ABSTRACT

In 2006, the Cameroonian State decided to monetize its gas reserves by allocating a significant portion of the existing gas discoveries to a single LNG export project, called Cameroon LNG Project. The preliminary studies are close to be completed, and Front end engineering phase is under preparation. For this new phase a robust and reliable design of basis will be important.

The determination of extreme weather conditions, part of the design of basis, is crucial for the design of maritime and ground infrastructures for the Cameroon LNG plant – 25 km south of Kribi. In order to determine these extrema, Cameroon LNG project is performing a 20-year climatic high resolution atmospheric hindcast based on a regional non-hydrostatic modelling. The methodology and the first results are presented in this paper.

The Regional Climate Models (RCM), commonly used, already demonstrate their ability to simulate the West African Monsoon cycle with all its seasonal phases. However, they failed to quantify gusts explicitly. Classical methods based on simple empirical/statistical ratio are irrelevant to produce extreme and unusual gust magnitudes despite the use of high resolution models. An off-line physical tool was developed for computation of the gusts, from the scenario provided by the RCM, by using the Turbulent Kinetic Energy (TKE) of the atmosphere.

Preliminary results about a specific month are presented here for the RCM assessment as well as the gust TKE method assessment. For the specific case of Cameroon coasts, it has been shown that:

- a RCM is a relevant tool for downscaling the atmospheric dynamics from global scale towards the regional and the local scales. It is not able to correctly reproduce extreme wind events;
- a TKE algorithm is necessary to improve the simulation of gust events by post-processing 3-D outputs of the RCM. It produces much better results than any wind gust ratio method.

This combine method (RCM+TKE) will be used over a 20-year period using higher resolution in the Kribi area, and simulations will be further validated against observations: satellite, meteorological bulletins and data from the on-site Meteorological station. This climatic hindcast will provide finally:

- a proper consideration of local weather conditions, including gusts, in the design of the Cameroon LNG plant,
- a basis for a predictive tool to support maritime operations, for instance, when the Cameroon LNG plant will be in operation.
1. INTRODUCTION

The determination of extreme weather conditions is crucial for the design of maritime and ground infrastructures for the Cameroon LNG plant – 25 km south of Kribi.

Even if benign weather conditions are the rule for the area, Mesoscale Convective System (MCS) can generate squalls and wind gusts, however limited data exist: about 100-150 storms are yearly recorded in the area, with wind speed up to 40 knots (80 km/h)!

The poor estimation of weather conditions can result in:
- design margins with an impact on CAPEX,
- low design margins with an impact on plant availability and LNG production losses.

Otherwise, an accurate estimation can contribute to optimize the NPV of the project.

This region has limited instruments. Data acquisition requires important and expensive measurement campaigns to define climatology over the region and to extract the extreme values. Long time series of data are currently not available. The project recently installed a meteorological station on site. However, the field campaign can miss the most powerful events because of its limited duration and/or the use of a singular station.

![Figure 1: On-site Meteorological station currently in service in Lolabé (Cameroon)](image)

Alternatively, is it possible to use a long term modeling approach? For the first phase of this study, the project is considering two levels of investigation:
- the production of a long term scenario by using a high resolution modeling, and
- the computation of gusts based on the long term scenario.

2. OBJECTIVE

Very intense MCS activity over West Africa and intensive convective diurnal cycles induce a strong vertical transfer of turbulent kinetic energy (TKE) ([1]) (Figure 2). The downward transfer branch is performed through a powerful release process called wind gust (Figure 3).

By definition, wind gust (or gust) is the maximum wind speed measured during a specified time period. The American Meteorological Society defines a wind gust as a sudden brief increase in the speed of the wind.
More specifically, the National Digital Forecast Database defines a wind gust as the maximum 3-second wind speed (in knots) forecast to occur within a 2-minute interval at a height of 10 meters (~32.8 feet).

Classical methods based on simple empirical ratio failed to quantify gusts despite the use of high resolution models.

![Intense convective activity over West Africa](image1)

**Figure 2:** Intense convective activity over West Africa composed by numbers of Mesoscale Convective System (MCS): Meteosat Imagery – IR 10.8 Brightness temperature of the cloud top Colors from yellow (-40°C) to red (-77°C)

![Conceptual model](image2)

**Figure 3:** Conceptual model of the kinetic, microphysical and radar echo structure of a convective structure with precipitation

In order to determine these extrema, Cameroon LNG project is performing a 20-year climatic high resolution hindcast based on a regional non-hydrostatic modeling.

The methodology and the first results are presented in this paper.

**3. DEVELOPMENT**

**3.1 Global to Regional**

Global climate information is available both for ocean and atmosphere states during the past twenty years. These datasets are not relevant for regional and local study where complex physics/chemistry interaction processes occur, inducing modification, enhancement, and inhibition of regional and local weather events.

All the processes occurring at horizontal resolution under the one of the global scale are thus not reproduced or are parameterized for the global scale. This explains the low intensity of the extreme events within the Global Reanalysis product. For instance, the higher horizontal resolution currently reached by the Reanalysis
products is 0.5° (~ 55 km x 55 km), which is too coarse to reproduce a convective event which presents a lower horizontal extension or meteorological phenomena occurring at a lower scale (precipitation, gust).

3.2 Regional Climate Model

The proposed method is based on a Regional Climate Model (RCM, named WRF (Weather Research and Forecasting) nested within 20-year global atmospheric re-analysis produced by a World Meteorological Center, and using a high resolution nested domain (Figure 4). RCM already demonstrates its ability to simulate the West African Monsoon cycle with all its seasonal phases ([2]). A numerical simulation method is used to produce long simulation at high spatial and time resolutions using supercomputer facilities.

The current regional simulations, whatever their horizontal and vertical resolution fail to correctly represent the extreme wind gust associated to a synoptic or a regional meteorological event producing strong wind gusts. The determination of extreme wind is usually performed by using a simple ratio method applied to the sustained winds (measured or simulated).

![Figure 4: The nested domains (17 km x 17 km) and the relief representation inside (left). The vertical discretization contains an irregular level spacing with a higher resolution close to the earth surface (right).](image)

The very intense MCS activity over West Africa as well as the intensive convective diurnal cycle ([3]) induce an important vertical transfer of turbulent kinetic energy (TKE). The downward branch of the transfer is usually performed by a rapid and efficient way called wind gust. The most powerful wind gusts can be directly associated to the MCSs.

3.2 The computation of the strong and rapid variability of the gusts is an issue

In order to quantify these gusts at the regional and local model scale outputs, a very simple empirical ratio method is generally used. This method does not take into account the physical processes associated with gusts.

Consequently, even with a very high time and space resolution model outputs, these methods failed to accurately estimate the strong and rapid variability of the gusts due to turbulent kinetic energy transfer towards the surface. Considering the very active MCSs activity over West Africa, this misrepresentation is supposed to be critical and recent studies on the gust generation underlined that these empirical and statistical method missed the extreme gusts (by definition, out of the statistical domain).
This Gust TKE algorithm aims to determine the gusts by a realistic and physically based method (Figure 5). This method is based on the fact that a gust is the result of the air parcel vertical deflection from an altitude level to the surface ([3]).

![Figure 5: Determination of the lower bound of the bounding interval on wind gust estimate based on local TKE](image)

Deterministic approach for gusts can occur when the TKE is high enough to permits this air parcel to move downwards, against the buoyancy gradient between the surface and higher levels of the planetary boundary layer. Several studies during the past few years showed that the deterministic method based on the TKE transfer produces very accurate result both on intensity and time variability compared to empirical/statistical methods. The TKE method approach is currently implemented in several national meteorological centers (as well as dedicated forecast system for airports) in order to forecast correctly the extreme winds associated with gusts.

![Figure 6: The Global re-analysis force a Regional Climate Model (RCM) at its lateral boundaries](image)

A dedicated off-line physical tool, named Gust module, was consequently developed for computation of the gusts from the scenario provided by a RCM (Figure 6). The TKE method requires a three dimensional information of the main atmospheric components (wind & temperature) as well as a three dimensional TKE field. The use of a RCM with a high level of turbulent closure scheme is thus necessary.
4. RESULTS

4.1 Validation of the RCM June 2006 simulation

Preliminary results about a specific month are presented here for the RCM assessment as well as the gust TKE method assessment (Figure 7). The Monthly wind field intensity and direction (wind barbs) for the RCM wind are presented in red and fit with Satellite Quickskat surface wind shown in black arrows.

The Quickskat satellite product can be used to assess the wind produced by the model. The Figure 7 presents the simulated mean monthly wind field compared to the Quickskat monthly wind field. The spatial variability of the model output is greater than the remote Quickskat data. Over the continent, this variability is the most marked but there is no data to assess it. Over the ocean part, the mean wind seems correctly simulated but the Quickskat resolution is poor compared to the model. The Figure 21 thus perfectly illustrates the difficulty to assess a model at high spatial resolution.

![Figure 7: Monthly wind field intensity and direction (wind barbs) for the RCM wind (red) versus Satellite Quickskat surface wind (black arrows)](image)

The Figure 8 presents standard skew T plots (temperature, dew-point and winds with height) of radiosoundings performed at Douala (observations) – red marks and red curves in the skew plots – compared to model outputs at the same location and time represented in black and blue marks for D01 (coarse resolution) and D02 (medium resolution) domains respectively. The dashed lines are for the water vapor mixing ratio (dew point) while the solid lines are for the potential temperature.
The vertical atmospheric in-situ radio-sounding in red is successfully compared to the RCM simulation (black, blue) for two situations (Figure 8).

The overall analysis of the RCM outputs revealed that the model produces a very good vertical potential temperature profile either for coarse or medium resolution. This remarkable accordance between model outputs and observation is likely related to the assimilation of observed temperature radiosonde data within the NCEP reanalysis system.

However, the simulated dew point (dash lines) is not as good as the potential temperature and some discrepancies can be exhibited all along the vertical. The bias in humidity can be systematic, positive or negative.

The vertical wind profile is well reproduced aloft the atmospheric boundary layer. Within the boundary layer, the observation revealed an important variability, mostly in direction while the wind intensity stays under 10 knots observed. Near the ground, the wind intensity is well reproduced in line with observations, which is in fact the most important.

4.2 Validation of the GUST post-processing method

Remarkable events at Douala can be sourced from observations either highlighted by Meteosat Imagery – IR 10.8 Brightness (Figure 9) or mentioned in standardized meteorological bulletins (Tableau 1).
Figure 9: Meteosat Imagery showing intense convective activity over West Africa, by IR 10.8 Brightness

Satellite pictures correspond actually to 71th and 398th hour of the time period for June 2006. All this stations are part of the WMO network and provide several standardized meteorological bulletins per days called METAR or SPECI. METAR stands for Meteorological Aerodrome Report; METARs typically come from airports or permanent weather observation stations. Reports are generated once an hour, but if conditions change significantly, a report known as a special (SPECI) may be issued.

The analyze of the METAR and SPECI identified some particular events with strong winds. The cases listed in Tableau 1 have been selected because, in the METAR or SPECI data, there are some mentions about specific activities. However, it DOES NOT mean that it is exclusive information. Some events can occur without being mentioned in METARs and SPECIs.

Tableau 1: METARs/SPECIs remarkable events at Douala (VRB for Variable, G for Gust)

<table>
<thead>
<tr>
<th>Date and Time</th>
<th>Wind dir/int. (°/knots)</th>
<th>T/Td (°C)</th>
<th>Miscellaneous</th>
<th>Hours after run start</th>
<th>Notice</th>
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<td>VRB10KT</td>
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</table>

The June 2006 time series of RCM 10 m wind (black), Gust Ratio method (red), Gust TKE method (blue) are compared in Figure 10 with remarkable events from bulletins (below right, black circles).
The Gust TKE method confirms here its ability to capture gust observations and evaluate properly their intensity at around +/- 20% in standard deviation. The Gust TKE method approach is currently implemented in several national meteorological centers, including airports, to forecast correctly the wind gusts.

5. CONCLUSION AND PERSPECTIVES

For the specific case of Cameroon coasts, it has been shown that:

- a RCM model is a relevant tool for downscaling the atmospheric dynamics from global scale towards the regional and the local scales. It is not able to correctly reproduce extreme wind events;

- a TKE algorithm is necessary to improve the simulation of gust events by post-processing 3-D outputs of the RCM. It produces much better results than any wind gust ratio method.

This combine method (RCM+TKE) will be used over a 20-year period using higher resolution in the Kribi area, and simulations will be further validated against observations: satellite, meteorological bulletins and data from the on-site Meteorological station. This climatic hindcast will provide finally:

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6. REFERENCES

