SPECIAL PROJECT FINAL REPORT

All the following mandatory information needs to be provided.

Project Title:	Assessment of the AROME NWP model at sub-kilometre horizontal resolution over highly orographic terrain (Arome-500)
Computer Project Account:	spfrmary
Start Year - End Year :	2015 - 2016
Principal Investigator(s)	Alexandre Mary
Affiliation/Address:	Météo-France
Other Researchers (Name/Affiliation):	Yann Seity Ghislain Faure Claude Fischer Marie-Dominique Leroux David Barbary Ludovic Auger Rachel Honnert

The following should cover the entire project duration.

Summary of project objectives

(10 lines max)

This special project aims at addressing by experimental means the properties of AROME for a typical resolution of 500m in mountainous regions both over inland France and over tropical islands (La Réunion or Tahiti). A specific attention will be paid to the four following issues:
A) locally steeper slopes;
B) 3D effects at surface level;
C) adaptation of turbulence schemes at sub-kilometre scale;
D) triggering of convection.

Summary of problems encountered

(If you encountered any problems of a more technical nature, please describe them here.)

Adaptations to be made to be able to run experiments within Météo-France/CNRM/GMAP environment onto the ECMWF computing facilities constrained our use of it, in terms of timetable repartition, especially in the beginning.

Experience with the Special Project framework

(Please let us know about your experience with administrative aspects like the application procedure, progress reporting etc.)

Progress reporting: the usefulness of the first interim progress report may be discussed, after only 6 months of computing facilities use (especially when facing environment portability problems).

Summary of results

(This section should comprise up to 10 pages and can be replaced by a short summary plus an existing scientific report on the project.)

Aim C: turbulence.

Hectometric resolutions are in the grey zone of turbulence as proved by Honnert et al. (2011). In this range of scale, the coarsest boundary-layer (BL) eddies (BL thermals) are partly resolved and partly subgrid. Thus, there parametrisations in numerical weather prediction (NWP) models at hectometric scale should be scale-aware. AROME BL parametrisation is an Eddy-Diffusivity Mass-Flux (EDMF) : the shallow convection as well as dry BL convection is treated by a mass-flux parametrisation (Pergaud et al., 2009) while the rest of the turbulence is treated by a K-gradient scheme (Cuxart et al, 2000). It has been proved that this mass-flux parametrisation is not adequate to represent the grey-zone thermals (Honnert et al. (2014)) in the grey zone. Pergaud's parametrisation has been modified to be scale-aware at hectometric resolutions.

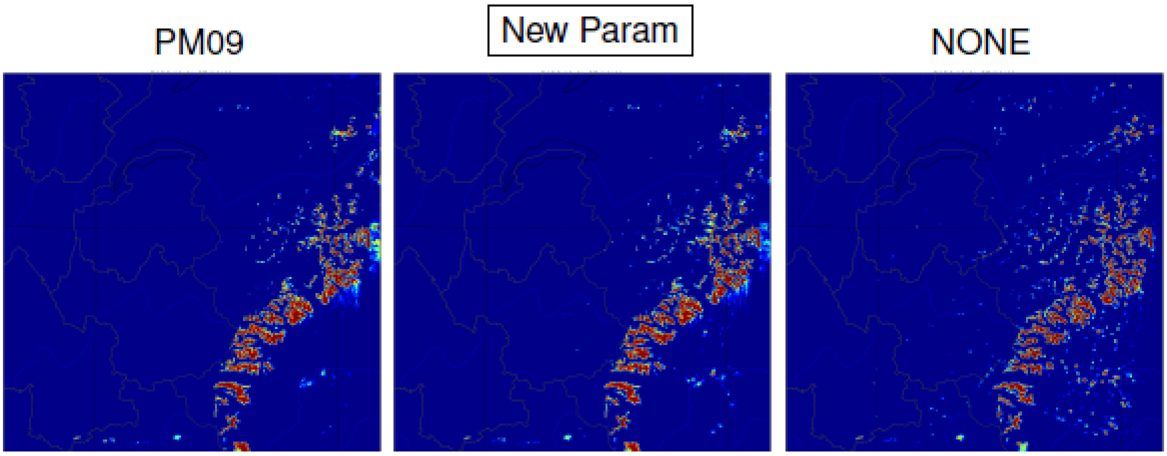
This new version has been tested in AROME at 500 m resolution over the Alps. 11 combinations of the following options of a new parametrisation in the gray zone based on Honnert et al. (2011) have been compared :

- PM09 Pergaud et al. (2009) : the current operational parametrization.
- NONE : switched off mass-flux scheme.
- HRIO : the new version of the mass-flux (without assumptions such as a small thermal fraction or a zero large scale vertical velocity, which are not verified in the grey zone). It is based on a parametrisation of Rio et al. (2008).
- LSAEDKF : A new scale-dependent initialisation of the mass-flux at the surface.
- RANDOM : The use of stochastic parametrisations in the grey zones is commonly justified by the large variance which exists in the responses to one forcing at these scales. A random version of LSAEDKF, based on Honnert et al. (2014).
- BLH/LUP : determination of the thermal height from the BL height (BLH) or from the upward part of the Bougeault-Laccarère mixing length (LUP) at the surface (Bougeault and Lacarrère, 1989).

The dynamical environment of these parametrization test has been proposed by Karim Yessad from the AROME version cy40.

General

In general, the new version of the scheme provide BL characteristics intermediate between the OPER and a version without mass-flux parametrization. In this matter, it reproduces well the behaviour of a half-parametrize thermal.



The thermal height

Contrary to tests in previous idealised cases, there is no real differences between LUP and BLH. It can be explained by the fact that the BL height is diagnosed from the TKE instead of the buoyancy flux. But LUP is easier to implement and use and it actually represent the thermals height which is more consistent with theoretical studies (Honnert et al. (2011, 2012)).

Randomisation or not randomisation

While there is no real differences between RANDOM and LSAEDKF at 1.3 km resolution, at 500~m resolution, RANDOM is colder (until 1K) than LSAEDKF

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Pergaud J and V. Masson and S. Malardel and F. Couvreux(2009)A parametrisation of dry thermals and shallow cumuli for mesoscale numerical weather prediction. Boundary-Layer Meteorol.132 : 83-106
Rio, C., et F. Hourdin, 2008, A thermal plume model for the convective boundary layer : Representation of cumulus clouds, J. Atmos. Sci., 65, 407–425, 2008.

Aim B: cf. attached report “note_arome-ororad_passy.pdf”.

Aims A&D of objectives have not been evaluated within this special project, due to other priorities.

List of publications/reports from the project with complete references

Future plans

(Please let us know of any imminent plans regarding a continuation of this research activity, in particular if they are linked to another/new Special Project.)

Validation of AROME and *ORORAD* scheme over the Passy area (Haute-Savoie, Alps, France) using the Passy campaign measurements.

A. Mary — June, 2017

1 ORORAD

The *ORORAD* scheme consists in 3 parametrizations of the radiation-surface interactions in orographic terrain:

- `LDSL`: the incident radiative solar direct flux at the surface is multiplied by the cosine of the angle between the solar direction and the local gridpoint slope normal. As a resultant effect, for instance, northward slopes of the mountains receive much less radiation than southward slopes in the middle of the day.
- `LDSH`: considering the local horizon from the gridpoint in the azimuth of the sun, if the solar zenithal angle is lower than the horizon, the solar direct radiative flux is switched off. As the horizon is computed from high resolution orography towards a low number of sectors (typically 8: N, NE, E, SE, S, SW, W, NW), and hence the standard deviation of the horizon is known in a given sector, the switch-off is progressive.
- `LDSV`: the radiative diffuse fluxes can be computed as the integration of directional, solid angles irradiances over the hemisphere. In orographic terrain, the discriminant part in this computation is the separation between irradiance coming from the sky and the irradiance coming from the adjacent slopes. Under certain hypothesis, usually admitted in first approximation, taking this into account leads to multiply the net diffuse radiative fluxes (both solar and thermal) by the so-called *sky-view factor* (SVF in the following), that represent the fraction of sky in the hemisphere above ground. Or, in other terms, the fraction of sky that is not obstructed by surrounding mountains. Over flat areas, the SVF is 1, whereas it can decrease to around 0.5 in deep and narrow valleys.

These parametrizations are described in Senkova et al. (2007). Once again, as the orography data used to compute the necessary parameters is of much higher resolution than the model resolution, we also introduce subgrid information for the slope of a gridpoint. Indeed, we store one slope by aspect sector (for the 8 cited above) and a fraction of that sector within the gridpoint.

The first two parametrizations, that concern only solar radiative fluxes, entered the operational AROME in April 2015 (Seity et al , 2011; Brousseau et al , 2016).

The last one (`LDSV`) did not, because it introduced a large positive increase in valley temperatures, degrading the 2m temperature scores.

This work is an investigation about the impact of this parametrization in AROME in the Passy area, using some Passy campaign measurements.

1.1 Refinement of the SVF

The computation of SVF in Senkova et al. (2007) is actually making a simplification in the integration of irradiances, considering the incidence angle to a flat gridpoint. In contrary, Manners et al. (2012) uses the local slope angle, which is more accurate and leads to a different formulation of the SVF, with values closer to 1.0 than Senkova et al. (2007).

Hence the two formulations have been implemented and tested in the model. Furthermore, the Manners et al. (2012) formulation has been implemented with two options: either using the local slope of the gridpoint, computed at grid scale, or using the subgrid scale fractional slopes.

For details of these computations, please refer to Mary (2016).

2 Dataset

2.1 Model

The validation has been daily performed from 2015-01-09 to 2015-02-28, with two sets of experiments, at 1250m and 500m resolution, and 90 levels. The base cycle used is CY41T1_op1, with the corresponding operational suite options for AROME in namelists. Initial states and lateral boundary conditions are taken from the AROME-France e-suite of that period:

- 1300m resolution, 90 vertical levels with last level at 5m above ground, and 50s timestep.
- 3D-VAR assimilation for upper-air fields every 1h, including incremental analysis update, optimal interpolation CANARI (Giard and Bazile , 2000) for surface fields every 3h.

The case study on which a focus is put is 2015-02-09, which corresponds to a stable, clear sky period, with snow on the ground (even at low altitude).

2.2 Observations

The model has been validated against:

- Passy campaign sites 1 & 3: temperature and humidity at 5m, upward/downward SW and LW radiation. Located on Fig. 1.
- Météo France regular automatic stations around Passy. Located on Fig. 2.

3 Reference

The reference is the AROME model at 1250m resolution, without any of the 3 ORORAD parametrizations activated. In the evaluation of the parametrizations below, it is refered to as NONE.

Figure 2 shows that the temperature is overestimated in valleys of low altitude, and underestimated in altitude (over 1500 m.a.s.l.). This pattern has more amplitude in clear sky situations than on cloudy situations. This is consistent with the results of Vionnet et al (2016).

These biases are already present at initial time, especially in clear sky situations. Hence, the data assimilation (of the coupling model) struggles to draw the low level temperatures towards the observations.

Figure 3 illustrates the 2m temperature for 2015-02-09 in SALLANCHES (541 m.a.s.l.) and AIGUILLES_ROUGES-NIVOSE (2365 m.a.s.l.) stations. It shows again the respectively over- and under-estimations already at the beginning of forecast.

This bias observed on the low-level temperatures prevented us to validate the ORORAD parametrizations against the observations dataset. The following subsections investigate this bias, trying to reduce it in sight of pursuing this validation.

3.1 Temperature over-estimation at low altitude in clear-sky situations

In this section we focus on the Passy site 1 location, where radiation observation is available from the Passy campaign. We try to understand the surface and near-surface temperature over-estimation, observed both in the reference and in the coupling model (initial time).

It appears that while the snow height on the ground reaches 40cm around the site 1, the model albedo – obtained from comparing downward and upward short-wave radiation at the surface $({}^{\downarrow}SW, {}^{\uparrow}SW)$ – is about half the albedo obtained from Passy site 1 measurements (0.66 vs 0.3). Also, the nocturn decrease of temperature near the surface has less amplitude in the model than in the observations, which also suggests an under-estimated snow fraction in the model gridpoint.

The snow fraction is computed differently depending on the presence or absence of vegetation in the surface scheme, resulting in lower snow fractions with vegetation. An alternate option for the snow fraction, hereafter called EBA, considers the absence-formula is still valid while the vegetation leaf area index (LAI) remains lower or equal to 3. On the Passy-site1 location, it

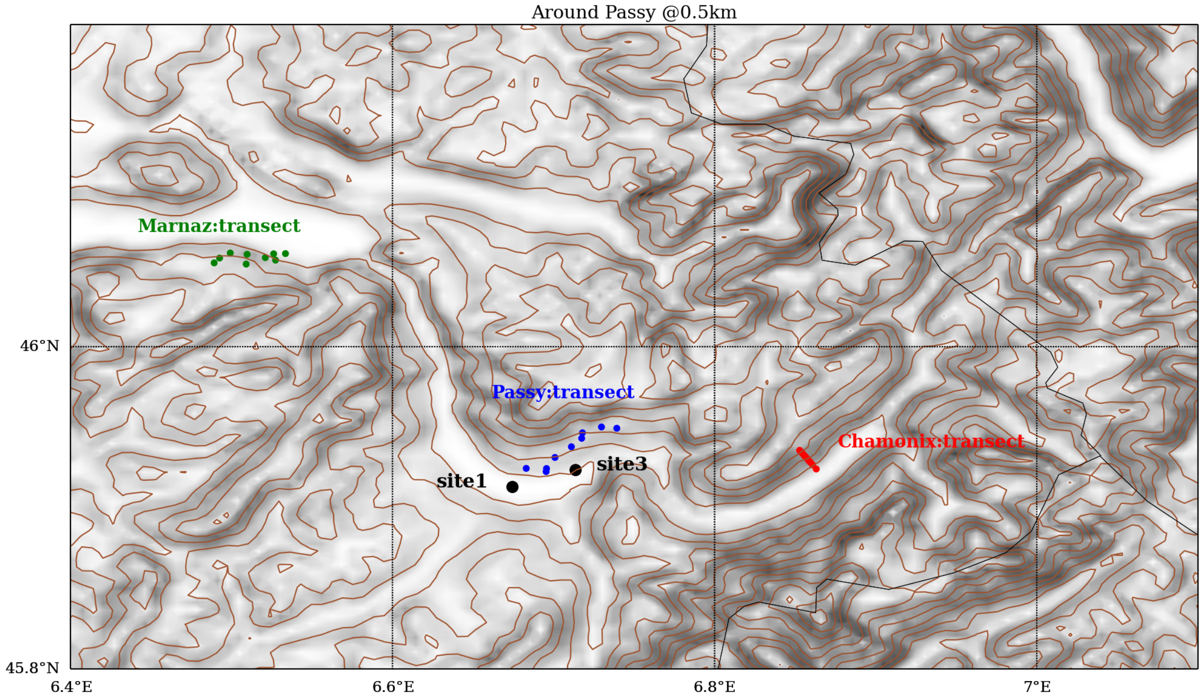


Figure 1: Location of measurement sites around Passy. Background is slope angle in shades of grey and altitude isolines.

results in a larger snow fraction (0.79 vs 0.059), and since, larger albedo (0.6).

This option, which seems more realistic at first sight, has been tested in a forecast starting from 2015-02-08 at 18UTC. The larger snow fraction indeed leads to an amplified decrease in surface and 2m temperatures, due to the small thermic inertia of snow, as illustrated on Fig.4.

The decrease in surface temperature due to EBA is even amplifiying in the end of the forecast, the following night.

However, it worth to be noted that the 5m temperature has the inverse pattern to surface or 2m, with higher temperatures at night with EBA, and a smaller diurnal cycle. Indeed, in such stable conditions, with a strong temperature inversion in low levels, this may probably be caused by a smaller turbulence when the surface is cooler, which leads to a less up-propagated cooling from the surface.

The EBA option hence results in an interesting amplification of the cooling of surface during night time. However, its impact on the 2m and 5m temperatures can not be addressed directly,

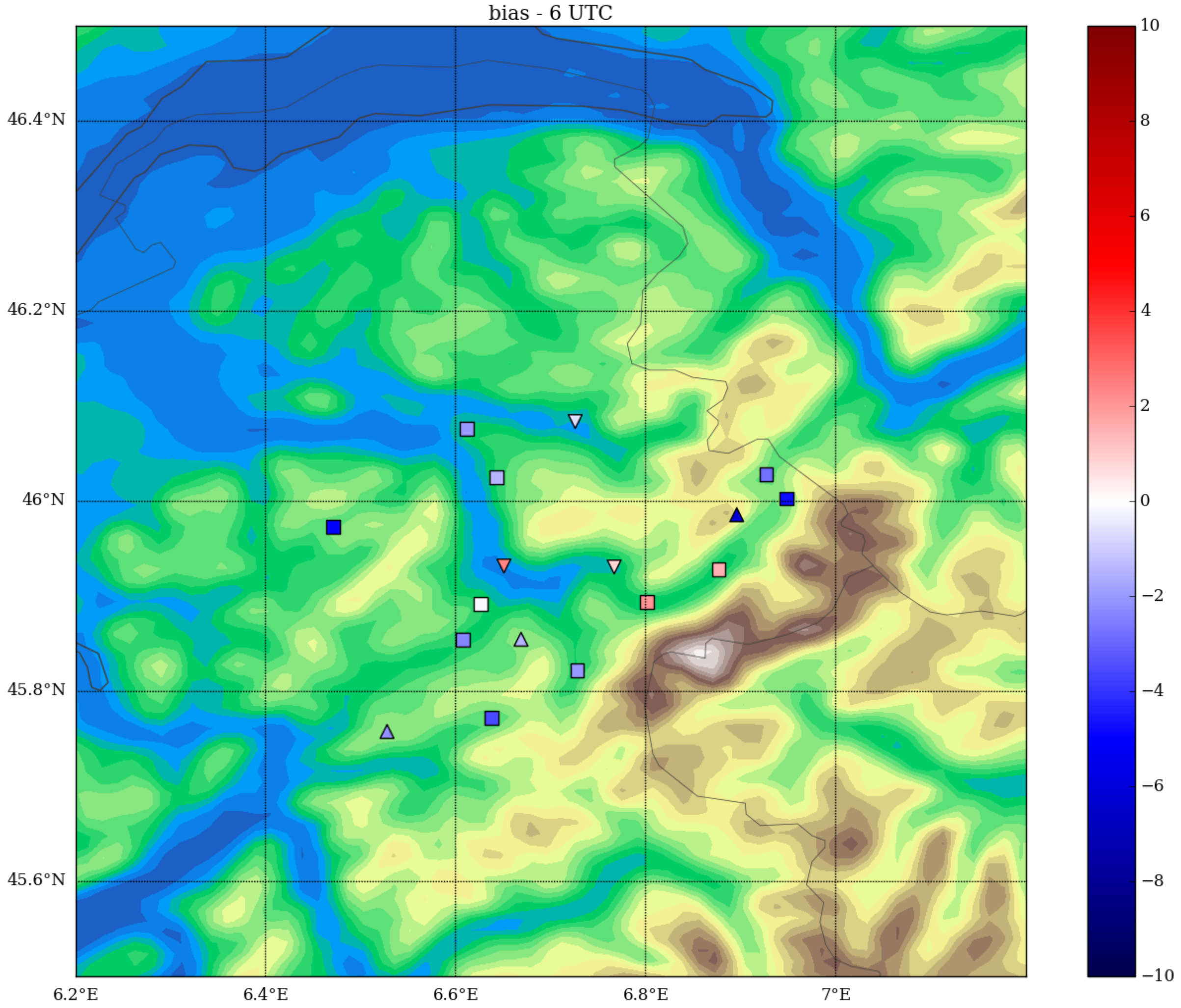
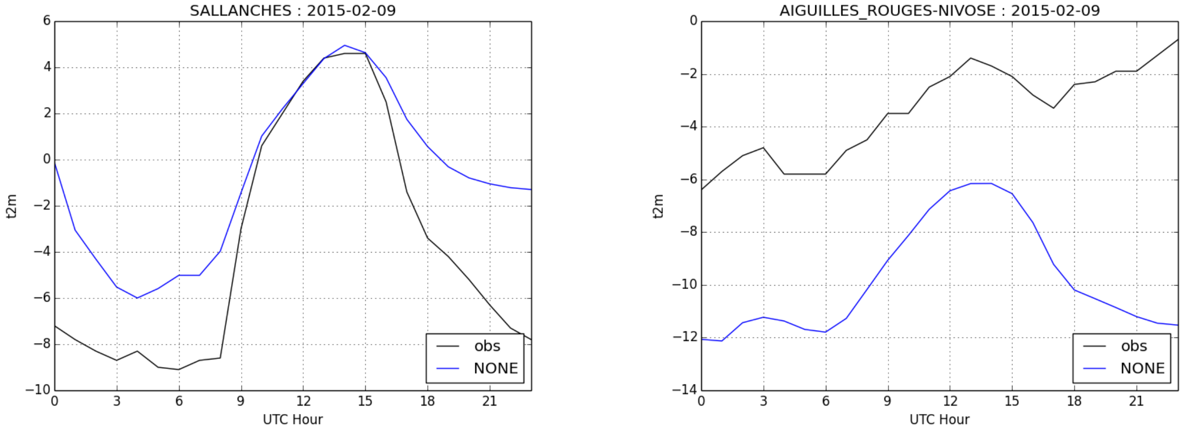


Figure 2: 2m temperature bias of the reference at 6 UTC, over the 2015-01-09:2015-02-28 period, in K. Downward triangles are situated below 1000 m.a.s.l., squares between 1000 and 1500m, upward triangles above 1500m. Background is the model orography.



(a)

(b)

Figure 3: 2m temperature reference and observation for 2015-02-09, at stations SALLANCHES (a) and AIGUILLES_ROUGES-NIVOSE (b), in K.

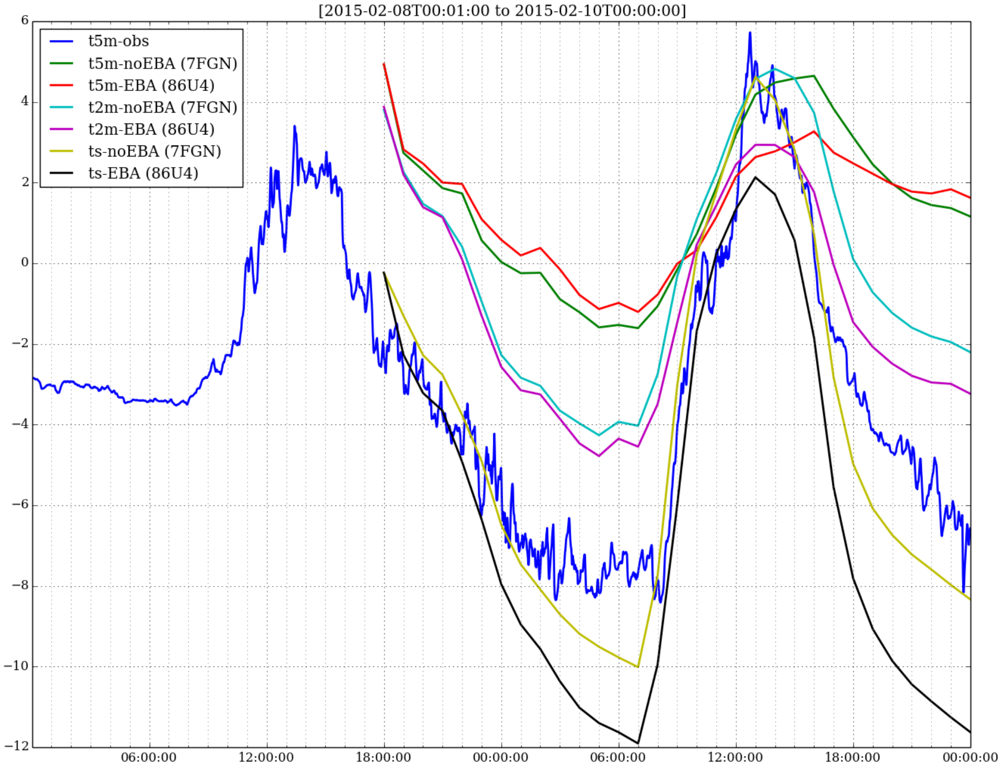


Figure 4: Temperatures observed (at 5m, in blue), and forecasted from an identical initial state, at the surface, 2m and 5m, with or without the EBA modification of snow fraction.

because of the exchanges with the deep soil, which characteristic time scale in the model is about 24h.

In the following, we therefore investigate the inclusion of the EBA in the assimilation cycle since 36h before the beginning of the test case forecasts.

3.2 Impact of data assimilation on surface temperatures

In the coupling model, the surface temperature is relaxed towards observations through CANARI data assimilation every 3h. A similar 3DVAR+CANARI cycle has been run with EBA option in the forecast step, experiment "*86TR*". The reference is referred to as "*dble*".

Figure 5 shows the surface temperatures in the model, both during integration and in the cycled analysis. Focus must be made on the Feb 8th, 12UTC — Feb 10th, 00UTC period. The excessive cooling on the Feb 7th-8th being indeed caused by insufficient cloudiness in the model. One can observe several features:

- comparing analysis and 30h integration for reference (dble), i.e. blue and green lines, it appears that the surface temperature decrease during nighttime is impeded by the surface analysis every 3h; analysis warms up the surface, while the model (guess, dashed) cools it down as expected.
- the 30h forecast starting at 12UTC using EBA option shows very good consistency with observations, which seems to confirm the capacity of the surface scheme.
- the cycled analysis including EBA option shows steeper coolings, though faded by the analysis.

As shown on Figure 6.a, the CANARI surface temperature increment only has large-scale patterns, which seems not very consistent in such mountainous area. The Mescan (Soci et al , 2016) surface assimilation scheme, still based on optimal interpolation, is of interest for it uses more comprehensive structure functions. Its structure functions do especially take orography better into account. The following investigation step has been to test it in this context.

The pink dots on Figure 5 show the analysed land surface temperatures, respectively for CANARI with diamonds and for Mescan with stars. The CANARI temperatures, consistently with the final surface temperature (in red), tend to warm up the surface during nighttime, contrary to expected; whereas the Mescan temperatures show, on the opposite, cooler analysed temperatures, more consistent with the observations [1].

Indeed, on Figure 6 the Mescan analyses show spatial structures consistent with the orography, which in this case avoid to warm up the surface temperatures in the valleys, but does only in altitude.

3.3 Resolution: (un-)resolved small-scales orographic flows

A similar set of simulations at the 500m resolution has been run, with activated diagnostics to investigate the parametrizations at stake in the nighttime cooling in the model.

At both scales, the cooling due to thermal radiation is similar near the surface and above. At 1250m, in the lower levels, Figure 7 shows no significant signal. Advection (residual) and turbulence compensate, with much variations within levels. On the opposite, at 500m, the

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[1] Note that these observations are independant from those used in the surface data assimilation system.

advection shows a clear cooling, very probably representing catabatic winds from adjacent slopes towards the bottom of the valley, in stable conditions.

This result suggests that part of the overestimation of low level temperatures in the model comes from small scales orographic flows, that the model is not able to represent due to insufficient resolution. Indeed, considering the typical width of the Arve valley around Passy (2km in the bottom, 8km from summit to summit), the effective resolution of the AROME model ($\sim 9\Delta x$ according to Ricard et al. (2012)) at 1.25km is yet to be enough (11.25km), whereas it begins to be at 500m (4.5km).

3.4 Conclusion on the reference flaws

It is observed that the nighttime cooling of the surface on clear-sky situations is much underestimated by the model, especially in presence of snow on the ground. This underestimation is

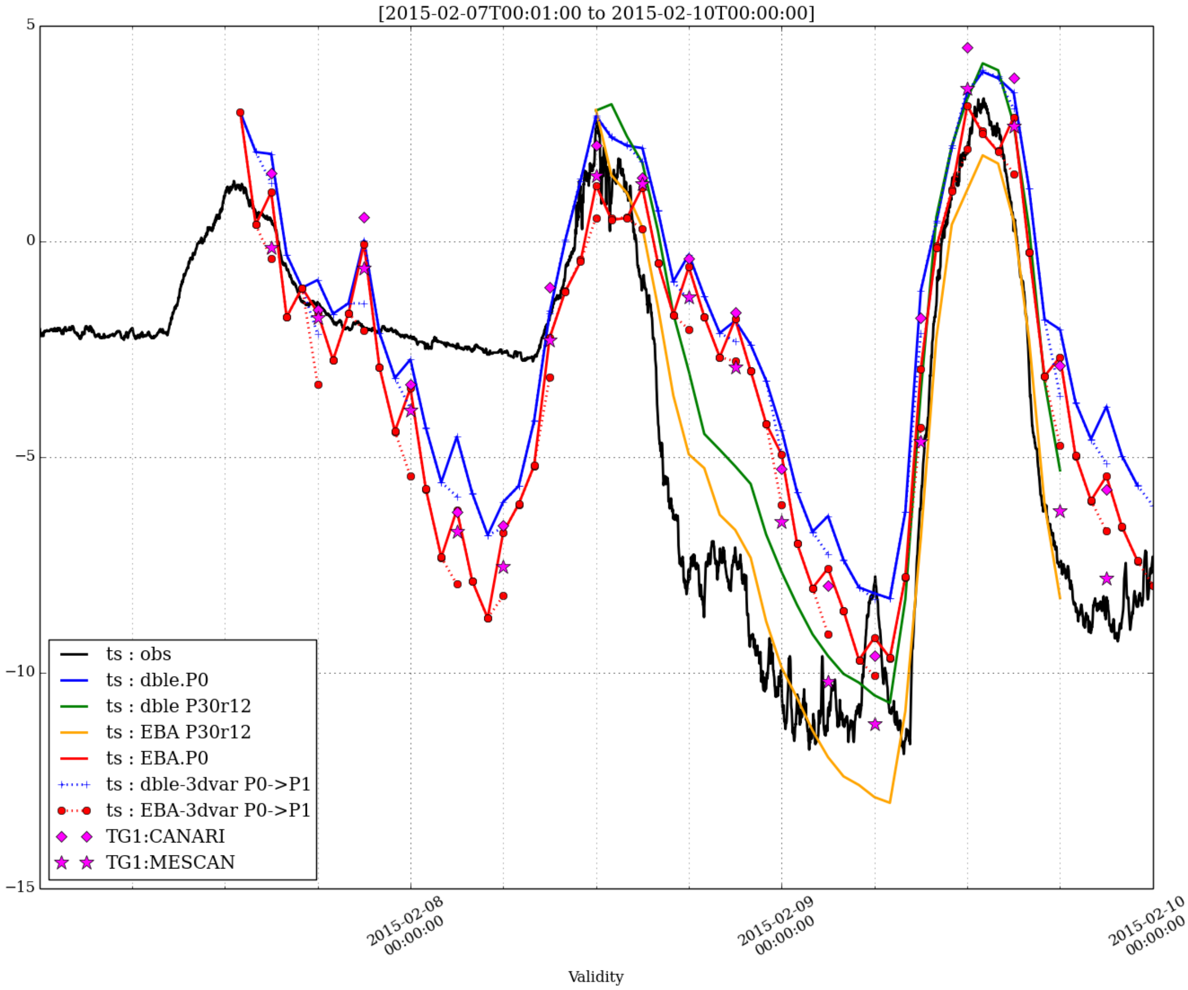
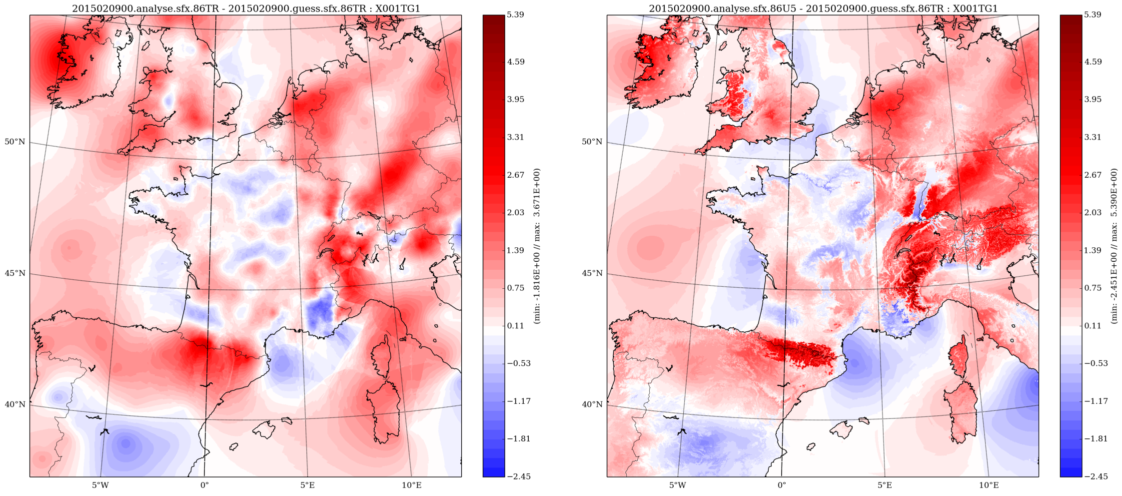


Figure 5: Surface temperatures: observed (inferred from LWup) in black; reference cycled forecast term 0 in blue; reference 30h forecast in green; EBA 30h forecast in yellow; EBA cycled forecast term 0 in red; in dashed lines, the 1h forecast ≡ guess used in surface data assimilation; pink diamonds: CANARI-analysed land surface temperature; pink stars: Mescan-analysed land surface temperature

here shown to be due do (at least) two identified patterns:

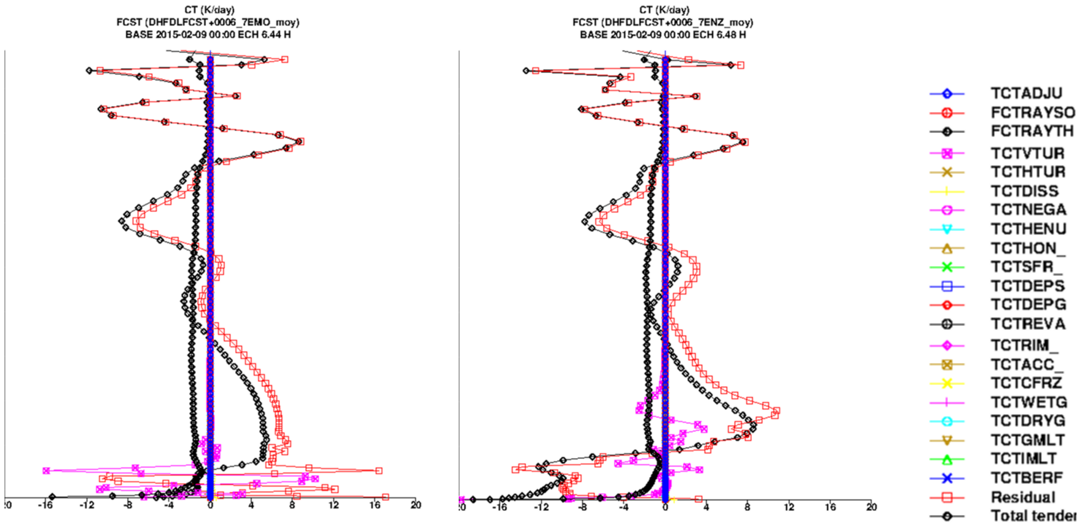
- an underestimation of snow fraction on the ground with little-LAI vegetation;
- an improper adaptation to orography of the surface data assimilation.

Alternatives to these two traps (resp. named EBA and Mescan) are identified to try to reduce the observed bias. Though, a more intensive and in a wider context testing of these options has



(a) (b)

Figure 6: Surface temperature increments over AROME-France domain with CANARI (a) and Mescan (b), in K, for 2015-02-09, 00UTC.



1250m 500m

Figure 7: Heating/cooling rates, in K/24h, of various processes of physics and dynamics of the model (not detailed), depending on the vertical level, over the first 6 hours of integration (00-06UTC), on Passy-site1. The *Residual* is what remains of the overwhole heating/cooling once removed all other processes, i.e. advection.

to be performed.

Yet, although with these options the surface temperature shows a good consistency with observations, remaining issues still show up in the atmospheric low-levels temperatures, that remain to be addressed. One identified cause is the incapacity to represent small scales orographic flows, especially catabatic winds. This hint still prevent a thorough validation of the ORORAD SVF parametrizations, which come as a second-order correction above a first-order modelling bias.

4 ORORAD validation

Still, under the above reservations, a brief evaluation of the ORORAD parametrizations has been led in the identified "optimal" conditions, namely EBA and starting from 12UTC, where the surface temperatures from the coupling and initialisation model show better agreement with the observations.

From Figure 8 is to be noticed the insufficient nighttime cooling of 5m temperature whatever the SVF parametrization is used. At 500m resolution though, the cooling is a little steeper and more satisfying.

Surface temperature are much closer to observations. Among the parametrizations, we can note that the Senkova's skyview factor clearly departs from the other parametrizations, and leads to a very large overestimation of surface (and to a less extent 5m) temperature. The gridscale and subscale versions of Manners' SVF formulation are very close, as could be expected with regards to SVF values. Though, this single test case do not allow us to conclude about the benefit of the (Manners formulation) SVF parametrization. More extensive testing is to be performed to address the potential benefits of this scheme.

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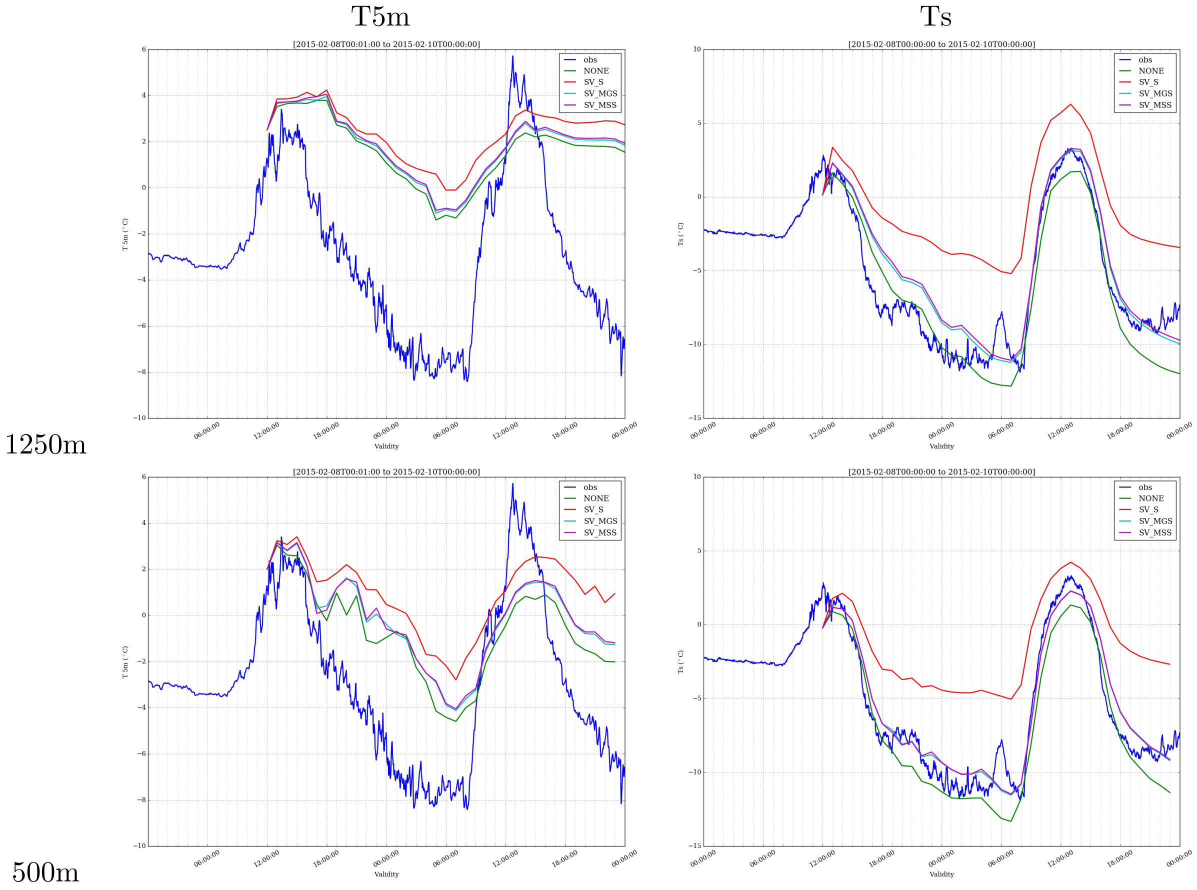

Figure 8: 5m and surface temperature forecasts with the parametrizations described in section1.1. SkyView Factor computations: SVF_S = Senkova et al. (2007) computation; SVF_MGS = Manners et al. (2012) gridscale; SVF_MSS = Manners et al. (2012) subscale.