COSMO radiation scheme

Implementation of a revised ice cloud optical properties in COSMO-EU

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thanks to Davide Cesari (ARPA-SIM), Jürgen Helmert, Axel Seifert, Bodo Ritter (DWD)

Aim of the study

- Verify the sensitivity of GCM and NWP models to changes in the cloud-radiation interaction and gaseous absorption

Focus on...

- Sensitivity of the COSMO-EU model to a new parameterization of ice cloud radiative effects based on the newest ice crystals optical properties

Outline

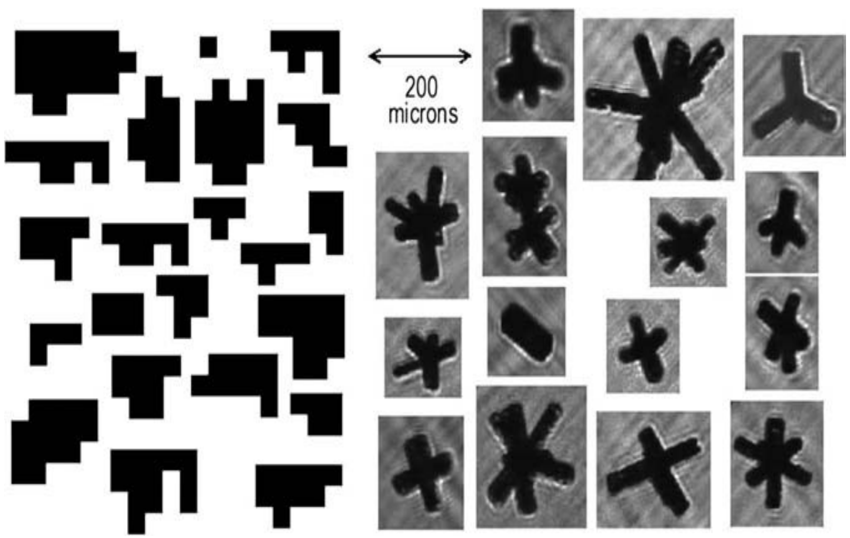
- Ice clouds optical properties: facts
- Ice clouds parameterization in COSMO: present vs revised scheme
- Model sensitivity tests
- Conclusions and suggestions

Facts about ice clouds optical properties in NWP and GC models

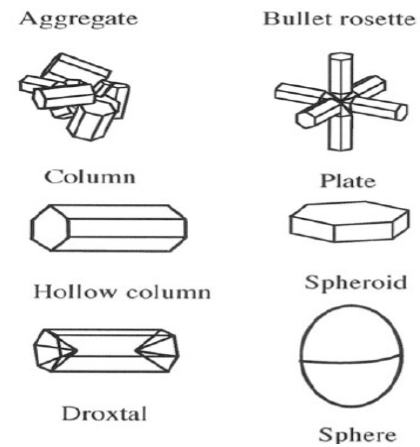
- Cirrus play an important role in energy balance of earth-atmosphere system through their interaction with SW and LW radiation (Liou, 1986; Ramaswamy and Ramanathan, 1989; Lynch et al., 2002)
- Treatment of ice particle size and habit may have a significant impact on climate change (Kristjansson et al., 2000) and wrong assumption about the crystal habit can lead to considerable errors in energy budget (Wyser 1999)
- In situ measurements of crystals in cirrus clouds are technically difficult (Gayet et al., 2002)
- Relation of crystal size and shape to the environment is not well understood (Edwards et al., 2006) and can limit the prediction of cirrus cloud feedback on climate (Stephens et al., 1990)

Ice clouds optical properties modeling

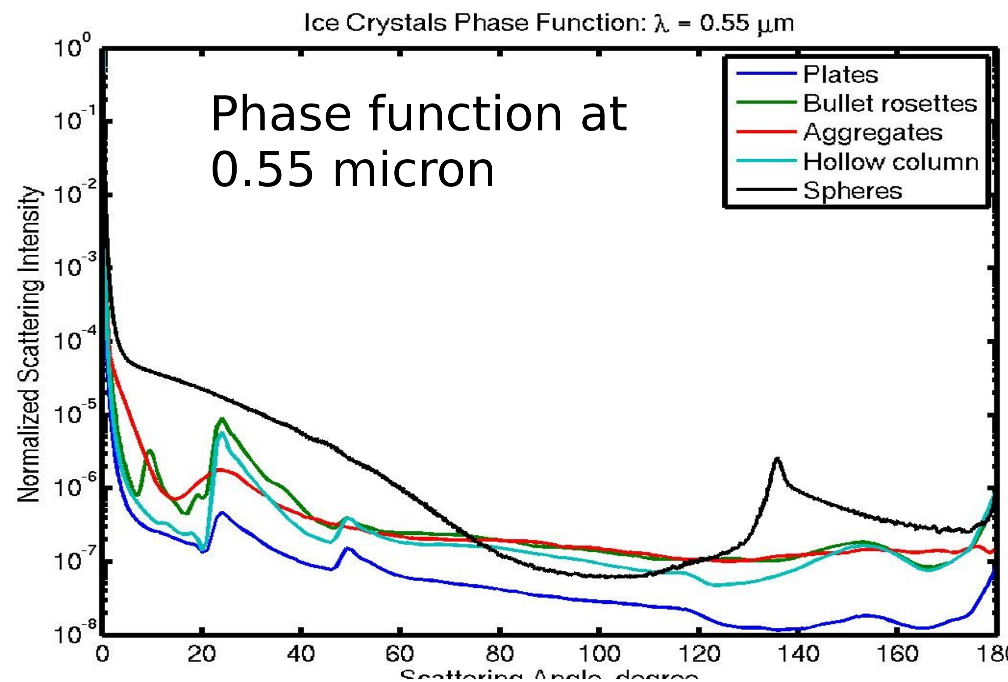
Until recently GCM simply assumed that ice crystals were spherical with size characterized by effective radius, but slightly larger than cloud droplets



Comparison between PMS 2D-C probe and CPI images (from Lawson et al., 2006)



Simulated ice crystals (Yang et al, 1998)



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High clouds optical properties in COSMO: present parameterization

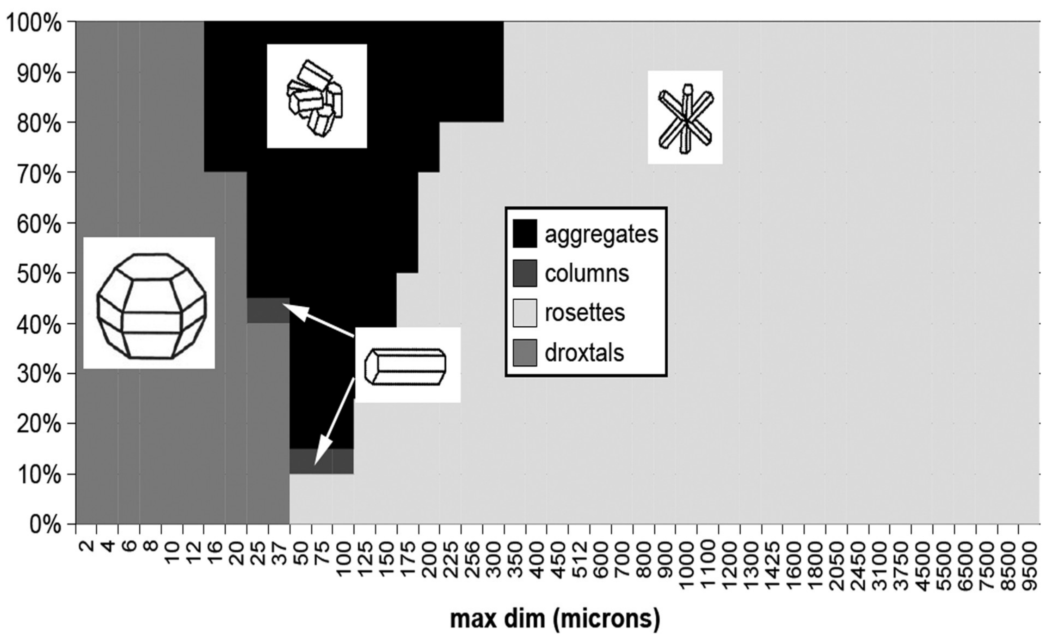
- Adapted from Rockel et al., 1991: Single Scattering Albedo (ω), Asymmetry Parameter (g) and Mass Extinction Coefficient (K_{ext}, m^2/Kg) are parametrized as function of IWC
  - $\omega = k_1 + k_2 * \ln(IWC)$
  - $g = k_3 + k_4 * \ln(IWC)$
  - $K_{ext} = k_5 + \frac{k_6}{k_7 + k_8 * IWC}$
- Ice crystals optical properties derived from ice spheres; high spectral properties averaged over broad spectral bands. Data from 40 PSDs covering a range of effective radii from 0.375 to 80 microns

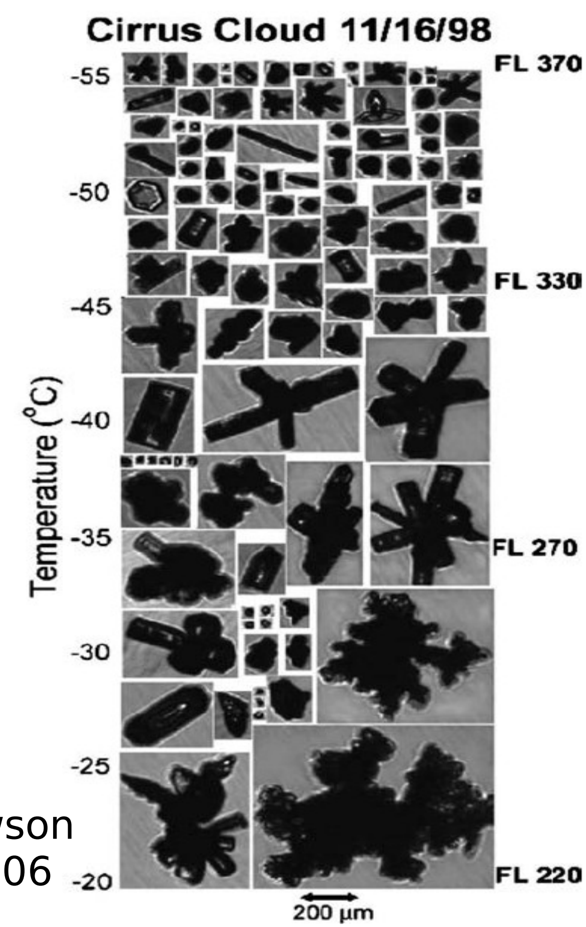
A parameterization for mid-lat cirrus clouds

ice habits mixture

- Optical properties of ice cloud could be better represented by mixtures of different habits (Key et al., 2002) --> little information from field exp.
- Our attempt: mixture of 4 ice crystals based on Lawson et al, 2006 (single scattering data from Ping Yang's data-set):

Mass fraction by habit





from Lawson et at., 2006

A parameterization for mid-lat cirrus clouds

Bulk optical properties parameterization

- Monochromatic optical properties are averaged over the 8 COSMO-LM broad spectral bands
- Broad band optical properties parametrized as function of PSD's effective dimension De:

$$g = a_0 + a_1 D_e + a_2 {D_e}^2 + a_3 {D_e}^3$$

$$\omega = b_0 + b_1 D_e + b_2 {D_e}^2 + b_3 {D_e}^3$$

$$k = c_0 + c_1 \frac{1}{D_e} + c_2 \frac{1}{{D_e}^2}$$

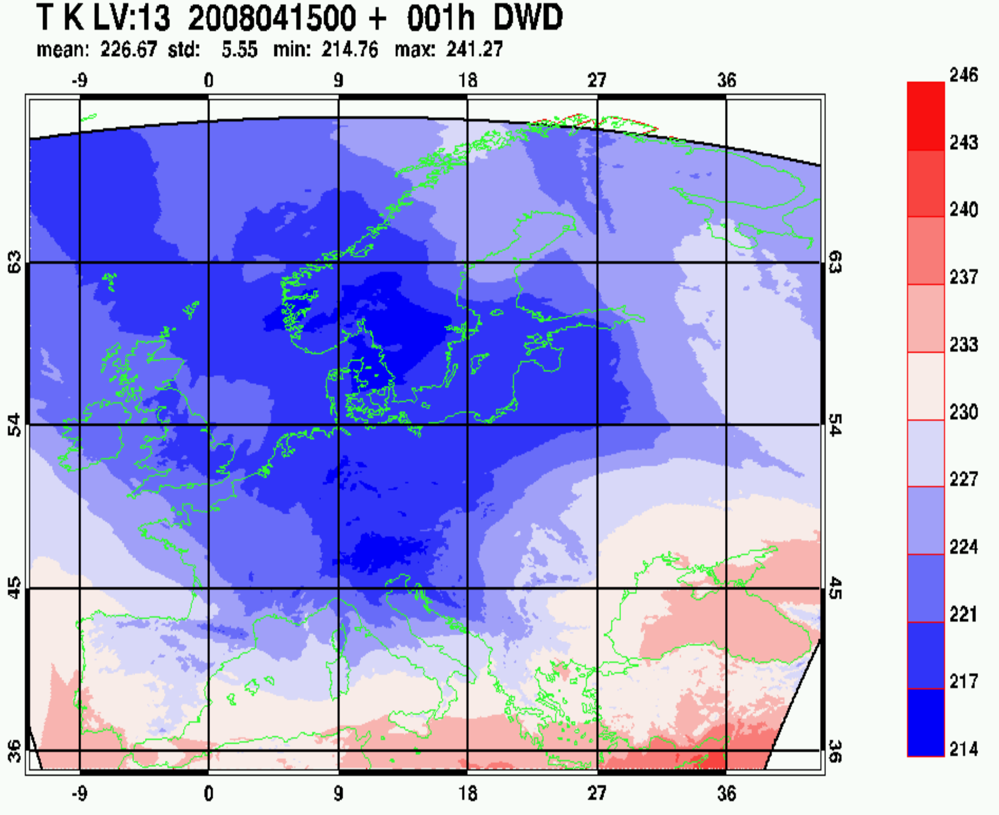
$$De = \frac{3}{2} \frac{\sum_{h=1}^{4} \left[\int V_h(D) n(h,D) dD \right]}{\sum_{h=1}^{4} \left[\int A_h(D) n(h,D) dD \right]}$$

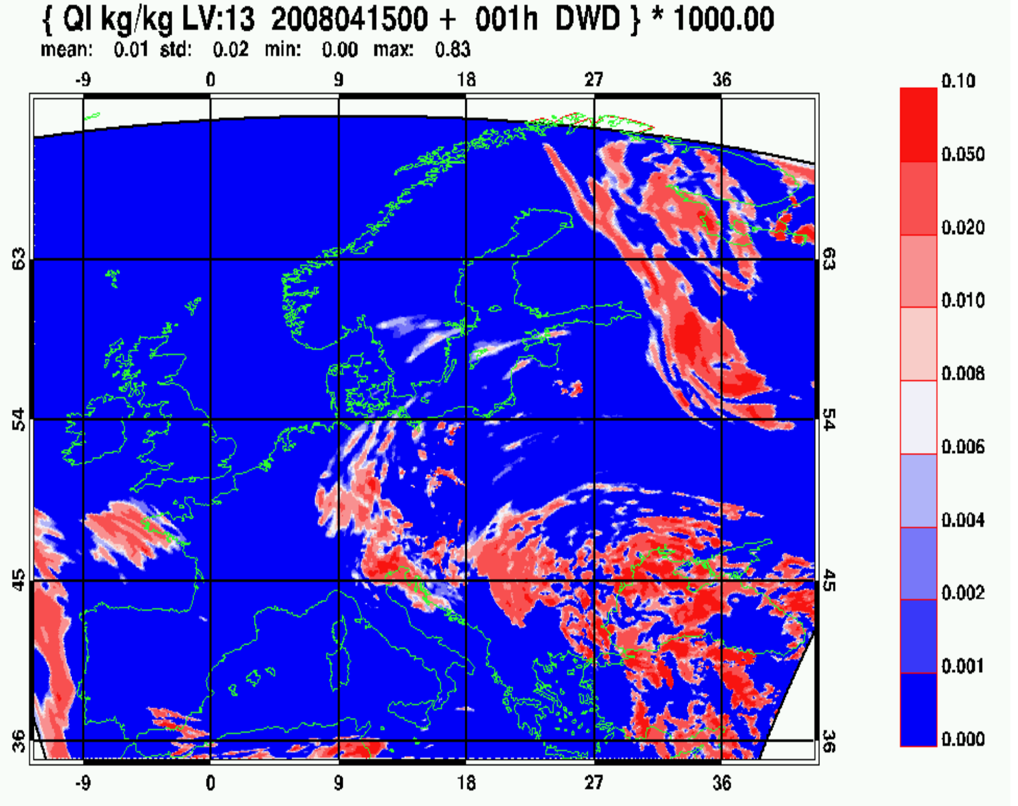
A parameterization for mid-lat cirrus clouds

Effective dimension parameterization

- The effective dimension of the PSD has been parametrized as function of temperature of the layer and IWC

$$De = c_0 + c_1 T + c_2 \log_{10}(IWC) + c_3 T^2 + c_4 \left[\log_{10}(IWC)\right]^2$$





A parameterization for mid-lat cirrus clouds

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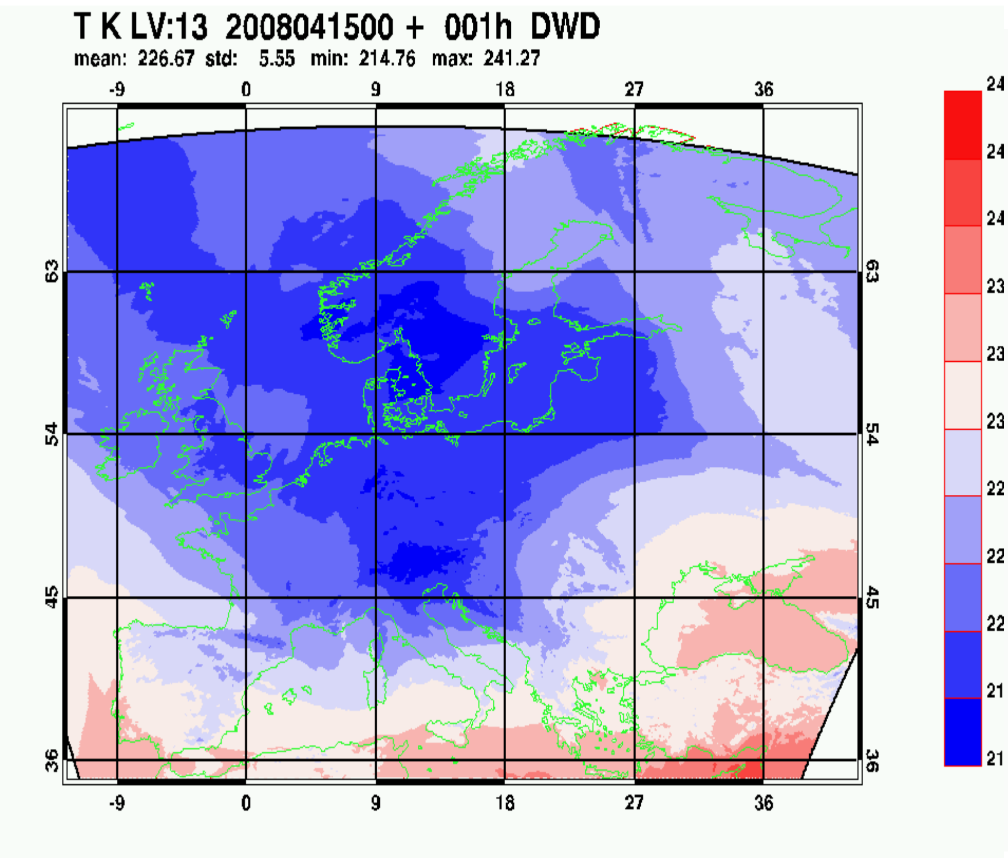

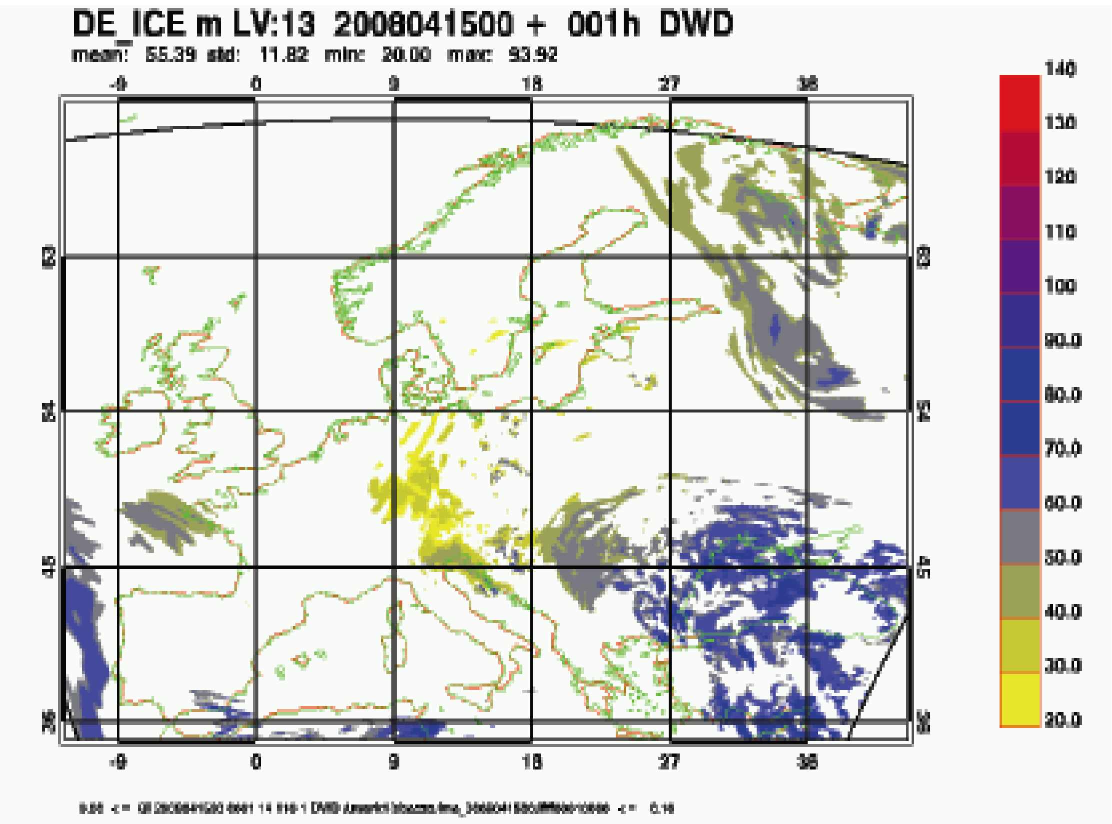

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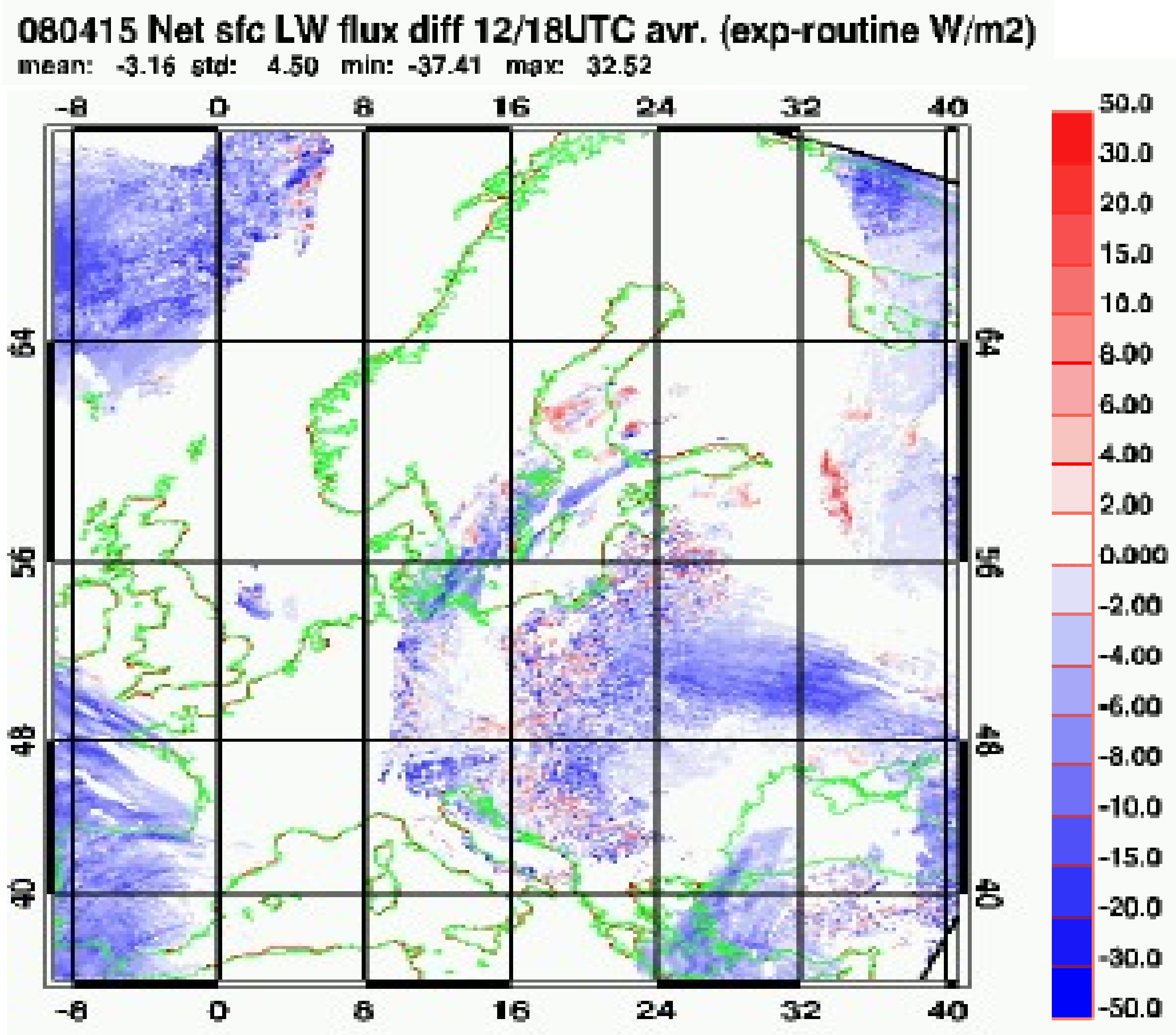
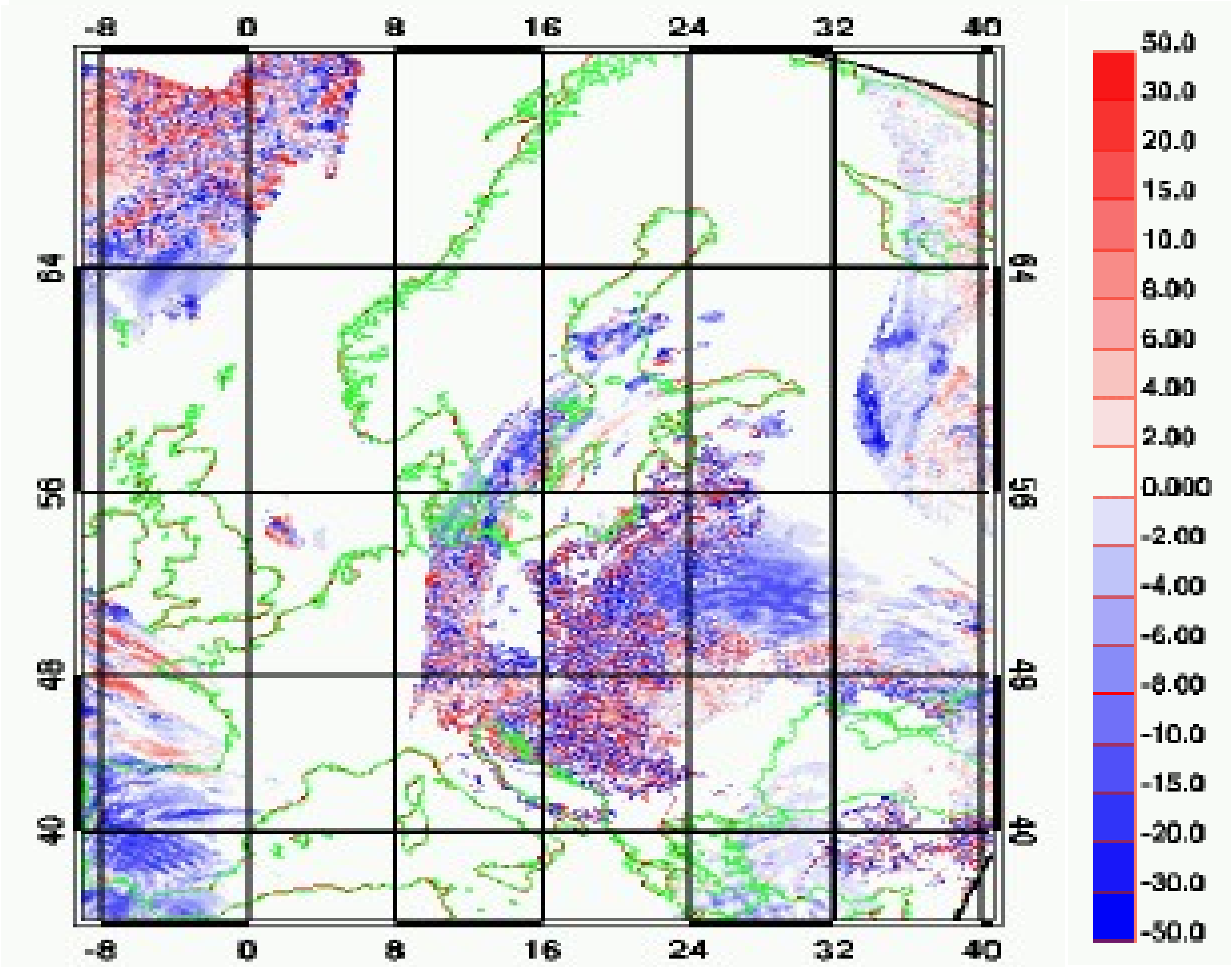


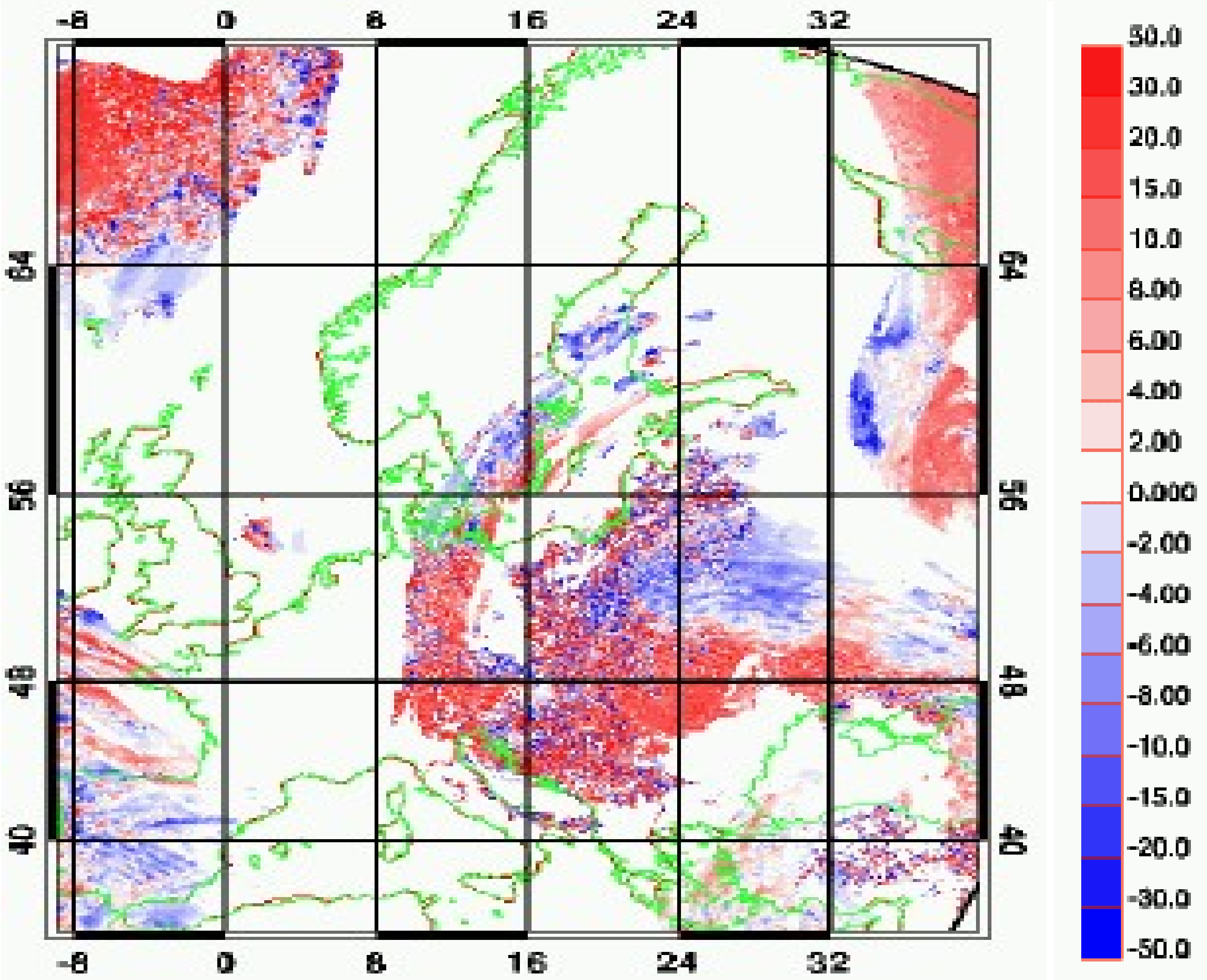
080415 Net sfc LW flux diff 12/18UTC avr. (exp-routine W/m2)
mean: -3.16 std: 4.50 min: -37.41 max: 32.52
-8
0
8
16
24
32
40
64
56
48
40
50.0
30.0
20.0
15.0
10.0
8.00
6.00
4.00
2.00
0.000
-2.00
-4.00
-6.00
-8.00
-10.0
-15.0
-20.0
-30.0
-50.0

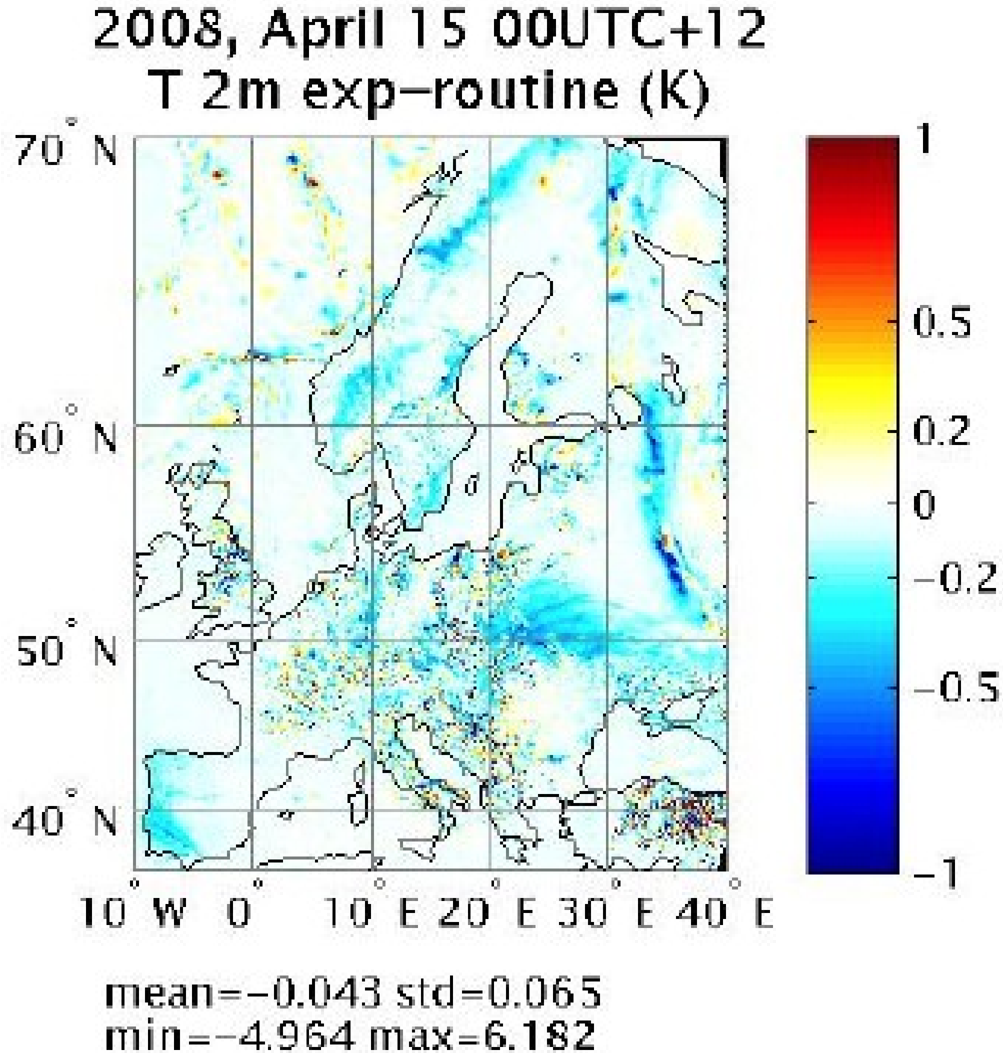
080415 Net sfc SW flux diff 12/18UTC avr. (exp-routine W/m2)

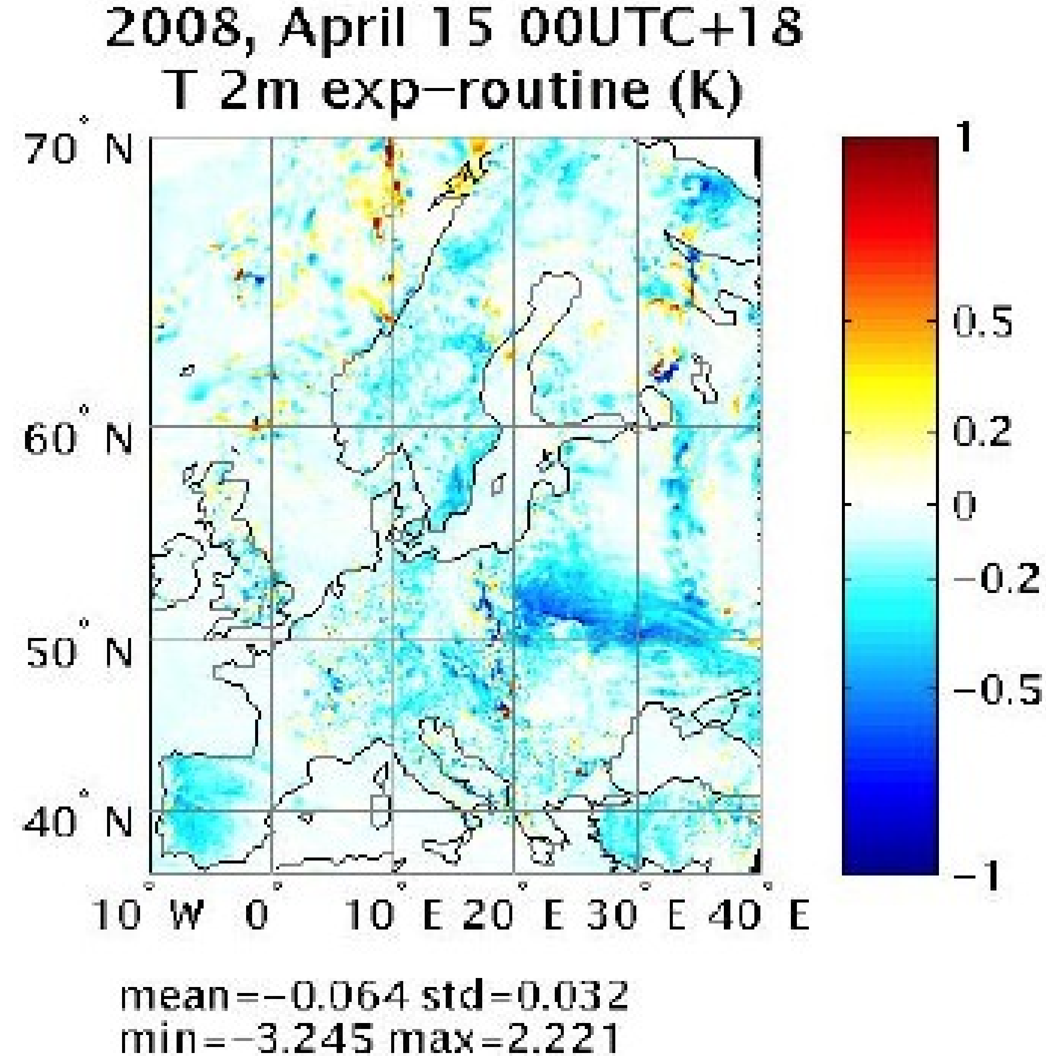
mean: -1.55 std: 12.64 min: -130.12 max: 122.94



080415 Net TOA SW flux diff; 12/18UTC avr. (exp-routine W/m2)
mean: 4.69 std: 13.32 min: -98.36 max: 127.36





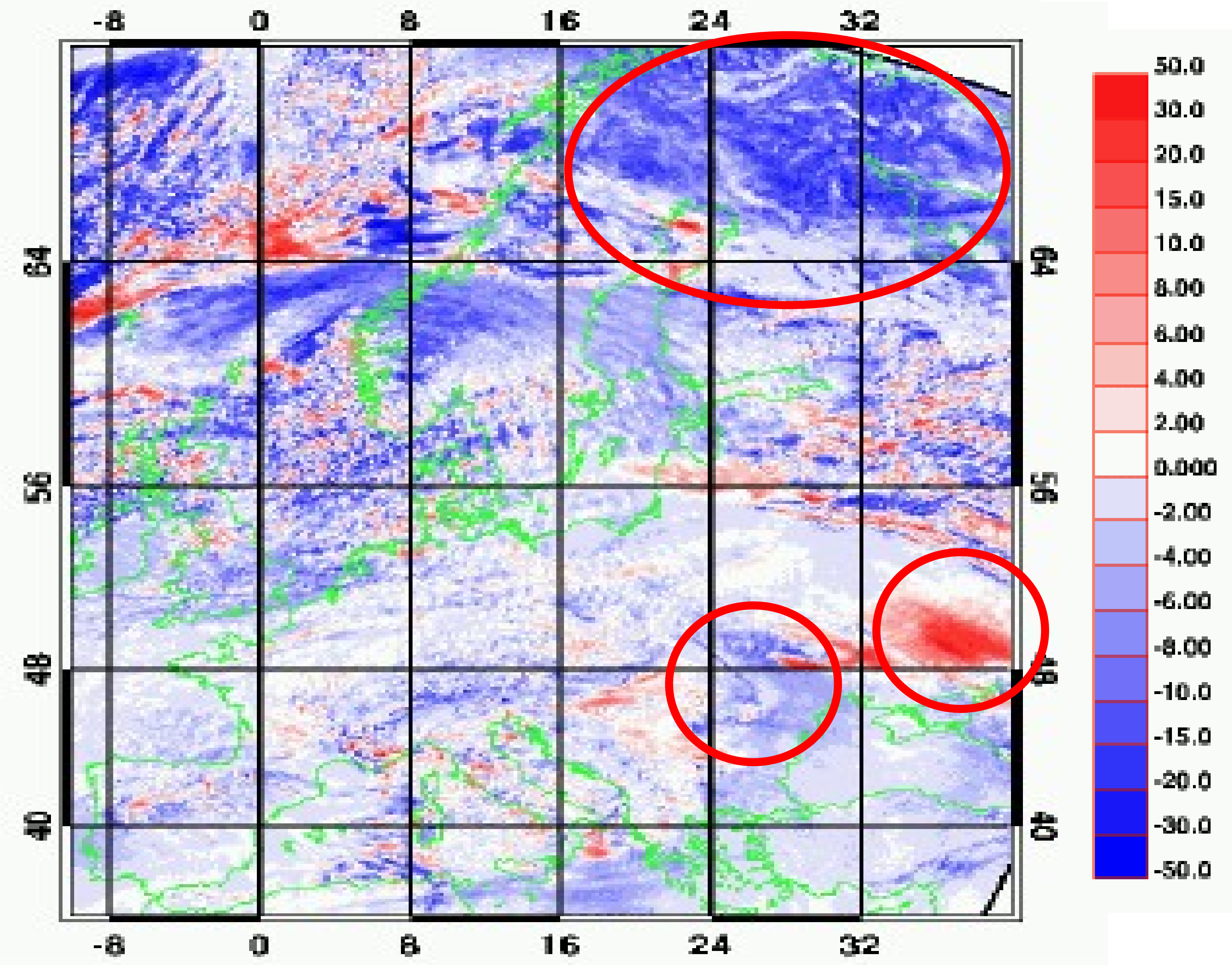


mean T 2m dif. & RMS (near. grid point)
exp−obs=−0.419 ; rms exp=2.899
rout−obs=−0.362 ; rms rout=2.896

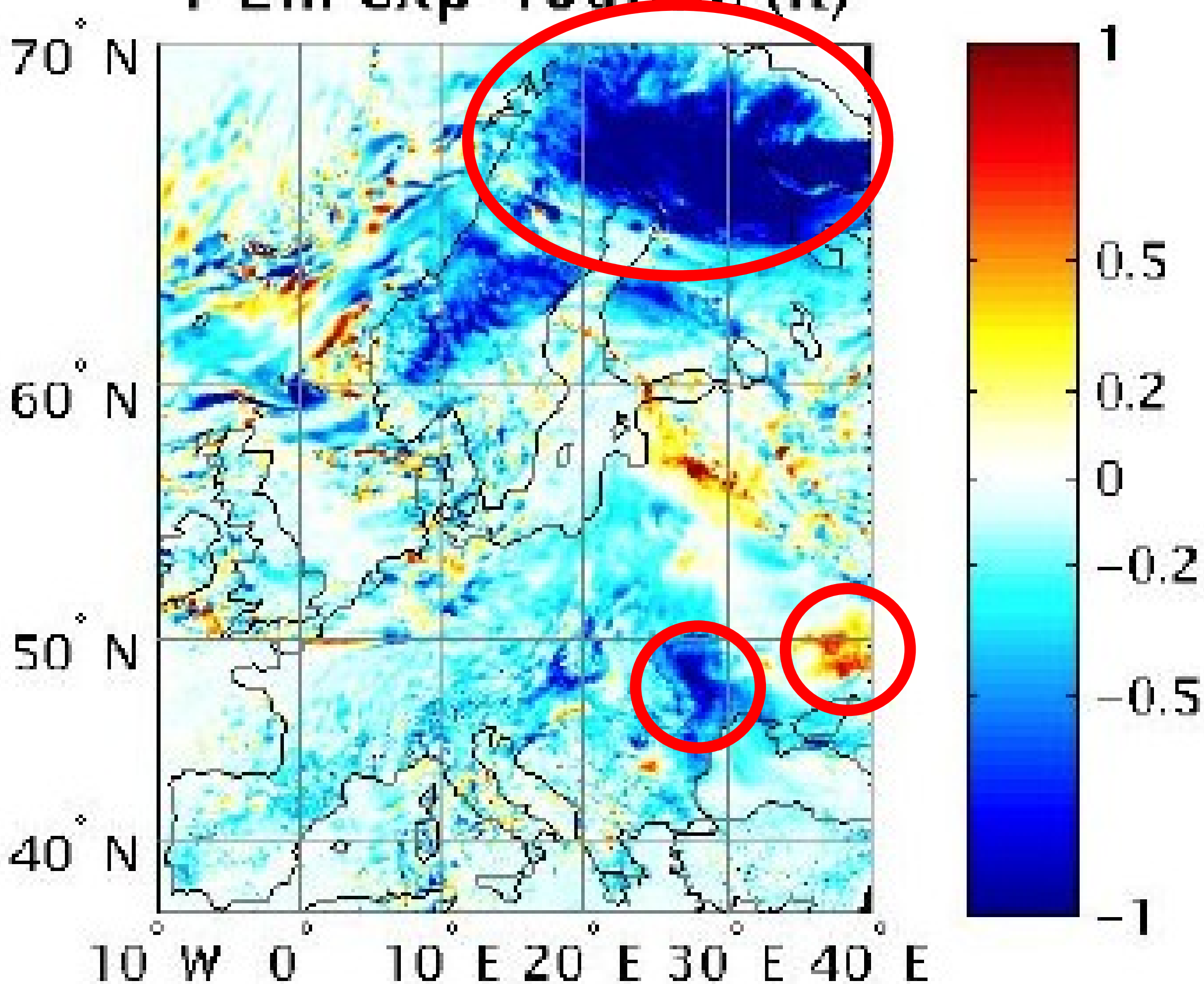
mean T 2m dif. & RMS (near. grid point)
exp−obs=0.108 ; rms exp=2.449
rout−obs=0.193 ; rms rout=2.457

070116+48 Net sfc LW flux diff; 12/24UTC avr. (exp-routine W/m2)

mean: -1.51 std: 5.04 min: -48.02 max: 45.35

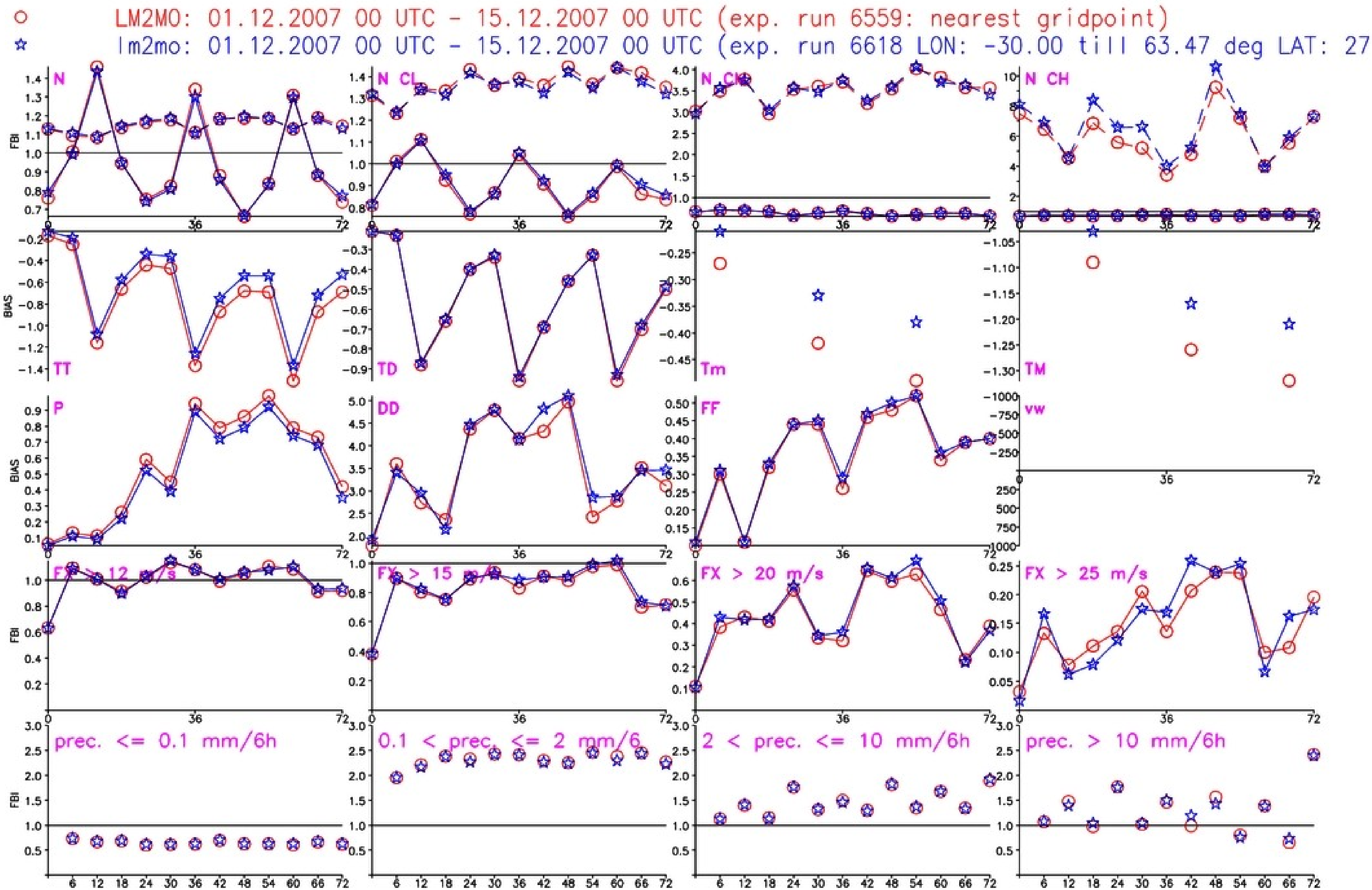


2007, January 16 00UTC+48
T 2m exp−routine (K)



mean=−0.118 std=0.085
min=−4.367 max=4.497

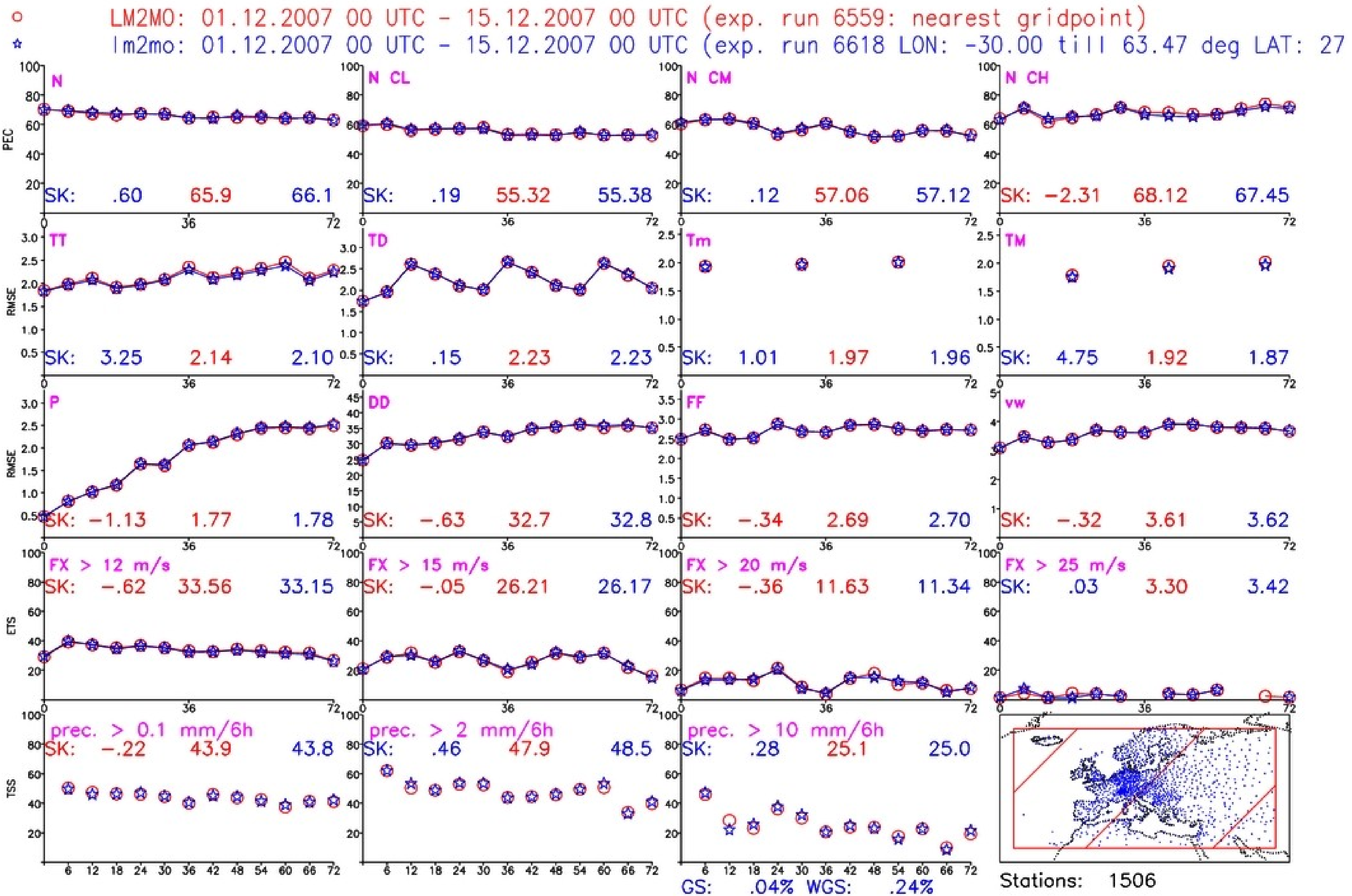
mean T 2m dif. & RMS (near. grid point)
exp−obs=−0.435 ; rms exp=2.558
rout−obs=−0.303 ; rms rout=2.550



Results of verification of forecasts for local weather elements at surface weather stations

frequency bias for cloud covers (–: 0-2/8, – –: 7-8/8) and precipitation T-1 till T, mean error for other elements

all stations



Results of verification of forecasts for local weather elements at surface weather stations

TSS for precipitation, ETS for gusts, percent correct for cloud cover, RMSE for other elements

all stations

Outline

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Ice cloud parameterization

conclusions

- The new parameterization accounts for variation of size and habit composition with temperature and IWC
- In absence of prognostic ice size information, a De parameterization must be used
- The net effect of the new clouds is a reduction of the incoming LW and SW radiation at the surface (about 15-20 W/m2 on average over a 6-12 hours period)
- Sensitivity tests show a tendency of a cooling effect (in average of 0.1-0.2 K, locally up to 2-4 K)

Bozzo, A., T. Maestri, R. Rizzi, and E. Tosi (2008), Parameterization of single scattering properties of mid-latitude cirrus clouds for fast radiative transfer models using particle mixtures, Geophys. Res. Lett., 35, L16809.

Ice cloud parameterization

further improvements and suggestions

- Sensitivity of ice clouds optical properties to mixture composition and tests against hyperspectral ariborne and satellite observations are subject of ongoing researches
- The dependence of the effective dimension of the ice crystals on temperature and IWC should be consistent with the microphysics of COSMO model
- The presence of radiative biases in clear sky conditions should be investigated in order to ensure the net effect of the revised cloud ice scheme

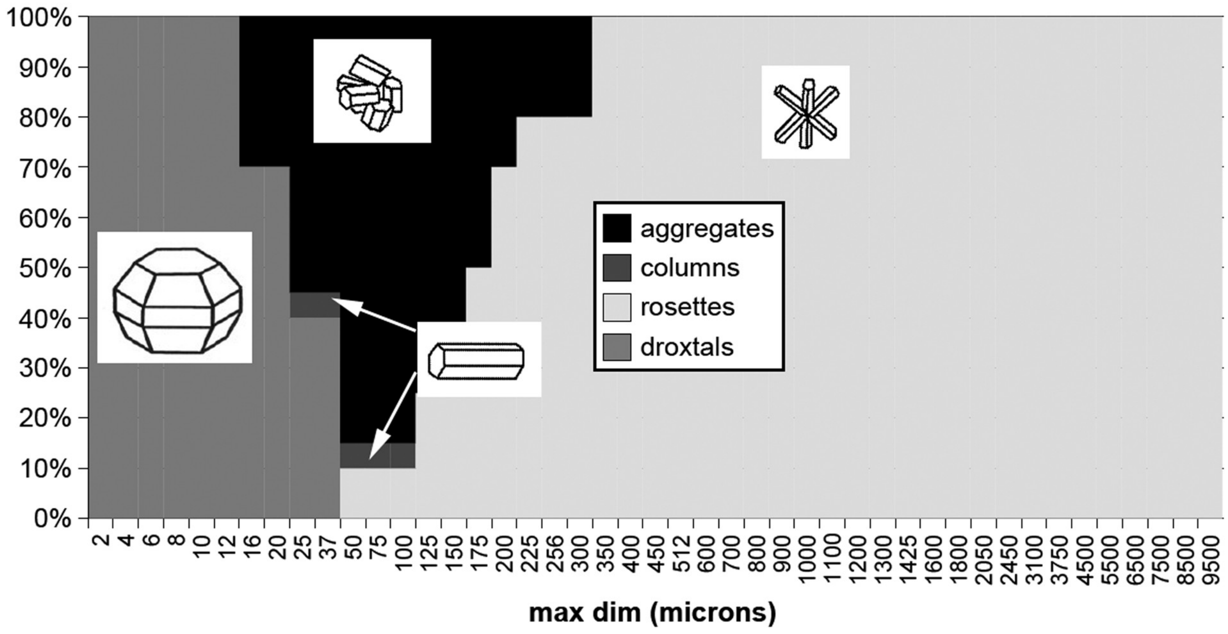

Thank you for your attention

A parameterization for mid-lat cirrus clouds

ice habits mixture

- Optical properties of ice cloud could be better represented by mixtures of different habits (Key et al., 2002) --> little information from field exp.
- Our attempt: mixture of 4 ice crystals based on Lawson et al, 2006 (single scattering data from Ping Yang's data-set):

Mass fraction by habit

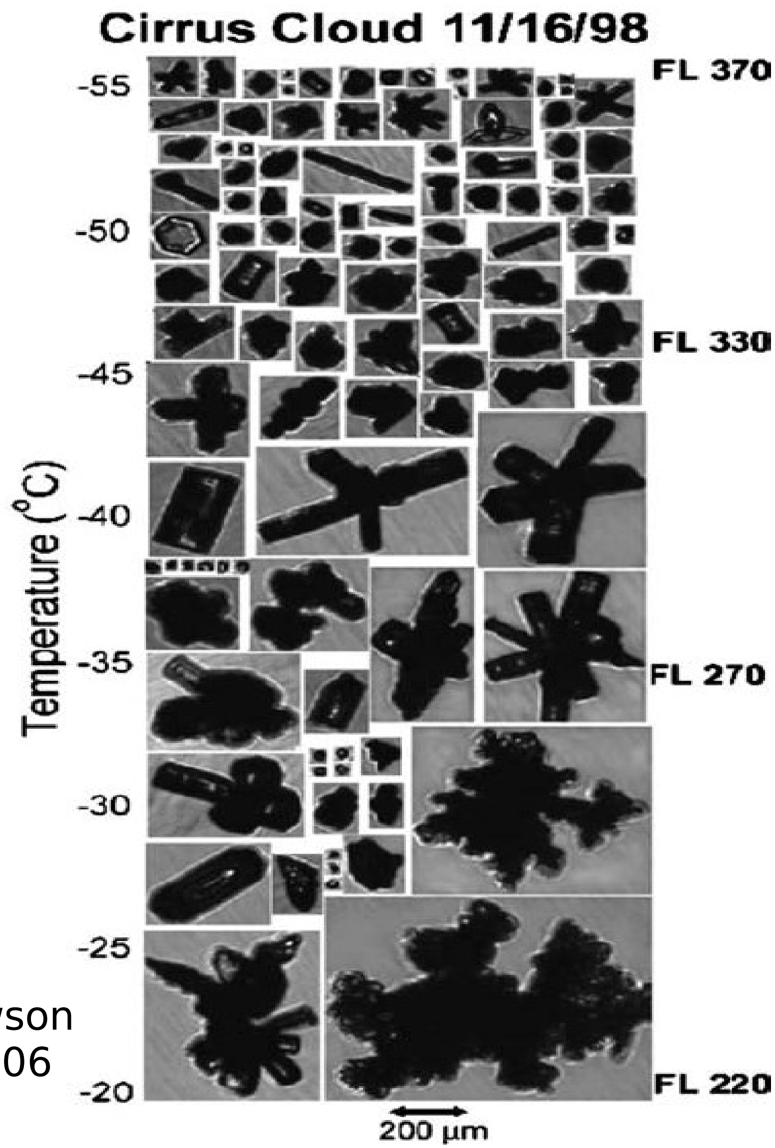


The optical properties for each size bin is computed as weighted sum of the properties of the habits (Key et al., 2002; Baum et al., 2005 I and II)

A parameterization for mid-lat cirrus clouds

Bulk optical properties parameterization

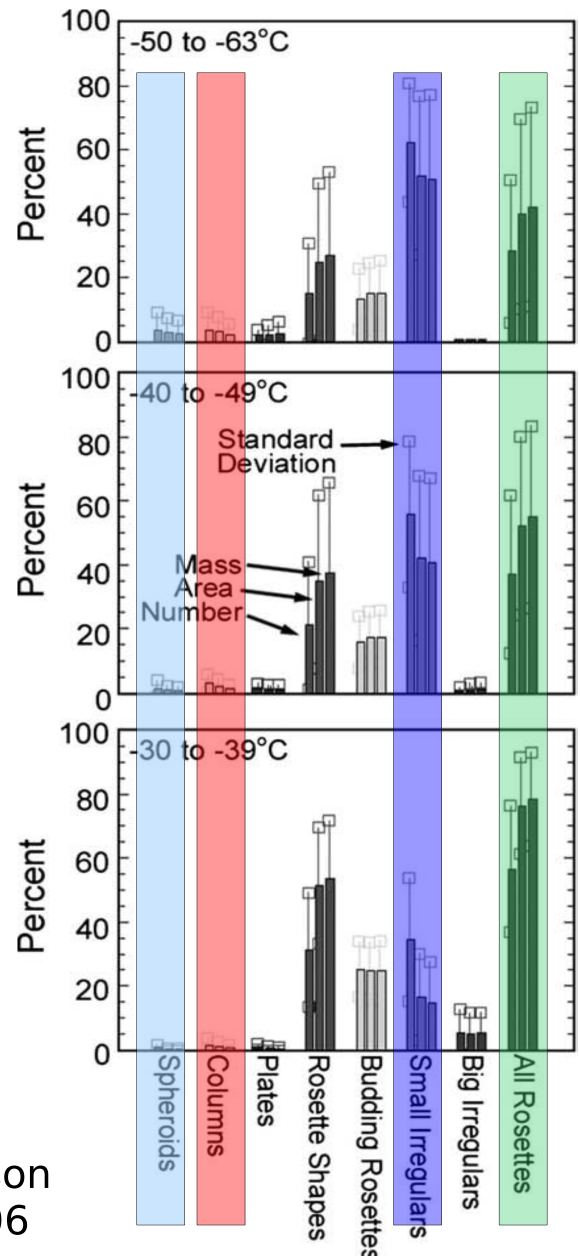
- The “MIXED” optical properties are integrated over 891 theoretical modified gamma-type PSDs representative of measured PSDs of mid-latitude cirrus clouds (Baum et al., 2005; Heymsfield et al., 2004)
- Data are taken from 3 field campaign FIRE I, FIRE II and ARM
- Cirrus clouds properties: observed habits distribution -->



from Lawson et at., 2006

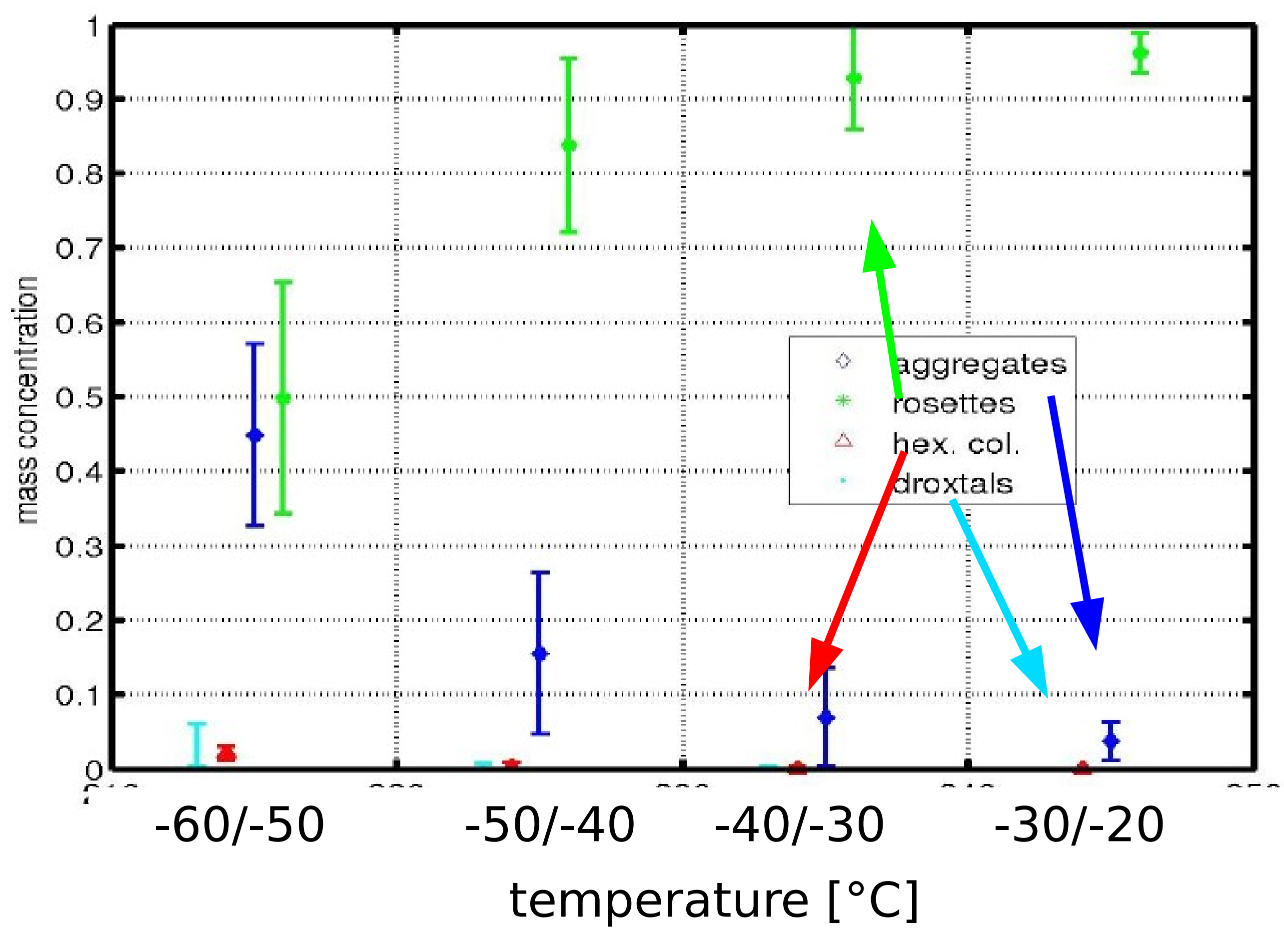
A parameterization for mid-lat cirrus clouds

habits distribution



from Lawson et at., 2006

HABIT COMPOSITION (MASS FRACTION)



A parameterization for mid-lat cirrus clouds

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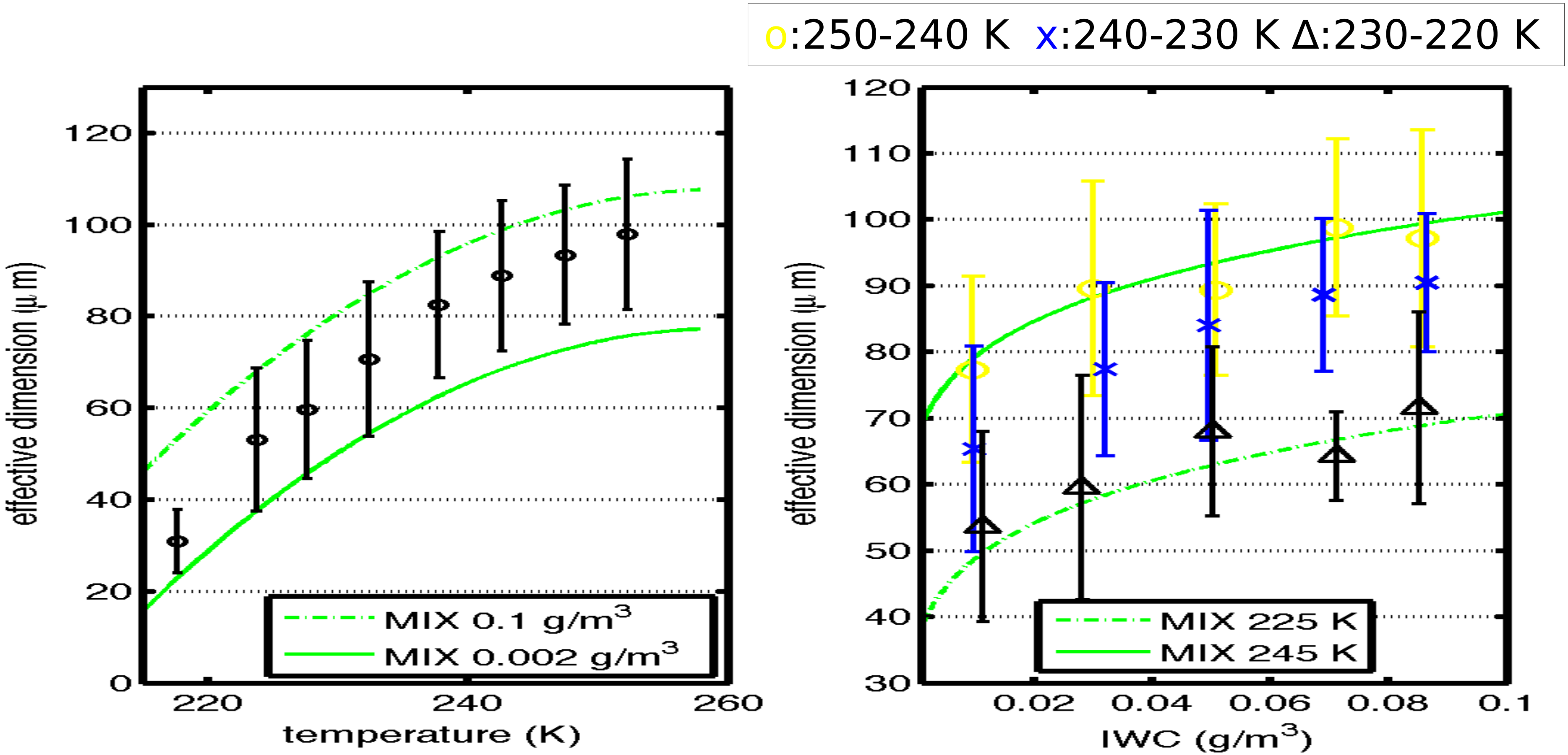
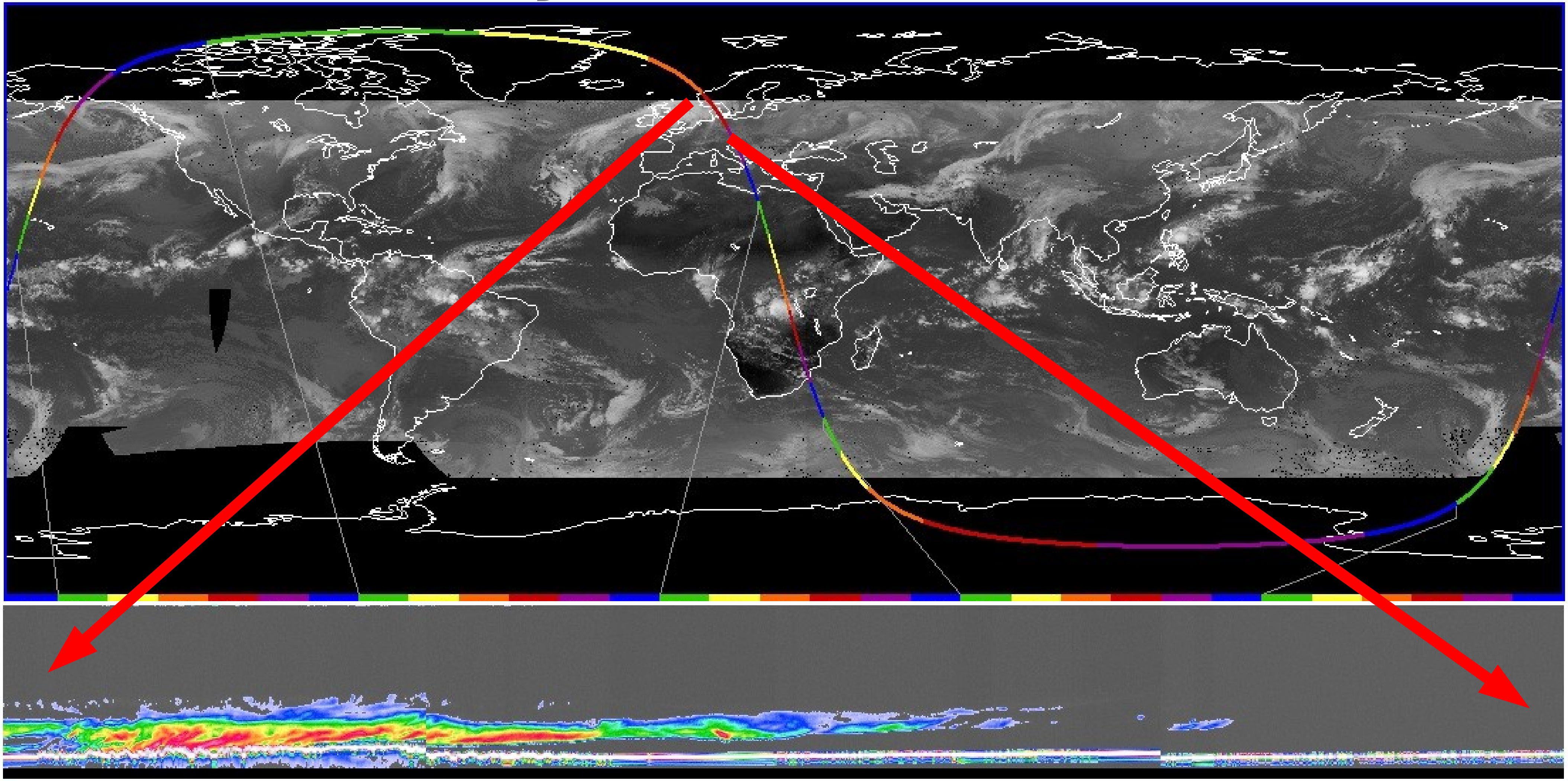


Case study no 2 (to be performed)



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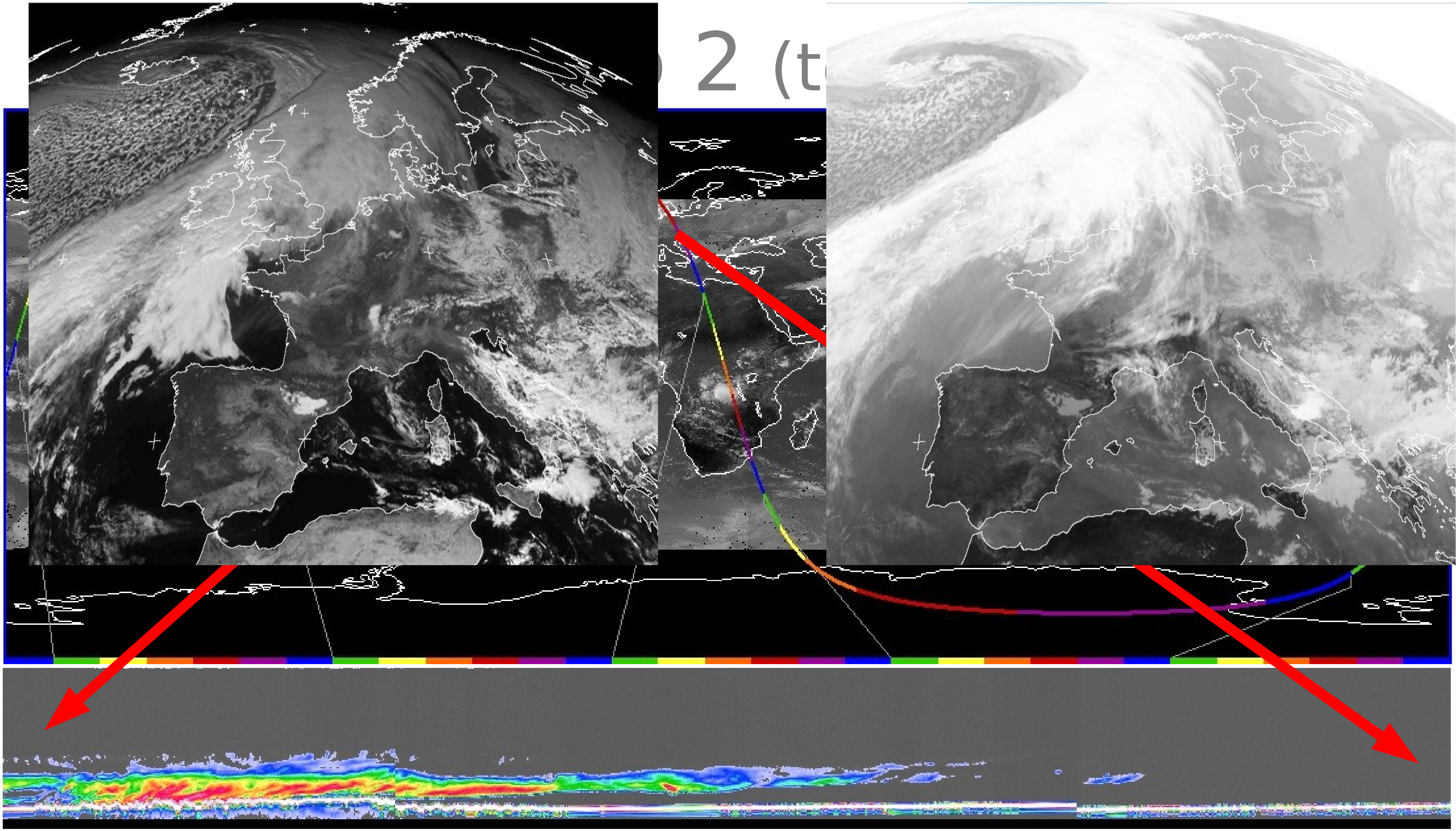
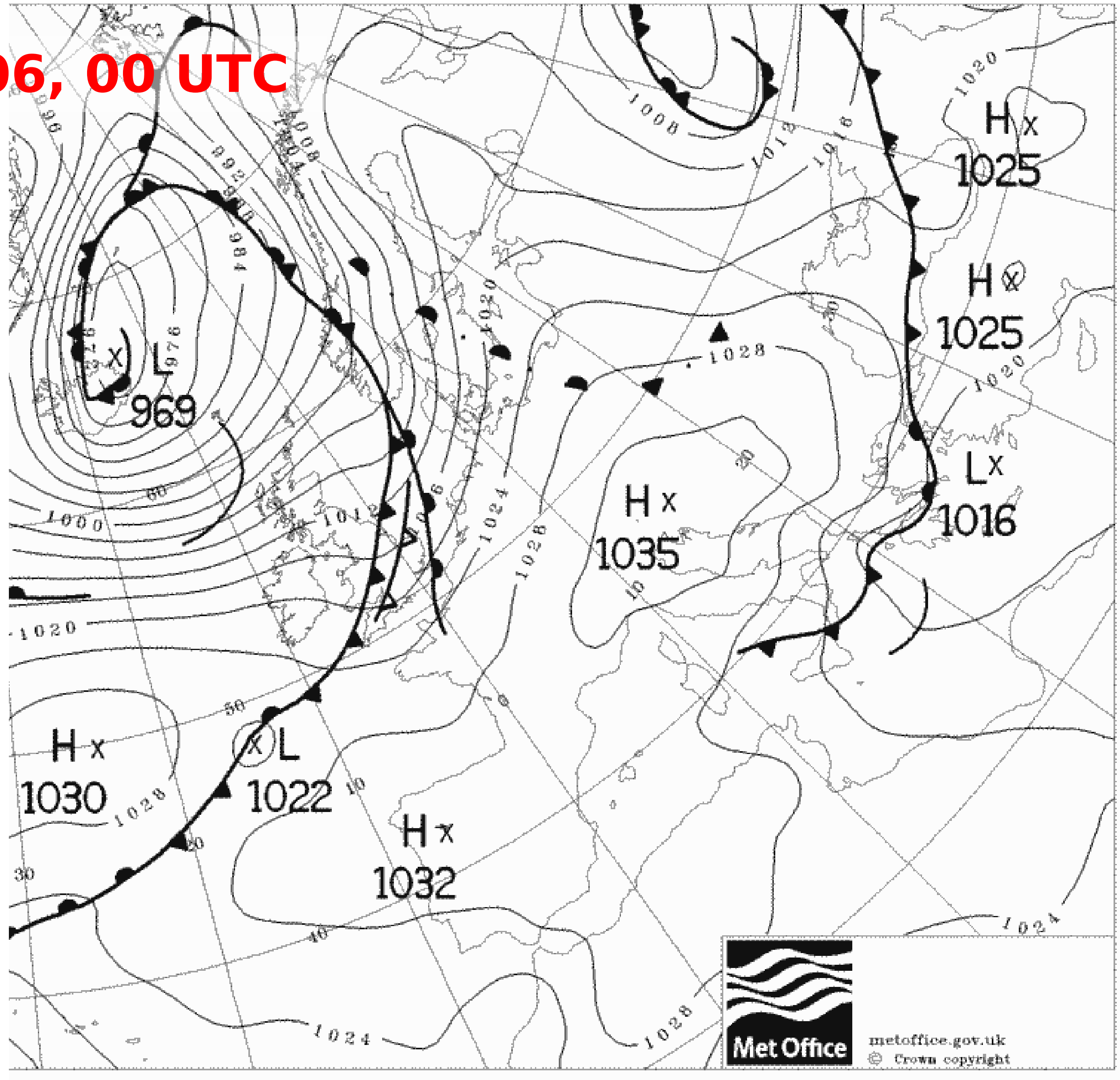


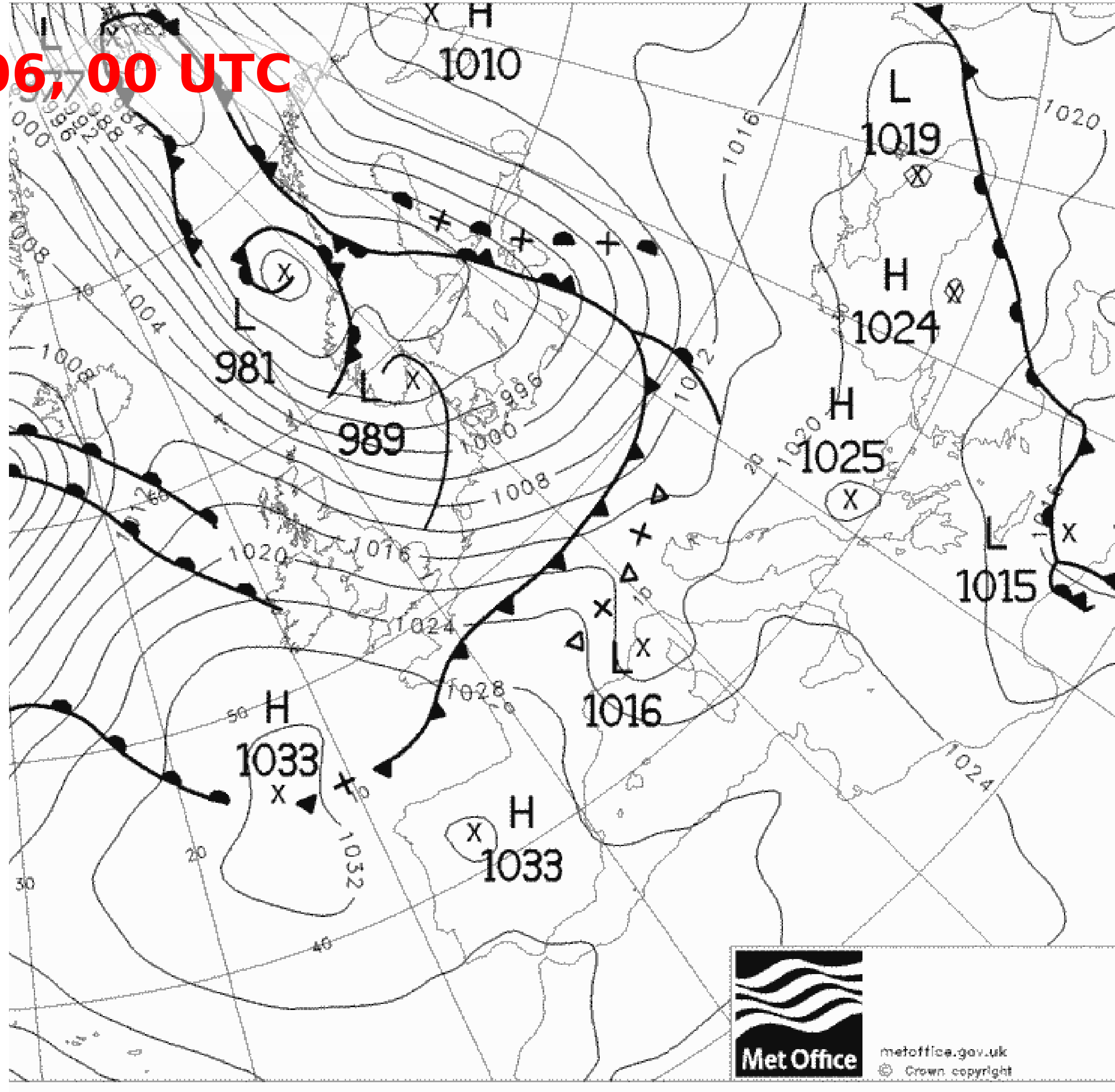
Case study no 2 (to be performed)

11 Nov 2006, 00 UTC

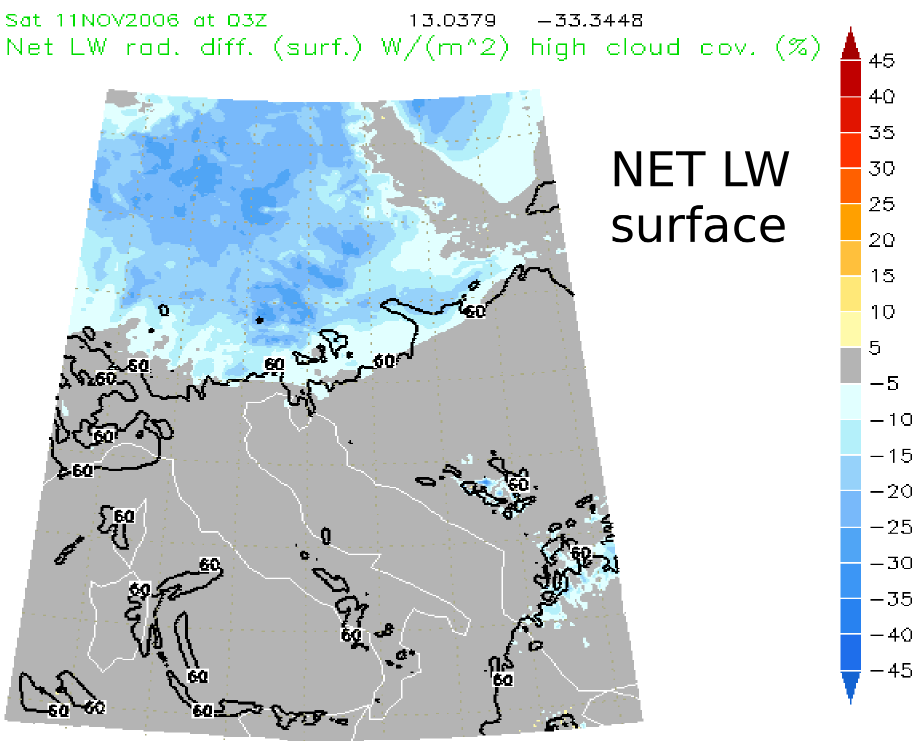


Case study no 2 (to be performed)

12 Nov 2006, 00 UTC

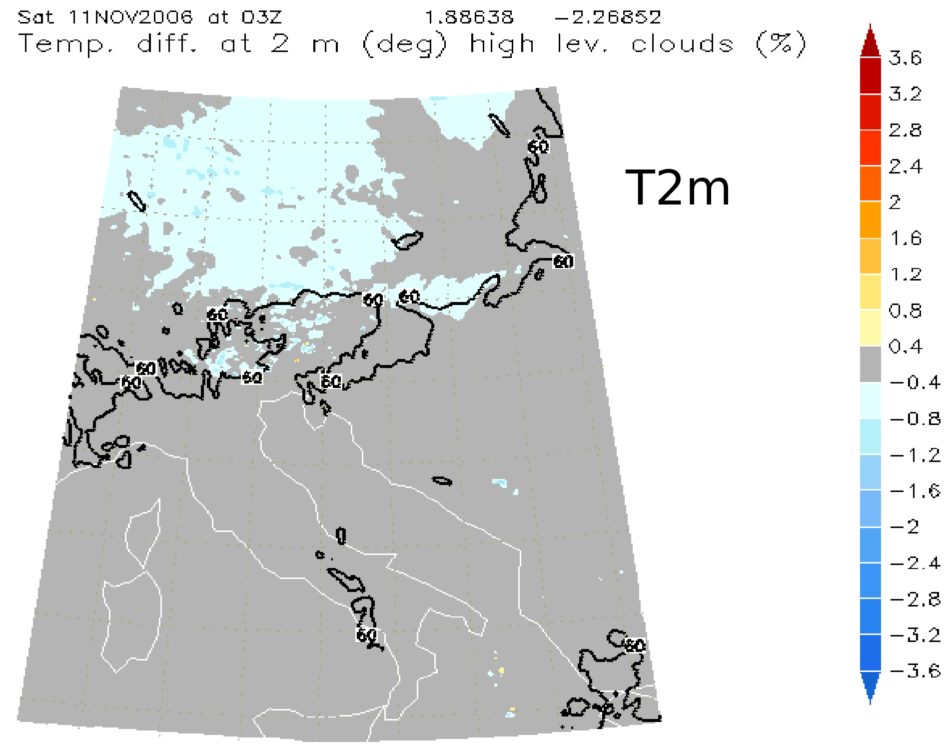


Case study no 2 (to be performed)

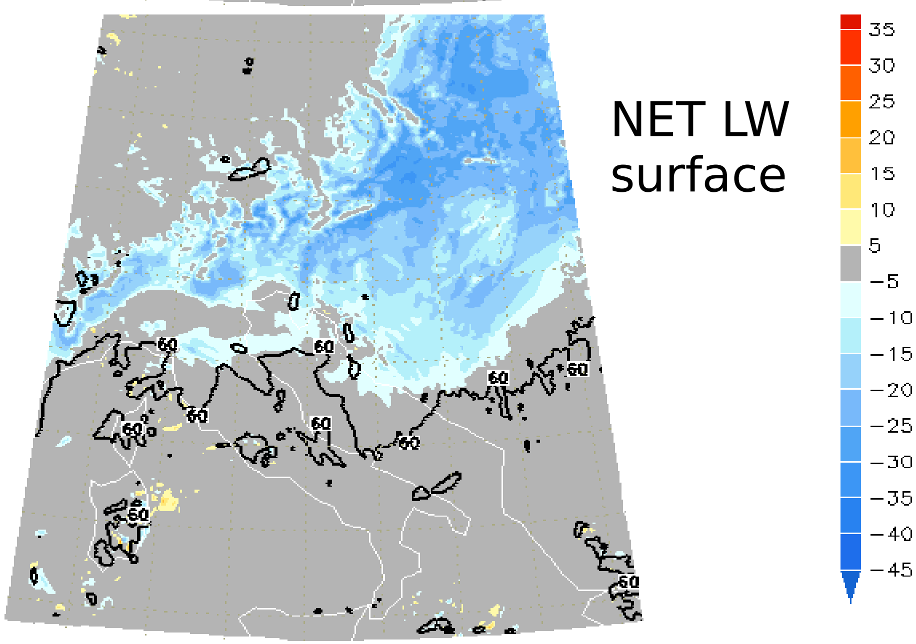


NET LW surface

+3h

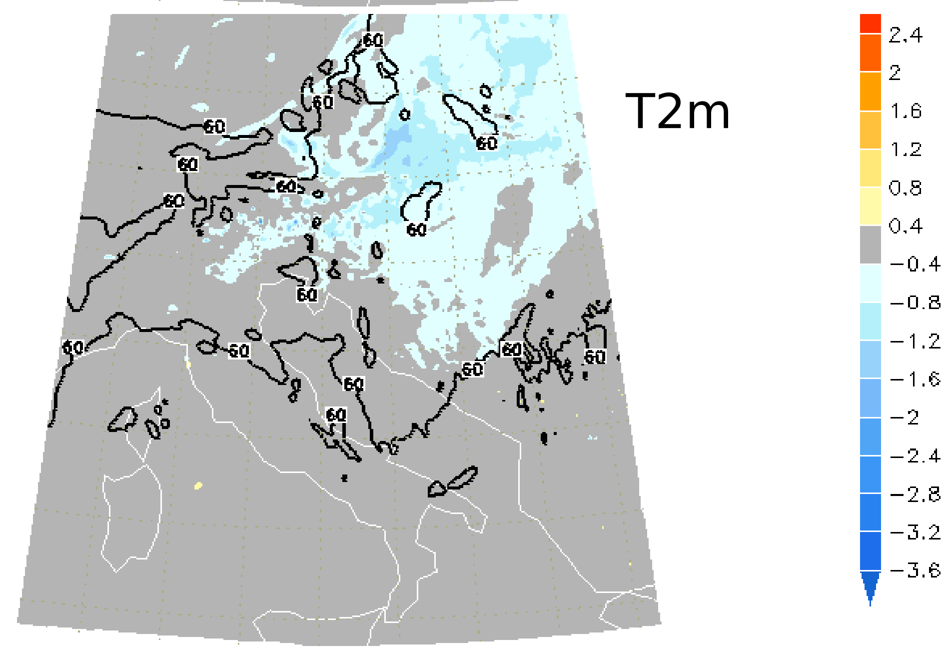


T2m



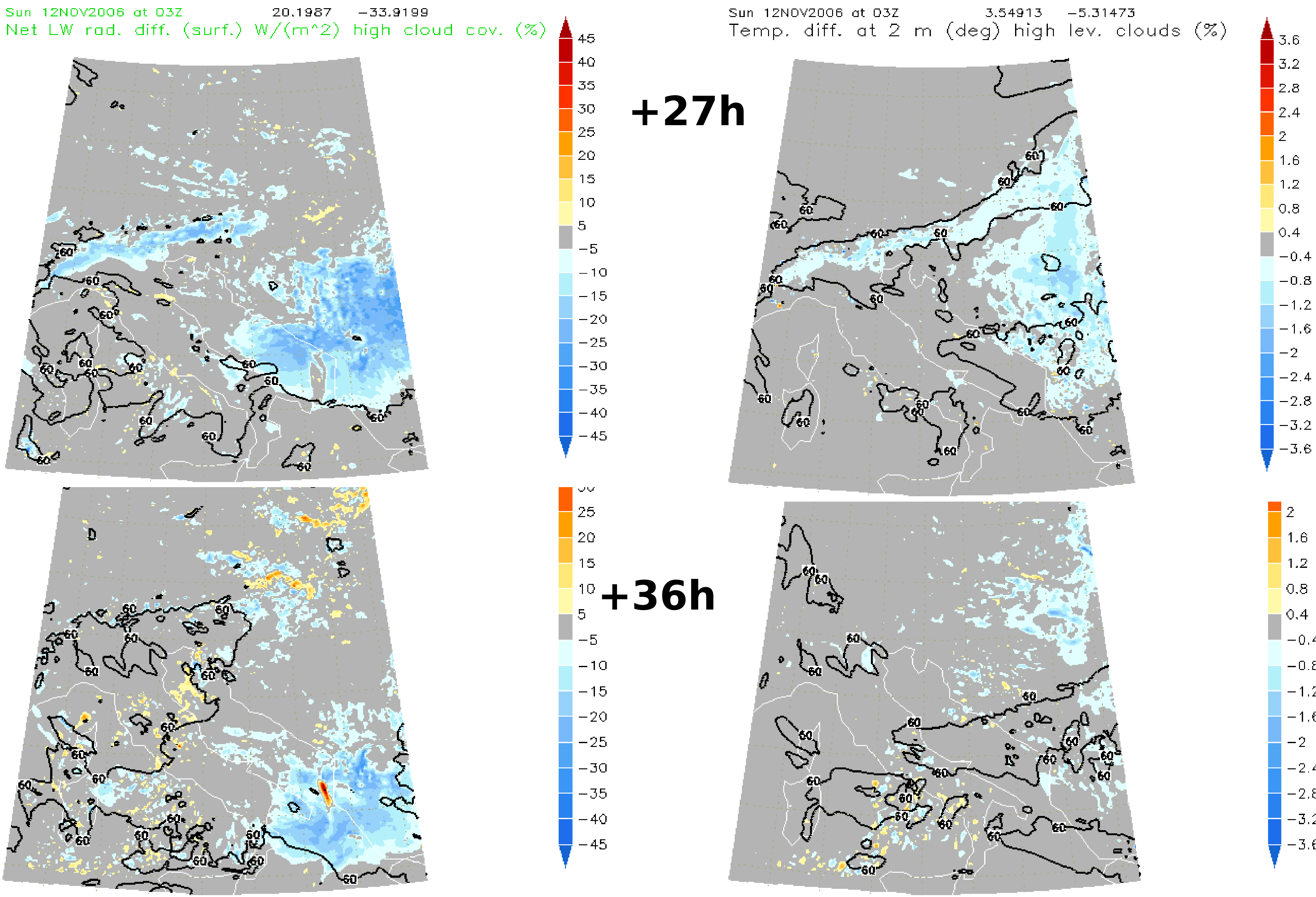
NET LW surface

+15h



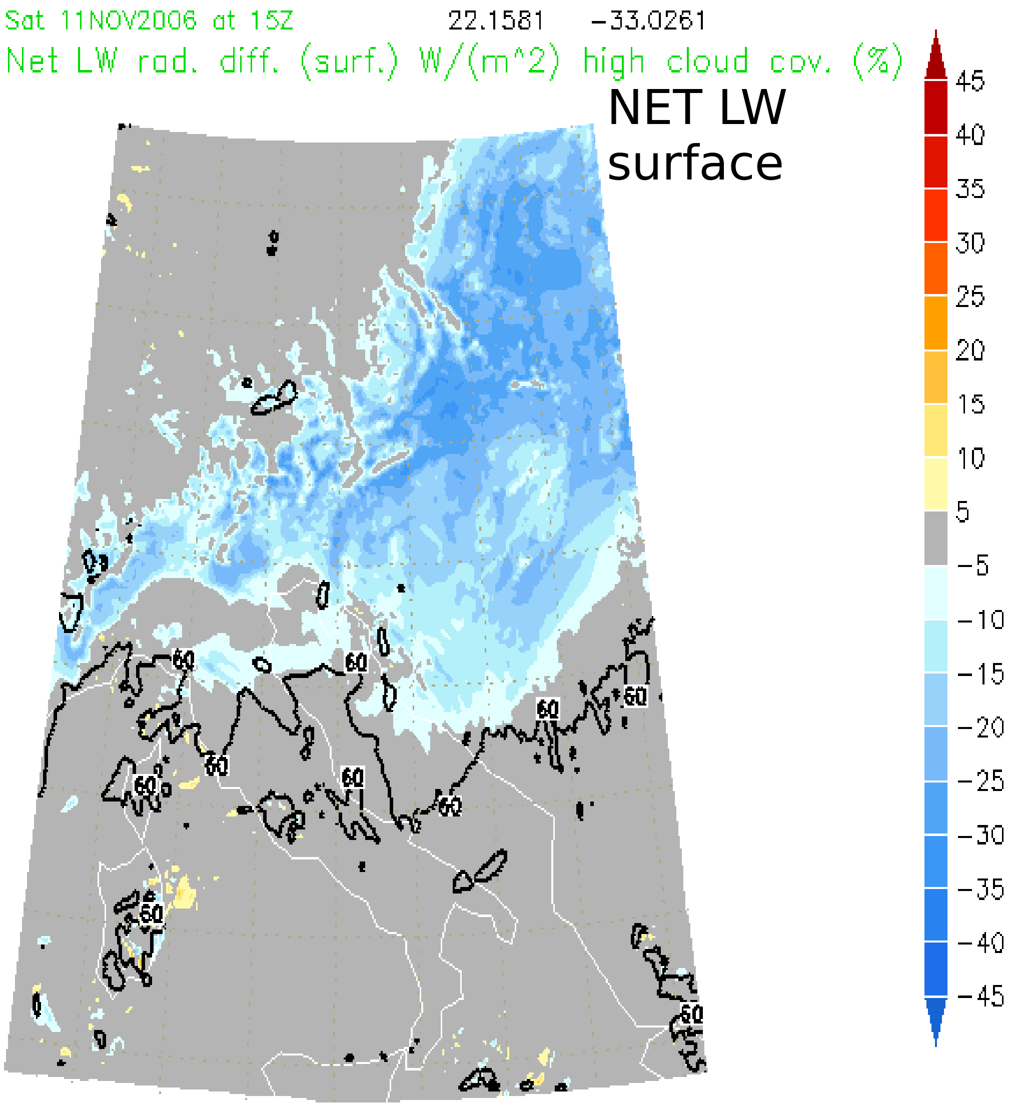
T2m

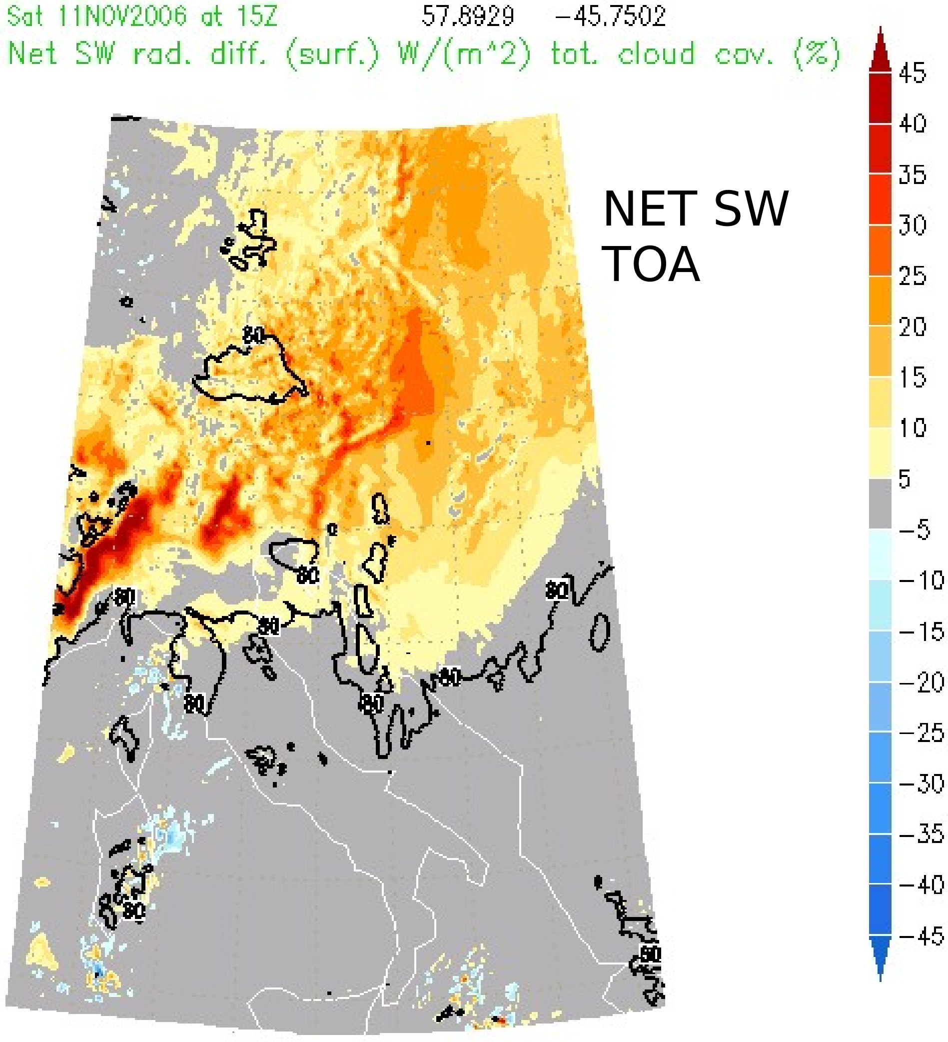
Case study no 2 (to be performed)

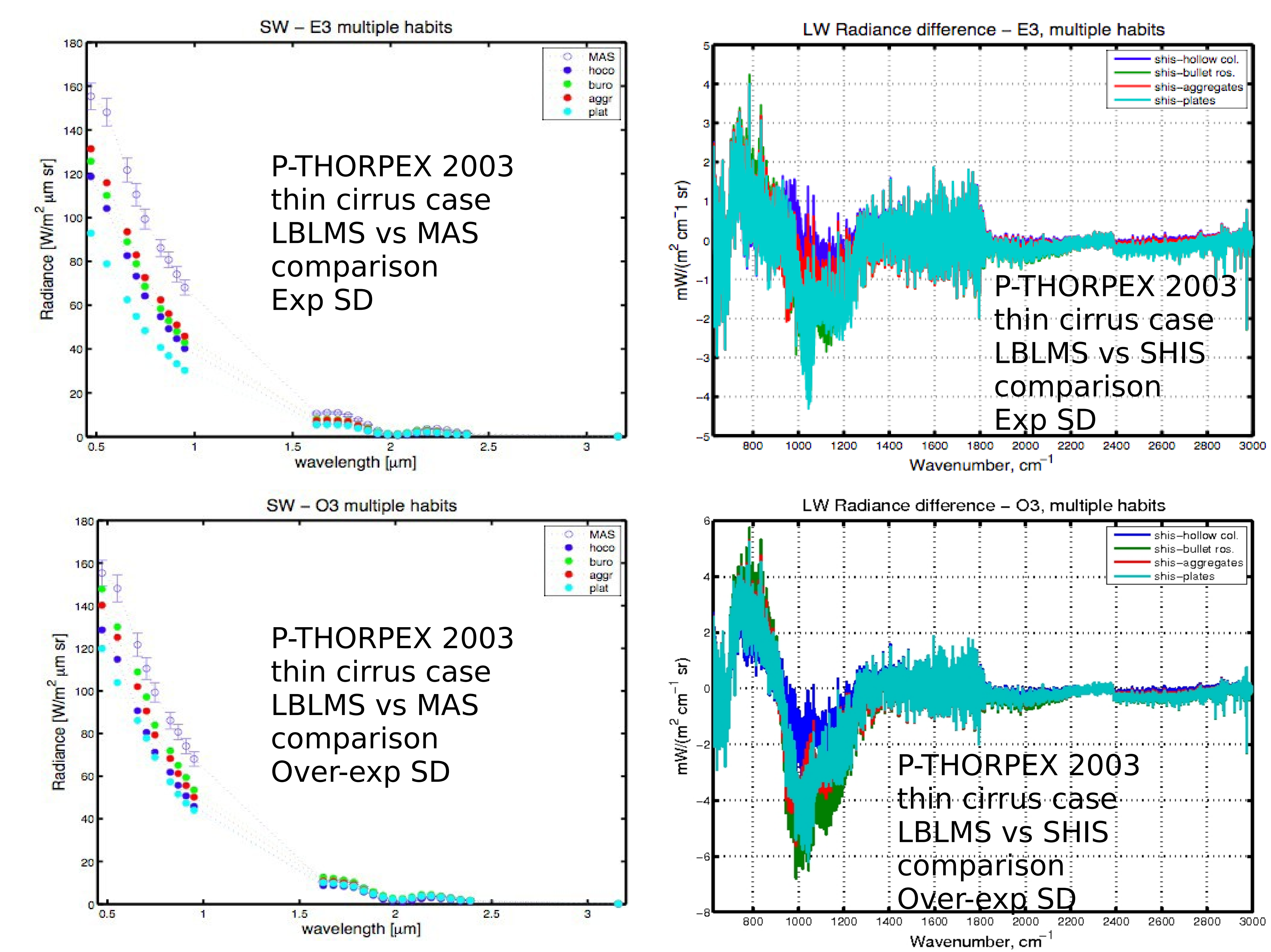


Case study no 2 (to be performed)

+15h






SW – E3 multiple habits
MAS
hoco
buro
aggr
plat
Radiance [W/m2 µm sr]
wavelength [µm]
P-THORPEX 2003
thin cirrus case
LBLMS vs MAS
comparison
Exp SD
LW Radiance difference – E3, multiple habits
shis–hollow col.
shis–bullet ros.
shis–aggregates
shis–plates
mW/(m2 cm-1 sr)
Wavenumber, cm-1
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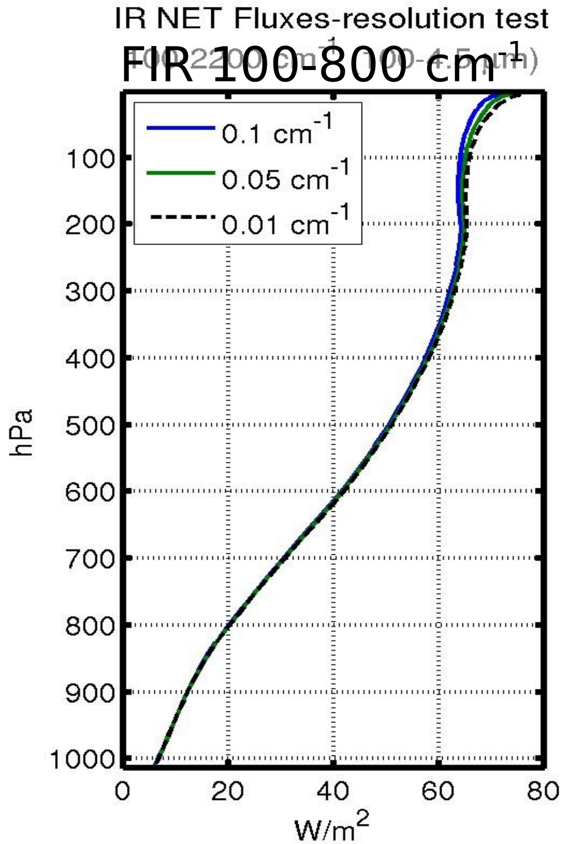
LbLMS-RTX vs LM rad scheme

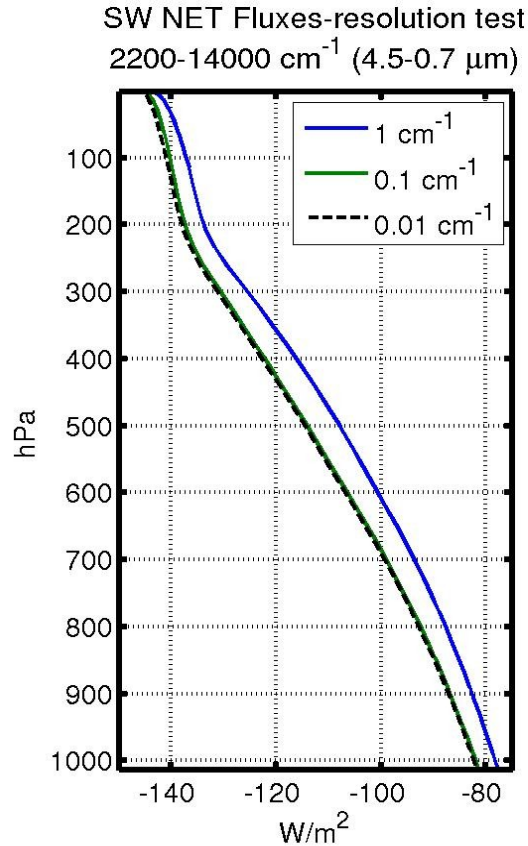
spectroscopic database and spectral resolution

- Spectroscopic database based on HITRAN2000 from FIR to 0.25 μm
- resolution 0.01 cm^{-1} from 10 to 3000 cm^{-1}; 0.1 cm^{-1} from 3000 to 10000 cm^{-1}; 1 cm^{-1} from 10000 to 40000 cm^{-1}

- Parameterization of gaseous absorption (AFGL '82 database) and cloud radiative properties over 8 broad band spectral intervals from 0.25 to 104 μm

RTX resolution tests

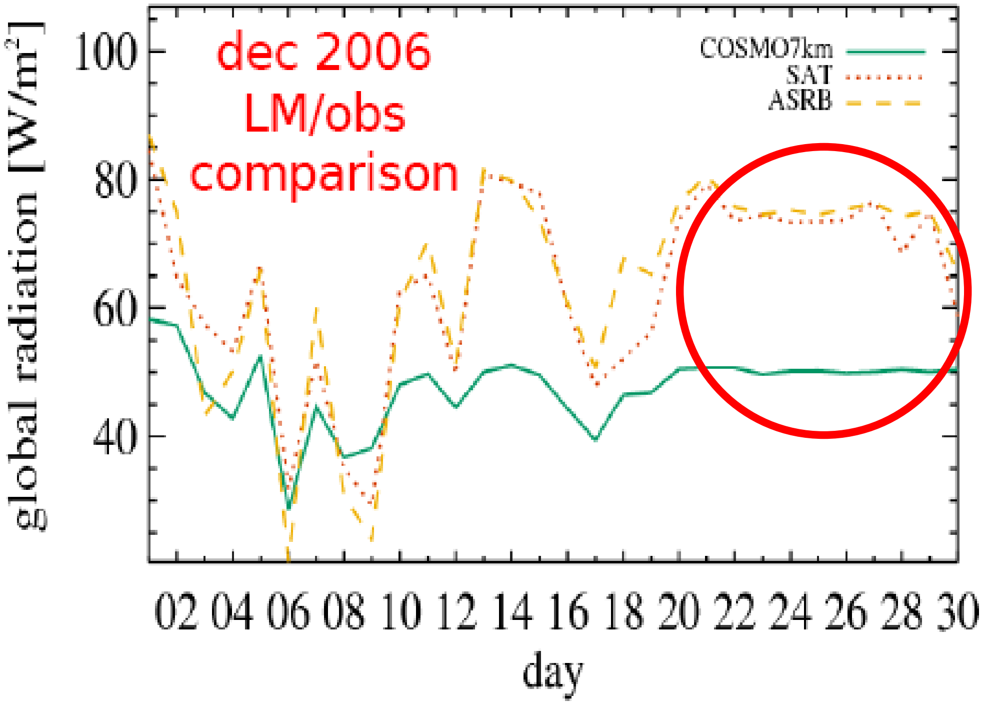




Clear sky comparisons

some comparisons with measurements

- Recent comparisons with MSG and ASRB:
  - D-LW surf flux: LM-obs: -20/-25 W/m^2. Diurnal and seasonal cycle. Max bias in cold and dry atmosphere (Duerr et al., 2005)
  - D-SW surf flux: LM-obs -20/-30 W/m^2, mostly during winter (Buzzi, Meteo-Schweiz preliminary results)



Surface down-welling fluxes: LM - RTX/HITRAN

	TRO	MLS	MLW	SAS	SAW
DSW (W/m2)	0.8	-4.7	**-13.7**	-8	**-8.9**
DLW (W/m2)	-3.7	-9.3	**-15.6**	-13.8	**-13.3**

Clear sky comparisons

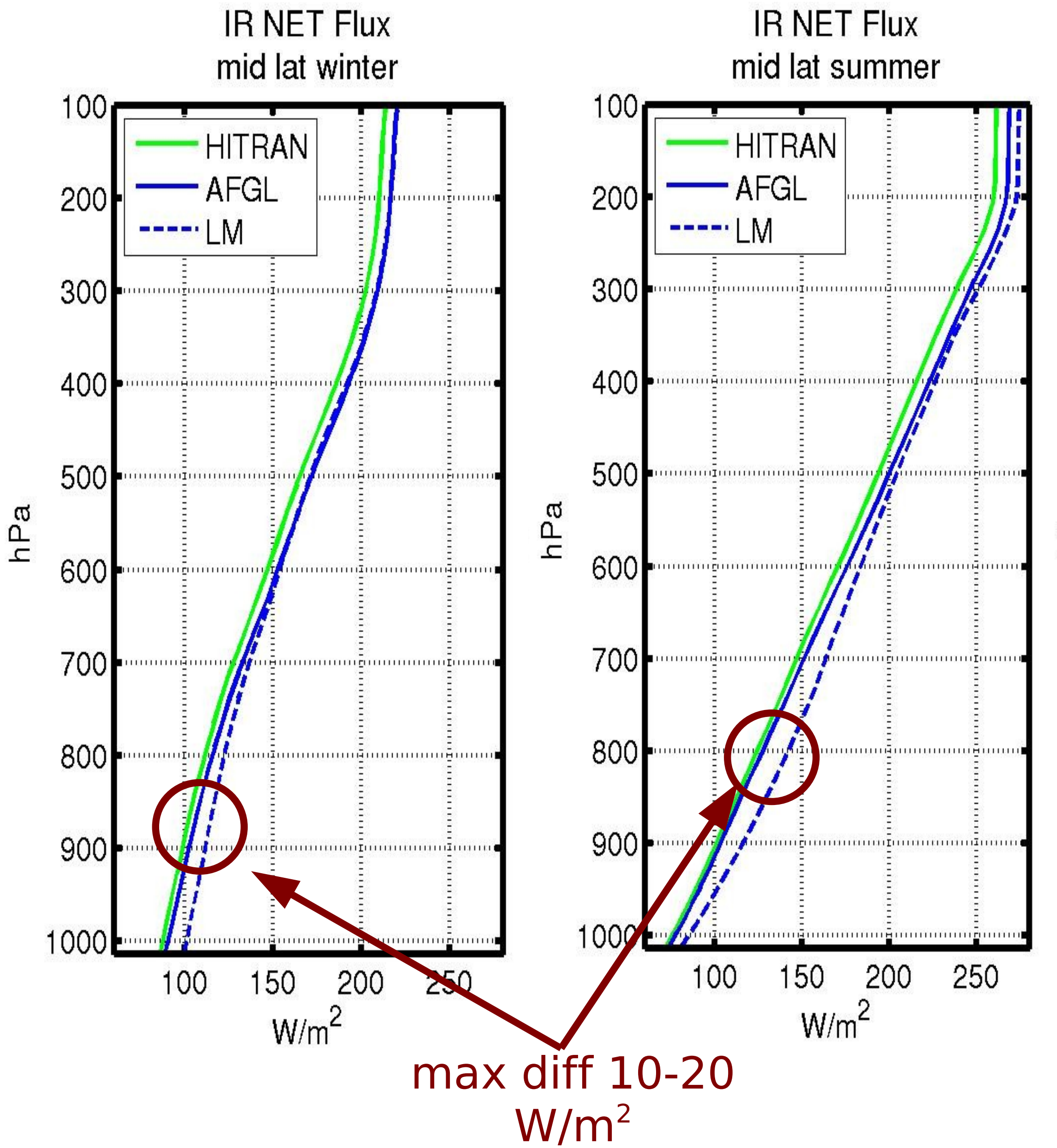
spectroscopic database comparison

- The upgrade of the spectroscopic database seems to account only for a few W/m², mostly in the thermal IR. The bias is distributed along the whole profile. Max diff below 600 hPa

RTX SURFACE NET IR FLUX DIFFERENCE

winter
HITRAN2K-AFGL '82= 2.8 W/m²

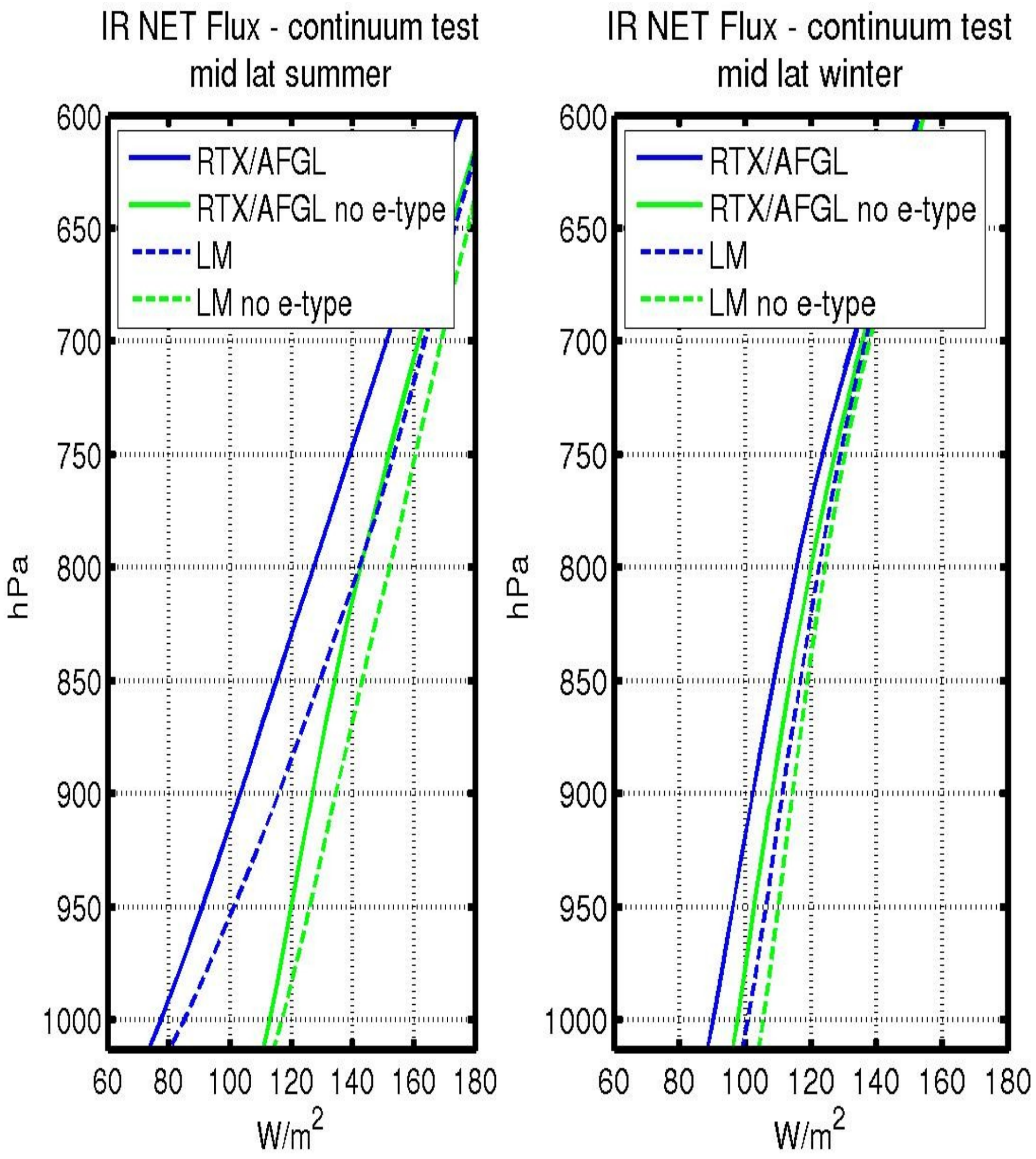
summer
HITRAN2K-AFGL '82 = 1.8 W/m²



Clear sky comparisons

on the H_2O-continuum absorption term

- First comparison to test the continuum absorption parameterization: the H_2O e-type continuum
- Differences still remain in the clear sky comparison:
  - pressure-type continuum parameterization
  - super-CO_2(+ N2O,CH4,CO): gases' relative concentrations



Clear sky comparisons

SW global radiation issues and uncertainties

- e-type continuum does not apply to the solar range..... pressure broadening?
- database upgrade gives only a few W/m^2. Dependence on dry/moist BL and SZA seems to appear from comparisons

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Clear sky

- LM radiation scheme
  - fast and accurate in LW range
  - for the first time it has been compared with LbLMS computations in SW
- LbLMS comparison between AFGL '82 and HITRAN2k4 suggests a minor influence of the upgrade of spectroscopic db in LM
- LW fluxes are influenced by the correct parameterization of H_2O continuum absorption
- SW fluxes discrepancies with LbLMS computation are still unresolved

Ice clouds optical properties modeling

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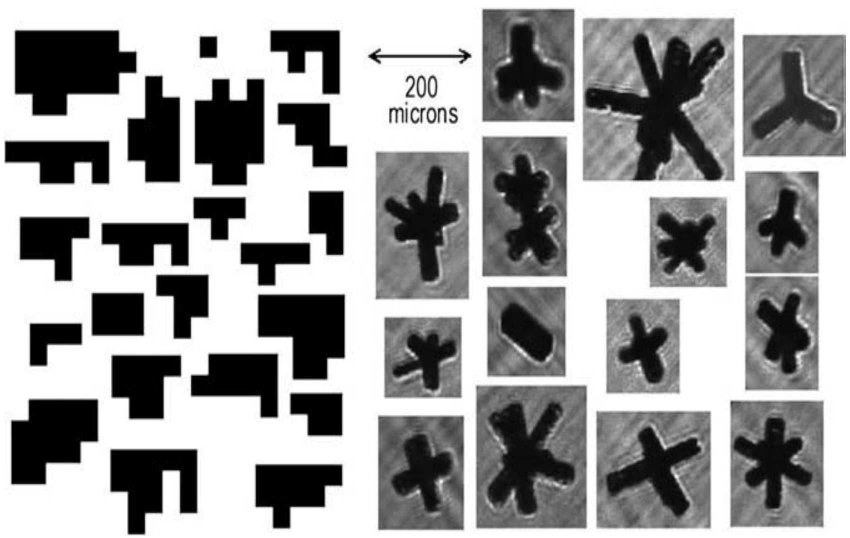
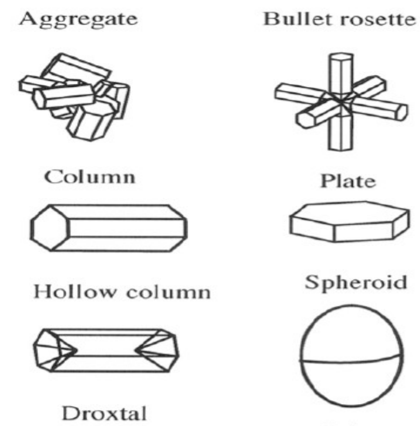


Comparison between PMS 2D-C probe and CPI images (from Lawson et al., 2006)



Simulated ice crystals (Yang et al, 1998)