALADIN.

4.7.3 Operationally available products

Toulouse is recognized as GPC for LRF (WMO-CBS – November 2006) and RCC_LRF for WMO RA VI and provides different LRF products for NMS users in a dedicated website : http://elaboration.seasonal.meteo.fr/en

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 (0.75° by 0.75°).

Variable:		Probabilities for tercile categories of 2m temperature	Probabilities for tercile categories of precipitation	Probabilities for tercile categories of SST (coupled models only)
Spatial resolution:		[0.75° x 0.75°]	[0.75° x 0.75°]	[0.75° x 0.75°]
Temporal Resolution:		1-month or 3-months	1-month or 3-months	1-month or 3-months
Coverage:		*[Global]*	*[Global]*	*[Global]*
Issue frequency:		*[montly]*	*[montly]*	*[montly]*
Lead-time	L0	Y	Y	Y
	L1	Y	Y	Y
	L2	Y	Y	Y
	L3	Y	Y	Y
	L4	Y	Y	Y
	L4+	Y	Y	Y
Location of rendered images:		http://elaboration.seasonal.meteo.fr/fr/content/prevision-arpege-sys5	http://elaboration.seasonal.meteo.fr/fr/content/prevision-arpege-sys5	http://elaboration.seasonal.meteo.fr/fr/content/prevision-arpege-sys5

5. Verification of prognostic products

5.1 Annual verification summary :

Scores against analyses

	24 hours			72 hours			
	NH	SH	TR		NH	SH	TR
Z500 RMSE	7.0	8.6			22.1	27.0	
W250 RMSEV	3.9	4.1	4.0		8.6	9.2	6.8
W850 RMSEV			2.7				3.9

NH : Northern Hemisphere SH : Southern Hemisphere TR : Tropics

Scores against observations

24 hours

	NA	EU	AS	AU/NZ	TR	NH	SH
Z500 RMSE	9.4	9.4	12.9	8.4		12.0	11.3
W250 RMSEV	6.1	5.2	5.4	5.2	5.3	5.3	5.7
W850 RMSEV	3.9	3.7	3.7	4.2	3.9	3.8	4.4

72 hours

	NA	EU	AS	AU/NZ	TR	NH	SH
Z500 RMSE	22.9	23.4	21.3	17.8		23.3	21.7

W250 RMSEV	10.4	9.8	9.0	8.6	7.2	9.2	9.3
W850 RMSEV	5.6	5.4	5.3	5.6	4.7	5.4	6.0

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

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

6.1 Development of the GDPFS

6.1.1 [major changes in the Operational DPFS which are expected in the next year]

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, Long-range Forecasting and Specialized Numerical Predictions

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

6.2.1 Planned Research Activities in NWP

Researches will focus on:

- improving many aspects of data assimilation, including extending the use of ensembles aside of variational data assimilation, improving the preconditioning of the variational minimizations, comparing various ways of using heterogeneous error correlations, the pros and cons of frequent 3D-Var analyses compared to 4D-Var for fine scale data assimilation, including versions of 4D-Var no more requiring adjoint models, including also surface data assimilation
- assimilation of observations, sometimes new ones, sometimes through improved usage of existing ones, focusing on the short term on cloudy radiances and new radar-derived data such as polarization, and, on the longer term, especially those that can improve the forecast of intense precipitation events (rain, snow) and visibility (fog, low could, aerosol); the use of remote sensing for surface data assimilation will also be a research topic;.
- A challenging NWP research topic is mesoscale data assimilation within cloud and precipitation that needs dedicated researches on observation operators and background error modelling. Improving parameterizations within the grey zone of the turbulence modelling is an other major research goal for kilometric and sub-kilometric scale NWP.
- an important new topic is predictability at convection-permitting scale and the development of an ensemble of convection-permitting models, its related ensemble assimilation configuration and its relationship with the ensemble, often of much larger size, that provides its lateral boundary conditions; here, the objective is to be able to implement a small ensemble 2.5km Arome on the next computer
- Research concentrates on definition and evaluation of dedicated perturbation generation methods for the convective scale and short forecast range. Coupling of this convection-permitting ensemble

prediction system with impact models such as hydrological models to issue probabilistic flash-flood forecasting is envisioned

- but some research work should continue on some aspects of the PEARP global (with zoom) ensemble, such as its representation of model error and the calibration of its products
- continuing work on precipitating convection parameterizations for the hydrostatic weather and climate forecast models, as well as on non-precipitating convection as a form of non-isotropic turbulence, with a view to ensure a smooth transition from parameterized convection scales to convection permitting scales
- the composite surface model SURFEX will continue to be expanded and further developed, while its usage will be even more ubiquitous, both off-line and closely coupled to all the atmospheric models. Evaluation of the benefits for each Météo-France climate and NWP systems of the science advances in surface modelling integrated within the externalized surface model SURFEX (ISBA schemes for natural surfaces, TEB for town, FLAKE for lake and air/sea fluxes parameterizations)
- the ability of the current base numerical discretization scheme employed in all our models to (i) remain efficient on new computer architectures (ii) enable further resolution increase in the hectometric scales will be reviewed, experience with alternative schemes will be acquired
- explore the importance of the feed-back between "water microphysics" and atmospheric chemistry (including aerosol) for short-range fine scale weather forecast, again with a view to improve fog and low visibility situations forecast; improving the microphysics schemes in various ways is also a topic of interest, with a view to provide explicit hail forecasts, for example,
- study the transition from the current representation of turbulence with a mix of coupled schemes to 3D turbulence
- evaluation of the benefits of coupling atmospheric mesoscale models with coastal ocean models for short-range forecast
- satellite data assimilation methods for the mountain snow cover
- modelling of the snow in plain taking into account progress in observation

Part of the above research activities will rely on process studies carried out within the framework of WWRP/THORPEX related field campaigns such as HyMeX (water cycle in Mediterranean) or T-NAWDEX (Rossby wave breaking over the Atlantic Ocean). They provide also an opportunity to develop seamless picture from the forecasting perspective to the climate point of view.

Experimentations will be performed with AROME using 500m horizontal resolution to evaluate the potential of such configuration for NWP depending on miscellaneous areas.

The next computer procurement project begins this year, with a view to replace the current NEC SX8 and SX9 systems at the beginning of 2014. Some resolution increases will then be implemented, with the Arome system changing from 2.5km to 1.3km for example. New applications will be introduced such as the above mentioned Arome ensemble, few instances of Arome 500m and a dedicated nowcasting Arome suite (see below). The oversea Aladin suites should be replaced by IFS itself by 2015, and refined forecast on the most populated islands will be provided by dedicated implementations of Arome.

6.2.2 Planned Research Activities in Nowcasting

Nowcasting will rely more and more on specific NWP-like approaches and products,. Research will use dedicated versions of the Arome data assimilation and forecast system. The ability of such models to properly handle convective cells, both in a frequent assimilation cycle and during the very first hours of model integration, is likely to remain an important research challenge. As indicated above, the aim is to replace the current hourly uncycled analysis by an Arome based full suite as soon as possible. The new needs of air traffic control management and optimization provide the initial incentive for this research, but there are others such as improving weather crisis management at local scale.
In the HAIC FP7 project *(*www.**haic**.eu/) RDT is evaluated regarding its performances concerning high IWC (Ice Water Content) risk.

6.2.3 Planned Research Activities in Long-range Forecasting

Météo-France is involved in Seasonal Forecasting and initiates studies about Decadal Forecasting. These operational and research activities are largely connected to the ones related to climate modeling activities. Météo-France is now preparing a next seasonal forecast system which will include a new set of physical parameterizations, as close a possible to the NWP and the CMIP6 versions. Horizontal resolution will be increased from tl255 to tl359 in the atmosphere.

Seasonal forecast is carried out in a large European context (EUROSIP). During the next few years, Météo-France will also contribute to COPERNICUS climate services.

The potential of seasonal forecast applied to water resources will be addressed and specific operational products should be delivered by 2016.

Operational products downscaled from seasonal forecast will be delivered for French oversea countries.

Some other research studies are also planned in the field of long-range predictability. This concerns in particular the role of continental surfaces and the role of the stratosphere on predictability. This also concerns the predictability of sea-ice coverage at the seasonal time scale.

6.2.4 Planned Research Activities in Specialized Numerical Predictions

AERONAUTICS : A specific model, called AROME-Airport, is being developed to provide detailed forecast in the TMA of an airport. The resolution will be 500m, the domain about 100kmx100km.. It will be run from the nowcasting version of Arome mentioned above, which may use specific observations such as new types of radars or boundary-layer dedicated instruments.

AIR QUALITY: for the Météo-France atmospheric chemistry model MOCAGE, on the main research activities are about:

4. the assimilation of aerosol lidar profiles and aerosol optical depth (both from ground-based and space-borne instruments), with the particular purpose of volcanic ash monitoring but also for air quality forecasts,
5. extended assimilation of in-situ observation, mostly in the context of the CAMS Air Quality Regional Production,
6. the refinement and extension of the aerosol scheme: formation of organic secondary aerosols, review of the multi-phasic equilibriums,
7. the refinement of emission processes, including the introduction of cycles for biogenic emissions (MEGAN), and taking into account how meteorology drives the emissions of some precursors (NH3 for instance),

development and optimization of the chemistry schemes and solver.

Meteo-France also develops and runs, sometimes in close cooperations with dedicated scientific communities, hydrological models, snow models, surface state models downstream of its NWP models,.

7. Consortium

7.1 System and/or Model

7.1.1 In operation

7.1.1 Planned Research Activities in NWP1

7.2 System run schedule and forecast ranges

7.3 List of countries participating in the Consortium

7.4 Data assimilation, objective analysis and initialization

7.4.1 In operation

7.4.2 Research performed in this field

7.5 Operationally available Numerical Weather Prediction (NWP) Products

7.6 Verification of prognostic products

7.7 Plans for the future (next 4 years)

7.7.1 Major changes in operations

7.7.2 Planned Research Activities

8. References

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/

P. Bénard, R. Laprise, J. Vivoda and P. Smolíková. 2004: Stability of Leapfrog Constant-Coefficients Semi-Implicit Schemes for the Fully Elastic System of Euler Equations: Flat-Terrain Case. *Mon. Wea. Rev.,* **132,** 1306–1318.

Bougeault P., 1985 : "Parameterization of cumulus convection for Gate. A diagnostic and semi-prognostic study". *Mon. Wea. Rev.*, 113, 2108-2121.

Bougeault and Lacarrère 1989: Parametrization of orography-induced turbulence in a Mesobeta-scale model, Mon. Wea.Rev, 117, 1872-1890

Bouteloup Y., 1995: "Improvement of the spectral representation of the earth topography with a variational method", *Mon. Wea. Rev.,* 123, 1560-1573

Cathala, M.-L., J. Pailleux and V.-H. Peuch, 2003 : Improving global simulations of UTLS ozone with assimilation of MOZAIC data, *Tellus*, 55B, 1-10.

Courtier, P. and J.F. Geleyn, 1988 :"A global numerical weather prediction model with variable resolution: application to the shallow-water equations"". *Quart. J. Roy. Meteor. Soc.*, 1114, 1321-1346.

Cuxart et al. 2000: A turbulence scheme allowing for mesoscale and large eddy simulations, Quart. J. Roy. Met. Soc. 126, 1-30. DOI: 10.1002/qj.49712656202

Ducrocq, V. D. Ricard, J.-P. Lafore and F. Orain, 2002: Storm-scale numerical rainfall prediction of precipitating events over France: on the importance of the initial humidity field. *Wea. Forecast.* **17,** 1236-1256.

Dufour, A., M. Amodei, G. Ancellet and V.-H. Peuch, 2004 : Observed and modelled "chemical weather" during ESCOMPTE, *Atmos. Res.*, in press.

Durand, Y., E. Brun, L. Merindol, G. Guyomarc'h, B. Lesaffre, and E. martin, A meteorological estimation of relevant parameters for snow schemes used with atmospheric models, *Ann. Of Glaciol*., 18, 65-71, 1993.

Giard, D., and E. Bazile, 1999 : Implementation of a new assimilation scheme for soil and surface variables in a global NWP model, submitted to *Mon. Wea. Rev.*.

Guérémy 2011: A continuous buoyancy based convection scheme: one and three dimensional validation. DOI 10.1111.j.1600-0870.2011.00521.x. Tellus, 63A, 687-706

Guérémy, J.-F., Laanaia, N., and Céron, J.-P.: Seasonal forecast of French Mediterranean heavy precipitating events linked to weather regimes, Nat. Hazards Earth Syst. Sci., 12, 2389-2398, doi:10.5194/nhess-12-2389-2012, 2012.

Lefèvre, F., G. P. Brasseur, I. Folkins, A. K. Smith and P. Simon, 1994 : Chemistry of the 1991-1992 stratospheric winter : three-dimensional model simulations, *J. Geophys. Res.*, 99(D4), 8183-8195.

Louis J.F., 1979: "A parametric model of vertical eddy fluxes in the atmosphere", *Bound. Lay. Met.,* 17, 187-202

Lafore , J.-P. et al., 1998 : The Meso-NH atmospheric simulation system. Part 1 : Adiabatic formulation and control simulations. *Ann.Geophysicae*, **16**, 209-228.

Lynch, P., D. Giard and V. Ivanovici, 1997 : Improving the efficiency of a digital filtering scheme for diabatic initialization, *Mon. Wea. Rev.*, 125, 1976-1982

Lopez 2002: Implementation and validation of new prognostic large-scale cloud and precipitation scheme for climate and data-assimilation purposes. Quart. J. R. Met. Soc. 128, 229-257.

Louis J.F., M. Tiedtke and J.F. Geleyn, 1981 :"A short history of the PBL parameterization at ECMWF". *ECMWF Workshop on PBL parameterization,* ECMWF, Reading, UK, 59-80.

Marécal, V., Peuch, V.-H., Andersson, C., Andersson, S., Arteta, J., Beekmann, M., Benedictow, A., Bergström, R., Bessagnet, B., Cansado, A., Chéroux, F., Colette, A., Coman, A., Curier, R. L., Denier van der Gon, H. A. C., Drouin, A., Elbern, H., Emili, E., Engelen, R. J., Eskes, H. J., Foret, G., Friese, E., Gauss, M., Giannaros, C., Guth, J., Joly, M., Jaumouillé, E., Josse, B., Kadygrov, N., Kaiser, J. W., Krajsek, K., Kuenen, J., Kumar, U., Liora, N., Lopez, E., Malherbe, L., Martinez, I., Melas, D., Meleux, F., Menut, L., Moinat, P., Morales, T., Parmentier, J., Piacentini, A., Plu, M., Poupkou, A., Queguiner, S., Robertson, L., Rouïl, L., Schaap, M., Segers, A., Sofiev, M., Tarasson, L., Thomas, M., Timmermans, R., Valdebenito, Á., van Velthoven, P., van Versendaal, R., Vira, J., and Ung, A.: A regional air quality forecasting system over Europe: the MACC-II daily ensemble production, Geosci. Model Dev., 8, 2777-2813, doi:10.5194/gmd-8-2777-2015, 2015.

Masson, V., Le Moigne, P., Martin, E., Faroux, S., Alias, A., Alkama, R., Belamari, S., Barbu, A., Boone, A., Bouyssel, F., Brousseau, P., Brun, E., Calvet, J.-C., Carrer, D., Decharme, B., Delire, C., Donier, S., Essaouini, K., Gibelin, A.-L., Giordani, H., Habets, F., Jidane, M., Kerdraon, G., Kourzeneva, E., Lafaysse, M., Lafont, S., Lebeaupin Brossier, C., Lemonsu, A., Mahfouf, J.-F., Marguinaud, P., Mokhtari, M., Morin, S., Pigeon, G., Salgado, R., Seity, Y., Taillefer, F., Tanguy, G., Tulet, P., Vincendon, B., Vionnet, V., and Voldoire, A. (2013). The SURFEXv7.2 land and ocean surface platform for coupled or offline simulation of earth surface variables and fluxes, Geosci. Model Dev., 6, 929-960, doi:10.5194/gmd-6-929-2013.

Morcrette, J.-J., 1991 : Radiation and clouds radiative properties in the European center for medium-range weather forecasts forecasting system. J. Geophys. Res., 96, 9121-9132.

Morcrette, J.-J., and Y. Fouquart, 1985: On systematic errors in parametrized calculations of longwave radiation transfer. Quart. J. Roy. Meteor. Soc., 111, 691-708.

Nicolau, J., 2002. Short-range ensemble forecasting. WMO/CSB Technical Conference meeting, Cairns (Australia), December 2002 (Proceedings).

Noilhan, J., and S. Planton, 1989 : A simple parameterization of land-surface processes for meteorological models, *Mon. Wea. Rev.,* 117, 536-549

Peuch, V.-H., M. Amodei, T. Barthet, M.-L. Cathala, B. Josse, M. Michou and P. Simon, 1999 : MOCAGE, MOdèle de Chimie Atmosphérique à Grande Echelle, Proceedings of “Atelier de Modélisation de l’Atmosphère”, Météo-France, December 1999, 33-36.

Piedelievre J.P., L. Musson-Genon and F. Bompay, 1990: MEDIA - An Eulerian model of atmospheric dispersion: first validation on the Chernobyl release, *Jour. of Appl. Met.*, vol. 29, N° 12, 1205-1220

Piriou et al. 2007: An approach for convective parameterization with memory, in separating microphysics and transport in grid-scale equations. DOI: 10.1175/2007JAS2144.1. Journal of Atm. Science, 64, 4127-4139.

Ricard, J.-L., and J.-F. Royer, 1993: A statistical cloud scheme for use in an AGCM. Ann. Geophys. 11, 1095-1115

Seity Y., P, Brousseau, S. Malardel, G. Hello, P. Benard, F. Bouttier, C. Lac and V. Masson, (2011) : The AROME-France convective-scale operational model, Monthly Weather Review, 976-991 (139

Simmons A.J. and D.M. Burridge, 1981 : "An energy and angular momentum conserving vertical finite difference scheme on a hybrid vertical coordinate". *Mon. Wea. Rev.*, 109, 758-766.

Watterson, I.G., J. Bathols and C. Heady, 2014. What Influences the Skill of Climate Models over the Continents? Bull. Amer. Meteor. Soc., 95, 689–700. doi: 10.1175/BAMS-D-12-00136.1

World Meteorological Organization, 1998 : Scientific assessment of ozone depletion 1998, Global Ozone Research and Monitoring Project, WMO report n°44.

Xu, K.M. and D. Randall, 1996: A semi-empirical cloudiness parameterisation for use in climate models. *J. Atm. Sci*., **53,** 3084-3102.

Yessad K. and P. Bénard, 1996 :"Introduction of a local mapping factor in the spectral part of the Météo_france global variable mesh numerical model". *Quart. J. Roy. Meteor. Soc.*, 122, 1701-1719.