Microphysics and radiation improvements regarding fog and low clouds (for HARMONIE AROME)

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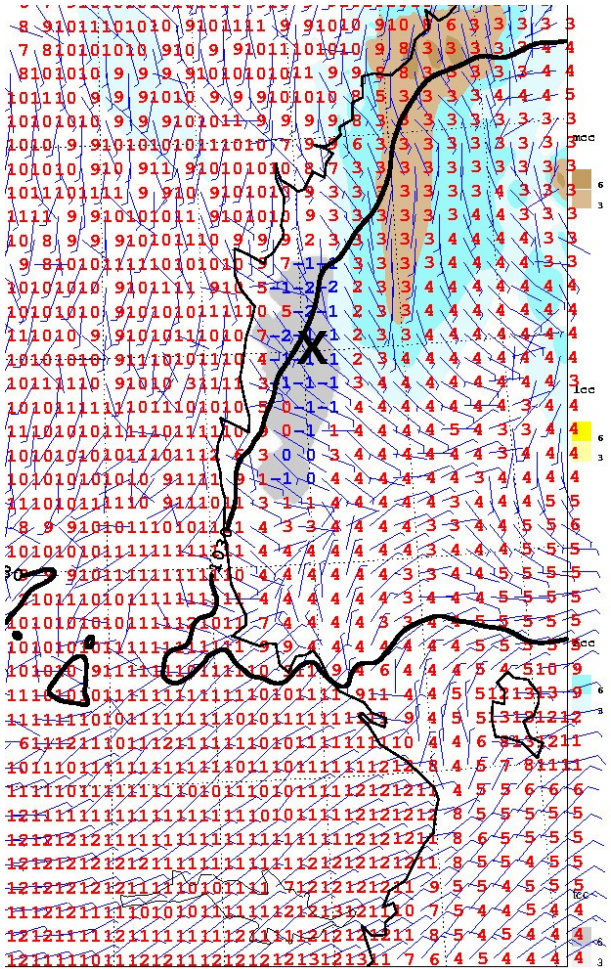
- The problems addressed here, and some ways to mitigate them.
- A typical case with too much fog over sea, and another one with too little low clouds.
- Summary

The problems addressed here

- Too much fog, especially over sea.
- In case of fog, the temperature in the fog layer is often unrealistically low.
- Under prediction of low clouds (mostly in anti-cyclone weather regimes)

A typical case with too much fog over sea



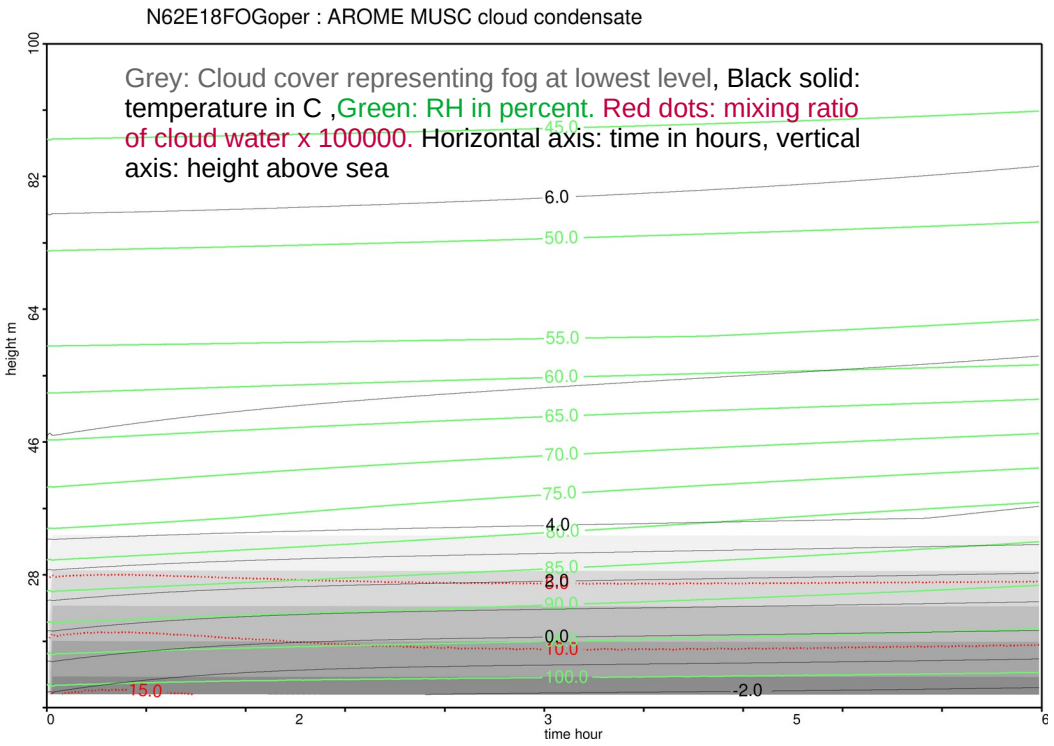
Spurious fog (grey shading) in MetCoOp operational deterministic run over Sea of Botnia 2021-04-19-06 + 03h.
MUSC tests follow for the point marked as '**X**', 62N,18E

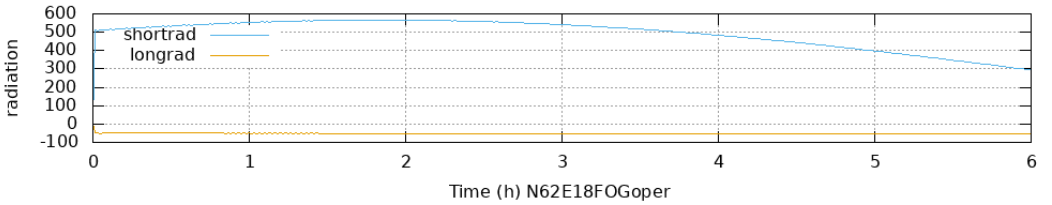
The fog disappeared in the forecast within 6 hours.

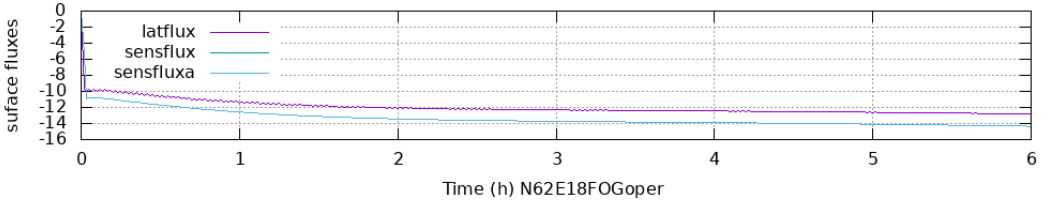
Operational settings:
LHGT_QS=T
RFRMIN(22) = 0.5
VSIGQSAT = 0.02
RFRMIN(26) is unset
and no ECUME6

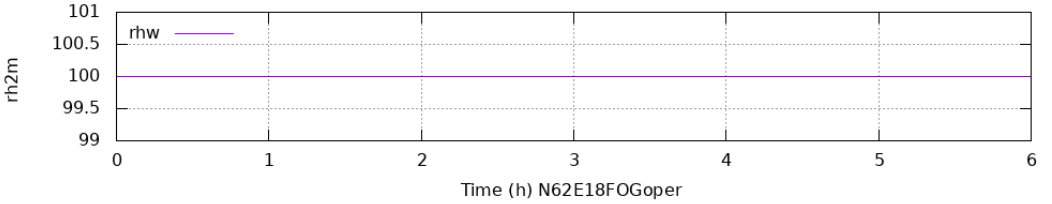
MUSC test with settings as the operational

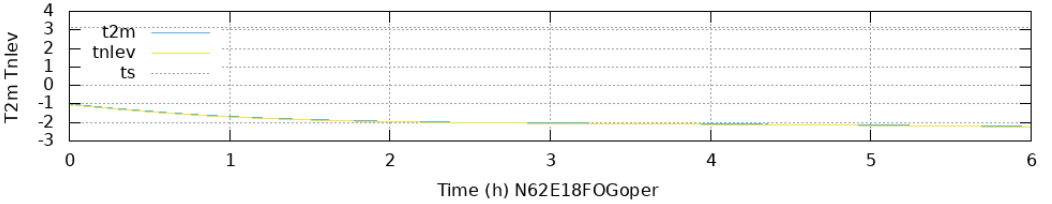
Result: Different from the 3D run, the fog remains, perhaps due to absence of advection. Temperature difference surface-air: ~5K (Too much !)

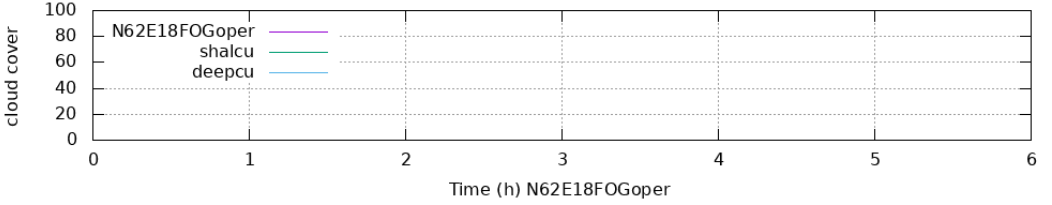










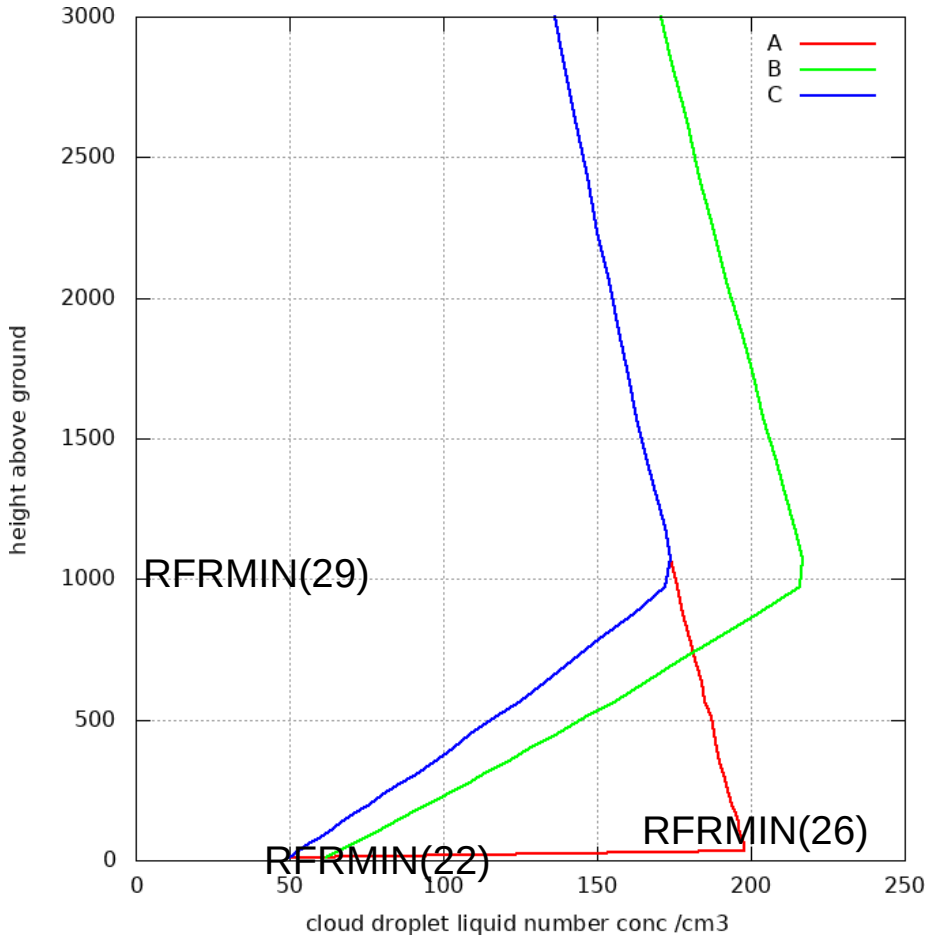


Radiation updates (Kristian)

1) The LW cloud liquid optical properties have been updated to fit Mie-Debye computations. The new scheme is added as an option in HARMONIE-AROME cy43h2.2. A presentation on this can be found here: http://www.umr-cnrm.fr/accord/?1st-ASW-12-16-April-2021-video-conference.

2) A modification has been made to cy43h2.2, so that a cloud droplet number concentration specified in the model namelist is used consistently in both the cloud microphysics and radiation schemes.

Tuning of cloud liquid number concentration (CLNC)



Default CLNC : 300/cm3 over land, 100/cm3 over sea and 500/cm3 over town (microphysics)

Examples:

Tuning A: RFRMIN(26) = 200E6 (in m-3) and RFRMIN(22)=0.25 gives 200x0.25=50E6 at lowest level

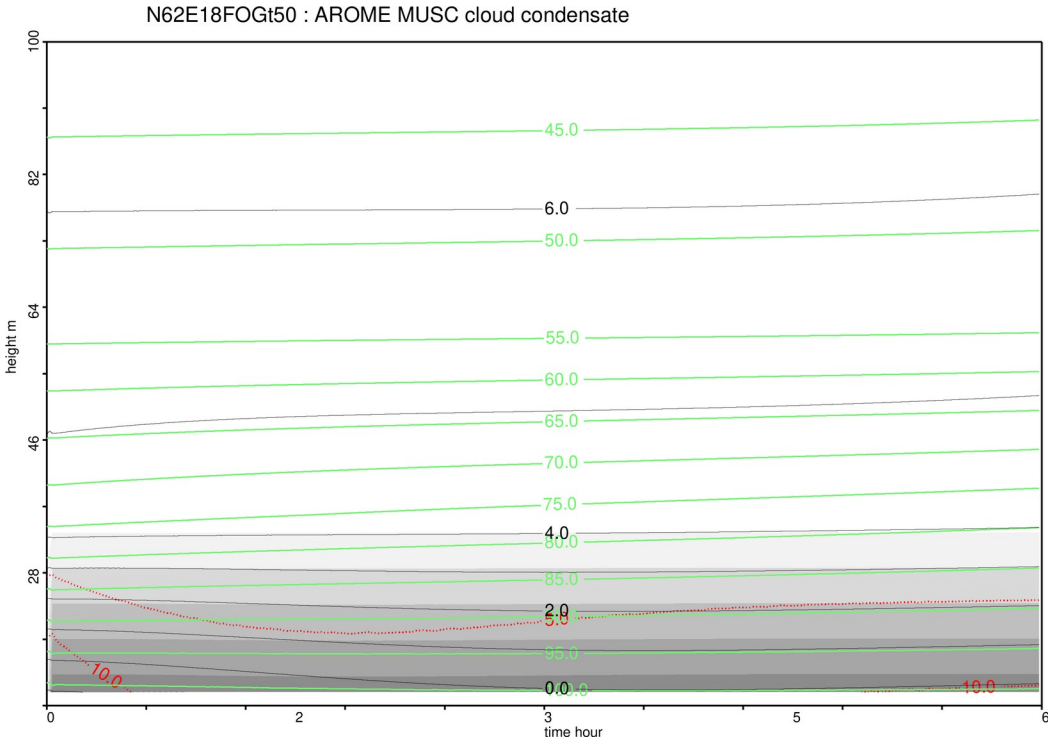
Tuning B: RFRMIN(26) = 250E6, RFRMIN(22)=0.25 and RFRMIN(29)=1000

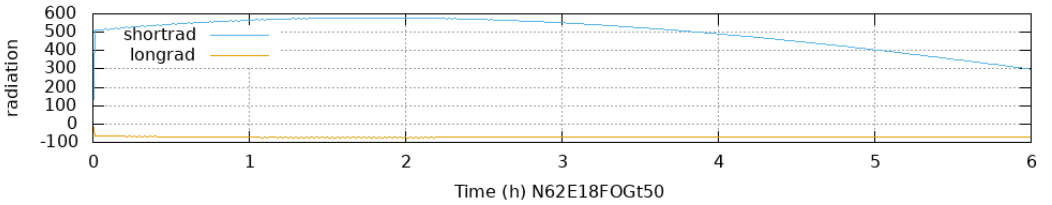
Tuning C: RFRMIN(26) = 200, RFRMIN(22)=0.25 and RFRMIN(29)=1000

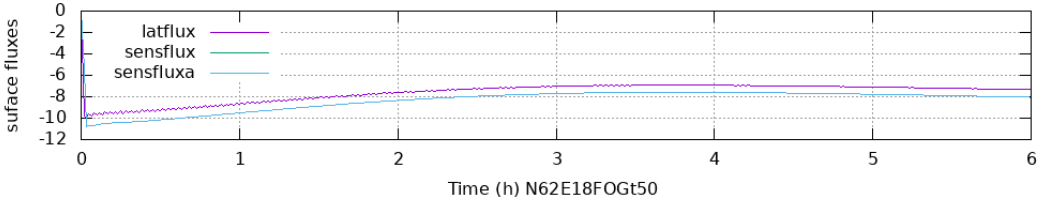
The same CLNC is applied for both microphysics and radiation.

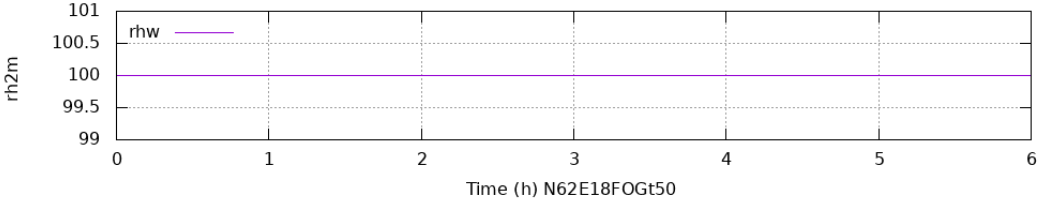
MUSC test with settings as operational + radiation update

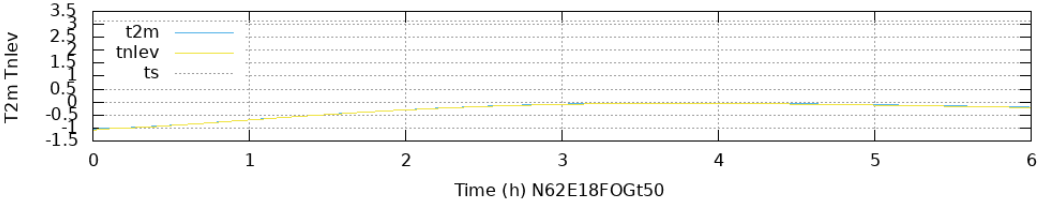
Result: A little less dense fog, and temperature difference surface-air: ~3K, which occasionally is observed for thin fog layers over sea. (More common is ~2 K) More long wave leaving ground and more short wave penetrating the fog, which means more transparent fog layer.

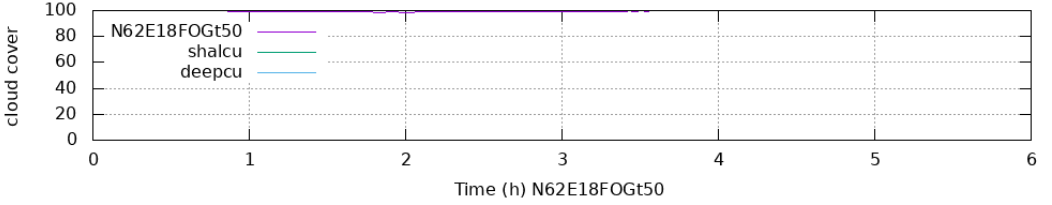






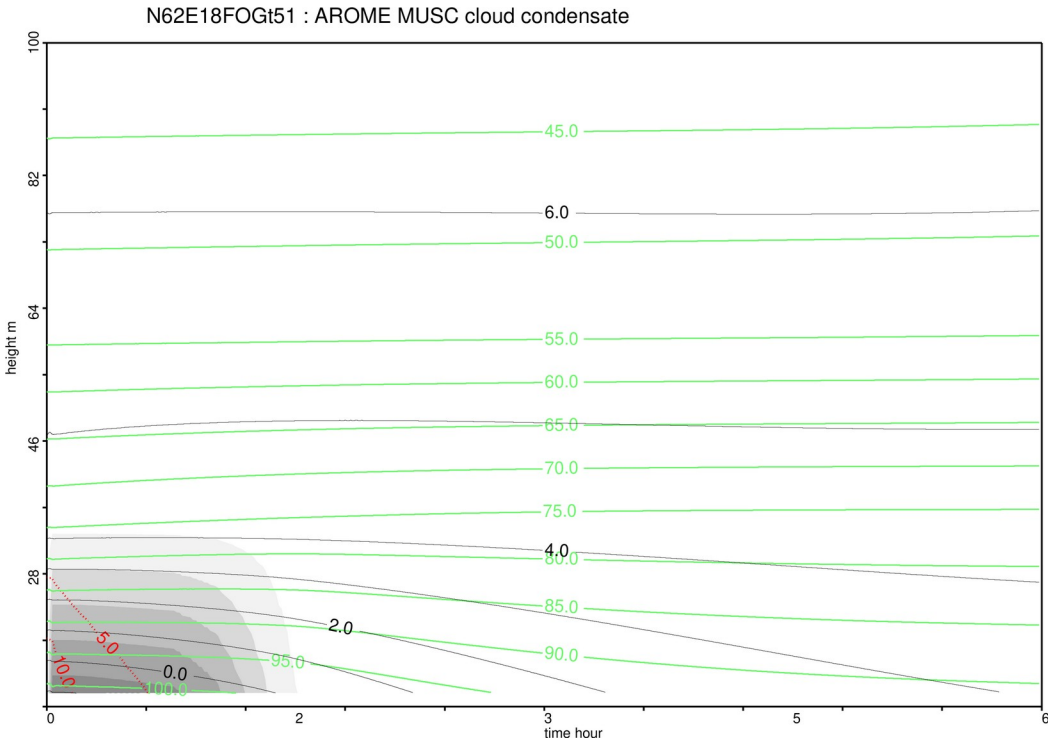


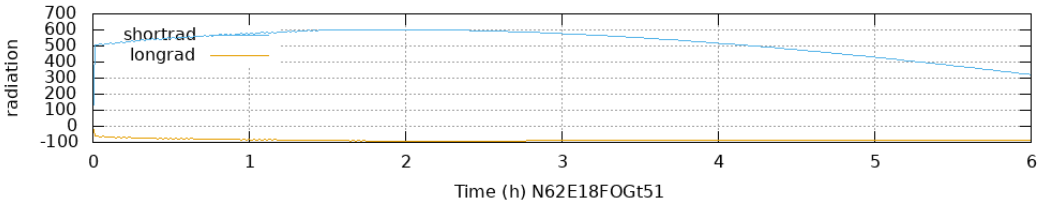


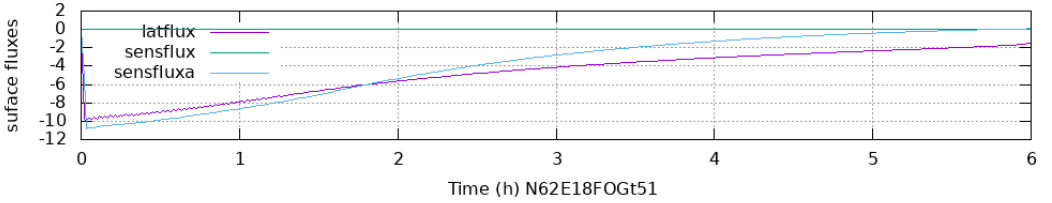


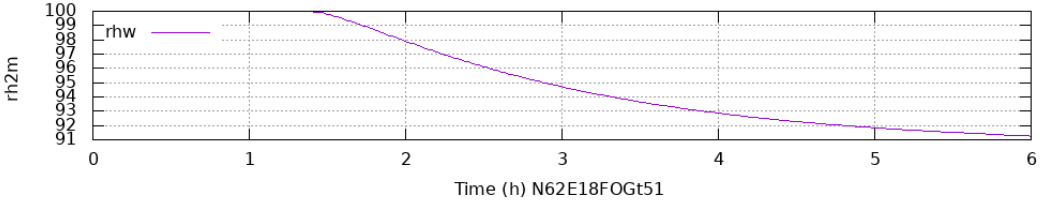
MUSC similar as operational + radiation update, LDNC=75/cm3 (gives 37.5 /cm3 at lowest level)

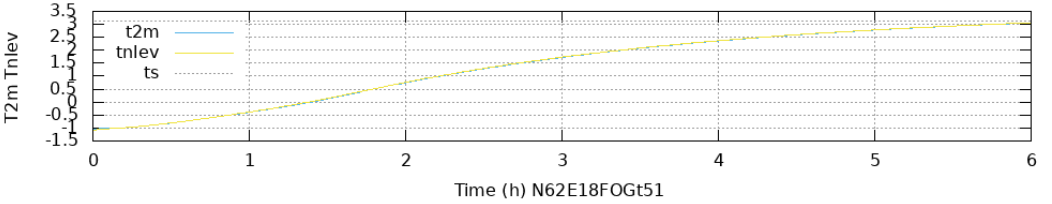
Result: The spurious fog disappear faster than in the operational run. At the end, the temperature difference surface-air vanish.

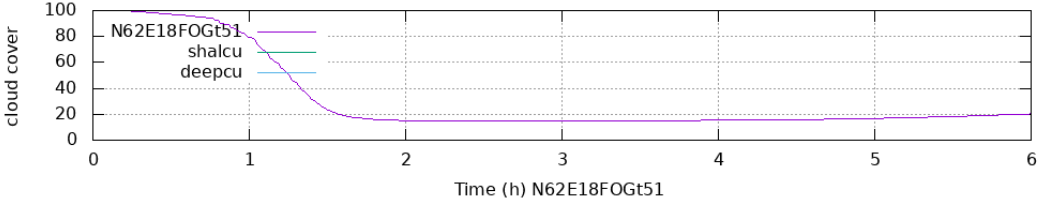












Different size distribution of the cloud droplets

The size distribution is assumed to follow the ‘general gamma function’ in ICE3 scheme :

$$g(D) = \frac{\alpha}{\Gamma(\nu)} \lambda^{\alpha\nu} D^{\alpha\nu-1} \exp(-(\lambda D)^{\alpha})$$

.. where

Table 1: Table of constants used for the different water species.

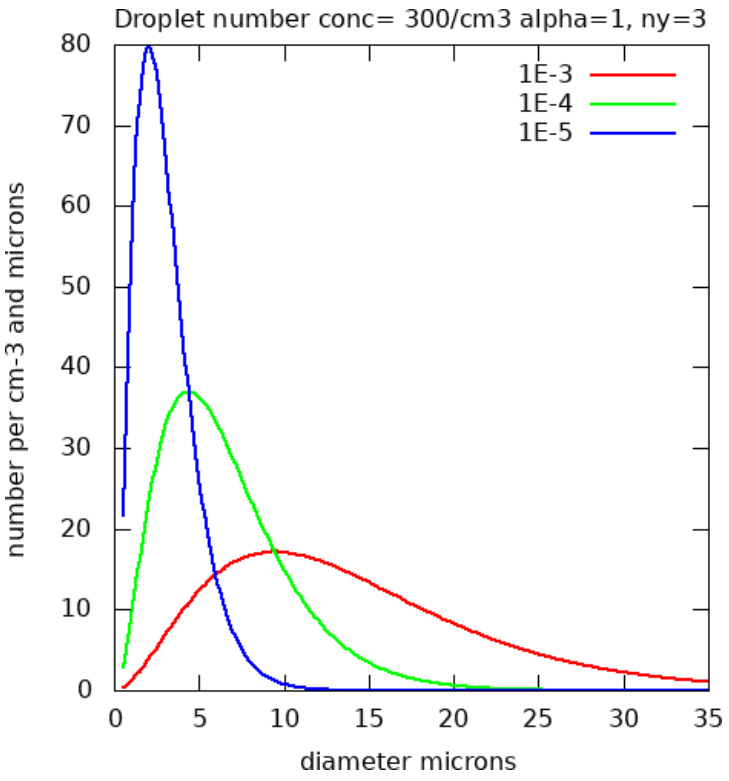
water specie	a	b	α	ν	C	x
cloud liquid water	524	3	3 on sea 1 on land	1 on sea 3 on land	CCN-conc	0
rain	524	3	1	1	$8\,10^6$	-1
cloud ice water	0.82	2.5	3	3	IN-conc	0
snow	0.02	1.9	1	1	5	1
graupel	19.6	2.8	1	1	$5\,10^5$	-0.5

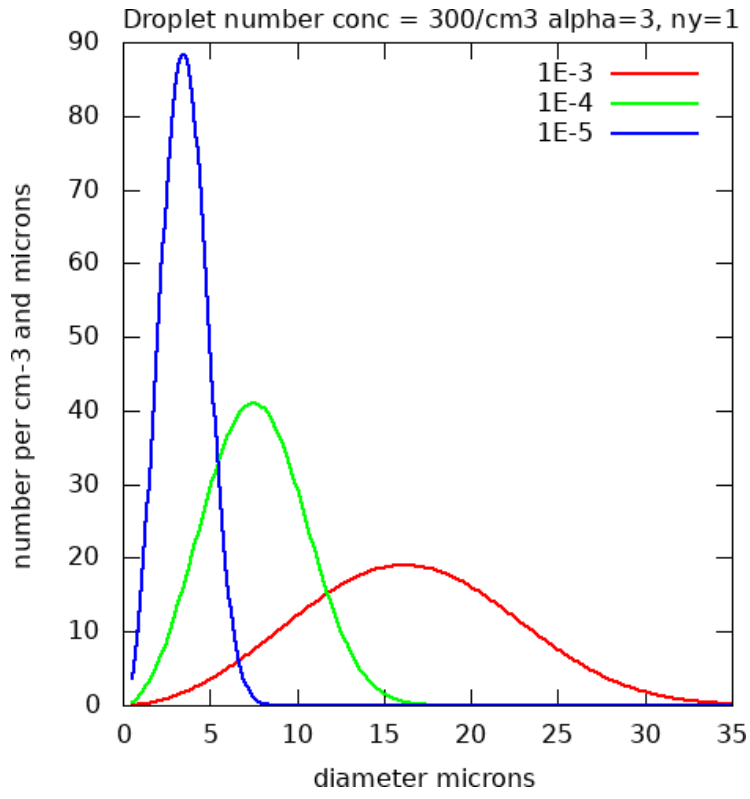
$$\lambda = \left[\frac{r \rho \Gamma(\nu)}{aC\ \Gamma(\nu + b/\alpha)} \right]^{\frac{1}{x-b}}$$

r	Mixing ratio of water vapour	$\mathrm{kg\,kg^{-1}}$
ρ	density of air	$\mathrm{kg\,m^{-3}}$

α and ν is set to 3 and 1 respectively over land but the opposite over sea. Those two parameters are important for the size distribution and affect the sedimentation rate. Here follows some studies with different settings.

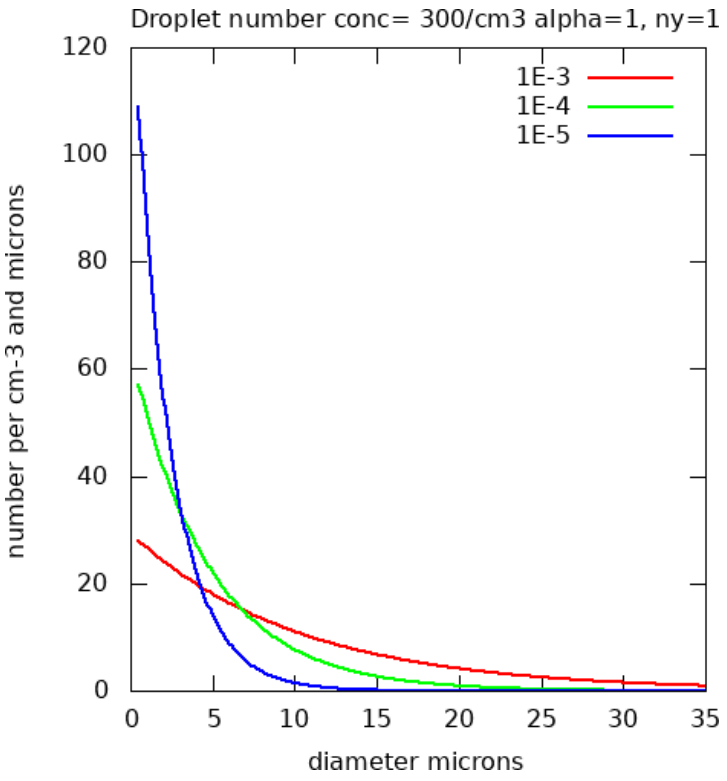
Different size distribution of the cloud droplets

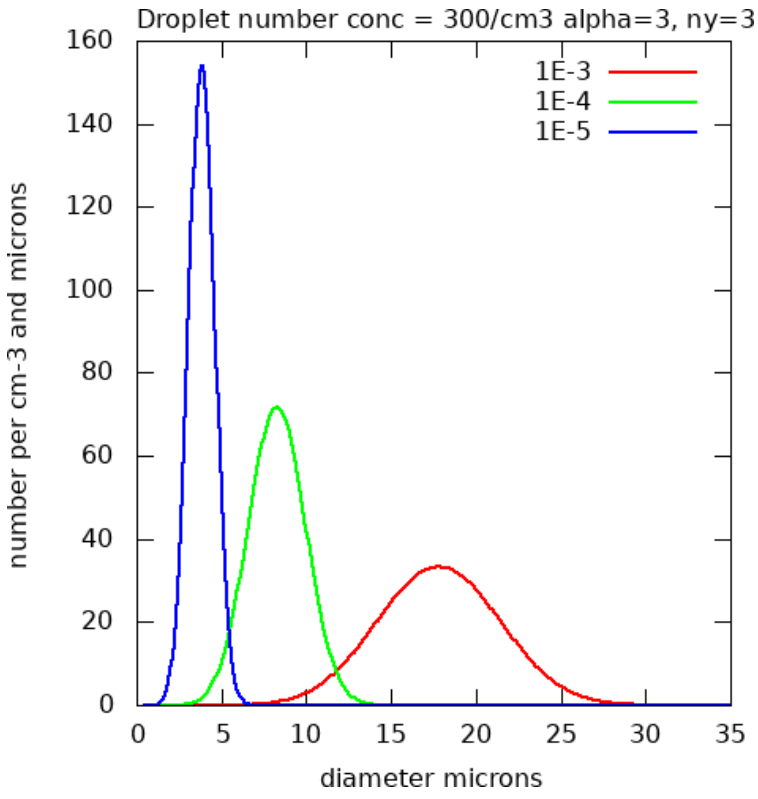




Left figure: Size distribution over land in original ICE3 settings, where $\alpha=1$ and $\nu=3$ for mixing ratios 1,E-3, 1.E-4 and 1,E-5 and number concentration of 300/ cm3. To the left the same for sea where $\alpha=3$ and $\nu=1$, and number concentration untouched for comparison. Broader spectra of diameters with $\alpha=1,\nu=3$ than $\alpha=3,\nu=1$ means more of the largest → faster sedimentation

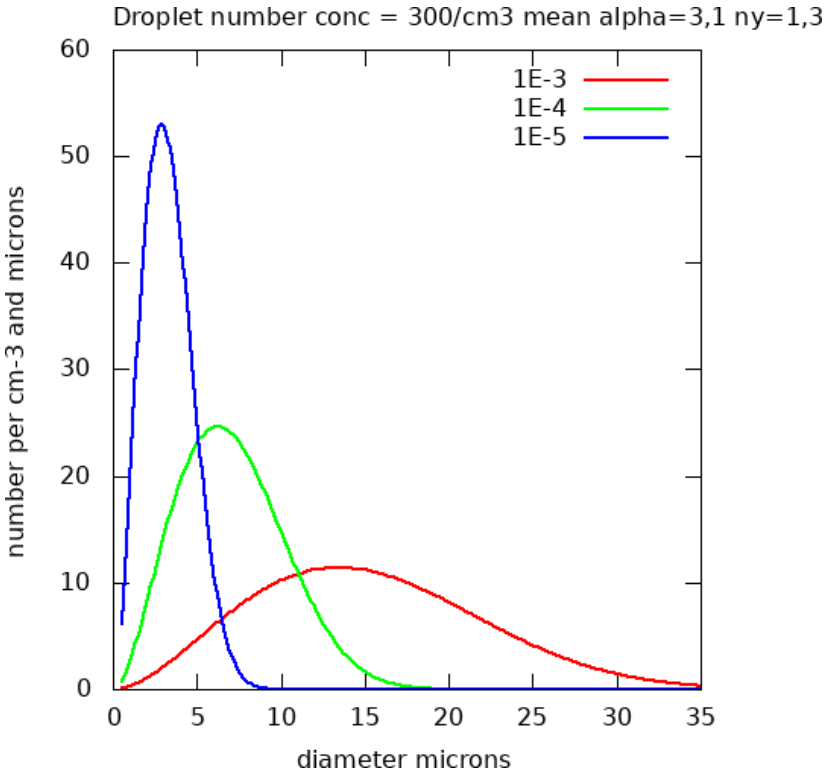
Different size distribution of the cloud droplets





Left figure: Size distribution where $\alpha = \nu = 1$ for mixing ratios 1,E-3, 1.E-4 and 1,E-5 and number concentration of 300/ cm3 To the right where $\alpha = \nu = 3$.

Different size distribution of the cloud droplets

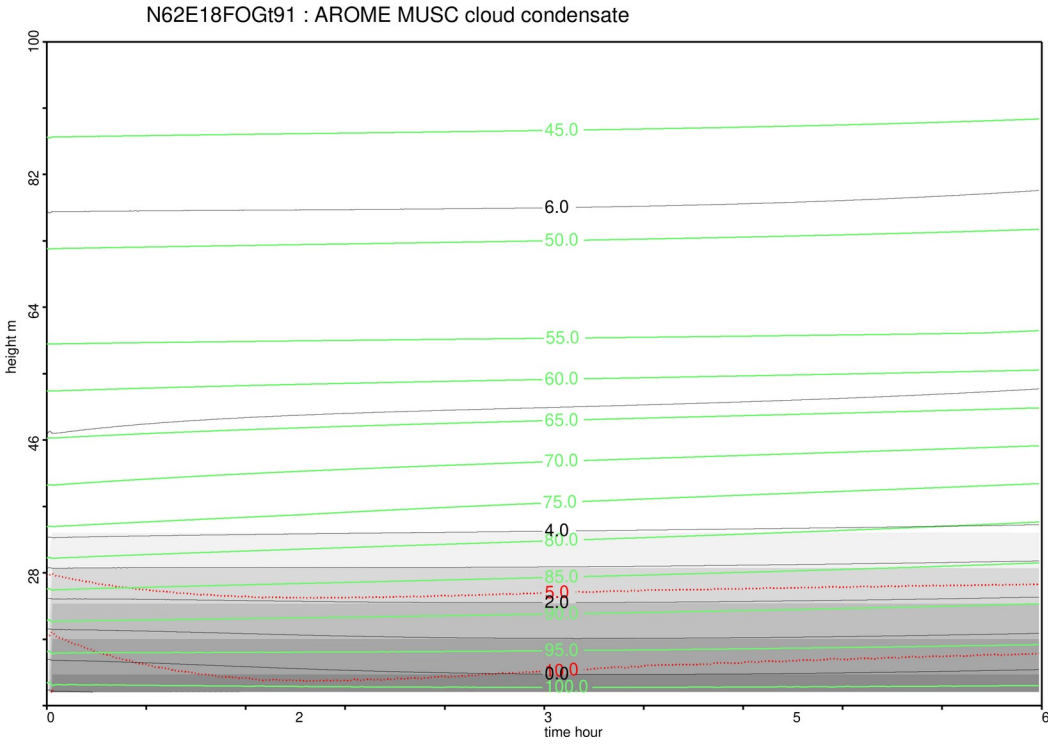


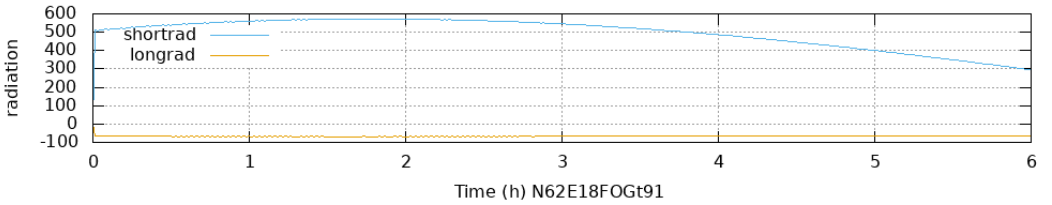
Size distributions as previous slide, land fraction 0.5, or when RFRMIN(26) is set.
A linear combination of α=1, ν=3 and α=3, ν=1.

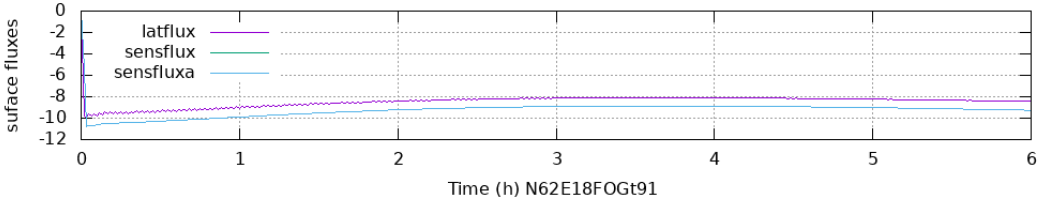
Test with settings as operational + radiation update, but alternative droplet size distribution where

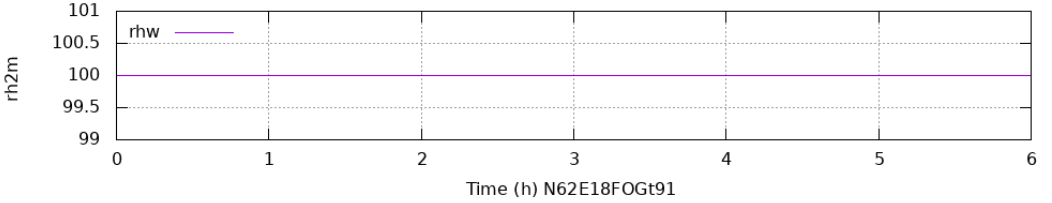
Thicker fog, temperature in the fog rises only marginally, and half degrees colder than the operational with a linear combination of $\alpha = 1, \nu = 3$ and $\alpha = 3, \nu = 1$

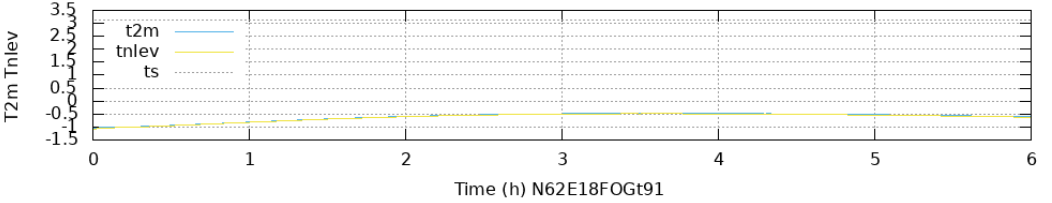
$\alpha = 3, \nu = 3$

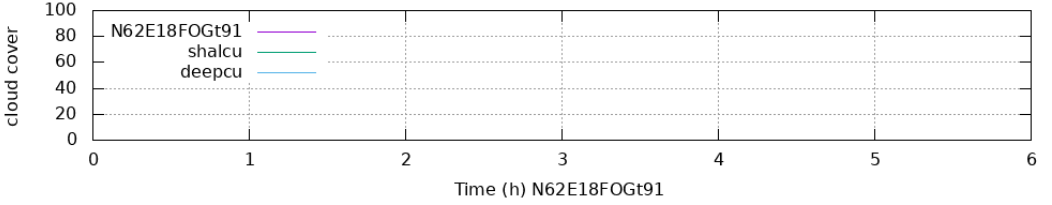






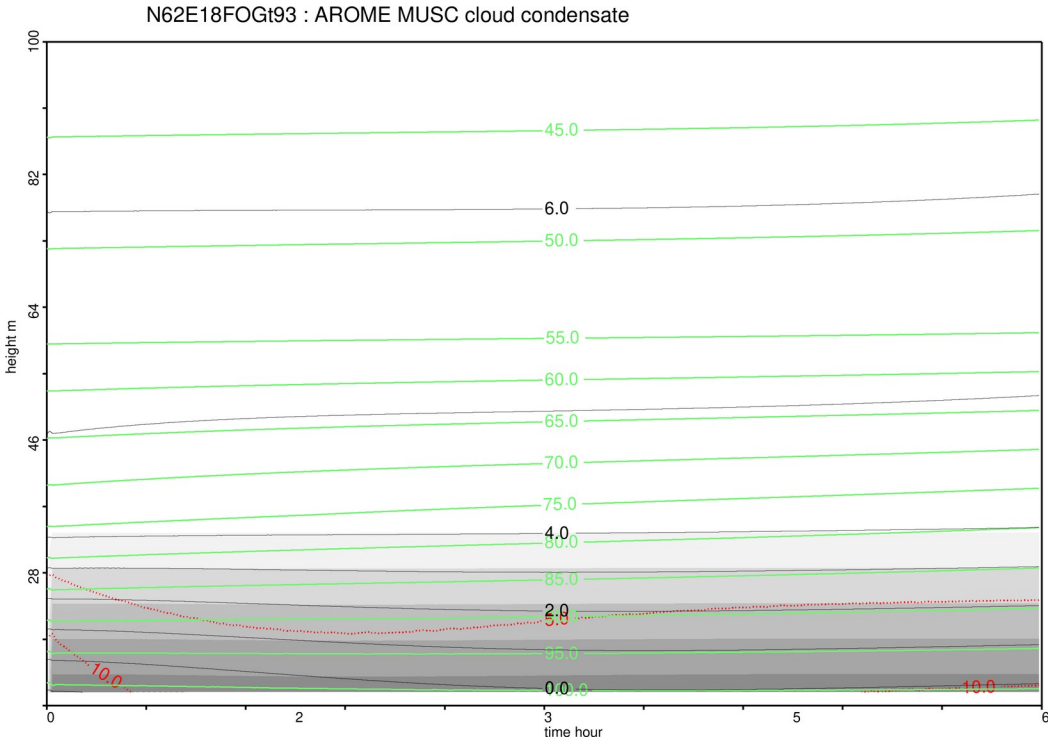


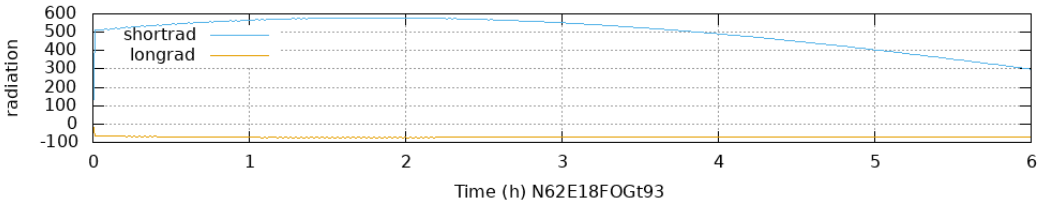


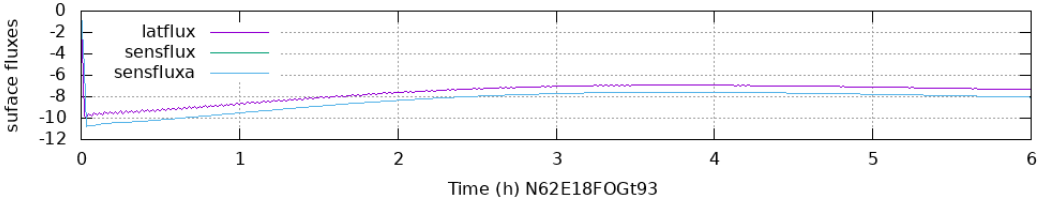


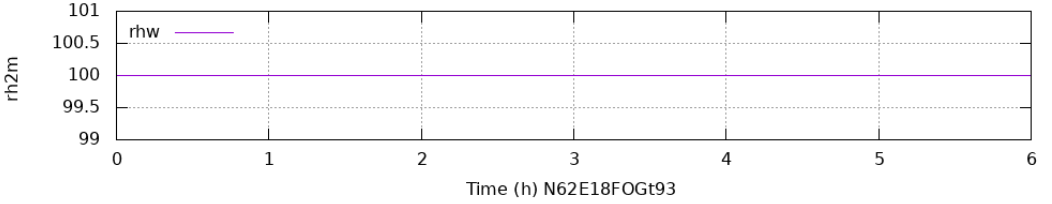
Equal to operational (!)

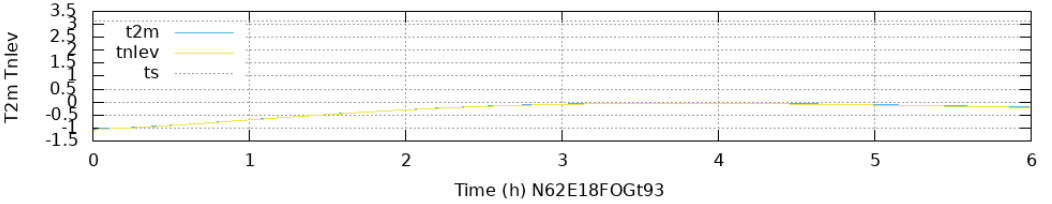
$\alpha = 3$,$\nu = 1$

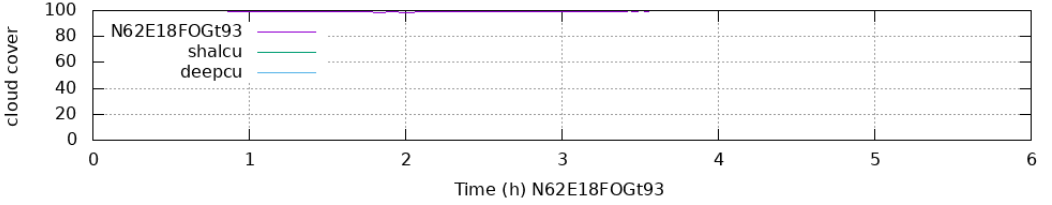






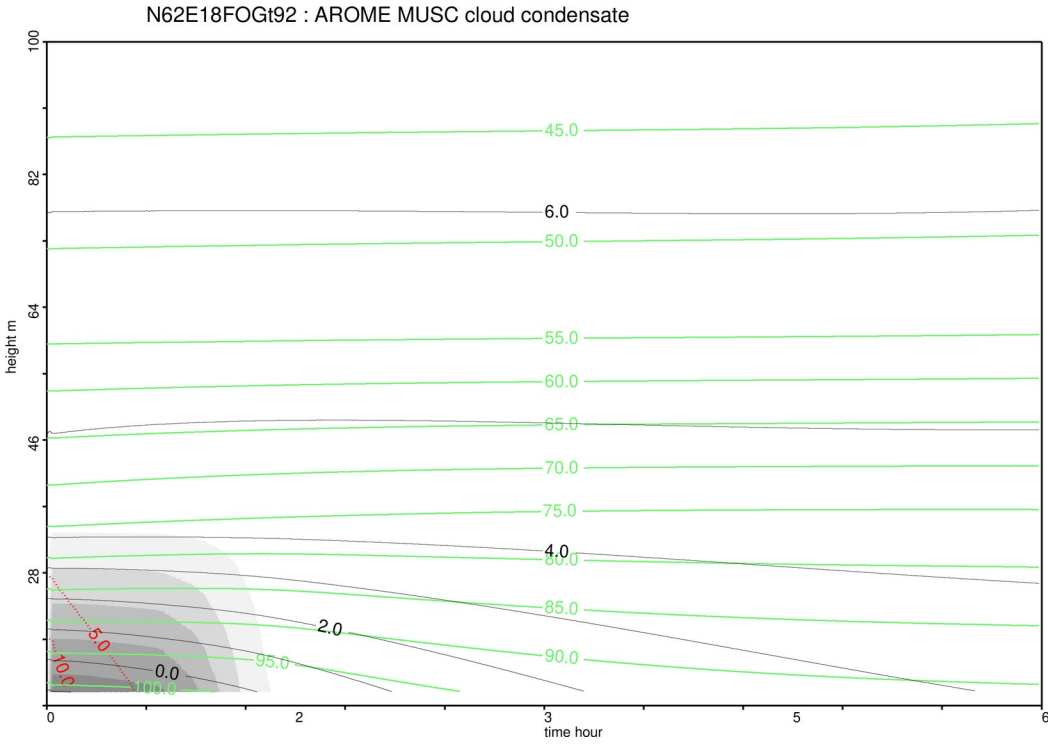


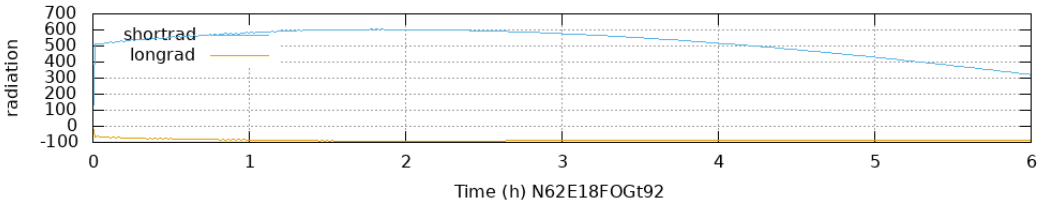


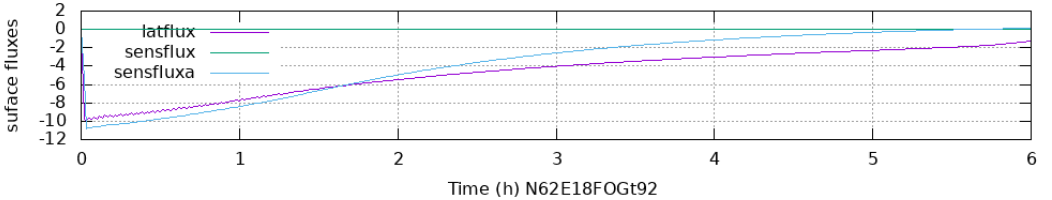


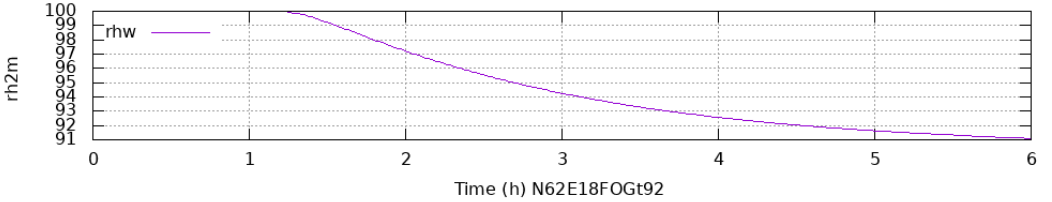
The fog disappears
in about 2 hours.

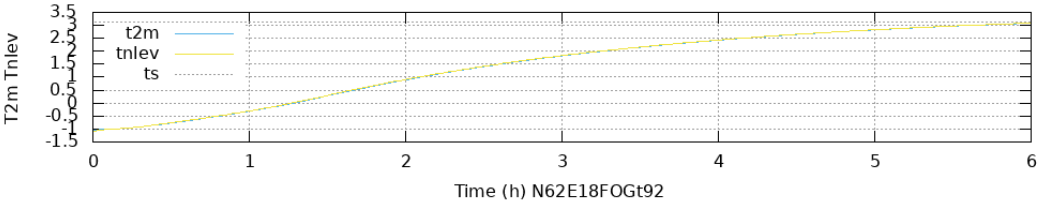
$\alpha = 1$, $\nu = 3$

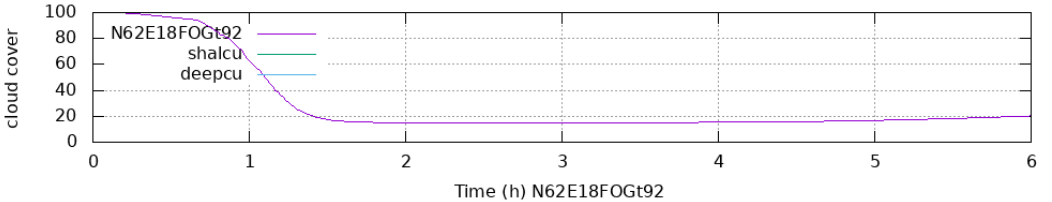






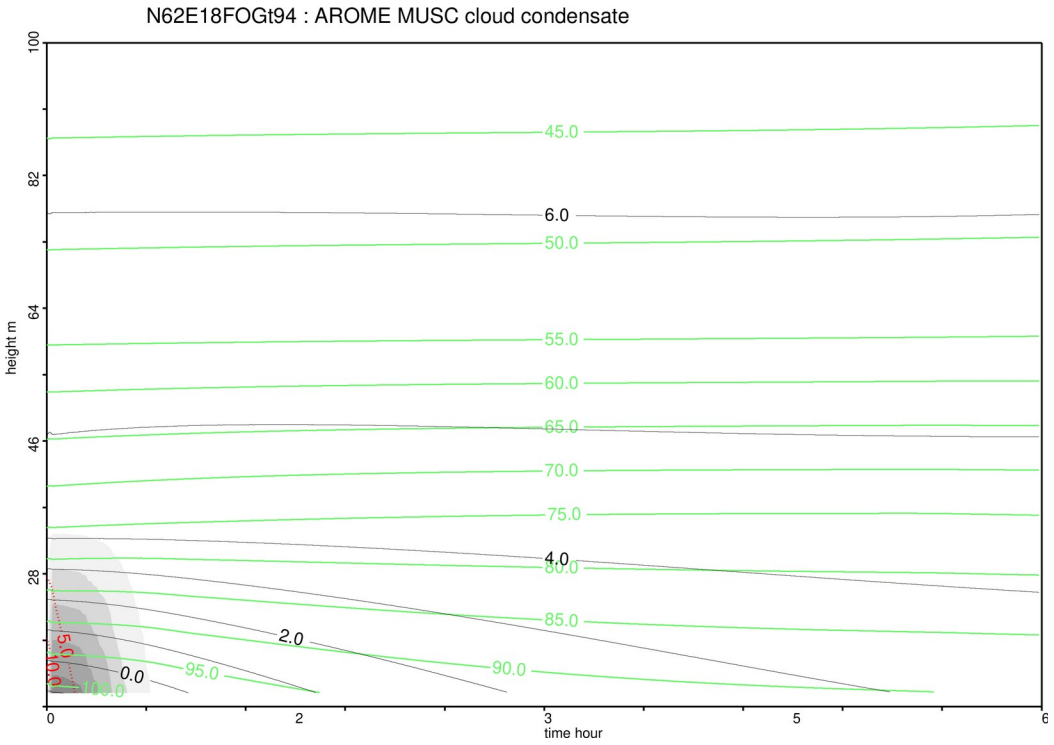


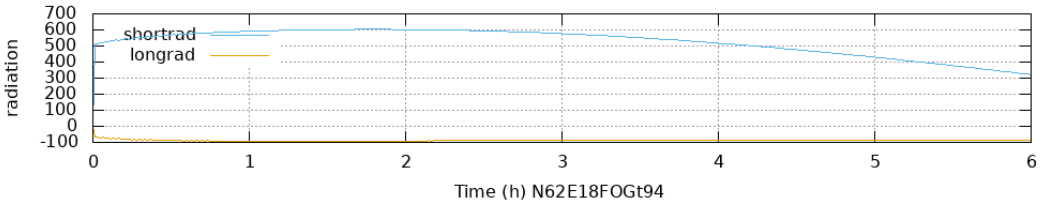


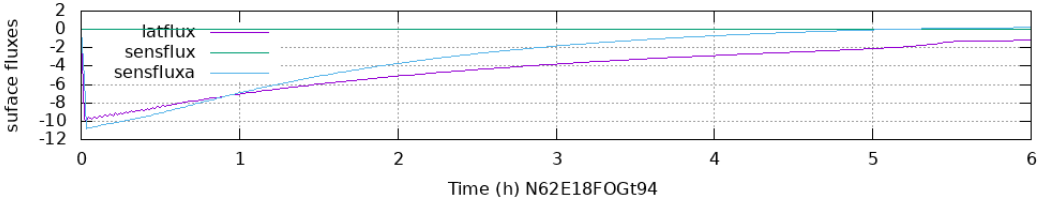


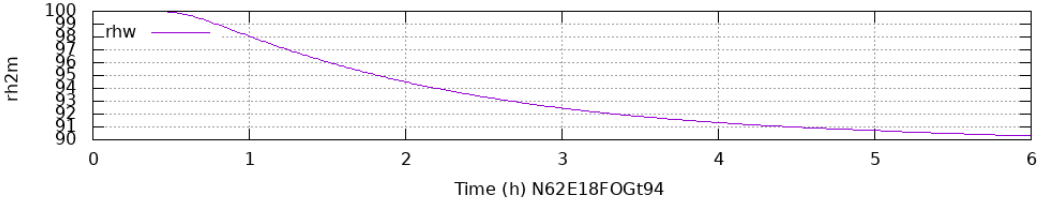
The fog disappears
in less than an hour.

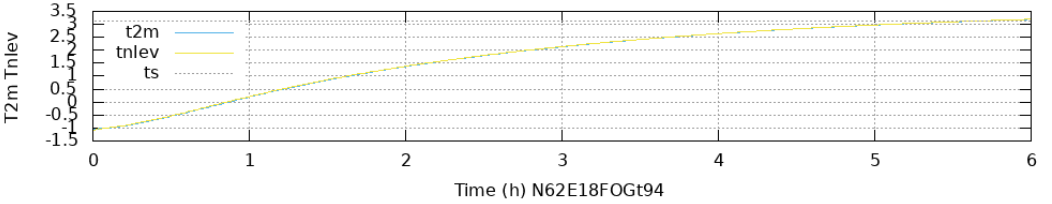
$\alpha = 1$,$\nu = 1$

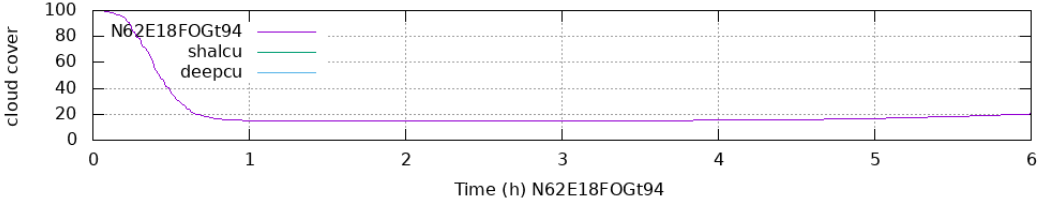












Try to improve low clouds (1): LHGT_QS

Initiated by forecasters complaints about too much fog but too little of low- and middle level clouds.

What is LHGT_QS?

LHGT_QS is a way of **tuning VSIGQSAT** dependent on the model level thickness.
What is then **VSIGQSAT?**
With VSIGQSAT, some extra variance of the distance between total humidity and saturation-humidity is added, which lower the threshold for liquid cloud formation, thus more clouds.
Example: VSIGQSAs= 0.02
VSIGQSAT remains 0.02 for a model thickness (ΔZ) of 30m. For other level thickness's it is VSIGQSAT* $\Delta Z/30$, with $\Delta Z/30$ limited to the range [0.5:1.5], which gives the VSIGQSAT range of [0.01:0.03]. With current 65 levels VSIGQSAT ~ 0.015 at lowest level, unchanged around 200m and 0.03 above 400 m.

The parameters 30m, 0.5 and 1.5 are tunable.

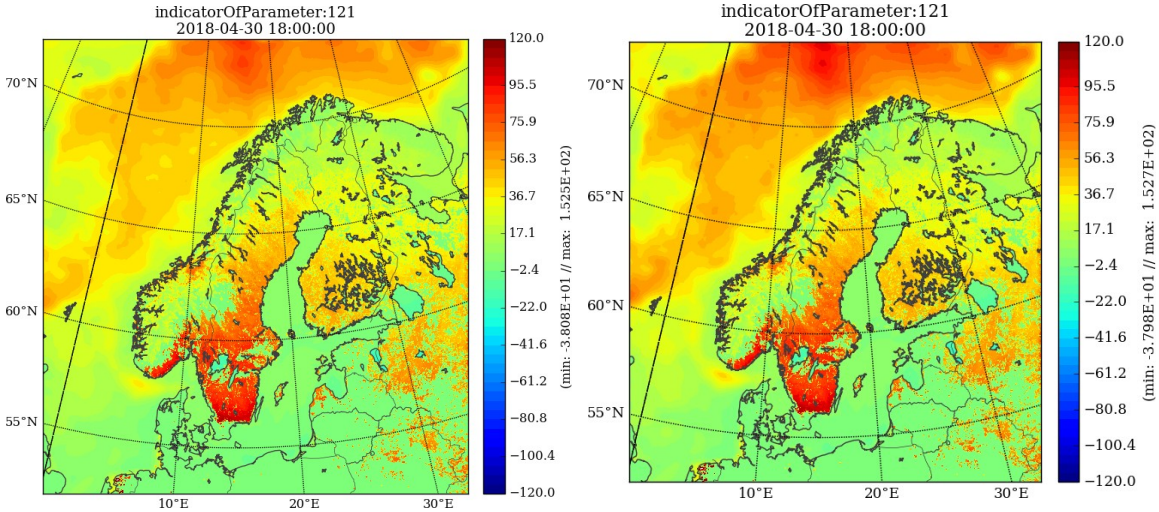
Physical reason for using LHGT_QS: Thicker levels have larger sub grid scale variation of humidity than thinner ones, but this variation is complex so a simple tuning is considered for the moment.

Try to improve low clouds (2): ECUME6:

What is ECUME6 ?

ECUME6 is the successor of ECUME version 5 scheme for fluxes over sea in SURFEX. (Developed by Meteo-France.) The fluxes of heat and moisture are generally somewhat larger with ECUME6 than with present ECUME

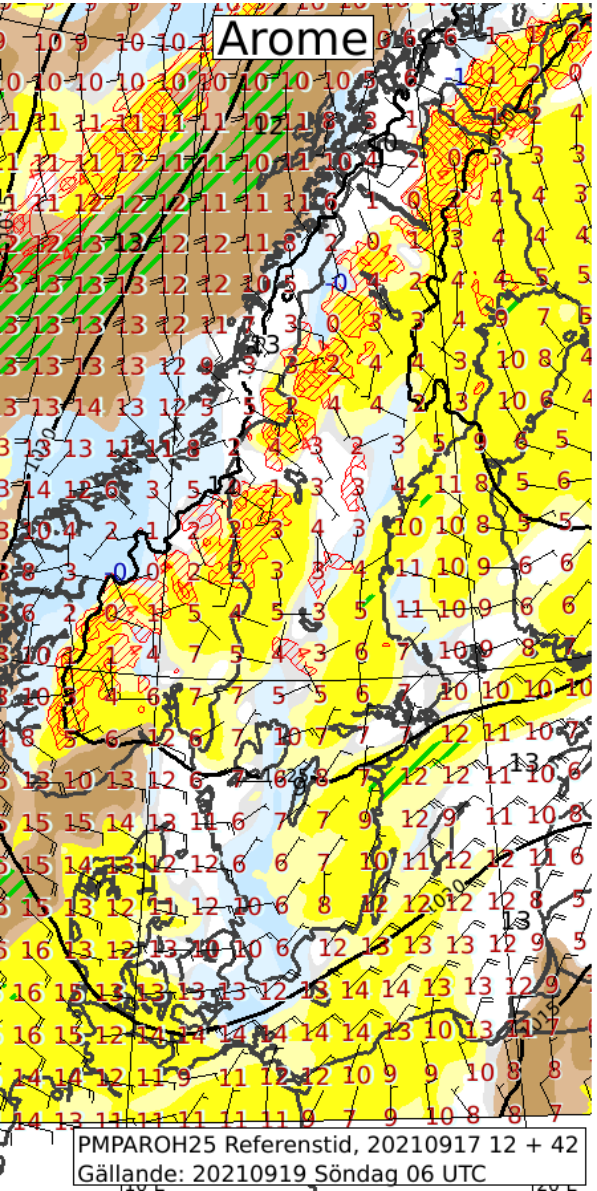
Tests, updated Cy43:
Mostly neutral or marginally better clouds and precipitation with ECUME6, e.g. little more low clouds
Small increase of fog, but since fog may be reduced with other tunings discussed here, it seems not problematic any more.
Other positive: Better T2M and better T,q verified against soundings

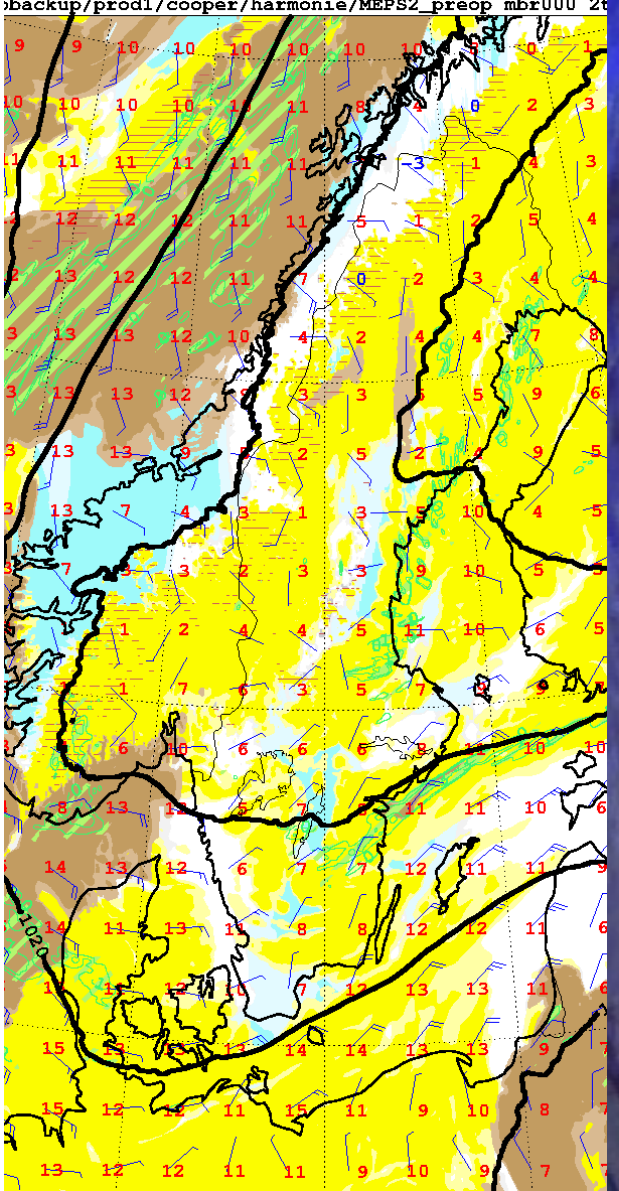


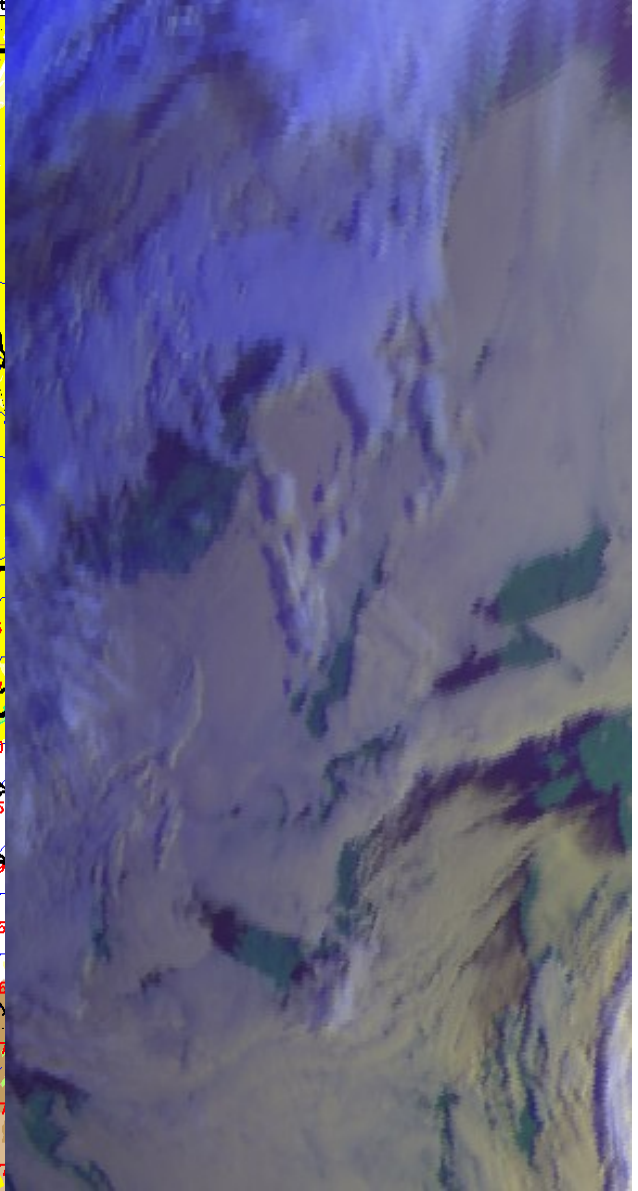
Latent heat flux in April 2018: Left ECUME5, right ECUME6

3D case with missing low clouds. Explanation of the following maps:

- To the left: forecast maps. Yellow is low clouds, brown middle level clouds, blue is high clouds. Precipitation in green. Observations in black.
- To the right: Satellite picture over roughly the same area. Yellow is water clouds, mainly being low- or middle level clouds. Red and brown are ice clouds or mixed phase clouds with ice /snow dominating near the top of the cloud.







Example when **combining ECUME6 and increasing VSIGQSAT for thicker levels: (from 0.03 to 0.05)** Left: original. Middle: combined. Right: Satellite picture. Still missing clouds but not that much.

Summary

- Reduction of too excessive fog can be achieved by reducing the cloud liquid number concentration, changing the size distribution in such way that the sedimentation rate increases and by improving the radiation scheme.
- Increasing low clouds can be obtained by increasing VSIGQSAT. With LHGT_QS this is possible without increasing fog. ECUME6 gives also more low clouds.

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