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Workshop on Atmospheric Deposition: Processesand Environmental Impacts

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Overview of the IDAF (IGAC DEBITS AFRICA) deposition program: Experience and Key results

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ICTP Workshop, Trieste, 21-25th May 2012

International Scientific Context

- IGBP International Geopshere Biosphere programme

- IGAC : International Global Atmospheric Chemistry (1990's)

Phase 1 Regional scale: tropics, boreal, polar, marine and temperate
1990-2006
Biosphere-atmosphere interactions
Oxydative capacity of the atmosphere, Atmospheric aerosols
2003: Atmospheric chemistry in a changing world (Brasseur, Prinn, Pszenny, 2003, Springer)

Phase 2 Role of the Atmospheric chemistry at the global scale
Atmospheric chemistry (ozone, aerosols, emissions, deposition) and climate change
Impacts of emission-deposition, transport and chemical transformation on air quality

- IGAC / GAW (Global Atmospheric Watch) (WMO) synergy:
Observatory to monitor the evolution of the atmosphere composition

Why Study Atmospheric Chemistry in the tropics ?

- **A major success of IGAC (phase 1) has been to stress the important influence of tropical atmospheric chemistry on global atmospheric composition and climate**

- **Tropical atmospheric Chemistry includes:**

  - high UV flux, high T, high water vapour content promote intense photochemistry

  - urbanization, industrialization, agriculture and biomass burning are increasing rapidly producing large emissions of gases and particles

  - deep convection provides rapid vertical transport into the upper troposphere and stratosphere and strong deposition

Back to Atmospheric Chemistry in Africa

80% Biomass burning in the tropics at global scale

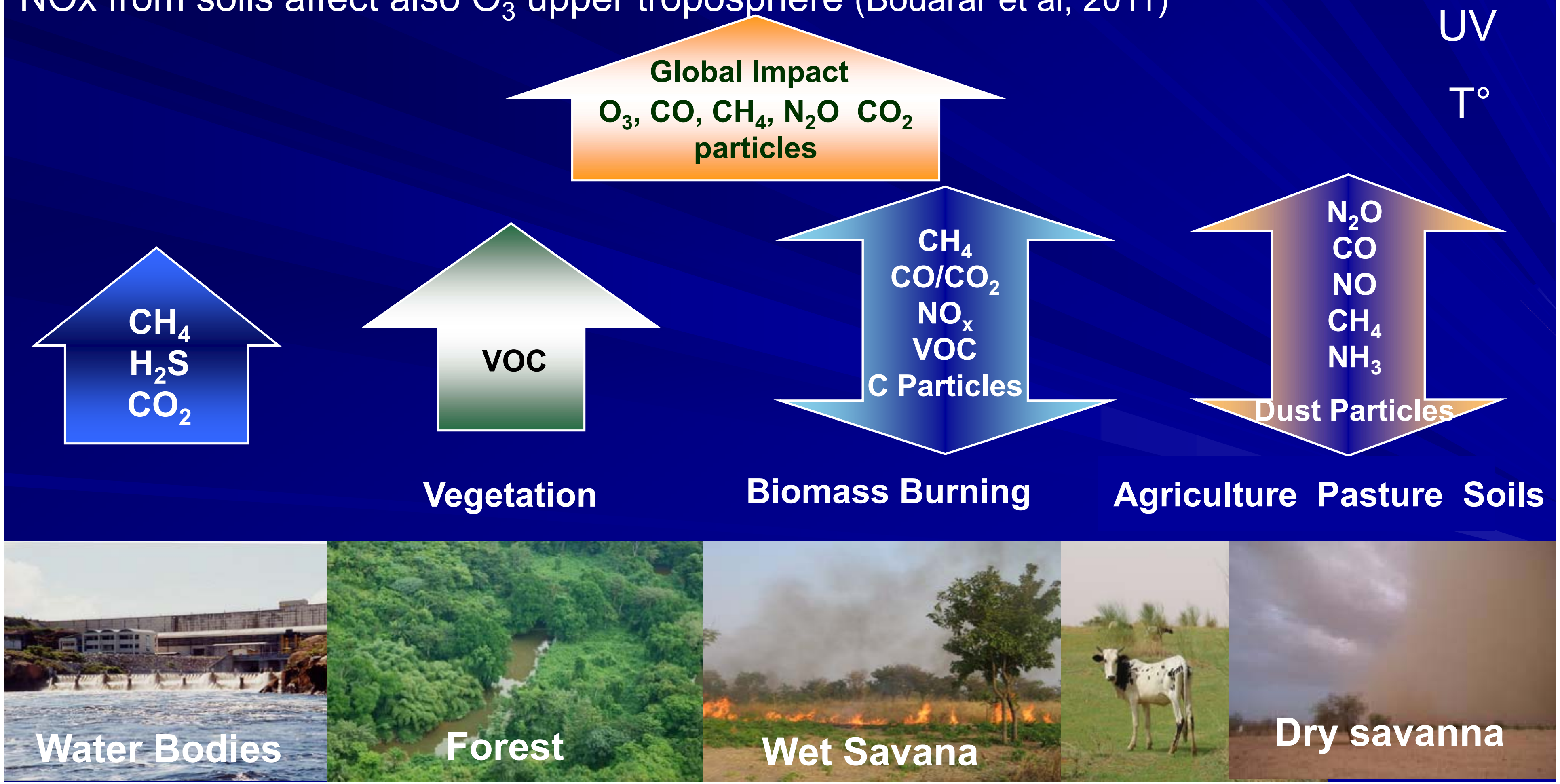
70% african savannas burned each year

Dust aerosol source: Sahara 30-50% global emission (IPCC 2007)

NOx from soils 3.3 Tg/yr^{-1} equivalent to NOx Biomass Burning 3.8 Tg/yr^{-1} (Jaegle et al, 2004)

NOx soils and VOC main contribution to O_3 in West Africa- BB in Central Africa.

NOx from soils affect also O_3 upper troposphere (Bouarar et al, 2011)



Why study atmospheric deposition?

- **Atmospheric deposition controls the concentration of chemical species and is the final step of interacting mechanisms such as**

  - amplitude of the gases and particles sources
  - transport and dynamic transfer in the atmosphere
  - physico-chemical transformation of the substance
  - amplitude of the dry and wet deposition

  → **Deposition measurement is a pertinent indicator of the evolution of the atmosphere chemical composition**

- **Atmospheric deposition acts as a source of nutrients or toxic substances to the biosphere**

Outline

- Precipitation Chemistry and Wet deposition
  - Presentation of the DEBITS/IDAF network
  - Precipitation chemistry characteristics
  - Wet deposition fluxes

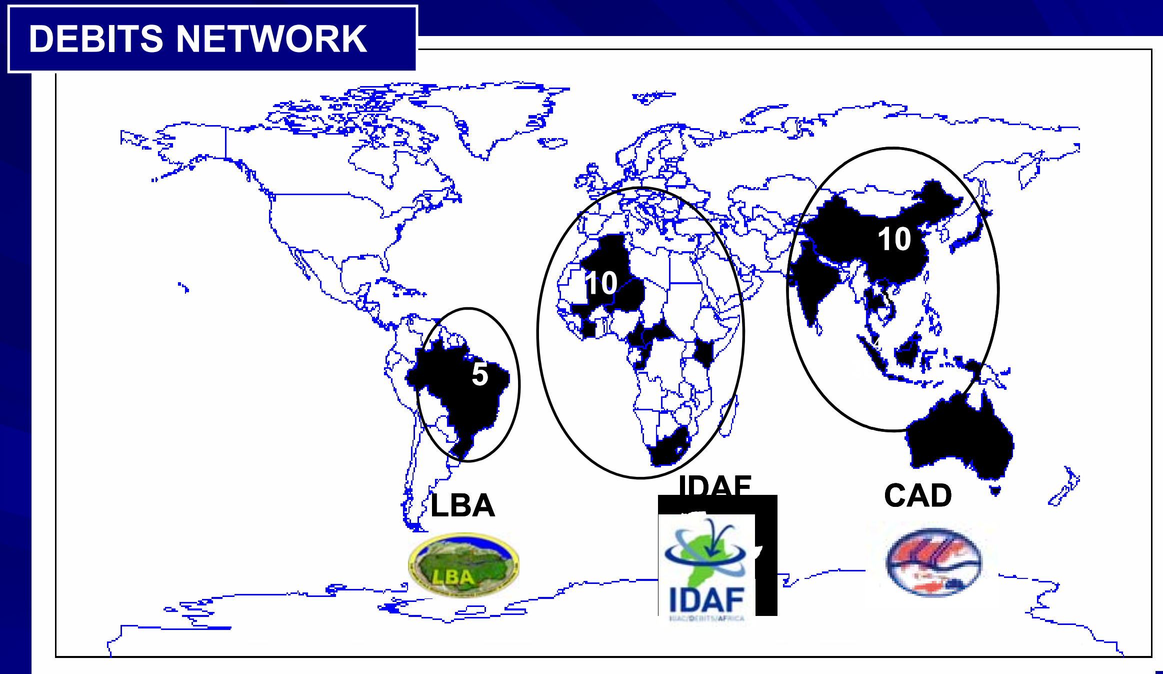
- Atmospheric nitrogen cycle
  - Gases concentrations measured on the african ecosystem transect (dry savannas/wet savannas/forest)
  - Nitrogen atmospheric deposition budget at the scale of the african ecosystems
  - A regional study: Nitrogen emission-deposition budget in the Sahel
  - Nitrogen emission-deposition budget at the scale of the african ecosystems

- Perspectives

DEBITS : a Task of IGAC II

Deposition of Biogeochemically Important Trace Species

DEBITS II



The international DEBITS network composed by 25 stations located all around the tropical belt.

DEBITS II task since 2004 accepted in the second phase of IGAC

- **CAAP (1990) / CAD (2000) Composition of Asian Deposition**
- **IDAF (IGAC DEBITS Africa) (1994)**
- **LBA The Large Scale Biosphere-Atmosphere Experiment in Amazonia (1998)**

DEBITS II scientific objectives

DEBITS II

- To measure the atmospheric removal rates by dry and wet deposition of biogeochemically trace species on a long term
- To study key regulating processes (interaction gas/aerosol/cloud/ecosystem) of deposition fluxes
- To establish at regional scale atmospheric budgets of key elements (N, S, C…)
- To relate the deposition fluxes measurements to impact studies

IDAF Observation Network

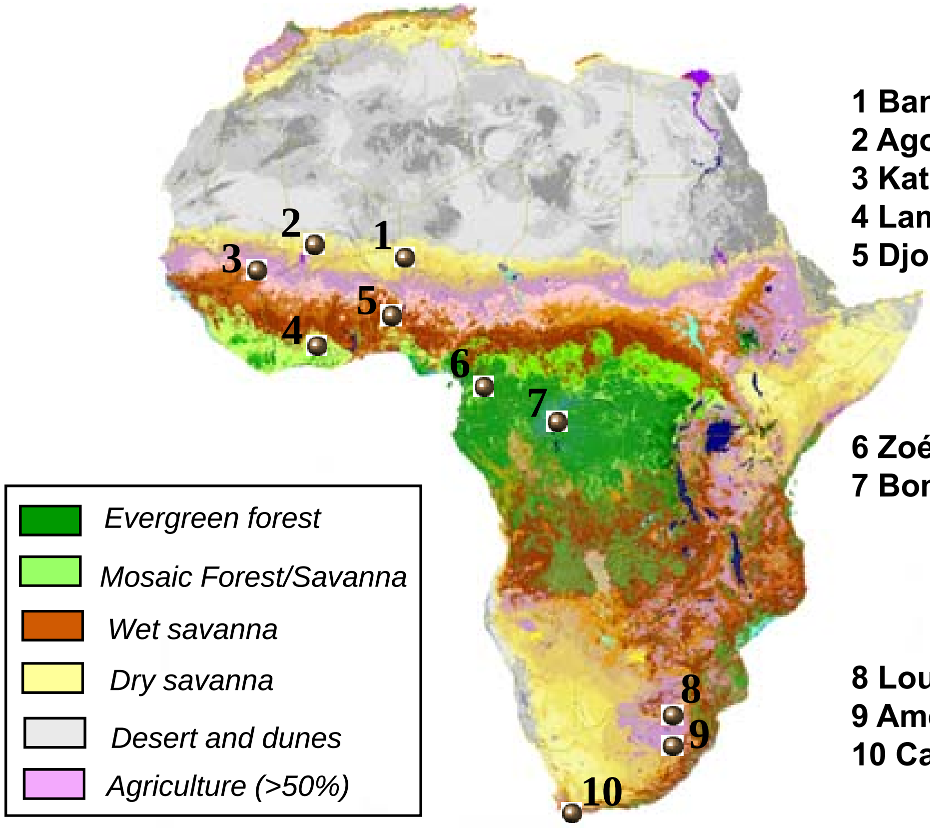
IDAF : African network of DEBITS II - Part of the AMMA AC programme (tasks of IGAC II)

(African Monsson Multidisciplanry program – Atmospheric Chemistry)

The IDAF network is composed by 10 stations representative of great african ecosystems

4 in South Africa (coordination North West University, ESKOM)

7 in West Central Africa (Cameroon, Benin, Mali, Niger, Côte d'Ivoire) (ORE CNRS-coordination Lab.Aérologie Toulouse).



1 Banizoumbou (Niger)
2 Agoufou (Mali)
3 Katibougou (Mali)
4 Lamto (Côte d'Ivoire)
5 Djougou (Benin)

6 Zoétélé (Cameroon)
7 Bomassa (Congo)

8 Louis Trichardt (SA)
9 Amersfoort (SA)
10 Cape point (SA)

Each IDAF site is under the responsibility of PI :

V. Yoboué, (Univ. Abidjan CI)

B. Diop (Univ. Bamako, Mali)

L. Dungall (Univ. Niamey, Niger)

A. Akpo (Univ. Cotonou)

L. Sigha (CRH/IRD Yaoundé)

K. Pienaar, North West Univ. (SA)

IDAF Scientific objectives

- **To study the chemical composition of the atmosphere in Africa**

The objective is to document the temporal and spatial evolution of gases and aerosols concentrations, and to analyze weekly, seasonal and inter annual variations

- **To study wet and dry atmospheric deposition** :

- To measure the atmospheric removal rates by dry and wet deposition of biogeochemically trace species on a long term using quality controlled measurements at the regional scale of the ecosystems

- To study key regulating processes (interaction gas/aerosol/cloud/ecosystem) of deposition fluxes

- To establish at regional scale atmospheric budgets of key elements (N, S, C…)

- To relate the deposition fluxes measurements to impact studies

The IDAF measurements

IDAF Measurements

10 stations representative of the great African ecosystems in 2010

Dry deposition fluxes: Gaseous concentrations ($S0_2$, $N0_2$, NH_3, $HN0_3$ and 0_3)

Aerosol collection for chemical analysis

Wet deposition fluxes: Sampling rainwater events for chemical analysis

DEBITS has define a set of experimental and analytical protocols to assure data quality

Control of Quality on collection

WMO N° 160: report of reference for GAW precipitation chemistry programme

and Analytical procedure (WMO, DEBITS protocols)

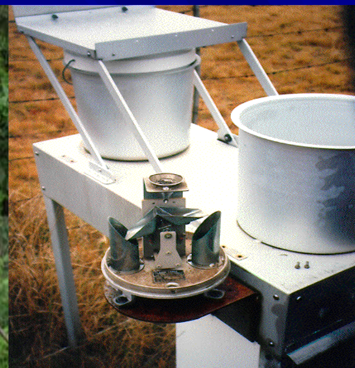
The LA and NWU analytical laboratory of chemistry receive IDAF sites samples. These laboratories participate to the international assurance quality programme organized by WMO.

IDAF measurements

- **Gas concentrations**

Passive gas sampling (month) for SO_2, NO_2, NH_3, HNO_3 and O_3

- **Chemical composition of precipitation**



Wet-only sampling (events), preservation by a biocide or by freezing US EPA quality criteria
Annual analytical laboratory performance (WMO)

pH, Conductivity, Inorganic and Organic major ions (Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, HCOOH, CH_3COOH, C_2H_5COOH)

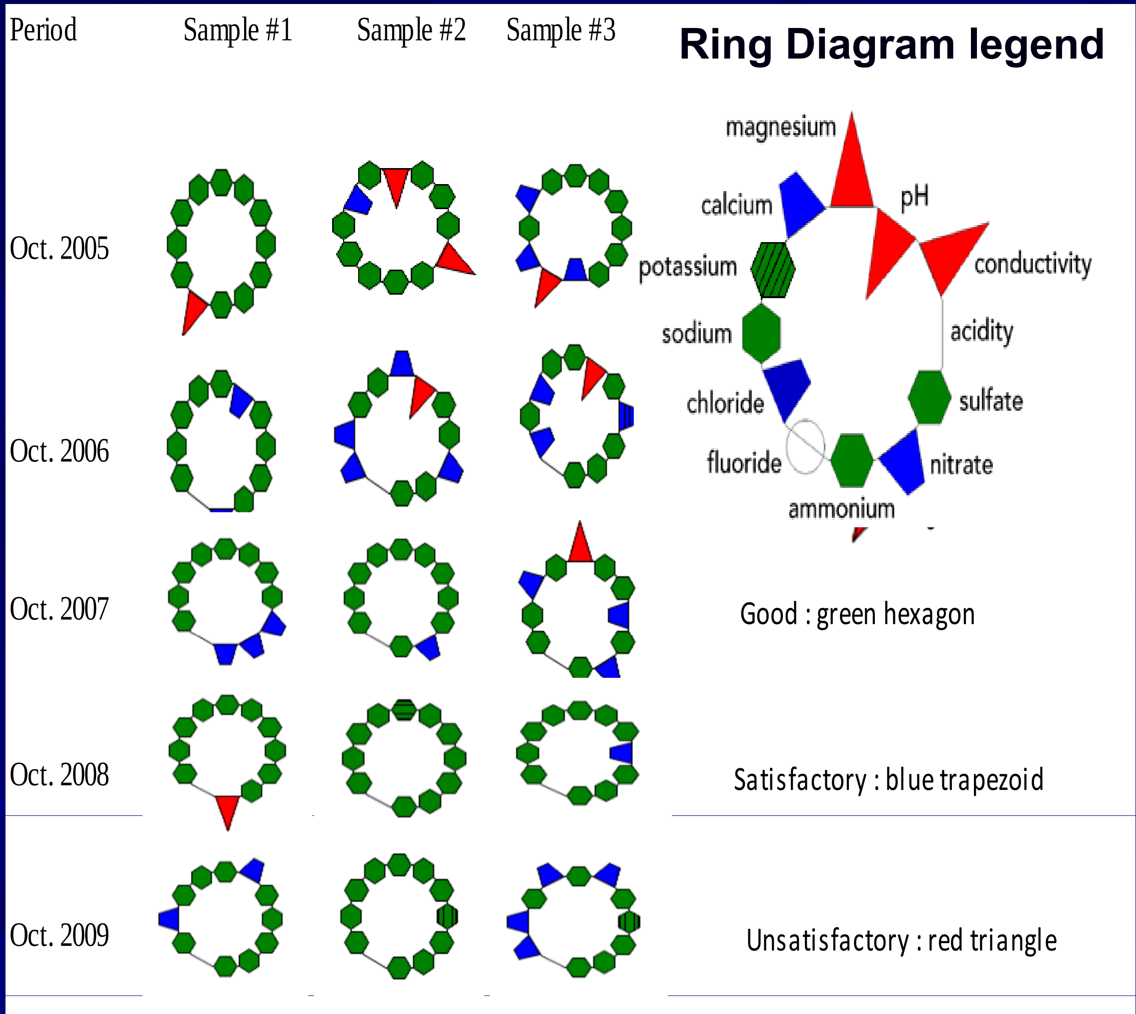
- **Chemical composition of aerosols**

Monthly sampling – PM2.5 and PM10

Inorganic and organic major ions
(Cl^-, NO_3^-, SO_4^{2-}, HCO_3^-, CO_3^{2-}, Na^+, NH_4^+, K^+, Mg^{2+}, Ca^{2+}, HCOOH, CH_3COOH, C_2H_5COOH)

Particulate carbon (TC, OC and BC)

The IDAF measurements: IC analysis



LA results to the WMO intercomparison program 2005-2009

LA participates since 1996 has the WMO quality control label

in IC:

Global estimated uncertainty

± 5% for all ions, pH and Ω

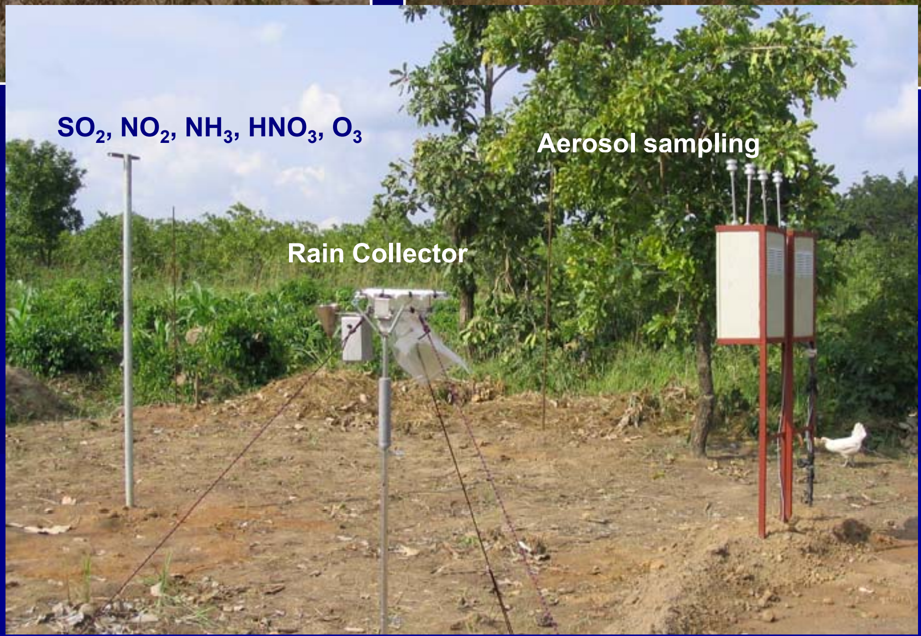
IDAF stations in West Central Africa: Dry savanna


Agoufou (Mali) Dry season


Agoufou Wet Season


Banizoumbou (Niger)

IDAF stations in West Central Africa



IDAF Station in Bénin (Djougou/Nangatchori)

Main IDAF achievements

- **Synthesis of wet deposition studies for the different ecosystems**

  Forest: *Sigha et al, JAC, 2003*

  Dry savannas in South African sites *Mphepya et al, JAC, 2004,2006*

  Wet savanna: *Yoboué et al, JAC, 2003*

  Dry savanna: *Galy-Lacaux et al, JAC, 1998, 2001,2009, Laouali et al, JAC 2006, 2011*

  Global*: Freydier et al, Atm Env. 1998, JGR 1999*

  Modeling intercomparison/validation*: Dentener at al, GBC 2006*

- **Wet deposition and Acidity**

  J.*P Lacaux et al, 2003, IGAC synthesis, Global change.*

  J.P Lacaux et al, IGACtivities Newsletter n°27, 2003.

- **Regulating processes of deposition fluxes: Heterogenous chemistry**

  Modeling and experimental study for the dry savanna *C. Galy et al, JGR, 2001, IGAC 2003*

- **Dry deposition: gases and aerosol chemical characterization**

  Wet savanna aerosol*: Yoboue et al, JAC 2006*

  Passive samplers gases concentrations*: Pienaar et al, 2006, Carmichael et al, 2003, Adon et al, 2010, Martins et al, 2007* **NOx budget (GOME):** *Jaegle et al, JGR 2004*

- **Atmospheric Nitrogen deposition over african ecosystems**

  Galy-Lacaux et al, *IGAC Newsletter, 2003*; *Laclau et al*, 2001, *Nzila et al, 2002, Bouillet et al*, 2002 *Delon et al. 2010, 2011, Galy-Lacaux et al, 2011*

Precipitation chemistry and wet deposition

- **1995 WMO assessment (Whelpdale and Kaiser)**
  Critical review of <u>acid wet deposition</u> at the global scale

- **IDAF (initiated in 1995): analysis of a long term database of rain chemistry Representative of the main african ecosystems**

Dry savannas in South African sites

Mphepya, Pienaar, Galy et al, 2004
Mphepya, Galy et al, 2006

Dry savanna

Galy-Lacaux and Modi, 1998
Galy-lacaux et al, 2001
Galy et al, 2009
Laouali, Galy et al, 2011

Wet savanna

Yoboué, Galy et al, 2005
Akpo, Galy et al, 2011

Forest

Sigha, Galy et al, JAC, 2003

⇒ Main characteristics of the precipitation chemistry at the regional scale of the ecosystems

in relation with the main sources of atmospheric gases and particles

⇓

Mineral terrigenous contribution

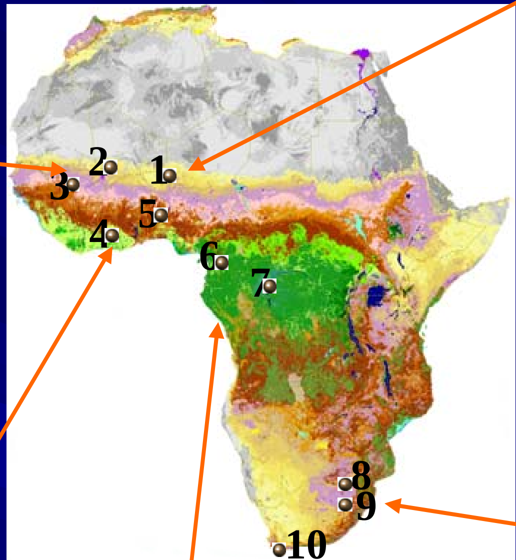
Marine contribution, N and S contribution

Acidity

IDAF Sites - Precipitation chemistry

3- Katibougou (Mali)
Active since 1997..

2- Agoufou Mali
Active 2004-2006 (AMMA)
Laouali et al, 2012, Atm Env



1- Banizoumbou (Niger)
Active since 1994…
Galy-lacaux et al, 2009, ACP

4- Lamto (CI)
Yoboué et al, 2006
Active since 1994..

5- Djougou (Benin)

Active 2005-2008 (AMMA)

6- Zoétélé (Cameroun)
Active since 1996

Sigha et al, 2005, JAC

6- Amersfoort 86-99 2009..

7- L. Trichardt 86-99 2009

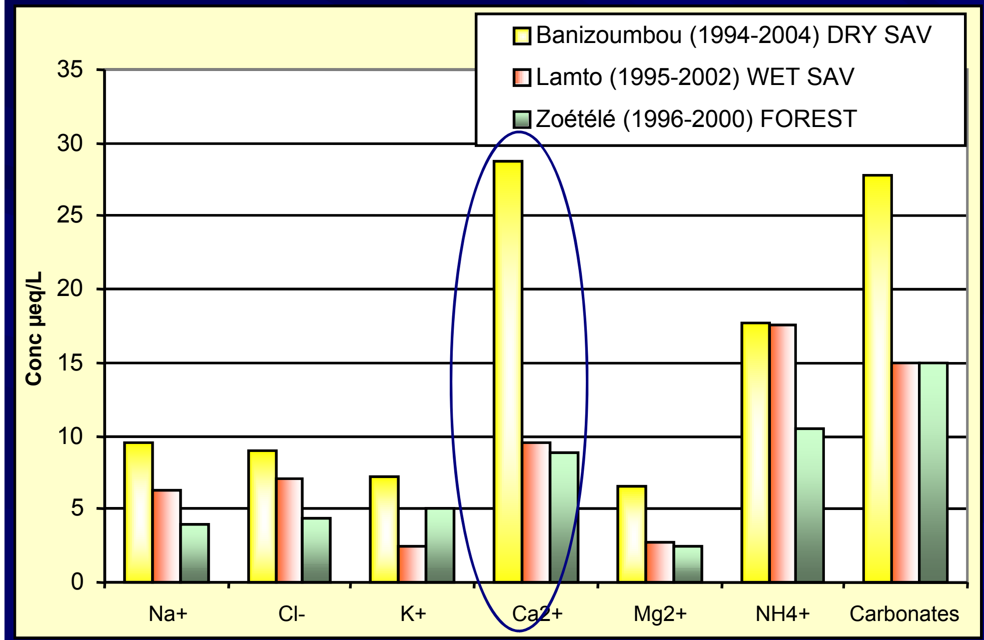
8- Cape Point 2004

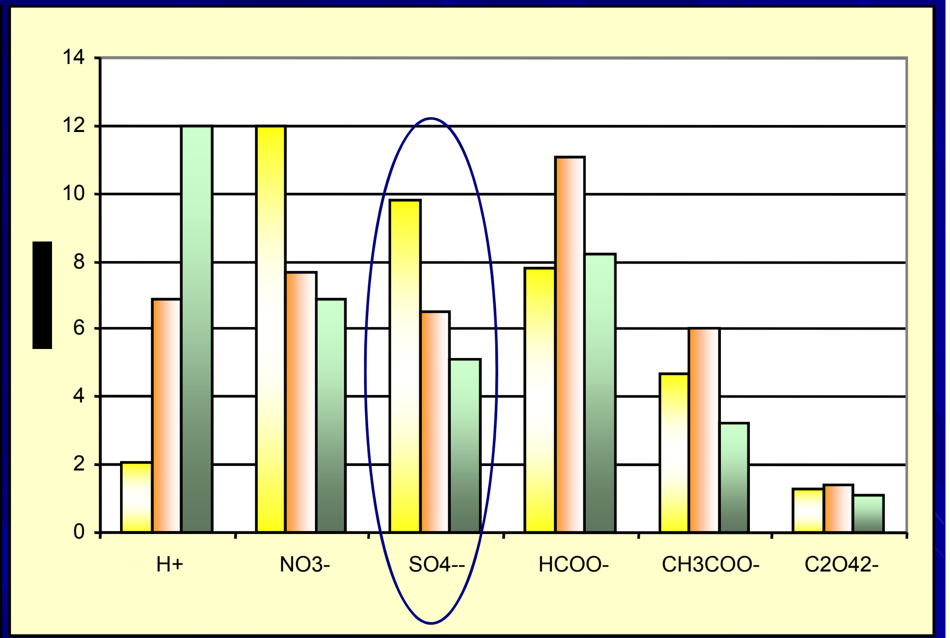
9 Skukuza 99-02 2009…

Mphepya et al, 2003, 2005, JAC

Chemical composition of precipitation

Mean annual Volume Weighted Mean concentration µeq.L^{-1}



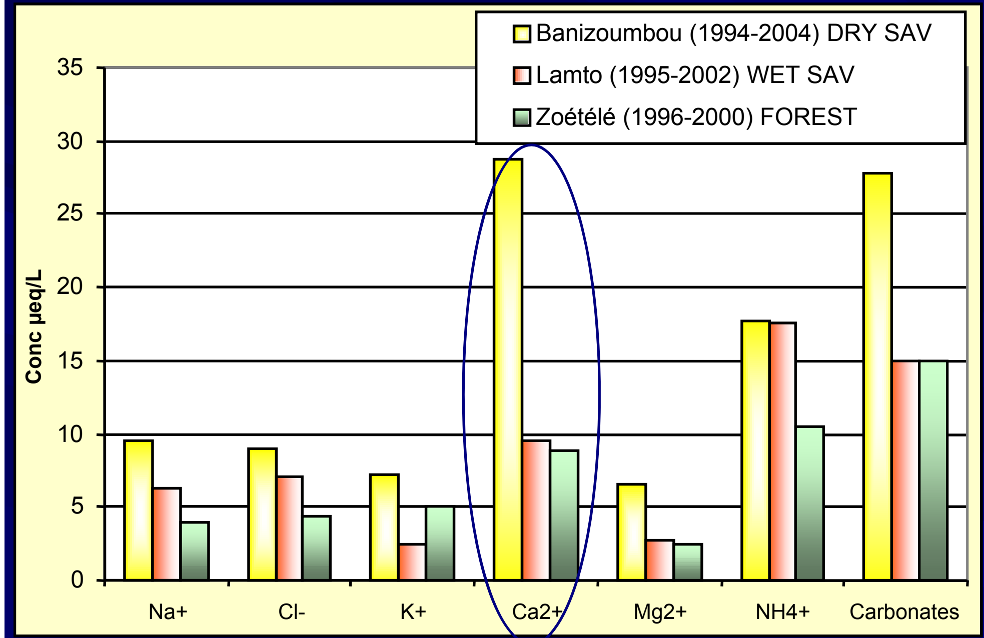


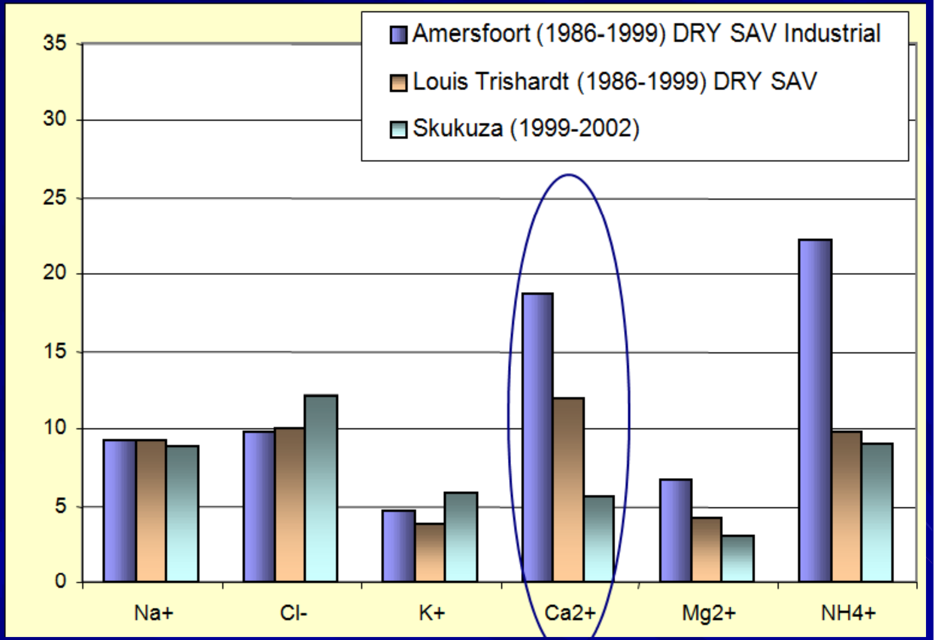
Terrigenous Contribution Tracers: calcium, magnesium, carbonates

Ca^{2+} : positive gradient from forest to dry savanna: 8 µeq.L^{-1} Zoétélé to 28 µeq.L^{-1} Banizoumbou
Mg^{2+} - K^{+} same gradient but lower concentrations 1.7 -7.6 µeq.L^{-1}

Chemical composition of precipitation

Mean annual Volume Weighted Mean concentration µeq.L^{-1}





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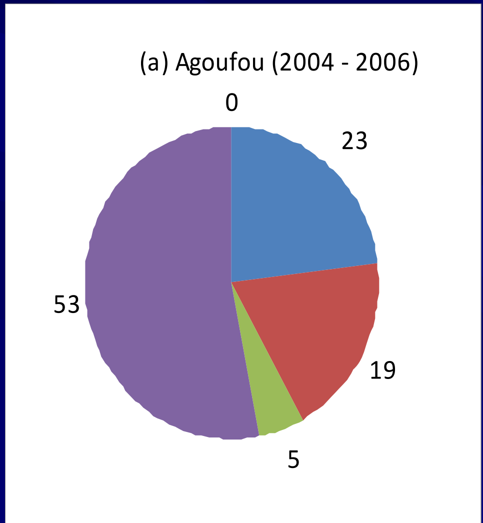
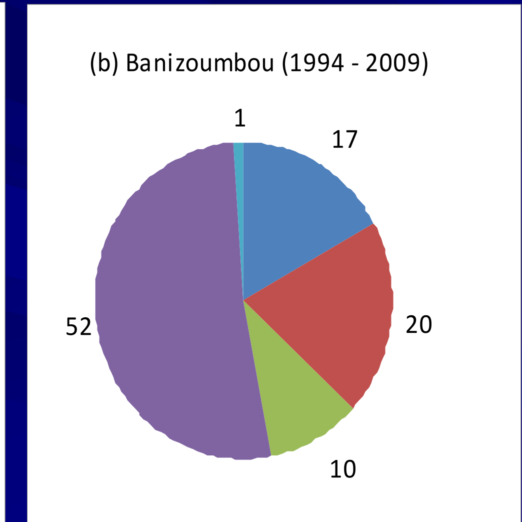
Dissolution of terrigenous particles : Calcite ($CaCO_3$), Dolomite (CaMg(CO3)2), Gypsum (CaSO4), or illite (K(Al,Mg)3SiAl10(OH))
Explain the Ca^{2+} ,Mg^{2+} , SO_4^{2-} and K^{+} enrichement of precipitation on the african continent.

Chemical composition of precipitation of sahelian dry savannas sites

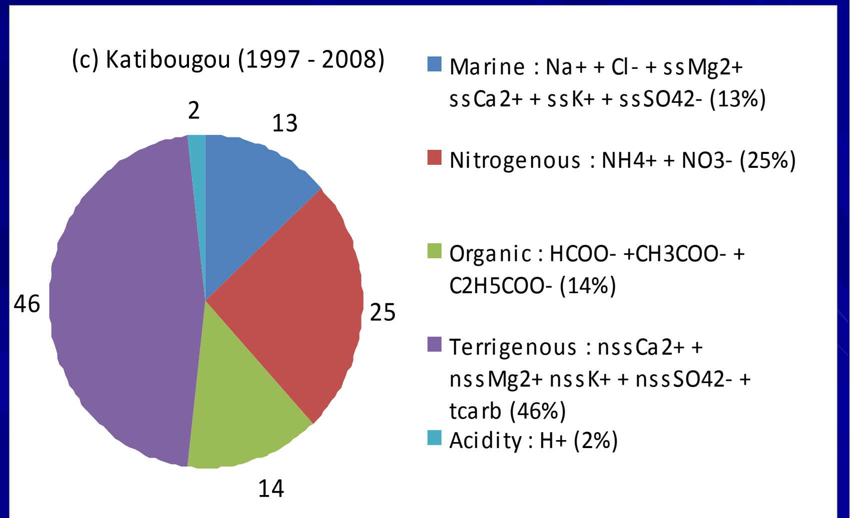
Agoufou (Mali)



Banizoumbou (Niger)



Katibougou (Mali)



Laouali, Galy et al, 2011

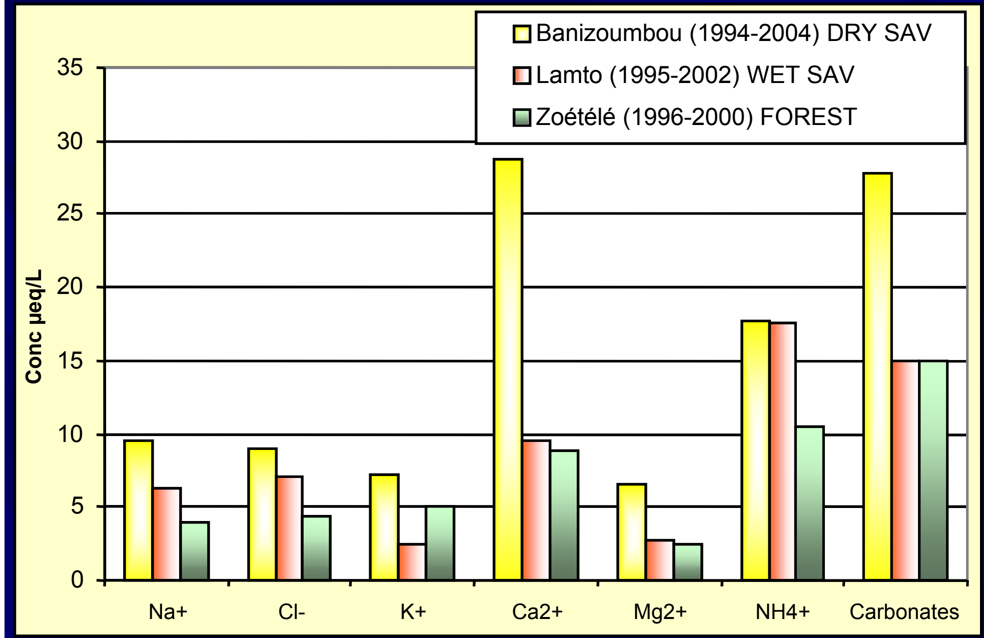
Terrigenous contribution in sahelian dry savannas sites: 46-53%

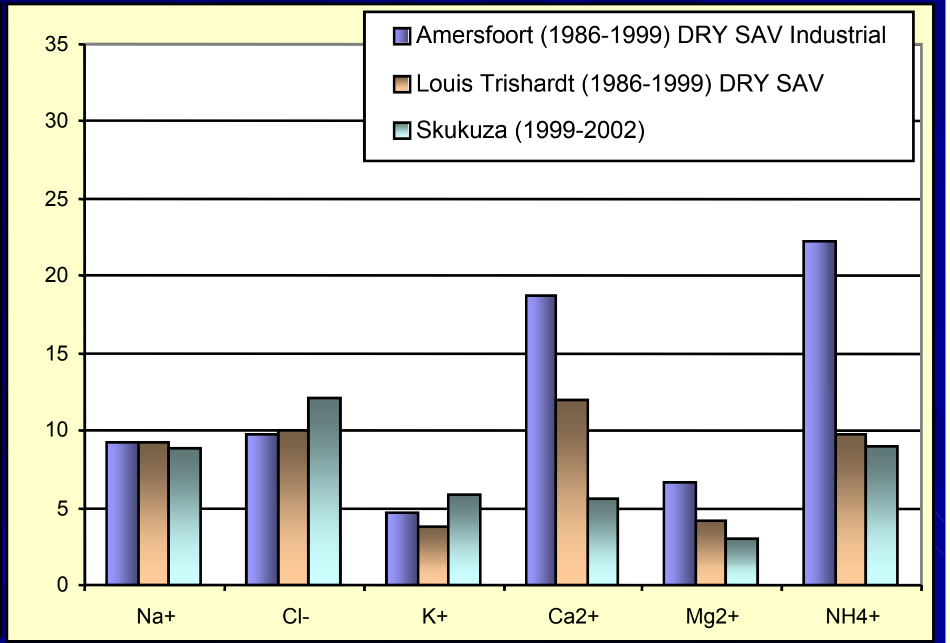
in wet savannas and forest: 30%

19% pour Amersfoort, 27% pour LT et 30% pour Skukuza

Chemical composition of precipitation

Mean annual volume weighted mean concentration µeq/L





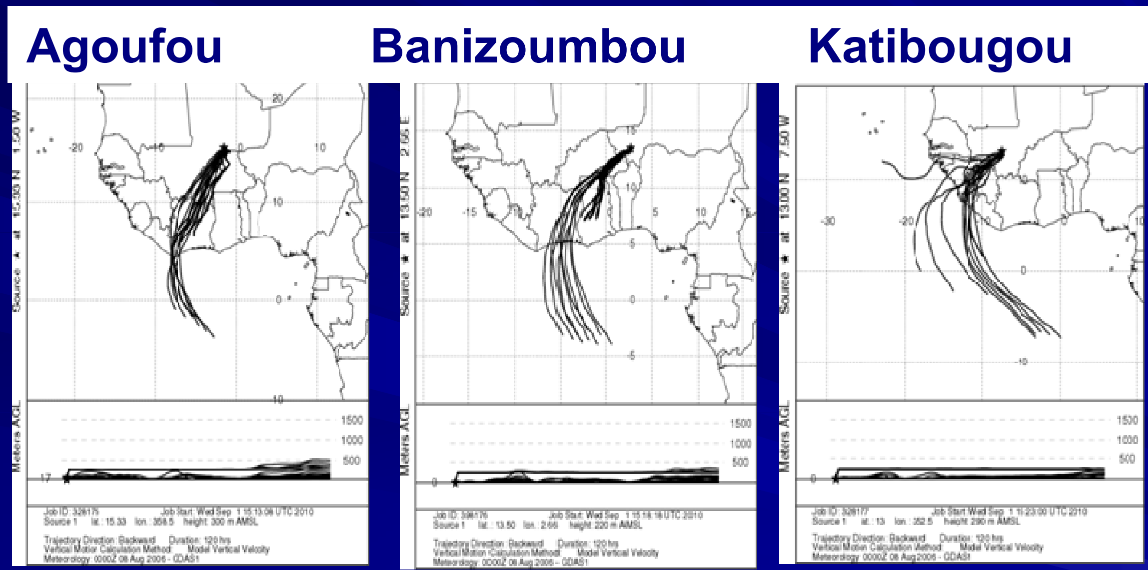
Marine source: tracers Na^+ and Cl^-

South African sites: Cl/Na closed to sea water ratio : 11% contribution Amersfoort, 23% LT and Skukuza 25% (indian ocean influence) (Mphepya, Galy et al, 2005, 2006)

Transect Dry sav/ Wet sav/ Forest: relative contribution 10-20%

Chemical composition of precipitation

Mean annual volume weighted mean concentration µeq/L



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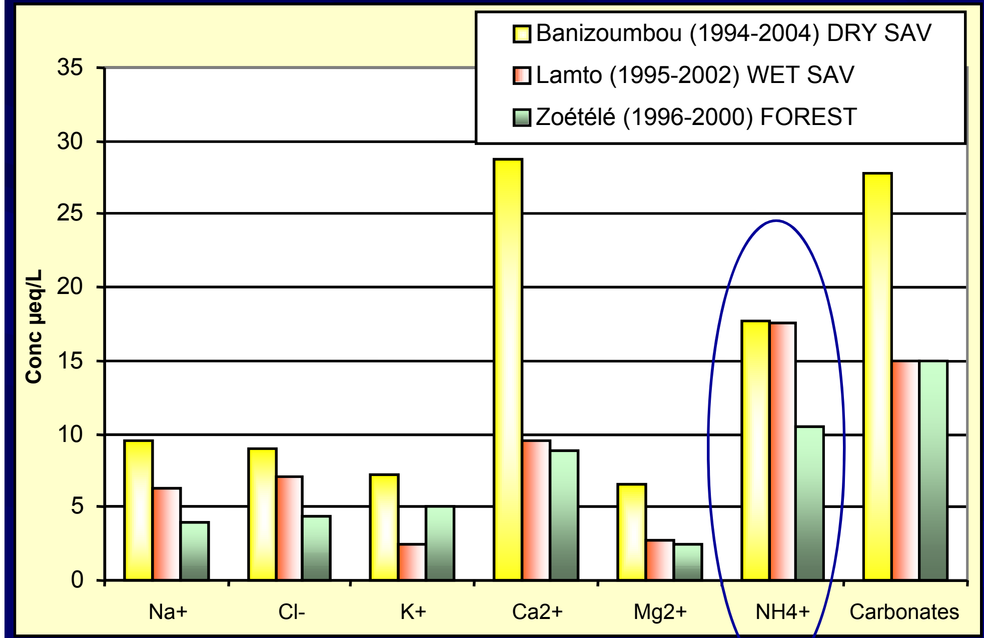
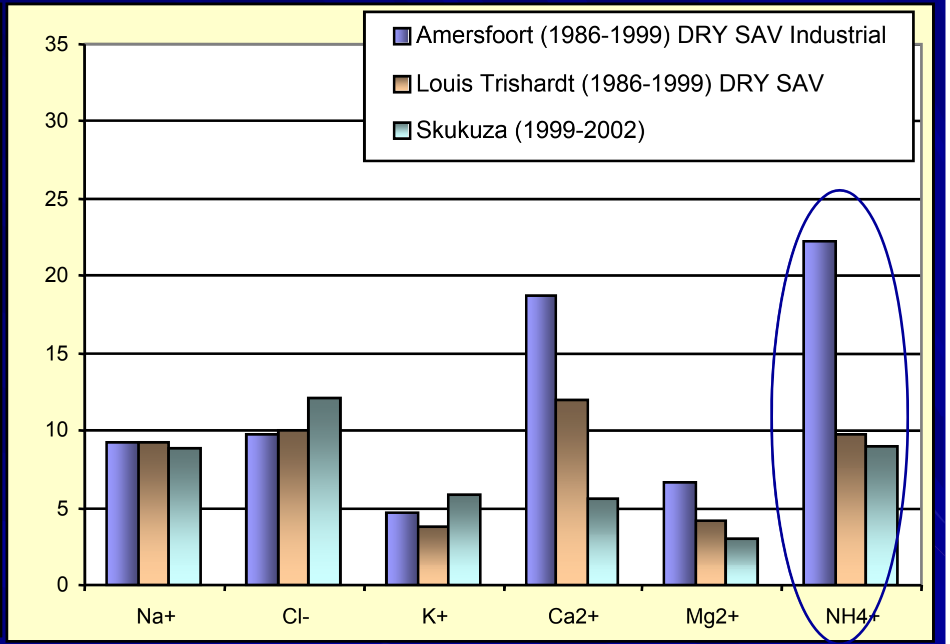
Transect Dry sav/ Wet sav/ Forest: relative contribution 10-20%

Chemical composition of precipitation

Mean annual Volume Weighted Mean concentration µeq.L-1



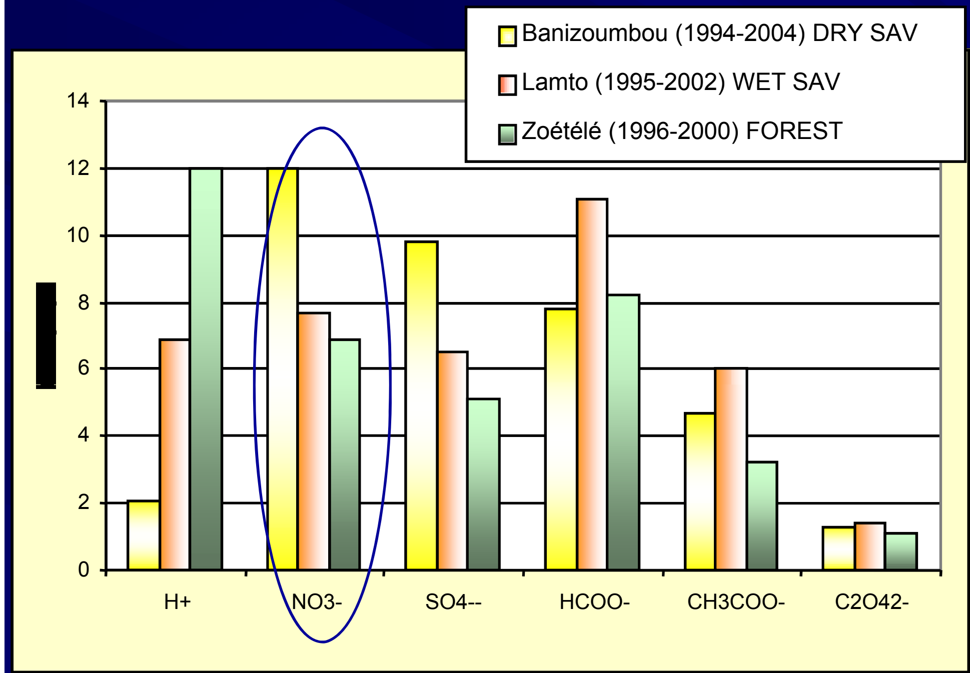


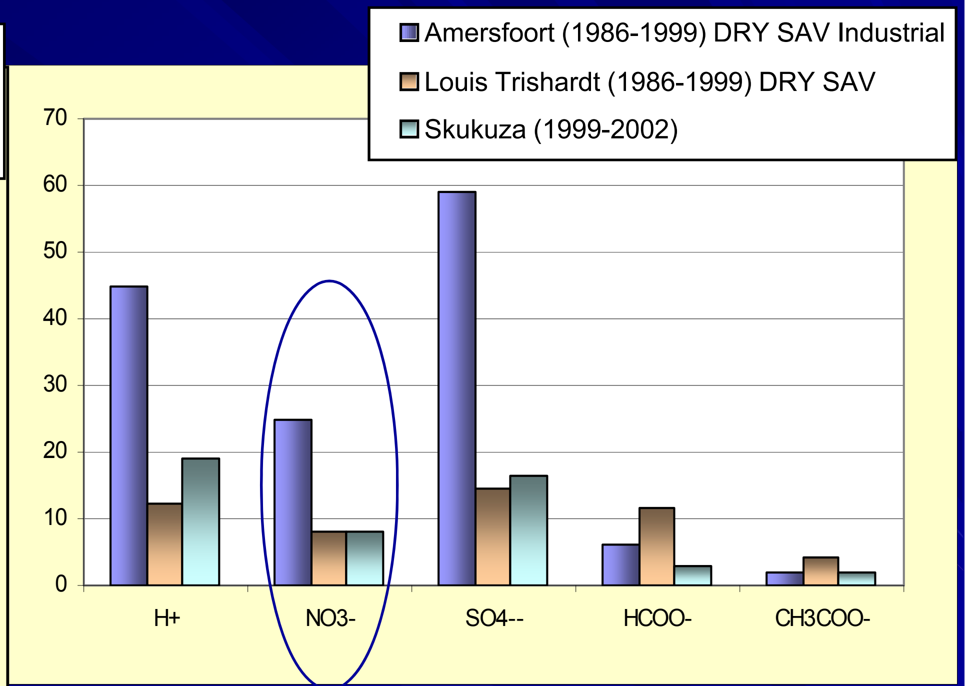
Nitrogenous contribution: tracers NO_3^- and NH_4^+

NH_4^+: 10 -18 $\mu eq.L^{-1}$ in West Central Africa, 10 -20 $\mu eq.L^{-1}$ in South Africa
Ammonia capture in cloud water and precipitation
In WCA dry savannas : strong animals source of NH_3 (natural soils emission and domestic combustion)
In SA: skukuza influenced by wild animals NH_3 sources (NH_3 from agricultural activities and petrochemical emissions)

Chemical composition of precipitation

Mean annual volume weighted mean concentration µeq/L





Nitrogenous contribution: Nitrate

WCA: 6-12 µeq.L^{-1} with a gradient from dry sav/wet sav/forest

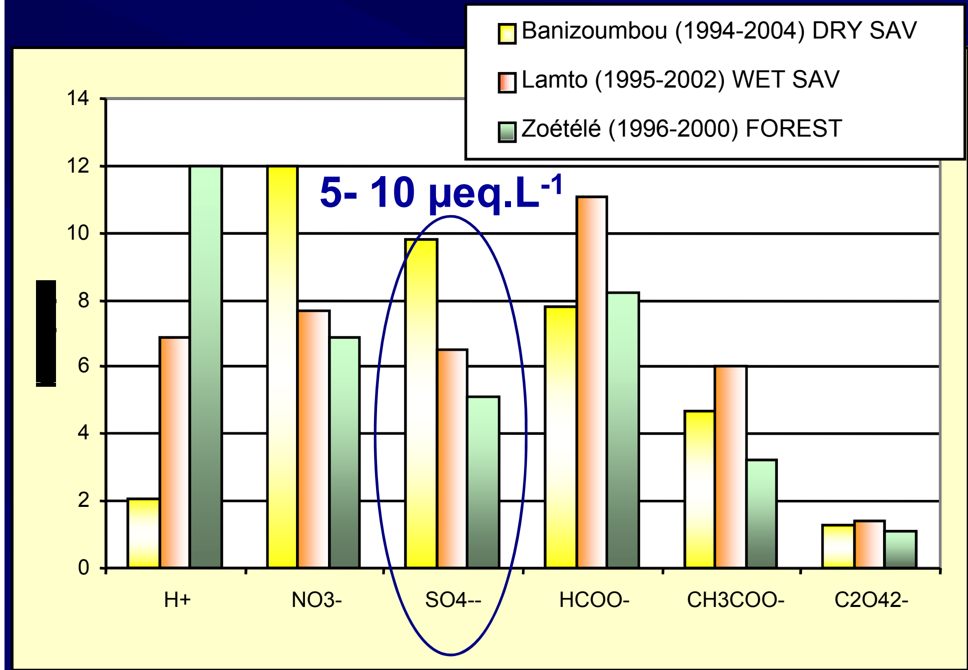
SA: AM 22µeq.L-1

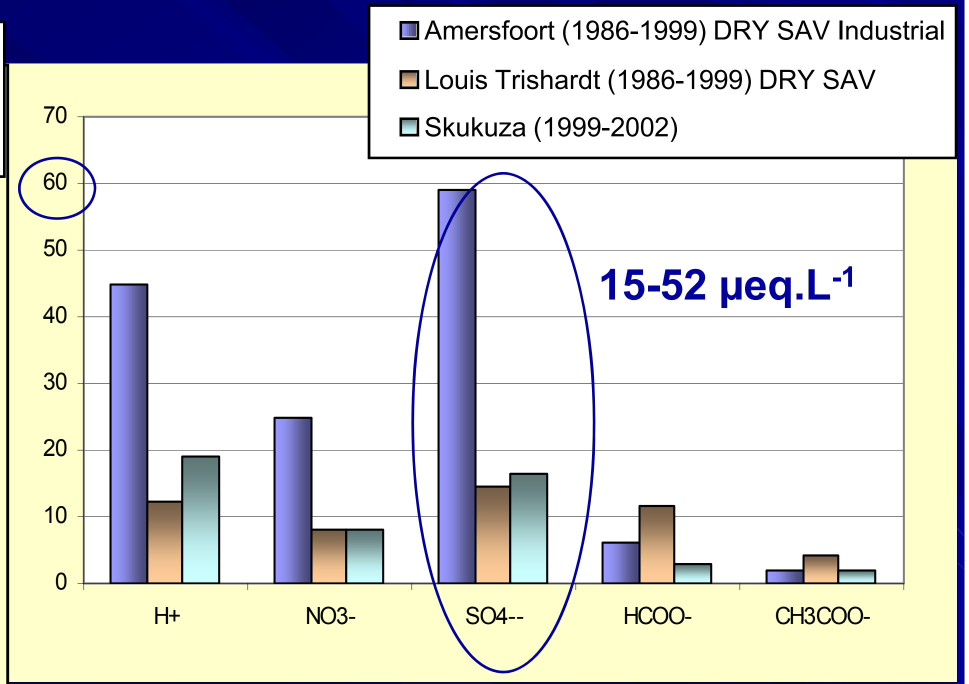
NO: emissions from soils + biomass burning: oxydized into HNO_3 easily scavenged by precipitatio

Industrial NOx in SA for AM site

Chemical composition of precipitation

Mean annual volume weighted mean concentration µeq/L





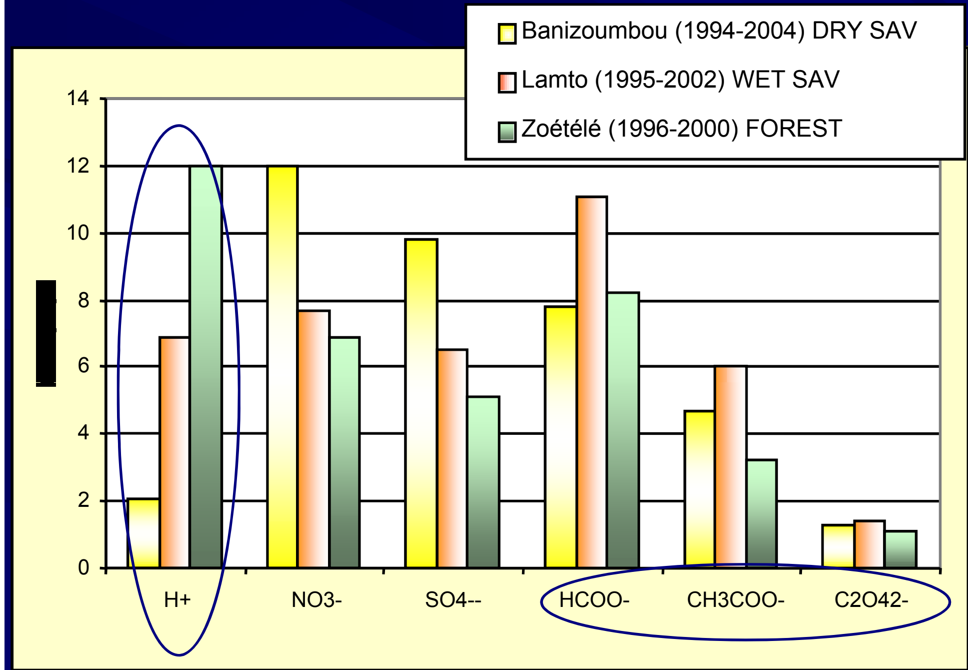
Sulfate contribution:

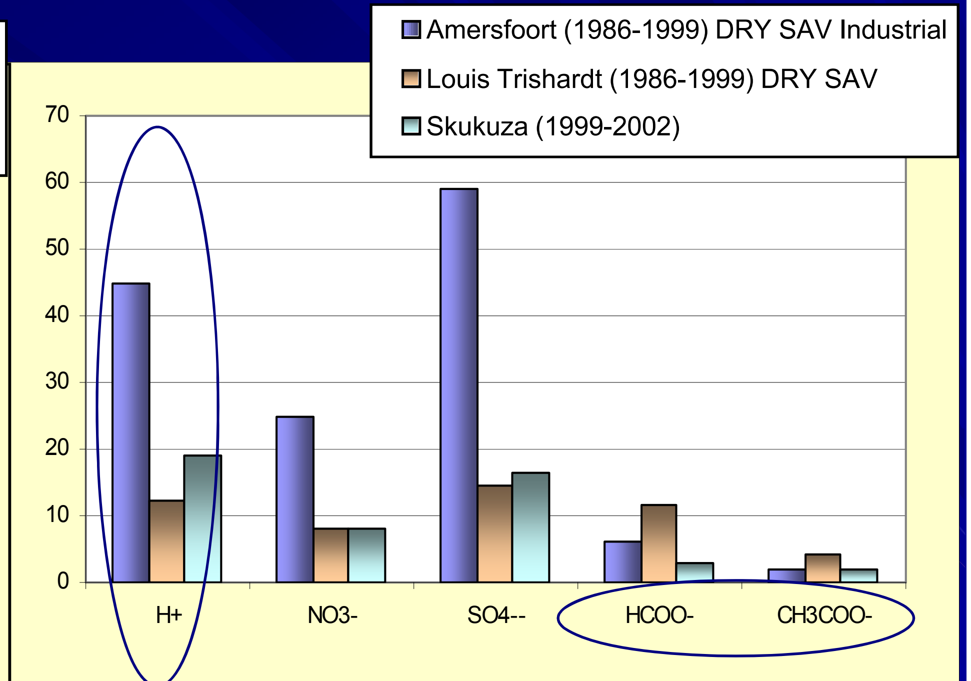
West and Central Africa: negative gradient dry savanna/forest SO_4^{2-} related to the terrigenous dust gradient

South Africa: AM 52 µeqL^{-1} related to anthropogenic emissions of SO_2 highveld (80%), LT (50%),

Chemical composition of precipitation

Mean annual volume weighted mean concentration µeq/L





Negative gradient of acidity from the forest to the dry savanna

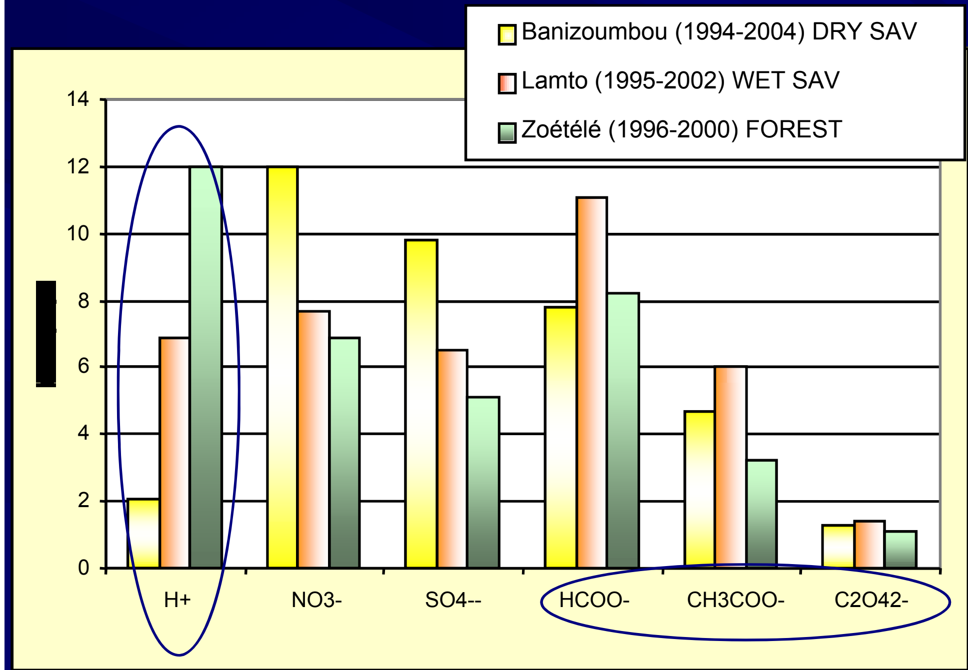
WCA: pH dry savanna 5.6 ⟶ Forest 4.8

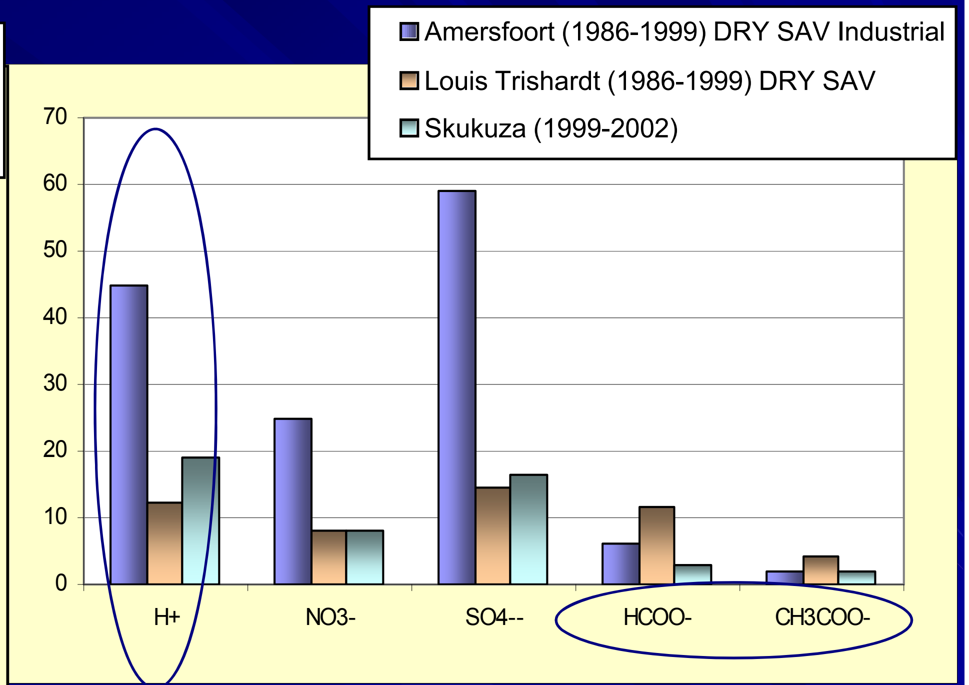
SA: pH 4.35 AM, 4.91 LT, 4.7 Skukuza

SA: organic acidity contribution is lower (except in LT), acidity is mainly related to mineral acidity coming from industrial highveld SO_2 and NOx emissions

Chemical composition of precipitation

Mean annual volume weighted mean concentration µeq/L





Concept of potential acidity: $NO_3^- + SO_4^{2-} + HCOO^- + CH_3COO^- + C_2O_4^{2-}$

Dry savanna: 35 µeq.L-1 pH 5.6

Wet savanna: 33 µeqL-1 pH 5.1

Forest: 27 µeqL-1 pH 4.8

Acidity gradient related to terrigenous alcaline species gradient on the transect

Neutralisation: Heterogenous chemistry alcaline particles with mineral acidity (HNO_3)

Heterogenous chemistry processes gas/particles Measurement/model study

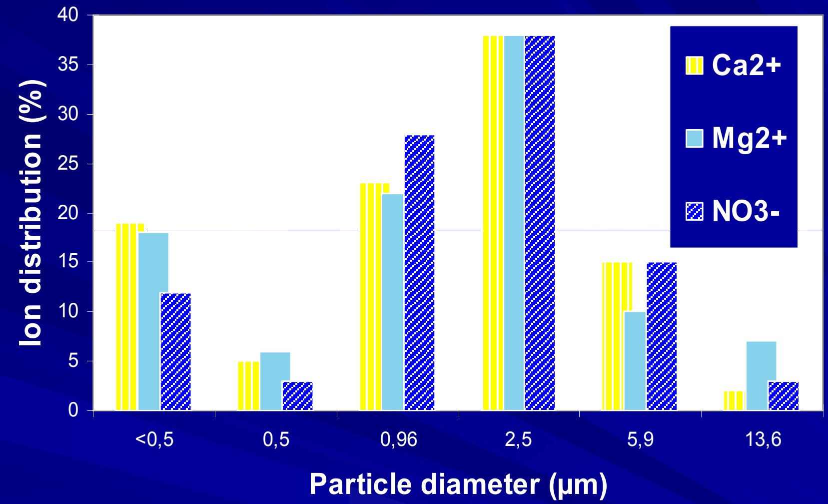
Precipitation chemistry in Banizoumbou

Ca^{2+} / Mg^{2+}	r = 0.89
Ca^{2+} / SO_4^{2-}	r = 0.71
Ca^{2+}, Mg^{2+}, SO_4^{2-} / NO_3^-	**r = 0.75 - 0.86**

Acidity

Cl-, SO_4^{2-}, NO_3^- / H^+	**r= 0.26**
HCOO$^-$, CH3COO$^-$ / H^+	**r=0.6 et 0.8**

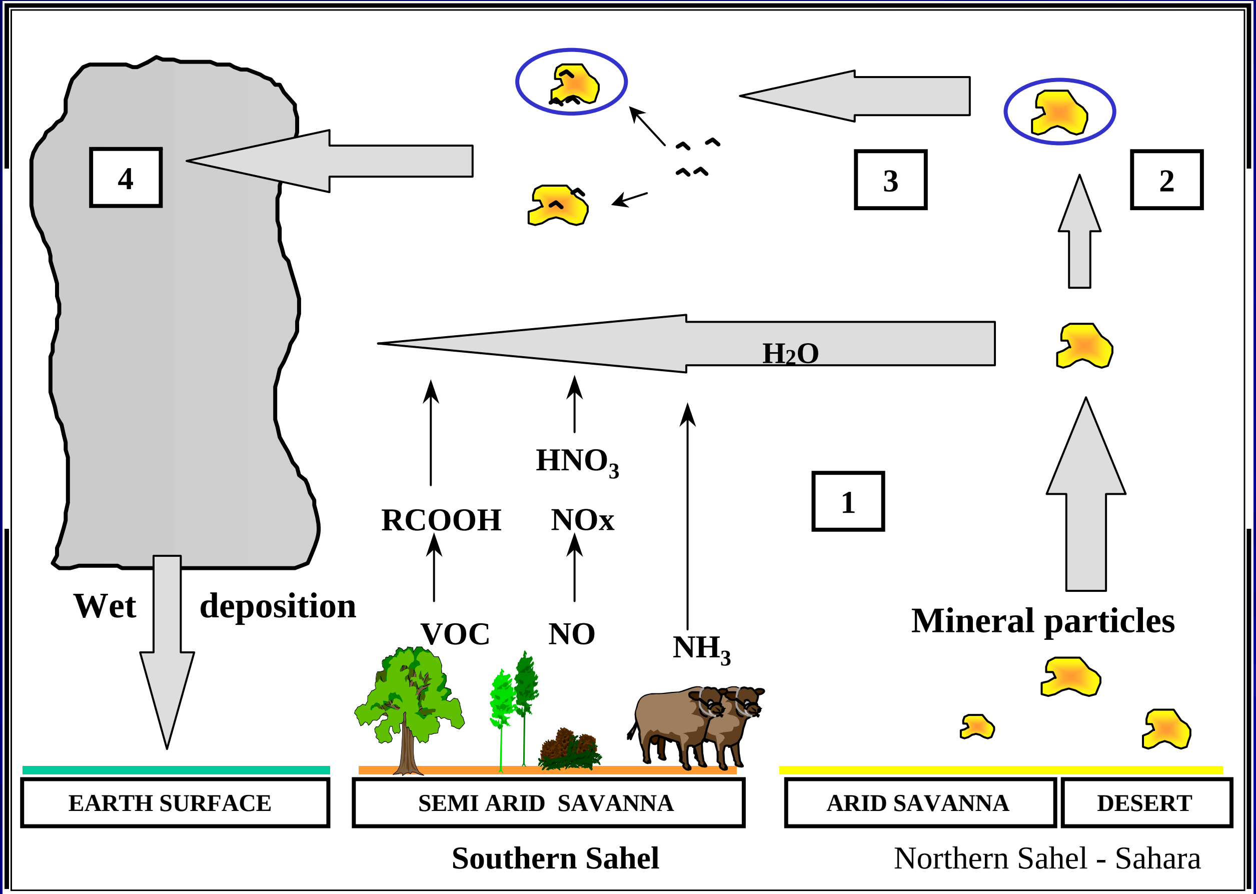
Aerosols chemistry



Ca^{2+}, Mg^{2+} / NO_3^- 0.95 < r < 1

Heterogenous chemistry between mineral aerosols and nitric acid

Conceptual scheme of atmospheric chemistry in the sahelian region



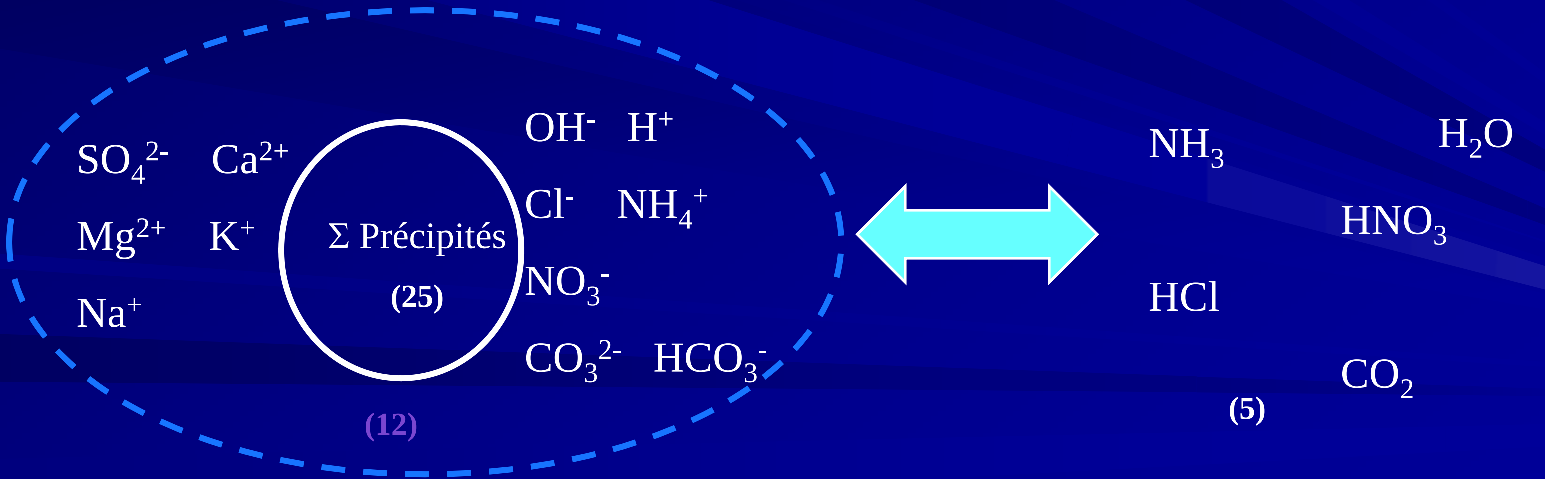
Galy and Modi, JAC 1999

Modeling study of heterogenous processes in the sahel

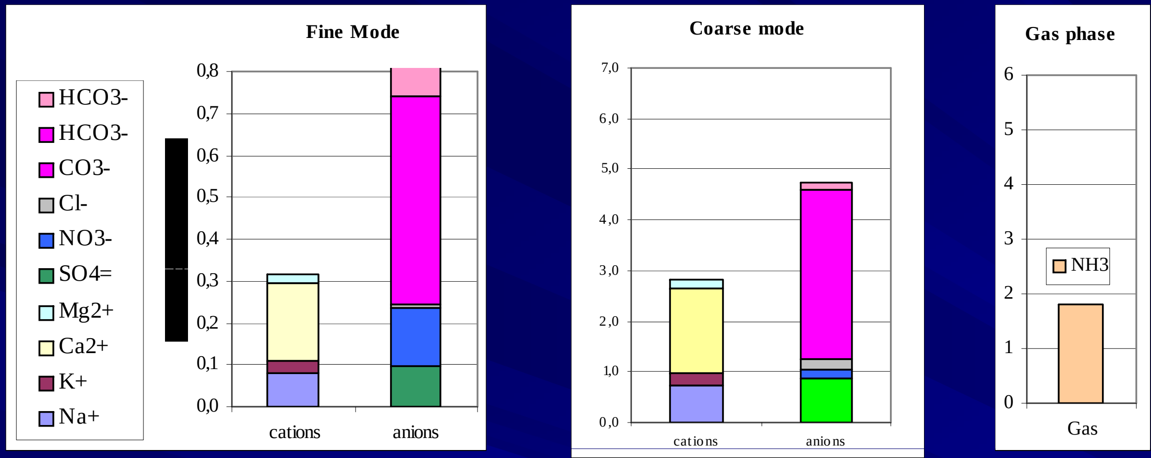
- **SCAPE** Simulating Composition of Atmospheric Particles at Equilibrium (Hayami and Carmichaël, 1997; 1998)

Thermodynamic equilibrium between gaseous volatile species and aerosol phase

SCAPE calculate the chemical composition of soluble inorganic species
And the equilibrium distribution between gas and aerosol phase

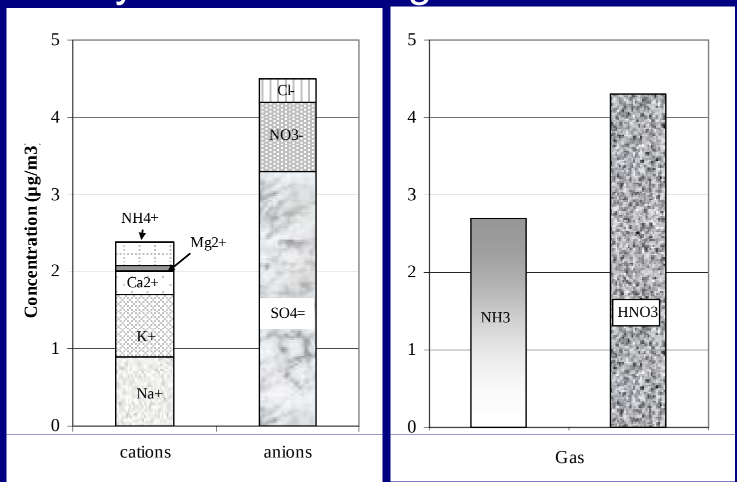


Heterogenous chemistry processes gas/particles



HNO_3 totally neutralized by the aerosol phase

Mean aerosol and gas concentrations calculated by SCAPE for the dry savanna of Niger



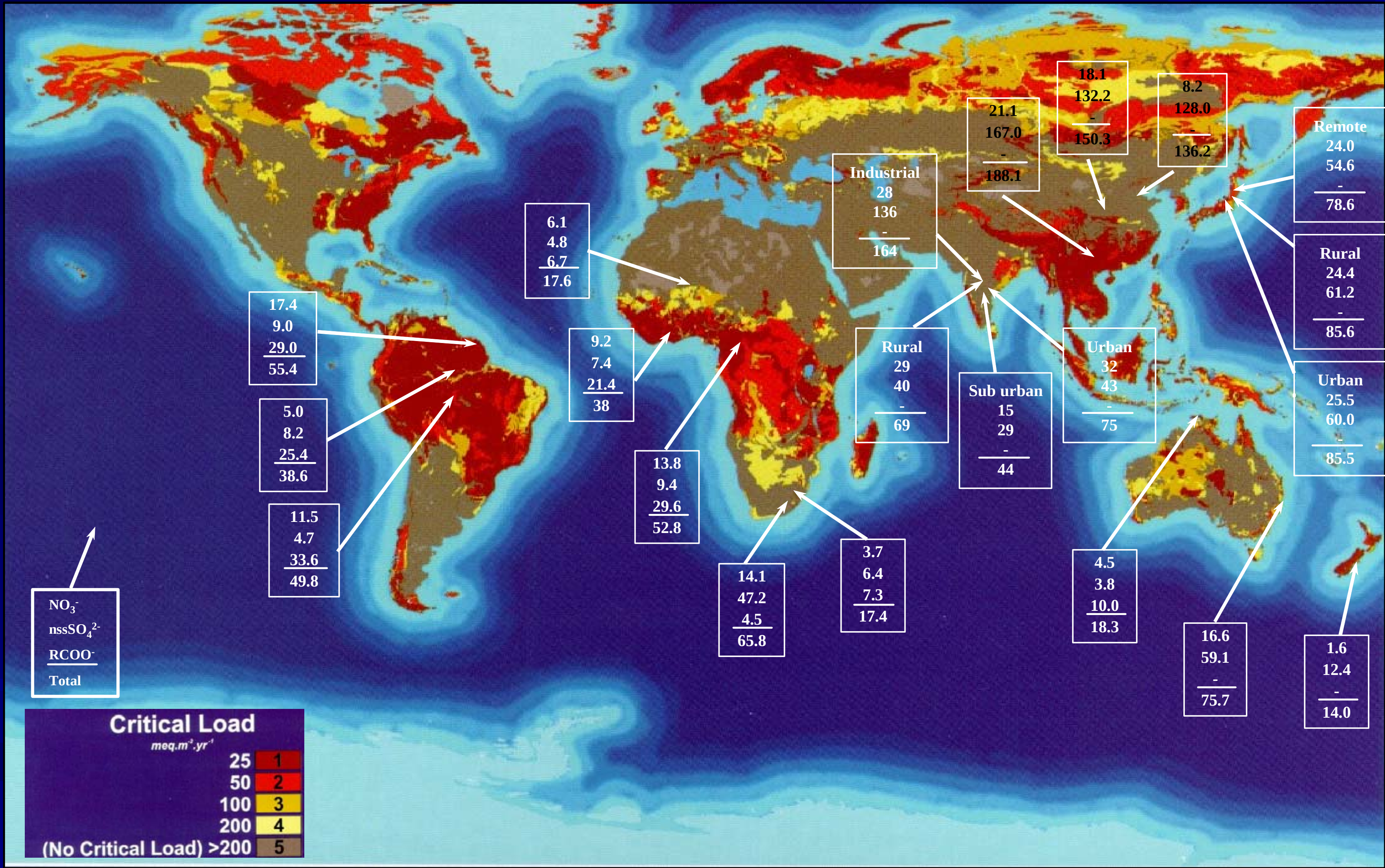
Partial neutralisation

HNO_3 remains in the gas phase

Mean aerosol and gas concentrations calculated by SCAPE for the EXPRESSO simulation (wet savana and forest)

Galy, Carmichael et al, JGR, 2001

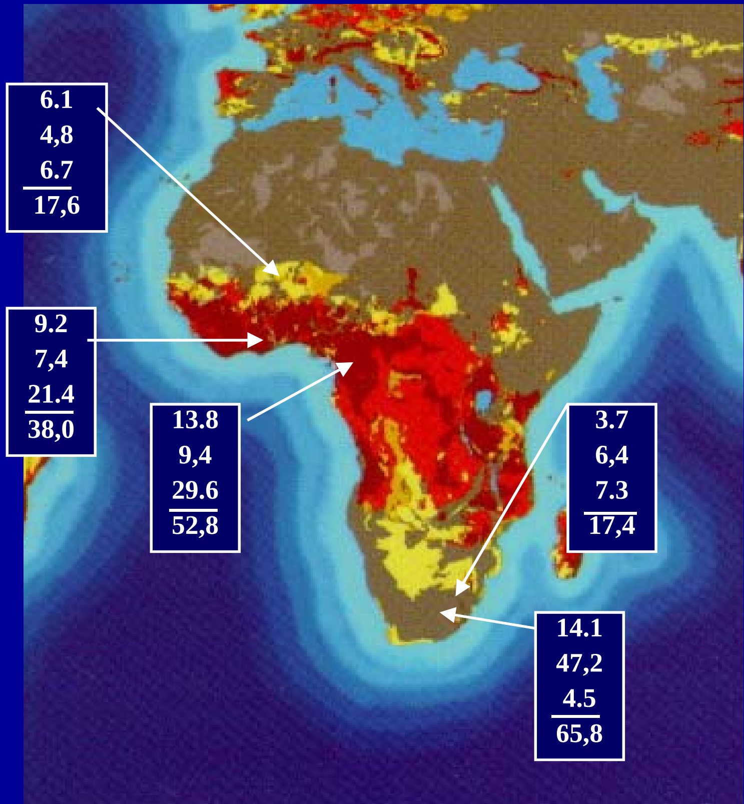
Wet deposition measurements of nitrate, non sea-salt sulfate and organic acids compared with ecosystem sensitivity to acidic deposition

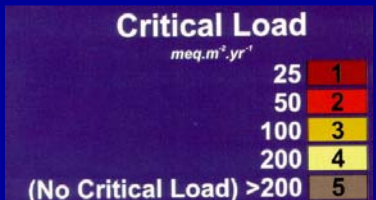


References: Wet deposition [Asia and Oceania (Ayers et al, 1996); Africa (Galy and Modi, 1998, Turner et al, 1996); Amazonia (Andreae et al, 1994, William et al, 1997) and Ecosystem sensitivity to acidic deposition (S. Cinderby et al, 1998)

Wet deposition measurements of nitrate, nss sulfate and organic acids compared with ecosystem sensitivity to acidic deposition

NO_3^-
$nssSO_4^{2-}$
$RCOO^-$
Total



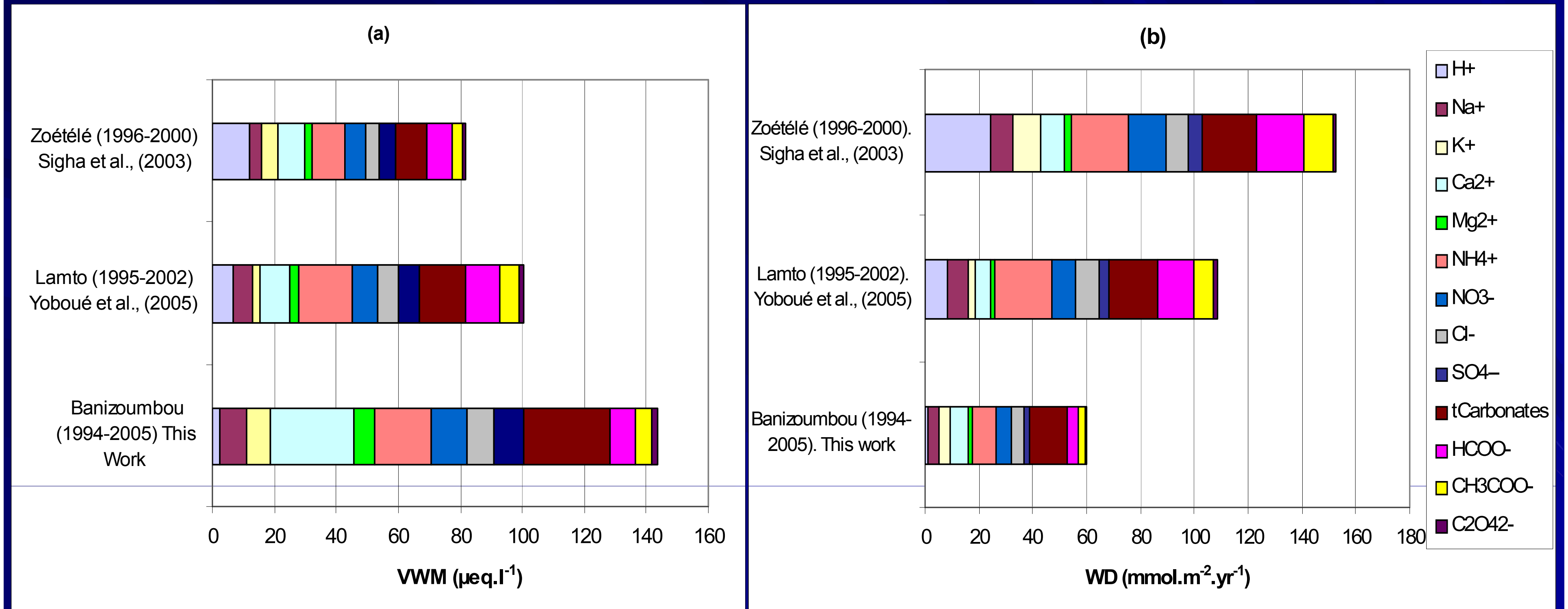


Five classes of sensitivity to acidic deposition

For tropical Africa, due to the relatively high contribution in mineral acidity of wet deposition, the critical load is nearly obtained in many parts of Western Africa. This comparison, acidic wet deposition and sensitivity map, represents only one part of the risk estimation. In some areas, dry deposition is at least as important as wet processes and must be considered in the calculation of total deposition (70% in forested sites).

References: Wet deposition Africa (JAC: Galy and Modi, 1998, Laouali et al, 2006, Yoboué et al. 2005, Sigha et al, 2003, Mphepya et al, 2004, 2005) and Ecosystem sensitivity to acidic deposition (S. Cinderby et al, 1998)

Wet deposition



Mean 2000-2007 449mm Banizoumbou, 744mm Katibougou, 1261mm à Djougou, 1274mm à Lamto 1558mm à Zoétélé.

Galy et al, 2009

South Africa: homogenous annual rainfall:
666mm AM, 690mm LT, 750 mm Skukuza.

Conclusion on Precipitation chemistry and wet deposition

Analysis of long term database on precipitation chemistry

-To determine the main characteristic of rain chemistry at the scale of the ecosystem

-To identify fondamental processes that regulate rain chemistry

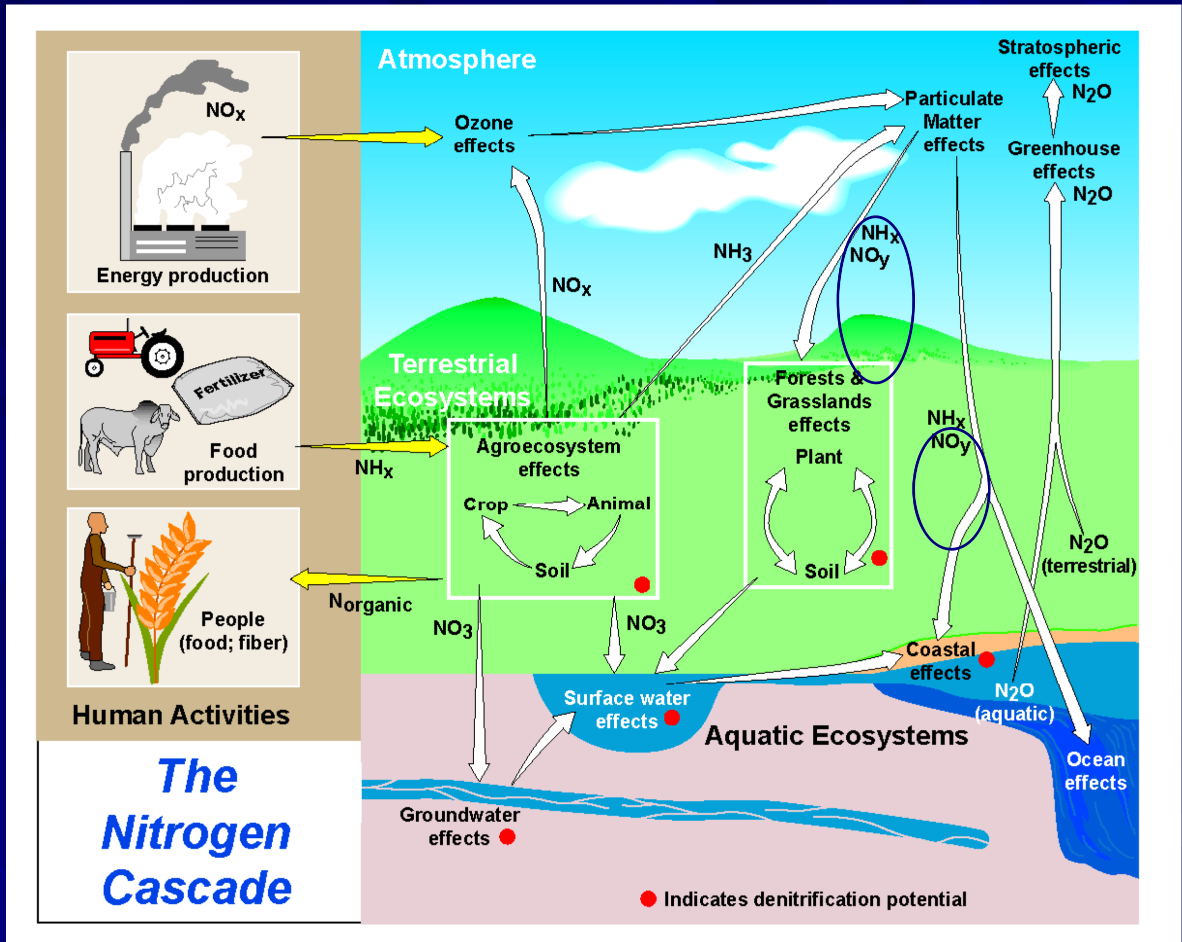
-To relate atmospheric gas and particles sources/ rain chemistry content

-To calculate mean wet deposition at the ecosystem african scale

Dry savannas in South African sites Mphepya, Pienaar, Galy et al, 2004
Mphepya, Galy et al, 2006
Dry savanna Galy-Lacaux and Modi, 1998, Galy-lacaux et al, 2001, Galy et al, 2009
Laouali, Galy et al, 2011
Wet savanna Yoboué, Galy et al, 2005, Akpo, Galy et al, 2011 .
Forest Sigha, Galy et al, JAC, 2003

Basement of the contribution to the african regional chapter in the WMO assessment (2012)

Nitrogen atmospheric cycle



Nitrogen cycle plays an essential role in biosphere-atmosphere exchanges. In the IDAF context, one of our objective deals with the undestanding of nitrogen atmospheric deposition processes at the regional scale of african ecosystems

Nitrogen atmospheric cycle

- To document the gases concentrations of the african ecosystem transect (dry savannas/wet savannas/forest)
  Focus NO_2
- Estimation of the Nitrogen atmospheric deposition budget at the scale of the african ecosystems
  Wet and Dry processes (gas and particles)
- A regional study: Nitrogen emission-deposition budget at the scale of the sahelian IDAF sites.
- Nitrogen emission-deposition budget at the scale of the african ecosystems

Gases Concentrations Measurements

Long term measurements of nitrogen dioxide, ammonia, nitric acid and ozone in Africa using passive samplers

<u>Main Objective</u>:
To report and analyze for the first time a long-term data series of NO_2, NH_3, HNO_3 and O_3 concentrations at 10 remote sites in West central Africa and SA.

Validation of the database from <u>1998 to 2007 WCA and 1995-2005</u>

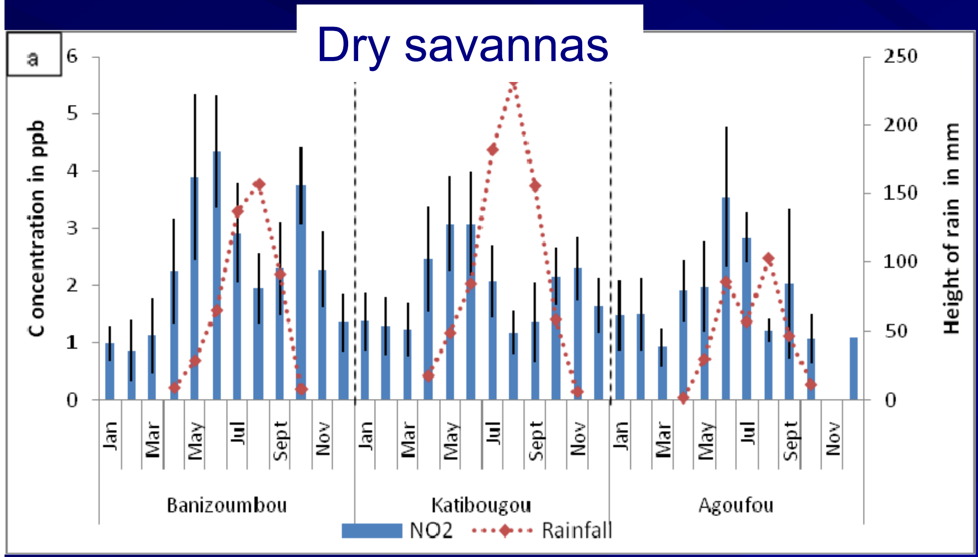
<u>Different step:</u>
To document the gases concentrations of the african ecosystem transect (dry savannas/wet savannas/forest)

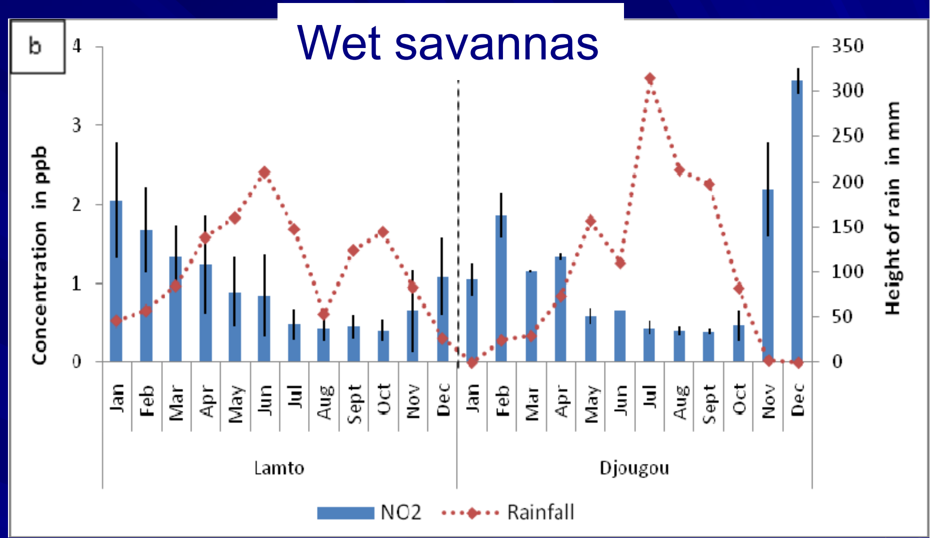
To document <u>seasonal</u> and interannual cycle at the scale of the ecosystems

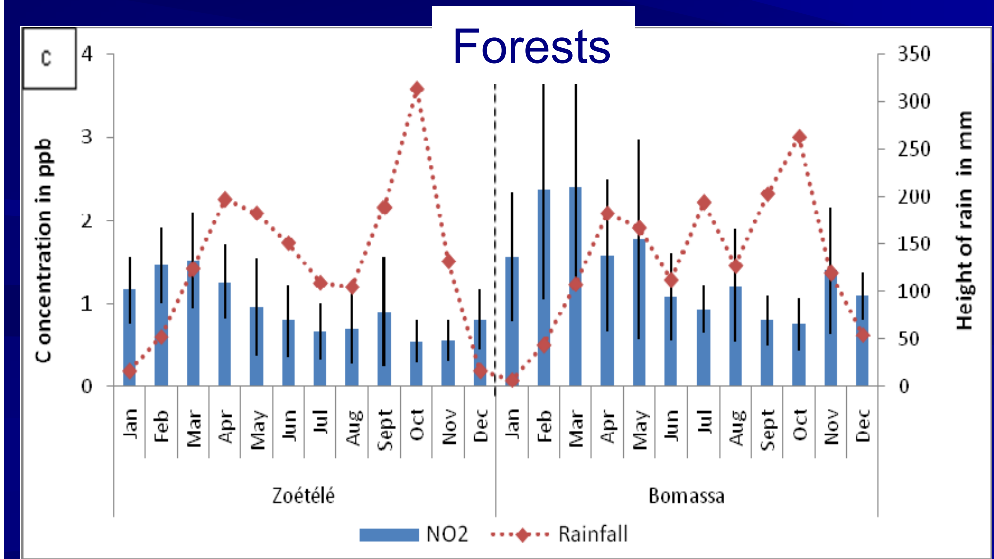
- M. Adon PhD (Co supervision V. Yoboué and C. Galy, UPS/U. Abidjan)
- K. Martins PhD 2007 (Co supervision K. Pienaar and C. Galy, UPS/NWU)

Gases Concentrations Measurements

Evolution of Monthly NO_2 concentrations on the transect







Blue bars: monthly mean NO_2 concentrations over 10 years 1998-2007

Agoufou and Djougou 2005-2007

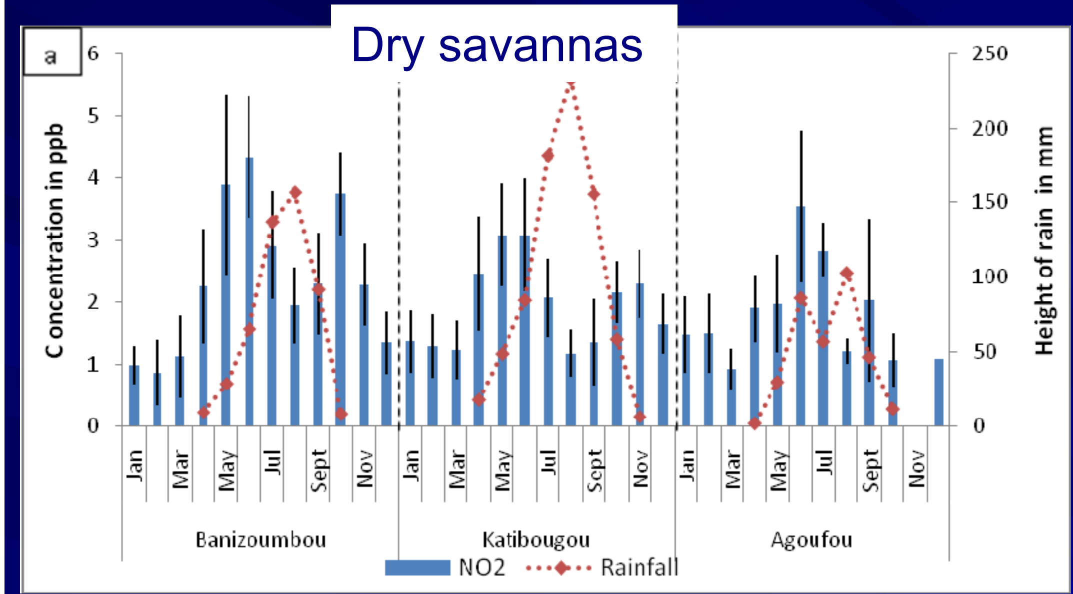
Red line: monthly mean precipitation (mm)

First comment: results representative of one ecosystem with 2-3 sites with homogenous levels of concentrations

It allows to give a caracterization for the different ecosystems

Gases Concentrations Measurements

Evolution of Monthly NO_2 concentrations on the transect



In dry savannas, a well marked seasonal cycle- Two maxima: May june, oct-nov

High NO_2 concentrations in the wet season: Biogenic pulse of NO_x emission at the early beginning of the rainy season, second peak related to biomass burning sources and new rain events on dry soils

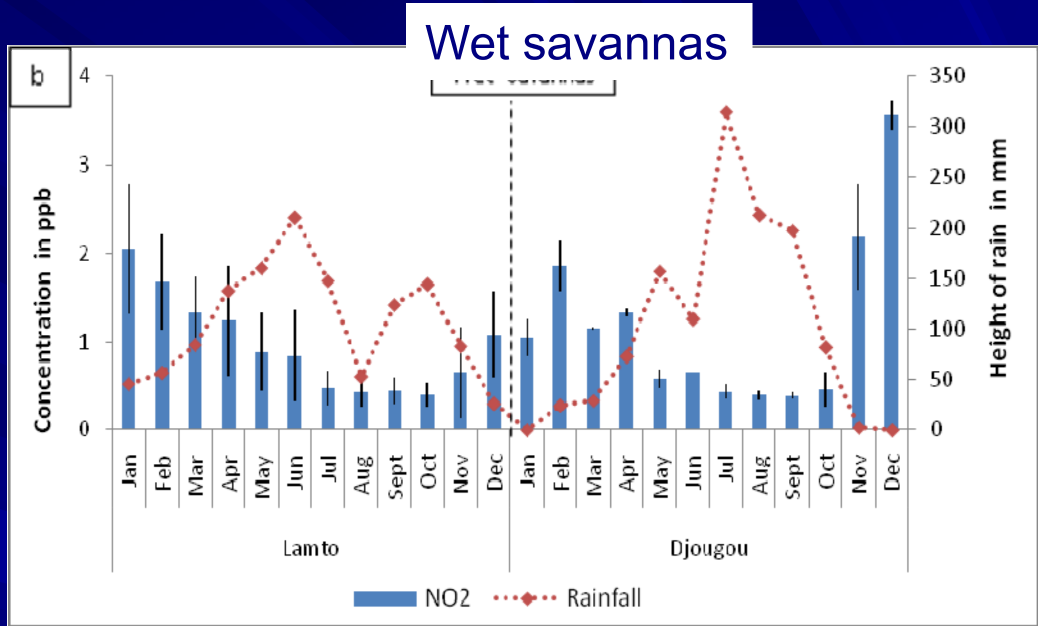
Mean seasonnal NO_2 concentrations Wet Season > Dry Season

Banizoumbou : 3.1±0.6 ppb in W.S. and 1.9±0.5 ppb in D.S.
Katibougou : 2.1±0.5 ppb in W.S. and 1.8±0.2 ppb in D.S.
Agoufou: 2.4±0.6 ppb in W.S. and 1.3±0.4 ppb in D.S.

Mean annual NO_2 concentration: 2.4±0.4 ppb in Bani., 1.9±0.3 ppb in Katib. and 1.8±0.4 ppb in Agoufou

Gases Concentrations Measurements

Evolution of Monthly NO_2 concentrations on the transect



In wet savannas: lower NO_2 concentrations

seasonal cycle driven by Higher NO_2 concentrations in the dry season from nov-feb : active biomass burning NO_x

Mean seasonnal NO_2 concentrations
Lamto : 0.7 ±0.2 ppb in W.S and 1.4 ±0.4 ppb in D.S
Djougou : 0.5 ppb in W.S. and 2.2±0.8 ppb in D.S.

Mean annual NO_2 concentrations: 1.0±0.3 ppb in Lamto and 1.2±0.1 ppb in Djougou

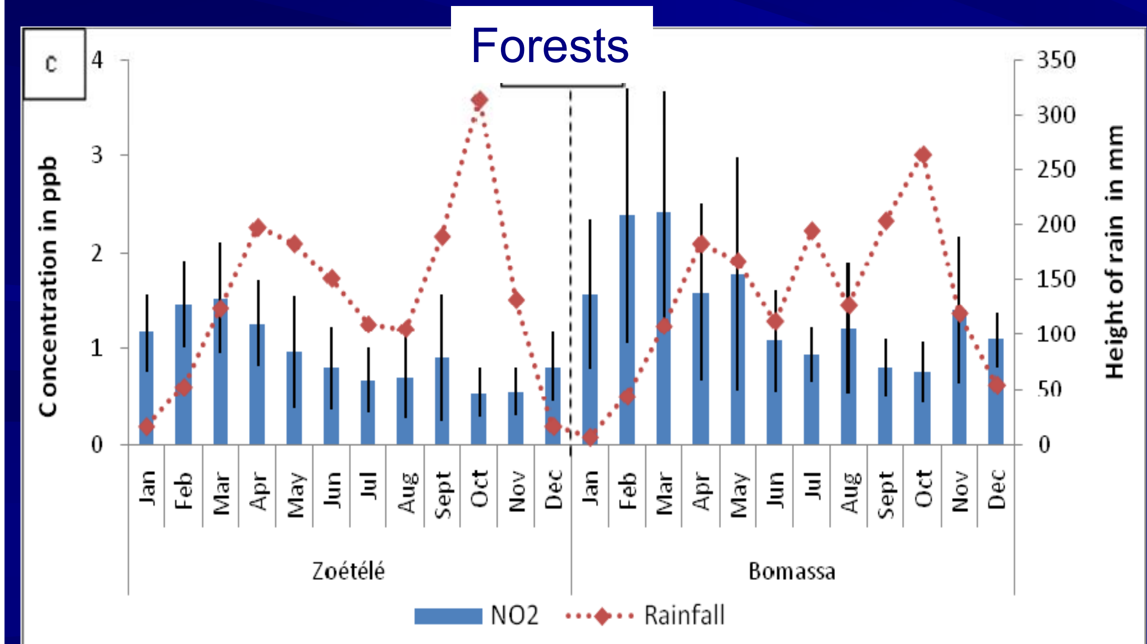
Gases Concentrations Measurements

Evolution of Monthly NO_2 concentrations on the transect

In forested ecosystems: same order of magnitude of NO_2 concentrations in DS, WS
A contribution of biomass burning sources from NH and SH

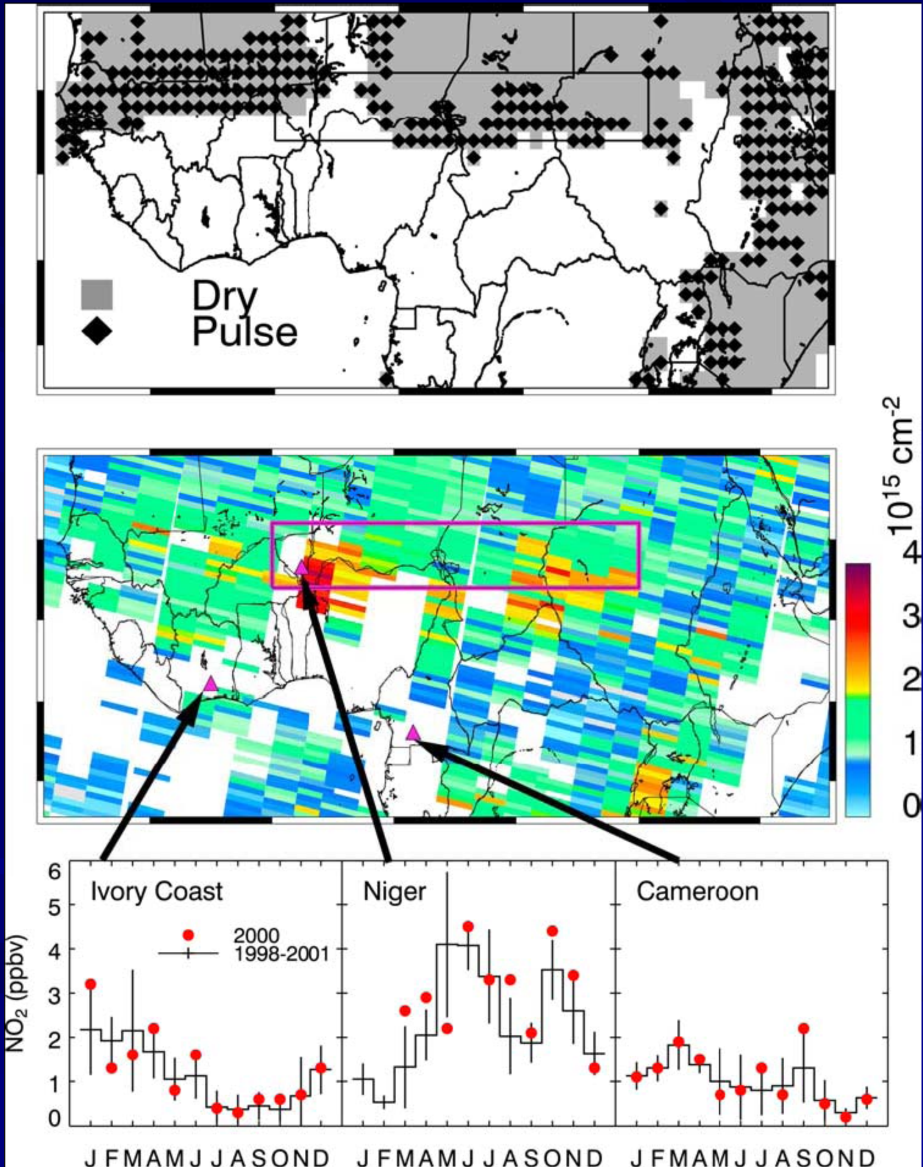
Mean seasonnal NO_2 concentrations
Zoétélé : 0.9±0.3 ppb in W.S. and 1.1±0.2 ppb in D.S.
Bomassa : 1.4±0.5 ppb in W.S. and 1.6±0.8 ppb in D.S.

Mean annual NO_2 concentrations: 0.9±0.2 ppb in Zoétélé and 1.4±0.4 ppb in Bomassa



Adon, Galy et al, 2010

Gases Concentrations Measurements



IDAF – GOME NO_2 measurement
Jaegle et al, 2004

Accumulated rainfall and soil pulsing derived from TRMM daily precipitation for 7–12 June 2000.
Gray areas indicate dry soils
Black diamonds correspond to dry soils with recent rainfall

Three-day composite map of GOME tropospheric NO_2 columns for 10–12 June 2000.
The thick rectangle shows the area plotted below

Monthly surface NO_2 measurements from the IDAF network in wet savanna (Lamto), semiarid savanna (Banizoumbou) and rain forest Zoétélé.

Red circles : 2000 observations
black lines show the mean (and deviations) for 98–01.

Annual means of gas concentration (ppb)
(DEBITS passive samplers)

	Station	SO_2/ppb	NO_2/ppb	HNO_3/ppb	O_3/ppb	NH_3/ppb
South Africa Dry savanna	**Louis Trichardt**	0.82±0.4	0.74± 0.2	0.23 ±0.1	35	1.2 ±0.5
Dry savanna industrial	**Amersfoort**	2.8 ±1	2.5 ±1	0.9 ±0.3	27	1.2 ±0.7
West Central Africa Dry Savanna	**Banizoumbou**	0.1-0.3	2.6 ± 0.4	0.5 ± 0.2	13	6.2 ± 2
Wet Savanna	**Lamto**	0.1-0.3	1.1 ± 0.3	0.3 ±0.1	11	3.9 ± 1.2
Forest	**Zoétélé**	0.1-0.3	1 ± 0.3	0.2 ±0.1	10	4.3 ± 1

South African sites: Pienaar et al, 2006 (mean 1995-2005 for SO_2, NO_2,O_3,NH_3, for HNO_3 2003-2005)
West central african sites: Ourabi, pHD, mean 1998-2004.

Nitrogen atmospheric deposition budget

- N Wet deposition fluxes

  Mean annual VWM of NH_4^+ and NO_3^- and annual mean precipitation over the period 2000-2007

  8 IDAF sites- Precipitation gradient

  500mm.yr^{-1} dry savanna to 1600mm.yr^{-1} forest

- N dry deposition

  Calculation of monthly dry deposition fluxes

  NO_2, HNO_3, NH_3 to calculate annual mean (2000-2007)

  and mean annual aerosols concentrations pNH_4+ and pNO_3-

Dry deposition flux (molec.cm^{-2}.s^{-1}) = Measured concentrations (molec.cm^{-3})
x deposition velocity (cm/s)

Estimation des flux de dépôt sec des gaz

Dry deposition flux

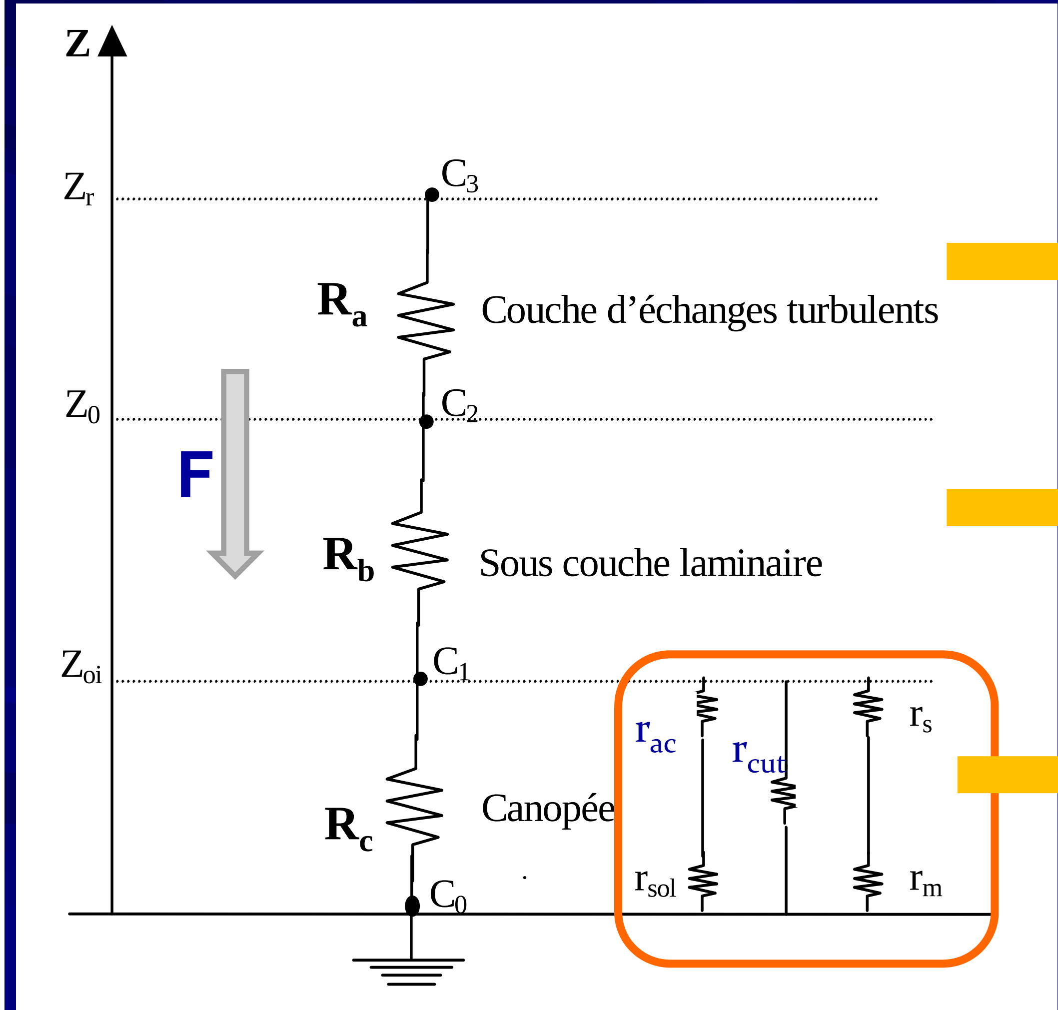
$$D_s = V_d(z).\ C(z)$$

Ds: Dry deposition flux ($kg.ha^{-1}.an^{-1}$)
V_d (z): Dry deposition velocity ($m.s^{-1}$)
C(z): Atmospheric concentration of the gas at a height z ($\mu g.m^{-3}$)

Dry deposition velocity calculation
(big leaf model, Zhang et al. (2003)

« big leaf » resistance model

$$V_d = \frac{1}{R_a + R_b + R_c} = -\frac{F}{C}$$



Deposition module:

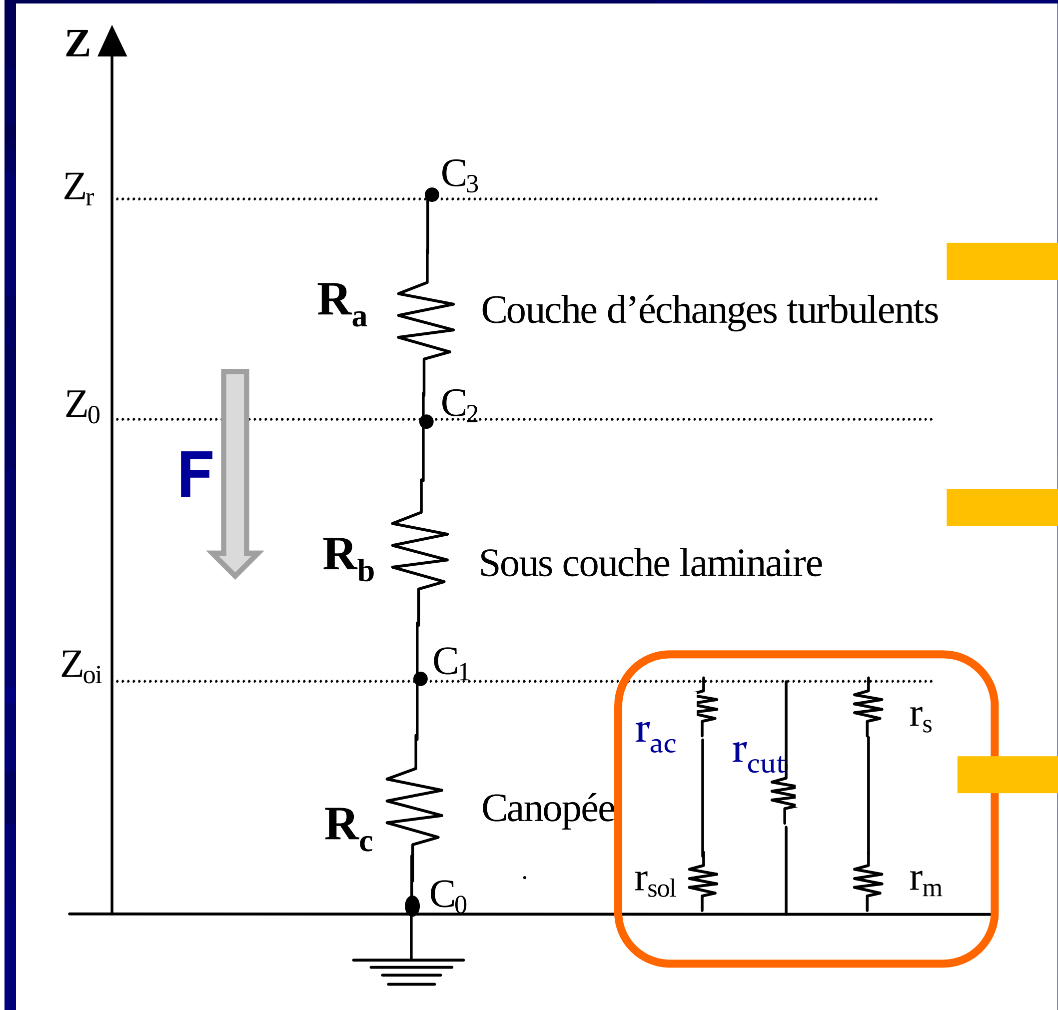
R_a: Aerodynamic resistance

R_b: Qusi-laminar resistance

R_c: Surface resistance

Dry deposition velocity calculation
(big leaf model, Zhang et al. (2003)

« big leaf » resistance model



$$V_d = \frac{1}{R_a+R_b+R_c} = -\frac{F}{C}$$

Deposition module:

$$R_a = \frac{1}{ku_*}\left[0,74\ ln\left(\frac{Z_r}{Z_0}\right) - \Psi\right]$$

(Padro et al., 1991)

$$R_b = \frac{2}{ku_*}\left(\frac{\vartheta}{D_i}\right)^{2/3}$$

(Hicks et al., 1987)

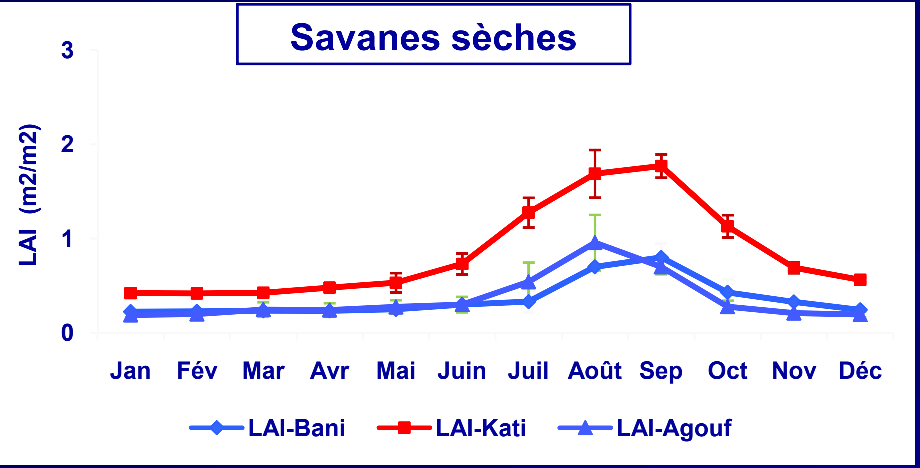
R_c (paramétrisation de Zhang et al., 2003)

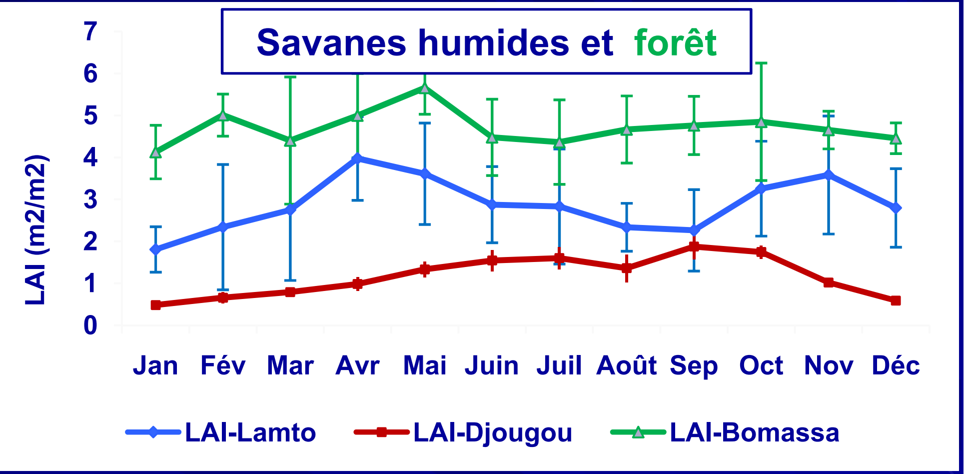
$$\frac{1}{R_c} = \frac{1-w_{st}}{R_{st}+R_m} + \frac{1}{R_{cut}} + \frac{1}{R_{ac}+R_{sol}}$$

Input data

➢ Biophysical data: LAI (MODIS 2000-2007)

LAI (leaf area index) is an important parameter in the calculation of the vegetation resistance résistances du couvert (R_{st}, R_{cut}, R_{ac})





Savanas: monthly LAI

Forests: LAI = 5 (constant Zhang et al., 2003 et Brook et al., 1999)

➢ Meteorological Data: ALMIP data (2002-2007)

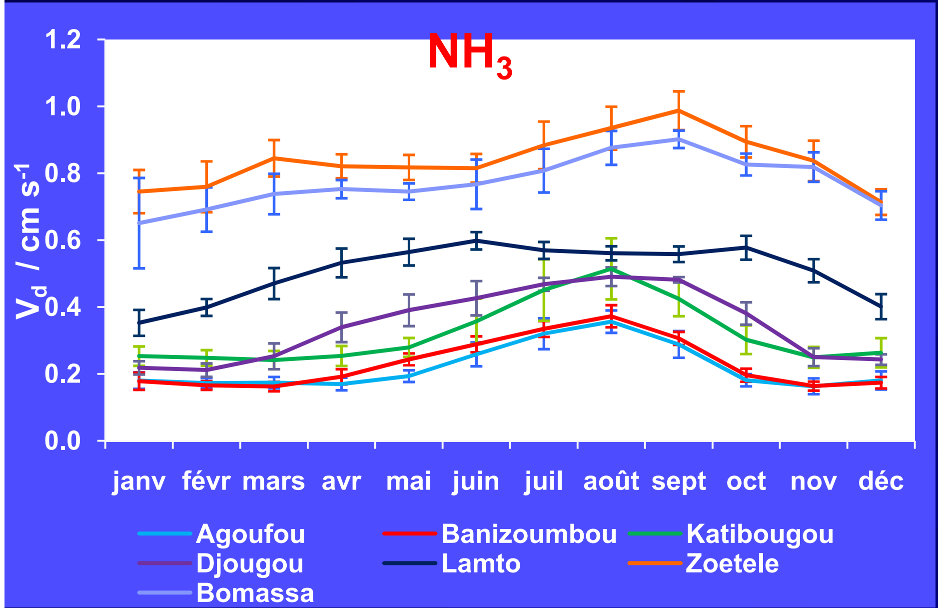
ALMIP (AMMA Land Surface Model Intercomparison Project

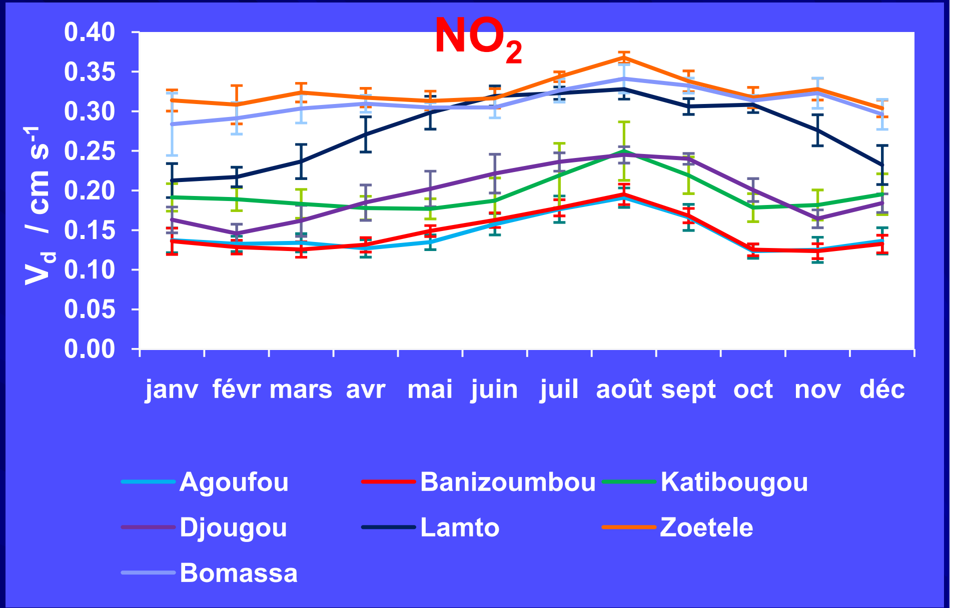
(Boone et al., 2009) (Résolution 0,5° × 0,5°)

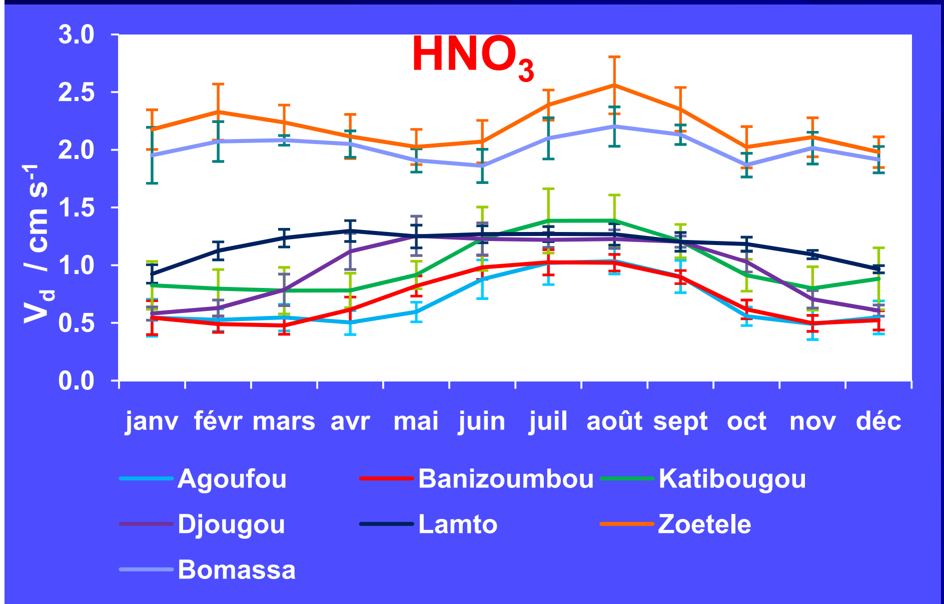
➢ Plant physiological data

Sites (climat)	**Biomes**	**référence**
Forests (Zoétélé et Bomassa) Equatorial	Tropical trees with large leaves	Zhang et al. (2003)
Grass Savanas (Agoufou et Banizoumbou) Sahelian	Short grass and herbaceous plant	Zhang et al. (2003)
Shrub savanas (Katibougou) Sahelian-soudanese	Long grass (R_{ac}, R_{cut}) Shrubs with large leaves with permanent plants * (R_{st})	Zhang et al. (2003) Brook et al. (1999)*
Savanas with trees (Lamto et Djougou) Guinean et Guinean-soudanese	Long Grass (R_{ac}, R_{cut}) Trees with large leaves and permanent plants* (R_{st})	Zhang et al. (2003) Brook et al. (1999)*

Monthly mean variation of Vd (NH_3 NO_2 et HNO_3) for IDAF sites







On the transect, montly mean v_d
- 0,16 to 0,99 cm.s^{-1} for NH_3
- 0,13 to 0,37 cm.s^{-1} for NO_2
- 0,48 to 2,58 cm.s^{-1} for HNO_3

On the ecosystemic transect, V_d gradient follow the climatic gradient, Vd increase with vegetation density, Vd are higher in the wet season

N budget atmospheric deposition (1998-2007)

N deposition (KgN/ha/an)		Dry deposition: Gaseous (NO_2+HNO_3+NH_3)	Dry deposition: Particles (pNO_3^- + pNH_4^+)	Wet dep. (NO_3^- + NH_4^+)	Total deposition
Dry savanas	Agoufou	4,0	/	1,6	**5,6**
	Banizoumbou	4,0	0,16	2,2	**6,4**
	Katibougou	5,3	0,16	3,2	**8,7**
Wet savanas	Djougou	3,4	/	3,5	**7,0**
	Lamto	4,6	0,16	5,2	**9,9**
Forests	Zoétélé	8,0	/	4,6	**12,6**
	Bomassa	8,5	/	/	/

N total deposition

10 kg N.ha-1.yr-1 Amersfoot dry sav in the highveld

46 kg N.ha-1.yr-1 Louis Trischardt and Skukuza

6 - 9 kgN.ha^{-1}.an^{-1} Dry savanas

7 - 10 kgN.ha^{-1}.an^{-1} Wet savanas

≈13 kgN.ha^{-1}.yr^{-1} Forest

Positive Gradient on the transect

Contribution to N total deposition

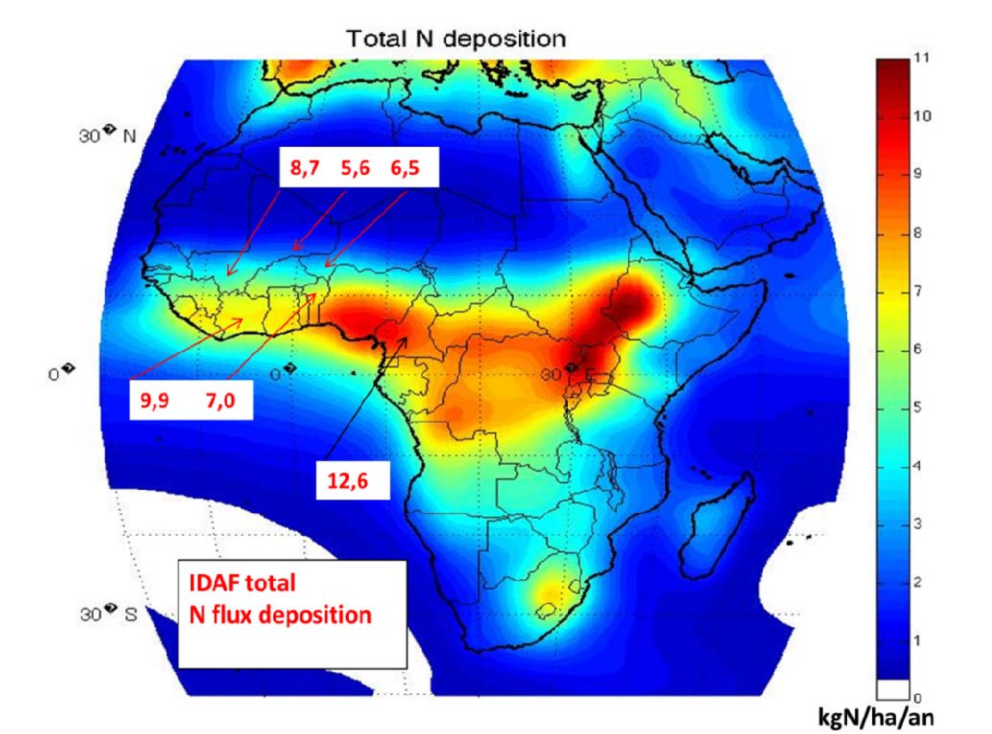
Dry deposition gases (Ds): 46 – 71 %

Wet deposition (Dh): 29 – 52%

Dry dep from particles (2%)

IDAF Mesurements and Global multi model study

(Dentener et al. (2006)



Total N deposition at the global scale simulated by Dentener et al.2006

Sahelian region : 2 - 4 kgN.ha^{-1}.an^{-1}

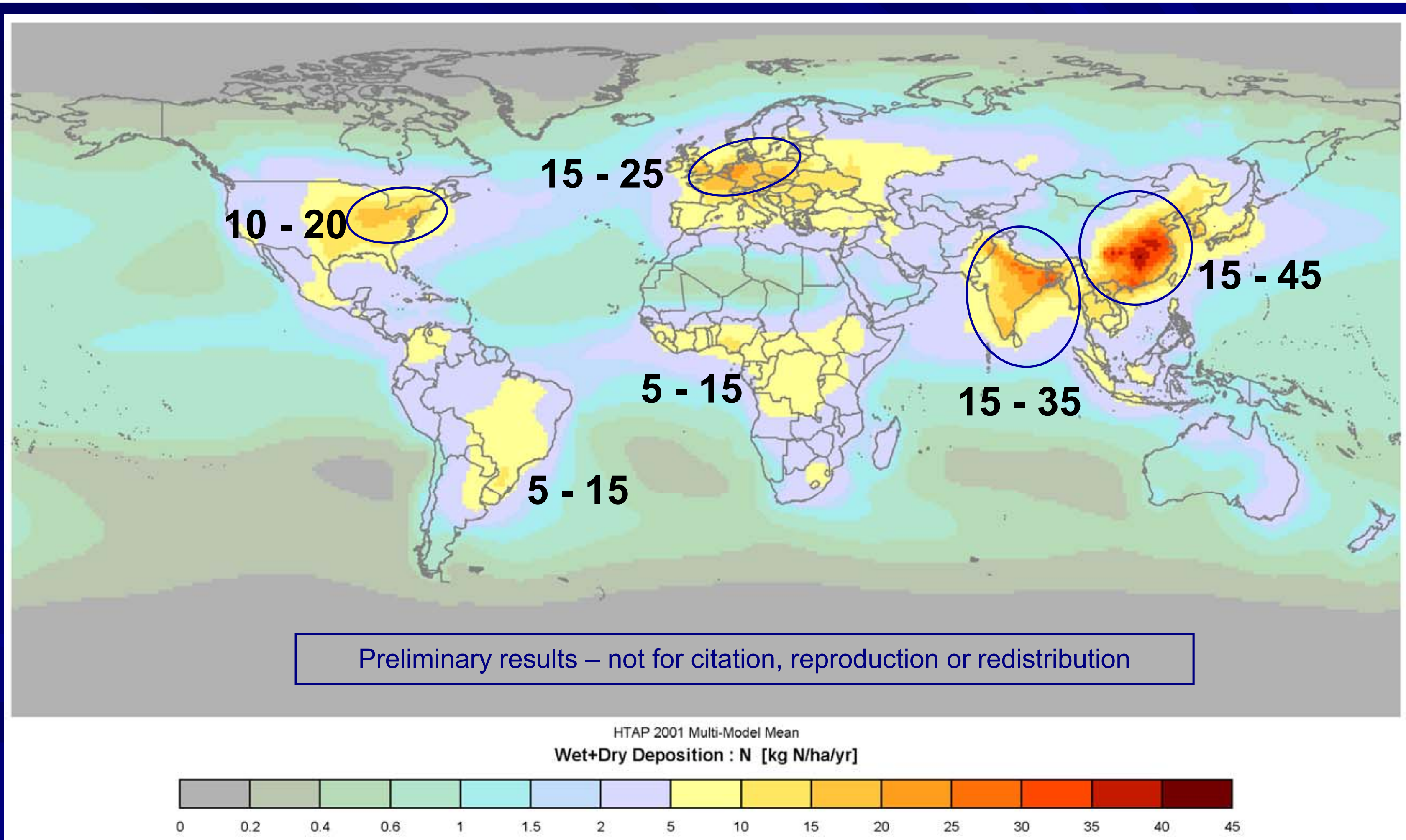
Wet savanas: 6 - 8 kgN.ha^{-1}.an^{-1}

Forest (cameroon): 8 - 10 kgN.ha^{-1}.an^{-1}

Sahelian region: model underestimates by a factor 2
(Sahel: Biogenic sources of NO and agro-pastoral NH_3 sources ?)

Comparison measure - model emphasizes the importance to measure nitrogenous compounds at remote sites for validation and adaptation of global models

What is the wet+dry deposition loading of $N_{oxidized} + N_{reduced}$ from model -based results?
2001 Ensemble Mean Modelling Result:
Wet+Dry Deposition of $N_{oxidized}$+$N_{reduced}$ (kg N/ha/yr)



HTAP simulation Hemispheric Transport Air Pollution

Regional study: Emission-Deposition budget in sahel

- Model-measure approach

- Three sites in dry savannas:

Banizoumbou (Niger)

Katibougou

Agoufou (Mali)

Emission and deposition of N compounds

Dry deposition
NO_2 - HNO_3 - NH_3

Wet deposition
NH_4^+, NO_3^-

NH_3 (Volatilization)

Biogenic NO emission from soils

NOx, NH_3 (biomass burning)

(domestic fires)




Emission and deposition of N compounds

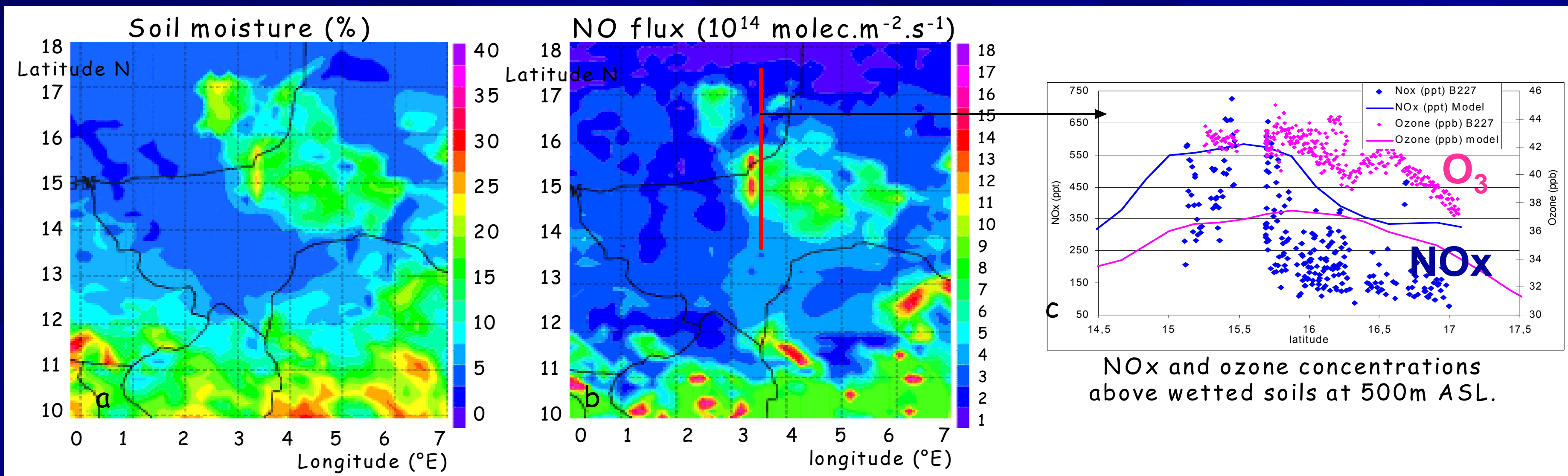
Biogenic NO

Biogenic NO emission from soils

Simulation from surface model (ISBA), coupled with the Neural Network derived emission module.
Emissions are dependent on environmental and soil parameters: Soil moisture, soil temperature, wind speed, pH, sand percentage, fertilization rate.
Meteorological forcing from satellite data (TRMM).

Validation in the Sahel, NO biogenic emissions from soils occur at the beginning of the wet season on very dry soils (pulse of emissions)

MesoNH-C simulations, coupled with the emission module for biogenic NO from soils, shows NOx and ozone increase close to Niamey after a rainfall event.



NOx and ozone concentrations above wetted soils at 500m ASL.

Delon et al, 2008

NH_3 volatilization

N release by livestock in $kgN.animal^{-1}.yr^{-1}$ (Schlecht et al., 1997, Mosier et al., 1998)

×

Animal population in each region (FAO, Glipha database)

→

Nitrogen input by organic fertilization:

25 $kgN.ha^{-1}.yr^{-1}$ in Banizoumbou
8 $kgN.ha^{-1}.yr^{-1}$ in Lamto

↓

30% released as volatilization of NH_3

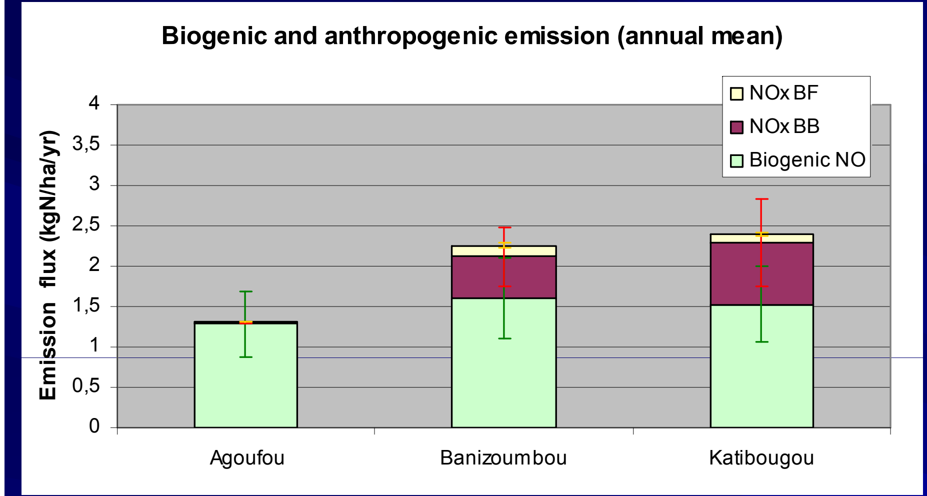
Biomass burning and domestic fires emission

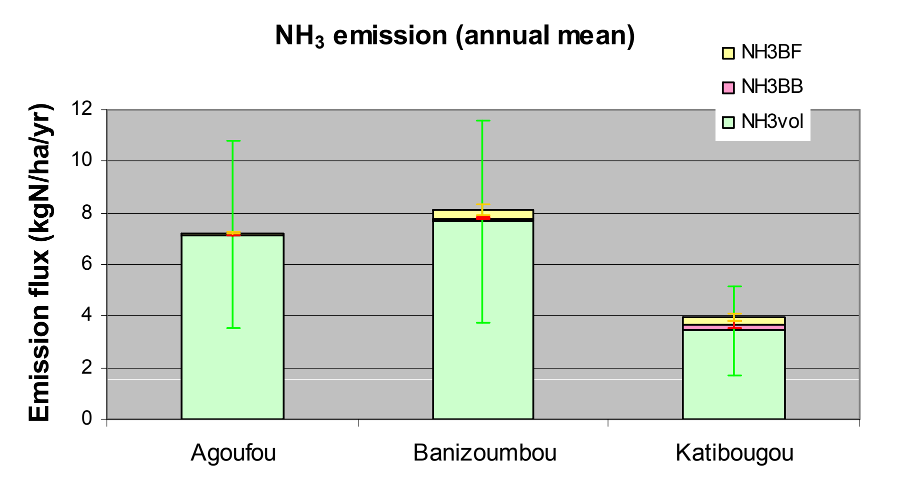
Global biomass burning inventories used for NOx and NH_3, monthly means, 5°/5° average around each station.
Liousse et al, 2010. (burned surface area SPOT and GLC with EF (Andreae et Merlet 2001)

Annual emissions are available each country (Assamoi & Liousse, 2009).
We use annual means, 5°/5° average around each station.
No interannual variability available. Negligible contribution.

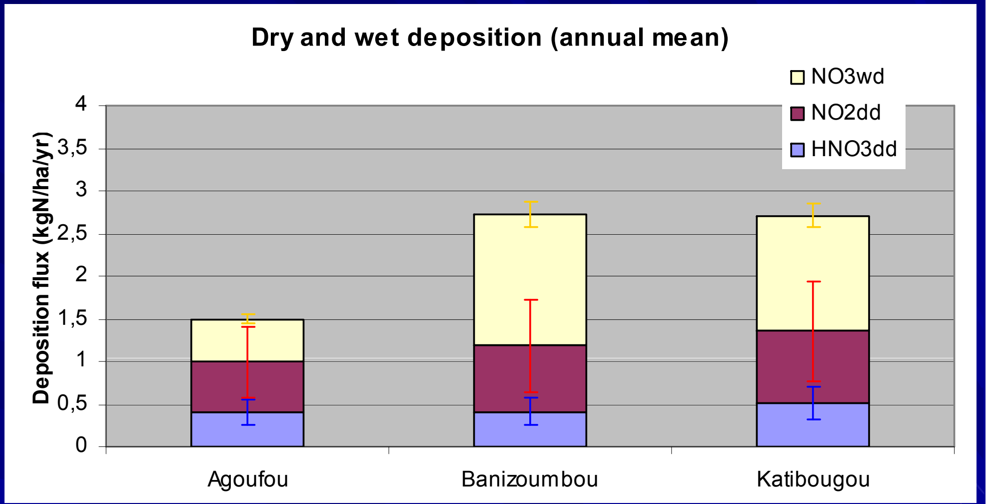
Annual budget N emission-deposition

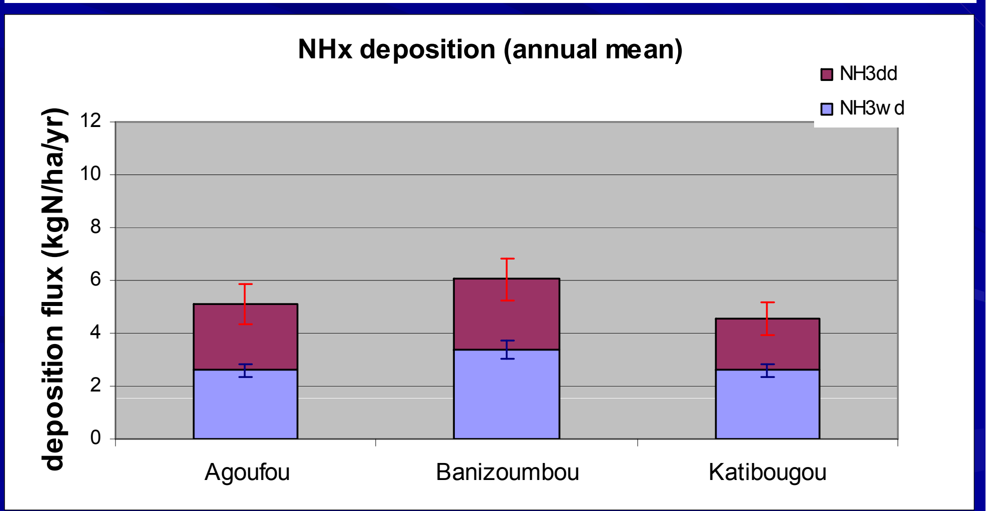
Emission





Deposition





Delon, Galy et al, 2010

Annual budget N emission-deposition

		Annual mean	
Site	Dépôt Total	Emission totale avec 30% et 50% de volatilisation	
Agoufou	6.6±1.6	8.5±3.8	13.7±6.5
Banizoumbou	8.8±2.0	10.4±4.9	15.1±7.2
Katibougou	7.3±1.8	6.3±2.8	8.6±4.0
moyenne	7.5±1.8	8.4 ±3.8	12.5±5.9

Mean deposition flux: 7.5 $kgN.ha^{-1}.yr^{-1}$

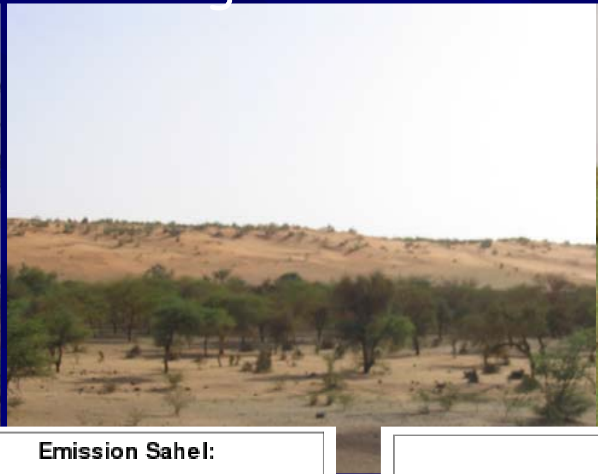
Mean emission flux: 8.4 $kgN.ha^{-1}.yr^{-1}$ (30% NH_3 volatilization)

Extrapolation at the sahel

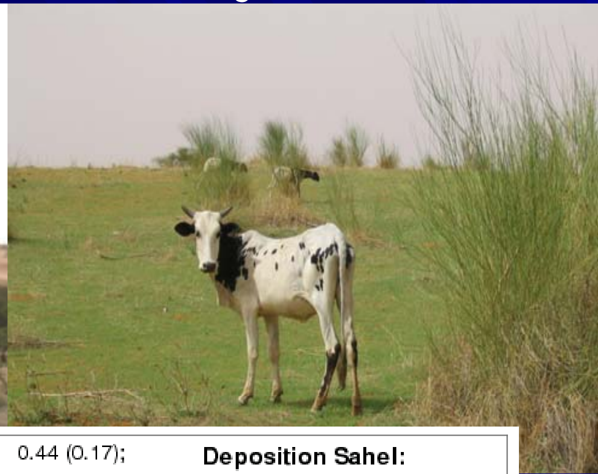
Nitrogen budget in the Sahel: emission-deposition

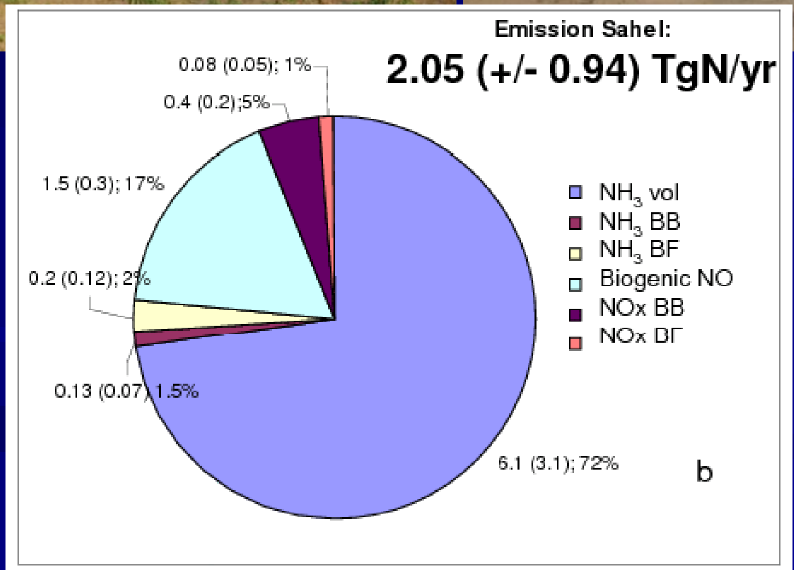
Biomass burning

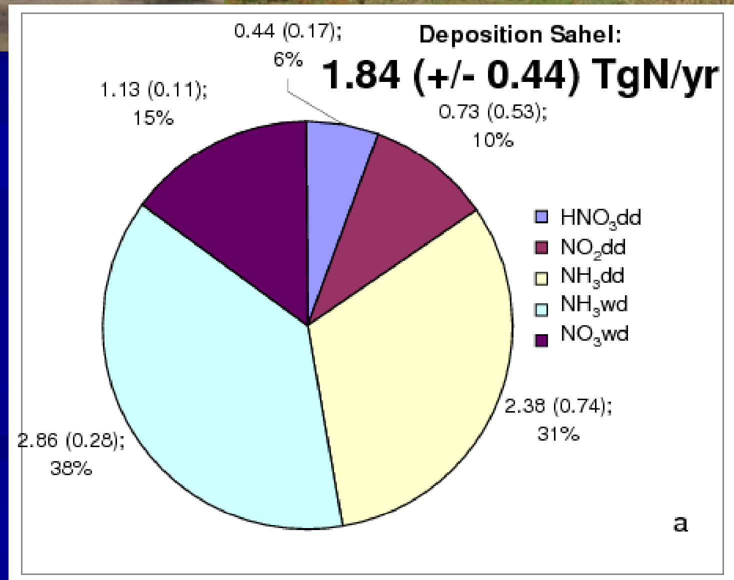
Biogenic NO



NH_3 volatilization



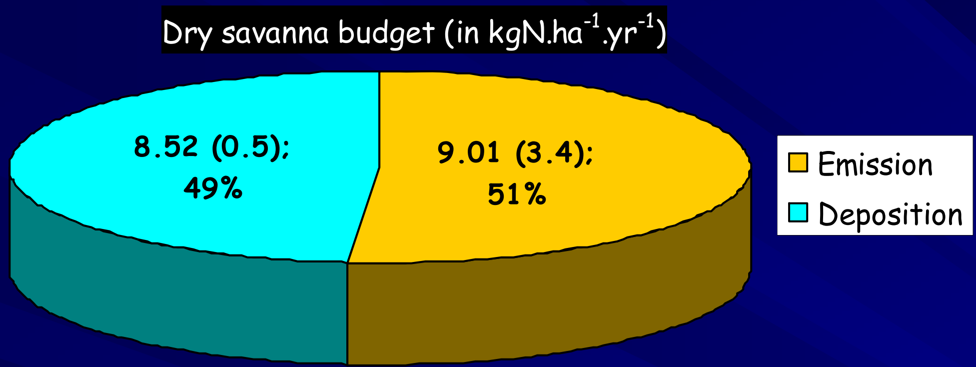




Delon, Galy et al, 2010

Sahel 4.4 millions of km2 (0.48% at the global scale)

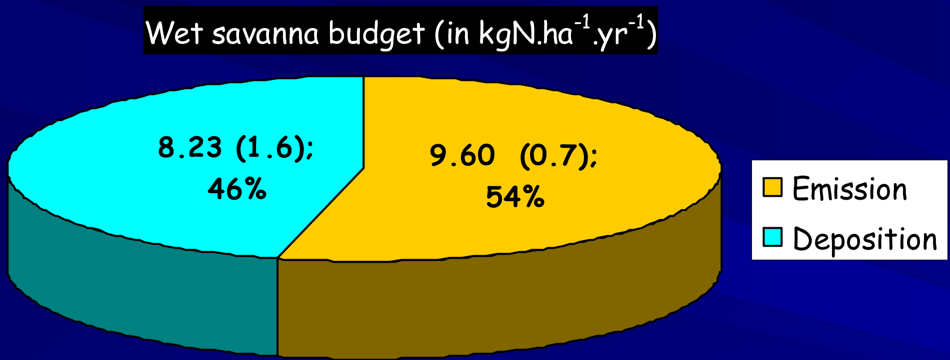
Nitrogen budget emission-deposition for all the ecosystems



Biomass Burning low

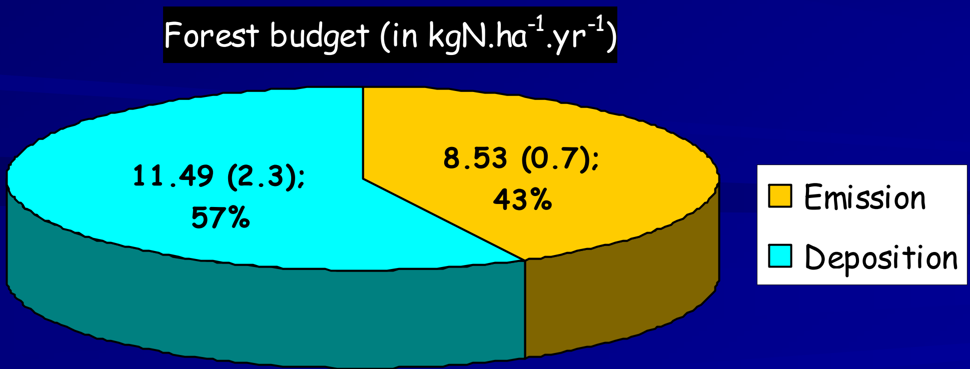
Pulse of NO soils important

High Emission of NH_3 animals, dry dep high



Biomass Burning 3x /biogenic

Lower NH_3 emissions, lower dry deposition



Biomass Burning dominate

NH and SH savanna burning

Galy and Delon, 2011

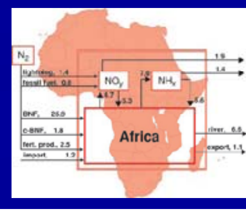
Conclusion on N deposition budget

- The IDAF database analysis: rain, aerosol, gas allow the first estimation of the nitrogen budget of deposition for african ecosystems

- This work is included in the future WMO assessment (Vet et al, 2012) in the african chapter (coordination: Galy and Pienaar)

- INI (International Nitrogen Initiative) SCOPE/IGBP: Overview of the impact of Nitrogen on African agriculture and the environment for the african continent Theme 1: continental overview of the N cascade and links to a global perspective, Background chapter

Galy and Delon, 2012



Conclusion

« I urge, therefore, that in future 'Global Change' research efforts substantially more attention is given to the tropics and the subtropics. This also requires the involvement and training of local scientists to participate in joint field programmes: A strong scientific basis in this part of the world will in future not only benefit progress in science, but will also lead to greatly improved scientific inputs in political decision making"

P. Crutzen, (Prix Nobel de Chimie, 1995),

United Nations University Millennium Conference

Scientific and technical animation in the IDAF program is key in the project

It allowed to build an environment monitoring system on a long term basis with real scientific collaborations since more than 10 years

IDAF scientific animation

- Capacity building and Transfer of technology

  Annual period of formation for African scientist to the Laboratoire d'Aérologie

  Formation of Students (exple PhD: J. Mphepya,2002; H. Al Ourabi, 2002, Adon, 2011)

- Data Diffusion Web site and IDAF database

http://www. idaf.sedoo.fr

Long term series of validated data for the 10 stations:

- Rain (quality criteria)
- Aerosol
- Gas

Conclusion

- **The IDAF program is a network** providing original measurements of quality since 10 years based on strong collaborations with African atmospheric scientists.
- **Measurements of dry and wet deposition are** pertinent indicators of the evolution of the atmospheric chemical composition (rain chemistry, aerosols chemistry and gas concentrations).
- **From the above database** the main chemical characteristics of wet- and dry-atmospheric depositions have been highlighted. This was accomplished for the main African ecosystems.
- **Data diffusion**: web site and IDAF database. **http://www.idaf.sedoo.fr**
- **Formation and capacity building** are an important mission of IDAF**.**
- **The IDAF program participates directly to: AMMA** program in West Central Africa (African Monsoon Multidisciplinary Approach) **and GDRI ARSAIO** (Atmospheric Research in SOuthern Africa and Indian Ocean) program in South Africa.













Many thanks to the IDAF team….

And to the EDI team….

IDAF objectives: present and future

- **To Maintain the existing network with:**

A uniform strategy for data acquisition and management

→ High quality data available for the scientific community comparable for all DEBITS sites / referenced with international standards

- **2005-2006: Extension of measurements to include new species**

Aerosol collection (PM2,5-PM10, mass)

Carbonaceous compounds (OC, BC)

Trace elements, and complementary measurements

(AMMA regional experiment West africa,

SACCLAP in south Africa)

- **To develop deposition modeling with new parameterisation**

example: to extend heterogeneous processes to new species, hygroscopicity processes, scavenging … better deposition modeling)