

# Why is Thermodynamic Profiling Essential for Improving the Performance of Nowcasting Systems?

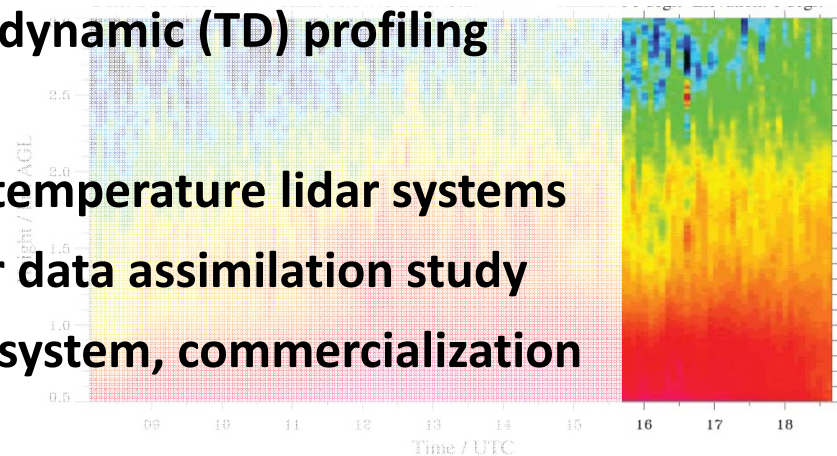
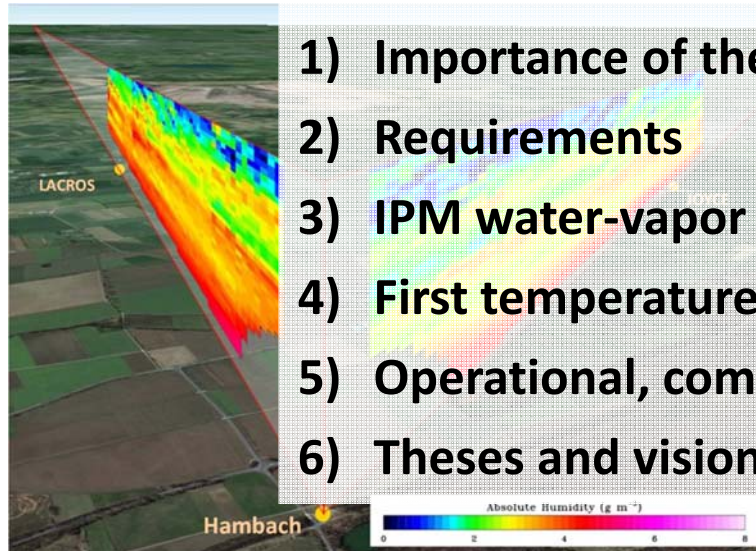
*Volker Wulfmeyer, Andreas Behrendt, Eva Hammann, Florian Späth, Shravan Muppa, Simon Metzendorf, Andrea Riede, Stephan Adam, Thomas Schwitalla*

*Institute of Physics and Meteorology (IPM)  
University of Hohenheim (UHOH)  
Stuttgart, Germany*

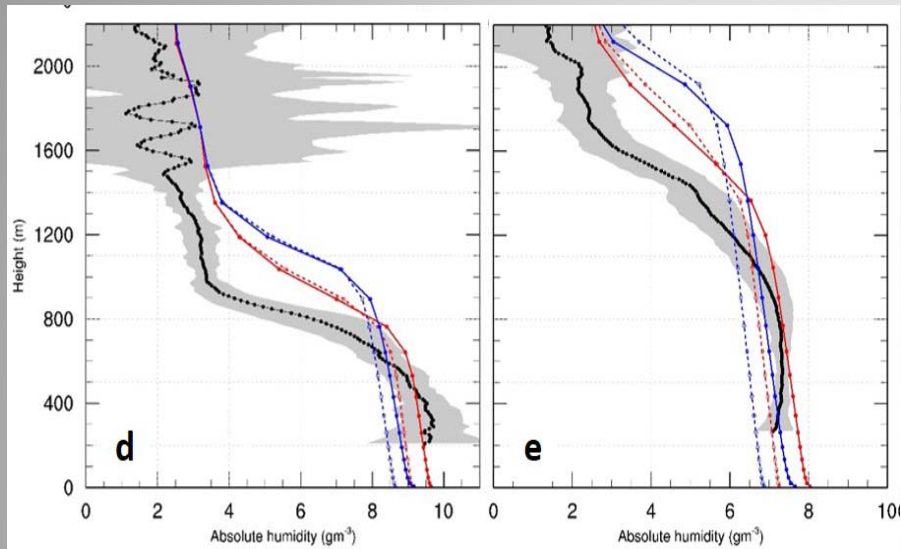


## Outline:

- 1) Importance of thermodynamic (TD) profiling
- 2) Requirements
- 3) IPM water-vapor and temperature lidar systems
- 4) First temperature lidar data assimilation study
- 5) Operational, compact system, commercialization
- 6) Theses and vision



## Sensitivity of Mesoscale Model Output to Turbulence Parameterization (TP) and LS-Schemes (WRF, 2km)

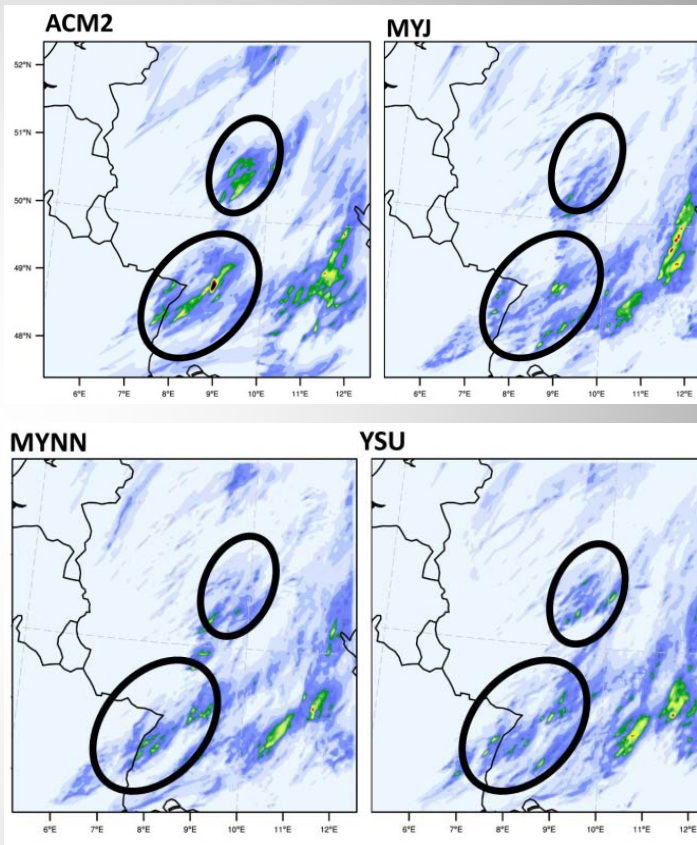


- DIAL
- - - YSU-NOAHMP
- YSU-NOAH
- - - MYNN-NOAHMP
- MYNN-NOAH

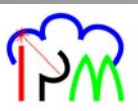
TR32, Sept. 8, 2009,  
Jülich, Germany  
(*Milovac et al. JGR 2016,*  
*PhD Thesis 2016*)

ABL too deep in all cases. Variability of the order of  $1 \text{ g m}^{-3}$ . Strong sensitivity on both LS-schemes and TPs.

## The Impact of TP on the Evolution of Clouds and Precipitation (WRF, 2km): 22.08. – 15.09.2009



Strong influence on clouds and precipitation.



July 25, 2016

WSN16, Hong Kong



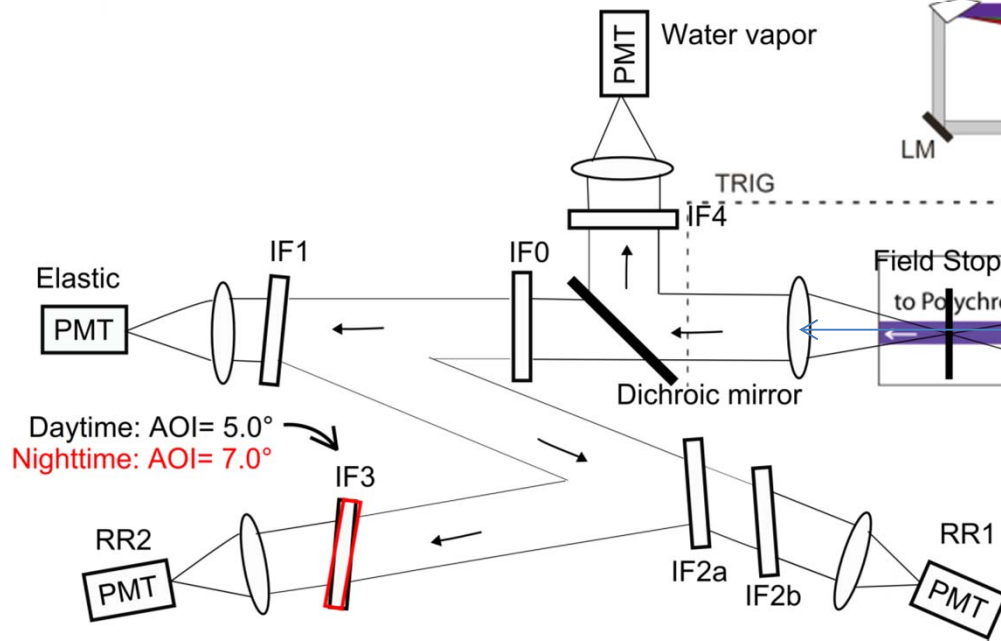
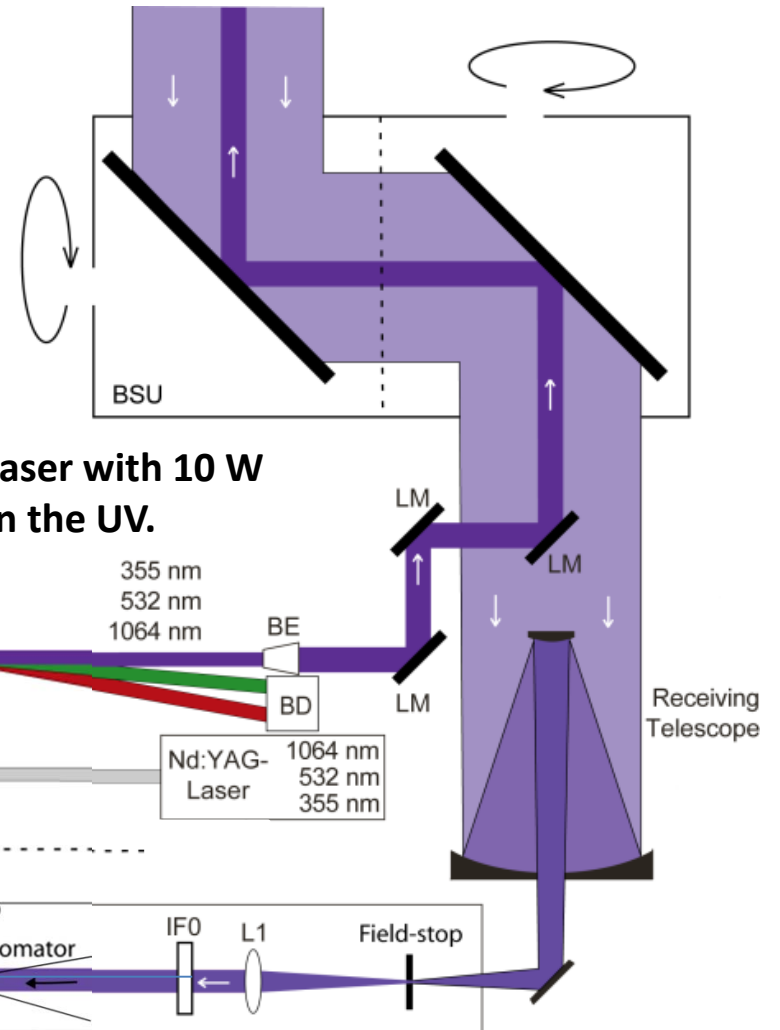
# Requirements for Thermodynamic (TD) Profiling and for Exploring the “Terra Incognita”: the ABL

Parameter	Monitoring	Verification	Data assimilation	Process studies
Vert. res. In ABL, m				
Surface layer	10 – 30	10 – 30	10 – 30	10
Mixed layer	100 – 300	100 – 300	100 – 300	10 – 100
Interfacial layer	10 - 100	100	100	10 – 100
Lower free trop.	300 - 500	300 - 500	300 – 500	100
Time resolution, min	< 60	< 15	5 – 15	1/60 - 1
WV noise error , %	< 10	< 5	< 10 + error covariance matrix	< 10
WV bias, %	2 – 5	2 – 5	< 5	< 10
T noise error , K	1	1	1	0.5
T bias , K	0.2 – 0.5	0.2 – 0.5	0.2 – 0.5	0.2 – 0.5
Latency , min	---	---	1 for nowcasting, 1 to 60 for short-range	---
Hor. res. of network	Down to meso- $\gamma$ -scale	Meso- $\gamma$ -scale	Meso- $\gamma$ -scale	Turbulent to meso- $\gamma$ -scale
Coverage	All climate regions			

# IPM 3D Temperature and Water-Vapor Lidar



Tripled Nd:YAG laser with 10 W average power in the UV.

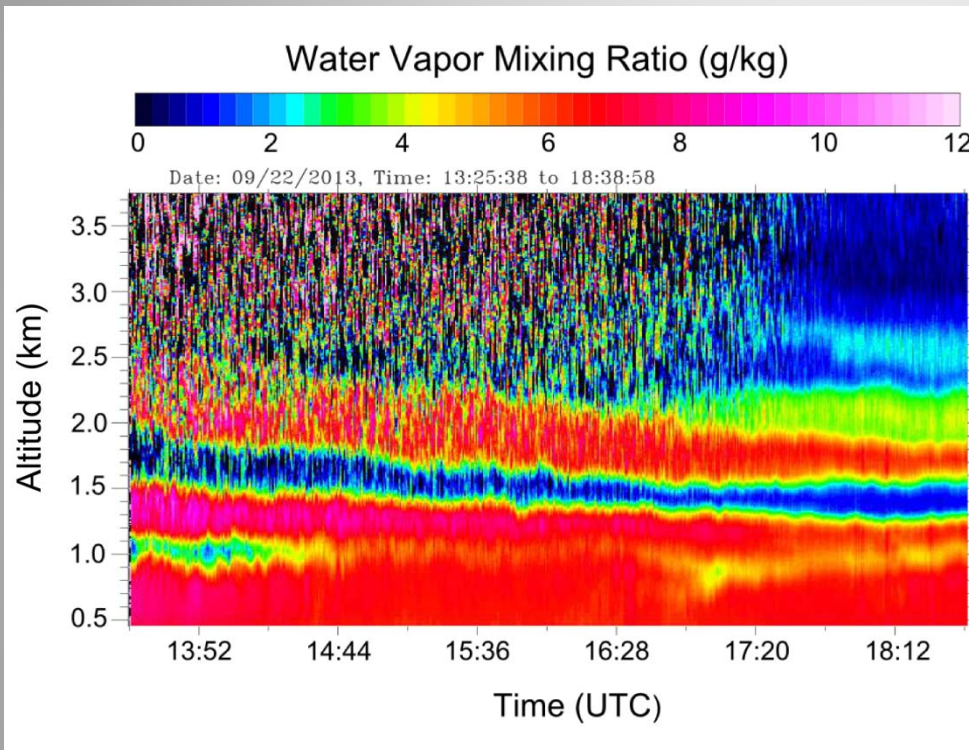


*Behrendt et al. AO 2004,  
Radlach et al. ACP 2008,  
Hammann et al. ACP 2015,  
Behrendt et al. ACP 2015*

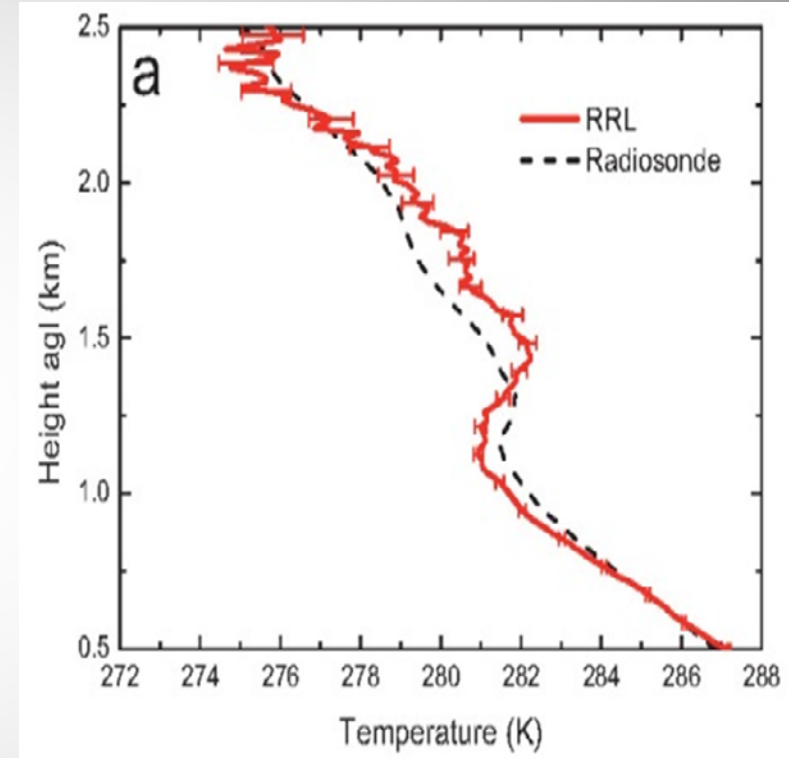


# IPM WV and T Raman Lidar Performance

Time-height cross section of water-vapor mixing ratio with resolutions of 30 s, 150 m:



Temperature profile, May 19, 2013, 13-13:30 UTC, 100-m resolution:



**Globally-unique, ground-based remote sensing system with high temporal and spatial resolution of 10 s- 10 min, 100-300 m up to 4 km with error of < 1 K (Wulfmeyer et al. ROG 2015, Behrendt et al. ACP 2015).**

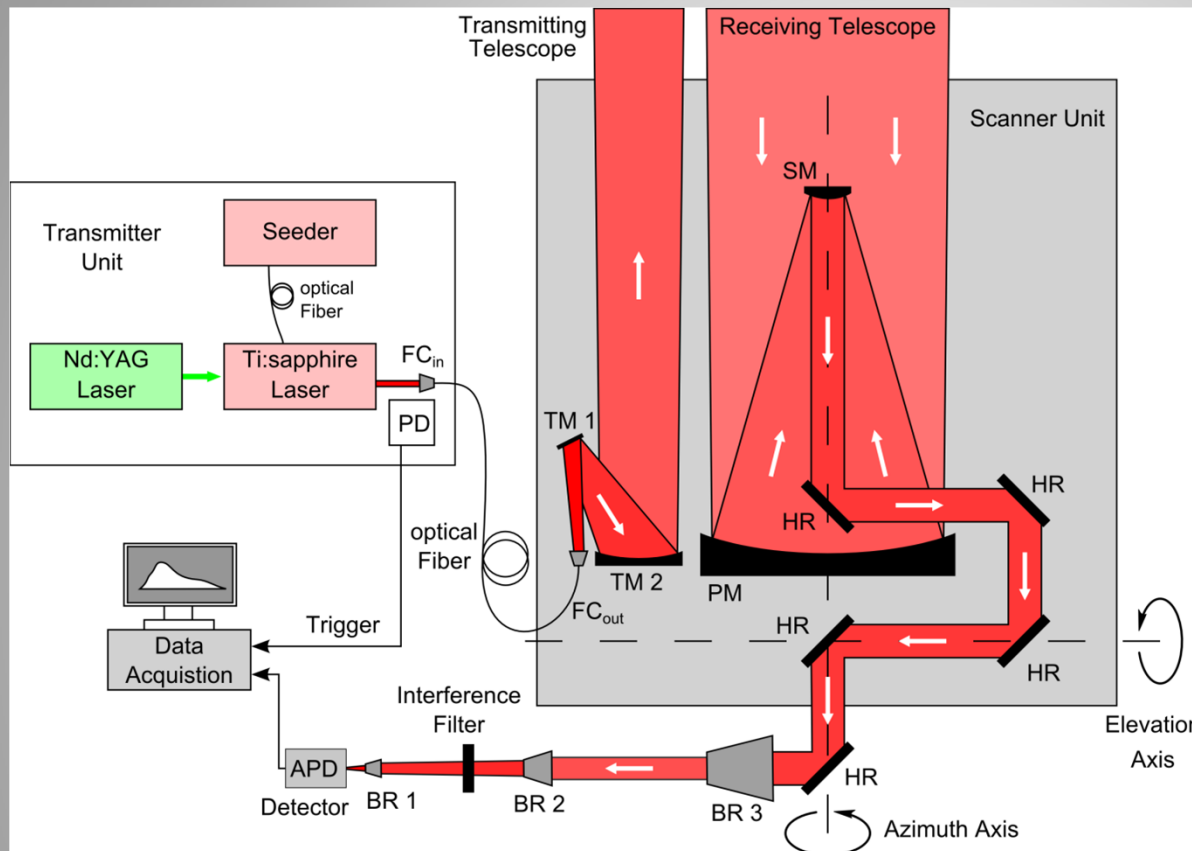


July 25, 2016

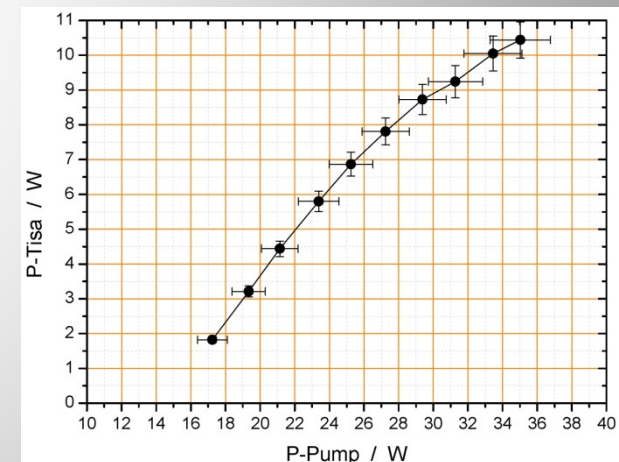
WSN16, Hong Kong



# IPM 3D Water-Vapor Differential Absorption Lidar



For further details see: *Wagner et al. AO 2011, 2013; Metzendorf et al. CLEO 2015; Späth et al. AMT 2016*)



**10-W laser transmitter with extraordinary power and stability**

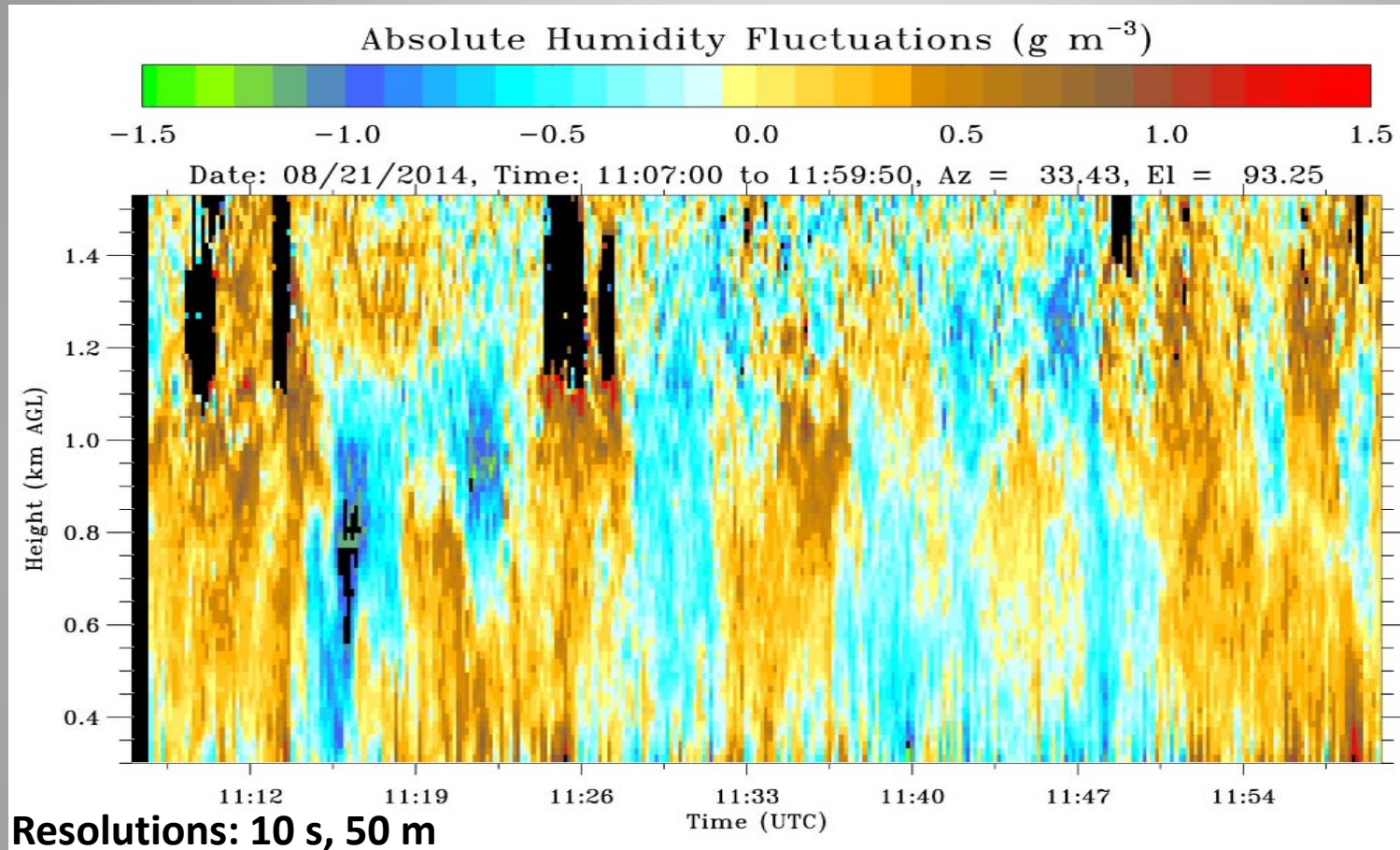


July 25, 2016

WSN16, Hong Kong



# Vertical Structure of the Water-Vapor Field



Highest resolution and accuracy demonstrated for water-vapor remote sensing yet. Turbulent moments up to the fourth order can be resolved (Wulfmeyer et al. JAS 2016).

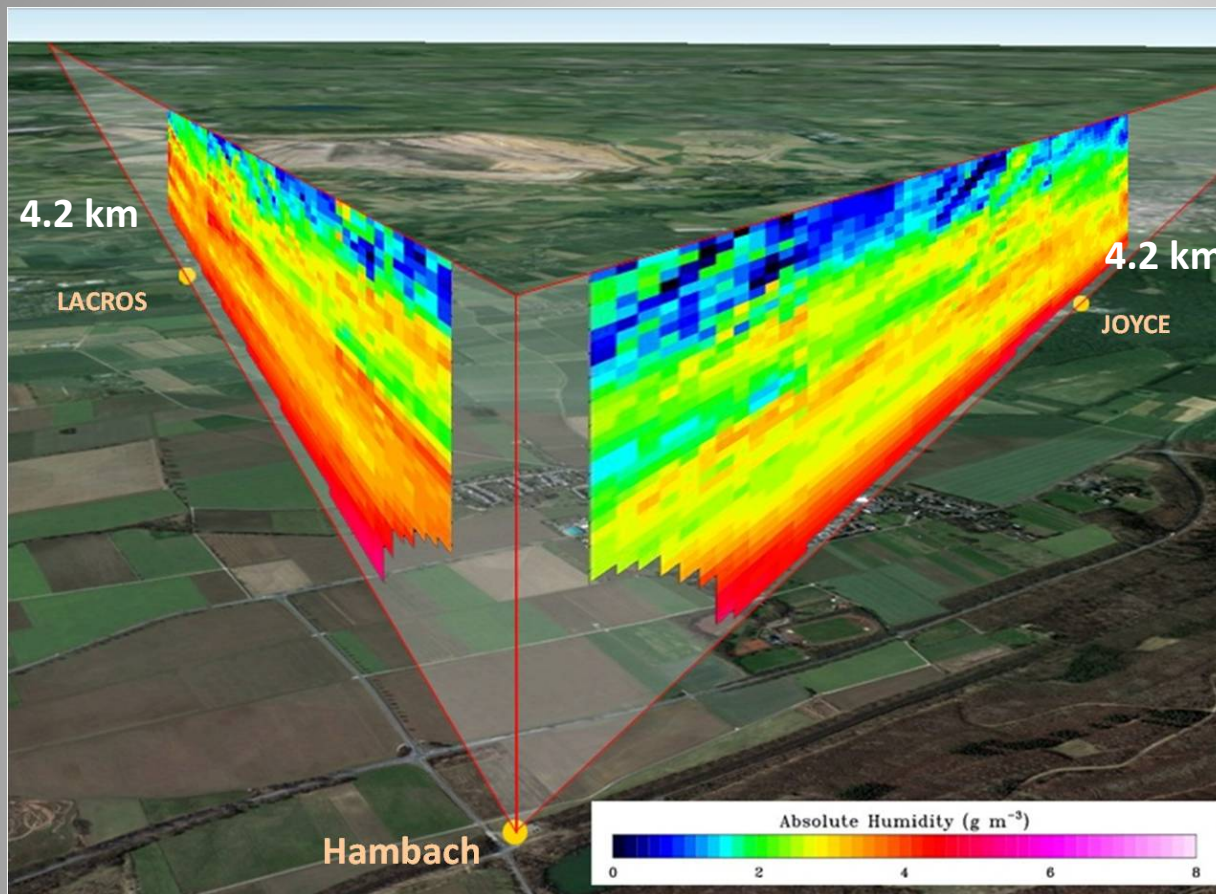


July 25, 2016

WSN16, Hong Kong



# 3D Water-Vapor Observations with DIAL During HOPE

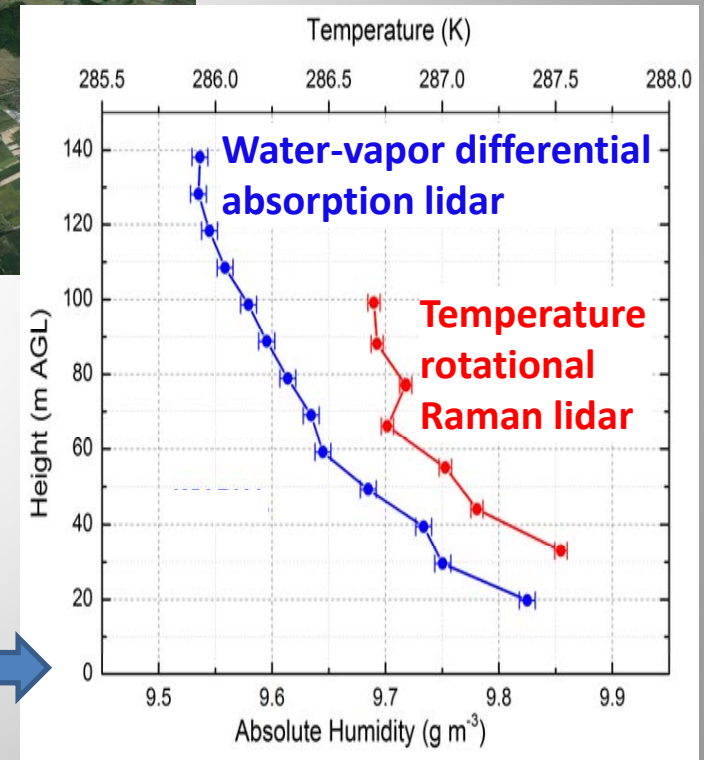
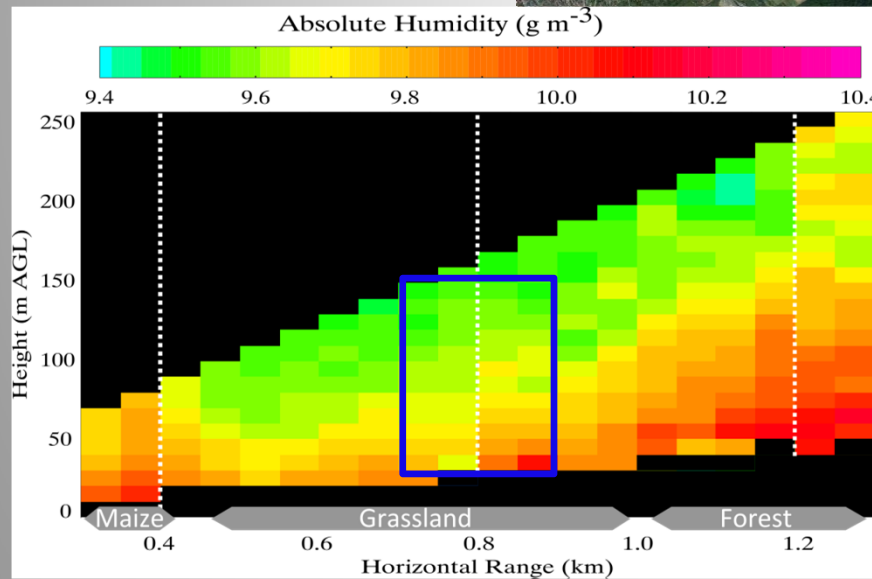
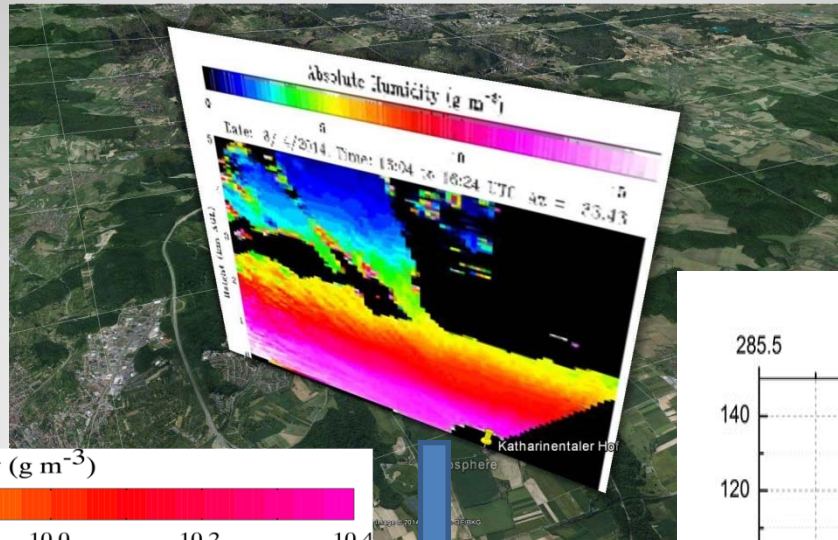


80-cm scanner

HD(CP)<sup>2</sup> Observational  
Prototype Experiment (HOPE)  
2013 (see [hdcp2.zmaw.de](http://hdcp2.zmaw.de)),  
IOP 5 on April 20, 2013,  
06:03-07:24 UTC, scan time:  
10 min, resolution: 60-300 m.

Globally-unique, ground-based remote sensing system with very high accuracy (bias  $\approx 2\%$ ) as well as temporal and spatial resolution of 1 s - 10 min, 50-300 m up to 4 km with error of  $< 0.1 \text{ g kg}^{-1}$  (Wagner et al. AO 2011, 2013; Späth et al. AMT 2016).

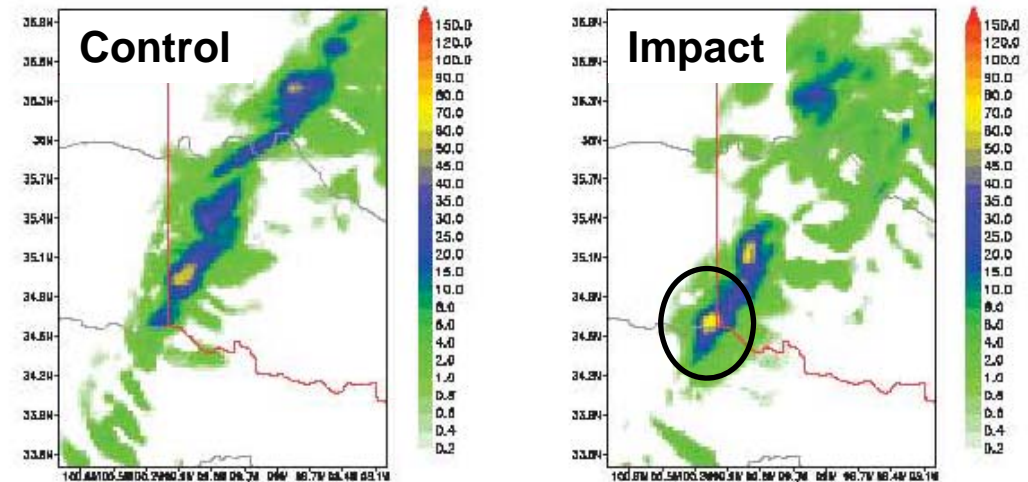
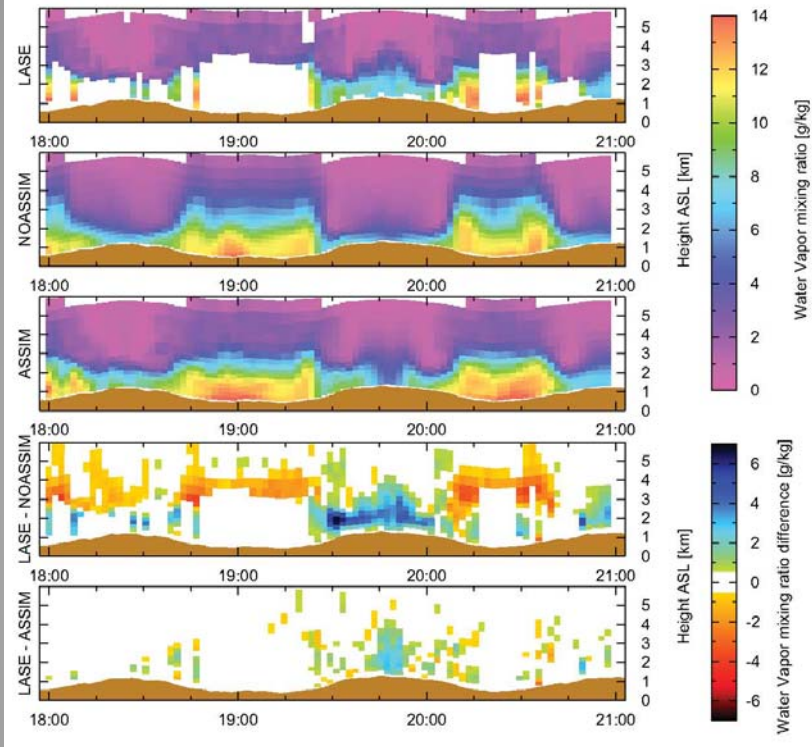
# First Simultaneous Remote Sensing of Surface Layer Water-Vapor and Temperature Profiles



# Requirements for Earth System Research and Predictions in Comparison to Ground-based Lidar Performance

Parameter	Monitoring	Verification	Data assimilation	Process studies	Lidar
Vert. res. In ABL, m					
Surface layer	10 – 30	10 – 30	10 – 30	10	2
Mixed layer	100 – 300	100 – 300	100 – 300	10 – 100	50
Interfacial layer	10 - 100	100	100	10 – 100	50
Lower free trop.	300 - 500	300 - 500	300 – 500	100	100
Time resolution, min	< 60	< 15	5 – 15	1/60 - 1	< 1/6 in ABL
WV noise error , %	< 10	< 5	< 10 + error covariance matrix	< 10	< 5 + error covariance
WV bias, %	2 – 5	2 – 5	< 5	< 10	2 – 5
T noise error , K	1	1	1	0.5	1 + err. cov.
T bias , K	0.2 – 0.5	0.2 – 0.5	0.2 – 0.5	0.2 – 0.5	0.2 – 0.5
Latency , min	---	---	1 for nowcasting, 1 to 60 for short-range	---	Immediately including errors
Hor. res. of network	Down to meso- $\gamma$ -scale	Meso- $\gamma$ -scale	Meso- $\gamma$ -scale	Turbulent to meso- $\gamma$ -scale	Tbd
Coverage	All climate regions				Yes

# 2006: First Assimilation of Airborne NASA WV DIAL Data in a Mesoscale Model Using 4DVAR during IHOP\_2002

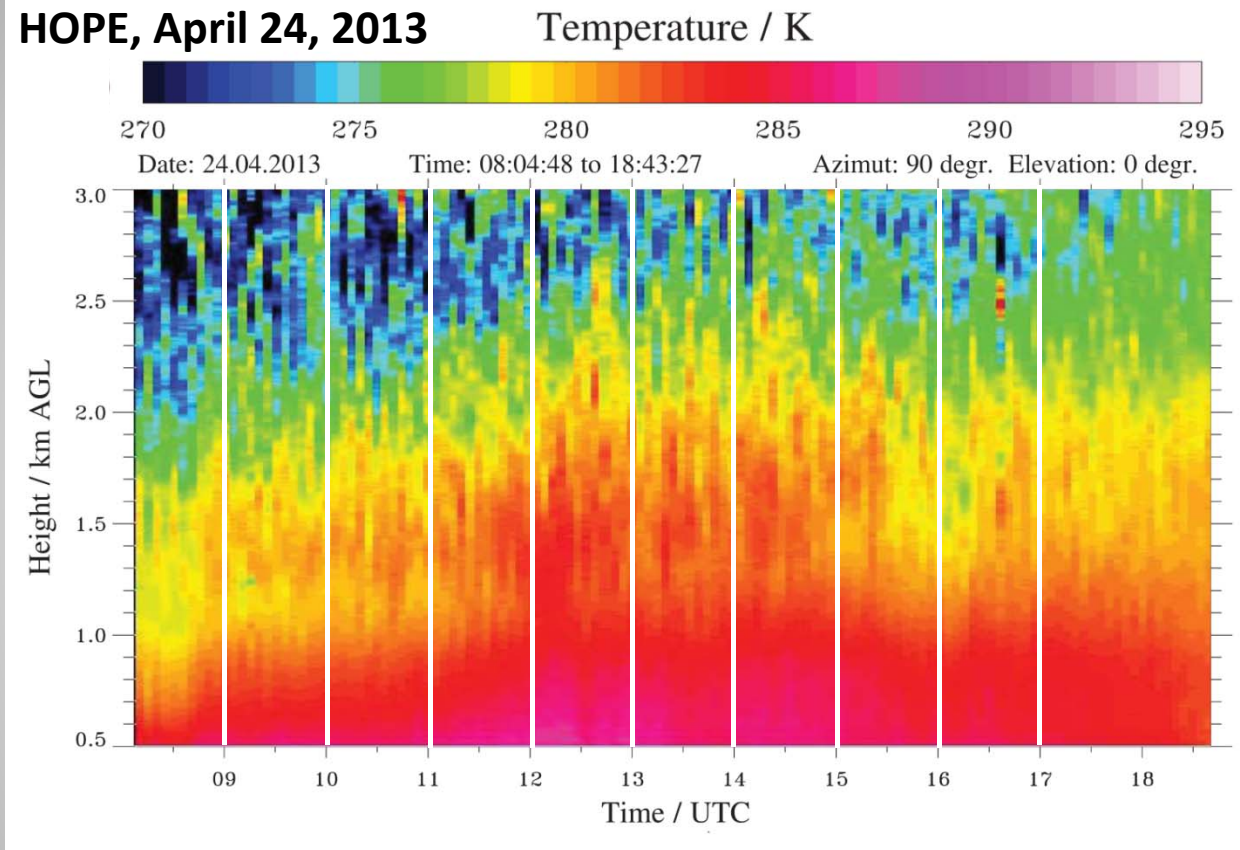


Precipitation fields: considerable improvement of the simulation of convection initiation

Huge impact on the WV field in the model. Also strong and positive analysis increments of wind and temperature leading to an improved prediction of convection initiation and precipitation (*Wulfmeyer et al. Mon. Wea. Rev. 2006*).



# 2016: First Temperature RRL Impact Study Using WRF 3DVAR 1-h RUC



Temperature field measurement with resolutions of 10 min and 200 m.  
Profiles and error covariances available in real time with negligible latency  
(Adam et al. QJRMS 2016, in press).

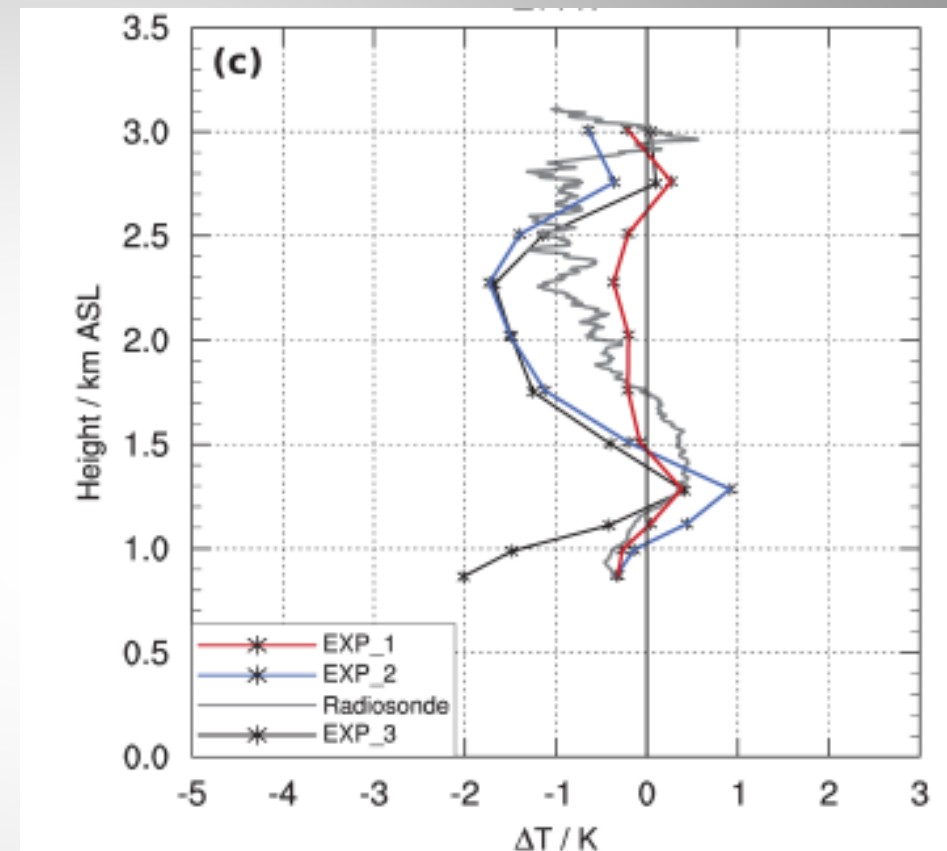
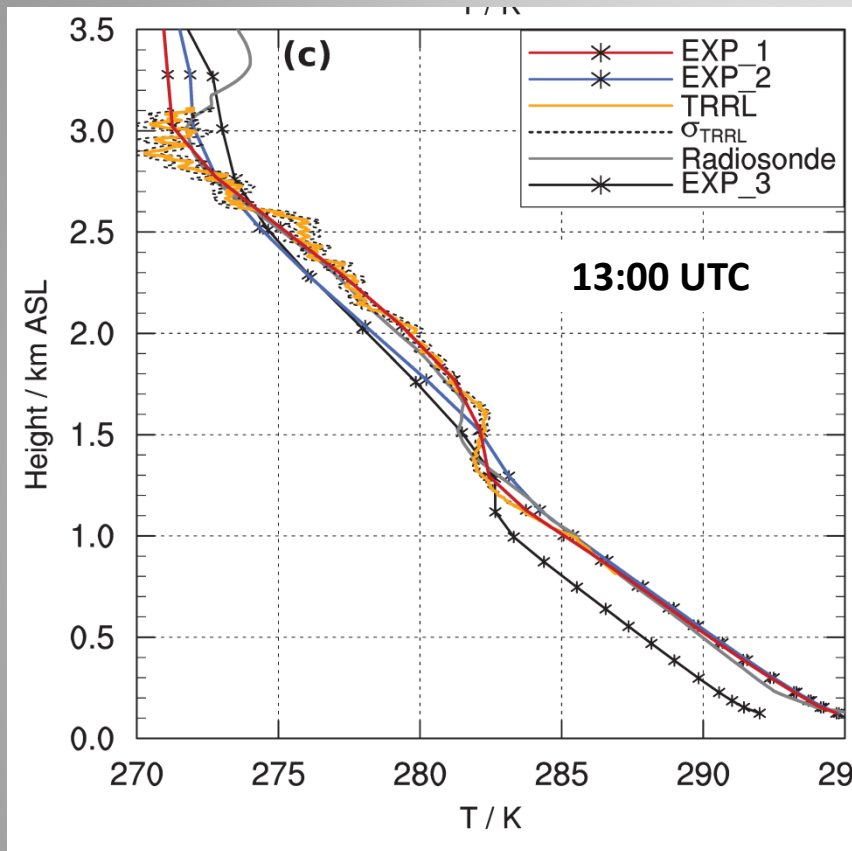


July 25, 2016

WSN16, Hong Kong



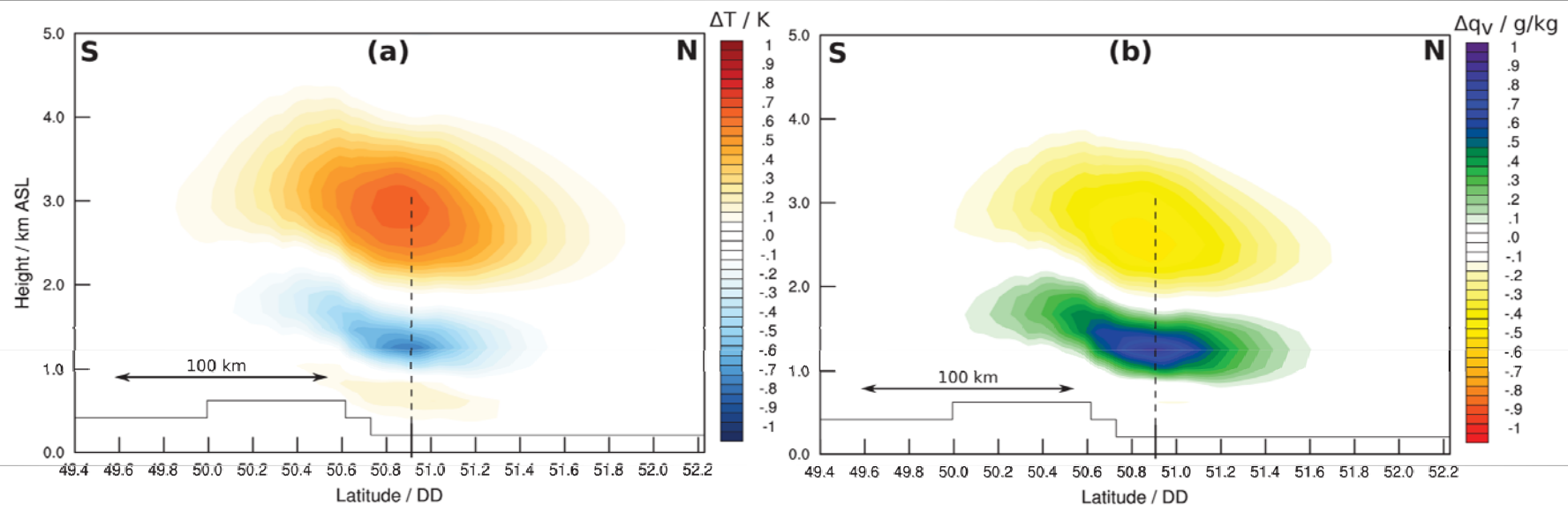
# Impact Analyses of TRRL DA



- Model temperature profiles corrected up to the lower troposphere.
- ABL depth and inversion strengths also corrected.



# Large-Scale Impact of TRRL DA



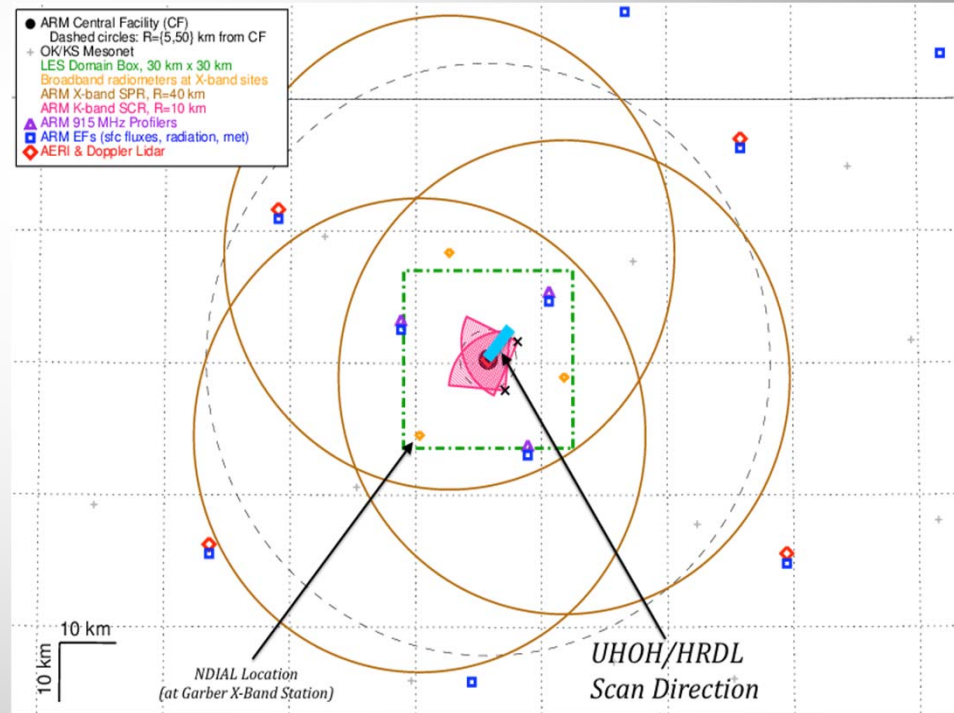
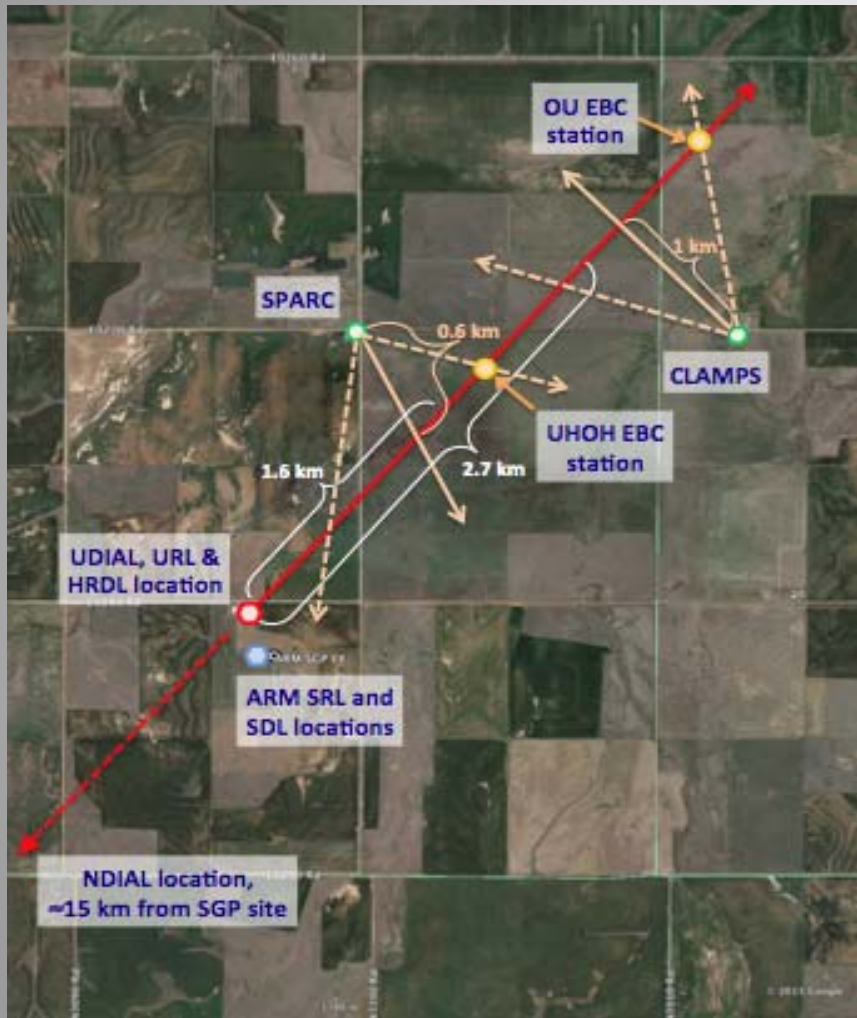
(a) cross section of the temperature difference  $\Delta T = T_{EXP\_1} - T_{EXP\_2}$  at 0900 UTC. (b) cross section of the water vapour mixing ratio difference  $\Delta q_v = q_{vEXP\_1} - q_{vEXP\_2}$ . The dashed line marks Jülich, S south, N north, DD stands for decimal degree.

*Adam et al. M.Sc. Thesis, University of Hohenheim 2015.*

- Impact region of 100 km, also influenced by B matrix.
- The dipole is mainly due to a correction of the inversion layer.
- Strong analysis increments in the water-vapor field.
- More case studies in preparation.

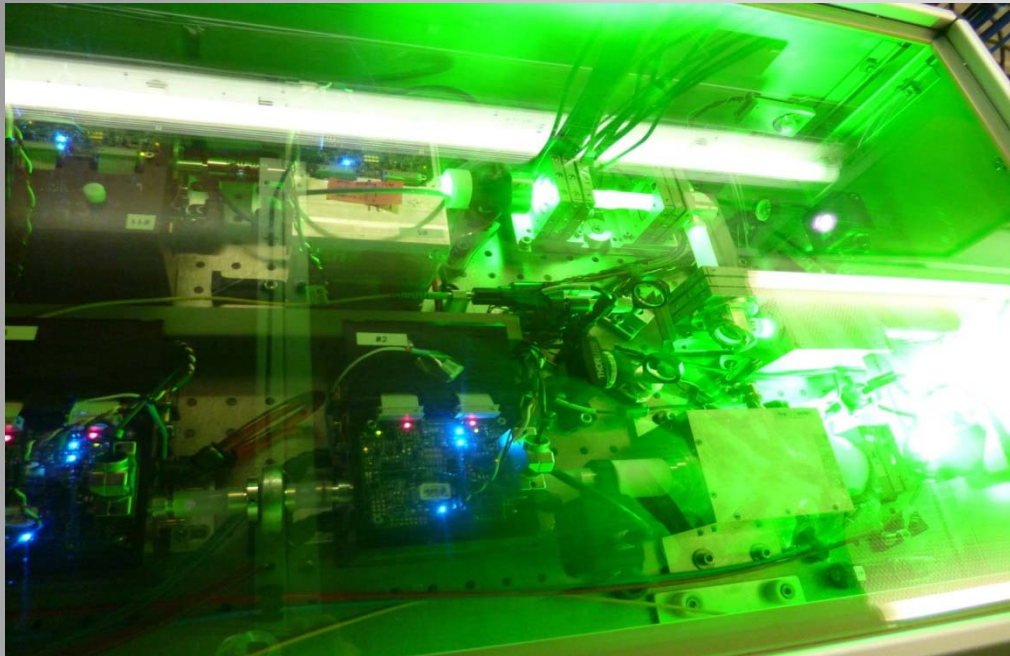


# Sensor Synergy Within the ARM Land-Atmosphere Feedback Experiment (LAFE), Aug. 2017

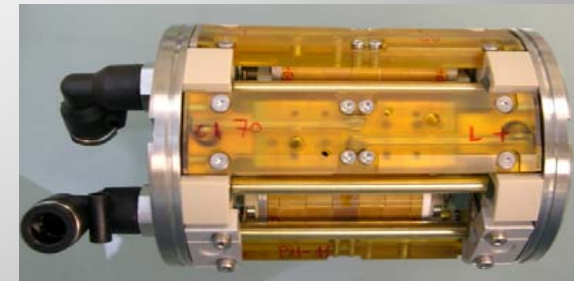
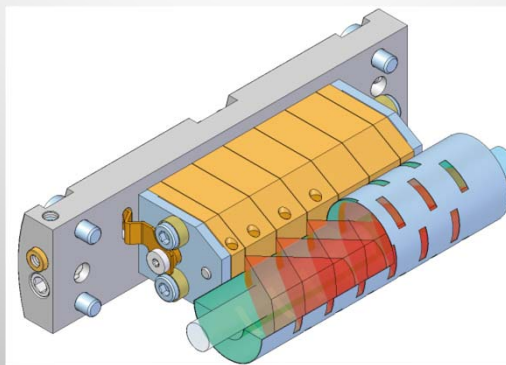
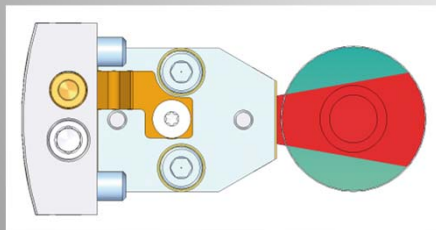
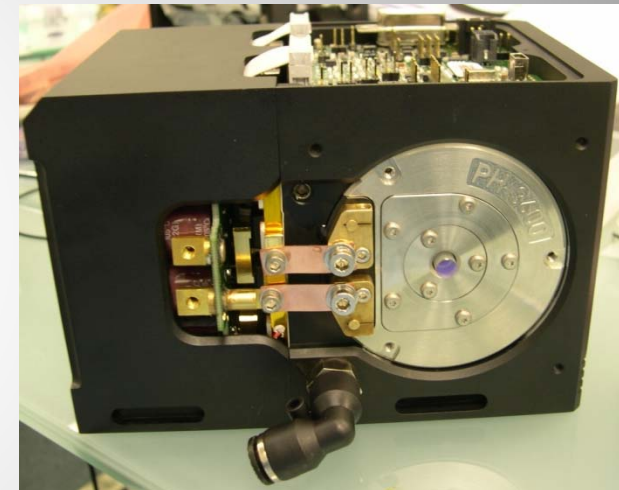


See <http://www.arm.gov/campaigns/sgp2017lafe>

# New Laser Technology, Output power: 120 W



L x B x H = 110 cm x 60 cm x 30 cm, weight:150 kg,  
lifetime of diodes: 5 years



July 25, 2016

WSN16, Hong Kong



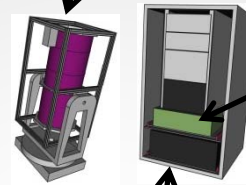
# New Operational, Autonomous WV and T Profiler



3D-scanning  
unit

Control  
unit

Receiver unit



High-power  
laser unit



## Key specifications:

- High accuracy and resolution of T and WV profiling during day- and nighttime up to  $\approx 4$  km
- Eye safe
- Size comparable to ceilometer
- Continuous operation for more than 5 years
- Operation on buoys considered
- Spaceborne operation envisioned in collaboration with ESA (EE10) and NASA via US NAS RFI#2



July 25, 2016

WSN16, Hong Kong



# Theses and Vision

An optimization of the observation network design is possible now for the benefit of society, economy, and aviation.

Only active thermodynamic profiling provides the vertical resolution and accuracy to explore „Terra Incognita“.

These profiles are fundamental for advanced predictions of convection initiation and convective systems.

Advanced network design and sensor synergies should contain WV and T lidar systems, which will significantly improve NWP from nowcasting up to the short range.

This network design will also reduce the severe model imbalances introduced by radar data assimilation.

Synergetic network design should be fostered by an extensive collaboration between NWP centers, aviation, air quality control, urban authorities, universities, and industry.



July 25, 2016

WSN16, Hong Kong

