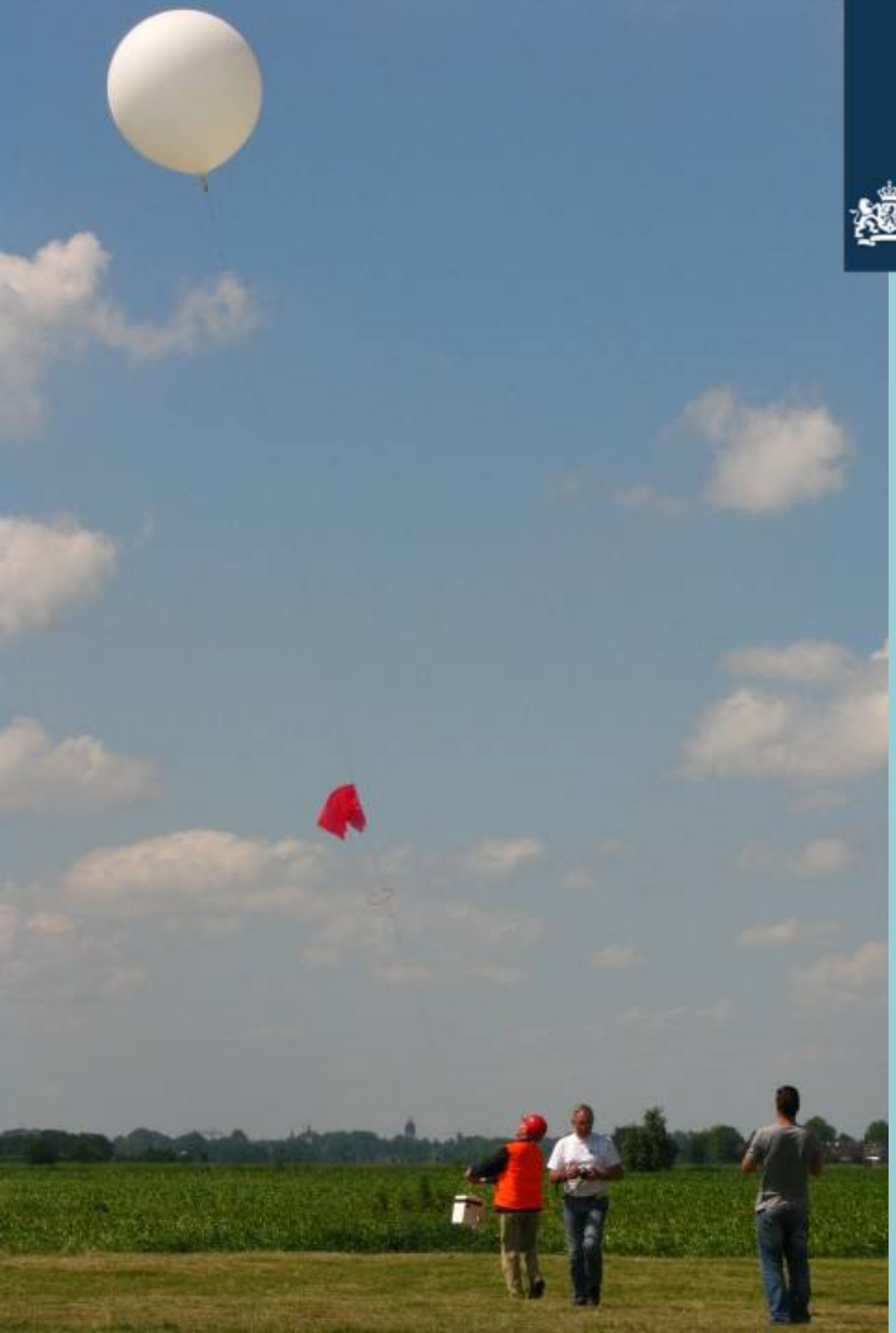


Royal Netherlands Meteorological Institute
Ministry of Infrastructure and Environment

Measuring vertical profiles of ozone and NO_2

Ankie Piters and Marc Allaart
KNMI

Atmospheric Composition Research

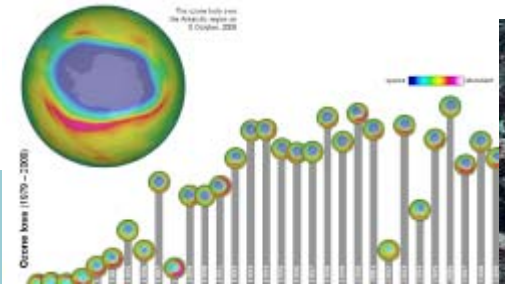
Main Scientific Themes: ozone layer, air quality, and chemistry-climate interaction
Division: 76 people (of which ~40 on OMI/TROPOMI - PI)

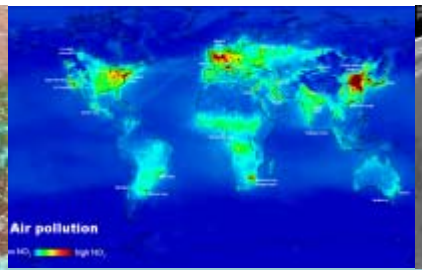
Observation group:

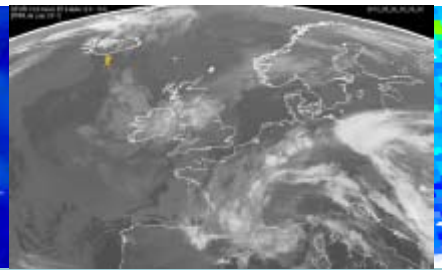
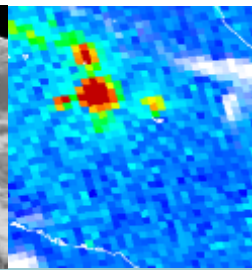
- Satellite observations: retrieval, validation and distribution of data. OMI, TROPOMI/S5p, GOME, SCIAMACHY, GOME-2, SEVIRI.
- Main products: O_3, NO_2, aerosols, clouds
- Ground-based measurements important for satellite and model validation

Modelling group:

- Coupling TM5 to EC Earth , focus: aerosols and non-CO2 GHG
- Air quality forecasts
- Data assimilation





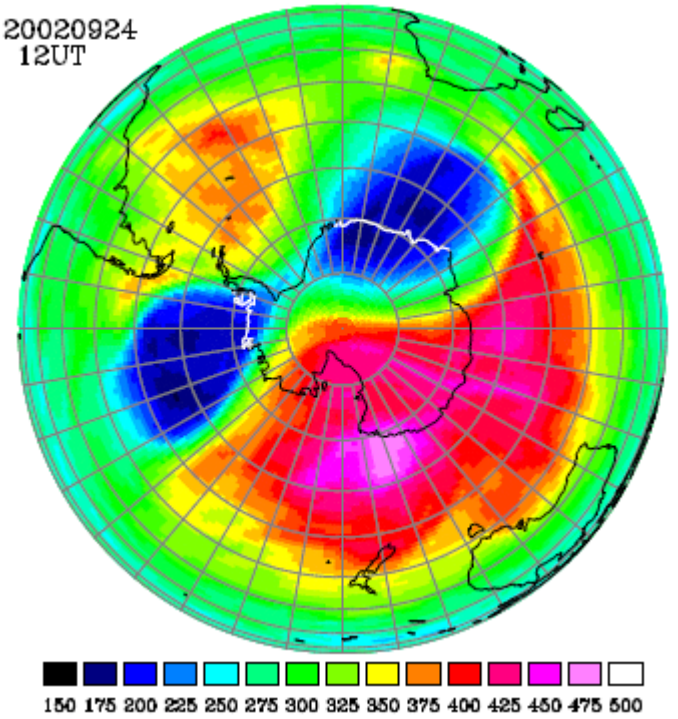
Integrated approach for optimal climate products

Long-term ozone data set: Multi Sensor Reanalysis (van der A et al, ACP, 2010)

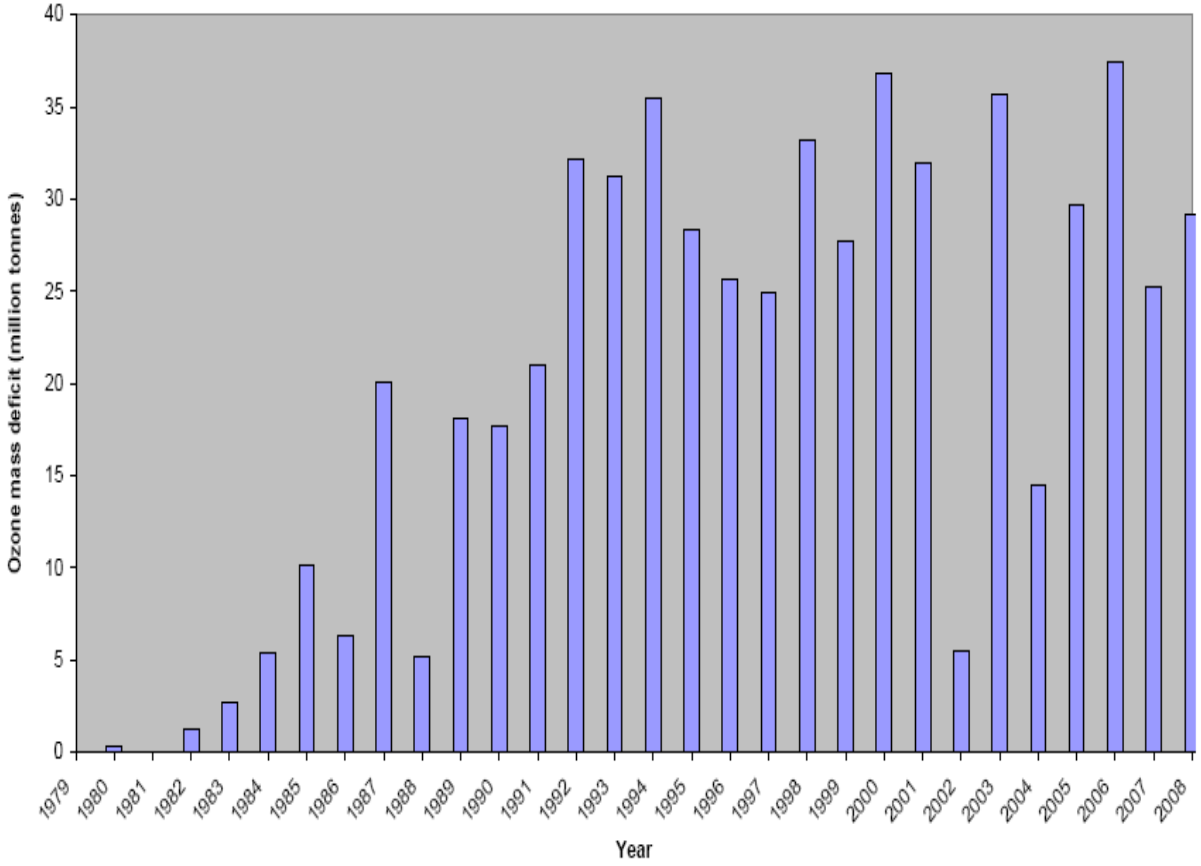
- 30 years of ozone satellite data 1978 – 2008
- bias corrected against ground-based Brewer/Dobson network, bias is allowed to depend on:
  - solar zenith angle
  - viewing angle
  - time (trend)
  - effective ozone temperature
- assimilated in a 3D model

Result: consistent long-term data set, which can be used for trend studies

Ozone mass deficit
21-30 Sept over Antarctica



Low mass in 2002 → early break-up of ozone hole



van der A et al, ACP, 2010

Ground-based measurements of O3 and NO2

operational measurements

ozonesondes in De Bilt since 1992

ozonesondes in Paramaribo (Surinam) since 1999

Brewer (O3 column) in De Bilt and Paramaribo (1994/1999)

2 MAX-DOAS (trop NO2) in De Bilt/Cabauw (2007)

participation in global networks: GAW/WOUDC, SHADOZ, NDACC

instrument development: NO2 sonde development since 2008

campaigns in Cabauw (focus NO2)

DANDELIONS 2005 & 2006

CINDI 2009

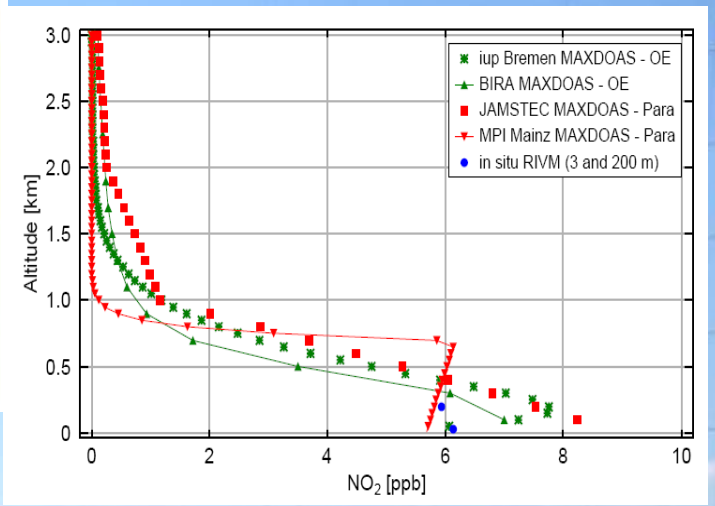
PEGASOS, 2012

other campaigns (with NO2 sonde)

DISCOVER-AQ, Washington/Baltimore, 2011

ACTRIS, Hohenpeissenberg, 2012

DISCOVER-AQ, California, 2013



Wittrock et al., in prep., AMT

Cabauw Intercomparison campaign for Nitrogen Dioxide measuring Instruments

overview: Piters et al, AMT, 2012

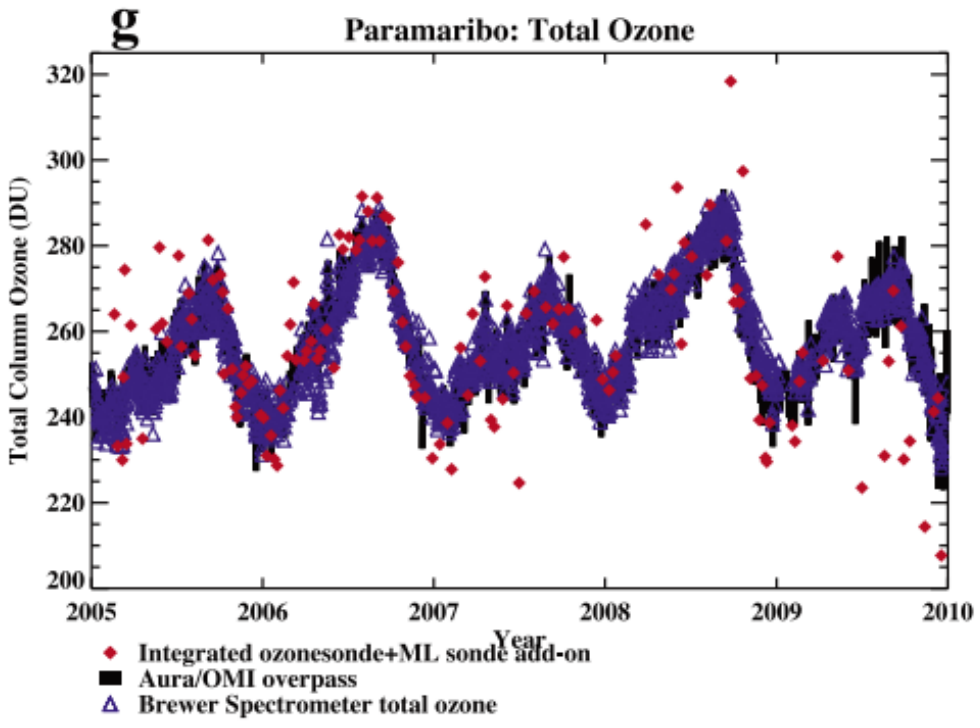
Photo: M. Kroon

Ozone sondes

Participation in ozone sonde homogenisation (lead: Herman Smit), framework: SPARC-IGACO-IOC Initiative “Past Changes in the Vertical Distribution of Ozone“:

- Find all changes in operation procedure since start of measurements
- Reprocessing according to common guidelines, including uncertainties

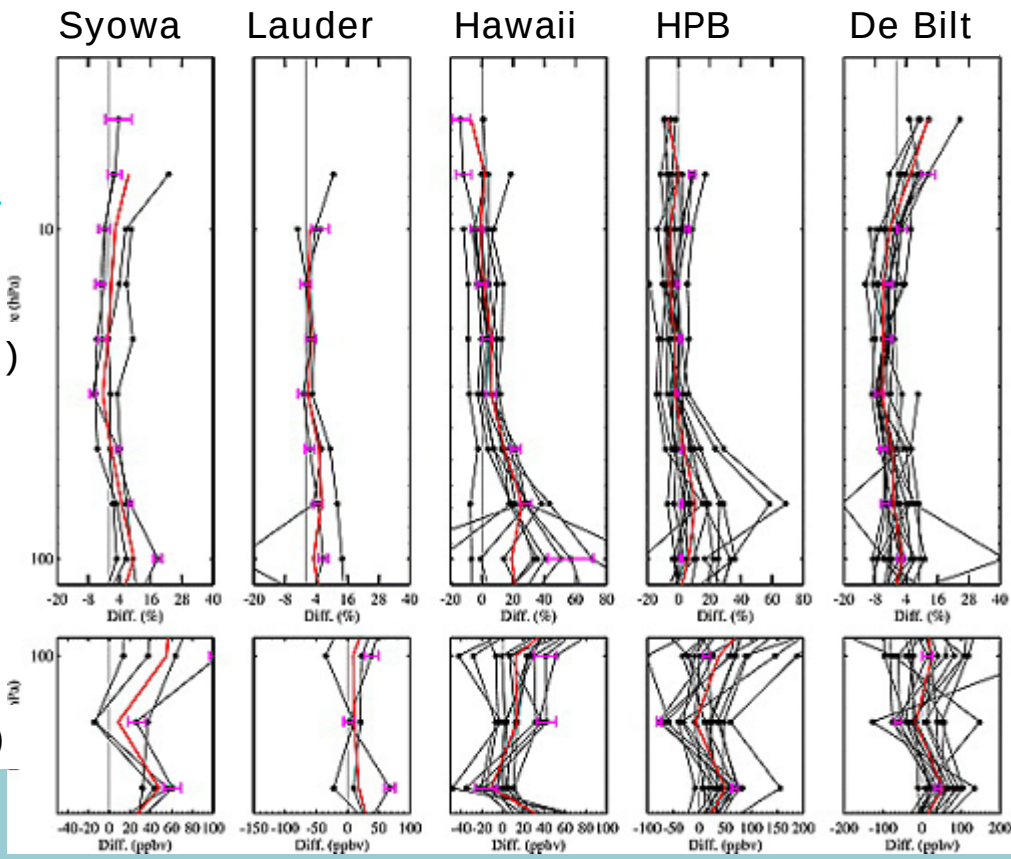
Paramaribo data set reprocessed (improved background correction), and included in SHADOZ (Thompson et al., JGR, 2012)



Use of ground-based measurements for satellite validation

Examples:

- ozone sondes used in several studies
- validation of ENVISAT ozone and temperature profiles (next presentation)
- MAXDOAS NO2 columns for OMI tropospheric NO2
- Integrated radiosondes (ECMWF-DB) for SCIAMACHY water vapour



< 100 hPa (%)

Jiang et al, JGR 112, D24S34, 2007:
Validation of Aura MLS Ozone (v2.2)
Average difference stratosphere <10%
Larger difference:
- Lower altitudes
- Tropical upper troposphere

> 100 hPa (ppbv)

MAX-DOAS tropospheric NO2 compared to OMI

Vlemmix et al, AMT, 2010

When aerosol correction applied: no sign. bias between OMI and MAX-DOAS

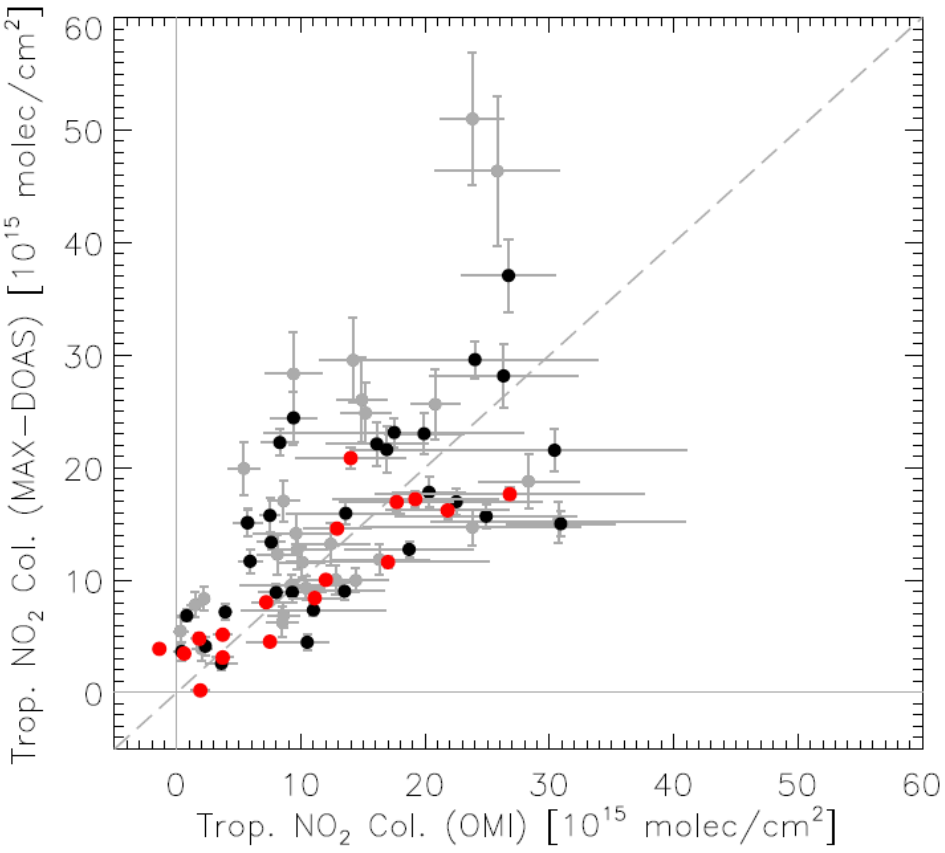
σ_{GB}< 30% : R=0.64 (grey)

σ_{GB}< 20% : R=0.73 (black)

σ_{GB}< 10% : R=0.88 (red)

Spread larger than expected from retrieval errors alone.

Difference in spatial representativity

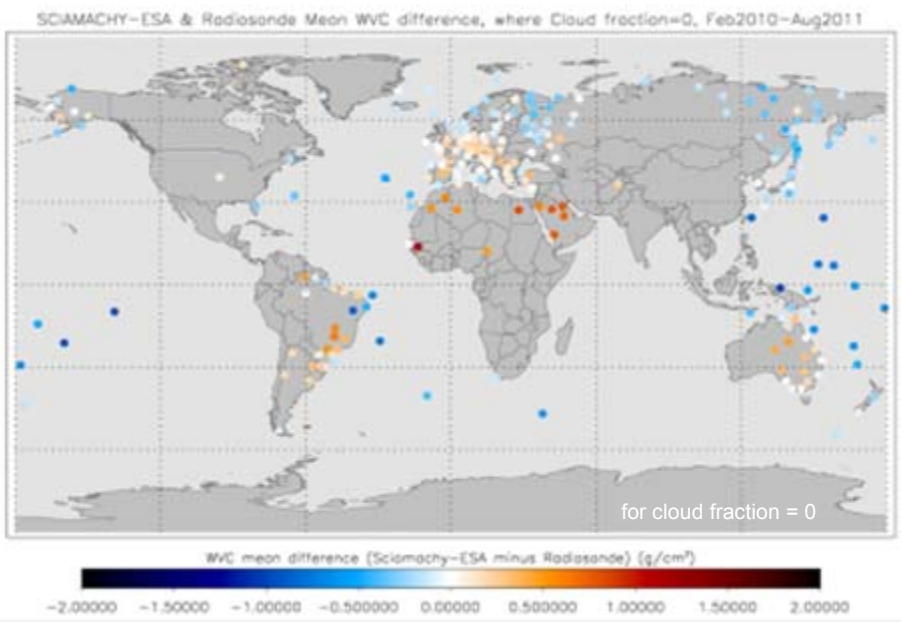


Validation of water vapour columns from SCIAMACHY

Du Piesanie et al, AMTD, 2013

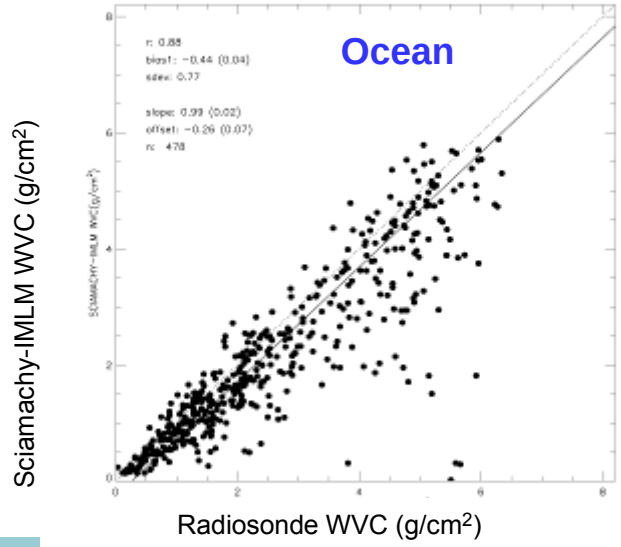
Retrieval: ESA-OL v5.01

Clear land-ocean difference: Positive bias over land & Negative bias over ocean



Sciamachy-ESA - Radiosonde WVC (g/cm^2)

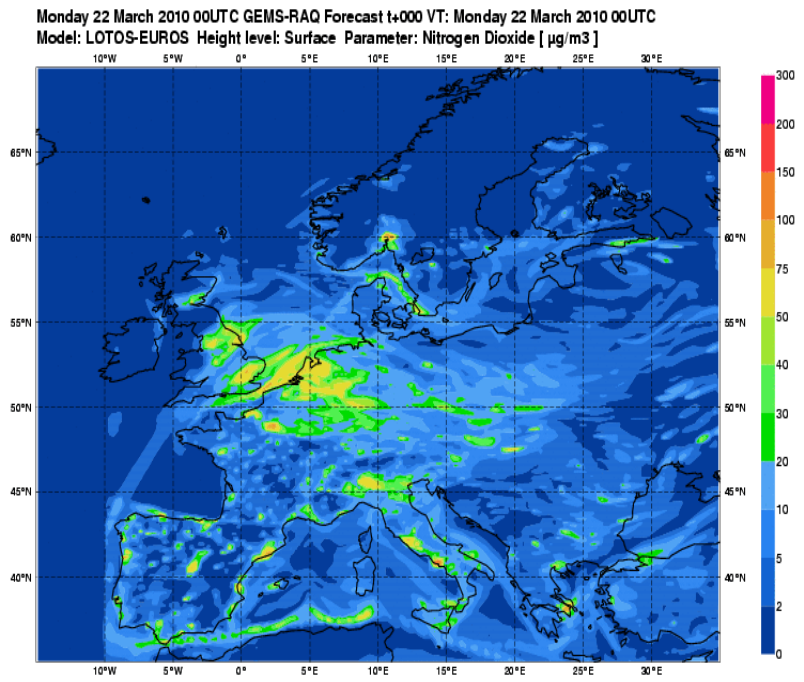
Retrieval: SRON-IMLM v7.4.1



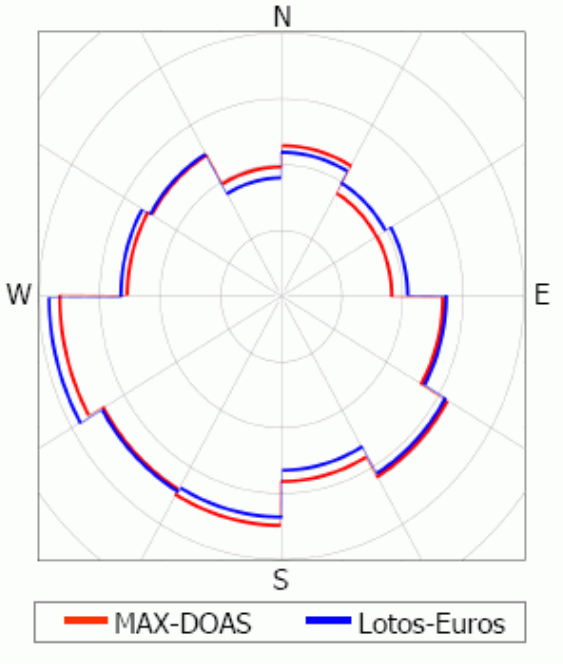
Retrievals over cloudy pixels over ocean surprisingly good.

Cloud pressure ≥ 930hPa,
signal ≥ 250BU/px

Use of MAX-DOAS data in model verification



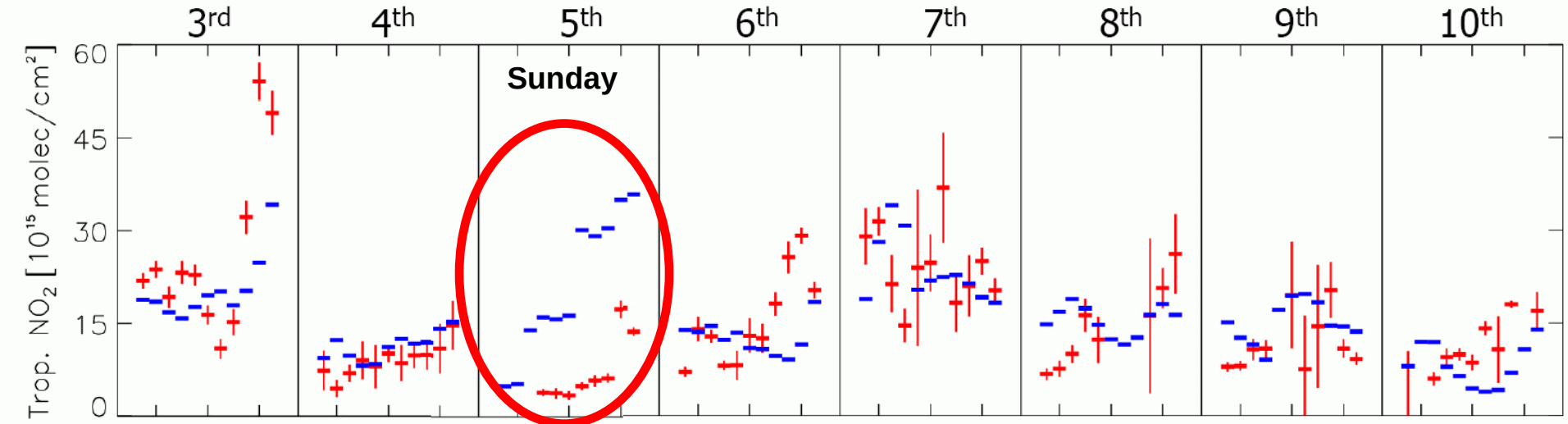
National Air Quality Model
Lotos-Euros



Average trop NO2 for different wind directions
($5 \cdot 10^{15}$ molec cm^{-2} per circle)

Vlemmix et al., ACPD 2012

April 2009

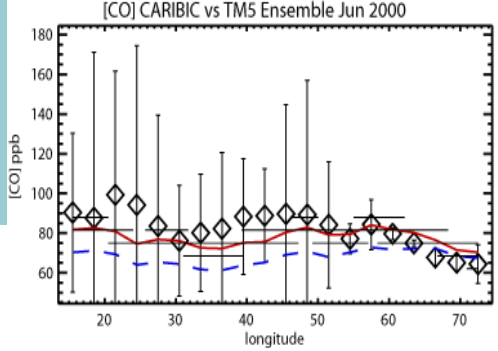


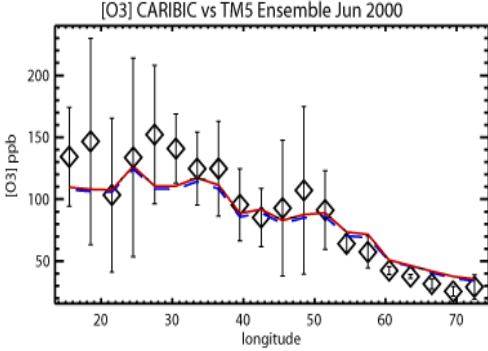
Use of aircraft observations in model verification

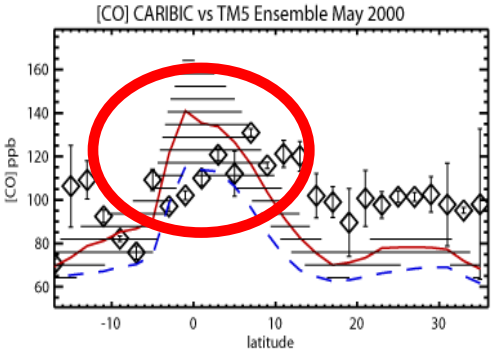
Example: IAGOS/MOZAIC data (diamond) versus TM5 (red line)

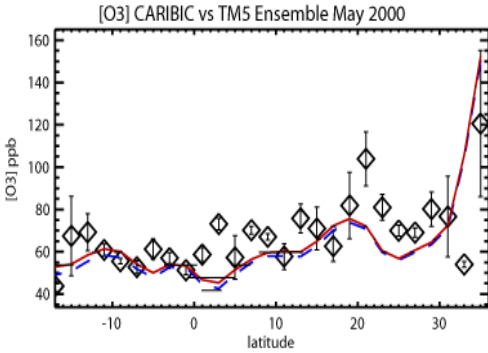
- Spatial gradients in CO and O3 are captured relatively well
- Over Africa near the ITCZ convective uplift is overestimated.

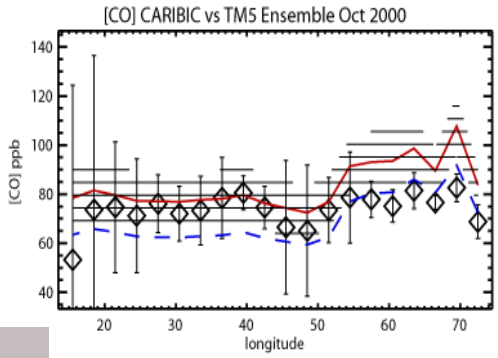
Williams et al., ACPD, 2012

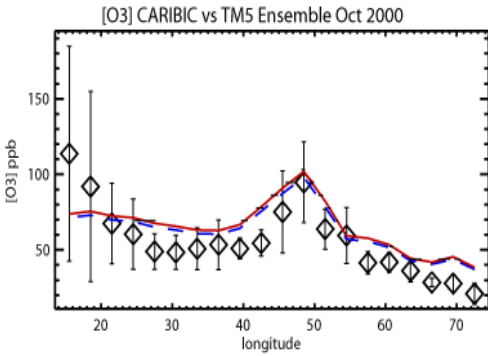


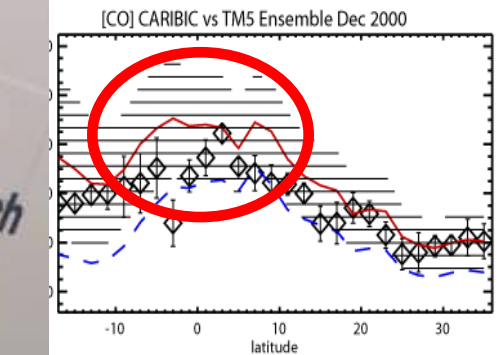


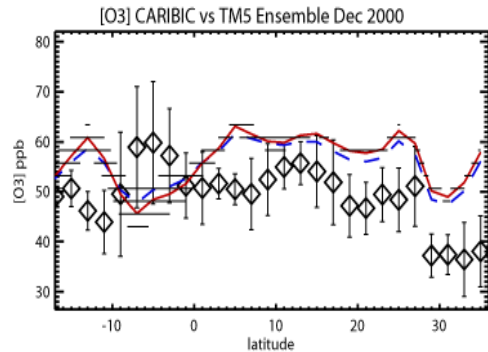












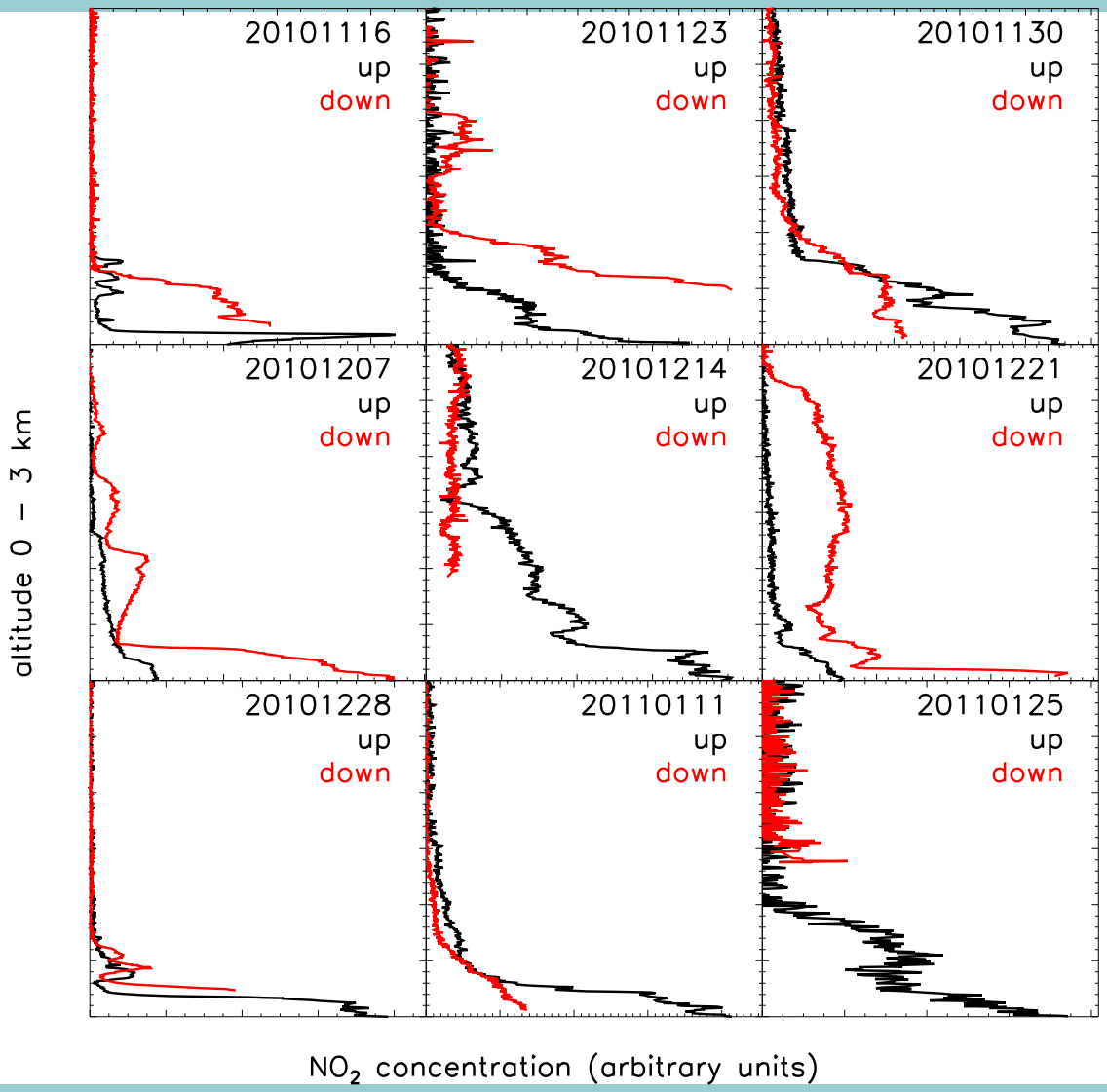
The NO2 sonde

- Measures high resolution NO2 profiles
- Light weight
- Low power consumption
- Can be launched on small weather balloon

Idea: Wesley Sluis

Chemistry: Mirjam den Hoed

Design: Marc Allaart



The NO_2 profiles

up to ~10km (balloon burst)

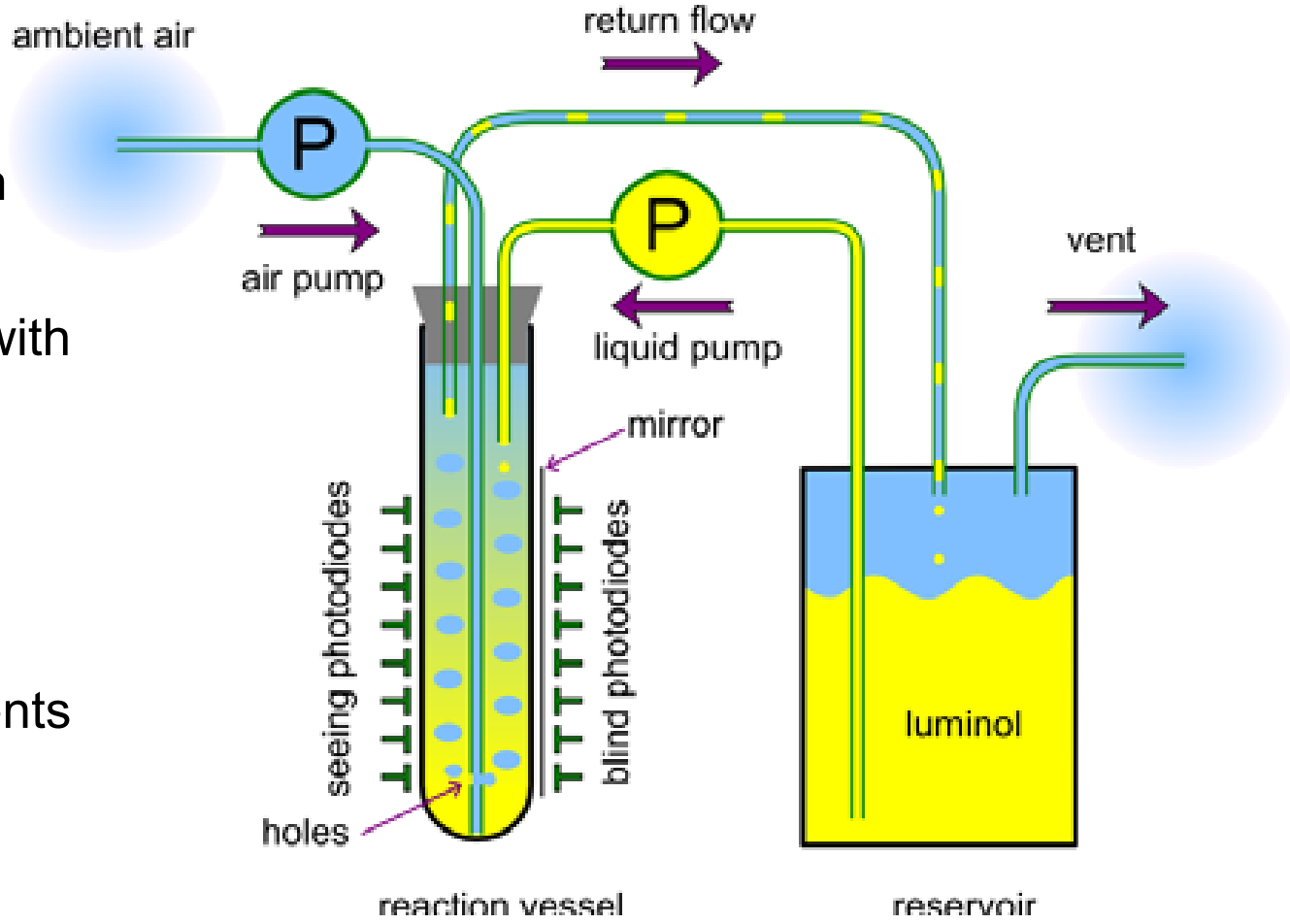
two profiles for each launch
('up' and 'down')

large variability in shapes

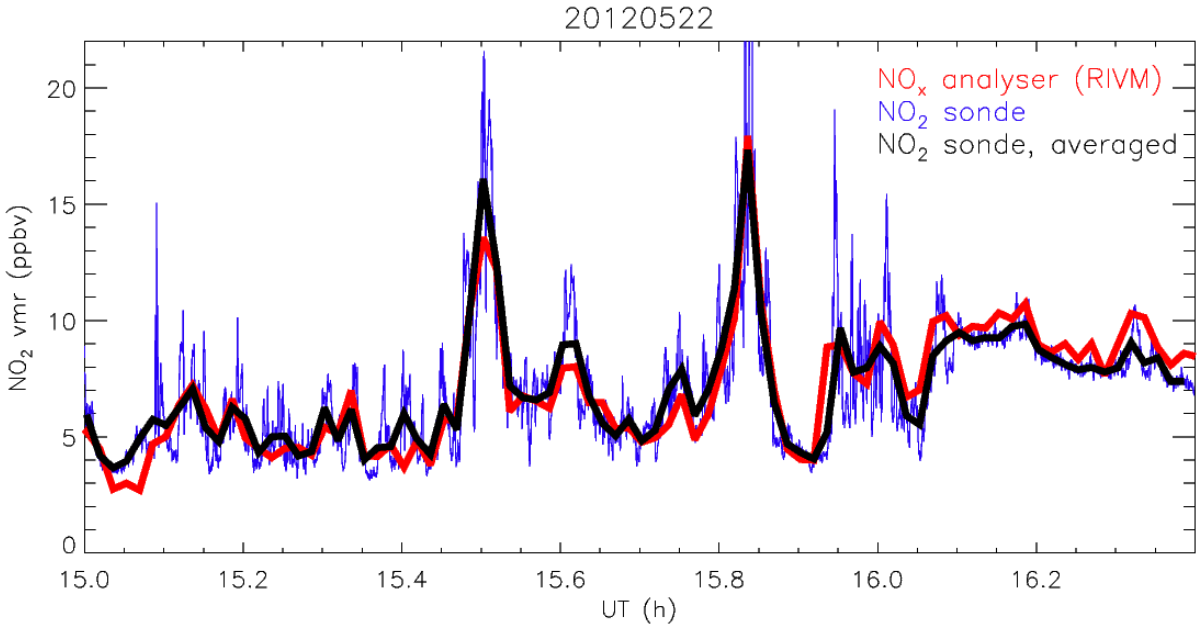
Winter 2010-2011

Measurement principle

- based on chemiluminescent reaction of NO_2 with luminol
- photons are detected with photodiode array
- electronics: converts femto-amperes to millivolts
- luminol reservoir prevents acidification by CO_2



Sluis et al., AMT, 2010



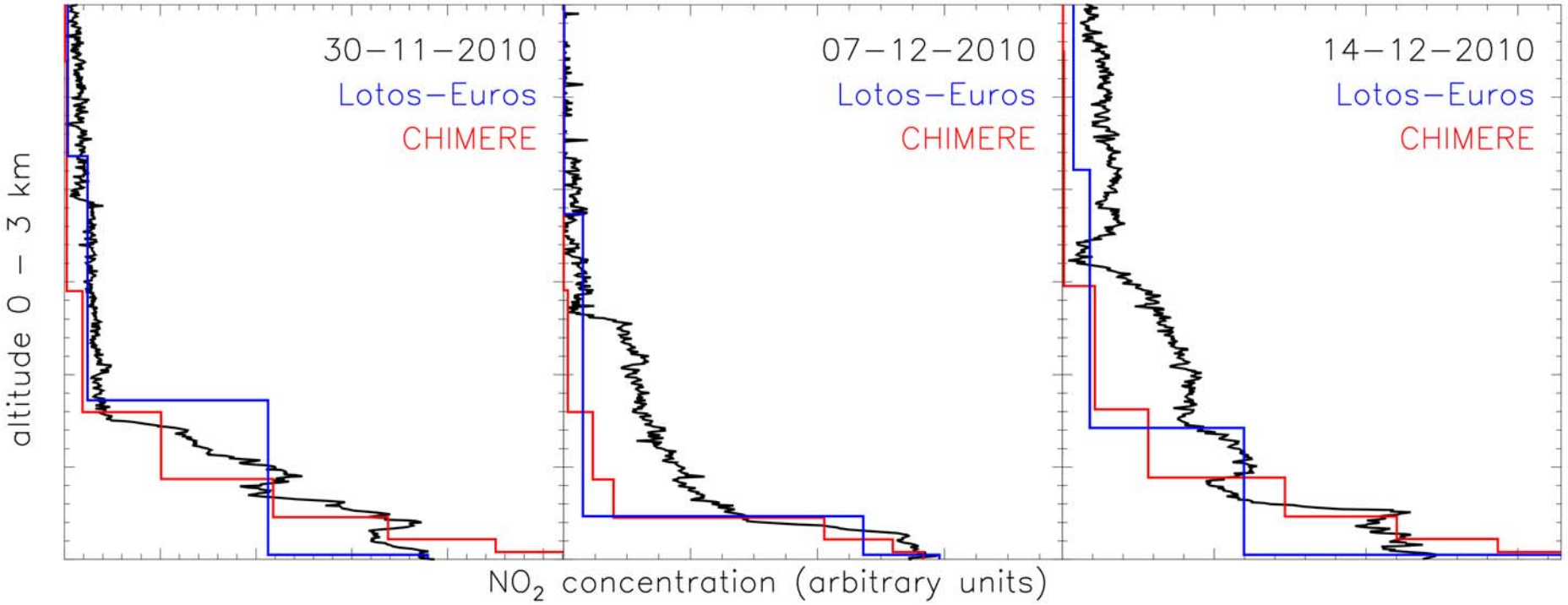
How accurate can we measure NO2?

NO_2 variations are very well captured.

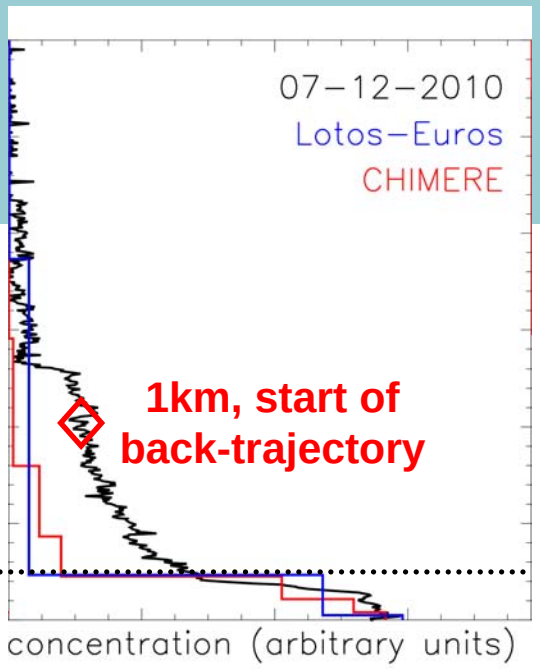
RMS difference is <10%

absolute calibration still to be optimized
(here: constant scaling factors applied)

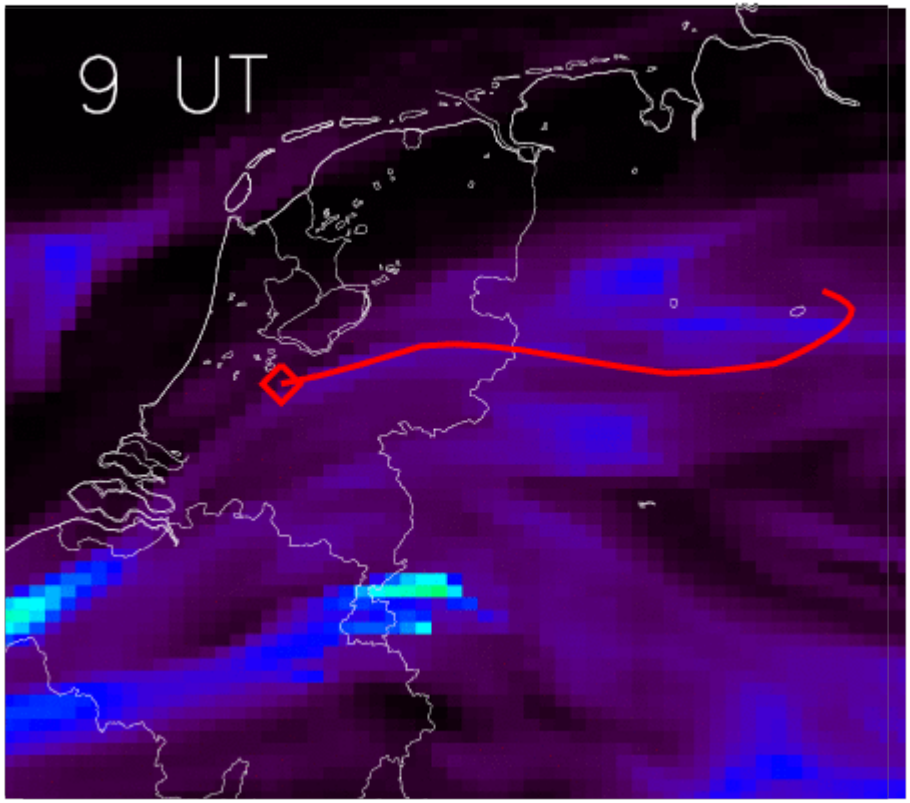
Comparing with AQ models



Thanks to: Henk Eskes and Patricia Castellanos, KNMI



Modeled NO_2 above boundary layer



The Lotos-Euros model shows:

NO_2 vertical transport to the free troposphere

Horizontal transport of free tropospheric NO_2

Possible origin of difference with sonde:

Life time of NO_2

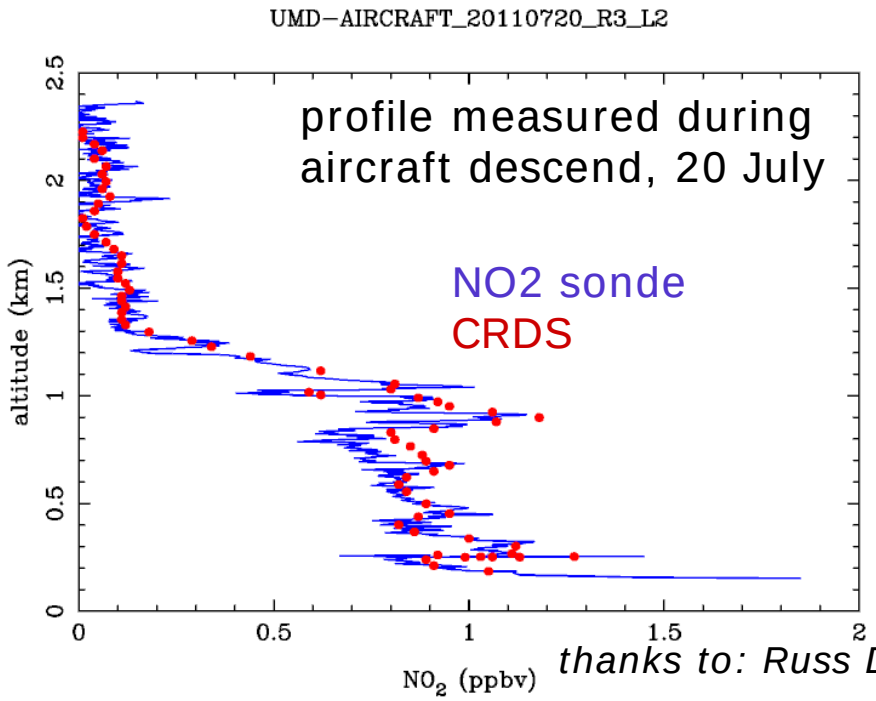
Vertical/horizontal transport

Surface emissions

24h backtrajectory at 1km height

◇ = measured air mass

DISCOVER-AQ campaign 2011, USA

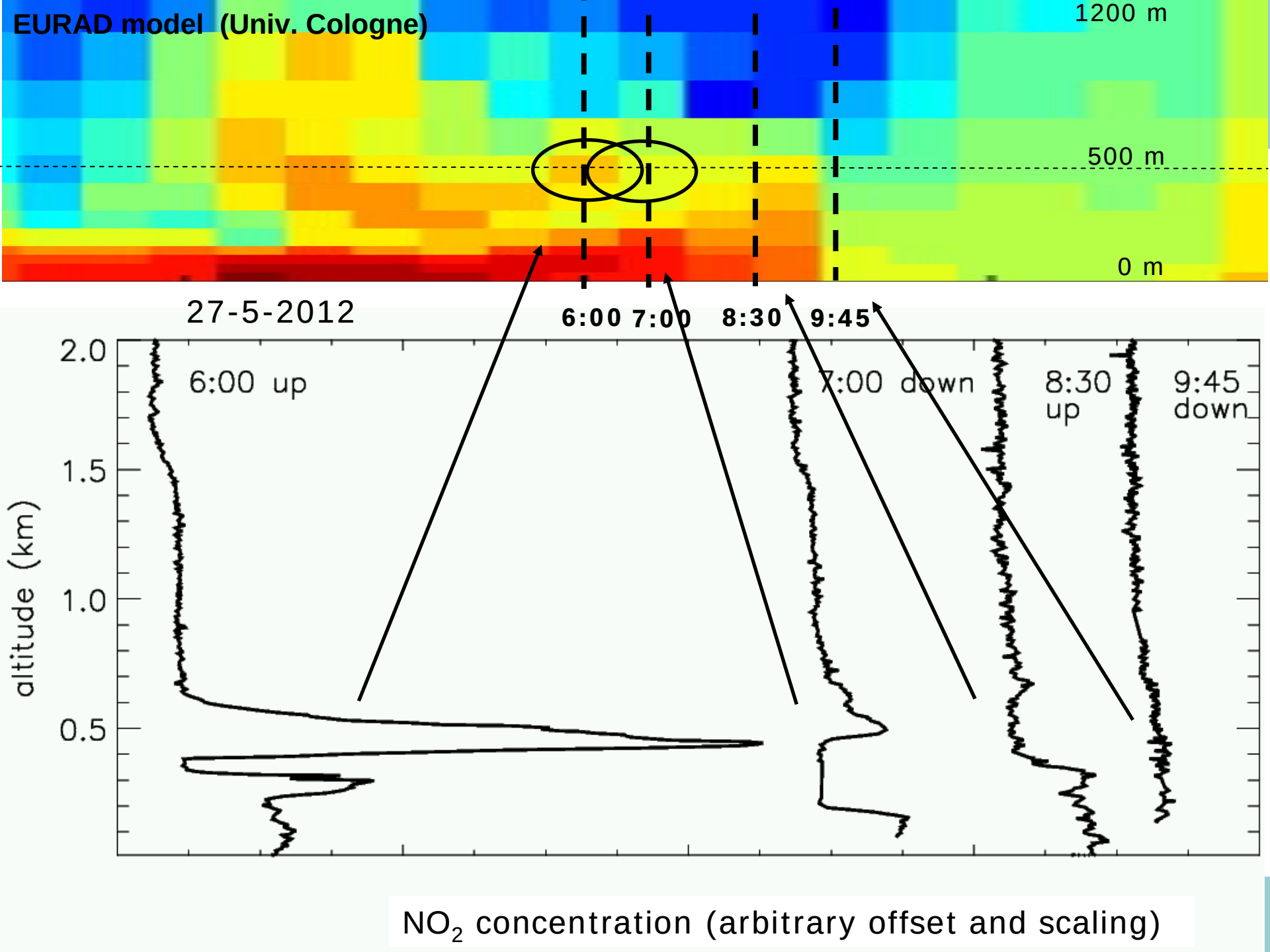


aircraft and tethered
balloon measurements

thanks to: Russ Dickerson (UMD) and Richard Clark (Millersville Univ)

PEGASOS campaign May 2012, Cabauw

(only NO_2 instruments are shown)


EURAD model (Univ. Cologne)
1200 m
500 m
0 m
27-5-2012
6:00
7:00
8:30
9:45
6:00 up
7:00 down
8:30 up
9:45 down
altitude (km)
2.0
1.5
1.0
0.5
NO2 concentration (arbitrary offset and scaling)

Future plans ...

- Optimisation of the calibration
- Optimisation of the design
- Transfer knowledge to industry for serial production
- Use it for the validation of models, MAXDOAS and indirectly of satellites

Marc and Deborah recovering a sonde

Photo: A. Apituley