CTBT: SCIENCE AND TECHNOLOGY 2017 CONFERENCE

2nd ATM Challenge 2016

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1. The problem and possible solutions

CTBTO/IDC is routinely checking air samples for traces of radio-xenon.

But radio-xenon is emitted from:

- nuclear (underground-) tests (~10E14 Bq) AND
- civil nuclear facilities like power plants and – most importantly - medical isotope production facilities (~10E15 Bq/Jahr)

Emissions from civil nuclear facilities thus generate a disturbing background (Minimum Detectable Concentration (MDC) at ~1 mBq/m³), particularly because the discrimination between CTBT-relevant events and background based on isotope ratios can be difficult or even impossible due to the lack of multiple isotope detections.

- Current corresponding projects and counteractive measures of CTBTO:
  - Xenon background measurements and determining the PSR (Probable Source Region) for events in questions.
  - Modeling of industrial xenon emissions based on pertinent emission data (see 1st & 2nd ATM-Challenge) and support for voluntary xenon emission reduction.

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2. 1st and 2nd ATM-challenge

- Purpose: „*To ascertain the level of agreement one can achieve between real IMS measurements and those simulated using only the stack release data and ATM*“
- History:

	Challenge 2015[1]	Challenge 2016
Nummer of participants	13	17
Emission source & time resolution	IRE (Belgium); Nov., 10th - Dec., 8th, 2013, 15min	ANSTO (Australia); May, 11th - Jun., 11th, 2016, hourly
IMS stations involved & distance	SEX33, 380 km	AUX04, AUX09, BRX11, FRX27, NZX46, GBX68; 670 - 13500 km
Method:	Time series for collection times with actual emissions given	Time series of dilution factors for individual unit emission releases, *actual emissions not given -> „Blind test“*
Isotope:	Xe-133	Xe-133 (Xe-135 investigated, but no measurements above MDC)

[1] Publication from P. W. Eslinger et al.: http://dx.doi.org/10.2016/j.jenvrad.2016.03.001

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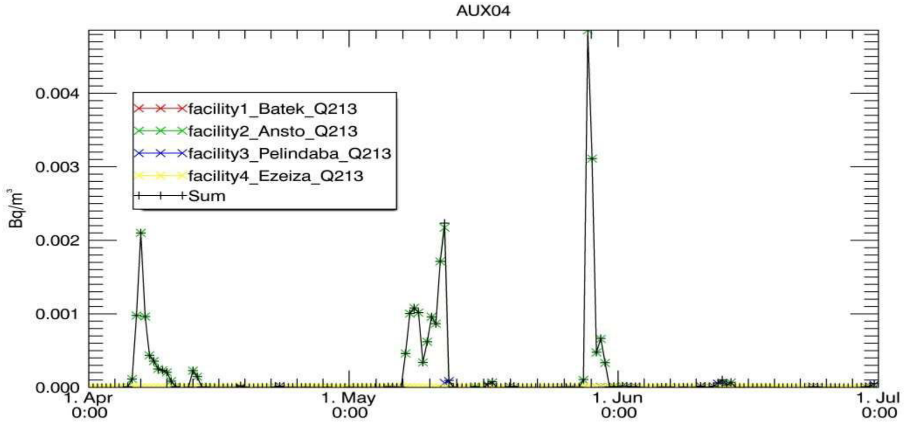
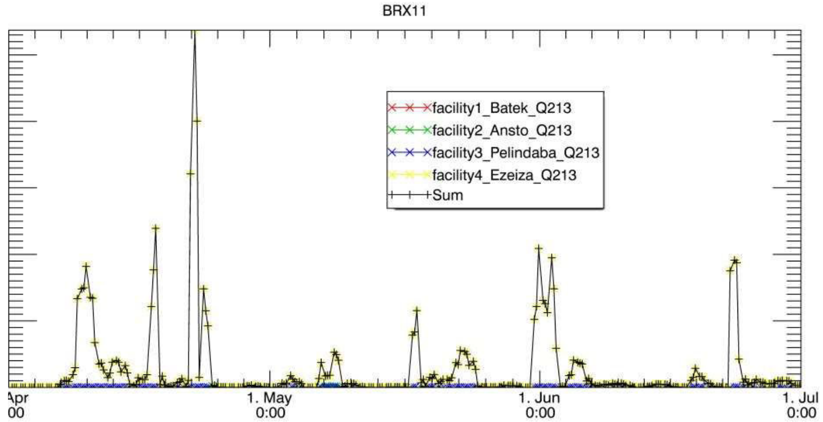
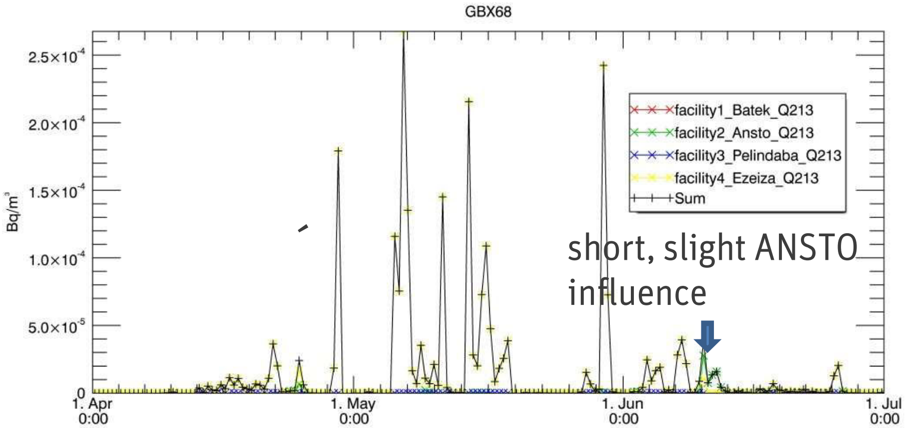
3. The challenge of defining a challenge





Emitter station sensitivities calculated with FLEXPART-ECMWF (WEBGRAPE)



One needs emission data and simultaneous/slightly time shifted IMS samples preferably not influenced by not quantified emissions!

- AUX04, AUX09, FRX27 and NZX46: only influenced by ANSTO, statistics can be calculated. But of course there may be unknown sources.

- BRX11: no reliable ANSTO influence
- GBX68: slight, short ANSTO influence, chosen due to big distance to source (11900 km)

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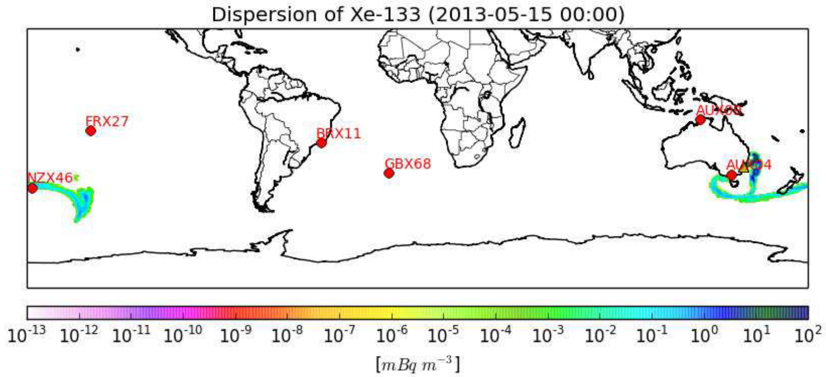
4. Participants: from all over the world

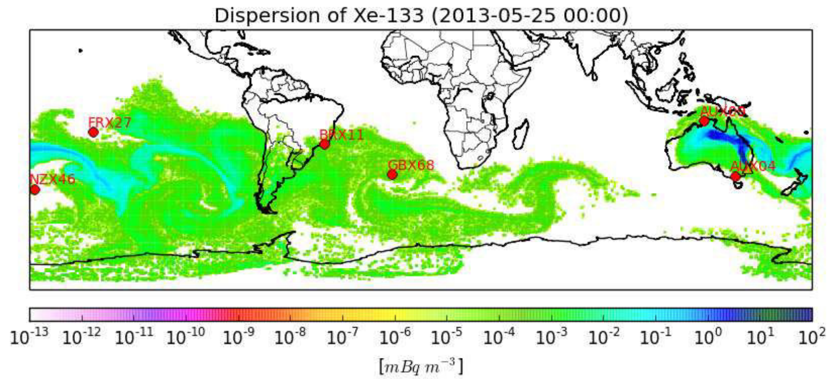
Table 1: Participants of the ATM-Challenge. **Organizations already participating in the last challenge.** *No blind test, since participants were involved in the scenario team drafting the challenge.

Organization Abbreviation	Name of participant(s)	Organization full name	Submission(s)
ARPANSA	Blake Orr	Australian Radiation Protection and Nuclear Safety Agency, Yallambie/Miranda, Australia	ARPANSA
BOKU	**Petra Seibert & Anne Philipp**	**University of Natural Resources and Life Sciences, Faculty of Earth Sciences & University of Vienna, Institute for Meteorology and Geophysics, Vienna, Austria**	$BOKU_{1-6}$
BGR	Ole Ross	**Federal Institute for Geosciences and Natural Resources (BGR), Hannover, Germany**	BGR
CEA	**Sylvia Generoso & Pascal Achim**	**Commissariat à l'Énergie Atomique, Arpajon, France**	CEA_{1-2}
CTBTO	**Jolanta Kusmierczyk-Michulec**	**Comprehensive Nuclear Test-Ban Treaty Organization, International Data Center, Vienna, Austria**	$CTBTO_1$*
CTBTO	Michael Schoeppner	Comprehensive Nuclear Test-Ban Treaty Organization, International Data Center, Vienna, Austria	$CTBTO_2$
ECCC-CMC	**Alain Malo**	**Environment and Climate Change Canada, Meteorological Service of Canada, Canadian Meteorological Centre, Environmental Emergency Response Section, RSMC Montreal, Dorval, Québec, Canada**	CMC_{1-2}
FOI	Anders Ringbom	Swedish Defence Research Agency, Stockholm, Sweden	FOI
IRSN	**Olivier Saunier, Denis Quelo, Anne Mathieu**	**French Institute for Radiation protection and Nuclear Safety, Fontenay-aux-Roses, France**	IRSN
JAEA	**Yuichi Kijima**	**Japan Atomic Energy Agency, Tokai, Ibaraki, Japan**	JAEA
NOAA-ARL	**Alice Crawford, Ariel Stein, Tianfeng Chai, Fong Ngan**	**National Oceanic and Atmospheric Administration Air Resources Laboratory, College Park, Maryland, USA**	NOAA-ARL_{1-4}
PNNL	**Paul W. Eslinger**	**Pacific Northwest National Laboratory, Richland, Washington, USA**	PNNL
Princeton University	**Michael Schoeppner**	**Program on Science and Global Security, Princeton, New Jersey, USA**	PU
Met.Office	Susan Leadbetter	Met. Office, Exeter, Devon, UK	
SCK•CEN RMI	Pieter De Meutter & Andy Delcloo	Belgian Nuclear Research Center, Mol, Belgium & Royal Meteorological Institute of Belgium, Brussels, Belgium	SCKCEN RMI_{1-2}
UK-NDC	**Rich Britton& Ashley Davies**	**UK-NDC, Aldermaston, Reading, UK**	UK-NDC
ZAMG	**Christian Maurer**	**Zentralanstalt fuer Meteorologie und Geodynamik, Vienna, Austria**	ZAMG*

17 participants from 10 different countries all over the world by Dec., 31st. 12 had already participated in the previous challenge.



AUX04 and NZX46 are hit around 15/5/2013 for the first time, remaining stations around 25/5/2013.



5. Participants: meta data

Submission-ID	ATM	NWP model	Met. δx and δy (° or km)	Met. δt (h)	Out. δx and δy (° or km)	Out. δt (h)	Model time dir.	Emiss. seg. res.	Num. o. part. rel. p. hour
ARPANSA	HYSPLIT ver. 0711	NCEP-GFS	1.0°	3	0.5°	3	Forw.	daily	20833
$BOKU_1$	FLEXPART $9.2_{beta.r3}$	ECMWF	0.125°	1	1.0° to 10 km (10 km x 100 m aver.)	1	Backw.	all	13441
$BOKU_2$	FLEXPART $9.2_{beta.r3}$	ECMWF	0.125°	1	1.0° to 10 km (10 km x 500 m aver.)	1	Backw.	all	13441
$BOKU_3$	FLEXPART $9.2_{beta.r3}$	ECMWF	0.125°	1	1.0° to 10 km (10 km x 1000 m aver.)	1	Backw.	all	13441
$BOKU_4$	FLEXPART $9.2_{beta.r3}$	ECMWF	0.125°	1	1.0° to 10 km (70 km x 500 m aver.)	1	Backw.	all	13441
$BOKU_5$	FLEXPART $9.2_{beta.r3}$	ECMWF	0.125°	1	1.0° to 10 km (130 km x 1000 m aver.)	1	Backw.	all	13441
$BOKU_6$	FLEXPART $9.2_{beta.r3}$	ECMWF	0.125°	1	1.0° to 10 km (250 km x 1000 m aver.)	1	Backw.	all	13441
BGR	HYSPLIT	NCEP-GDAS	0.5°	3	0.5°	3	Forw.	daily	20800
CEA_1	FLEXPART 8.2, variable time step	NCEP-GFS	0.5°	6	recep. point output	1	Forw.	all	416666 to 1000000
CEA_2	FLEXPART 8.2, fixed time step	NCEP-GFS	0.5°	6	recep. point output	1	Forw.	all	416666 to 1000000
CMC_1	MLPD	GDPS-analysis	0.22°x0.35°	6	0.25°	0.0833 (5 min)	Forw.	daily, half-daily, 3-hourly	41667 to 333333
CMC_2	MLPD	GDPS-forecast	0.22°x0.35°	3	0.25°	0.0833 (5 min)	Forw.	daily, half-daily, 3-hourly	41667 to 333333
$CTBTO_1$	FLEXPART 9.2	ECMWF	0.5°	3	0.5°	3	Forw.	daily, half-daily, 3-hourly	83333 to 666670
$CTBTO_2$	FLEXPART-WRF	WRF(NCEP)	1.0° to 20km	1	20km	1	Backw.	hourly	83000
FOI	HYSPLIT ver. 20150916	NCEP-GDAS	1.0°	3	1.0°	3	Forw.	daily, 3-hourly	20833 and 166666
IRSN	IdX-C3X	ARPEGE	0.5°	3	0.5°	1	Forw.	all	Eulerian
JAEA	HYSPLIT ver. 4	NCEP-GDAS	0.5°	3	0.5°	1	Forw.	daily, half-daily	16666
NOAA-ARL_1	HYSPLIT	ECMWF-ERA-Interim	0.75°	3	1.0°	0.25	Forw.	all	250000
NOAA-ARL_2	HYSPLIT	NCEP-GDAS	1.0°	3	1.0°	0.25	Forw.	all	250000
NOAA-ARL_3	HYSPLIT-GEM	NCEP-GDAS	1.0°	3	1.0°	0.25	Forw.	all	250000
NOAA-ARL_4	HYSPLIT	NCEP-NCAR	2.5°	6	1.0°	0.25	Forw.	all	250000
PNNL	HYSPLIT par. ver. 0113	NCEP-GDAS	1.0°	3	0.5°	1	Forw.	all	416667 to 500000
PU	FLEXPART 8.23	NCEP-GDAS	0.5°	3	0.5°	3	Backw.	3-hourly	83000
Met.Office	NAME	Met Office Unified Model-Global	0.35°x0.23°	3	1.0°	0.25	Forw.	all	42000
SCKCEN RMI_1	FLEXPART 9.02	ECMWF	1.0°	3	1.0°	1	Forw.	all	100000
SCKCEN RMI_2	FLEXPART 9.02	ECMWF	0.5°	3	0.5°	1	Forw.	all	100000
UK-NDC	FLEXPART	ECMWF	1.0°	3	1.0°	3	Backw.	daily	50000 to 100000
ZAMG	FLEXPART 8.23	ECMWF	0.5°	3	0.5°	1	Forw.	all	80645

- Contributions per organization: up to 6
- Models: HYSPLIT (8 runs), FLEXPART (15), MLPD (2), IdX (1), NAME (1), HYSPLIT-GEM (1)
- NWP data: ECMWF, ECMWF ERA-Interim, NCEP-GFS, NCEP-GDAS, NCEP-NCAR, GDPS, WRF, ARPEGE, Met Office Unified Modell-Global
- Modell direction: 19 forward, 9 backward
- Horizontal (extracted) meteorological resolution: 0.125° to 2.5°
- Horizontal model output resolution: 0.125° to 1.0°

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6. Overall statistics

Table 4: Average statistics per submission-ID over all time resolutions and stations AUX04, AUX09, FRX27, NZX46 and GBX68 ordered by Rank. *: GBX68 not available. **: FRX27, BRX11 and GBX68 not available.+: GBX68 not considered.++: Undefined statistical scores for GBX68.

Submission-ID	R	FB	F5 [%]	RMSE	NMSE	ACC [%]	NAAD [%]	CR (t)	Rank
$BOKU_6$	0.44	-1.63	7	0.16	6.1E8	79	104	0.75 (-10)	1.34
$BOKU_5$	0.60	-1.50	8	0.18	6484	79	104	0.73 (-11)	1.50^{++}
$BOKU_1$	0.64	-1.40	8	0.17	9356	79	100	0.73 (-11)	1.51^{++}
$BOKU_4$	0.62	-1.46	8	0.18	6963	79	104	0.73 (-11)	1.51^{++}
$BOKU_{1-6}$	0.62	-1.46	8	0.18	6979	79	102	0.73 (-11)	1.51^{+}
$BOKU_2$	0.65	-1.43	8	0.17	6662	79	101	0.74 (-11)	1.53^{++}
$BOKU_3$	0.64	-1.45	8	0.17	7088	79	100	0.73 (-11)	1.54^{++}
NOAA-ARL_4	0.18	-0.57	16	0.19	34	79	116	0.68 (-6)	1.67
CMC_2	0.45	-0.38	15	0.37	199	81	216	0.70 (12)	1.68
UK-NDC	0.48	-0.31	19	0.25	48	80	198	0.76 (8)	1.69
IRSN	0.43	-0.13	17	0.40	20	77	165	0.64 (15)	1.76^{++}
CMC_{1-2}	0.41	-0.48	19	0.31	205	81	173	0.66 (13)	1.78
$CTBTO_2$	0.67	0.59	15	0.75	61	86	456	0.74 (-1)	1.78^{**}
NOAA-ARL_1	0.48	-0.33	15	0.35	46	82	200	0.71 (3)	1.78
CMC_1	0.42	-0.51	25	0.25	210	81	141	0.66 (13)	1.97
$CTBTO_{1-2}$	0.54	0.92	34	1.05	45	82	403	0.71 (7)	1.98
BGR	0.56	0.09	35	0.32	115	81	261	0.73 (6)	2.03
$CTBTO_1$	0.50	1.00	39	1.13	41	81	389	0.70 (9)	2.03^{*}
NOAA-ARL_{1-4}	0.47	-0.23	28	0.23	28	83	138	0.71 (2)	2.03
FOI	0.56	0.08	29	0.35	54	85	162	0.70 (6)	2.06
JAEA	0.49	0.28	41	0.43	45	81	365	0.67 (6)	2.06
PU	0.55	0.23	30	0.45	38	82	222	0.74 (6)	2.09^{**}
CEA_1	0.58	0.92	40	1.11	48	82	404	0.73 (9)	2.11
NOAA-ARL_2	0.56	0.00	28	0.25	21	83	140	0.72 (6)	2.11
CEA_{1-2}	0.55	0.67	39	0.81	38	82	293	0.72 (8)	2.14
ZAMG	0.53	-0.36	33	0.24	23	83	114	0.76 (5)	2.12
CEA_2	0.53	0.47	38	0.52	34	83	206	0.73 (4)	2.15
PNNL	0.57	0.10	35	0.23	25	82	134	0.78 (6)	2.23
Met.Office	0.56	-0.15	36	0.20	15	82	129	0.70 (11)	2.27
$SCKCENRMI_2$	0.64	-0.18	39	0.36	26	84	170	0.80 (7)	2.33
$SCKCENRMI_{1-2}$	0.66	-0.11	44	0.28	21	84	146	0.79 (5)	2.41
$SCKCENRMI_1$	0.68	-0.04	49	0.21	16	84	122	0.77 (3)	2.48
NOAA-ARL_3	0.60	-0.14	49	0.17	13	87	90	0.70 (12)	2.51
ARPANSA	0.73	0.02	55	0.23	14	88	125	0.73 (0)	2.66
Average	0.53	-0.21	25	0.37	1839	80	191	0.73 (2)	1.90^{+}

- The overall correlation of 0.53 is rather moderate, an average time shift of two sample periods increases correlation significantly.
- We slightly underestimate the measured values (FB).
- RMSE of around +/- 0.4 mBq/m3 has to be seen under the light of rather small simulated and measured values (NMSE).
- The Normalized Average Absolute Deviation, which excludes time steps for which simulations and measurements add up to zero, gives around 191%.
- According to the Accuracy (ACC) detection and non-dections could be discriminated on average in 80% of the cases.

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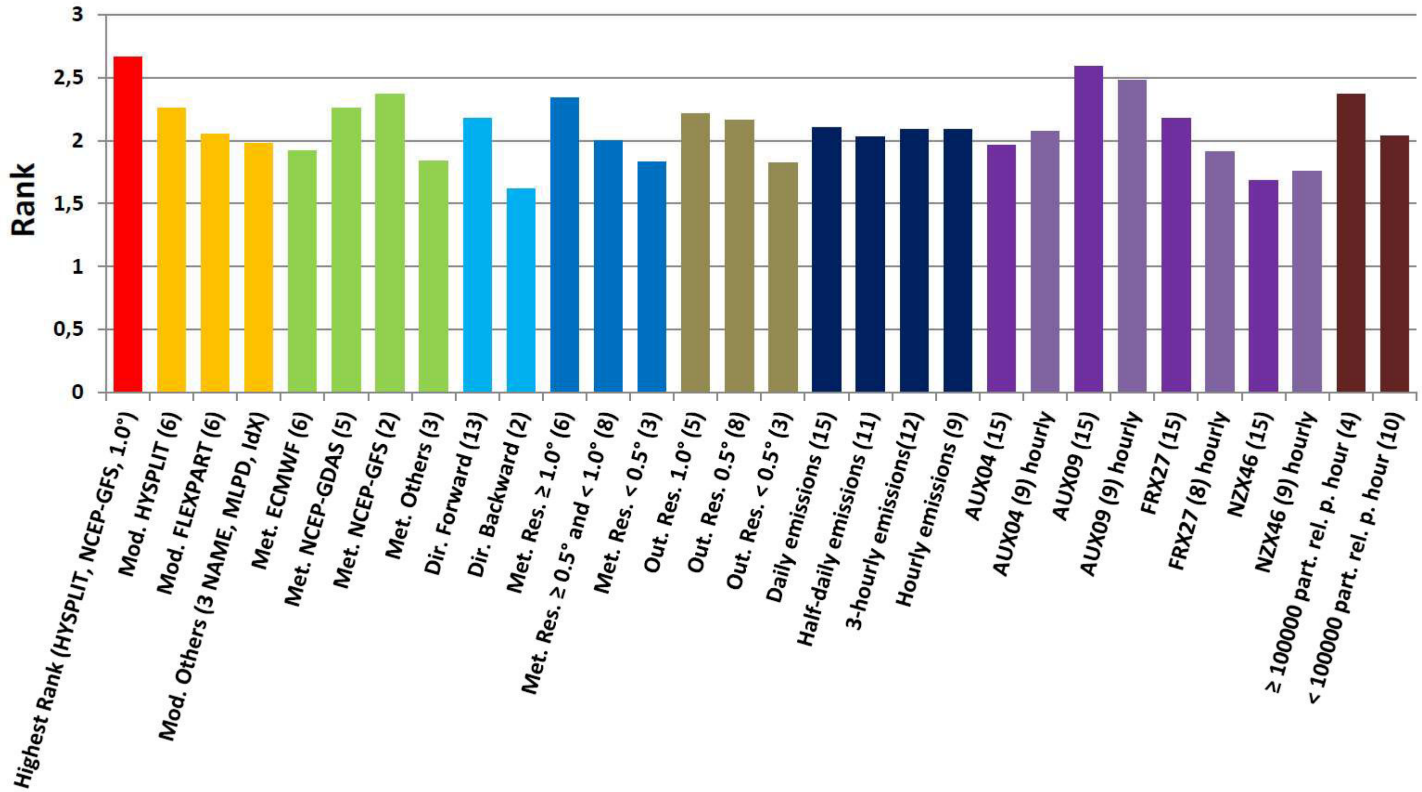
7. Statistics splitted according to meta data



Common characteristics with Challenge-2015:

- Relation of highest to average Rank, although at lower absolute level
- Forward better than backward (technical reasons under discussion)
- Meteorological and output field resolution < 1.0° yields no advantage
- Daily resolved emission values do not result in any disadvantage compared to higher resolved ones.

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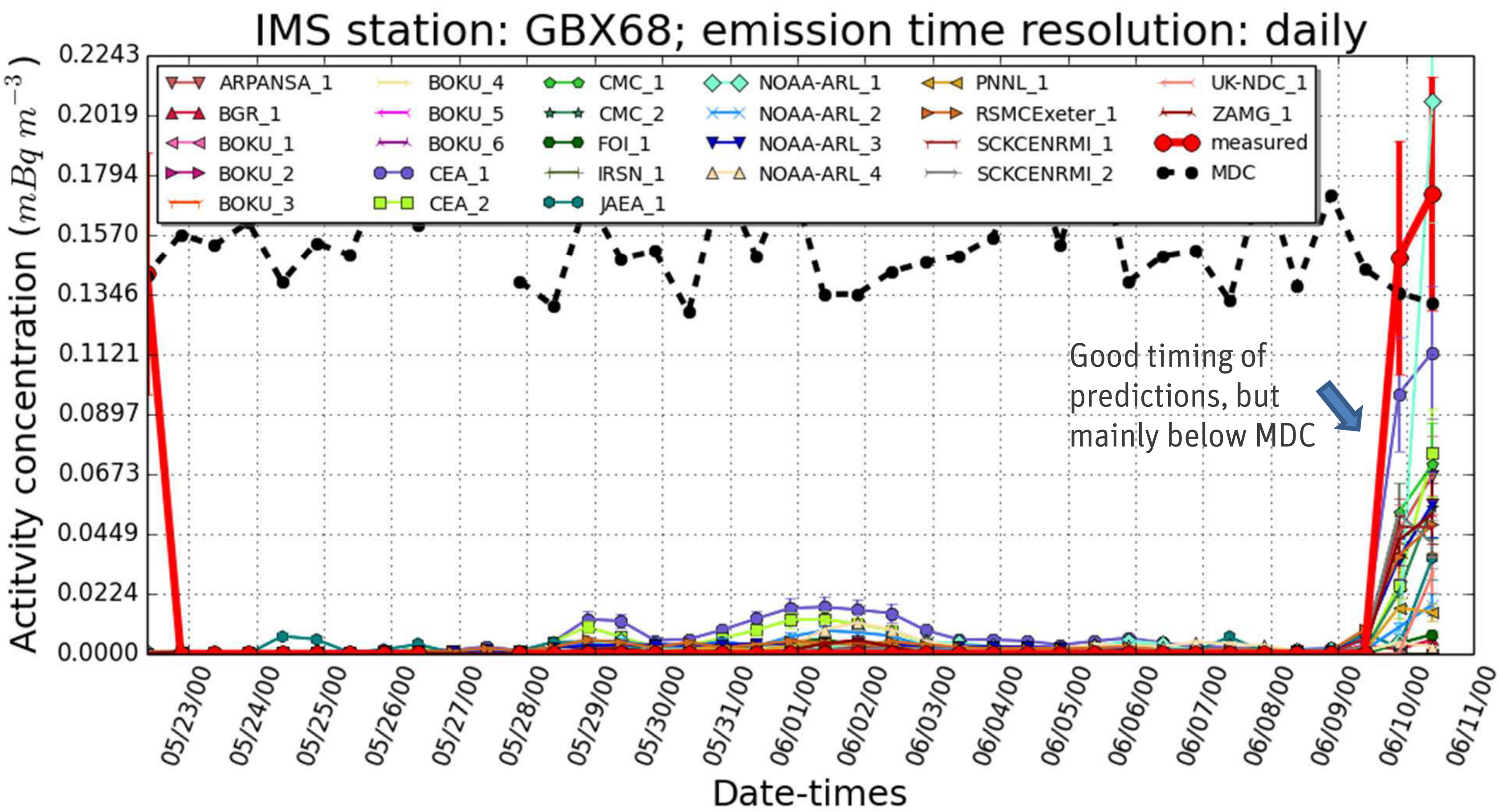
8. Time series for GBX68 (Tristan da Cunha) for daily source resolution

Good news: ATM can yield reasonable results even 12000 km away from source



Topographic characteristics: 56 m a.s.l., distance to source ~11900 km, station on island (volcano)

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9. Conclusions I

- The performance of individual submissions at individual stations is quite diverse. There exists no single model-meteorology combination which performs best for all stations (and daily source time resolution).
- However, the finding of the 1st Challenge that a coarse (extracted) resolution of meteorology (1°) and a coarse resolution of the source (daily) is not detrimental is supported. The overall best run for Challenge-2016 uses 1° data and daily emission chunks.
- Also the finding that forward simuations are superior to backward simulations is supported. CTBTO collection times (12 or 24 hours) may be the reason for this.

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9. Conclusions II

- The station statistics do not depend on the distance between the source and the individual stations. Remote stations can have better statistics than close ones (e.g. FRX27 vs. AUX04).
- Assuming a more conservative uncertainty of around 20% in the daily stack emission values does not account for most of the observed deficiencies in the predictions.
- The average deviation for simulated values with measurements or simulations above MDC adds up to 200% considering also phase shifts of simulations with regard to measurements.

Paper in preparation: "*International challenge to model the long-range transport of radio-xenon released from medical isotope production to six Comprehensive Nuclear Test-Ban Treaty monitoring stations*"

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10. Outlook

- ATM Challenge side meeting on 26 June during S&T 2017: Participants views, feedback and ideas how to proceed
- From a scientific point of view: Scenario with multiple IMS stations hit regularly by known emitters over an extended period in order to end up with more significant statistics would be desirable.
- Also, more of the model parameters (like the meteorological driver, emission segment length, meteorological input and model output grid resolution) should be pre-scribed for a more coherent analysis.

THANK YOU FOR YOUR ATTENTION!

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