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2- Rain measurement systems

3- Basic of area-time integrals methods

4- Study area and data

5-Results and discussions

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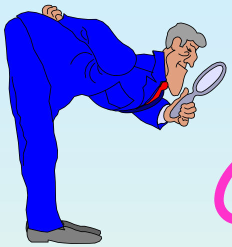
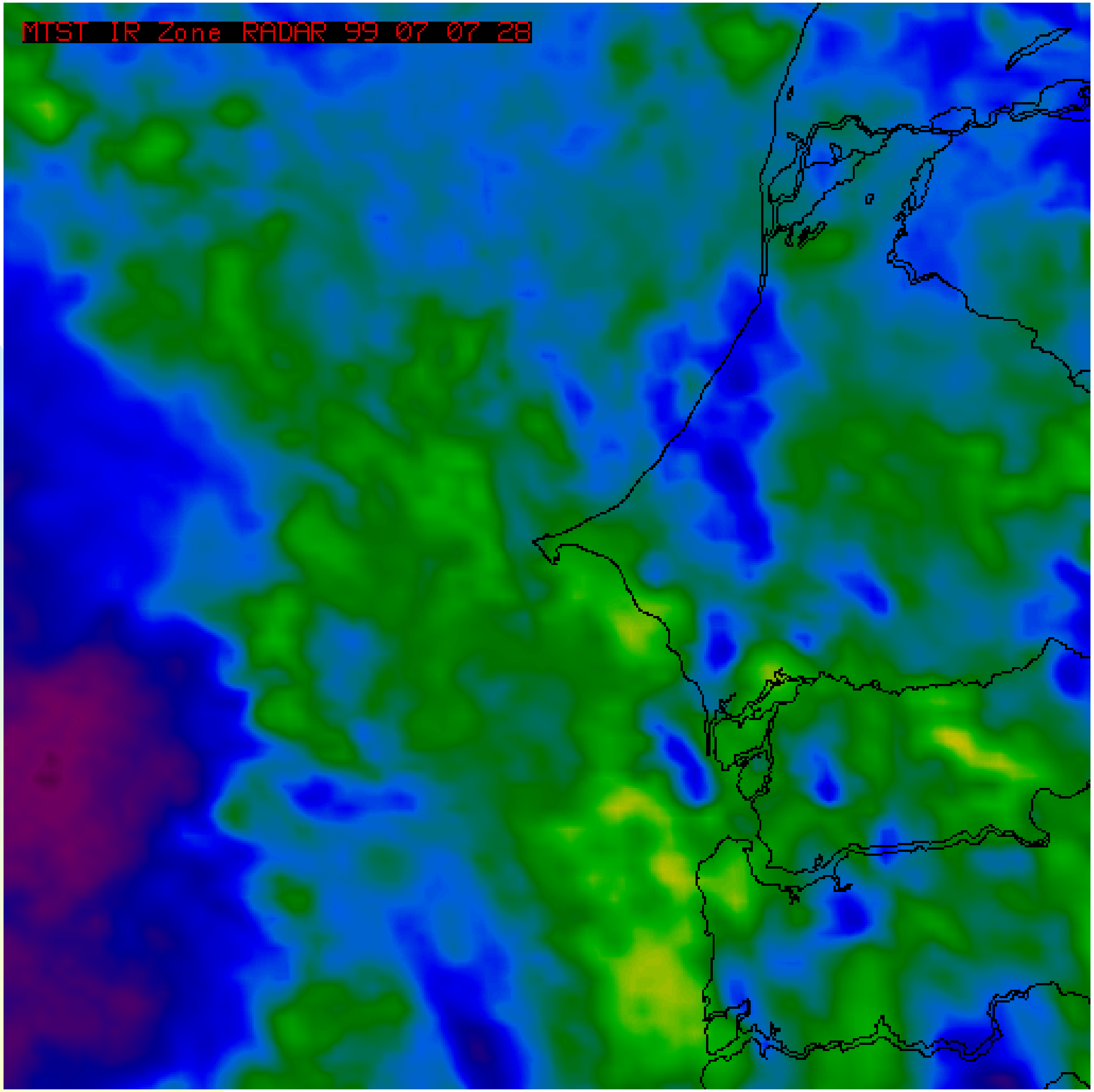
5-2 Some rainfall estimation with IR data at Senegal using area-time integrals methods

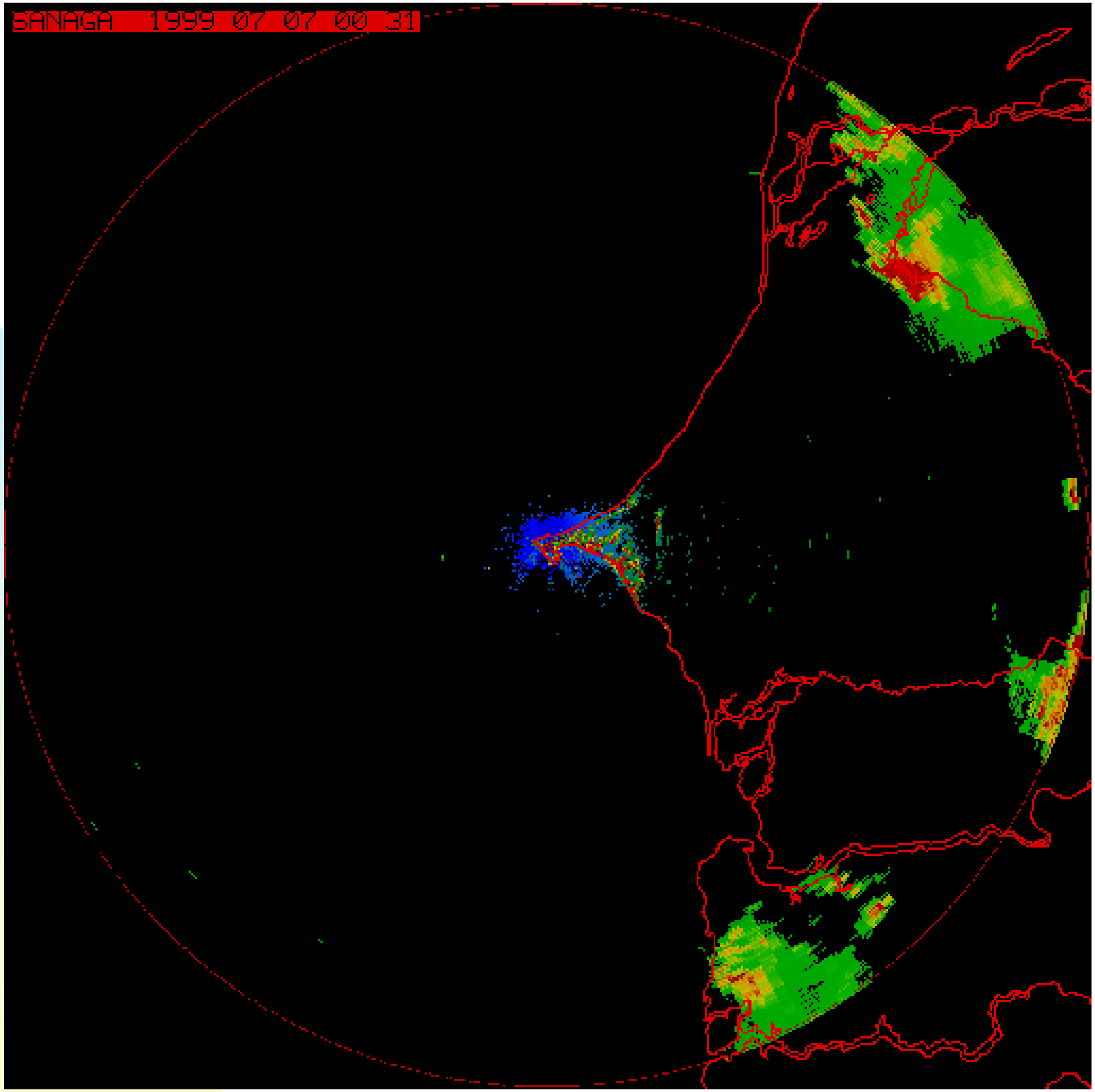


Characteristics of precipitation in tropical systems :

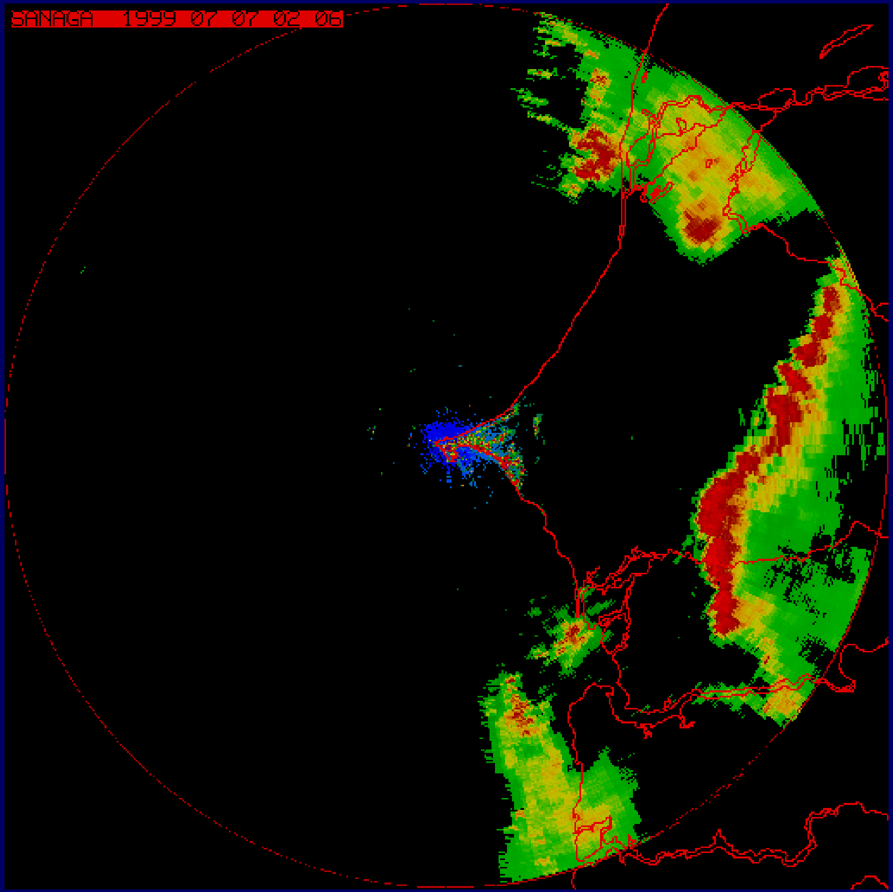
radar and satellite signatures of Sahelian Squall lines



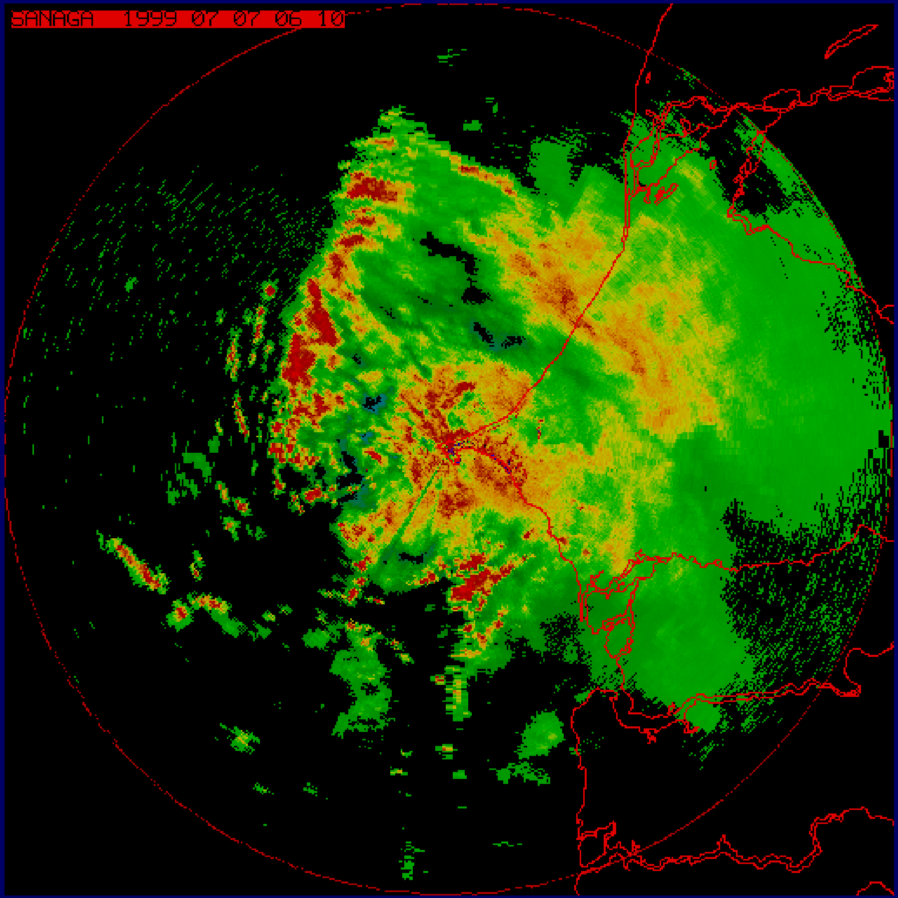
Squall lines crossing Senegalese coast (July/07/1999)
(METEOSAT OBSERVATIONS)



Squall lines crossing the Senegalese coasts (07/07/1999)
Radar Observations



Land



Sea

Squall lines crossing the Senegalese coasts (July /07/1999)

Characteristics of precipitation in tropical systems

high spatial variability :
rainfall fields not homogeneous inside the pixel

spatial resolution is important

☞ high temporal variability :
temporal resolution is important

☞ Influence of local climatic parameter like :
- seasonal and coastal effects
- Orography

Rain measurement systems - rain gauges

<u>Advantages:</u>

- "True" measurement of rain

<u>Disadvantages:</u>

- No coverage over oceans or remote regions
- Point measurement not representative of area
- Wind ⌫ underestimates of rain
- Different gauge designs

Rain measurement systems - radar

Advantages:

- Excellent space and time resolution
- Observations in real time

Disadvantages:

- Little coverage over oceans or remote regions
- Signal calibration
- Corrections required for beam filling, bright band, anomalous propagation, attenuation, etc.
- Z-R relationship
- Expensive to operate

Theses aspects lead to consider the paramount importance of achieving a correct interpretation of satellite data in term of precipitation at the ground

Rain measurement systems - geostationary satellite (VIS/IR)

Advantages:

- Good space and time resolution
- Observations in near real time
- Samples oceans and remote regions

Disadvantages:

- **Measures cloud-top properties instead of rain**
- Spatial and/or temporal resolution may be too coarse
- Large data volume (problem of storage)

Amoung the means proposed to reach the objectives of rainfal estimation by satellite, the thresholds Methods
There are attractive because of their simplicity and the quality of the results the yields

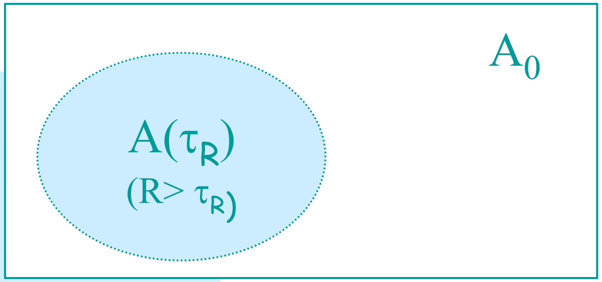
Basics concepts of area time-Integrals Methods (thresholds methods)

The threshold methods consider the relation between the area occupied by the clouds having a top with an equivalent blackbody brightness temperature (TB) colder than a threshold and the Rain volume (V), or the area-averaged rain rate <R>, inside an observed area of finite size.

This approach has notably led to the GOES Precipitation Index (GPI)

A similar methodological development has occurred for the Hydrological processing of radar data with the area-time Integral (ATI) methods

Area time integrals method : Basic concepts and definitions



☞ If in an area of observation A_0 , we have a field of rain rate, R, represented by P(R) (Probability density of function) of R, the area-averaged conditional (climatic) rain can be written as

- ☞

$$< R > = \int_0^\infty R P(R) dR \qquad \text{pour } R > 0 \qquad (1)$$

-and the area occupied by the rain having a rate higher than a threshold τ_R, that is, the fractional area, is →

$$F(\tau_R) = \frac{A(\tau)}{A_0} = \int_{\tau_R}^\infty P(R) dR \qquad (2)$$

The combination of (1) and (2) gives the relation

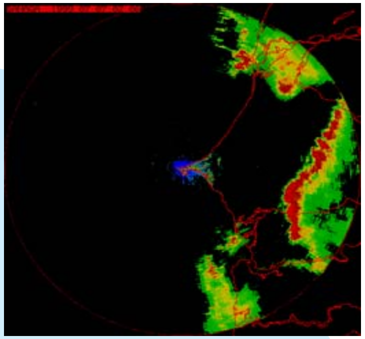
<R> = S(τ_R) F(τ_R) (3)

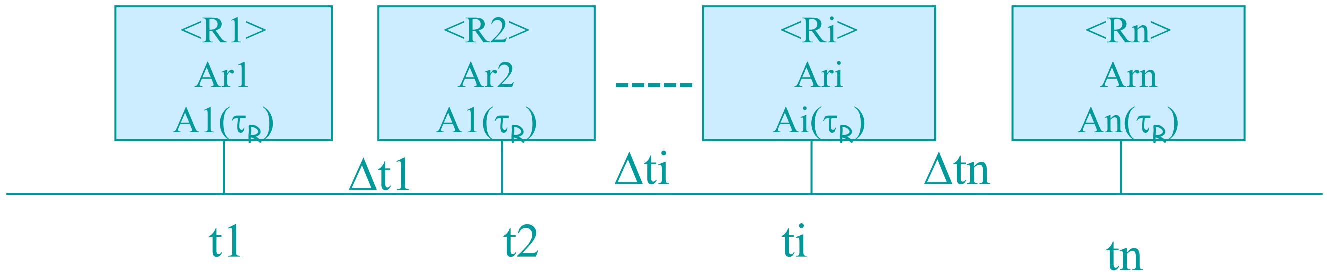
with ☞

$$S(\tau_R) = \frac{\int_0^\infty R P(R) dR}{\int_{\tau_R}^\infty P(R) dR} \qquad (4)$$

(4) shows that <R> is linearly linked to the fractional area F(τ_R) by the factor S(τ_R) depending Only on P(R) and on the threshold τ_R

Equation (3) can be applied to a snapshot over the area A_0





If, at time ti, $A_i(\tau_R)$ is the area with $R > \tau_R$, with $A_i(\tau_R = 0) = A_{ri}$ and $\langle R_i \rangle$ is the area- averaged rain rate over Ari, the summation over time series gives

$$\underbrace{\sum_i \langle R_i \rangle A_{r_i} \Delta t_i}_{V} = S(\tau_R) \underbrace{\sum_i A_i(\tau_R) \Delta t_i}_{(ATI)_R} \qquad \textbf{(5)}$$

The left member of (5) represents the rain volume V fallen during the observation time inside the observed area and the summation in the right member represents $(ATI)_R$, the radar observed ATI for the threshold in the same area

Thus (5) can be written as: ☞ $V = S(\tau_R)\,(ATI)_R$ **(6)**

The concept of ATI, whose implementation to radar data is rather straightforward, can also be used with satellite data

In this work, the relation between rainfall and cloud-top area, is written in a form identical to (6), in witch τ_R is replace by τ_{TB}, $S(\tau_R)$ by $G(\tau_{TB})$ and $(ATI)_R$ by $(ATI)_{TB}$.

We obtain : ☞ $V = G(\tau_{TB})\,(ATI)_{TB}$ **(7)**

AREA OF STUDY AND DATA

Area of study

The study area considered to study is located at the western end of Sahelian Africa, at the transition from an arid to an equatorial climate, were two strong gradients, land-sea and north-south of the seasonal cumulative rain depth are observed.

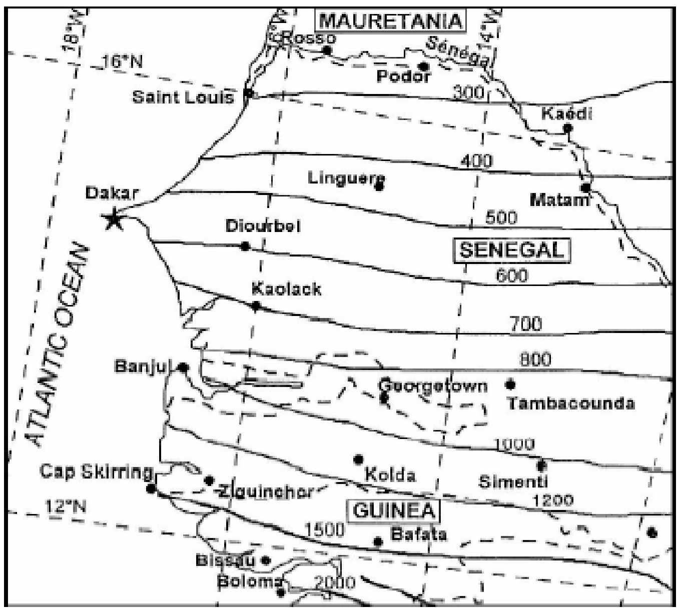


FIG. 1. Gauge-based mean annual rainfall accumulation for Senegal computed over a period of 39 yr (1951–89). Isohyetal lines are labeled in mm yr^{-1}. The star shows the radar location. The dots are the synoptic observational station handled by the national meteorological services (L'hote and Mahé 1996).

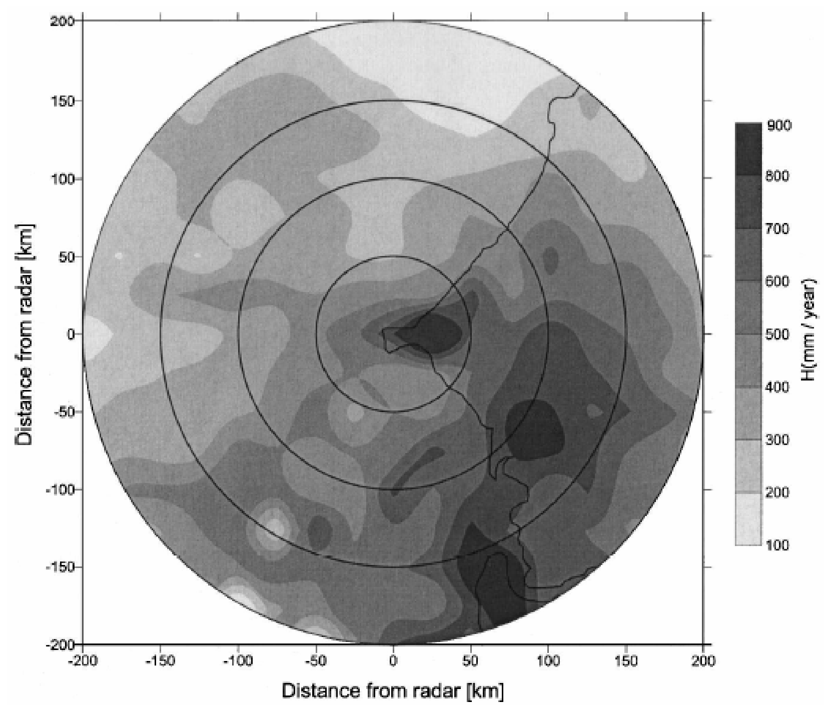
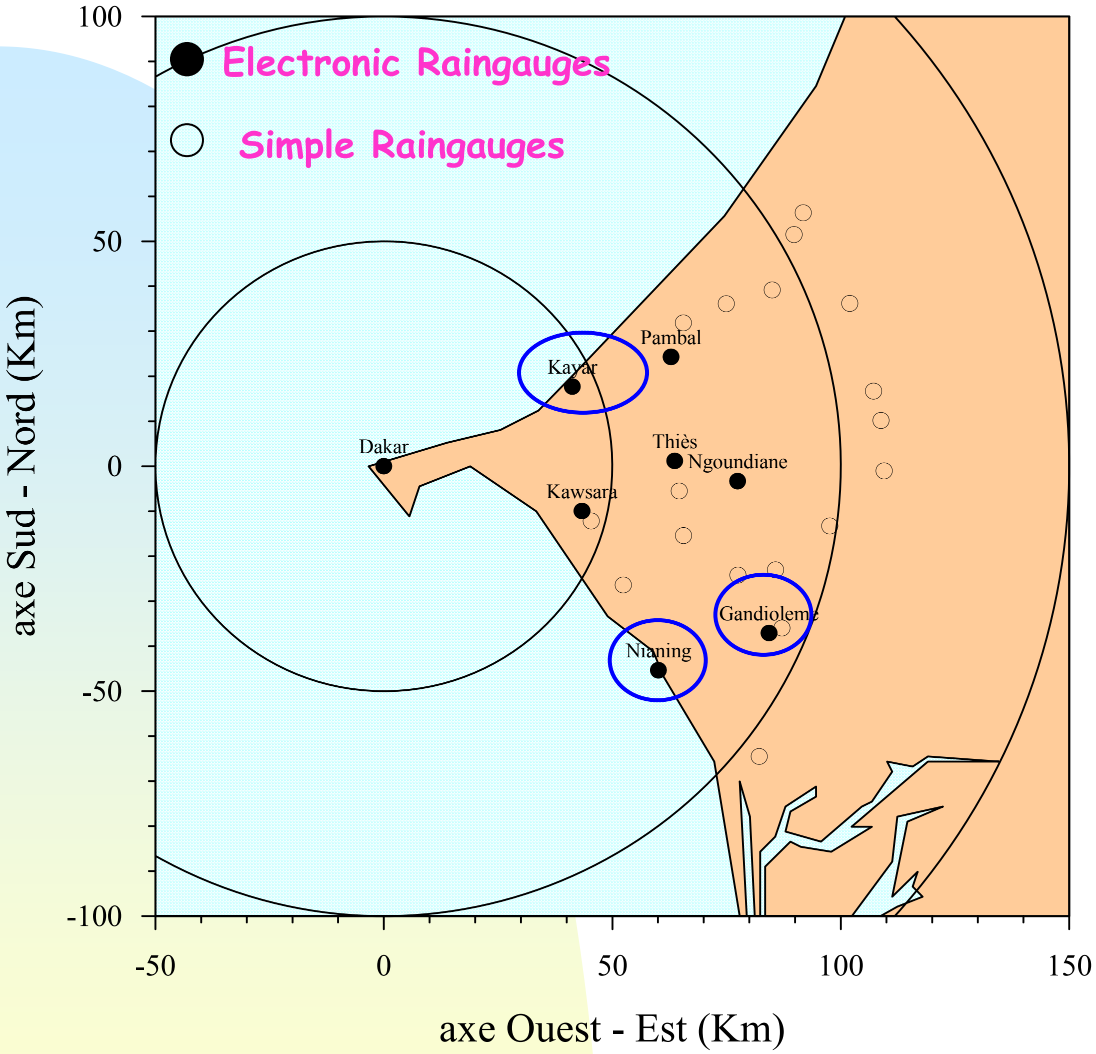


FIG. 2. Distribution of the mean annual rainfall accumulation in the Dakar area calculated from the Dakar-Yoff radar data over a 7-yr period (1993–99). Values higher than 1000 mm for a radar distance smaller than 60 km are due to ground echoes. The bold lines are range markers and coasts (NS02).

Ground true



Disdrometer on the roof of The LPAOSF

Data set

Radar data Band C

Period of observation	Jul–Oct 1993–99
Scanning mode	PPI ($\alpha = 0.8°$)
Scanning interval	Between 10 and 20 min
Pixel size	1×1 km^2
No. of steps for Z coding	256
Yr	1996 1997 1998 1999
No. of scans	1684 1012 2245 2730

Satellite Data

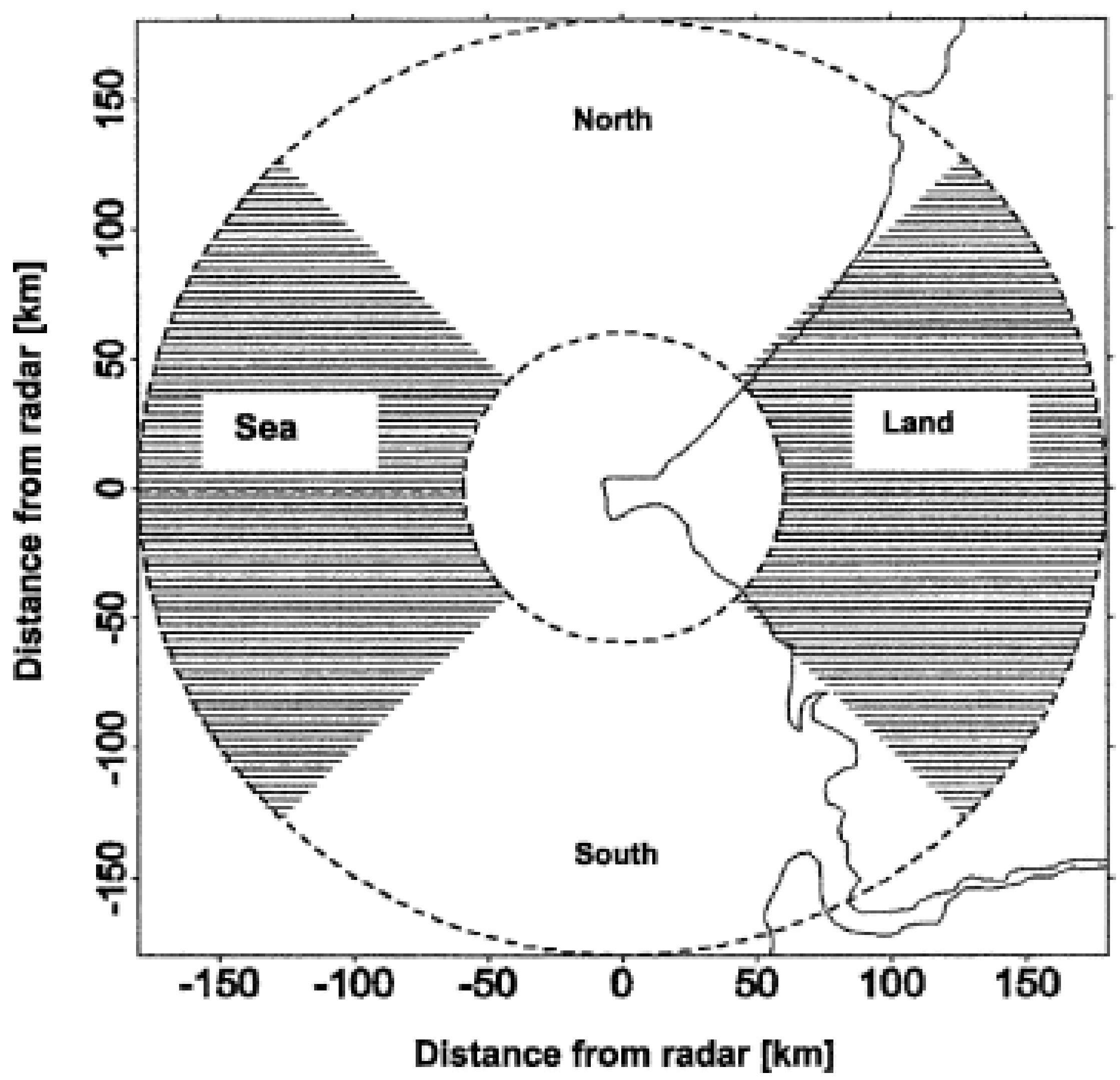
Meteosat 7

Scanning interval	**30 minutes**
Pixel side	**5 km^2**

MSG

Scanning interval	**15 minutes**
Pixel side	**3 km^2**

Sub-domains for the computation of $G(\tau_{TB})$



Results and discussions:

Variability of the volumetric rainfall to ATI relation from satellite IR data

Algorithme for the computation of $G(\tau_{TB})$

Data set of radar corresponding of rainy events

Data set of IR meteosat corresponding to the same rainy events

Correction, calibration, and colocalisation of Radar and stellite data

Matrix of rainrate in rectangular coordinate (1km x 1km)

Matrix of brightness temperature (TB) in the same area (1km x 1km)

Sampling of data in the 4 subdomains (land, sea,north and south, total area)

-computation of $Ai(\tau_R)$ and $Ai(\tau_{TB})$

Temporal series of $Ai(\tau_R)$ in variabletime steps in 4 subdomains and in the total area

Temporal series of $Ai(\tau_{TB})$ in 30 min time sampling in the 4 subdomains and in the total area

Time integration on all snapshot of the rainy event

$$(T_i = \sum_i \Delta t_i)_{\text{satellite}} = (T_i = \sum_i \Delta t_i)_{\text{radar}}$$

$$V = S(\tau_R)\sum_i A_i(\tau_R)\Delta t_i$$

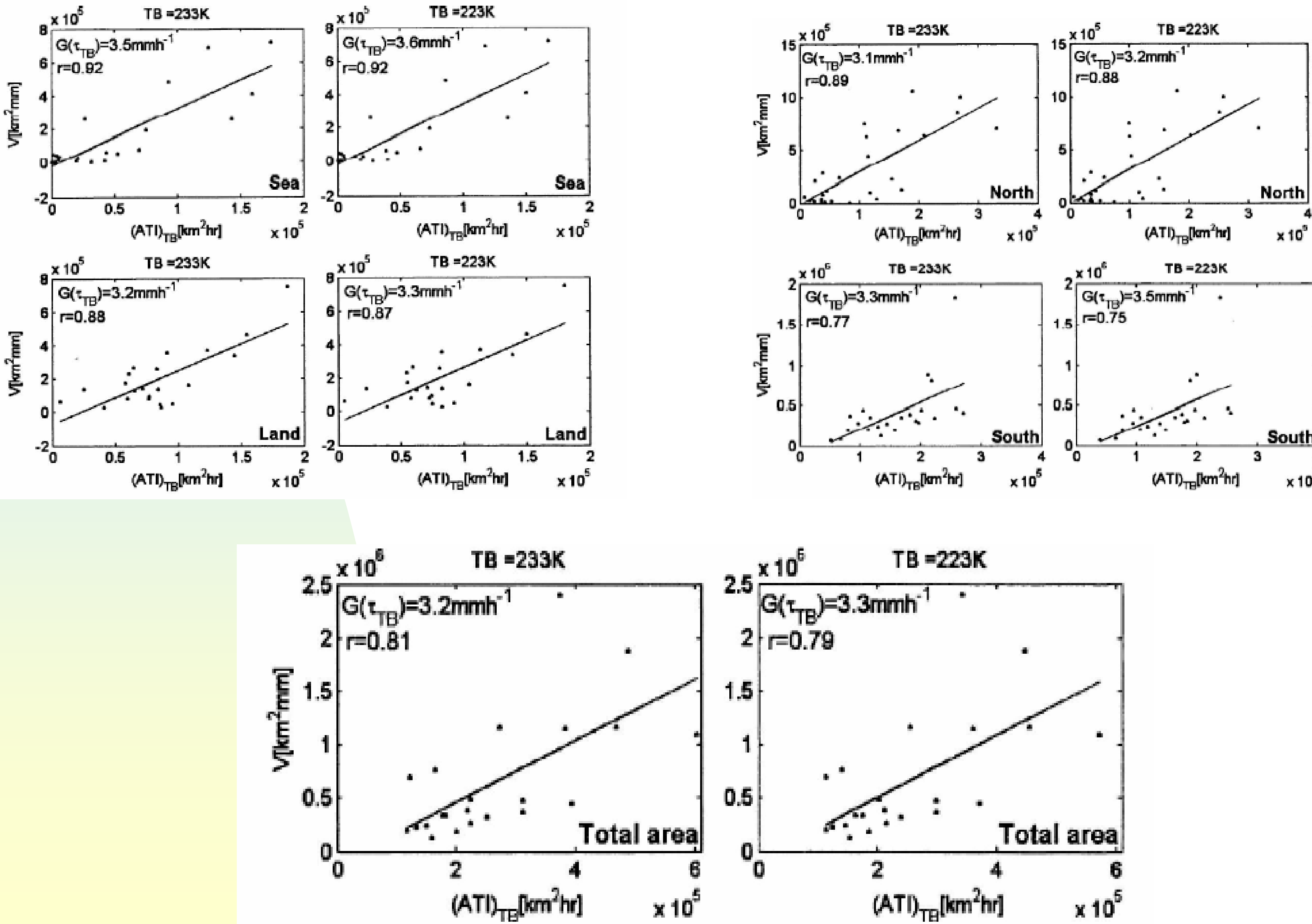
$$(ATI)_{TB} = \sum_i A_i(\tau_{TB})\Delta t_i$$

Regression of corresponding pairs [V, $(ATI)_{TB}$] of all the 23 events of the dataset gathered between (1996-1999)

$G(\tau_{TB})= V/(ATI)_{TB}$

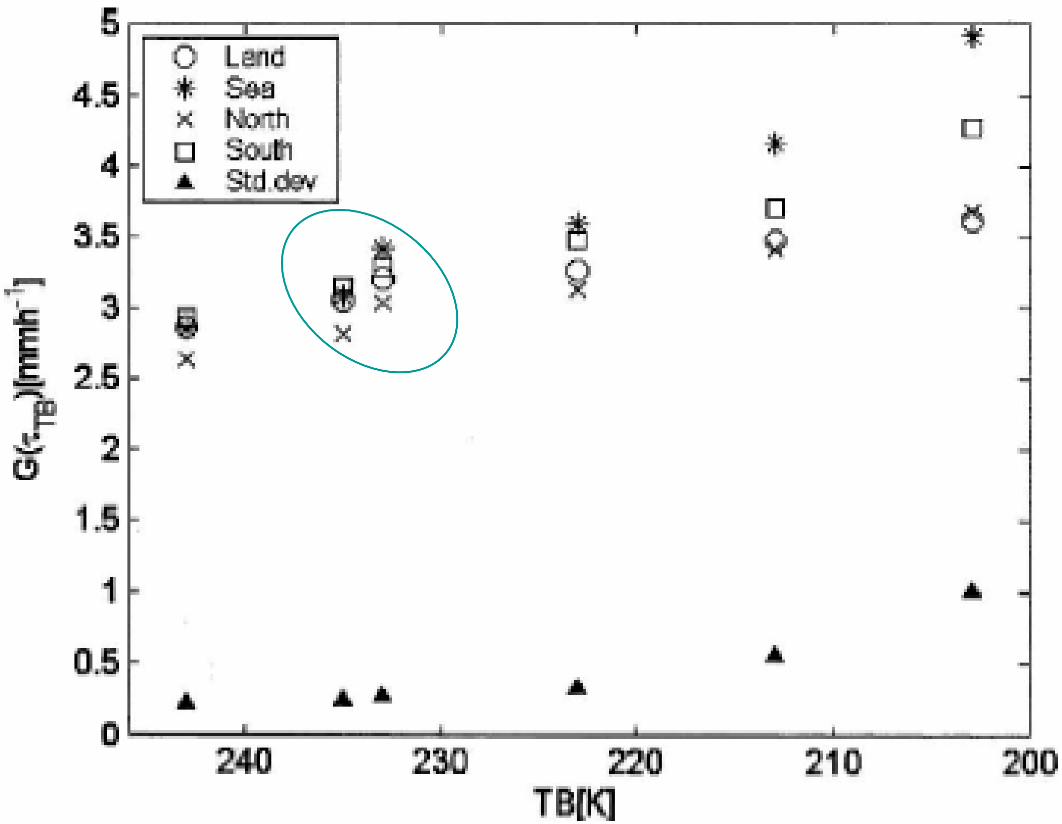
$G(\tau_{TB})$

Regressions V-$(ATI)_{TB}$



Variability of $G(\tau_{TB})$

-Plot of the linear coefficient $G(\tau_{TB})$ versus TB for the 1996-1999 Data set for the four 4 sub-areas.



-for τ_{TB} = 235 K the mean value of **$G(\tau_{TB})$ is 3.02 mm/h**, almost exactly that found for the GPI coefficient for the GATE area.

Results and discussions:

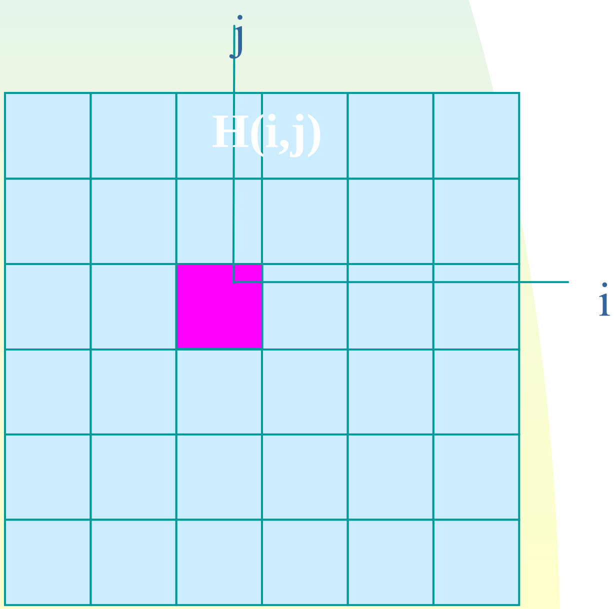
Some rainfall estimation by IR data in Senegal using area-time integrals methods

- Using data set from Meteosat 7 between 1996 and 1999

-Using the threshold of 235 K corresponding to $G(\tau_{TB})$ =3 mmh^{-1} identical to the GPI of Arkin

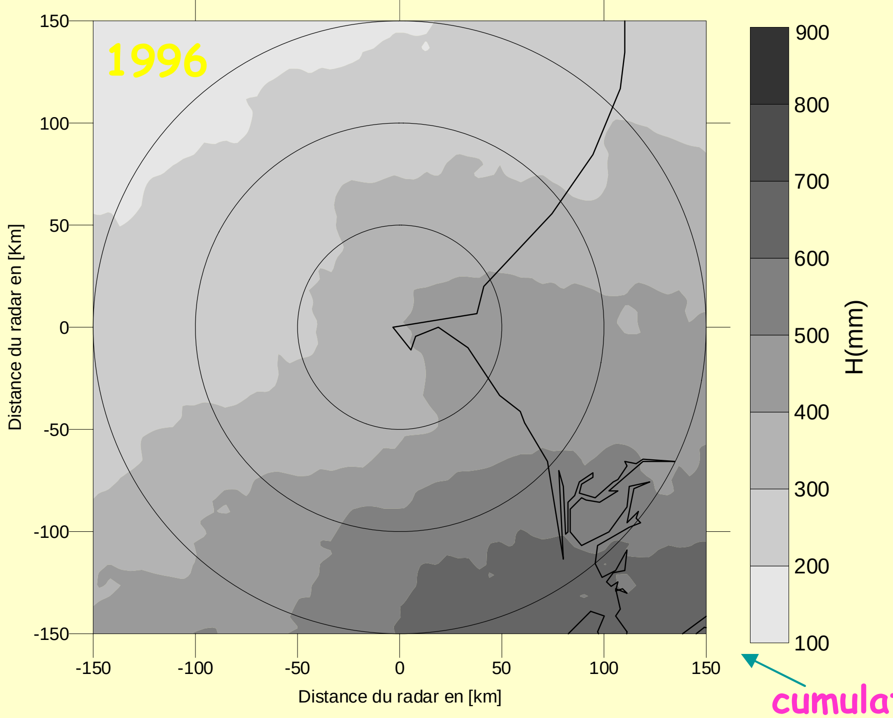
In the pixel scale, we can estimate the cumulative rainfall using the relation (8)
Where :

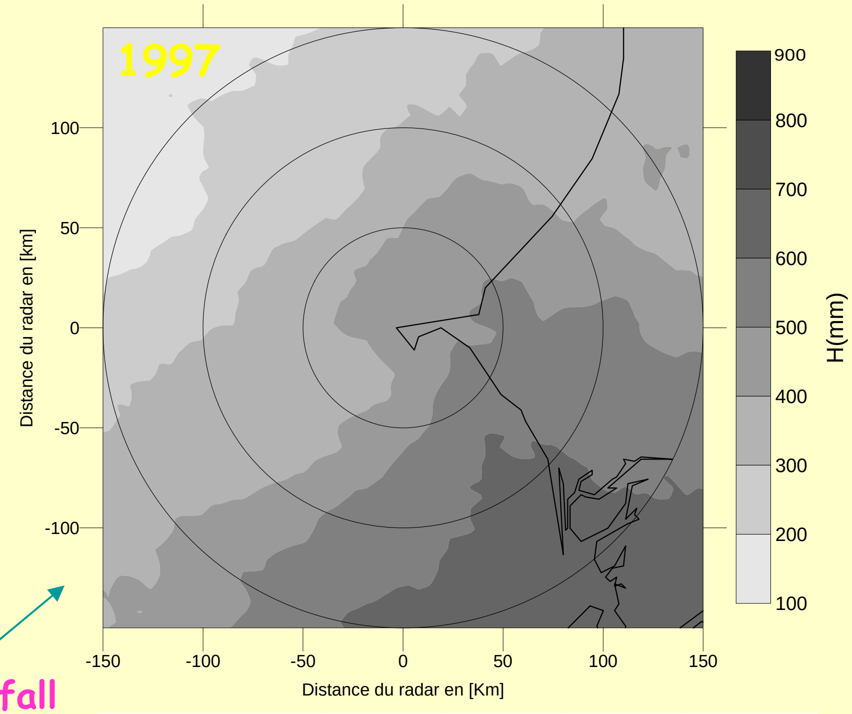
- S(i,j) is a cumulative value of pixels corresponding to temperature colder than the threshold 235 K during the time period of estimation
- Δt is the time sampling of data set used in hour (1/2 for Meteosat 7 and for MSG)



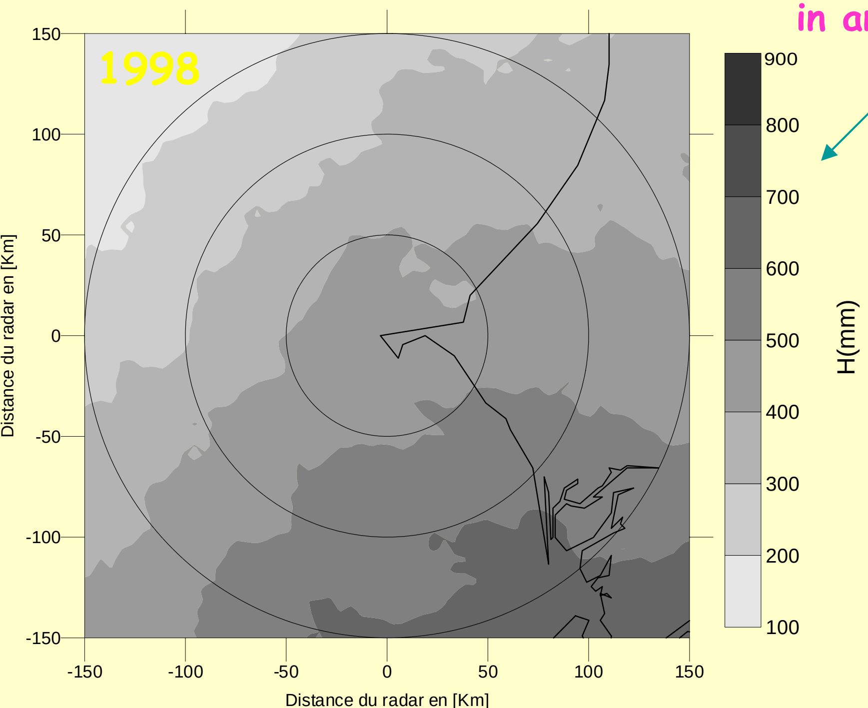
$$H(i,j) = G(\tau_{TB}) \sum_{l=1}^{l=N} S^{l}(i,j)\Delta t \qquad (8)$$

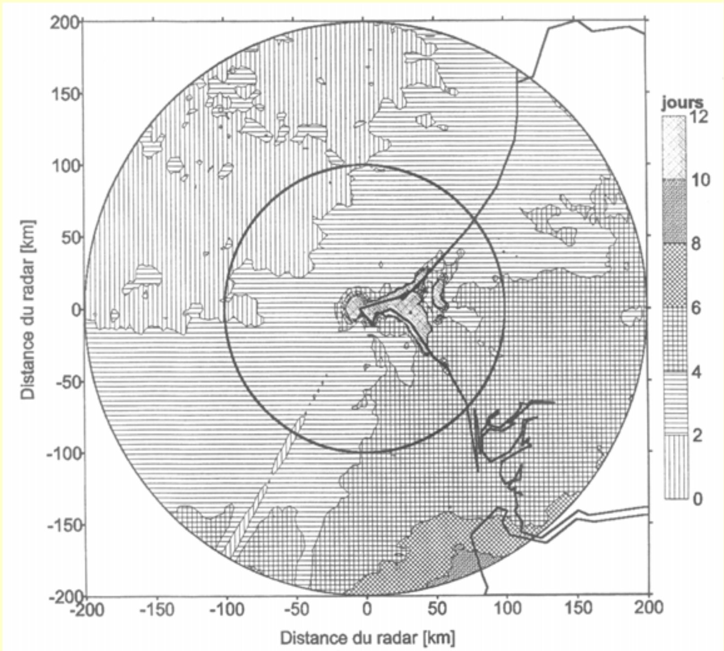
Computation on different time scales:
-field of precipitation in annual mean
-field of precipitation in monthly mean
-temporal series of 5 days cumulative rainfall



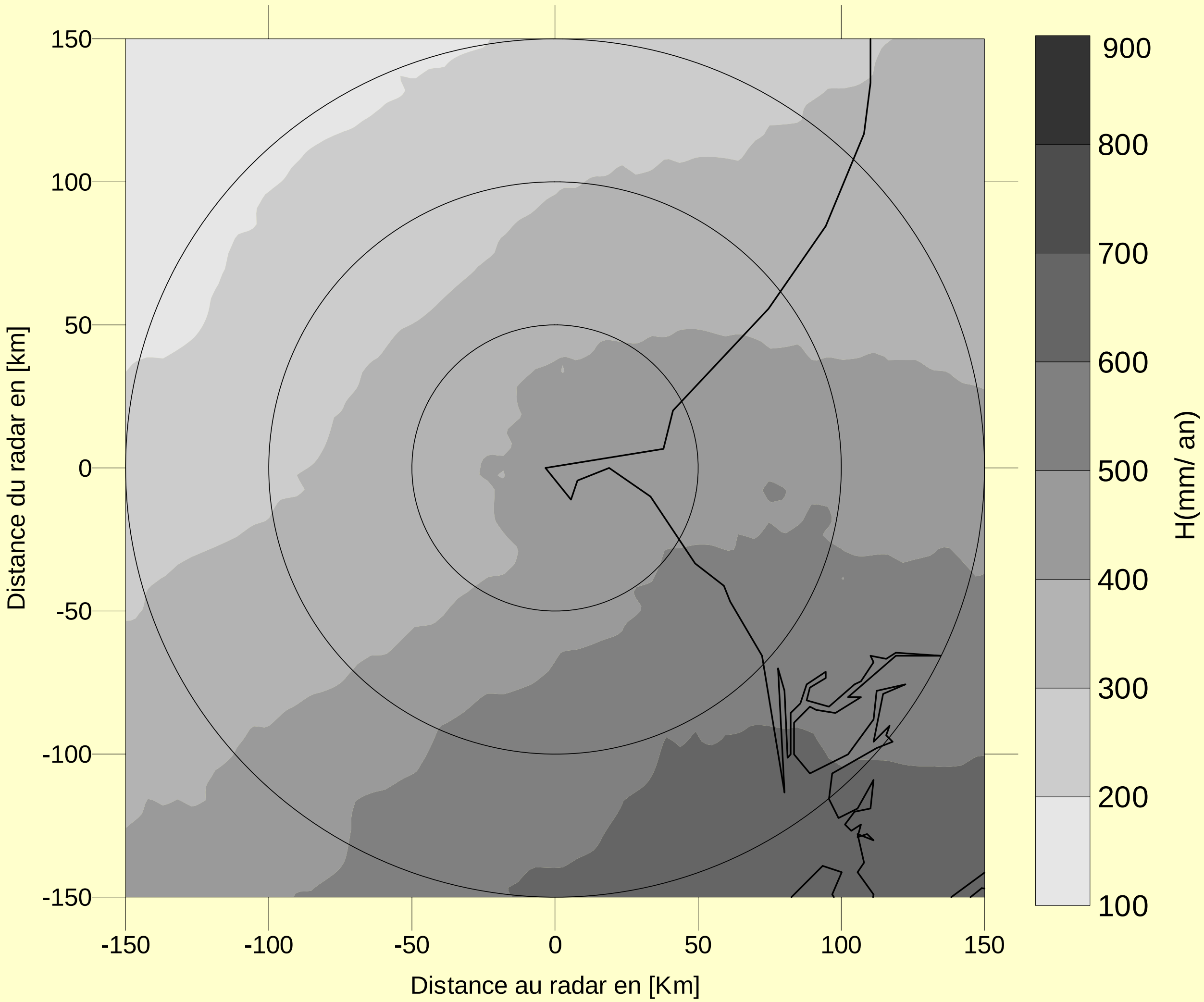


cumulative rainfall in annual mean (J A S)





Distribution of the rain duration (in days) at Dakar area in annual Mean computing using radar data of Dakar Yoff (1993-1999)

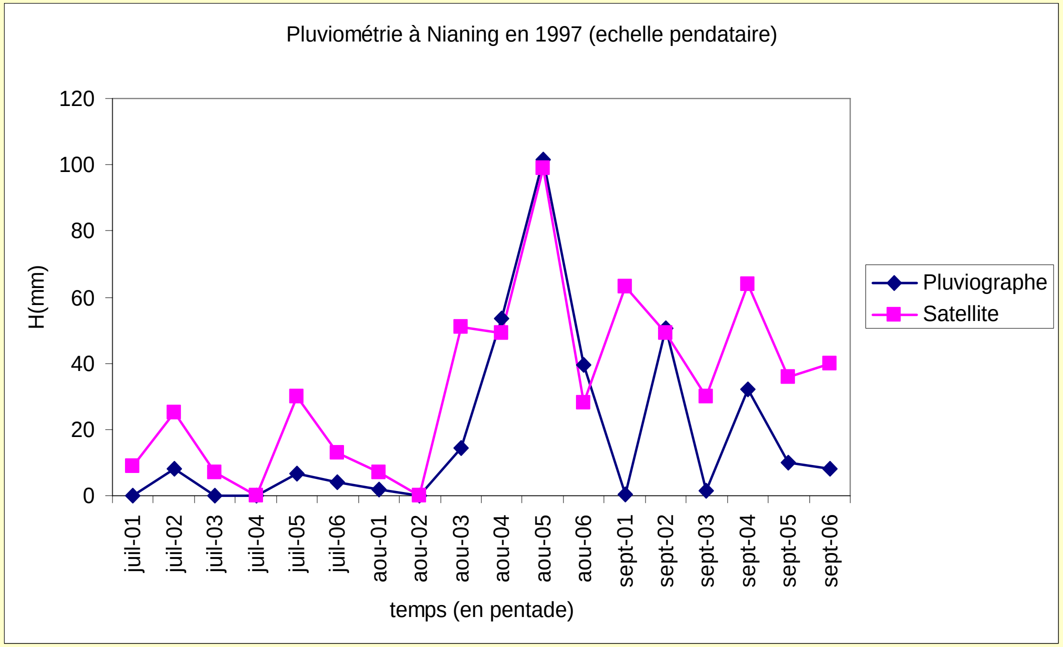


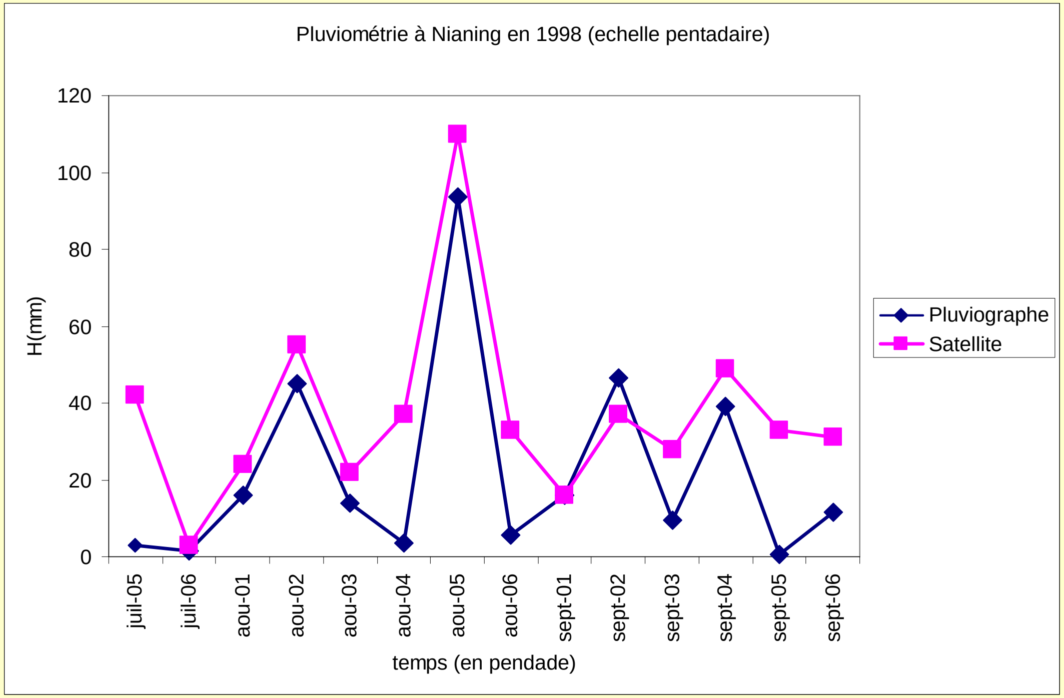
Distribution of cumulative rainfall at Dakar in annual mean (1996-1998)

- Southwest- northeast orientation of the isohyets as seen in radar and raingauge data

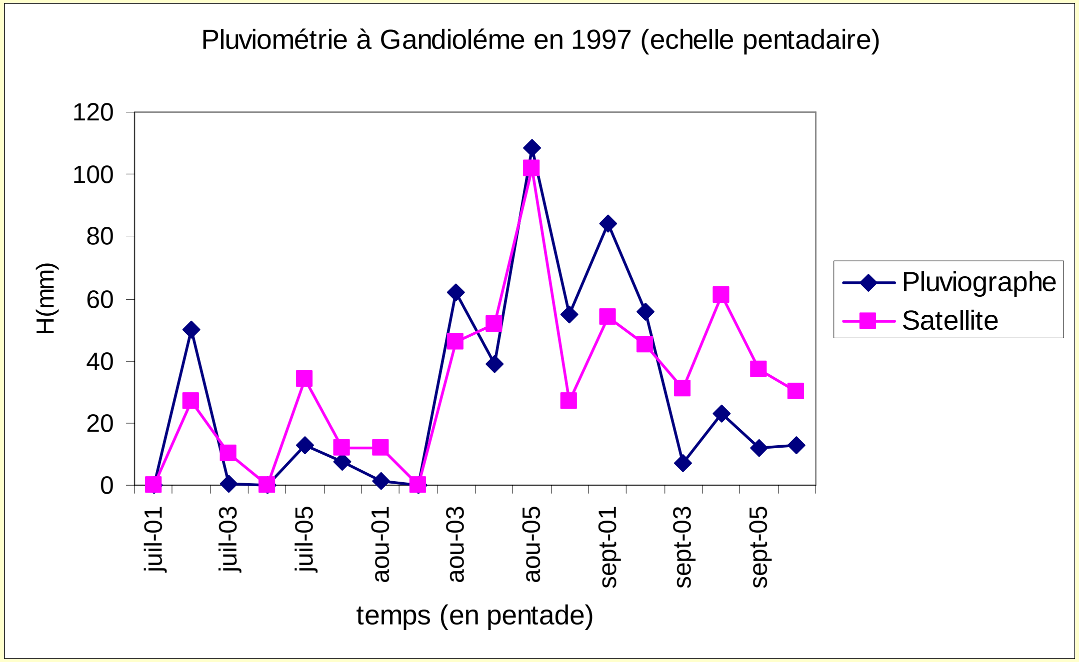
5 days cumulative rainfall estimation

- -5 days rainfall estimation in pixels under 3 raingauges in EPSAT-Senegal site :
  - -KAYAR
  - -Nianing
  - - Gandioléme

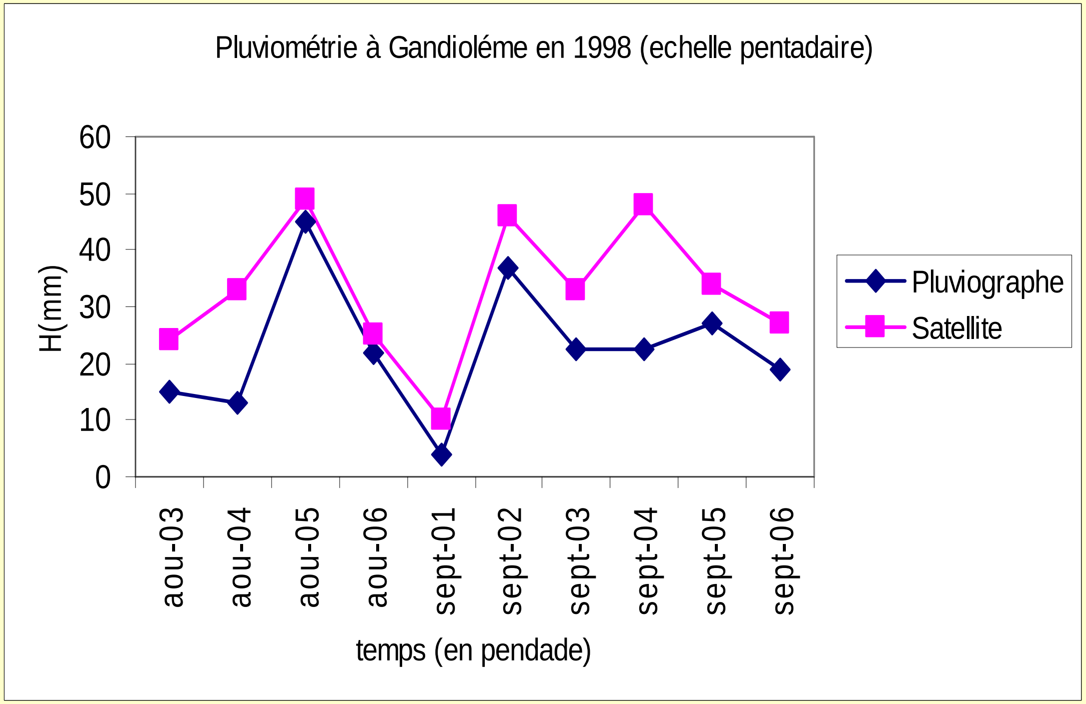


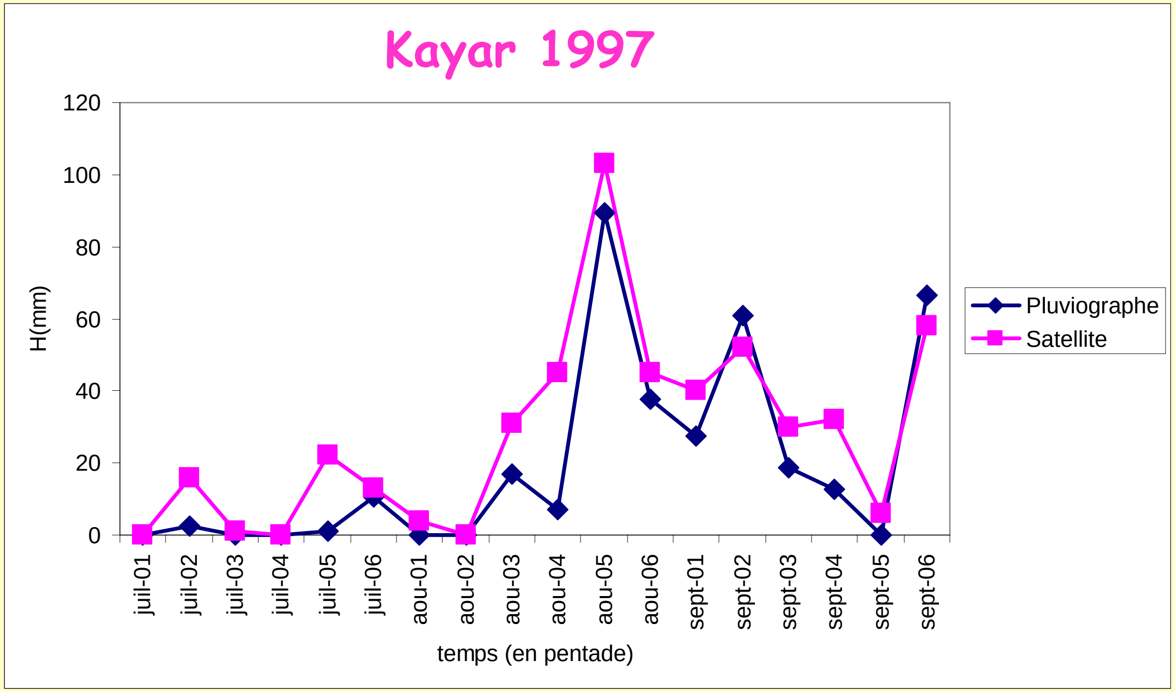


Nianing 1997 et 1998



Gandioléme 1997 et 1998





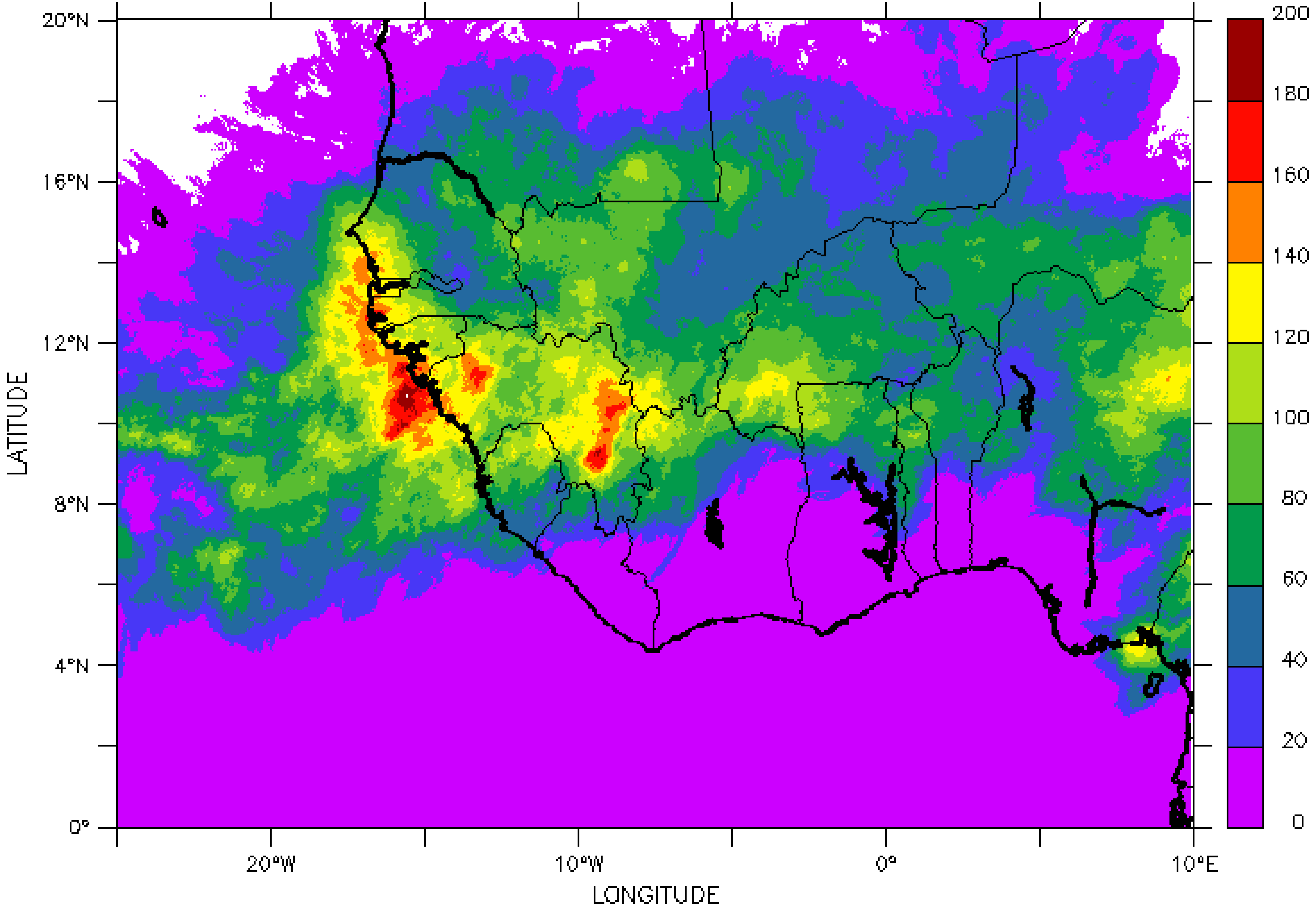
-Good correspondence between the cumulative rainfall obtained from raingauge and satellite

-the better result are observed during august when the ITCZ is well located in Senegal

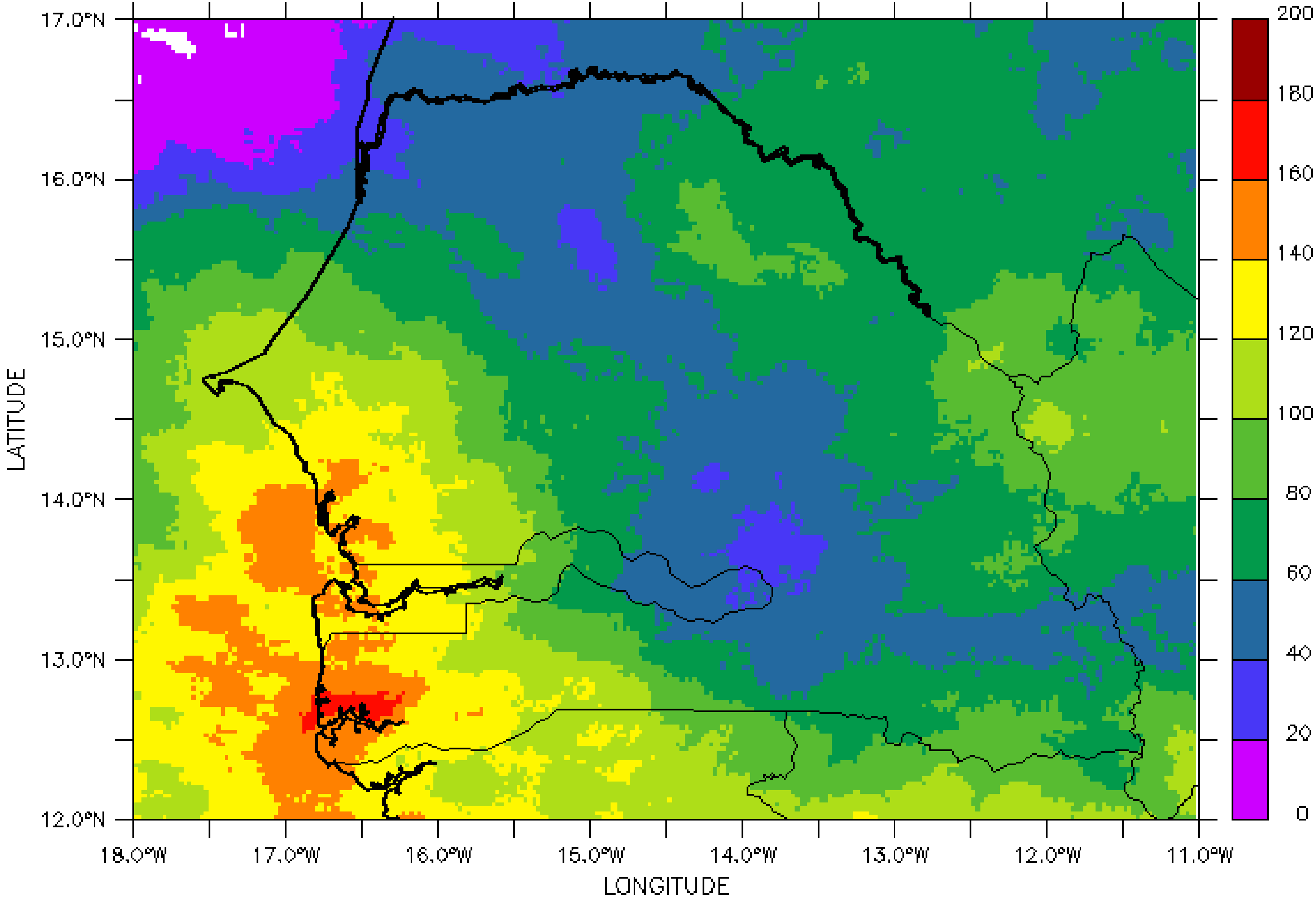
-strength occurrence of rain systems associated to precipitable cloud who can explain the good precision in rain area estimation and consequently rainfall accumulation gained with the area time integrals methods.

-Meanwhile at the onset and the end of the rainy season, some errors are noted. We can explain this by the low quantity of rain, corresponding to big variance on the rain estimation

Rainfall estimation using MSG



10 days cumulative rainfall(11–20/08/2006)



10 days cumulative rainfall(11-20/08/2006)

Article publish in Journal of Climate

KEBE, C.M.F., H.SAUVAGEOT and A. NZEUKOU,2005:The relation between rainfall and area-time integrals at the transition from an arid to an equatorial climate

Thanks for your attention