Assimilation of DIAL water vapour observations into the ECMWF global model

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DIAL: high precision and high spatial resolution **water vapour observations**

Assess and demonstrate **impact of lidar instruments on NWP**

The airborne water vapor differential absorption lidar (DIAL) WALES:

- uses four-wavelength/three-absorption line measurement scheme in the 935 nm water vapour absorption band
- no calibration of system
- no system constants need to be specified
- high accuracy measurements (error ~ 5-7 %)
- DIAL equation:

$$n \approx \frac{1}{2\Delta\sigma \cdot \Delta R} ln(\frac{P_{off}(r+\Delta R/2) \cdot P_{on}(r-\Delta R/2)}{P_{on}(r+\Delta R/2) \cdot P_{off}(r-\Delta R/2)})$$

- resolution: vertical ~300 m, horizontal ~ 30 s (4 - 7 km)

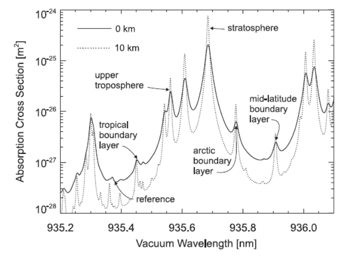
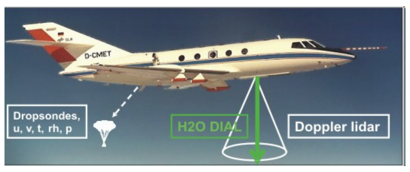
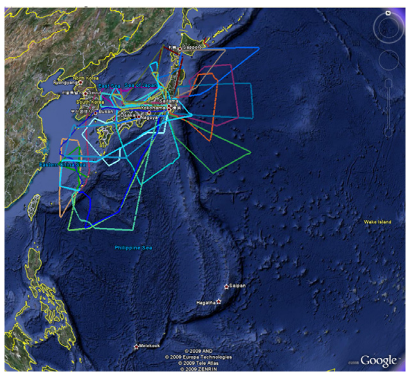


Fig. 1 H2O-absorption lines used for the WALES demonstrator. Absorption cross section data calculated from HITRAN 2006 [8] for sea level conditions (*solid line*) and at 10 km altitude (*dashed line*) using the US-standard atmosphere. Possible wavelengths of operation are indicated by *arrows*, where the current system is able to use four at a time.
From Wirth et al 2009

The THORPEX-Pacific Asian Regional (T-PARC) campaign 2008



Measurement equipment of the DLR Falcon:
- Dropsonde system (u, v , T, rh, p)
- 2 µm Doppler wind lidar
- four-wavelength water vapour DIAL



DLR Falcon objectives:
- typhoon targeting
- extratropical transition of tropical cylcones
- lidar observations for NWP

DLR Falcon operations
23 August - 3 October 2008 in Japan
25 research flights, 93 flight hours in total

DLR Falcon funding institutions
DLR (Germany), NSF (USA), JMA (Japan)
Forschungszentrum Karlsruhe (Germany),
NIMR (Korea), Environment Canada, EUCOS

The assimilation input variable precipitable water content (PWC)

- observations are assimilated as water content layer observations in kg m^{-2}
- observation operator **H** available from the SBUV (solar backscattering UV) instrument
- number density of water molecules N_w (m^{-3}) → absolute humidity M_w (kg m^{-3}):

$$M_w(z) = N_w(z) \cdot \frac{m^*_{H_2O}}{N_A} \cdot 10^{-3} \qquad m^*_{H_2O} = 18.015\,\mathrm{g\,mol^{-1}} \quad N_A = 6.022 \cdot 10^{23}\,\mathrm{mol^{-1}}$$

- the variable of PWC is the absolute humidity multiplied by a vertical thickness:

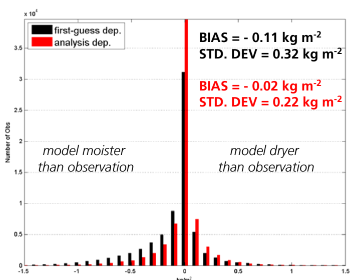
$$PWC(z) = M_w(z) \cdot \Delta z$$

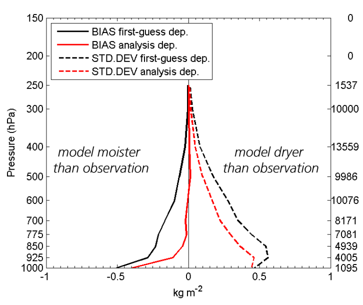
- vertical thickness is distance between model levels (~250 m in the lower troposphere and ~ 425 m in the upper troposphere

The operational ECMWF model and assimilation system

- spectral resolution of T799 and 91 vertical levels
- 4D-variational data assimilation system with a 12-hourly assimilation window and an incremental formulation for the minimisation process: nonlinear 'outer loop' update (T799 with 91 levels) and linearised 'inner loop' minimisation (three runs: T95, T159 and T255 with 91 levels)

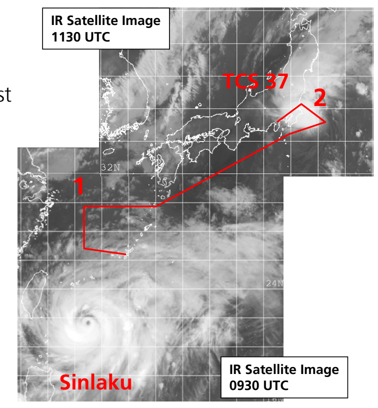
Assimilation statistics of PWC data for the T-PARC period





Example case 11 September 2008:

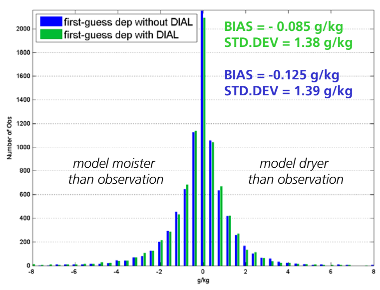
- flight track North of Typhoon Sinlaku
- water vapour transport towards the Northeast
- TCS 37 shows a thick layer of moist air
- large scale structure of the observations are also evident in the model first-guess
- differences in smaller scale structures
- broad areas where the observations have less PWC than the model first-guess
- information content is used successfully
- small scale features can not be resolved in the current 4D-Var data assimilation system

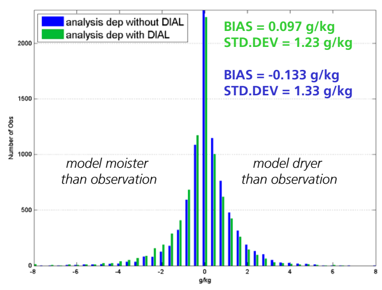


source of satellite images:
https://www.fnmoc.navy.mil/tcweb/cgi-bin/tc_home.cgi/

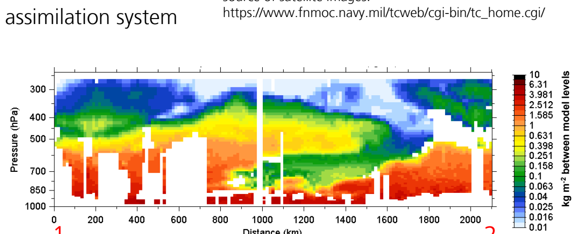
Departure statistics of passive dropsonde data

- difference between dropsonde specific humidity and model first-guess and analysis with and without assimilated PWC observations

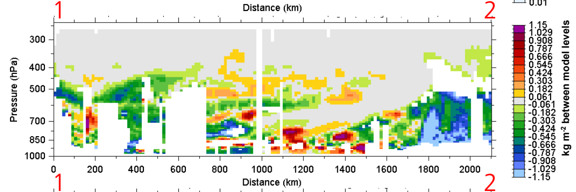




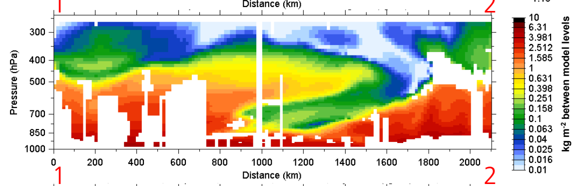
observation PWC



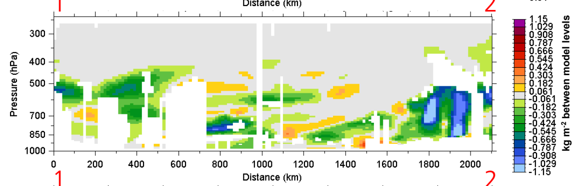
first-guess departure = observation PWC - model first-guess PWC



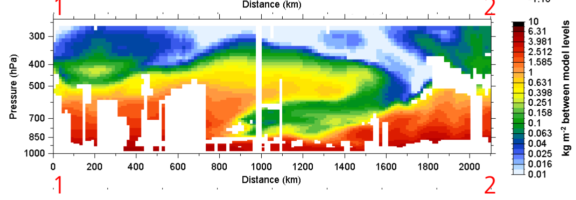
model **first-guess** PWC



analysis **increments** PWC (first-guess + analysis incr = analysis)



model **analysis** PWC



Verification of the model analysis with passive dropsonde data

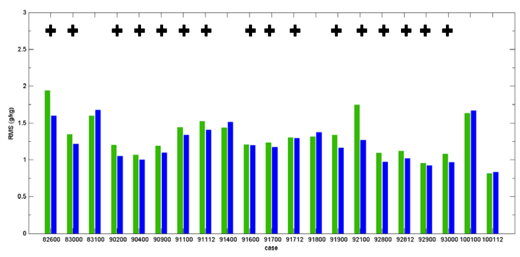
- definition of dropsonde specific humidity (q) as pseudo-truth

$$dq = q_{dropsonde} - q_{analysis}$$

$$RMS = \sqrt{(\overline{dq})^2 + \sigma^2_{(dq)}}$$

Analysis with DIAL

Analysis without DIAL



References:
- Wirth, M., A. Fix, P. Mahnke, H. Schwarzer, F. Schrandt, and G. Ehret, 2009: The airborne multi-wavelength water vapor differential absorption lidar WALES: system design and performance. *Appl. Phys. B*, **96**, 201-213.

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