RELATIONSHIPS BETWEEN THE WATER VAPOR ABOVE THE ATLANTIC AND WESTERN AFRICA AND REGIONAL CLIMATE: INTRODUCTION OF FLUVAP PROJECT.

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Abstract:
Various opportunities to track the atmospheric humidity over the tropical Atlantic area have been used:

- the Meteosat Water Vapor channel data providing an indirect indication of the vertical velocity in the area of the St. Helena anticyclone, the relevant radiances have been analyzed and correlated with vertical velocity at 500hPa, and with divergence at 200hPa.
- this information about the relative intensity of the southern branch of the Hadley cell, matches well with the rainfall anomalies observed in the Sahel for the 1983-1994 period: it suggested that an easternmost position of the St. Helena anticyclone, over the cold waters of Benguela current (which enhance subsidence), may induce more intense horizontal fluxes (SE trades, thus SW monsoon fluxes), and therefore a wetter rainy season over the Sahel; opposite situations and results being true.

- the availability of water vapor has been analyzed through TOVS-Pathfinder-A data series (DACC/GSFC — NASA Mission to Planet Earth) over the area 20N-20S, 60W-20E:
  - the integrated water vapor is a seasonal signal, which is explained for 57% of the variance by the water vapor over the oceanic domain and for 30% of the variance by water vapor standing over Western Africa (forest area) and the western adjacent oceanic area;
  - a EOF analysis of the anomalies indicates that the first two eigenvalues are of the same order (17% and 13%); the first principal component, related to the ITCZ above the ocean, underlines the more important weight of the years 1985 to 1988, when compared to the rest of the period; the second principal component remains roughly with the same weight throughout the period 1985-1992;

Based mainly on satellite data, the aim of the FLUVAP project is to improve the knowledge of humidity in the Atlantic and African tropical area, and to couple these observations to conventional one’s to provide regional coverage of the water vapor flux, feeding the west African monsoon.

1. INTRODUCTION

Atmospheric water vapor, a key parameter for climate’s studies, remains one of the less well known in the intertropical area. The multiple causes of this situation (economy of developing countries, weakness of the synoptic network, coverage of oceanic areas ...) lead to an extended use of satellite observations as an alternative to conventional one’s.

The rainfall chronicle of the 1983-1993 decade over the Sahel has been reviewed versus:
- the Meteosat Water Vapor channel (Meteosat-WV) data, for what concerns a relative indication about the strength of the subsidence in the St. Helena area;
2. METEOSAT-WV DATA

2.1 Data processing and analysis

Meteosat-WV radiances are assumed to be representative of the 500-600hpa level. On cloud-free images, these radiances are related to the water vapor content at this level (Poc, 1981); moreover, Ramond et al. (1981) analyzed these images for subsidence motion.

The broader meridional spreading of the ITCZ noticed during a wetter rainy season in the sahelian area by Picon and Desbois (1986), led us to attempt a monitoring of the intensity of the Hadley cell, independently of model outputs.

Three areas have been selected for Meteosat-WV analysis (fig.1):

![Figure 1: Location of the selected areas over the "Meteosat disc"](image)

The first one (ITCZ area) has been chosen within the convective zone, where Meteosat-WV radiances correspond to a practically saturated signal, in a location where cold clouds are always present; this area will be considered as a cold reference.

Over the South Atlantic area, in the subsidence area of the southern subtropical height, two cells have been selected, east and west of the Greenwich meridian, to analyze the relative variation of WV radiances with longitude.

Meteosat-WV data series, have been calibrated in brightness temperatures (Tb) using the calibration process recommended by ESOC and averaged for each quarter of month, from July to September (1983-1993); results are displayed in figure 2: In spite of the known and experienced
difficulty for a precise Meteosat-WV radiances calibration, (Meteosat-2, -3 and -4 were in operation during the 1983-93 period), the radiances retrieved for the ITCZ area, remain reasonably stable:

![Figure 2: Mean values of Meteosat-WV counts (by quarter of month) in the ITCZ area (thick upper line) in the subsidence area (2+3) and in area 3 (thinner line).](image)

The mean values retrieved in the ITCZ area (our cold reference) stand around 130 from July 1983 to mid 1987 and around 120 for the remaining period until the end of September 1993. If we except a short period during 1987, there is no obvious variation which might suggest an instrumental error throughout the period.

Over the St-Helena anticyclone, the radiances retrieved in area (2+3) and in area 3, indicate that the lower values are always found in the easternmost area (zone 3); in other words, the maximum of the subsidence is found in the eastern side of this region of the South Atlantic ocean, that is to say over the cold waters of the Benguela current. Thompson et al. (1993) conclude similarly when analyzing the distribution of marine stratus with ISCCP data over the 1983-1990 period.

Analyzing now both time series over the South Atlantic subtropical height, the most striking feature throughout the period remains the considerable decrease in radiative counts during the 1988 northern summer; another one can also be depicted in 1985.

If the ITCZ area (1) radiances are taken as a reference, the difference: \{Meteosat-WV-area (1) – Meteosat-WV-area (2+3)\}, may be considered as a qualitative index of the strength of the subsidence in the Southern Atlantic.

Keeping in mind the fact the fact that the Hadley cell intensity determines the wind gradient at the sea level, and therefore the SE trades and the SW monsoon winds, it is satisfactory to observe that the highest values of our « subsidence index » are found in 1985 and 1988, which coincided with a wetter rainy season in the Sahel; at the opposite, the lowest ones were found in 1983, 1984, 1992 and 1993, which were also among the driest rainy seasons in the Sahel (Citeau, 1992; Citeau et al., 1994).
2.2 Comparison with ECMWF analysis:

A comparison between Meteosat-WV data and ECMWF analysis has also been performed in the area of the Southern subtropical height: maps of ECMWF relative humidity at 500hPa are consistent with those of Meteosat-WV data. Moreover, these data are significantly correlated with the wind divergence at 200hPa (fig. 3).

A main characteristic of the south Atlantic ocean is the SST (sea surface temperature) gradient between the Benguela cold waters (20° C) on the eastern side and the warm Brazilian ones (25°C) on the western edge. One can conclude (if all other parameters remain constant), that an easterly (westerly) shift of the southern anticyclone over colder (warmer) waters, may induce greater (lower) subsidence, a more (less) intense pressure gradient at sea level, and to stronger (lower) SE trades, which will turn into SW monsoon flux after crossing the equator.

In conclusion, Meteosat-WV channel data provide a useful and simple way to watch qualitatively, the position and relative strength of the Southern subtropical Height (St. Helena Anticyclone).

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Figure 3: a) seasonal covariations of the wind divergence at 200hPa (thin line) and Meteosat-WV counts (thick line), over the St-Helena area (3) for the July to September period of 1983-1989; b) linear regression between these parameters.
3. TOVS-PATHFINDER-A DATA PROCESSING AND ANALYSIS

The availability of the water vapor which feeds the western african monsoon is another question: Possible sources of humidity are the Gulf of Guinea, the wide equatorial forest of Africa and the Indian Ocean by upper air jets: their relative weights are not well known:

- De Félice and al (1982), and Cadet and Nnoli (1987) showed the importance of flows in the middle (850-600hPa) and higher (600-300hPa) layers of the atmosphere, which support the main humidity fluxes transport over Western Africa,

- Krishnamurti and Kanamitsu, (1978), consider the Hadley cell intensity to be the key of rainfall variability along the intertropical zone,

- according to Dhomoneur (1974) the limiting factor of a good rainy season over Sahel is more the water vapor transportation than its availability,

- Stephens (1990) established the existence of seasonal relationships between the integrated water vapor content of the atmosphere and SST.

TOVS Pathfinder A data (DACC/GSFC/NASA' Mission to Planet Earth) providing information in different layers of the atmosphere, the time series of TOVS integrated water vapor, over the area 20N-20S, 60W-20E, have been analyzed regarding the major climatic episodes of the period 1985-1992 in West Africa; the results indicate that:

- in the sahelian and Gulf of Guinea areas, the integrated water vapor (PRWAT) in all layers varies in accordance with the regional variability of rainfall (the variability of the two lower layers being the most important);
- the series corresponding to the driest (or wettest) episodes wrap all the other observations.
- an EOF analysis of these data and their anomalies leads to the following preliminary conclusions:
- the integrated water vapor is a seasonal signal, which is explained for 57% of the variance by the water vapor over the oceanic domain and for 30% of the variance by water vapor standing over Western Africa (forest area) and western adjacent oceanic area;
- a closer look has been given to three typical years (1987, 1988 and 1992):
  -1987: abnormally wet in the vicinity of the Gulf of Guinea and abnormally dry in the Sahel;
  -1988: standing for a very abnormally wet season, on the whole Western Africa;
  -1992: standing for a very abnormally dry season, on the whole Western Africa.
Results:
a) over the Gulf of Guinea area, the integrated water vapour content are similar for 1987 and 1988; moreover, the overlap of the relevant time series (July to September), may be related to the very strong positive anomalies of rainfall observed in 1987, in the countries bordering the Gulf of Guinea;
b) over the Sahelian area, the integrated water vapor, always lesser in 1987 than in 1988, may be associated to the simultaneously clear decrease in the intensity of the circulation of Hadley (NCEP vertical wind at 500 hPa): both are in agreement with the drastic rainfall contrast between these two years;
c) but, in 1988 (wet) and 1992 (dry), NCEP vertical wind velocities which were in the same order, fail to provide similar explanation; it is more the availability (or anomalies) in water vapour which may be considered as preliminary contribution to the large rainfall deficit observed in 1992 over the sahelian area.

- an EOF analysis of the PRWAT anomalies (fig.4) indicates that the first two eigenvalues are of the same order (17% and 13%); the first principal component, related to the ITCZ above the ocean, underlines the more important weight of the years 1985 to 1988, when compared to the rest of the period;
- the second principal component remains roughly with the same weight throughout the period 1985-1992;

As a preliminary result, availability of water vapor and transportation are among the main factors to be taken into account. The variable weight of the oceanic contribution in water vapor is clear, and the decrease in the weight of the leading factor during the 1989-1992 period may be related to the very poor rainy season observed over the sahelian area during this time.

Coupling these satellite data (and more recent ones) to wind (model analysis) will be the objective of the FLUVAP project for an analysis of the water vapor fluxes feeding the african monsoon.

Moreover, its associated “Satellite & Tropical Atmospheric Profiles” network, will provide facilities to validate humidity profiles over the tropical Atlantic, using:
- Noaa data (received at Fortaleza, Dakar and Niamey),
- an inversion software from Météo-France,
- the PIRATA buoys and PIRATA oceanographic cruises will be used for validation.
Figure 4: First, Second and Third Eigenfactor for anomalies of integrated water vapor content for the 1985-1992 period; DAAC/NASA/GSFC-TOVS data; processed by Statistica and Triskel.
Figure 5: Weight of the leading and the second eigen factor for anomalies of integrated humidity (PRWAT-DAAC/GSFC-TOVS 1985-1992 data)

Conclusion

On one hand, Meteosat-WV data may deliver a relative information on the location and strength of the southern subtropical height over the Atlantic ocean. On the other hand, the availability and the variability of the water vapor which feeds the western african monsoon, may be precised using TOVS-Pathfinder-A data set. This preliminary (and on going) work highlights in particular the variable weight of the oceanic contribution in the water vapor during the 1985-1992 period and provides some degrees of explanation of the Western Africa monsoon flux and the rainfall anomalies observed in the sahelian area: that will be the objective of the FLUVAP project and its associated "Satellite & Tropical Atmospheric Profiles" Network.
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