Estimation of cloud radiative impacts over West Africa, seasonal and meridional patterns.

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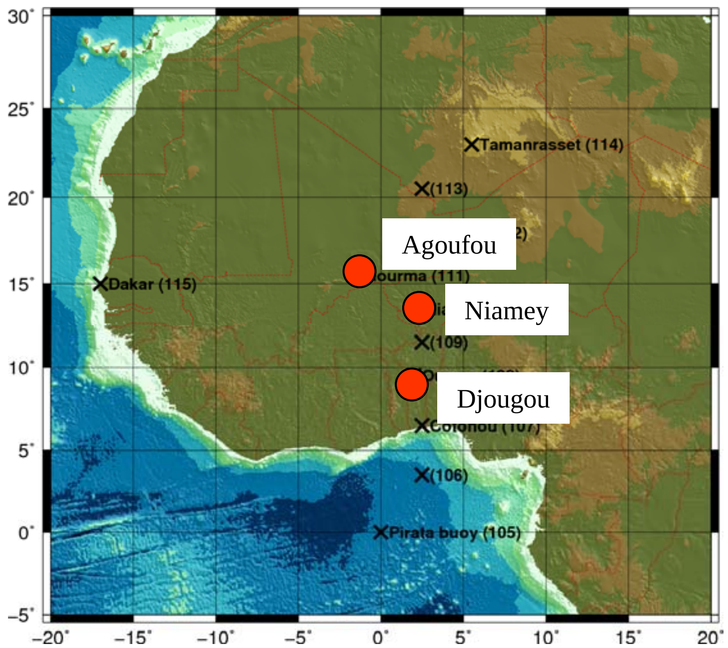
Context and objectives

West Africa specificities:
- Continental zone with large meridional gradient in temperature, rain and vegetation.
- Large annual cycle of humidity, temperature, aerosols, clouds and rain related to the West African Monsoon.
- Large atmosphere loading of mineral dust (Slingo, 2006).
- Different cloud types occur in this region (Bouniol et al, 2012)

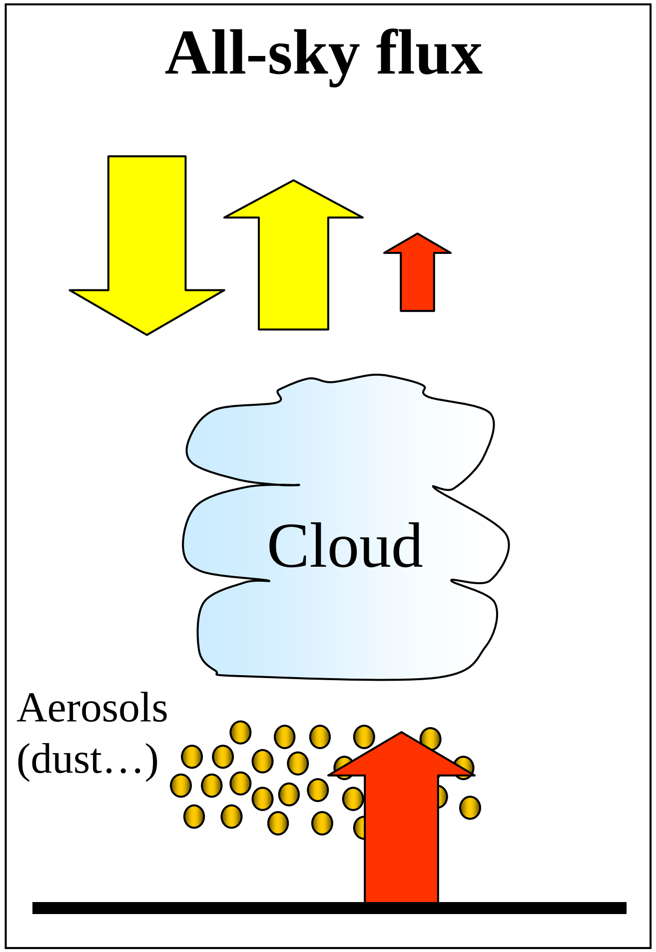


Objective:
Determination of the CRE
- At different location (meridional **transect**)
- **Seasonal variability**
- For **different cloud types**
- At **TOA** and **surface**

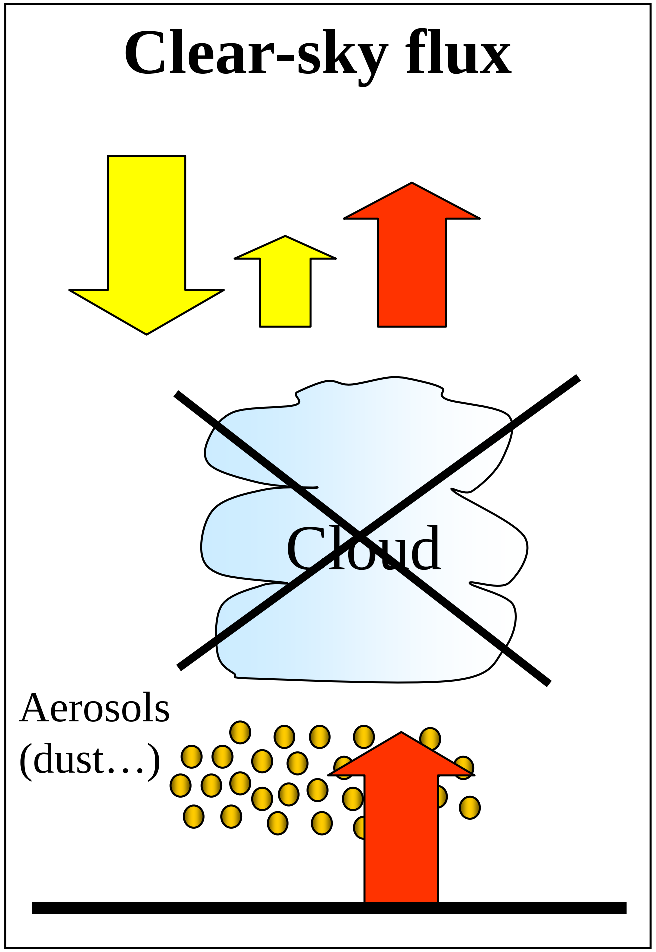
→ Identification of main bias in GCMs

Method

CRE=



minus



Non observed
→ Use of a Radiative transfert model:

Method: use of a Radiative transfer model to evaluate clear-sky fluxes

Data and method

Data from AMMA, ARM, AMMA-CATCH

RRTM Inputs
→ Greenhouse gazes from RRTM climatology.
→ **Humidity** and **temperature profiles** from radiosondes extended by ECMWF AMMA reanalysis in the stratosphere.
Radiosonde (4 to 8 per day)
ECWMF AMMA reanalysis (4 per day),
→ **Aerosols** Optical Depth (**AOD**) and optical properties **SSA**, **AP** from AERONET (1 per hour).
→ Surface albedo from SW surface flux (from AMF)
or LSA-SAF product (*D. Carrer, C. Meurey*)
→ surface temperature from LW flux (from AMF)

Radiative fluxes from RADAGAST, AMMA-CATCH
→**Surface LW / SW** from AMF (**ARM Mobile Facility**)
(temporal resolution: 1 min) *(Slingo et al.,2006; 2009)*
→**TOA LW / SW** from **GERB** data
(temporal resolution: 15 min) *(Slingo et al.,2006; 2009)*

Additional data for analysis
- **Cloud masks (***Illingworth et al., 2007***)** from radar, lidar from AMF
- GPS measurements: Integrated water vapor (1 per hour).
- Precipitation

INPUTS

Radiative transfer model:
- RRTM LW and SW (AER)
(*Iacono et al, 2008; Morcrette et al, 2008*).
- Resolution: 100 levels

Radiatives fluxes
Clear sky - Clean sky
LW - SW
TOA - Surface

CRE (at 30 min resolution)

Plan

I. Focus on Niamey

(full documentation of the structure of the atmosphere, AMF)

- Clean sky, Clear sky
- Cloud radiative effect CRE

II. Meridional Transect

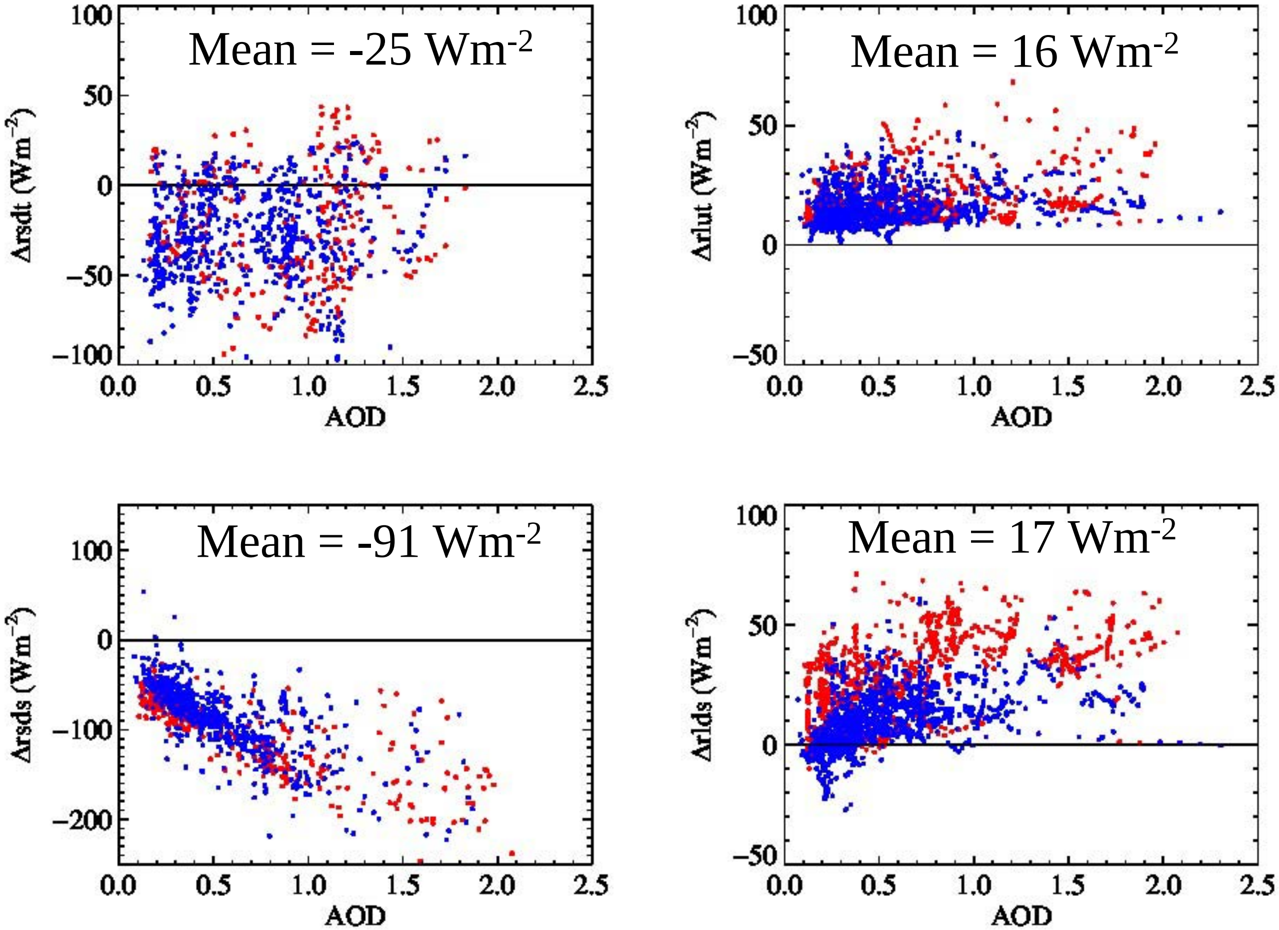
(3 sites: Djougou + Niamey + Agoufou)

OBS-RRTM, clear-sky, without aerosols

SW LW

TOA

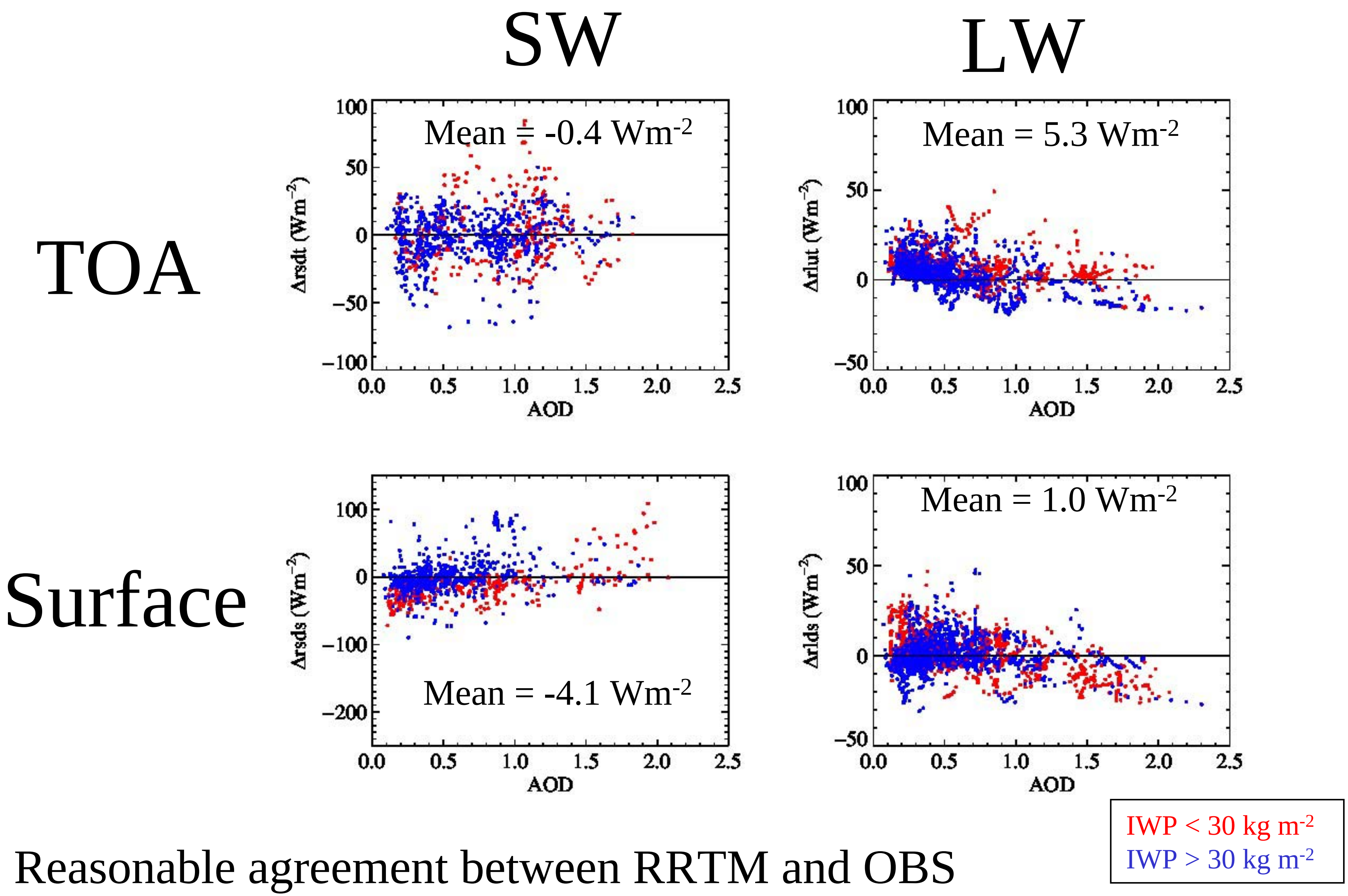
Surface



Bias ~ aerosol radiative effect

IWP < 30 kg m^{-2}
IWP > 30 kg m^{-2}

OBS-RRTM, clear-sky, with aerosols

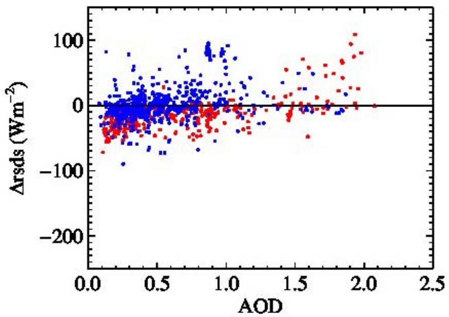


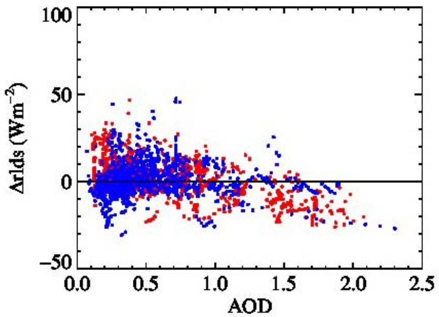
Reasonable agreement between RRTM and OBS

OBS-RRTM & OBS-ECMWF
Clear-sky, surface fluxes

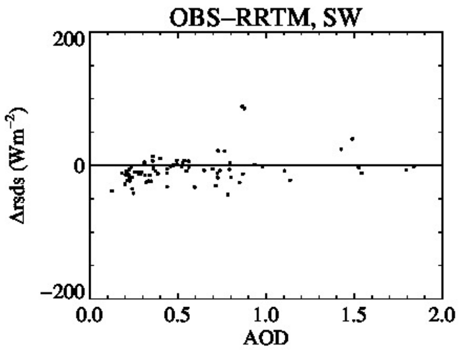
OBS-RRTM, SW | OBS-RRTM, LW | OBS-ECMWF, SW | OBS-ECMWF, LW

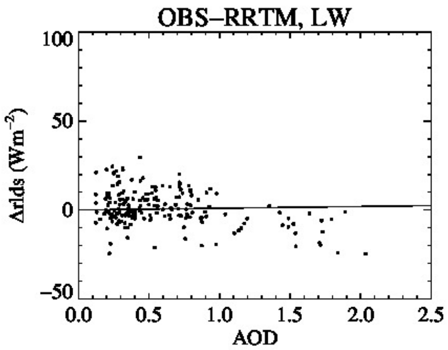
30-min average



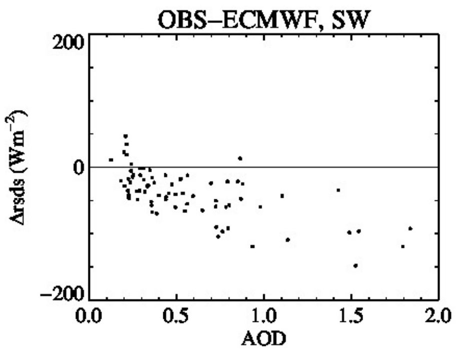


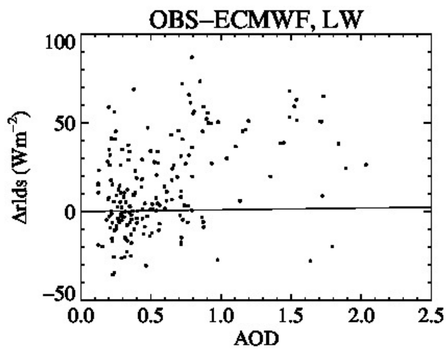
3-H average





3-H average

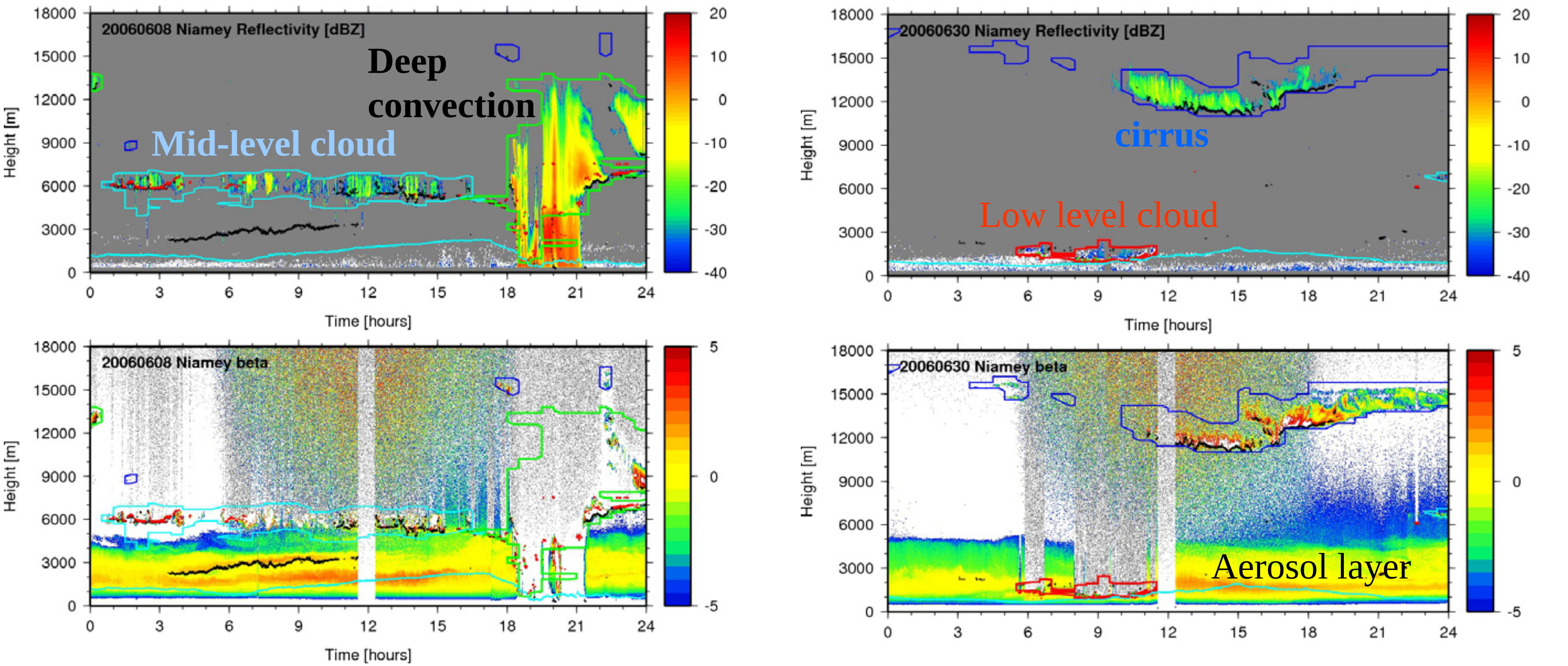




- Better results with **RRTM clear-sky fluxes** (versus ECMWF clear-sky fluxes)

4 Cloud types:
Anvil, cirrus mid-level, low level

Exemple of the different cloud types and aerosol layer diurnal structure

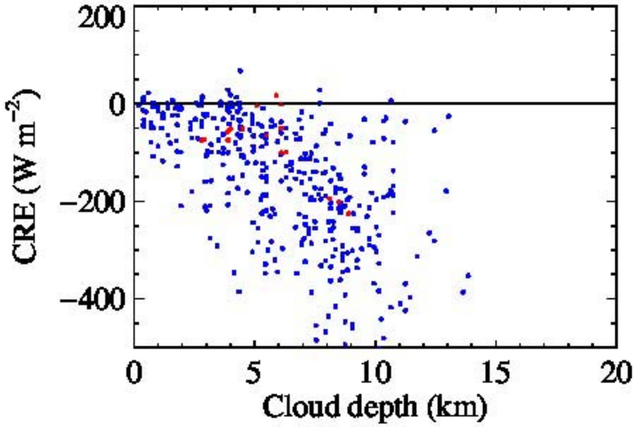


Upper panels: diurnal time serie of radar reflectivity
Bottom panels: diurnal time serie of lidar measurement

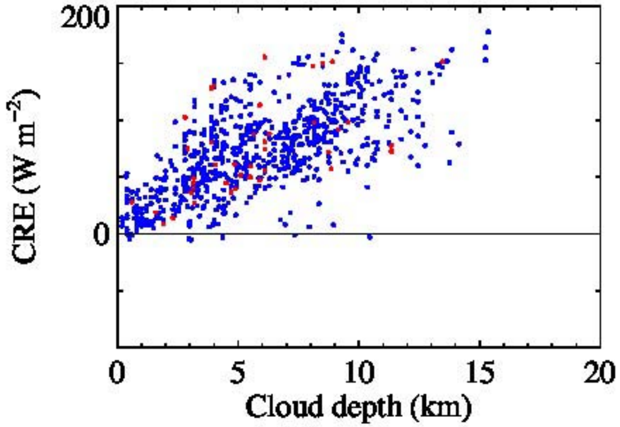
CRE=f(depth), anvil cloud

SW | LW

TOA net

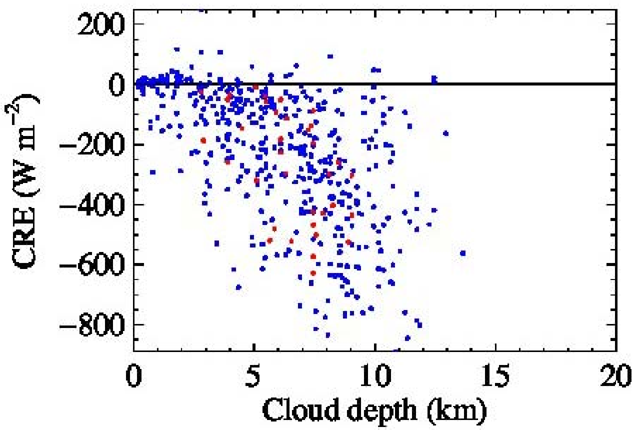


<CRE> = -155 W m^{-2}

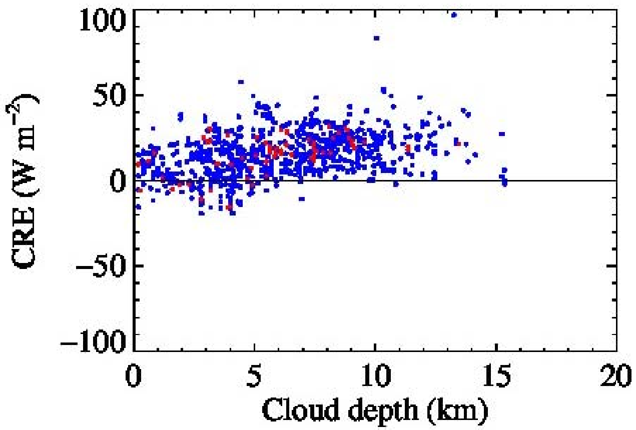


<CRE> = 74 W m^{-2}

Surface downward



<CRE> = -250 W m^{-2}



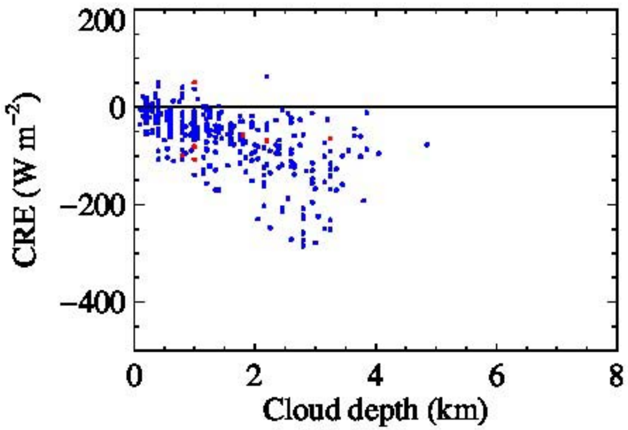
<CRE> = 15 W m^{-2}

CRE=f(depth), mid-level cloud

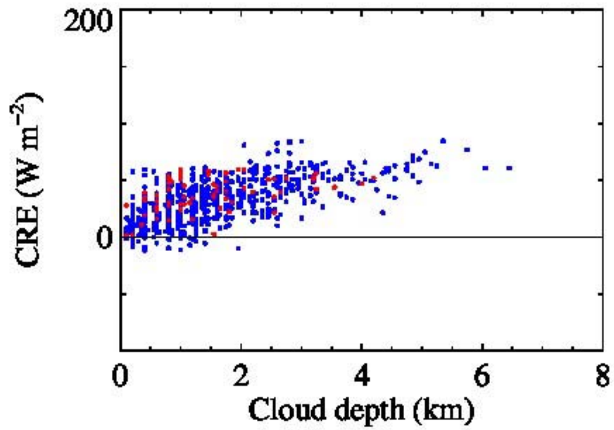
SW

LW

TOA net

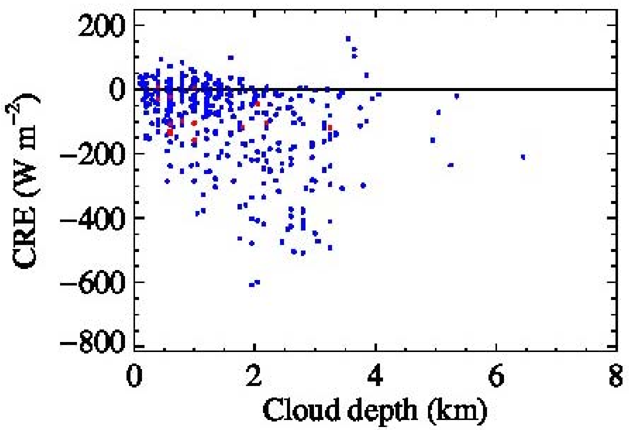


<CRE> = -65 W m^{-2}

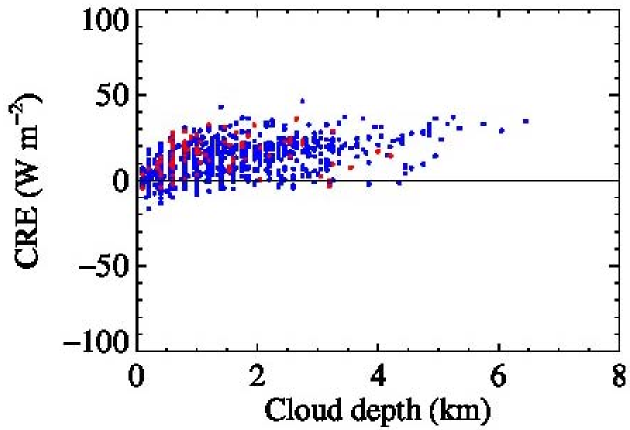


<CRE> = 32 W m^{-2}

Surface downward



<CRE> = -98 W m^{-2}

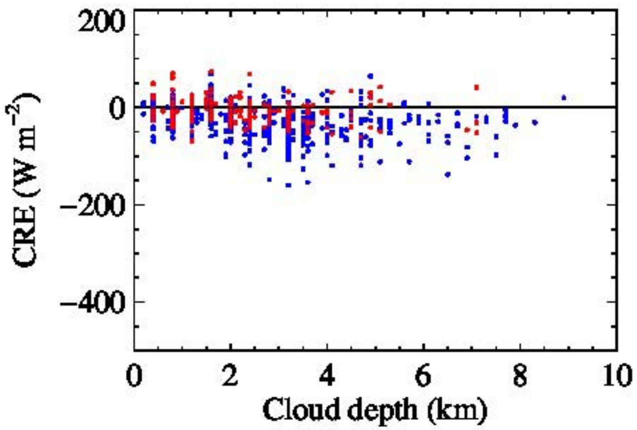


<CRE> = 12 W m^{-2}

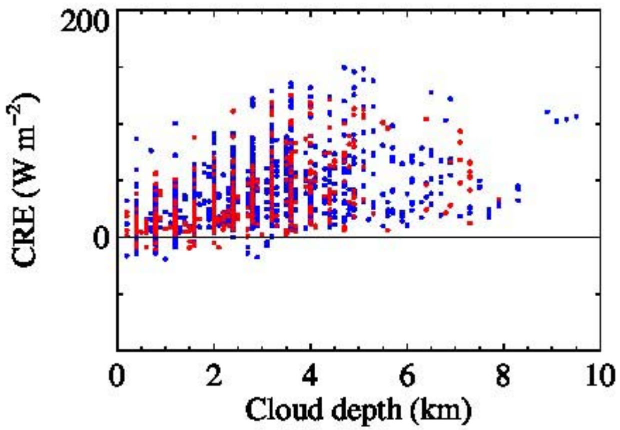
CRE=f(depth), cirrus

SW | LW

TOA net

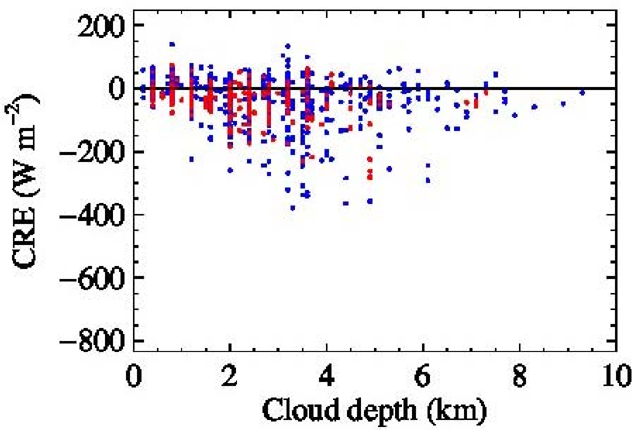


<CRE> = -19 W m^{-2}

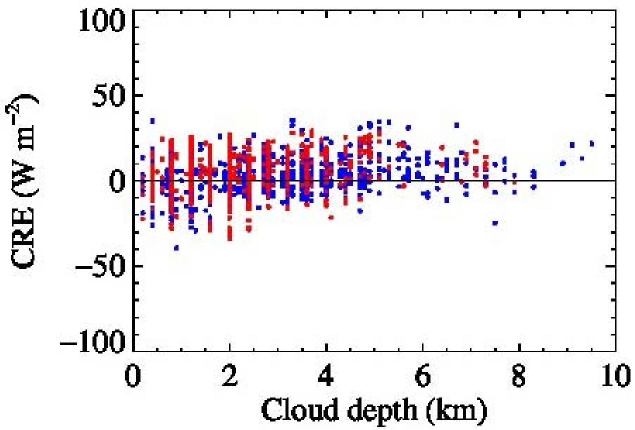


<CRE> = 31 W m^{-2}

Surface downward

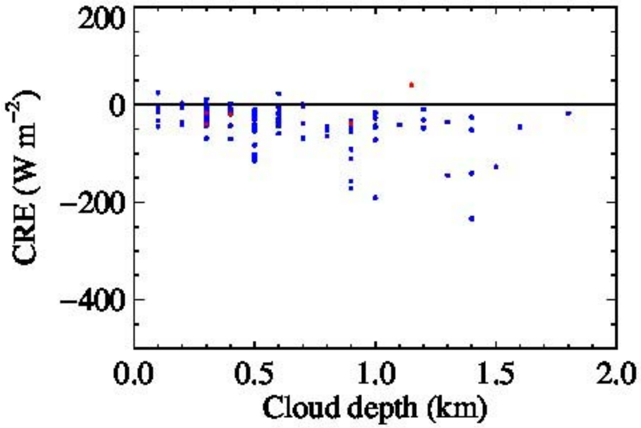
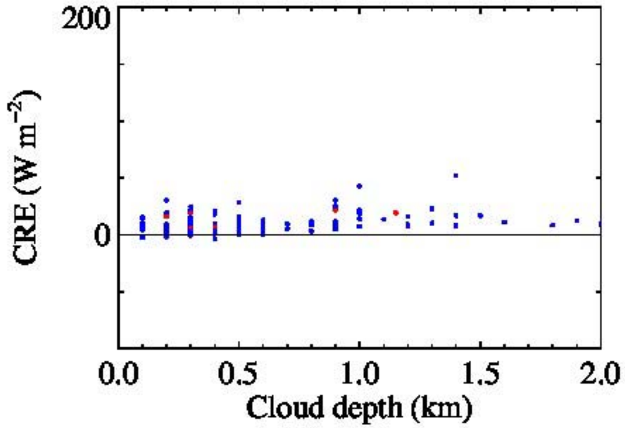
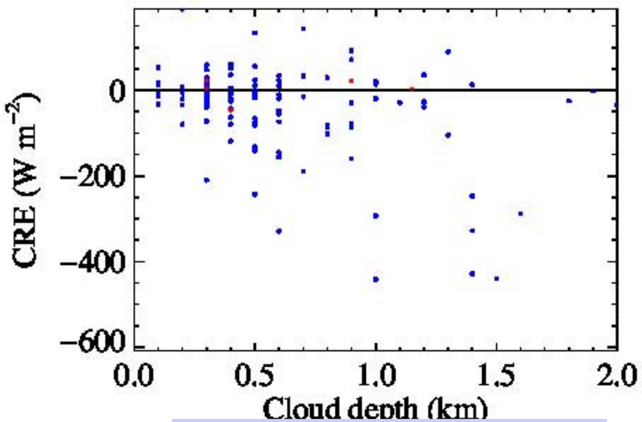
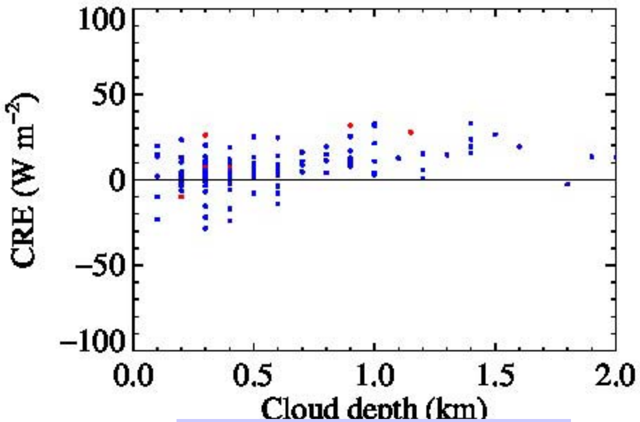


<CRE> = -31 W m^{-2}



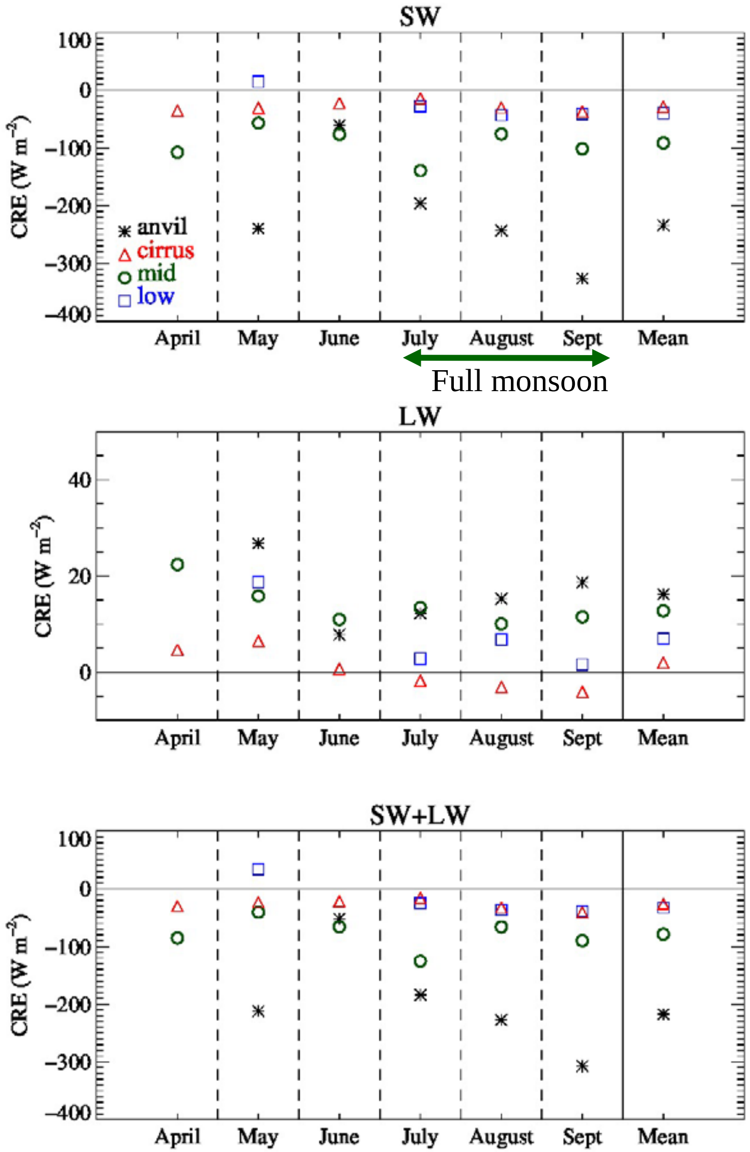
<CRE> = 2 W m^{-2}

CRE=f(depth), low-level cloud

	SW	LW
TOA net		
	<CRE> = -37 W m^{-2}	<CRE> = 9 W m^{-2}
Surface downward		
	<CRE> = -40 W m^{-2}	<CRE> = 7 W m^{-2}

CRE / cloud type - seasonal

Surface downward

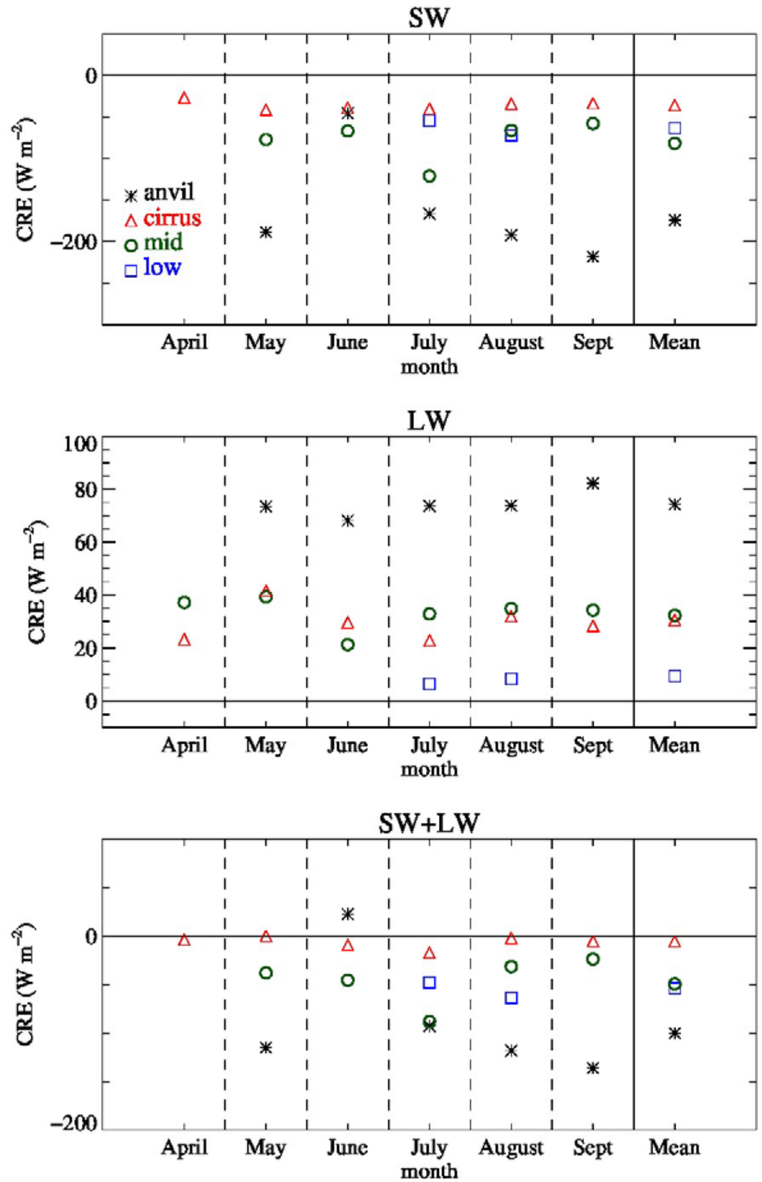


SW

LW

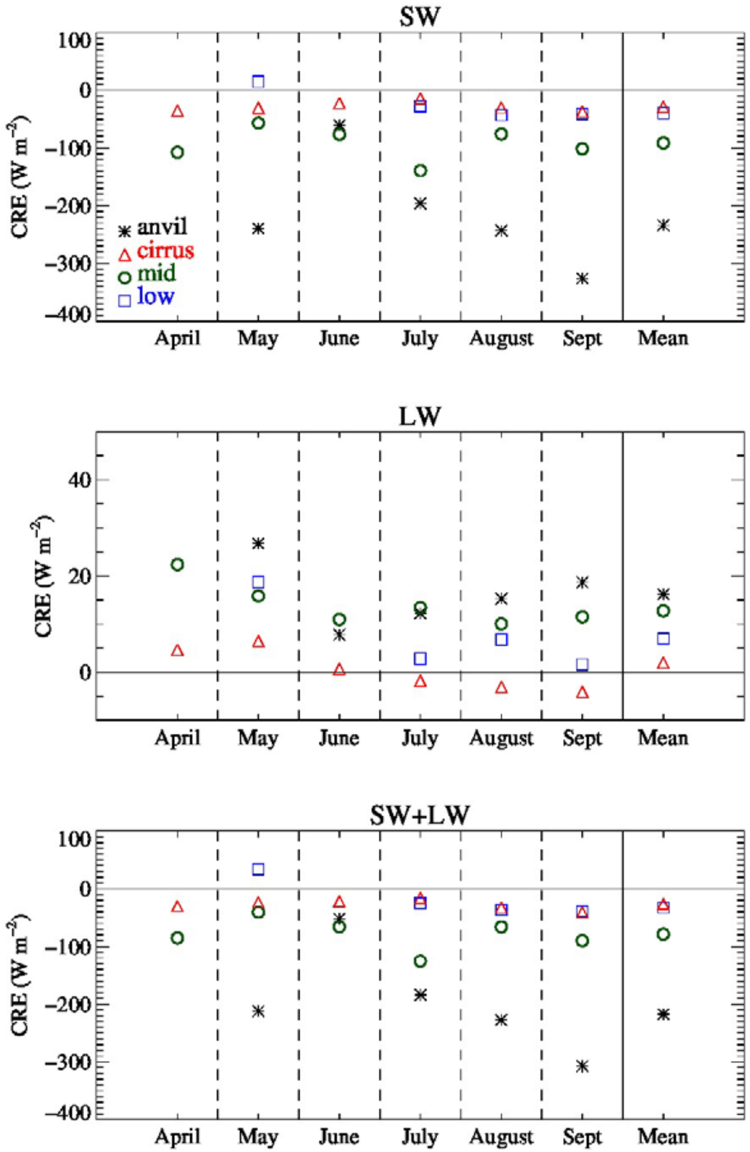
SW
+
LW

TOA

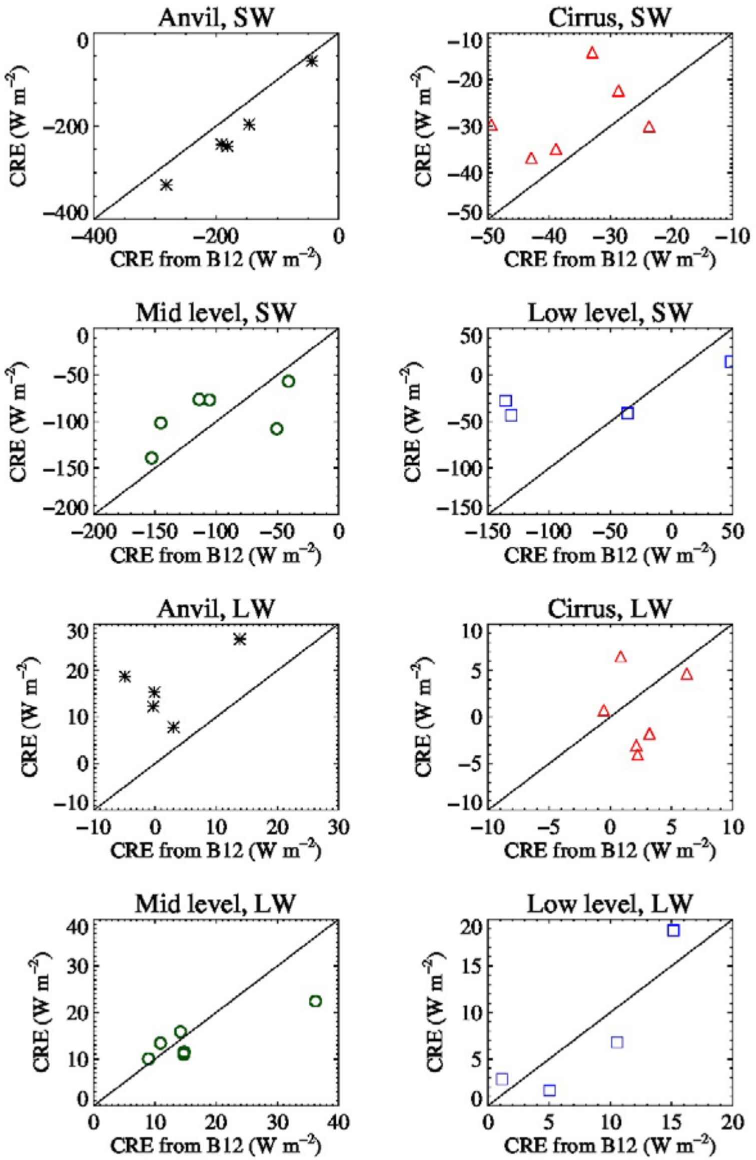


CRE / cloud type - seasonal

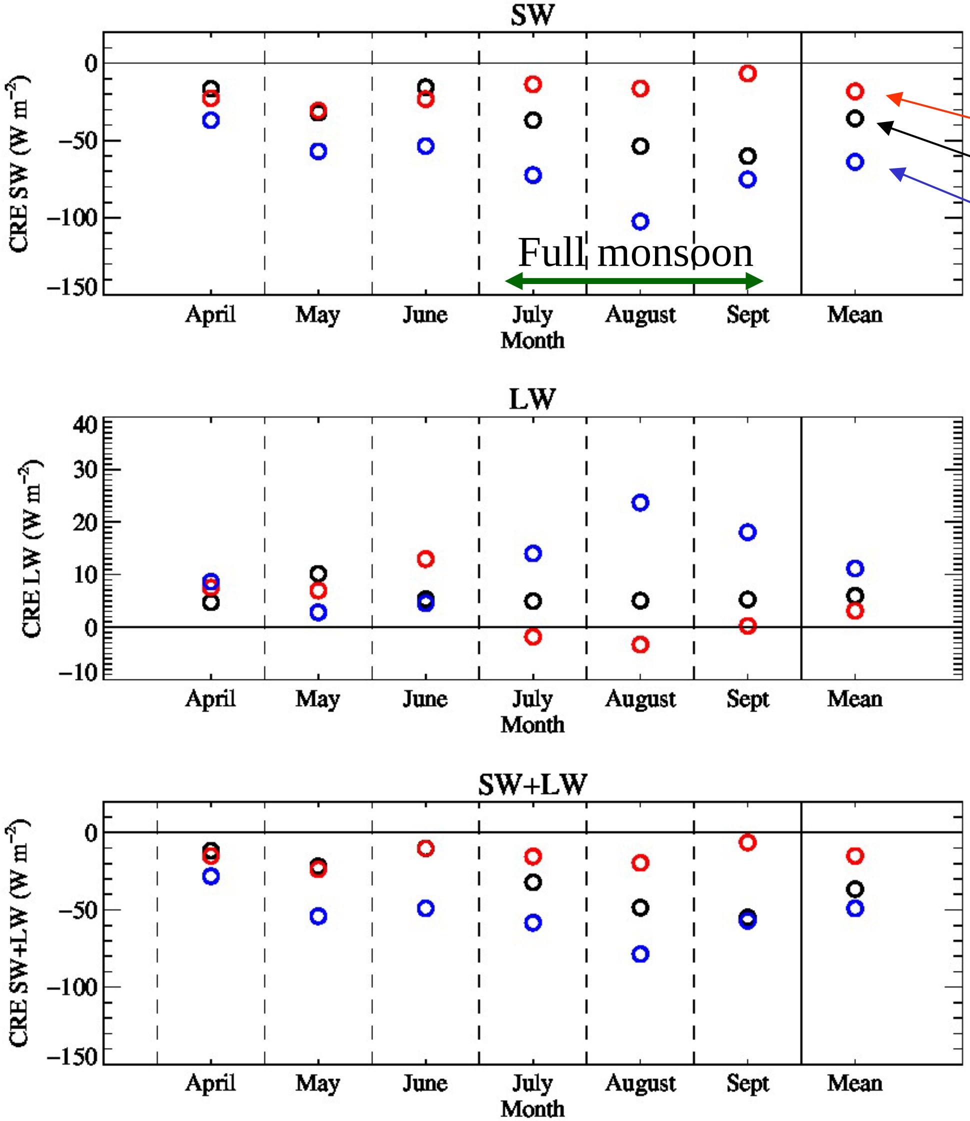
Surface downward

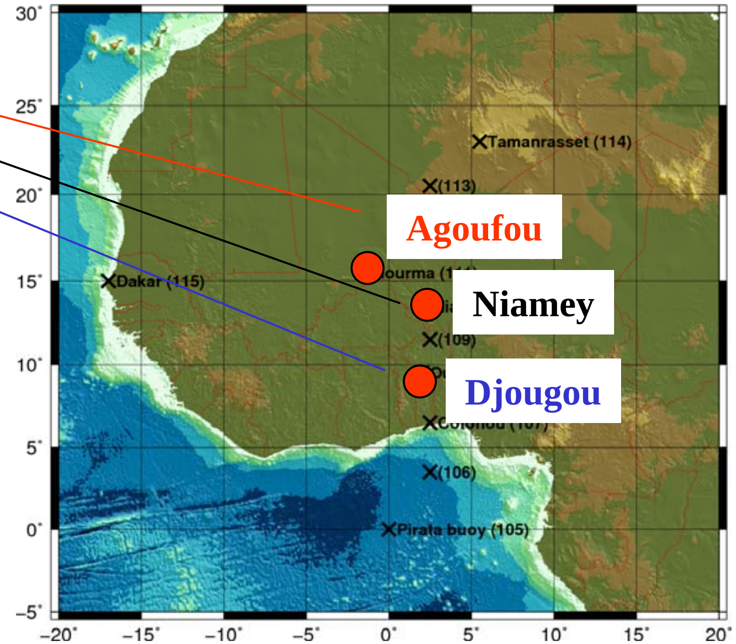


Comparison with Bouniol et al (2012)



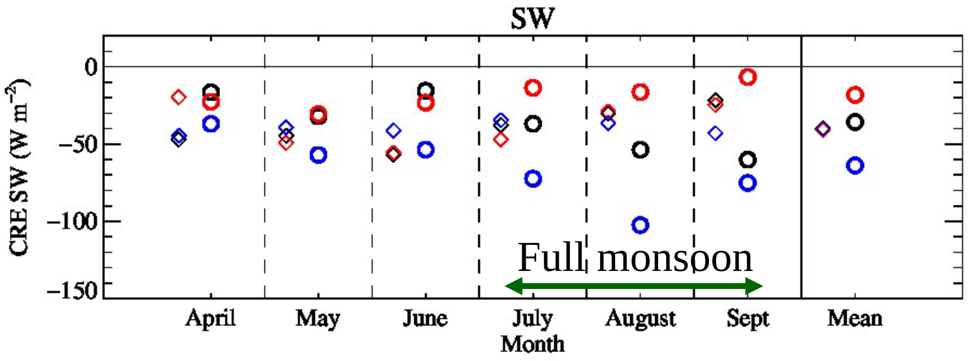
All cloud type CRE (surface downward fluxes) seasonal - transect

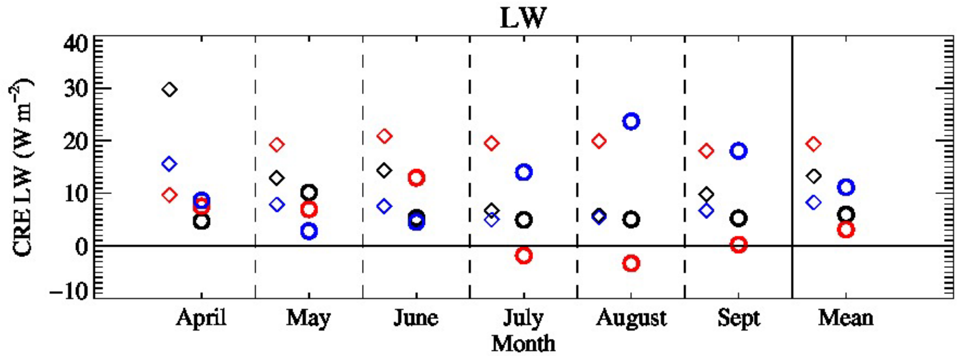


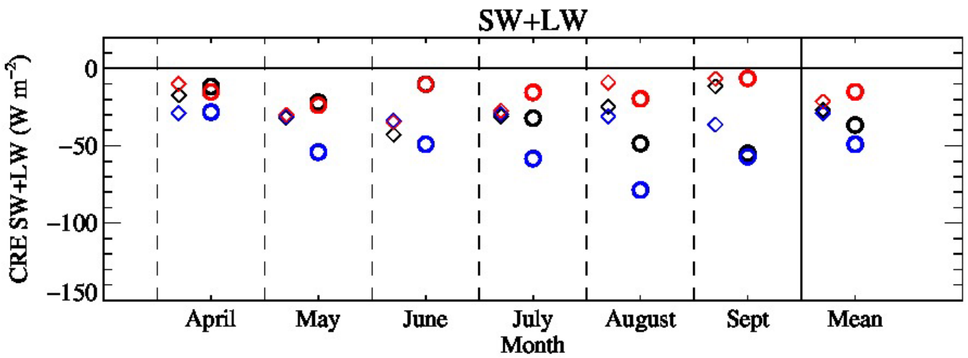


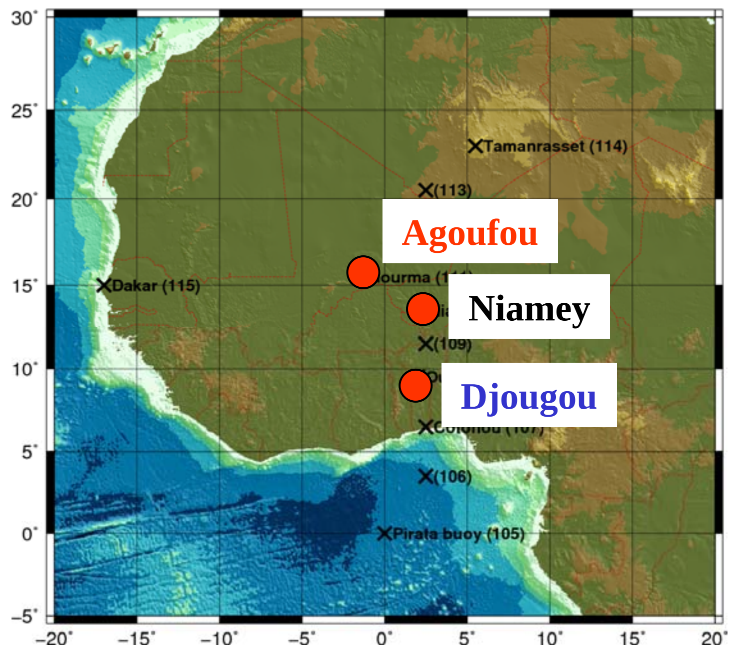
Monthly-mean Cloud Radiative Effect CRE = all sky – clear sky

CRE (surface downward fluxes) seasonal - transect





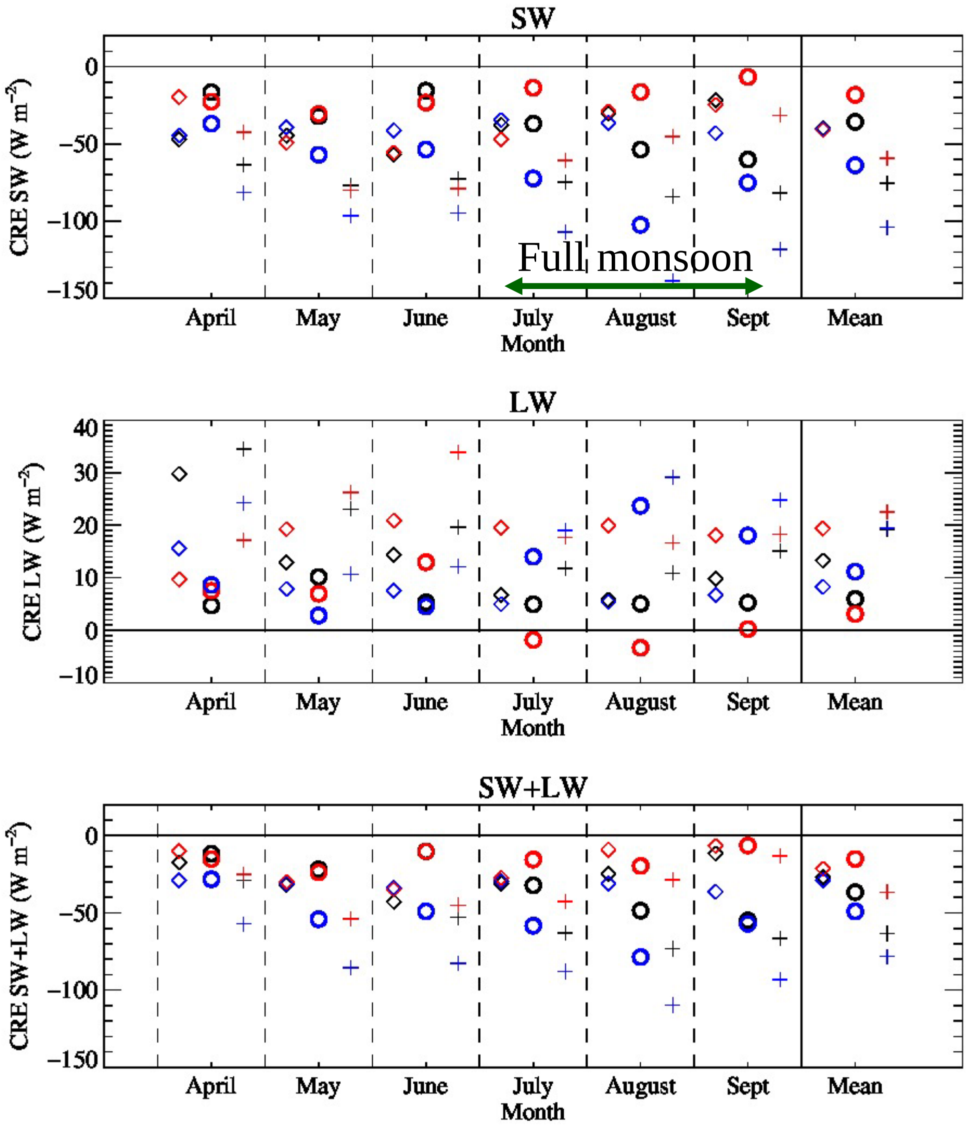


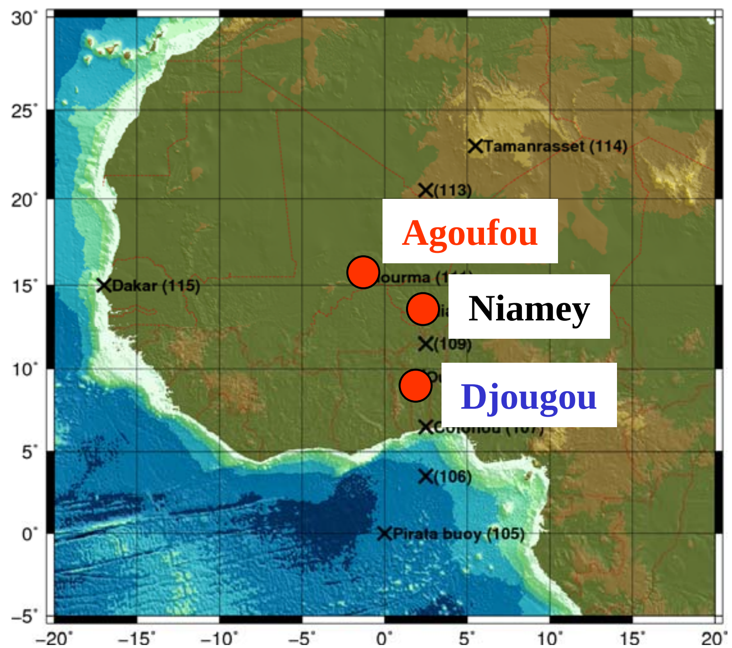


Monthly-mean Cloud Radiative Effect CRE = all sky – clear sky

Monthly-mean Aerosol Radiative Effect ARE = clear sky – clean sky

CRE (surface downward fluxes) seasonal - transect





○ Monthly-mean Cloud Radiative Effect CRE = all sky – clear sky

◇ Monthly-mean Aerosol Radiative Effect ARE = clear sky – clean sky

\+ CRE + ARE = all sky – clean sky

Conclusion and perspective

Use of AMMA, AMF data and RRTM to diagnose clear (and clean) – sky fluxes in Niamey
→ Clear sky fluxes in good agreement with measurements whereas some biases specially for dry cases. Allows estimation of aerosol radiative effet
→ Estimation of CRE for the 4 cloud types. Results in agreement with Bouniol et al. (2012)
SW at Surf and TOA and LW at surf: Largest effet for anvil, then mid, then low level then cirrus

+ RRTM+obs (AMMA-CATCH) + ECMWF profiles + AERONET in Agoufou & Djougou
→ Estimate of CRE over a meridional transect and its annual evolution at surface and TOA
Seasonal a meridional variation of CRE and ARE coherent with West African Monsoon

Perspectives:
- Extend to net CRE at surface, and mean ACRE (atmospheric CRE)
- Extend to TOA CRE for Agoufou and Djougou
- Analysis of CMIP5 AOGCMs in this region

→ Possibility to adapt such an approach to Cloudsat-Calipso cloud data for site with no information about the type of cloud in presence.
→ determine main errors associated with cloud amount, cloud diurnal timing, cloud radiative properties, vertical structure... versus other sources of errors (aerosols, water vapour, temperature).

Aerosols

→ **Vertical profil** of aerosols:
Redistribution of AOD in each layers by using MACC profiles of aerosol mixing ratio

→ **AOD** for each **wavelength band** of RRTM
AERONET provides AOD at different wavelength (in the SW)
- Extrapolation to **SW** wavelength bands using **Angstrom relationship**, Angstrom coefficient from AERONET
- Extrapolation to **LW** wavelength bands using Stanelle et al (2010) **tabulated values** of specific extinction coefficient, SSA

→ **SSA** and **asymmetry parameter** for each **wavelength band** (only for **SW**):
from AERONET (4 wavelength) and linear interpolation for other wavelength.

Clear sky, aerosol radiative effect (ARE)

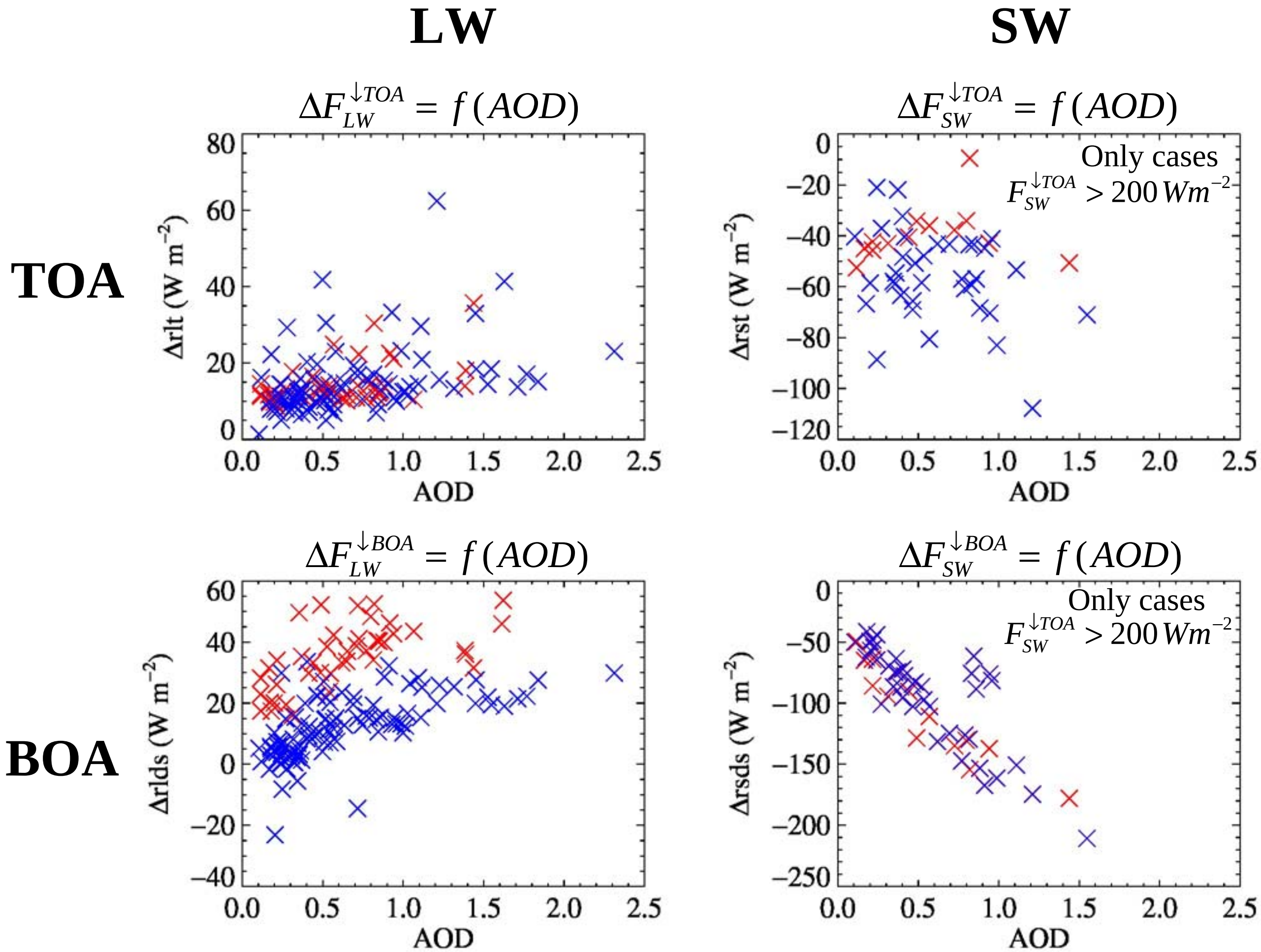


Figure 2a:
Estimation of the LW and SW downward ARE at TOA and BOA as a function of the AOD in wavelength 1020 nm.
The ARE is defined as the difference between the measured flux (only clear sky cases) and the corresponding clean sky flux from RRTMG.
Colors indicate the amount of the integrated water vapor (IWP).

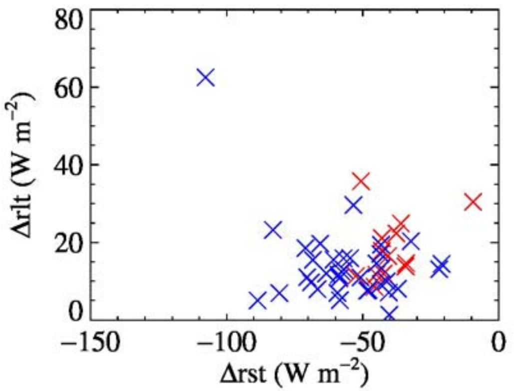
IWP < 25 kg m^{-2}
IWP > 25 kg m^{-2}

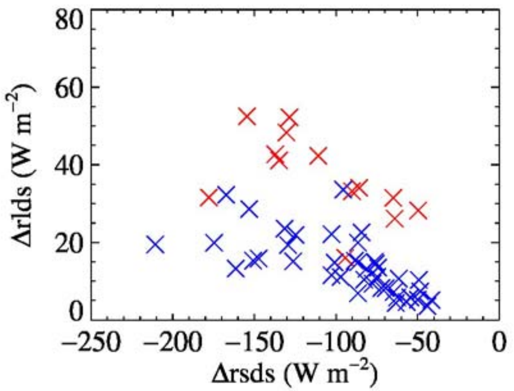
- Positive effect of aerosols at TOA and BOA in the LW (greenhouse effect)
- Negative effect of aerosols at TOA and BOA in the SW (parasol effect)
- Competiting effect between aerosols and water vapor in the LW.

Clear sky, aerosol radiative effect (ARE)

TOA **BOA**

$\Delta F_{LW}^{\downarrow TOA} = f(\Delta F_{SW}^{\downarrow TOA})$ $\Delta F_{LW}^{\downarrow BOA} = f(\Delta F_{SW}^{\downarrow BOA})$





IWP < 25 kg m^{-2}
IWP > 25 kg m^{-2}

Only cases: $F_{SW}^{\downarrow TOA} > 200\,Wm^{-2}$

Figure 2b: LW ARE in function of SW ARE at TOA and BOA

- During the day: larger effect in the SW than in the LW at TOA and BOA.
- Larger effect in the SW at BOA than at TOA.
- Larger effect in the LW at BOA than at TOA, particularly for dry cases.
  ← aerosols are in the low levels.

Niamey

Flux Ciel clair - Apport d'initialiser avec les radiosondages ?

- RRTM ob / , Obs
- RRTM ec / RRTM ob / Obs
- ECMWF / RRTM ob / Obs

Effet des aérosols

- Dépendence à l'AOD
- Aerosol radiative effect LW, SW

Cloud radiative effect

- Saisonal dependence

Meridional Transect

(Agoufou, Niamey, Djougou)

- Saisonal dependence
- Aerosols, clouds
- Models ?

Cirrus

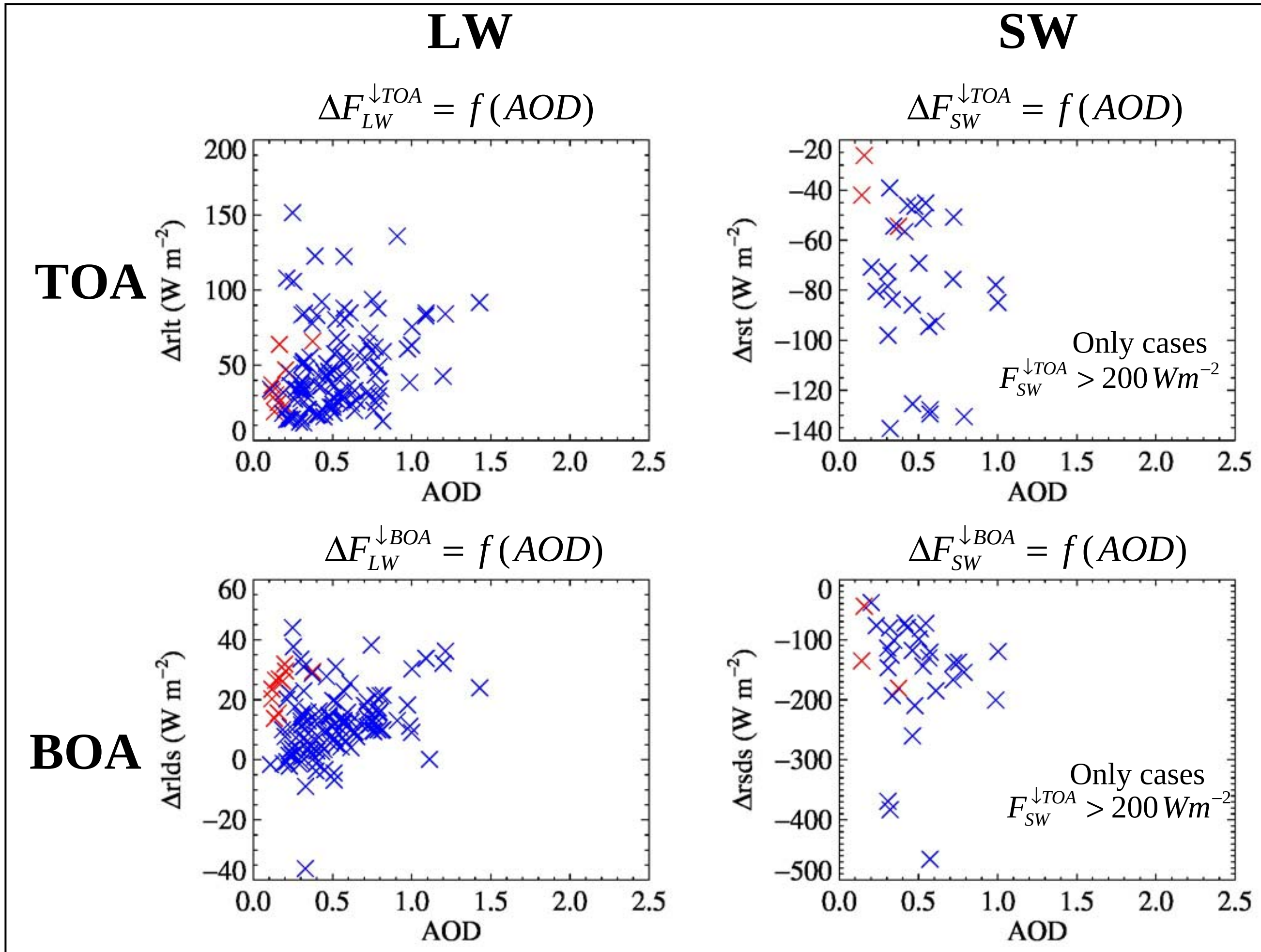


Figure 4:
Estimation of the LW and SW downward ARE+CRE of cirrus clouds at TOA and BOA as a function of the AOD in wavelength 1020 nm.
The ARE+CRE is defined as the difference between the measured flux (cirrus cases) and the corresponding clean sky flux from RRTMG.
Colors indicate the amount of the integrated water vapor (IWP).

IWP < 25 kg m^{-2}
IWP > 25 kg m^{-2}

Deep convection

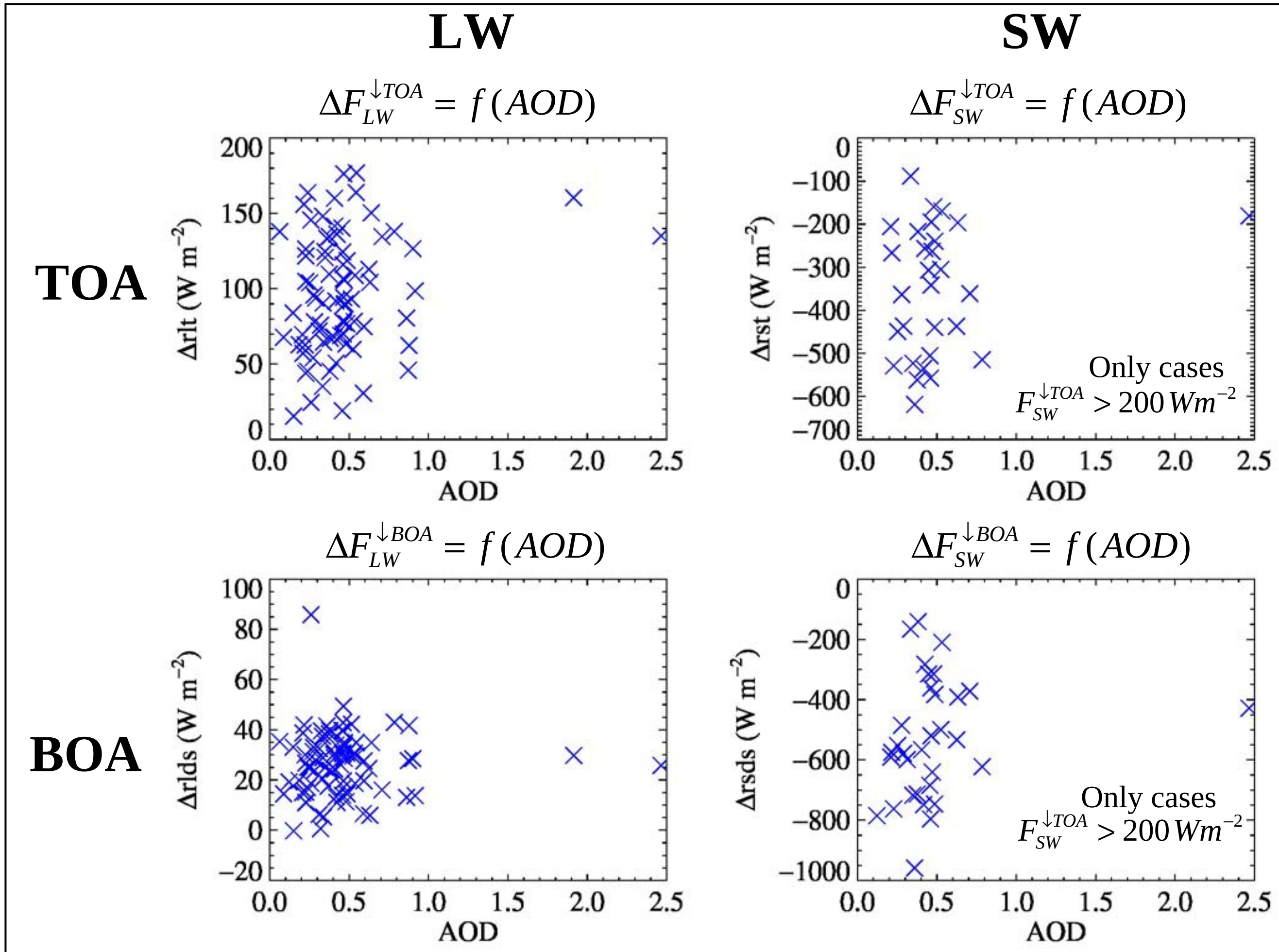


Figure 5:
Estimation of the LW and SW downward ARE+CRE of deep convective clouds at TOA and BOA as a function of the AOD in wavelength 1020 nm.
The ARE+CRE is defined as the difference between the measured flux (deep convective cloud cases) and the corresponding clean sky flux from RRTMG. Colors indicate the amount of the integrated water vapor (IWP).

IWP < 25 kg m^{-2}
IWP > 25 kg m^{-2}

Mid-level clouds

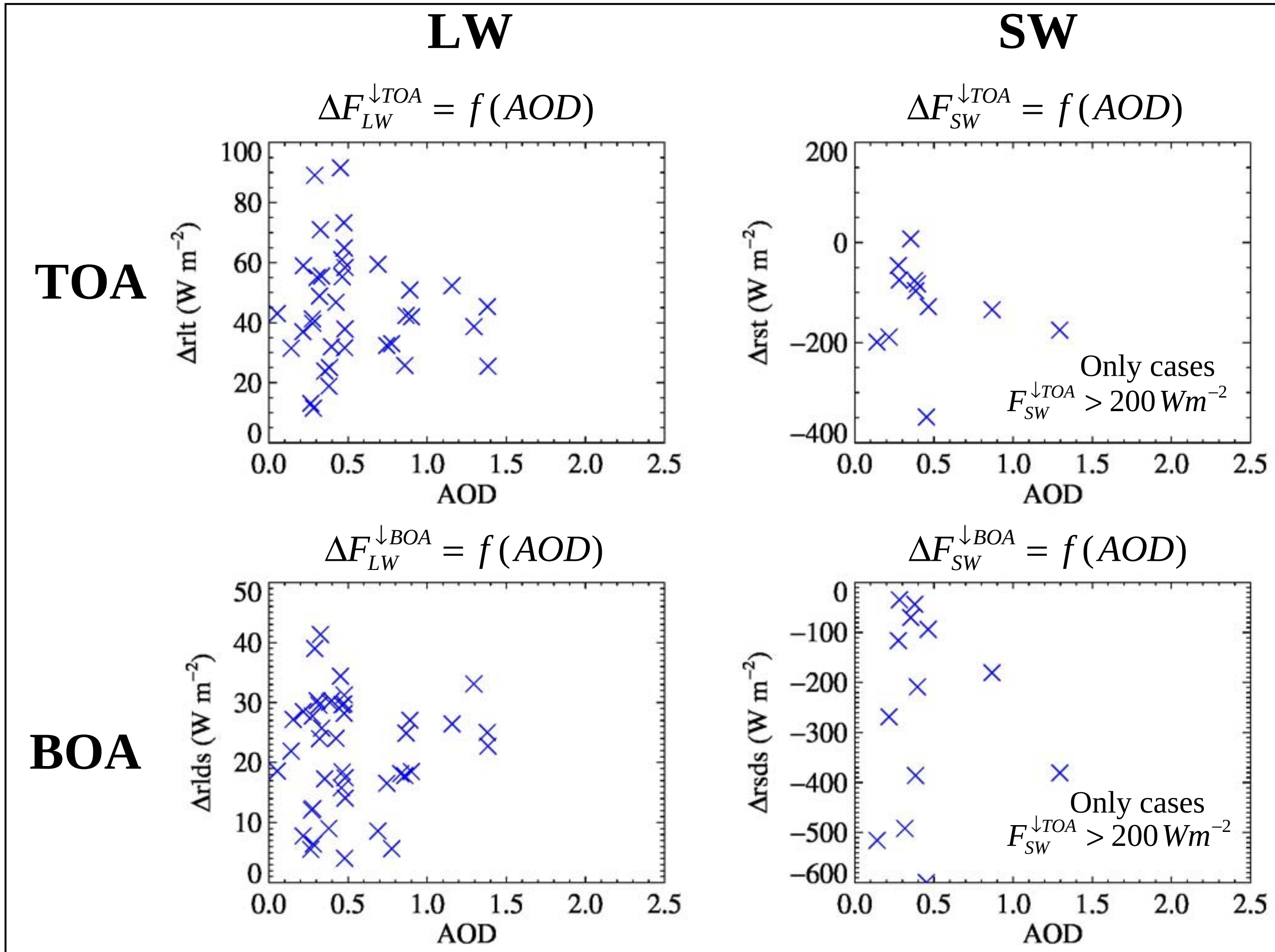


Figure 6:
Estimation of the LW and SW downward ARE+CRE of mid-level clouds at TOA and BOA as a function of the AOD in wavelength 1020 nm.
The ARE+CRE is defined as the difference between the measured flux (mid-level cloud cases) and the corresponding clean sky flux from RRTMG.
Colors indicate the amount of the integrated water vapor (IWP).

IWP < 25 kg m^{-2}
IWP > 25 kg m^{-2}

Low level clouds

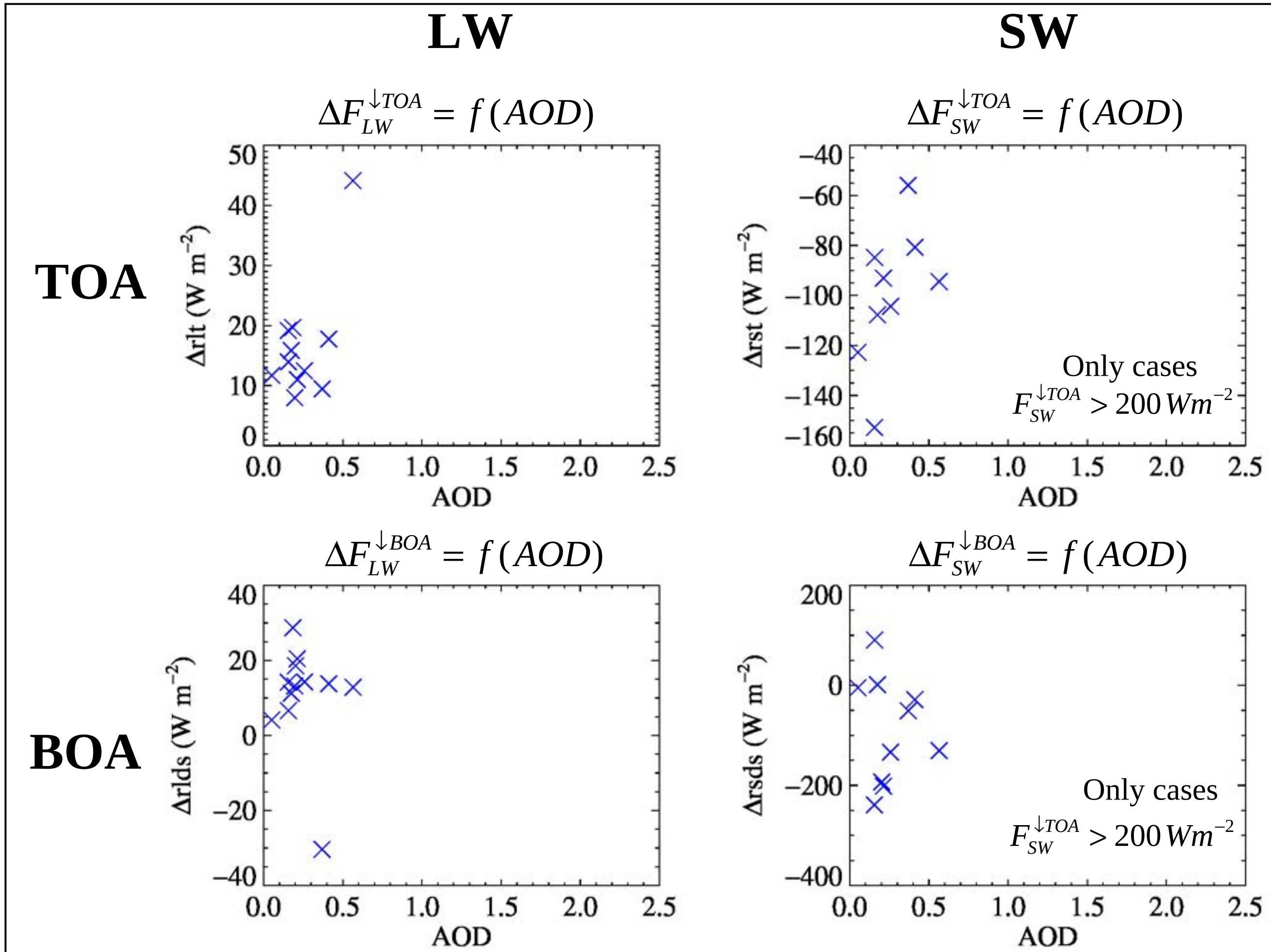


Figure 7:
Estimation of the LW and SW downward ARE+CRE of low level clouds at TOA and BOA as a function of the AOD in wavelength 1020 nm.
The ARE+CRE is defined as the difference between the measured flux (low level clouds cases) and the corresponding clean sky flux from RRTMG.
Colors indicate the amount of the integrated water vapor (IWP).

IWP < 25 kg m^{-2}
IWP > 25 kg m^{-2}

Data

Measurements are used as inputs of a RTM in order to provide an accurate estimate of radiative fluxes in **clean sky** (no aerosol, no cloud) and **clear sky** (no cloud).
The measurements also provide the magnitude of the different fluxes in **cloudy sky** at both TOA and BOA.

Data (AMMA):
- ARM mobile facility located in Niamey (Fig. 1) in 2006: Cloud radar, lidar, LW and SW fluxes (temporal resolution of radiative fluxes: 1 min).
- GERB data: TOA LW and SW fluxes (temporal resolution: 15 min),
- Radiosonde (4 to 8 per day): temperature, humidity, pressure, altitude,
- ECWMF AMMA reanalysis (4 per day),
- Aeronet (Banizoumbou): AOD (1 per hour).
- GPS measurement: Integrated water vapor (1 per hour).

Radiative transfert model:
- RRTMG LW and SW (Iacono et al, 2008; Morcrette et al, 2008). Resolution: 200 levels with constant layer thickness in pressure from the pressure surface to 0.1 mb.

Focus on moist months (May to September) when clouds are more numerous.