Towards an improved representation of Fog and Low Stratus in the Swiss numerical weather prediction models

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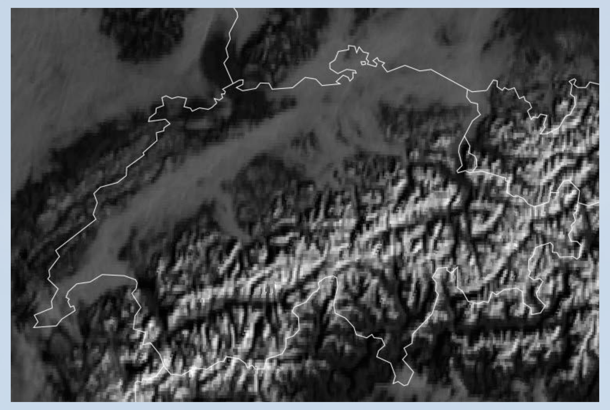
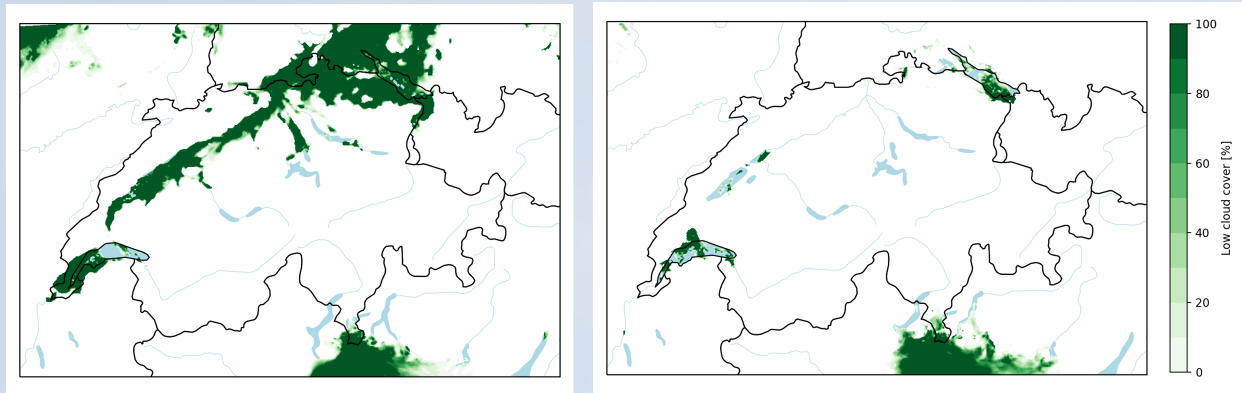
1.Why are Fog and Low Stratus (FLS) important?

- Landing capacity at Zürich airport reduced from 40 to 28 airplanes per hour in foggy conditions.
- Forecasters at MeteoSwiss have to predict visibility very accurately (~100s of meters) hours to days ahead.
- High-resolution numerical weather prediction model: COSMO-1 (1km horizontal and 20m vertical resolution in lowest model layers).
- Fog and low stratus (FLS) often underestimated.
- No output variable «visibility» yet available.


1a: High-resolution visible channel 25 Dec 2017, 12UTC.


1b: COSMO-1 Low Cloud Cover 25 Dec 2017, 09UTC (left) resp. 12UTC (right).

2. How to evaluate FLS forecasts?

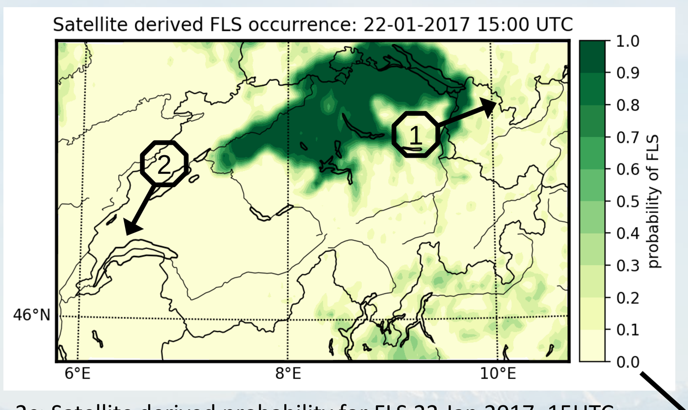
Goal: An objective spatial verification applicable to both case studies and longer forecast periods.

- Liquid cloud confidence level from Meteosat Second Generation infrared channels (Cermak, personal communication).
- Filter for high and medium clouds from Nowcasting Satellite Application Facility Cloud Type product.
- Modelled integrated liquid cloud water.
- Fractions skill score (Roberts, 2008).

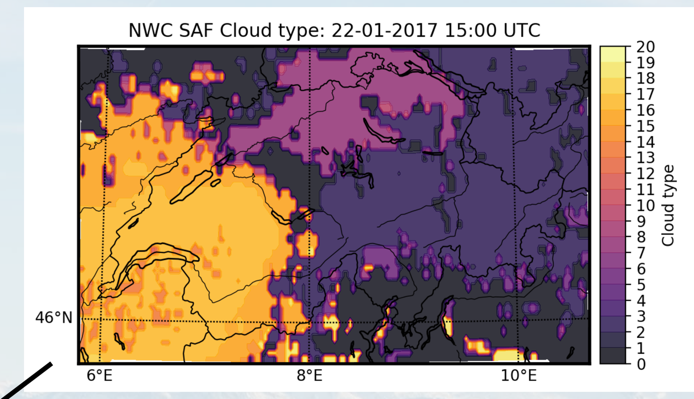
Observations: Satellite imagery


2a: Webcam showing the foggy Rheintal 22 Jan 2017, 15 UTC.

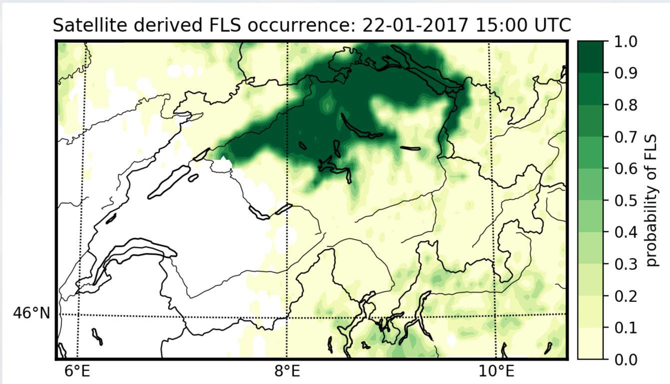

2b: Webcam showing the foggy Plateau 22 Jan 2017, 15 UTC.



2c: Satellite derived probability for FLS 22 Jan 2017, 15UTC; 1 & 2 showing the location and direction of the Webcams.

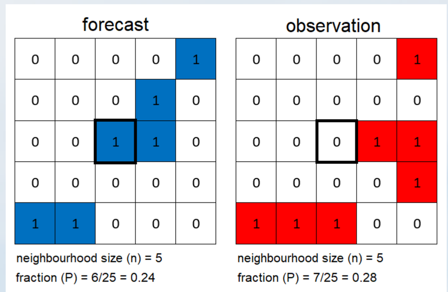


2d: Satellite derived cloud typesFLS 22 Jan 2017, 15UTC; cloud types > 8 showing mid- and high-level clouds.



2e: Satellite derived probability for FLS 22 Jan 2017, 15UTC; Pixels covered by mid- and high-level clouds are filtered.

Fractions skill score (FSS)



2f: How to calculate the fraction of gridpoints exhibiting a «signal».

Fractions Skill Score (FSS)

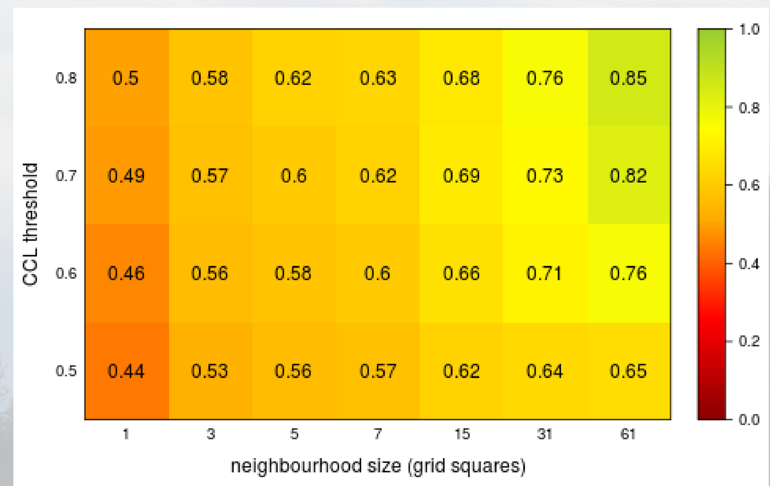
A scale-selective verification method based on the Fractions Brier Score (FBS).

A threshold is applied to both forecast and observation to obtain binary fields.

The ratios, O(bservation) and F(orecast), of grid points exceeding this threshold in the neighbourhood of each grid point are compared for all grid points and varying neighbourhood sizes (defined by N).

$$FSS = 1 - \frac{FBS}{FBS_{worst}} \quad \text{with} \quad FBS = \frac{1}{N}\sum_{j=1}^{N}(O_j - F_j)^2 ,$$

$$FBS_{worst} = \frac{1}{N}\left[\sum_{j=1}^{N} O_j^{\,2} + \sum_{j=1}^{N} F_j^{\,2}\right]$$



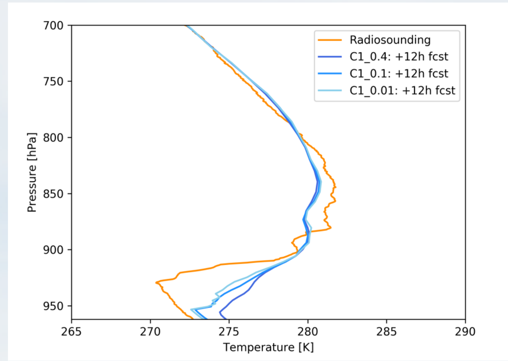
2g: Fractions skill scores for COSMO-1 integrated liquid cloud water forecasts during Dec 2016.

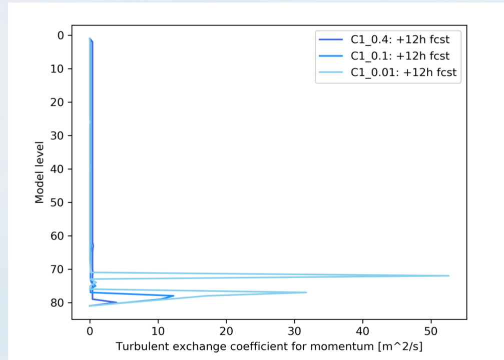
3. How to improve FLS forecasts?

Goal: Improving COSMO-1 FLS forecasts up to 24h ahead: Formation, dissipation, extent of clouds as well as horizontal visibility.

- Case 25 Dec 2017: COSMO-1 wrongly dissipated FLS during morning hours -> Reducing vertical minimum turbulent diffusion coefficients (from 0.4 to 0.1 and 0.01) helps to maintain temperature inversion but numerical instabilities occur.

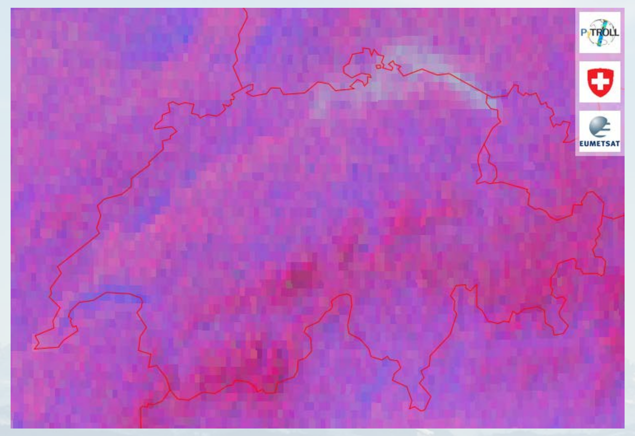
3a: Temperature profile at Payerne 25 Dec 2017; measured (orange), modeled by COSMO-1 (blue) for varying TKHmin and TKMmin-values.

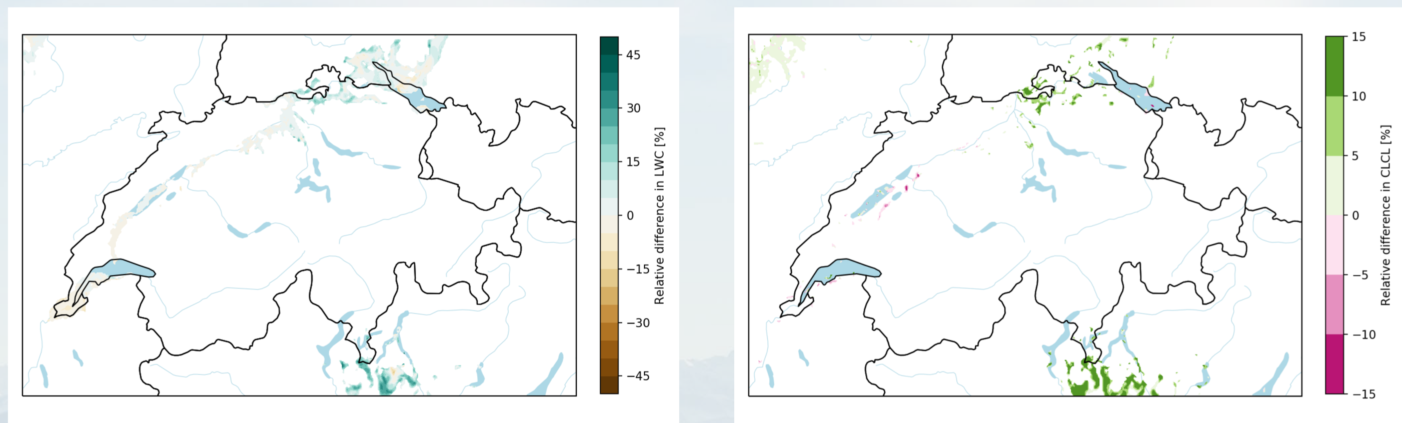




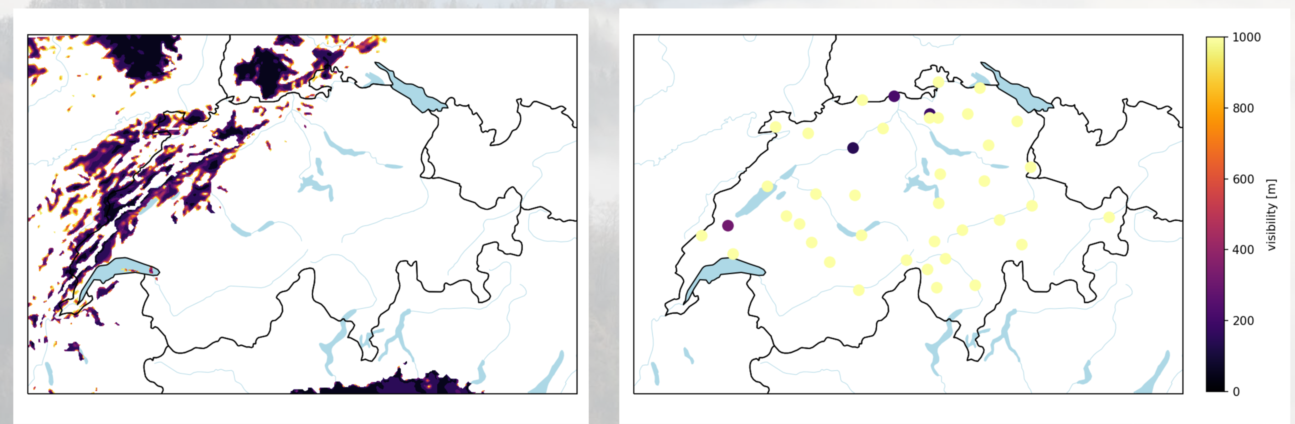
3b: Profile for the turbulent exchange coefficient for momentum at Payerne 25 Dec 2017.

- Case 16 Oct 2017: COSMO-1 overestimated FLS on western Plateau -> Not assimilating 2m relative humidity shows small effect in lowest model layers.


3c: Night microphysics MSG image 16 Oct 2017.


3d: Relative difference in liquid water content (left) and low clouds (right) when 2m relative humidity measurements are excluded in data assimilation 16 Oct 2017, 00 UTC + 3h forecast.

- Case 29 Jan 2018: Visibility diagnostic based on liquid water content (Gultepe, 2006; after Kunkel, 1984) fails to give an accurate forecasts within 1km visibility -> Test PAFOG two-moment microphysics scheme (Bott and Trautmann, 2002).


3e: Horizontal visibility at the ground 29 Jan 2018, 00 UTC +2h forecast ; modeled by COSMO-1 (left) and measured (right).

COSMO-1 microphysics	PAFOG microphysics
one-moment scheme: mass concentration	two-moment scheme: mass and cloud droplet number conc.
infinite number of cloud condensation nuclei available	number of activated nuclei is calculated
saturation adjustment	supersaturation required for droplet activation
rain, snow and graupel fall to the ground	sedimentation of cloud droplets

References
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Kunkel, B. A. (1984). Parameterization of droplet terminal velocity and extinction coefficient in fog models. *Journal of Climate and applied meteorology*, *23*(1), 34-41.
Gultepe, I., Müller, M. D., & Boybeyi, Z. (2006). A new visibility parameterization for warm-fog applications in numerical weather prediction models. *Journal of applied meteorology and climatology*, *45*(11), 1469-1480.
Roberts, N. (2008). Assessing the spatial and temporal variation in the skill of precipitation forecasts from an NWP model. *Meteorological Applications*, *15*(1), 163-169.