Clear Air Turbulence observed across a tropopause fold over the Drake Passage – A Case Study

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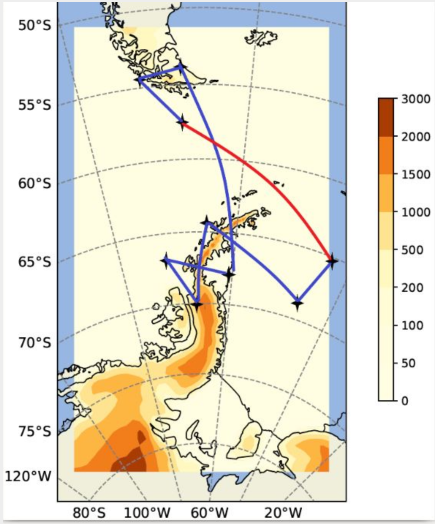
Outline

Clear Air Turbulence observed across a tropopause fold over the Drake Passage – A Case Study*

- Study and characterization of clear air turbulence (CAT) encounter by HALO when flying between east Marambio and Rio Grande (red part of flight path)

1. **Large scale pattern suitable for CAT scenario:**
   a. Synoptic analysis
   b. CAT indices reproduced by NMP: ERA5 dataset
2. **Mesoscale phenomena accounting for turbulence**
   a. Marambio radiosounding
   b. Comparison with regional NPM WRF-Polar
3. **BAHAMAS 10 Hz dataset**
   a. Time series and spectra
   b. **T**urbulent **K**inetic **E**nergy (**TKE**) and **E**ddy **D**issipation **R**ate (**EDR**)
   c. Structure functions

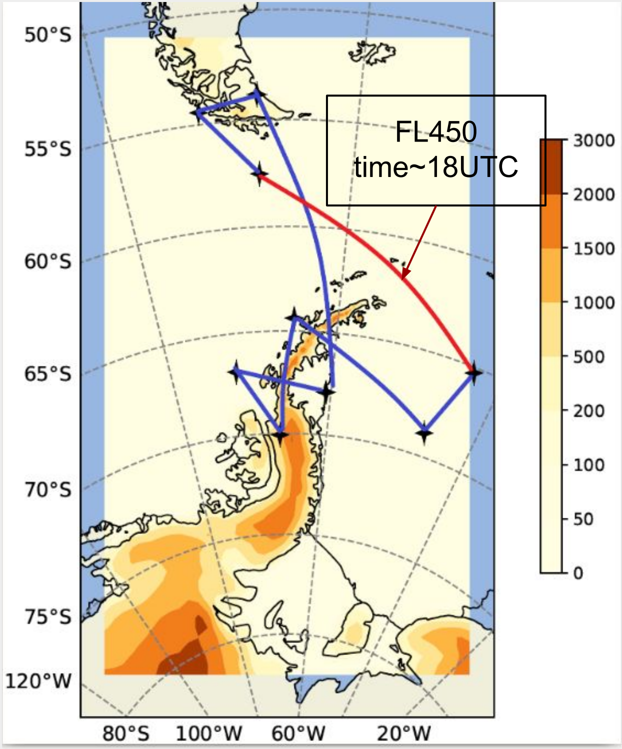
HALO flight track 12 Nov (ST25)

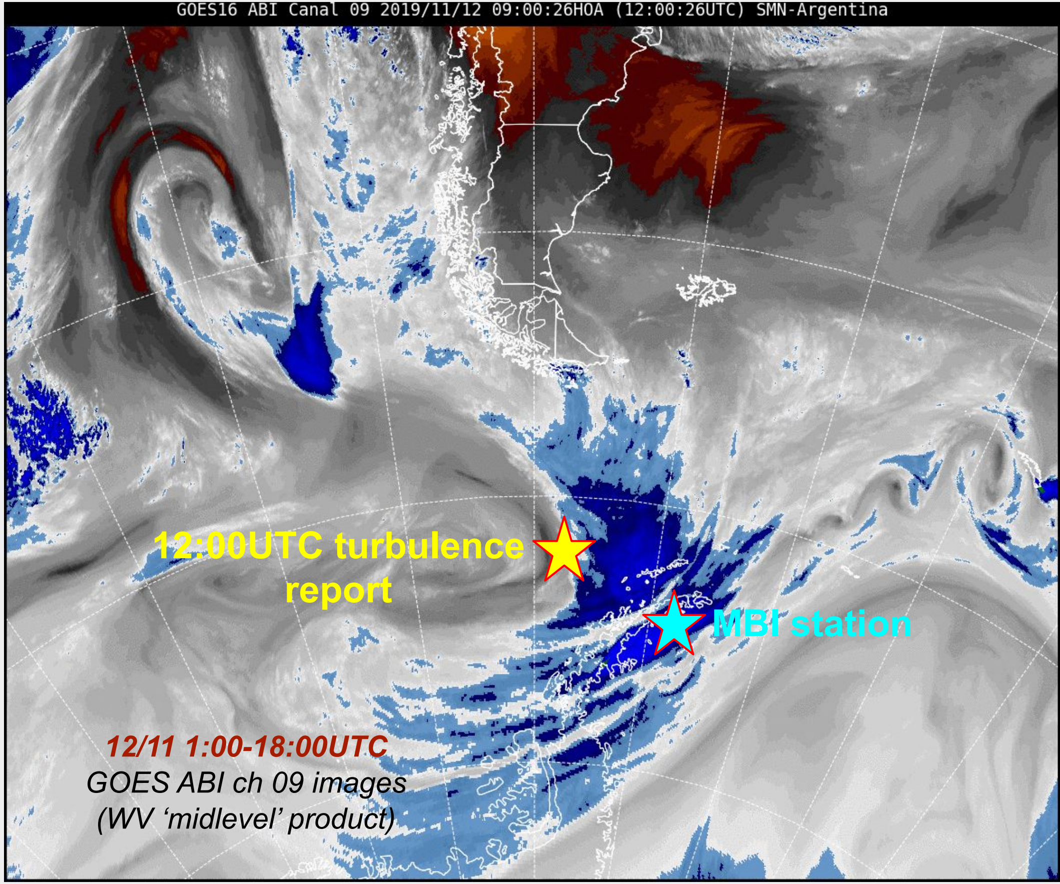


*Submitted to JGR-Atmospheres. ST " SOUTHTRAC-GW"

Introduction

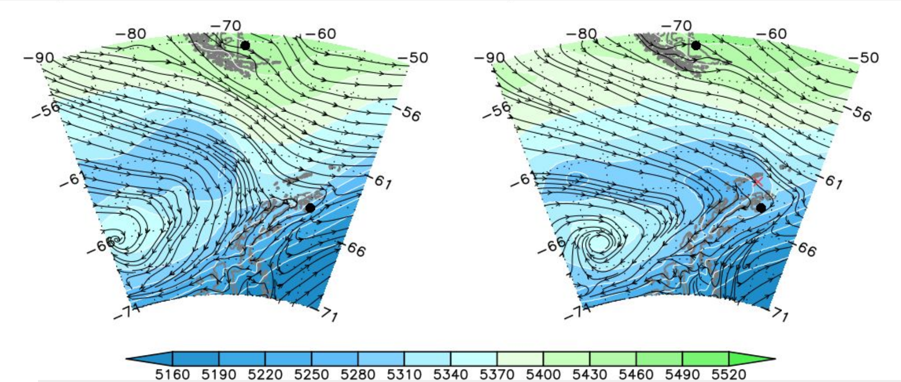
HALO flight track on 12 Nov (ST25),



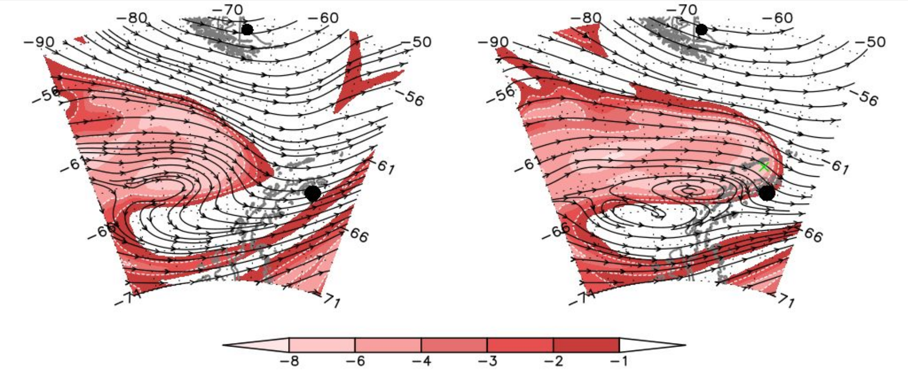


Synoptic conditions during ST25 (ERA5), maps for 12 and 18 UTC, Nov 12

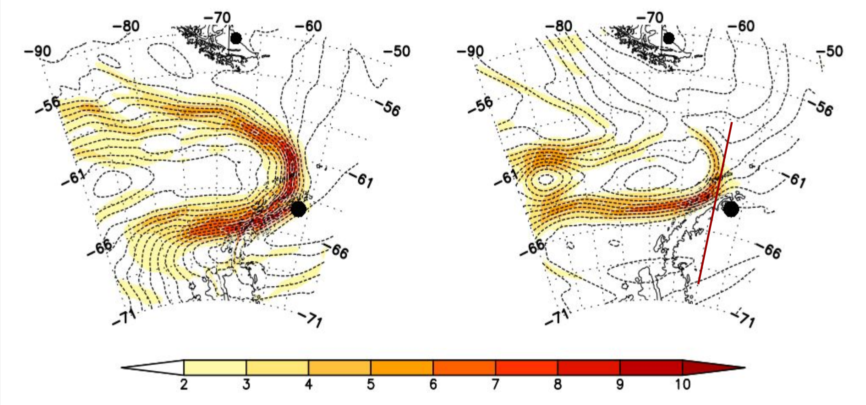
Streamlines 1000 hPa, thickness (shaded) 1000/500 hPa

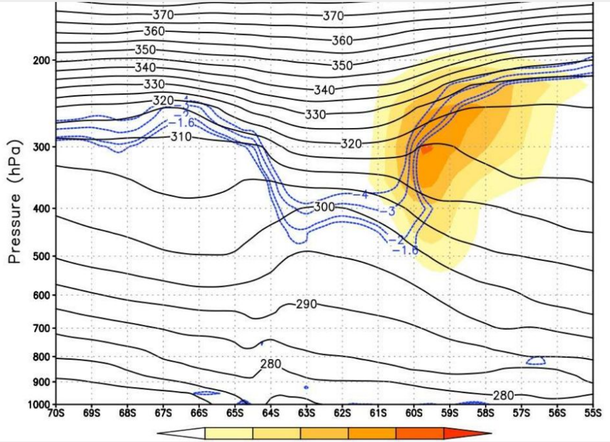


Streamlines and PV (shaded) 300 hPa



Horizontal temperature gradient at 250 and 300 hPa



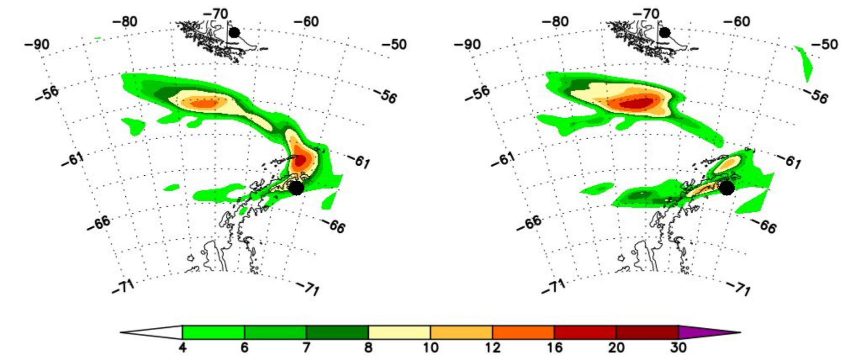


North-South cross section along 60°W . Potential vorticity (-1.6 to -4 PVU, blue contours), horizontal wind greater than 40 m s^{-1} (color-shaded) and potential temperature (K, black lines) at 18:00 UTC.

CAT indices from ERA5, 18 UTC Nov 12

CAT indices commonly used to forecast aircraft turbulence.
Most significant level at 250 hPa

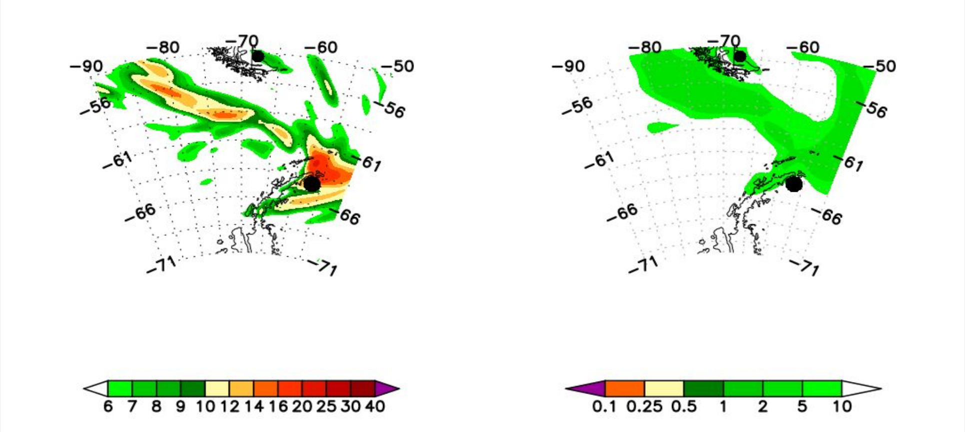
Ellrod TI1 and TI2 at 250 hPa



Ellrod: horizontal deformation x vertical shear (TI1); including divergence (TI2)

Smooth	**4**
Moderate	**8**
Severe	**12**

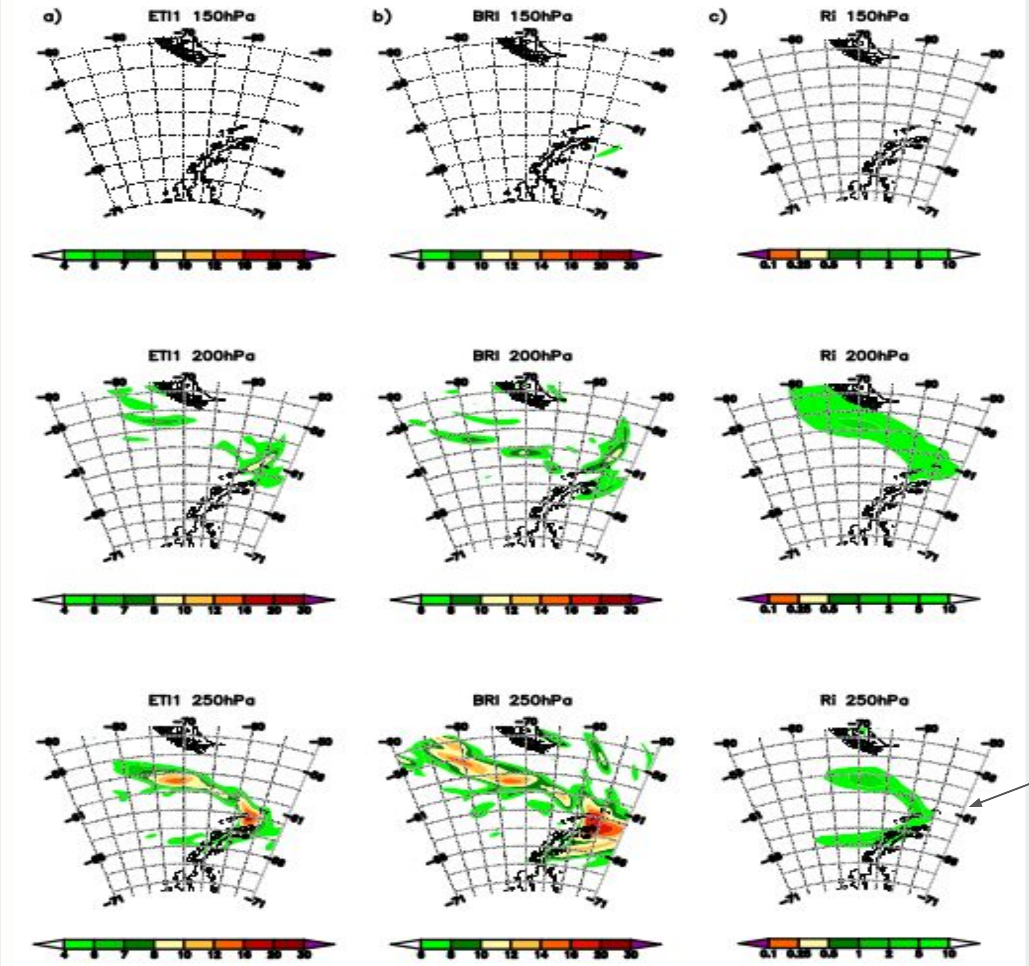
Brown and Richardson number



Brown: shear deformation x stretch deformation (empiric)

Richardson: Stratification/ Vertical shear.
Richardson threshold = 0.25

CAT indices from ERA5, 18 UTC Nov 12



Most significant at 250 hPa

Observation of tropopause fold over Marambio

Radiosonde: Vaisala RS92 SGP

Launch time: 17:47 UTC from Marambio st.

Location: Marambio st., Argentina, ~64ºS-56ºO

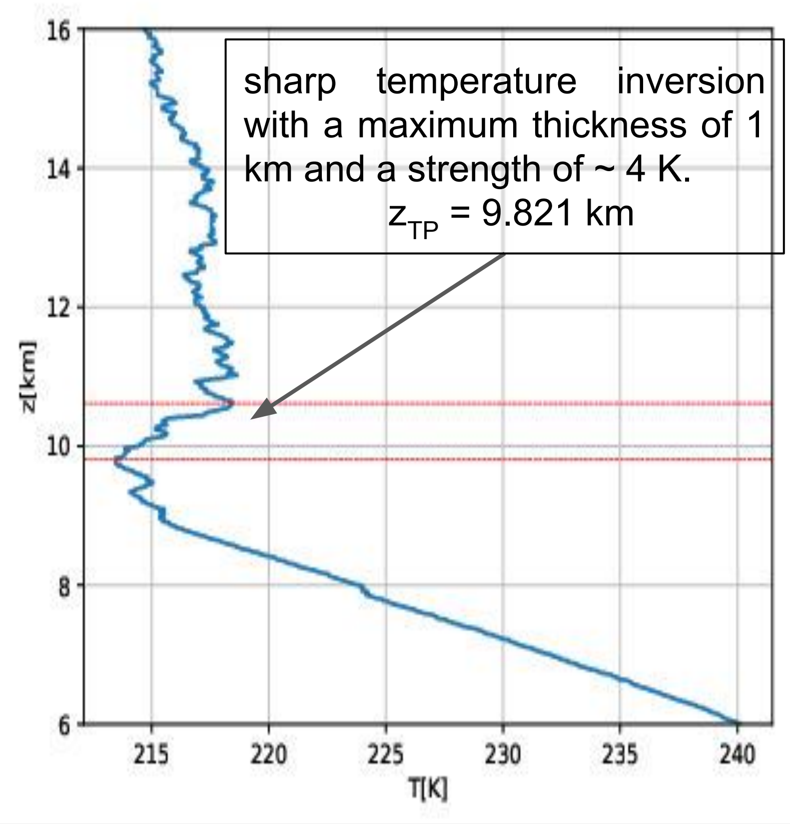
Mean vertical resolution ~6 m

Frequency: 1 Hz

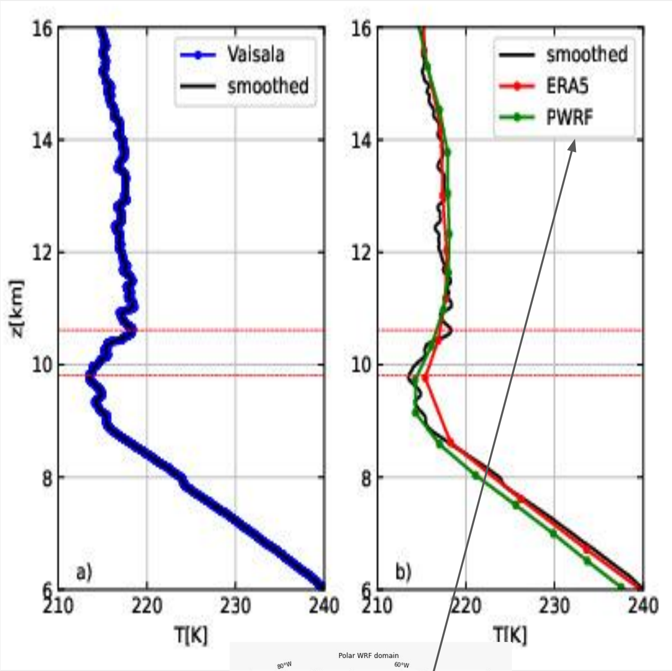
Standard deviation of noise in T: ~0.2 ºC in TP

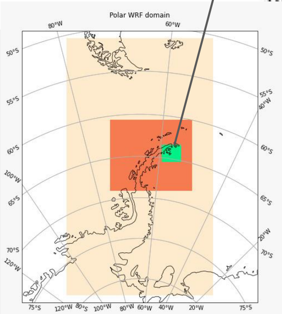
TP level acoording Γ below 2 K/km

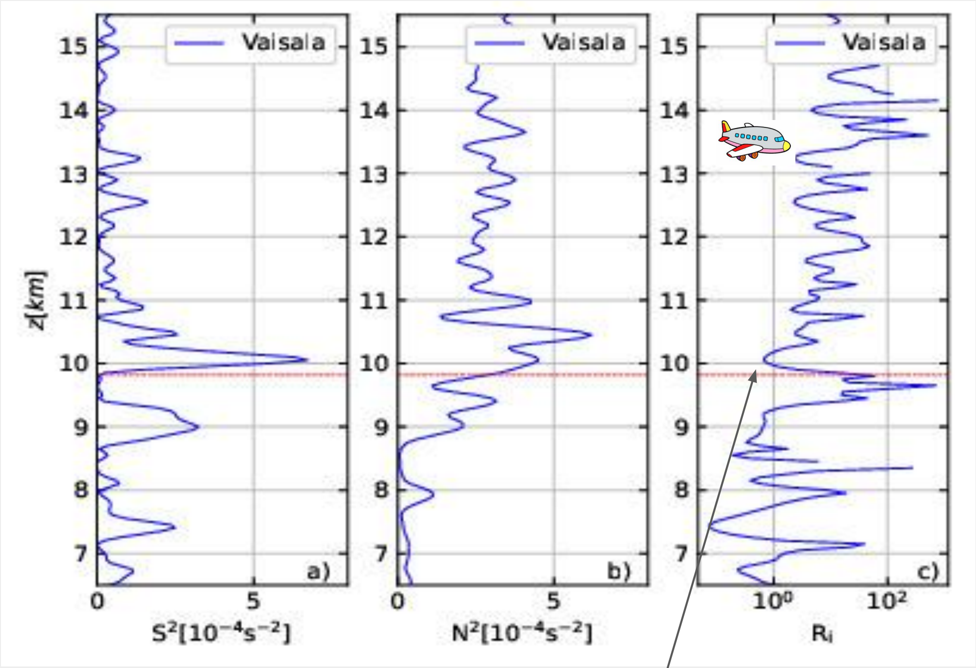
- **z_{TP} = 9.821 km, 247.9 hPa at 18:20 UTC.**
- **HALO ~FL450, ~160hPa at 18:20**



Observation of tropopause fold over Marambio





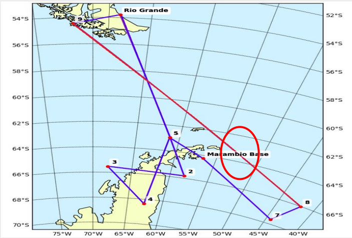


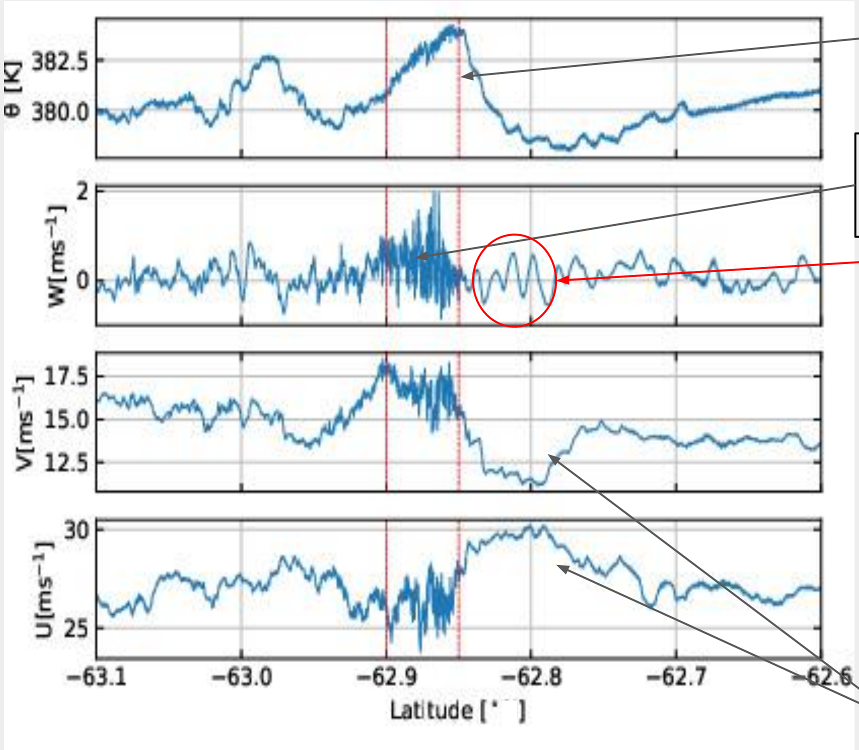
- WRF Polar 12/11/2019
- 24 hs spin up
- 50 km domaincon 71x41 grid points
- 50º-80º S, 20º-120º W
- two nested domains
  10 km, 111x96 grid points
  2 km, 126x110 grid points
- 61 vertical levels

Ri close to critical values for the occurence of Turbulence (~0.25), right above z_{Tp}

BAHAMAS data: time series

Time series of meteorological parameters around 18 UTC





Temperature front

Turbulence report: increase in fluctuations in all parameters

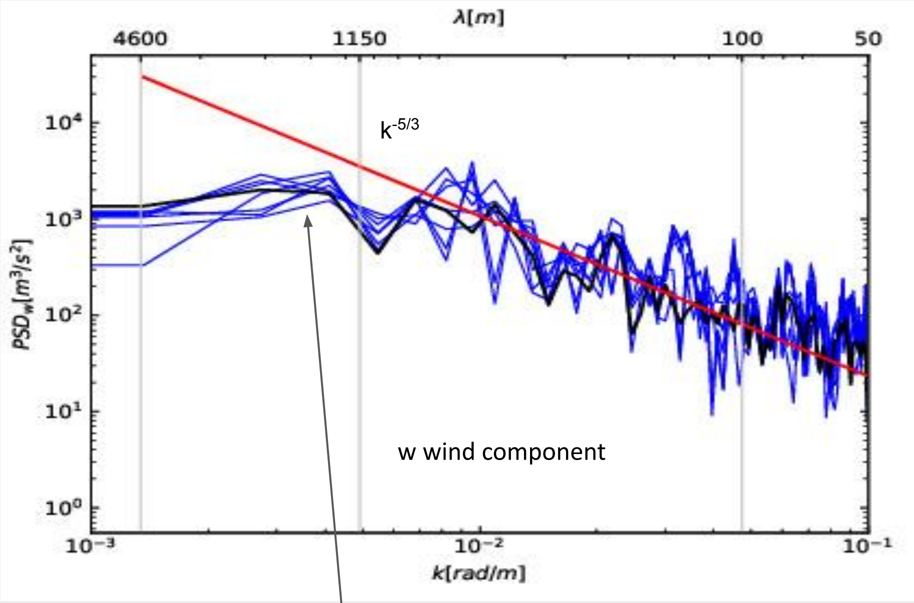
gravity waves

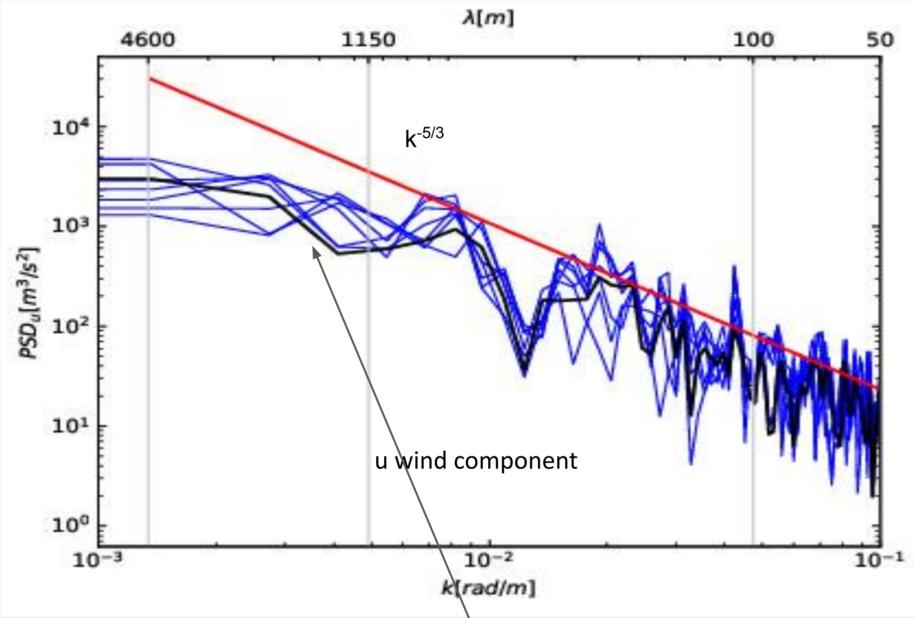
Two regions clearly delimited in space,, separated by a temperature front and a turbulence avent between 62.9 S- 62.85 S
North: cold air, stronger zonal wind and GW, followed by constant values. This is consistent with an anisotropic flow, more stratified with the mean wind.
South: Turbulence transport accounts for energy transfer in the wind. Isotropic flow

Change in the horizontal wind

BAHAMAS data: Spectra

Spectral energy density at and around turbulence peak in 16 km overlapping sublegs (Welch method using a Tukey window)





FLAT for scales larger than ~1300 m

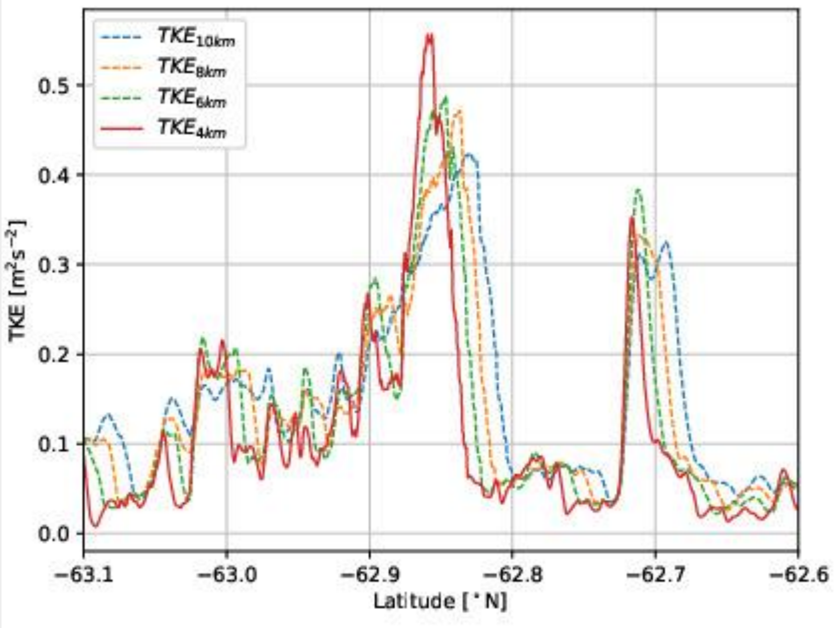
L_B~V/N ~ 1556 m

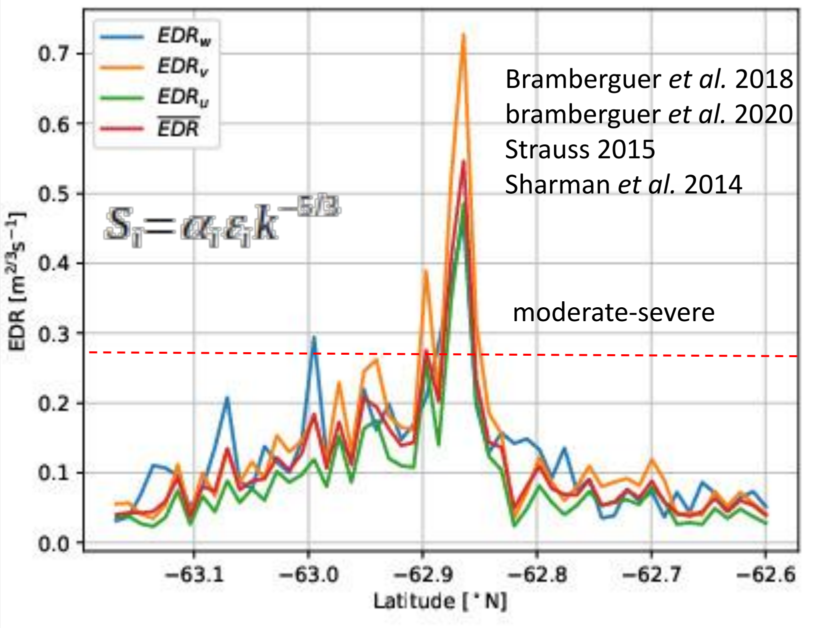
NOT flat around 1300 km

BAHAMAS data: TKE and EDR in 4 km sublegs

TKE: **T**urbulent **K**inetic **E**nergy, large energy-containing eddies

EDR: (**E**nergy **D**issipation **R**ate)$^{1/3}$, given by $\varepsilon^{1/3}$ rate of conversion of the turbulence kinetic energy into thermal energy, which takes place at small scales.





$TKE=(\sigma^2_u+\sigma^2_v+\sigma^2_w)/2$

EDR=spectra normalized by $k^{-5/3}$

Froude ~0.13 !

Rorai et al. (2014), Ferraco et al. (2018)

BAHAMAS data: structure functions

Structure functions

Monin & Yaglom (1975)

$$Sp_{u_i}(x,l)=\langle|u_i(x+l)-u_i(x)|^p\rangle=\langle|\delta u^p|\rangle$$

Energy in real space

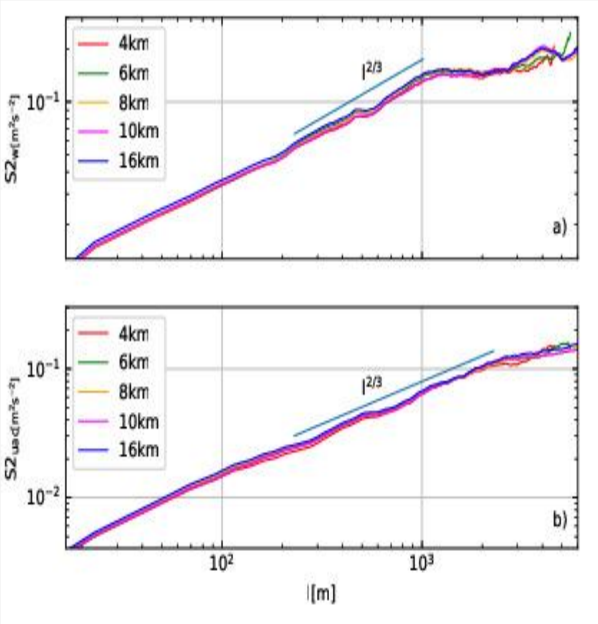
$$S2_{u_i}(x,l)=\langle|u_i(x+l)-u_i(x)|^2\rangle=C_2\,\varepsilon l^{2/3}$$

Second order structure functions

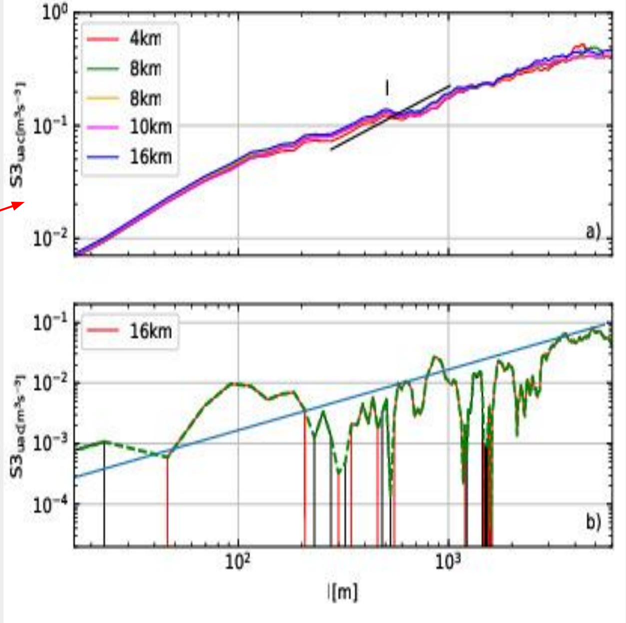
$$S3_{u_i}(x,l)=\langle|u_i(x+l)-u_i(x)|^3\rangle=-\frac{4}{3}\varepsilon l$$

Third order structure functions

EDR!

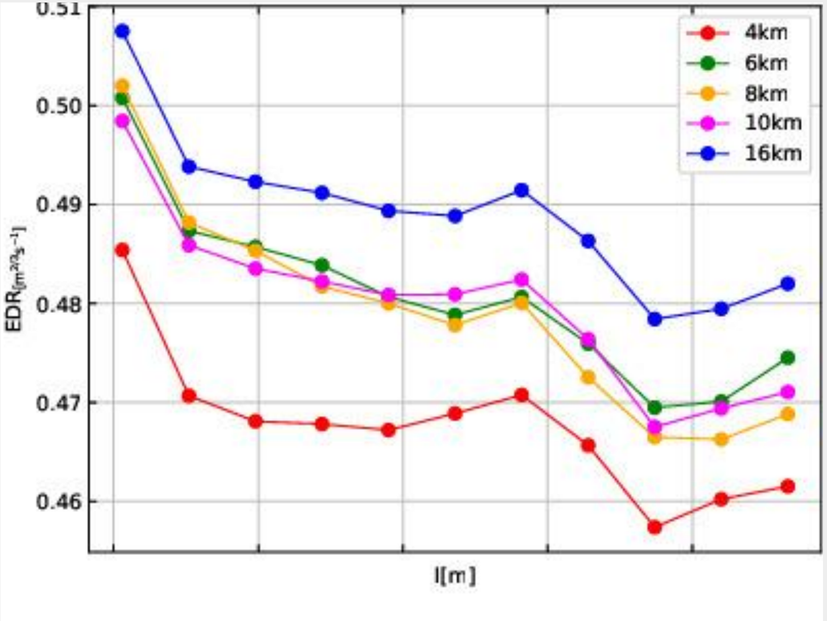


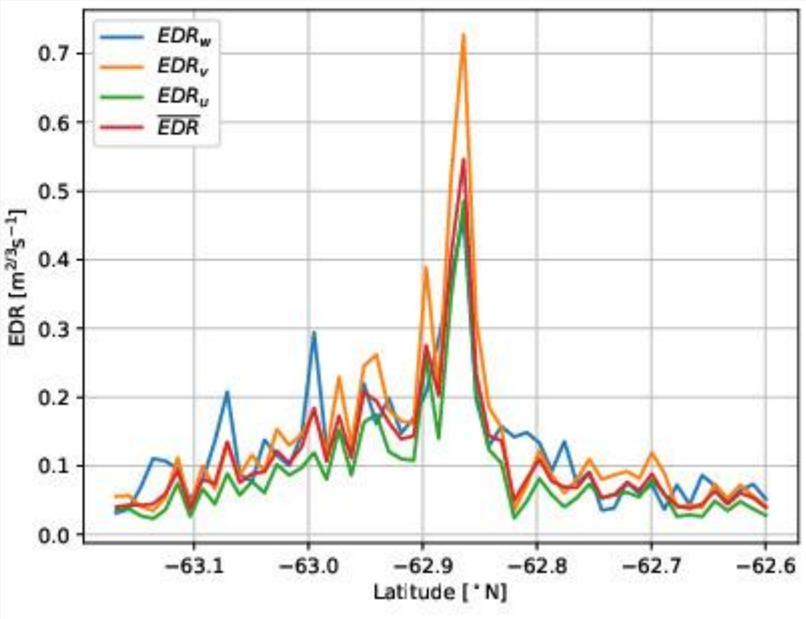
$$S3_{u_i}(x,l)=\langle|\delta U|^2\cdot\delta u_{ac}\rangle=-\frac{4}{3}\varepsilon l$$



BAHAMAS data: EDR from structure functions

Mean EDR from third order structure functions for all sublegs



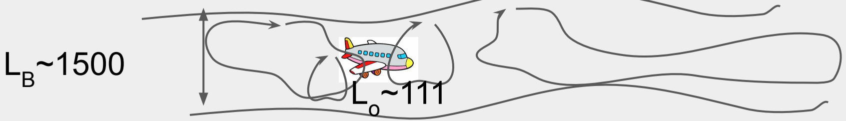


$$L_O = (\varepsilon/N^{1/3})^{½} \sim 111 \text{ m}$$

“Clear Air Turbulence observed across a tropopause fold over the Drake Passage – A Case Study” Submitted to JGR-Atmospheres, “ST SOUTHRAC GW”

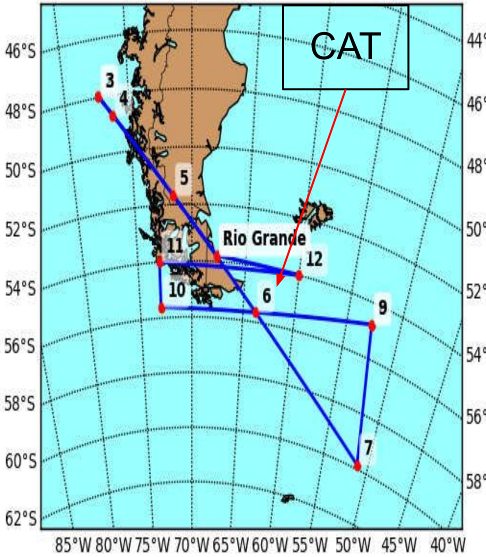
Conclusions

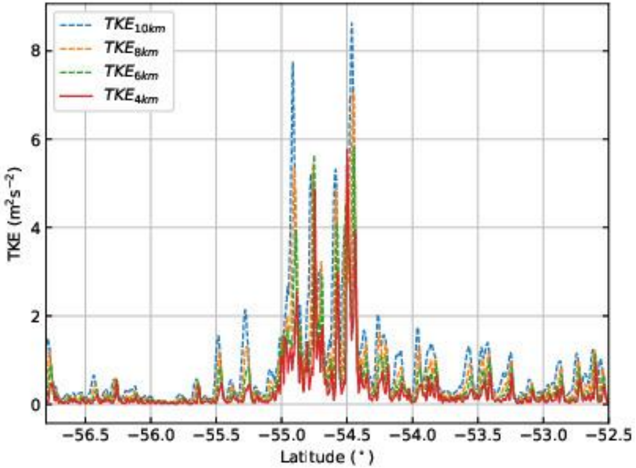
1. **Large scale pattern suitable for CAT scenario:**
The **polar low** can be identified as the large-scale pattern forcing the favorable environment for CAT development, providing flow **deformation**. As the structure moves north towards the Peninsula, deformation at the higher levels is enhanced by the jet around Drake's Passage, where a stratospheric air intrusion is strongly advected to the east, conserving a pool shape structure, and generating a temperature front and the subsequent tropopause folding.
2. **Mesoscale phenomena accounting for turbulence**
Tropopause inversion may account for the physical characteristic and cause of microscale CAT, through vertical shear of horizontal wind, as suggested by the vertical profile of the Richardson number from radiosonde measurements and numerical models.
3. **BAHAMAS 10 Hz dataset**
   a. Time series and spectra: Fully developed turbulence with K41 spectra, but signatures of anisotropy due stratification
   b. **TKE** and **EDR**: presence of strong turbulence nearly 4 km above, and slightly east of the folding. Also, they reveal **Intermittency**, **anisotropy** and **dependence with mean wind** orientation.
   c. Structure functions: evidence of turbulent atmospheric conditions with Kolmogorov scaling, with signatures of anisotropy generated by stratification, as prescribed by both, horizontal and vertical energy spectra. **Third order structure function confirm a forward energy cascade**, and a mean EDR **with very close values to those obtained using spectral methods**. Finally, from the radiosonde and HALO measurements it can be inferred that the range of scales involved lies between the buoyancy length scale, LB ≈1500 m and the Ozmidov scale LO ≈111 m.

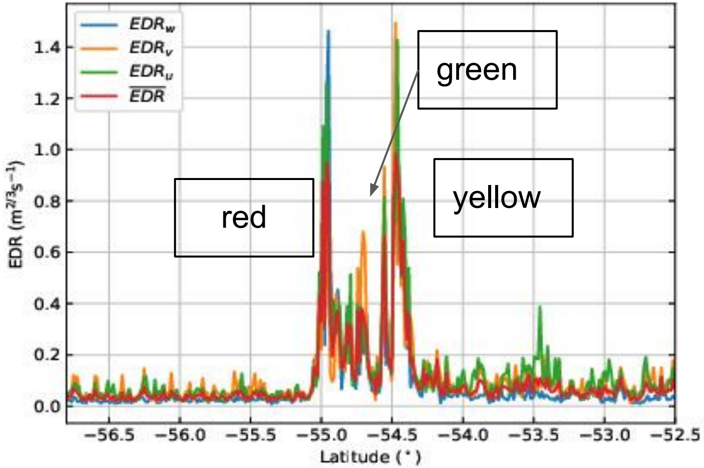


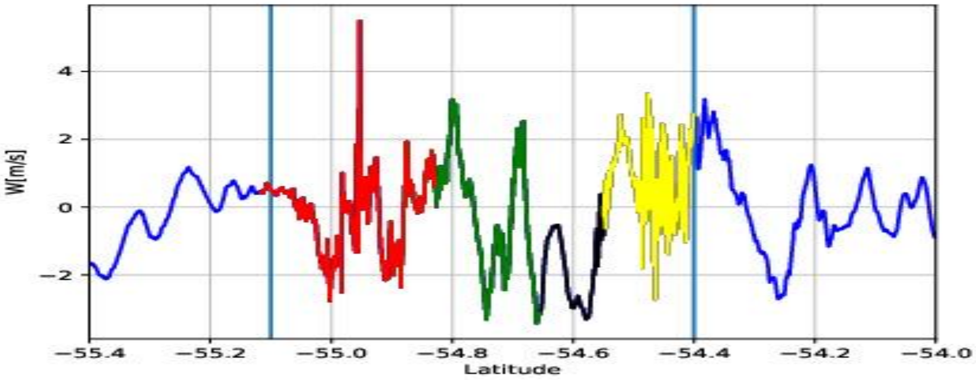
Carefull! Not all CAT is Kolmogorov

Gravity wave breaking CAT event during HALO flight on the southern Andes









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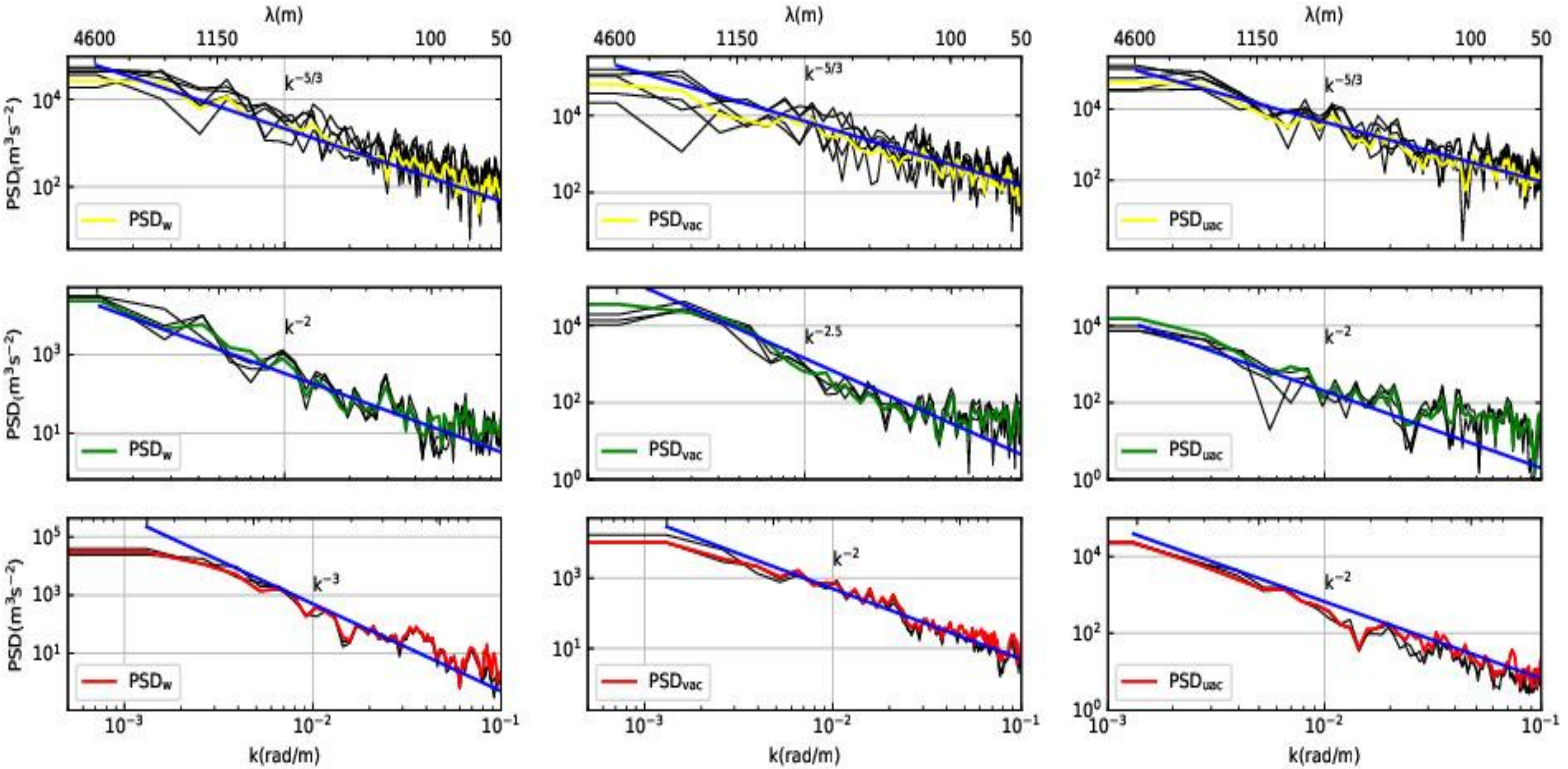


Carefull! Not all CAT is Kolmogorov

- **CAT is recognized as a bursty (intermittent) event**

- **Turbulence comes in burst in stratified flows.** (*Rorai, C., Mininni, P. D., & Pouquet, A. (2014). Phys. Rev. E , 89 , 043002*)

- **These bursts have been observed in DNS, GOMs and measurements in the atmosphere**

  Direct numerical simulations: *Vertical drafts and mixing in stratified turbulence: sharp transition with Froude number*. Marino, R., Feraco, F., Primavera, L., Pumir, A., Pouquet, A., Rosenberg, D., &990 Mininni, P. D. (2021). https://arxiv.org/abs/2106.15219)

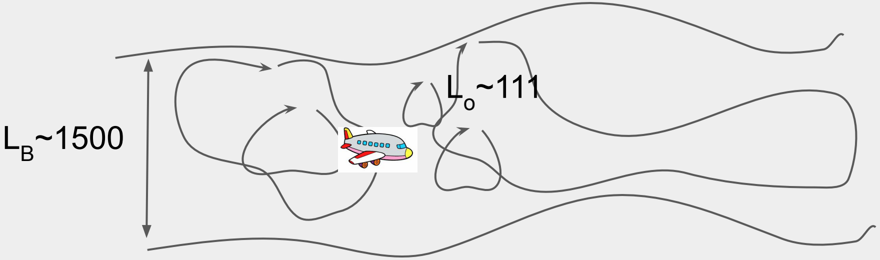
  Observations: *Radar Observation of Extreme Vertical Drafts in the Polar Summer Mesosphere* Chau, J. L., Marino, R., Feraco, F., Urco, J. M., Baumgarten, G., Lübken, F.-J., et al. (2021). *Geophysical Research Letters*, 48, e2021GL094918. https://doi.org/10.1029/2021GL094918

  Global ocean models: *Log-normal turbulence dissipation in global ocean models Pearson,* B., & Fox-Kemper, B. (2018, Feb). Phys. Rev. Lett., 120 , 094501. doi: 10.1103/PhysRevLett120.094501

- **In the context of operational forecasts**

  Wrong values of EDR ➡ CAT forecasts and related products

  Wrong global statistics ➡ global and regional numerical prediction models



Thank you!