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Performance Assessment of the High-Resolution Atmospheric Transport Model at the IDC of the CTBTO

Michael Schoeppner, Martin Kalinowski, Jolanta Kusmierczyk-Michulec, Gerald Klinkl
CTBTO, International Data Centre

CTBTO PREPARATORY COMMISSION

Abstract

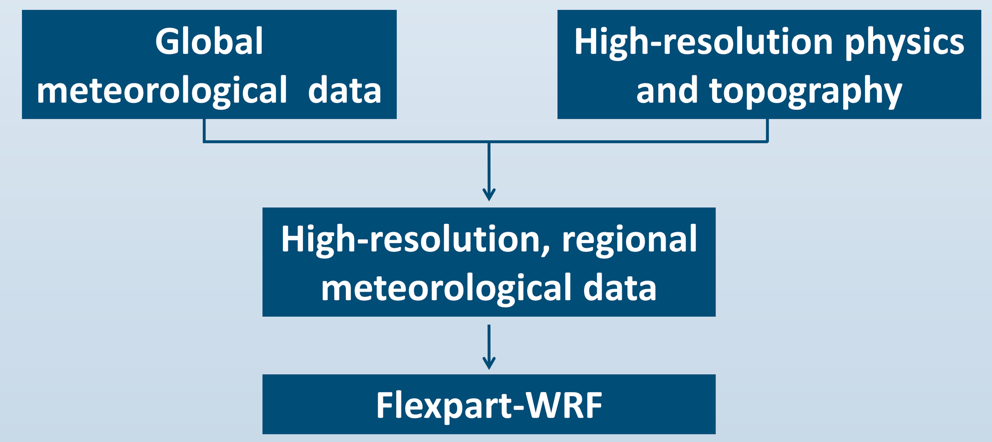
The International Data Centre (IDC) of the CTBTO is developing a capability to do High-Resolution Atmospheric Transport Modelling (HRATM) using Flexpart-WRF. Compared to conventional atmospheric transport modelling, HRATM is folding the available meteorological data in coarse resolution with a static, high-resolution topography of the Earth to create new meteorological data with a resolution down to a few kilometers. The performance of Flexpart-WRF at the IDC is assessed by comparing its output to the results of the 1st and 2nd ATM Challenge. The goal of both international exercises was to predict the impact of known radioxenon releases from a strong regional source on radionuclide stations of the CTBT International Monitoring System (IMS). For both scenarios, the IDC's HRATM installation of Flexpart-WRF is used to simulate the time series of noble gas detections that stem from the major regional emitter and to compare the results with the modelling results of all participants in those challenges.

References

[1] A Description of the Advanced Research WRF Version 3 – William C. Skamarock et al. (NCAR/TN–475+STR NCAR Technical Note, June 2008).
[2] The Lagrangian particle dispersion model FLEXPART-WRF version 3.1 – J. Brioude et al. (Geosci. Model Dev., 6, pp. 1889–1904, 2013).
[3] International challenge to predict the impact of radioxenon releases from medical isotope production on a comprehensive nuclear test ban treaty sampling station – Paul W. Eslinger et al. (Journal of Environmental Radioactivity 157, 41–51, 2016).
[4] Influence of Small-Scale Radioxenon Sources on the Background Levels at CTBT IMS Noble Gas Stations – M. Schoeppner et al. (Poster at Science and Technology 2017)
[5] 2nd ATM challenge 2016 – Christian Maurer (Presentation T1.3-O1 at Science and Technology 2017)

Introduction

A high-resolution atmospheric transport model consisting of the Weather Research and Forecasting Model (WRF) and a special Flexpart version (Flexpart-WRF) was introduced at the IDC.
WRF is folding the conventional met data with a high resolution topography data set to produce improved meterological data for Flexpart-WRF:



The calculation of the refined met data and running an atmospheric transport model with increased resolution both require substantial computational resources. Thus, it would currently not be suitable to run Flexpart-WRF in an operational setting for all radionuclide and noble gas stations. However, scenarios in a regional setting with complex topography could benefit from this method, e.g. case studies or actual events such as unusual detections, nuclear accidents , nuclear tests or On-Site Inspections.
The early stages of development of the high-resolution ATM capability at the IDC aims at validation through the radioxenon background based on stack emission data and the influence on downwind noble gas stations.

WRF Enhancement methods

The high-resolution geophysical fields allows WRF to modulate the conventional meteorological data to higher resolution, see Figure 1 below. The wind gradient around the mountain would not have been resolved by coarser wind fields.

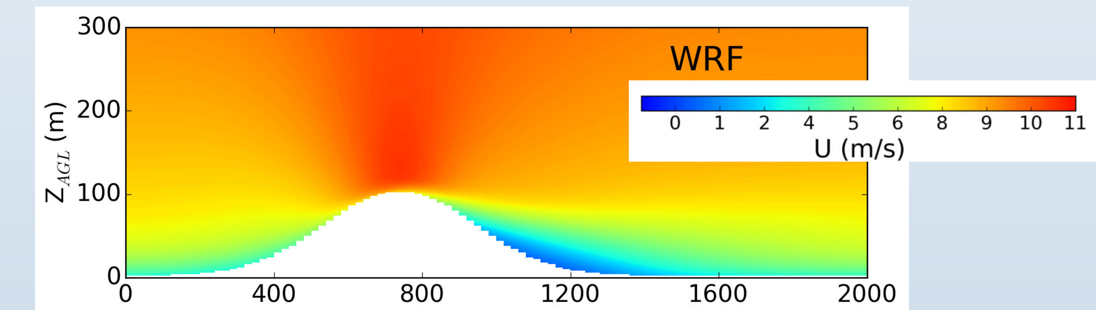


Figure 1. WRF-based interpolation of wind speed around a mountain.

The resolution is commonly enhanced by factor between 3 and 5. Below it is shown how 0.5 deg data (~50km) can be refined to 12 km resolution.

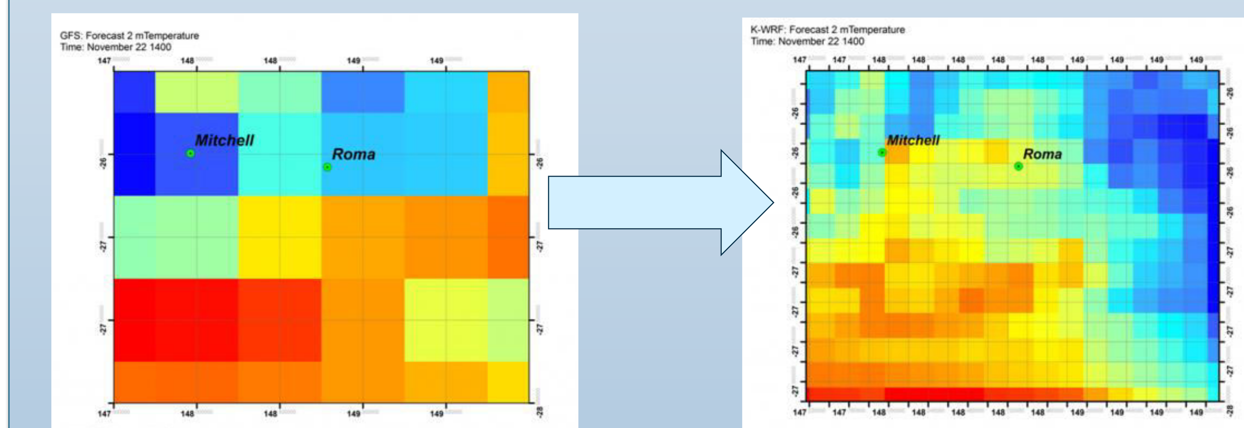


Figure 2. Resolution enhancement from conventional met data to WRF output.

Nesting around coordinates of interest

For a representative atmospheric transport modelling of radioxenon dispersion it is beneficial to have high resolution of complex terrain around the release point and the monitoring station., where complex terrain has the biggest influence on the wind flow.

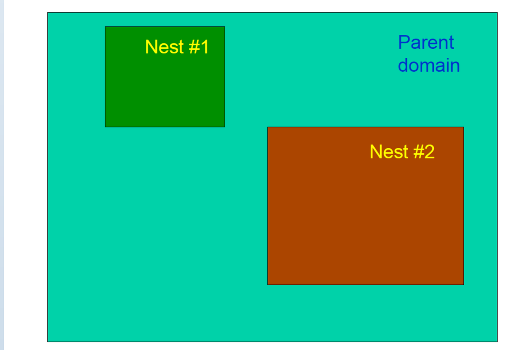


Figure 3. Concept of nesting.
Nests are embedded into a parent domain around points of interests to provide a higher resolution to areas around sources and monitoring stations.

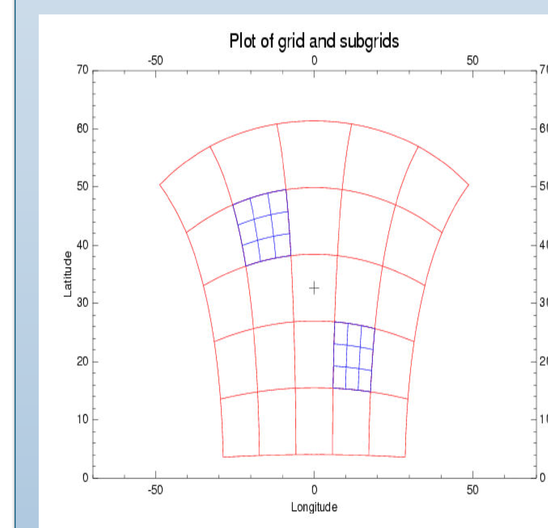


Figure 4. Example of a refined nest resolution by a factor of three.
Within nests the resolution is higher compared to the parent domain usually by a factor of 3 – 5. The size of nests are limited by the increase of the required computational resources.

Benchmarking with 1st ATM challenge

The goal of the first ATM challenge in 2015 was to simulate the stack emissions from the medical isotope production at IRE, Belgium, and reproduce the time series of detections at monitoring station DEX33 close to Freiburg, Germany. This scenario has been used retrospectively to benchmark the Flexpart-WRF installation. The results from the 26 submissions to the challenge provide a good basis for a comparison of the Flexpart-WRF installation with other models.

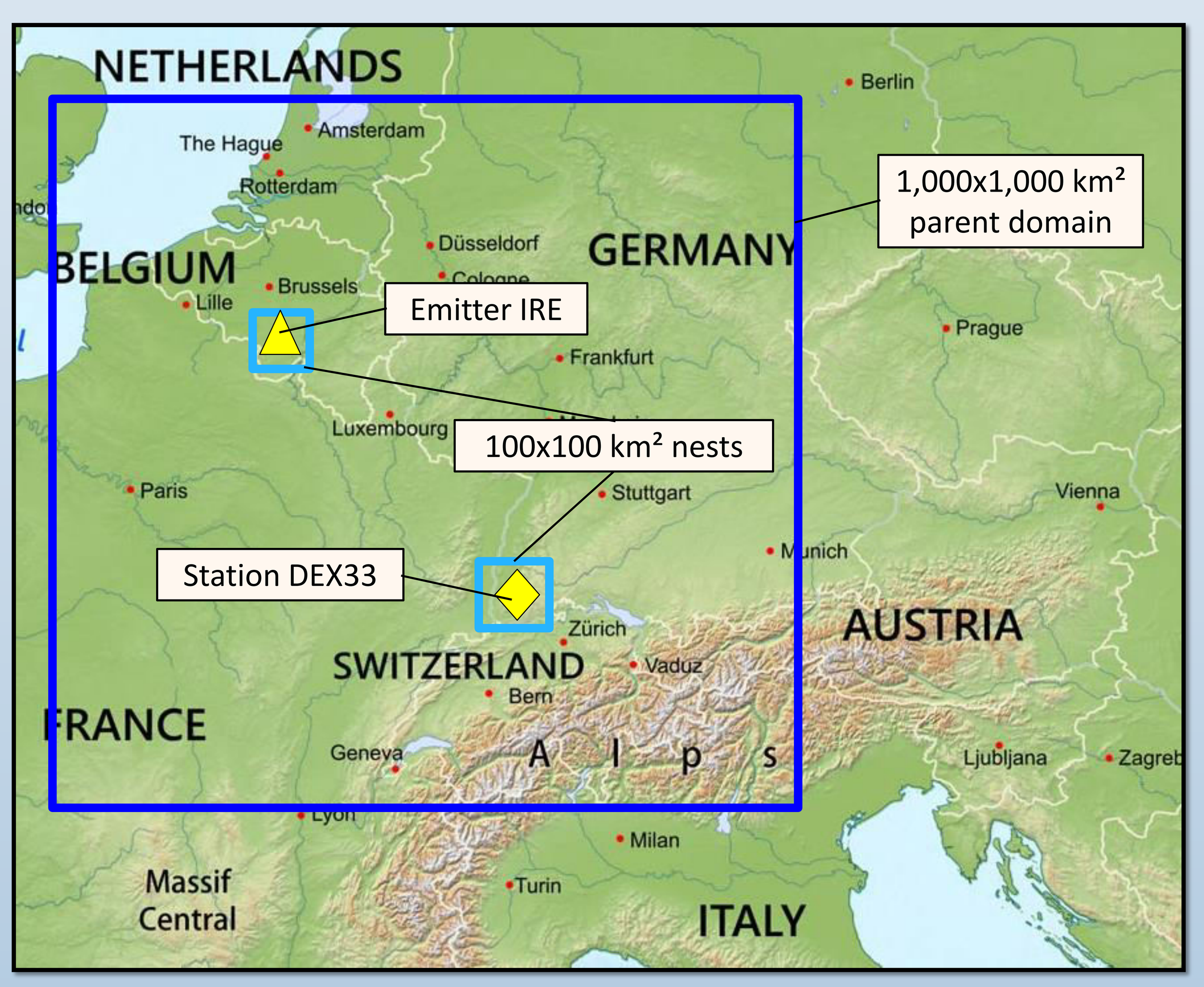
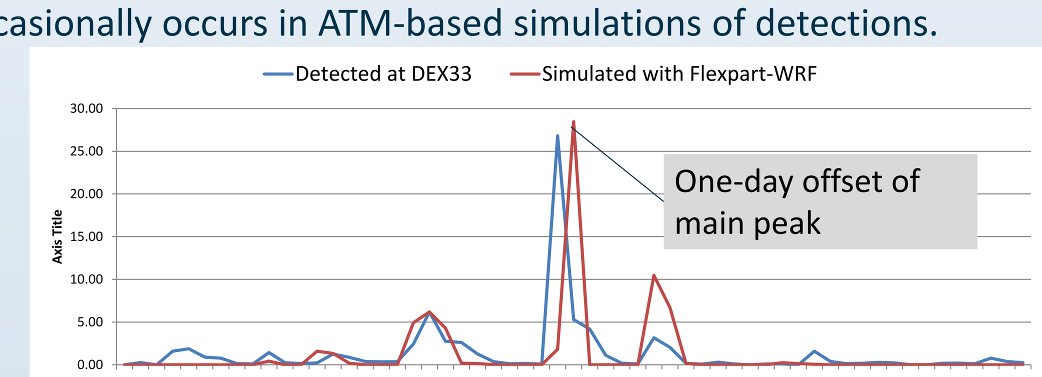


Figure 5. Regional overview of domain and nests for the 2015 ATM challenge.

The main characteristics of the detected time series are well represented in the simulations resulting in a high correlation. The predicted arrival time of the main peak is delayed by one day, which occasionally occurs in ATM-based simulations of detections.



The model is validated by using a rank as described in [3,4]. Beside the original simulations, also an alternative, 'fixed' time series has been prepared, where the simulated main peak has been manually shifted to one day earlier to fit the detected main peak.

Comparison to other submitted results

Models sorted by overall rank

"Fixed" Flexpart-WRF output — In the manually "fixed" output the one-day offset of the main peak has been compensated.

Conventional models in operation at CTBTO

Rank based on Flexpart-WRF output

Other two WRF submissions

Model	KS	R	FB	F5	Rank	NMSE	MSE
Sch[a]	0.10	0.89	0.50	0.81	3.25	2.63	19.2
Hof 4	0.39	0.94	0.03	0.61	**3.09**	**0.63**	18.3
Mau 3	0.45	0.93	**−0.02**	0.52	2.92	0.81	**3.50**
Sau	0.52	0.92	−0.33	0.52	2.68	1.77	5.60
Hof 3	0.45	0.90	−0.58	0.55	2.62	4.25	36.5
Hof 1	0.45	0.75	−0.32	0.58	2.53	3.79	25.9
					2.44		
Hof 2	0.45	**0.97**	−0.89	0.39	2.43	5.87	25.0
Rob	**0.29**	0.35	−0.19	**0.68**	2.41	5.72	20.8
Ros 2	0.52	0.81	−0.56	0.39	2.24	4.87	11.9
Mau 1	0.58	0.79	−0.36	0.35	2.22	3.24	9.90
Ros 1	0.52	0.73	−0.56	0.45	2.18	5.42	13.3
Kry 1	0.42	0.47	−0.42	0.58	2.17	6.41	16.2
Sei 1	0.52	0.46	0.13	0.45	2.08	5.45	25.0
Gen	0.39	0.23	0.36	0.58	2.06	6.56	20.5
Esl	0.45	0.30	−0.08	0.35	1.95	7.62	41.4
Sei 2	0.55	0.43	−0.07	0.35	1.95	6.14	37.5
Kry 2	0.52	0.61	−0.67	0.35	1.87	7.40	27.3
Kij	0.45	0.17	−0.13	0.35	1.87	9.80	40.0
Sei 3	0.58	0.20	−0.03	0.35	1.80	8.89	36.6
Sei 7	0.55	0.19	−0.10	0.35	1.79	9.27	35.7
Sei 8	0.55	0.19	−0.13	0.35	1.78	9.29	59.7
					1.64		
Sei 9	0.58	0.19	0.28	0.32	1.64	10.3	25.5
Hay	0.65	0.71	−1.41	0.16	1.31	26.9	25.3
Cha	0.71	0.83	−1.69	0.06	1.20	62.7	23.2
Mau 2	0.58	0.59	1.75	0.23	1.12	192.	12400
Ros 3	0.55	0.18	−1.17	0.23	1.12	21.5	24.5
Average[b]	0.42	0.69	0.27	0.61	2.53	3.52	19.6

Participation in 2nd ATM challenge

The second ATM challenge involves stack emissions from the ANSTO facility close to Sydney, Australia, and six IMS noble gas stations on the Southern Hemisphere from Australia to the South Atlantic [5].
Since Flexpart-WRF is more suitable for regional scenarios instead of intercontinental simulations, only the three nearest stations to the source have been considered in the Flexpart-WRF submission from the IDC, see Figure 6.

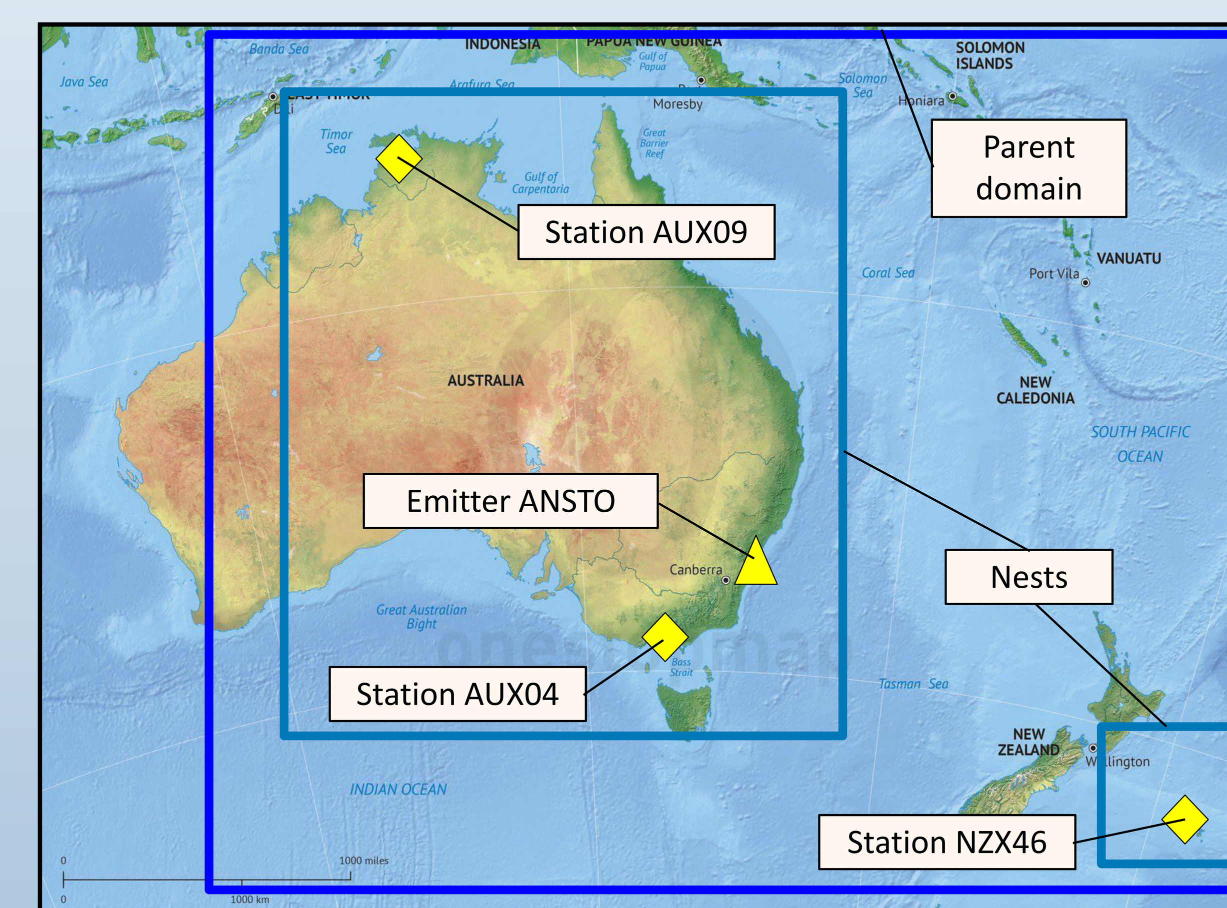


Figure 6. Regional overview of domain and nests for the 2nd ATM challenge.

Comparison to other submitted results

Compared to the 1st ATM challenge the Flexpart-WRF model improved relatively compared to the field of submissions.

Standard, operational Flexpart model at CTBTO

Flexpart-WRF at CTBTO

Comparison of data from single stations needed. Flexpart-WRF is expected to be stronger for shorter distances, e.g. ANSTO to AUX04.

Models sorted by overall rank

Submission	R	FB	F5	Rank	NMSE	RMSE
ARPANSA	0.73	0.02	0.55	2.66	14	0.23
NOAA-ARL3	0.60	-0.14	0.49	2.51	13	0.17
SCKCENRMI1	0.68	-0.04	0.49	2.48	16	0.21
SCKCENRMI1-2	0.66	-0.11	0.44	2.41	21	0.28
SCKCENRMI2	0.64	-0.18	0.39	2.33	26	0.36
RSMCExeter	0.56	-0.15	0.36	2.27	15	0.2
PNNL	0.57	0.10	0.35	2.23	25	0.23
CEA2	0.53	0.47	0.38	2.15	34	0.52
CEA1-2	0.55	0.67	0.39	2.14	38	0.81
ZAMG	0.53	-0.36	0.33	2.12	23	0.24
CEA1	0.58	0.92	0.40	2.11	48	1.11
NOAA-ARL2	0.56	0.00	0.28	2.11	21	0.25
PU	0.55	0.23	0.30	2.09	38	0.45
FOI	0.56	0.08	0.29	2.06	54	0.35
JAEA	0.49	0.28	0.41	2.06	45	0.43
BGR	0.56	0.09	0.35	2.03	115	0.32
CTBTO1	0.50	1.00	0.39	2.03	41	1.13
NOAA-ARL1-4	0.47	-0.23	0.28	2.03	28	0.23
CTBTO1-2	0.54	0.92	0.34	1.98	45	1.05
CMC1	0.42	-0.51	0.25	1.97	210	0.25
CMC1-2	0.41	-0.48	0.19	1.78	205	0.31
CTBTO2	0.67	0.59	0.15	1.78	61	0.75
NOAA-ARL1	0.48	-0.33	0.15	1.78	46	0.35
IRSN	0.43	-0.13	0.17	1.76	20	0.4
UK-NDC	0.48	-0.31	0.19	1.69	48	0.25
CMC2	0.45	-0.38	0.15	1.68	199	0.37
NOAA-ARL4	0.18	-0.57	0.16	1.67	34	0.19
BOKU3	0.64	-1.45	0.08	1.54	7088	0.17
BOKU2	0.65	-1.43	0.08	1.53	6662	0.17
BOKU1	0.64	-1.40	0.08	1.51	9356	0.17
BOKU4	0.62	-1.46	0.08	1.51	6963	0.18
BOKU1-6	0.62	-1.46	0.08	1.51	6979	0.18
BOKU5	0.60	-1.50	0.08	1.50	6484	0.18
BOKU6	0.44	-1.63	0.07	1.34	6.10E+08	0.16
Average	0.53	-0.21	0.25	1.90	1839	0.37

Summary

- The protoype high-resolution atmospheric transport model consisting of WRF and Flexpart-WRF has been installed and its usage simplified at CTBTO.
- High-resolution modelling will be used for regional case studies.
- Validation with two ATM challenges has shown great potential: better ranking than other WRF submissions and on a par with the field of conventional models.
- Performance of high-resolution model still depends on scenario.

Outlook

- Further optimization of physical parameters (>200) needed.
- Further validation on as many cases as possible.
- Case study based on time-resolved stack emission data from medical isotope production facility IRE in Belgium.
- Other fields of application, e.g. CTBT On-Site Inspection, will be explored.

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