Convection parameterization in the CNRM climate model: calibration and structural limits

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Context and motivations

New atmospheric physics in CNRM-CM6-1 (Roehrig et al. 2019):

- Calibration over the past 4-5 years (back and forth with development)
- Calibration "by hand", one or two parameters at the same time
- Difficulty to calibrate this physics to make it work for both shallow and deep convection ("unified" convection parameterization)

Recent developments (especially along the French High-Tune project):

- Use of statistical tools from the *Uncertainty Quantification* community
- Help to rigorously explore the sensitivity of a physics/parameterization to its internal parameters, even though simulations can have significant computing time
- Framework to identify which model errors are related to calibration issues and which are structural to the model

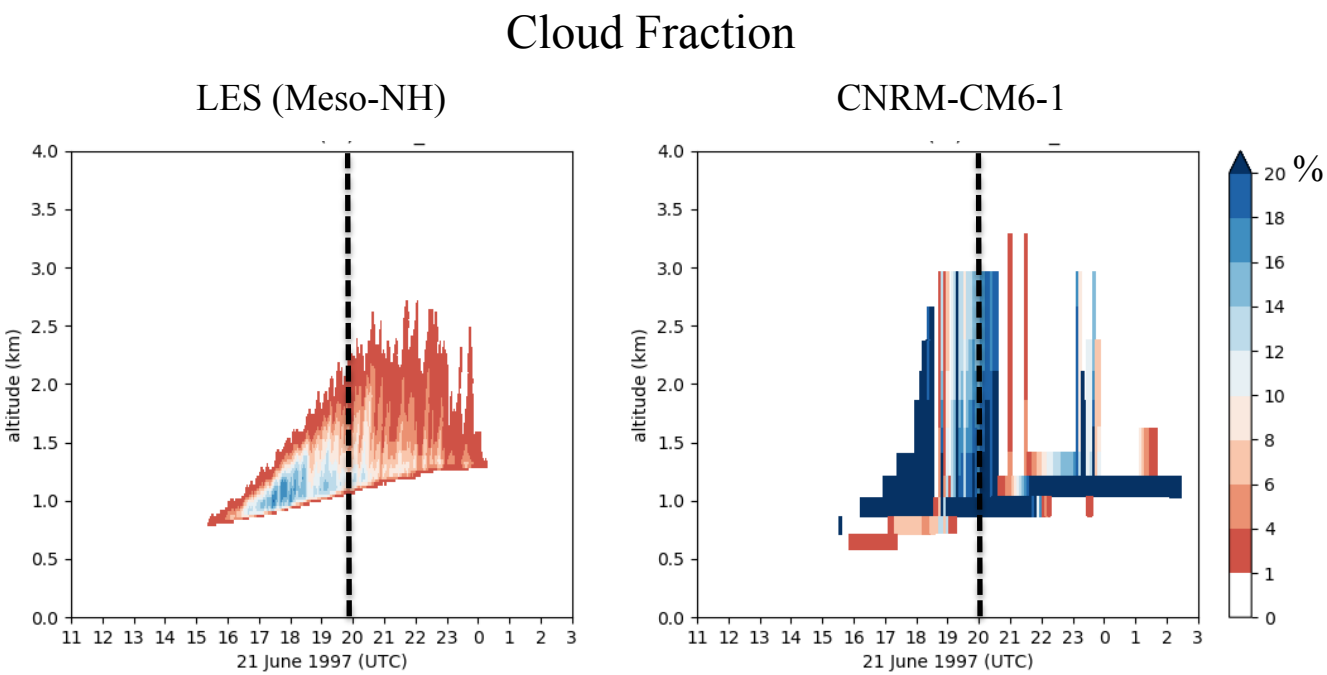
The 1D framework:

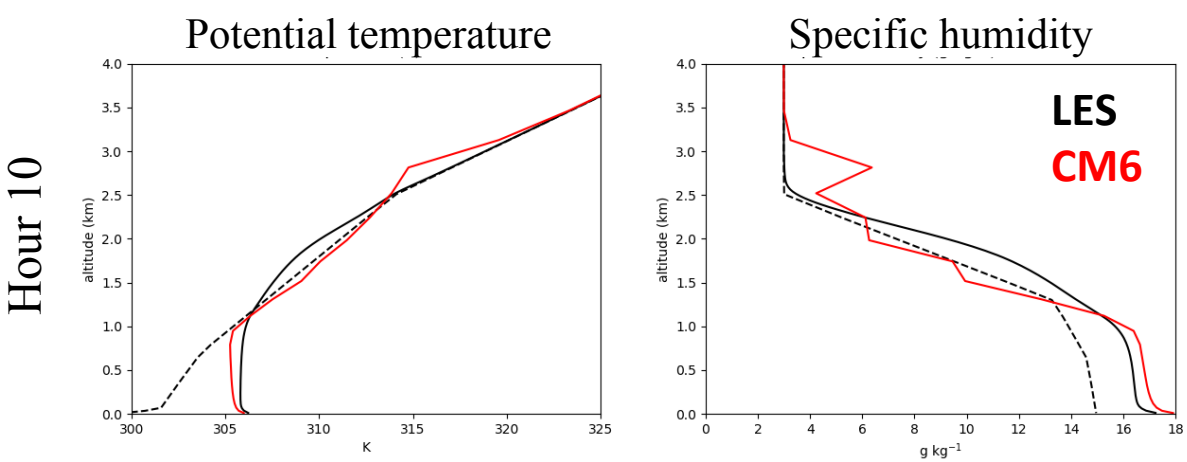
- Key step in the development process of atmospheric parameterizations
- Step that allows to be really close to physical processes, and during it is easier to understand compensations of errors; use of LES/CRM simulations is often key
- A wide range of cases is now available, with reference simulations.
  - Necessary condition for a parameterization to be validated?

All these provide a rigorous framework to address questions such as:

- In a given model (or environment), and independently of calibration issues, is parameterization A better than parameterization B ?
- Can a unified convection parameterization (such as the one used in CNRM-CM6-1) really capture dry, shallow and deep convection?

ARM-Cumulus : diurnal cycle of continental cumulus





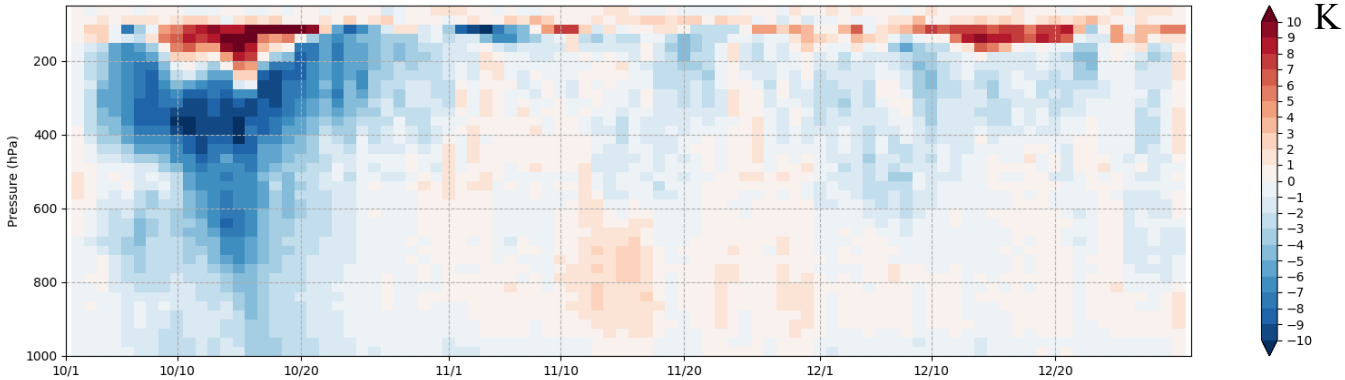
- Overestimate of cloud fraction
- Cloud base too low
- BL not deep enough, mixing too weak
- Intermittency and numerical issues

Convection during CINDY2011/DYNAMO

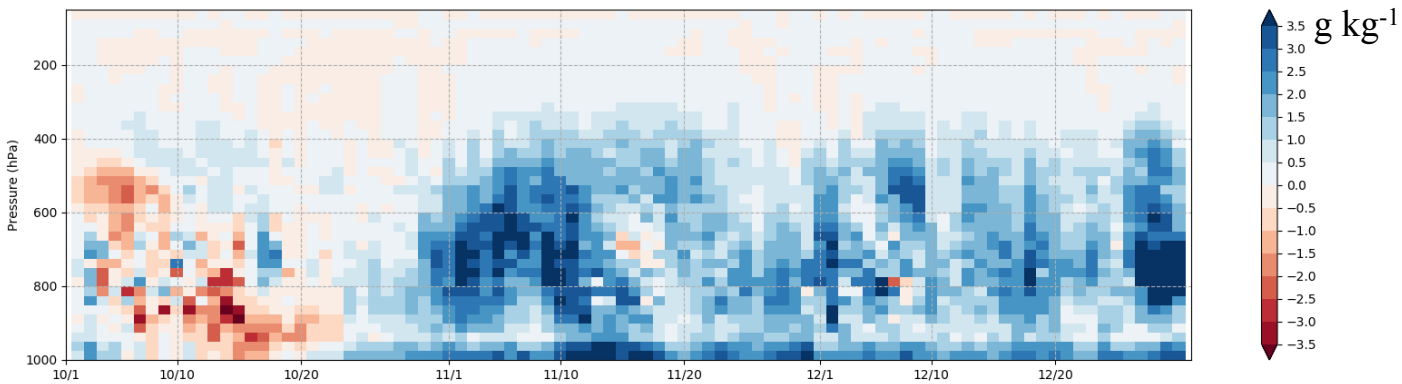
Field campaign in OND 2011, documenting energy and moisture budget over two arrays in the Indian Ocean (Johnson and Ciesielski, 2013)

Northern Sounding Array

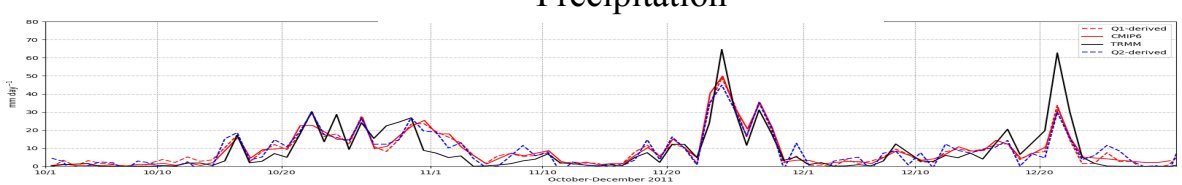
CM6 Potential temperature bias



CM6 Specific humidity bias



Precipitation



Objectives and Framework

Objectives

- Explore the parametric uncertainty of the CNRM-CM6-1 convection parameterization for the ARM-Cumulus et CINDY2011/DYNAMO cases
- Which errors are calibration issues ? Which are structural ?

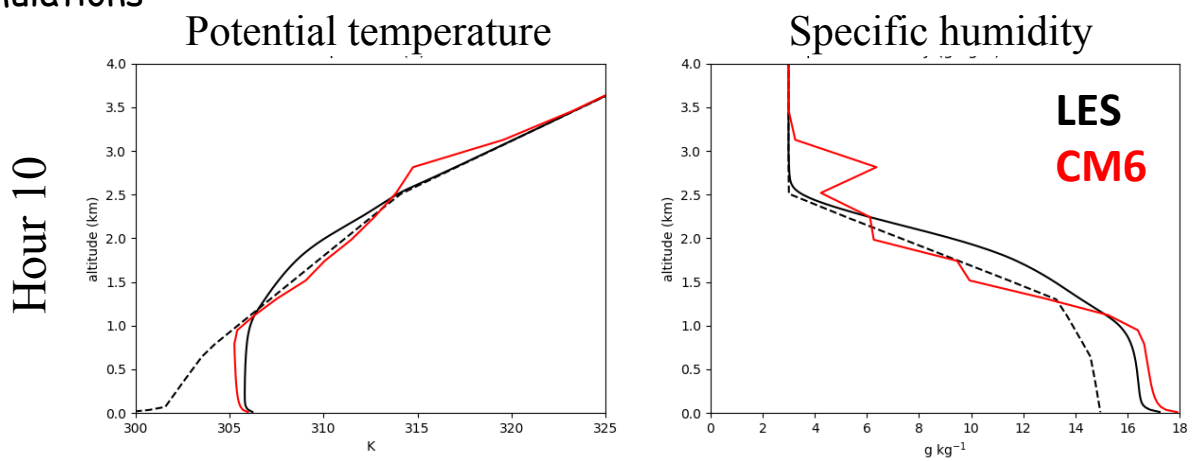
Framework : *Iterative refocussing*

(Williamson et al. 2017, Salter et al. 2018)

- Define target metrics m_i and associated references
- Identify relevant uncertain parameters **x** and their uncertainty ranges **x** $\in$ X
- Build an experimental design (learning dataset)
- Build emulators $f_i(\mathbf{x})$ for each metrics m_i (Gaussian Processes)
- Identify the subset of X which cannot be ruled out yet (NROY space) knowing (*implausibility*) :
  - Reference uncertainties,
  - Emulator uncertainties,
  - Some tolerance (*discrepancy*) quantifying how close to the reference we think our model can be.
- Continue with a 2nd, 3rd, … wave, as long as we need to improve the emulator forecasts (but only where it is needed), until convergence towards the true NROY is approximately achieved

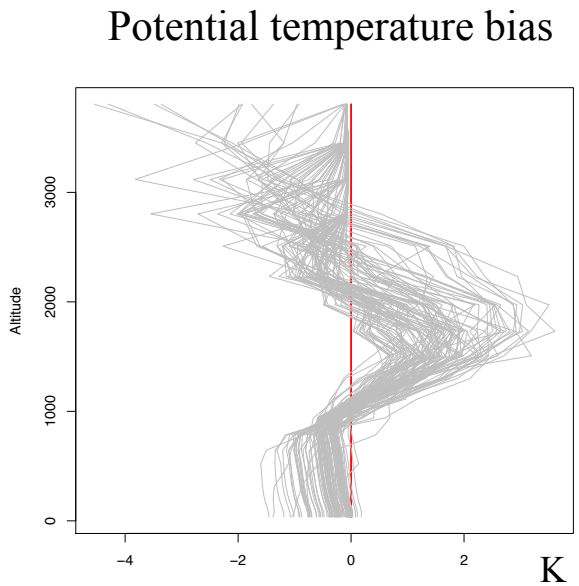
Metrics, parameters and experimental design

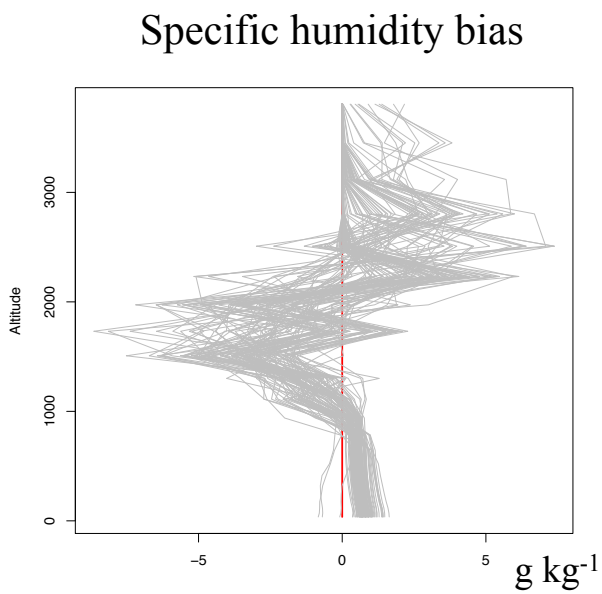
- Direct emulation of vertical profiles of temperature and specific humidity (Hour 10 of ARM-Cumulus case)
- Metrics to define the NROY space ~ Euclidean norm
- Reference: LES simulation with Meso-NH, uncertainty from an ensemble of LES simulations



- 13 parameters:
  - 8 related to convective transport (entrainment/detrainment, drag, buoyancy parameter)
  - 2 related with convective closure
  - 1 related to convective cloudiness
  - 2 related with liquid water microphysics
- Wave 1: 100 simulations, sampling based on a Latin hypercube
- Next waves: 50 simulations

Wave 1: 100 simulations



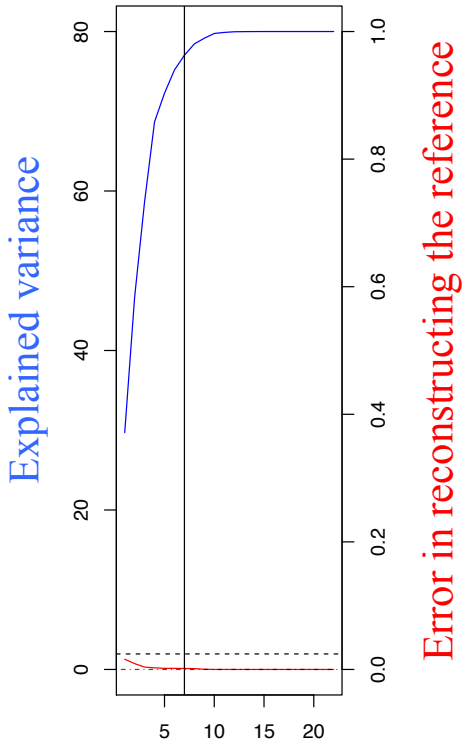


Discrepancies (constant along the vertical):

- Potential temperature: 0.5 K
- Specific humidity: 1. g kg^{-1}

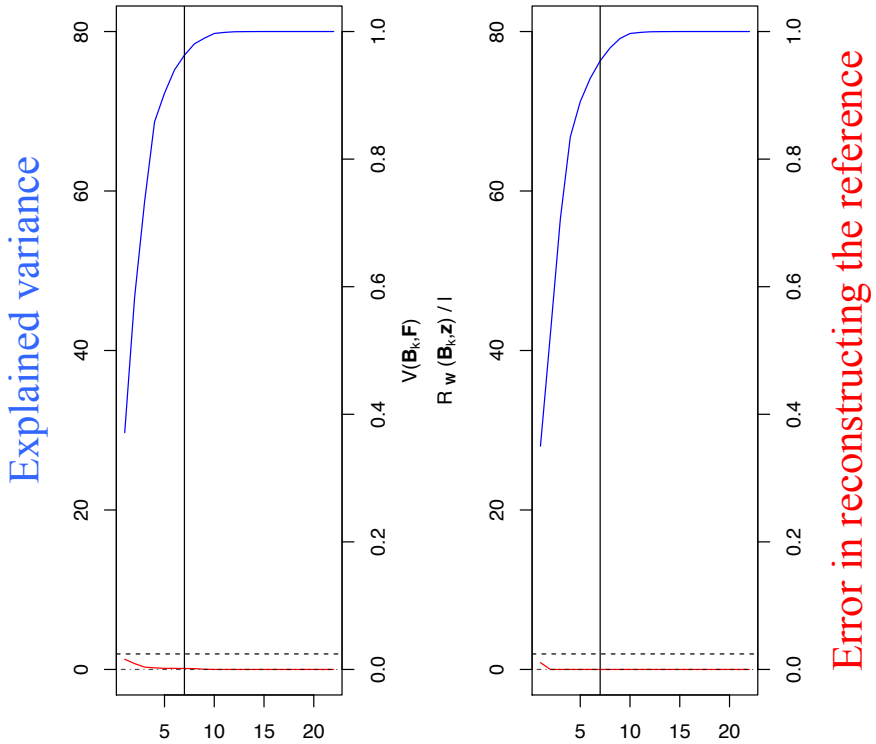
Reducing the number of dimensions

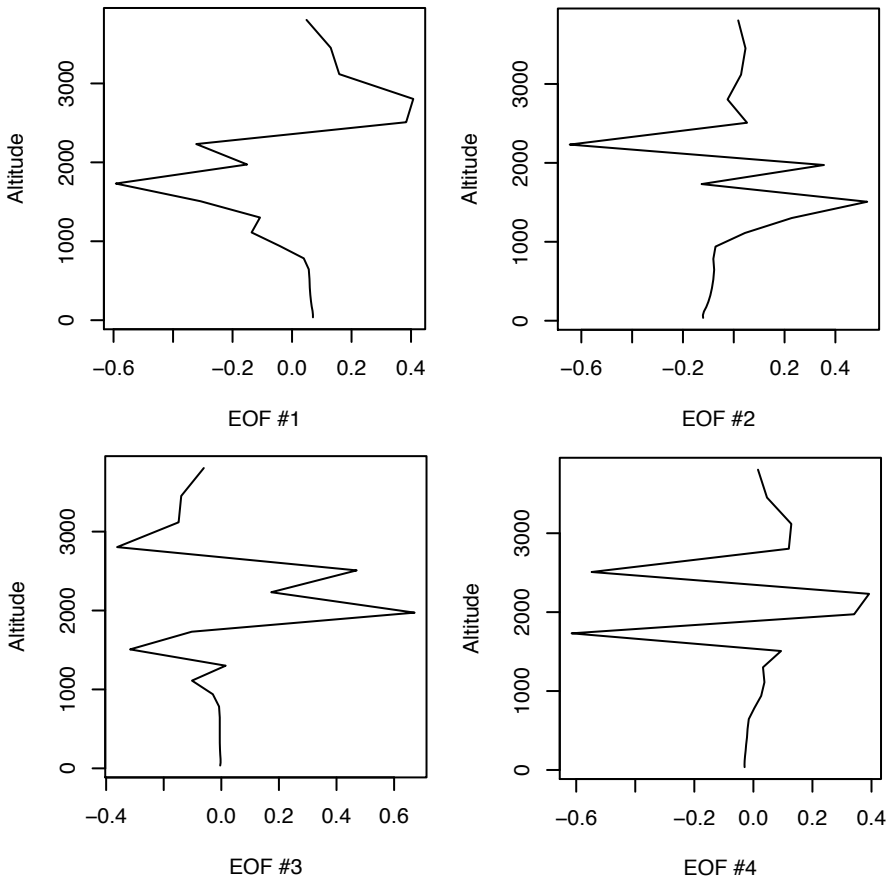
- Rather than emulate each level (22), the number of dimensions is reduced using EOFs.
- The first 7 EOFs (explained variance > 95%) would be used.



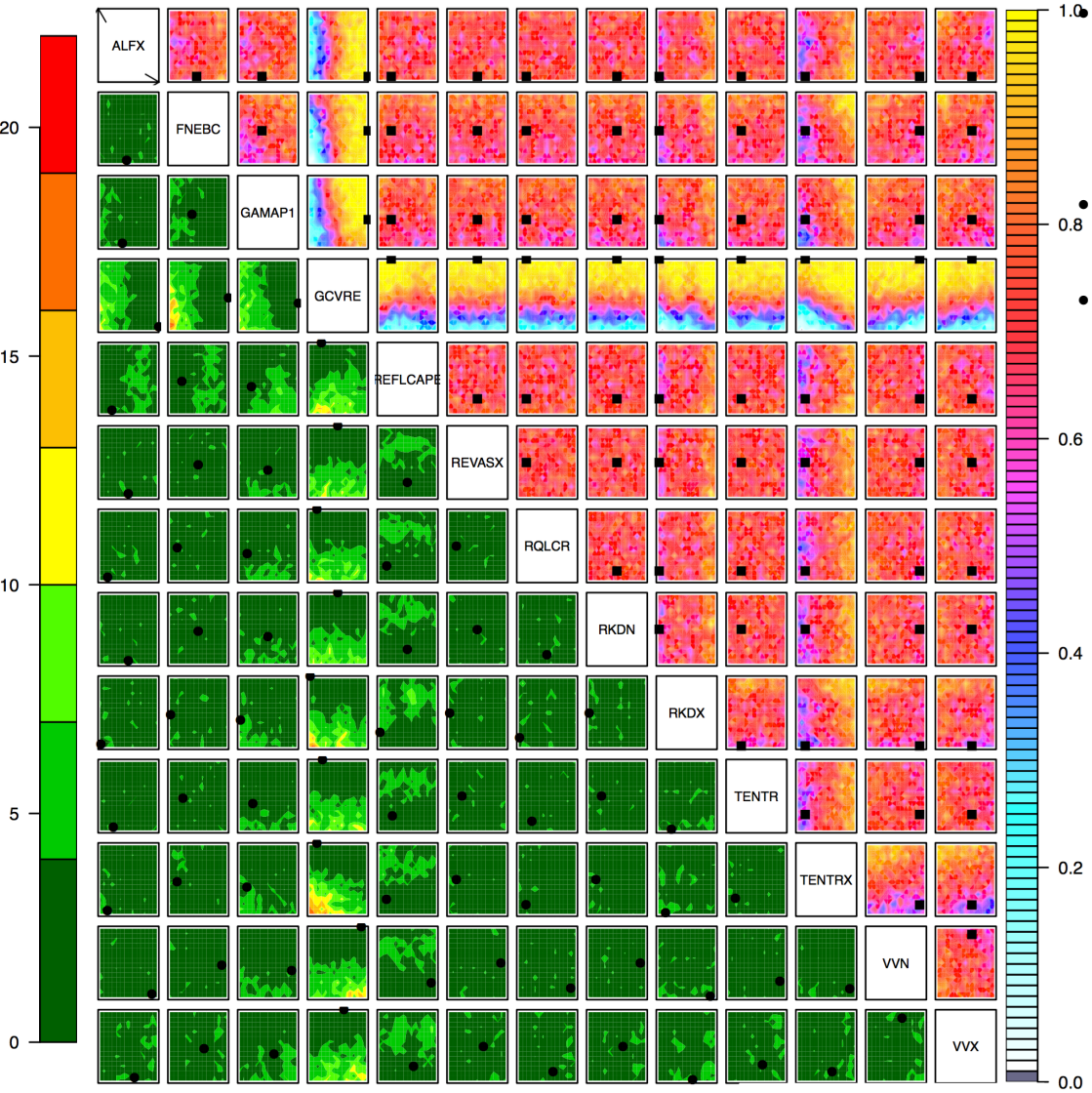
Reducing the number of dimensions

- Rather than emulate each level (22), the number of dimensions is reduced using EOFs.
- The first 7 EOFs (explained variance > 95%) would be used.
- However, these classic EOFs cannot generally reproduce the reference. Risk of *terminal case*.
  - Rotation (Salter et al. 2018)





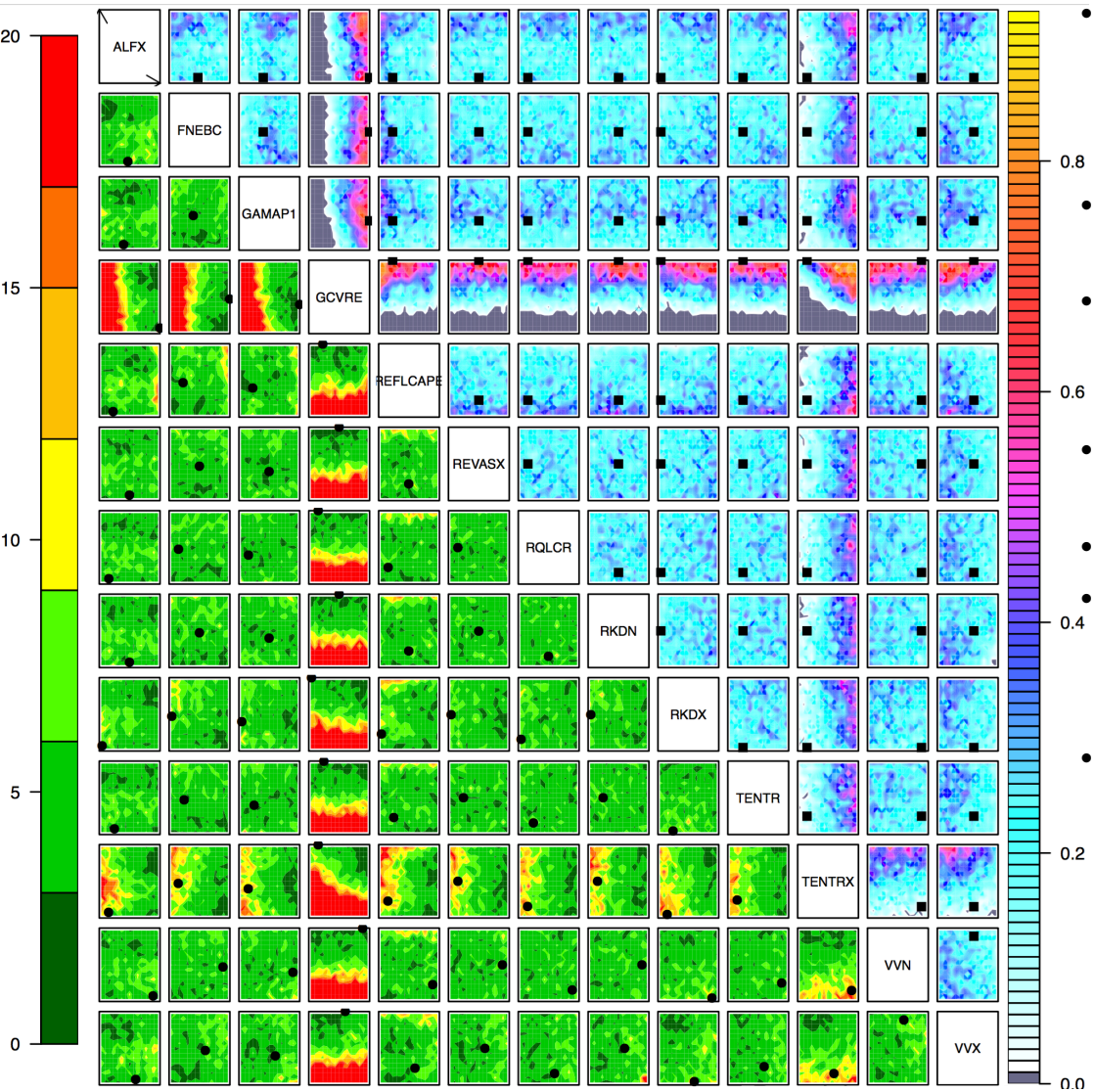
Not Ruled Out Yet Space – Wave 1



Implausibility threshold based on a χ^2 distribution with 7 degrees of freedom (99%).

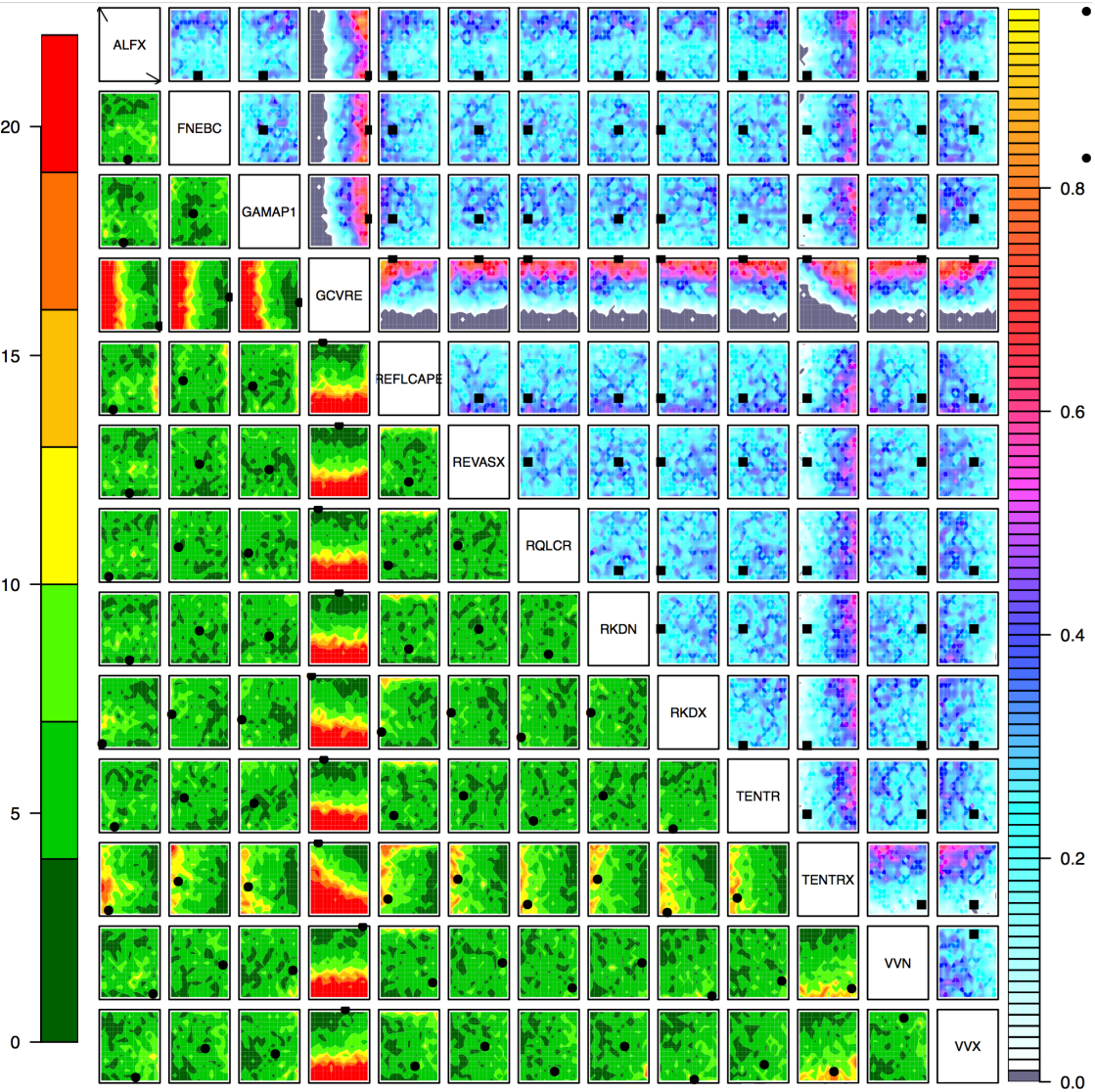
- After Wave 1, NROY space ~71% of the departure space.
- But the emulator uncertainty dominates the implausibility

Not Ruled Out Yet Space – Wave 5



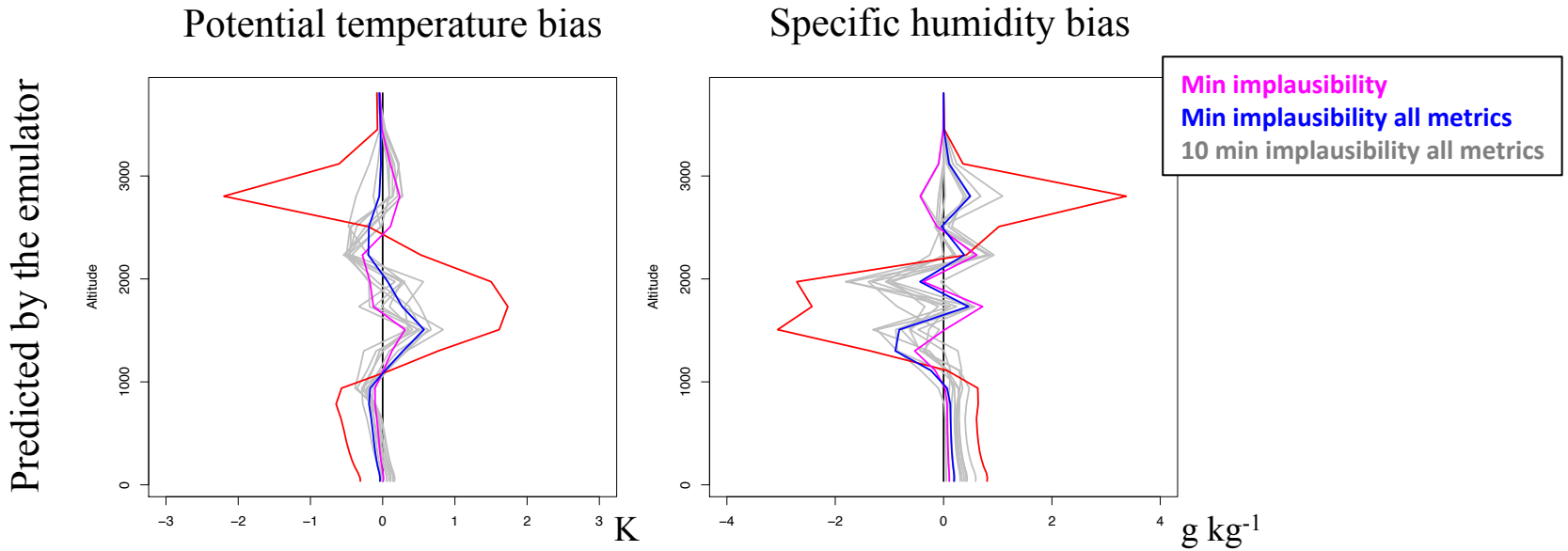
- *Implausibility* threshold based on a χ^2 distribution with 7 degrees of freedom (99%).
- After Wave 1, NROY space ~71% of the departure space.
- But the emulator uncertainty dominates the implausibility
- After Wave 5, NROY space ~23% of the departure space.
- Convergence approximately achieved
- Dominant parameters:
  - Organized entrainement modulation factor (GCVRE)
  - Maximum turbulent entrainment (TENTRX)
- A few others parameters are important
  - Coefficient in convective CAPE closure (REFLCAPE)
  - Transition vertical velocity for turbulent entrainment (VVX)
  - …

Combining temperature and specific humidity



- Consistent behaviour for potential temperature.
- High values of entrainment are required (GCVRE and TENTRX)

First drafted calibration?



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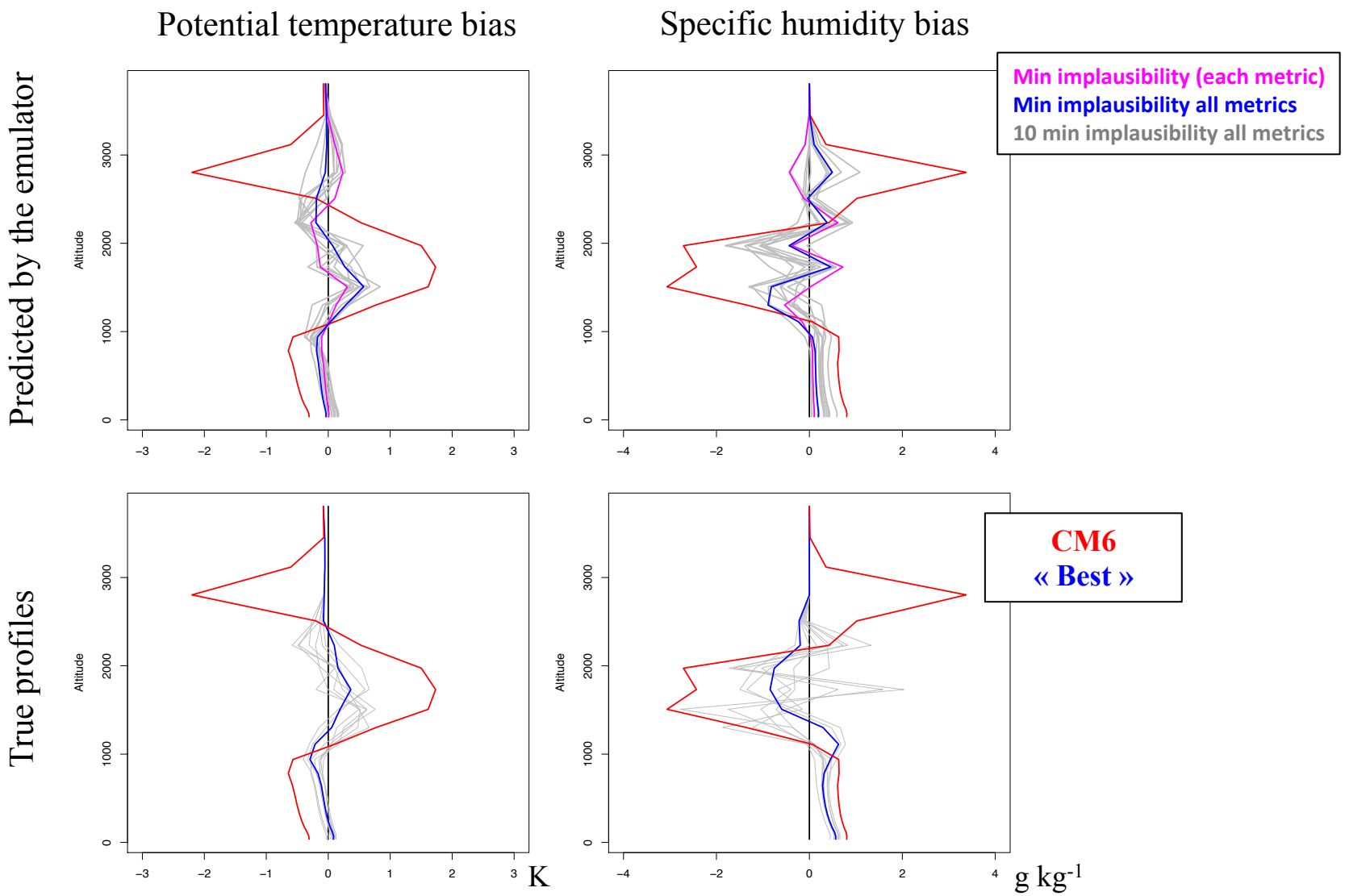
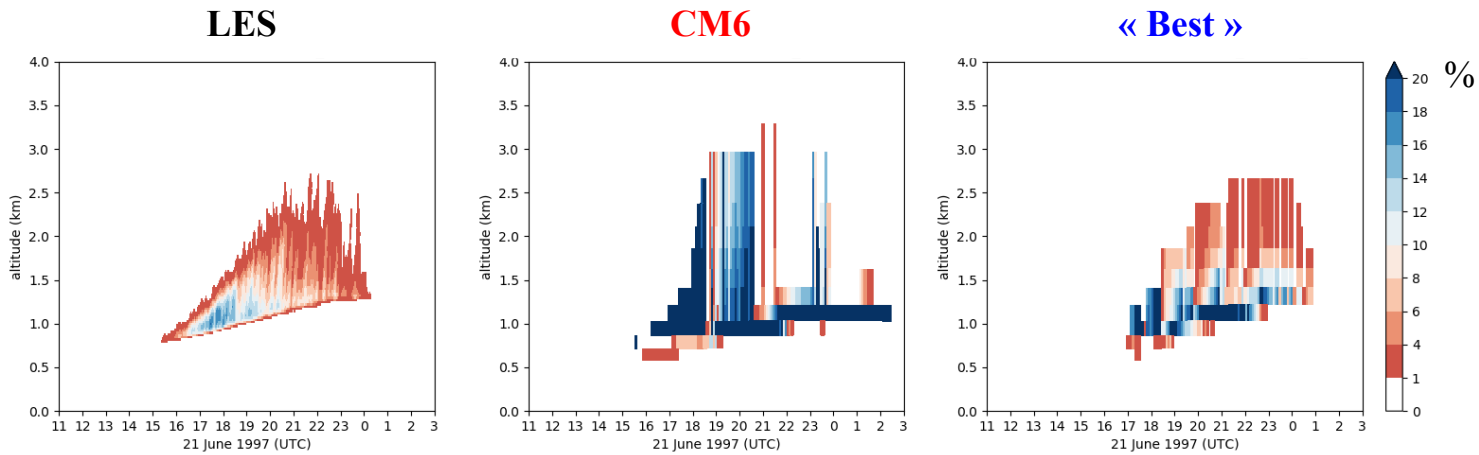
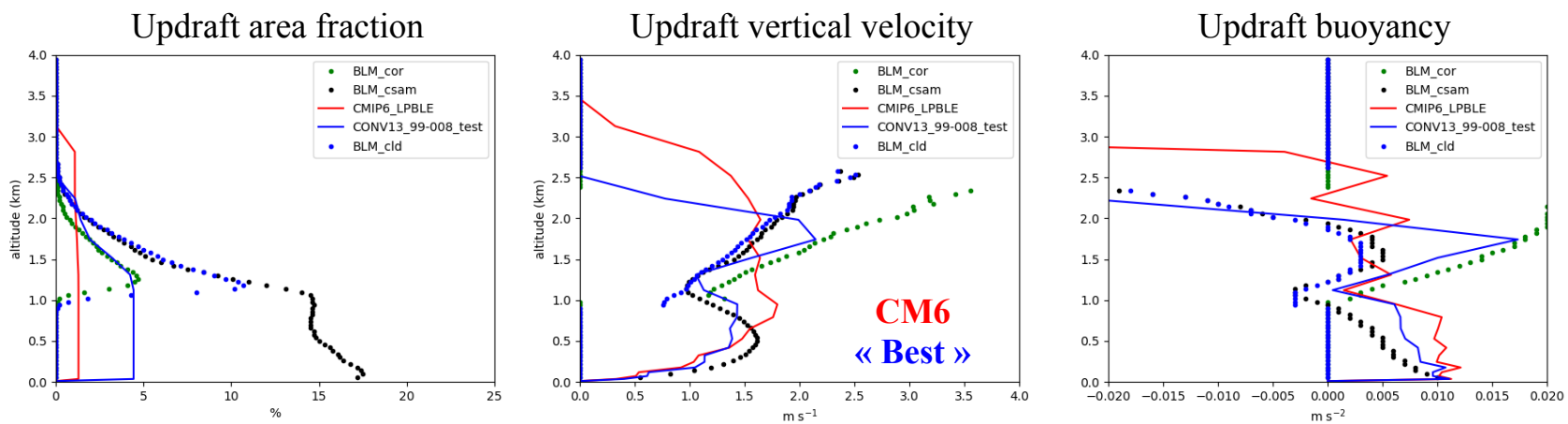


And over the full case?

Cloud Fraction



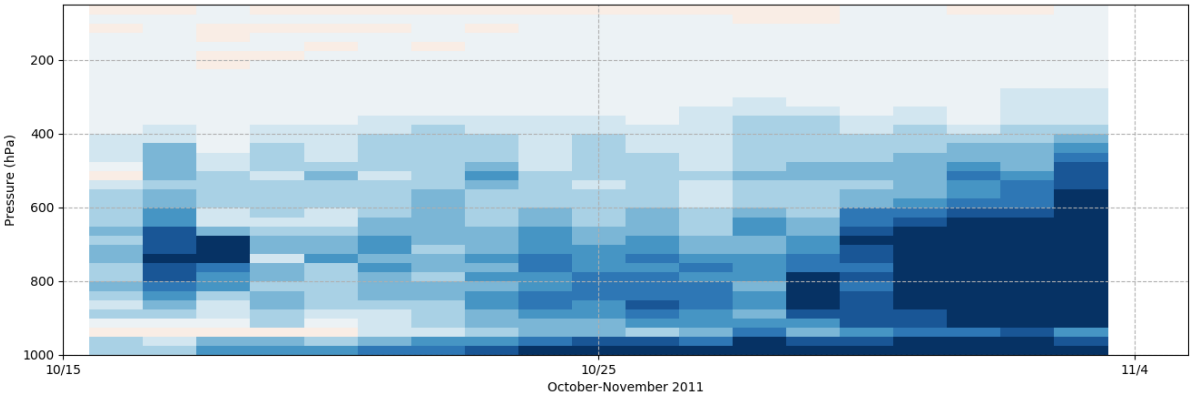
Hour 10

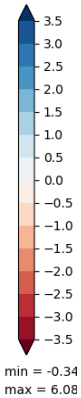


Metrics, parameters and experimental design

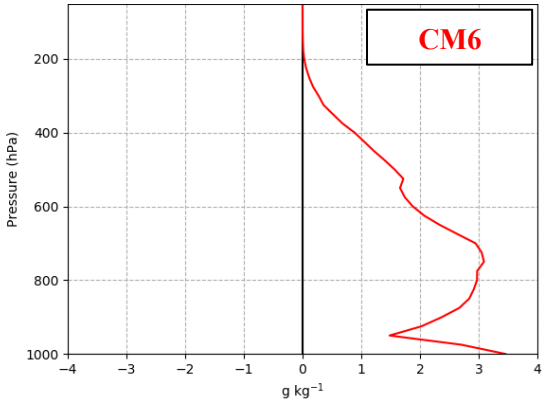
- Focus on the first MJO event, and on the specific humidity profile
- Metrics to define the NROY space ~ Euclidean norm
- Reference: field campaign observation (radiosounding array),
  humidity uncertainty ~0.5 g kg^{-1} (to be improved)

Specific humidity bias





20-day average bias



Metrics, parameters and experimental design

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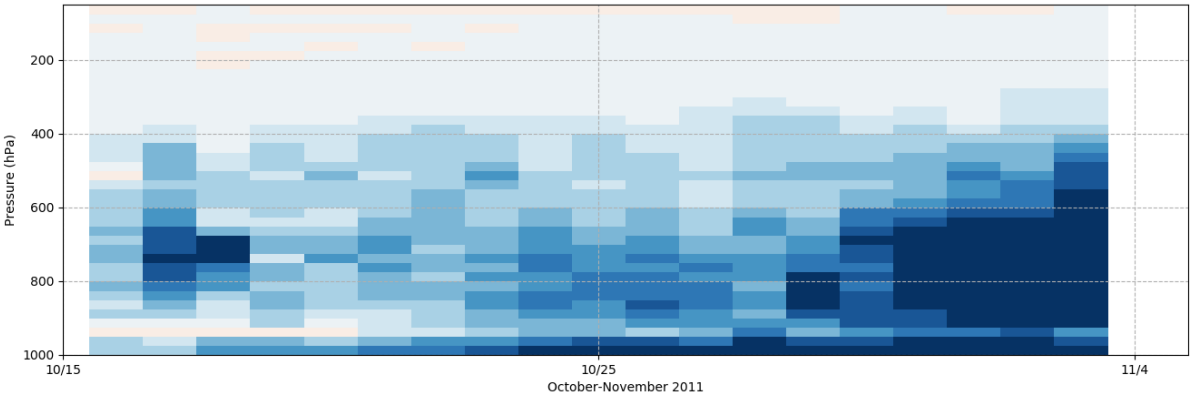
- Metrics to define the NROY space ~ Euclidean norm
- Reference: field campaign observation (radiosounding array),
  humidity uncertainty ~0.5 g kg^{-1} (to be improved)

- Same 12 parameters as before + 3 for ice microphysics
- Wave 1: 100 simulations (Latin hypercube) for Wave 1, then 50

Specific humidity bias



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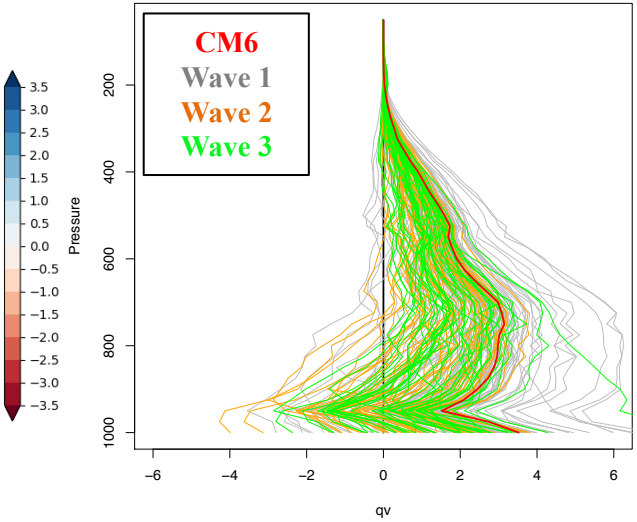
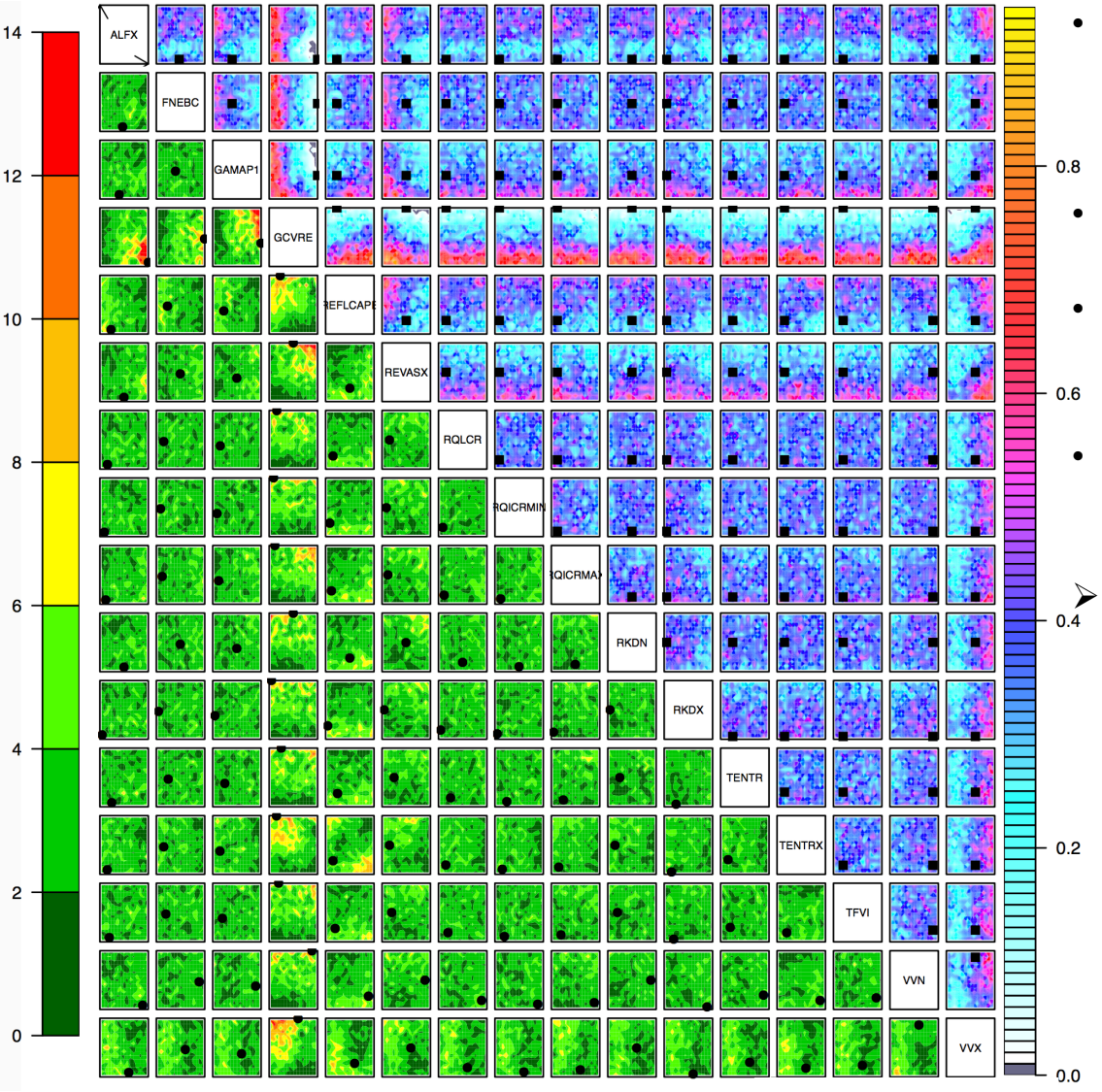


Not Ruled Out Yet Space – Wave 3



- *Implausibility* threshold based on a χ^2 distribution with 4 degrees of freedom (99%).
- After Wave 3, NROY space ~27% of the original space.
- Some further waves required to achieve convergence.
- Similar parameters as for ARM-Cumulus are involved, but with opposite patterns
- Probably hard to find an appropriate tuning for both shallow and deep convection…

Conclusions and perspectives

Conclusions

- *Iterative refocussing* provides a framework to rigorously explore the parametric calibration of a parameterization or a model, and more generally many questions in atmospheric modelling
- It is possible to achieve a better tuning of the CNRM convective parameterization for some 1D cases.
- However, in its present state, the CNRM convective parameterization does not seem to be able to capture both shallow and deep convective regimes

A few thoughts

- The 1D framework should be seen as a necessary step to:
  - Reduce the parameter space which is relevant for tests in more complex configurations
  - Identify as early and efficient as possible the structural limits of a given atmospheric physics
- Choice of metrics (or the "eye of the expert") is crucial to analyse the NROY space, avoid compensations of errors, and further reduce the possibilities
- A few waves (3 to 10) are often required to reach the point where the emulator uncertainty < reference uncertainty/discrepancy
- Discrepancy is critical. A priori based on modellers' experience, but methodologies should be develop to help us to better quantify it
- Need to increase the diversity of 1D cases, to avoid the *over-fitting* trap. Also connect with more complex configurations (towards 3D).