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Short-Term Wind Forecast for Space Rider Mission at the Kourou Landing Site

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Abstract

This work describes a system to support the Space RIDER mission by providing a characterization of the wind field in the area of Kourou, French Guiana, by means of a numerical weather forecast model, specifically the weather research and forecasting (WRF) model. The study primarily aims to assess the ability of the numerical forecast model to reproduce the wind fields within the area of interest for a period of one year. The validation process compares the simulated vertical wind profiles and surface wind with measures obtained from the closest available data sources: radiosonde, ground weather stations and a weather measurement tower. The results achieved highlight that the in-situ observations are consistent (with each other) and their use in the validation process emphasizes that the adopted WRF model, with the selected configuration, confidently predicts the wind speed, within an error range of 3 m/s. Validation concerning the wind direction is still ongoing.

Keywords: (wind forecast, weather research and forecasting model, radiosonde, GNC)

Acronyms/Abbreviations

Acronym	*Definition*
CAS	Cayenne Airport weather Station
CSG	Centre Spatial Guyanais weather station
GFS	Global Forecast System
GNC	Guidance, Navigation and Control
MAST	Measurement tower
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
Space RIDER	Space Reusable Integrated Demonstrator for Europe Return
WRF	Weather Research and Forecasting

1. Introduction

Space RIDER is an uncrewed robotic laboratory. After launch it will stay in low earth orbit for about two months. Experiments inside its cargo bay will allow technological demonstration and research benefits in pharmaceutics, biomedicine, biology and physical science. At the end of its mission, Space Rider will return to Earth with its payloads and land on a runway to be unloaded and refurbished before a new flight.

Upon atmospheric entry, the lifting body shape will decelerate the spacecraft to subsonic speed (below Mach 0.8), when a drogue parachute will be deployed at about 15-16 km altitude to further slow it to Mach 0.18 - 0.22. Next, a controllable gliding parachute called parafoil will be deployed at 5,5km altitude and will begin the controlled descent phase for a nearly horizontal touchdown (<15 m/s horizontally and <3 m/s vertical). The touchdown area will have a diameter of about 300 m with a roll-out of about 30-50 m. In order to ensure the landing within the touchdown zone, a reliable model of the wind must be included in the GNC system. Such model must represent the wind from a height of 5 km down to about 10 m with a maximum error of approximately 4 m/s. In order to design a robust parafoil guidance system, the atmosphere and the winds need to be properly modelled and the GNC verified.

This work describes the Wind4SR system developed to support the Space RIDER mission by providing a characterization of the wind field for the Kourou landing site, French Guiana, by means of a numerical weather forecast model, the WRF modeling system [1]. Previous studies were performed exploiting weather-forecast models to support space missions [2], [3] but without a specific focus on the wind forecasts. In [4], some wind degrading effects, impacting on space missions, were observed and in [5] a first attempt to optimize wind forecasts in order to predict such wind effects was performed. In the above cited works, wind was forecasted together with other variables thus preventing a full exploitation of the potentialities of the adopted models when focused on the wind variable. Several studies can be found in literature concerning the WRF set up for optimizing wind predictions [6]-[10] but they are not referred to specific climatic areas.

This study primarily aims to assess the ability of the forecast model to reproduce the wind fields within the landing area in French Guyana. The validation process compares the WRF simulated vertical wind profiles and surface wind with measurements from the nearest available data sources (specifically, 11 locations) over a period of 1 year: radio soundings, ground weather stations and a weather MAST.

2. Adopted Model and configuration

The regional mesoscale WRF model is selected to produce wind forecasts using global data acquired by the GFS model from the NCEP for the initialization. The following assumptions are considered:

- the WRF model configuration [11], [12] has been chosen using a limited set of 5 tests. A more extensive site characterization could provide more robust results.
- forecast accuracy has been assessed over the CAS and the CSG for a year's worth of data;
- forecasts generated from two daily runs starting at 12:00 and 00:00 UTC are considered best representatives of the atmospheric conditions as observed by in-situ available observing systems;
- for each run the forecasted values of wind speed between the 11th and the 13th hour of prediction are compared to the observations made by the ascending radiosondes generally launched 45 minutes prior nominal launching time;
- for each run the forecasted values of wind speed at ground and near the surface have been validated with ground and near ground observations with time resolution spanning from 1min to 30min;
- all the forecasted values and all the available observations are considered representative for an assessment of the temporal and spatial variability of the wind speed, air temperature and relative humidity fields.
- variability of the vertical component of the wind is estimated only using the WRF model output.

The chosen WRF model configuration encompasses three two-way nested domains (Fig. 1), with horizontal grids spacing of 9 km (d01), 3 km (d02) and 1 km (d03) respectively, centered over the area of interest. Fifty-one levels in the vertical direction are used and the vertical spacing is on the order of tens of meters for the levels nearest the ground (up to 500m), and gradually increases with height. The model top is fixed at 100 hPa, which corresponds to a height of about 16/17 km above the ground level.

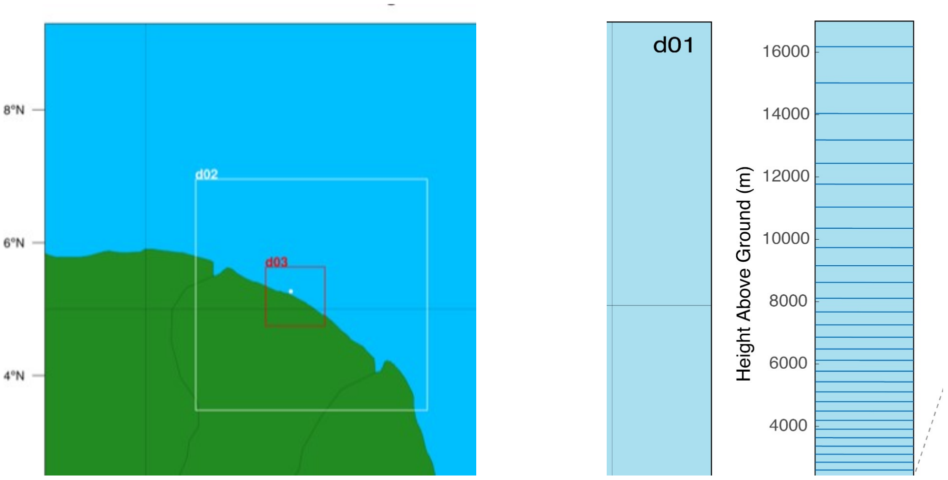

Fig. 1 WRF spatial and vertical configurations

The GFS (0.25 ° x 0.25° lat/long grid) analyses and forecasts are used as initial and boundary conditions. The model integration time is 30 seconds for the d01 domain, 10 seconds for the d02 and 3.333 seconds for the d03 domain. Two runs per day are performed with initial times at 00:00 and 12:00 UTC and the simulation length is 18 h. The 3D forecasted fields output are saved with a 15 min frequency. Time series of vertical profiles of specific meteorological variables (including the wind components U, V, W) at the 51 and 101 model vertical levels are extracted and saved with a temporal resolution of 30 seconds for d01, 10 seconds for d02 and 3.333 seconds for d03 (matching the integration time) at the eleven sites of interest (cf. Fig. 2).

WRF model is run to generate time series of forecasted zonal and meridional wind components over the 11 sites and over a year, from 1st February 2021 to 31th January 2022. Besides for the generation of forecasts, different statistical tools are adopted for data analysis and comparison with measurements such as:

- mean and standard deviation calculator;
- median and 25%/75% percentile calculator;
- gradient calculator;
- Wind Knowledge Error calculator.

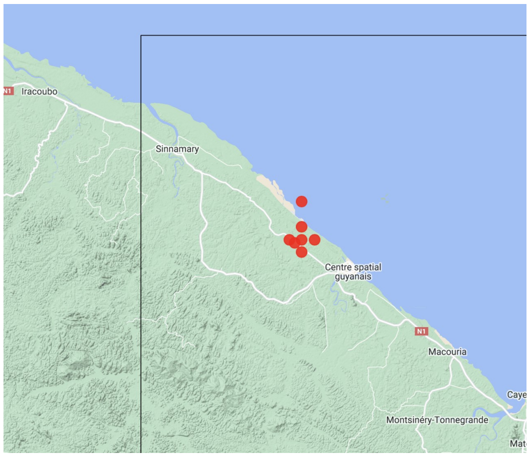

Fig. 2 Map with the location of the sites under investigation

3. Available measurements

The following In-Situ measurements are available:

- Upper Air observations from radiosondes launched in Cayenne: temperature, relative humidity, Wind Speed and Direction;
- METAR and SYNOP ground observations for the Cayenne Ground Station (also referred to as CAS): temperature, relative humidity, Wind Speed and Direction, Precipitation;
- ground observations collected at the Centre Spatial Guyanais (also referred to as CSG): temperature, relative humidity, Wind Speed and Direction;
- MAST observations collected at the Centre Spatial Guyanais (also referred to as CSG): Wind Speed and Direction.

3.1 Upper air radiosonde data

Radiosondes are battery-powered telemetry instruments carried into the atmosphere by a weather balloon that measure various atmospheric parameters and transmit them by radio to a ground receiver. Modern radiosondes (Fig. 3) can measure altitude, pressure, air temperature, relative humidity, wind speed and wind direction.

In this study wind speed, wind direction (ongoing), temperature and relative humidity are obtained from radiosondes launched from the station number 81405, Cayenne/Rochambeau located at 04.50N 52.22W at an elevation on the sea level of 8m, between September 11th and October 10th 2021. Radiosondes are associated with nominal launching time (usually 00:00 and 12:00 UTC), however the balloons are generally released 45 minutes prior launching nominal time, and reach the highest vertical point, generally, 1 hour after launching nominal time.

Radiosondes provide point measures of the vertical air column, however they usually tend to drift during the ascending phase. Horizontal displacements with respect to launching sites depend on the wind intensity and directions.

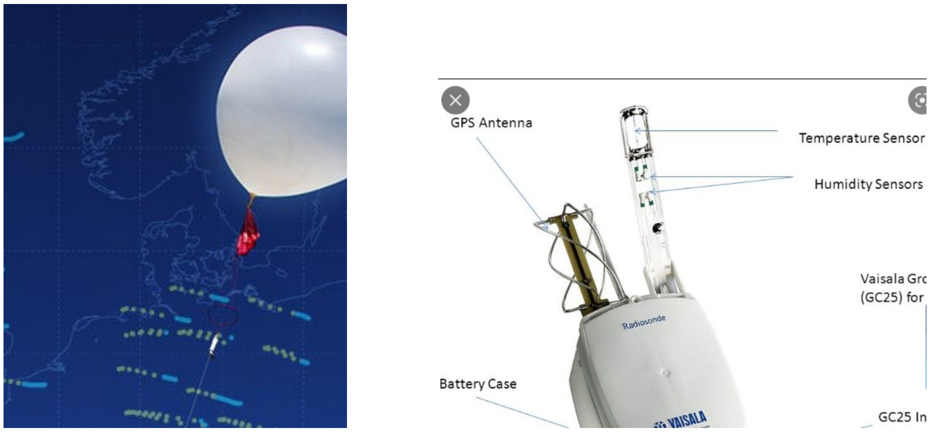

Fig. 3 Example of radiosonde balloon and instrumentations

3.2 Ground Station Data (CSG and CAS)

Two weather stations were considered for the validation of surface wind, temperature and relative humidity fields. One station (CSG site) is located 8 km from the Technical Centre of the CSG, the other is located at the Félix Éboué Airport in Cayenne (CAS). Data relevant for the period of analysis were provided by ESA for the CSG station, while observations from the CAS station were downloaded from the NOAA Integrated Surface Dataset [13].

Ground data from Cayenne (METAR and SYNOP) and from CSG have been used to generate information regarding the local:

- seasonal variability of wind speed and wind direction;
- time variability of wind speed and wind direction gradients.

3.3 MAST observation data

A year-worth of wind data was collected from the MAST located at CSG. Wind speed and direction are measured by sensors placed at 10, 20, 25, 35, 50, 75 and 100 meters along the height of the MAST with a temporal resolution of 10 min. MAST data have been used to derive the annual variability and to check consistency with the other available in-situ observations.

Beside the WRF validation, MAST data have been used for a consistency check with the Ground observations at CSG. A full year of data from the 10m elevation anemometer have been used in the comparison.

4. Results

WRF forecasted variables (wind speed, temperature, relative humidity, precipitation) were validated with all the in-situ collected data: METAR, SYNOP ground data, and Radiosonde in Cayenne; Ground and MAST data in Centre Spatial Guyanais. The aim of the validation is to provide an assessment of the uncertainty of the Wind Forecast provided by the WRF model operated according to the configuration described in the previous sections.

4.1 WRF validation with Upper Air observations

The comparison between the forecasted wind profiles and the observations made available by the radiosondes is done by dividing the sonde vertical profiles in 5 min vertical segments comparing, for each segment, the observed data with the corresponding (in elevation and time) WRF values. To allow a fair comparison, the model time series at the Cayenne location (the closest to the sonde launching site) is sampled around the 6th hour of forecast (from the 11th to the 13th hour of the 00:00 and 12:00 UTC forecast).

The radiosondes provide direct measures of horizontal wind speed, wind direction and air temperature. The vertical component of the wind is not directly observed as it is in general too small for accurate measurements. Although it could be estimated from the vertical displacement of the balloon, in this study the vertical component of the wind is not estimated from the radiosondes. The air relative humidity is computed from the observed air temperature and dew point. The WRF model provides forecasts of the zonal, meridional, and vertical component of the wind.

4.1.1 Forecasted wind speed validation

To estimate the WRF wind forecast accuracy, in terms of wind speed, the WRF-model zonal and meridional wind components at Cayenne, properly combined, were compared with wind speed coming from available radiosondes.

According to the obtained results, when validated with the available radiosonde data, the WRF 6h - forecast wind speed at Cayenne shows a root mean square error (RMSE) between 2 and 3 m/s for altitude between 0 and 10000 m.

4.1.2 Atmospheric Forecast validation (Temperature and Relative Humidity)

Following the same validation procedure used for wind, WRF model forecasted atmospheric temperature and relative humidity data have been compared to radiosonde observations and the RMSE was computed along the vertical profiles. Overall, the temperature RMSE is ~ 1 degree Kelvin throughout almost the entire vertical column while the Relative Humidity RMSE shows values between 20% and 30% throughout most of the atmosphere, and even lower values (<10%) in the lowest atmospheric layers (< 1500m).

4.2 WRF validation with Ground Observations in Cayenne

WRF D03 surface Time Series have been validated using the METAR and SYNOP observations in Cayenne. The Index of Agreement, the bias, the root mean square error, and the bias corrected Root Mean Square Error are calculated. The bias corrected RMSE, calculated over the entire year, for wind speed is about 1.4 m/s.

Given the region's climatology, characterized by two long rainy seasons and two relatively short dry seasons, the WRF model accuracy in predicting the 3h-accumulated precipitation was also assessed: the model accuracy in terms of rain/no rain prediction turned out to be about 60%.

4.3 WRF validation with Ground Observations at Centre Spatial Guyanais

Following the same procedure described in section 4.2, WRF D03 surface Time Series have been validated using the ground observations at Centre Spatial Guyanais.

The Index of Agreement, bias, Root Mean Square Error, and the bias corrected RMSE were computed. The bias corrected RMSE for wind speed, calculated over the entire year, is about 1.2 m/s.

4.4 WRF validation with MAST observations at Centre Spatial Guyanais

Anemometers on the MAST located near the Landing Site (in proximity of Centre Spatial Guyanais) have been used to validate WRF model predicted wind at different altitudes above the ground: 10, 25, 35, 50, 75 and 100m.

After a quality control check of MAST data, the RMSE in wind speed ranges from 1.4 and 2.3 m/s, in good agreement with the results obtained with the other in-situ observations.

5. Conclusions and future works

Wind4SR came up to support the Space RIDER mission by providing a characterization of the wind field in the area of Kourou, French Guiana, using the WRF modelling system. The study primarily aims to assess the ability of the numerical forecast model to reproduce the wind fields within the area of interest in a one year period. To validate the WRF results, simulated vertical and surface profiles, were compared to local measurements acquired from the available data sources.

The results of such comparison highlights that the WRF model system, with the selected configuration, predicts the wind speed with an error within 3 m/s. The validation on the wind direction is still ongoing. The performed statistical analysis will allow a refining of the wind model included in the GNC for the Space RIDER mission.

Future developments of this work will be devoted to refine the developed system in order to reduce the estimation errors caused by biases through resorting to adaptive systems such as neural networks. In addition, weather drones could be considered as an additional data source representing a viable technology for high vertical, and relatively high temporal resolution wind profiling.

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