Cloud Data Assimilation Using Observation Operator Defined by the Penalty Function. Proof of Concept

Alina Lerner-Vilu[1,3], Siebren de Haan[2], Aarne Männik[3]

[1]Estonian Environment Agency, [2]The Royal Netherlands Meteorological Institute, [3]Tallinn University of Technology

Concept

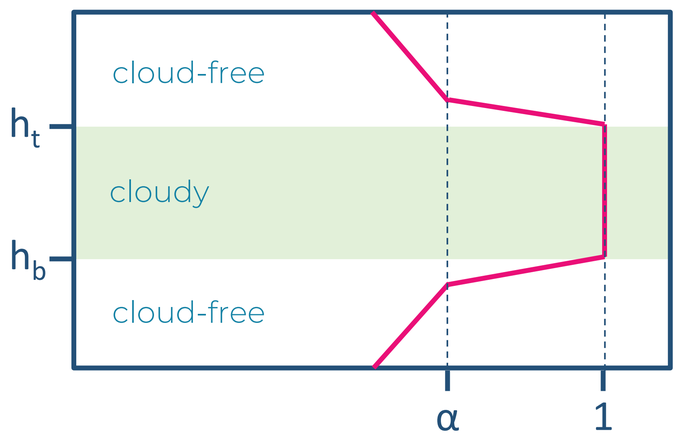
We assume the cloud layer is located between h_b - cloud base height - and h_t - cloud top height.

For simplicity, we assume cloud cover is 8/8 and saturated relative humidity is 100%

It implies:

$$\begin{cases} RH = 1 \text{ if } h_b \le h \le h_t \\ RH \le \alpha < 1 \text{ otherwise} \end{cases}$$ where α *is the threshold value*

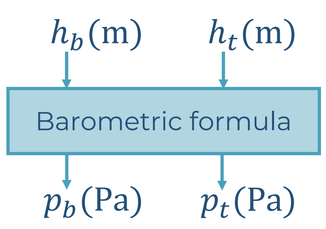
Relative humidity profile



Observations

1) Ceilometer observation of cloud base altitude h_b

2) Satellite observation of cloud top altitude h_t at ceilometer coordinate



OBSOUL (schematic)

Header ...

	vl_a 0
	vl_b 0
p_t →	
	vl_c 1
	vl_d 1
	vl_e 1
p_b →	
	vl_f 0
	vl_g 0

where vl are the model vertical levels

Penalty Function Definition

Instead of the observation operator, we construct the observation penalty function, which penalizes:

- too low RH values inside the cloud layer
- too high RH values outside the cloud layer

1) Constraints definition

$$P(vl) = \begin{cases} RH(vl) - 1, & \text{for} \quad vl \in [p_b, p_t] \\ RH(vl) - \alpha, & \text{for} \quad vl \notin [p_b, p_t] \ \ and \ \ RH(vl) > \alpha \\ 0, & \text{for} \quad vl \notin [p_b, p_t] \ \ and \ \ RH(vl) \le \alpha \end{cases}$$

where vl – vertical model level;
$RH(vl)$ – relative humidity computed from the first guess p, T, q fields;
α – threshold value.

2) Observation operator → Penalty function

$$H(x) = \tilde{P} = y + P$$

where $H(x)$ – observation operator;
$\tilde{P}$ – penalty function;
y – observation.

3) Contribution to J_o

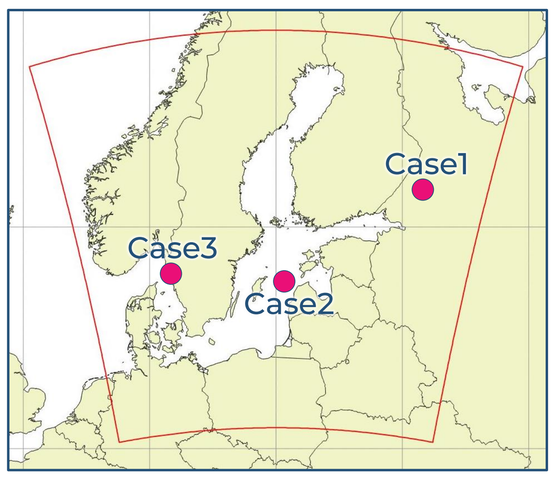
$$J_o = \frac{1}{2}[y - H(x)]^T R^{-1}[y - H(x)]$$
$$= \frac{1}{2}(y - \cancel{y} - P)^T R^{-1}(y - \cancel{y} - P) =$$
$$\frac{1}{2}(-P)^T R^{-1}(-P)$$

where J_o – observation term of the cost function of the analysis;
R – observation error covariances matrix.

Acknowledgements

The collaboration on this research is supported by ACCORD consortium. The Harmonie-Arome model environment is provided by Hirlam consortium.

Experimental Setup



Harmonie cy43h2.2.1
Single observation
DA: 3D-Var
Domain: HMEST25
Grid: 2.5 km
Date: 24/06/2023
Time: 12 to 21 UTC

Case1 61.42°N, 31.96°E
Case2 57.65°N, 20.55°E
Case3 58.08°N, 11.76°E

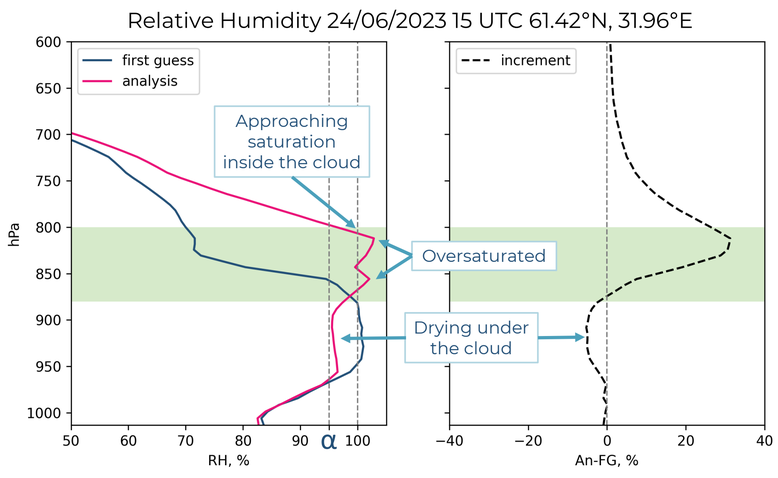
Case1 (15 UTC) - Cloud shift
- First guess: cloud layer at ca. 950-870 hPa
- Experiment: shift cloud layer to 880-800 hPa

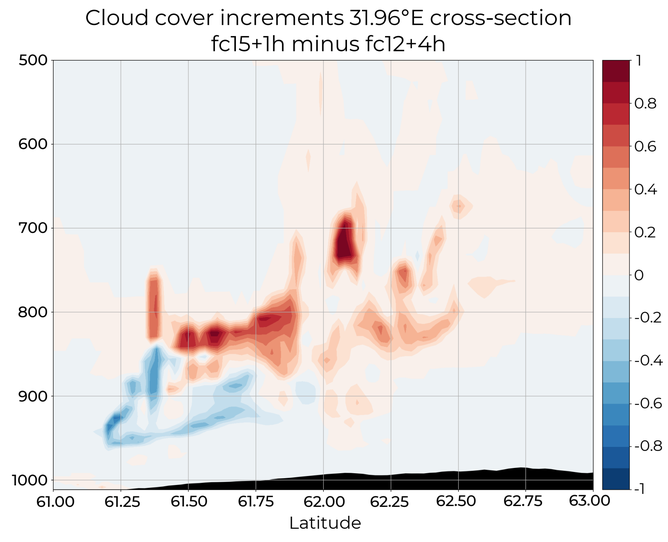
Case2 (18 UTC) - Cloud creation
- First guess: no low clouds
- Experiment: create cloud layer at 925-870 hPa

Case3 (21 UTC) - Cloud elimination
- First guess: cloud layer at ca. 990-970 hPa
- Experiment: cloud-free

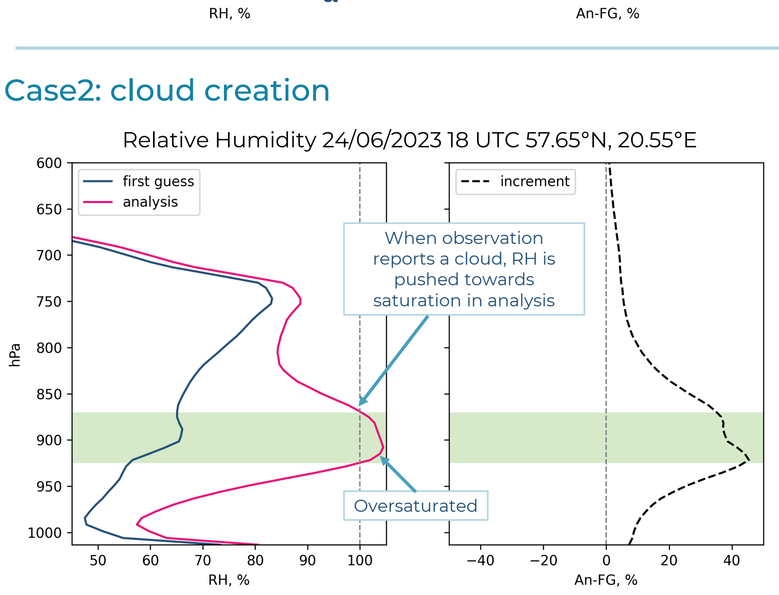
Results

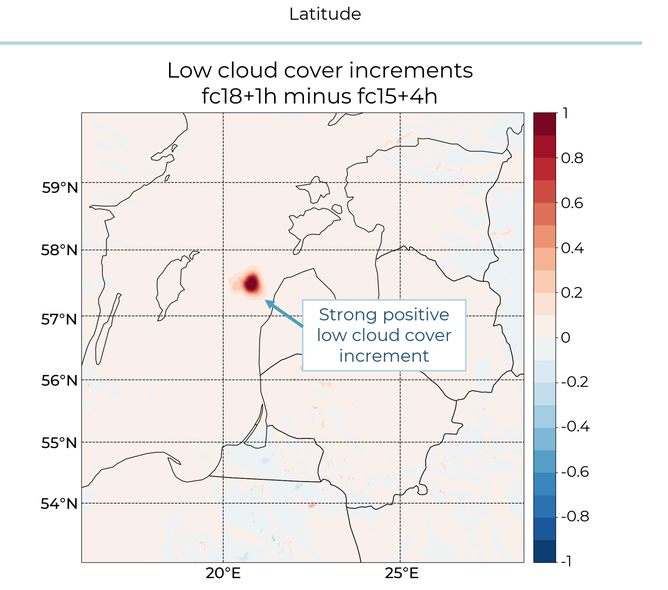
Case1: cloud shift



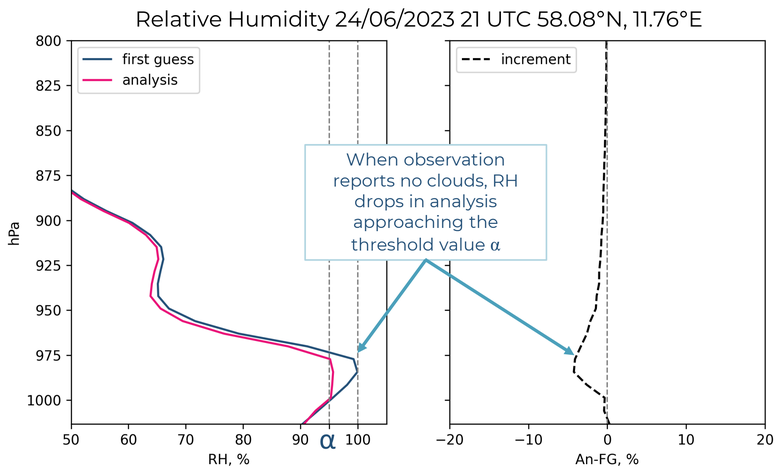


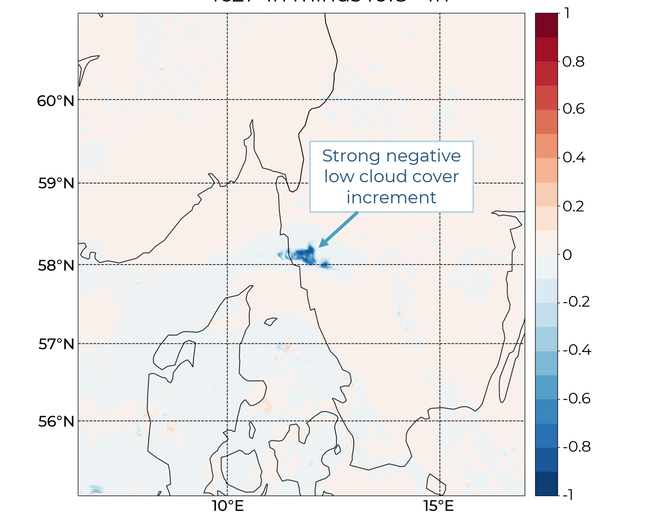
Case2: cloud creation





Case3: cloud elimination





Conclusions

- A new scheme of cloud data assimilation is being developed based on the concept of defining the observation operator through the penalty function.
- Three single pseudo-observation experiments have been conducted using a Harmonie-Arome model setup with the cy43h2.2.1 in the HMEST25 domain.
- All three cases have demonstrated the sensitivity of RH values to the artificial cloud observations while small oversaturation is generated in the middle of the cloud layer.
- RH updates in the analyses have the according impact on the forecasted cloud cover when compared to the forecast from the previous analysis step.
- The next step for the scheme requires formulation of a cloud top height estimate in addition to the cloud base measurements from the ceilometer with subsequent real case experiments.