Harnessing Machine Learning to Improve Cloud Radiative Effect Predictions in Large-Scale Models

Najda Villefranque, HIGH-TUNE team, Robin Hogan

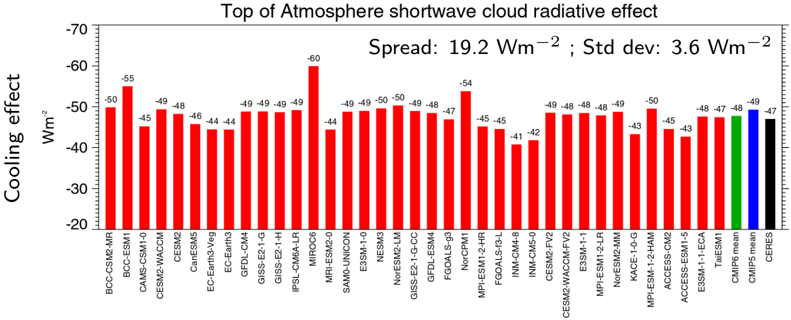
April 14, 2021

Villefranque, N., Blanco, S., Couvreux, F., Fournier, R., Gautrais, J., Hogan, R. J., et al. (2021). Process-based climate model development harnessing machine learning: III. The Representation of Cumulus Geometry and their 3D Radiative Effects. *Journal of Advances in Modeling Earth Systems*, 13. https://doi.org/10.1029/2020MS002423

Cloud radiative effect to measure model quality

The global energy balance as represented in CMIP6 climate models

M. Wild (2020)



... but a common tuning practice (Hourdin et al. 2017):
adjusting cloud parameters to match observed radiation

Wrong radiation will lead to wrong clouds

Cloud fraction and water content	$\longrightarrow$	radiation scheme	$\longrightarrow$	radiative fluxes
from cloud parameterization		two-stream based		cloud radiative effect

Wrong radiation will lead to wrong clouds

Cloud fraction and water content $\longrightarrow$ radiation scheme $\longrightarrow$ radiative fluxes

from cloud parameterization　　two-stream based　　cloud radiative effect

$\uparrow$　　　　　　　　　　　　　　　　　　　　$\downarrow$

cloud parameters $\longleftarrow$ $\boxed{\text{tuning process}}$ — target observation

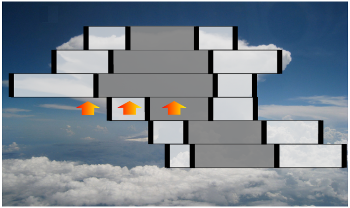
Wrong radiation will lead to wrong clouds

Cloud fraction and water content → radiation scheme → radiative fluxes

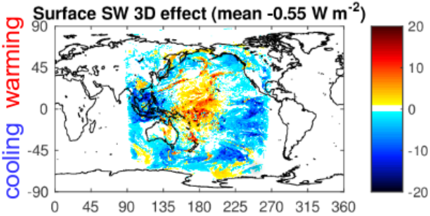
from cloud parameterization — two-stream based — cloud radiative effect

cloud parameters ← $\boxed{\text{tuning process}}$ — target observation

One climate model column



Subgrid clouds as seen from a radiation scheme



These 3D effects are usually neglected in climate models

(Conceptual scheme and figure from Robin Hogan (2018?))

The HIGH-TUNE project

Process-based calibration to avoid compensation errors

Single Column Models vs. Large-Eddy Simulations

The HIGH-TUNE project

Process-based calibration to avoid compensation errors

Single Column Models vs. Large-Eddy Simulations

Using ~~machine learning~~ statistics to do this efficiently

Emulating SCMs to rule out unacceptable parameter space

The HIGH-TUNE project

Process-based calibration to avoid compensation errors

Single Column Models vs. Large-Eddy Simulations

Using ~~machine learning~~ statistics to do this efficiently

Emulating SCMs to rule out unacceptable parameter space

Here: **focus on the radiation scheme**

More in the next six slides!

Offline radiation scheme evaluation in cumulus clouds

ecRad scheme $\longrightarrow$ F_p

(Hogan and Bozzo 2018)

Cloud geometry parameters p

Vertical overlap, horizontal heterogeneity, cloud size

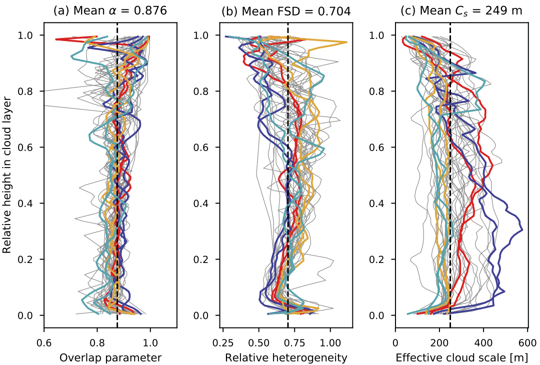
1D cloud profiles

Cloud fraction and water content

Offline radiation scheme evaluation in cumulus clouds

ecRad scheme → F_p

(Hogan and Bozzo 2018)



Cloud geometry parameters p

Vertical overlap, horizontal heterogeneity, cloud size

1D cloud profiles ← Horizontal averaging — 3D clouds from LES

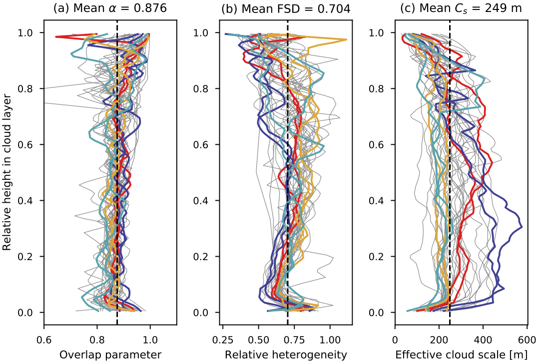
Cloud fraction and water content

Meso-NH (Lafore et al. 97, Lac et al 2017)

Offline radiation scheme evaluation in cumulus clouds

ecRad scheme ⟶ F_p F_r ⟵ Monte Carlo model

(Hogan and Bozzo 2018) (Villefranque et al. 2019)



Cloud geometry parameters p

Vertical overlap, horizontal heterogeneity, cloud size

1D cloud profiles ⟵ Horizontal averaging ⟵ 3D clouds from LES

Cloud fraction and water content

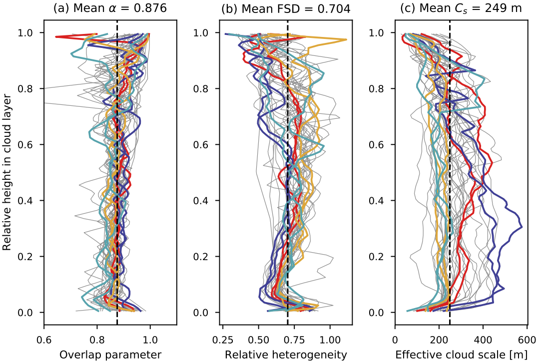
Meso-NH (Lafore et al. 97, Lac et al 2017)

Offline radiation scheme evaluation in cumulus clouds

ecRad scheme ⟶ $F_p \xleftrightarrow[\Delta_p]{} F_r$ ⟵ Monte Carlo model

(Hogan and Bozzo 2018)

(Villefranque et al. 2019)



Cloud geometry parameters p

Vertical overlap, horizontal heterogeneity, cloud size

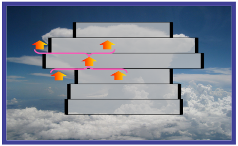
1D cloud profiles ⟵ Horizontal averaging ⟵ 3D clouds from LES

Cloud fraction and water content

Meso-NH (Lafore et al. 97, Lac et al 2017)

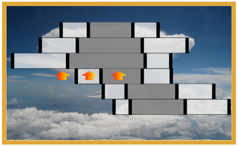
Different levels of complexity in cloud representation

1D homogeneous

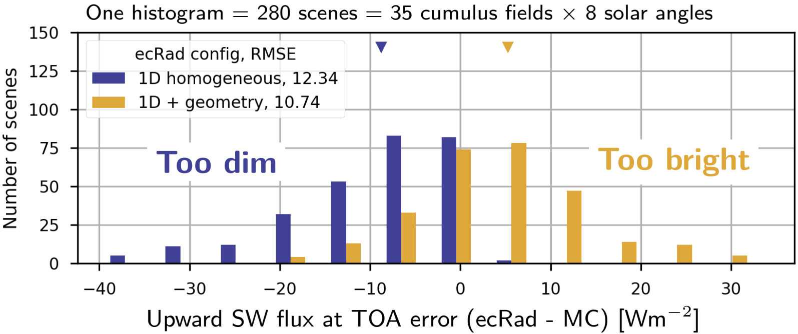


Triplecloud[1]
$\alpha = 1$, FSD=0

1D + geometry

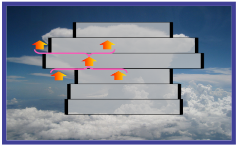
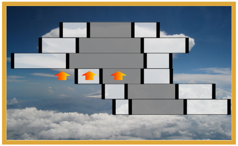
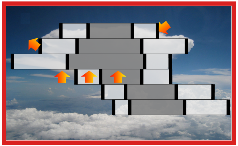


Tripleclouds[1]
α, FSD from LES

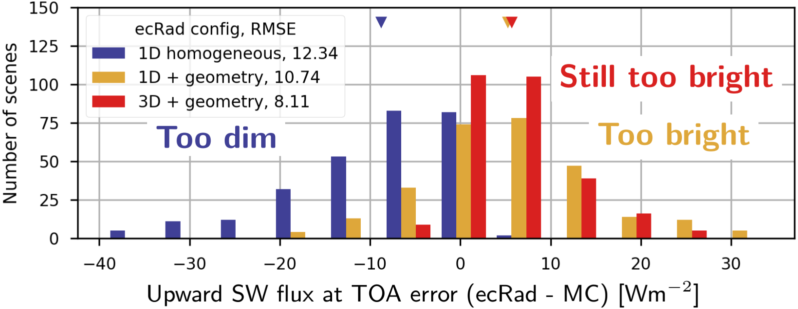


[1] Shonk and Hogan, 2008 ; [2] Schäfer et al., 2016, Hogan et al., 2016, 2019

Different levels of complexity in cloud representation

1D homogeneous	1D + geometry	3D + geometry
		
Triplecloud[1] $\alpha = 1$, FSD=0	Triplecloud[1] α, FSD from LES	SPARTACUS[2] α, FSD, C_s from LES

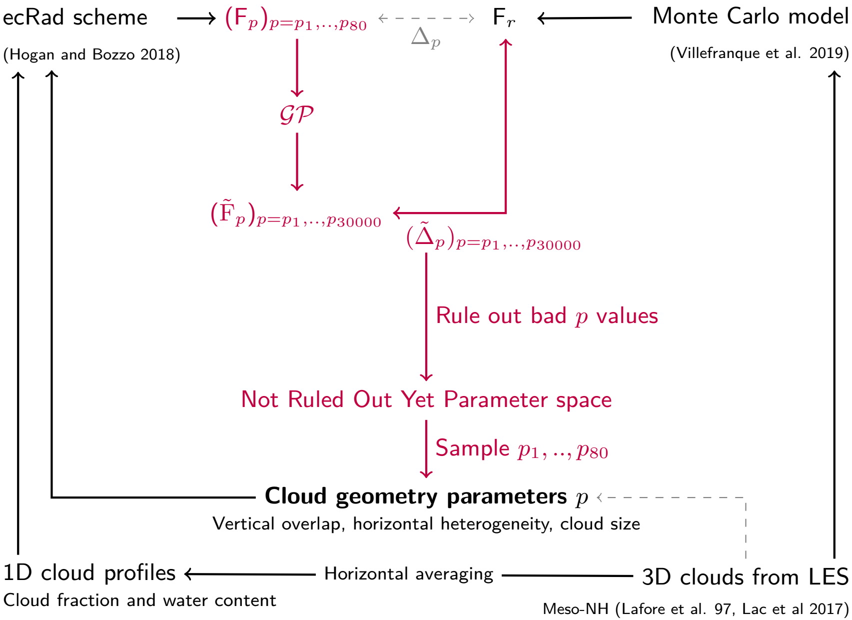
One histogram = 280 scenes = 35 cumulus fields × 8 solar angles



[1] Shonk and Hogan, 2008 ; [2] Schäfer et al., 2016, Hogan et al., 2016, 2019

Introducing the High-Tune:Explorer tool

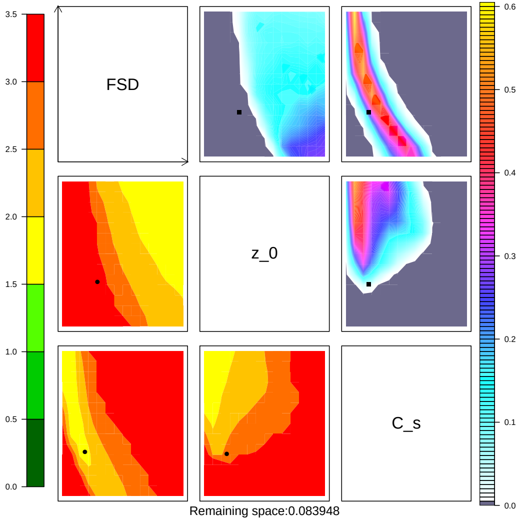
(Couvreux et al., 2020, Hourdin et al., 2020, Villefranque et al. 2021)



Not Ruled Out Yet space after 13 iterations

72 metrics: upward TOA, downward surface, absorbed $\times$ 8 cumulus field $\times$ 3 solar angles

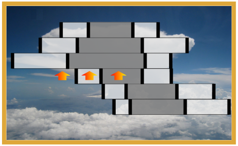
3 parameters: FSD=horizontal heterogeneity; z_0=overlap decorrelation length; C$_s$=cloud size



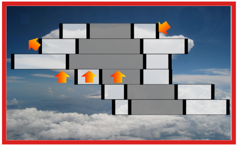
- Reject parameters if at least one metric is bad
- Large FSD = less reflective clouds
- Small z_0 = overlap $\rightarrow$ maximum (cloud cover too small)
- Small C$_s$ = more 3D effects
- Heterogeneity and 3D effects compensate each other
- LES-derived values (black dots) not in NROY space

Testing one good configuration (FSD, z_0, C$_s$)

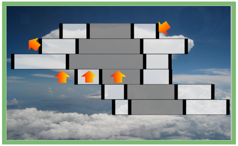
1D + LES geometry



3D + LES geometry



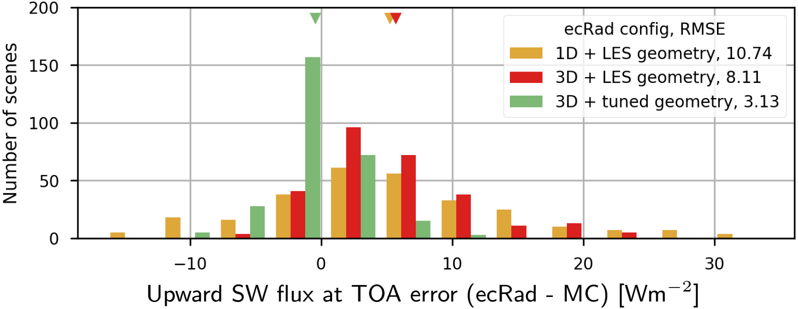
3D + tuned geometry



Mean LES-derived: (0.7, 187 m, 247 m)

htexplo: (1.1, 436 m, 155 m)

One histogram = 280 scenes = 35 cumulus fields × 8 solar angles



Conclusions, remaining questions and further work

- Parameterizations need *effective* parameter values rather than observed
- 3D effects are a big deal and SPARTACUS is doing quite well
- Tuning using only a few fields and solar zenith angles works
- Even using bulk parameters instead of case-dependent vertical profiles

- Remaining errors = "structural errors"?
- Outside the cumulus regime?
- Parameterize the parameters?
  $\Rightarrow$ **More parameters to tune? No longer a bad news!**

- Next: tuning clouds and radiation together in SCM/LES/MC framework

Conclusions, remaining questions and further work

- Parameterizations need *effective* parameter values rather than observed
- 3D effects are a big deal and SPARTACUS is doing quite well
- Tuning using only a few fields and solar zenith angles works
- Even using bulk parameters instead of case-dependent vertical profiles

- Remaining errors = "structural errors"?
- Outside the cumulus regime?
- Parameterize the parameters?
  $\Rightarrow$ **More parameters to tune? No longer a bad news!**

- Next: tuning clouds and radiation together in SCM/LES/MC framework

Thanks! Questions?