Going through the grey zone of deep convection with the ALADIN System

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Degrauwe, M. Vanginderachter, R. De Troch, P.
De Meutter, N. Pristov,

and many others...

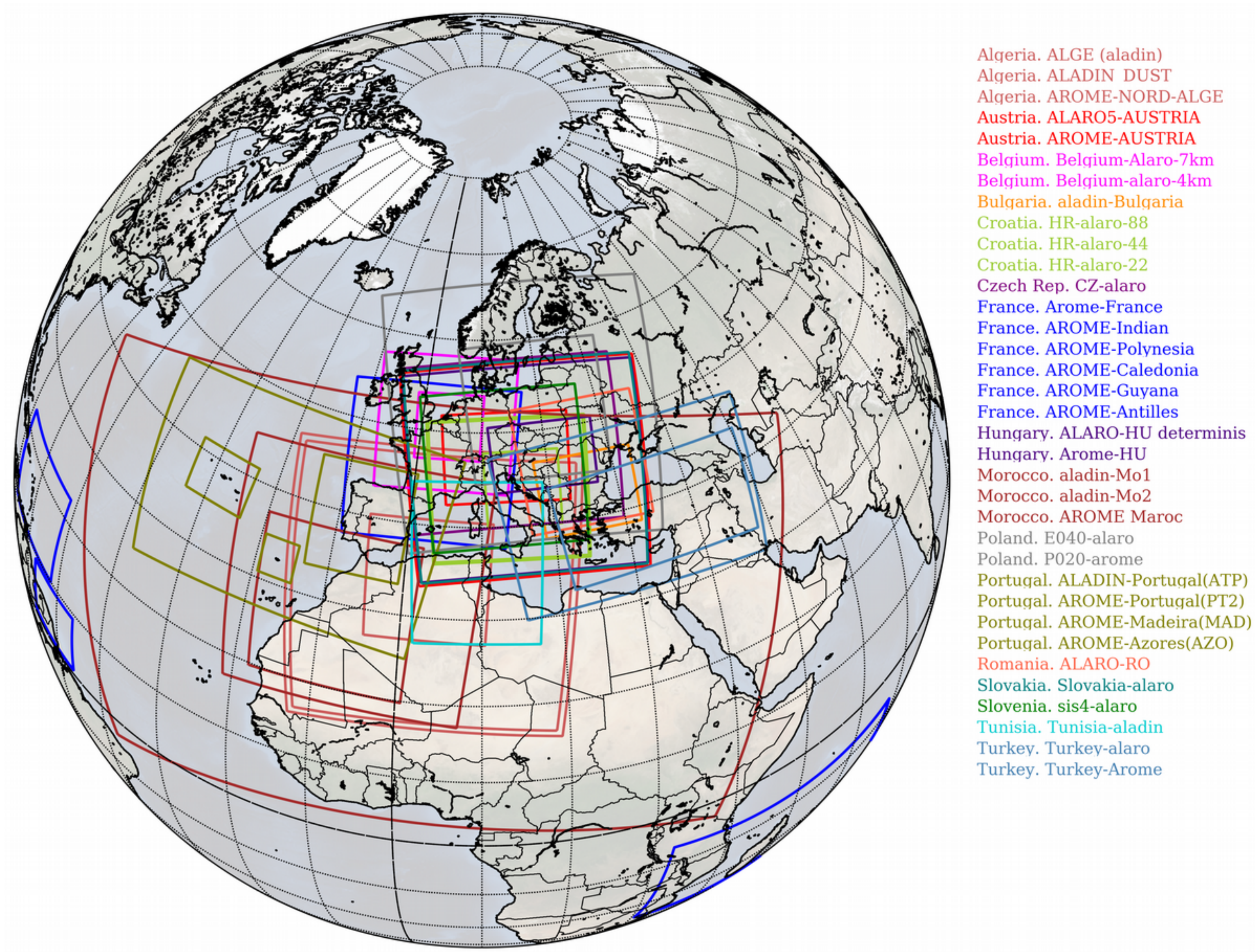
http://www.cnrm.meteo.fr/aladin/

Shedding light on the grey zone, 14 November 2017, ECMWF

Content

1) Why multiscale deep convection parameterization?
2) The 3MT approach (and the CSD scheme)
3) The physics-dynamics coupling
4) The ALARO configuration as a scientific tool to shed light on model-error in the grey zone

The limited areas of the ALADIN partners



The need for a scale-aware parameterization of deep convection

- There has always been a wide spread in the computing platform that the ALADIN partners could afford.
- So there was (and even today there is) a need for a model that can seamlessly run across resolution from the meso-scale to the convection permitting scales (10 → 1 km):
  - The same scientific basis
  - Limit maintenance (code developments, sanity checks and validation).

The ALADIN "Canonical" Model Configurations of the ALADIN-HIRLAM System

ALARO config: a vehicle to go through the grey zone of DC

- Code shared with HIRLAM (Bengtsson et al. 2017)
- Code shared with the IFS
- Historical care for long time steps

Termonia et al., 2017, GMD

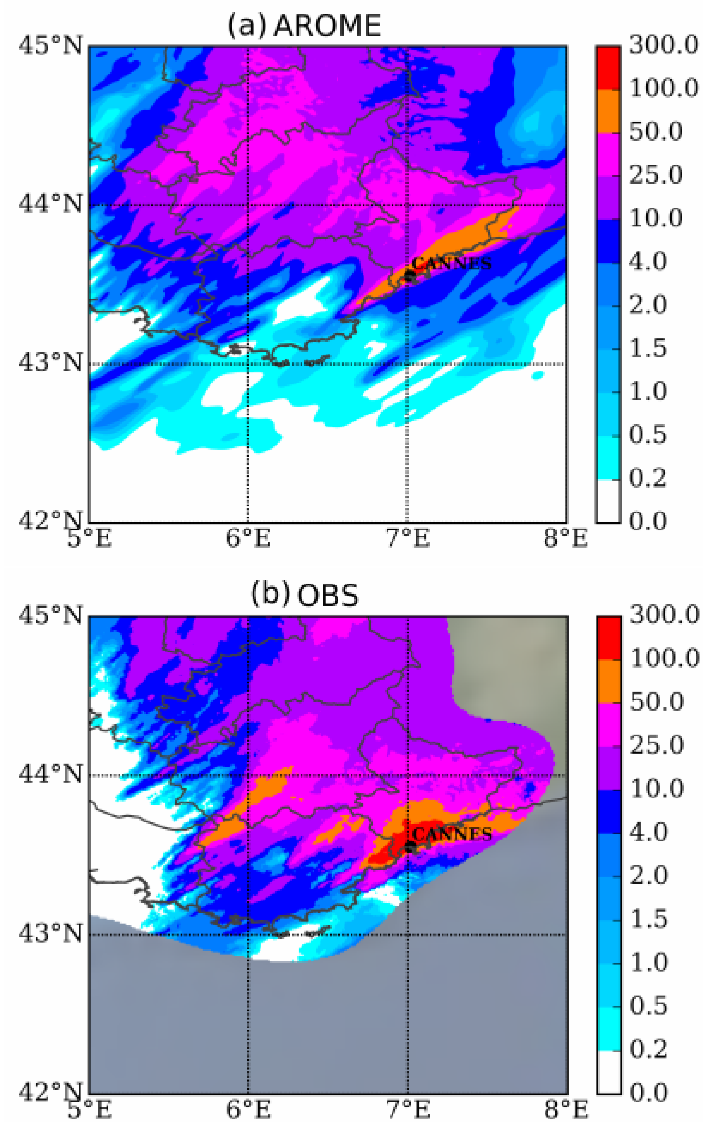
ZAMG IRM DHMZ METEO FRANCE OMSZ MAROC METEO IMGW ipma instituto português do mar e da atmosfera METEO ROMANIA SHMU ARSO VREME METEOROLOJİ

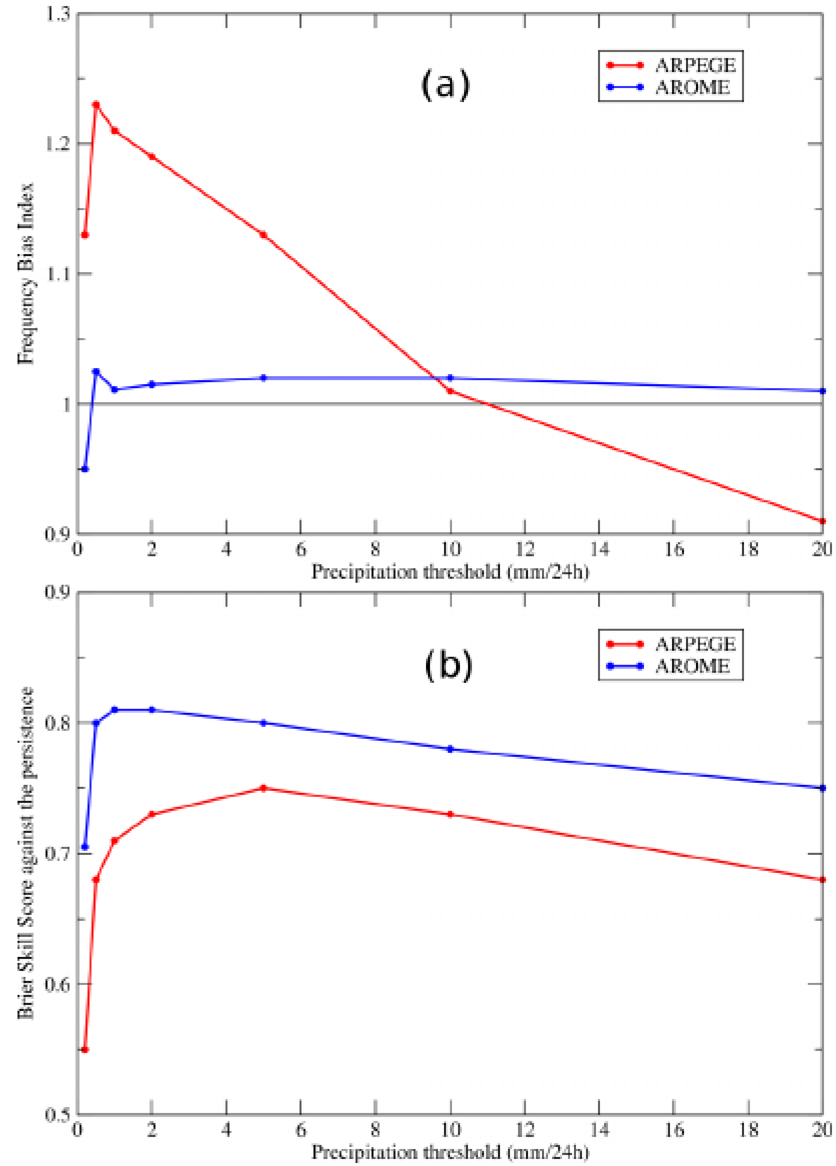
The operational configurations of the ALADIN System

Table 4. The current configurations of the ALADIN System running in the ALADIN partner countries, with their nationally-used name, horizontal resolution (HRES), domain size, number of vertical levels (NLEV), Version of the ALADIN System, coupling model and the used configuration (ALADIN, ALARO, AROME).

Partner	Oper. Model	HRES	Domain size	NLEV	Model version	Coupled with	Configuration
Algeria	ALADIN-ALGE	8.00	450x450	70	CY40T1	ARPEGE	ALADIN
Algeria	ALADIN-DUST	14.00	250x250	70	CY38T1	ARPEGE	ALADIN
Algeria	AROME-NORD-ALGE	3.00	500x500	41	CY40T1	ALADIN-ALGE	AROME
Austria	ALARO5-AUSTRIA	4.82	540x600	60	CY36T1	IFS	ALARO
Austria	AROME-AUSTRIA	2.50	432x600	90	CY40T1	IFS	AROME
Belgium	Belgium-Alaro-7km	6.97	240x240	46	CY38T1	ARPEGE	ALARO
Belgium	Belgium-alaro-4km	4.01	181x181	46	CY38T1	ARPEGE	ALARO
Bulgaria	aladin-Bulgaria	7.00	144x180	70	CY38T1	ARPEGE	ALADIN
Croatia	HR-alaro-88	8.00	216x240	37	CY38T1	IFS	ALARO
Croatia	HR-alaro-44	4.00	432x480	73	CY38T1	IFS	ALARO
Croatia	HR-alaro-22	2.00	450x450	37	CY36T1	HR-alaro-88	ALARO
Croatia	HR-alaro-HRDA	2.00	450x450	15	CY38T1	HR-alaro-88	ALARO
Czech Rep	CZ-alaro	4.71	432x540	87	CY38T1	ARPEGE	ALARO
France	Arome-France	1.30	1440x1536	90	CY41T1	ARPEGE	AROME
France	AROME-Indean Ocean	2.50	900x1600	90	CY41T1	IFS	AROME
France	AROME-Polynesia	2.50	600x600	90	CY41T1	IFS	AROME
France	AROME-Caledonia	2.50	600x600	90	CY41T1	IFS	AROME
France	AROME-Guyana	2.50	384x500	90	CY41T1	IFS	AROME
France	AROME-Caribbean	2.50	576x720	90	CY41T1	IFS	AROME
Hungary	ALARO-HU determinis	7.96	320x360	49	CY38T1	IFS	ALARO
Hungary	Arome-HU	2.50	320x500	60	CY38T1	IFS	AROME
Morocco	Aladin-NORAF	18.00	324x540	70	CY41T1	ARPEGE	ALADIN
Morocco	ALADIN Maroc	7.50	400x400	70	CY41T1	ARPEGE	ALADIN
Morocco	ALADIN Ma 3DVar	10.00	320X320	60	CY36T1	ARPEGE	AROME
Morocco	AROME Maroc	2.50	800x800	60	CY41T1	ALADIN Ma 3DVar	AROME
Poland	E040-alaro	4.00	800x800	60	CY40T1	ARPEGE	ALARO
Poland	P020-arome	2.04	810x810	60	CY40T1	E040-alaro	AROME
Portugal	ALADIN-Portugal(ATP)	9.00	288x450	46	CY38T1	ARPEGE	ALADIN
Portugal	AROME-Portugal(PT2)	2.50	540x480	46	CY38T1	ARPEGE	AROME
Portugal	AROME-Madeira(MAD)	2.50	200x192	46	CY38T1	ARPEGE	AROME
Portugal	AROME-Azores(AZO)	2.50	270x360	46	CY38T1	ARPEGE	AROME
Romania	ALARO-RO	6.50	240x240	60	CY40T1	ARPEGE	ALARO
Slovakia	Slovakia-alaro	4.50	576x625	63	CY36T1	ARPEGE	ALARO
Slovenia	sis4-alaro	4.40	432x432	87	CY38T1	IFS	ALARO
Tunisia	Tunisia-ALADIN	7.50	216x270	70	CY38T1	ARPEGE	ALADIN
Turkey	Turkey-alaro	4.50	450x720	60	CY38T1	ARPEGE	ALARO
Turkey	Turkey-Arome	2.50	512x1000	60	CY38T1	ARPEGE	AROME

AROME France, results w.r.t. the global model





The M-T approach as the basis
Piriou et al. 2007

- Convective schemes can be validated against:
  - Observation
  - Cloud-system resolving models (CSRMs)
- One could try to develop NWP parameterization that should behave as CSRM in the convection-permitting limit.

Piriou et al. 2007: try to mimic CSRMs by parameterizations by MTCS

Form of the Eqs. Of CSRMs

$$\begin{cases} \frac{\partial q}{\partial t} = T_q - C + E_C + E_P - (\mathbf{u}\cdot\nabla)q \\ \frac{\partial s}{\partial t} = T_s + R + L(C - E_C - E_P) + H - (\mathbf{u}\cdot\nabla)s \\ \frac{\partial u}{\partial t} = \dot{u}_p - (\mathbf{u}\cdot\nabla)u \\ \frac{\partial v}{\partial t} = \dot{v}_p - (\mathbf{u}\cdot\nabla)v \end{cases}$$

Equivalent from for parameterizations

$$\begin{cases} \left(\frac{\partial \overline{q}}{\partial t}\right)_{\text{conv}} = -C + E_C + E_P - \frac{\partial \omega^*(q_c - \overline{q})}{\partial p} \\ \left(\frac{\partial \overline{s}}{\partial t}\right)_{\text{conv}} = L(C - E_C - E_P) + H - \frac{\partial \omega^*(s_c - \overline{s})}{\partial p} \\ \left(\frac{\partial \overline{u}}{\partial t}\right)_{\text{conv}} = - \frac{\partial \omega^*(u_c - \overline{u})}{\partial p} \\ \left(\frac{\partial \overline{v}}{\partial t}\right)_{\text{conv}} = - \frac{\partial \omega^*(v_c - \overline{v})}{\partial p} \end{cases}$$

Like in CSRMs individual microphysics terms can be diagnosed independently from the transport and this should improve the validation w.r.t. to CSRMs. This is the **M-T concept**.

Assumption of stationarity of cloud budget

Cloud budget

$$\begin{cases} \dfrac{\partial \sigma}{\partial t} = -D + E - \dfrac{\partial \omega^*}{\partial p} & \text{(mass)} \\ \dfrac{\partial \sigma q_c}{\partial t} = -Dq_c + E\overline{q} - \dfrac{\partial \omega^* q_c}{\partial p} - C & \text{(water vapor)} \\ \dfrac{\partial \sigma s_c}{\partial t} = -Ds_c + E\overline{s} - \dfrac{\partial \omega^* s_c}{\partial p} + LC & \text{(heat),} \end{cases}$$

$$\frac{\partial \sigma}{\partial t} = \frac{\partial \sigma q_c}{\partial t} = \frac{\partial \sigma s_c}{\partial t} = 0$$

$$\begin{cases} \left(\dfrac{\partial \overline{q}}{\partial t}\right)_{\text{conv}} = \omega^* \dfrac{\partial \overline{q}}{\partial p} + D(q_c - \overline{q}) + E_C + E_P \\ \left(\dfrac{\partial \overline{s}}{\partial t}\right)_{\text{conv}} = \omega^* \dfrac{\partial \overline{s}}{\partial p} + D(s_c - \overline{s}) - L(E_C + E_P), \end{cases}$$

- Detailed comparison with CSRMs not possible.
- The detrainment D is part of the r.h.s forcing and should be paramterized

Gerard & Geleyn (2005)

- Gerard and Geleyn (2005) introduced mass-flux scheme with a prognostic updraft vertical velocity and a prognostic updraft mesh fraction, allowing to depart from the Quasi-Equilibrium hypothesis.
- Designed to complete Bougeault (1985)'s scheme that is part of the ARPEGE model and the ALADIN-baseline

$$\frac{\partial \omega_{\mathrm{u}}^{*}}{\partial t} = -\frac{g^2}{1+\gamma'} \frac{p}{R_{\mathrm{a}}} \frac{T_{\mathrm{vu}} - \overline{T_{\mathrm{v}}}}{\overline{T_{\mathrm{v}}} T_{\mathrm{vu}}} + \frac{\omega_{\mathrm{u}}^{*2}}{p} \{1 + (\lambda_{\mathrm{u}} + \mathcal{K}_{\mathrm{du}}/g) R_{\mathrm{a}} T_{\mathrm{vu}}\} - \frac{1}{2} \frac{\partial \omega_{\mathrm{u}}^{*2}}{\partial p}$$

$$\underbrace{\frac{\partial \sigma_{\mathrm{u}}}{\partial t} \int_{p_{\mathrm{t}}}^{p_{\mathrm{b}}} (h_{\mathrm{u}} - \overline{h}) \frac{\mathrm{d}p}{g}}_{\text{storage}} = \underbrace{L \int_{p_{\mathrm{t}}}^{p_{\mathrm{b}}} \sigma_{\mathrm{u}} \omega_{\mathrm{u}}^{*} \frac{\partial \overline{q}}{\partial p} \frac{\mathrm{d}p}{g}}_{-\text{consumption}} + \underbrace{L \cdot \mathrm{TMC}}_{\text{input}}$$

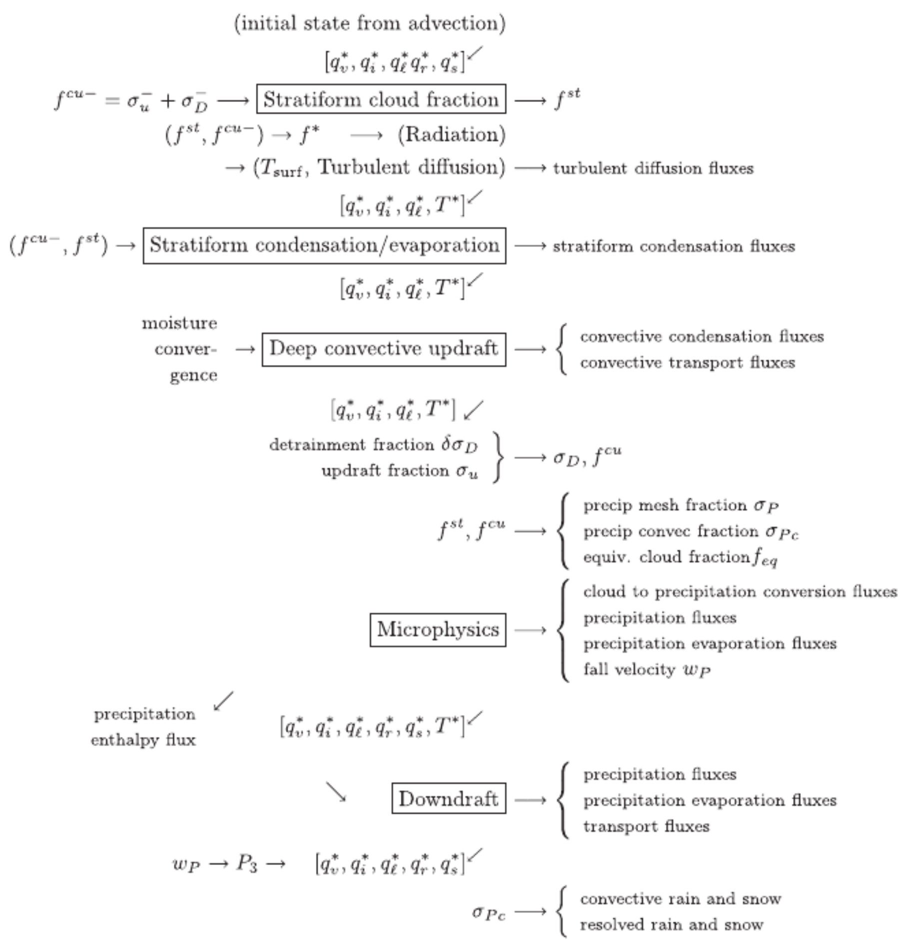
Gerard et al. (2009): 3MT
Modular, Multiscale, Microphysics and Transport

- Using the M-T concept of Piriou et al. (2007)
- The detrainment D disappears

$$\left(\frac{\partial\overline{\psi}}{\partial t}\right)_{\mathrm{cu}} = \sigma_u(\omega_u-\omega_e)\frac{\partial\overline{\psi}}{\partial p} + D_u(\psi_u-\psi_e) + \text{evaporation}$$

$$\left(\frac{\partial\overline{\psi}}{\partial t}\right)_{\mathrm{cu}} = -\frac{\partial[\sigma_u(\omega_u-\omega_e)(\psi_u-\overline{\psi})]}{\partial p} + \text{condensation} + \text{evaporation}$$

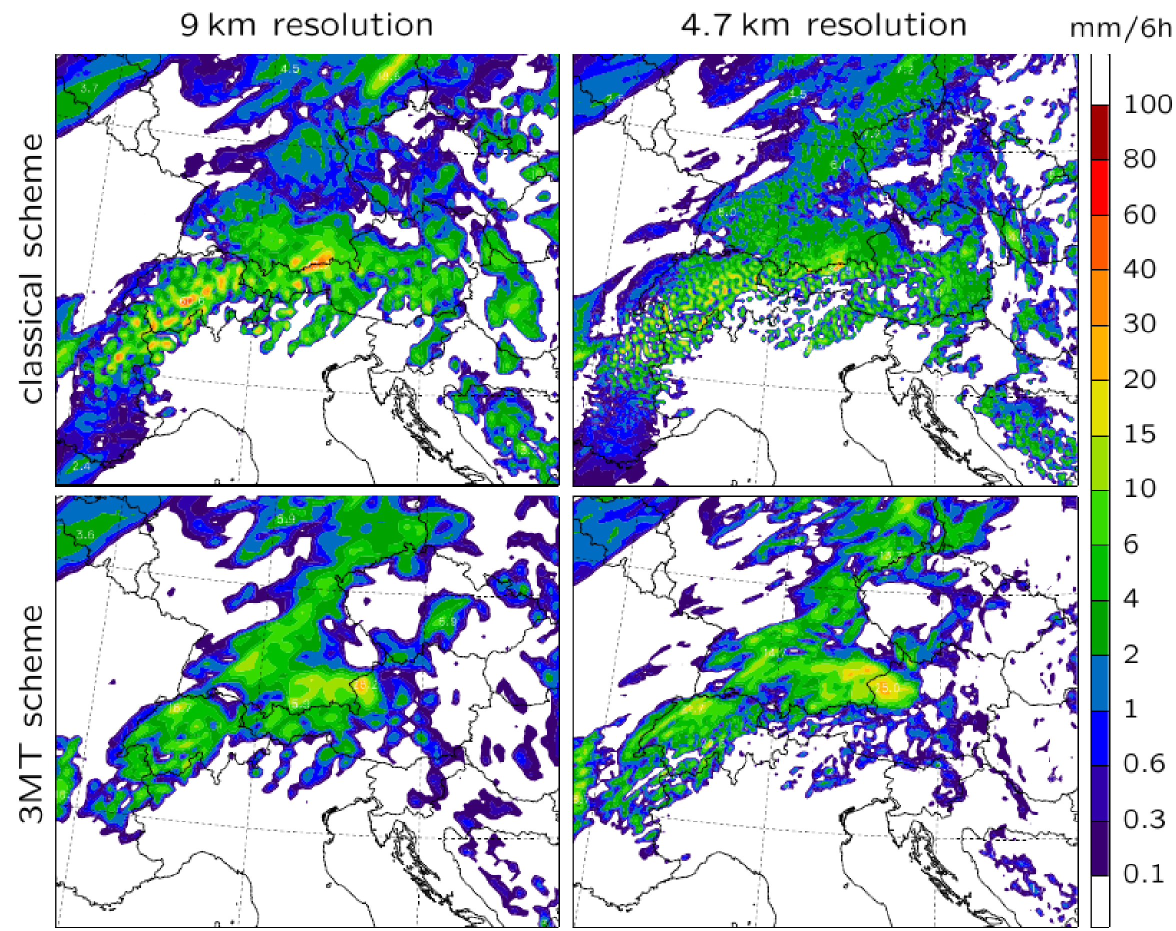
Modular: the cascade



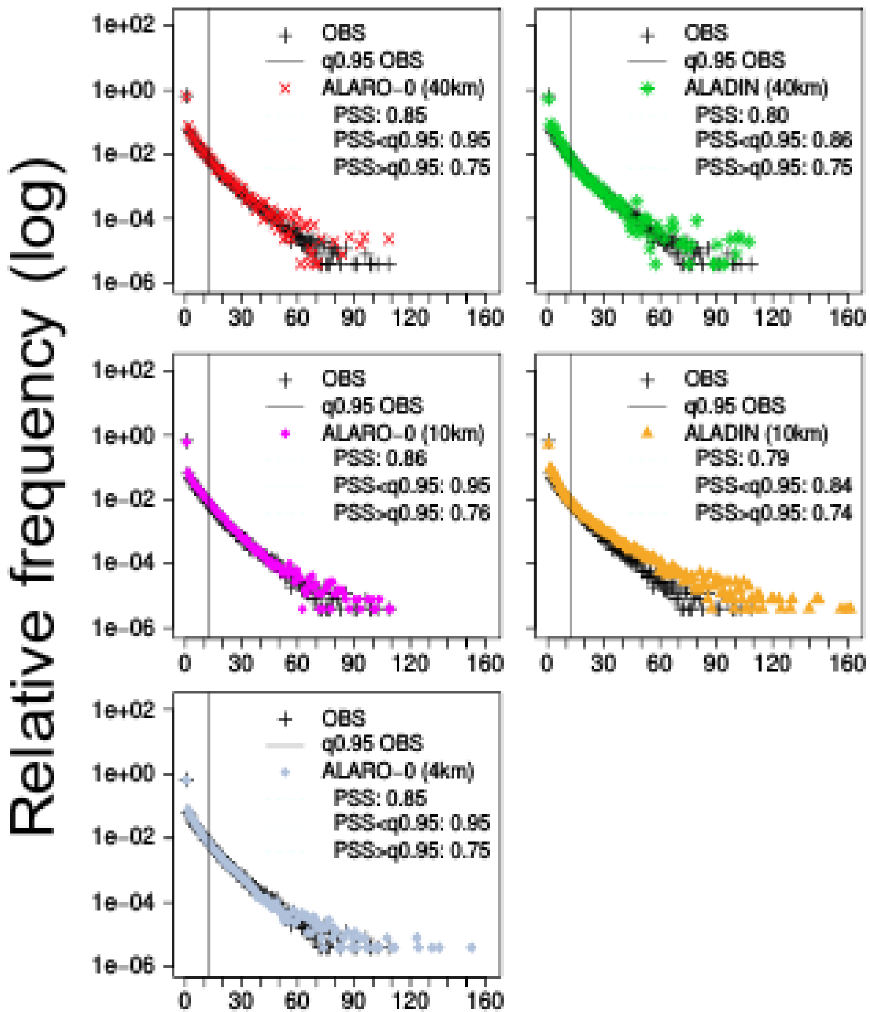
- By a careful design of the sequence of calls, all of the condensation sources can be summed to provide them for one single call of the microphysics.
- This allows to avoid double counting of consensable water vapor.

Multiscale

- No parameterized detrainment => detrainment and subsequent subsidence can happen across grid boxes: LATERALITY
- Prognostic equation for the mesh fractions => MEMORY
- May be tuned for Multiscale behaviour



Long runs (climate)

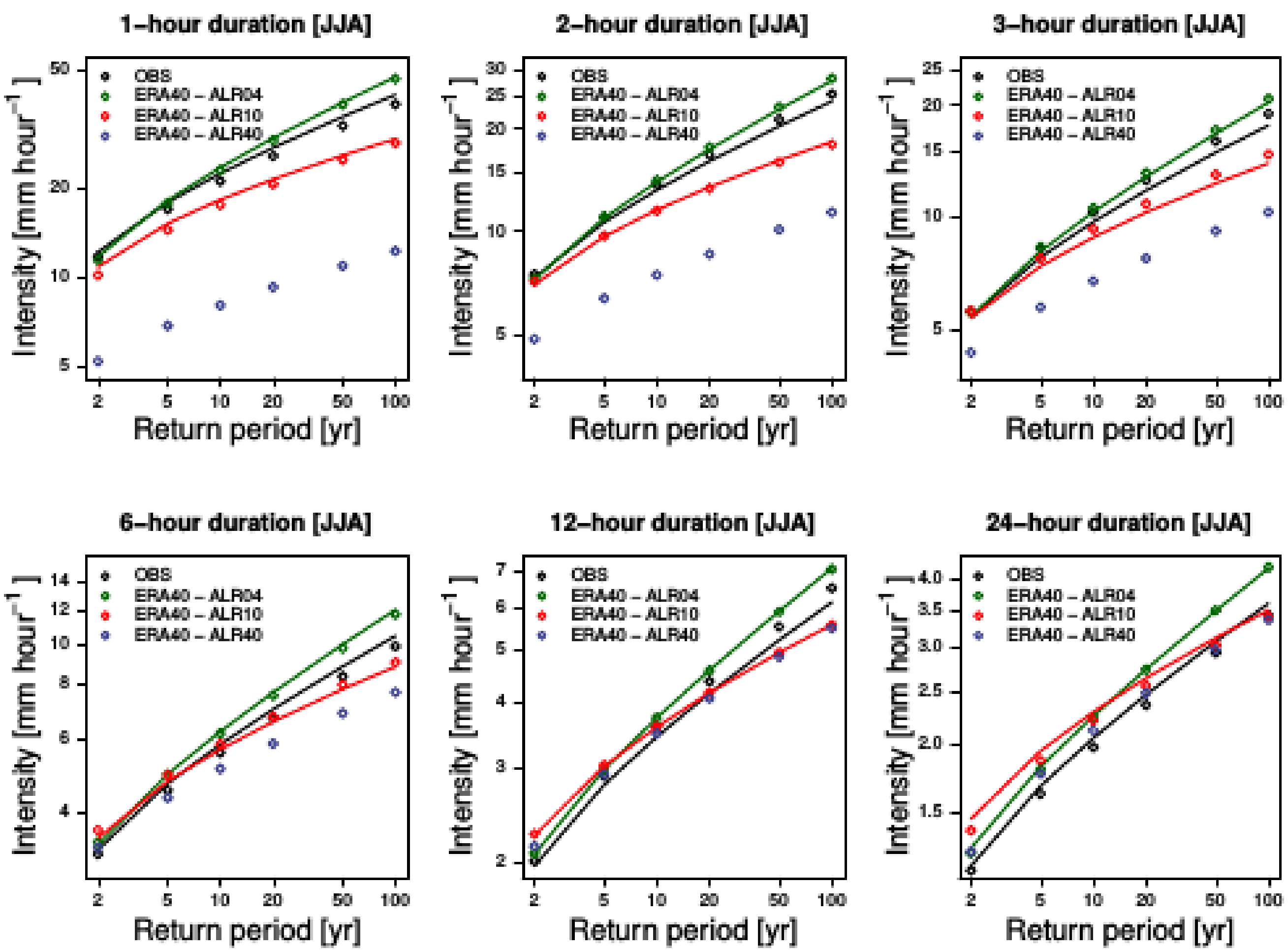


- Coupling ALADIN and ALARO to ERA-Interim in downscaling mode.
- 40 km → 10 km → 4 km
- Relative frequency vs. precipitation quantity (mm/day)

De Troch et al. (2013)

Intensity-Duration-Frequency

IDF relationship based upon power law

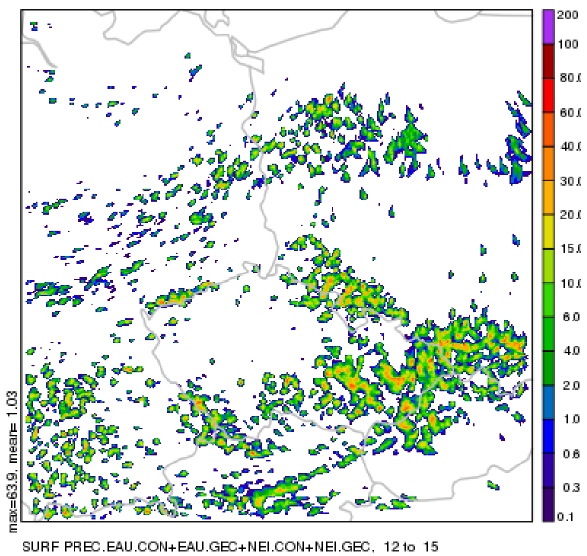
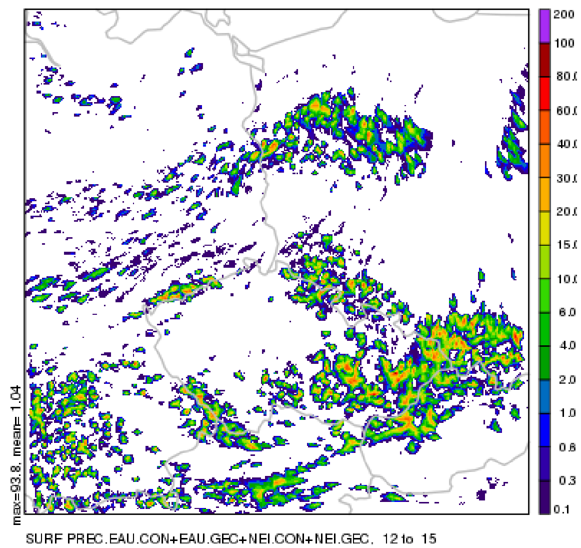
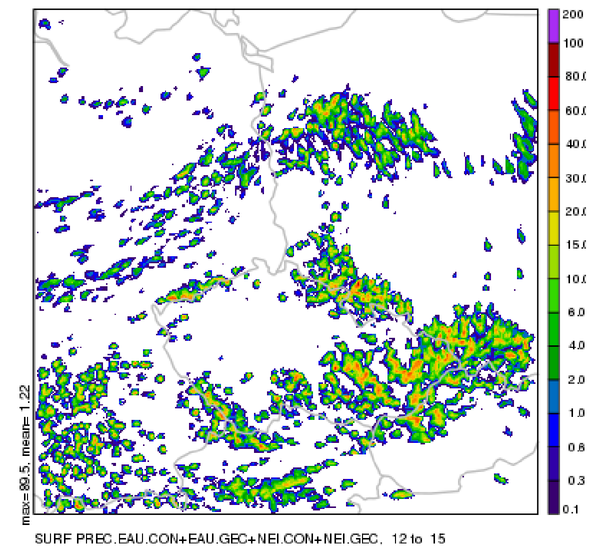
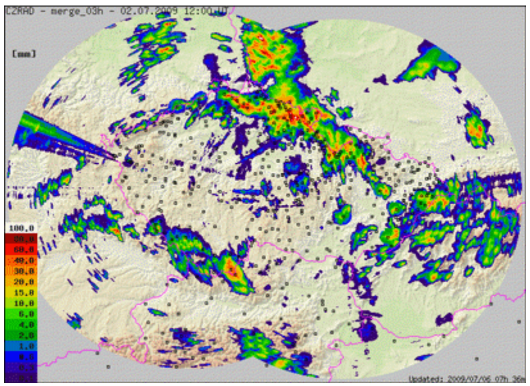
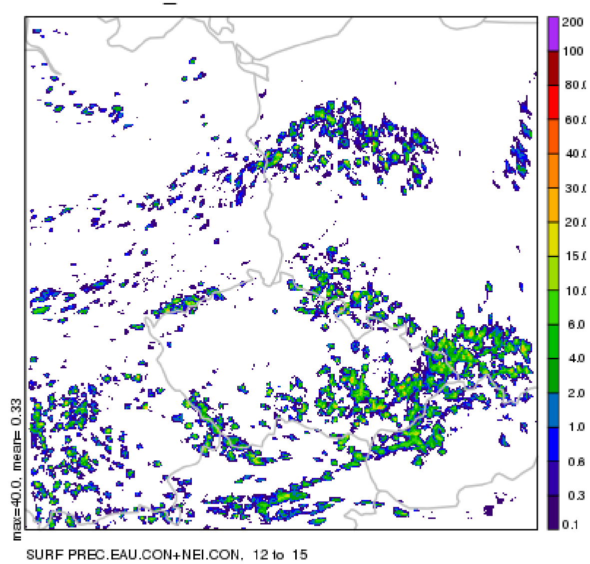
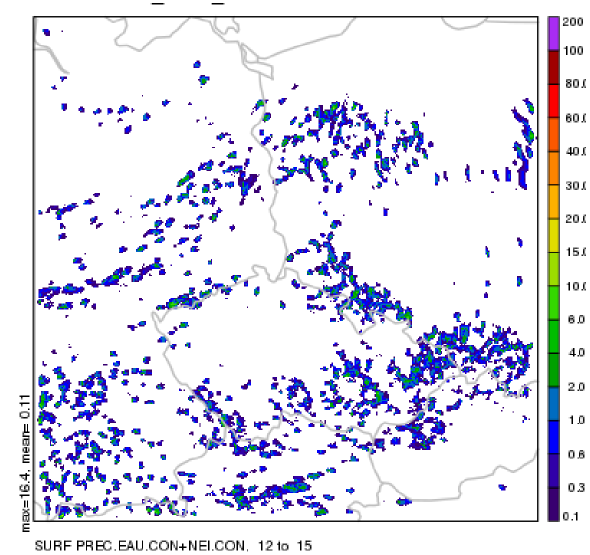


R. De Troch, PhD

Towards true scale-awareness: CSD

- Complementary subgrid draught scheme (CSD, Gerard 2015): the parametrization produces a complement (expressed as a kind of perturbations on top of the resolved background) to the resolved signal, fading out at very fine resolution.
- Mixed closure (CAPE and Moisture convergence)
- Prognostic evolution (updraught fraction and velocity, cloud elevation) is essential
- Triggering of the perturbation updraught based on resolved condensation
- Stochastic component (Cellular Automaton, Bengtsson et al. 2013, seeded where TKE< threshold) acts on triggering and closure.

Compared behaviour (res. 2km)

NO DC param	3MT	CSD+CA	
			total
			subgrid part

3-h accumulated precipitation

TOUCANS, Ďurán, Geleyn, Váňa (2014)

- TOUCANS:
  - Treatment of TKE as an extension of a Louis-type of turbulence, while maintaining the possibility to use the implicit solver that exists in the code.
  - Can "emulate" Quasi-normal scale elimination (QNSE), Energy Flux Budget (EFB), and introduce Third-Order Moments (TOMs).
  - There is no critical Ri
  - Account for anisotropy in turbulence
- Shallow convection (i.e. non-precipitating convection) is included in TOUCANS, using the moist Brunt-Väisälä Frequency of Marquet and Geleyn, 2013.

The physic-dynamics interface

- All terms of the physics-dynamics coupling are expressed in a flux-conservative form:

$$\frac{\partial q_k}{\partial t} = -g\frac{\partial}{\partial p}\left[\sum_{j=1}^{m}\lambda_{kj}R_j + P_k + D_k\right], \quad \text{for } k = 0,\ldots,n$$

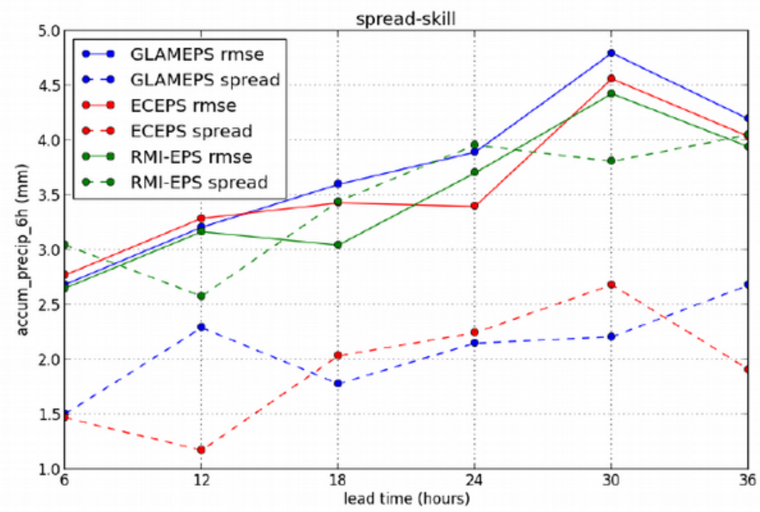
$$\frac{\partial}{\partial t}(c_pT) = -g\frac{\partial}{\partial p}\left[\sum_{k=0}^{n}c_kP_kT + J_s + J_{\text{rad}} - \sum_{j=1}^{m}\Lambda_j^0R_j\right].$$

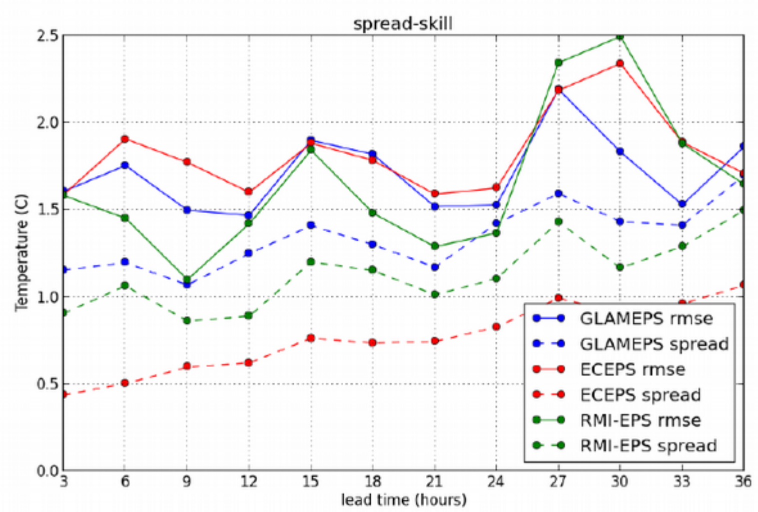
Catry et al. (2007), Degrauwe et al. (2016)

Stochastics/model error

Multimodel EPS

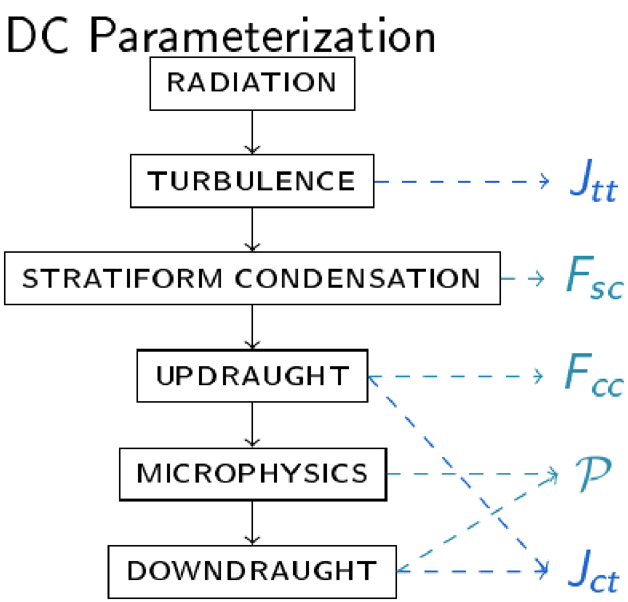
- AROME and ALARO model configs. (both at 2.5km) are coupled to ECMWF ENS (vertical 65L).
- 22 limited area ensemble members: 10+1 from ALARO and 10+1 from AROME (cy38h1.1, both with SURFEX).
- Forecast range: 36 hours (at 00 and 12 UTC).
- Surface assimilation cycle (CANARI) + 3DVar
- upper-air data assimilation for control members.

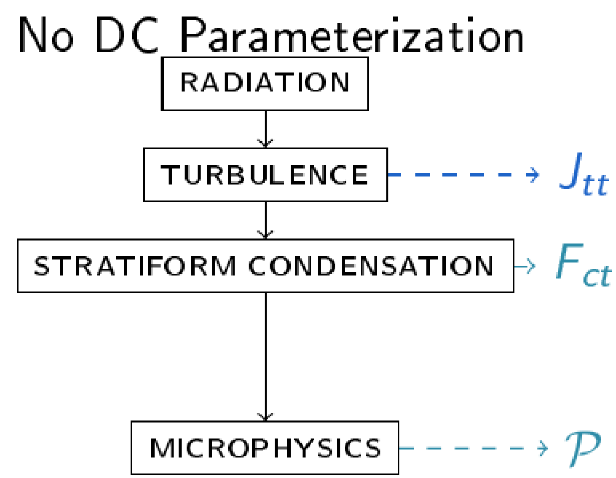




What if we switch off the DCS?

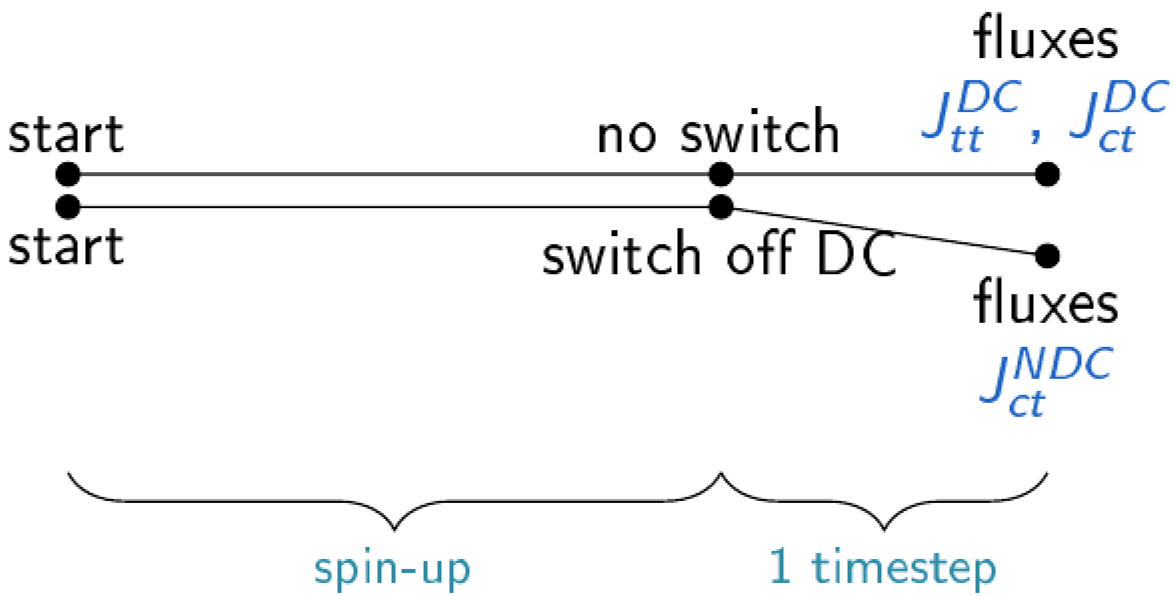
- then what is the “model-error”
- We can switch off the DC scheme
- We should study this in a probabilistic sense



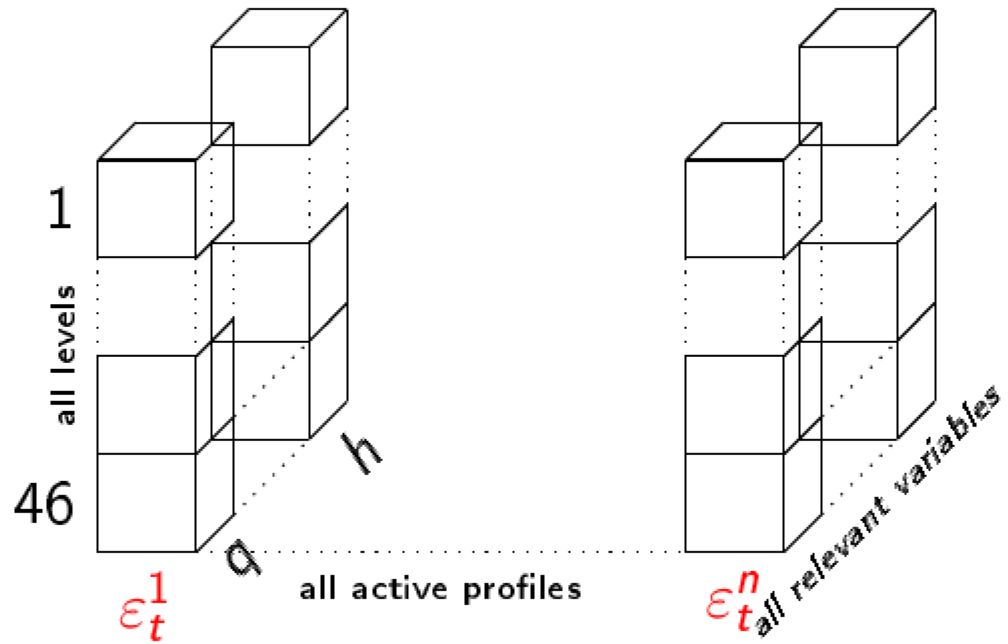


Physically-based estimate of the error

- Experiment: consider the configuration with the DC scheme as the "perfect" model
- And consider the error: $\varepsilon_\psi = -\varepsilon'_\psi = J^{\mathrm{conv}}_{\psi,\mathrm{3MT}} + J^{\mathrm{turb}}_{\psi,\mathrm{3MT}} - J^{\mathrm{turb}}_{\psi,\mathrm{STRAPRO}}$
- Compute it (including some spin up)



Add stochastics by a resampling

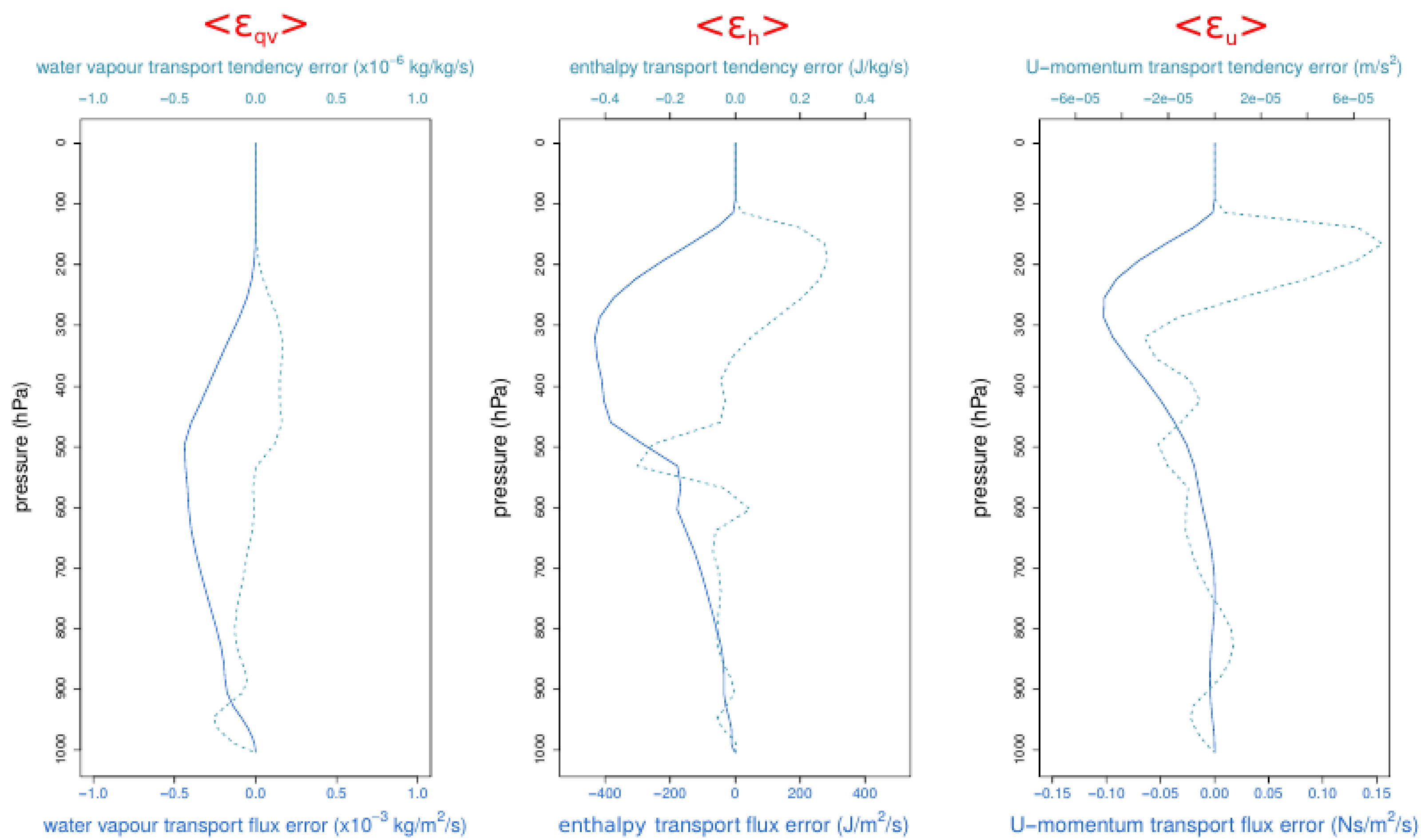


- Draw now the error randomly from the sample set and treat it an additive perturbation to the turbulence pseudo flux:
- This creates flux-conservative perturbations:

$$\left(\frac{\partial \psi}{\partial t}\right)_{\Phi}^{i} = -g\frac{\partial}{\partial p}\left\{J_{\psi,\mathrm{STRAPRO}}^{\mathrm{turb},i} + \varepsilon_{\psi}^{i} + \text{other param.}\right\}$$

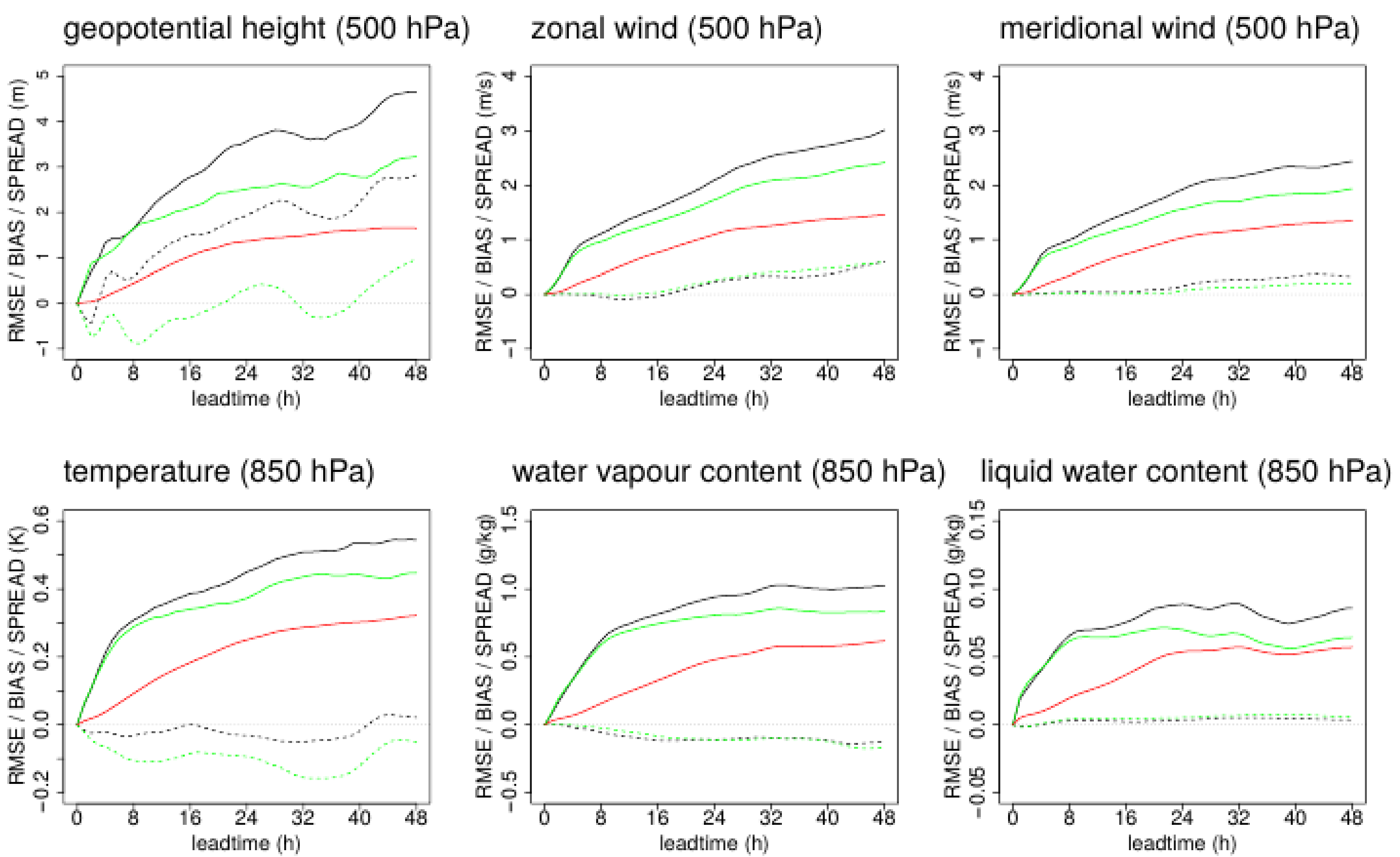
Some examples

- Vertical transport flux error and corresponding tendency



Can an ensemble (15 members) get close to a deterministic run with 3MT?

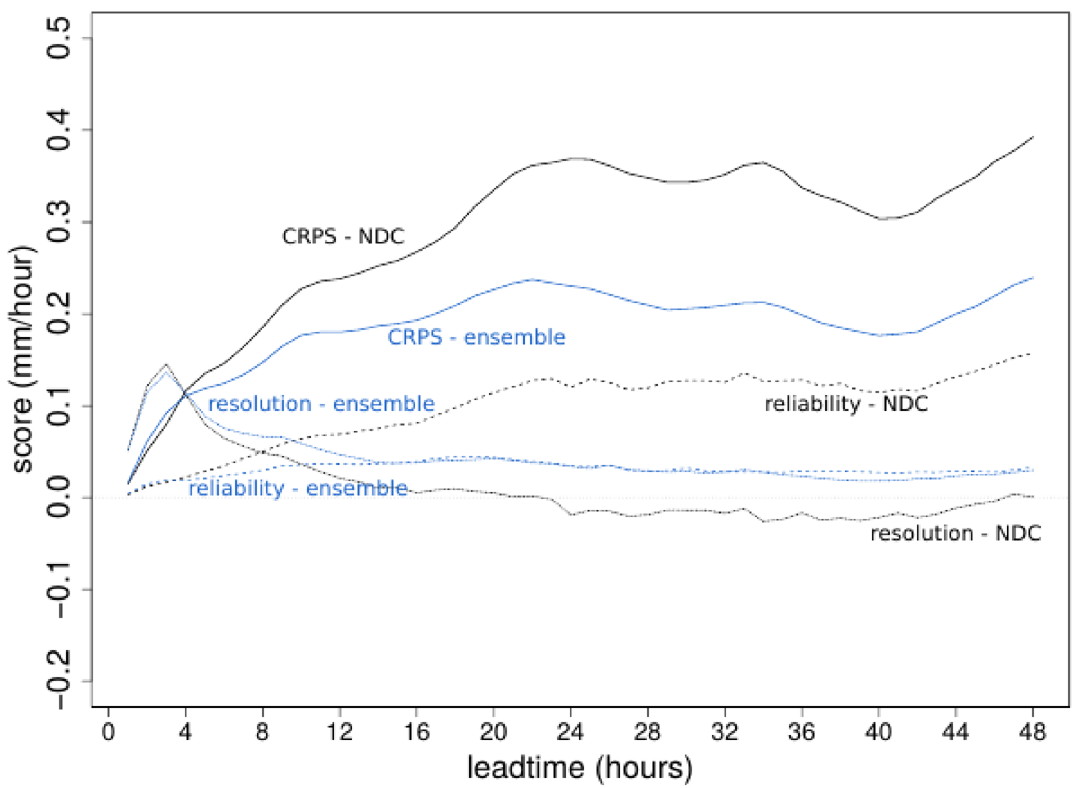
- RMSE and BIAS of the NDC-run vs the RMSE and BIAS of the ensemble
- RMS SPREAD of the ensemble



Courtesy M. Vanginderachter

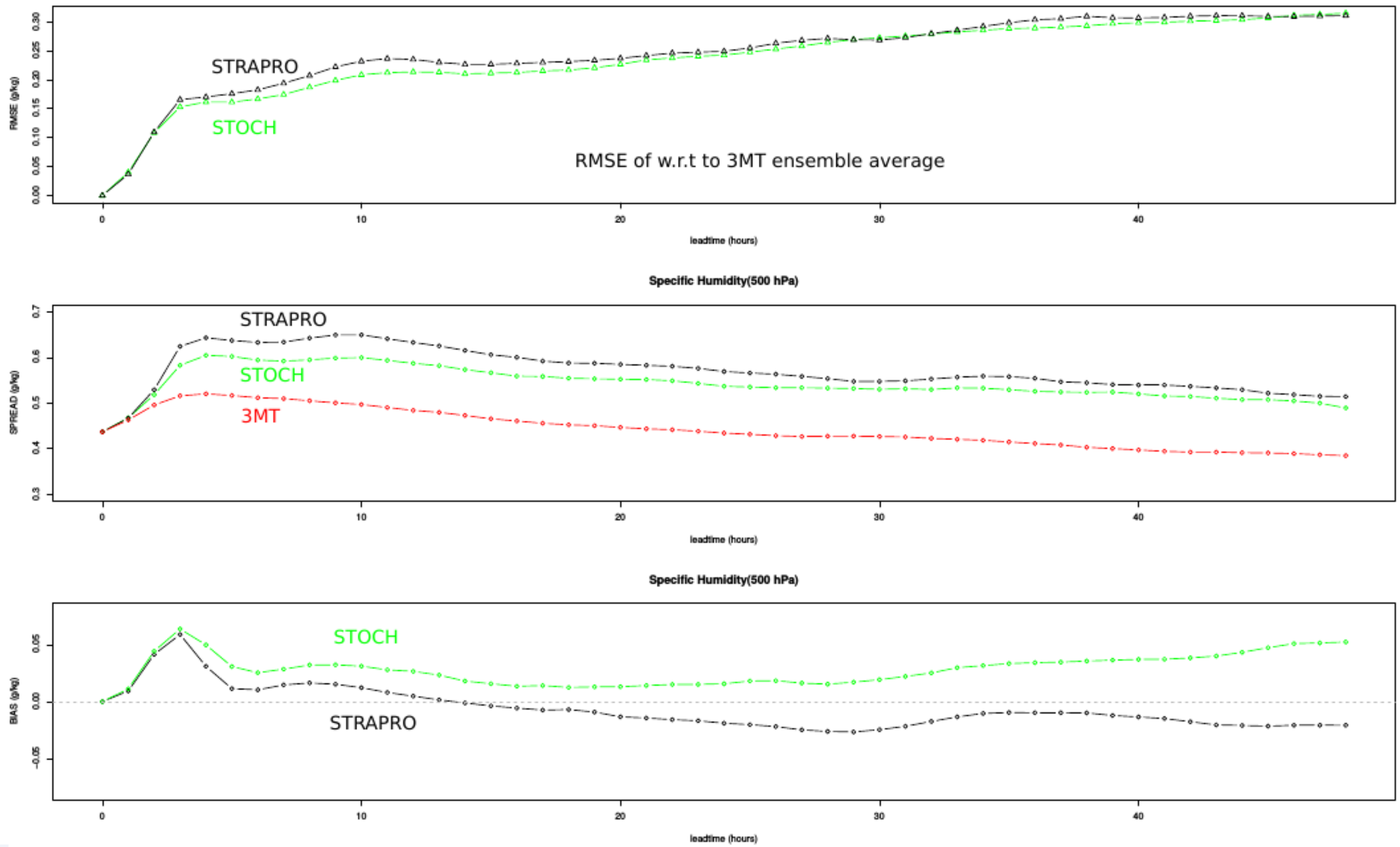
Results

- Precipitation (DC - NDC - ENSEMBLE)
- Continuously ranked probability score = Uncertainty + Reliability - Resolution

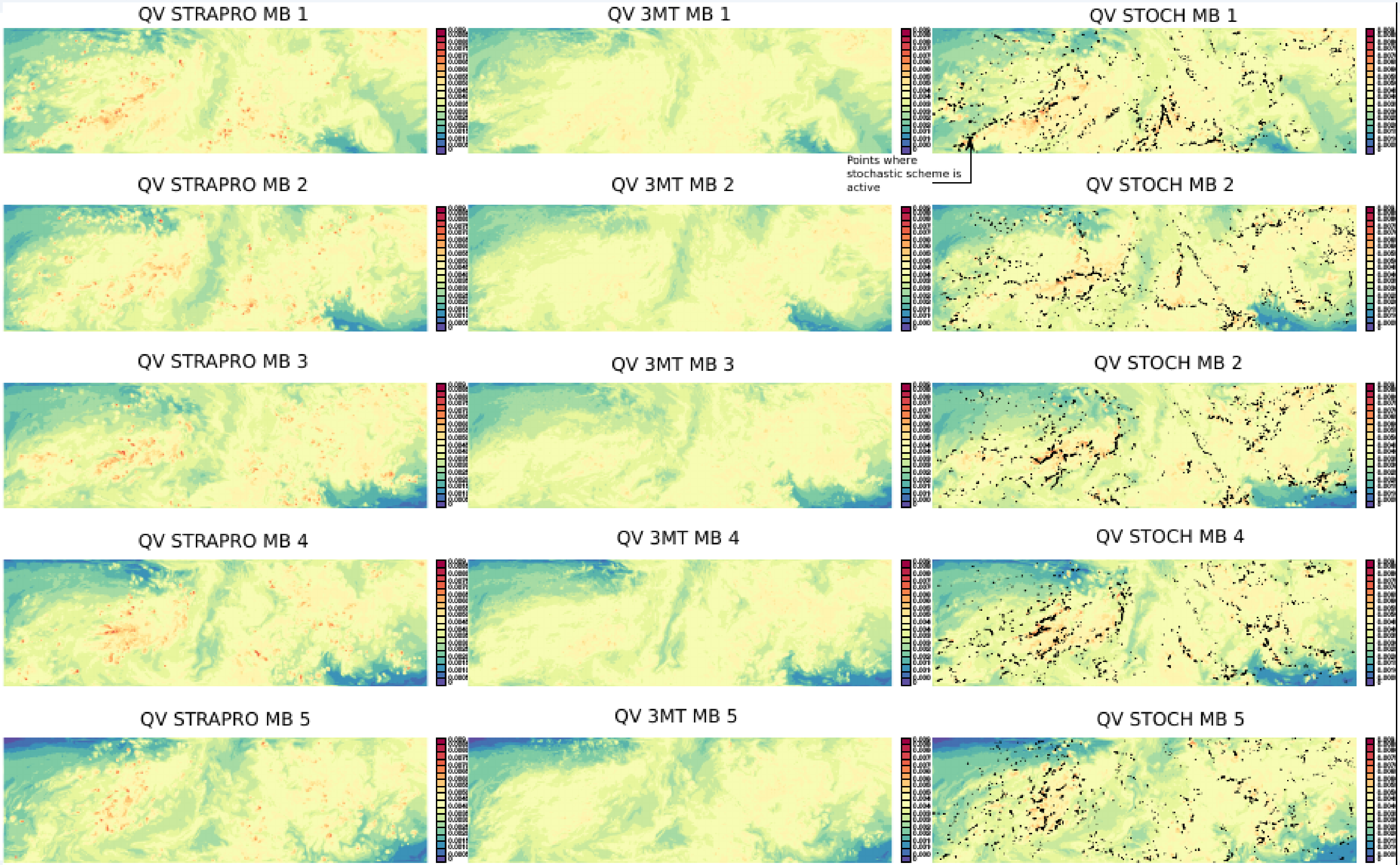


Application in a lagged ensemble

- 3 lagged ensembles (5 members): using 3MT, NODC (STRAPRO) and NODC with sampled model-error based stochastics (STOCH)
- **The perturbations reduce the spread! But nevertheless bring the NODC closer to the 3MT configuration**



The effect of the perturbation



Discussion

- The collaboration between 16 partners with varying available computing resources created a need for a multiscale solution for the treatment of deep convection.
- Seamless transition from the older scheme led to the choice of a bulk mass flux scheme for deep convection. And a treatment of the non-precipitating convection by a moist turbulence scheme.
- This ALARO configuration is operationally used both in NWP, but also in climate, where multiscale applications are also needed.
- We have a model with an option for a DC scheme. This allows to switch it on/off and can be used for scientific tests, eventually to develop physically model-error based stochastics.

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