Wind engineering in Africa

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Abstract

The International Association for Wind Engineering (IAWE) has very few contacts in Africa, the second-largest continent. This paper reviews important wind-related African issues. They all require data on wind climate, which are very sparse in Africa. Wind engineering in Africa can assist in collecting data on wind climate, developing wind energy, reducing the adverse effects of wind and related drifting sand in building activities and agriculture, and limiting other wind-related disasters, in environment and ecology, such as those caused by erosion and fire. The paper aims to encourage Africa-oriented supportive research, especially better data coverage; quality control of existing data; search of historical archives; generation of data by numerical weather analyses; and validation of extrapolation techniques. We envisage promising cooperation with Africa, despite the fact that African countries do not currently participate in the international exchange and co-operation in these fields. African priorities presently seem to be different, while funds and other facilities are lacking. Capacity-building in wind engineering and support issues should be initiated by agencies such as UNEP, FAO, EU, WMO, NGOs, etc. The necessity of professional wind engineering input in these activities should also be recognized. Interaction of IAWE with these agencies is necessary.

Keywords: African environment; African wind climate; Agricultural meteorology; Building damage; Development collaboration; Forest fires; Science policies; Wind energy; Wind engineering

1. Introduction

The International Association for Wind Engineering (IAWE) has three regions: Asia-Pacific, Europe-Africa and the Americas (Solari, 2005). Europe and Africa were lumped together for pragmatic reasons, without exchange of views or knowledge between the two continents. Almost no African scientists participate in the activities of the region Europe-Africa, with the exception of colleagues from the Republic of South Africa and some Afro-Mediterranean countries.

1.1 African participation in the International Association for Wind Engineering

It is surprising that there is such limited contact on wind engineering with the second-largest continent in the world, which constitutes 20% of the earth's surface. This

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is in stark contrast to some related fields of applied science, because of external support from the Western world (e.g. Olufayo et al., 1998; Stigter et al., 2005b).

The lack of African participation in the activities of the region was discussed during the second European & African Conference on Wind Engineering, EACWE2, in 1997 in Genova, Italy. EACWE 3, which took place in 2001 in Eindhoven, the Netherlands, had a first plenary session on wind engineering in Africa. Goliger (2001) discussed the relevance of wind engineering under African conditions and Stigter et al. (2001) presented some African case studies of problems caused by wind in smallholder agroforestry. The meeting of national representatives established a working group, the "Europe Africa Initiative" (EAI), for further action. The internet facilitated some contact with African researchers who responded to the website of EAI. Despite special funding, difficulties in obtaining visas prevented interested Africans from participating in 3 EACWE.

1.2 African wind engineering issues

This list of issues below is based on two sources of information: firstly, on e-mail exchanges with a number of Africans, who responded to an internet-posted questionnaire, and secondly, on policy reports by African governments, prepared in cooperation with international agencies in order to apply for development aid.

Despite this highly appreciated input, the picture is far from complete. Moreover, European initiatives are still dominant. The EAI-working group tried to organize a get-together with interested African scientists, but failed to raise the necessary funding.

The following six topics appeared to be relevant issues in African wind engineering:

- Data on wind climate
- Wind energy
- Storm damage to buildings
- Wind and agriculture
- Wind and environment
- Wind and fire propagation

These issues will be reviewed in the sections below.

1.3 The scope of wind engineering

IAWE has not formally defined the scope of wind engineering. Cermak (1975) comprehensively stated that "Wind engineering is best defined as the rational treatment of the interactions between wind in the atmospheric boundary layer and man and his works on the surface of the earth". The mission statement of the American Association for Wind Engineering notes that "the multi-disciplinary field of wind engineering considers problems related to wind and associated water penetration on buildings and structures, societal impact of winds, hurricane and tornado risk assessment, cost-benefit analysis, codes and standards, dispersion of urban and industrial pollution, support for wind energy activities and urban aerodynamics".

The UK Wind Engineering Society defines wind engineering as "a wide ranging multi-disciplinary subject that has developed over the last few decades, and is concerned with the effects of wind on the natural and built environment. These effects can be both catastrophic, leading to the failure of major buildings or other structures, or can lead to discomfort and disruption”.

The German “Windtechnologische Gesellschaft“ mentions the following wind engineering topics on its website: wind effects on structures, environmental problems caused by wind, wind noise at buildings and structures, ventilation caused by wind.

The Italian Association ANIV mentions wind climatology, modeling of the wind structure, aerodynamics, wind effects on structures, natural ventilation, and environmental effects of wind, atmospheric diffusion and wind energy.

The Netherlands “Stuurgroep Windtechnologie” mentions a similar list of issues. The above demonstrates that the African issues identified in section 1.2 do fall within the generally accepted scope of wind engineering. Since all topics in wind engineering are multi-disciplinary, cooperation with other disciplines and organizations is essential.

2. Data on wind climate

Wind engineering needs statistics of wind speed as function of wind direction. There are five sources of wind data:

- operational data administered by WMO;
- published data;
- historical data;
- numerical data analysis and forecasting;
- extrapolation of local measurements and of numerical data.

2.1 Operational data administered by the World Meteorological Organization (WMO)

Generally, wind engineers use wind data acquired routinely by operational meteorology. Routine measurements of national meteorological and hydrological services are collected, distributed and archived in the Global Observing System (GOS), as well as in the Global Climate Observing Systems (GCOS). GOS is designed for weather forecasting, and timely exchange of data is essential. GCOS serves climatological purposes. Exchange in a 10-day or monthly rhythm is sufficient. WMO (2006) administers both networks.

The system transmits all GOS data to weather forecasting centers. Fig. 1 shows places and ships from which data were received in time for the weather forecasting cycle on an arbitrary but representative date of 17 February 2005 by ECMWF, the European Centre for Medium-Range Weather Forecasts.

The Integrated Surface Hourly Database at NCDC, Asheville, North Carolina has one of the most expansive synoptic data collections. The centre archives data of the worldwide network of GOS and contains data from about 20.000 synoptic locations worldwide. Most of the data have been archived since the early 1970s. There are separate databases for observations over the oceans (WMO, 2006).

The coverage of the GCOS network is more uniform, as shown by the dots in Fig. 2. Fig.2 also shows that in the year 2002, data from the majority of African stations had not yet been received by the international centre in Japan at 20 days after reports were due. Data available for the African continent are sparse; the WMO strongly supports more observations from the African continent, but socio-economic obstacles have to be overcome.

2.2 Published data

Descriptions of African climates as well as climate data, including wind, may among others be found in Flohn (1969), Griffiths (1972), Ojo (1977), Tyson and Preston-Whyte's (2002) descriptions of African climates and climate data, including wind. Many data are visual observations. Too low surface wind speeds reported throughout Africa are due to lack of equipment maintenance and unreported increased roughness and obstacles near weather stations (e.g. Mohammed et al., 1999). Moreover, measuring height is often not stated.

Examples of available data are listed below. These are by-products of projects in the fields of wind energy, energy consumption of buildings, agrometeorology and some others.

- The Wind Energy Department at Risø National Laboratory publishes a world map of average mean wind speed (WAsP, 2006). For the African continent, a wind atlas is available for Egypt, South Africa and Algeria. Sections 2.4 and 2.5 give some details.
- Since about 1980, several models have been developed and commercialized to calculate the energy consumption of buildings. Climatological data for these models are presented in Meteotest (2005). A CD-Rom with monthly climatological means of various parameters, including wind speed and direction, from 413 stations in Africa, 1793 stations in the USA and 1169 stations in Europe, as well as a "world wind atlas" for wind at 50m height and Weibull parameters, are for sale (Meteotest, 2005).
- The FAO (1984) collected agroclimatological data for Africa from a variety of sources, including monthly average wind speed at a height of 2m, for agricultural purposes.
- Rosen et al. (2004) discuss the wind climate of Eritrea. The authors conclude that in Eritrea the most promising wind energy sites exist by virtue of channeling and local enhancement of flows in a wintertime inversion layer.
- Young and Holland (1996) offer wind data useful for wind engineering at the African coast.
- The CSIR (2005) developed a wind resource atlas for South Africa, which presents minimum, maximum, and mean annual wind speeds in ms^{-1} at a 10m height above ground level.
- Climatological normals for Egypt present wind data for 55 stations up to 1945. A considerable number of stations have more than 30 years of observations. The data are given as Beaufort class for visual observations and in km per hour for anemometer observations, Ministry of War and Marine, Egypt (1950).
- Escudero and Morales (2001) present climatology of wind at Casablanca.
- Abu Bakr (1988) presents shelter-corrected data for two stations, Khartoum and Wad Madani, Central Sudan, for the years 1983 and 1984.
- Mohammed et al. (1999) give monthly average wind data and diurnal average wind data at 2 m height for the period 1987 – 1989 for two areas with different roughness in the Gezira scheme (Sudan), west of the line Khartoum/Wad Medani.

Assessing wind energy potential, wind speed distributions for each wind direction sector are calculated. In publications on wind energy only combined all-sector distribution counts. For example, Abramowski and Posorski (2000) report on wind measurement campaigns in Morocco, Namibia and Jordan. Weibull distributions are given, but not as a function of wind direction. Abdel Wahab and Sayed (2001) discuss mean wind speed and power density at a 10, 20, 30 and 40m height at 23 stations in

Egypt, Libya and Sudan. These authors also present Weibull distributions irrespective of wind direction.

2.3 Historical data

Goliger (2001) suggested a search of the archives of the weather monitoring organisations of the former colonial countries for valuable data. Since then, Griffiths and Peterson (2004) have drawn up an inventory of climatological data in connection with the NOAA Climate and Global Change Climate Data and Detection Program and the WMO World Climate Program. In addition, Moisselin (2001) reports on an archive that contains surface and upper-air climatological data of 14 African countries. It is a challenge for wind engineering to follow up the work done by these scientists and study these historical archives.

2.4. Wind data from numerical weather prediction systems

Figs. 1 and 2 show that African data do not flow abundantly to data collection-centers. The quality control is questionable, and it appears that data for wind climate have to be gathered through individual projects. An option to integrate all meteorological observations into a system to calculate wind fields is discussed below.

A numerical forecasting system analyses the state of the atmosphere observed by satellites, airplanes, buoys, ships, as well as conventional observations on land as collected in GOS. After this analysis a prognosis is calculated. In the last decades, High Resolution Limited Area Models (HIRLAM) have become operational. In Europe, a team of several European countries (Denmark, Finland, France, Iceland, Ireland, the Netherlands, Norway, Spain, and Sweden) developed such a HIRLAM. Undén et al. (2002) provide extensive documentation. The model is a hydrostatic grid-point model, while the resolution presently in use is up to 5km horizontally, and 16 to 31 levels in the vertical. A two-layer scheme handles surface processes with snow, ice and soil moisture included. The analysis of surface pressure, atmospheric temperature, wind and humidity is based on an optimum interpolation scheme, derived from the one developed at ECMWF in the eighties. Most institutes use a six-hour data assimilation cycle, but some use a three-hour cycle.

In fact, the European HIRLAM is used for operational wind forecast in Europe. Verkaik (2006) discusses the quality of these forecasts and the input of surface roughness for the Netherlands.

It is tempting to use such models to generate wind statistics for data-sparse regions south of the Sahara. If this were to be done, series of input data and information on the state of the surface would be needed.

The ECMWF reanalysis project ERA-40 offers worldwide data and maps of the state of the atmosphere including 10m isotachs (Kållberg et al., 2005). This data set has been available since February 2006. In addition, NCEP/NCAR has a reanalysis programme in which a state-of-the-art analysis/forecast system assimilates data from 1948 to the present (Kalnay et al., 1996). A suitable HIRLAM can generate wind data; one may wonder whether such data could be useful in wind engineering.

We recognize three weak points: firstly, the data coverage over Africa might not be good enough, even for the mix of meteorological data including satellite. Secondly, description of wind flow by mid-latitude models might be less reliable in the tropics because of decreased Coriolis effects and increased solar radiation input. Wind caused by meso-scale phenomena like land-sea breeze, valley winds, squall lines and thermal convection with associated wind systems could be very important and the models used could be insufficiently detailed to simulate these winds. An experiment in regional climate modeling for Central Africa showed that the models produced frontal rainfall. Of the observed rainfall, a large proportion fell from isolated, intense meso-scale convective complexes, likely requiring an even higher resolution of the models (Undén et al. 2002).

As a third weak point of the option, wind engineering needs data on extreme winds. In mid-latitudes, extremes are generally associated with cyclones, which have dimensions of hundreds of kilometers. Larsén et al. (2002) applied a statistical model to surface pressures included in the NCEP/NCAR reanalysis data over Denmark to estimate extreme wind speeds. For mid-latitudes, the method was promising. In the tropics, these extremes are likely to be associated with a complex of convective cells, with dimensions of tens of kilometers at the most. Could a HIRLAM analyze such small phenomena satisfactorily?

In the meantime, the internet carries daily wind maps for Africa. The African Desk of the USA National Weather Service uses a model with a grid of 0.375 degrees or 41,7km at the equator. Weather Underground Inc. (2005) transforms these data into wind maps for the African continent on the internet. CSAG, the climatology research group of the University of Cape Town, presents very detailed daily wind forecasts on their website. The present authors are not aware of any validation results for all these products.

Summarizing, we may conclude that many wind data generated by numerical forecasting are ready for evaluation by wind engineers. There is a research opportunity for the wind engineering community to work with meteorologists and wind energy scientists for exploration of these techniques. From a wind engineering point of view, it seems timely to start a project to study the three weak points identified above.

2.5 Extrapolation of measurements

Whether wind data are measured or calculated in grid points of a HIRLAM, the data must be extrapolated over a landscape. There are several commercial software packages for extrapolation based on linear theory (Jackson and Hunt, 1975). These packages yield estimates of wind energy potential directly, if combined with geographic information systems (GISs) on terrain features. However, these packages are for flat to medium complex terrain and mid-latitude flow. At the turn of the century, these software packages were up-to-date technology. Now, computational fluid dynamics (CFD) is available for extrapolation. For example, assessing wind energy in a region with steep slopes in Japan, Murakami et al. (2003 a, b) developed a Local Area Wind Energy Prediction System (LAWEPS). LAWEPS uses five domains, from a horizontal area of 500x500 km to a horizontal area of 1x1 km and a horizontal resolution of 10m. In fact, LAWEPS is a further refinement of the meteorological models mentioned in section 2.4. Again, there is no evaluation of this model in tropical regions.

The best-known software package for extrapolation based on linear theory is the Wind Atlas Application and Analysis Program, WAsP. Risø National Laboratory developed this software (Troen and Petersen 1989, Abild et al. 1992, Giebel 2000, WAsP 2006). Some hundred nations in the world used the WAsP-methodology. Three sub-models deal respectively with hills and other orographic features, with roughness changes for hub height and with shelter effects behind obstacles. The package presents wind data as Weibull distributions.

The applicabilty of WAsP in the tropics is questionable. Firstly, the more wind is caused by large-scale phenomena, the more the data will adhere to Weibull statistics. However, wind statistics deviate from a Weibull distribution if local winds are thermally driven. Orographic effects also cause such a deviation. Secondly, WAsP uses a geostrophic drag law with average stability constants. This law is not very reliable in the tropics because the Coriolis force vanishes near the equator. This increases cross-isobaric flow and augments the relative importance of convection and of large-scale flow convergence. Therefore, near the equator mid-latitude wind profile models for the planetary boundary layer are less applicable. It is difficult to specify to which extent WAsP or other extrapolation methods are reliable in the tropics or in hilly areas. The CSIR (2005) reports on application in the mountainous Eastern Cape of South Africa. The South African wind atlas is based on a combination of WAsP extrapolation and numerical modeling. In Eritrea channeling and local enhancement of flows in a wintertime inversion layer are important for wind energy. WAsP is irrelevant in such a flow (Rosen et al. (2004); Van Buskirk, private communication, (2005)). We may conclude that a validation of extrapolation techniques in the tropics is necessary.

3. Wind energy.

We summarize information on wind energy potential in regions of the African continent. Fig. 3 by Czisch (1999) suggests that in large parts of the African continent 1,5MW turbines at a height of 80m will only yield 1,5MW during 1000 hours per year, which is only 11 % of the time. On the other hand, Czisch concluded that a 1,5MW turbine has good possibilities in North Sudan, Southern Egypt, South Algeria, and the Atlantic Coasts of Morocco, Namibia, and the Republic of South Africa and at the coast of the Gulf of Suez. Czisch estimated wind energy potential on the basis of ECMWF data for the period 1979-1993. He calculated wind data for 33 and 144m height in a grid of about 125 x 113km and time steps of 6 hours. Because of this coarse grid, the data presented in Fig. 3 do not contain information on local winds, since mesoscale systems are poorly simulated. There could be more wind power than suggested. After all, at the coast of Nigeria, small sailing boats use sea wind to sail the first few kilometers land inwards.

UNEP conducts a project titled Solar and Wind Energy Resource Assessment (SWERA). Fig. 5 presents the wind energy potential in Ghana at a height of 50m, as calculated by SWERA (UNEP, 2004). It is clear that wind power is significant at the coast as well as in the mountains, with a height up to 900m at the Eastern border with Togo. This is in contrast to the results of Figs. 3 and 4 but recognizable in Fig.6 as to the coast. Fig. 5 uses a 1km grid wind map prepared by NREL. No information on the applied methodology or on validation is offered.

Fig. 4 presents mean wind speed at 50m height (African Development Bank, 2004). The forecasting models with a grid of 50km are from Canada and the USA. The consultant Helimax Ltd used its own techniques to adjust wind velocities to local terrain. The study selects 15 countries with high wind energy potential: South Africa, Lesotho, Madagascar and Mauritius in Southern Africa; Djibouti, Eritrea, Seychelles and Somalia in East Africa; Algeria, Egypt, Morocco and Tunisia in North Africa; Cape Verde and Mauritania in West Africa; and Chad in Central Africa. The project recommends a mix of large-scale and small-scale wind power projects for these 15 countries to address rural and urban needs. Fig. 4 gives a wind speed of less than 4m/s at 50m height at the coast of the Gulf of Guinea. This is substantially less than 620W/m^2 (Table 1). Apparently, a 50km resolution is too coarse to include wind caused by mesoscale circulations.

Fig. 6 presents a section of a world map of average mean wind speed at a height of 10m for the period 1976-1995 as prepared by the Wind Energy Department at Risø National Laboratory, Denmark (WAsP 2004). They used NCEP/NCAR reanalysis data for the years 1976-1995. This map gives substantially lower wind speeds. Comparison with Table 1 shows that, on the basis of Fig. 6, wind energy would not be possible.

Wind energy maps are prepared for Algeria, Egypt and South Africa. The map for Egypt covers more than one million square kilometers – much of which consists of mountains and remote desert tracts. The project used observations from more than 30 stations all over Egypt and WAsP, as well as long-term reanalysis data and a mesoscale model (WAsP, 2004, also for further information on the maps for these three regions).

This review indicates that it is a scientific and technical challenge to assess wind energy potential in Africa. We need better data and models. The African Development Bank (2004) states that "The target of energizing the African continent must include renewable energy technologies at both large-scale and small-scale levels. While large-scale wind energy projects do support current electricity grids, it must be noted that small-scale decentralized wind energy projects can have a higher impact on the lives of the majority of poor people in Africa who have no access to the grid, and at business-as-usual will not be reached by the grid in the foreseeable future". Indeed, the average number of people per square mile varies from more than 71 in a small part of the continent to less than 20 over the majority of Africa. Almost 75% of the population still relies on wood fuel as its main source of energy. Elmissiry and Punungwe (1998) state that in Zimbabwe only 28% of rural households have electricity. Wind energy may be affordable; solar systems are too expensive according to these authors.

The Newsletter of Small Scale Wind Energy Systems (SSWES, 2002) states: "we perceive a huge gap between the complex and expensive equipment offered by industrialized-world manufacturers, and local efforts focusing on effective, low-cost solutions. Designers and manufacturers in the South continue to be hampered by scarce resources and limited production skills".

It appears important to develop small wind turbines for local electricity generation or for water pumping (e.g. Wright and Wood, 2004; US Dept. of Energy, 2002; Di Maria et al., 1997; African Wind Power, 2004). The typical 19th century windmill power was 10kW. At the end of World War I, it had been increased to 25kW. At the end of the 1960s, 200kW was possible. Nowadays, micro turbines as small as 20- 500Watt and large turbines of 3,6MW are technically possible. Presently, 5MW turbines are being developed. Lodge (2002) as well as van Kuik and Bierbooms (2005) present information on the development of turbines.

The authors conclude that projects to generate wind data as mentioned in section 2 are necessary to assess African wind power. In cooperation with meteorologists, the discipline of wind engineering could contribute to the publication of wind data and scientific validation of techniques in the tropics. For Africa, development of small turbines is useful.

4. Wind-related building disasters

There is little information on wind damage to buildings and structures on the African continent. Only damage in the Republic of South Africa has been documented (Goliger, 2002). Data from insurance companies are lacking, because informal housing is not insured. Many rural houses are isolated. Moreover, a widespread traditional African pattern of settlement has been that of scattered villages and hamlets, large enough for defense and domestic cooperation, but rarely permanent because of the requirements of shifting cultivation and the use of short-lived building materials. Most African housing consists of mud and wattle with roofs of thatch or palm leaves. Niemann et al. (personal communication, 2002) studied the geometry of African settlements and wind damage.

Goliger (2001, 2002) describes the impact of sand erosion on building and structures. The internet carries some information on storm damage in Africa. There are many items on casualties because of heavy rain and flooding, but most entries on wind damage refer to South Africa, Mozambique, Madagascar and Mauritius. Seemingly, there is no mechanical wind damage to informal buildings in the greater part of Africa. However, most of the continent - which extends from latitude 35° S to about latitude 37° N - lies within the tropical zone. Table 2 summarizes information on extreme winds. Indeed, one might expect damage to buildings and to crops by severe weather associated with convective systems (e.g. the example reported from Tanzania in Stigter et al., 2002).

Cyclones with associated tornadoes are a feature of mid-latitude circulation, which dominates wind engineering in general and affects the northern region of the African continent, especially north of the Atlas Mountains and the southeast sector of Africa. Goliger (2002) reports extensive wind damage to buildings in cyclonic conditions. In West Africa, the interaction between the harmattan and the monsoon sometimes produces West African tornadoes.

Tropical cyclones enter Mauritius, Madagascar and the east coast of Mozambique. In 1995, a cyclone killed at least 30 persons and injured hundreds in northern Somalia. Table 3 gives the number of tropical cyclones in years in which they were most numerous, in three classes of wind speed, over the SW Indian Ocean (Landsea, 2004; Australian Bureau of Meteorology, 2006). It should be noted that in connection with the anticipated global temperature rise, an increase in the number of cyclones and their intensity is expected. (Zhao et al., 2005). It is a challenge for wind engineering to follow up the work done by these scientists and study these historical archives.

In 1995 a cyclone lashed the northern province of Nampula in Mozambique. In Madagascar the 1995 cyclone Geralda was billed as the “cyclone of the century”. She lashed the island with torrential rains and winds of up to 97m/s. Several significant wind disasters have occurred in Mauritius.

Various projects emphasize improved construction methods and available materials for simple, economic building strategies for housing (Mathur, 1993; Eaton, 1981, 1995; Hutz, 2003). The traditional lightweight components may be replaced with better and new materials. A recent project in Nigeria (Beushausen, 2002) investigated the utilization of bamboo as reinforcement of concrete. Moreau and Gandemer (1988) composed a brochure with basics for informal building of dwellings in the tropics.

In conclusion, wind damage on the African continent generally passes unnoticed by the press. Perhaps, it is accepted as an unavoidable fact of life. Application of wind engineering to reduce damage to informal housing will be a practical challenge for Africans, who are acquainted with local building, and who can be supported by the international wind engineering community. A socio-cultural awareness programme may be a first step.

5. **Wind and agriculture**

Agriculture is by far the most important economic activity in Africa. It provides employment for about two-thirds of the continent's working population and it contributes an average of 30 to 60 percent of gross domestic product and about 30 percent of the value of exports of a country. Agriculture used to be largely subsistence farming and considerably dependent on the system of shifting cultivation, in which land is temporarily cultivated with simple implements until its fertility decreases and then abandoned for a time to allow the soil to regenerate. But population pressure now forces farmers to grow crop after crop, "mining" or depleting the soil of nutrients, and with little access to fertilizers, the farmers are forced to bring less fertile soils on marginal land into production, at the expense of Africa's wildlife and forests (e.g. Henao and Baanante, 2006). Over most of Africa, complex systems of communal and family ownership and insecurely or badly registered tenure allocate land. Peasant farmers often only have rights to use relatively small and scattered holdings. Innovation and investment are very difficult in this context, while policies, science and services are lacking or wrongly focused (Stigter, 2006). A contribution by wind engineering technologies initially asks more for governmental policies and institutions than science (e.g. Matlon, 2003).

However, wind has a severe impact on African agricultural crops and yields. Strong winds cause mechanical damage to trees and crops, while hot and dry winds desiccate crops. Drifting sand from wind erosion burrows or scours crops. Deposition can also block irrigation canals. For example, in Sudan, the irrigated narrow fertile strips along the river Nile north of Khartoum and along the White Nile north of Ed-Deium, as well as parts of the huge Gezira irrigation scheme, are being encroached by drifting sands and sand dunes from both banks and in neighboring unvegetated areas, necessitating the urgent design of defense measures (Mohammed et al., 1996; Al-Amin et al., 2005; Stigter et al. 2001; 2002; 2005a).

Wind engineering might indeed mitigate these adverse effects of wind by sheltering crops with shelterbelts or scattered trees in such a way that mechanical damage is prevented (e.g. Oteng'i et al., 2000), deposition of sand at the wrong place is avoided (e.g. Al-Amin et al., 2006) and damage from hot air is reduced (Onyewotu et al., 2004). However, the local context is very important. It could be that shelter by scattered trees is more effective. A shelterbelt changes layouts of agricultural land and tracks for people and animals. Moreover, the shelter may be used as a supply for fuel. For example Onyewotu (1983), Brenner et al. (1995), Mohammed et al. (1996), Stigter et al. (2001, 2002, 2005a), Onyewotu et al. (2003) address these complicated design issues and some of their consequences.

The aerodynamics of the effects of shelterbelts is a long-standing issue in wind engineering and agrometeorology, as reviewed by Van Eimern (1964), Nägeli (1965), Gandemer (1981), Brandle et al. (1988); Stigter et al. (1989) and Wieringa and Lomas (2001). More knowledge on these matters became available from combined wind tunnel and field experiments (e.g. Jacobs, 1983; Papesch, 1992; Judd et al., 1996; Wang and Takle, 1997; Stigter et al., 2005b; Raupach et al., 2006). However, there is a lack of knowledge on the aerodynamical properties of local biological shelter. A new CFD approach is available to model sand transport and sedimentation over a shelterbelt and over a make-up of shelterbelts (Wang and Takle, 1997).

Aerodynamic effects of biological shelterbelts and scattered trees might be a subject for design-supportive research in a laboratory of the industrialized world, preferably by an African guest. Cooperation with African specialists and a policy for capacity building and transfer of know-how are essential for success in this regard. Stigter et al. (2005a) discuss a participatory research agenda with pilot projects on wind engineering and agricultural meteorology. They give guidelines on the development of optimum tree and biomass distributions for various protection purposes, soils, climate conditions and rural environments.

6. Wind and environment

The UN Economic Commission for Africa (2001) presents an extensive discussion of environmental problems in Africa, identifying many important issues, such as deforestation, desertification, need of fresh water supply, etc. The nexus of poverty, environment and health yield an unenviable condition for the population, who suffers from a lack of choice. There is no reference to neither sand or wind problems nor to air pollution and other wind engineering issues, but only to wind erosion. Accordingly, the committee received only one reaction to the issue of wind and environment from Senegal (Kuismanen, personal communication, 2004).

Trying to design dwellings into which no sand and dust could penetrate is a challenge to wind engineering, which can only be effectively addressed in close cooperation with local builders. Dust and sand storms are a plague in many parts of the world and certainly in the Sahel and other fringes of deserts.

The harmattan is a hot and dry wind that blows from the northeast or east in the southern Sahara, mainly in winter. It usually carries large amounts of dust. The haboob is a hot and moist, strong wind that occurs along the southern edges of the Sahara in the Sudan and is associated with large sandstorms. A haboob may transport huge quantities of sand or dust, which move as a dense wall that can reach a height of 900 meters. In the eastern Mediterranean a wind blows out from Libya and Egypt, known as the Khamsin. This is a wind that is hated by the people living there and indeed in the centuries passed was dreaded as a killer.

It is remarkable that no wind engineering issue pertaining to the environment is identified, but the sand and dust sealed dwellings. Apparently, African priorities are different.

7. Wind and fire propagation

Fire is a natural phenomenon inherent to semi-humid ecosystems. However, anthropogenic ignition is a threat to African ecology. Natural fire is an essential phenomenon in ecosystems; anthropogenic fire is not. The following case studies (FAO, 2001) illustrate the magnitude of wildfires that affect forest and non-forest ecosystems:

- Benin: 7.5 million ha of forests exposed to fire annually,
- Botswana, 1996, 1998: 6.2 and 3 million ha of vegetated land burned,
- Namibia, 1997: 3 million ha of vegetated land burned,
- Senegal, 1995-1996: >0,5 million ha of vegetated land burned,
- Sudan: 60 million ha of vegetated land exposed to fire annually, and

- Sub-equatorial Africa: ca. 170 million ha of vegetated land burned.

FAO (2001) also presents an overview of many socio-agricultural aspects of forest fires. Symposia on Fire and Forest Meteorology, organized by the American Meteorological Society, discuss physical phenomena pertaining to forest fire. The International Journal of Wildland Fire, published by CSIRO, Australia, on behalf of the International Association of Wildland Fire, publishes papers presented at these symposia. In fire management, forecasting is important. WMO (1991) presents papers on forest fire forecasting, with one of the papers (Felber and Bartelt, 1991) reporting on the statistical relation of fire and nine environmental parameters: soil humidity, litter humidity, maximum air temperature, relative humidity, air pressure, precipitation, global radiation, sun duration and wind speed. WMO (2007) has updated and expanded its sections on prescribed burning, specialized fire weather observations and fuel-state assessment for forest, bush and grass fires in the Chapter on applications of meteorology to forestry and non-forest trees.

Wind engineering contributes to forest fire research outside Africa (Lopes et al., 1993; Viegas, 2004). IAWE could further exchange of know-how with Africans. Current projects (Viegas, 2004) provide good opportunities to exchange experiences and expertise between Europe and Africa. However, we did not receive any reaction from Africans. First, IAWE should try to encourage communications.

8. Conclusions

From a scientific or technical point of view, wind engineering in Africa is necessary in the same wide range of activities as elsewhere. However, in policy papers, the introduction of wind energy and agricultural development are identified as main African topics. This paper argues that wind engineering could assist in addressing some important African problems, such as acquiring data on wind climate, developing wind energy in Africa, fighting storm damage and sand penetration to/in buildings, reducing the adverse effects of wind and drifting sand on agriculture and further researching other environmental destructions and engineering aspects of combating forest fires.

This difference between general wind engineering issues and African issues should guide the funding of projects and we envisage co-operation with Africans on these issues. Apart from private sources, funding requires African input in the definition of pilot projects and formal African support with regard to priorities. Moreover, it is not only the project that must be funded; African researchers need funding and visas to start up communication and facilitate the exchange of knowledge. Stigter et al. (2005) developed an approach.

All wind engineering applications require data on wind climate, which are very sparse in Africa. The authors stumbled on five lines of action to generate more and better wind data. These actions could partly be implemented as research in developed countries, in cooperation with African guests. They are: (i) better African coverage of the GCOS network (section 2.1); (ii) quality control of existing data (section 2.2); (iii) better use of historical data, including a survey of archives of former colonial powers (section 2.3); (iv) a generation of wind field data by numerical weather analysis systems for tropical conditions, with special attention to terrain modification of wind and the three weaknesses detailed in the paper (section 2.4); and (v) validation of extrapolation techniques in the tropics (section 2.5).

To reduce the adverse effects of wind and drifting sand on agriculture, more knowledge is needed on the effects of shelter belts of local bushes and scattered trees.

Moreover, this shelter has to be combined with information on the deposition of drifting sand. Although this subject is suitable for research outside Africa, local African input is essential.

In all fields, capacity building is essential. This requires interaction between active members of IAWE and African researchers. International bodies such as UNEP, UNDP, FAO, UNESCO, ECOSOC, WMO and INSAM as well as the World Wind Energy Association and non-governmental organizations are active in the fields of African climate, wind energy, agrometeorology and related local services, policies and institutions in Africa. It is a challenge for IAWE to cooperate with these people and to state our cause.

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11. Abbreviations

ANIV Associazione Nazionale per l'Ingegneria del Vento
CFD Computational Fluid Dynamics
CSIR Council for Scientific and Industrial Research
EACWE European & African Conference on Wind Engineering
EAI European Africa Initiative
ECMWF European Centre for Medium-Range Weather Forecasts
ECOSOC Economic and Social Commission of the United Nations
FAO Food and Agriculture Organization of the United Nations
GCOS Global Climate Observing System
GIS Geographic Information System
GOS Global Observing System
HIRLAM High Resolution Limited Area Model
IAWE International Association for Wind Engineering
INSAM International Society for Agricultural Meteorology
LAWEPS Local Area Wind Energy Prediction System
NCAR National Centre for Atmospheric Research
NCDC National Climatic Data Centre
NCEP National Centers for Environmental Protection
NOOA National Oceanic and Atmospheric Administration
NREL National Renewable Energy Laboratory
RreDC Renewable Resource Data Centre
SSWES Small Scale Wind Energy Systems
SWERA Solar and Wind Energy Resource Assessment
UNEP United Nations Environment Programme
UNDP United Nations Development Programme
UNESCO United Nations Educational, Scientific and Cultural Organization
WAsP Wind Atlas Analysis and Application Program
WMO World Meteorological Organization (of the United Nations)

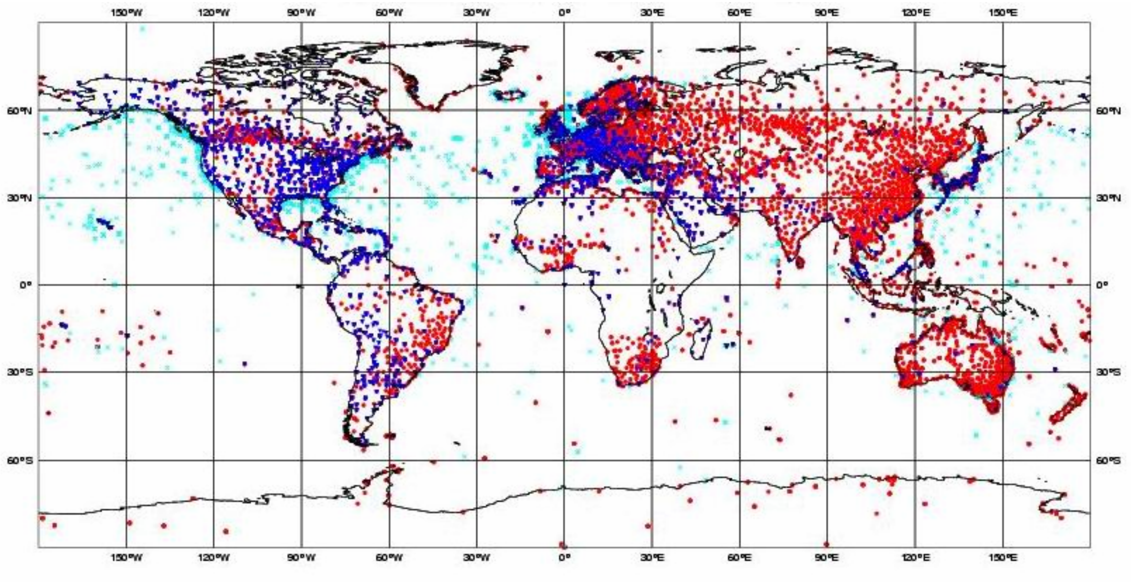

Fig. 1. Places and ships from which data were received in time for the weather forecasting cycle on an arbitrary but representative date of 17 February 2005 by ECMWF, the European Centre for Medium-Range Weather Forecasts, (WMO, 2005).

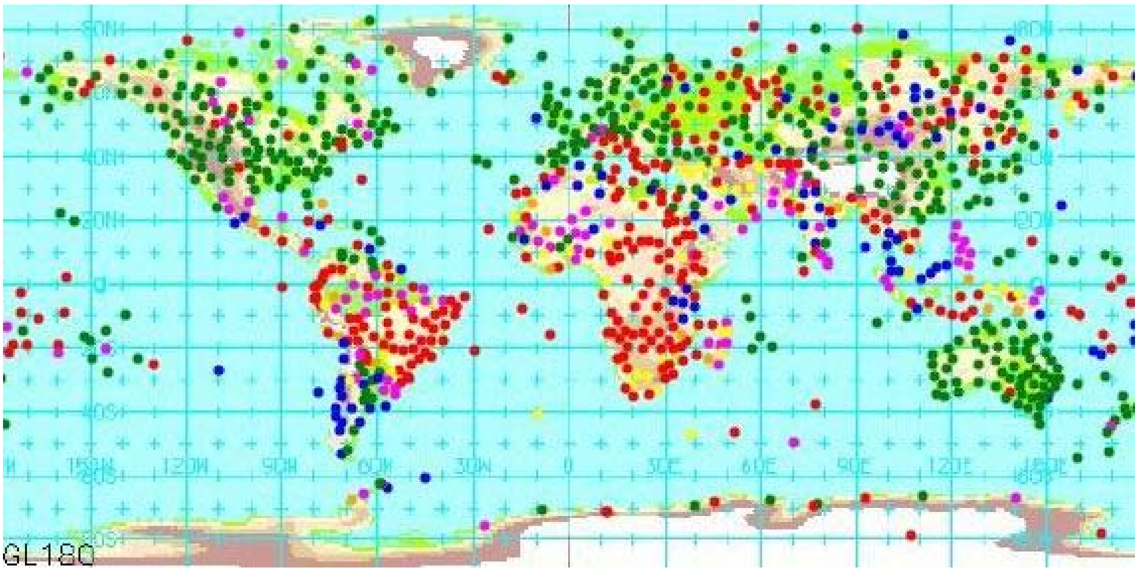

Fig. 2. Percentage of reports within the Global Climate Observing System (GCOS), received in 2002 by the international centre in Japan, within 20 days after reports were due; green is 100%; red is 0% .

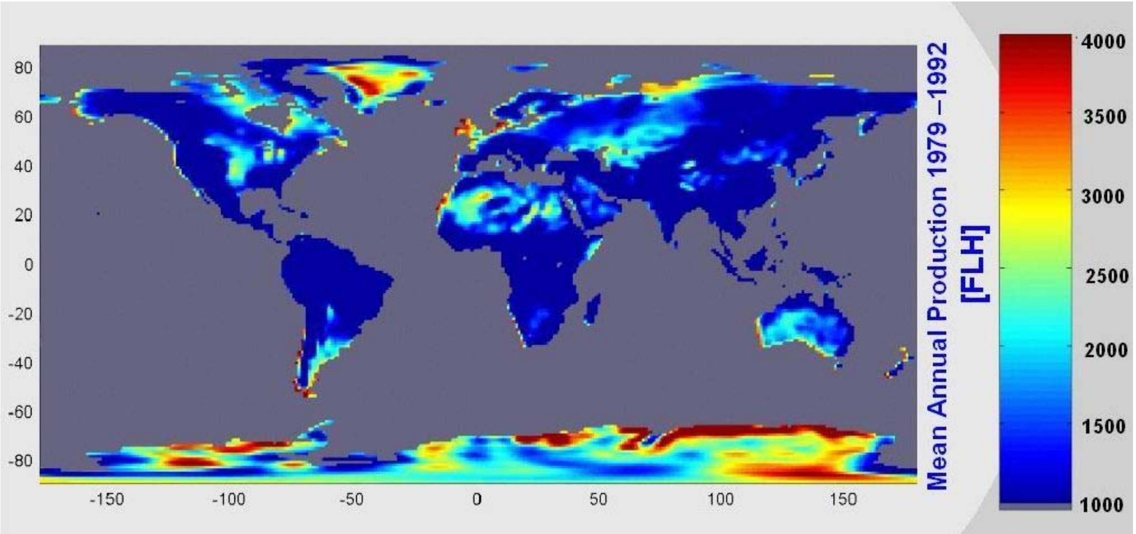

Fig. 3. Mean annual production of a 1,5MW variable speed wind turbine in full load hours. The height of the axis is 80m. ECMWF data for the period 1979-1993, (Czisch, 1999).

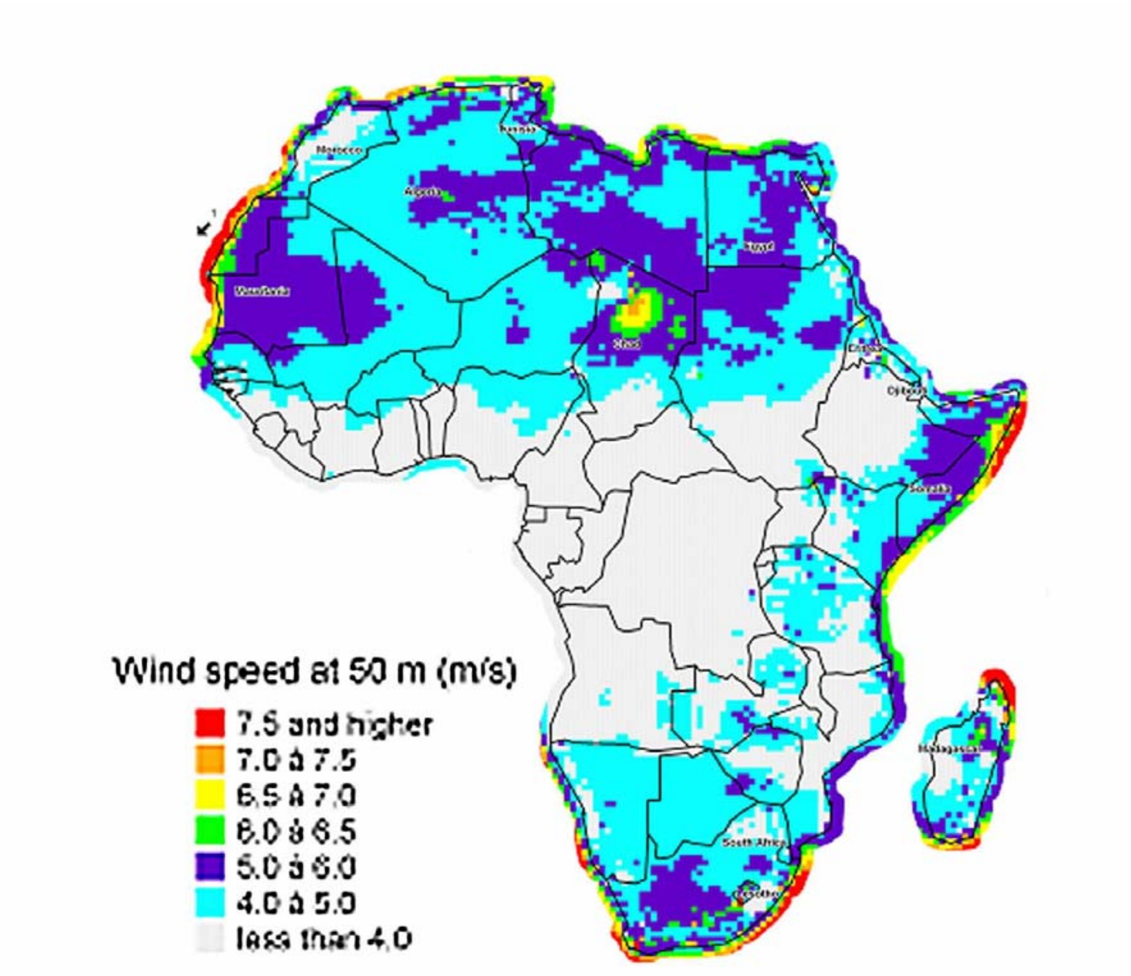

Fig.4. Annual mean wind speed in m/s, 50m.a.g.l. in m/s as generated, with a grid of 50km, (African Development Bank, 2004).

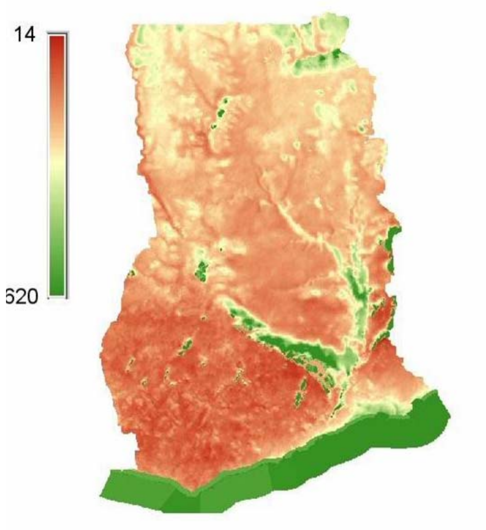

Fig.5. Wind power density in W/m^2 at 50m height in Ghana. The green zones indicate 600 to 620W/m^2, located in the coastal belt and in the mountains. The highest mountains (900m) are at the east boarder (UNEP, 2004).

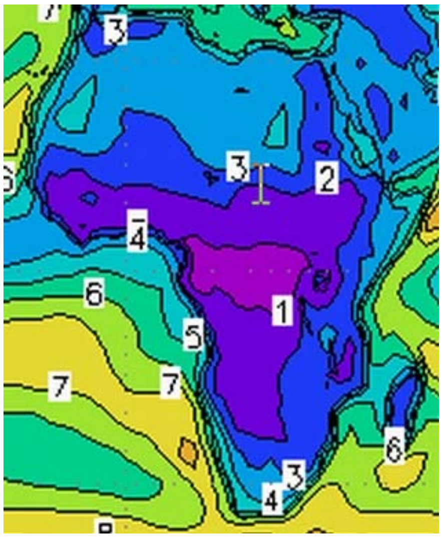

Fig. 6. Detail of a world map of annual mean wind speed in m/s, 10m.a.g.l., 1976-1995 (WAsP, 2004).

Table 1. Classes of wind power density at 10m and 50m(1) (Renewable Resource Data Center, 2004)

Wind Power Class	10m		50m	
	Wind Power Density (W/m^2)	Speed(2) m/s	Wind Power Density (W/m^2)	Speed(2) m/s
1		0	0	0
	100	4.4	200	5.6
2				
	150	5.1	300	6.4
3				
	200	5.6	400	7.0
4				
	250	6.0	500	7.5
5				
	300	6.4	600	8.0
6				
	400	7.0	800	8.8
7				
	1000	9.4	2000	11.9

1) Vertical extrapolation of wind speed based on the 1/7 power law.
(2) Mean wind speed is based on Rayleigh speed distribution of equivalent mean wind power density. Wind speed is for standard sea-level conditions

Table 2. Observed maximum gusts in Africa (Griffiths 1972, Clausen 2004)

Country	Gust speed	frequency
Nigeria	> 17m/s	2-10 times per year
Eritrea-Somalia; Ethiopia	> 8 Beaufort	53 days per year
Malawi, Zimbabwe, Zambia	32, 23, 35m/s	(mainly in squalls)
Congo Baklava Kinshasa	 21.5m/s 28.3m/s	
Lesotho	31.9; 38.2;36.0m/s	3 sec gusts during a wind energy project

Table 3. Number of storms per year in the SW Indian Ocean based on data from 1968/69 to 1989/90 (Landsea, 2004; Australian Bureau of Meteorology, 2006)

Tropical Storm or stronger (greater than 17m/s sustained)			Hurricane/Typhoon/ Severe Tropical Cyclone (greater than 33m/s sustained)		
Most	Least	Average	Most	Least	Average