Dear Editor,

Thank you for providing us with the additional reviews on our revised manuscript. We appreciate the feedback from the reviewers. We have addressed all of their concerns in our revised manuscript and have provided detailed responses to their comments below.

Thank you for your time and consideration.

Referee #1:

General comments:

1) The article is centered on the consequences of hypothetical Barakah powerplant accidents in Qatar only, and I'm wondering if the paper is within the scope of the ACP journal in its present form. The results of this paper made me wonder why focusing on Qatar and the Barakah powerplant in the first place, while the results are relevant for a larger region. The authors justify their analysis because new nuclear facilities are planned in the Middle East/North Africa region. Why not extending the analysis to the region covered by the WRF domain used in the paper for instance? Then, the Barakah power plant is not the only one in the region. The Bushehr powerplant in Iran, the second active nuclear power plant in the region if I'm not mistaken, could also be used in the FLEXPART simulations. This powerplant is located within the WRF simulation domain used by the authors, and it should not be too much of a problem to add the calculations from hypothetical accidents from this powerplant.

- ✓ **We would like to thank the reviewer for their valuable input regarding the inclusion of Bushehr nuclear power plant in the updated version. We have taken the suggestion into consideration, and we have implemented the emission from Bushehr NPP for a one-year period using the ERA5-WRF dataset, which has been fed into FLEXPART-WRF. In the subsection 3.4, we have included simulations of this sensitivity test, along with three other sensitivity runs that consider different release conditions, to also account for the points raised by Referee 2. These simulations are then compared to the control run.**

  Lines 79-84:

“Moreover, we investigated the sensitivity of our simulations to different turbulence schemes under convective conditions, as well as variations in the vertical profile, temporal profile, and point of emission. Specifically, we examined two different vertical profiles, two points of emission, and two temporal profiles of emissions, with one main variant and one secondary variant for each variation. The main variants were used in most of the manuscript, while the secondary variants were used in a small sensitivity test to evaluate the impact of these variations on our results.”

Lines 229-232:

“The third sensitivity test, designated as the Release Location Sensitivity Test (RLST), is conducted by releasing radionuclides from the Bushehr nuclear power plant (Bu-NPP) and investigating the impact of source-receptor position on the transport of radionuclides, particularly in relation to seasonal variations in atmospheric patterns.”

Lines 476-494:

“The RLST run investigates the effect of changing the emission point from B-NPP to Bu-NPP. As expected, this change leads to significant differences in the amount of radioactive materials transported to Qatar. In general, the results show that the occurrence of a nuclear accident in Bu-NPP will be associated with the transfer of less radioactive materials to Qatar, which is the case almost throughout the year. The upper quartile of the full-year median of ^{131}I concentrations and ^{137}Cs deposition in RLST simulations a decrease by a factor of approximately 2.2 and more than 3, respectively. The seasonal variability of the transport and deposition of radioactive materials from Bu-NPP is a noteworthy aspect to consider in our analysis. the simulations of the RLST run show that ^{137}Cs deposition is more prominent in winter and spring compared to other seasons. Moreover, the upper quartile value of ^{131}I concentrations from Bu-NPP exceeds that of B-NPP by more than 80% in spring which is in contrast to the simulations of other seasons.”

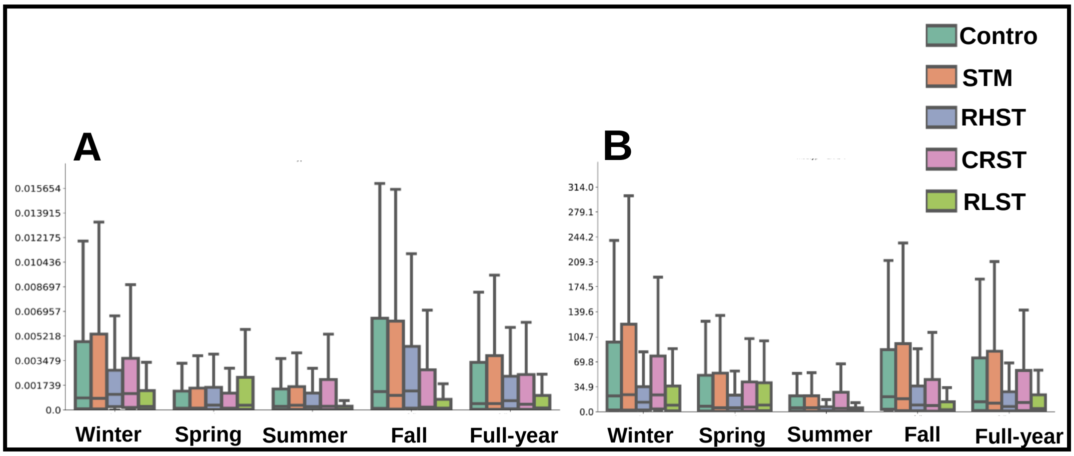


Figure 1 A: These boxplots depict the **96-hour integrated simulations of** ^{131}I concentrations (**ng m**$^{-3}$) based on ERA5-WRF inputs. The simulations include control runs shown in cyan, and sensitivity runs with the skewed turbulence model (STM) in brown, modified release height from the 100-300m agl to the 100-700m agl (RHST) in blue, increased release duration from 24 to 96 hours (CRST) in pink, and a change in the release location from Barakah to Bushehr nuclear power plant (RLST) in green. B: These boxplots show the same for total deposition of 137Cs (**ng m**$^{-2}$). The quartiles of the simulations are depicted by the box borders, while the whiskers illustrate the range between 1.5 times the interquartile range above the upper quartile and below the lower quartile.

Lines 618-619:

"Changing the emission point from B-NPP to Bushehr-NPP leads to less transfer of radioactive materials to Qatar."

2) Then the authors could just show the total deposition from both powerplants, with contours that would represent the contribution from Barakah or Bushehr within the WRF domain. That way, the authors would treat the potential of nuclear accidents within a larger region, and from the two active power plants of the region. In that case, the paper would better fit in the ACP scope. The authors could still present a zoom on the Qatar country.

✓ **The main objective of our study is to investigate the impact of meteorological inputs and simulation codes on the transport of particles, along with their seasonal and diurnal variations. We now also include the Bushehr-NPP as suggested by the referee, focusing on Qatar as the main catchment area for the impact of any single point of release independently. Further investigating multiple emission and receptor points in a wide range would indeed be a worthwhile topic for future studies.**

3) The validation of the met models could still be limited to the stations in Qatar. the validation of the met models against observations need to be improved. We don't know what kind of instruments generated those observations, and how the stations are covering Qatar. I doubt that the 140 stations have the same quality standards in terms of observation. The authors should select the stations with the best instruments, and for specific part of the domain (shore, inland, etc.).

- ✓ **We have incorporated information regarding the quality of the meteorological data used in the study into the revised text.**

  Lines 198-202:

  "The GSOD data is subject to a rigorous two-tier quality control (QC) process (https://www.ncei.noaa.gov/data/global-summary-of-the-day/doc/readme.txt, last accessed: May 5, 2023). The first level entails the application of meticulous automated QC procedures that effectively purge the raw data of random errors. The second level of QC is performed to create daily summaries. However, there is still a slight likelihood of unknown errors being present within the GSOD dataset."

- ✓ **We would like to emphasize that we utilized the majority of available meteorological observations to evaluate the inputs of atmospheric transport models at regional scales, which may also impact the quality of simulations over the catchment of interest. In addition, we did not find specific criteria or information for distinguishing the quality of stations in coastal areas or in any other regions. And we also did not find data susceptibilities in the used observations. While we acknowledge that there may be variability in the quality of meteorological data across the study area, we relied on the quality measurement techniques employed by the data producer, a widely recognized authority in the field.**
- ✓ **Regarding the comprison of the met models with the stations in Qatar,**

Lines 270-276:

"In order to deepen our understanding of the model performance at the primary emission source and receptors in Qatar, we conducted a similar analysis on 12 stations within the area encompassing the B-NPP and the state of Qatar (S-5, -6, and -7). Although some variations are noted, such as an improvement in the correlations between simulated and observed wind speed, the overall patterns of performance for the input datasets over this region remain consistent with those identified earlier. Based on these findings, we infer that the FNL- and ERA5-WRF (downscaled) datasets exhibit a better correlation with observations. However, this comes at the expense of increased error and bias values when compared to the FNL and GFS datasets."

4) The statistical analysis should be modified. For temperature, the authors could compare mean diurnal profiles for each season. For precipitation, the authors could present maps of

seasonal mean precipitation observed by the stations, and simulated by the models, instead of comparing the precipitation for each site.

- ✓ **Due to limited access to hourly-resolved data, we are unable to compare the diurnal distribution of temperature for each season, as stated in the previous version of the manuscript (line). To address the referee's comment, we produced seasonal boxplots for precipitation, wind speed, and temperature (available in supplementary S4 and S7). This analysis contributes to the discussion of the potential underestimation or overestimation of these meteorological factors in our simulations.**

5) Figure 2, 12 and 13 are hard to interpret. The scatterplots are impossible to read (the authors should use a pdf or something else).

- ✓ **Done. The quality of these images has been improved.**

6) I'm wondering if those plots should be directly in the supplement materials.

- ✓ **We have moved Figure 2, along with other figures related to the evaluation of meteorological inputs, to the supplementary (S2-7). Figures 12 and 13 (Figures 11 and 12 in the new version) were retained in the main body due to their importance in the discussion.**

7) Figure 5 is hardly used in the paper, and could be put directly in the supplement.

- ✓ **This figure is necessary for discussing the relationship between particle ages and the deposition of Cs137 (deposition speed) in the study area. Hence, we have opted to retain Figure 4 (previously Figure 5) in the revised manuscript.**

Reviewer 2:

EMISSION SCENARIO

1) The selection of the emission scenario limits the applicability of the study. Taking an envelope from Fukushima accident (different reactor type and thermal power) and also constant emission for 24 hours at a constant height is too limited to draw sound conclusions and, specially, to be used in the formulation of preparedness plans. It is clear that the emission height and the shape of the release (some hours with more release, others smaller, others at higher levels etc) significantly affects the outcome of the simulations and the transport and deposition patterns. I would suggest that there is a preliminary work to try to identify those realistic scenarios that provide the right starting point. There is no need to have many of such scenarios but a worst case (low probability high impact) and a more

probable (more probable with less impact) should be approached. In this way the starting point of all the study would be more realistic and sustain better the conclusions.

- ✓ **We would like to thank the referee for the suggestion. While the analysis of release conditions was not the focus of our study, this point is valuable in improving our work. In light of the computational load required, we conducted three sensitivity runs using ERA5-WRF (with FLEXPART-WRF), examining the impact of changes in height, duration, and point of emissions on the simulations. These results are discussed in a new subsection 3.4. We note that the investigation of other possible release conditions could be explored further in a separate study. More details of these changes are presented below**

  Lines 79-84: "Moreover, we investigated the sensitivity of our simulations to different turbulence schemes under convective conditions, while considering the effect of variations in the vertical profile, temporal profile, and point of emission. Specifically, we examined two different vertical profiles, two points of emission, and two temporal profiles of emissions, with one main variant and one secondary variant for each variation. The main variants were used in most of the manuscript, while the secondary variants were used in a small sensitivity test to evaluate the impact of these variations on our results."

  Lines 446-484:

3.4 Sensitivity of simulations to turbulence scheme, emission profiles, and emission location

"This section focuses on investigating the sensitivity of radionuclide simulations using ERA5-WRF inputs through four distinct sensitivity runs. Each of these runs explores specific variations in model setup, such as turbulence scheme, emission duration, emission height, and emission location. To establish a baseline, all sensitivity runs are compared against the control run that utilizes GTM as the turbulence scheme and emission characteristics that are explained in the subsection in 2.3. Results show that the use of the skewed turbulence model (STM) **leads to a more frequent occurrence of high ^{131}I concentrations and ^{137}Cs deposition within Qatar (Fig. 10). The upper quartiles of the STM-based ^{131}I concentrations are around 10% and 16% higher than those of the GTM-based, control simulations in winter and year-round, respectively. The upper quartiles of STM-based deposition simulations also increase by 23% and 12% over the same periods in comparison to GTM-based, control deposition simulations. As noted previously, the**

elevation in ^{131}I concentrations and ^{137}Cs deposition based on STM is not surprising, given that STM promotes more downdrafts than updrafts. This pattern leads to higher surface concentrations and deposition in the proximity of pollution sources Pisso et al. (2019)**.**

In the CRST run with the extension of the release duration from 24 hours to 96 hours, a decrease in the amount of ^{131}I concentrations and ^{137}Cs deposition compared to the control run is observed, except for ^{131}I concentrations in spring. This result is to be expected, as the particles released at the end of the 96-hour simulation period have less time to reach the study area, resulting in a considerable decrease in the concentration/deposition of radioactive materials. For instance, this implementation leads to a reduction of approximately 75% and 45% (170% and 140%) of the upper quartiles of ^{131}I concentrations (^{137}Cs deposition) in winter and fall, compared to the control run.

Morino et al. (2011) used the Eulerian chemical transport model, CMAQ, to investigate the sensitivity of ^{131}I and ^{137}Cs deposition to the vertical profile of emissions from the Fukushima nuclear accident. They concluded that the fractions of ^{131}I and ^{137}Cs deposition were insensitive to the change in emission height. In contrast, our simulations indicate that an increase in emission height leads to a significant decrease in ^{131}I concentrations and ^{137}Cs deposition, except in the summer. Specifically, the upper quartile of ^{131}I concentrations in the RHST run decreases by approximately 25% and 130% in the winter and fall, respectively, compared to the control run. Similarly, the increase in emission height is associated with a decrease in ^{137}Cs deposition, with the upper quartile of simulations showing a considerable decrease of up to 65% in RHST simulations compared to the control implementation during the fall. The severity of deposition reduction lessens during the winter and spring seasons, and is instead accompanied by a slight increase during the summer. It seems that increasing the release height results in particle entry into the upper layers of the atmosphere, especially during the cold months when regional and larger-scale atmospheric patterns are more prevalent. This results in the transportation of the majority of radionuclides to more distant locations, leading to a decrease in ^{131}I concentrations and ^{137}Cs deposition.

The RLST run investigates the effect of changing the emission point from B-NPP to Bu-NPP. As expected, this change leads to significant differences in the amount of radioactive materials transported to Qatar. In general, the results show that the occurrence of a

nuclear accident in Bu-NPP will be associated with the transfer of less radioactive materials to Qatar, which is the case almost throughout the year. The upper quartile of the full-year median of ^{131}I concentrations and ^{137}Cs deposition in RLST simulations a decrease by a factor of approximately 2.2 and more than 3, respectively. The seasonal variability of the transport and deposition of radioactive materials from Bu-NPP is a noteworthy aspect to consider in our analysis. the simulations of the RLST run show that ^{137}Cs deposition is more prominent in winter and spring compared to other seasons. Moreover, the upper quartile value of ^{131}I concentrations from Bu-NPP exceeds that of B-NPP by more than 80% in spring which is in contrast to the simulations of other seasons."

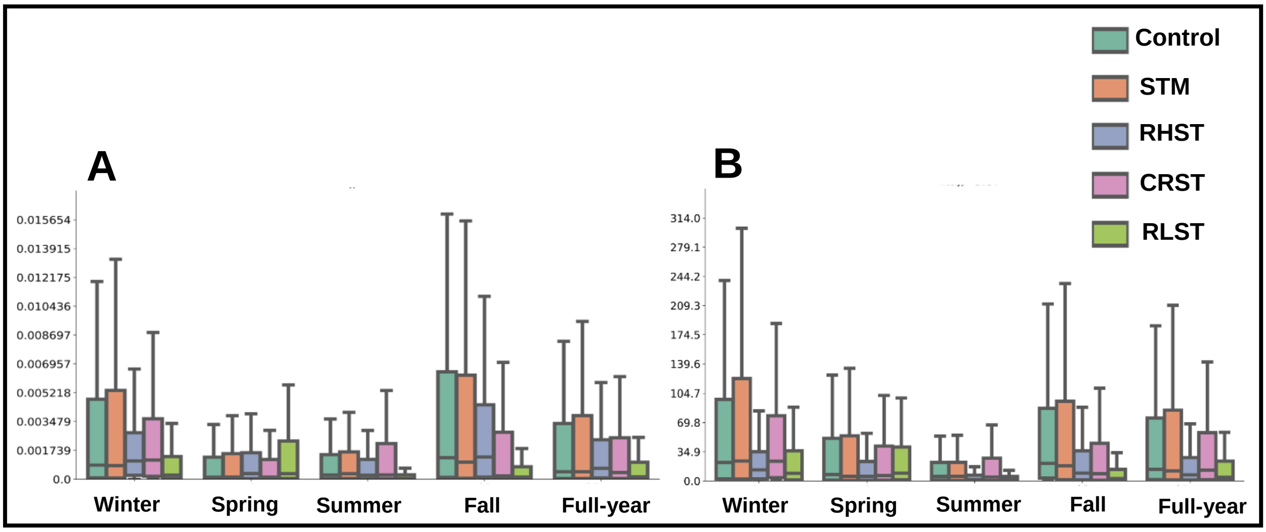


Figure 2 A: These boxplots depict the **96-hour integrated simulations of** ^{131}I concentrations (**ng m**$^{-3}$) based on ERA5-WRF inputs. The simulations include control runs shown in cyan, and sensitivity runs with the skewed turbulence model (STM) in brown, modified release height from the 100-300m agl to the 100-700m agl (RHST) in blue, increased release duration from 24 to 96 hours (CRST) in pink, and a change in the release location from Barakah to Bushehr nuclear power plant (RLST) in green. B: These boxplots show the same for total deposition of 137Cs (**ng m**$^{-2}$). The quartiles of the simulations are depicted by the box borders, while the whiskers illustrate the range between 1.5 times the interquartile range above the upper quartile and below the lower quartile. "

Lines 613-623:

"Sensitivity of simulations to model parameters and emission characteristics:

We analyzed the sensitivity of radionuclide simulations based on ERA5-WRF dataset to four variations of model setup. Results show that the use of the skewed turbulence model (STM) leads to a more frequent occurrence of high ^{131}I concentrations and ^{137}Cs deposition within Qatar. Increasing emission height leads to a significant decrease in ^{131}I concentrations and ^{137}Cs deposition, particularly during the cold period. Extending the emission duration causes a decrease in the amount of ^{131}I concentrations and ^{137}Cs deposition. Changing the emission point from B-NPP to

Bushehr-NPP leads to less transfer of radioactive materials to Qatar. The significant changes observed in the simulations during the sensitivity analysis can be attributed to the promotion of more downdrafts than updrafts with the STM, particle entry into the upper layers of the atmosphere with increasing emission height, less time for particles to reach the study area with extended emission duration, and the seasonal differences in the atmospheric transport of radionuclides with changing emission point. "

Referee #2:

DOSIMETRIC DISCUSSION

2) In order to talk about relative contributions, there is no need to go towards the actual dose calculations and could be worked out with the concentrations and depositions. The moment the doses are provided the consequences are thought and this is a very sensitive issue. Should a dosimetric approach be desired, then it is important to have an improved emission scenario, as explained in the former section. This should be also followed by a better description of the approximations taken to calculate doses (semi-infinite loud, dosimetric dose coefficients etc) and compare them with the regulatory thresholds. In this way, the work would be indeed valuable for preparedness plans and understanding and definition of potential mitigation measures preparations according to regions and seasons.

✓ **Indeed, the scope and the primary focus of our study was not on dosimetry, but we received a request from one of the reviewers in a previous round to pay more attention to this topic in our analysis. To avoid any unnecessary sensitivity regarding our results, we now present the simulations in the form of concentrations (ng/m3) and deposition (ng/m2) in the revised version, as suggested. Additionally, we conducted three sensitivity runs to investigate the effects of changes in emission scenarios on our simulations, independent of dosimetry considerations.**

In addition, please consider the following remarks:

3) The work presents and ensemble of 4 members two of which are of similar nature. Therefore it is hard to argue this is a real ensemble. Please be so kind to mention it as a mini-ensemble.

✓ **Done. All occurrences of ensemble in the manuscript changed to mini-ensemble.**

4) Why was not ERA5 used directly to drive the simulations? Why was not the ECMWF forecasted fields used to drive the simulations?

- ✓ **We have now added consideration and discussion for the reason we did not use ERA5 directly for FLEXPART:**

  Lines 183-188:

  Though we devoted efforts to incorporate ERA5 reanalysis data directly as inputs for FLEXPART, we were hindered by technical difficulties encountered with the data preprocessor tool, flex_extract, thereby impeding our ability to do so. While we were working to resolve the technical issues with the developers, a solution was not readily available during the writing and revision of this manuscript. We have indirectly employed ERA5 reanalysis data from the Research Data Archive (RDA) by incorporating it into the WRF model and subsequently into the FLEXPART-WRF.

- ✓ **We refer the referee/reader to an older communication of the primary author with the FLEXPART developers regarding the problem with the retrieval of ERA5 using Flex_extract. The details of our communication can be found in the following link: https://www.flexpart.eu/ticket/300.**

5) The former two questions relate to the potential applicability of the study: do we want a tool and system to prepare or do we want a system to respond? if the second, then the computational speed is key and one could argue about the need of having the downscaling approach. It would be good to have further discussion on this.

   - ✓ **We see the scope of our study as creating awareness and preparing for a potential nuclear accident, rather than responding to a real occurrence. Specifically, we aimed to identify areas and time periods with a higher risk of radionuclide deposition/concentrations and to guide preparedness, mitigation, and adaptation plans. Our results can also assist in selecting suitable locations for setting up radioactivity measurement stations to monitor any unusual changes in the values of concentrations and settlements of radioactive materials. Additionally, the simulations of the member based of GFS forecast can still provide insights for an ongoing nuclear accident. We agree that the degree of uncertainty associated with these results is likely to be higher compared to the output ensembles (lines 86-90).**

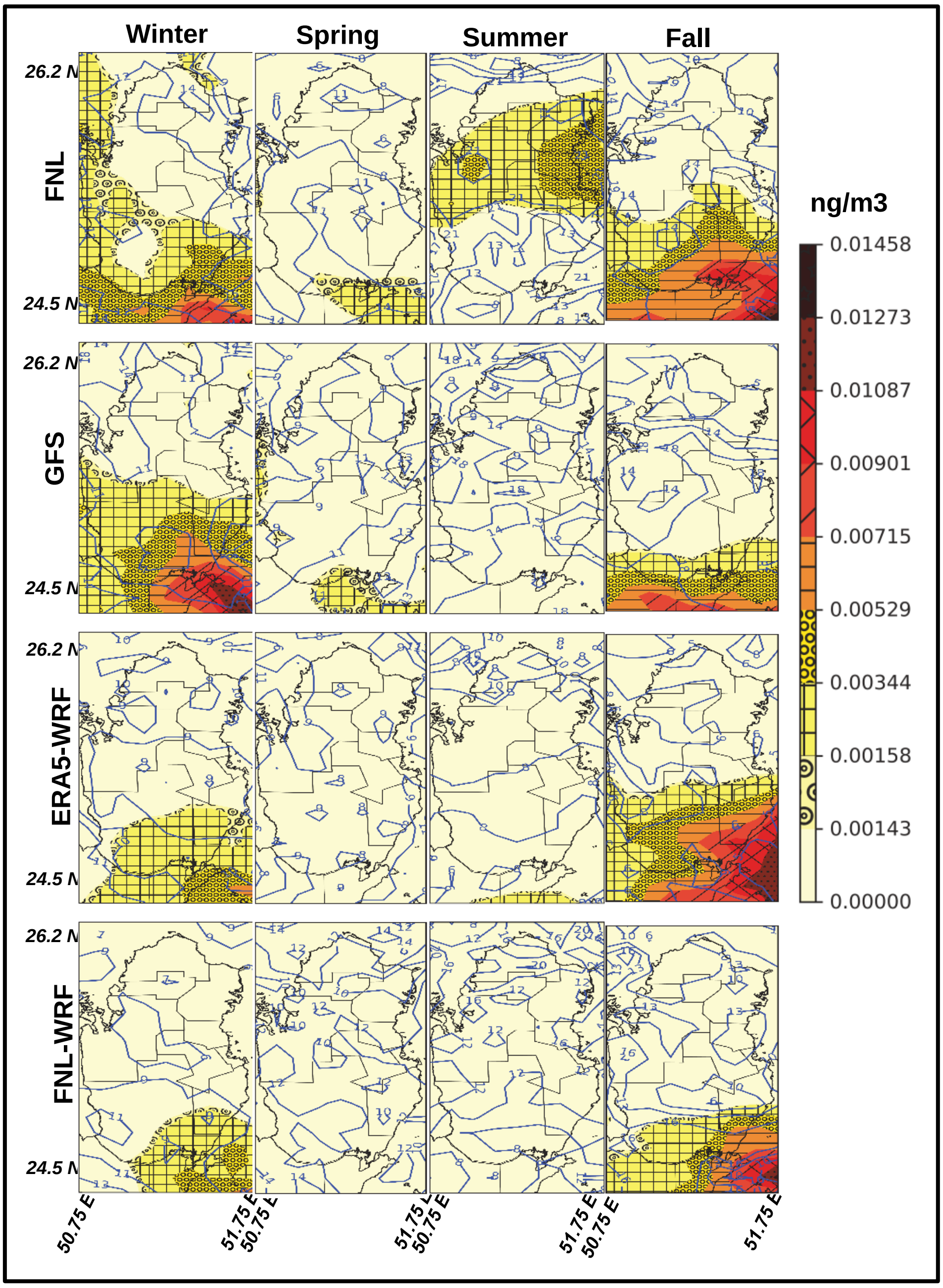
6) It would be interesting to see whether a higher resolved WRF would make a difference.

   - ✓ **In an attempt to comply with one of the editor's suggestions in the previous round of revision, we made an effort to utilize FNL inputs downscaled to 4 and 2 km resolutions. Despite our best efforts, we encountered technical difficulties that**

hindered our ability to reconcile the simulation output with the observations. Consequently, we made a decision to omit the 4km and 2km sensitivity analysis from this paper and defer it to future research.

7) Figures 6,7,8 (specially 6) have a color scale hard to read and to differentiate the isolines.

- ✓ **Done. In order to enhance the visual clarity and facilitate interpretation of the figures, we have incorporated a hash pattern into them. As an example, please refer to the figure below:**



✓

- ✓ **Figure 3 Seasonal median of 96-hour integrated ^{131}I concentrations ($^{131}I^{intg_conc_seas}$). The contour lines (in local time, hours of the day) depict the seasonal median of the Lagrangian particle release time coinciding with the maximum $^{131}I^{intg\_conc\_seas}$ found in each 96-hour run.**

8) If the aim is to prepare the tools, materials and approaches for the preparedness plans, it would be interesting to see whether other NPPs in the region (the one operating or planned to be operative in the future) are

- ✓ **We have followed up on this comment, also considering a similar request by the first reviewer. We have now added an investigation of the concentrations and deposition of radioactive materials from the Bushehr nuclear power plant in the region. For further details, we refer to our response to Reviewer 1.**

MORINO, Y., OHARA, T. & NISHIZAWA, M. 2011. Atmospheric behavior, deposition, and budget of radioactive materials from the Fukushima Daiichi nuclear power plant in March 2011. *Geophysical research letters,* 38.

PISSO, I., SOLLUM, E., GRYTHE, H., KRISTIANSEN, N. I., CASSIANI, M., ECKHARDT, S., ARNOLD, D., MORTON, D., THOMPSON, R. L. & GROOT ZWAAFTINK, C. D. 2019. The Lagrangian particle dispersion model FLEXPART version 10.4. *Geoscientific Model Development,* 12**,** 4955-4997.