CAPE Singular vectors

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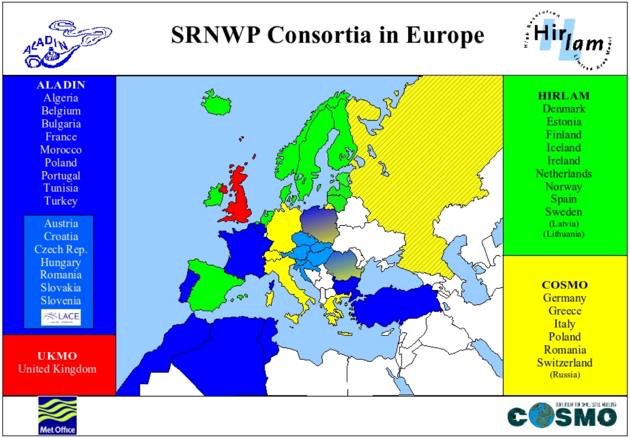
Motivation

One of the main tasks of LAMs is prediction of high impact weather. Here we look at the possibility to develop a short range EPS in Hirlam which focuses on predictability of deep convection.



Overview

- Theory
  - Singular vectors
  - Convective Available Potential Energy (CAPE)
  - CAPE as final time norm
- Case study
  - Experiment setup
  - Structure TE-SV versus CAPE-SVs
  - Test linearity assumption
- Conclusions and future plans

Singular vectors

Let $\dot{x} = g(x)$ and define $\epsilon(t)$ as

$$\epsilon(t) = x(t) - x_0(t)$$

Time evolution ϵ assumed linear

$$\dot{\epsilon} \approx \left.\frac{\partial g}{\partial x}\right|_{x_0(t)} \epsilon$$

Integration from $t = 0$ to $t = T$

$$\epsilon(T) = M(0, T)\epsilon(0)$$

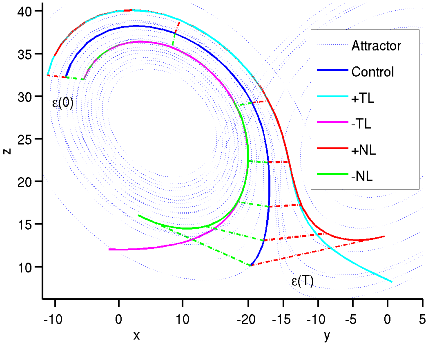
Singular vectors are vectors $\epsilon(0)$ that maximize the ratio

$$\frac{||PM\epsilon(0)||_{C_1}}{||\epsilon(0)||_{C_0}}$$

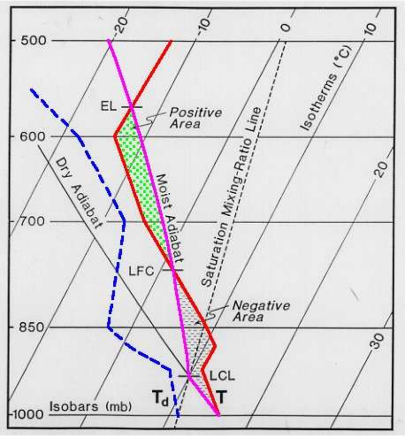
P is a projection operator.

This is equivalent to solving the eigenvector problem

$$M^* P C_1 P M v = \sigma^2 C_0 v$$



CAPE-norm



Let x_r denote a reference model state and $\mathcal{C}$ a routine that computes CAPE

$$\mathcal{C}(x_r + \epsilon) - \mathcal{C}(x_r) \approx \left.\frac{\partial \mathcal{C}}{\partial x}\right|_{x_r} \epsilon \equiv C_{x_r}\epsilon$$

The CAPE-norm is given by

$$||\epsilon(T)|| = \langle C_{x(T)}\epsilon(T), C_{x(T)}\epsilon(T) \rangle$$

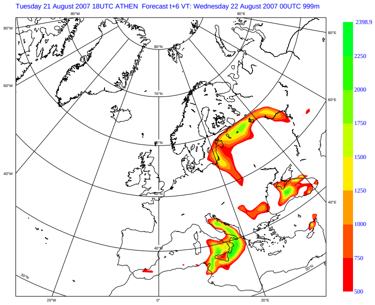
In the SV-calculation we also need the adjoint of C

$$M^* G^* C^*_{x(T)} C_{x(T)} G M \epsilon_0 = \sigma^2 C_0 \epsilon_0$$

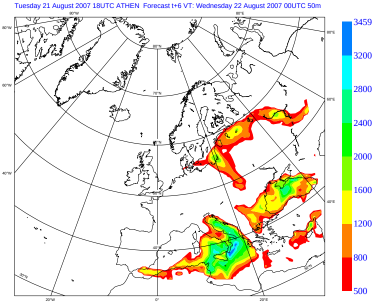
C and C^* are obtained using TAMC

ECMWF CAPE versus Hirlam CAPE

$$\mathrm{CAPE} = g \int \frac{\theta_{e_{\mathrm{up}}} - \theta_{e_{\mathrm{sat}}}}{\theta_{e_{\mathrm{sat}}}} \, \mathrm{d}z \qquad \mathrm{CAPE} = g \int_{\mathrm{LFC}}^{\mathrm{EL}} \frac{T_v(z') - \bar{T}_v(z')}{\bar{T}_v(z')} \, \mathrm{d}z'$$



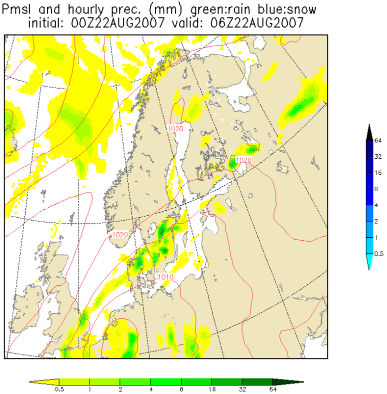
ECMWF CAPE



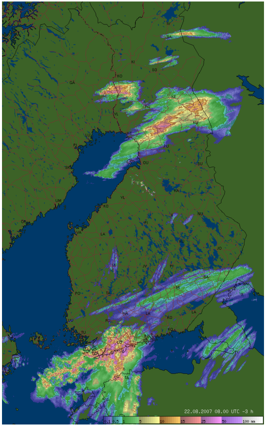
CAPE 50 hPa

Aug. 22, 2007 6UTC: Forecast and measurements

FMI +6h forecast (1h Acc. Precip.)



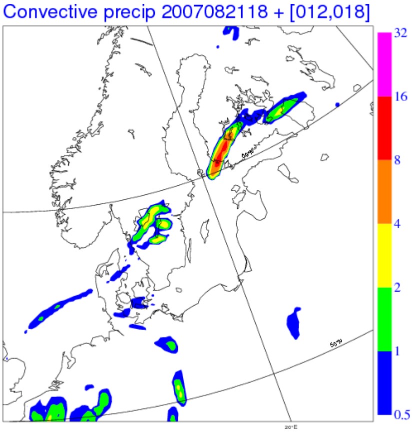
5-8UTC Acc. Prec. Radar



The Finnish Hirlam model failed to forecast this thunderstorm in any cycle verifying at the same time (Pictures from T. Iversen)

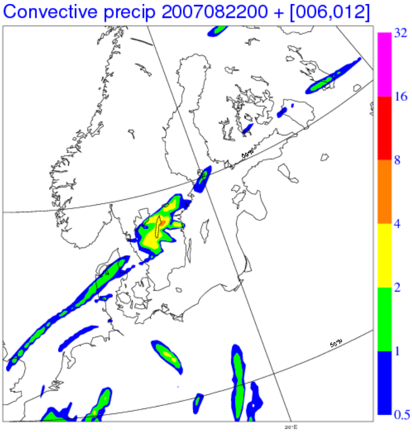
KNMI Hirlam Conv. Prec. Aug 22, 6–12 UTC

12h forecast Conv. Precip.



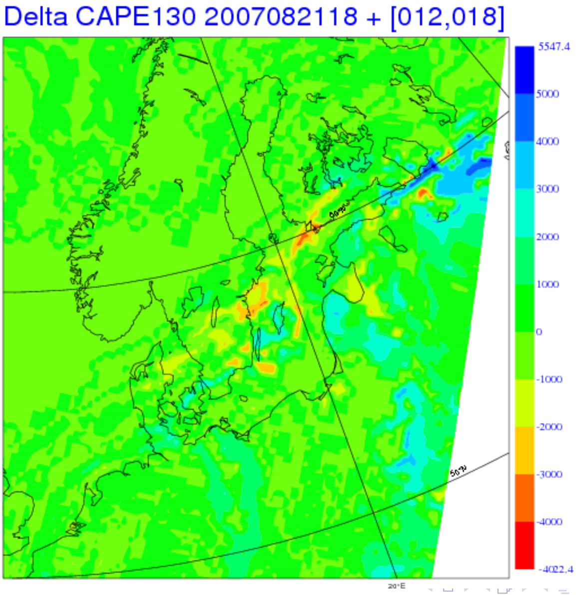
$\frac{1}{6}(AP_{18} - AP_{12})$

6h forecast Conv. Precip.



$\frac{1}{6}(AP_{12} - AP_{6})$

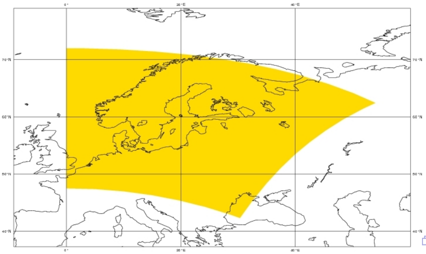
Change in Max CAPE +018 - +012



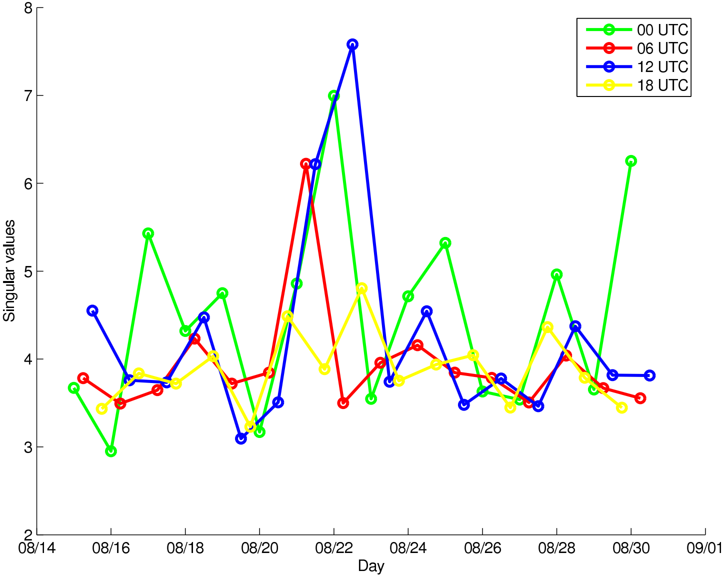
SV Experiment settings

- Resolution: $0.5^\circ \times 0.5^\circ$
- Optimization time: 12 h
- Nonlinear trajectory updated every hour in TL-model
- Dry total energy norm at initial time
- Cape/TE-norm at final time
- Adjoint model uses Meteo France simplified physics:

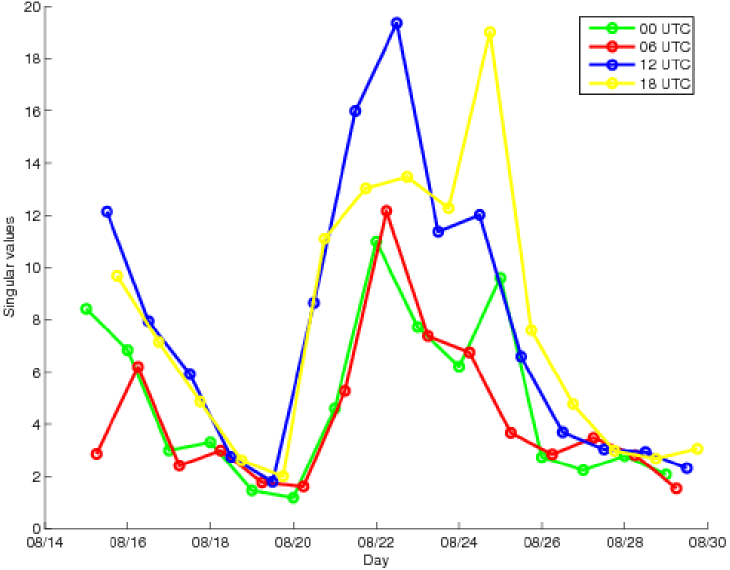
Dry	Moist
Vertical diffusion	Vertical diffusion Convection Large scale condensation



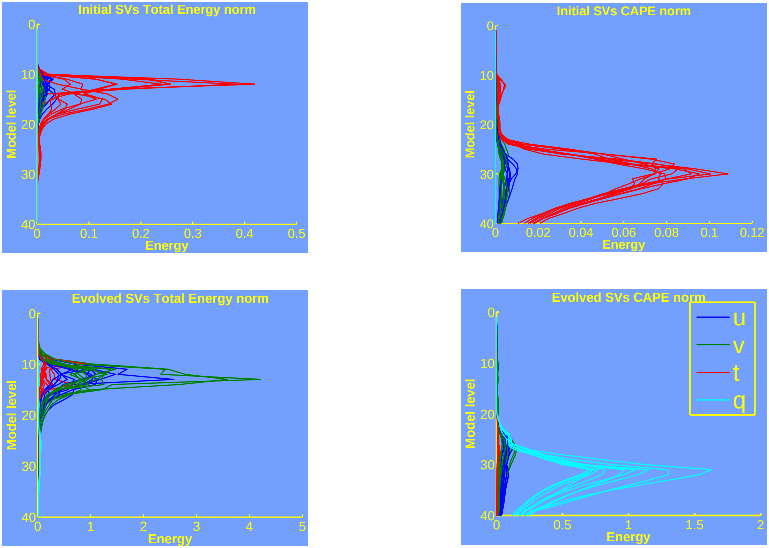
Leading TE Singular values dry TLM



Leading CAPE-Singular values dry TLM



Vertical energy distribution SVs Aug. 21 18 UTC

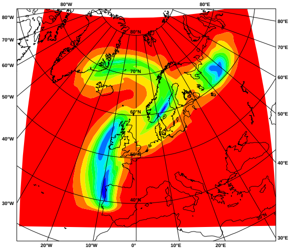


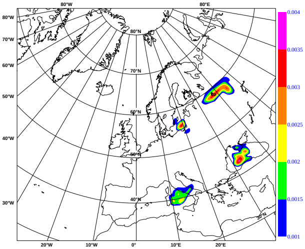
Top(Initial SVs) Bottom(Evolved SVs) Left (TE) Right(CAPE)

Horizontal structure evolved SVs (10 SV average)

TE-SVs

CAPE-SVs

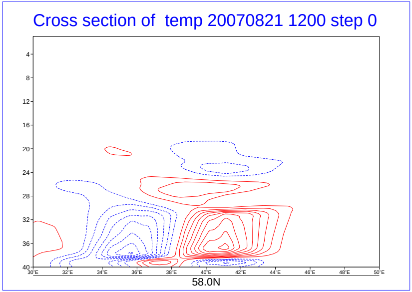


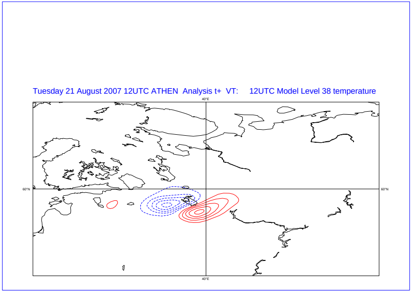


Vert. integrated kinetic energy

Vert. integrated specific humidity

Temperature evolved CAPE-SVs





Twin experiments

Let

$$\epsilon^{+}(t) = x^{+}(t) - x^{0}(t)$$

and

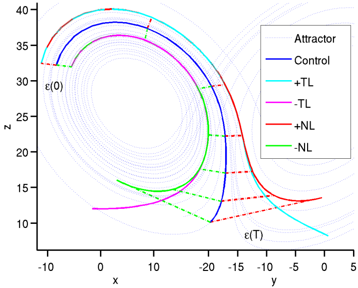
$$\epsilon^{-}(t) = x^{-}(t) - x^{0}(t)$$

In a linear model we have

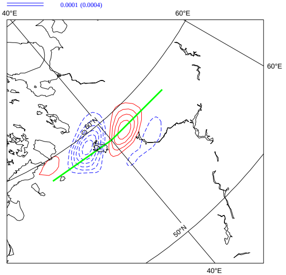
$$\frac{\langle \epsilon^{+}(t), \epsilon^{-}(t) \rangle}{||\epsilon^{+}(t)|| \quad ||\epsilon^{-}(t)||} = -1$$

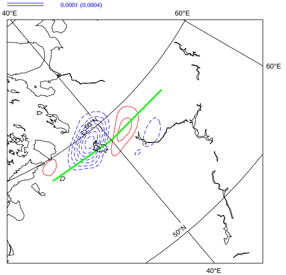
Settings

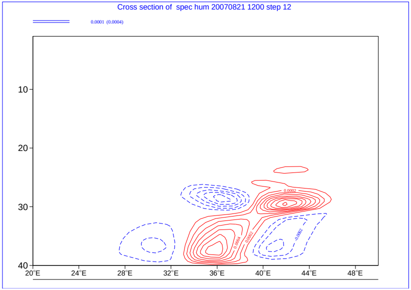
- IC : ECMWF analysis
- No DFI no NMI
- Pert.: leading CAPE-SV
- Physics: Savijarvi, Straco, ISBA,CBR
- Scaling $T_{max} = 0.4$ K, u_{max}, v_{max} 0.3 m/s

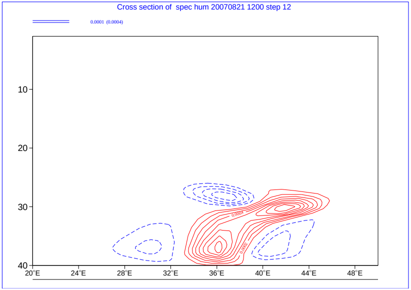


Twin experiment specific humidity (t=12h)

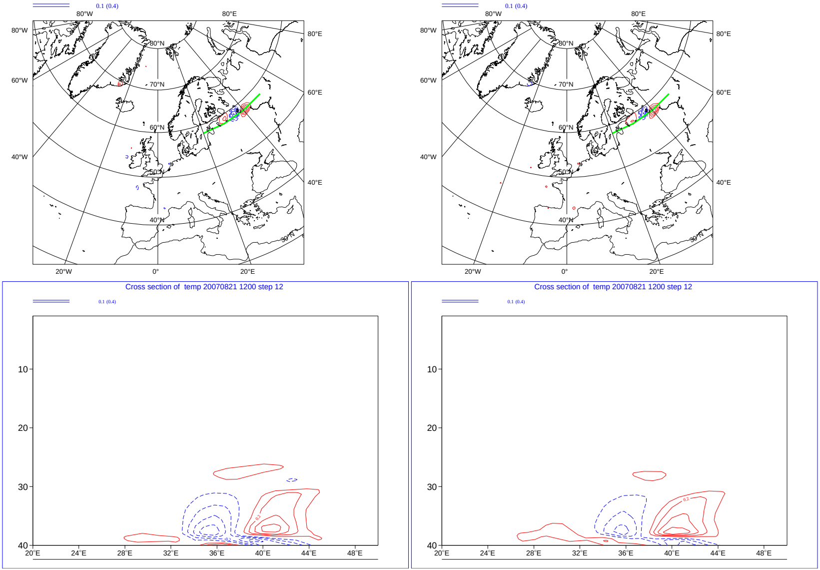




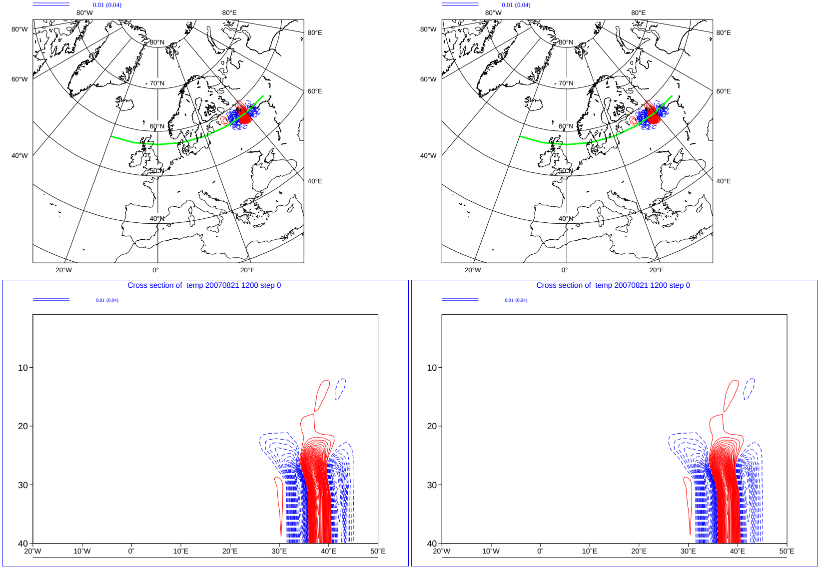




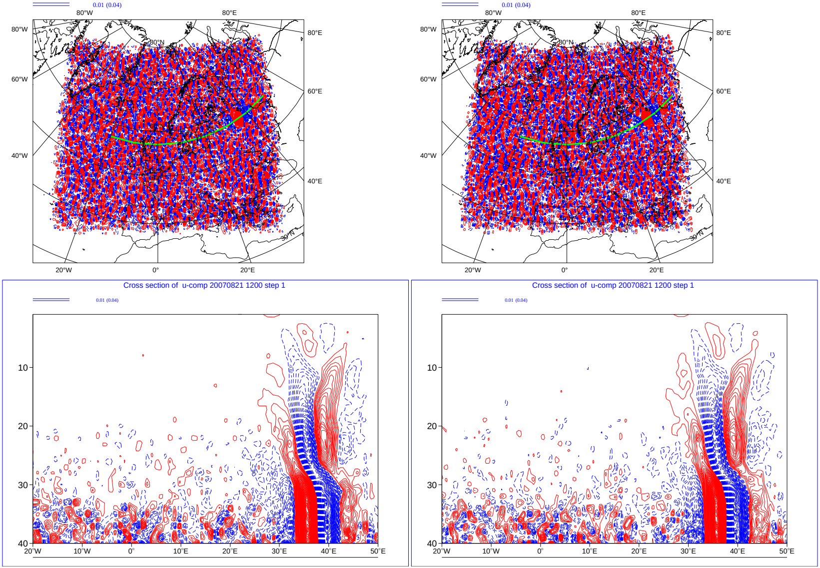
Twin experiment temperature (t=12h)



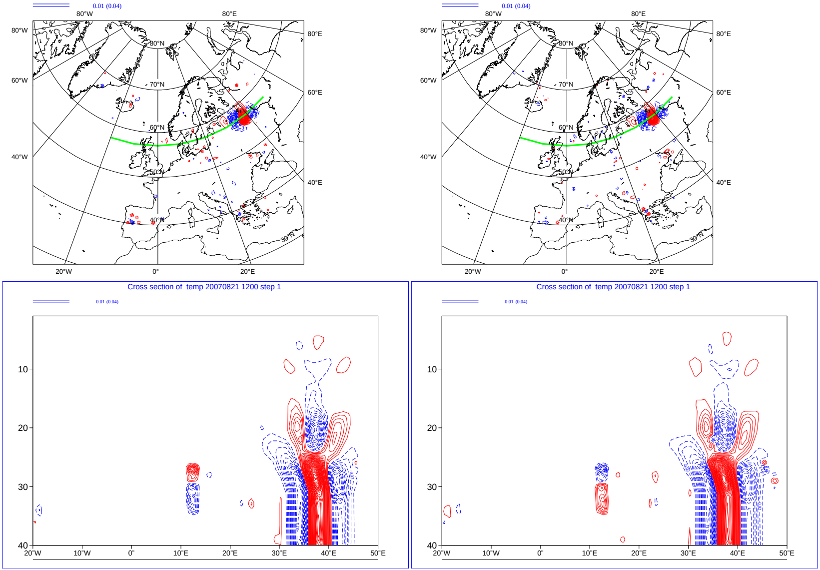
Twin experiment Temperature (t=0)



Twin experiment u-comp wind (t=1h)



Twin experiment Temperature (t=1h)



Conclusions

- Both CAPE and TE SVs indicate that the 12 hour forecasts around August 22 are sensitive to initial conditions.
- The TE-SVs in Hirlam show well known features: most energy in the temperature field at initial time and most energy in the wind-field at final time near the jetstream.
- CAPE-SVs are situated much lower in the troposphere and at final time the "energy" is mostly in the specific humidity field. 12 hour CAPE forecast are most sensitive to the analysis temperature at 850 hPa.
- The twin experiments show that the tangent linear approximation using CAPE-SVs as IC perturbations is valid up to 12 hours at 0.5° resolution
- The twin experiments show that there is "noise" in the entire boundary layer (expect for regions close to the lateral boundary) in the forecast after 1h

Future plans

- Further investigate the Finnish case (Higher resolution, OT=24h, etc)
- Investigate the noise in the twin experiment
- Modify CAPE-norm to include CIN
- Look at integrated water vapor as final time norm
- Further test linearity compare TE-SVs versus CAPE-SVs
- How to use (CAPE)-SVs as building blocks for EPS members (in GLAMEPS)?