

This study compares several skin temperature products: four remote sensing products and one reanalysis (ERA5) product. It considers their spatial biases as well as biases in global-mean trends. In principle, if carefully done, this is a valuable exercise and could be very useful to the community. In its current form, however, large ambiguities in make the study's results difficult to interpret. I recommend major revisions.

We thank the reviewer for their comments. We revised the manuscript. Our responses are listed in blue hereafter. Added text is shown in italic.

General Comments

Please address what "skin temperature" actually means. For the ocean surface, does it refer to the upper micrometers? Millimeters? Does the quantity measured depend on the remote sensing method? There can be significant thermal contrasts in just the very top of the ocean surface, so this is important to address.

The following sentence was added:

"Over the ocean, the term "skin temperature" specifically refers to the radiometric temperature of the uppermost ~10–20 μm of the water column — the so-called cool skin layer — which is typically 0.1–0.5 K cooler than the water just below, owing to net heat loss at the air–sea interface (Donlon et al., 2002; Minnett et al., 2019)."

Sea ice: How do these different datasets measure the skin temperature in areas with sea ice, and how might this affect the overall results of your study?

Indeed. We now acknowledge the limitation of infrared sounders over sea ice. We add the following in the added section 2.7:

"Over sea-ice-covered regions, the definition and measurement of T_{skin} becomes more complex. Infrared satellite retrievals such as IASI and MODIS are sensitive to the radiometric skin temperature of the ice surface, but their accuracy depends on cloud screening and surface emissivity characterisation, both of which are particularly challenging in polar regions. ERA5 treats sea ice explicitly through a dedicated surface scheme. In this study, sea-ice-covered areas are not analysed separately, and the inter-dataset biases observed at high latitudes and discussed later are partly attributable to these differences in sea-ice treatment across datasets."

Clouds: it doesn't make sense to directly compare temperatures in clear-sky and all-sky datasets.

All datasets are now cloud-filtered (based on the comments of Reviewers 1 and 2). The following section has been added, and the figures and the analysis updated.

"2.8 Cloud filtering strategy

To ensure a physically consistent intercomparison, all datasets are evaluated under clear-sky conditions. Each dataset is filtered using the most appropriate cloud screening method. For IASI-NN, clear-sky retrievals are already guaranteed by the cloud mask of Whitburn et al. (2022),

which is applied at the pixel level prior to retrieval. The same cloud mask is applied to IASI-CDR, retaining only those IASI-CDR retrievals collocated in space and time with IASI-NN clear-sky pixels. Since both products share the same instrument, orbital swath, and overpass times, this constitutes a physically consistent filter that ensures both IASI products are evaluated over identical scenes.

For ERA5, we apply a threshold on the total cloud cover (tcc) variable, ERA5's native cloud diagnostic, retaining only grid points and time steps where $tcc < 0.2$ (20%). This clear-sky criterion is consistent with the approach used in comparable studies (Ermida et al., 2019; Ermida & Trigo, 2022), which also demonstrate through sensitivity analysis that varying the cloud fraction threshold between 1% and 30% changes the derived clear-sky bias by less than 0.5 K for 85% of grid points. Moreover, the ERA5 Tskin trends derived from monthly cloud-filtered data are shown to be robust across a wide range of cloud cover thresholds (Wang et al., 2022).

MODIS Terra LST (v6.1) and ESA LST CCI (v3.00) are clear-sky products by construction, as their retrieval algorithms only produce valid retrievals under cloud-free conditions; no additional cloud filtering is therefore applied to these datasets. The ESA SST CCI/C3S SST and IST product combines infrared clear-sky retrievals with all-sky passive microwave observations through optimal interpolation, and is therefore not cloud-filtered. Applying a cloud mask, a posteriori, using ERA5 monthly cloud cover fraction, for example, would be the only feasible approach to approximate clear-sky conditions, but this would introduce an ERA5-dependent filtering that is inconsistent with the cloud screening applied to IASI and MODIS, which is based on their own instrument-level detection. We therefore present the ESA CCI/C3S SST and IST product as an all-sky all-day reference.”

It's unclear to me how discontinuities in satellite observations in space and time are accounted for in this analysis. In spatially and temporally complete SST or near-surface land temperature products, algorithmic adjustments are made to fill in spatial and temporal gaps, such that averaged values can be interpreted to represent a best estimate of a global mean or a daily/monthly mean. To what extent are these observational products homogenized? See comments below.

Temporal coverage: Are “daytime” temperatures specifically referring to 9:30am or 10am temperatures? Please be more specific about how the correction to the temperatures based on local crossing times are made.

Yes. Daytime and nighttime temperatures in this study refer to the morning (~09:30–10:30 local solar time) and evening (~21:30–22:30 local solar time) overpasses respectively. We make this clear in the beginning of Section 3:

“In terms of temporal sampling, all datasets are evaluated at comparable local solar times (except for the ESA CCI/C3S SST), spanning a window of approximately 09:30 to 10:30 for daytime and 21:30 to 22:30 for nighttime. Specifically, IASI crosses the equator at 09:30 local solar time, MODIS Terra at approximately 10:30, and LST CCI is provided at 10:00. ERA5 hourly data are sampled at 10:00 local solar time by applying a longitude-based offset (15° longitude = 1 hour), without correction for daylight saving time, consistent with the fixed solar crossing

times of polar-orbiting satellites. No further correction for the residual 30–60 minute spread between instruments is applied beyond what is already performed internally within the LST CCI product (Ghent et al., 2025). At the monthly timescale used throughout this study, this residual temporal offset is not expected to introduce biases of climatological significance.”

Spatial coverage: Is the spatial coverage clear sky or all sky? Are we considering a true global mean? If so, how are areas not “seen” by the satellite filled in? These are all major ambiguities that must be accounted for and described before making an “apples to apples” comparison between data products.

The current products are now cloud free as per the Reviewers’ suggestion. Indeed, this means that there will be areas that are not “seen” by the satellite, typically around the Equator. And these will depend on each of the products’ cloud coverage algorithms. This applies to all products, including ERA5, when we use the cloud filtering approach (see added Section 2.8).

Generally, these issues must be treated with more specificity, rather than with broad allusion, for the comparisons made to be useful and interpretable.

In order to make the analysis concise and clear, the following paragraph is now added as an introduction to section 3 Results. It serves as a summary of our approach to dataset harmonization and comparability.

“In terms of temporal sampling, all datasets are evaluated at comparable local solar times (except for the ESA CCI/C3S SST), spanning a window of approximately 09:30 to 10:30 for daytime and 21:30 to 22:30 for nighttime. Specifically, IASI crosses the equator at 09:30 local solar time, MODIS Terra at approximately 10:30, and LST CCI is provided at 10:00. ERA5 hourly data are sampled at 10:00 local solar time by applying a longitude-based offset (15° longitude = 1 hour), without correction for daylight saving time, consistent with the fixed solar crossing times of polar-orbiting satellites. No further correction for the residual 30–60 minute spread between instruments is applied beyond what is already performed internally within the LST CCI product (Ghent et al., 2025). At the monthly timescale used throughout this study, this residual temporal offset is not expected to introduce biases of climatological significance. Furthermore, all datasets are evaluated under clear-sky conditions, as described in detail in Section 2.8. It should be noted that the cloud screening method differs necessarily across datasets, as each product applies its own retrieval-specific approach. While this means the clear-sky subsets are not strictly identical across products, no universally applicable cloud mask exists that could be applied consistently across such diverse observing systems and reanalysis products, and the approach adopted here represents the most physically appropriate filtering strategy for each dataset. One additional asymmetry in the cloud filtering strategy concerns ERA5. Unlike the satellite products, for which cloud screening is applied at the individual retrieval or overpass level before monthly aggregation, ERA5 cloud filtering is applied to monthly-mean total cloud cover. This means that months with episodic cloudiness but low mean cloud cover may be retained, resulting in a less strict effective clear-sky selection than for the satellite datasets.”

On the use of reanalysis: in this study, reanalysis is treated as if it were another observational product. However, reanalysis is a fundamentally different type of data

product, as it assimilates observations into a model, and prognostically predicts skin temperature. It is interesting to include reanalysis but these distinctions should be maintained throughout the text.

Considering the other Reviewers comments the ERA5 section has been rewritten to clarify Tskin is a prognostic variable. Here is the new section 2.3

“ERA5 Tskin

We use the Tskin variable from the ERA5 reanalysis (Hersbach et al., 2020), produced by ECMWF, which is framed within the Copernicus Climate Change Service (C3S) of the European Commission. ERA5 datasets are at $0.25^\circ \times 0.25^\circ$ resolution (native horizontal resolution of ERA5 is ~ 31 km), that are regridded to a $1^\circ \times 1^\circ$ grid size for the study.

Hourly averages are computed for each month of the year and are then converted to local time by calculating the time zone offset based on the longitude ($15^\circ = 1$ hour). Our analysis does not account for daylight saving time. This is consistent with satellite local-solar-time definitions, as polar-orbiting instruments such as IASI maintain fixed solar crossing times (e.g., 09:30/21:30), independent of civil time zones.

“ERA5 should not be treated as an independent ground truth, but rather as a physically consistent reference that is subject to its own model-dependent uncertainties. Over land, ERA5 Tskin is a prognostic variable computed within the HTESSEL (Hydrology-Tiled ECMWF Scheme for Surface Exchanges over Land) land surface scheme (Balsamo et al., 2009), as part of the Integrated Forecast System (IFS). It is integrated forward in time by solving the surface energy balance at each model timestep, and is therefore sensitive to model parameterisations of soil thermal properties, vegetation, and snow. Over ocean, ERA5 Tskin is not prognostic but is instead derived from a prescribed SST analysis with a diagnostic cool-skin correction applied (Hirahara et al., 2016; Zeng & Beljaars, 2005). ERA5 does not directly assimilate Tskin, but does assimilate SST analyses over ocean and infrared radiances over both land and sea (Hersbach et al., 2020), which carry indirect surface temperature information.”

Also, have there been comparisons between skin temperature values in other reanalysis products?

We thank the reviewer for raising this point. Skin temperature has been intercompared across reanalysis products in few previous studies, although such comparisons remain less common than those for 2 m air temperature and have largely focused on the marine domain (SST) rather than land. Over the ocean, SST in MERRA-2 and ERA-Interim has been evaluated against independent shipborne M-AERI measurements from the AEROSE cruises, with mean differences on the order of 0.1 K (Luo et al., 2020), and ERA5 SSTskin has been similarly assessed against M-AERI data (Luo & Minnett, 2020). At the global scale, surface skin temperature trends over 2003–2021 have been compared between ERA5 and

JRA-55 and found to be in good mutual agreement and consistent with AIRS satellite observations (Wan et al., 2024). These studies indicate broad consistency in skin temperature between modern reanalyses, particularly in trend patterns, while also showing that systematic differences arise from each product's cool-skin parameterization and assimilated observations. Our analysis complements this body of work by extending the comparison to satellite-derived skin/land surface temperature products (IASI, MODIS, ESA CCI) alongside ERA5, with explicit separation of day and night orbital phases.

Since there are little literature review on LST, we choose not to add anything to the main manuscript.

Some figure captions are not adequately descriptive.

Most captions have been updated with more description (see for example the captions for Figures 3 and 5 hereafter).

Data availability: can you make the regridded and harmonized (to local time) data available? Or the code used to perform the harmonization?

The code is now available here (added to the section data availability statement):

<https://github.com/sarahsafieddine/utc-to-local-time/tree/main>

Specific comments

Introduction: As written, the introduction doesn't provide adequate context for the reader, instead jumping immediately into the details of each dataset. The paper should be accessible to researchers who may be interested in using skin temperature for scientific analysis, but may not be already familiar with each of the individual data products. In the introduction, therefore, I would suggest the following. Around line 40, instead of or in addition to presenting a general statement of Planck's law, some broad discussion of remote sensing methods capable of measuring skin temperature and the strengths and weaknesses of these methods would be warranted. I.e., infrared sensing offers a good measure of physical temperatures as surfaces tend to have emissivities close to unity at thermal IR wavelengths, but infrared sensing of surface temperature is only possible in cloud-free areas, and there is some sensitivity to water vapor as well. Microwave sensing is less sensitive to clouds, but emissivity vary and the resolution is less sharp... etc. Satellites have incomplete spatial coverage, moreover... Basically, before you discuss each of the individual datasets, it would be helpful to discuss: what are some of the key sources of uncertainty that could lead to variation across these products?

We thank the reviewer for this recommendation. We now added the following paragraph after Planck's Equation:

"Satellite-based T_{skin} retrievals rely primarily on thermal infrared (TIR) radiometry in atmospheric window channels (8–13 μm), where most natural surfaces have emissivities close

to unity, making TIR-derived temperatures a close approximation of the physical skin temperature (Guillevic et al., 2018; Hulley et al., 2019). However, TIR retrievals are only possible under cloud-free conditions, and all TIR observations are affected by atmospheric water vapour absorption. Passive microwave radiometry is less sensitive to cloud cover but surface emissivity in the microwave is highly variable, particularly over land and sea ice, and spatial resolution is considerably coarser (Prigent et al., 2016). Reanalysis products such as ERA5 provide spatially complete, all-sky fields but Tskin is a prognostic model variable constrained by data assimilation rather than a direct observation, making it sensitive to model parameterisations of surface energy balance and land surface properties (Hersbach et al., 2020). These fundamental differences in measurement principle, spatial sampling, and retrieval methodology mean that no single dataset can be considered a universal reference, and systematic intercomparison across products is essential to assess the robustness of Tskin-based climate signals (Ermida et al., 2019; Hulley et al., 2019). »

Line 70: you don't need to repeat that you regridded to 1x1 for every dataset. Also to clarify, did you regrid for all the analysis, or just the spatial comparison?

This line was removed. The regridding is done for all the analysis as it is now clear in the introductory paragraph of Section 3.

Line 86: Please add a little more detail about how this adjustment was made.

The phrase "The MODIS brightness temperature data was also intercalibrated against IASI." Is now changed to:

"In addition, an adjustment is made to account for the half-hour difference in the satellites' equatorial crossing times; this correction is computed in brightness temperature space using radiative transfer simulations."

Line 90: ERA5 is reanalysis, not an observational product. How is surface temperature data assimilated into ERA5?

This paragraph is now added (also added as a response to a previous comment):

"ERA5 should not be treated as an independent ground truth, but rather as a physically consistent reference that is subject to its own model-dependent uncertainties. Over land, ERA5 Tskin is a prognostic variable computed within the HTESEL (Hydrology-Tiled ECMWF Scheme for Surface Exchanges over Land) land surface scheme (Balsamo et al., 2009), as part of the Integrated Forecast System (IFS). It is integrated forward in time by solving the surface energy balance at each model timestep, and is therefore sensitive to model parameterisations of soil thermal properties, vegetation, and snow. Over ocean, ERA5 Tskin is not prognostic but is instead derived from a prescribed SST analysis with a diagnostic cool-skin correction applied (Hirahara et al., 2016; Zeng & Beljaars, 2005). ERA5 does not directly assimilate Tskin, but does assimilate SST analyses over ocean and infrared radiances over both land and sea (Hersbach et al., 2020), which carry indirect surface temperature information."

Section 2: In general, what criteria did you use to select which datasets to analyze?

The datasets were selected based on three main criteria: availability, overpass time consistency, and complementarity. Overpass time is a particularly critical constraint — products with significantly different equatorial crossing times, such as AIRS, cannot be meaningfully compared with IASI without introducing substantial diurnal sampling biases. A second motivation was the validation of our newly developed IASI-NN product, for which the EUMETSAT IASI-CDR constitutes a natural comparator, as both are derived from the same instrument. To broaden the intercomparison, we additionally included a well-established heritage satellite product (MODIS Terra), a multi-sensor climate data record (ESA LST CCI v3.00), and a reanalysis product (ERA5) as a physically consistent reference. Together, these five datasets span a range of retrieval methodologies, temporal homogenisation strategies, and spatial sampling approaches, making them well suited for a systematic intercomparison of Tskin-based climate signals.

We choose to not add anything to the manuscript since everything we mentioned in our answer can be now implied in this new version of the manuscript.

Line 197: This version of the CCI product “has not been fully validated” – so it has been partly validated already? If so, how? What are the implications of using unvalidated data in your analysis?

We thank the reviewer for this comment. The phrasing has been corrected to "not yet been validated" to avoid ambiguity. By this we mean that LST CCI v3.00 is a recently released product (August 2025) for which a comprehensive, peer-reviewed validation against independent datasets has not yet been published. Rather than relying on external validation, we use the intercomparison itself as an internal consistency check, and we explicitly flag the sensor-transition discontinuities visible in the anomaly time series as evidence of residual inhomogeneities that users should be aware of. The inclusion of an unvalidated product is therefore deliberate — identifying such issues across datasets is precisely one of the contributions of this intercomparison.

Line 213: Please describe the local time conversion method.

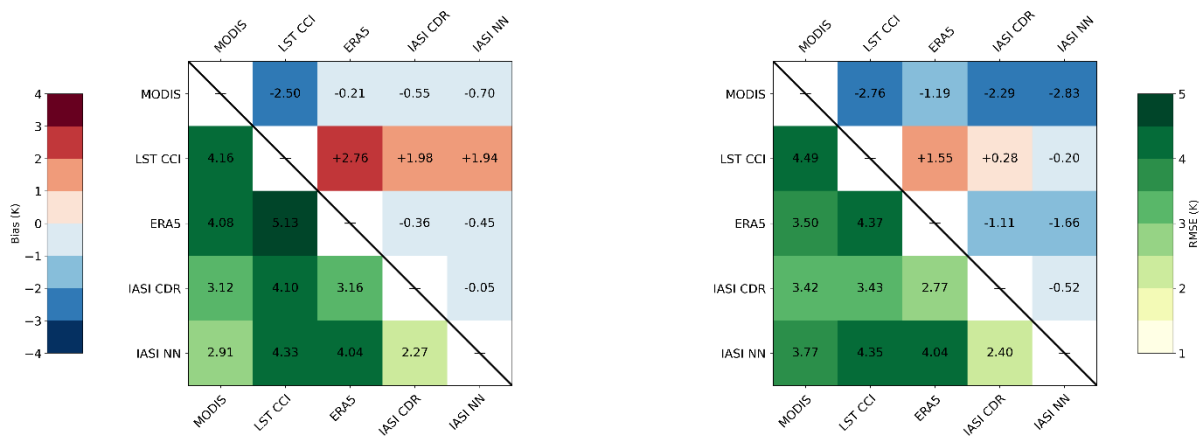
The local time conversion method is described in Section 2.4 as follows:

“Hourly averages are computed for each month of the year and are then converted to local time by calculating the time zone offset based on the longitude ($15^\circ = 1$ hour). Our analysis does not account for daylight saving time. This is consistent with satellite local-solar-time definitions, as polar-orbiting instruments such as IASI maintain fixed solar crossing times (e.g., 09:30/21:30), independent of civil time zones.”

... and has now been explicitly referenced at this point in the text to guide the reader directly to the relevant explanation.

Figure 3: I'm confused about what these global mean values are meant to capture. What happens over sea ice, what happens over

The ERA5 land-sea mask, which is used to separate land and ocean grid cells in Figure 3 (which has been introduced in this new version of the manuscript), classifies sea ice as ocean rather than land. Sea-ice-covered grid cells are therefore excluded from the land statistics shown in Figure 3. The figure caption has been updated to make this explicit as such:



“Figure 3. Upper triangle (blue to red): global mean bias (row - column); Lower triangle (in yellow to green): root mean square error (RMSE) between the different pairs of LST datasets, for daytime (left) and nighttime (right). Statistics are computed over land grid cells only (using the ERA5 land-sea mask) and weighted by cosine-latitude.”

Figure 4: how do you treat sea ice?

Ocean grid cells are defined using the ERA5 land-sea mask, which classifies sea ice as ocean; sea-ice-covered areas are therefore included in the global mean SST and spatial bias maps. The three datasets treat sea ice differently: ERA5 computes T_{skin} over sea ice through a dedicated sea-ice scheme, while IASI-NN and IASI-CDR retrieve the radiometric skin temperature of the ice surface where cloud-free conditions allow, with reduced accuracy due to variable emissivity and low thermal contrast. These differences in sea-ice treatment contribute to the larger inter-dataset biases observed at high latitudes in Figure 5, as already noted in Section 2.7.

Moreover, we have now added the L4 ESA CCI and C3S combined SST product that provides temperatures over sea and ice surfaces, based on Reviewer 2 comments. The discussion of the SST is updated throughout the manuscript.

In order to make this clear, we have added the following into the legend of Figure 5:

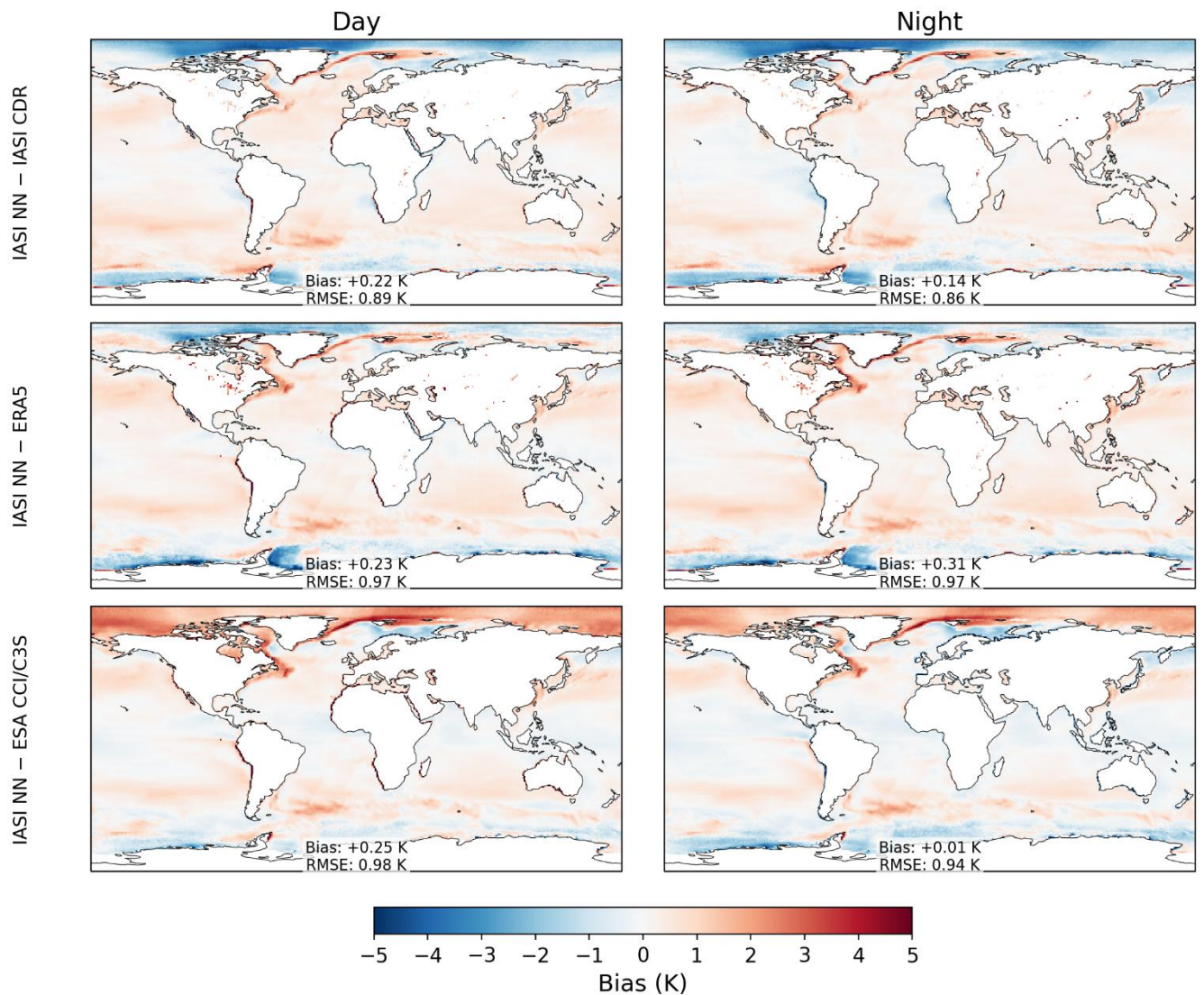


Figure 5. Spatial bias of IASI-NN ocean skin temperature relative to IASI-CDR, ERA5, and the ESA CCI/C3S SST analysis. Maps show daytime (left column) and nighttime (right column) biases, computed as the time mean of the monthly-mean differences over the datasets' common period (2008–2022). The ESA CCI/C3S product is a gap-filled, all-sky, daily-mean analysis with no day/night separation, so the same daily field is differenced against both the daytime and nighttime IASI-NN fields; IASI and ERA5 are restricted to clear-sky scenes. All datasets were regridded to a common $1^\circ \times 1^\circ$ grid and land points were masked using the ERA5 land–sea mask. **Sea-ice-covered grid cells are classified as ocean by this mask and are therefore included.** Global mean bias and RMSE, area-weighted by the cosine of latitude, are indicated in each panel.

Line 251: Biases between the SST datasets?

Yes, we rephrased the sentence to “biases between the datasets over the sea”.

Line 284: historical trends – over what period?

We believe that the Reviewer is referring to this line/sentence:

“Both observations and general circulation model projections suggest current and future significant temperature increases in Siberia consistent with the effects of Arctic amplification, with an increase mostly pronounced in central Siberia reaching 4°C over the past few decades (Masson-Delmotte, et al., 2021; Tchebakova et al., 2009).”

We add more information on the period and rephrase the sentence as such:

“Both observations and general circulation model projections suggest significant temperature increases consistent with Arctic amplification, *with the Arctic warming nearly four times faster than the global average over 1979–2021* (Masson-Delmotte, et al., 2021; Rantanen et al., 2022). *This broad Arctic warming pattern is consistent with the strong positive Tskin trends observed in Alaska and Siberia in our 2008–2022 dataset.*”

Line 295: Regarding extreme rainfall events, how is this related to heating and cooling trends?

This sentence suggests reasons to explain the cooling trends. We rephrase it to make this clear:

“This cooling trend is also seen in central and east Africa. In warm tropical environments, *increased cloud cover and latent heat release associated with more frequent and intense extreme rainfall events can suppress surface temperatures* (Hegerl et al., 2007), *providing a physical mechanism consistent with the observed cooling signal.*”

Figure 6: What is the color coding?

This whole figure has now been updated as follows:

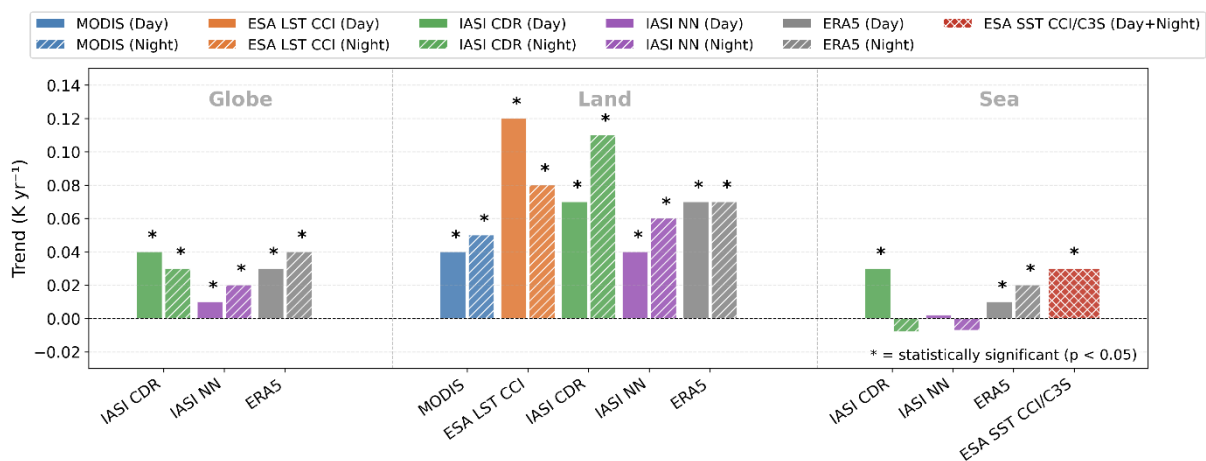


Figure 6. (b) Global (Tskin), sea (SST), land (LST) trends (K/yr) from MODIS, ESA CCI LST, IASI-CDR, IASI-NN, ERA5, and ESA CCI/C3S SST over the period [January 2008–December 2022].

Trends are computed with the Theil–Sen estimator on annual latitude-weighted and deseasonalised averages. Significant trends are marked with an Asterix (*) above the bars.

Technical corrections

Line 66: should read “between 9:30am and 10:30pm”

This line has been rephrased to:

“For consistency between datasets, the satellites orbits are all between 9:30am/pm and 10:30 am/pm. Reanalysis data is chosen at 10 am/pm.”

Line 81: “is” à “has been” :

Corrected

Citation: <https://doi.org/10.5194/egusphere-2026-400-RC3>

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