The Impact of cloud condensation nuclei (CCN) concentration and ice- nucleus (IN) concentration on clouds and precipitation in Hirlam (and perhaps other models)

Karl-Ivar-Ivarsson. Workshop on moist processes in future high resolution NWP/Climate models, SMHI, Norrköping Sweden
email: karl-ivar.ivarsson@smhi.se

In this presentation:

- Aim of this study.
- Recent developments of the Rasch-Kristjansson (RK) condensation scheme and Kain-Fritsch (KF) convection scheme.
- Impact of CCN concentration in the current parametrization of clouds, condensation and radiation.
- Results of CCN sensitivity tests
- Impact of IN concentration in the current prognostic cloud ice formulation.
- Results of ice nuclei concentration sensitivity tests
- Conclusions

Aim of this study

- Increasing interest of 2-way coupling of chemistry modeling and condensation and radiation.
- Such models more computer demanding – increasing numbers of 'passive' scalars, lager output files etc.
- Hove much to gain in forecast quality ?
- Start with a sensitivity study to see a possible impact.

Recent developments of the Rasch-Kristjansson (RK) condensations scheme and Kain-Fritsch (KF) convection scheme.

- Tuning, code cleaning.
- Possibility to use Bechtold KF
- New max-random cloud overlap formulation (also in our local versions of Alaro,Arome)
- IFS – coding (Both RK and KF)

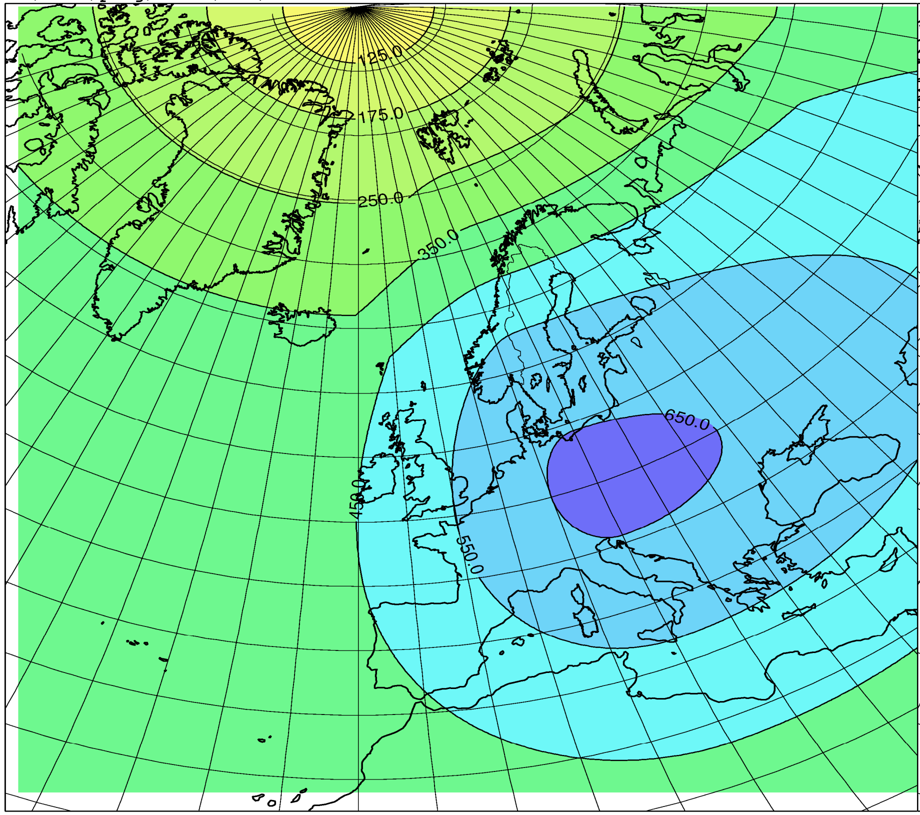
The CCN concentration in the current parametrization of clouds,condensation and radiation.

- Clouds – not directly.
- Condensation : the expression for the Kogan autoconversion of cloudwater $A\, q_l^{2.47}\, C_{cn}^{-1.79}$
- Radiation : Effective radius : $r_e = (\frac{3q_l}{4\pi\rho_l k C_{cn}})^{1/3}$
- Not included : Haze, affecting radiation, hygroscopic effects on the effective relative humidity for condensation ... ...

Experiments:

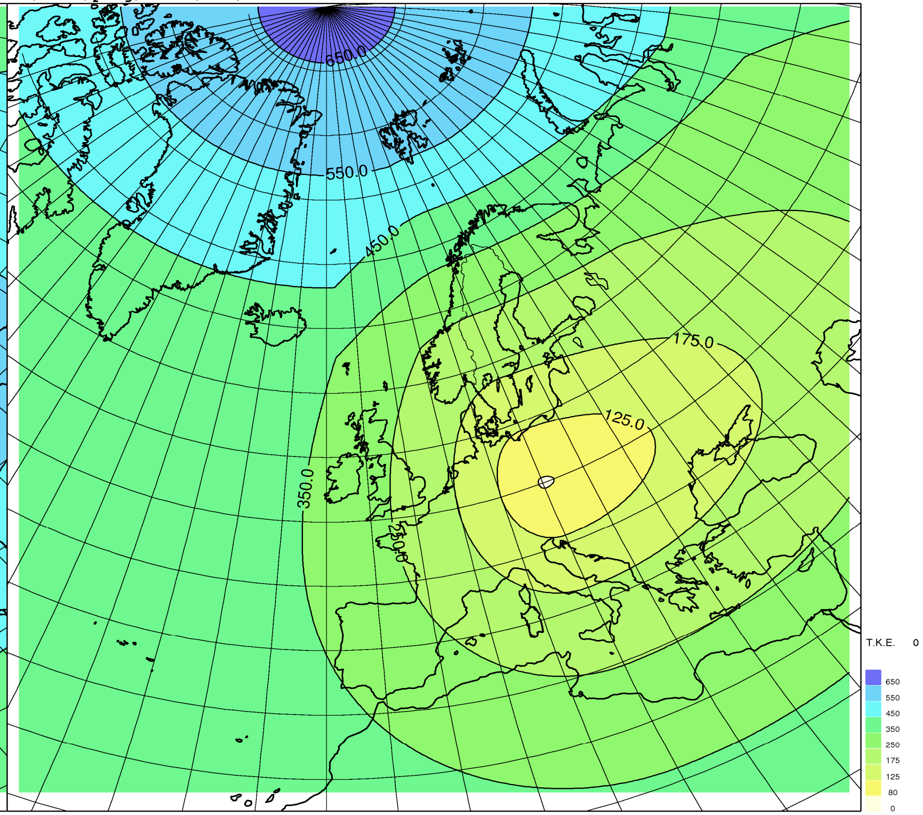
- 22km resolution 40 levels. January 2006 + July 2007. Newsnow scheme + “orosur” + QNSE + “Colin-2”- radiation + ifs-coded KFRK (old KF)
- Current CCN concentration in RK and radia (C3J) replaced by a change in boundary layer. (no change above)
- A maximum in central Europe, C3o,C3u,C3U , minimum near the north pole.
- Reversed, C3p,C3v,C3V, unrealistic, but interesting for a sensitivity test)

/data/proj/verif/ver/ver HI8 140



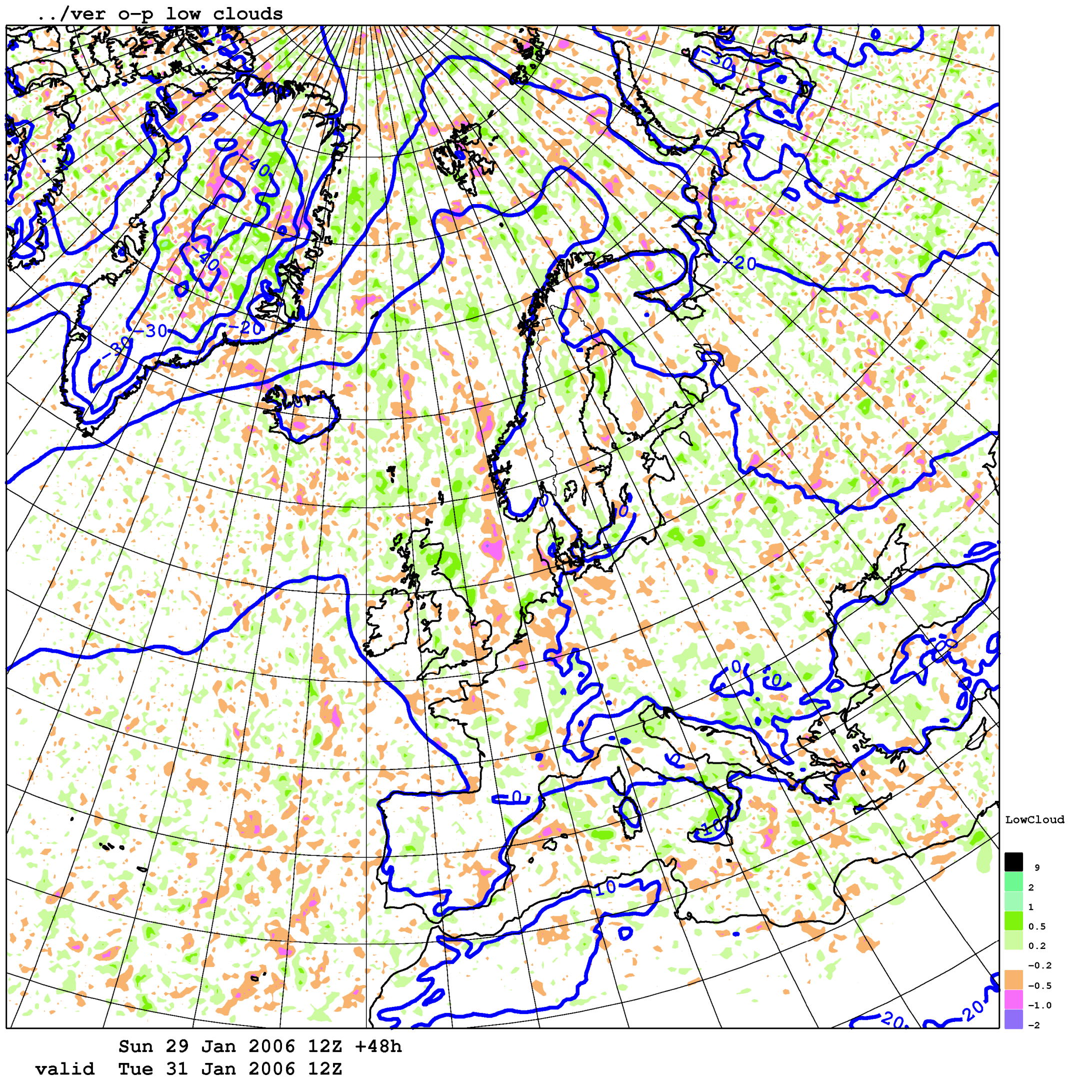
Tue 28 Apr 2009 00Z +12h
valid Tue 28 Apr 2009 12Z

/data/proj/verif/ver/ver HI8 140

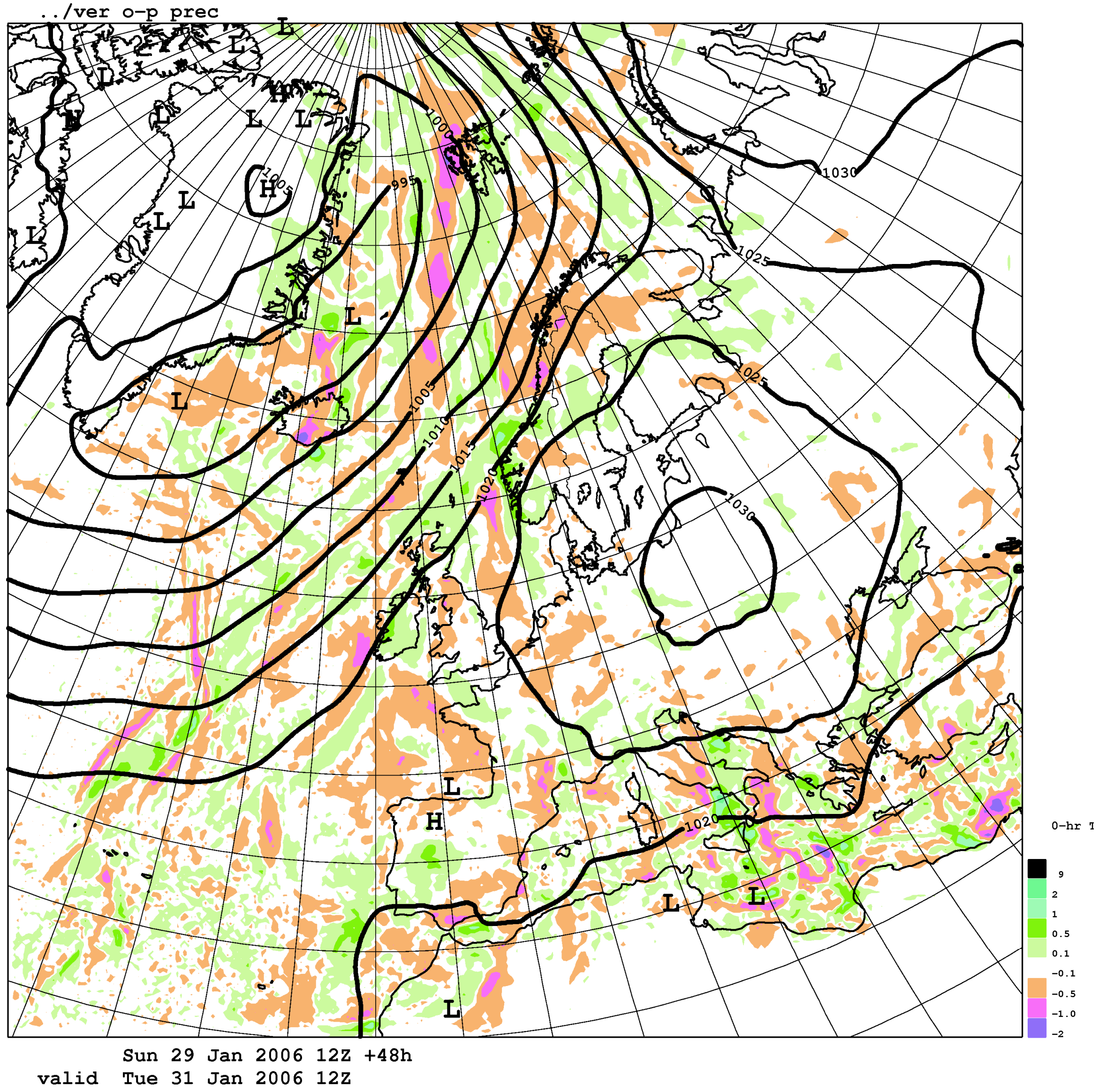


Tue 28 Apr 2009 00Z +12h
valid Tue 28 Apr 2009 12Z

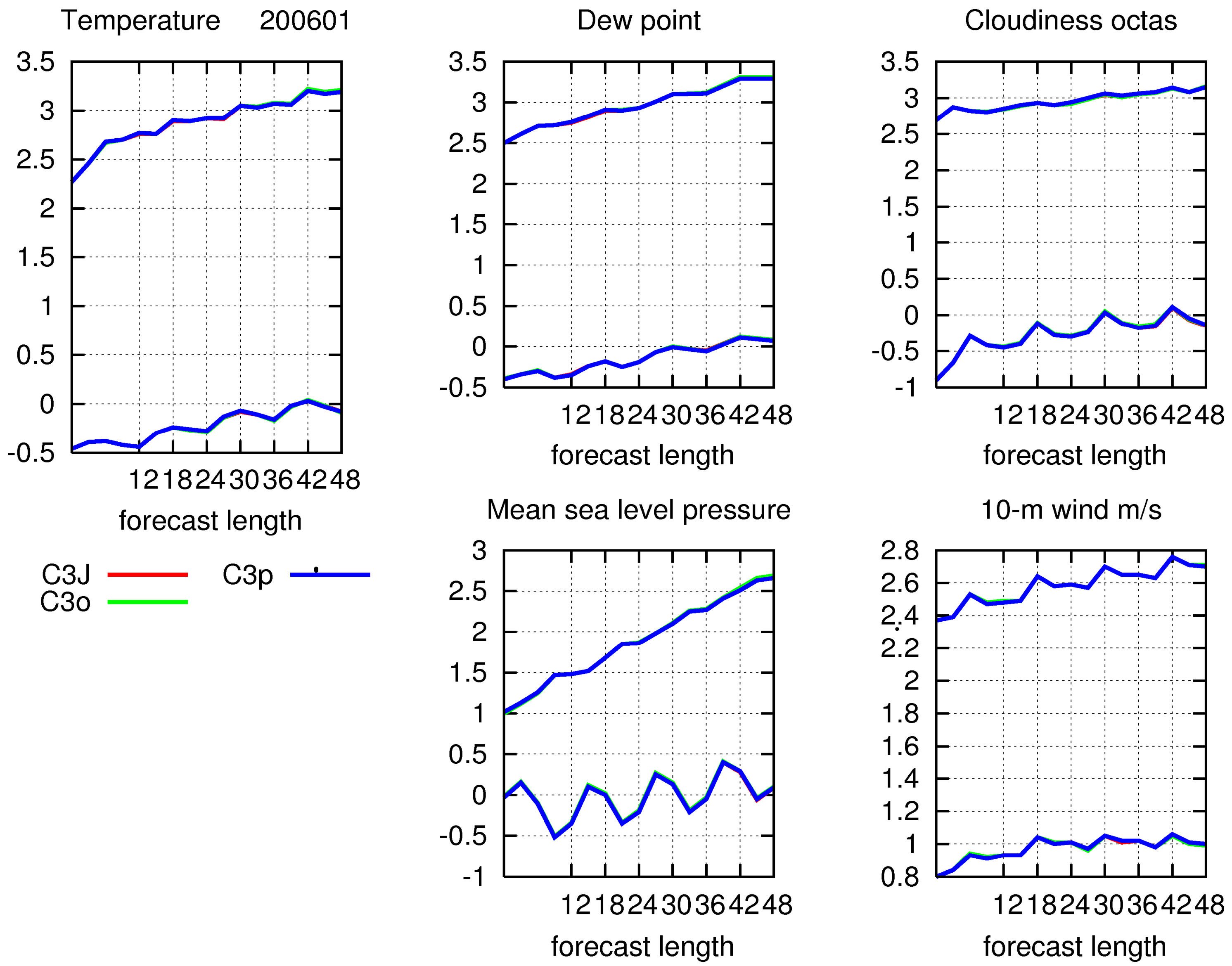
Winter : Difference map – low clouds (C3o – C3p) Note x 80! reddish : less low clouds 'normal' CCN distribution, greenish : more low clouds 'normal' CCN distribution



Winter : Difference map – precipitation (C3o – C3p) mm during 28 days reddish : less for 'normal' CCN distribution, greenish : more for clouds 'normal' CCN distribution



Verification winter: C3J: orig CCN concentration. C3o : most in central Europe C3p: reversed



Reasons for low impact

- Cloud drop dependence on collection of cloud water by falling rain and snow not included in current scheme.

- Extend differences in CCN to above PBL

Collection of cloud water by snow, original :
Bulk formula:

$$P_{sacw} = C_{sac} E_{sw} q_w \tag{1}$$

Here, C_{sac} = constant dependent on microphysics (Lin et al) q_w = cloud-water content , E_{sw} = collision efficiency , 0.1

New (From Lohmann , 2004) :

$$E_{sw} = 0.939 St^{2.657} \tag{2}$$

Here, $St = \frac{2(V_t - v_t)v_t}{Dg}$ is the stokes number, V_t = fall speed of snow (currently just 0.9 m/s), v_t = fall speed of cloud droplets (here comes CCN concentration in), D = maximum dimension of snow crystal (5 mm) and g = gravity acceleration

Collection of cloud water by rain, original bulk formula :

$$P_{racw} = C_{racw} q_w \tag{3}$$

New (Rogers and Yau , 1989)

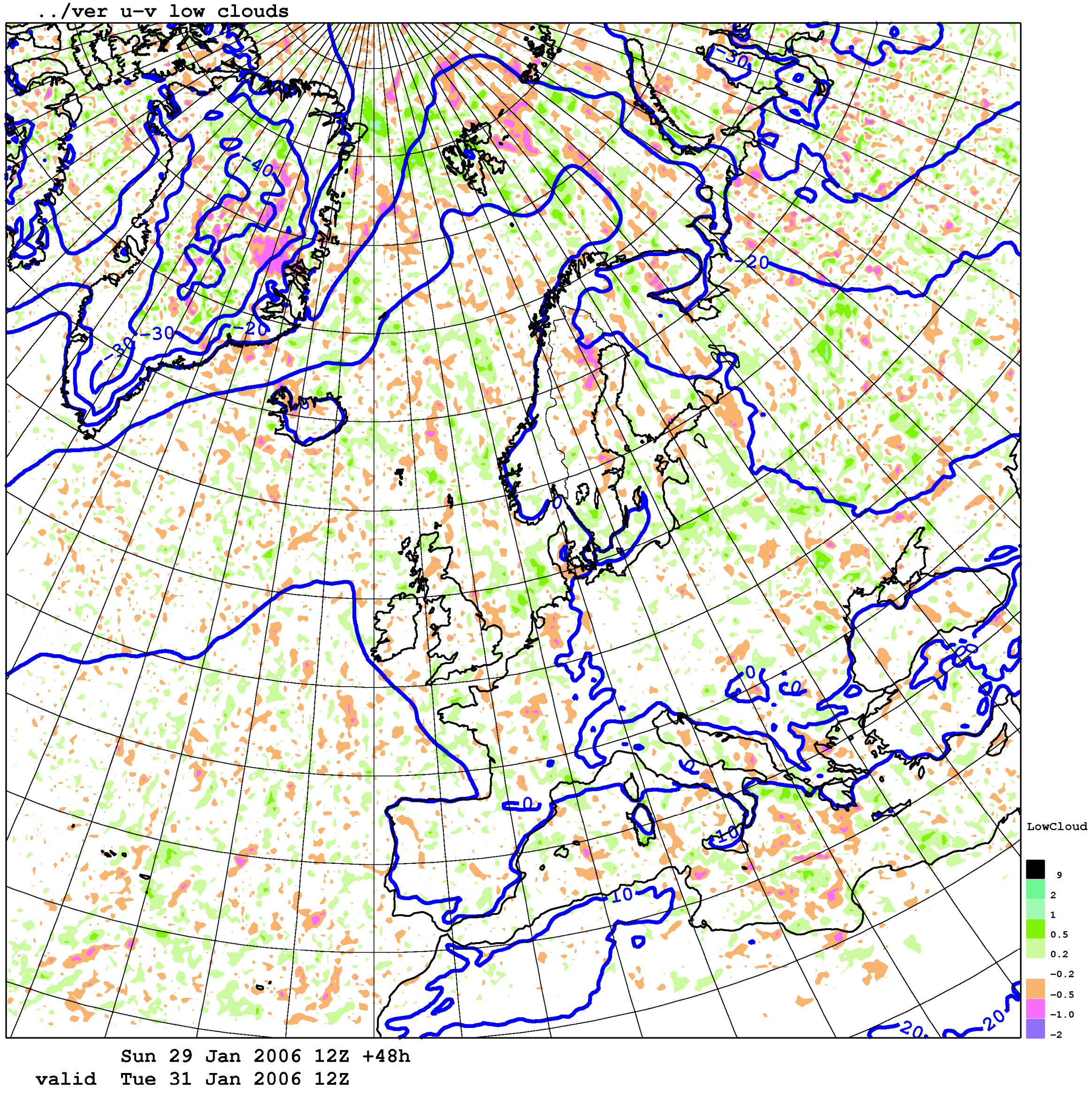
$$P_{racw} = 2 C_{racw} E_{rw} q_w \tag{4}$$

Here, C_{racw} = constant dependent on microphysics, etc E_{rw} = collision efficiency , function of drop radius :

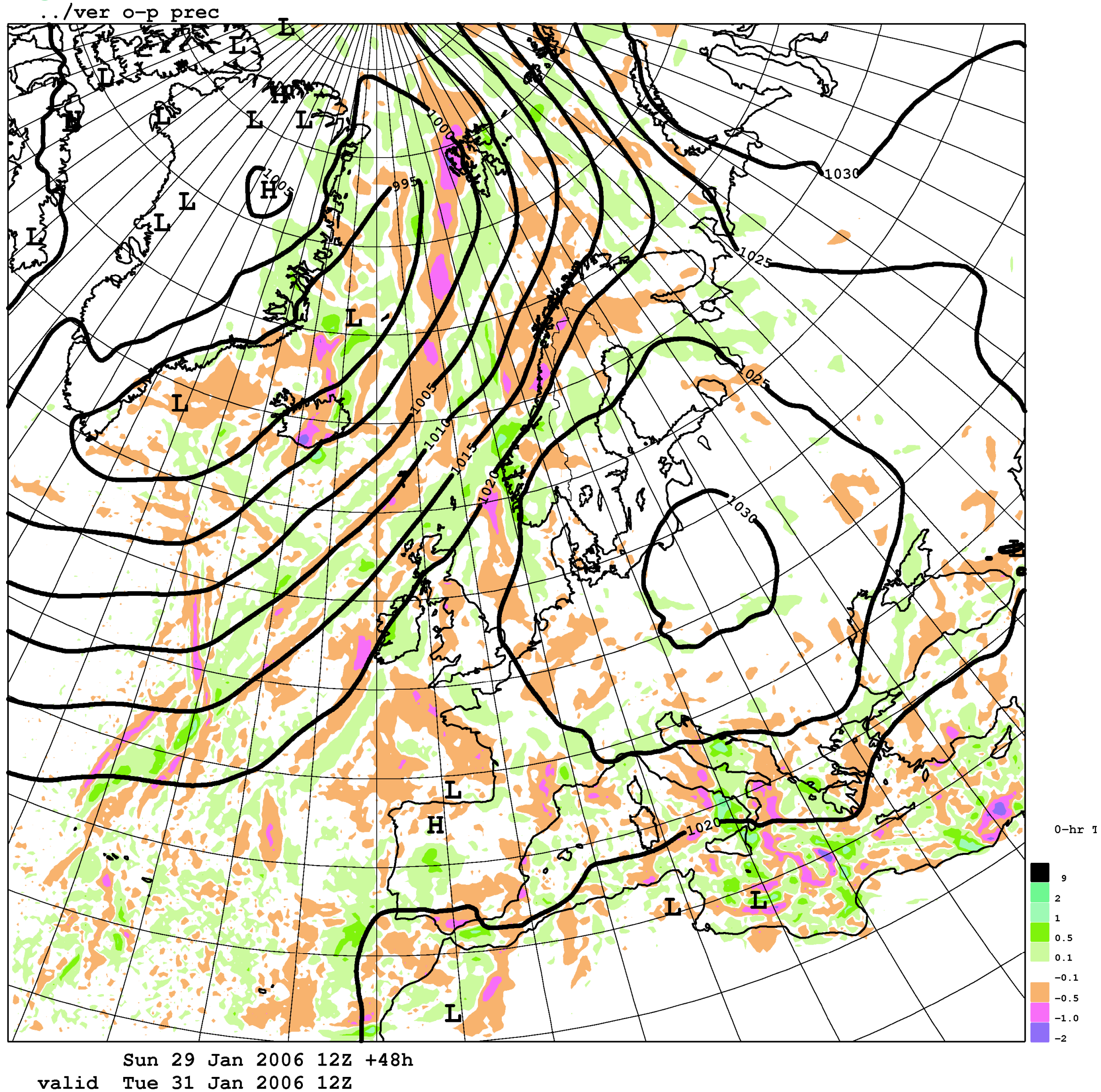
$$E_{rw} = \frac{e^{Ar} - 1}{e^{Ar} + 1} \tag{5}$$

$A = 2.5x10^5$, r = mean cloud droplet radius, m

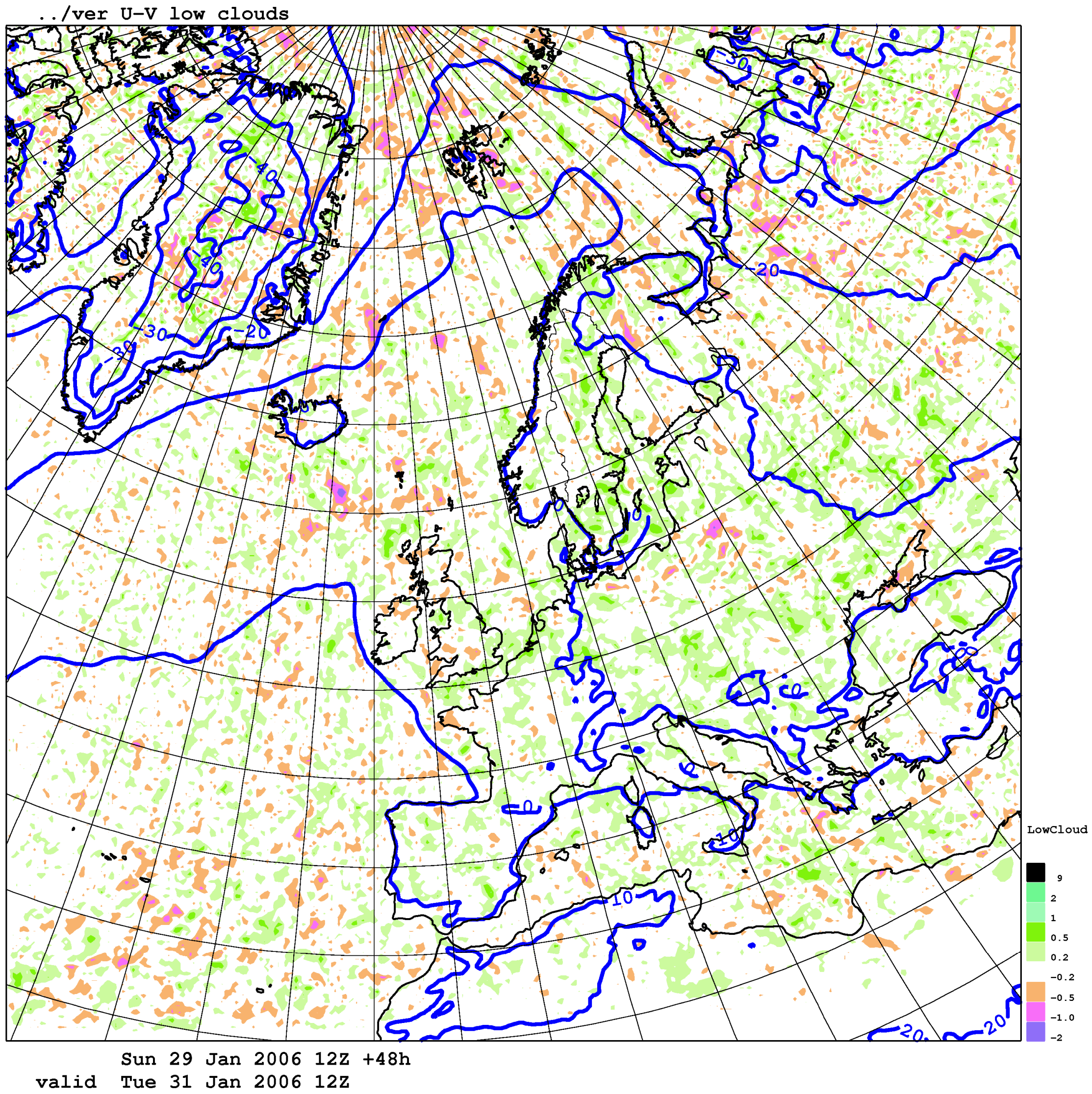
Winter :After including drop size dependency in collision efficiency :Difference map – low clouds (C3u – C3v) Note x 80! reddish : less low clouds 'normal' CCN distribution, greenish : more low clouds 'normal' CCN distribution



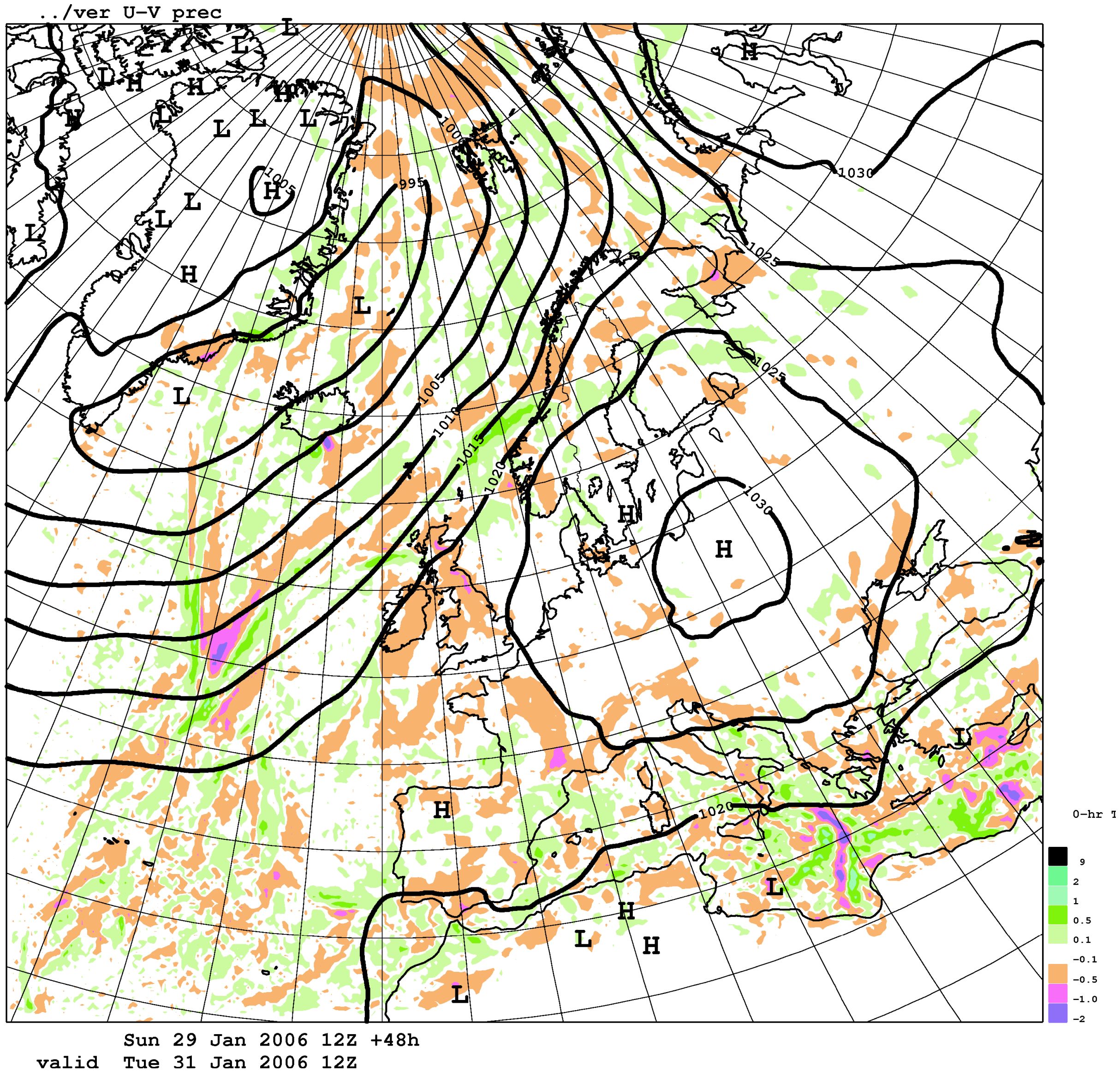
Winter : After including drop size dependency in collision efficiency : Difference map – low clouds (C3u – C3v) Note x 80! reddish : less low clouds 'normal' CCN distribution, greenish : more low clouds 'normal' CCN distribution



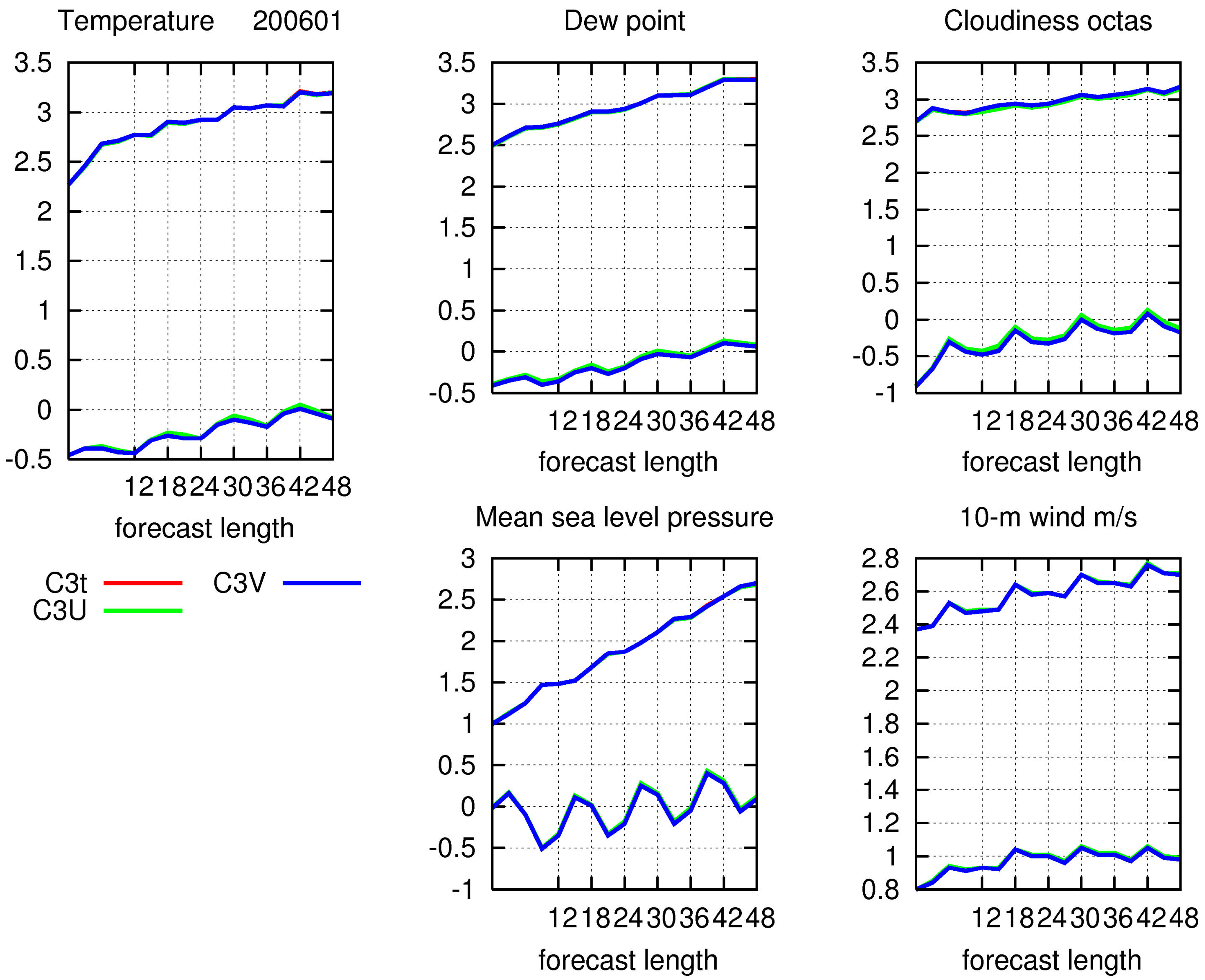
Winter :After also including CCN changes above PBL:Difference map – low clouds (C3U – C3V) Note x 80! reddish : less low clouds 'normal' CCN distribution, greenish : more low clouds 'normal' CCN distribution



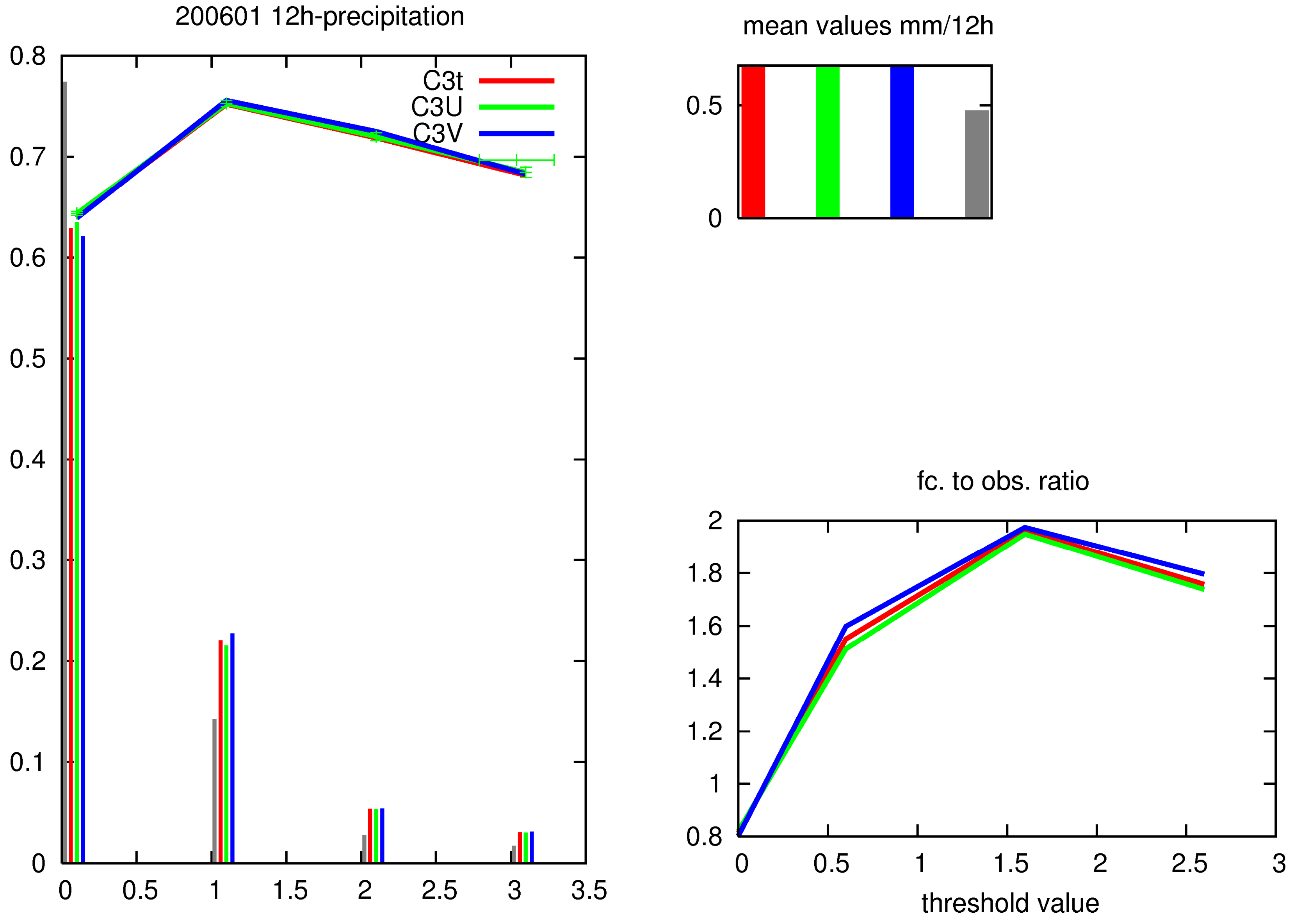
Winter : After also including CCN changes above PBL: Difference map – precipitation (C3U – C3V) mm during 28 days reddish : less for 'normal' CCN distribution, greenish : more for clouds 'normal' CCN distribution



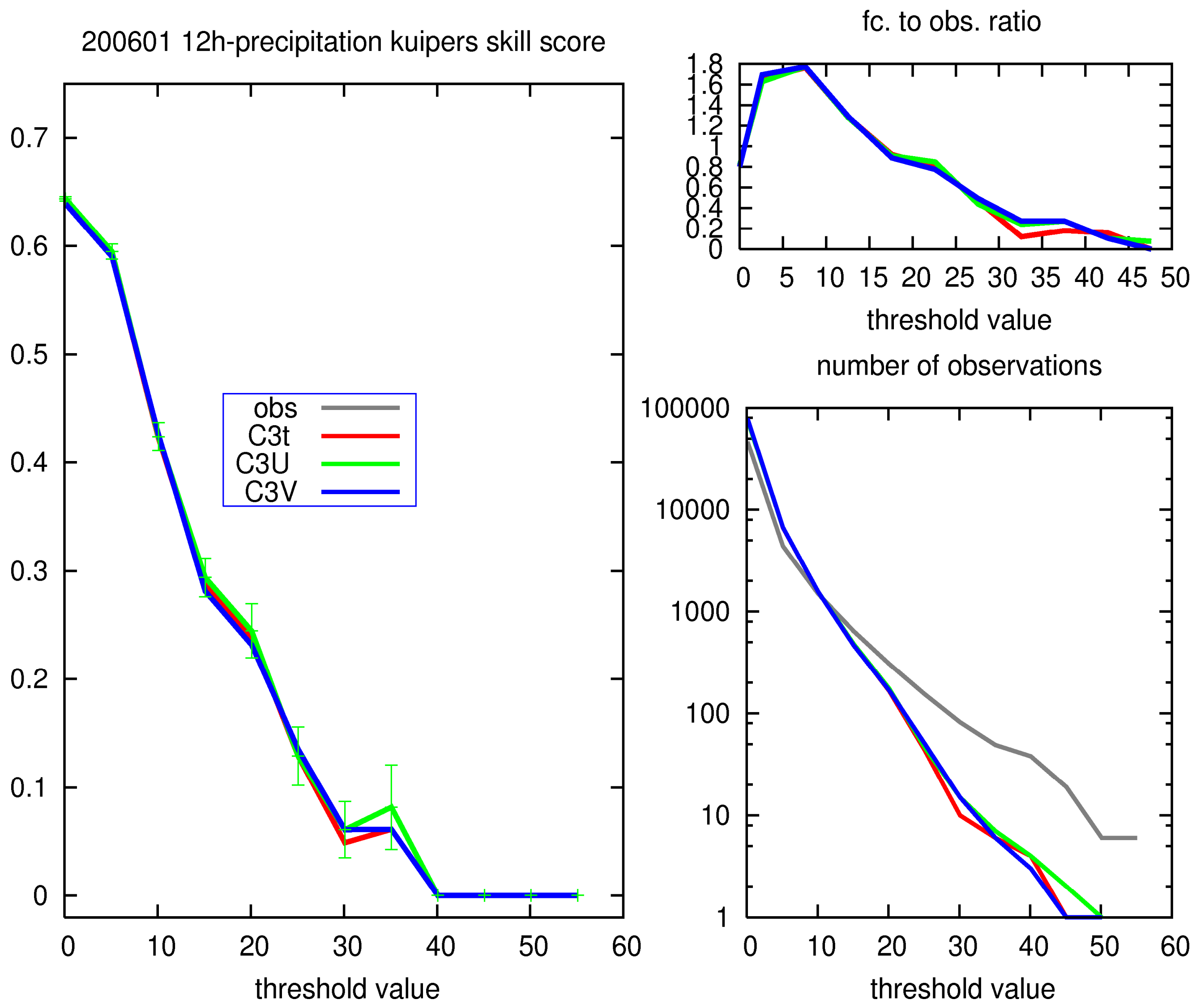
Verification winter: C3t: orig CCN concentration. C3U : most in central Europe
C3V: reversed



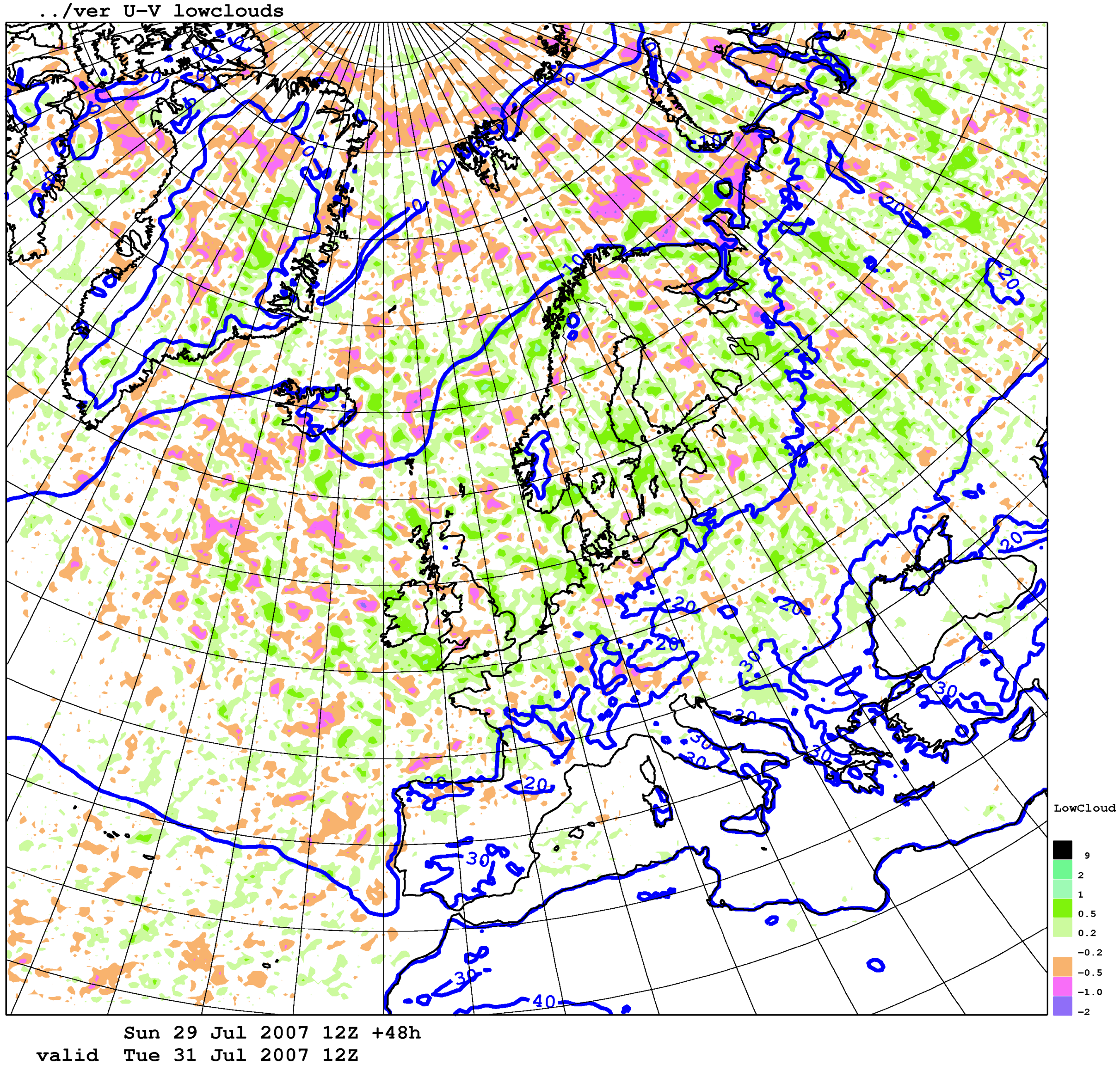
Precipitation:Verification winter: C3t: orig CCN C3U : most CCN in central Europe C3V: reversed



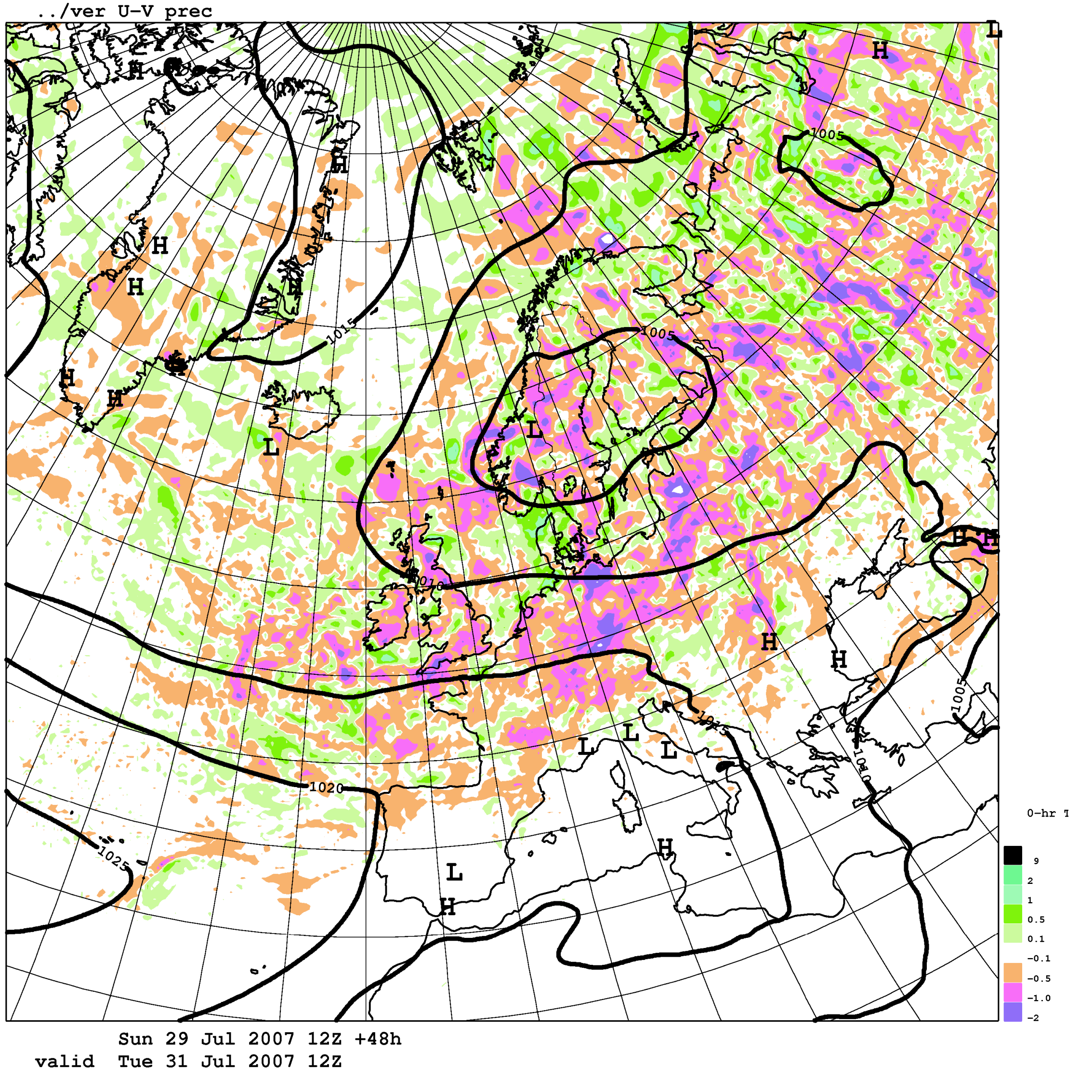
Precipitation:Verification winter: C3t: orig CCN C3U : most CCN in central Europe C3V: reversed



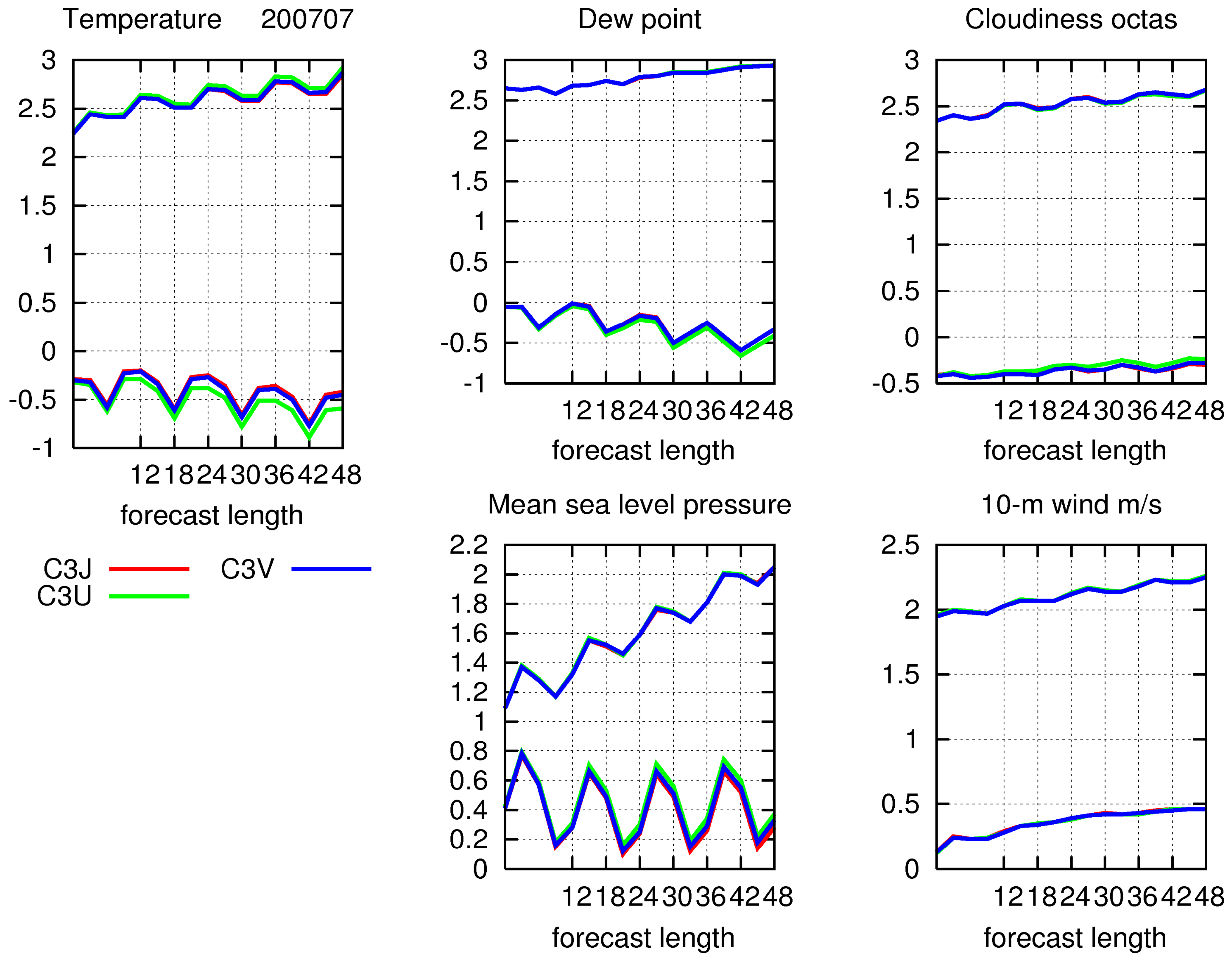
Summer :After also including CCN changes above PBL (July 2007) :Difference map – low clouds (C3U – C3V) Note x 80! reddish : less low clouds 'normal' CCN distribution, greenish : more low clouds 'normal' CCN distribution



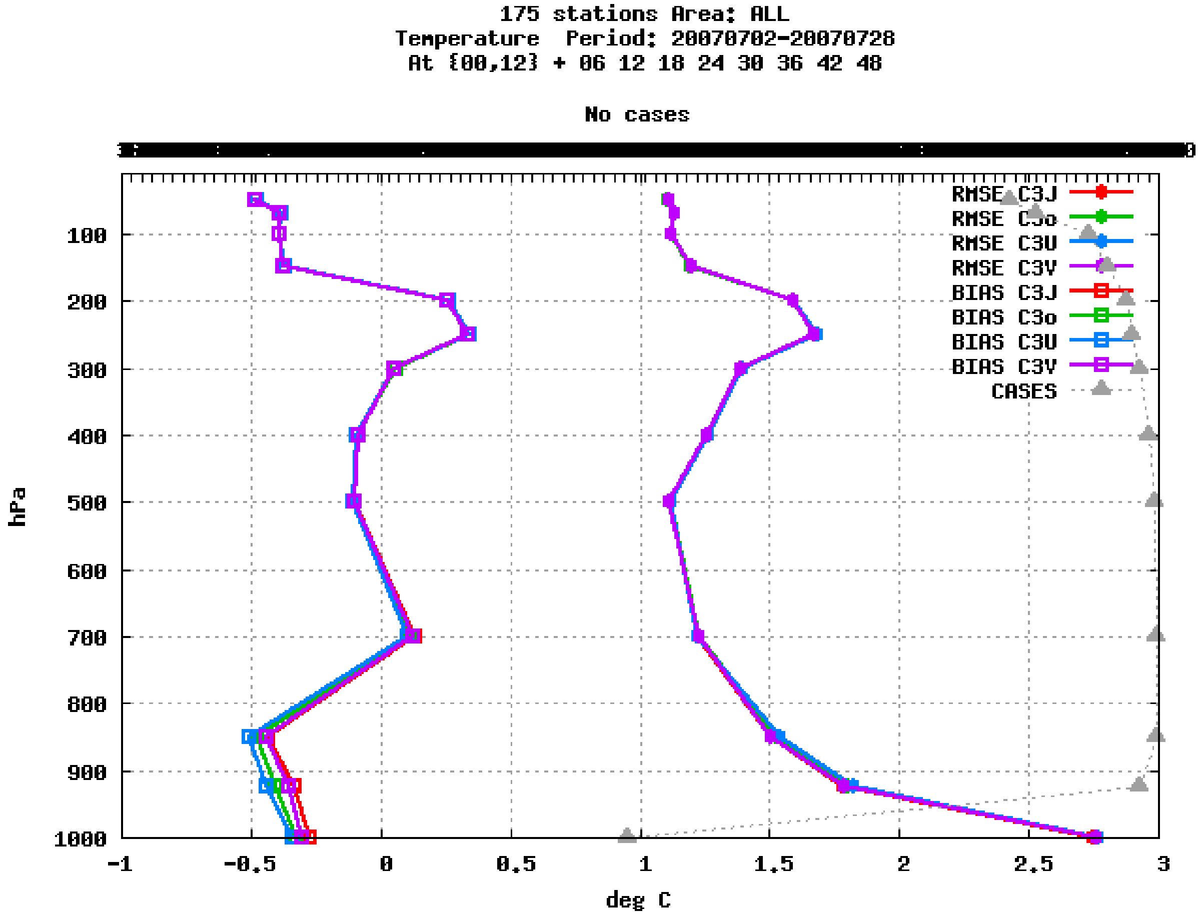
Summer: After also including CCN changes above PBL Difference map – precipitation (C3U – C3V) mm during 28 days reddish : less for 'normal' CCN distribution, greenish : more for clouds 'normal' CCN distribution



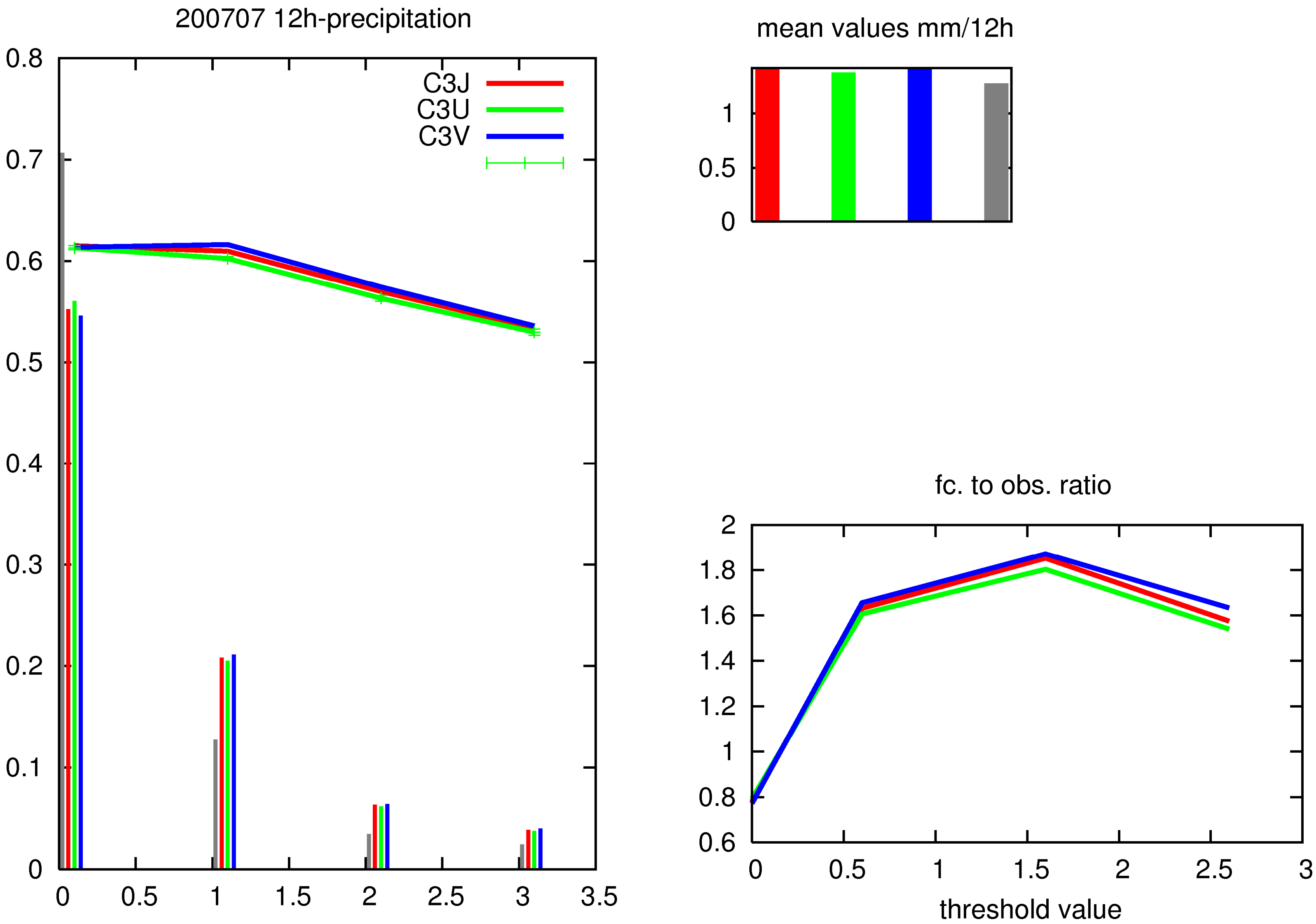
Verification summer: C3J: orig CCN concentration. C3U : most in central Europe
C3V: reversed



Vertical temperature profile, summer



Precipitation:Verification summer: C3J: orig CCN C3U : most CCN in central Europe C3V: reversed



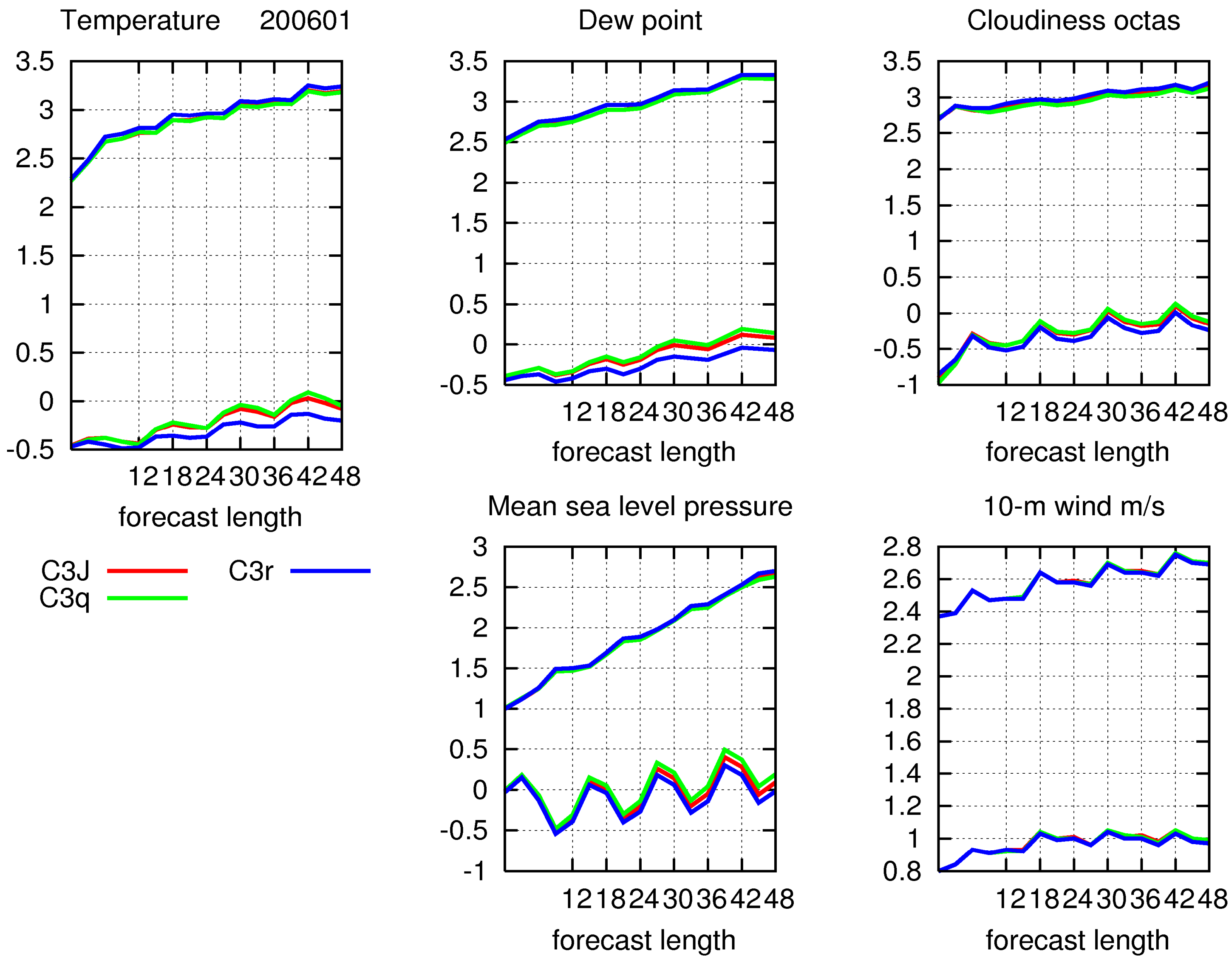
Results, discussion, questions (CCN)

- Including drop size dependency on collection of cloud-water by precipitation gives a slightly larger response on changing CCN, also if CCN is changed above PBL.
- After changes described above: A tendency of an increase of low clouds and a decrease of precipitation for high CCN amounts in the PBL.
- Cloud droplet size not included in sedimentation of cloud water. Should be tested...

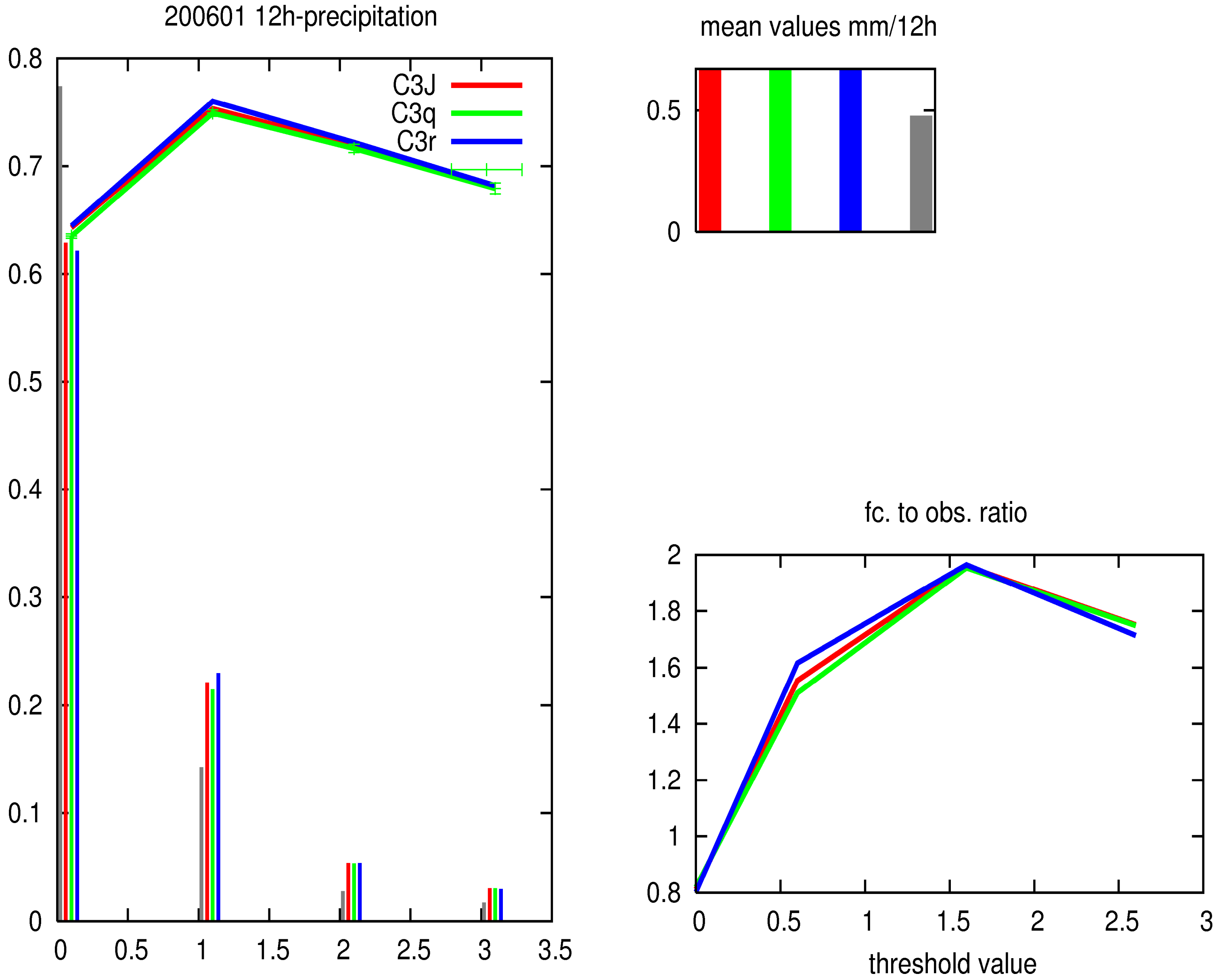
Impact of ice nuclei concentration in the current prognostic cloud ice formulation

- Only just a function of temperature in current parametrization (Mayers, 1992) The colder it is, the more particles are assumed to be active for triggering heterogeneous freezing.
- Formula: K exp(12.96(es(wat) -es(ice))/es(ice)-0.639)), es= saturation pressure.
- Here, testing only the change of the constant K. It will make the glaciation of supercooled clouds go faster or slower everywhere.
- C3J original ,K=500. C3q: K=125 C3r: K=2000.

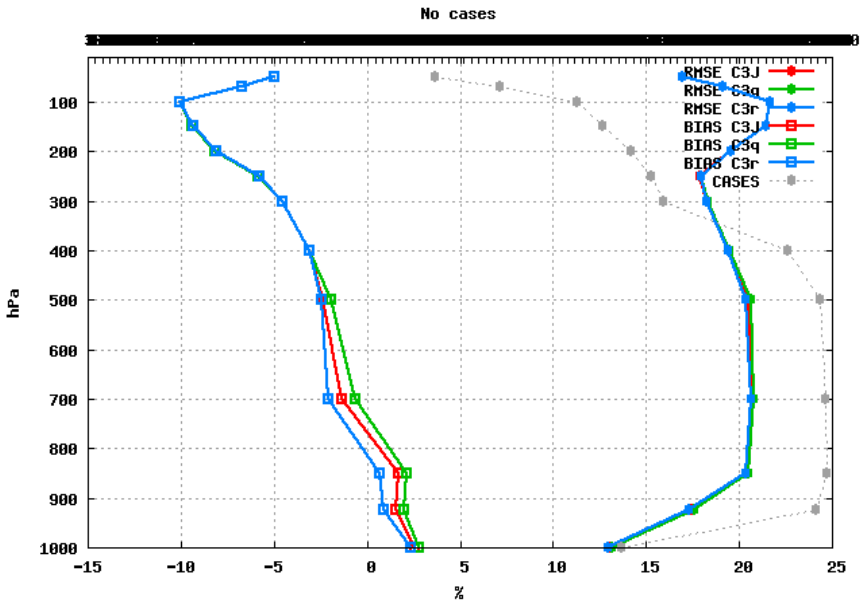
Verification winter: C3J: orig IN concentration C3q : 25% C3r: 400%



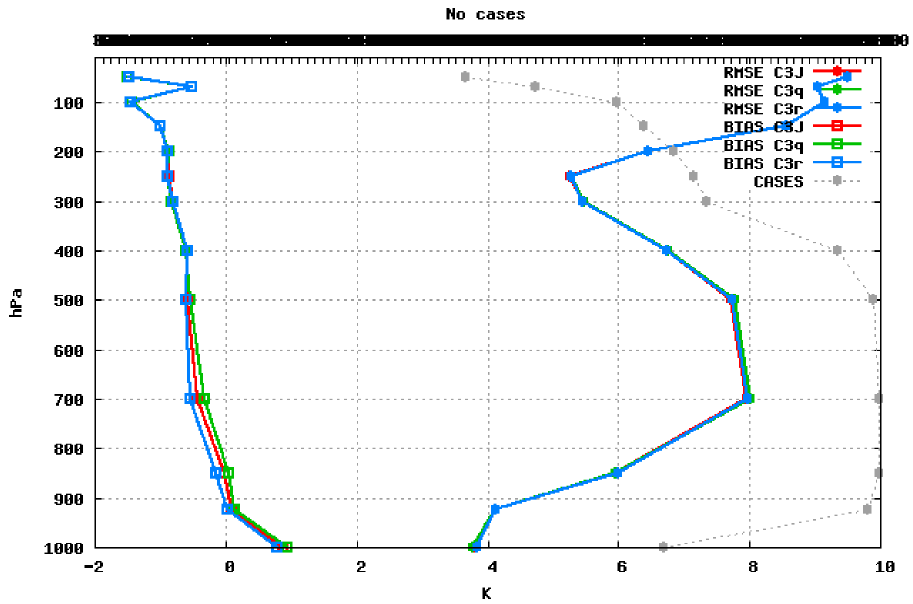
Verification winter: C3J: orig IN concentration C3q : 25% C3r: 400%



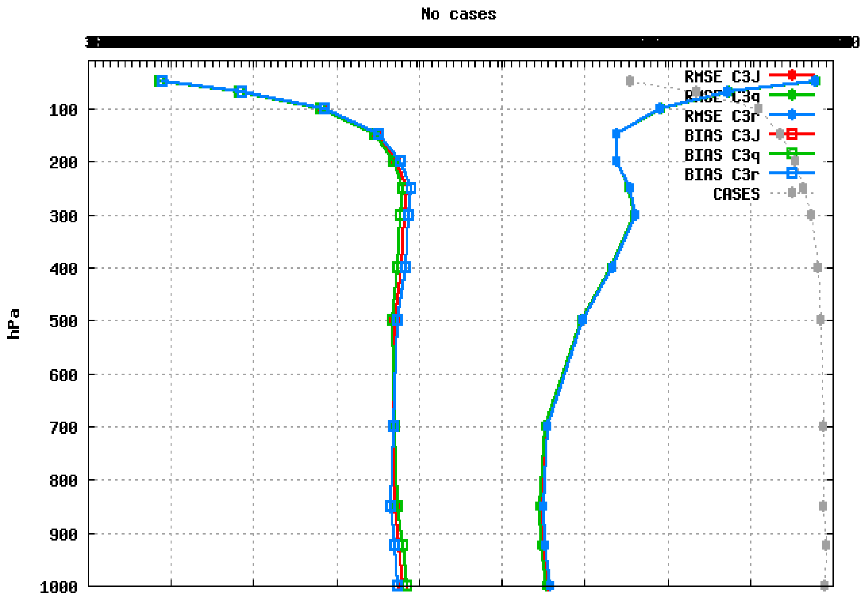
170 stations Area: ALL
Relative Humidity Period: 20060102-20060128
At {00,12} + 06 12 18 24 30 36 42 48



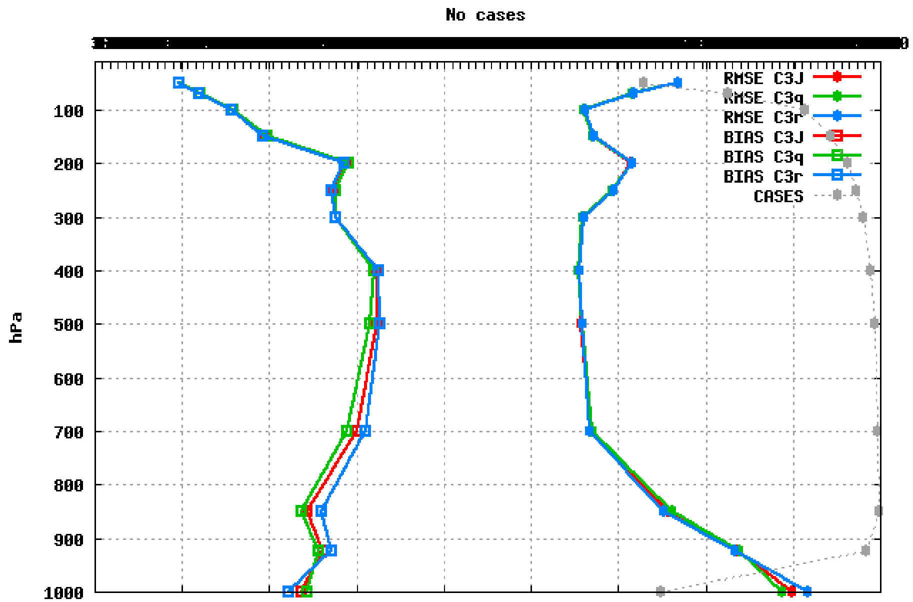
170 stations Area: ALL
Dew point temperature Period: 20060102-20060128
At {00,12} + 06 12 18 24 30 36 42 48



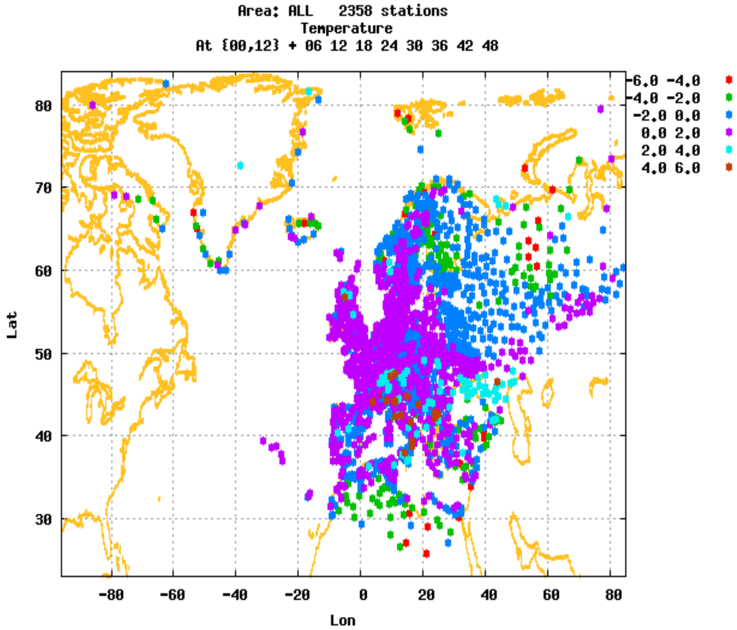
170 stations Area: ALL
Height Period: 20060102-20060128
At {00,12} + 06 12 18 24 30 36 42 48

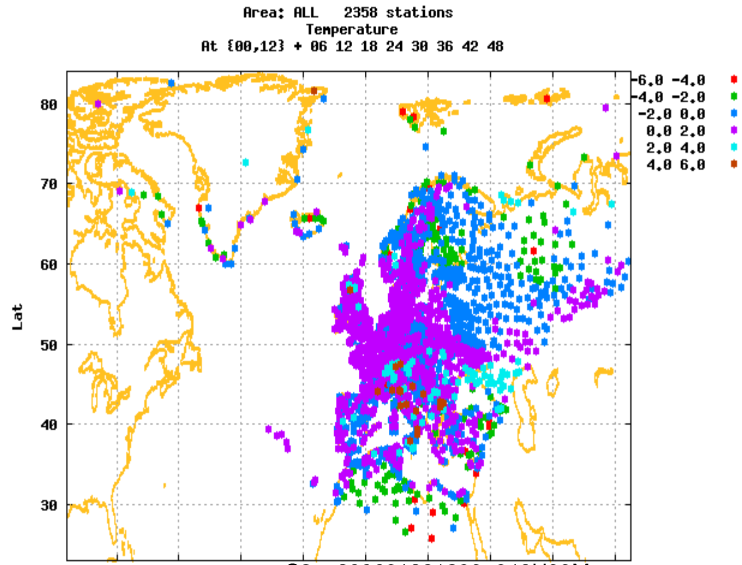


170 stations Area: ALL
Temperature Period: 20060102-20060128
At {00,12} + 06 12 18 24 30 36 42 48

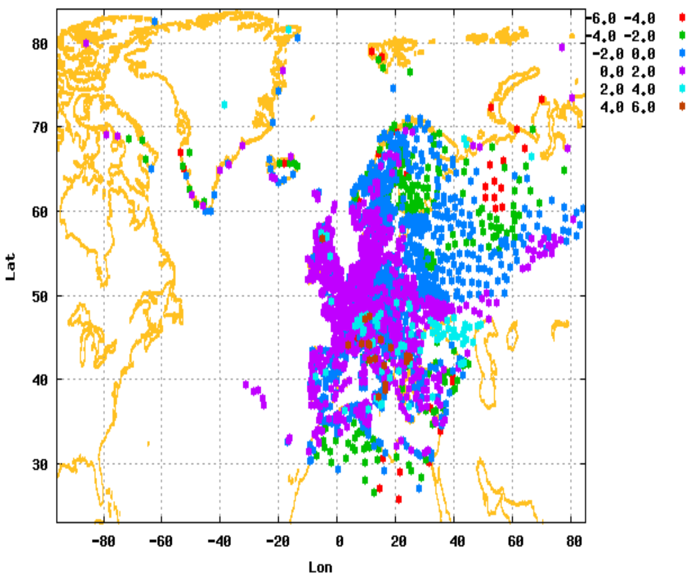


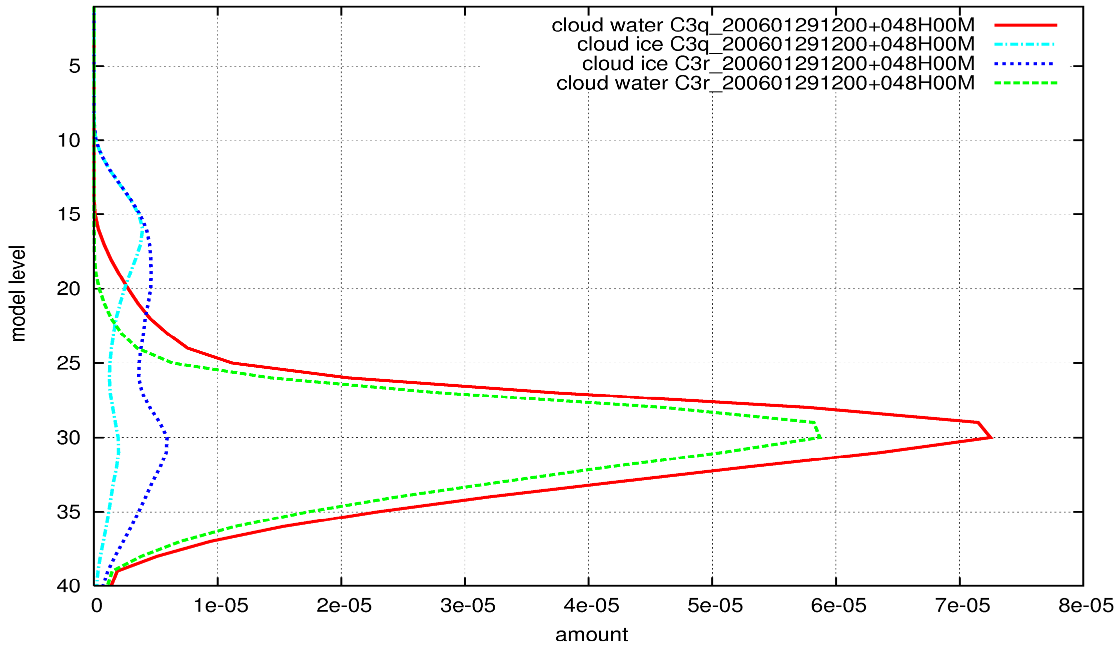
left top: CrJ, right top: C3r Bottom left: C3q



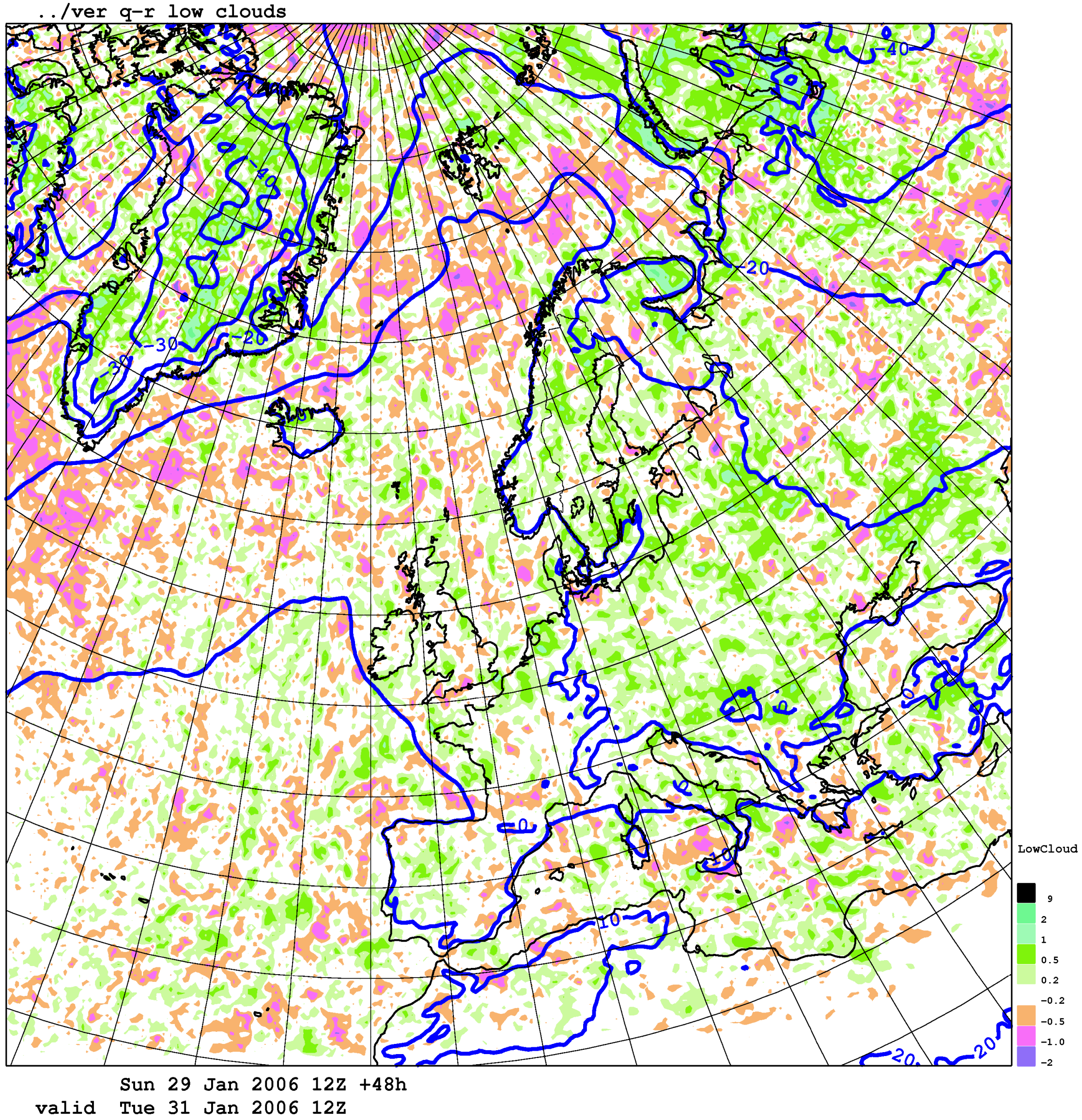


C3q_200601291200+048H00M

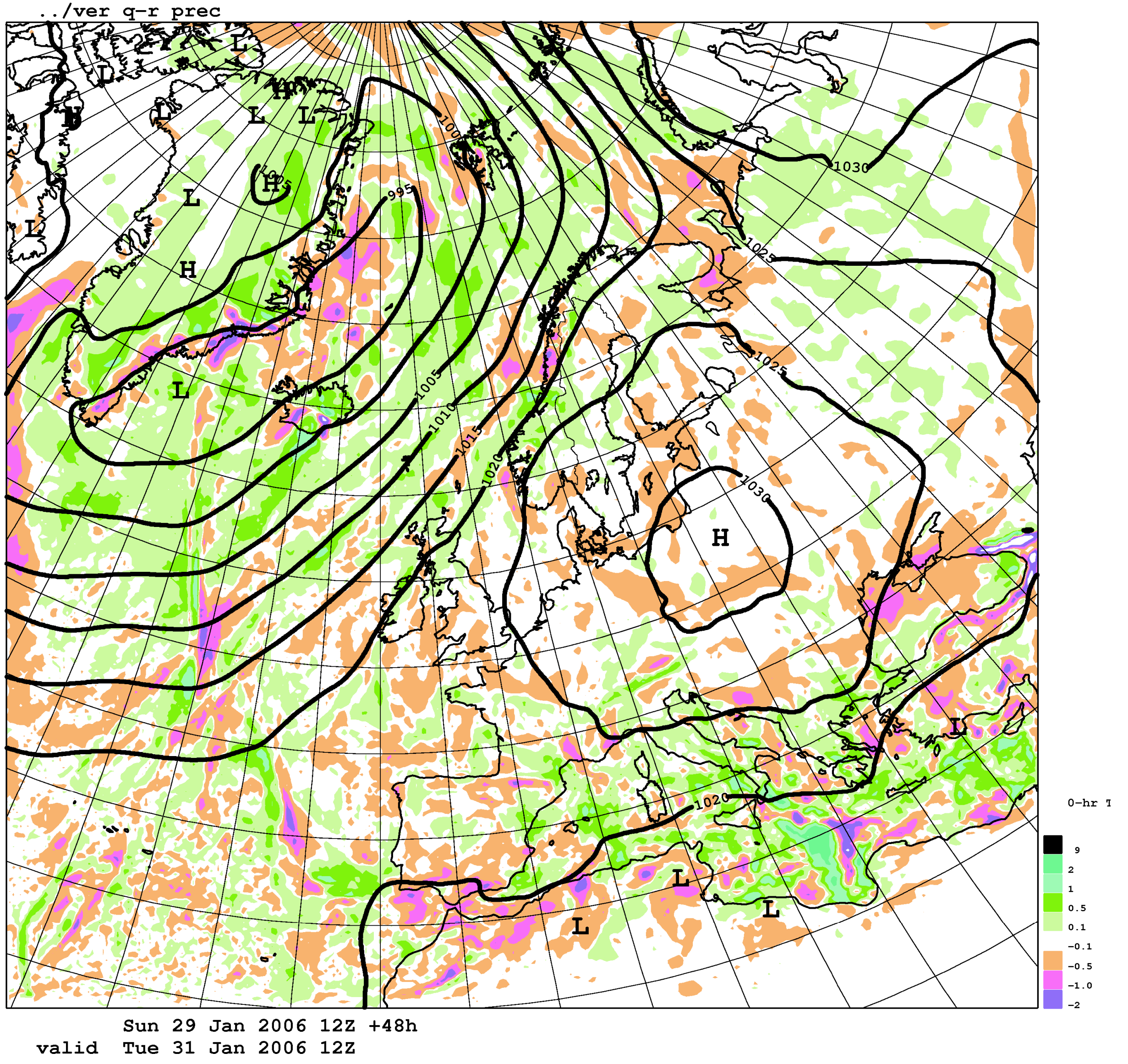




Winter :Difference map – low clouds (C3q – C3r) x 80 reddish : less low clouds low IN distribution, greenish : more low clouds for low IN distribution



Winter :Difference map – precipitation (C3q – C3r) mm 28 days reddish : less for low IN distribution, greenish : more for low IN distribution



Results, discussion, IN-concentration.

- Somewhat stronger signal for changes in concentrations of IN than for CCN in winter but almost no signal in summer. (not shown) Reason: less supercooled clouds in summer
- Lower IN gives less cloud ice --> relative humidity more related to water saturation --> less clouds.
- But less cloud ice also gives lower Bergeron-Findeisen effect --> less precipitation, so existing clouds stay longer --> more clouds
- The latter effect seems to dominate.
- Better temperature forecasts in winter with lower IN, in summer almost no effect. (But doesn't prove that lower IN is more physical realistic due to possible compensating errors)

Conclusions (uncertain)

- CCN on radiation only: Little impact (not shown)
- CCN on condensation: Little in winter, moderate in summer. (reservation: CCN effect on sedimentation not tested ...)
- IN: moderate in winter, little in summer.
- But: locally due to very large CCN/IN anomalous, bigger effect may be possible.

References

- Meyers et al: New primary ice-nucleation parametrization in an explicit cloud model J. Appl. Metetor. 31, 708-721
- Kogan et al 2000: A new cloud physics parametrization in large-eddy simulation model of marine stratocumulus. Mon. wea. rev.,Vol 128 p 1070-1088.
- Lin et al 1983: Bulk parametrization of the snow field in a cloud model. J Appl. Meteor. 22 1065-1092
- Rogers R R , M K Yau. 1989 : A short course in cloud physics. 3D Pergamon 293 pp.
- Lohmann U. 2004: Can anthropogenic aerosols decrease the snowfall rate? J A S Vol 61 p 2457-2468