



Global Source-Receptor Modeling of POPs in Support of the Convention on Long-range Transboundary Air Pollution

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Safety and
Environmental
Technology Group



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Ufficio federale dell'ambiente UFAM
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The UNECE LRTAP Convention

- 1979: “Geneva Convention” on long-range trans-boundary air pollution signed by 32 states
- Goal: To reduce and prevent trans-boundary air pollution
- 1998: “Aarhus Protocol” on Persistent Organic Pollutants (POPs) adopted
 - Targets 16 substances
 - 11 pesticides, 2 industrial chemicals, 3 by-products

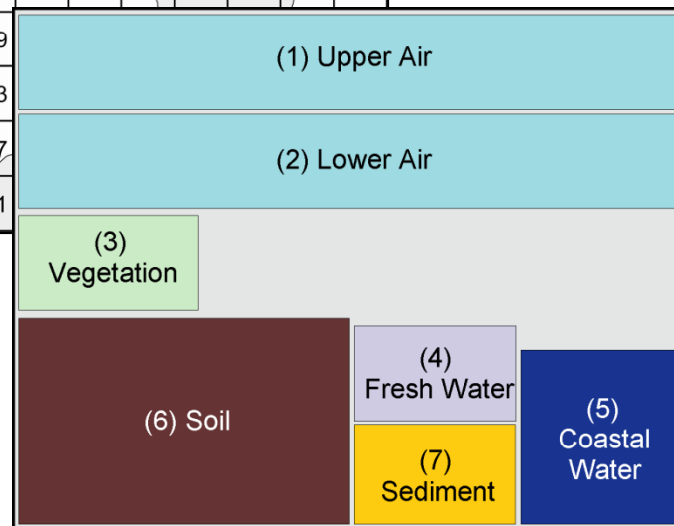


The TF HTAP

- A scientific task force established by the Executive Body of the CLRTAP
- Goals:
 - Improve understanding of hemispheric transport of air pollution
 - Estimate the extent of hemispheric transport of air pollutants for use in reviews of the convention protocols

BETR-Global: A fugacity-based mass balance contaminant fate model

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96
97	98	99	100	101	102	103	104	105	106	107	108	109	110	111	112	113	114	115	116	117	118	119	120
121	122	123	124	125	126	127	128	129	130	131	132	133	134	135	136	137	138	139	140	141	142	143	144
145	146	147	148	149	150	151	152	153	154	155	156	157	158	159	160	161	162	163	164	165	166	167	168
169	170	171	172	173	174	175	176	177	178	179	180	181	182	183	184	185	186	187	188	189	190	191	192
193	194	195	196	197	198	199	200	201	202	203	204	205	206	207	208	209							
217	218	219	220	221	222	223	224	225	226	227	228	229	230	231	232	233							
241	242	243	244	245	246	247	248	249	250	251	252	253	254	255	256	257							
265	266	267	268	269	270	271	272	273	274	275	276	277	278	279	280	281							



BETR-Global



BETR-Global: Environmental Parameterization

- Prescribed atmospheric and ocean circulation data obtained from general circulation models
 - Monthly temporal resolution
- Environmental database includes:
 - windfields, precipitation amount and frequency, temperature, leaf area index, soil organic carbon, ocean particle sinking flux, OH radical concentrations



BETR-Global: Applications

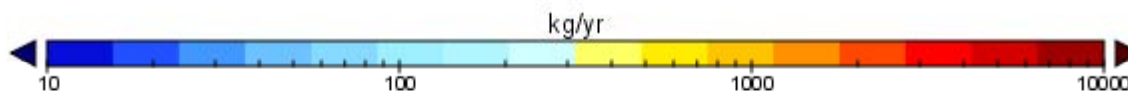
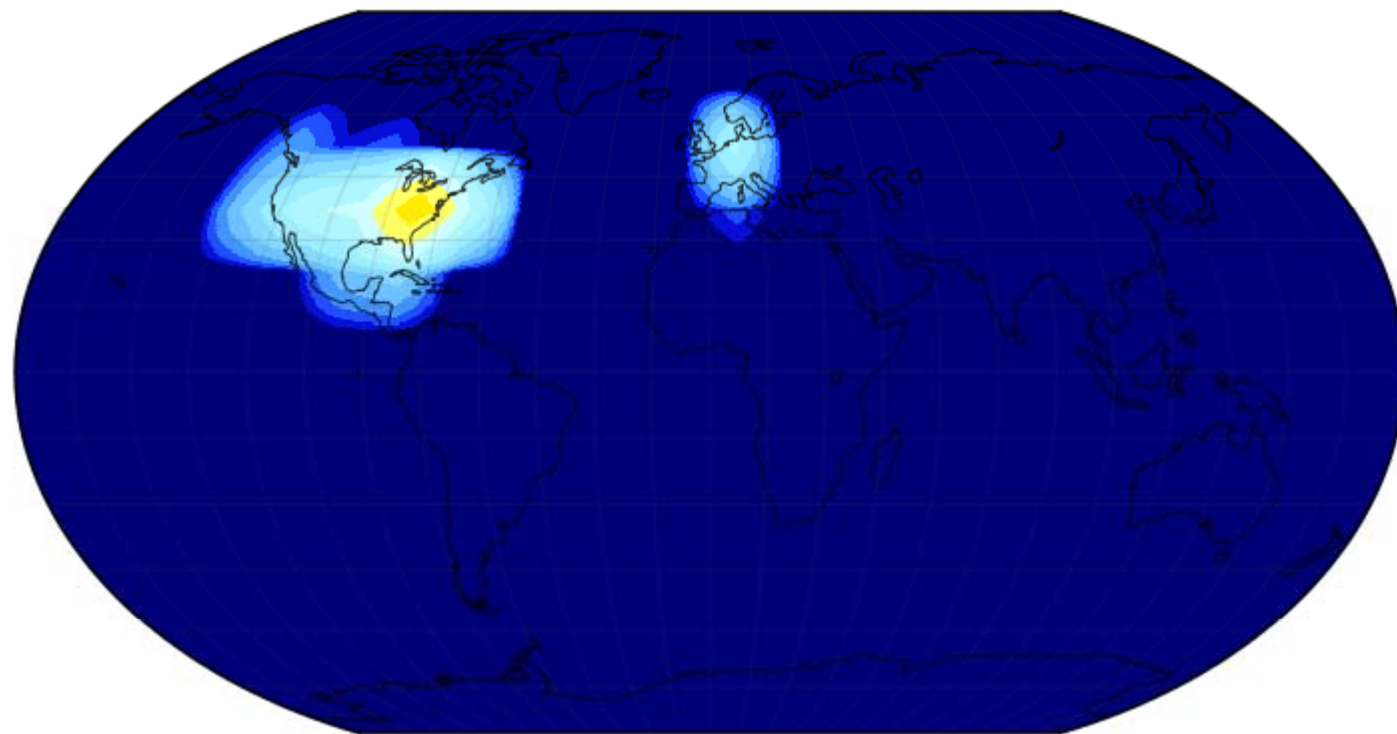
- Simulative
 - Evaluate our knowledge of sources, fate & transport and sinks against monitoring data
 - Build confidence that the model is a useful abstraction of the real system
- Scenario analysis
 - Evaluate alternative management actions or environmental scenarios



BETR-Global: Simulative Application to PCB 153

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1931 (Breivik Maximum Scenario)



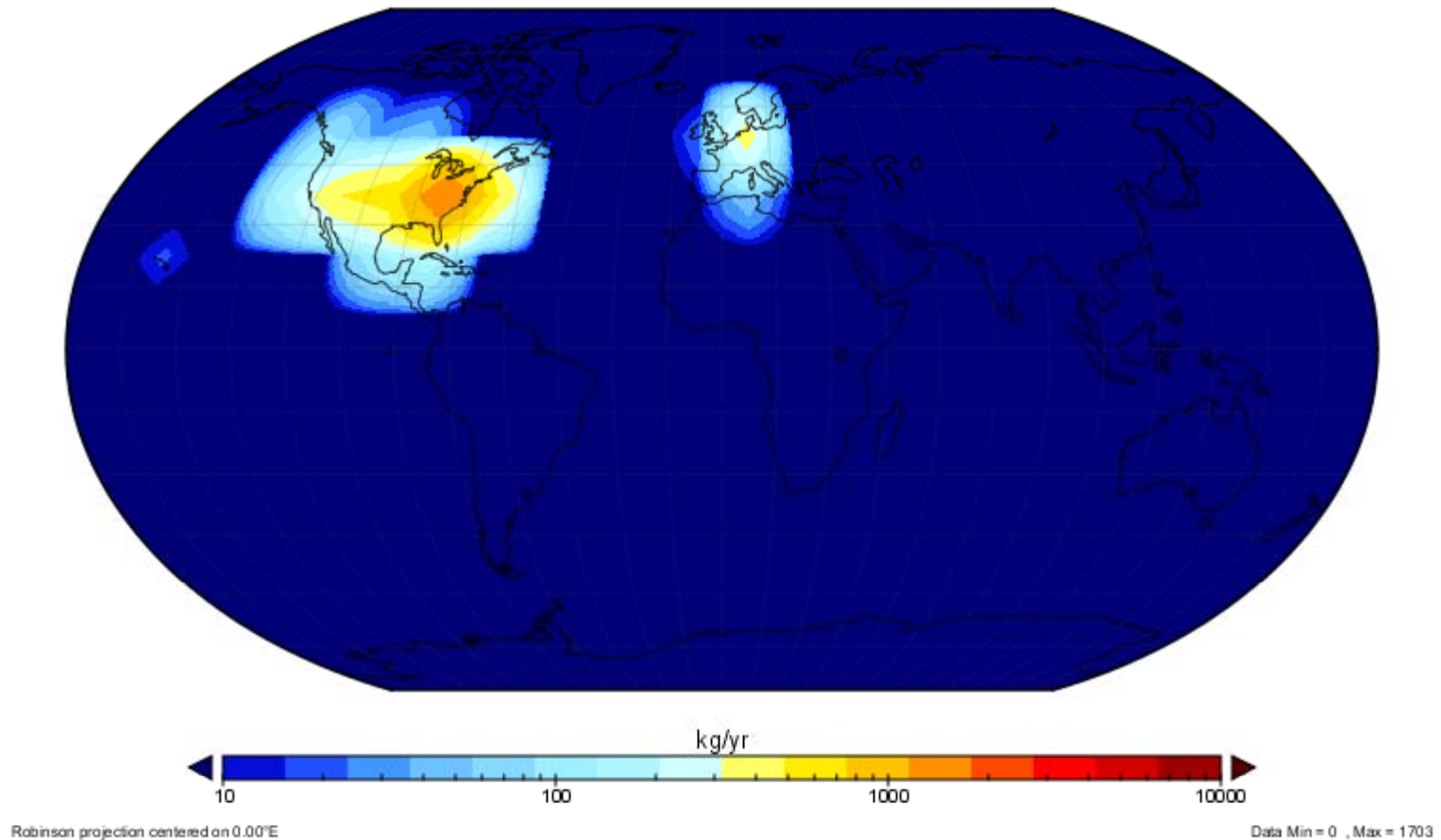
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 648

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

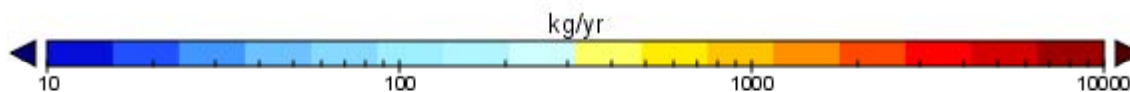
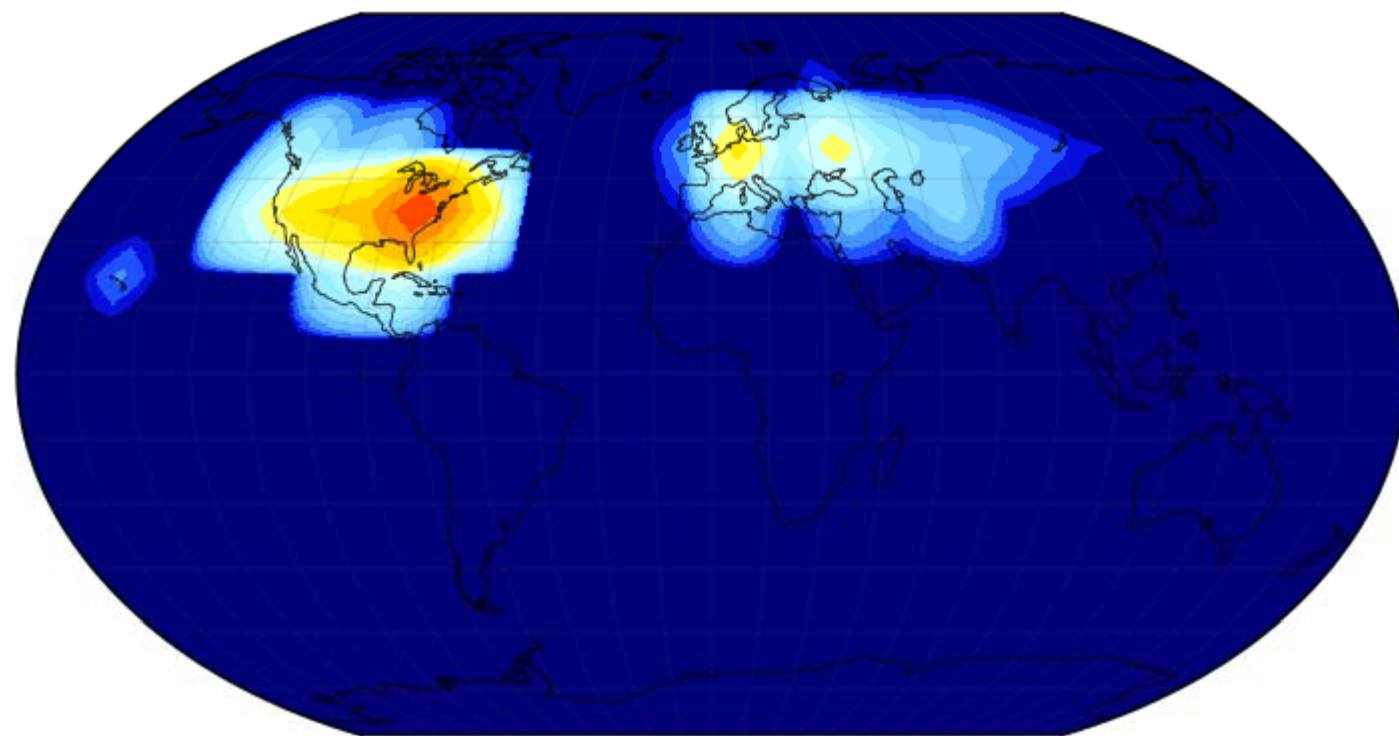
PCB153 Emissions to Air in 1936 (Breivik Maximum Scenario)



Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1941 (Breivik Maximum Scenario)



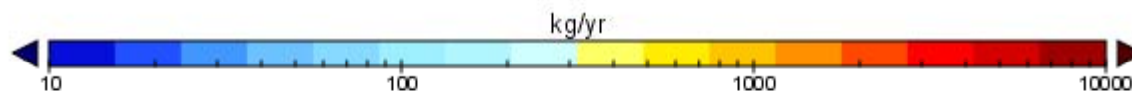
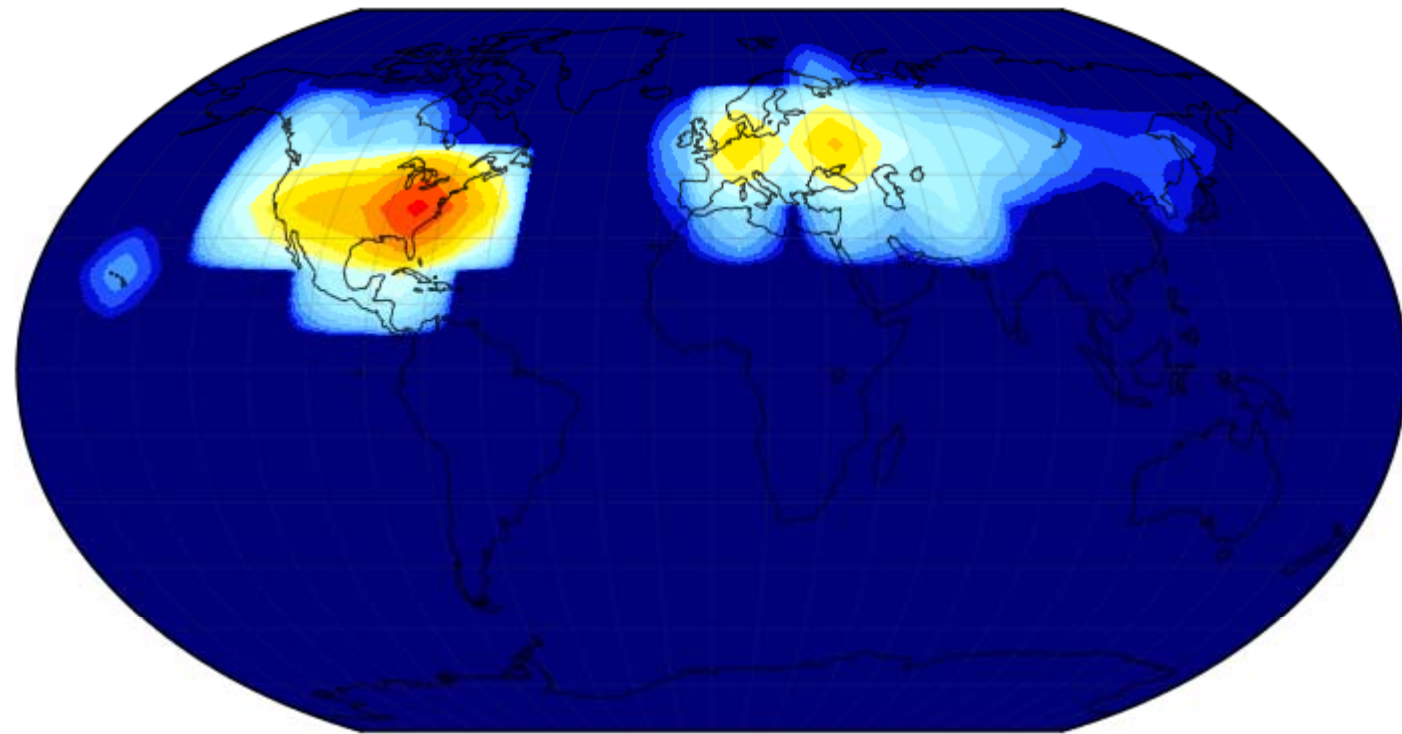
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 2521

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1946 (Breivik Maximum Scenario)



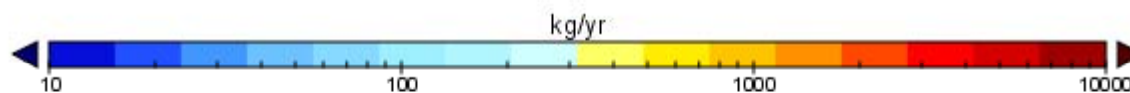
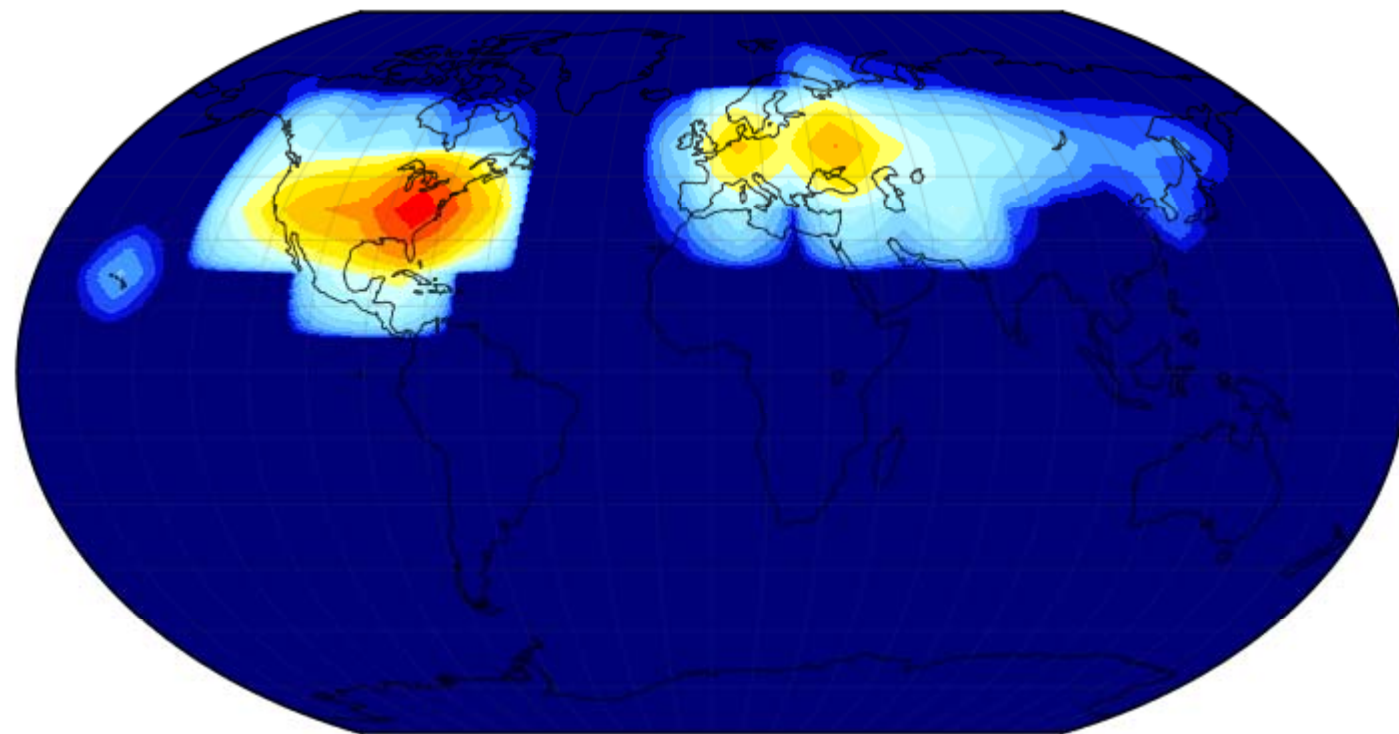
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 3218

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1951 (Breivik Maximum Scenario)



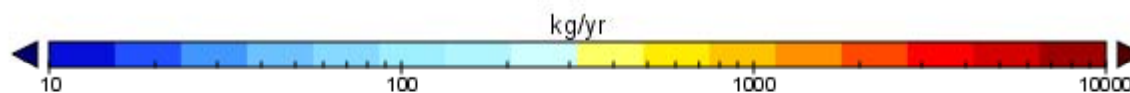
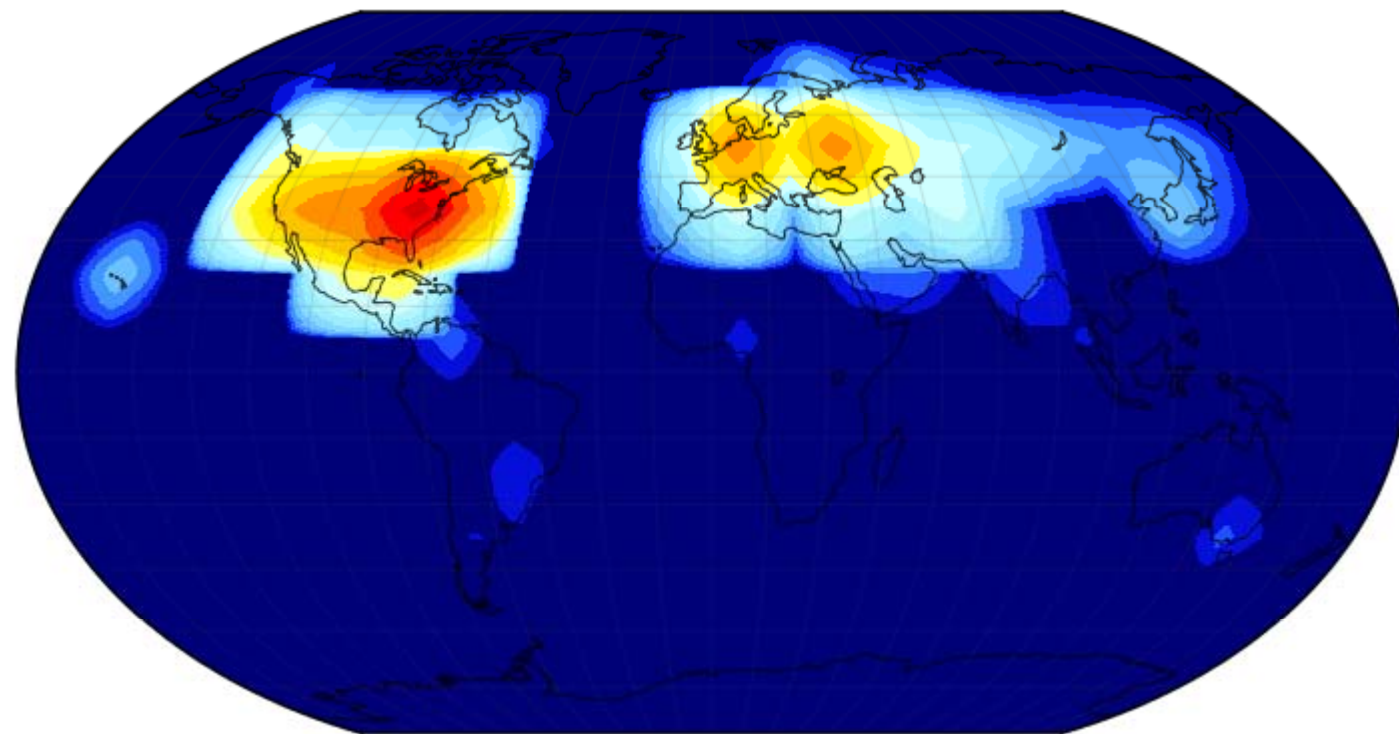
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 3796

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1956 (Breivik Maximum Scenario)



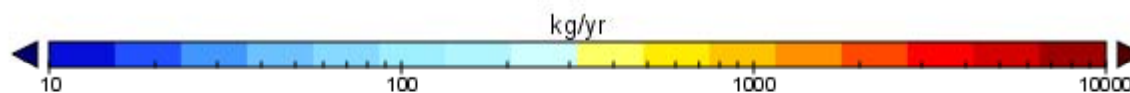
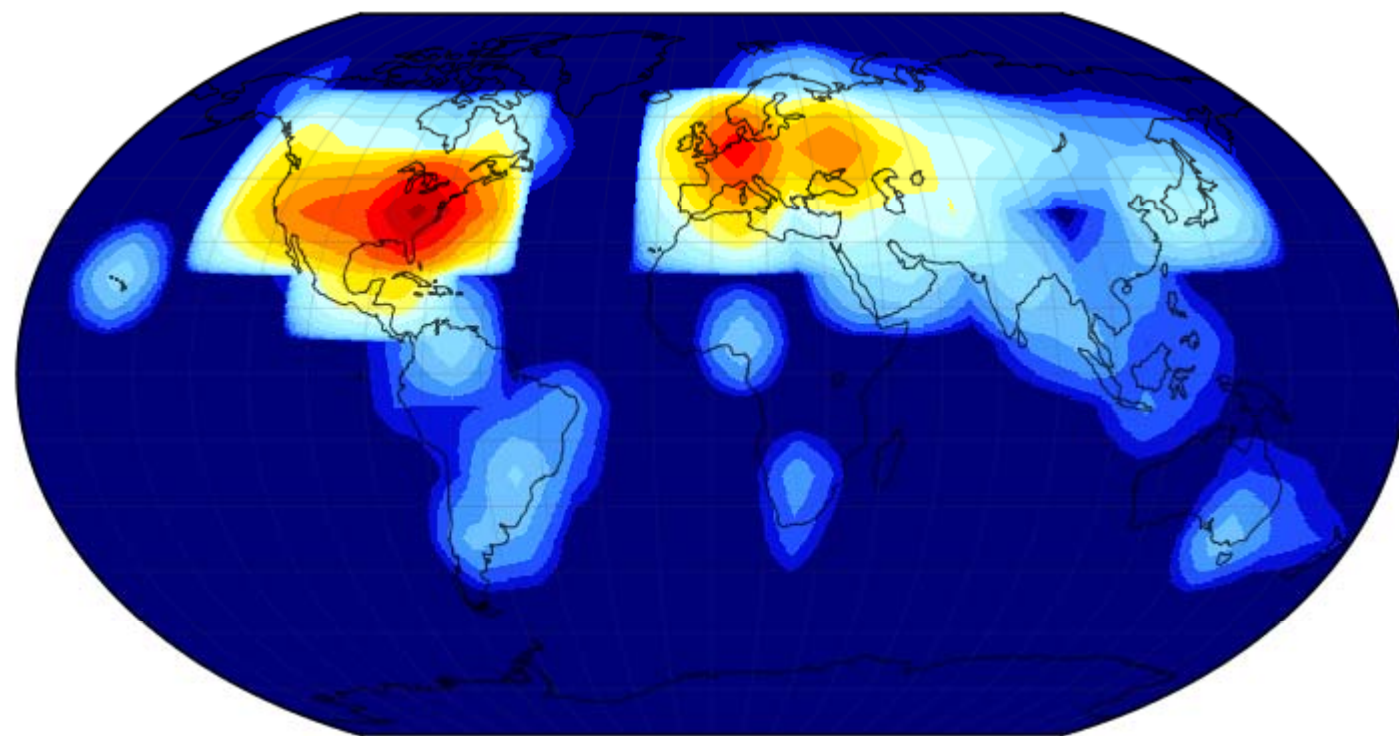
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 5153

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1961 (Breivik Maximum Scenario)



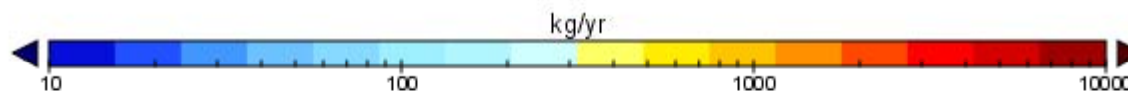
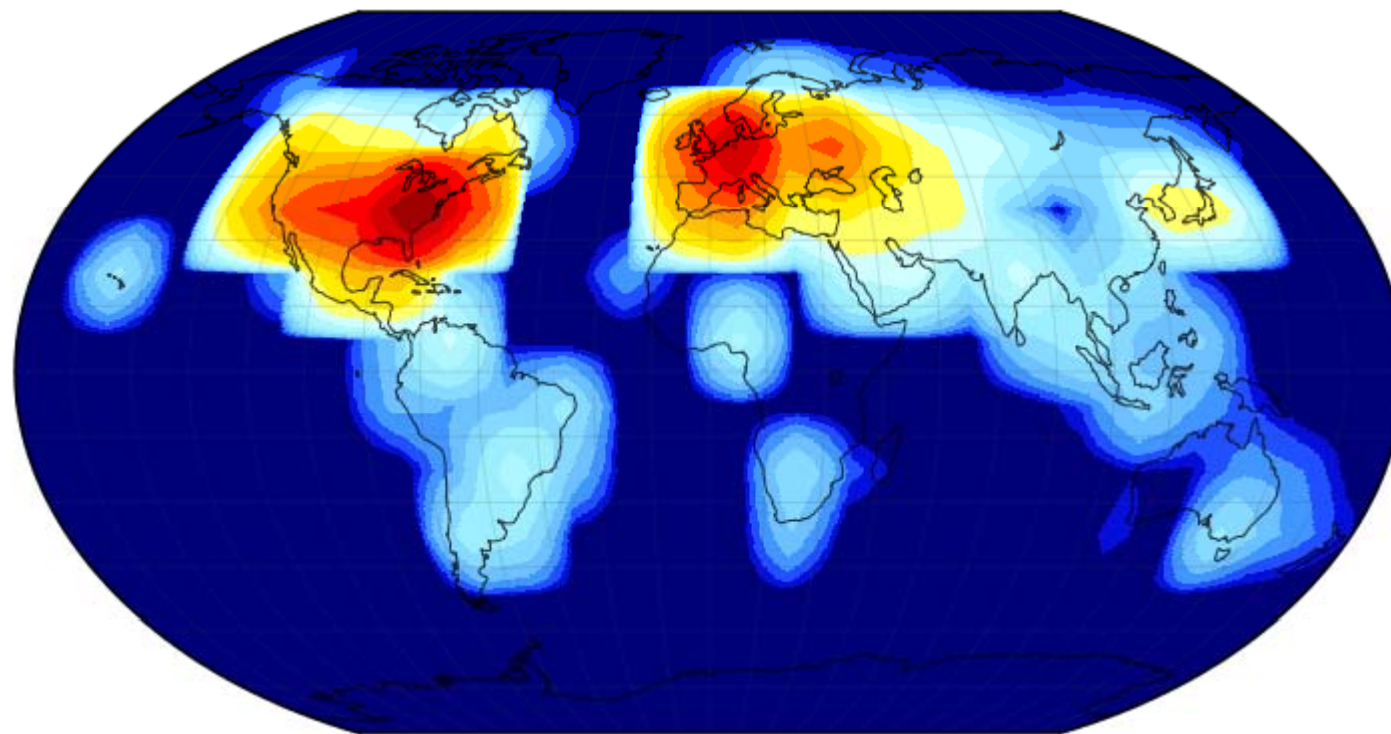
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 7510

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1966 (Breivik Maximum Scenario)



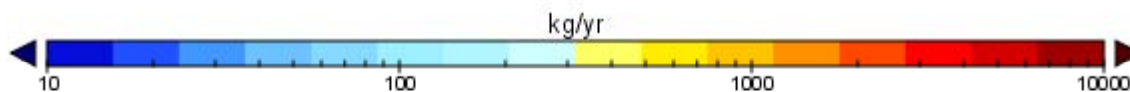
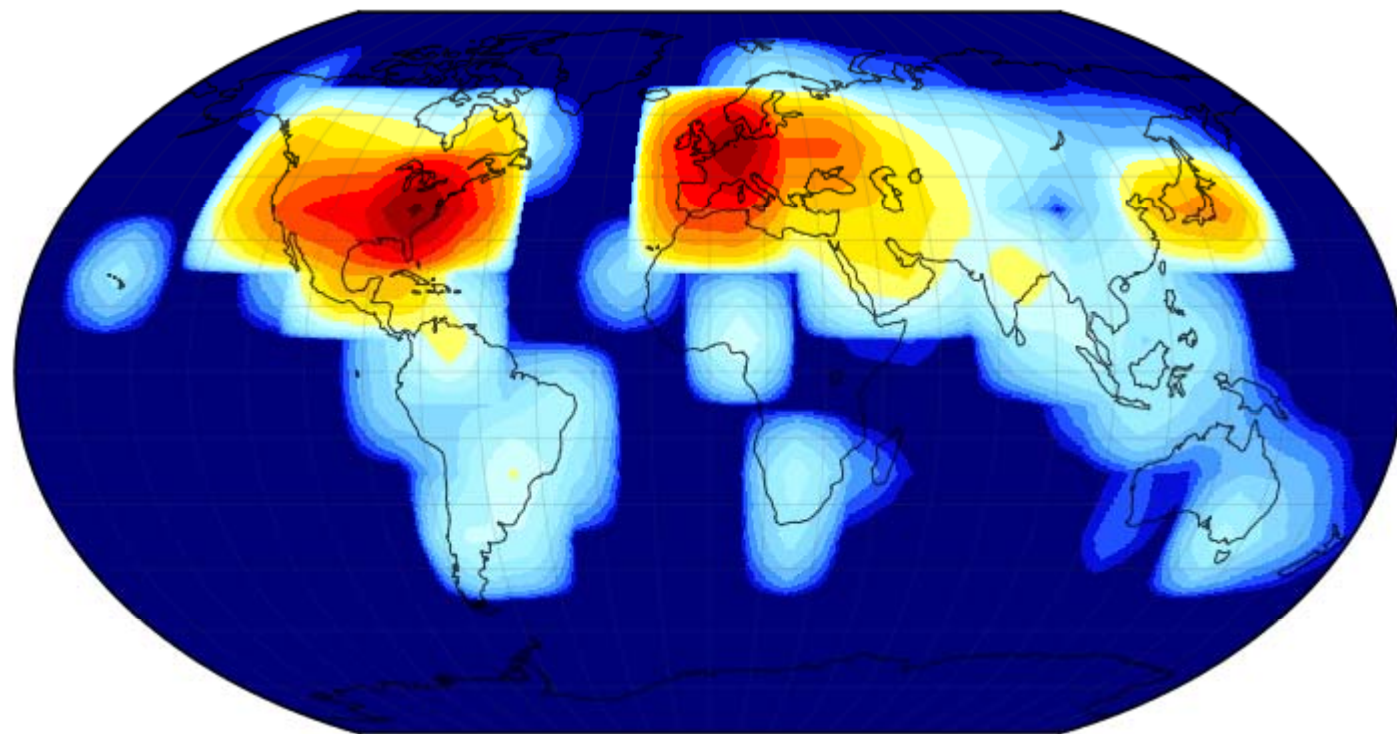
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 9879

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1971 (Breivik Maximum Scenario)



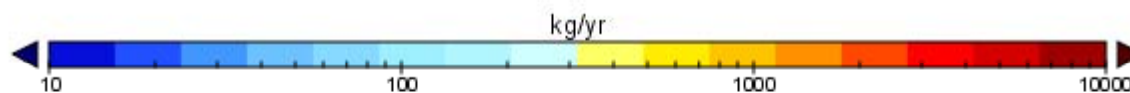
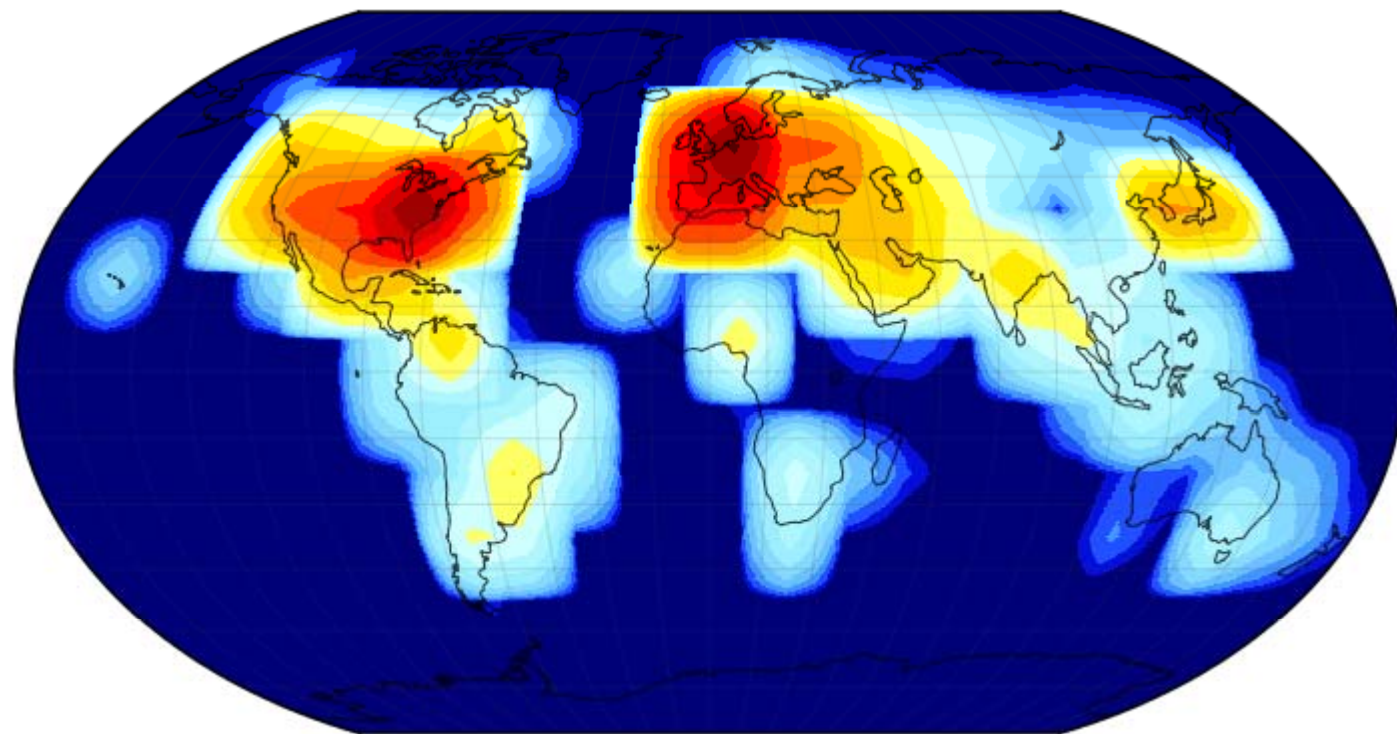
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 11302

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1976 (Breivik Maximum Scenario)



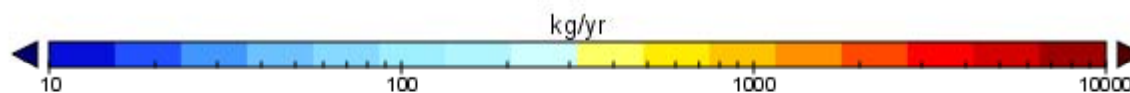
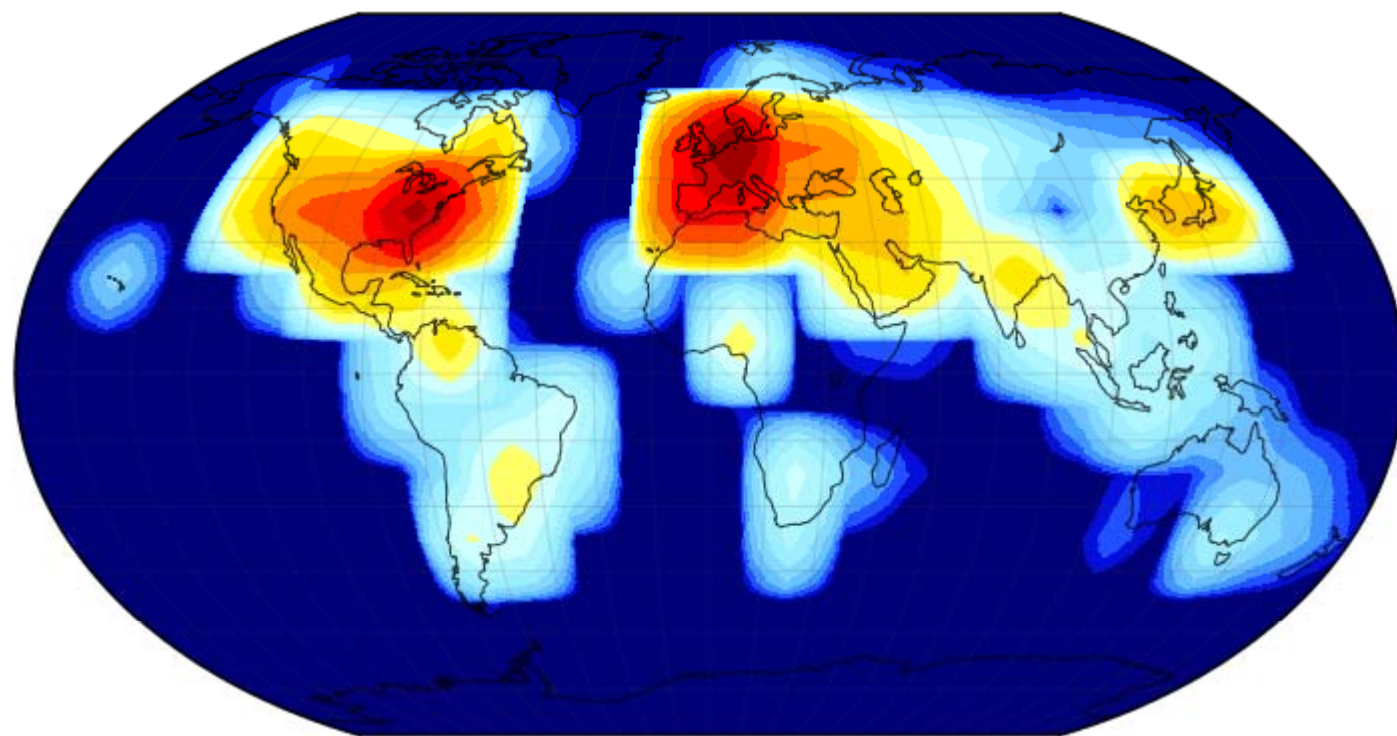
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 10962

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1981 (Breivik Maximum Scenario)



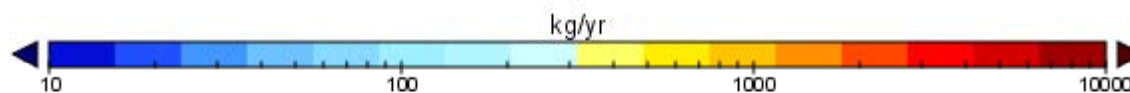
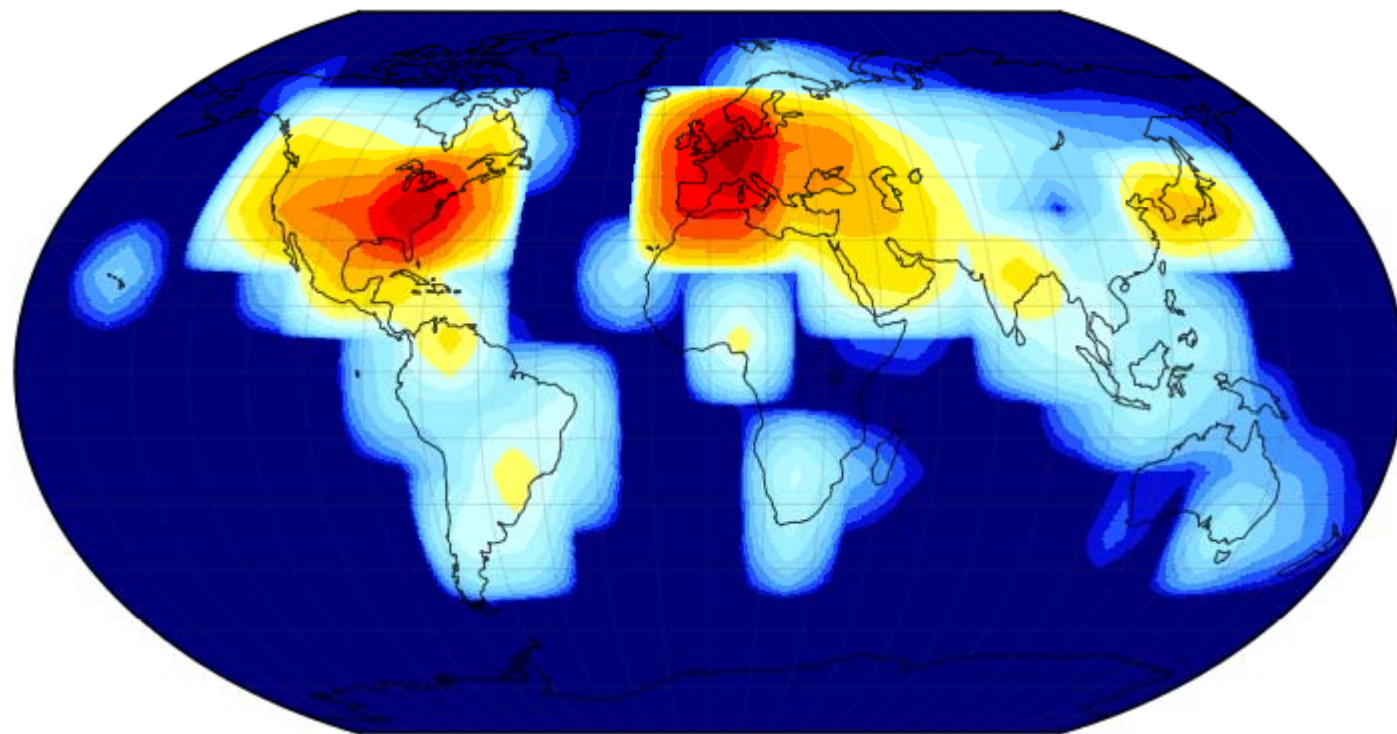
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 10415

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1986 (Breivik Maximum Scenario)



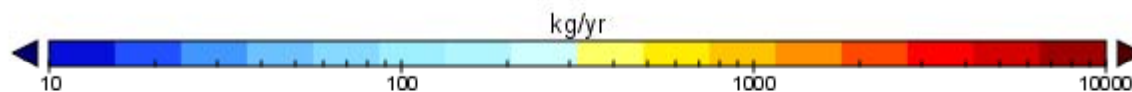
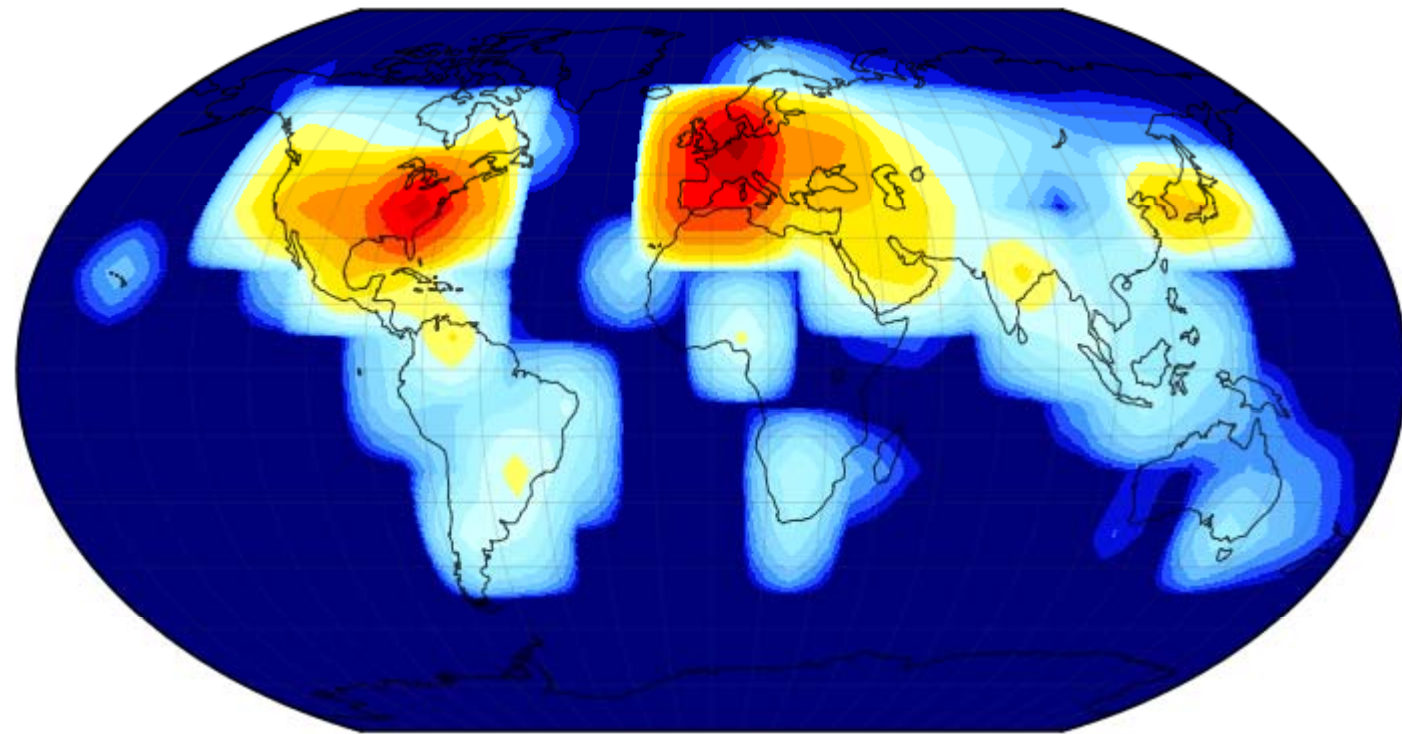
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 9359

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1991 (Breivik Maximum Scenario)



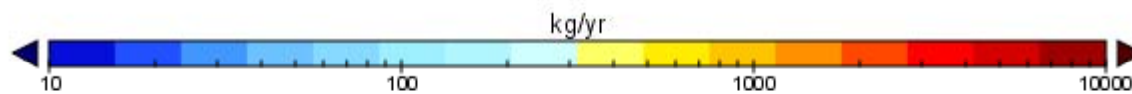
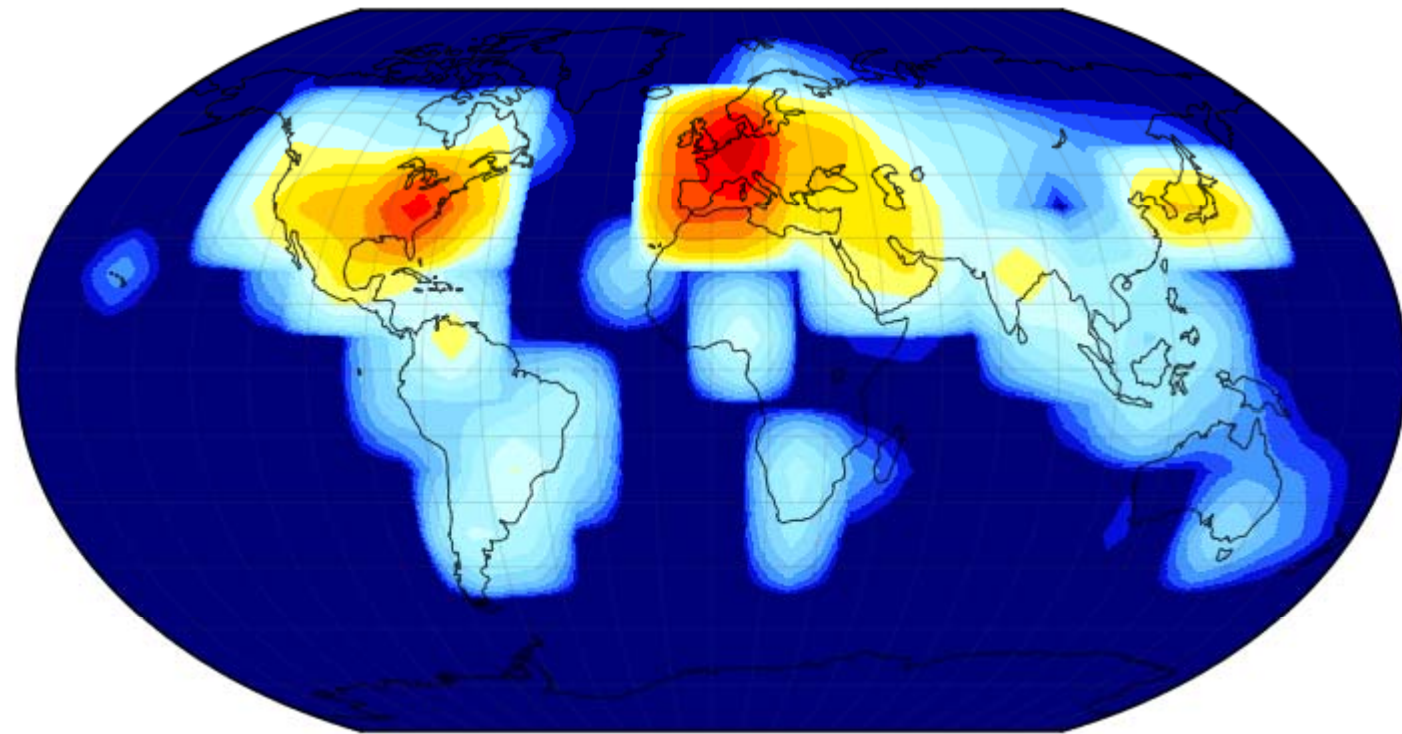
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 7956

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 1996 (Breivik Maximum Scenario)



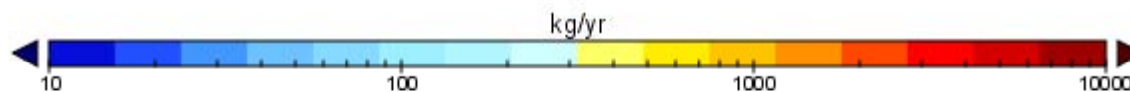
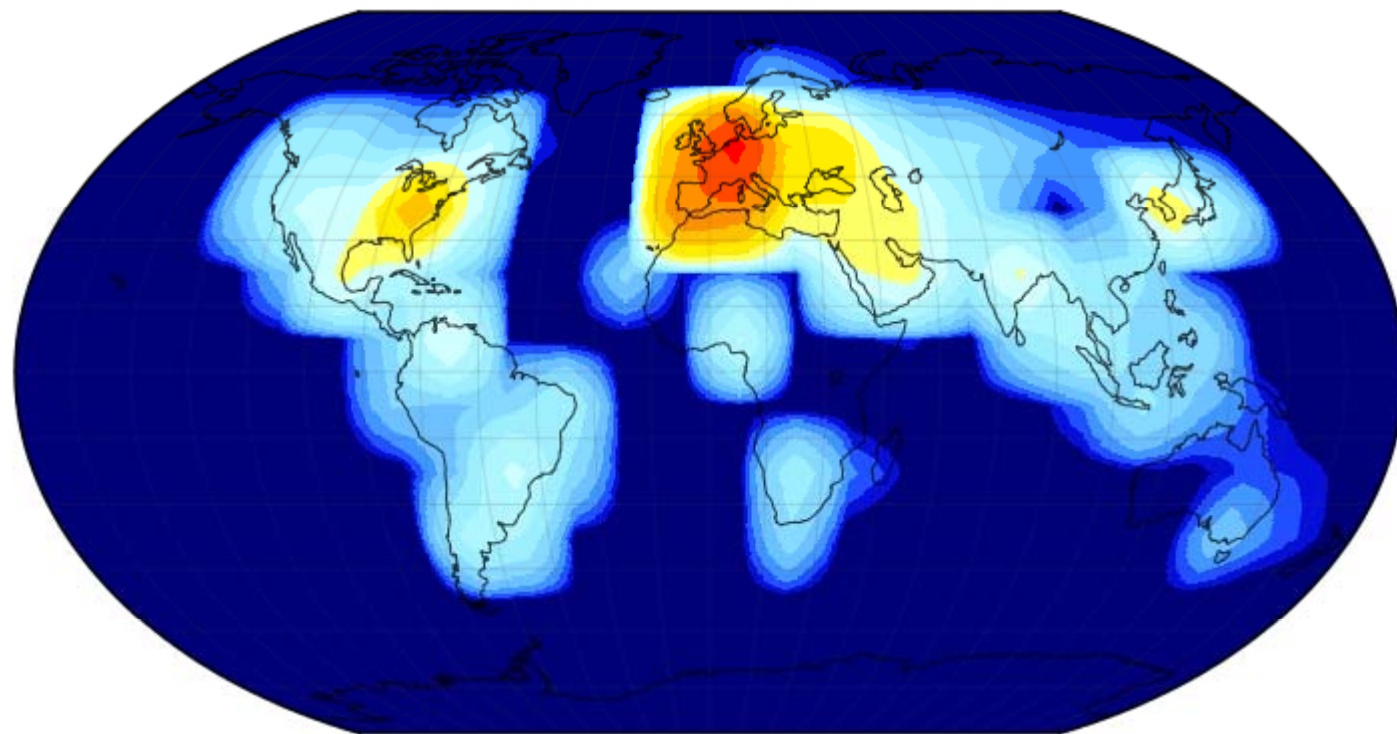
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 6019

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 2001 (Breivik Maximum Scenario)



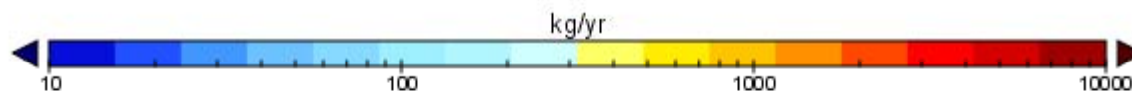
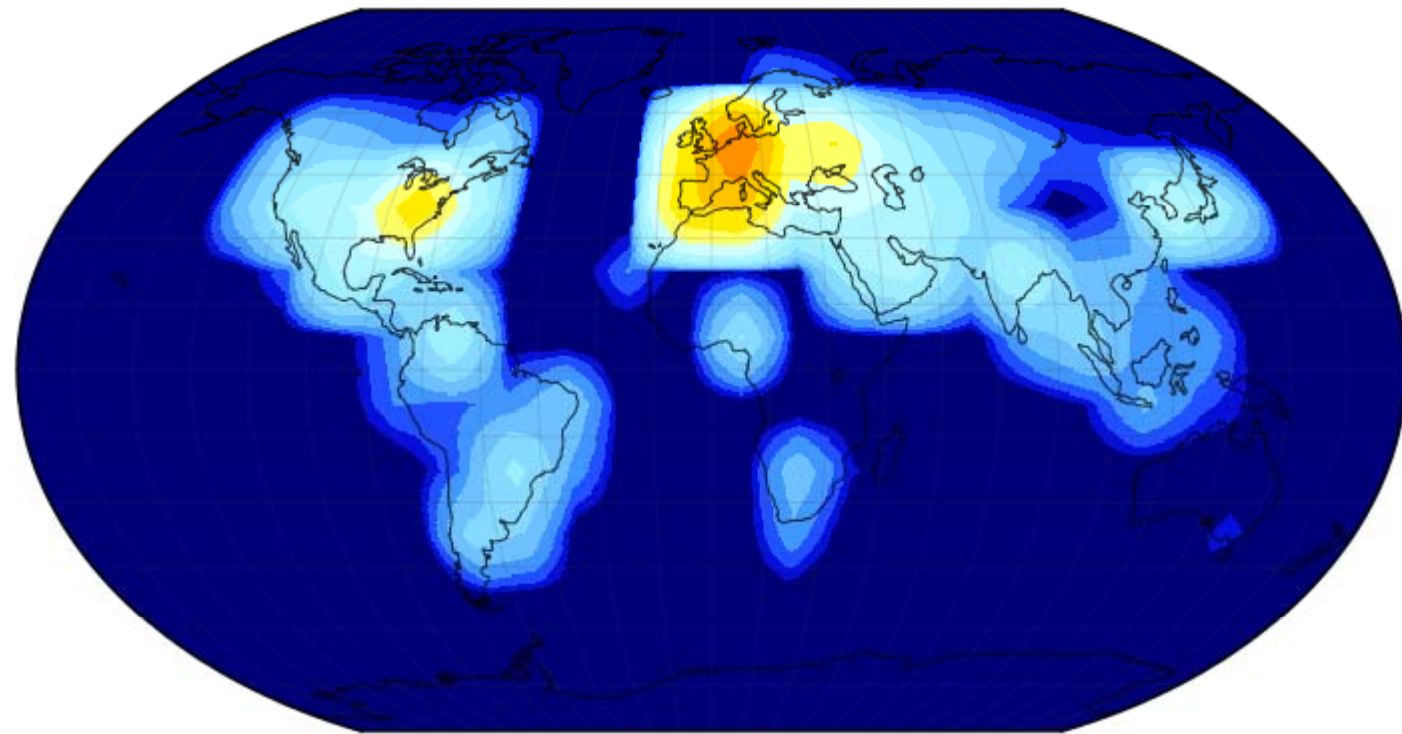
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 3284

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 2006 (Breivik Maximum Scenario)



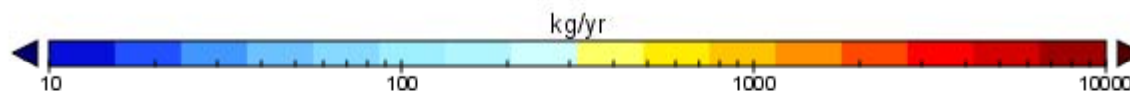
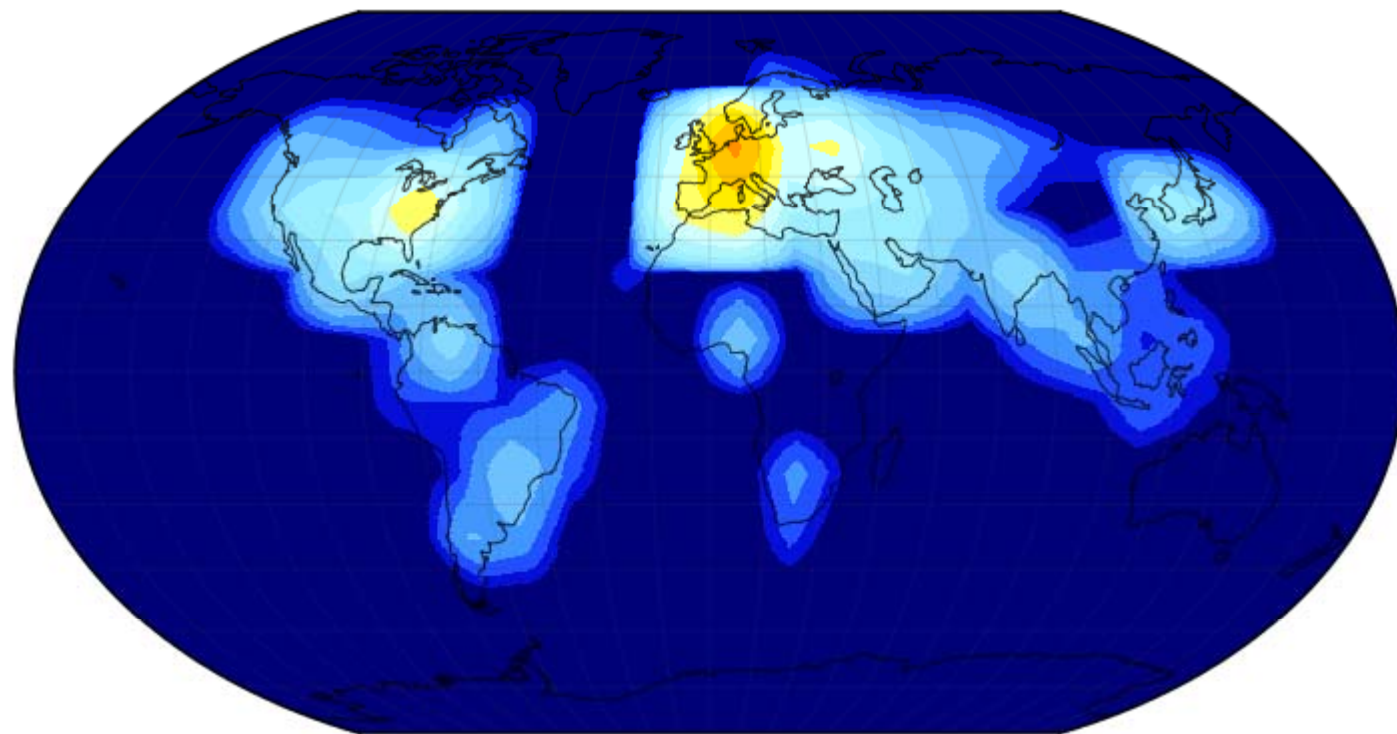
Robinson projection centered on 0.00°E

Data Min = 0 , Max = 1763

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of PCB 153

PCB153 Emissions to Air in 2011 (Breivik Maximum Scenario)

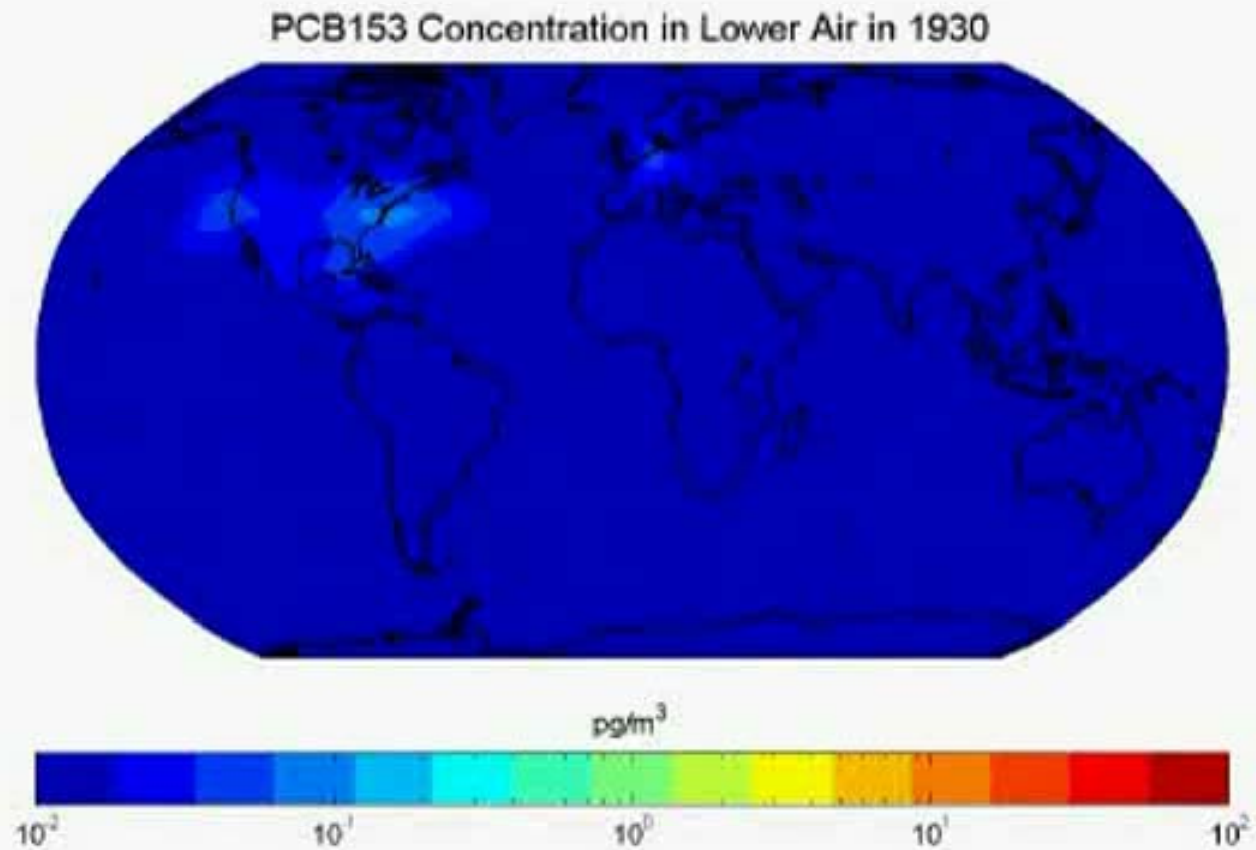


Robinson projection centered on 0.00°E

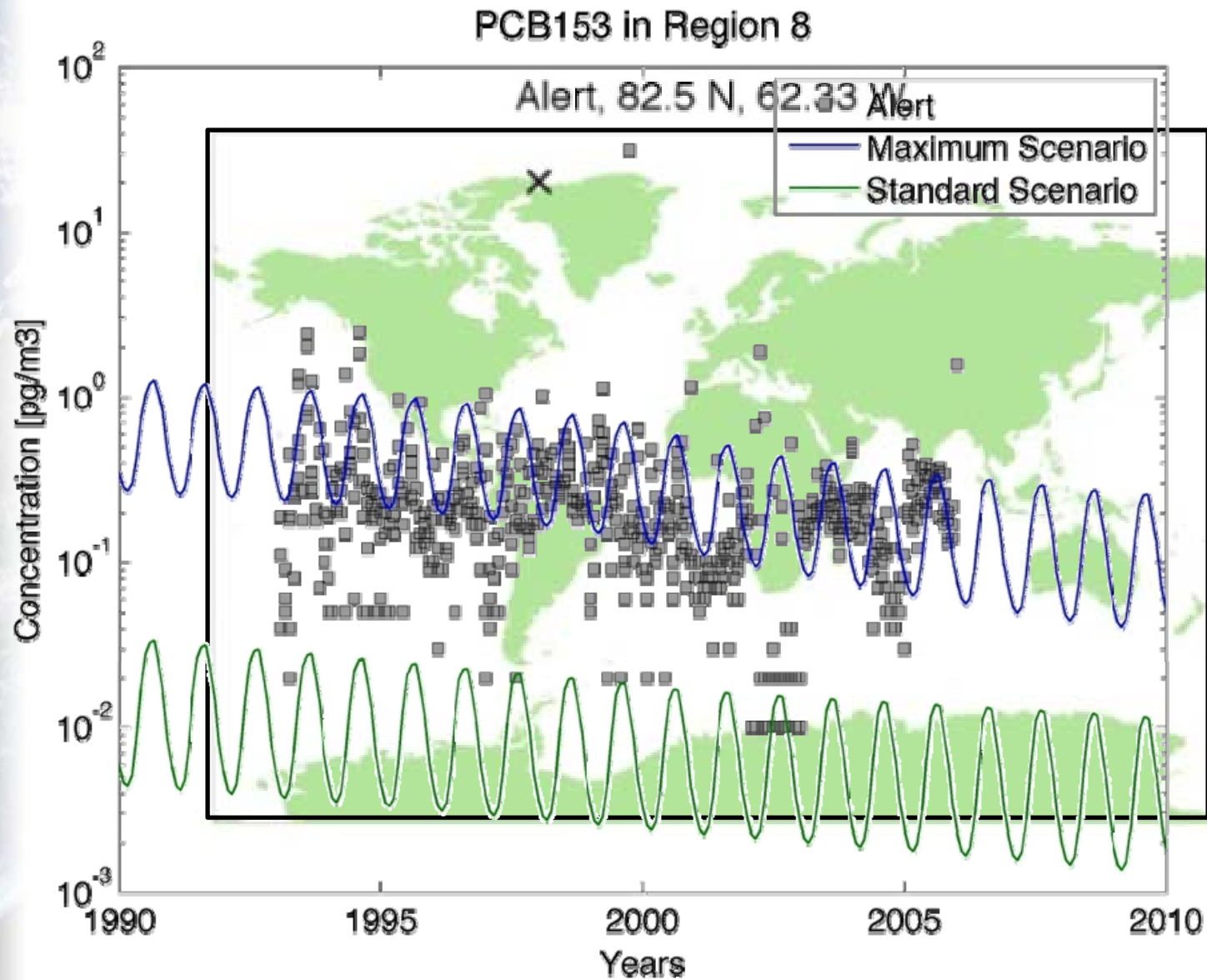
Data Min = 0 , Max = 1321

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

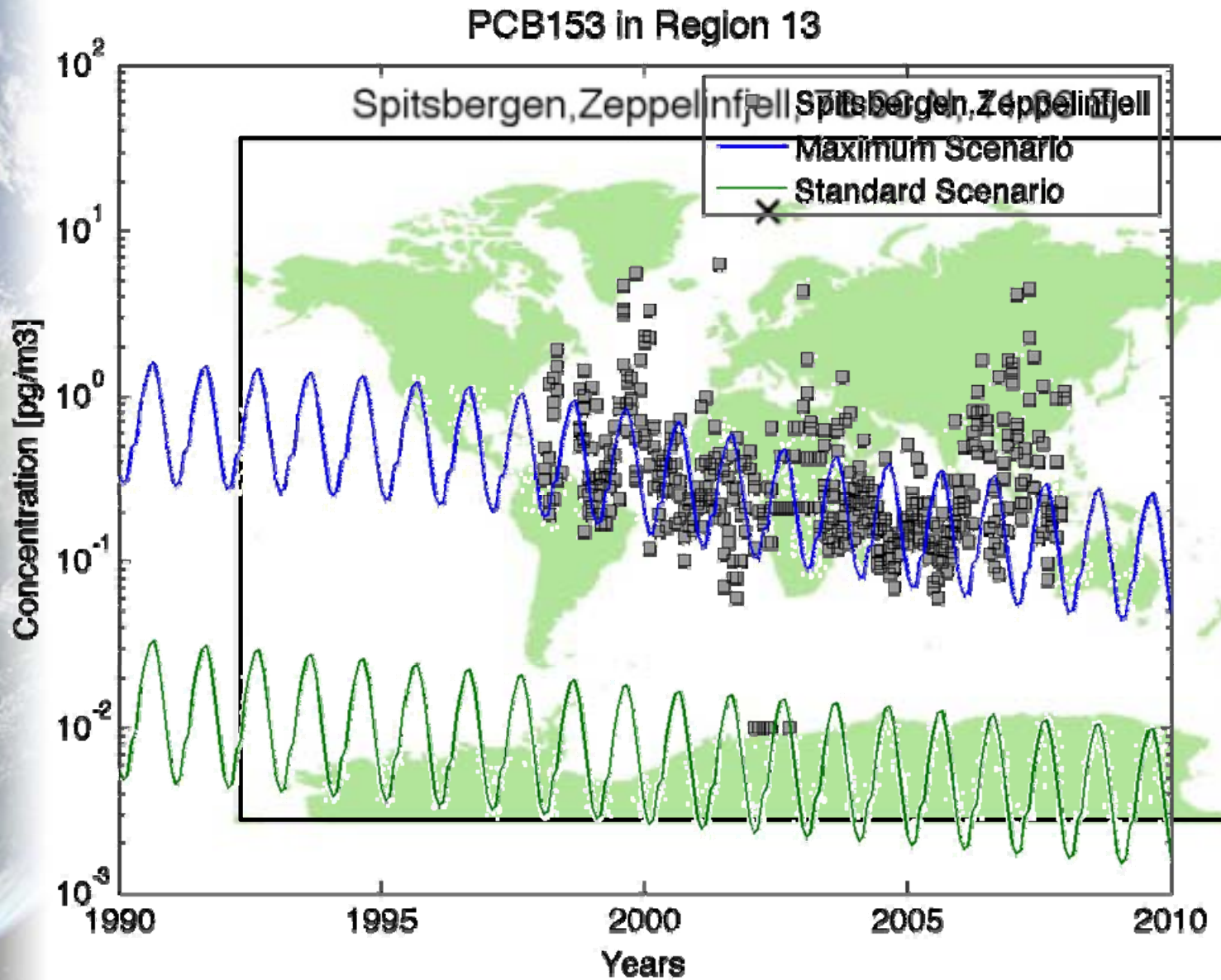
BETR-Global: Modeled concentration of PCB 153



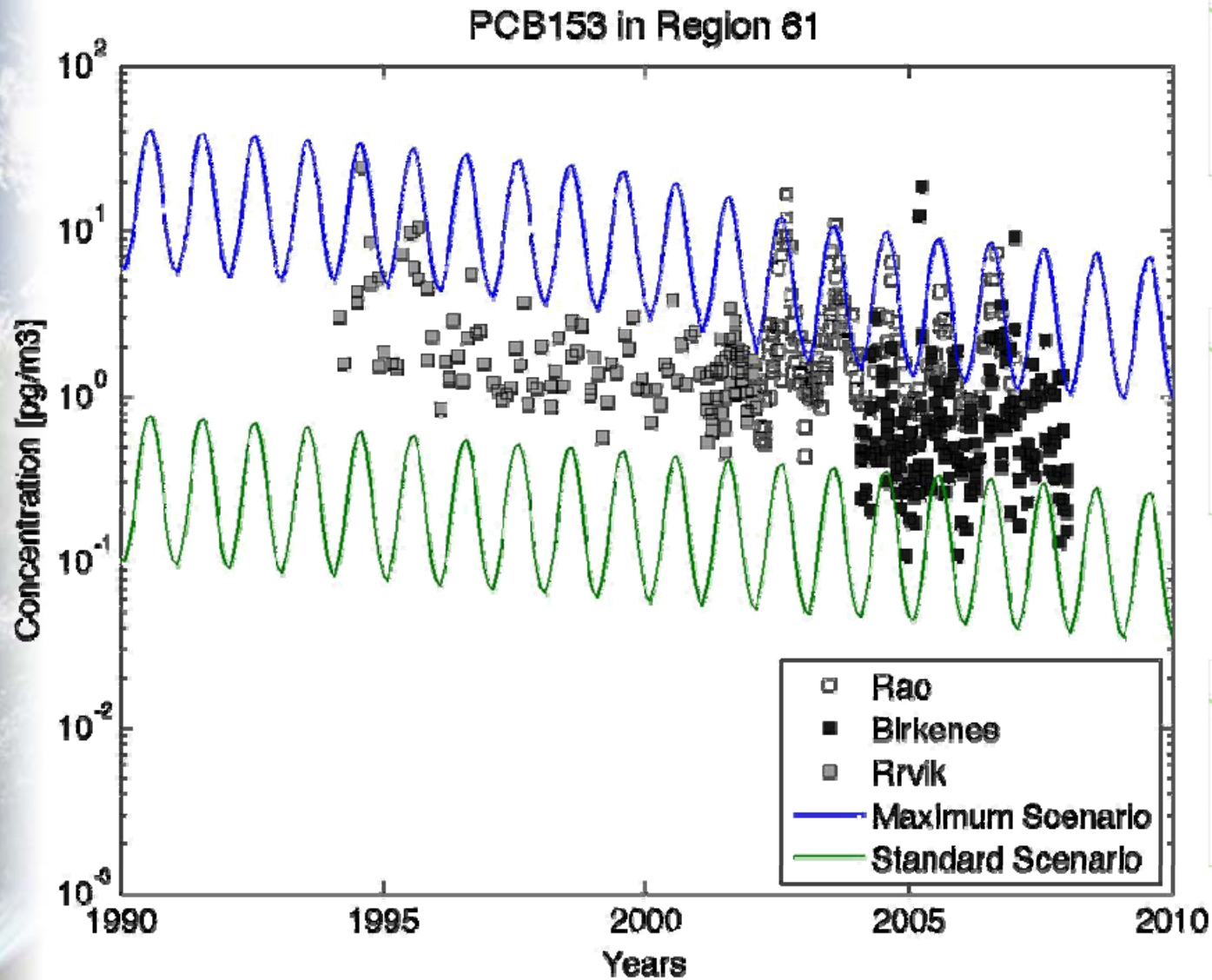
Model Evaluation: PCB 153



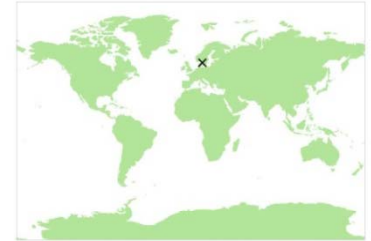
Model Evaluation: PCB 153



Model Evaluation: PCB 153



Rao, 57.39 N, 11.91 E



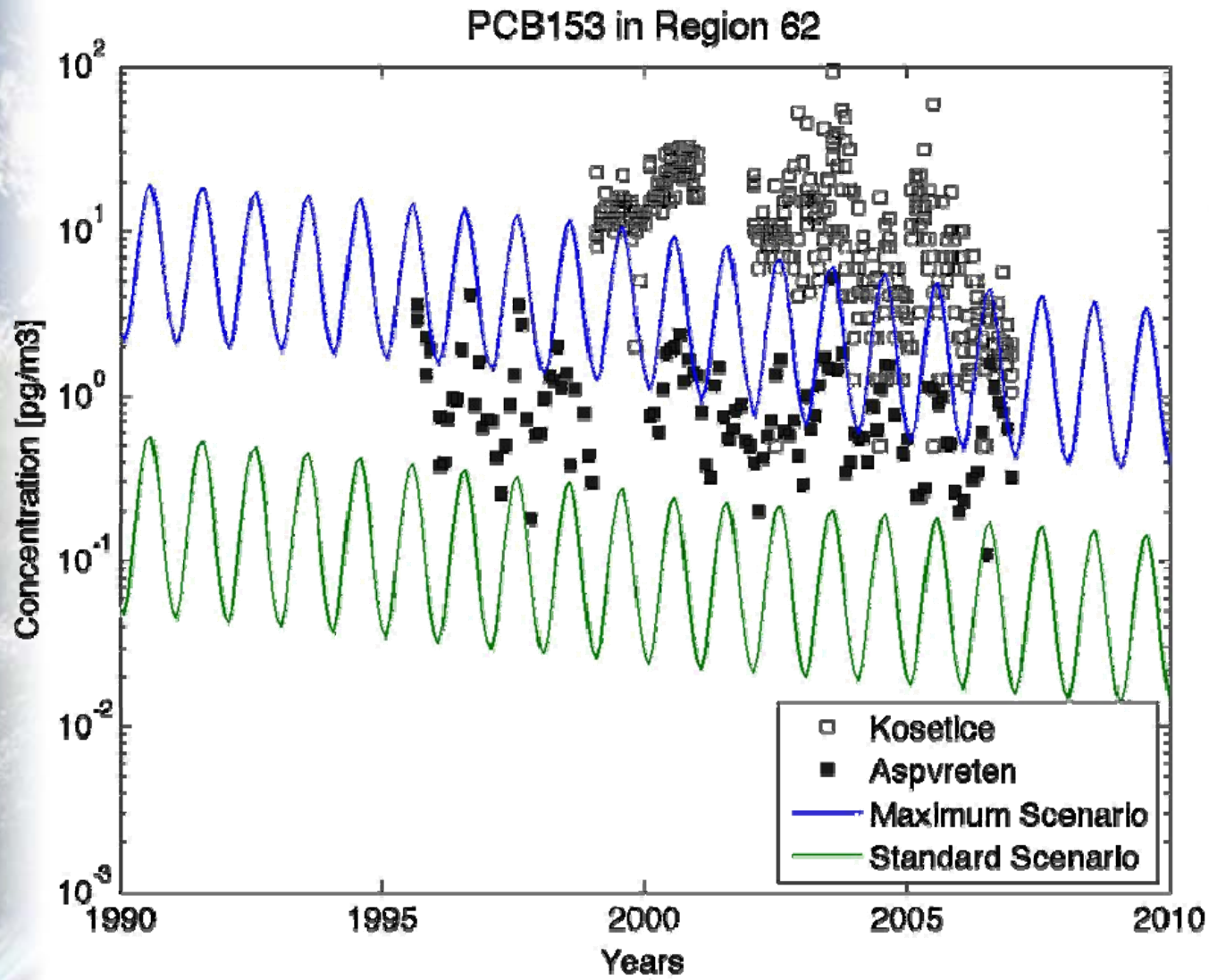
Birkenes, 58.38 N, 8.25 E



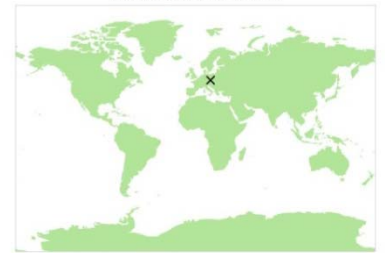
Rrvik, 57.42 N, 11.93 E



Model Evaluation: PCB 153



Kosetice, 49.58 N, 15.08 E

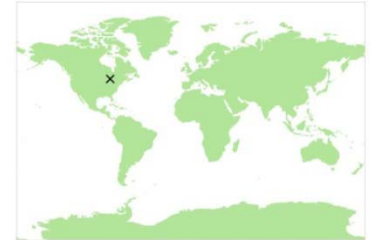


Aspvreten, 58.80 N, 17.98 E

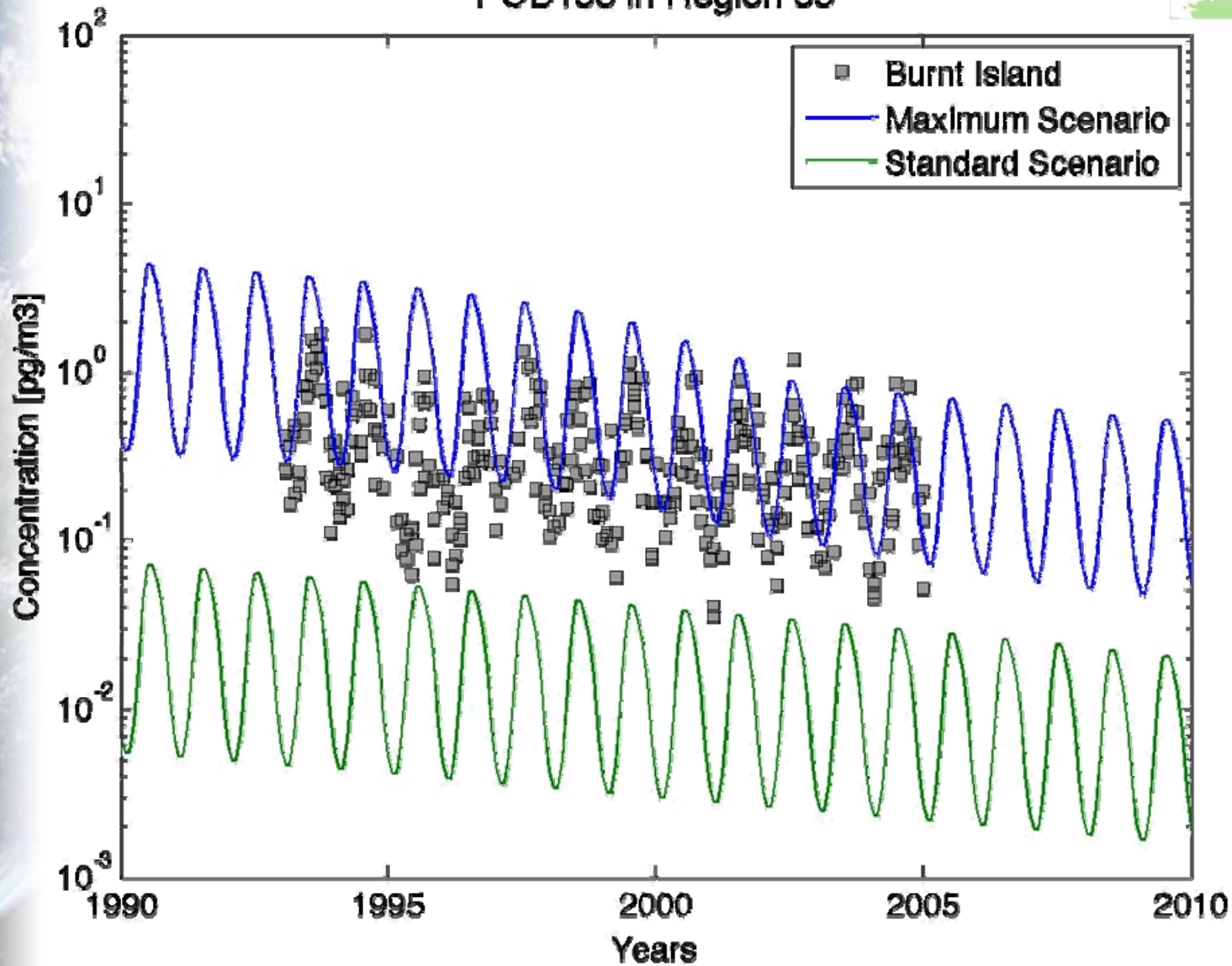


Model Evaluation: PCB 153

Burnt-Island, 45.8 N, 82.95 W



PCB153 in Region 55

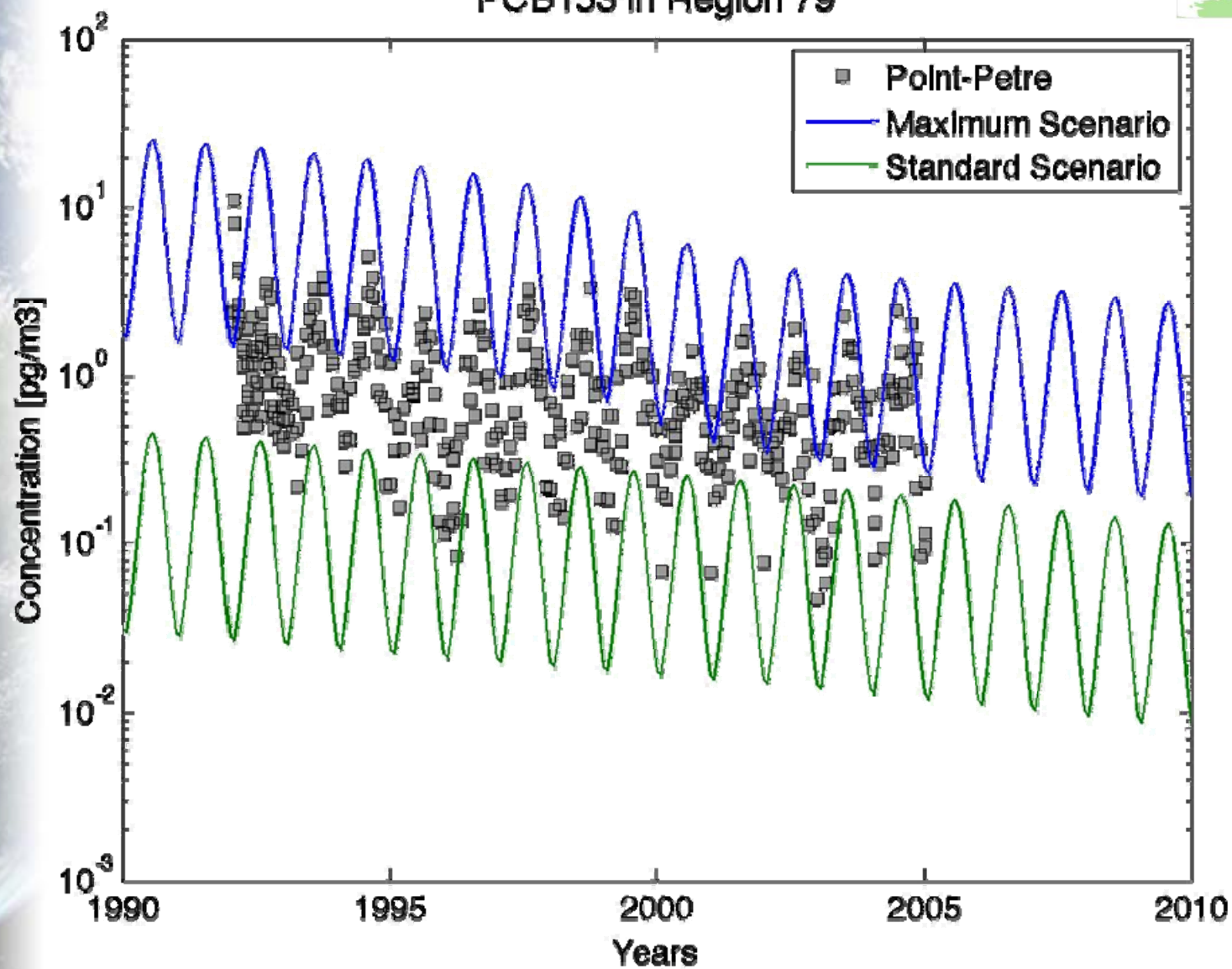


Model Evaluation: PCB 153

Point-Petre, 43.84 N, 77.15 W



PCB153 in Region 79

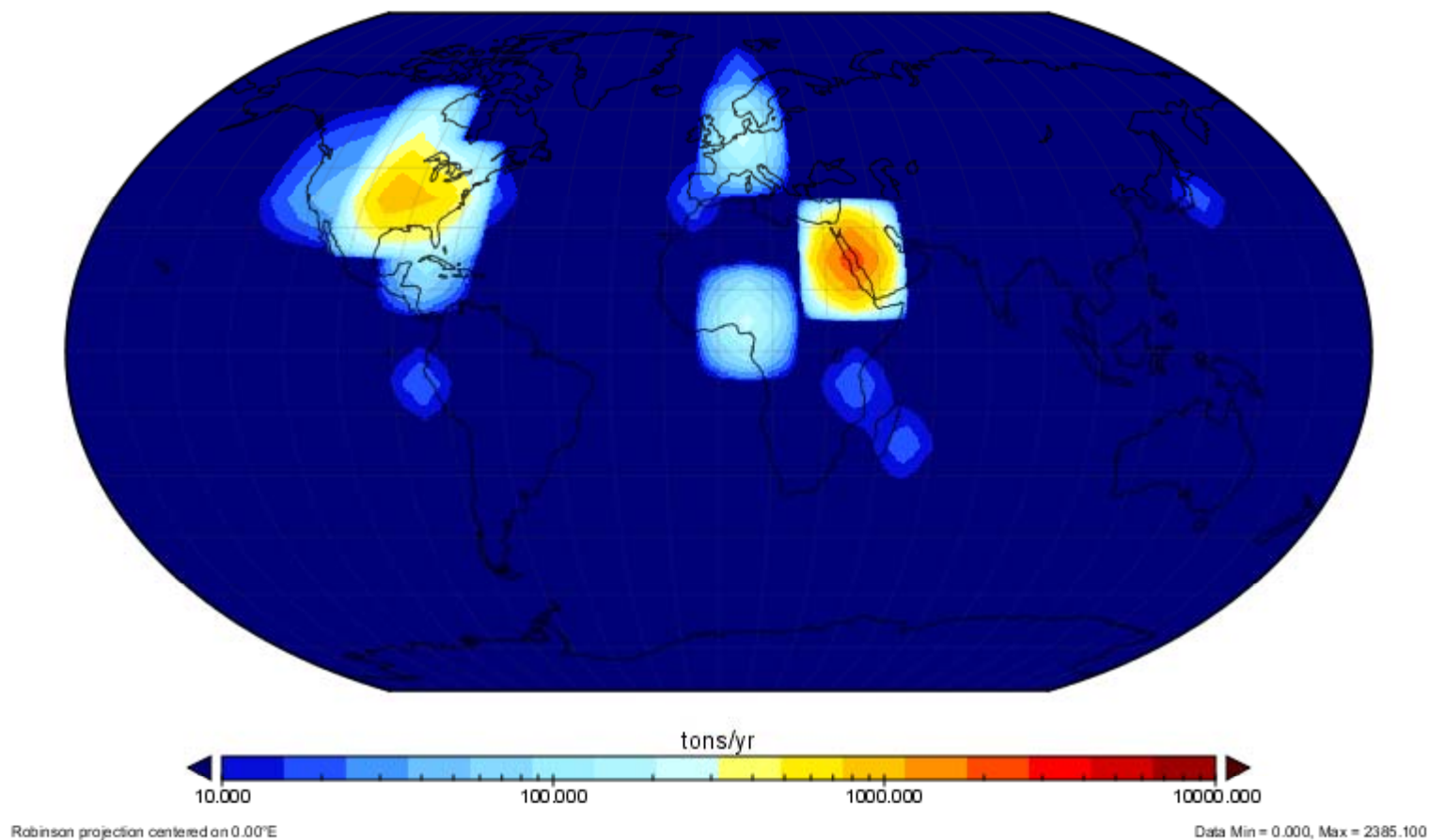




BETR-Global: Simulative Application to α -HCH

BETR-Global: Estimated emissions of a-HCH

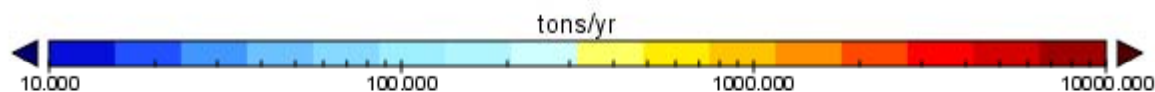
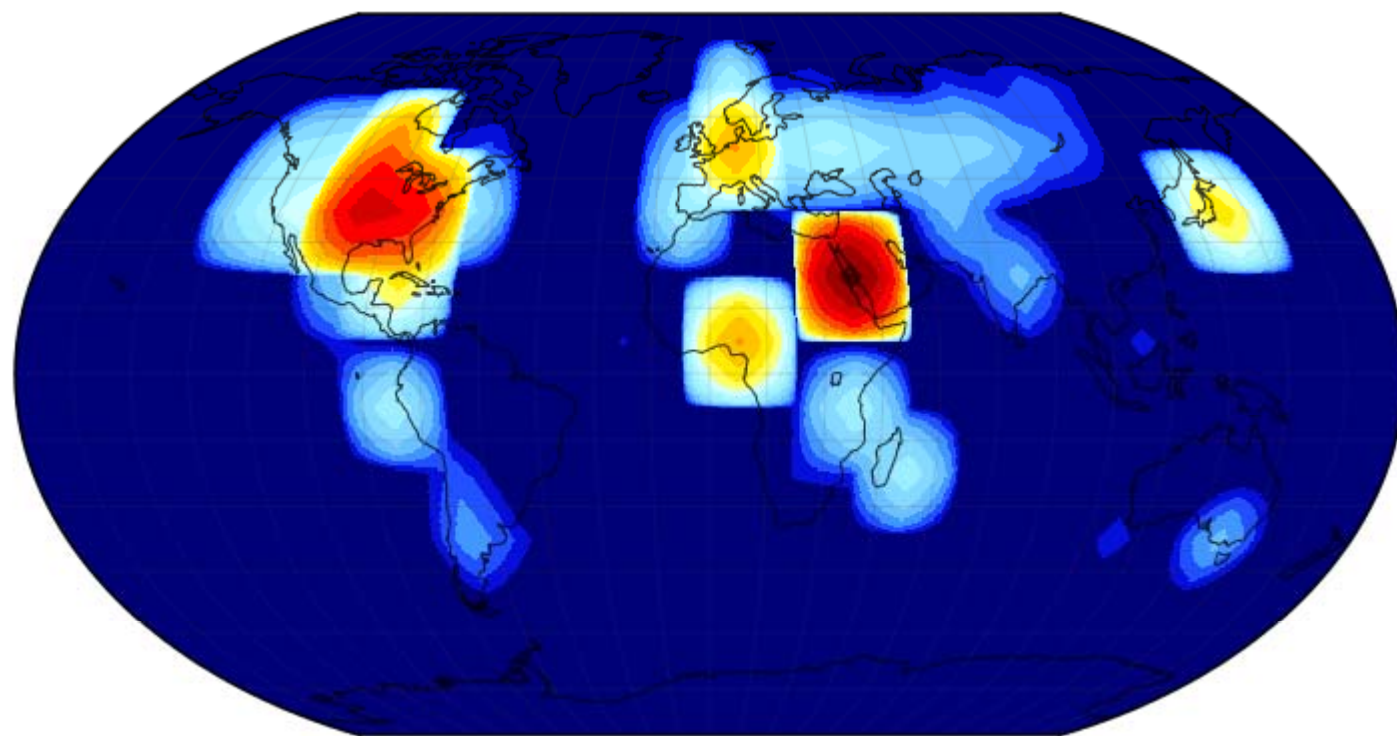
a-HCH Emissions in 1941



Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 1946



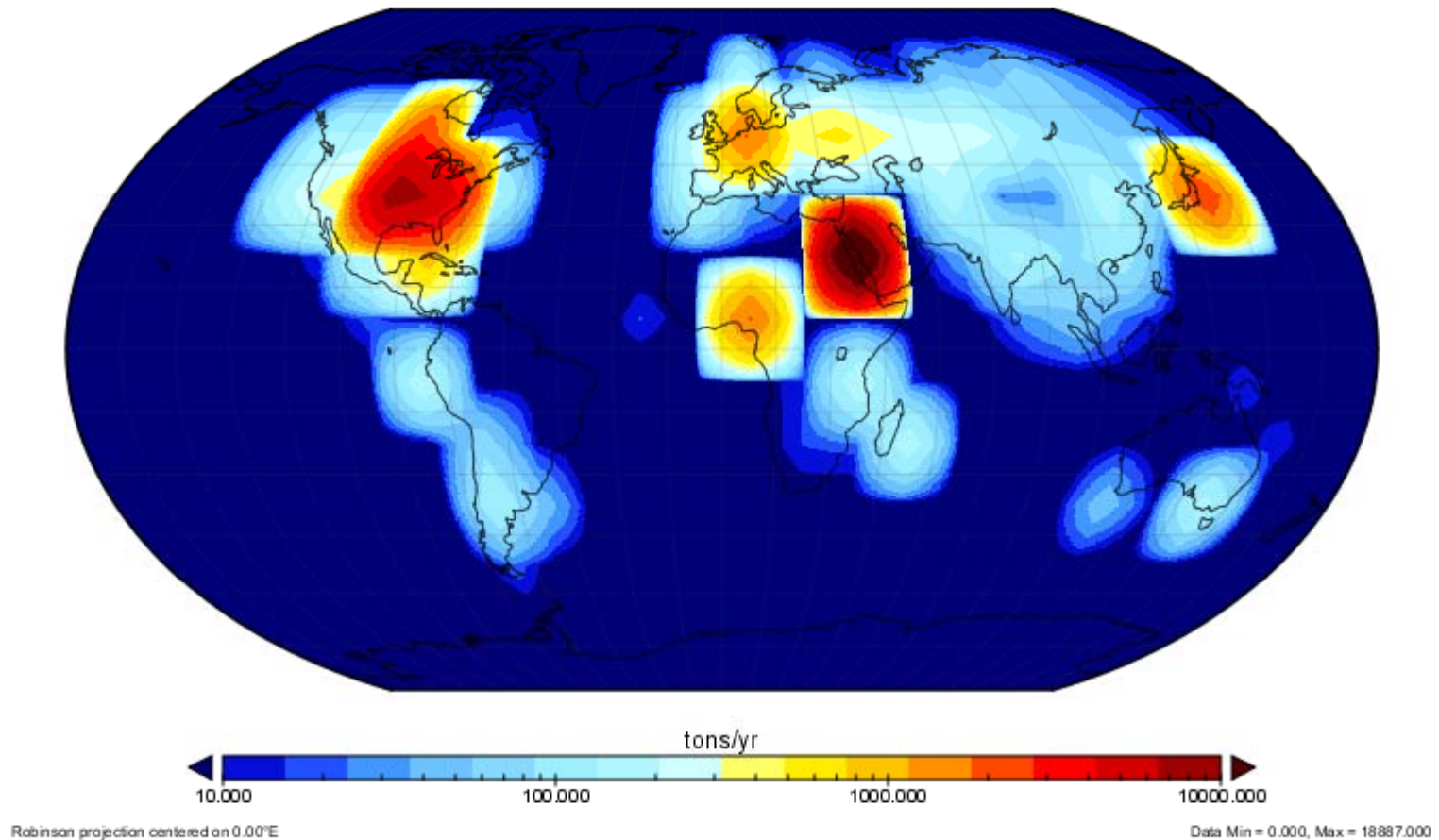
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 12751.000

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

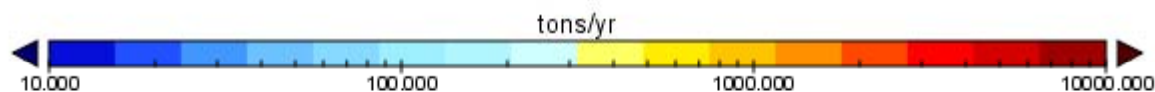
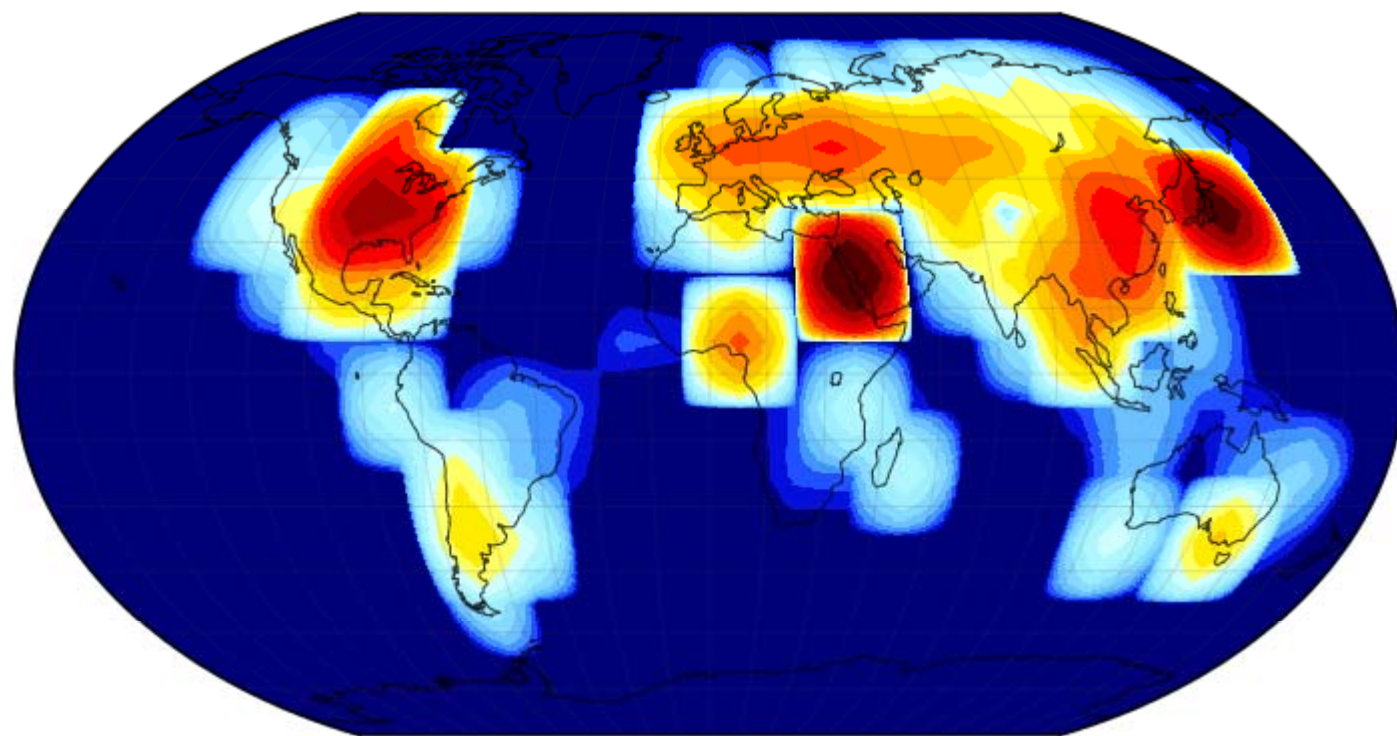
a-HCH Emissions in 1951



Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 1956



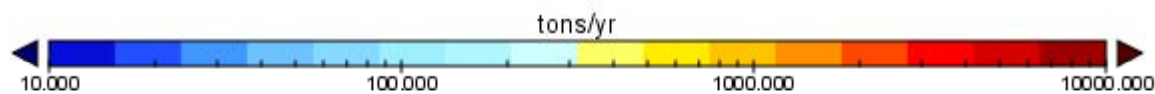
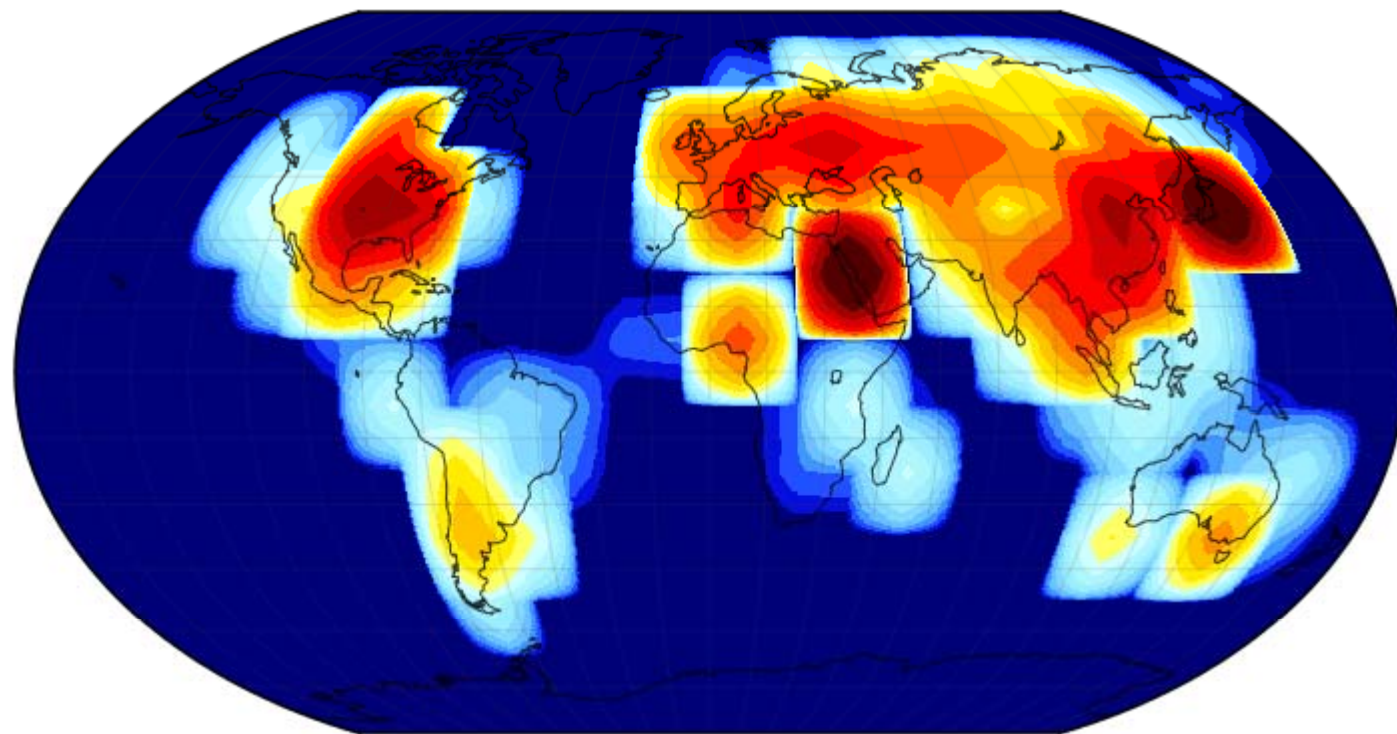
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 22559.000

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 1961



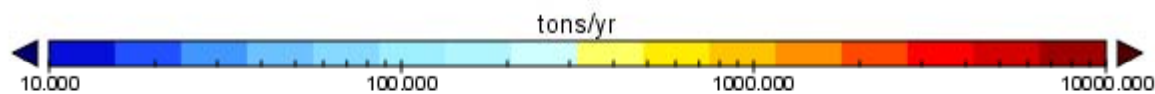
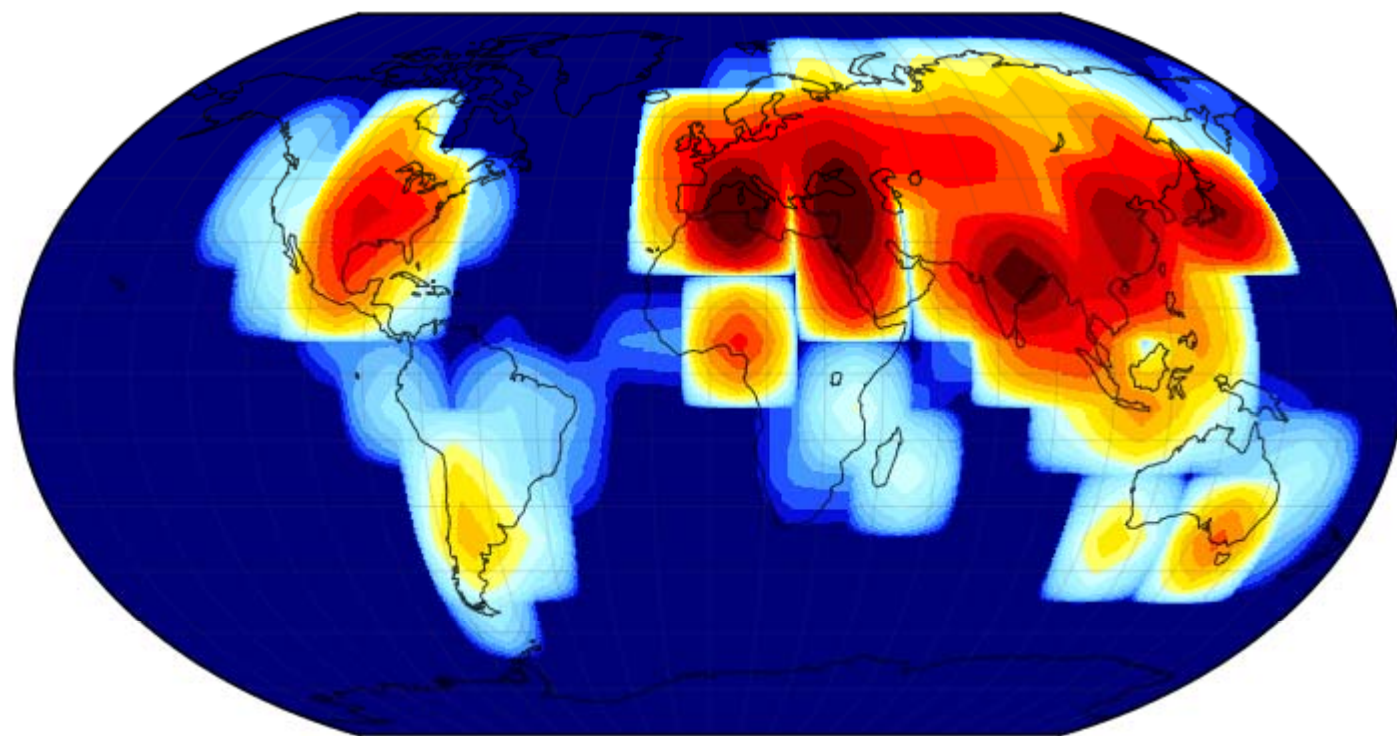
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 23231.000

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 1966



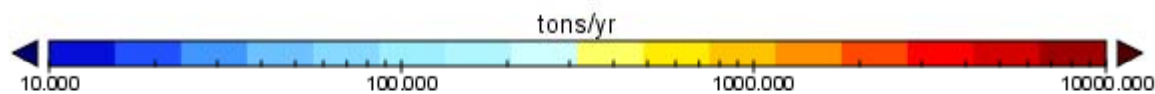
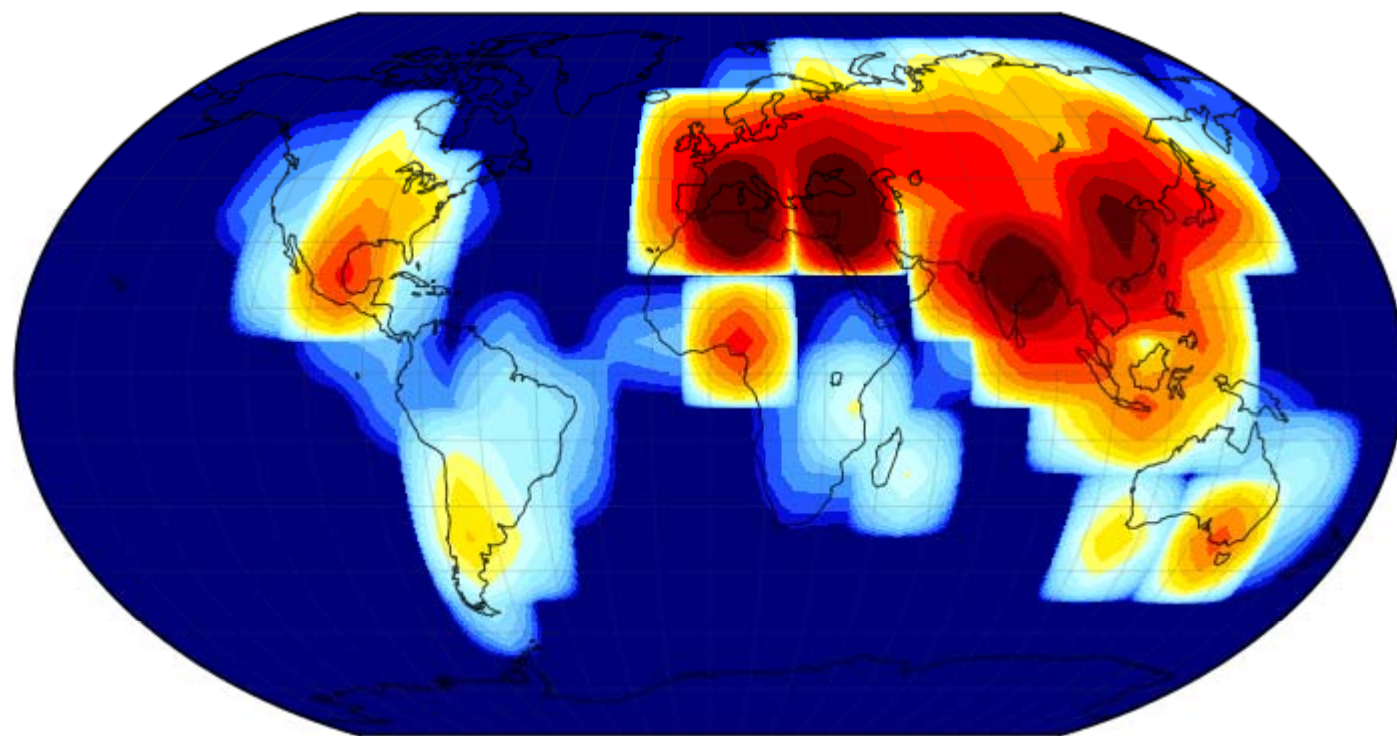
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 24875.000

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 1971



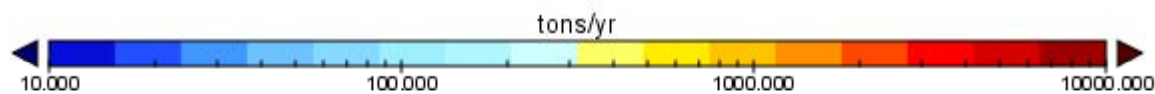
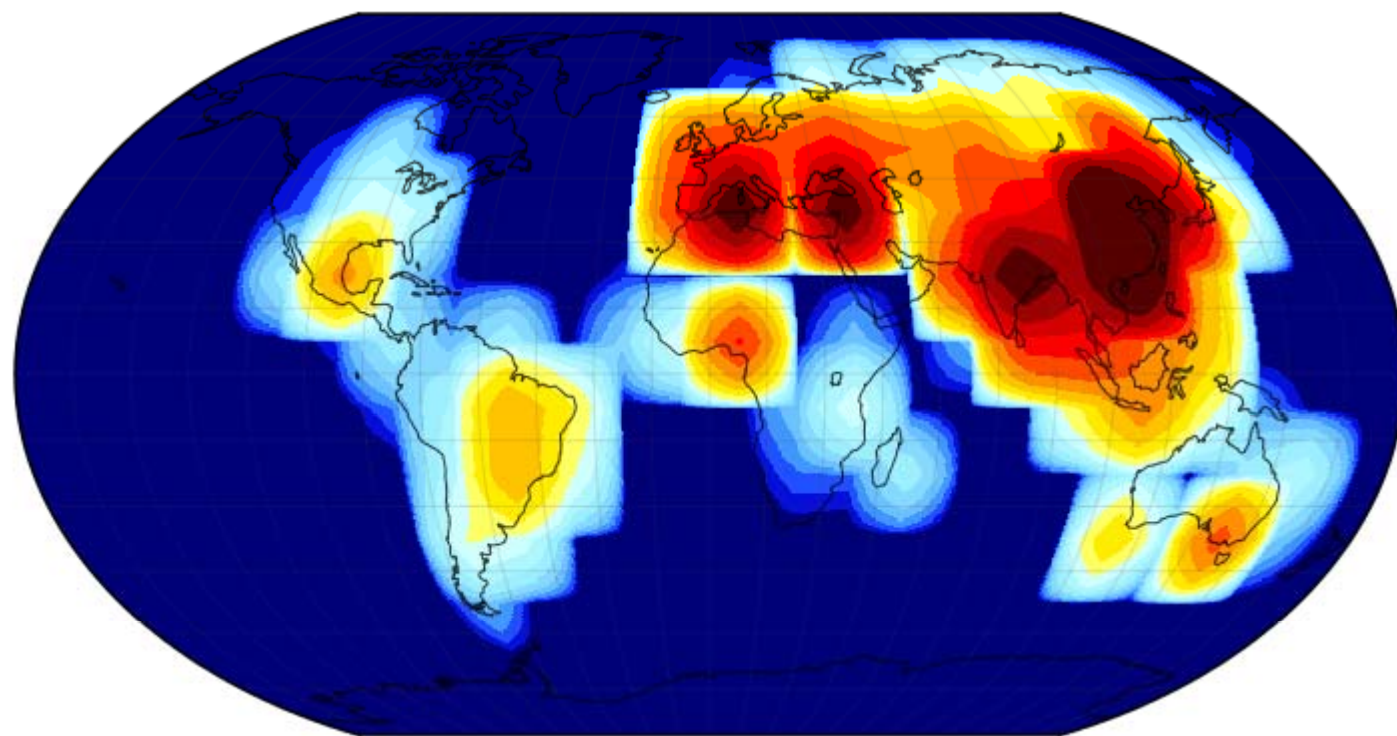
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 35555.000

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 1976



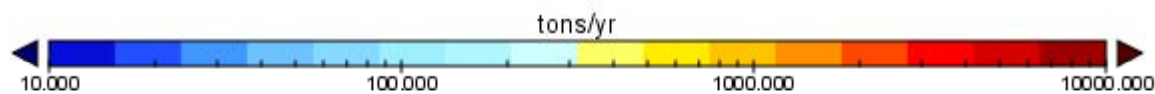
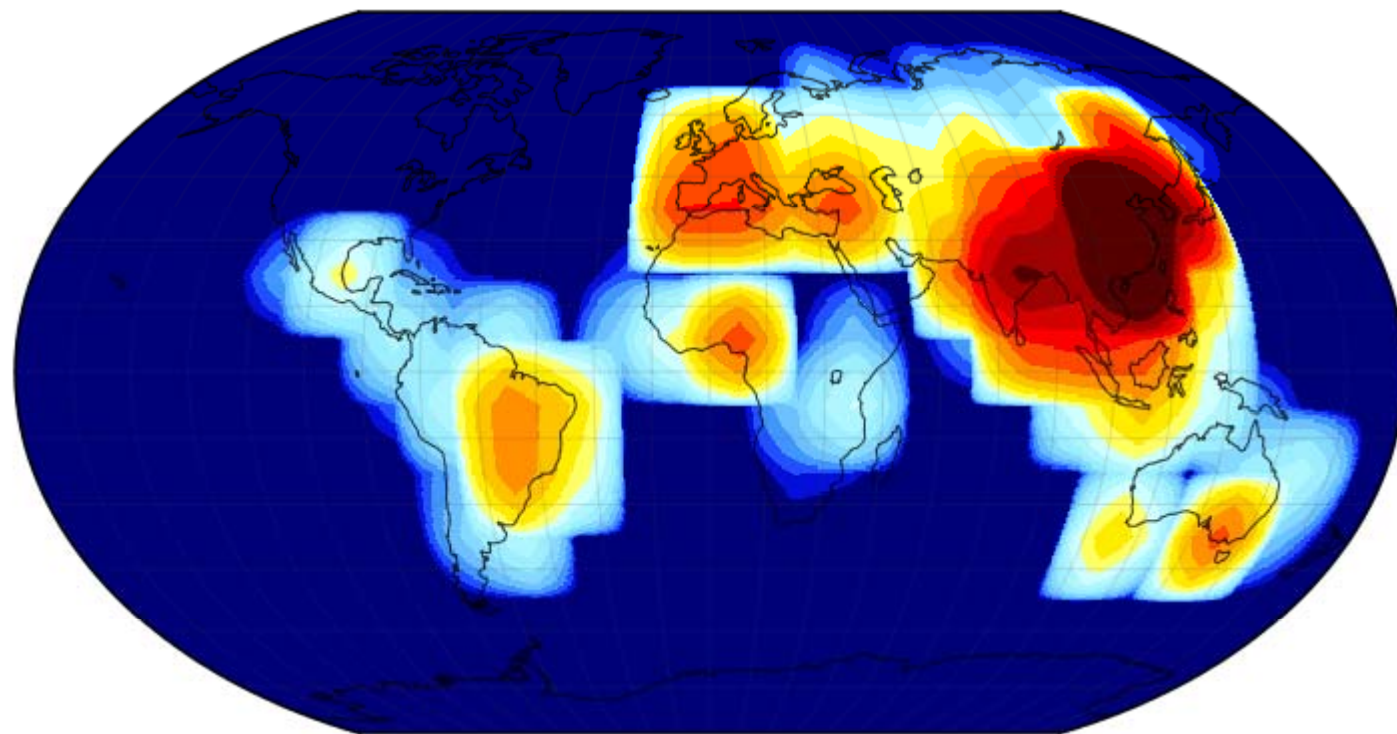
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 33581.000

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 1981



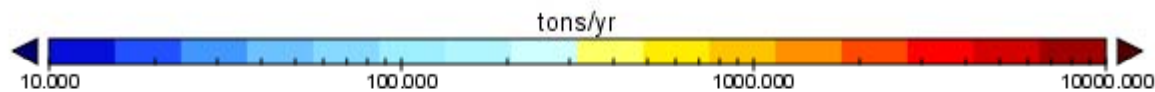
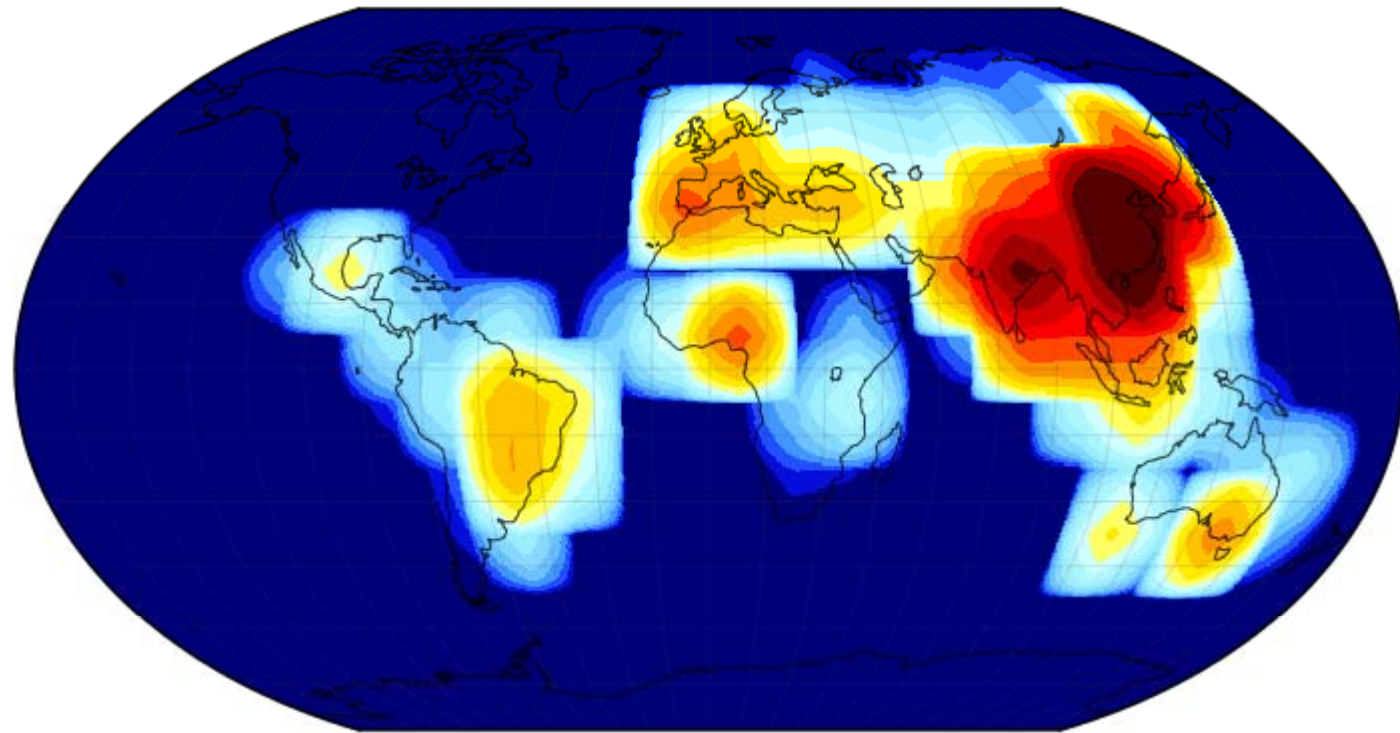
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 43678.000

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 1986



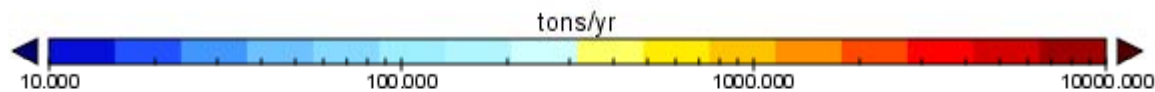
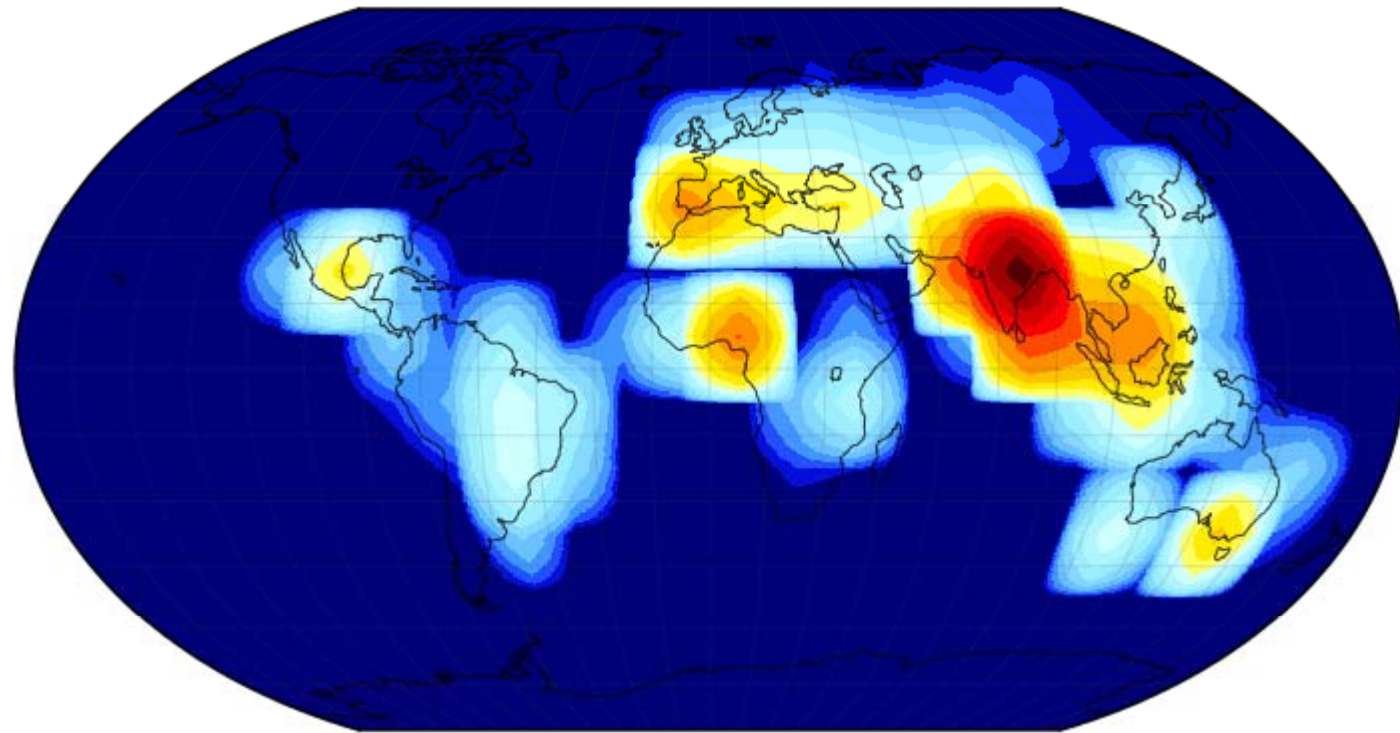
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 27411.000

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 1991



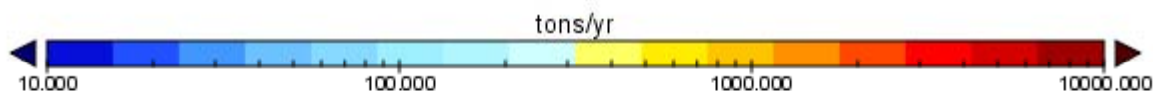
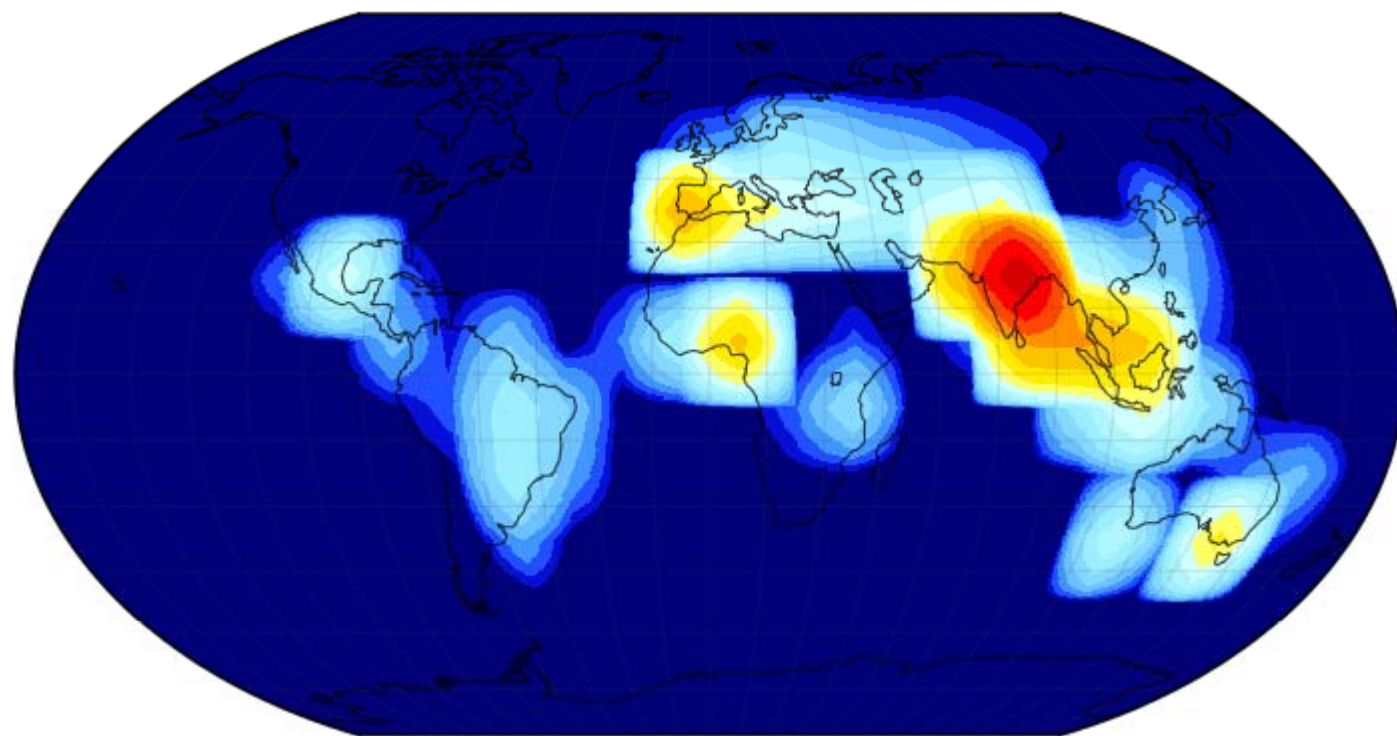
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 12870.000

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 1996



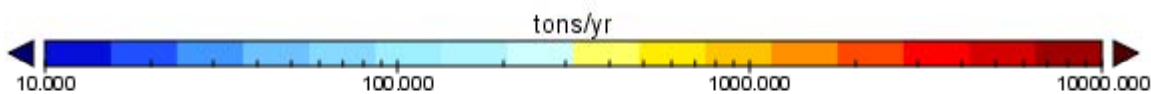
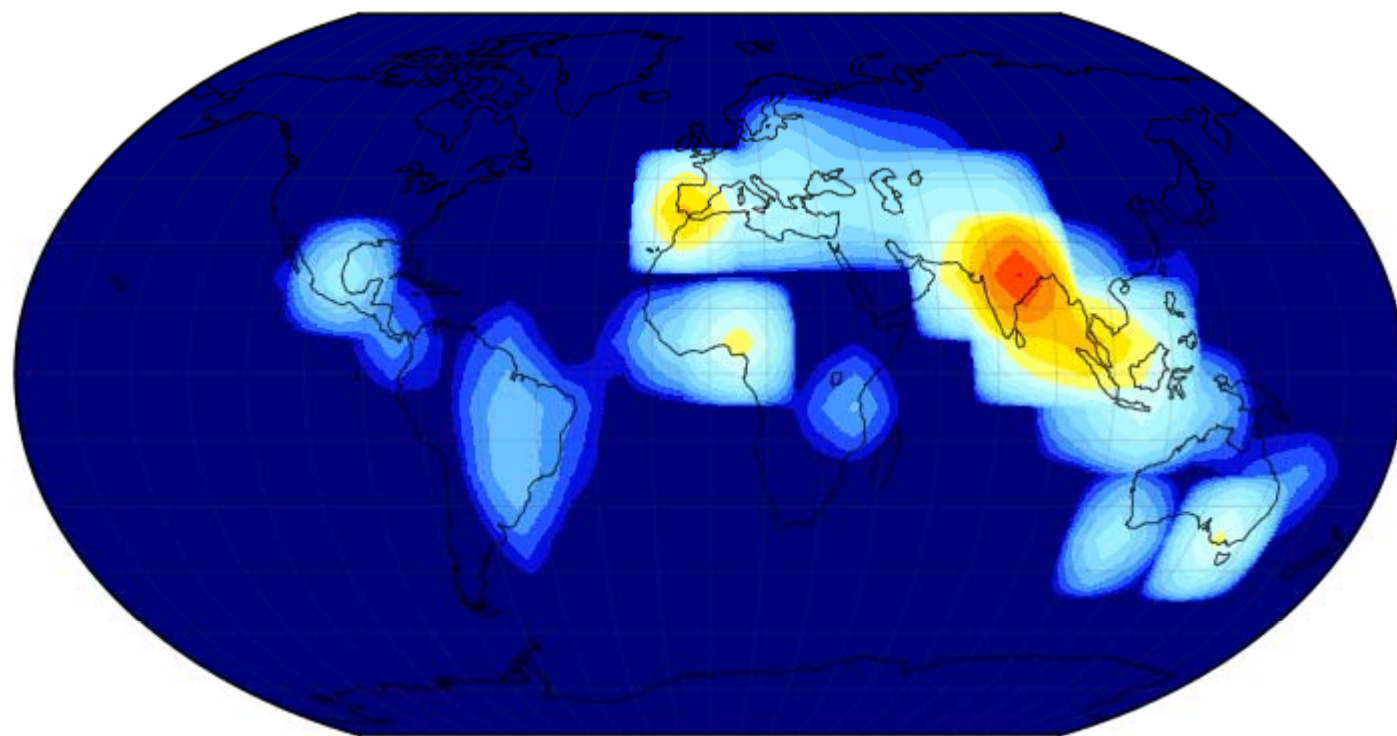
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 6072.000

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 2001



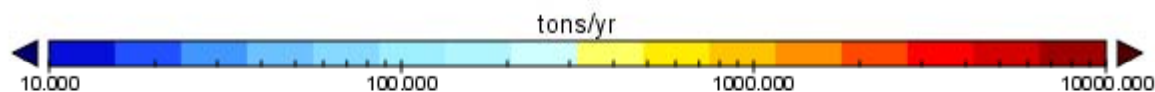
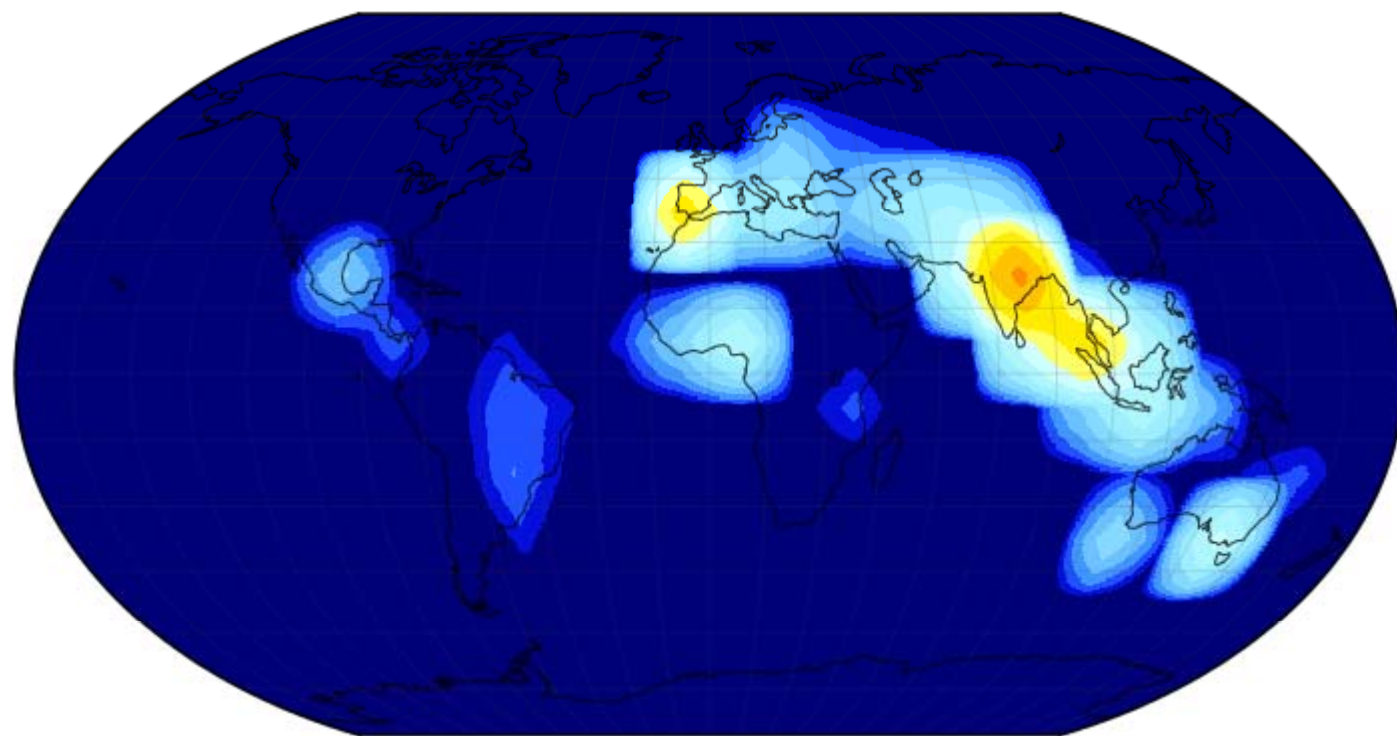
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 2864.800

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 2006



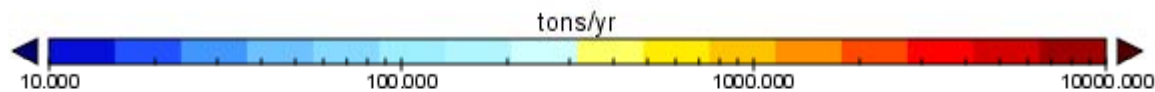
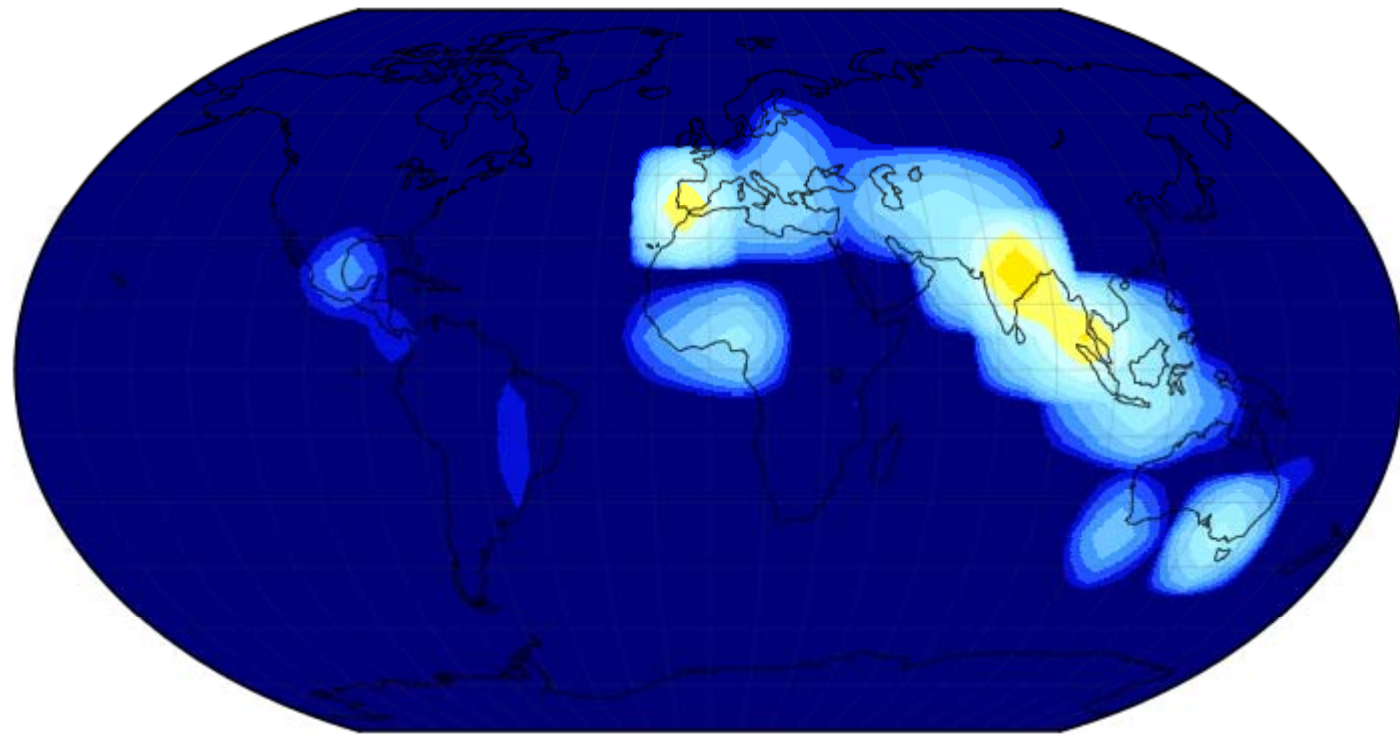
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 1351.600

Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Estimated emissions of a-HCH

a-HCH Emissions in 2011



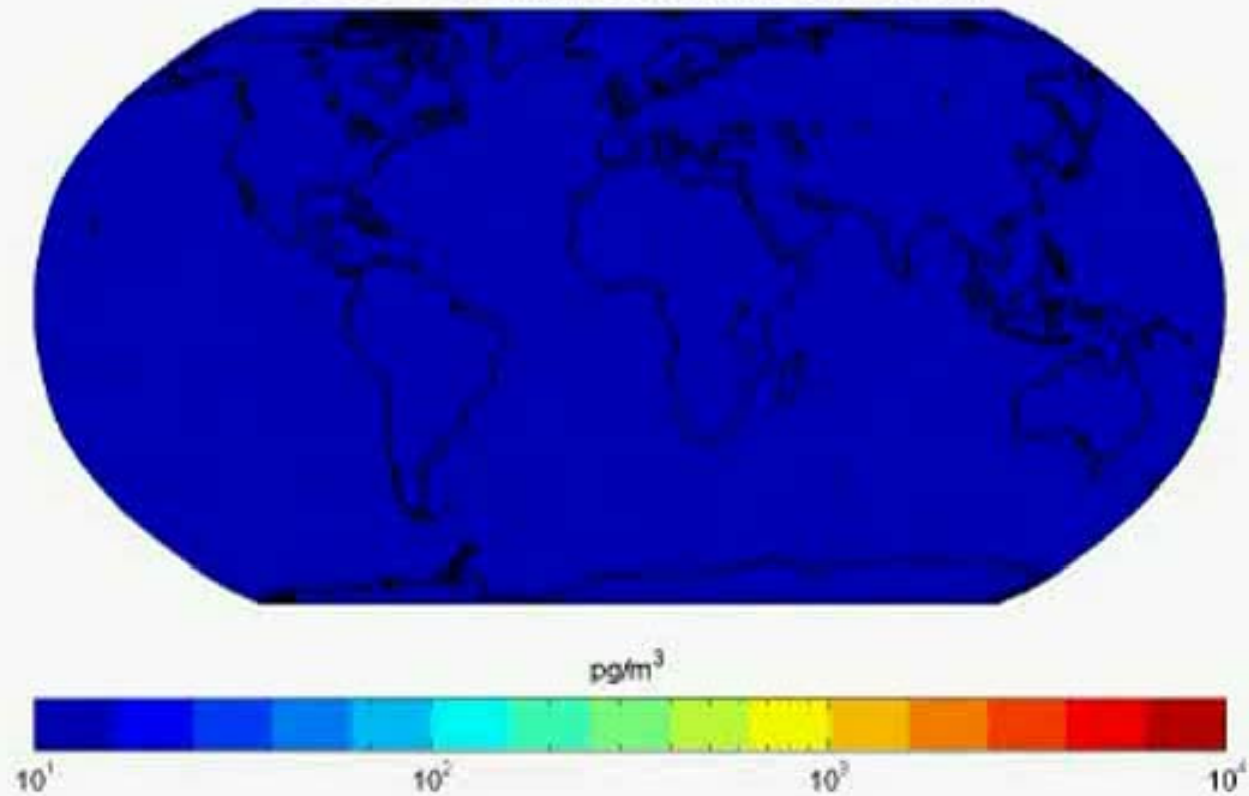
Robinson projection centered on 0.00°E

Data Min = 0.000, Max = 741.070

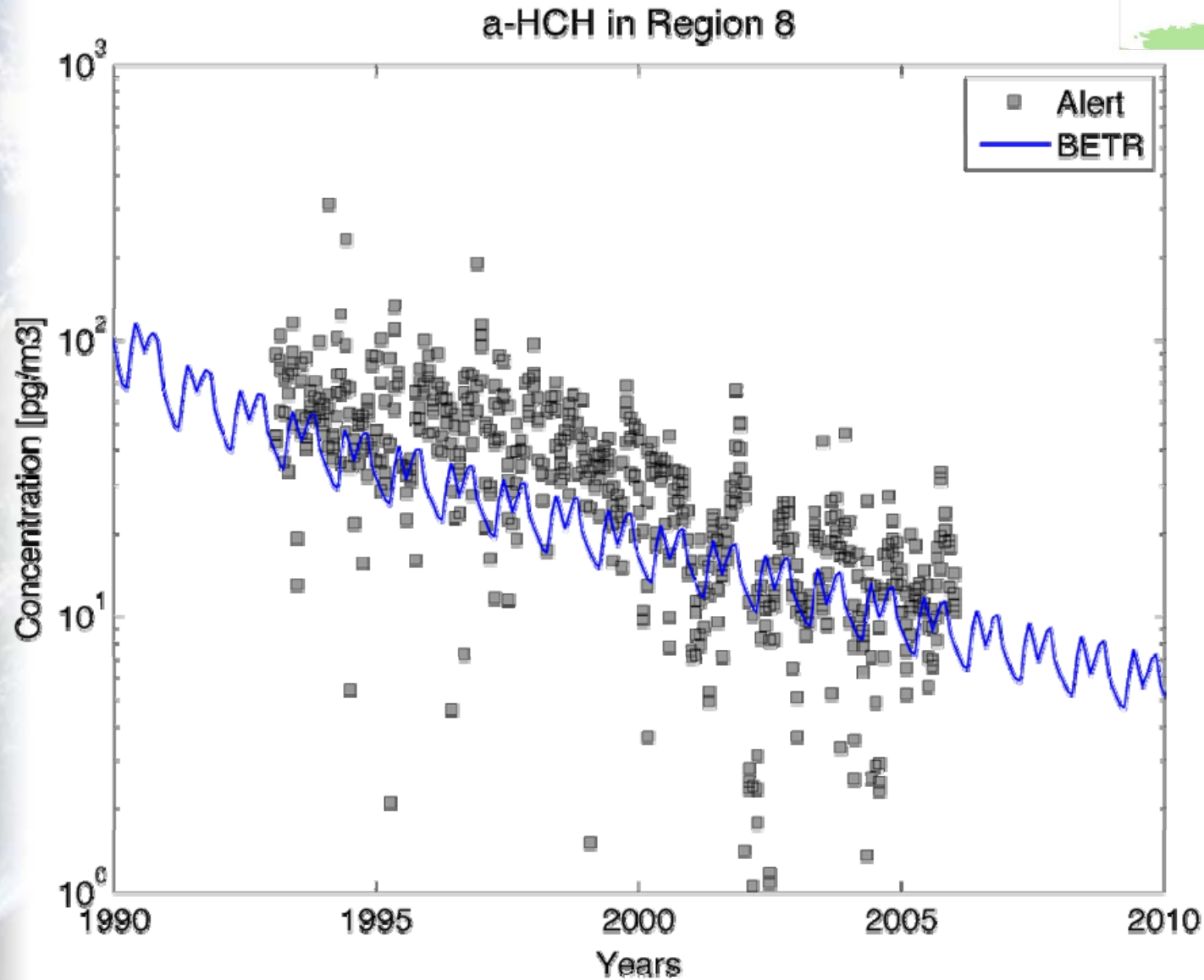
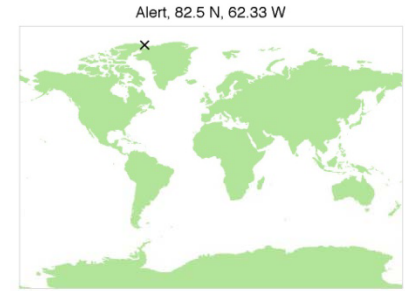
Breivik et al. *Science of the Total Environment*, 377(2-3), 296 – 307 2007.

BETR-Global: Modeled concentration of a-HCH

a-HCH Concentration in Lower Air in 1940



Model Evaluation: α -HCH

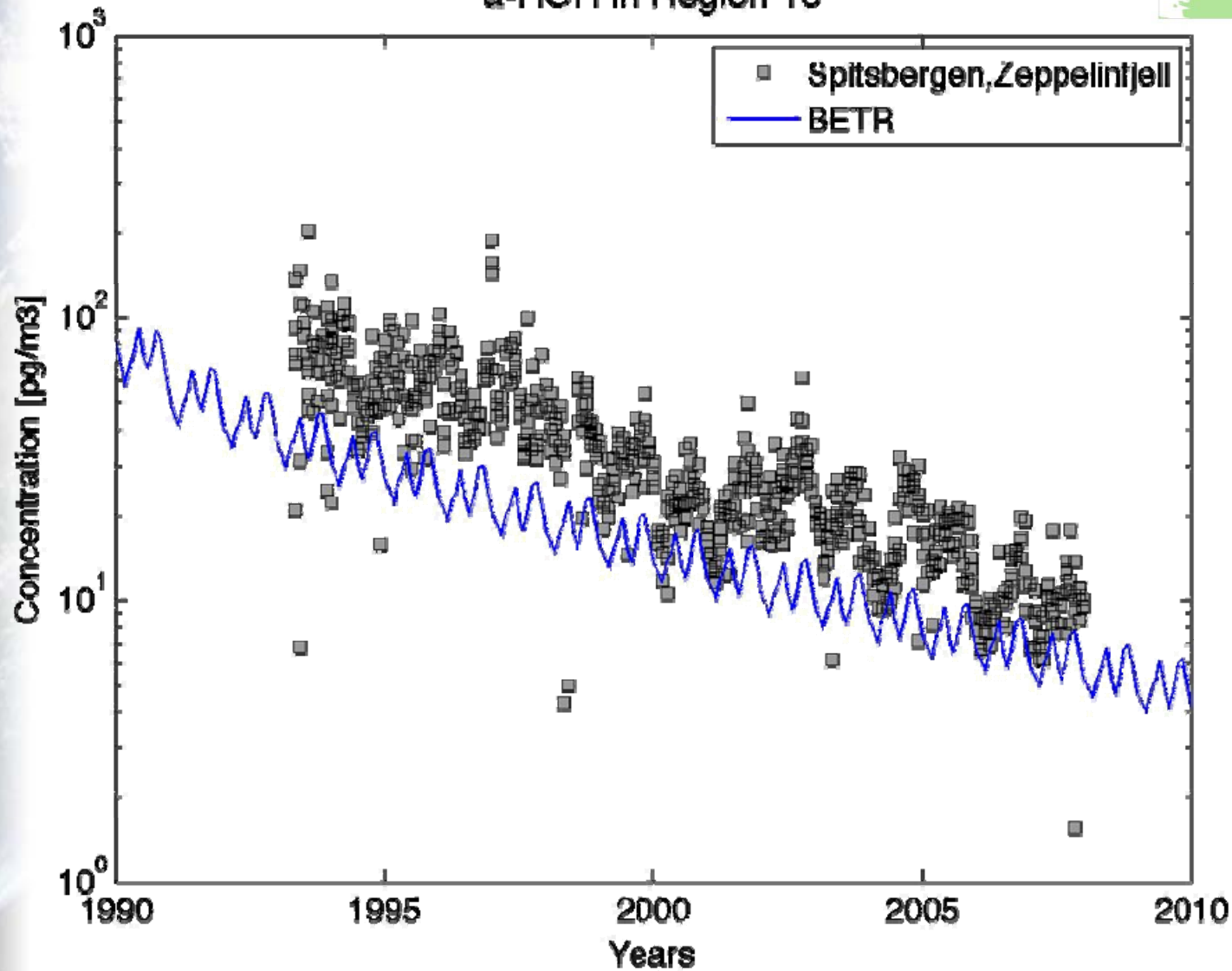


Model Evaluation: α -HCH

Spitsbergen, Zeppelintjell, 78.90 N, 11.88 E



α -HCH in Region 13

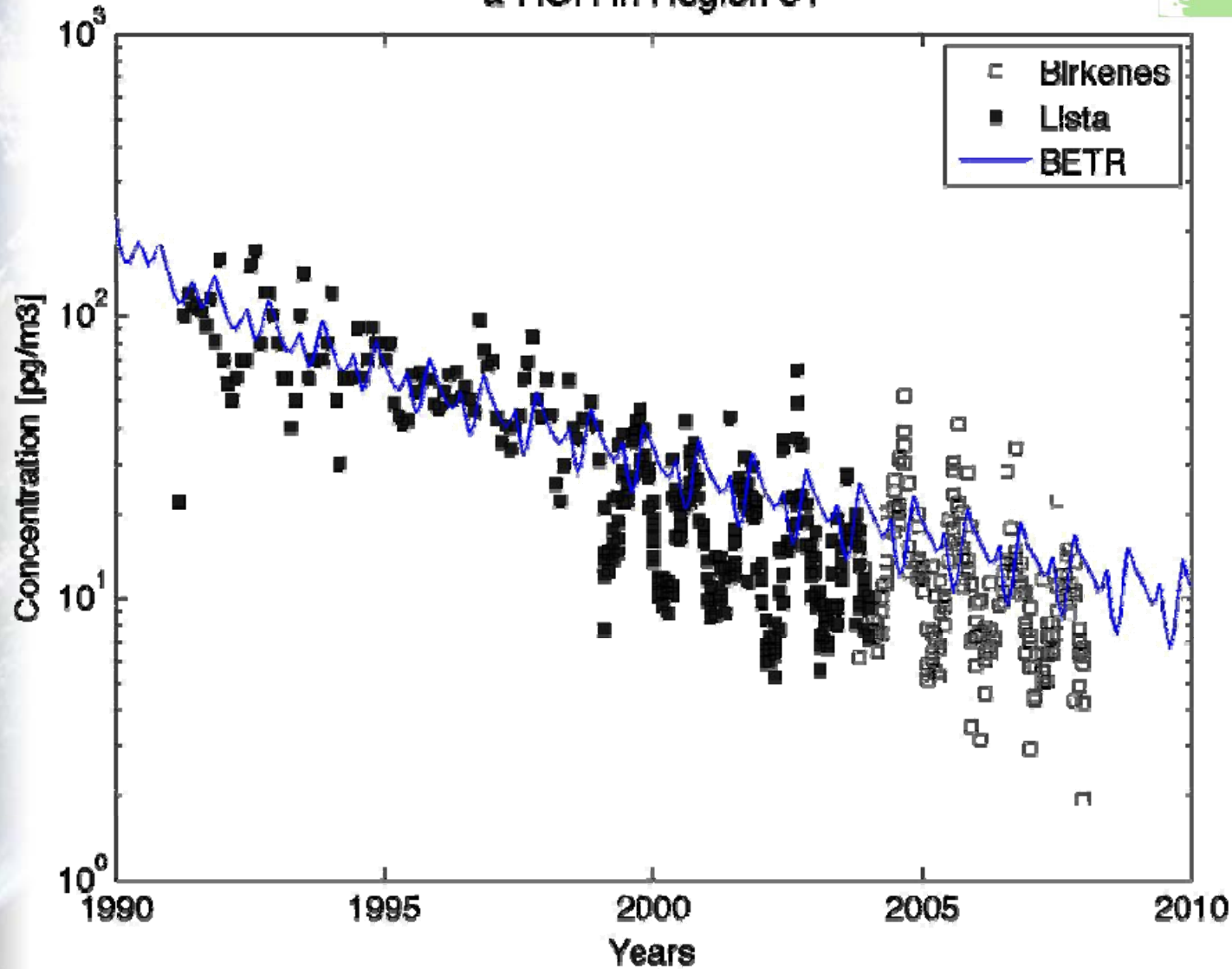


Model Evaluation: α -HCH

Birkenes, 58.38 N, 8.25 E

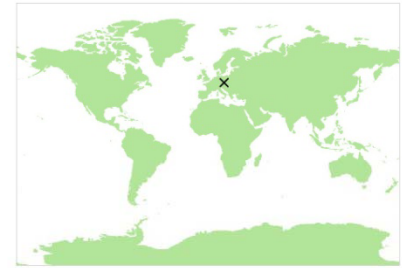


α -HCH in Region 61

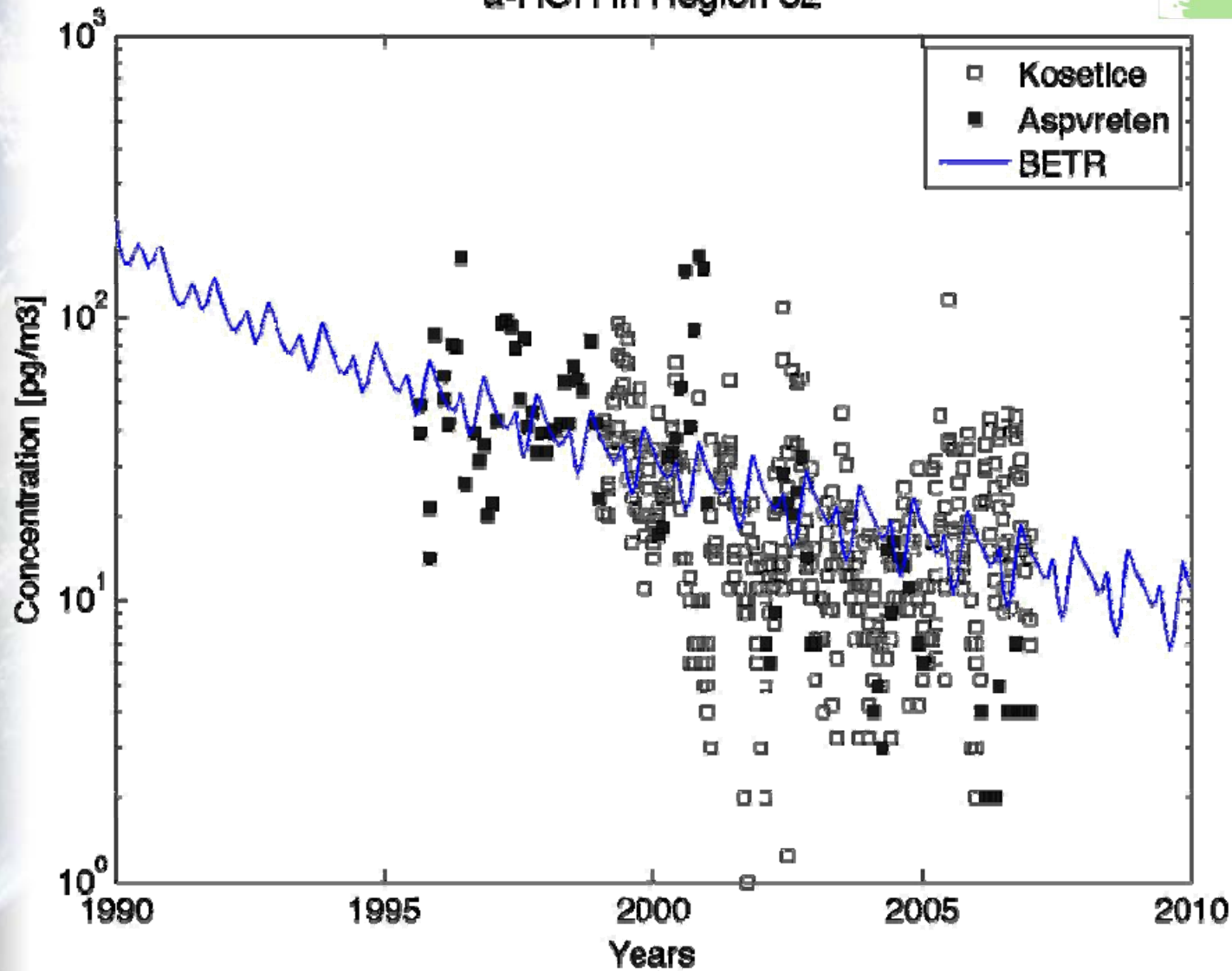


Model Evaluation: α -HCH

Kosetice, 49.58 N, 15.08 E



α -HCH in Region 62

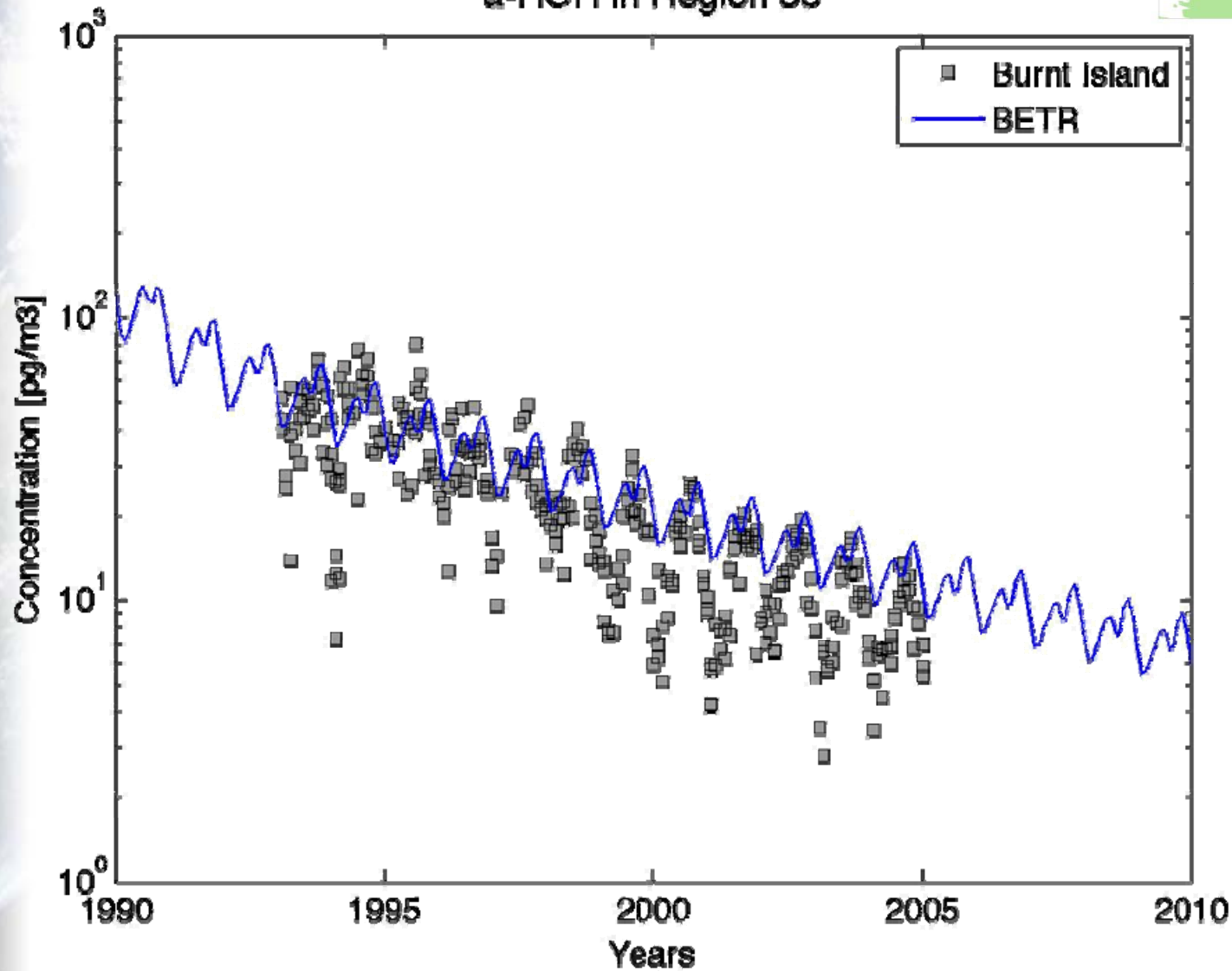


Model Evaluation: α -HCH

Burnt-Island, 45.8 N, 82.95 W



α -HCH in Region 55

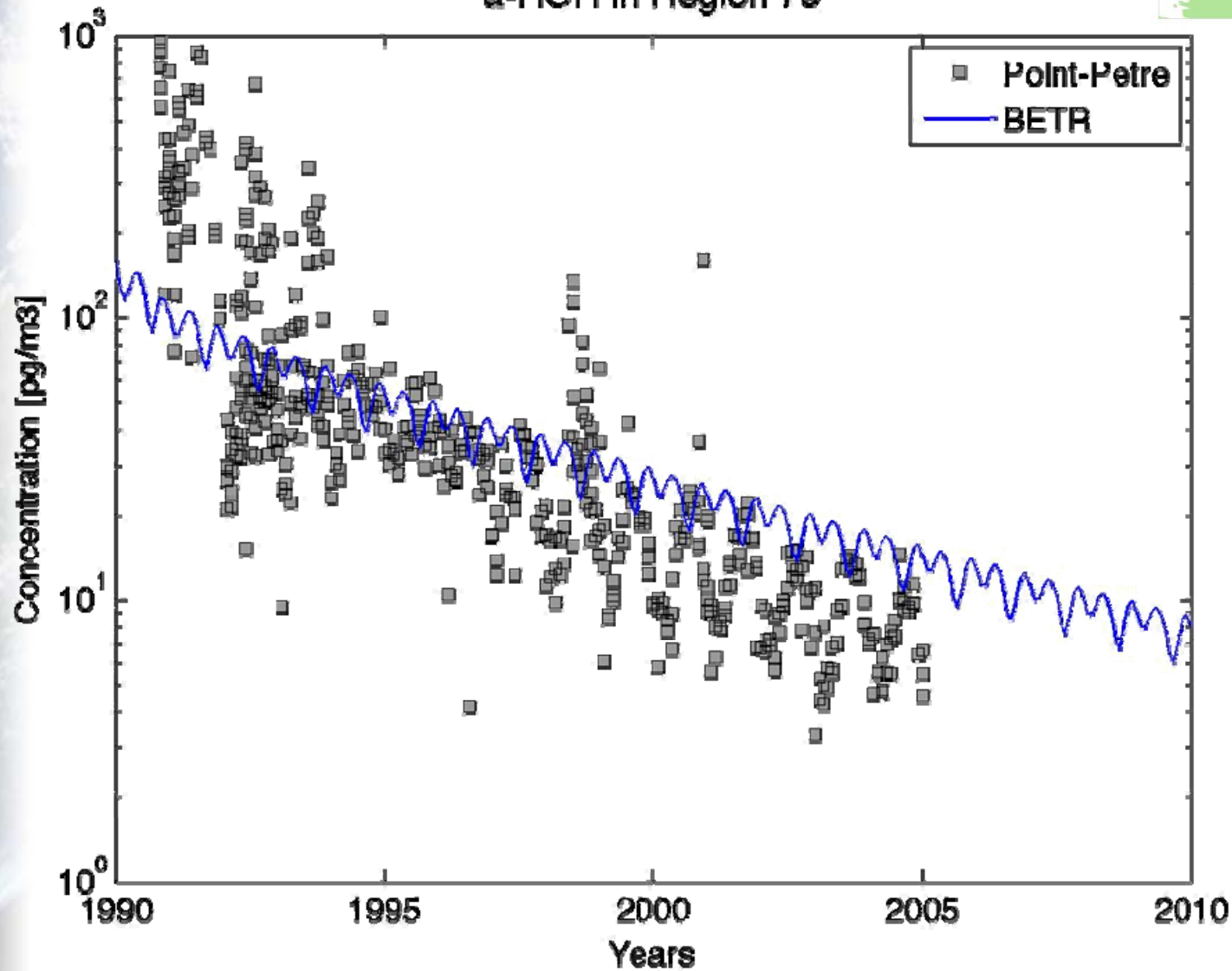


Model Evaluation: α -HCH

Point-Petre, 43.84 N, 77.15 W



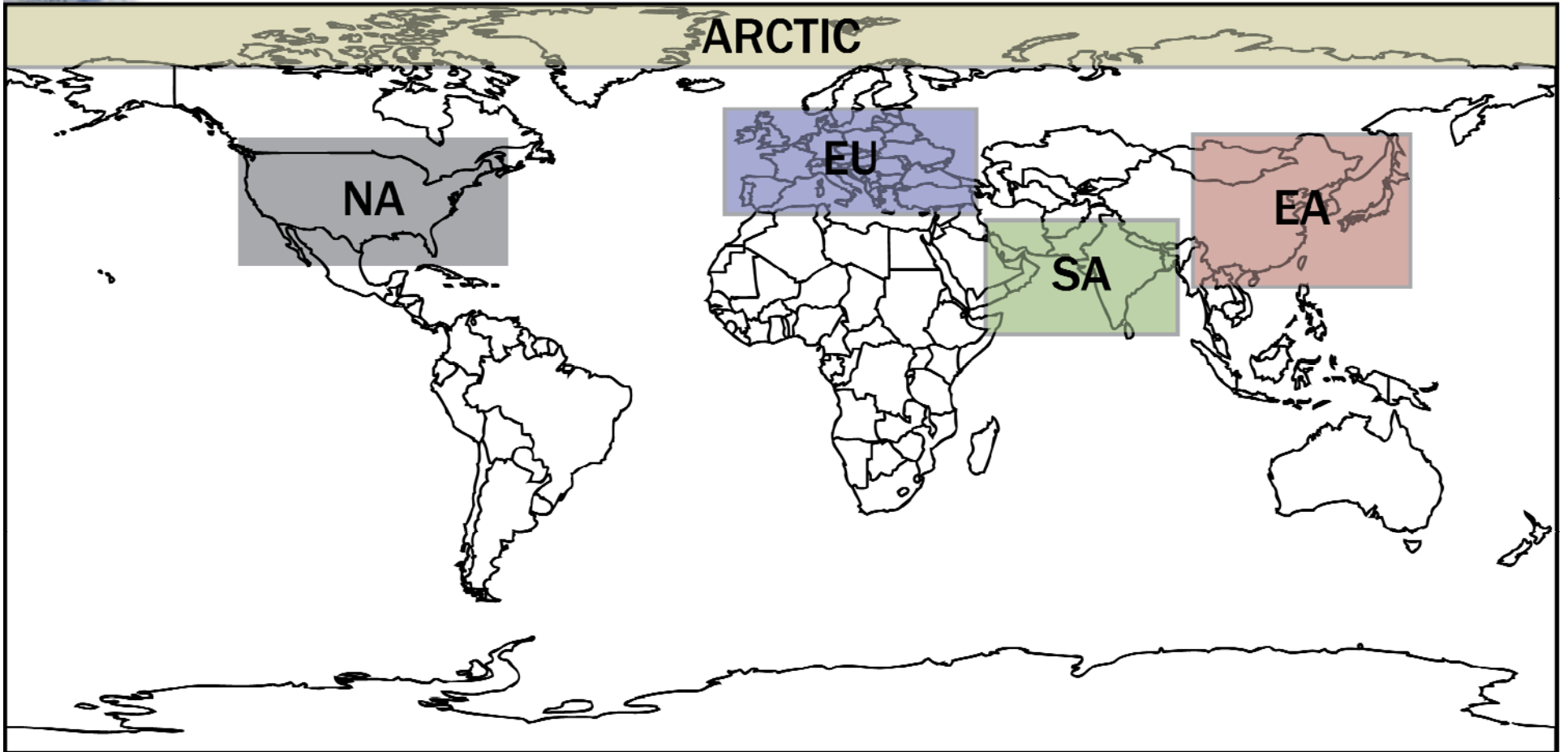
α -HCH in Region 79



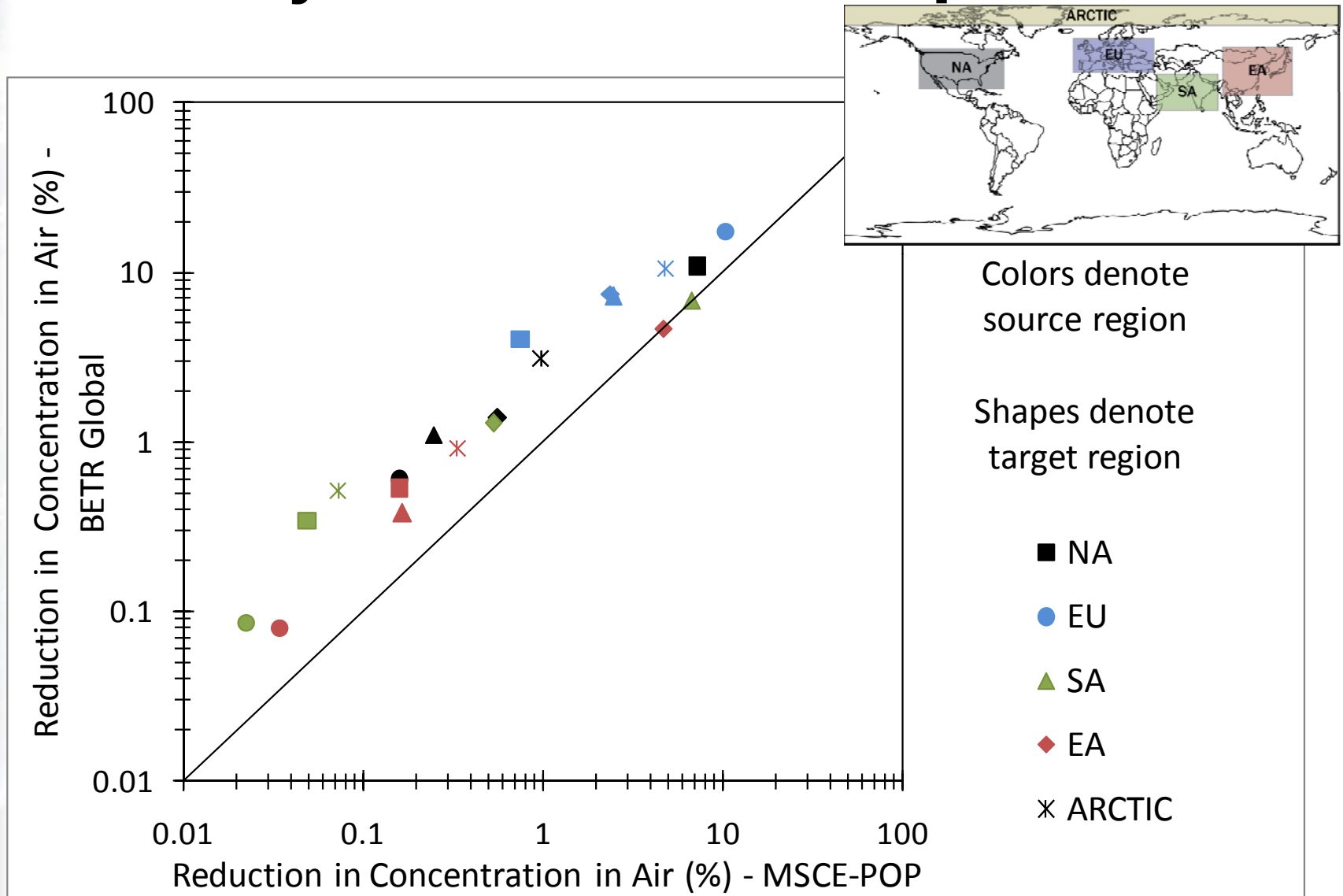
HTAP Emission Reduction Scenario Analysis



HTAP Emission Reduction Scenario Analysis



Emission Reduction Scenario Analysis: Model Comparison





Summary

- Simulative application of BETR Global provides a satisfactory quantitative description of PCB 153 and α -HCH in the global environment compared to observations
- HTAP Source-to-receptor calculations have been completed and show good agreement between models



Ongoing work...

- Further refinement of α -HCH case study
- Scenario analysis for climate change
 - With Lara Lamon, University Ca' Foscari, Venice, Santa Marta, Italy
- Mass balance modeling of manufacturing emissions of perfluorinated acids
 - James Armitage & Ian Cousins, ITM Stockholm, Sweden



Acknowledgments

Research Collaborators

- Prof. Dr. Thomas E. McKone & Dr. Bill Riley, Lawrence Berkeley National Laboratory, Berkeley, USA

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Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Umwelt BAFU
Office fédéral de l'environnement OFEV
Ufficio federale dell'ambiente UFAM
Uffizi federal d'ambient UFAM

BETR-Global: HTAP Emission Reduction Scenario Analysis

PCB 153: Deposition Flux to Surface

20% reduction in 2001 emissions in:

PCB153	NA	EU	SA	EA
NA	14	2.3	0.19	0.45
EU	0.40	17.4	0.03	0.05
SA	0.63	5.7	10.4	0.17
EA	0.75	6.0	1.8	7.5
ARCTIC	3.1	10.8	0.36	0.85

Results in a %
Reduction in





BETR-Global: HTAP Emission Reduction Scenario Analysis

PCB 153: Deposition Flux to Surface

1% reduction in global emissions in 2001 in:

Results in
a %
Reduction
in

PCB153	NA	EU	SA	EA
NA	4.1	0.19	0.22	0.52
EU	0.12	1.4	0.04	0.05
SA	0.18	0.47	12.3	0.20
EA	0.22	0.49	2.2	8.6
ARCTIC	0.90	0.89	0.42	0.98



BETR-Global: HTAP Emission Reduction Scenario Analysis

α -HCH: Deposition Flux to Surface

20% reduction in 2001 emissions in:

Results in
a %
Reduction
in

α -HCH	NA	EU	SA	EA
NA	3.71	0.68	0.78	1.06
EU	0.51	2.36	0.28	0.37
SA	0.08	0.18	1.74	0.22
EA	0.18	0.37	1.16	3.38
ARCTIC	0.76	0.86	0.71	0.94



BETR-Global: HTAP Emission Reduction Scenario Analysis

α -HCH : Deposition Flux to Surface

1% reduction in global emissions in 2001 in:

Results in
a %
Reduction
in

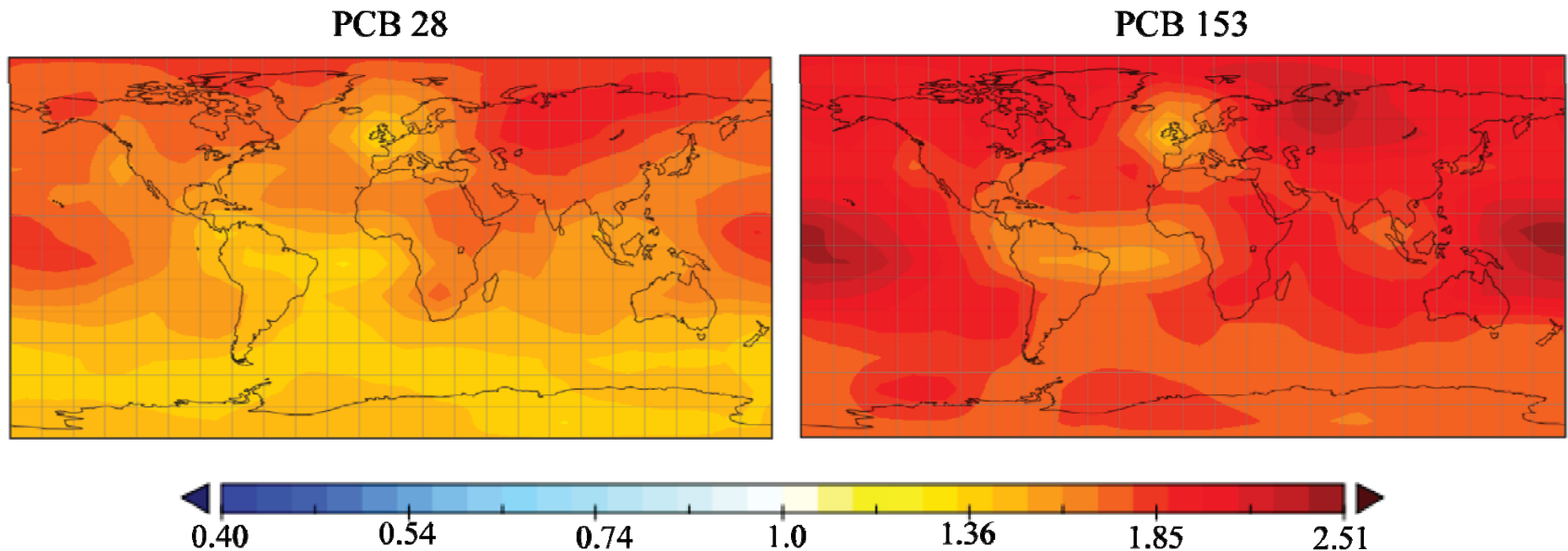
α -HCH	NA	EU	SA	EA
NA	3.7	0.68	0.78	1.1
EU	0.51	2.4	0.28	0.37
SA	0.08	0.18	1.7	0.22
EA	0.18	0.37	1.2	3.4
ARCTIC	0.76	0.86	0.71	0.94



Evaluation of Changes in global fate and transport under a climate change scenario

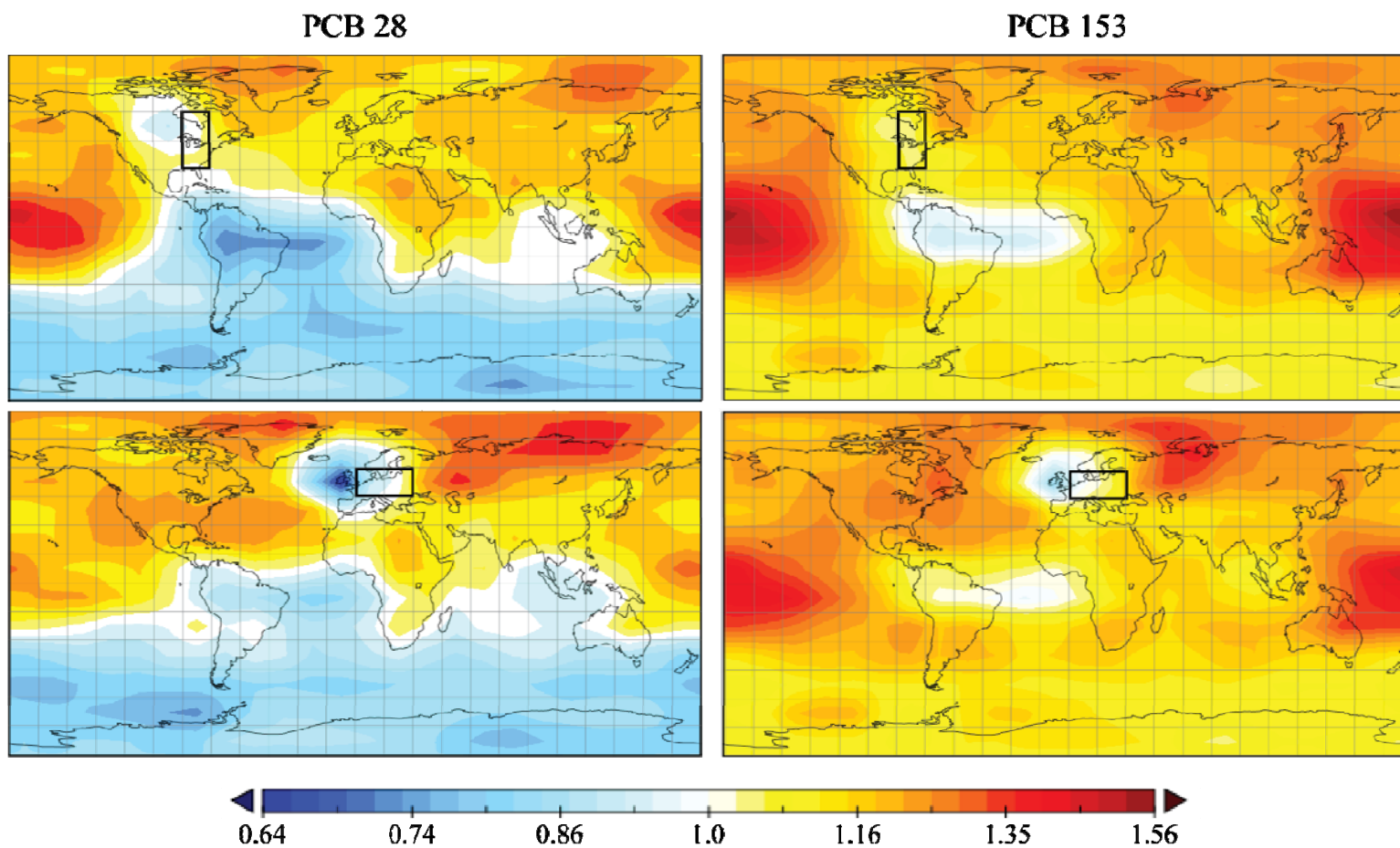
- Compare model results using a contemporary 20th century climate versus the IPCC A2 future scenario
- Climate data from ECHAM5 for:
 - Temperature
 - Atmospheric circulation
 - Ocean circulation
 - Precipitation

Effects of temperature dominate differences in dynamics of PCBs in the climate change scenario



Ratio of modeled concentrations in air in the A2 scenario vs. the 20th century climate scenario

Modeled transport of PCBs to the Arctic is more efficient in the climate change scenario



Ratio of modeled concentrations in air in the A2 scenario vs. the 20th century climate scenario

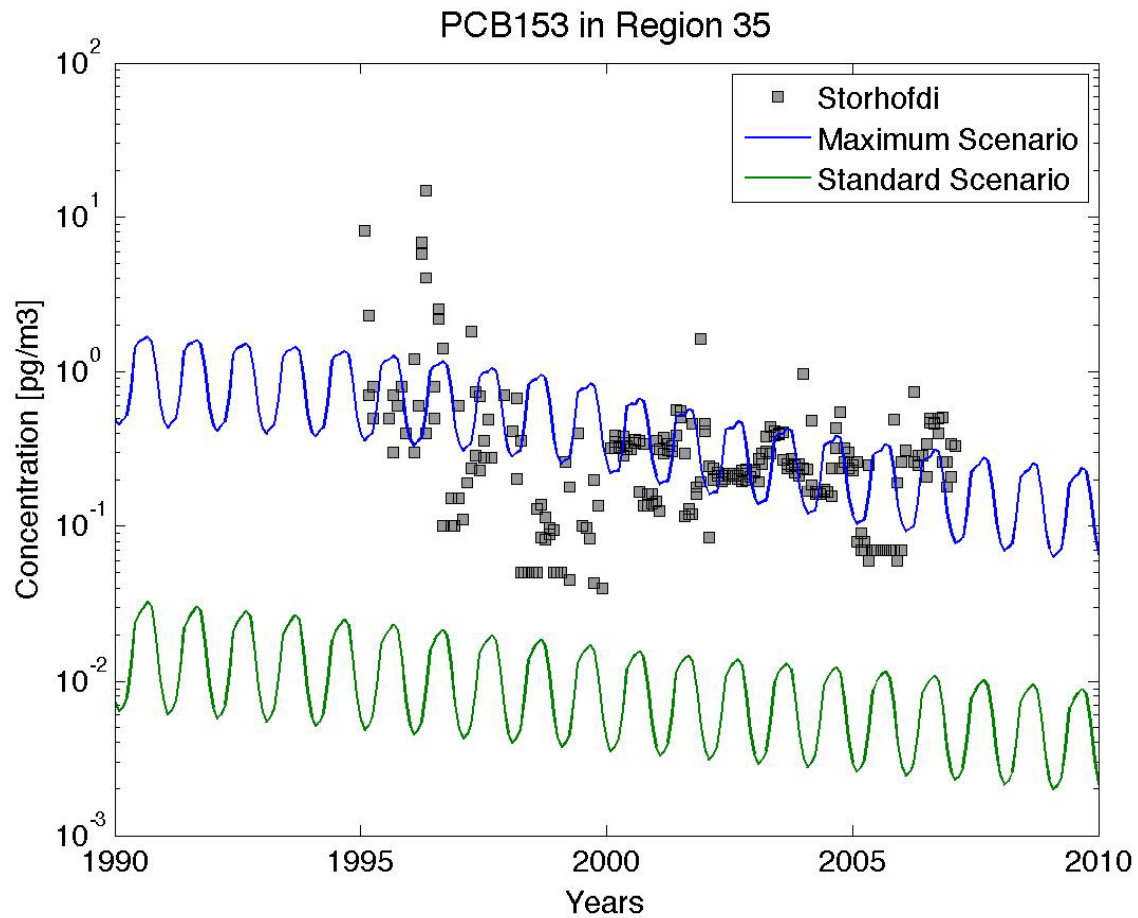
Lamon et al. *Environmental Science & Technology*, (submitted).



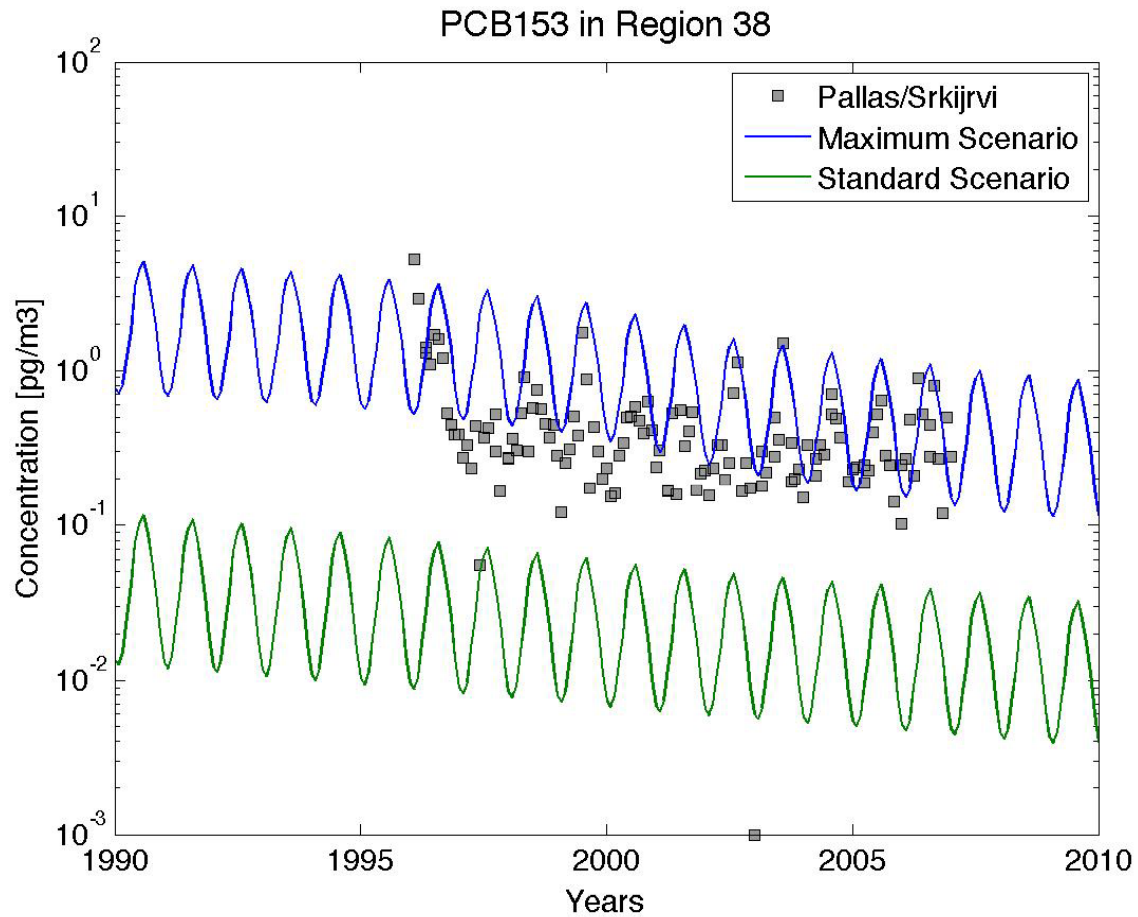
Climate change will make semi-volatile contaminants more problematic

- Increasing primary emissions by volatilization is the single most influential effect of the climate change scenario on the global dynamics of PCBs
- Increased wind speeds in the climate change scenario drive more efficient long-range transport of PCBs to remote locations

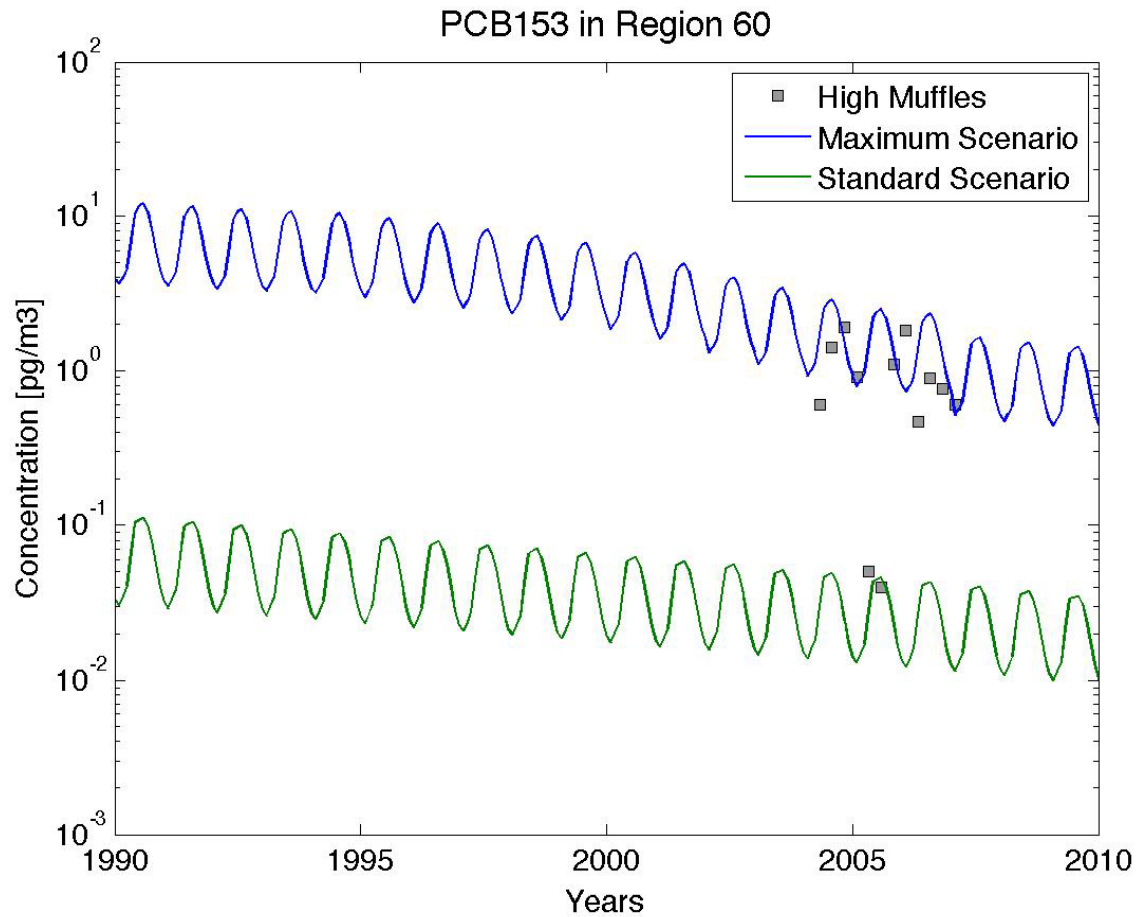
Model Results for PCB 153



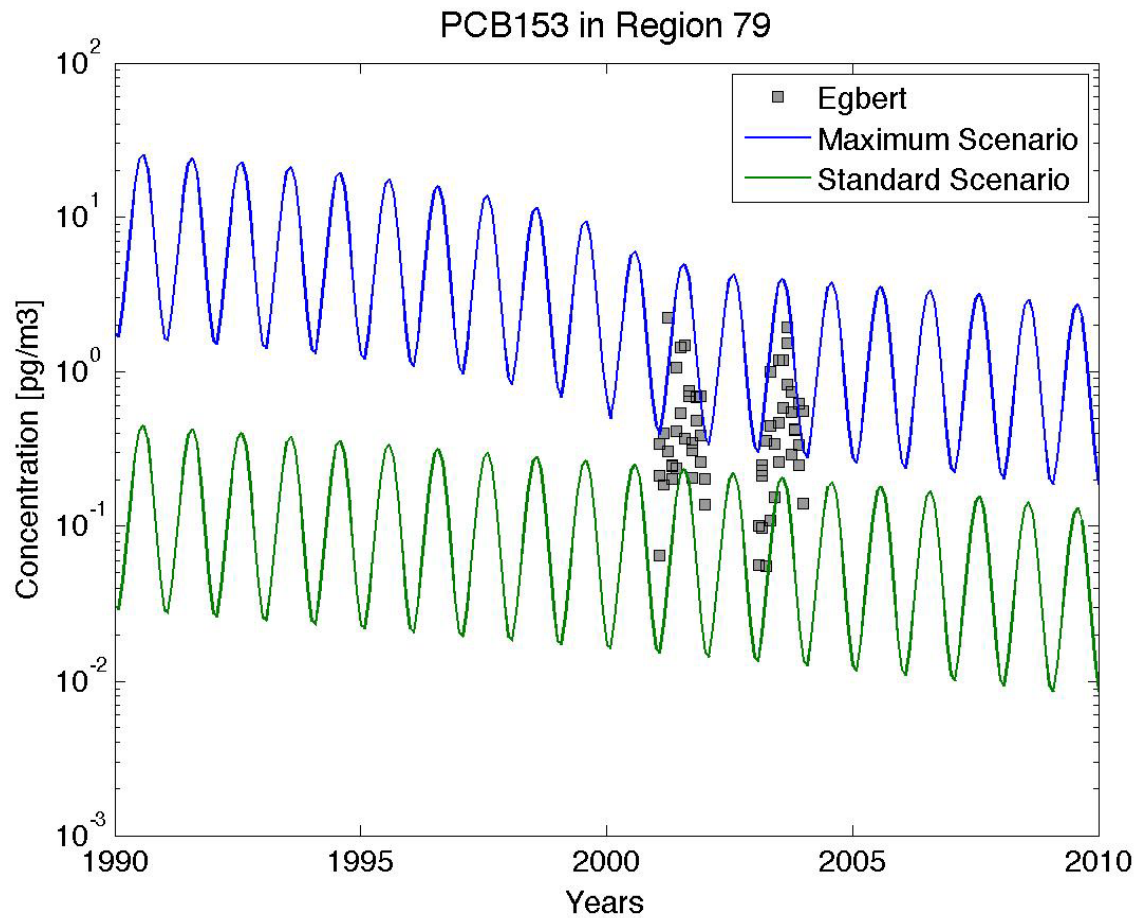
Model Results for PCB 153



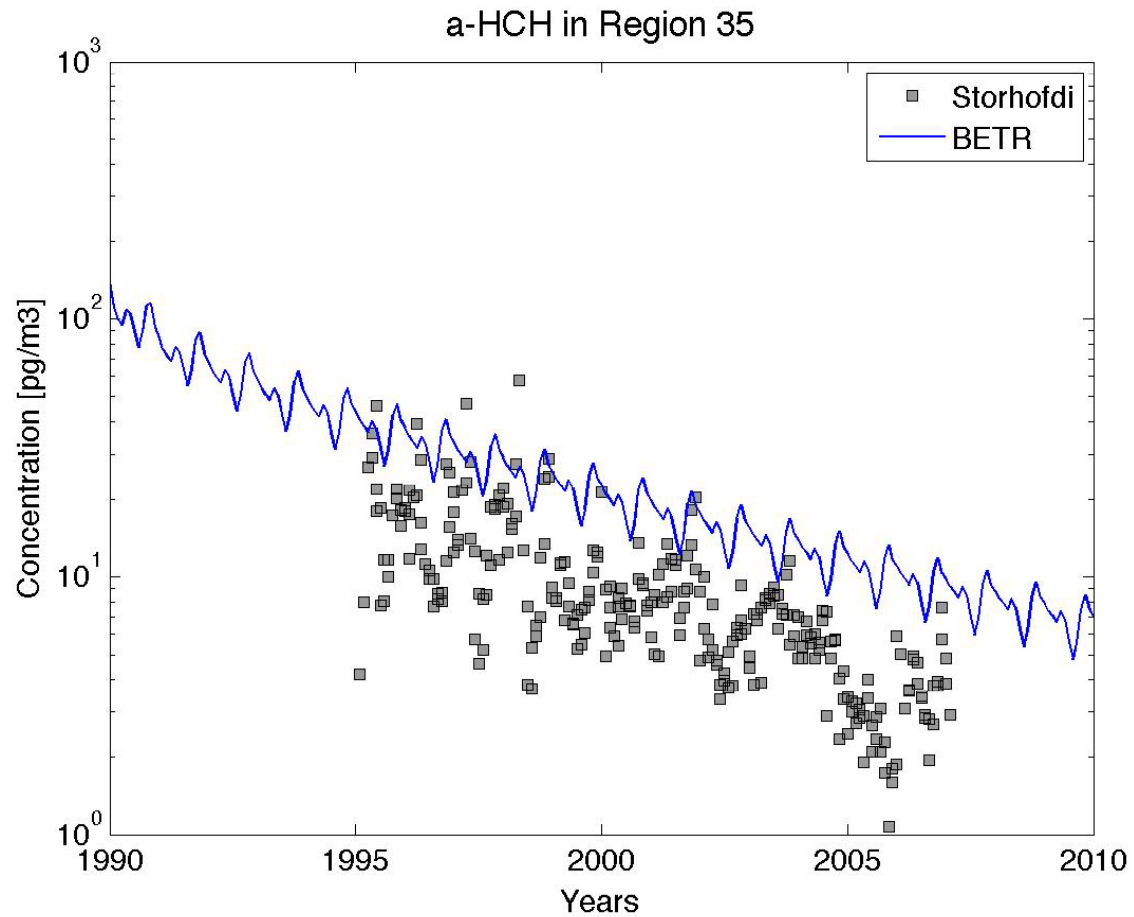
Model Results for PCB 153



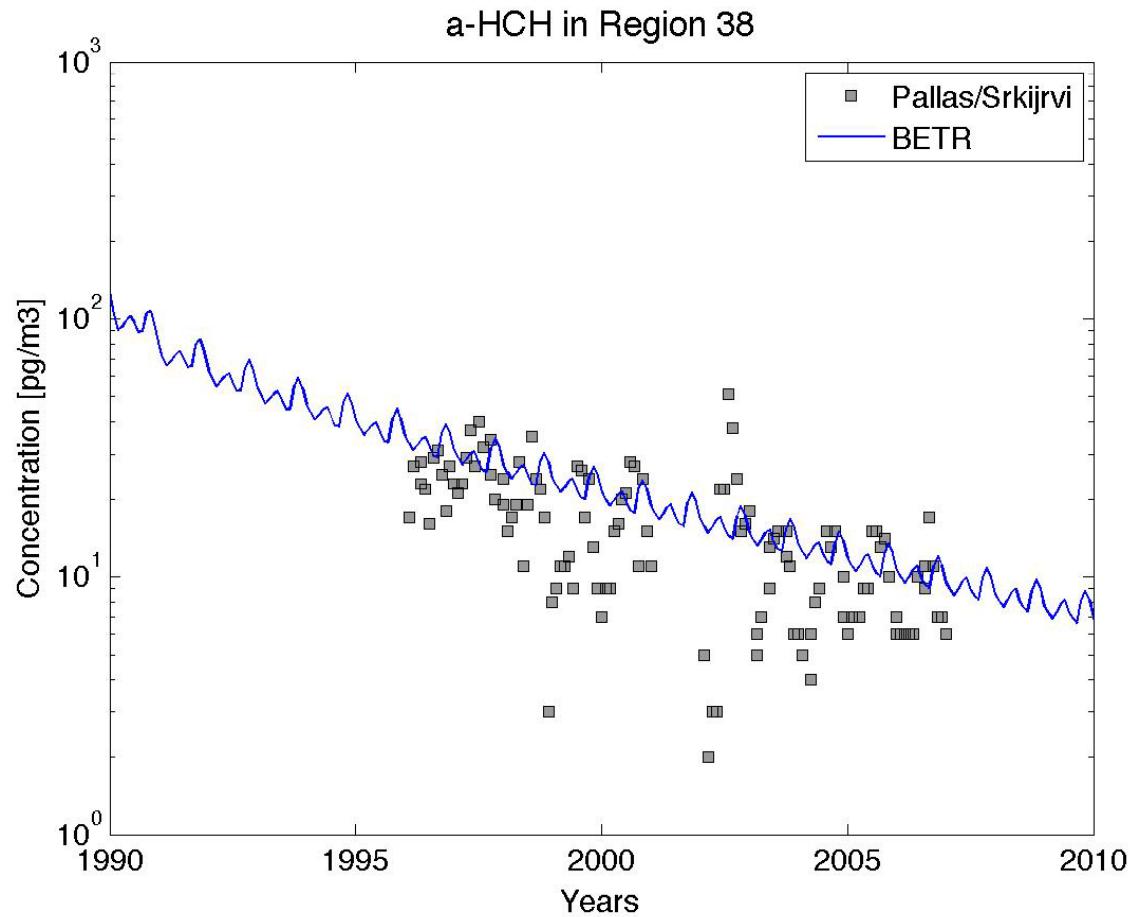
Model Results for PCB 153



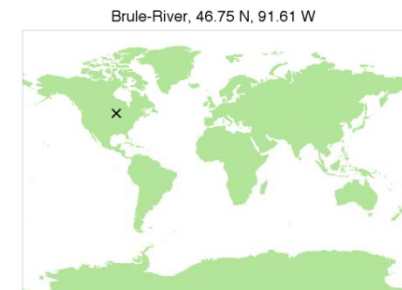
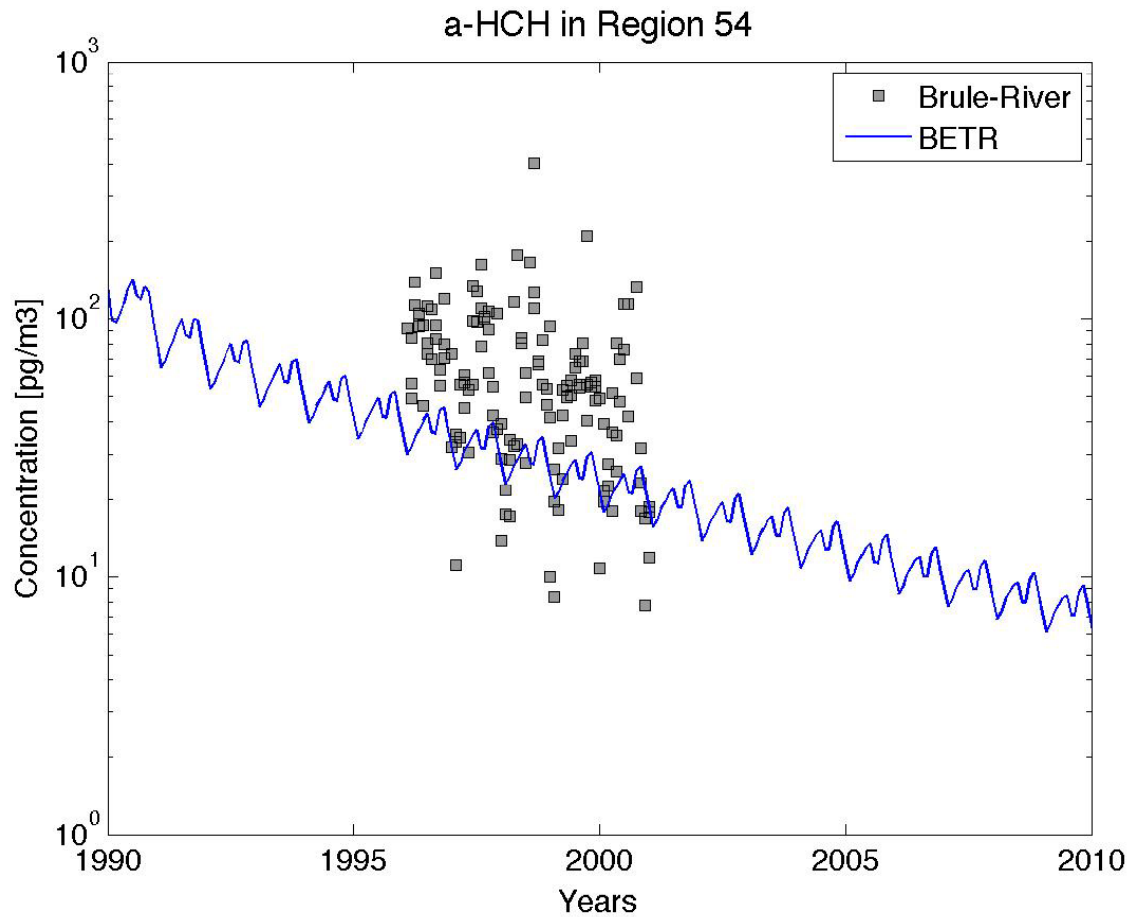
Model Results for a-HCH



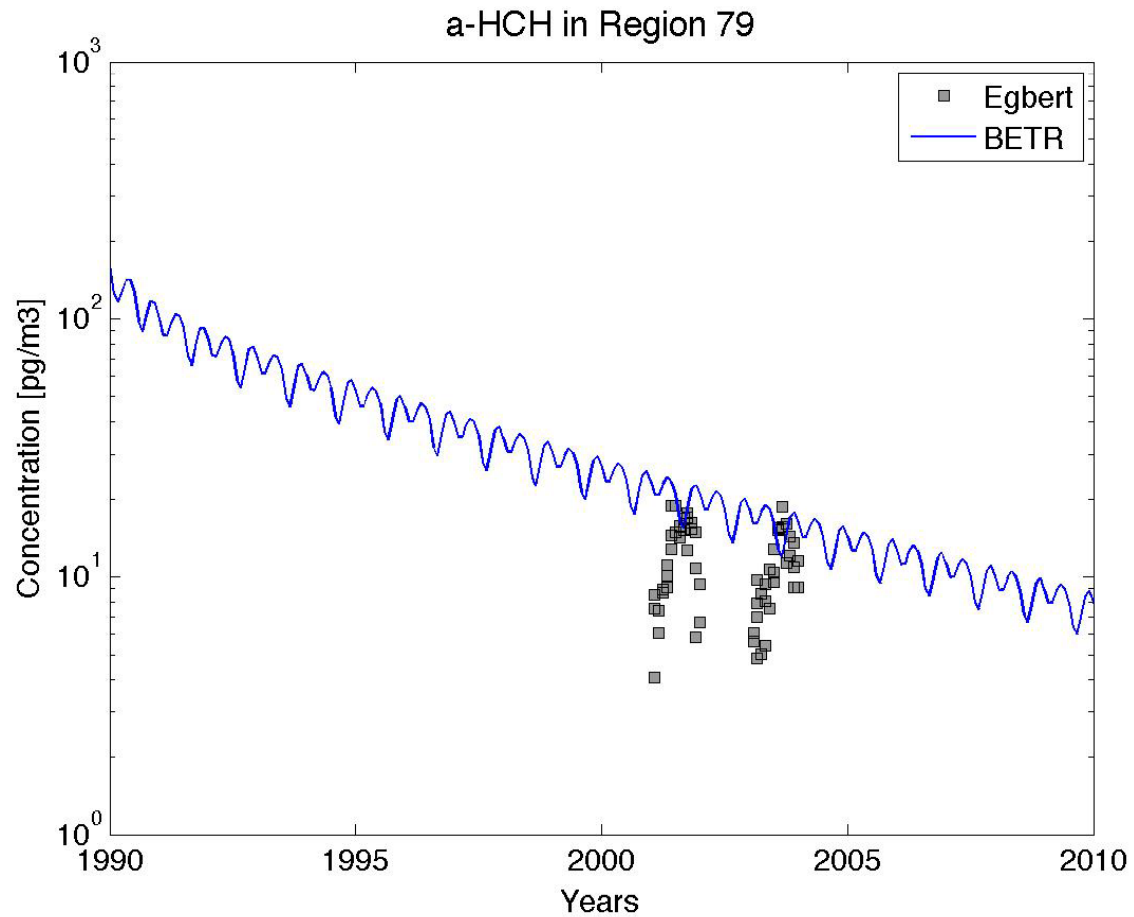
Model Results for a-HCH



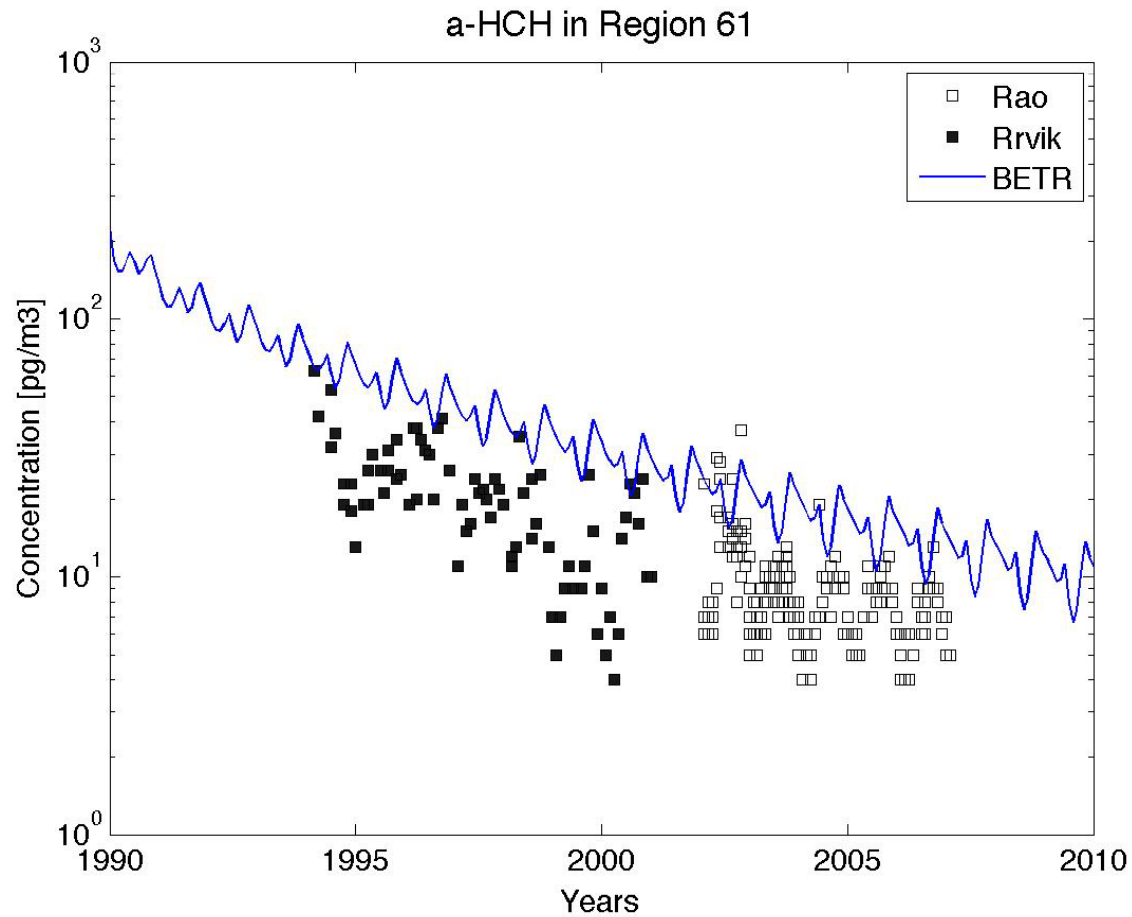
Model Results for a-HCH



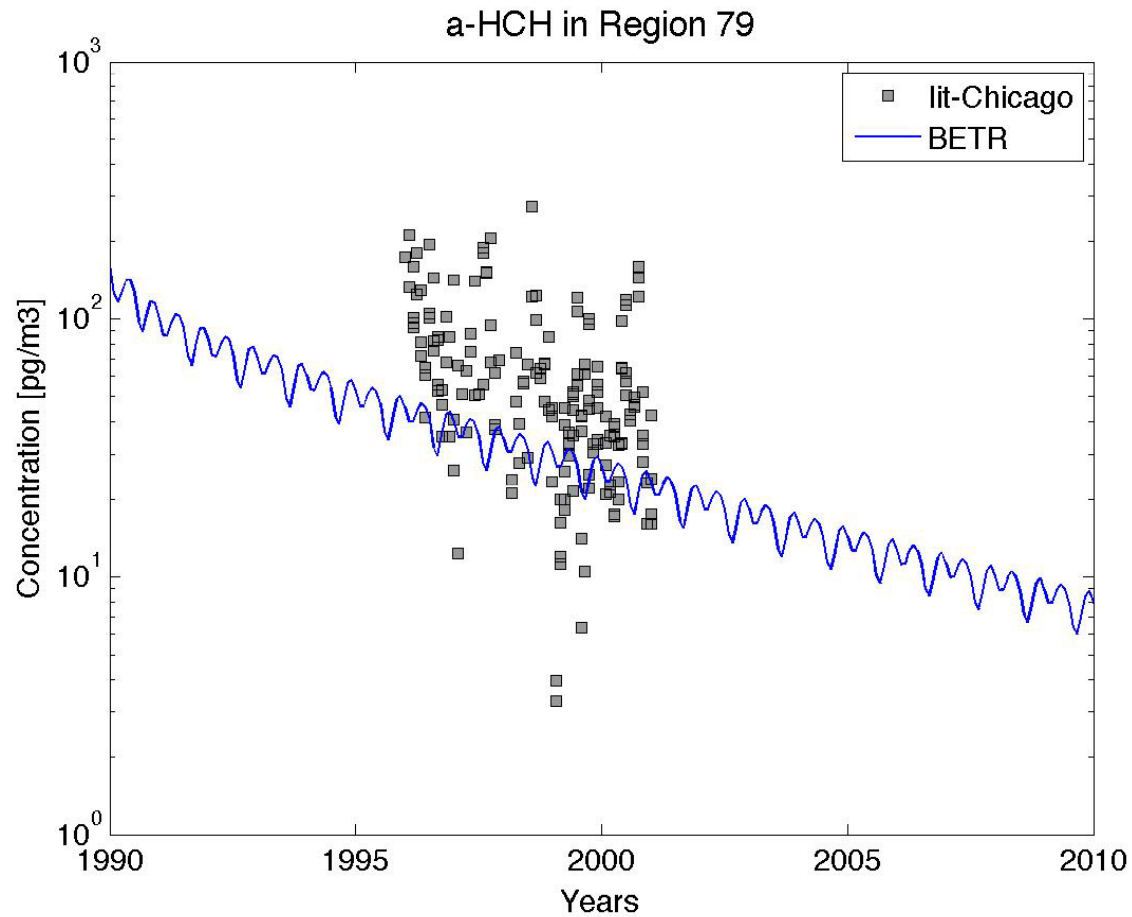
Model Results for a-HCH



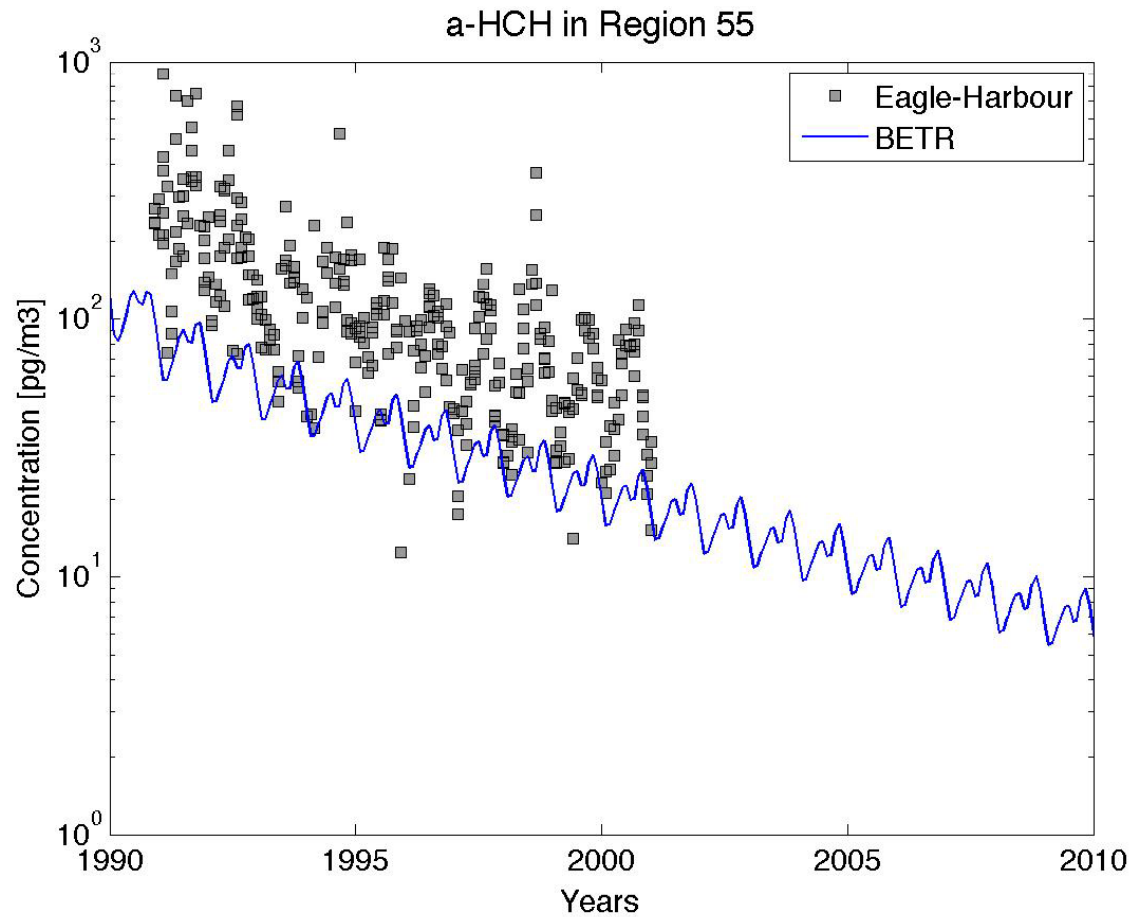
Model Results for a-HCH



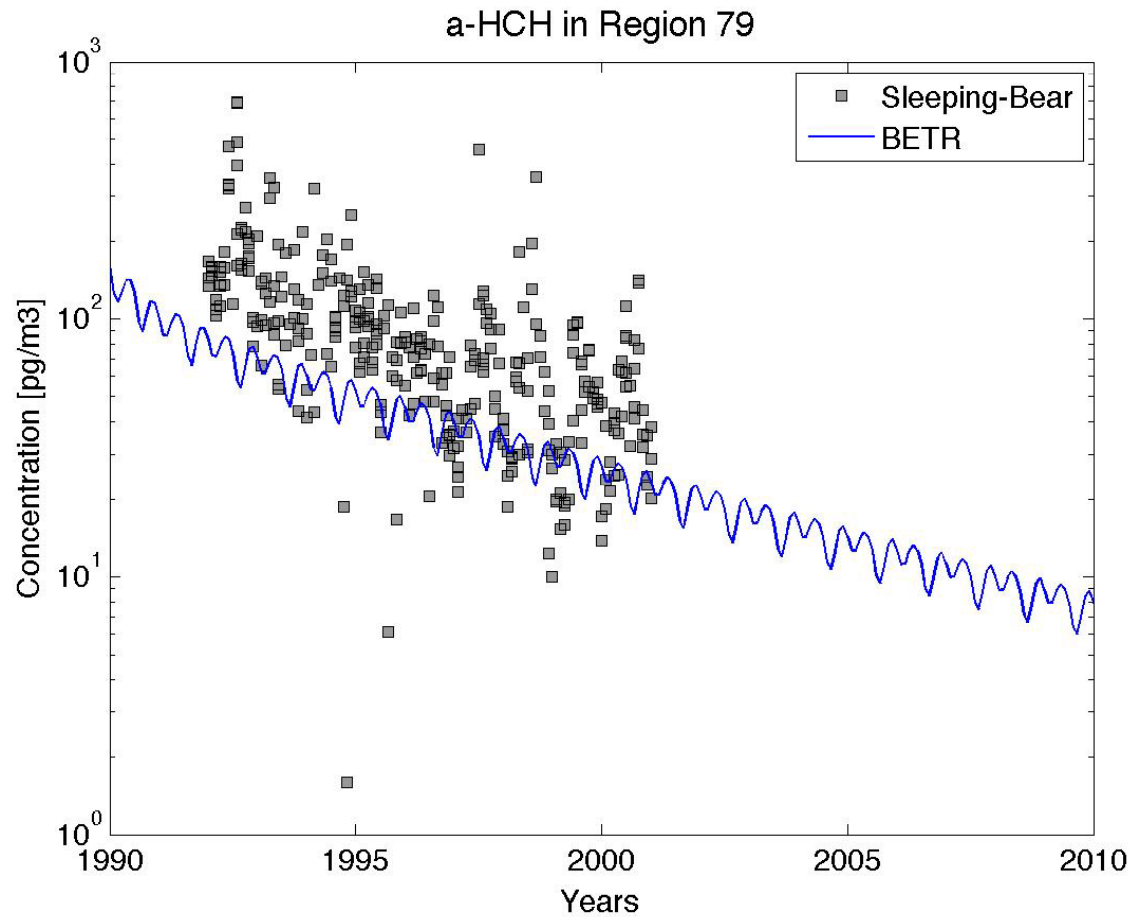
Model Results for a-HCH



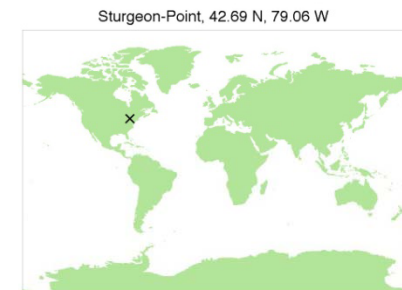
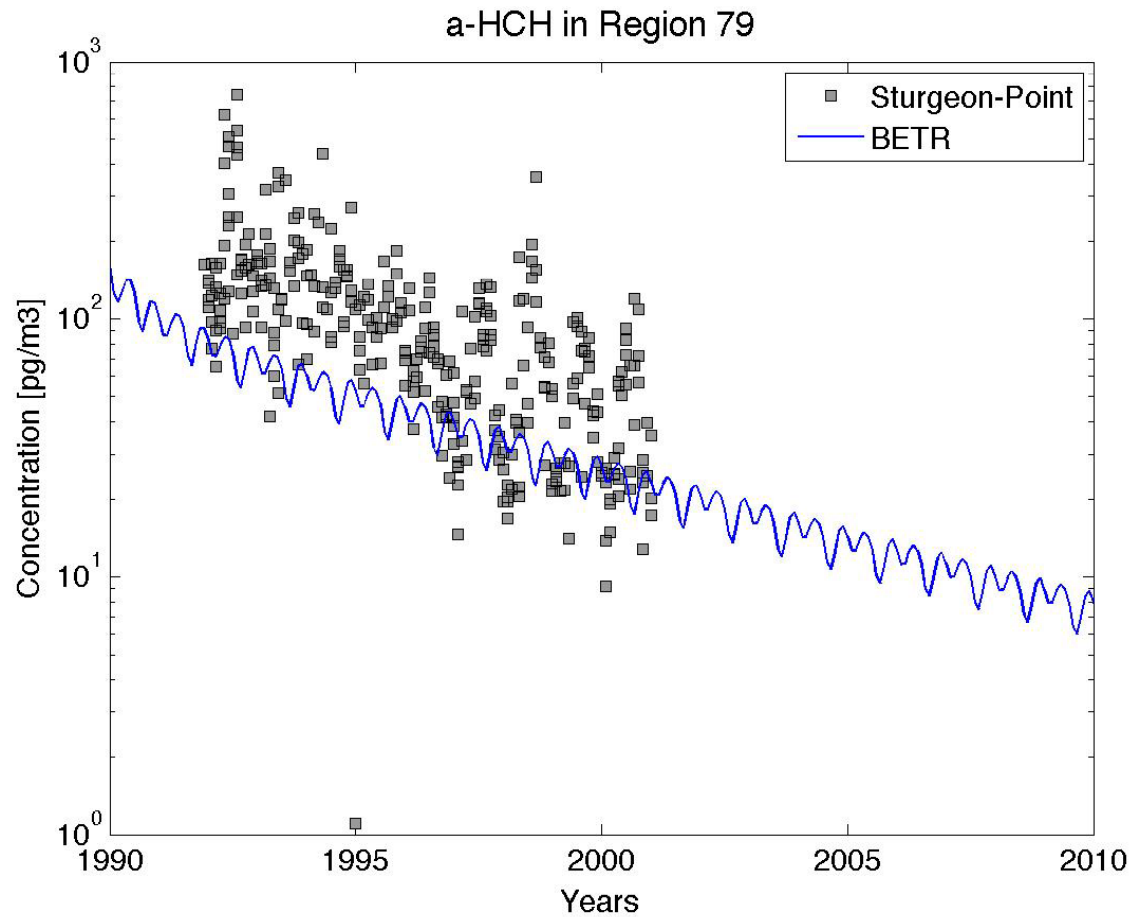
Model Results for a-HCH



Model Results for a-HCH



Model Results for a-HCH



BETR-Global: HTAP Emission Reduction Scenario Analysis

Concentration in Lower Air

20% Reduction in 2001 Emissions in:

PCB153	NA	EU	SA	EA
NA	13.52	2.65	0.23	0.54
EU	0.47	17.70	0.04	0.05
SA	0.63	5.83	10.23	0.16
EA	0.75	5.90	1.63	7.90
ARCTIC	3.06	10.50	0.36	0.81

Results in a %
Reduction in



BETR-Global: HTAP Emission Reduction Scenario Analysis

Concentration in Lower Air

1% Red in 2001 Global Emissions in:

PCB153	NA	EU	SA	EA
NA	3.94	0.22	0.27	0.62
EU	0.14	1.46	0.04	0.06
SA	0.18	0.48	12.09	0.18
EA	0.22	0.49	1.92	9.04
ARCTIC	0.89	0.87	0.42	0.92

Results in a %
Reduction in



BETR-Global: HTAP Emission Reduction Scenario Analysis

Concentration in Lower Air

20% Reduction in 2001 Emissions in:

A-HCH	NA	EU	SA	EA
NA	1.50	2.93	6.63	0.26
EU	0.16	12.01	1.86	0.07
SA	0.03	0.87	14.81	0.05
EA	0.07	1.69	9.77	0.76
ARCTIC	0.29	3.87	6.05	0.23

Results in a %
Reduction in



BETR-Global: HTAP Emission Reduction Scenario Analysis

Concentration in Lower Air

1% Red in 2001 Global Emissions in:

Results in a %
Reduction in

A-HCH	NA	EU	SA	EA
NA	4.05	0.66	0.78	1.06
EU	0.42	2.71	0.22	0.28
SA	0.08	0.20	1.73	0.21
EA	0.19	0.38	1.14	3.13
ARCTIC	0.77	0.87	0.71	0.96