# A review of the available snow schemes in ARPEGE/ALADIN

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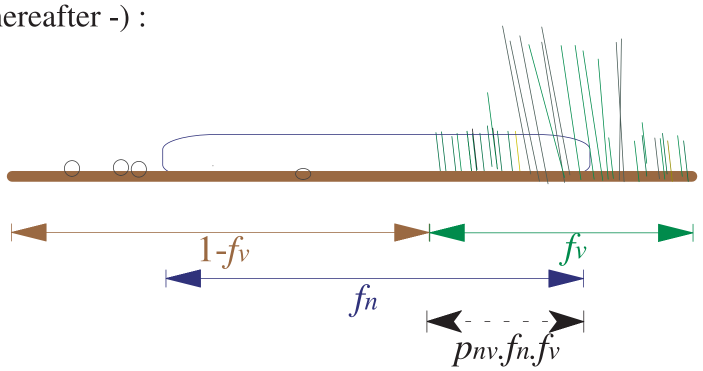
## Introduction

Recurrent problems in the initialization and the forecast of the snow cover (hence in the forecast of surface temperature) have been noticed along the last winters, both at large and small scales. This fostered research in two directions :

- improving the formulation of the surface albedo, taking into account the part of vegetation that may partly mask the snow cover. This study was triggered by a simple glance at the Swedish forests in winter and the study of Viterbo and Betts (1999).
- testing once again, in ARPEGE and in a quasi-parallel suite (i.e. including assimilation), the Douville's scheme. The corresponding code is available in ARPEGE/ALADIN for years, and this scheme was tested several times in ALADIN, in pure dynamical adaptation mode. But results were quite deceiving so far.

Both alternatives to the old scheme aim at considering the overlapping between snow and vegetation, as illustrated below ( $f_n$ and $f_v$ are the fractions of the grid-box covered with snow and vegetation respectively - more generally indices $n$, $v$ and $s$ refer to snow, vegetation and bare ground, respectively, hereafter -) :




## The old (operational) description of snow cover

The old scheme is very simple :

- 1 prognostic variable :
  $W_n$ : equivalent water content
- albedo of snow :
  $\alpha_n$, constant (set to : $\alpha_n = .70$)
- fraction of snow cover :
  $f_n$, independent of surface characteristics and computed as : $f_n = W_n \,/\, (W_n + W_n^c)$
- formulation of the surface albedo :
  $\alpha = max\,(\alpha_n, \alpha_{s-v}) \cdot f_n + \alpha_{s-v} \cdot (1 - f_n)$ , with : $\alpha_{s-v} = \alpha_v \cdot f_v + \alpha_s \cdot (1 - f_n)$
- impact on thermal inertia :
  none : $h = h_{s-v} = max\,[h_v \cdot f_v + h_s \cdot (1 - f_v)\,,\, h_x]$
- impact on roughness length :
  $z0 = z0_{s-v} \cdot (1 - f_n'[z0_{s-v}]\,) + z0_n \cdot f_n'[z0_{s-v}]$ , with : $f_n' = W_n \,/\, (W_n + W_n^c + \beta\, z0_{s-v})$

## The Douville's scheme

- 3 prognostic variables :
  $W_n$ : equivalent water content
  $\alpha_n$ : albedo
  $\rho_n$ : density
- albedo of snow :
  evolution depending on surface melting and snow-falls
  - no melting : slow linear decrease from $\alpha_n^{max}$ ( $\alpha_n^{max}$=.85)
  - melting : exponential decrease towards $\alpha_n^{min}$ ( $\alpha_n^{min}$=.65)
  - snow-falls tend to bring it back to $\alpha_n^{max}$
- fraction of snow cover :
  2 formulations for bare ground and 1 for vegetation

$$f_n^{a/b} = f_{nv} \cdot f_v + f_{ns}^{a/b} \cdot (1 - f_v)$$

$$f_{ns}^a = \frac{W_n}{W_n + W_n^b (1 + \lambda\, z0_{rel})} \quad , \; f_{ns}^b = min(1, \frac{W_n}{W_n^c}) \quad , \; f_{nv} = min( f_{ns}^b , \frac{W_n + W_n^g}{W_n + \lambda\, \rho_n\, z0_v} \cdot f_{ns}^a )$$

- formulation of the surface albedo :

$$\alpha = \alpha_n \cdot f_n^a + \alpha_v \cdot (1 - f_{nv}) \cdot f_v + \alpha_s \cdot (1 - f_{ns}^a) \cdot (1 - f_v)$$

- impact on thermal inertia :

$$h = h_n \cdot f_n^b + h_v \cdot f_v \cdot (1 - f_{nv}) + max\,[h_s, h_x] \cdot (1 - f_v) \cdot (1 - f_{ns}^b)$$

- impact on roughness length :

$$z0 = \sqrt{(1 - f_{nv}) \cdot z0_{s-v}^2 + f_{nv} \cdot ( z0_n^2 + z0_{rel}^2 )}$$

## The newly proposed parameterization

The new scheme, developed under the leadership of Eric Bazile, is of intermediate complexity :

- 2 prognostic variables :
  $W_n$ : equivalent water content
  $\alpha_n$ : albedo
- albedo of snow :
  evolution depending on surface melting and snow-falls, following Douville with changes in extrema
- fraction of snow cover :
  depending on the vegetation cover (horizontal and vertical extension, $f_v$ and $LAI$) and on the "age of snow", estimated from its albedo :

$$f_n = (p_{nv}[LAI, \alpha_n] \cdot f_v + 1 - f_v) \cdot f_n^0 \,, \qquad f_n^0 = \frac{W_n}{W_n + W_n^c} \,,$$

$$p_{nv} = 1 - \frac{LAI}{LAI^1} \cdot \frac{\alpha_n^1 - max(\alpha_n^0, \alpha_n)}{\alpha_n^1 - \alpha_n^0} \quad \text{if } LAI > LAI^0, \; 1 \text{ else}$$

- formulation of the surface albedo :

$$\alpha = \alpha_n \cdot f_n \; + \; \alpha_v \cdot (1 - p_{nv}\,[LAI, \alpha_n] \cdot f_n^{\,0}) \cdot f_v \; + \; \alpha_s \cdot (1 - f_n^{\,0}) \cdot (1 - f_v)$$

- impact on thermal inertia and roughness length : as with the old scheme

The intuitive necessity of introducing an increased dependency on vegetation, especially on the Leaf Area Index, was confirmed by diagnostic studies with ARPEGE and ALADIN-Bulgaria, where a significant correlation between forecast errors in presence of snow and areas of high LAI was to underline.

As a further step, the use of snow density as a diagnostic variable is considered (i.e. computation as in the Douville scheme, but with no feedback on other fields) to help evaluating snow depth, for diagnostic purposes and to improve the snow-cover analysis.

**Impact studies : Douville's scheme**

The Douville's parameterization was first tested in ALADIN, in dynamical adaptation mode, by Adam Dziedzic in 1997. Experiments were performed on the LACE domain with the very first operational version of ISBA. Various initial settings for snow albedo and density were tested, covering the whole range of allowed values [ $.50 \le \alpha_n \le .85$ , $0.1 \le \rho_n \le 0.3$ ]. Scores for 2m temperature (T2m) were globally worse than with the old snow scheme.

Some more experiments were performed afterwards by Andrey Bogatchev and Valery Spiridonov, with ALADIN-Bulgaria and the most recent version of ISBA, including the parameterization of soil-freezing processes. The Douville's scheme led to clearly worse scores (against analysis, due to the sparse observations of snow cover) when compared to the operational one, once again. The discrepancy remains when trying to introduce a better description of the impact of vegetation in both schemes.

To take into account the feedbacks that appear within an assimilation cycle, and also try to close this issue, the parameterization was extensively tested in ARPEGE by Adam Dziedzic. He launched a 3d-var assimilation experiment along the 4 months of winter 2000-2001, with one 96 h forecast per day. Due to an external mistake, two experiments were run : one with the standard scheme, and one with the albedo of snow kept constant, equal to .70. Scores were computed against analyses and against SYNOP observations (T2m), over several representative domains. The Douville's scheme leads to worse forecasts, almost everywhere and all along the winter, as illustrated by the table in appendix. The deterioration is enhanced by the mistake, i.e. when snow density is the only effective prognostic variable, which indirectly confirms the choices retained for the new snow scheme.

**Impact studies : Bazile's scheme**

The new parameterization was tested in several frameworks. The first tests and retunings were based on 30-day forecasts starting from 4 days in March 2000. Second the scheme was proposed to the SNOWMIP experiment (SNOW Model Intercomparison Project), for comparison to 25 other research or operational parameterizations and 4 experimental datasets. The retained tunings were the following :

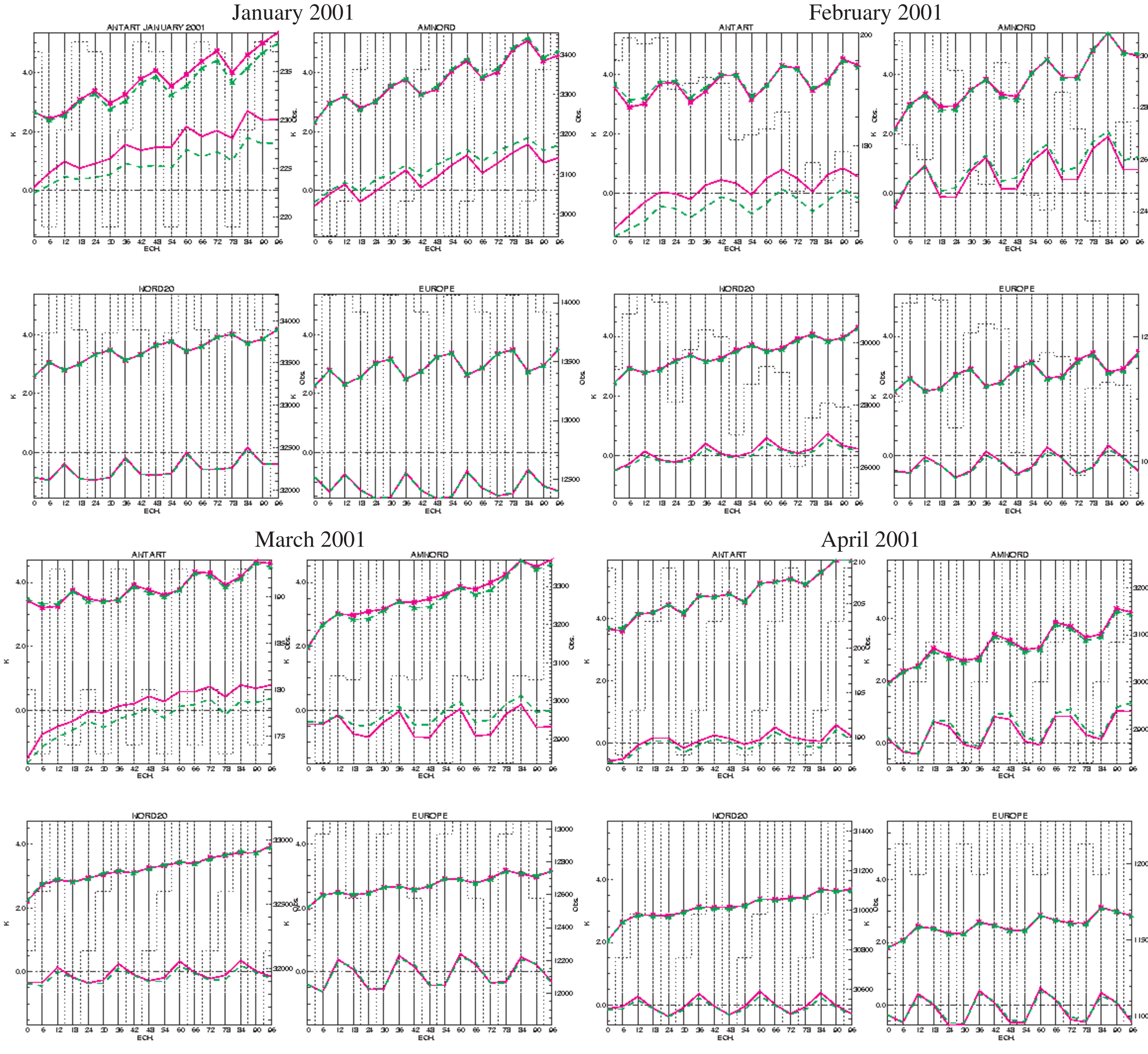
$$\alpha_n^{max} = .85 \, , \; \alpha_n^{min} = .70 \, , \; \alpha_n^{1} = .87 \, , \; \alpha_n^{0} = .84 \, , \; LAI^{\,1} = 7. \, , \; LAI^{\,0} = 3. \, ,$$

The new model behaved quite well, taking into account its simplicity. Its main handicap was the constant snow density, for the forecast of snow depth.

Further validations were based on data assimilation experiments with ARPEGE. A first 15-day test, based on 4d-var assimilation and 96 h forecasts, covered the period 3-18 March 2001. Scores against SYNOP observations showed an improvement of T2m forecasts over large areas, with neutral results else. Changes were as expected. A longer experiment, covering the full winter 2000-

2001, from December to April, and based on 3d-var analysis, was run afterwards. The tunings were the same as for SNOWMIP. Scores were computed against SYNOP and TEMP observations. A significant positive impact on surface fields is observed over Antarctica in December and January (reduction of the warm bias, though no vegetation !), over Northern America in March (reduction of the cold bias). Else scores are slightly positive or neutral. Results are illustrated hereafter.

Skill of 96 h forecasts, with the old and the new snow schemes
comparison to T2m SYNOP observations (bias and rmse), monthly average for 4 domains
red : old scheme, green : new scheme, dotted : number of observations considered (left scale)




## Perspectives

The new parameterization has been introduced in the present operational library and in the last cycle. It is expected to be tested in a parallel suite for ARPEGE and ALADIN-France this autumn, together with other modifications in physics and surface analysis.

The next step will be a better description of sea ice, taking into account the evolution of albedo.

## Appendix

Monthly scores against analyses for temperature at 1000 hPa, for 4 domains (from A. Dziedzic)

| Experiment | Operational scheme | Douville's scheme | Douville's scheme modified |
|---|---|---|---|
| | Dec 00 / Jan 01 / Feb 01 / Mar 01 | Dec 00 / Jan 01 / Feb 01 / Mar 01 | Dec 00 / Jan 01 / Feb 01 / Mar 01 |
| Domain : "Globe" | | | |
| bias at 96 h | 0.339 / 0.303 / 0.246 / 0.004 | 0.359 / 0.320 / 0.293 / 0.073 | 0.365 / 0.338 / 0.302 / 0.080 |
| *rmse at 96 h* | *1.748 / 1.609 / 1.652 / 1.906* | *1.765 / 1.627 / 1.680 / 1.923* | *1.770 / 1.635 / 1.682 / 1.926* |
| bias at 84 h | 0.306 / 0.258 / 0.203 / 0.009 | 0.323 / 0.278 / 0.249 / 0.073 | 0.331 / 0.293 / 0.256 / 0.079 |
| *rmse at 84 h* | *1.607 / 1.479 / 1.512 / 1.761* | *1.623 / 1.494 / 1.533 / 1.772* | *1.625 / 1.501 / 1.533 / 1.776* |
| Domain : "North America" [25 °N, 145 °W - 60 °N, 50 °W] | | | |
| bias at 96 h | 1.439 / 0.673 / 0.783 / 0.134 | 1.610 / 0.879 / 1.040 / 0.431 | 1.625 / 0.897 / 1.058 / 0.444 |
| *rmse at 96 h* | *4.039 / 2.657 / 3.259 / 2.956* | *4.088 / 2.766 / 3.288 / 2.959* | *4.081 / 2.752 / 3.296 / 2.959* |
| bias at 84 h | 1.500 / 0.759 / 0.879 / 0.320 | 1.650 / 0.948 / 1.106 / 0.596 | 1.663 / 0.952 / 1.116 / 0.613 |
| *rmse at 84 h* | *3.863 / 2.472 / 2.922 / 2.733* | *3.919 / 2.596 / 2.987 / 2.780* | *3.912 / 2.586 / 2.988 / 2.780* |
| Domain : "Grand Nord" [25 °N, 180 °W - 90 °N, 0 °E] | | | |
| bias at 96 h | 1.098 / 0.676 / 0.645 / 0.309 | 1.197 / 0.778 / 0.786 / 0.505 | 1.196 / 0.800 / 0.801 / 0.522 |
| *rmse at 96 h* | *3.314 / 2.542 / 2.907 / 2.703* | *3.343 / 2.623 / 2.925 / 2.737* | *3.350 / 2.612 / 2.924 / 2.744* |
| bias at 84 h | 1.070 / 0.662 / 0.710 / 0.421 | 1.155 / 0.748 / 0.835 / 0.599 | 1.163 / 0.761 / 0.842 / 0.612 |
| *rmse at 84 h* | *3.091 / 2.347 / 2.661 / 2.474* | *3.128 / 2.426 / 2.697 / 2.533* | *3.129 / 2.419 / 2.686 / 2.533* |
| Domain : "Eurasia" [25 °N, 10 °W - 90 °N, 170 °E] | | | |
| bias at 96 h | 1.566 / 1.450 / 1.176 / 0.470 | 1.685 / 1.597 / 1.460 / 0.829 | 1.684 / 1.609 / 1.455 / 0.842 |
| *rmse at 96 h* | *3.233 / 3.066 / 3.113 / 2.766* | *3.347 / 3.172 / 3.286 / 2.830* | *3.347 / 3.164 / 3.280 / 2.846* |
| bias at 84 h | 1.275 / 1.101 / 0.783 / 0.235 | 1.404 / 1.257 / 1.083 / 0.573 | 1.406 / 1.275 / 1.084 / 0.589 |
| *rmse at 84 h* | *2.820 / 2.688 / 2.678 / 2.416* | *2.919 / 2.764 / 2.785 / 2.428* | *2.908 / 2.764 / 2.777 / 2.440* |

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