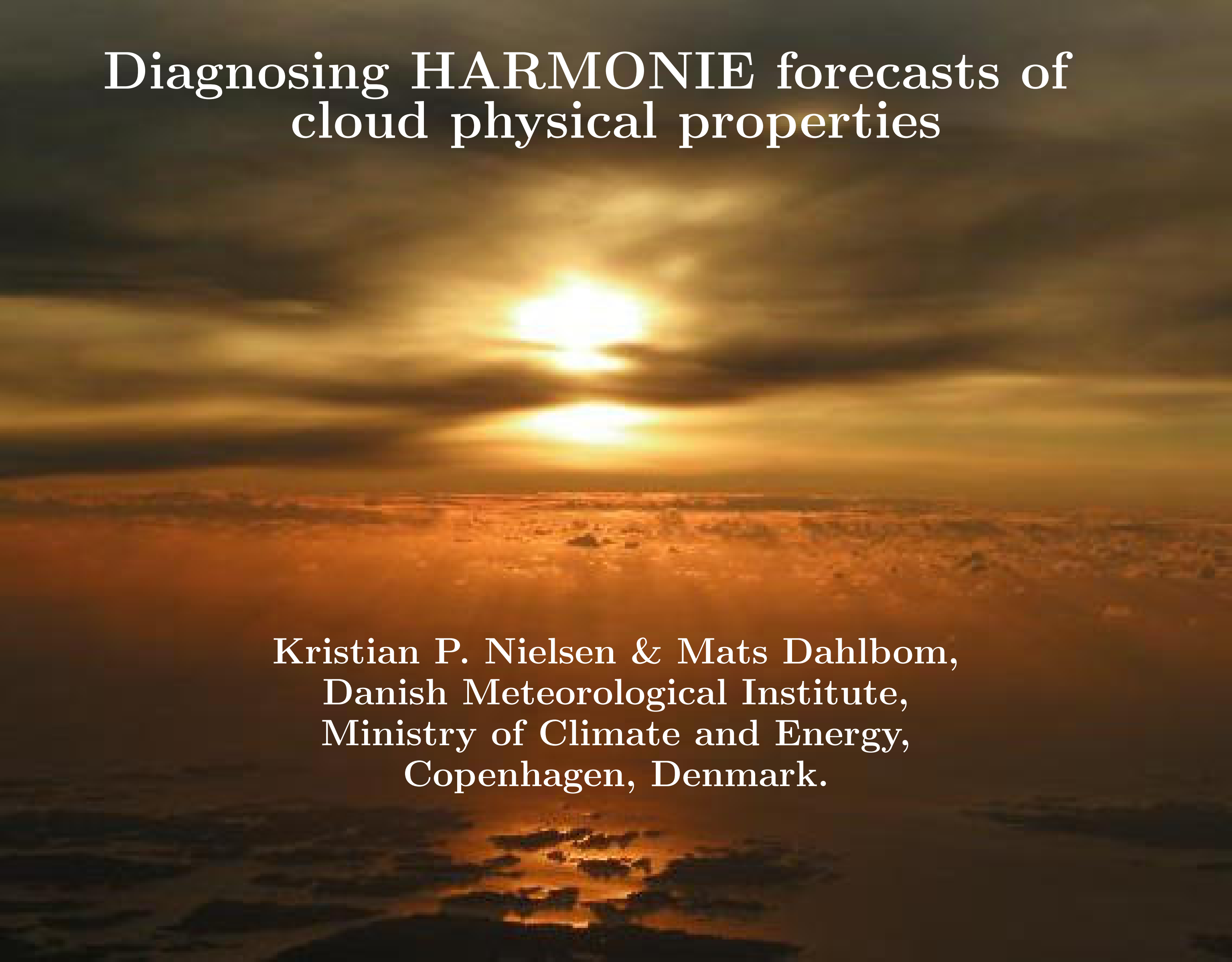

Diagnosing HARMONIE forecasts of cloud physical properties

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DMI

MINISTRY OF CLIMATE AND ENERGY

Introduction

- Clouds are affected by virtually all processes in the atmosphere;
- Cloud prediction is essential for prediction of radiative forcing and precipitation;
- New satellite data give 3D-information on clouds.

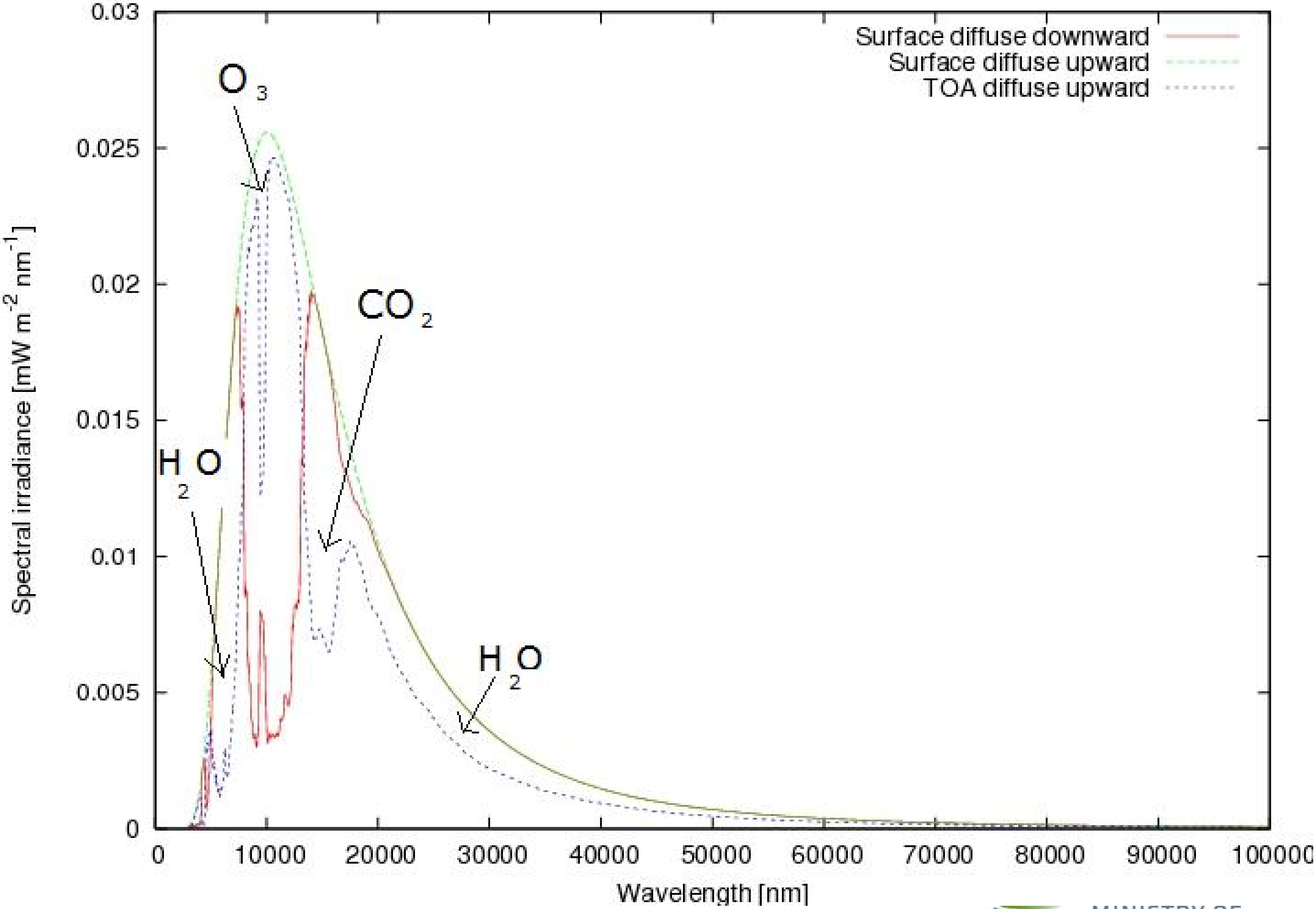
Theory

The equation of radiative transfer:

$$\mu\frac{dI_\lambda(\tau,\mu,\phi)}{d\tau} = I_\lambda(\tau,\mu,\phi) - (1-a)B_\lambda(T;\tau) - \frac{a}{4\pi}\int_{4\pi} d\omega' p(\tau,\mu',\phi')I_\lambda(\tau,\mu,\phi) - S^*_\lambda(\tau,\mu,\phi) \quad (1)$$

Chandrasekhar (*Radiative Transfer*, Dover, New York, 1960.)

Thomas and Stamnes (*Radiative Transfer in the Atmosphere and Ocean*, Cambridge University Press, New York, 2002.)



MINISTRY OF CLIMATE AND ENERGY

Inherent optical properties (1)

- τ: Optical depth [-], the integrated extinction;
- a: Single scattering albedo = 1 - emittance [-];
- p: Phase function [-], in practice a function only of the asymmetry factor g (Henyey & Greenstein 1941);
- Lower boundary albedo / BRDF [-].

MINISTRY OF CLIMATE AND ENERGY

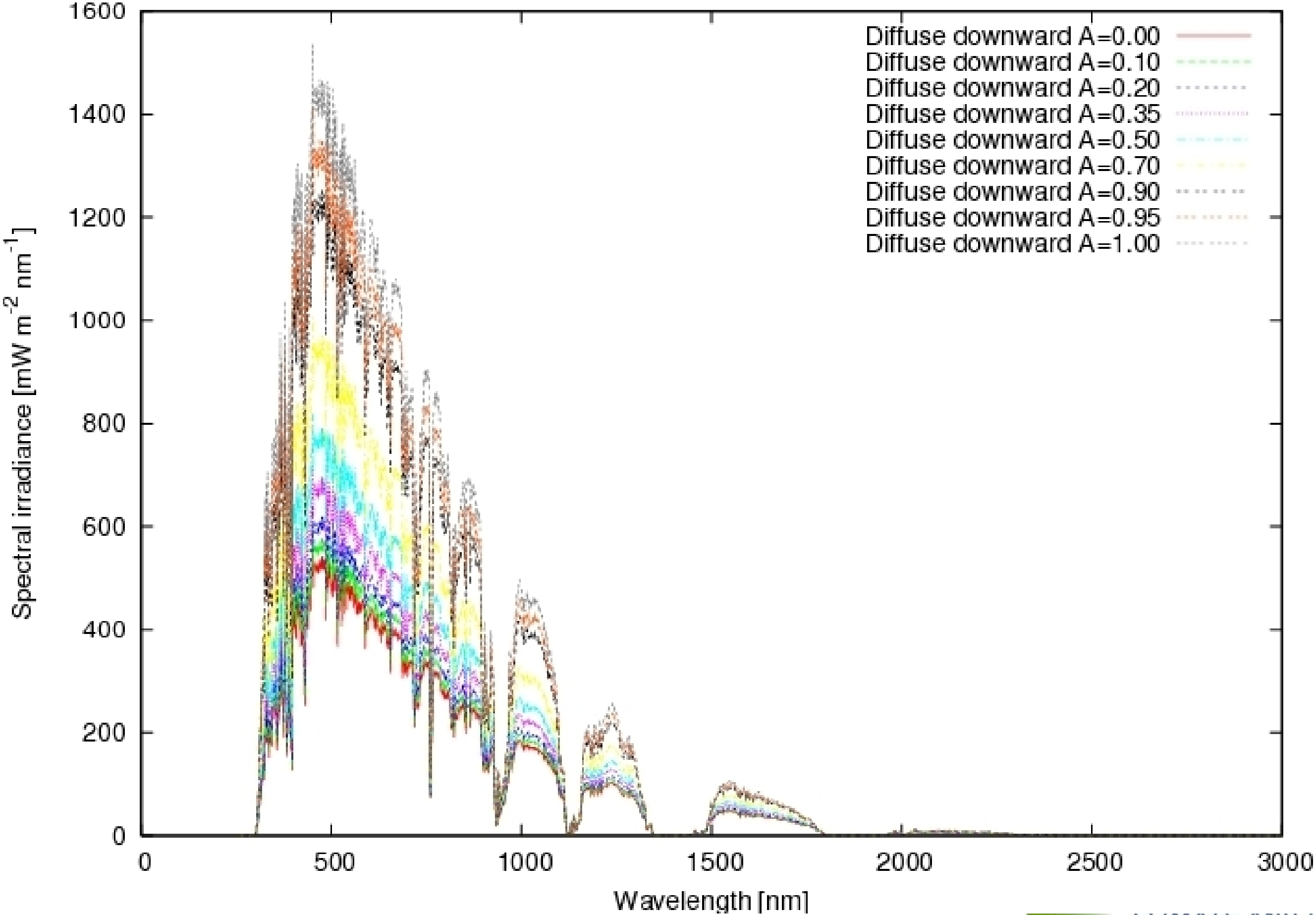
Inherent optical properties (2)

- τ: Optical depth [-], the integrated extinction;
- a: Single scattering albedo
  = 1 - emittance [-];
- p: Phase function [-], in practice a function only of the asymmetry factor g (Henyey & Greenstein 1941);
- Lower boundary albedo / BRDF [-].
- **"Cloud albedo" is not an inherent optical property!**

Sagan and Pollack: "Anisotropic nonconservative scattering and the clouds of Venus", (*JGR*, 1967: 72: 469–477).

MINISTRY OF CLIMATE AND ENERGY

Clouds AOPs affected by surroundings



CLIMATE AND ENERGY

Inherent optical properties (3)

The good news is that the cloud IOPs can be adequately derived from only two physical quatities

- Cloud liquid water path (CLWP) [kg/m^2];
- Effective cloud drop radius (r_e) [μm].

$$\tau_{vis} = \frac{3CLWP}{2r_e\rho_l}, \quad a_{vis} = 1, \quad g_{vis} = 0.85 \tag{2}$$

$$r_e \equiv \int_0^\infty dr n(r) r^3 / \int_0^\infty dr n(r) r^2 \tag{3}$$

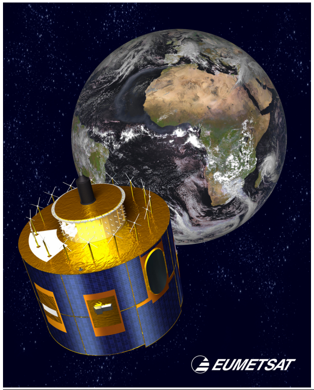
Hu & Stamnes (*J. Climate*, 1993; 6: 728–742.)

MINISTRY OF CLIMATE AND ENERGY

Satellite data

- MSG Cloud physical products (CPP) (Roebeling *et al. JGR*, 2006; 111: D20210; Meirink *et al.* 2009);

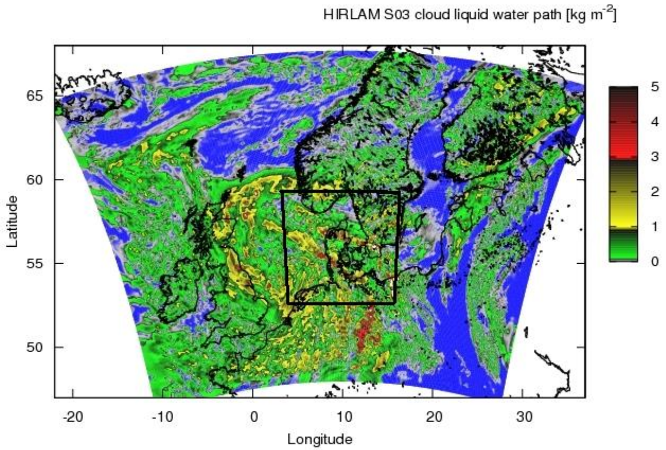
- CloudSat 2B-tau (Stephens *et al. JGR*, 2008; 113: D00A18).

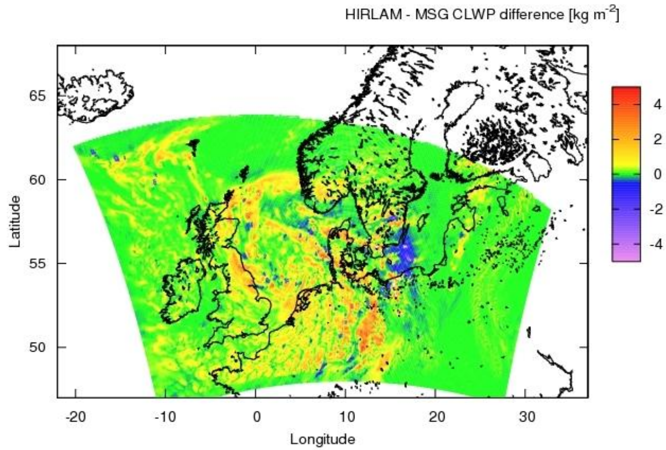


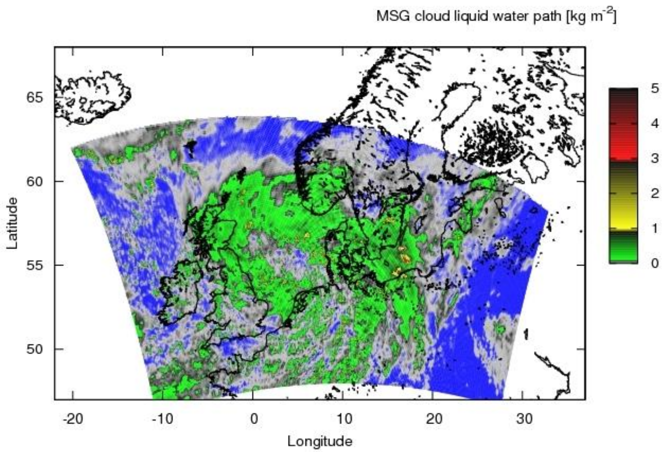
Model data

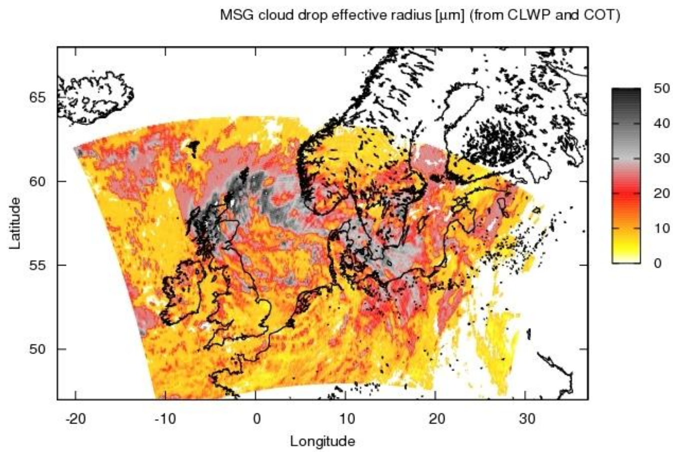
- **DMI-HIRLAM S03;**
- **HARMONIE Denmark (non-hydrostatic).**

DMI-HIRLAM & MSG CPPs









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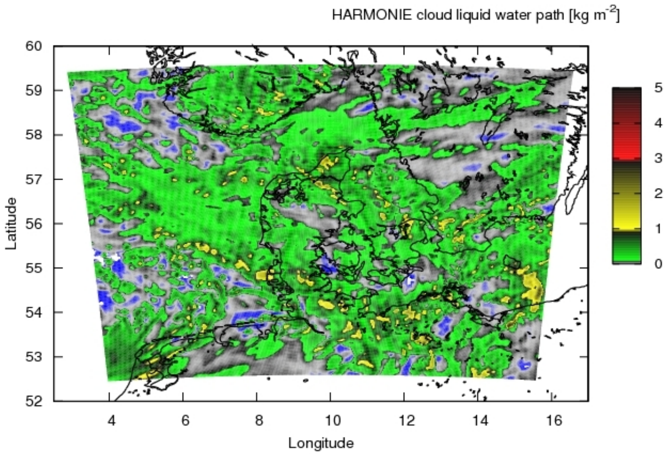
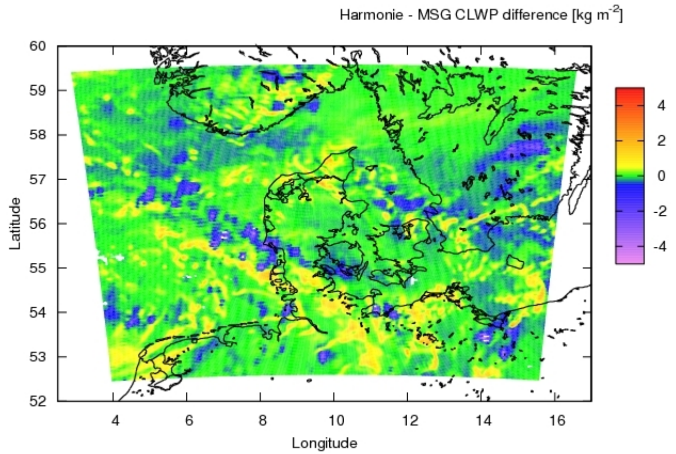
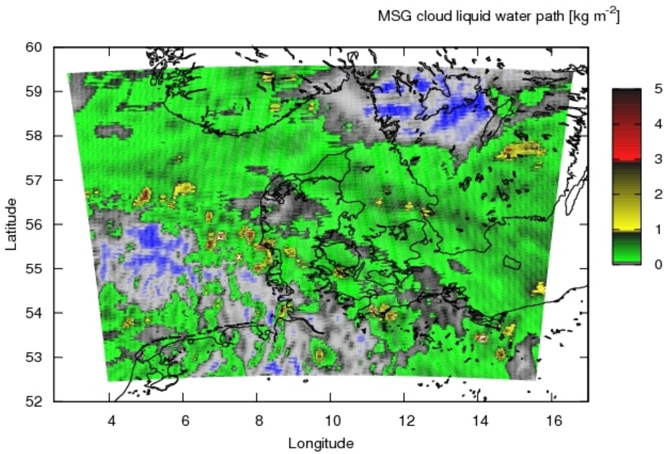
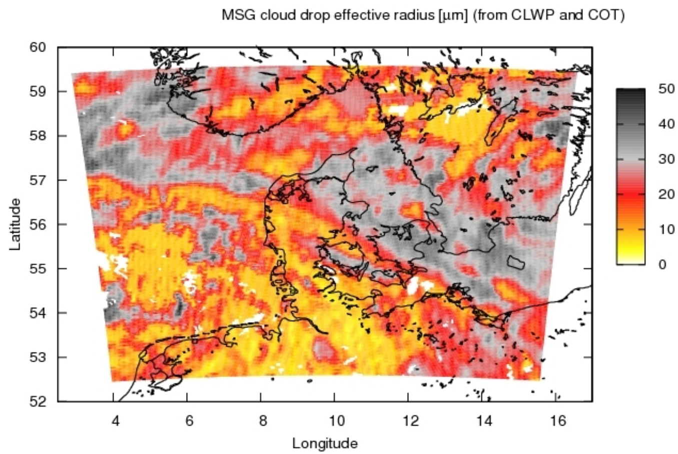
HARMONIE DK & MSG CPPs









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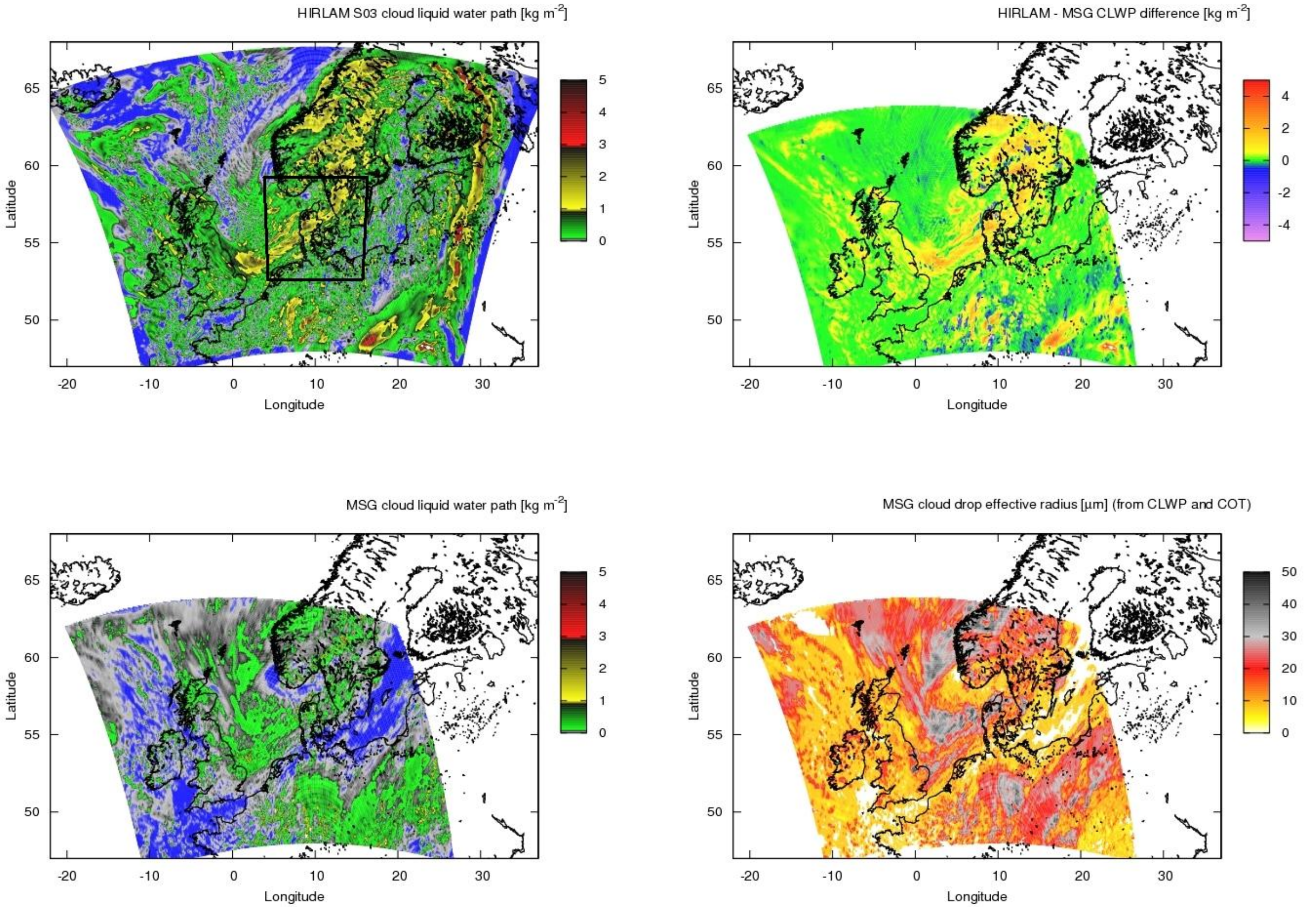

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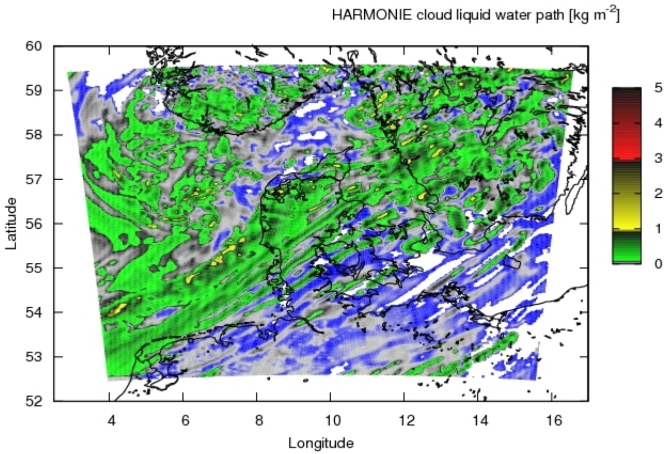
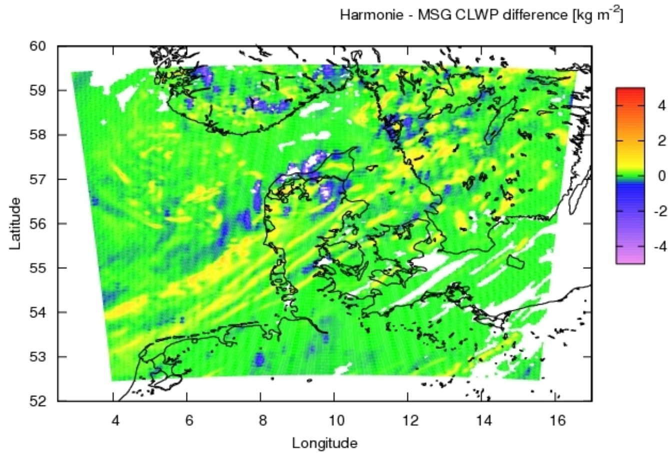
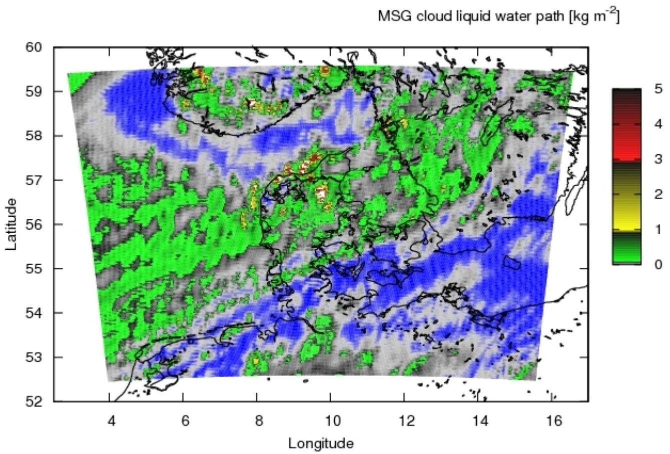
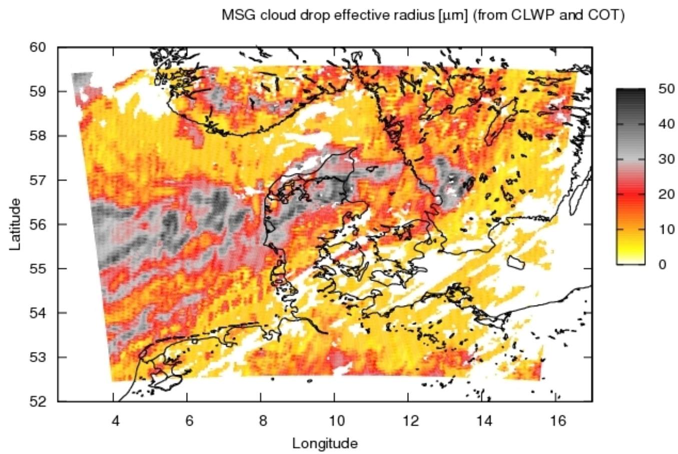
HARMONIE DK & MSG CPPs









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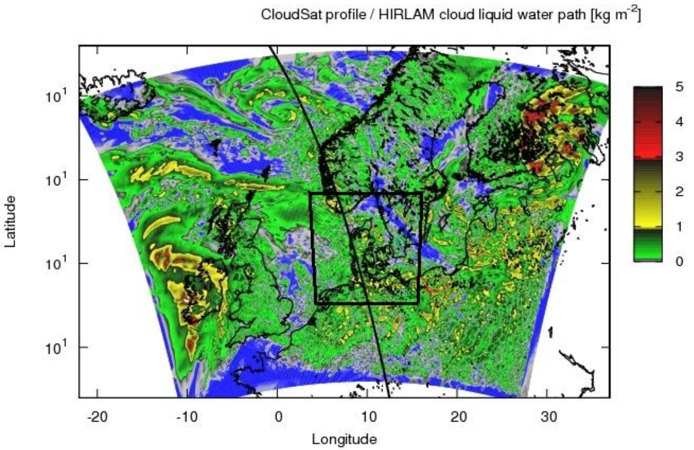
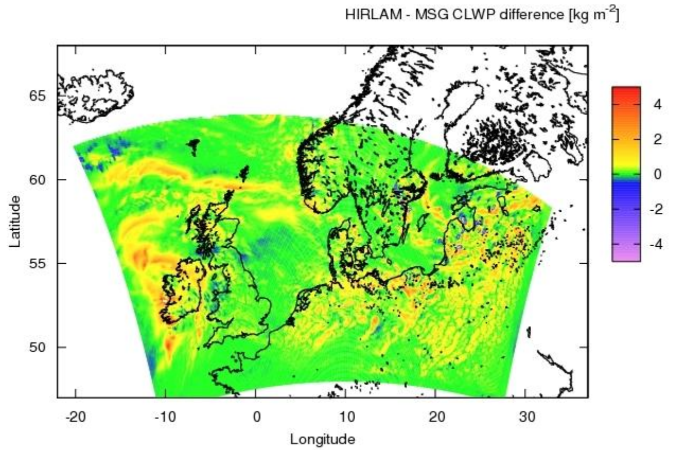
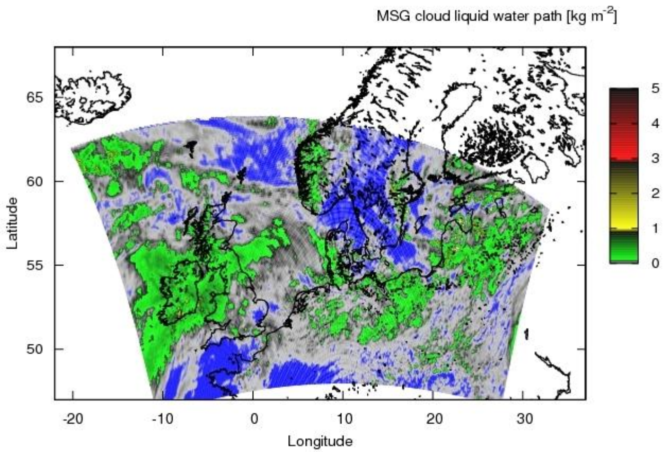
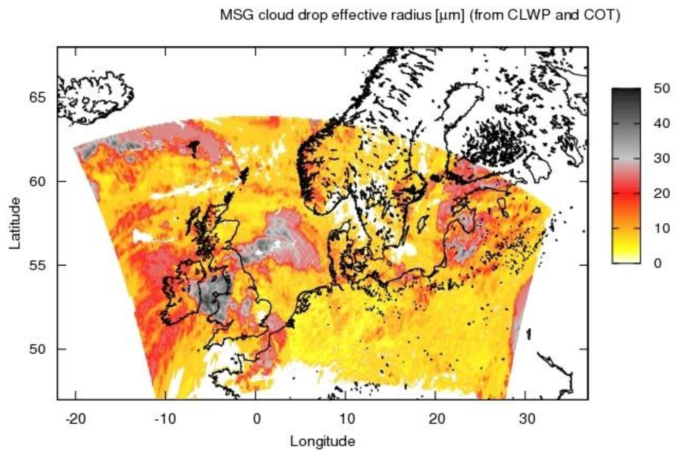
DMI-HIRLAM & MSG CPPs









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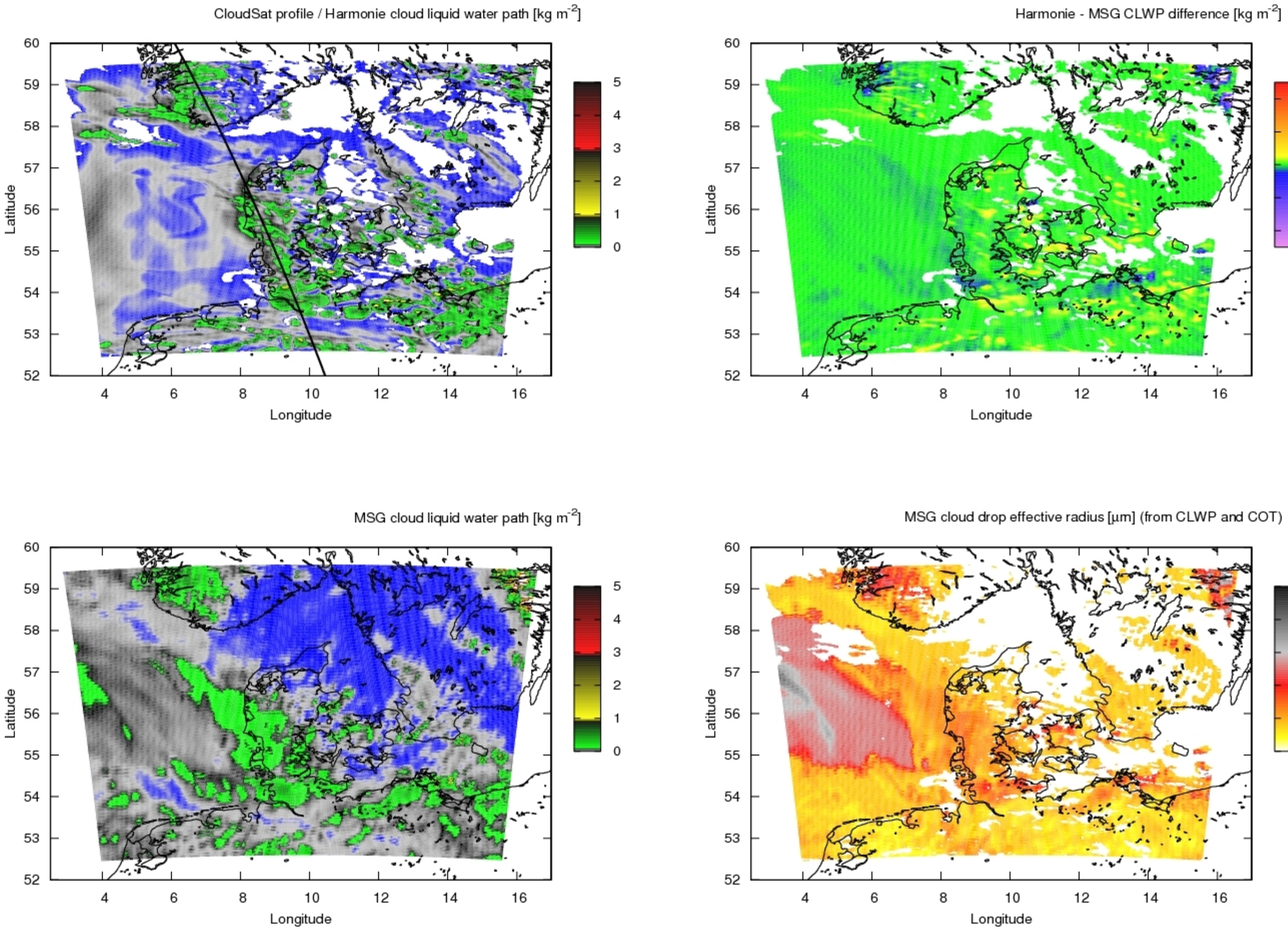

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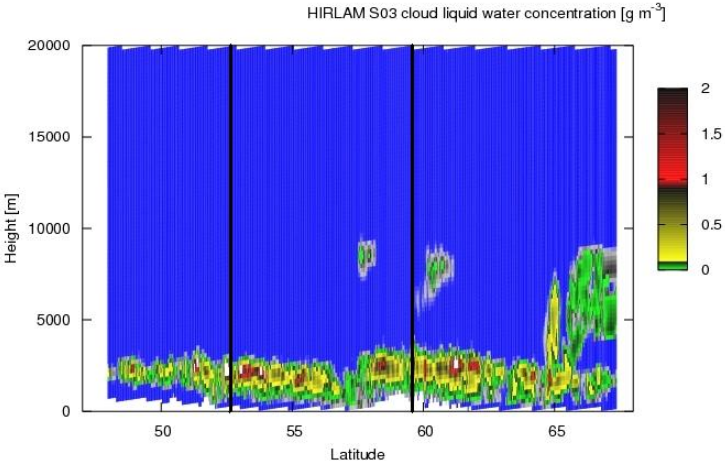
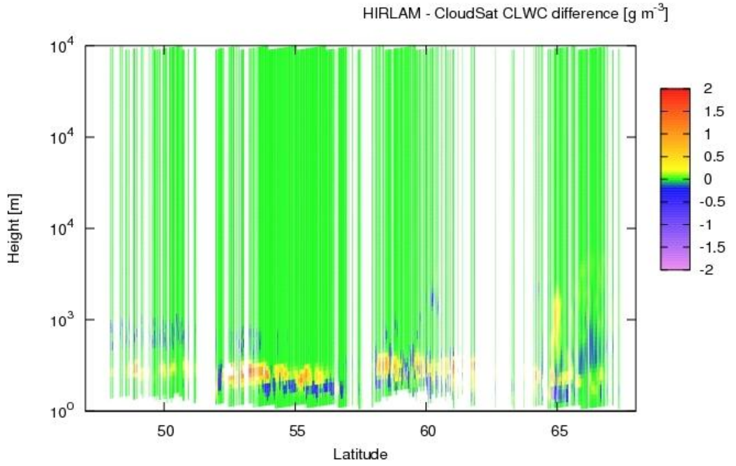
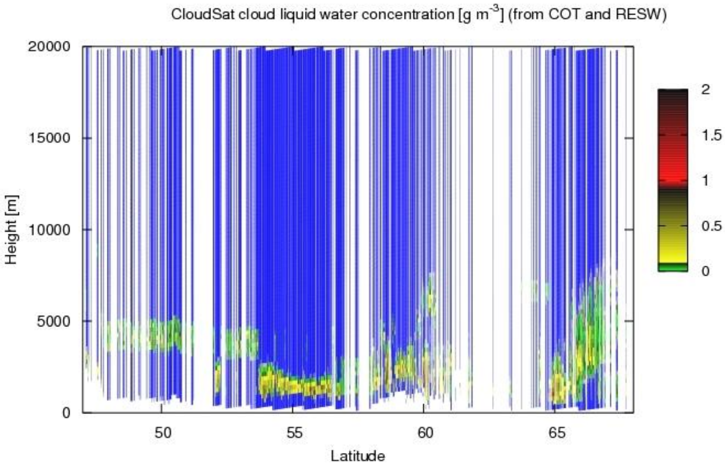
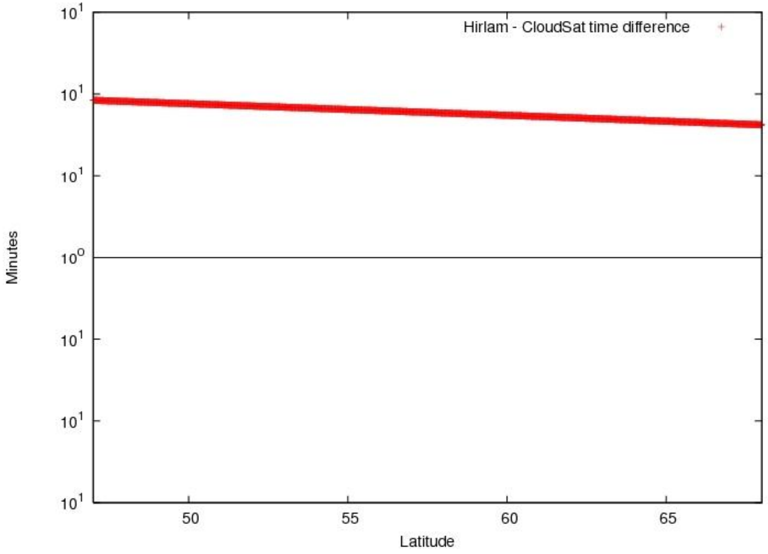
DMI-HIRLAM & CloudSat CPPs









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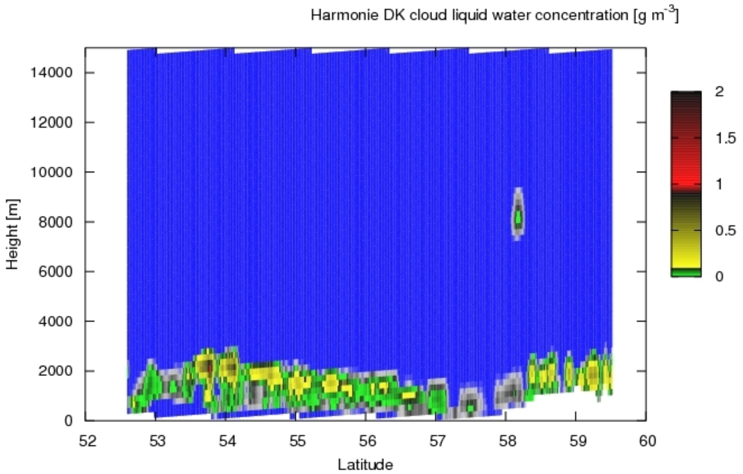
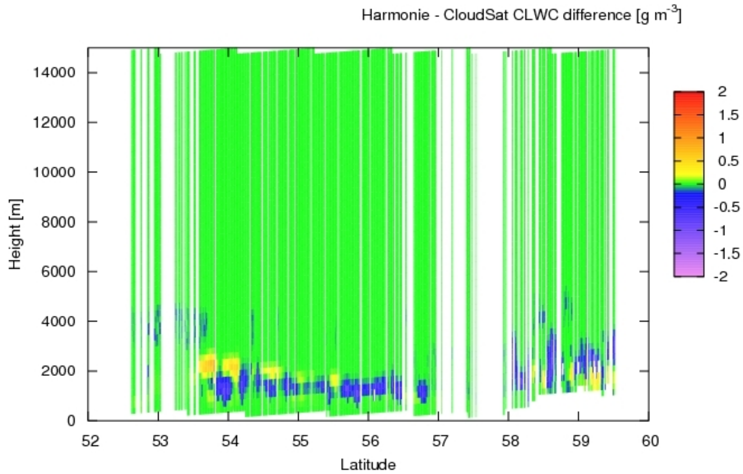
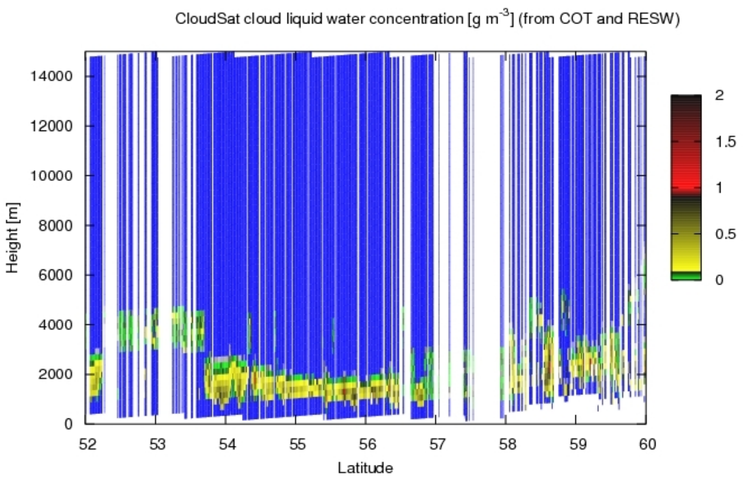
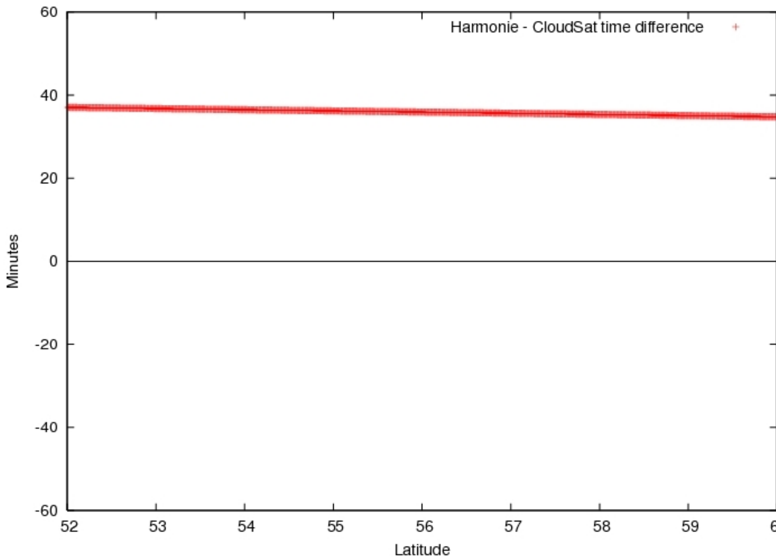
HARMONIE DK & CloudSat CPPs









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Conclusion

- New satellite data of CPPs is likely to be a great tool for NWP verification;

- First results show more realistic cloud liquid water concentration in non-hydrostatic HARMONIE forecasts than in hydrostatic HIRLAM forecasts.

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