Analysis of Wind Shear Intensity at Constantine Airport

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Introduction

Wind shear is a critical factor in aviation safety, particularly during takeoff and landing. Detecting and forecasting these events is challenging due to wind variability and terrain influences. Constantine, with its mountainous landscape, is especially susceptible to wind shear, making it an important study area.

Figure 1 presents the monthly wind distribution at Constantine Airport, highlighting predominant wind directions and speeds. These variations emphasize the need for localized monitoring and forecasting to enhance safety.

This study analyzes wind shear intensity at Constantine Airport, focusing on peak shear levels at key altitudes and evaluating wind shear output from the AROME model. By examining significant wind shear periods and the effects of local topography, the research aims to improve understanding and forecasting in the region.

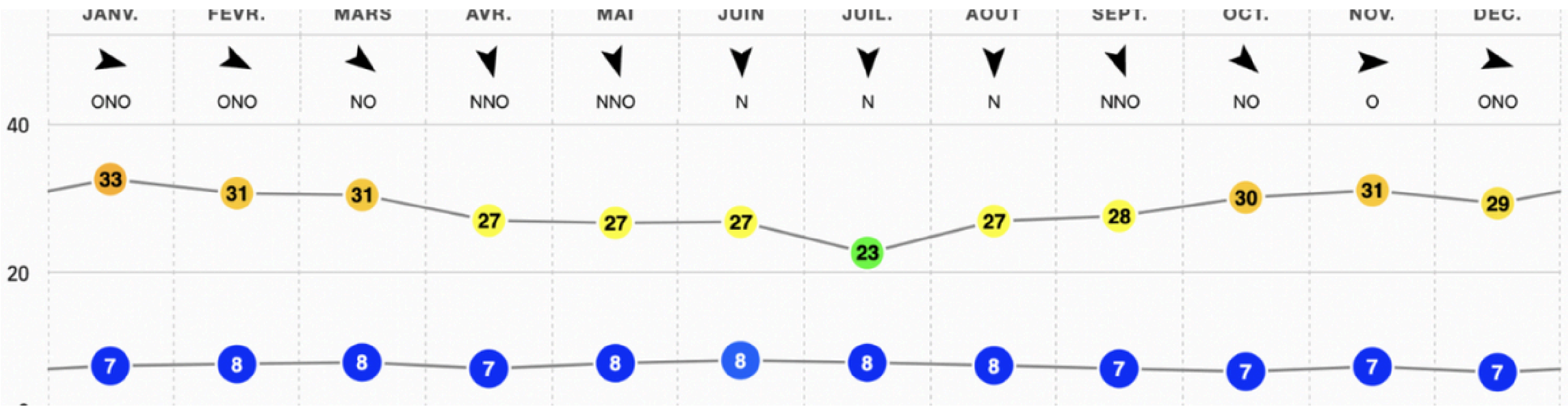


Figure 1: Monthly Distribution of Wind Speed (kt) and Direction at Constantine Airport [1]

Methodolohy

For this study, the AROME model based on CY46 cycle with 500 meters resolution was used to simulate atmospheric conditions around Constantine Airport. AROME is a high-resolution, non-hydrostatic, numerical weather prediction (NWP) model, which is well-suited for capturing small-scale atmospheric phenomena such as turbulence, wind shear, and localized convective systems. The model configuration is mentioned in the Table 1.

AROME was initialized and coupled with boundary conditions from ALADIN forecast models every 3 hours and generates outputs hourly

Model	**AROME 500m**	
Horizontal resolution	500 x 500 m	
Vertical resolution	41 levels	
Grid points	320*320	
Initial conditions	Aladin	
Forecast range	48 h	
Time Step	60s	
Area	**Lat**	35.61 – 36.95 N
	Lon	5.78 E – 7.44 E

3.2 Development: Addition of the Shear Equation

To calculate vertical wind shear, the APL_AROME.F90 routine was modified to include the shear calculation, which is performed after the turbulence calculation block in the model's processing chain. Vertical wind shear is defined as the difference in wind speed between two adjacent vertical levels, providing an indicator of how rapidly the wind changes with height, which is a critical parameter for assessing turbulence and flight safety.

The formula :

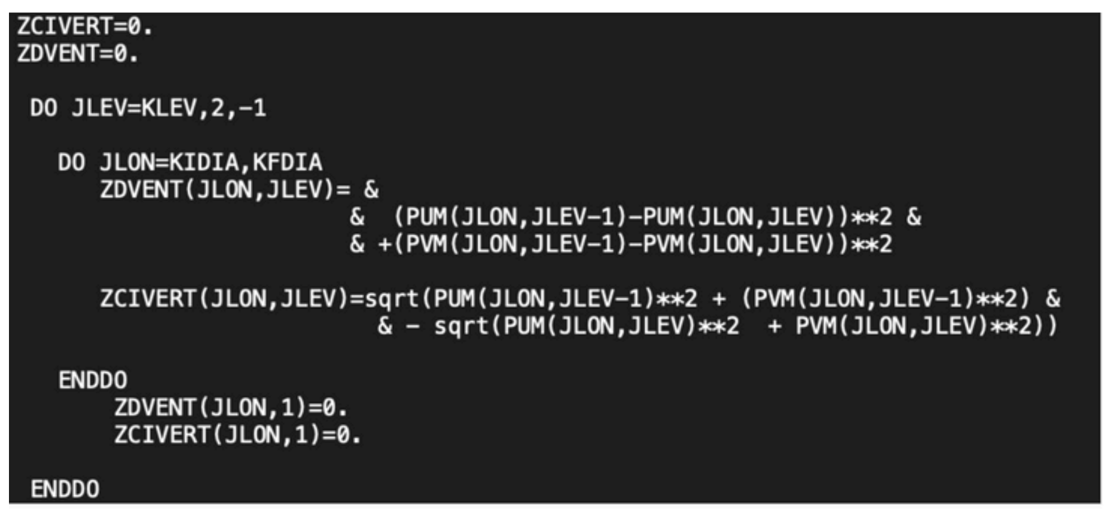
Vshear = |Vlevel1 – Vlevel2|

where:

Vlevel1: The wind speed at the upper atmospheric level

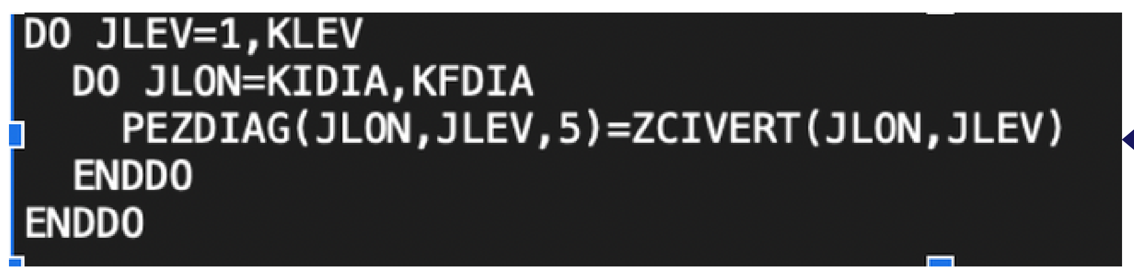
Vlevel2: The wind speed at the lower atmospheric level

In the code :



```
ZCIVERT=0.
ZDVENT=0.

 DO JLEV=KLEV,2,-1

   DO JLON=KIDIA,KFDIA
      ZDVENT(JLON,JLEV)= &
                        &  (PUM(JLON,JLEV-1)-PUM(JLON,JLEV))**2 &
                        & +(PVM(JLON,JLEV-1)-PVM(JLON,JLEV))**2

      ZCIVERT(JLON,JLEV)=sqrt(PUM(JLON,JLEV-1)**2 + (PVM(JLON,JLEV-1)**2) &
                          & - sqrt(PUM(JLON,JLEV)**2  + PVM(JLON,JLEV)**2))

   ENDDO
     ZDVENT(JLON,1)=0.
     ZCIVERT(JLON,1)=0.

 ENDDO
```

Adding the Equation into the Routine



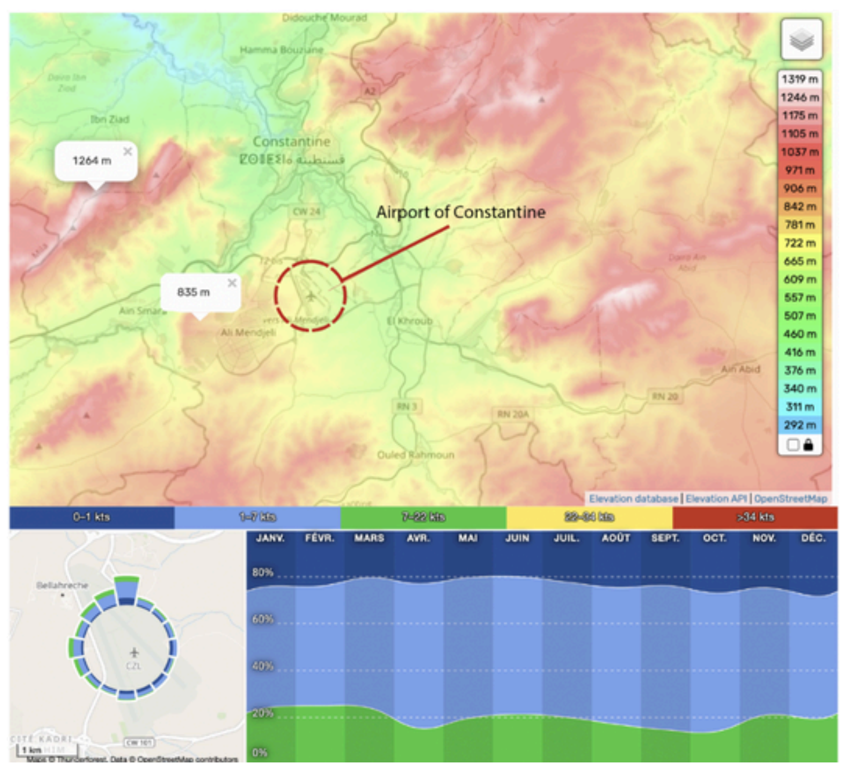
```
DO JLEV=1,KLEV
  DO JLON=KIDIA,KFDIA
    PEZDIAG(JLON,JLEV,5)=ZCIVERT(JLON,JLEV)
  ENDDO
ENDDO
```

Create the 5th diagnostic and add the wind shear

The computed vertical wind shear values stored in the array ZCIVERT are transferred to the diagnostic array PEZDIAG. The third dimension of the PEZDIAG array (indexed by 5 in this case) corresponds to the specific diagnostic variable for vertical wind shear. This array will then contain the wind shear values at each horizontal grid point and vertical level, ready for output.

This integration ensures that the wind shear variable is seamlessly incorporated into the model's diagnostic system and outputs, making it a valuable addition to the meteorological data generated by the AROME model as FULLPOSS (pressure and geopotential levels) and ICMSH (model levels).

Geographical Position and Orientation of Constantine Airport



Constantine Mohamed Boudiaf Airport is situated at an altitude of 685 meters in a mountainous region of the Constantine province. Surrounded by elevations ranging from 880 to 1300 meters, the complex terrain influences local air circulation and weather phenomena.

The airport experiences interactions between maritime air masses from the West and Northwest and continental air masses from the Southwest and South, leading to turbulence and rapid weather shifts that can impact operations.

To optimize flight conditions, the airport's runways are aligned with the dominant wind directions, ensuring aircraft face into the wind during takeoff and landing. The two main runways are oriented at 337°-157° and 314°-134°, benefiting from prevailing winds, particularly from the Northwest, to enhance flight safety.

Figure 2: Geographical Location of Constantine Airport and Surrounding Mountain Ranges and Monthly Distribution of Wind Direction and Strength [1] [2]

Study Case

This study focuses on two specific wind shear events identified by an aerial operator: one on February 2, 2023, and the other on June 8, 2024. These periods were chosen due to their significance in understanding wind shear phenomena during critical phases of flight, particularly during takeoff and landing. The study provides detailed shear maps, quantitative analyses, and comparisons with known critical thresholds for vertical wind shear. Periods Analyzed:

February 2, 2023: Between 07:00 and 07:40 UTC.

June 8, 2024: From 11:25 to 11:40 UTC, and from 19:05 to 19:25 UTC.

The analysis focuses on the altitude levels ranging from 0 to 1000 feet, a critical altitude zone for flight operations, specifically during the takeoff and landing phases. This range was selected because it is within the typical altitude band where wind shear can have the most significant impact on aircraft performance, especially in relation to low-altitude flight dynamics.

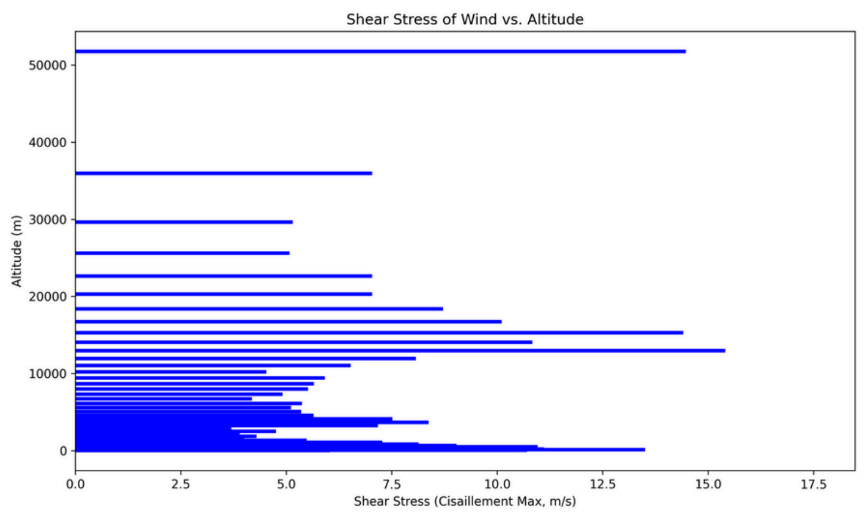


Figure 6: Vertical Profile of Maximum Wind Shear simulated by AROME over Constantine Airport for June 8, 2024 at 19 UTC; This vertical section bar depicts the maximum observed wind shear at different altitudes on June 8, 2024, highlighting the shear distribution at various levels.

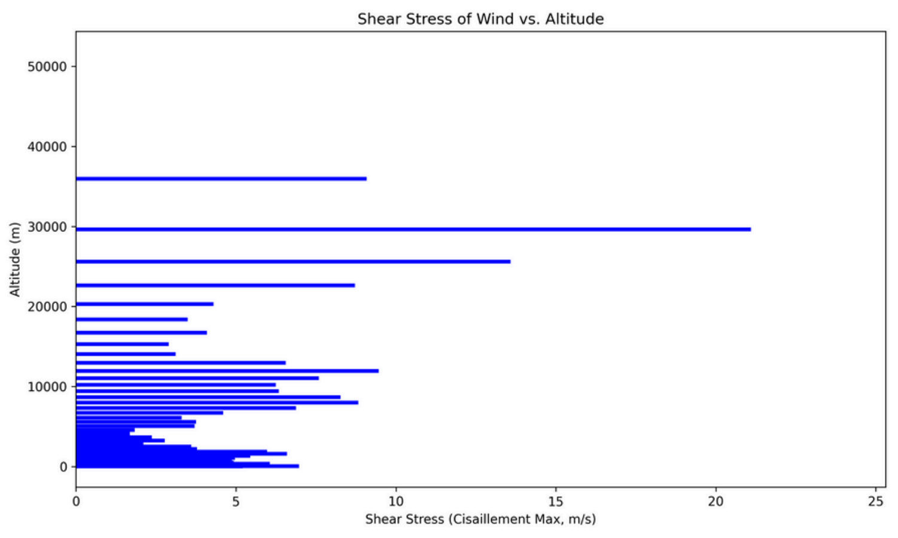


Figure 5: Vertical Profile of Maximum Wind Shear simulated by AROME over Constantine Airport for February 2, 2023 at 7 UTC; This vertical section bar represents the wind shear intensity at various model levels for February 2, 2023, showing how shear changes with altitude.

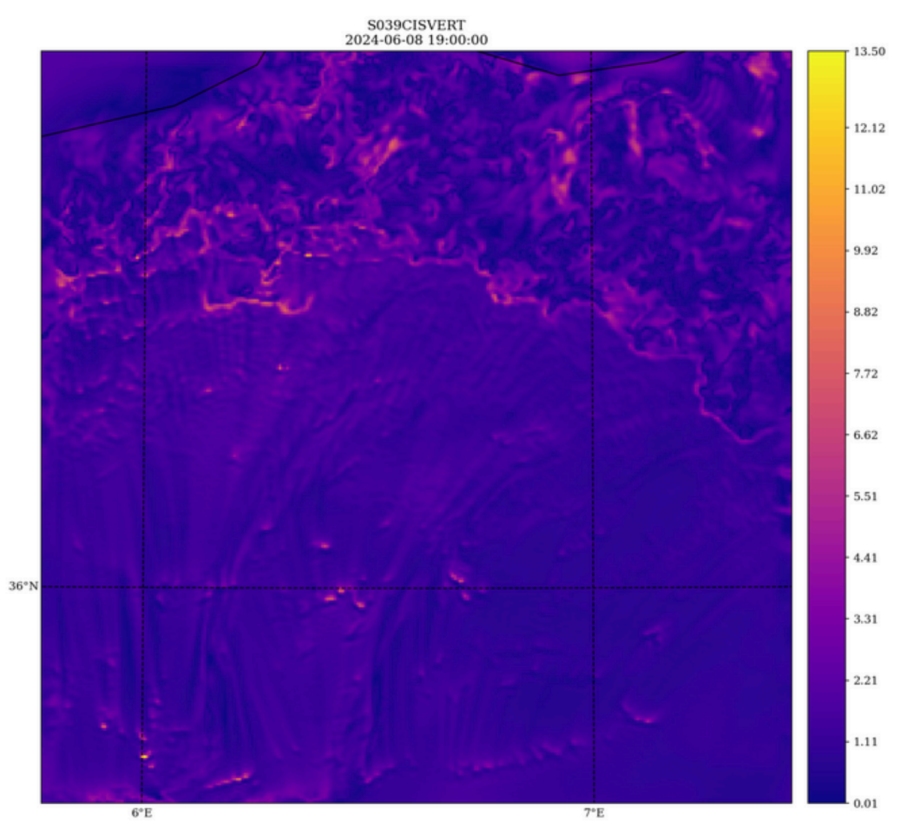


Figure 4: Wind Shear Distribution at Level 39 (~99 meters from the ground) over Constantine Airport, June 8, 2024, at 19 UTC .

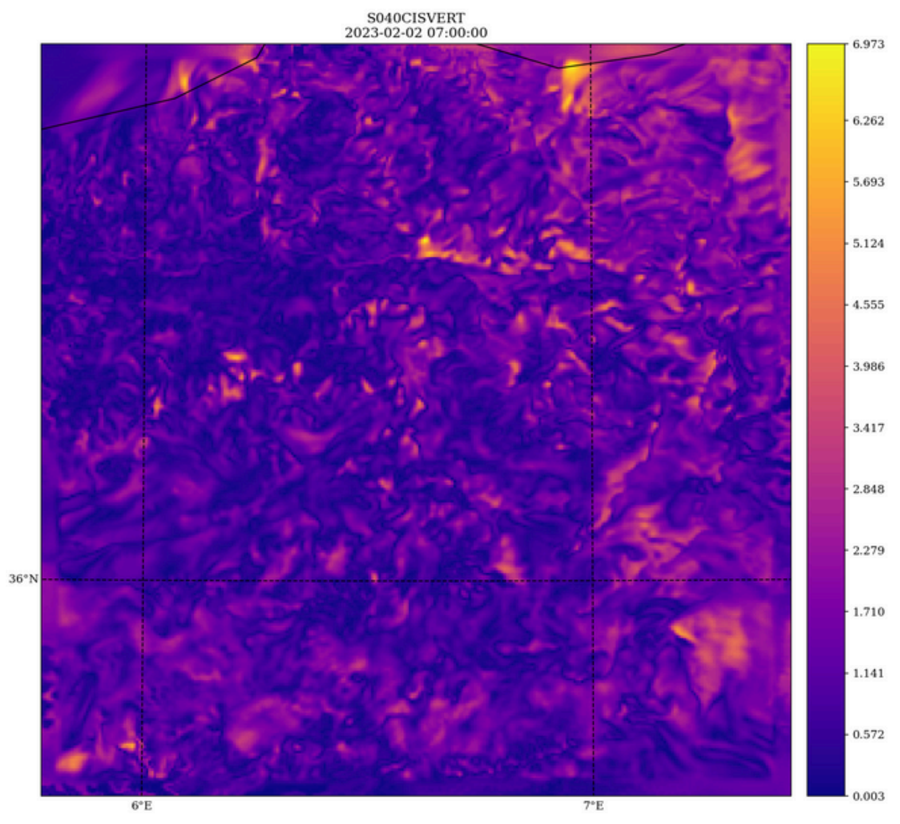


Figure 3: Wind Shear Distribution at Level 40 (~73 meters from the ground) over Constantine Airport, February 2, 2023, at 7 UTC

Perspective

Building upon the findings of this study, future research will aim to extend the analysis of wind shear at Constantine airport over a longer time period to better understand the seasonal variations and long-term trends in wind shear intensity. This expanded timeframe will allow for a more comprehensive understanding of the frequency, intensity, and distribution of wind shear events throughout the year, particularly in relation to the different meteorological conditions and topographical influences.

Furthermore, future studies will incorporate the direction of wind shear alongside its intensity. The directional component is crucial for understanding how wind shear impacts aircraft depending on its orientation relative to the flight path. By analyzing both the intensity and direction of wind shear, we can gain deeper insights into the spatial variability of shear events and their potential impact on flight safety during takeoff and landing phases.

The integration of wind shear direction will also enable the development of more precise forecasting tools and early warning systems, tailored to the specific needs of Constantine airport and similar locations with challenging terrain. This directionality analysis will be crucial in providing a more holistic view of the wind shear phenomena, allowing aviation authorities and pilots to take appropriate precautionary measures in real-time.

By expanding the temporal scope and adding wind shear direction to the analysis, the next phase of this study will provide a more robust dataset for aviation safety, helping to mitigate risks and optimize flight operations in the region.