We acknowledge the reviewer for the precise and important comments on this paper. The actions that we will take in the review are detailed below in blue.

Reviewer #2

REVIEW OF MANUSCRIPT SUBMITTED TO Atmos. Meas. Tech. Discuss.

Authors: Stefano Federico, Rosa Claudia Torcasio, Paolo Sanò, Daniele Casella, Monica Campanelli, Jan Fokke Meirink, Ping Wang, Stefania Vergari, Henri Diémoz, Stefano Dietrich

Title: Comparison of hourly surface downwelling solar radiation estimated from MSG/SEVIRI and forecast by RAMS model with pyranometers over Italy

Date of review: 02 APR 2017

OVERALL EVALUATION

The manuscript presents a one-year comparison between satellite-estimated and numerical weather prediction model –forecasted solar radiation with ground- based measurements at Italian sites. The paper is of interest as it involves both weather forecasting and satellite algorithms, considering a topical subject connected to solar energy production.

The manuscript presents a fairly thorough evaluation of the performance of these two sources of solar radiation information for the chosen Italian sites. The figures presented and the used equations seem correct. However, the manuscript occasionally presents conclusions that are not supported by the evidence presented in this study, and furthermore suffers from unclear sentences that perhaps could be improved through a proper language check / proof reading.

I would recommend major revisions before accepting this manuscript. Note, however, that I do not believe that the actual scientific work will require a deep revision, but rather, that the authors need to pay attention to way things are expressed and what conclusions can be made based on the results presented in their manuscript.

SOMEWHAT GENERAL COMMENTS

- L59-61 and elsewhere: throughout the manuscript, it would be important to emphasize (and remind the reader of the fact) that RAMS is a forecast (for the day ahead), and MSG-GHI is a satellite-based estimate (available some time after the satellite observations have been made). This needs to always be kept in mind when comparing the performance of the two – the present manuscript is occasionally somewhat sloppy on this.

-Ok. This will be clarified throughout the paper. Where appropriate we will use: "RAMS-GHI one-day ahead hourly forecast"

- L110—118: The RAMS model should be properly introduced before starting the paragraph on exchange between atmosphere and surface. What is the RAMS model?

- Thank you for noting this point. We will introduce what is RAMS writing: "RAMS is a general purpose limited area model designed to be used at the mesoscale (horizontal grid spacing ≈ 1-100 km) or higher horizontal resolutions. It is based on a full set of non-hydrostatic, compressible equations of the atmospheric dynamics and thermodynamics, plus conservation equations for scalar quantities such as water vapour and liquid and ice hydrometeor mixing ratios. The model is widely used for research as well as for weather forecast (Cotton et al., 2003)."

- L151—164: The text seems somewhat unclear here, should be clarified. It seems to me that maybe there are two different groups of pyranometers used: (i) L151-157, and (ii) L158-164. The stability of the pyranometer in Aosta is documented, but nothing is said about the other pyranometers. If sunshine duration is used (point 2), which stations have sunshine duration available? How is the Aosta check against libRadtran done, what are the criteria for data removal? Which institutes are responsible for the pyranometer measurements?

The pyranometers are managed by two different institutions and each institution is responsible for its own observations. The Aosta pyranometer is managed by Arpa Valle D'Aosta, while all other pyranometers are managed by the Aeronautica Militare. The check with the LibRadtran software for Aosta is made to test for electric wiring faults. In particular, measurements higher than 200% of the daily maximum expected from libRadtran in clear-sky conditions are removed. We will also comment on the stability of the other pyranometers.

- Fig 6 + analysis: The manuscript up to this point has explained/speculated about the role of clouds in the performance. Now, Fig 6 finally shows quantitative results on how the performance behaves as a function of cloud classification. To me, it would make sense to bring this figure more toward the early part of the manuscript, so that the remaining analysis already could make use of these results as this would reduce the need for indirect determination.

- Thank you for noting this point. We will move the analysis of Figure 6 (Figure 4 in the revised version) at the end of Section 3.1, to show the impact of the cloud coverage on the RAMS-GHI forecast and MSG-GHI estimation performance for all stations. We believe that this clarifies the following analysis, as you suggested.

- Conclusions -> (suggestion) Summary and Conclusion: The section is in its present form to a large extent repeating/summarizing the results presented in previous sections. It would be more interesting for the reader if some more discussion/conclusions would be added. Perhaps the section could also be shortened.

-Considering this comment and that of the first reviewer about the conclusions, the "Conclusion" section ("Summary and Conclusions" in the revised version) will be shortened about the results of this paper, while the results of the paper will be compared with similar studies in other Mediterranean countries. Also, a discussion on the specific version of the RAMS model used in this paper will be included considering the recent developments to the model.

- L448: Are any evidence presented in the manuscript that show that the radiative scheme is unable to simulate cloudy conditions correctly? Where does this statement come from?

- We agree that the worse simulation of the GHI in cloudy conditions in not necessarily a consequence of the radiative scheme as other errors, for example the estimation of the hydrometeor concentrations, have a role. We will modify the sentence writing: “The increase of the RMSE with the cloud coverage, as determined by the CPP algorithm (Roebling et al., 2008), is a combination of both the inability of the two methods to correctly represent the cloud coverage and by the difficulty to compute the GHI in cloudy conditions.”

SPECIFIC SUGGESTIONS

- L25-26: this is not always true (see e.g. L445—446).

We will modify the sentence: “Results on hourly data show an evident dependence on the sky conditions, with the Root Mean Square Error (RMSE) increasing from clear to cloudy conditions.”

- L27: RMSE increases for Alpine stations (and similar statements elsewhere). This seems a bit misleading. I would suggest saying “is higher” or “is lower”.

- This will be corrected according to the reviewer comment.

- L30: “RMSE ranges from 152 W/m2 to...” – here (and elsewhere) it should be defined that the RMSE has been calculated for hourly values.

- This will be corrected according to the reviewer comment.

- L36: “a reduction” -> “lower”

-Ok. We will write: “Results for daily integrated GHI show lower RMSE compared to hourly GHI evaluation for both RAMS-GHI one-day forecast and MSG-GHI estimate. Considering the yearly evaluation, the RMSE of daily integrated GHI is at least 9% lower (in percentage units, from 31% to 22% for RAMS in Cozzo Spadaro) that the RMSE computed for hourly data for each station.”

- L36: “of at least 10%” – here, it needs to defined what 10% means (10% of the base value, or a change corresponding to 10% steps/units (e.g. from 20 to 10%). Also elsewhere.

-The value refers to a change in the percentage units (as in the previous comment). This will be clarified throughout the paper.

- L46: two specific papers are cited for a scope very wide. I would suggest removing the references.

-ok.

- L51: Yes, PV can convert GHI to electricity, but much more commonly, they convert tilted GHI, or perhaps more generally, just solar radiation, to electricity.

- We will use "solar power".

- L91: suggest to remove "So"

- Ok.

- L92: particle size is not an optical property

- Ok.

- L94: could you clarify the text here, is a mixture of ice/water clouds possible?

- This will be clarified: a mixture of ice/water cloud is not possible.

- L112: "most of Europe" seems a bit exaggerated

- We will use "Central Europe".

- L131-132: Somewhat unclear what exactly this means. Could be elaborated more.

We will add the following comment to clarify the point: "In particular, the scheme uses an "effective emissivity" for cloud layers, where the cloud emissivity is parametrized empirically from observations (Stephens 1978). The "effective emissivity" is a function of the total condensate water path, computed summing all hydrometeors mixing ratios (liquid, i.e. cloud and rain, solid, i.e. ice and snow, and mixed phase, i.e. graupel) and integrating over the cloud-layer (Chen and Cotton, 1983).". In the "Summary and Conclusion" section will be discussed the important impact of taking into account for the different phases of the condensate water.

- L133-136: Please clarify, are there any additional data assimilated into the RAMS model, e.g. weather observations, or is the RAMS model's initial state fully determined purely by ECMWF?

No additional data are assimilated into the RAMS model and the initial state is fully determined by the ECMWF. We will write: "No additional data are assimilated into the RAMS model."

- L138-139: Seems contradicting that a weather forecasting model would need a spin up time of 12 hours.

- The model configuration of this paper use a cold start with no clouds nor precipitation at initial time. Previous unpublished studies with RAMS showed that 12 h are enough for the model to reach a dynamical equilibrium between the dynamic, thermodynamic and cloud-precipitation fields starting from a cold start. The 6 h spin-up time is enough for most cases, but there are occasions where a longer spin-up time is required. We will discuss a bit this issue in the paper:

"The model was run for a whole year (1 June 2013 - 31 May 2014) with the above configuration. This configuration uses a cold start with no clouds nor precipitation at initial time. Previous unpublished studies with RAMS showed that 12 h are enough for the model to reach a dynamical equilibrium between the dynamic, thermodynamic and cloud-precipitation fields starting from a cold start. Because of the cold start, each simulation lasts 36 h and starts at 12 UTC of the day before the day of interest, and the first 12 h are used as spin-up time and discarded. The model output is available hourly."

- Section 2.3: could be separated into two: (i) surface observations / (ii) evaluation methodology

- We will the section in two parts, as it is clearer.

- L146: "Vigna di Valle is still" -> "Vigna di Valle is" (remove still)

- Ok.

- L165: "environmental characteristics" seem to actually mean cloud classification by the satellite method, is that correct? Please clarify text and use suitable terminology.

- We will change the sentence: "Table 3 shows, for each station and season, as well as for the whole year, the percentage of data in clear, contaminated and overcast conditions, classified by the satellite method of Section 2.1."

- L170: (language) "with the stations" -> "between different stations" ?

- Ok.

- L174-175: somewhat unclear sentence, please clarify

- The sentence will be rephrased: "The RAMS GHI forecast is available hourly, while the frequency of pyranometer observations and MSG-GHI estimate is every half an hour. Pyranometer observations and MSG-GHI estimates were considered hourly, at the same time of the RAMS forecast output."

- L178-179 + L188-189: why not use equation numbers?

- We will add the equation numbers.

- Figure 3: I would suggest swapping the axes, so that pyranometer values are on the x-axis and estimated values on the y-axis. This makes values above the 1:1 line correspond to overestimation and vice versa, which is more logical. Also, I think it would be interesting to add this kind of figure for each station as a supplement or appendix as some readers will be interested in that information. Finally, the figure would be easier to read if grid lines and a legend were added, and if the point style would be modified so that points would not overlap (as much) in the busy areas of the plot.

- Figure 3 will changed according to this comment. The Figures for other stations will be added as a supplement to the paper (and are shown at the end of this answer for completeness).

- L196 / Fig. 3: clarify how the regression lines were determined

- Clarified. Linear regression is computed using the pyranometer values as *x* and MSG-GHI estimation (Figure 3a) or RAMS-GHI one-day ahead hourly forecast (Figure 3b) as *y*. The black regression line is for clear sky, the red one is for cloudy conditions (both contaminated and overcast), the blue is for all data dataset. This has been clarified both into the text and adding a legend to Figure 3.

- L201-202 and L220: "it is apparent the larger scatter" -> (language) please rephrase (also similar sentence construction elsewhere)

- This will be rephrased: "The data for cloudy conditions of Figure 3a are more scattered around their regression line compared to clear sky data." Also in line 220: "The RAMS-GHI forecast data are more scattered around their regression line compared to MSG-GHI". Also in lines 210-211 "b) the correlation coefficient for cloudy conditions is lower compared to clear sky data and shows….".

- L229-230: in point b, it needs to be emphasized that RAMS is a forecast and thus not directly comparable to MSG.

- Ok. We will write: "For the latter point, however, it is emphasized that the MSG and RAMS performance cannot be directly compared because RAMS is a forecast, while MSG gives an estimate of the GHI from radiance observations".

- L256-257: It is unclear to the reader how the conclusion about clouds being the main source of error was made. Could this be elaborated?

- In the revised version of the paper there will be a reference to the supplement where we show the scatter plots of the GHI for the pyranometer and RAMS-GHI one-day ahead hourly forecast. From these figures, it is apparent the over forecast of cloudy conditions by RAMS (points in the lower part of the figures). We will write: "The inspection of the model output for those stations reveals that the main source of errors was the over forecast of cloudy conditions, as shown by the scatter plots for these stations between the RAMS-GHI forecast and the pyranometer values given as a supplement to this paper."

- L257-264: This seems to be mostly somewhat loose speculation, although things are expressed as hard facts. The evidence presented in the manuscript does not support all these statements. Therefore, I recommend rewriting, to use more careful statements.

-Lines 262-264 will be removed, while the rest of the discussion will be rewritten using more careful statements. We will write: "It is not easy to find the reason for this behaviour, because several factors could be involved as errors in the physical and numerical parameterizations of the model, and errors in the initial and boundary conditions. Also, the 4 km horizontal resolution is not enough to resolve the fine orographic structures over the Alps (Aosta and Paganella) and over the Apennines (Monte Cimone), and their interaction with large scale atmospheric systems. "

- L268-274: On a general level, I believe the explanations presented here to be plausible. However, I also find that the authors focus too much on explanations that have to do with local orography and horizontal resolution. Could there be something else involved as well? For example, one factor that certainly plays a role here is the fact that mountain stations have more clouds and clouds are difficult for the satellite algorithm (as seen later on in Fig 6).

-We will add the following reasons: “The classification of sky conditions is more difficult where the soil is covered by snow and, because this condition is more frequent in mountainous stations, it increases the MSG-GHI error for those stations. Also, the estimation of the GHI by the MSG is more difficult in cloudy conditions (Figure 4), which are more frequent for mountainous stations.”

- L287: RMSE -> rRMSE?

- Ok.

- L288-289: unclear to me what is meant by “statistic shows more clearly the impact of ...”

- Ok. We will use “… this analysis ….”

- L294 + Fig 5 caption: “RAMS-GHI one-day forecast”. Here (and elsewhere when mentioning RAMS one-day forecast) it would be important to emphasize that RMSE is based on hourly values of the day ahead forecast from RAMS. The present text leads me to think that values may be daily.

- This will be clarified throughout the paper. We will use “RAMS-GHI one-day ahead hourly forecast”

- L301: I find it odd to say “This result is caused by RMSE statistics”.

- Ok. “This result is caused by the large differences between the RAMS-GHI one-day forecast and observations.”

- L321: “all sky conditions, which showed” -> (suggest) “all sky conditions, which indirectly showed...”

- Ok.

- L329-331: Unclear how this explains the difference?

- We will remove the sentence because it was misleading.

- L333: Not completely true, compare with L445-446

- This will be corrected. We will consider only clean and cloudy avoiding the difference between scattered and overcast.

- L344-346: Please clarify how the persistence forecast is created. Are values hour by hour assumed to be the same between the two days?

-We will write: “The one-day persistence forecast was computed using hour by hour the observed values of the previous day”.

- L345: I find the use of the short-version “1D” somewhat misleading (as it makes me think of one-dimensional) and therefore suggest writing it out: one-day.

-Ok. Corrected everywhere.

- Section 3.3: split into two separate sections? (i) Daily evaluation / (ii) MOS application

-We will divide Section 3.3 in two sections according to this comment.

- L381-383: There may also be other sources of MBE

-This sentence will be modified according to the comment to this comment adding additional sources of systematic errors. We will write:

“The MOS technique is used to reduce the MBE of the RAMS-GHI forecast and MSG-GHI estimate. The MBE is caused by several factors related to both modelling and observations. In the context of this paper the most important are: a) the approximations in the meteorological model and in the methodology used to estimate GHI from MSG data, and; b) the horizontal grid used to represent the real world, which smoothens the surface features causing systematic errors. Other contributions derive from: a) time differences between the pyranometer observations and MSG-GHI estimates (few minutes), or time differences between the pyranometer observations and the model output validity time (few minutes); b) small and undetected systematic errors in the observations. “

- L384: “The MOS consists of” -> (suggestion) “The MOS used here consists of”

- The introduction on MOS will be moved in section 2.4.

- L389-393: Unclear how exactly this works, please clarify.

We will clarify the methodology. We wrote “This method is a cross-validation method to assess how the MOS prediction will perform in practice. For each hour of a season, the dataset is divided in two parts: a) the actual data (or actual value), which is the value at the selected hour of the RAMS one-day ahead hourly forecast (or the MSG estimate of GHI) and the corresponding pyranometer observation, and: b) the training dataset, which is composed by all data in the season with the exception of the actual data. The Eqn. (1) is computed for the training dataset (y is the pyranometer value and x is the RAMS one-day ahead hourly forecast or the MSG estimate of GHI), and it is applied to the actual data, which is the x, to give the corrected forecast/estimate. Because the MOS is computed starting from hourly data, the training period is all the season but one hour. This procedure was repeated for all the hourly data in the season, obtaining the time series of corrected RAMS one-day ahead hourly forecast and the MSG corrected estimation of the GHI. The RMSE and rRMSE were computed for the corrected forecast/estimate of the GHI. In this way, the data used for computing MOS is statistically independent from the dataset used for the verification.”

- L402: Somewhat unclear how this conclusion can be made based on the above sentences.

-Ok. We will remove the sentence because it is not a direct consequence of the above sentences.

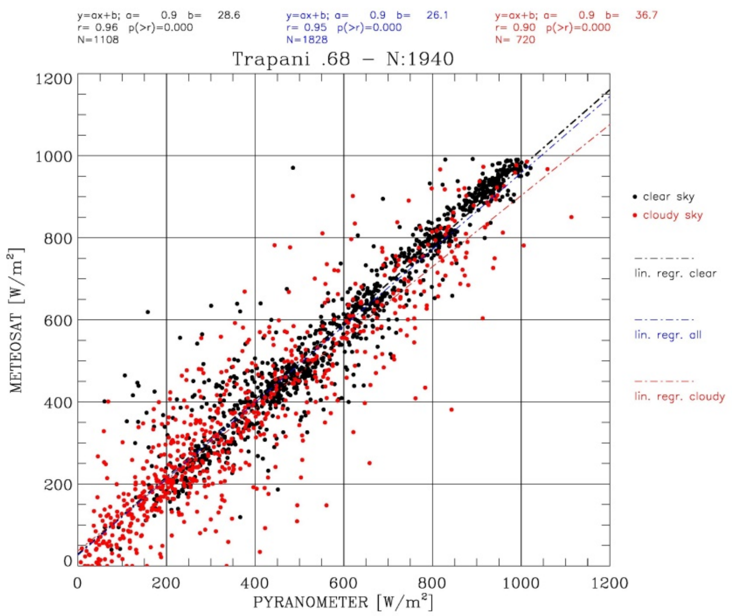
- L436-440 / L441-446: the latter paragraph presents discussion on performance as function of cloud classification, while the previous contains similar information, but indirectly. Maybe the paragraphs could be combined into one, or the order be changed, to make more effective and convincing communication.

-We will change the order of the two paragraphs and we will join them. We will write: "The cloud coverage has an important impact also on the RMSE of both MSG-GHI estimate and RAMS-GHI one-day forecast. The error is higher for cloudy conditions compared to clear sky. This is especially evident for RAMS because the RMSE averaged over all the stations varies from 91 W/m^2, to 191 W/m^2, and to 245 W/m^2 for clear, contaminated and overcast conditions, respectively; for MSG-GHI, the RMSE averaged over all stations varies from 68 W/m^2, to 123 W/m^2, and to 98 W/m^2 for clear, contaminated and overcast conditions, respectively. However, the analysis of the rRMSE reveals more clearly the impact of the cloud coverage on the performance. Both RAMS-GHI one-day forecast and MSG-GHI estimate show the largest rRMSE in winter and the lowest in summer, following the behaviour of the cloud coverage. It is also noted that the rRMSE of the RAMS-GHI one-day forecast for Trieste, Cimone and Aosta is about 100 % in winter."

Supplemental material

In the following, we show the scatterplots of the pyranometers and MSG-GHI hourly estimate (Figures 1-12 a) and the scatterplots of the pyranometers and RAMS-GHI one-day ahead hourly forecast (Figures 1-12 b) for all the stations considered in this paper. These figures will be given as a supplement to the paper.

a)



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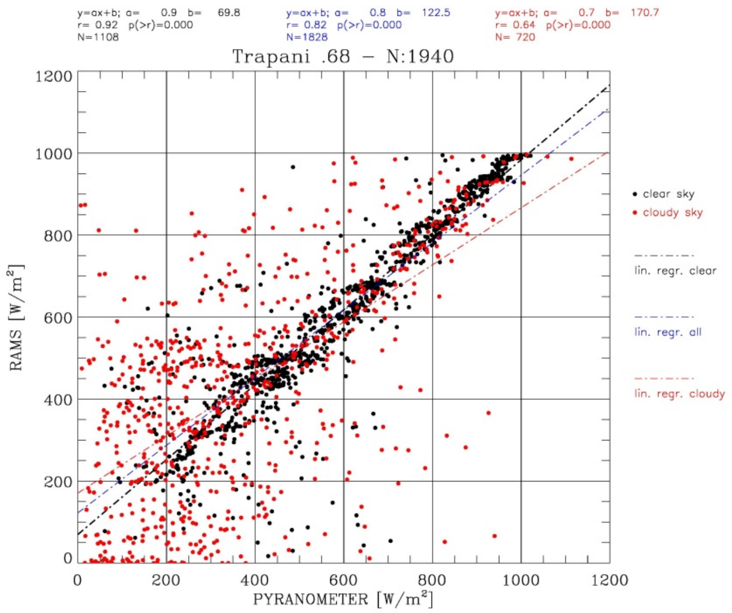
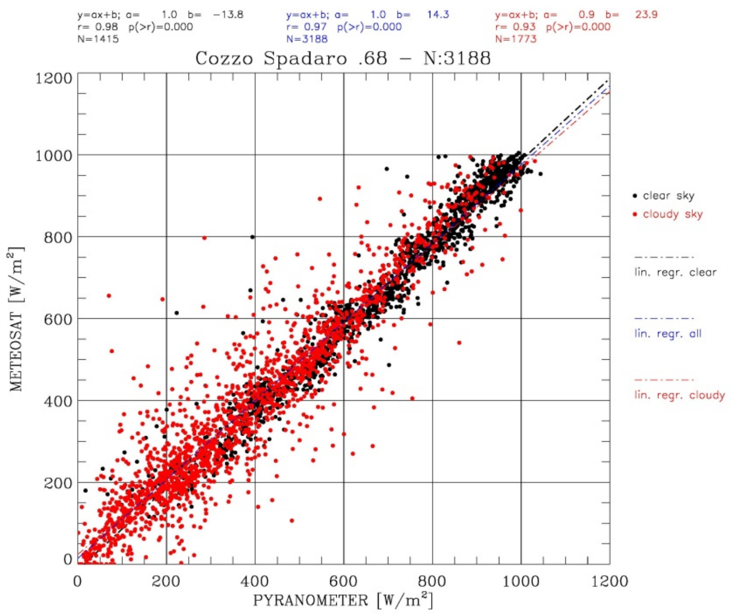


Figure 1 - TRAPANI: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



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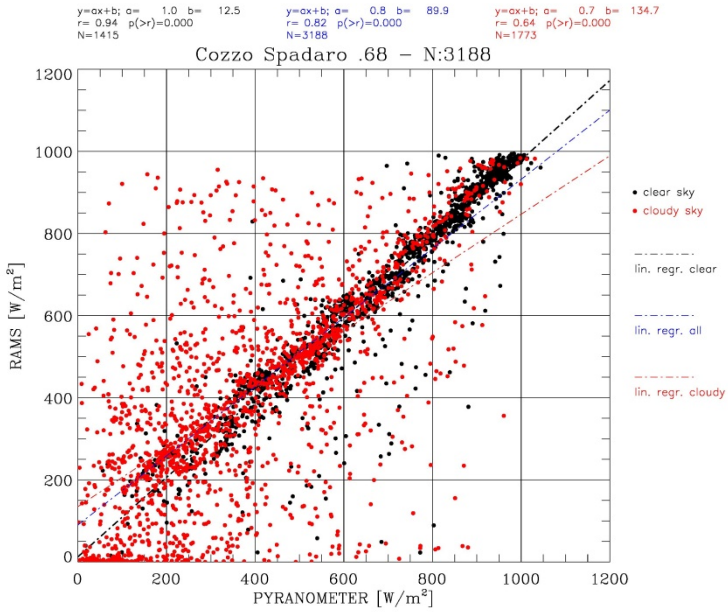
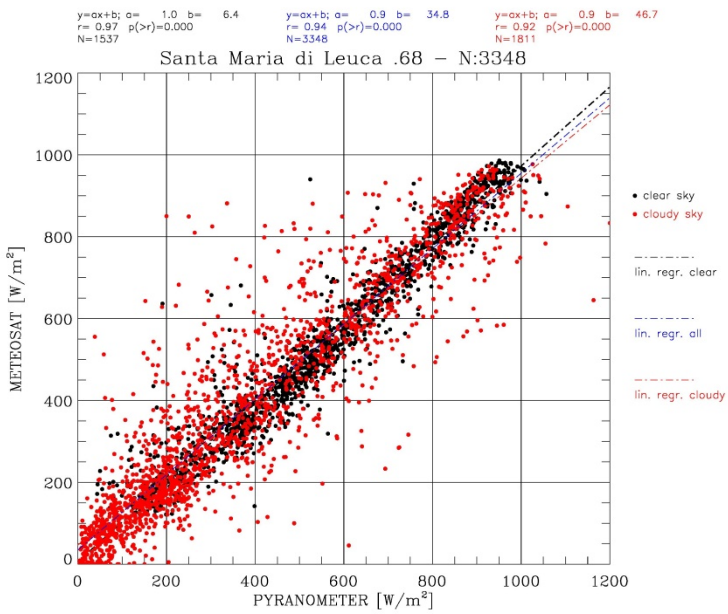


Figure 2 - COZZO SPADARO: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



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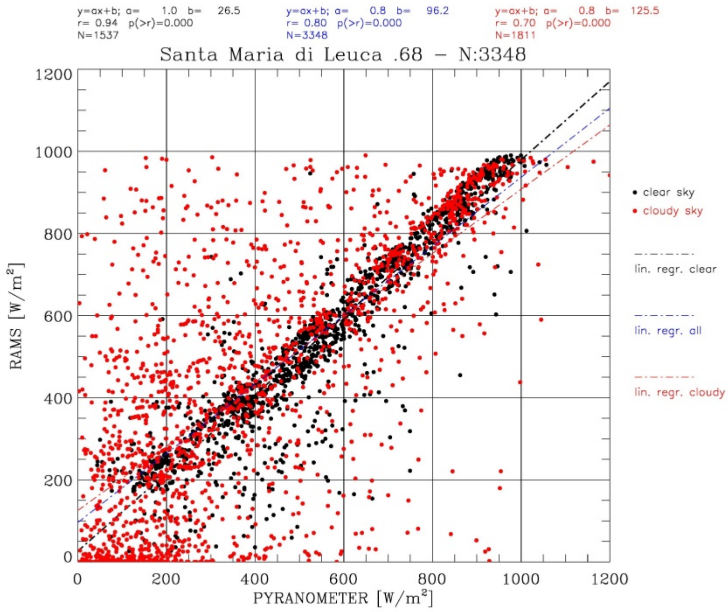
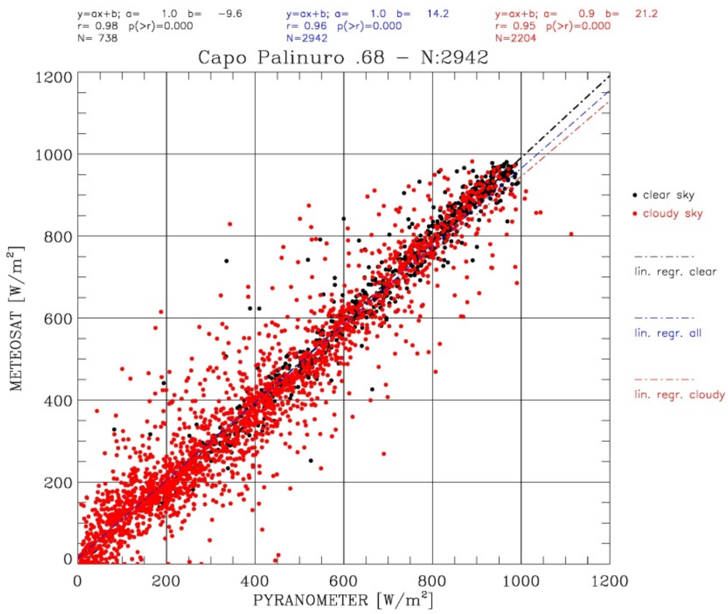


Figure 3 - SANTA MARIA DI LEUCA: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



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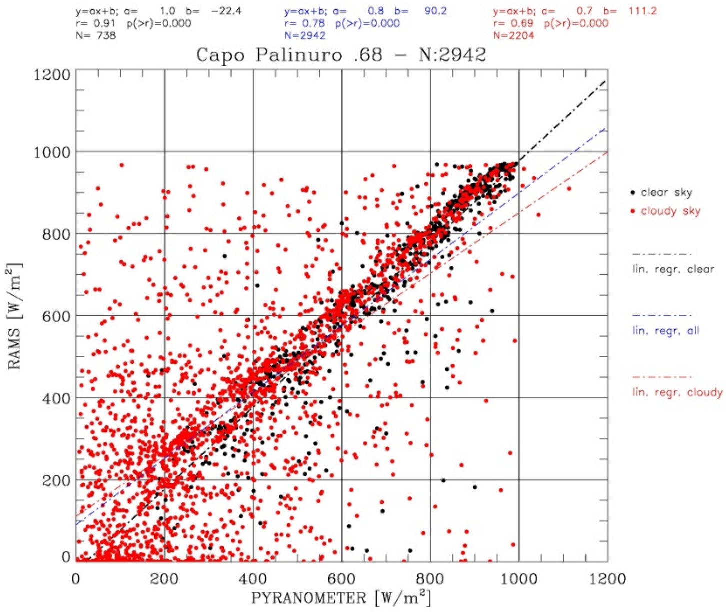
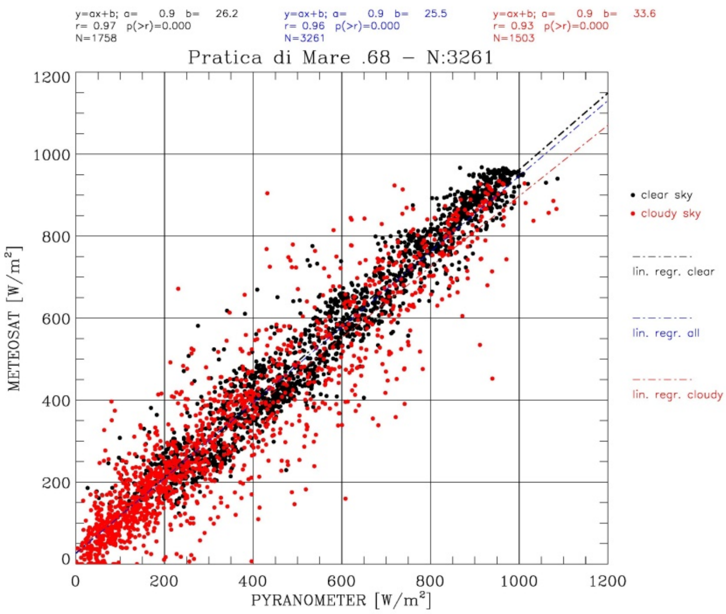


Figure 4 – PALINURO: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



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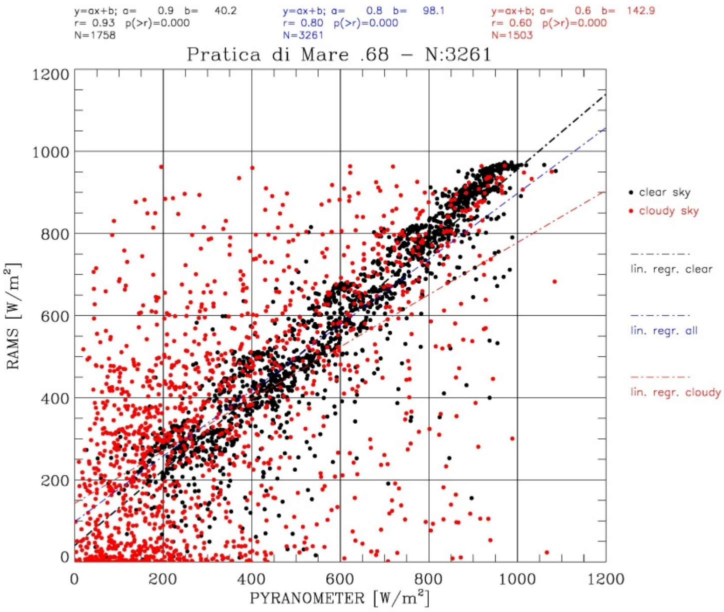
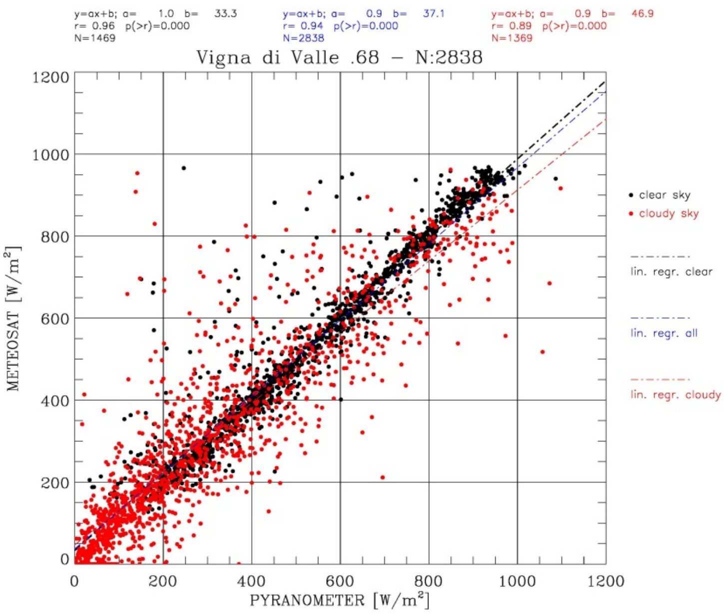


Figure 5 - PRATICA DI MARE: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



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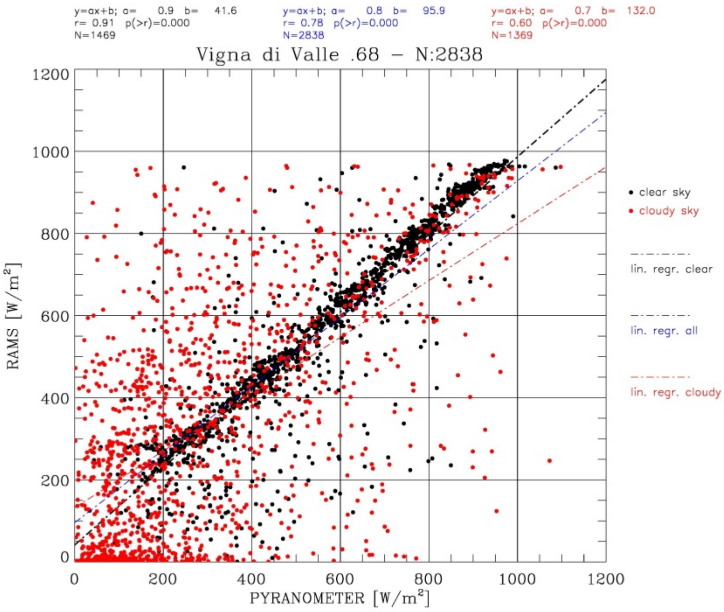
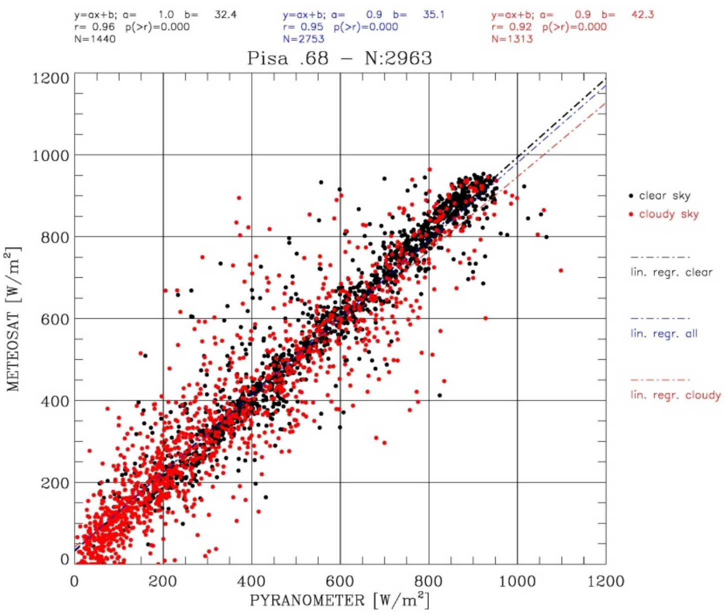


Figure 6 - VIGNA DI VALLE: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



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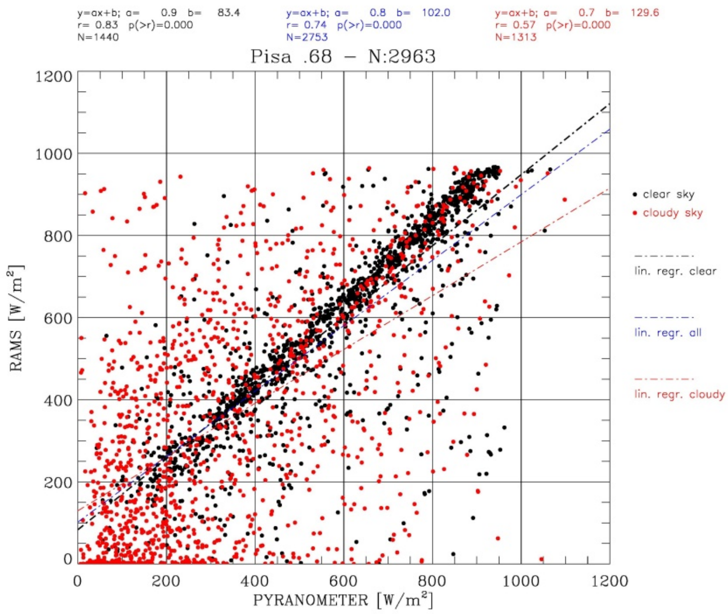
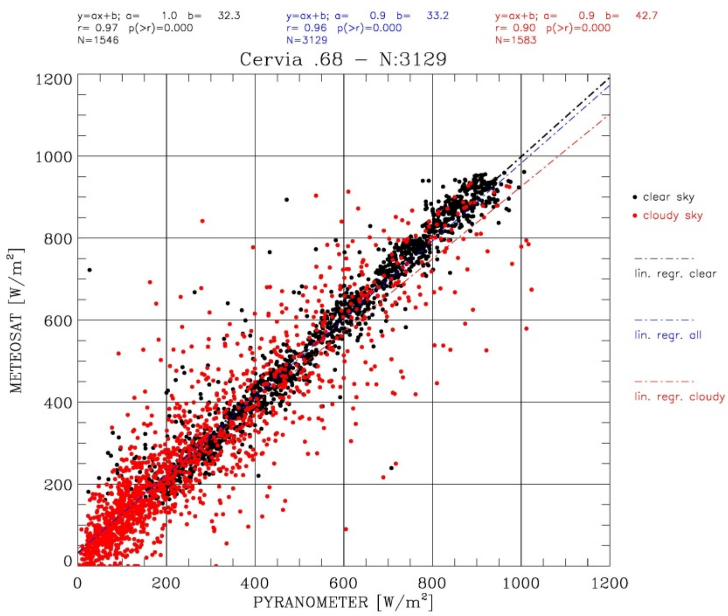


Figure 7 – PISA: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



b)

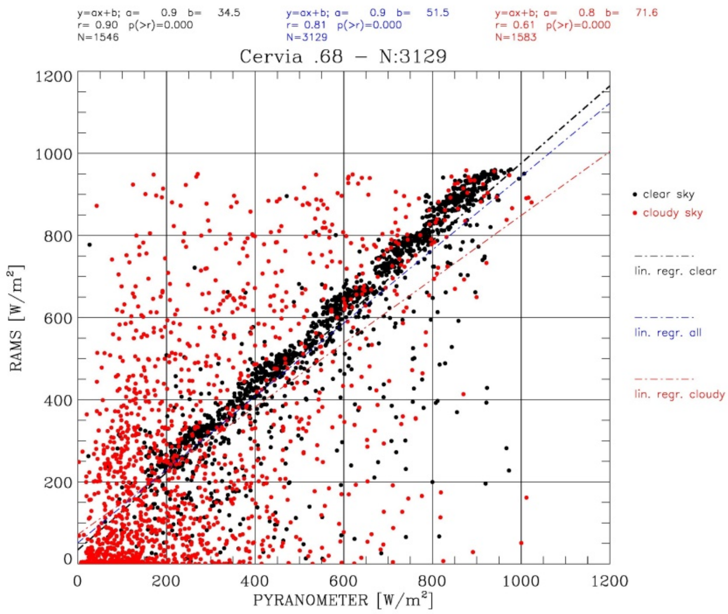
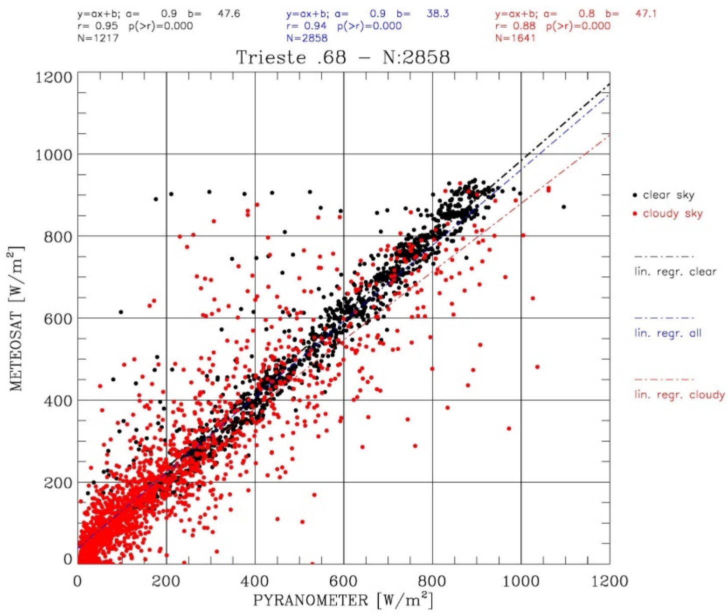


Figure 8 – CERVIA: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



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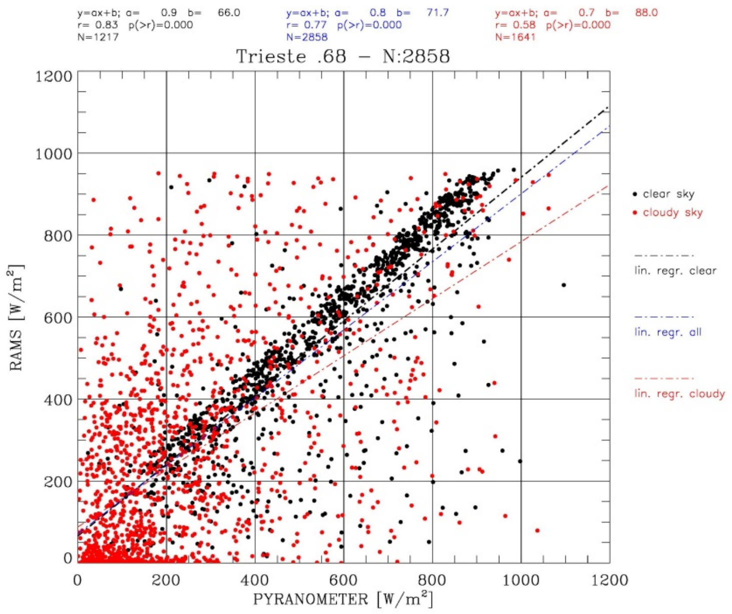
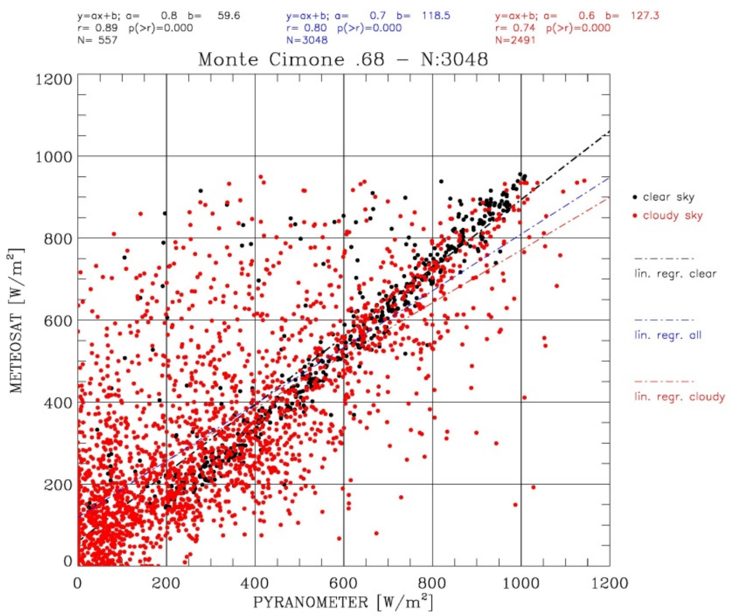


Figure 9 – TRIESTE: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



b)

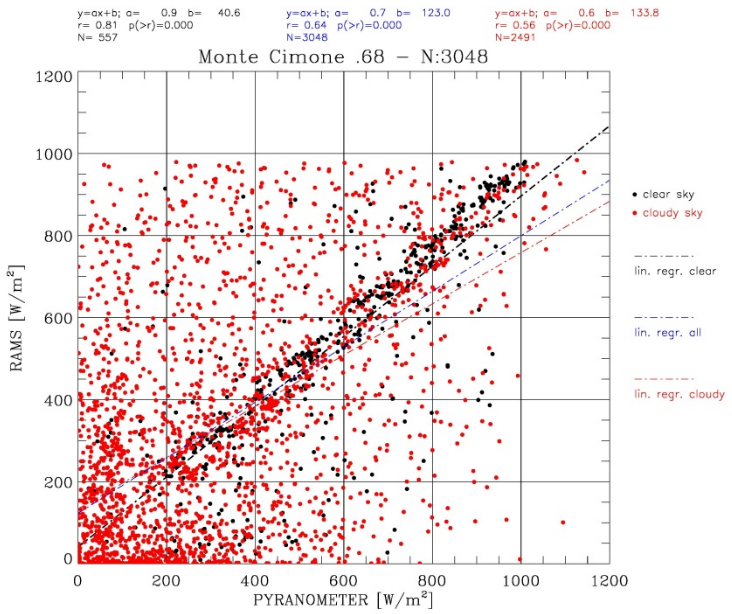
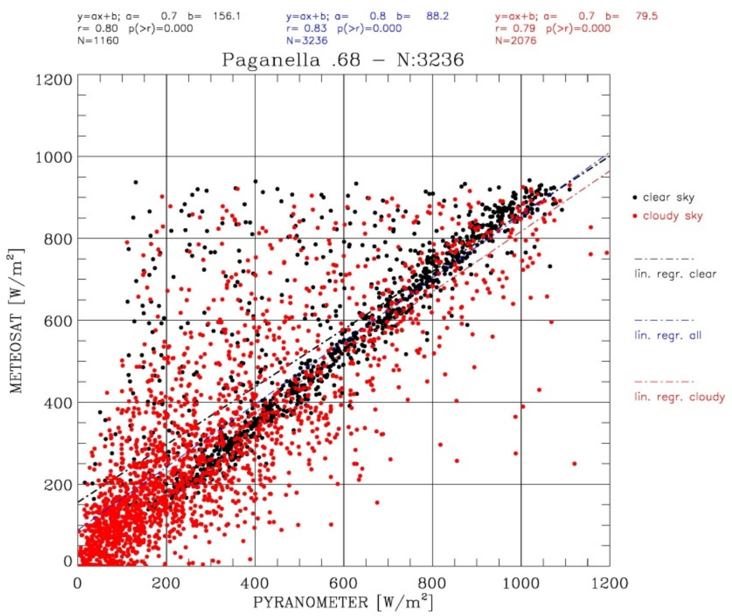


Figure 10 - MONTE CIMONE: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



b)

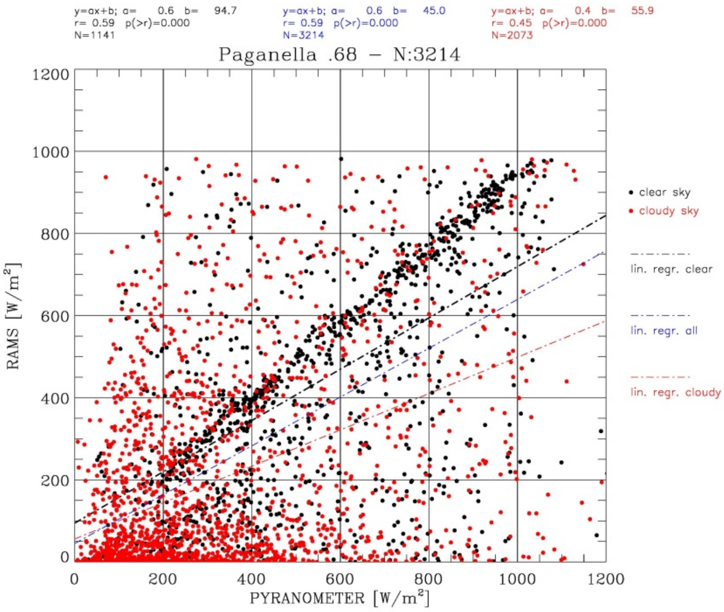
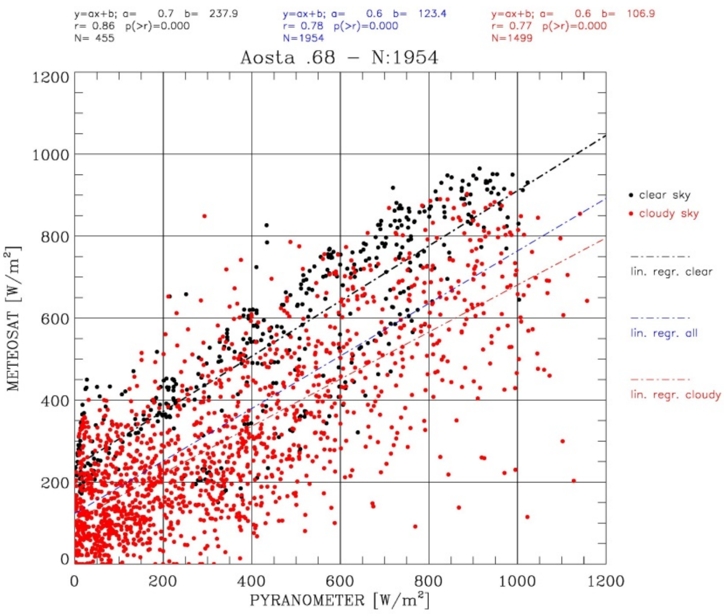


Figure 11 – PAGANELLA: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).

a)



b)

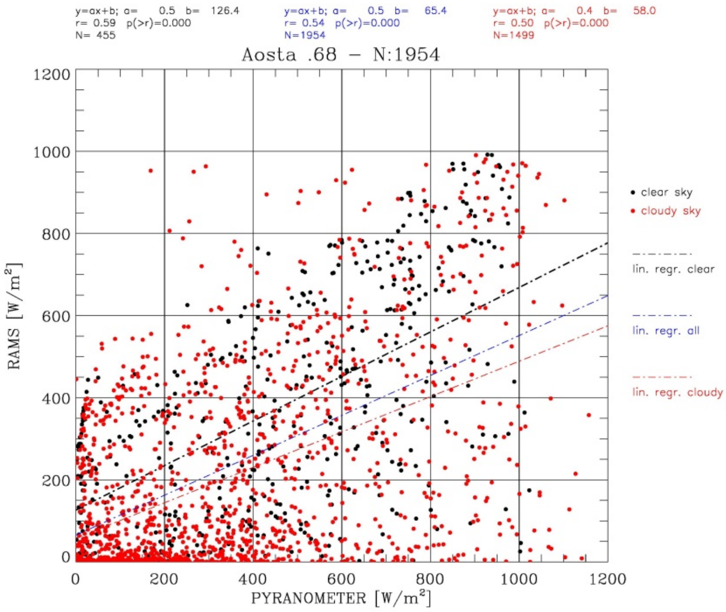


Figure 12 – AOSTA: a) scatter plot of the GHI for the pyranometer (x-axis) and MSG (y-axis). The black dots are for clear sky conditions while the red dots are for both contaminated and overcast skies; b) as in a) for the RAMS one-day ahead hourly forecast. Regression lines are shown in their respective colours (blue is for all data, i.e. both clear and cloudy conditions).