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Federal Department of Home Affairs FDHA
Federal Office of Meteorology and Climatology MeteoSwiss

Data Assimilation Activities at MeteoSwiss

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MeteoSwiss

COSMO General Meeting, 14.–18.9.2026, Rome



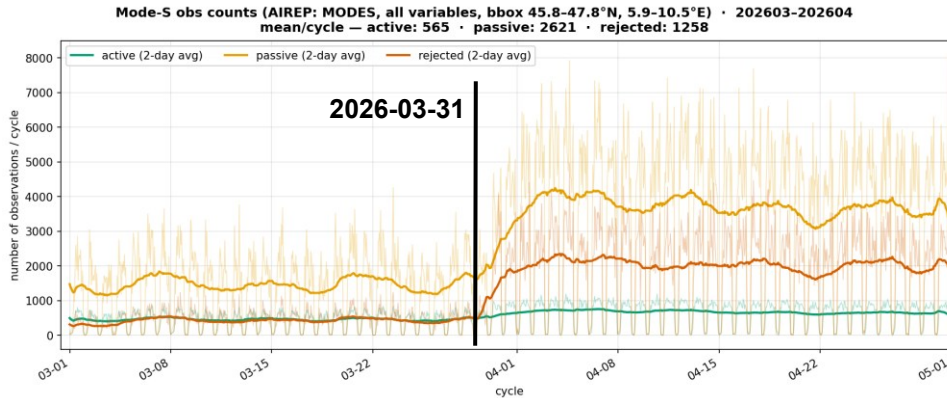
Overview

- Operational changes
- 3D Radar volume assimilation of Swiss Radars
- Clouds in KENDA-CH1
- Plans for next COSMO year

Operational Changes to KENDA-CH1

- 2026-03-31: Swiss MODE-S receivers
- 2026-08-12: Introduction of APT

Number of MODE-S obs over Switzerland





Adaptive Parameter Tuning Setup

- Tuned parameters using T2m and RH2m obs increments
 - Evapotranspiration
 - Heat conductivity and capacity
 - Land and snow albedo
 - Near-surface minimum diffusion
 - Soil moisture
- Surface friction tuning has not yet worked satisfactorily in complex terrain and is thus currently not used
- Wind assimilation still restricted to stations below 100masl
- E-suites for 6-week Summer and 2-week Winter periods

Adaptive Parameter Tuning Results

ICON-CH1-EPS

PARAMETER	ASTDE / REF STDE						Δ[ME] POOLED / REF STDE					
	SP		AV		AM		SP		AV		AM	
	01-12	13-24	01-12	13-24	01-12	13-24	01-12	13-24	01-12	13-24	01-12	13-24
T_2M	-8%	-6%	-5%	-6%	-1%	-2%	-1%	+1%	-13%	-6%	-10%	-7%
TD_2M	-3%	+1%	+4%	+4%	-2%	-3%	+5%	-15%	-14%	-16%	-3%	-0%
RELHUM_2M	-8%	-4%	-2%	-2%	-3%	-3%	-8%	-23%	-30%	-33%	-6%	-3%
PS	-4%	-2%	-0%	-1%	-2%	-2%	-4%	-13%	-5%	-8%	-4%	-4%
PMSL	-2%	-4%	+2%	-2%	n.a.	n.a.	+4%	+11%	+11%	+15%	n.a.	n.a.
CLCT	+1%	-2%	-1%	-1%	-3%	-0%	+1%	+1%	+0%	-1%	+0%	-2%
GLOB	-2%	-1%	-0%	-0%	-1%	-2%	+1%	+2%	-2%	-2%	-1%	+1%
DURSUN1	-0%	-0%	-0%	-0%	-2%	-1%	+1%	+2%	-0%	-1%	+1%	+0%

Summer

PARAMETER	ASTDE / REF STDE						Δ[ME] POOLED / REF STDE					
	SP		AV		AM		SP		AV		AM	
	01-12	13-24	01-12	13-24	01-12	13-24	01-12	13-24	01-12	13-24	01-12	13-24
T_2M	-0%	-2%	-3%	-0%	+1%	-0%	+22%	+20%	-37%	-28%	-6%	-4%
TD_2M	-0%	-4%	+3%	+3%	-1%	+1%	-32%	-38%	-5%	-12%	+1%	+1%
RELHUM_2M	-2%	-4%	-2%	-2%	-2%	+0%	-30%	-30%	-30%	-35%	-0%	+0%
PS	-3%	+0%	-1%	-0%	-1%	+0%	+3%	-1%	-0%	-2%	+3%	+4%
PMSL	-1%	+2%	-2%	-2%	n.a.	n.a.	-4%	-7%	-12%	-16%	n.a.	n.a.
CLCT	-0%	-2%	+0%	-1%	+2%	+0%	+1%	+5%	+0%	+1%	+1%	+1%
GLOB	-0%	-0%	-0%	+1%	-0%	+1%	-2%	-4%	+0%	-0%	-4%	+1%
DURSUN1	+0%	+2%	-0%	-0%	+0%	-2%	+1%	+4%	+0%	+2%	-0%	-0%

Winter

ICON-CH2-EPS

PARAMETER	ASTDE / REF STDE										Δ[ME] POOLED / REF STDE									
	SP				AV				AM		SP				AV				AM	
	01-12	13-24	61-72	109-120	01-12	13-24	61-72	109-120	01-12	13-24	01-12	13-24	61-72	109-120	01-12	13-24	61-72	109-120	01-12	13-24
T_2M	-3%	-4%	-2%	-2%	+3%	+1%	+2%	+1%	+3%	+1%	-0%	-0%	-0%	-0%	+8%	+8%	-4%	+1%	+1%	+5%
TD_2M	-1%	+1%	-0%	+2%	+3%	+4%	+5%	+4%	-2%	-2%	-2%	-2%	-2%	-2%	+8%	-13%	-16%	-12%	+5%	-5%
RELHUM_2M	-4%	-3%	+1%	+1%	+1%	+1%	+2%	+2%	-2%	-2%	-1%	+0%	+0%	+0%	+3%	-19%	-22%	-16%	-15%	-18%
PS	-3%	-6%	-1%	+0%	+0%	-3%	+0%	0%	-1%	-2%	-1%	-0%	-0%	-0%	-3%	+6%	-8%	-3%	+4%	+6%
PMSL	-3%	-7%	-1%	-0%	+1%	-3%	+0%	-0%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	0%	+6%	+8%	+4%	+7%	+10%
CLCT	-0%	-2%	-2%	-1%	-1%	-1%	-0%	-0%	-3%	-2%	-1%	-0%	-0%	-0%	+2%	+2%	+2%	+0%	+0%	-1%
GLOB	-1%	-1%	-3%	-3%	+1%	-1%	-1%	-1%	-0%	-1%	-1%	-1%	-1%	-1%	+1%	+2%	+1%	+1%	-1%	-2%
DURSUN1	+1%	-0%	-2%	-2%	+0%	-1%	+0%	-0%	-0%	-1%	-0%	+1%	+1%	+1%	+1%	+2%	-3%	+1%	+0%	-1%

PARAMETER	ASTDE / REF STDE										Δ[ME] POOLED / REF STDE									
	SP				AV				AM		SP				AV				AM	
	01-12	13-24	61-72	109-120	01-12	13-24	61-72	109-120	01-12	13-24	01-12	13-24	61-72	109-120	01-12	13-24	61-72	109-120	01-12	13-24
T_2M	-1%	-4%	-1%	+0%	-1%	-0%	+2%	+5%	+1%	+1%	+1%	+1%	+1%	+1%	+11%	+11%	-15%	-9%	-36%	-33%
TD_2M	+1%	-3%	-3%	-3%	+5%	+5%	+4%	+5%	+0%	+1%	+1%	+0%	+0%	+0%	-32%	-37%	+19%	+19%	-10%	-15%
RELHUM_2M	-1%	-4%	-3%	-2%	-0%	-2%	-2%	-1%	-1%	-0%	+1%	+0%	+0%	+0%	-31%	-35%	-12%	+7%	-33%	-35%
PS	-2%	-1%	-0%	-0%	+1%	+0%	+1%	+0%	-1%	-1%	+0%	+0%	+0%	+0%	-3%	-7%	-2%	+1%	-7%	-8%
PMSL	-2%	-1%	-1%	-1%	-0%	-0%	+1%	+0%	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	+8%	-12%	-4%	+1%	-18%	-21%
CLCT	-1%	-3%	-1%	-3%	-0%	-0%	-1%	-0%	+2%	+2%	+1%	+0%	+0%	+0%	+1%	+1%	+0%	+0%	+2%	+1%
GLOB	-1%	-1%	-1%	-0%	+1%	+0%	+1%	+0%	-0%	+0%	+1%	+2%	+2%	+2%	-2%	-5%	-3%	-1%	+0%	-0%
DURSUN1	+2%	-0%	-3%	-1%	-1%	-1%	+0%	-0%	+0%	-1%	-0%	-0%	-0%	-0%	+1%	+4%	+3%	+2%	-0%	-1%

SP: Swiss Plateau AV: Alpine Valleys AM: Alpine Mountains

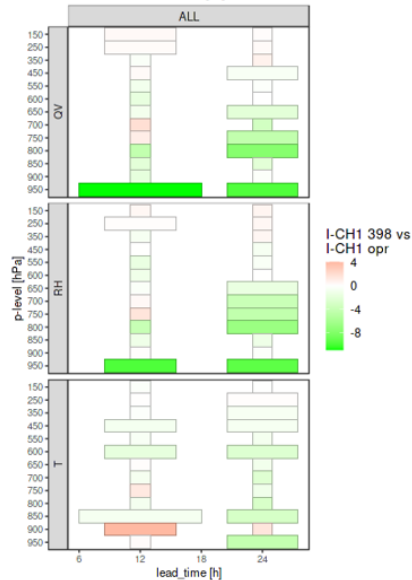


Adaptive Parameter Tuning Results

Summer

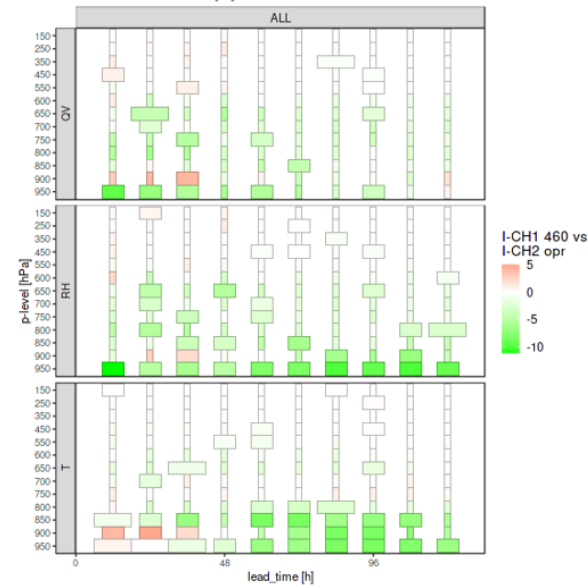
ICON-CH1-EPS

Verification period: 2026/05/13 - 2026/05/27
INI: 00, 12UTC, SIGN, TEST: TRUE
Data selection by initial-date
Reduction of CRPSF [%]



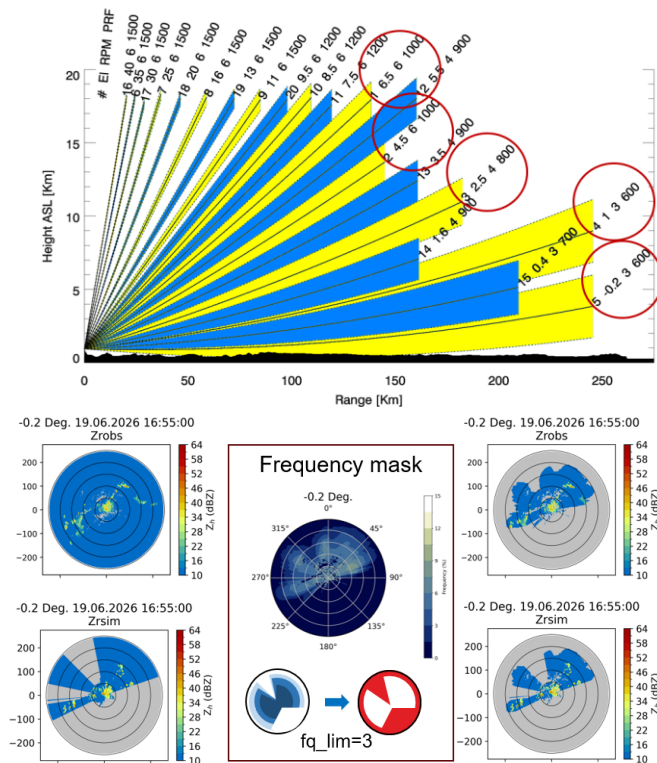
ICON-CH2-EPS

Verification period: 2026/05/13 - 2026/05/27
INI: 00, 12UTC, SIGN, TEST: TRUE
Data selection by initial-date
Reduction of CRPSF [%]





3D Radar DA

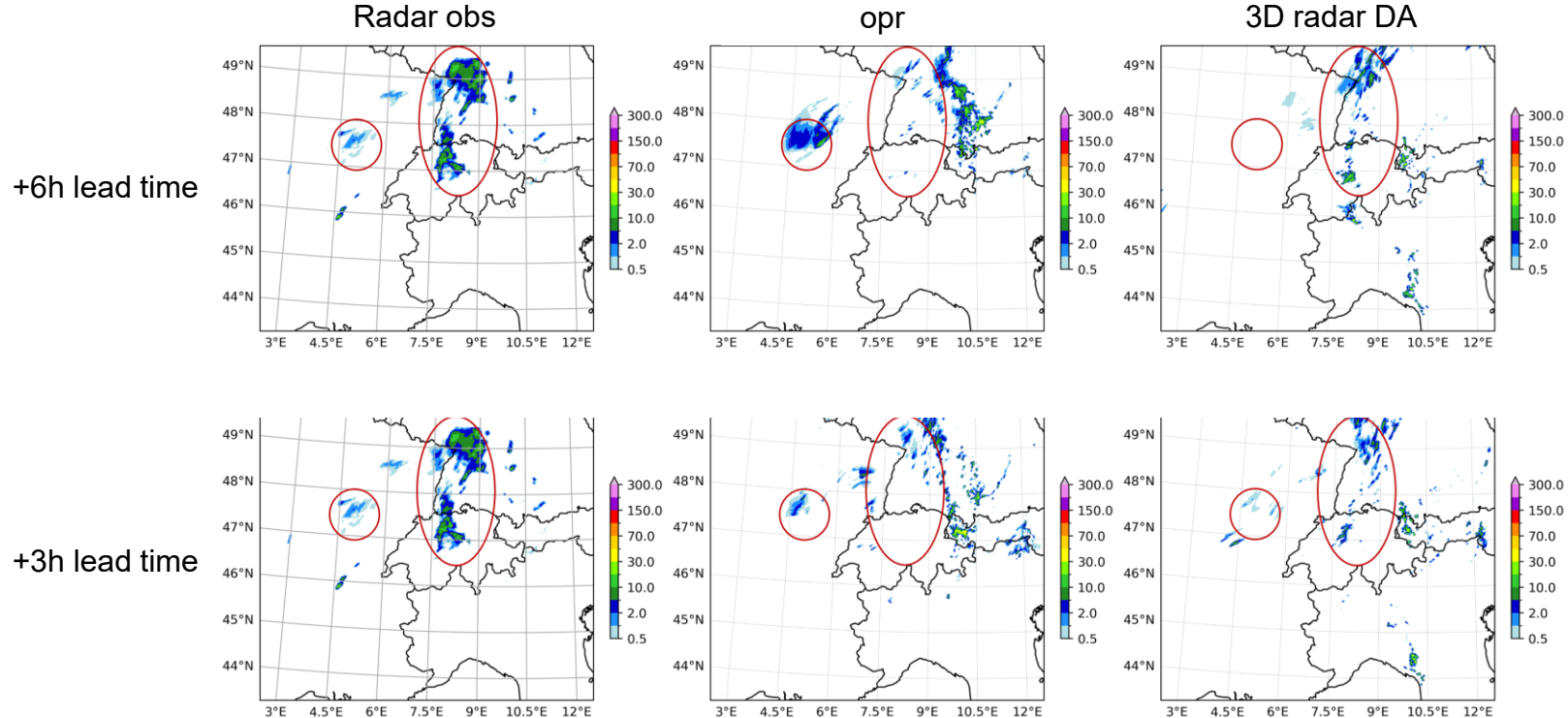


MeteoSwiss

- **KENDA-CH1 with EMVORADO**
ICON-CH1-EPS forecasts (every 3h, +24h)
- **Summer period with diurnal convection**
(18.06.2026 12 UTC - 02.07.2026 12 UTC),
reference: opr
experiment: opr + 3D radar DA
 - 5 elevations, 0 to 9000 m;
 - Obs and sim below 10 dBZ are set to 10 dBZ;
 - Obs pre-processed with freq. maps (threshold = 3);
 - 5 km superobbing, 8 km horizontal localisation;
 - Const obs error of 10 dBZ.

Impact of 3D radar DA on precipitation

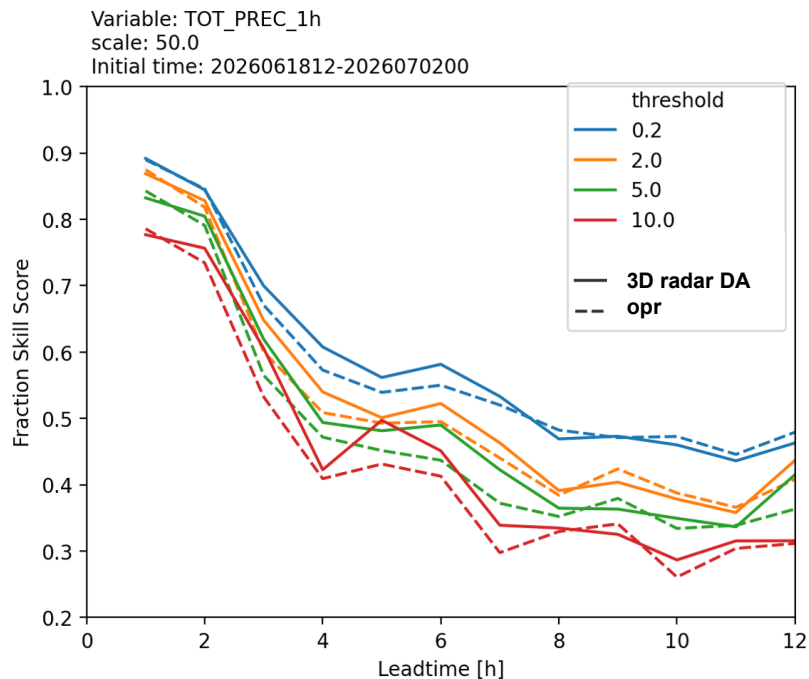
Hourly precip sums from radar and ICON-CH1-CTRL forecasts valid at 2026-06-29 06UTC



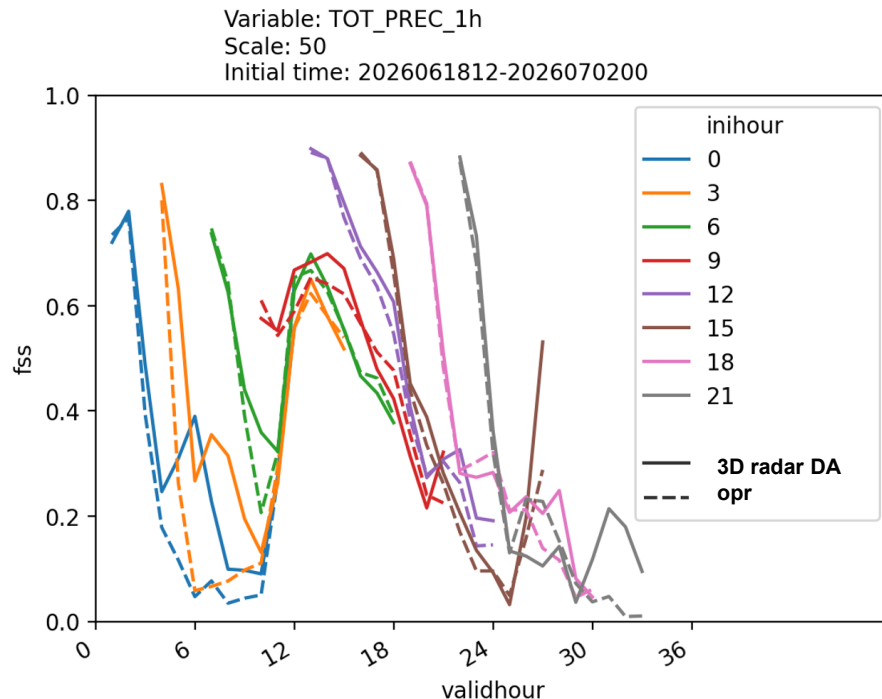


Spatial verification

FSS against the COMBIPRECIP product (radar obs corrected with rain gauges)



MeteoSwiss

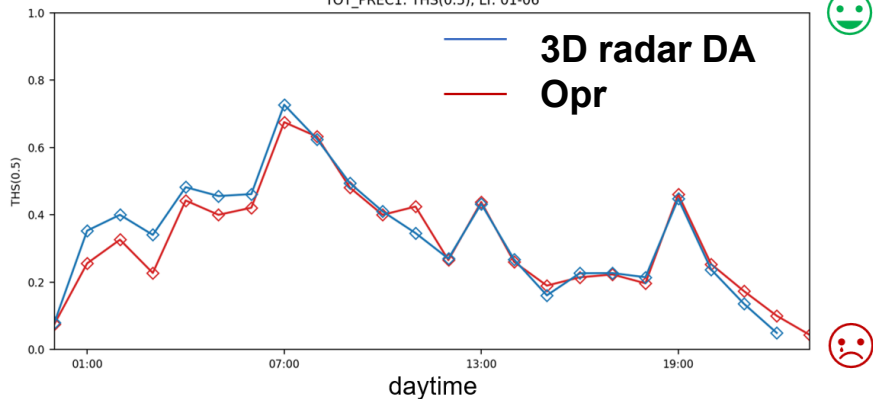




Verification with gauges

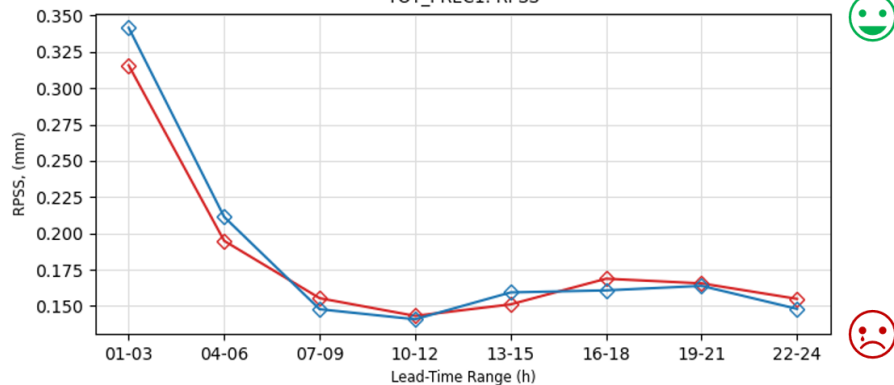
Threat score for 1h total precipitation (0.5 mm),
lead times 01-06 h

TOT_PREC1: THS(0.5), LT: 01-06



Ranked probability skill score
for 1h total precipitation

TOT_PREC1: RPSS



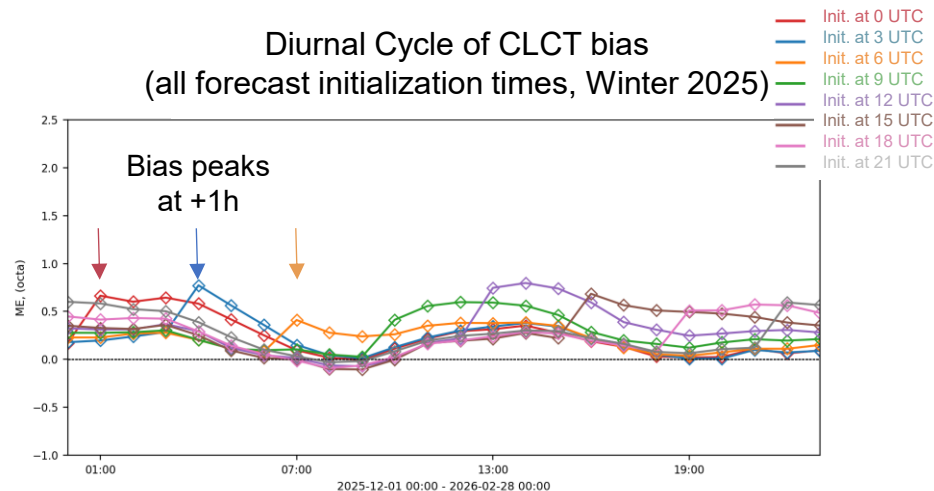


3D Radar DA Conclusions

- Small but consistent improvement in many scores for total precipitation forecast due to radar reflectivity assimilation in the summer convective period.
- Minor impact in the winter period (not shown).
- Reduction of excess light rain in the model.
- Improvement apparent for short lead times (up to +6 h).
- No degradation in other parameters or scores.
- Latent heat nudging is still needed.
- Pre-processing of reflectivity observations with quality flags from frequency maps has been implemented in EMVORADO (merged in master) and is thus available to everyone.

Spin-Down in ICON Cloud Forecasts

- Systematic larger CLCT bias at +1h compared to +24h in ICON forecasts
 - Mainly under stable conditions (e.g. only during night in summer)
 - Not visible for other scores and variables
- Does assimilation of T2m and RH2m negatively impact CLCT under stable conditions?
 - Hypothesis: Sfc observation influences model levels above inversion layer → CLCT performance worsens





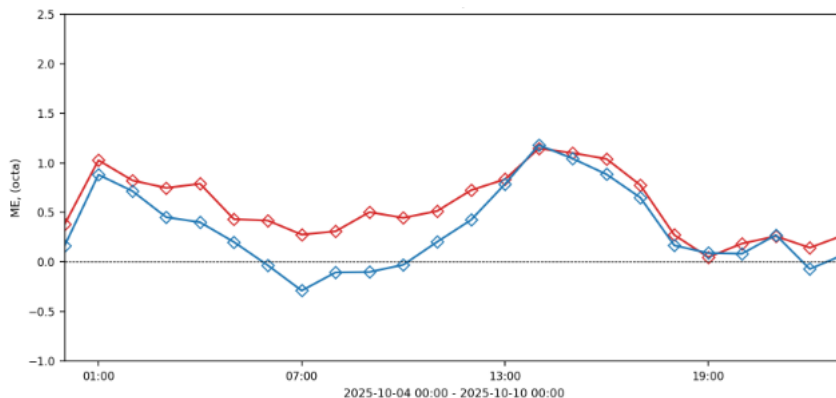
KENDA-CH1 Experiments

- Experiment without T2m and RH2m assimilation
- Selected Period: 4 - 9 Oct. 2025 (features inversions at Payerne and high forecast errors)
- **Results:** Improves CLCT bias diurnal cycle, but negative impact on other scores and variables
 - Particularly also for short- and longwave-radiation and sunshine duration

Diurnal Cycle of KENDA-CH1 CLCT First Guess Bias

Operational Setup (T2m and RH2m assimilated)

Experiment (T2m and RH2m not assimilated)





Further Planned Experiments

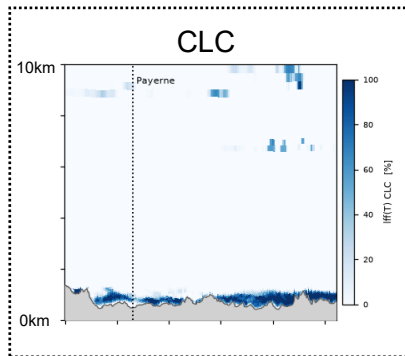
- Investigating first guess, increment and analysis of operational vs. experiment suggests
 1. Spurious QC increments (e.g. adding QC at timesteps where the CLCT bias was already positive) → non-optimal QC covariances in the LETKF?
 2. Mean vertical profiles of QV and QC averaged over the experiment period differ between operational and experimental setup up to several kilometers above ground
- New experiments in pipeline:
 1. Only T2m assimilation (RH2m passive)
 2. Not applying QC increments to KENDA first guess
 3. Reducing the vertical localization radius of T2m and RH2m observations (and perhaps even other variables at 2m) in the LETKF



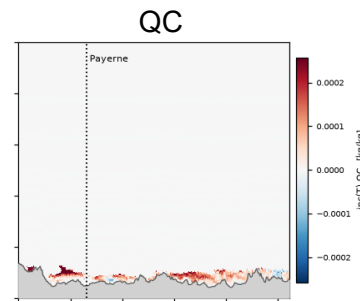
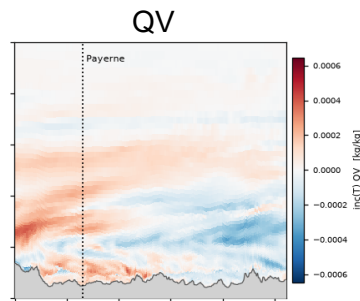
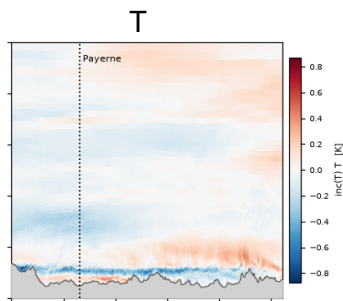
Spurious QC Increments Example

- A vertical cross section of the Swiss Plateau was compared to station CLCT bias over the experiment period for the same geographical region
- **Problem:** In the plot below, the KENDA first guess already overestimates by 1 octa, yet increments add QC where clouds are already present, T and QV do not counteract this
- The phenomenon was repeatedly observed during the experiment period

First Guess



Increments



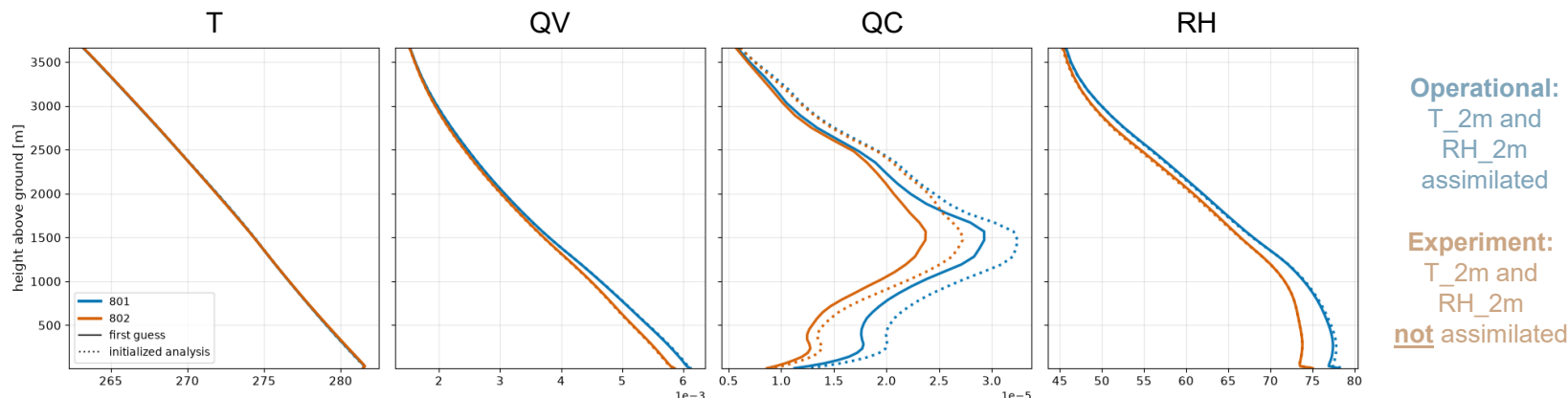
Increase

Decrease



Average Vertical Profiles Comparison of First Guess and Analysis

- **Problem:** When averaged over Switzerland for the experiment period, vertical profiles of cloud relevant variables diverge until several kilometers above ground between operational setup and experiment
- This occurs both for KENDA first guess and initialized analysis





CLCT Verification Using NWCSAF Satellite Cloud Mask

- Preprocessing:
 - Regrid ICON to NWCSAF
 - Parallax correction
 - Remove snow/ice
- NWCSAF is binary, KENDA CLCT is continuous → a threshold τ is used to classify a grid point as cloudy (Crocker & Mittermaier 2013)
- Fit τ to maximise Peirce skill score POD – POFD (Manzato 2007)
 - Sweep τ from 0–100%; call KENDA cloudy where $CLCT \geq \tau$
 - POD = of observed cloud, how much we catch
 - POFD = of observed clear sky, how much we wrongly call cloud
 - Pick τ maximising $J = POD - POFD$ (done separately for night and day)
 - Fit on calibration data (4-6 Oct.), use on held-out data (7-9 Oct.)



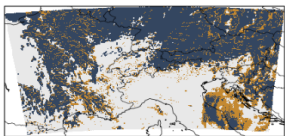
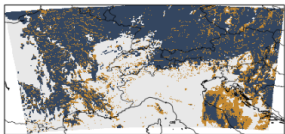
CLCT Verification Using NWCSAF Satellite Cloud Mask

- **Results:** best $\tau = 66\%$ (for daytime) and 77% (for nighttime, not shown here), Example of output for 7 Oct. 07:00 UTC shown below
- Some of the NWCSAF cells become NaN due to the parallax correction (i.e. displaced clouds leave empty cells behind)

Cloudy Cells

NaN Cells
(due to parallax
displacement)

NWCSAF (Processed)



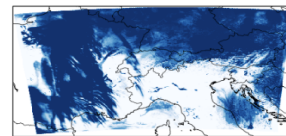
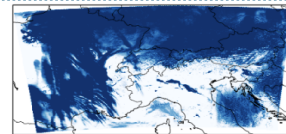
CLCT $\geq 66\%$ $\rightarrow$ Cloud



CLCT $\geq 12.5\%$ $\rightarrow$ Cloud

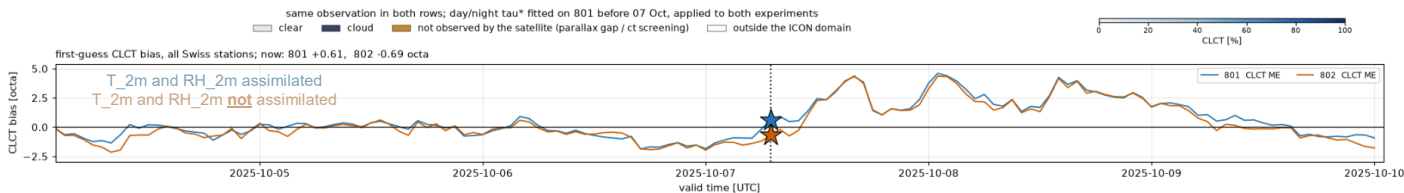


KENDA First Guess CLCT



Operational:
T_{2m} and
RH_{2m}
assimilated

Experiment:
T_{2m} and
RH_{2m}
not assimilated



CLCT ground
observation bias at
Swiss stations



Plans for next year

- Radar Data Assimilation
 - Bring 3D volume radar data assimilation to operations
- Continue APT tests with newest APT version
 - Add wind (not yet included)
 - Revisit setup for ICON-CH2-EPS
- Prepare for the reanalysis of the TEAMx EOP's (GREAT)
 - Port KENDA-CH1 to a new (elastic) platform
 - Do KENDA-CH1 experiments with additional datasets
- Upgrade REA-L-CH1 (2005-2024) to version 2 (details to be defined)
 - Train ML models

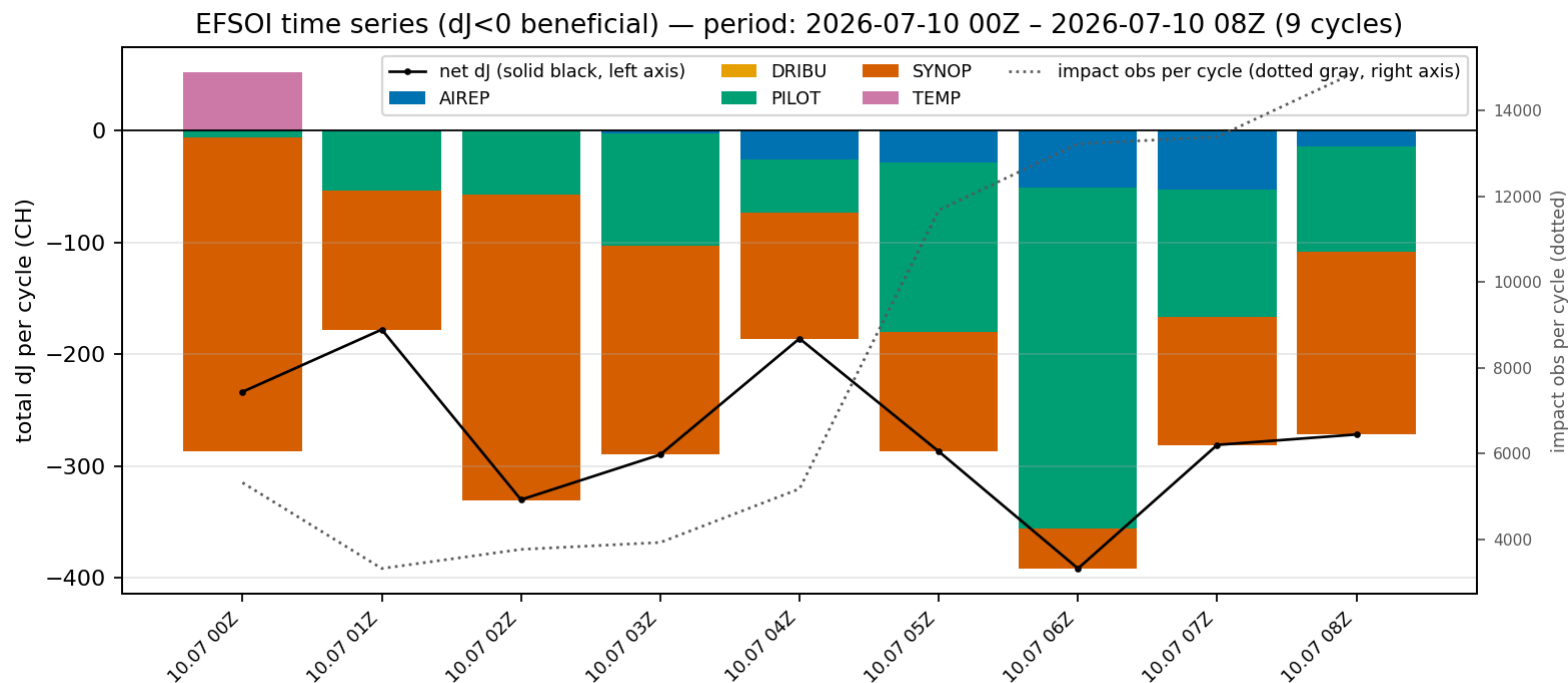


Ideas for AI use in Data Assimilation

- Different potential categories
 - Use AI to assess the current KENDA performance
 - Use AI components in KENDA
 - Use AI to minimize DA cost function
 - Use direct observation prediction
- Use Code Agents to assess the KENDA performance in terms of
 - Quality
 - Statistical consistency
 - Observation impact (EFSOI)
 - Runtime

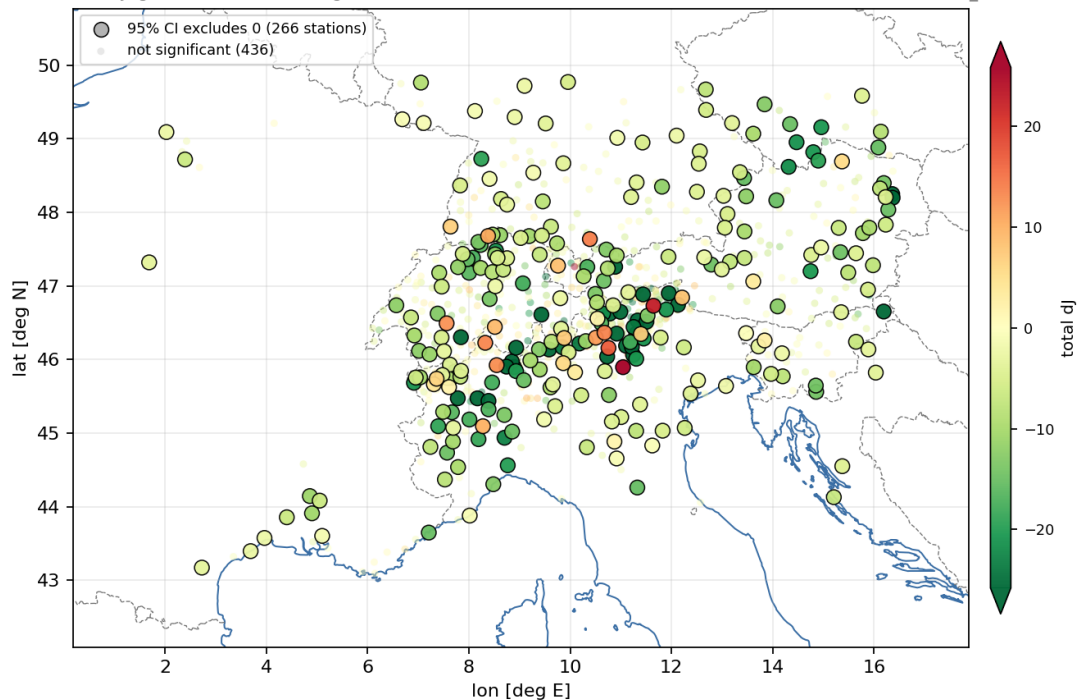


Observation Impact (EFSOI) per Obs Type



SYNOP Observation Impact (EFSOI) per Station

color: total dj (green = beneficial) · edged markers: 95% CI excludes zero · 702 stations / 16807 obs (CIs in stations_*.csv)





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MétéoSuisse

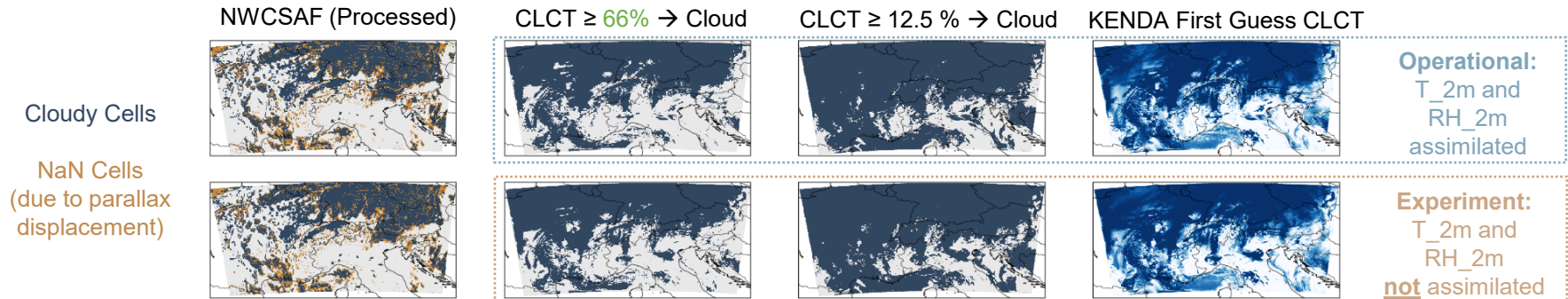
Chemin de l'Aérologie
CH-1530 Payerne
T +41 58 460 94 44
www.meteosuisse.ch

MeteoSwiss



CLCT Verification Using NWCSAF Satellite Cloud Mask

- **Results:** best $\tau = 66\%$ (for daytime) and 77% (for nighttime, not shown here)
- Example of output for 8 Oct. 07:00 shown below
- Some of the NWCSAF cells become NaN due to the parallax correction (i.e. displaced clouds leave empty cells behind)





A GRey-zone Ensemble Analysis for TEAMx (GREAT)

- Joint project by Uni Vienna, Uni Innsbruck, KIT, MeteoSwiss, and DWD
- 3y funding for 3 Postdocs and 2 PhDs
- KENDA-CH1 Reanalysis of TEAMx EOP's (2 x 6 weeks) using additional, high-res TEAMx campaign observations (SYNOP, TEMP, Wind Lidar, Aircraft, Temperatur and humidity profiler)
- Generation of an ICON-LES KENDA Analysis of selected TEAMx IOP's

Plans for REA-L-CH1 v2 (2005-2024)

- add TERRA-URB
 - add EUCOM / OPERA for LHN (2016 ff)
 - add multi-layer snow model NIX
 - assess quality of new 2d-Var snow analysis
 - use APT climatology (?)
-
- use ERA6 (instead of ERA5; promised for end of 2027) as LBC (tbd; maybe ERA6 will be pushed back to v3)
-
- open access to REA-L-CH1 v1 will hopefully be provided soonish