Verification of Hirlam/Aladin cloud forecasts with MSG cloud physical products

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Introduction

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

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Theory

The equation of radiative transfer:

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

Lommel (*Ann. Phys. U. Chem.*, **1889; 36: 473–502.**)

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

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

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 [-].

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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).

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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].

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

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

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

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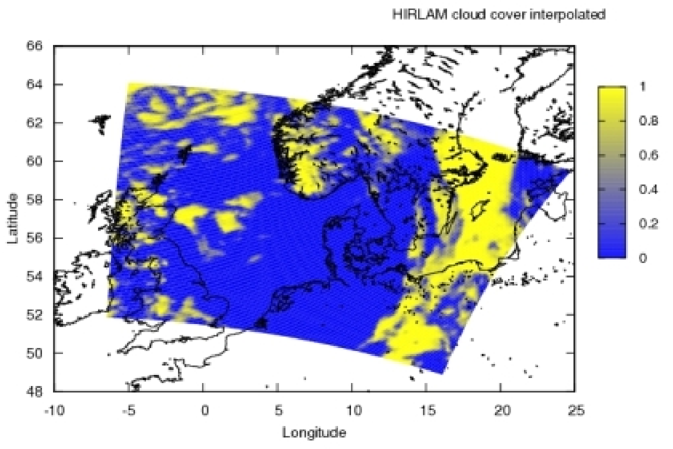
Satellite data

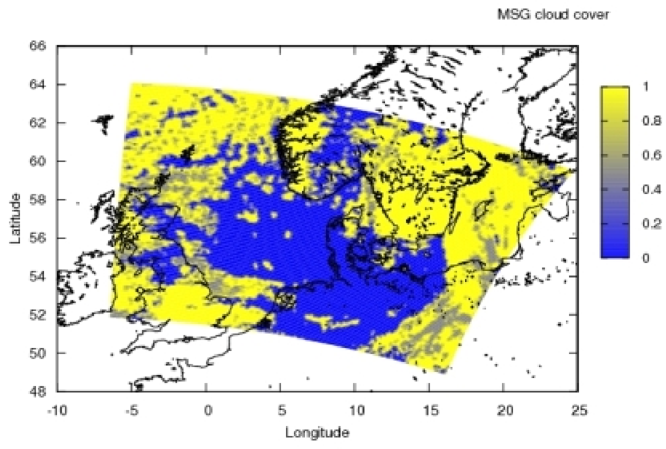
- **MSG Cloud mask;**
- **MSG Cloud physical products (CPP) (Roebeling** *et al. JGR*, **2006; 111: D20210; Meirink** *et al.* **2009);**
- **CloudSat (Stephens** *et al. JGR*, **2008; 113: D00A18).**

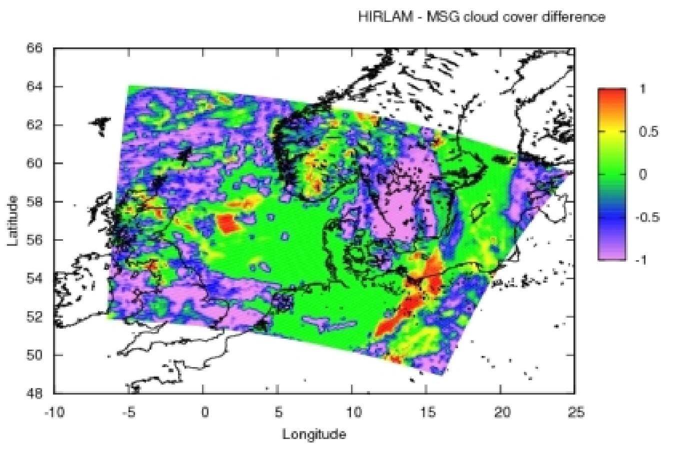
Model data

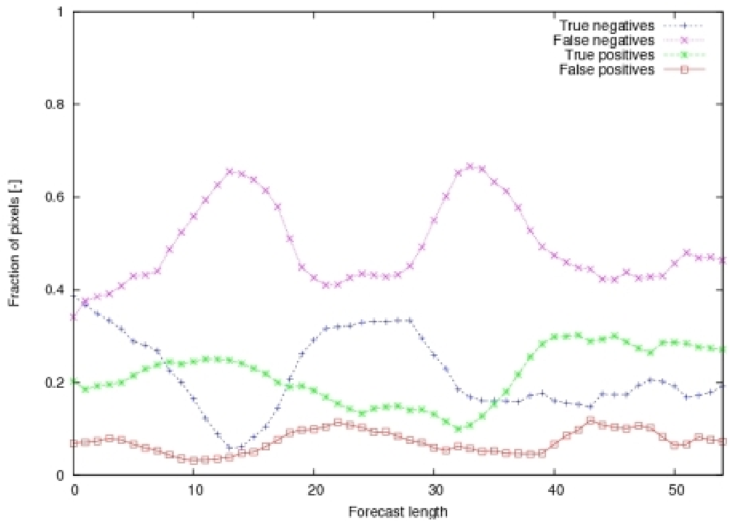
- DMI-HIRLAM;
- REF-HIRLAM with updated STRACO scheme;
- ALADIN Scandinavia (hydrostatic);
- AROME Denmark (non-hydrostatic).

DMI-HIRLAM cloud cover



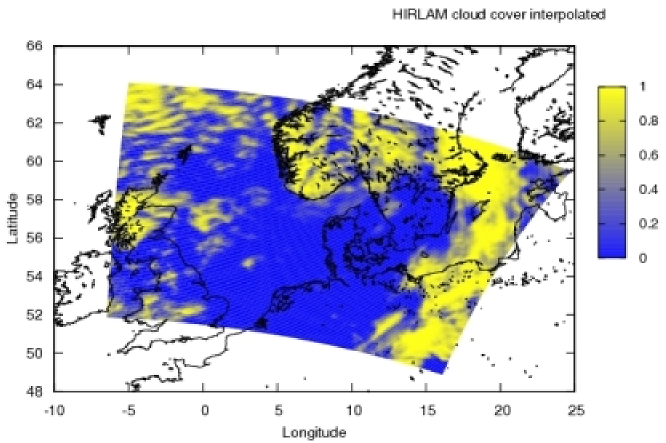


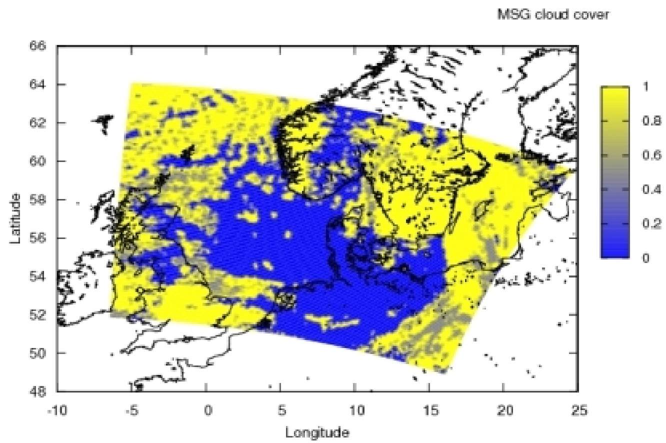


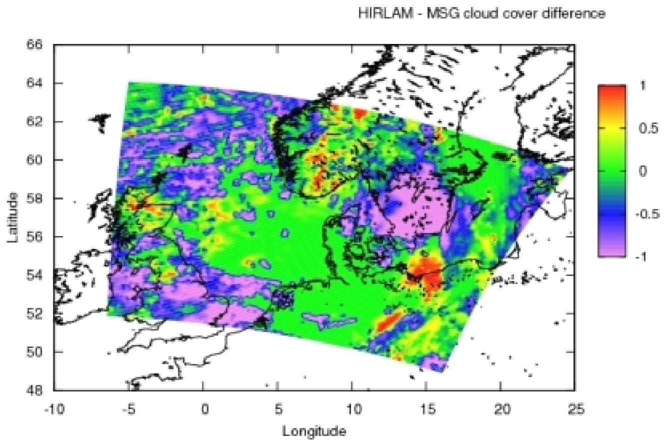


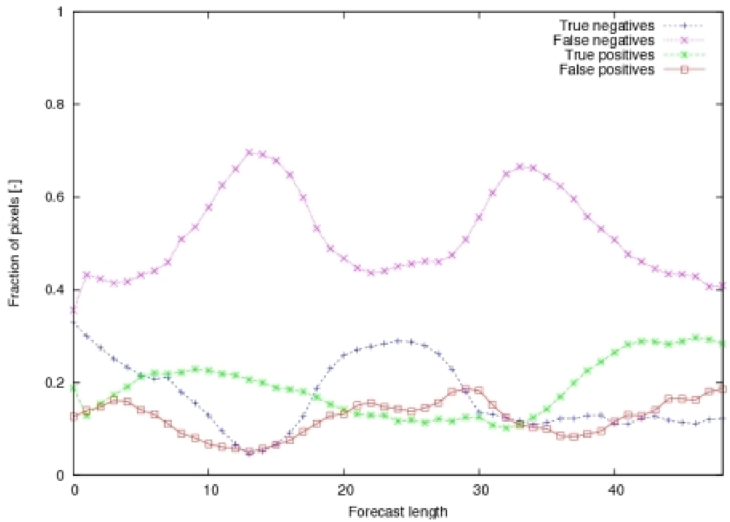
2009-05-08 00:00 +24h forecast

REF-HIRLAM cloud cover









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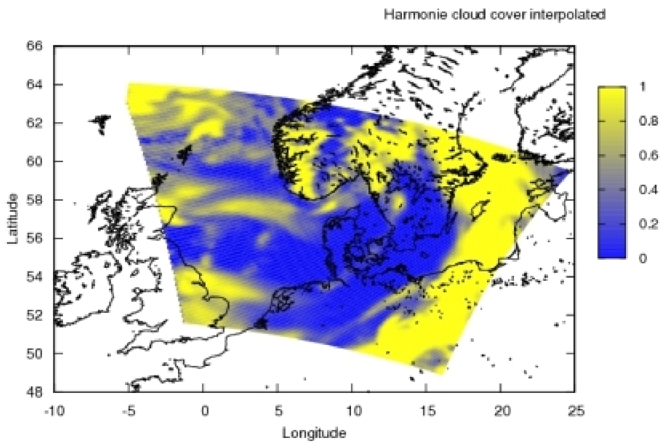
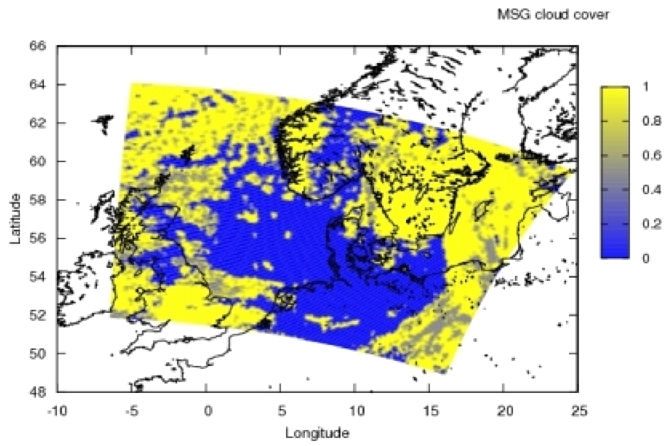
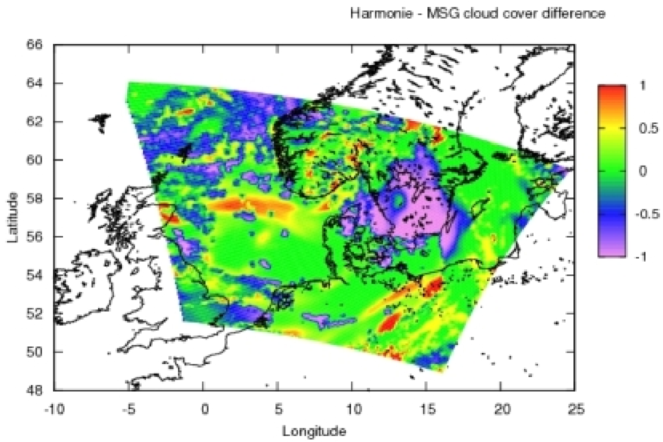
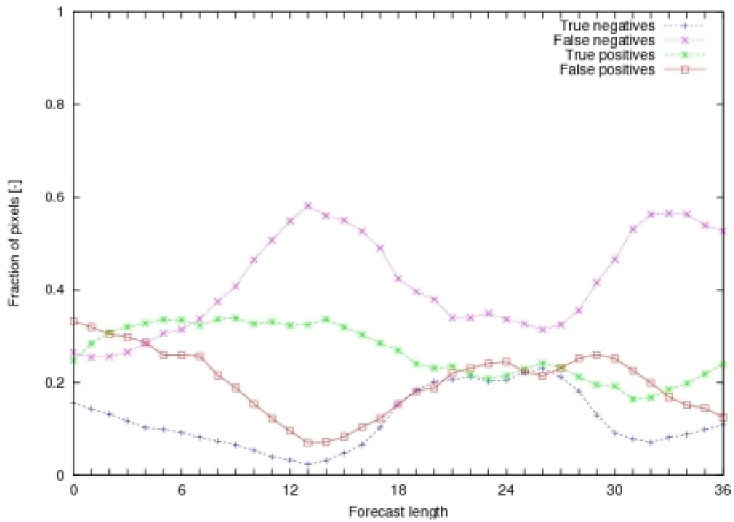
ALADIN cloud cover









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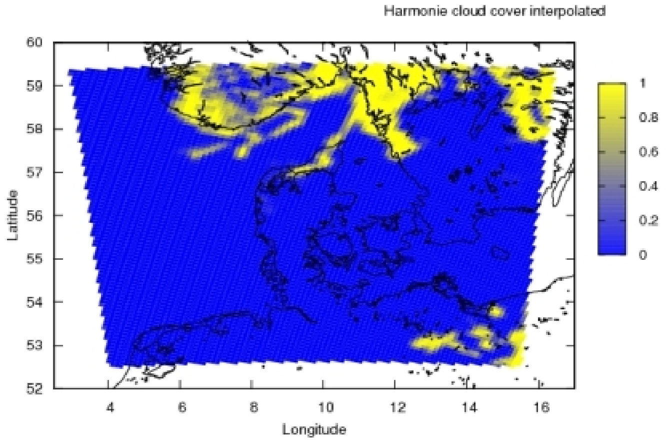
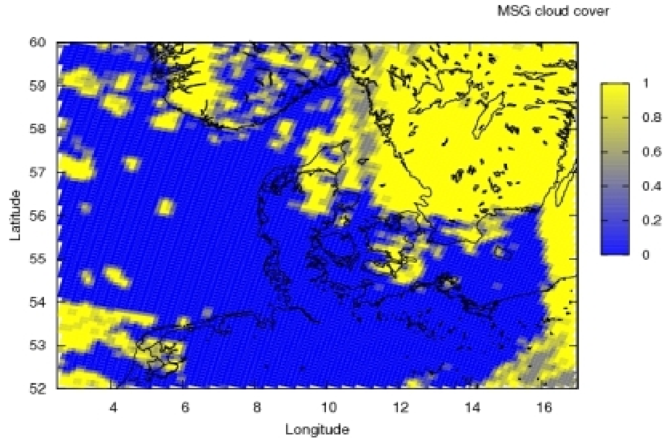
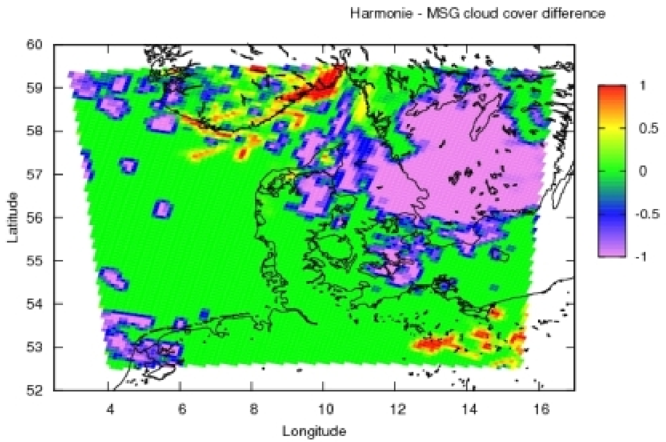
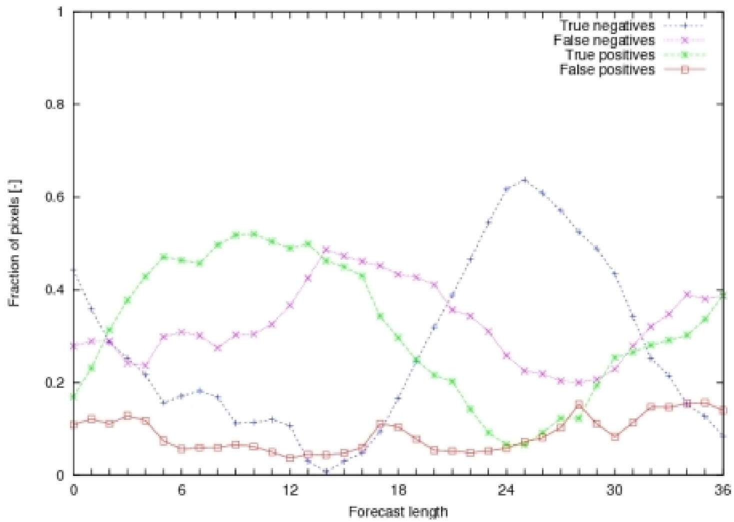
AROME cloud cover







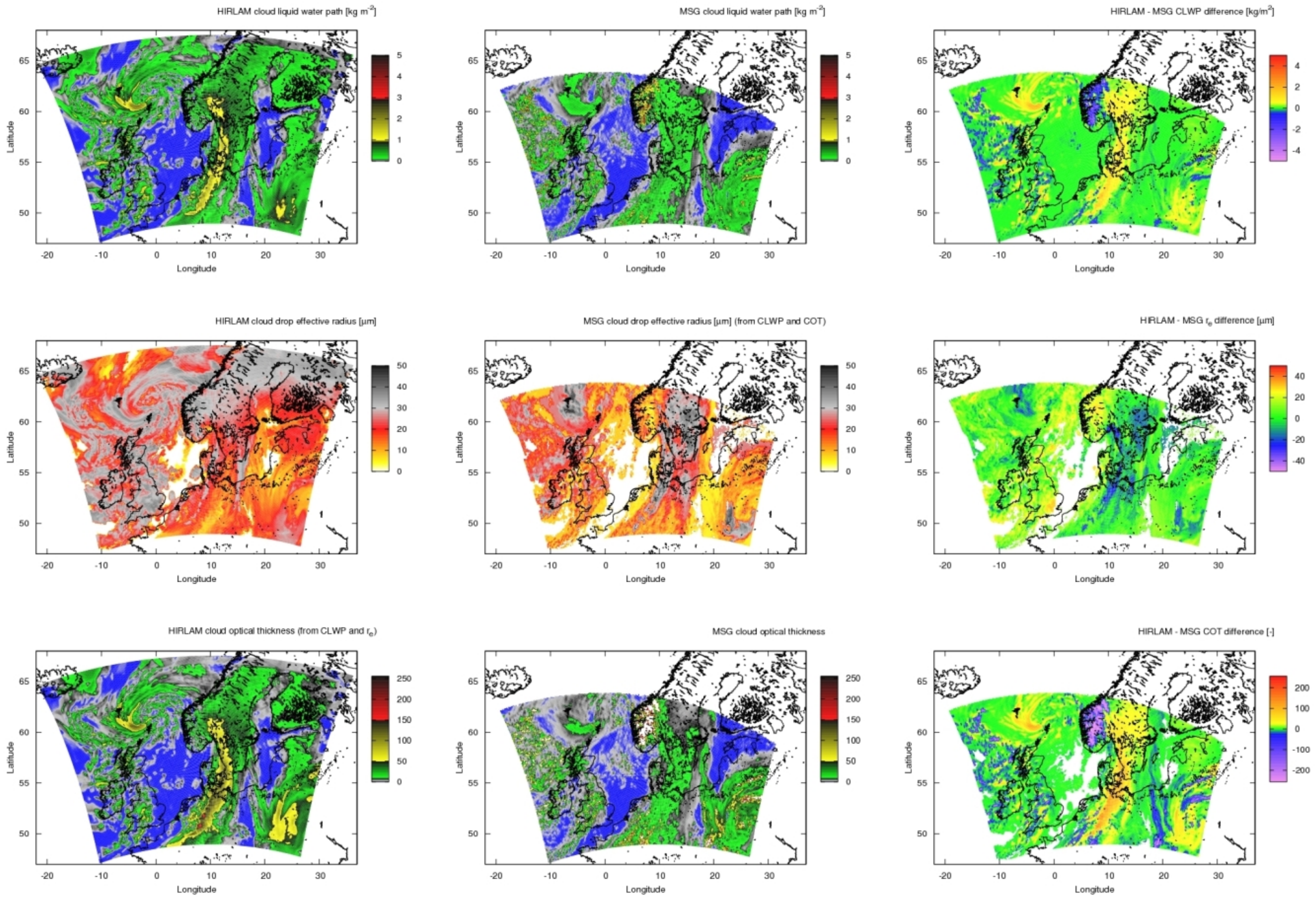


2009-05-08 00:00 +24h forecast

Discussion (1)

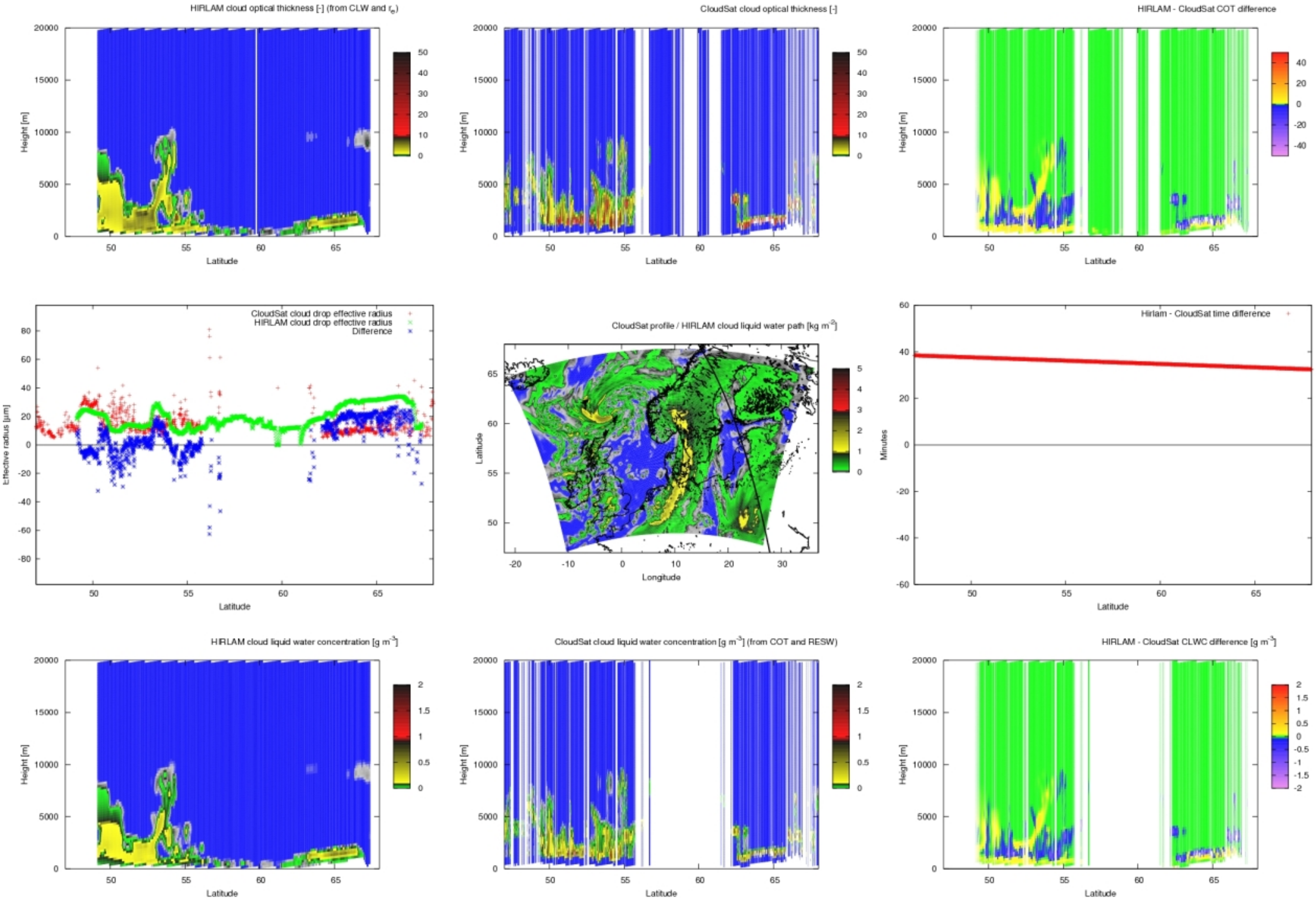
- Cloud cover is a 2-dimensional dataset;
- No information on cloud optical thickness;
- Discrete data:
  1. Cloud free;
  2. Partly cloudy;
  3. Cloudy.
- . . . difficult to verify quantifically.

DMI-HIRLAM & MSG CPPs



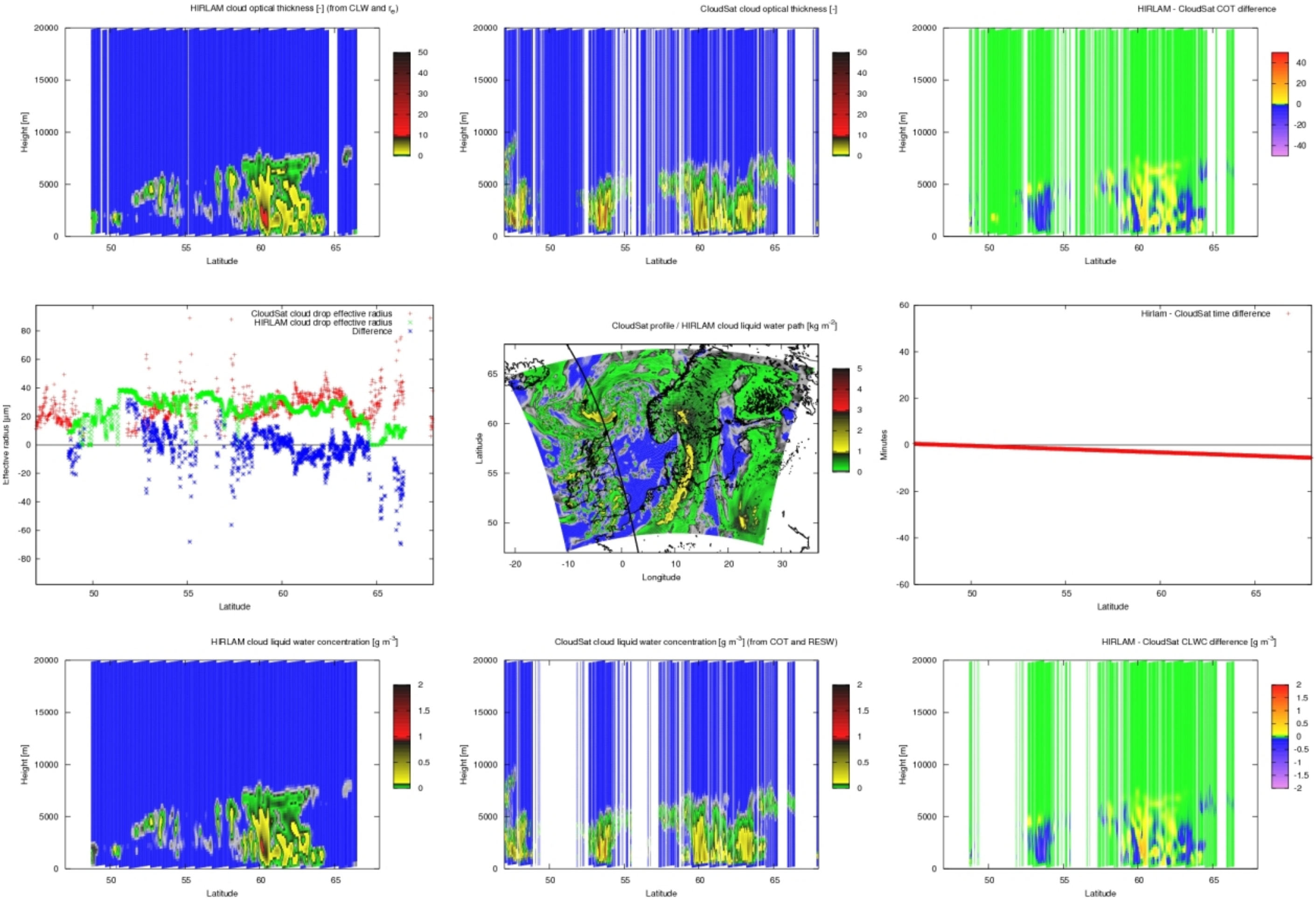
2009-03-08 00:00 +12h forecast

DMI-HIRLAM & CloudSat CPPs



2009-03-08 00:00 +12h forecast

DMI-HIRLAM & CloudSat CPPs



2009-03-08 00:00 +13h forecast

Discussion (2) / Conclusion

- **New satellite products with CPPs have great potential for NWP verification;**
- **Continous variables - can be quantified;**
- **Possible MSG CPP issues:**
  - **Snow cover in northern Scandinavia?**
  - **Low sensitivity to high optical thickness ($\tau > 50$)?**
- **Vertical variations of r_e not (yet) available;**

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Acknowledgements

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- Kai Sattler, DMI.
- Rainer Hollman, DWD.
- Rob Roebeling, KNMI.
- CloudSat Data Processing Center.

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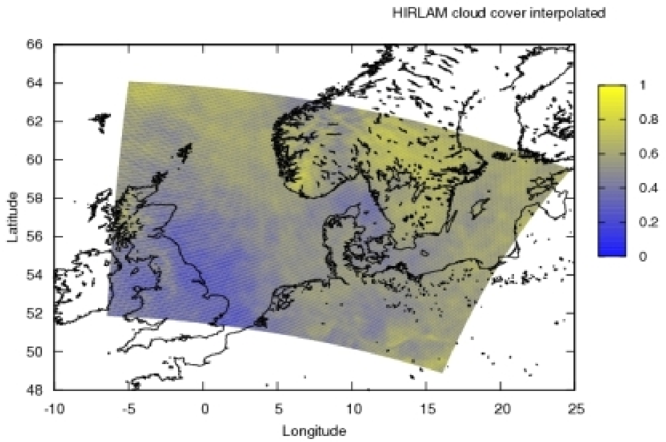
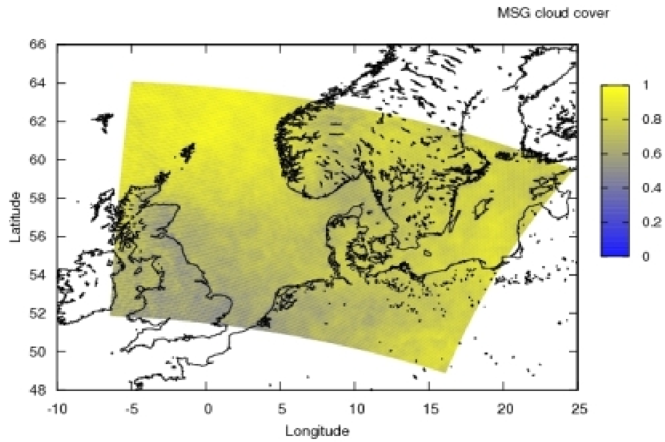
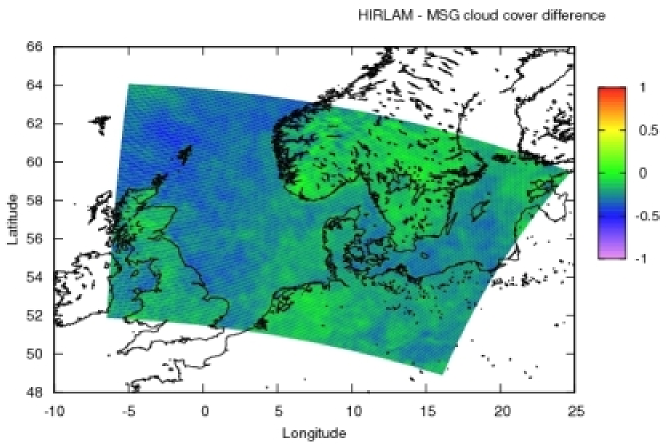
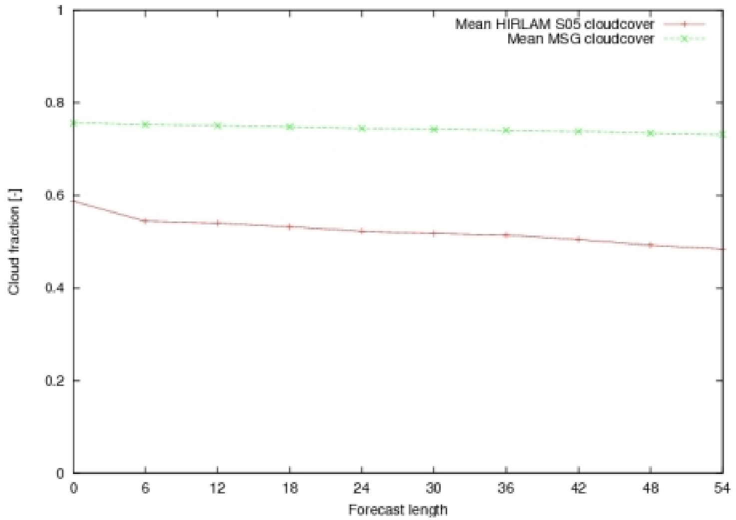
DMI-HIRLAM cloud cover









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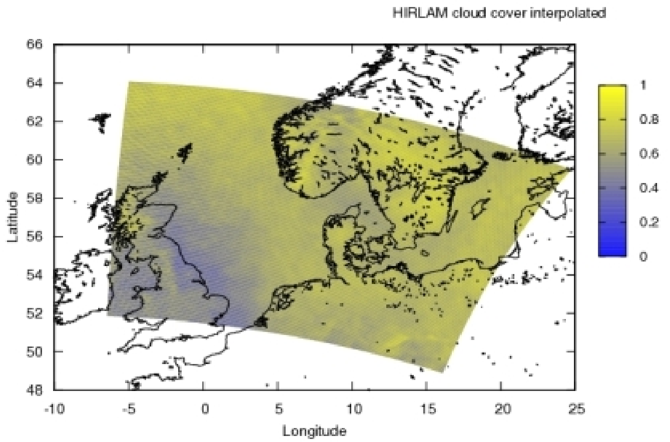
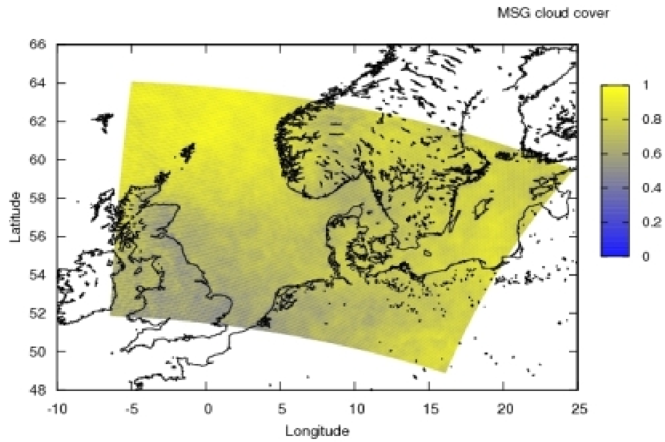
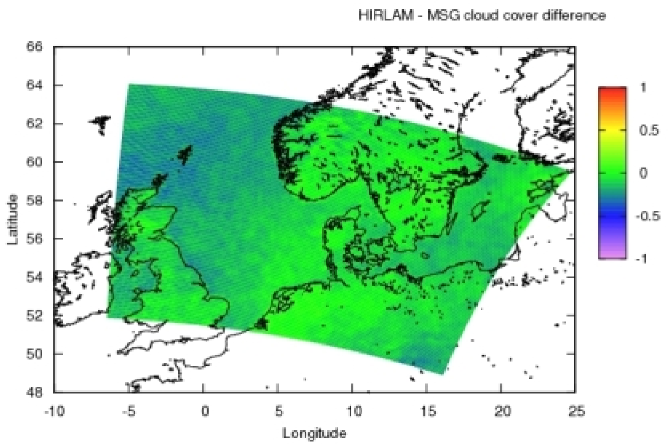
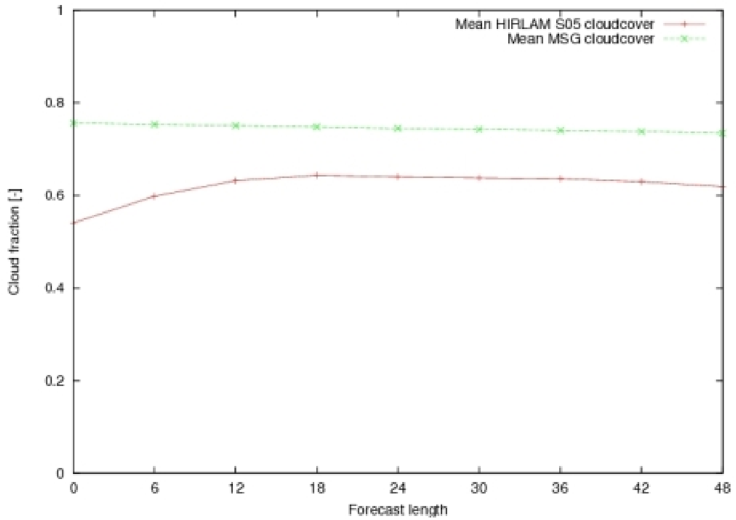
REF-HIRLAM cloud cover









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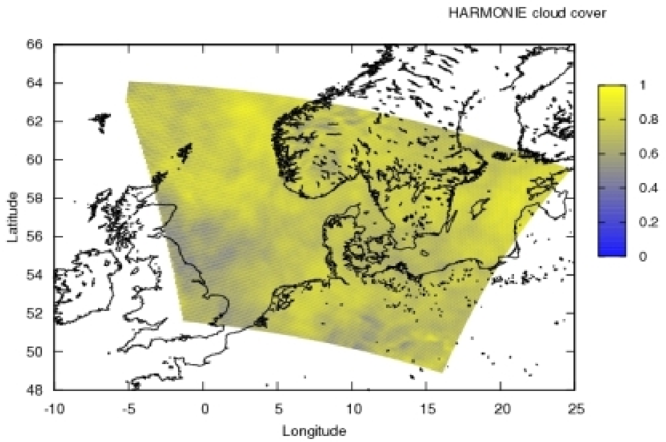
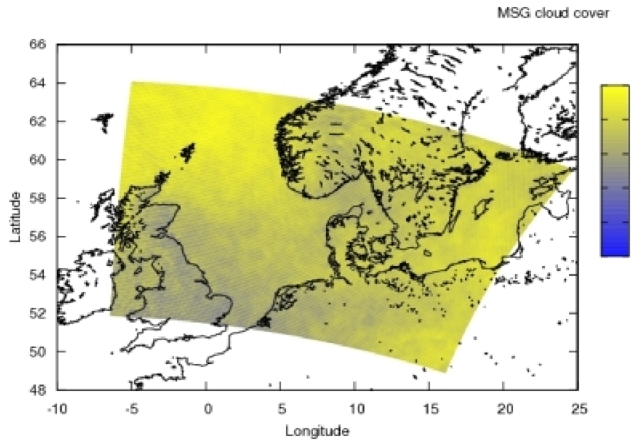
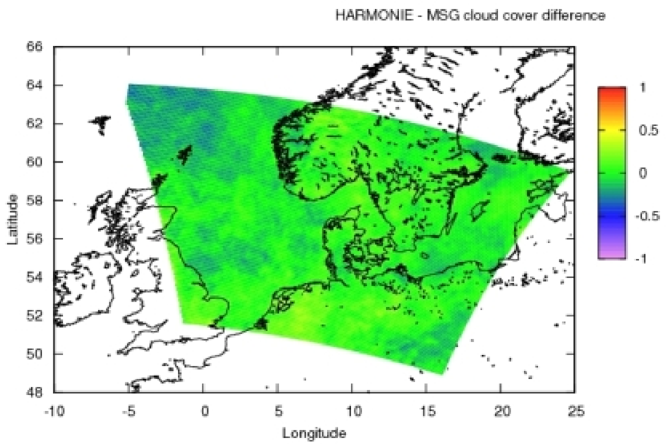
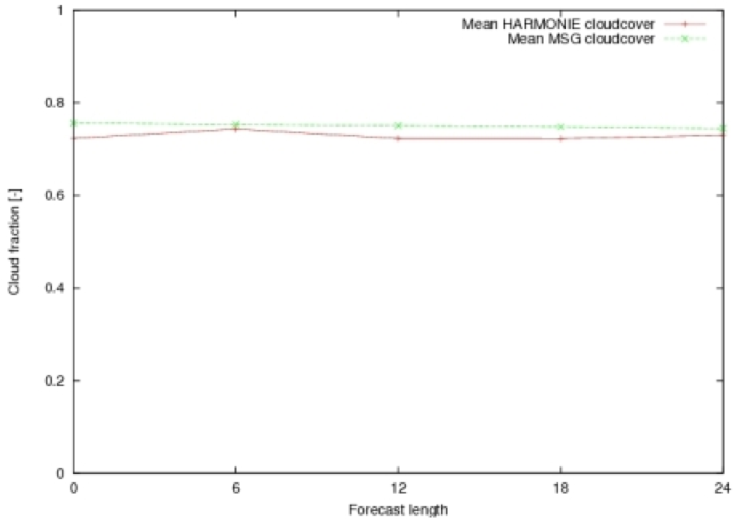
ALADIN cloud cover









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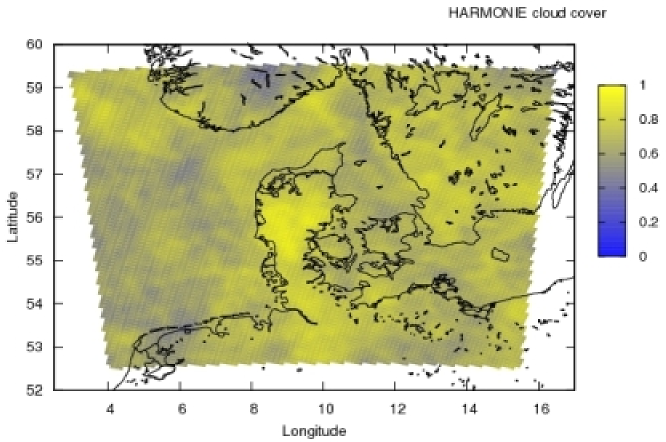
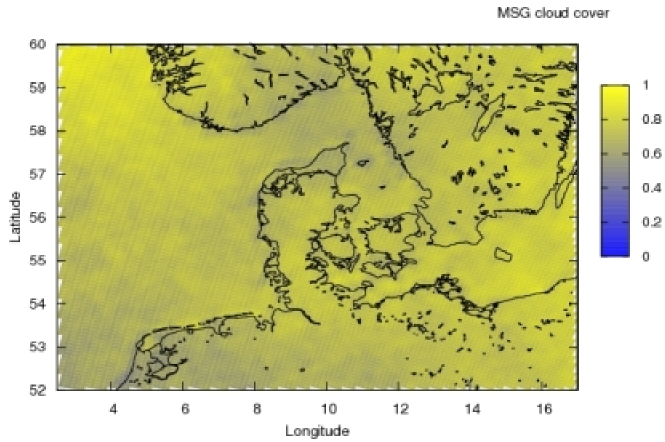
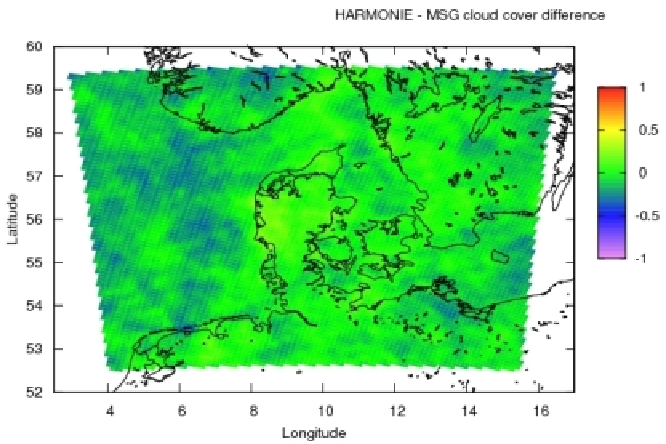
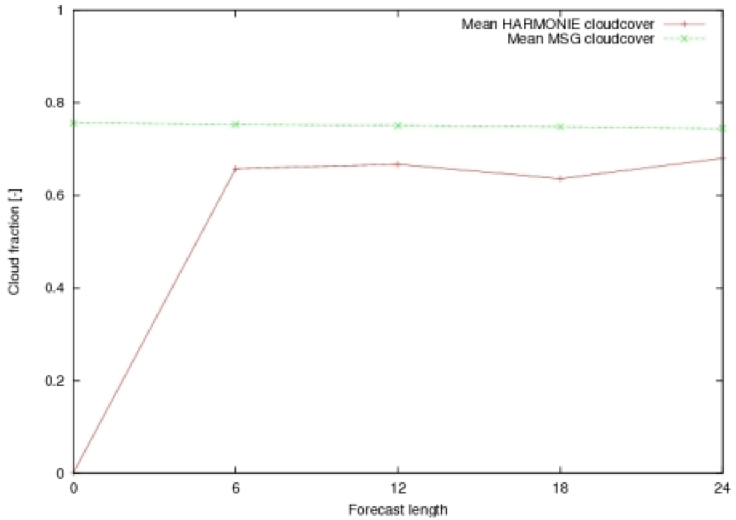
AROME cloud cover









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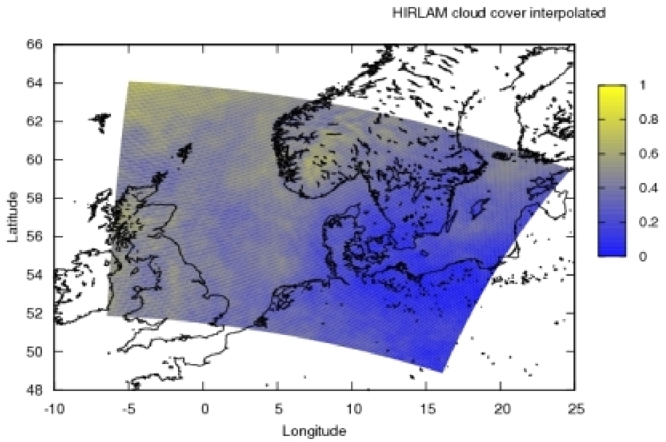
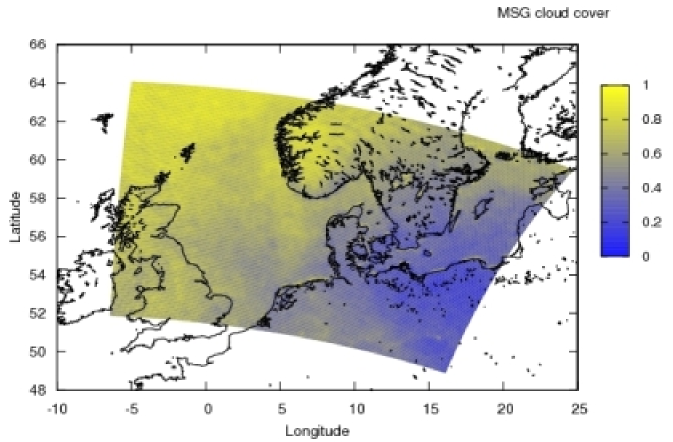
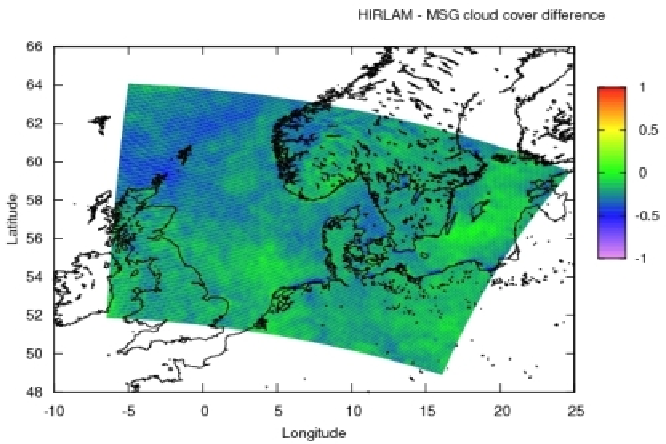
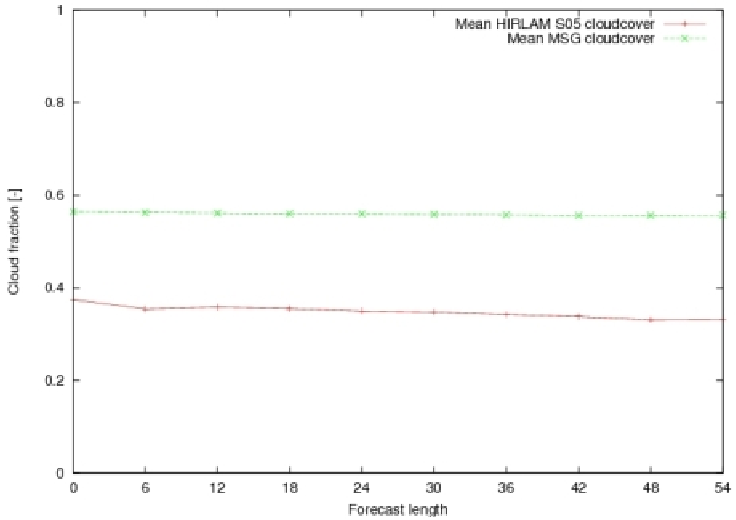
DMI-HIRLAM cloud cover









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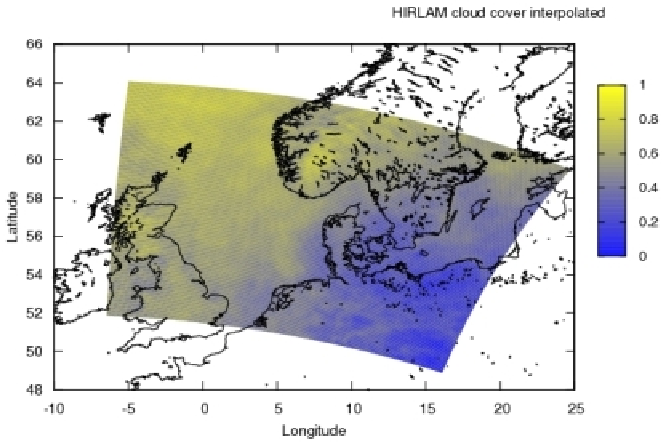
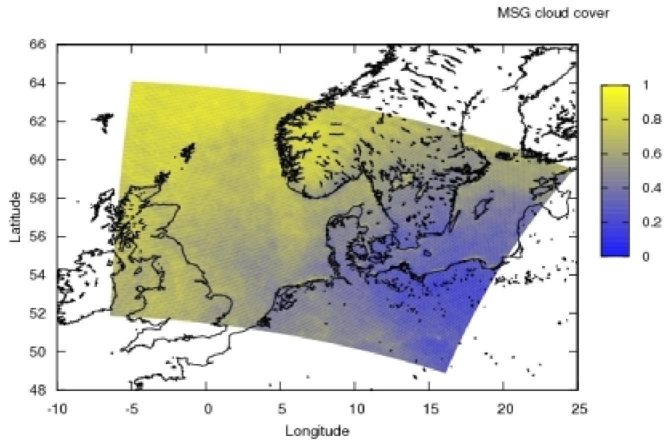
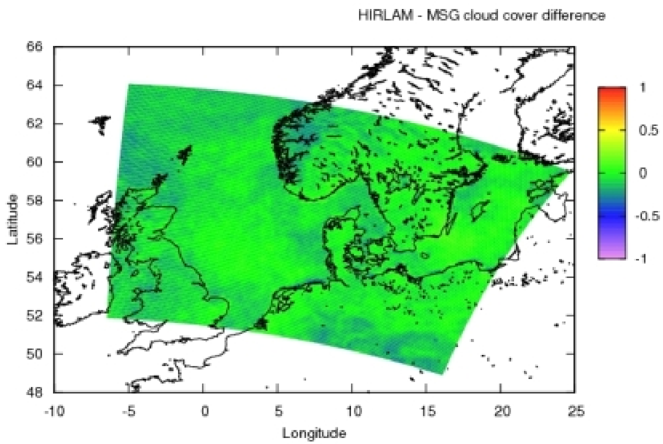
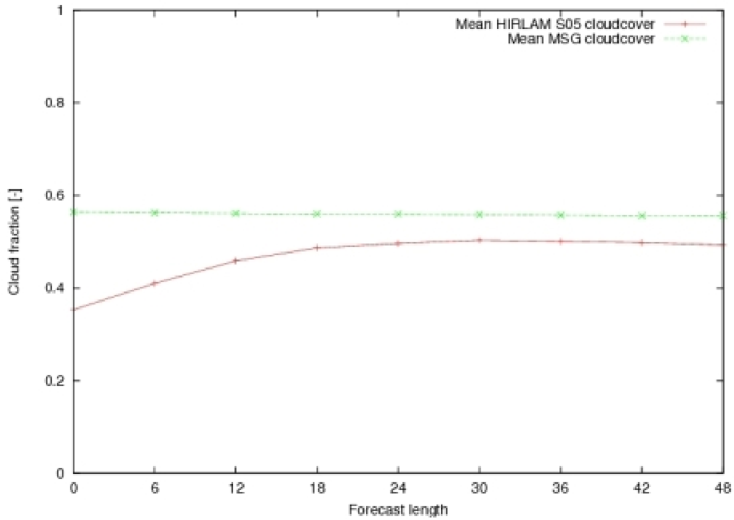
REF-HIRLAM cloud cover









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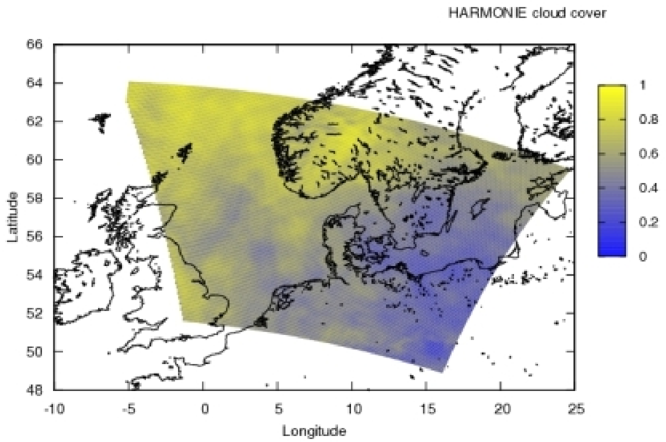
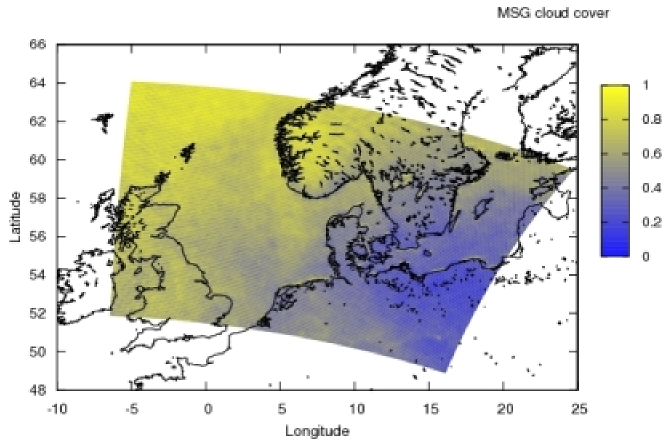
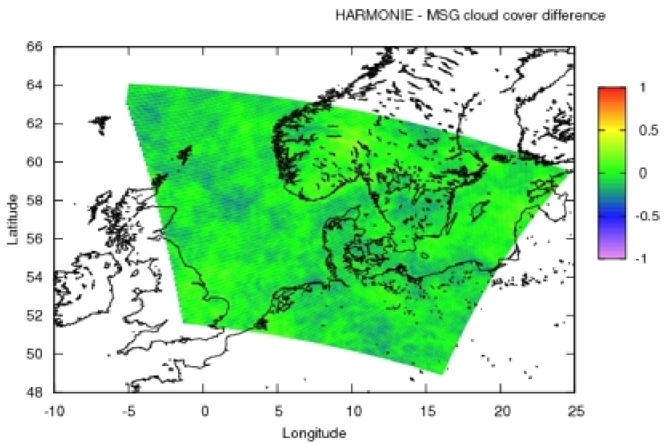
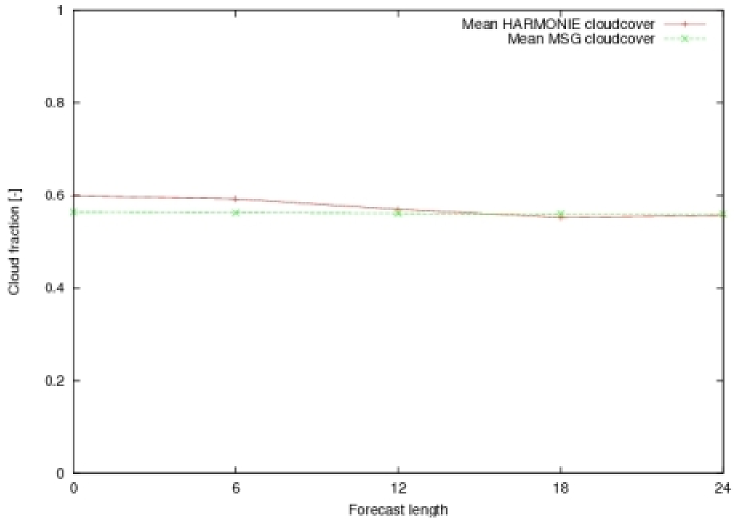
ALADIN cloud cover









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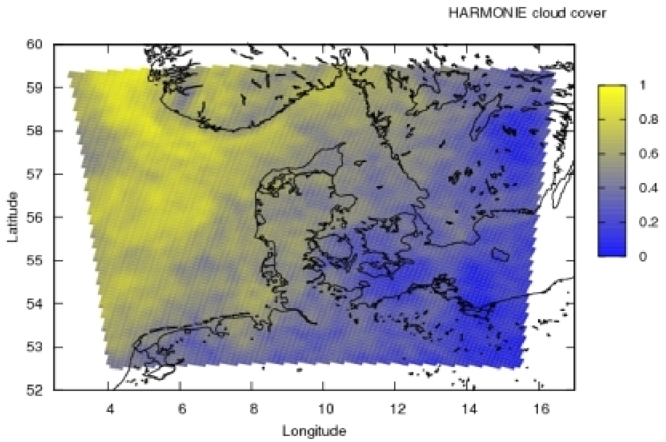
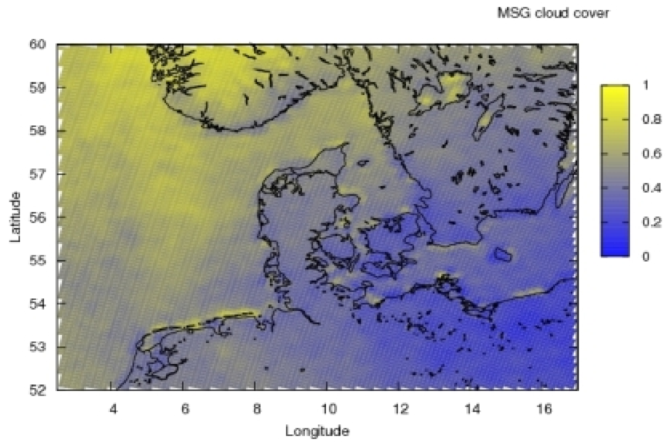
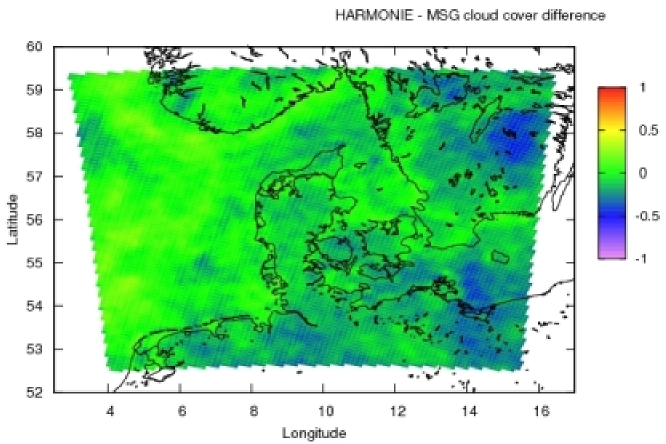
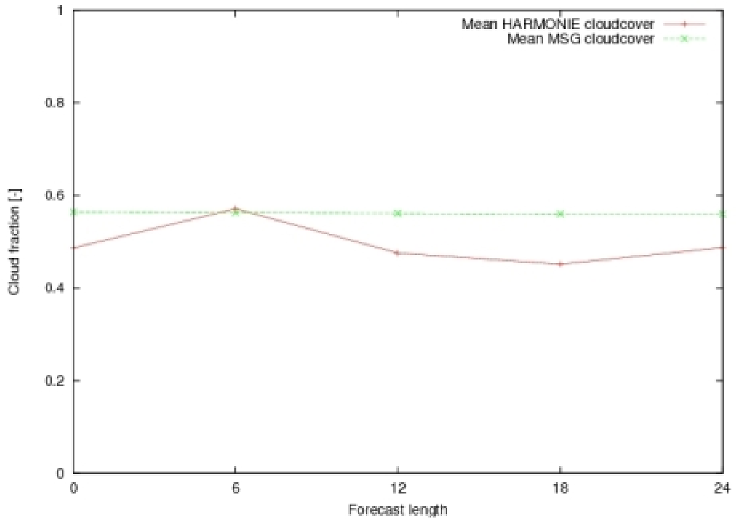
AROME cloud cover









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