(Two) Ongoing efforts in the French NWP/climate modelling community

R. Roehrig[1], F. Couvreux[1], F. Hourdin[2], C. Rio[1], F. Lohou[3], the High-Tune and DEPHY communities…

[1] CNRM, Université de Toulouse, Météo-France, CNRS, Toulouse, France
[2] LMD, IPSL, Sorbonne Universités, CNRS, Paris, France
[3] Laboratoire d'Aérologie, Université de Toulouse, Toulouse, France

METEO FRANCE

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Legacy of the High-Tune project (2018-2021)

Initial motivations

- Model <u>**calibration/tuning**</u>: bottleneck in NWP/climate modelling
- Critical role of <u>**boundary-layer clouds**</u> in the Earth system
- Lack of references to benchmark boundary-layer <u>**cloud radiative effects**</u>

➢ **Process-based climate model development harnessing machine learning**

A new philosophy for climate (and NWP) model calibration

- **Formalized** calibration process (transparent, reproducible)
- Starting at the **process level** (1D / LES or Observations)
- Natural articulation between 1D and 3D (and coupled) configurations
- Accounting for sources of **uncertainties**
- Rather than optimize, **identify sets of parameters compatible** with a set of given constraints

A statistical framework to better address the complexity of the calibration process, and to accelerate it

- **History matching with iterative refocusing** (Williamson et al. 2015, 2017)
- Use statistical **emulators** to explore the whole space of parameters, at quasi-null computational cost
- Be **parsimonious** in terms of "true", expensive simulations

Game changer in climate modelling

- Separation of concerns between development of model physical content and parameter calibration
- Increased efficiency in implementing new developments and quantify their true benefit
- Rigorous comparison between parameterizations or between model physics
- Exploring model parametric uncertainty, and thereby the model emergent properties

Couvreux et al. (2021, <u>10.1029/2020MS002217</u>), Hourdin et al. (2021, <u>10.1029/2020MS002225</u>), …

History matching with iterative refocusing

Framework

- Define targeted **metrics** f_k, their **references** and their **uncertainties**
- Identify the relevant model **parameters** $\boldsymbol{\lambda}$ and their "acceptable" ranges (**input parameter space** $\boldsymbol{\Lambda}$)
- Build an experimental design (learning dataset)
- Build an **emulator** $f_k(\boldsymbol{\lambda})$ for each metrics (Gaussian Processes)
- Identify the sub-space of $\boldsymbol{\Lambda}$ which is not compatible with the chosen constraints (**Not-Ruled-Out-Yet – NROY – space**) knowing:
  - The reference uncertainty,
  - The uncertainty due to the emulator,
  - The model structural uncertainty (interpreted so far as a tolerance to error)
  - **Implausibility, cutoff** (T=3)

$$I_f(\boldsymbol{\lambda}) = \frac{|r_f - \mathrm{E}\left[f(\boldsymbol{\lambda})\right]|}{\sqrt{\sigma_{r,f}^2 + \sigma_{d,f}^2 + \mathrm{Var}\left[f(\boldsymbol{\lambda})\right]}}.$$

$$\mathrm{NROY}_f^1 = \{\lambda \mid I_f(\lambda) < T\}$$

$$\mathrm{NROY}^1 = \bigcap_f \mathrm{NROY}_f^1 = \{\lambda \mid I_f\left(\lambda\right) < T, \text{for all } f\}$$

- Iterate over several **waves** to reduce the emulator uncertainty in NROY^{N-1}, until convergence

Couvreux et al. (2021, 10.1029/2020MS002217)

Proof of concept: from 1D to 3D with LMDZ

Multi 1D case approach (focus on boundary-layer clouds)

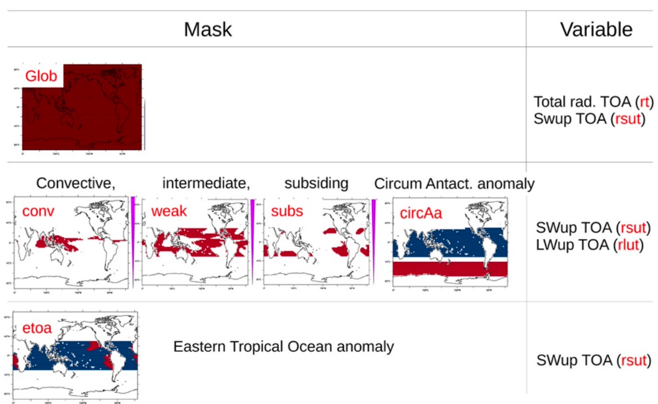
- Dry convective boundary layer (IHOP, Couvreux et al. 1996)
- Continental cumulus (ARMCU, Brown et al. 2002)
- Marine cumulus (RICO, van Zanten et al. 2011)
- Stratocumulus-cumulus transition (SANDU, Sandu et al. 2011)
- Reference LES: Meso-NH or UCLA

Metrics Retained for the SCM/LES Tuning

Case	IHOP	ARMCU	RICO	SANDU	SANDU	SANDU
Subcase	REF	REF	REF	REF	SLOW	FAST
Time	7–9	7–9	19–25	50–60	50–60	50–60
$\theta_{400-600\ m}$	X	X	-	-	-	-
$q_{v,400-600\ m}$	-	X	-	-	-	-
$\alpha_{cld,max}$	-	X	X	-	-	-
$z_{cld,ave}$	-	X	-	X	-	-
$z_{cld,max}$	-	X	-	X	X	X

Metrics

- 11 metrics in 1D: potential temperature, moisture averaged in the boundary layer, cloud cover
- 11 metrics in 3D: TOA radiative budget components, global/regional averages



Metrics	target W m^{-2}	error W m^{-2}
glob.rt	2.5	0.2
glob.rsut	99.6	5
circAa.rsut	24.0	5
circAa.rlut	-48.6	5
subs.rsut	84.9	5
weak.rsut	81.8	5
conv.rsut	103.2	5
subs.rlut	274.6	5
weak.rlut	264.3	5
conv.rlut	235.8	5
etoa.rsut	11.0	5

Parameters

- 9 parameters from the cloud, shallow convection and microphysics parameterizations

Waves

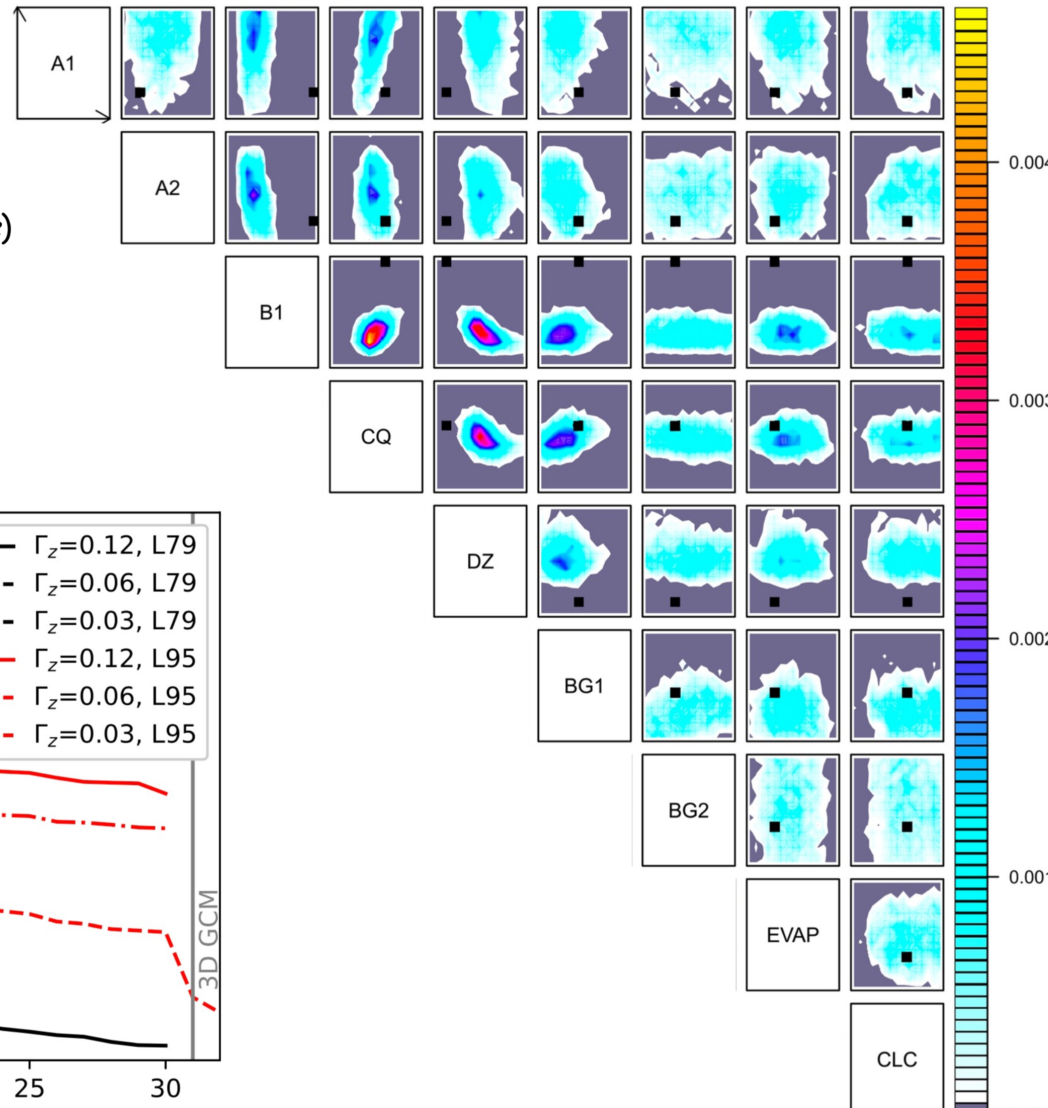
- 30 waves in 1D, with a progressive reduction of the implausibility cutoff (de 3 à 2)
- 2 waves then in 3D

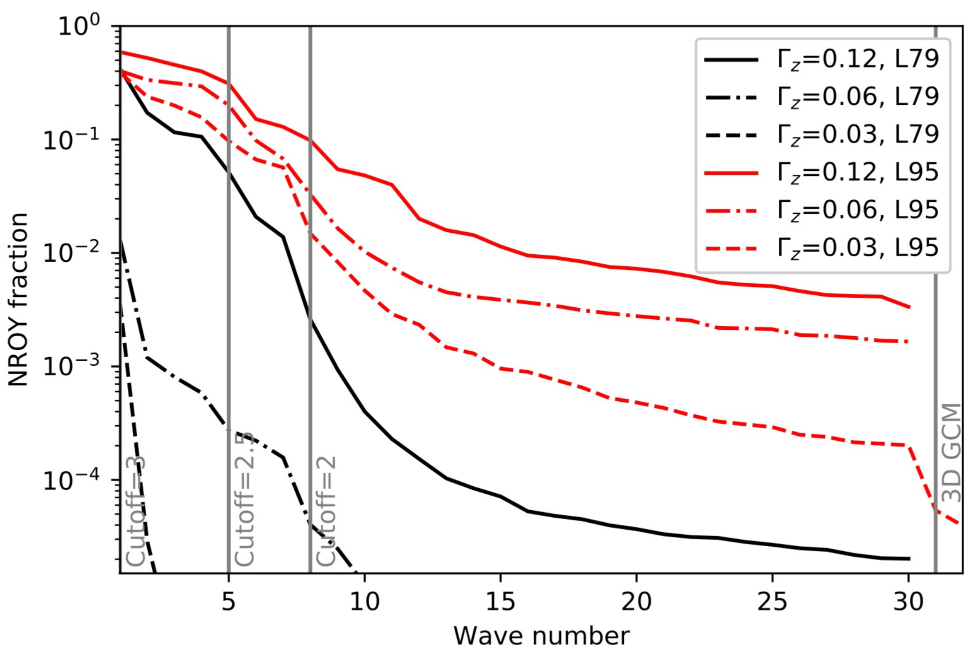
Hourdin et al. (2021, 10.1029/2020MS002225)

After 30 waves in 1D

NROY space - Implausibility matrix

- Algorithm convergence
- Non-empty space (0.02% from the *input space*)
- LMDZ6 tuning non-optimal





Hourdin et al. (2021, 10.1029/2020MS002225)

Proof of concept: from 1D to 3D with LMDZ

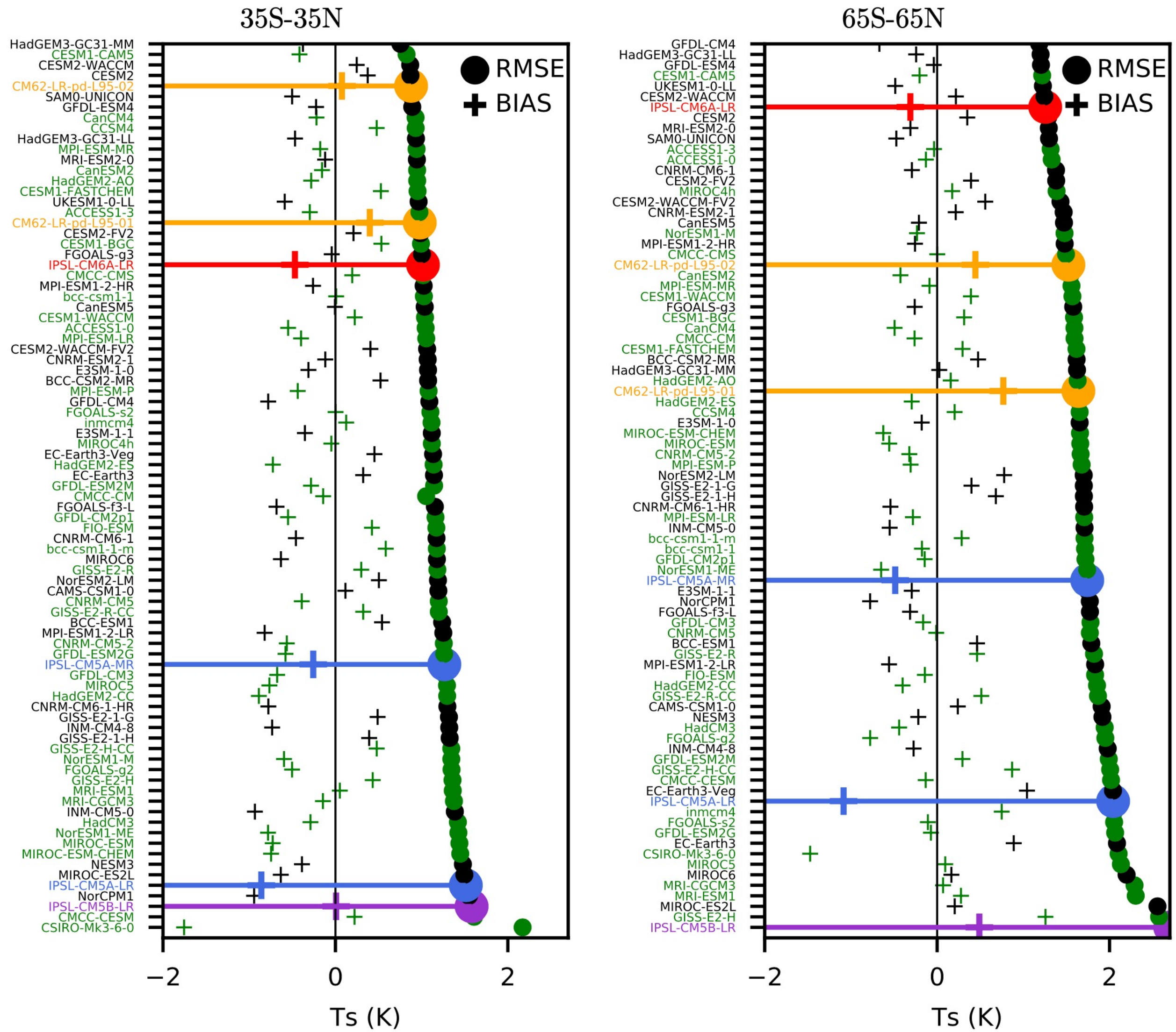
From 1D to 3D to coupled

3D model calibration starting from the 1D NROY space

- Non-empty space (0.004% from the input space)
- The 1D setup has efficiently provided pre-conditioning of the 3D configuration
- LMDZ6 tuning "by hand" good, though slight not optimal
- Probably a need to add a few further waves

From 3D to coupled

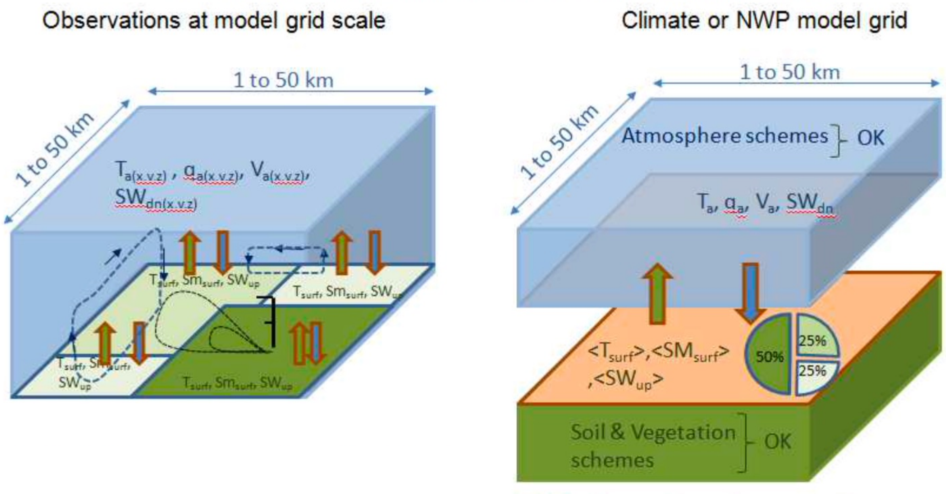
- Recalibration by hand of the TOA radiation budget (1 parameter)
- Behaviour ~similar the version tuned "by hand" during 2-3 years.

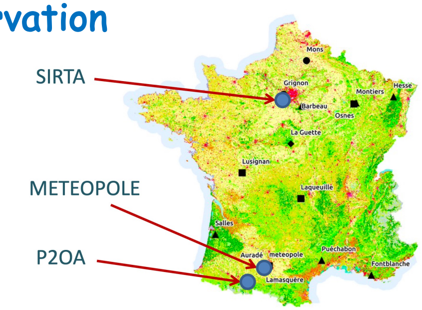


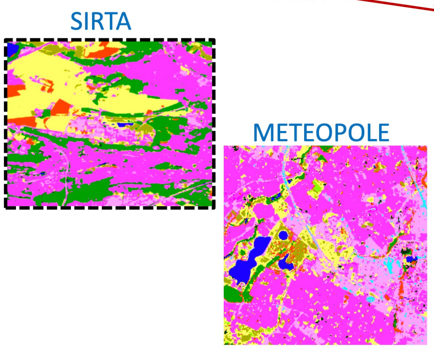
Hourdin et al. (2021, 10.1029/2020MS002225)

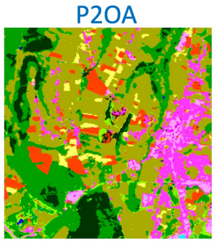
MOSAI (2021-2024)
Models and Observations for Surface-Atmosphere Interactions

- **Better account for surface heterogeneities in the observation and modelling of land-atmosphere coupling**









WP1: Uncertainty and representativeness of L-A exchanges measured over heterogeneous landscapes

WP2: Model evaluation using long-term measurements

WP3: Better account for the sub-grid landscape heterogeneities in the coupling between LSM and atmospheric models. Assess the impact of current simplifications.

Enhanced Observing Periods
- METEOPOLE: 06/2020 – 07/2021
- SIRTA: 12/2021 – 10/2022
- P2OA: 12/2022 – 10/2023

https://mosai.aeris-data.fr