The Météo-France operational NWP system: description and recent changes (May 2016)

1. Formulation

1.a. System overview

The atmospheric models used in Météo-France for NWP and climate modeling are all derived from the IFS/ARPEGE software. Different formulations are used in each configuration as a compromise between computational cost, meteorological performance and the timing of new scientific developments.

The resolutions and grids used by the different configurations are listed in the following table.

ARPEGE global system:

- horizontal grid: global with Schmidt projection, spectral T1198c2.2 (i.e. resolution from 7km over France to 33km over the South Pacific),
- vertical grid & time-step: L105 & dt=360s, lowest and highest model levels at 10m and 0.1hPa
- data assimilation: 6-hourly incremental 4D-Var with T149c1 (135km) and T399c1 (50km) increments,
- forecasts: to about 4 days, 4 times per day up to 114h

ARPEGE Ensemble Data Assimilation (AEARP):

- horizontal grid: global uniform resolution T479
- vertical grid : L105
- data assimilation: 6-hourly incremental 4DVar with T149 increments
- forecasts: 25 members, 6-h cycle

ARPEGE global Ensemble Prediction System (PEARP):

- horizontal grid: global Schmidt T798c2.4 (i.e. 10km to 60km),
- vertical grid : L90
- initialization: 25 background states and the mean of AEARP, singular vectors computed over 7 areas
- forecasts: 35 members using 10 physical packages, twice per day: 90 h range from 06UTC analysis, 108 h range from 18UTC analysis

AROME-France system:

- horizontal grid: regional Lambert, one domain with 1.3km (1536x1440) grid
- vertical grid & time-step: L90 & dt=50s
- data assimilation: 1-hourly 3DVar with assimilation of radar reflectivities and radial winds
- forecasts: 5 times per day up to 42h

AROME-France nowcasting system:

- same geographical domain, model and analysis configuration as AROME-France, 1.3km L90
- hourly analysis with very short cut-off (~10 min) and 6h forecast

AROME-Overseas system:

- horizontal grid: regional Lambert, five domains at 2.5km L90
- dynamical adaptation using IFS for initial and lateral conditions, 4 times per day up to 42h

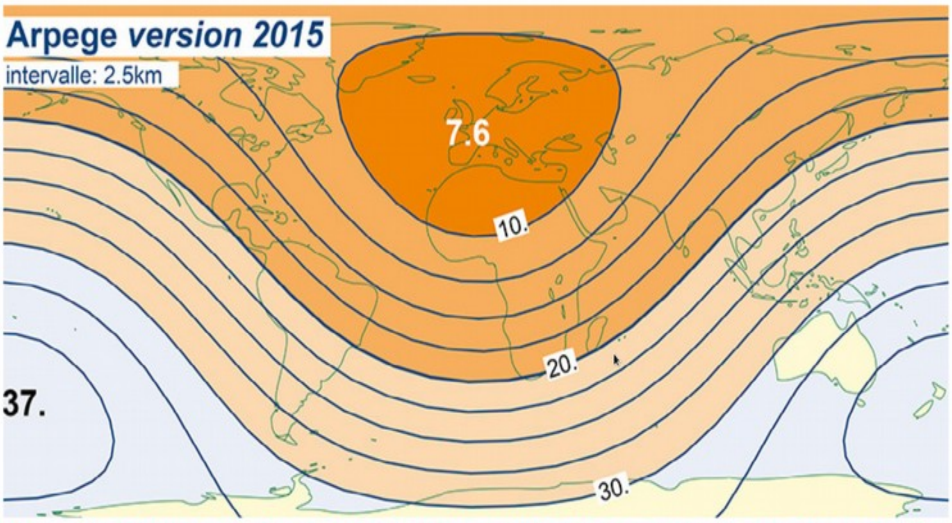
AROME regional Ensemble Prediction System (PEARO):

(to be operational by end 2016)

- horizontal grid: same geographical domain as AROME-France, 2.5km L90 grid
- initial conditions and perturbations from PEARP, initial condition centered on interpolated Arome-1.3km analysis perturbed surface & model physics (SPPT stochastic scheme)
- forecasts: 12 members, twice per day: 42h range from 09 and 21UTC

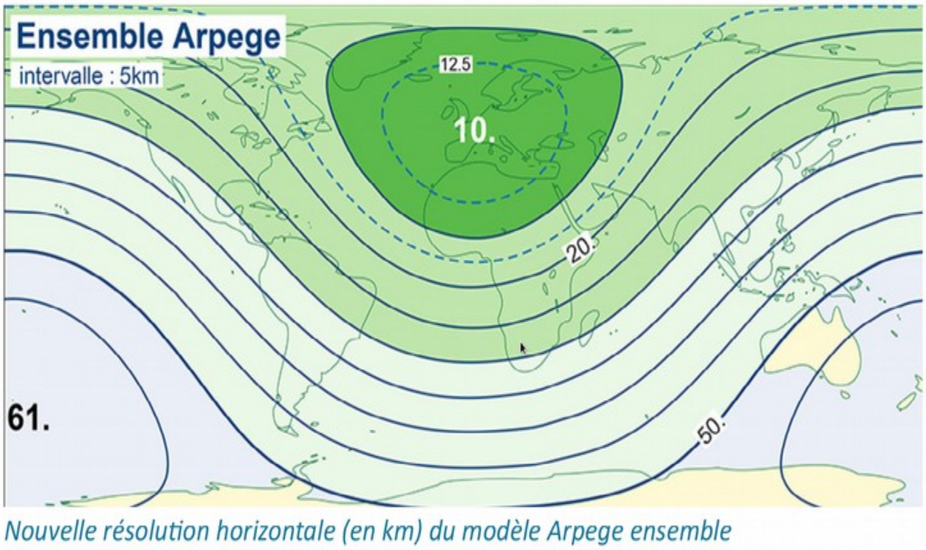
Several ALADIN (limited-area version of ARPEGE model) and AROME configurations in dynamical adaptation are used operationally for assistance and commercial purposes.

The ARPEGE and PEARP horizontal resolutions, the AROME-France and the AROME-Overseas geographical domains are shown by the following maps.

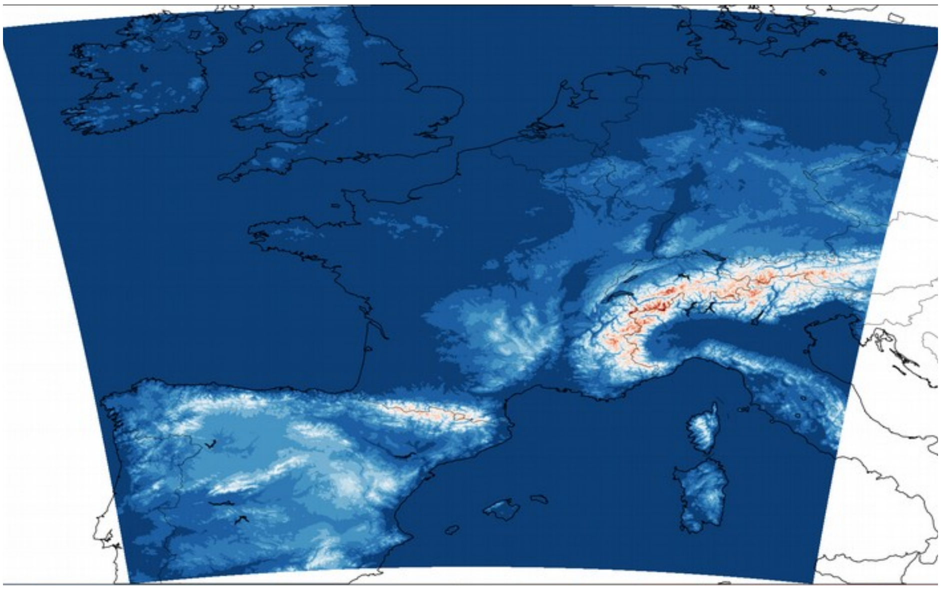


Nouvelle résolution horizontale (en km) du modèle Arpege en version « déterministe »

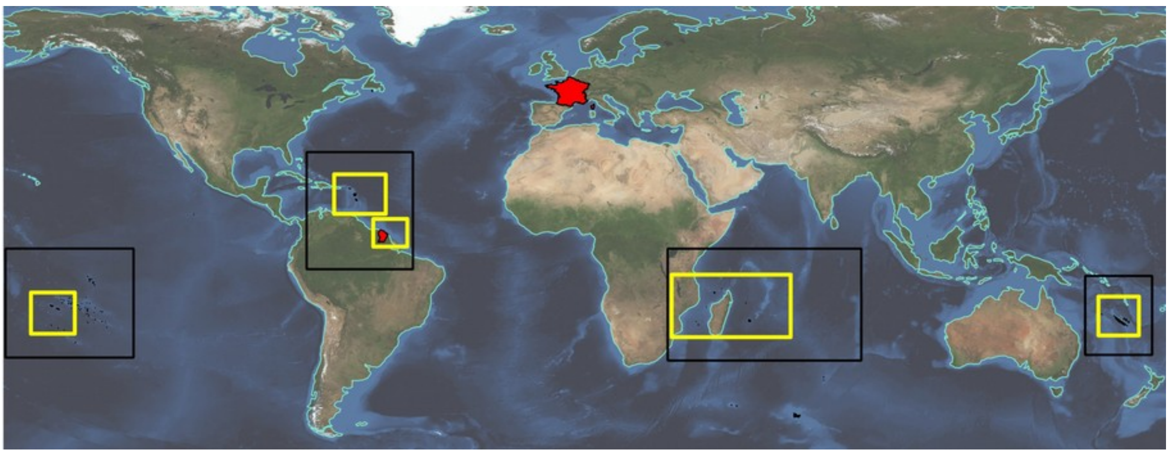
ARPEGE horizontal resolution (in km)



PEARP horizontal resolution (in km)

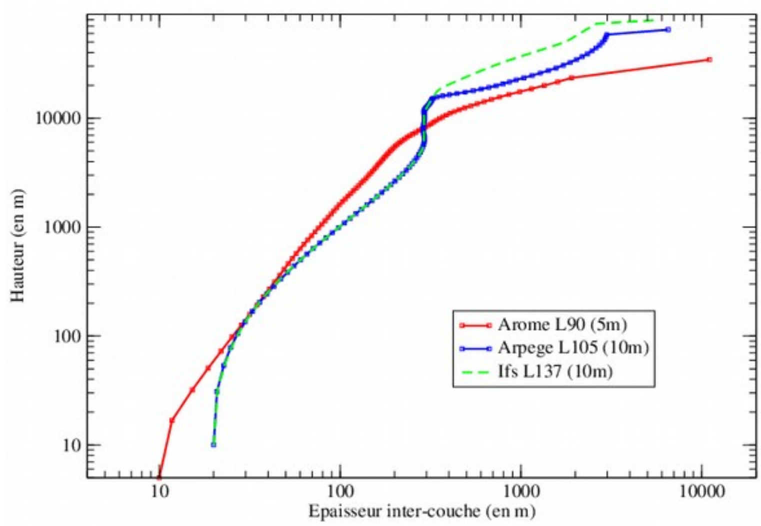


AROME-France, AROME-Nowcasting, AROME-EPS geographical domain



AROME-Overseas geographical domains (in yellow)

The vertical resolutions over low terrain are represented in the following figures for AROME, ARPEGE and IFS systems.



1.b. Discretization & dynamics

The atmospheric models rely on a spectral discretisation in the horizontal, and a mass-based grid in the vertical, which is terrain-following near the surface and evolving to constant pressure at model top.

In the horizontal all model variables are held at the same points and the spectral technique is used to compute exact derivatives. The global models use a triangular spectral truncation of spherical harmonics (i.e. Legendre functions times Fourier transforms), and a reduced Gaussian collocation grid. All models use a quasi-linear collocation, so that there is virtually no spectral aliasing. The ARPEGE model uses a stretched Schmidt conformal mapping with maximum resolution over France, minimum resolution in the South Pacific, and a smooth variable horizontal resolution in between. The ALADIN and AROME regional models use a Lambert conformal projection with a bi-Fourier spectral representation and elliptical truncation. Periodicity of the bi-Fourier representation on a two-dimensional torus is achieved via a numerical extension zone. All models except the stretched ARPEGE have quasi-uniform resolution over the whole extension domain. The spatial distribution of the ARPEGE resolution is shown in the following figure (the colors indicate the horizontal resolution of the collocation grid). Reference:

Courtier, P. and J.-F. Geleyn, 1988: A global numerical weather prediction model with variable resolution: application to the shallow-water equations. Quart. Jour. Roy. Meteor. Soc., 114, 1321-1346.

Yessad, K. and P. Bénard, 1996 : Introduction of a local mapping factor in the spectral part of the Meteo-France global variable mesh numerical weather forecast model. Quart. Jour. Roy. Meteor. Soc., 122, pp. 1701-1719.

In the vertical all model variables are held at the same levels except vertical velocity which is staggered. The geometry of the vertical discretisation is summarized below for the highest and lowest levels in a standard atmosphere (over orography the lower levels are stretched to remain at a quasi constant height above ground, the stretching reduces to nil above 100hPa where the levels are pure pressure-levels). These are 'full' model levels, i.e. the ones that hold the prognostic variables.

ARPEGE and ALADIN use the hydrostatic primitive equations form of the adiabatic equations, with a thin layer approximation of the atmosphere. The dynamical prognostic variables are surface pressure, temperature, concentration of water vapor, and horizontal wind. Other advected 3D fields include cloud and precipitating water species (four prognostic variables), which are coupled to the dynamics through changes in density and specific heat of the moist air particles. Turbulent kinetic energy is also a 3D advected variable. Advection is computed using a semi-Lagrangian scheme. Advection and physics tendencies are computed on a physical collocation grid: a Gaussian reduced grid of the Earth surface with variable-mesh Schmidt conformal mapping in ARPEGE, a regular x-y grid on a conformal Lambert projection in ALADIN and AROME. The remaining computations (horizontal derivatives, horizontal numerical diffusion, dry dynamical computations and timestepping) are performed in spectral space, which is defined on the model's horizontal surfaces: using spherical harmonics (i.e. Legendre polynomials) in ARPEGE, using 2D fast Fourier transforms in ALADIN and AROME. The 2D fast Fourier transforms involve a biperiodization of the horizontal fields in the x and y directions, the biperiodization is done using a thin numerical grid extension zone on the sides of the ALADIN and AROME domains. The biperiodization is only a numerical device to facilitate spectral computations, its impact on the physical gridpoint values is negligible.

The spectral timestepping uses a spectral semi-implicit solver of the linearized dynamical equations, whereby the fast waves are treated implicitly, so that the timestep of the model discretisation is limited by accuracy, rather than stability, constraints. Horizontal wind is represented by vorticity and divergence. In ARPEGE and ALADIN, the dynamical equations are the hydrostatic primitive equations (HPE) system on a mass-based vertical coordinate, vertical wind is diagnosed through mass conservation and hydrostatic balance constraints. In AROME, the dynamical equations are compressible non-hydrostatic equations on a hydrostatic pressure vertical coordinate, vertical wind is represented as a vertical divergence with suitable boundary conditions, the relative departure of pressure from hydrostatic pressure is a prognostic variable . Apart from the horizontal geometry and the presence of a lateral boundary condition (for coupling to a larger-scale model), the ARPEGE and ALADIN dynamical formulations are identical. They are themselves quasi identical to the IFS formulation of ECMWF, and strictly identical to the ARPEGE Climate model. With the exception of the non-hydrostatic parts of the dynamics, the AROME dynamical formulation is the same as IFS, ARPEGE, and ALADIN, and most of the software is identical. References:

P. Benard, J. Vivoda, J Masek. P. Smolikova, K. Yessad, C. Smith, R. Brozkova and J.-F. Geleyn., 2009: Dynamical kernel of the Aladin-NH spectral limited-area model: revised formulation and sensitivity experiments. Accepted for publication in Q. J. R. Meteorol. Soc. in Sept 2009.

Bubnová, R., G. Hello, P. Bénard and J.-F. Geleyn, 1995 : Integration of the fully elastic equations cast in the hydrostatic pressure terrain-following coordinate in the framework of the ARPEGE/ALADIN NWP system, Mon. Wea. Rev., 123, 515-535.

1.c. ARPEGE/ALADIN physics

The ARPEGE, ALADIN and AROME physics are currently restricted to representing physical interactions inside each model column. Chemical and aerosol fields are prescribed i.e. they are not interactive.

The ARPEGE and ALADIN physics comprise the following parametrization schemes. A general review is provided in:

Bouteloup, Y., E. Bazile, F. Bouyssel and P. Marquet, 2009: Evolution of the physical parametrisations of ARPEGE and ALADIN-MF. Aladin Newsletter 35, pp.48-58, available from http://www.cnrm.meteo.fr/aladin/newsletters/newsletters.html

Lopez microphysics: a prognostic cloud condensation and precipitation scheme, that accounts for 3D advection of condensed water fields, ice phase, and cloud cover representation. The sedimentation (i.e. fallout of precipitation and cloud condensates) part of the scheme uses an original statistical algorithm in order to save CPU without compromising physical accuracy. References:

Bouteloup, Y., F. Bouyssel and P. Marquet, 2006: Improvements of Lopez's prognostic large scale cloud and precipitation scheme. ALADIN newsletter 28, available from http://www.cnrm.meteo.fr/aladin/newsletters/newsletters.html

Bouteloup, Y. et al. 2011: Description of the sedimentation scheme used operationally in all Météo-France NWP Models. Tellus., 63A, 300–311.

Geleyn, J.-F., B. Catry, Y. Bouteloup and R. Brožková, 2008 : A statistical approach for sedimentation inside a micro-physical precipitation scheme, Tellus A, Volume 60 Issue 4, pp 649-662

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

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

RRTM/FM radiation: an adaptation of an older version of the ECMWF IFS radiation scheme, with two-stream representation of radiative transfer in sixteen infrared and six visible bands, and cloud/radiation interaction. The computation of transmissivities is updated every 3 hours. Monthly climatologies are used for ozone (function of latitude and pressure) and aerosols. References:

Fortuin, J.P.F. and Langematz, U. (1994): An update on the global ozone climatology and on concurrent ozone and temperature trends. Proceedings SPIE. Atmos. Sensing and Modeling, 2311, 207-216.

Mlawer, E. J., Taubman, S. J., Brown, P. D., Iacono, M. J. and Clough, S. A. (1997). Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave. J. Geophys. Res., 102D, 16663–16682.

Morcrette, J.-J. (1991). Radiation and cloud radiative properties in the ECMWF operational weather forecast model. J. Geophys. Res., 96D, 9121–9132.

Geleyn/Bougeault ACCVIMP convection: a parametrisation of the effects of subgrid, deep precipitating convective clouds, based on a idealised representation of updraughts and downdraughts inside each model column, simple microphysics, closure hypotheses and cloud cover assumptions. Reference:

Bougeault, P., 1985: A simple parameterization of the large-scale effects of cumulus convection. Mon. Wea. rev., 113, 2108-2121.

CBR/KFB turbulence: Vertical mixing scheme based on a prognostic turbulence scheme derived from the Cuxart-Bougeault-Redelsperger proposal, with the Bougeault-Lacarrère mixing length formulation (modified in order to account for shallow and deep convection turbulence effects). It is coupled to a Kain-Fristch-Bechtold non-precipitating shallow convection scheme that accounts for moist mixing by subgrid clouds such as cumuli and stratocumuli (top PBL entrainment scheme); subgrid shallow convection is a source of turbulence. Specific subgrid **orographic drag scheme**, using envelope orography. References:

Bougeault, P. and P. Lacarrère, 1989 : Parameterization of orography-induced turbulence in a meso-beta scale model, Mon. Wea. Rev.,117,1870-1888.

Cuxart, J., Ph. Bougeault, and J.L. Redelsperger, 2000: A turbulence scheme allowing for mesoscale and large eddy simulations. Q. J. R. Meteorol. Soc., 126, 1-30.

Bechtold, P., E. Bazile, F. Guichard, P. Mascart and E. Richard, 2001 : A mass flux convection scheme for regional and global models. Quart. Jour. Roy. Meteor. Soc., 127, pp. 869-886.

Catry, B., J.-F. Geleyn, F. Bouyssel, J. Cedilnik, R. Brožková, M. Derkova and R. Mladek, 2008: A new sub-grid scale lift formulation in a mountain drag parameterisation scheme , Meteorologische Zeitschrift, Vol 17, N.2, pp. 193-208(16)

Empirical wind drag scheme and sponge near the model top.

Prognostic land surface scheme derived from ISBA on land surfaces (i.e. bare soil + vegetation fraction), and a prescribed SST/ice field with Charnock parametrisation of mixing coefficients over sea, plus a simple snow-on-ground scheme. Prognostic surface fields include: soil liquid water and ice content on two levels, snow depth and albedo. The vertical mixing is implicitly coupled with the surface flux computation inside each timestep. The fluxes over sea are computed using the ECUME empirical formulae. References:

Belamari S., Caniaux G., and Tcham M., 2005: Optimisation of the one year POMME experiment bulk fluxes data set using a one dimensional approach together with genetic algorithms (poster). EGU Meeting, Vienne, 25-29 April, 2005.

Giard, D., and E. Bazile, 2000: Implementation of a new assimilation scheme for soil and surface variables in a global NWP model. Mon. Wea. Rev., 128, 997-1015.

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

Noilhan, J. and J.-F. Mahfouf, 1996: The ISBA land surface parameterization scheme. Global and Plan.

Change, 13, 145-159.

Surface physiographies are prescribed using global databases (GTOPT030 and Henderson-Sellers). Soil moisture and temperature are assimilated using a 6-hourly optimal interpolation to compensate for errors in observed SYNOP 2m temperature and humidities. Ice caps and SST are reinterpolated from NESDIS (SSMI-based) gridded products.

1.d. AROME physics

The AROME physics are distinct from the ARPEGE/ALADIN parametrizations, and strictly identical to the corresponding schemes in the Méso-NH model. A general documentation of the AROME system is provided in http://www.cnrm.meteo.fr/arome/

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)

ICE3 cloud microphysics and precipitation scheme with 5 prognostic 3D fields (cloud water and ice, precipitating rain, snow and graupel), using a conservative instantaneous adjustment scheme, and a statistical scheme to compute the sedimentation. References:

Geleyn, J.-F., B. Catry, Y. Bouteloup and R. Brožková, 2008 : A statistical approach for sedimentation inside a micro-physical precipitation scheme, Tellus A, Volume 60 Issue 4, pp 649-662

Pinty, J.P. & P. Jabouille, 1998 : A mixed-phased cloud parameterization for use in a mesoscale non-hydrostatic model: simulations of a squall line and of orographic precipitation. Preprints of Conf. On Cloud Physics, Everett, WA, Amer. Meteor. Soc., 217-220.

Vertical mixing scheme based on a prognostic turbulence scheme derived from the Cuxart-Bougeault-Redelsperger proposal, with the Bougeault-Lacarrère mixing length formulation. "EDKF" shallow subgrid (i.e. cumulus) convection scheme using an adaptation of the Kain-Fritsch scheme with a mass-flux closure approach.

Cuxart, J., Ph. Bougeault, and J.L. Redelsperger, 2000: A turbulence scheme allowing for mesoscale and large eddy simulations. Q. J. R. Meteorol. Soc., 126, 1-30.

RRTM/FM radiation scheme: the same as in ARPEGE/ALADIN-France, the transmissivities are updated every hour. References:

Mlawer, E. J., Taubman, S. J., Brown, P. D., Iacono, M. J. and Clough, S. A. (1997). Radiative transfer for inhomogeneous atmospheres: RRTM, a validated correlated-k model for the longwave. J. Geophys. Res., 102D, 16663–16682.

Morcrette, J.-J. (1991). Radiation and cloud radiative properties in the ECMWF operational weather forecast model. J. Geophys. Res., 96D, 9121–9132.

SURFEX surface scheme with a tiling approach and explicit coupling with the vertical diffusion. Four tiles are allowed in each model gridbox: nature, town, sea, lake. Sea/Lakes may be frozen, Nature/Town may be covered with snow (prognostic multilayer snow scheme). The nature tile may be an aggregation of several nature types and is based on the ISBA formulation (bare soil + vegetation fractions, several ground layers). The town tile is based on the TEB (Town Energy Budget) scheme. The sea tile is a simple prescribed SST, which is currently being upgraded to a 1D prognostic model of the ocean mixing layer. The lake tile is being upgraded to the FLAKE prognostic scheme. The low-level diagnostics and flux computation over land are calculated using a high-vertical-resolution, subgrid 1D column model on each model grid box ('Canopy' model). The fluxes over sea are computed using the Ecume empirical formulae. References:

Masson, V., 2000 : A physically-based scheme for the urban energy budget in atmospheric models. Bound. Layer Meteor, 1994, 357-397.

Masson, V. and Y. Seity : Including atmospheric layers in vegetation and urban surface schemes, submitted in 2007 to Journal of Applied Meteorology and Climatology.

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

Noilhan, J. and J.-F. Mahfouf, 1996: The ISBA land surface parameterization scheme. Global and Plan. Change, 13, 145-159.

ECOCLIMAP surface physiographies: prescribed using a global 1km database, with a 250m refinements over Europe with the CORINE database. Prognostic surface characteristics from Eumetsat's Land SAF are being implemented, as well as a variational assimilation of soil moisture and temperature. Reference:

Champeaux, J.L., V. Masson and R. Chauvin, 2005 : Ecoclimap : A global database of land surface parameters at 1 km resolution. Meteorological Applications, 12 (1), p 29-32.

1.e. Data Assimilation

The ARPEGE, ALADIN and AROME data assimilation software are very similar, and they are derived from the formulation of ECMWF's IFS 4D-Var.

The ARPEGE data assimilation algorithm is a sequential, 6-hourly incremental 4D-Var technique whereby uniform-resolution global corrections of wind, temperature, humidity and surface pressure are analysed using background fields (provided by the previous variable-resolution ARPEGE forecast), observations (listed below), and a digital filter weak variational constraint to control spurious fast tendencies. Each ARPEGE 4D-Var analysis run comprises two inner-loop incremental minimizations, the final one is at T399 resolution (with the same vertical grid as the forecast model); these minimizations deliver a uniform-resolution T399 increment that is added to the higher-resolution stretched ARPEGE background in order to produce a high-resolution stretched analysis. References:

Courtier, P., E. Andersson, W. Heckley, J. Pailleux, D. Vasiljevic, M. Hamrud, A. Hollingsworth, F. Rabier and M. Fischer, 1998 : The ECMWF implementation of three-dimensional variational assimilation (3D-Var). I : formulation. Quart. Jour. Roy. Meteor. Soc., 124, pp. 1783-1808.

Courtier P., J-N. Thépaut and A. Hollingsworth, 1994 : A stategy for operational implementation of 4 D-VAR using an incremental approach. Quart. Jour. Roy. Meteor. Soc. 120, 1367-1387.

Derber J. and F. Bouttier : A reformulation of the background error covariance in the RCMWF global data assimilation system. Tellus, 40A, 1-25. .

Gauthier, P. and J.N. Thépaut, 2001 : Impact of the digital filter as a weak constraint in the pre-operational 4D-Var assimilation system of Météo-France. Mon. Wea. Rev., 129, pp. 2089-2102.

Mahfouf, J.F. and F. Rabier, 2000 : The ECMWF operational implementation of four dimensional variational assimilation. Part. II : experimental results with improved physics. Quart. Jour. Roy. Meteor. Soc., 126, pp. 1171-1190.

Rabier F., C. Faccani, N. Fourrié, F. Karbou, P. Moll, J-F. Lafore, M. Nuret, F. Hdidou & O. Bock : The impact of the AMMA radiosonde data on the French global assimilation and forecast system, Weather and Forecasting, submitted in 2008.

The ARPEGE inner loops use the dynamics of the dry linearized ARPEGE model (in the vicinity of the background forecast), with a minimal set of physics (vertical diffusion, mostly).

The ARPEGE data assimilation uses the following data sources, which are all subjected to various quality control checks (selection of stations, levels and channels; flow-dependent background departure check; redundancy check; horizontal and vertical thinning of data denser than the model grid; variational buddy-check quality control; etc.) and variational bias correction:

- land surface stations: Synop, Metar, French automatic Radome stations. The parameter selection is detailed in a table below.

• surface sea stations: drifting and moored buoys, Ship reports. Surface pressure and wind are used.

• aircraft data: Airep, Amdar and Acars reports i.e. cruise level and ascent/descent mesaurements of temperature and wind.

• in-situ sounding data: Temp and Pilot balloon reports, dropsondes. Temperature, wind and humidity are used.

• European wind profiler radar data.

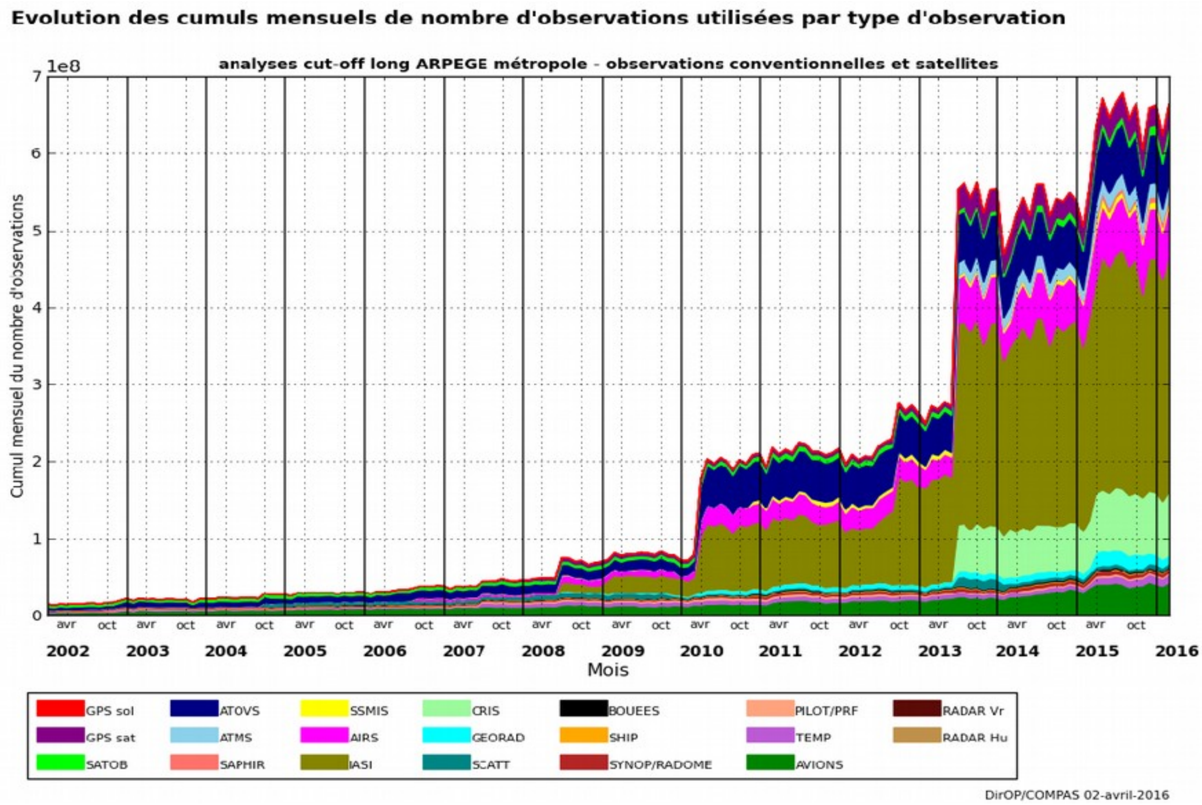
• GPS data: land-based zenith total delays are used, which mainly affect tropospheric humidity, and space-based descending radio occultations from the COSMIC, CHAMP, GRACE, Metop/GRAS (when available) instruments.

• geostationary satellite data: atmospheric motion wind vectors derived from the Meteosat, GOES, and MTSAT satellites. Clear-Sky radiances from Meteosat.

• polar-orbiting infrared data: cloud-free HIRS (NOAA series satellites), IASI/A and IASI/B (Metop satellites) and AIRS, CRIS (Aqua and NPP satellites) radiometer channels, sensitive to temperature and humidity. Some cloud-affected channels are also used.

• polar-orbiting microwave data: cloud-free AMSU (NOAA series satellites) , MHS (MetOp satellites), SSMI/S (DMSP series satellites) radiometer channels, sensitive to temperature and humidity. Some channels sensitive to low levels are used thanks to a parametrization of land surface microwave emissivity.

• polar-orbiting scatterometer data: ambiguous sea-surface wind retrievals from the Quikscat satellite, Metop/ASCAT and ERS2/AMI.



With a few exceptions, observed data is taken from WMO's Global Telecommunications System in BUFR format. Fixed stations are used at up to hourly frequency. References:

Auligné, T., 2007 : An objective approach to modelling biases in satellite radiances : application to AIRS and AMSU-A. Q. J. R. Meteorol. Soc. 133 p. 1789–1801 (2007)

Chapnik, B., G. Desroziers, F. Rabier and O. Talagrand, 2006 : Diagnosis and tuning of observational error in a quasi-operational data assimilation setting. Quart. Jour. Roy. Meteor. Soc., 132, pp.543-565.

Guedj, S., F. Karbou and F. Rabier, 2011 : Land surface temperature estimation to improve the assimilation of SEVIRI radiances over land. Journal of Geophysical Research, 116, D14, DOI:10.1029/2011/JD015776

Karbou, F., E. Gérard, and F. Rabier, 2006 : Microwave Land Emissivity and Skin Temperature For AMSU-A & -B Assimilation Over Land. Quart. Jour. Roy. Meteor. Soc., 132, pp.2333-2355.

Karbou F., E. Gérard, F. Rabier : Global 4D-Var assimilation and forecast experiments using land surface emissivities from AMSU-A & AMSU-B observations. PartI : Impact on sounding channels. Weather and Forecasting, submitted in 2009

Karbou, F., E. Rabier, and C. Prigent, 2014 : The assimilation of observations from the Advanced Microwave Sounding Unit over sea ice in the French global Numerical Weather Prediction System. Monthly Weather Review, 142, 125-140.

Poli, P., P. Moll, D. Puech, F. Rabier, and S. B. Healy, 2007 : Quality control, error analysis, and impact assessment of FORMOSAT-3/COSMIC in numerical weather prediction. Terrestrial, Atmospheric and Oceanic Sciences

Poli P., S.B. Healy, F. Rabier, and J. Pailleux : Preliminary Assessment of the Scalability of GPS Radio Occultations Impact in Numerical Weather Prediction. Geophysical Research Letters, in press.

Rabier F., P. Poli, V. Guidard, N. Fourrié, E. Gérard, F. Karbou, P. Moll and C. Payan : Current developments on global satellite data assimilation at Météo-France. WMO CAS/JSC WGNE Blue Book, 2008. Edited by J. Côté

The ALADIN 3D-Var data assimilation is identical to ARPEGE, except for the limited area geometry, the use of 6-hourly 3D-Var instead of 4D-Var, the use of land surface stations (see the table below), and the use of Meteosat cloud-free radiances and GPS ground station delays, mainly sensitive to tropospheric humidity. References:

Berre, L., 2000 : Estimation of synoptic and mesoscale forecast error covariances in a limited area model. Mon. Wea. Rev., 128, pp. 644-667.

Fischer C., T. Montmerle, L. Berre, L. Auger and S.E. Stefanescu, 2006 : An overview of the variational assimilation in the ALADIN/FRANCE NWP system. Quart. Jour. Roy. Meteor. Soc.,613, pp. 3477-3492.

Guidard V., C. Fischer, M. Nuret and A. Dziedzic, 2006 : Evaluation of the ALADIN 3D-Var with observations of the MAP campaign. Meteorol. Atmos. Phys., 92, pp.161-173.

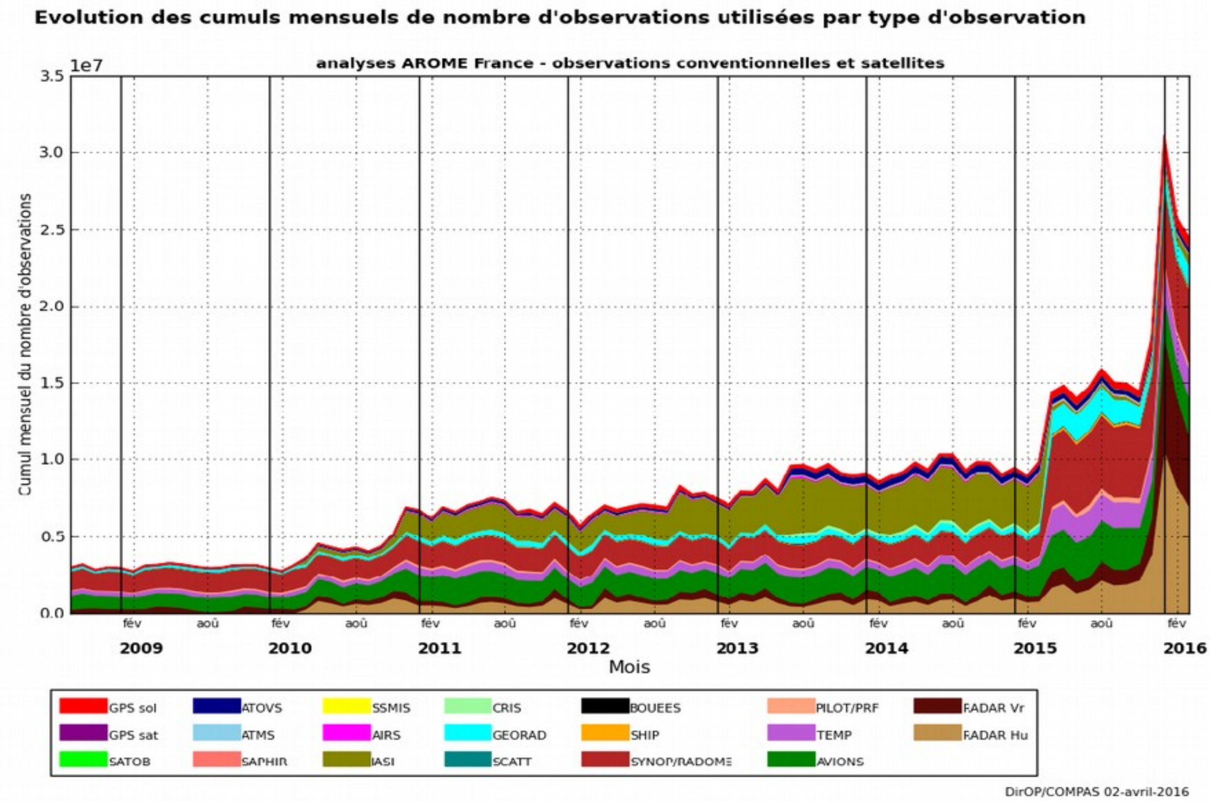
Montmerle, T., F. Rabier and C. Fischer, 2006 : Respective impact of polar orbiting and geostationary satellite observations in the Aladin/France NWP system. Quart. Jour. Roy. Meteor. Soc., 133, pp 655-671.

Yan X., V. Ducrocq, P. Poli, G. Jaubert, A. Walpersdorf, 2008 : Mesoscale GPS Zenith Delay assimilation during a Mediterranean heavy precipitation event, Advances in Geosciences, 17, 71-77.

The **AROME 3D-Var data assimilation** is identical to the ALADIN 3D-Var, except for the use of much sharper structure functions, a shorter 3-hourly assimilation cycle, and the use of French radar Doppler wind components and the assimilation of humidity retrievals from 3D radar reflectivities.

References:

Brousseau, P. and Y. Seity, 2006 : A first prototype for the AROME data assimilation scheme, in Aladin newsletter N30. http://www.cnrm.meteo.fr/aladin/newsletters/newsletters.html



Brousseau P., Desroziers G., Bouttier F. and Chapnik B. 2013. A posteriori diagnostics of the impact of observations on the AROME-France convective-scale data-assimilation system. QJRMS, DOI: 10.1002/qj.2179

Ducrocq, V., D. Ricard, J.P. Lafore and F. Orain, 2002 : Storm-scale numerical rainfall prediction for five precipirating events over France: On the importance of the initial humidity field, Weather and Forecasting, 17, 1236-1256

Guidard V., N. Fourrié, P. Brousseau and F. Rabier: Impact of IASI assimilation at global and convective scales and challenges for the assimilation of cloudy scenes. Quarterly Journal of Royal Meteorological Society, Volume: 137 Issue : 661, Special Issue : SI, Pages : 1975-1987, Doi : 10.1002/qj.928 Part: Part b. Published : OCT 2011.

Mahfouf, J.-F. and Bliznak, V., 2011: Combined assimilation of screen-level observations and radar derived precipitation for soil moisture analysis. Quarterly Journal of the Royal Meteorological Society, Volume : 137, Issue : 656, Pages : 709-722, Part : Part A, Published : APR 2011. Doi : 10.1002/qj.791

Montmerle, T. and C. Faccani, 2009 : Mesoscale assimilation of radial velocities from Doppler radar in a pre-operational framework. Mon. Wea. Rev., in press.

Wattrelot E, O. Caumont & J-F. Mahfouf (2014) : Operational implementation of the 1D+3DVar assimilation method of radar reflectivity data in the AROME model. Monthly Weather Review, in Press

The background error covariance model in ARPEGE 4D-Var, ALADIN & AROME 3D-Var is based on the spectral vorticity-based multivariate formulation of Derber and Bouttier, with time-independent correlations derived from offline ensembles of the same models, and time-dependent variances derived from the ARPEGE ensemble of assimilations.

Low-level in situ observation usage: all models use soil temperature & moisture inferred through linear regression from T2m, HU2m reports. In the atmospheric analysis, frequently reporting stations are used every 1h, 6h and 1h in ARPEGE, ALADIN and AROME, respectively. When used, T2m is corrected for orography mismatch using a climatological lapse rate, or rejected if the mismatch is greater than 200m. The static data selection is as follows; it is combined with a monthly station-dependent selection list, and real-time quality checks:

	ARPEGE	ALADIN	AROME
pressure	used	used	used
V10m	over sea only	used	used
T2m	not used	daytime only	daytime only
HU2m	not used	daytime only	daytime only

1.f. Ensemble forecasting & ensemble assimilation

The Météo-France **ensemble forecasting system** (PEARP) is based on ARPEGE model, with a set of 10 physical packages (including that of operational ARPEGE model) to represent model uncertainties. PEARP resolution is T798C2.4L90, i.e. slightly coarser resolution than the deterministic run. One unperturbed plus 34 perturbed ARPEGE forecasts run every day at 108h range, which make up an 35-member ensemble with the unperturbed, deterministic ARPEGE 18UTC run. The initial perturbations of the ensemble are obtained from the 25 background states and the mean from the ensemble data assimilation (AEARP) and singular vectors computed over 7 areas using a flow-dependent background error estimate.

Descamps L, Labadie C, Joly A, Bazile E, Arbogast P, Cébron P. 2014. PEARP, the Météo-France short-range ensemble prediction system. Quart. J. Roy. Meteor. Soc.: DOI:10.1002/qj.2469.

Descamps L, Labadie C, Joly A, Arbogast P, 2013. Ensemble assessment using the TIGGE database. WMO CAS/JSC WGNE Blue Book, 2013. Edited by J. Côté

M.Boisserie, P. Arbogast, L. Descamps, O. Pannekoucke, L. Raynaud, 2013: Estimating and diagnosing model error variances in the Météo-France global NWP model. QJRMS (accepted).

M.Boisserie, L. Descamps, Ph. Arbogast, 2014: Calibrating short-range ensemble forecasts using estimated model error variances. QJRMS(in revision).

Descamps, L., Labadie, C., Joly, A., Bazile, E., Arbogast, P. and Cébron, P. (2015), PEARP, the Météo-France short-range ensemble prediction system. Q.J.R. Meteorol. Soc., 141: 1671–1685. doi: 10.1002/qj.2469

An assimilation ensemble system (coupled with the PEARP system) runs in real time since early 2008. It contains 25 instances of the ARPEGE assimilation perturbed by adding random noise to observations, with a few differences from the main, unperturbed ARPEGE system: lower, uniform horizontal resolution (T399c1). Background error covariances predicted by this ensemble are used. They are fed into the 4DVar background error model, which gives flow-dependent weight to observations, and into the initial perturbation generation for the PEARP ensemble forecasting system. Reference:

Belo Pereira, M. and L. Berre, 2006 : The use of an ensemble approach to study the background error covariance in a global NWP model. Mon.Wea.Rev., 134, pp.2466-2489.

Berre, L., 2000 : Estimation of synoptic and mesoscale forecast error covariances in a limited area model. Mon. Wea. Rev., 128, pp. 644-667.

Berre, L., G. Desroziers, 2010: Filtering of Background Error Variances and Correlations by Local Spatial Averaging: A Review. Mon. Wea. Rev., 138, 3693–3720.

Desroziers, G. and L. Berre: Accelerating and parallelizing minimizations in ensemble and deterministic variational assimilations. Quarterly Journal of Royal Meteorological Society, Volume : 138, Issue : 667, *Pages : 1599-1610, DOI : 10.1002/qj.1886. Part : Part b. Published : JUL 2012.*

Pannekoucke O., L. Berre and G. Desroziers, 2008 : Background error correlation length-scale estimates and their sampling statistics. Quart. Jour. Roy. Meteor. Soc. 134 : 497-508

Raynaud L., L. Berre et G. Desroziers, 2008 : Spatial averaging of ensemble-based background error variances. Q. J. R. Meteorol. Soc., 134, 1003-1014.

Raynaud L., Berre L. and Desroziers G.: An extended specification of flow-dependent background error variances in the Météo-France global 4D-Var system. Quarterly Journal of the Royal Meteorological Society. Volume: 137, Issue: 656, Pages: 607-619, Part: Part a, Published: APR 2011. DOI: 10.1002/qj.795

Raynaud, L., L. Berre, G. Desroziers: Accounting for model error in the Météo-France ensemble data assimilation system. Quarterly Journal of Royal Meteorological Society, Volume : 138, Issue : 662, Pages : 249-262, DOI : 10.1002/qj.906. Part: Part a. Published: JAN 2012.

Varella, H., Berre, L. and Desroziers, G. (2011), Diagnostic and impact studies of a wavelet formulation of background-error correlations in a global model. Q.J.R. Meteorol. Soc., 137: 1369–1379. doi: 10.1002/qj.845.

2. Operational system

The NWP system is organized around the production of analyses at 00, 06, 12 and 18UTC, and the ensuing forecasts; the tasks are run nearly identically every 6 hours.

Each ARPEGE 4D-Var analysis is run twice, once with a short cutoff (one hour before the end of the nominal observation window) to initialize the real-time forecast, once with a longer cutoff (nearly five hours after the end of the observation window) to initialize a 6-hour forecast that is used to provide the background fields for the next 4D-Var analysis. The use of a longer cutoff is particularly important for the assimilation of polar-orbiting satellite data.

Near 00UTC only, a third *'very short cutoff'* ARPEGE analysis is run with a simpler 4DVar analysis algorithm (one minimisation), in order to launch an early set of ARPEGE, ALADIN and AROME forecasts.

Each ARPEGE atmospheric 4D-Var analysis, and the corresponding global surface analysis, is used to launch an (approximately 3-day range) ARPEGE forecast, which provides lateral boundary condition data to the ALADIN-Overseas and AROME-France systems.

The PEARP ARPEGE ensemble prediction system is run twice a day, shortly after the 06UTC and 18UTC deterministic forecasts. Since October 2007, PEARP is sent to the ECMWF TIGGE database at 1.5 degree global resolution.

3. Recent changes in operational NWP systems

Older changes:

Feb 2007, cy31T1 upgrade: improvement of soil freezing in analysis, and other technical changes. Implementation of ALADIN 3DVar assimilation over the SW Indian Ocean.

May 2007, cy31T1 upgrade: Switchover of the whole production to the new NEC SX8 supercomputer platform, with no meteorological impact.

3.a. Aug 2007, cy32T0 upgrade

assimilation of GPS radio-occultation (COSMIC, CHAMP, GRACE), assimilation of MetOp satellite data (AMSU-A, MHS, monitoring of ASCAT, HIRS), assimilation of ERS2 AMI scatterometer, increase of GPS ZTD use change in IR radiance cloud detection; withdrawal of some AMSU-A NOAA16 channels

use 1/12degree NESDIS product in SST analysis

correction of evaporation of precipitation (reduces spurious low-level divergence)

in ALADIN-France only: assimilation of 10m wind observations

in ALADIN-Reunion only: multivariate background balance constraint in background error covariance model (non-linear with omega equation)

The impact is a general, significant improvement of most forecast scores on all domains, particularly in the lower stratosphere and the Southern Hemisphere. The impact is small over North America and Europe. In ALADIN, the short-range low-level wind forecasts are improved.

3.b. Feb 2008, cy32T2 upgrade

increase of horizontal and vertical resolutions in ARPEGE/ALADIN: the vertical resolution in both models is increased from 46 to 60 levels, with the extra resolution concentrated near the tropopause; the ARPEGE model resolution is increased from T358 to T538 ; the ARPEGE 4DVar horizontal resolution of increments is increased from T159 to T224.

vertical discretisation based on vertical finite elements

variational bias correction scheme for satellite radiances

assimilation of Metop ASCAT, revision of the bias correction for Quikscat and ERS2 data, monitoring of IASI

new (pdf-based) precipitation sedimentation algorithm

ALADIN-specific modifications: AIRS radiances, incremental digital filter initialisation, reduction of obs weight in 3DVar

PEARP: increase in vertical resolution, use evolved perturbations from previous run, flow-dependent background error in singular vector computation, add targeted singular vectors over Northern, Southern Hemispheres and Tropics, which enforces an acceptable dispersion over the whole globe. Dissemination to TIGGE.

Tropical system: global ARPEGE-Tropics model (at uniform resolution) is now initialised from the ARPEGE-France analysis, there is no longer an ARPEGE-Tropics 4DVar assimilation. Extension of the ALADIN-Réunion model domain, which is coupled to ARPEGE-France instead of ARPEGE-Tropics.

3.c. June 2008 cy33T0 upgrade of ARPEGE/ALADIN

assimilation of more satellites radiances: Metop/IASI (50 channels) and Metop/HIRS radiances; more Aqua/AIRS channels in the troposphere; DMSP-F14/SSMI microwaves; Meteosat-9/SEVIRI clear-sky water vapour radiances in ARPEGE (SEVIRI raw radiances are already used in ALADIN);

assimilation of surface-sensitive microwave channels over land using a new representation of land surface emissivities (for AMSU-A, AMSU-B, MHS from NOAA and Metop satellites)

assimilation of more tropospheric GPS radio-occultations and more aircraft reports

4D-Var background error variances are flow-dependent and derived from the ensemble data assimilation system (6 ARPEGE 3DVar-FGAT assimilations at T358L60c1 resolution with perturbed observations)

blacklist night time T2m and HU2m observations

physics: improve the low-level vertical diffusion in stable conditions, the subgrid orographic drag parametrisation, and snowmelt in the precipitation scheme.

ALADIN only: timestep changed to 450s, postprocessing change over lakes, variational bias correction for Meteosat/SEVIRI radiances.

ARPEGE Tropics only: upgrade resolution to T539L55 i.e. 37km uniform horizontal resolution, and retire ARPEGE-Tropics assimilation (forecasts are now initialized from the variable resolution ARPEGE 4DVar assimilation)

3.d. Dec 2008 operational implementation of AROME

The initial version of the AROME system (2.5km model over France with 3D-Var data assimilation) has been declared operational on 18 Dec 2008.

3.e. Feb 2009 cy33T1 upgrade of ARPEGE/ALADIN

new vertical diffusion / boundary layer scheme in ARPEGE/ALADIN: CBR prognostic 1D turbulent kinetic energy coupled with Kain-Fritsch-Bechtold (KFB) shallow convection scheme (through a dedicated thermal production term, and convection-sensitive turbulent length scale

damping of deep convection scheme in order to avoid double-counting with KFB scheme

radiation parametrisation: increase number of solar spectral bands from 2 to 6; use new ozone climatology following *Fortuin and Langematz(1994)*

new 'ECUME' sea surface flux parametrisation in ARPEGE/ALADIN

retuning of numerical horizontal diffusion

assimilate more IASI channels, particularly over land and sea ice

debiasing of scatterometre winds

assimilate cloudy AIRS radiances using CO2-slicing technique to derive cloud parameters

assimilate EARS Modis wind data

implementation of own surface assimilation (SST/ice and soil variables) in ALADIN

the PEARP ensemble prediction scheme, the ensemble data assimilation, and all French ALADIN models inherit from the above changes.

3.f. Apr 2010 cy35t2 upgrade of ARPEGE/ALADIN/AROME

The whole NWP suite has been migrated to a new supercomputer platform (NEC SX9) and a new production/database management software in summer 2009.

The AROME-2.5km regional prediction system over mainland France has been modified as follows:

- increase of the number of vertical levels from 41 to 60 levels, the corresponding enhancement of vertical resolution is mainly located in the lower troposphere
- activation of an absorbing upper boundary condition with relaxation of the large-scales to the NWP boundary condition model
- change of the boundary condition model from the regional ALADIN-France to the global ARPEGE system, with hourly updated lateral and upper boundary conditions
- update of the background error covariance model used by the AROME 3DVar data assimilation, use of flow-dependent background error variances provided by the ARPEGE ensemble assimilation system
- assimilation of AIRS, IASI and SSM/I radiances; implementation of a variational bias correction scheme for the assimilation of SEVIRI radiances; radiances are used with an increased density
- assimilation of radar reflectivities through Bayesian retrievals of vertical humidity profiles

upgrades to the EDKF shallow convection scheme, implementation of fog sedimentation, improvement of the gust diagnostic computation.

The ARPEGE global prediction system has been modified as follows:

increase of the model horizontal resolution from T538 to T798 stretched spectral truncation i.e. from 15 to 10.5km resolution over Western Europe (and to 60km over the South Pacific), timestep 900s

increase of the model vertical resolution from 60 to 70 levels, most of the enhancement is located in the lower troposphere

increase of the 4DVar assimilation increment resolution from T224 to T323 i.e. from 90 to 60km

increase of the density of assimilated satellite radiances to 125km, activation of extra radiance data in the 4DVar data assimilation: AMSU-B channel 5 over land (see contribution by F. Karbou et al elsewhere in this volume), IASI water vapour channels, and the NOAA19 satellite. Assimilation of MODIS clear-sky water vapour winds

increased dependency of the ARPEGE 4DVar assimilation on the ensemble assimilation system, which provides flow-dependent background error variances for all mass and wind control variables.

improvement of the turbulent kinetic energy scheme and of the 4DVar simplified physics, improvement of the gust diagnostic computation.

The ALADIN regional systems have inherited from the ARPEGE modifications, the ALADIN horizontal resolution is now 7.5km over France and 8km over the SW Indian Ocean. The ARPEGE ensemble prediction system (PEARP) has been upgraded in December 2009:

increase of the number of members from 11 to 35

increase of the vertical resolution from 55 to 65 levels

initial perturbations are derived from the ARPEGE ensemble assimilation, on top of the previously used singular vectors.

model error is represented in the forecasts using varying physical parametrization setups.

more frequent ensemble forecasts (from the 06 and 18UTC analyses; previously, PEARP was only run from the 18UTC analysis)

The ARPEGE ensemble assimilation system, which now runs 6 members at T399 uniform resolution (i.e. 50km) has been upgraded to use 4DVar (3DVar was previously used) with 190-km increments. (described elsewhere in this volume)

The combined impact of the above changes is beneficial in terms of most forecast scores at large and regional scale. They have received favourable subjective evaluations both in routine forecasts and in severe weather events such as the Xynthia storm that hit Southwestern Europe on 27/28 February 2010. The corresponding software developments have been included into the IFS/ARPEGE software that is used by ECMWF and the ALADIN and HIRLAM consortia.

3.g. Nov 2010 cy36t1_op1 upgrade of ARPEGE/ALADIN/AROME

The ARPEGE global prediction system has been modified as follows:

Assimilation of the SSMIS data, new algorithm to compute the winds of the ASCAT scatterometer, assimilation of GPS satellite from 25 to 36 km heights and AMSU A and B above sea ice

New bias removal of radiosounding for temperature and humidity

Use of the SST OSTIA, computed by the Met Office

Assimilation of 2 meters humidity during day time σb recovered from the AEARP for all assimilated variables

modification of roughness lengths in the turbulence scheme and fall velocities in the microphysical scheme

The AROME model has specific modifications listed below:

increase of the simulation domain

assimilation of 7 supplementary french radars (Doppler winds and relflectivities)

screening of satellite data at a finer resolution

increase of the orographic roughness length

AROME analysis replaces the first ARPEGE coupling file

3.h. Sep 2011 cy36t1_op2 upgrade of ARPEGE/ALADIN/AROME

Arpege analysis : New RT-coefficients for IASI & AIRS, Assimilation of RARS/ATOVS over Pacific and Asia, EARS-La Réunion, & Miami, SSMI-S of F-18, GPS RO from the Terrasar-X, SAC-C et C/NOFS satellites

Simplified physics: new tuning of critical relative humidity in the Smith scheme (TL/AD code)

4D-VAR low resolution orography computed from the 2°30’ input dataset rather than interpolated from high resolution.

Changes in the deep convection scheme in order to increase the activity of convective precipitations in given circumstances (more convective parameterized precipitation w/r to the resolved one).

Take into account TKE at t+dt (instead of t-dt) when computing wind gust diagnostics

Proper phase changes and budgets in falling precipitations (rain and snow; re-freezing processes of rain)

SURFEX used in Aladin with 3DVar (based on Arome-FR version: ISBA3L, ...) & ECOCLIMAP & CANOPY. TEB is not used.; new orography computed from GTOPO30 using the prepPGD program; envelope orography is abandoned.

Arome physics : Additional contribution to turbulence in the adjustment process, representing sub-grid variability of clouds, Revised low level drag: limit the orographic roughness length to a maximal value, Hail diagnostic

Arome analysis : Strong increase of the ground based GPS stations assimilated

3.i. Sep 2012 cy37t1_op1 upgrade of ARPEGE/ALADIN/AROME

Optimisation of observation errors for AMSU-A, IASI, GPS-RO, TEMP, wind profilers, AIREP and ASCAT.

Assimilation of more observations (110 IASI channels instead of 77 previously, cloudy IASI radiances with CO2-slicing method, GPS-Ground of EGVAP network, IASI from EARS network, ASCAT from RARS, new radar data from Plabennec in Arome, etc.).

Model error included via inflation technique in Arpege ensemble data assimilation (AEARP) and adaptation of Arpege ensemble prediction forecasts (PEARP).

Tunings in the convection scheme in Arpege/Aladin to improve precipitation.

Better representation of ice phase and clouds in the Arome shallow convection scheme. Higher resolution databases for orography and soil texture used in Arome.

3.j. July 2013 cy38t1_op1 upgrade of ARPEGE/ALADIN/AROME

A new version of the operational models became operational in July 2013./ The changes are listed below:

Assimilation of satellite data from new instruments : Suomi-NPP/ATMS + CriS radiances, Oceansat2/OSCAT winds, METOP-B instruments (IASI, AMSU-A, MHS, GRAS, ASCAT)

Increased usage of existing instruments : METOP-A/GRAS, METOP-A/IASI WV channels, Aqua/AIRS (over land+additional upper tropospheric channels), GNSS-RO(reduced vertical thinning), SSMI/S sounding channels, METOP-A/MHS, CSR from GOES-13 and GOES-14

Denser thinning of AMSU-A (80km) and SSMI/S (139km), assimilation of Doppler winds from one X-band radar (Mont-Maurel, Var) and more SEVIRI radiances over land in Arome system only

Wavelet approach for a flow dependent B matrix from an ensemble data assimilation ensemble

Changes in the Arpege/Aladin physics (improvements in the shallow convection scheme, improved description of surface properties over ice caps (thermal inertia, albedo, roughness length))

New climatology for sand & clay (HWSD) and for orography (GMTED2010) in Aladin regional systems

3.k. January 2014 cy38t1_op2 upgrade of ARPEGE/ALADIN/AROME

All the operational models ran on the new supercomputers BULL of Météo-France.

3.l. July 2014 cy38t1_op3 upgrade of ARPEGE/ALADIN/AROME

All the operational NWP scripts handle files produced with an I/O server. The I/O server is activated in Arome and Arpege forecasts.

3.m. April 2015 cy40_op1 and December 2015 cy41t1_op1 upgrades of ARPEGE/ALADIN/AROME

The global and regional prediction systems have undergone significant changes, in two steps, in April and in December 2015.

Global NWP systems based on ARPEGE model

The horizontal resolution of the global deterministic system is improved, from 10 to 7.5 km over Western Europe and from 60 to 36 km over Southern Pacific (spectral resolution T_l1198 linear grid with a stretching factor 2.2). The 4DVar minimizations resolutions are now T_l149 and T_l399. The vertical resolution is increased from 70 to 105 levels, with a lowest model level at 10m.

Background error covariances used in the 4D-Var analysis are better sampled thanks to the implementation of a new version of the ensemble data assimilation (EDA), based on 25 members at uniform resolution T_l479 L105, with a temporal average reduced to one day and a half (instead of 4 days), and an update of correlations every 6 hours (instead of 24 hours). The figure 1 illustrates that a more frequent update of correlations enables to account for the geographical variations of horizontal correlations length scales, estimated 15 November 2013 at 06UTC and at 12UTC respectively. One can observe in particular that these length scales evolve significantly over 6 hours in this area, which is linked, among other things, to the displacement of low pressure systems.

The horizontal resolution of the 35 members of the global ensemble prediction system (EPS) is improved, from 15 to 10 km over Western Europe (spectral resolution T_l798 linear grid with a stretching factor 2.4). The vertical resolution is finer: 90 levels instead of 65.

Others modifications are:

- Calibration in EDA and background error variances filtering
- New version of RTTOV (v11). Interpolation done in RTTOV with new coefficients

- 30' time-slots in Arpege 4D-Var (instead of 1h), “Jc_dfi” term revision in 4D-Var
- Assimilation of new observations: 6 SSMI/S sounding channels of DMSP-F17 and F18, edge swath ATMS data, 6 sounding channels of SAPHIR on Megha-Tropiques, new GPS-RO data, new CrIS tropospheric channels (+27 over sea, +8 over land), EARS ASCAT Metop-B, Clear Sky Radiances of Meteosat-7 and MTSAT-2, new GPS ground observation, radiosoundings in BUFR format, AMV and CSR data from Himawari 8, surface winds from RapidSCAT
- New observation errors for GPS-RO, AMSU-B, MHS. Algorithmic improvements for SSMI/S assimilation. Higher radiances density (factor 2) as input data in screening
- Radiation computations every hour (instead of 3h)
- Use of EDA background states and the mean in EPS
- New set of 10 physical packages (including a new prognostic convection scheme “PCMT”) in EPS
- Use of OSI-SAF sea ice fraction

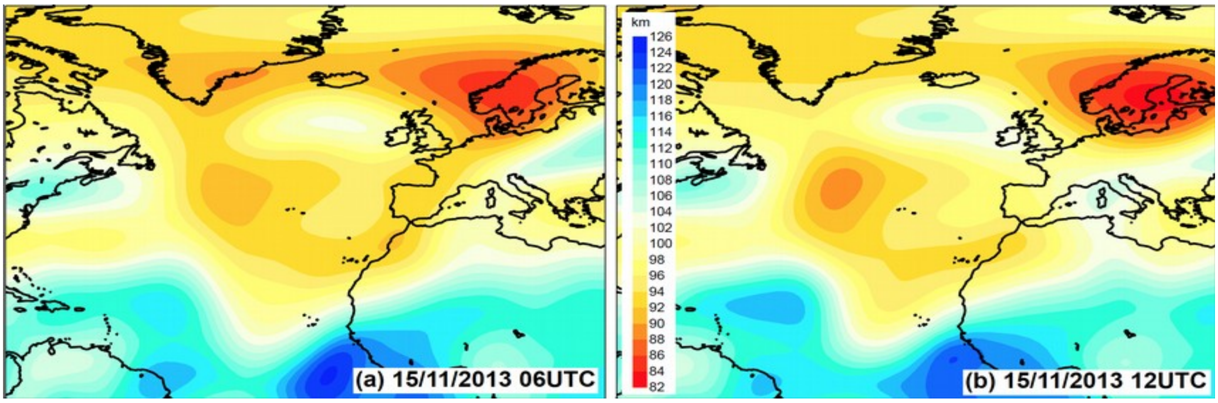


Figure1: Horizontal length scales of forecast correlations errors of wind near 500 hPa (5.6 km height, color shading, in km), estimated 15 November 2013 at 06UTC (a) and at 12UTC (b). The length scale of a local correlation function is a measure of its spatial extension.

<u>Regional NWP systems based on non-hydrostatic AROME model</u>

The convective-permitting scale AROME-France system is now running with a horizontal resolution of 1.3 km, namely a halving relative to the previous version. Vertical resolution has also been increased, with a change from 60 to 90 levels with a lowest model level at 5m. Two of the most significant changes are a move towards a more continuous data assimilation process and a change in the spatial density (from 16 km to 8 km) of radar data (reflectivities and radial winds) used in the assimilation. The AROME variational data assimilation cycle remains 3D-Var, but the frequency of the analyses steps has been increased from 8 to 24 per day, thus potentially trebling the number of data used.

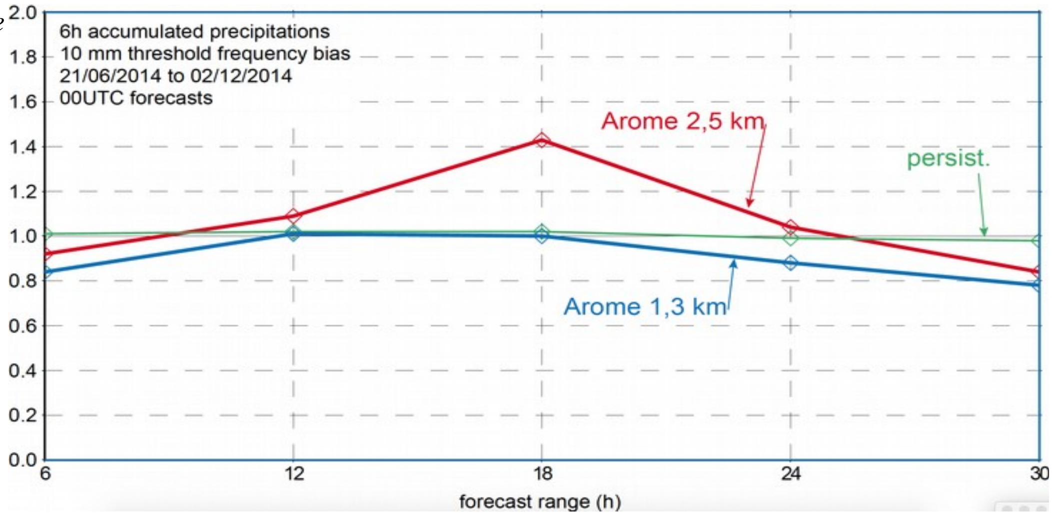
Two new systems have been introduced in the operational NWP suite for: i) nowcasting (called AROME-PI) with hourly analysis with 10' cut-off plus 6h short-range forecast with the same 1.3 km configuration than AROME-France, ii) weather forecasting over overseas territorial collectivities (called AROME-OM) with configurations at 2.5 km running four times par day up to 48h range over five tropical areas.

Others modifications are:

- Same changes for observations as in ARPEGE system
- New selection of IASI channels used for cloud detection
- Incremental Analysis Update (IAU)
- Predictor-corrector temporal scheme with one iteration
- Modified semi-lagrangian advection scheme taking into account the flow deformation
- Numerical diffusion tunings (spectral and grid-point)
- New orographic database (GMTED 2010 at 250m resolution)
- Changes in the physics: autoconversion, orographic surface drag, orography slopes and shadowing effects on surface radiation fluxes

Scores and case studies confirm a significant improvement of precipitation forecasts, including, as illustrated in the figure, a reduction of the positive bias, which was particularly pronounced between 12 and 18 TU (occurrence of the maximum of convective precipitation).

Figure 2:



Frequency biases of 6 hourly accumulated precipitation forecasts above given thresholds, 10 mm/6h in this case, against forecast range between 21 June and 2 December 2014. Forecasts are started from 00UTC. Red curve: old operational Arome (2.5 km resolution); blue curve: new operational Arome (1.3 km resolution); green curve: persistence forecast.

The triggering of some convective cells, hardly simulated with the AROME system at 2.5 km resolution, have been described with this new configuration. It is illustrated by a convective case on the 19 th September 2014 over the Mediterranean (Figure b) associated to the development of a strong super-cell that reached the city of Toulon the following morning. With the high-density radar data, the convection is triggered at the correct location, even if the model fails to reproduce both the observed extent and intensity.

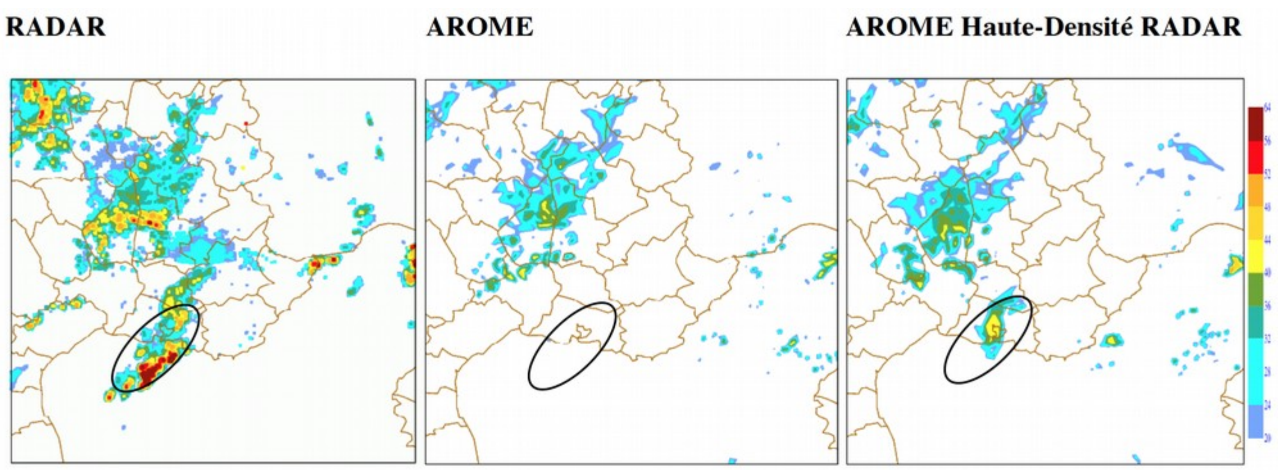
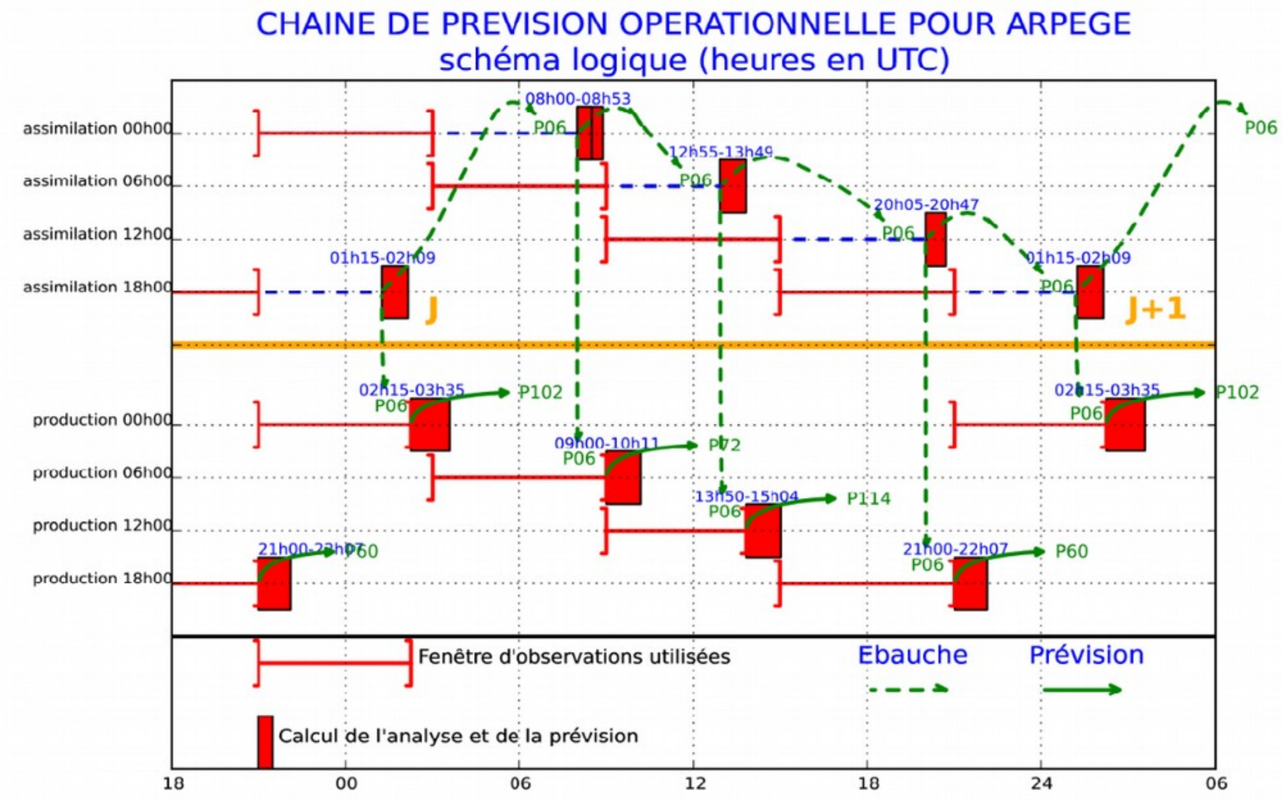
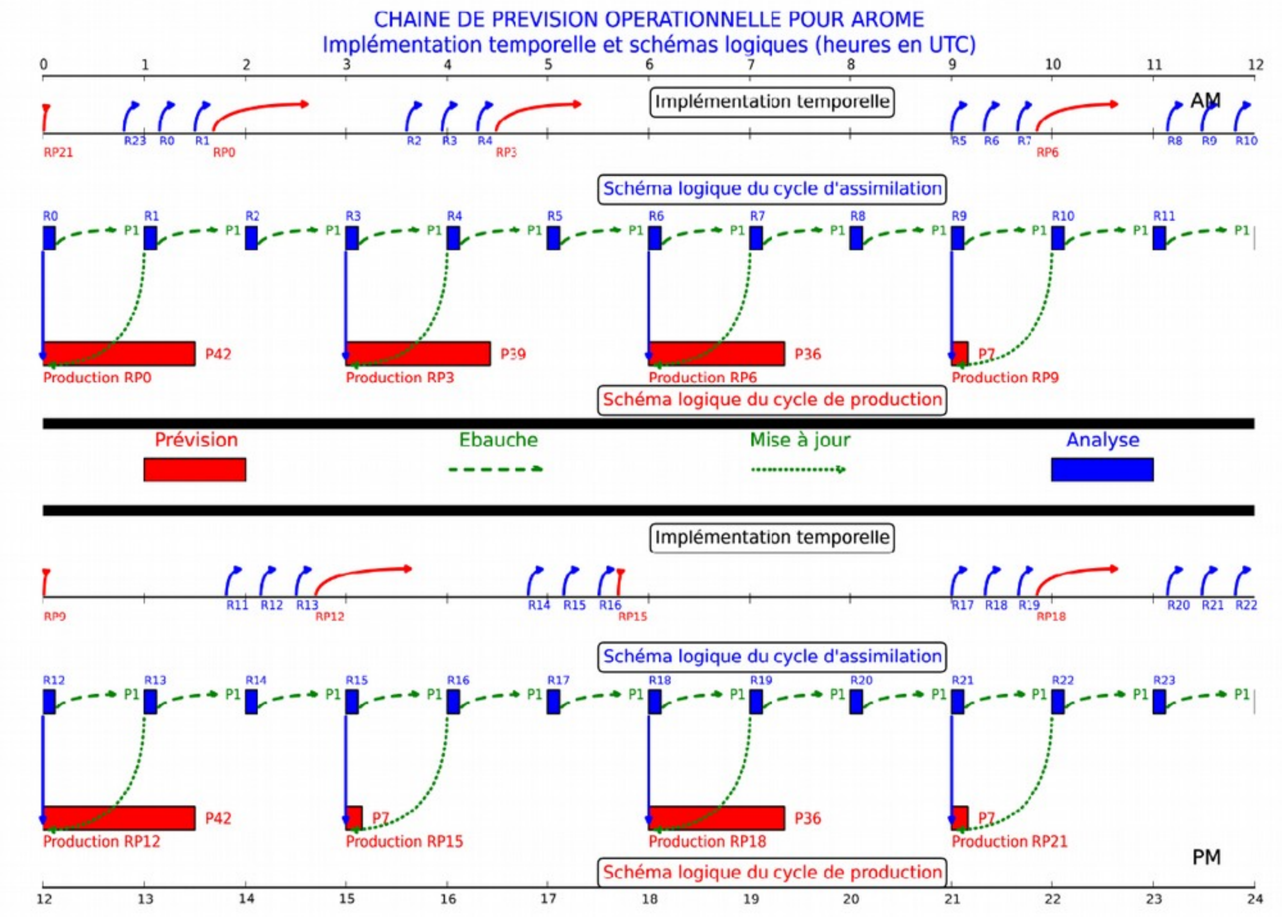


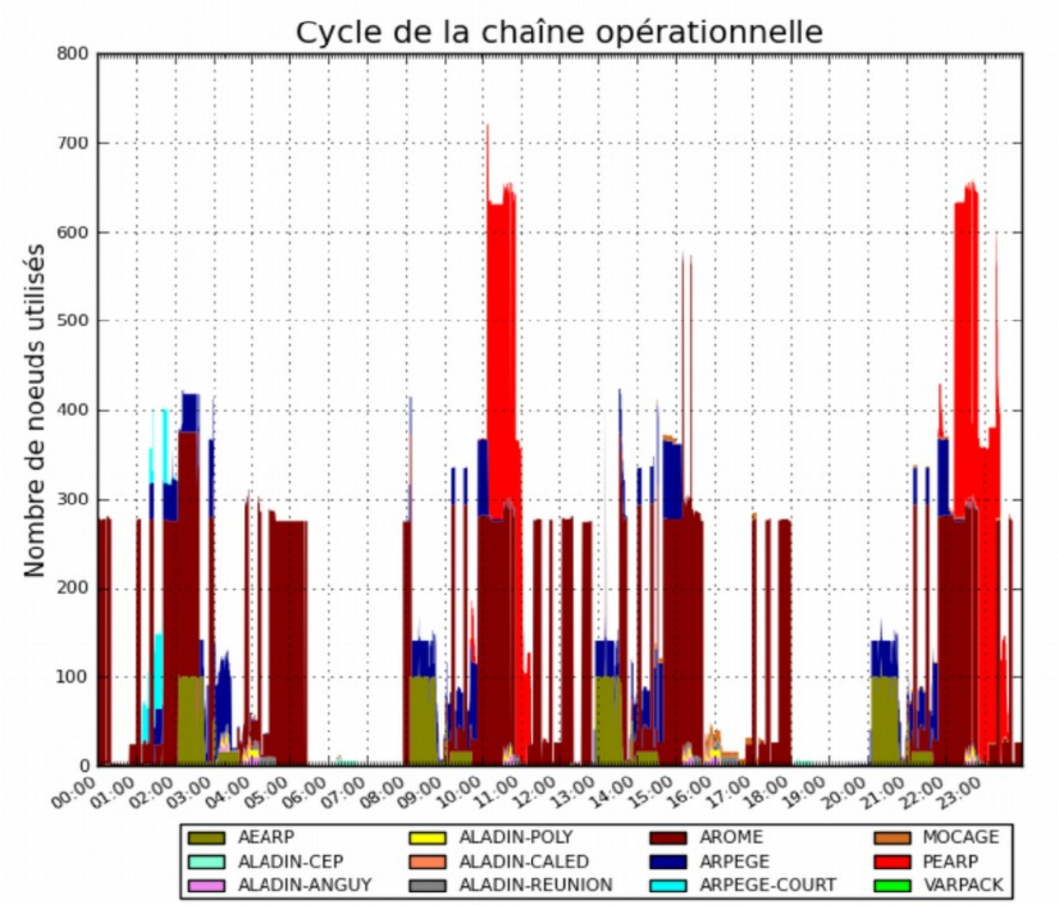
Figure 3: Over the South-East of France on the 19th September 2014 :radar composite (left) at 07h TU, and simulated radar reflectivity at 700 hPa from the cycled 1-hour AROME forecasts at the valid time 0700 UTC, for the reference (middle) and for an experiment with radar data at high-density (right).

4. Temporal implementation of ARPEGE and AROME operational suites





CHAINE DE PREVISION OPERATIONNELLE POUR AROME
Implémentation temporelle et schémas logiques (heures en UTC)
Implémentation temporelle
AM
Schéma logique du cycle d'assimilation
Production RP0
Production RP3
Production RP6
Production RP9
Schéma logique du cycle de production
Prévision
Ebauche
Mise à jour
Analyse
Production RP12
Production RP15
Production RP18
Production RP21
PM



Number of nodes used by the operational suite (before implementation of AROME-Nowcasting, AROME-Overseas and AROME-EPS)

5. Verification procedures

ARPEGE forecast errors are assessed with respect to ARPEGE analyses, ECMWF analyses, TEMP and SYNOP observations. They are compared with other models using standardized WMO scores.

ALADIN forecast errors are assessed with respect to ALADIN analyses, TEMP and SYNOP observations. AROME forecast errors are assessed with respect to TEMP and Radome observations, plus Quantitative Precipitation Forecasts with respect to 24-h and 6-h accumulations, and comparison between satellite images and RTTOV-simulated radiances. Real-time intercomparisons with other models are limited (e.g. HIRLAM mast measurements, MAP D-PHASE FDP, HYMEX field experiments).

6. Cooperations

The R&D in numerical weather prediction (NWP) is carried out in connection with many cooperation networks. The most active ones lately have been:

- the IFS/ARPEGE software cooperation with ECMWF, see http://www.ecmwf.int/
- the ALADIN consortium with several services of Europe and North Africa, see http://www.cnrm.meteo.fr/aladin/
- the HIRLAM consortium with several other European meteorological services see http://hirlam.org/
- the Méso-NH mesoscale modelling group, see http://mesonh.aero.obs-mip.fr/mesonh/

- the SRNWP European coordination body (funded by EUMETNET), see http://srnwp.cscs.ch/ and http://www.eumetnet.eu.org/
