Solution of the "NPE-2019" by Using Inverse Atmospheric Transport Modelling

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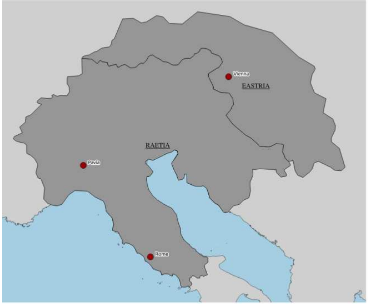
CTBT: Science and Technology Conference 2023 - SnT2023

Senario of NPE-2019

TRIGA reactor Accident on 30 July 2019

The national nuclear safety authority of the state of RAETIA released the following public announcement.

"An accident at TRIGA reactor facility located in Pavia, RAETIA, has occurred this morning 30th July 2019. We are expecting some small release of radioactive isotopes, but well below the hazardous limit for human health. A dedicated monitoring system has been activated around the facility and in the neighbouring in order to monitor the radioactivity in the air".



There is no need to activate any emergency procedures for the population neither any closure of schools and public areas is required"

Abnormal Radionuclide detections (Cs-134 & Cs-137)

Table: CS-134

STN	Collection Stop	Conc.	Freq.
VIP00	2019-08-02 09:00	2100	?
LYP41	2019-08-06 23:15	24.7	?
	2019-08-07 23:29	19.2	
	2019-08-08 23:49	17.4	
	2019-08-09 23:45	15.8	
	2019-08-10 23:00	18.7	
	2019-08-11 23:40	4.7	
KWP40	2019-08-06 06:00	7.5	Fukushima
	2019-08-07 06:00	10.2	
	2019-08-08 06:00	8.9	
	2019-08-09 06:00	13.5	
	2019-08-10 06:00	19.1	
	2019-08-11 06:00	17.4	
NEP48	2019-08-09 09:00	5.0	0
RNP36	2019-08-10 00:00	3.5	0
RUP55	2019-08-10 00:00	7.1	0
	2019-08-10 23:55	5.7	
CNP21	2019-08-10 23:29	29.1	0
	2019-08-11 23:50	39.3	

Table: CS-137

STN	Collection Stop	Conc.	Freq.
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	2019-08-07 23:29	4.8	
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	2019-08-09 23:45	4.0	
	2019-08-10 23:00	4.7	
KWP40	2019-08-09 06:00	3.4	1447
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CNP21	2019-08-10 23:29	7.4	6
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- The second highest concentration detections at CNP21!

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- The highest Concentration at VIP00. This may lead to assume a source near VIP00.
- The second highest concentration detections at CNP21!
- There is a detection of Cs-134 on KWP40, 17 hours before LYP41?
- While Cs-137 is frequently measured in KWP40, but during 2-12 Aug. only three detections?

Abnormal Radionuclide detections (LA-140 & BA-140)

LA-140 and BA-140 are never previously measured at stations: CNP21 and KWP40.

Table: LA-140

STN	Collection Stop	Conc.
VIP00	2019-08-02 09:00	1200
LYP41	2019-08-06 23:15	11.1
	2019-08-07 23:29	8.4
	2019-08-08 23:49	7.1
	2019-08-09 23:45	6.2
	2019-08-10 23:00	6.9
KWP40	2019-08-06 06:00	3.4
	2019-08-07 06:00	4.4
	2019-08-08 06:00	3.6
	2019-08-09 06:00	5.2
	2019-08-10 06:00	6.9
	2019-08-11 06:00	6.0
CNP21	2019-08-10 23:29	10.5
	2019-08-11 23:50	13.7

Table: BA-140

STN	Collection Stop	Conc.
VIP00	2019-08-02 09:00	1000
LYP41	2019-08-06 23:15	10.2
	2019-08-07 23:29	7.7
	2019-08-08 23:49	6.6
	2019-08-09 23:45	5.7
	2019-08-10 23:00	6.4
KWP40	2019-08-06 06:00	3.1
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- The highest Concentration at VIP00. The second highest concentration detections at CNP21.

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- The highest Concentration at VIP00. The second highest concentration detections at CNP21.
- There are detections of both LA-140 and BA-140 on KWP40, 17 hours before LYP41?

Xenon Detections

Table: Xenon Istopes Detections During NPE-2019

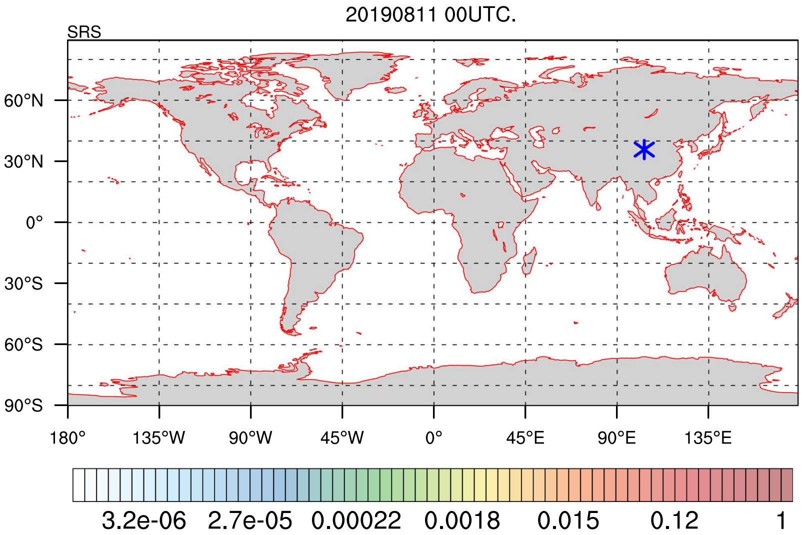
STN	Collection Stop	Xe-133	Xe-135	Xe-131m	Xe-133m
DEX33	2019/08/02 06	22.6	6.39		1.53
	2019/08/03 06	9.6	1.1		
	2019/08/04 06	16.6			
	2019/08/05 06	4.9			
	2019/08/06 06	0.97			
NEX48	2019/08/09 06	0.44			
VIX00	2019/08/02 06	52	15	1.5	3.5
	2019/08/03 06	121	7		6.6
	2019/08/04 06	24			
	2019/08/05 06	6.4			
	2019/08/06 06	6.7			
	2019/08/07 06	93		1.6	2.
	2019/08/08 06	22			

Table: Freq. of Xenon detections

STN	Iso.	Freq.
DEX33	Xe-133	2909
DEX33	Xe-135	30
DEX33	Xe-131m	6
DEX33	Xe-133m	18

Atmospheric Transport Modeling

Adjoint Atmospheric Transport Modeling From IMS



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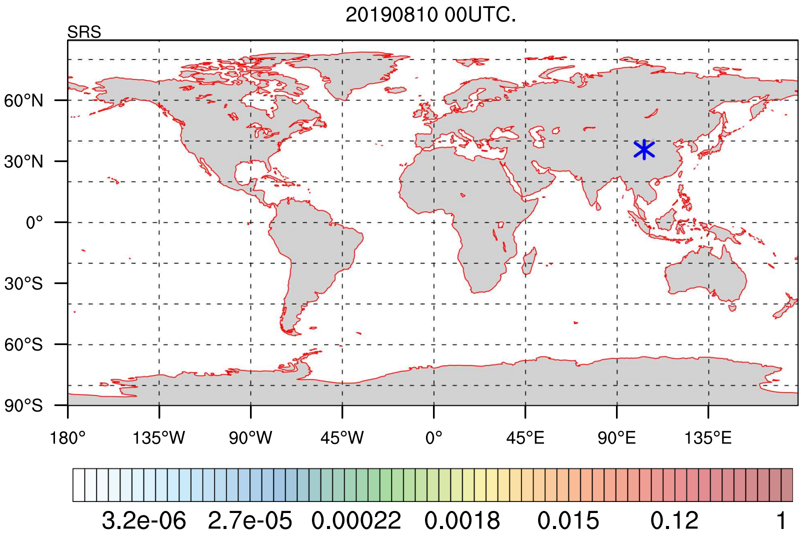

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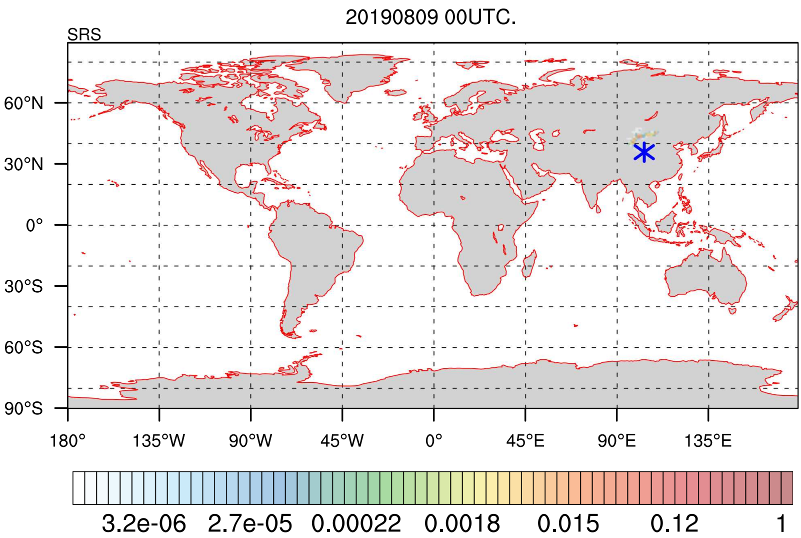

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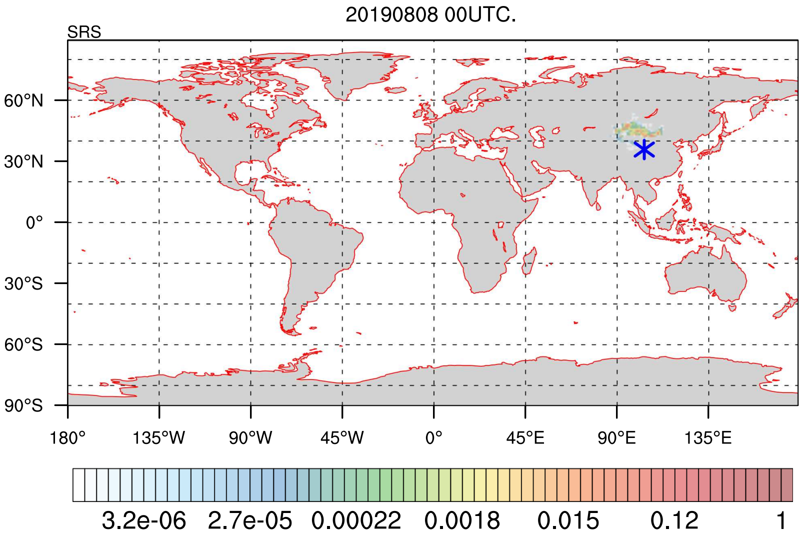

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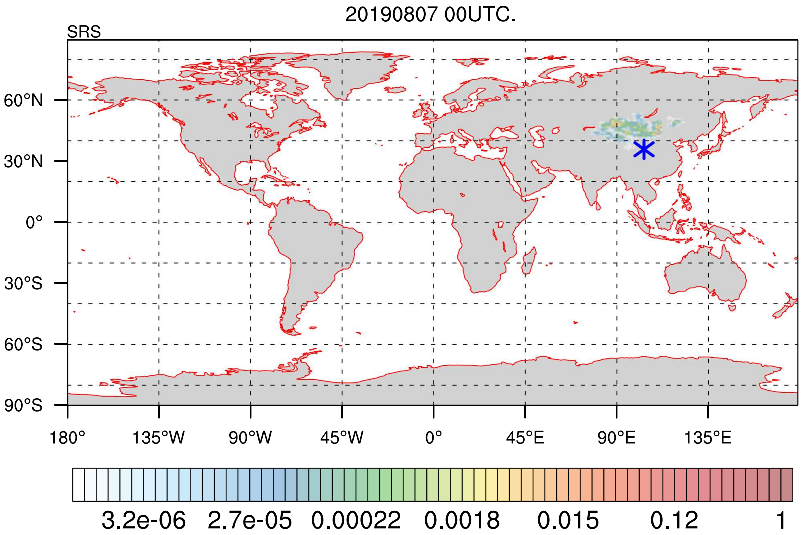

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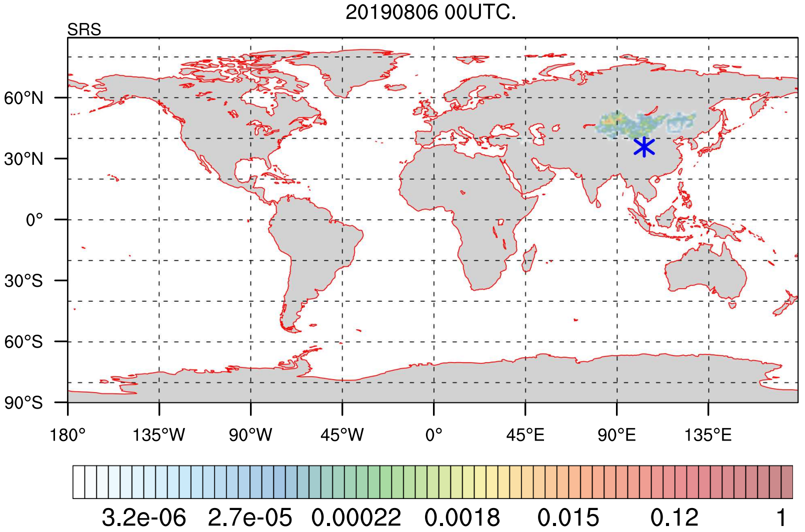

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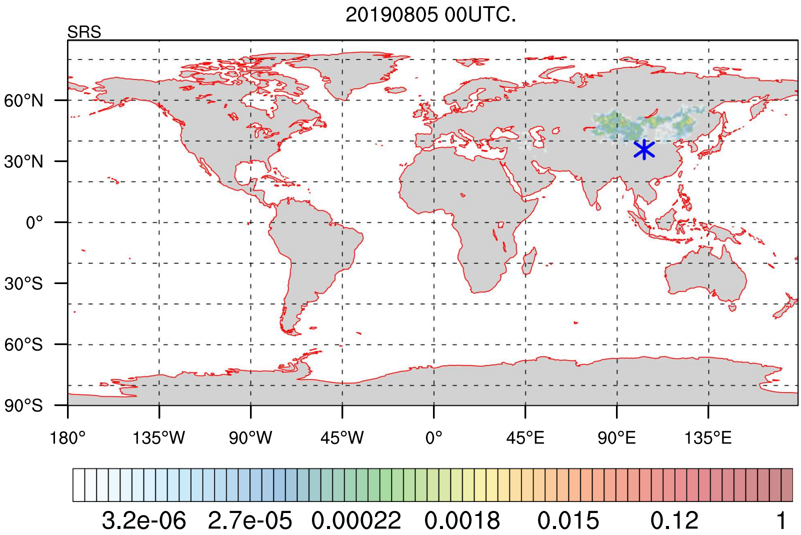

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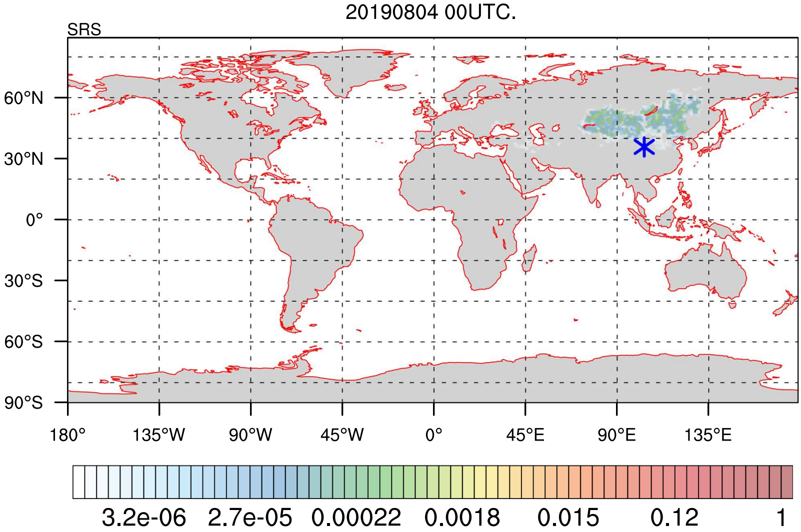

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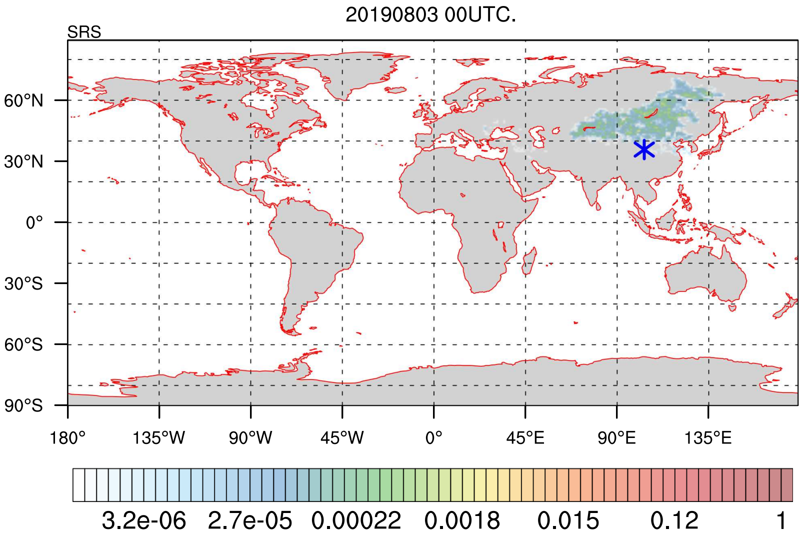

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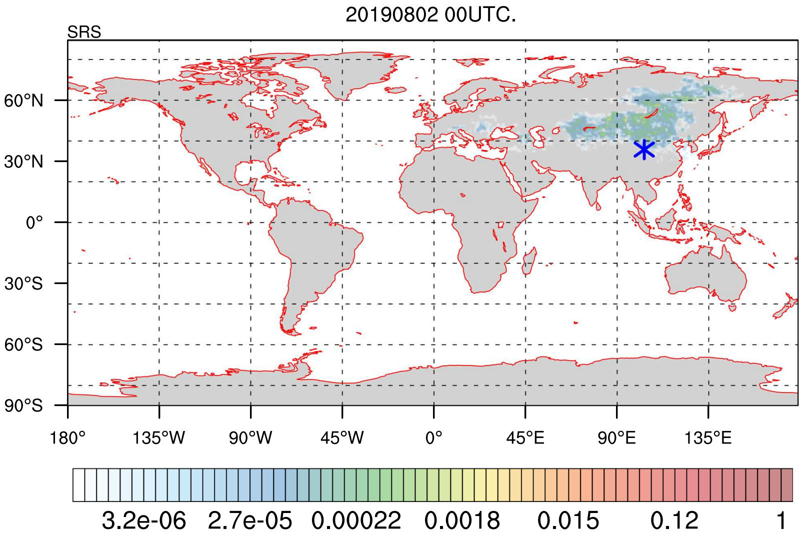

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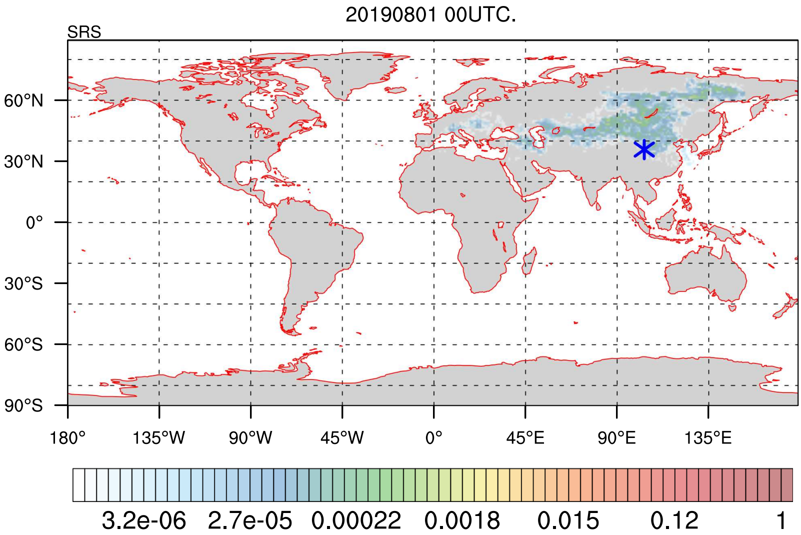

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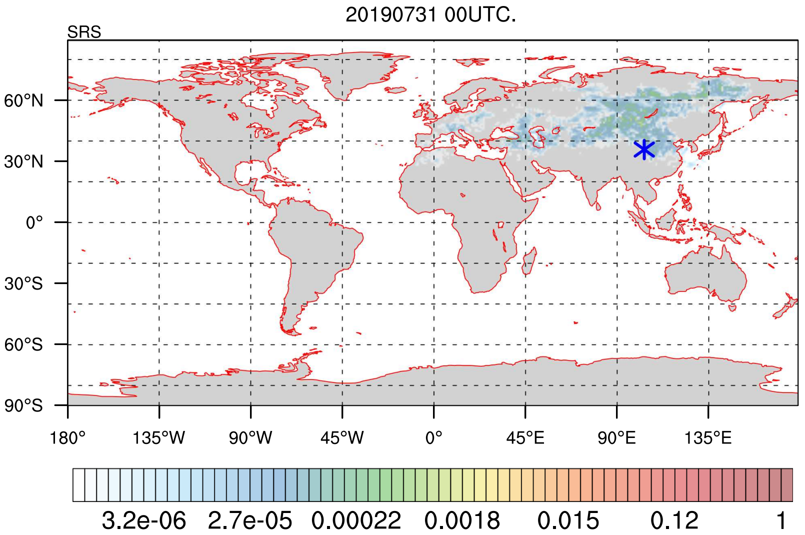

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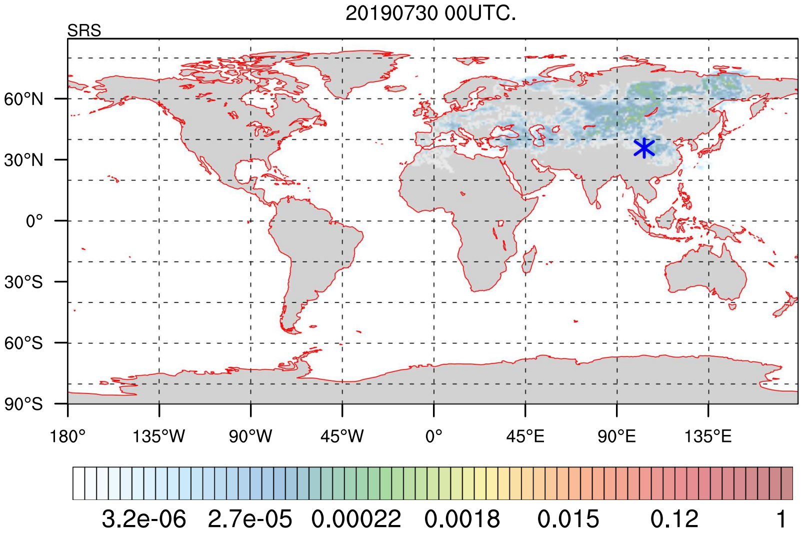

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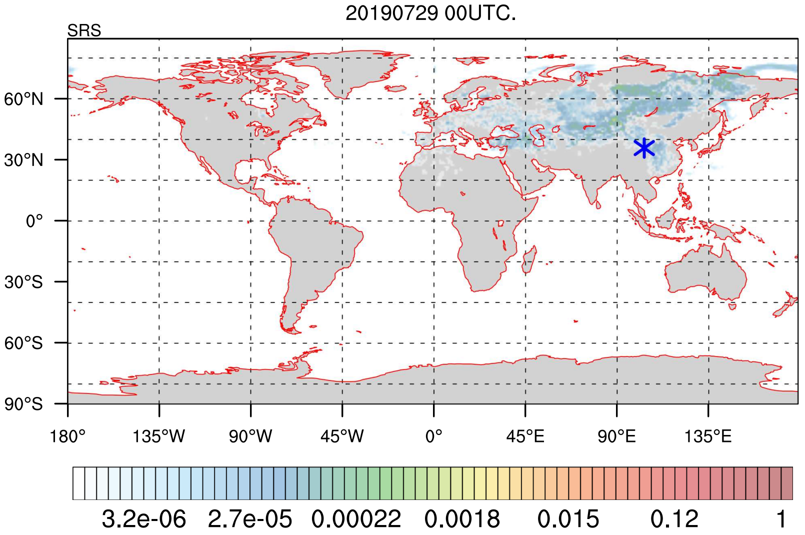


Inverse Modelling Methodology

The adjoint transport and dispersion equation has the following form in the Lagrangian specification:

$$-\frac{D\overline{C^*}}{Dt} - \nabla \cdot (K\nabla\overline{C^*}) = R \tag{1}$$

Where the observed concentration values are related to the *source-receptor-sensitivity* (SRS) field as follows

$$C_k^{obs} = \sum_n \sum_i \sum_j S_{ijn} C^*_{ijnk} \quad \text{k=1,2,}\cdots\text{,K} \tag{2}$$

where K is the number of samples and S_{ijn} is the spatial-temporal source field.
The estimation of modeled concentrations values

$$C^{est}_{ijnk} = \alpha_{ijn} C^*_{ijnk} + \beta_{ijn} \tag{3}$$

Estimation of Likelihood

$$\mathbb{P}(C|S_{ijn}(s), I) \propto exp\Big(-\frac{1}{2}\sum_{k}\frac{(C_k^{obs} - C_{ijnk}^{est}(s))^2}{(\sigma_k^{obs})^2 + (\sigma_k^{est})^2}\Big) \quad (4)$$

where the likelihood function, $\mathbb{P}(C|S_{ijn}(s), I)$, represents the probability that the source, $S_{ijn}(s)$, which is located at grid point i, j and released during time interval n with fixed rate s will give estimated concentrations $C_{ijnk}^{est}(s)$, which matches the observed data C_k^{obs}.

Bayesian Approach

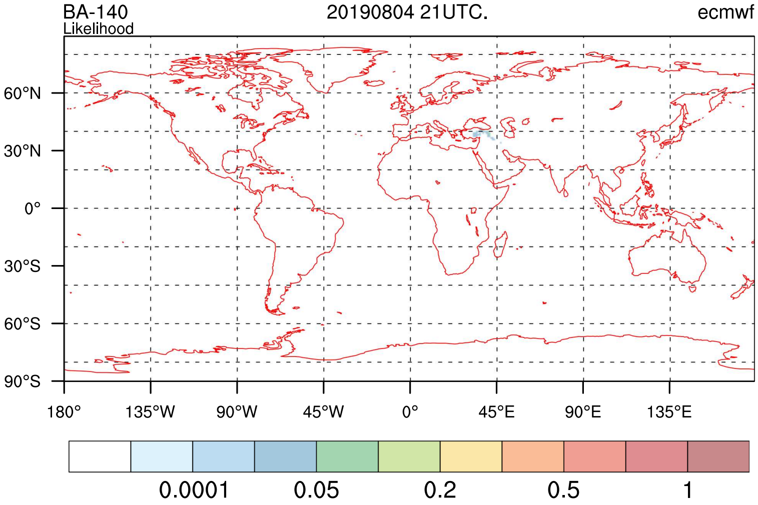
$$P(S|C,I) = \frac{P(S|I)\mathbb{P}(C|S,I)}{P(C|I)} \tag{5}$$

- I represents the prior information,
- C is concentration measurements,
- S is the source parameters,
- $P(S|I)$ is the prior PDF of the source, which is the conditional PDF of source parameters S, given only the prior information I.
- $\mathbb{P}(C|S,I)$ is the likelihood function, which measures how good the fitting between the observed and the modeled concentration, given the assumed source parameter S and the prior information.
- $P(S|C,I)$ is the posterior PDF of the source parameters, given the measurements C and the prior information.
- $P(C|I)$ is the marginal distribution, which is obtained by summation the numerator of Eq. 5 overall assumed values of S. Thus, it is independent of S, and it can be considered as a normalization constant.

$$P(C|I) = \sum_{S} P(S|I)\mathbb{P}(C|S,I) \tag{6}$$

Results

Relative Likelihood using Flexpart-ECMWF (Ba-140)



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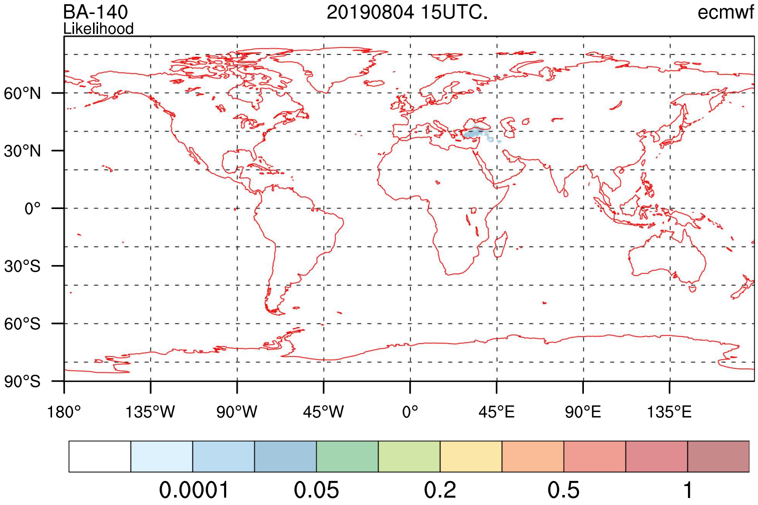

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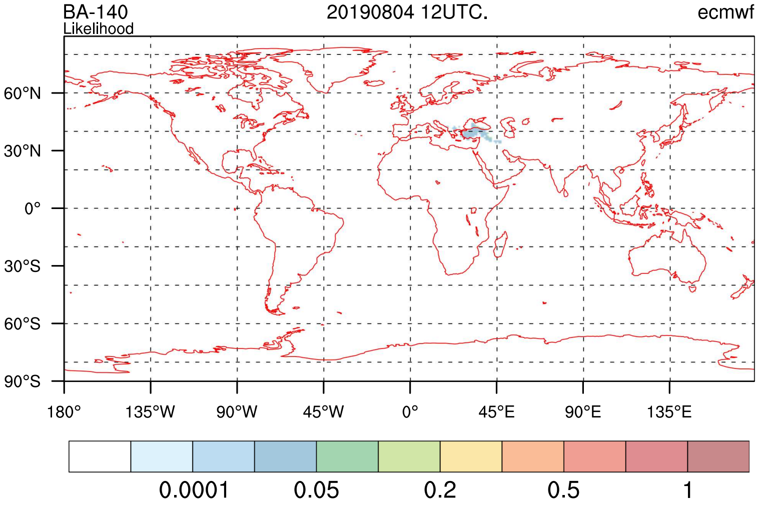
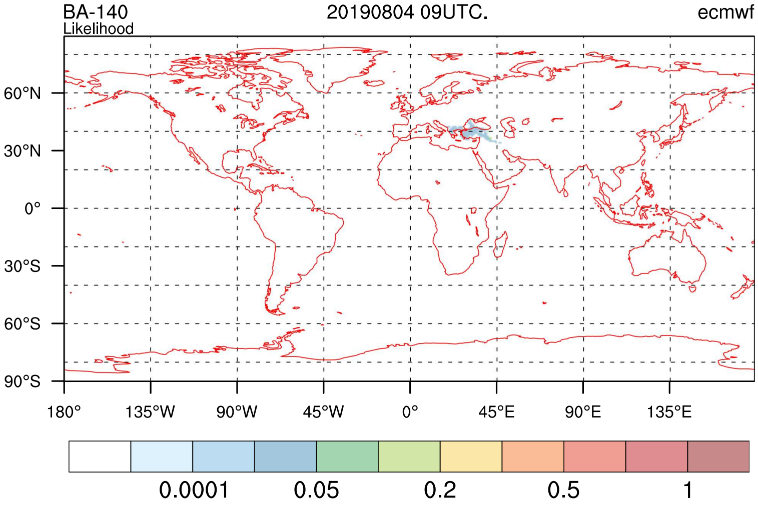


Relative Likelihood using Flexpart-ECMWF (Ba-140)



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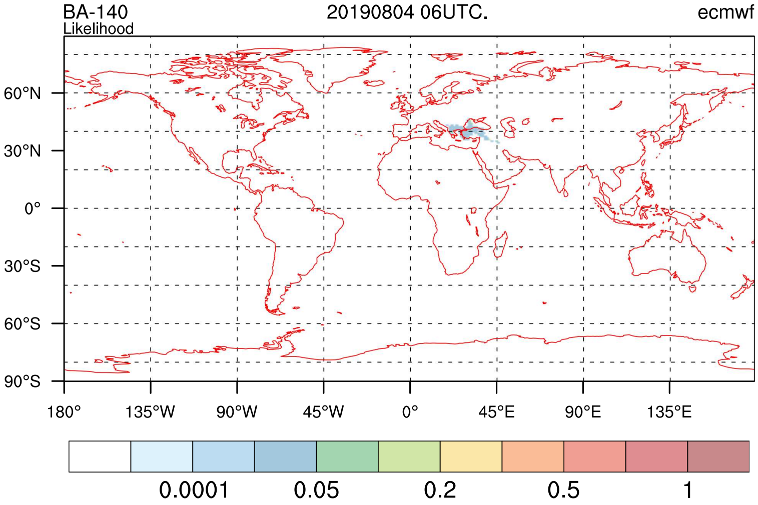

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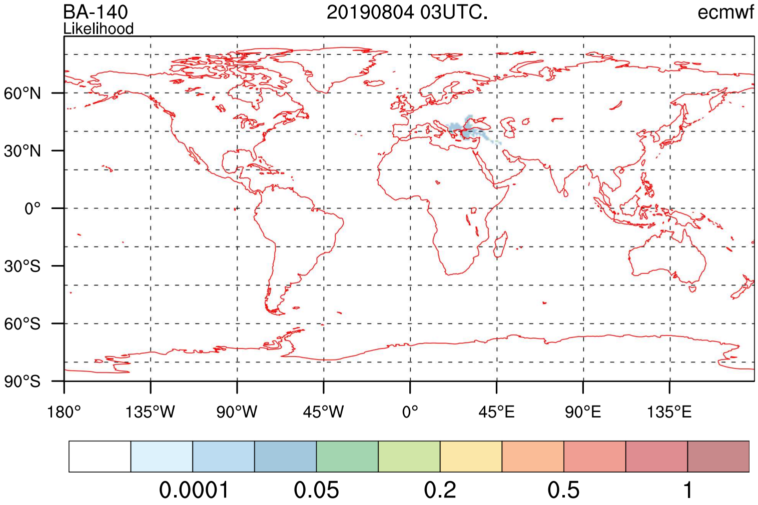

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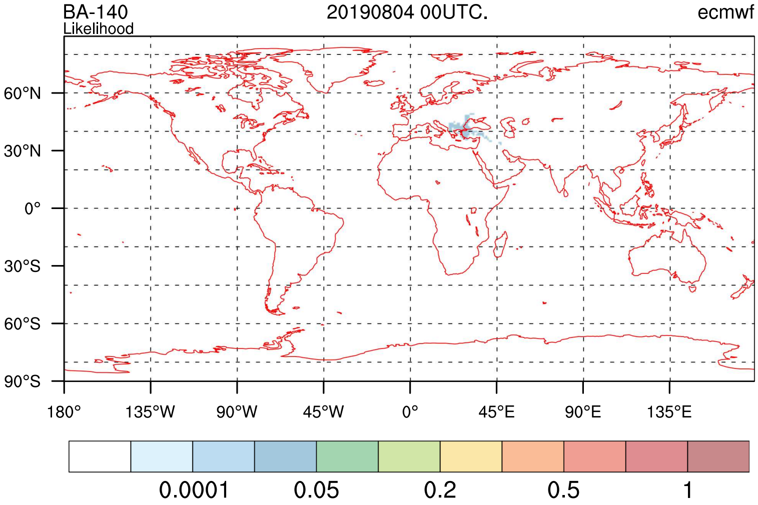

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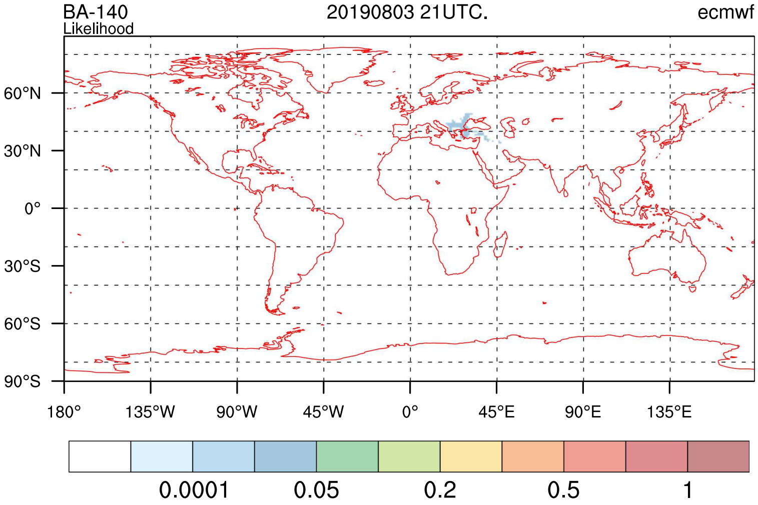

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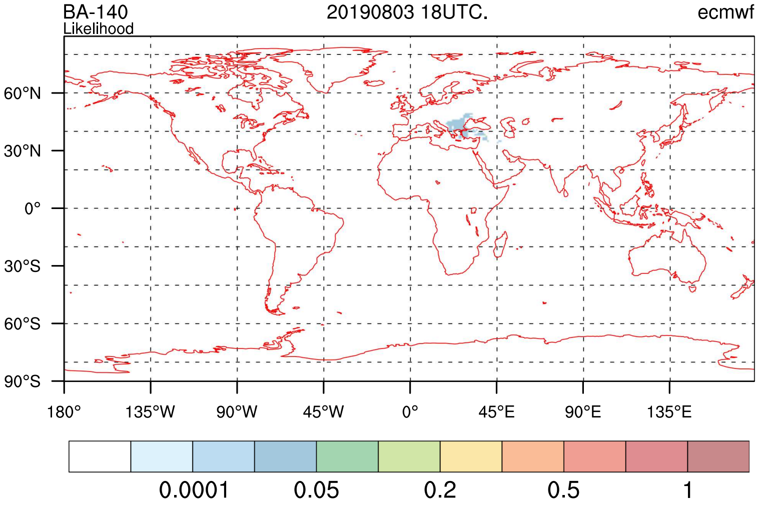

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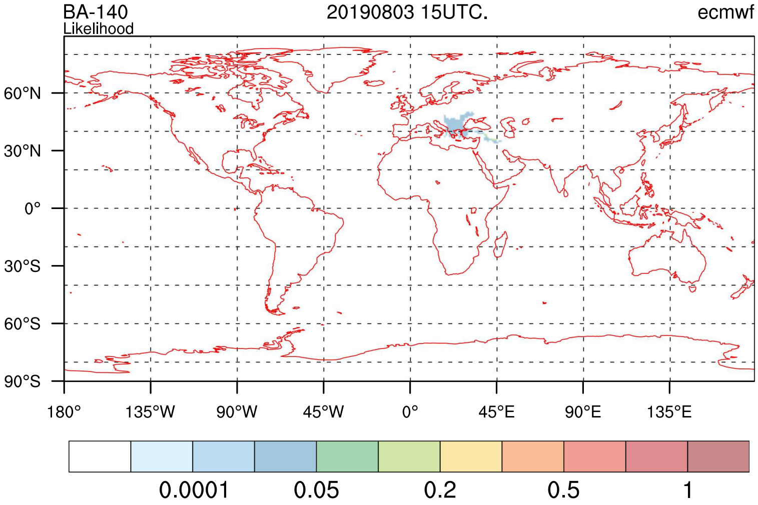

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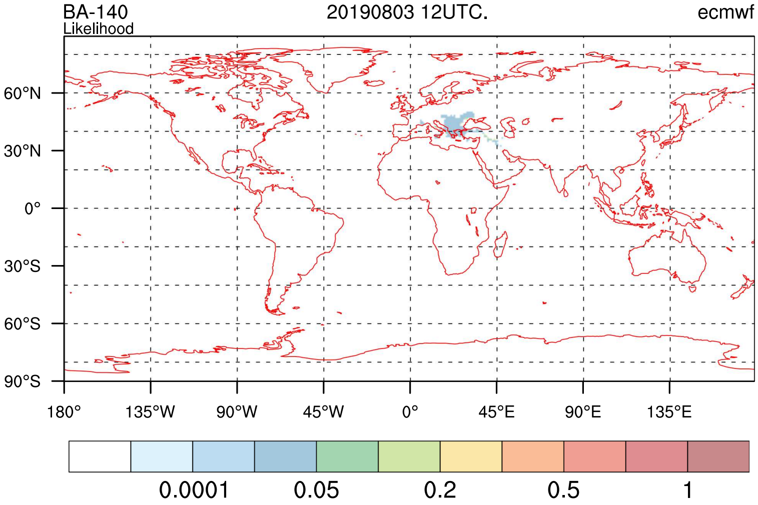

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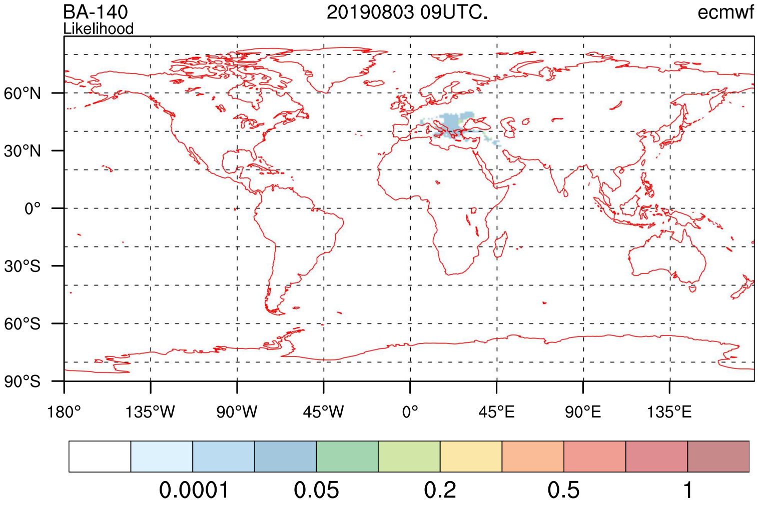

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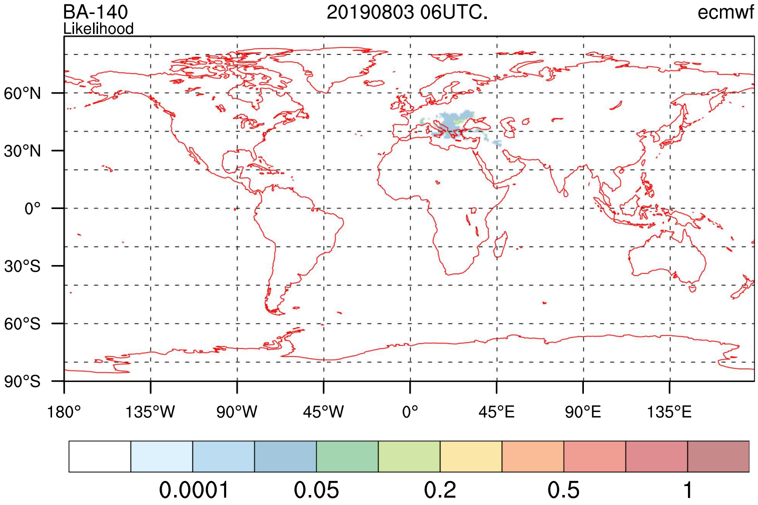

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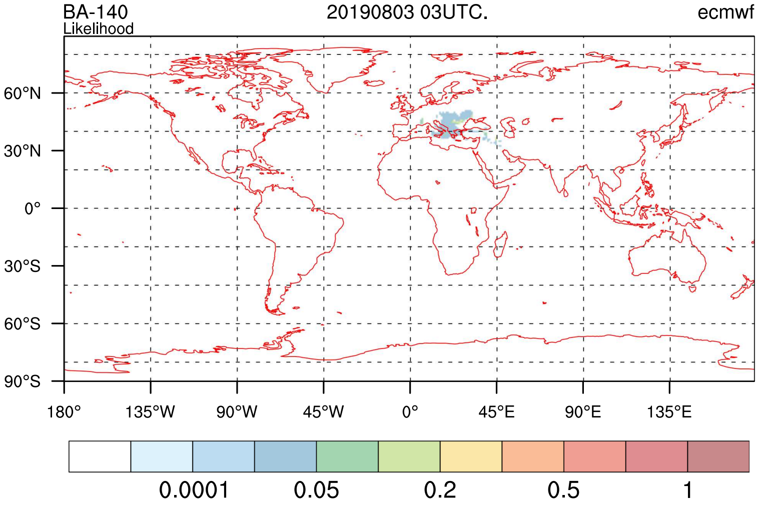

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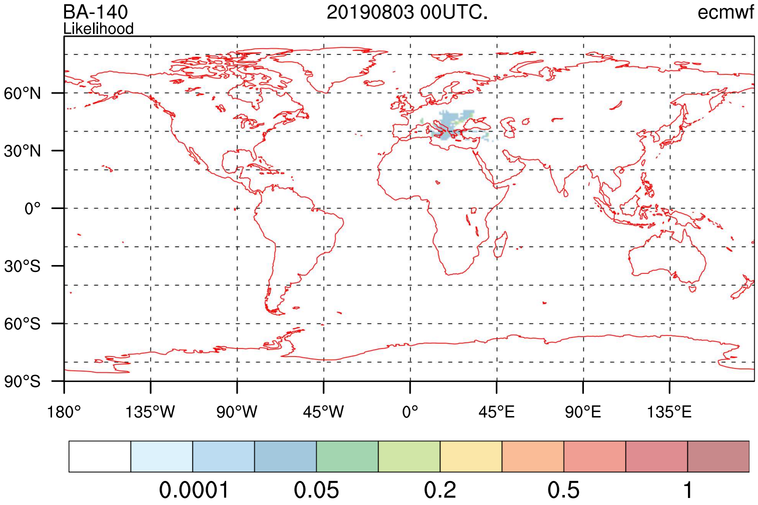

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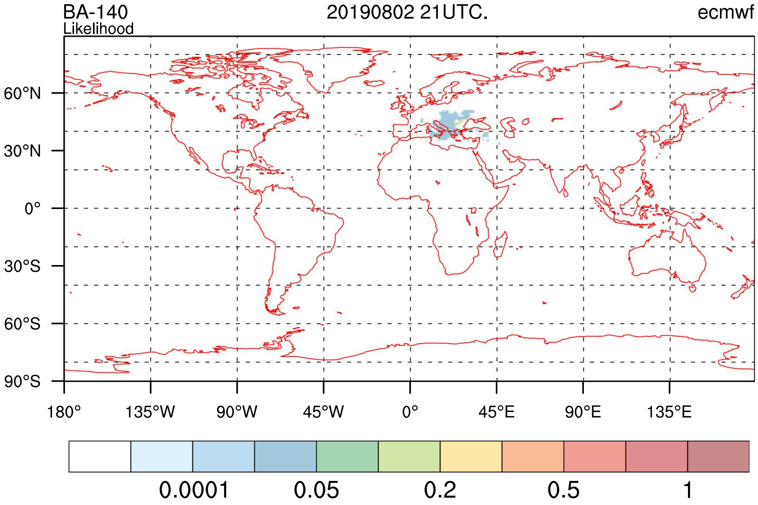

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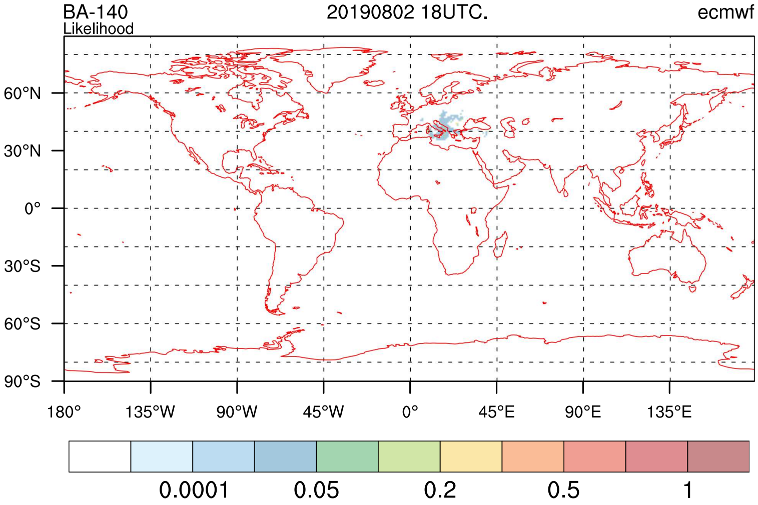

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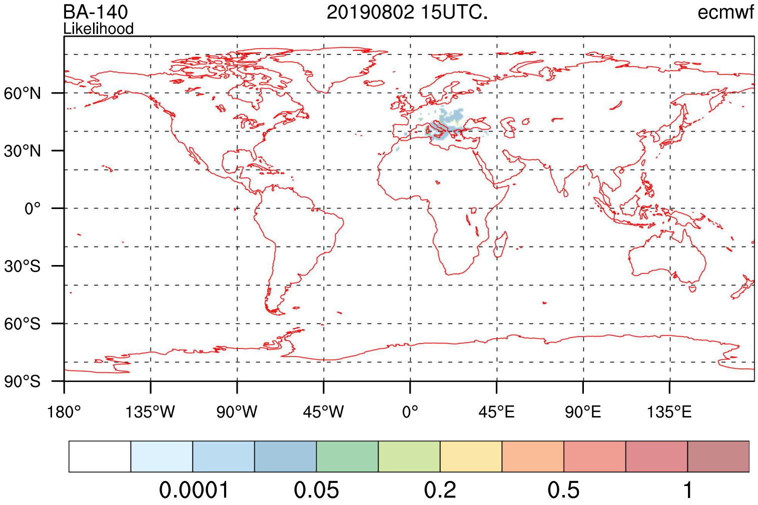

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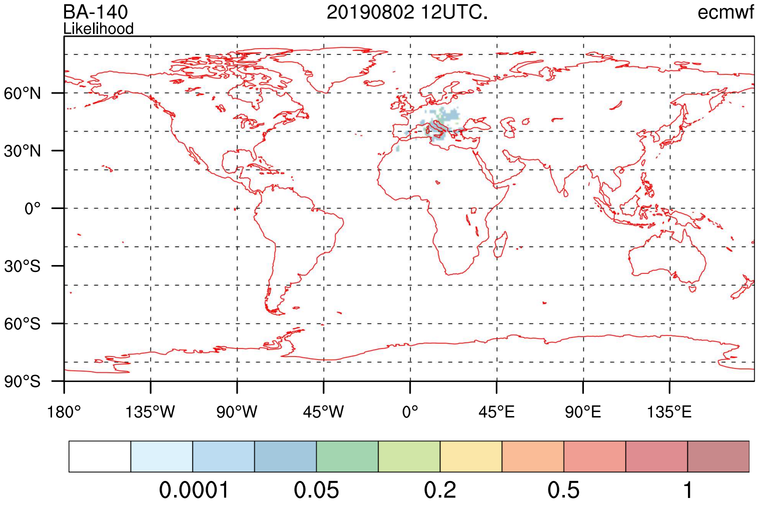

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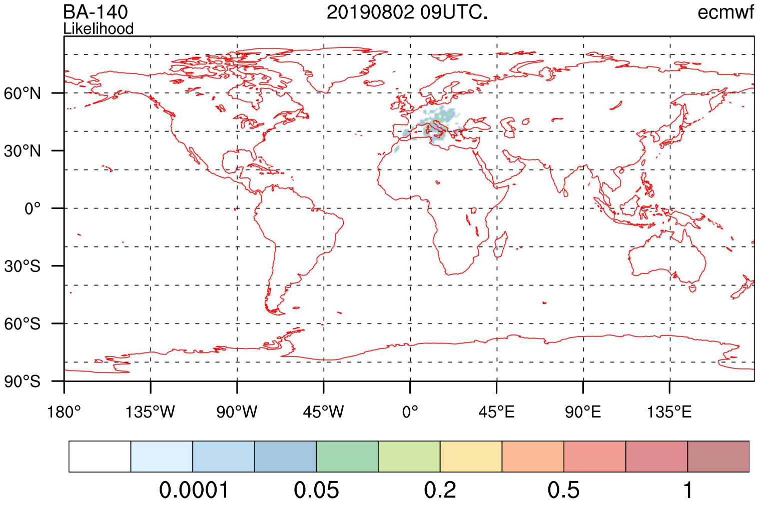

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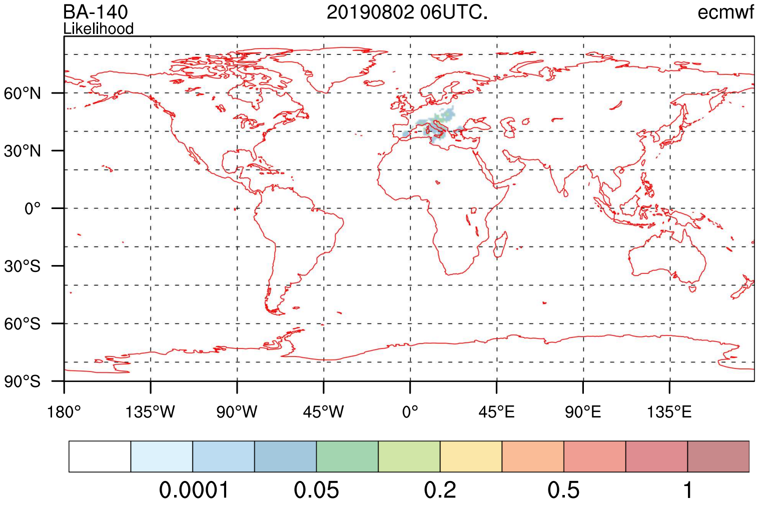

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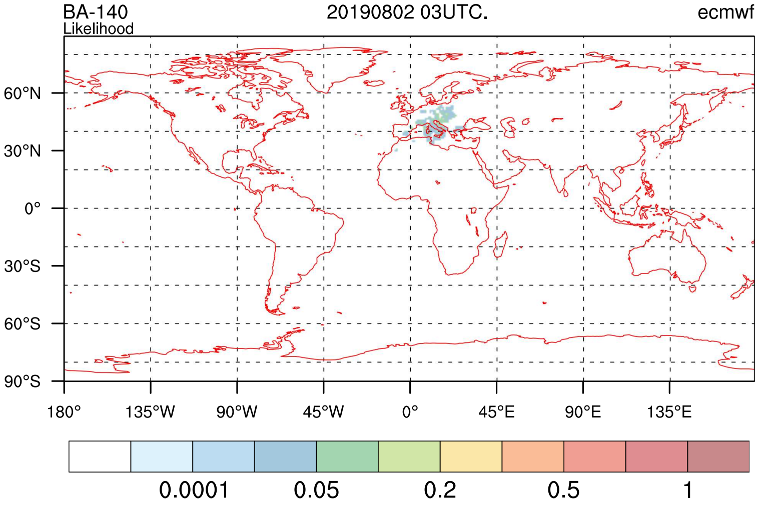

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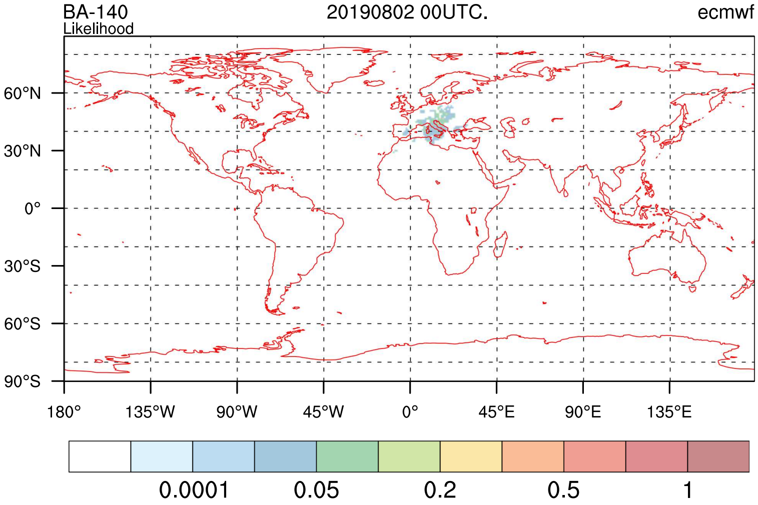

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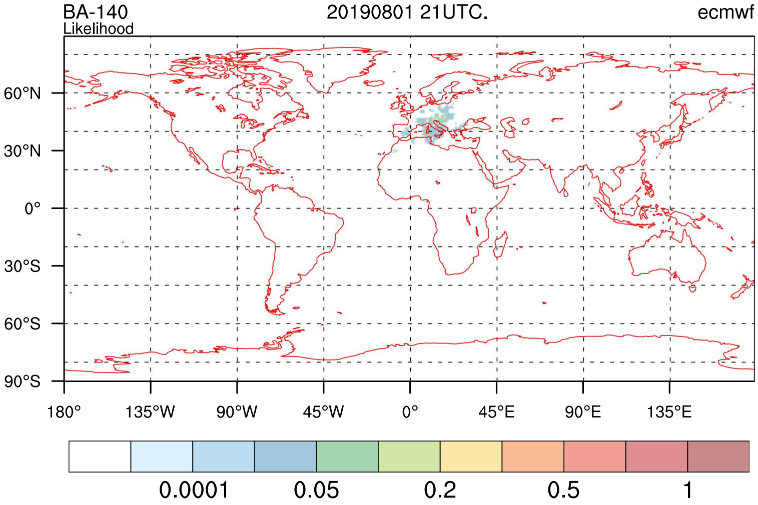

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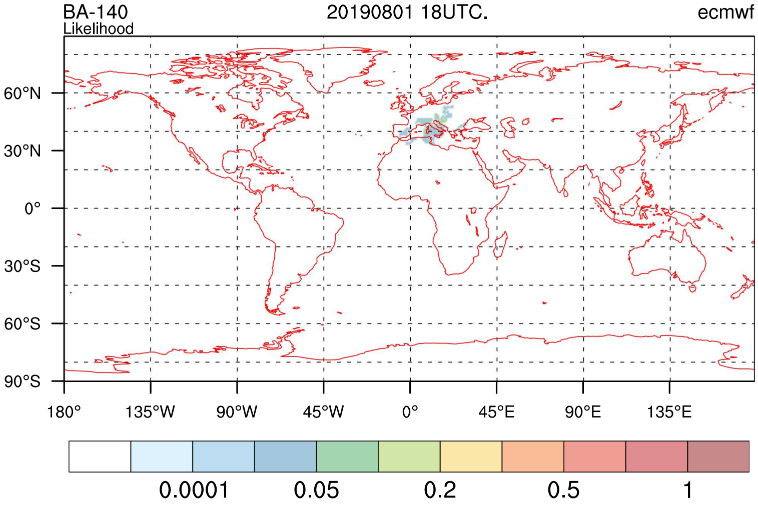

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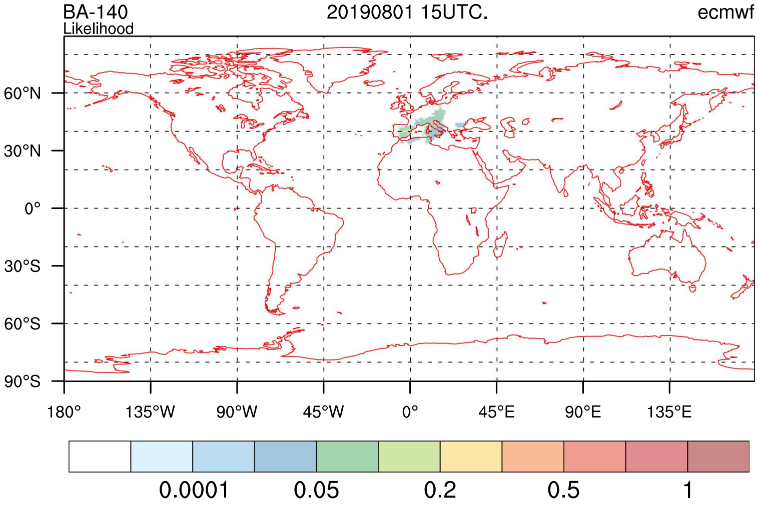

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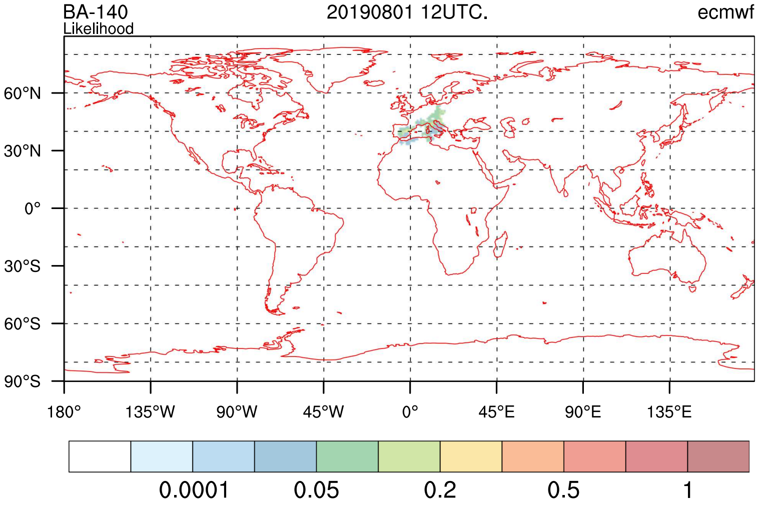

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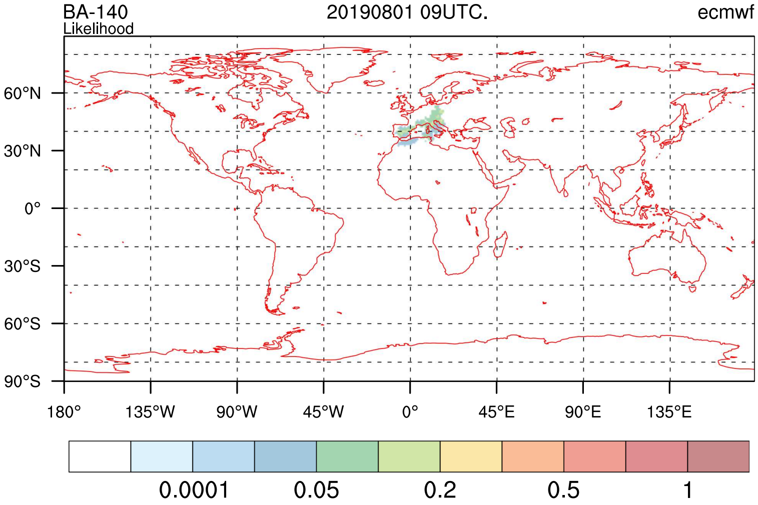

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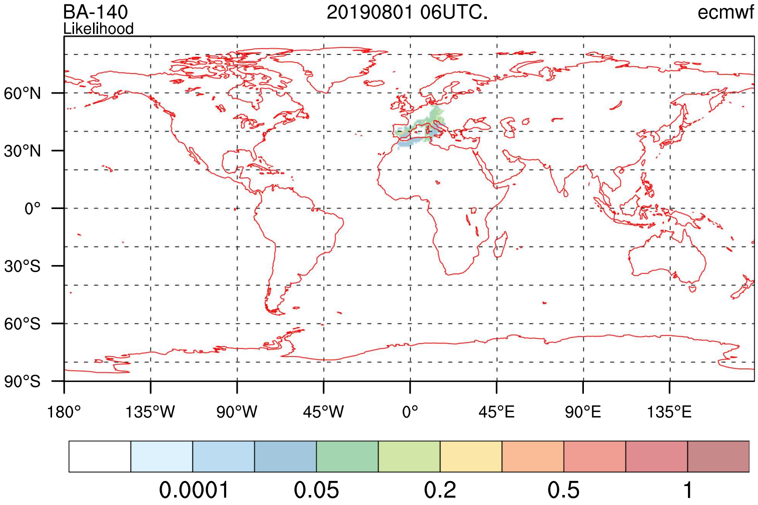

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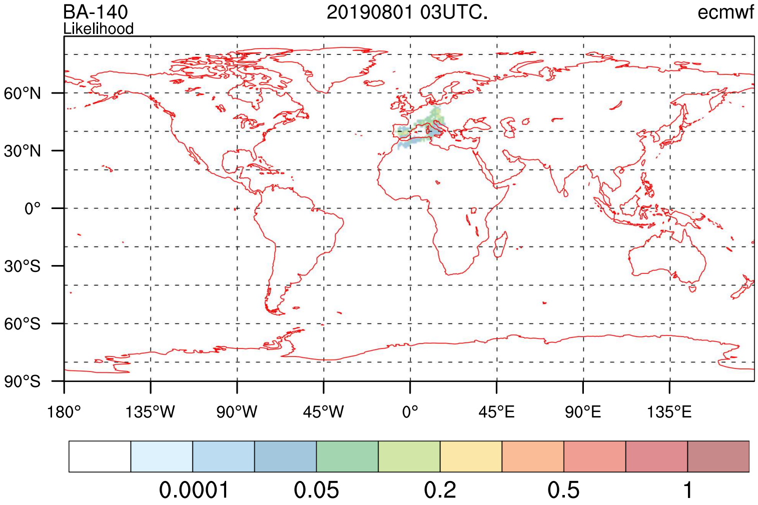

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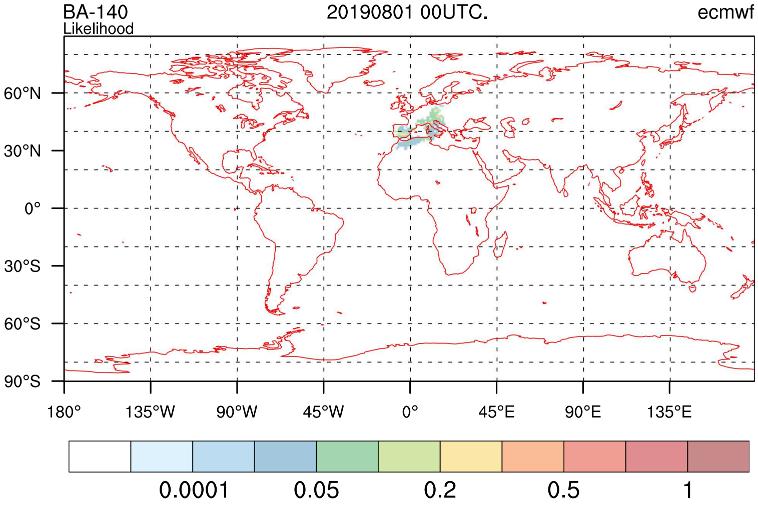

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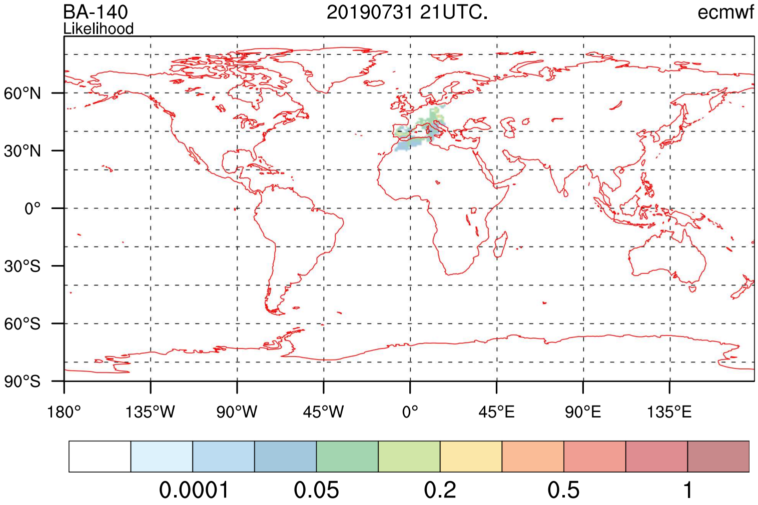

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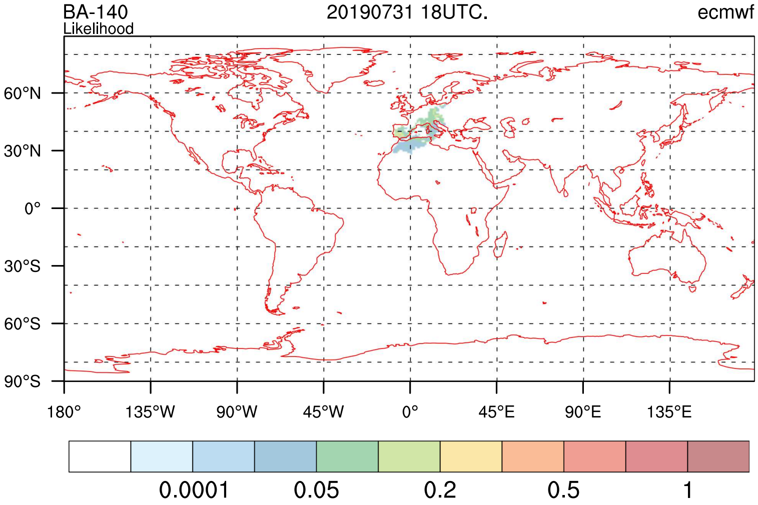

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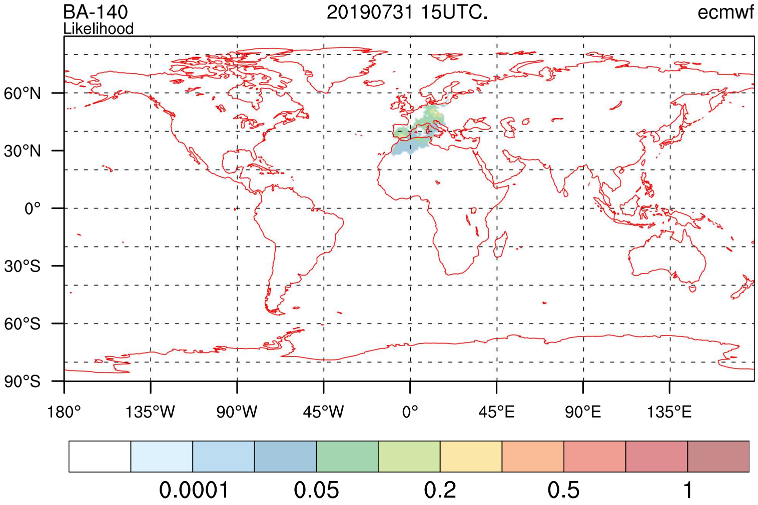

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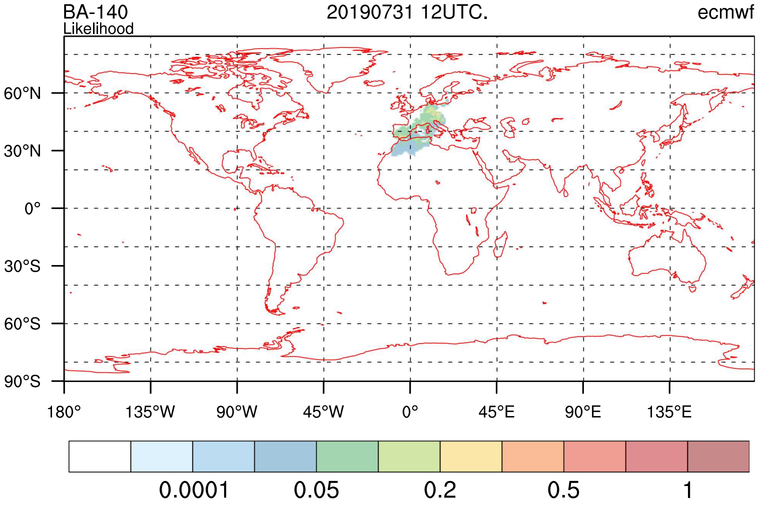

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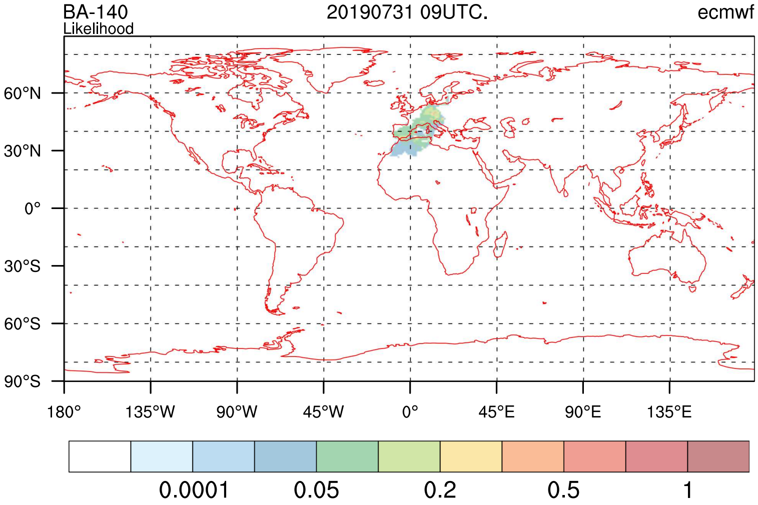

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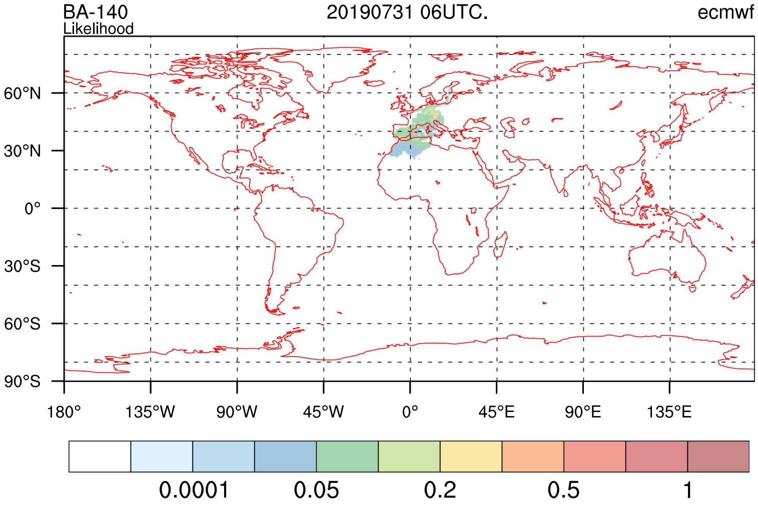

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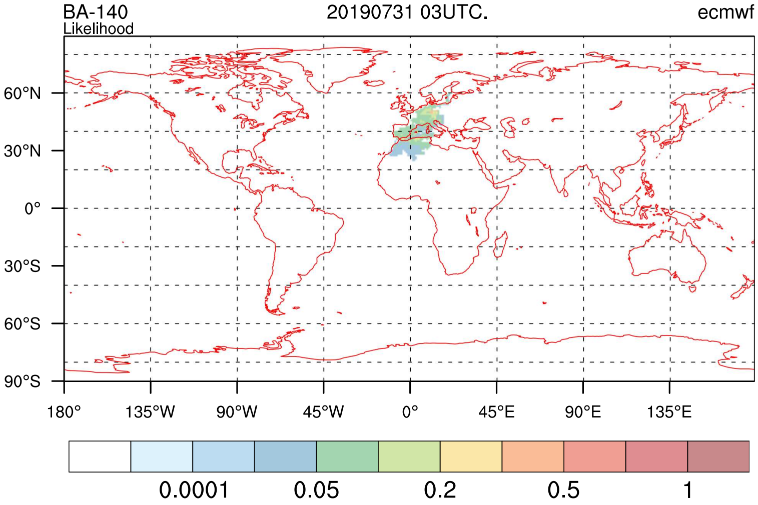

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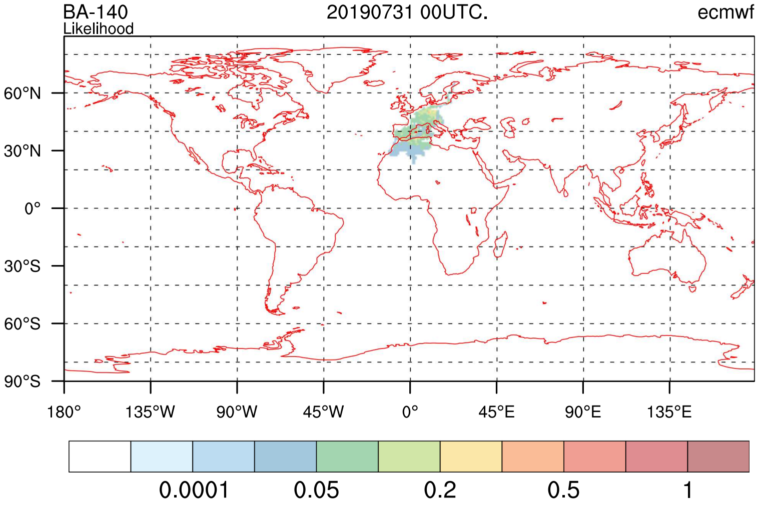

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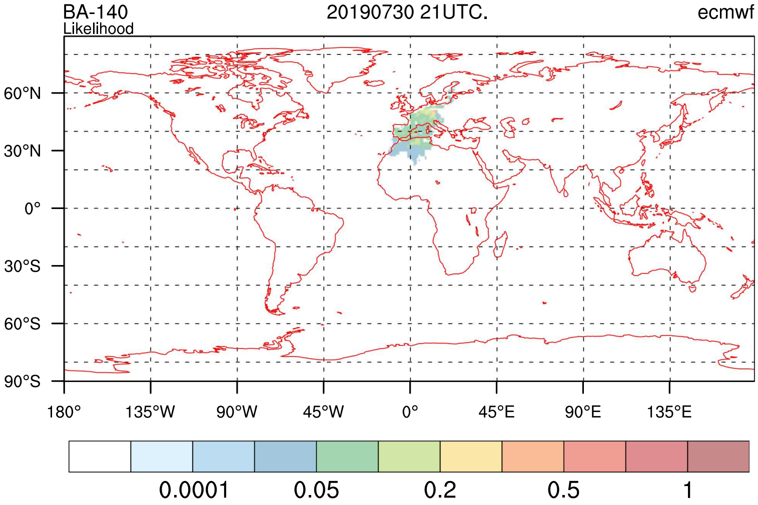

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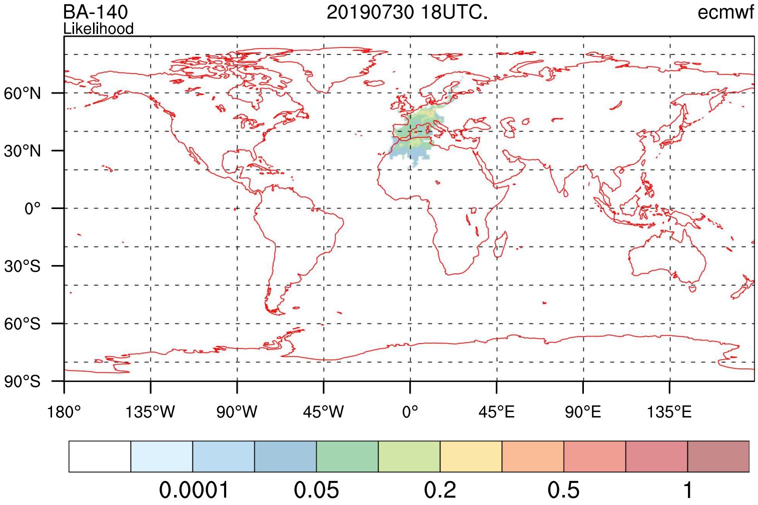

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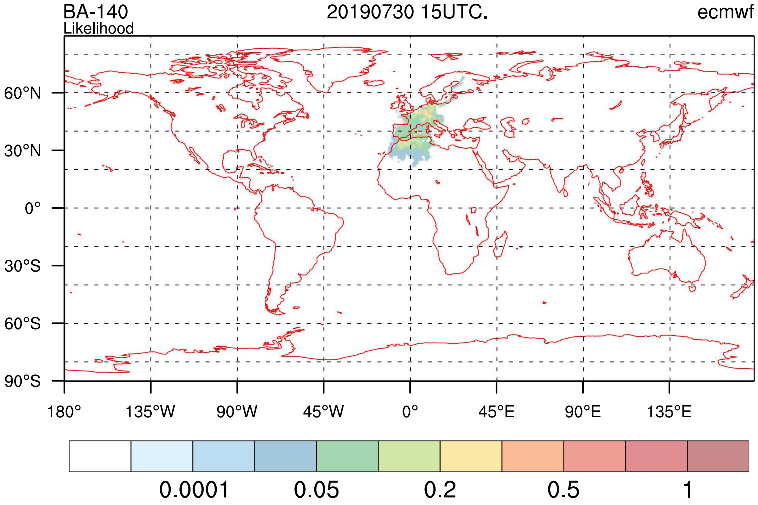

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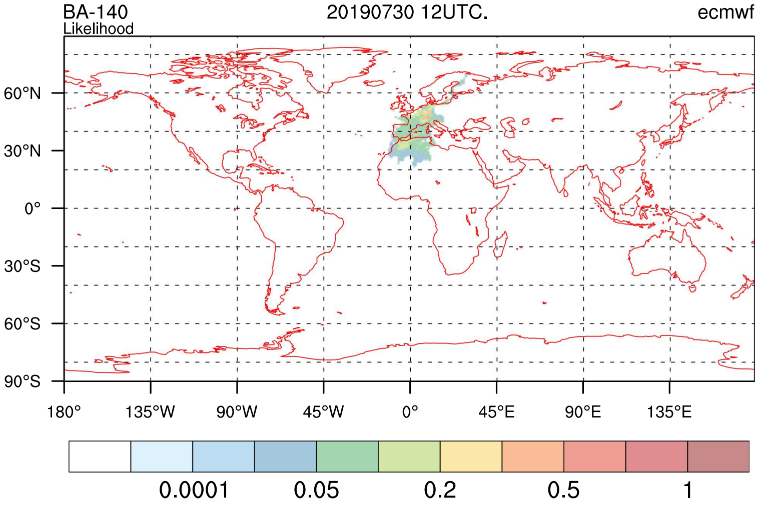

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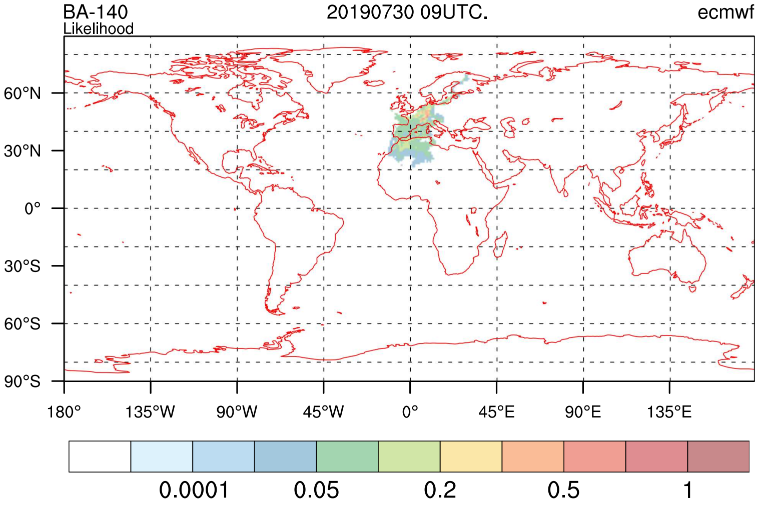

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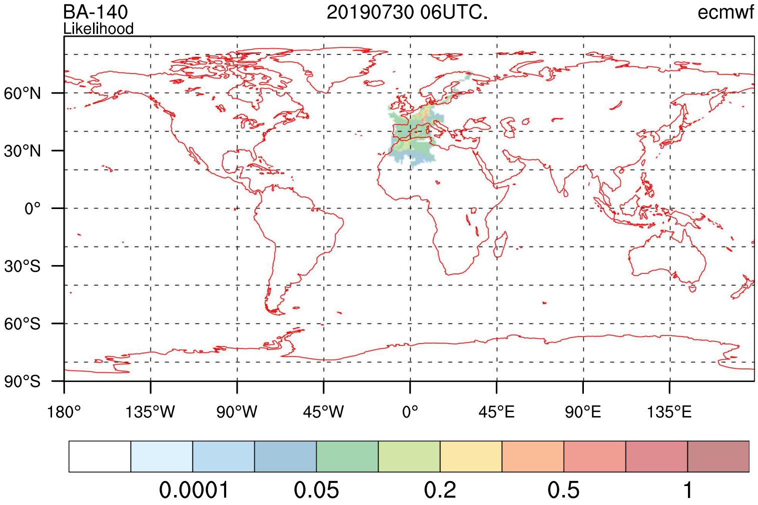

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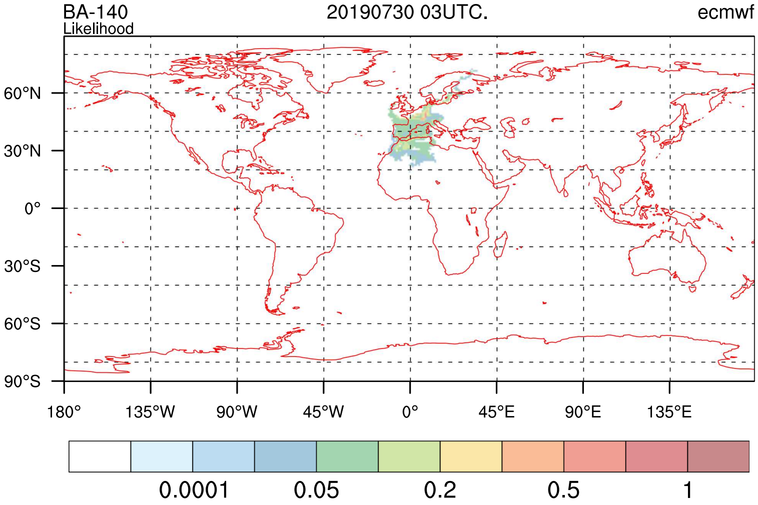

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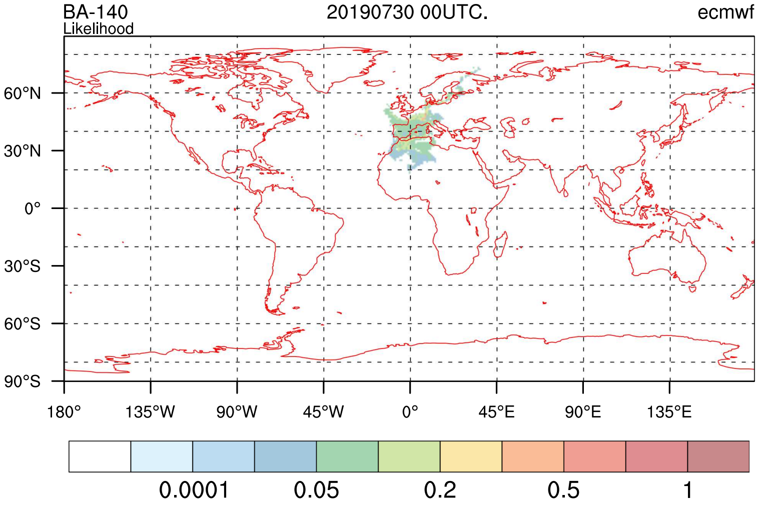

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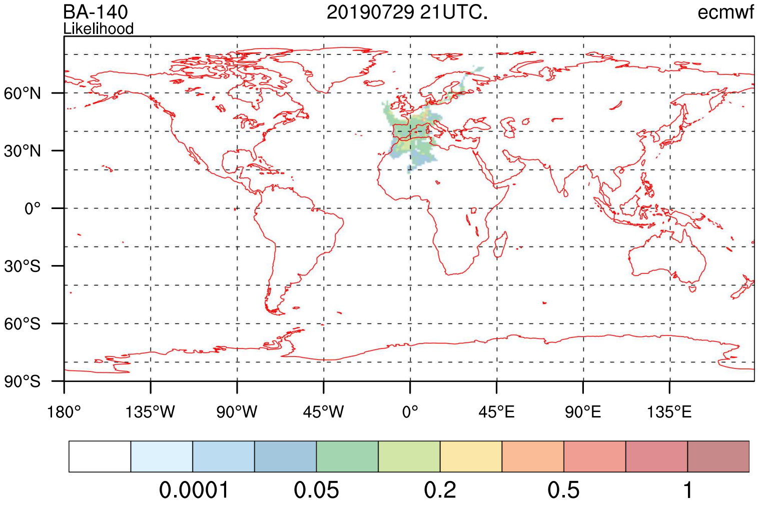

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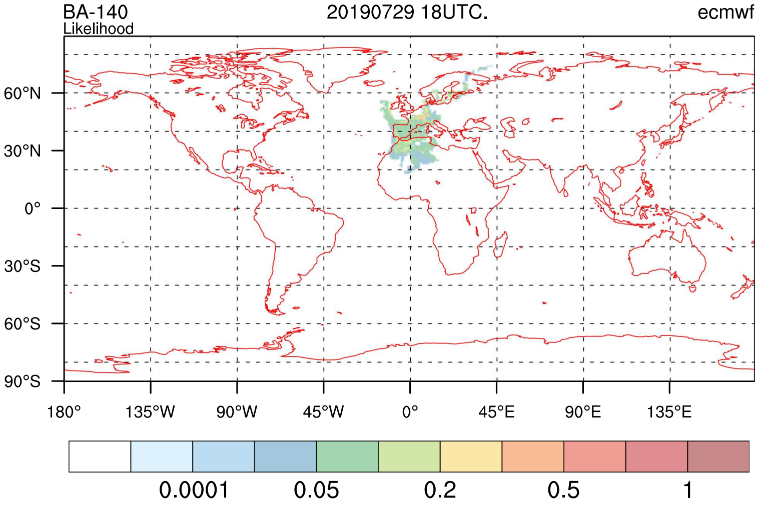

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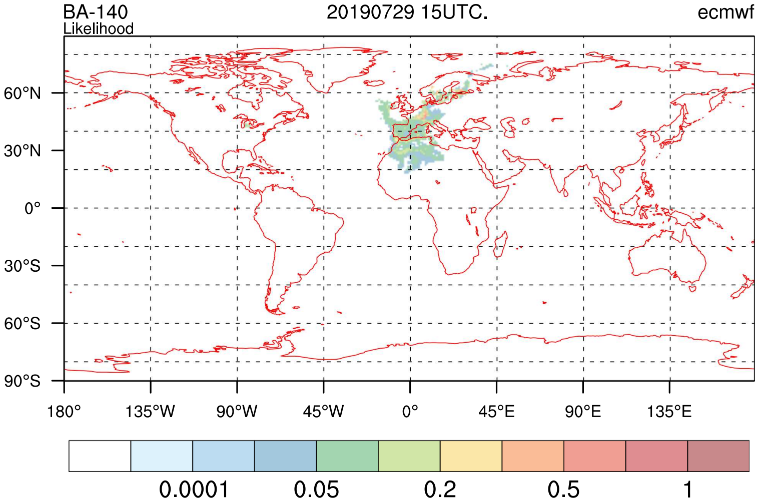

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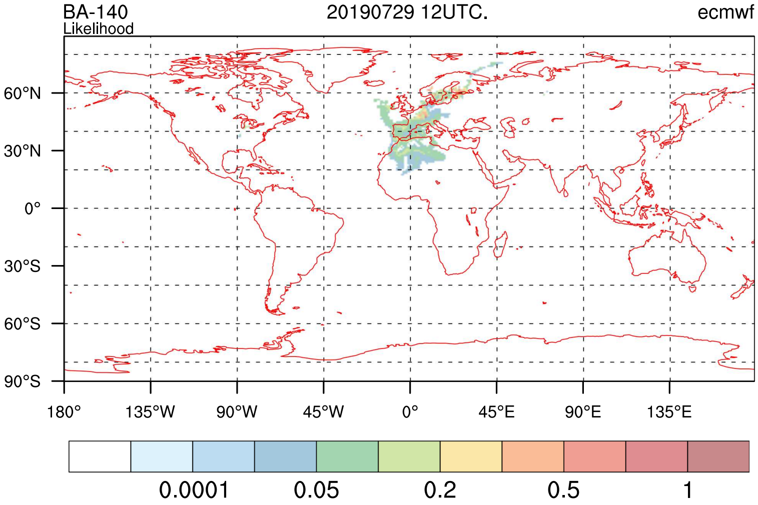

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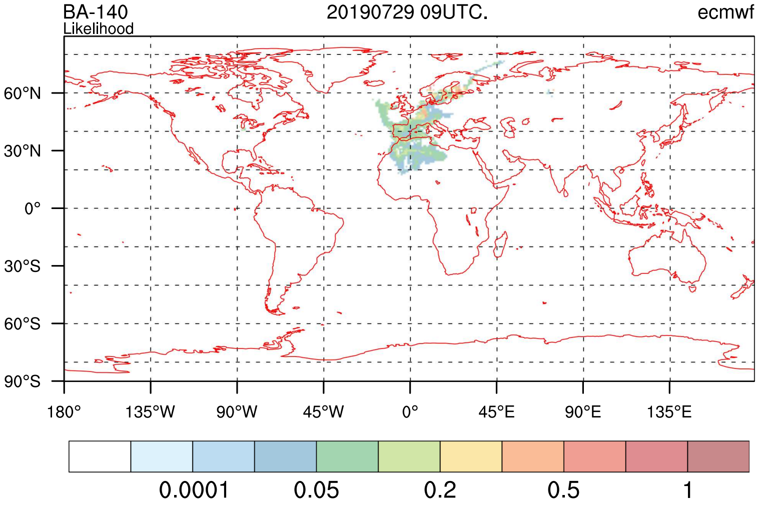

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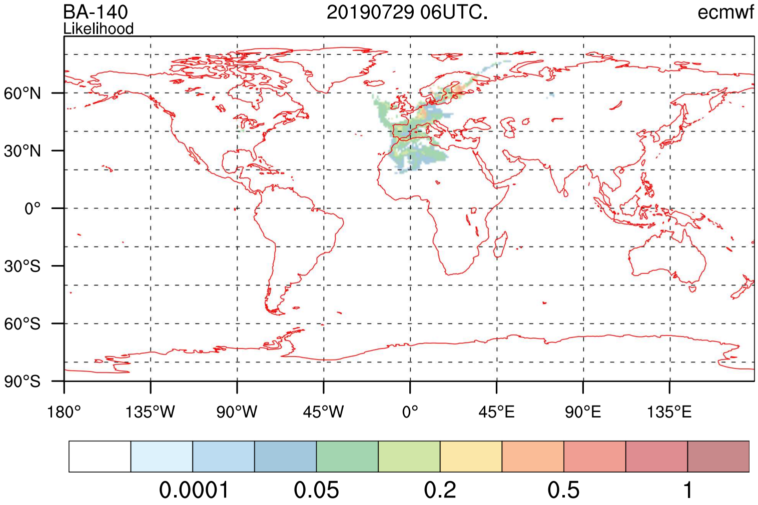

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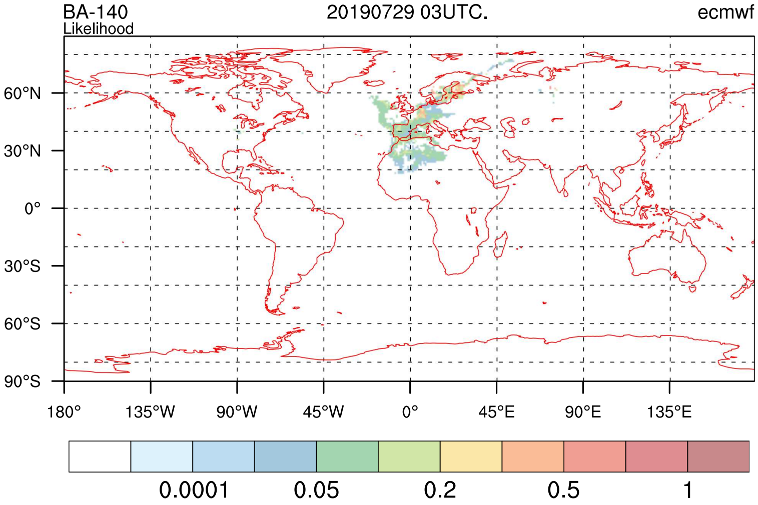

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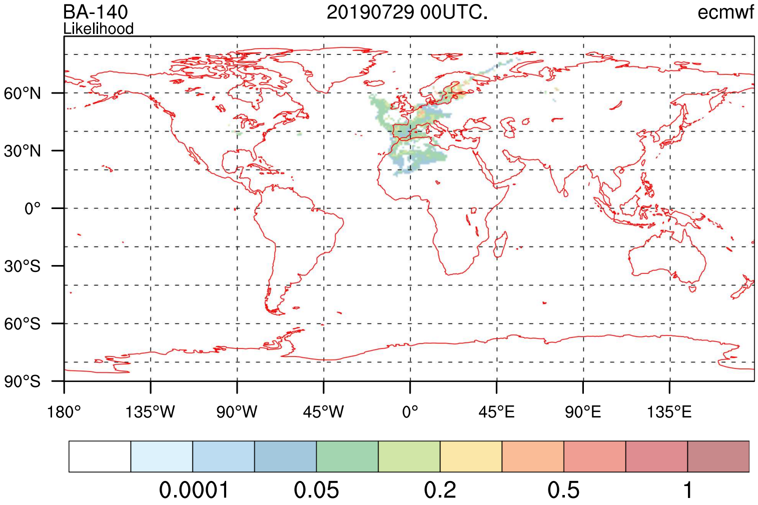

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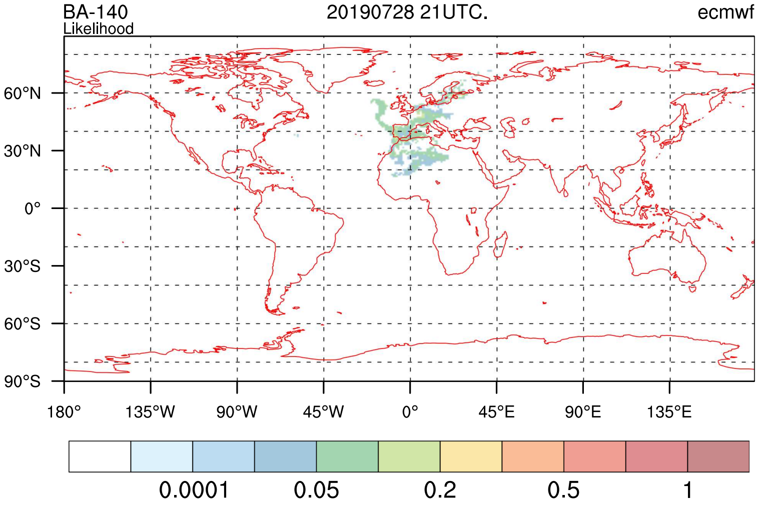

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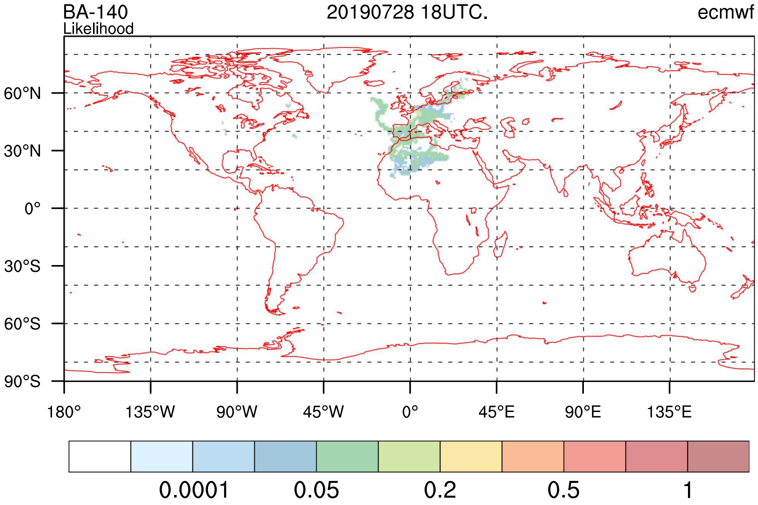

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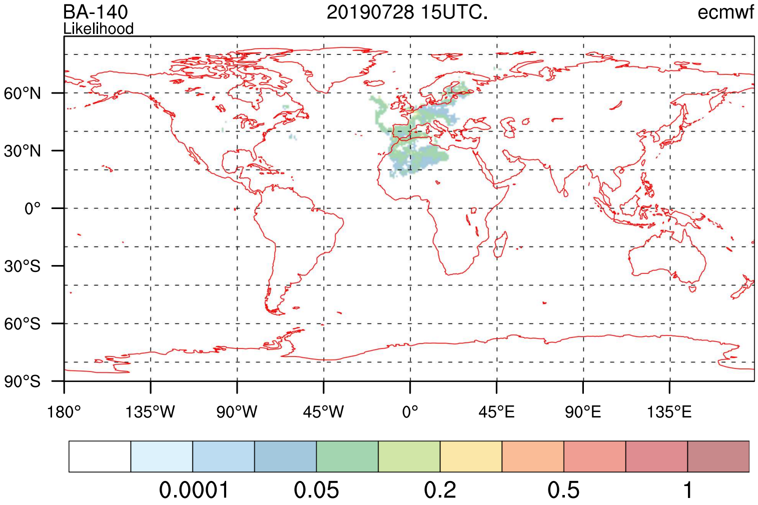

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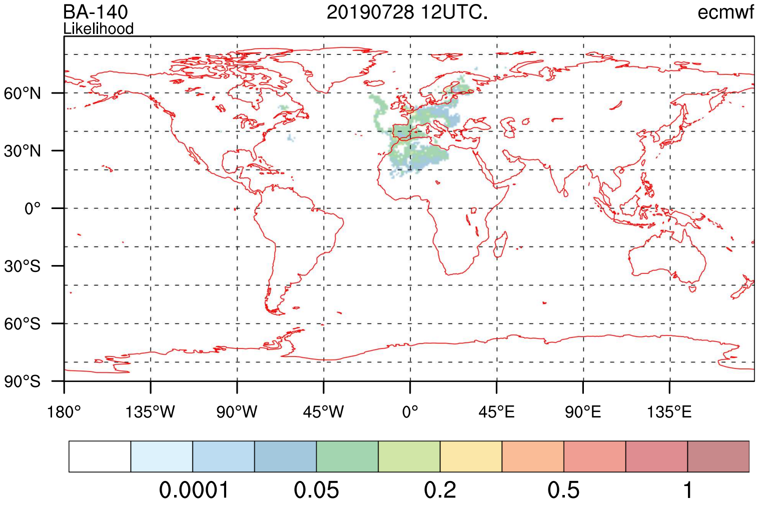

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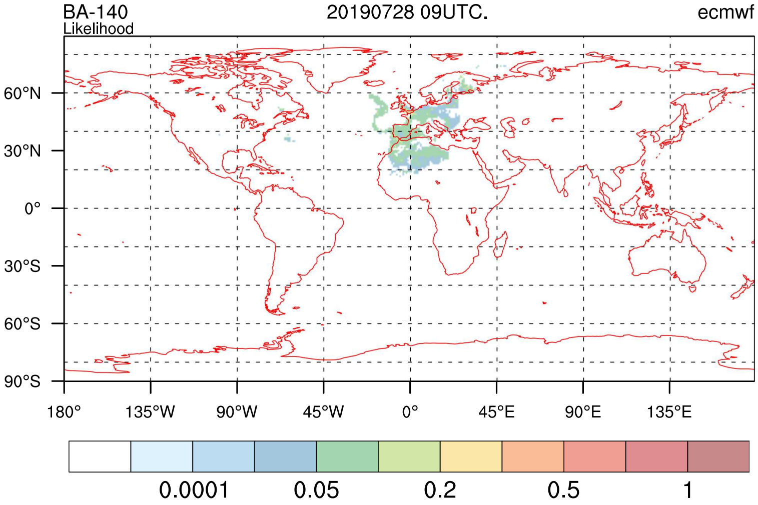

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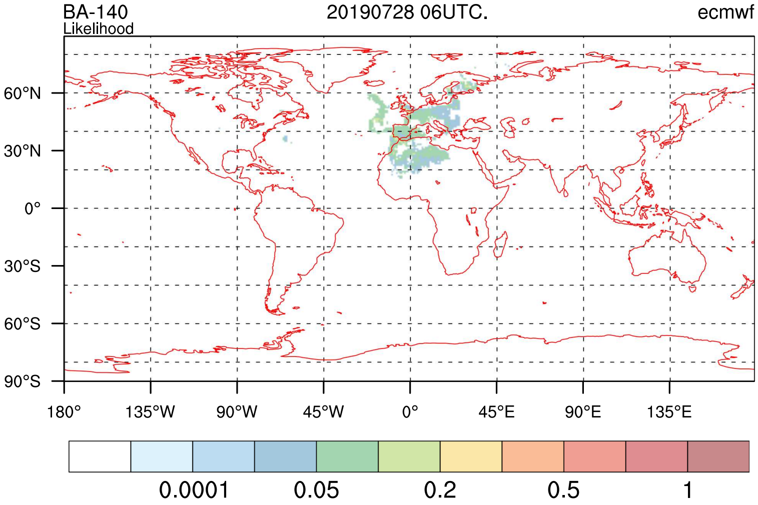

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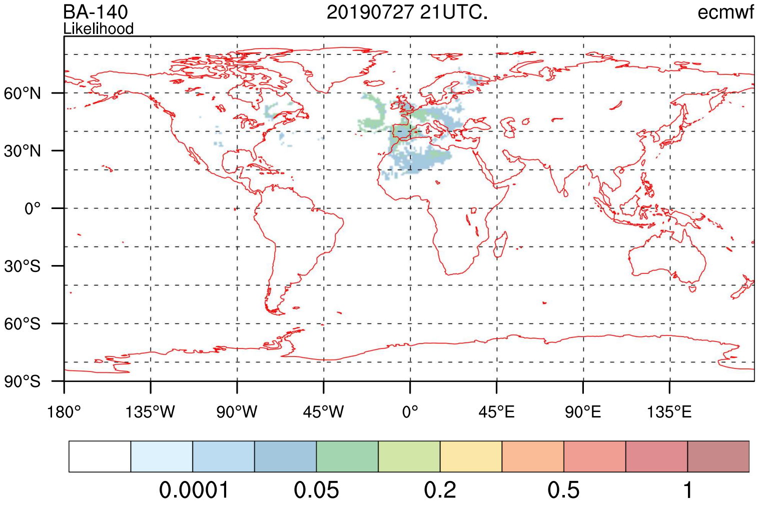

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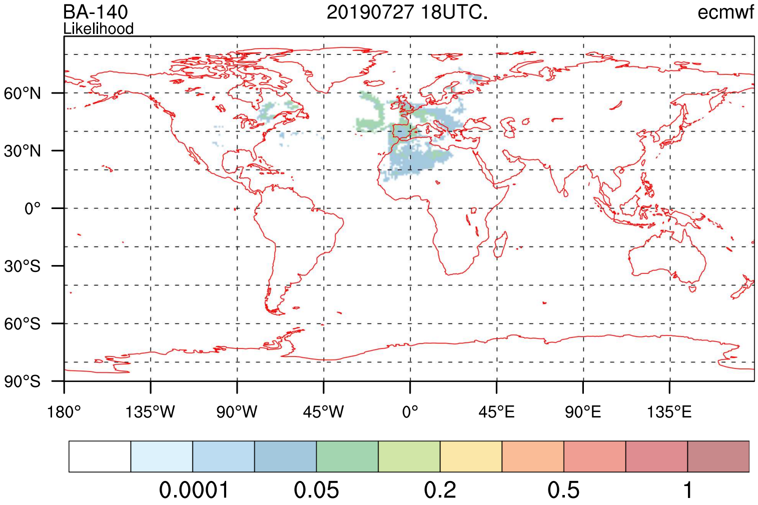

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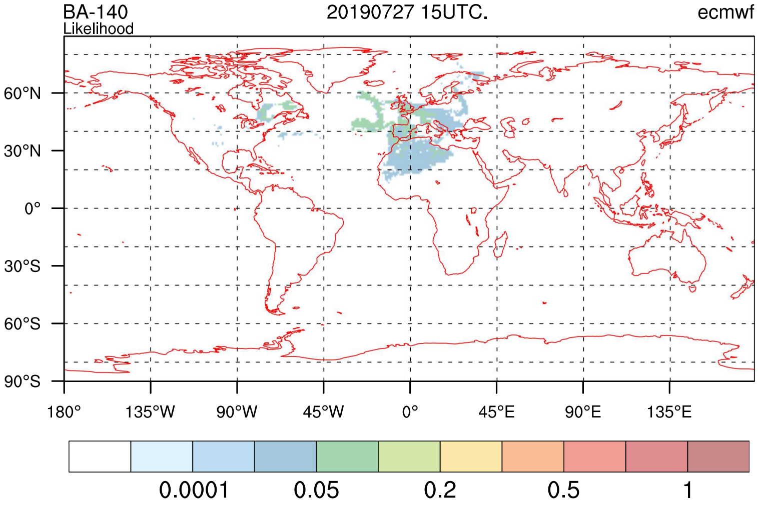

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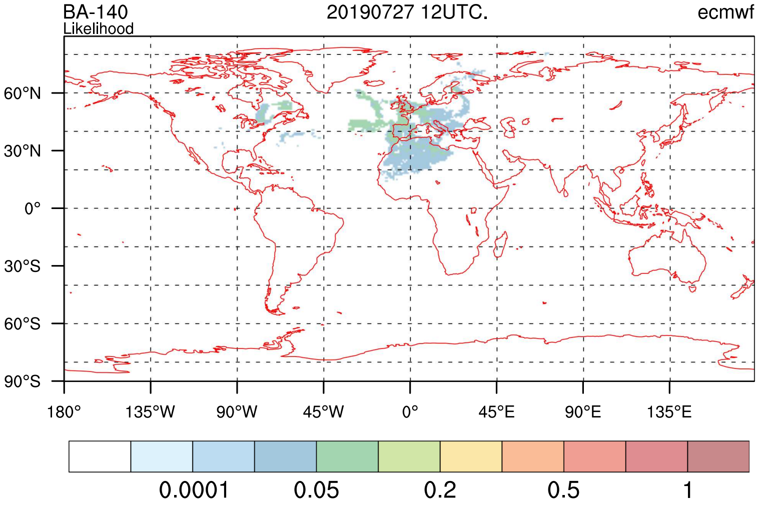

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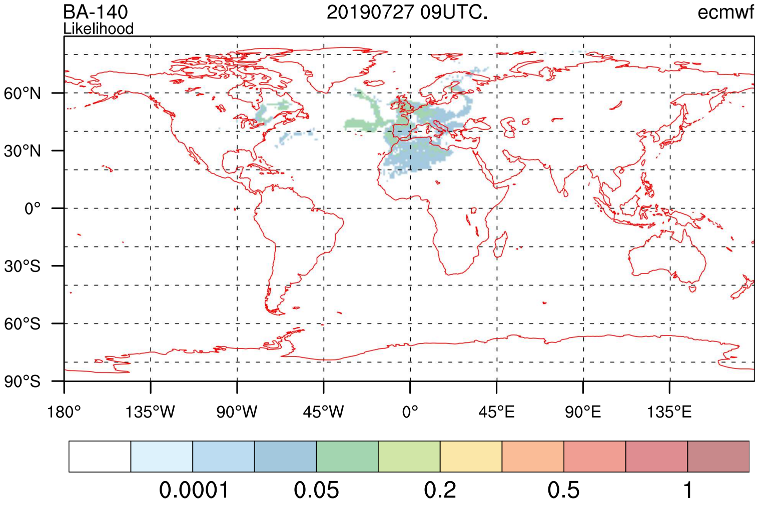

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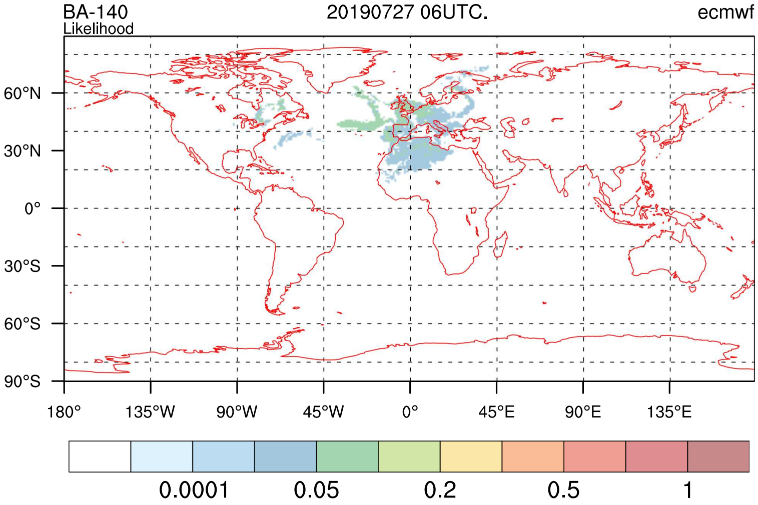

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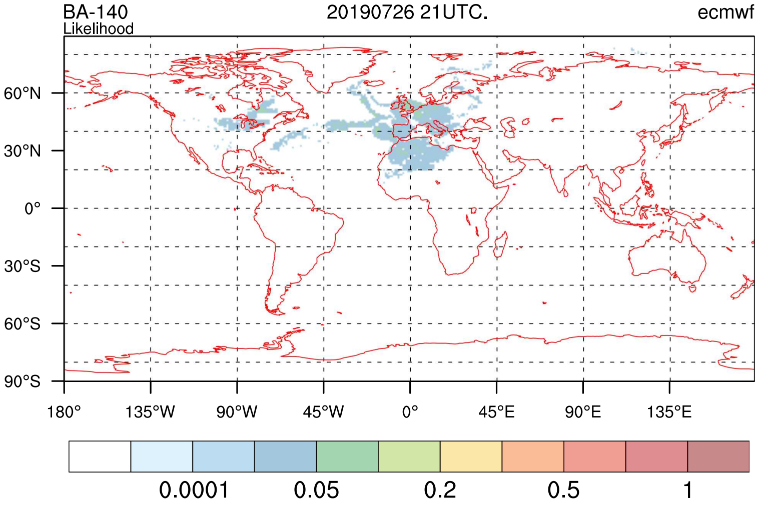

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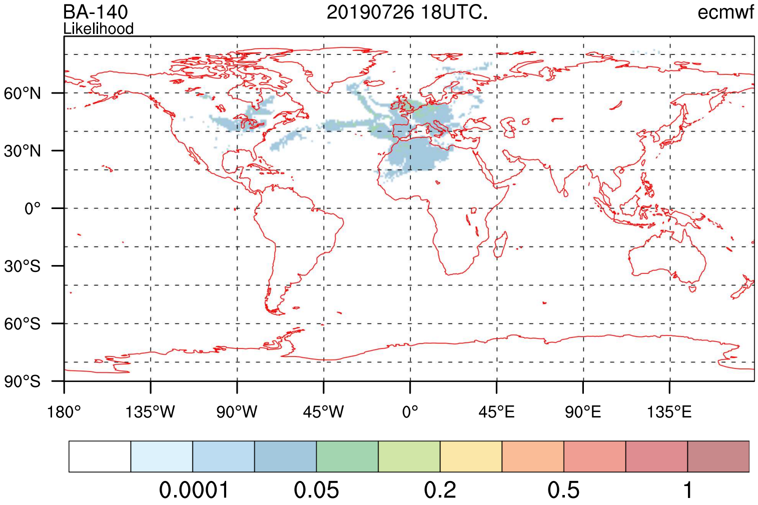

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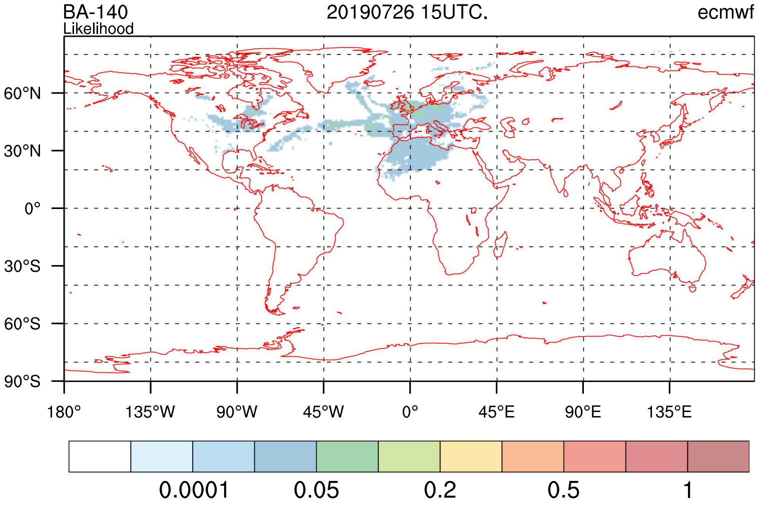
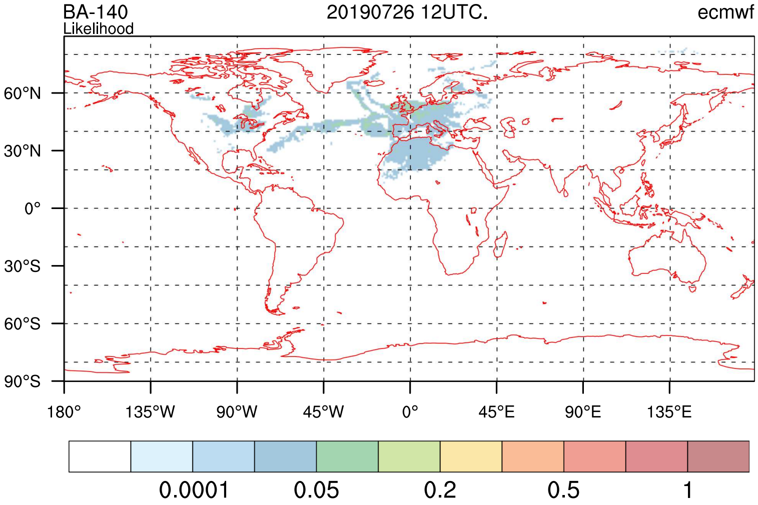
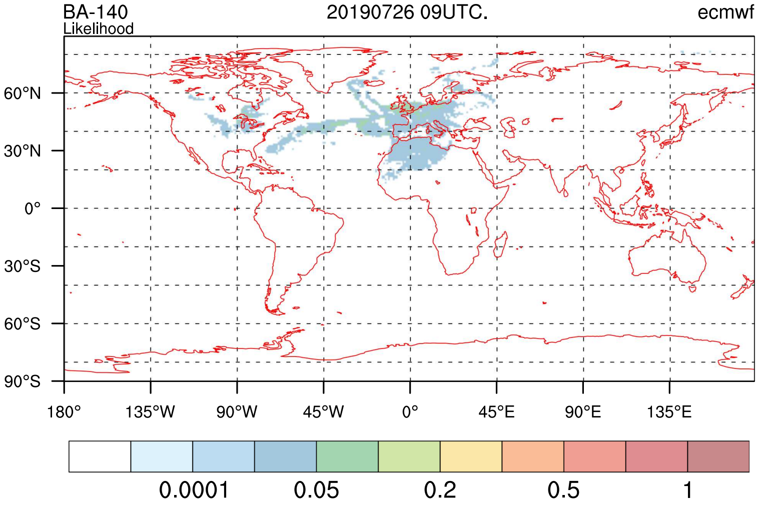


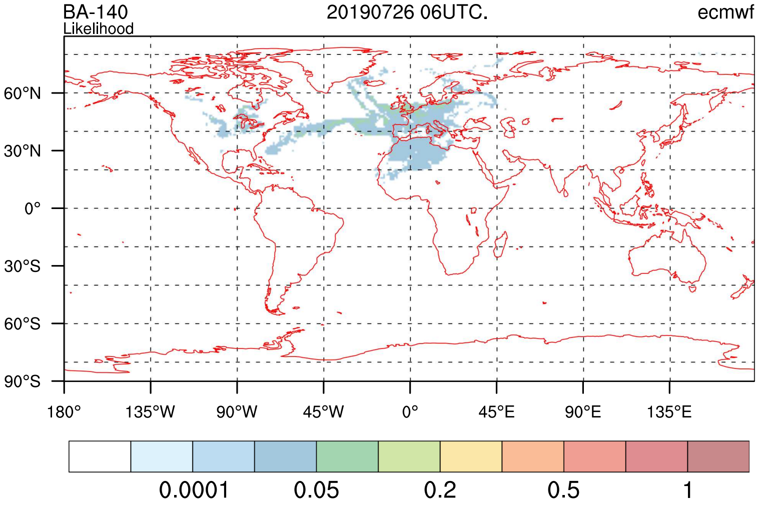
Relative Likelihood using Flexpart-ECMWF (Ba-140)



Relative Likelihood using Flexpart-ECMWF (Ba-140)



Relative Likelihood using Flexpart-ECMWF (Ba-140)



SHI Analysis

By

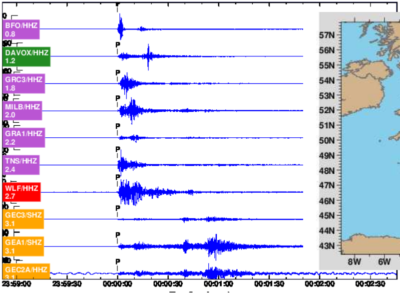
Mona Abdel Azem, Adel Samy, Islam Hamama

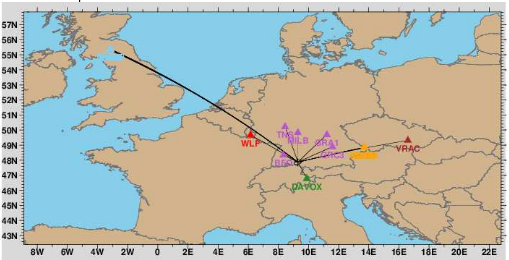
Seismic and Infrasound Detections

To search for possible events related to the unusual radionuclide detections, the IMS stations and Eastria National SHI data are used and we found the following event:

- Seismic Event:

Date_time	Latitude	Longitude	Magnitude	Depth
2019/07/29 23:17:47.3	47.8660	9.2899	Ml 4.4	0





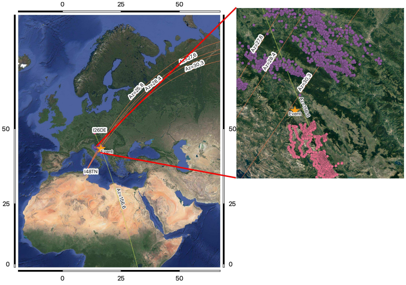
Seismic and Infrasound Detections

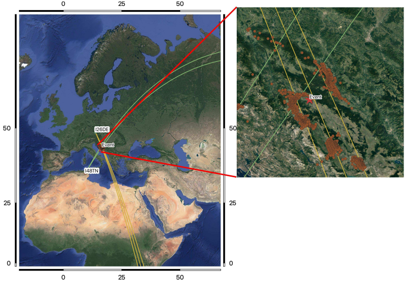
To search for possible events related to the unusual radionuclide detections, the IMS stations and Eastria National SHI data are used and we found the following event:

- Two Infrasound Events:

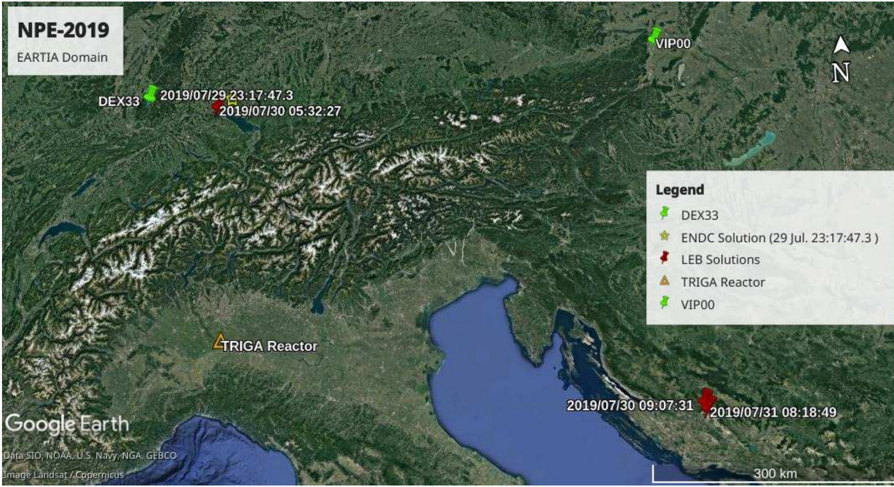
Date_time	Latitude	Longitude
2019/07/30 09:07:31	44.2204	16.39

Date_time	Latitude	Longitude
2019/08/01 08:00:37.5	44.3006	16.5513



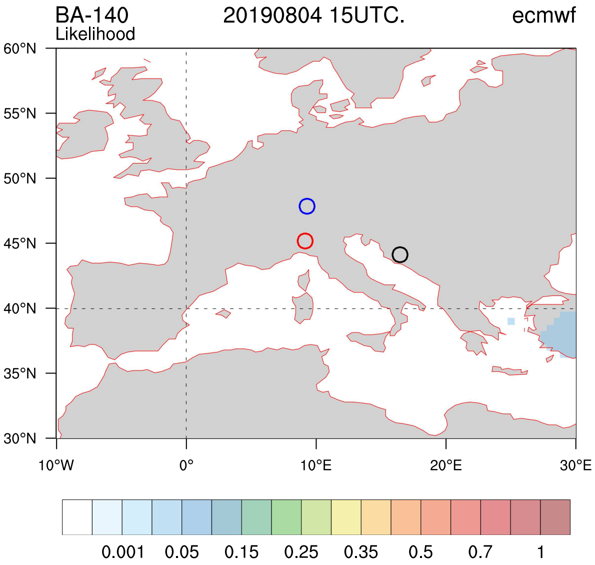


Summary of SHI detections

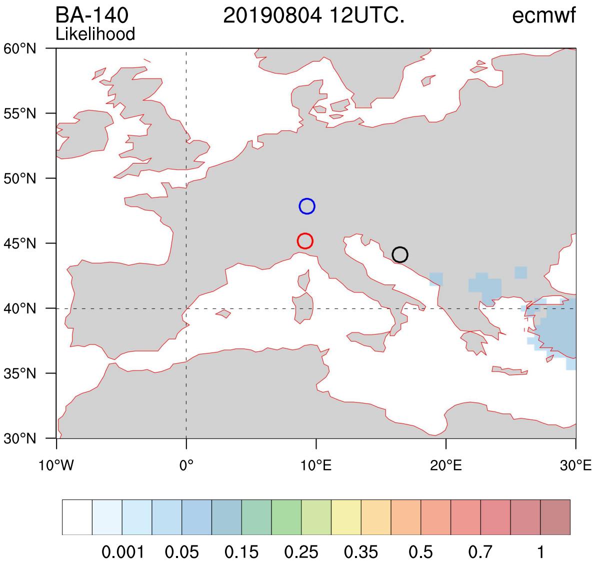


Source Determination

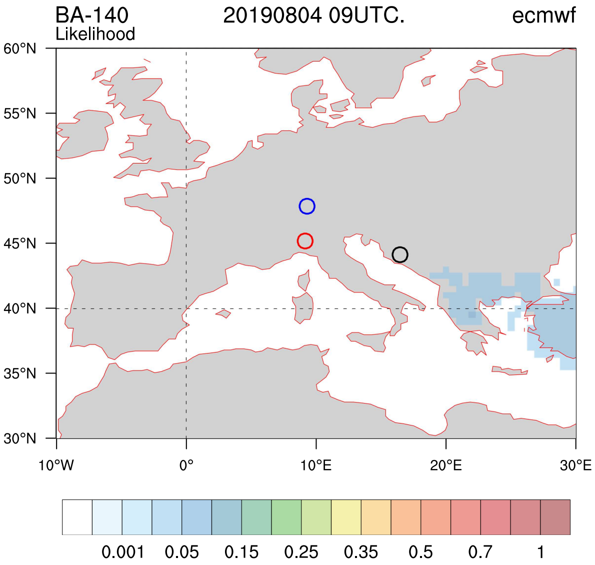
Relative Likelihood using Flexpart-ECMWF (Ba-140)



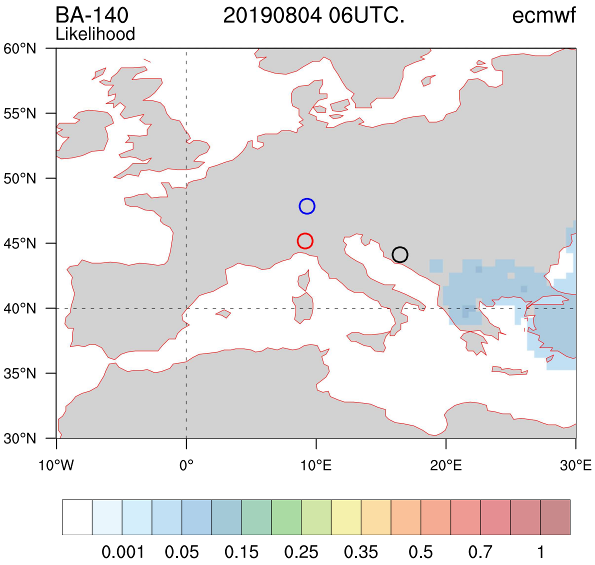
Relative Likelihood using Flexpart-ECMWF (Ba-140)



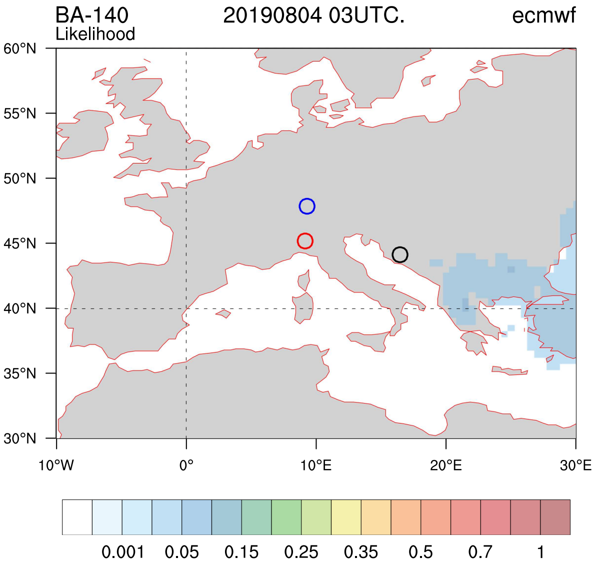
Relative Likelihood using Flexpart-ECMWF (Ba-140)



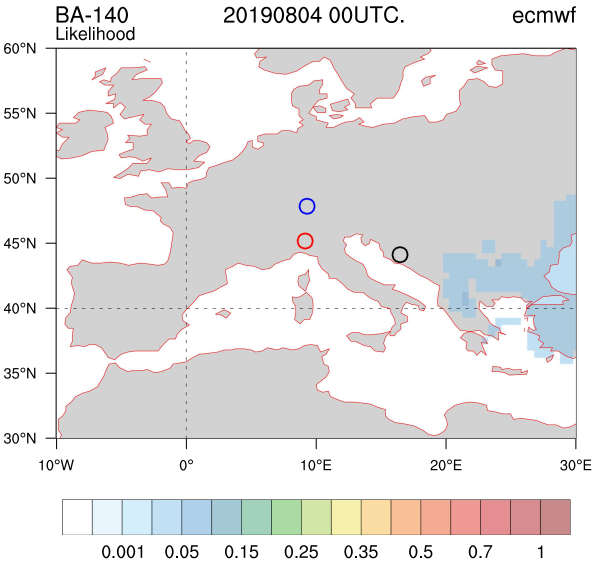
Relative Likelihood using Flexpart-ECMWF (Ba-140)



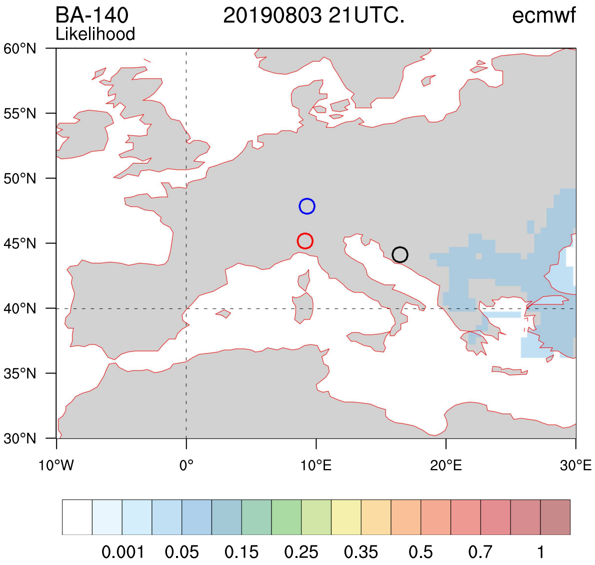
Relative Likelihood using Flexpart-ECMWF (Ba-140)



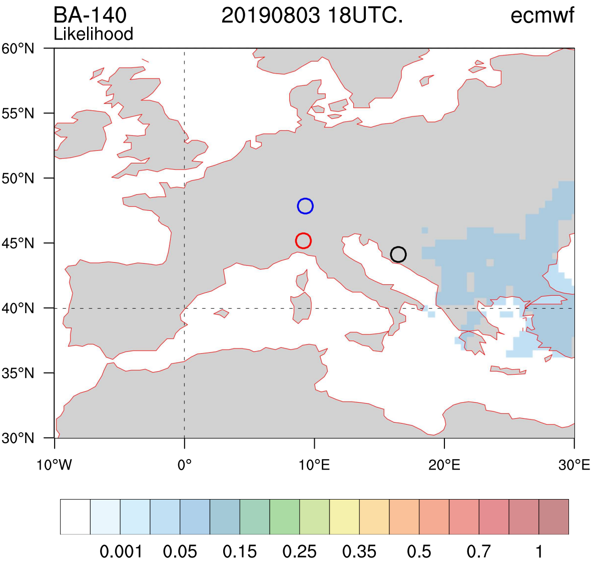
Relative Likelihood using Flexpart-ECMWF (Ba-140)



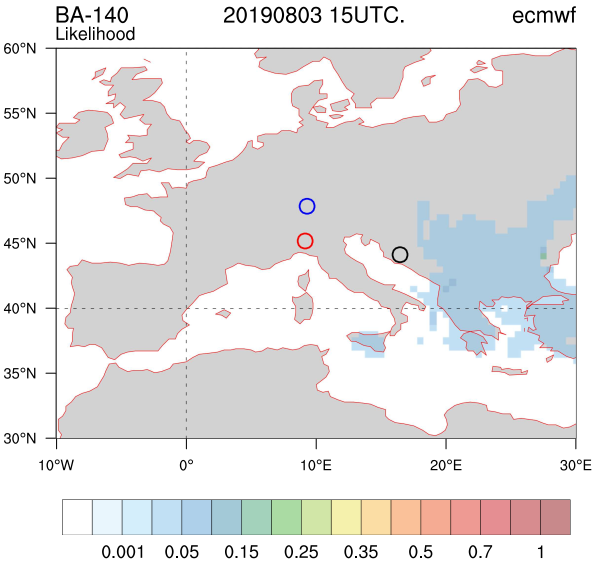
Relative Likelihood using Flexpart-ECMWF (Ba-140)



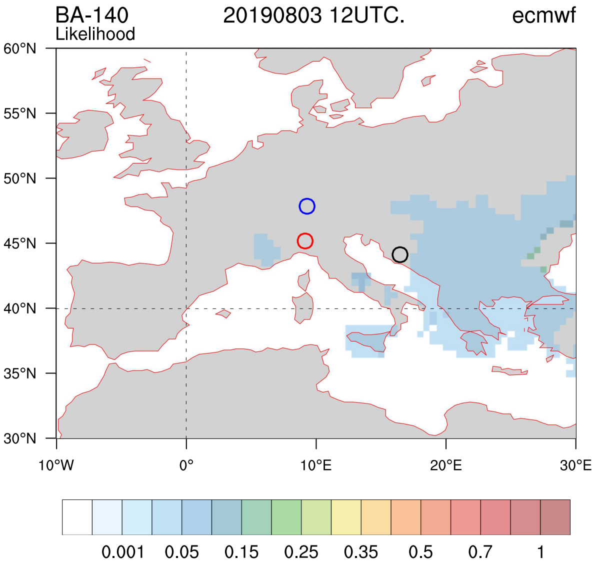
Relative Likelihood using Flexpart-ECMWF (Ba-140)



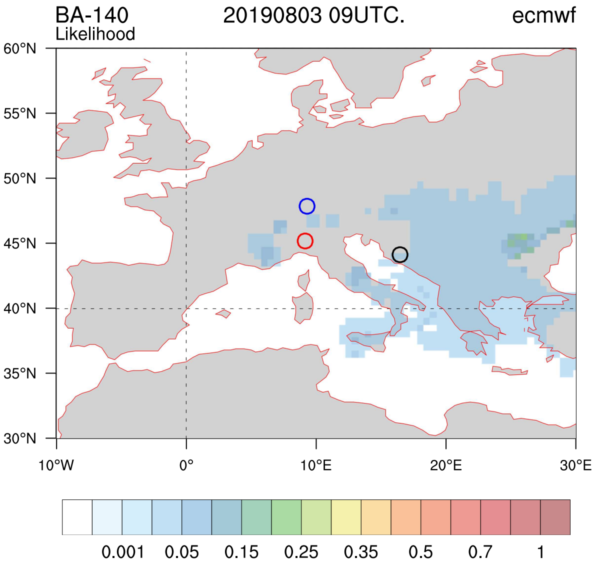
Relative Likelihood using Flexpart-ECMWF (Ba-140)



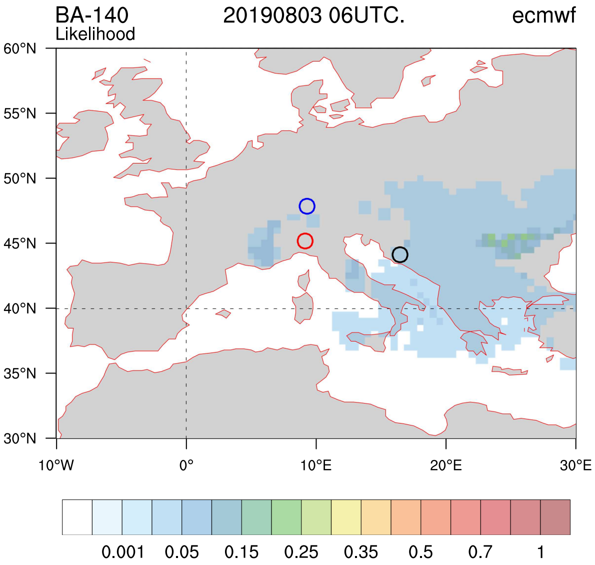
Relative Likelihood using Flexpart-ECMWF (Ba-140)



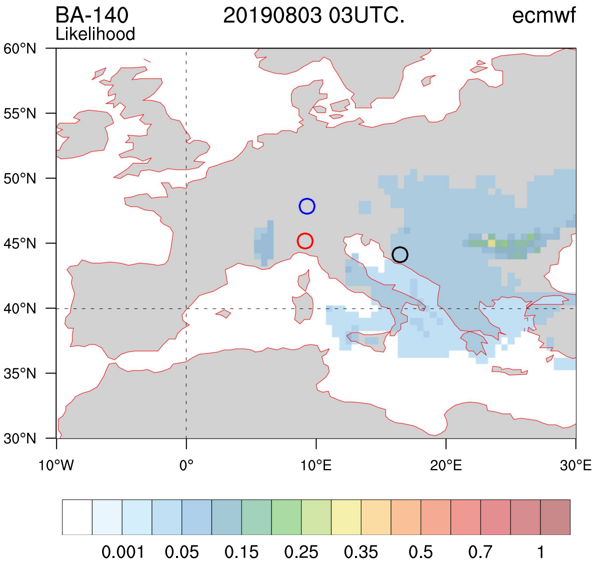
Relative Likelihood using Flexpart-ECMWF (Ba-140)



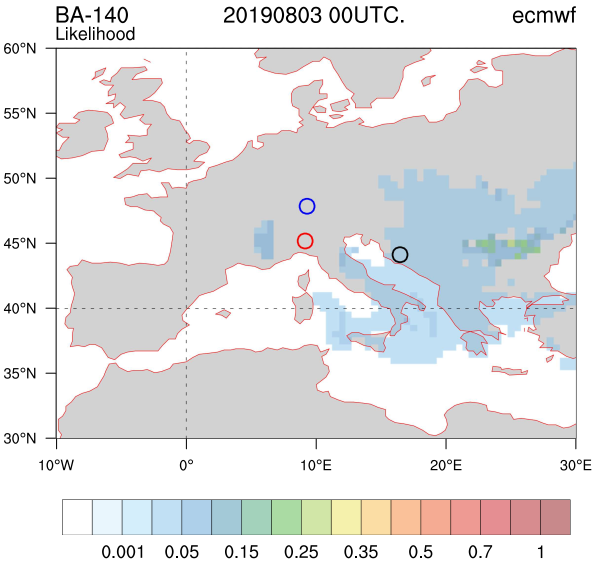
Relative Likelihood using Flexpart-ECMWF (Ba-140)



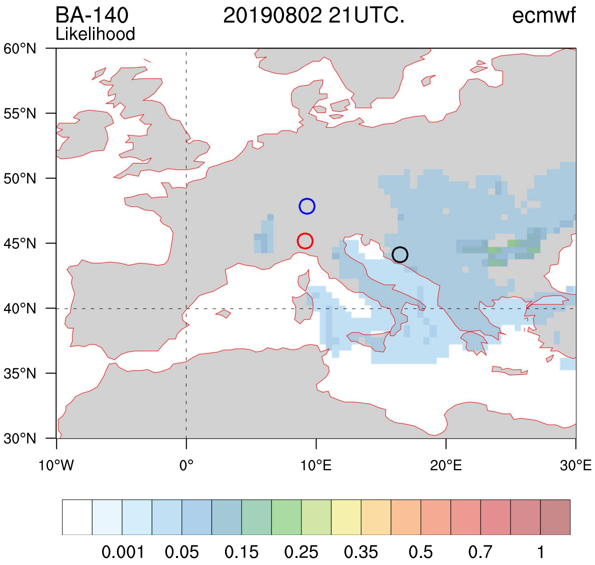
Relative Likelihood using Flexpart-ECMWF (Ba-140)



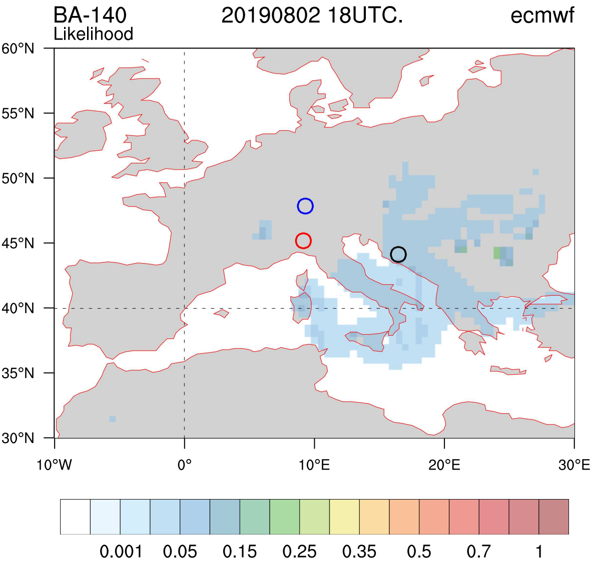
Relative Likelihood using Flexpart-ECMWF (Ba-140)



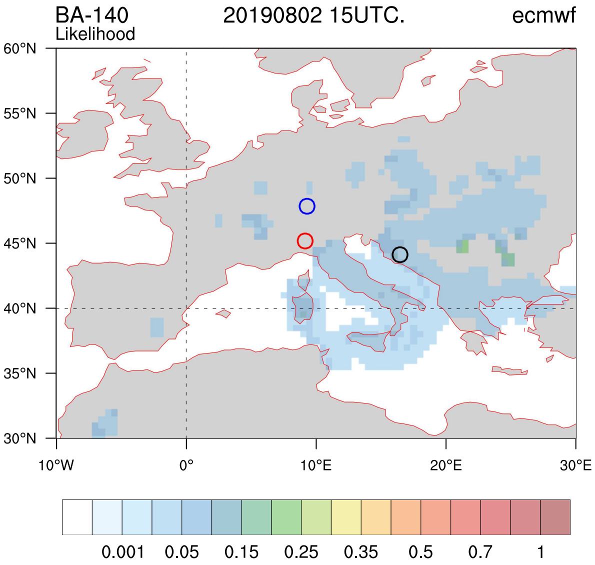
Relative Likelihood using Flexpart-ECMWF (Ba-140)



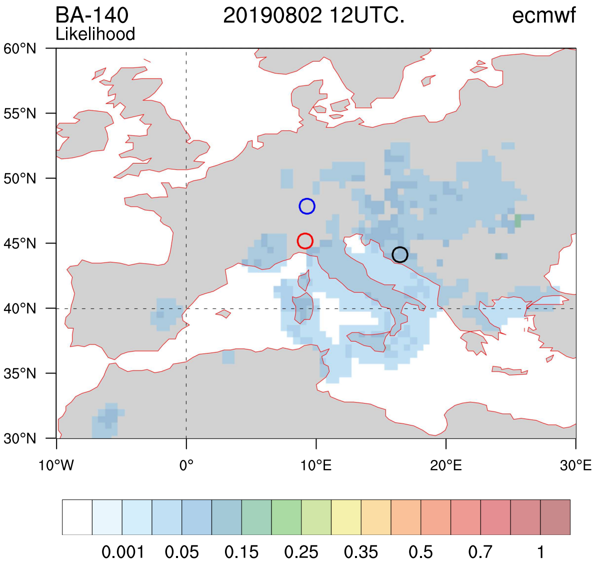
Relative Likelihood using Flexpart-ECMWF (Ba-140)



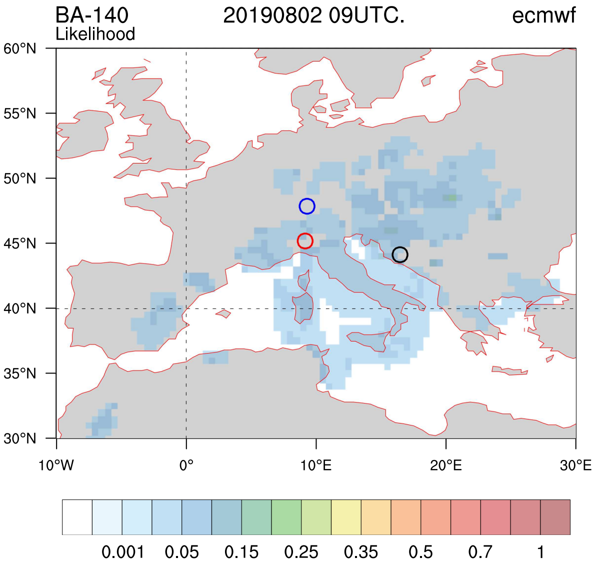
Relative Likelihood using Flexpart-ECMWF (Ba-140)



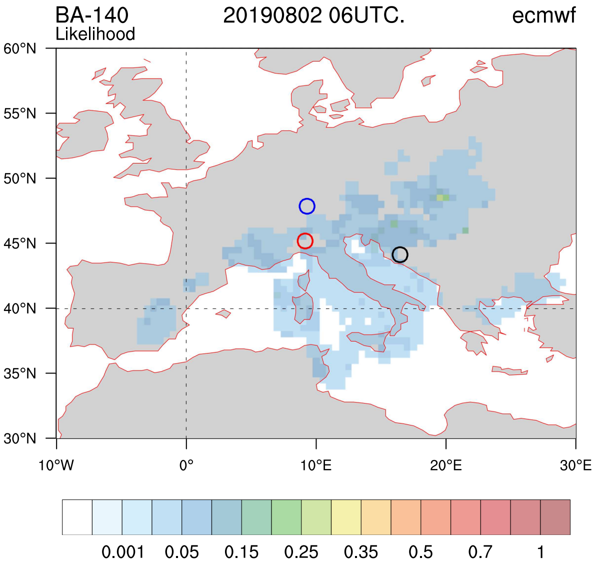
Relative Likelihood using Flexpart-ECMWF (Ba-140)



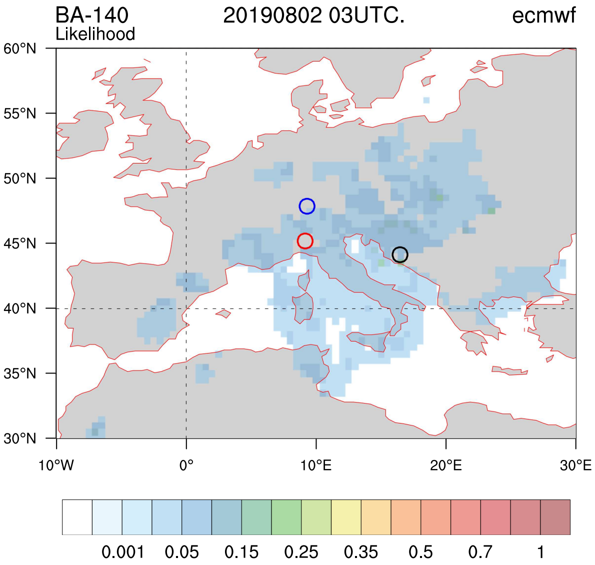
Relative Likelihood using Flexpart-ECMWF (Ba-140)



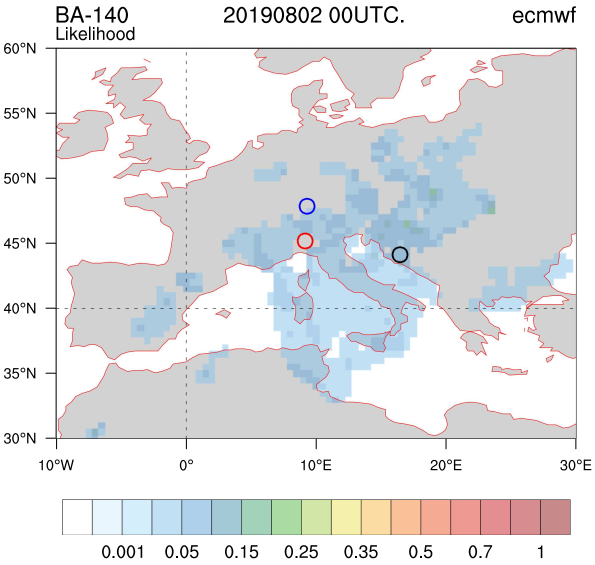
Relative Likelihood using Flexpart-ECMWF (Ba-140)



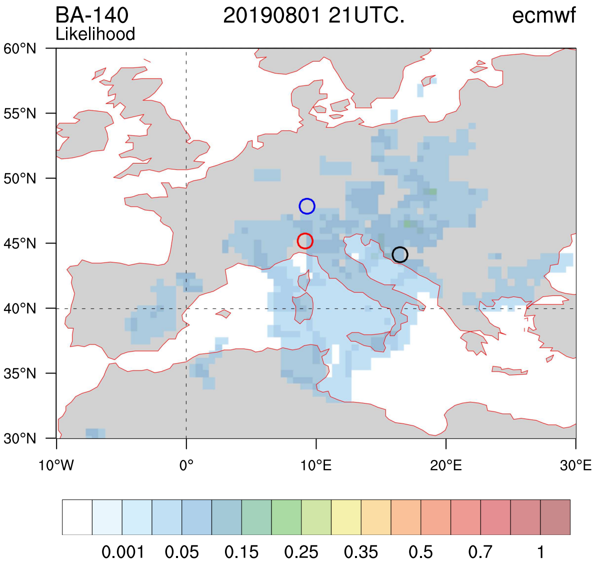
Relative Likelihood using Flexpart-ECMWF (Ba-140)



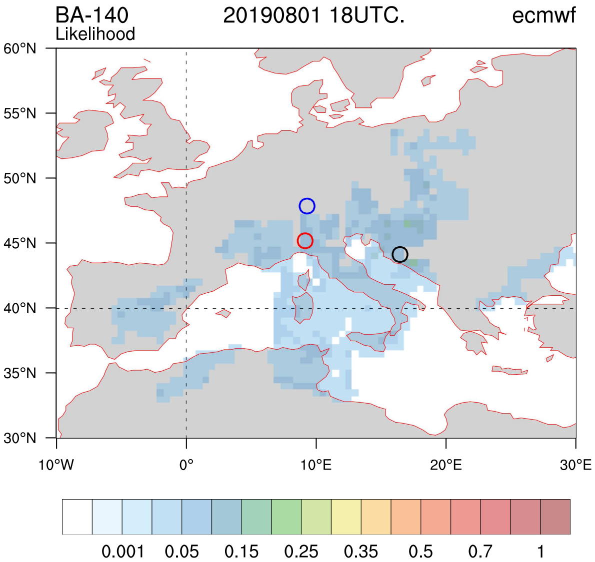
Relative Likelihood using Flexpart-ECMWF (Ba-140)



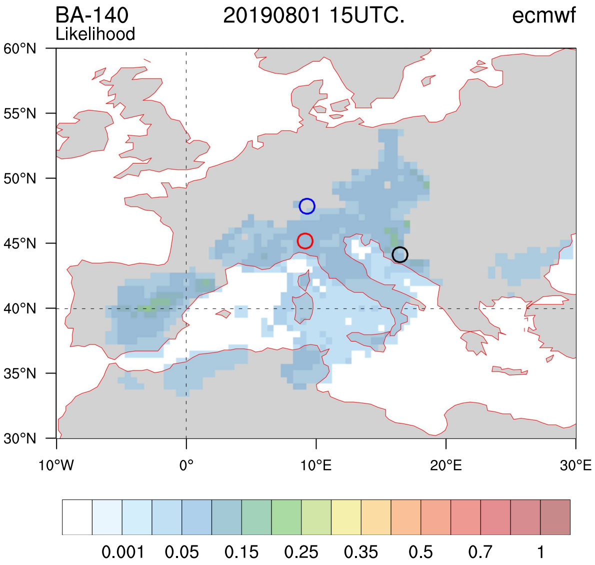
Relative Likelihood using Flexpart-ECMWF (Ba-140)



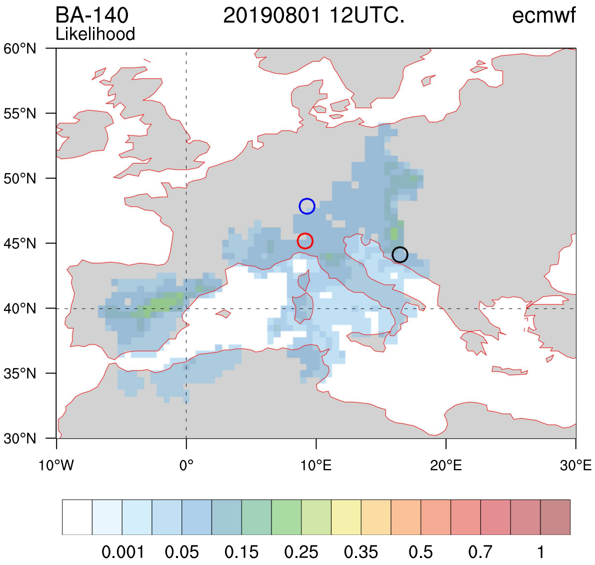
Relative Likelihood using Flexpart-ECMWF (Ba-140)



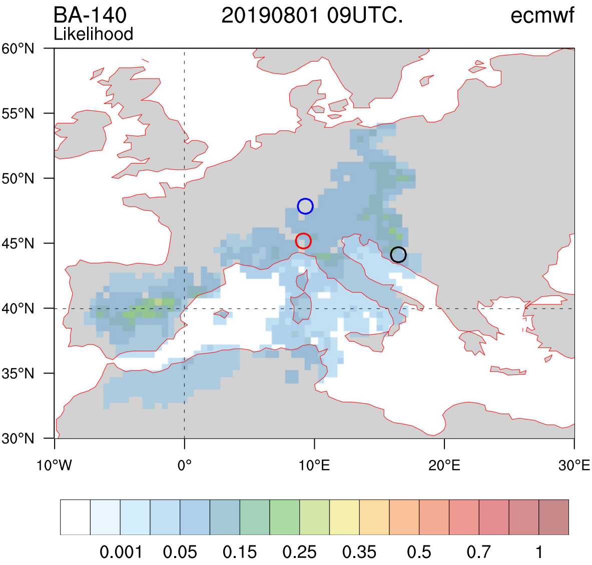
Relative Likelihood using Flexpart-ECMWF (Ba-140)



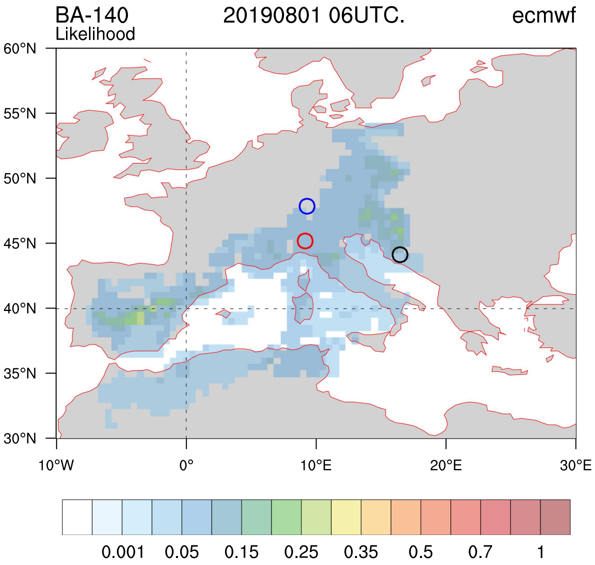
Relative Likelihood using Flexpart-ECMWF (Ba-140)



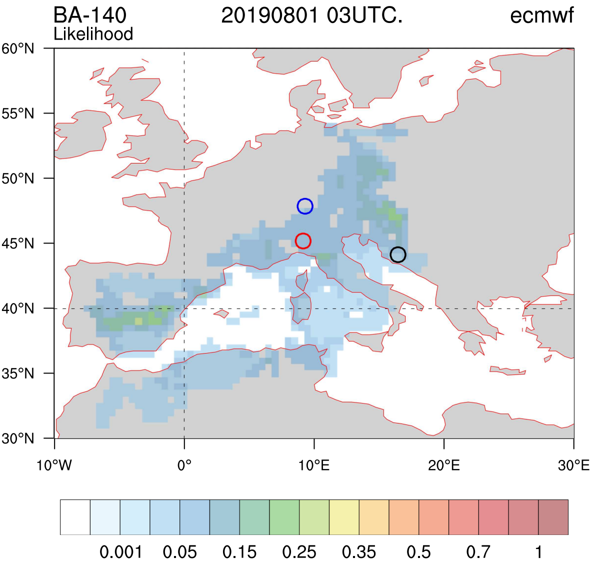
Relative Likelihood using Flexpart-ECMWF (Ba-140)



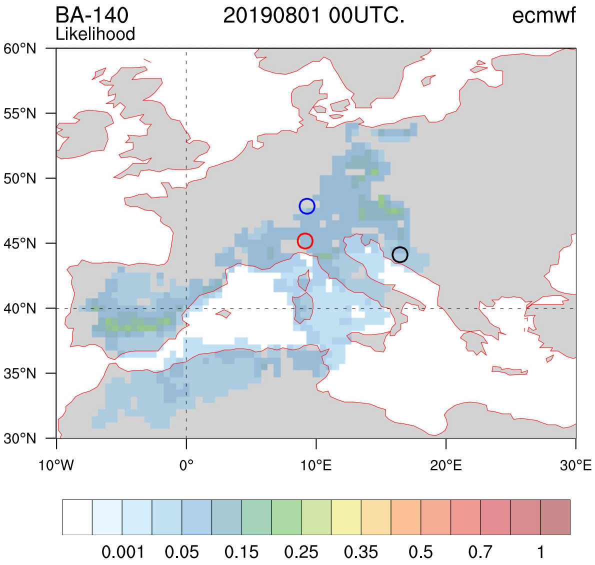
Relative Likelihood using Flexpart-ECMWF (Ba-140)



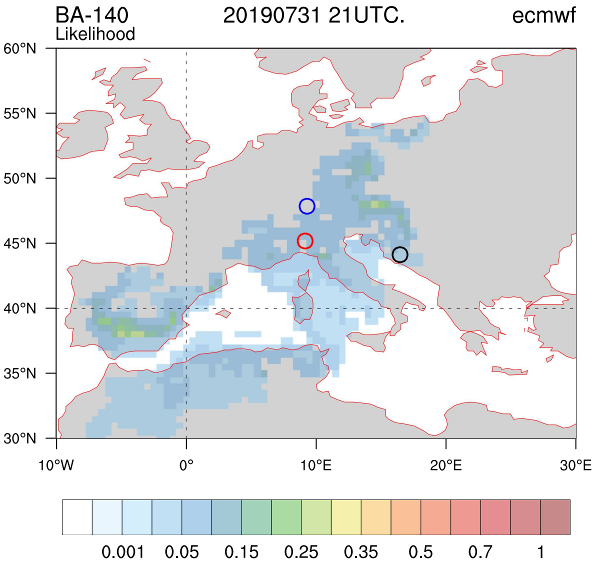
Relative Likelihood using Flexpart-ECMWF (Ba-140)



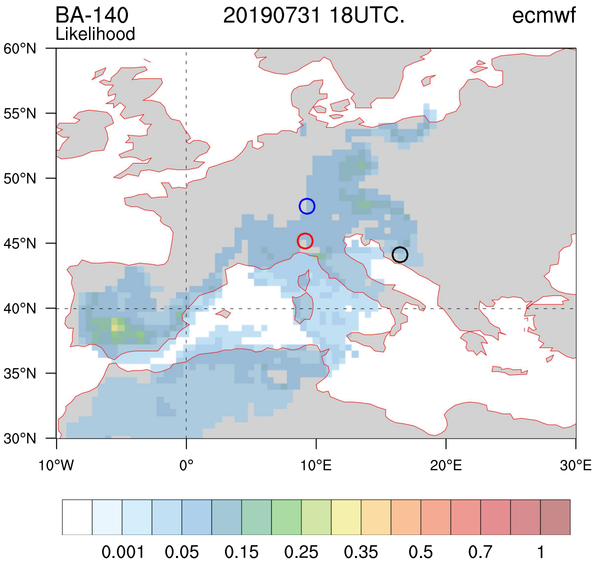
Relative Likelihood using Flexpart-ECMWF (Ba-140)



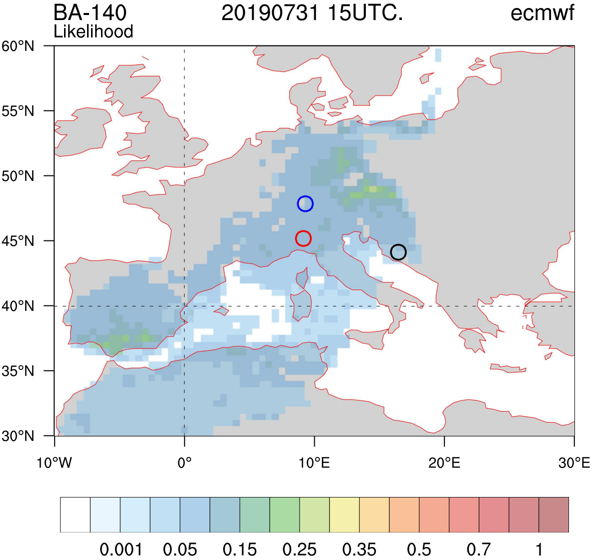
Relative Likelihood using Flexpart-ECMWF (Ba-140)



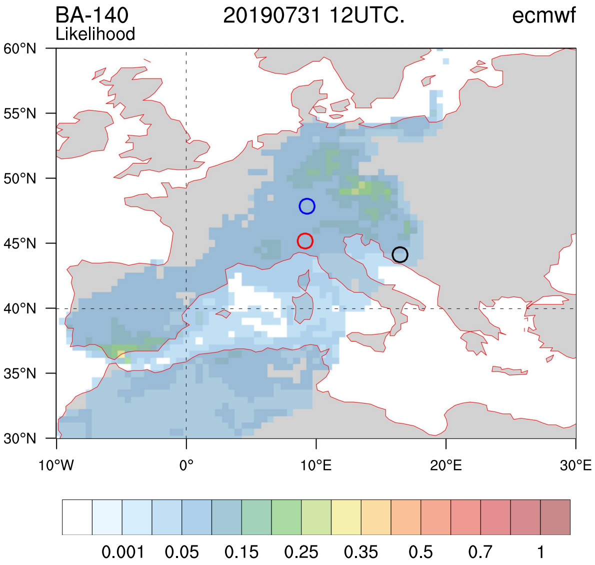
Relative Likelihood using Flexpart-ECMWF (Ba-140)



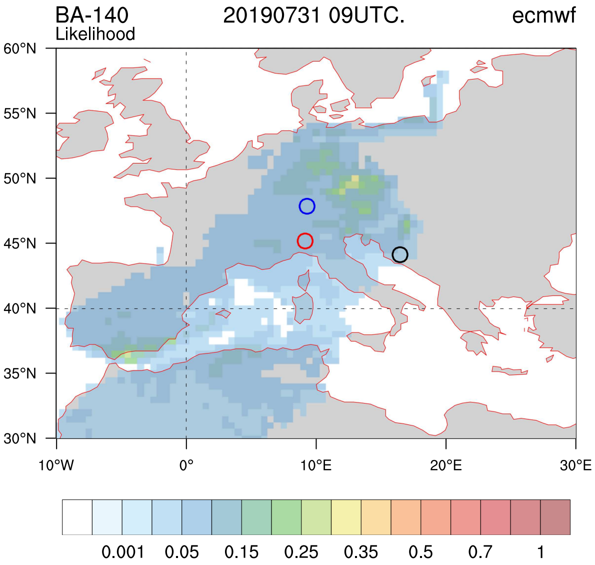
Relative Likelihood using Flexpart-ECMWF (Ba-140)



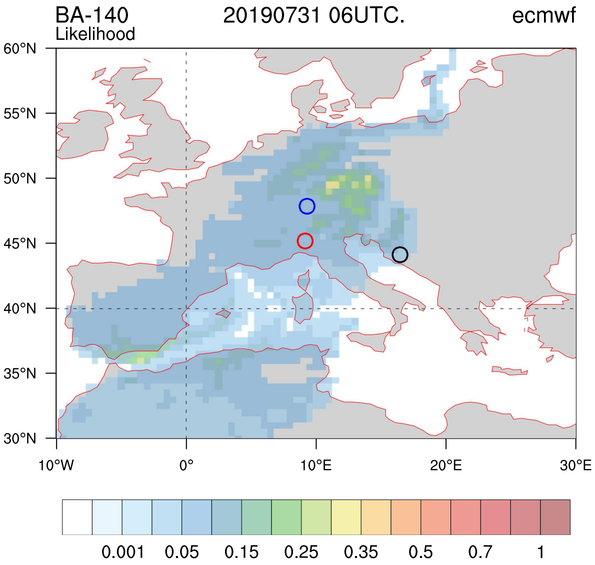
Relative Likelihood using Flexpart-ECMWF (Ba-140)



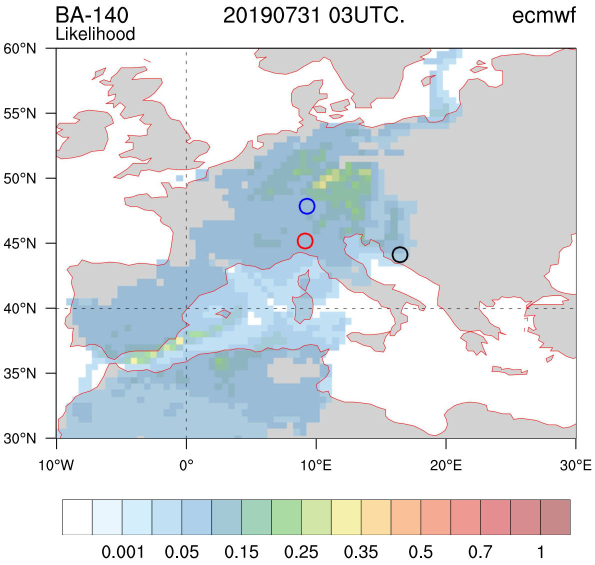
Relative Likelihood using Flexpart-ECMWF (Ba-140)



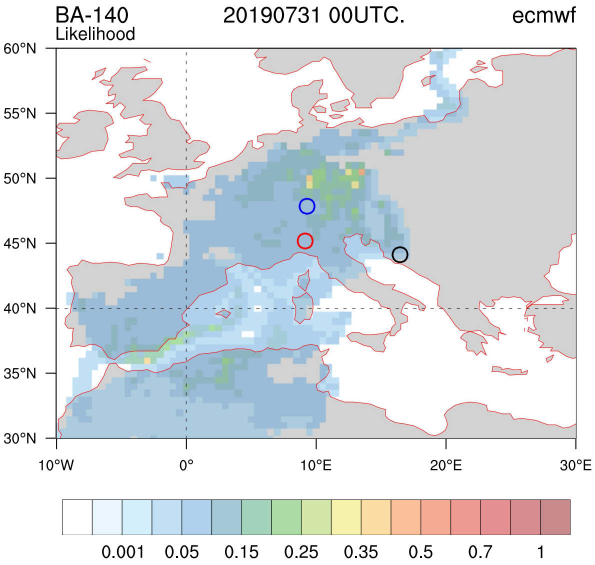
Relative Likelihood using Flexpart-ECMWF (Ba-140)



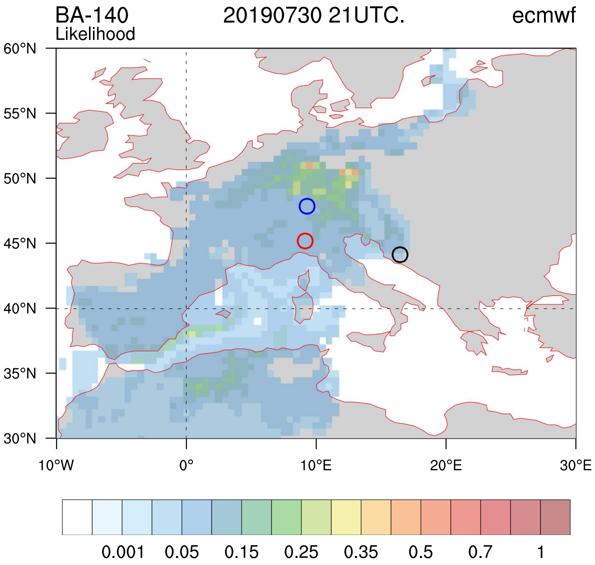
Relative Likelihood using Flexpart-ECMWF (Ba-140)



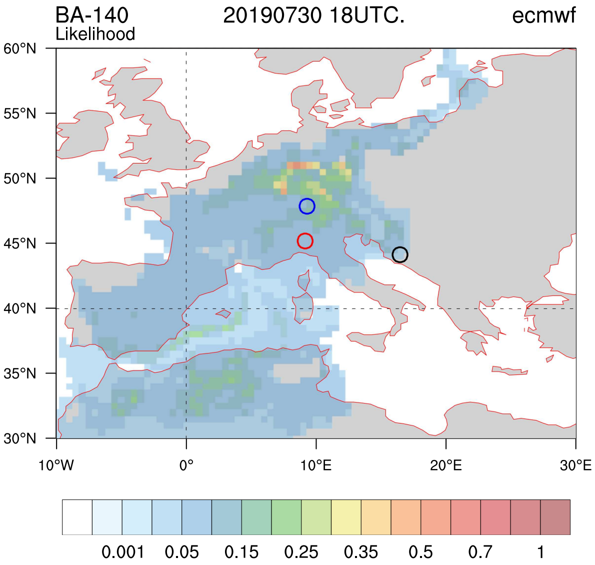
Relative Likelihood using Flexpart-ECMWF (Ba-140)



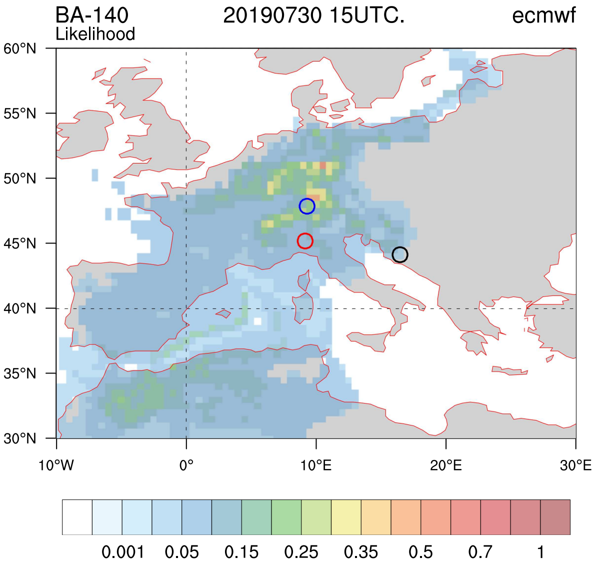
Relative Likelihood using Flexpart-ECMWF (Ba-140)



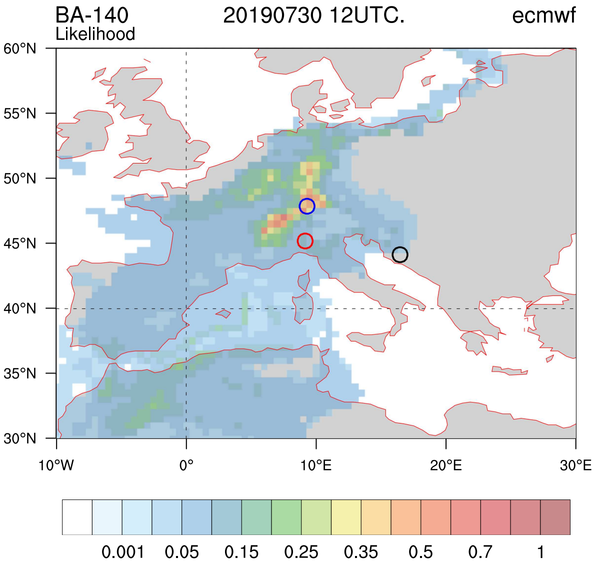
Relative Likelihood using Flexpart-ECMWF (Ba-140)



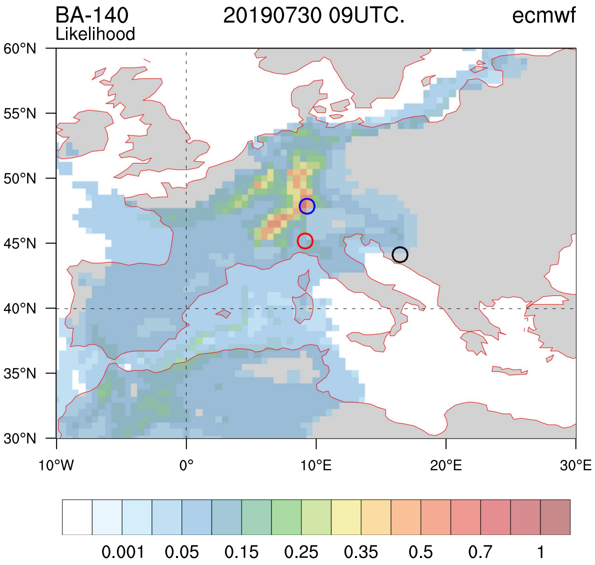
Relative Likelihood using Flexpart-ECMWF (Ba-140)



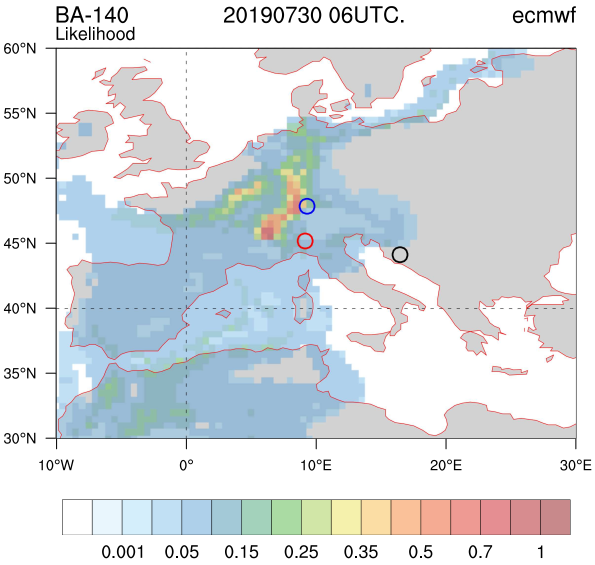
Relative Likelihood using Flexpart-ECMWF (Ba-140)



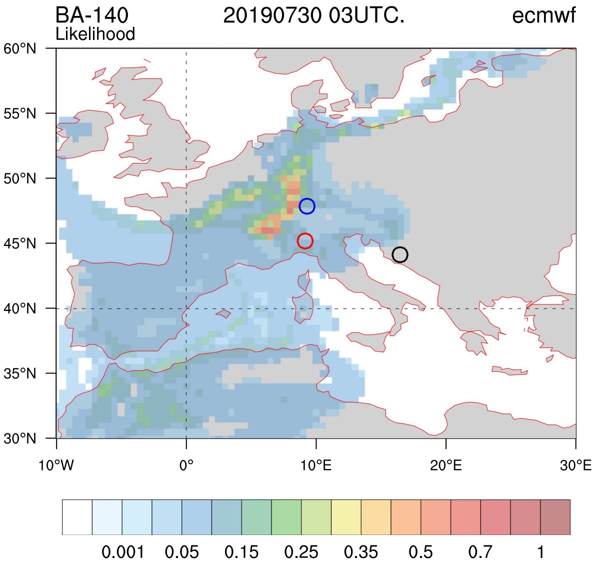
Relative Likelihood using Flexpart-ECMWF (Ba-140)



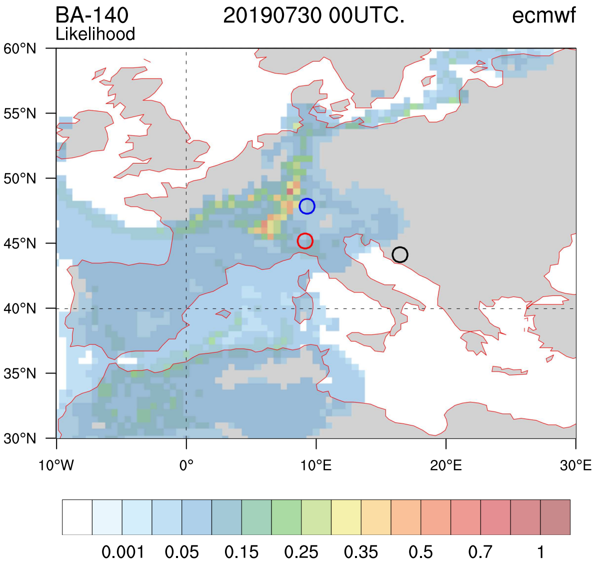
Relative Likelihood using Flexpart-ECMWF (Ba-140)



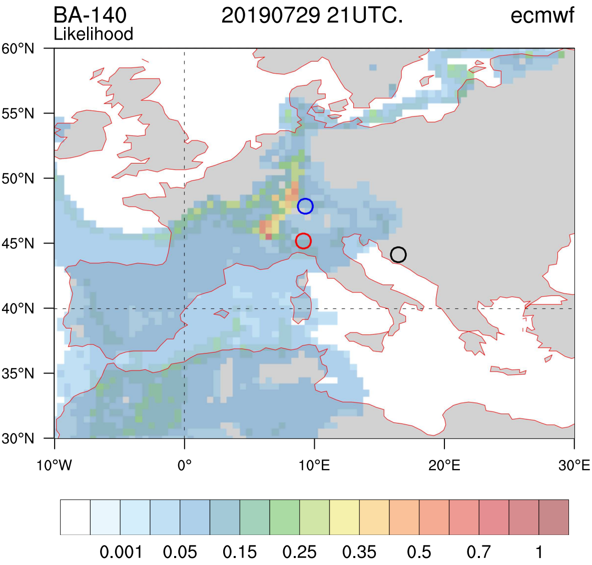
Relative Likelihood using Flexpart-ECMWF (Ba-140)



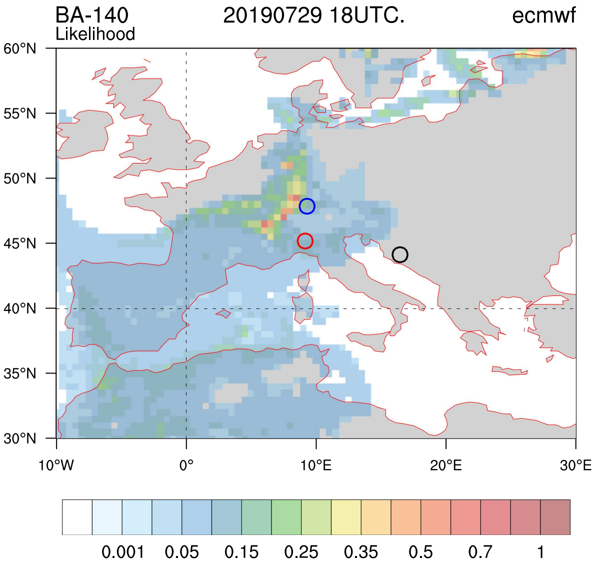
Relative Likelihood using Flexpart-ECMWF (Ba-140)



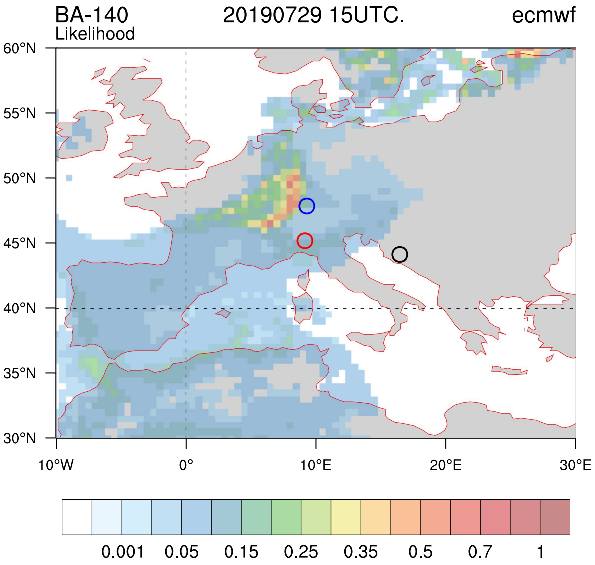
Relative Likelihood using Flexpart-ECMWF (Ba-140)



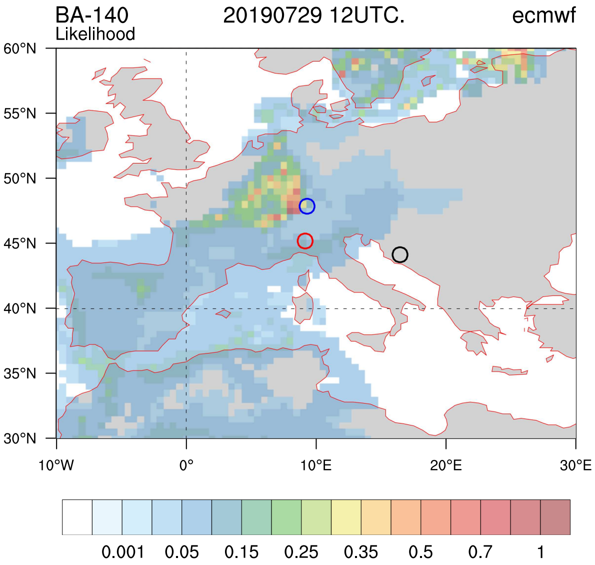
Relative Likelihood using Flexpart-ECMWF (Ba-140)



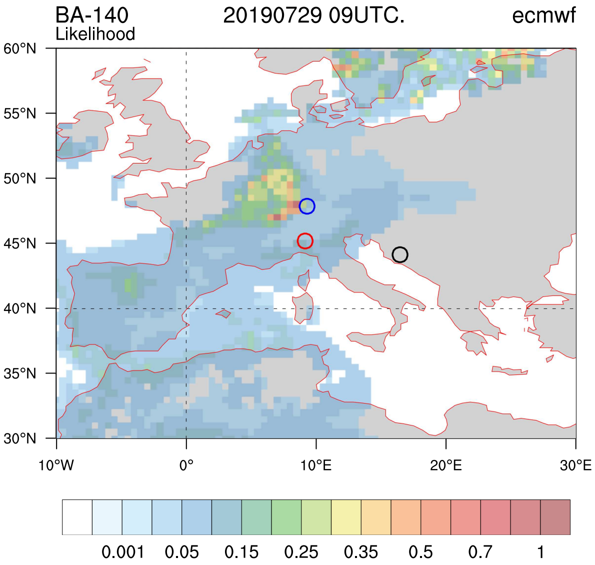
Relative Likelihood using Flexpart-ECMWF (Ba-140)



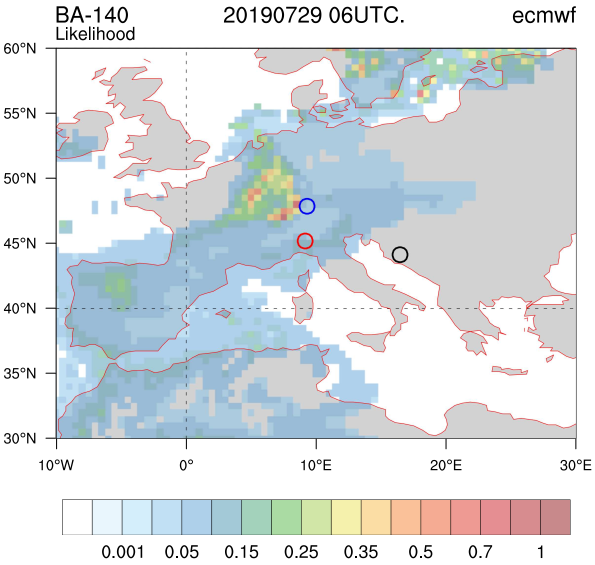
Relative Likelihood using Flexpart-ECMWF (Ba-140)



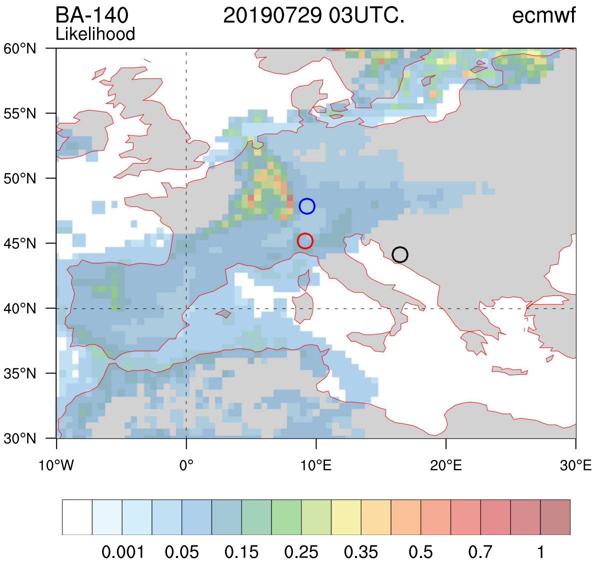
Relative Likelihood using Flexpart-ECMWF (Ba-140)



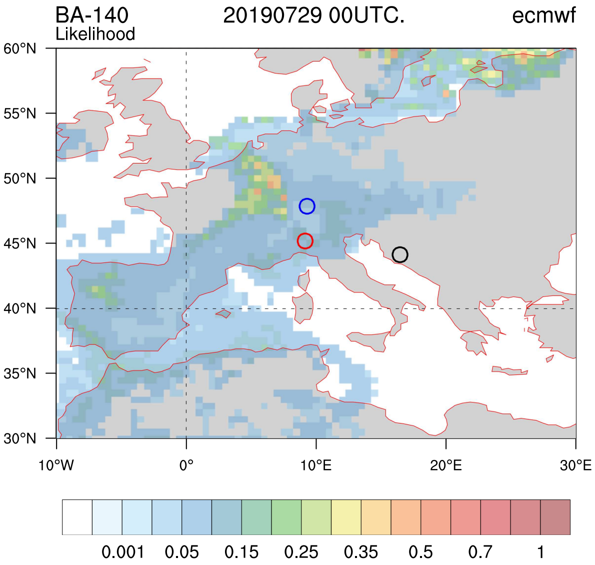
Relative Likelihood using Flexpart-ECMWF (Ba-140)



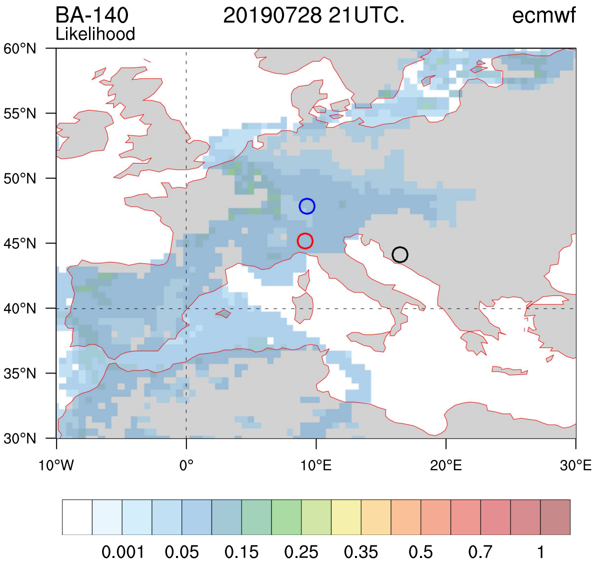
Relative Likelihood using Flexpart-ECMWF (Ba-140)



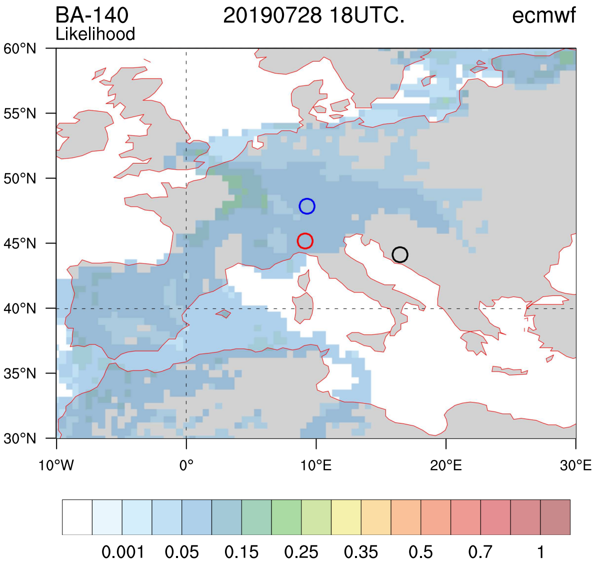
Relative Likelihood using Flexpart-ECMWF (Ba-140)



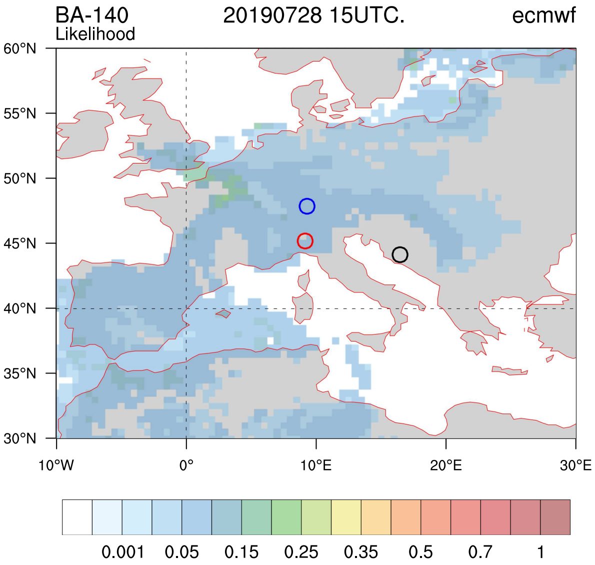
Relative Likelihood using Flexpart-ECMWF (Ba-140)



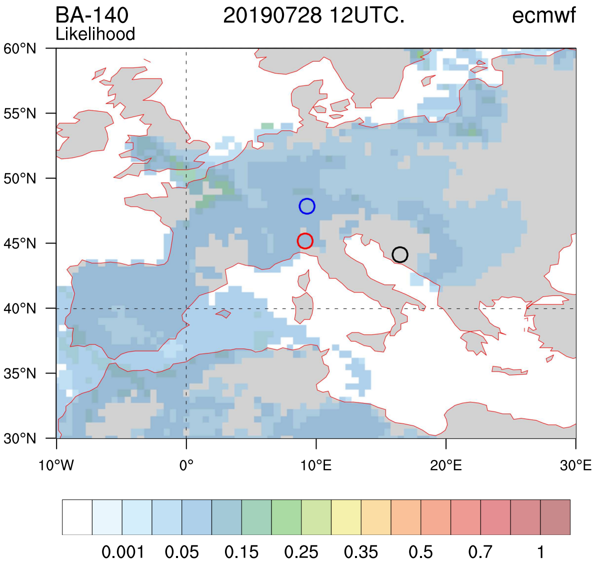
Relative Likelihood using Flexpart-ECMWF (Ba-140)



Relative Likelihood using Flexpart-ECMWF (Ba-140)



Relative Likelihood using Flexpart-ECMWF (Ba-140)



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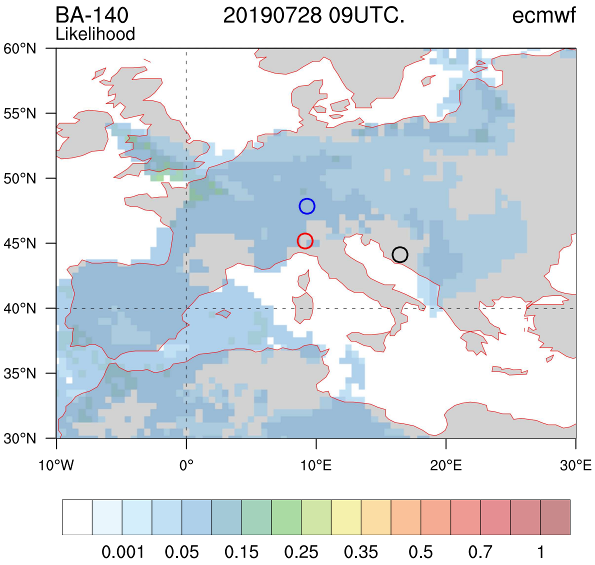

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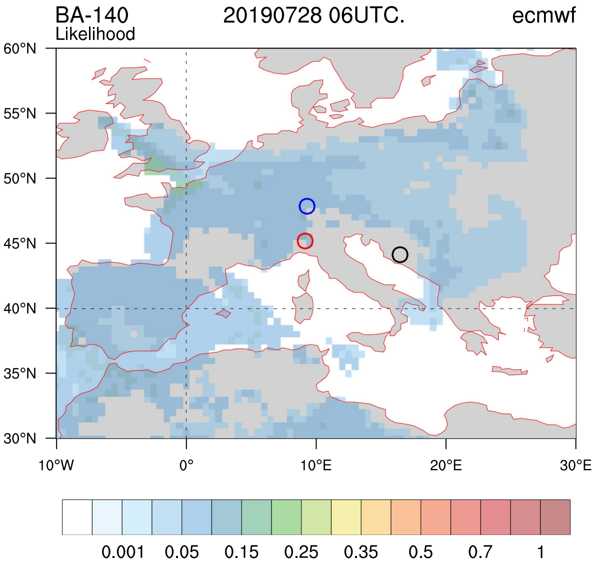

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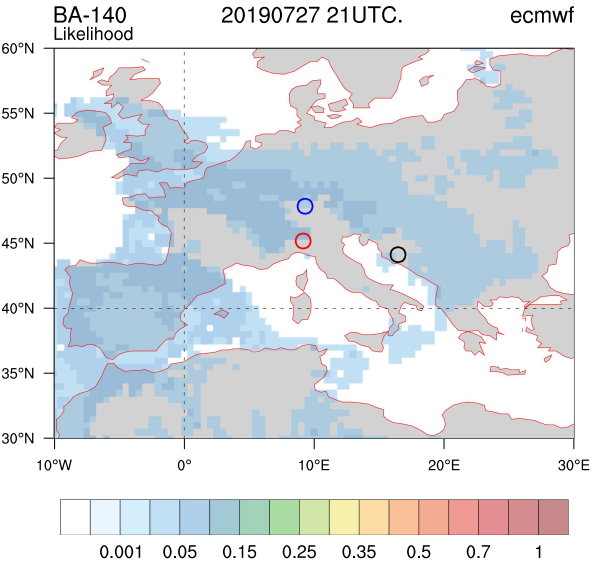

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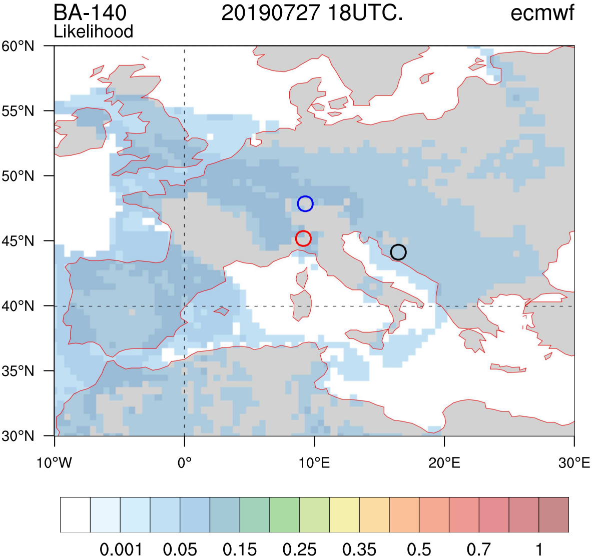

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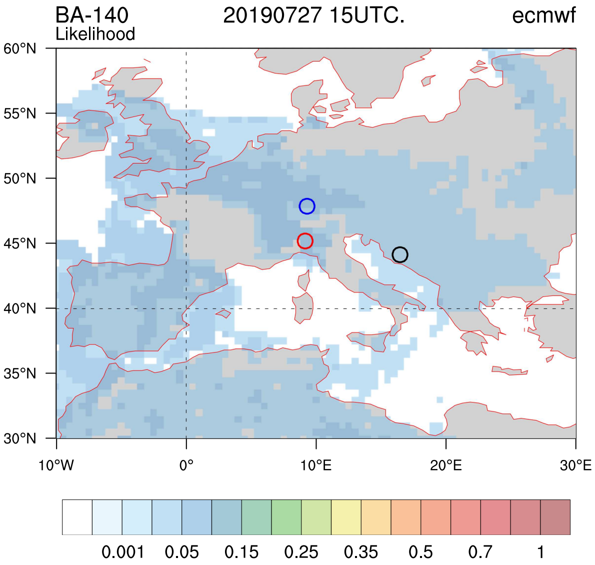

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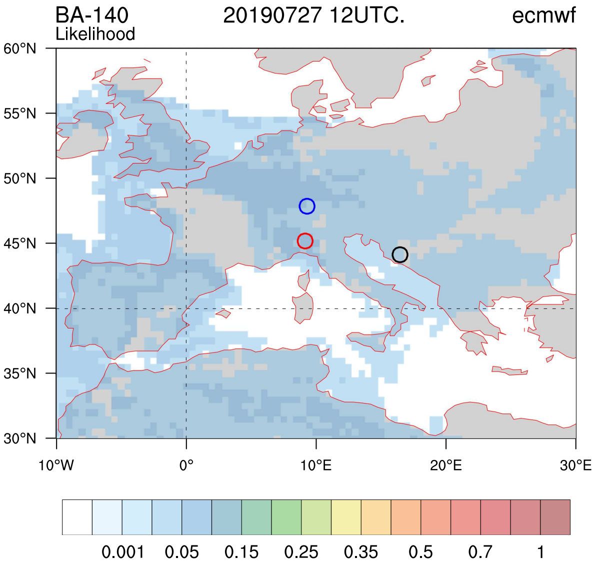

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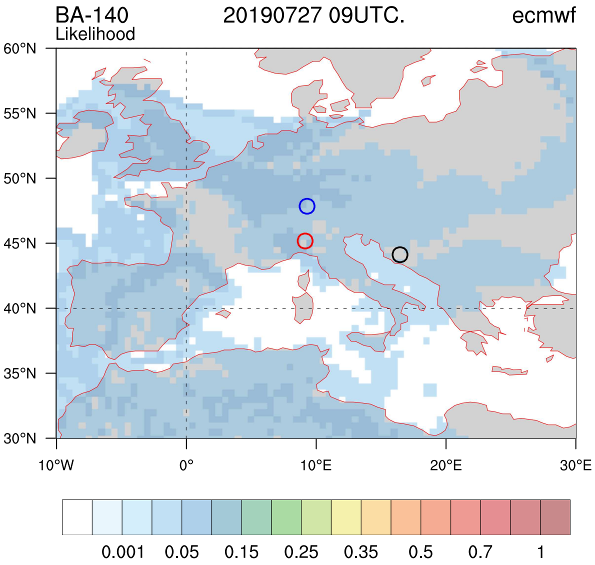

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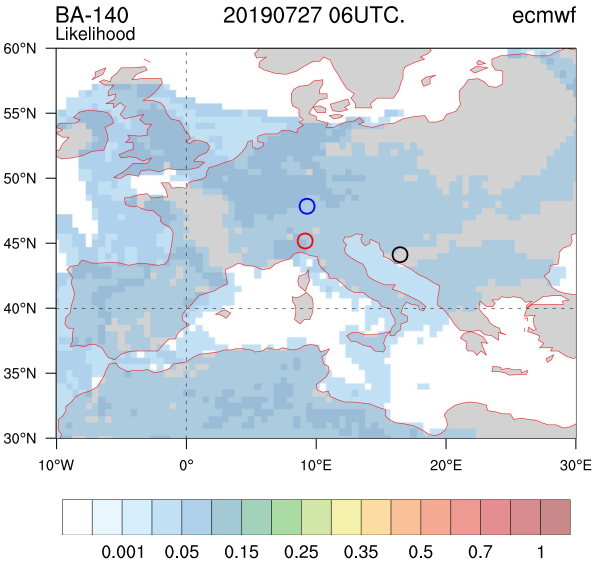

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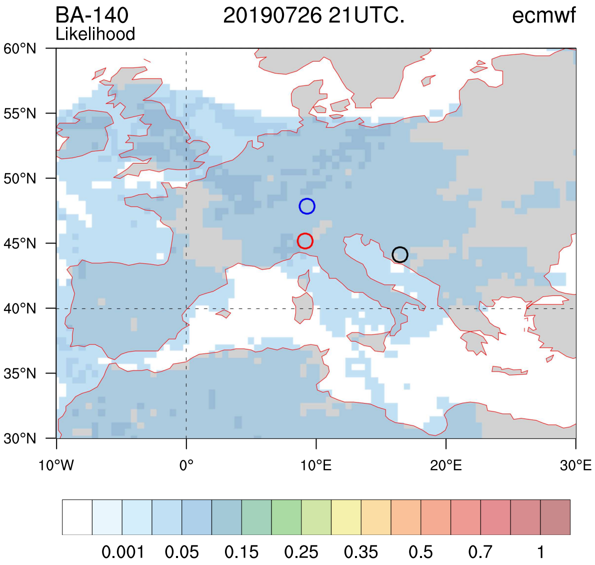

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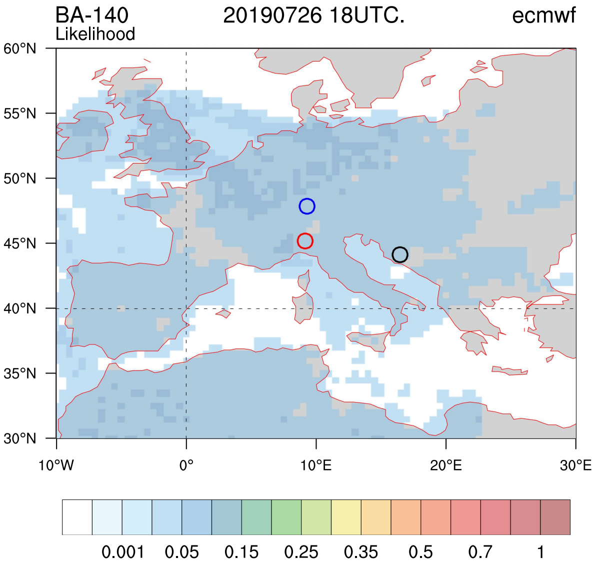

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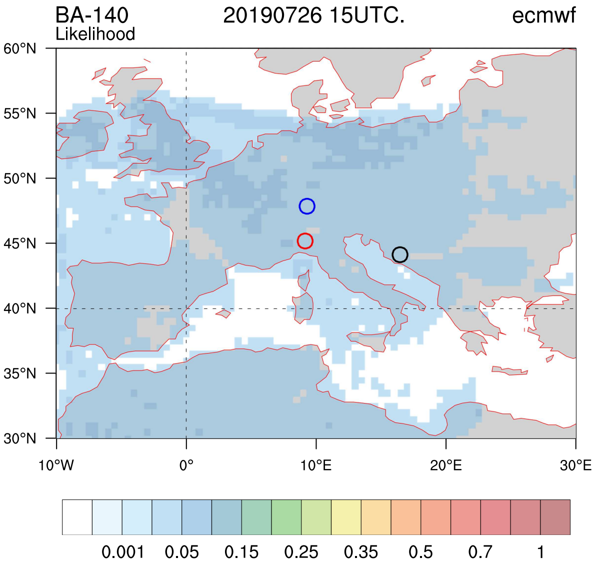

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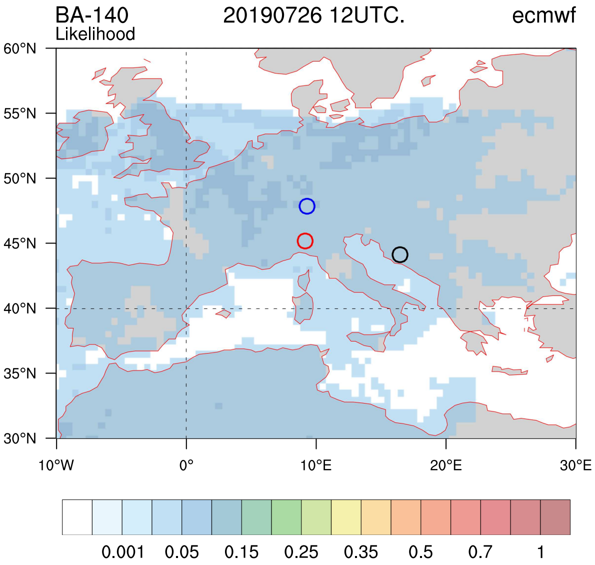

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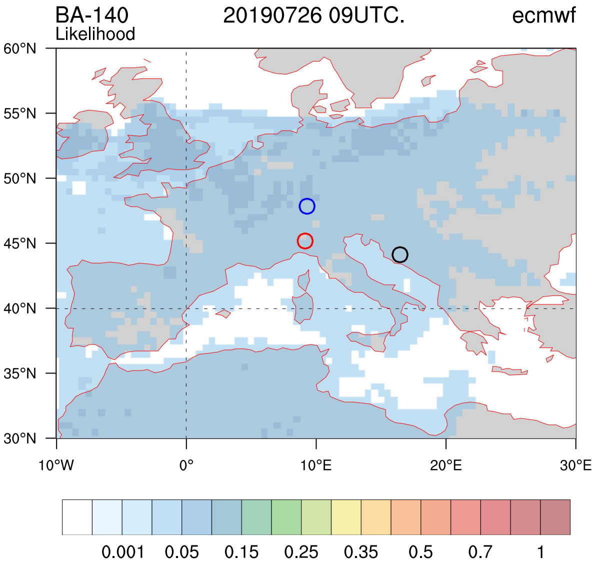

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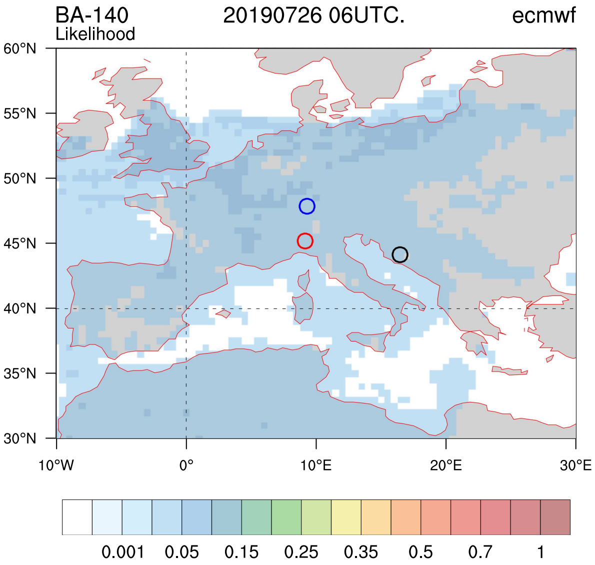

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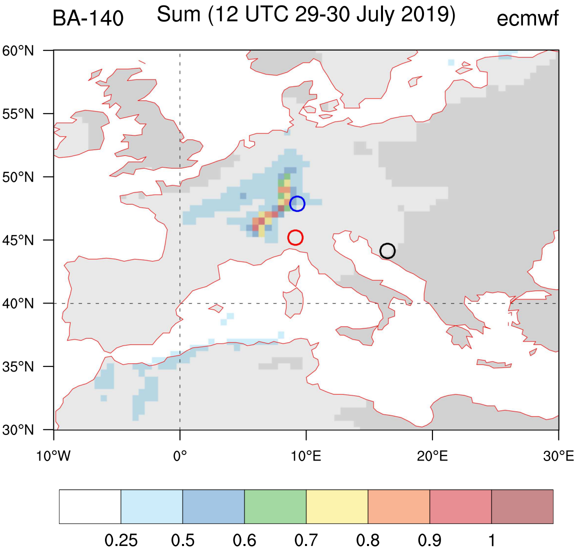
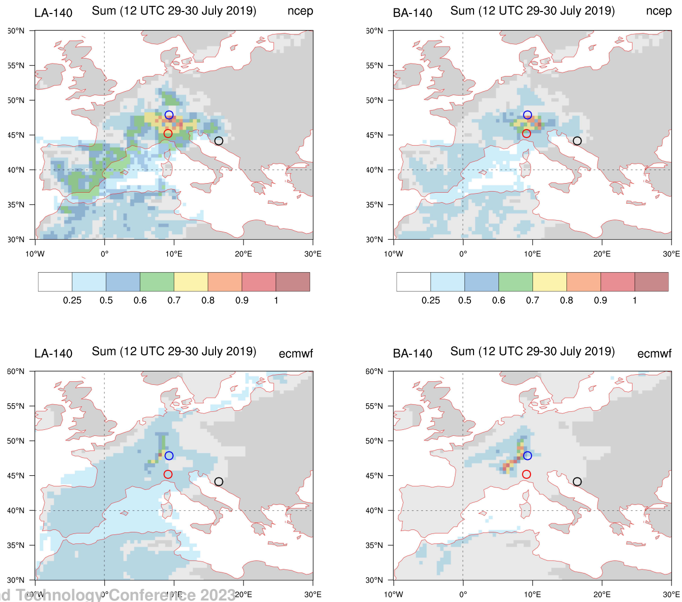
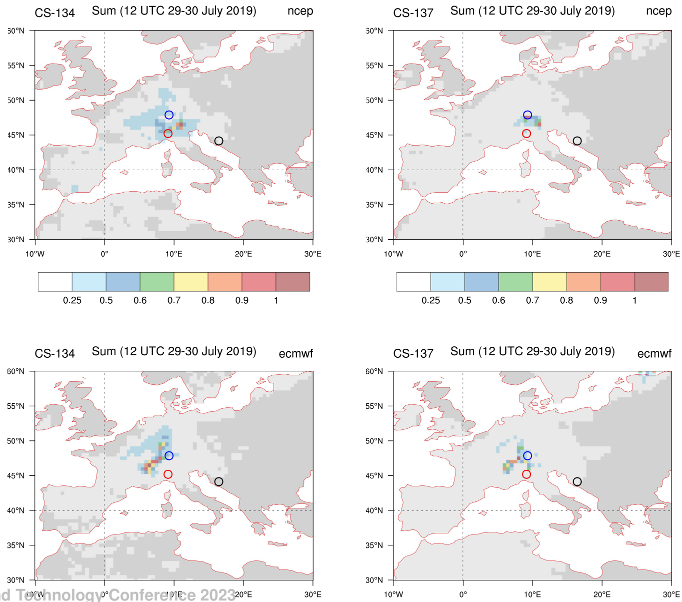


Possible Source Regions (using La-140 & Ba-140)

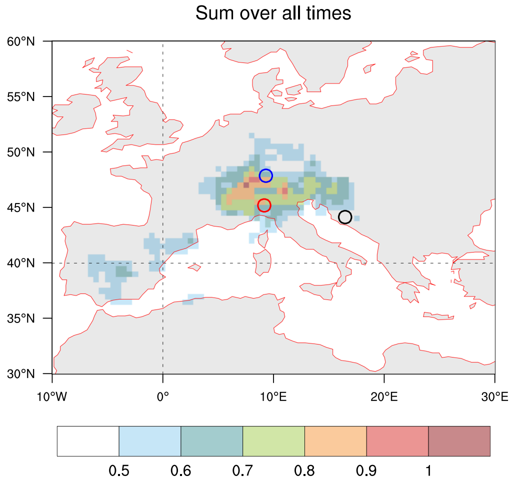


Possible Source Regions (using Cs-134 & Cs-137)



Ensemble Mean Likelihood (All Nuclides & Modoles)

Under assumption that all nuclides are release from the same sources, we can calculate the ensemble mean using all nuclides and models.



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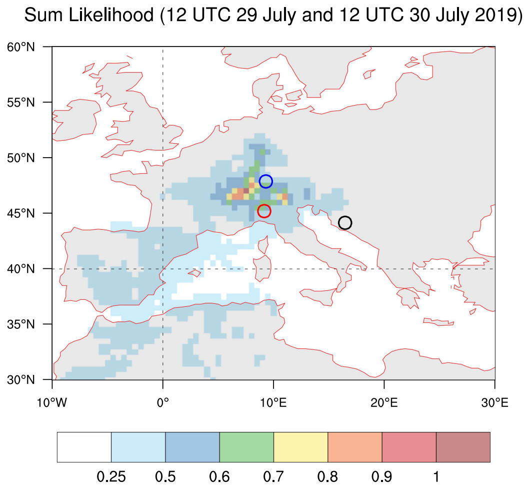
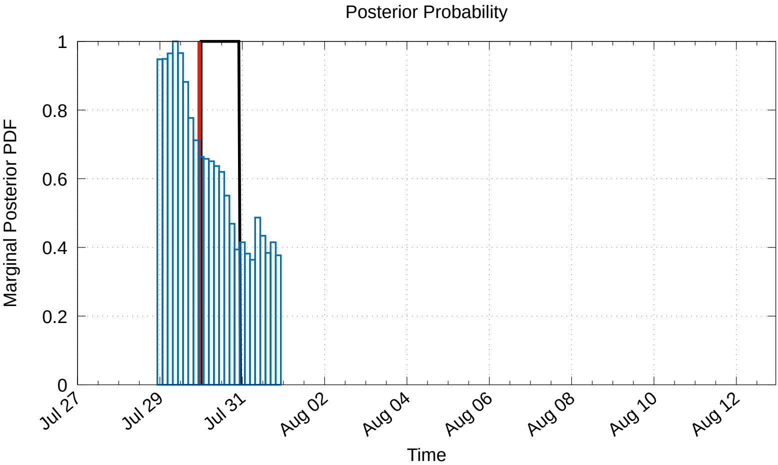
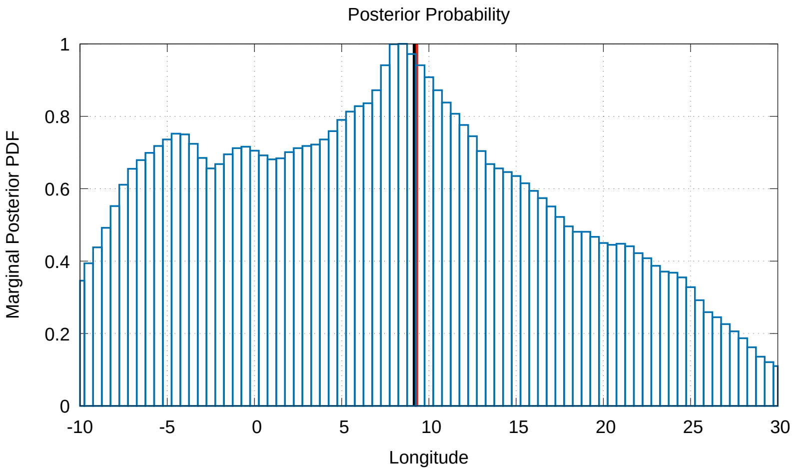


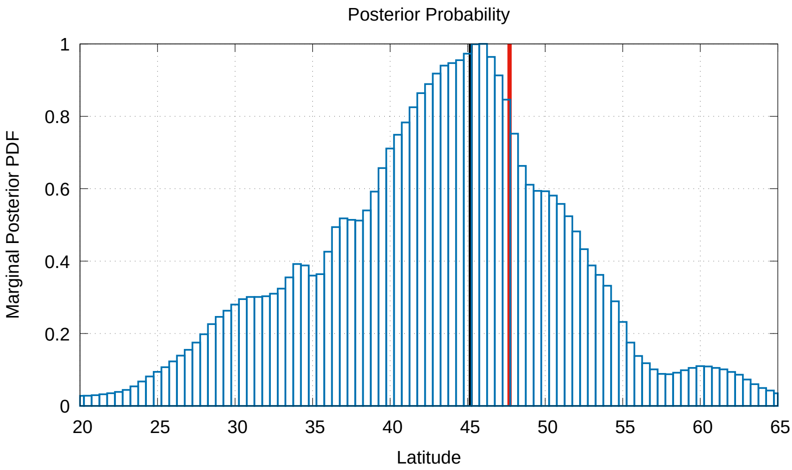
Marginal Temporal PDF



Marginal Longitudinal PDF

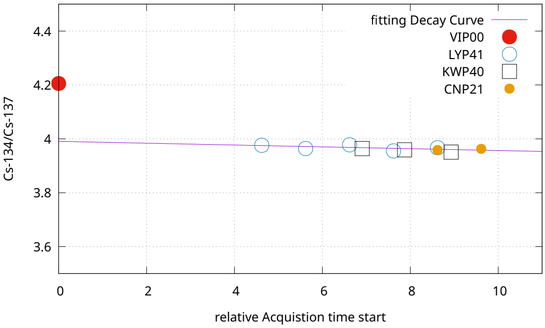


Marginal Meridional PDF



Isotopic Ratios

Cs-134/Cs-137 Activity Ratio



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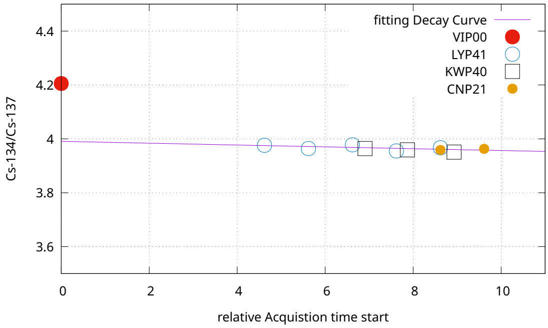

- The Cs-134/Cs-137 Activity Ratio for stations:LYP41, KWP40, and CNP21 are between 3.9506 and 3.9777, while that for VIP00 is 4.205.

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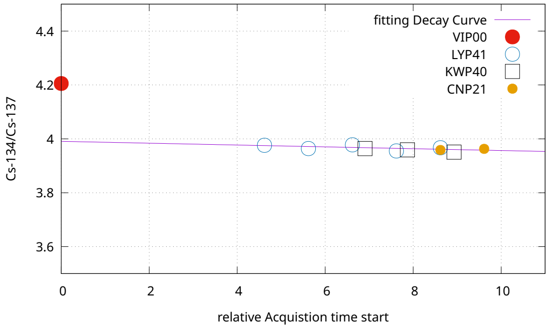

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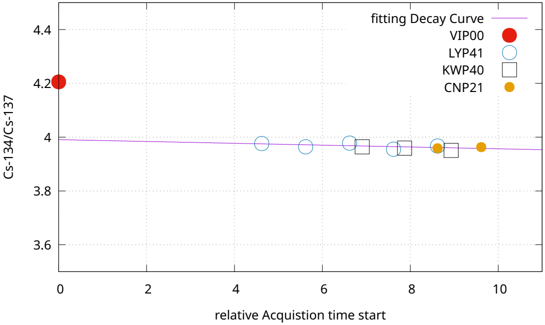

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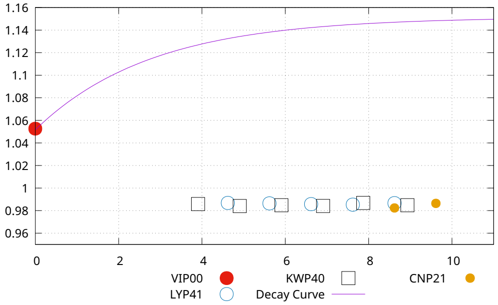
La-140/Ba-140 Activity Ratio



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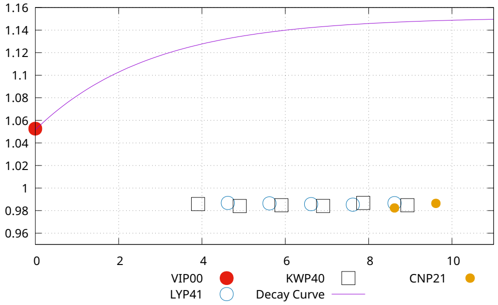

- La-140/Ba-140 Ratio for stations:LYP41, KWP40, and CNP21 are between 0.982 and 0.987, while that for VIP00 is 1.053.

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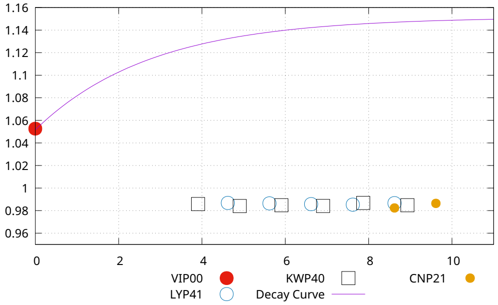

- La-140/Ba-140 Ratio for stations:LYP41, KWP40, and CNP21 are between 0.982 and 0.987, while that for VIP00 is 1.053.
- The difference of La-140/Ba-140 ratio for VIP00 from other stations suggests that its detections are from different source than the source causes the detections in LYP41, KWP40, and CNP21.
- By assuming that source related to VIP00 detections is nuclear test, the zero release time will 6.83 days (27 July).

Conclusion

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- The radionuclide isotopic ratios analysis shows that there are two different sources at least.
- The Seismic and infrasound analysis techniques determine three shock waves in the area of interest. Two purely infrasound and one seismic event. Only the North pure Seismic location (47.7° N, 9.29° E) is consistent with the ATM inverse modeling.

Conclusion -II

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- While the adopted approach assumes that one source, it can be used to determine multi-sources (two in the current case) according to the spatial distribution of the likelihood function.

Thank You