THREE-DIMENSIONAL CHEMISTRY-TRANSPORT MODELLING: UNCERTAINTIES CONNECTED TO THE METEOROLOGICAL INPUT

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HIRLAM – High Resolution Limited Area Model

10-15 model releases per year in 2000's

The effect of variation in the meteorological parameters to the results of a 3D chemistry-transport model (CTM) Hilatar

the life-time of air pollutants depends on

the mixing height (hmix), precipitation intensity (P), wind velocity (uabs) and direction (udir), friction velocity (u*), Monin-Obukhov length (1/L), surface roughness (zo), temperature scale (t*), humidity, temperature (T) and the total cloudiness.

The forecasted parameters of Hirlam 2. vs. measured values at Jokioinen at the corresponding grid over the period 1996-1998.

Differences in forecasted meteorological fields using HIRLAM versions 4.6 and 5.2 over five months in spring 2003, and their effect to the air pollution load estimates are analyzed.

The wind sensor is at a height of 30 m in a tower located in an edge of a pine forest with 20-25 m height trees. The temperature sensor is at 2 m.

HIRLAM (HIgh Resolution Limited Area Model)

- hydrostatic weather prediction model
- since 1990 operationally at the FMI.
- Horizontal: rotated spherical grid coordinates
- Vertically hybrid η terrain-following coordinates.
- updated and improved continuously :
- physical parameterization, analysis, grid resolution
- numerics

- 1996-1997: HIRLAM 2
- an improved radiation scheme,
- a parallelized version since the end of 1997.
- July 2001 -> ECMWF lateral boundary conditions.

- November 1999 -> May 2003 HIRLAM 4.6.2
- Jan 2003 -> HIRLAM 5.2.1
- Feb 2004 -> RCR (0.2^o)
- On-line verification: spring 2004

differences: Hirlam 4.6 -> 5.2
- ground and surface: reference (Louis) -> ISBA;
- analysis: optimal interpolation -> 3DVar;
- TEMP, PILOT, SYNOP, AIREP and DRIBU observations;
- convection and condensation: STRACO -> RK/KF[*)];
- horizontal grid 44 km(ATA) /22km(ENO) -> 33 km (ATC) ;
- vertical grid: 31 -> 40 levels;

On-line documentation: http://hirlam.knmi.nl/
http://hirlam.knmi.nl/open/publications/
NewsLetters; HLworkshops; SciDoc; TechReports

*) Rash&Kristjanssen J.Climatol 11,1998/ Kain & Fritsch, J.Atm.Sci., 47,1990, AMS 1993

Hilatar (*Hongisto* 1998, 2003)

- Eulerian type numerical grid model
- air quality and deposition at the background areas.
- advection, vertical diffusion, emissions, chemical transformation and dry and wet deposition.
- Vertical mixing: gradient transport theory: the turbulent fluxes are assumed to be proportional to local mean concentration gradients
- the proportionality factor, the eddy diffusivity is analogical to molecular diffusion but 10^4-10^5 times stronger.
- The meteorological input: 6-hour predictions of the HIRLAM model.

Applications:

- European scale concentrations and depositions of nitrogen and sulphur compounds in background areas since 1995
- over Scandinavia 1993 -> (1985, 1988, 1991 ->)
- the nutrient flux and its variation to the Baltic Sea,
- some dust episodes
- heavy metal transport over the Nordic countries.

Verification:

- daily concentrations of SO_2, NO_2, NH_3, SO_4^{2-}, NO_3^-, NH_4^+, HNO_3^+, NO_3^- and NH_3+NH_4^+ in air,
- monthly mean wet depositions of $SO_4^=$, NO_3^- and NH_4^+, comparison with EMEP/NILU measurements;
- Comparison with ship measurements (BASYS), urban air quality network measurements and other field campaigns

HIRLAM VS SOUNDING
COMPARISON OF ABL PARAMETERS, 1996-1998

2 m temperature T(2m),
relative humidity RH, %
Precipitation P REC, mm
ABL height hmix,
Wind direction udir, 30 m
Wind velocity uabs, 30 m
Friction velocity u*, cm/s
Monin-Obukhov length 1/L, 1/m and
Temperature scale t*

measured at Jokioinen or calculated from the Jokioinen soundings or from the HIRLAM profile at the corresponding grid.
- all soundings, years 1996-1998.
- the ABL parameters were not directly available from HIRLAM, they were estimated for both data sets with the same method, FMI meteorological pre-processor adapted from the local dispersion model system, as described in *Hongisto* (1998) p. 22-23.

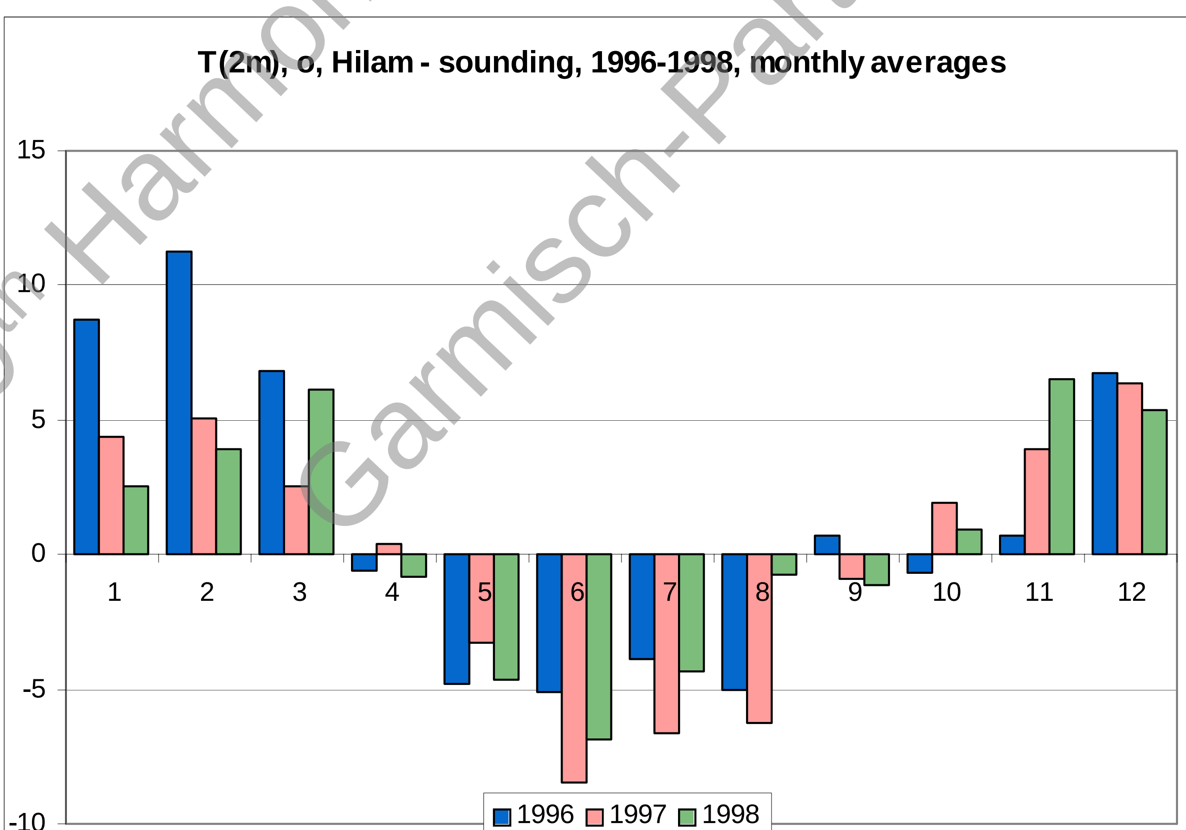
As annual averages the differences were very small (Table 1) the instant deviations, under- or overestimations cancel each other.

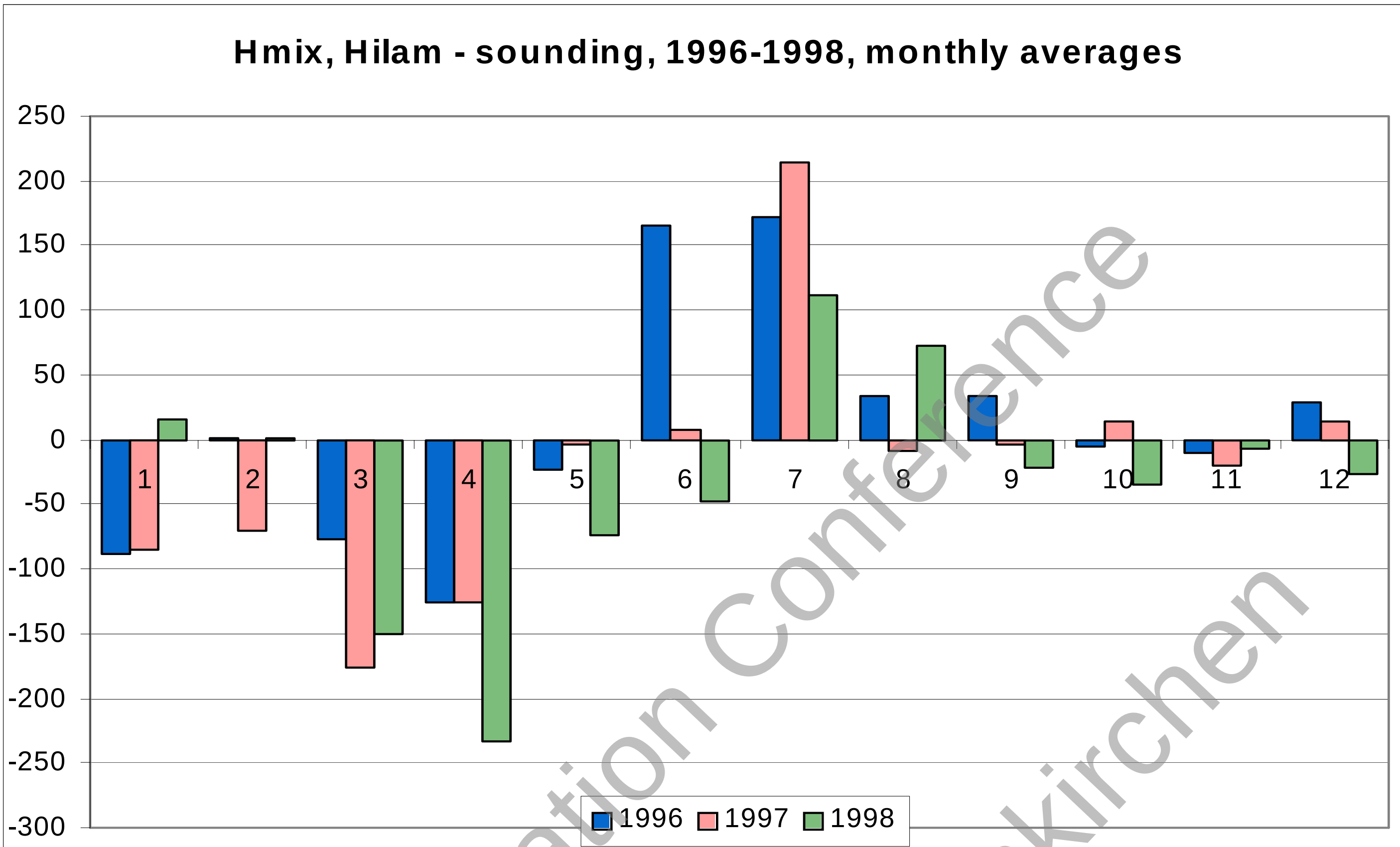
<u>Table 1 HIRLAM estimate minus the sounding value</u>

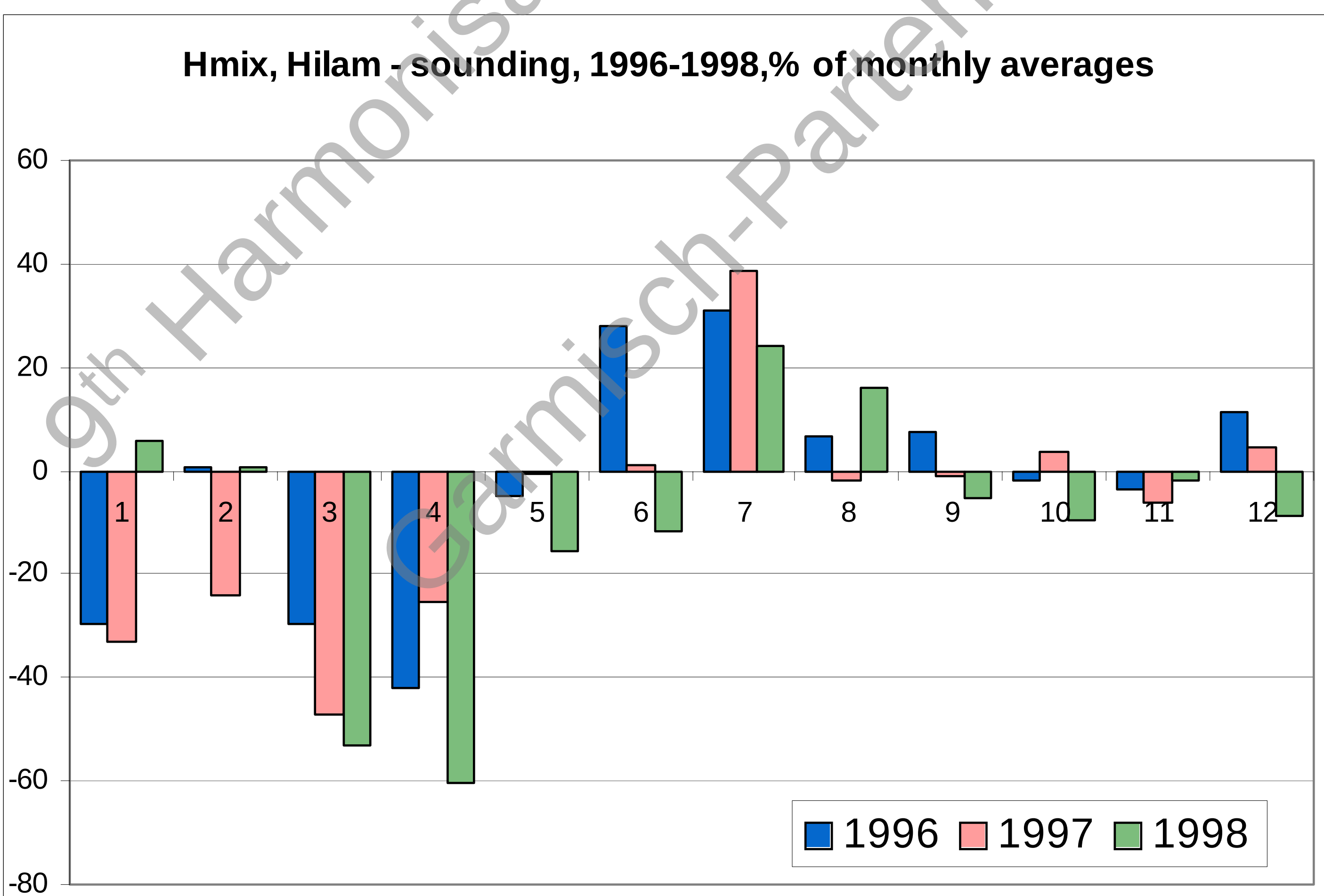
	T(2m)	RH	PREC	UDIR	uabs	1/L	t*	u*	hmix
	oC	%	mm	O	M s^{-1}	1/m	oC	m s^{-1}	m
1996	1.17	2.71	-169.85	19.19	0.51	-0.08	-0.05	0.16	8.33
1997	-0.10	2.63	-141.45	32.65	0.60	-0.13	-0.03	0.14	-18.55
1998	0.56	4.82	84.83	30.14	0.90	-0.08	-0.02	0.19	-32.66

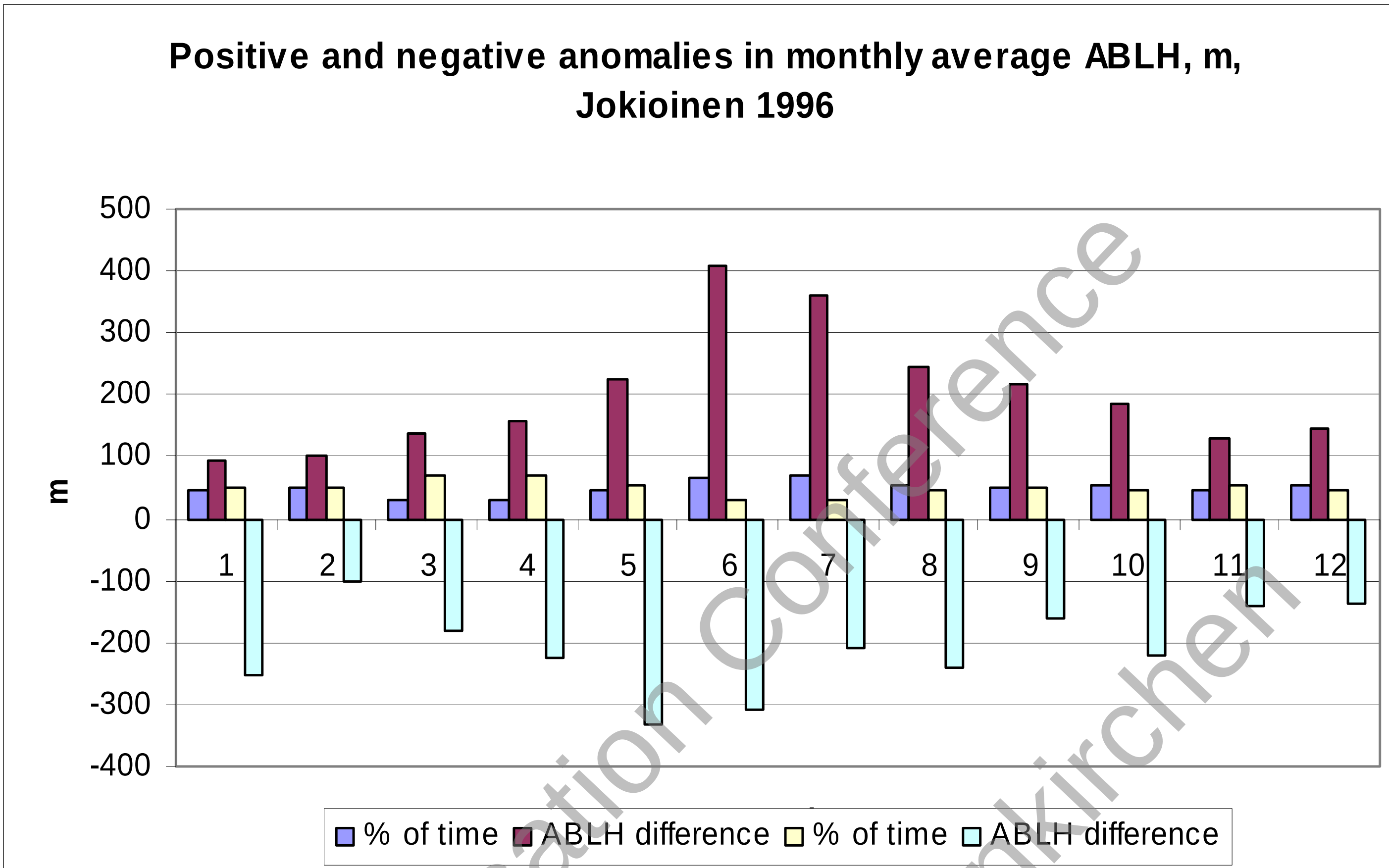
COMPARISON OF ABL PARAMETERS, 1996-1998

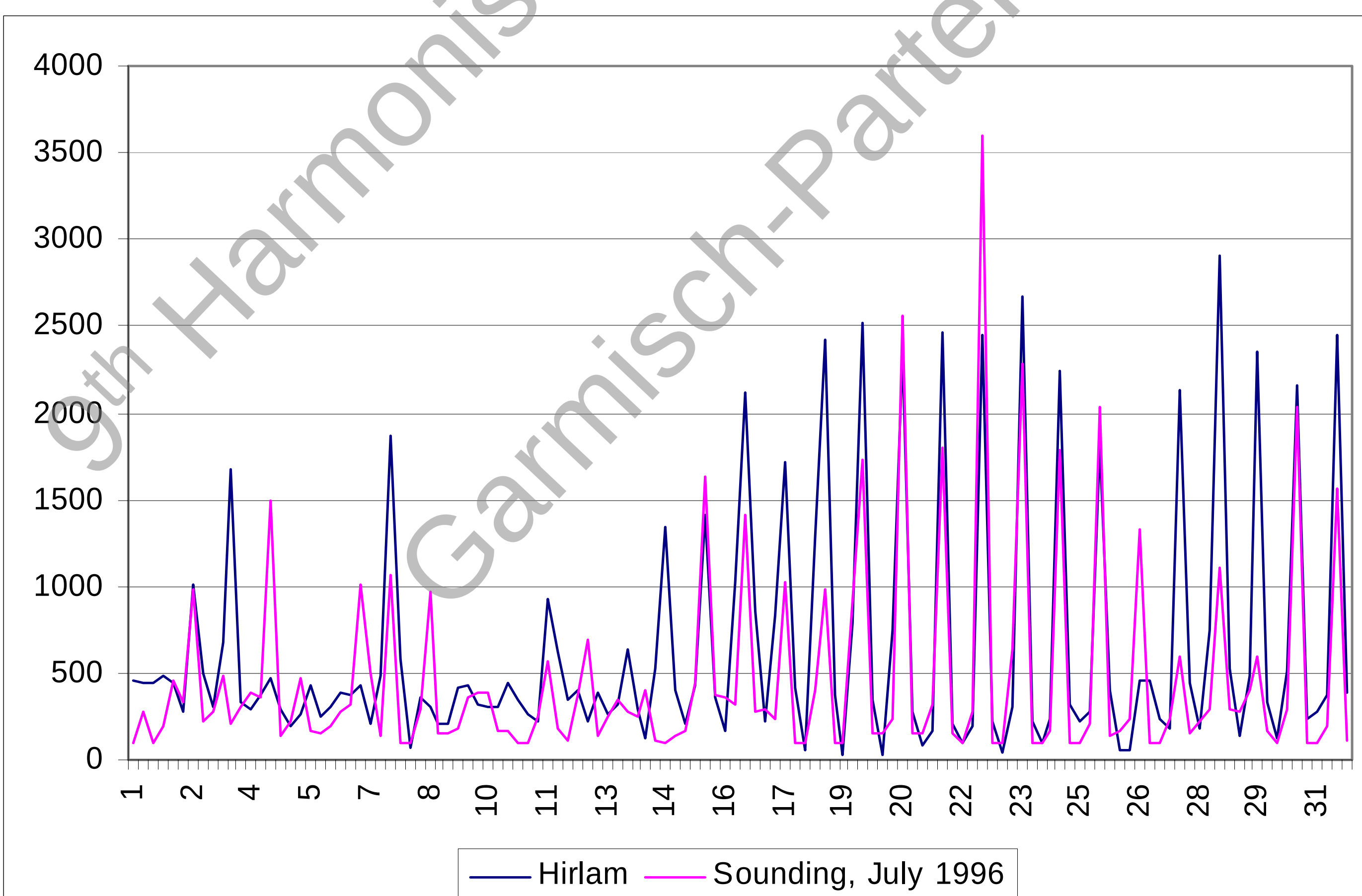
-HIRLAM surface seems to be too cold in summer, too warm in winter.
- slightly too high winds at 30 m,
- overestimated mechanical turbulence.
- T(2m): too warm in spring and winter nights; inversions difficult to predict. Too much evaporation – limited, ½ value.
Hmix
- during spring months smaller
- in June and July the anomaly is positive
- The night-time difference was in 1996 +- 150 m throughout the year, while during daytime the instant difference could exceed 2 km.

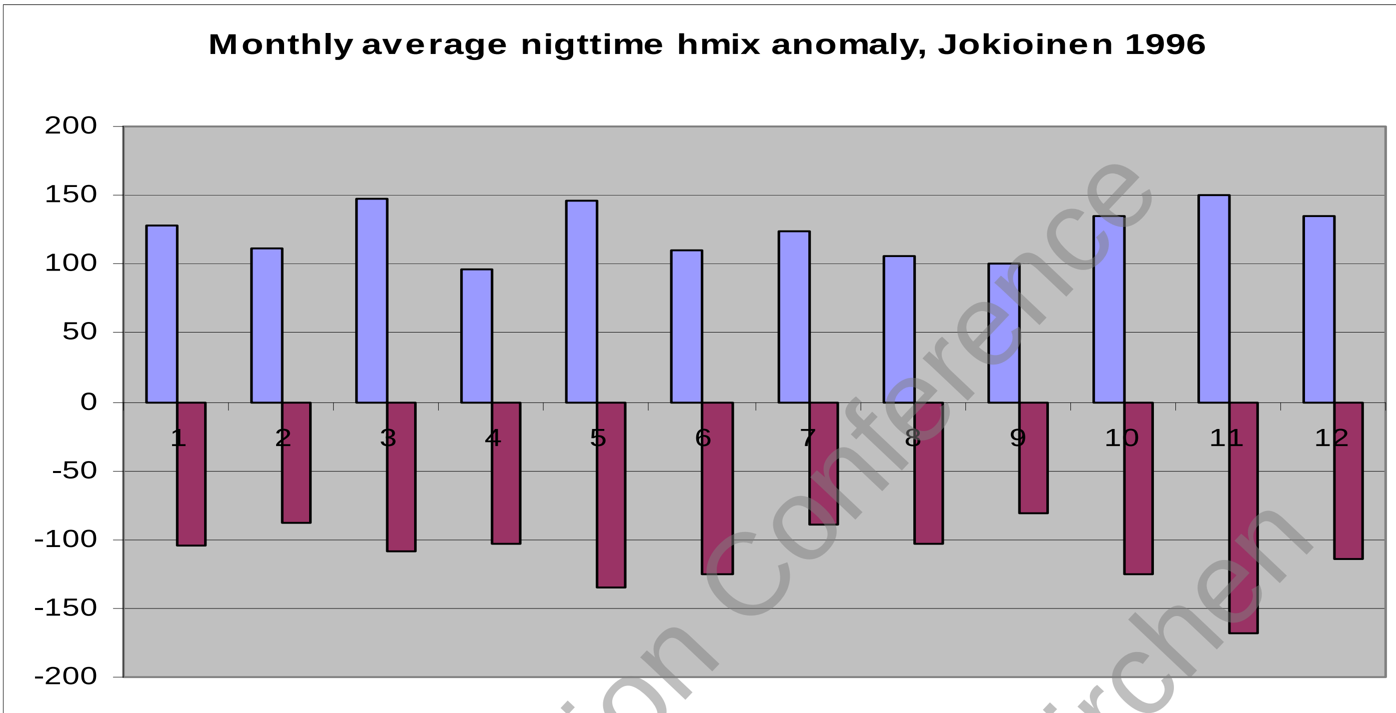


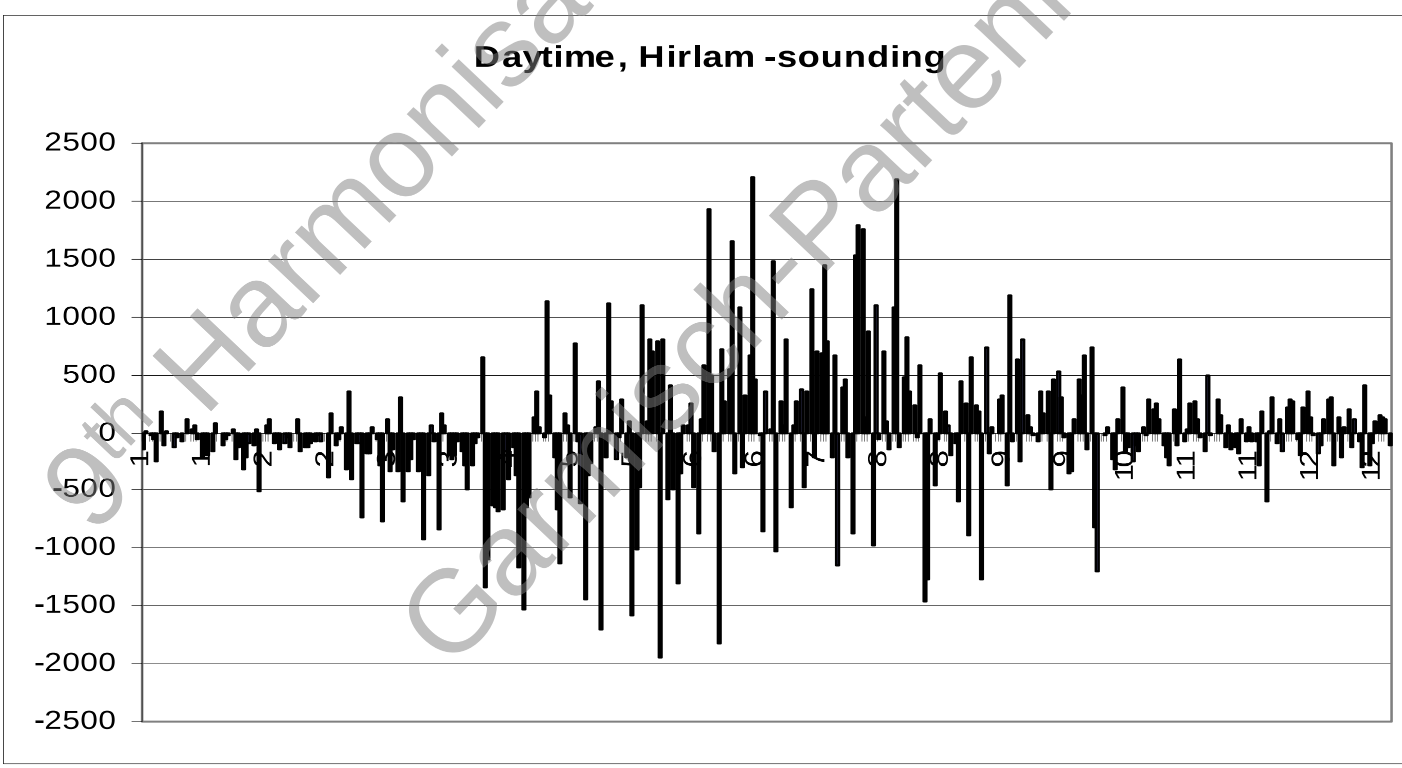

Hmix, Hilam - sounding, 1996-1998, monthly averages
250
200
150
100
50
0
-50
-100
-150
-200
-250
-300
1 2 3 4 5 6 7 8 9 10 11 12
1996 1997 1998

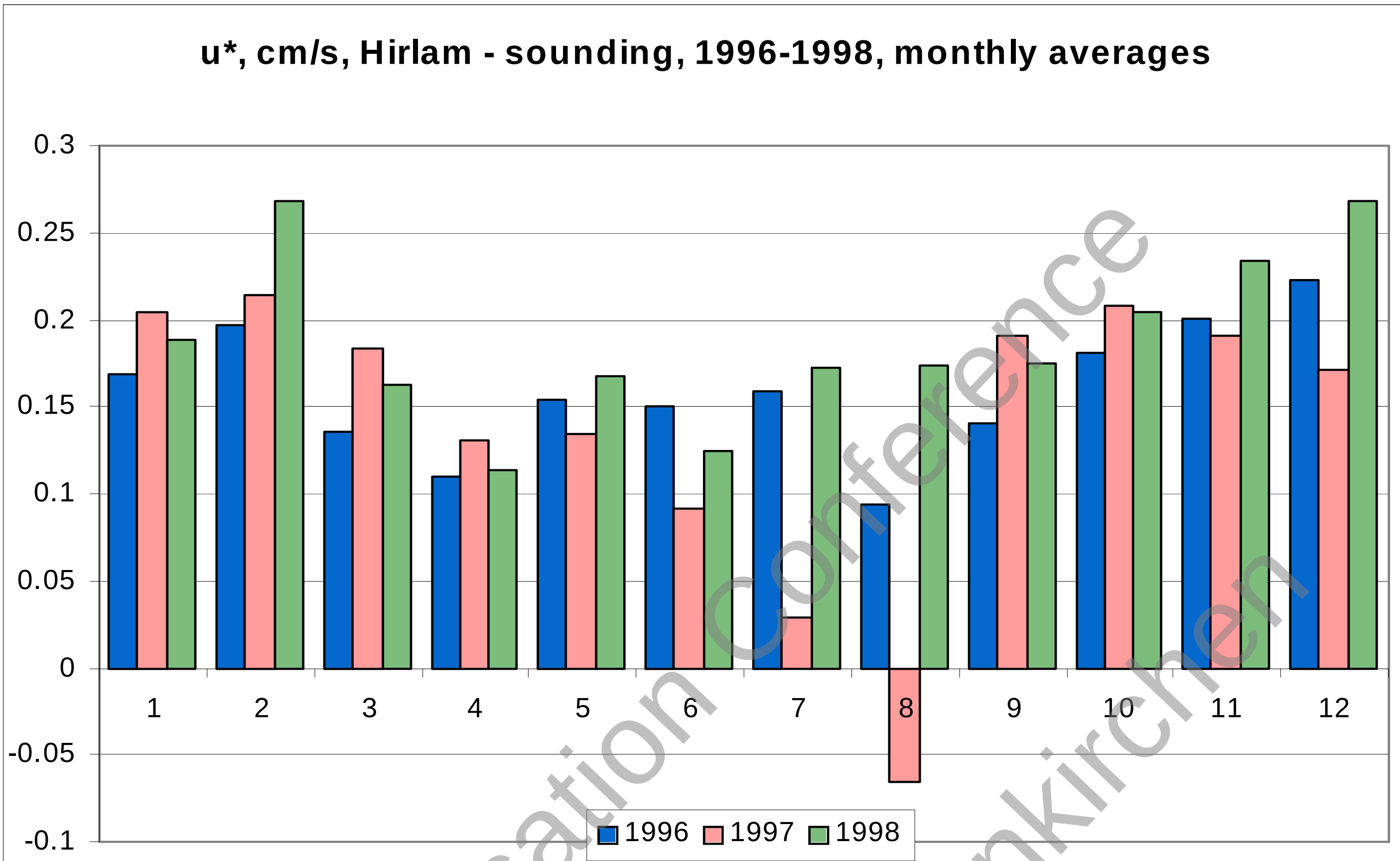

Hmix, Hilam - sounding, 1996-1998,% of monthly averages
60
40
20
0
-20
-40
-60
-80
1 2 3 4 5 6 7 8 9 10 11 12
1996 1997 1998

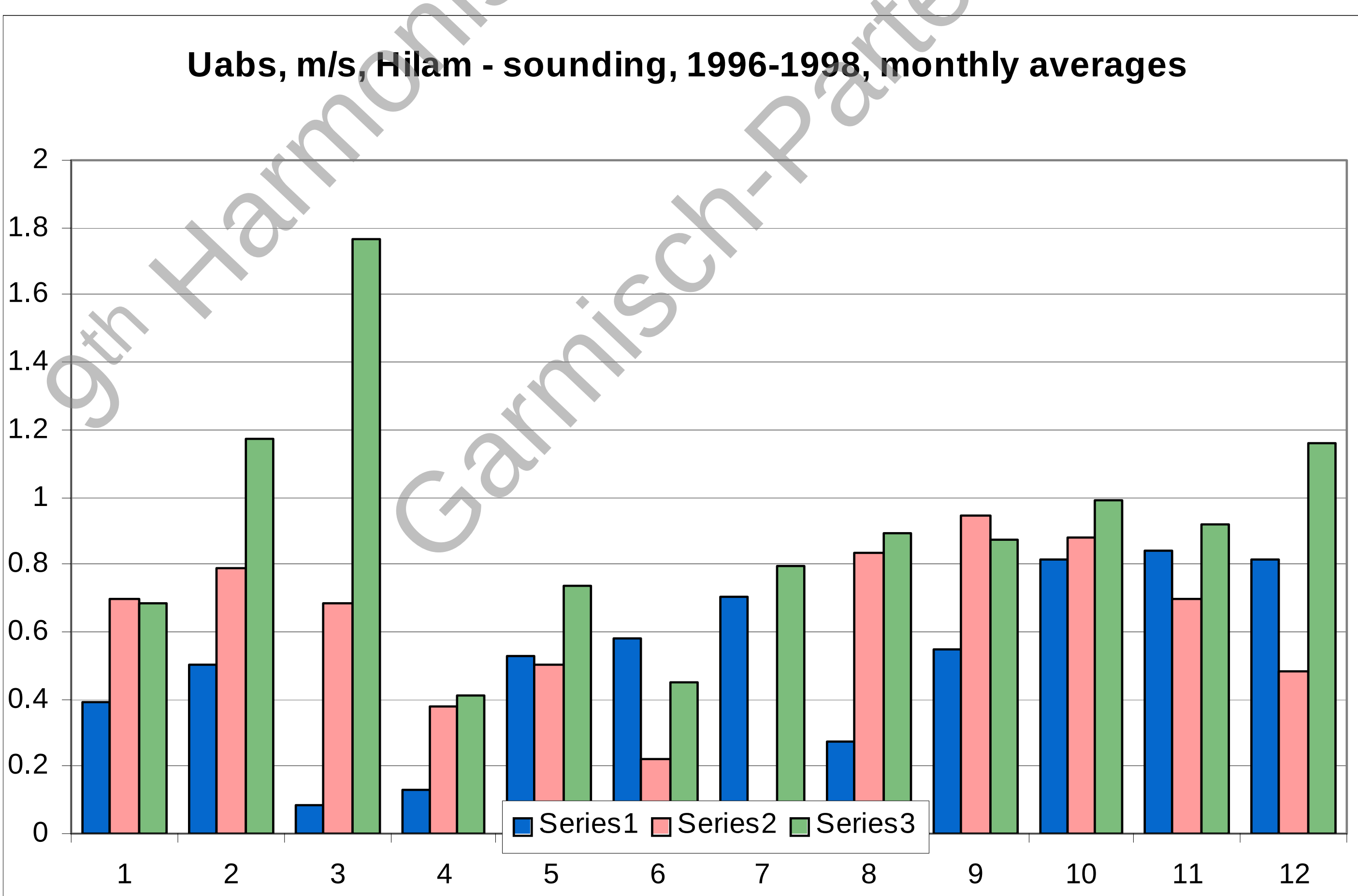

Positive and negative anomalies in monthly average ABLH, m, Jokioinen 1996
500
400
300
200
100
0
-100
-200
-300
-400
m
1
2
3
4
5
6
7
8
9
10
11
12
% of time
ABLH difference
% of time
ABLH difference


4000
3500
3000
2500
2000
1500
1000
500
0
1
2
4
5
7
8
10
11
13
14
16
17
19
20
22
23
25
26
28
29
31
Hirlam
Sounding, July 1996


Monthly average nigttime hmix anomaly, Jokioinen 1996
200
150
100
50
0
-50
-100
-150
-200
1
2
3
4
5
6
7
8
9
10
11
12


Daytime, Hirlam -sounding
2500
2000
1500
1000
500
0
-500
-1000
-1500
-2000
-2500


u*, cm/s, Hirlam - sounding, 1996-1998, monthly averages
0.3
0.25
0.2
0.15
0.1
0.05
0
-0.05
-0.1
1
2
3
4
5
6
7
8
9
10
11
12
1996
1997
1998


Uabs, m/s, Hilam - sounding, 1996-1998, monthly averages
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1
2
3
4
5
6
7
8
9
10
11
12
Series1
Series2
Series3

COMPARISON OF ATMOSPHERIC BOUNDARY LAYER PARAMETERS CALCULATED BY DIFFERENT HIRLAM VERSIONS

6th hour forecasts

hmix, P, uabs, udir, T(2m) and q(2m): HIRLAM

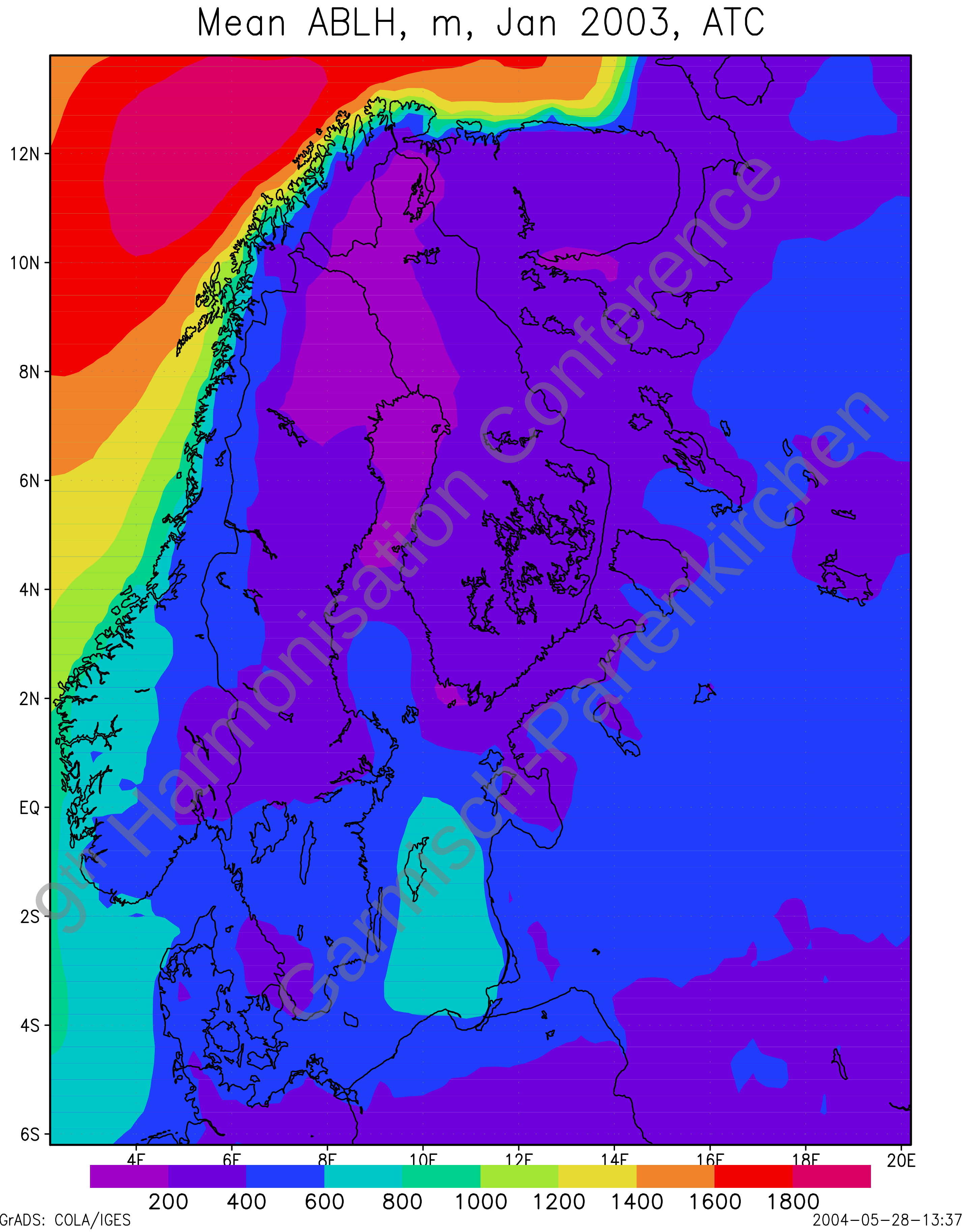
u*, 1/L and t*: postprocessed

HIRLAM versions:

ATA-, HIRLAM 4. with 0.4° grid and

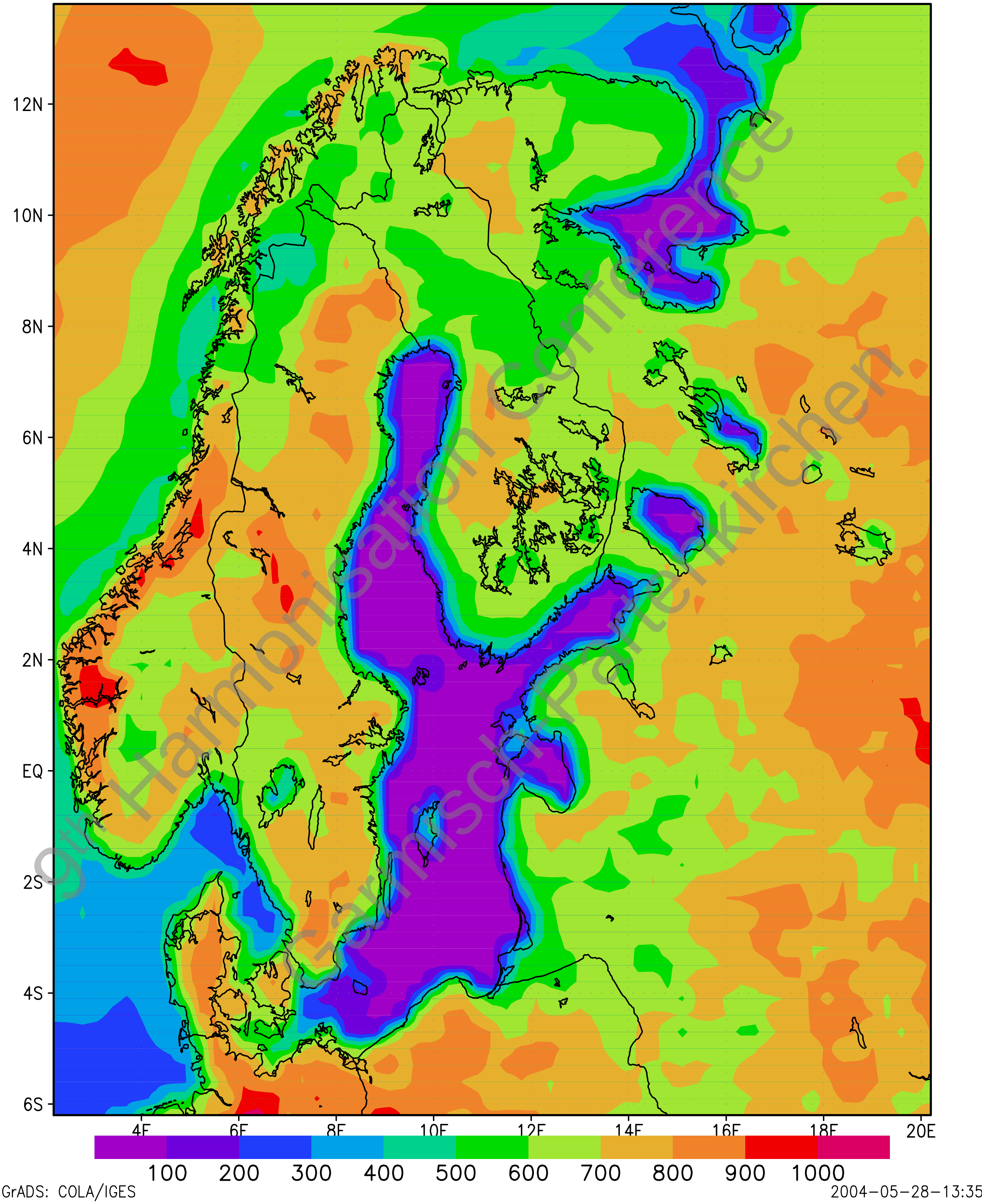
ATC-, HIRLAM 5.1 with a 0.3° grid)

comparison over the Scandinavia.

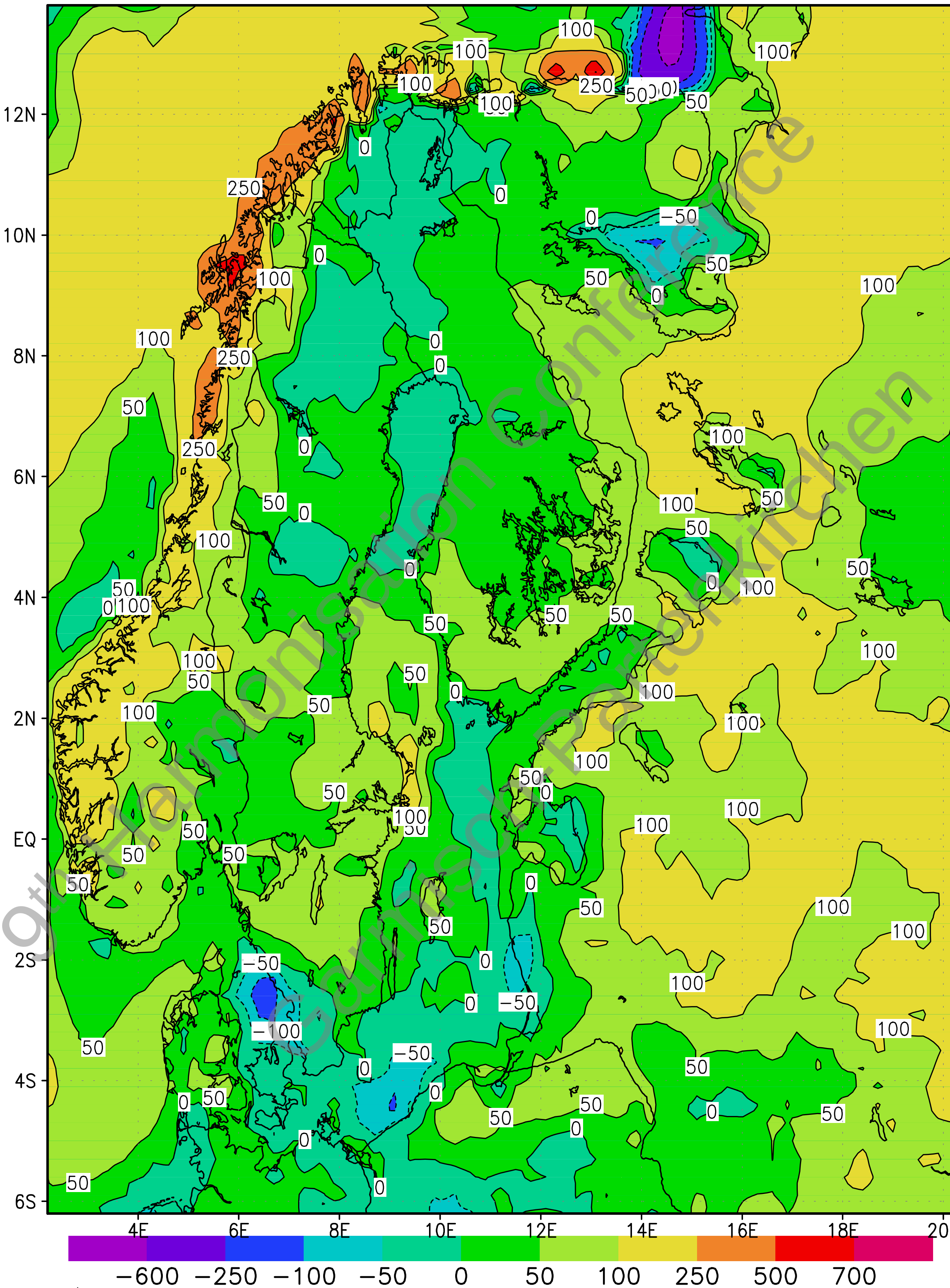


Mean ABLH, m, Jan 2003, ATC
12N
10N
8N
6N
4N
2N
EQ
2S
4S
6S
4E
6E
8E
10E
12E
14E
16E
18E
20E
200
400
600
800
1000
1200
1400
1600
1800
GrADS: COLA/IGES
2004-05-28-13:37

Mean ABLH, m, May 2003, ATC



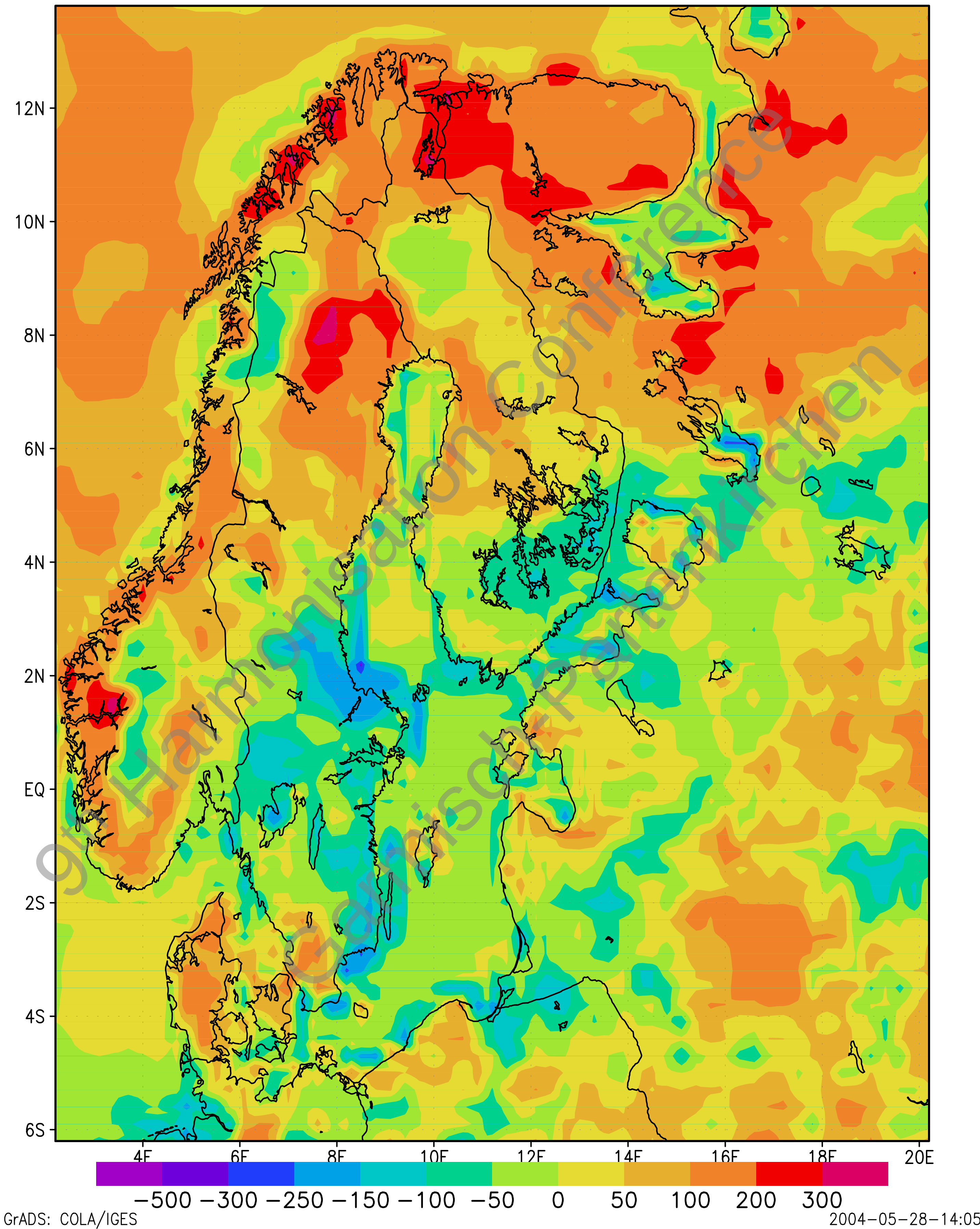
ABLH, m, Jan 2003, ATC–ATA



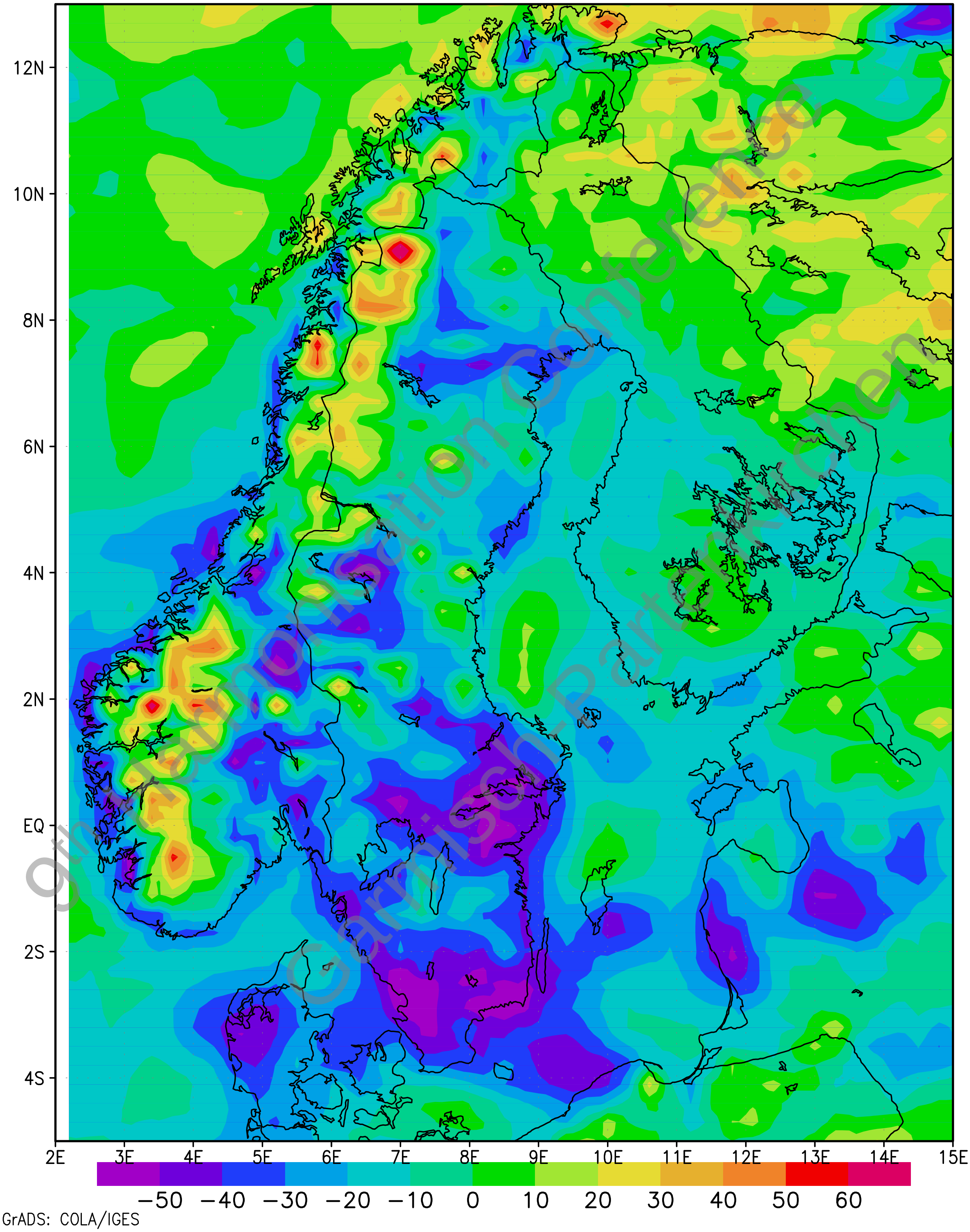
GrADS: COLA/IGES

2003–11–13–17:

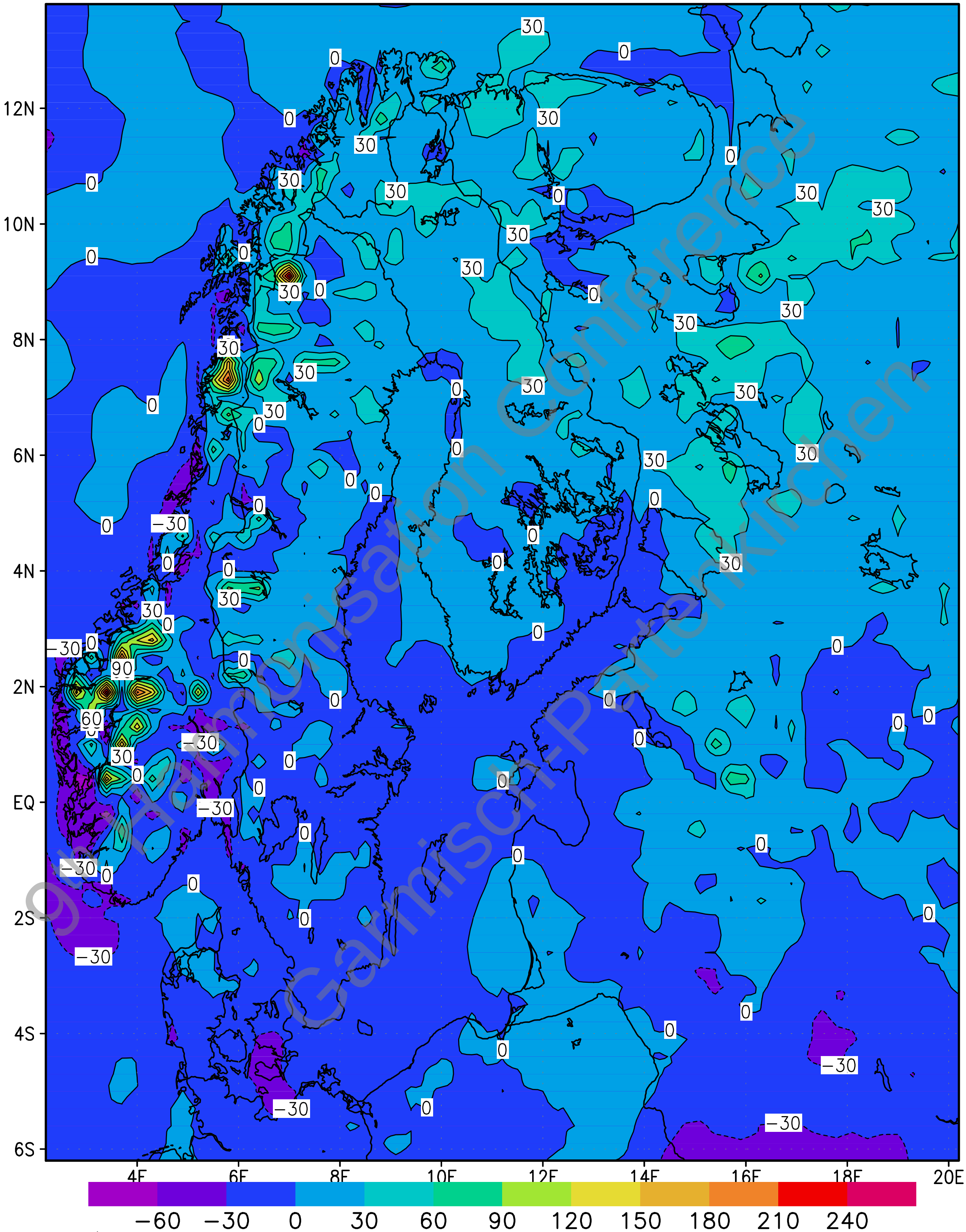
hmixdif, May 2003, m, ATC–ATA



precipitation difference, Jan 2003, %

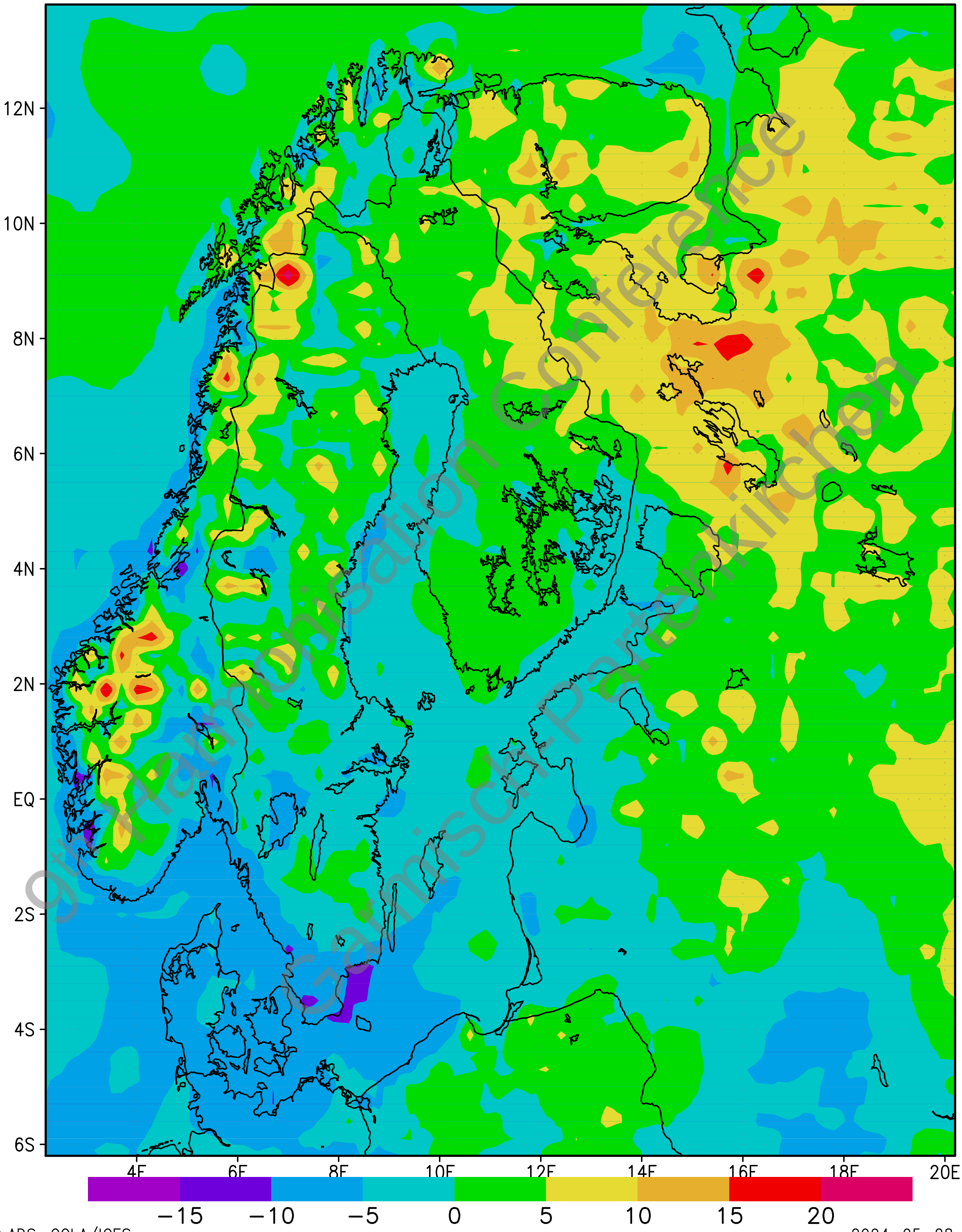


Precipitation, mm May2003, ATC-ATA



GrADS: COLA/IGES 2004-05-27-21:21

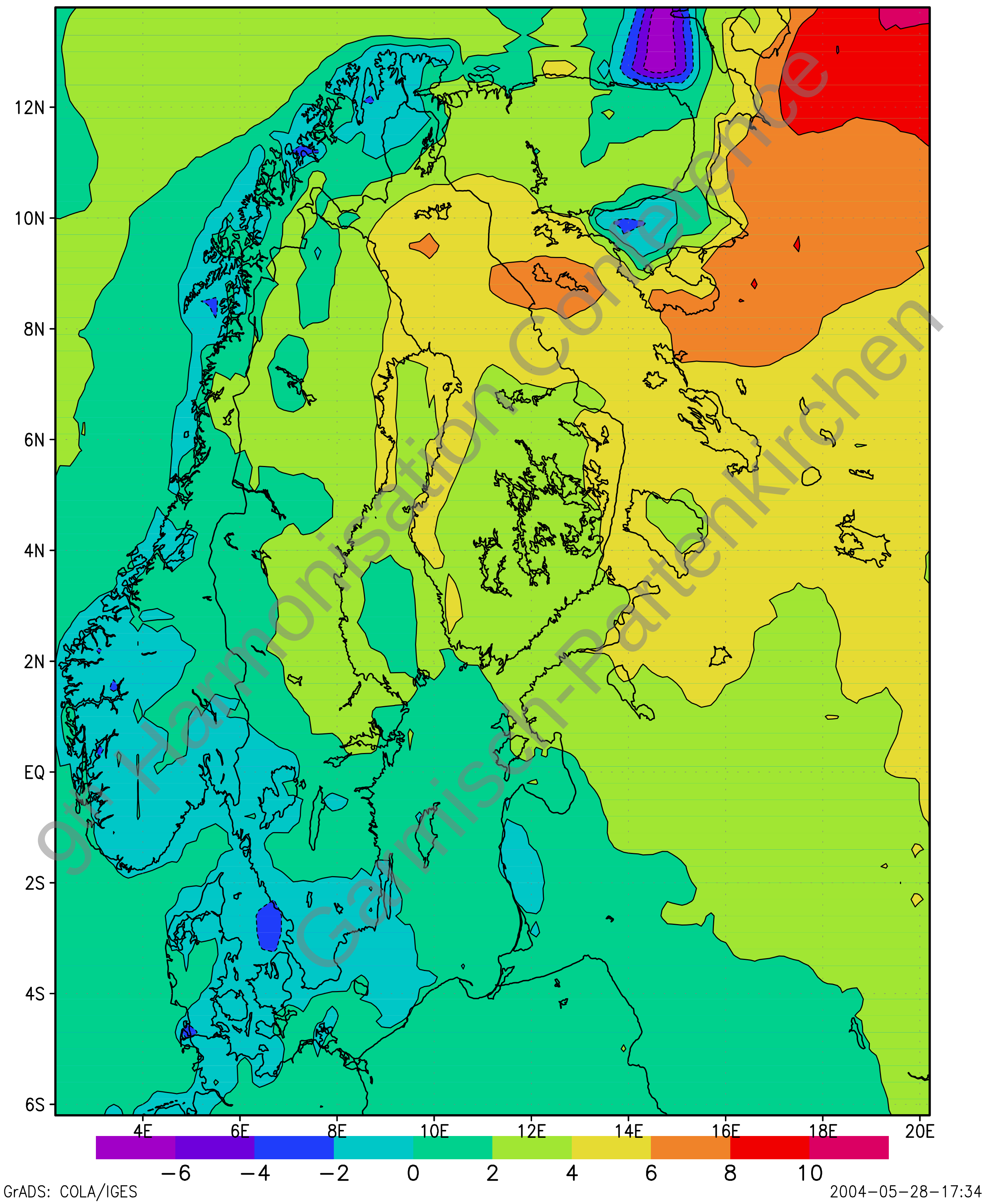
Precipitation dif, %, 1.1–31.5.2003 ATC–ATA



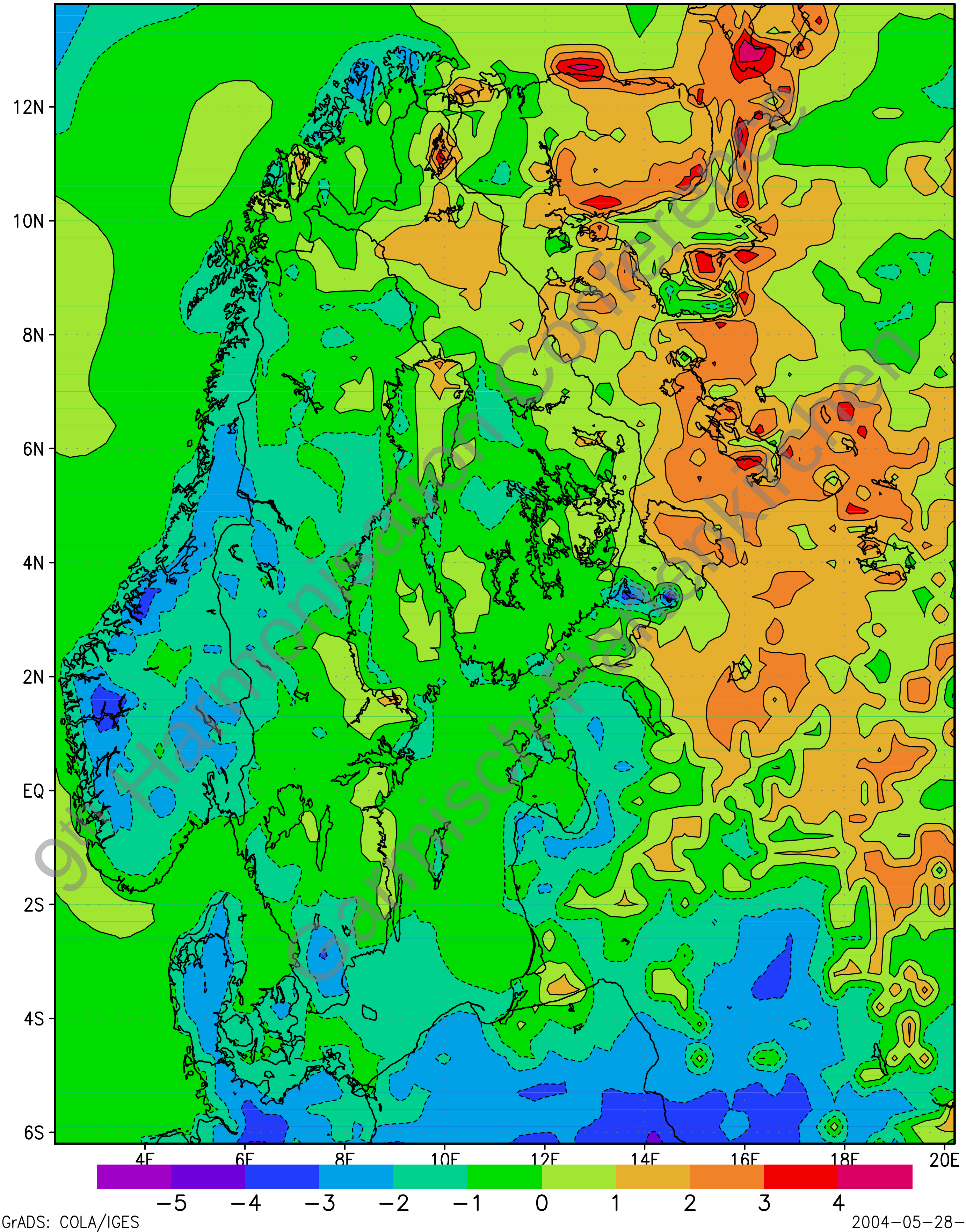
GrADS: COLA/IGES

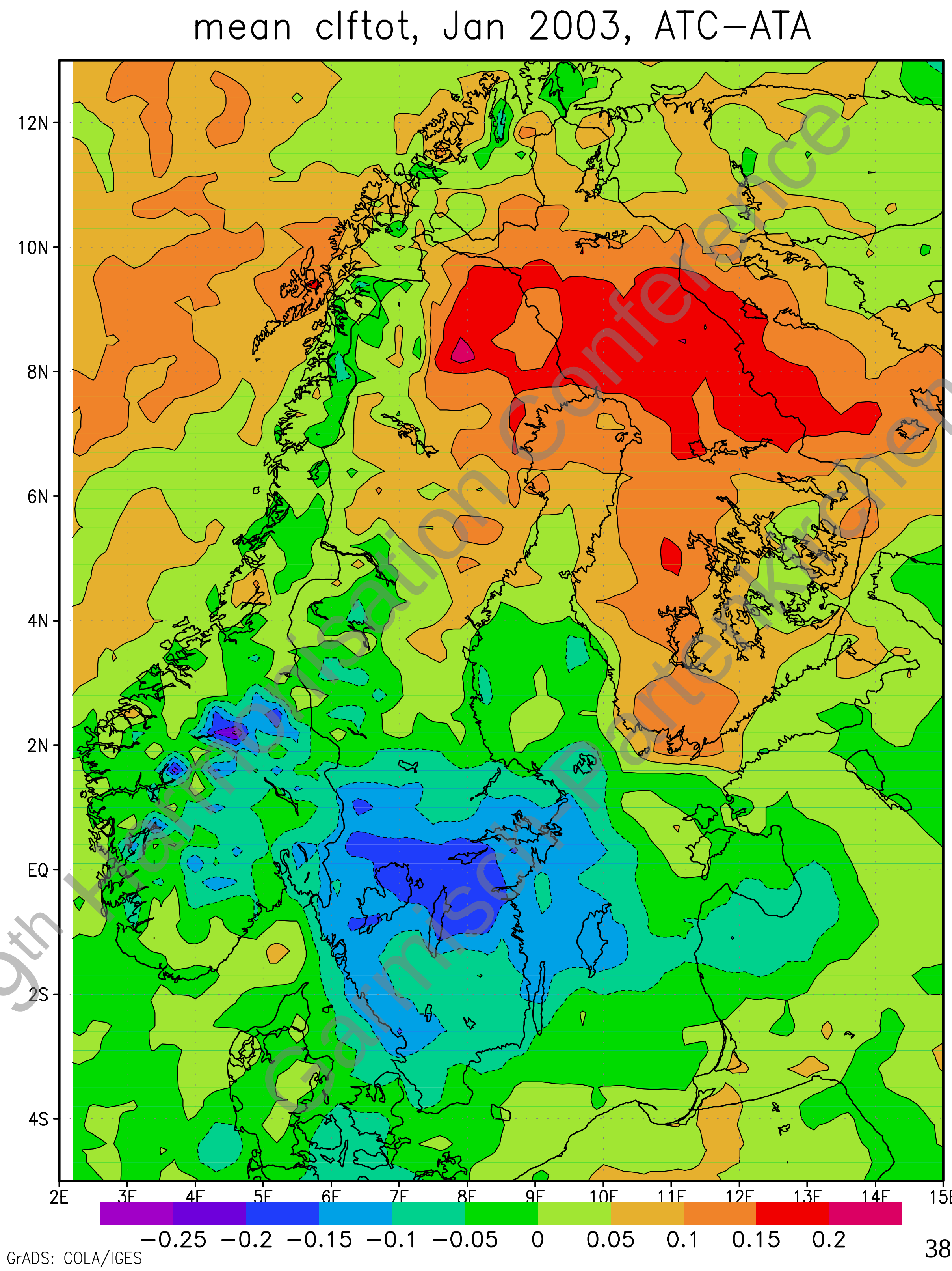
2004–05–28–10:2

q2, ATC-ATA, January 2003, %



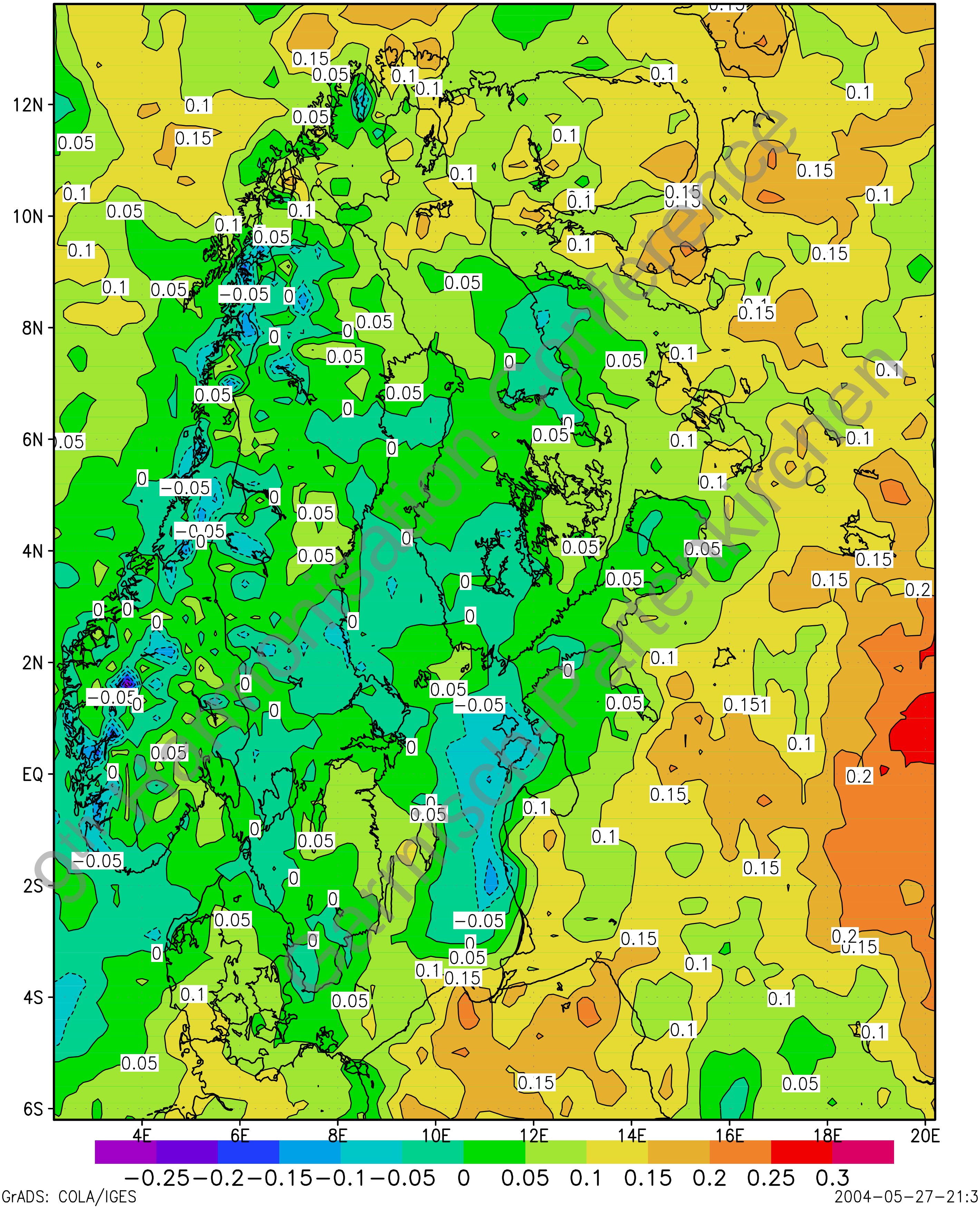
q2m, ATC−ATA, %, May 2003



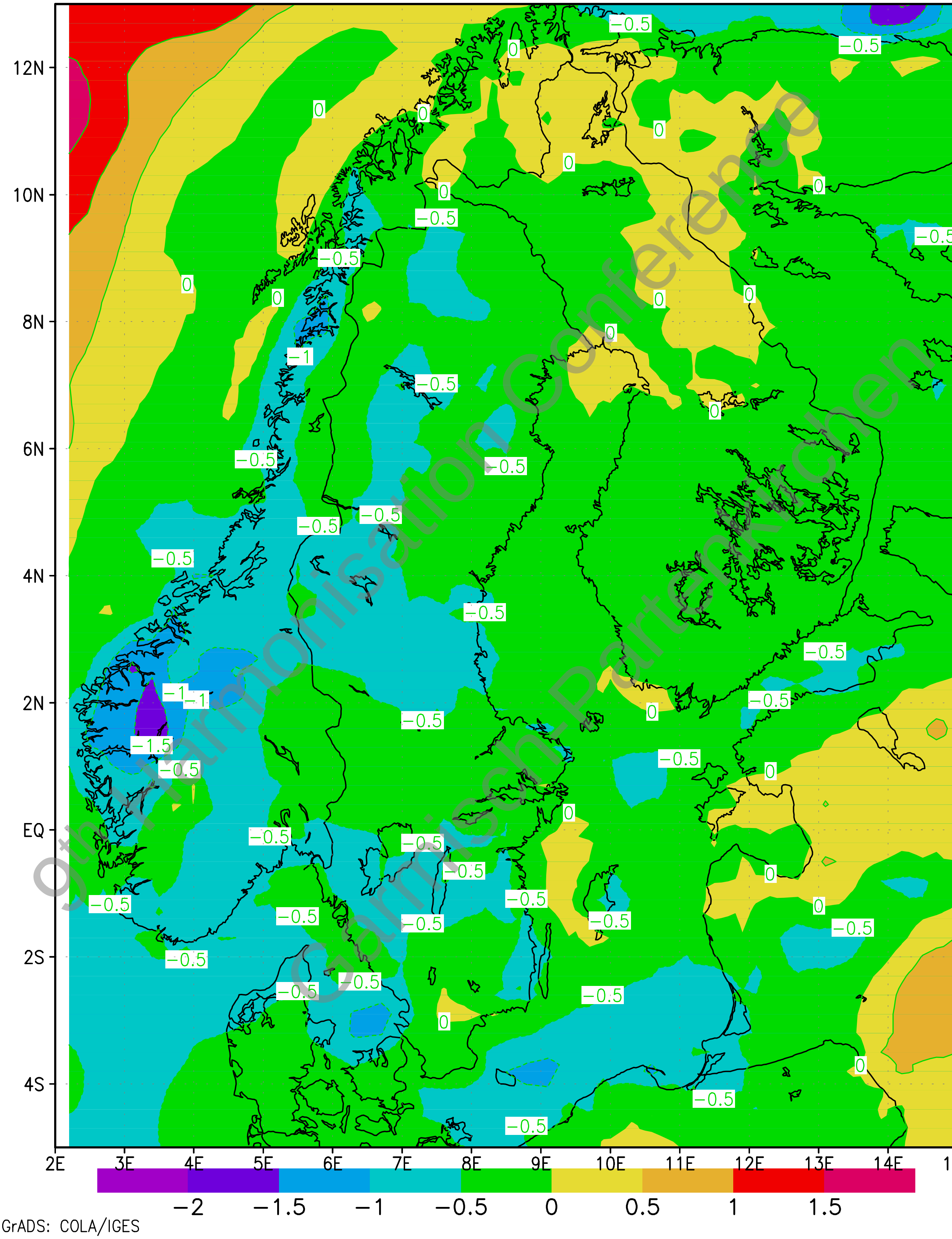


mean clftot, Jan 2003, ATC–ATA
12N
10N
8N
6N
4N
2N
EQ
2S
4S
2E
3E
4E
5E
6E
7E
8E
9E
10E
11E
12E
13E
14E
15E
–0.25
–0.2
–0.15
–0.1
–0.05
0
0.05
0.1
0.15
0.2
GrADS: COLA/IGES

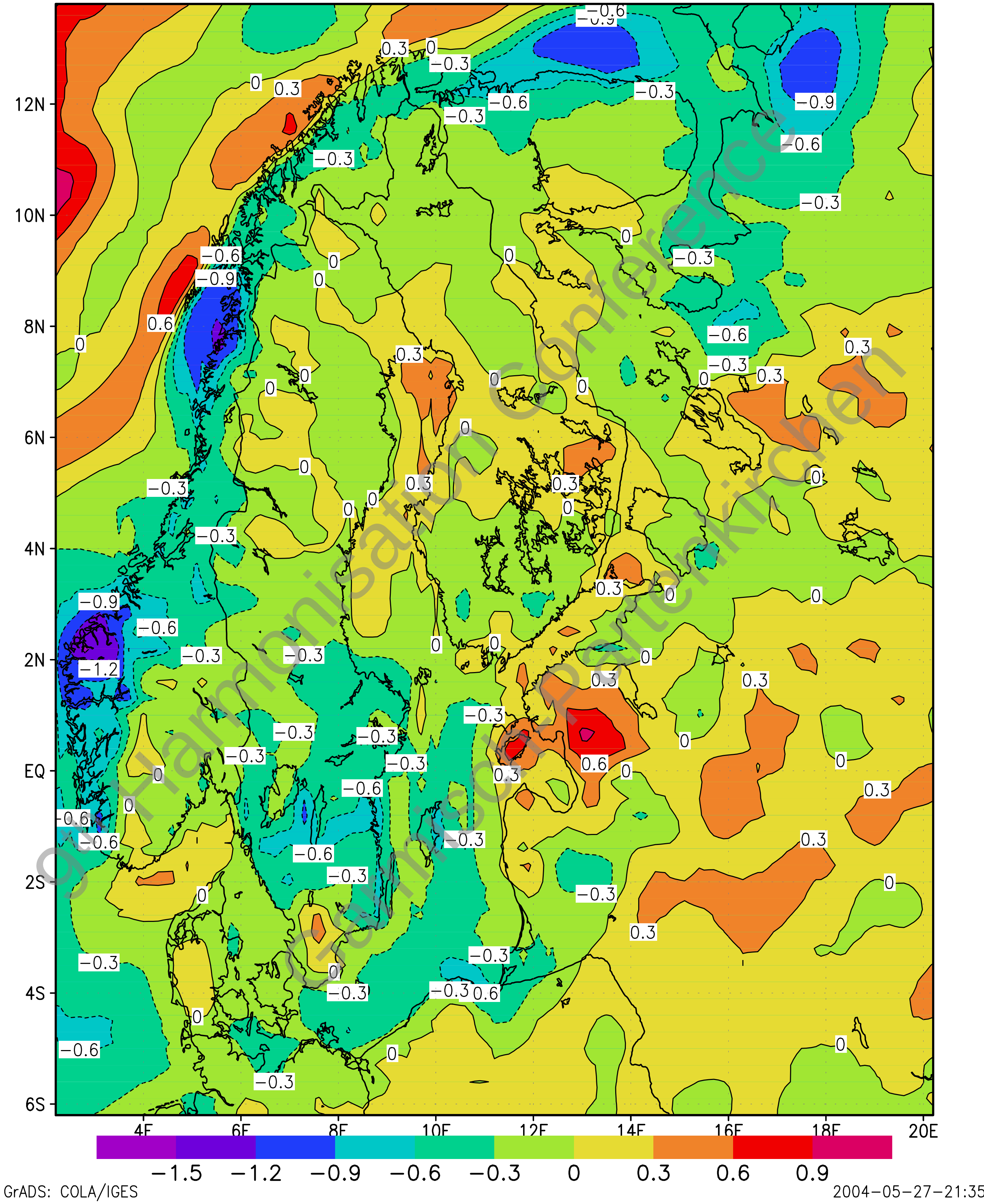
total cloudiness, ATC – ATA May2003



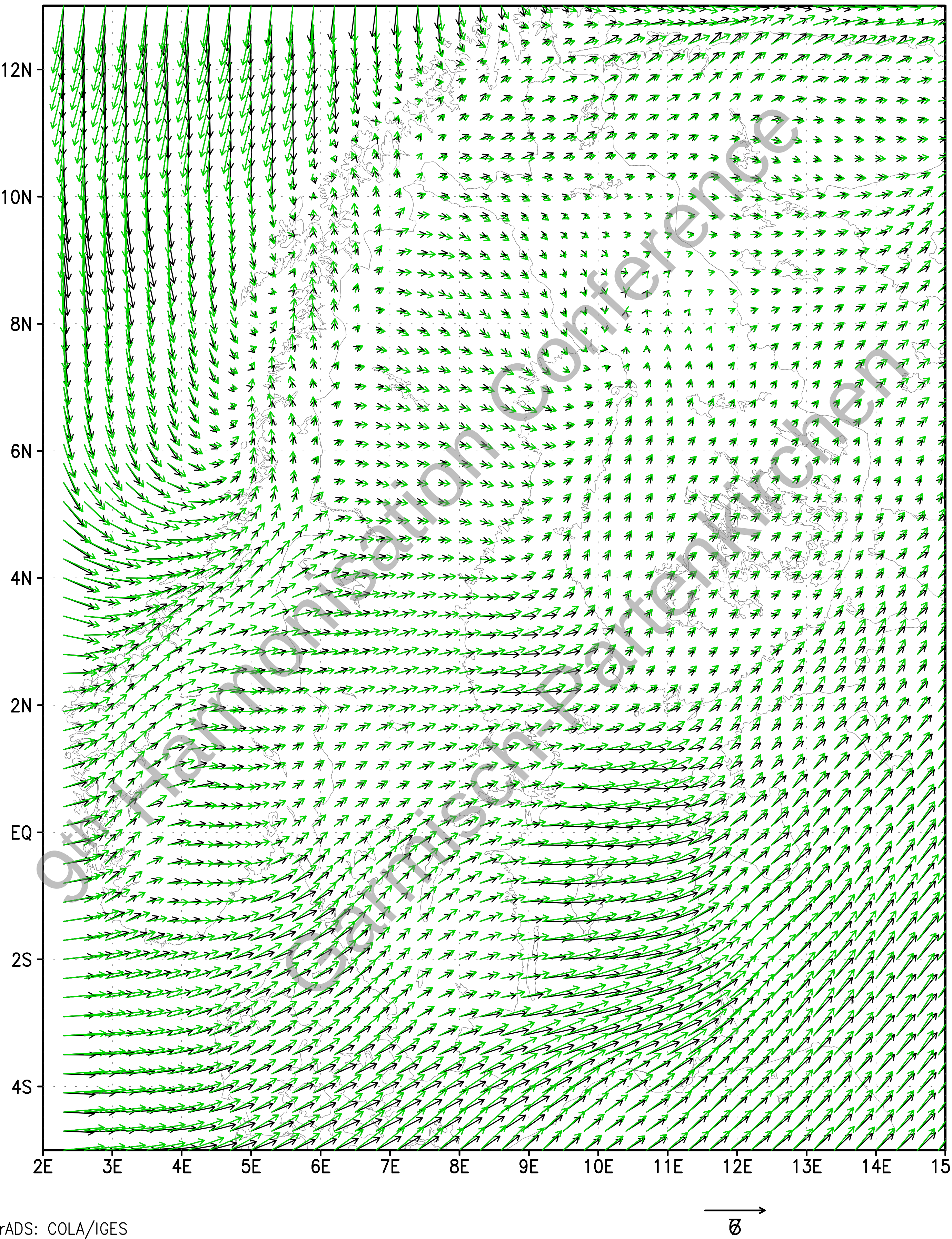
0301, mean u(10)absatc – u(10)absata, m/s



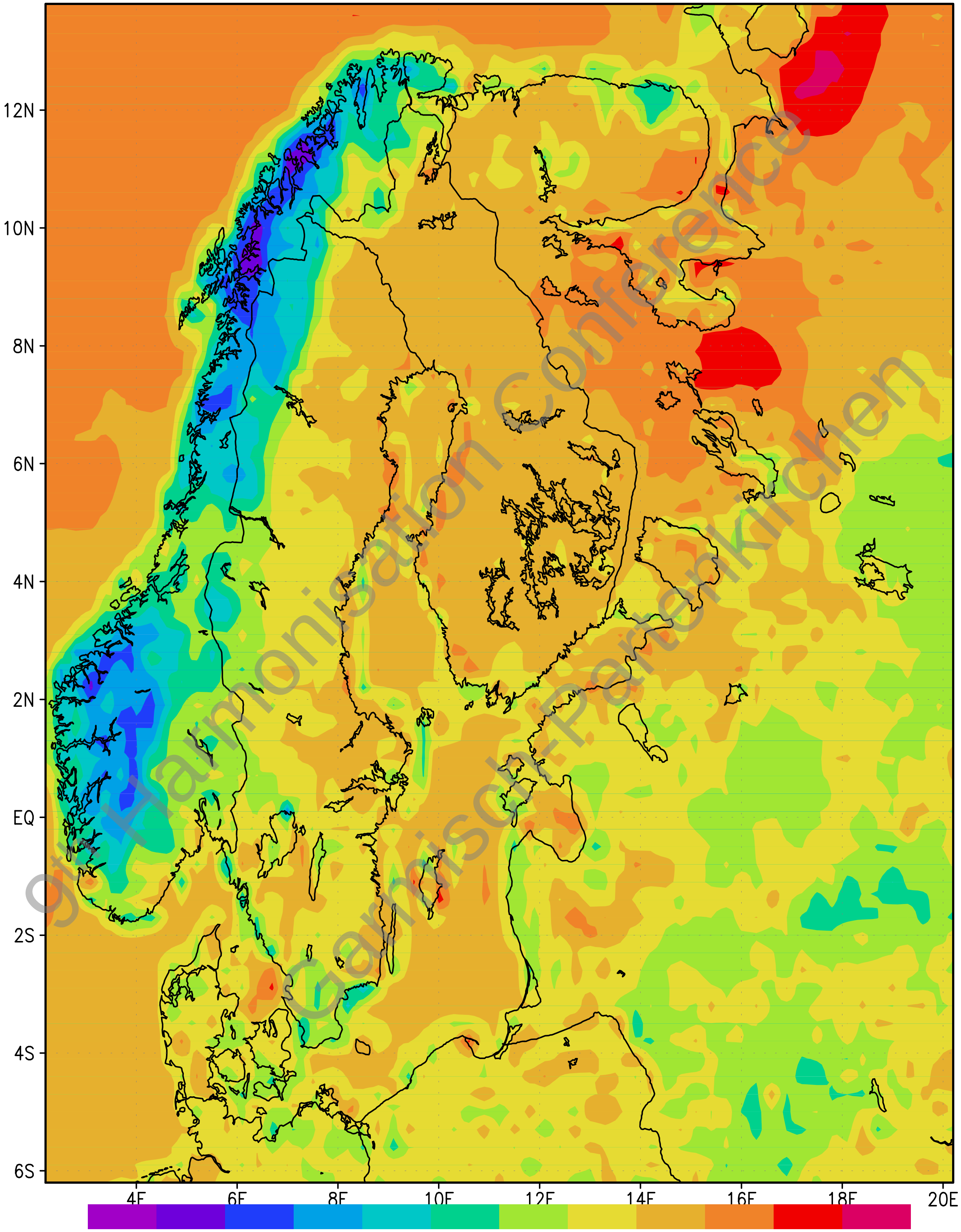
Uabs, ATC – ATA May2003



0301, mean uatc(white) vs uata(green)



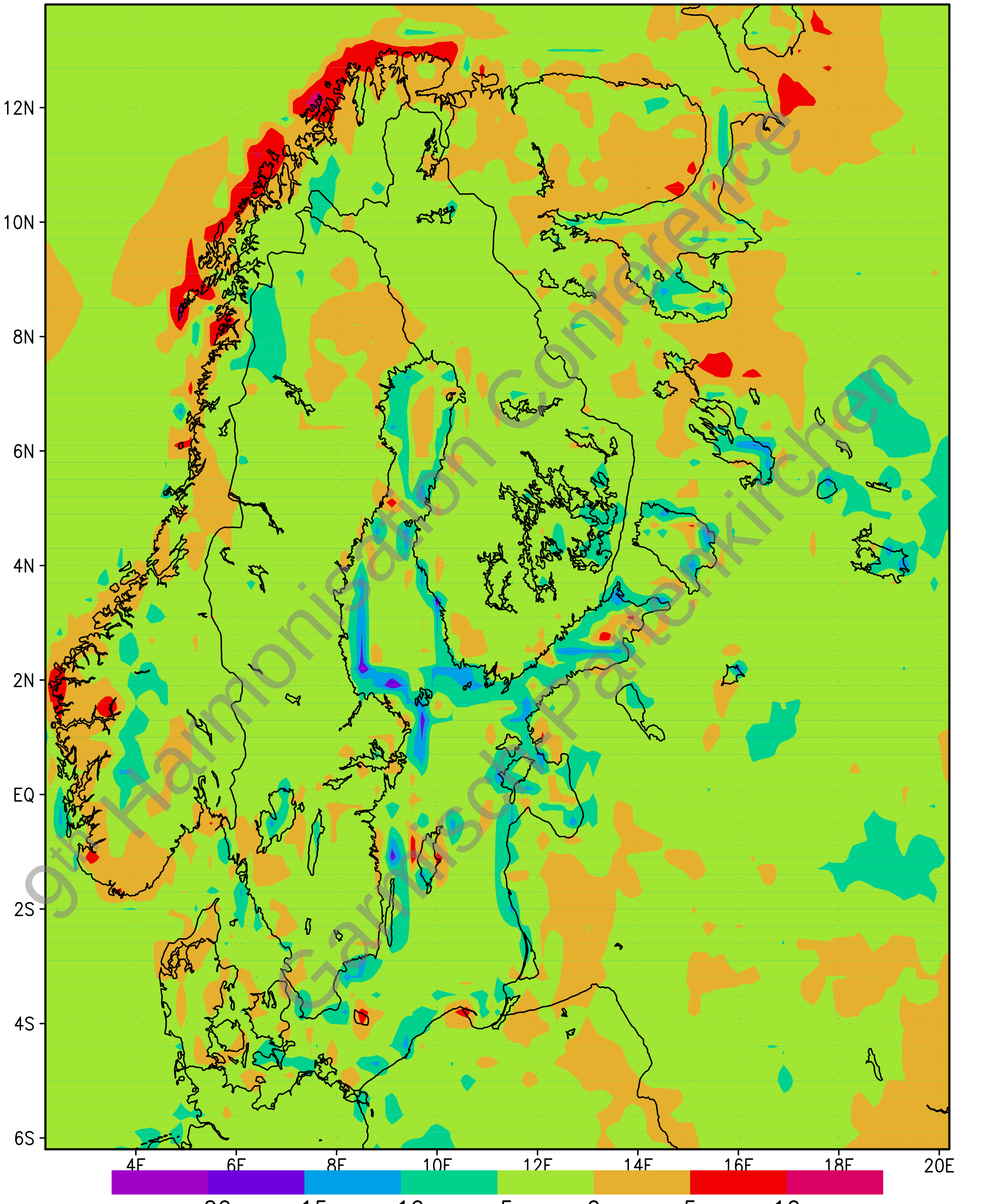
u*, ATC–ATA, %, January 2003



GrADS: COLA/IGES

2004–05–28–18:00

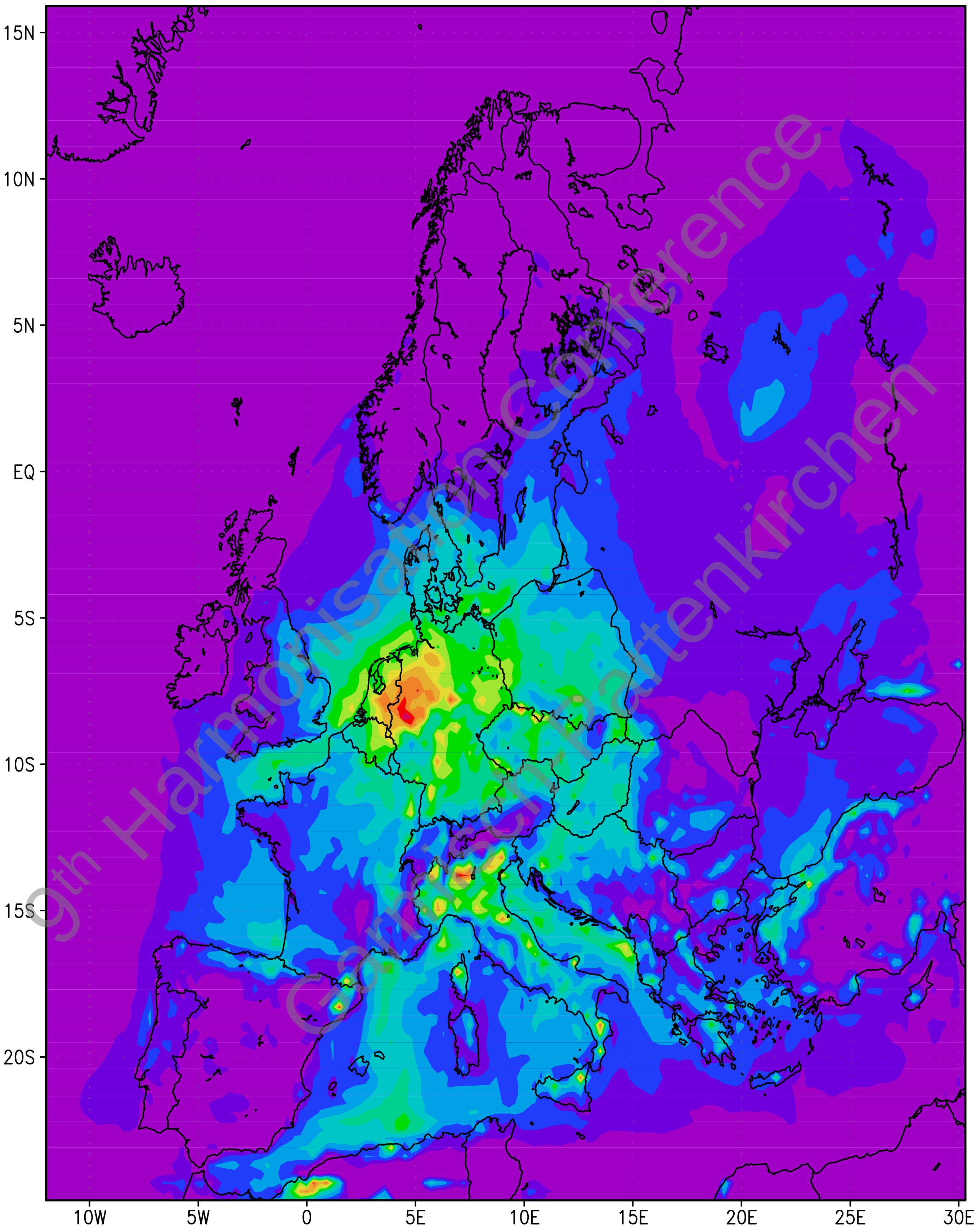
UT, change %, May 2003, ATC–ATA



GrADS: COLA/IGES 2004–05–28–11:4

Impact to the model results

NOxdep Jan 2003 1-29 ATC



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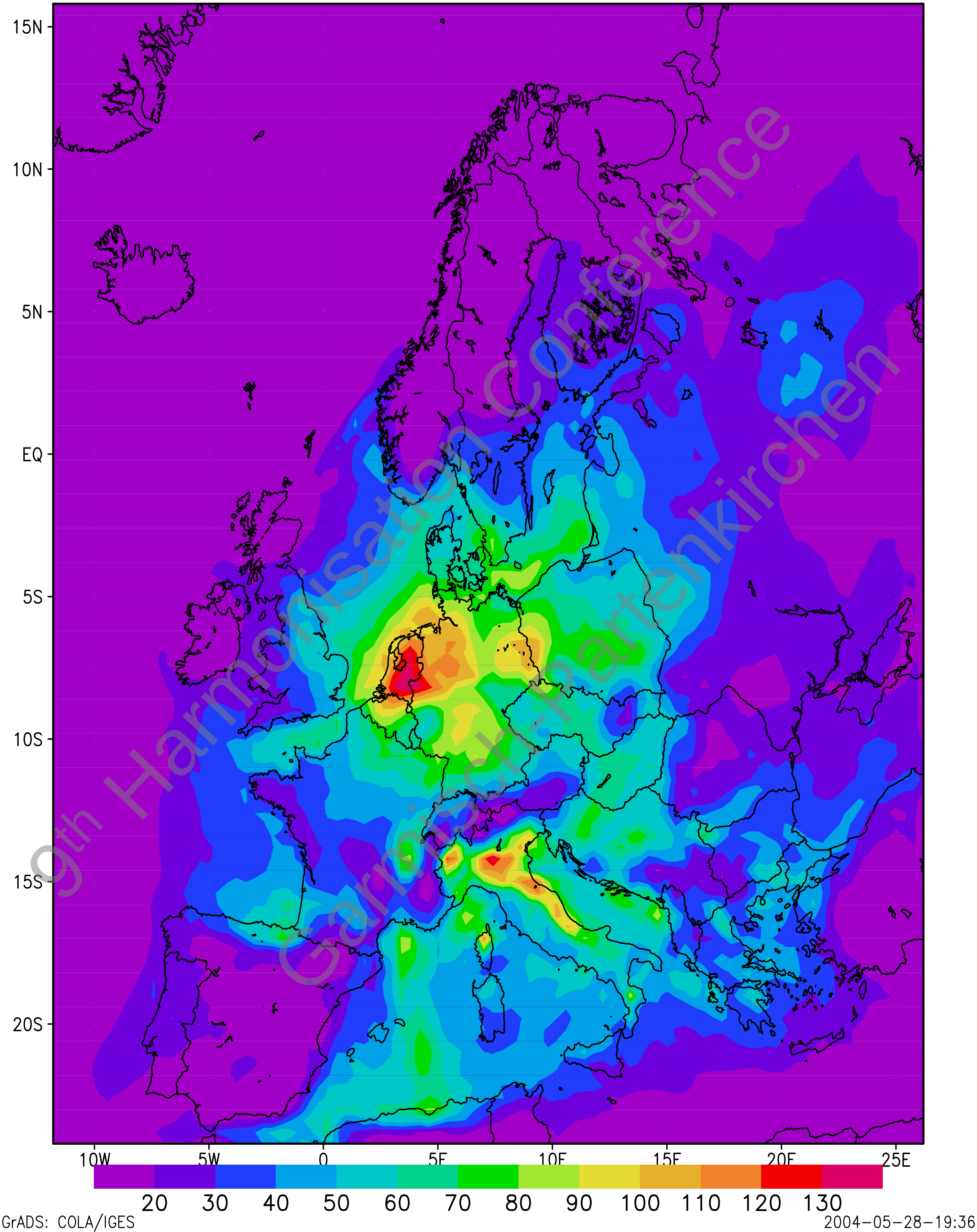
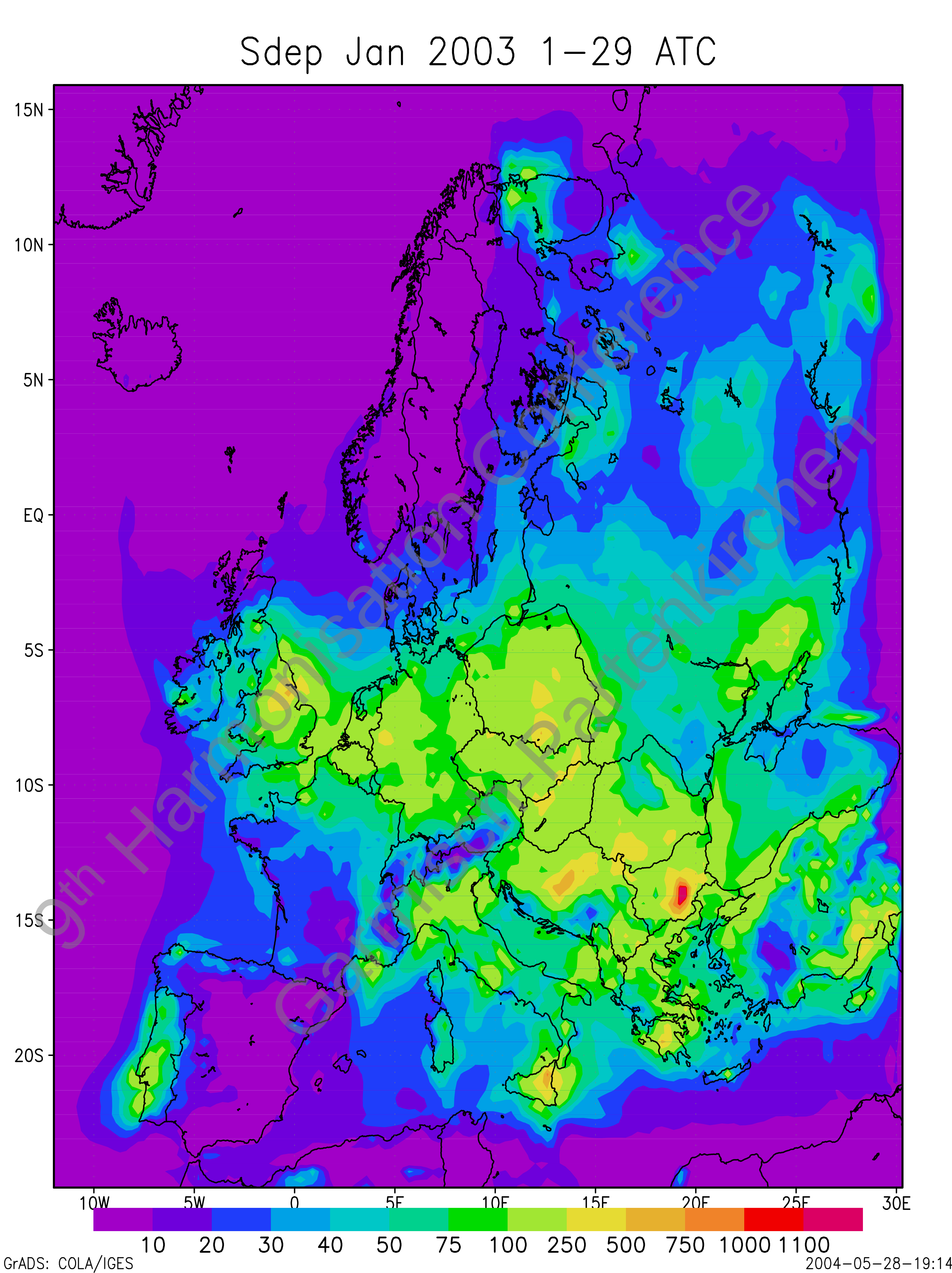
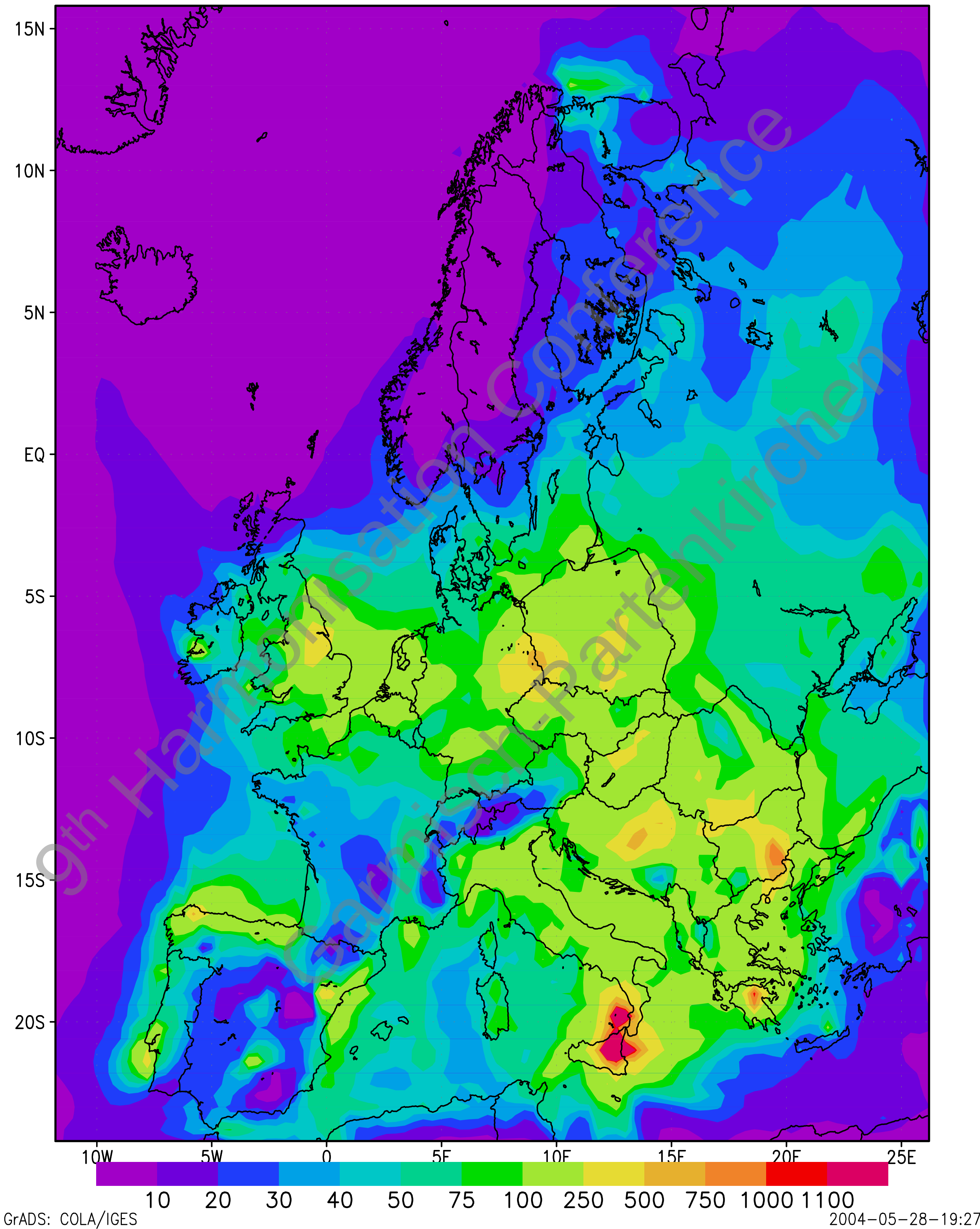
NOxdep Jan 2003 1–29 ATA

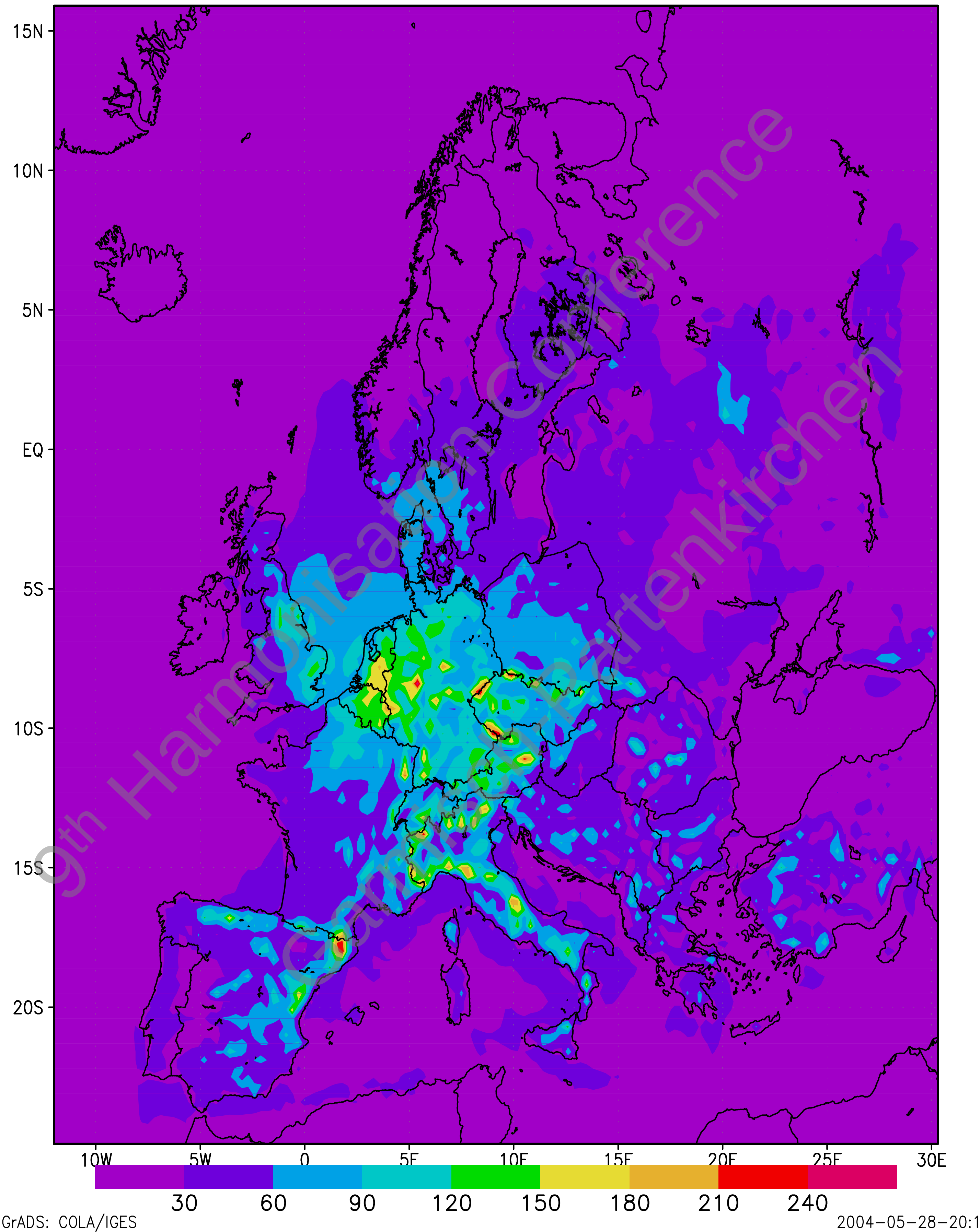


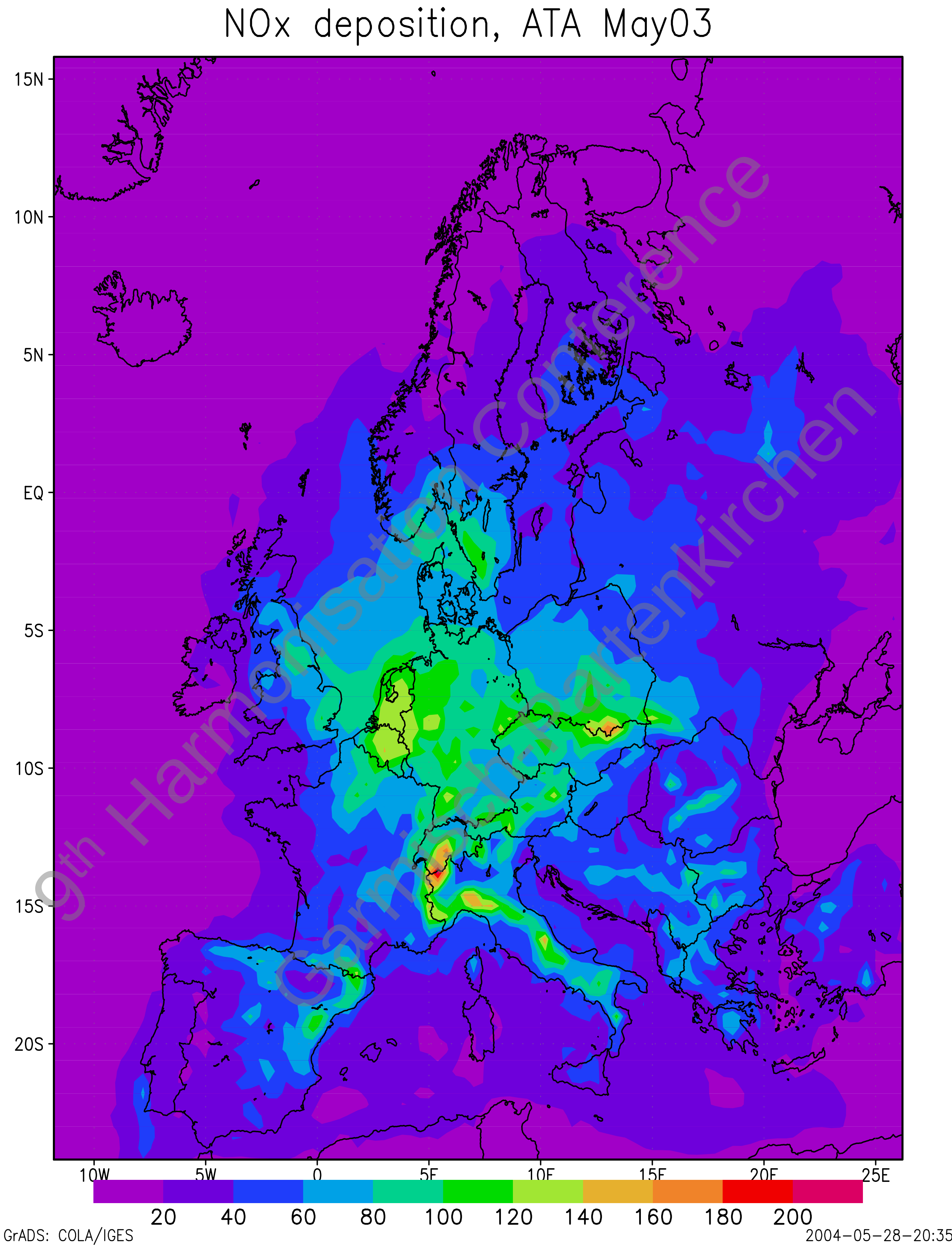

Sdep Jan 2003 1-29 ATC
15N
10N
5N
EQ
5S
10S
15S
20S
10W
5W
0
5E
10E
15E
20E
25E
30E
10 20 30 40 50 75 100 250 500 750 1000 1100
GrADS: COLA/IGES
2004-05-28-19:14

Sdep Jan 2003 1-29 ATA

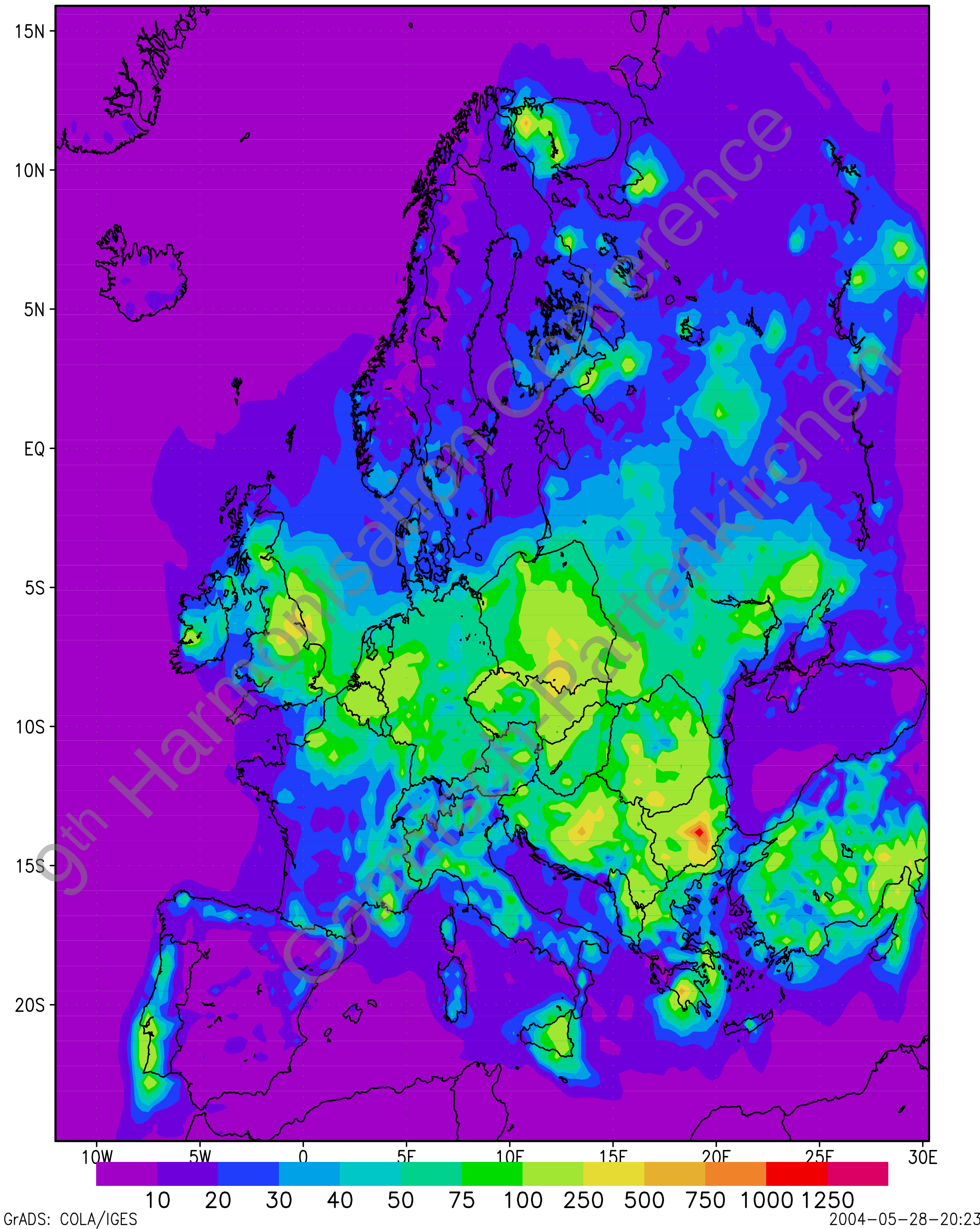


NOx deposition, ATC May03

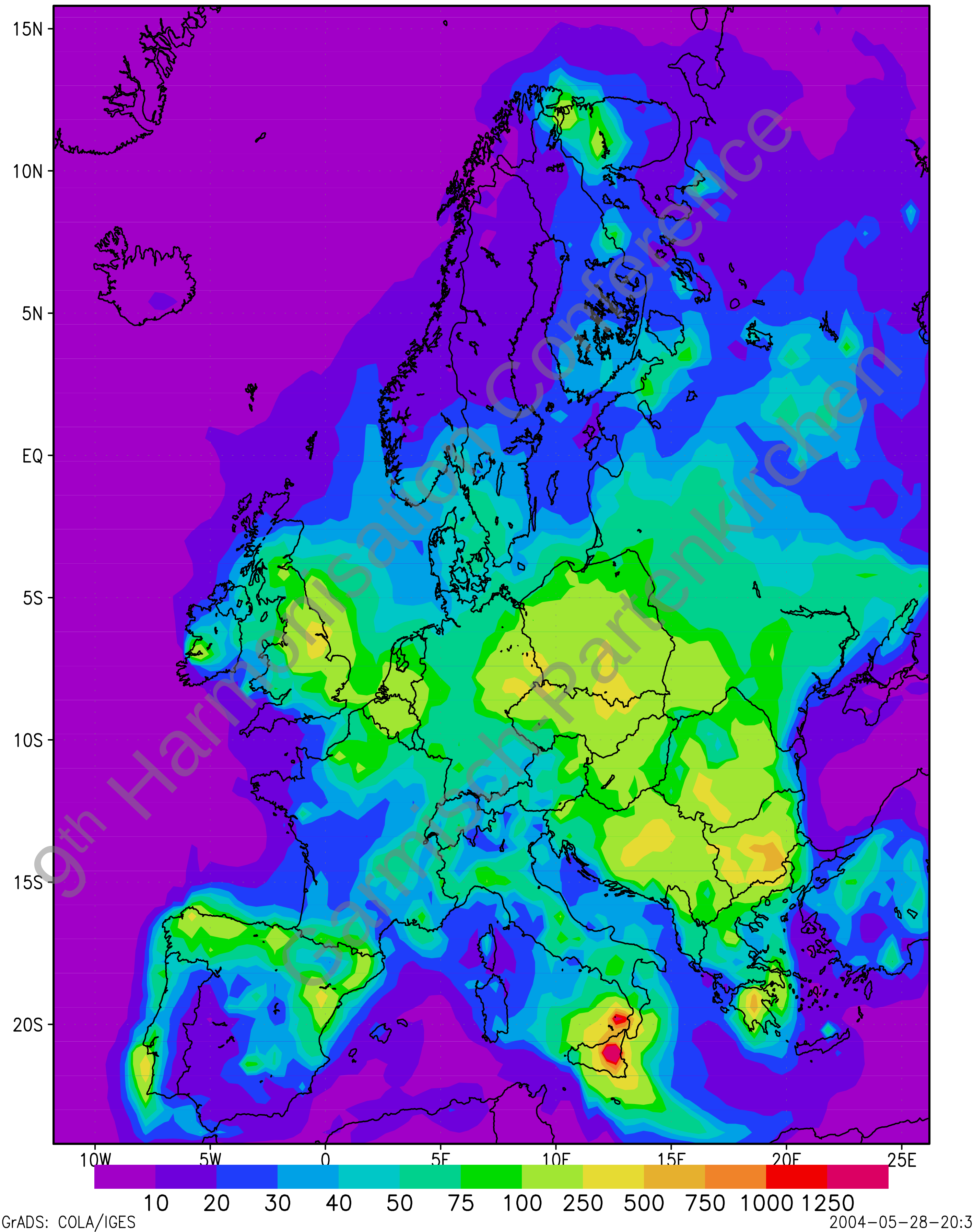



NOx deposition, ATA May03
15N
10N
5N
EQ
5S
10S
15S
20S
10W
5W
0
5E
10E
15E
20E
25E
20
40
60
80
100
120
140
160
180
200
GrADS: COLA/IGES
2004-05-28-20:35

S deposition, ATC May03



S deposition, ATA May03



Conclusions from CTM model results

- Different emission inventories -> smaller deposition in ATC
- Scandinavia: ABLH increase by 50-250 m -> smaller concentrations
- finer scale structure
- Jan: general precipitation decrease in Central Europe, increase in North-Eastern areas (up to 50 %) and over mountains; increase in convective rain -> respective changes in wet deposition.
- May: Increased Prec over Atlantic, in East; decreased in C-Europe and Scandinavia
- %-month Prec decrease by 5-10 % over the Baltic Sea
- u* decrease in Scandinavia -> vd decrease
- local changes in q2,clf, uabs, udir -> chemistry
- t* , 1/L increase over Finland
- Fine-scale structure - high depositions near the sources slightly shorter transport distances, in Finland and over the Baltic Sea use of the new data will reduce calculated deposition estimates in winter

Conclusions from met. model fields

- Theoretical, beautiful, logarithmic profiles vs reality
- sounding is a point measurement
- every cloud contains a small inversion
- When the predicted T_s was 10^{o}C too high during one inversion case (Minna Rantamäki) for the reason it was proposed that the evaporation from the cold surfaces was too high
- the diurnal cycle of the temperature is strongly underestimated in the forecasts, still in the RCR version. During the daytime the temperatures are too low and in the night-time too warm. The same is also seen in the two meter humidity values. This feature is most prominent in winter and in spring, however, well seen also in summer.
- -> Strong inversions, important for air pollution studies, are difficult to forecast. In spring the difficulties are often during the day, when the predicted temperature is too cold.