Estimation of fine-scale relative humidity profiles: an issue for understanding the atmospheric water cycle

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Scientific issue

Microphysical processes driving cloud -and water vapour- related distribution and variability in the troposphere are not well known

↳ an important source of uncertainty in climate models

Data

The micro-physical properties described by the satellite CALIPSO (Scattering Ratio/SR = large cloud droplet size, non precipitating clouds) [1, 2] and CloudSat (Radar Reflectivity/RR = small particles) [3], can be strongly influenced by the Relative Humidity (RH, in %), described by the SAPHIR [4] satellite in the whole troposphere, but :

↳ **these instruments have different spatial resolutions :**

- Megha-Tropiques (2011) : SAPHIR micro-wave radiometer, 10km
- A-Train constellation (2006) : CALIPSO, 90m ; CloudSat 1,4km

↳ **clouds are heterogeneous variables ≠ humidity is a continuous field**

References:

[1] BrogniezH. et al., 2015, doi10.1175/JAMC-D-14-0096.1

[2] Brogniez, H.et al., 2016, doi:10.1175/JTECH-D-15-0237.1, 2016

[3] Marchand, R. et al., 2008, https://doi.org/10.1175/2007JTECHA1006.1

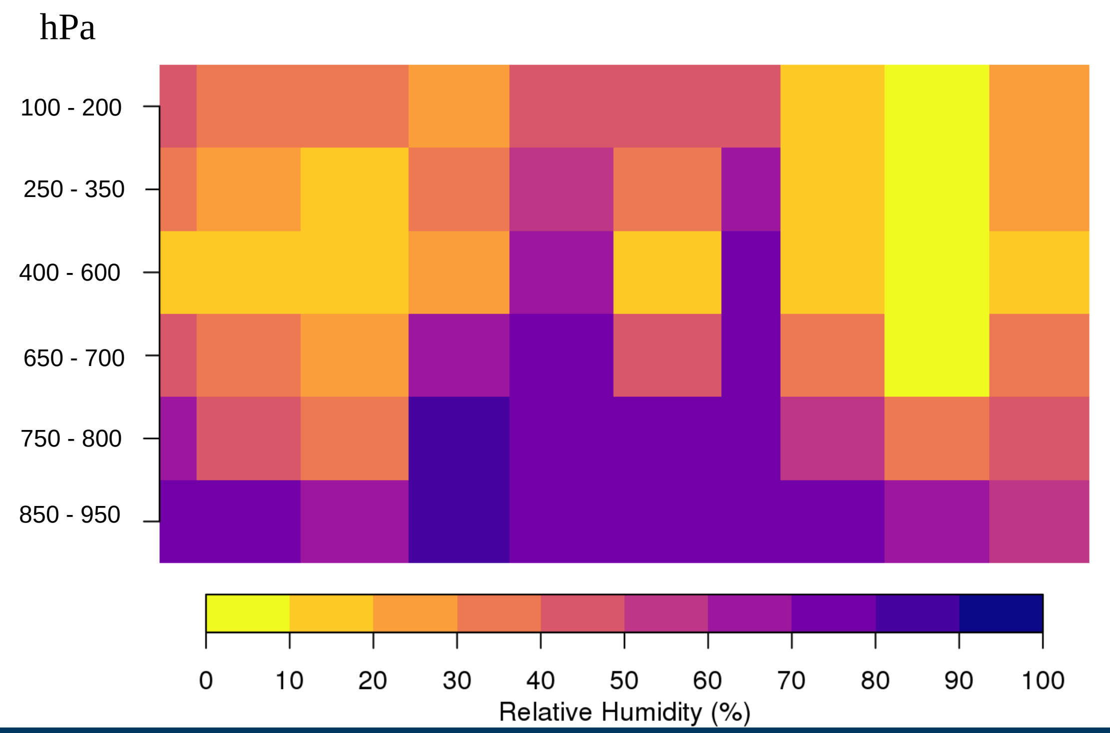
[4] Chepfer, H. et al., 2010,doi: 10.1029/2009JD012251

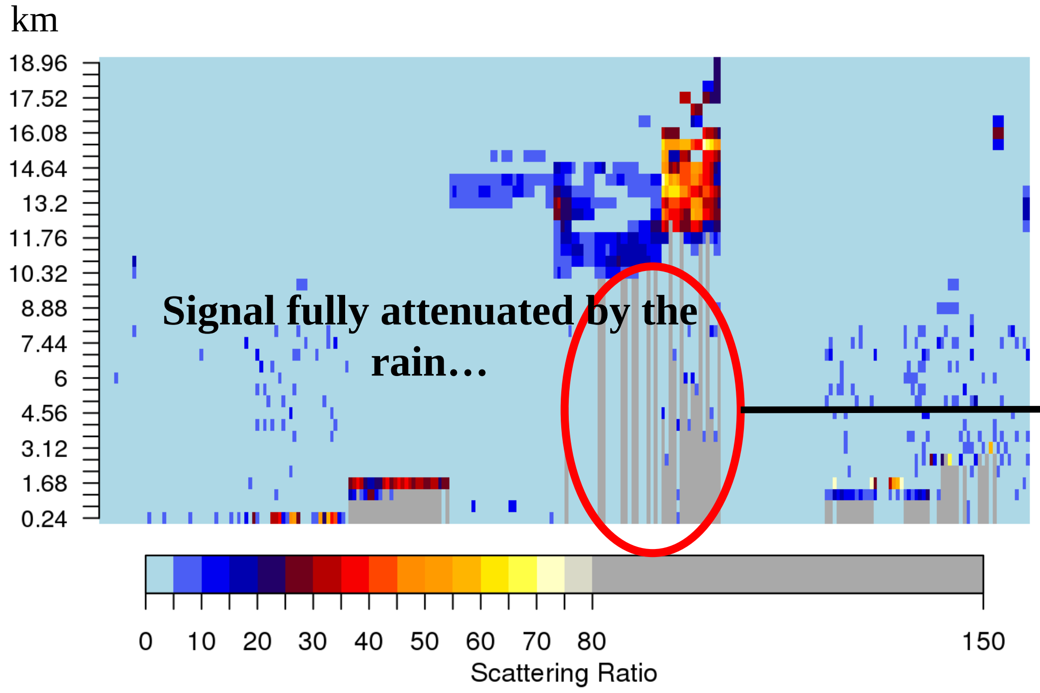
Relative humidity and cloud structure data

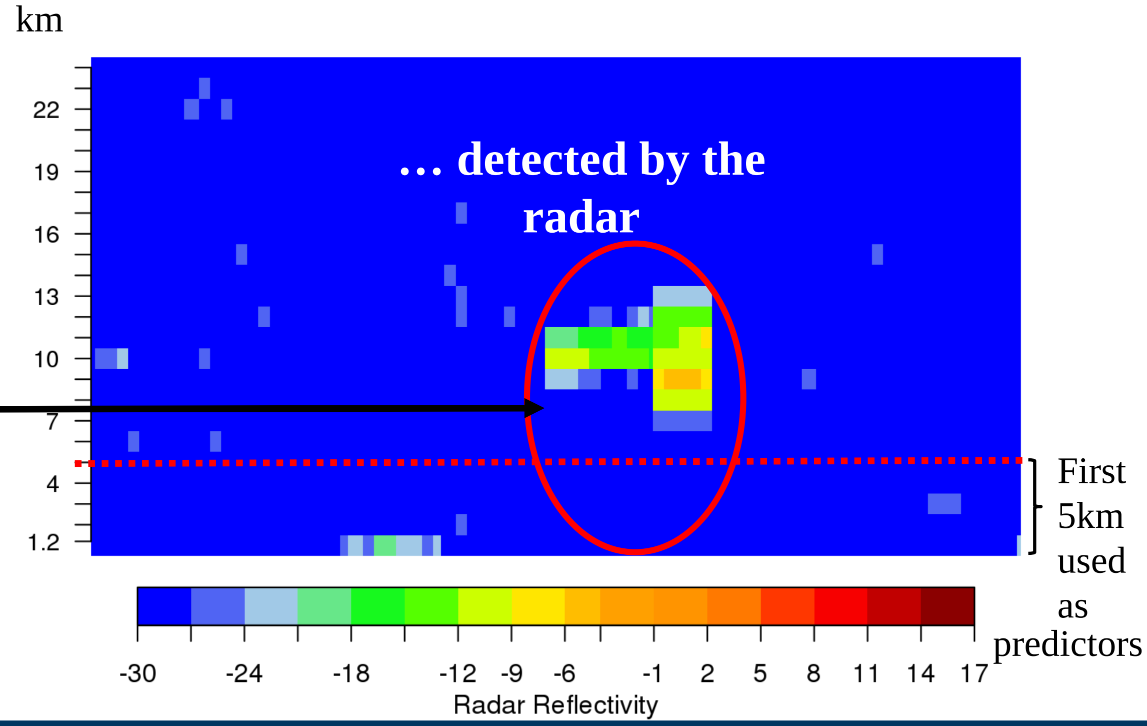
SAPHIR :
Relative Humidity for 6 pressure levels

CALIPSO :
Optically thin and non precipitating clouds

CloudSat :
Optically thick and potentially rainy clouds







X axis : SAPHIR-CALIPSO-CloudSaT co-located pixels
Y axis : altitude or pressure level

Objectives : Prediction of RH from cloud profiles

Generate possible RH profiles at the scale of the cloud profiles (90m) that would be linked to the different types of clouds with different microphysical properties

↳ **statistical downscaling**

$$RH_l \sim \left(\{SR_1, SR_2, \dots, SR_s\}, \{PH_1, PH_2, \dots, PH_s\}, \{RR_1, RR_2, \dots, RR_r\}\right)$$

Where:

- RHl is the 10km-RH resolution of SAPHIR at atmospheric layer (l=1 to 6)
- $SR_{1\dots s}$ is the Scattering Ratio of CALIPSO (s=40)
- $PH_{1\dots s}$ is the Phase cloud from SR of CALIPSO (s=40)
- $RR_{1\dots r}$ is the Radar Reflectivity from CloudSat (r=5)

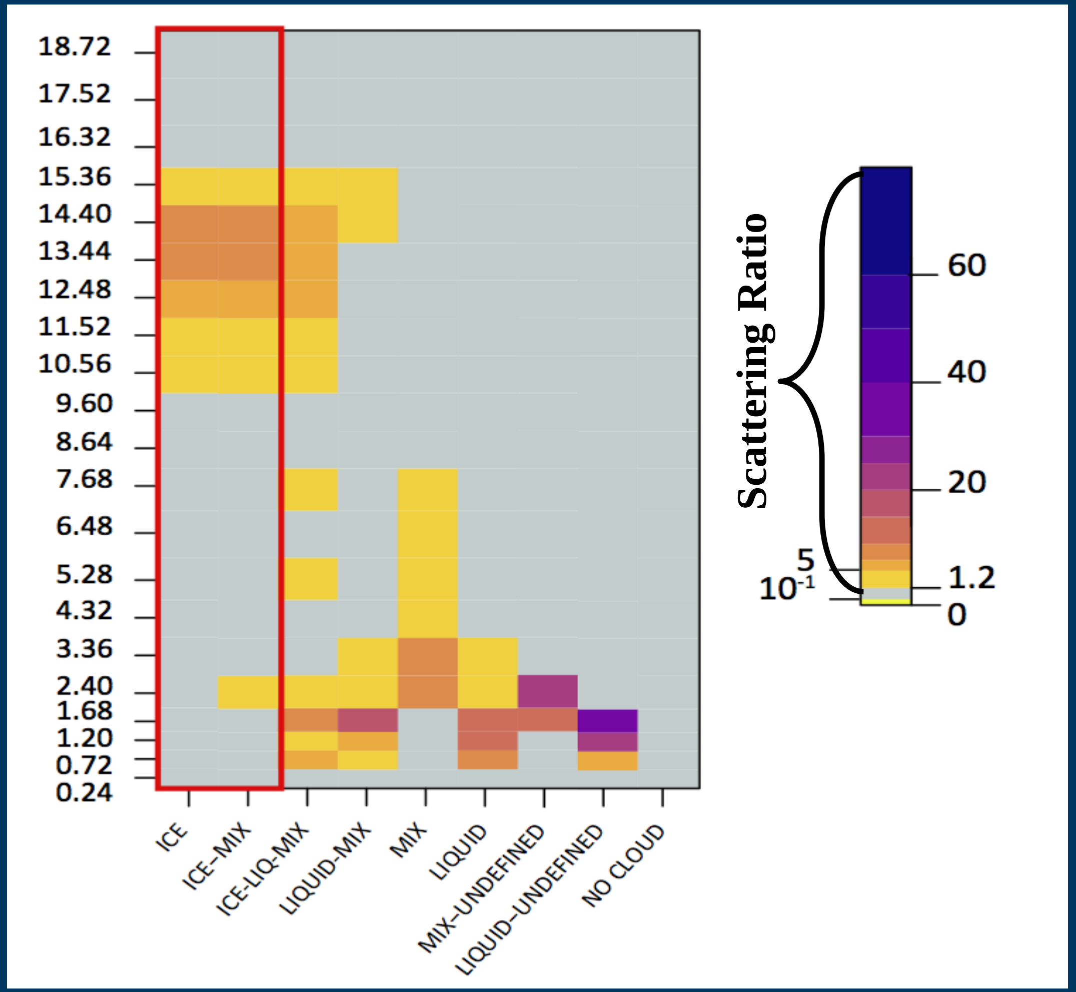
Design of the downscaling model

Following Carella et al. 2020 [6]:

CALIPSO data & 1 month (July 2013) & 1 ocean (Indian Ocean) & 1 cloud type (ice phase clouds)

↳ Quantile Regression Forest algorithm (iteratively applied) [7]

Mean SR profiles per cluster derived by combining the cloud phase flags in Cesana and Chepfer [7]



References:

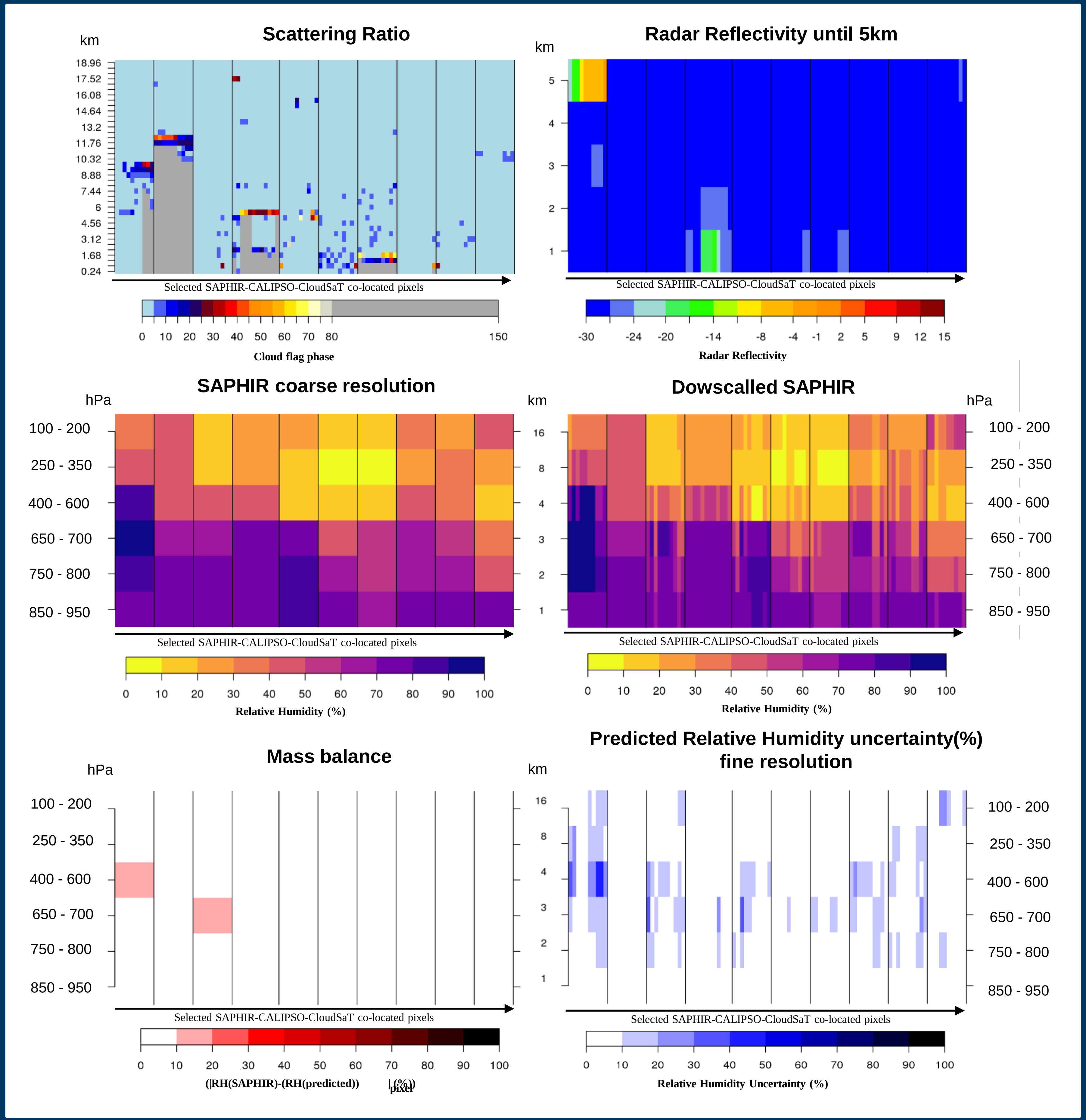
[6] Carella G. et al., 2020, ESSD, https://doi.org/10.5194/essd-2018-138

[7] Meinshausen , N.: Quantile regression forests, J. Mach. Learn. Res., 7, 983 999, 2006

[8] Cesana et Chepfer, 2013, doi: 30 10.1002/jgrd.50376

Design of the downscaling model

Here we combine the information provided by CALIPSO and CloudSat to generalize the method to all cloud types for July 2013 over the Indian Ocean

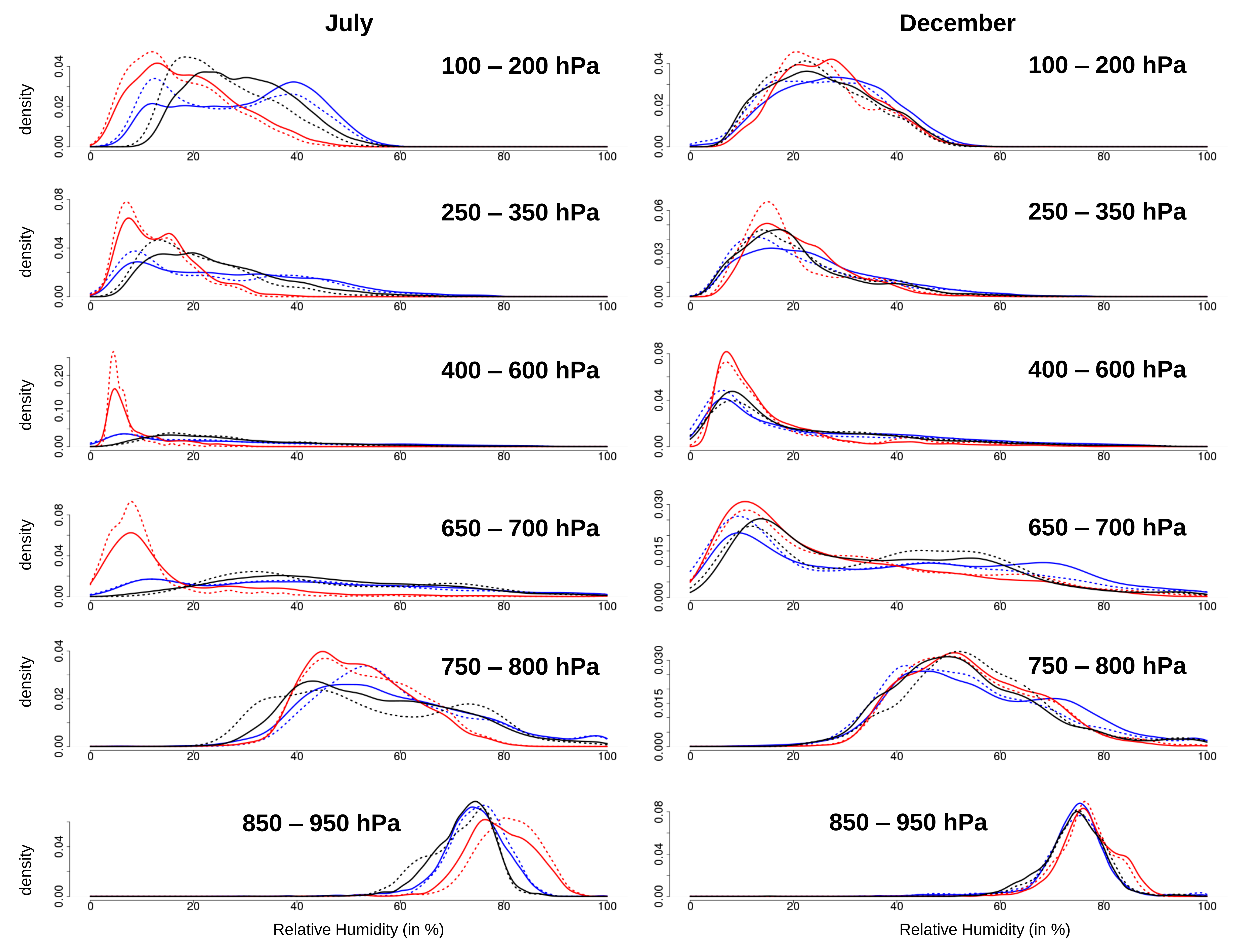


Mass Balance: Absolute differences between the HR observed in each SAPHIR pixel and the average of the HR values it contains.

Model reproducibility: spatial and temporal robustness

The distribution of Relative Humidity shows for each SAPHIR layer a variability between oceans and seasons.

We are therefore seeking to know the impact that this spatial and temporal variability can have on the method in order to know to what extent it is possible to generalize it.



PDF of the RH for all the month of July (left column) and December (right column) between 2012 and 2016 over Indian Ocean (solid blue line), South Atlantic (solid red line), North Atlantic (solid dark line) and for July and December 2013 over Indian Ocean (dashed blue line), South Atlantic (dashed red line), North Atlantic (dashed black line)

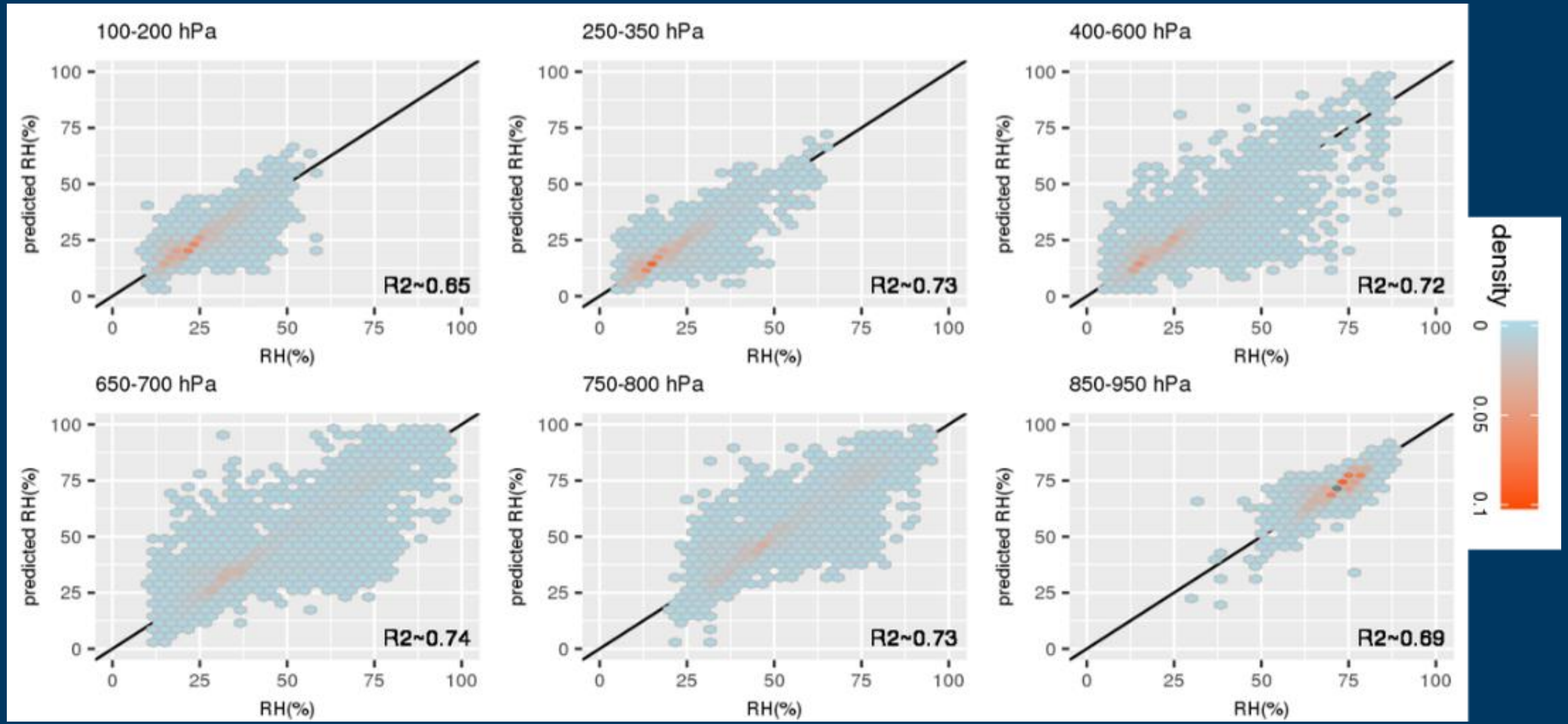
Sensitivity of the method to the training dataset : regional and temporal tests

The model based on learning relative humidity profiles over one ocean gives accurate predictions over the same region, but does not correctly predict RH profiles over another ocean. These results could be explained, in part, by spatial differences in the distribution of RH

Coefficient of determination (R2) scores of downscaling for each RH_l with the QRF method for several kind of calibration strategies

Sample calibration		*Sample prediction*		R^2					
Ocean	Date	Ocean	Date	100:200 hPa	250:350 hPa	400:600 hPa	650:700 hPa	750:800 hPa	850:950 hPa
Indian Ocean	July 2013	Indian Ocean	July 2013	0.76	0.80	0.76	0.74	0.75	0.66
			December 2013	0.18	0.34	0.29	0.16	0.18	0.01
		Tropical North Atlantic	July 2013	0.07	0.18	0.20	0.25	0.21	0.02
Tropical North Atlantic	July 2013	Tropical North Atlantic	July 2013	0.65	0.73	0.72	0.74	0.73	0.69
			December 2013	0.12	0.26	0.24	0.15	0.13	0.02

Scatter plot of the predicted RH (y-axis) vs the original SAPHIR RH (x-axis) for the six atmospheric layers, for the test sample of July 2013.



Evaluation of the downscaled RH values with in-situ measurements

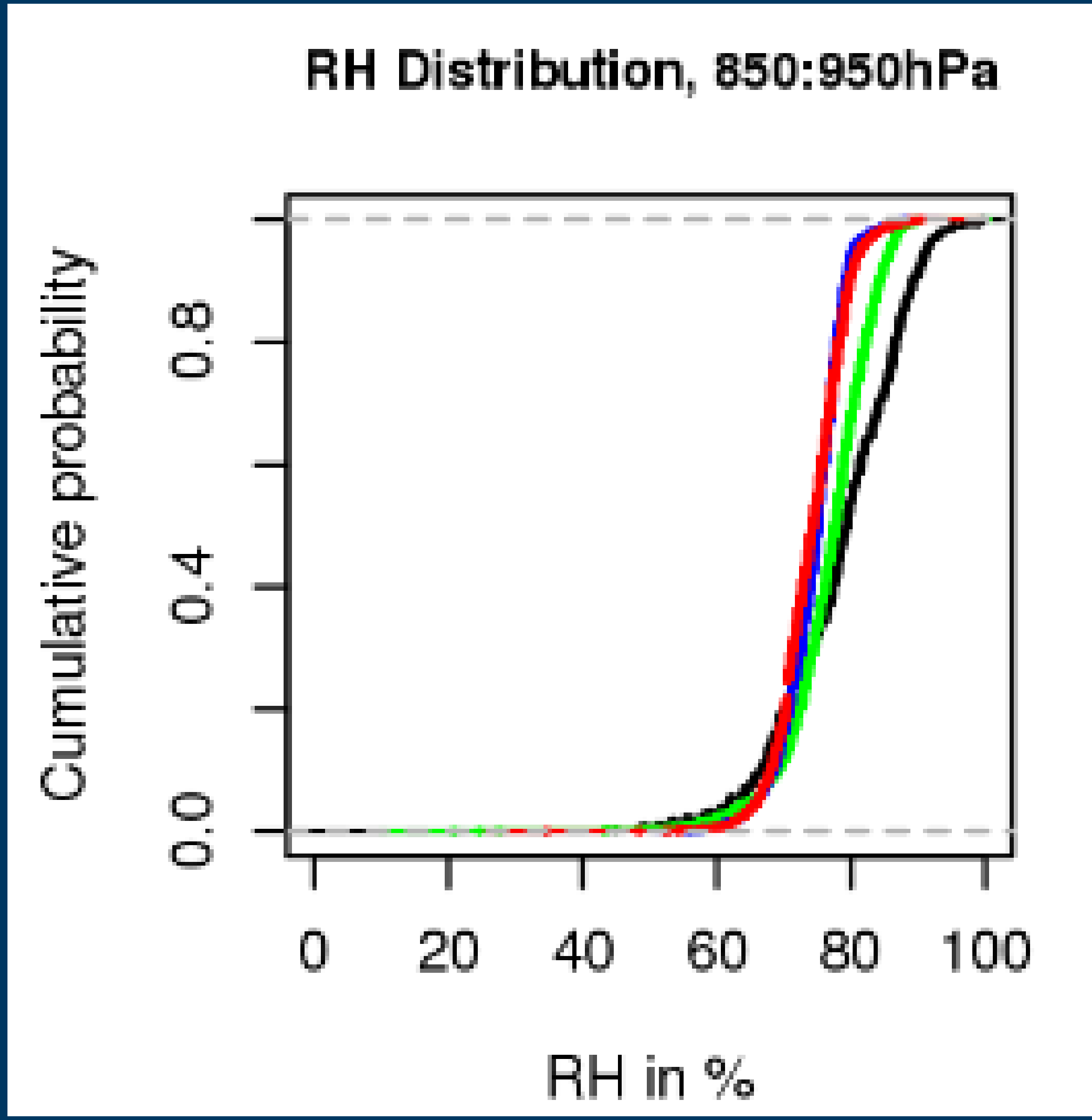
Evaluation of the high-resolution RH performed by the comparison of the cumulative distribution functions (CDF) of the original low resolution RH, the predicted high resolution RH, the RH from NARVAL and the RH from the Météo-France radiosonde, for July and August 2013 over the tropical North Atlantic.

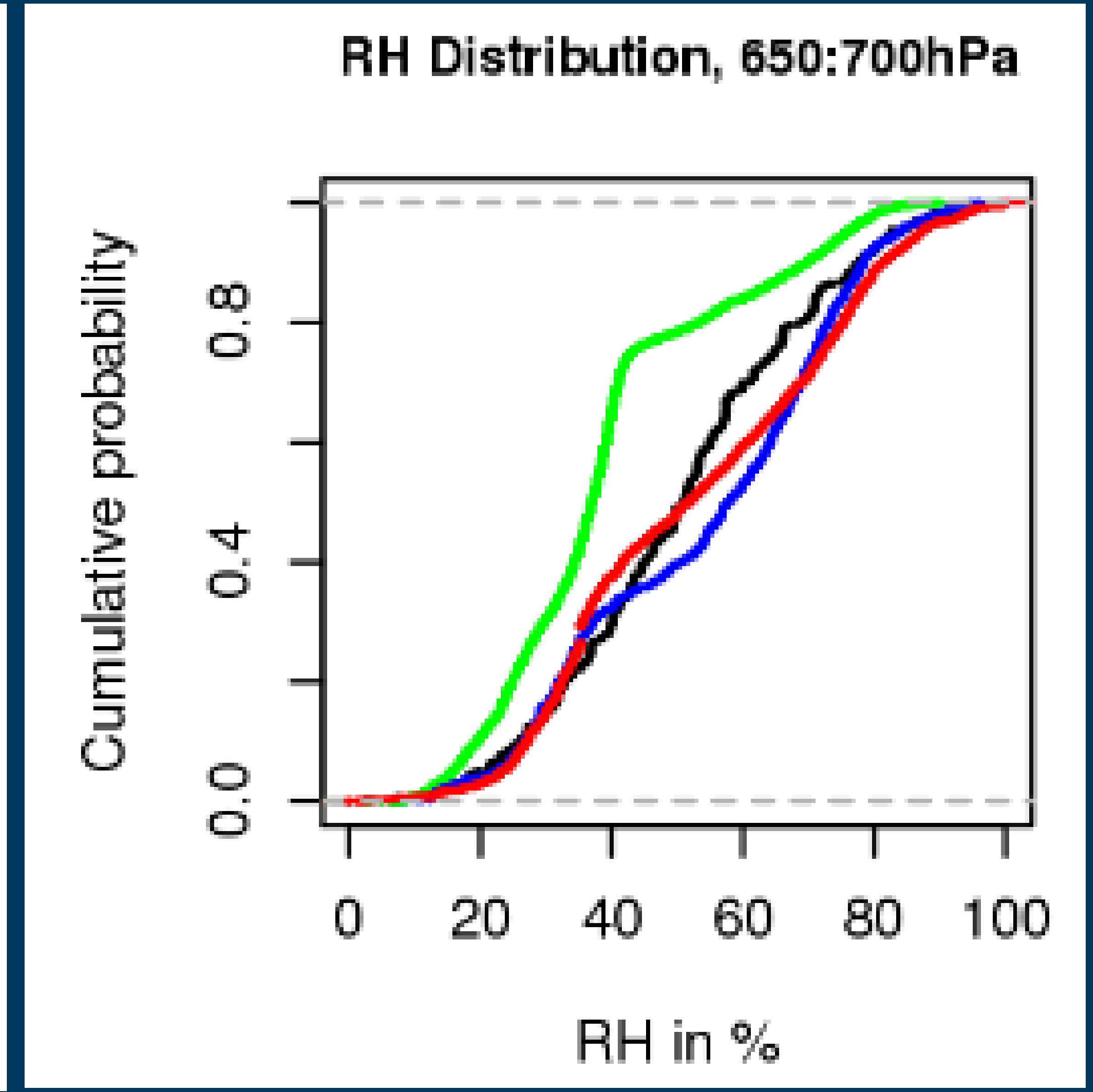
CDFs of RH at the original 10km resolution and the prediction at the 90m resolution are very close and relatively close to radiosonde and Narval at lower atmosphere. But, RH CDFs highly differ from the Narval RH that show a drier troposphere at middle altitudes.

NARVAL : data from an airborne water vapor lidar that observed the tropical North Atlantic atmosphere.

Météo-France radiosonde: data from the EUREC4A (Elucidating the role of clouds-circulation coupling in climate) international campaign that observed the tropical North Atlantic atmosphere near the Barbados.

CDFs of SAPHIR RH (blue line), predicted RH (red line), NARVAL data (green line) and Météo-France radiosonde data (black line), for August 2013 over the tropical North Atlantic.





Work in Progress

-> Establish the level of possible spatial generalization of the method

Perspectives

-> adaptation and application of the method to the continents

-> Use of the new HR dataset for the study of multi-scale interactions: stratocumulus to cumulus transition profile; low cloud and HR feedback in trade wind areas; processes associated with MJO...