Karlsruhe Institute of Technology

KIT-Campus Alpin
IMK-IFU: Atmosphärische Umweltforschung

WindForS
Wind Energy Research Cluster

# Low-level Jet Climatologies for Northern and Southern Germany from SODAR and RASS Measurements

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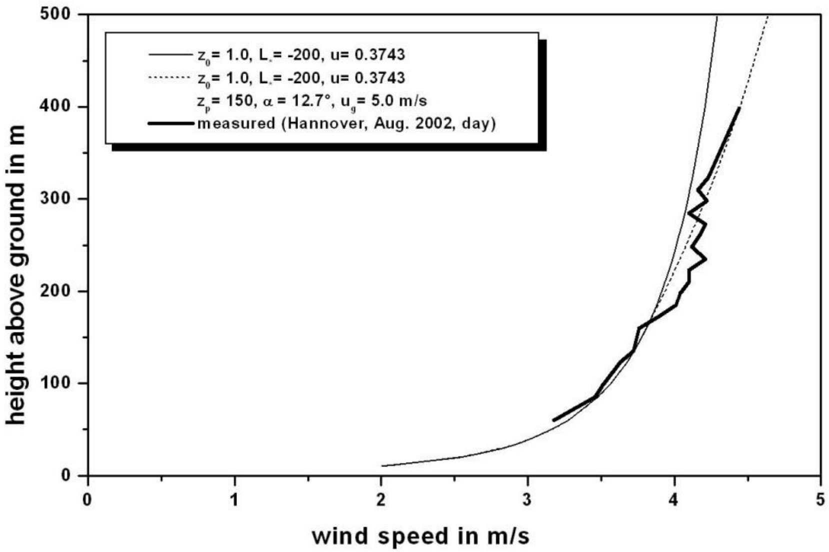
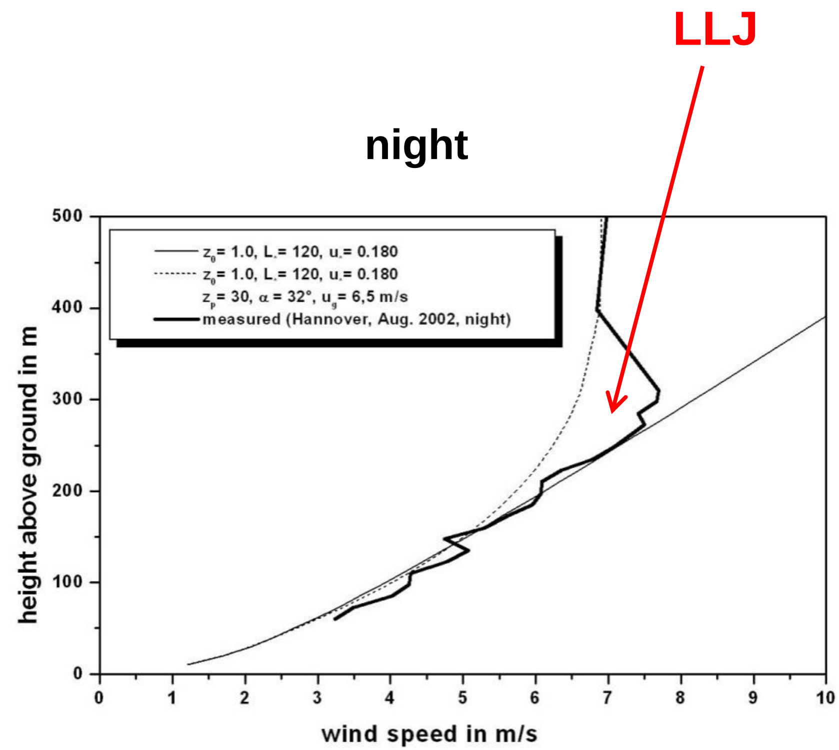
| | |
|---|---|
| 1 | Introduction to low-level jets |
| 2 | Sodar observations in Northern Germany |
| 3 | RASS observations in Southern Germany |
| 4 | uncommon LLJ |

# Sodar observations
# monthly mean vertical wind profiles
# August 2002, 17 nights with LLJ

## daytime



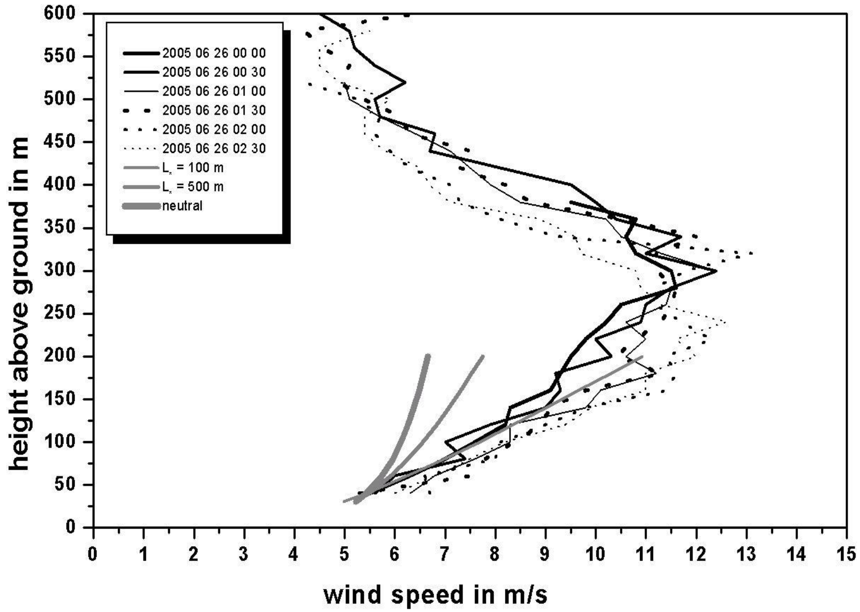

## night

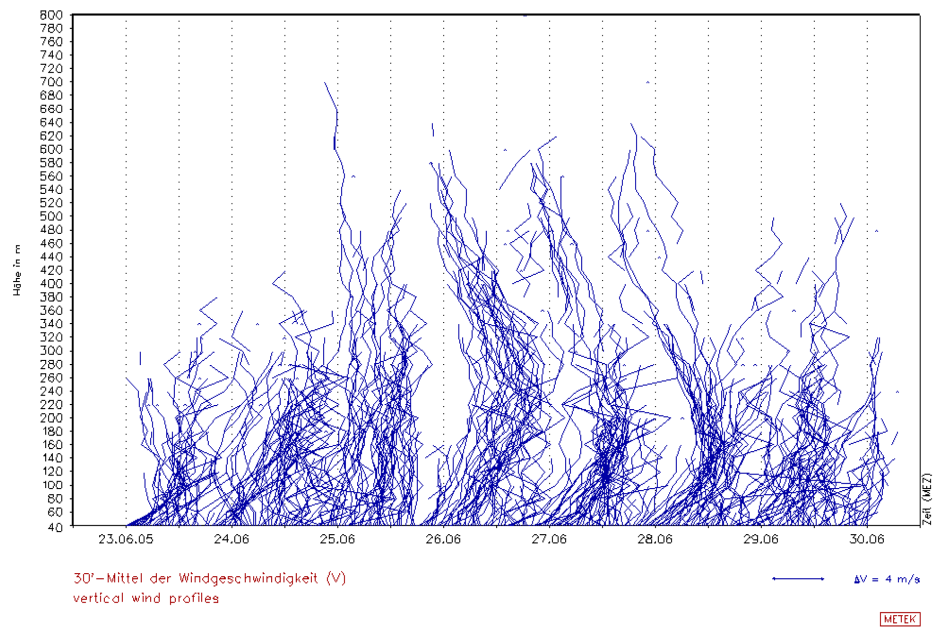


# Sodar observation of a low-level jet

## vertical wind profiles (30 min mean)

**26 June 2005** **23-30 June 2005**



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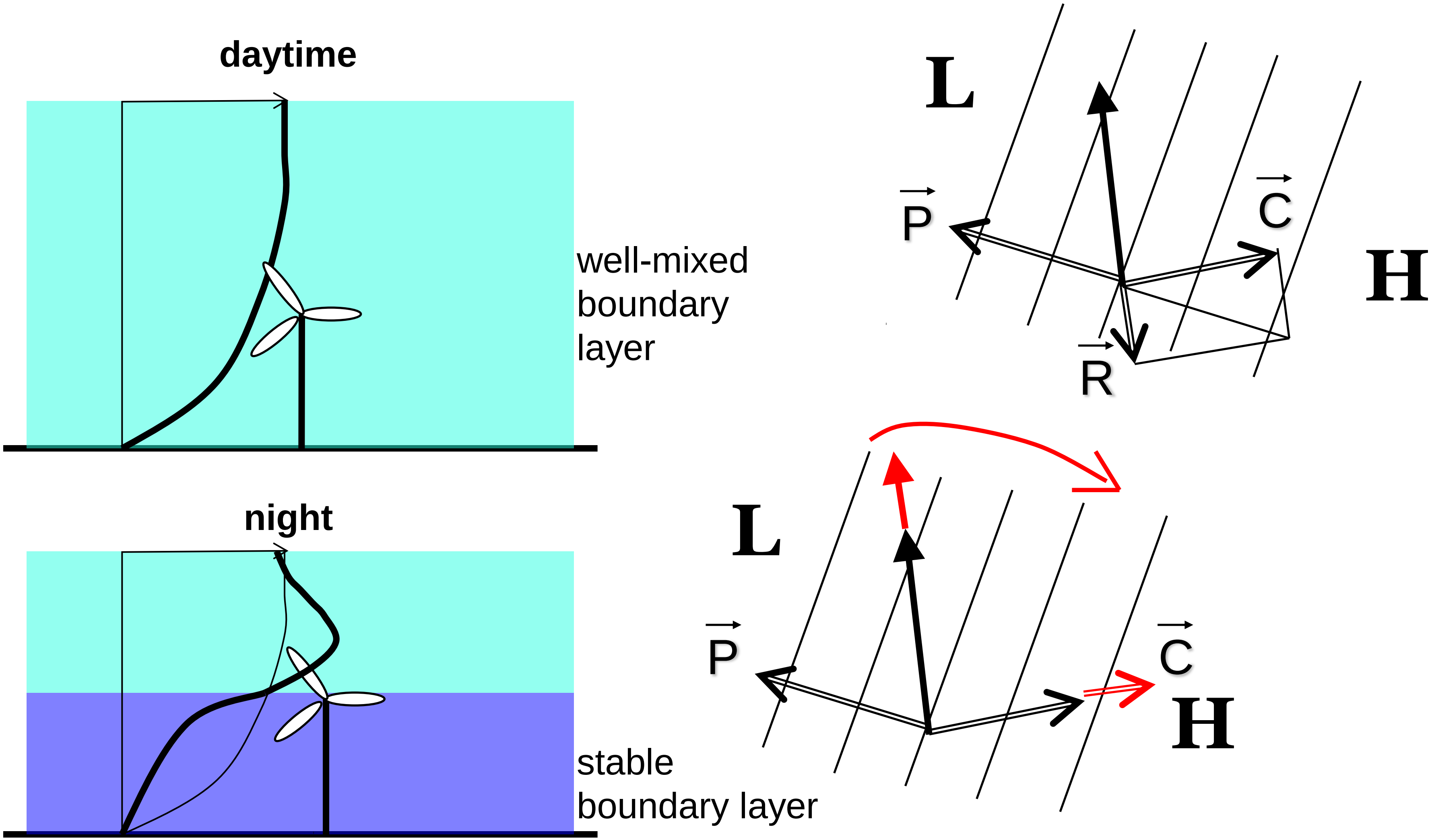
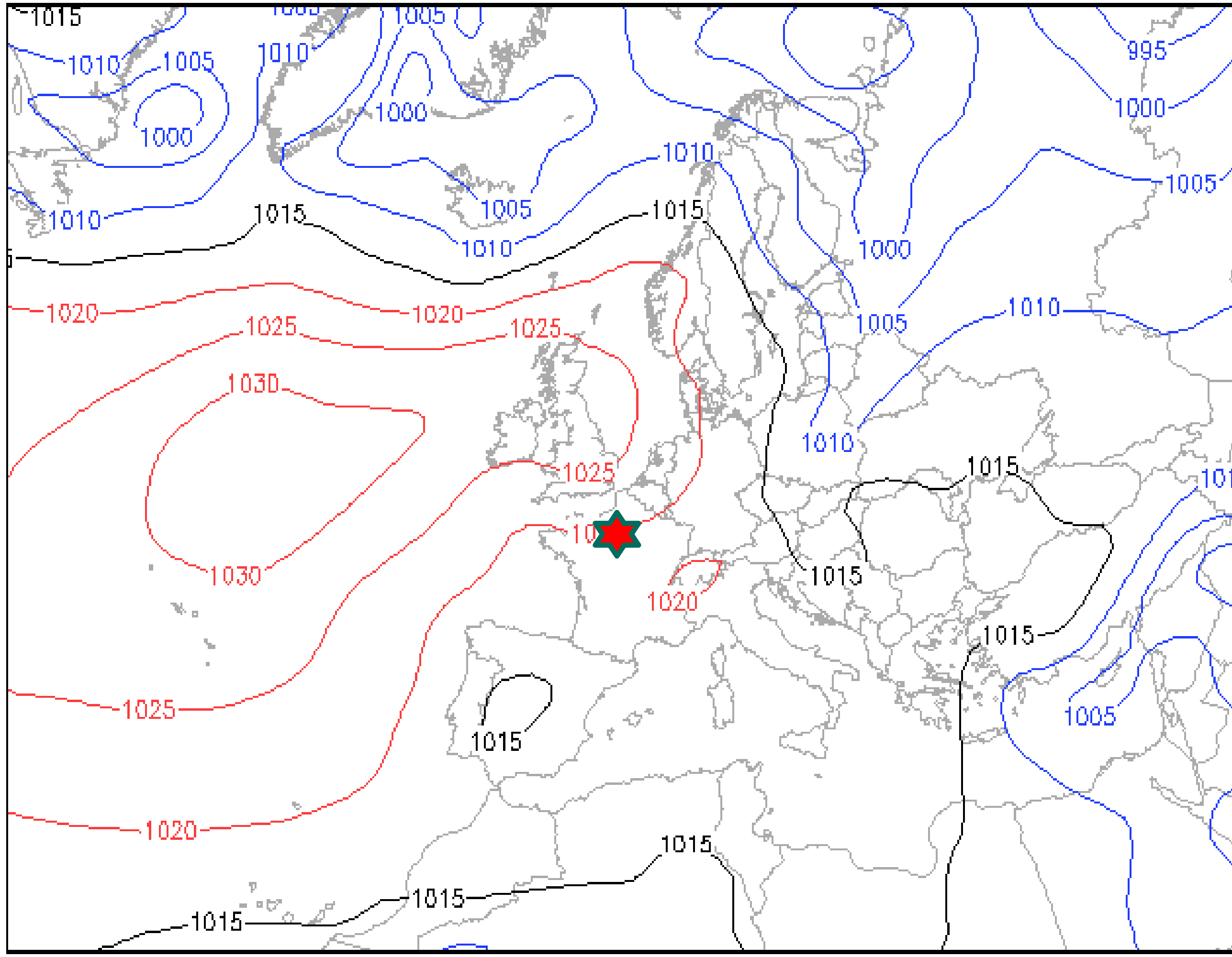

daytime
well-mixed boundary layer
night
stable boundary layer
L
H
P
C
R
L
H
P
C

**sea-level pressure**
**00 GMT**

**26 June 2005**

**asterisk:**
**observation site**




Bodendruck GFS (hPa)
So 26.06.05 00 GMT (Sa 00 + 24)
WetterOnline

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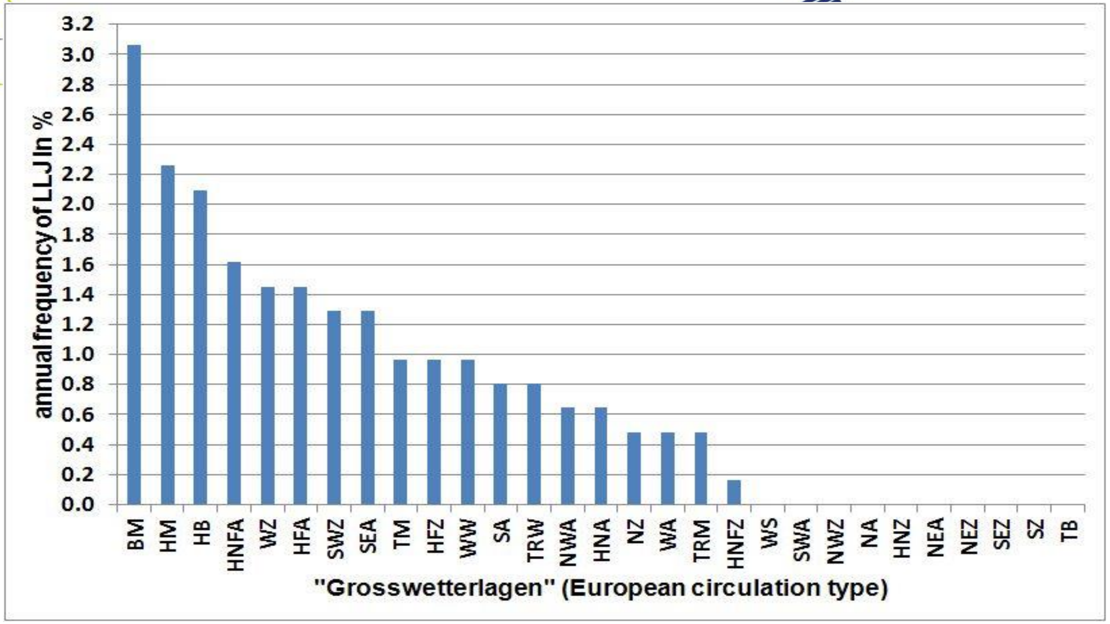
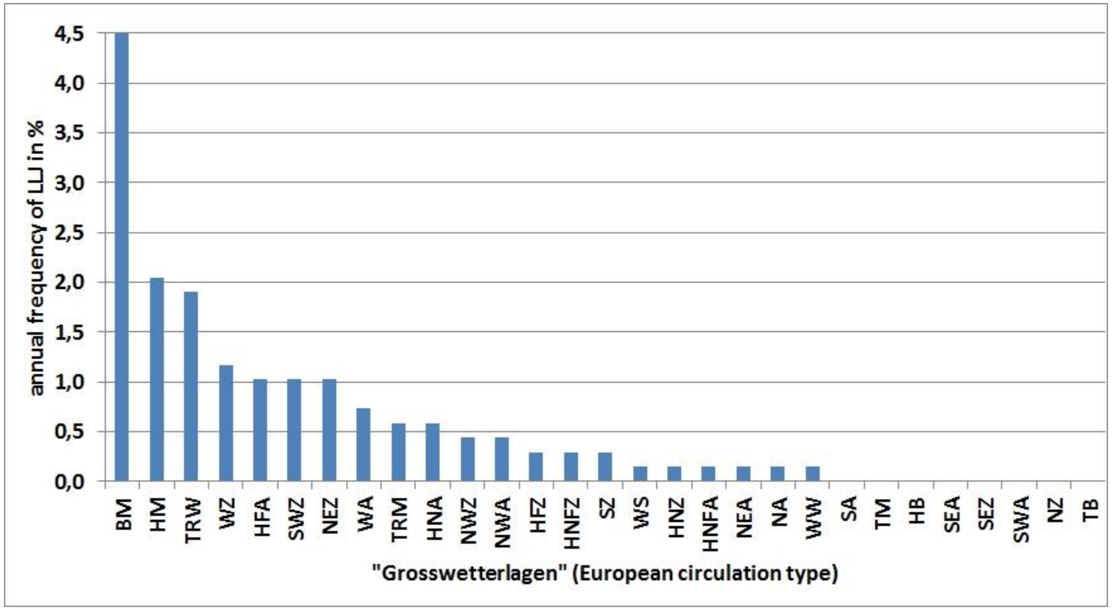
**SODAR**

**SODAR-RASS**




**frequency of LLJ over Hannover for 20 months in the years 2001 to 2003**

**roughly 22 % of all nights**

**over Augsburg in the years 2008-2010, 2014**

**roughly 17,5 % of all nights**

**Circulation types:**

**BM bridge Central Europe**
**HB high Brit. Isles**
**HM high Central Europe**
**...**

**HFA/HFZ high Scandinavia**
**HNFA high Northern Atlantic**
**...**

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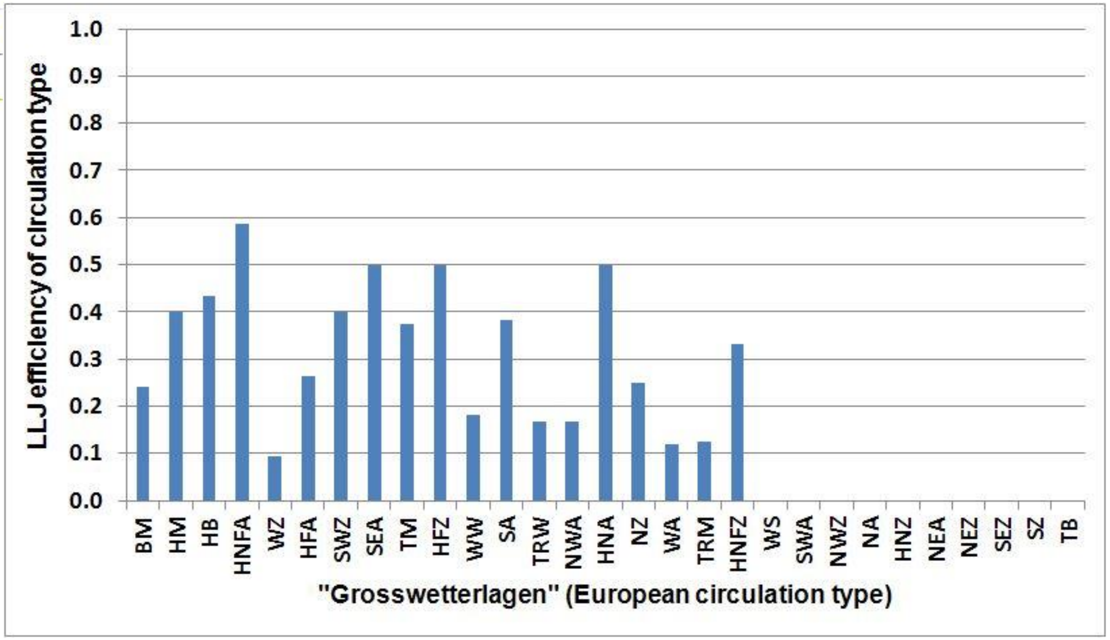
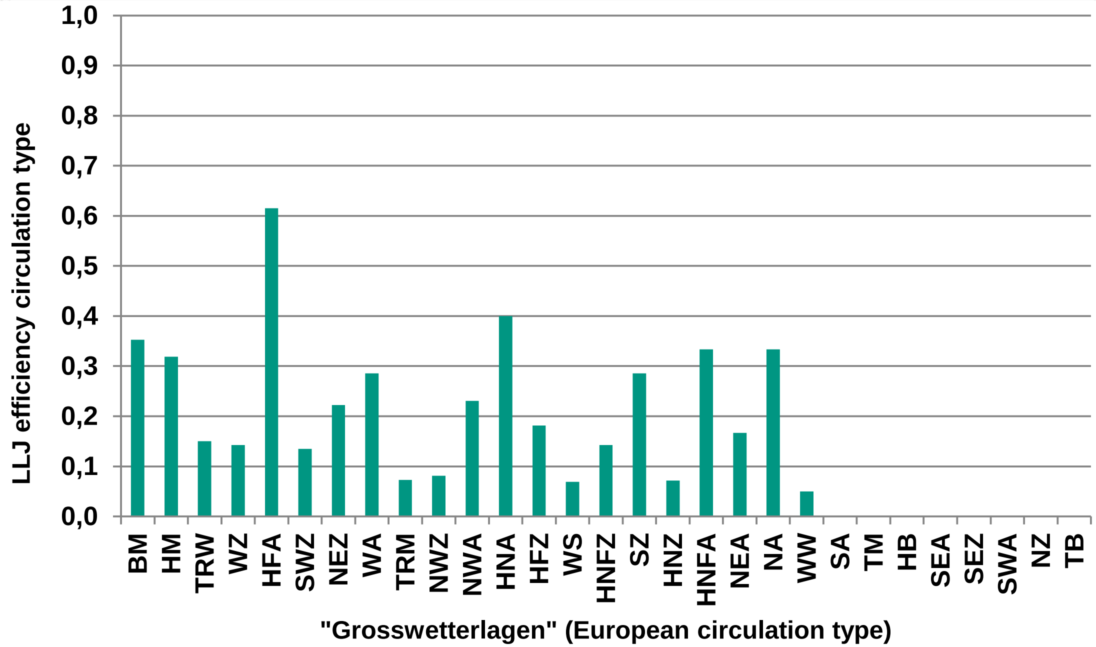



**"effectivity" for forming a low-level jet**

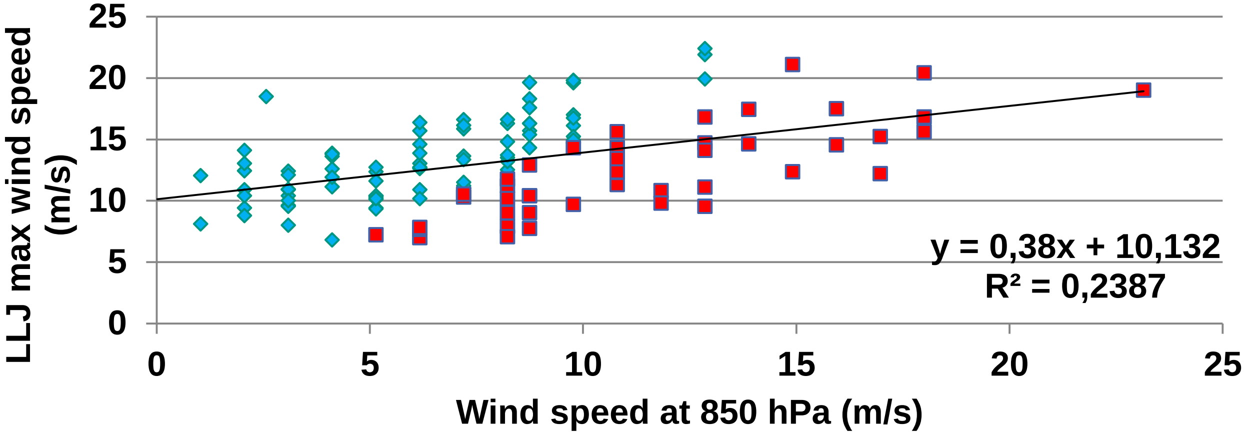
**top: Hannover**
**bottom: Augsburg**

**Circulation types:**

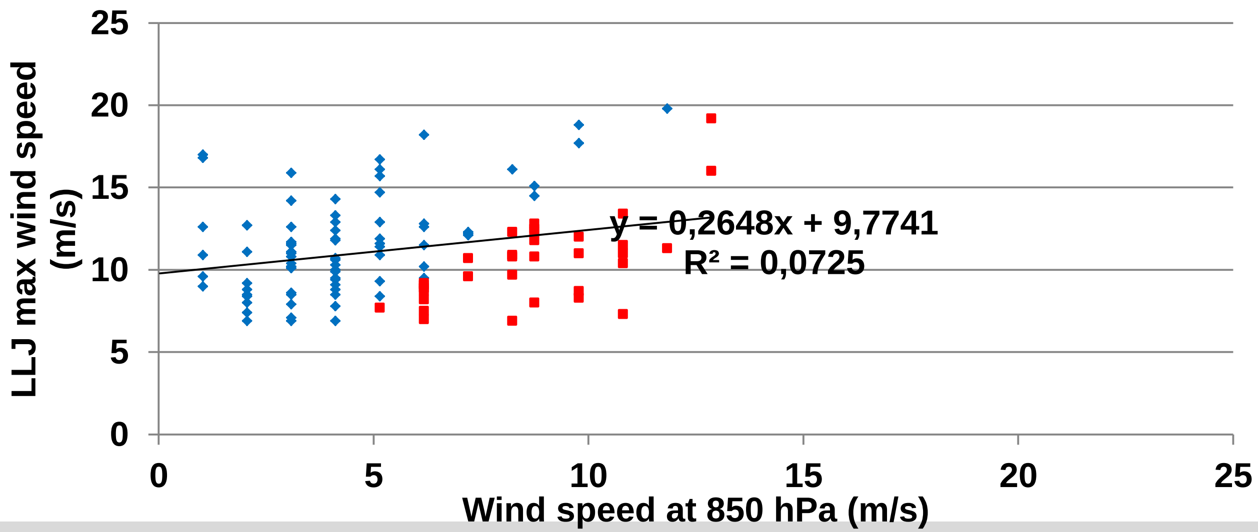
**BM** **bridge Central Europe**
**HB** **high Brit. Isles**
**HM** **high Central Europe**
**...**

**HFA/HFZ high Scandinavia**
**HNFA** **high Northern Atlantic**
**...**

# maximum core wind speed of LLJ and driving pressure gradient (blue symbols: LLJ core speed more than 1.5 times 850 hPa wind speed)

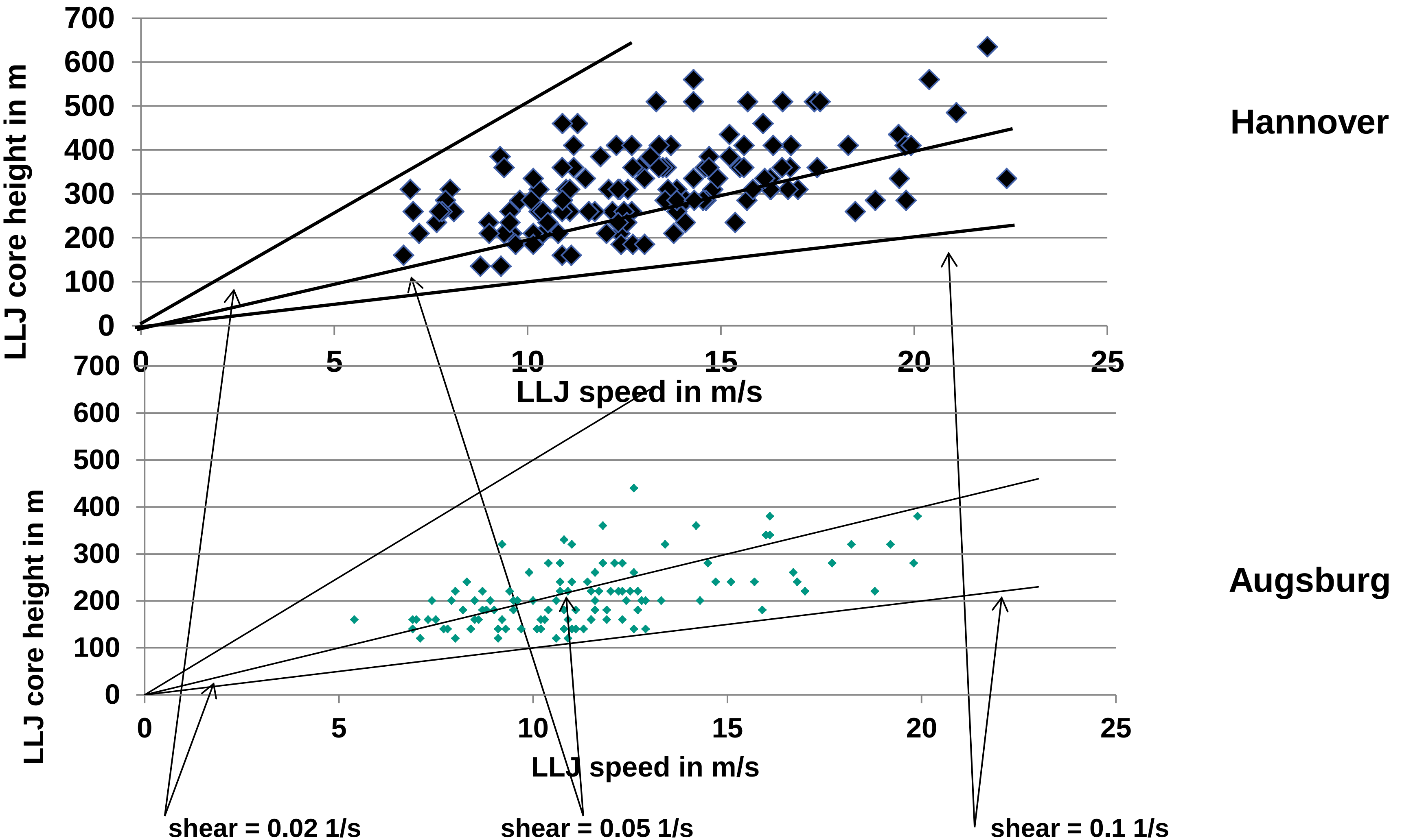



Hannover




Augsburg

## LLJ core height in m and LLJ core wind speed in m/s



Critical Richardson number is limiting condition for vertical shear

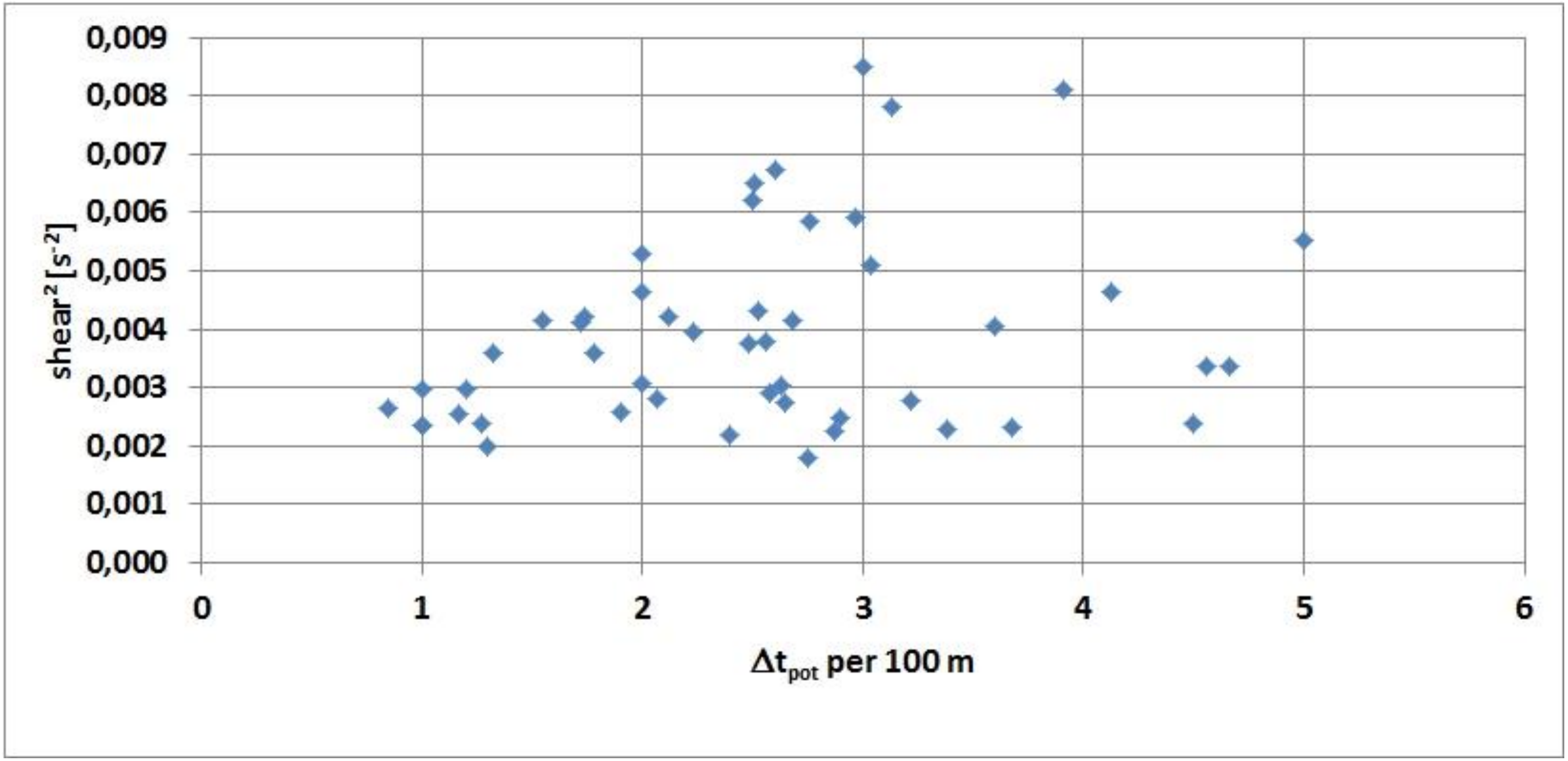
(mechanical turbulence is generated if Ri falls below $Ri_{krit}$)

$$Ri_{krit} = \frac{g\partial\Theta/\partial z}{\Theta(\partial u/\partial z)^2} \approx 0.25$$

| | |
|---|---|
| Θ (z) | potential temperature |
| g | gravitational acceleration |
| u (z) | wind speed |
| z | vertical coordinate |

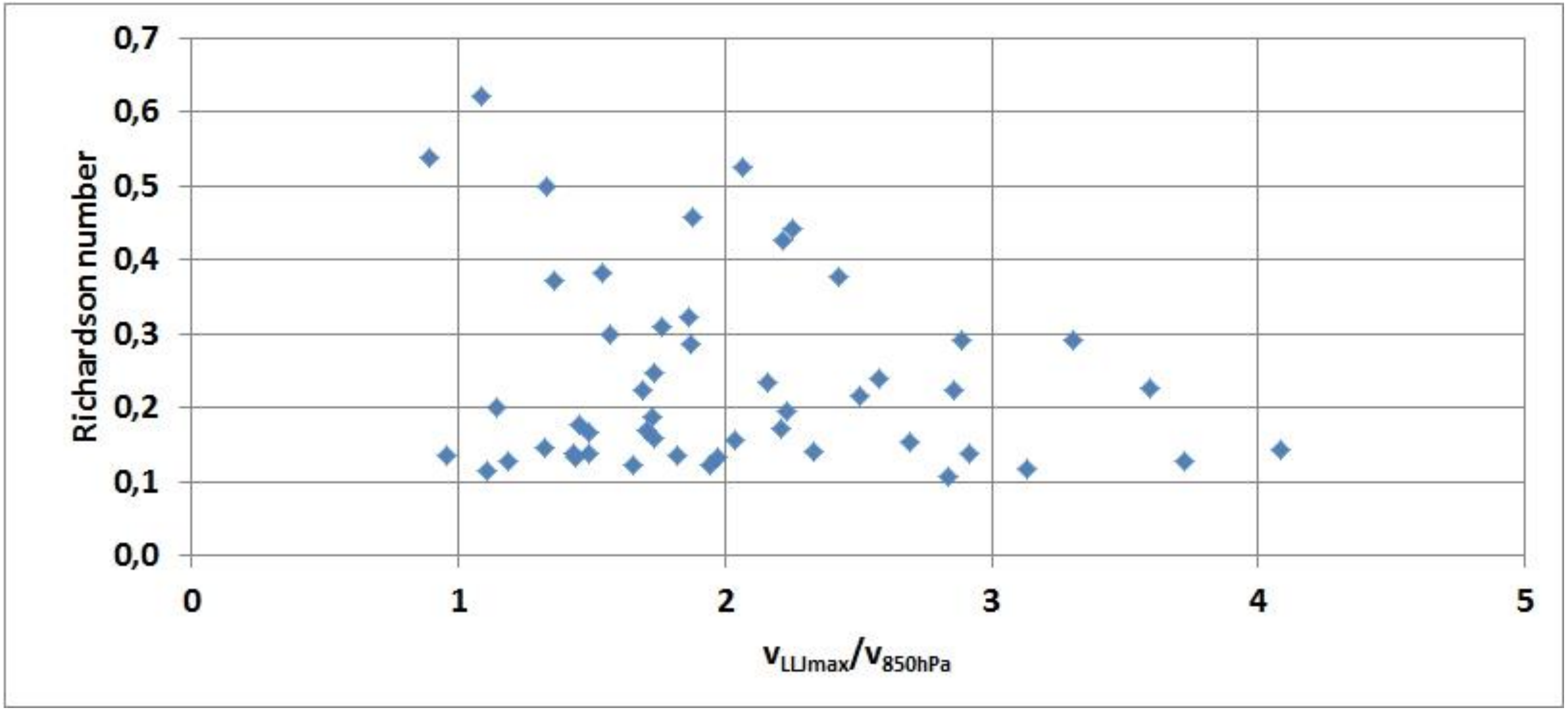
# RASS observations Augsburg

## correlation between shear and temperature gradient



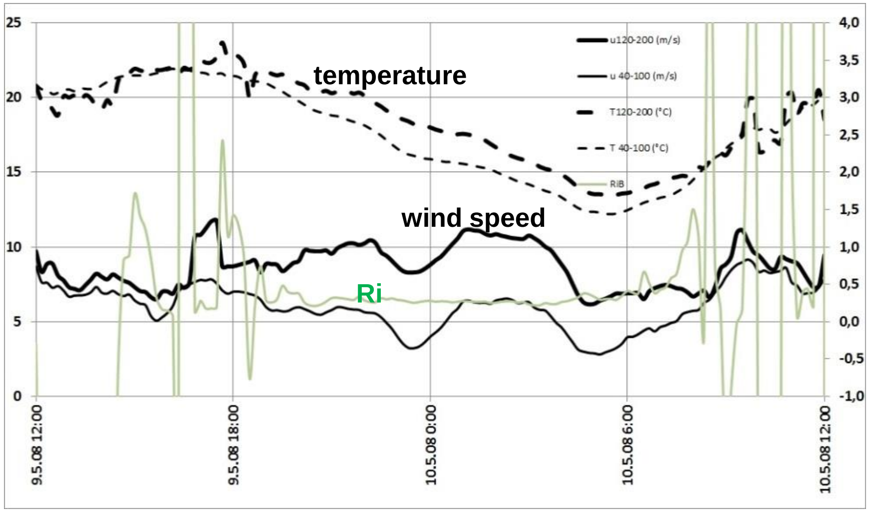
# RASS observations Augsburg

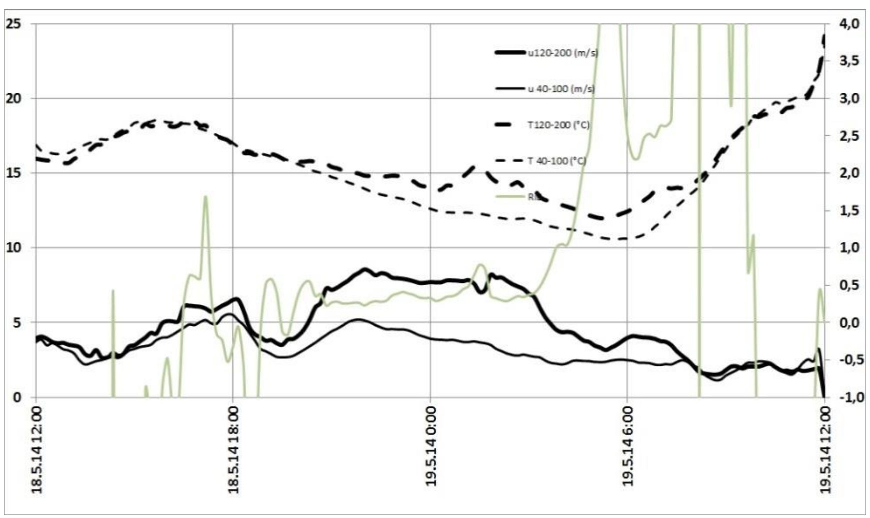
## Richardson number during LLJ events

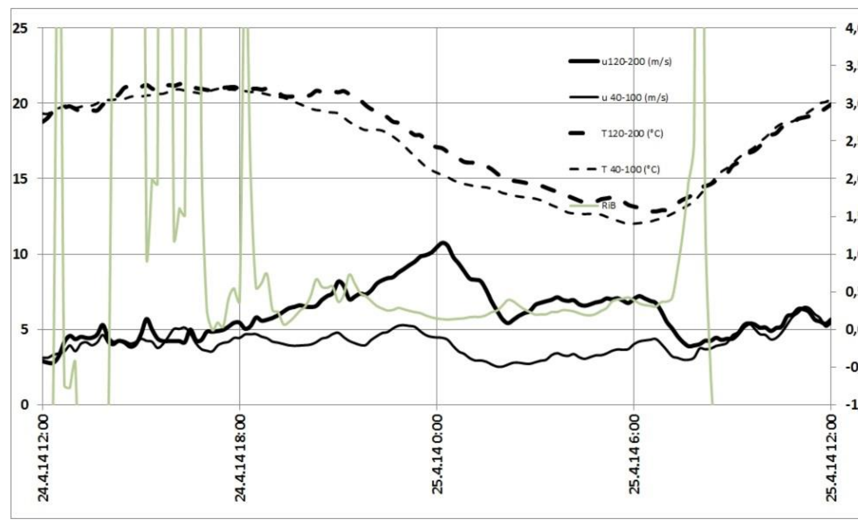


# RASS observations Augsburg

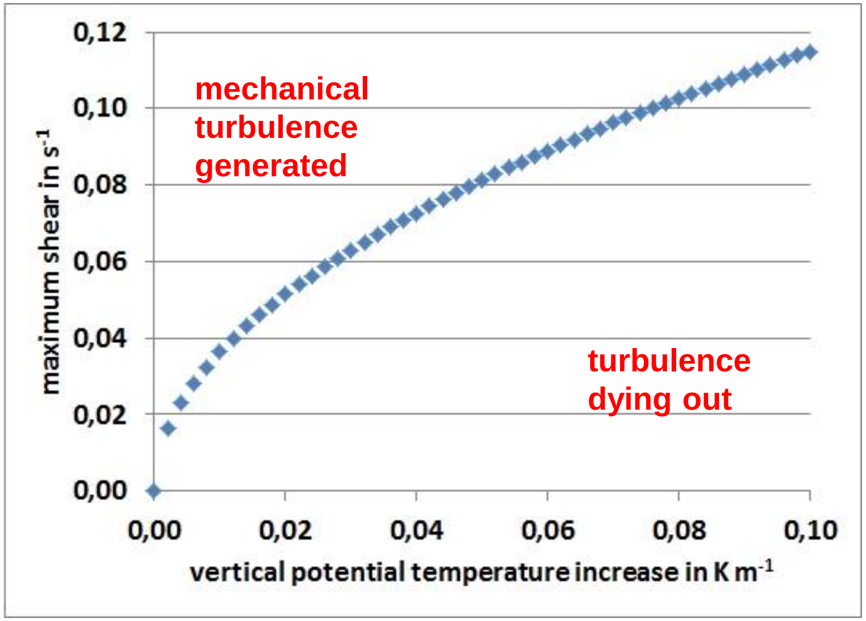
**critical Richardson Number between 40 and 200 m above ground as limiting value for nocturnal LLJ**



## maximum possible shear for a given $Ri_{krit}$ = 0.25




$$Ri_{krit} = \frac{g \partial \Theta / \partial z}{\Theta (\partial u / \partial z)^2} \approx 0.25$$

# 4 uncommon LLJ

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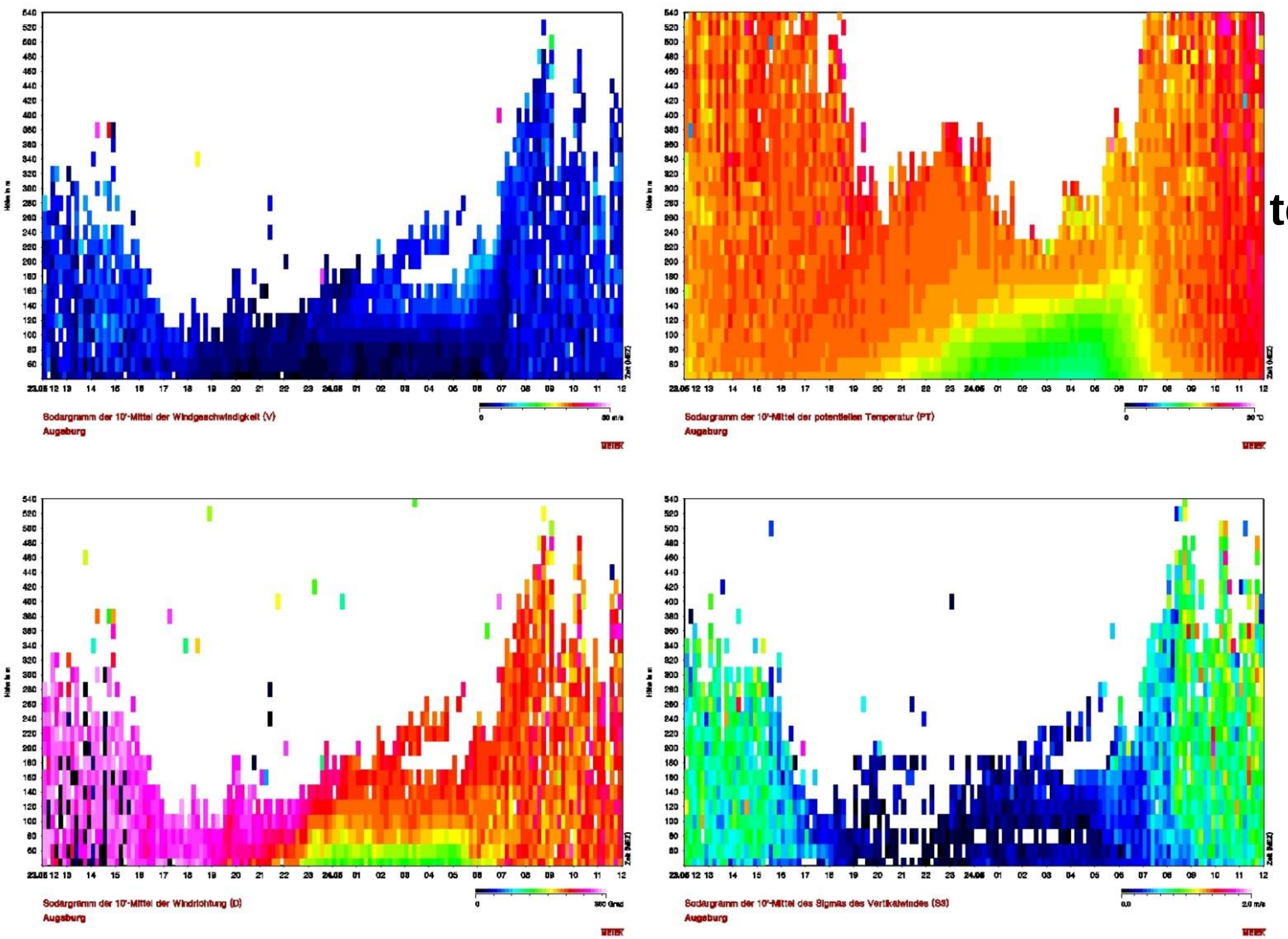
# RASS observations Augsburg, 23 May 2010

wind

potential temperature

wind direction

$\sigma_w$



## Summary

**climatology**

- **LLJ in 17 - 21% of all nights (in de Bilt about 20%, de Baas et al. 2009)**
- **uncommon LLJ in 2 – 3 % of all nights (requires complex terrain)**
- **core height between 135 and 650 m**
- **core wind speed between 7 and 23 m/s (height and speed correlated ➔ shear limited)**

**correlation with driving forces**

- **LLJ form for 850 hPa wind speeds between 1 and 18 m/s (Kottmeier et al. 1983: 6-11 m/s)**
- **LLJ core speed positively correlated with 850 hPa wind speed (maximum at 13 m/s)**
- **LLJ core speed slightly negatively correlated with 850 hPa relative humidity**

**shear**

- **shear is limited by critical Richardson number**

**impact on wind turbines**

- **shear over the rotor plane is about 0.04 to 0.08 1/s during LLJ events**
- **directional shear is about 0.1 to 0.2 degrees/m**

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**References:**

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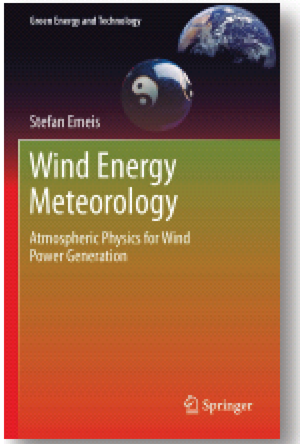
DOI: 10.1127/0941-2948/2014/0551**

**Emeis, S., 2014: Current issues in wind energy meteorology. Meteorol. Appl., 21, 803-819.
DOI: 10.1002/met.1472**

**Emeis, S., 2012: Wind Energy Meteorology - Atmospheric Physics for Wind Power Generation. Series: Green Energy and Technology. Springer, Heidelberg etc., XIV+196 pp., 94 illus., 16 in colour. ISBN H/C: 978-3-642-30522-1, e-book: 978-3-642-30523-8, S/C: 978-3-642-42959-0.**

**Chinese Edition: 国际电气工程先进技术译丛：风能气象学
(Guo ji dian qi gong cheng xian jin ji shu yi cong: Feng neng qi xiang xue), China Machine Press Advanced Technology of Electrical Engineering International Translations, ISBN: 978-7-111-44668-2.**




2013, 2013, XIV, 196 p. 94 illus., 16 in color.

**Printed book**

**Hardcover**

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- ***106,95 € (D) | 109,95 € (A) | CHF 133.50**

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## Wind Energy Meteorology

**Atmospheric Physics for Wind Power Generation**

- First book devoted solely to the meteorological basics of wind power generation
- Presents the meteorological basics  for large wind turbines and wind parks
- Gives guidance to plan offshore wind parks

This book is intended to give an introduction into the meteorological boundary conditions for power generation from the wind, onshore and offshore. It is to provide reliable meteorological information for the planning and running of this important kind of renewable energy. This includes the derivation of wind laws and wind profile descriptions, especially those above the logarithmic surface layer. Winds over complex terrain and nocturnal low-level jets are considered as well. A special chapter is devoted to the efficiency of large wind parks and their wakes.

# Thank you very much for your attention