International challenge to model the long-range transport of radioxenon released from medical isotope production to six Comprehensive Nuclear Test-BanTreaty monitoring stations

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H18-131

Summary

After a first Atmospheric Transport Modelling (ATM) challenge in 2015, a second, more comprehensive and technically more demanding challenge was conducted within the Comprehensive nuclear Test-Ban Treaty (CTBT) context in 2016. One aim of this exercise was again to *ascertain the level of agreement one can achieve between real International Monitoring System (IMS) measurements and those simulated using only stack release data of Xe-133 and ATM*. Another aim consisted in gaining further evidence of an optimal parameter setting (like temporal resolution of emissions) for predicting industry related radioxenon samples at IMS stations. Whereas the distance between the source (IRE, Belgium) and the selected IMS station (Schauinsland, Germany) added up to around 380 km in 2015's exercise, distances between the source (ANSTO, Australia) and the selected IMS stations - six in the Southern Hemisphere - vary between 670 (Melbourne, Australia) and around 13,500 km (Rio de Janeiro, Brazil) for the current exercise. The 1st and the 2nd ATM Challenge are the first two in a row of exercises that will continue in the coming years. Ideally one would like to have a scenario with multiple IMS stations hit regularly by several known emitters over an extended period in order to end up with significant statistics. Further, different, prescribed model parameters (like resolution) should be explored in a more coherent manner. Prescribing emission segments was a first step to overcome the risk of lacking comparability. In order to prevent participants from being guided by expectations it was tried to undertake a blind test as much as possible. For this purpose a unit emission approach with prescribed emission intervals was applied. Nevertheless, the challenge had 17 participating organizations from all over the world. Scaling with the real ANSTO emissions was done in a post-processing step. Several statistical metrics were calculated, including a rank measure, for four out of the six stations. Those stations were found to be very likely influenced at least only by one main emitter, i.e. ANSTO.

Paper submitted to Journal of Environmental Radioactivity and currently under revision: ***"International challenge to model the long-range transport of radioxenon released from medical isotope production to six Comprehensive Nuclear Test-Ban Treaty monitoring stations"***

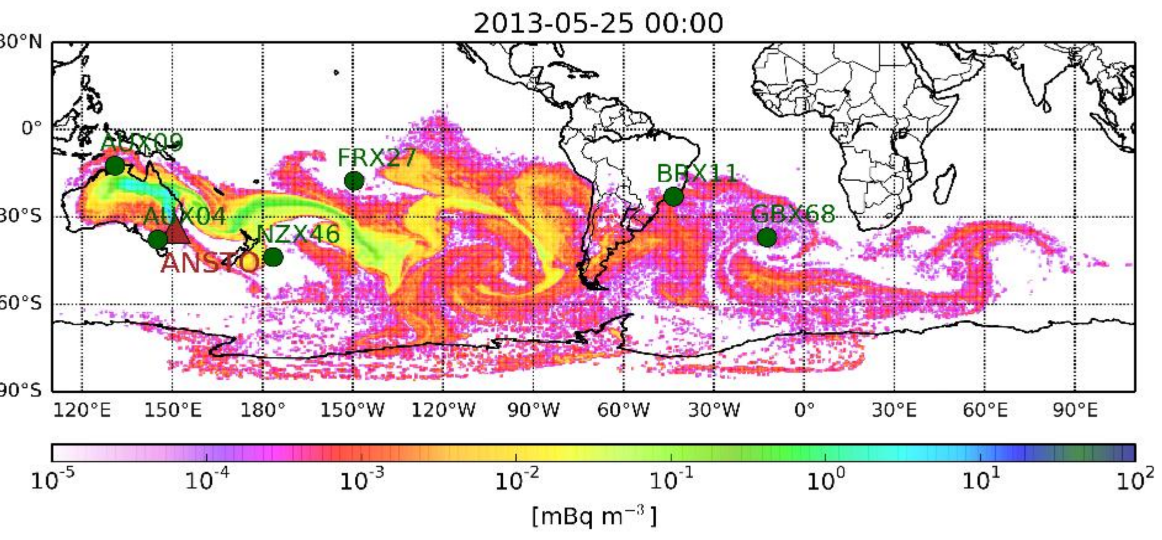
Participants and overall statistics of the 2nd ATM Challenge 2016

Table 1: Participants of the ATM Challenge. Organizations participating in the 1st challenge are printed **bold**. *No blind test, involved in drafting the challenge.

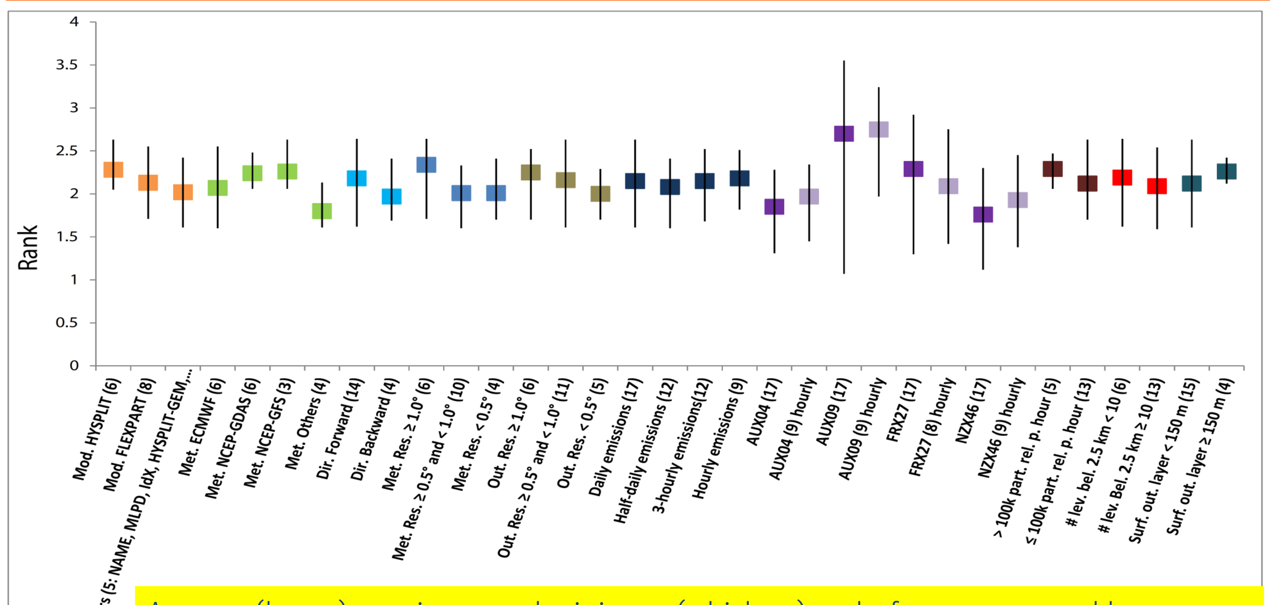
Organization Abbreviation	Name(s) of participant(s)	Organization full name	Submission(s)
ARPANSA	Blake Orr	Australian Radiation Protection and Nuclear Safety Agency, Yallambie/Miranda, Australia	ARPANSA
BOKU	Petra Seibert & Anne Philipp	University of Natural Resources and Life Sciences, Institute of Meteorology & University of Vienna, Department of 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
LLNL	Lee G. Glascoe, Donald D. Lucas, Matthew D. Simpson, Phil Vogt	National Atmospheric Release Advisory Center (NARAC) at the Lawrence Livermore National Laboratory (LLNL), Livermore, California, USA	$LLNL_{1-2}$
Met. Office	Susan J. Leadbetter	Met. Office, Exeter, Devon, UK	METOFFICE
NOAA-ARL	Alice Crawford, Ariel Stein, Tianfeng Chai, Fong Ngan	National Oceanic and Atmospheric Administration Air Resources Laboratory, College Park, Maryland, USA	$NOAA\text{-}ARL_{1-4}$
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
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	United Kingdom-National Data Center (NDC), Aldermaston, Reading, UK	UK-NDC
ZAMG*	Christian Maurer	Zentralanstalt fuer Meteorologie und Geodynamik, Vienna, Austria	ZAMG

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, and GBX68 not available. +: GBX68 not considered. ++: Undefined statistical scores for GBX68.

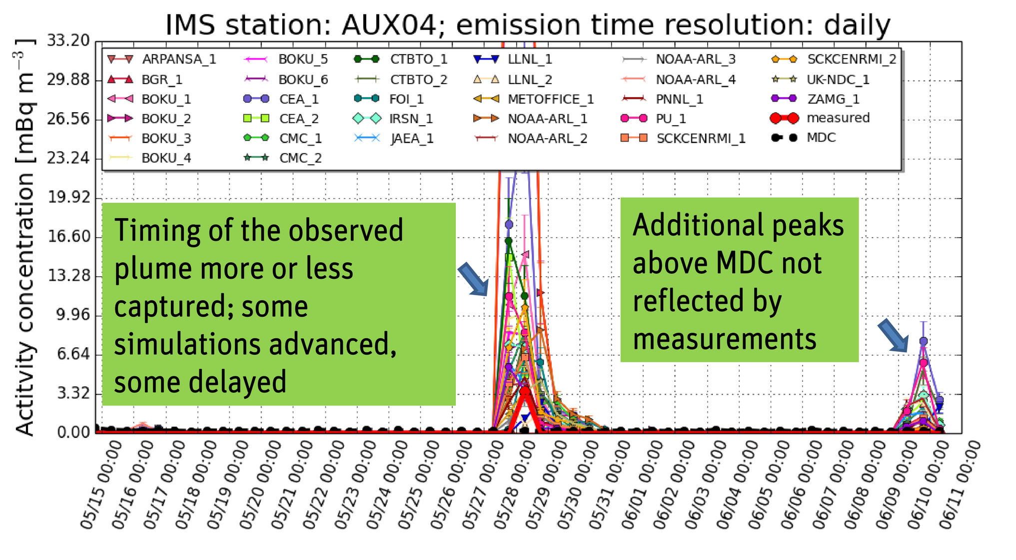
Submission-ID	R	FB	F5 [%]	RMSE	NMSE	ACC [%]	NAAD [%]	CRmax ($\hat{t}$)	**Rank**
ARPANSA	**0.73**	0.02	**55**	0.23	14	**88**	125	0.73 **(0)**	**2.66**
$NOAA\text{-}ARL_3$	0.60	-0.14	49	**0.17**	**13**	87	**90**	0.70 (12)	**2.51**
$SCKCENRMI_1$	0.68	-0.04	49	0.21	16	84	122	0.77 (3)	**2.48**
$SCKCENRMI_{1-2}$	0.66	-0.11	44	0.28	21	84	146	0.79 (5)	**2.41**
$SCKCENRMI_2$	0.64	-0.18	39	0.36	26	84	170	**0.80** (7)	**2.33**
METOFFICE	0.56	-0.15	36	0.20	15	82	129	0.70 (11)	**2.27**
PNNL	0.57	0.10	35	0.23	25	82	134	0.78 (6)	**2.23**
$BOKU_6$	0.51	-0.01	30	0.29	25	85	146	0.67 (3)	**2.16**
CEA_2	0.53	0.47	38	0.52	34	83	206	0.73 (4)	**2.15**
CEA_{1-2}	0.55	0.67	39	0.81	38	82	293	0.72 (8)	**2.14**
$BOKU_5$	0.48	0.02	29	0.34	29	84	161	0.67 (1)	**2.12**
ZAMG	0.53	-0.36	33	0.24	23	83	114	0.76 (5)	**2.12**
$NOAA\text{-}ARL_2$	0.56	**0.00**	28	0.25	21	83	140	0.72 (6)	**2.11**
CEA_1	0.58	0.92	40	1.11	48	82	404	0.73 (9)	**2.11**
$BOKU_1$	0.48	0.27	30	0.55	38	84	245	0.70 (1)	**2.10**
PU	0.55	0.23	33	0.47	37	82	245	0.74 (6)	**2.09**
$BOKU_4$	0.47	0.12	30	0.42	33	85	188	0.68 (-3)	**2.08**
$LLNL_2$	0.42	0.23	31	0.26	18	82	164	0.70 (6)	**2.08**
JAEA	0.49	0.28	41	0.43	45	81	365	0.67 (6)	**2.06**
FOI	0.56	0.08	29	0.35	54	85	162	0.70 (6)	**2.06**
$LLNL_1$	0.58	-0.50	23	0.18	52	84	114	0.71 (6)	**2.06**
$NOAA\text{-}ARL_{1-4}$	0.47	-0.23	28	0.23	28	83	138	0.71 (2)	**2.03**
$CTBTO_1$	0.50	1.00	39	1.13	41	81	389	0.70 (9)	**2.03***
BGR	0.56	0.09	35	0.32	115	81	261	0.73 (6)	**2.03**
$LLNL_{1-2}$	0.48	-0.17	27	0.22	35	83	140	0.68 (6)	**2.02**
$BOKU_{1-6}$	0.48	0.51	29	1.19	85	82	511	0.69 (-1)	**1.98**
CMC_1	0.42	-0.51	25	0.25	210	81	141	0.66 (13)	**1.97**
$CTBTO_{1-2}$	0.48	0.60	25	0.74	44	87	305	0.66 (11)	**1.86****
$NOAA\text{-}ARL_1$	0.48	-0.33	15	0.35	46	82	200	0.71 (3)	**1.78**
CMC_{1-2}	0.41	-0.48	19	0.31	205	81	173	0.66 (13)	**1.78**
IRSN	0.43	-0.13	17	0.40	20	77	165	0.64 (15)	**1.76**++
$CTBTO_2$	0.63	0.54	15	0.68	51	85	403	0.74 (-1)	**1.74****
$BOKU_2$	0.48	1.29	26	2.65	178	79	1095	0.70 (-2)	**1.73**
UK-NDC	0.48	-0.31	19	0.25	48	80	198	0.76 (8)	**1.69**
CMC_2	0.45	-0.38	15	0.37	199	81	216	0.70 (12)	**1.68**
$BOKU_3$	0.48	1.37	26	2.95	201	78	1230	0.70 (-4)	**1.67**
$NOAA\text{-}ARL_4$	0.18	-0.57	16	0.19	34	79	116	0.68 (-6)	**1.67**
Mean	**0.51**	**0.33**	**32**	**0.48**	**44**	**80**	**253**	**0.72 (6)**	**2.06**+
Median	**0.50**	**0.26**	**32**	**0.36**	**25**	**80**	**221**	**0.72 (7)**	**2.07**+

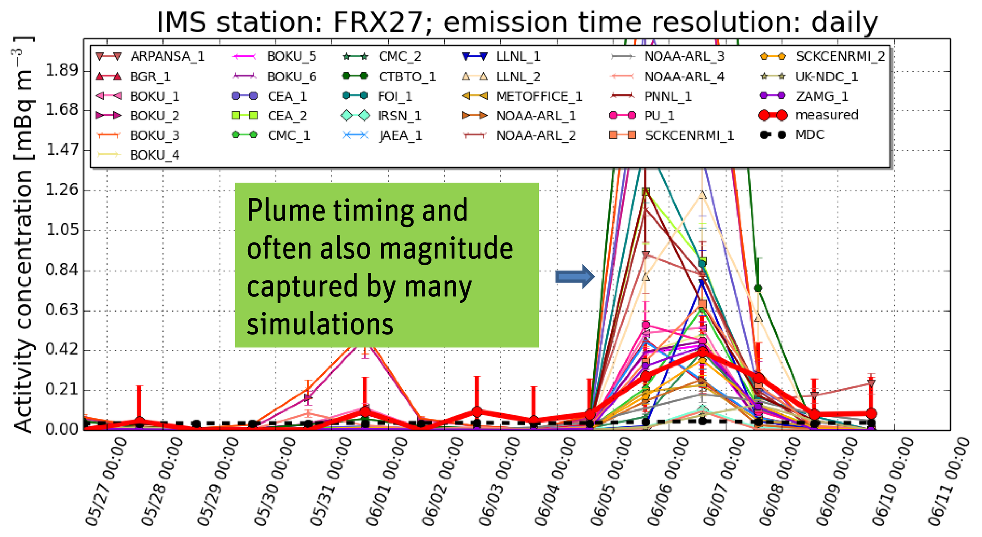


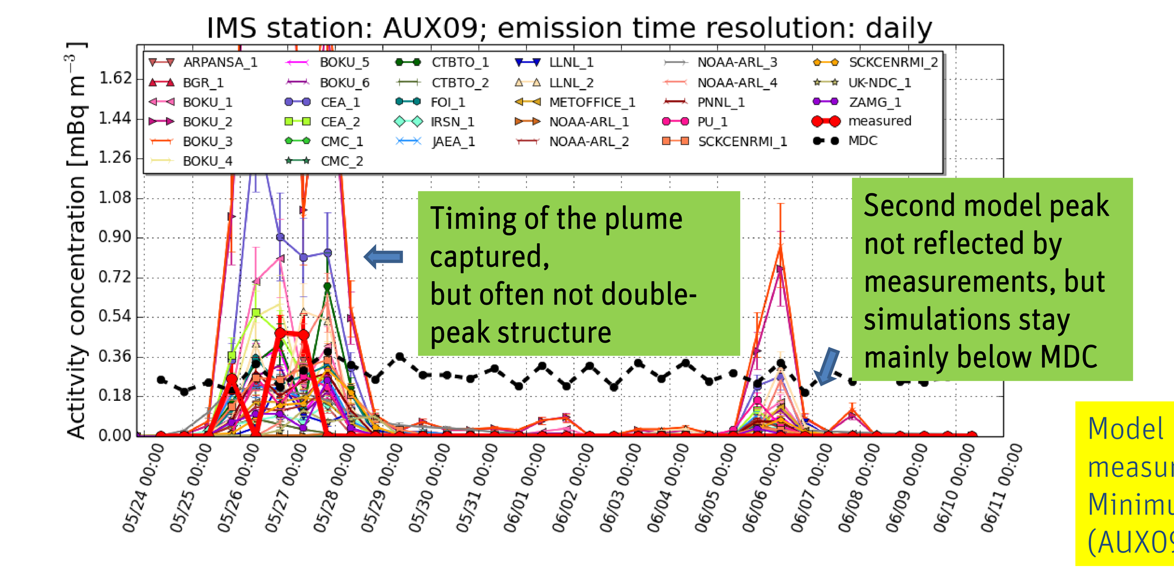
Detailed analysis



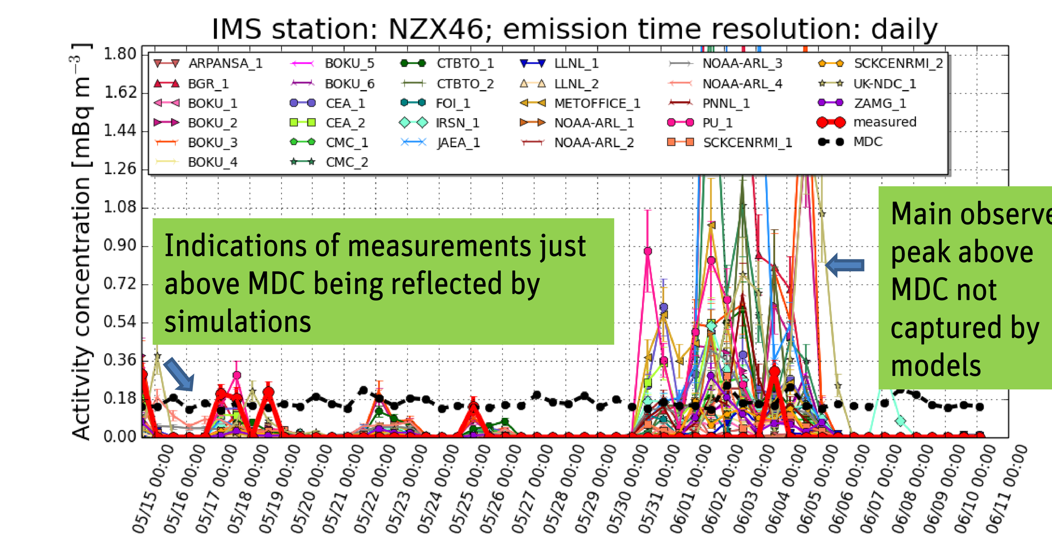
Average (boxes), maximum and minimum (whiskers) ranks for runs grouped by common characteristics. All values pertain to runs based on daily emissions if not indicated otherwise in the bar label. Numbers in brackets give the number of contributing runs.

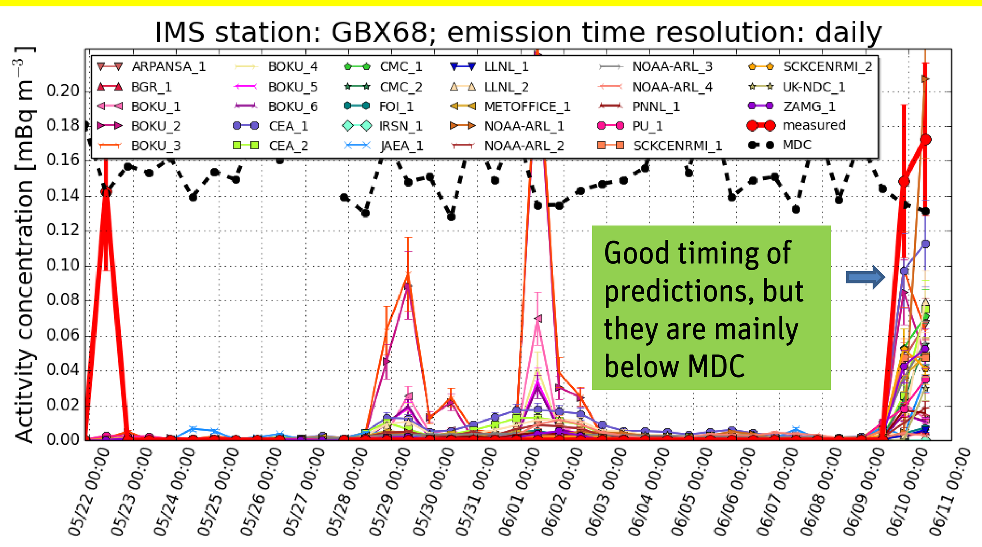




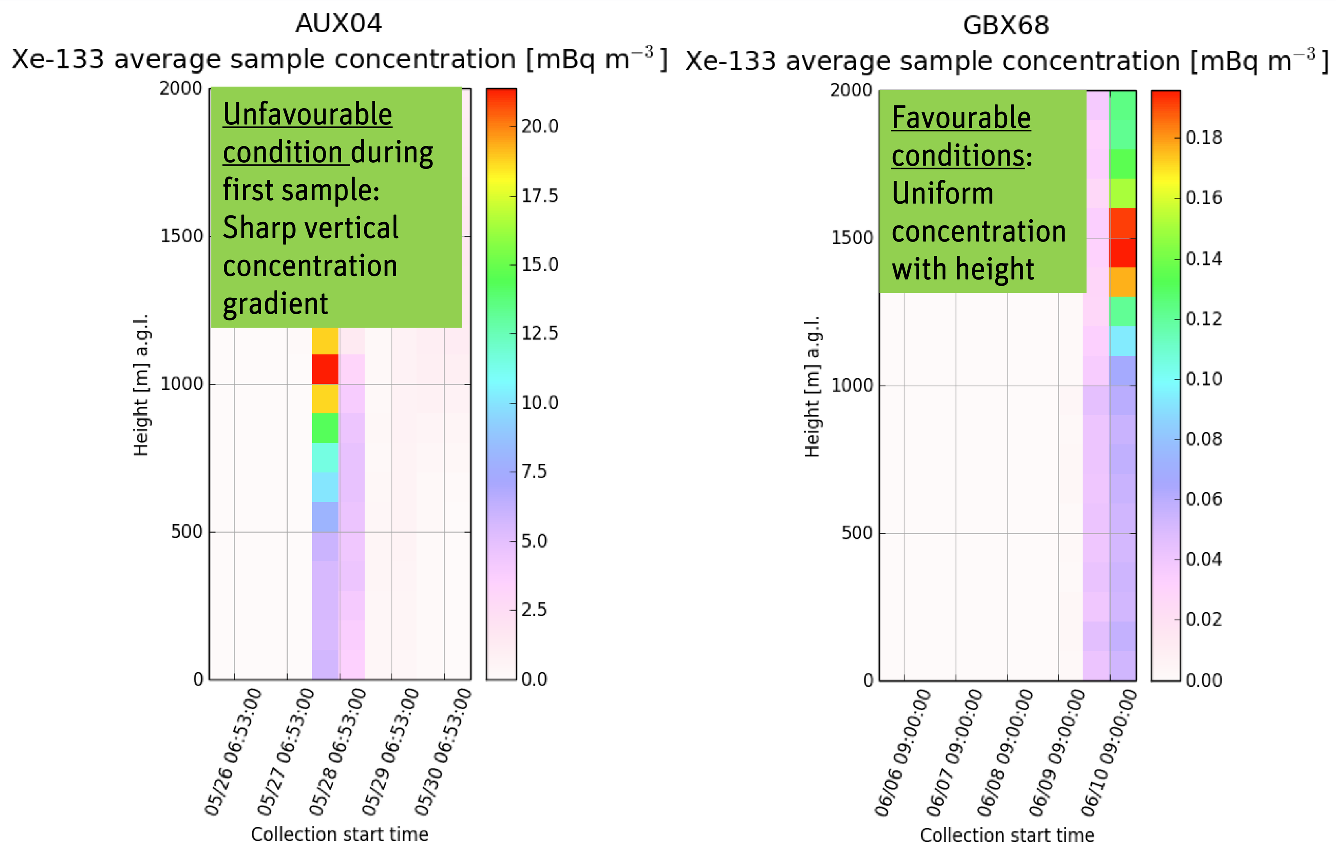


Model simulations with error bars due to errors in the measurement system at the stack, measurements with error bars due to errors in the measurement system at the station and Minimum Detectable Concentrations (MDCs) for IMS stations Melbourne (AUX04), Darwin (AUX09), Chatham Island (NZX46), Papeete/Tahiti (FRX27) and Tristan da Cunha (GBX68).

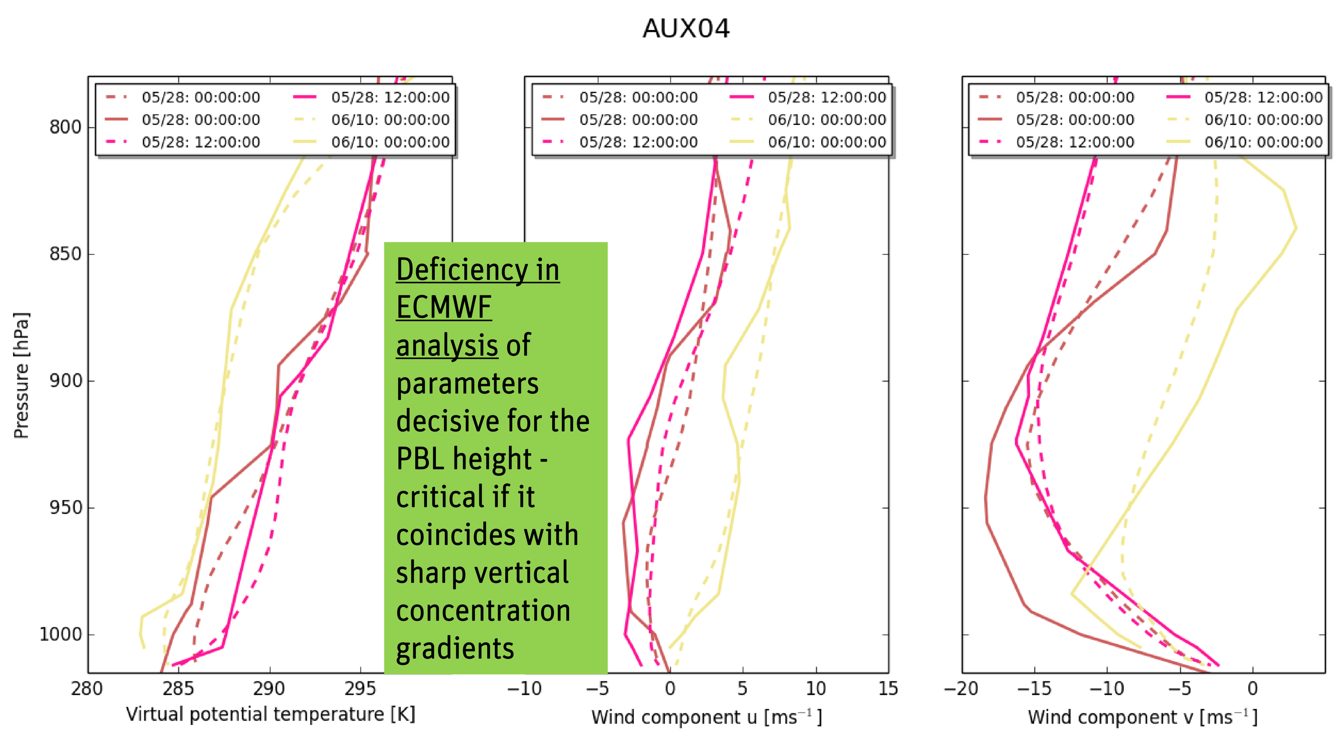




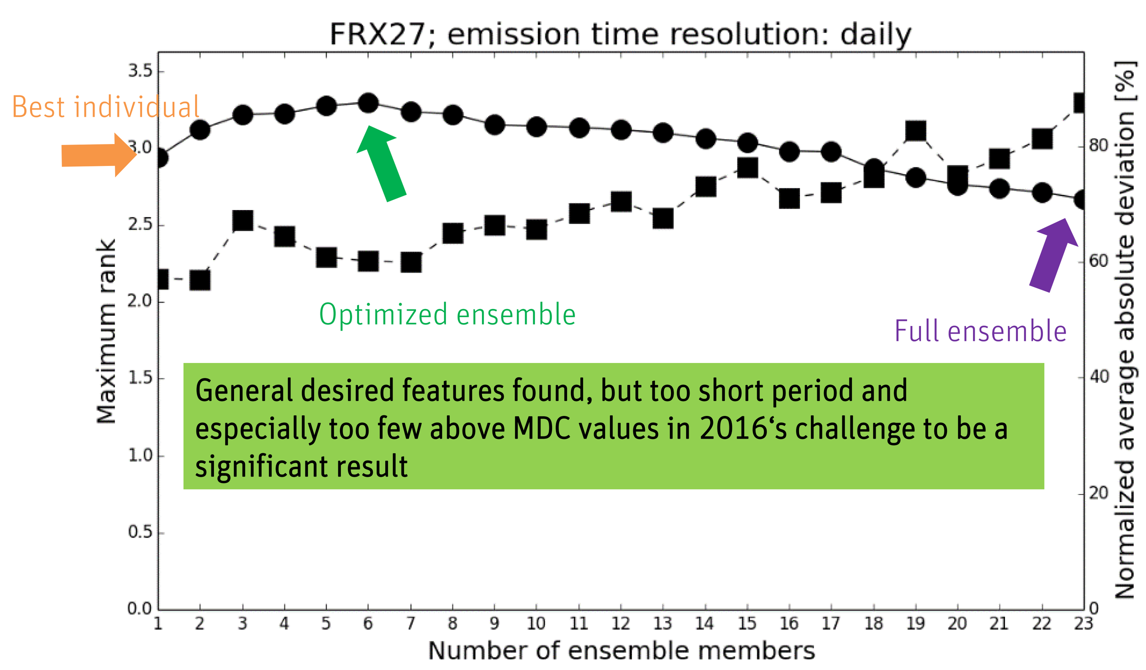
Modelling deficiencies



Upper panel: Time-height cross sections of average concentrations for sample collection times for stations Melbourne (AUX04) and Tristan da Cunha (GBX68) based on the ZAMG-FLEXPART run.
Lower panel: Observed (solid line) and ECMWF model (dashed line) vertical profiles of virtual potential temperature, wind component u and wind component v for the three sample periods with the biggest ZAMG model concentrations in the surface layer (0-100 m a.g.l.).



Ensemble approach



Maximum rank and corresponding normalized average absolute deviation as function of ensemble size.

Aim for a next challenge based on a longer simulation period with lots of above MDC values : <u>Training of an optimized ensemble, which significantly outperforms the full ensemble, but also the best individual run.</u>

Conclusions

- The **performance of individual submissions at individual stations** is **quite diverse**. There exists **no single model-meteorology combination** which **performs best for all stations.**
- 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** for a study like this **is supported**. The overall **best run for Challenge-2016** uses **1° data** and **daily emission chunks.**
- **No specific model-meteorology combination should be preferred.** For each challenge another model and another meteorological input scores best.
- 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 ~250% considering also phase shifts** of simulations with regard to measurements.

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