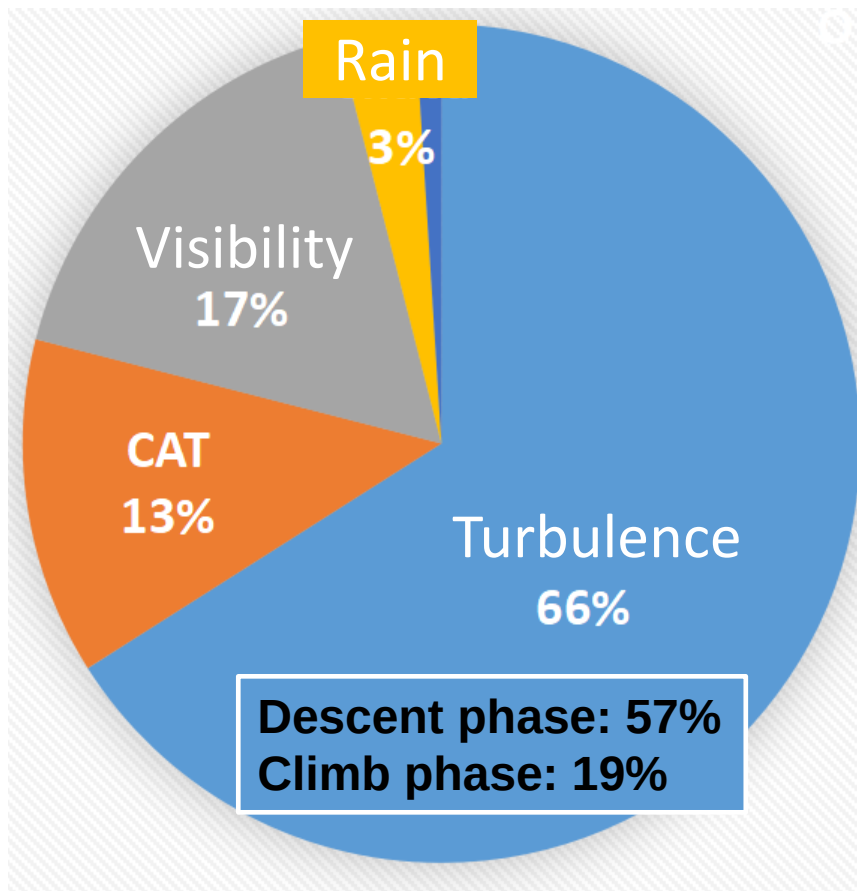


Aviation Turbulence Forecasting over the Portuguese Flight Information Regions: Objective Verification and case study

Belo-Pereira, Margarida, 2022. "Aviation Turbulence Forecasting over the Portuguese Flight Information Regions: Algorithm and Objective Verification" *Atmosphere* 13, no. 3, 422. <https://doi.org/10.3390/atmos13030422>

Cruise phase (Mazon et al, 2017)



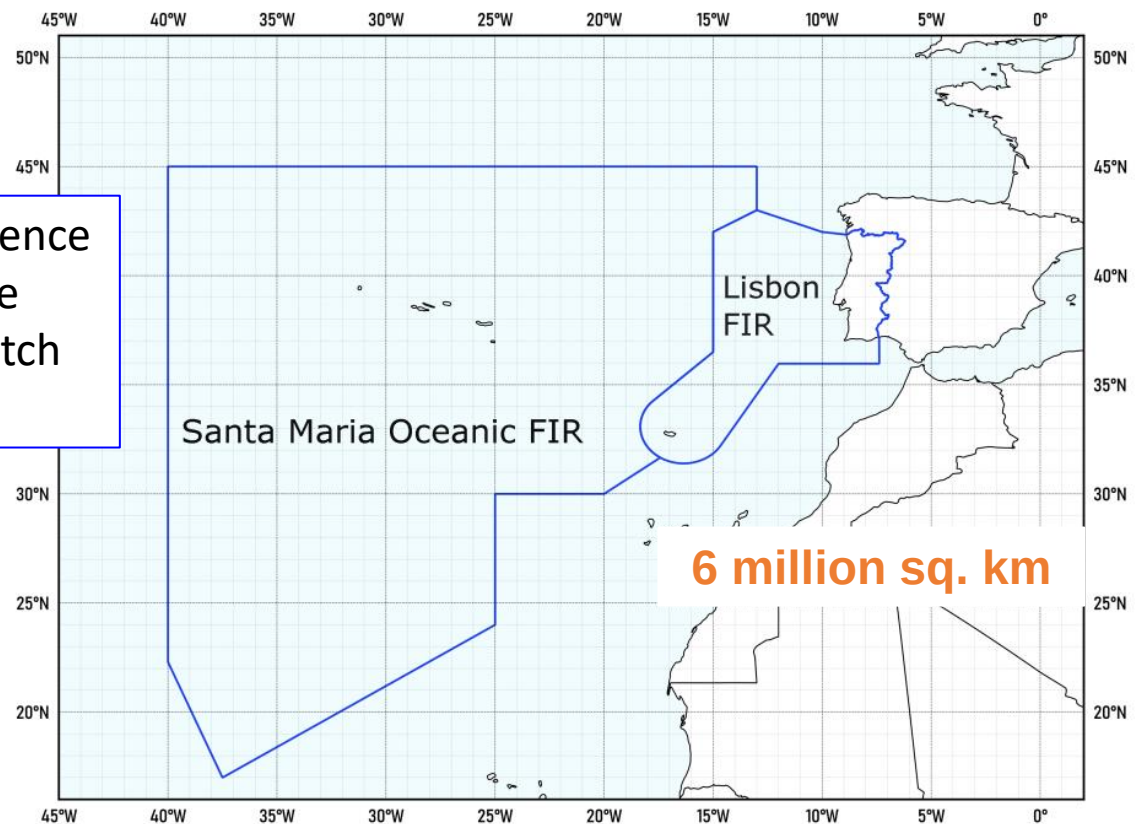
Aviation turbulence, experienced as in-flight bumpiness, is atmospheric turbulence caused by turbulent eddies with scales that can affect aircraft in flight.

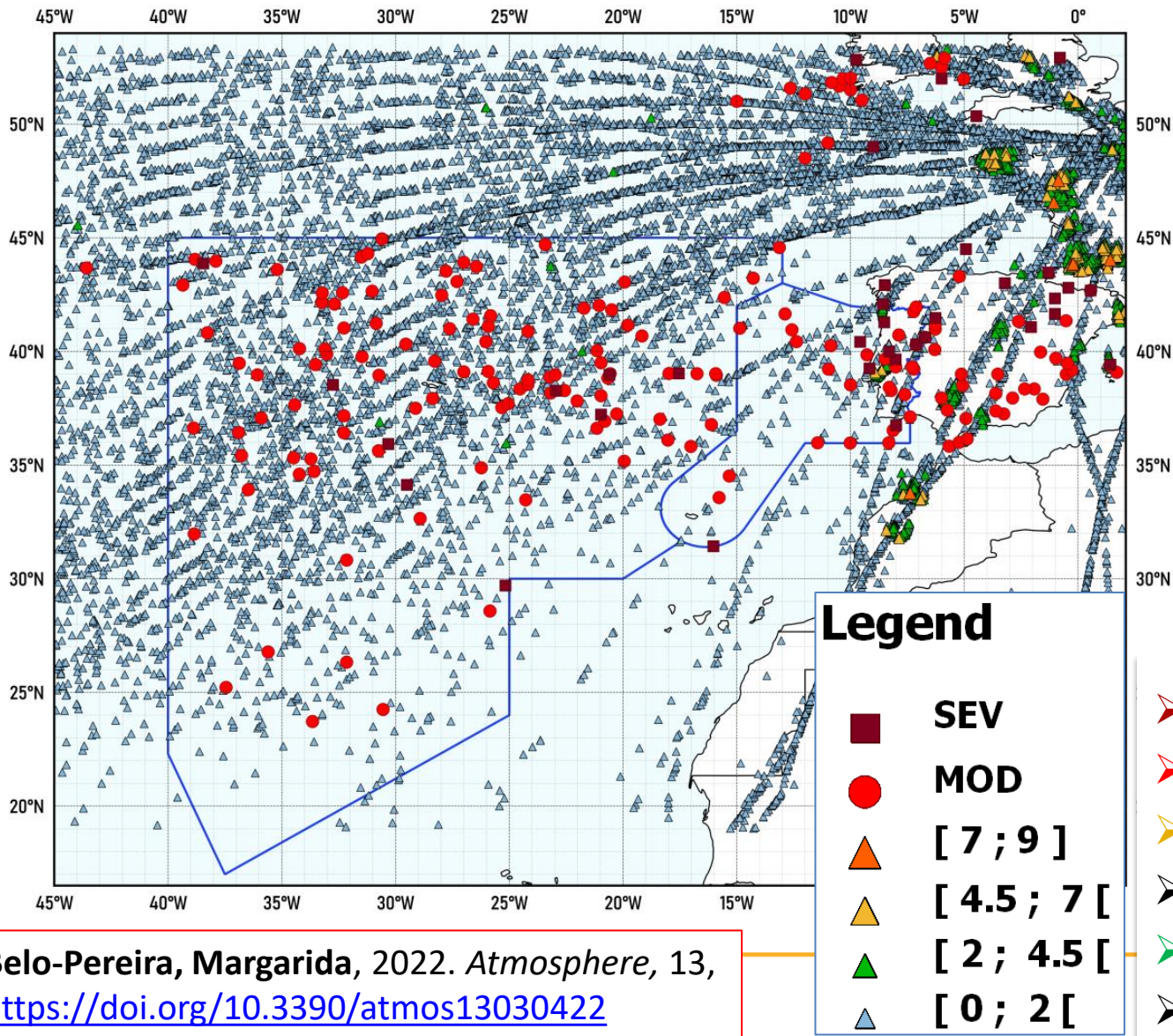
Turbulence remains a major aviation hazard, as it is the leading cause of weather-caused accidents worldwide, at cruise and descent phases (Mazon et al, 2017).

A major part of the incidents and accidents attributed to the weather occur in latitudes between 12° and 38° in both hemispheres (Mazon et al, 2017).

Instituto Português do Mar e da Atmosfera (IPMA), as MWO, is responsible to prepare and disseminate SIGMET (Information issued by a meteorological watch office concerning the occurrence or expected occurrence of specified en-route weather and other phenomena in the atmosphere that may affect the safety of aircraft operations) to two flight information regions (FIR)

The goal is to develop a turbulence index for operational use in the Portuguese meteorological watch office (MWO).





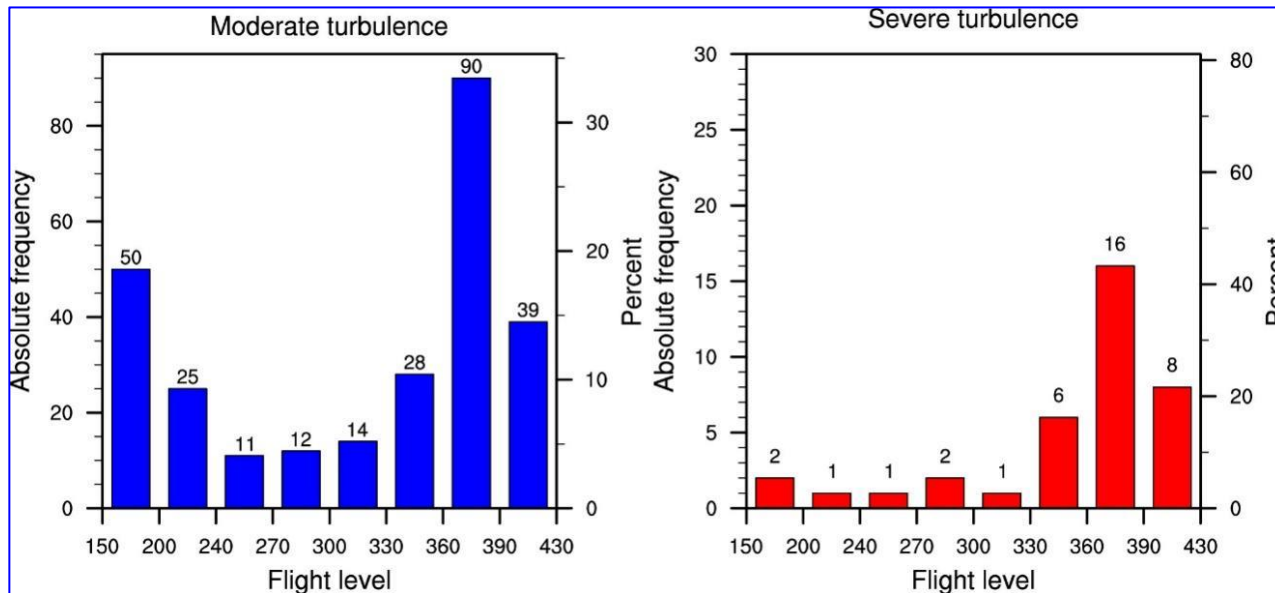
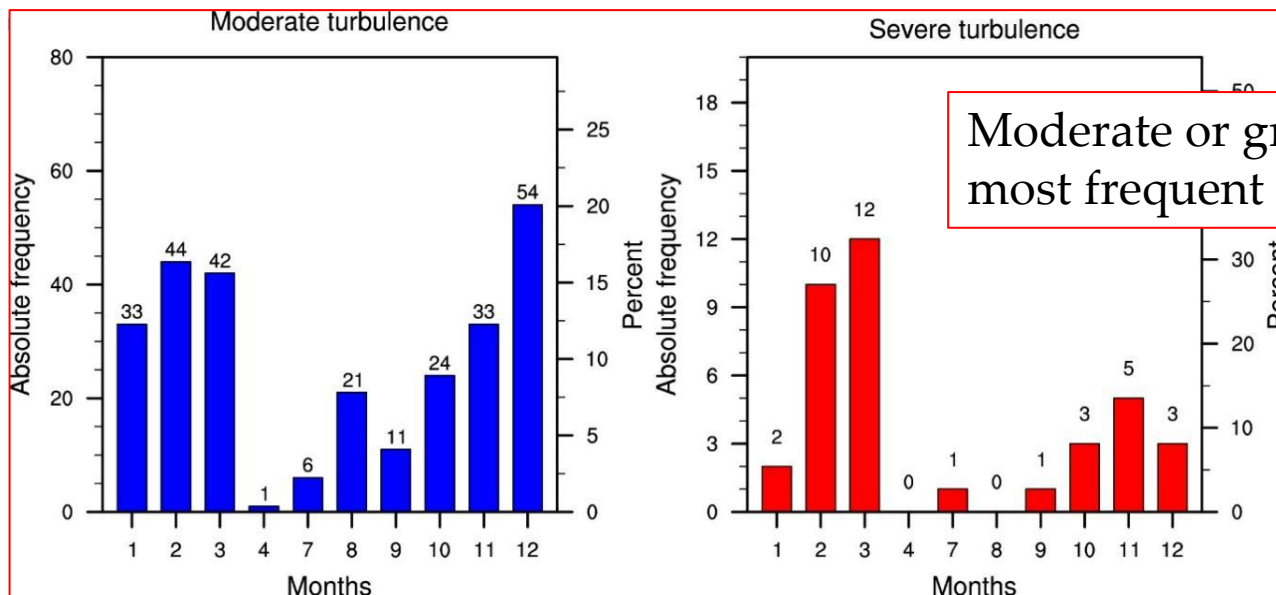
Observations

- 19120 DEVG
- 222 AIREPs

Null cases (92.4%)

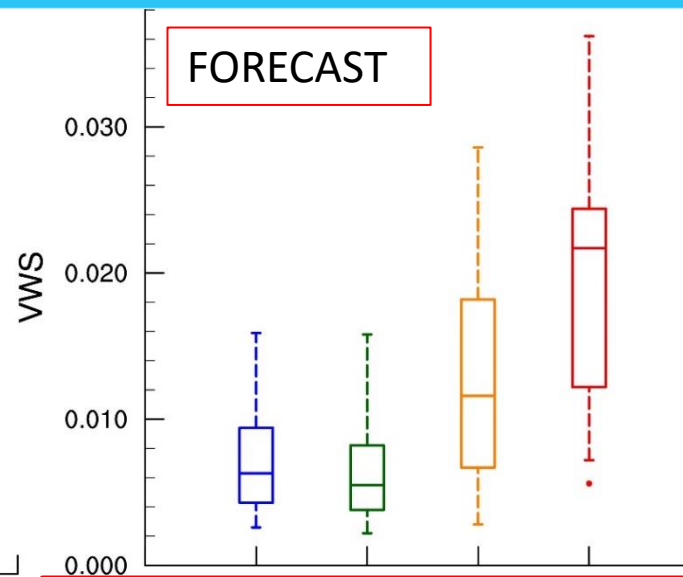
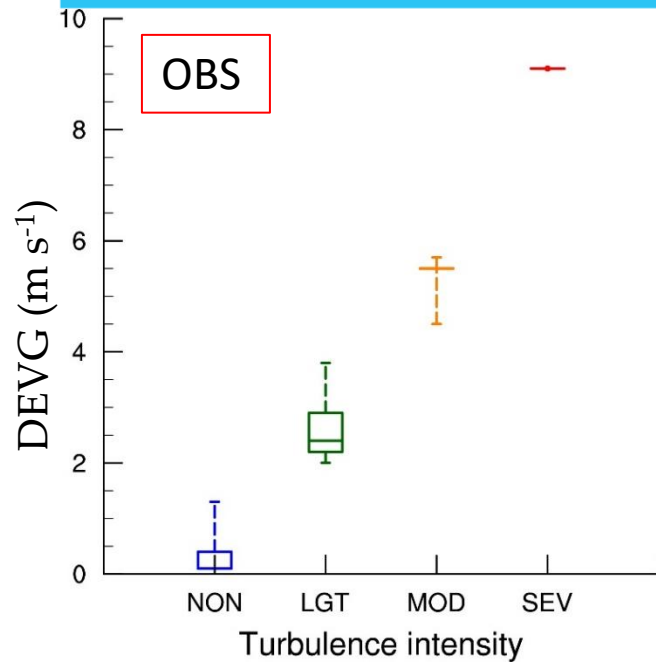
LGT turbulence :
7.2% of the DEVG data

Characterization of turbulence observations



MOG turbulence:

- peaks in FL360/390
- second maximum in FL390/430

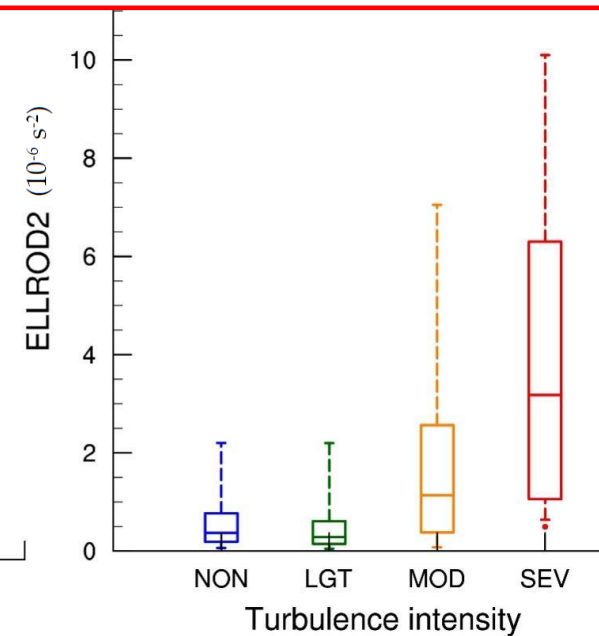
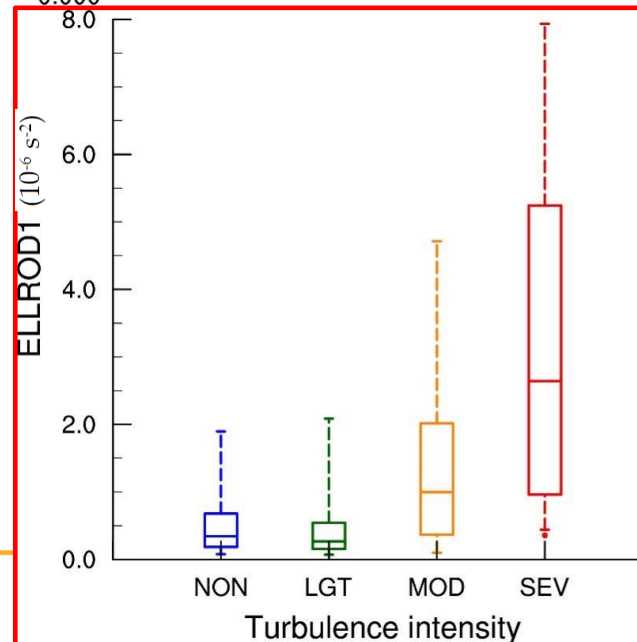


Model data

Deterministic ECMWF forecasts

$$VWS = \sqrt{\left(\frac{\partial u}{\partial z}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2}$$

$$ELLROD1 = VWS \times DEF$$



Brown index:

$$EE = \frac{1}{24} VWS^2 \left(\sqrt{0.3\zeta_a^2 + DSH^2 + DST^2} \right), \quad DST = \frac{\partial u}{\partial x} - \frac{\partial v}{\partial y}; \quad DSH = \frac{\partial v}{\partial x} + \frac{\partial u}{\partial y}$$

$$DUTTON = 1.25 HWS_k + (0.25 VWS_k^2) + 10.5, (A6)$$

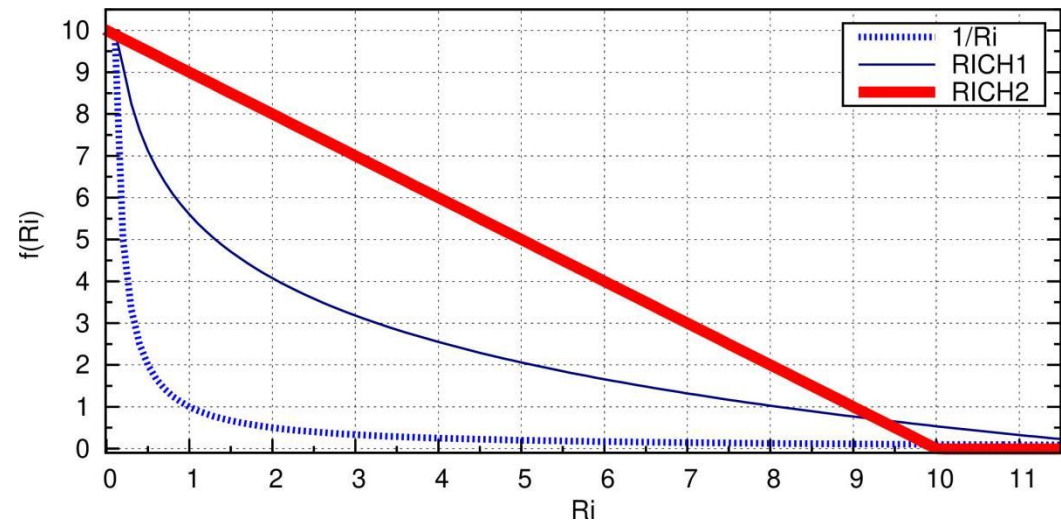
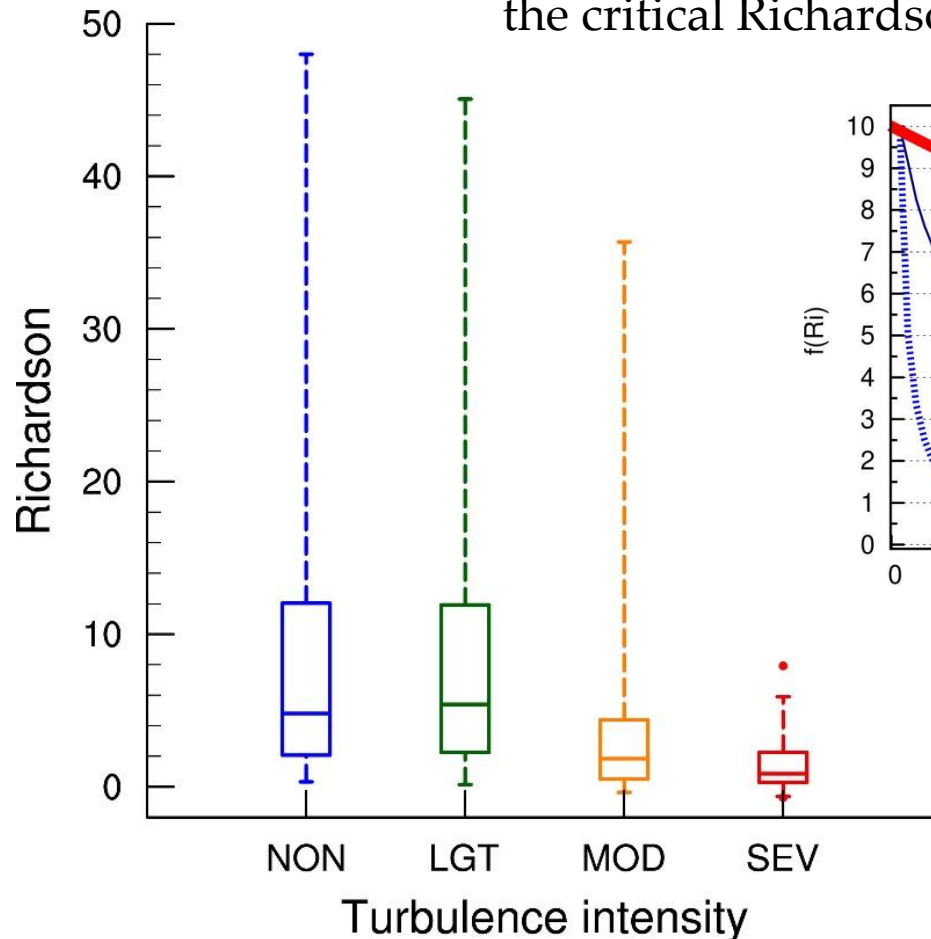
where $VWS_k = VWS \times 10^3$ denotes the vertical wind shear in $\text{ms}^{-1} \text{km}^{-1}$ and

$HWS_k = HWS \times 10^5$ denotes the horizontal wind shear in $\text{ms}^{-1} / 100 \text{ km}$ and HWS (in s^{-1})

$$CAT1 = VV \times DEF,$$

$$CAT2 = \left| \frac{\partial T}{\partial z} \right| \times DEF,$$

Kelvin–Helmholtz instability (KHI) is a known source of CAT and this instability is favored when R_i is less than the critical Richardson number (R_{ic})



RICH1 decays with R_i more steeply than RICH2, but more slowly than $1/R_i$.

Forecast	Observation	
	Obs < o_i (No)	Obs $\geq o_i$ (Yes)
Index < f_i (No)	NN	NY
Index $\geq f_i$ (Yes)	YN	YY

$$TSS = POD - POFD$$

$$POFD = YN / (YN + NN)$$

$$POD = YY / (YY + NY)$$

$$SEDS = \frac{\log(q) - \log(POD)}{\log(BR) + \log(POD)}$$

$$q = (YY + YN)/N$$

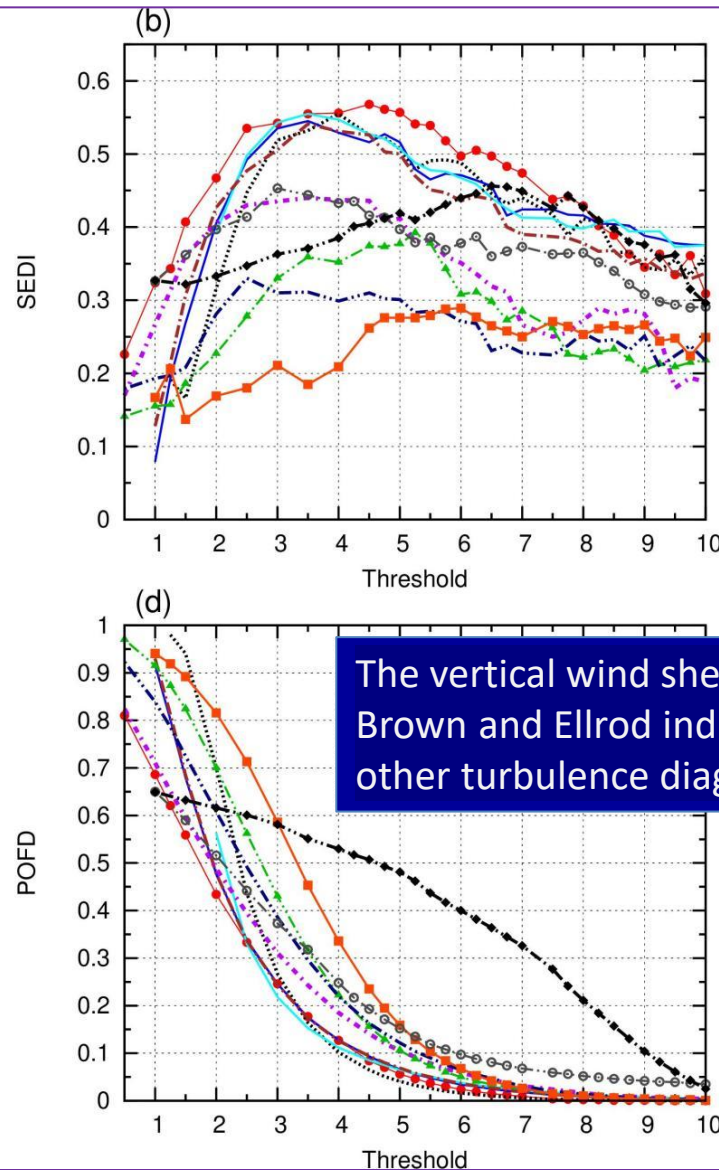
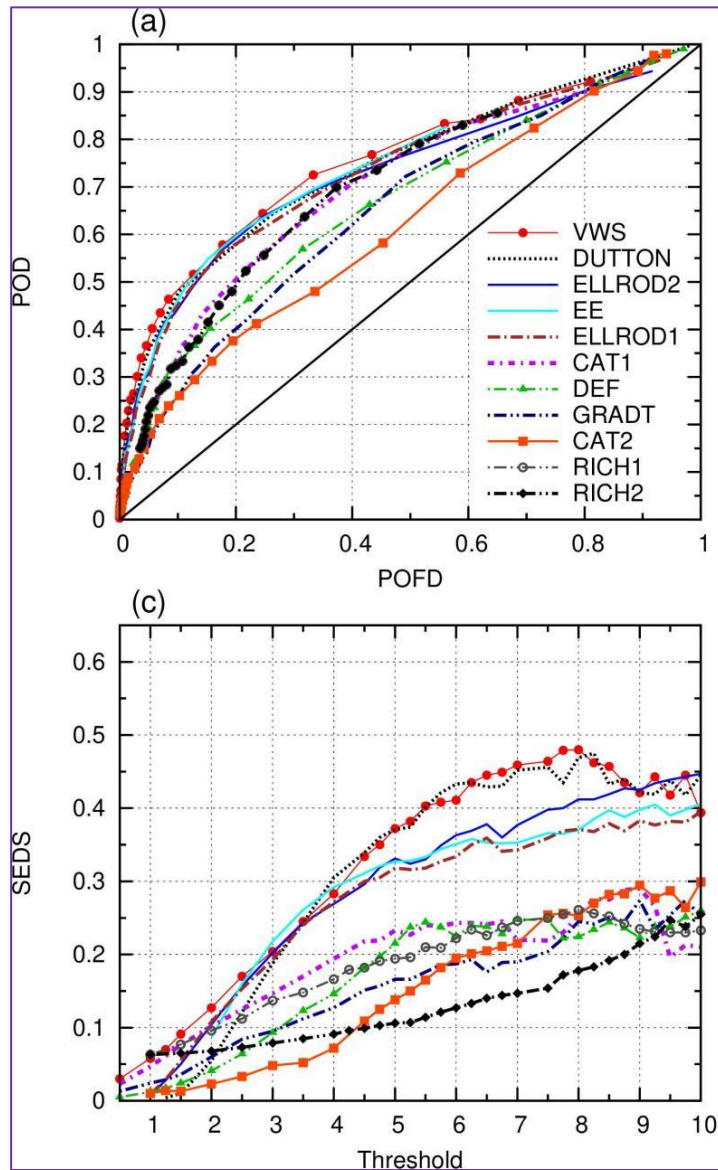
$$BR = (YY + NY)/N$$

[Hogan et al. \[2009\]](#)

$$SEDI = \frac{\log(POFD) - \log(POD) + \log(1 - POD) - \log(1 - POFD)}{\log(POD) + \log(POFD) + \log(1 - POD) + \log(1 - POFD)}$$



Scores of individual predictors



SEDS achieve higher values for higher thresholds (compared to SEDI)

The vertical wind shear (VWS), DUTTON, Brown and Ellrod indices outperform the other turbulence diagnostics.

The turbulence diagnostics can be combined into a single turbulence index using a weighted average of several indices:

$$\text{MULTI} = \sum_{i=1}^N w_i \max(0, IT_i), \quad w_i = AUC_i^2 / \sum_{i=1}^N AUC_i^2$$

 *f(turbulence index)*

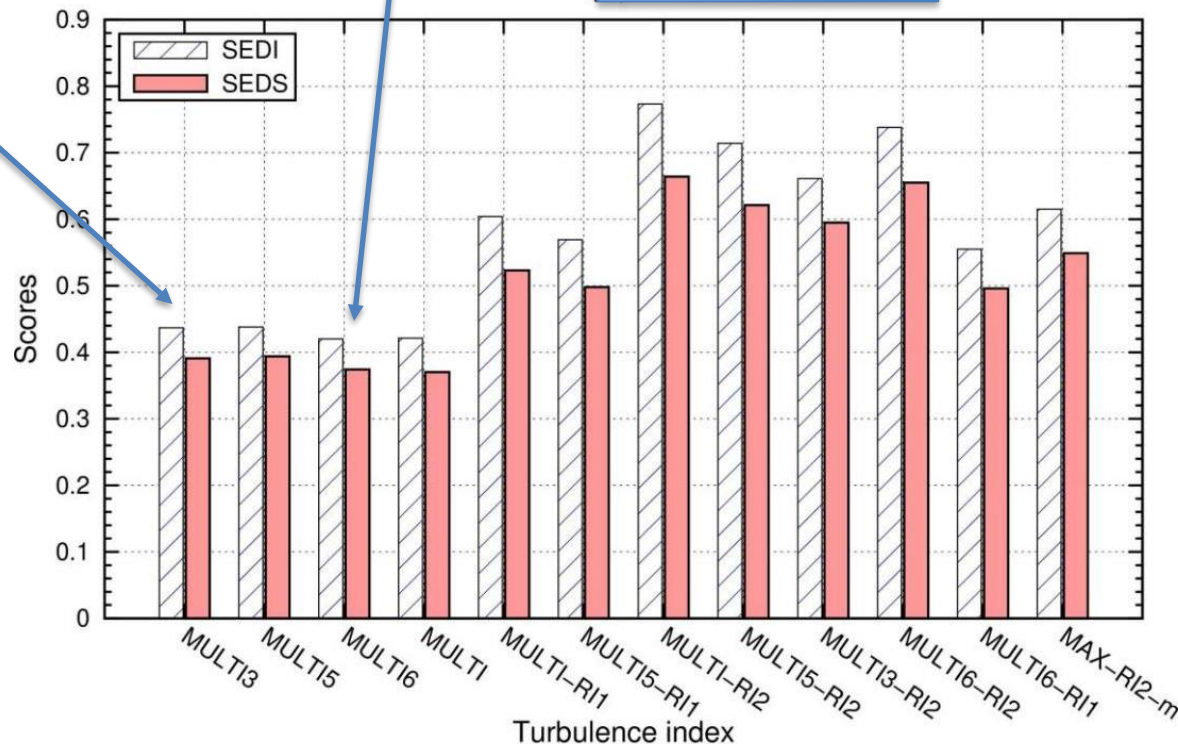
 **Area Under the ROC curve**

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$$\text{MULTI6} = f(\text{EE}, \text{ELLROD2}, \text{VWS}, \text{DUTTON}, \text{CAT1}, \text{DEF})$$

$$\text{MULTI-RI2} = (1 - \text{coef}) \text{MULTI} + \text{coef} \times \text{RICH2}$$

$$\text{MULTI3} = f(\text{EE}, \text{ELLROD2}, \text{DUTTON})$$





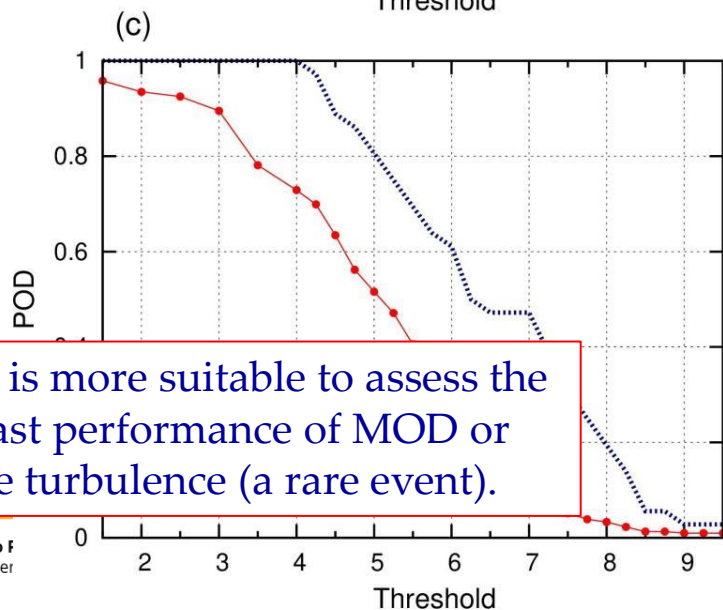
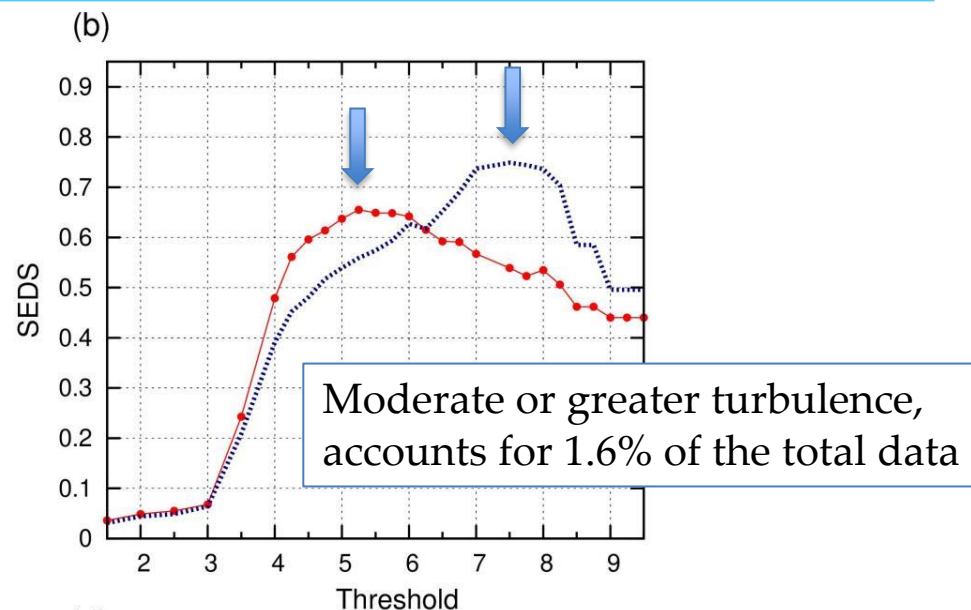
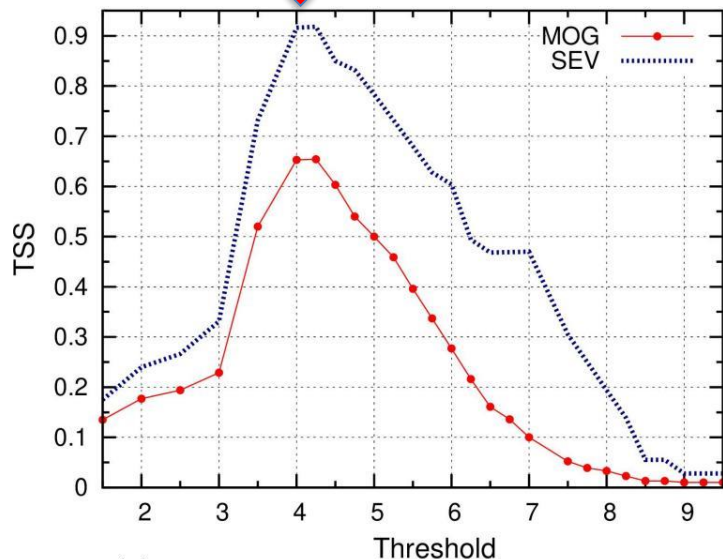
IPMA

Instituto
Português
do Mar e da
Atmosfera

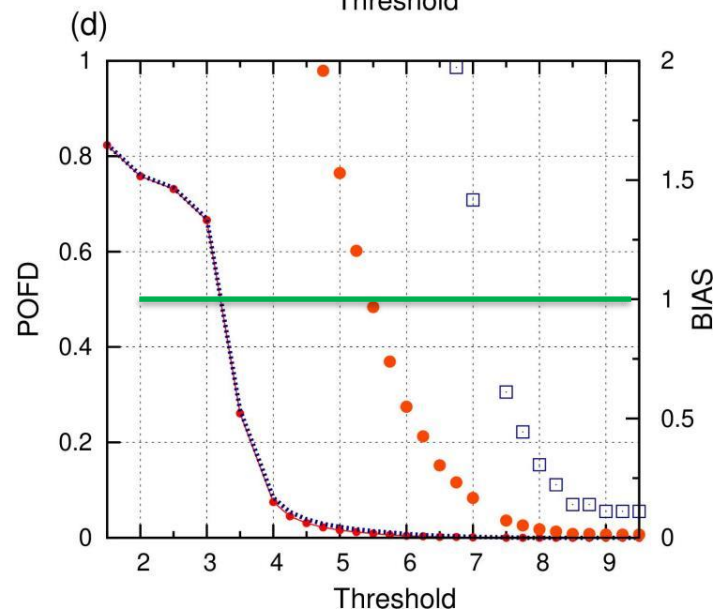
Scores of $TURB_{IPMA}$

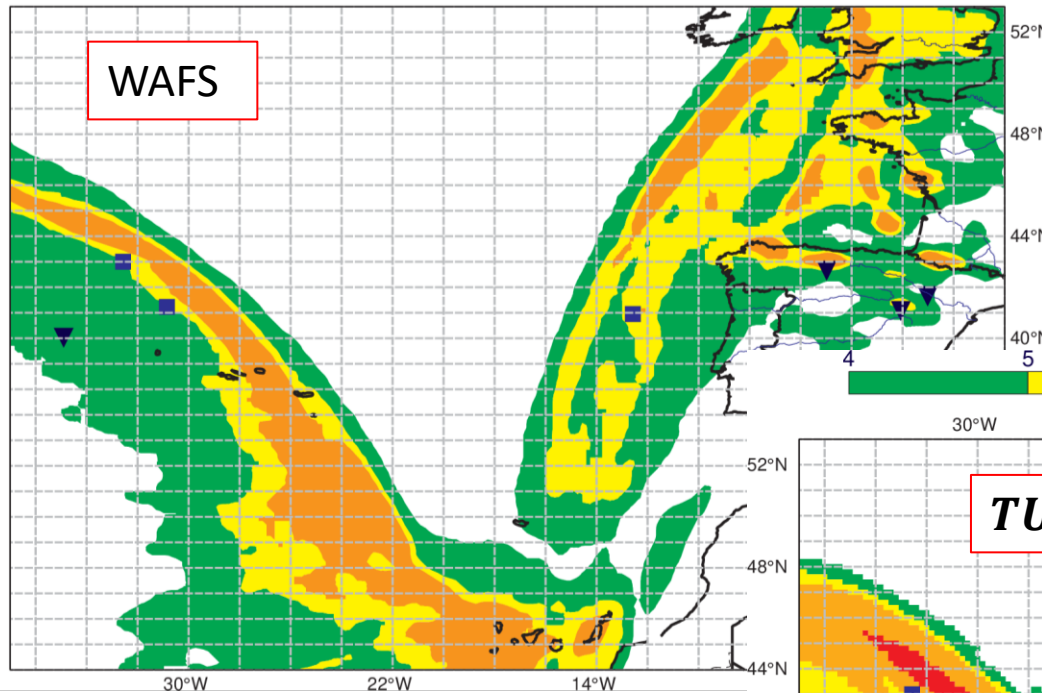


MULTI6-RI2



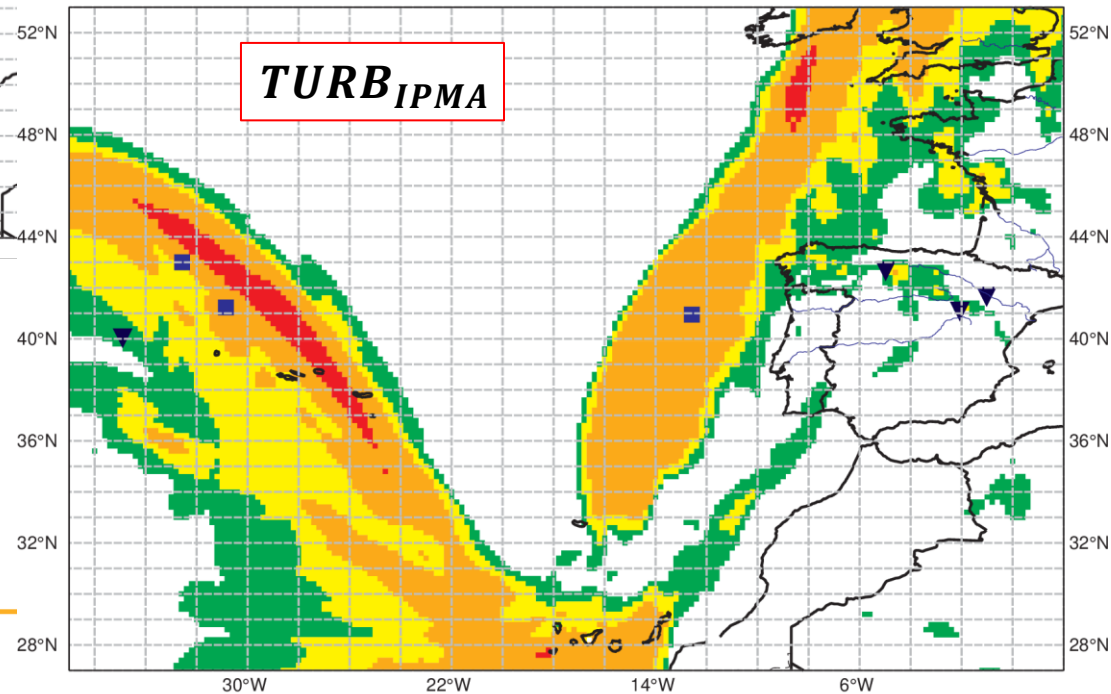
SEDS is more suitable to assess the forecast performance of MOD or severe turbulence (a rare event).





On 20 February 2021, the Canadian and Portuguese MWOs issued turbulence SIGMETs, respectively, for Gander and Santa Maria Oceanic FIRs

These turbulence zones lie on the western edge of an upper-level trough.



Belo-Pereira, Margarida,
2022. *Atmosphere*, 13

Thanks you for the attention !

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