

TCCON & MUSICA

water vapour intercomparison

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& MUSICA and TCCON teams

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Outline

Motivation

Data

Network comparisons

Site examples

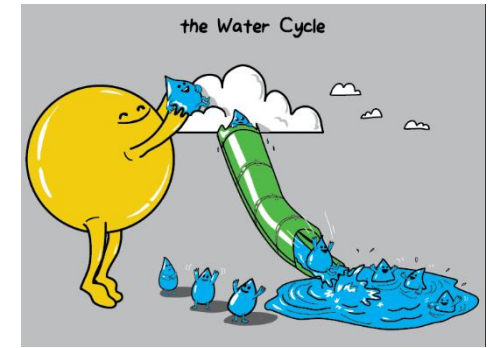
Summary

Future work





Why study water vapour?



The water cycle plays a central role in Earth's climate system

- Improving understanding of water cycle is a priority of the climate community (IPCC, 2007)
- Plays major role in the radiation balance as the dominant greenhouse gas & through feedback effects
- Models do not yet capture water cycle well, especially at high latitudes (Schneider et al. 2012)
- Shifts to water cycle will impact society, environment

Isotopologues

- H_2O , HDO , H_2^{18}O : can be used as a tracer to infer transport history.
- Transport & changes of state depletes air of heavier water vapour isotopologues

$$\delta\text{D} = 1000\text{‰} * \left(\frac{\frac{\text{HDO}}{\text{H}_2\text{O}}}{\text{SMOW}} - 1 \right)$$

where $\text{SMOW} = 3.11 \times 10^{-4}$

(Craig, 1961)

Until recently, very limited atmospheric data has been available

Networks

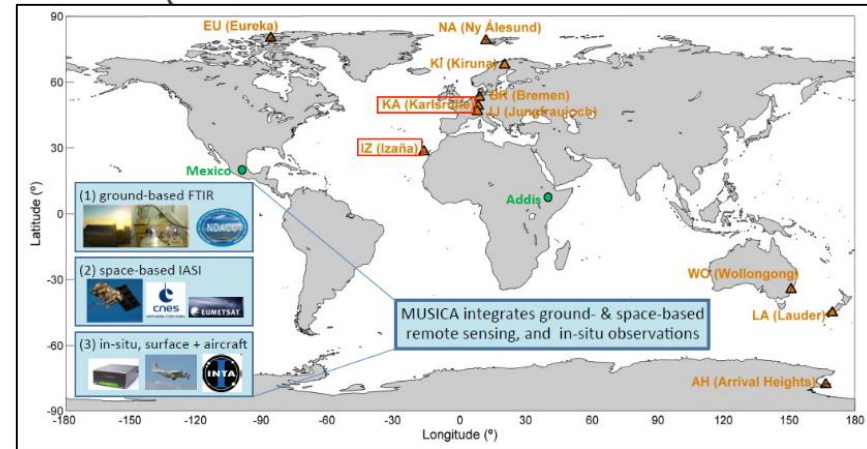
NDACC/MUSICA

The **M**ulti-platform remote **S**ensing of **I**sotopologues for investigating the **C**ycle of **A**tmospheric water **N**etwork

- NDACC is a network of ground-based instruments. Many sites include FTIR solar absorption spectrometers which record mid-infrared (MIR) spectra
- MUSICA retrievals use NDACC MIR spectra, and are optimized to give precise and accurate information about H_2O , HDO, and δD
- MUSICA products have been validated by extensive intercomparisons with in-situ and satellite-based remote sensing measurements.



MUSICA-participating NDACC stations map



TCCON

The **T**otal **C**arbon **C**olumn **O**bserving **N**etwork

- Network of ground-based FTIR spectrometers which record solar absorption spectra in the near-infrared (NIR).
- Measurements optimized for carbon cycle studies (i.e. CO_2 , CH_4);
- TCCON's retrievals also produce H_2O and HDO products.
 δD values used for comparisons are calculated.



TCCON stations map



Data

Sites

- Eureka
- Ny Ålesund
- Kiruna/Sodankylä
- Bremen
- Karlsruhe
- Izaña
- Wollongong
- Lauder

Measurements

- **TCCON** (NIR FTIR)
 - H_2O , HDO
- **NDACC/MUSICA** (MIR FTIR)
 - H_2O , HDO, δD
- **Radiosondes**
 - H_2O

Overlap: MUSICA ends 2012-2013
and TCCON begins ~2005-2012

Data

Sites

- Eureka
- Ny Ålesund
- Kiruna/Sodankylä
- Bremen
- Karlsruhe
Stuttgart RS?
- Izaña
- Wollongong
Sydney RS?
- Lauder

Measurements

- **TCCON** (NIR FTIR)
 - H₂O, HDO
- **NDACC/MUSICA** (MIR FTIR)
 - H₂O, HDO, δD
- **Radiosondes**
 - H₂O

Overlap: MUSICA ends 2012-2013
and TCCON begins ~2005-2012

Technique differences

TCCON

- NIR FTIR measurements
- Max OPD: 45 cm
- Optimized for carbon cycle studies
- Variable *a priori*
- Scaled retrieval (GGG)
 - 1 DOFS
- Official data product is in X-gas (dry air mole fraction); H₂O and HDO total columns
- δD is calculated *a posteriori*
- Not well validated

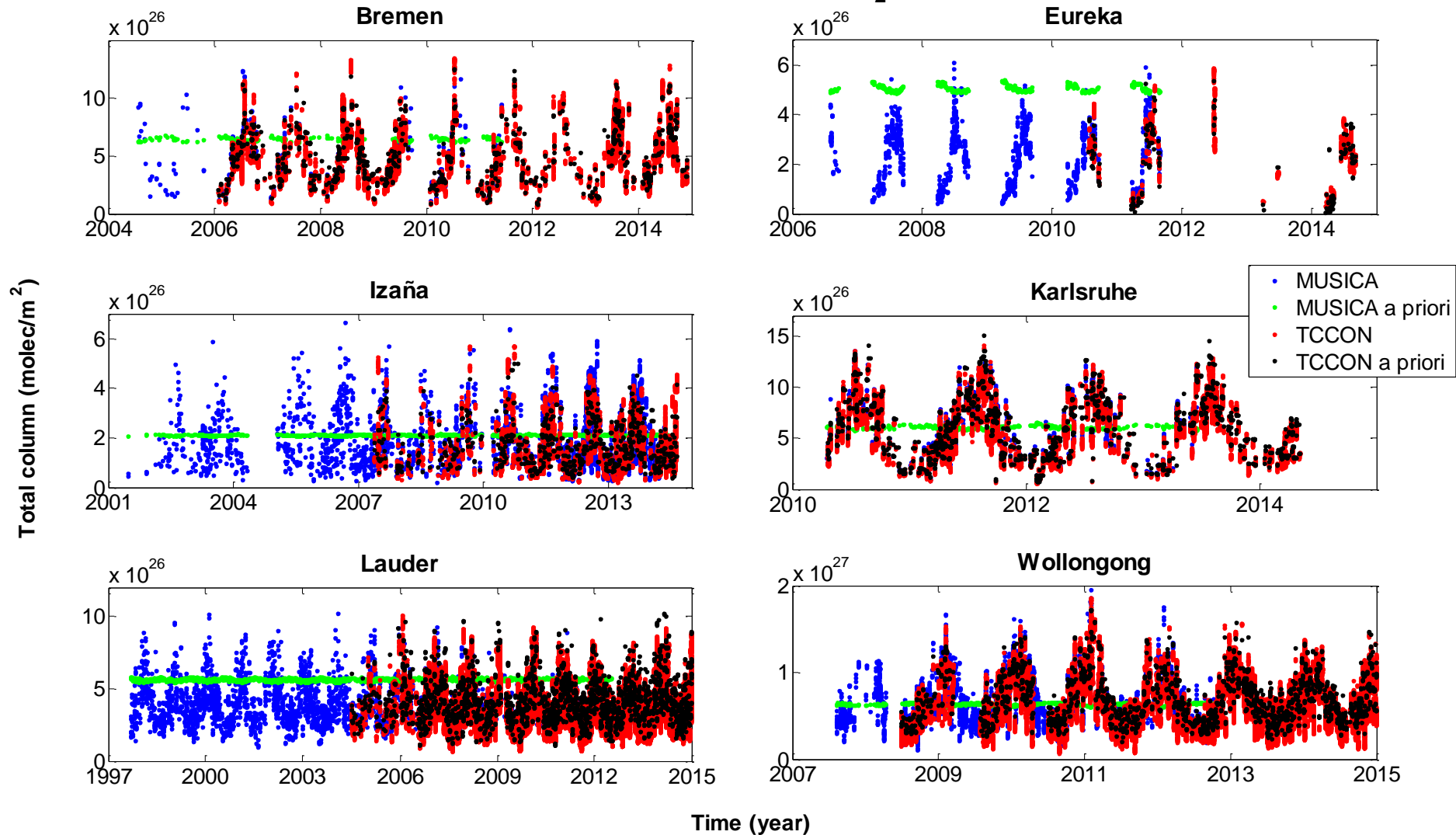
MUSICA

- MIR FTIR measurements
- Max OPD: 257 cm
- Optimized for water cycle studies
- ~Constant *a priori*
- Profile retrieval (PROFFIT)
 - 2 – 3 DOFS
- Data product includes profiles and total columns of H₂O, HDO, and
- δD is measured
- Extensively validated (aircraft, satellite, radiosonde, ground-based measurements)

Similarities: using the same instrument!

FTIR datasets

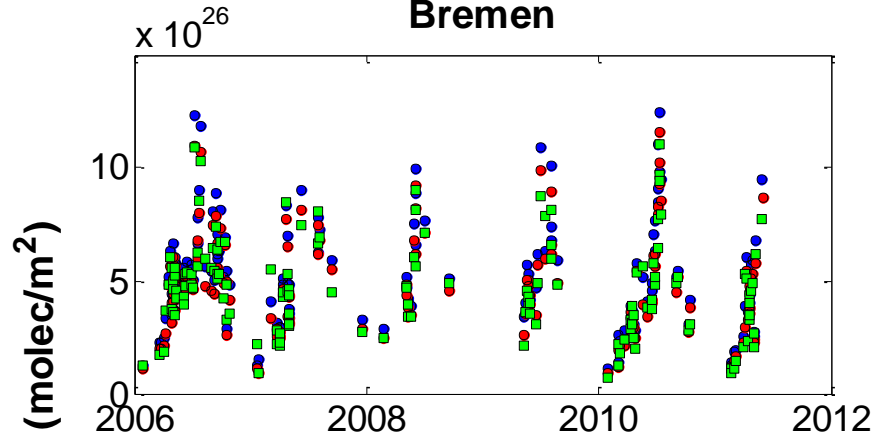
MUSICA and TCCON H₂O



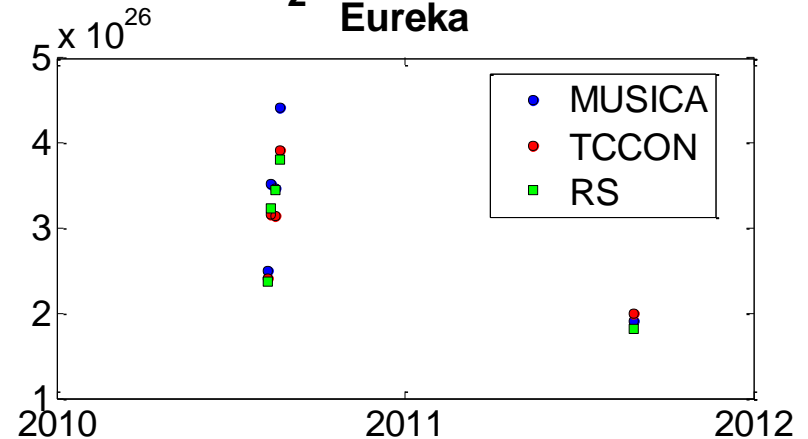
2-hr coincident radiosondes

Coincident MUSICA and TCCON and H₂O

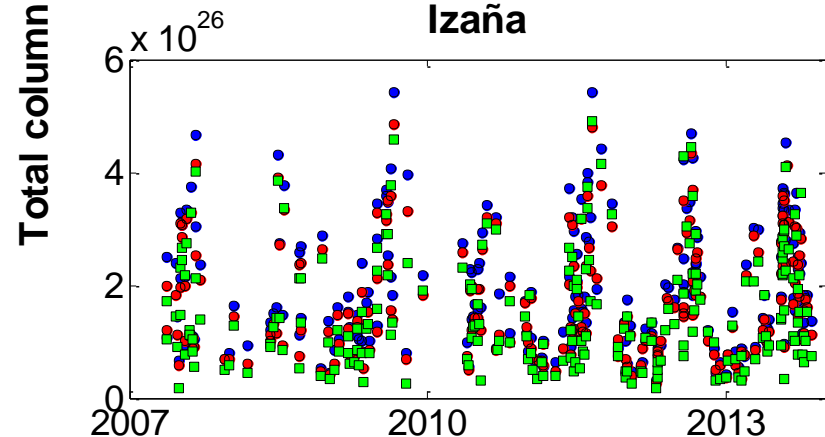
Bremen



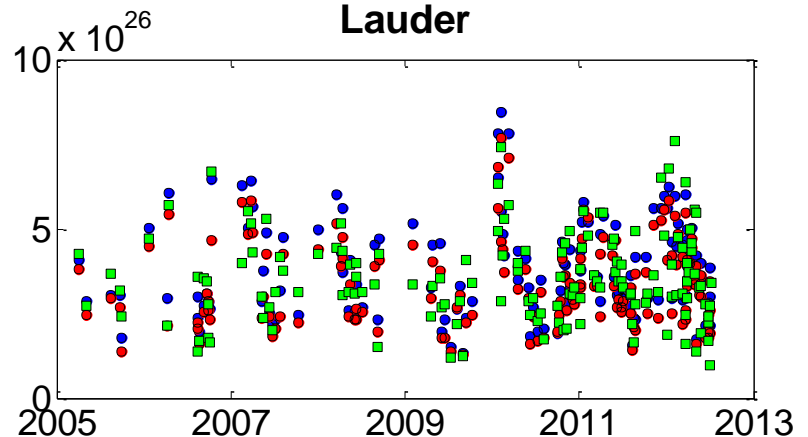
Eureka



Izaña



Lauder



Time (year)

* Izaña & Lauder radiosonde columns are partial columns from FTIR altitude

Comparison methods

- MUSICA and TCCON measurements within 2 hours
 - Only the closest pairs kept
 - Measurements used only once
- Instruments co-located
- Radiosondes within 2 hours of either MUSICA or TCCON
- Radiosonde partial columns to FTIR altitude used for this comparison
- *Not yet smoothed with averaging kernels!*

Network-wide comparisons

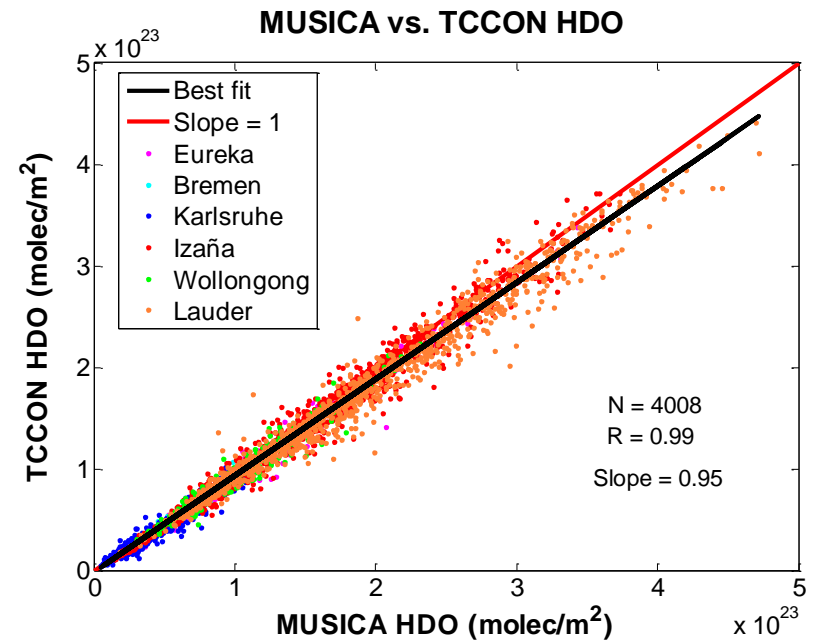
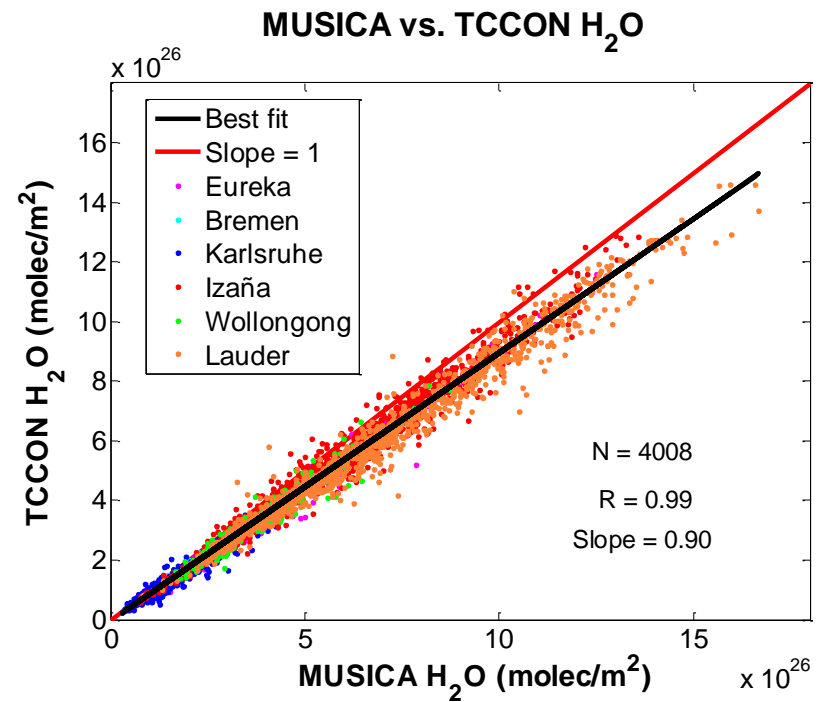
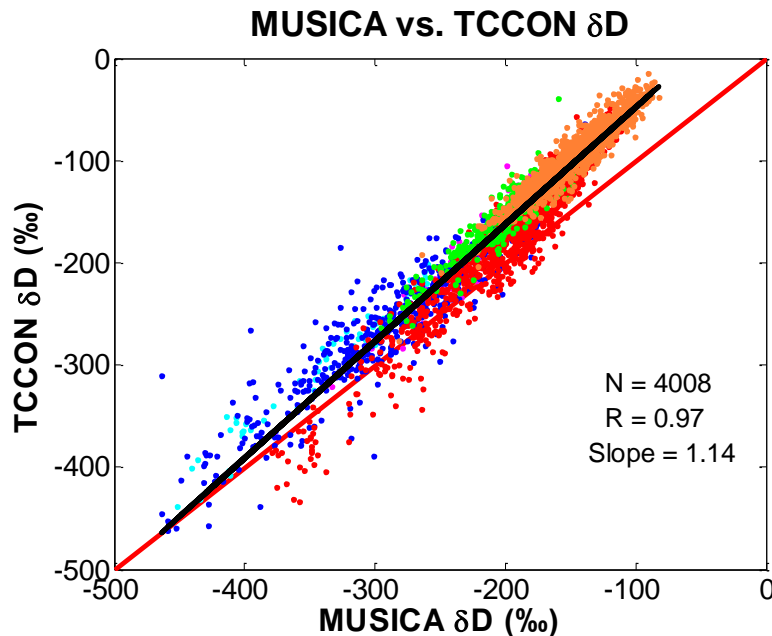
N = 4008

R > 0.97

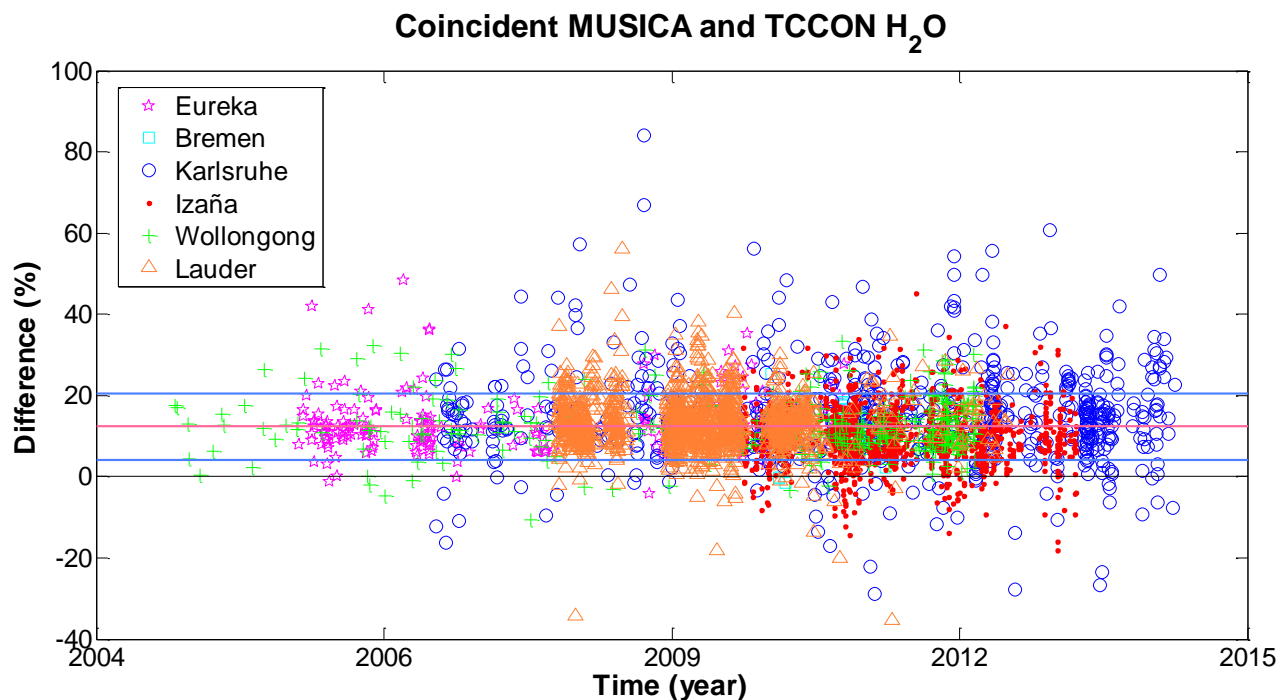
H₂O: Mean difference: $12.3 \pm 8.16\%$

HDO: Mean difference: $7.70 \pm 9.11\%$

δD : Mean difference: $30.2 \pm 21.7\%$



GGG2012 VS GGG2014



Individual site H₂O comparisons are very similar, though there is less scatter in HDO and δD agreement improves

MUSICA vs. GGG2014

$R = 0.99$

Slope = 0.90

Mean = 12.3%

$\sigma = 8.16\%$

MUSICA vs GGG2012

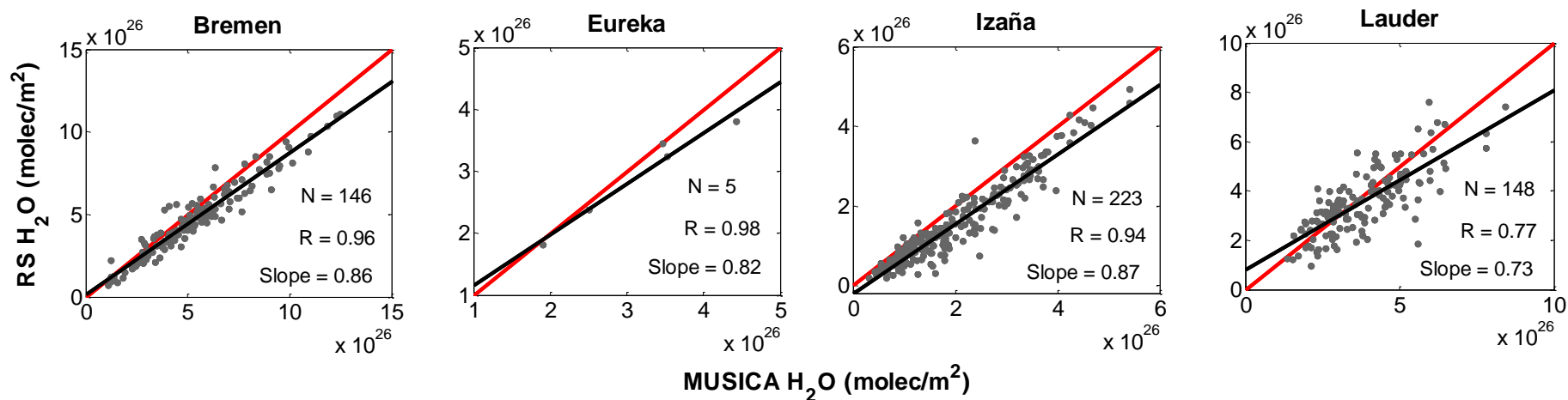
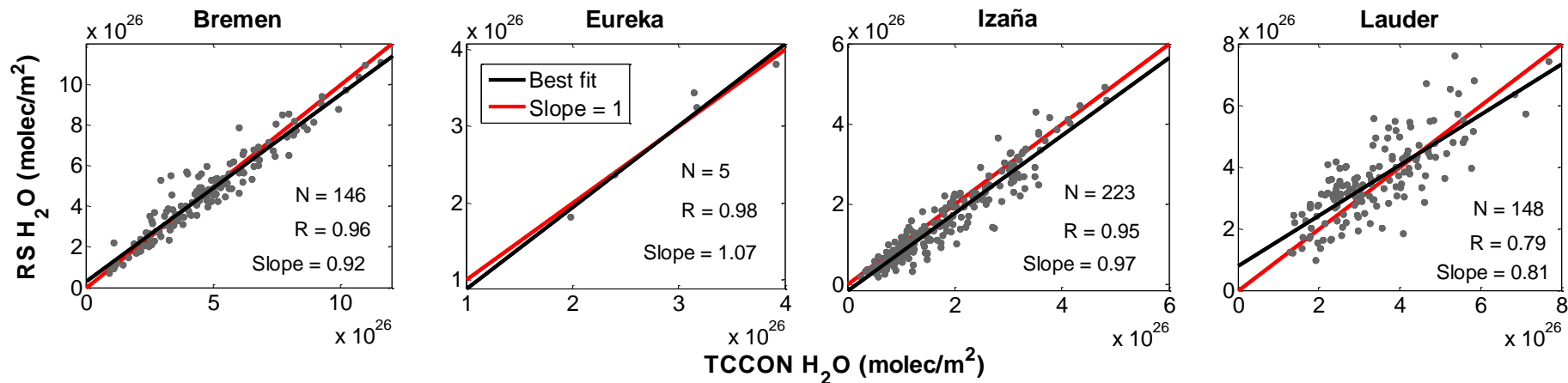
$R = 0.99$

Slope = 0.91

Mean = 11.4%

$\sigma = 10.8\%$

Coincident **MUSICA** & **TCCON** & **RS**

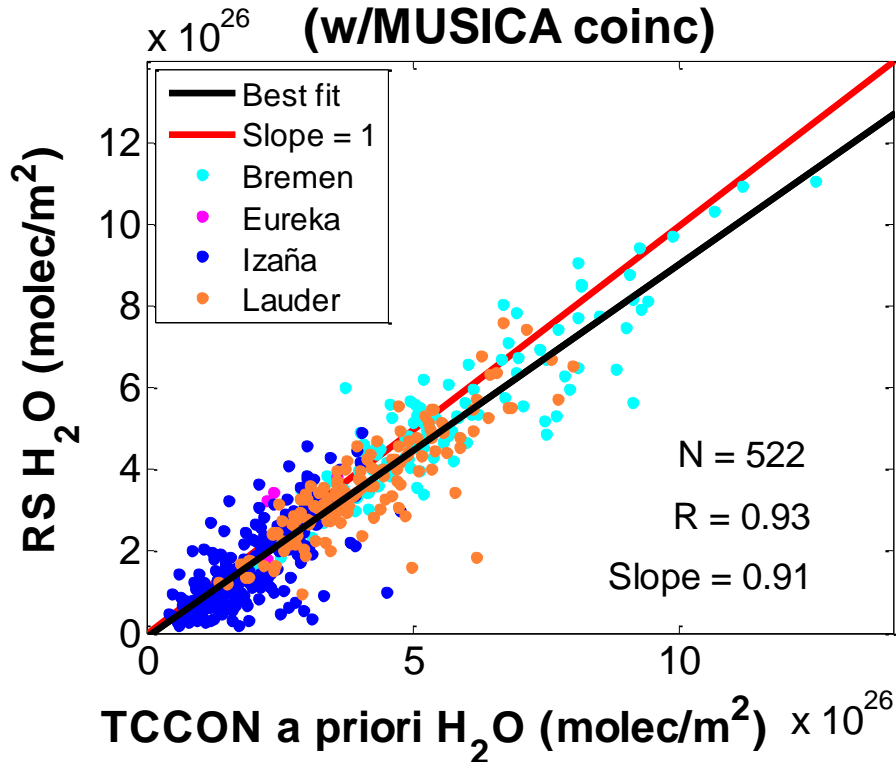


Does TCCON's data agree better than its a priori?

- TCCON agreed better than its a priori with RS at each site
- Both MUSICA and TCCON are high relative to RS

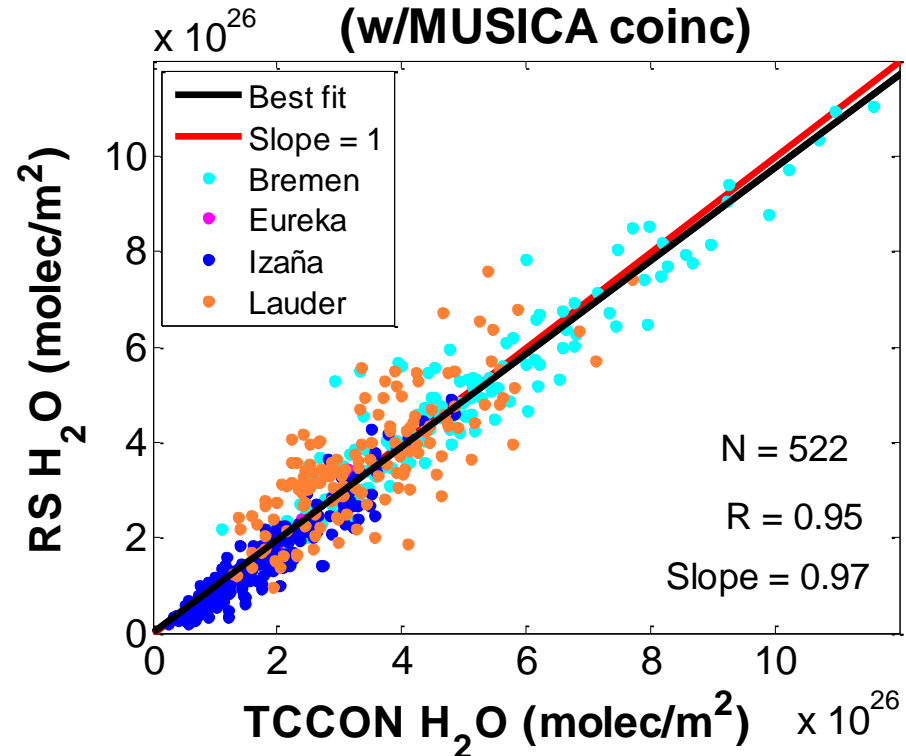
TCCON a priori vs. RS H₂O

(w/MUSICA coinc)



TCCON vs. RS H₂O

(w/MUSICA coinc)



Lauder's two Brukers offer illustrative example of network-wide bias

N = 364

H₂O

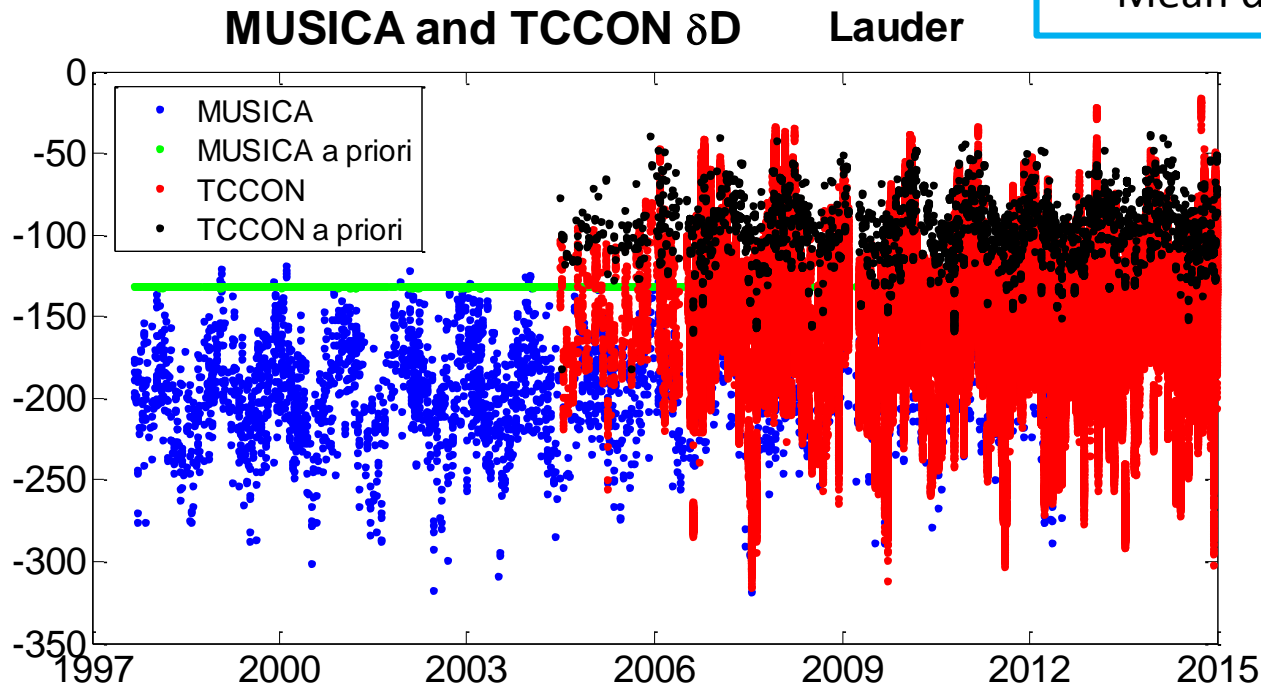
- R = 0.98, slope = 0.90
- mean difference: $12.6 \pm 6.9\%$

HDO

- R=0.98, slope = 0.95
- Mean difference: $7.1 \pm 7.3\%$

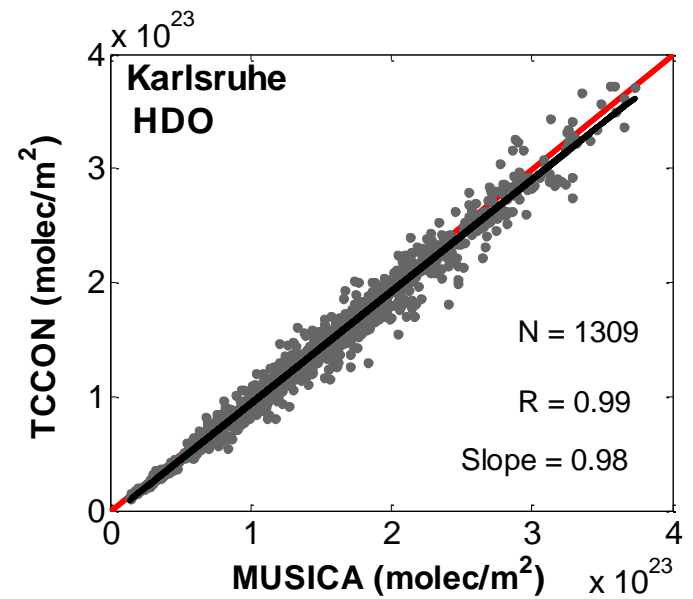
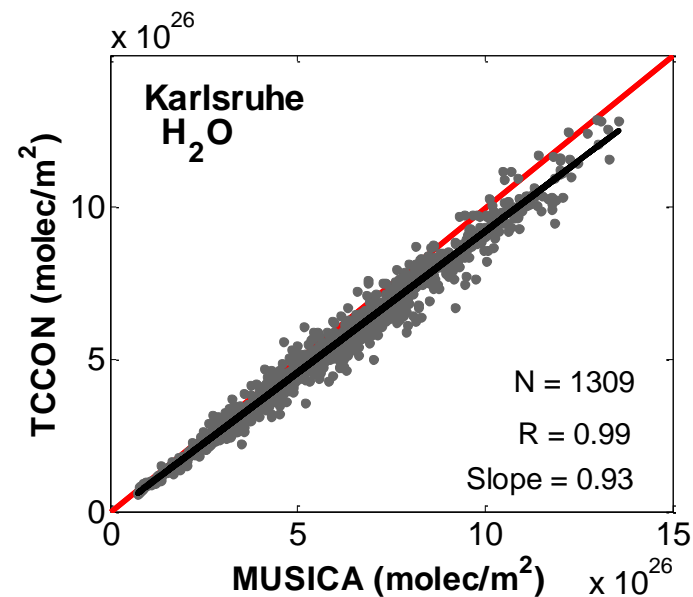
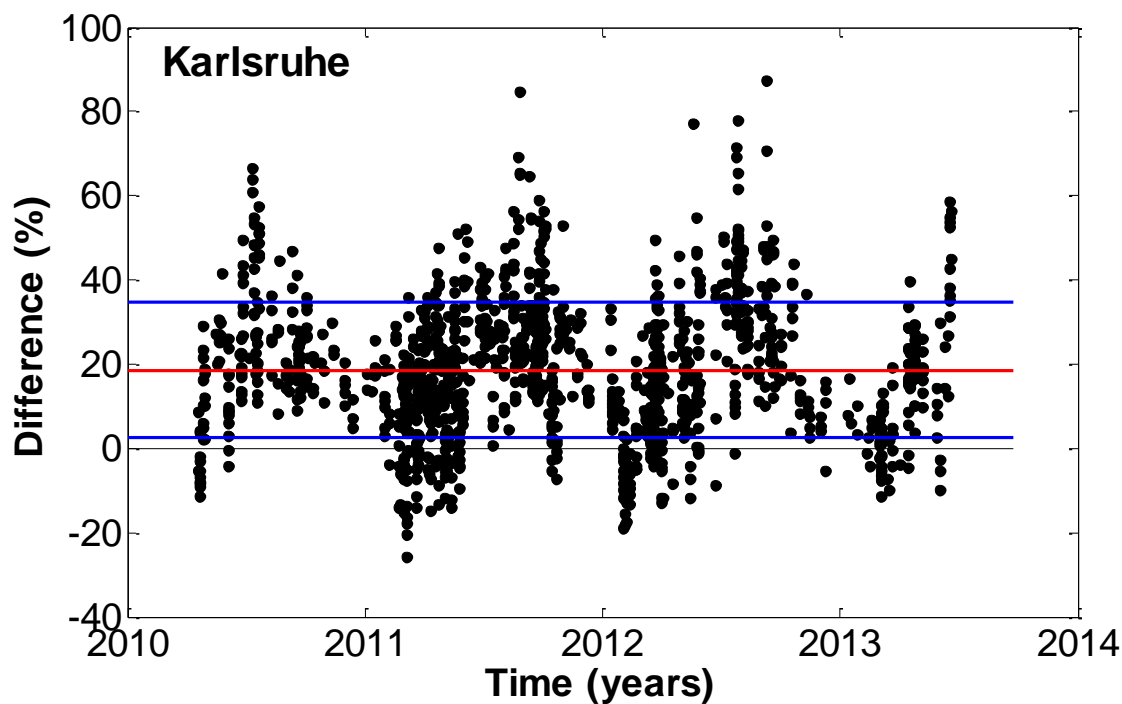
δD

- R = 0.94, slope = 1.07
- Mean difference: $27.7 \pm 11.1\%$



Karlsruhe (Germany) δD agreement shows seasonality

MUSICA and TCCON δD percent differences



Summary of site-by-site MUSICA vs. TCCON comparisons

Site	Location		N	H ₂ O				δD			
	Lat.	Long.		mean % diff.	σ	R	slope	mean % diff.	σ	R	slope
Eureka	80	-86.4	58	11.8	5.13	0.99	0.90	13.7	5.80	0.98	1.09
Ny Ålesund	78.9	11.9	141	12	5.56	1	0.89	14.1	6.21	0.96	1.03
Kiruna/ Sodankylä	67.9/ 67.4	20.2/ 26.6	205	-1.16	21.1	0.93	1.03	27.3	17.4	0.81	0.98
Bremen	53.2	8.85	217	13.1	7.32	0.99	0.92	26.5	12.4	0.97	1.15
Karlsruhe	49.1	8.44	1309	9.74	6.93	0.99	0.93	18.6	16.2	0.96	1.29
Izaña	28.3	-16.5	644	15.4	12.3	0.98	0.87	17.0	13.9	0.96	1.06
Wollongong	-34.4	150.9	1416	13.1	6.48	0.99	0.88	48.7	19.7	0.95	1.08
Lauder	-45	169.7	364	12.6	6.92	0.98	0.90	27.7	11.1	0.94	1.07

Product	N	R	slope	mean % diff.	σ
H ₂ O	4008	0.99	0.90	12.3	8.16
HDO		0.99	0.95	8.16	9.11
δD		0.97	1.14	30.2	21.7

Summary

- Overall, there is good agreement between MUSICA & TCCON
- TCCON agrees better with radiosondes than MUSICA
- The limited coincidences found by some sites are due in part to the fact that some sites do not take both NDACC/MUSICA and TCCON measurements every day.
- **MUSICA H₂O and HDO measurements show higher values than TCCON total columns**
- **TCCON shows higher δD values than MUSICA.** This is similar to results by Scheepmaker et al. (2014)
- Karlsruhe agreement shows seasonality not seen in other sites
- Excluding the Kiruna/Sodankylä comparison, due to wide geographic separation,
 - **R values are all above 0.87**
 - **Slopes close to one**



Next

- Smooth MUSICA data using TCCON averaging kernels!
- Seek out radiosonde data near Wollongong & Karlsruhe
- Add Ny Alesund once GGG2014 data is available
- Think about seasonality in Karlsruhe agreement
- Identify cases where TCCON's a priori doesn't capture atmosphere as well

