Water Vapor Variability in the Tropics Observed by Airborne Lidar and Modelling

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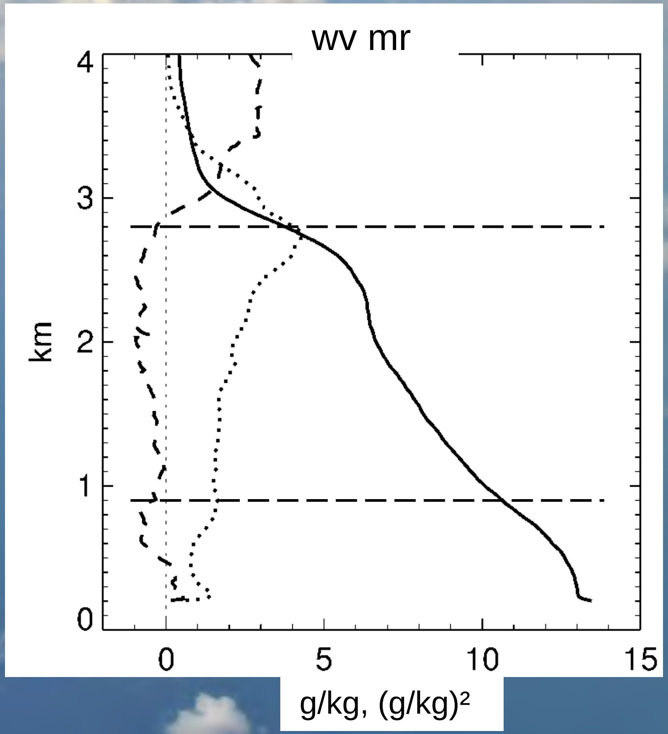
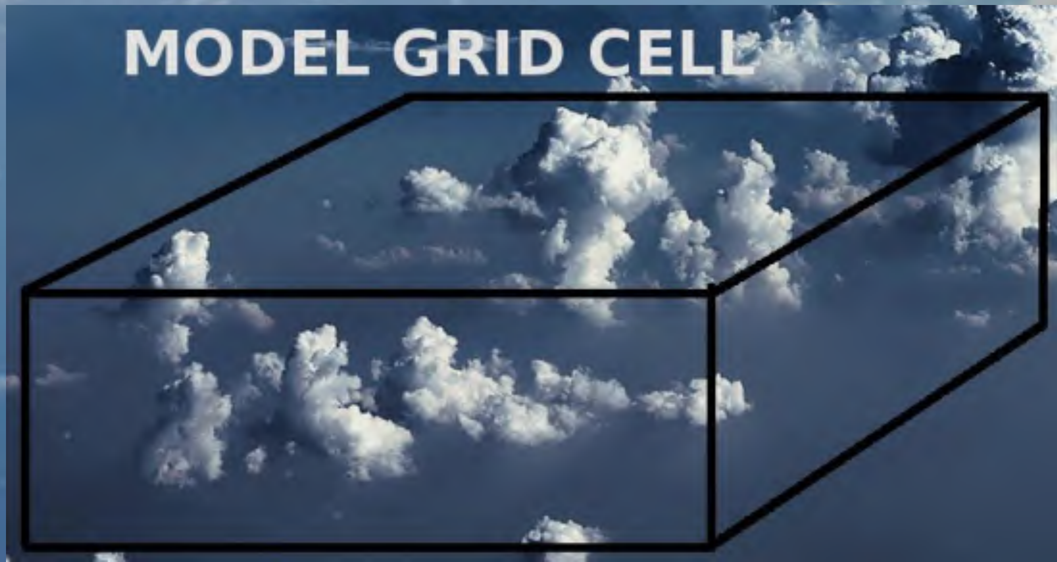
with contributions by
Silke Gross and Martin Wirth (DLR), Daniel Klocke (MPI)



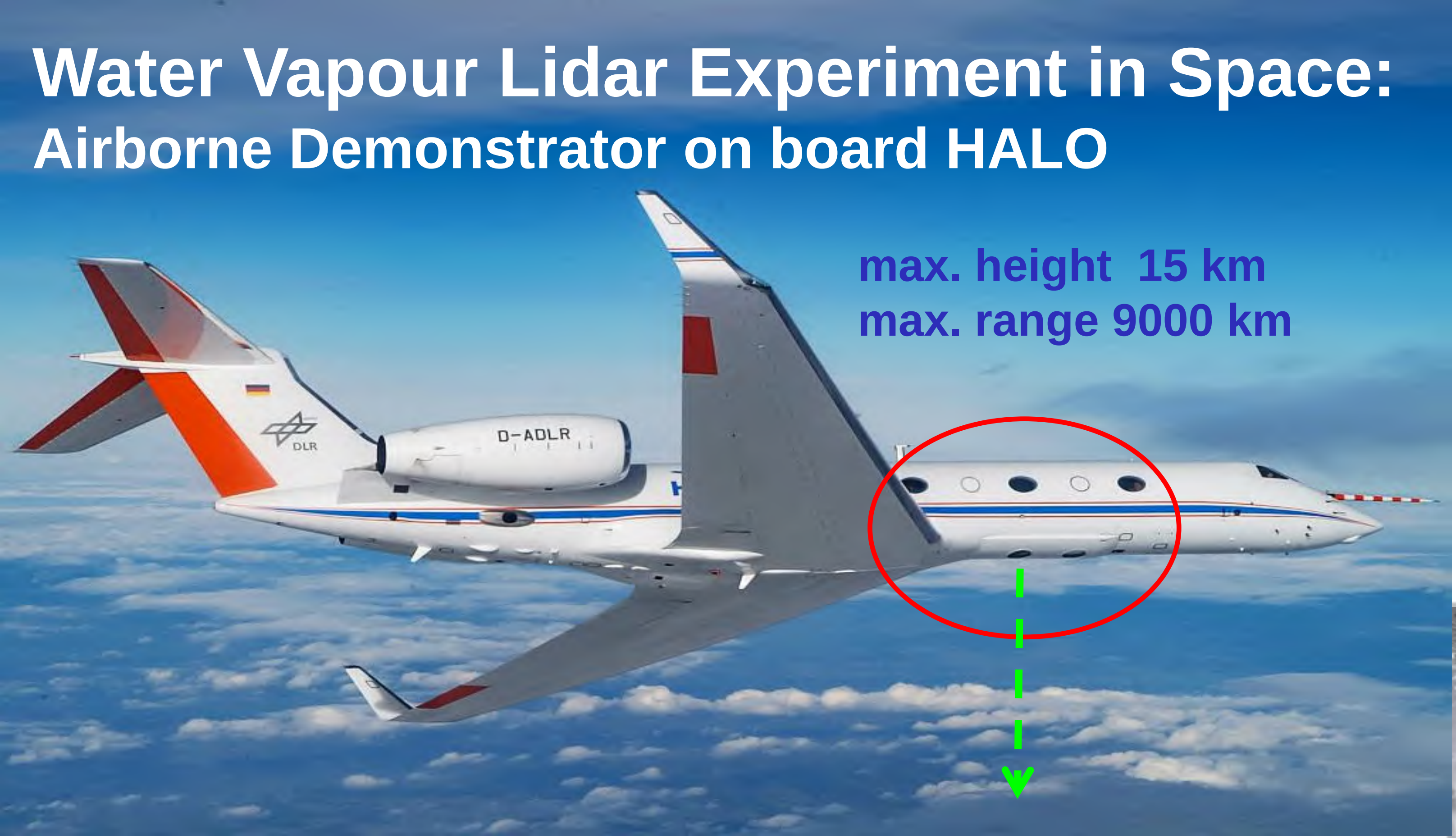
- **Tropics and trade wind regions are key to Earth’s climate.**
- **Water vapor influences radiation, clouds, and circulation.**
- **Models have difficulties to reproduce the <u>shallow convection</u>.**

Cloud layer humidity determines dilution of clouds by entrainment

<u>Vertical profile</u> of water vapor determines radiative cooling (e.g. Muller and Bony, 2015)



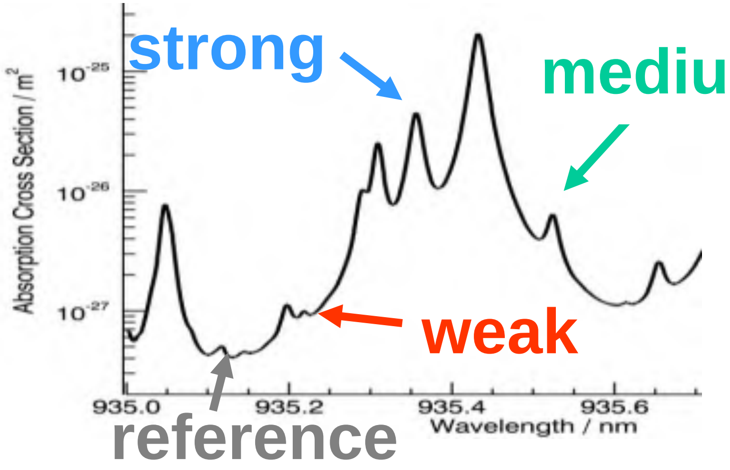
Water Vapour Lidar Experiment in Space:
Airborne Demonstrator on board HALO



WALES

- Differential Absorption Lidar, DIAL
- solid-state laser, OPO
- 8 W power at 935 nm
- High-Spectral-Resolution Lidar, HSRL
- 3 onlines for full troposphere coverage

Tropical H_2O absorption line selection:



Water Vapour Lidar onboard HALO

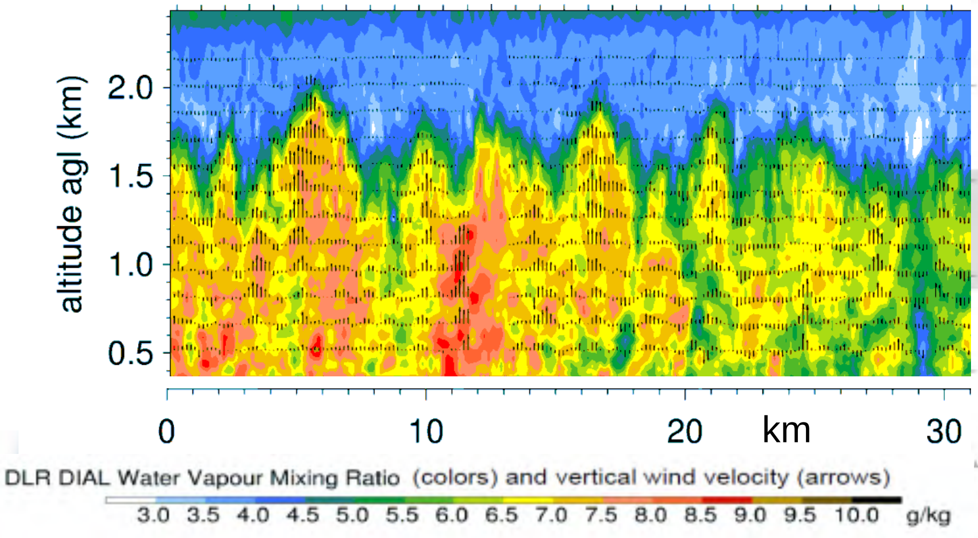
NARVAL Flight Experiment:

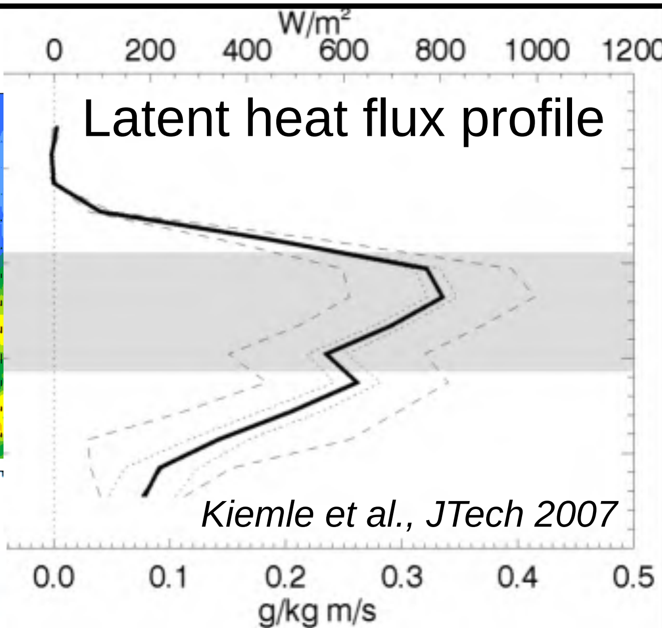
Next Generation Aircraft Remote Sensing for Validation Studies

Lidar – Radar combination in view of ESA EarthCare

See contribution on Tuesday by S. Gross presented by M. Hagen

Before 2010:
*combination with **wind lidar for moisture transport** process studies on DLR Falcon aircraft*





DLR

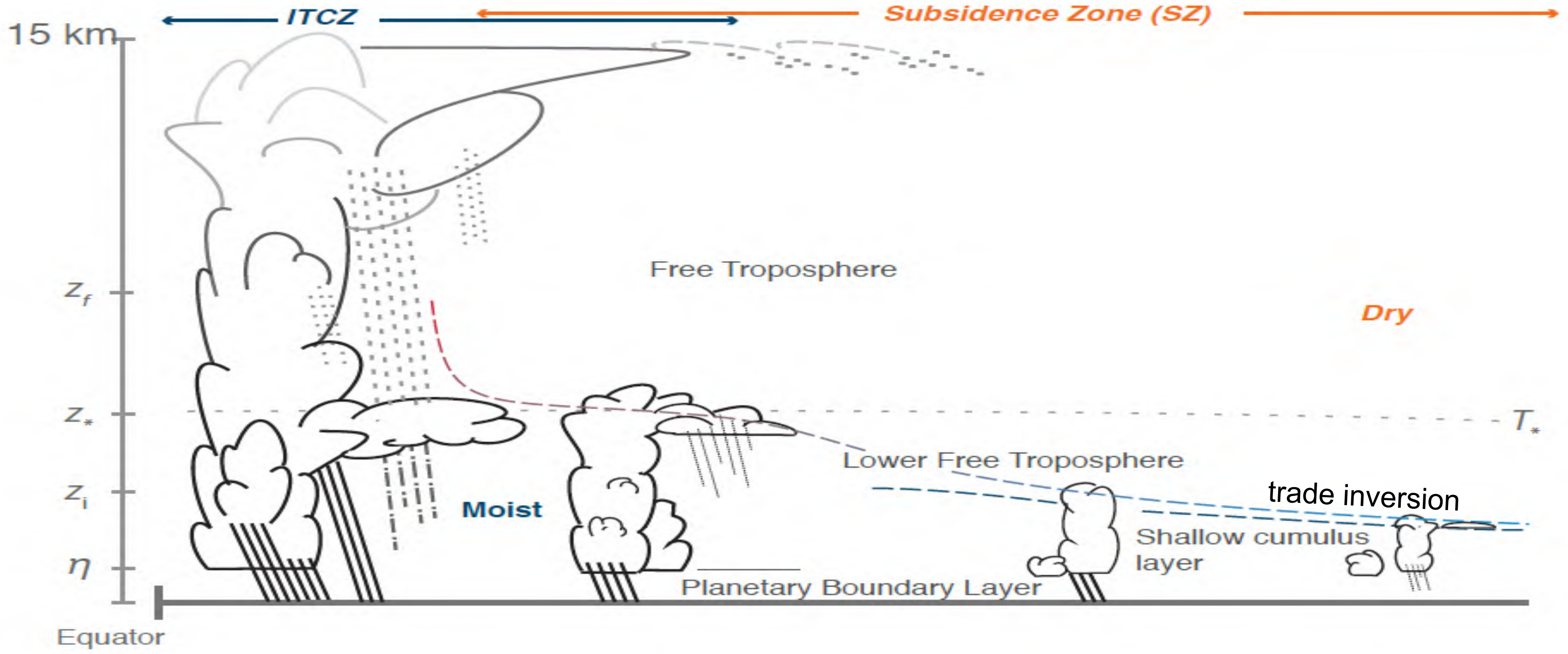
Tropical HALO Flights:

North Atlantic, East of Barbados

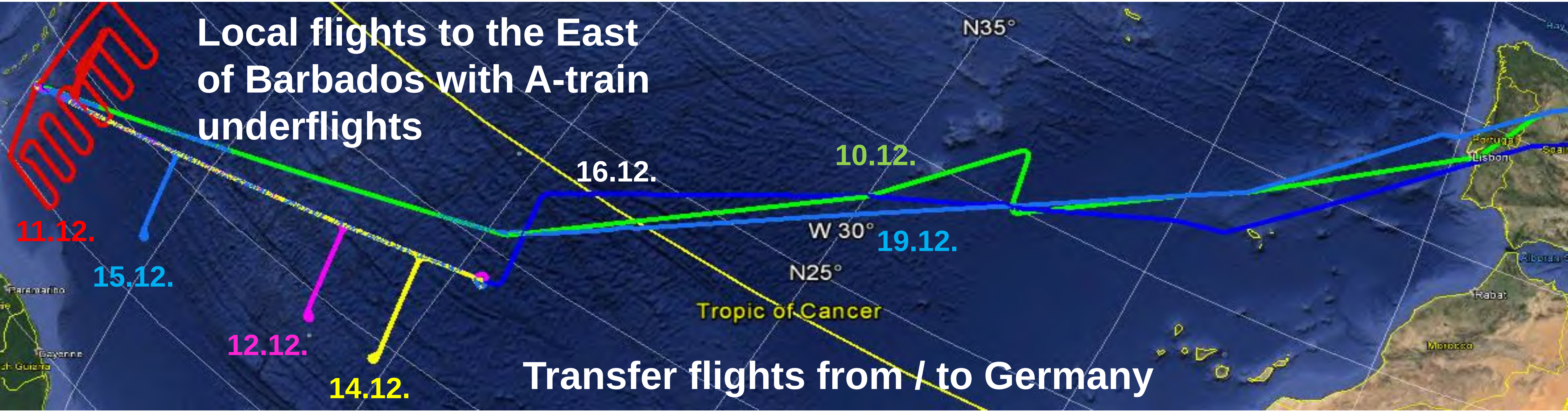
Dec. 2013 Winter Trades

Aug. 2016 Summer Trades

Jan. 2020 EUREC4A



NARVAL1 flights, Dec. 2013:



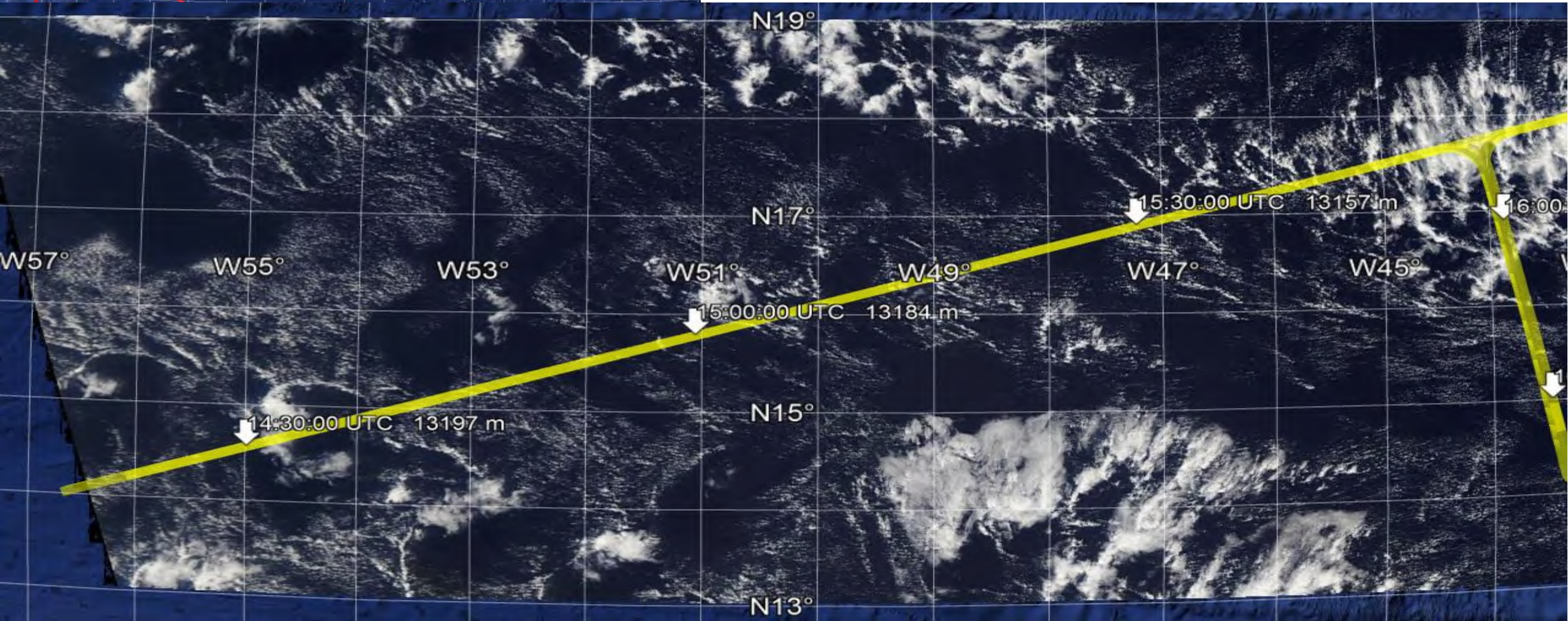
NARVAL-1

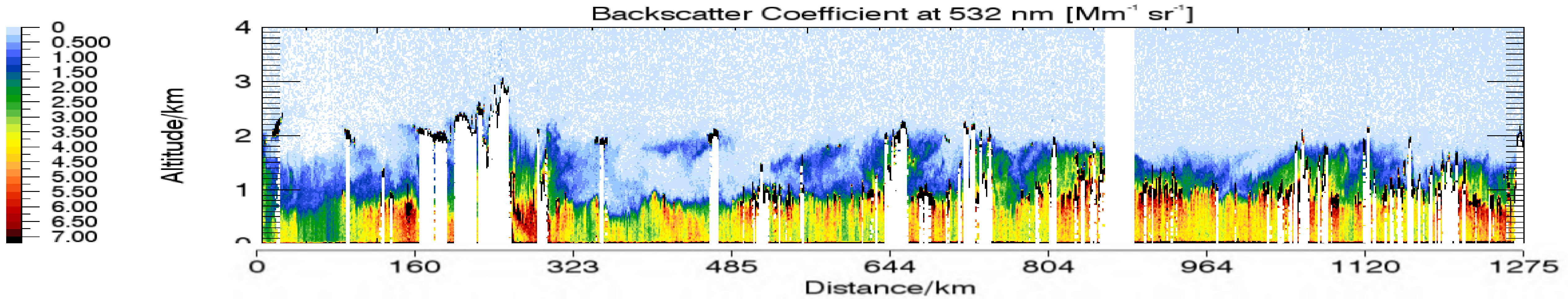
12. Dec. 13

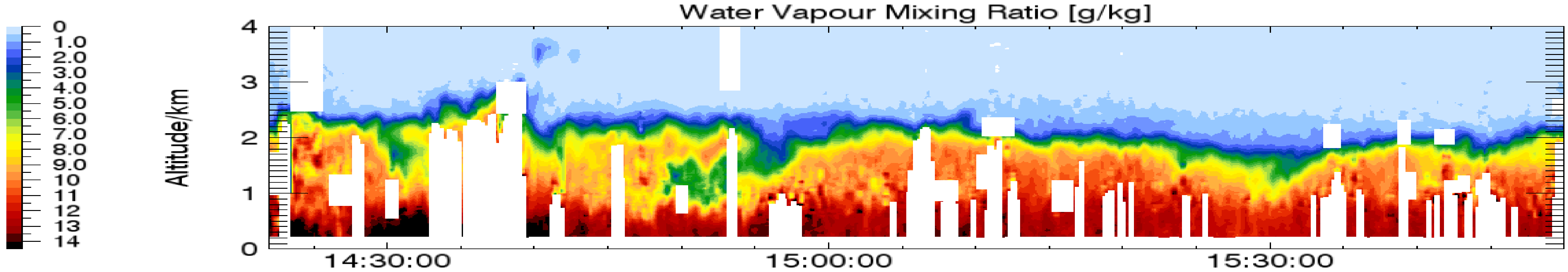
MODIS 16:30

HALO track

NARVAL
next-generation aircraft remote-sensing for validation studies







NARVAL-1

12. Dec. 13

MODIS 16:30

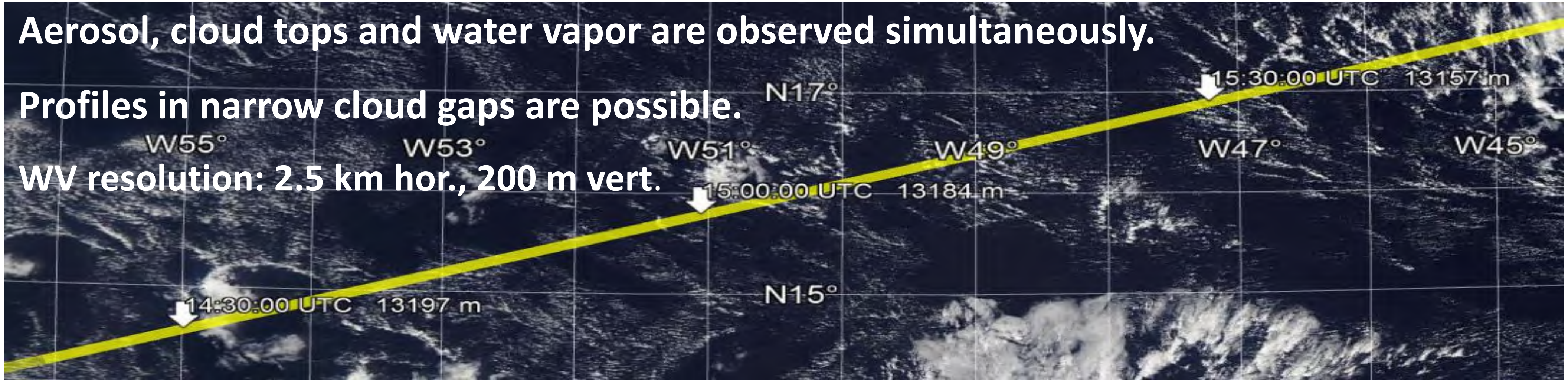
HALO track

2h·15m/s=108 km

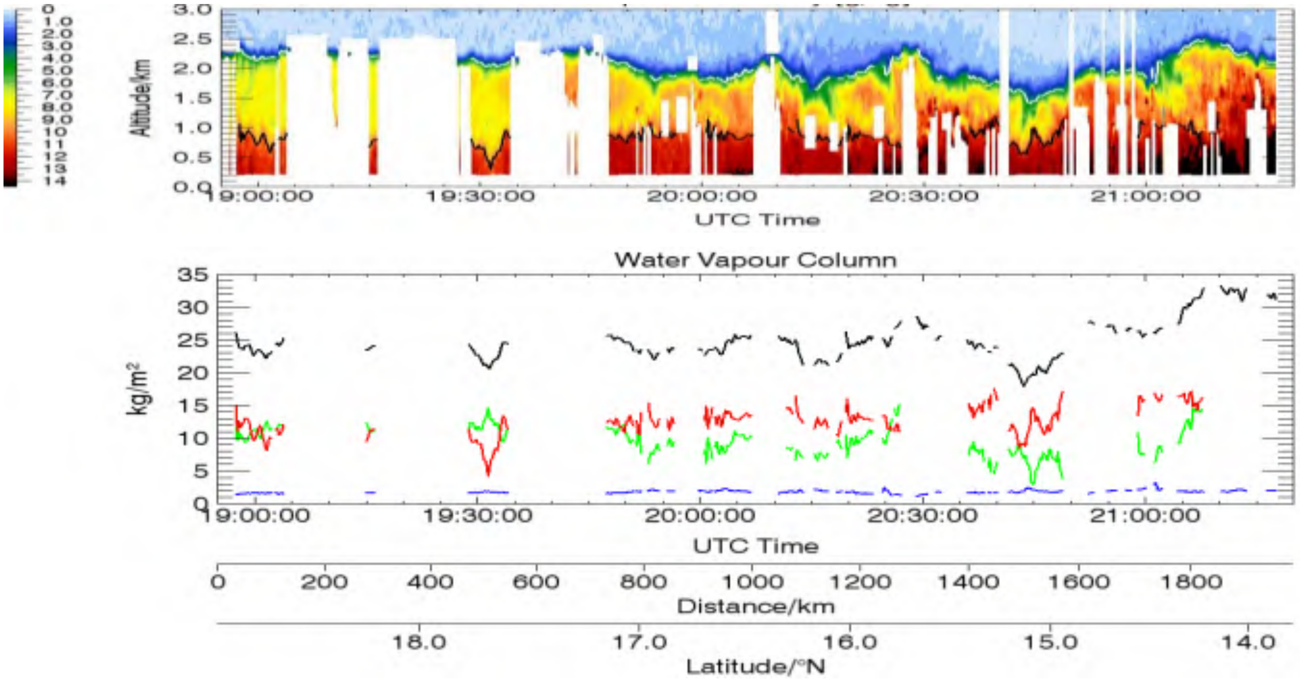
Aerosol, cloud tops and water vapor are observed simultaneously.

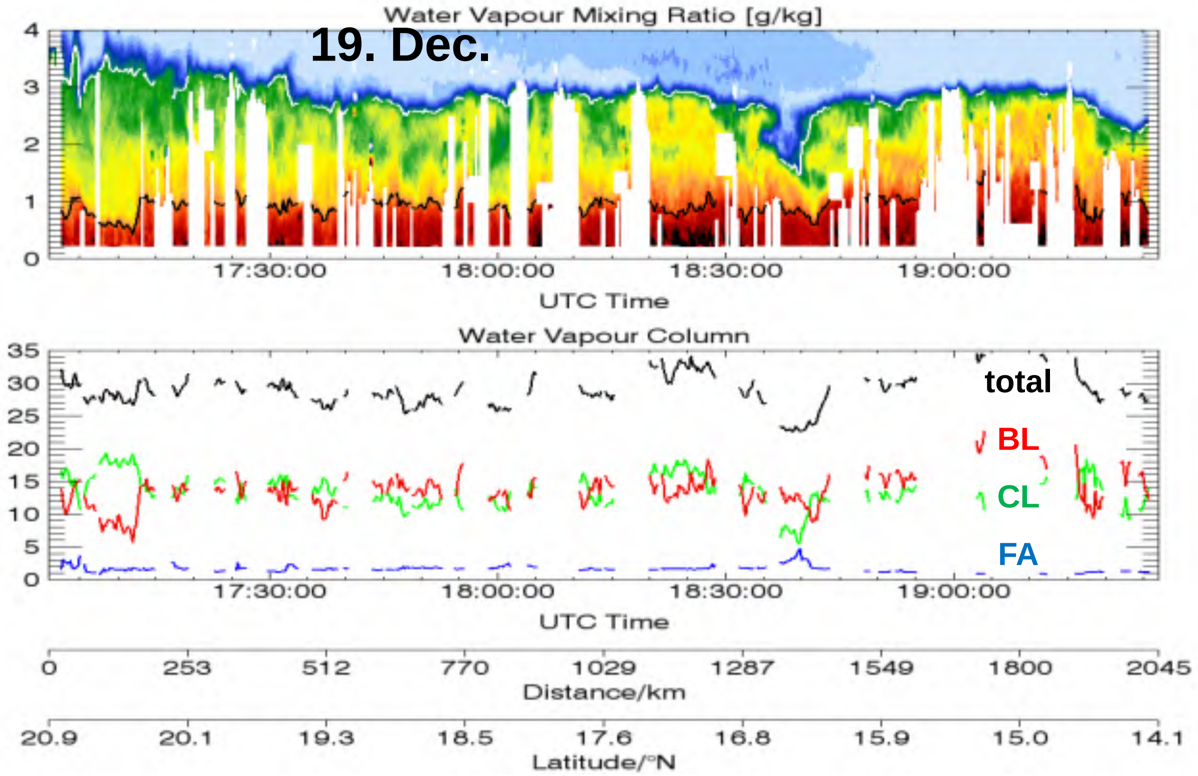
Profiles in narrow cloud gaps are possible.

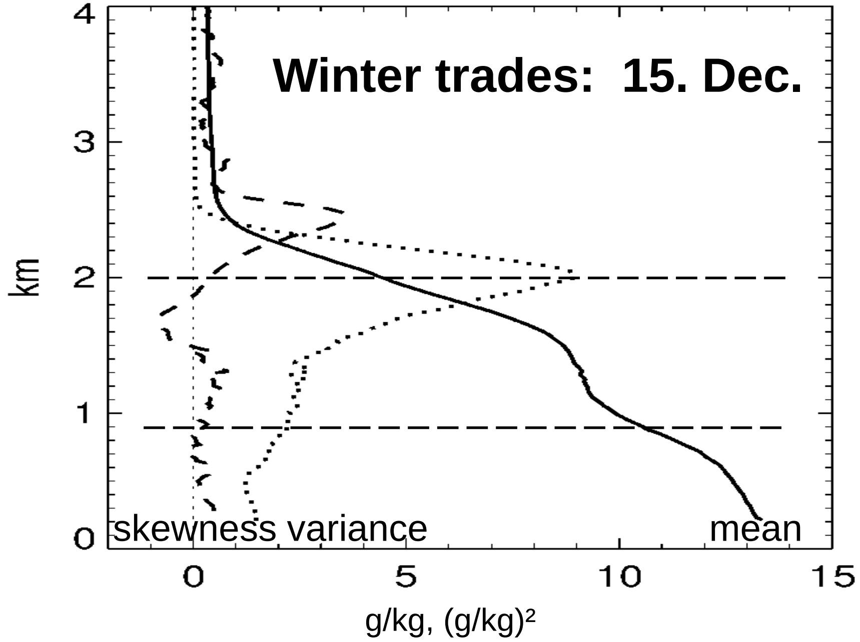
WV resolution: 2.5 km hor., 200 m vert.

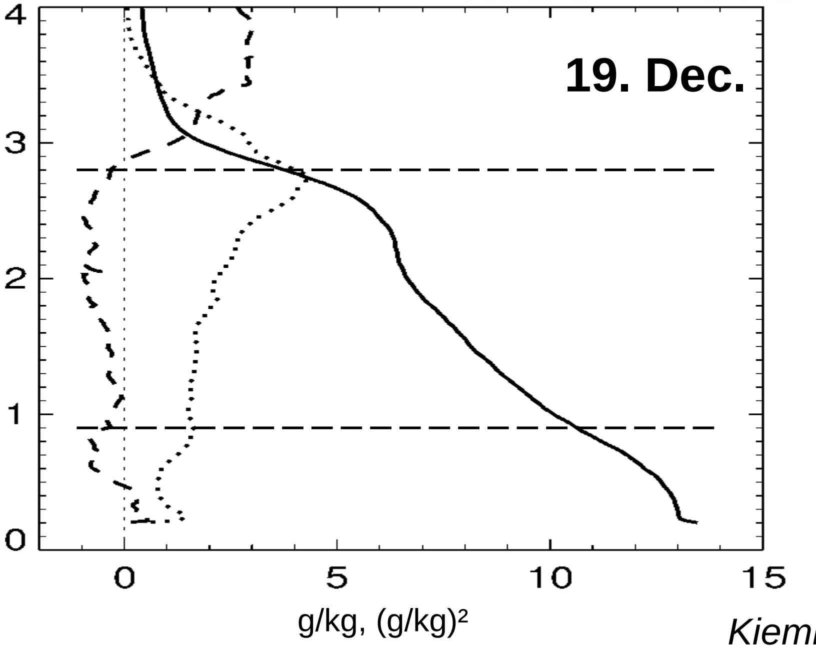


Winter trades: 15. Dec.









vertical wv column =
water vapor path (wvp) =
$\int mmr(z) \cdot \rho_{air}(z)\, dz$

air density ρ_{air} from dropsondes

Kiemle, Groß, Wirth, Bugliaro, Surv. Geophys. 2017

Tropical Winter – Summer Differences

in specific humidity profiles from dropsondes

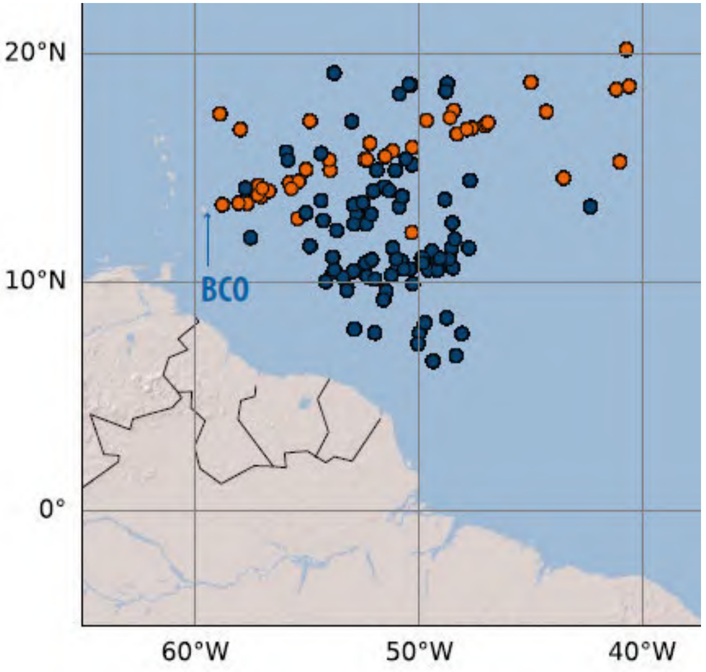
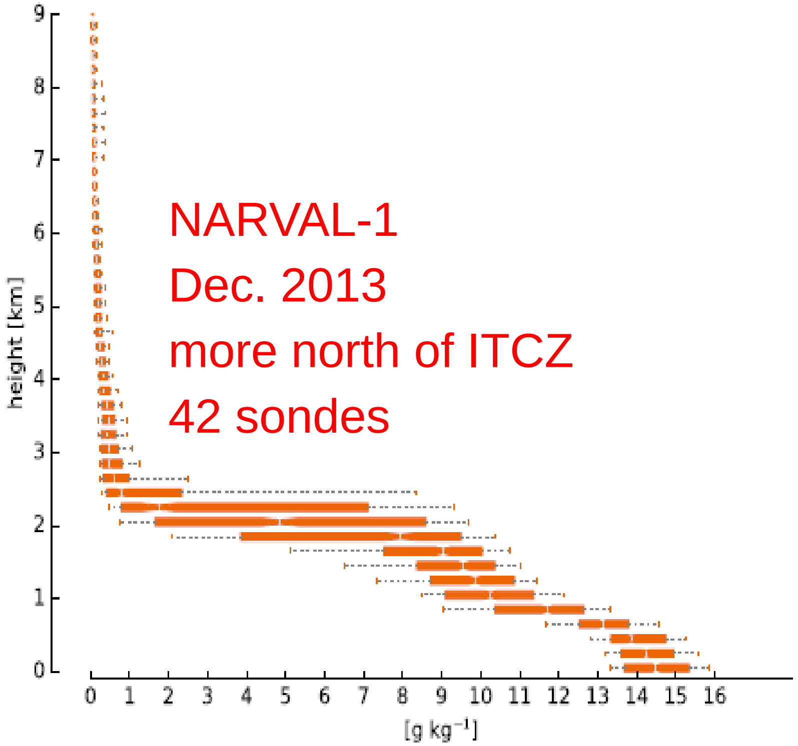
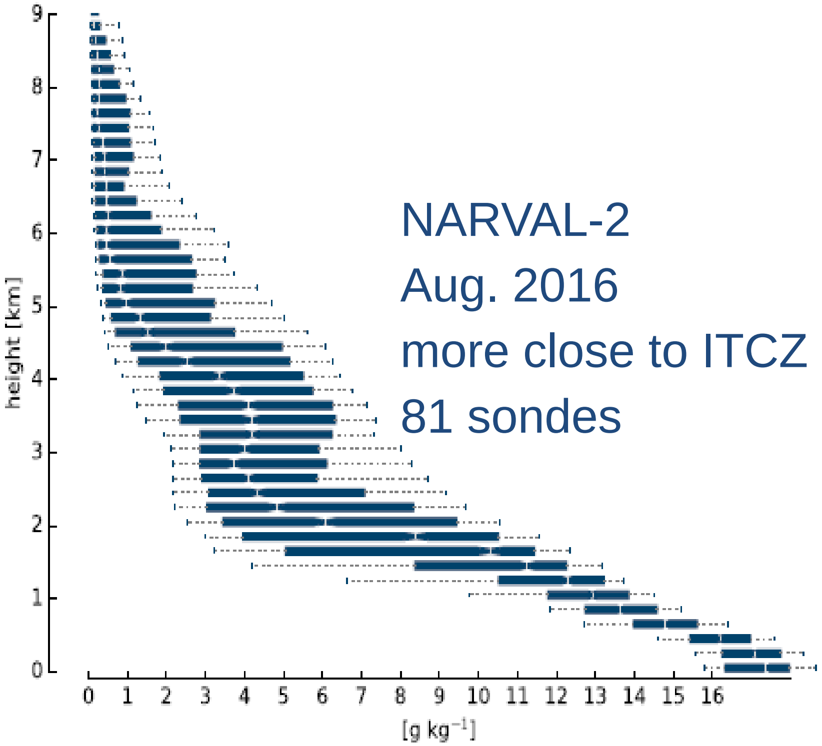


Fig. 2 Location of NARVAL-1 (orange) and NARVAL-2 (blue) sondes



NARVAL-1
Dec. 2013
more north of ITCZ
42 sondes



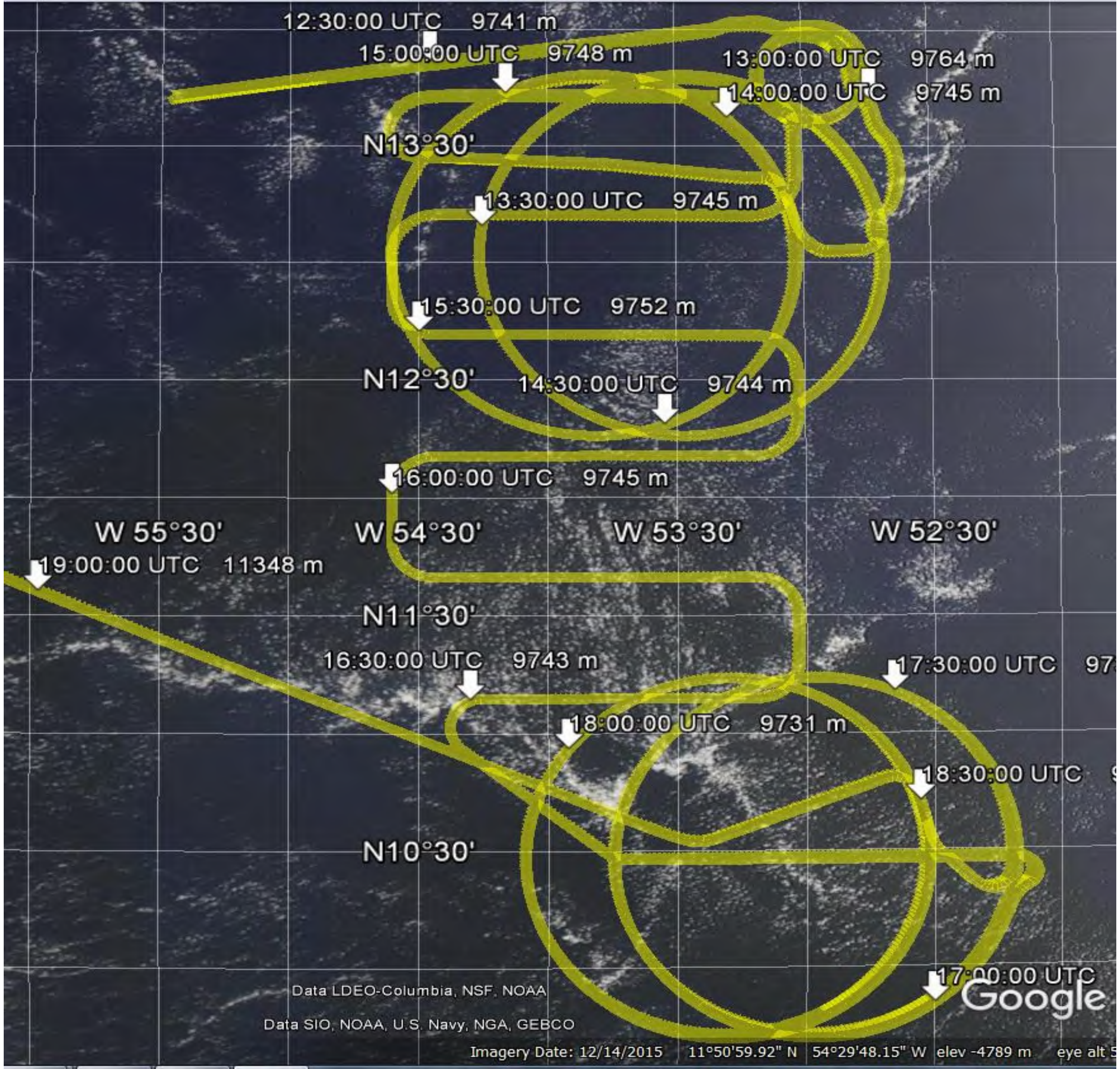
NARVAL-2
Aug. 2016
more close to ITCZ
81 sondes

Stevens, Brogniez, Kiemle, et al., Surv. Geophys. 2017

Summer Trades
12. Aug. 2016
MODIS 16:40
HALO track

Photos Bjorn Stevens

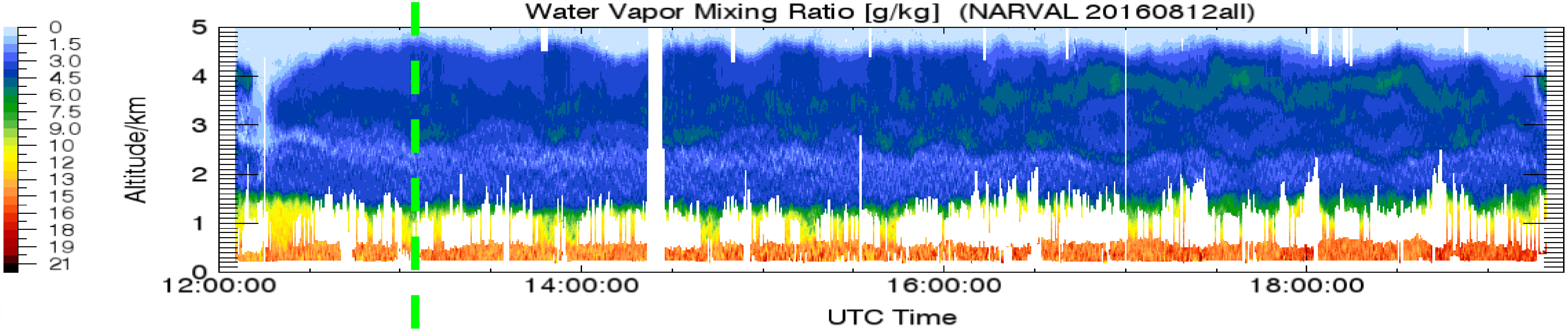
Flight report: “tenuous low clouds in a dusty atmosphere”

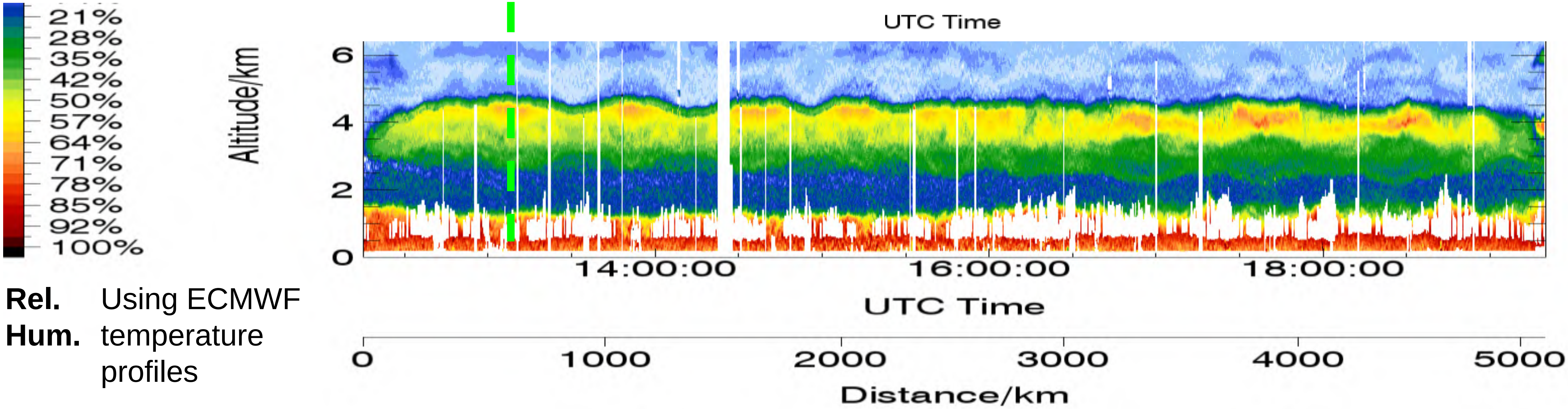


Summer Trades
12. Aug. 2016

NARVAL next-generation aircraft remote-sensing for validation studies

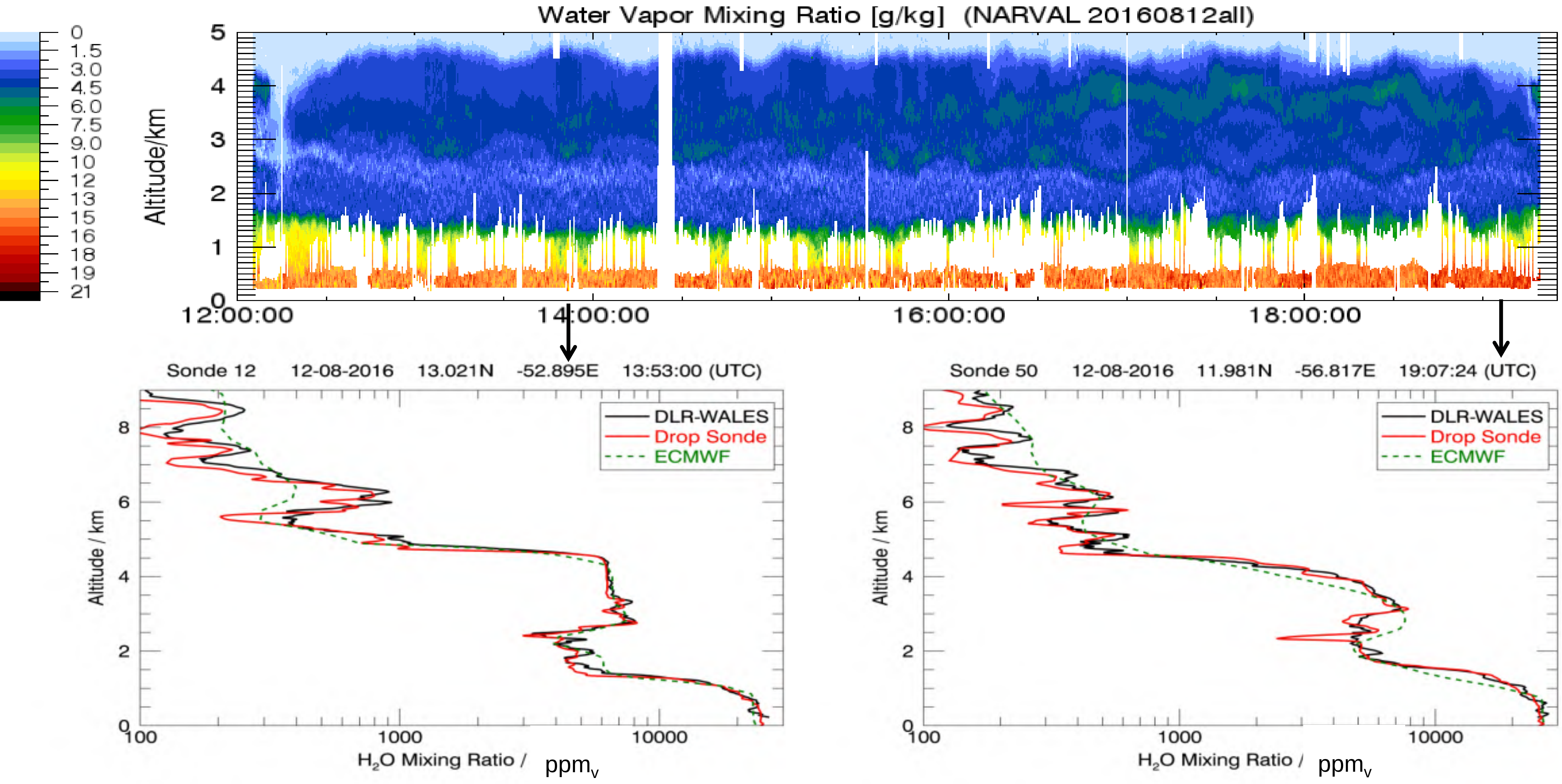
mr [g/kg]



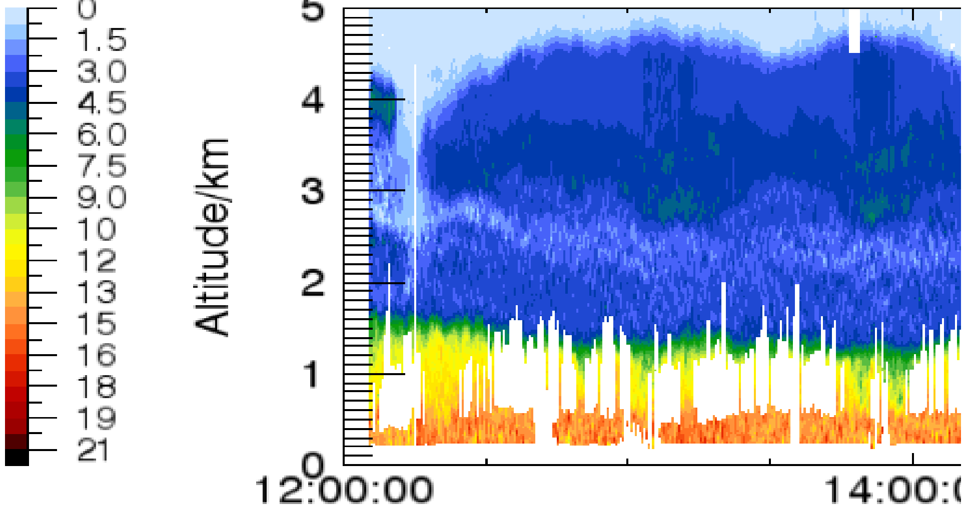


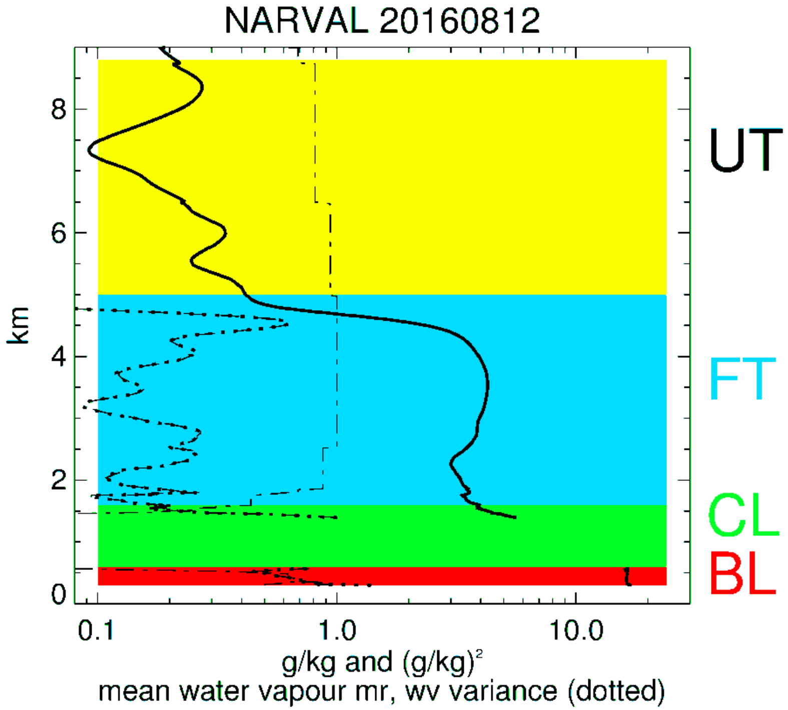
Rel. Hum. Using ECMWF temperature profiles

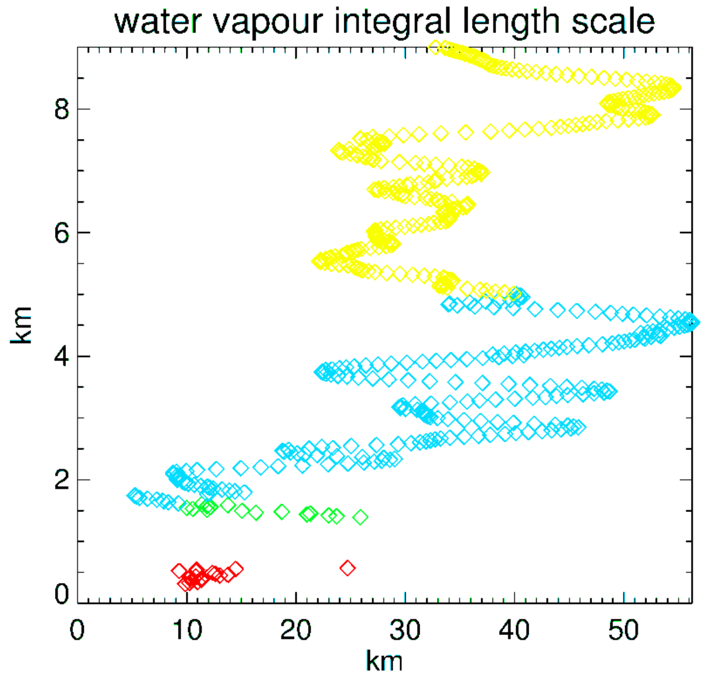
NARVAL 12 Aug. 16: WALES – Dropsonde – ECMWF Comparison



NARVAL 12 Aug. 16: WALES Spectral Analyses



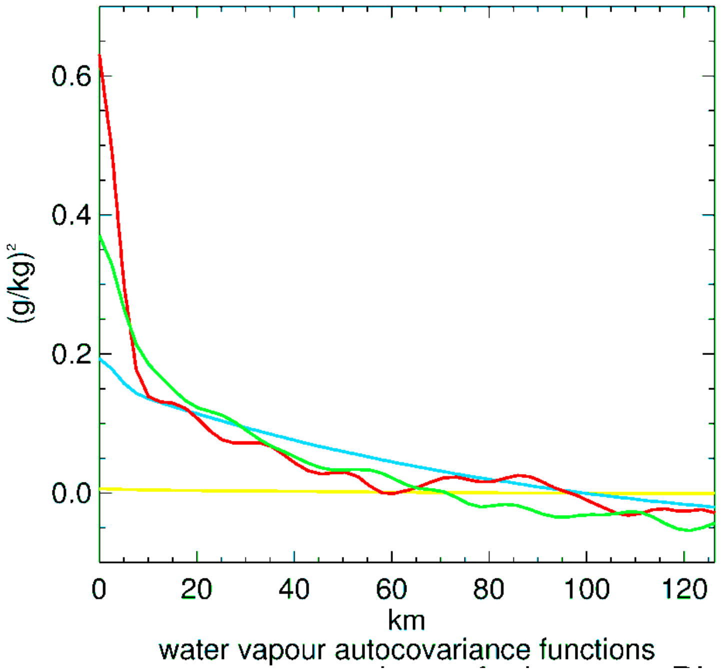


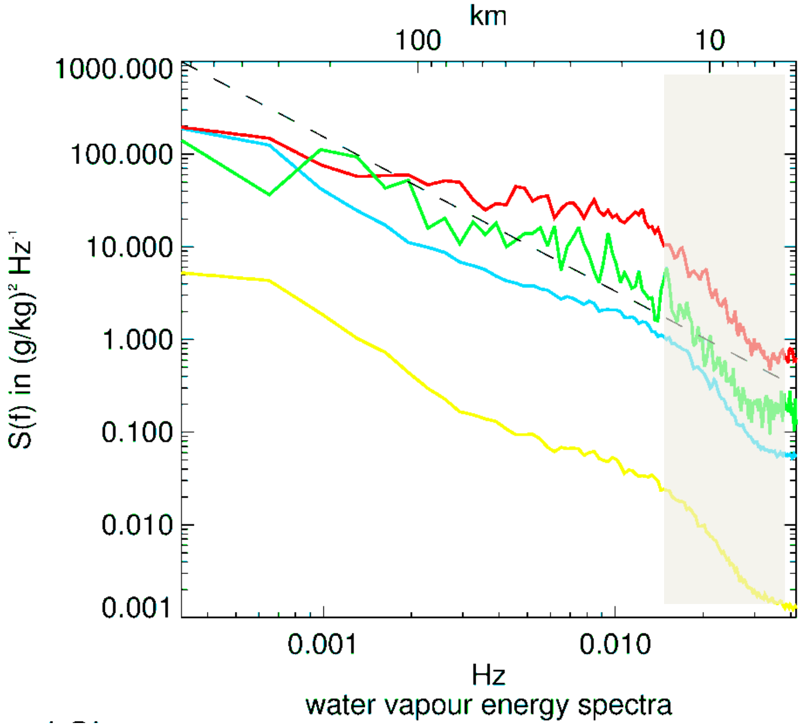


Integral length scale:
Integral of autocorrelation function
(Lenschow & Stankov, 1986)

Fourier spectra:
- across horizontal 600-km time series,
- vertically averaged to reduce noise and sampling uncertainties (4 layers),
- normalized by n/n_{good} to restore variance lost by gaps due to clouds.

(Kiemle et al., QJRMS, 2011)



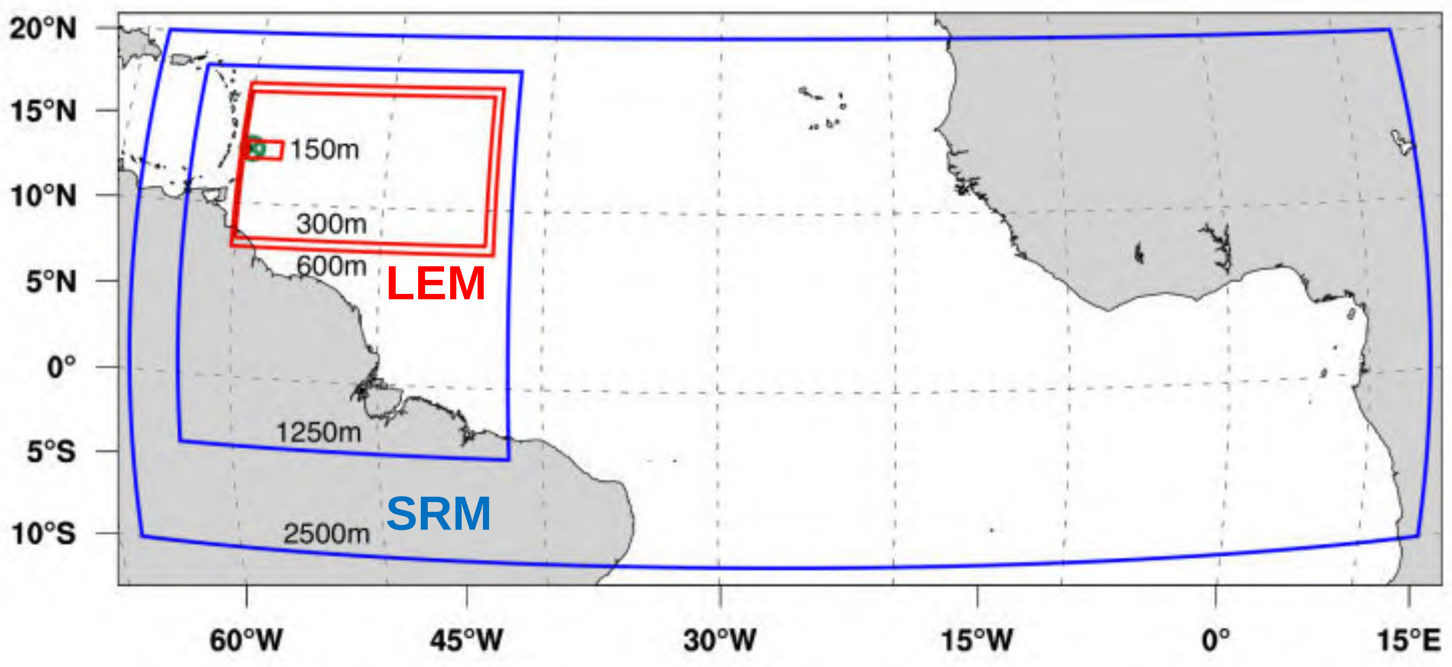


How can we compare Lidar and model results?

Max-Planck-Institut für Meteorologie

1. Use average profiles across the domain: mean, variance, …
2. Use correlation functions, spectra, …
3. **Sort all wv profiles from driest to wettest into „moisture space“**

ICON model domains

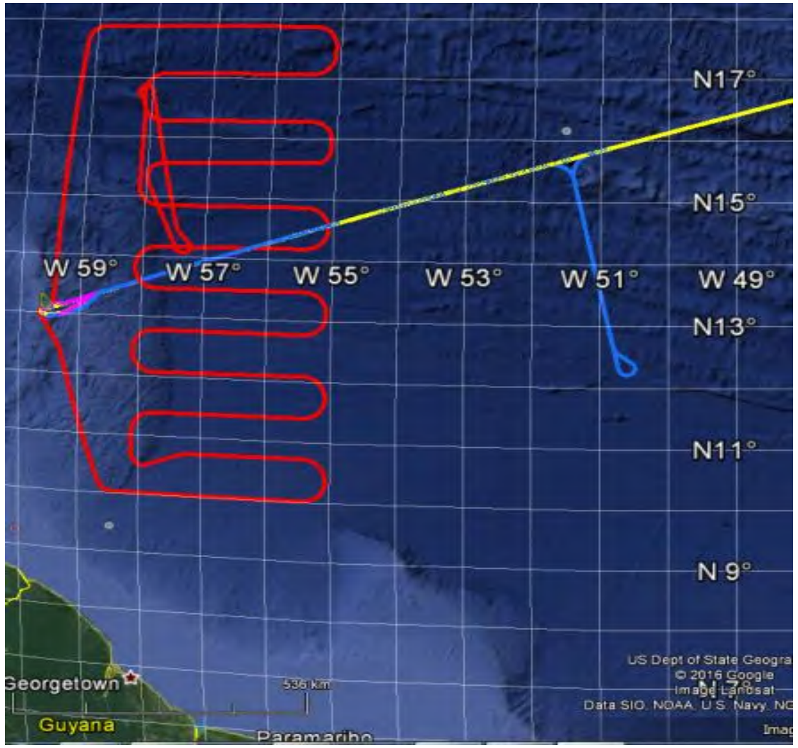


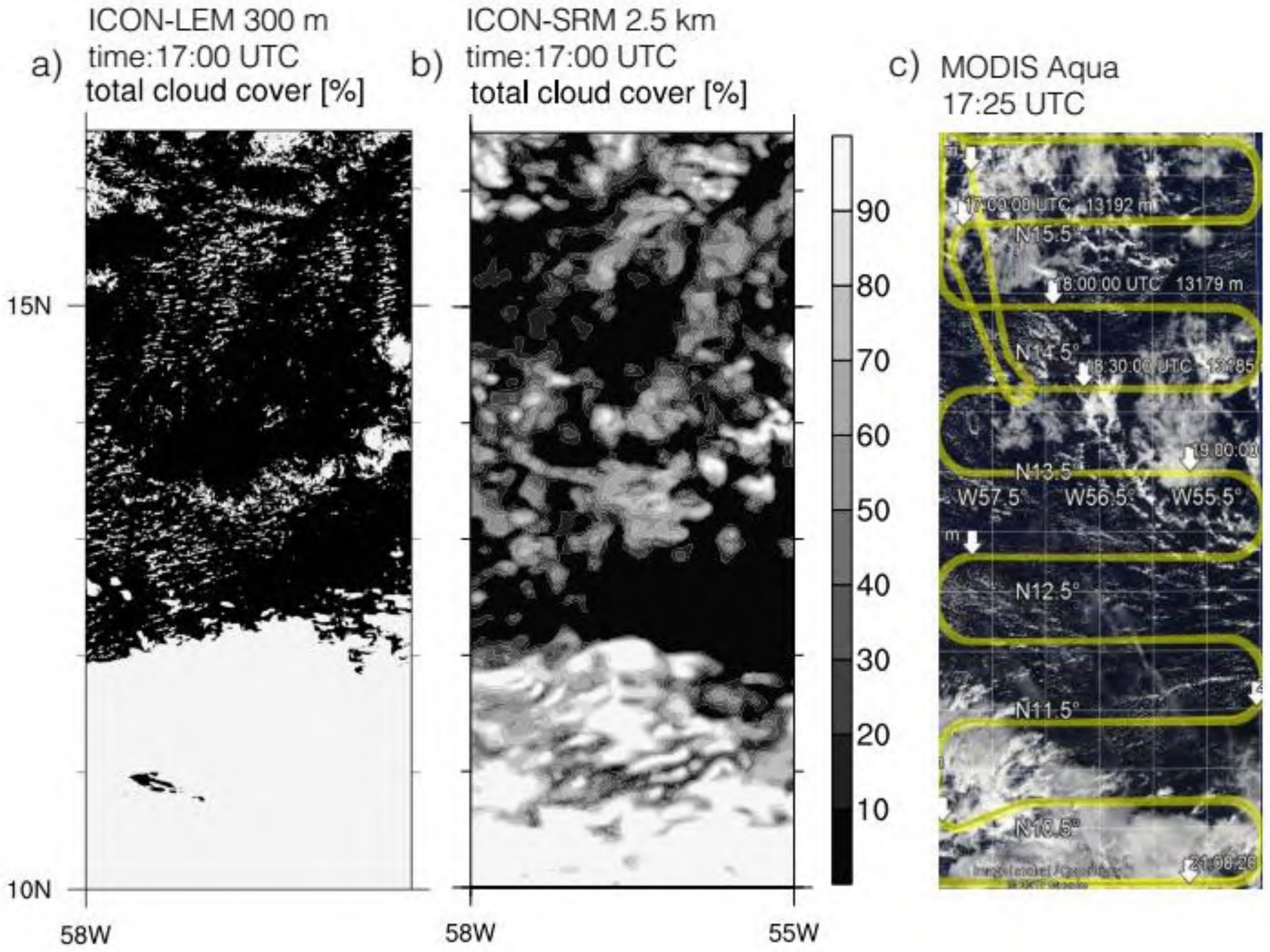
- all simulations without convective parameterization
- initial + boundary conditions: ECMWF reanalyses
- one-way nesting of higher resolution in low resolution simulations

Ann Kristin Naumann, Matthias Brück, Daniel Klocke,
MPI for Meteorology, Hamburg

How can we compare Lidar and model results?

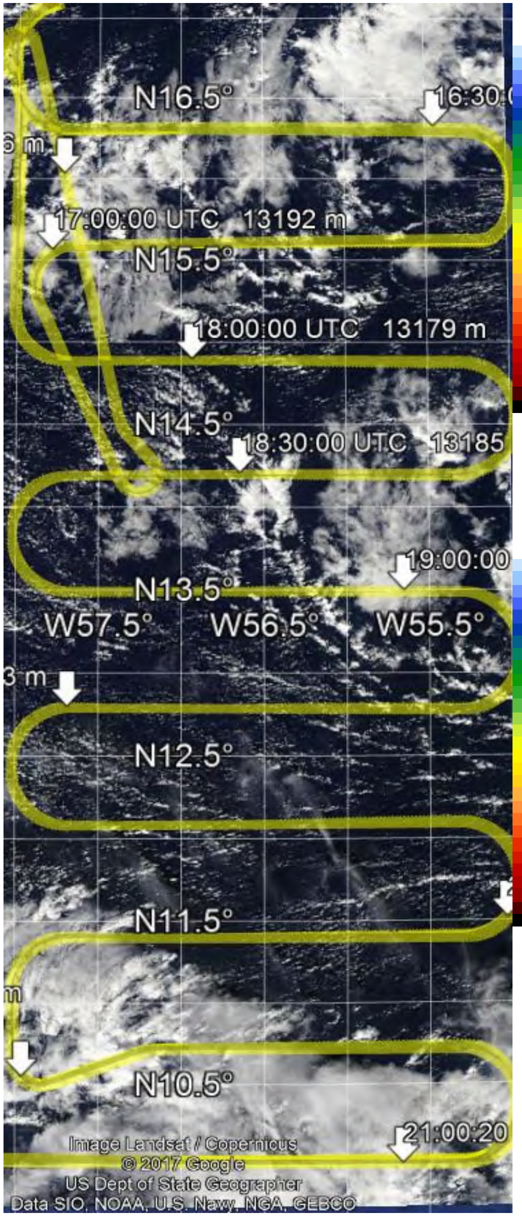
NARVAL1 HALO flight, 11. 12. 2013

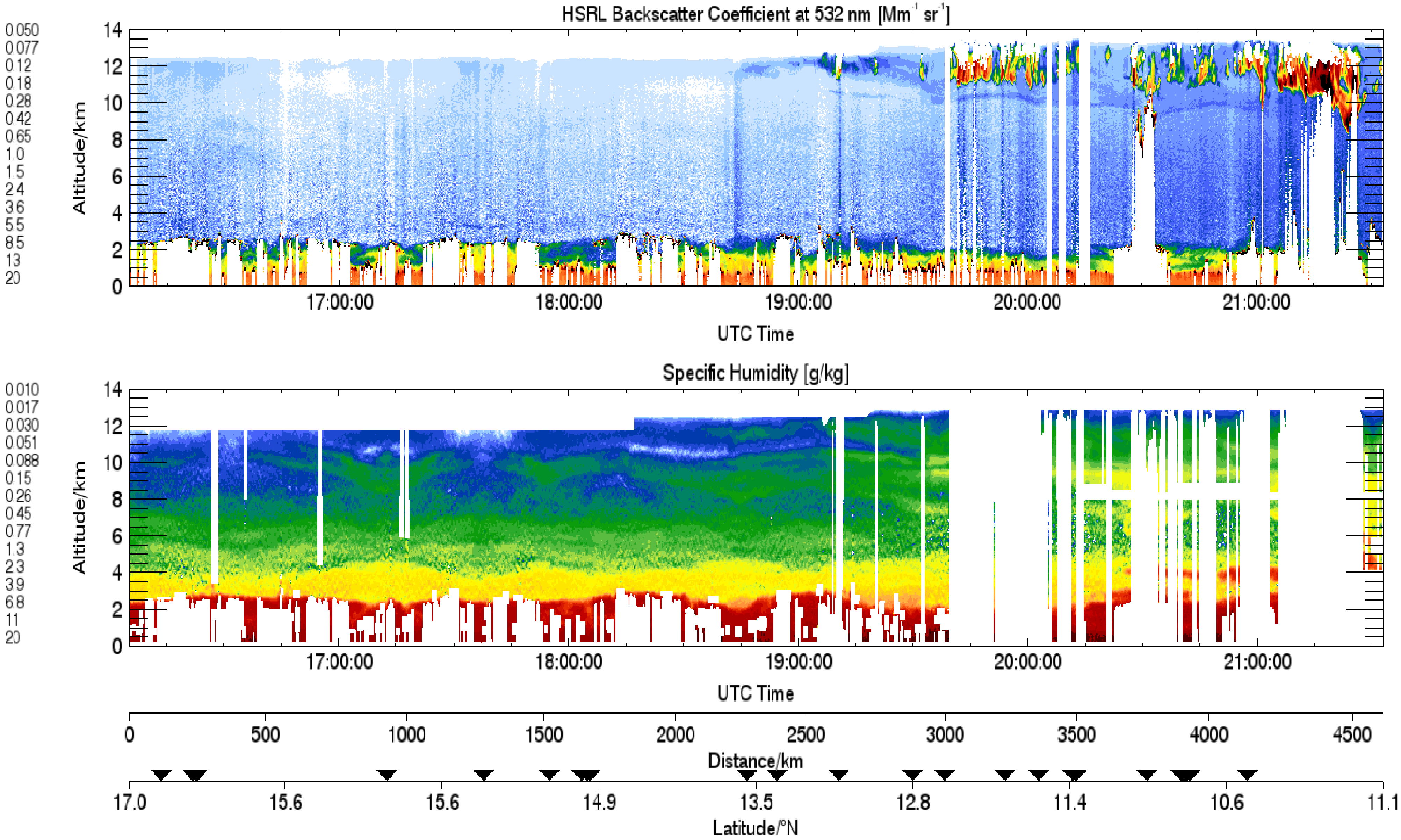




11.12.13.: From the Trades into the ITCZ

MODIS 17:25 UT





How can we compare Lidar and model results?

Sort all wv profiles from driest to wettest into „moisture space“

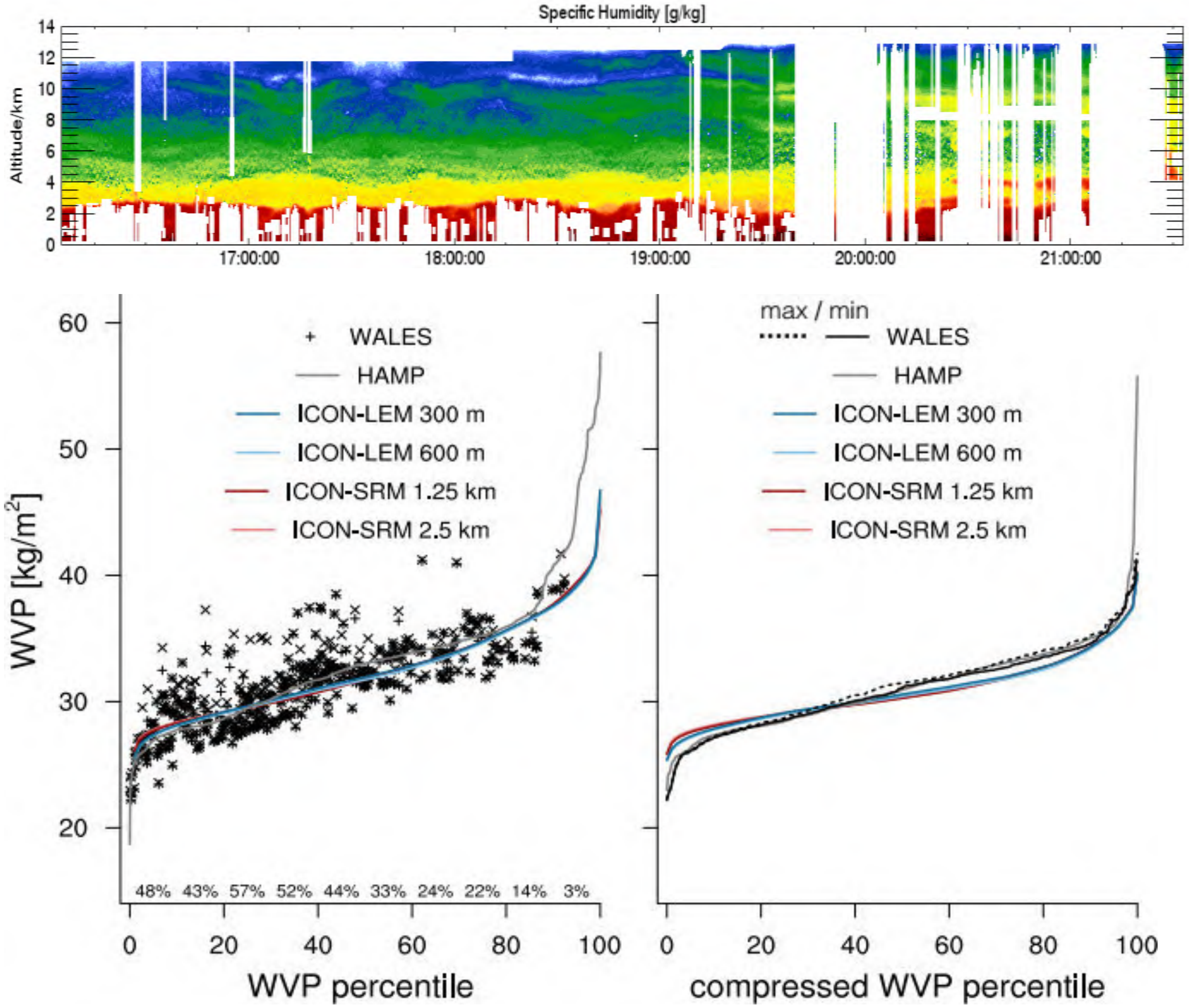
Issue 1: Lidar misses 50 % of profiles, and even more at the moist end of the cumulative wvp distribution.

Issue 2: does ICON perform well?

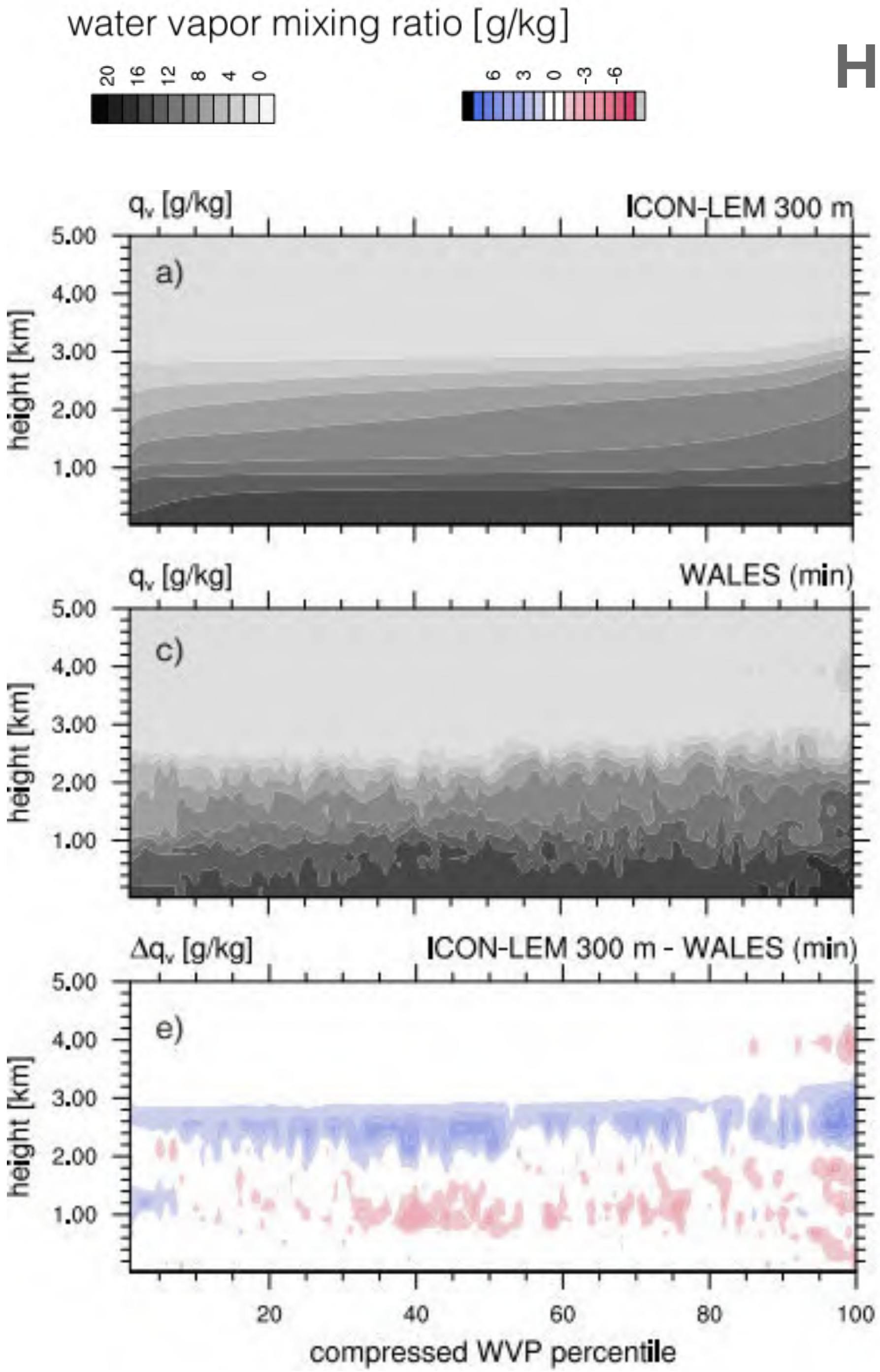
Solution: use the collocated HALO **HAMP radiometer wvp** data to span up the full moisture space.

Then: tailor the ICON wvp distribution to match the Lidar wvp range.

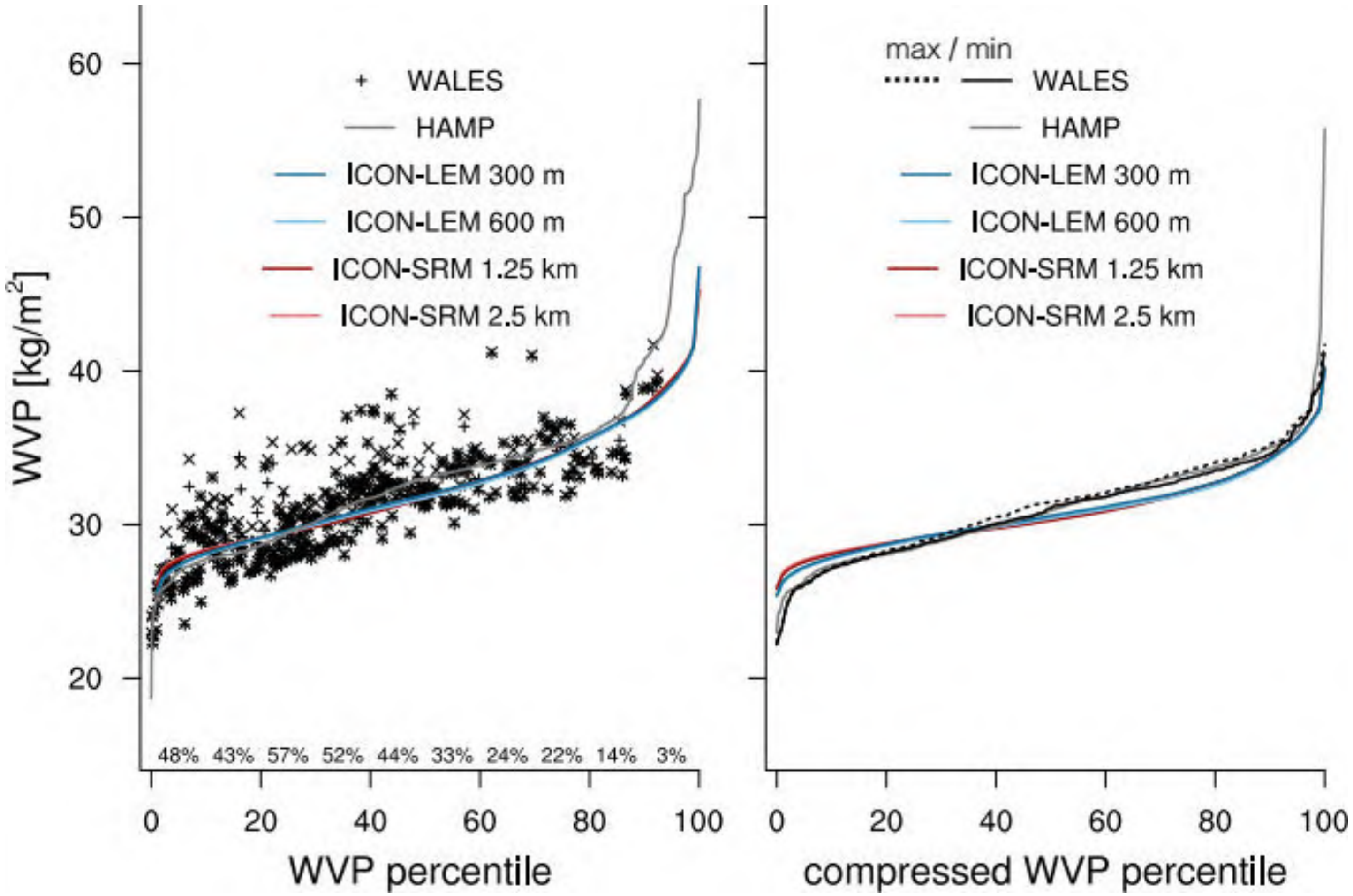
Radiometer data from Marek Jacob, IGM, Univ. Köln



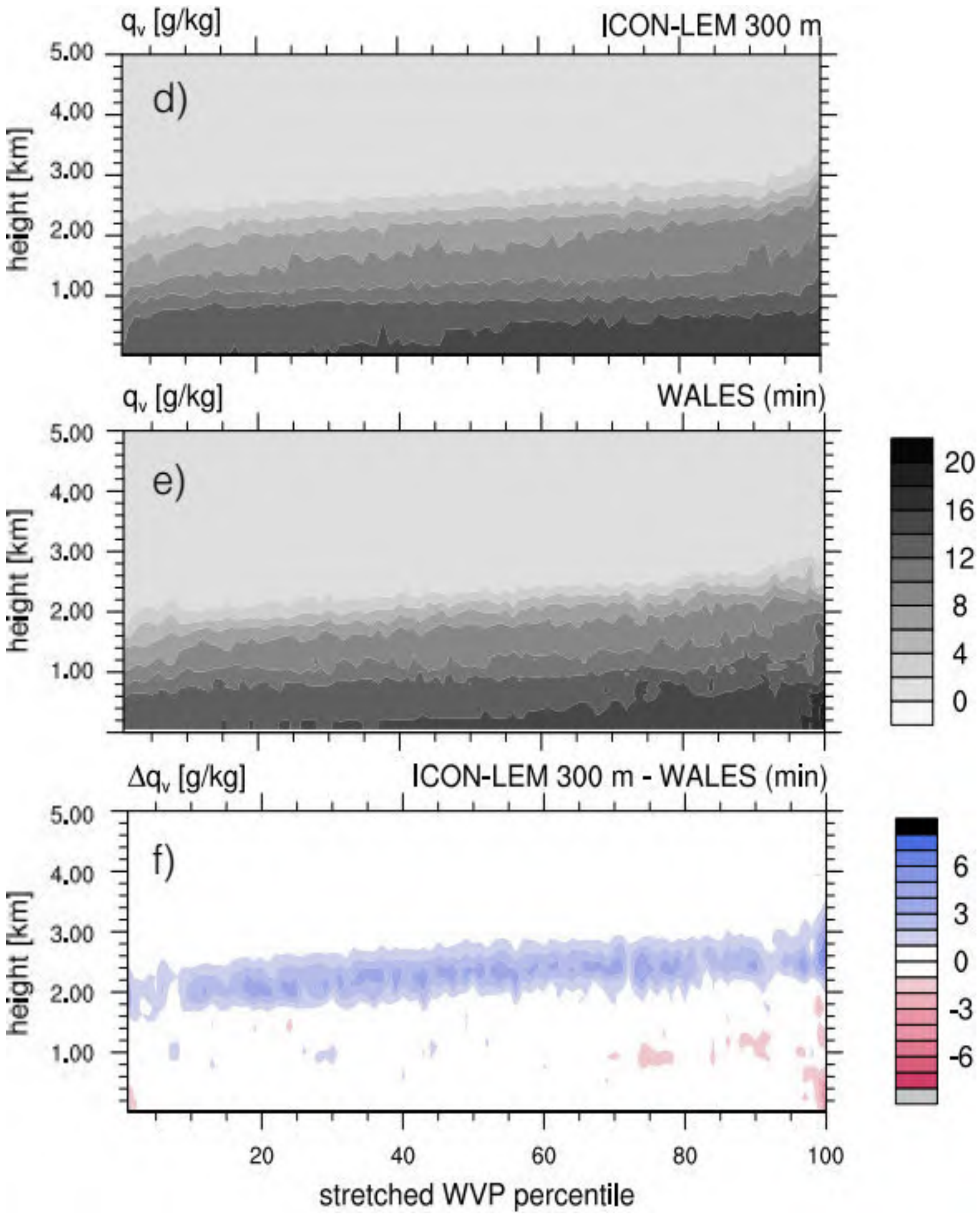
How can we compare Lidar and model results?



Sort all wv profiles from driest to wettest into „moisture space“

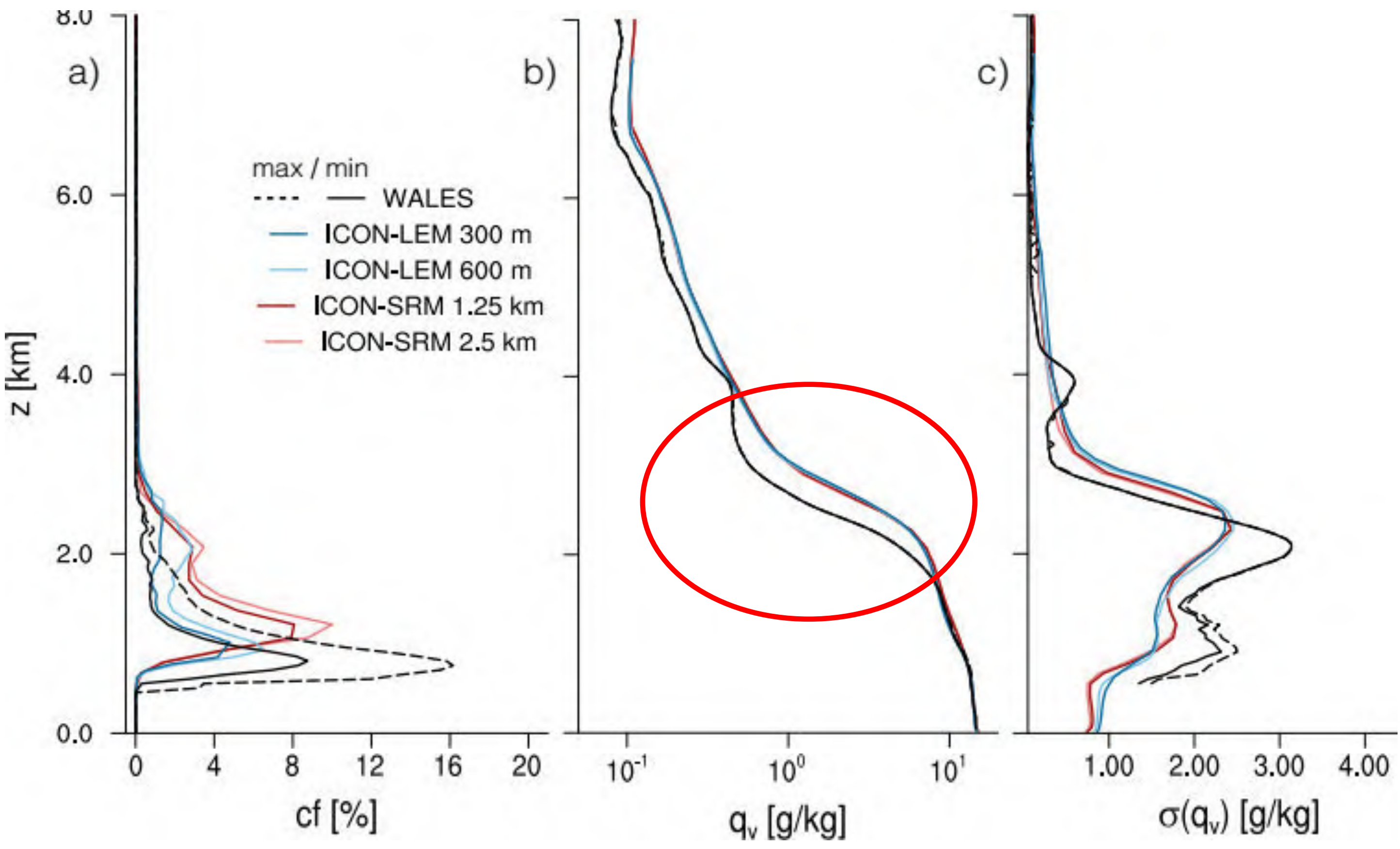


3 flights together: 11., 12., 15. Dec 2013

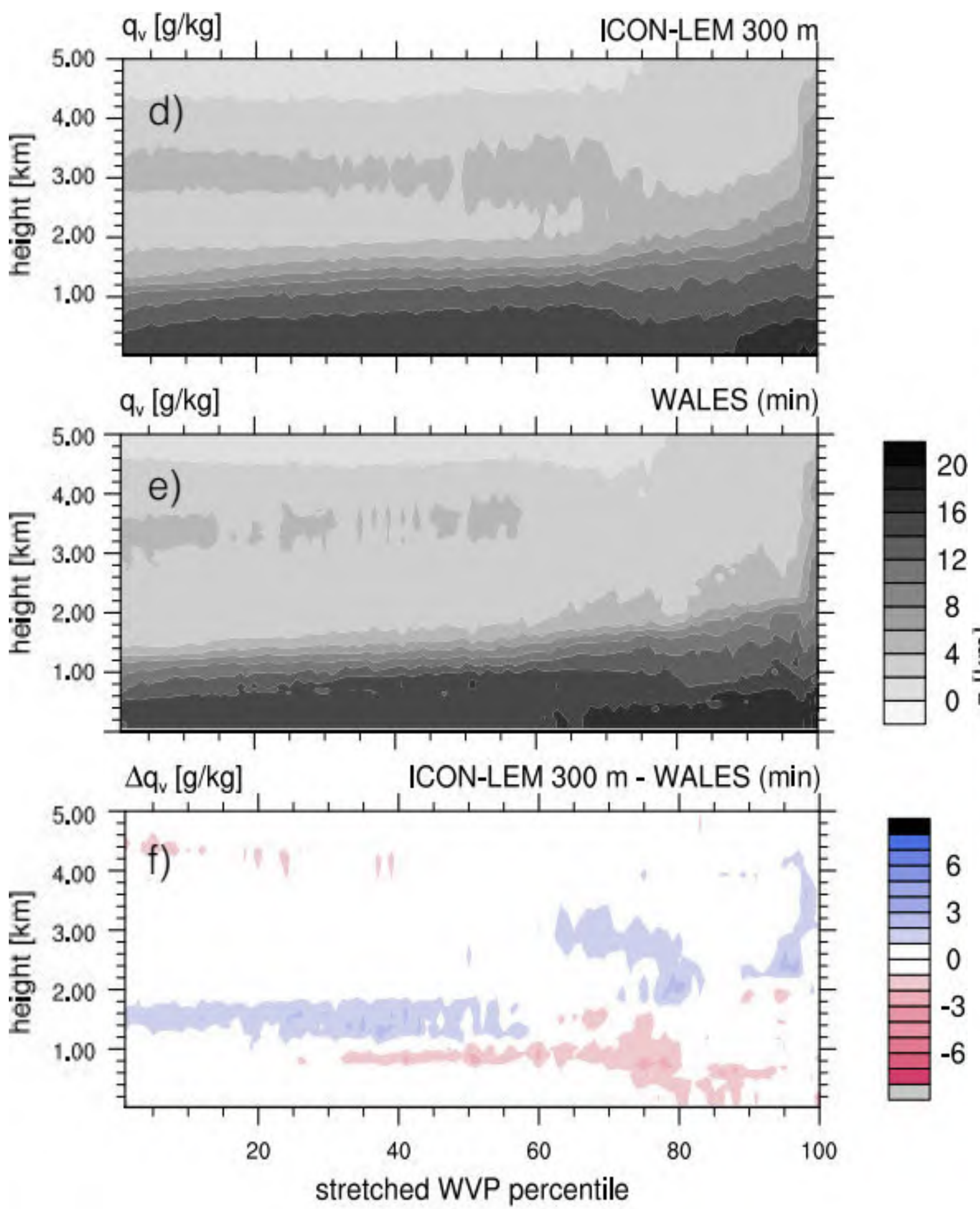


average profiles across the domain:

cloud fraction **mean wv** **stddev (wv)**

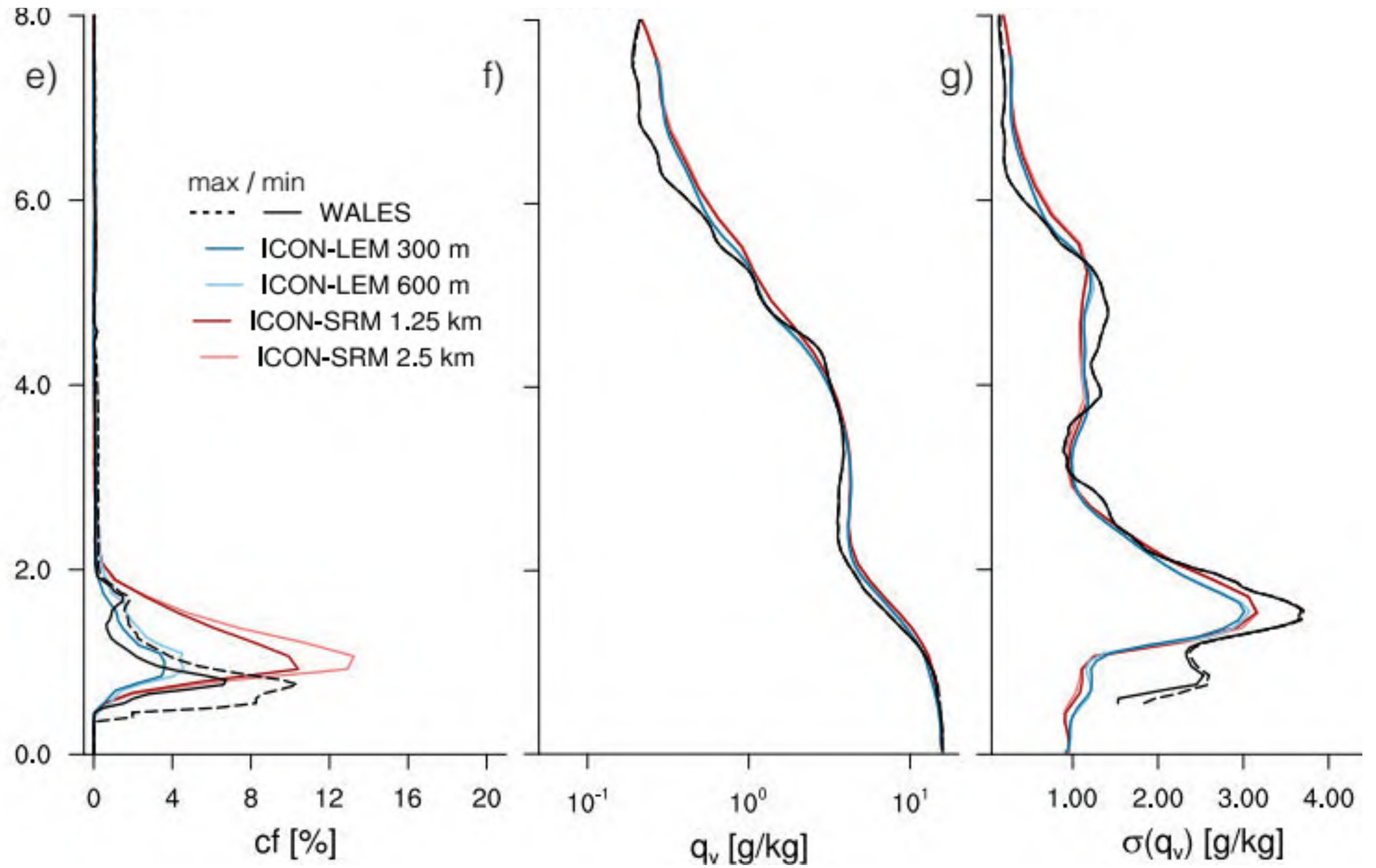


3 flights together: 12., 19., 24. Aug. 2016



average profiles across the domain:

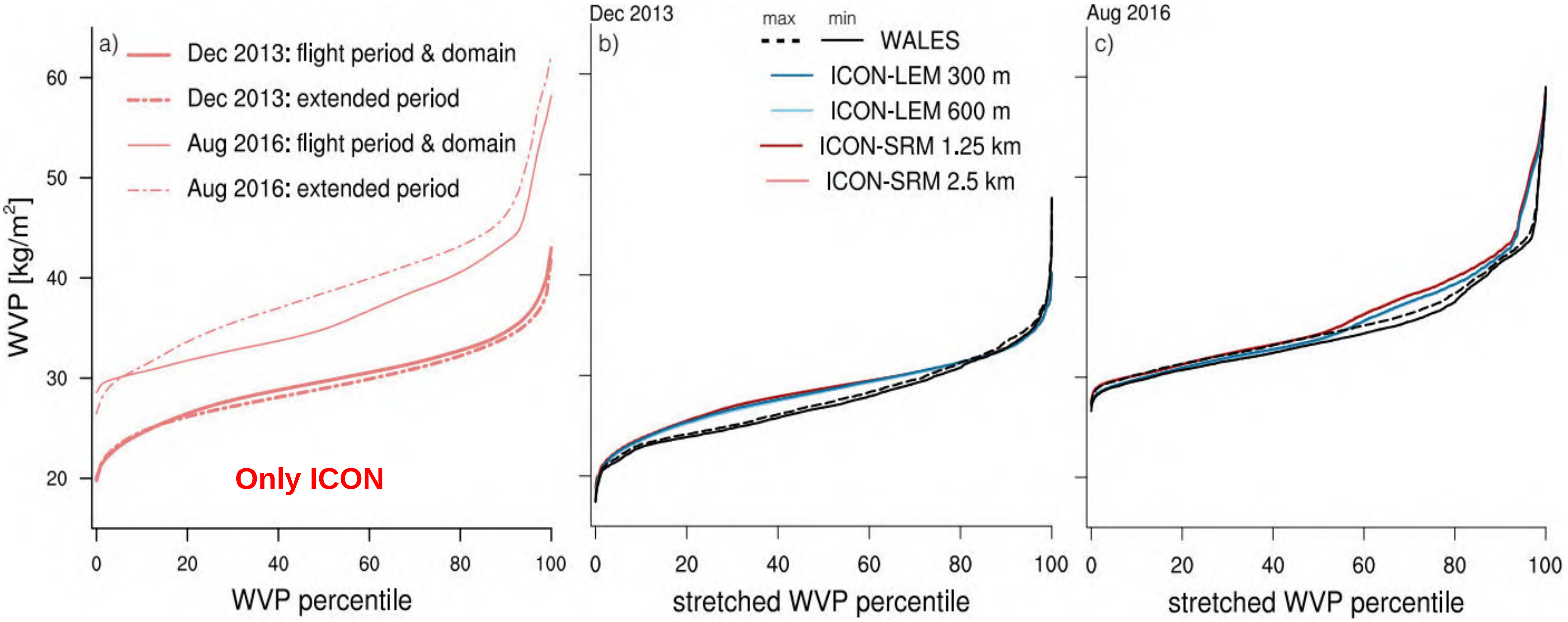
cloud fraction **mean wv** **stddev (wv)**



Are the cases representative?

3 flights in Dec 2013

3 flights in Aug 2016



Conclusions and Outlook

- Airborne lidar profiles in the Trades can quantify the humidity variability.
- Lidar sees wv gradients, dry layers, and profiles in between clouds.
- ICON shows a good skill in reproducing the lidar wv path. Comparisons with lidar profiles show a moist model bias near the cloud layer top.
- An additional wind lidar would be nice to quantify wv fluxes & transport.
- Our last proposal for an ESA Earth Explorer Water Vapor Lidar Mission was not yet successful, despite a very high scientific ranking.
- EUREC^{4}A experiment 2020: cloud – wv – radiation – circulation coupling