Characteristics of the Low-Level Jets Observed over Dunkerque (North Sea French coast) using 4 years of wind lidar data

E. Dieudonné[1,*], H. Delbarre[1], A. Sokolov[1], F. Ebojie[1], P. Augustin[1], M. Fourmentin[1]

[1] Laboratory for Physico-Chemistry of the Atmosphere, University of Littoral and Opal Coast, Dunkerque, France

[*] Contact: elsa.dieudonne@univ-littoral.fr

Low-Level Jets (LLJs), i.e. low-altitude wind maxima, are a frequent feature in the atmosphere. They have been observed worldwide, over continents as over seas, and under all climates, though their formation mechanisms differ. LLJs play a great role in the **transport of heat, moisture, wildfire smoke and pollutants** over ten to hundreds of km. The strong wind shear below LLJs, that also generates a lot of turbulence, is a **problem for aviation** (plane landings and take-offs) **and the maritime traffic** (the largest ships have a ~75 m air draft). It is also a major stake for predicting **power generation and turbine fatigue in wind farms**.

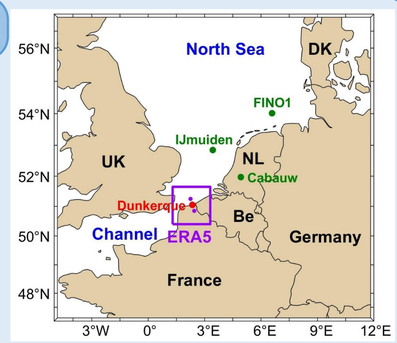
In Dunkerque, the interest for LLJs was raised by the building of a new wind farm and the extension of the port shipping container terminal. Previous studies in the North Sea were performed either fully offshore or inland, and farther from the English Channel, in which wind channeling is possible (Capon, 2003).

1/ Observation site & instrumentation

Previous observation-based studies about LLJs in the North Sea:

- **Cabauw**, ~50 km inland (Baas et al., 2009)
- **IJmuiden**, ~85 km offshore (Duncan, 2018; Kalverla et al., 2019, 2017)
- **FINO1**, ~50 km offshore (Wagner et al., 2019)

→ **completion by a coastal site, closer from the English Channel**





Background image from https://www.geoportail.gouv.fr/

Dunkerque: coastal city located in the Flanders Plain, ~40km from the narrowest point of the English channel (Dover Straight).

Ground altitude ~5 m above mean sea level (AMSL) for the coastal band

Doppler lidar (Leosphere WindCube v2)
+ sonic anemometer (Metek USA-1) close from the coastline

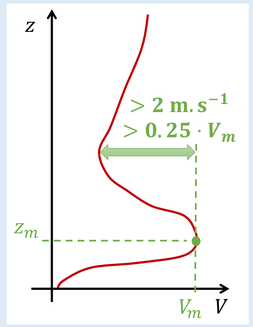
10-minute average wind profiles
13 altitude levels from 22 to 304 m AMSL

Only 49 % of profiles actually extend up to 304 m (change of settings + low clouds cutting the beams) but almost 96 % extend up to 234 m

2/ LLJ detection & characterization

Detection criteria:

- At least 2 m/s and 25 % decrease of horizontal wind speed V from the maximum V_m to the background wind above
- At least 2 points with observations above the maximum
- At least 2 consecutive profiles with such maximum



Main characteristics:

- **Jet core height** z_m = altitude of the wind maximum
- **Jet core speed** V_m = wind speed at the maximum
- **Jet core direction** θ_m = wind direction at the maximum

Classification (see also box 4):

- Six classes of core speed, defined from the speed distribution percentiles
- Four direction modes, defined from the core direction wind rose

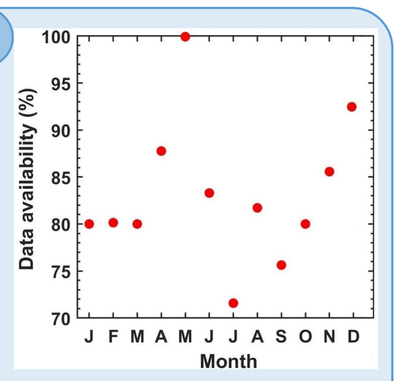
3/ Data availability & LLJ database

Four years of observations ranging from August 2016 to September 2021 with several interruptions:

- 1-15 June 2017 (power failure)
- Aug. to Nov. 2017 (change of lidar)
- Mid Dec. 2018 – mid April 2019 } other campaigns
- Mid June – mid July 2019

No anemometer data for the first 5 months (breakdown)

Data availability from 73 to 100 % depending on the month
→ **LLJ monthly frequencies are corrected for the data availability**



11,462 wind profiles with a LLJ
→ robust database for a statistical study

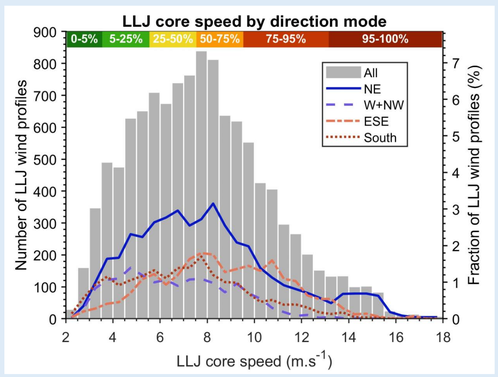
5 % of the profiles exhibit a LLJ.

Fraction of time with LLJ variable from year-to-year, though part of it is due to data availability issues

	Nb. wind profile	Nb. LLJ profiles	Frac. with LLJ (%)
Aug 2016 - Jul 2017	50,250	2,008	4.00
Aug 2017 - Jul 2018	36,330	1,426	3.93
Aug 2018 - Jul 2019	29,120	1,309	4.50
Aug 2019 - Jul 2020	50,875	3,263	6.41
Aug 2020 - Jul 2021	52,124	3,043	5.84
Whole period	**227,694**	**11,462**	**5.03**

4/ Jet core properties

Max. core speed of 33 m/s (4 values above 18 m/s).
Average ± 1σ = 7.8 ± 3.0 m/s
Core speeds >13.5 m/s belong almost exclusively to the NE mode



Speed distribution very similar to the Cabauw site.

In IJmuiden, the peak is also around 8 m/s but there are more strong jets (10-20 m/s).

No similar figure for FINO1.

LLJs in Dunkerque have **two well-defined dominant modes in the NE and ESE directions**, plus two more spread minor modes (South and N+NW):

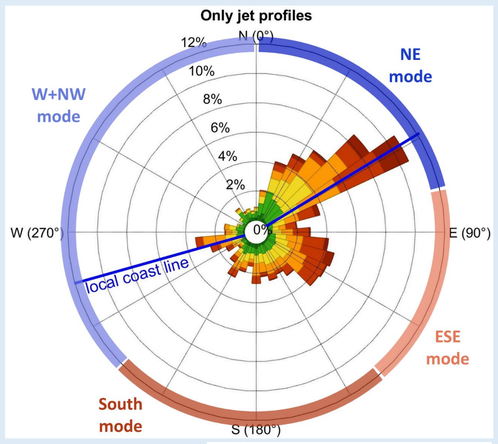
Mode name	Orientation	Azimuth range	Fraction of LLJs
Northeast (NE)	Onshore coastwise	0° - 80°	41 %
East-southeast (ESE)	Offshore cross-coast	80° - 140°	23 %
South	Offshore cross-coast	140° - 230°	21 %
West & North-west (W+NW)	Onshore cross-coast	230° - 360°	15 %

NE coastwise mode possibly due to wind channeling in the Dover Straight.

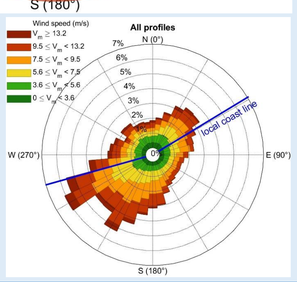
IJmuiden and FINO1 have a dominant SW or SSW mode. In Dunkerque, that direction is present on the general wind rose, but not on the jet core rose
→ possible effect of the limited measurement altitude?

Secondary mode from SE-ESE at FINO1 and NNE at IJmuiden: the differences in direction with Dunkerque can be due to coast orientation.

No similar figure for Cabauw.



↑ *Wind rose of the jet core directions*



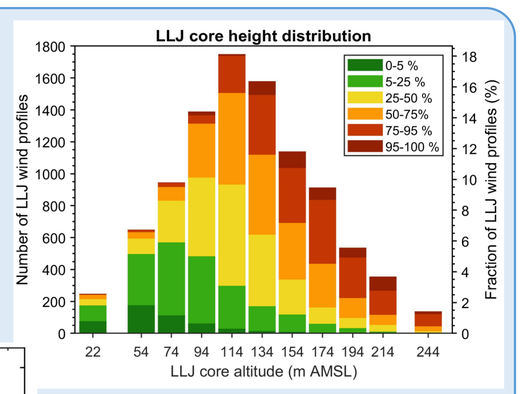
General wind rose at 114 m AMSL →

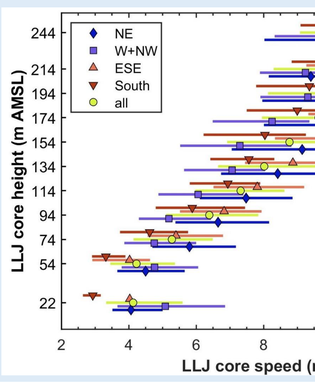
Core altitudes in Dunkerque peak around 114 m.

Similar to IJmuiden (90-100 m) and Cabauw (~140 m, though observations up to 500 m). Much higher peak at FINO1 (240 m), farther from the coast + observation up to 500 m.

Very little jets at 22 m (2.8 %) and 244 m (1.7 %). More elevated jets (>200 m) in Cabauw, though rare.

Weakest jets mostly below 100 m while strongest jets mostly above 100 m.





← *Median core speed as a function of core altitude; bars are 1st-3rd quartiles*

Very similar behavior as Cabauw.

No common behavior for the two offshore or the two onshore modes.

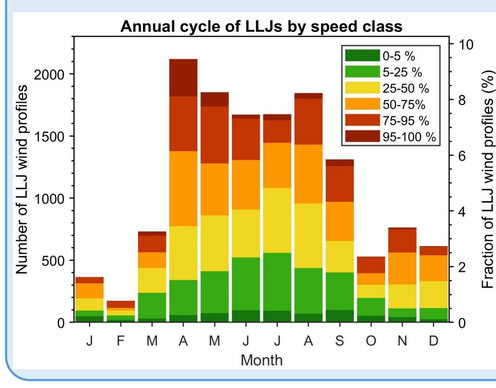
Stronger core speeds for the dominant modes (NE & ESE), except at the lowest altitude where the W+NW mode blows the strongest.

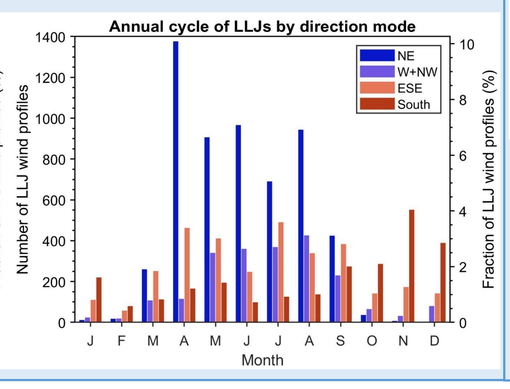
/!\ very few offshore jets at the 2 lowest altitudes while little onshore jets at the top altitude

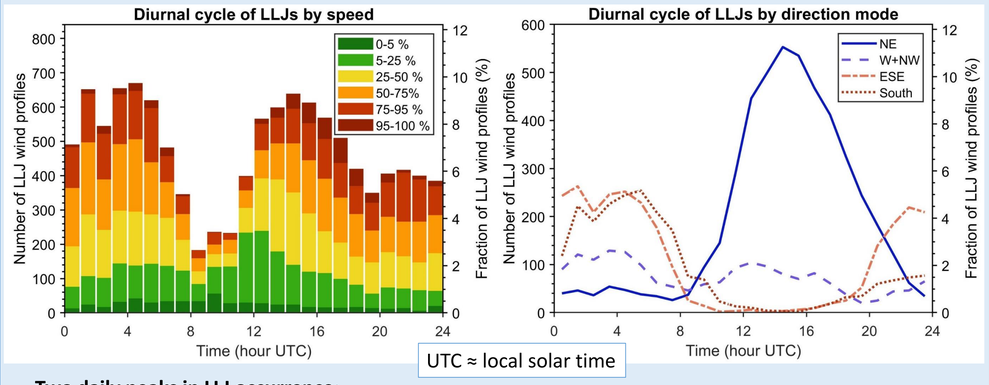
5/ Annual & diurnal variability

The annual cycle of LLJ occurrence in Dunkerque has a **spring-summer maximum** and a **late winter minimum**, like at IJmuiden, though the jet season last longer in Dunkerque (May to July at IJmuiden). In Cabauw, spring is an intermediate season and LLJ activity peaks in July-August.

The dominant NE mode is responsible for the spring/summer maxima in LLJ frequency but disappears from October to February. The cycle for the W+SW and ESE modes is similar. Only the South mode behaves differently, with a maximum from October to January.







UTC ≈ local solar time

Two daily peaks in LLJ occurrence:

- late night (00:00 to 07:00 UTC) due to the 2 offshore modes
- afternoon (12:00 to 18:00 UTC) due to the NE mode

Strong jets occur mostly in the afternoon.
Weak jets peak around noon, at the onset of the afternoon events.

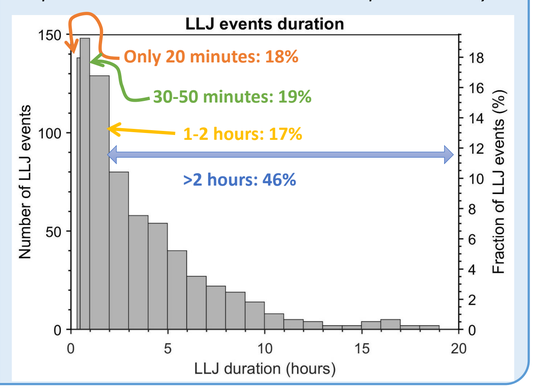
At the other sites, the situation is very different with a daytime minimum and night-time maximum
→ the afternoon peak is related with the coastal situation or English Channel vicinity

LLJ wind profiles were grouped into **"jet events"** using a time continuity criterion (max. 3-hour interruption). Results were eye-checked to discard abrupt changes in LLJ core direction.

→ 769 events **up to 26.3 hours**

→ **Average duration ± 1σ = 3.1 ± 3.7 hours**

NB. Impossible to attribute the events to direction modes or speed classes as the core direction or speed can vary.

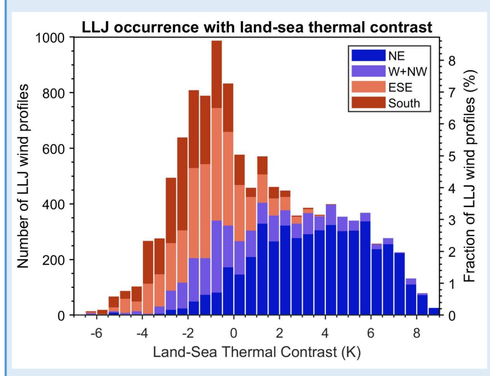


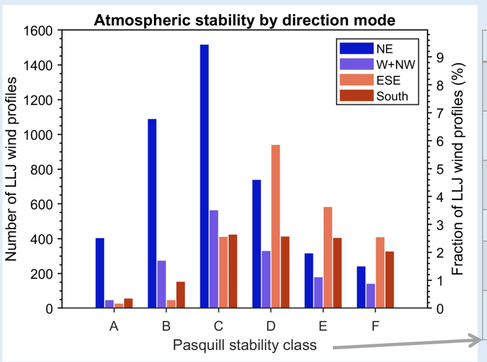
6/ Conditions of occurrence and possible formation mechanisms

Atmospheric stability: Monin-Obukhov stability parameter from the ultrasonic anemometer
values sorted into modified Pasquill stability classes for a 50 cm roughness length (Mohan & Siddiqui, 1998; Golder, 1972)

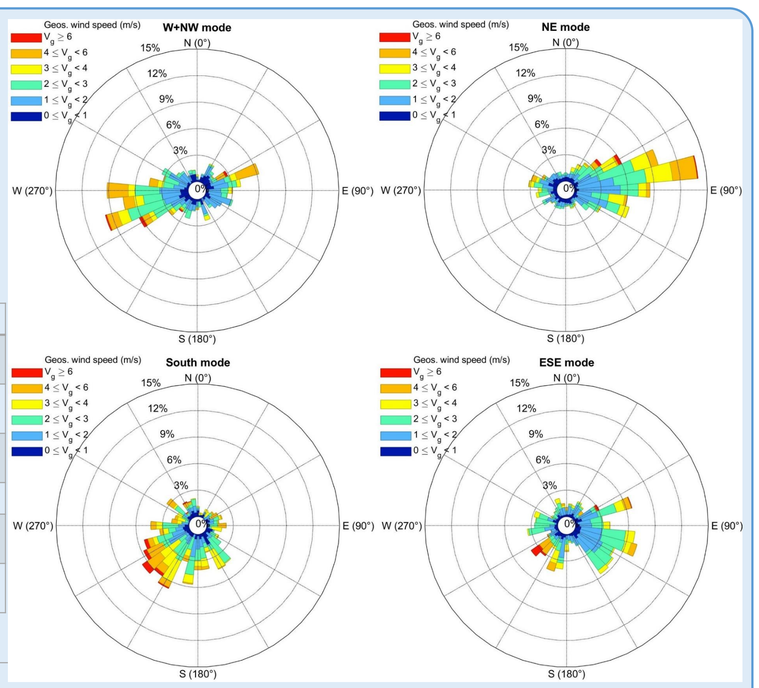
Extraction of **ERA5 reanalysis data at 0.25° and 1-hour resolution** in a square surrounding Dunkerque (see box #1 map), interpolation at the LLJ wind profile time (/!\ different from jet event onset time):

- **Land-sea thermal contrast** (LSTC): difference in 2-m temperature between the 2 purple dots
- **Geostrophic wind**: planar fit of the mean sea-level pressure values in the square





Class	Stability
A	Extremely unstable
B	Moderately unstable
C	Slightly unstable
D	Neutral
E	Moderately stable
F	Extremely stable



Mode	LSTC	Stability	Geostrophic flow	Likely type of jet
W+NW	Around 0	Moderately unstable to neutral	Westerly	Sea breeze (cyclonic conditions) and ?? (nocturnal occurrences)
NE	Warmer land	Extremely unstable to neutral	Easterly	Sea breeze (anticyclonic cond.) or anticyclonic flow channeled in the Dover Straight
ESE	Warmer sea	Slightly unstable to extremely stable	Moderate SE or strong SW	Land breeze, nocturnal LLJ
South	Warmer sea	Slightly unstable to extremely stable	Strong SW	Frontal passage, channeling of a cyclonic flow in the Dover Straight

7/ Conclusions & perspectives

Conclusions

- **A LLJ was present on 5% of the wind profiles** (11,462)
- The typical LLJ in Dunkerque has a core wind speed of 7-8 m/s and a core altitude around 114 m AMSL.
- Different behavior from the other North Sea area sites:
  - **The dominant LLJ core direction is not SW, but NE** (onshore coastwise) with 41% of the wind profiles with LLJ.
  - **The NE mode and total LLJ activity peak in the afternoon**, though a late night peak similar to other sites exists, that is due to offshore jets.
- The conditions of occurrence of the dominant NE mode point towards sea-breezes (under anticyclonic conditions) and anticyclonic flows channeled into the Dover Straight

Perspectives

- Process **observations with higher vertical extension** (existing dataset of ~2.7 years of WLS100 Doppler lidar at yellow site)
- Develop **more evolved grouping strategies into LLJ modes**, e.g. using machine learning
- **Quantify the share of local** (sea/land breeze), **regional** (channeling in the Dover Straight) **and large-scale** (frontal passages) **LLJs using ERA5 reanalyses**

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