Coupling CALIOP observations and regional simulations at 20km resolution: is that a good candidate to study cloud variability at the regional scale?

Meriem Chakroun, Sophie Bastin, Marjolaine Chiriaco, Hélène Chepfer

Coupling CALIOP observations and regional simulations at 20km resolution: is that a good candidate to study cloud variability at the regional scale?

M. Chakroun*[(1)], S. Bastin[(1)], M. Chiriaco[(1)], H. Chepfer[(2)]

1 LATMOS/IPSL/UVSQ/CNRS ; 2 LMD/IPSL/UPMC

** meriem.chakroun@latmos.ipsl.fr*

Context

This work aims to study the clouds' role on regional climate variability. At first order, European climate is driven by large scale circulations. However, clouds are known to have two major radiative effects impacting the surface temperature: the greenhouse effect and the albedo effect. These effects are strongly dependent on macrophysical and microphysical properties of clouds. It is then necessary to consider the vertical distribution of clouds to better understand their impact on regional climate.

Since June 2006, A-train observations are available and allow the description of this vertical distribution and of other microphysical properties. However, the sampling is limited when considering small scale variability. To complete these observations, we use a regional climate model which may allow to extend the period of study and to better understand the link between clouds and surface temperature.

In this study we address the ability of our tools to study impact of clouds on European climate at a resolution suitable to take into account the complex terrain of this area. Seasonal and inter annual clouds variability is presented for observations and simulations. We also evaluate the amplitude of clouds variability in the simulations and the uncertainties linked to the satellite sampling.

A. Tools

GCM Oriented Calipso Cloud Product-GOCCP (Chepfer et al., 2010)

- Vertical structure of clouds (40 levels)
- Products comparable to GCM data
- Measurement frequency: every 16 days

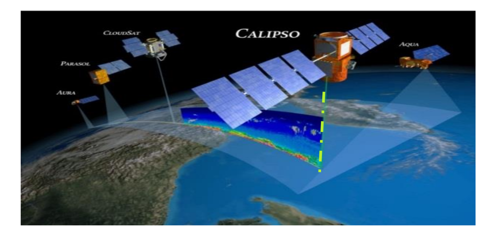

Fig1: CALIPSO's lidar track

- 30-60m vertical resolution
- horizontal day track resolution 330m

$$ATB(z) = (\beta_{sca,part} + \beta_{sca,mol})\, e^{-2\int_{TOA}^{z}(0.7\alpha_{sca,part}(z) + \alpha_{sca,mol}(z))dz}$$

2 GOCCP products have been used for this study:

- Scattering Ratio: $SR = \frac{ATB_{tot}}{ATB_{mol}}$
- Cloud fraction (z) : % of SR>5 on 20km grid (tab. 1)

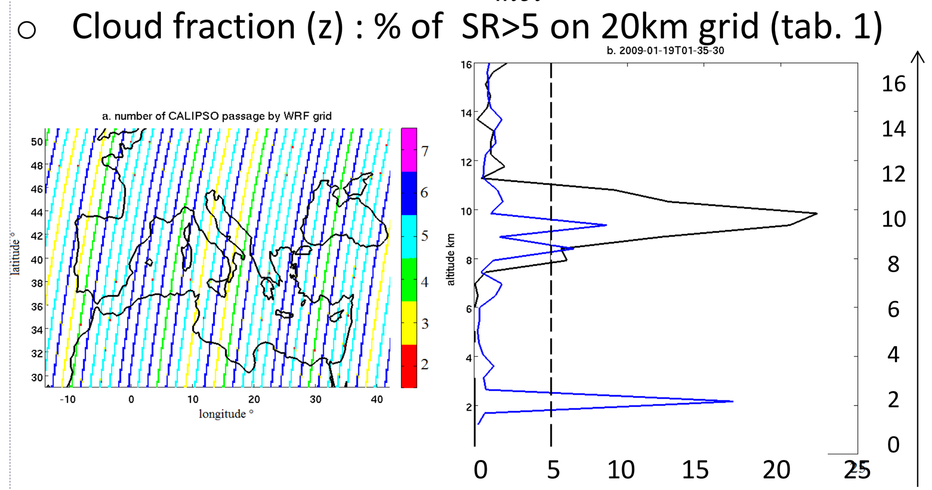

Fig2: (a) CALIPSO track occurrence in JJA 2008
(b) example of two SR GOCCP profiles (19/01/2009 at night)

WRF-MedCordex simulations

We use a WRF simulation performed in the framework of MED-CORDEX (downscaling of ERA-interim reanalyses) at 20 km resolution that covers the Mediterranean domain, over the period 1989-2011 (details in Stefanon et al., 2014).

- horizontal resolution: 20km
- 28 vertical levels, outputs every 3 hours

=> 2 issues:

- Two different samplings due to spatial and temporal resolutions (Fig. 2a)
- WRF outputs generate mixing ratios of ice, snow and liquid clouds (WSM5 scheme): Not comparable to the lidar signal (SR)! => lidar simulator

SR threshold	detection
0<SR<0.01	Fully attenuated
0.01<SR<1.2	clear
1.2<SR<5	unclassified
5<SR	cloudy

Tab1: SR detection threshold

Adaptation of COSP Lidar Simulator

Using the microphysical properties of the simulated clouds, we compute the SR that would be observed by the CALIOP lidar. We can then use the same cloud diagnostics for both observations and simulations

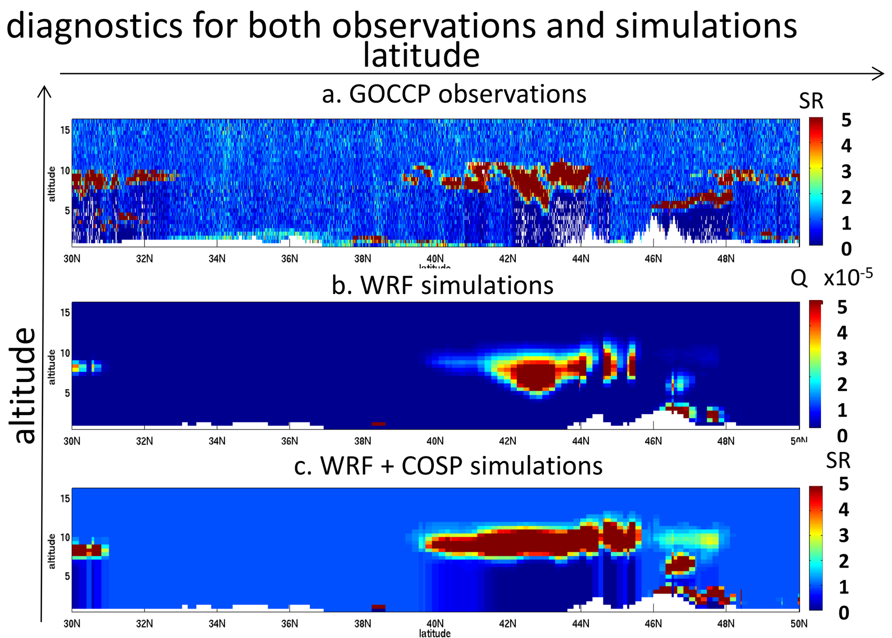

Fig3: Instant SR 19/01/2009 night: (a) Observations, (b) WRF simulations and (c) WRF+lidar simulator simulations

	2006-2011 CALIPSO sampling	2006-2011 WRF sampling	1989-2011 WRF sampling
GOCCP	$SR\_GOCCP_{CALIPSO}$ $CF\_GOCCP_{CALIPSO}$	-	-
WRF + COSP	$SR\_WRF_{CALIPSO}$ $CF\_WRF_{CALIPSO}$	$SR\_WRF_{2006-2011}$ $CF\_WRF_{2006-2011}$	$SR\_WRF_{1989-2011}$ $CF\_WRF_{1989-2011}$

Tab2: Dataset for the study.First row define the sampling method and the study period while the first column stands for the product used

B. Effect of satellite under sampling

Evaluation of CALIPSO sampling using the WRF+COSP simulations

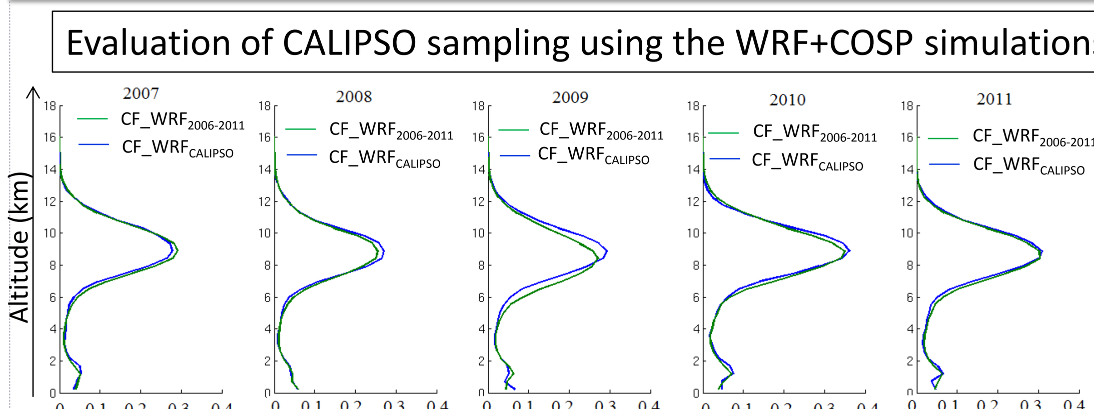

Fig4: horizontally averaged cloud fraction monthly means in WRF sampling (blue) and in CALIPSO sampling from 2007 to 2011

Comparison between *Sat. sampling* and *WRF sampling* for cloud fraction

$CF\_WRF_{CALIPSO}$ = WRF profiles where/when there is CALIPSO measurement

$CF\_WRF_{2006-2011}$ = one profile per night at each grid point

- Very similar profiles of cloud fraction (CF)
- High clouds (10 km): in average, differences <=5% of Cloud fraction for winter but differences can reach several % at some levels for some years.
- Mid and low clouds differences can't be seen because too few clouds in the WRF+COSP simulations (cf. C.1). => need to compute CF from mixing ratios
- SR histograms for all seasons very similar for both samplings
- Underestimation of optically thin high clouds (11-14 km) of 1%
- Overestimation of optically thin high clouds (8-10 km) of 1%

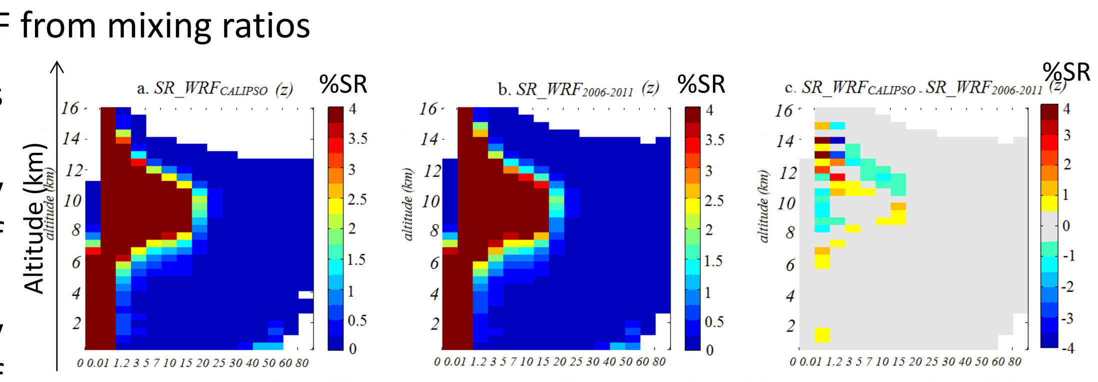

Fig5: SR simulated histograms, satellite sampling(a); WRF sampling (b); Sat. sampling – WRF sampling (c)

C.1. Model evaluation: seasonal variability

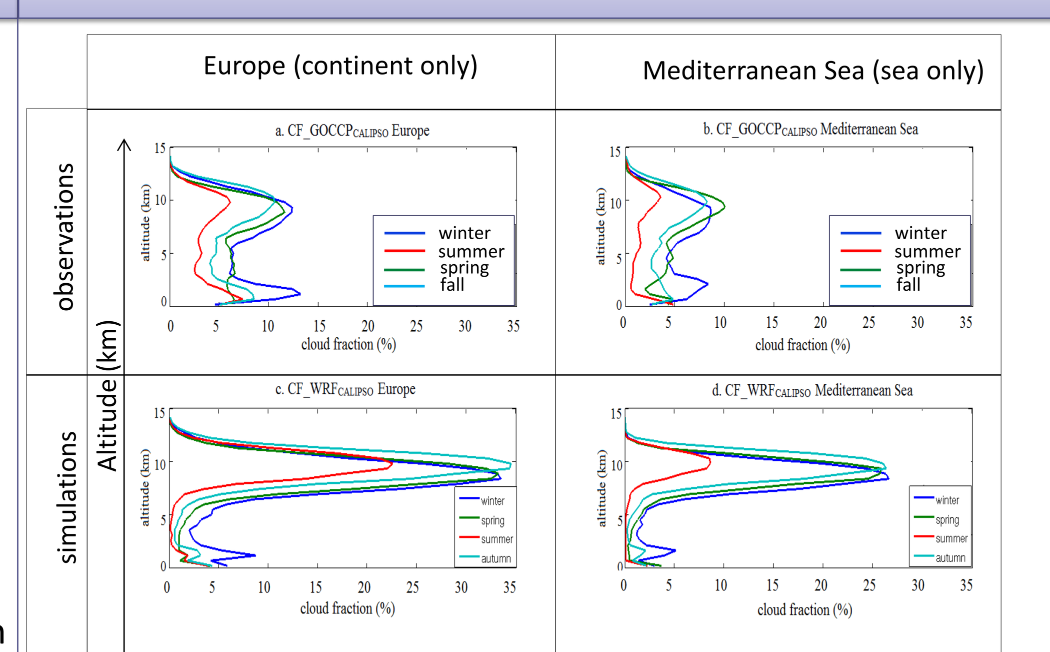

Fig 6: Vertical clouds distribution zonally averaged for observations (1st row) and simulations (2nd row) mean 2006-2011 for each season

- Overestimation of high clouds in the model (Fig. 6)
- Overestimation of high cloud vertical depth (although less optically thick clouds (Fig. 7) => more profiles are fully attenuated under 7 km => less low clouds detected by SR threshold

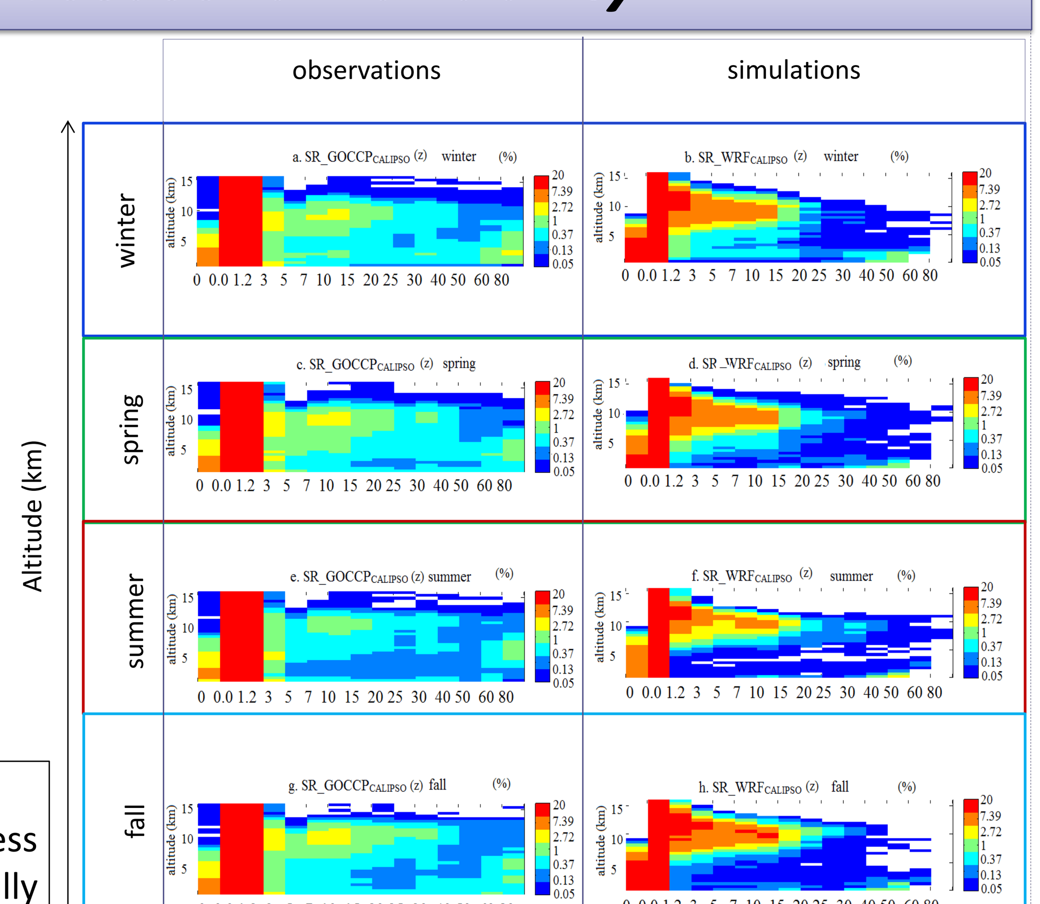

Fig7: SR histograms for cumulated SR between 06/2006 and 11/2011 in winter, spring, summer and fall for observations and simulations

- Underestimation of low clouds, especially in summer=> need complementary analyses
  - WRF simulations underestimate low clouds: the result is amplified with lidar simulator
- Observed seasonality reproduced by the simulations with different cloud fraction and SR values: the difference between observation and simulations is reduced in summer

C.2. Model evaluation: inter annual variability

Amplitude of variability (Fig. 8):

Winter: same shape for obs and simu with more variability for high clouds than low clouds. Simulations tend to overestimate high cloud inter-annual variability.

Summer: observations show less variability than winter, especially over the sea. Model overestimates the high cloud variability and underestimate the lower layers' one. ..

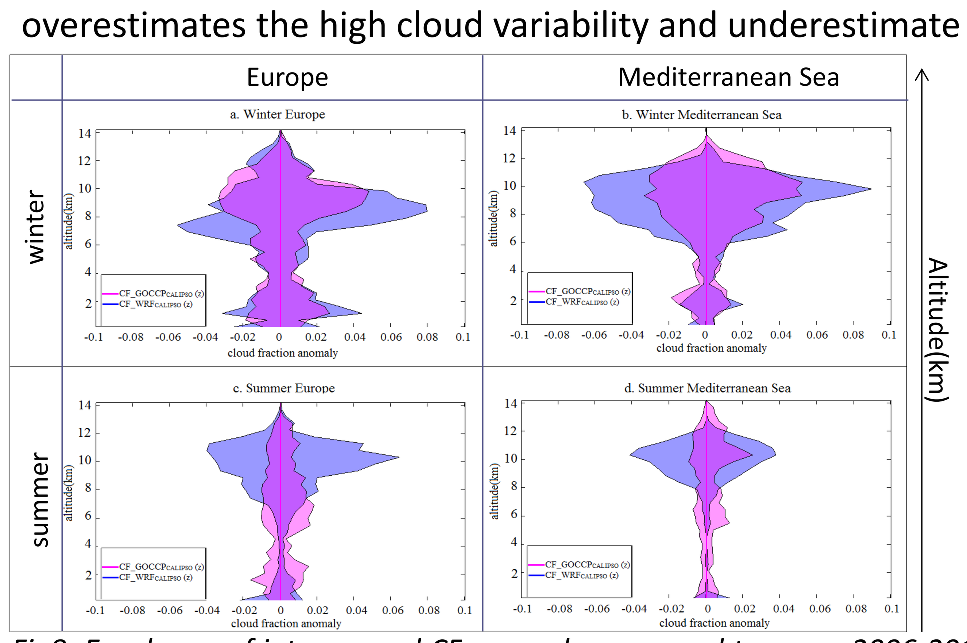

Fig8: Enveloppe of inter annual CF anomaly compared to mean 2006-2011 of horizontally averaged CF (observations; simulations with CALIPSO-sampling) for Europe and Mediterranean Sea in summer and winter

Cloud variability well simulated over the Mediterranean sea in winter -> quid of year to year variability (Fig. 9) ?

- Despite the bias (Fig. 6), the 2007-2011 year to year variability is well reproduced by simulations
- The amplitude of variability of 2007-2011 is comparable to the other years (1990-2006) (fig. 9a)

Some specific years appear (e.g 1992-1993)

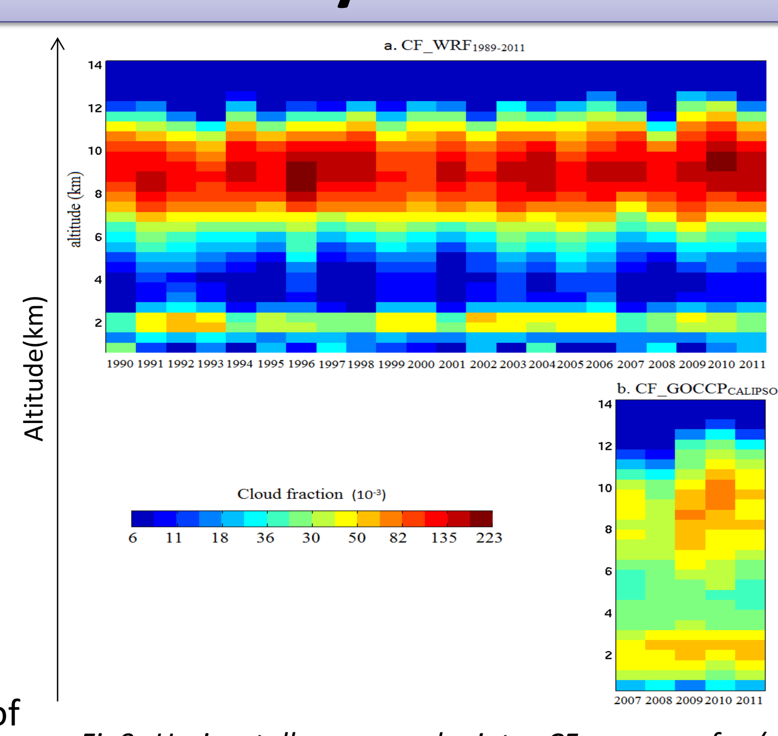

Fig9: Horizontally averaged winter CF over sea for (a) simulations (1990-2011) and (b) observations (2007-2011)

D.1 Discussion #1

The sampling effect on CF estimation is significant when studying the interannual variability: The vertical distribution at high levels is modified and the amplitude is reduced for high clouds in summer.

Is it different when only considering 3 layers (high, mid and low clouds) instead of detailed vertical distribution?

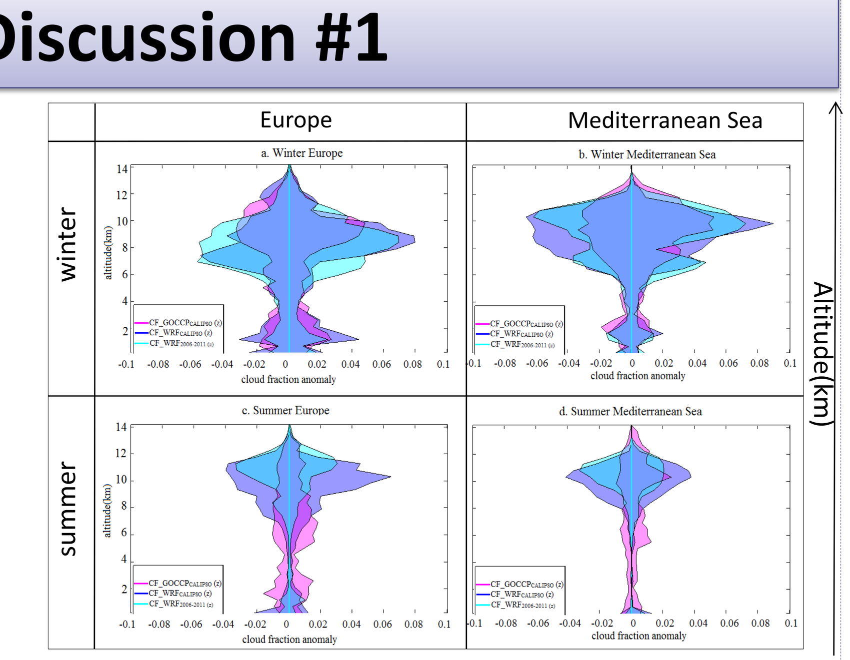

Fig10: Envelope of inter annual CF anomaly compared to mean 2006-2011 of horizontally averaged over Europe (only continent) and over the Mediterranean sea (only sea) cloud fraction (observations; simulations with sat. sampling; simulations with WRF sampling) for winter and summer

D.2 Discussion #2

What is the impact of having only 6 common years? How many years do we need to be sure that the years' selection will not impact the results? i. e how many years until the amplitude of inter annual variability stabilizes for observations? For simulations?

Standard deviation computed over N - N ∈ [1,7] - random years of low/high clouds compared to mean of N years.

Repeat 1000 times to cover all the possibilities: we obtain the shade.

The lines are the mean of all the possibilities, red for observations and black for simulations.

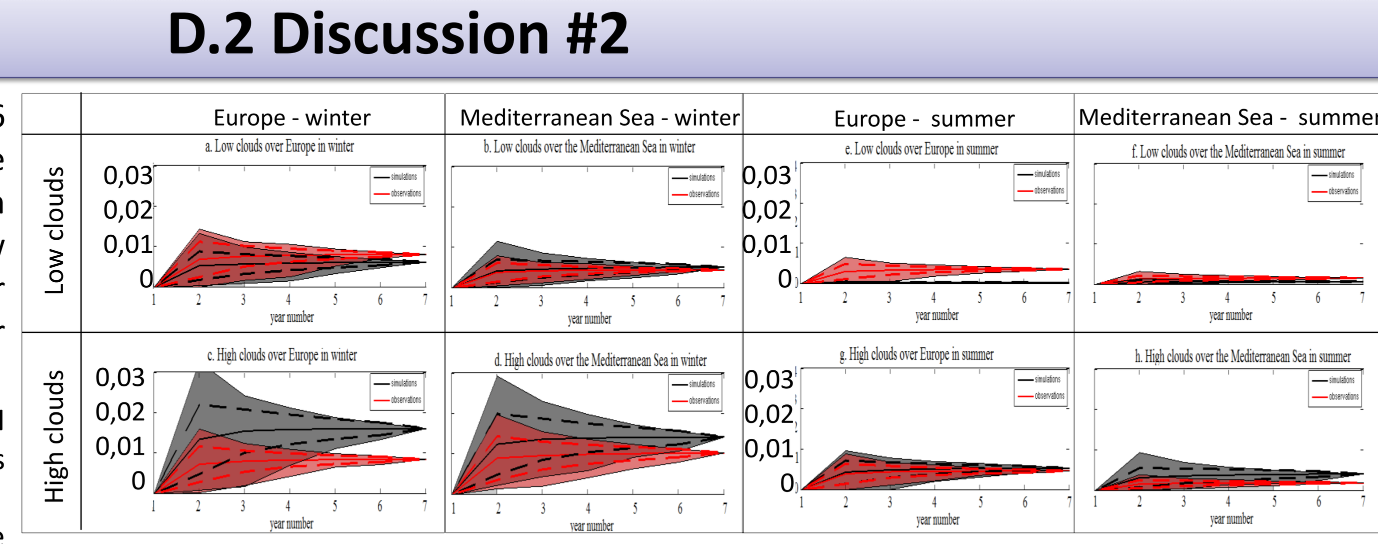

Fig. 11:Random draw of the amplitude (standard deviation) of low and high clouds as function of the number of years for observations and simulations over Europe (only continent) and Mediterranean sea (only sea) in winter and summer

The 7 random years: 2004-2011 for simulations 2006-2013 for observations: are results modified if we change the 7 years's period for simulations?

Conclusion and Perspectives

Deeper investigations and improvements are needed but results show:

- Sat. sampling: Not enough tracks over a season to study interannual variability or anomaly in each grid point at 20 km resolution (max 6 profiles by grid points). It is significant when studying interannual variability at specific levels.
- Model overestimates high clouds occurrence and vertical depth and therefore more profiles are attenuated. Radiative impacts of such differences need to be evaluated

Less low cloud detection (amplified by the use of lidar simulator and overestimation of high clouds): difficult to evaluate simulation low clouds against CALIPSO data.

To be done: - Characterize clouds radiative forcing with A-train observations
- Associate cloud variability to large scale atmospheric dynamics (North Atlantic oscillation)
- Understand cloud variability over the continent (mesoscale variability)

References and acknowledgements

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This work is a contribution to the EECLAT project through LEFE-INSU and TOSCA-CNES support and to the HyMeX program (HYdrological cycle in The Mediterranean EXperiment) through INSU-MISTRALS support and the Med-CORDEX program (COordinated Regional climate Downscaling EXperiment Mediterranean region), with granted access to the HPC resources of IDRIS (under allocation i2011010227).