Environmental factors and population dynamics as determinants of meningococcal meningitis epidemics in the Sahel: an investigation of NASA and NOAA products

NASA-Roses: 1 Yr Feasibility Study
Sept 1, 2009 - Aug 31, 2010, no cost extension till April 30, 2011

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Meningococcal Meningitis – a few facts

- Bacterial meningitis
- Human to human transmitted
- High rate of asymptomatic carriers (10-20% of general population)

Pathogenesis

- Respiratory acquisition
- Colonization of the nasopharynx
- Penetration the respiratory mucosa and entrance into the bloodstream

- If untreated fatality rates > 50%, and 10% despite treatment
- 10-20% of survivors develop severe neurological sequelae

Meningococcal Meningitis – a few facts

- **Highest prevalence in Subsaharan Africa**
  => Meningitis belt
- **Highly seasonal**
- **Identified since 1963 (Lapeyssonie, 1963)**
- **Population at risk each year**
>450 million, 25 countries
- **Largest recorded outbreak, in 1996: 250,000 cases, approx. 25,000 deaths and at least 50,000 persons suffered permanent disability**

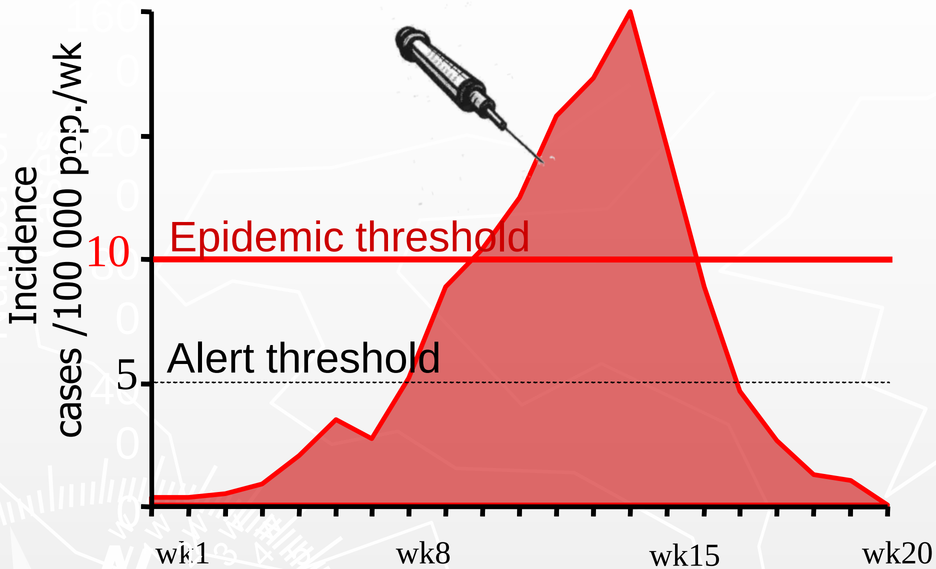
Courtesy CDC

- **The burden is estimated to be more than $11 million/year in diagnostic, tests and case treatment costs.**
- **Additional burden at the household level in Burkina Faso:**
$90/case – 34% annual GDP/capita –
and up to $154 more when permanent disability occurred.

Yet, no efficient preventive treatment exist.

Control Strategies

- **Current control: reactive vaccination, polysaccharide vaccine**



CHALLENGES:

☛timely vaccination to optimize the control of the epidemics

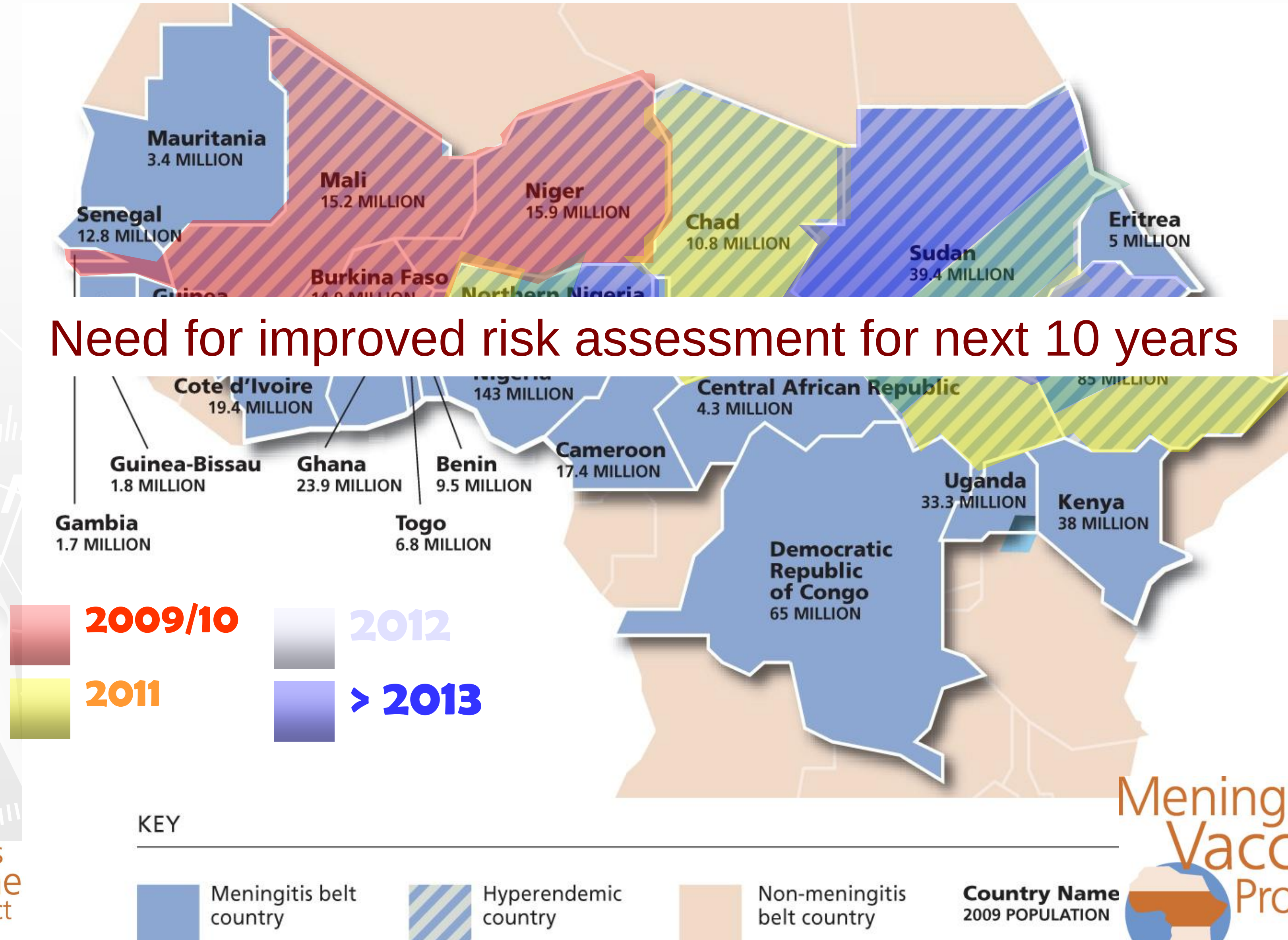
☛Vaccination campaign 2-3 weeks after alert threshold

- **Future control**

– **Preventive vaccination Men A conjugate vaccine**
– **Reactive vaccination for other strains and/or in places where MenA not implemented**

☛ **Need for any timely information on risk**

Proposed MenA conjugate vaccine introduction



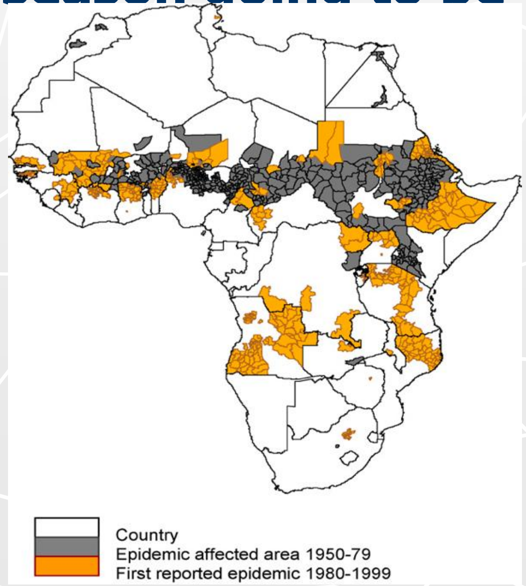
Need for improved risk assessment for next 10 years

Meningitis Vaccine Project

Stake-holders and decisions

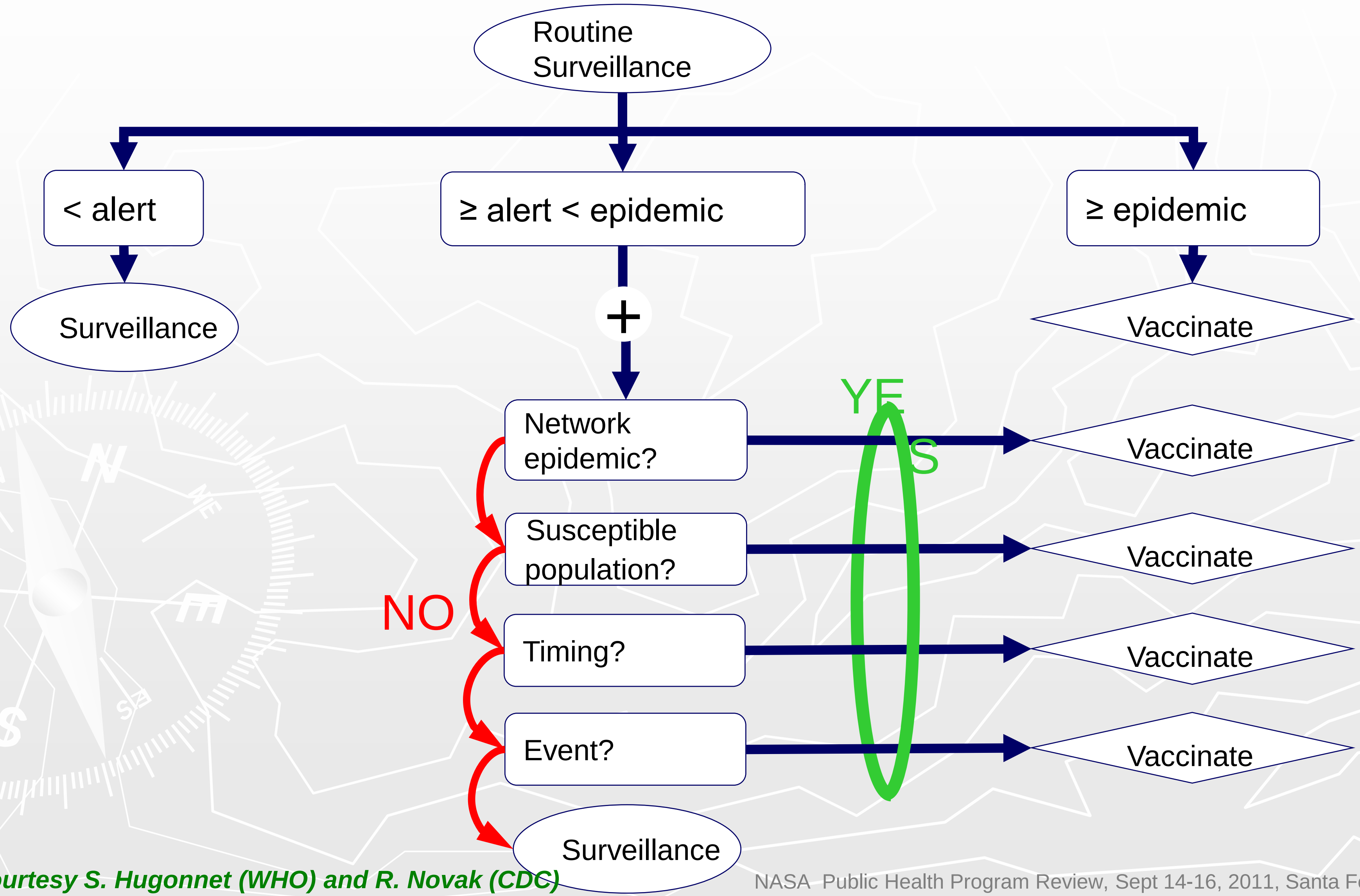
- **WHO – Global Alert and Response**
  National Public Health Ministries and Services
  Meningitis Vaccine Project
  MERIT

- **Decisions:**
  - **–Short term, within season (2-3 weeks): which district to vaccinate**
    - ☛ **to reduce operational delays, to decide whether vaccinate (U**
  - **–Seasonal, before the season: how bad is the season going to be**
    - ☛ **enhance surveillance, capacity building**
  - **– Annual**
    - ☛**vaccine production, stockpile (ICG)**
  - **– Decadal**
    - ☛ **changes in Meningitis Belt**



Changes in the areas of MM epidemics risk in Africa between 1950-79 and 1980-1999 periods, Cuevas et al. 2007

Hypothetical decision tree adding an "alert+" action threshold



Courtesy S. Hugonnet (WHO) and R. Novak (CDC)

Specificity/timeliness trade-off (REQUIRES 5/100,000 IN DISTRICT): *include neighboring districts in epidemic*

Neighbors in epidemic cutpoint for action	Specificity	Lower CL for specificity	Upper CL for specificity	Mean improvement in timeliness (weeks)
none	**85.22**	**0.82477**	**0.87682**	**1.891156463**
1	**93.34**	**0.91316**	**0.95018**	**0.972789116**
2	**97.07**	**0.95598**	**0.98155**	**0.544217687**
3	**98.93**	**0.97912**	**0.99539**	**0.238095238**
4	**99.87**	**0.9926**	**0.99997**	**0.074829932**
5	**99.87**	**0.9926**	**0.99997**	**0.040816327**
6	**100**	**0.9951**	**1**	**0.027210884**
7	**100**	**0.9951**	**1**	**0.006802721**
8	**100**	**0.9951**	**1**	**0.006802721**
9	**100**	**0.9951**	**1**	**0**
10	**100**	**0.9951**	**1**	**0**
Ignore neighbors	**100**	**0.9951**	**1**	**0**

Courtesy S. Hugonnet (WHO) and R. Novak (CDC)

Causes of meningitis epidemics still poorly understood

❑ Known Risk Factors

- Individual and population risk factors
  - –Age-related acquisition of bactericidal antibodies
  - –Underlyinng immune defects (i.e., asplenia, genetics)
  - –Crowding
  - –Smoke exposure
  - –Upper respiratory tract infections
- Climatic conditions (dry season)
  - –Excessively dry& hot season
  - –Dust storms
- Immunological susceptibility
  - –Introduction of a novel, virulent strain
  - –Waning herd immunity
  - –Large population movements

Courtesy CDC

IMPACT OF THE ENVIRONMENT

❑ On the pathway of infection

Pharyngeal carrier

↓

Respiratory droplets (meningococci) ← Survival of meningococci in droplets

↓

Susceptible host

↓ ← Damage to mucosa facilitating colonisation

Pharyngeal carrier

↓ ← Damage to mucosa facilitating invasion; Influence on the immune response

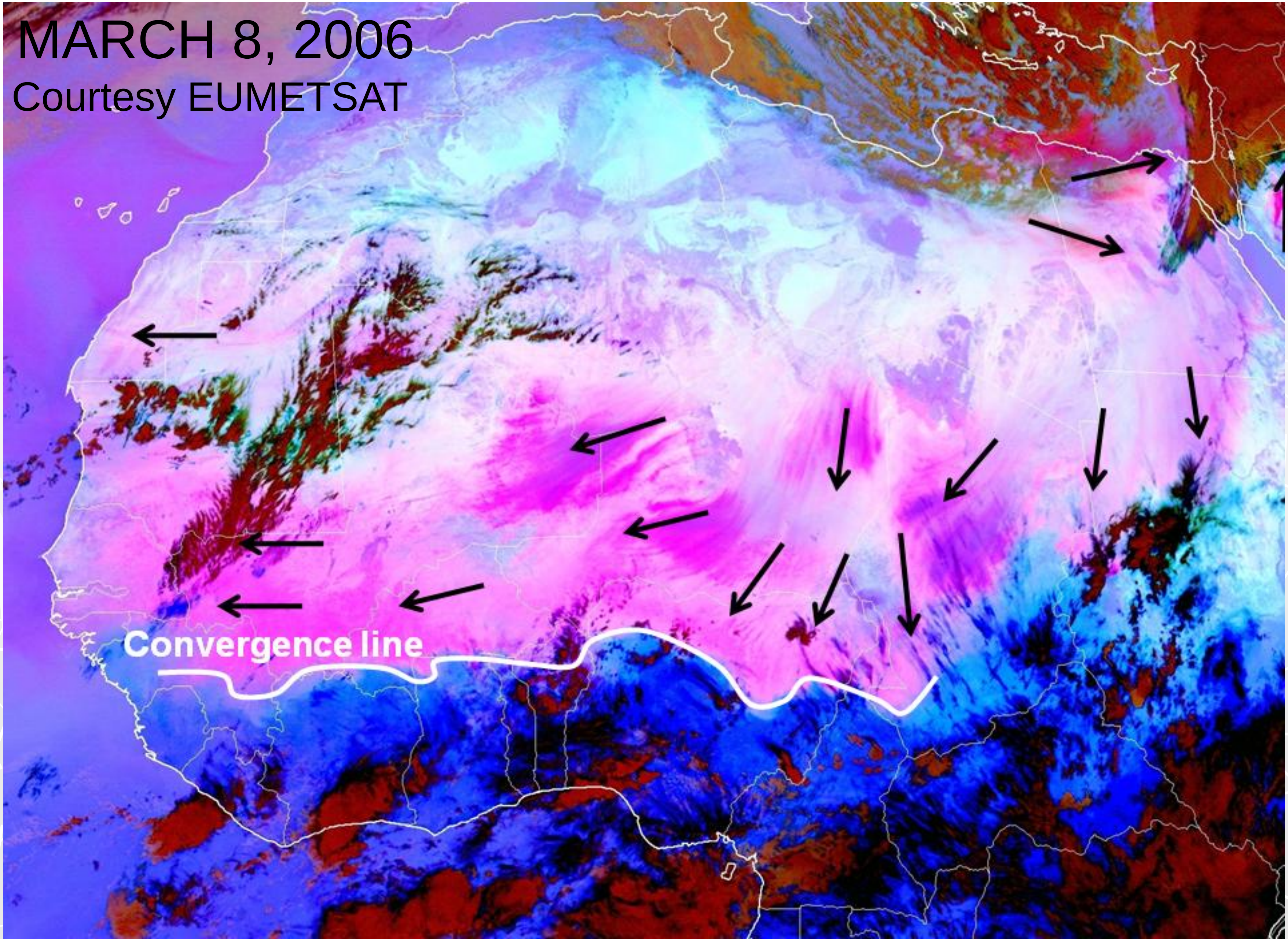
Case

Courtesy Brian Greenwood

❑ Indirect

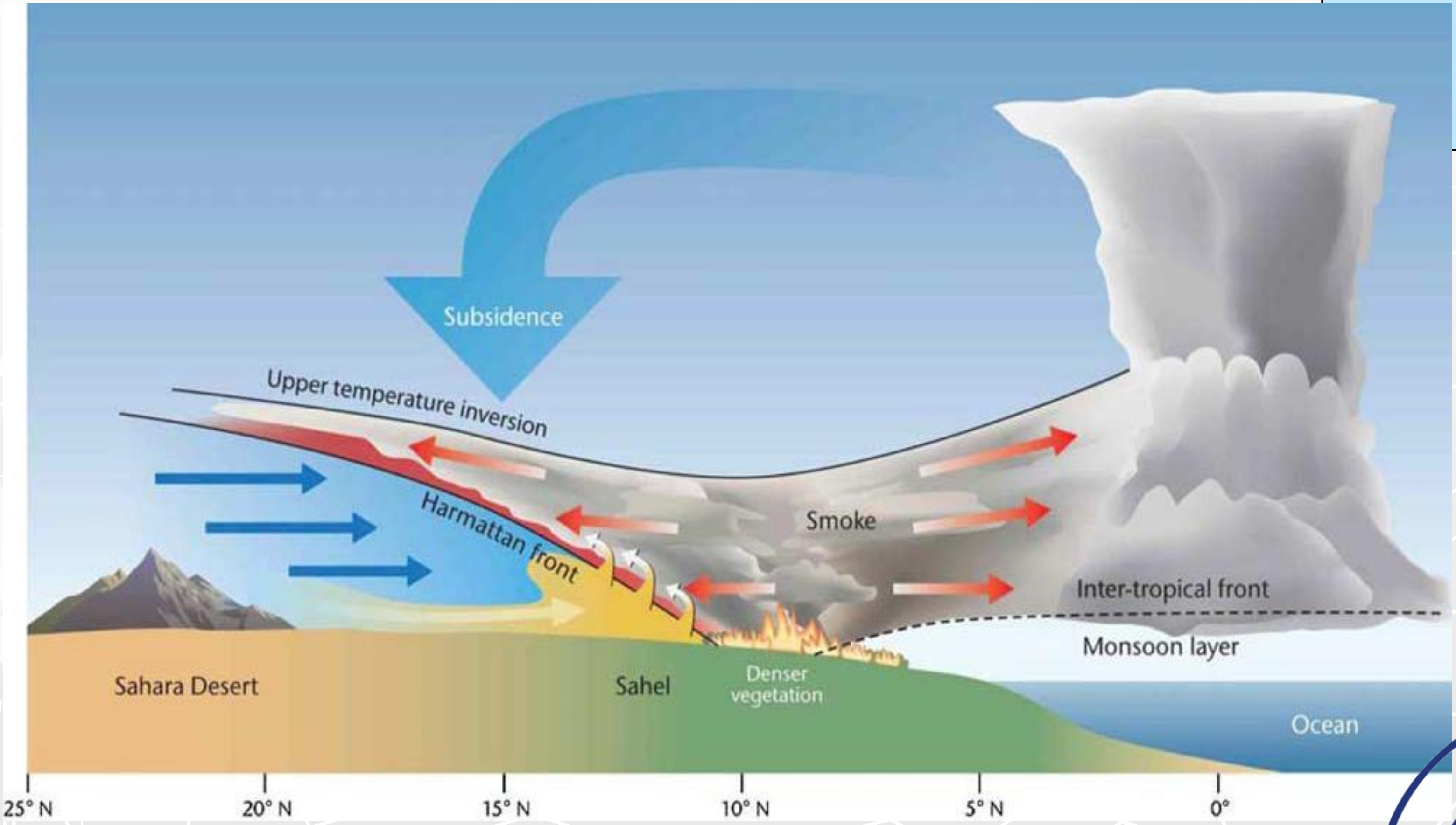
1. Enhancing bacterial survival via iron content of dust
2. High dust levels affecting human behaviour, including crowding and reduced ventilation
   (e.g. blocking windows)
3. (More controversially) serving as carriers for bacteria

Dust



Climate features in the Meningitis Belt/Sahel

Schematic meridional cross section of atmospheric circulations over West Africa. *(Haywood et al., 2008).*



Project Objectives

Statistical model, forecasting the likelihood of epidemic threshold to be crossed (or not) at a given district at different time leads (before, at the beginning and during the season)

Using environmental <u>and</u> demographic predictors

- **Detect the optimal combination of predictors at different time lags**
- **Evaluate model's skill (capacity to predict past epidemics and their timing)**
- **Demonstrate that different decision can be made based on the available forecasts**

- **Meningitis data for Niger: weekly district level, 1086-May 2008, QC**

Using multiple source information information for predicting meningitis risk

Population factors:
- •Population density
- •Population stratification: gender, Age, Rural-urban
- •Mobility

Environmental factors
- ▪Dust (concentration, particle size….) from in-situ observation, Satellite (MISR), Models (global and regional) and dust forecasts
- ▪Weather and Climate Conditions - wind, humidity, temperature, rainfall - in situ (Met Station), Satellite (TRMM), NCEP Reanalysis
- ▪Seasonal forecasts (ECHAM4.5)

Epidemiological state of the population at the district level based on:
- Past history of epidemics
- Past history of immunization
- Migration paths
- Seasonality

Generalized Linear Model to predict crossing alert/epidemic threshold
- For each district and at country level
- At different lead-times: seasonal, monthly, 2 weeks and simultaneous
- •Probability based on historical model performance

Skill assessment

GIS based maps to display the probability of alert/epidemic threshold
- •For each district and at country level
- At different lead-times

Outputs

•Build GIS based predictive tool using models and predictors selected in the project to provide risk maps at district and country level at different lead-times

☛ **Extract relevant climate information**

Related research

•Quantify the relationship dust-meningitis

•Quantify the relationships between atmospheric conditions (wind, temperature, humidity…) and meningitis

•Validate dust products

•Validate seasonal forecast models

•Assess the usefulness of satellite and model data for predictive purposes

•Investigate a range of statistical models, predictors and lead-times and select most appropriate

Project participants and their responsibilities

IRI:

- **analysis of relationships between atmospheric conditions & dust and meningitis, analysis of their predictability; construction and evaluation of the model - S. Trzaska, L. Cibrelus;**
- **advisory role on the use of satellite data - P. Ceccato, T. Dinku;**
- **advisory role on links between environmental conditions and meningitis and on general statistical model - M. Thomson;**
- **advisory role on the evaluation of decision improvement processes - M. Madajewicz**

CIESIN:

- **population mapping by age structure, urban/rural distribution, population mobility, georefernced datasets, construction of predictive model - S. Adamo, G. Yetman);**
- **advisory role on data integration and model construction – M. Levy;**

GISS:

- **aerosols simulation – J. Perlwitz**
- **advisory role on validation and interpretation of model results – R. Miller**

JPL:

- **MISR data and related technical expertise - O. Kalashnikova**

Where we are now…

- Important effort of data collection, archiving & tool development
- Dust products validation & assessment of relevance for meningitis prediction
- Assessment of predictability of meningitis based on environmental and epidemiological information
- Analysis of spatial characteristics of meninigitis outbreaks

Data Collected

Epi

•Meningitis data in Niger, weekly, district, 1986-May 2008

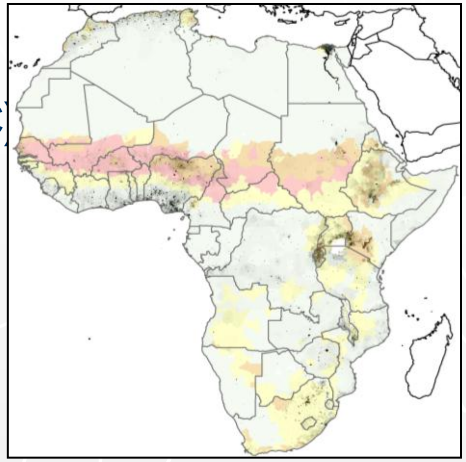
• Weekly alert/epi status & weekly case number at country level for the belt 2002-present, from WHO Weekly Epidemiological Reports

Pop

•CIESIN Gridded Population data (GRUMP/SEDAC)

- •pop density
- •urban /rural
- •age structure

•Literature review of migration patterns and data; some data gathered



Dust

•Aeronet data from 16 stations across Africa N of equator

•Visibility data from Niamey

•MISR Aerosol data

•TOMMS OMI

•Outputs from model simulation of mineral dust (regional and global)

Climate

•Temperature, wind data from NCEP reanalysis

•TRMM rainfall estimates

•IRI Seasonal Forecast Outputs

Data (cont.)

Archived in Data Library:

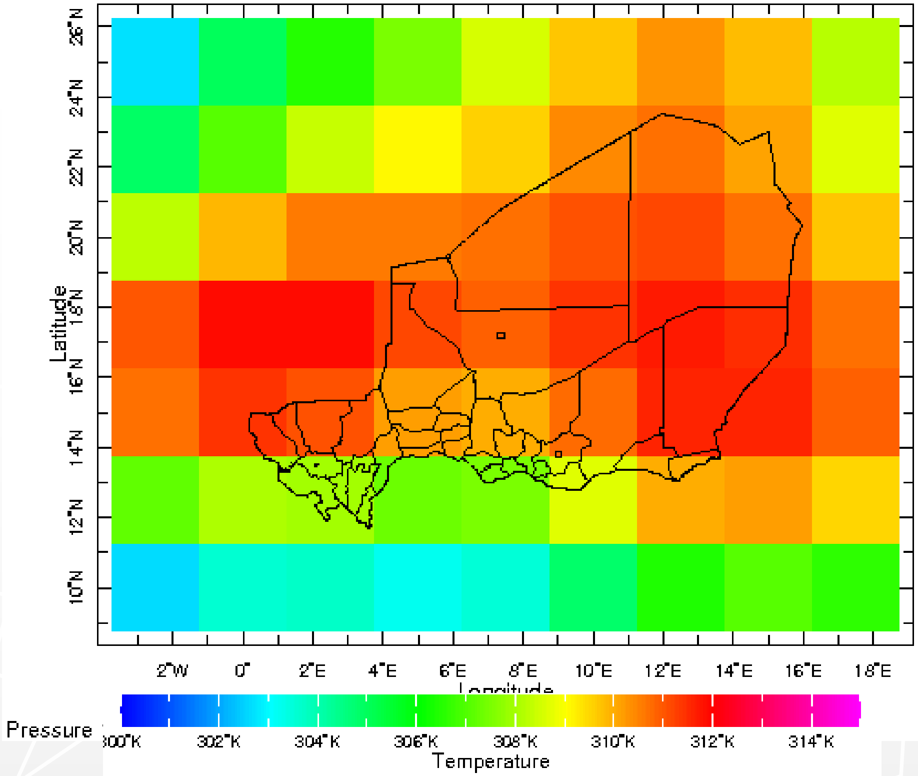
http://iridl.ldeo.columbia.edu/maproom/.Health/.Regional/.Africa/.Meningitis/

Descriptions and relevant bibliography on project accessible portal

Metadata of the Nasa/Roses project

	Variable category	Variable name	Source of the data	Origin of the data	Type of variable	Computation of the variable	Time resolution	Spatial resolution	Time coverage	Spatial coverage	Missing data
EPIDEM IO-	Epidemiological	**Incidence of meningitis**	Ground	WHO routine surveillance	Count	Derived from the number of meningitis cases	**Week**	**District**	Dec 1985 - May 2008	All districts, Niger	
	Immunological state of the population	**Recent history of outbreaks**	Ground	WHO routine surveillance	Count	Derived from the number of meningitis cases	**Week**	**District**	Dec 1985 - May 2008	All districts, Niger	
CLIMATE	Aerosol/Dust	**Absorption Angstrom Exponent (α)**	Satellite	AERONET[i], NASA	Continuous		Daily	Single point	Oct 1995- June 2009	Banizoumbou, Niger	
			Satellite	MISR[ii], NASA	Continuous		Daily	0.25x0.25	Apr 2000-Apr 2009	Africa north of the Equator Longitude: [74.875W,64.875E]; Latitude: [0.125N,34.875N]	
		AOD[iii]/ AOT[iv]	Satellite	AERONET, NASA	Continuous		Daily	Single point	Oct 1995- June 2009	Banizoumbou, Niger	
			Satellite	MISR, NASA	Continuous		Daily	0.25x0.25	Apr 2000-Apr 2009	Longitude: [74.875W,64.875E]; Latitude: [0.125N,34.875N]	
			Model	Mineral Dust aerosol model GISS, NASA: Global Climate Model E	Continuous		Hourly and Monthly	Horizontal: 144x90 grid cells (2.5°x2°) Vertical : Total over troposphere	1984-2009	Global	
		Dust fraction: Total, large, medium, small	Satellite	MISR, NASA	Continuous		Daily	0.25x0.25	Apr 2000-Apr 2009	Longitude: [74.875W,64.875E]; Latitude: [0.125N,34.875N]	
		Dust surface concentration	Model	Mineral Dust aerosol model GISS[v], NASA: Global Climate Model E	Continuous		Hourly and Monthly	Horizontal: 144x90 grid cells (2.5° x 2°) Vertical : surface layer	1984-2009	Global	
		Visibility	Ground	Met Station	Continuous		Daily	Single point	1995-2009	Niamey, Niger	
	Wind	**Wind speed**	Ground	Met Station	Continuous		Daily	Single point	1995-2009	Niamey, Niger	
			Model	Seasonal forecast	Continuous		Daily and monthly	Vertical: near surface (2m, 10m) and Plevels (925, 950, 850 etc) Horizontal: ECHAM 4.5 T42: 2.5°x2.5°			
			Model	NCEP/NCAR Reanalysis	Continuous		Daily and monthly	Vertical: 1.'diagnostic' or 'near-surface' (also 'top') variables: one level, specified (surface, 2m, 10m etc) 2.'intrinsic' variables: across the atmospheric depth, on specified Pressure levels (950hPa, 500hPa, sea level pressure) or total atmospheric column Horizontal: 1. diagnostic ' variables : 1.875° (long)x2.5° (lat). 2.'intrinsic' variables 2.5°x2.5°	1948 -present (last week for daily, last month for monthly)		
		Wind direction	Model	Seasonal forecast	Categorical		Daily and monthly	Vertical: near surface (2m, 10m) and Plevels (925, 950, 850 etc) Horizontal: ECHAM 4.5 T42: 2.5°x2.5°			
			Model	NCEP/NCAR Reanalysis	Categorical		Daily and monthly	Vertical: 1.'diagnostic' or 'near-surface' (also 'top') variables: one level, specified (surface, 2m, 10m etc) . 2.'intrinsic' variables: across the atmospheric depth, on specified Pressure levels (950hPa, 500hPa, sea level pressure) or total atmospheric column Horizontal: 1. diagnostic ' variables : 1.875° (long)x2.5° (lat). 2.'intrinsic' variables 2.5°x2.5°	1948 -present (last week for daily, last month for monthly)		
	Humidity	**Dew point**	Ground	Met Station	Continuous		(unitless) ordered (1.) to (137231.)	Single point	(unitless) ordered (1.) to (137231.)	Niamey, Niger	

Some issues/solutions



Spatial scale

- Extract information at district level
- Specific tool in IRI Data Library

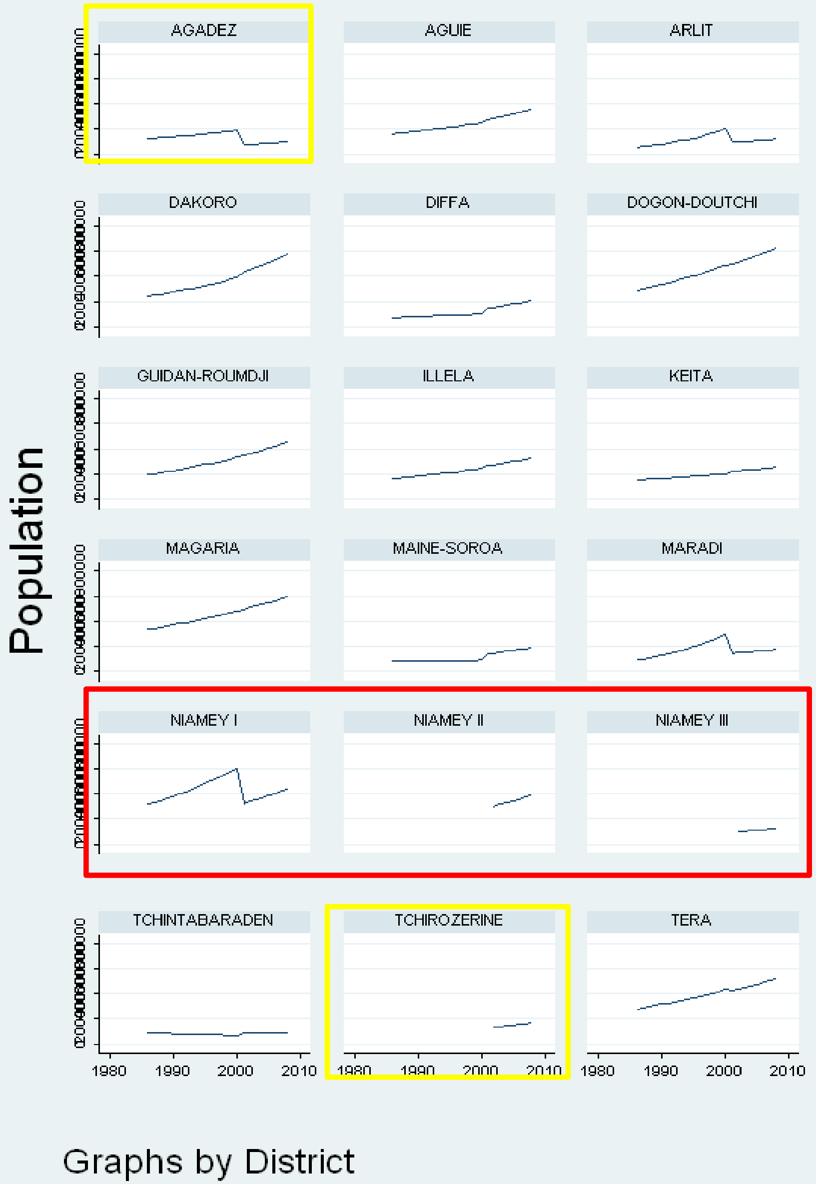
Time resolution

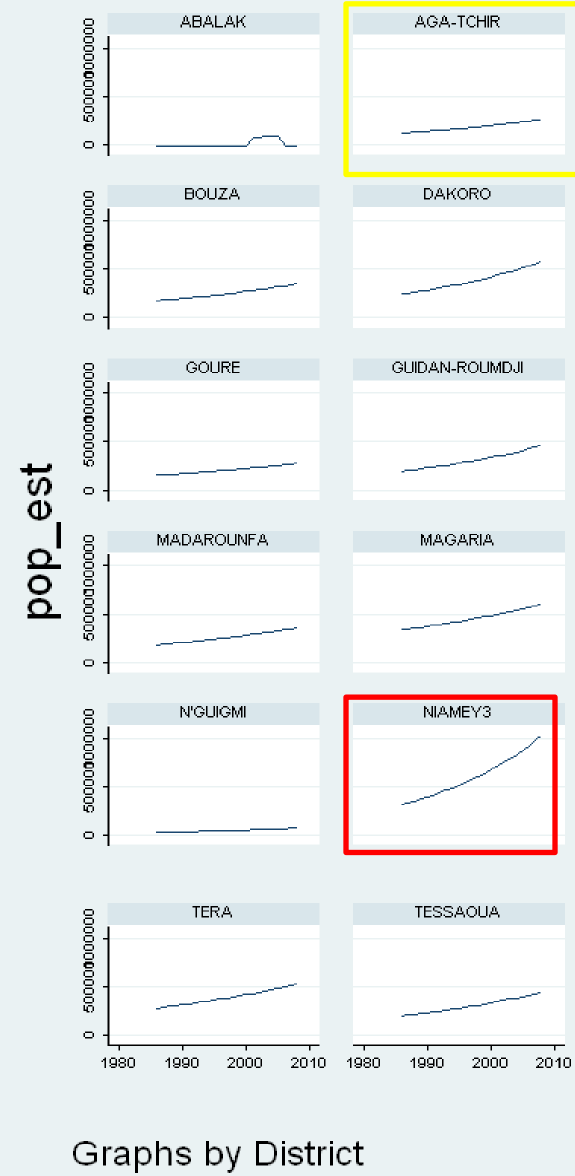
- Weeks: Monday to Sunday
- Calendar done for 1986-2008
- DL extracts weekly averages according to this calendar

Year	Starting Week	Ending Week	Number of Weeks
1986	12/29/1985	01/03/1987	53
1987	01/04/87	01/02/88	52
1988	01/03/88	12/31/88	52
1989	01/01/89	12/30/89	52
1990	12/31/89	12/29/90	52
1991	12/30/90	12/28/91	52
1992	12/29/92	01/02/93	53
1993	01/03/93	01/01/94	52
1994	01/02/94	12/31/94	52
1995	01/01/95	12/30/95	52
1996	12/31/95	12/28/96	52
1997	12/29/96	01/03/98	53
1998	01/04/98	01/02/99	52
1999	01/03/99	01/01/00	52
2000	01/02/00	12/30/00	52
2001	12/31/00	12/29/01	52
2005	12/30/01	12/28/02	52

Some issues (cont.)

Pop Data

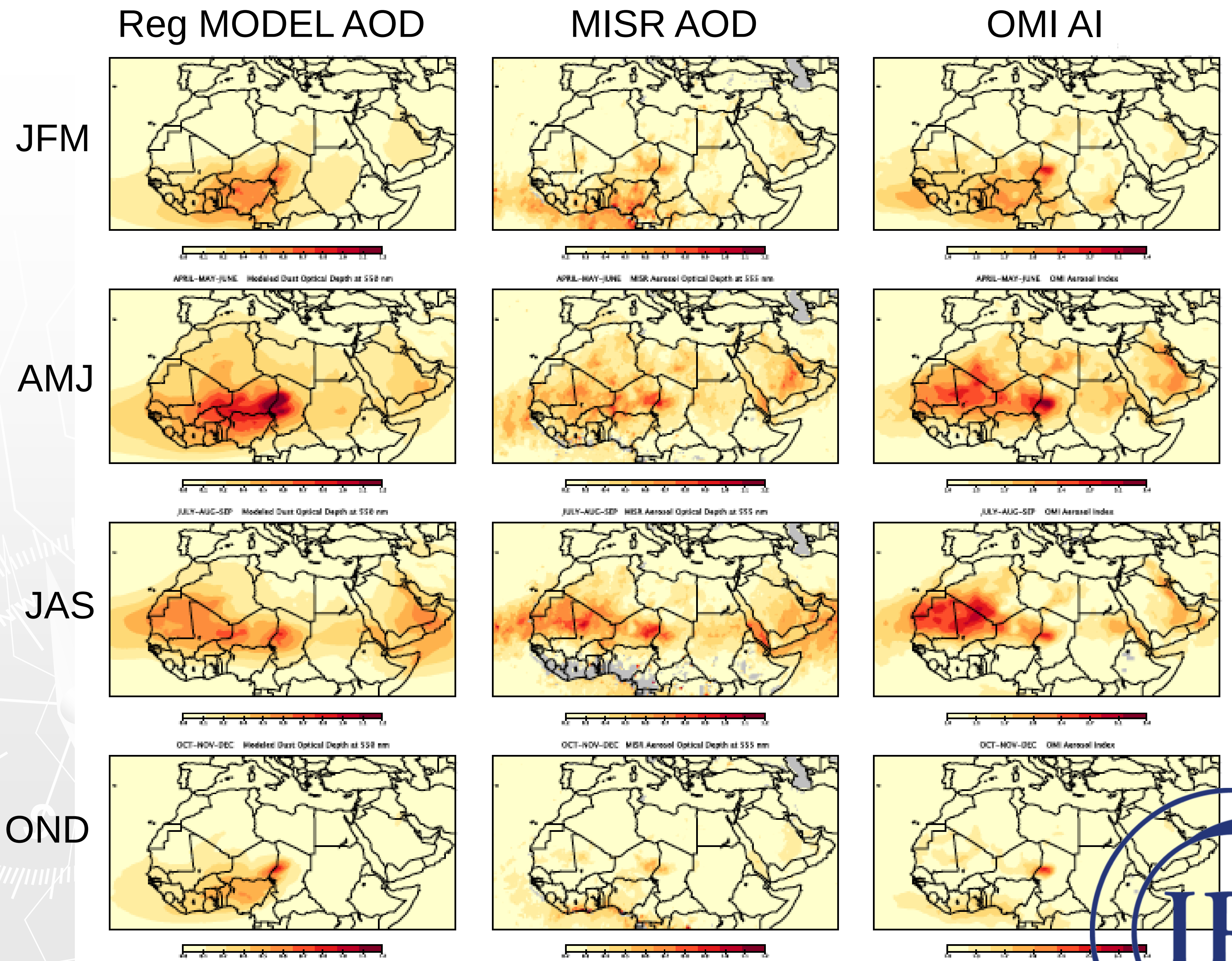




S. Adamo

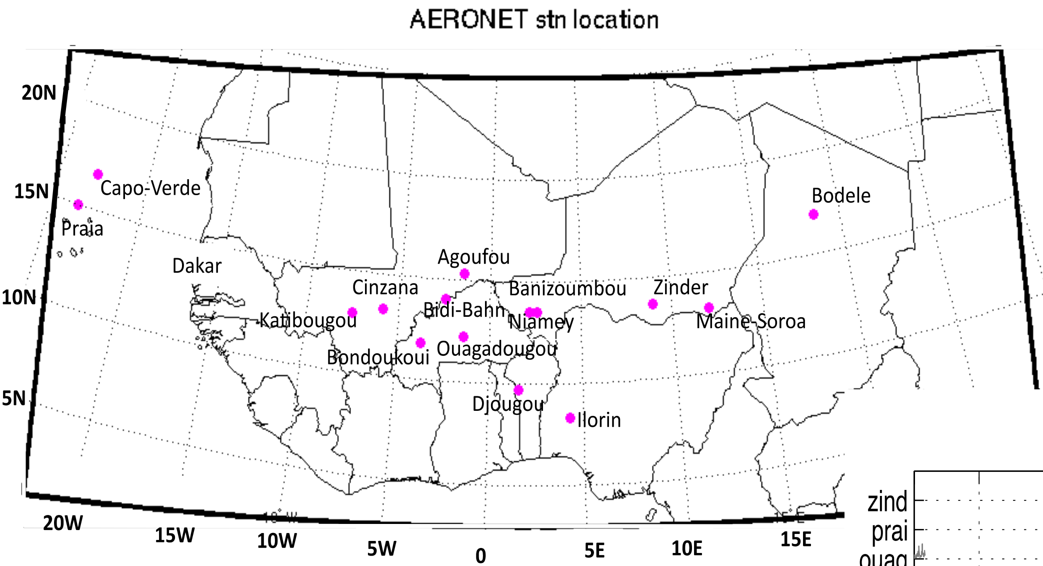
Dust products validation & assessment of relevance for meningitis prediction

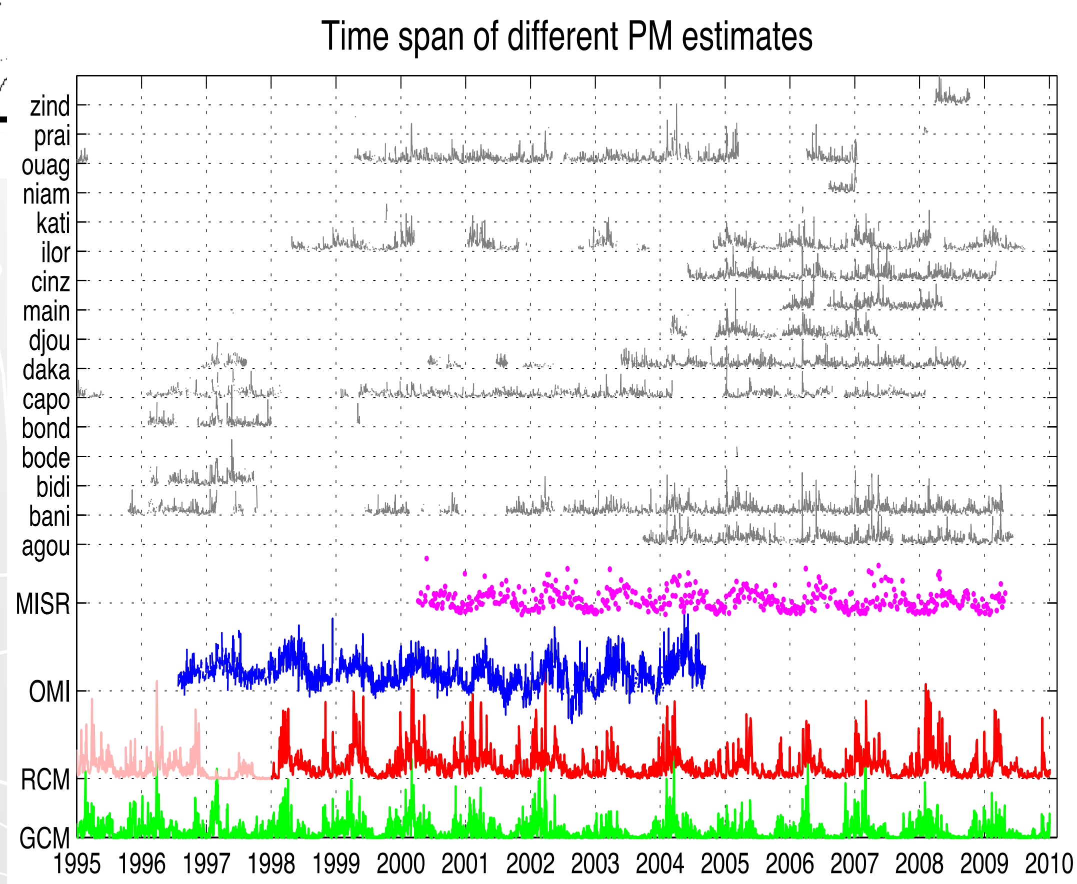
- **MISR (2000-2009)**
- **TOMMS-OMI (1997-2008)**
- **Regional model (NMMB/BSC-Dust,1979-2008)**
- **Global model (NASA GISS ModelE, 1979-2008)**



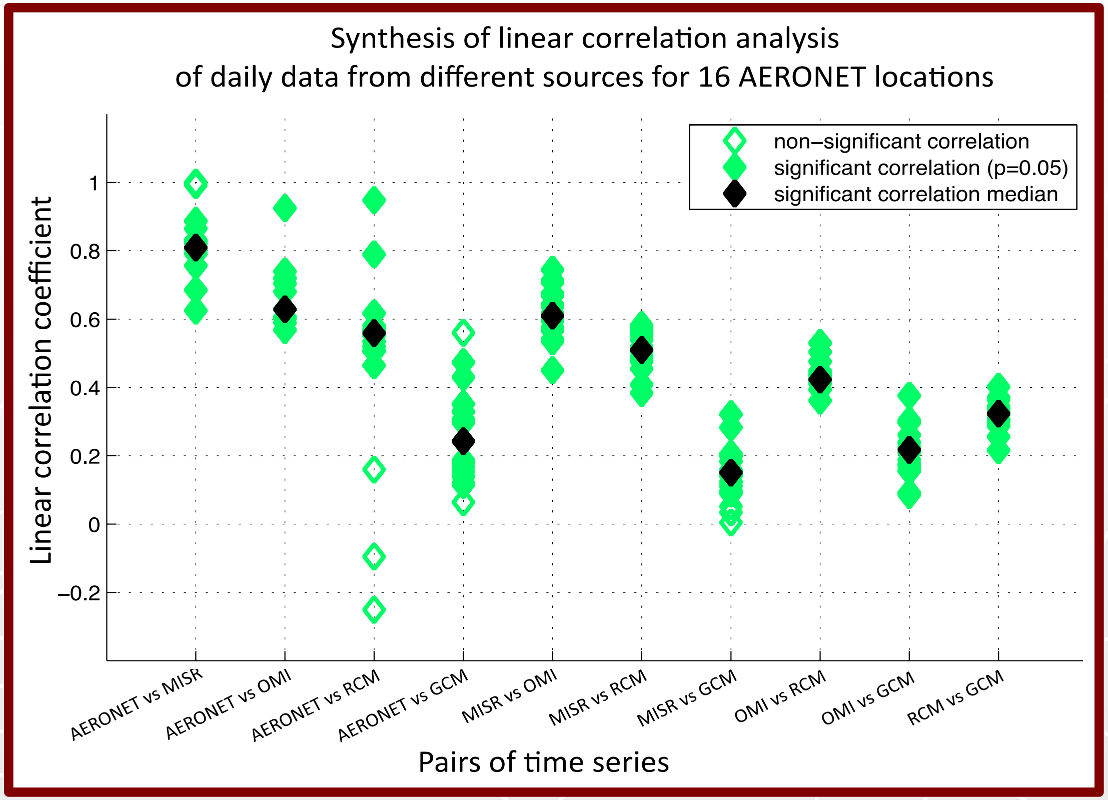
Reg MODEL AOD
MISR AOD
OMI AI
JFM
AMJ
JAS
OND
APRIL-MAY-JUNE Modeled Dust Optical Depth at 550 nm
APRIL-MAY-JUNE MISR Aerosol Optical Depth at 555 nm
APRIL-MAY-JUNE OMI Aerosol Index
JULY-AUG-SEP Modeled Dust Optical Depth at 550 nm
JULY-AUG-SEP MISR Aerosol Optical Depth at 555 nm
JULY-AUG-SEP OMI Aerosol Index
OCT-NOV-DEC Modeled Dust Optical Depth at 550 nm
OCT-NOV-DEC MISR Aerosol Optical Depth at 555 nm
OCT-NOV-DEC OMI Aerosol Index

Dust products validation

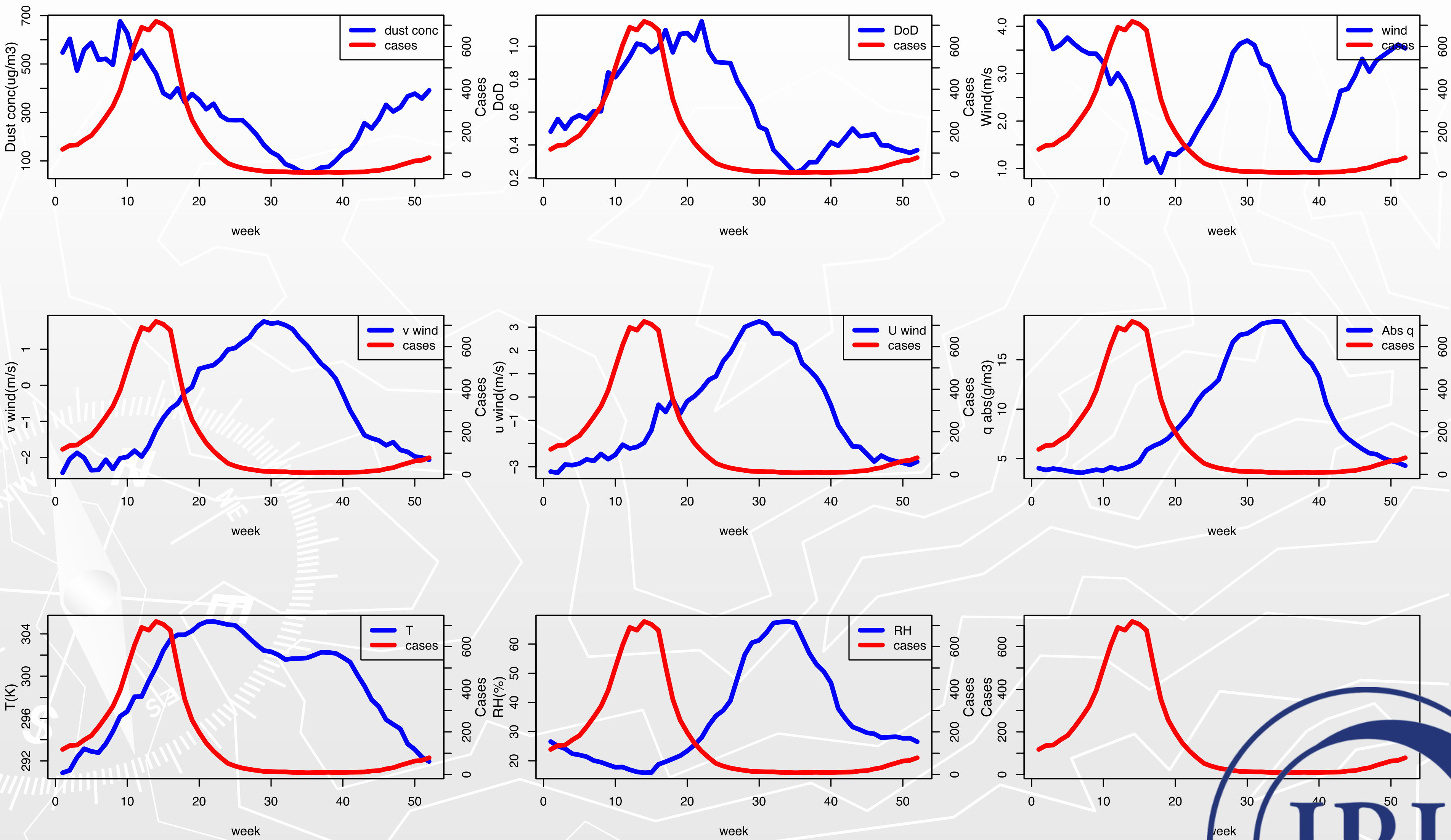




Dust - time series validation



Seasonal cycles (weekly, national)



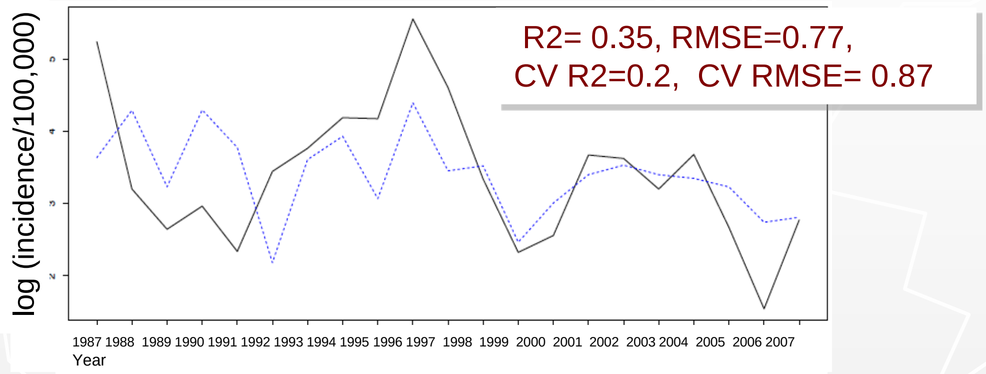
Assessment of predictability of meningitis based on environmental and epidemiological information

- Seasonal & weekly scale
- National & district scale

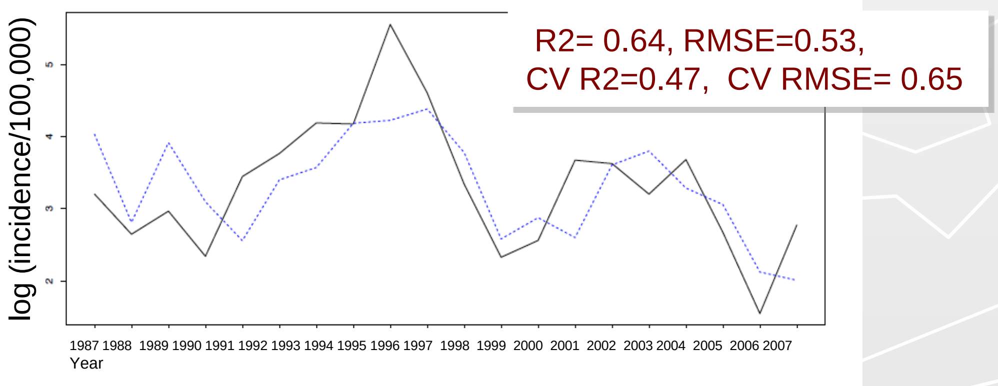
Annual attack rates in Niger

NATIONAL SCALE

Log (incidence JAN-MARCH)
~ Log (early season Climate)

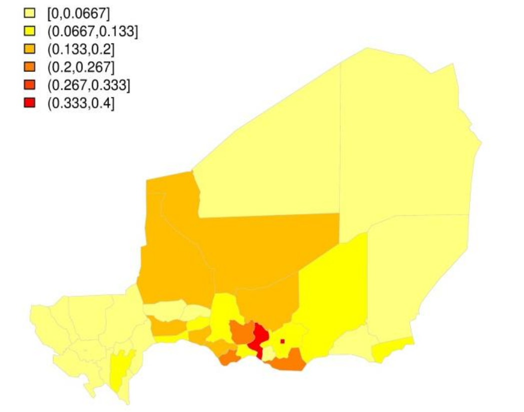


Log (incidence JAN-MARCH)
~ Log (early season Climate)& Log (incidence DEC)

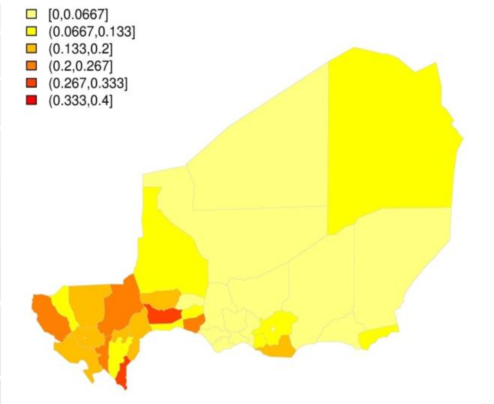


DISTRICT SCALE

Log (incidence JAN-MARCH)
~ Humidity (DEC)



Log (incidence JAN-MARCH) ~ Min Surface Temperature (FEB)



with M. Stanton (U. Lancaster)

Weekly incidence in Niger

MODELS

- three types of models were fitted to the data:
  - a linear model
  - a model with a fixed seasonal cycle
  - a dynamic linear model, with a varying season cycle
- several forms of the climate variables:
  - single week lagged climate anomalies
  - lagged climate anomalies averaged over the previous four weeks to account for the cumulative affects of climate on the disease
  - the information about incidence levels in previous weeks

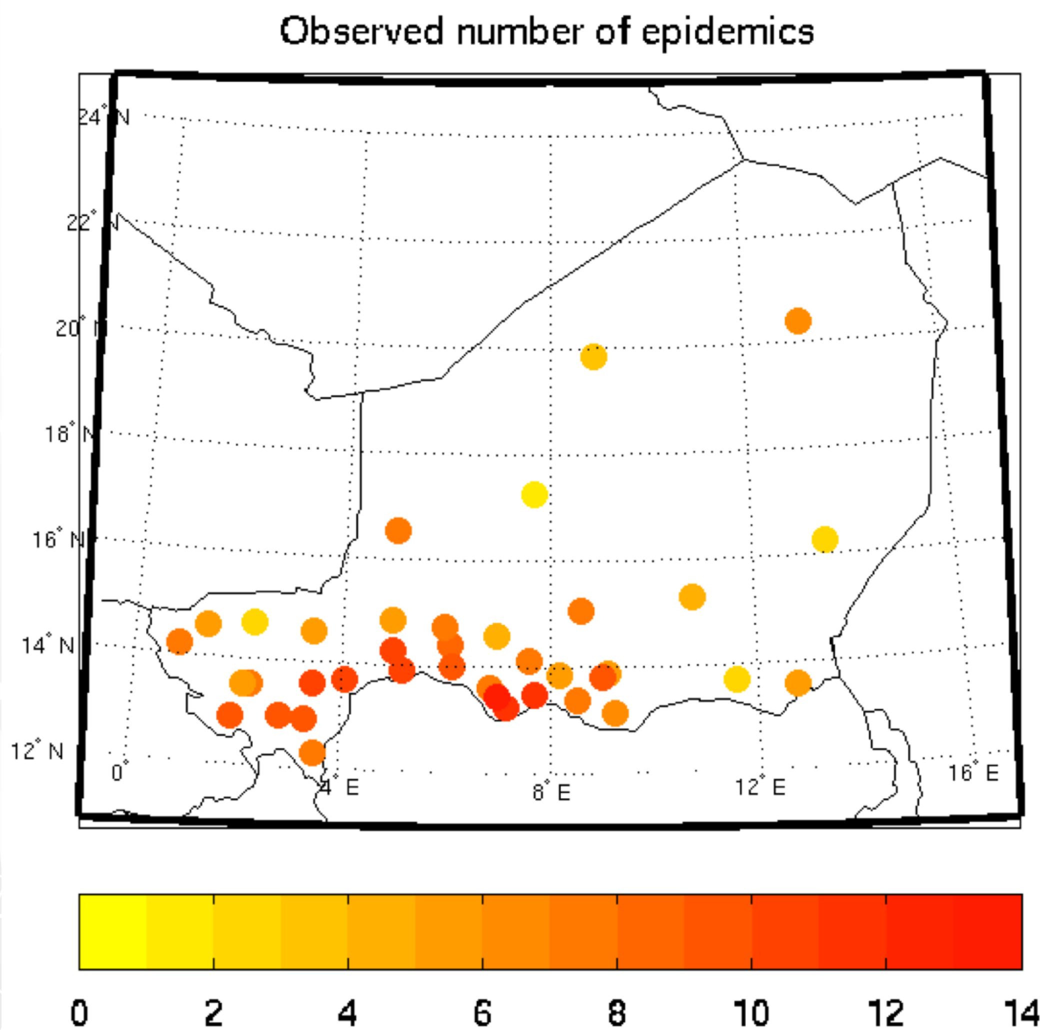
RESULTS

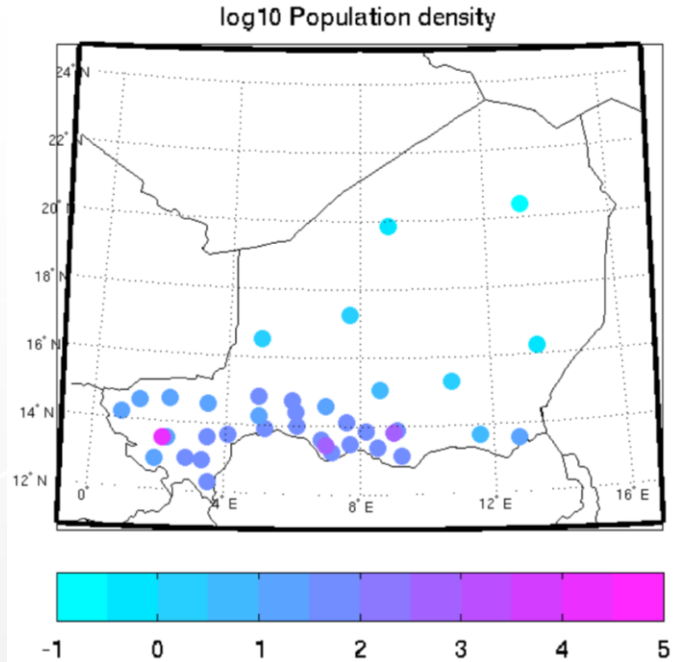
- national scale
  - several climate variables with significant correlation but none stood out
  - best results obtained when previous week(s) incidence included
  - only small improvement when adding climate variables
- district level
  - Similar conclusions to national scale
- dynamic linear model yielded similar results as the model with fixed seasonal cycle

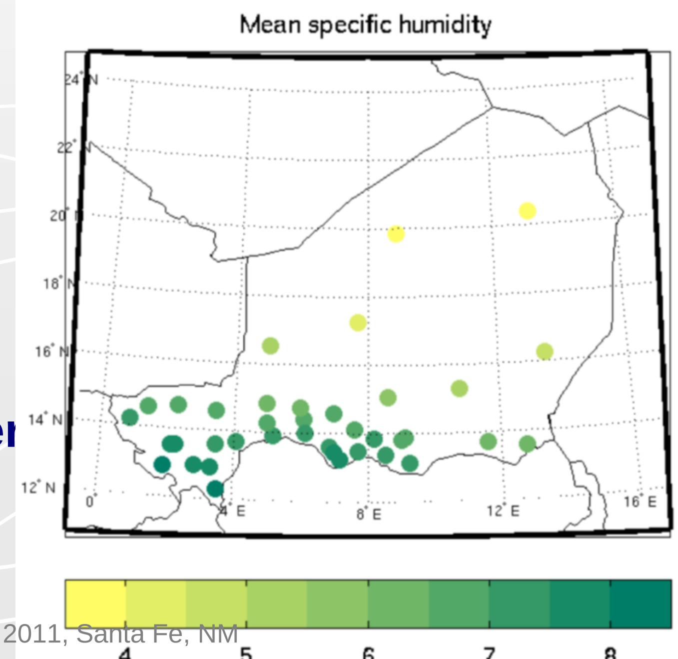
with M. Stanton (U. Lancaster)

Analysis of spatial characteristics of epidemic outbreaks in Niger

Spatial distribution of recorded epidemics







- Highest epidemic numbers along southern border
- Approx southward gradient
- Other variables show similar structures

Stepwise multiple linear regression

Different combinations of potential predictors at district level

- Population and geography:
  Pop=[log10(pop density), log10(pop), percentage urban, latitude(centroid, longitude(centroid)]

- Annual means of climate variables:
  Clim_ann=[meanU_ann, meanV_ann, meanT_ann, mean SpecHum_ann]

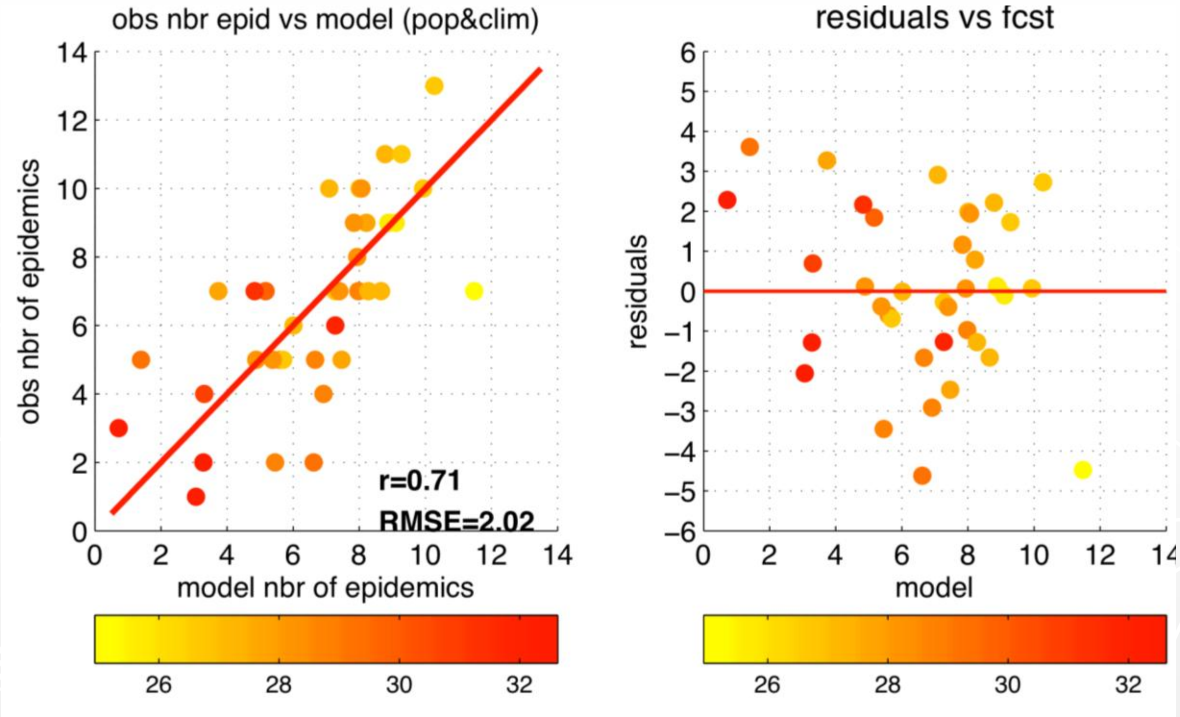
- Dry season means of climate variables (Jan-Apr):
  Clim_dry=[meanU_d, meanV_d, meanT_d, mean SpecHum_d]

- Wet season means of climate variables (Jul_Sept):
  - Clim_wet=[meanU_w, meanV_w, meanT_w, mean SpecHum_w]

- Combinations:
  Pop & Annual, Dry, Wet means

All

Crossvalidated multiple linear regression



Nbr_epid=f(Twet, log10(pop), Vdry, Udry)

- Extend this analysis to Burkina Faso & Mali and the whole belt
- Include mobility indicators (incl. road network)
- Investigate spatial characteristics of the epidemic onset (first district) & relationships with demographic/geographic characteristics (incl. migration patterns and roads)

Meningitis thresholds in Niger

Epid threshold				Alert+ epid	Epid +non epid
10 cases/week@distr	Nbr yr.distr inc>10	**epid**	223	363	835
	Nbr yr.distr 5<inc<10	**alert, no epid**	140		
	Nbr yr.distr inc<10	**all non epid**	612	X	
15 cases/week@distr	Nbr yr.distr inc>15	**epid**	149	363	835
	Nbr yr.distr 5<inc<15	**alert, no epid**	214		
	Nbr yr.distr inc<15	**all non epid**	686	X	

- Approx. 61% (41%) of yr.distr that cross alert threshold, cross the epidemic threshold=10 (15 resp.)
- Approx. 20% (30%) of yr.distr that do not reach the epidemic threshold=10 (resp.15) cross the threshold=5 cases/100,000
- The spatial differentiation is less sharp when the threshold=15 is used, as if the higher threshold was crossed less frequently in the South, with no impact of the threshold in the other regions.

Using multiple source information information for predicting meningitis risk

Environmental factors

▪Dust (concentration, particle size….) from in-situ observation, Satellite (MISR), Models (global and regional) and dust forecasts
▪Weather and Climate Conditions - wind, humidity, temperature, rainfall - in situ (Met Station), Satellite (TRMM), NCEP Reanalysis
▪Seasonal forecasts (ECHAM4.5)

Population factors:

•Population density
•Population stratification: gender, Age, Rural-urban
•Mobility

Epidemiological state of the population at the district level based on:

- Past history of epidemics
- Past history of immunization
- Migration paths
- Seasonality

Generalized Linear Model to predict crossing alert/epidemic threshold

- For each district and at country level
- At different lead-times: seasonal, monthly, 2 weeks and simultaneous

•Probability based on historical model performance
Skill assessment

GIS based maps to display the probability of alert/epidemic threshold
•For each district and at country level
• At different lead-times

Outputs

•Build GIS based predictive tool using models and predictors selected in the project to provide risk maps at district and country level at different lead-times

☛ **Extract relevant climate information** ✓

Related research

•Quantify the relationship dust-meningitis ✓

•Quantify the relationships between atmospheric conditions (wind, temperature, humidity…) and meningitis ✓

•Validate dust products ✓

•Validate seasonal forecast models ✗

•Assess the usefulness of satellite and model data for predictive purposes ✓

•Investigate a range of statistical models, predictors and lead-times and select most appropriate ✓

Outputs

- Annotated Database& Tools, publicly available
  - original model simulations e.g. BSC regional reanalysis
  - U Lancaster
- Contribution to MERIT, link to WHO
  - evolution of project following this interaction
- Publications

Published:

1.Pérez, C., Haustein, K., Janjic, Z., Jorba, O., Huneeus, N., Baldasano, J.M, Black, T., Basart, S., Nickovic, S., Miller, R.L, Perlwitz, J.P, Schulz, M. and Thomson, M., (2011) Atmospheric dust modeling from meso toglobal scales with the online NMMB/BSC-Dust model: 1. Model description, annual simulations andevaluation. Atmos. Chem. Phys. Discuss, doi:10.5194/acpd-11-17551-2011 (accepted)

Submitted

1. Haustein, K., Pérez, C., Baldasano, J.M, Jorba, O., Basart, S., Miller, R.L, Janjic, Z., Black, T., Nickovic, S.,Todd, M., and Washington, R., (2011) Atmospheric dust modeling from meso to global scales with the online NMMB/BSC-Dust model: 2. Regional experiments in North Africa (prepared for Atmos. Chem. Phys.)

In preparation

1. S. Trzaska, S. Adamo, G. Yetman, J. del Corral, M. Thomson, 2011: 'Assessing the importance of environmental factors in Meningococcal Meningitis risk in Niger'.

2. P. Ceccato, C. Perez, S. Trzaska, O. Kalashnikova, R. Miller, J. P. Perlwitz, J. del Corral, 2011: 'Modeled and Observed Atmospheric Mineral Dust Aerosol in Sub-Saharan Africa – a regional validation'.

3. S. Trzaska, M. Thomson, C. Perez, P. Ceccato, J. del Corral, 2011: 'Assessing the importance of environmental factors in Meningococcal Meningitis risk in Niger'.

4. C. Perez, M. Stanton , S. Trzaska , M.Thomson , P. Diggle , R. Miller , J.M. Baldasano , and E. Cuevas 2011: Climate, dust and seasonal meningococal meningitis incidence at national and district levels in Niger.

5. S. Trzaska, 2012: 'Intraseasonal characteristics of the dry season in the Sahel'

6. S. Trzaska, 2012: 'Predictability of the intraseasonal characteristics of the dry season in the Sahel.'

▪Publications (cont.)

Presentations

−S. Adamo, S. Trzaska, G. Yetman, J. del Corral, M. Thomson and C. Perez. 2011 at Population Association of America Annual Meeting, Washington, DC, March 31-April 2, 2011

−S. Trzaska, M. Thomson, S. Adamo, J. del Corral, C. Perez, 'Meningitis in Niger - Some preliminary results' MRC project 'Forecasting and controlling meningitis epidemics in sub-saharan Africa' (PI: P. Diggle) MRC Kick-off meeting, School of Health and Medicine, Lancaster University, Lancaster, UK Nov. 4-5, 2010.

−S. Trzaska, S. Adamo, G. Yetman, J. del Corral, C. Perez, M. Thomson, 'Demographic and Environmental Factors in Meningococcal Meningitis Outbreak Frequency in Niger', poster at the 4th annual MERIT meeting, Addis Ababa, November 19-20, 2010.

−S. Trzaska, T. Seydou, M. Kadi S. Hugonnet, E. Bertherat M. Bell, M.-Ch. Dufresne E. Firth. K. Fernandez C. Perez, M. Thomson, '2010 Meningitis Epidemic Season in West Africa: Experimental Real-time Monitoring of the Environmental conditions', presentation at the 4th annual MERIT meeting, Addis Ababa, November 19-20, 2010.

−C. Perez Garcia-Pando, M. Thomson, S. Trzaska, 'A 30-year high resolution model reanalysis of dust and climate for the Meningitis Belt', presentation at the 4th annual MERIT meeting, Addis Ababa, November 19-20, 2010.

−S. Trzaska: 'End-to-end and interdisciplinary approach to climate research at the International Research Institute for Climate and Society: Investigating the role of climate in epidemic outbreaks of Meningococcal Meningitis in the Sahel.', seminar at the Addis Ababa University, Dept of Physics, November 23, 2010.

−S. Trzaska and co-investigators, 'Environmental factors and population dynamics as determinants of meningococcal meningitis epidemics in the Sahel: an investigation of NASA and NOAA products', Presentation at NASA-Roses Applied Sciences in Public Health Program Review, San Antonio, TX, Sept 27-29, 2010.

−S. Trzaska et al. 2010: 'Following the On-going Meningitis Season and its Associated Regional and Global Climatic Patterns', 'mini_MERIT' meeting, IRI, Palisades, New York, May 25-28, 2010.

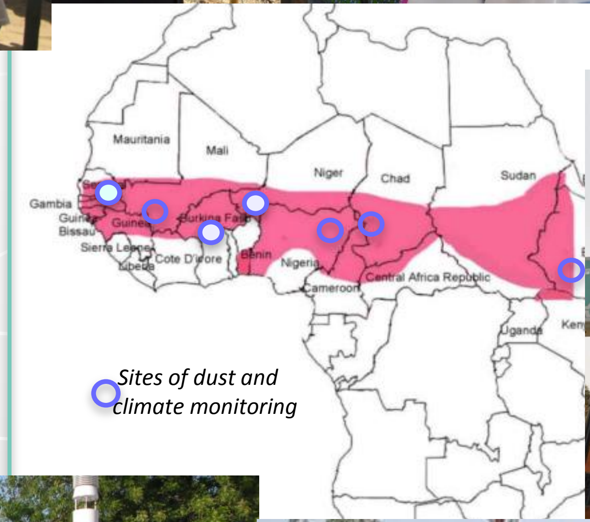
−S. Trzaska et al. 2010: 'The NASA/ROSES Pilot Project: Environmental factors and population dynamics as determinants of meningococcal meningitis epidemics in the Sahel', 'mini_MERIT' meeting, IRI, Palisades, New York May 25-28, 2010.

−S. Trzaska 2010: 'A pilot project to monitor dust in West Africa' presentation ate the 2nd annual MenAfriCar consortium meeting, January 20-22nd 2010, Addis Ababa, Ethiopia;.

−S. Trzaska et al., "Climate Information for Meningitis", 3rd technical MERIT meeting, November 9-11, 2009, Niamey, Niger.

Dust and Climate monitoring

Instruments installed Feb-March 2011


Mauritania
Mali
Niger
Chad
Sudan
Gambia
Guinea Bissau
Burkina Faso
Sierra Leone
Liberia
Cote D'ivore
Benin
Nigeria
Cameroon
Central Africa Republic
Uganda
Sites of dust and climate monitoring