An objective hail size forecasting method based on mesoscale model output

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Summary

The Fawbush-Miller (FB) hail forecast method was modified and implemented as a computer algorithm to design an objective hail size forecasting method. The mesoscale Eta model output is introduced in the FB computer algorithm. Four severe summertime weather events are examined, with 3 events producing large hail stones and the results are close to reality in each of the cases. This suggests it is possible to forecast large hailstones associated with severe convective weather in the Benelux

countries. The modified FB-technique shows skill for hail forecasting in warmest half of the year.

1. Introduction

Hail, associated with severe thunderstorms, has the potential to damage crops, greenhouses, plastic roofs, cars ... and to injure people in some cases. Forecasting hailstone size remains a challenge, even with current mesoscale weather models.

The most important task of National Met. Services is to warn the public and government of potential dangerous weather events, so preventive measures, if possible, can be taken in time. Therefore, it is important to develop a succesful objective hail forecast scheme, fed with the results of a mesoscale model.

The Royal Meteorological Institute of Belgium (RMI) recently started a hail research project. The aim is to analyse hail events, to improve radar-based hail detection algorithms and to explore methods of forecasting hail, especially large hailstones, which are almost exclusively formed in summertime (Delobbe et al, in preparation).

2. Mesoscale model

The operational mesoscale model of the National Centers of Environmental Predicion (NCEP), Eta (Janjic, 1990) is chosen as limited area model, because the available NCEP/NCAR reanalysis data can be smoothly introduced in the model and serves as initial and boundary conditions for the older case studies. The workstation version of Eta, distributed by NCEP, is used for this study. The model is ran with 45 vertical levels and a horizontal resolution of 0.1°. The NCEP/NCAR reanalyses have 17 pressure levels. For the more recent cases, archived runs of the NCEP global model AVN (30 pressure levels) were used. Convective parametrisation is described by the adjustment scheme of Betts-Miller-Janjic or the mass flux scheme of Kain-Fritsch (Kain et al, 2003). The Kain-Fritsch scheme is used in all cases, because of the more explicit approach of convection, compared to the Betts-Miller-Janjic scheme. The model's domain is shown in fig. 1.

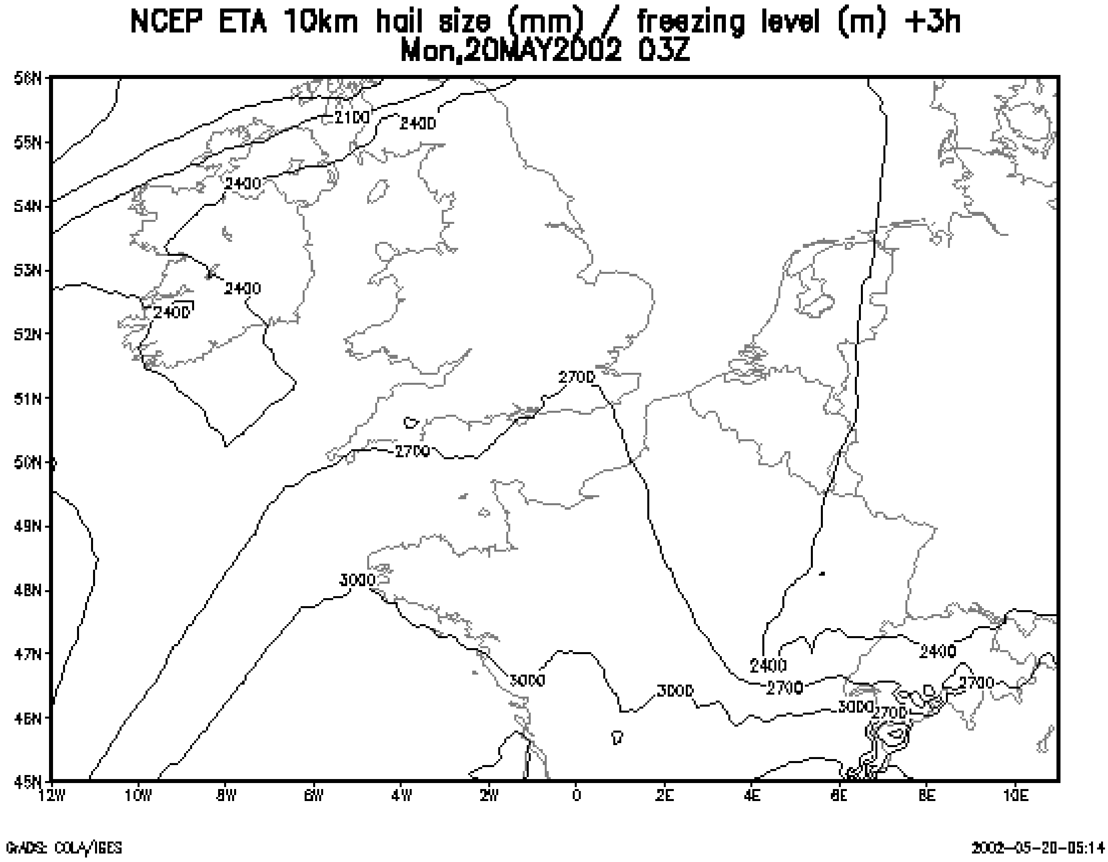


fig1: domain of the ETA 10 km model

3. Hail forecasting technique

The hail forecast scheme is based on the Fawbush-Miller (FB) method. Although the technique is old, it is still used in operational hail forecasting in the US (Gordon, 2000).

The idea is based on modeling two phenomena believed to be important for causing large hailstones: sufficient upward motion in clouds, to support larger hail, and the potential for hail growth, which is necessary for really large stones to develop.

The upward motion in clouds is related with the Convective Available Potential Energy (CAPE). Fawbush and Miller (Miller 1972) state that only a part of the cloud CAPE needs to be calculated, in an indirect way, from the base up to the -5°C level. We therefore first determine the convective condensation level (CCL) in fig. 2. From this point ascend up a saturated adiabat to reach the point *b* which is at the level of the –5 deg C environment temperature *B*. The temperature difference *b-B* is a measure of the amount of CAPE gained and hence the vertical velocity acquired by a parcel ascending in the lower part of the cloud below the -5°C level.
The potential for hail growth can be assessed by considering the cloud layer below the -5°C level. In fig. 2, we can obtain the approximative cloud thickness below the -5°C level : from the point *B* descend dry adiabatically to reach *c* at the CCL. The difference C-B is the desired thickness.

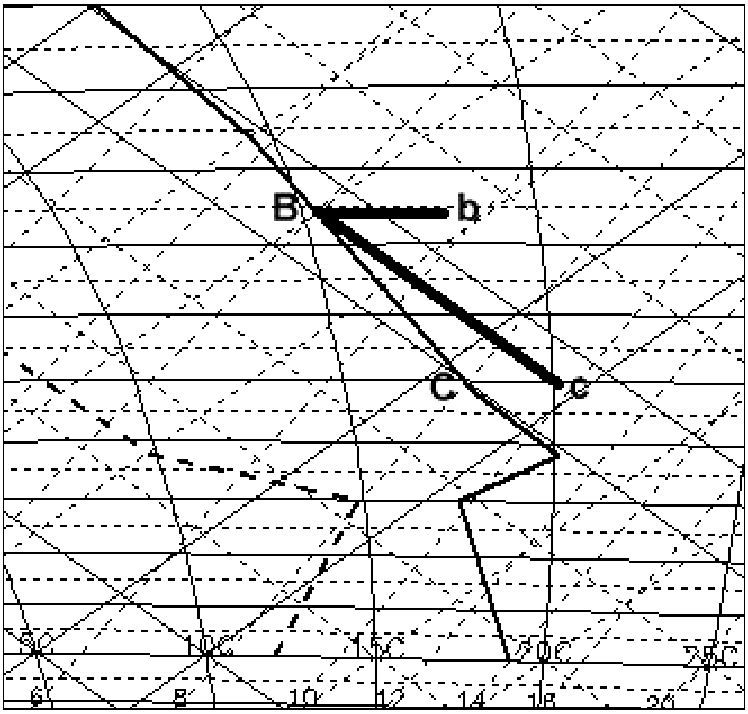


fig 2: Fawbush-Miller construction

In the original diagrams provided by Miller, table 1 was in the form of a nomogram thus providing hail diameter as a continuous function of temperature differences *b-B* (delta 1) and *c-B* (delta 2). In order to automate the process, the nomogram has been discretized with hail sizes converted to millimetres (Hand, 2000). The temperature difference *b-B* has been specified to the nearest half degree (although only whole degree values are shown in the table for clarity). The temperature difference *c-B* is calculated to the nearest ten degrees. Thus a look-up table provides the forecast hail size once *b-B* and *c-B* are known.

Temperature difference c-B : delta 2 (along left-hand side)														
50	5	10	20	25	35	45	50	60	75	85	99	99	99	99
45	0	5	20	25	35	45	50	60	65	80	90	99	99	99
40	0	5	15	20	30	40	45	55	60	70	80	85	99	99
35	0	5	15	20	30	40	45	50	55	60	70	75	80	80
30	0	0	10	20	25	35	40	45	50	55	60	60	65	65
25	0	0	5	15	20	30	35	40	40	45	50	50	50	55
20	0	0	0	5	15	20	25	30	35	40	40	45	45	50
15	0	0	0	0	10	15	20	20	25	25	30	35	35	35
10	0	0	0	0	0	5	10	15	15	15	20	20	25	25

0	0	0	0	0	0	0	5	5	10	10	10	10	15	15
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**
Temperature difference b-B : delta 1 (along bottom)														

table 1: hail size as a function of temperature differences b-B and c-B

In Miller's original nomograms there was a third step which was necessary if the wet-bulb freezing level (WBZ) was above 3350m to allow for possible melting of large stones in warm air. This step reduced the hail stone size as a function of diameter derived from table 1 and the WBZ. This has been coded up based on table 2 which is also a discretization of the published nomogram (Hand, 2000).

Wet-bulb freezing level in metres (along left-hand side)								
4400	0	0	0	0	0	0	0	0
4150	0	0	0	0	0	0	5	5
3950	0	0	0	0	5	10	10	10
3750	0	0	0	5	10	15	15	15
3550	0	0	5	10	20	20	25	30
3350	0	5	10	15	25	50	65	75
	5	**10**	**20**	**25**	**50**	**75**	**100**	**125**
	Hail diameter (mm) from Table 1							

table 2: hail size correction of table 1 as a function of WBZ-height

4. Implementation of the FB-technique and modifications

The FB-technique was primarily used by forecasters manually working with soundings, but we developed a computer algorithm which is fed with the output of a numerical weather prediction model (NWP).

The raw FB technique applied to the Eta model output, gave a high false alarm rate. We modified the original technique somewhat to obtain more realistic results. We applied the Fawbush-Miller technique only to Eta output gridpoints that satisfy following criteria:

* Convective Available Potential Energy (CAPE) $\geq$ 800 J /kg
* Convective precipitation amount > 0 mm

This reduced the false alarm rates and singled out the regions with highest probability of hail.

The convective condensation level CCL is estimated as follows. The temperatures lying on the saturated mixing ratio line through the lowest model level dewpoint are compared with model temperatures on the same level. Interpolation is performed between successive levels where this temperature difference changes of sign.

Second, the -5°C level is found by linear interpolation between successive levels with temperatures respectively higher and lower than -5°.

The wet adiabat is constructed with a piecewise linear method, where the slopes of the wet adiabat are dependent on temperature.

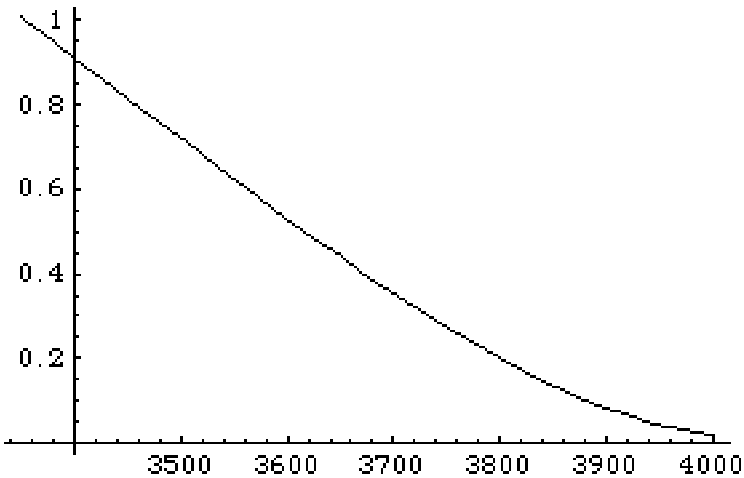
The wet bulb zero height is approximated by the model's direct freezing level output.

The hailsize function hsize1, based on the values in table1,

hsize1= (delta1)*(delta2) / 5

gives a realistic prediction of hailsize with a larger error for the cases of small hail or no hail. The maximum error is then 5-10 mm, which is still very good to assess the possibility of large and damaging hailstones (≥ 1.5-2 cm).

If the wet bulb freezing level is above 3350 m, an adjustment to the predicted hail size is needed to allow for possible melting of large stones in warm air.



The correction factor is determined by a curve fitting of the results of table 2:

fig 3 : Curve fitting of the results of table 2

$$cor=2.4269\ 10^{-10}x + 1.777\ 10^{-7}x^2 + 2.74566\ 10^{-10}\ x^3 - 1.53595\ 10^{-13}\ x^4 + 1.85681\ 10^{-17}x^5$$

where x is the freezing level height (m).

The maximum errors are between 5 en 15% for WBZ < 4000m, for WBZ > 4000m, errors rise up to 50% in a few cases. The corrected hail size becomes

hsize = hsize1*cor

Hail forecasting is a complex matter, with more processes involved than suggested by the Fawbush-Miller method (Brimelow et al, 2002) and also because of the approximations used in the latter, the deterministic hail size forecast should be considered with caution. We want to explore however, if a modified FB method is still capable of realistically forecasting hail when coupled to a NWP.

To introduce a more probabilistic aspect in the forecast, a second hail forecast is executed with no correction for WBZ height - and not allowing hailstones to start melting- to have an idea of the expected maximum size of hailstones.

Combining these two forecasts indicate the range of the diameter of the hailstones, between a probable hail size (calculated with the correction factor) and a maximum hail size, which could occur in a shower with heavy downbursts, where hailstones have less time to start melting.

5. Case studies

The case studies are thought to be major severe weather events in Belgium and the Netherlands, related to hail or precipitation, for which good observations were available, allowing a verification of the method.

The tornadic hailstorms of 25th June 1967

On 25th June 1967 the low countries and Northern France were struck by devastating tornadoes and severe thunderstorms, producing large hail. Although observations are scarce, a few large hail reports were collected.
In the late afternoon, hailstones with diameter around 5 cm were reported along the French-Belgian border, near 50.5° E, 3-4° E. Also other parts of Belgium were covered by severe convective weather between 12z and 15z, with smaller hailstones locally.

The Fawbush-Miller technique applied to the ETA-model is able to pinpoint the location of the largest hailstones accurately and to provide very good guidance on the size of the hailstones . Figs. 4 and 5 show the predicted hail size and theoretical maximum hail size.

The tornadoes and hail showers then moved towards the Netherlands, where hailstones fell with mostly diameters between 2 cm and 4 cm and, locally up to 6 cm. The largest hailstones were located in the provinces of Gelderland (around 52°N and 5° E) and Utrecht (52N and 6-7°E). Again, as shown in figs. 6 and 7, the max. hail forecast location is very realistic, including both provinces, with predicted hail sizes between 3.5 and 4.6 cm, indicating the possibility for large hailstones.

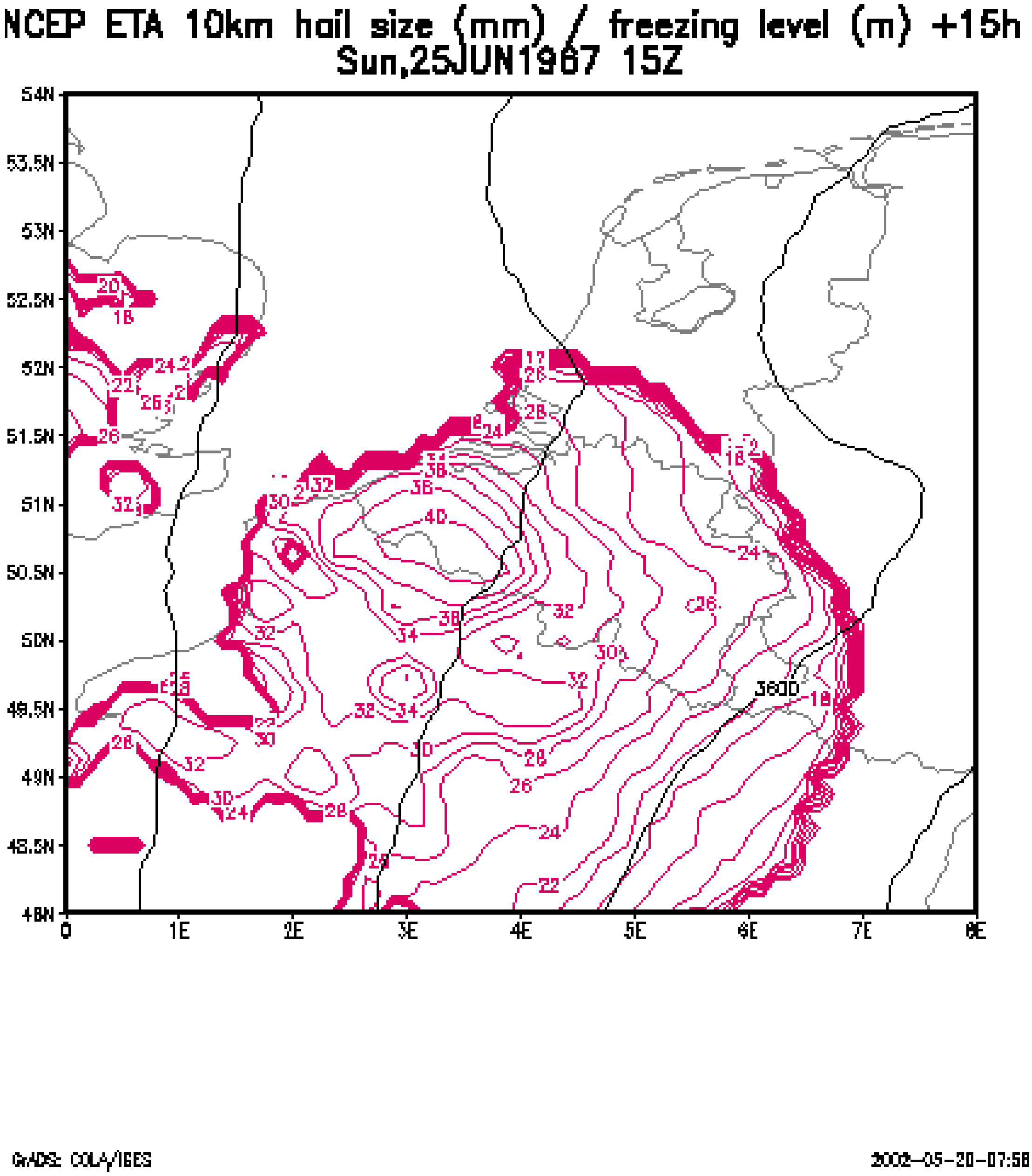


fig 4: hail size forecast for 25/6/67 15z

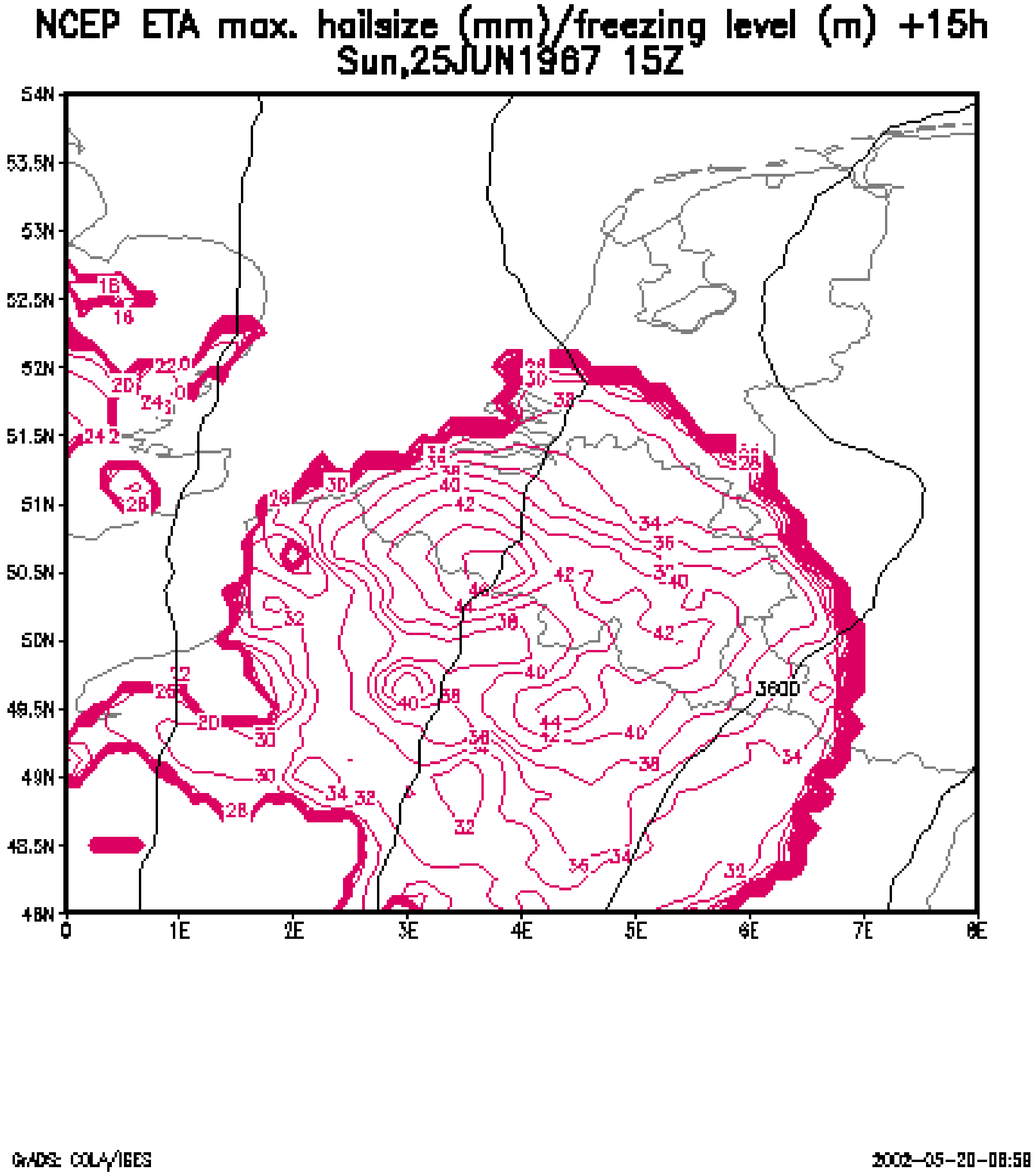


fig 5: maximum hail size forecast

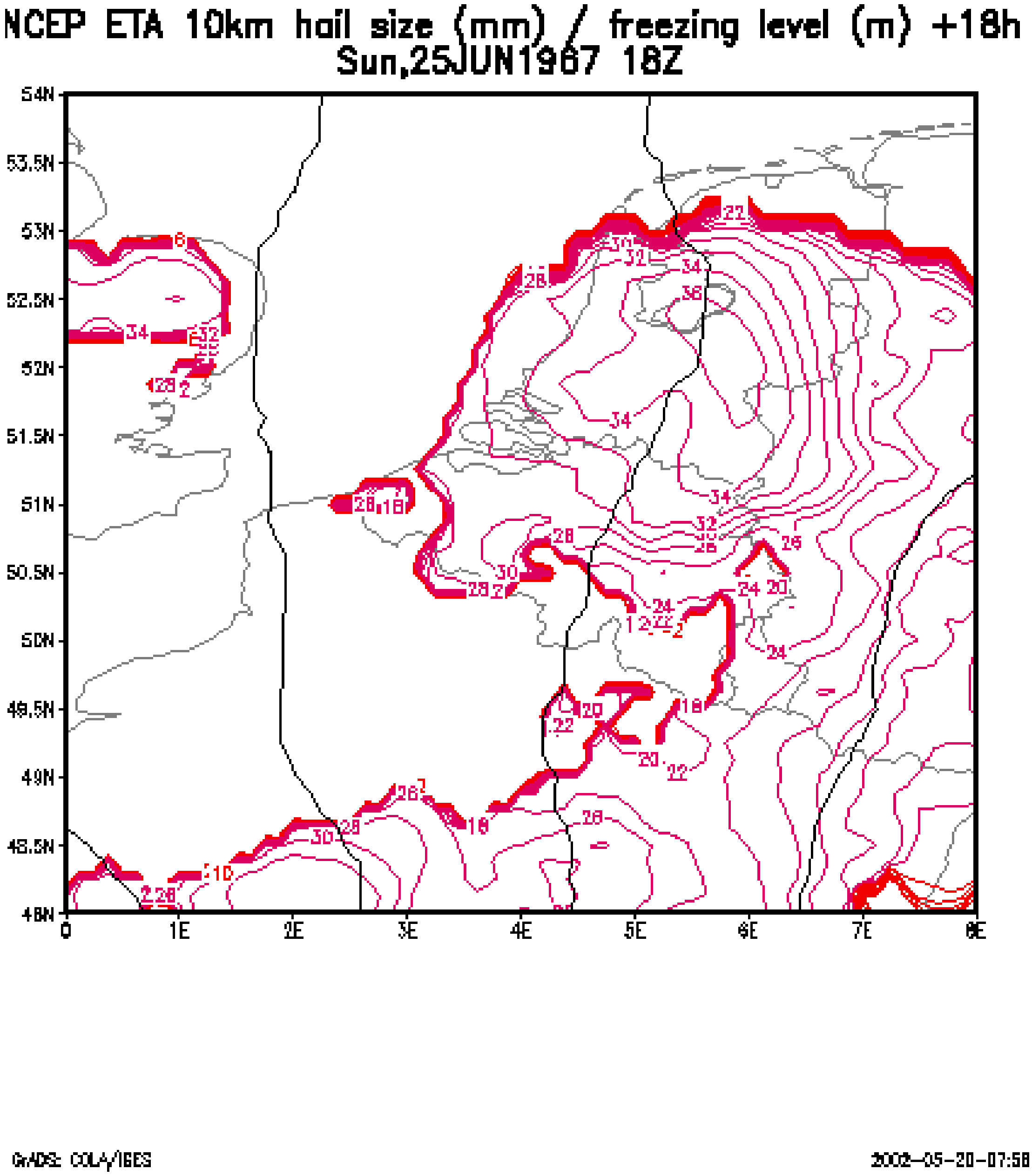


fig 6: hail size forecast 25/6/67 18z

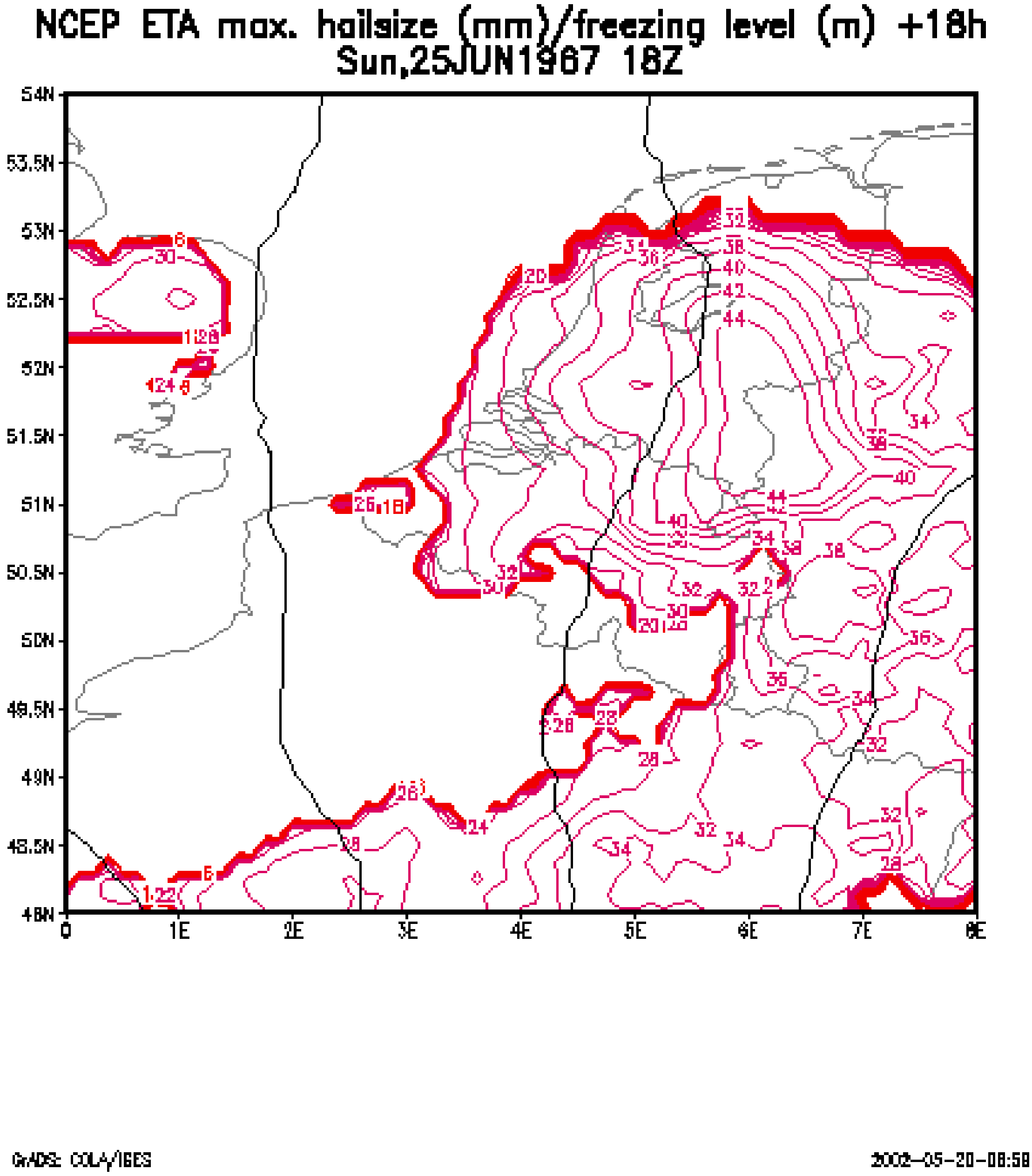


fig 7: maximum hail size forecast

6th June 1998 severe thunderstorms with damaging hail

Severe thunderstorms coming from the north-western part of France slipped into Belgium and the Netherlands. Hailstorms damaged roofs, greenhouses and cars, mainly in the western part of Belgium. Hailsize was more than 2 cm, according to local observations. The Eta model forecasted severe convection and the FB-method indicated large hail in a part of Belgium (fig. 8).

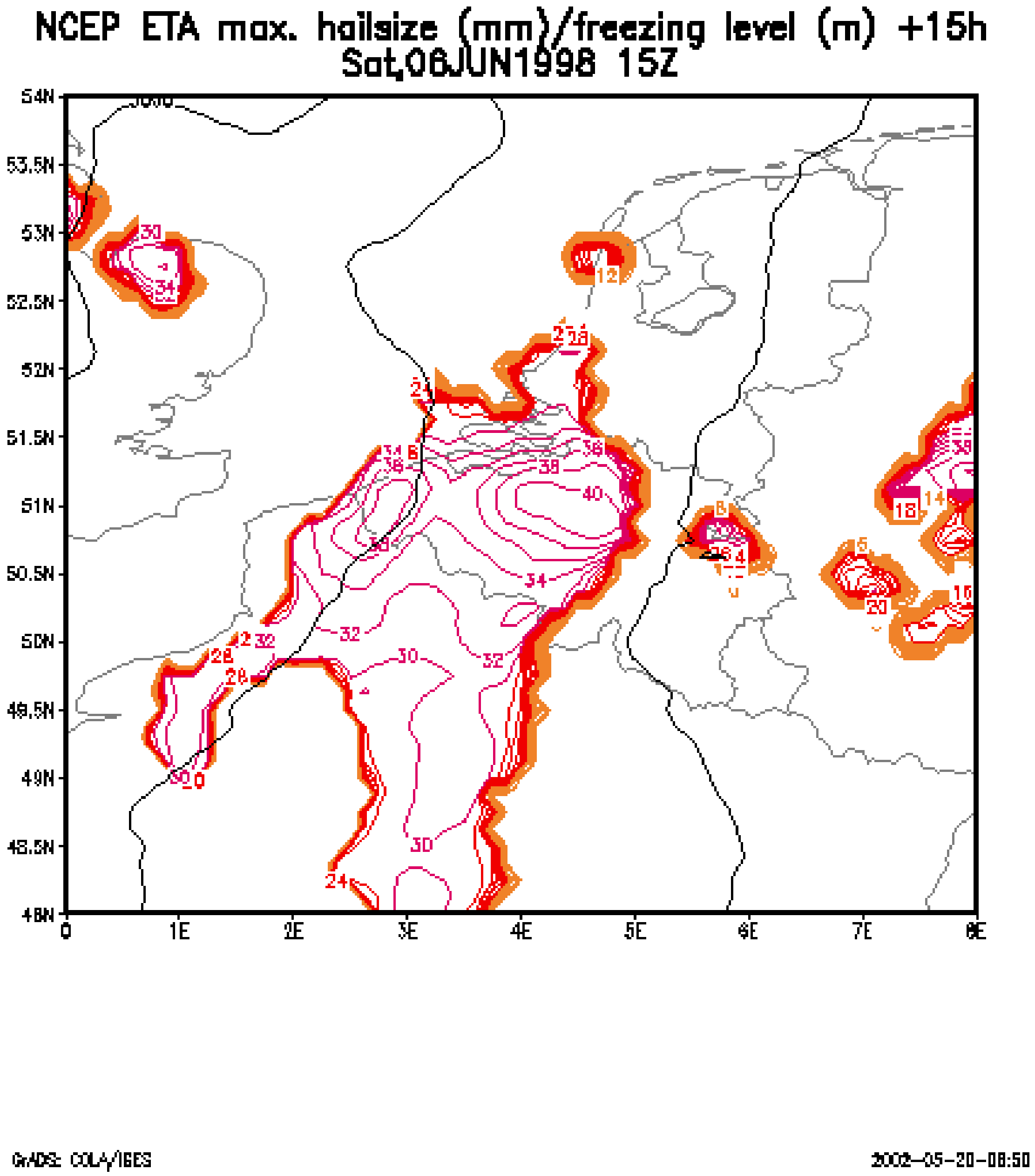


fig 8: maximum hail size forecast 06/06/98 15z

The hailstorms arrived in the Netherlands in the early evening, producing large hailstones, mostly 3-4 cm, but locally up to 6 cm in the northern part of the province of Gelderland, 52.5° N, 6° E. Although the maximum hail size is underestimated in the model (4.5 cm) (fig. 9), it is representative for the large majority of the hail reports in that region. The maximum hail forecast location again matches with observations.

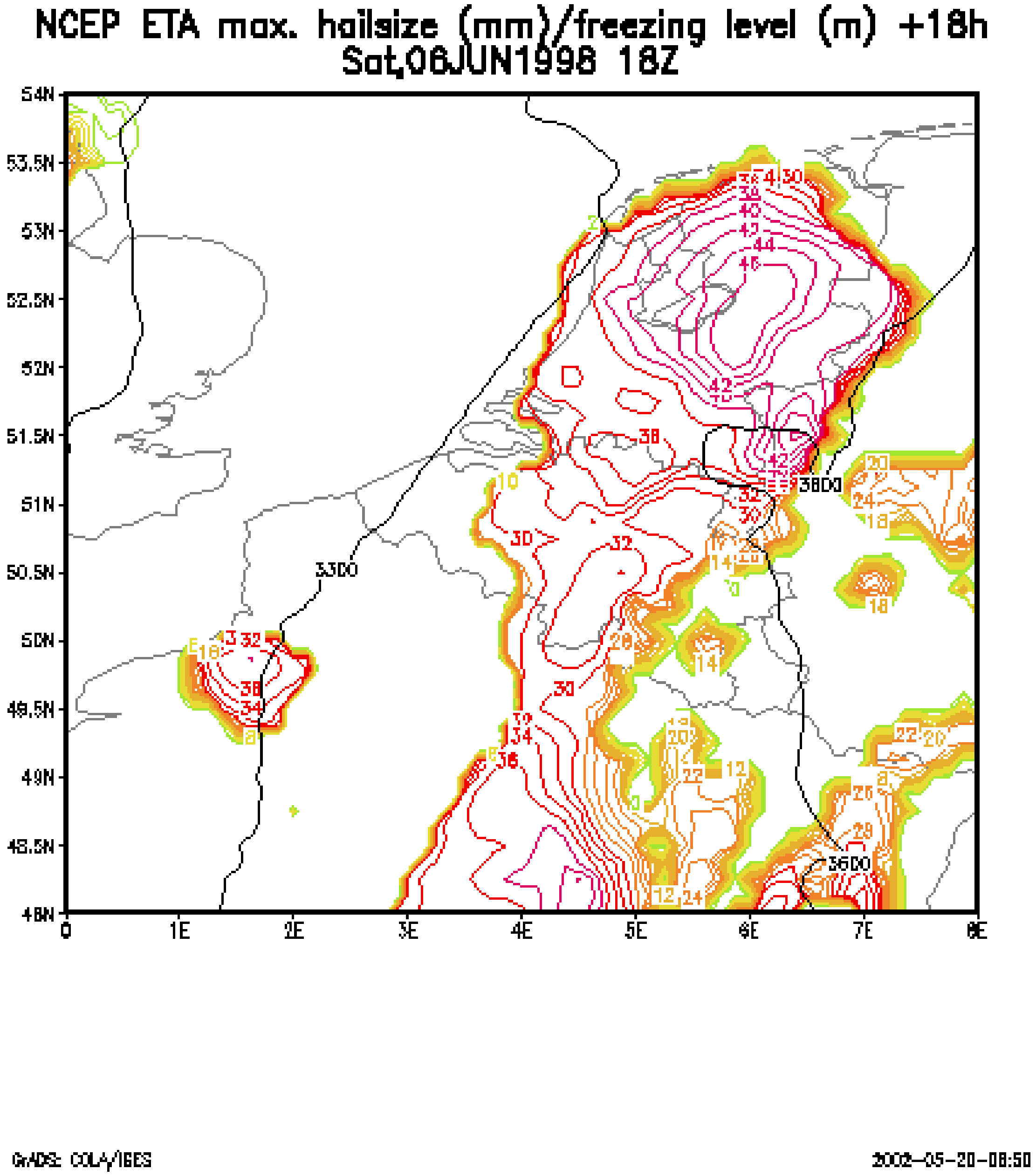


fig 9 : max hail forecast 06/06/98 18z

3rd June 2000 hailstorms and flash floods

Thunderstorms developed over Belgium, except at the coast, and caused large hail and flash floods in central Belgium. Hail stones of maximum 5 cm diameter were observed in the region 20 km north of Brussels.

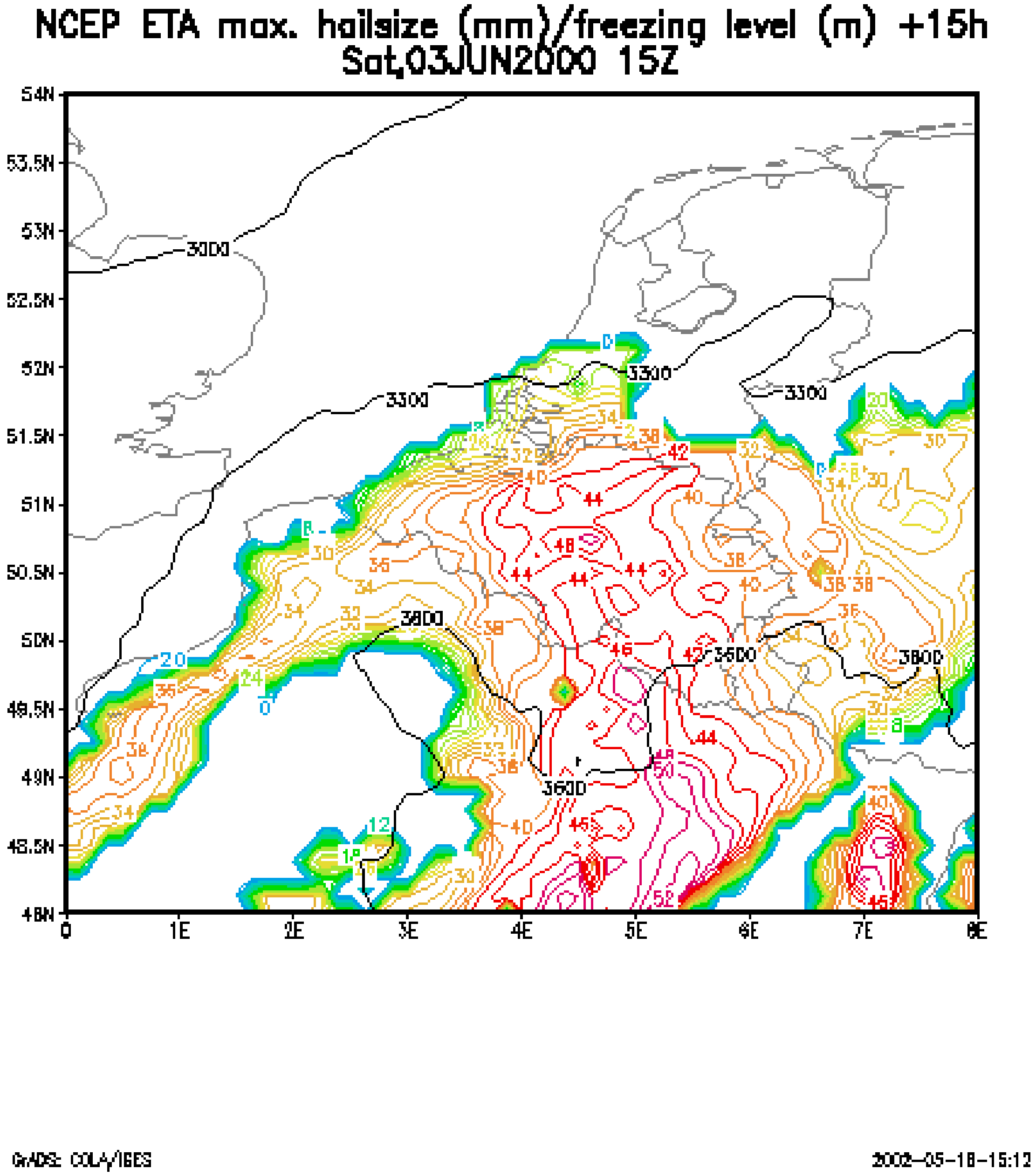


fig 10: max hailsize forecast 03/06/00 15z

Although the model forecast is wrong for the coastal region with a 10-20 km fault margin, the area of maximum hail size is well placed and the predicted 4.5-5 cm hailstones were observed.

Floodings of 13^{th}-14^{th} September 1998

In the night of 13^{th}-14^{th} September 1998 and during the first part of the 14^{th}, northern and eastern parts of Belgium suffered from the largest floodings in 20 years, with precipitations locally exceeding 140 mm in 12 hours. Although intensities of more than 30-50 mm/h were observed with radar, no hail was observed in Belgium, as correctly forecast by the model (figs. 11 and 12).

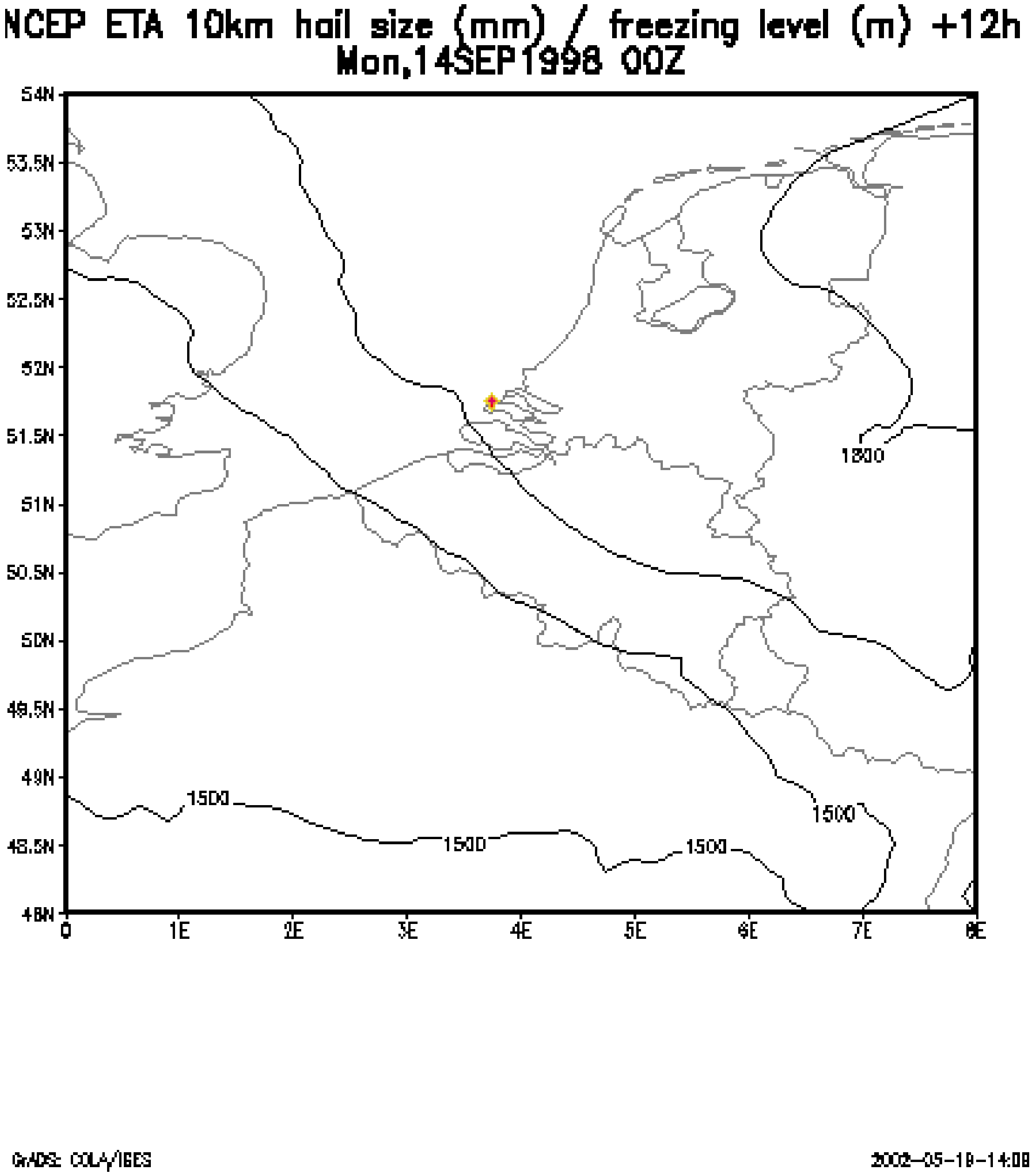


fig 11: hail size forecast 14/09/98 0z

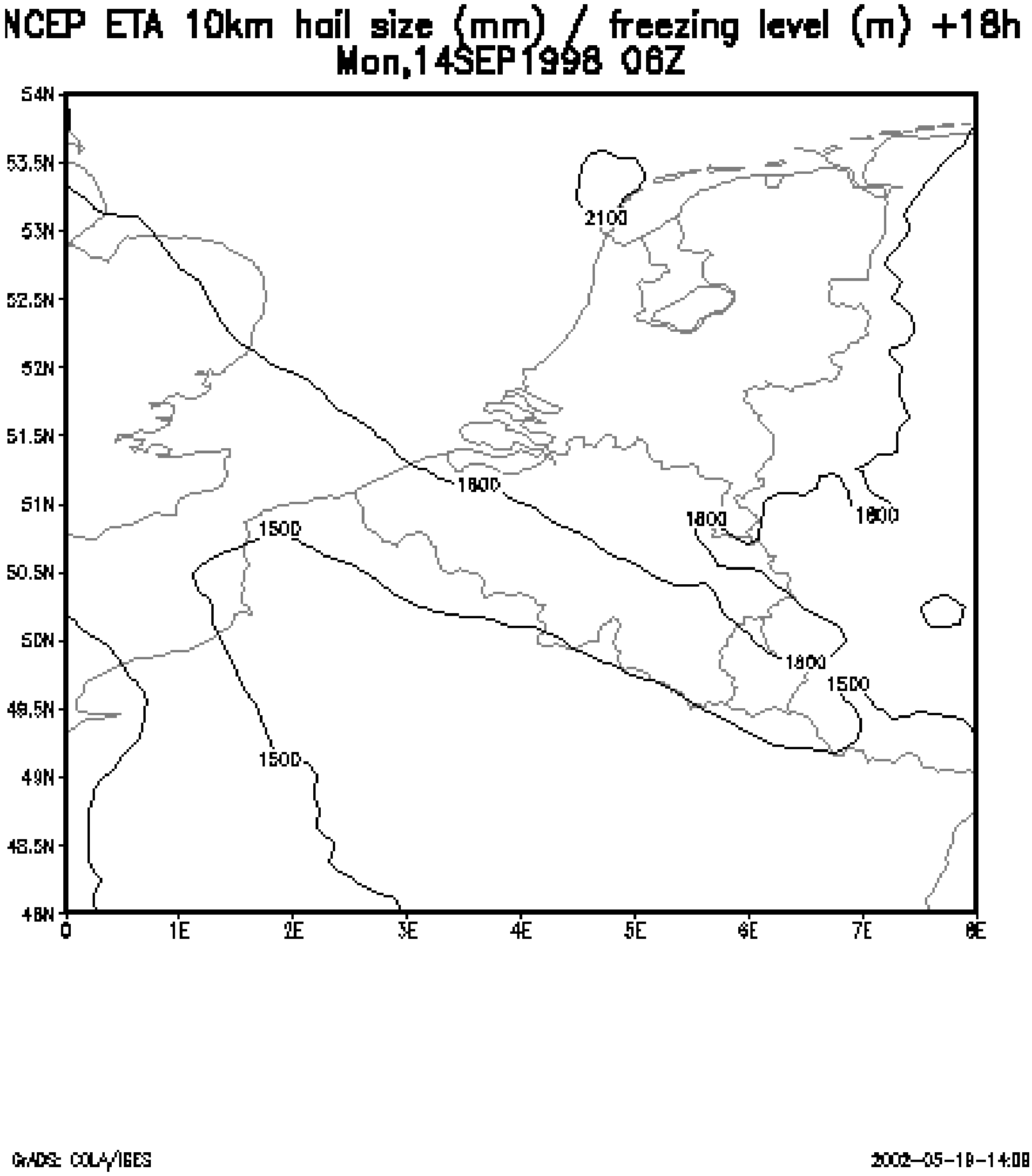


fig 12: hail size forecast 14/09/98 6z

Conclusion

This study has shown the modified Fawbush-Miller hail forecasting technique can be used succesfully to forecast large hail from mesoscale model output. The examined cases proved to be in good agreement with available observations, and were the most memorable severe (convective) Belgian weather events since 1967. Although the cases are limited in number and more research is needed, the results are extremely encouraging. It would be interesting to compare the results with the method used to model maximum hail size in Alberta (Brimelow et al, 2002).

6. References

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