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 shallow convection.

Cloud layer humidity determines dilution of clouds by entrainment

**Vertical profile of water vapor determines radiative cooling** (e.g. Muller and Bony, 2015)
Water Vapour Lidar Experiment in Space: Airborne Demonstrator on board HALO

- 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$_2$O absorption line selection:

max. height 15 km
max. range 9000 km
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

Latent heat flux profile

Kiemle et al., JTech 2007
Tropical HALO Flights:
North Atlantic, East of Barbados

Dec. 2013 Winter Trades
Aug. 2016 Summer Trades
Jan. 2020 EUREC4A

NARVAL1 flights, Dec. 2013:
Local flights to the East of Barbados with A-train underflights

Transfer flights from/to Germany
NARVAL-1

12. Dec. 13

MODIS 16:30

HALO track
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.

2h-15m/s=108 km

Water Vapour Column

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

air density \( \rho_{\text{air}} \) from dropsondes

Kiemle, Groß, Wirth, Bugliaro, Surv. Geophys. 2017
Tropical Winter – Summer Differences

in specific humidity profiles from dropsondes

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

Using ECMWF temperature profiles

ISTP 11, Toulouse > Airborne Lidar Observations of Water Vapor in the Tropics • Kiemle > 20.05.2019

Water Vapor Mixing Ratio [g/kg] (NARVAL 20160812all)

mr [g/kg]

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

Water Vapor Mixing Ratio [g/kg] (NARVAL 20160812all)

Altitude/km

12:00:00 14:00:00 16:00:00 18:00:00

H₂O Mixing Ratio / ppmv

Sonde 12  12-08-2016  13.021N  -52.895E  13:53:00 (UTC)

Sonde 50  12-08-2016  11.981N  -56.817E  19:07:24 (UTC)

DLR-WALES  Drop Sonde  ECMWF
**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?

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

HSRL Backscatter Coefficient at 532 nm [Mm⁻¹ sr⁻¹]

Specific Humidity [g/kg]
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"

average profiles across the domain:

- cloud fraction
- mean wv
- stddev (wv)

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

Only ICON
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.