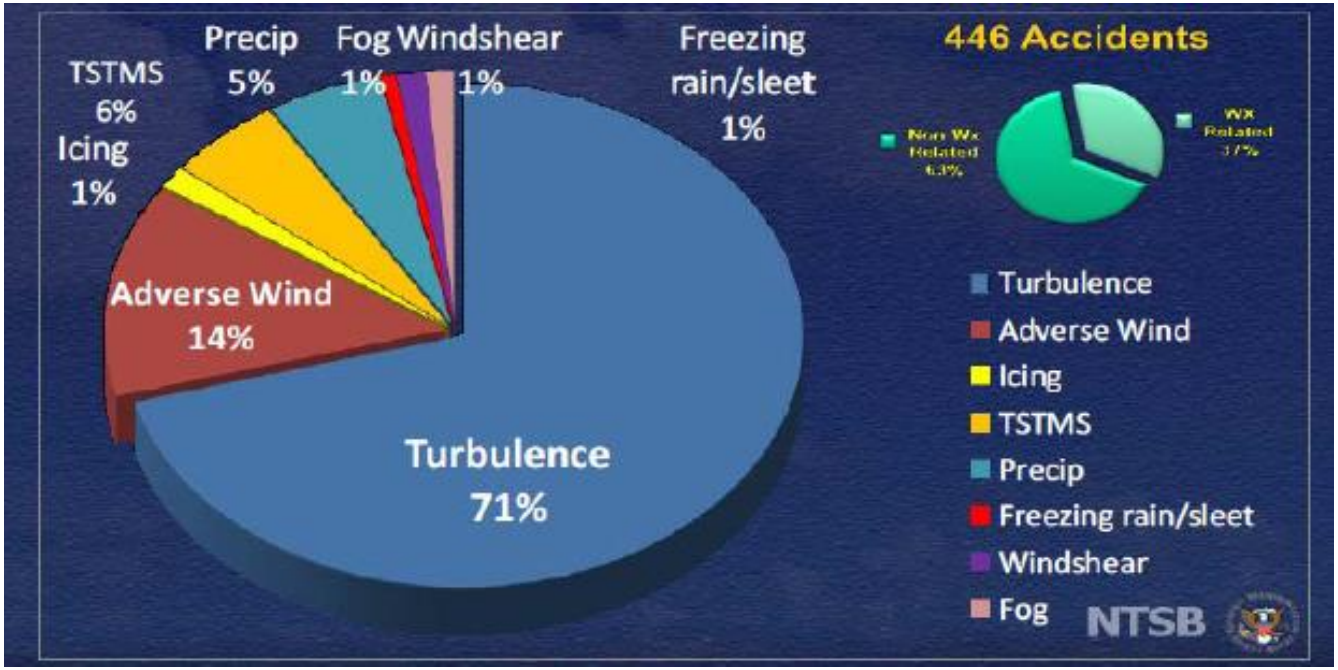
Clear Air Turbulence (CAT)
and other turbulence

Peter Schmitt, Deutscher Wetterdienst

Overview

1) Motivation
2) Classification of turbulence
3) Jet Stream and CAT
4) Satellite Images and CAT
5) Turbulence Forecasting at DWD
6) Summary
7) Learning Material

Air Carrier Weather Related Cause/Factors 2000-2011

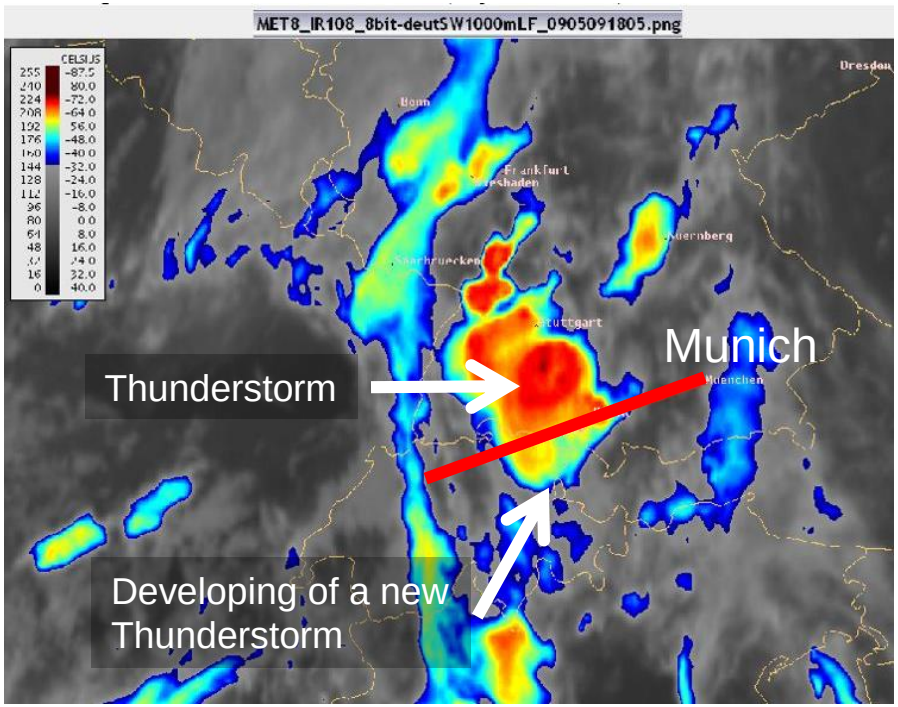


Source: National Transportation Safety Board

„Horror-Flight“ with 15 injured person

9 May 2009 / Airbus 321 / Munich - Lisbon
Severe Turbulence in the alps – FL280-300
Emergency landing in Geneva

This was Severe Turbulence !
But was it „Clear Air Turbulence“ ?



Source: Axel Barleben, DWD

2 – Classification of Turbulence

HLT (High Level Turbulence)

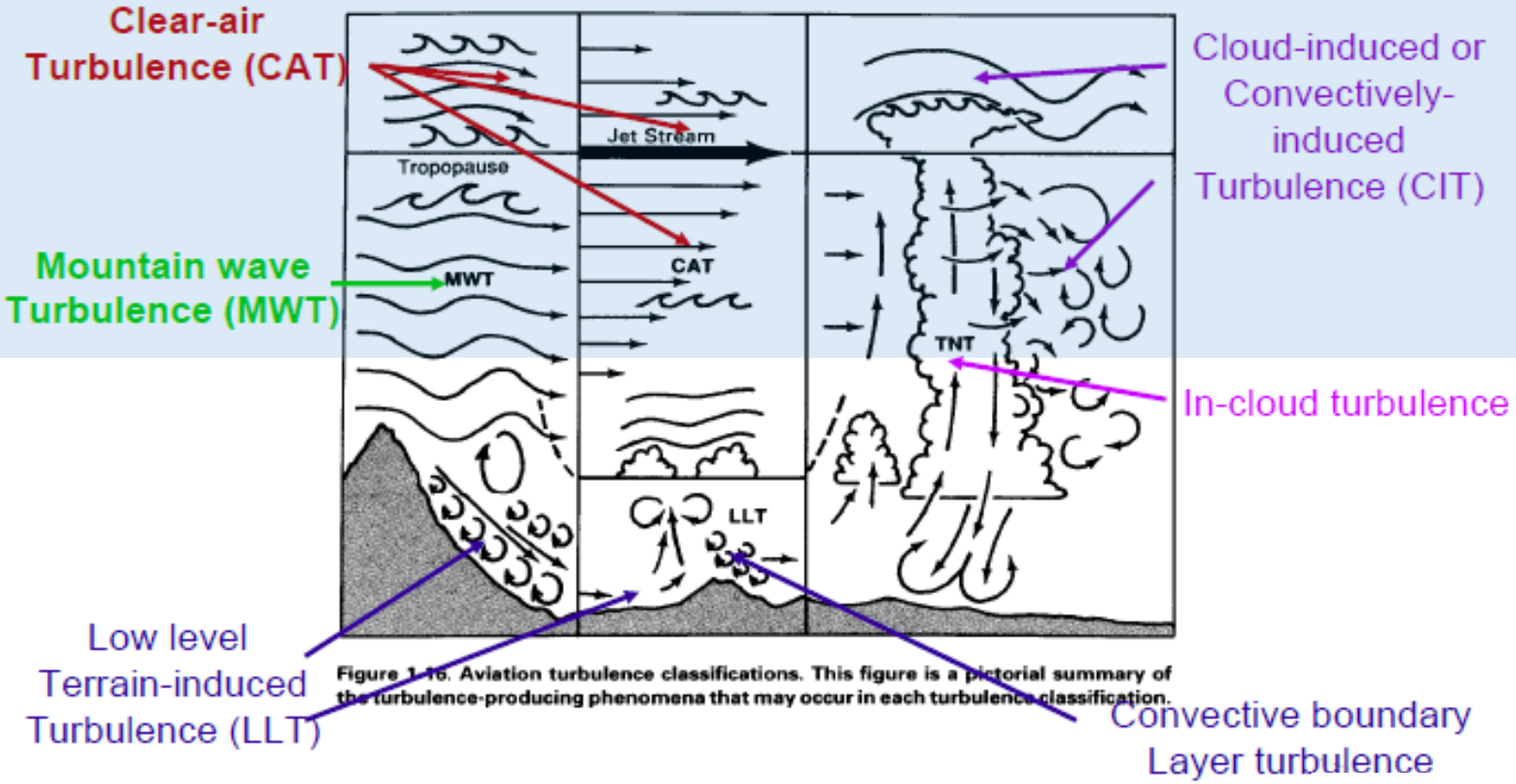


Figure 1-16. Aviation turbulence classifications. This figure is a pictorial summary of the turbulence-producing phenomena that may occur in each turbulence classification.

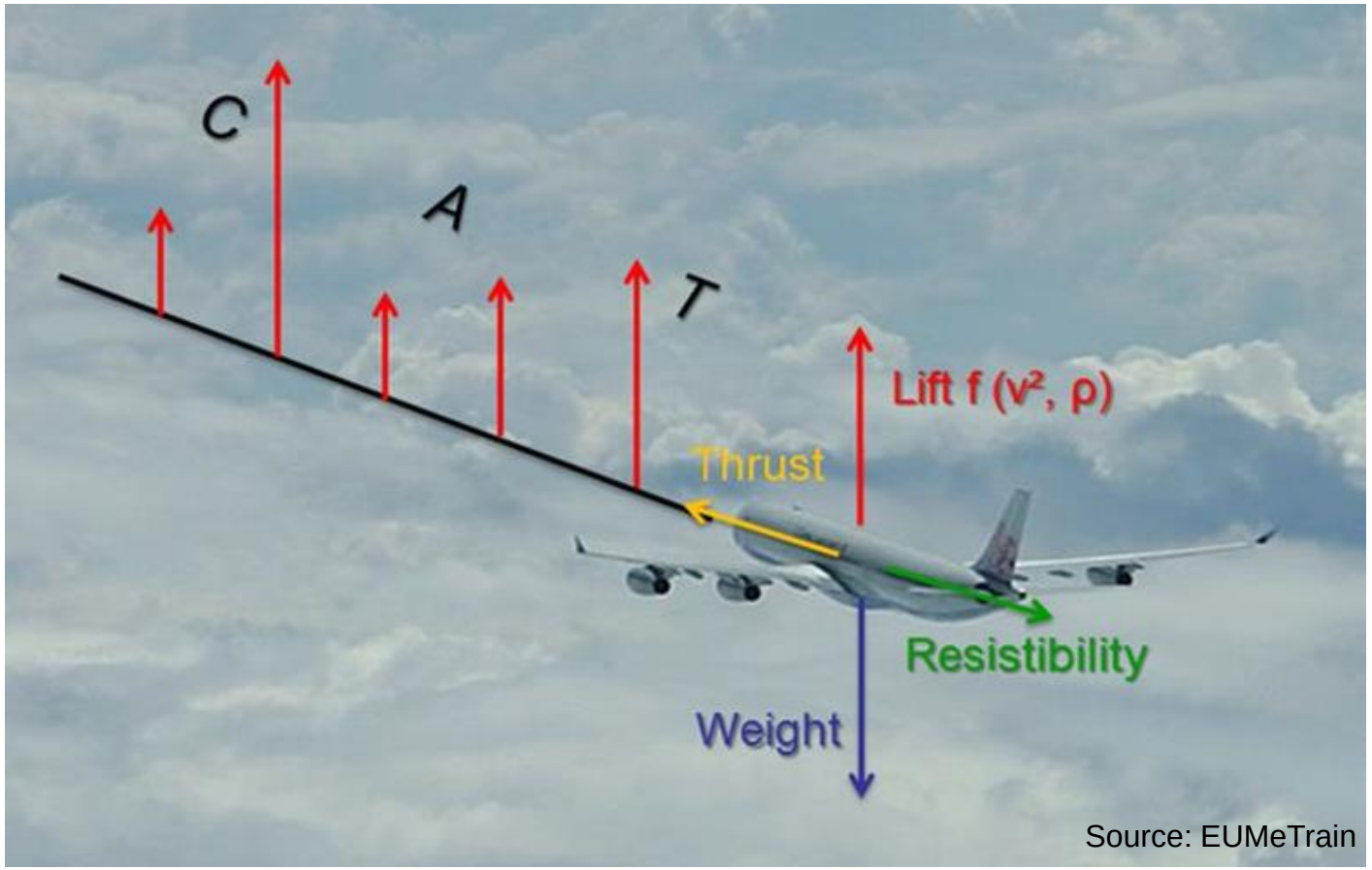
Source: P. Lester, "Turbulence – A new perspective for pilots," Jeppesen, 1994

Source: Axel Barleben, DWD

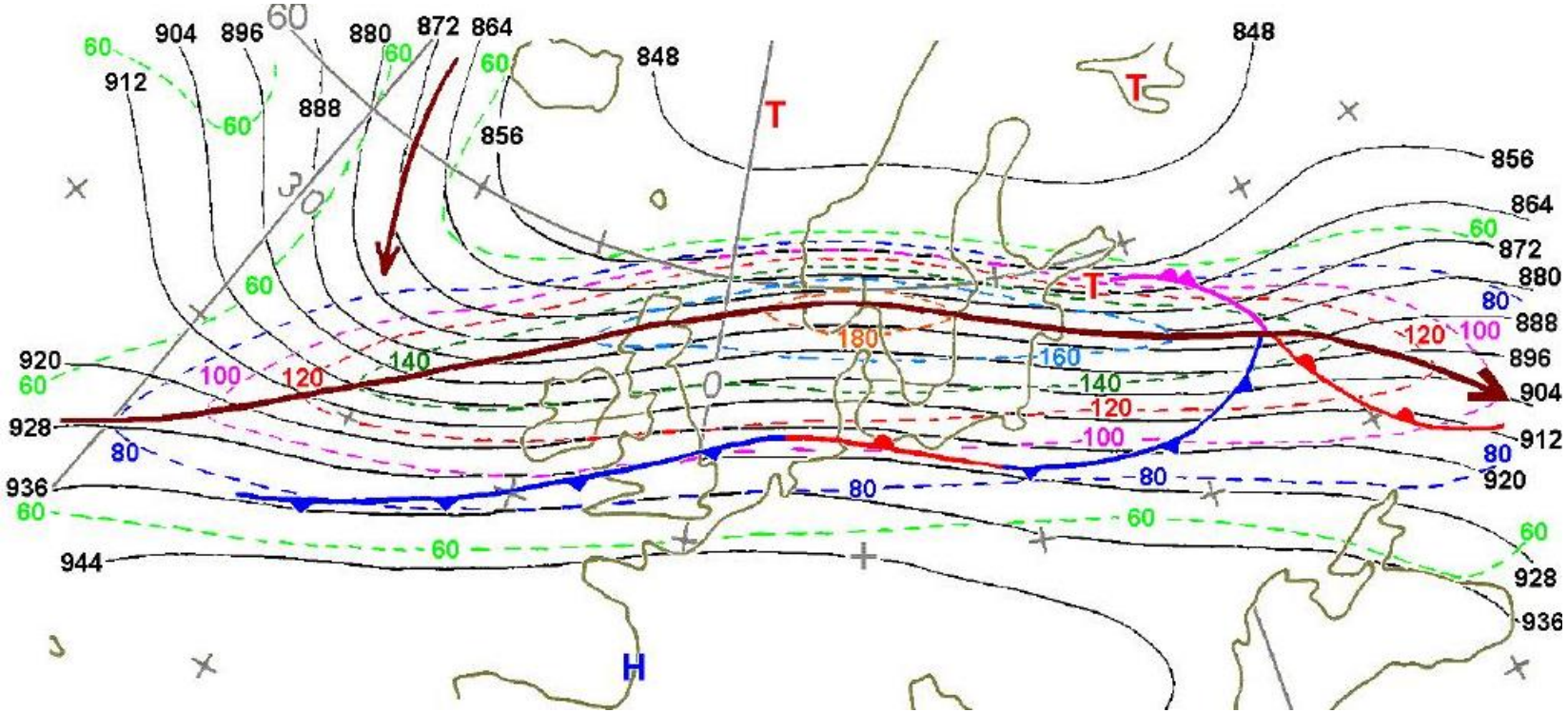
Types of Clear Air Turbulence (CAT)

Intensity	Aircraft reaction	Reaction inside aircraft
Light not shown in sign. Weather Charts	Turbulence that causes slight changes in altitude and/or attitude (pich, roll, yaw). IAS (Indicated Air Speed) fluctuates 5 – 15 kt < 0.5g at the aircraft's centre of gravity	Occupants may feel a slight strain against seat belts or shoulder straps. Unsecured objects may be displaced slightly. Food service may be conducted and little or no difficulty is encountered when walking.
Moderate	Turbulence with a greater intensity as light Turbulence. Changes in altitude and/or attitude, but the aircraft remains in positive control all times. IAS fluctuates 15 – 25 kt 0.5 -1.0g at the aircraft's centre of gravity	Occupants feel definite strain against seat belts or shoulder straps. Unsecured object are dislodged. Food service and walking are difficult.
Severe	Turbulence that causes large, abrupt changes in altitude and/or attitude. Aircraft may be momentarily out of control. IAS fluctuates more as 25 kt. > 1.0g at the aircraft's centre of gravity	Occupants are forced violently against seat belts or shoulder straps. Unsecured objects are tossed about. Food service and walking are impossible.

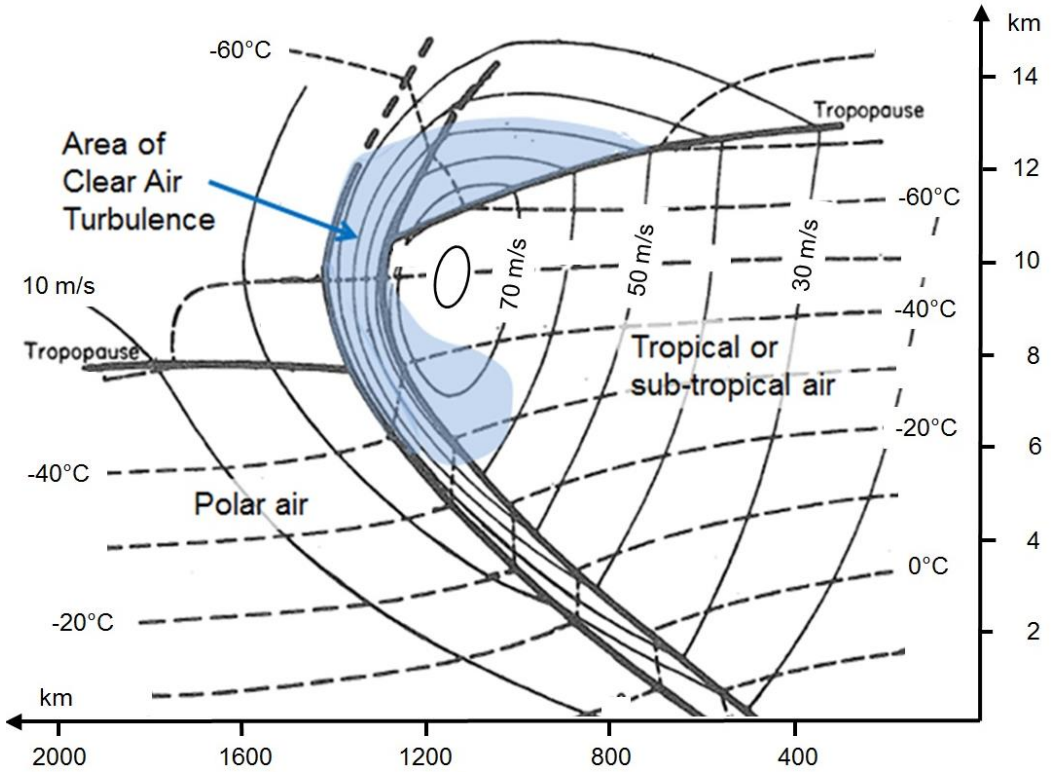
Forces affecting an aircraft



Polar front jet at 300 hPa with isotachs (> 60 kt)

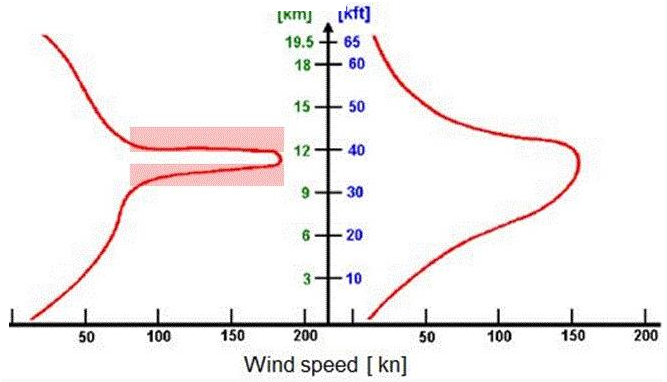


Vertical cross section of a polar jet stream



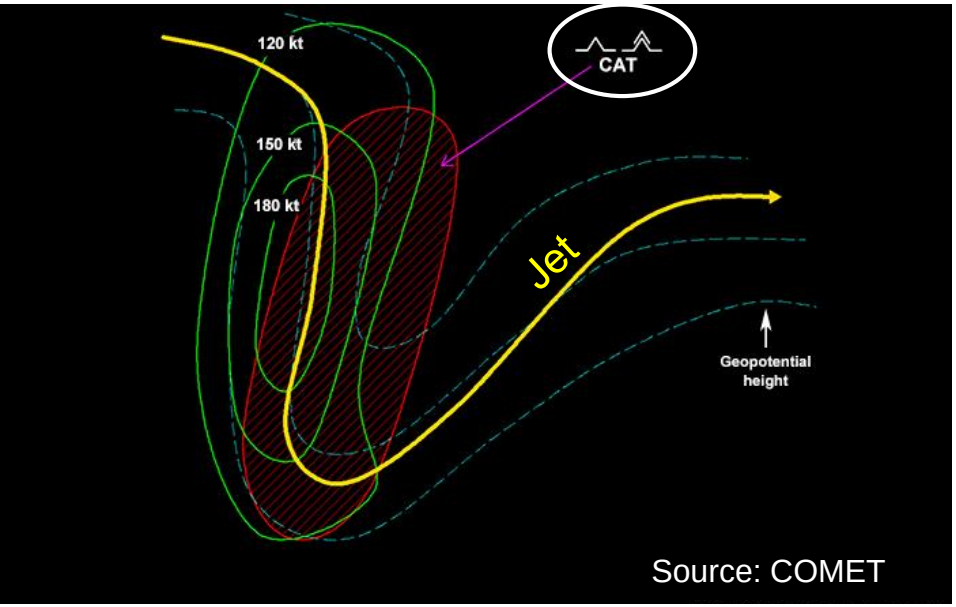
High risk of CAT above and below the jet core
High wind shear (red area)

Low risk of CAT with low wind shear

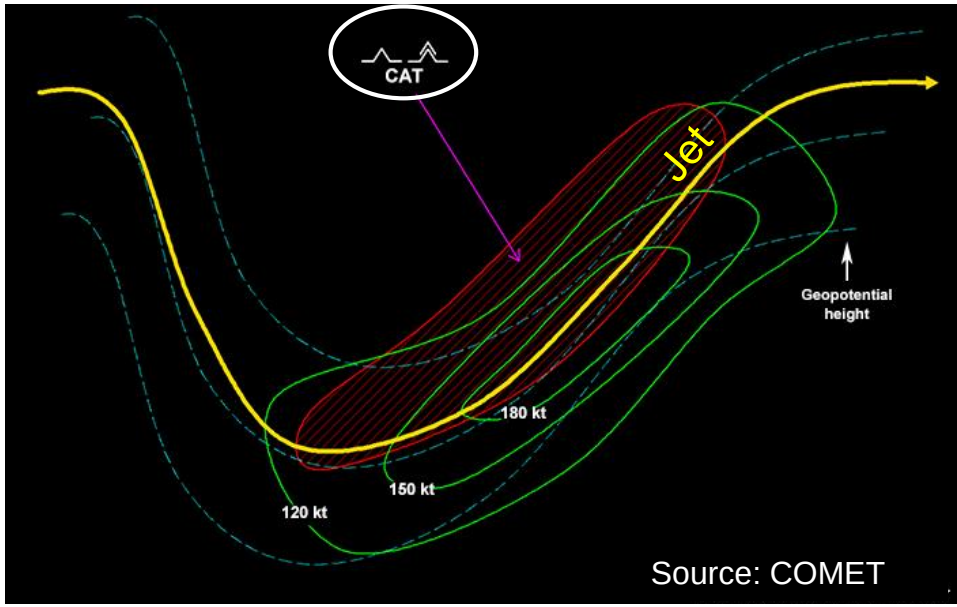


Sharp trough

Jet stream maximum **upstream** of a deepening trough with moderate to severe CAT probable in the red area

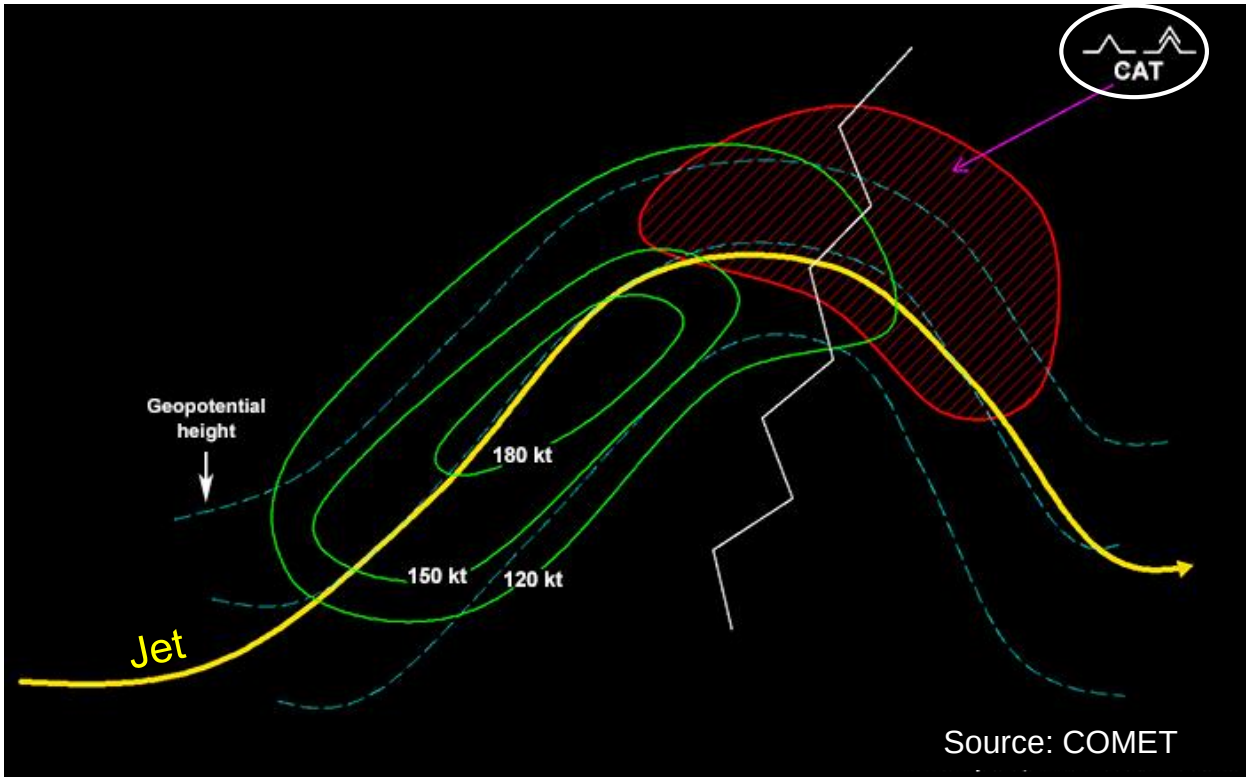


Jet streak **downstream** of the trough with moderate to severe turbulence probable in the red area



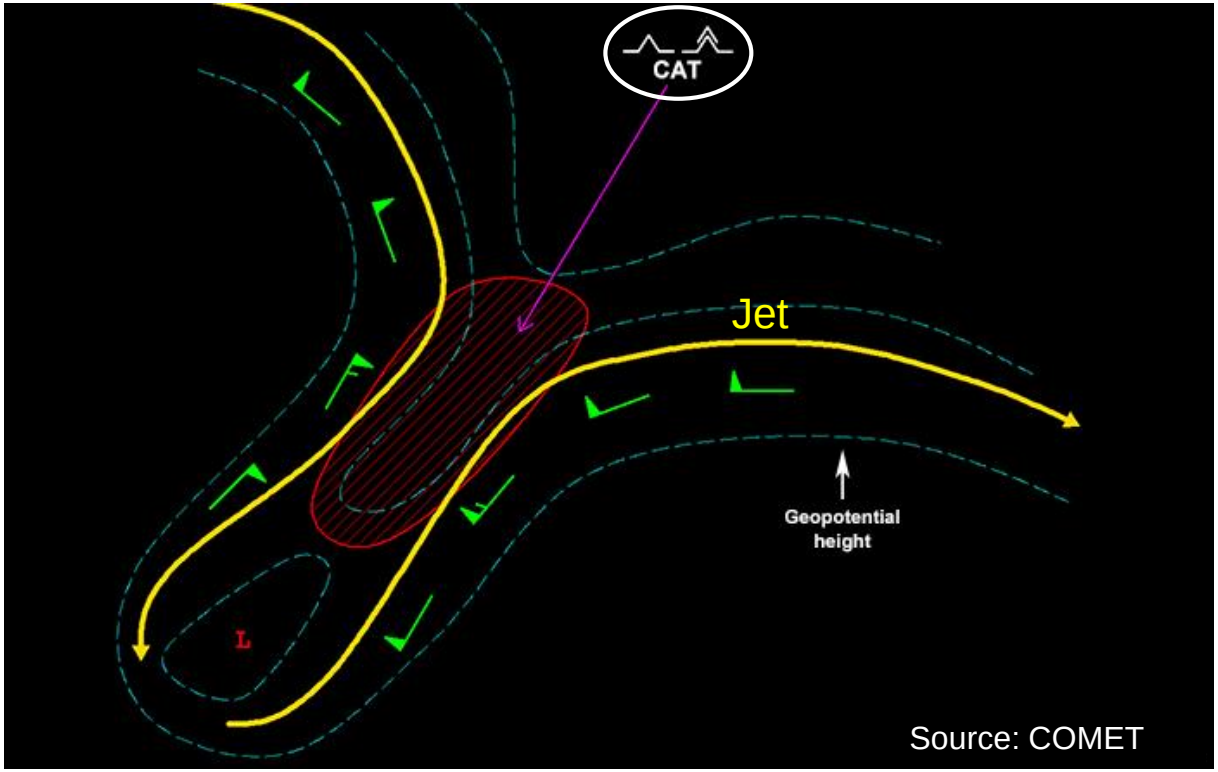
Building ridge

Upper-level building ridge with moderate to severe CAT probable in the red areas



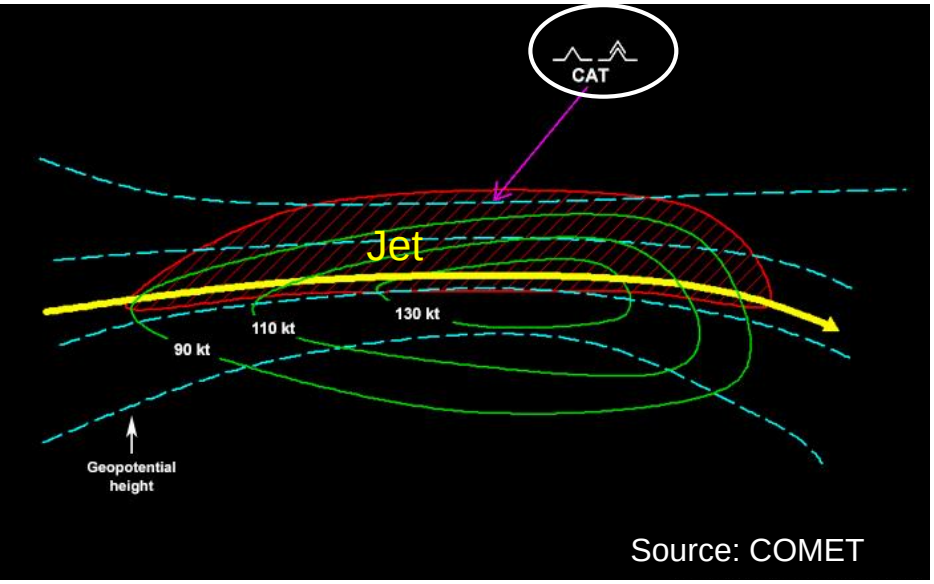
Closed upper low

Cutoff low in upper-level flow with moderate to severe CAT probable in the red area

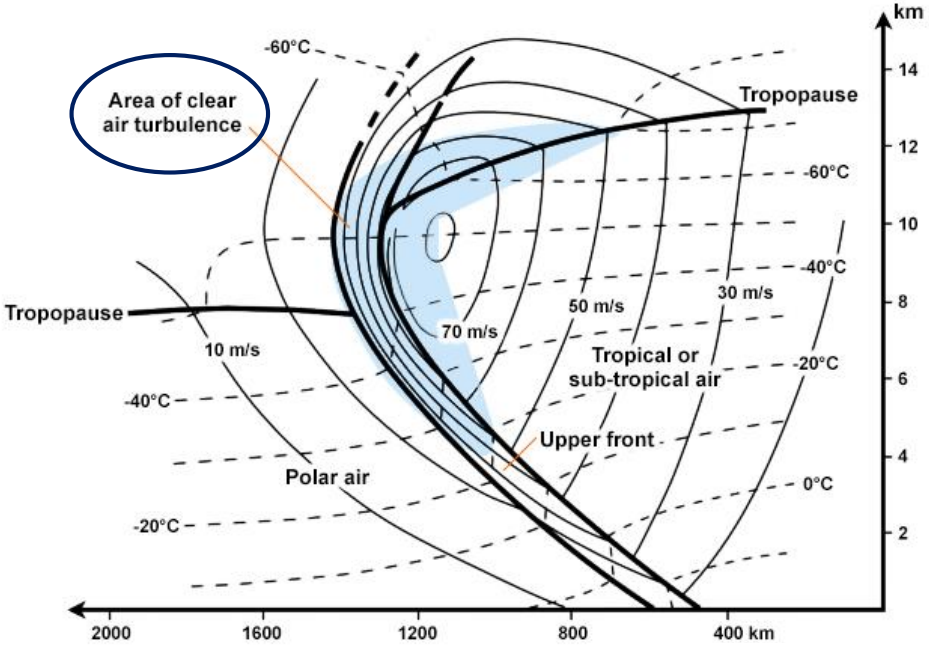


Jet stream pattern

Jet stream CAT pattern with moderate to severe turbulence, probable in the red area.



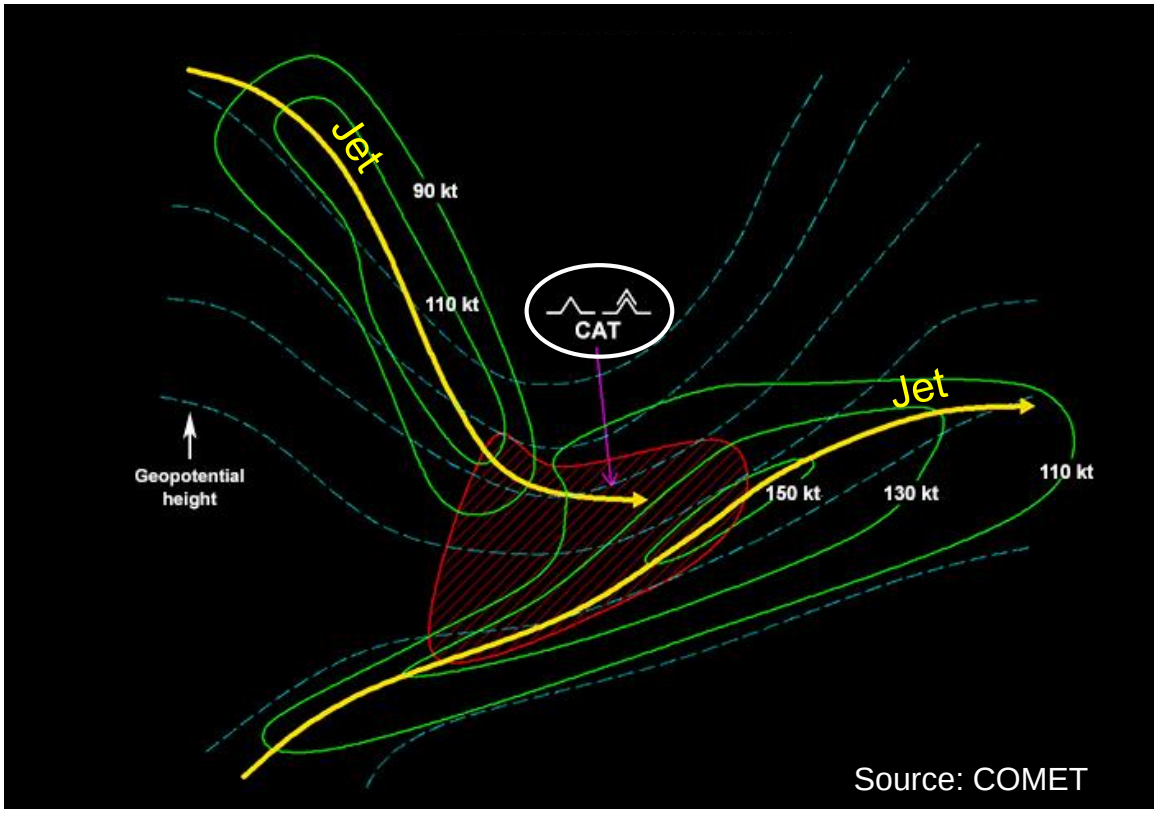
Vertical cross-section of an upper-level front with moderate to severe turbulence in the shaded areas



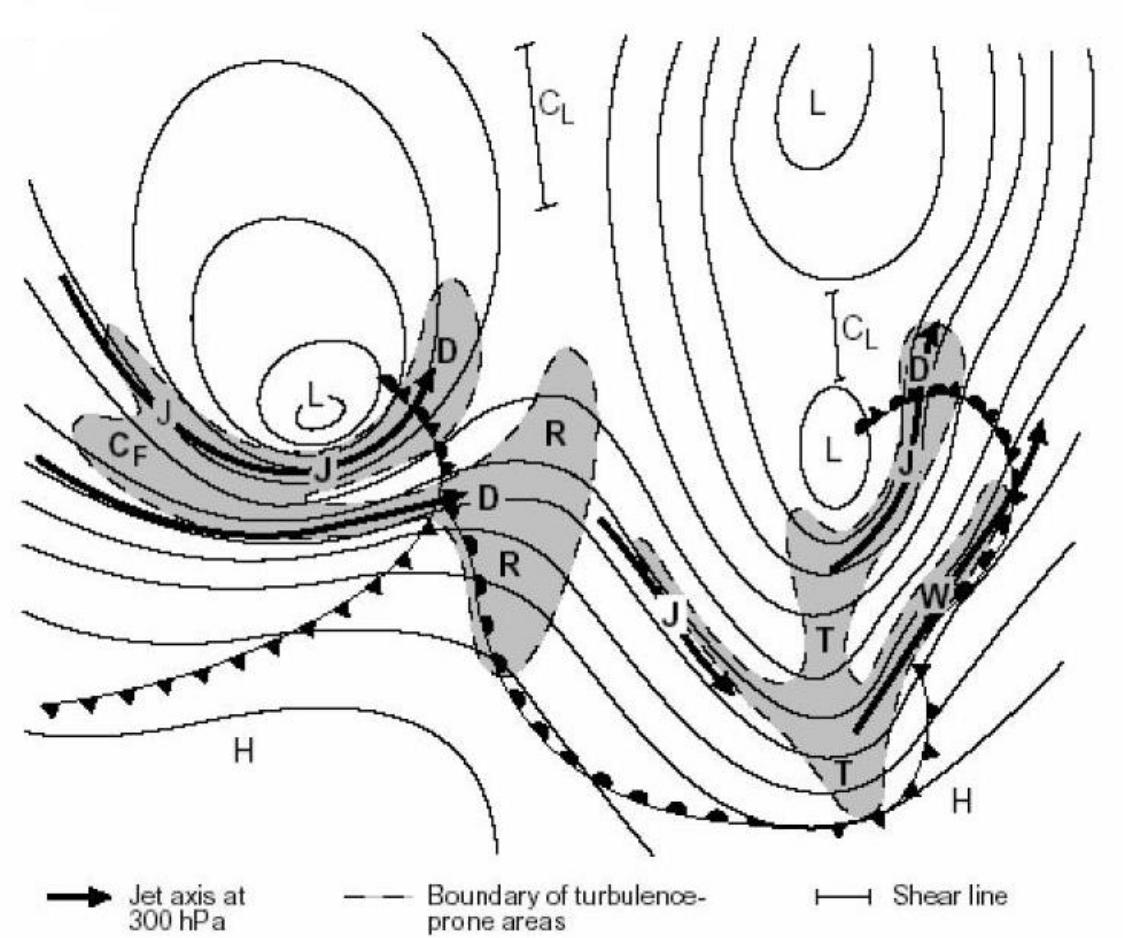
Source: COMET

T-bone or merging jet stream

T-bone or merging jet stream pattern with moderate or severe turbulence probable in the red area

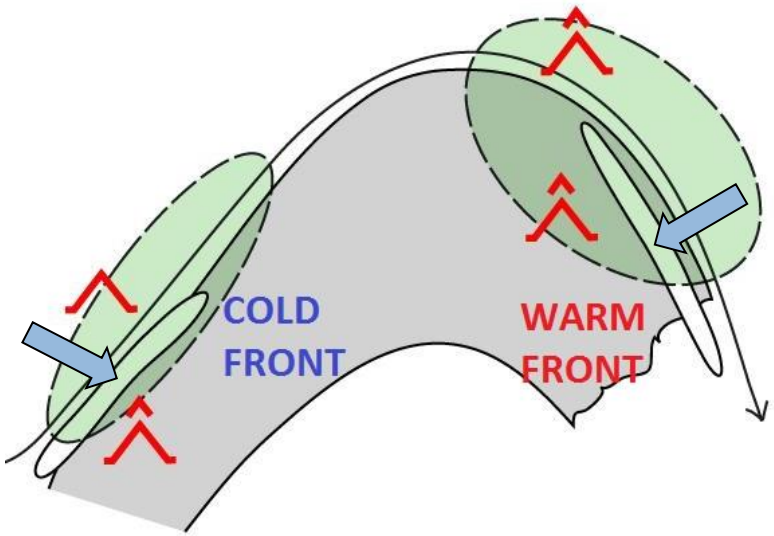


Schematic showing analysis of 300 hPa geopotential and areas prone to CAT. (WMO Aviation Hazards)

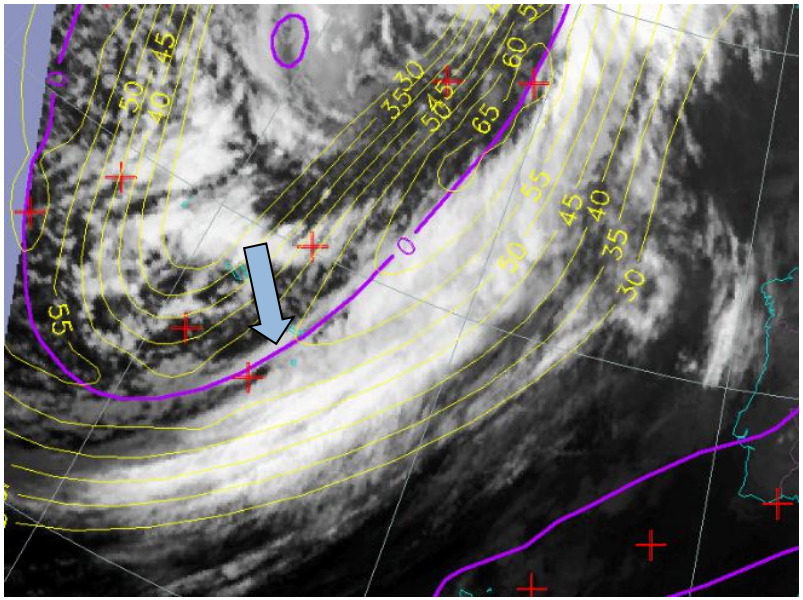


Source: WMO Aviation Hazard

CAT in the vicinity of jet fibres

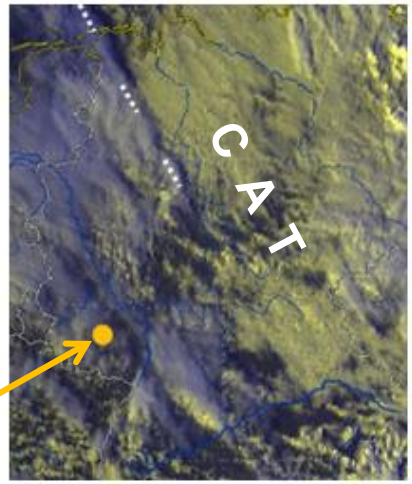


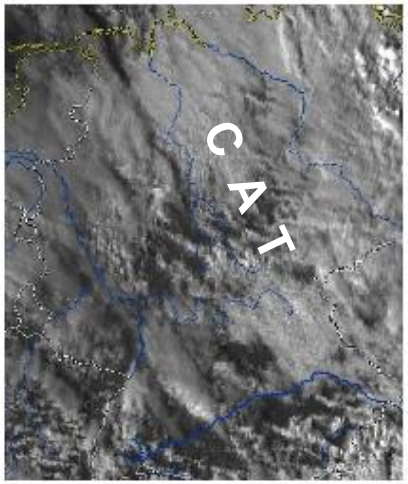
Jet fibres over warm front shields and behind a cold front.
Conceptional model



Jet fibres behind a cold front.
IR10.8 satellite image.

HRV Cloud RGB



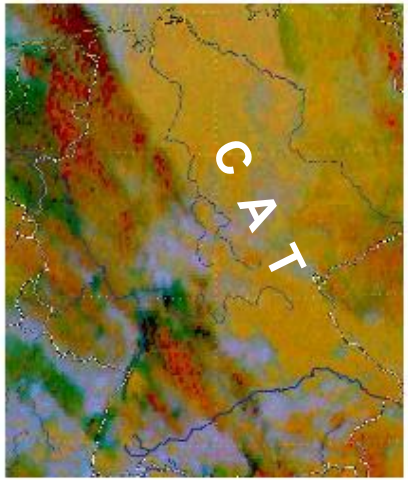


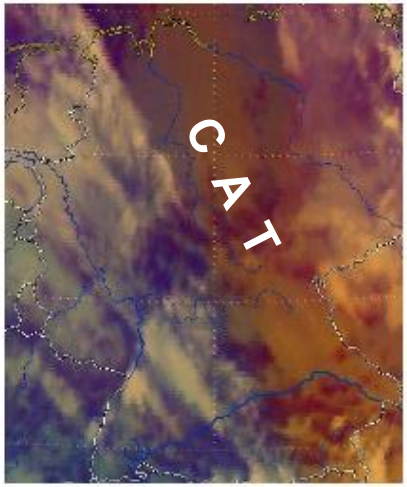
HRV

Sounding
Idar Oberstein
next slide

CAT in the vicinity of jet fibres

Dust RGB

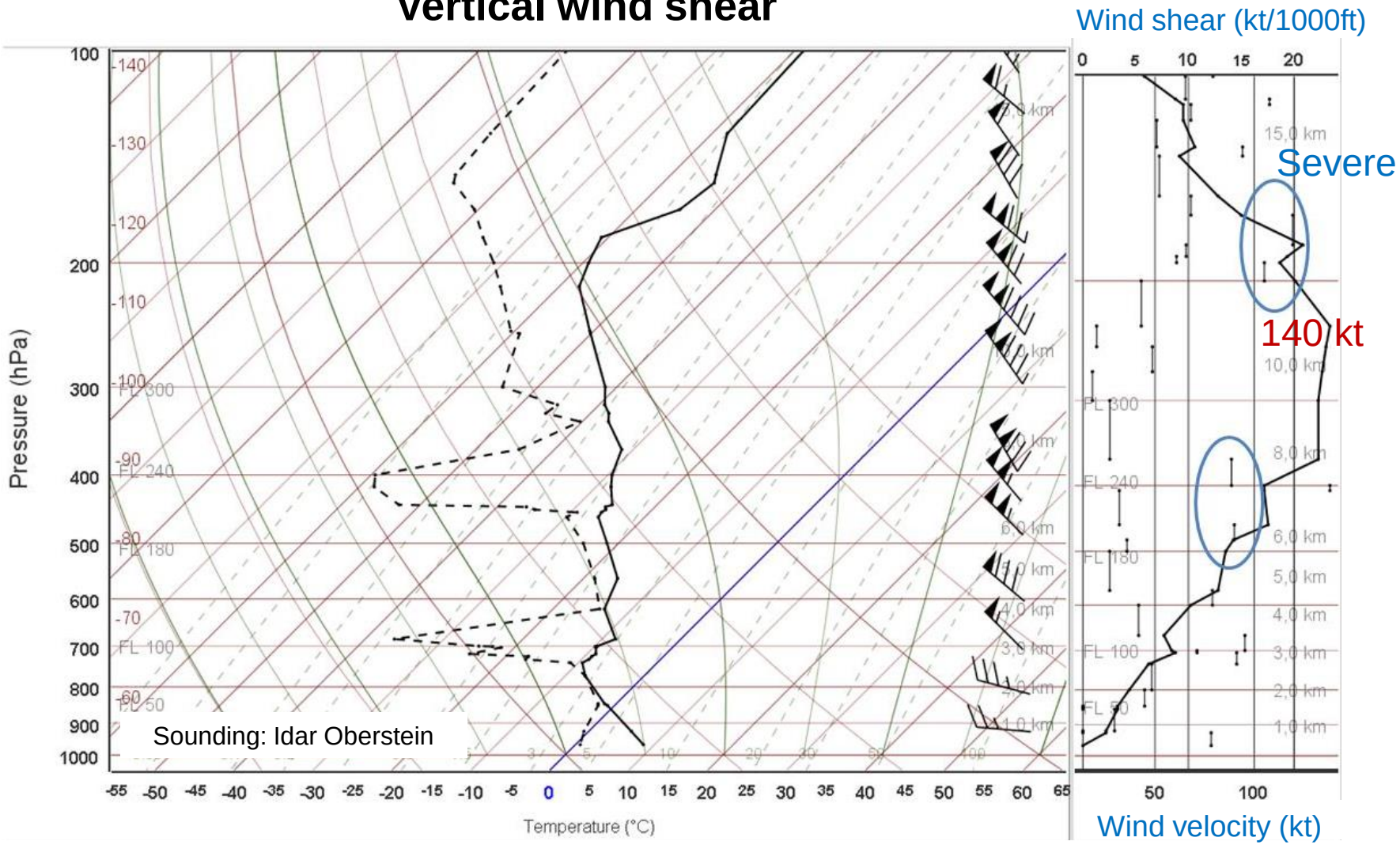




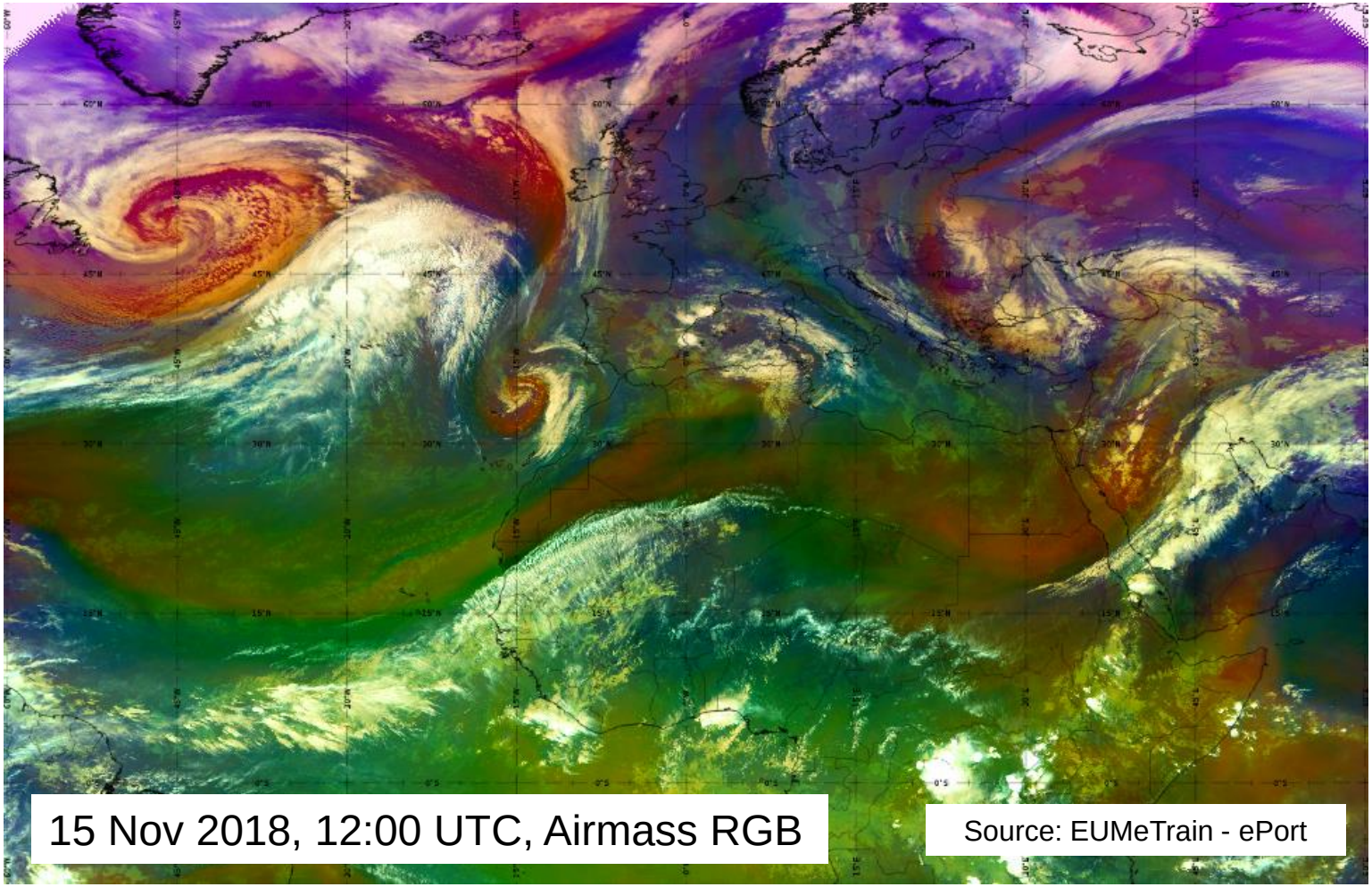
Airmass RGB

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Vertical wind shear



Where do you expect Clear Air Turbulence?



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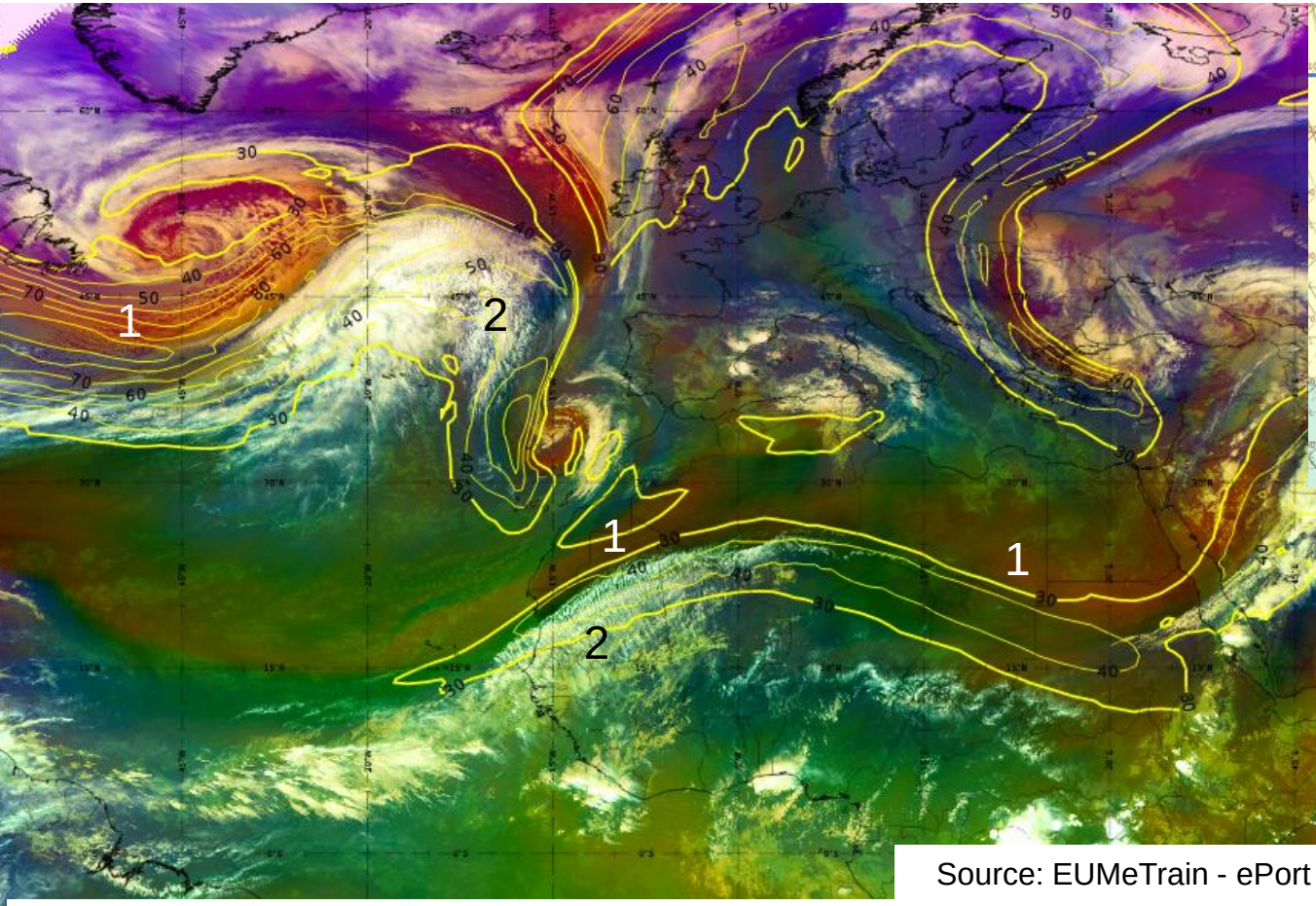
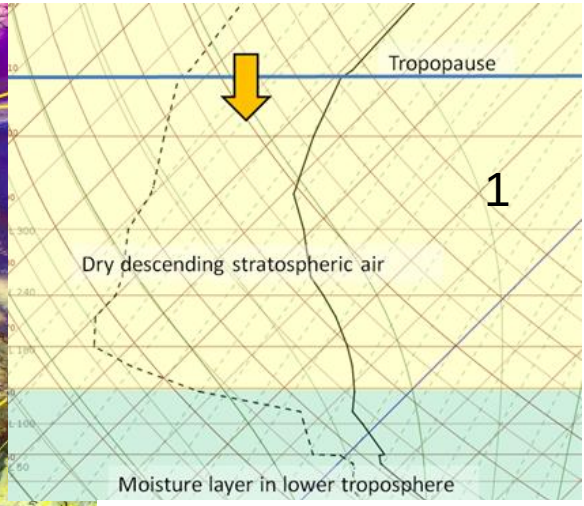
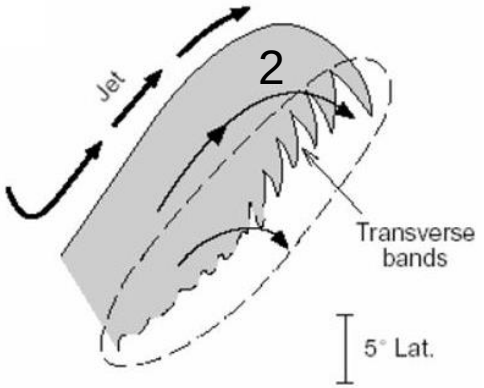


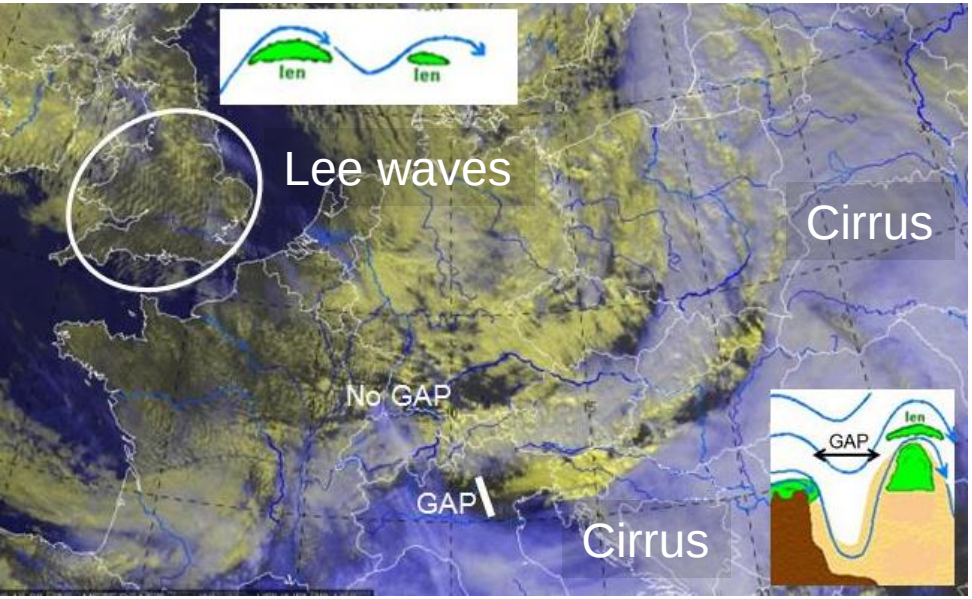


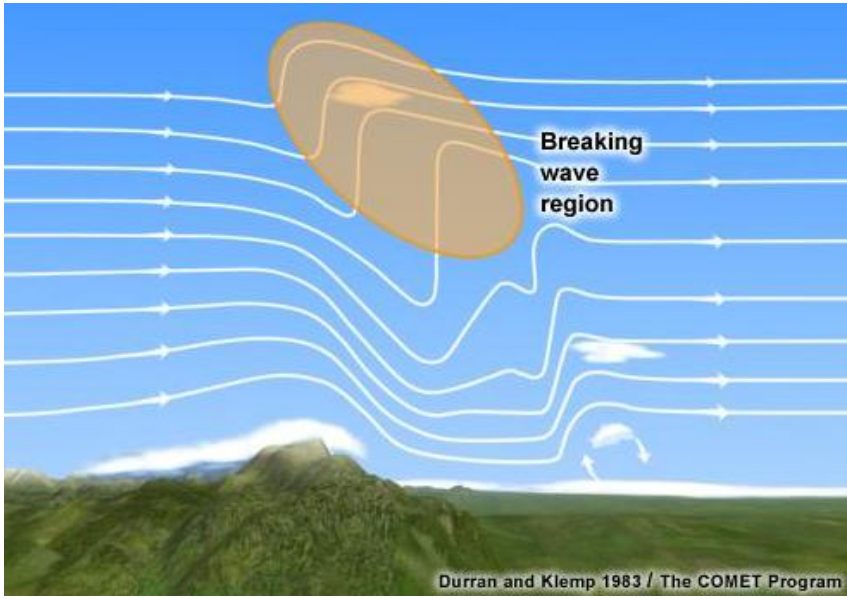


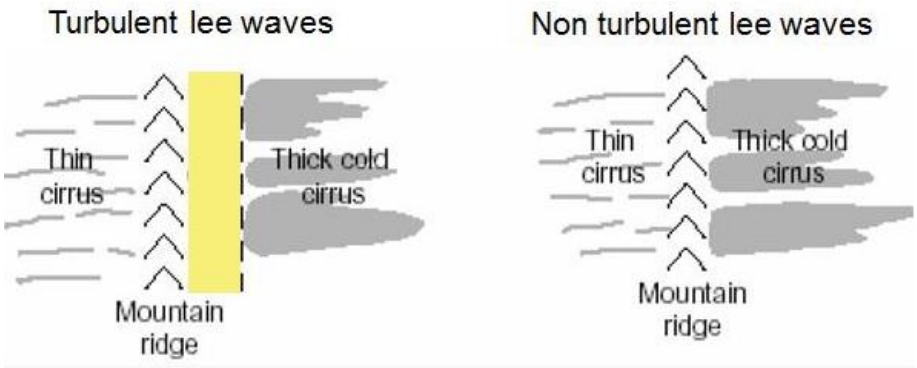
Source: EUMeTrain - ePort

15 Nov 2018, 12:00 UTC, Airmass RGB, Isotachs 300 hPa in kt

Storm Situation over Europe with turbulence

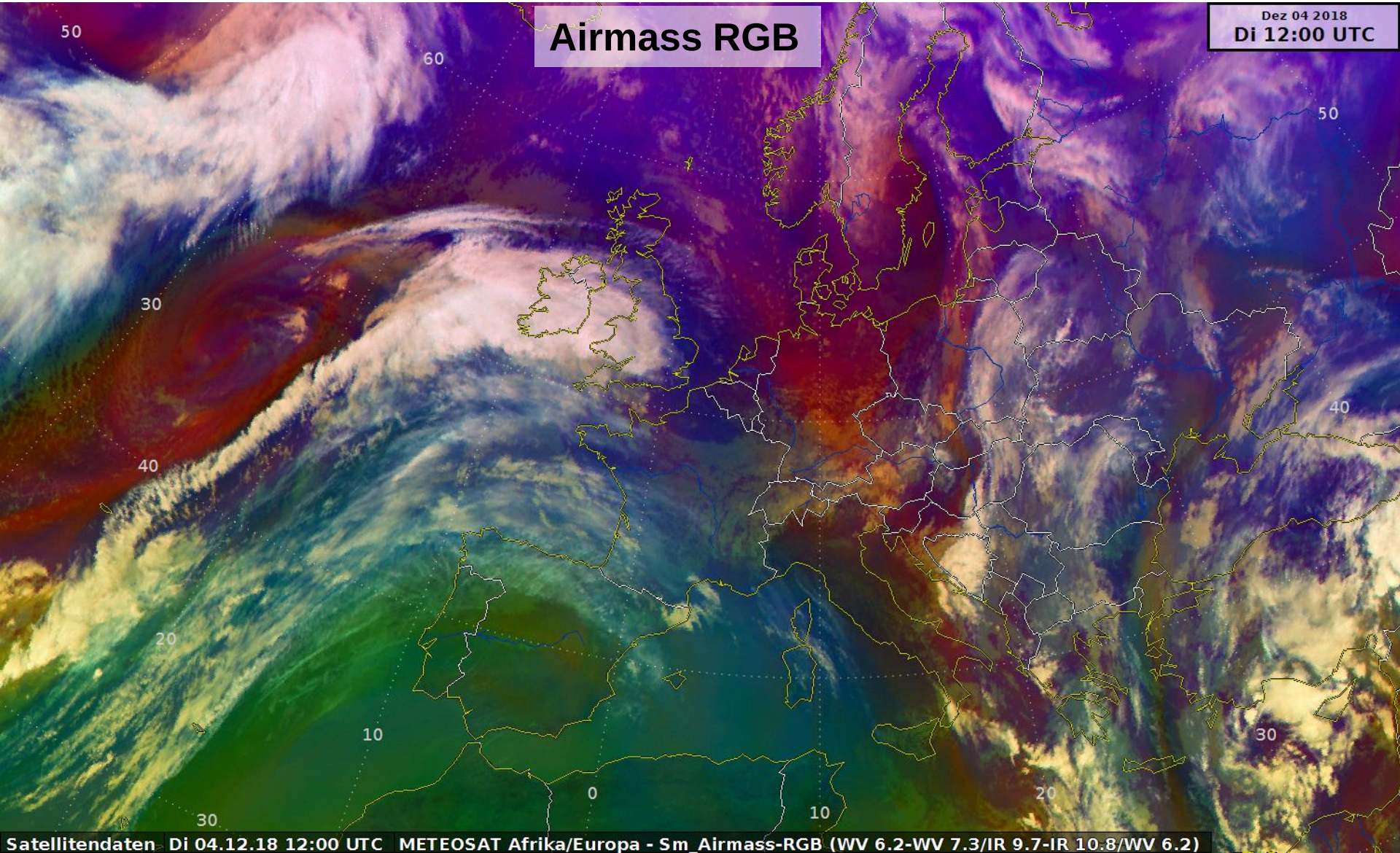






4 – Satellite Images and Turbulence

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



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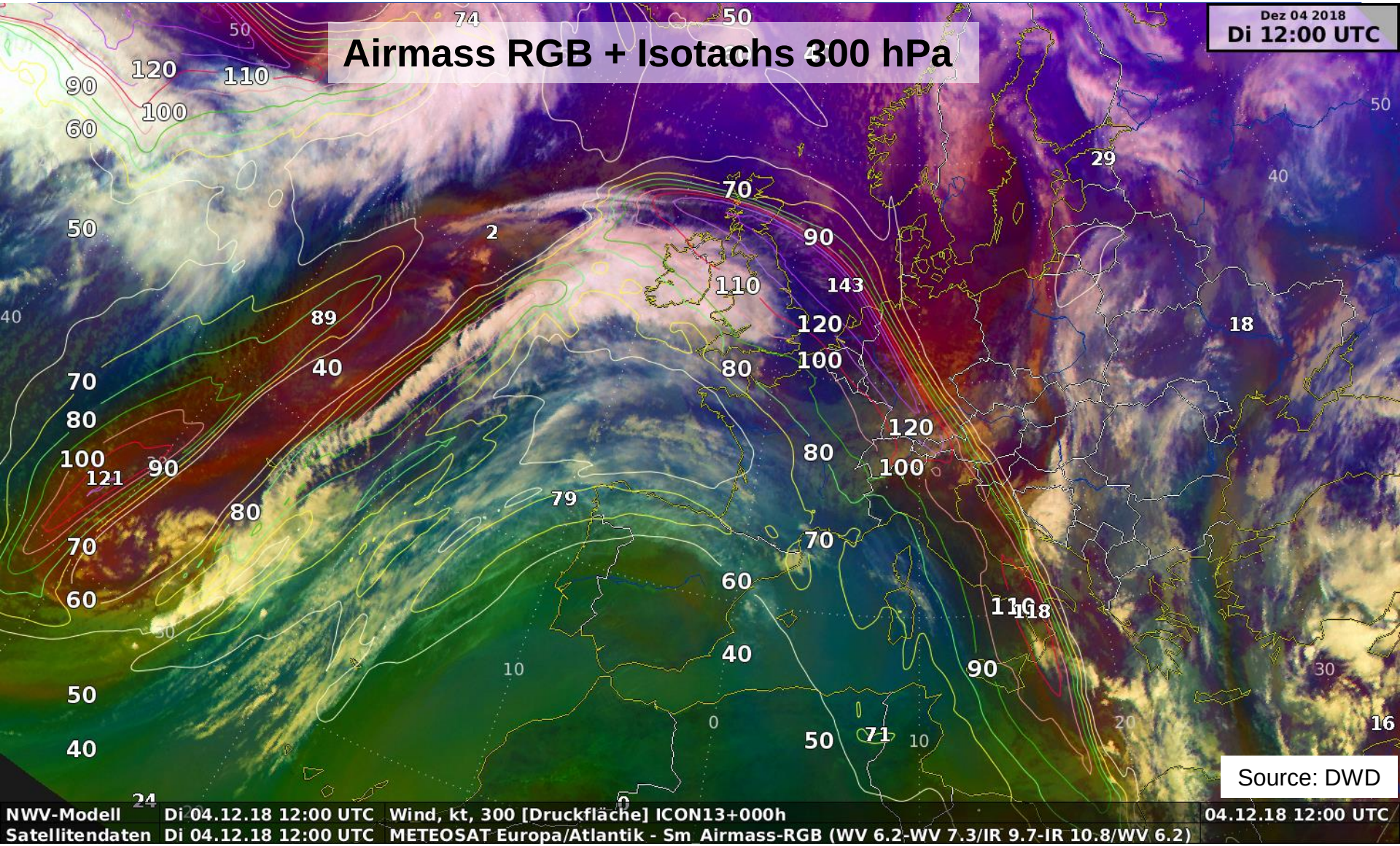

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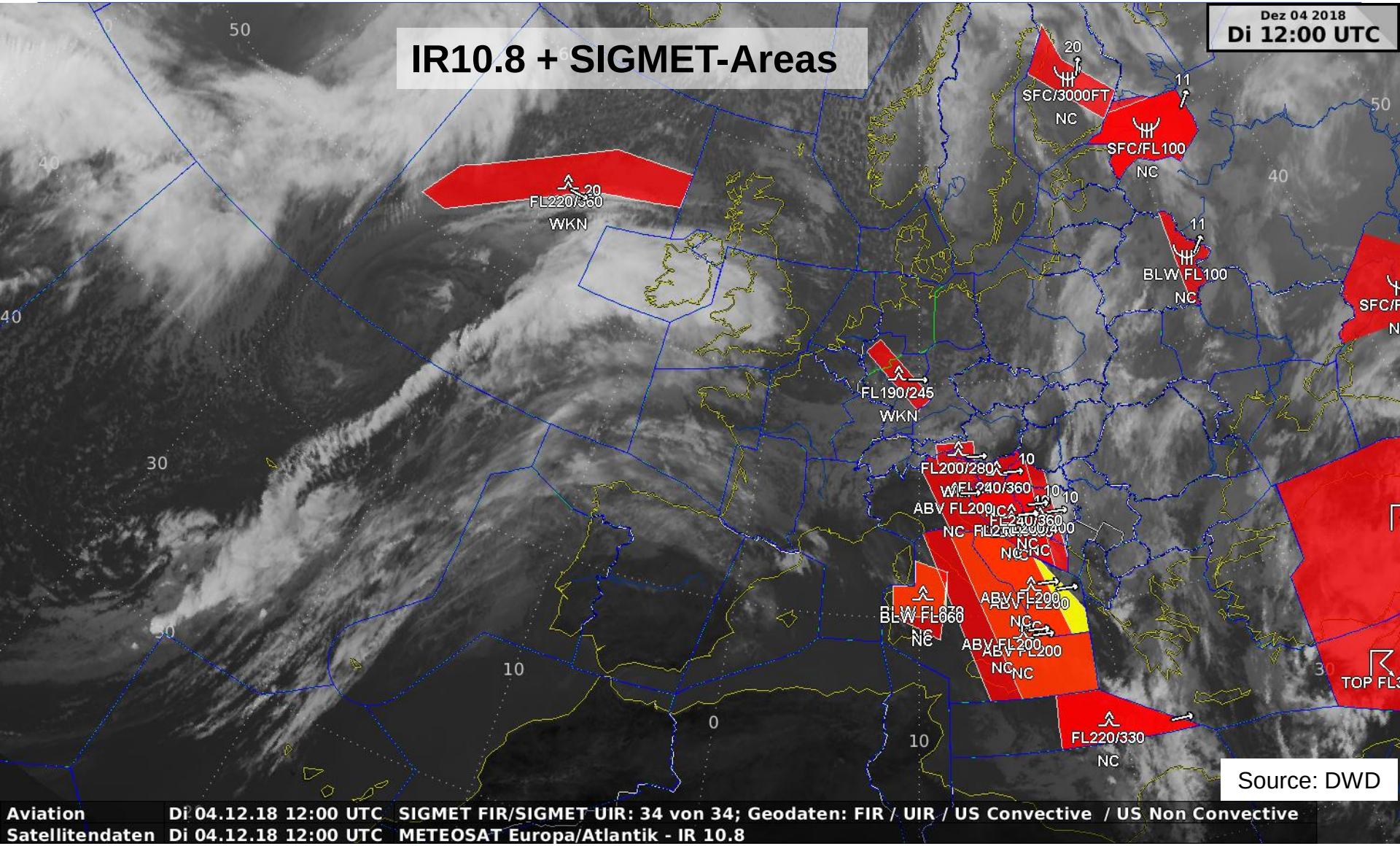

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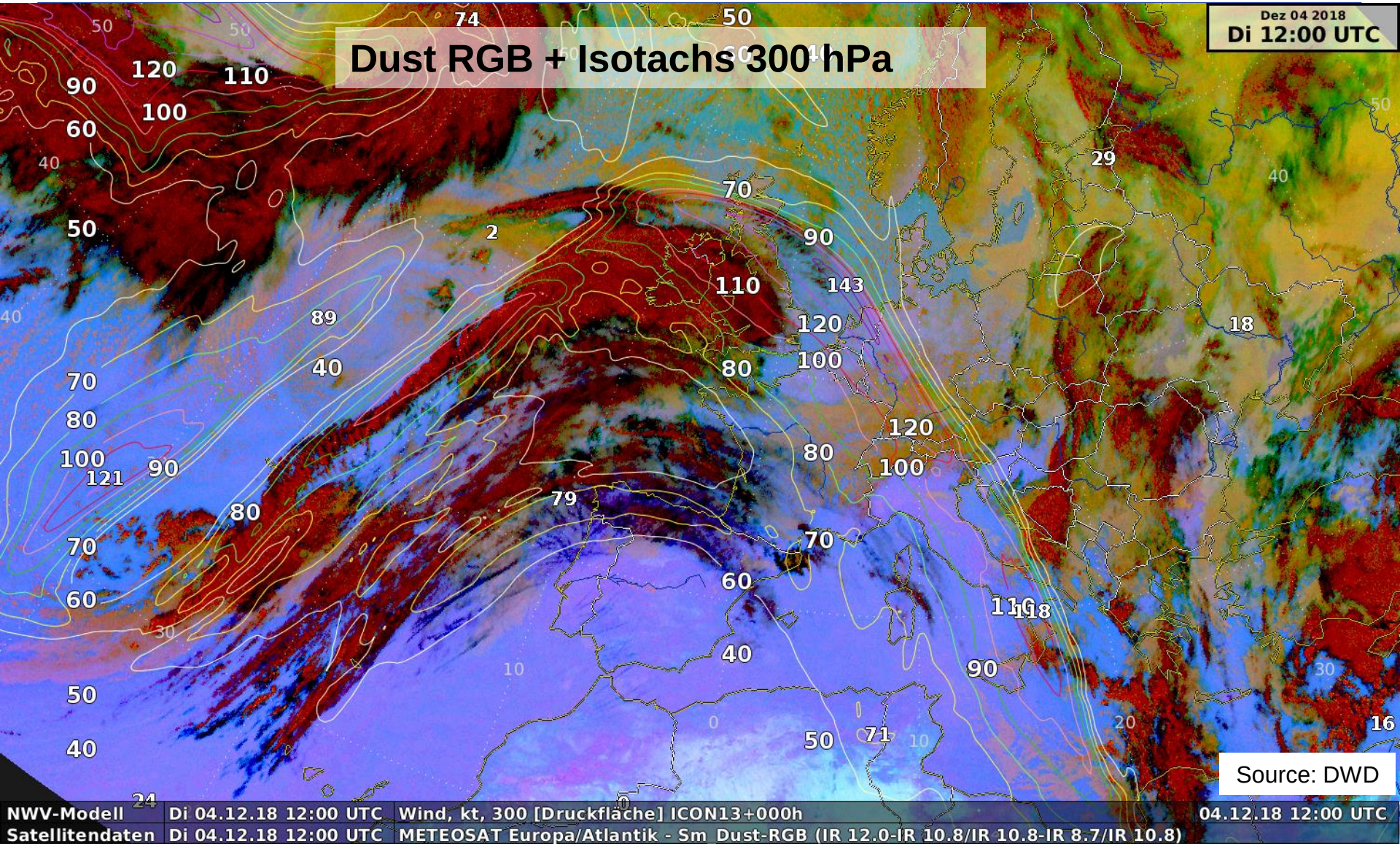

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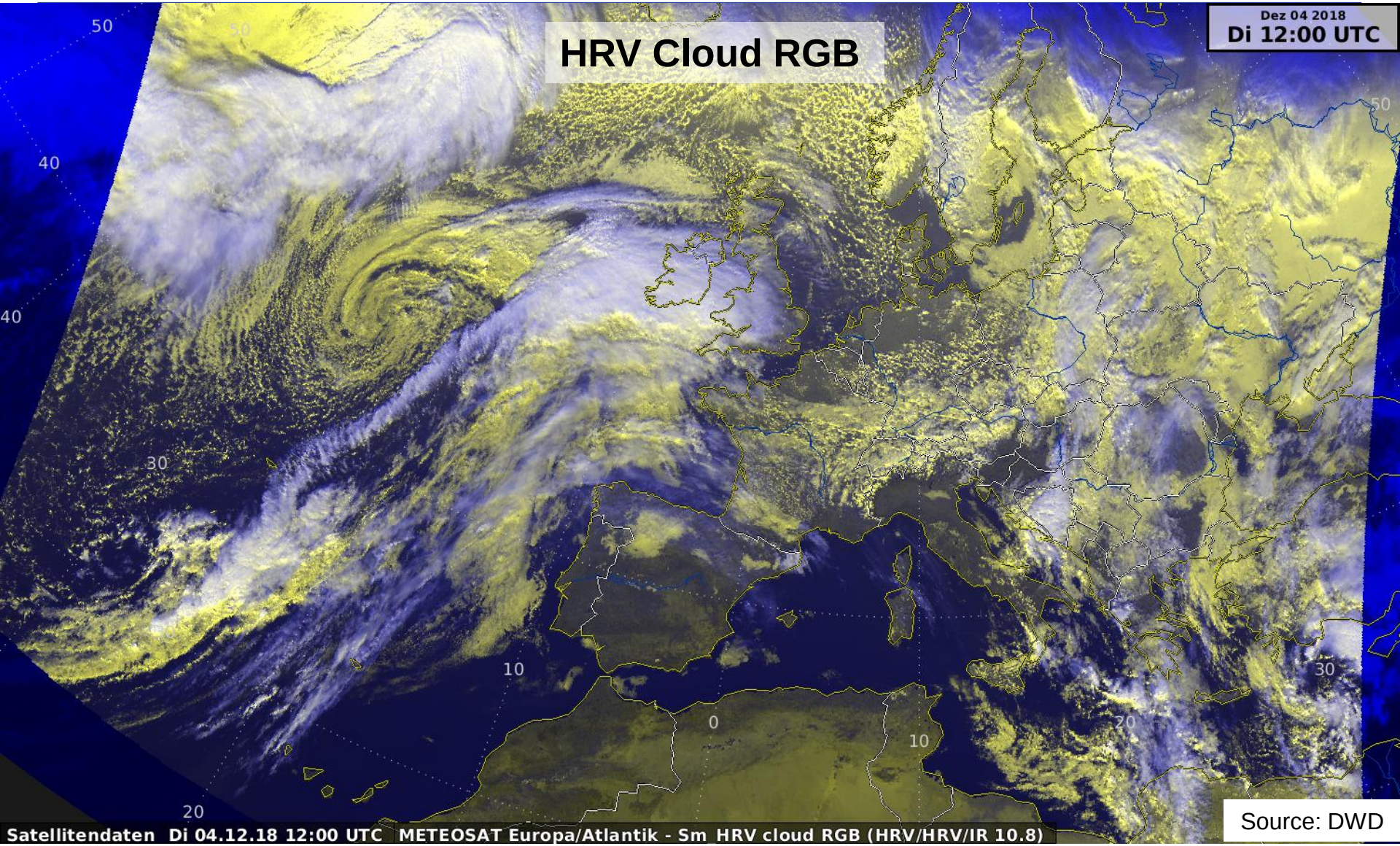
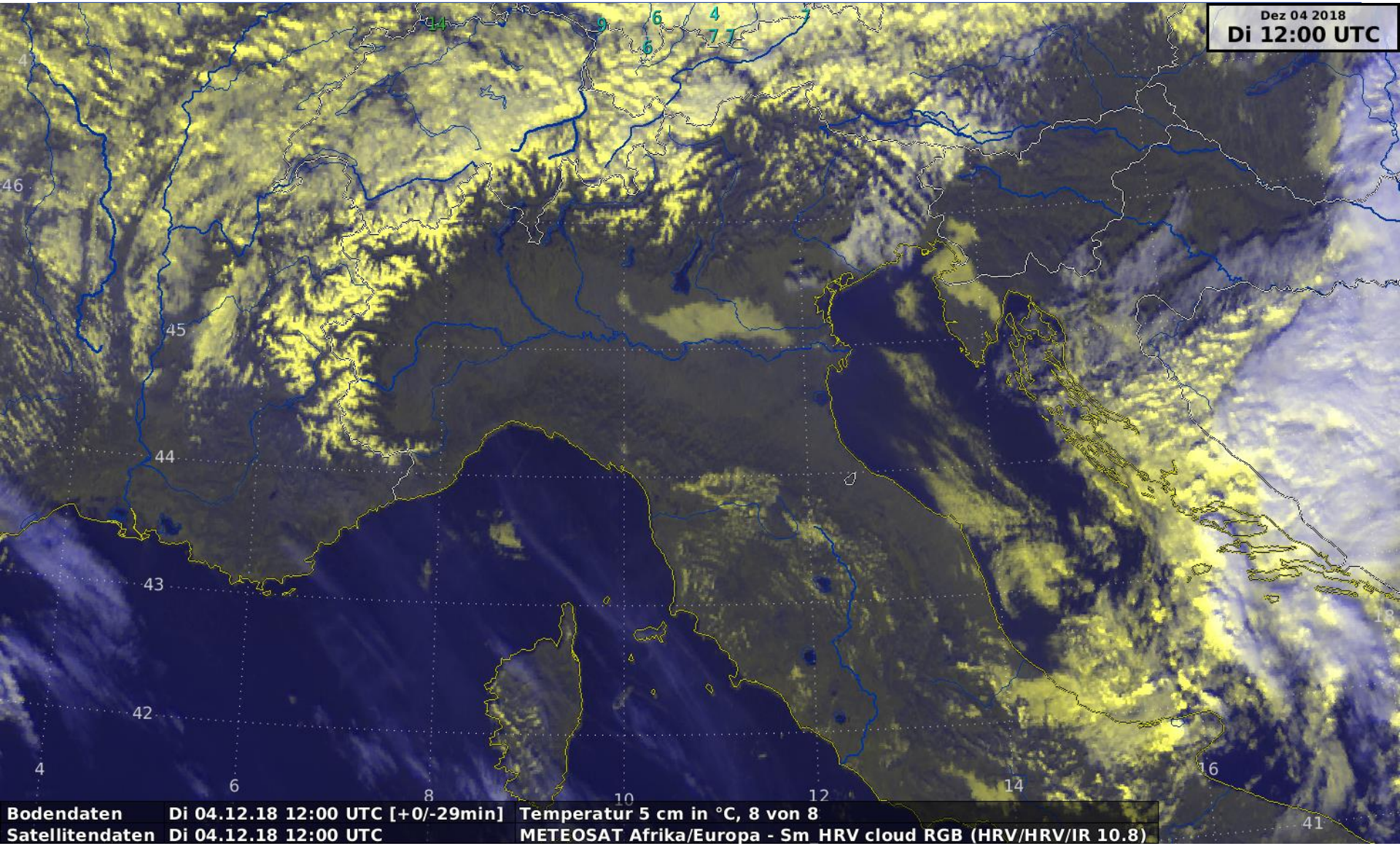


Source: DWD

4 – Satellite Images and Turbulence



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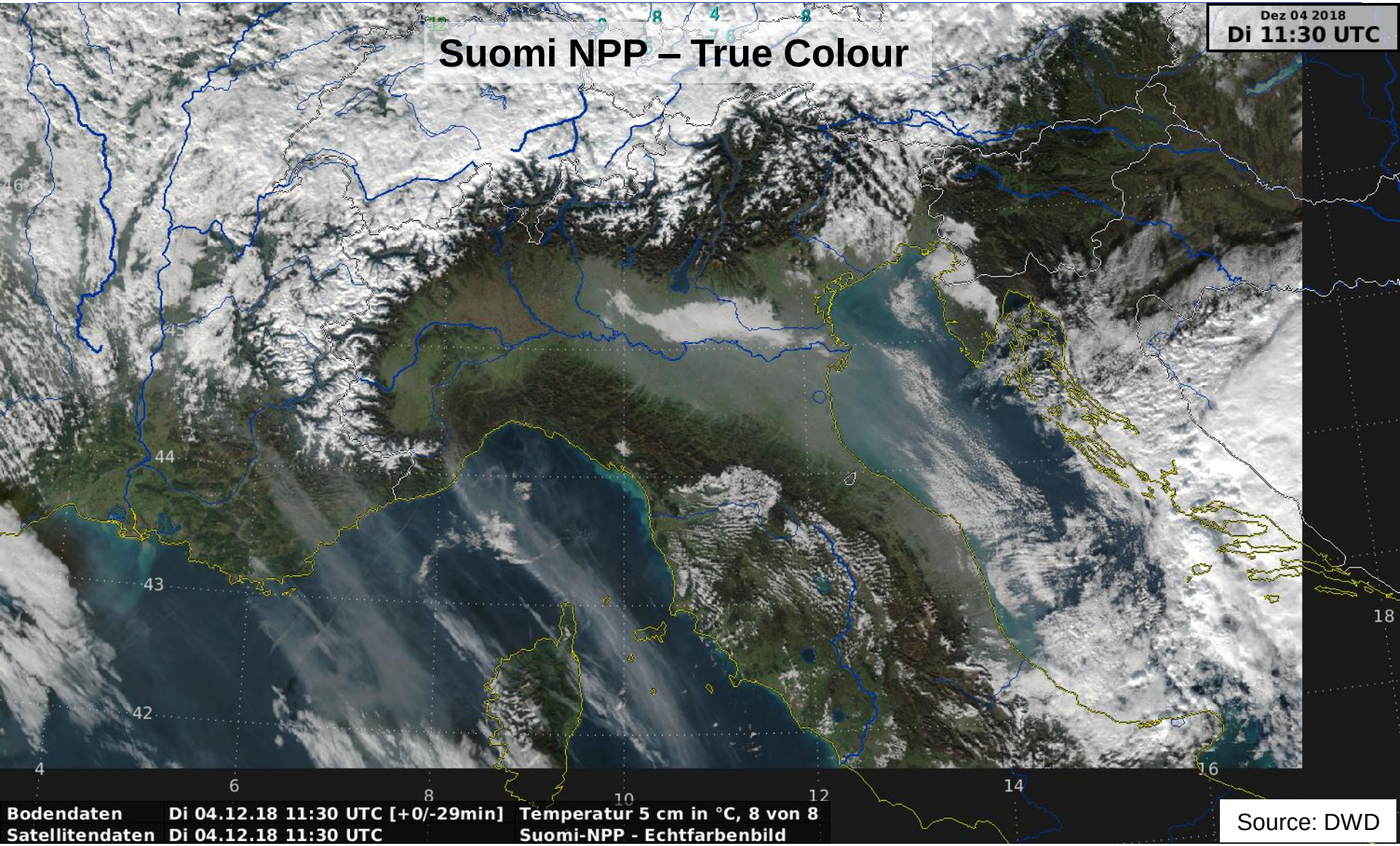
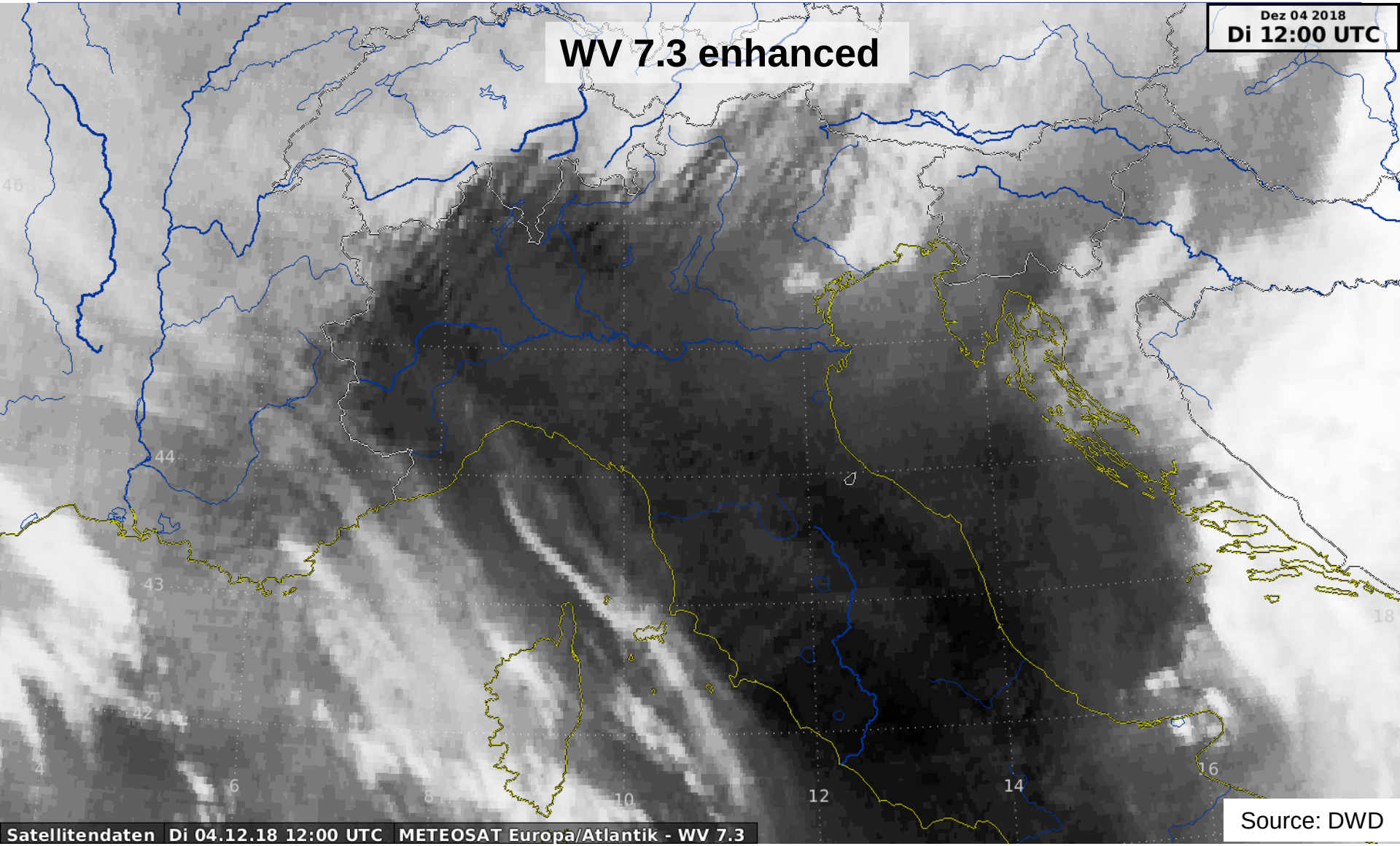


Source: DWD

4 – Satellite Images and Turbulence

Deutscher Wetterdienst
Wetter und Klima aus einer Hand



Source: DWD

Deutscher Wetterdienst
Wetter und Klima aus einer Hand

Probability of Occurrence of Tropopause Folding
ASII-NG (Automatic Satellite Image Interpretation – New Generation)
4 Dec 2018, 12 UTC

NWC SAF

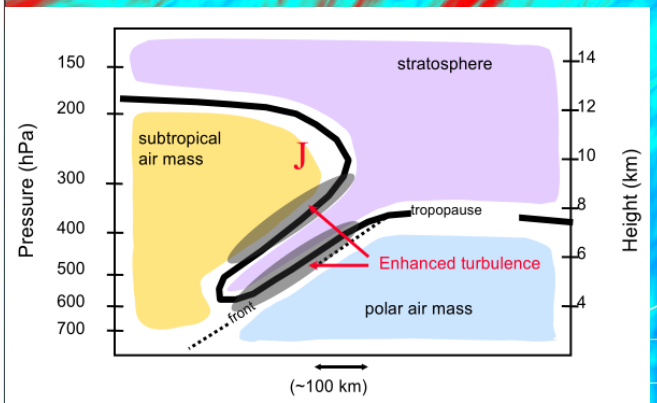
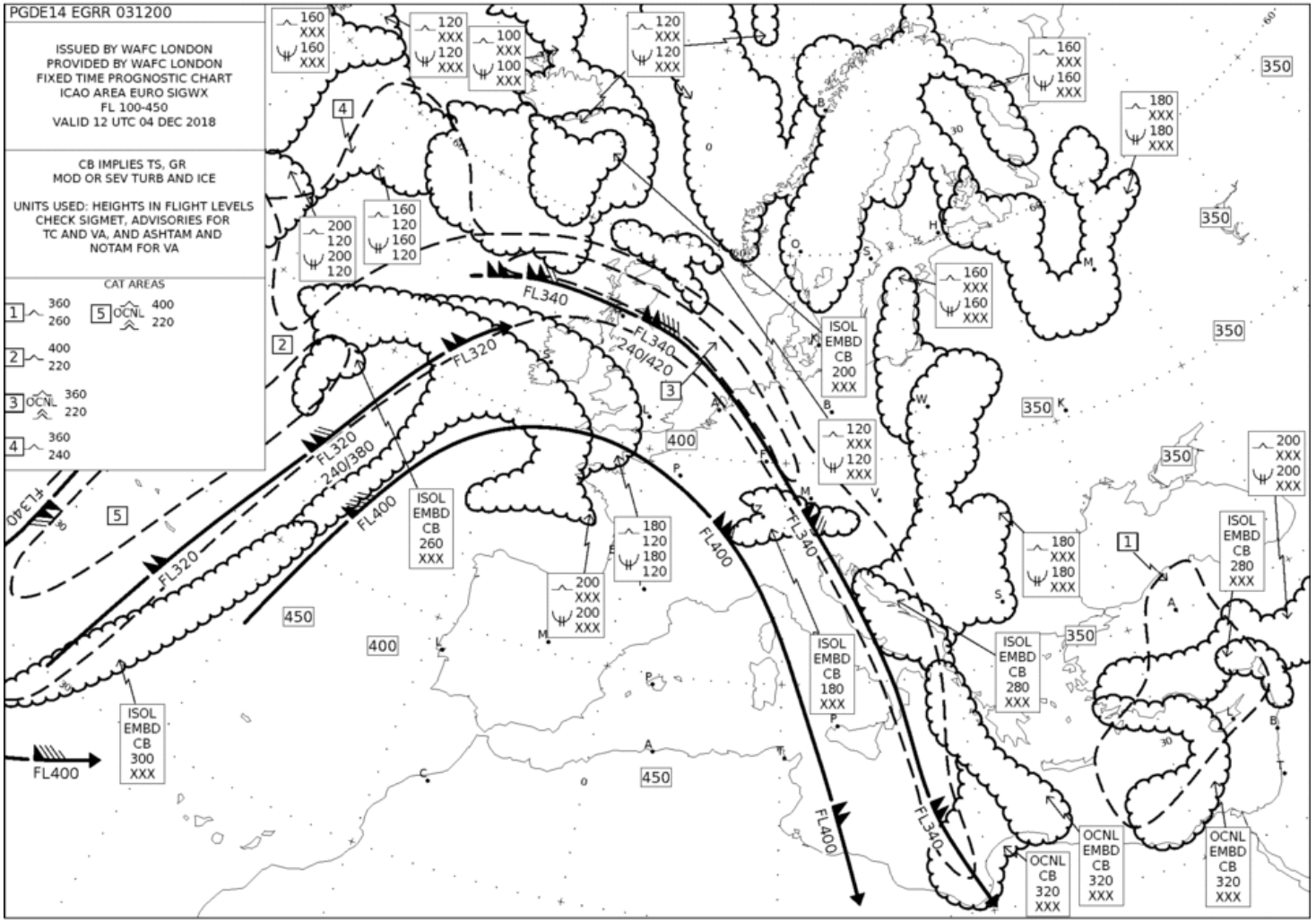


Figure 1: Illustration of a tropopause fold. (© Feltz and Wimmers 2010)

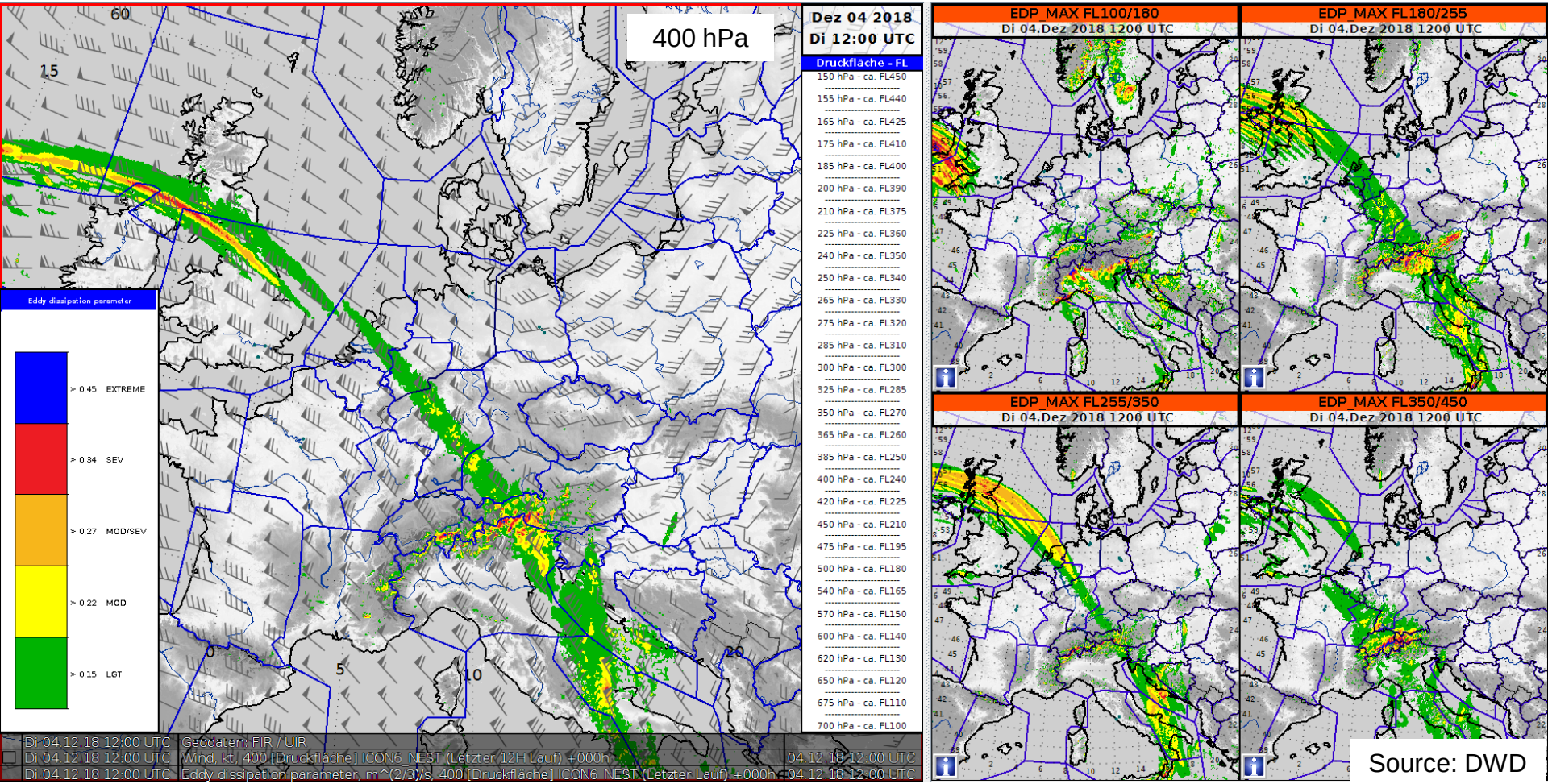
Probability of turbulence due to tropopause foldings (%)

0 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100

SWC EUR, 4 Dec 2018, 12:00 UTC

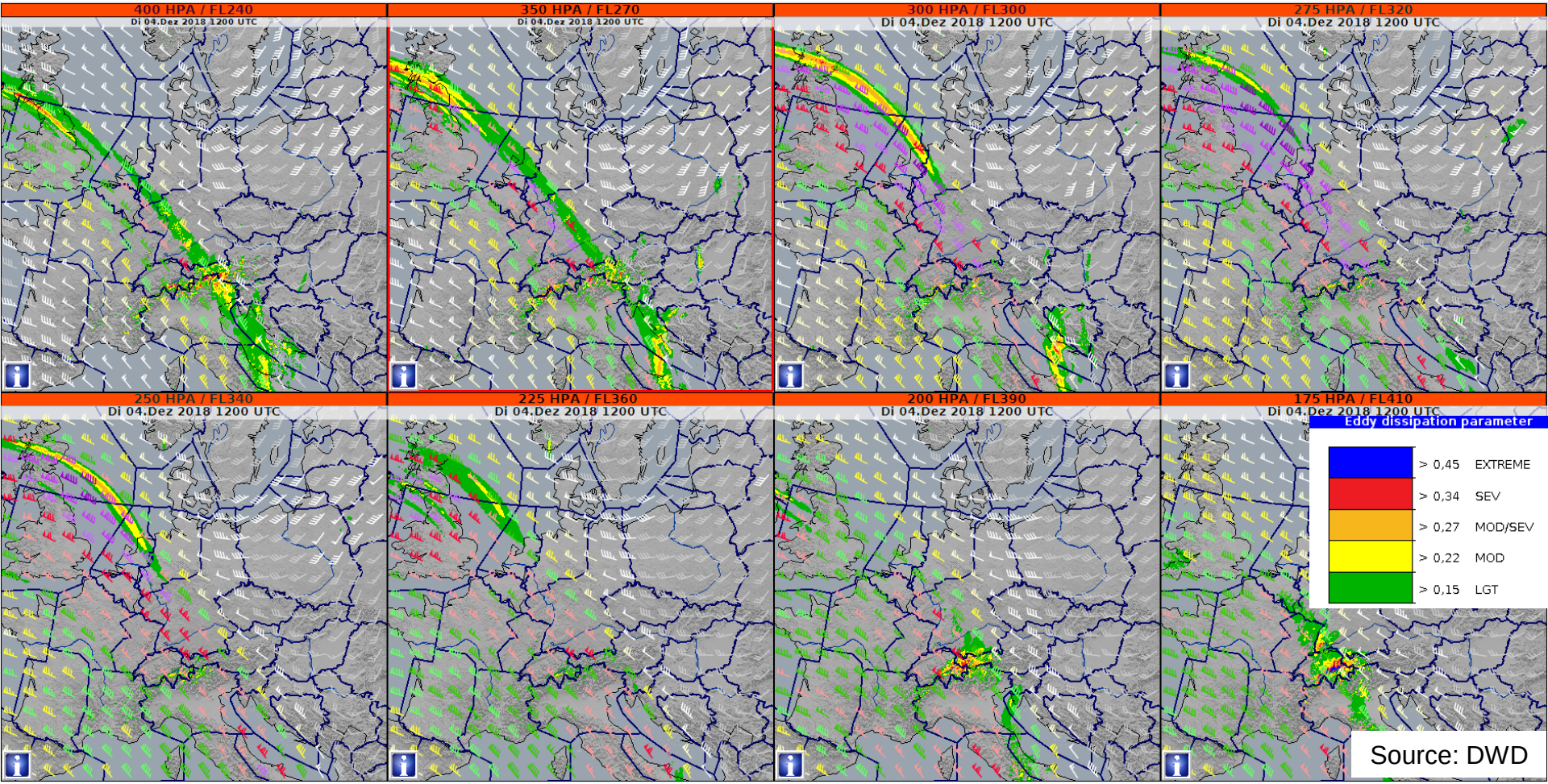


EDP (Eddy dissipation parameter), 4 Dec 2018, 12:00 UTC



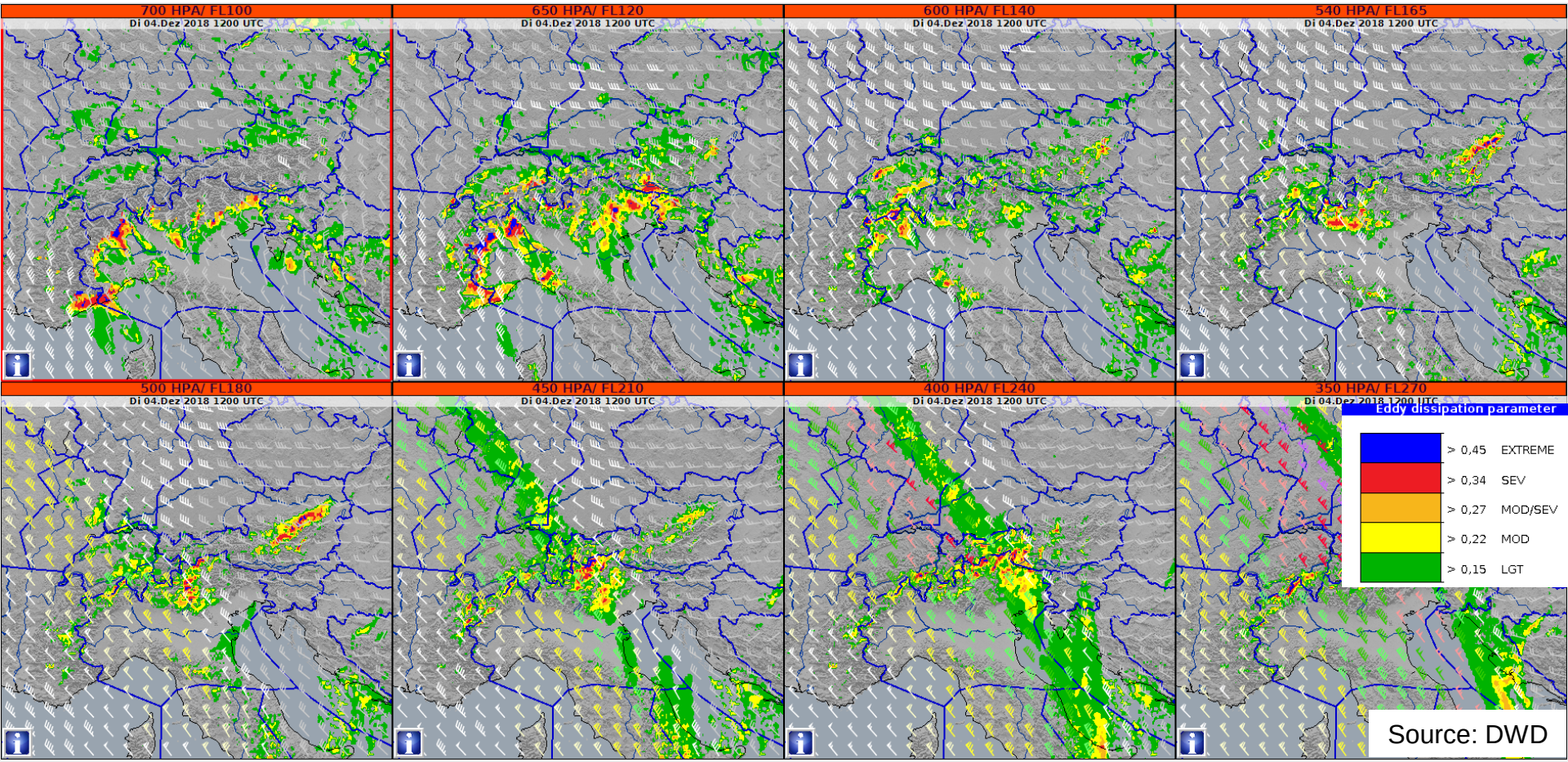
Source: DWD

EDP (Eddy dissipation parameter), UIR, 4 Dec 2018, 12:00 UTC



Source: DWD

EDP (Eddy dissipation parameter), FIR, 4 Dec 2018, 12:00 UTC



Turbulence prediction for aviation in DWD

- Forecast of EDR (Eddy Dissipation Rate).
  It descripes the reduction of turbulent kinetic energy (TKE).

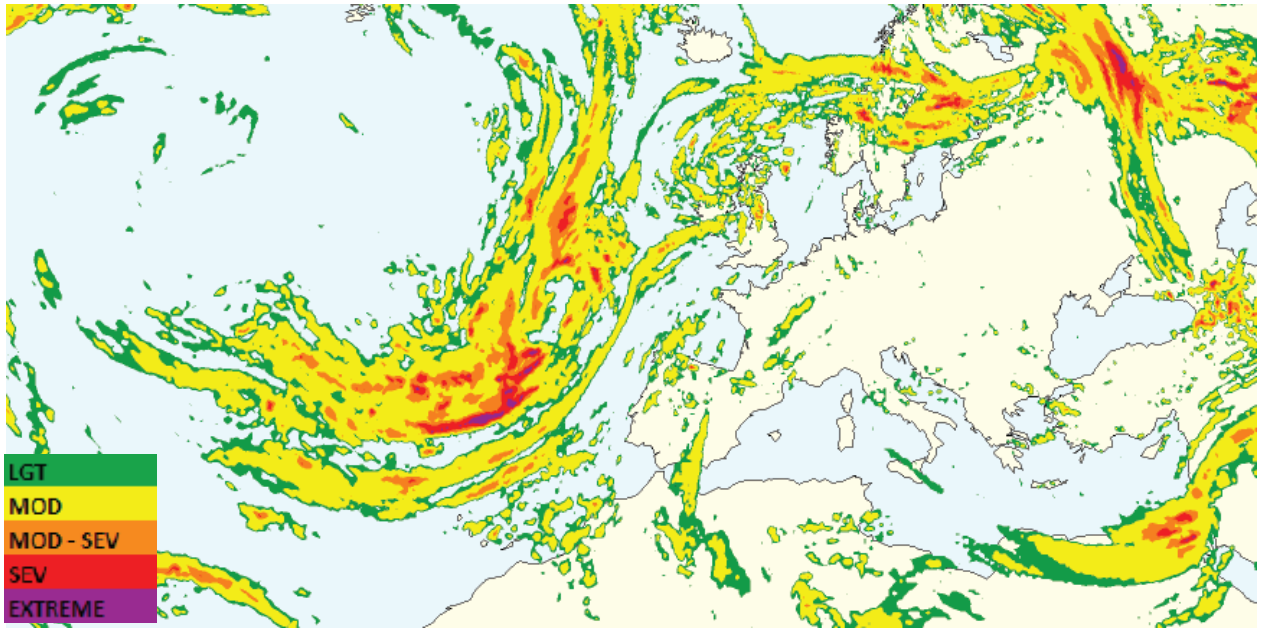
- Global numerical weather prediction of DWD (ICON):
  The name for EDR is **EDP,** since 2015 operational.

- It is not possible to detect the turbulent eddies (100 m … 1km).
  With the help of parametrisation it is possible to derive the EDP.

- Realy turbulence for airplanes for this phenomena:
  - Kelvin-Helmholz-waves with windshear (Clear Air Turbulence)
  - Shear of convective circulation (Convective Induced Turbulence)
  - Orographic Shear (Mountain Wave Turbulence)

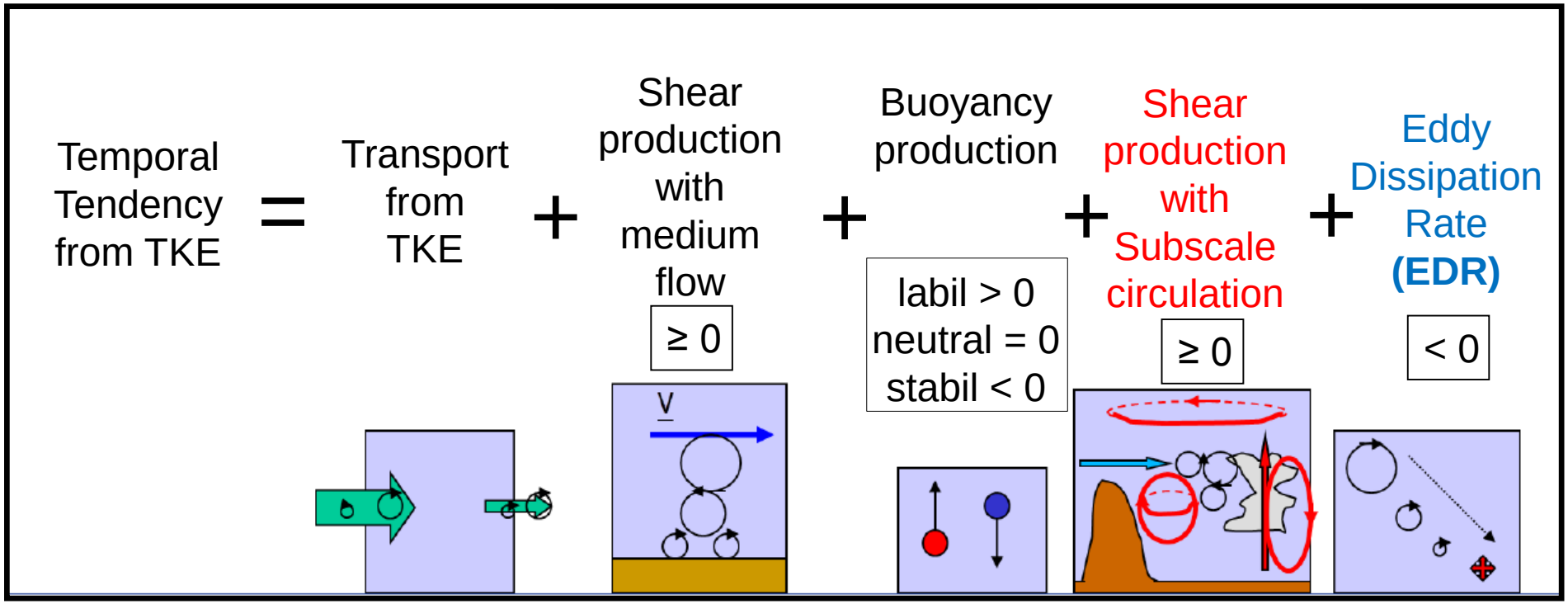
Turbulence prediction for aviation in DWD

- All 6 hours with the ICON model (global)
- With a higher resolution for Europe (30 isobaric surfaces) between FL100 and 450.



Max. Turbulence Intensity with EDP, FL245-335, 17 Oct 2017, 00 UTC

Schematic presentation of the temporal trend from TKE, determined by source terms and transspport terms



Summary

- Take care in the use of the definition of Clear Air Turbulence
- Use forecast parameters for turbulence (e.g. EDP)
- Look to Airmass RGB, HRV Cloud RGB, Dust RGB
- Look to pattern of analysis 300 hPa with Jet Stream
- Use radiosoundings, PIREP

Recommended learning material:

- COMET: Jet Streams (English, German, French, Spanish)
  https://www.meted.ucar.edu/tropical/synoptic/jetstreams/
- COMET: Forecasting Clear Air Turbulence for Aviation (English)
  https://www.meted.ucar.edu/avn_int/turbulence/
- EUMeTrain Training Module: Clear Air Turbulence (English)
  http://www.eumetrain.org/resources/cat_2014.html
- EUMeTrain Training Module: Gravity Waves (English)
  http://www.eumetrain.org/resources/gravity_waves.html
- EUMETSAT Case Study (English)
  https://www.eumetsat.int/website/home/Images/ImageLibrary/DAT_IL_09_11_09_A.html

Recommended learning material for RGB satellite images:

- EUMeTrain: Quick Guides (English)
  http://www.eumetrain.org/rgb_quick_guides/index.html
- EUMeTrain: RGB Colour Interpretation Guide (English)
  http://eumetrain.org/RGBguide/rgbs.html?page=1&sat=-1&rgb=-1&colour=-1&recent=false
- EUMeTrain Training Module: Operational use of RGBs: Part 1 (English)
  http://www.eumetrain.org/resources/operational_use_rgb.html
- EUMeTrain Training Module: Operational use of RGBs: Part 2 (English)
  http://www.eumetrain.org/resources/operational_use_rgb2.html


Thank you!
peter.schmitt@dwd.de
1 Nov 2018, 07:45 UTC
Bremerhaven