FESSTVaL
Field Experiment on Submesoscale Spatio-Temporal Variability in Lindenberg

Lecture Series

From the ground up –
Rethinking observations in meteorology

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and many others…

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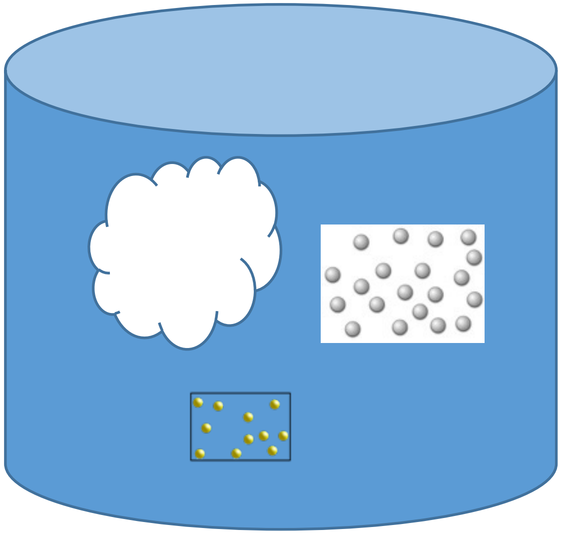
Motivation

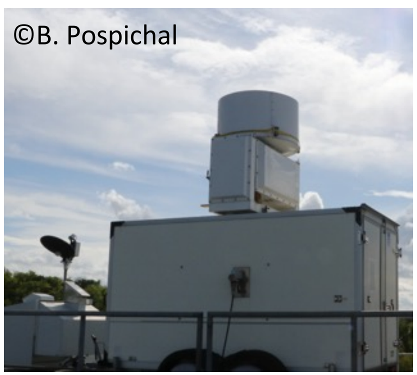
- Convection permitting models require observations that can capture the scales of mid-latitude convection
- “Classical” observations typically do not fulfill this requirement in an adequate way
- New observation approaches required, so think

From the ground up ..

(Not so much focusing on weather radar, because Felix Ament told you all about that two weeks ago…)

From the ground up…




©B. Pospichal


https://weathermap.netatmo.com/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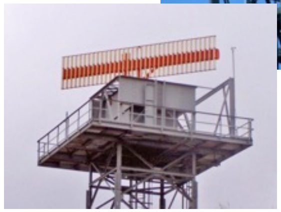
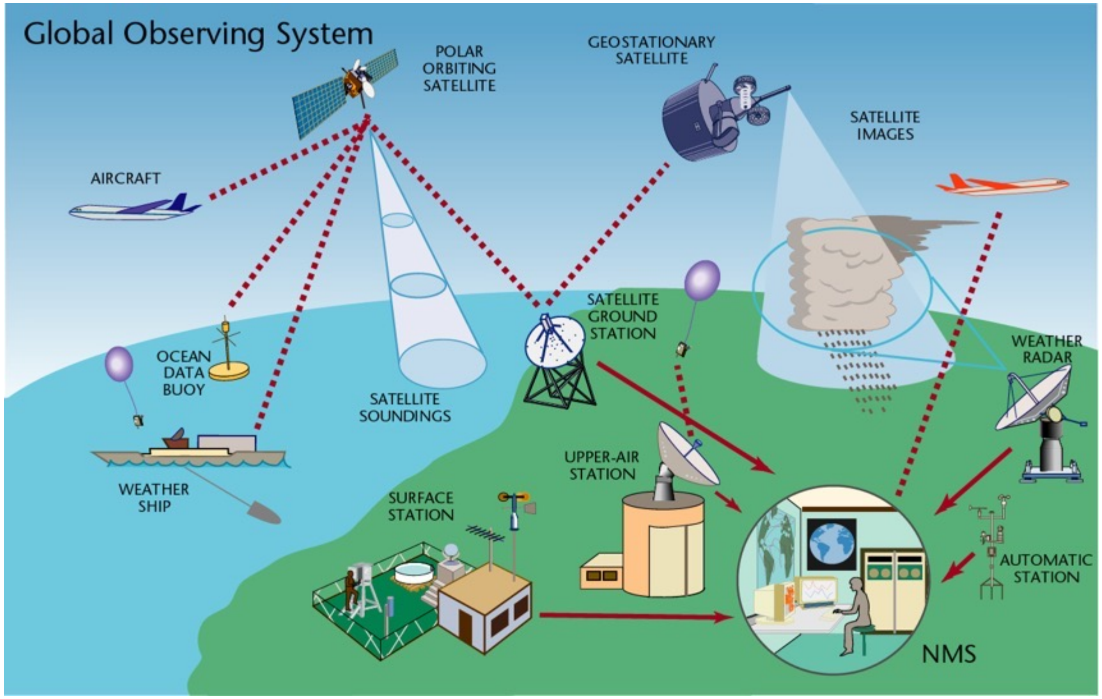


Dynamically and rapidly evolving!

Guide through this talk

- **Current state of meteorological observations**
- Rethinking observations
  - ✓ Evolving networks
  - ✓ Synergy!
  - ✓ in applications (renewables)
  - ✓ FESSTVaL
  - ✓ New sources



Observation components of the WMO Global Observing System

http://www.wmo.int/pages/prog/www/OSY/Gos-components.html

Surface,
Upper-air,
Marine,
Satellite,
Aircraft-based,
Weather radar,
...

What's missing, most needed?

- Humidity, wind and temperature profiles (ABL!)
- Major gaps in horizontal spacing and observation cycle

EUMETNET Observation Gaps Analysis

Status of atmospheric profiling

- Upper-air observations (radiosondes)
  → Problem horizontal and temporal coverage: diurnal cycle and meso-scale circulation not resolvable
- Aircraft (AMDAR, E-AMDAR, MODE-S,..)
  → Regionally limited to areas around large airports & no humidity yet
- Polar-orbiting satellites (AMSU-A/B, AIRS, IASI,..): ~2x daily overpasses deliver world-wide coverage of T and WV profiles, as well as clouds
  → Atmospheric Boundary Layer (ABL) **hardly resolved** (variable surface emissivity and low vertical resolution)

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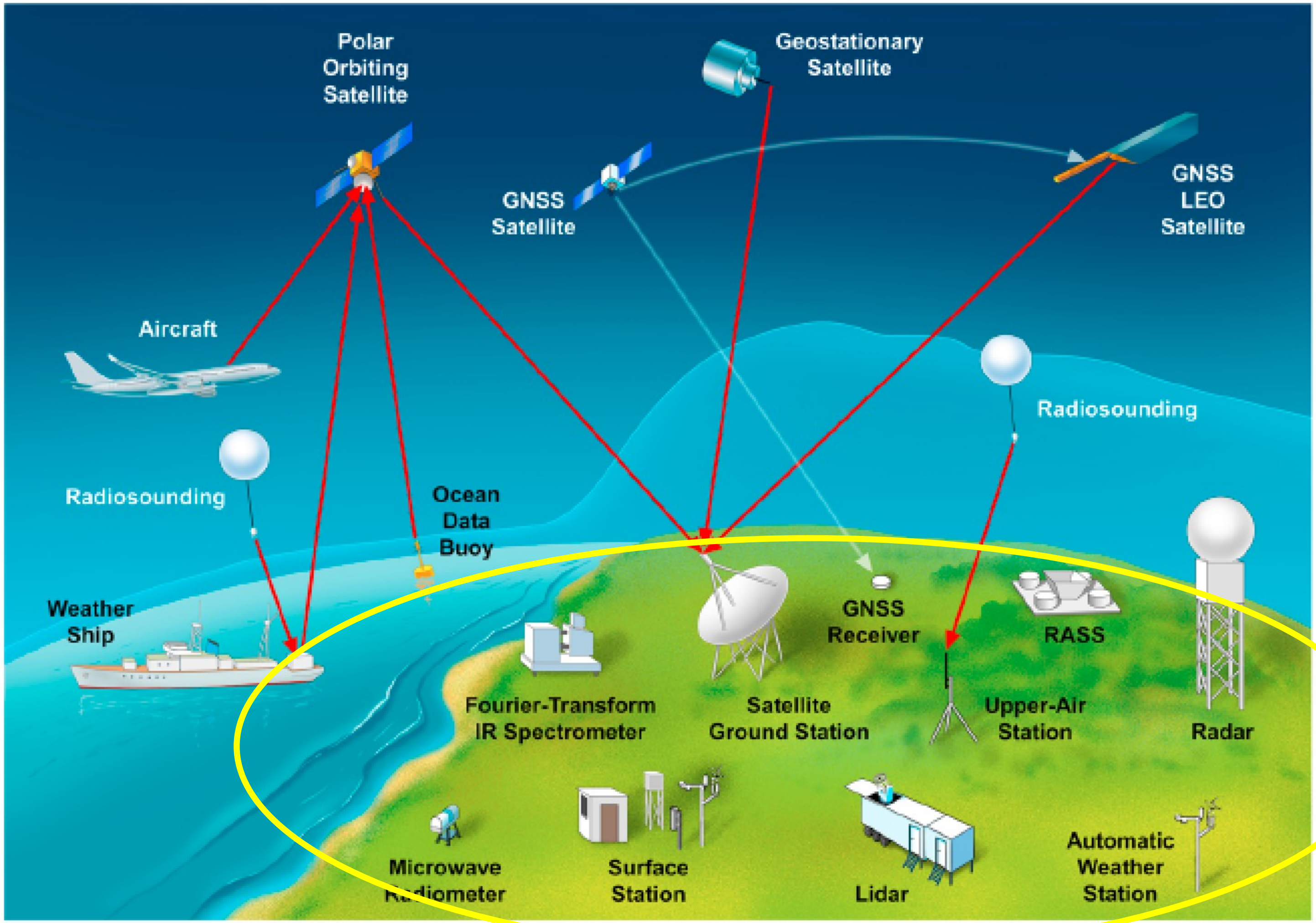
A future Global Observing System ?

Wulfmeyer et al. 2015



Surface-based remote sensing delivers a more detailed view of the ABL

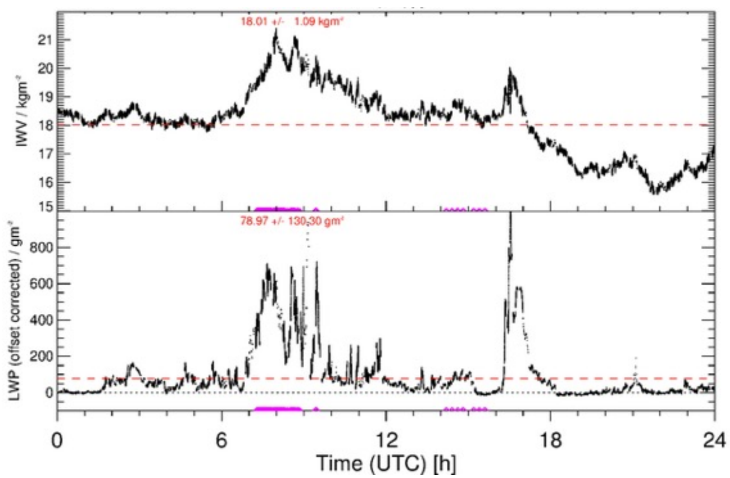
Example: Surface-based microwave radiometers

Continuous data in all-sky conditions: resolution of seconds to minutes

Low resolution **water vapor profile**, but excellent path-integrated values

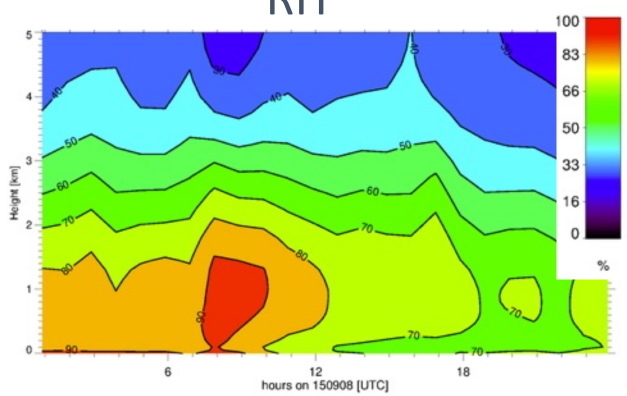
Measurement focus: ABL

Temperature profile of the ABL, low resolution profile above



Path-integrated **cloud liquid water** (unique)

RH



Commercially available > 10 years, ready for network application

Evolving networks

European Research Infrastructure for the observation of Aerosol, Clouds, and Trace gases (on ESFRI roadmap)

Research

ACTRIS Cloud Remote Sensing Center

- **Research data:** clouds, thermodynamics, and wind profiling
- **Access** to methods & platforms

Operational

Observations Capability Area E-PROFILE

- Provide centrally data to the European Weather Services
- Up to hundreds of instruments per network

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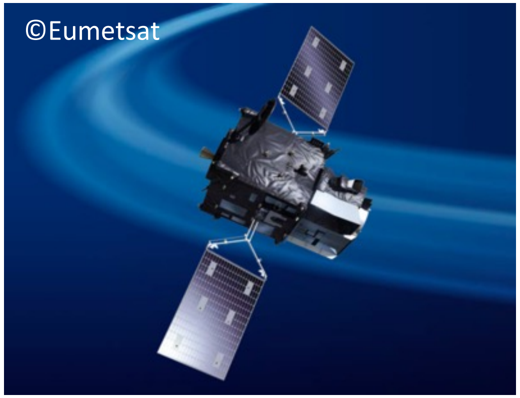
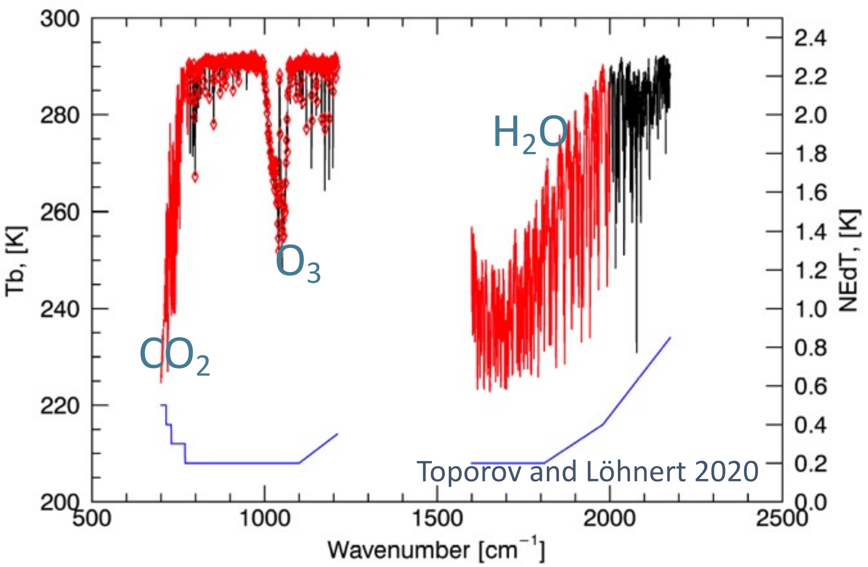
Meteo Sat Third Generation Sounding Mission (MTG-S)

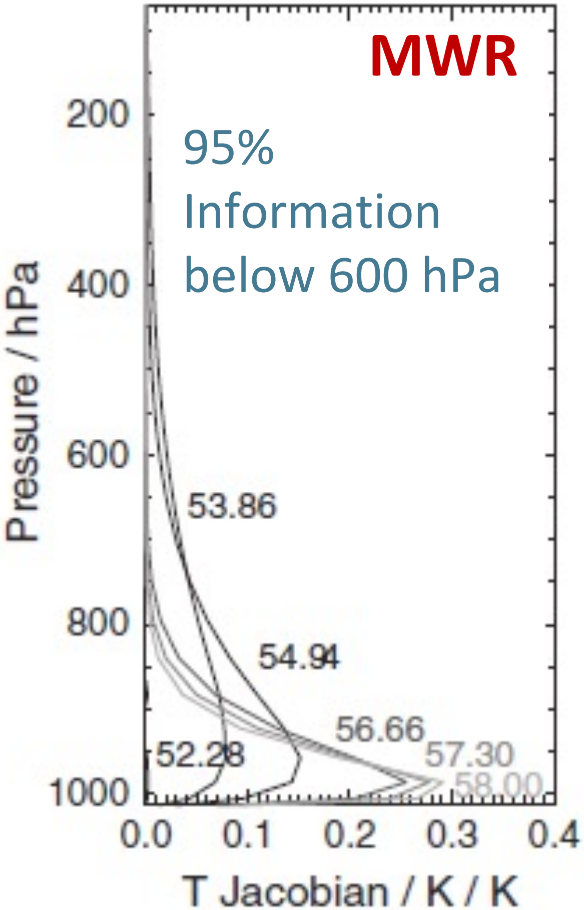


- Hyperspectral infrared sounding mission (IRS)
- 3D weather cube: temperature, water vapor, ozone every 30 min(!) over Europe
- Planned from 2024 onwards

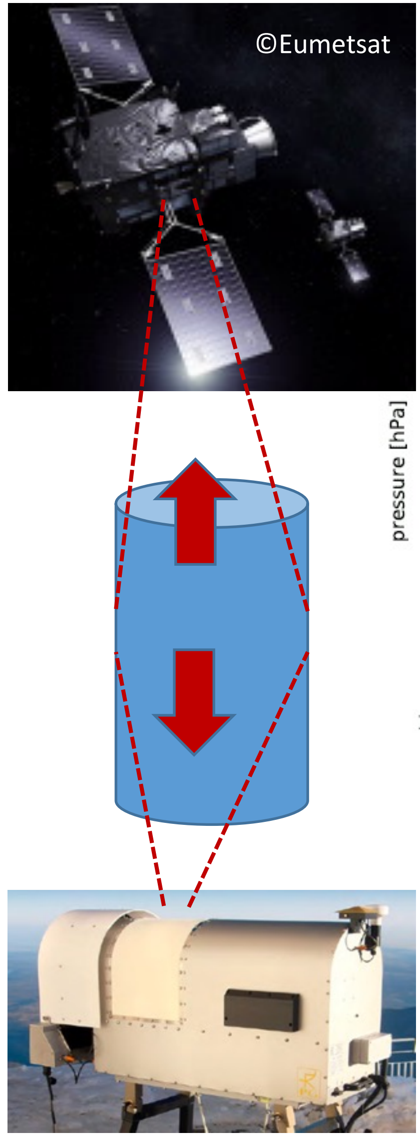


Potential to "revolutionize" weather observations?

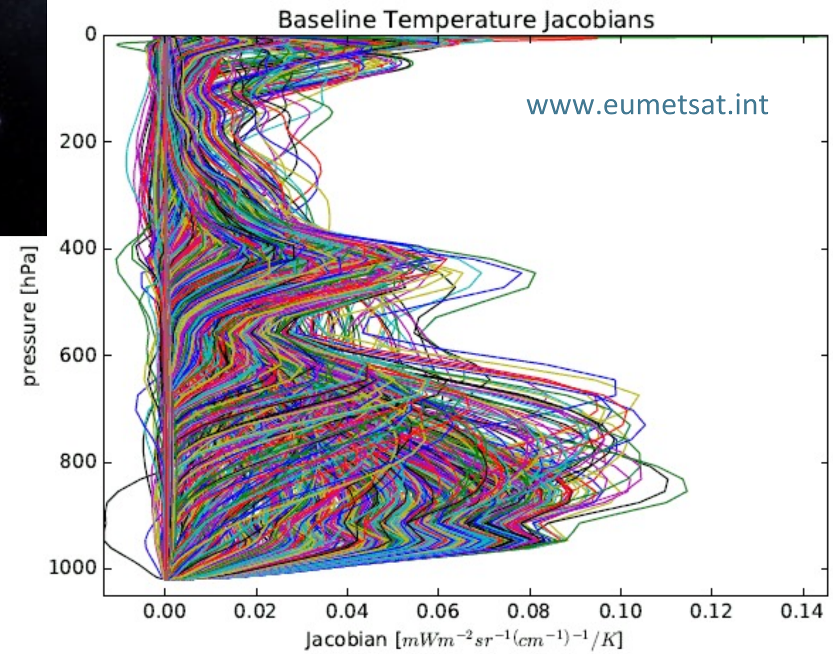
In synergy!



Ebell et al. 2013

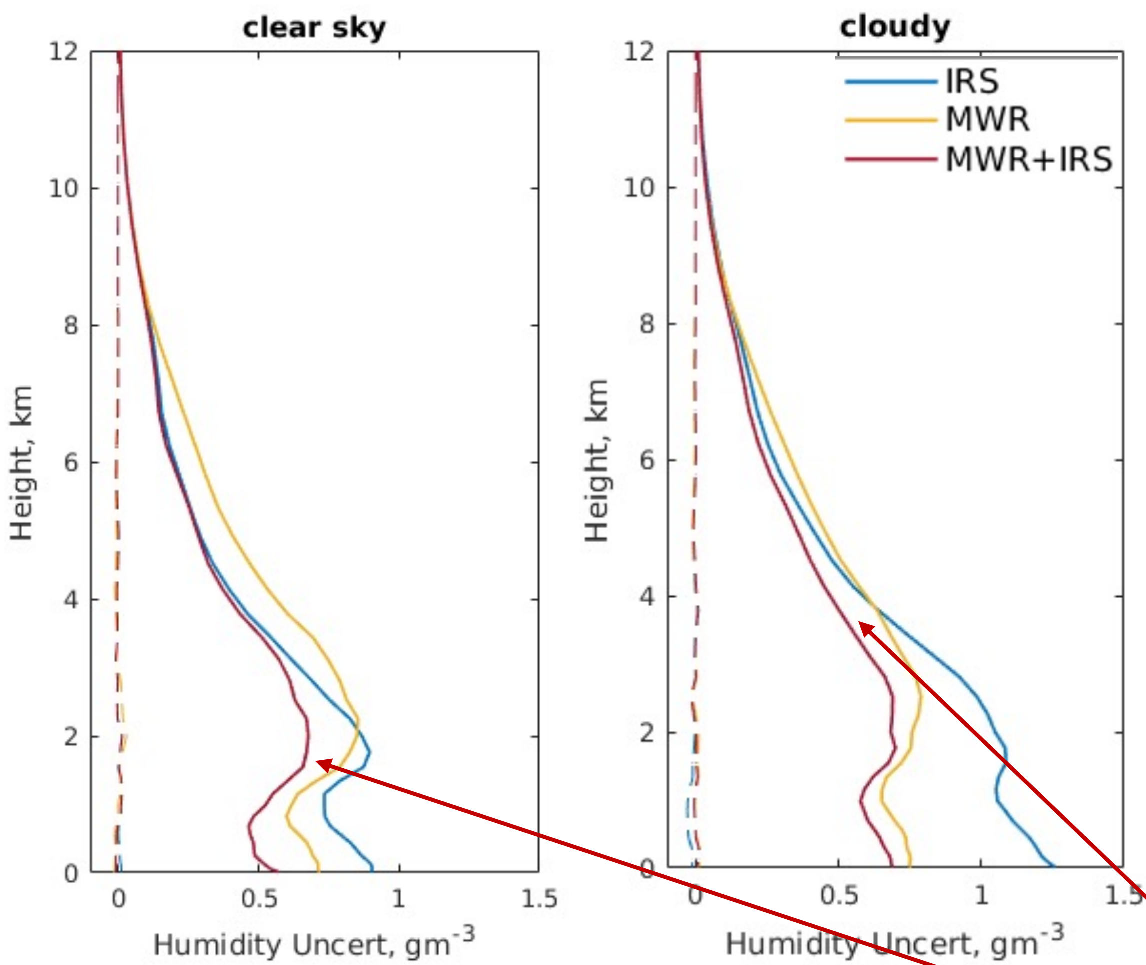


IRS on MTG



~complementary Weighting Functions

Thermodynamic profile retrievals - humidity



M. Toporov

Theoretical performance

- NN retrievals based on COSMO REA2 output
- Ground-based retrievals with better performance in ABL and lower troposphere, especially in cloudy cases
- Synergy retrieval best throughout the troposphere

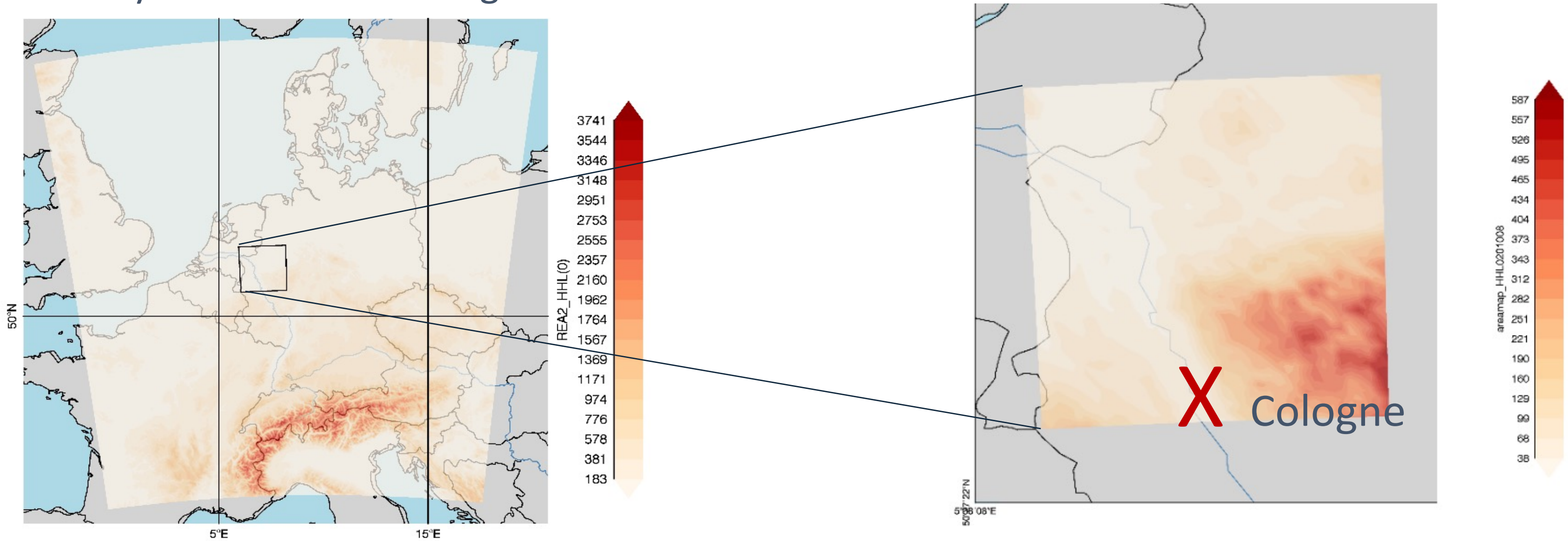
Synergy benefit!

2D: Lifted Index (Stability)

- LI = T(500 hPa) – T(parcel from surface → 500 hPa)
- LI < 1°C: Chance for thunderstorms
- the smaller, the more probable
- Typical values from -10°C (very instable) to +15°C (very stable)

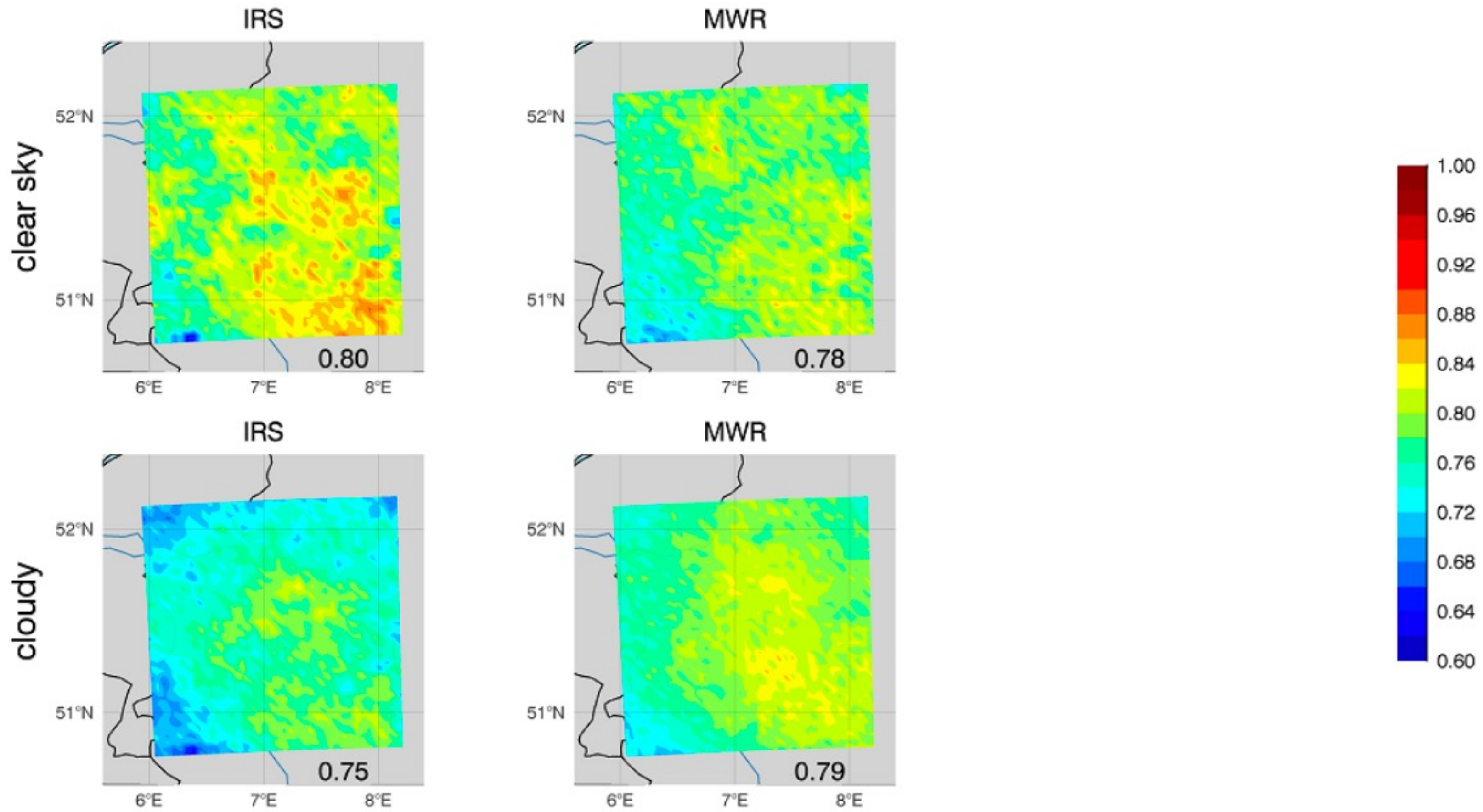
Reanalysis COSMO-REA2 region

"Rhein-Ruhr-Area"



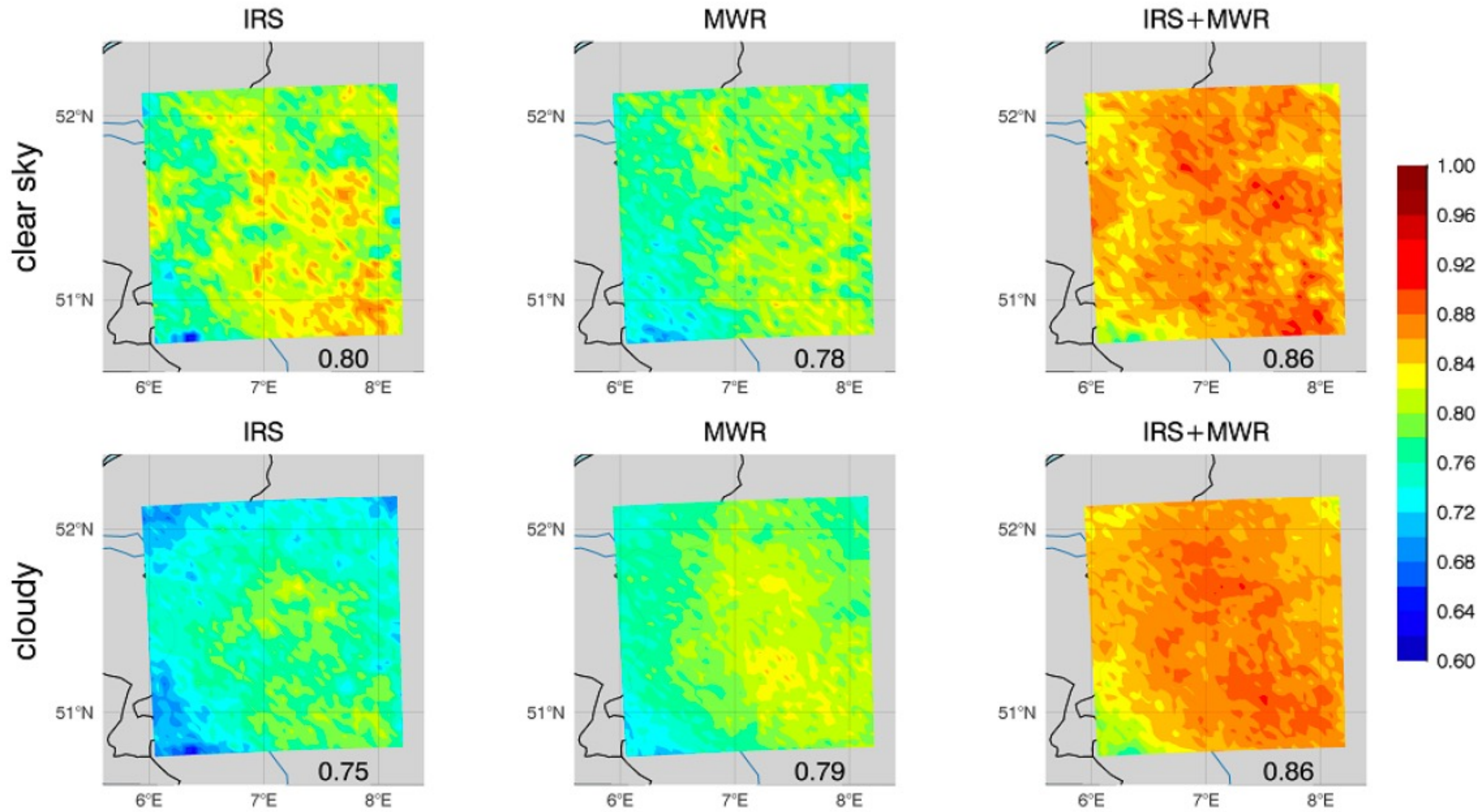
(Bollmeyer et. al. 2015)

Probability of detecting a thunderstorm



M. Toporov

Probability of detecting a thunderstorm



M. Toporov

BUT: over 1000 MWRs distributed in the area…

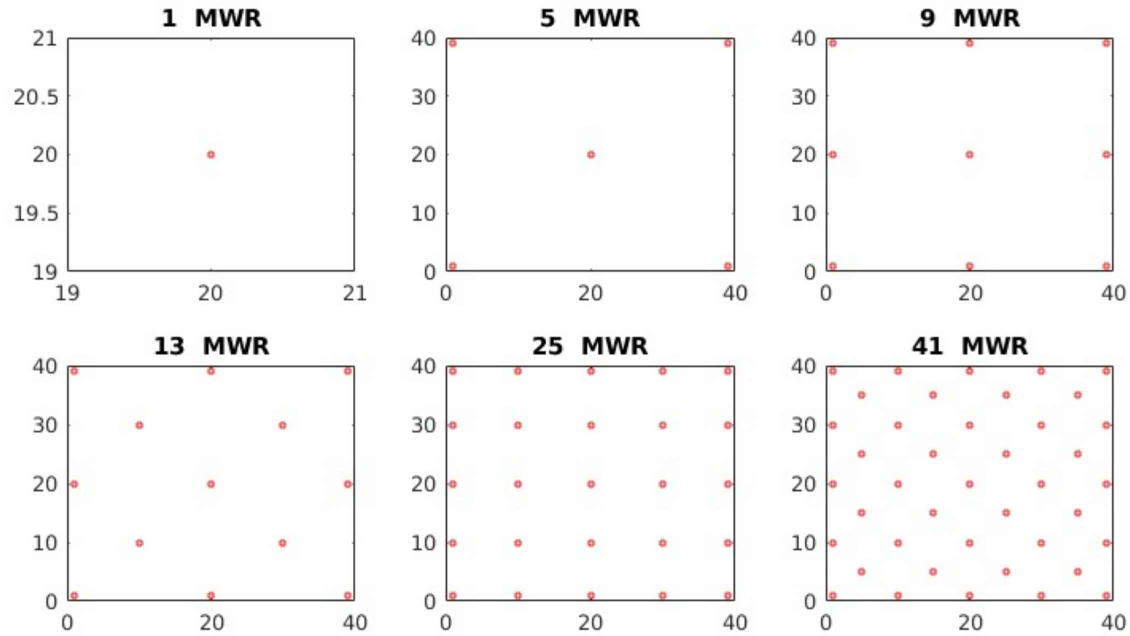
Impact of a (realistic) ground-based network

X_b: background (LI from IRS)
Y: observations (LI retrieved from synergy @ n MWR points)

$$X_a = X_b + W(Y - H(X_b))$$

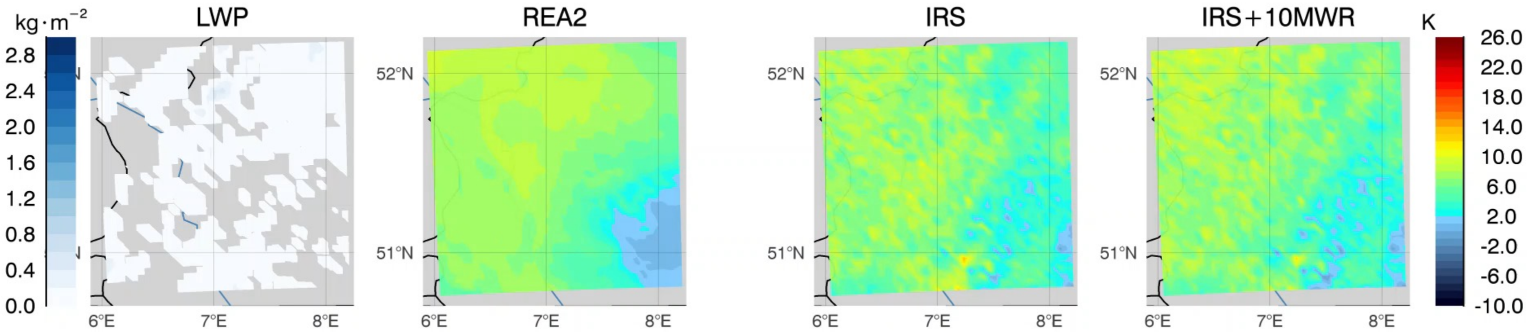
$$W = BH^T(HBH^T + R)^{-1}$$

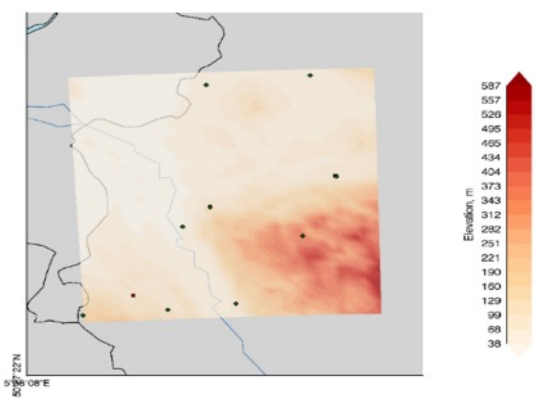
B: background error covariance (IRS)
R: observation error (MWR+IRS retrieval)



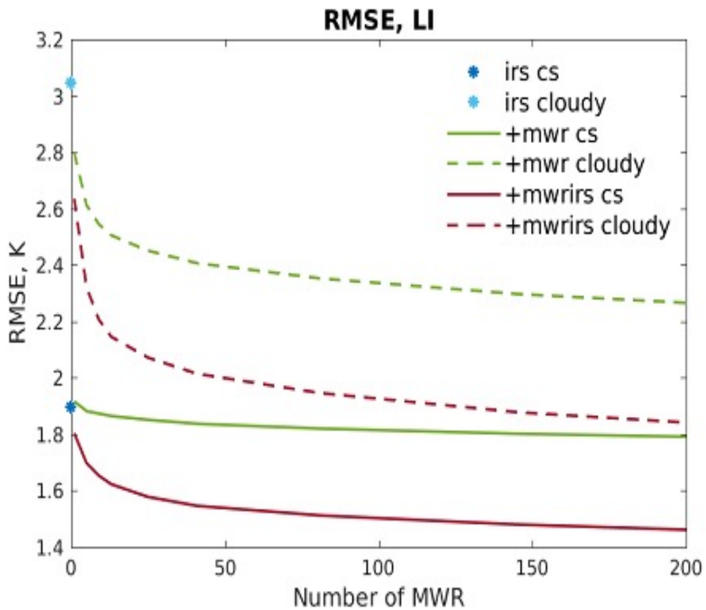
Impact of a (realistic) ground-based network

LI, 24.08.2011





Ceilometer, SYNOP stations



M. Toporov

Short Break

- Strech & open windows…
- Time for FESSTVaLers to check the radar…!
- We will continue in 5 min!

Guide through this talk

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- **Rethinking observations**
  - ✓Evolving networks
  - ✓Synergy!
  - ✓**in applications (renewables)**
  - ✓FESSTVaL
  - ✓New sources

Motivation

Hans-Ertel-Zentrum für Wetterforschung

Tatiana Nomokonova

- Renewable energy requires skillful short-term forecast
- Assimilation of new observation types could help
- Ground-based observations are potentially valuable for data assimilation

universität wien

Tobias Necker, Philipp Griewank, Martin Weissmann

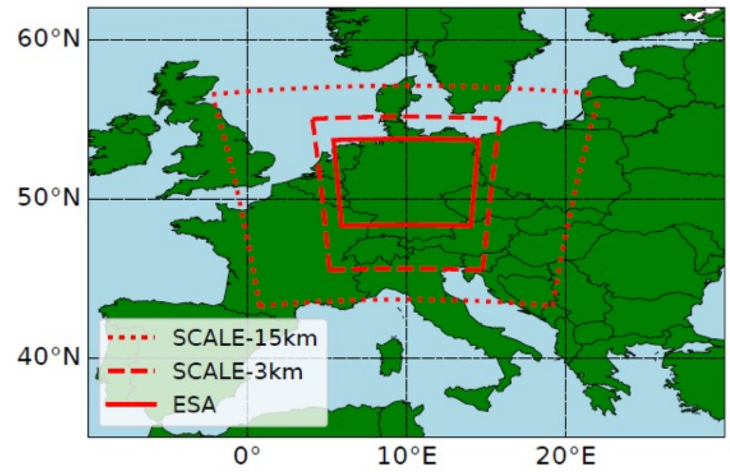
Research questions

- How much can specific ground-based remote sensing instruments improve short-term forecasts (**low level wind** & cloudiness)?
- How dense should the station network be?

Variance reduction based on ensemble sensitivity analysis

Model data

- SCALE-RM output over Germany
- Convective-scale 1000-member ensemble (Necker et al, 2020) (focus over Germany, 3 km)



Necker et al., 2020

Simulated observations:

Wind profiles from Doppler lidar: wind vector within the ABL

Variance reduction:

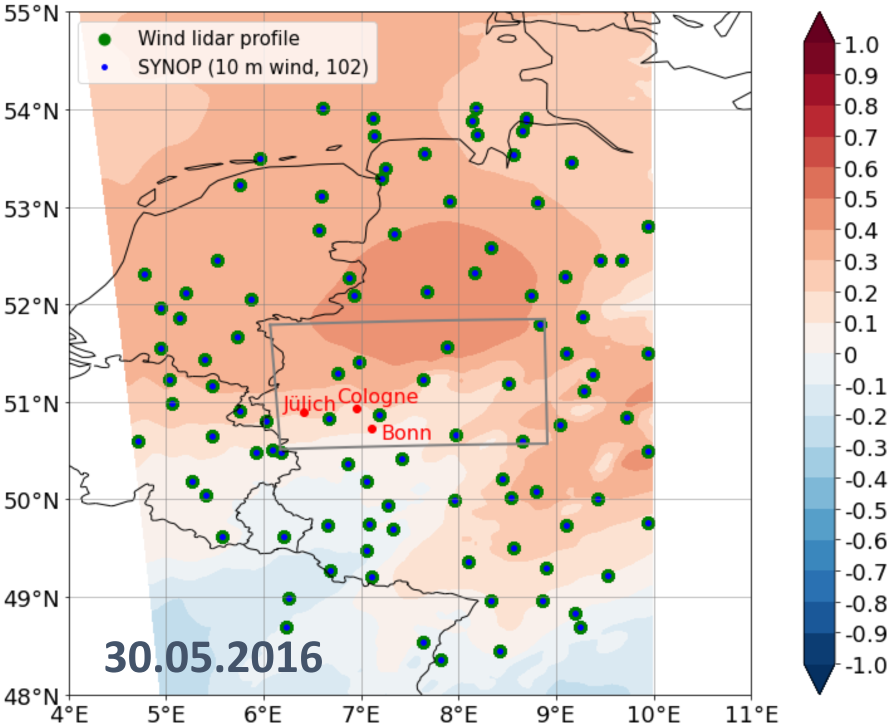
$$\delta\sigma^2 = \delta\mathbf{J} * [\delta\mathbf{x}]^T * \mathbf{B}^{+} * (\mathbf{B}' - \mathbf{B}) * \mathbf{B}^{+} * \delta\mathbf{x} * [\delta\mathbf{J}]^T ,$$

where $\mathbf{J}$ – forecast metric, $\mathbf{x}$ - state vector of initial conditions,
$\mathbf{B}$ - state covariance matrix, **+** denotes pseudoinverse matrix,
$\mathbf{B}'$ - covariance matrix updated using hypothetical observations

Experimental setup

Potential wind lidar network to improve 3-hour forecasted low-level wind

Correlation between domain-averaged wind speed at 80 m (17 UTC) and wind at 2845 m (14 UTC)



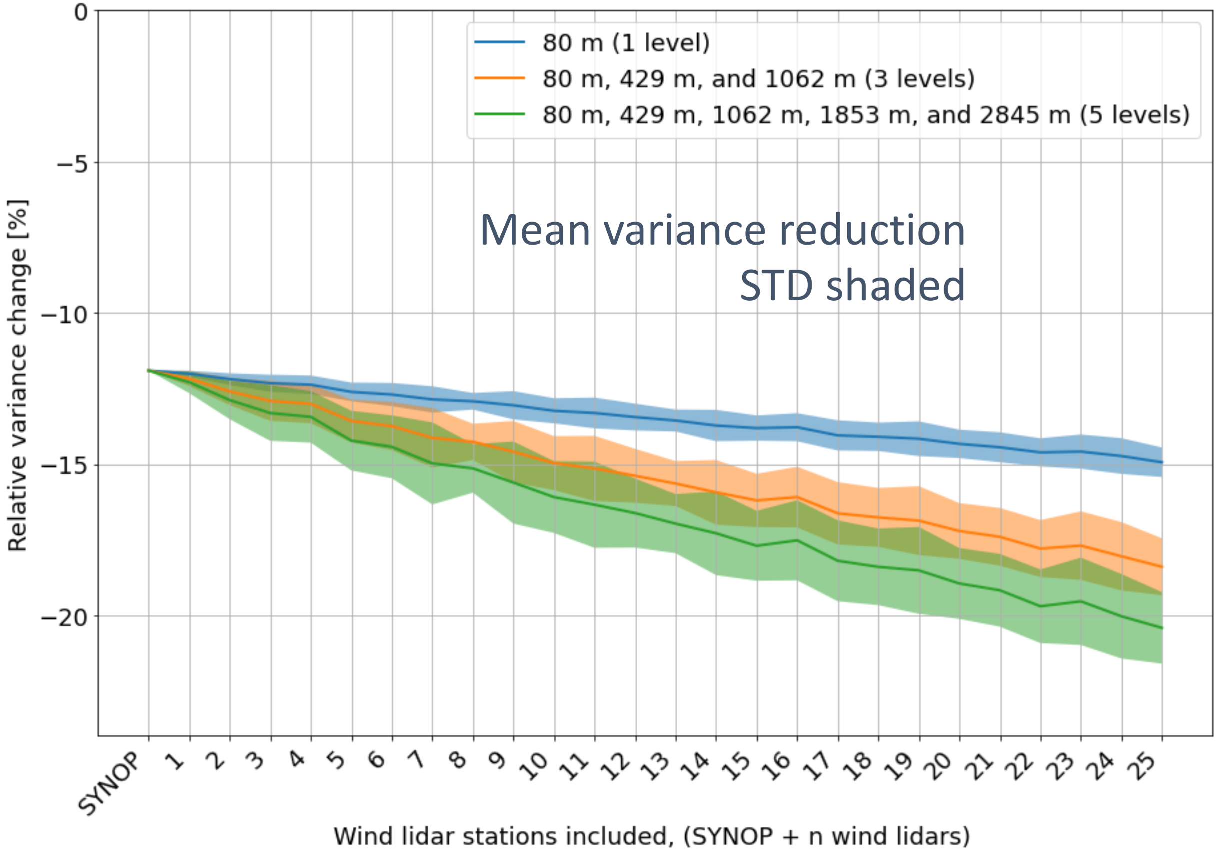
First experiment

- Quantify uncertainty reduction of domain-averaged 80 m wind
- Domain: Rhein-Ruhr-Area

Incorporated observations

- Wind speed at 10 m (102 SYNOP stations)
- Wind speed profiles (25)
- 1 to 5 levels included: 80, 429, 1062, 1853, 2845 m

Preliminary results



- SYNOP 102 stations (10 m wind) reduce wind forecast variance by **12%**
- SYNOP + 25 additional wind lidars up to **22%**
- Additional variance reduction due to wind lidar profiles ranges from **2%** to **10%** depending on different wind lidar ranges (influenced by ABL conditions)

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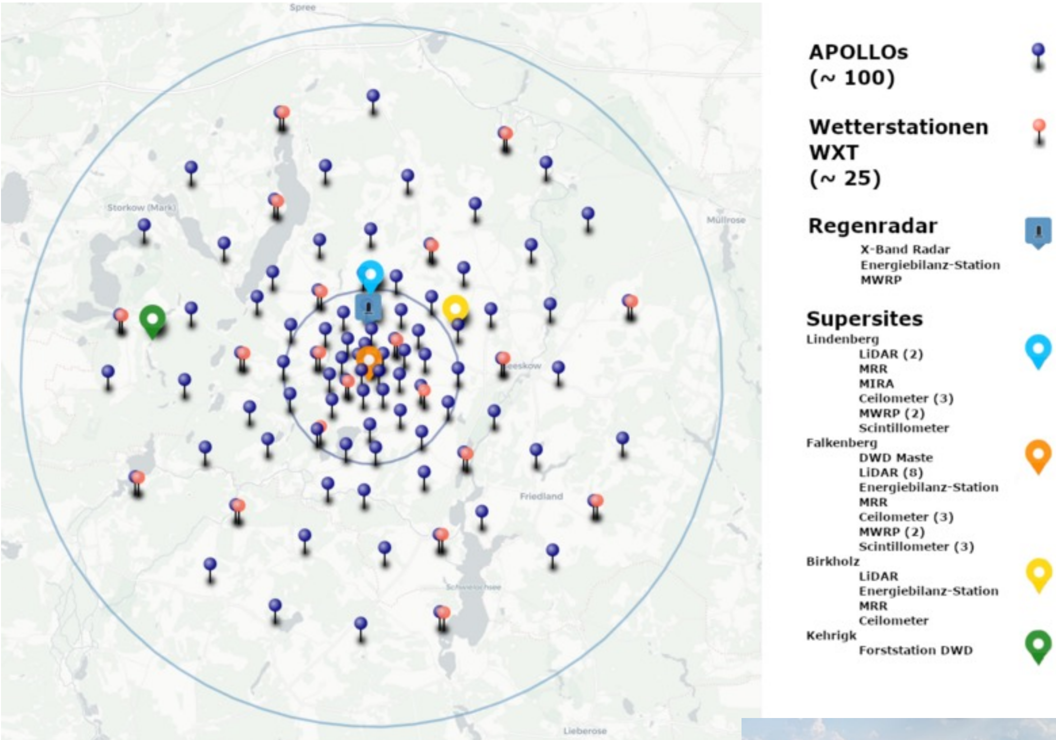
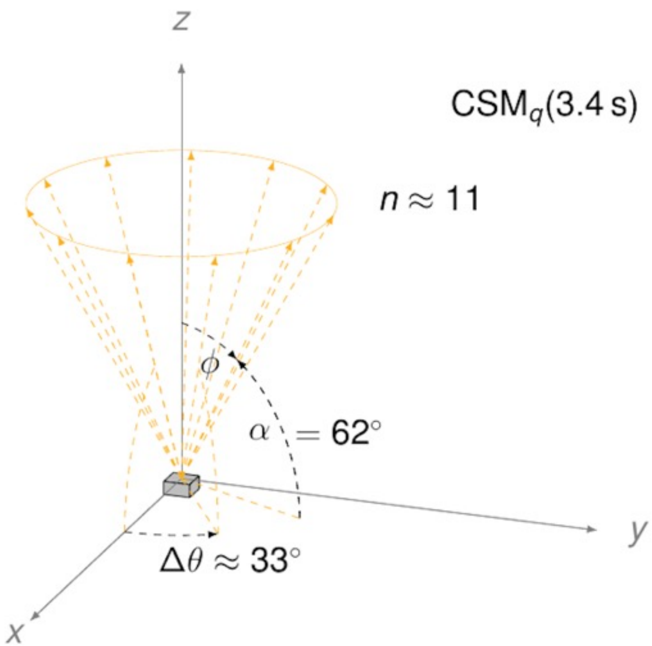
Ground-based remote sensing @ FESSTVaL

See talk by Dave Turner July 19



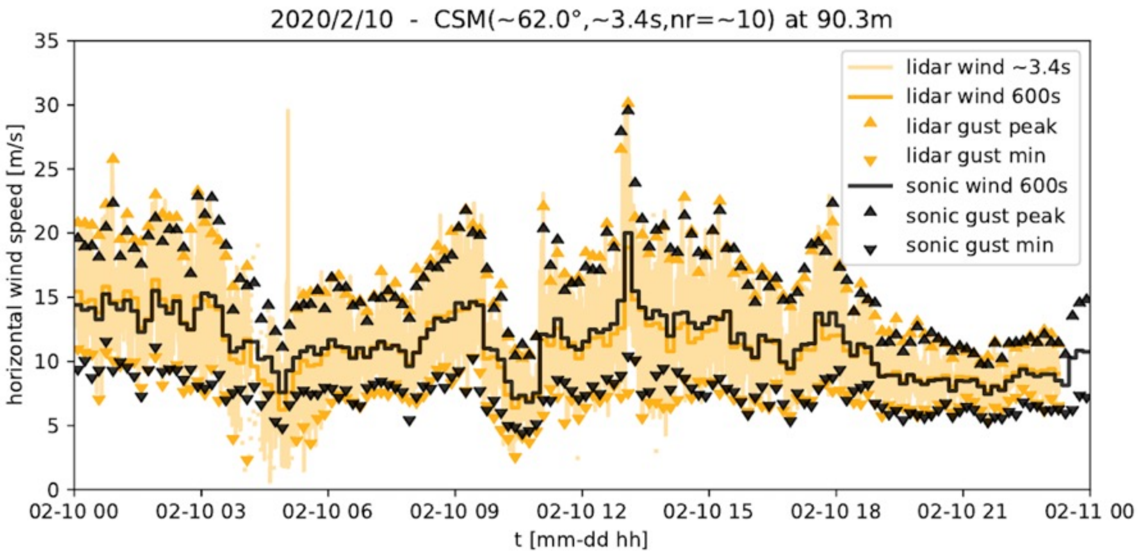
Wind gusts



- Doppler lidar typically suited for mean winds (> 10 min)
- Potential for deriving gusts still open; need to measure down to ~3s

Wind gusts

Julian Steinheuer (UzK) & Carola Detering (DWD)



Winter storm "Sabine"
Feb. 10, 2020
→ promising results!

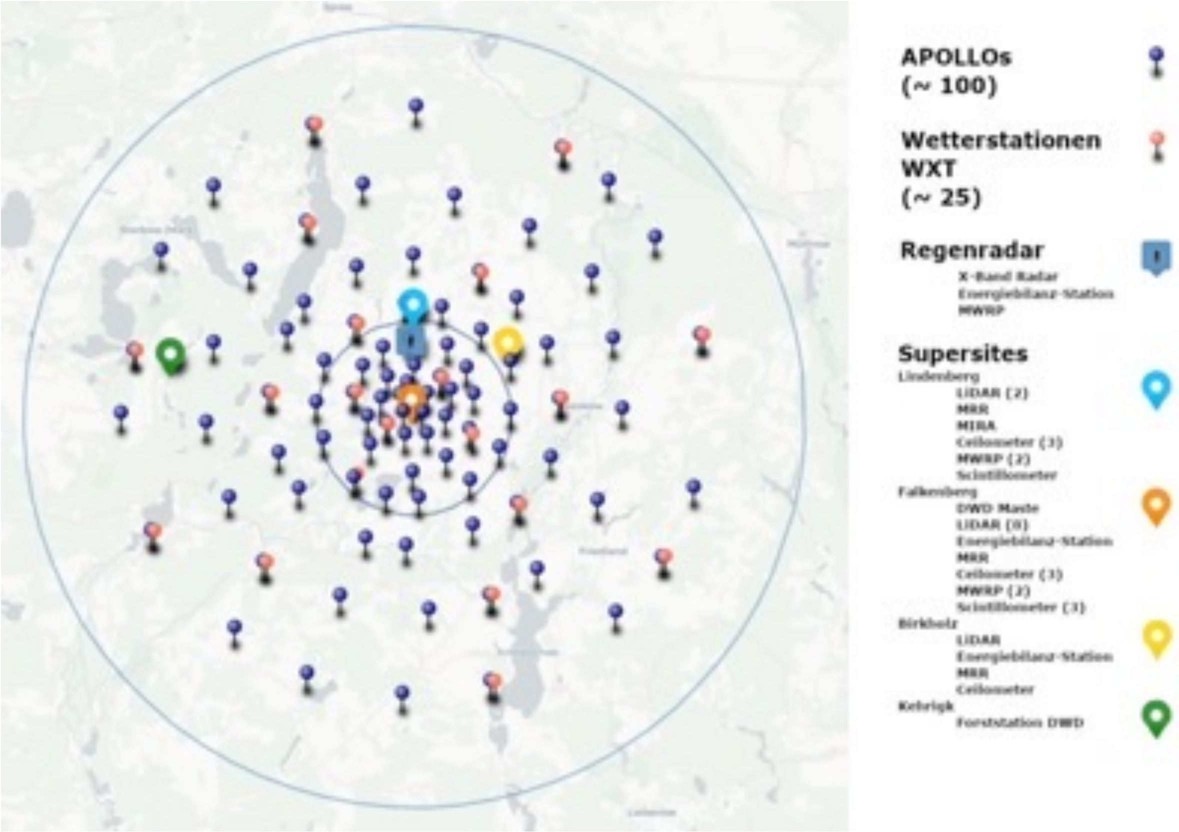
Gust mode operation ~1y

- Statistical analysis: compare to 90m tower (sonic)
- Goal: improve model parametrizations at levels up ~2 km

@ FESSTVaL: "triangle" set-up (~4 km base length)

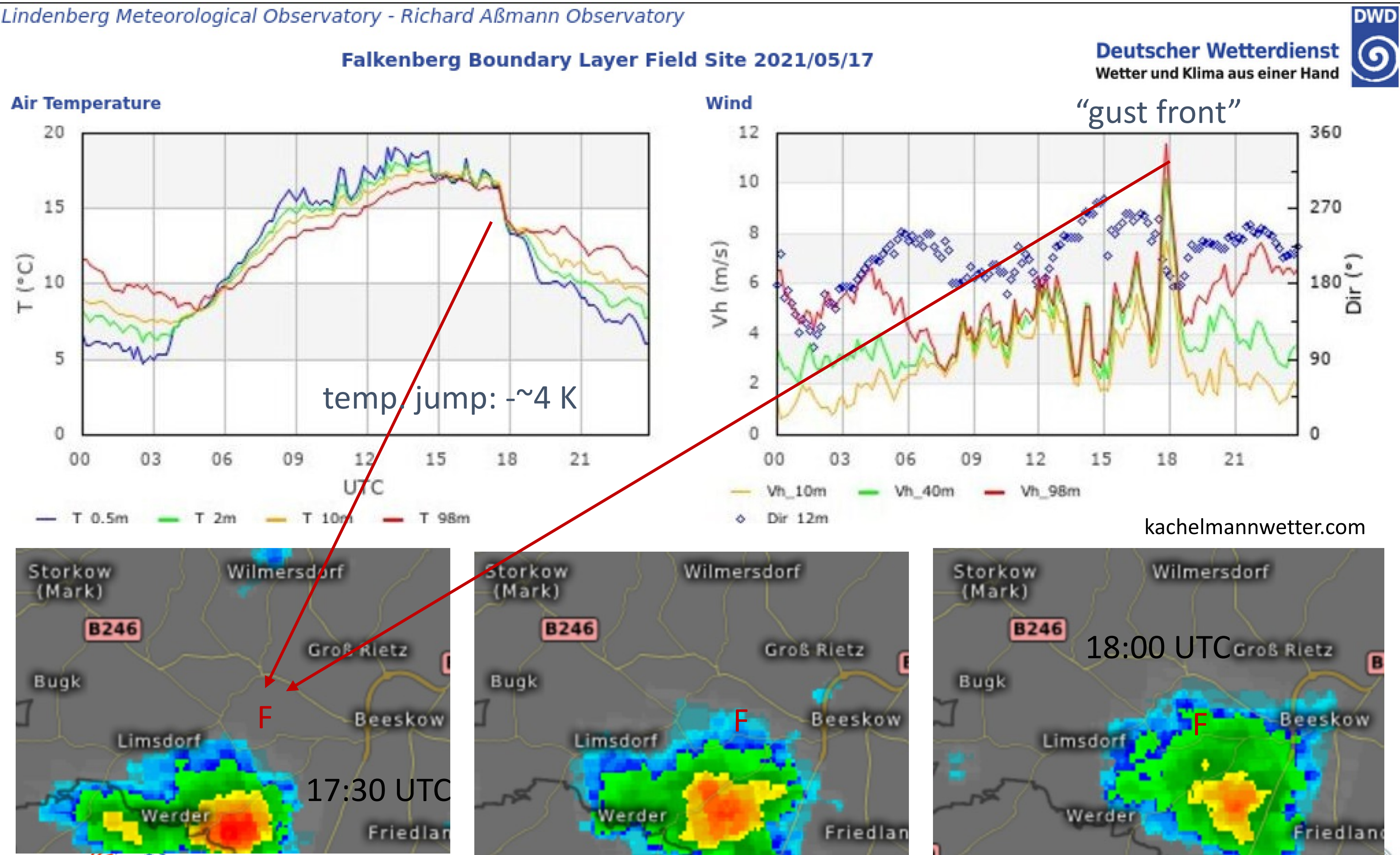
- Capture wind gusts during cold pools
- Wind gust front propagation

Cold pools

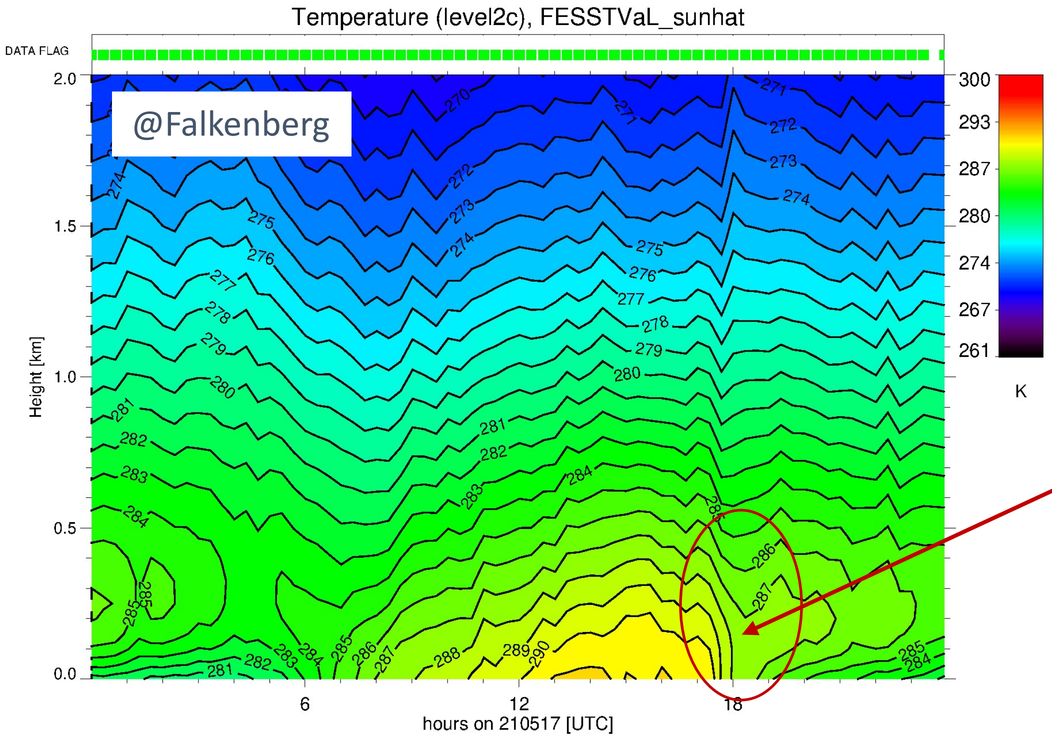


- APOLLOs: horizontal detection & propagation
- In addition: remote sensing for vertical structure
  → Doppler lidar, Microwave radiometer

“Cold pool”: 17.5.21 @ Falkenberg



“Cold pool”: 17.5.21 from MWRs



- Strong temp. drop, up to 5 K within ~30 min
- Observable up to ~400 m

kachelmannwetter.com

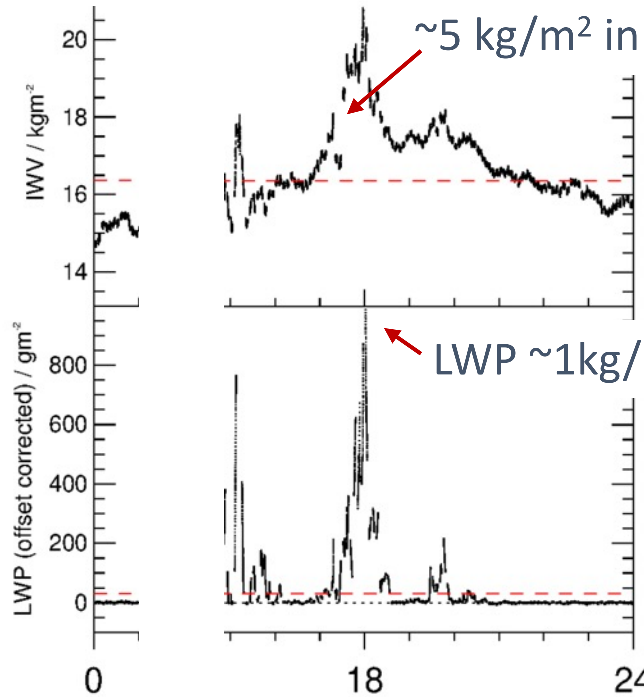
17:45 UTC

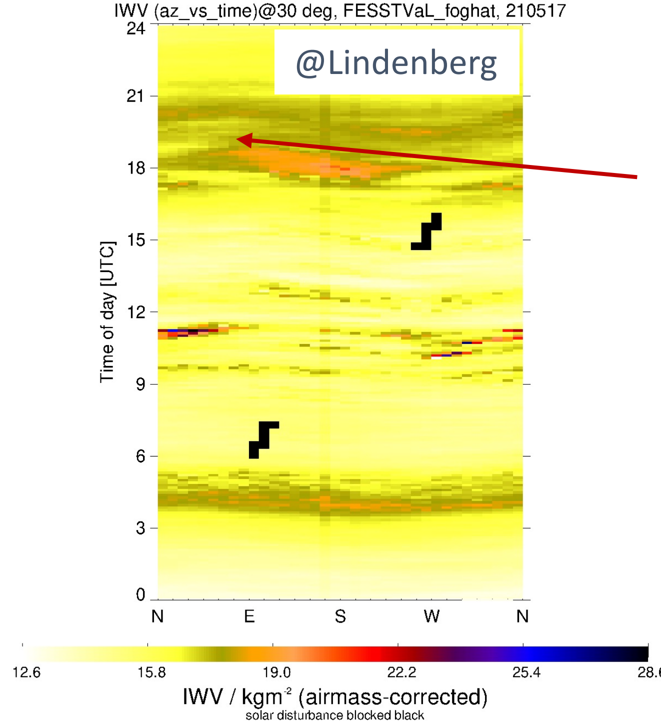
WV Anomaly: 17.5.21 from MWRs

@Falkenberg

IWV increase by ~5 kg/m² in 1 h

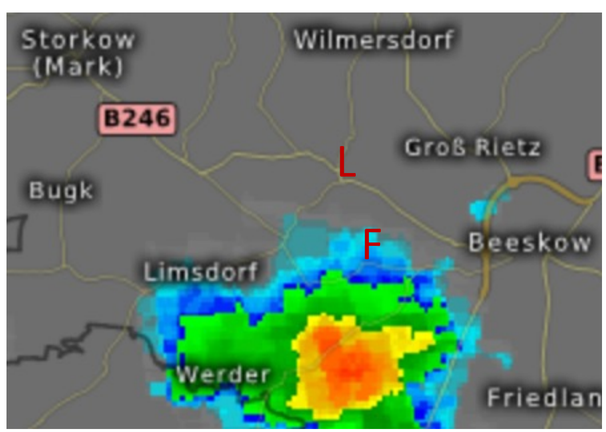
LWP ~1kg/m²





IWV anomaly propagating from SW to SE, corresponding to storm movement

kachelmannwetter.com



17:45 UTC

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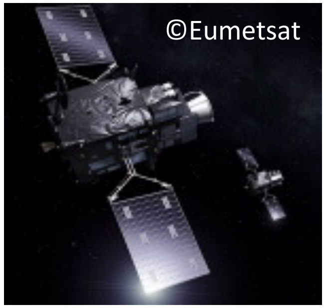
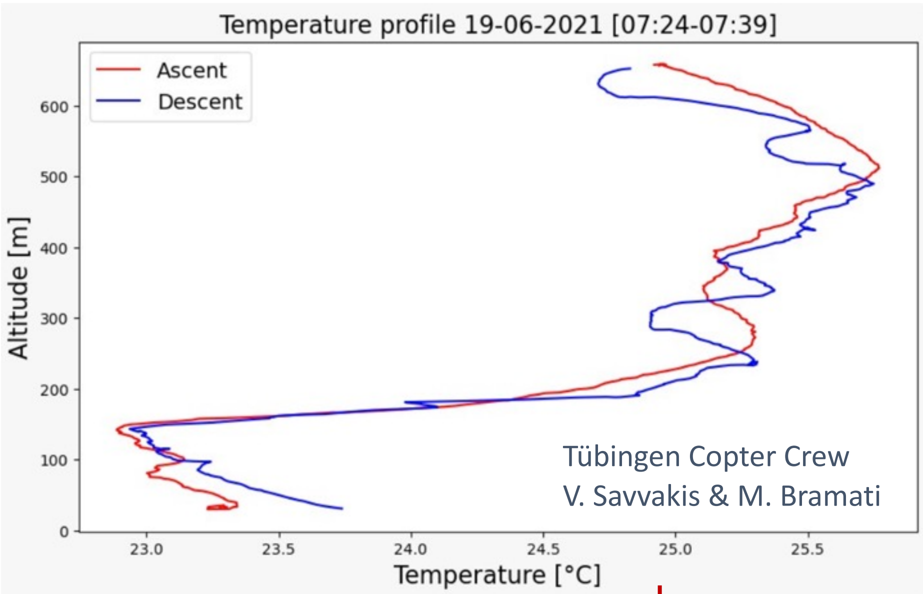
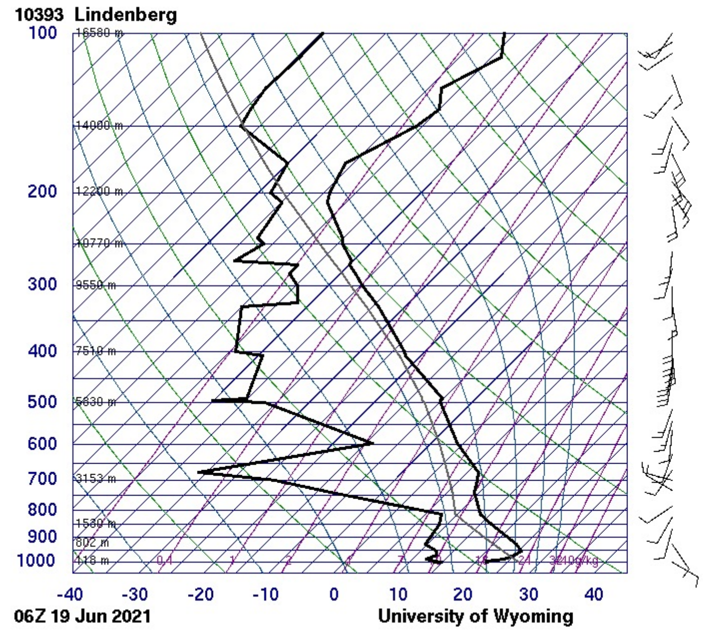
Potential new sources of observations…

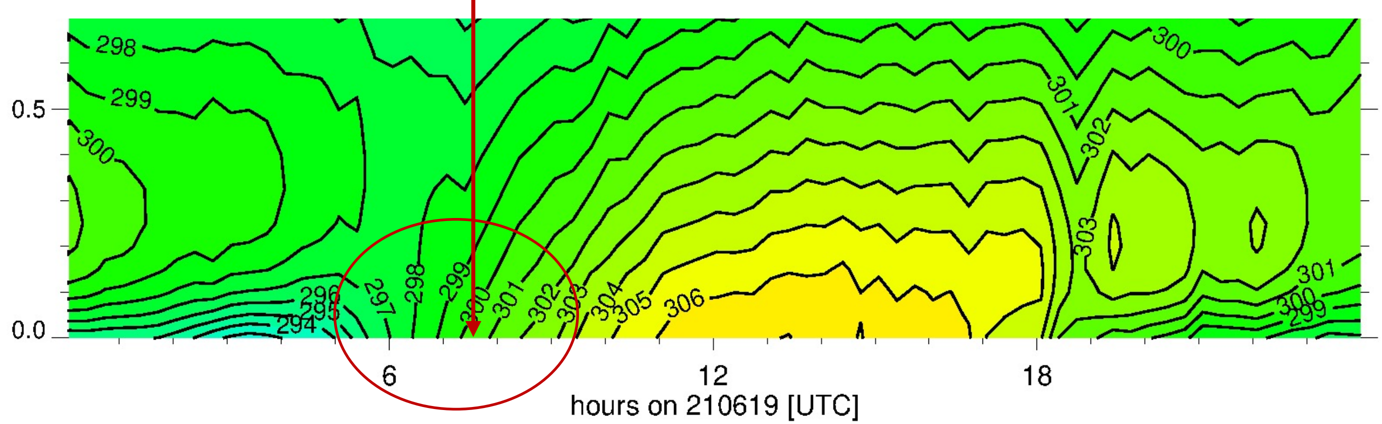


- Personal Weather Stations
- Crowd-sourced data
- Drones (swarms)
- Communication links
- Public transportation
- …

FESSTVaL: 19.6.2021







MWR

Take home messages…

Ground-based remote sensing: Evolving networks!

Doppler Lidar, Microwave radiometer, Ceilometer, Cloud radar…

New types of observations: on the horizon and developing fast!

Applications: from process understanding over short-term forecasting to renewable energy

Rethink: use which observations and how?

Exploit the synergy!

Thank you!
I’m happy to take questions

Literature

Bollmeyer, C., J. Keller, C. Ohlwein, S. Bentzien, S. Crewell, P. Friedrichs, A. Hense, J. Keune, S. Kneifel, I. Pscheidt, S. Redl, S. Steinke, 2015: Towards a high-resolution regional reanalysis for the European CORDEX domain, *Quarterly Journal of the Royal Meteorological Society*, 141 (86), 1–15. Featured Research Article. doi:10.1002/qj.2486.

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