We thank both anonymous referees for their insightful, positive and constructive comments. We reply to these comments point-by-point in the following, including the full original reviews in green, our response in black and planned updates to the manuscript in blue.

Referee#1:

This manuscript presents a method for propagating local sea-ice concentration uncertainties to hemispheric sea-ice area estimates over the passive microwave record. The study makes three clear contributions that advance our understanding of observational uncertainty in sea ice.

1. The work provides a dynamic, daily and monthly uncertainty product that is self-contained within a single satellite record (OSI SAF) and does not depend on the availability or selection of other products. This fills a gap in the community's toolkit for assessing the significance of new SIA extremes and for climate model evaluation.

2. Secondly, the authors identify the Marginal Ice Zone as the primary physical driver of the seasonality of SIA uncertainty.

3. Finally, the comparison between the single-product stochastic uncertainty and the inter-product spread provides compelling evidence that the large differences between existing SIA trend estimates are dominated by systematic methodological choices in the processing chains, rather than noise. The implication that extending the time series alone will not resolve trend uncertainties is an important message for both the observational and modelling communities.

The study is both timely and important. Reliable uncertainty estimates for SIA are needed for climate assessments and model evaluation, but little is known about these uncertainties over the full satellite record. By separating the stochastic and systematic components, the authors provide appropriate uncertainty estimates for relative comparisons. The Monte Carlo generates a 50-member ensemble that preserves the spatial and temporal error correlations. Three refinements to a previously published method improve consistency with the operational sea ice index. The study acknowledges limitations: it relies entirely on the OSI SAF SIC uncertainties without independent verification and only partially captures systematic errors from melt ponds and interpolation. However, this first step constitutes an important contribution and, following consideration of my points outlined below, would make an interesting contribution to The Cryosphere

The manuscript is generally well-structured and explains complex statistical concepts clearly, though some sections rely heavily on prior work. The statistical framework is rigorous, the validation strategy of comparing the ensemble spread against bias-corrected inter-product differences is well conceived, and the paper is concise and logically structured.

Thank you very much for your positive overall assessment of our paper!

Major concerns:

1. Definition of the MIZ. The finding that SIA uncertainty scales with the square root of MIZ length (the 50% SIC contour) is important. But the width of the MIZ varies regionally and seasonally due to wave exposure, ocean heat and ice dynamics. This is particularly relevant for Antarctica, where a substantial MIZ is almost always present. Would a 2D metric (e.g. MIZ area, or area of grid cells

within 15-80% concentration or similar) provide a stronger or more physically complete predictor? If MIZ length already captures most of the variability, demonstrating this explicitly would strengthen the physical interpretation and help assess robustness under future conditions where MIZ character may change.

This is a great suggestion, based on which we moved away from referring to “the MIZ” as a whole. This is because in response to this comment, we tried different definitions of the MIZ (including the suggested 15%-80% SIC area) and found correlations with the SIA uncertainty significantly higher than the correlation between uncertainty and the SIA itself, but lower than the correlation between uncertainty and the length of the 50% contour. We think this has at least two reasons: (1) the 15%-80% SIC area can in summer include areas far away from the ice edge (sometimes more than 1000 km) which we would not consider to be part of the MIZ. And (2) the mentioned widening of the MIZ in summer increases the MIZ area but is not necessarily creating more challenges for the SIA estimation (the distance between ocean and pack-ice becomes larger -> the local SIC gradients can become smaller -> mismatches between measurements in different frequencies become less relevant). Our analysis therefor shows that the SIA uncertainty is to a large degree driven by the length of the sea-ice edge, and not primarily by the MIZ. Despite being related, we now avoid treating the sea-ice edge (50% SIC contour) as a proxy for “the MIZ” and adjusted the wording in the manuscript accordingly.

By changing the wording away from “the MIZ”, we now prevent any possible misconception regarding the physical relationship between the uncertainty estimates and their physical drivers.

2. The paper relies heavily on Wernecke et al. (2024), and while the three refinements introduced here are clearly described, readers unfamiliar with the earlier work may struggle to follow key steps. I found it necessary to consult the 2024 paper to fully understand the processing chain. A brief step-by-step summary of the workflow (even in schematic or bullet-point form) would substantially improve accessibility without requiring full re-derivation of the method.

We revised the description of the processing and extended it as suggested by a step-by-step guide. The main addition is:

The uncertainty propagation makes use of a Monte-Carlo (MC) approach which relies on a stochastic representation of the SIC uncertainties to generate an ensemble of daily SIC maps. The spread between SIC ensemble members represents the SIC uncertainty which translates into the SIA uncertainty when we derive the corresponding ensemble of SIA time series and analyse its spread. The processing is performed on daily data from a given month at a time and involves the following steps: (1) create a spatio-temporal field of noise with radially declining autocorrelation in space and time, (2) normalize the amplitude of that field to a standard deviation of one and multiply with the OSI SAF *total_uncertainty* variable, (3) add the scaled noise to daily SIC fields, (4) derive the daily and monthly mean SIA for this ensemble member and (5) repeat from step (1) until the desired number of ensemble members is reached (here: 50 members).

3. The authors are transparent that their method is fully reliant on the SIC uncertainty component from OSI SAF without independent verification. The agreement with bias-free inter-product spread

provides indirect validation, but a discussion on whether this could be partly coincidental if both approaches share common limitations would be helpful/ A brief sensitivity analysis, or at a minimum adding a short discussion of how results might change if input SIC uncertainties were scaled by some factor, would help readers assess the robustness of the quantitative estimates.

Thank you for the suggestion. To perform meaningful sensitivity runs we first had to define a reasonable range of SIC uncertainty mismatches. In other words: We look for a measure of how good the provided uncertainties are before we can say how big the impact on the SIA uncertainty estimates would be. The number of published reports on the quality of the OSI SAF SIC uncertainty estimate is unfortunately small and they focus on near 100% SIC and near 0% SIC conditions (CDR SVR, CCI+ PVIR, Lavergne et al. 2019). For those conditions the total_uncertainty is generally small (<= ~5% SIC). According to the CDR SVR, for near 100% SIC conditions the OSI-450a total uncertainty is typically within 0.5% SIC of the RMSE of the OSI-450a SIC with high quality validation data (winter time converging ice motion from SAR). For near 0% SIC conditions the OSI-450a total_uncertainty typically overestimate the RMSE by about 1% SIC. However, since this represents only cases with relatively small SIC total_uncertainty values it is likely an underestimation of the uncertainty of the total_uncertainty variable for locations with higher values. We run sensitivity experiments for an increase and decrease of the total_uncertainty by 25 percent (relative). For context, the hemispheric mean total_uncertainty for ice covered regions is about 9% (absolute), meaning that the sensitivity runs equate to an average increase/decrease of more than twice the values in the Scientific Validation Report.

CDR SVR: OSI SAF SIC CDR Scientific Validation Report; https://osisaf-hl.met.no/sites/osisaf-hl/files/validation_reports/osisaf_cdop3_ss2_svr_sea-ice-conc-climate-data-record_v3p1.pdf)

CCI+ PVIR: CCI+ Sea Ice ECV SEA ICE CONCENTRATION PRODUCT VALIDATION AND INTERCOMPARISON REPORT: https://docs.google.com/document/d/1RBGG-gAcz3fY8PUkojQY8vA8IuJhdhJAgQWVRuc8wXY/edit?tab=t.0

Within this range SIA uncertainty is largely proportional to the SIC uncertainty. We add a section to the Supplement and refer to it in the main text by:

If the OSI SAF SIC uncertainties are overestimated or underestimated, this will also manifest in the SIA uncertainties presented here. We carried out a related sensitivity analysis and found that SIA uncertainty is linearly related to the absolute amount of SIC uncertainty (Supplement Section S4).

Minor points

Title: The current title repeats "Sea-Ice Area" twice, which reads awkwardly. You might consider rewording this.

We revised the title to:

Uncertainty of the Satellite-Retrieved Sea-Ice Area record and its Trend

Abstract: The finding about systematic uncertainties and their implications for trend analysis is arguably the paper's most consequential message, but is somewhat buried in the final sentences. You might consider elevating this. Several sentences are long and could be broken for clarity. Hedging phrases such as "so called" and "among other things" could be trimmed without loss of meaning.

Thank you for pointing this out. We reworded the abstract for clarity and provide more information about the systematic trend uncertainties. The respective part of the proposed abstract now reads:

Our analysis shows that systematic uncertainties are present in the SIA trend estimates. This indicates that a longer time-series will not be sufficient to remove trend uncertainties. For an extensive uncertainty quantification, systematic uncertainties should be represented explicitly. These uncertainties are related to methodological choices in the SIC product development, such as the homogenization across passive microwave sensors, applied masks, corrections and interpolations. The respective influence of these choices on SIA trend observations requires further research.

Figure 1 caption: the abbreviation STD is not defined (elsewhere in the manuscript your write out "standard deviation").
Done

Line 120: (or at the most appropriate location) The choice of 60 Monte Carlo ensemble members is stated but not justified. A brief note on why 50 is sufficient or a reference to convergence testing in the 2024 paper would be helpful.

The standard error of the standard deviation is 1/sqrt(2*N)=0.1 times the standard deviation for N=50. This assumes a normal distribution of the sample, but to avoid confusion we only provide the 10% value in the manuscript. We will add something like:

When deriving SIA standard deviations we can expect the estimate to be within 10% (1/sqrt(2*N) with N=50 being the sample size) of the population standard deviation. The population standard deviation is the analytical value of a distribution to which estimates converge with increasing sample size. This estimation uncertainty is reduced further for averages over the record or if running means are applied (Figure 1).

Line 151: "ocen" should read "ocean"

Corrected

Referee#2:

This paper presents an improved uncertainty estimation method to propagate local OSI SAF sea-ice concentration uncertainties to hemispheric sea-ice area uncertainty estimates. The results show that the seasonal variability of SIA uncertainty is more closely related to the spatial distribution of sea ice than to the seasonal cycle of SIA itself. The authors further compare these stochastic uncertainty estimates with the inter-product spread from the UHH SIA product. After removing their systematic biases, the remaining differences between SIA products are consistent with the proposed single-product uncertainty. They also suggest that the difference between SIA trend estimates is largely driven by systematic methodological differences. The study represents a timely and valuable contribution, particularly given that uncertainty quantification for long-term SIA records remains insufficiently developed. The manuscript is generally well written, and the results are of clear interest to the community. Overall, I support publication after minor revisions.

Thank you very much for your positive overall assessment of our paper!

General comments：

Using the local SIC uncertainty estimates from the OSI SAF product is reasonable. While these uncertainties are discussed later in Section 5.2, the manuscript lacks a general description of these uncertainties at their first introduction. It would be helpful to include a brief overview of the OSI SAF SIC uncertainty, particularly in Section 2.1 (Lines 68–73), as this would help readers better understand what sources of uncertainty are represented in the subsequent SIA uncertainty estimates.

We agree, such description would be very helpful! We have therefore added the following to Section 2.1:

The OSI SAF SIC uncertainty variable *total_uncertainty* used here is the quadratic sum of two components: (1) the *algorithm_uncertainty*, which accounts for sensor noise and residual geophysical variability derived from the algorithm performance over open-water and consolidated-ice training data. And (2) the *smearing_uncertainty*, which represents mismatches between sensor footprints and the target grid as well as differing channel fields of view. Smearing uncertainty is strongest in regions with strong SIC gradients and is parametrized as a function of the local SIC range within a 3×3 neighbourhood, with the proportionality factor calibrated using MODIS-based (optical) footprint simulations (Lavergne et al., 2019). The *total_uncertainty* field, along with its algorithmic and smearing components, is provided with the OSI SAF SIC product.

It would be helpful to clarify the rationale for defining the size of the MIZ as the 50% SIC contour of the 25 km resolution SIC product (Line 153), and to briefly discuss the advantages of this choice. This definition may influence the results, particularly in fragmented coastal regions or areas with low ice concentration.

You are right. After additional analysis, we now no longer link the contour length to “the MIZ”. Please see the response to the first comment of the other review for details.

Figure 4: Why are the probability distributions of the SIA trend ensemble estimates in the Arctic similar in March and September, whereas in the Antarctic they differ markedly, with a smaller distribution in March and a larger one in September? Could this difference be related to the number of available SIA products included in the analysis (as mentioned in Sect. 5.3, where only a small number of products are used for March)? Please clarify and discuss this point.

The reason why the Antarctic September trend uncertainty is larger than the other three shown in this figure is because the SIA uncertainty is the largest for that month and hemisphere (Figure 1a). This is now mentioned in the manuscript:

The trend uncertainty for September in Antarctica is larger than for March and larger than the uncertainty of the Arctic trends shown in Figure 4, which is consistent with the fact that the uncertainty of average Antarctic September SIA is also the largest of the four month/hemisphere combinations shown here (Figure 1a).

The number of products described in Section 5.3 was meant to refer to the three SIA products shown with the probability distribution. It is therefore the same for all month of the year and hemispheres. This section has been clarified.

Supplementary Figures 2 and 3: The black line marking the 50 % SIC contour is not very clear in several panels, as it appears to overlap visually with the land mask or coastline. I guess you could consider using a more contrasting color or line style to improve visibility.

Agreed. These Figures have been updated.

Specific comments:

Line 12: “is characterized by” should be “are characterized by”.

This is now correct because we refer to ‘the spread’ instead of ‘the differences’

Line 151: Typo, “ocen” should be “ocean”.

Corrected

Line 233: the correlation of sea ice cover variability with climate indices?

Yes, we meant the variability here.

Line 200: “effected by” should be “affected by”.

Good catch, thank you.

Line 240: “represent” should be “represents”.

Corrected