Mid-level clouds in West Africa : observation, characterisation, modelling

PhD Defense presented by

Elsa BOURGEOIS

CNRM, CNRS/Météo-France, Toulouse

Under the supervision of

Dominique BOUNIOL, Fleur COUVREUX and Françoise GUICHARD

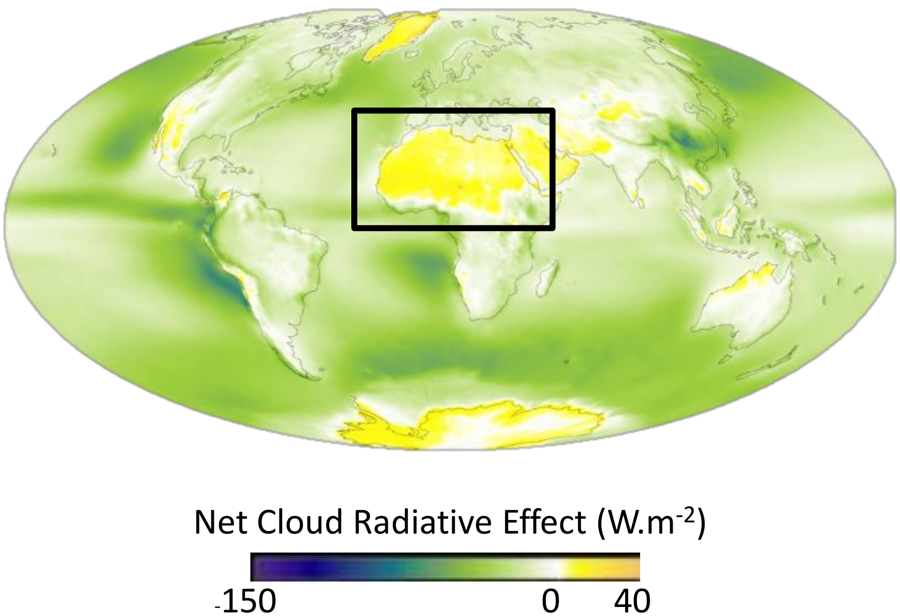
Mali – August 2005 - F. Guichard

7th December 2017

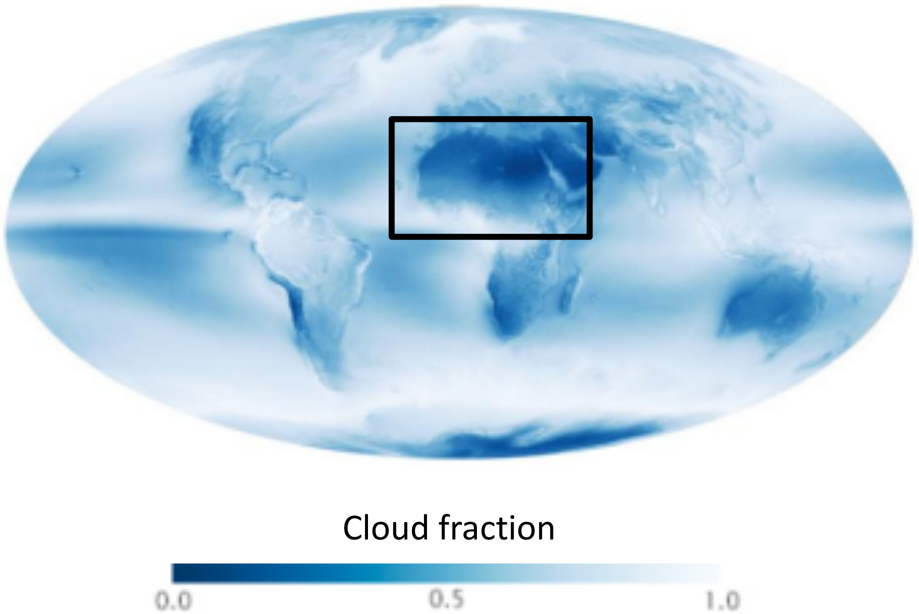
I. Context and objectives

Radiative impact

- Clouds have a major impact on the distribution of water and energy fluxes within the atmosphere *(Zhang and Rossow, 1997; Kato et al., 2008; Stephens, 2005)*



Cloud radiative impact at TOA (CERES 2000 - 2015)



Cloud fraction (MODIS 2002 - 2015)

car la zone délimitée par ton carré ne correspond ni à "l'Afrique de l'ouest" ni au "Sahel et Sahara"

positive (cf remarques précedentes) *meridional gradient of (idem)*

North

In ~~West~~ Africa ~~(Sahel and Sahara)~~, ~~high~~ cloud radiative effect at TOA and ~~low~~ cloud fraction.

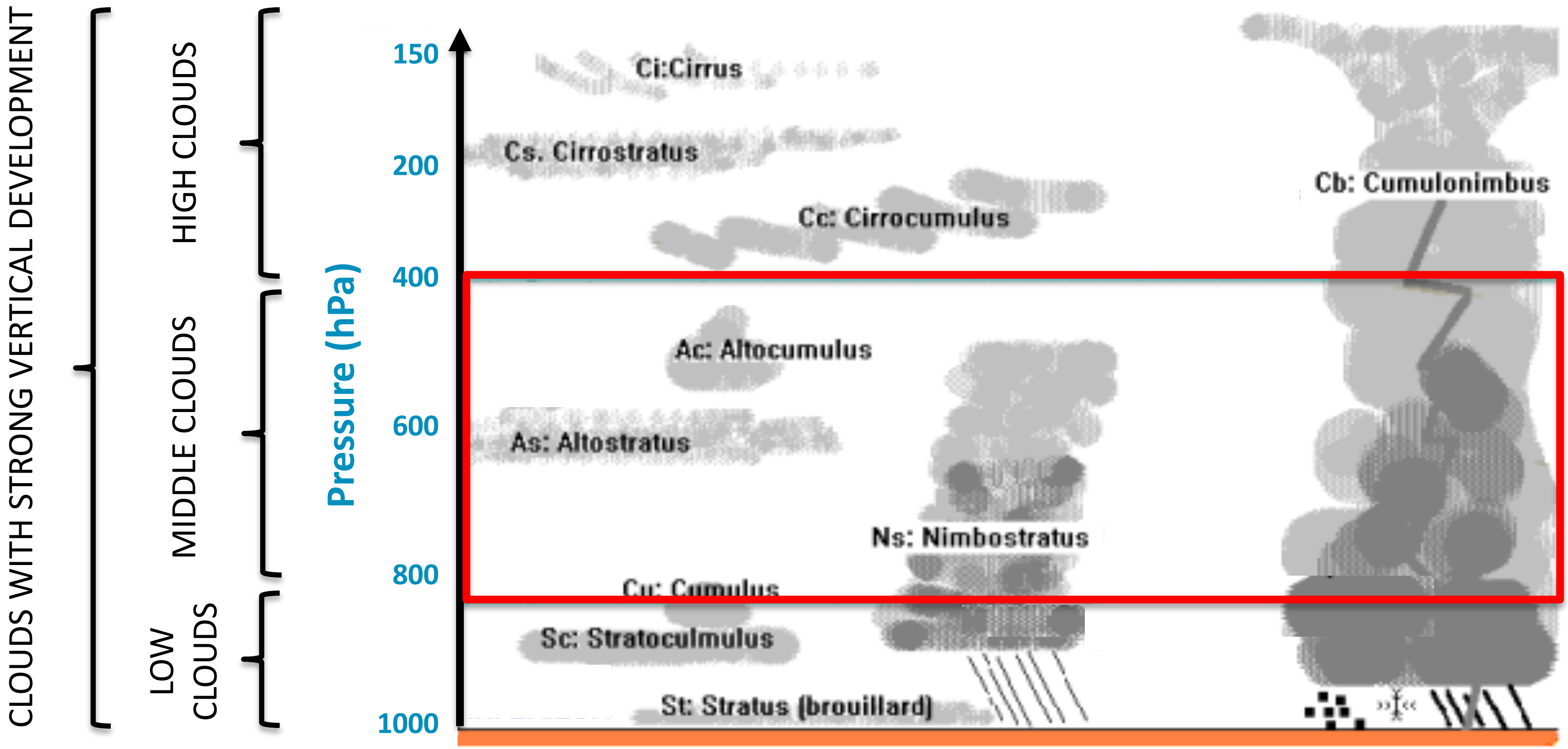
il faut que tu choisisses: soit "North Africa" soit "Sahel et Sahara" c'est pas la même chose.

je trouve pas que ça soit une bonne idée ici de dire qu'il y a peu de nuages

I. Context and objectives

The different cloud types

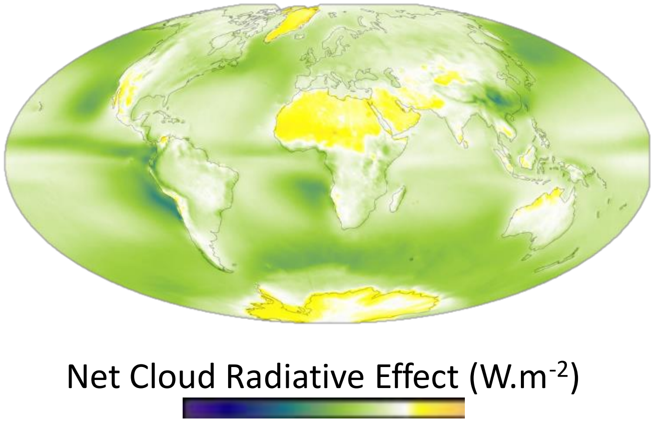
- "A cloud is a cluster of tiny drops of water or ice crystals or both in the atmosphere" *(Malardel 2009)*
- According to World Meteorological Organization (WMO), 10 cloud types ~~dividing~~ organized (anglais) in 4 families



Cloud classification (adapted ~~to~~ from http://cyclonextreme.com)

Clouds distribution - Trimodal

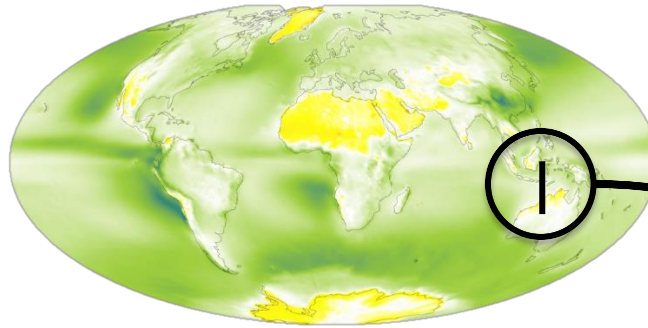
Global scale



Cloud radiative impact at TOA
(CERES 2000 - 2015)

Clouds distribution - Trimodal

Global scale



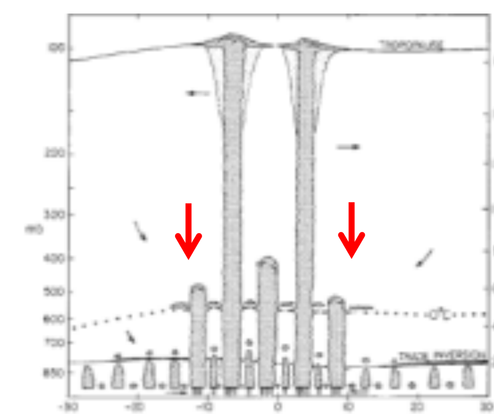
Net Cloud Radiative Effect (W.m^{-2})

-150 0 40

Cloud radiative impact at TOA (CERES 2000 - 2015)

Tropical Pacific Ocean

Mid-level processes - Isotherm 0°C

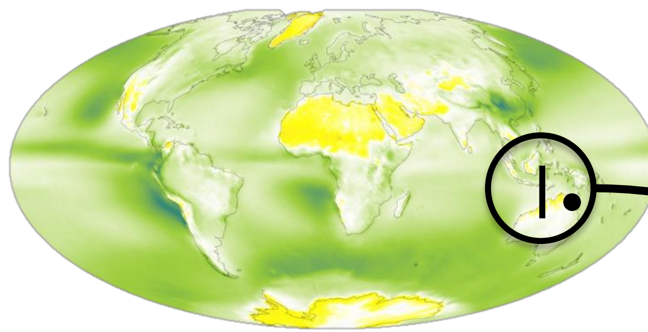


(Johnson et al., 1999)

I. Context and objectives

Clouds distribution - Trimodal

Global scale



Net Cloud Radiative Effect (W.m^{-2})

-150 0 40

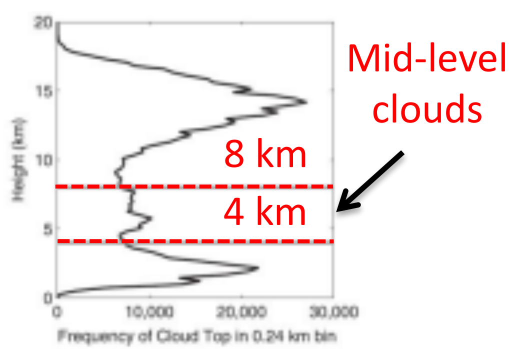
Cloud radiative impact at TOA

(CERES 2000 - 2015)

Tropical Pacific Ocean

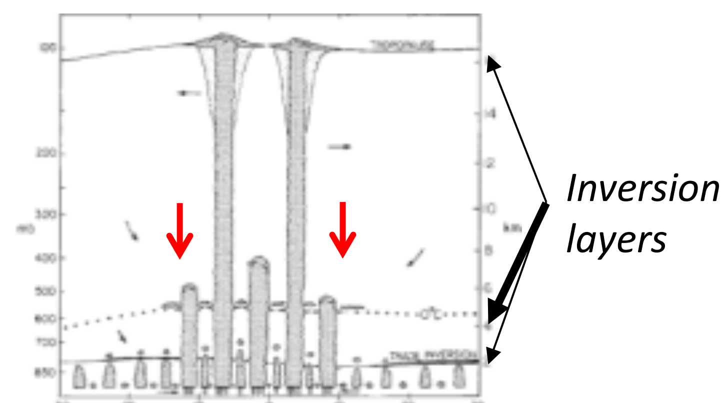
Darwin (Australia)

Observation ~~of mid-level clouds~~



(Riihimaki et al., 2012)

Mid-level processes - Isotherm 0°C



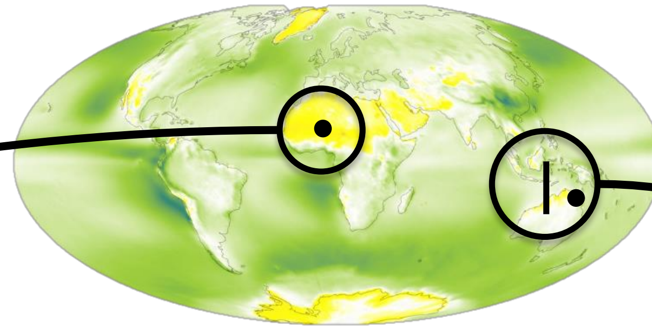
(Johnson et al., 1999)

I. Context and objectives

Clouds distribution - Trimodal

Global scale

ton point Niamey n'est pas
très bien positionné
Trop au Nord



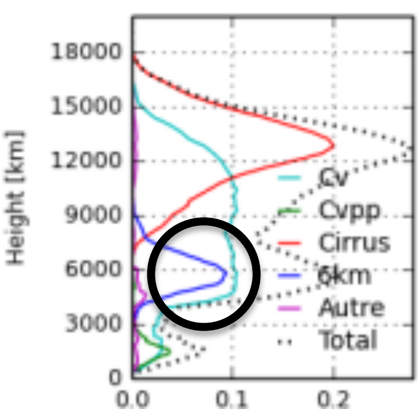
Net Cloud Radiative Effect (W.m^{-2})

-150 0 40

Cloud radiative impact at TOA
(CERES 2000 - 2015)

West Africa
Niamey (Niger)

Observation
of mid-level clouds

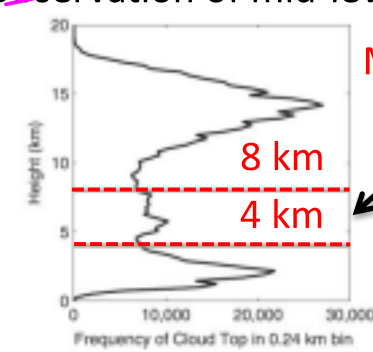


Frequency of occurrence

(Bouniol et al., 2012)

Darwin (Australia)

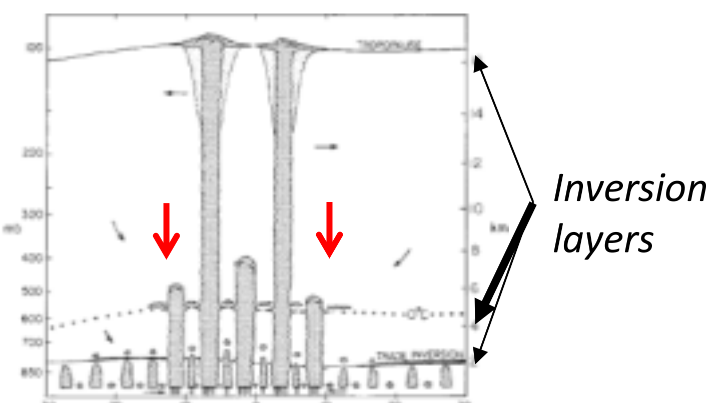
~~Observation of~~ mid-level clouds



(Riihimaki et al., 2012)

Tropical Pacific Ocean

Mid-level processes - Isotherm 0°C



(Johnson et al., 1999)

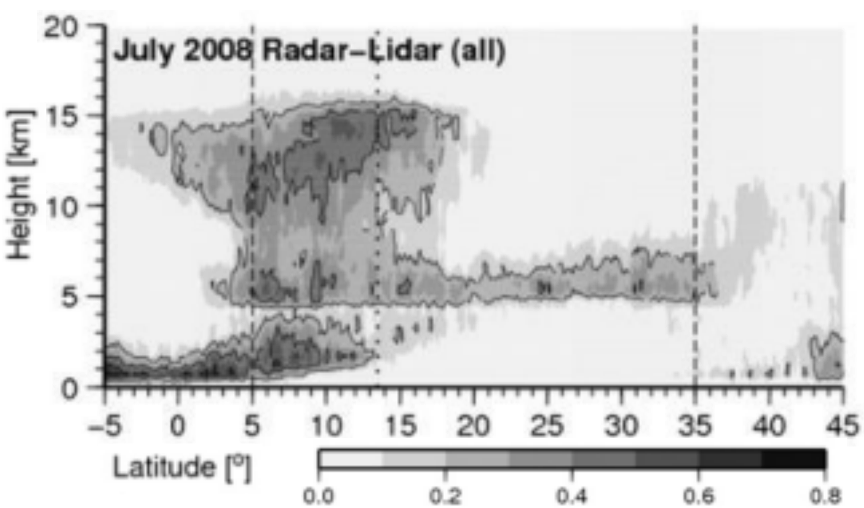
I. Context and objectives

Mid-level clouds in West Africa

- Large amount of mid-level clouds over ~~the~~ land
- Presence of mid-level clouds between midnight and 6 o'clock

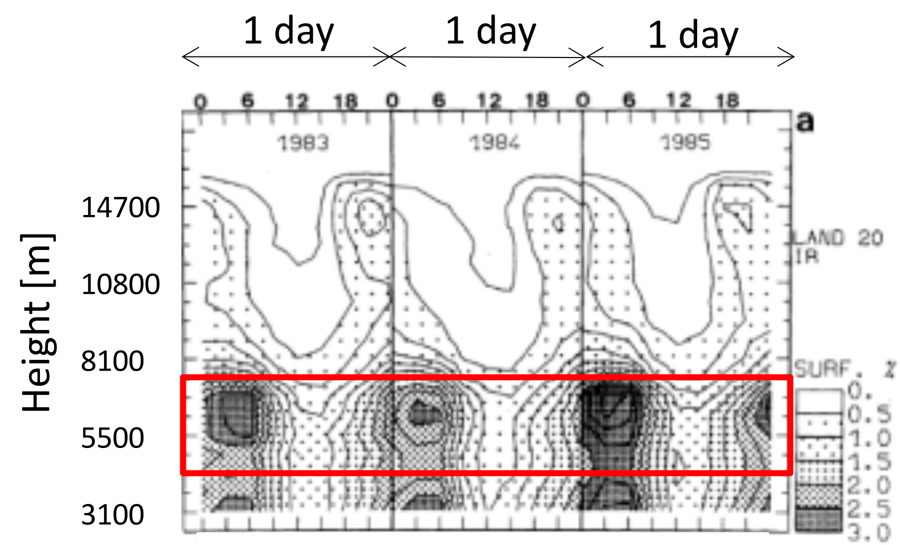
plutot 0h and 6h

Cloud frequency of occurrence



(Bouniol et al., 2012)

Cloud cover climatology



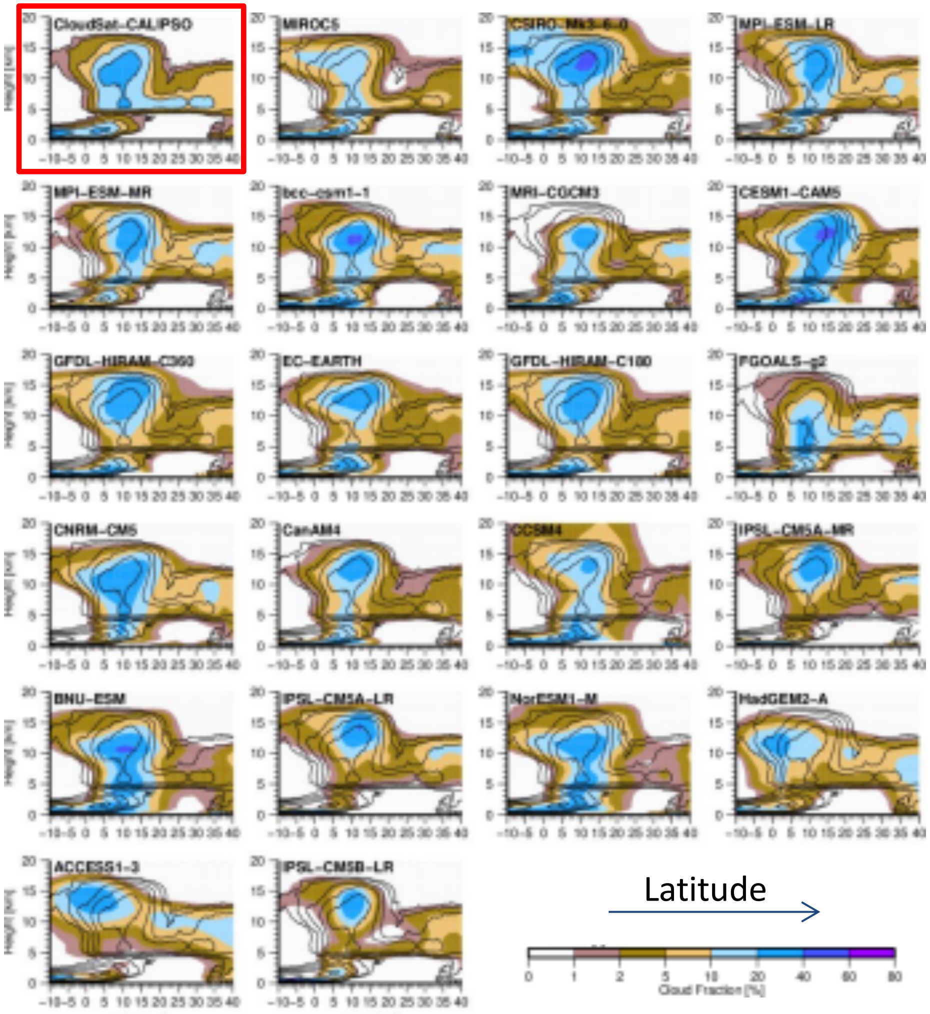
(Duvel, 1989)

I. Context and objectives

Representation of mid-level clouds in the climate models

- Inability of climate models to simulate the occurrence of mid-level clouds

correctly



Latitude – altitude diagrams of the mean cloud fraction ~~averaged between~~ 10° W ~~and~~ 10° E ~~from~~ July to September.

CloudSat-CALIPSO : 2006 - 2010

CMIP5 models : 1979 - 2008

(Roehrig et al., 2013)

trop d'espace entre ° et W et ° et E

10° W 10° E

Questions

(i) What are the characteristics of mid-level clouds in West Africa?

Questions

(i) What are the characteristics of mid-level clouds in West Africa?

(ii) In what environment do mid-level clouds occur in this region ?

Questions

(i) What are the characteristics of mid-level clouds in West Africa?

(ii) In what environment do mid-level clouds occur in this region ?

(iii) What is their radiative impact ?

Questions

(i) What are the characteristics of mid-level clouds in West Africa?

(ii) In what environment do mid-level clouds occur in this region ?

(iii) What is their radiative impact ?

(iv) Are there different types of mid-level clouds ?

I. Context and objectives

Questions

(i) What are the characteristics of mid-level clouds in West Africa?

(ii) In what environment do mid-level clouds occur in this region ?

(iii) What is their radiative impact ?

(iv) Are there different types of mid-level clouds ?

(v) How the mid-level clouds are simulated in models ?

Outline

I. Context and objectives
- ❑ Large amount of mid-level clouds in the tropical belt especially over the land
- ❑ Maximum of mid-level clouds near the 0-degree-isotherm (5 km height)
- ❑ Underestimation of mid-level clouds in climate models

II. Observations and methodologies

III. Mean characteristics of mid-level clouds in West Africa

demander à Ross, je suis pas sure que ça soit le bon mot

IV. Multi-type of mid-level clouds in West Africa

over

V. Representation of mid-level clouds in models ~~in~~ West Africa

VI. Summary and perspectives

Outline

I. Context and objectives
- ❑ Large amount of mid-level clouds in the tropical belt especially over the land
- ❑ Maximum of mid-level clouds near the 0-degree-isotherm (5 km height)
- ❑ Underestimation of mid-level clouds in climate models

II. Observations and methodologies

III. Mean characteristics of mid-level clouds in West Africa

IV. Multi-type of mid-level clouds in West Africa

V. Representation of mid-level clouds in models in West Africa

VI. Summary and perspectives

Study area

Il y a la Gulf of Guinea (~> 5°N)
la Guinean Coast (~5-7°N)
La zone Soudanienne (7°N-10-11°N)

12°N à 17°N c'est un Sahel un peu réduit, parfois on va de 10 à 20°N
cf remarque que je t'ai déjà faite, 17°N c'est un peu trop sud

- Four sub-regions from South to North

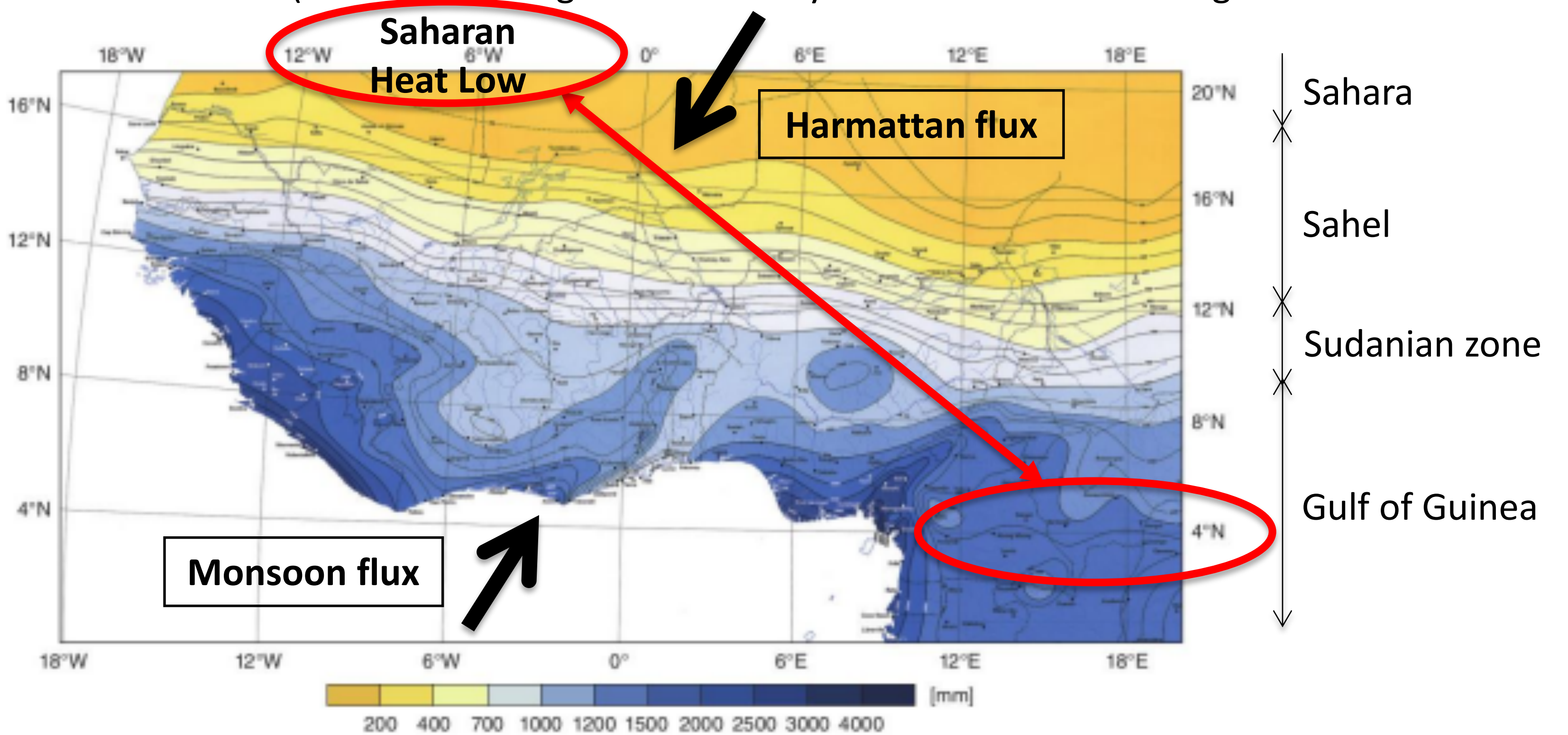
  - Gulf of Guinea (< 7.5 N) : very wet region with precipitation all year

  je pense que c'est pas tout à fait vrai.

  - Sudan (7.5 N – 12.5 N) : slightly drier region than Gulf of Guinea

  cf remarque tu as oublié de corrigé ici le Sudan, c'est un pays

  - Sahel (12.5 N – 17 N) : semi-arid region with precipitation occurring only during the monsoon period (June to September)
  - Sahara (> 17 N) : arid region covered by the desert and receiving almost no rain



Mean annual precipitation for the period 1951-1989. Fink et al., 2017, IRD.

II. Observations and methodologies

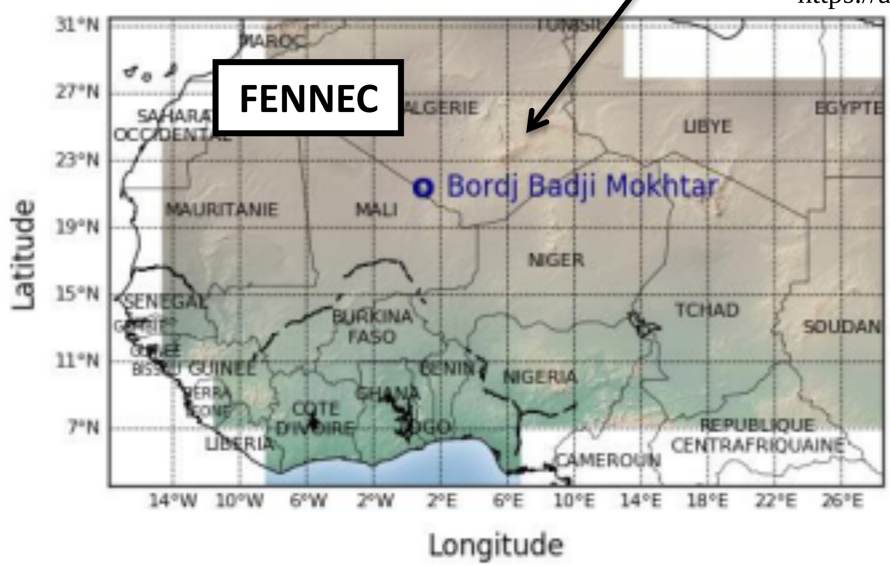
Observations

BBM instrumentation (June 2011)

https://africanclimateoxford.net/projects/fennec/

Lidar,
Radiosondes,
Radiometer, …

Marsham et al., 2013



Sahara

Sahel

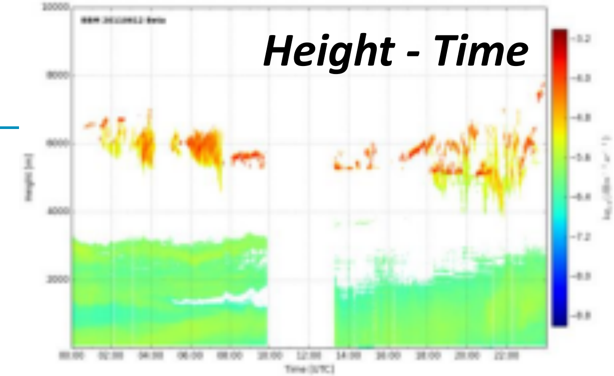
Sudanian zone

Gulf of Guinea

II. Observations and methodologies

Observations

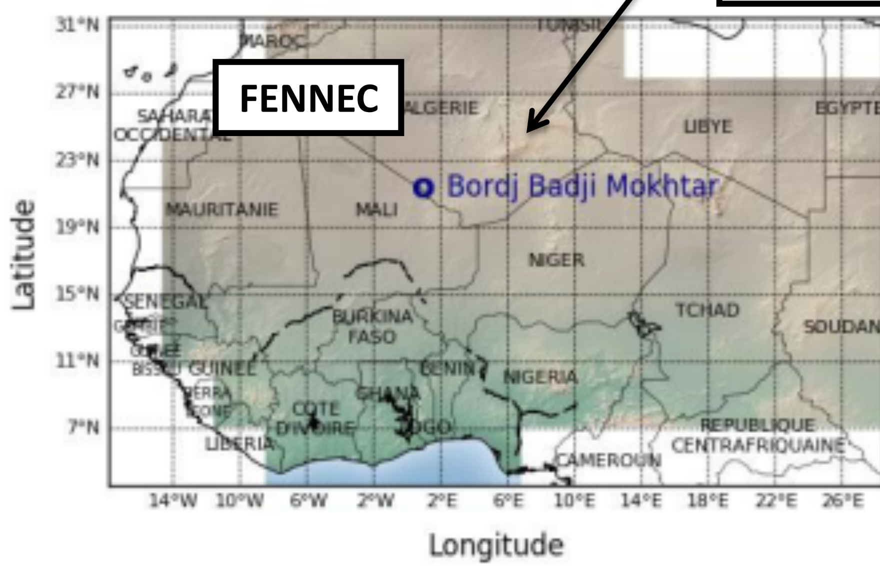
BBM instrumentation (June 2011)



Lidar,
Radiosondes,
Radiometer, …

Marsham et al., 2013

Resolution : 30s - 30m



Sahara

Sahel

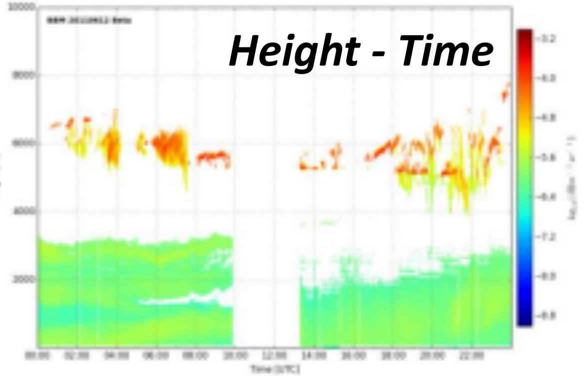
Sudanian zone

Gulf of Guinea

II. Observations and methodologies

Observations

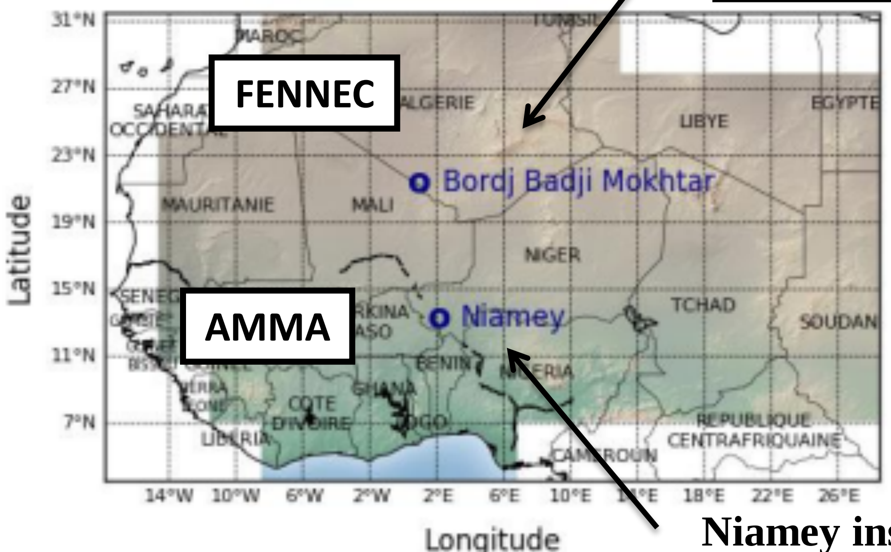
BBM instrumentation (June 2011)



Lidar,
Radiosondes,
Radiometer, …

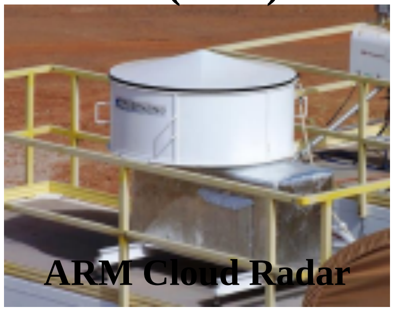
Resolution : 30s - 30m

Marsham et al., 2013



Miller and Slingo, 2007;
Stokes and Schwartz, 1994

Niamey instrumentation (2006)



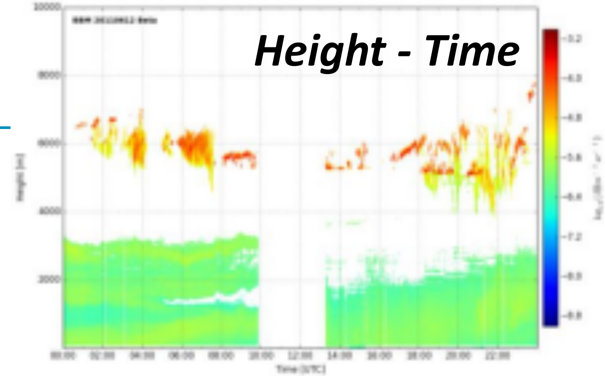
ARM Climate Research Facility

Radar, Lidar,
Radiosondes,
AWS (meteo,
radiometers)

II. Observations and methodologies

Observations

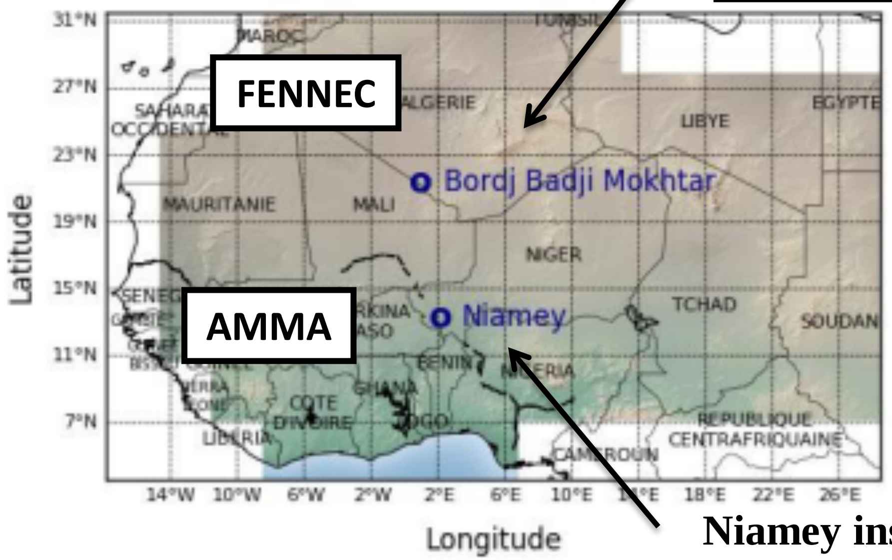
BBM instrumentation (June 2011)



Lidar, Radiosondes, Radiometer, …

Marsham et al., 2013

Resolution : 30s - 30m



Sahara

Sahel

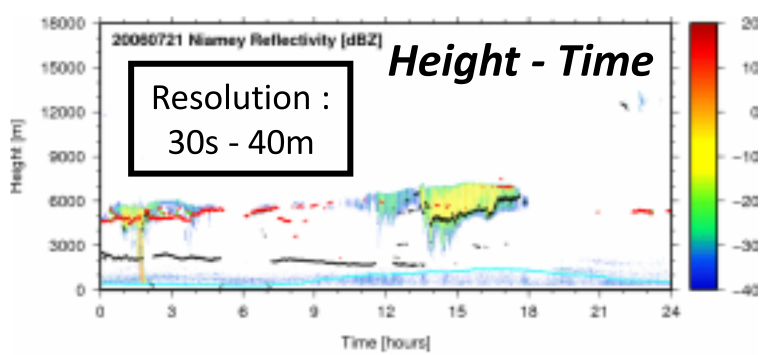
Sudanian zone

Gulf of Guinea

Miller and Slingo, 2007;
Stokes and Schwartz, 1994

Radar, Lidar, Radiosondes, AWS (meteo, radiometers)

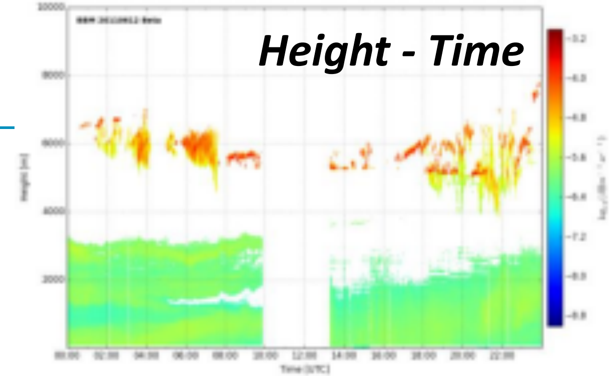
Niamey instrumentation (2006)



II. Observations and methodologies

Observations

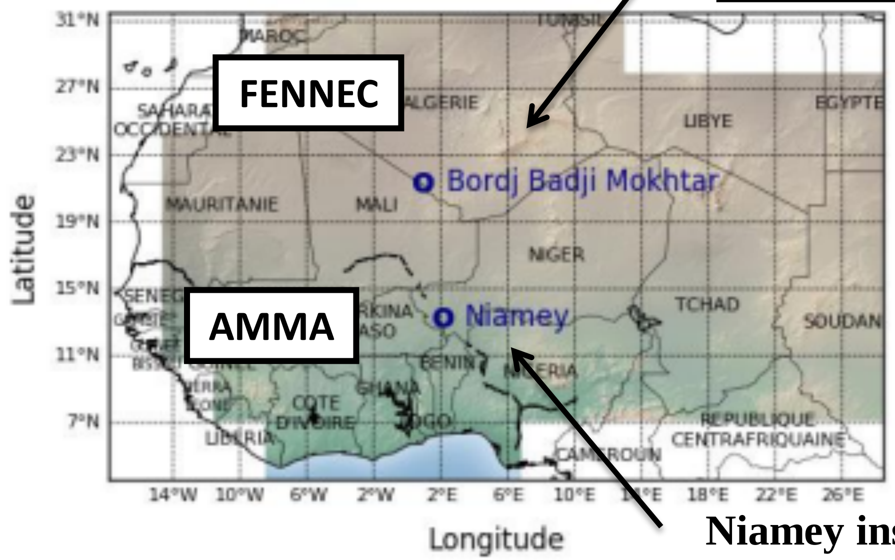
BBM instrumentation (June 2011)

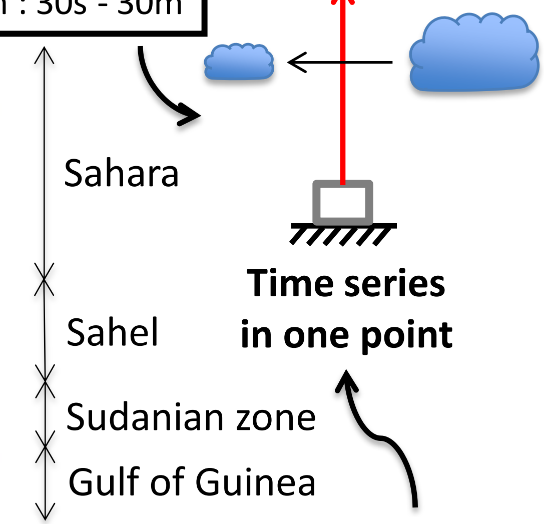


Lidar,
Radiosondes,
Radiometer, …

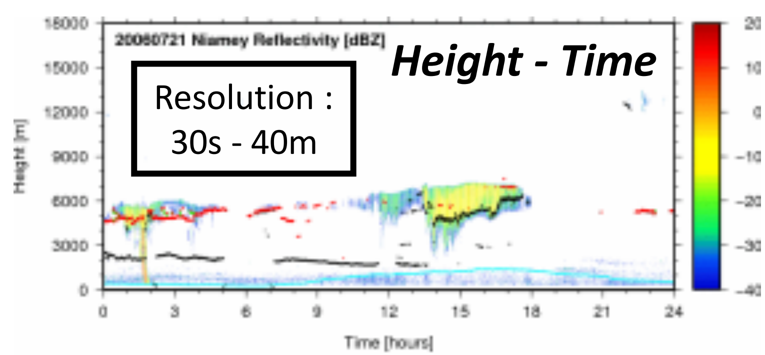
Marsham et al., 2013

Resolution : 30s - 30m





Niamey instrumentation (2006)



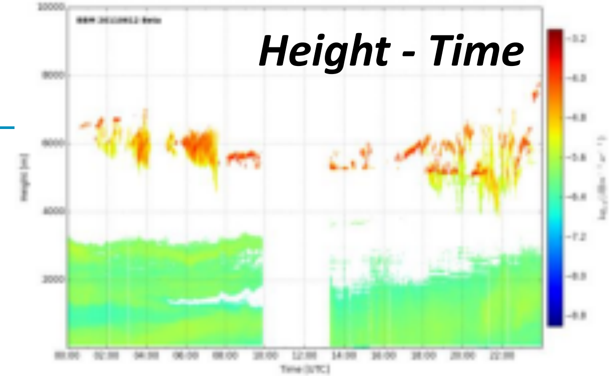
Miller and Slingo, 2007;
Stokes and Schwartz, 1994

Radar, Lidar,
Radiosondes,
AWS (meteo,
radiometers)

II. Observations and methodologies

Observations

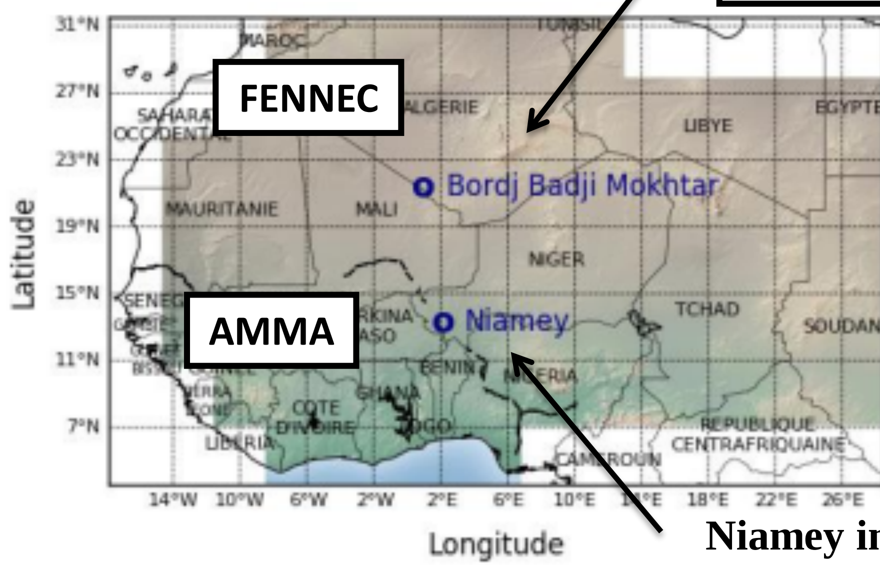
BBM instrumentation (June 2011)

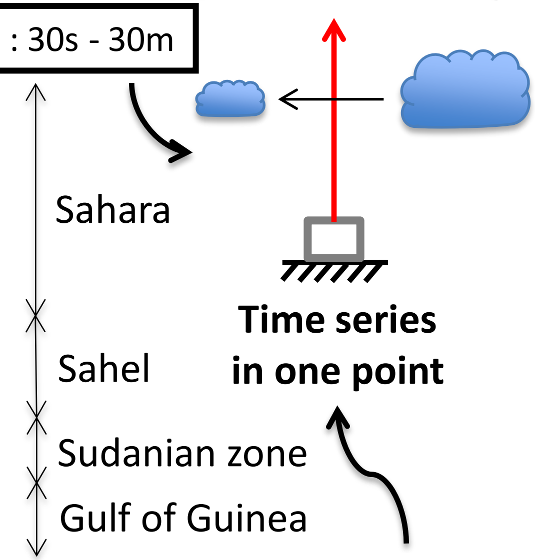


Lidar,
Radiosondes,
Radiometer, …

Marsham et al., 2013

Resolution : 30s - 30m





Niamey instrumentation (2006)

Miller and Slingo, 2007;
Stokes and Schwartz, 1994

Radar, Lidar,
Radiosondes,
AWS (meteo,
radiometers)

II. Observations and methodologies

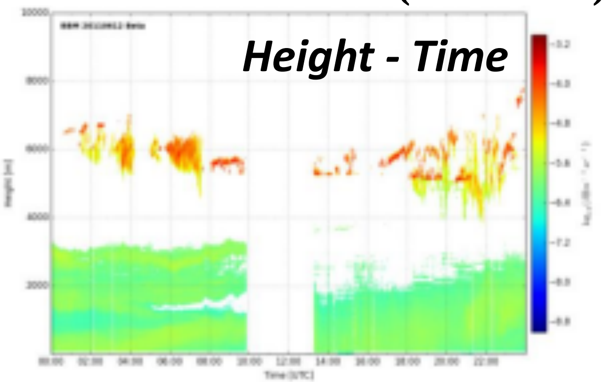
Observations

A-Train constellation (NASA)

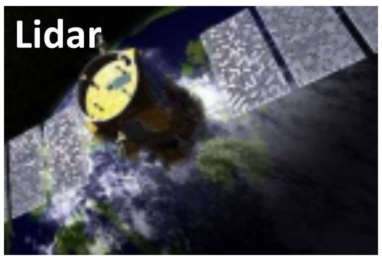
Lidar, Radiosondes, Radiometer, …

Marsham et al., 2013

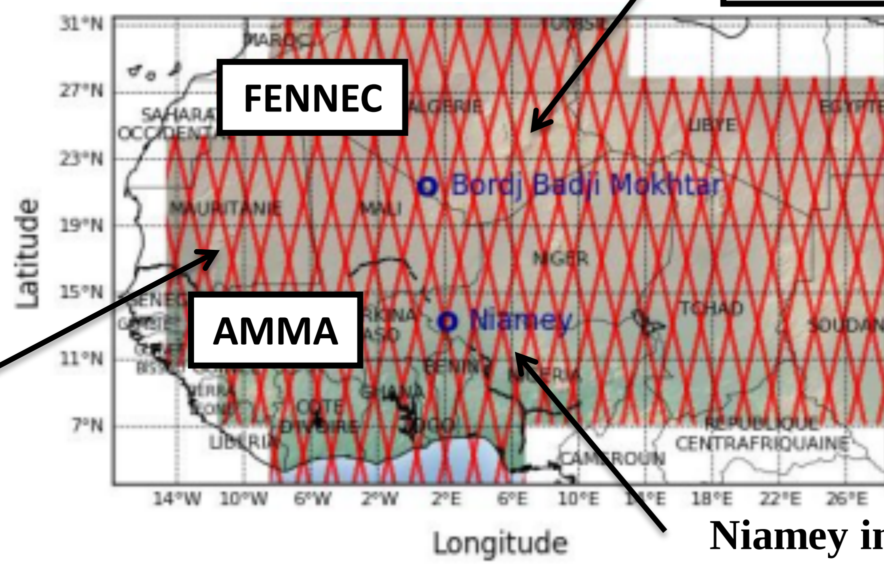
BBM instrumentation (June 2011)



Resolution : 30s - 30m



CALIPSO (NASA)
Winker et al., 2007



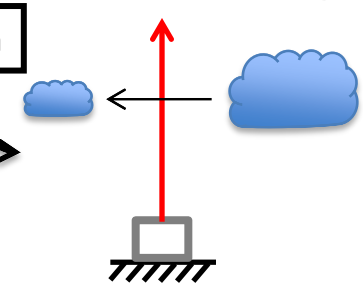
Miller and Slingo, 2007; Stokes and Schwartz, 1994

Sahara

Sahel

Sudanian zone

Gulf of Guinea



Time series in one point

Niamey instrumentation (2006)

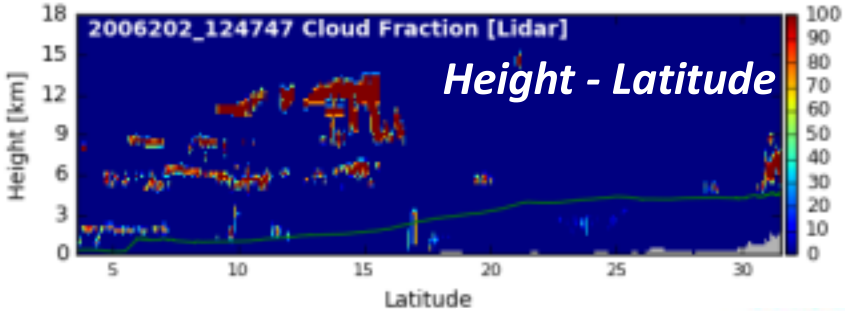
CloudSat (NASA)
Stephens et al., 2002

June 2006 to May 2010

Radar, Lidar, Radiosondes, AWS (meteo, radiometers)

II. Observations and methodologies

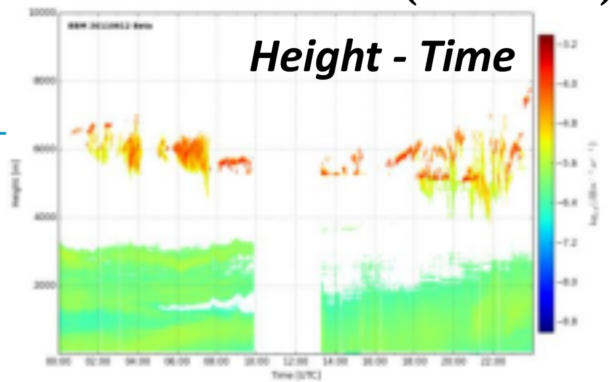
Observations



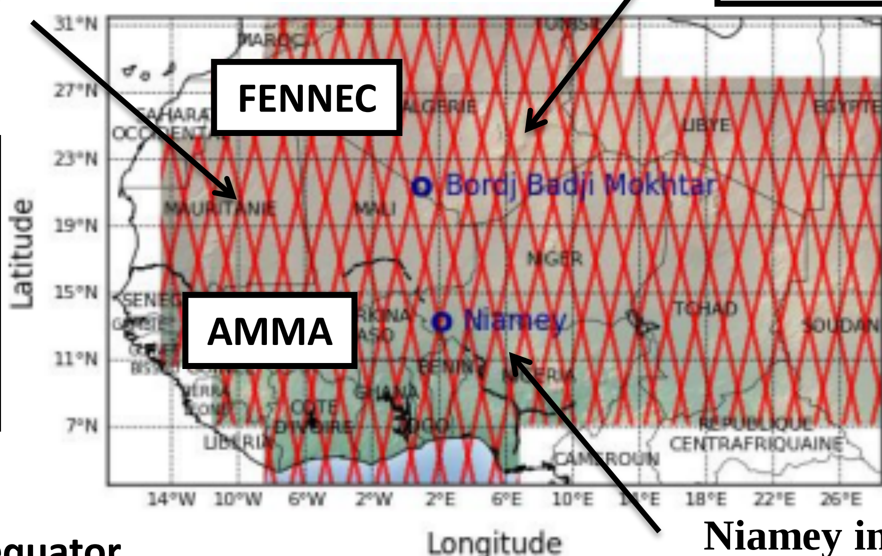
2B-CDLCLASS-LIDAR product
Resolution:
- 1.5 km across-track
- 2.5 km along-track
- 240 m vertically
- 0.16 seconds

Cross the equator at 0130 and 1330

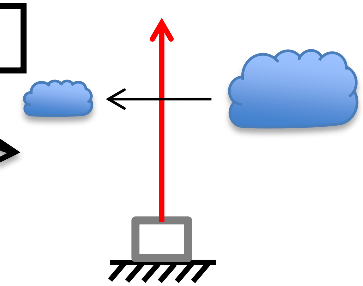
BBM instrumentation (June 2011)



Resolution : 30s - 30m



Sahara
Sahel
Sudanian zone
Gulf of Guinea



Time series in one point

Niamey instrumentation (2006)

→ Diurnal cycle documented with ground-based data only

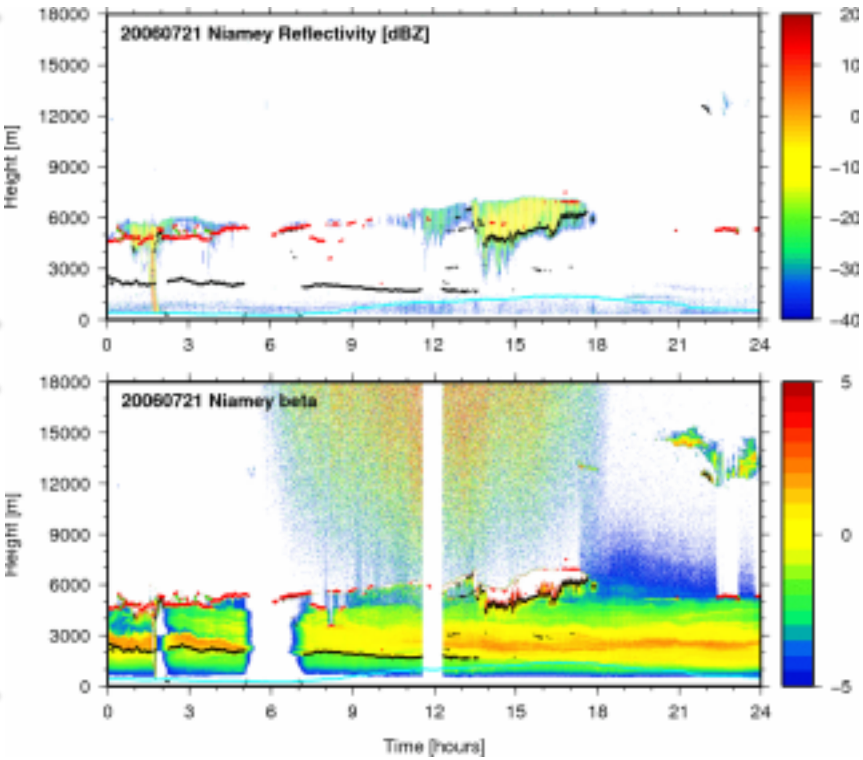
II. Observations and methodologies

Instrumental complementarity and classification

Ground-based observations

RADAR

LIDAR



- Case 1 : Radar + Lidar → Niamey (April to Dec. 2006) and West-Africa (CloudSat-CALIPSO)
- Case 2 : Lidar → Bordj Badji Mokhtar and Niamey (Janv. to March 2006)

II. Observations and methodologies

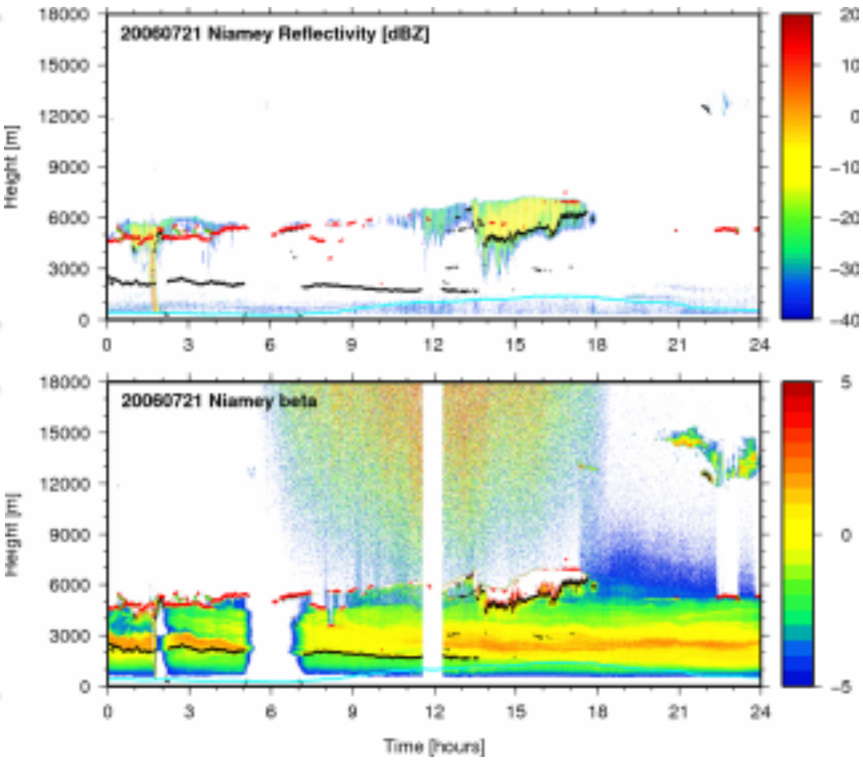
Instrumental complementarity and classification

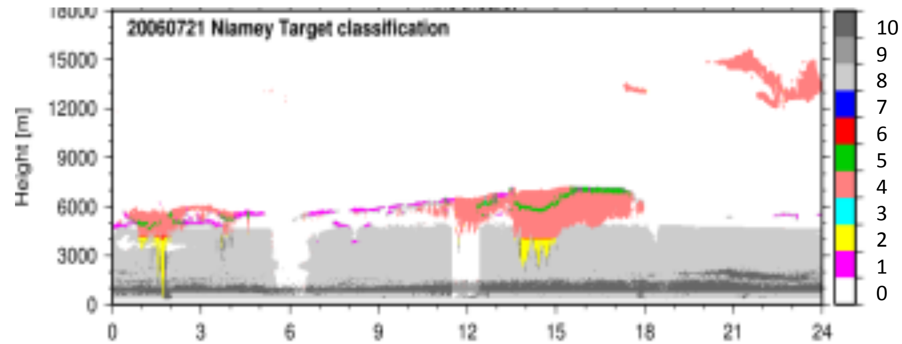
Ground-based observations

(Hogan and O'Connor, 2004; Illingworth et al., 2007)

RADAR

LIDAR



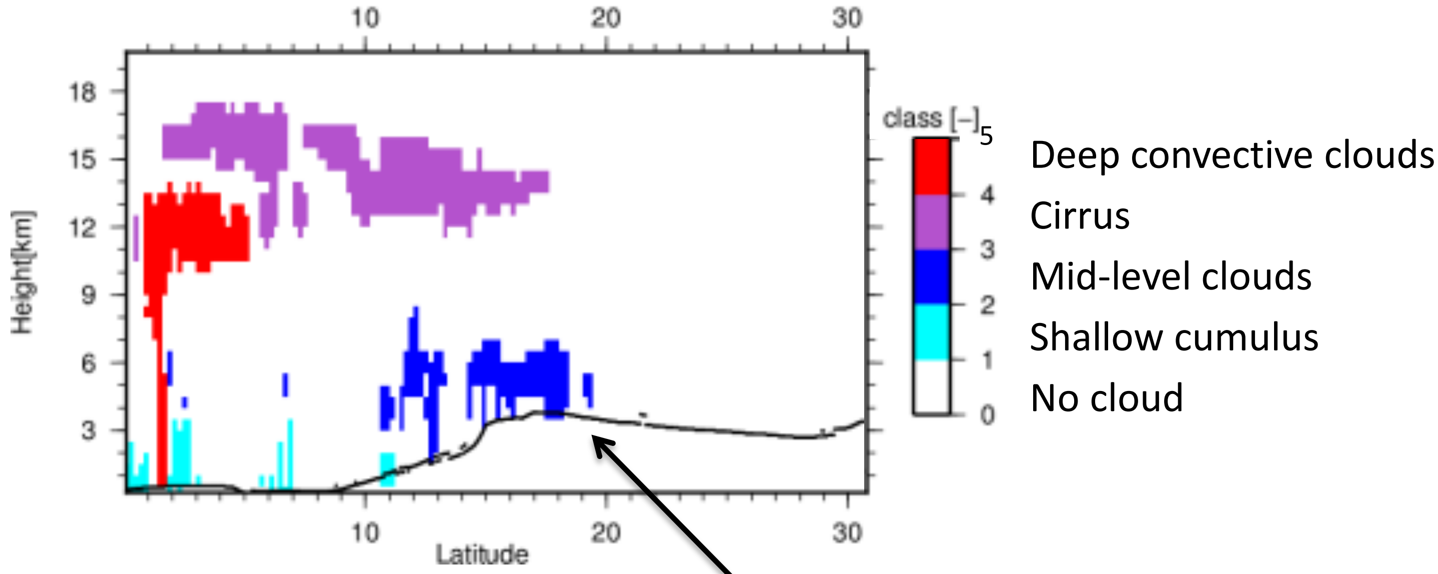


10 Aerosols & insects
9 Insects
8 Aerosols
7 Melting ice & cloud liquid droplets
6 Melting ice
5 Ice & supercooled liquid droplets
4 Ice
3 Drizzle or rain & cloud liquid droplets
2 Drizzle or rain
1 Cloud liquid droplets only
0 Clear sky

- Case 1 : Radar + Lidar → Niamey (April to Dec. 2006) and West-Africa (CloudSat-CALIPSO)
- Case 2 : Lidar → Bordj Badji Mokhtar and Niamey (Janv. to March 2006)

II. Observations and methodologies

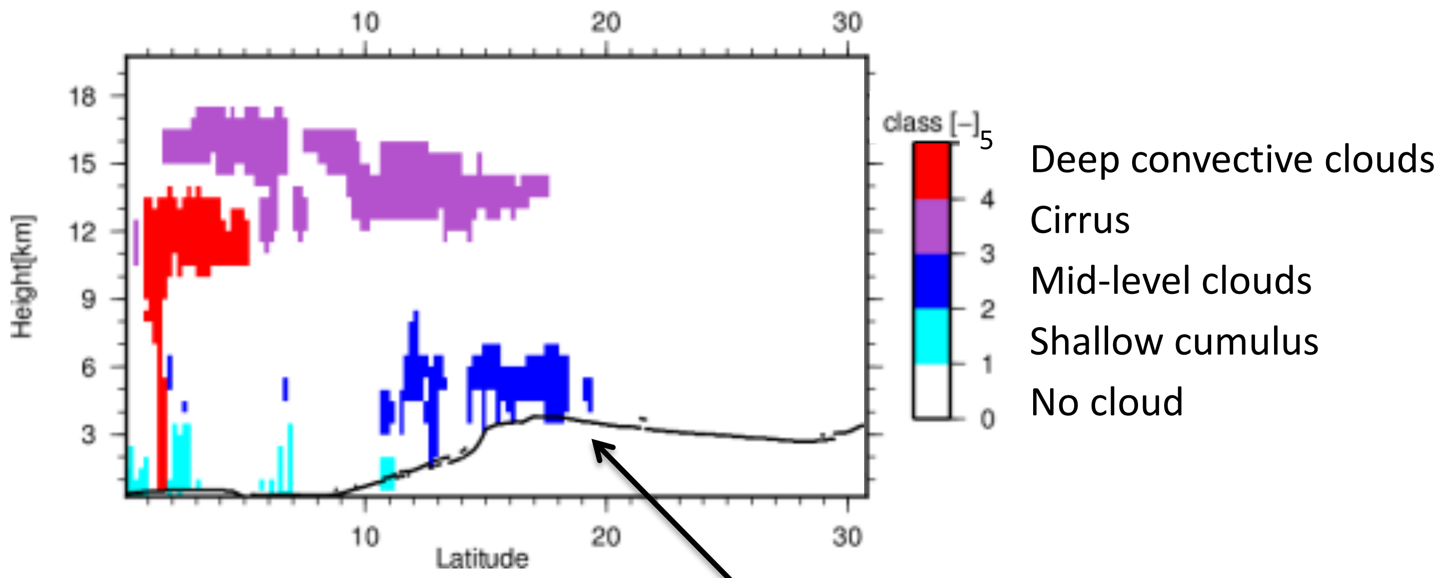
Identification and characterisation of mid-level clouds



Mid-level clouds definition :
base ≥ 3 km
top ≤ 9 km
Composition :
Cloudy hydrometeors

- 1) Classification in four cloud types *(Bouniol et al., 2012)*

Identification and characterisation of mid-level clouds



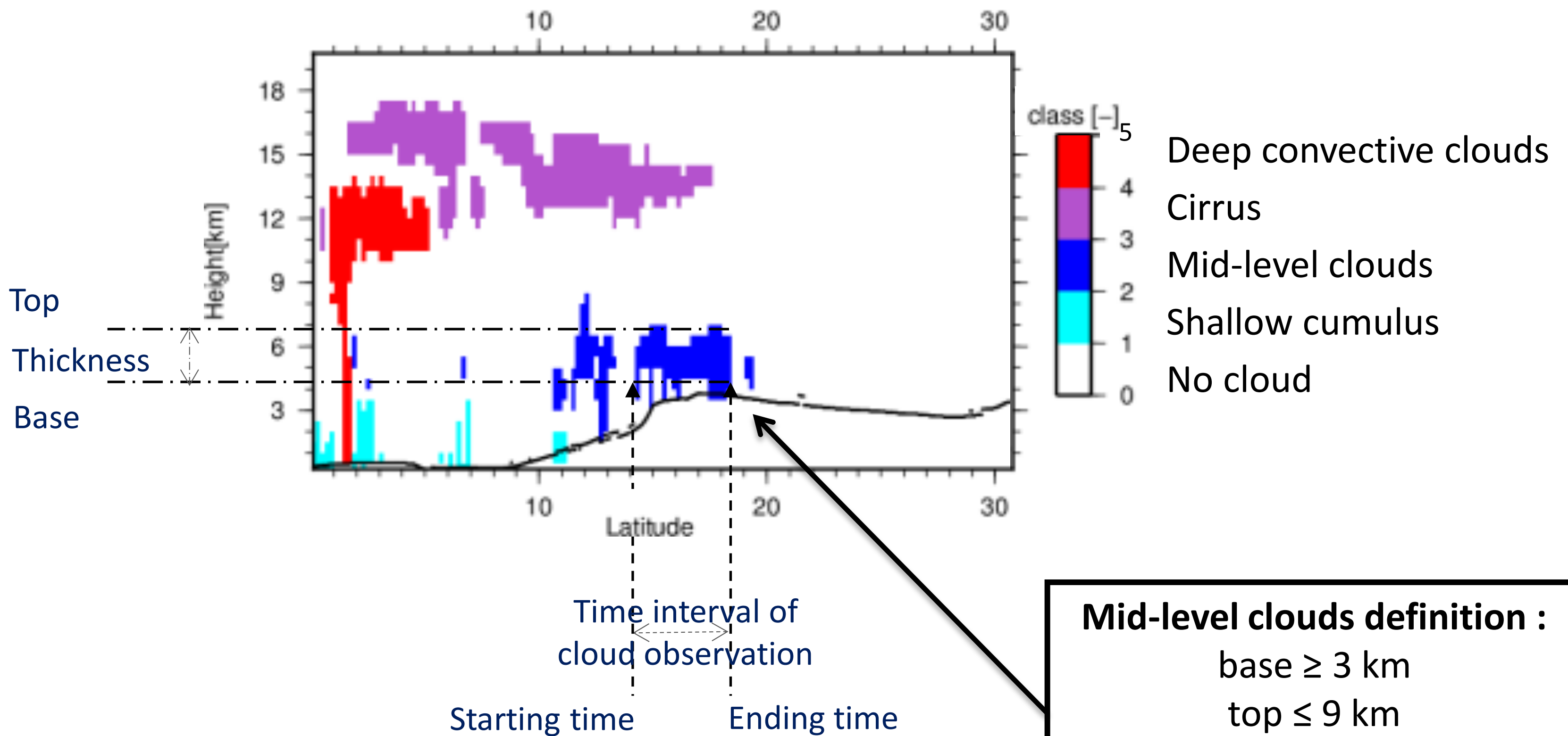
Mid-level clouds definition :
base ≥ 3 km
top ≤ 9 km
Composition :
Cloudy hydrometeors

- 1) Classification in four cloud types *(Bouniol et al., 2012)*

Mid-level cloud number observed : **Bordj Badji Mokhtar : 94 / Niamey : 482 / West Africa : 43115**

II. Observations and methodologies

Identification and characterisation of mid-level clouds



Mid-level clouds definition :
base ≥ 3 km
top ≤ 9 km
Composition :
Cloudy hydrometeors

- 1) Classification in four cloud types *(Bouniol et al., 2012)*

Mid-level cloud number observed : **Bordj Badji Mokhtar : 94 / Niamey : 482 / West Africa : 43115**

- 2) Detection of cloud characteristics
  - i) Macrophysics properties

II. Observations and methodologies

Identification and characterisation of mid-level clouds

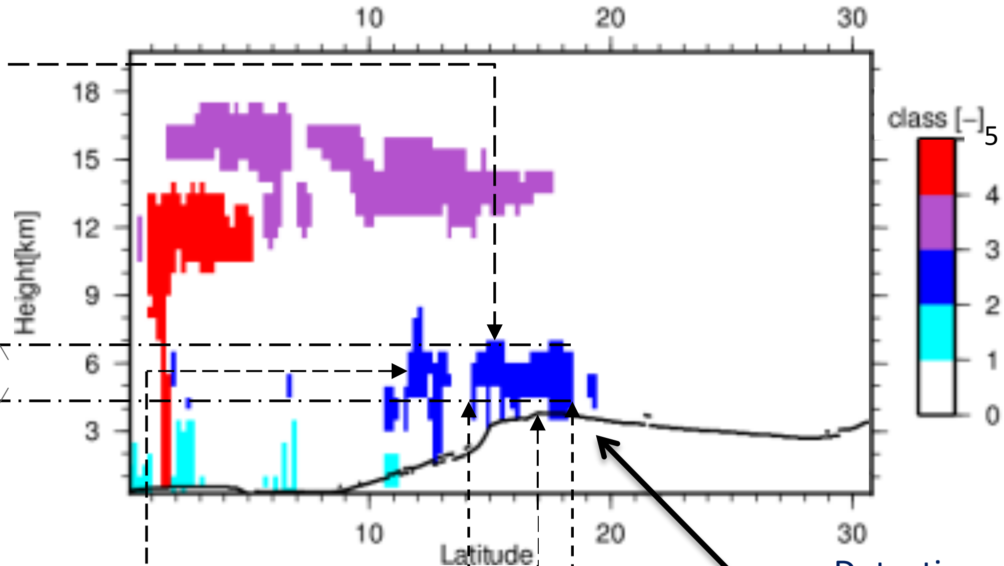
Reflectivity

Doppler velocity

Top

Thickness

Base



Deep convective clouds

Cirrus

Mid-level clouds

Shallow cumulus

No cloud

Detection of precipitation

Composition :

- Ice ?
- Melting ice ?
- Melting ice and cloud liquid droplets ?
- Ice and supercooled liquid droplets ?
- Cloud liquid droplets only ?
- Drizzle or rain and cloud liquid droplets ?

Time interval of cloud observation

Starting time

Ending time

Mid-level clouds definition :

base ≥ 3 km

top ≤ 9 km

Composition :

Cloudy hydrometeors

- 1) Classification in four cloud types *(Bouniol et al., 2012)*

Mid-level cloud number observed : **Bordj Badji Mokhtar : 94 / Niamey : 482 / West Africa : 43115**

- 2) Detection of cloud characteristics

  i) Macro- and microphysics properties

II. Observations and methodologies

Identification and characterisation of mid-level clouds

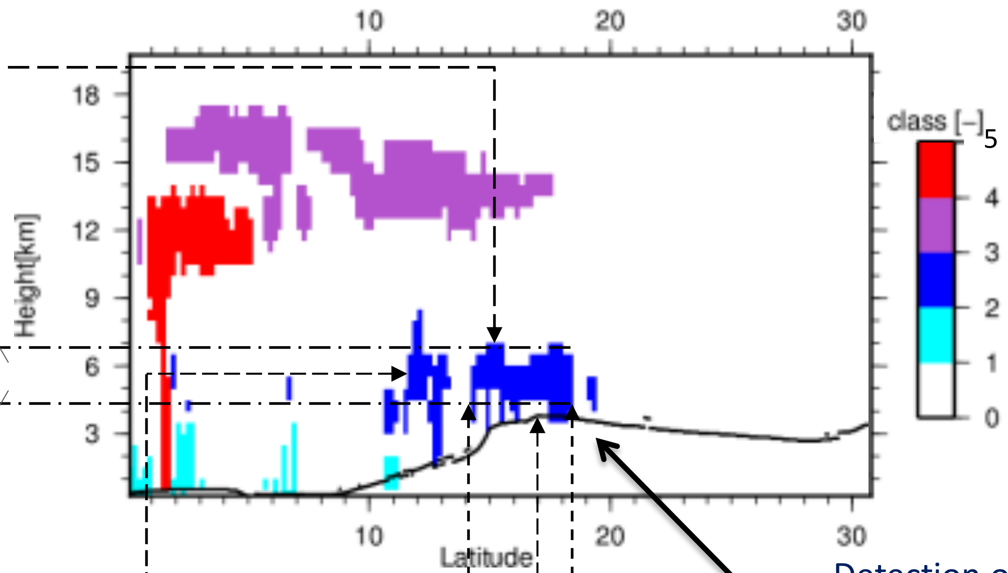
Reflectivity

Doppler velocity

Top

Thickness

Base



Deep convective clouds

Cirrus

Mid-level clouds

Shallow cumulus

No cloud

Detection of precipitation

Composition :

- Ice ?
- Melting ice ?
- Melting ice and cloud liquid droplets ?
- Ice and supercooled liquid droplets ?
- Cloud liquid droplets only ?
- Drizzle or rain and cloud liquid droplets ?

Time interval of cloud observation

Starting time

Ending time

Mid-level clouds definition :
base ≥ 3 km
top ≤ 9 km
Composition :
Cloudy hydrometeors

- 1) Classification in four cloud types *(Bouniol et al., 2012)*

Mid-level cloud number observed : **Bordj Badji Mokhtar : 94 / Niamey : 482 / West Africa : 43115**

- 2) Detection of cloud characteristics

i) Macro- and microphysics properties ii) Thermodynamics aspects

II. Observations and methodologies

Identification and characterisation of mid-level clouds

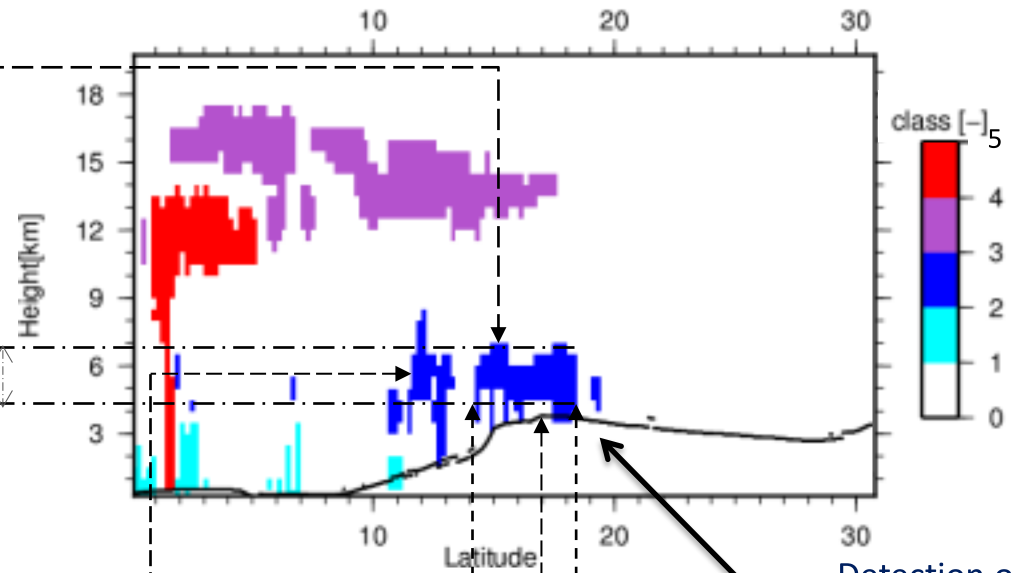
Reflectivity

Doppler velocity

Top

Thickness

Base



Deep convective clouds

Cirrus

Mid-level clouds

Shallow cumulus

No cloud

Composition :

- Ice ?
- Melting ice ?
- Melting ice and cloud liquid droplets ?
- Ice and supercooled liquid droplets ?
- Cloud liquid droplets only ?
- Drizzle or rain and cloud liquid droplets ?

Time interval of cloud observation

Starting time

Ending time

Detection of precipitation

Mid-level clouds definition :

base ≥ 3 km

top ≤ 9 km

Composition :

Cloudy hydrometeors

- 1) Classification in four cloud types *(Bouniol et al., 2012)*

Mid-level cloud number observed : **Bordj Badji Mokhtar : 94 / Niamey : 482 / West Africa : 43115**

- 2) Detection of cloud characteristics

i) Macro- and microphysics properties ii) Thermodynamics aspects iii) Radiative impacts

Outline

I. Context and objectives

II. Observations and methodologies

- ❑ Two ground-based sites : one in the Sahel (Niamey, AMMA campaign, 2006) and the other in the Sahara (Borjd Badji Mokhtar, Fennec campaign, June 2011)
- ❑ CloudSat-CALIPSO satellite products to describe mid-level clouds in West Africa
- ❑ Combination of radar and lidar instruments
- ❑ Different properties of mid-level clouds retrieved

III. Mean characteristics of mid-level clouds in West Africa

IV. Multi-type of mid-level clouds in West Africa

V. Representation of mid-level clouds in models in West Africa

VI. Summary and perspectives

III. Mean characteristics of mid-level clouds in West Africa

Regional climatology from CloudSat-CALIPSO

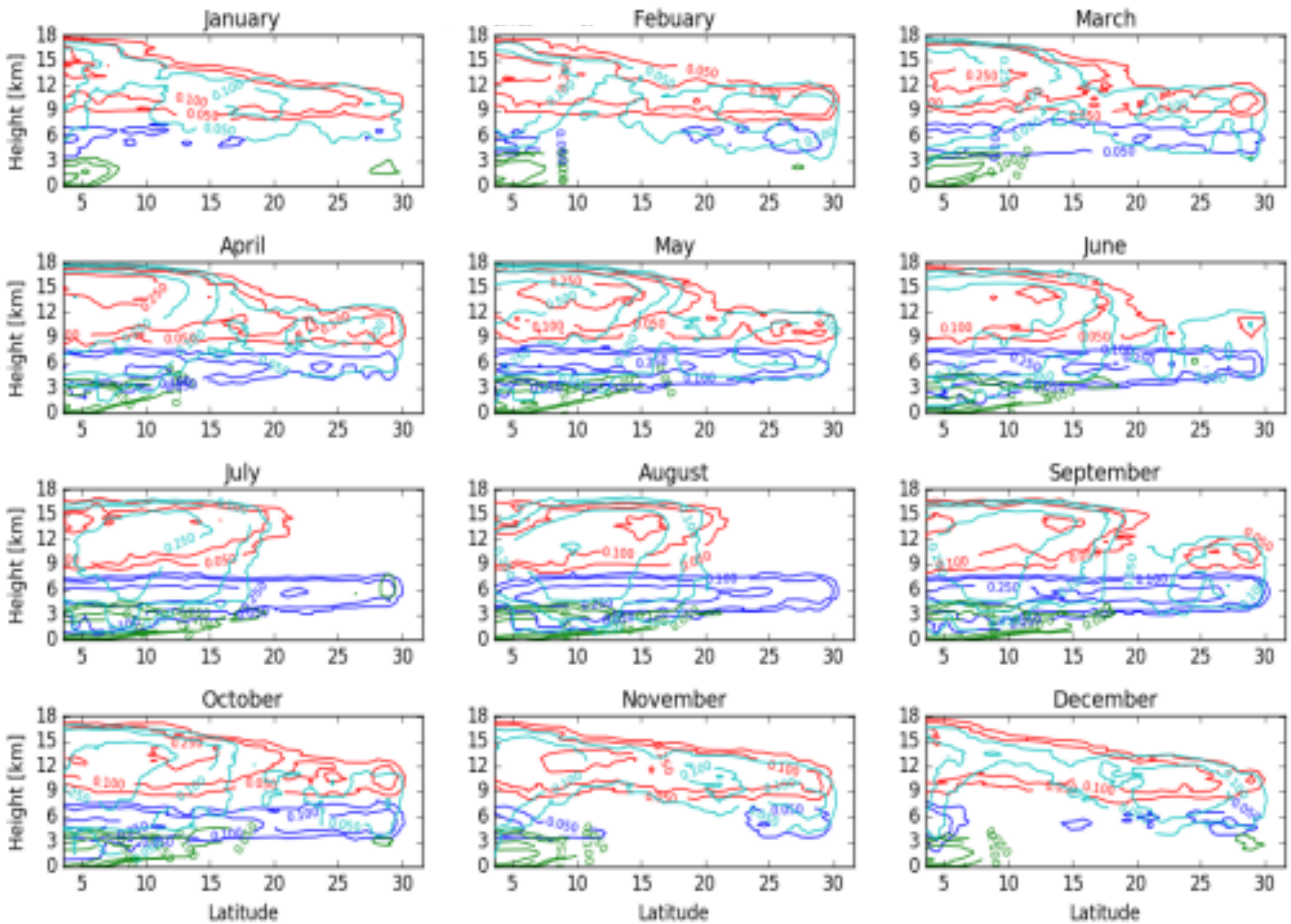
- Cirrus and deep convective clouds occur all months ~~and are~~ thicker close to Gulf of Guinea,
  - Shallow cumulus occur in the south of West Africa ~~and~~ less than other cloud types,
    - Mid-level clouds occur mainly between March and October in West Africa.

Shallow Cumulus

6 km

Cirrus

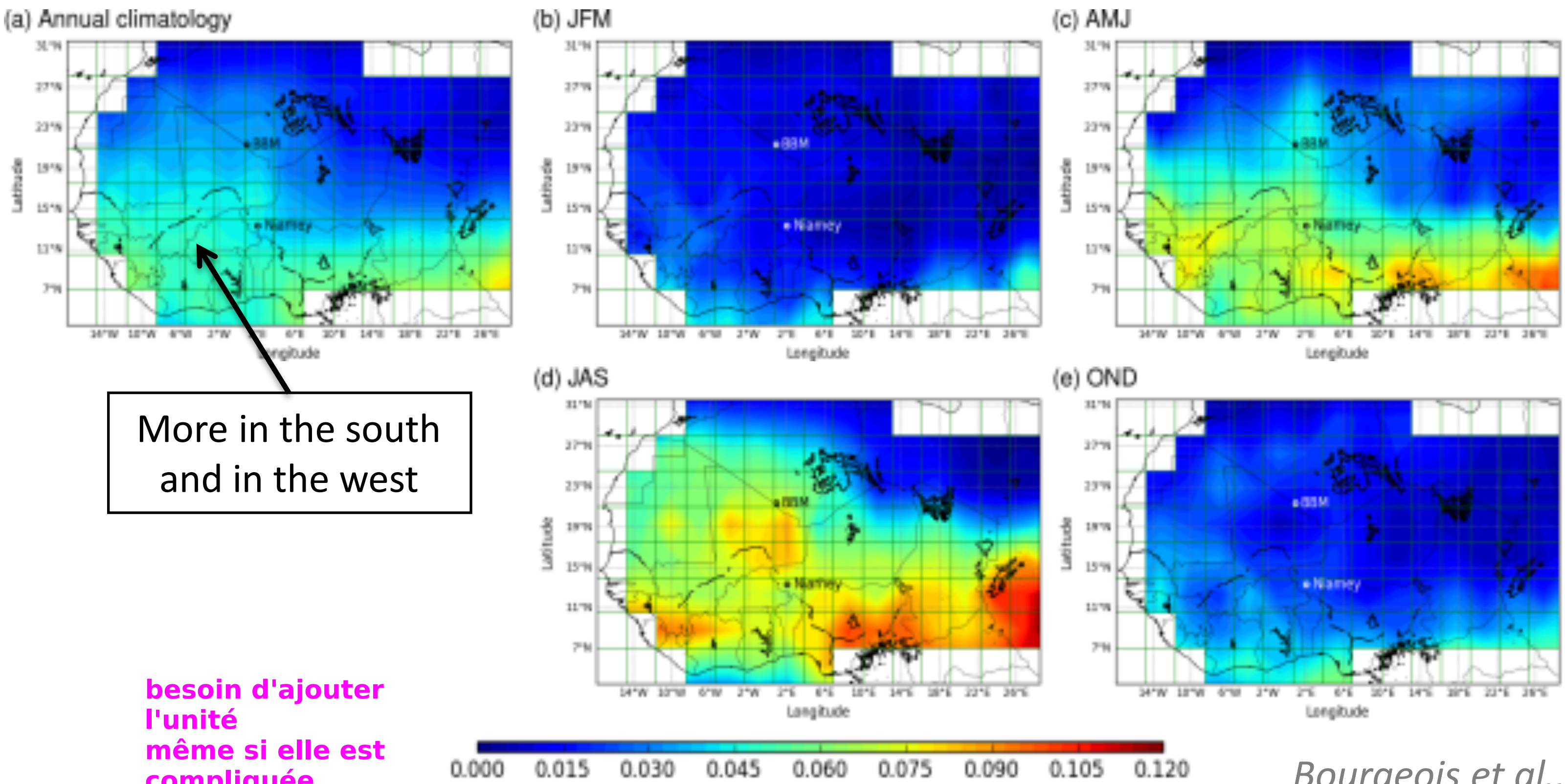
Deep convective clouds



Monthly climatology of the cloud fraction (June 2006 – May 2010)

III. Mean characteristics of mid-level clouds in West Africa

Regional climatology from CloudSat-CALIPSO



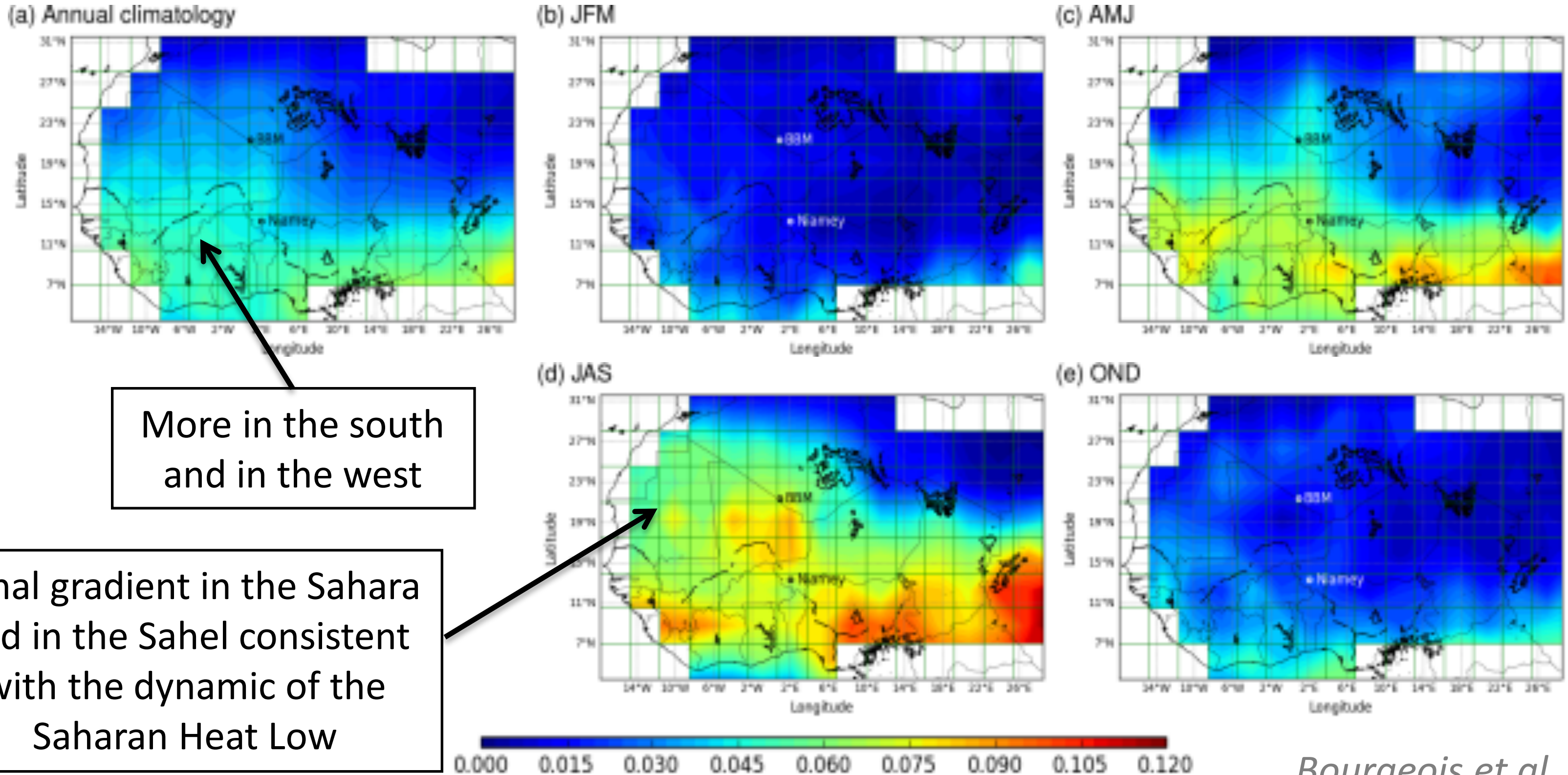
besoin d'ajouter l'unité
même si elle est compliquée

Bourgeois et al., 2017

Annual climatology of the density of mid-level clouds.

III. Mean characteristics of mid-level clouds in West Africa

Regional climatology from CloudSat-CALIPSO

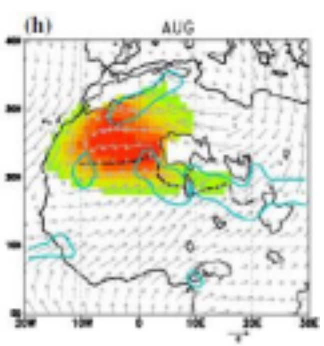


More in the south and in the west

Zonal gradient in the Sahara and in the Sahel consistent with the dynamic of the Saharan Heat Low

Bourgeois et al., 2017

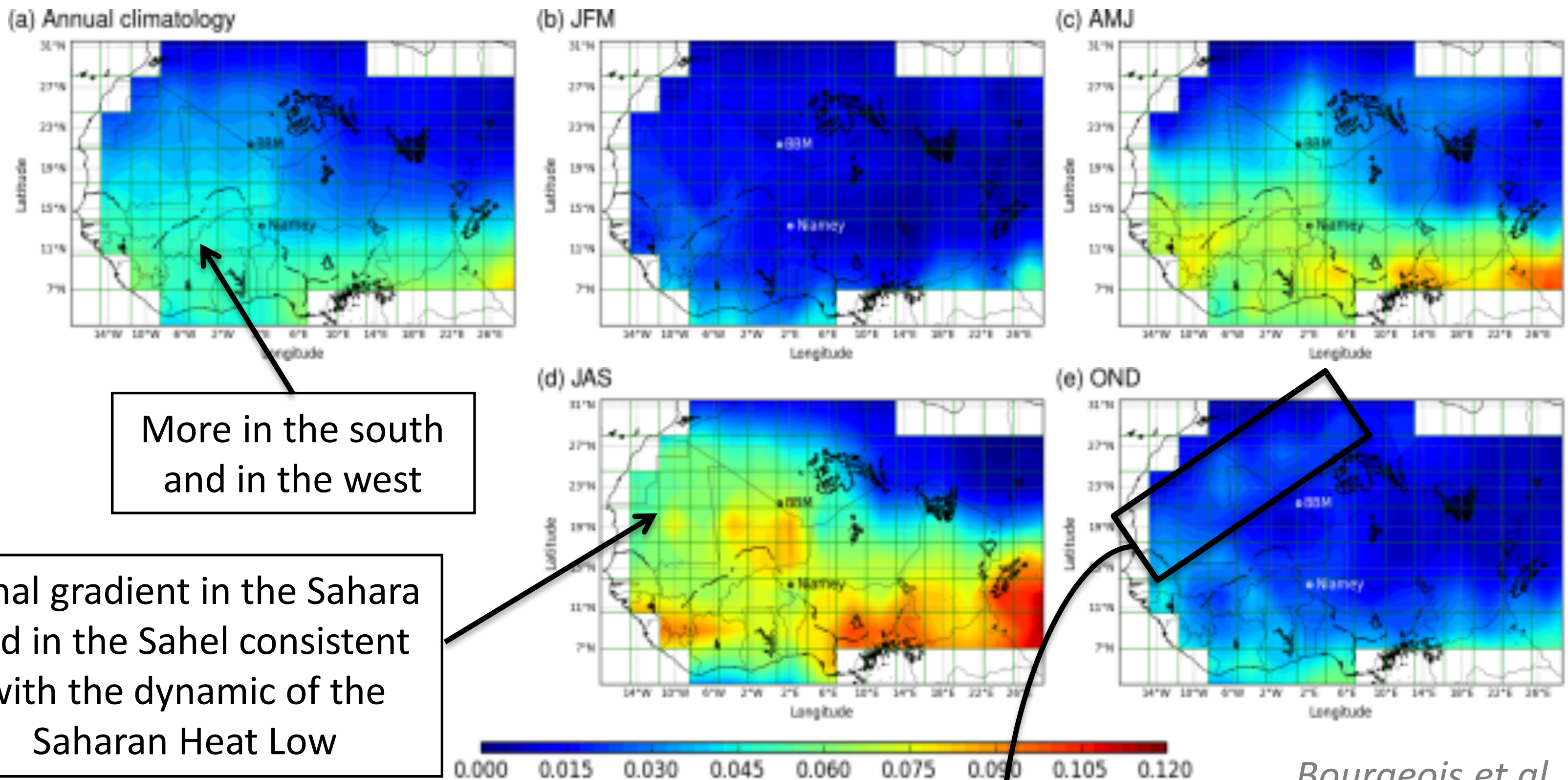
Annual climatology of the density of mid-level clouds.



Heat Low frequency of occurrence for August (Lavaysse et al., 2009)

III. Mean characteristics of mid-level clouds in West Africa

Regional climatology from CloudSat-CALIPSO



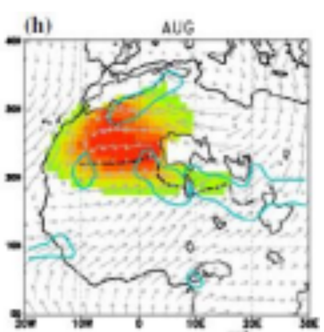
More in the south and in the west

Zonal gradient in the Sahara and in the Sahel consistent with the dynamic of the Saharan Heat Low

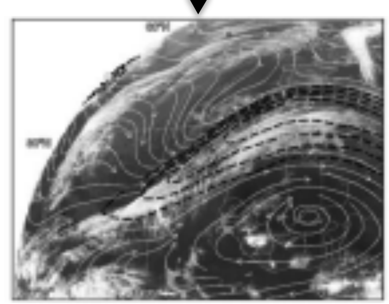
Bourgeois et al., 2017

Annual climatology of the density of mid-level clouds.

CF remarque précédente as tu essayé une palette qui permette de voir?



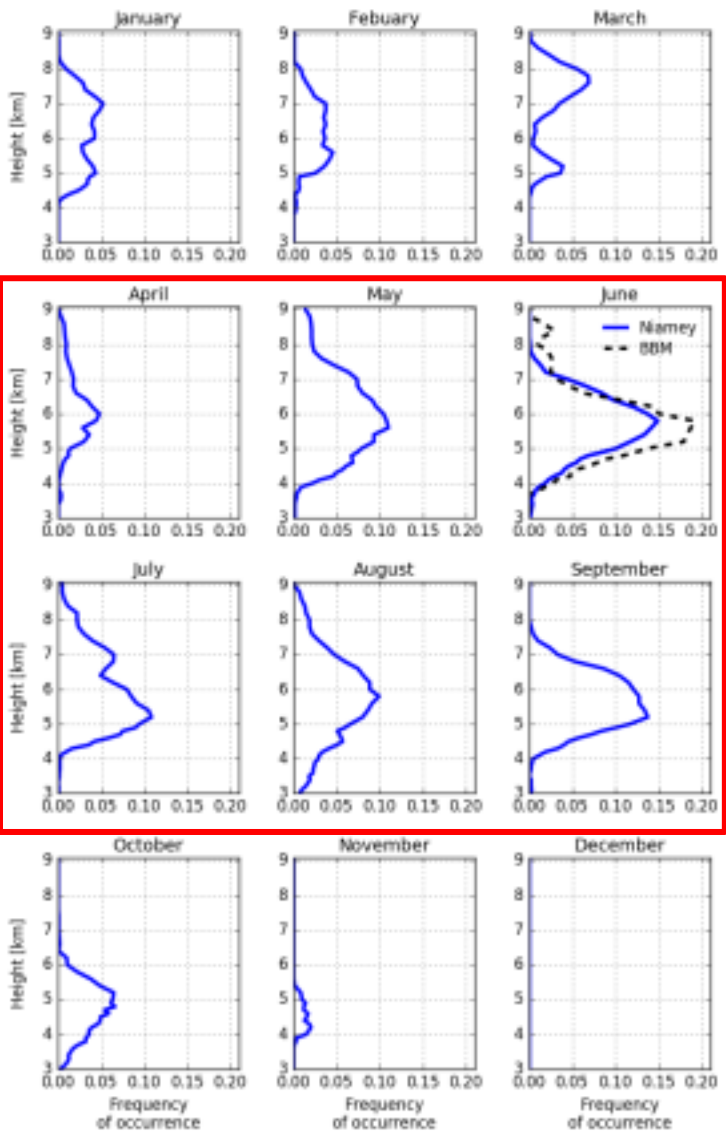
Heat Low frequency of occurrence for August (Lavaysse et al., 2009)



Tropical Plumes at the North-West of Africa the 31 March 2002 at 0000 UTC from MétéoSat (MSG) (Knippertz, 2007) (Fink and Knippertz, 2003, Fröhlich et al. 2013)

III. Mean characteristics of mid-level clouds in West Africa

Cloud frequency of occurrence



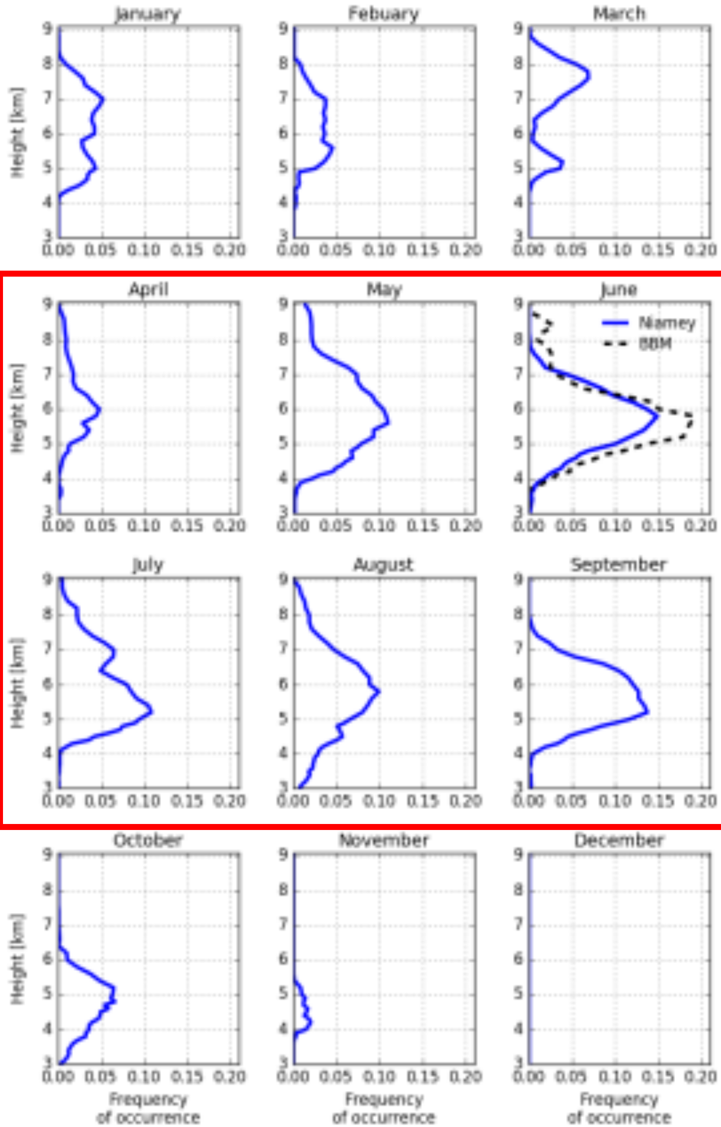
Mid-level clouds frequency of occurrence (AMMA - ARM Niamey 2006 and Fennec - BBM June 2011)

Large occurrence

Bourgeois et al., 2017

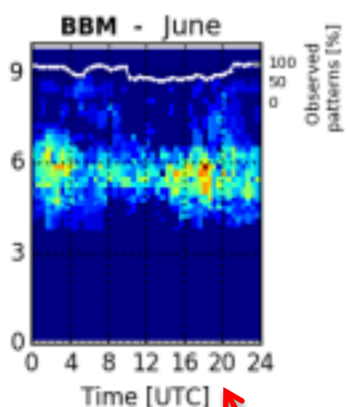
III. Mean characteristics of mid-level clouds in West Africa

Cloud frequency of occurrence and diurnal cycle



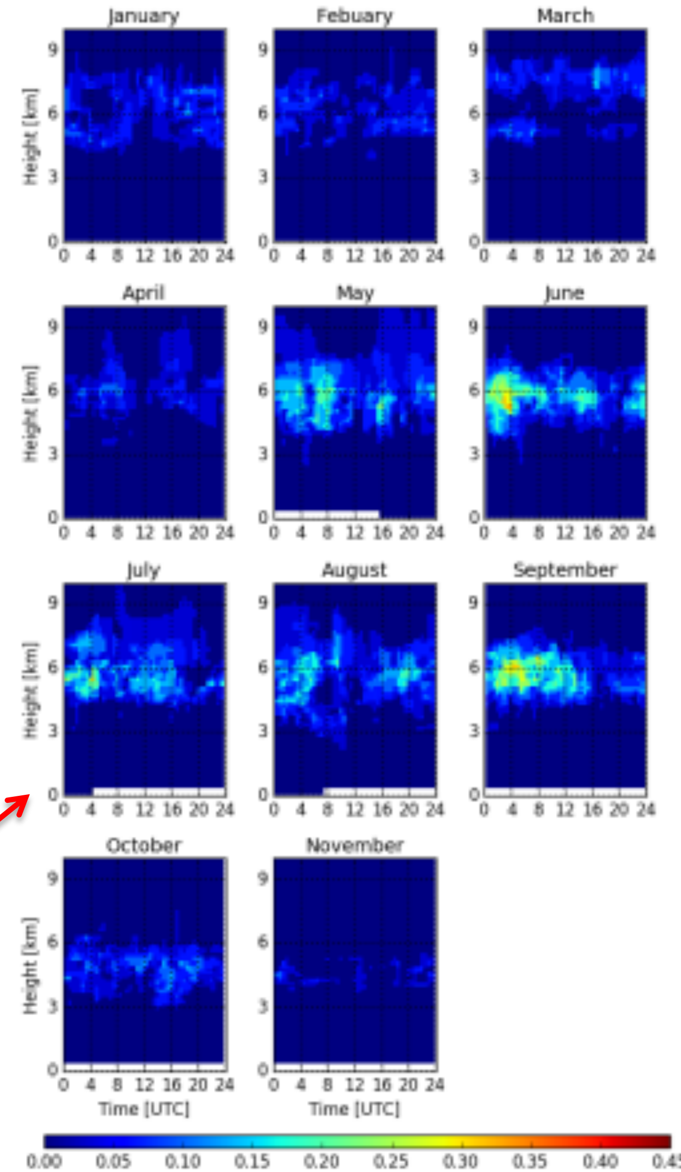
Mid-level clouds frequency of occurrence (AMMA - ARM Niamey 2006 and Fennec - BBM June 2011)

Large occurrence



Presence all day

Monthly diurnal cycle of mid-level clouds (AMMA - ARM Niamey 2006 and Fennec - BBM June 2011)

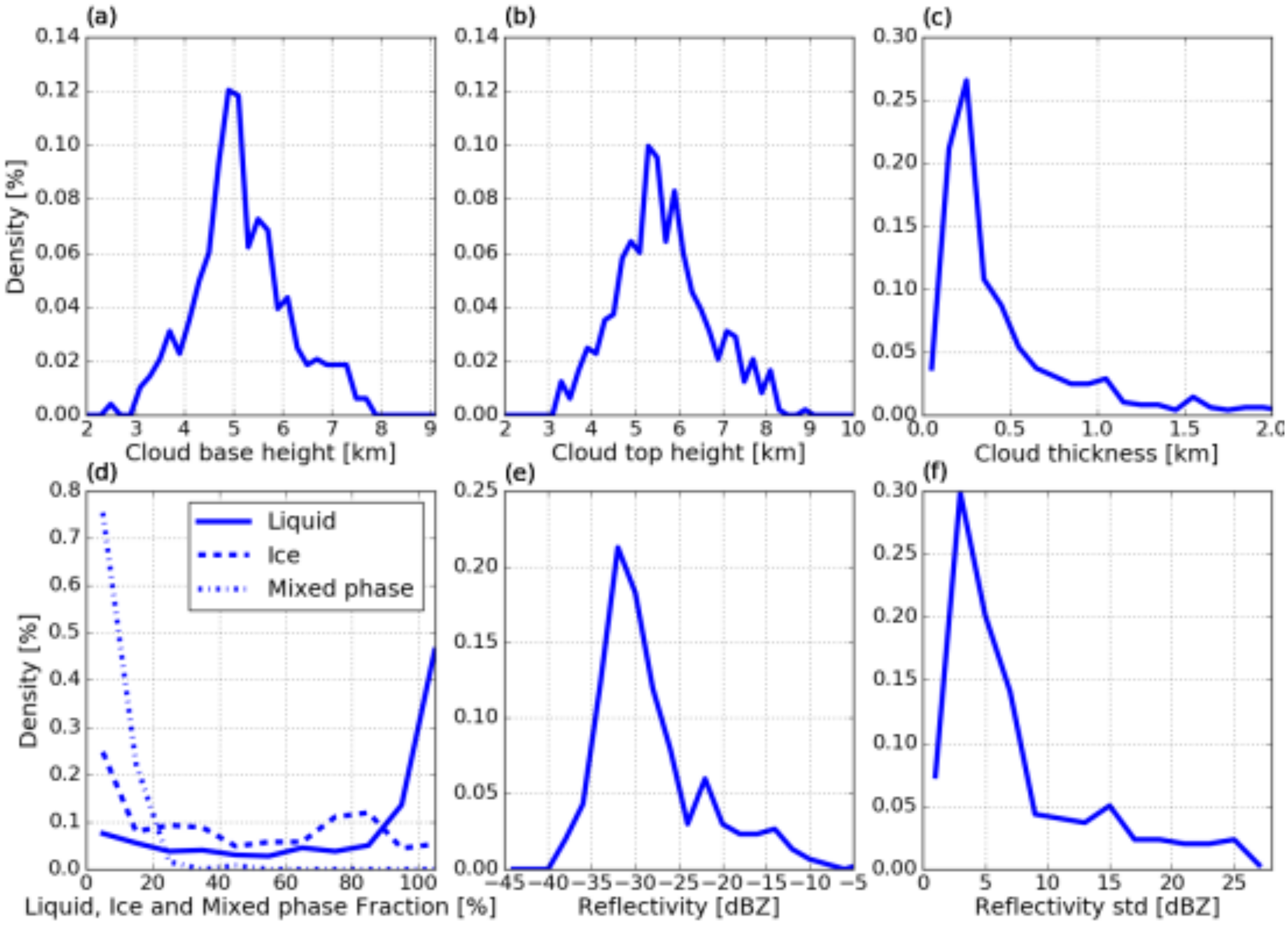


Bourgeois et al., 2017

Bourgeois et al., 2017

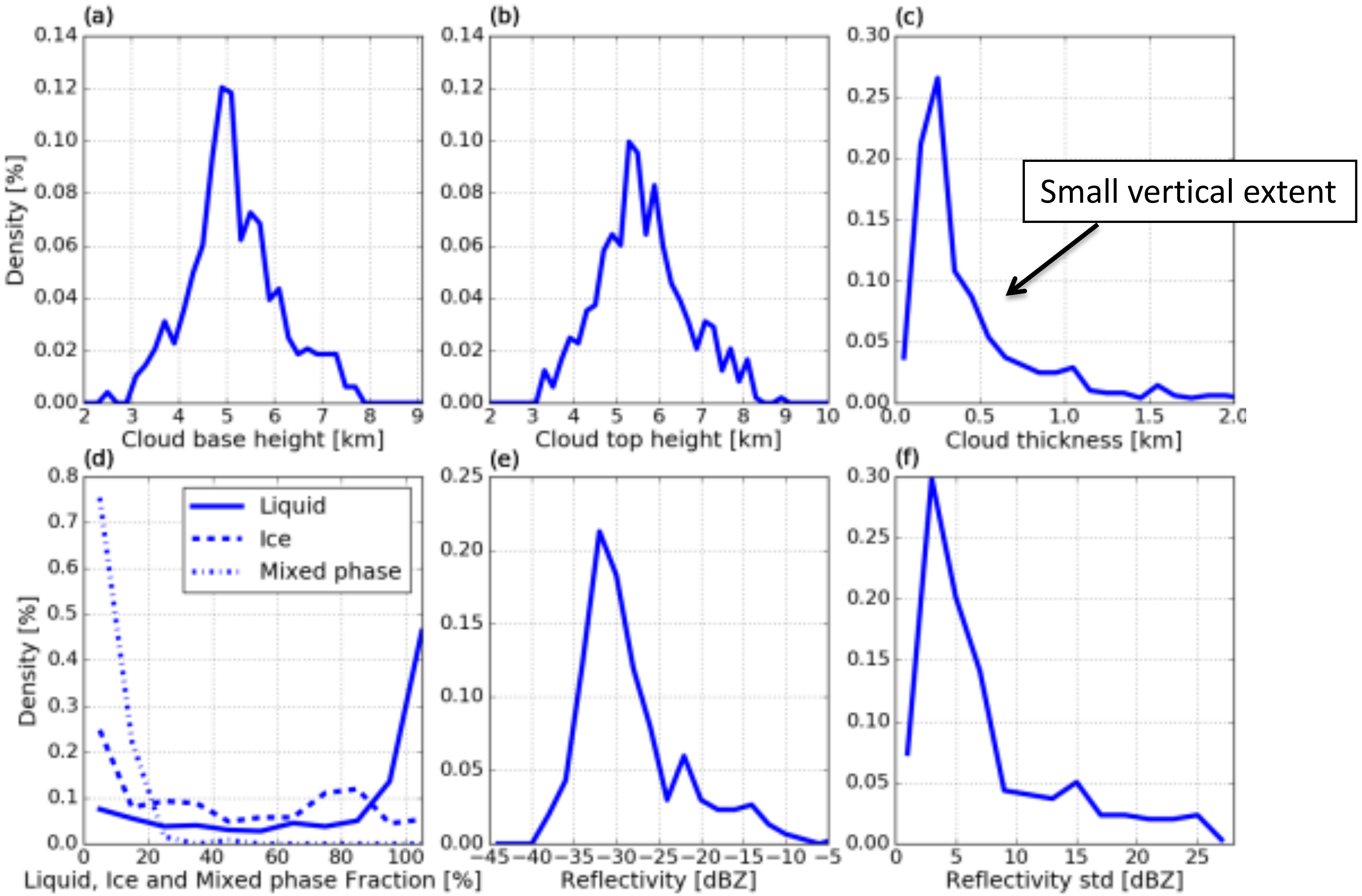
III. Mean characteristics of mid-level clouds in West Africa

Macro- and microphysical characteristics



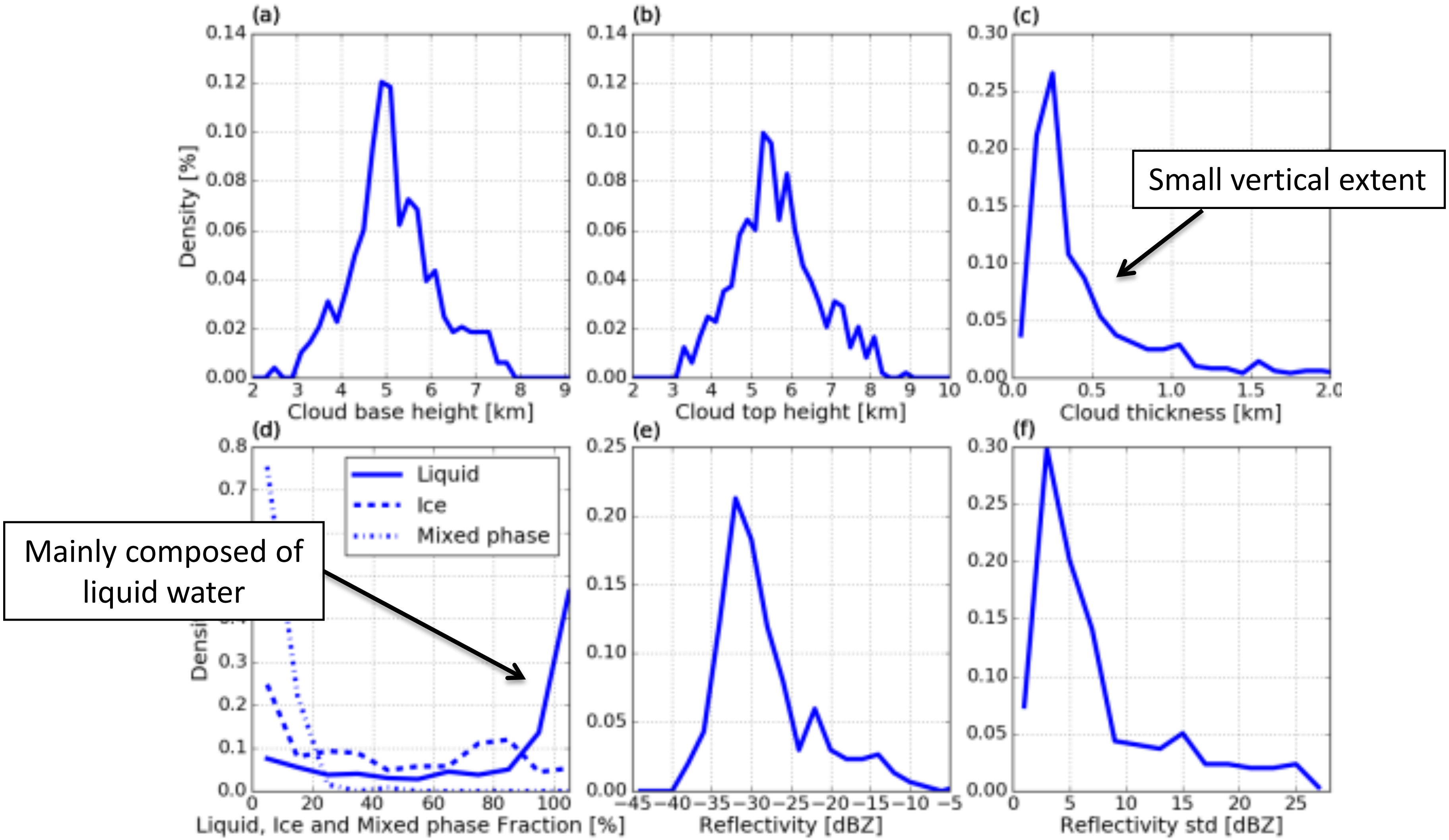
III. Mean characteristics of mid-level clouds in West Africa

Macro- and microphysical characteristics



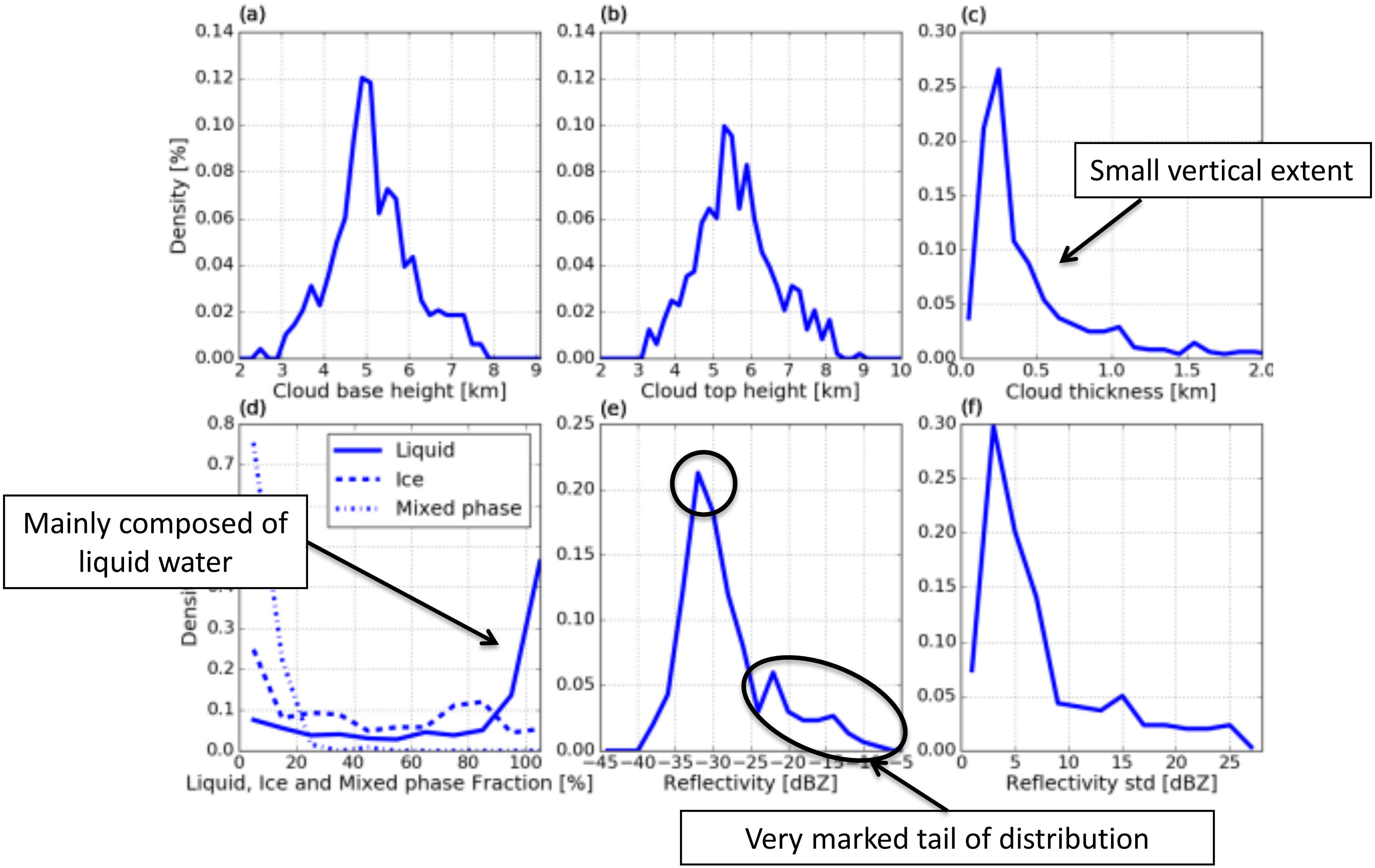
III. Mean characteristics of mid-level clouds in West Africa

Macro- and microphysical characteristics



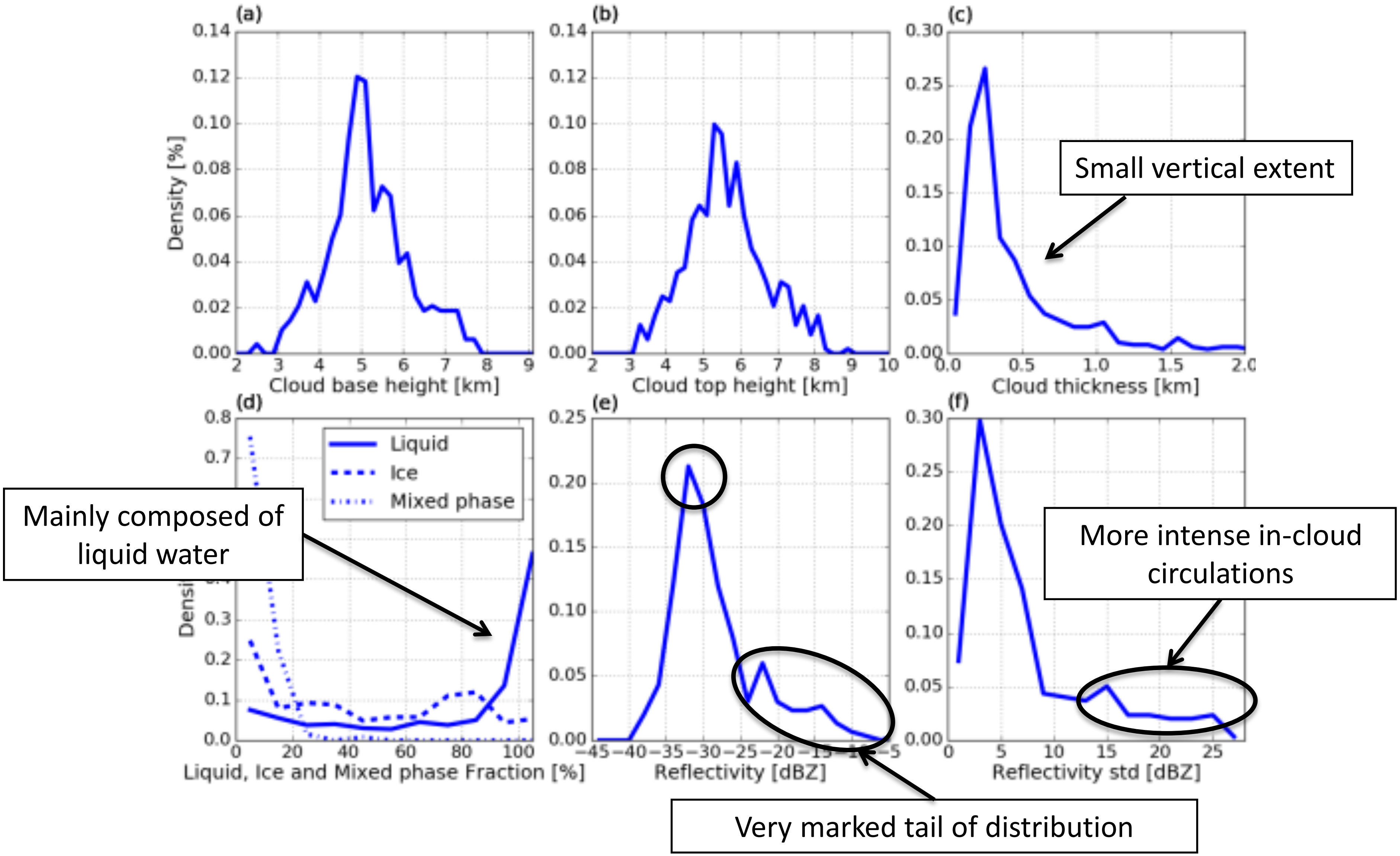
III. Mean characteristics of mid-level clouds in West Africa

Macro- and microphysical characteristics



III. Mean characteristics of mid-level clouds in West Africa

Macro- and microphysical characteristics



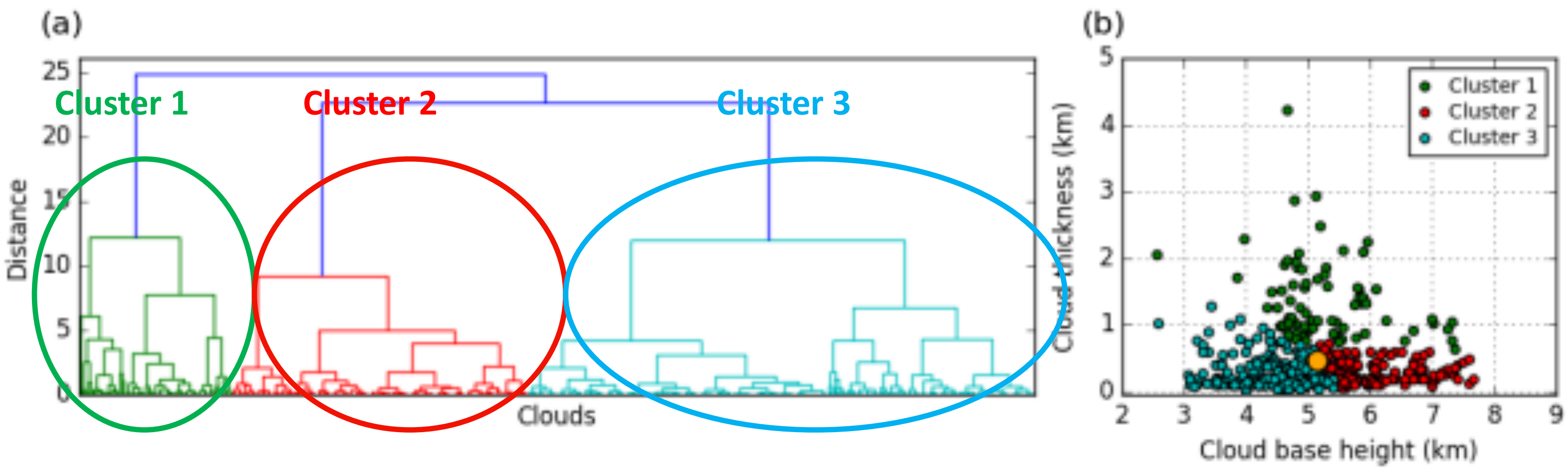
Outline

IV. Multi-type of mid-level clouds in West Africa

Hierarchical clustering – Ward method – Niamey 2006

- Statistical methods (**clustering methods**) to objectively identify clouds having similarities *(Hoareau et al., 2013; Pope et al., 2009ab; Jakob and Tselioudis, 2003)*

- Input data : **base** and **thickness**

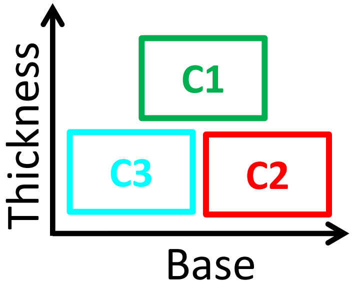


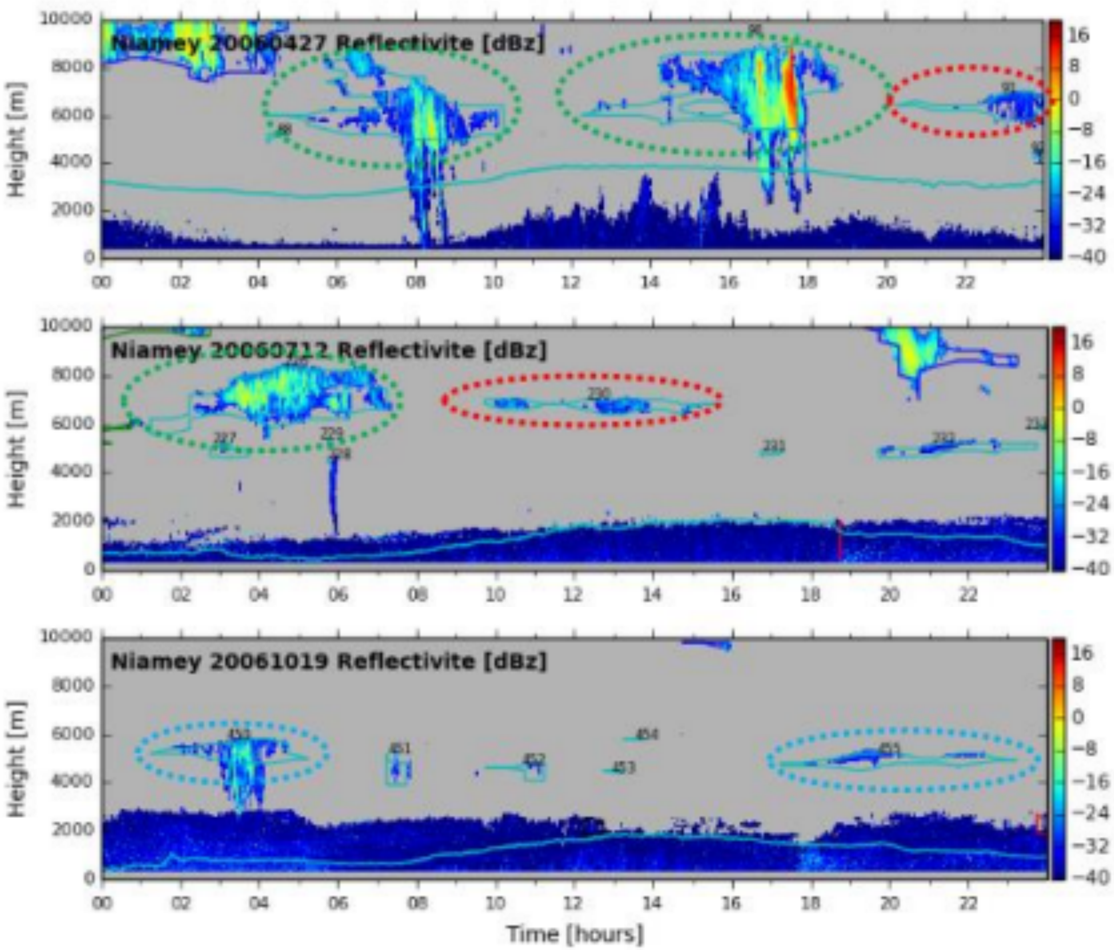
(a) Dendrogram obtained from clustering method and
(b) distribution of the cloud thickness and cloud base
(Bourgeois et al., 2017)

→ Similar results, consequently independant of the methods

IV. Multi-type of mid-level clouds in West Africa

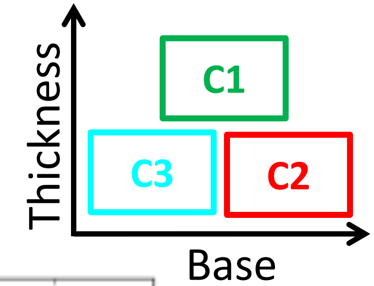
Hierarchical clustering – Ward method – Niamey 2006



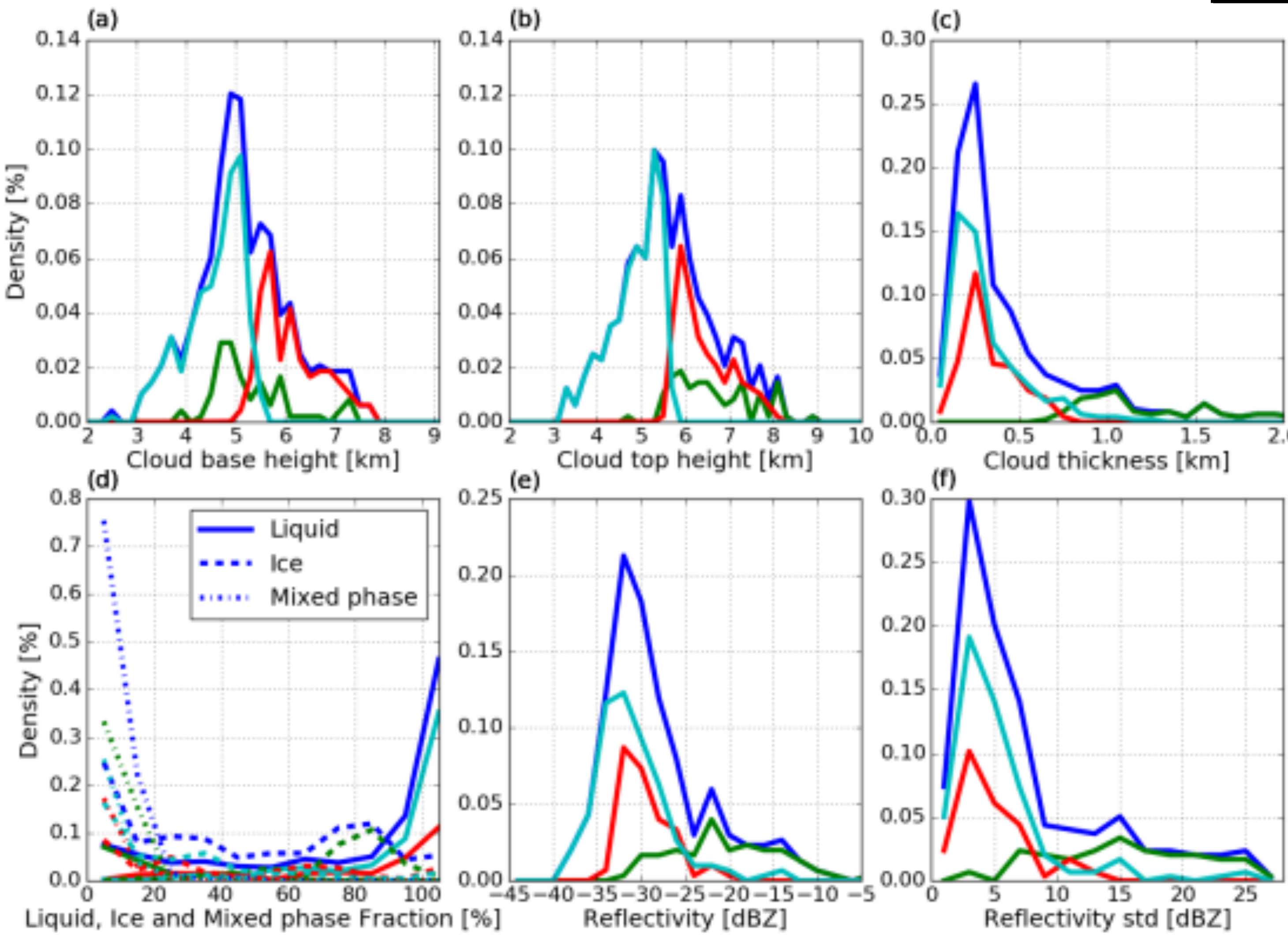


Time-altitude transect of the reflectivity from three different days in 2006 where clouds belonging ~~of~~ **to** *the three clusters are observed.*

IV. Multi-type of mid-level clouds in West Africa
Hierarchical clustering – Ward method – Niamey 2006

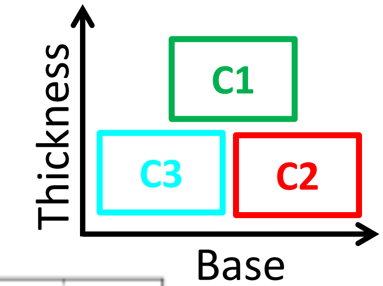


Global
Cluster 1
Cluster 2
Cluster 3

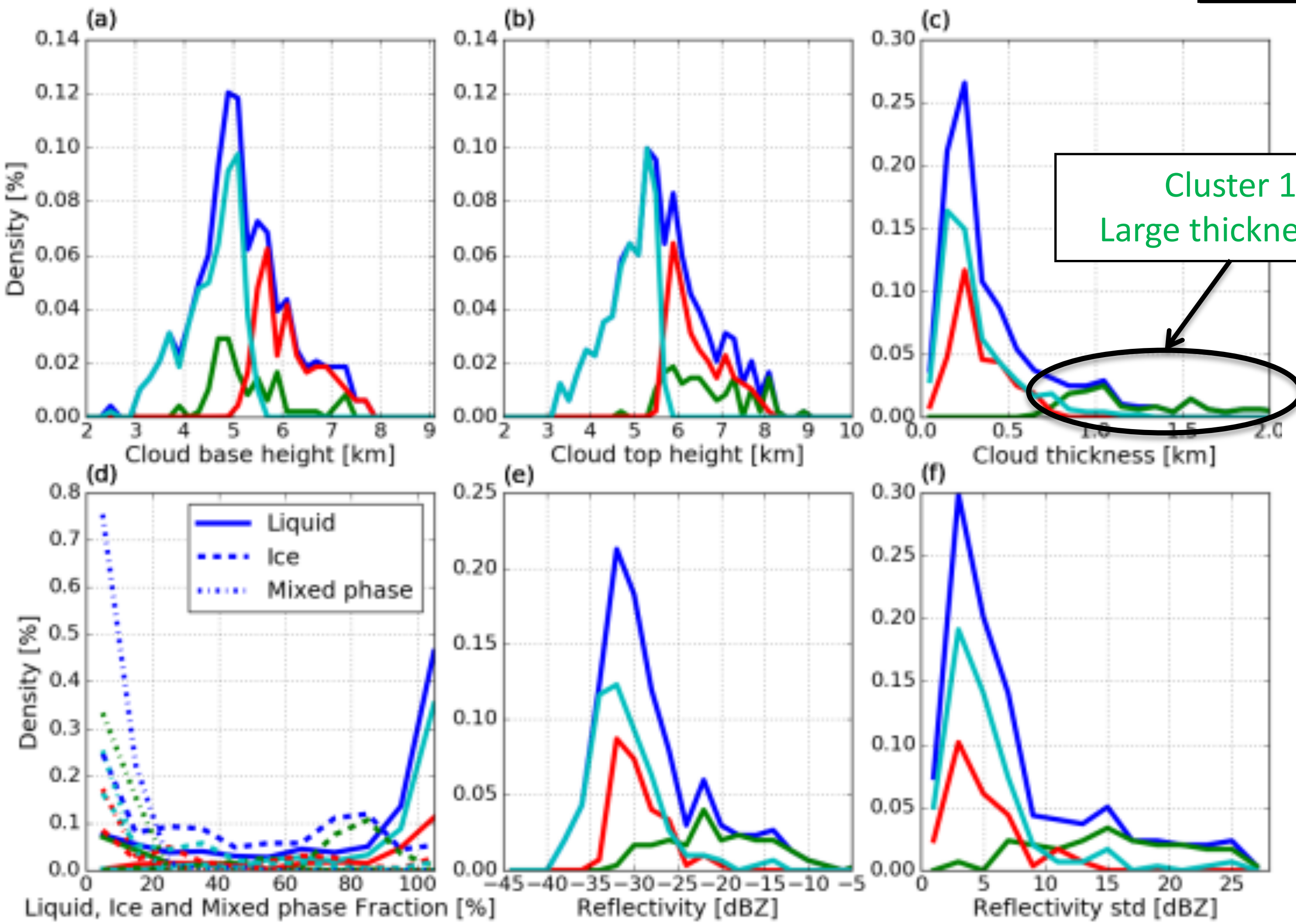


Bourgeois et al., 2017

IV. Multi-type of mid-level clouds in West Africa
Hierarchical clustering – Ward method – Niamey 2006

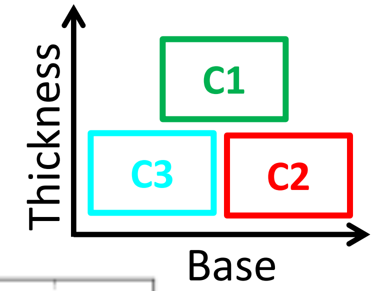


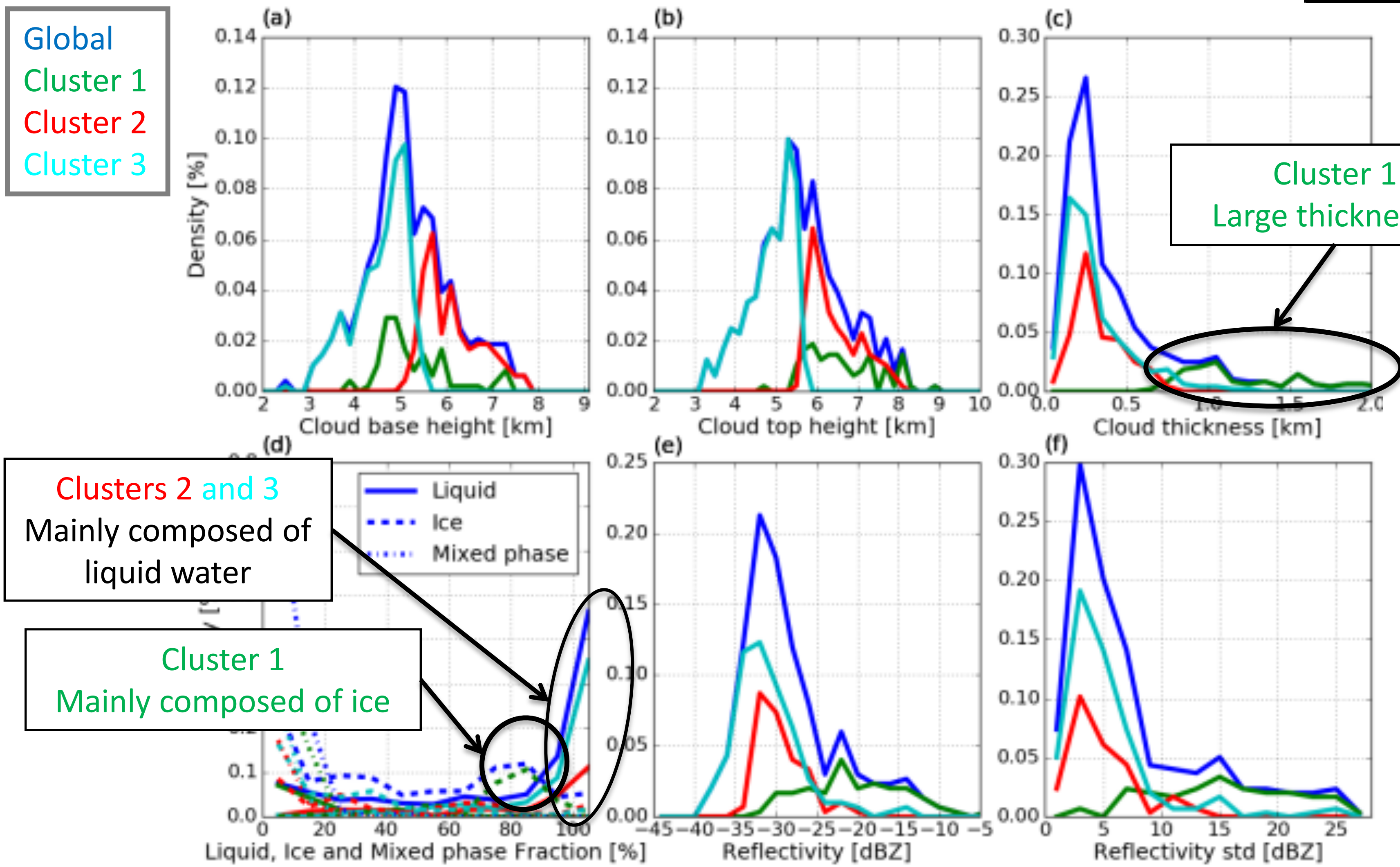
Global
Cluster 1
Cluster 2
Cluster 3



Bourgeois et al., 2017

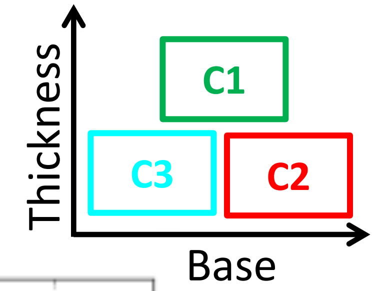
IV. Multi-type of mid-level clouds in West Africa
Hierarchical clustering – Ward method – Niamey 2006

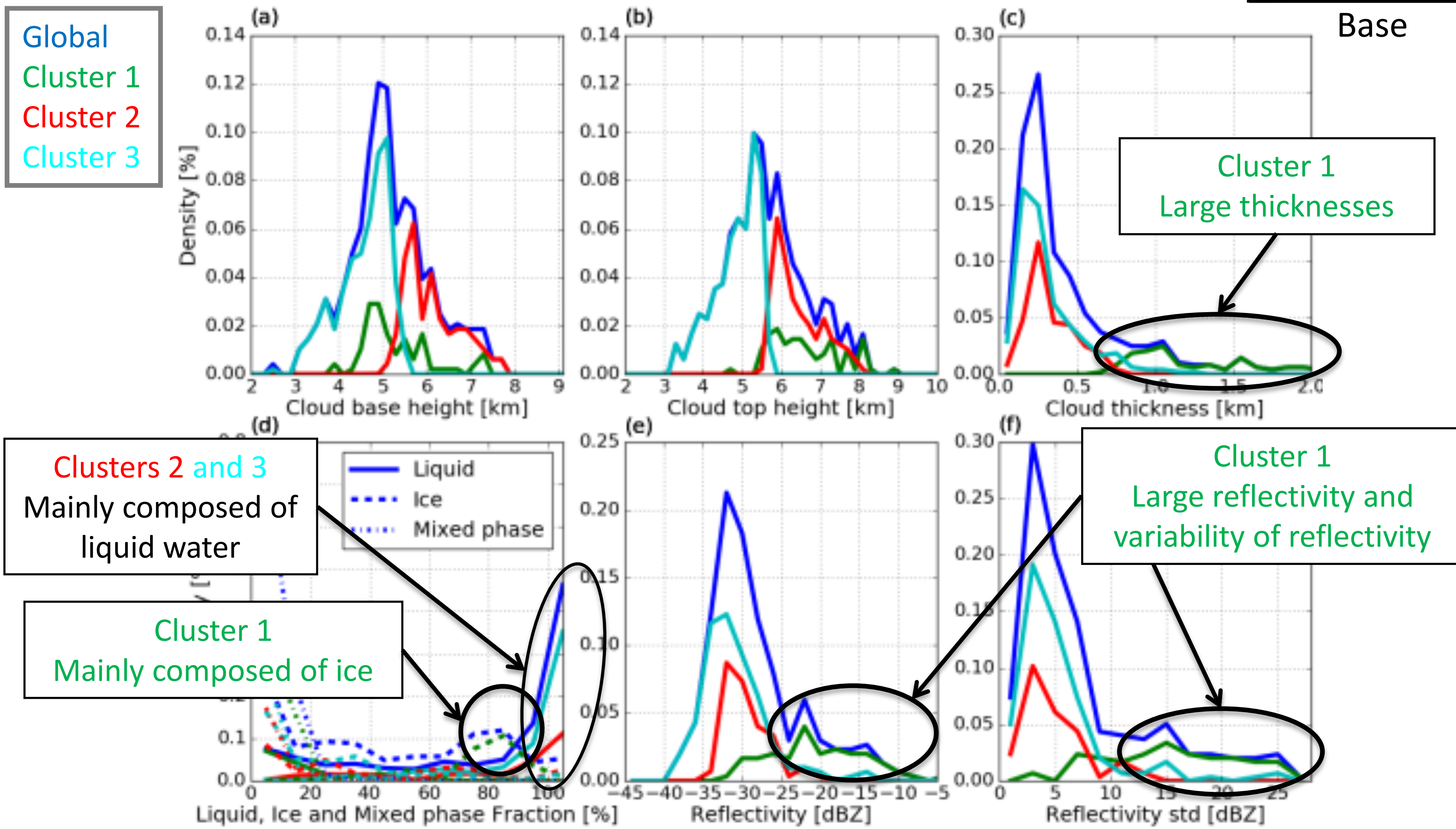




Bourgeois et al., 2017

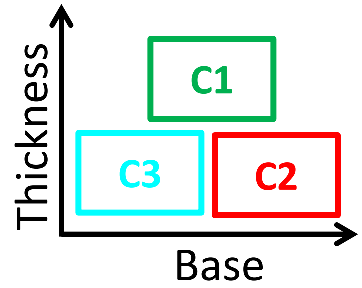
IV. Multi-type of mid-level clouds in West Africa
Hierarchical clustering – Ward method – Niamey 2006

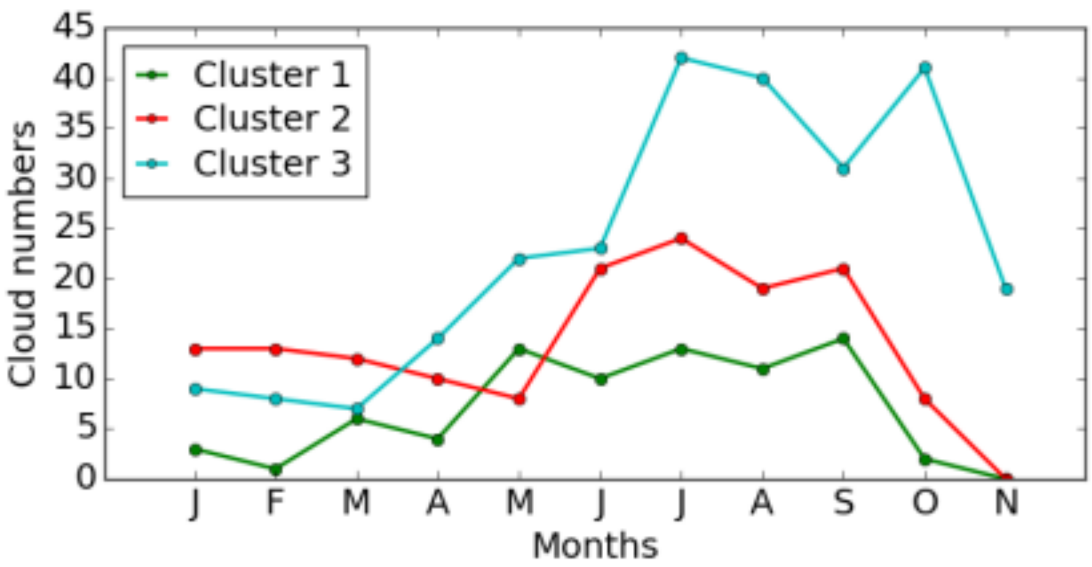




Bourgeois et al., 2017

IV. Multi-type of mid-level clouds in West Africa
Hierarchical clustering – Ward method – Niamey 2006





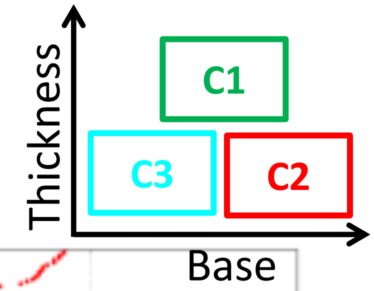
Monthly frequency occurrence of mid-level clouds number for each cluster (Bourgeois et al., 2017)

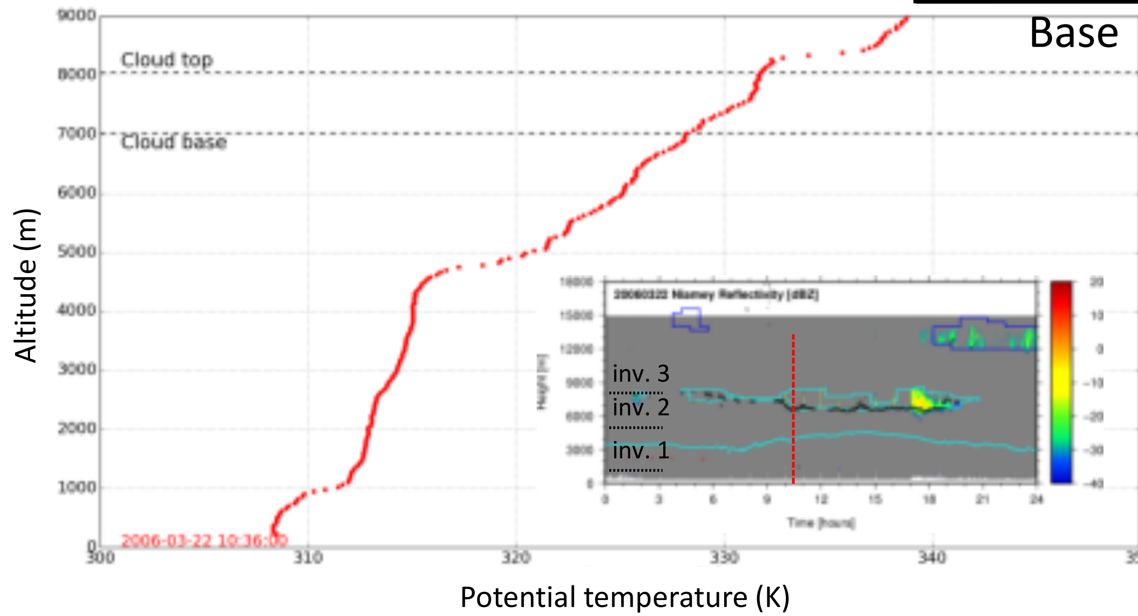
enlever les virgules et les points

Cluster 1 : During the monsoon,
Cluster 2 : Before and during the monsoon,
Cluster 3 : During and after the monsoon. ~~The only one cluster with clouds in November.~~

cf remarque précédente, je pense que ça n'a pas beaucoup d'intérêt

IV. Multi-type of mid-level clouds in West Africa
Hierarchical clustering – Ward method – Niamey 2006

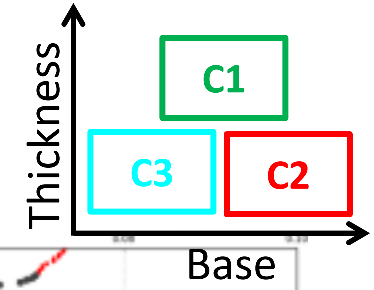


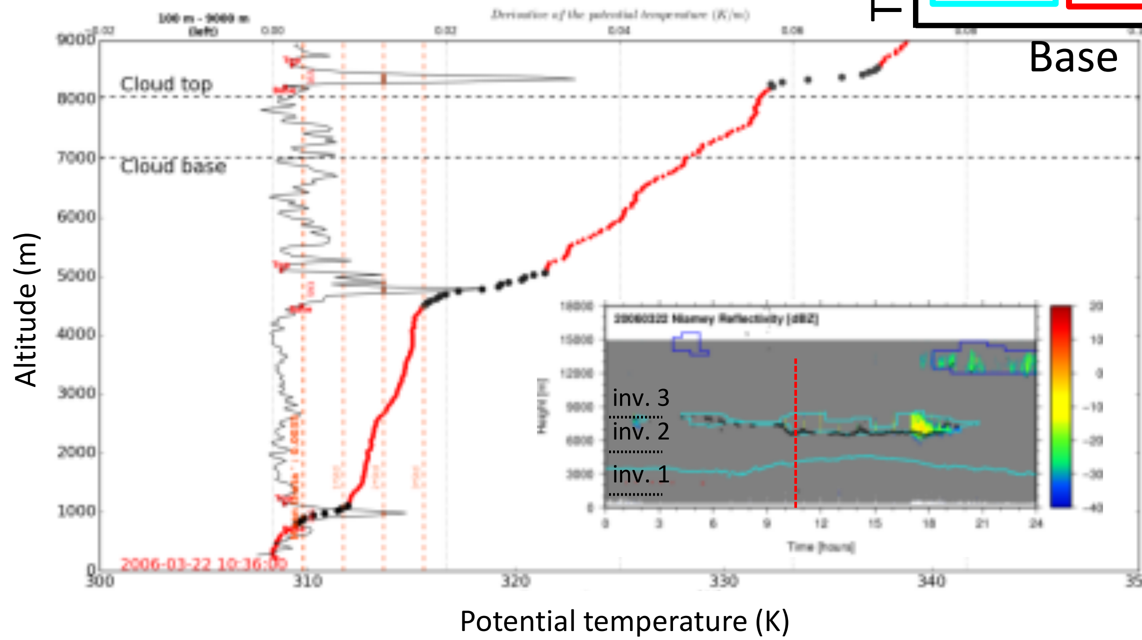


Method used to detect theta inversion (Haikin et al. 2015)

IV. Multi-type of mid-level clouds in West Africa

Hierarchical clustering – Ward method – Niamey 2006

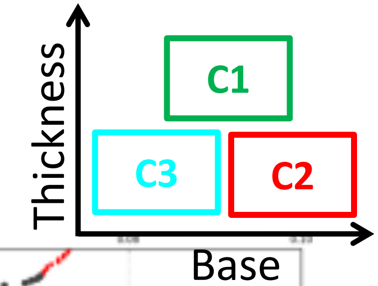




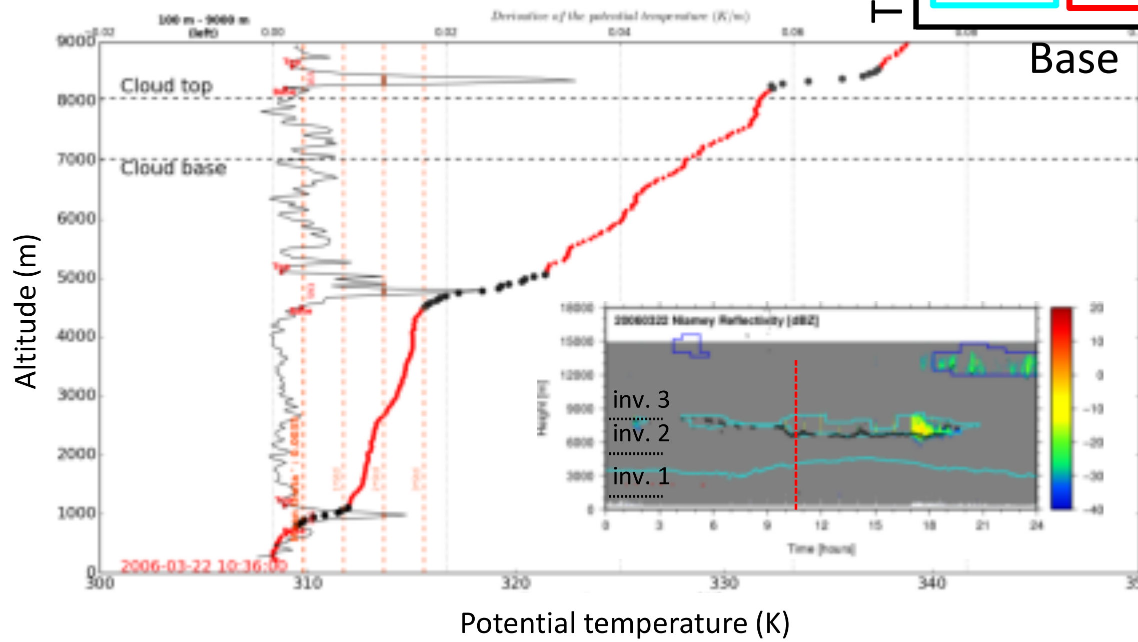
Method used to detect theta inversion (Haikin et al. 2015)

IV. Multi-type of mid-level clouds in West Africa

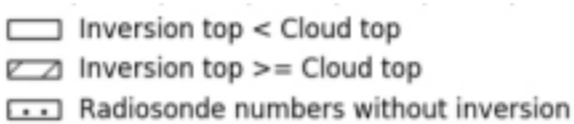
Hierarchical clustering – Ward method – Niamey 2006

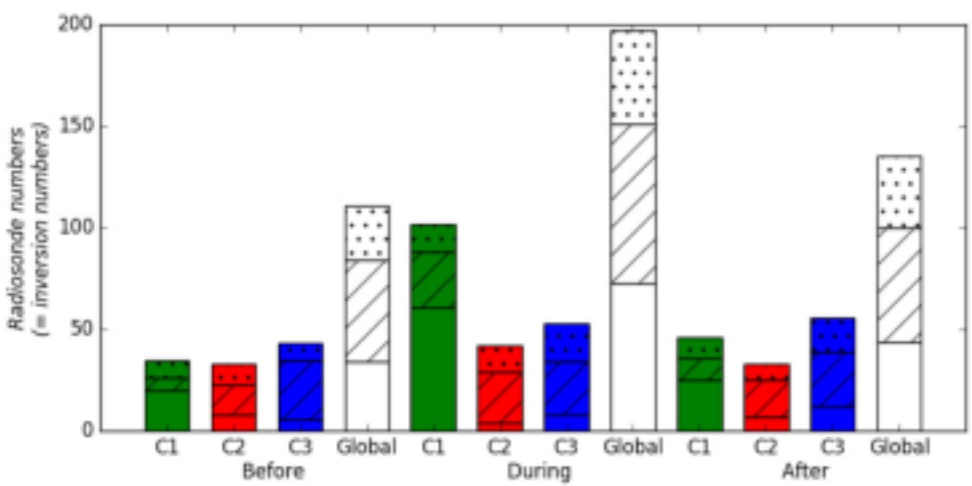


Histogram of the radiosonde numbers in function of the location of inversion with respect to the cloud top for each cluster and each period
(Bourgeois et al., 2017)



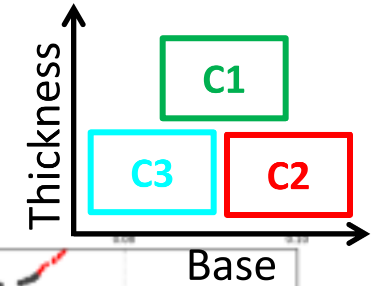
Method used to detect theta inversion *(Haikin et al. 2015)*





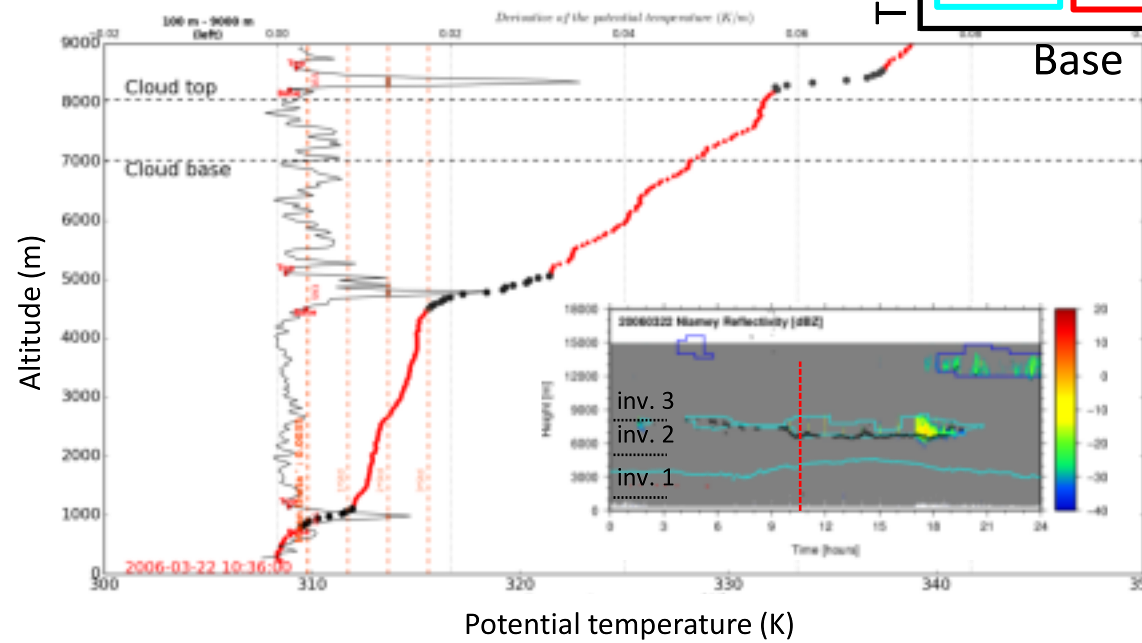
j'ai trouvé que tu présentais trop vite ce graphe

IV. Multi-type of mid-level clouds in West Africa
Hierarchical clustering – Ward method – Niamey 2006

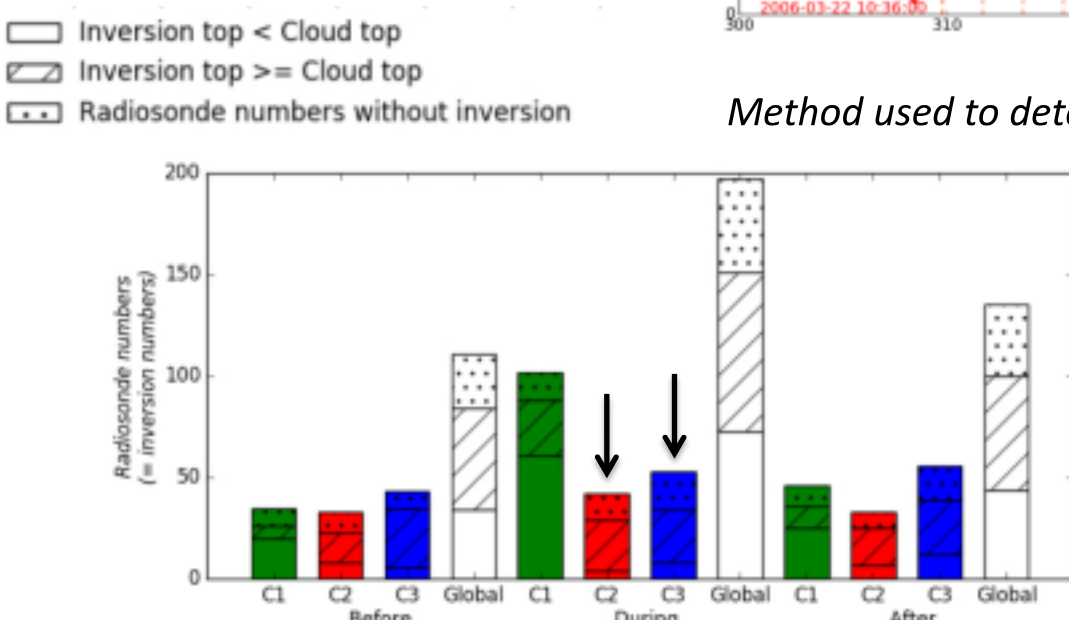


as a

Histogram of the radiosonde numbers ~~in~~ function of the location of inversion with respect to the cloud top for each cluster and each period
(Bourgeois et al., 2017)



Method used to detect theta inversion (Haikin et al. 2015)



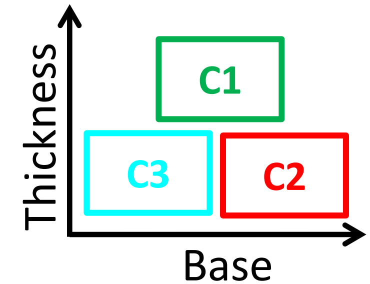
Inversions at the top of clouds of clusters 2 and 3

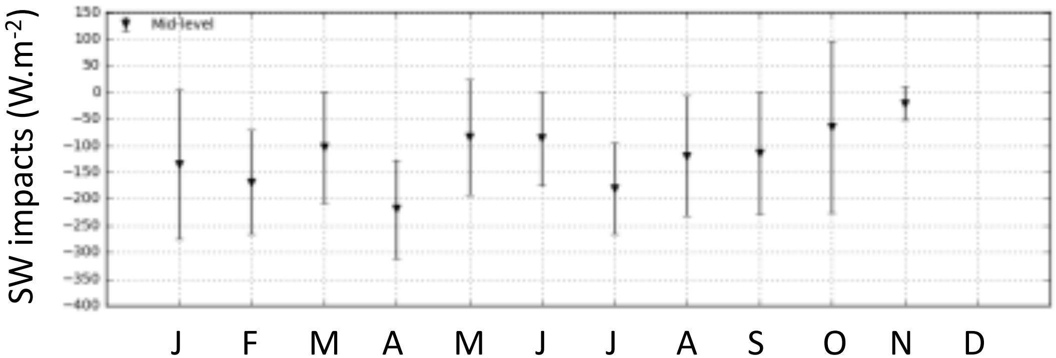
(Johnson et al., 1999; Johnson et al., 1996; Zuidema, 1998)

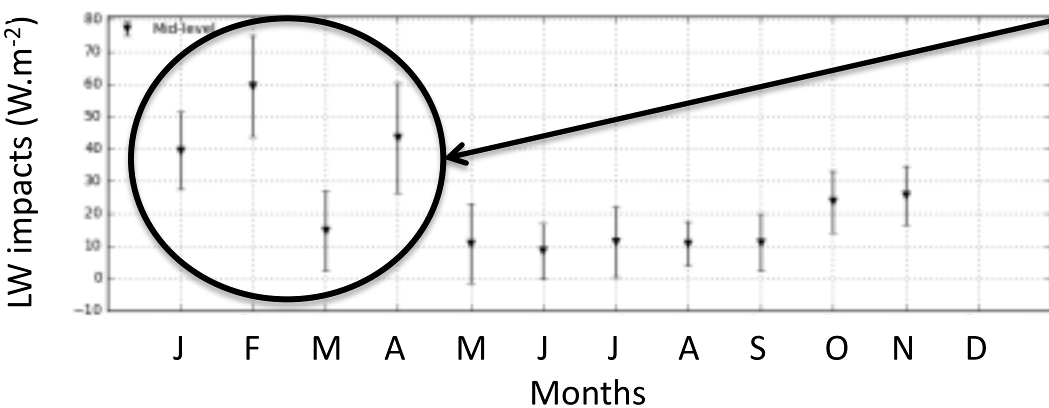
IV. Multi-type of mid-level clouds in West Africa

Radiative effect – Niamey 2006

(Ramanathan et al.,1989; Bouniol et al., 2012)







Surface mid-level cloud radiative effect at Niamey in the shortwave (a) and in the longwave (b) domains
(Bourgeois et al., 2017)

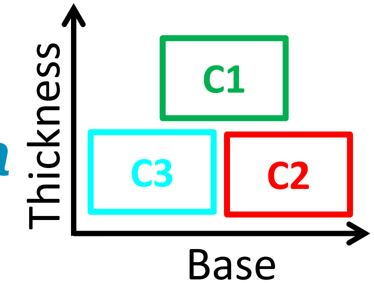
Large impact of mid-level clouds during the winter in the longwave domain

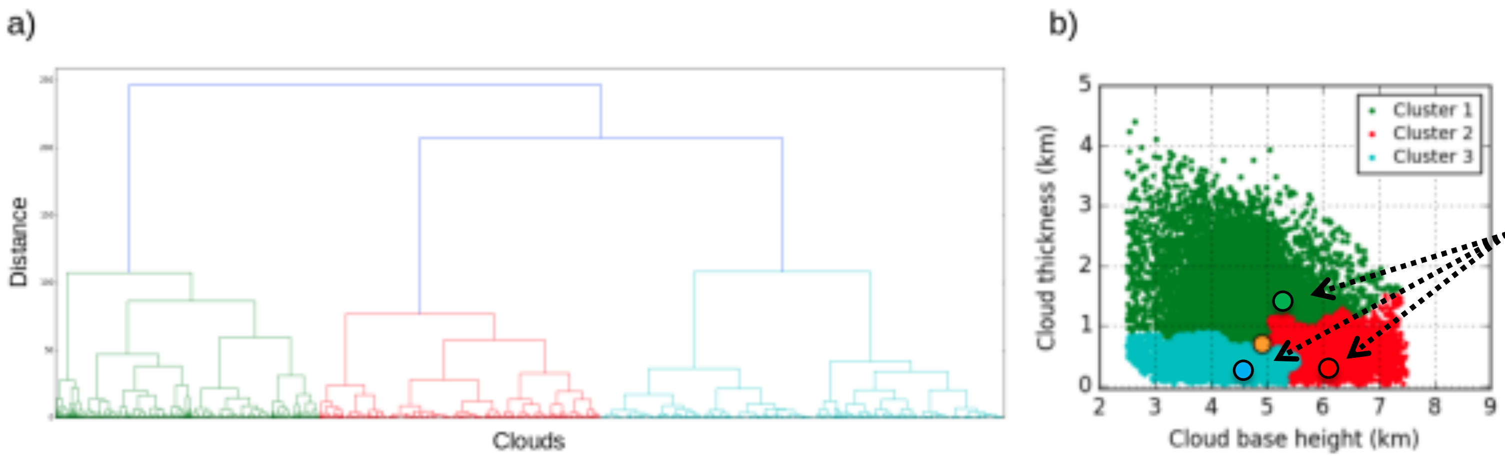
Large impact of clouds of cluster 1 during the year

At the surface	Cluster 1	Cluster 2	Cluster 3
Shortwave	-153.0 W.m^{-2}	-32.0 W.m^{-2}	-47.5 W.m^{-2}
Longwave	19.5 W.m^{-2}	13.5 W.m^{-2}	16.6 W.m^{-2}

IV. Multi-type of mid-level clouds in West Africa

Clustering applied on CloudSat-CALIPSO data





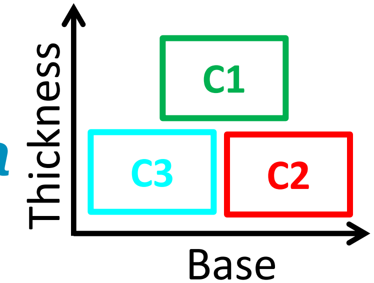
Barycentres obtained at Niamey site

(a) Dendrogram obtained from clustering method ~~and~~
(b) distribution of the cloud thickness and cloud base.

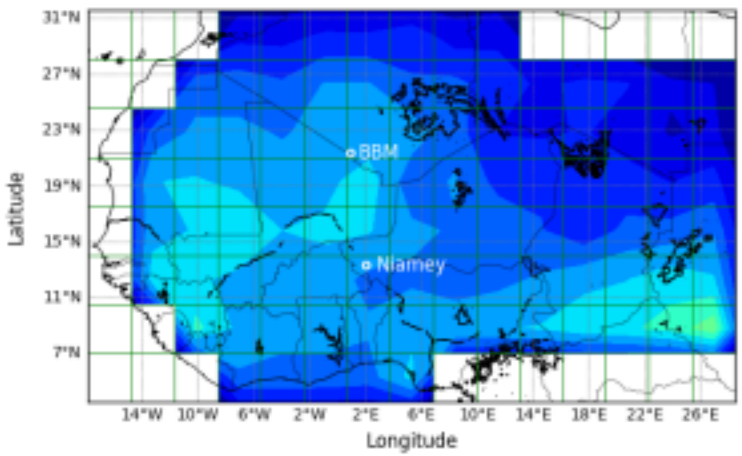
Same clusters with spatial and temporal datasets

IV. Multi-type of mid-level clouds in West Africa

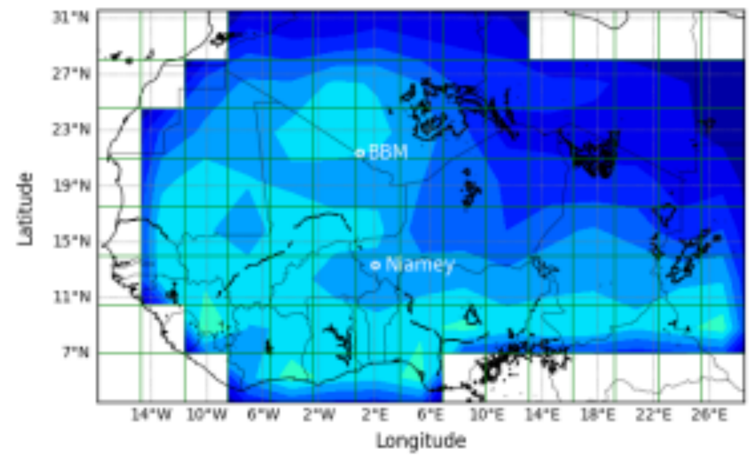
Clustering applied on CloudSat-CALIPSO data



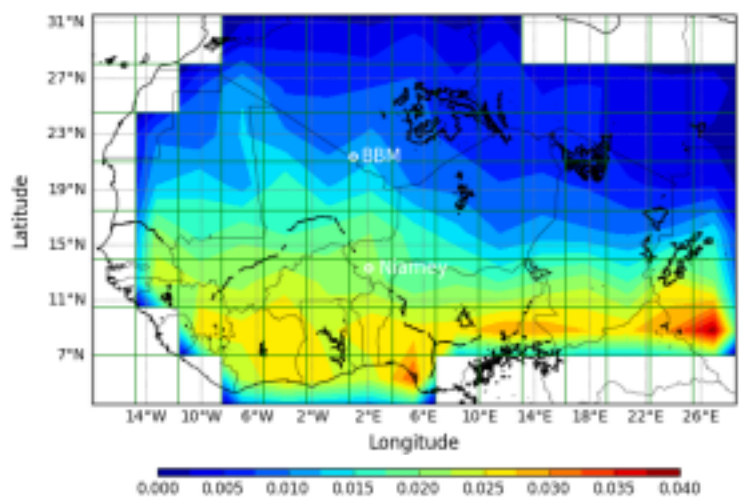
Cluster 1



Cluster 2



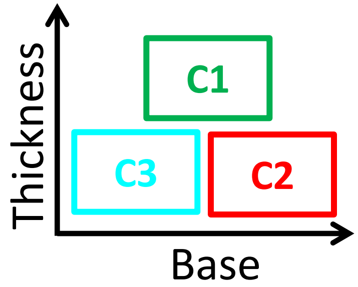
Cluster 3



Geographical repartition of mid-level clouds for each of the three clusters

IV. Multi-type of mid-level clouds in West Africa

Summary – Niamey 2006



Characteristics	Cluster 1	Cluster 2	Cluster 3
Bases (km)	2.5 < bases < 7.5	5.0 < bases	bases < 5.5
Thicknesses (km)	0.6 < thicknesses	thicknesses < 0.8	thicknesses < 1.3
Reflectivities et σ (dBz)	**- 30 < reflectivities 5 < σ**	reflectivities < - 20 σ < 10	reflectivities < - 20 σ < 10
Composition	Mostly of ice	Mostly of liquid water	Mostly of liquid water
Precipitations	**With precipitation**	Without precipitation	Very few precipitation
Duration (hours)	3 < duration	duration < 3	duration < 3
Annual distribution	During monsoon	Before and during monsoon	During and after monsoon
Thermodynamic	**Larger transport of water vapour**	Lower transport of water vapour	Lower transport of water vapour
Inversions	No linked to cloud bases/tops	**Linked to cloud tops**	**Linked to cloud tops**
SW/LW radiative effect (BOA)	**Strong impact**	Small impact	Small (SW) and slightly stronger (LW) impact
Supposed origin	**Convective**	**Stratiform**	**Stratiform**

Outline

I. Context and objectives

II. Observations and methodologies

III. Mean characteristics of mid-level clouds in West Africa

IV. Multi-type of mid-level clouds in West Africa
- ❑ Three clusters at Niamey site in 2006 : one with high thicknesses (cluster 1), one with high bases (cluster 2) and another with low bases (cluster 3)
- ❑ Same clusters observed in West Africa from CloudSat-CALIPSO satellite products between June 2006 and May 2010
- ❑ Clouds of cluster 1 show properties closer to convective clouds and clouds of clusters 2 and 3 to stratiform clouds

V. Representation of mid-level clouds in models in West Africa

VI. Summary and perspectives

V. Representation of mid-level clouds in models

Global and regional simulations

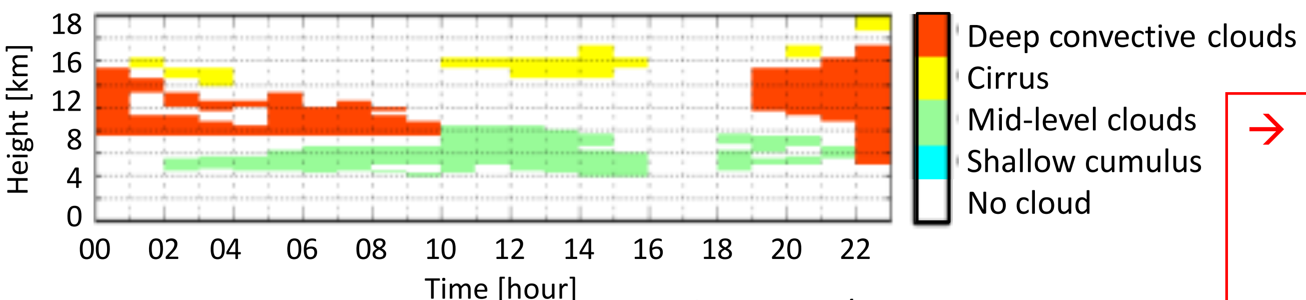
Global simulations

- Models of CMIP5 project ~~used~~
- Five models: CanAM4, CNRM-CM5, HadGEM2-A, IPSL (5A-LR/5B-LR) and MPI-ESM-LR
- AMIP simulations corresponding to present climate with SST fixed
- Temporal resolution : 30 minutes
- Period : 2006
- Extraction of Niamey site cfSites

Regional simulations

- Simulations of SWAMMA (Saharan West African Monsoon Multi-scale Analysis) project ~~used~~
- Based on Met Office Unified Model
- Temporal resolution : 1 hour
- 01/05/2011 to 30/10/2011 in West Africa
- Extraction of Niamey and Bordj Badji Mokhtar sites

Horizontal resolutions	4km	12km	40km
Explicit convection	X	X	
Parameterised convection		X	X

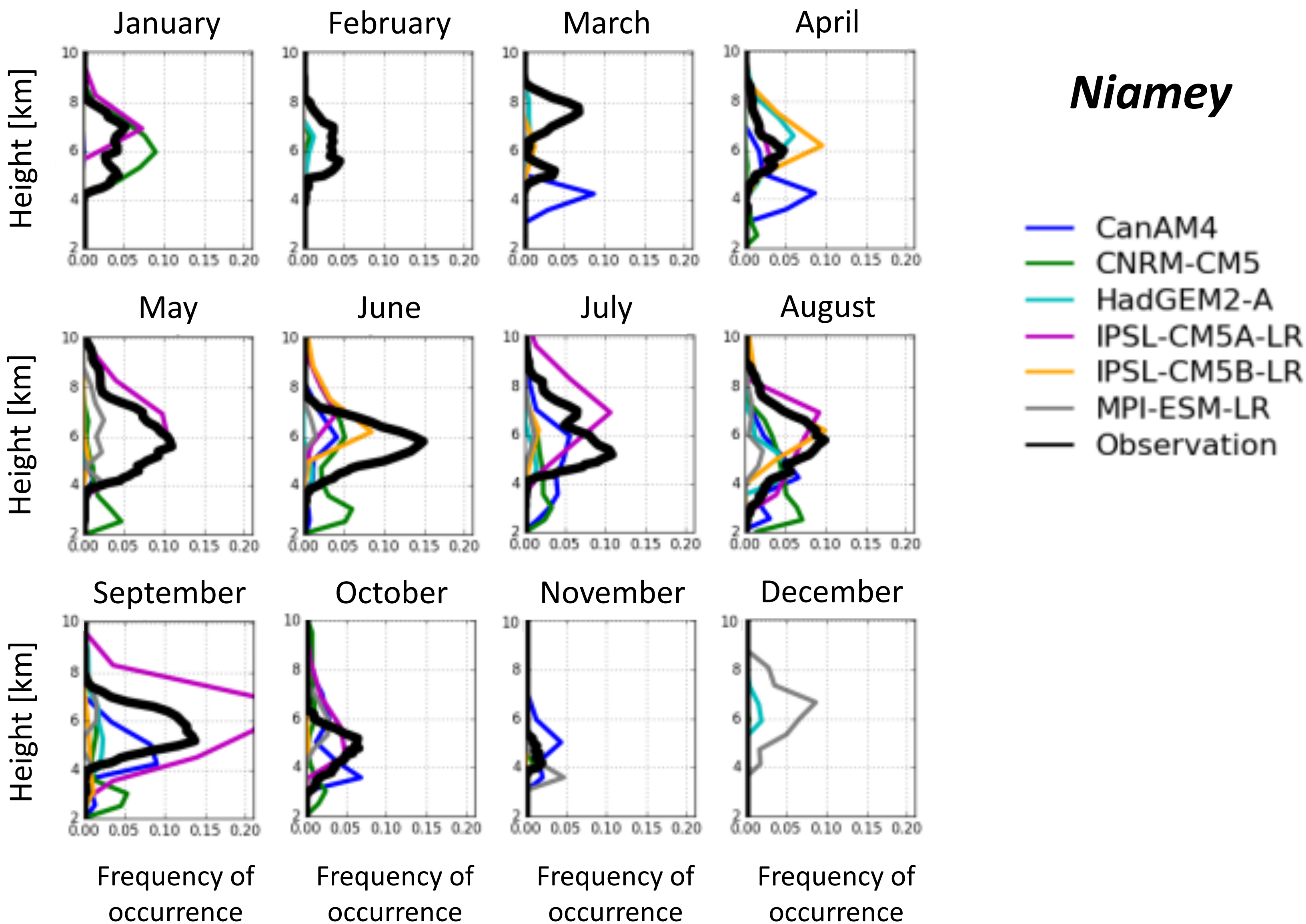


Niamey – 4 km

→ Classification in four cloud types
→ Instrumental sensitivity considered to compare with observations

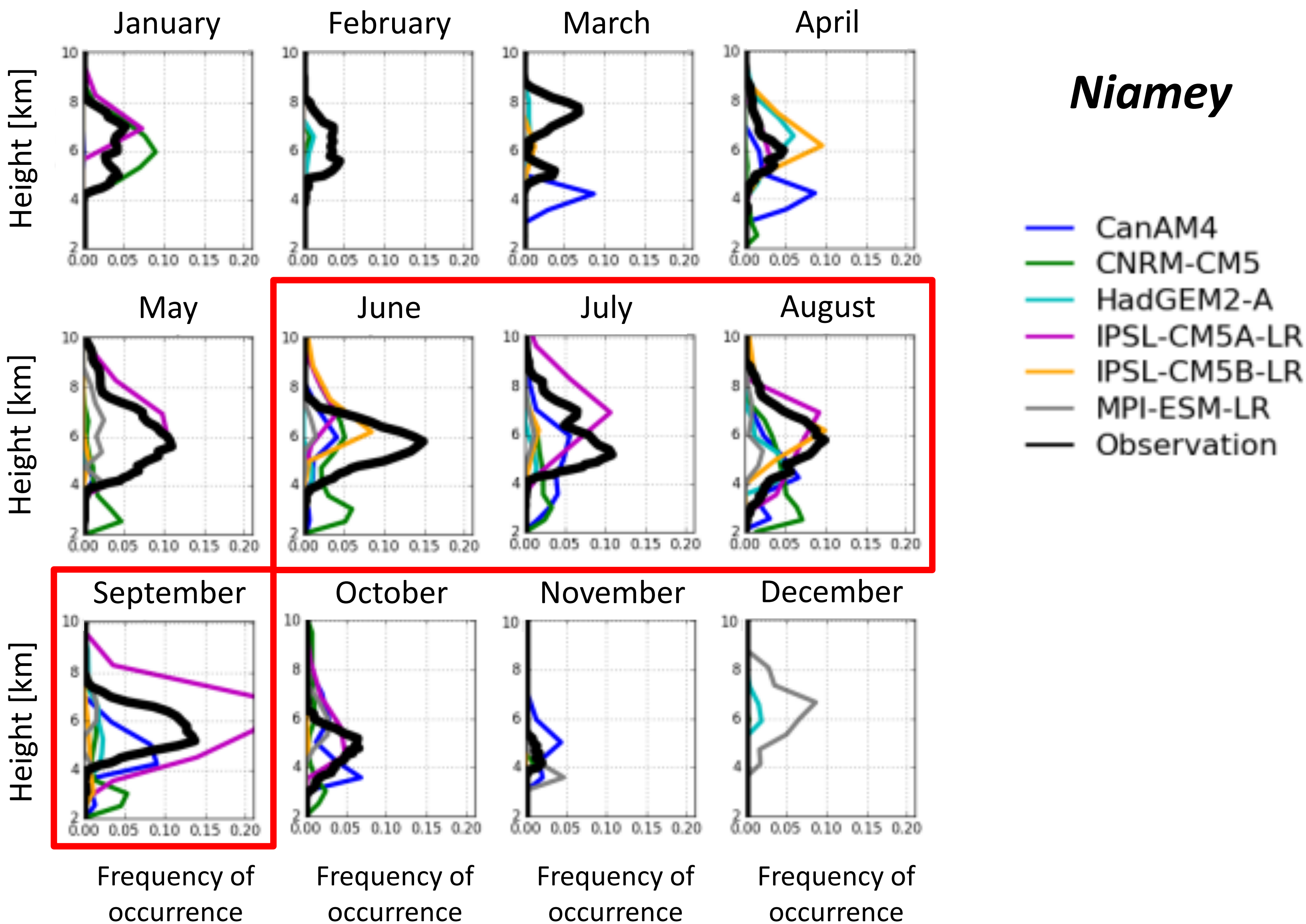
V. Representation of mid-level clouds in models

Cloud frequency of occurrence in global simulations



V. Representation of mid-level clouds in models

Cloud frequency of occurrence in global simulations

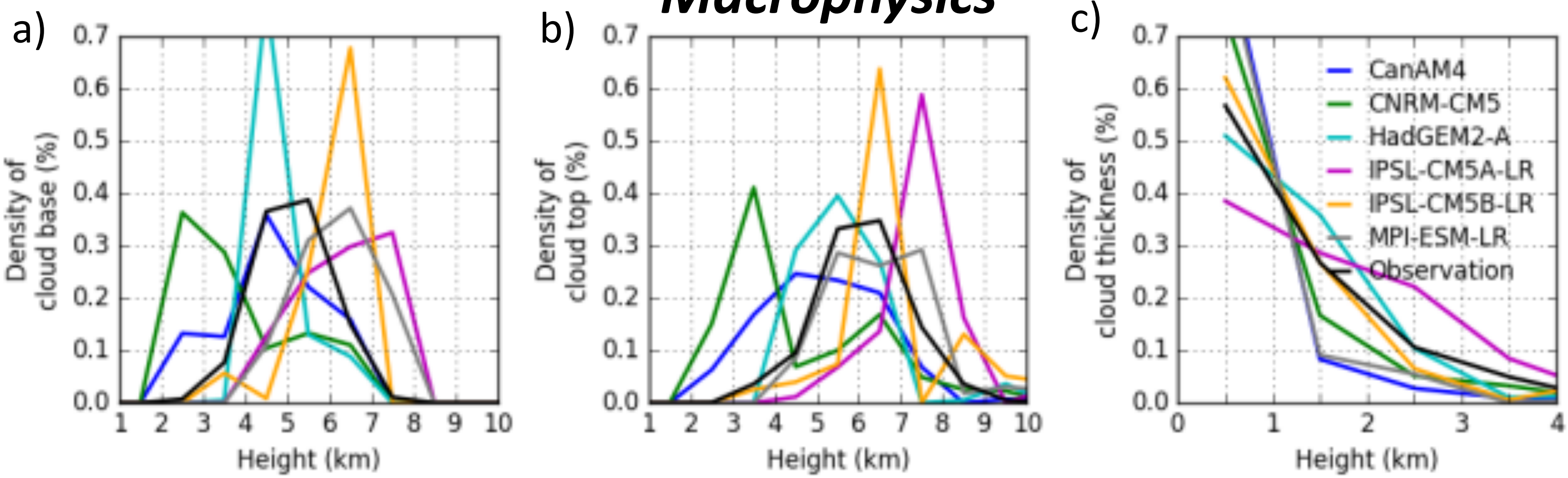


Niamey

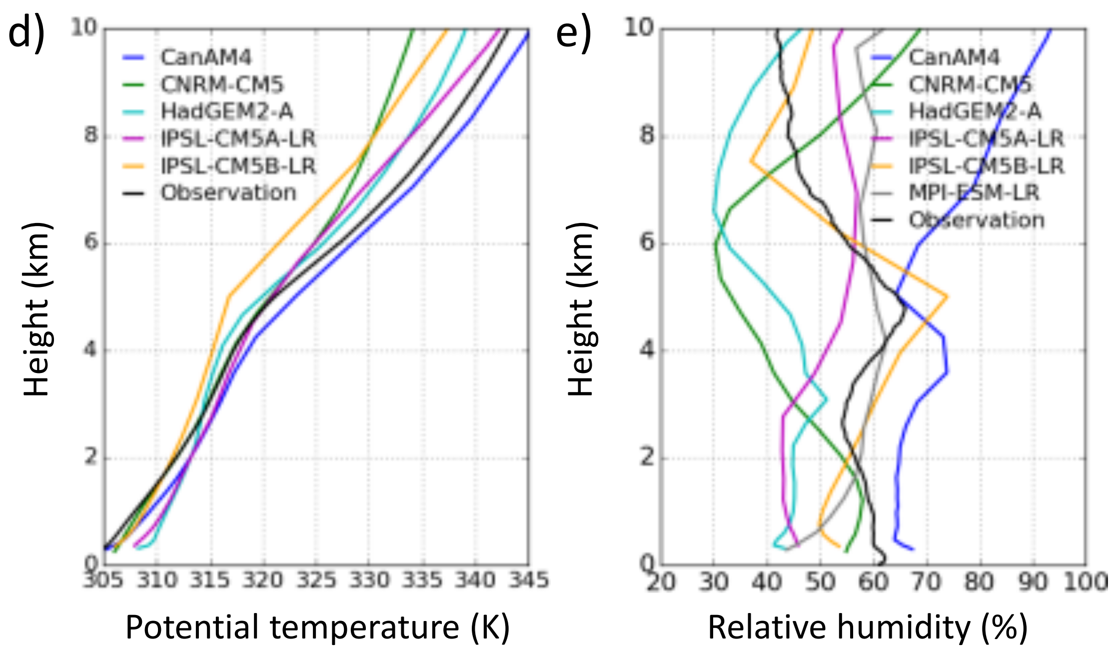
V. Representation of mid-level clouds in models

Cloud properties in global simulations

Macrophysics



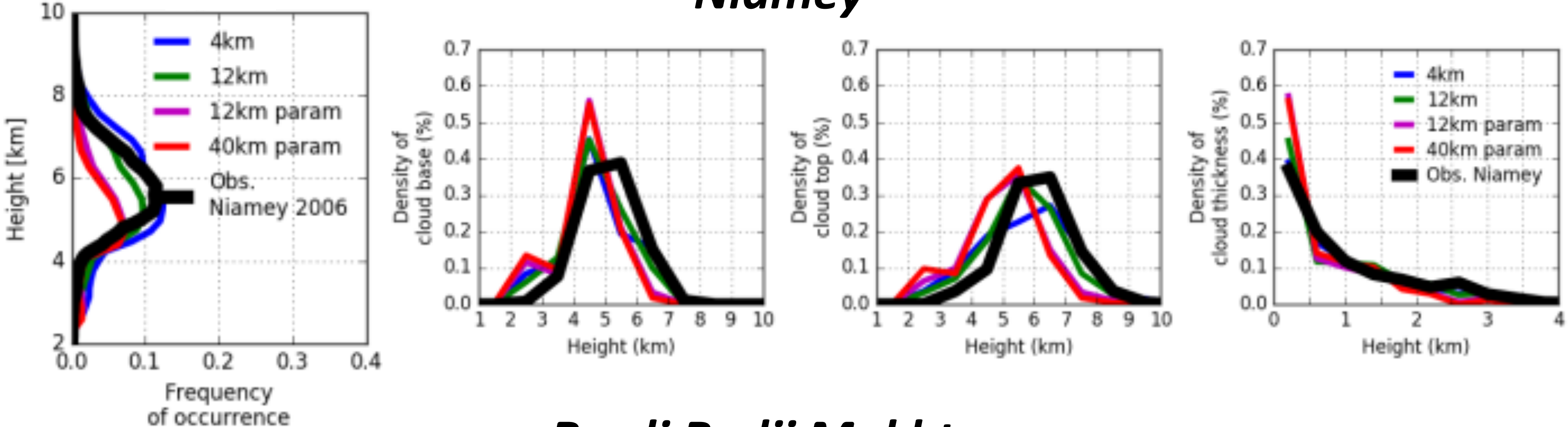
Thermodynamics



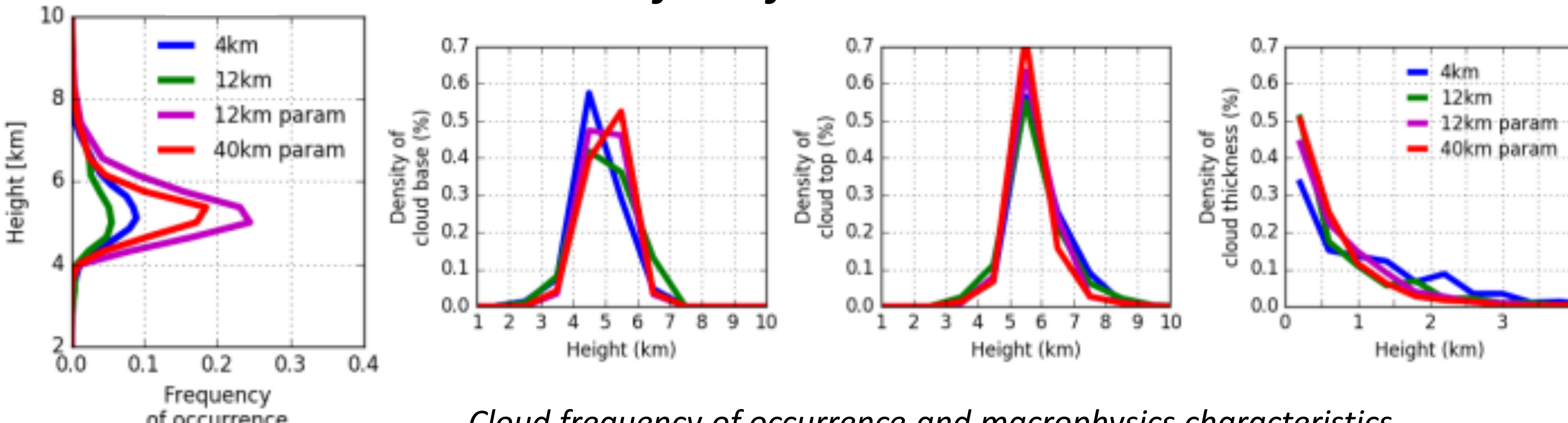
V. Representation of mid-level clouds in models

Cloud frequency of occurrence and properties in regional simulations

Niamey



Bordj Badji Mokhtar



Cloud frequency of occurrence and macrophysics characteristics of mid-level clouds in JJAS at Niamey and Bordj Badji Mokhtar

Outline

I. Context and objectives

II. Observations and methodologies

III. Mean characteristics of mid-level clouds in West Africa

IV. Multi-type of mid-level clouds in West Africa

V. Representation of mid-level clouds in models in West Africa
- ❑ Use of climate models and regional simulations
- ❑ All models and simulations simulate clouds
- ❑ Mid-level cloud properties are not similar to those of observations
- ❑ No simple link between cloud occurrence and relative humidity

VI. Summary and perspectives

VI. Summary and perspectives

Summary

du détail: je pense qu'il faut enlever les points car ce ne sont pas des phrases

- Combination of observational data from two ground sites, Niamey (Sahel) and Bordj Badji Mokhtar (Sahara), with merged CloudSat-CALIPSO satellite products.

VI. Summary and perspectives

Summary

- Combination of observational data from two ground sites, Niamey (Sahel) and Bordj Badji Mokhtar (Sahara), with merged CloudSat-CALIPSO satellite products.

- CloudSat-CALIPSO show a large spatio-temporal coverage of clouds with more mid-level clouds in the south and in the west associated with the monsoon dynamic.

VI. Summary and perspectives

Summary

- Combination of observational data from two ground sites, Niamey (Sahel) and Bordj Badji Mokhtar (Sahara), with merged CloudSat-CALIPSO satellite products.

- CloudSat-CALIPSO show a large spatio-temporal coverage of clouds with more mid-level clouds in the south and in the west associated with the monsoon dynamic.

- Characteristics of mid-level clouds in West Africa :
  - (i) Larger occurrence during the monsoon and during the night,
  - (ii) Very thin clouds (< 1000m),
  - (iii) Mainly composed of liquid water.

Summary

- Combination of observational data from two ground sites, Niamey (Sahel) and Bordj Badji Mokhtar (Sahara), with merged CloudSat-CALIPSO satellite products.

- CloudSat-CALIPSO show a large spatio-temporal coverage of clouds with more mid-level clouds in the south and in the west associated with the monsoon dynamic.

- Characteristics of mid-level clouds in West Africa :
  - (i) Larger occurrence during the monsoon and during the night,
  - (ii) Very thin clouds (< 1000m),
  - (iii) Mainly composed of liquid water.

- Three mid-level cloud families: one with convective processes and two with properties closer to stratiform clouds.

Summary

- Combination of observational data from two ground sites, Niamey (Sahel) and Bordj Badji Mokhtar (Sahara), with merged CloudSat-CALIPSO satellite products.

- CloudSat-CALIPSO show a large spatio-temporal coverage of clouds with more mid-level clouds in the south and in the west associated with the monsoon dynamic.

- Characteristics of mid-level clouds in West Africa :
  - (i) Larger occurrence during the monsoon and during the night,
  - (ii) Very thin clouds (< 1000m),
  - (iii) Mainly composed of liquid water.

- Three mid-level cloud families: one with convective processes and two with properties closer to stratiform clouds.

- CMIP5 simulations show large spread of cloud occurrence in term of intensity, seasonal cycle and vertical extent.

VI. Summary and perspectives

Summary

- Combination of observational data from two ground sites, Niamey (Sahel) and Bordj Badji Mokhtar (Sahara), with merged CloudSat-CALIPSO satellite products.

- CloudSat-CALIPSO show a large spatio-temporal coverage of clouds with more mid-level clouds in the south and in the west associated with the monsoon dynamic.

- Characteristics of mid-level clouds in West Africa :
  - (i) Larger occurrence during the monsoon and during the night,
  - (ii) Very thin clouds (< 1000m),
  - (iii) Mainly composed of liquid water.

- Three mid-level cloud families: one with convective processes and two with properties closer to stratiform clouds.

- CMIP5 simulations show large spread of cloud occurrence in term of intensity, seasonal cycle and vertical extent.

- In SWAMMA simulations, parameterization generates different cloud occurrences : more clouds at Niamey with explicit convection (low horizontal resolution) and at Bordj Badji Mokhtar with parameterised convection (high horizontal resolution). c'est l'inverse (high/low)

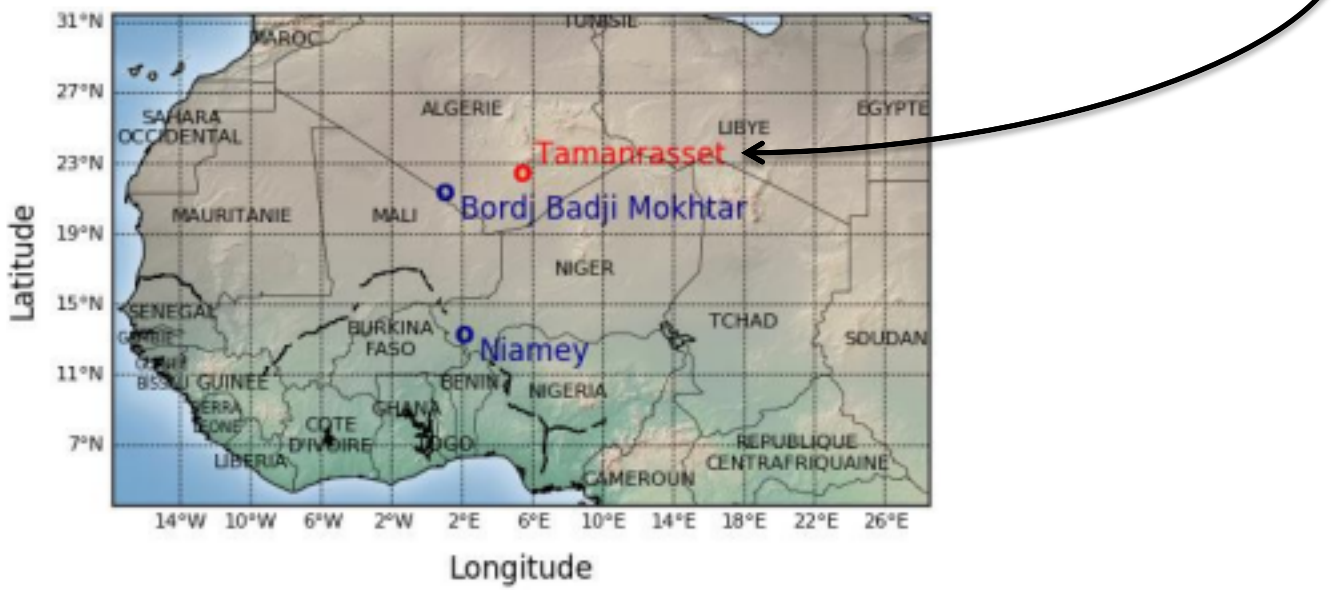
Perspectives(1)

- ***Observations of mid-level clouds***
  - To use CloudSat-CALIPSO satellite data to study the cloud composition from the classification established in DARDAR Project *(Delanoë and Hogan, 2010)* and their radiative impacts,

Perspectives(1)

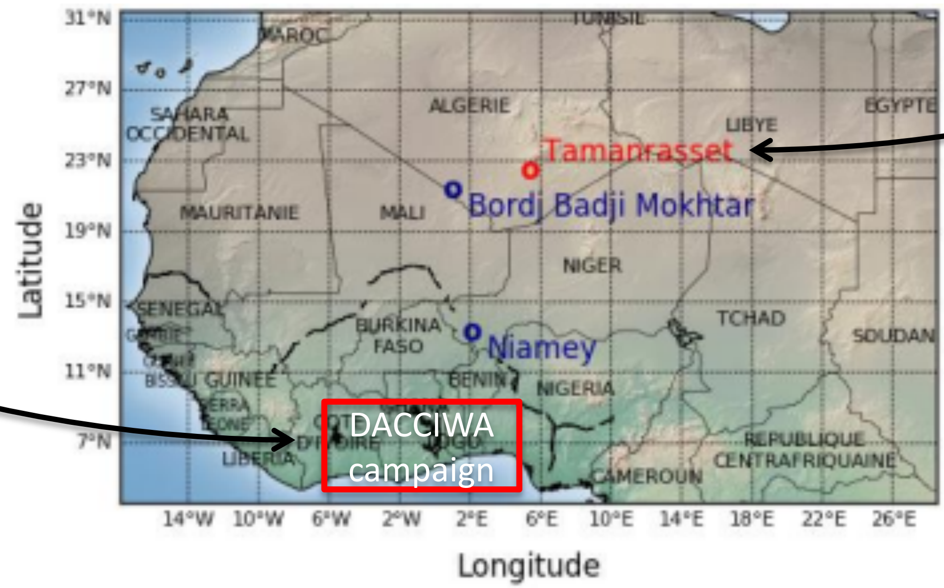
❑ ***Observations of mid-level clouds***

- To use CloudSat-CALIPSO satellite data to study the cloud composition from the classification established in DARDAR Project *(Delanoë and Hogan, 2010)* and their radiative impacts,
- To explain the different clouds observed at ground-based sites, the dataset acquired at Tamanrasset during the AMMA campaign *(Cuesta et al., 2008)* could provide more information in the Sahara region.



Perspectives(1)

- ***Observations of mid-level clouds***
  - To use CloudSat-CALIPSO satellite data to study the cloud composition from the classification established in DARDAR Project *(Delanoë and Hogan, 2010)* and their radiative impacts,
  - To explain the different clouds observed at ground-based sites, the dataset acquired at Tamanrasset during the AMMA campaign *(Cuesta et al., 2008)* could provide more information in the Sahara region.
  - To understand the interaction between aerosols and the cloud characteristics in Golf of Guinea, the data of DACCIWA campaign *(Knippertz et al., 2015)* could be used. Also the aerosols in the Sahara *(Cuesta et al., 2008; Marsham et al., 2013)*.

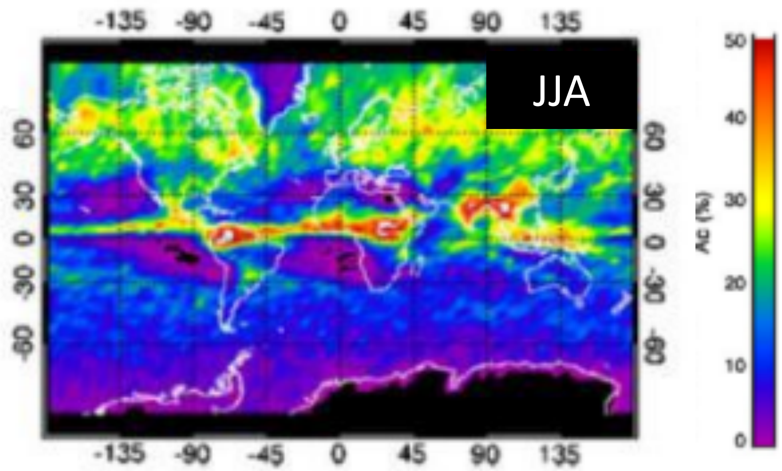


Perspectives(1)

❑ ***Observations of mid-level clouds***

- To use CloudSat-CALIPSO satellite data to study the cloud composition from the classification established in DARDAR Project *(Delanoë and Hogan, 2010)* and their radiative impacts,
- To explain the different clouds observed at ground-based sites, the dataset acquired at Tamanrasset during the AMMA campaign *(Cuesta et al., 2008)* could provide more information in the Sahara region.
- To understand the interaction between aerosols and the cloud characteristics in Golf of Guinea, the data of DACCIWA campaign *(Knippertz et al., 2015)* could be used. Also the aerosols in the Sahara *(Cuesta et al., 2008; Marsham et al., 2013)*.
- To apply the method used here at other ARM sites.

cf remarque précédente j'aurais envie d'ouvrir avec CloudSat Calipso sur une zone plus grande que l'Afrique



(Sassen et Wang, 2012)

VI. Summary and perspectives

Perspectives(2)

- ***Mechanisms responsible of the formation and maintenance of mid-level clouds***
  - To analyse the role of the circulation on the formation of mid-level clouds in taking an interest in the vertical structure of water vapour balance with SWAMMA,

Perspectives(2)

- ***Mechanisms responsible of the formation and maintenance of mid-level clouds***
  - To analyse the role of the circulation on the formation of mid-level clouds in taking an interest in the vertical structure of water vapour balance with SWAMMA,
  - To use back-trajectories to determine the origin of the humidity responsible of the formation of mid-level clouds,

Perspectives(2)

- ***Mechanisms responsible of the formation and maintenance of mid-level clouds***
  - To analyse the role of the circulation on the formation of mid-level clouds in taking an interest in the vertical structure of water vapour balance with SWAMMA,
  - To use back-trajectories to determine the origin of the humidity responsible of the formation of mid-level clouds,
  - Simulations with Meso-NH on the three clusters. ? pas hyper clair

Perspectives(2)

- ***Mechanisms responsible of the formation and maintenance of mid-level clouds***
  - To analyse the role of the circulation on the formation of mid-level clouds in taking an interest in the vertical structure of water vapour balance with SWAMMA,
  - To use back-trajectories to determine the origin of the humidity responsible of the formation of mid-level clouds,
  - Simulations with Meso-NH on the three clusters.

- ***Evaluation and amelioration of mid-level cloud representation in models***
  - To understand what parameterizations are responsible of mid-level cloud occurrence,

Perspectives(2)

- ***Mechanisms responsible of the formation and maintenance of mid-level clouds***
  - To analyse the role of the circulation on the formation of mid-level clouds in taking an interest in the vertical structure of water vapour balance with SWAMMA,
  - To use back-trajectories to determine the origin of the humidity responsible of the formation of mid-level clouds,
  - Simulations with Meso-NH on the three clusters.

- ***Evaluation and amelioration of mid-level cloud representation in models***
  - To understand what parameterizations are responsible of mid-level cloud occurrence,
  - To study the cloud composition and their radiative impacts,

Perspectives(2)

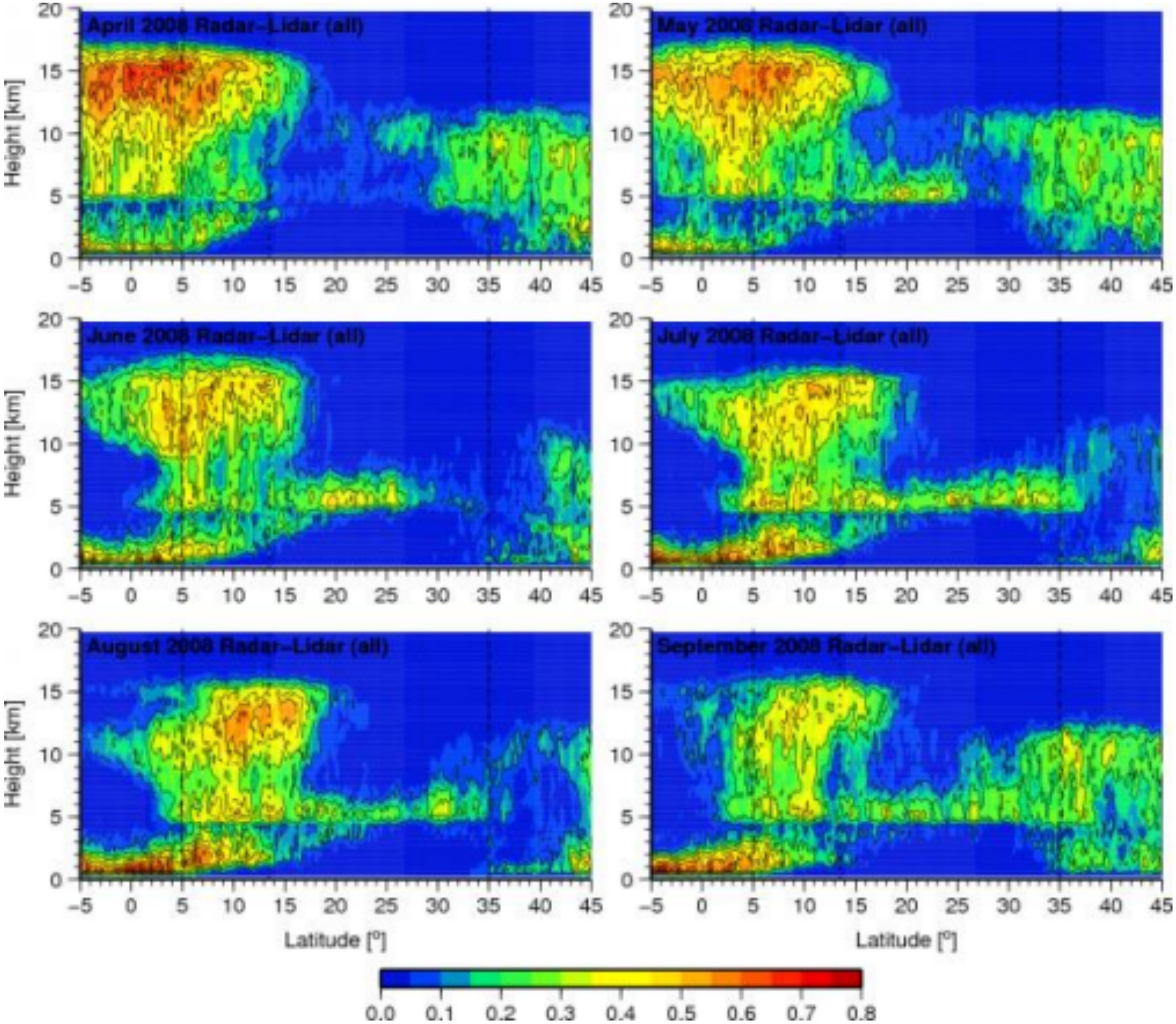
- ***Mechanisms responsible of the formation and maintenance of mid-level clouds***
  - To analyse the role of the circulation on the formation of mid-level clouds in taking an interest in the vertical structure of water vapour balance with SWAMMA,
  - To use back-trajectories to determine the origin of the humidity responsible of the formation of mid-level clouds,
  - Simulations with Meso-NH on the three clusters.

- ***Evaluation and amelioration of mid-level cloud representation in models***
  - To understand what parameterizations are responsible of mid-level cloud occurrence,
  - To study the cloud composition and their radiative impacts,
  - To apply clustering method on clouds detected with SWAMMA simulations at 4 km.


Thank you for your attention

Annexes

CloudSat-CALIPSO data during the monsoon period in 2008



Instruments and parameters used

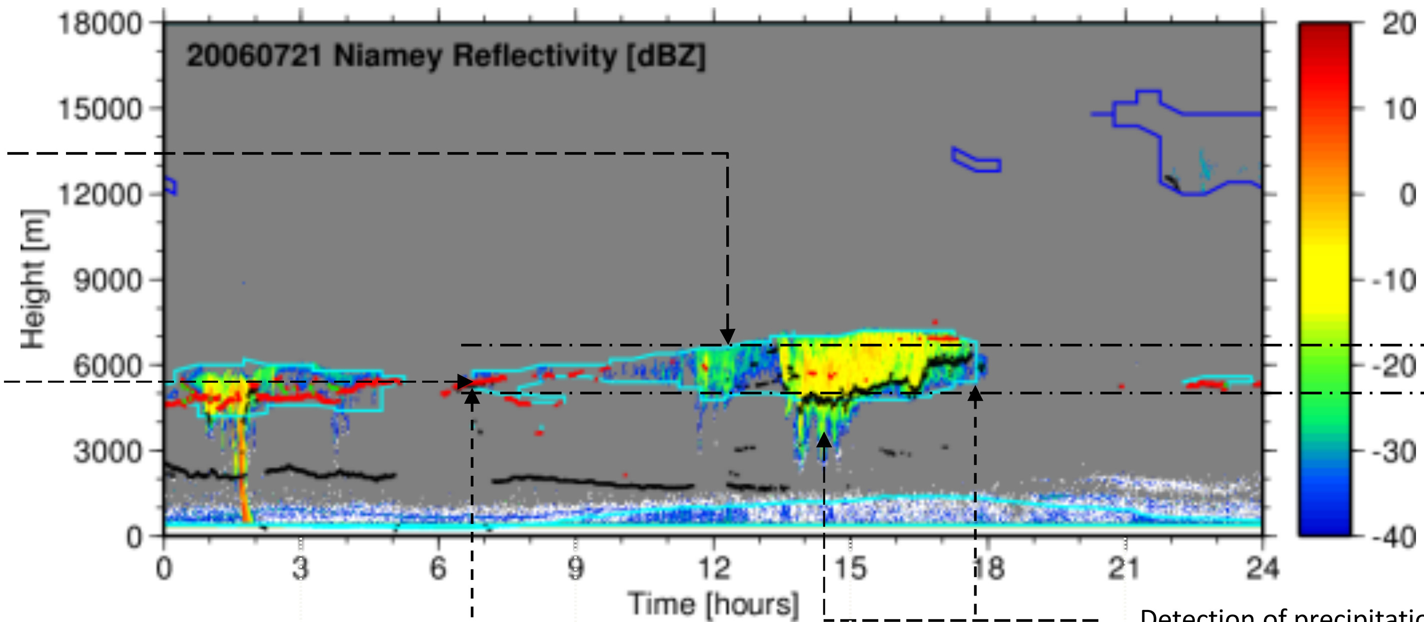
Instruments	Measured parameters	Computed parameters	Temporal and spatial resolutions	Deployment duration
AMMA (ARM-Mobile Facility Niamey) - 2006 - Sol				
Cloud radar (WACR) (95-GHz)	Reflectivity (Z) Doppler velocity Depolarisation ratio	Cloud occurrence and cloud classification and cloud masks and macro and microphysics properties	30 s / 40 m	1 April - 31 December 2006
Micropulse radar (523 nm wavelength)	Backscattering coefficient (β) Depolarisation ratio	Cloud occurrence and cloud classification and cloud masks and macrophysics properties	30 – 60 s / 30 m	1 January - 31 December 2006
Radiosondes (RS92 GPS / Vaisala)	θ, T, q, p	Thermodynamics properties and inversions	6 hourly	1 January - 31 December 2006
Microwave Radiometer (MWR)		Cloud classification	20 s	1 January - 31 December 2006
Microwave Radiometer Profiler (MWR-P)		Cloud classification	5 min	1 January - 31 December 2006
Rain gauge		Cloud classification		1 January - 31 December 2006
Downwelling radiation (SKYRAD)	SW, LW	Radiation	1 min	1 January - 31 December 2006
Surface meteorology		Lifting condensation level	1 min	1 January - 31 December 2006
Fennec (Bordj Badji Mokhtar) - June 2011 - Sol				
Doppler lidar (1550 nm wavelength)	Backscattering coefficient (β)	Cloud occurrence and cloud classification and cloud masks and macrophysics properties	30 s / 30 m	2 June - 1 July 2011
A-Train - CloudSat-CALIPSO - June 2006 to May 2010 - Satellites				
Cloud Profiling Radar (CPR) (94-GHz)	Reflectivity (Z)	Cloud occurrence and cloud classification and cloud masks and macro and microphysics properties	Cross-track : 1.4 km Along-track : 3.5 km / 480 m	June 2006 – May 2010
Cloud-Aerosol Lidar with Orthogonal Polarization (CALIOP) (532 and 1064 nm wavelength)	Backscattering coefficient (β)	Cloud occurrence and cloud classification and cloud masks and macrophysics properties	333 m / 30 m - 60m	June 2006 – May 2010
MSG-1 - 2006				
Radiometer (GERB)	SW, LW (TOA)	Radiation	15 min	1 January - 31 December 2006

II. Observations and methodologies

Identification and characterisation of mid-level clouds

Reflectivity

Doppler velocity



Top

Thickness

Base

Detection of precipitation

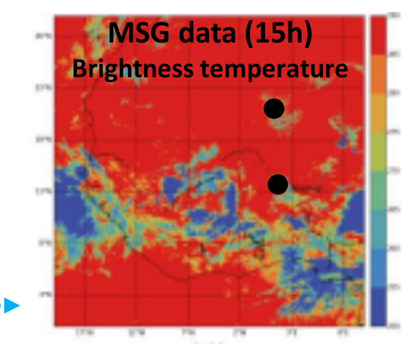
Starting time

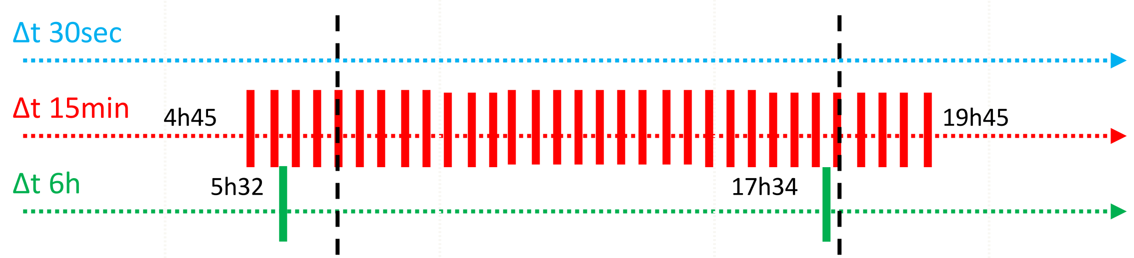
Time interval of cloud observation

Ending time

Composition :

- Ice ?
- Melting ice ?
- Melting ice and cloud liquid droplets ?
- Ice and supercooled liquid droplets ?
- Cloud liquid droplets only ?
- Drizzle or rain and cloud liquid droplets ?





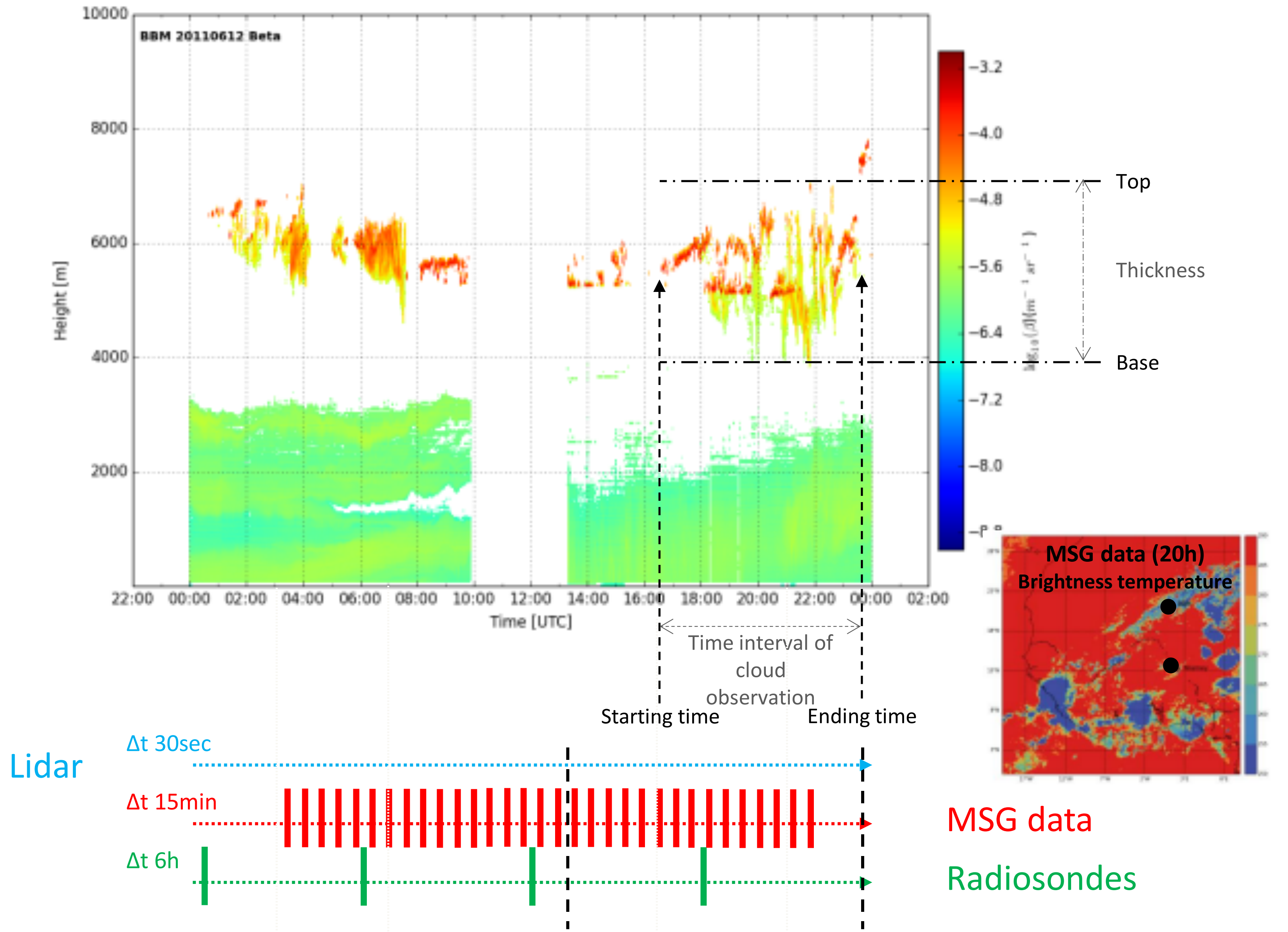
Lidar / Radar

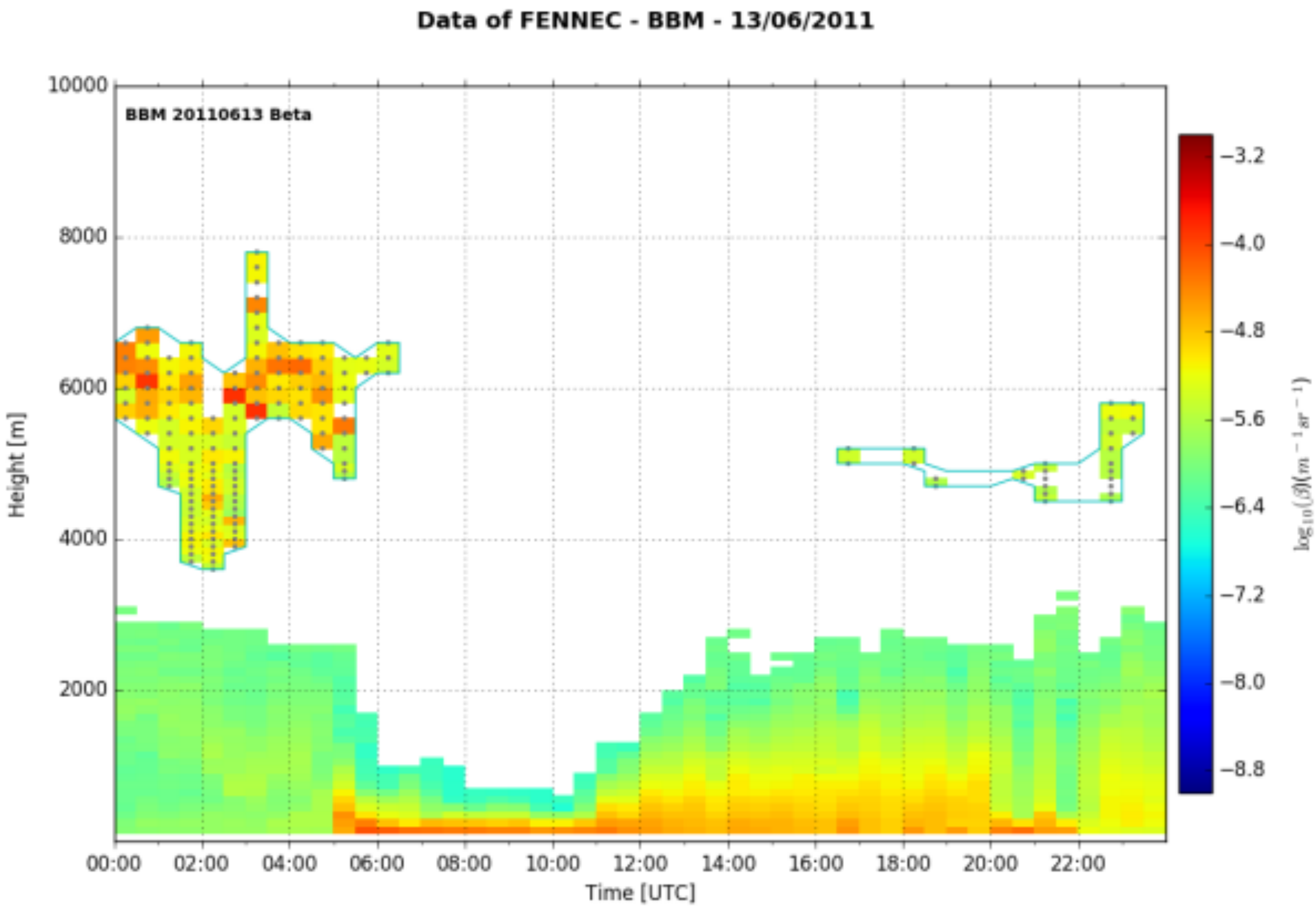
MSG data

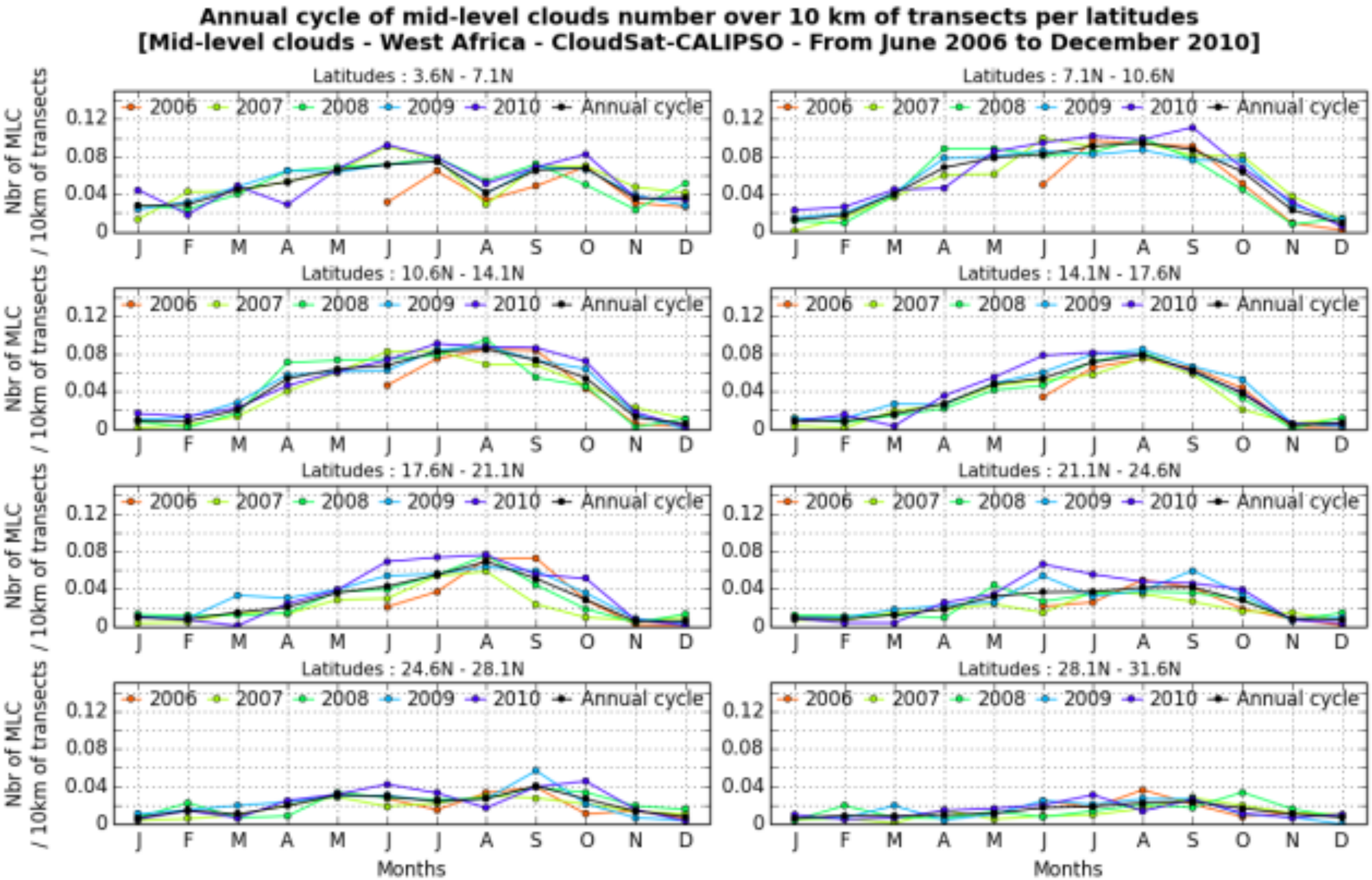
Radiosondes

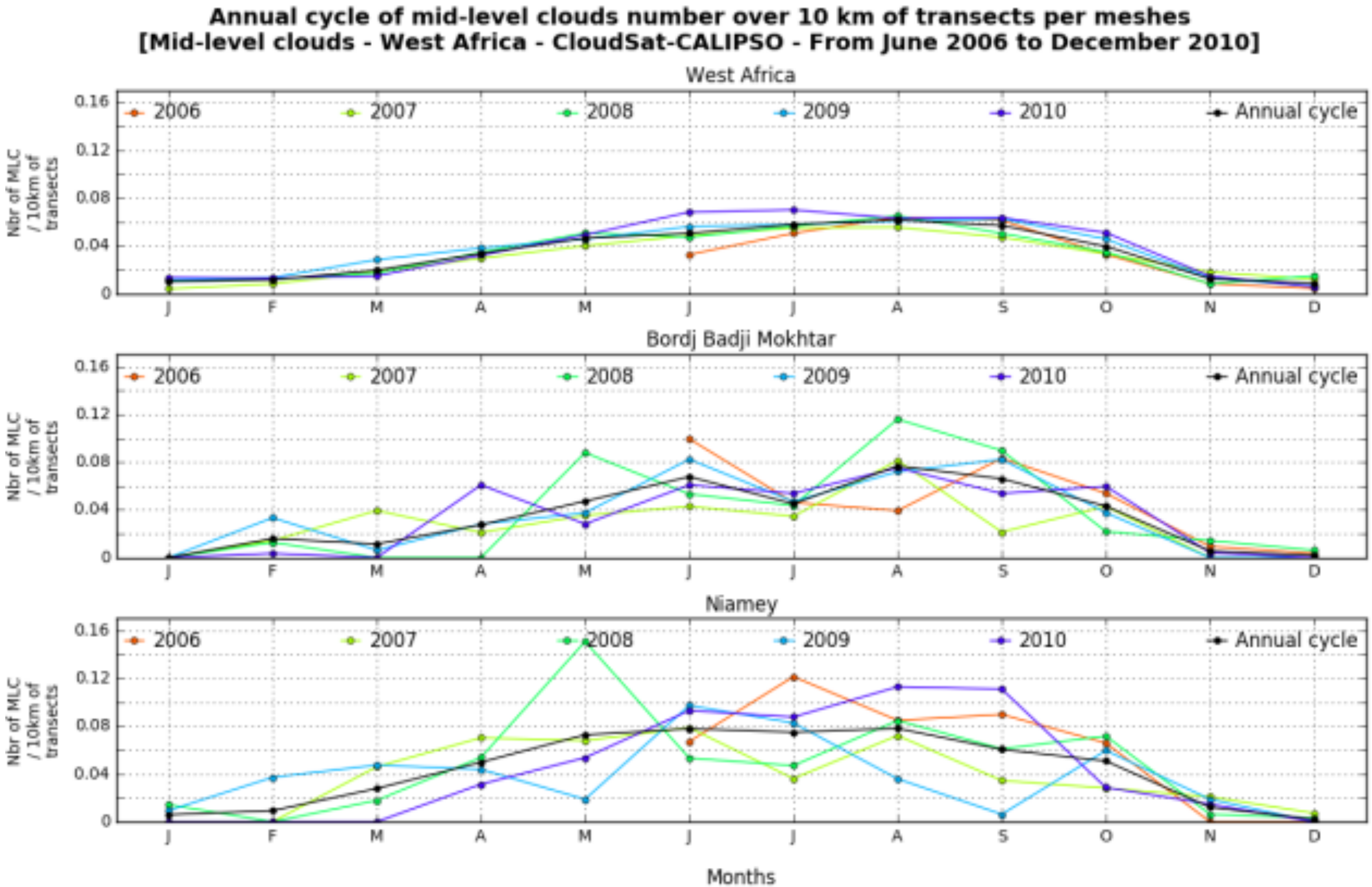
II. Observations and methodologies

Identification and characterisation of mid-level clouds




Data of FENNEC - BBM - 13/06/2011
BBM 20110613 Beta
Height [m]
10000
8000
6000
4000
2000
00:00
02:00
04:00
06:00
08:00
10:00
12:00
14:00
16:00
18:00
20:00
22:00
Time [UTC]
−3.2
−4.0
−4.8
−5.6
−6.4
−7.2
−8.0
−8.8
$\log_{10}(\beta)(m^{-1}sr^{-1})$

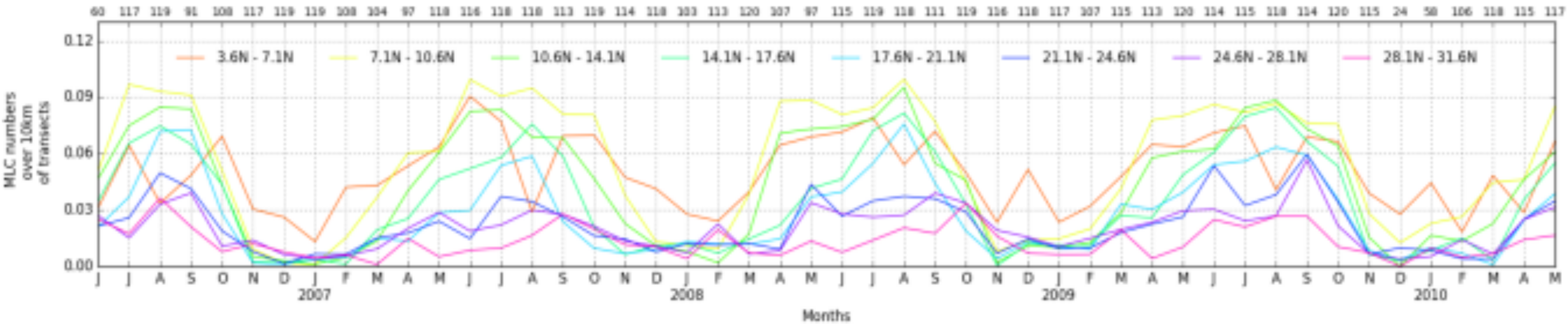

Annual cycle of mid-level clouds number over 10 km of transects per latitudes
[Mid-level clouds - West Africa - CloudSat-CALIPSO - From June 2006 to December 2010]
Latitudes : 3.6N - 7.1N
Latitudes : 7.1N - 10.6N
Latitudes : 10.6N - 14.1N
Latitudes : 14.1N - 17.6N
Latitudes : 17.6N - 21.1N
Latitudes : 21.1N - 24.6N
Latitudes : 24.6N - 28.1N
Latitudes : 28.1N - 31.6N
2006
2007
2008
2009
2010
Annual cycle
Nbr of MLC / 10km of transects
Months
J F M A M J J A S O N D
0 0.04 0.08 0.12


Annual cycle of mid-level clouds number over 10 km of transects per meshes
[Mid-level clouds - West Africa - CloudSat-CALIPSO - From June 2006 to December 2010]
West Africa
Bordj Badji Mokhtar
Niamey
2006
2007
2008
2009
2010
Annual cycle
Nbr of MLC / 10km of transects
0.16
0.12
0.08
0.04
0
J F M A M J J A S O N D
Months

III. Observations of mid-level clouds in West Africa (3)

Regional climatology from CloudSat-CALIPSO (June 2006 to May 2010)

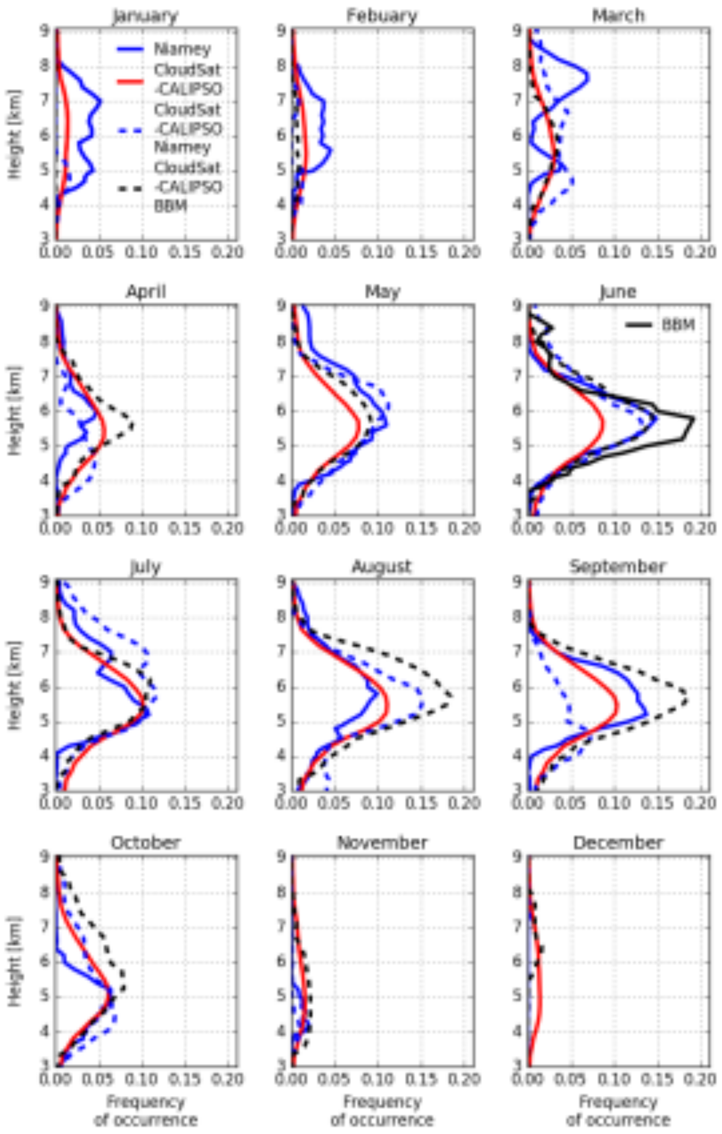
- In the North of Sahara, the amplitude of the annual cycle is lower than in the South.
- Tropical Plumes could explained the presence of mid-level clouds during autumn and spring in these regions.



Annual cycle of the density of mid-level clouds for latitudinal bands.

III. Observations of mid-level clouds in West Africa (6)

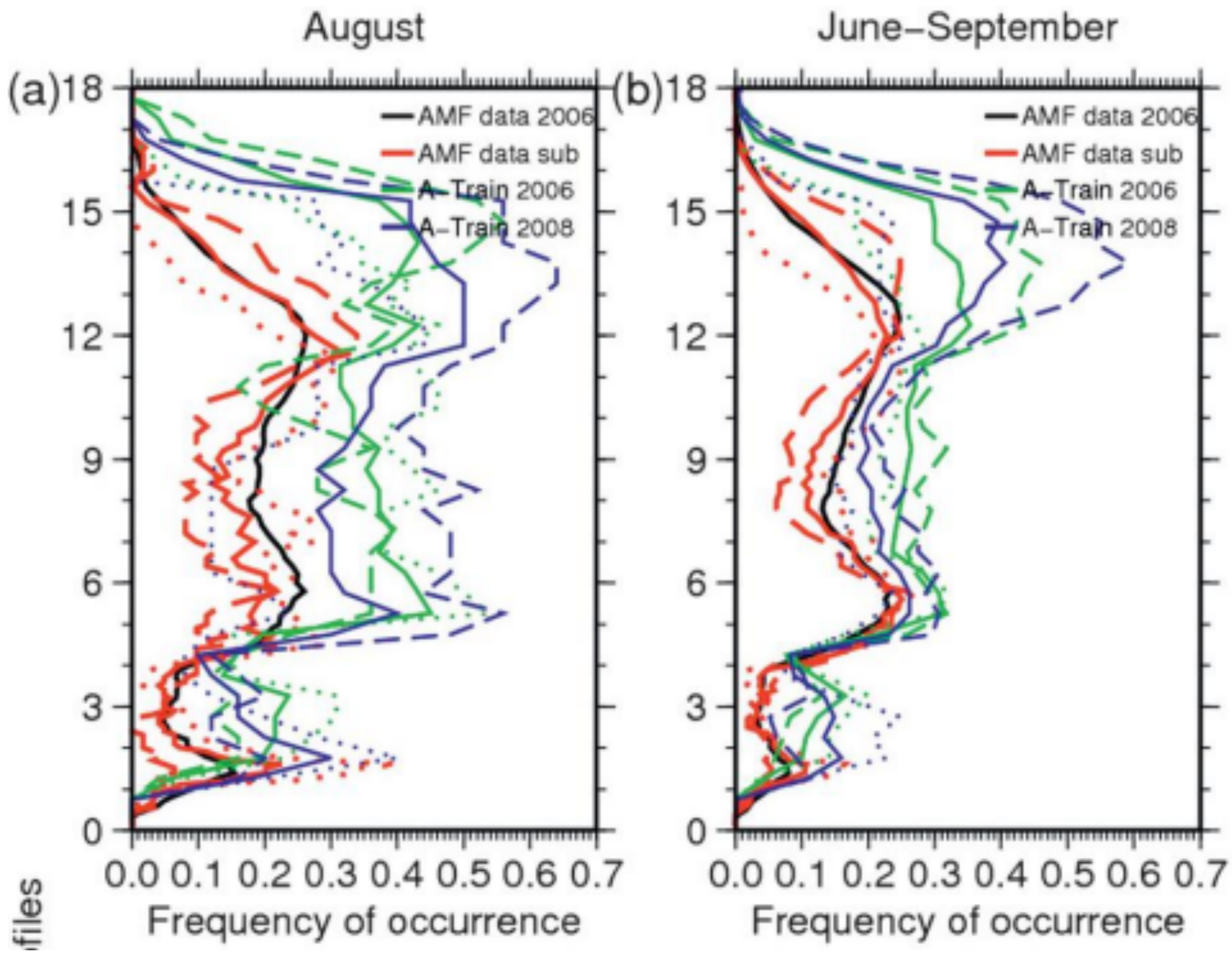
Cloud frequency of occurrence – Annual period



Mid-level clouds frequency of occurrence at Niamey 2006 (blue) and at BBM in June 2011 (black) and with satellite observations (red for West Africa [10° W-10° E] and dotted line for two sites)

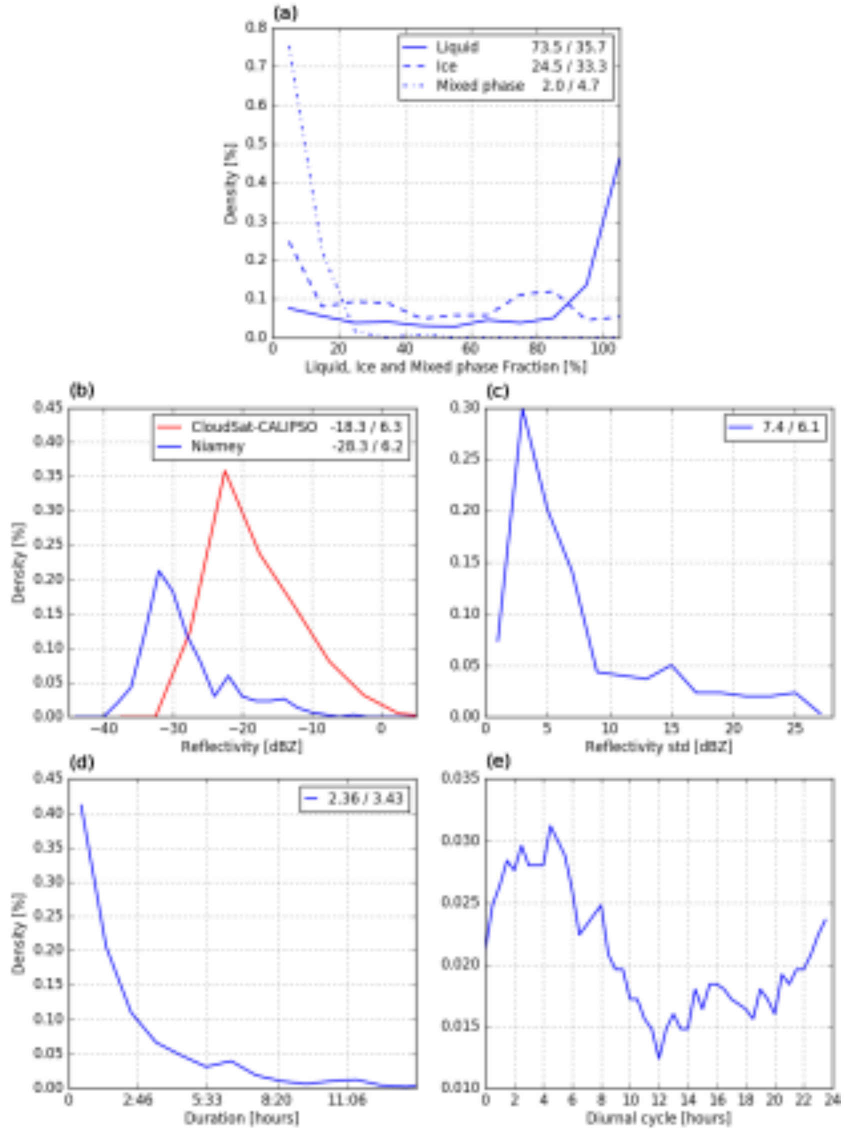
III. Observations of mid-level clouds in West Africa (6)

Ground-based data versus satellite data

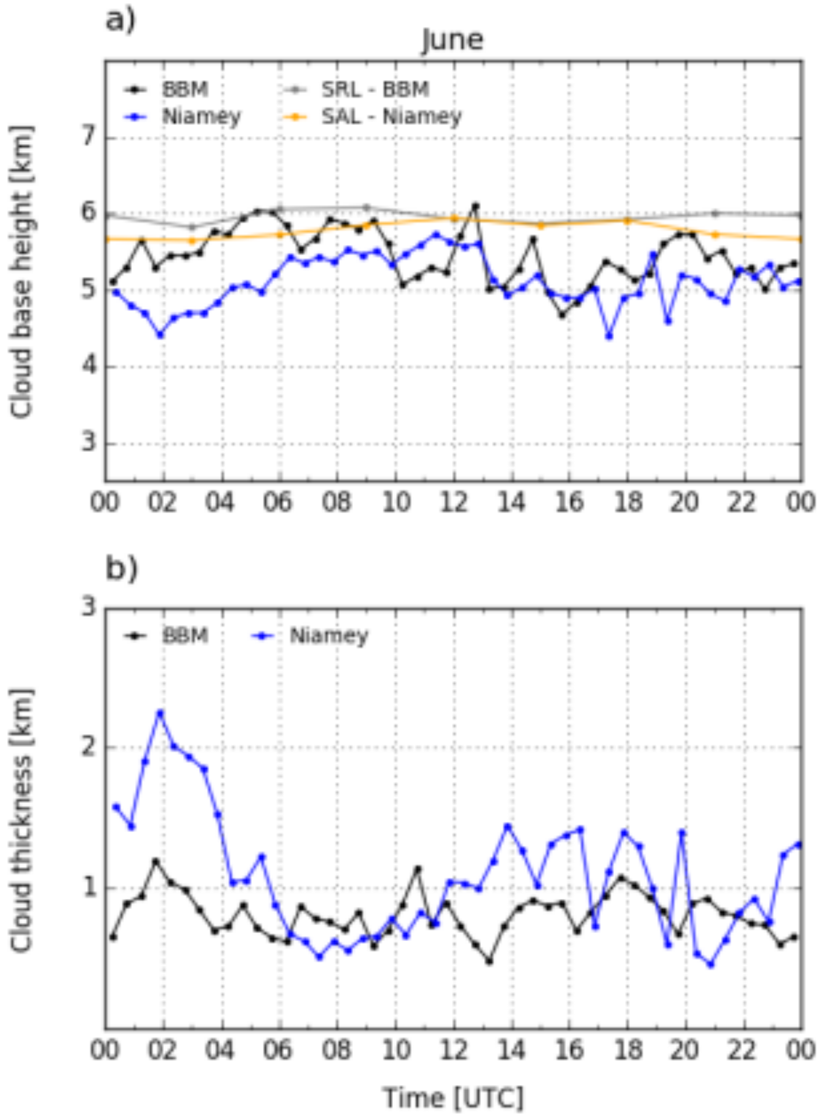


Bouniol et al., 2012

Microphysics characteristics of mid-level clouds



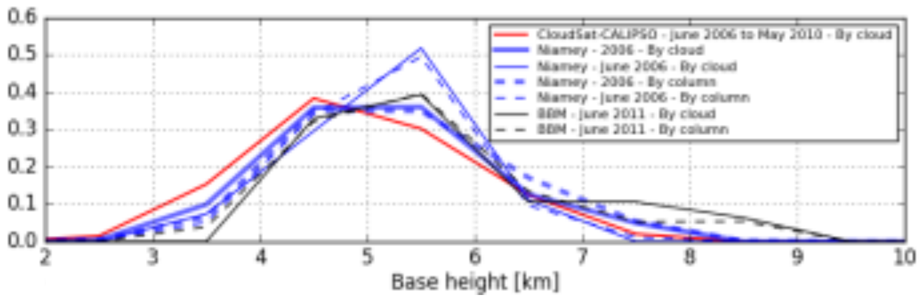
Microphysics characteristics of mid-level clouds

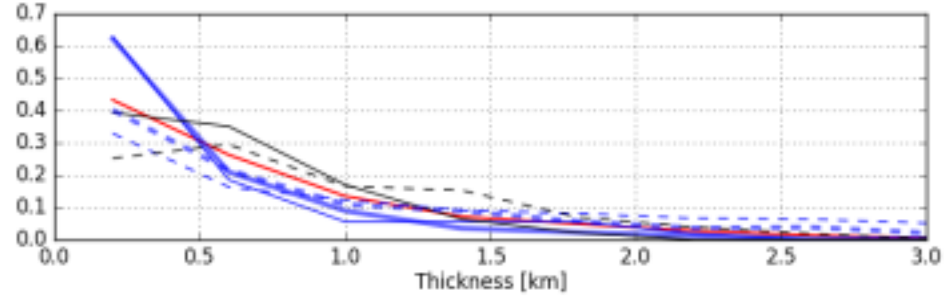


III. Observations of mid-level clouds in West Africa

Macro- and microphysical characteristics

- Small vertical extent of mid-level clouds.





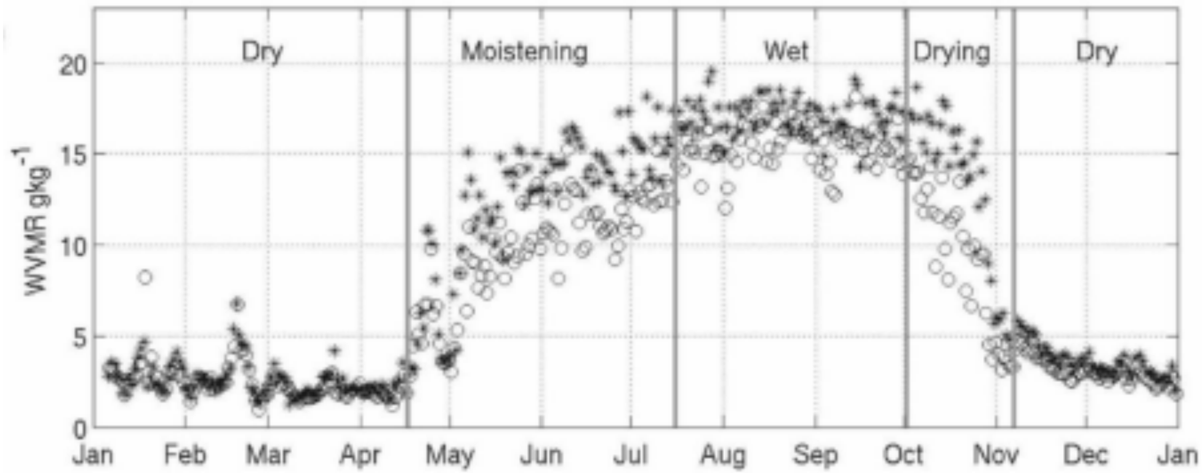
Distributions of cloud base height (left) and cloud thickness (right).

Références	< 500 m	< 1 km	< 2 km
Riihimaki et al., 2012 (Darwin, Australia)		50 %	70 %
Niamey, 2006	71 %	88 %	98 %
BBM, June 2011	57 %	82 %	100 %

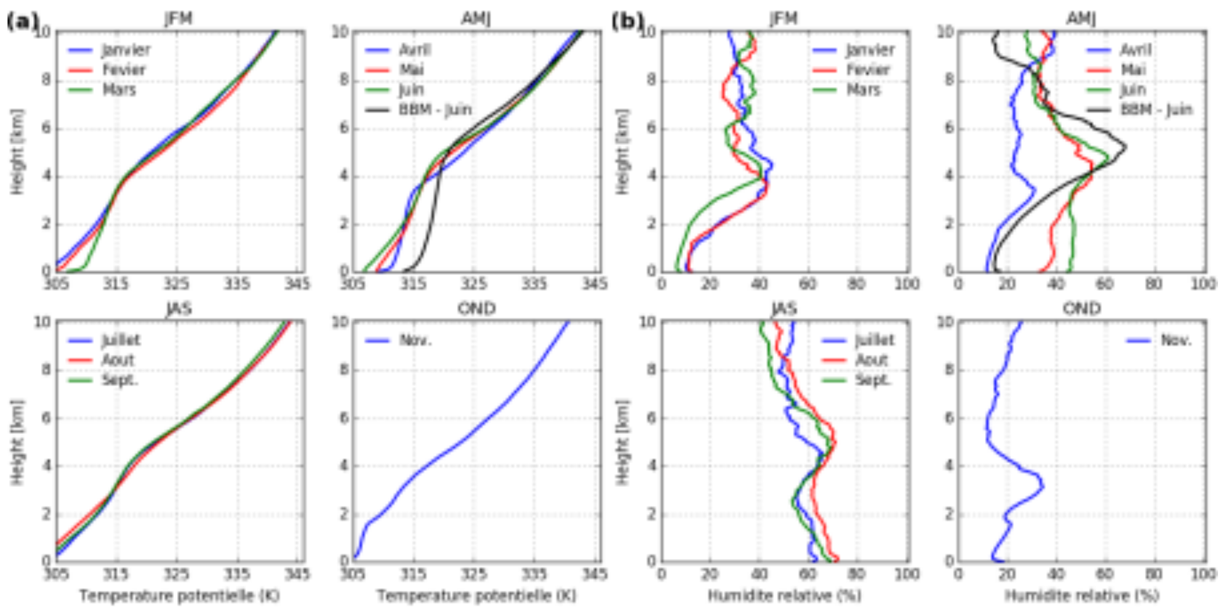
Relationships between the different variables are not obvious and it is difficult to identify various families of mid-level clouds.

→ Statistical method to objectively identify clouds having similarities

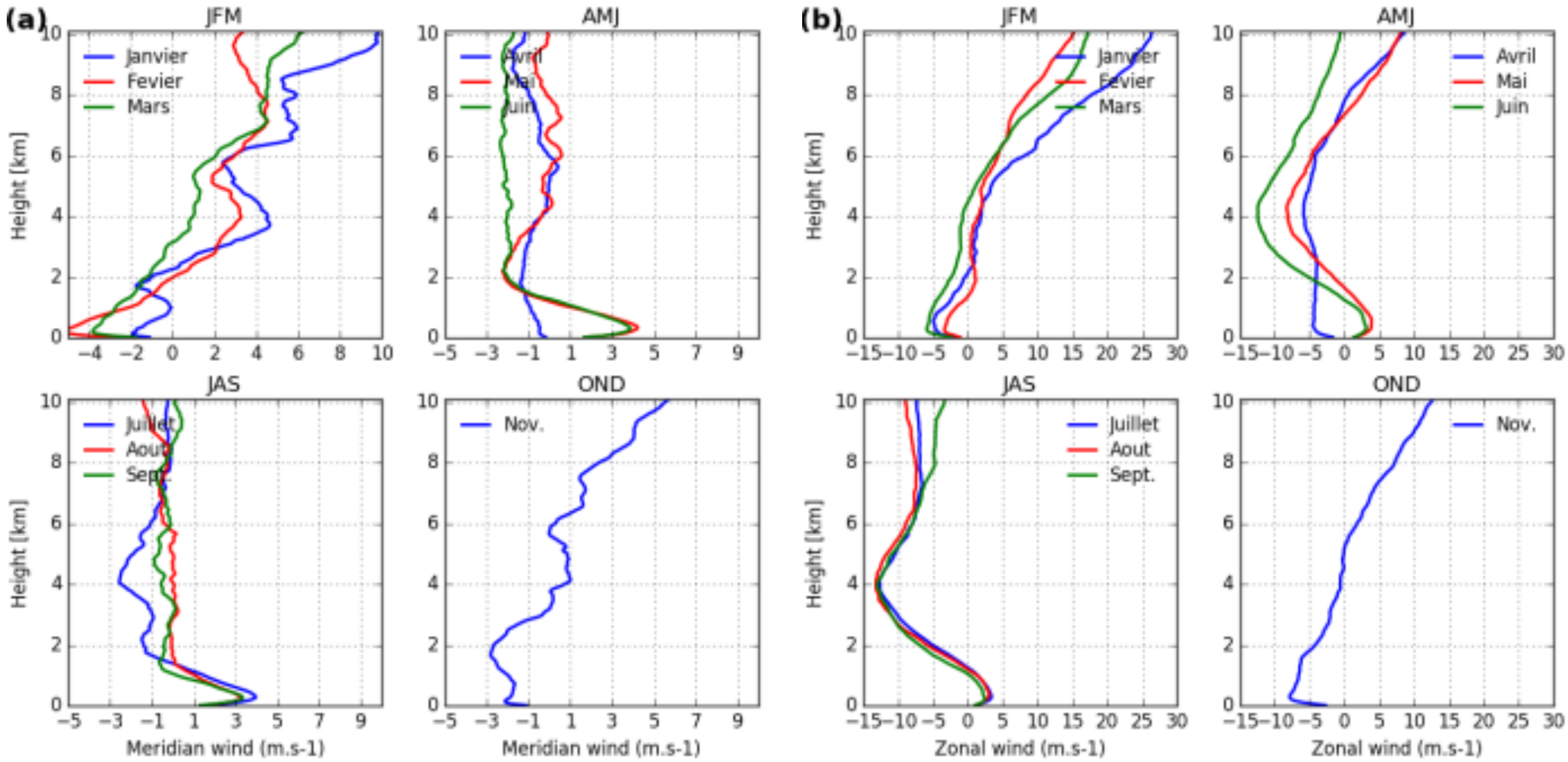
Thermodynamic characteristics



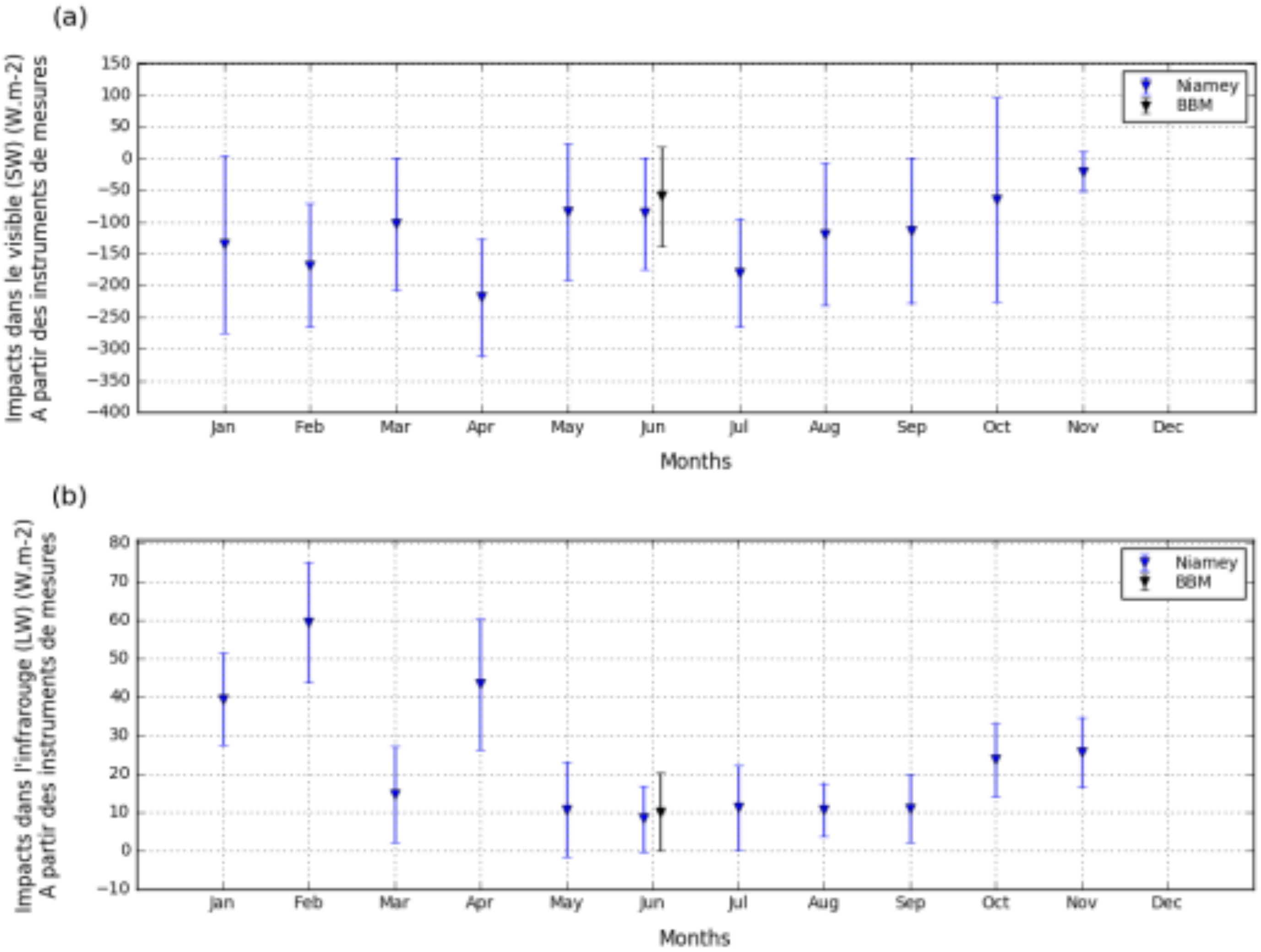
(Lothon et al. 2008)



Dynamic characteristics



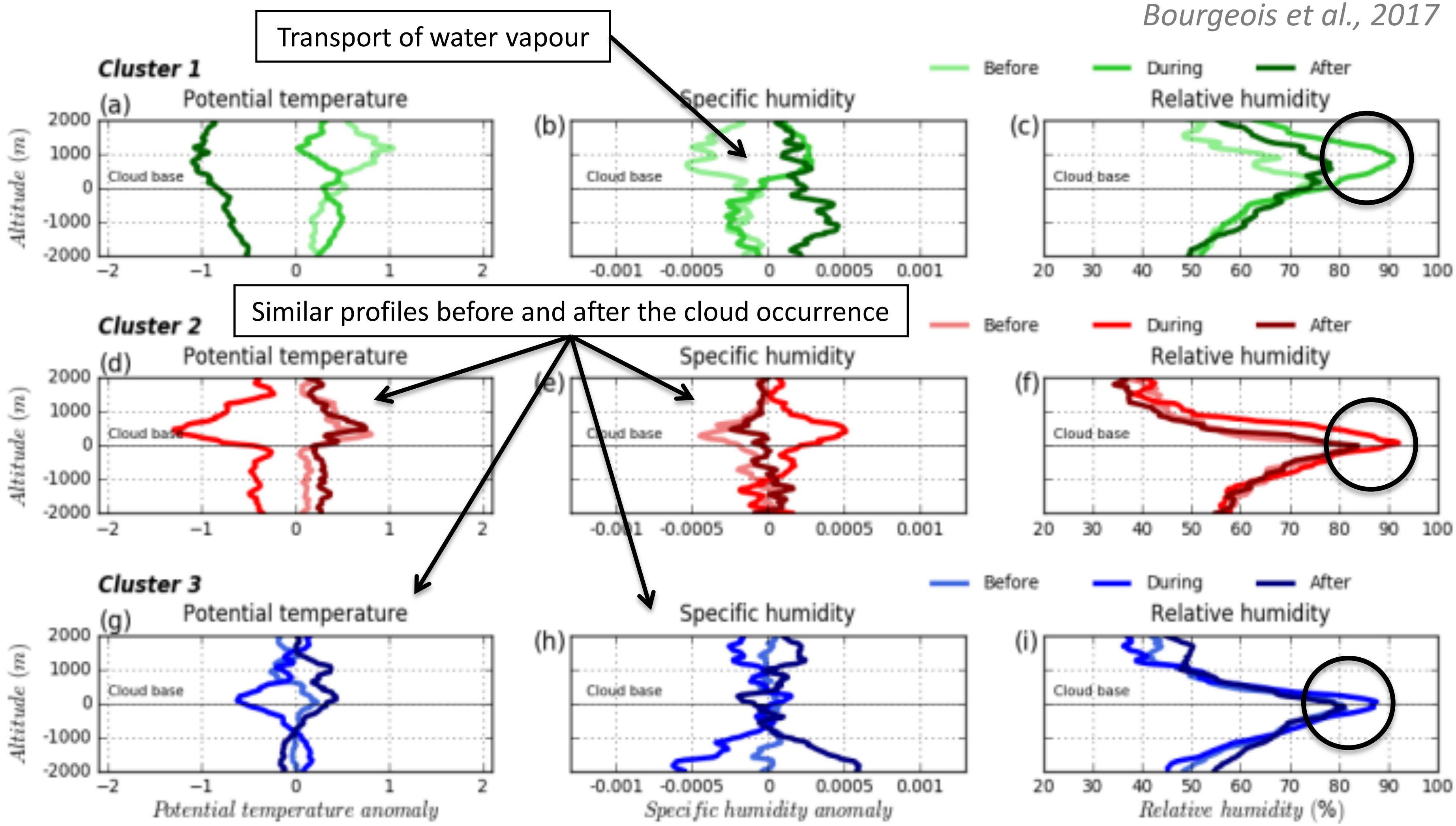
Radiative characteristics



IV. Multi-type of mid-level clouds in West Africa

Thermodynamic profiles – Niamey 2006

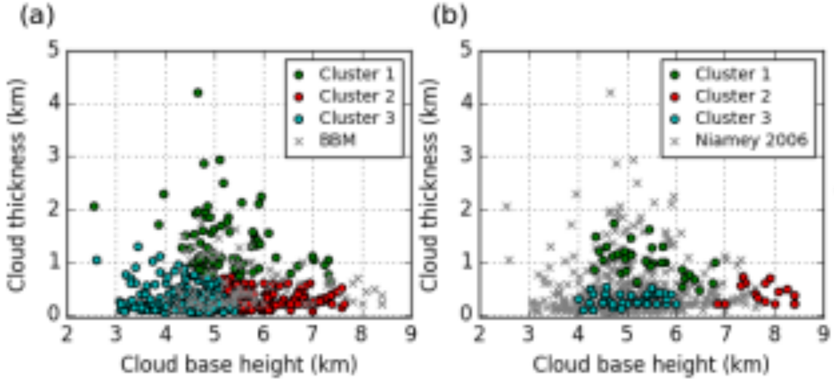
Bourgeois et al., 2017



Composites of vertical profiles of thermodynamic characteristics, potential temperature, specific humidity and relative humidity, from radiosondes at ARM station at Niamey in 2006

IV. Diversity of mid-level clouds in West Africa (6)

Summary – Niamey ARM Station - 2006

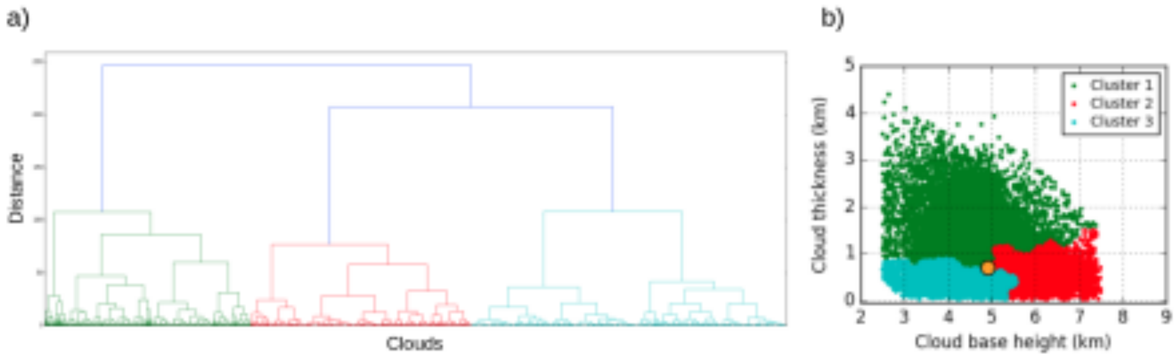


Cloud base height – cloud thickness distribution of the three clusters with the clouds observed at BBM in June 2011.

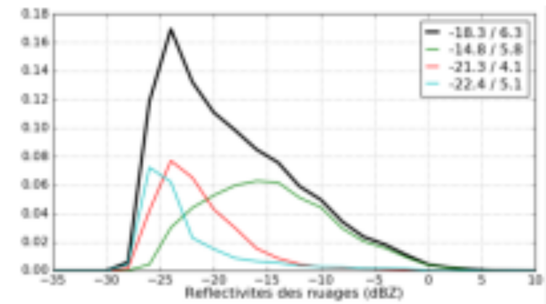
Three clusters obtained at BBM too

IV. Diversity of mid-level clouds in West Africa (6)

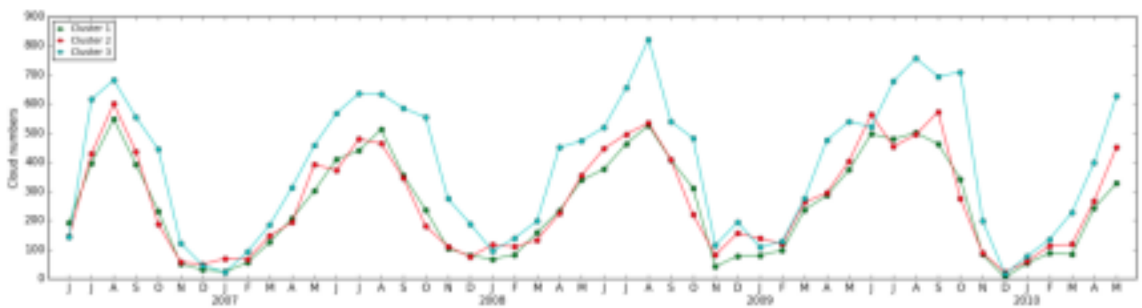
Clustering applied on CloudSat-CALIPSO data (June 2006 – May 2010)



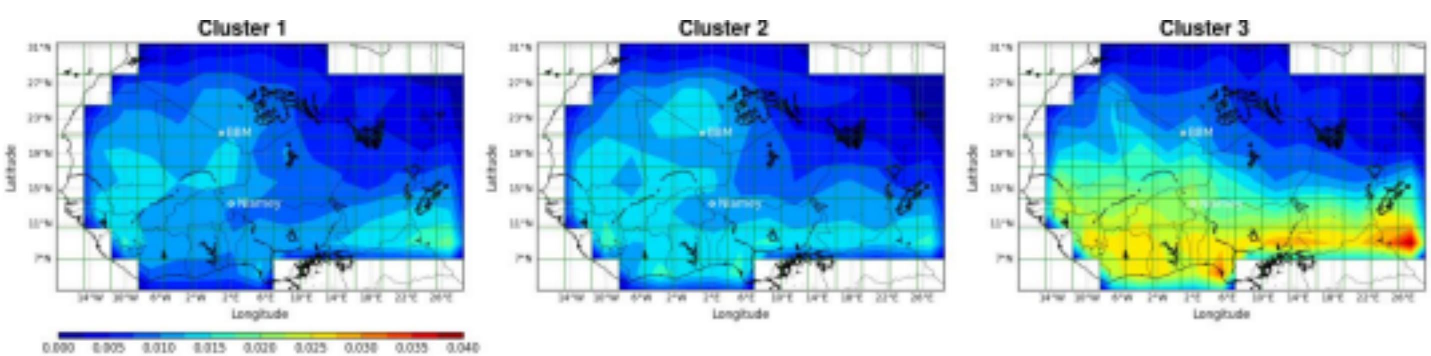
(a) Dendrogram obtained from clustering method and (b) distribution of the cloud thickness and cloud base.



Distribution of the reflectivity.

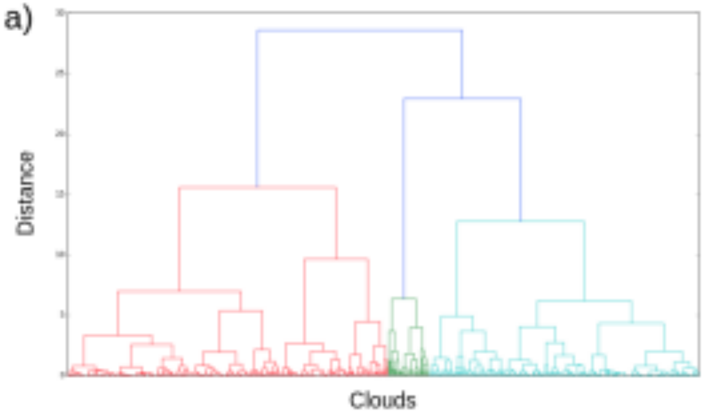


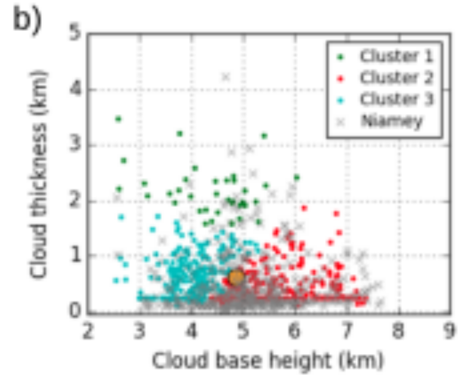
Annual frequency occurrence of mid-level clouds number for each cluster.

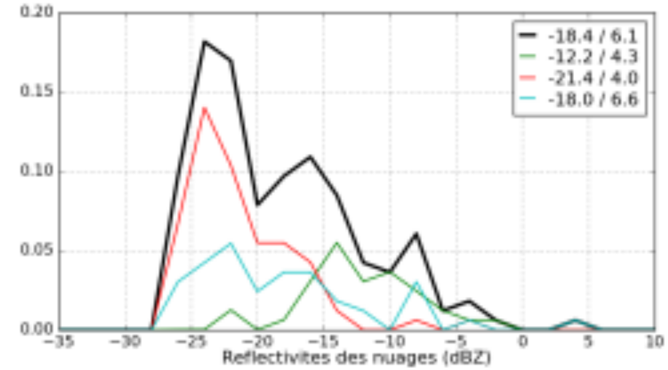


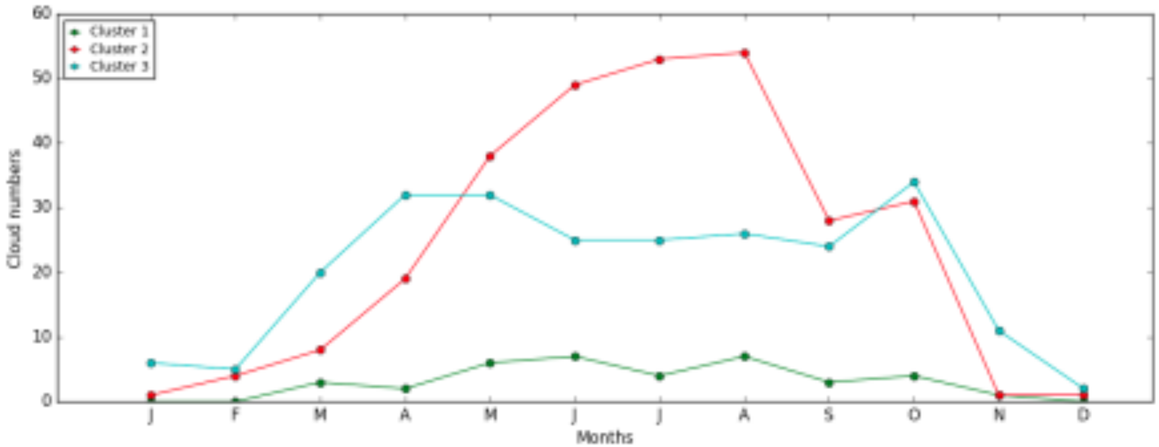
Geographical repartition of mid-level clouds for each of the three clusters

Clustering applied on CloudSat-CALIPSO data in Niamey (June 2006 – May 2010)

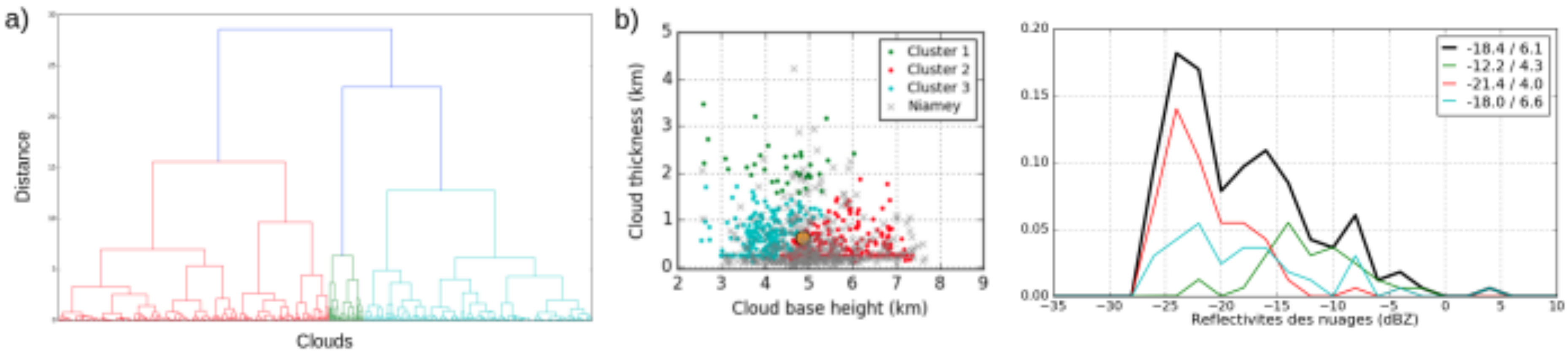








Clustering applied on CloudSat-CALIPSO data in Niamey (June 2006 – May 2010)



Mois	J	F	M	A	M	J	J	A	S	O	N	D
2006	-	-	-	-	-	8	34	27	25	21	0	0
2007	0	0	11	14	19	25	10	23	11	9	5	2
2008	4	0	5	15	36	17	15	27	17	20	2	1
2009	3	9	15	14	6	31	23	10	2	19	6	0
2010	0	0	0	10	15	-	-	-	-	-	-	-
Total	7	9	31	53	76	81	82	87	55	69	13	3

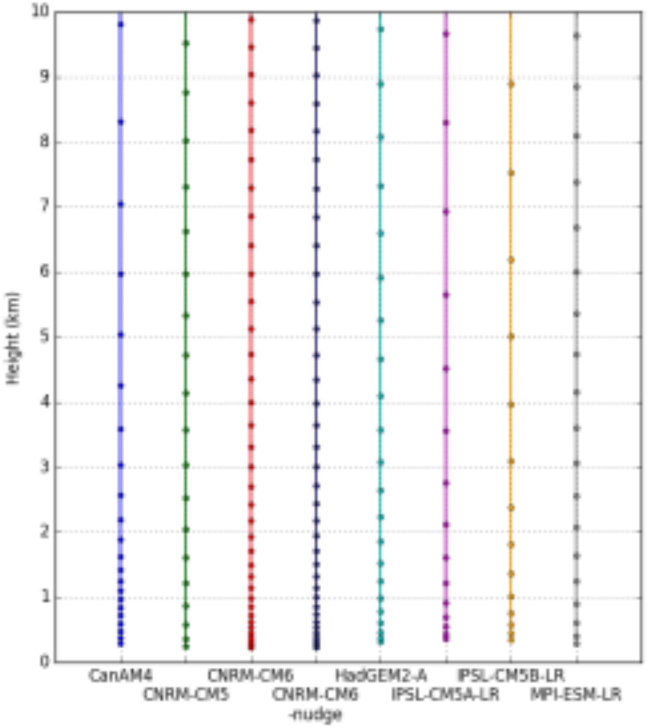
V. Representation of mid-level clouds in models

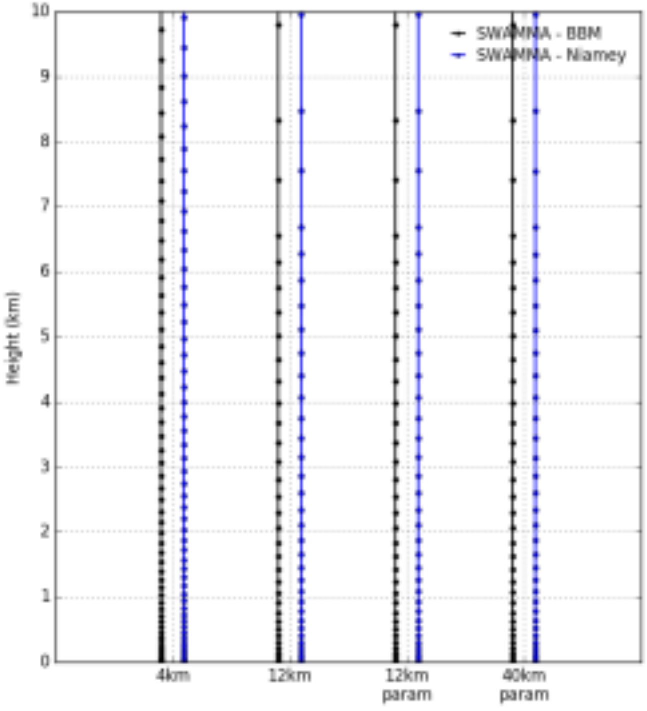
Climate models at Niamey

Modèles de Climat	Institut, Pays	Résolution horizontale	Nombre de niveaux verticaux	Périodes
CanAM4	Centre Canadien de la Modélisation et de l'Analyse Climatique, Canada	T63 (1.875° x 1.875°)	35	2006
CNRM-CM5	Centre National de Recherches Météorologiques (CNRM-CERFACS), Météo-France, France	T127 (1.4° x 1.4°)	31	2007
HadGEM2-A	Centre Hadley pour la Recherche et la Prévision Climatique, Royaume-Uni	1.25° x 1.875°	38	2006
IPSL-CM5A	Institut Pierre Simon Laplace (IPSL), France	1.895° x 3.75°	39	2006
IPSL-CM5B	Institut Pierre Simon Laplace (IPSL), France	1.895° x 3.75°	39	2006
MPI-ESM-LR	Institut Max-Planck de Météorologie (MPI-M), Hamburg, Allemagne	T63 (1.875° x 1.875°)	47	2006

V. Representation of mid-level clouds in models

Climate models at Niamey

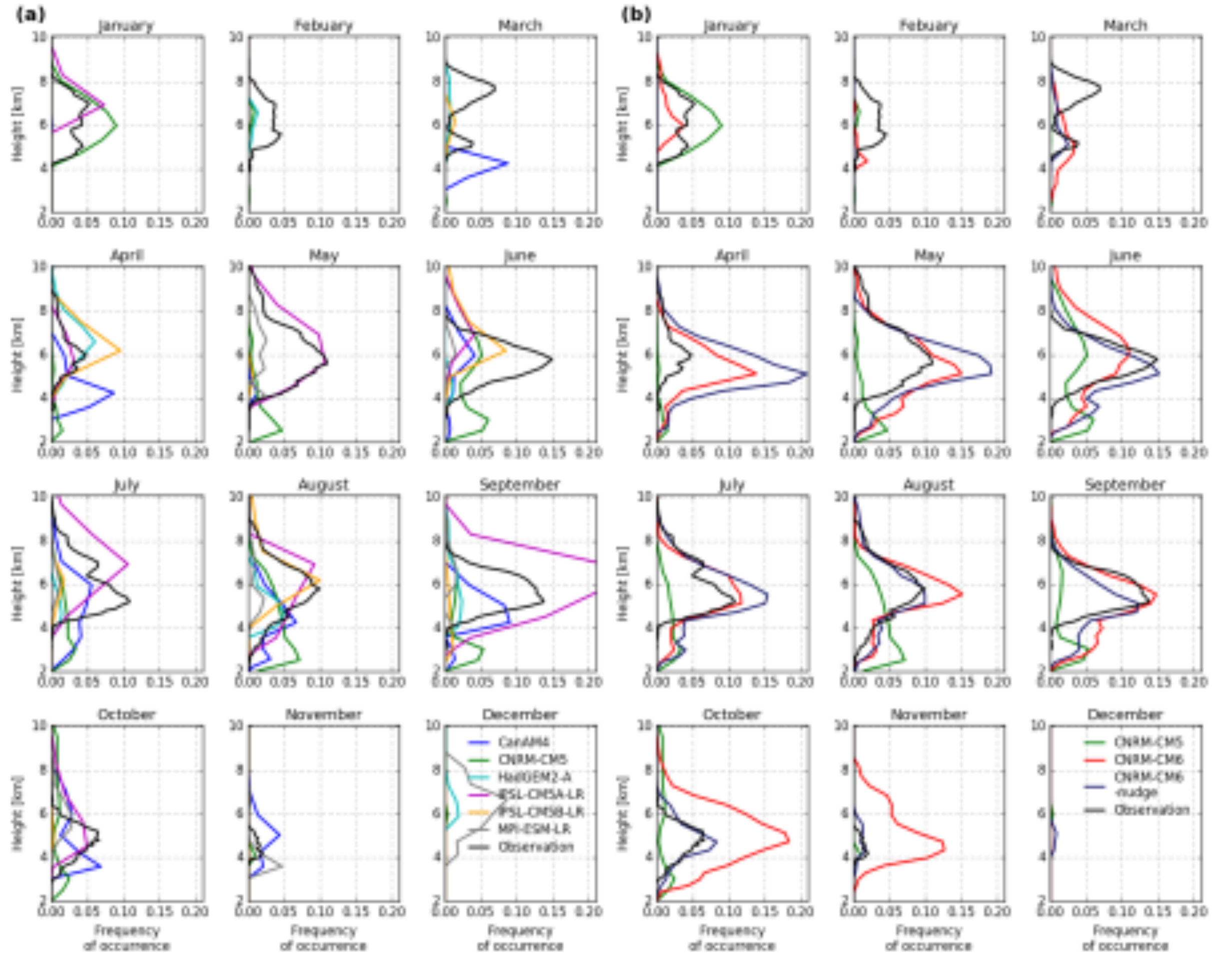




V. Representation of mid-level clouds in models

Climate models at Niamey

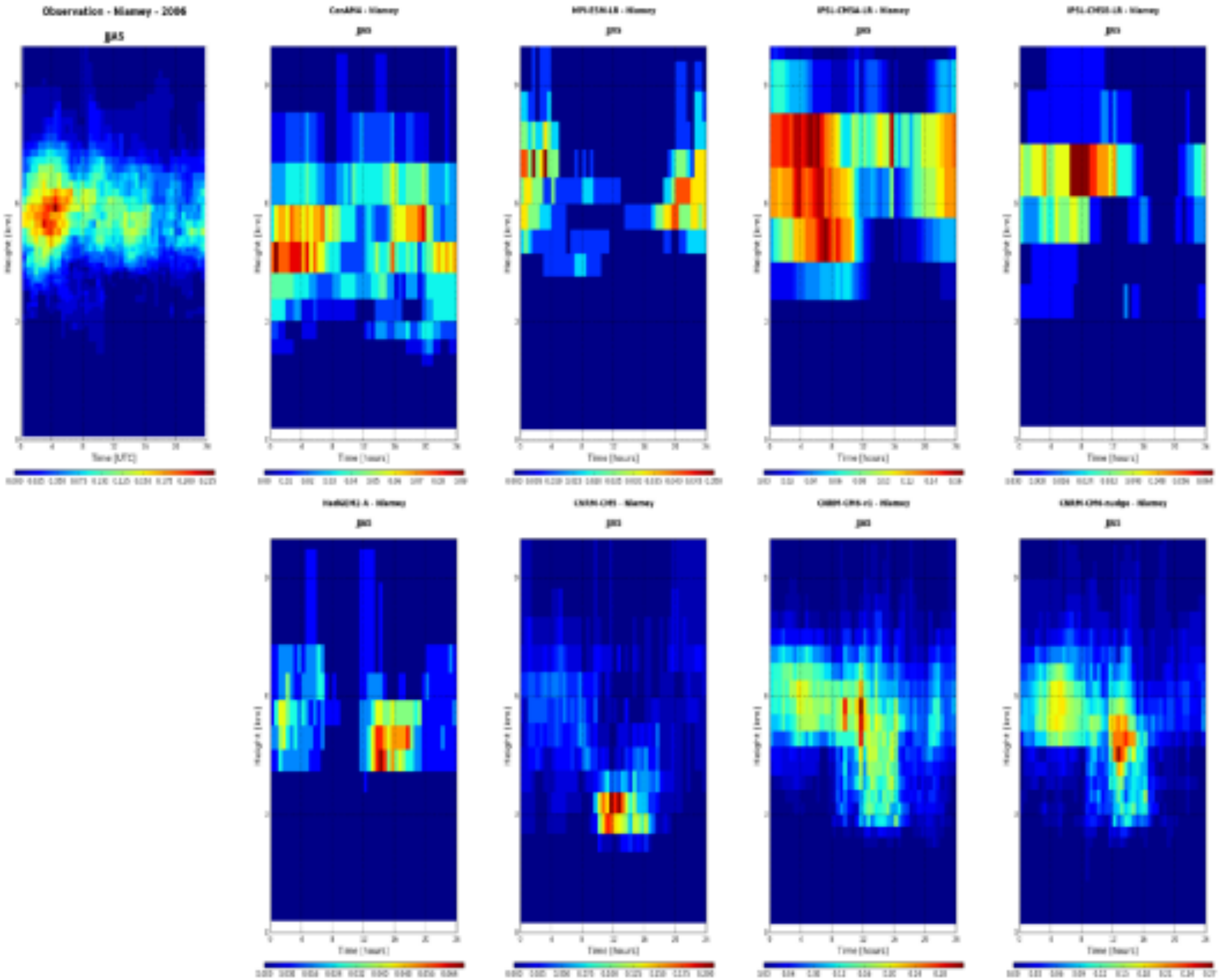
- …



Mid-level clouds frequency of occurrence

V. Representation of mid-level clouds in models (2)

Climate models at Niamey

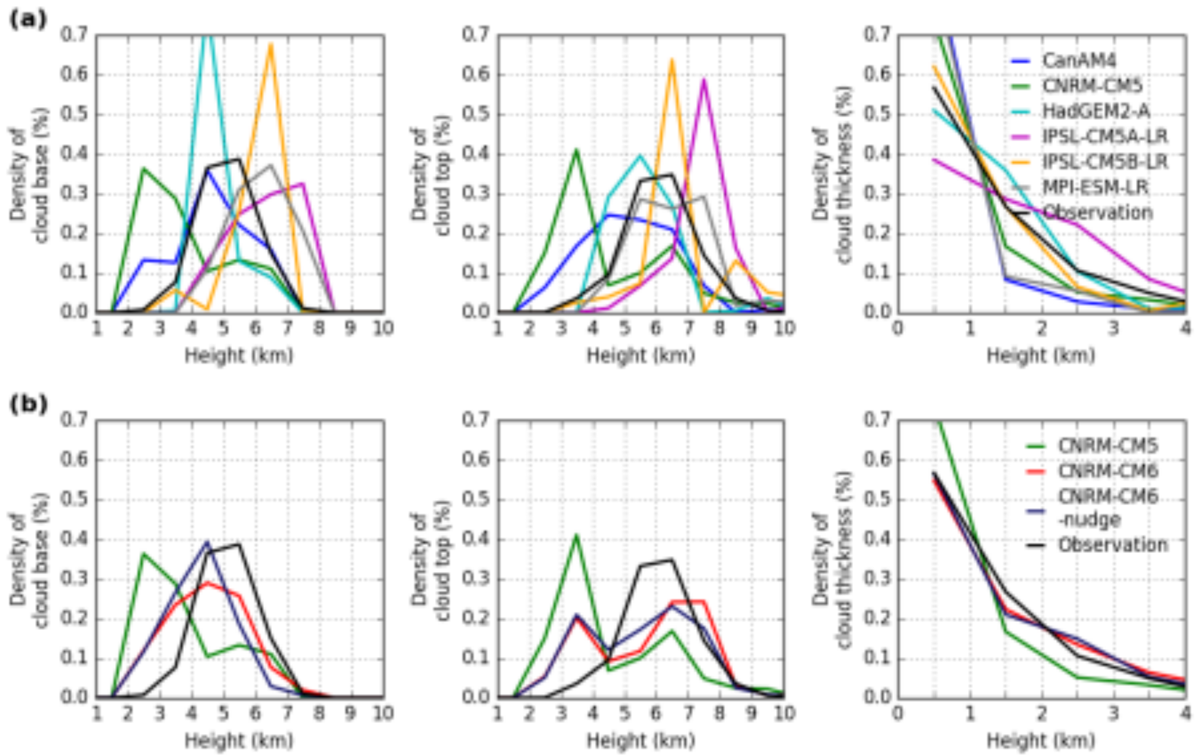


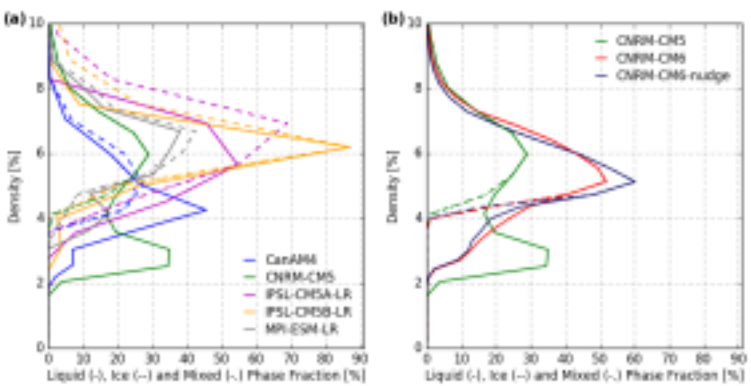
Monthly diurnal cycle of mid-level clouds

V. Representation of mid-level clouds in models

Climate models at Niamey

Macrophysics characteristics of mid-level clouds

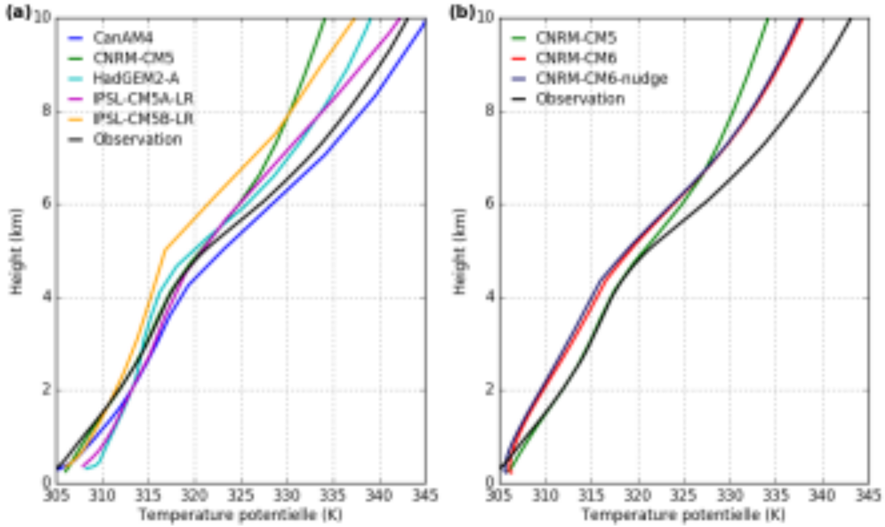




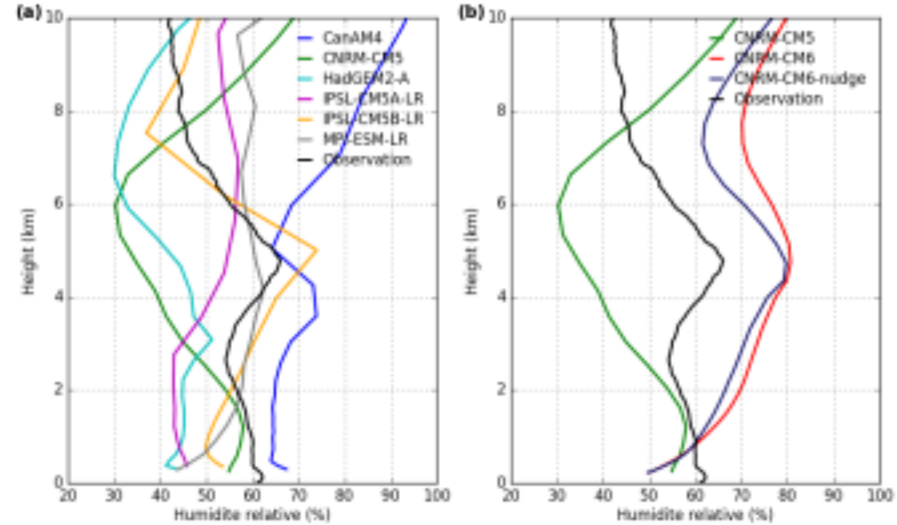
Microphysics characteristics of mid-level clouds

V. Representation of mid-level clouds in models (4)

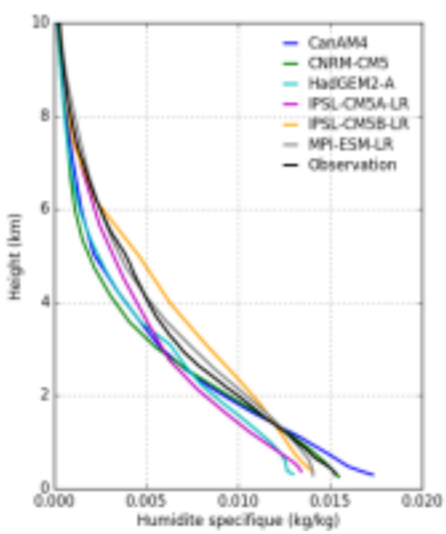
Climate models at Niamey

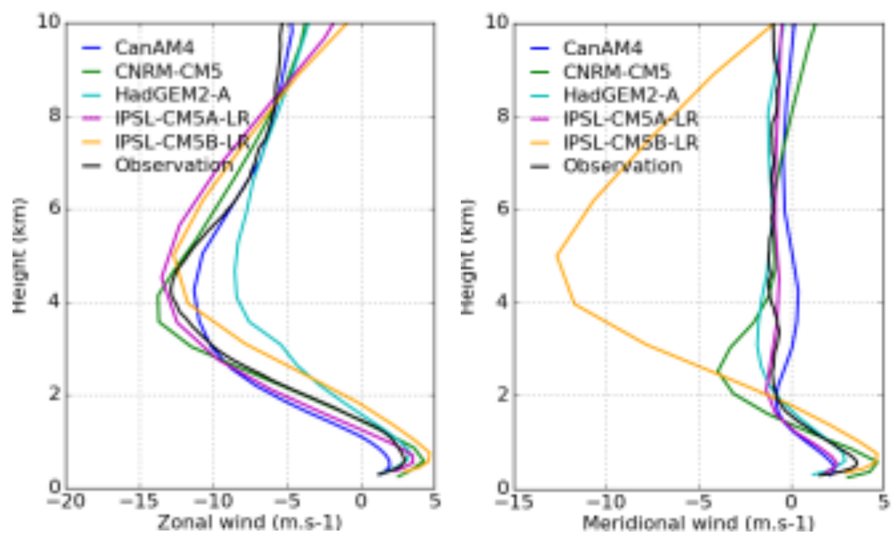


Profiles of potential temperature



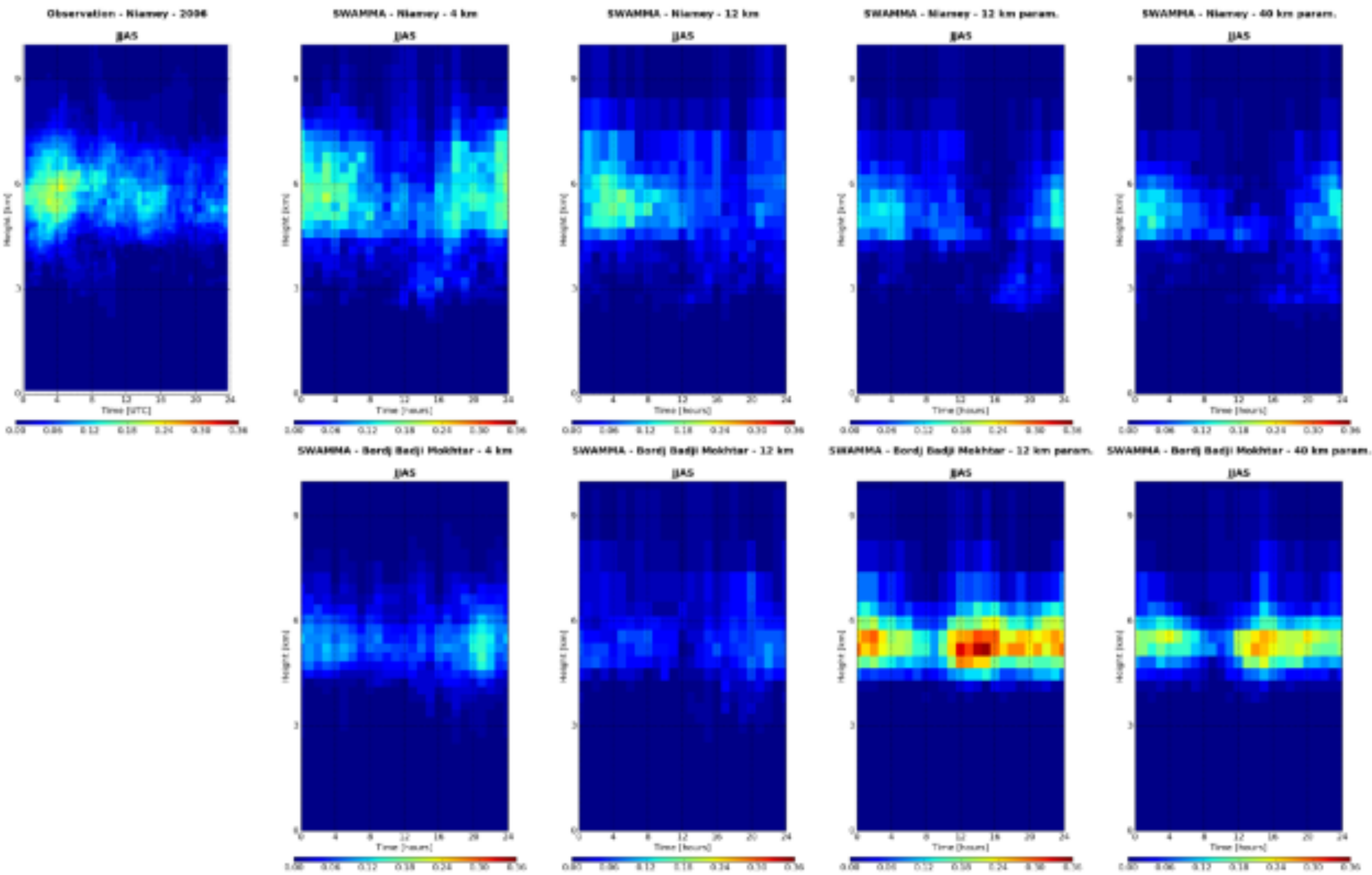
Profiles of relative humidity





V. Representation of mid-level clouds in models (6)

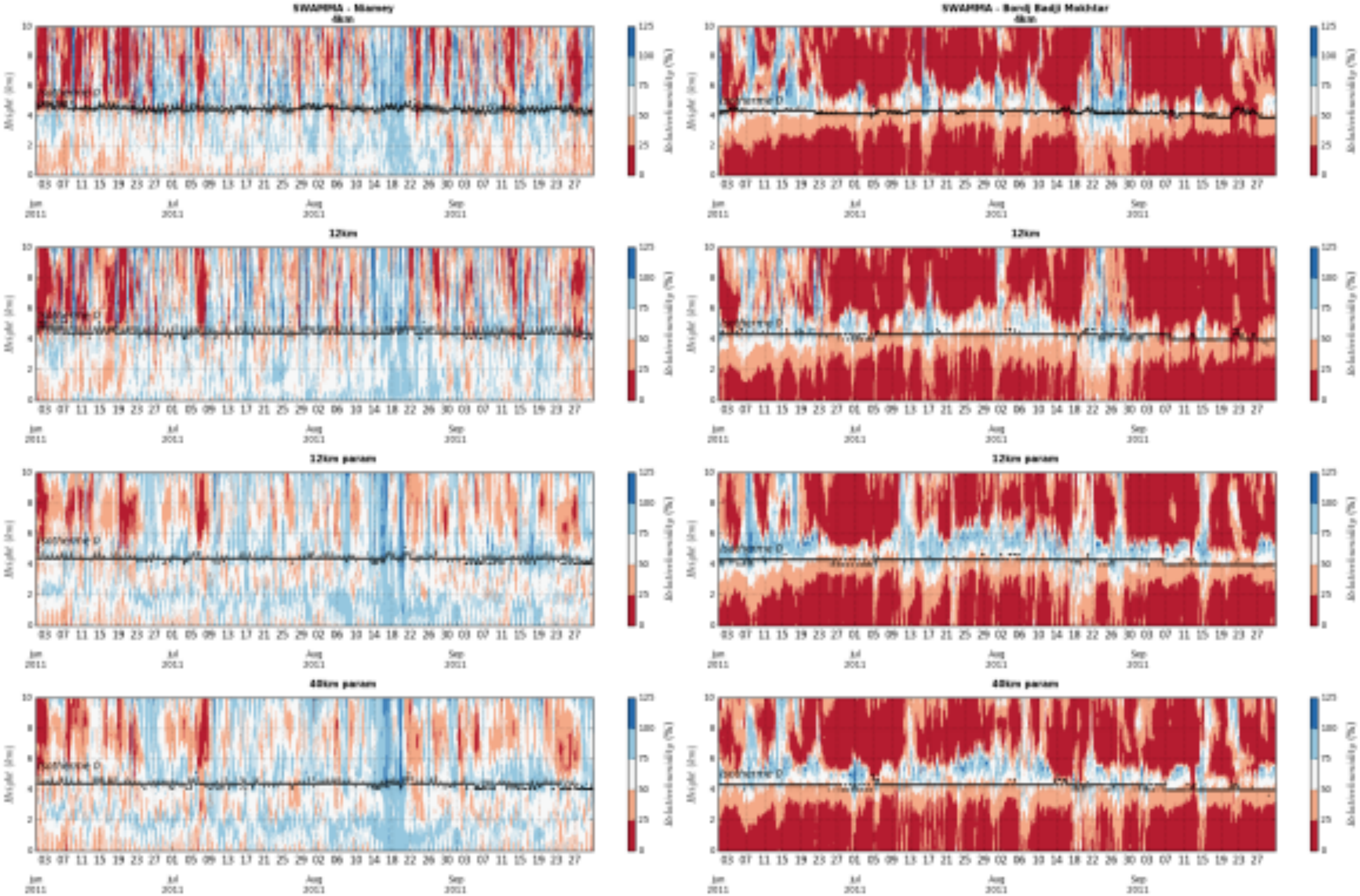
Regional simulations SWAMMA



Monthly diurnal cycle of mid-level clouds

V. Representation of mid-level clouds in models (8)

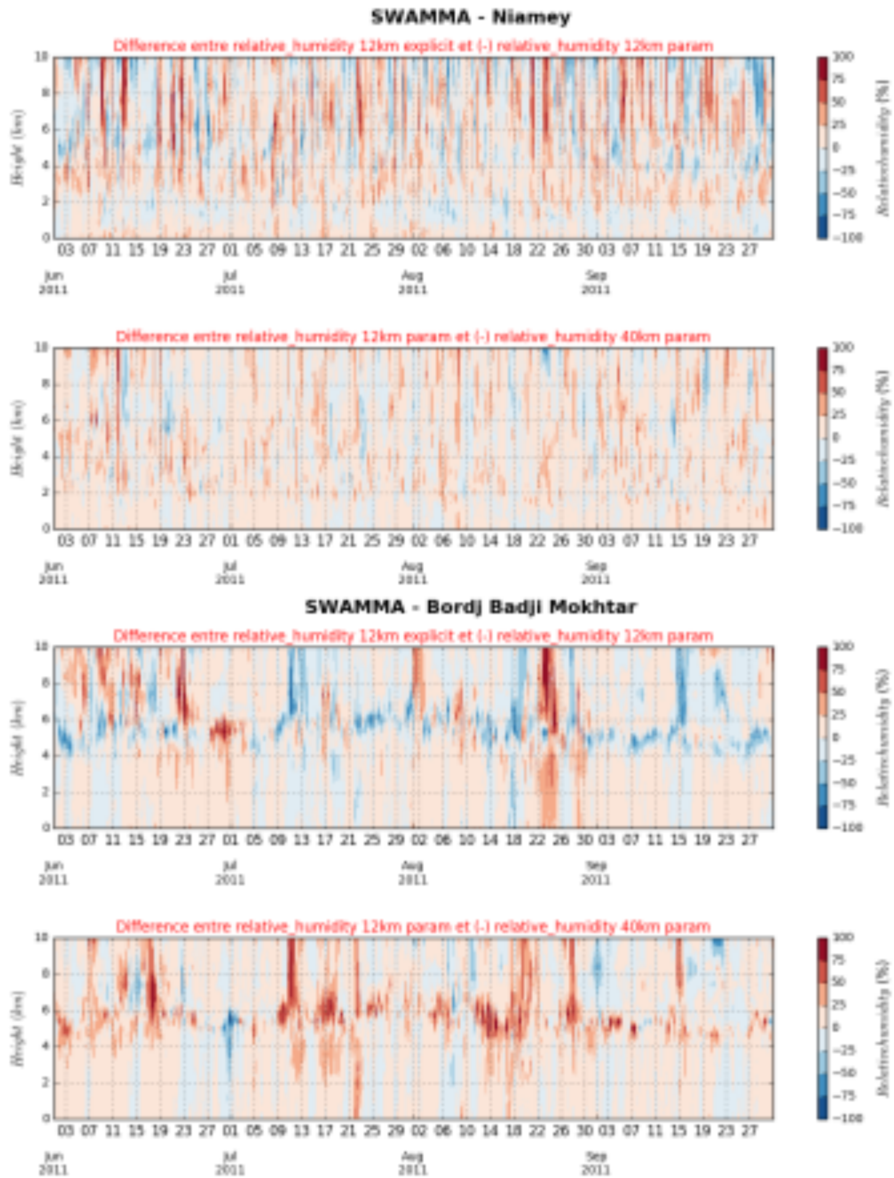
Regional simulations SWAMMA



Relative humidity in JJAS

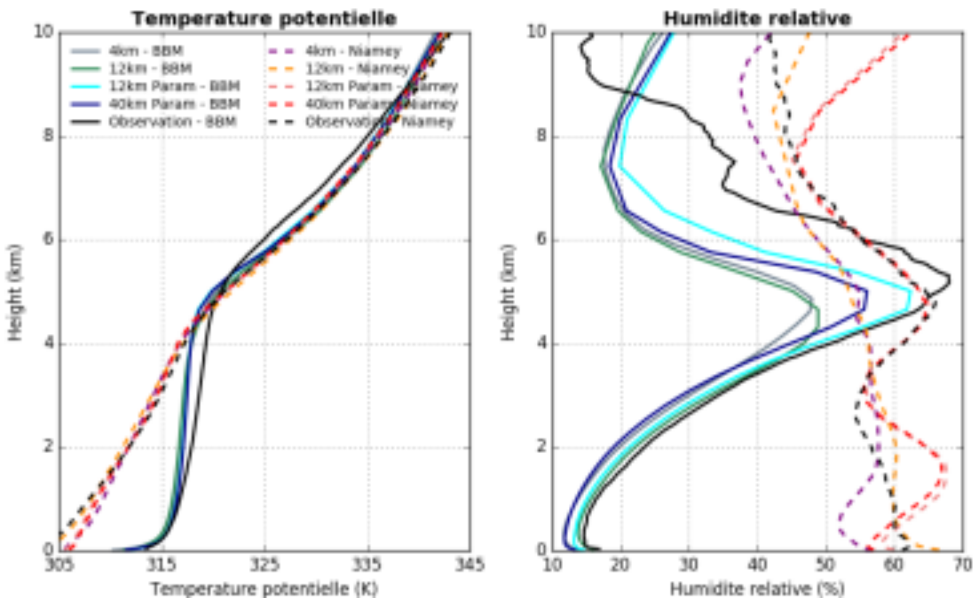
Regional simulations SWAMMA

Relative humidity



V. Representation of mid-level clouds in models (9)

Regional simulations SWAMMA



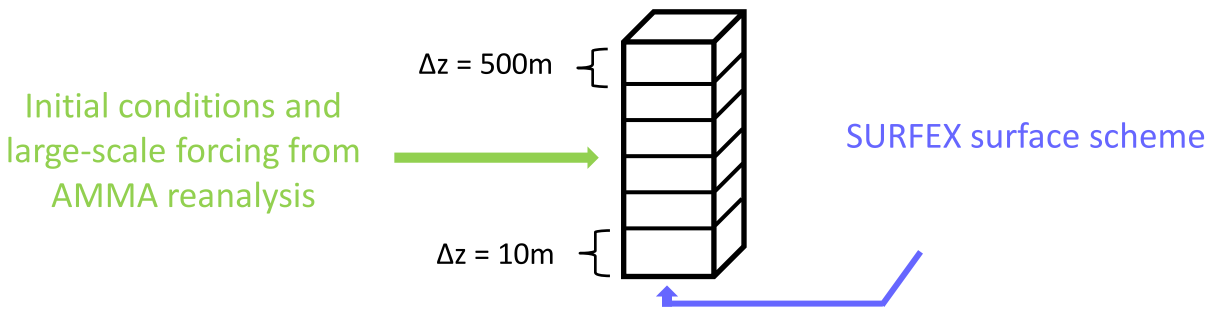
Profiles of (a) potential temperature and (b) relative humidity.

Profils de u et v

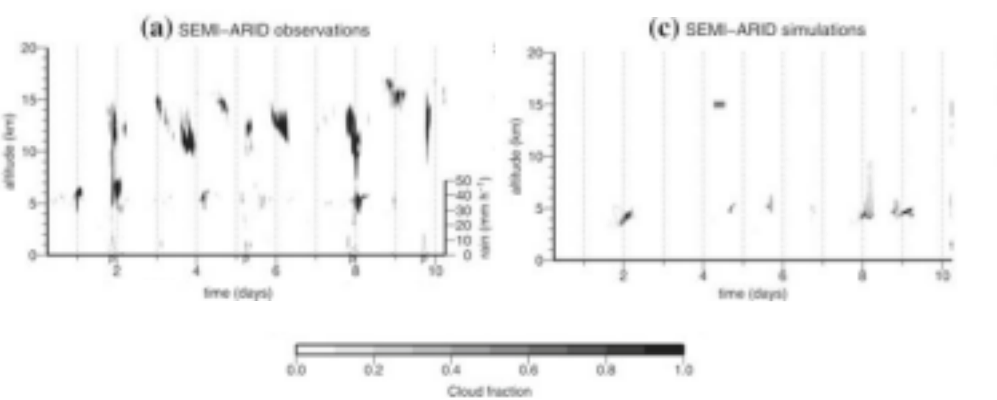
Cloud simulations with model meso-NH in 1D configuration

1D Simulation - ARM Niamey (Niger) - Semi-arid regime (Gounou et al., 2012)

From the 20 to the 30 june of 2006

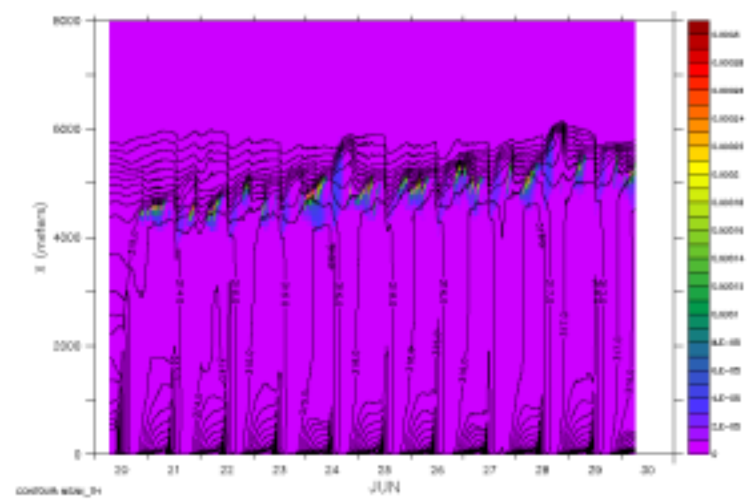


10 * 1 day



*Simulated and observed vertical profiles of cloud fraction at ARM station of Niamey on 10*1 day. (Couvreux et al., 2014)*

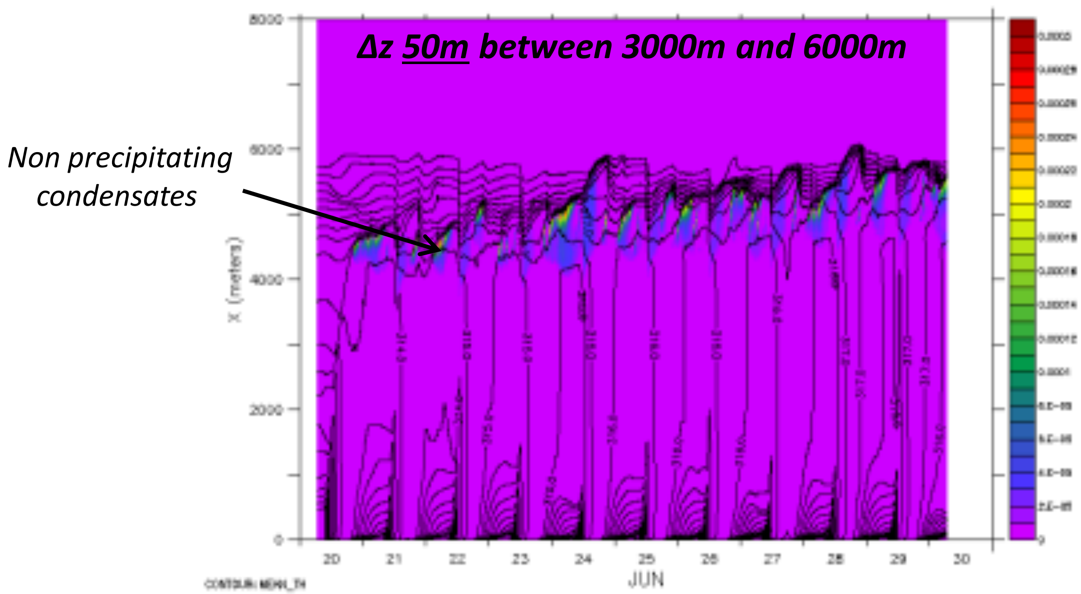
1 * 10 days



*Simulated vertical profiles of non precipitating condensates on 1*10 days and corresponding theta profiles.*

Cloud simulations with model meso-NH in 1D configuration

Sensitivity test to vertical resolution (50m – 1000m)

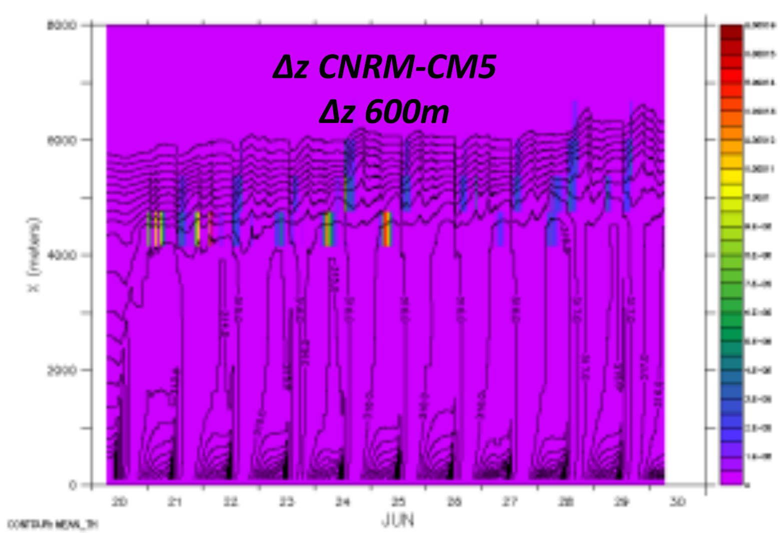


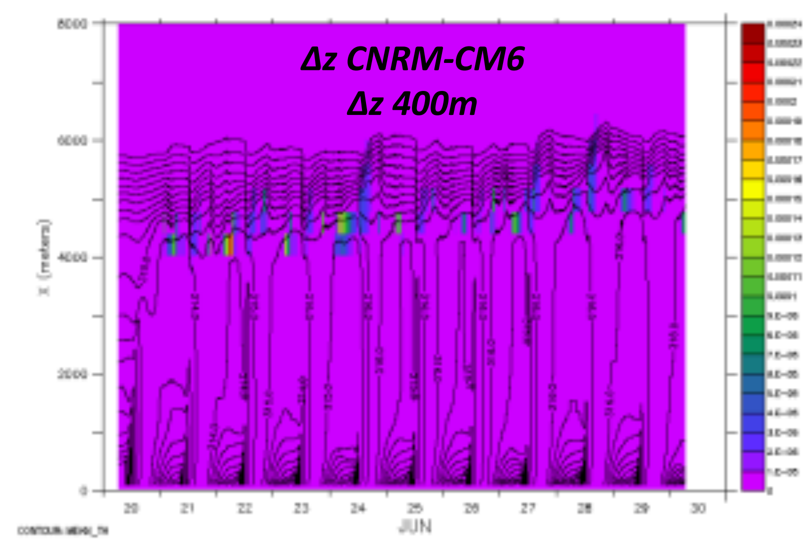
The **finer vertical resolution**,

i) The more **accurate the representation** of clouds,

ii) The **lower the cloud tops** and the **higher the cloud bases**,

iii) The **higher the liquid/ice water fraction at the top** of the clouds.





West Africa – Aerosol – 2001/2006
Malavelle et al., 2011
Long-term simulations (2001-2006) of biomass burning and mineral dust optical properties over West Africa : comparisons with new satellite retrievals