The EUMETSAT Network of Satellite Application Facilities

NWC SAF

Support to Nowcasting and Very Short Range Forecasting

Scientific and Validation Report for the Extrapolated Imagery Processor of the NWC/GEO

NWC/CDOP3/GEO/ZAMG/SCI/VR/EXIM, Issue 1.0

21 January 2019

Applicable to

GEO-EXIM-v2.0 (NWC-044)

Prepared by ZAMG

REPORT SIGNATURE TABLE

Function	Name	Signature	Date
Prepared by	A. Jann (ZAMG) R. Goler (ZAMG)		*21 January 2019*
Reviewed by	A. Giannakos (ZAMG) A. Jann (ZAMG)		*21 January 2019*
Authorised by	Pilar Rípodas (AEMET) *SAFNWC Project Manager*		*21 January 2019*

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1. INTRODUCTION

The EUMETSAT's "Satellite Application Facilities" (SAFs) are dedicated centres of excellence for processing satellite data, and form an integral part of the distributed EUMETSAT Application Ground Segment (http://www.eumetsat.int). This documentation is provided by the SAF on Support to Nowcasting and Very Short Range Forecasting, NWC SAF. The main objective of NWC SAF is to provide, further develop and maintain software packages to be used for Nowcasting applications of operational meteorological satellite data by National Meteorological Services. More information can be found at the NWC SAF webpage, http://www.nwc-saf.eumetsat.int.

1.1 Scope and purpose of the document

This document is the Validation Report for NWC/GEO Extrapolated Imagery Products (PGE16), for the NWC/GEO release 2018.

This document contains a description of the validation method and the corresponding results for the above-mentioned product.

1.2 Definitions, acronyms and abbreviations

BT	Brightness Temperature
CDOP	Continuous Development and Operations Phase
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
EXIM	Extrapolated Imagery
HRW	High-Resolution Winds
IR	Infrared
MSG	Meteosat Second Generation
NWP	Numerical Weather Prediction
PSS	Peirce Skill Score
PGE	Product Generation Element
SAF	Satellite Application Facility
SAFNWC	SAF to support NoWCasting and Very-Short-Range Forecasting
SEVIRI	Spinning Enhanced Visible and Infrared Imager
VIS	Visible
WV	Water Vapour

1.3 REFERENCES

1.3.1 Applicable Documents

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.X].

For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the current edition of the document referred applies.

Current documentation can be found at the NWC SAF Helpdesk web: http://www.nwc-saf.eumetsat.int.

Ref	Title	Code	Vers	Date
[AD.1]	Project Plan for the NWCSAF CDOP3 phase	NWC/CDOP3/SAF/AEMET/MGT/PP	1.0	06/03/18
[AD.2]	NWCSAF CDOP3 Project Plan Master Schedule	NWC/CDOP3/SAF/AEMET/MGT/PP/MasterSchedule	1.1	28/02/18
[AD.3]	Configuration Management Plan for the NWC SAF	NWC/CDOP3/SAF/AEMET/MGT/CMP	1.0	21/02/18
[AD.4]	System and Components Requirements Document for the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/SCRD	2.1	21/01/19
[AD.5]	Interface Control Document for Internal and External Interfaces of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/ICD/1	1.0	21/01/19
[AD.6]	Interface Control Document for the NWCLIB of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SW/ICD/2	1.0	21/01/19
[AD.7]	Data Output Format	NWC/CDOP3/GEO/AEMET/SW/DOF	1.0	21/01/19
[AD.8]	Component Design Document for the NWCLIB of the NWC/GEO	NWC/CDOP2/GEO/AEMET/SW/ACDD/NWCLIB	2.0	27/02/17
[AD.9]	NWC SAF Product Requirements Document	NWC/CDOP3/GEO/AEMET/MGT/PRD	1.0	01/18
[AD.10]	User Manual for the Tools of the NWC/GEO	NWC/CDOP3/GEO/AEMET/SCI/UM/Tools	1.0	21/01/19

Table 1: *List of Applicable Documents*

1.3.2 Reference Documents

The reference documents contain useful information related to the subject of the project. These reference documents complement the applicable ones, and can be looked up to enhance the information included in this document if it is desired. They are referenced in this document in the form [RD.X].

For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the current edition of the document referred applies.

Current documentation can be found at the NWC SAF Helpdesk web: http://www.nwc-saf.eumetsat.int.

Ref	Title	Code	Vers	Date
[RD.1]	The Nowcasting SAF Glossary	NWC/CDOP2/SAF/AEMET/MGT/GLO		
[RD.2]	User Manual for the Extrapolated Imagery Processor of the NWC/GEO: Science Part	NWC/CDOP3/GEO/ZAMG/SCI/UM/EXIM	1.0	21/01/19
[RD.3]	Algorithm Theoretical Basis Document for the Extrapolated Imagery Processor of the NWC/GEO	NWC/CDOP3/GEO/ZAMG/SW/ATBD/EXIM	2.1	21/01/19
[RD.4]	Scientific and Validation Report for the Extrapolated Imagery Processor of the NWC/GEO	NWC/CDOP2/GEO/ZAMG/SCI/VR/EXIM	1.0	22/05/17
[RD.5]	NWC SAF Product Requirements Document	NWC/CDOP3/SAF/AEMET/MGT/PRD	1.0	21/01/19

Table 2: *List of Referenced Documents*

2. GENERAL ASPECTS OF THE VALIDATION APPROACH

2.1 INPUT DATA

Table 3 lists the SEVIRI channels and the NWCSAF products to which EXIM has been applied in this evaluation exercise. All SAF products (including the high-resolution winds used for extrapolation) were computed using the consortium-internal pre-releases of the software for v2018.

Product	Abbreviation	Details
SEVIRI thermal infrared	IR3.9, IR8.7, IR9.7, IR10.8, IR12.0, IR13.4	3.9 µm, 8.7 µm, 9.7 µm, 10.8 µm, 12.0 µm, 13.4 µm
SEVIRI thermal water vapour	WV6.2, WV7.3	6.2 µm, 7.3 µm
SEVIRI visible	VIS0.6, VIS0.8, NIR1.6	0.6 µm, 0.8 µm, 1.6 µm
Convective Rainfall Rate	CRR	
Convective Rainfall Rate from Cloud Physical Properties	CRPh	
Cloud Mask	CMa	
Cloud Type	CT	
Cloud Top Temperature and Height	CTTH	
Precipitating Clouds	PC	
Precipitating Clouds from Cloud Physical Properties	PCPh	
Cloud Microphysics	CMIC	

***Table 3:** Satellite data and NWCSAF products used in this analysis*

2.2 METHODOLOGICAL ASPECTS

The NWCSAF Product Requirements Table (PRT) ([RD.5]) defines the threshold accuracy of EXIM as "*on average better than persistence forecast*". The target accuracy is to be "*always better than persistence forecast*". Thus, the validation approach is to compare the EXIM forecast with what was actually observed and verify that the displacement actually made a positive contribution to a skill score.

The Peirce Skill Score, also known as the "true skill statistic", is a measure of skill obtained by the difference between the hit rate and the false alarm rate of a forecast (see e.g. Wilks[1] 2006). For

[1] Wilks, 2006: Statistical Methods in the Atmospheric Sciences, Elsevier Inc., 649pp.

the 2 × 2 contingency table shown in Figure 1, the hit rate (*H*) or probability of detection is defined as:

$$H = \frac{a}{a+c} \qquad \text{Range } [0,1].$$

The false alarm rate (*F*) is defined as:

$$F = \frac{b}{b+d} \qquad \text{Range } [0,1].$$

The Peirce Skill Score (*PSS*) is thus defined as:

$$PSS = H - F = \frac{ad - bc}{(a+c)(b+d)} \qquad \text{Range } [-1,1].$$

If the PSS is greater than zero, then the number of hits exceeds the false alarms and the forecast has some skill.

		Observed: Yes	Observed: No	
Forecast	Yes	a	b	a + b
Forecast	No	c	d	c + d
		a + c	b + d	n = a + b + c + d

Figure 1: *A 2 × 2 contingency table showing the relationship between counts (letters a, b, c, d) of forecast/event pairs.*

The PSS is used here to evaluate the performance of EXIM against the persistence forecast. The analysis of each product is done by choosing a threshold value and assigning a "Yes" ("No") to each pixel depending on whether its value is above (equal to or below) this threshold. This is done for both EXIM, persistence, and the observed field. The results of each pixel from the EXIM and persistence forecasts, respectively, are then compared with those of the observed field and the number of hits and misclassifications are counted. It is from these values that the PSS is calculated. The only two products where this method cannot be applied are:

- the Cloud Type product which has a (large) number of qualitative categories;
- the Cloud Phase sub-product of the Cloud Microphysics package, with the three categories "liquid", "ice", "mixed".

For these, a multicategorical variant of the PSS was used, as provided by the *R* package 'verification', routine *multi.cont*.

For each lead time (+15, +30, +45, +60 minutes), the PSS was calculated over the whole domain twice, using:

(i) EXIM as a forecast: PSS(EXIM), and

(ii) Persistence as a forecast: PSS(Persistence).

For a given lead time, this domain average will be referred to as a "case".

2.3 BACKGROUND

The EXIM software underwent an important change between the evaluations described in the main body of the precursor validation report [RD.4] and the release in a patch to NWC/GEO v2016. In the initial version, a single displacement field was used for all satellite channels and NWC/GEO products, mixing vectors derived from all channels and being assigned to any height. It was agreed later after some expert discussions to concentrate on extrapolation of the features most prominently reflected in the individual channels, and in turn to discard displacement vectors stemming from other layers. Hence, IR imagery eventually was extrapolated with high-level IR/VIS vectors ("high level" means: < 400 hPa; the vectors are derived from VIS 0.6 and 0.8, HRVIS, IR 10.8 and 12.0; for GOES-N, just VIS 0.7 and IR 10.7 are available), VIS imagery with low-level IR/VIS AMVs (> 700 hPa). The extrapolated NWCSAF products were assumed to be generally driven to a higher degree by the higher clouds, so the used trajectories were the same high-level ones as for the IR imagery. The water vapour absorption bands have different characteristics which should allow to avoid any thresholding, i.e. WV6.2 is extrapolated with all WV6.2 vectors that are generated by the HrW module (and analogously for WV7.3).

Preliminary evaluation results on this changed use of IR/VIS vectors were already presented in a last-minute Annex C in [RD.4]. The first impression expressed there was that the superiority of EXIM (over persistence) was still visible but being less pronounced than before. Subsequently, we found particularly strong deterioration of the results of extrapolating the CMa product. An obvious candidate for explaining such a deterioration is the reduced number of vectors describing the extrapolation field compared to the previous EXIM version, thus perhaps leading to an inferior description of the overall atmospheric movement. This suspicion can be easily substantiated by consulting the presentation of the HrW product on the NWCSAF HelpDesk and exploiting the "visualization-by-layer" option there: **Figure 2** shows a visualization of high-layer vectors, while **Figure 3** shows the vectors in the layer 600-1000 hPa, and **Figure 4** comprises all vectors derived by the NWCSAF reference system for that particular slot. Clearly, if one accepts only vectors from the highest layer, wide low-cloud areas over the Atlantic Ocean will be treated with vectors derived from high-cloud areas being thousands of kilometres away. On the other hand, though there are also considerable data-void areas in **Figure 3**, the high-cloud areas often have several low-layer vectors at the edge, hence the process to derive vectors in the voids often has the character of interpolation (over smaller distances) rather than extrapolation. This could ultimately explain why e.g. the CMa extrapolation was found to work better with the low-level displacement field, contrary to the first-guess assumption implemented in version 2016.

An important background information for the assessment is that the interpolation approach exploits at any pixel the closest five HrW vectors only [RD.3]. Moreover, cloudfree pixels are not subject to any extrapolation in VIS/IR channels or SAF products. With this in mind, it is hard to spot places in **Figure 4** where distinctly different flow regimes in the high and low layer are actually mixed: only at the rear side of the frontal band south of Iceland, the direction shows a 90° jump and interpolated vectors may therefore fit neither, but it is very doubtful whether this local problem in one place serves as a justification to withdraw consistent vectors over major parts of the scene. As **Figure 4** also suggests, whatever pressure threshold is set to delimit the layer of accepted vectors, the adjacent 100-hPa band contains then-omitted additional information, which generally complements the used vectors seamlessly. The "two-layer" approach described below might be a way to reconcile both ambitions: 1) to strictly separate low-level and high-level flow; 2) to make maximum use of the available HrW information about the atmospheric flow[2].

Yet, of course, **Figure 2-Figure 4** merely gave a spotlight on a single case, so the idea behind the present validation is to provide a sound statistical basis to make statements about the impact of differently formed displacement fields on the various channels/products potentially displaced by the EXIM software. In every case considered in this exercise, there were four extrapolation runs using different models of deriving the displacement fields from the HrW input:

1. Accepting only low-layer winds, where "low layer" is defined as the layer from 700 hPa to the Earth surface
2. Accepting only high-layer winds, where "high layer" is defined as everything above 400 hPa
3. The "two-layer model", which computes a displacement field for the "high layer" and one for the "low layer". It is determined for every pixel whether the majority in the vicinity are "high-level" or "low-level" vectors and the respective displacement field is applied to that pixel.
4. The "All HrW" approach, accepting every vector found in the HrW output.

(Note: Users of NWC/GEO v2018 can actually switch between those alternatives via modification of parameters in configuration files; cf. section 4 and the detailed instructions in [RD.2].)

[2] A remaining open issue is that, in the current implementation of the "two-layer" scheme, it may happen that some low-layer/high-layer pixels are interpolated with vectors from the other layer. Inclusion of CTTH-based filtering and assessment of its benefit shall be investigated in the subsequent validation exercise.

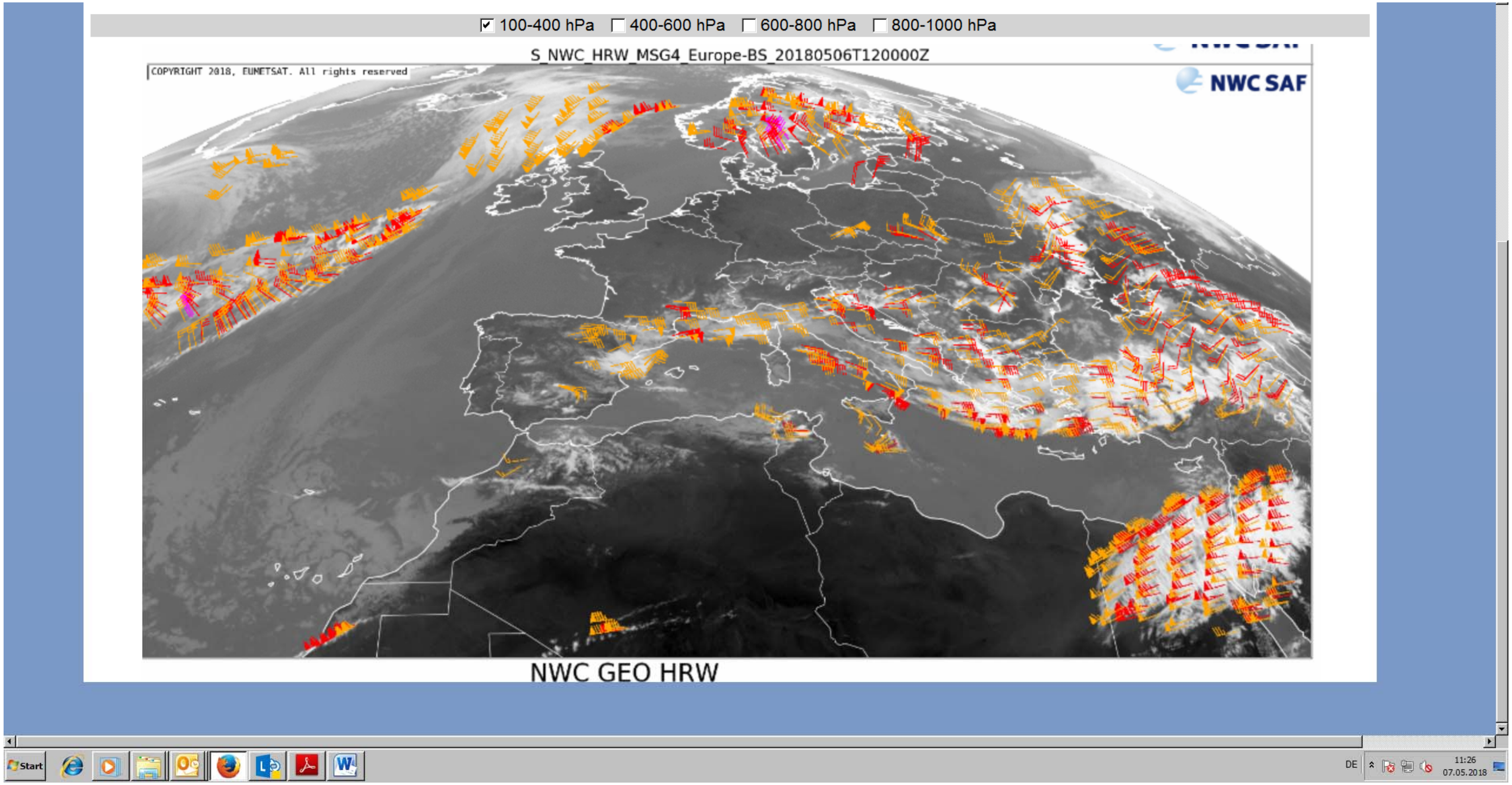


Figure 2: *HrW visualization on the NWCSAF HelpDesk for 6 May 2018, 12 UTC, only vectors from high atmospheric layers (magenta: 100-200 hPa; red: 200-300 hPa; orange: 300-400 hPa).*

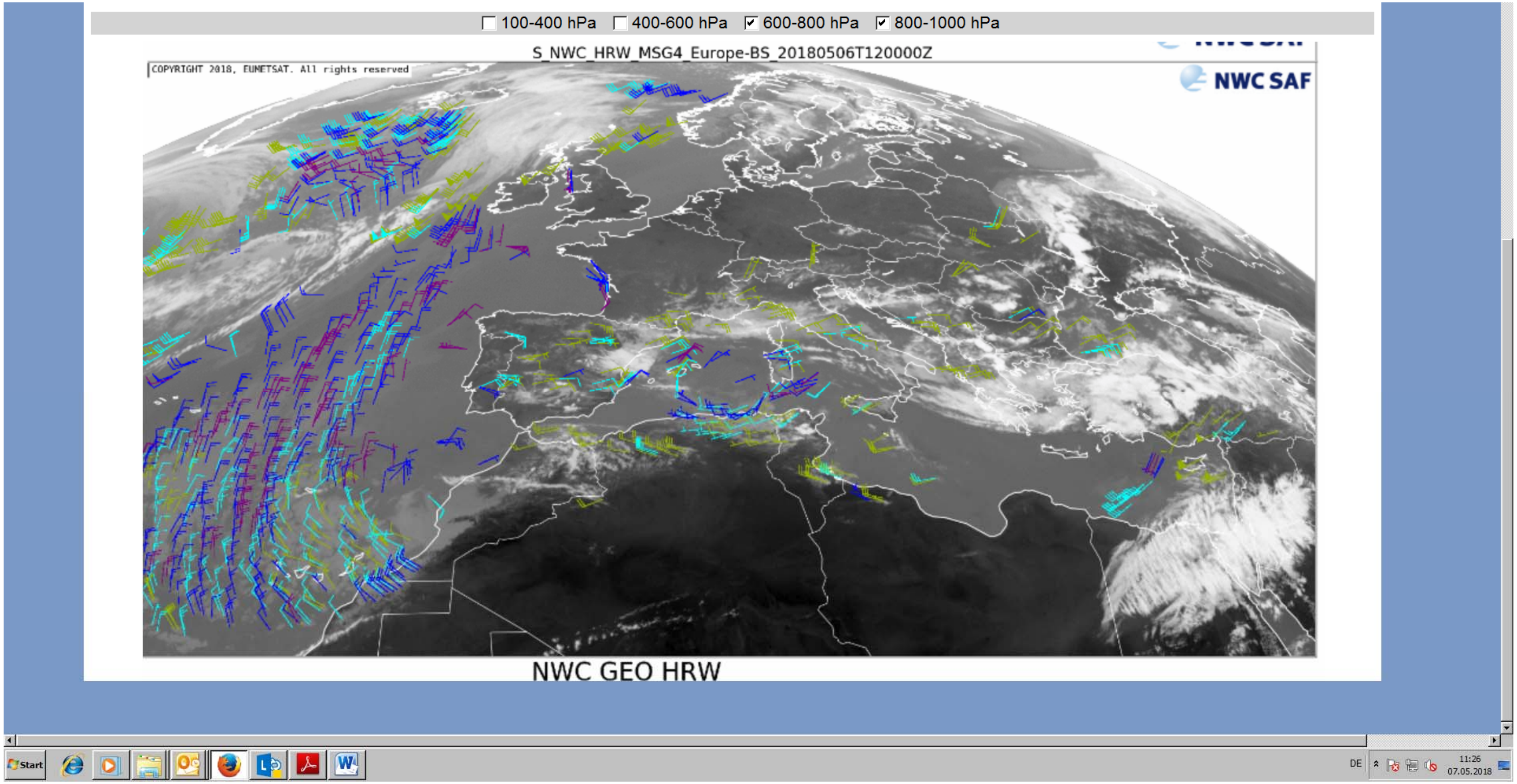


Figure 3: *HrW visualization on the NWCSAF HelpDesk for 6 May 2018, 12 UTC, only vectors from low atmospheric layers (green: 600-700 hPa; cyan: 700-800 hPa; blue: 800-900 hPa; violet: 900-1000 hPa).*

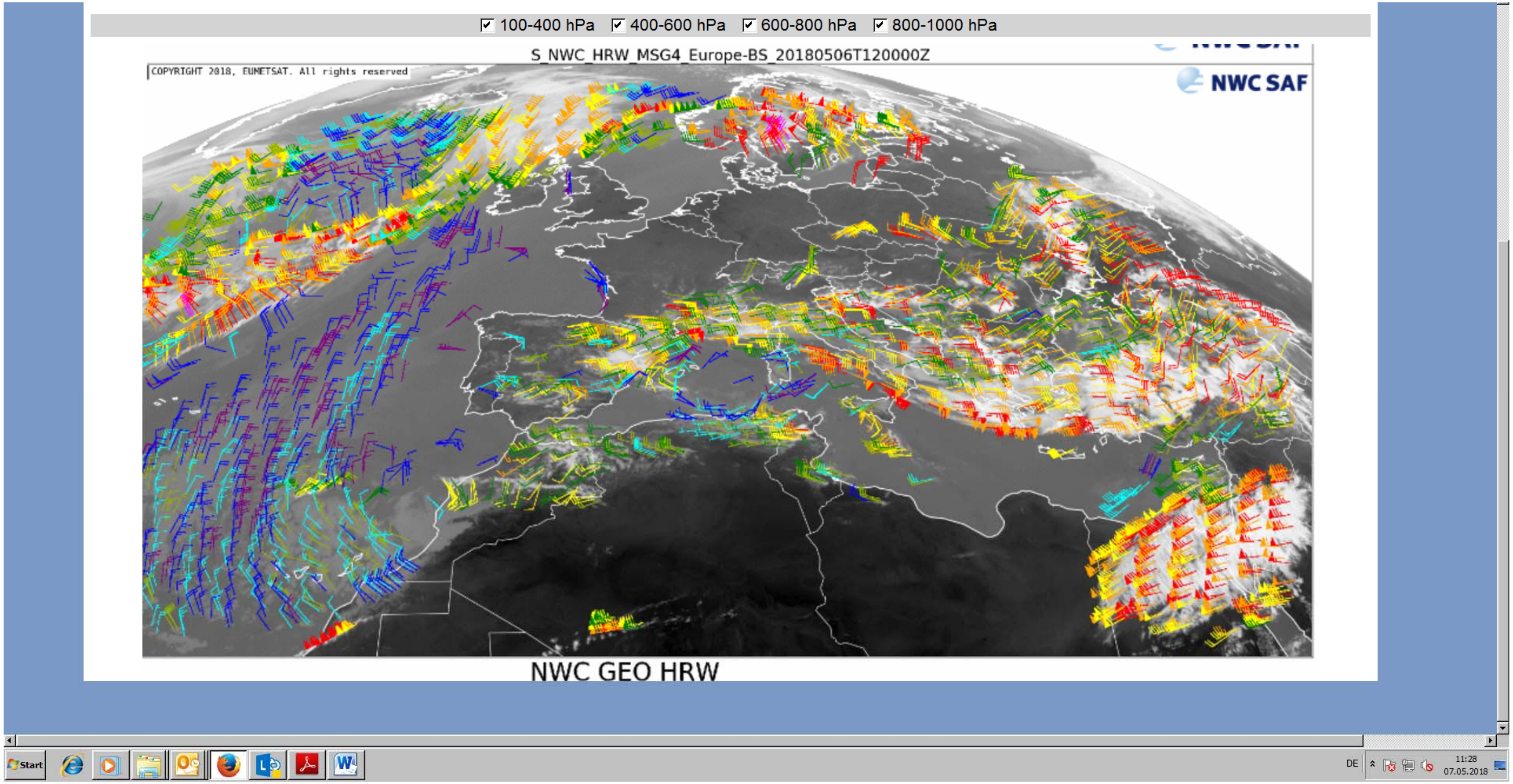


Figure 4: *HrW visualization on the NWCSAF HelpDesk for 6 May 2018, 12 UTC, all atmospheric layers (magenta: 100-200 hPa; red: 200-300 hPa; orange: 300-400 hPa; yellow: 400-500 hPa; dark green: 500-600 hPa, light green: 600-700 hPa; cyan: 700-800 hPa; blue: 800-900 hPa; violet: 900-1000 hPa).*

2.4 VALIDATION DATASET

For the validation activities, a descoped operational chain v2018 was established (i.e. suppressing all NWCSAF components not needed for the EXIM evaluation). No change was applied to the High-resolution Winds (HRW, v6.0) default model configuration file. On the other hand (as announced in the precursor [RD.4], to address a problem in CTTH evaluations detected there), the internal segment size used during computation of cloud products was configured to be 1 (i.e. everything computed on single-pixel basis). The covered geographical area is shown in Figure 5; 3-hourly ECMWF data (0.25º resolution) formed the supplementary NWP input.

A side effect of the chosen NRT approach (and the considerable computation time of four EXIM runs plus associated evaluations) is the more comprehensive evaluation of shorter lead times since the Task Manager regularly removed older satellite images that would have been required as starting point of computation of the forecast. Still, the results differed not so much between the tested lead times, so that it was decided to not invest perfective efforts on this aspect. The positive effect of the NRT approach of course is the much larger number of cases than could have been obtained with a more manually driven collection of cases.

The EXIM skill scores were logged every hour (i.e. up to 24 times per day, where the channel or the product allows it). The four considered lead times, for which EXIM forecasts were evaluated, were: +15, +30, +45, and +60 minutes.

The evaluations ran over the period 18 April – 6 June 2018. It was intended to investigate, as a side-issue, the impact of a user-configurable switch to include cloudfree areas in the extrapolated product, for the VIS and IR channels (available since v2016). The setting may have an impact on the evaluation statistics yet had not been addressed before. Hence, in Phase I (18-30 April 2018), this switch was turned to "off", in Phase II (commencing on 1 May 2018) it was turned "on" (while the sequential procedure is sub-optimum from a methodological point of view, the unaffordable demands of eight parallel runs for cloudfree "yes vs. no" plus four extrapolation schemes dictated to do so). Then, on 8 May, it was discovered that there was a slight omission in the adaptation of the two-layer approach to new naming conventions of the HrW input, whereby the two-layer approach did not exploit the HRVIS winds (whereas the three competing schemes did, inadvertently favouring them). The correction of this glitch called for the definition of Phase III (9 May – 6 June 2018). At that point, it was deemed that w.r.t. the extrapolation of the WV channels (neither affected by the low-layer vs. high-layer issues nor by the question of inclusion of cloudfree areas), enough material had already been collected in the first two phases, so the experiments were relieved from the respective computations in this phase. **Table 4** summarizes the characteristics of the phases.

Phase	Period (in 2018)	Cloudfree areas in VIS/IR?	Remark
I	18-30 April	No	Two-layer extrapolation approach ran without HRVIS HrW
II	1-8 May	Yes	Two-layer extrapolation approach ran without HRVIS HrW
III	9 May-6 June	Yes	Extrapolation of WV 6.2 and 7.3 suspended

Table 4: *The three phases of the validation.*

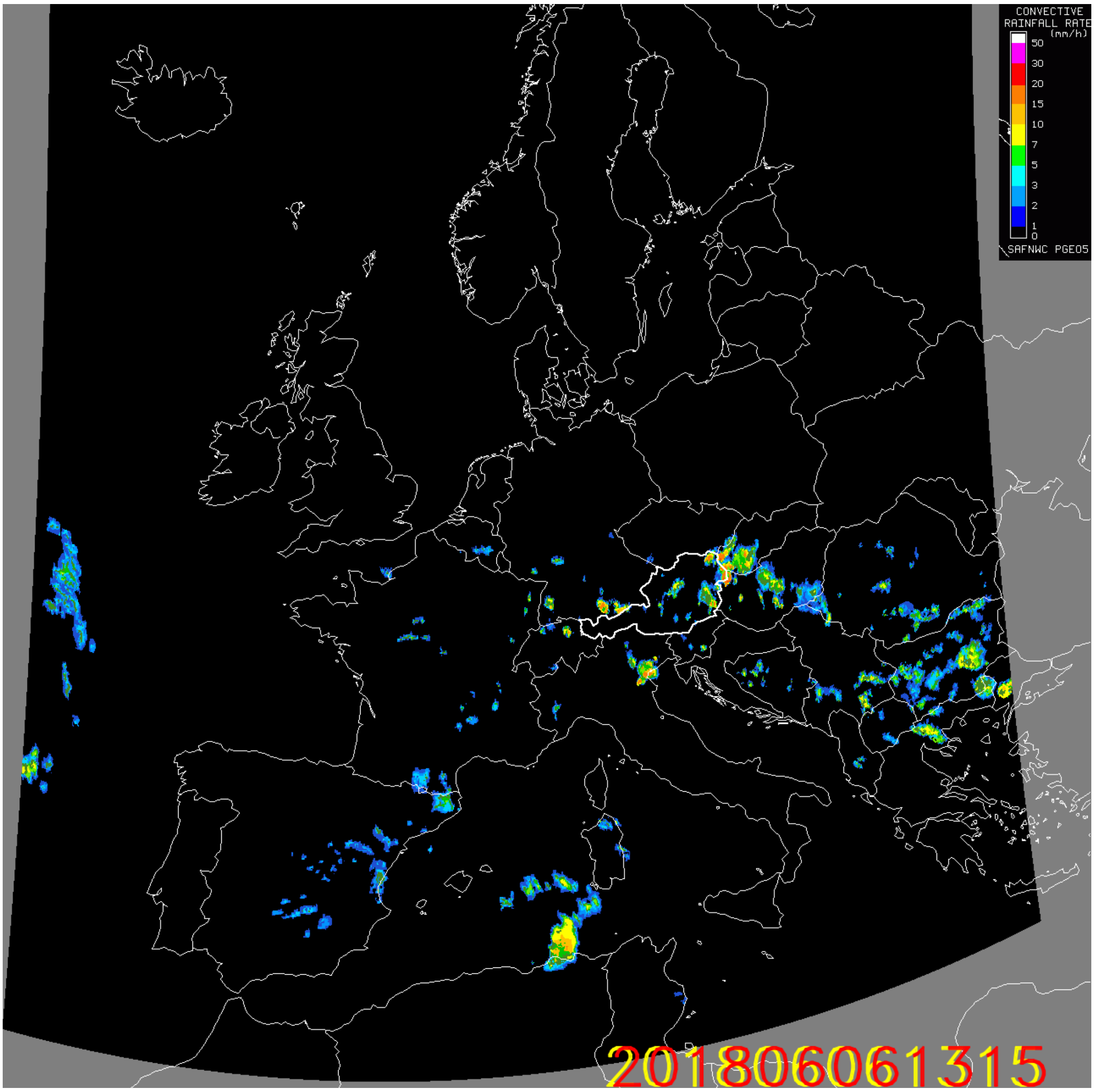


Figure 5: *Geographical area over which the analyses were performed.*

3. RESULTS

Only summary interpretations of the numerical results are provided in this chapter; detailed supplementary material is provided in an Annex, section 6.

3.1 THERMAL CHANNELS: INFRARED

This section presents results for the SEVIRI thermal infrared channels, i.e. wavelengths 3.9 µm - 13.4 µm with the exception of the two water vapour channels which are dealt with in 3.3.

3.1.1 Disregarding cloudfree areas (=Phase I, 18-30 April 2018)

The tables and graphics documenting the skill score evaluations in detail can be found in the Annex, ch. 6.1.1. The statistics confirmed that the approach implemented in version 2016, using only high-layer vectors cannot be maintained, but also the self-constraint to low-layer vectors shows consistent weaknesses, particularly in the colder areas of the 8-13 micron images (HrW voids, where the displacement is done with interpolated low-level vectors from greater distances). From the tables, the empirical diagnosis is extremely clear for the infrared channels. “All HrW” is the clear winner, followed by the two-layer model being the best choice among the variants not mixing vectors from different layers. As the diagrams show, there is in most cases only a narrow (albeit systematic) margin between the two; this may justify speculations that a two-layer scheme using all vectors (the employed variant neglected those between 400 and 700 hPa, cf. ch.2.3) could well compete with the “All HrW” scheme.

3.1.2 Under inclusion of cloudfree areas (Phases II and III, 1 May – 6 June 2018)

The tables and graphics documenting the skill score evaluations in detail can be found in the Annex, ch. 6.1.2. Though a few figures in the tables are surprising, not yet well understood and perhaps worth further thoughts[3], the conclusions are the same as in 3.1.1 with respect to the main question addressed by the validation.

[3] e.g. a “High-layer HrW” success rate for channel 12.0, 270 K, 60 minutes lead time, that jumps from 0 to around 90% by adding the cloudfree areas to the output image – beating the persistence much more often by adding persistence forecast there. The samples were not the same, of course, but this difference nevertheless appears quite hefty. The explanation may lie in a combination of smaller number of pixels and/or more uncertainties in the CMa at the warmer temperature (nothing comparable is found for the 240 K isoline!).

3.2 VISIBLE CHANNELS

This section presents results for the SEVIRI visible channels 0.6 and 0.8 µm, the evaluations in this case being carried out on the forecasts of the parameter reflectivity (expressed in %).

3.2.1 Disregarding cloudfree areas (=Phase I, 18-30 April 2018)

The tables and graphics documenting the skill score evaluations in detail can be found in the Annex, ch. 6.2.1. Though the scheme implemented in version 2016, using only low-layer winds for visible channels, occasionally yields the highest *PSS* values (usually for the darker portions of the image), the overall impression is that one generally fares better when allowing the full set of vectors. No clear winner can be identified from the comparison between low-layer and two-layer approach yet the differences are so substantial in some instances that one cannot consider the approaches as “equivalent”. The comparison of extrapolation versus persistence for any vector field suggests that the EXIM forecasts for the leadtime of +60 minutes have little prognostic value.

In general, the performance of EXIM for the visible channels is not as good as for the thermal channels. One important factor (impacting also the readability of the graphics in 6.2) are the diurnally varying illumination conditions. Even though (Central European) night hours were excluded from the evaluation, the predictability of isolines is clearly affected, particularly strong where dusk/dawn conditions are present over parts of the domain (no illumination corrections were attempted during this exercise). The EXIM forecast imagery may still be useful there for a qualitative application, but for quantitative evaluations like those presented here, one should envisage a restriction to pixels with high solar zenith angle in future.

3.2.2 Under inclusion of cloudfree areas (Phases II and III, 1 May – 6 June 2018)

The tables and graphics documenting the skill score evaluations in detail can be found in the Annex, ch. 6.2.2. As in 3.2.1, the “All HrW” scheme tends to show the best scores, whereas it is hard to decide between the “low-layer HrW” scheme (again strong in the darker parts) and the two-layer model (where the inclusion of high-level winds brings benefit only to the brighter/higher parts). The scores for EXIM vs. persistence generally went down compared to 3.2.1 (explanation pending), which supports the decision to make the suppression of cloudfree areas in the output the default.

3.3 THERMAL CHANNELS: WATER VAPOUR

The SEVIRI thermal water vapour channels consist of the spectral bands centred on the wavelengths 6.2 µm and 7.3 µm. The situation with respect to the displacement field is more straightforward than for the other channels as the height variations of the signals are comparatively small. Here is no need to investigate about which layers / set of vectors to use: these channels can safely be extrapolated using their respective HrW winds, and this has indeed always been done in EXIM’s history. The very satisfactory results reported in [RD.4] could be reproduced for the new HrW release:

- For WV6.2, the EXIM forecast of the 225-K isoline beats persistence in 99.7%/97.9%/98.1%/90.9% of the investigated cases for lead times +15/+30/+45/+60 minutes.
- The corresponding figures for the 235-K isoline are 94.2%/95.8%/98.6%/100%.
- For WV7.3, the EXIM forecast of the 230-K isoline beats persistence in 99.2%/98.8%/100%/97.3% of the investigated cases for lead times +15/+30/+45/+60 minutes.

- The corresponding figures for the 250-K isoline are 100%/100%/100%/98.6%.

The time series plots of skill scores can be found in the Annex, ch. 6.3.

3.4 CMA: CLOUD MASK

The tables and graphics documenting the skill score evaluations in detail can be found in the Annex, ch. 6.4.1. From them, it is all too obvious that the extrapolation with high-layer HrW carried out in v2016 can no longer be maintained in light of these evaluation results. The empirical diagnosis leads to the clear recommendation to use the “All HrW” approach, followed by the two-layer model being the best choice among the variants not mixing vectors from different layers.

It is interesting to see how the scores went down in Phase III, despite having added the HRVIS vectors. This requires an additional study with another setup, however, before making any general statement/recommendation.

3.5 CT: CLOUD TYPE

After having presented the results for IR channels and the CMa product, the conclusions from the statistics for the Cloud Type (CT) product are hardly surprising (the tables and graphics documenting the skill score evaluations in detail can be found in the Annex, ch. 6.4.2). We see a clear recommendation to use the “All HrW” approach, followed by the two-layer model being the best alternative among the variants not mixing vectors from different layers.

Interestingly, the inclusion of HRVIS winds in phase III had a positive impact, except for the low-layer approach (recall that this was not the case for the CMa product, ch 3.4).

3.6 CTTH: CLOUD TOP TEMPERATURE AND HEIGHT

The tables and graphics documenting the skill score evaluations in detail can be found in the Annex, ch. 6.4.3. Not unexpectedly, the CTTH results most conspicuously demonstrate the impact of confining oneself to a narrow layer of HrW input: the low-layer approach seems acceptable for the 4000m-isoline whereas for the 8000m-isoline, the high-layer approach clearly performs better. The schemes using vectors from (almost) all layers of course lead the overall statistics, “All HrW” doing a little better.

3.7 CMIC: CLOUD MICROPHYSICS

The CMIC (Cloud Microphysics) product suite has been considered as a potential EXIM output in v2018 for the first time. In such a situation, the basic question to be answered by the evaluation is whether it is justified that the quantities are to be included in the EXIM program. Some quantities simply do not move with the atmospheric flow (such as the iSHAI output that was excluded already in v2016) and should be withheld from the EXIM portfolio. The considered five CMIC parameters comprise: cloud thermodynamical phase, drop effective radius, cloud optical thickness liquid water path, and ice water path.

For the sake of brevity, no detailed numerical results are presented for “liquid water path” and “cloud effective radius” – the comparison of EXIM vs. persistence forecast clearly revealed that these two parameters are not amenable to the kinematic extrapolation technique. Tables and graphics documenting the skill score evaluations for the other CMIC parameters can be found in the Annex, ch. 6.4.4.

For "cloud optical thickness", there is some skill, but only if the "All HrW" approach is chosen and even then the numbers are not convincingly far from the 50/50 mark. For "ice water path", a similar picture emerged, so both should probably not be offered in the EXIM module at the time being. Rather, the user acceptance of the "All HrW" approach and the actual user need of extrapolation of these parameters should be assessed before an experimental release is envisaged. However, it is proposed to take the CMIC "cloud phase" on board in v2018 since the value of the forecasts is very nicely substantiated by the obtained skill scores. The arguments to choose the "All HrW" option are particularly striking for this parameter.

3.8 CRR: Convective Rainfall Rate

The Convective Rainfall Rate (CRR) product estimates the rain rate from convective clouds. The tables and graphics documenting the skill score evaluations in detail can be found in the Annex, ch. 6.4.5.

For this parameter, the assumption of v2016 that its displacement is driven mainly by the high-layer HrW obviously applies (it is in fact to be expected from the product design that signals are linked to high clouds). The improvements incurred by "All HrW" and the two-layer model seem rather marginal.

The high fluctuations in **Figure 45** and **Figure 46** are due to cases with only a few pixels above the threshold (forecast success then becomes rather random). The April/May period was certainly not the optimum one to investigate this particular product; the usual life cycle of convective activity leads to further reduction of high-rate pixels during night, which should explain the apparent diurnal variation in the figures.

3.9 CRR-Ph: Convective Rainfall Rate from Cloud Physical Properties

The tables and graphics documenting the skill score evaluations in detail can be found in the Annex, ch. 6.4.6.

Like for the CRR product in 3.8, the scores clearly reflect the fact that rain shown in the CRR-Ph product is rather associated with high clouds → as long as we have the high-layer vectors somehow included in the extrapolation, the results are good. The comparison identifies "All HrW" as the empirically best approach, followed by "two-layer" and "high-layer".

The fluctuations in predictability are even more pronounced than for CRR. In fact, from **Figure 48**, one might suspect that the CRR_Ph forecast is worthless most of the time. However, the same comments as for CRR (section 3.8) apply, and very low skill scores observed in cases of almost no convective precipitation should not be misconstrued as quality measures of the forecast product as a whole (for statements on this, one should rather consult [RD.4]).

3.10 PC: Precipitating Clouds

The Precipitation Clouds (PC) product estimates the likelihood of precipitation occurrence. Though we are aware that there is a considerable difference between the day and night algorithm of this product, we made no attempts to discriminate between the two (or to avoid the night algorithm, which is known to yield worse results, as in [RD.4]). The scope is different this time, and a large sample for relative comparison judged more important than the cleanness of absolute skill score values (the strong diurnal variations exhibited in **Figure 49** and **Figure 50** therefore had to be expected; the graphics and all tables documenting the skill score evaluations in detail can be found in the Annex, ch. 6.4.7).

Unlike the CRR product, PC yields also substantial non-zero signals in areas covered by low clouds. Though it is still true that the assumption of v2016 to displace it by the high-layer HrW is the more appropriate choice than the low-layer candidate, the improvements incurred by "All HrW" and the two-layer model are more pronounced than in the CRR case, and it seems logical to expect this difference coming mainly from the better handling of the low-cloud areas.

3.11 PCPH: PRECIPITATING CLOUDS FROM CLOUD PHYSICAL PROPERTIES

The Precipitation Clouds from Cloud Physical Properties (PCPh) product provides an estimation on the probability of precipitation occurrence which is similar to PC, but instead uses the cloud top microphysical properties, effective radius, and cloud optical thickness. The tables and graphics documenting the skill score evaluations in detail can be found in the Annex, ch. 6.4.8.

The "better than persistence" scores are higher than for PC, so the patterns of the "physical" product somehow better observe the atmospheric flow indicated by HrW. And the different character of the physical product also seems to make modelling the low-layer flow less relevant as the "high-layer HrW" approach is more competitive here. Still, the ranking sees "All HrW" as the winner, followed by the two-layer approach.

4. CONCLUSIONS

EXIM utilises calculated atmospheric motion vectors (AMVs) to extrapolate the motion of features from satellite data, or products generated from satellite data, to produce nowcasts in 15 minute intervals out to one hour. The success of the forecasts from EXIM has been evaluated by comparing them with what was observed. As a basis to determine how good EXIM is, the persistence forecast is also compared with the observations. The success of both EXIM and Persistence were evaluated using the Peirce Skill Score (PSS), with higher values corresponding to a better performance.

As mentioned earlier, the NWCSAF Product Requirements Table in [RD.5] defines the threshold accuracy of EXIM as "*on average better than persistence forecast*". The target accuracy is defined as "*always better than persistence forecast*"; the optimal accuracy (which by construction is almost impossible to achieve) is described as "all advective changes are perfectly captured". Non-advective changes are one argument to justify a certain tolerance about the term "always" when judging whether target accuracy is reached or not: in cases of newly developing or strongly decaying systems, neither EXIM nor persistence may capture the near future very well, and the relative performance is fairly random. Hence, for verifying on target accuracy, we rather check here whether EXIM performs better in the vast majority of cases, and thus arrive at the following judgements. The table in [RD.4] was derived from results of an "All HrW" approach, and the current situation is described again using the "All HrW" results shown in ch. 3. This "All HrW" approach is generally, judged by the *PSS* values, the optimum scheme so that it is to be used in order to describe what can in principle be accomplished with the EXIM software (relevant changes with respect to [RD.4] are noted in the table where applicable):

Parameter	Threshold accuracy reached?	Target accuracy reached?
SEVIRI IR Channels	Yes	Yes over most of the temperature range; the incorporation of the cloud mask to suppress extrapolation in cloud free areas is accomplished in v2018
SEVIRI WV channels	Yes	Yes
SEVIRI VIS channels	Yes (recommendation to choose the option of masking cloudfree areas)	No. Incorporation of the cloud mask to suppress extrapolation in cloud free areas is accomplished in v2018
SEVIRI NIR1.6	No (from [RD.4], not re-evaluated in the current validation)	No
CMa	Yes	Yes for leadtime 15 minutes
CT	Yes	Yes
CTTH	Yes	Yes
CMIC	Yes for "cloud phase". No for the other sub-products, but keep "cloud optical thickness" and "ice water path" as candidates in the next evaluation; the results for "cloud effective radius" and	Yes for "cloud phase"

	"liquid water path" do not warrant any further consideration of these sub-products.	
PC	Yes	No
PC-Ph	Yes	Yes
CRR	Yes	Yes for leadtime ≤ 30 minutes
CRR-Ph	Yes	Not yet (but improved compared to precursor CRR-Ph version)
iSHAI	No (from [RD.4], not re-evaluated in the current validation)	No

If one considers the results from the low end of the performance rankings, there is a group of parameters where one should certainly NOT choose the "high-layer HrW" approach: the VIS channels, CMa, CT, CMIC. For the other input (IR channels, CTTH, PC, PCPh, CRR, CRRPh), the "high –layer HrW" approach can make sense, but usually only for those parts of the image related to the higher clouds. One may assume that these are the most interesting parts where a good forecast is desired. With that, one arrives at the conclusion that the EXIM software shall offer options to define one selection of layer(s) to extrapolate VIS, CMa, CT, CMIC, and another selection to extrapolate IR, CTTH, PC, PCPh, CRR, CRRPh. Actually, however, the EXIM developers must recommend, on the basis of the evaluation results, not to differentiate and to use in both cases the "All HrW" approach.

5. OUTLOOK

It is foreseen to address in the next round of validation efforts the issue briefly mentioned in footnote 2: in the current version, it may happen that some low-layer/high-layer pixels are interpolated with vectors from the other layer (this is true for each of the four candidate schemes compared here). The statistics shall give insight into the benefit of extrapolating pixels with the "right" layer (using the CTTH product to determine it). The ultimate product design will be decided upon the evaluation results (plus user consultation): a newly introduced quality flag may inform about any unfavourable local conditions, or pixels could even be entirely removed from the extrapolation process if no suitable vectors are found in the vicinity.

6. ANNEX

In this annex, selected validation statistics are presented both in tabular and graphical form. Every sub-chapter starts with a collection of tables presenting first the percentage of cases where the EXIM forecast for the indicated channel, brightness temperature isoline and leadtime excelled the persistence "forecast". Then the tables show the comparisons of the skill scores obtained for the four tested displacement fields; for this, the skill scores were ranked for any case and ranks were counted. The tables show the percentages of how often a certain displacement field gave the best, second-best,…,worst *PSS* among the four candidates. As a concrete example, we consider the following table, showing results for forecasts of the 270 K-isoline of channel IR8.7:

Channel 8.7, 270 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	97.5	100.0	20.3	100.0
Best	0.0	100.0	0.0	0.0
Second-best	93.7	0.0	0.0	6.3
Third	6.3	0.0	3.8	89.9
Fourth	0.0	0.0	96.2	3.8

The first line shows that the requirement of being better than persistence is very well met with three of the four displacement fields; only the usage of "high-layer HrW" is apparently inadequate for this relatively warm (=low-level) brightness temperature values. Inspecting the three promising candidates further, we see that the "All HrW" approach yielded the highest *PSS* in all investigated cases, the two-layer model (despite its non-perfect score against persistence) ranked second in 93.7% of all cases, in that sense outperforming the "low-layer HrW" approach, with just 6.3% in that category and 89.9% being only third in the comparison of actual extrapolations.

Still, in order to have the full picture, one should also consider how significant the numerical difference in PSS between the investigated schemes is. Therefore, every set of tables for a certain channel and isoline is supplemented by diagrams showing PSS time series[4] for the used forecast models. The presentation is restricted to leadtimes of +15 and +60 minutes; one can safely assume that the values for +30 and +45 minutes lie in-between the two extremes. Also the range of investigated isolines was wider than indicated in the tables/graphics, yet we strived to limit the presentation to a few representative values (i.e. where the skill score does not depend on the correct forecast of a few extreme pixels).

[4] The time series feature 8 additional days (until 14 June 2018) as the quadruple EXIM runs were inadvertently continued over this period after the evaluations for the tables had been carried out.

It is perhaps worth recalling that the *PSS* is based on assigning a "Yes" to each pixel where the parameter value is above the threshold indicated in the upper left corner of the table, and a "No" for values equal to or below this threshold.

6.1 Thermal Channels: Infrared

6.1.1 Disregarding cloudfree areas (=Phase I, 18-30 April 2018)

Channel 3.9, 260 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	87.9	96.6
Best	0.0	100.0	0.0	0.0
Second-best	97.1	0.0	2.9	0.0
Third	2.9	0.0	66.2	30.9
Fourth	0.0	0.0	30.9	69.1

Channel 3.9, 260 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	99.5	100.0	86.6	95.7
Best	0.0	100.0	0.0	0.0
Second-best	97.9	0.0	2.1	0.0
Third	2.1	0.0	70.1	27.8
Fourth	0.0	0.0	27.8	72.2

Channel 3.9, 260 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	81.5	98.8
Best	0.0	100.0	0.0	0.0
Second-best	98.8	0.0	0.0	1.2
Third	1.2	0.0	67.9	30.9
Fourth	0.0	0.0	32.1	67.9

Channel 3.9, 260 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	95.5	100.0	45.5	95.5
Best	0.0	100.0	0.0	0.0
Second-best	90.9	0.0	0.0	9.1
Third	9.1	0.0	31.8	59.1
Fourth	0.0	0.0	68.2	31.8

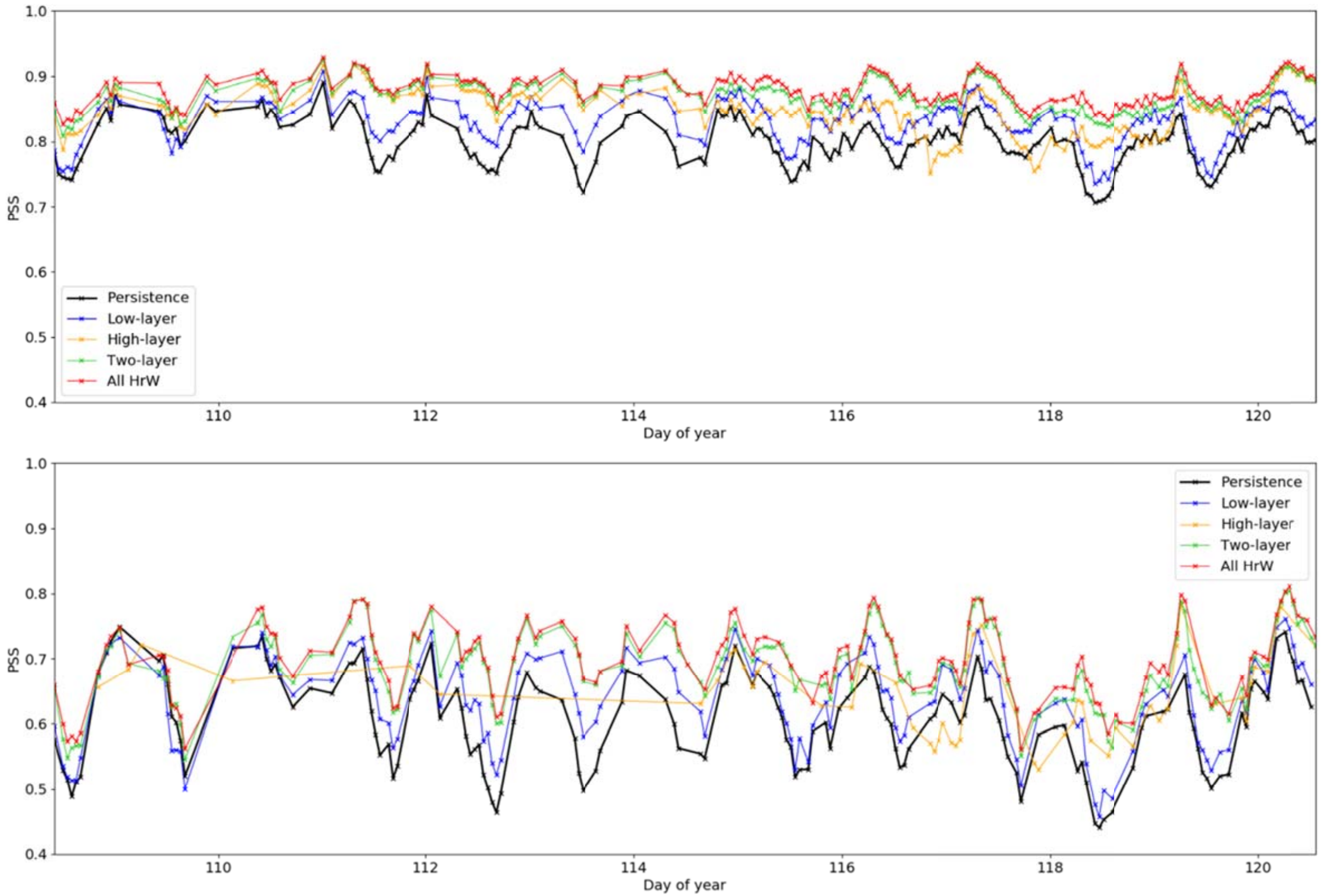


Figure 6: *PSS time series for the IR3.9 260K-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

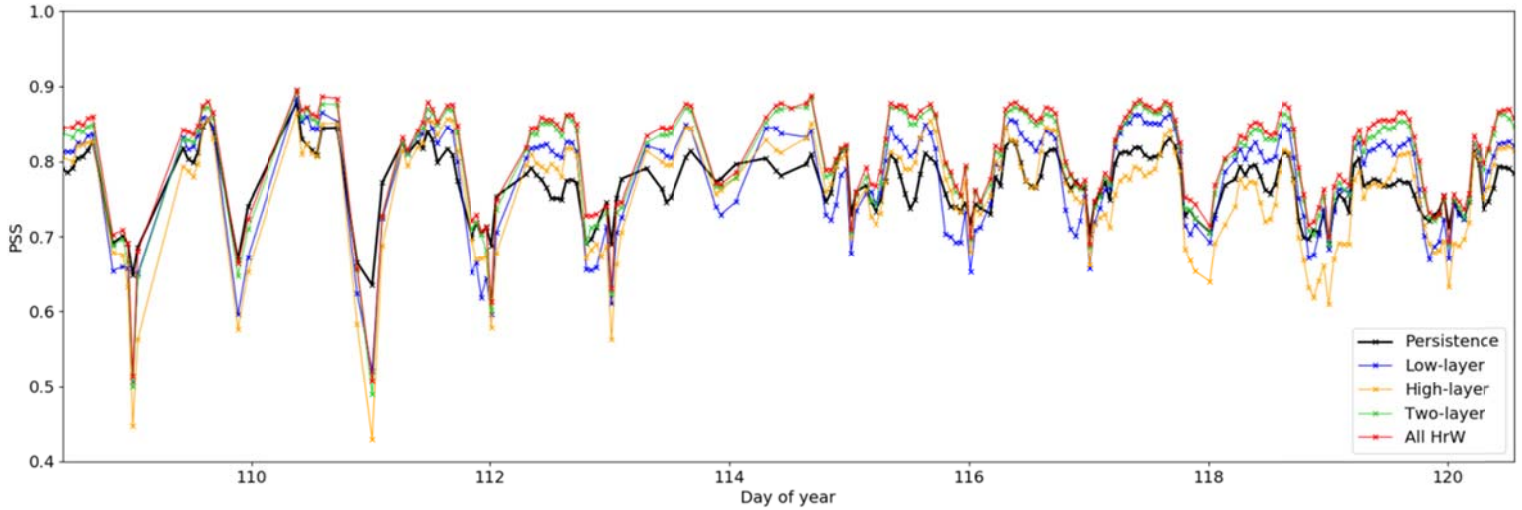
Channel 3.9, 280 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	69.6	76.8	34.8	66.2
Best	0.0	99.5	0.0	0.5
Second-best	95.2	0.5	0.0	4.3
Third	4.8	0.0	25.1	70.0
Fourth	0.0	0.0	74.9	25.1

Channel 3.9, 280 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	63.6	66.3	29.9	60.4
Best	0.5	97.9	0.0	1.6
Second-best	92.5	2.1	0.0	5.3
Third	7.0	0.0	30.5	62.6
Fourth	0.0	0.0	69.5	30.5

Channel 3.9, 280 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	61.7	64.2	25.9	64.2
Best	3.7	93.8	0.0	2.5

Second-best	84.0	4.9	0.0	11.1
Third	12.3	1.2	25.9	60.5
Fourth	0.0	0.0	74.1	25.9

Channel 3.9, 280 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	18.2	18.2	0.0	18.2
Best	9.1	72.7	0.0	18.2
Second-best	68.2	22.7	0.0	9.1
Third	22.7	4.5	27.3	45.5
Fourth	0.0	0.0	72.7	27.3



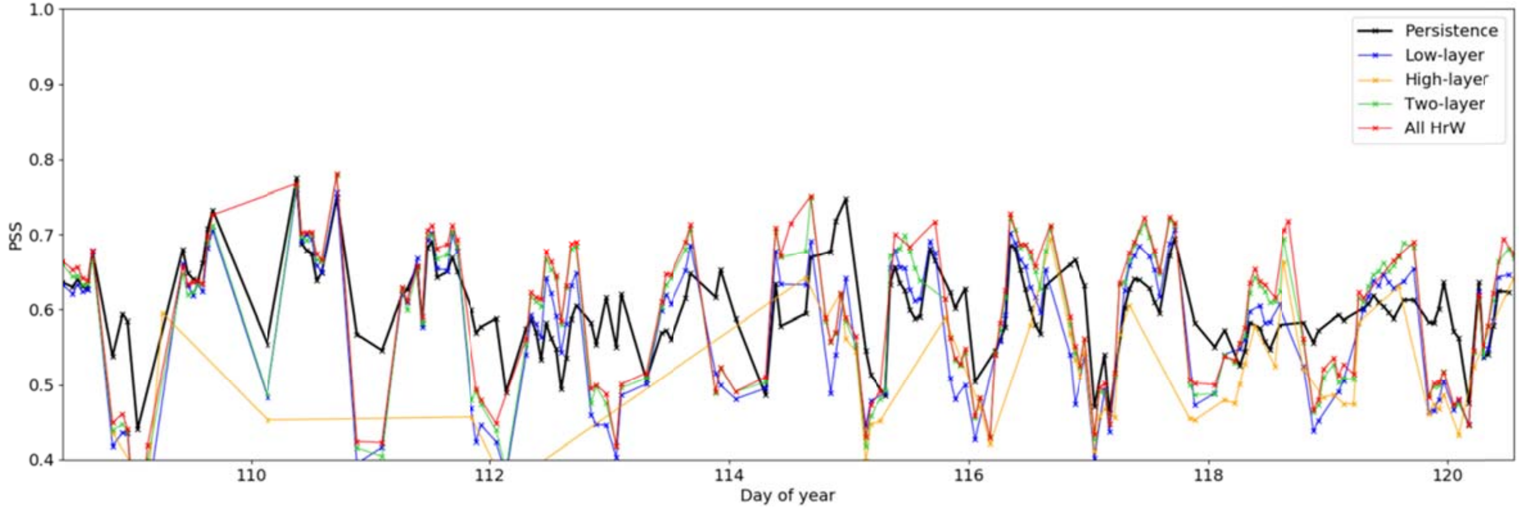


Figure 7: *PSS time series for the IR3.9 280K-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 8.7, 240 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	100.0	94.8
Best	1.5	98.5	0.0	0.0
Second-best	79.9	1.5	18.7	0.0
Third	18.7	0.0	81.3	0.0
Fourth	0.0	0.0	0.0	100.0

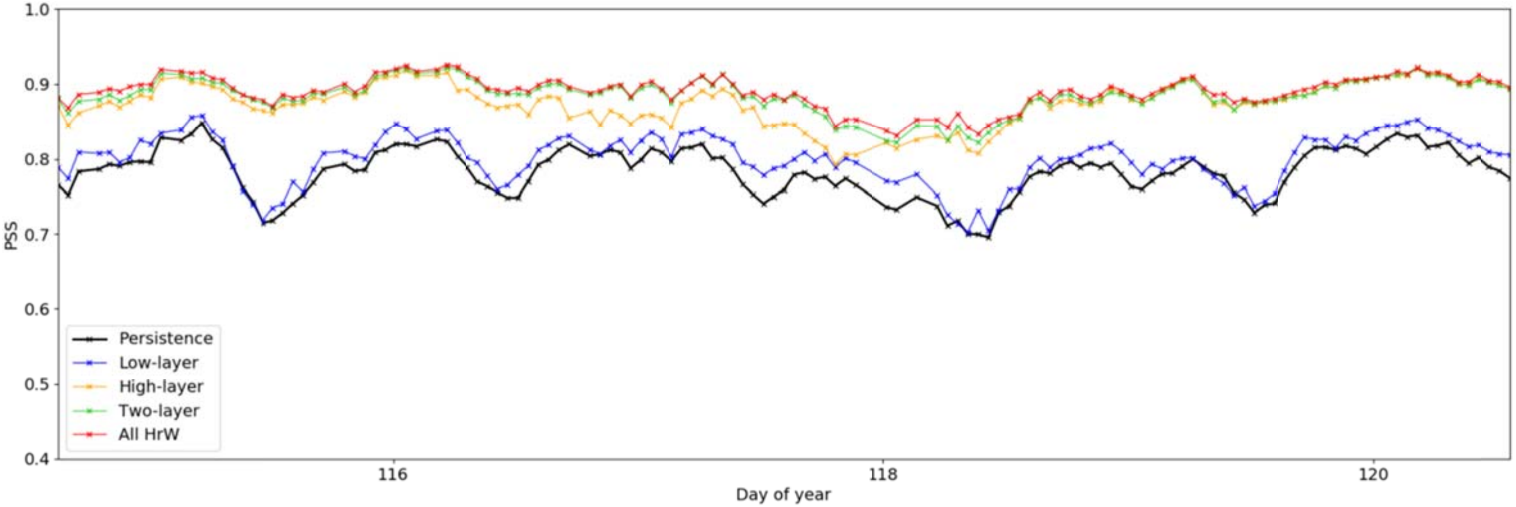
Channel 8.7, 240 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	100.0	100.0	100.0	95.0
Best	1.7	96.6	1.7	0.0
Second-best	79.0	2.5	18.5	0.0
Third	19.3	0.8	79.8	0.0
Fourth	0.0	0.0	0.0	100.0

Channel 8.7, 240 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	100.0	91.1
Best	5.1	94.9	0.0	0.0
Second-best	75.9	5.1	19.0	0.0
Third	19.0	0.0	81.0	0.0
Fourth	0.0	0.0	0.0	100.0

Channel 8.7, 240 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	100.0	97.1
Best	8.6	82.9	8.6	0.0
Second-best	80.0	14.3	5.7	0.0
Third	11.4	2.9	82.9	2.9

Fourth	0.0	0.0	2.9	97.1



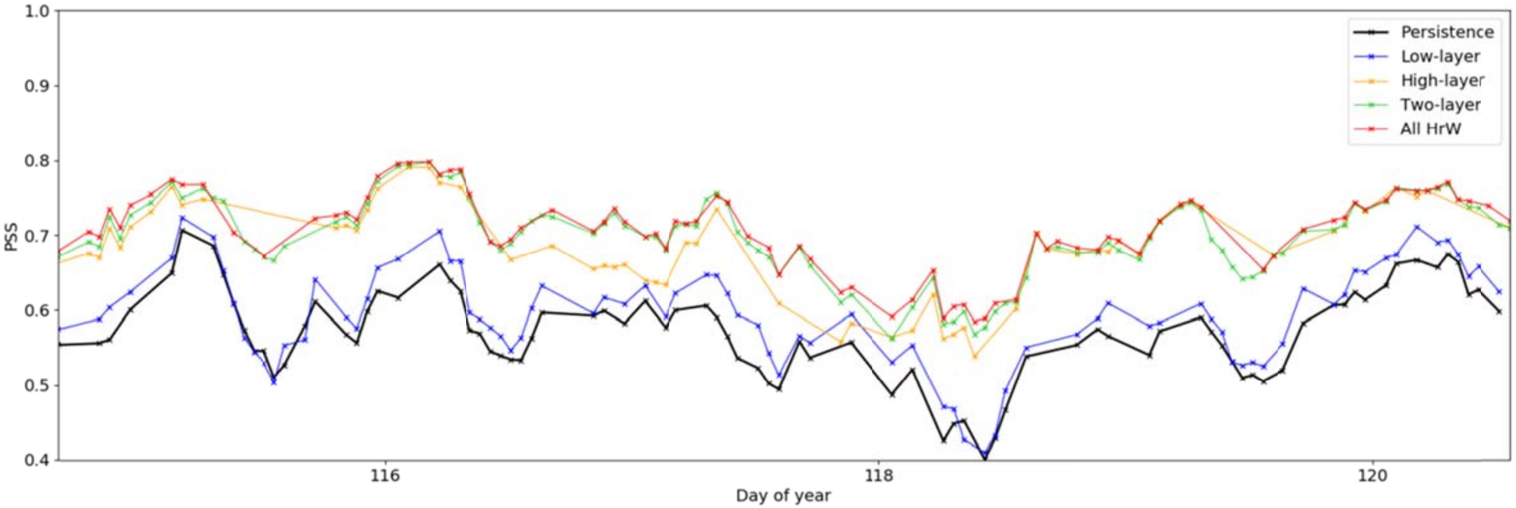


Figure 8: *PSS time series for the IR8.7 240K-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 8.7, 270 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	47.0	100.0
Best	0.0	100.0	0.0	0.0
Second-best	98.5	0.0	0.0	1.5
Third	1.5	0.0	0.7	97.8
Fourth	0.0	0.0	99.3	0.7

Channel 8.7, 270 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	37.8	100.0
Best	0.0	100.0	0.0	0.0
Second-best	98.3	0.0	0.0	1.7
Third	1.7	0.0	5.9	92.4
Fourth	0.0	0.0	94.1	5.9

Channel 8.7, 270 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	97.5	100.0	20.3	100.0
Best	0.0	100.0	0.0	0.0
Second-best	93.7	0.0	0.0	6.3
Third	6.3	0.0	3.8	89.9
Fourth	0.0	0.0	96.2	3.8

Channel 8.7, 270 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	85.7	97.1	5.7	71.4
Best	0.0	100.0	0.0	0.0
Second-best	85.7	0.0	0.0	14.3
Third	14.3	0.0	14.3	71.4
Fourth	0.0	0.0	85.7	14.3

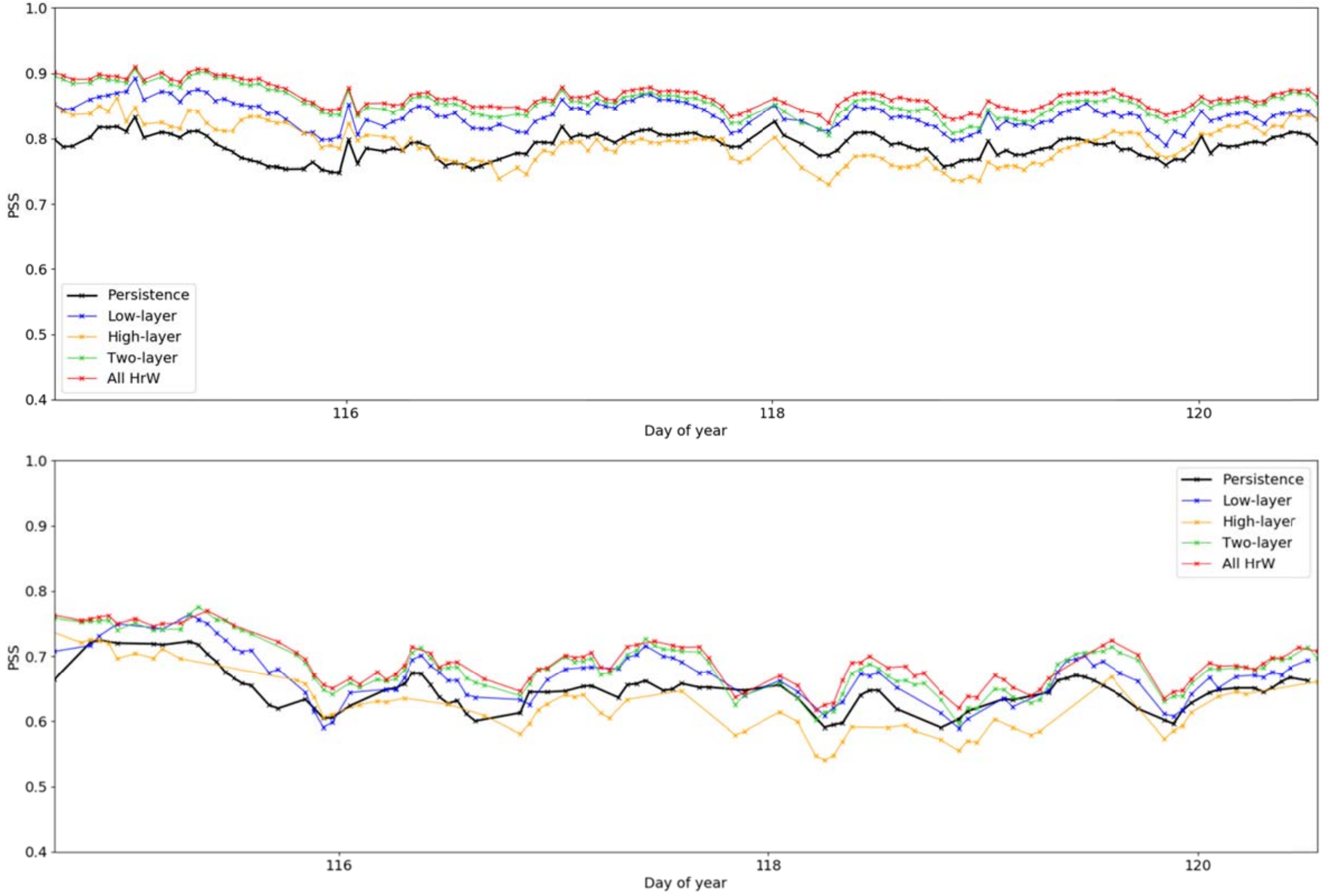


Figure 9: *PSS time series for the IR8.7 270K-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

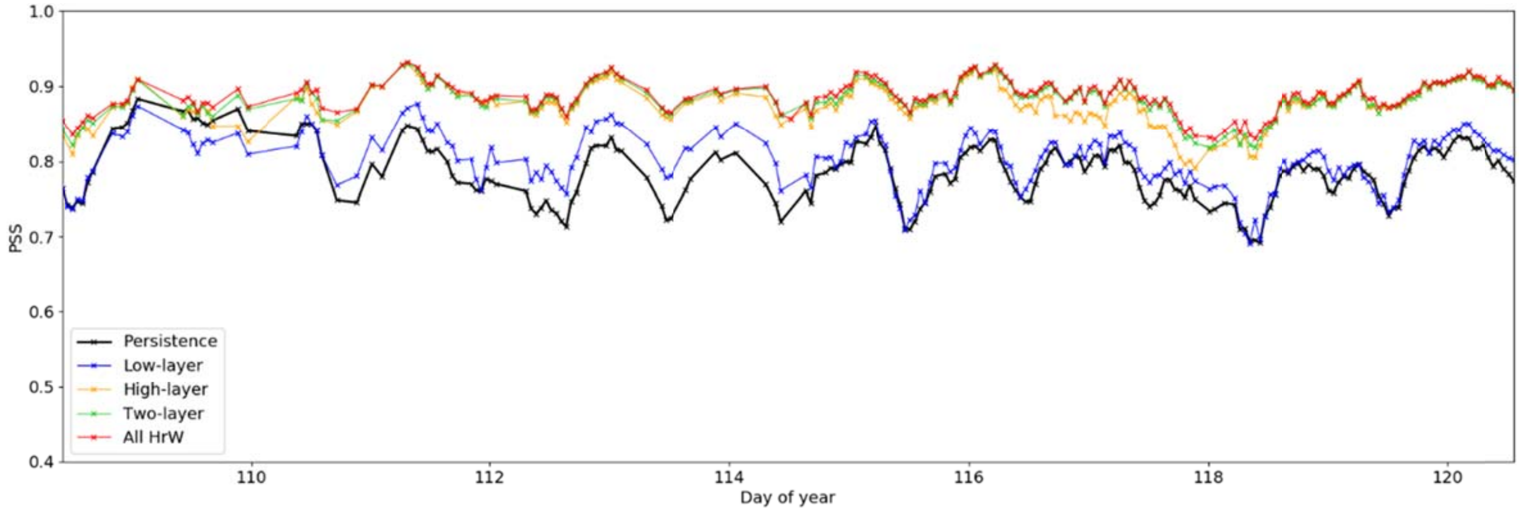
Channel 10.8, 240 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	99.5	100.0	98.1	83.8
Best	0.5	98.1	1.4	0.0
Second-best	78.6	1.9	19.5	0.0
Third	21.0	0.0	79.0	0.0
Fourth	0.0	0.0	0.0	100.0

Channel 10.8, 240 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.9	99.5	97.4	82.1
Best	3.2	94.7	2.1	0.0
Second-best	74.7	4.7	20.0	0.0
Third	22.1	0.5	77.4	0.5
Fourth	0.0	0.0	0.5	99.5

Channel 10.8, 240 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.9	100.0	100.0	83.9
Best	4.6	92.0	3.4	0.0

Second-best	71.3	8.0	20.7	0.0
Third	24.1	0.0	75.9	0.0
Fourth	0.0	0.0	0.0	100.0

Channel 10.8, 240 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	100.0	91.2
Best	8.8	82.4	8.8	0.0
Second-best	76.5	14.7	8.8	0.0
Third	14.7	2.9	79.4	2.9
Fourth	0.0	0.0	2.9	97.1



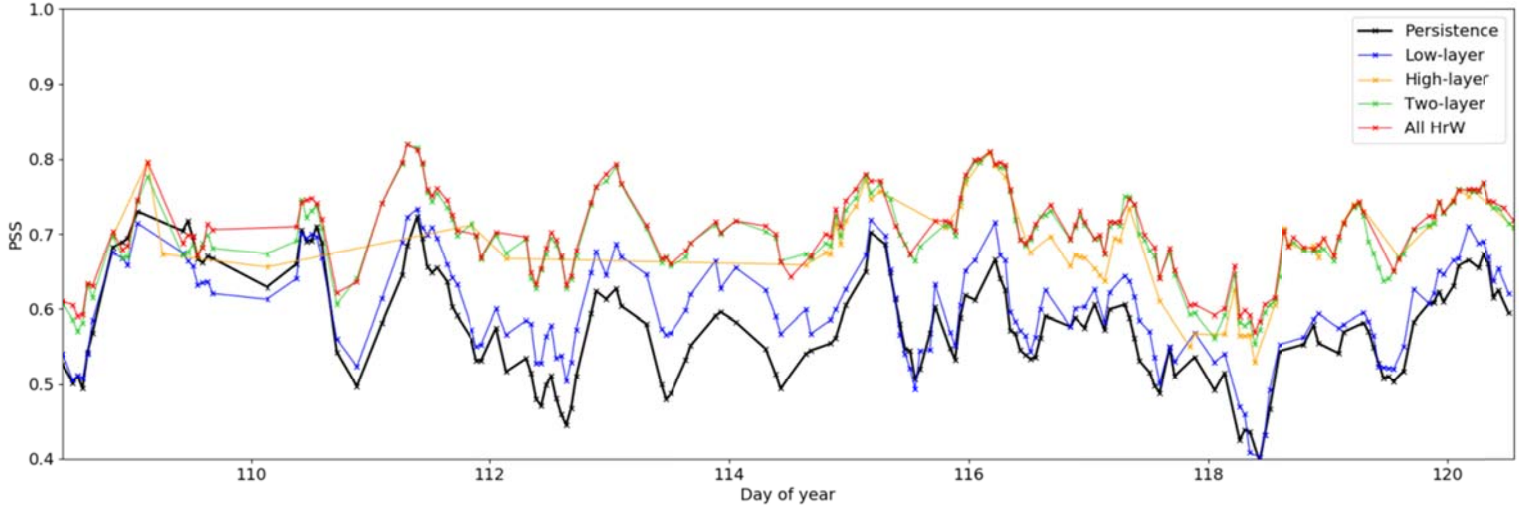


Figure 10: *PSS time series for the IR10.8 240K-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 10.8, 270 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	65.2	100.0
Best	0.0	100.0	0.0	0.0
Second-best	99.0	0.0	0.0	1.0
Third	1.0	0.0	22.9	76.2
Fourth	0.0	0.0	77.1	22.9

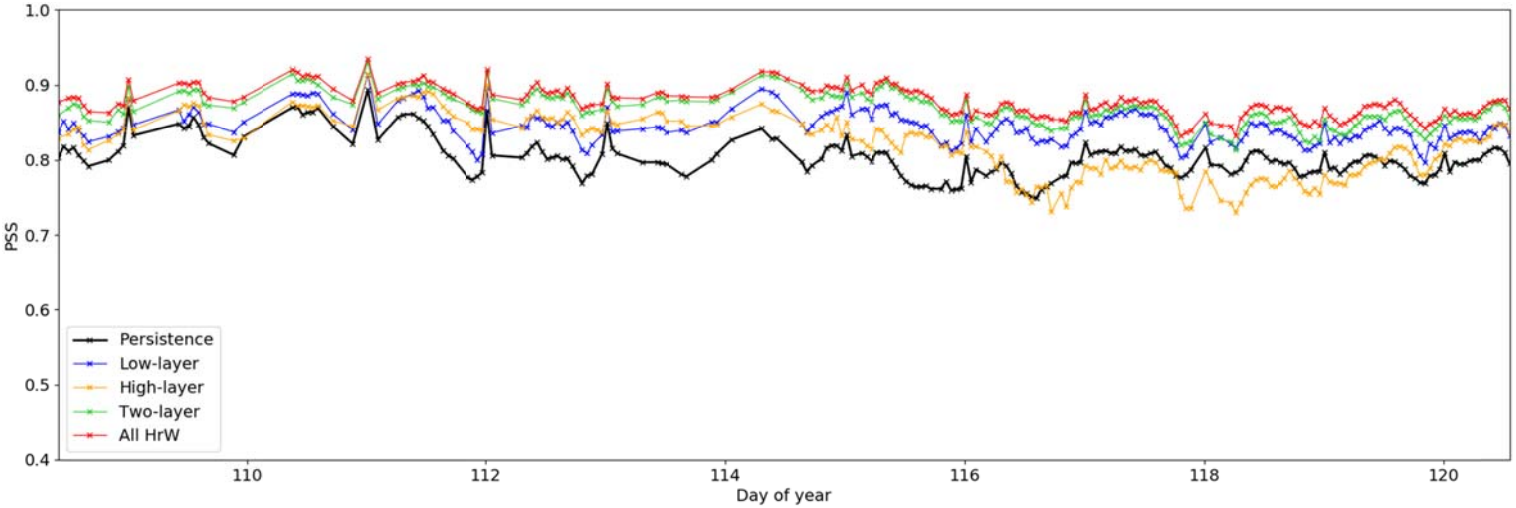
Channel 10.8, 270 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	100.0	100.0	58.9	100.0
Best	0.0	100.0	0.0	0.0
Second-best	100.0	0.0	0.0	0.0
Third	0.0	0.0	20.5	79.5
Fourth	0.0	0.0	79.5	20.5

Channel 10.8, 270 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	26.4	95.4
Best	0.0	100.0	0.0	0.0
Second-best	95.4	0.0	0.0	4.6
Third	4.6	0.0	5.7	89.7
Fourth	0.0	0.0	94.3	5.7

Channel 10.8, 270 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	2.9	94.1
Best	0.0	100.0	0.0	0.0
Second-best	82.4	0.0	0.0	17.6
Third	17.6	0.0	8.8	73.5

Fourth	0.0	0.0	91.2	8.8



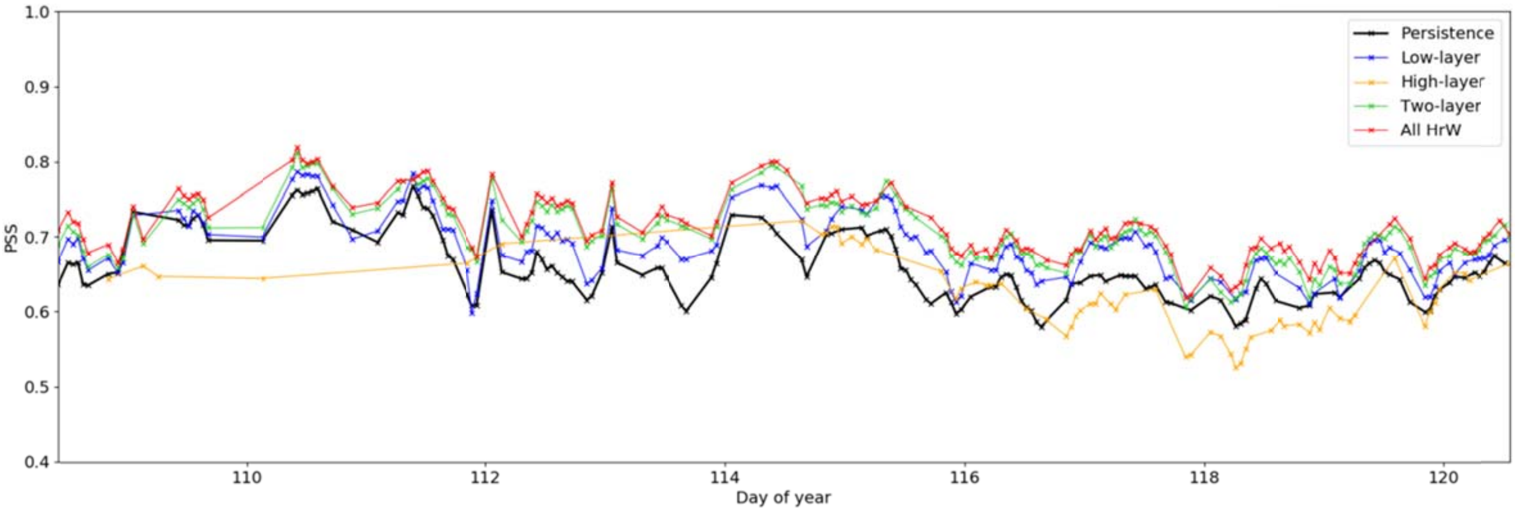


Figure 11: *PSS time series for the IR10.8 270K-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 12.0, 240 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	98.1	90.0
Best	1.4	96.2	2.4	0.0
Second-best	78.6	3.8	17.6	0.0
Third	20.0	0.0	80.0	0.0
Fourth	0.0	0.0	0.0	100.0

Channel 12.0, 240 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.9	100.0	97.4	87.9
Best	3.2	94.2	2.6	0.0
Second-best	75.8	5.3	18.9	0.0
Third	21.1	0.5	77.9	0.5
Fourth	0.0	0.0	0.5	99.5

Channel 12.0, 240 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	100.0	87.2

Best	4.7	91.9	3.5	0.0
Second-best	70.9	8.1	20.9	0.0
Third	24.4	0.0	75.6	0.0
Fourth	0.0	0.0	0.0	100.0

Channel 12.0, 240 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	100.0	96.9
Best	9.4	84.4	6.2	0.0
Second-best	78.1	12.5	9.4	0.0
Third	12.5	3.1	81.2	3.1
Fourth	0.0	0.0	3.1	96.9

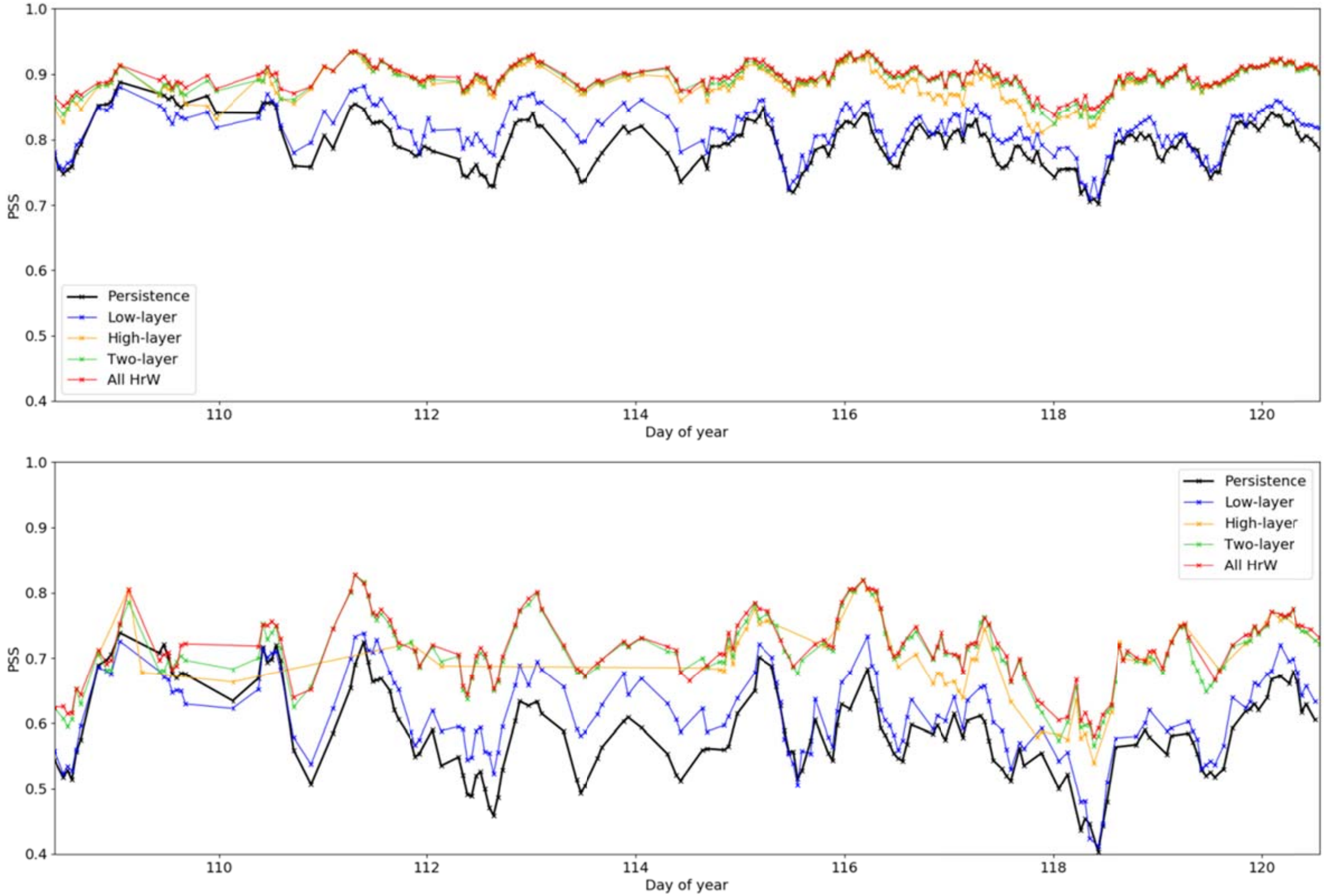


Figure 12: *PSS time series for the IR12.0 240K-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

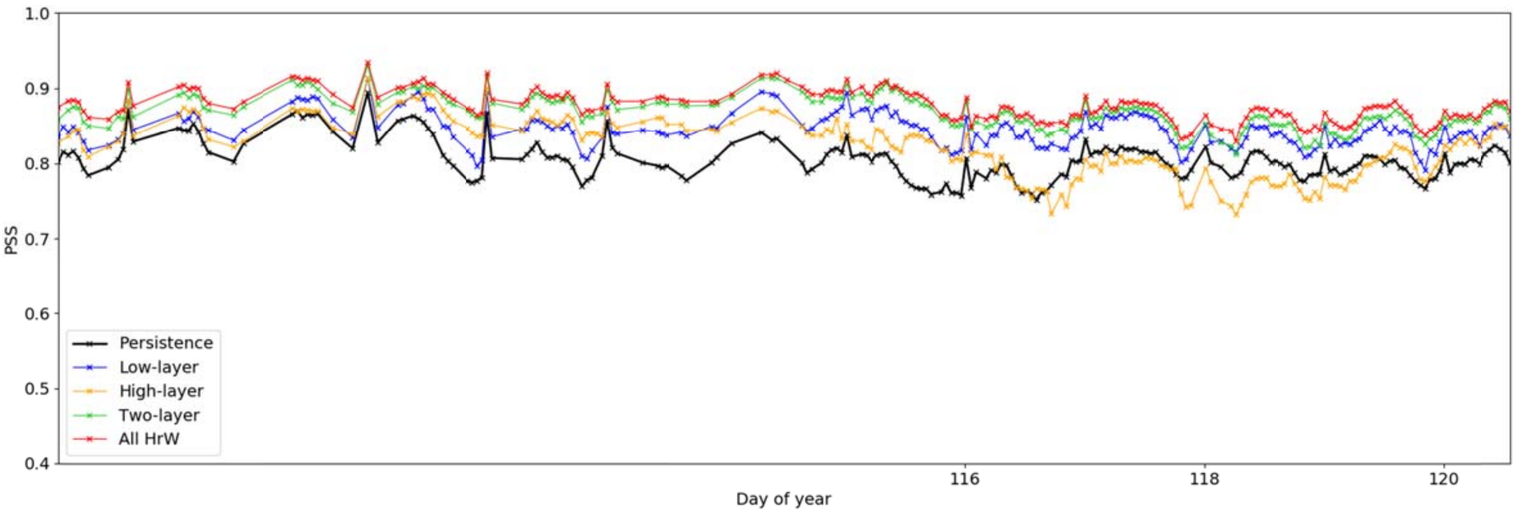
Channel 12.0, 270 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	65.2	100.0
Best	0.0	100.0	0.0	0.0
Second-best	99.0	0.0	0.0	1.0
Third	1.0	0.0	22.9	76.2
Fourth	0.0	0.0	77.1	22.9

Channel 12.0, 270 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	56.8	100.0
Best	0.0	100.0	0.0	0.0
Second-best	99.5	0.0	0.0	0.5
Third	0.5	0.0	19.5	80.0
Fourth	0.0	0.0	80.5	19.5

Channel 12.0, 270 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.8	100.0	24.4	95.3
Best	0.0	100.0	0.0	0.0

Second-best	95.3	0.0	0.0	4.7
Third	4.7	0.0	7.0	88.4
Fourth	0.0	0.0	93.0	7.0

Channel 12.0, 270 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	90.6	96.9	0.0	84.4
Best	0.0	100.0	0.0	0.0
Second-best	84.4	0.0	0.0	15.6
Third	15.6	0.0	6.2	78.1
Fourth	0.0	0.0	93.8	6.2



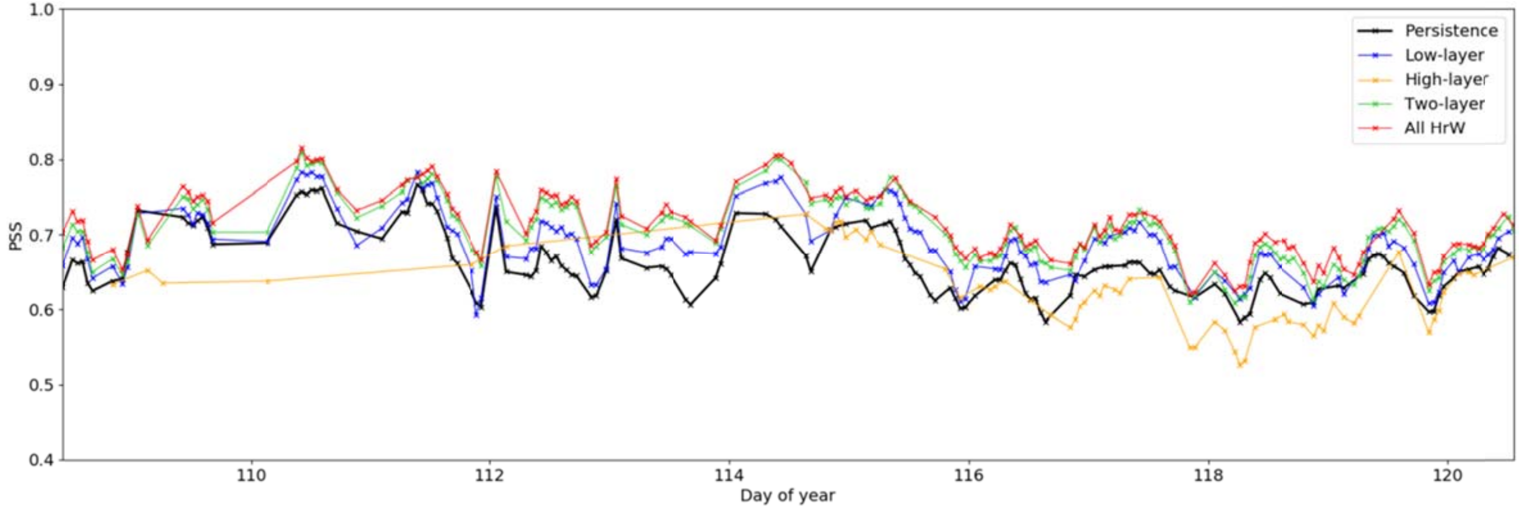


Figure 13: *PSS time series for the IR12.0 270K-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 13.4, 240 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	95.5	100.0
Best	0.0	100.0	0.0	0.0
Second-best	100.0	0.0	0.0	0.0
Third	0.0	0.0	79.1	20.9
Fourth	0.0	0.0	20.9	79.1

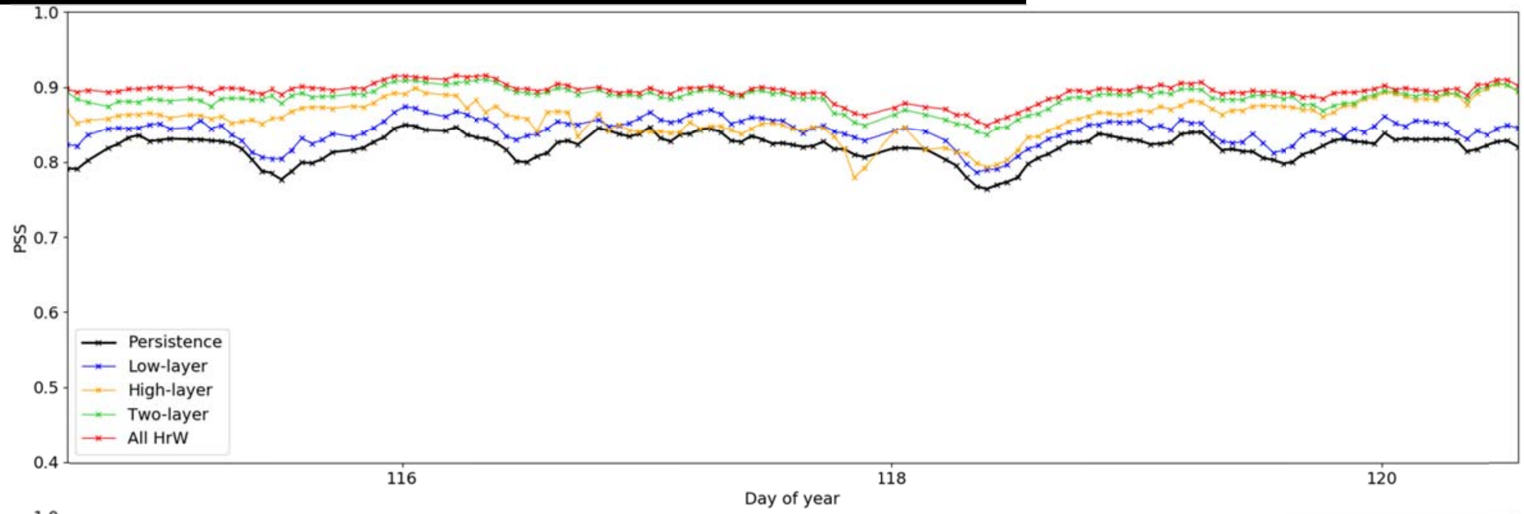
Channel 13.4, 240 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	100.0	100.0	92.4	100.0
Best	0.0	100.0	0.0	0.0
Second-best	100.0	0.0	0.0	0.0
Third	0.0	0.0	71.4	28.6
Fourth	0.0	0.0	28.6	71.4

Channel 13.4, 240 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	88.3	100.0
Best	0.0	100.0	0.0	0.0
Second-best	100.0	0.0	0.0	0.0
Third	0.0	0.0	59.7	40.3
Fourth	0.0	0.0	40.3	59.7

Channel 13.4, 240 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	65.2	100.0
Best	0.0	100.0	0.0	0.0
Second-best	100.0	0.0	0.0	0.0
Third	0.0	0.0	43.5	56.5

Fourth	0.0	0.0	56.5	43.5



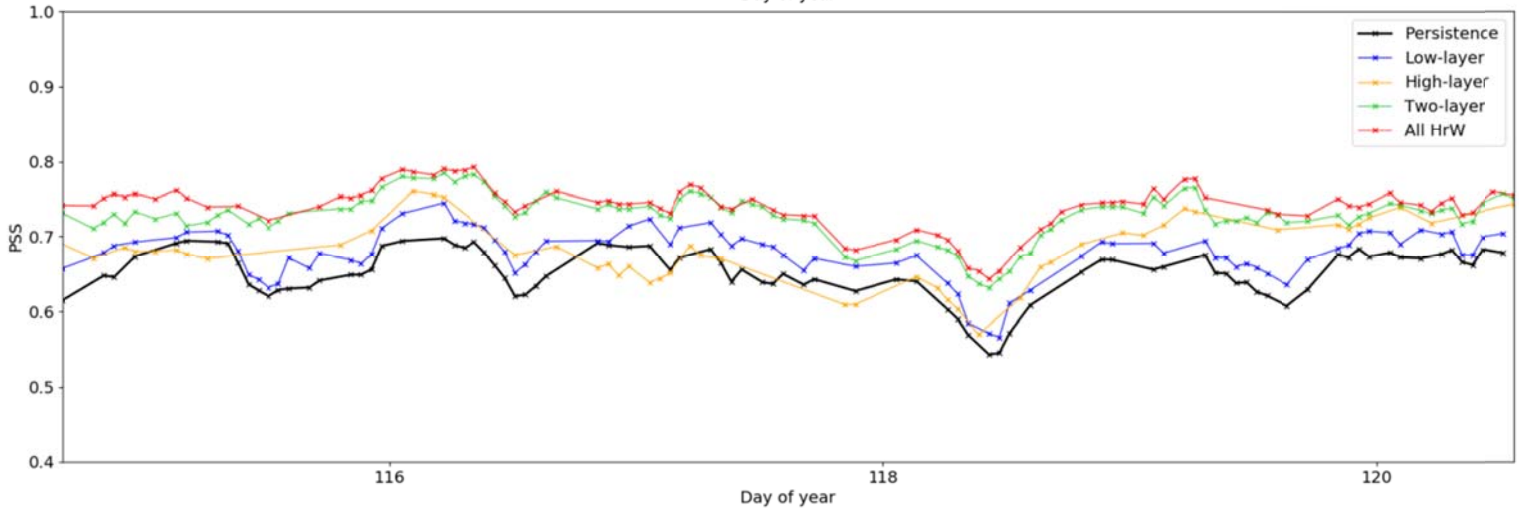


Figure 14: *PSS time series for the IR13.4 240K-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 13.4, 250 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	97.8	100.0
Best	0.0	100.0	0.0	0.0
Second-best	100.0	0.0	0.0	0.0
Third	0.0	0.0	35.1	64.9
Fourth	0.0	0.0	64.9	35.1

Channel 13.4, 250 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	90.8	100.0
Best	0.0	100.0	0.0	0.0
Second-best	100.0	0.0	0.0	0.0
Third	0.0	0.0	37.8	62.2
Fourth	0.0	0.0	62.2	37.8

Channel 13.4, 250 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	100.0	81.8	100.0

Best	0.0	100.0	0.0	0.0
Second-best	97.4	0.0	0.0	2.6
Third	2.6	0.0	32.5	64.9
Fourth	0.0	0.0	67.5	32.5

Channel 13.4, 250 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	95.7	100.0	43.5	91.3
Best	0.0	100.0	0.0	0.0
Second-best	91.3	0.0	0.0	8.7
Third	8.7	0.0	8.7	82.6
Fourth	0.0	0.0	91.3	8.7

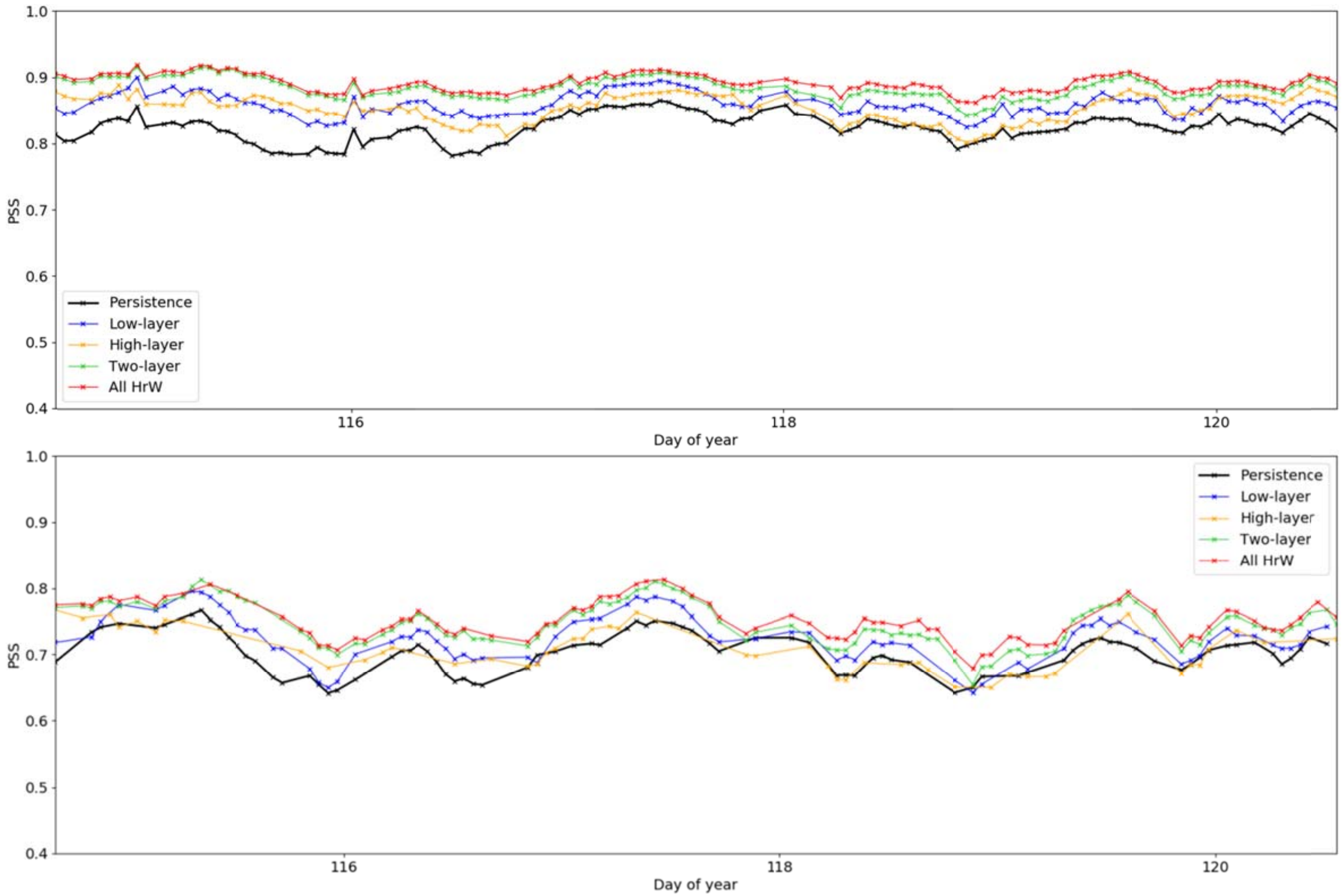


***Figure 15:** PSS time series for the IR13.4 250K-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

6.1.2 Under inclusion of cloudfree areas (Phases II and III, 1 May – 6 June 2018)

In the following tables, the first number in each cell refers to phase II (1-8 May 2018), the second number is from phase III (9 May – 6 June 2018) (cf. the definition of the phases in section 2.4). As the number of cases in phase III was considerably higher and the two-layer approach ran in its corrected form including HRVIS vectors, higher confidence should be put in the second number. On the same grounds, it was deemed appropriate to present only the phase-III results in the diagrams included in this section.

Channel 3.9, 260 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100./100.	93.0 / 100.0	97.5 / 97.2
Best	0.0 / 0.7	100./99.2	0.0 / 0.0	0.0 / 0.0
Second-best	97.5 / 93.0	0.0 / 0.7	2.5 / 6.5	0.0 / 0.0
Third	2.5 / 6.3	0.0 / 0.1	77.2 / 88.6	20.2 / 4.9
Fourth	0.0 / 0.0	0.0 / 0.0	20.2 / 4.9	79.8 / 95.1

Channel 3.9, 260 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	99.7 / 100.0	100./100.	92.3 / 99.7	96.6 / 94.1
Best	0.0 / 1.2	100./98.3	0.0 / 0.5	0.0 / 0.0
Second-best	96.9 / 92.8	0.0 / 1.2	3.1 / 5.8	0.0 / 0.2
Third	3.1 / 5.9	0.0 / 0.5	77.7 / 89.4	19.2 / 4.2
Fourth	0.0 / 0.0	0.0 / 0.0	19.2 / 4.4	80.8 / 95.6

Channel 3.9, 260 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 99.8	100./99.8	91.8 / 99.4	97.3 / 92.4
Best	0.5 / 1.8	99.5/97.1	0.0 / 1.0	0.0 / 0.2
Second-best	96.7 / 90.0	0.5 / 2.5	2.2 / 7.3	0.5 / 0.2
Third	2.7 / 8.3	0.0 / 0.3	77.6 / 85.8	19.7 / 5.6
Fourth	0.0 / 0.0	0.0 / 0.0	20.2 / 5.9	79.8 / 94.1

Channel 3.9, 260 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	97.2 / 100.0	100./100.	66.7 / 99.1	97.2 / 90.0
Best	2.8 / 7.0	97.2/92.7	0.0 / 0.3	0.0 / 0.0
Second-best	88.9 / 86.9	0.0 / 6.1	5.6 / 6.7	5.6 / 0.3
Third	8.3 / 6.1	2.8 / 1.2	50.0 / 83.3	38.9 / 9.4
Fourth	0.0 / 0.0	0.0 / 0.0	44.4 / 9.7	55.6 / 90.3

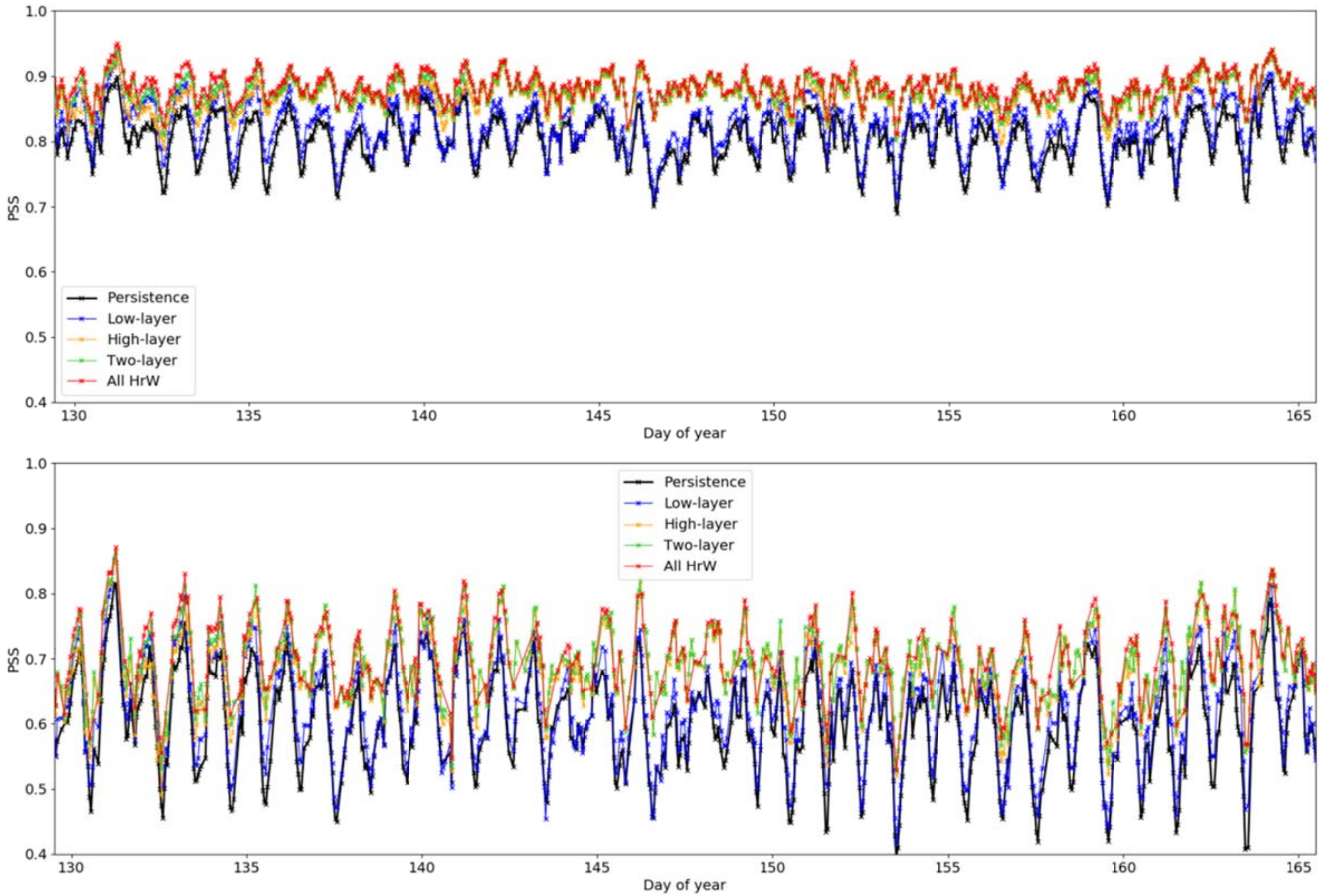


Figure 16: *PSS time series for the IR3.9 260K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

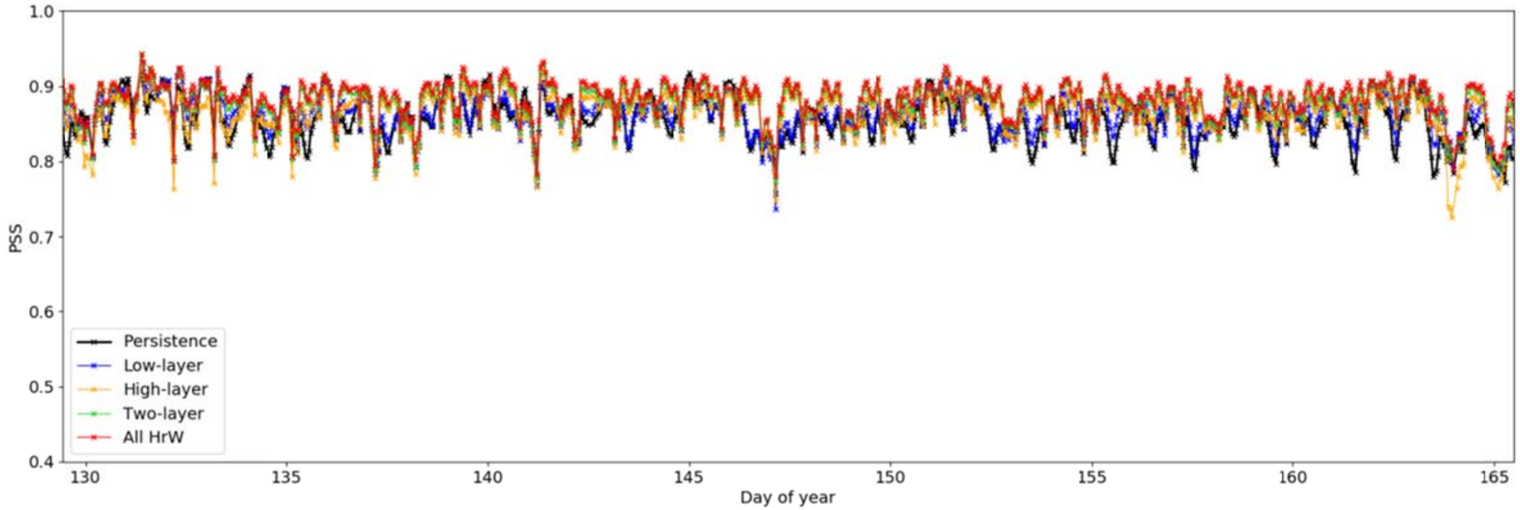
Channel 3.9, 280 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	66.4 / 71.9	73.8/81.0	45.6 / 53.3	61.1 / 61.3
Best	0.7 / 0.2	95.3/95.0	0.0 / 0.0	4.0 / 4.6
Second-best	75.8 / 85.8	4.7 / 5.0	0.0 / 0.2	19.5 / 9.2
Third	23.5 / 14.0	0.0 / 0.0	24.8 / 47.8	51.7 / 38.2
Fourth	0.0 / 0.0	0.0 / 0.0	75.2 / 52.0	24.8 / 48.0

Channel 3.9, 280 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	72.8 / 77.9	77.2/83.2	47.1 / 57.7	64.0 / 69.8
Best	0.0 / 0.2	91.2/92.3	0.0 / 0.0	8.8 / 7.5
Second-best	75.0 / 82.6	7.4 / 7.3	0.0 / 0.0	17.6 / 10.1
Third	25.0 / 17.2	1.5 / 0.4	30.9 / 48.0	42.6 / 34.4
Fourth	0.0 / 0.0	0.0 / 0.0	69.1 / 52.0	30.9 / 48.0

Channel 3.9, 280 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	68.6 / 74.1	74.5/79.4	46.1 / 55.7	64.7 / 68.1
Best	2.0 / 0.8	85.3/87.0	0.0 / 0.0	12.7 / 12.2

Second-best	66.7 / 76.6	14.7/12.6	0.0 / 0.0	18.6 / 10.8
Third	31.4 / 22.6	0.0 / 0.4	22.5 / 48.5	46.1 / 28.5
Fourth	0.0 / 0.0	0.0 / 0.0	77.5 / 51.5	22.5 / 48.5

Channel 3.9, 280 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	42.9 / 59.6	57.1/64.9	21.4 / 43.8	35.7 / 58.1
Best	7.1 / 3.8	64.3/70.9	0.0 / 0.0	28.6 / 25.3
Second-best	50.0 / 62.6	28.6/26.8	0.0 / 0.0	21.4 / 10.6
Third	42.9 / 33.2	7.1 / 2.3	21.4 / 42.3	28.6 / 22.3
Fourth	0.0 / 0.4	0.0 / 0.0	78.6 / 57.7	21.4 / 41.9



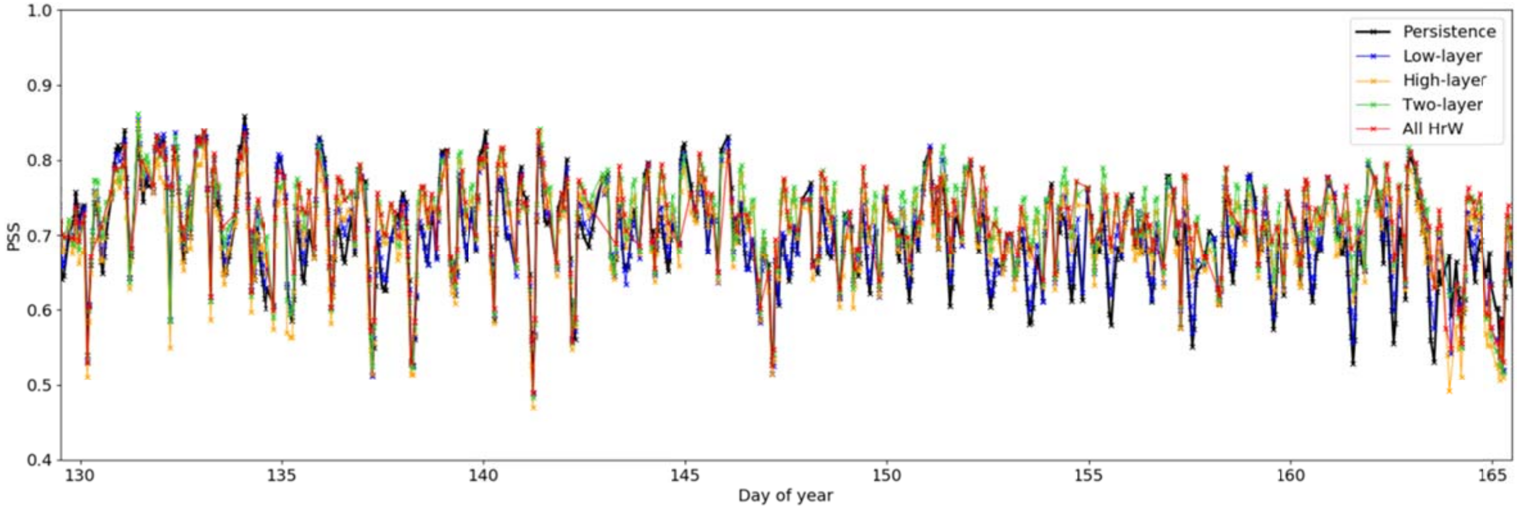


Figure 17: *PSS time series for the IR3.9 280K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 8.7, 240 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0/100.0	100./100.	100.0/99.5	91.4/85.6
Best	1.3 / 6.9	96.7/90.6	2.0 / 2.6	0.0 / 0.0
Second-best	83.6/77.0	2.6 / 8.1	13.8/14.9	0.0 / 0.0
Third	15.1 / 16.1	0.7 / 1.4	84.2/82.0	0.0 / 0.5
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 0.5	100.0/99.5

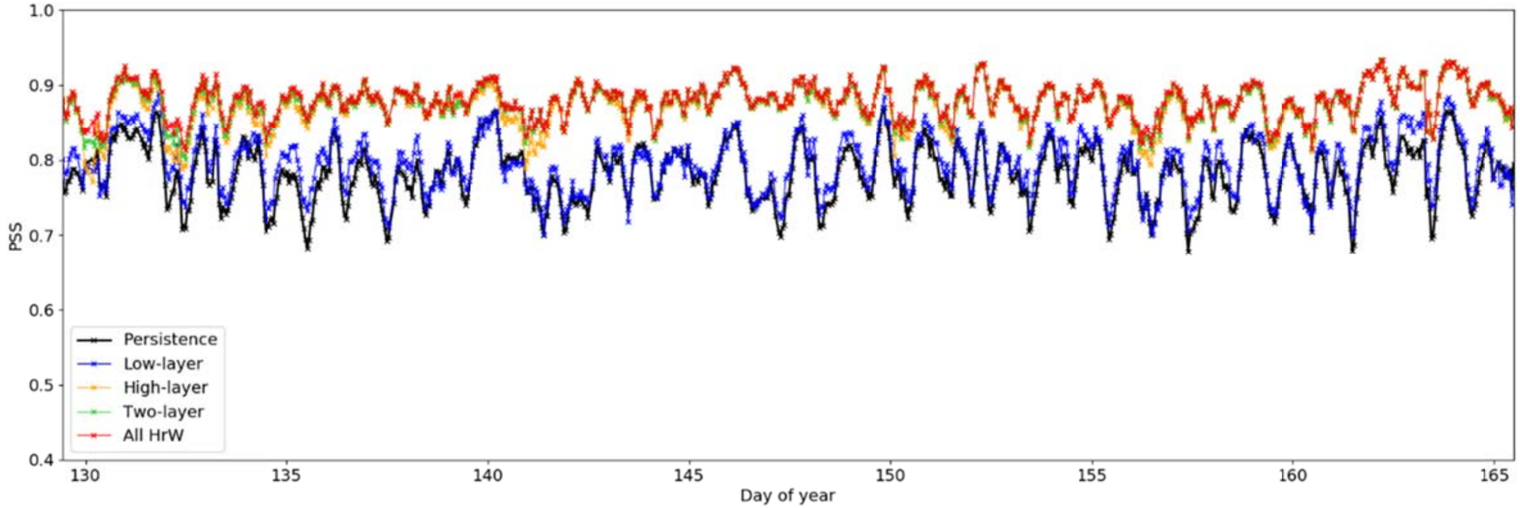
Channel 8.7, 240 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	100.0 / 100.0	100./100.	100.0 / 99.4	90.8 / 81.3
Best	6.4 / 9.8	90.1/85.4	3.5 / 4.8	0.0 / 0.0
Second-best	78.0 / 74.8	7.8 / 12.3	14.2 / 12.9	0.0 / 0.0
Third	15.6 / 15.4	2.1 / 2.3	82.3 / 80.7	0.0 / 1.5
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 1.5	100.0 / 98.5

Channel 8.7, 240 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100./100.	100.0 / 99.4	87.7 / 80.0
Best	11.4 / 13.5	81.6/82.2	7.0 / 4.3	0.0 / 0.0
Second-best	74.6 / 73.1	12.3/12.9	13.2 / 13.7	0.0 / 0.2
Third	14.0 / 13.3	6.1 / 4.9	79.8 / 79.8	0.0 / 2.0
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 2.2	100.0 / 97.8

Channel 8.7, 240 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 98.9	100./99.6	100.0 / 97.5	78.3 / 74.6
Best	34.8 / 20.3	60.9/75.7	4.3 / 3.3	0.0 / 0.7
Second-best	60.9 / 64.9	26.1/19.2	13.0 / 15.6	0.0 / 0.4
Third	4.3 / 14.9	13.0 / 5.1	82.6 / 77.5	0.0 / 2.5

Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 3.6	100.0 / 96.4



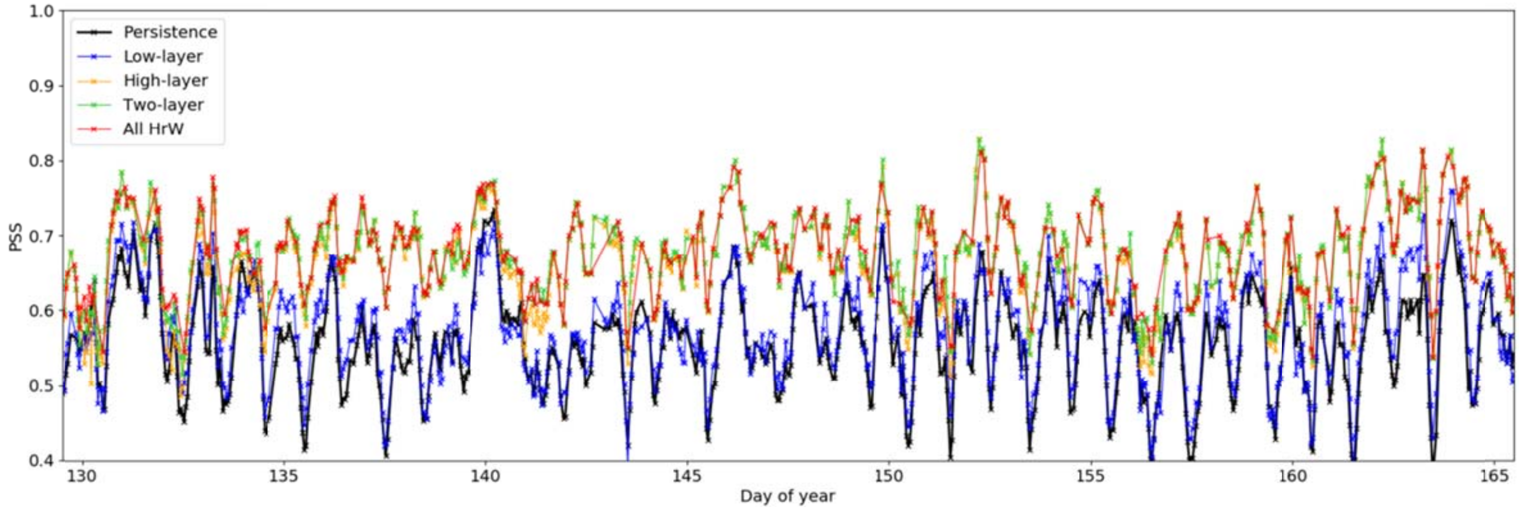


Figure 18: *PSS time series for the IR8.7 240K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 8.7, 270 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.7 / 100.0	100./100.	86.8 / 94.9	96.1 / 97.4
Best	0.0 / 0.0	100./100.	0.0 / 0.0	0.0 / 0.0
Second-best	99.3 / 99.7	0.0 / 0.0	0.0 / 0.0	0.7 / 0.3
Third	0.7 / 0.3	0.0 / 0.0	31.6 / 66.9	67.8 / 32.8
Fourth	0.0 / 0.0	0.0 / 0.0	68.4 / 33.1	31.6 / 66.9

Channel 8.7, 270 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.6 / 100.0	100./100.	84.4 / 94.4	96.5 / 96.7
Best	0.0 / 0.0	100./100.	0.0 / 0.0	0.0 / 0.0
Second-best	98.6 / 98.8	0.0 / 0.0	0.0 / 0.0	1.4 / 1.2
Third	1.4 / 1.2	0.0 / 0.0	29.1 / 67.2	69.5 / 31.6
Fourth	0.0 / 0.0	0.0 / 0.0	70.9 / 32.8	29.1 / 67.2

Channel 8.7, 270 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.2 / 100.0	100./100.	80.7 / 91.0	95.6 / 96.3

Best	0.0 / 0.0	100./100.	0.0 / 0.0	0.0 / 0.0
Second-best	96.5 / 98.0	0.0 / 0.0	0.0 / 0.0	3.5 / 2.0
Third	3.5 / 2.0	0.0 / 0.0	25.4 / 64.9	71.1 / 33.1
Fourth	0.0 / 0.0	0.0 / 0.0	74.6 / 35.1	25.4 / 64.9

Channel 8.7, 270 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100./100.	65.2 / 85.5	87.0 / 93.8
Best	8.7 / 0.0	91.3/98.9	0.0 / 0.0	0.0 / 1.1
Second-best	82.6 / 96.0	0.0 / 1.1	4.3 / 0.0	13.0 / 2.9
Third	8.7 / 4.0	8.7 / 0.0	17.4 / 56.9	65.2 / 39.1
Fourth	0.0 / 0.0	0.0 / 0.0	78.3 / 43.1	21.7 / 56.9

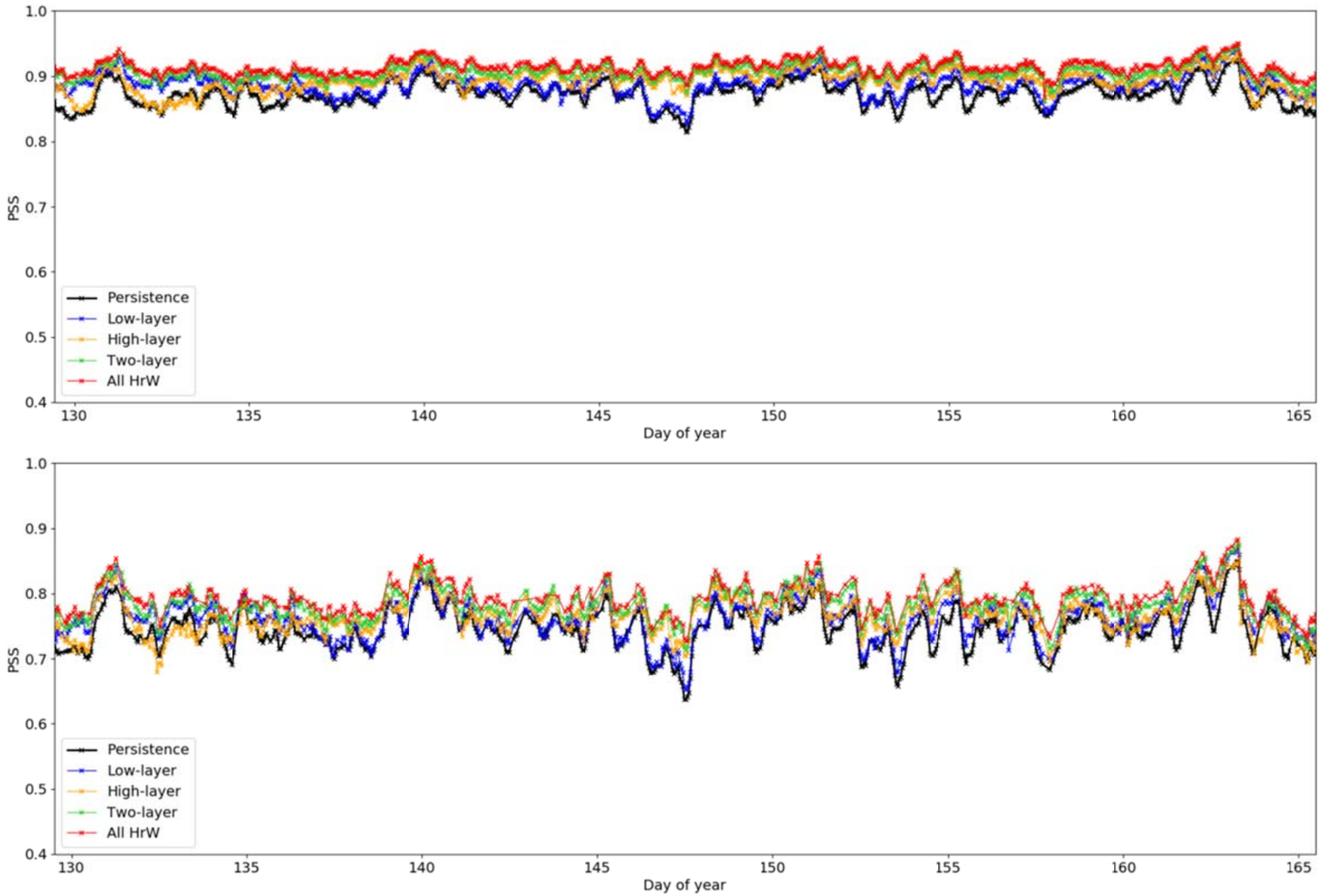


Figure 19: *PSS time series for the IR8.7 270K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

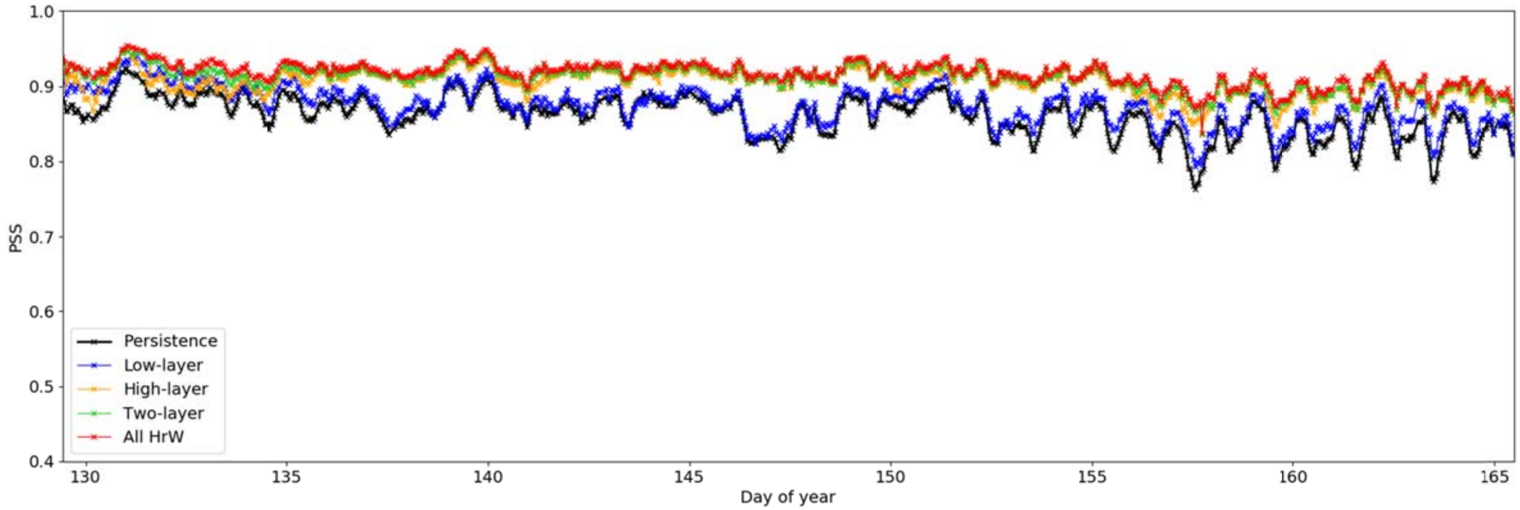
Channel 9.7, 240 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0/100.0	100./100.	100.0/100.0	100.0/96.7
Best	0.0 / 0.2	100./99.7	0.0 / 0.0	0.0 / 0.0
Second-best	100.0/96.9	0.0 / 0.3	0.0 / 2.9	0.0 / 0.0
Third	0.0 / 2.9	0.0 / 0.0	100.0 / 86.1	0.0 / 11.0
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 11.0	100.0 / 89.0

Channel 9.7, 240 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100./100.	100.0 / 99.6	100.0 / 94.4
Best	0.0 / 0.0	100./100.	0.0 / 0.0	0.0 / 0.0
Second-best	100.0 / 97.5	0.0 / 0.0	0.0 / 2.3	0.0 / 0.2
Third	0.0 / 2.5	0.0 / 0.0	88.9 / 87.1	11.1 / 10.4
Fourth	0.0 / 0.0	0.0 / 0.0	11.1 / 10.6	88.9 / 89.4

Channel 9.7, 240 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100./100.	100.0 / 98.6	100.0 / 92.9
Best	0.0 / 0.2	100./99.8	0.0 / 0.0	0.0 / 0.0

Second-best	100.0 / 96.7	0.0 / 0.2	0.0 / 2.4	0.0 / 0.8
Third	0.0 / 3.1	0.0 / 0.0	76.9 / 86.4	23.1 / 10.4
Fourth	0.0 / 0.0	0.0 / 0.0	23.1 / 11.2	76.9 / 88.8

Channel 9.7, 240 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100./100.	100.0 / 96.7	100.0 / 90.2
Best	0.0 / 1.1	100./98.6	0.0 / 0.4	0.0 / 0.0
Second-best	100.0 / 96.0	0.0 / 1.4	0.0 / 1.8	0.0 / 0.7
Third	0.0 / 2.9	0.0 / 0.0	50.0 / 83.3	50.0 / 13.8
Fourth	0.0 / 0.0	0.0 / 0.0	50.0 / 14.5	50.0 / 85.5



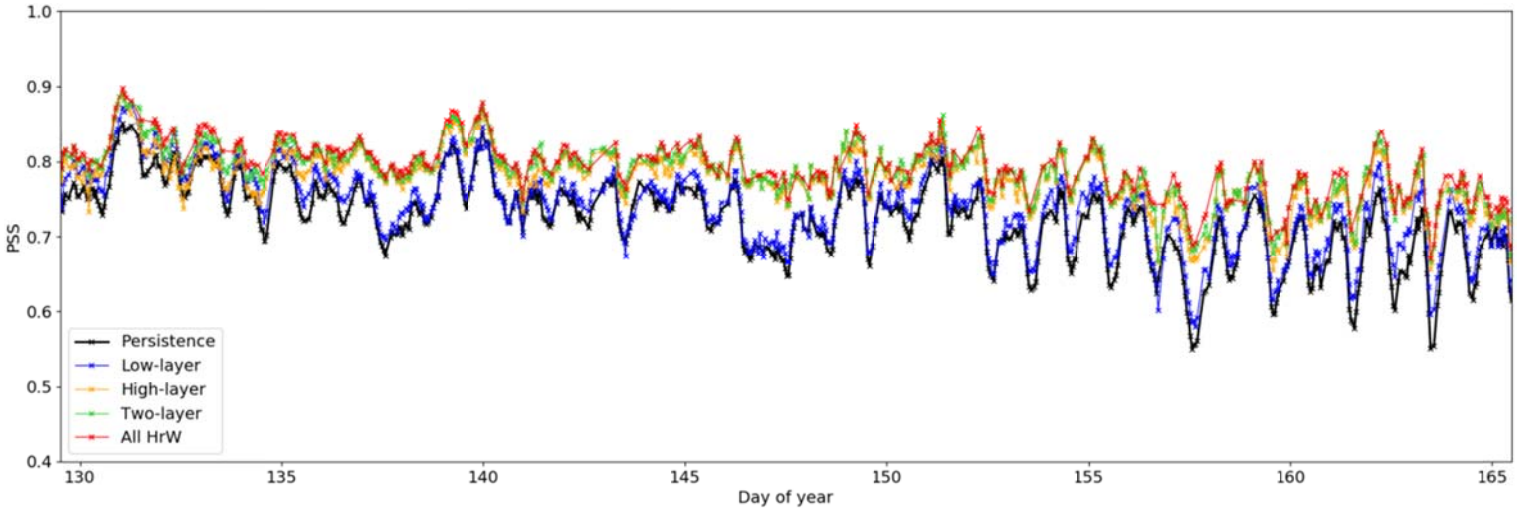


Figure 20: *PSS time series for the IR9.7 240K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 9.7, 250 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 97.9	100./100.	100.0 / 80.6	100.0 / 69.1
Best	0.0 / 0.0	100./99.8	0.0 / 0.0	0.0 / 0.0
Second-best	100.0 / 98.6	0.0 / 0.2	0.0 / 0.2	0.0 / 1.2
Third	0.0 / 1.4	0.0 / 0.0	84.2 / 68.8	15.8 / 29.8
Fourth	0.0 / 0.0	0.0 / 0.0	15.8 / 31.0	84.2 / 69.0

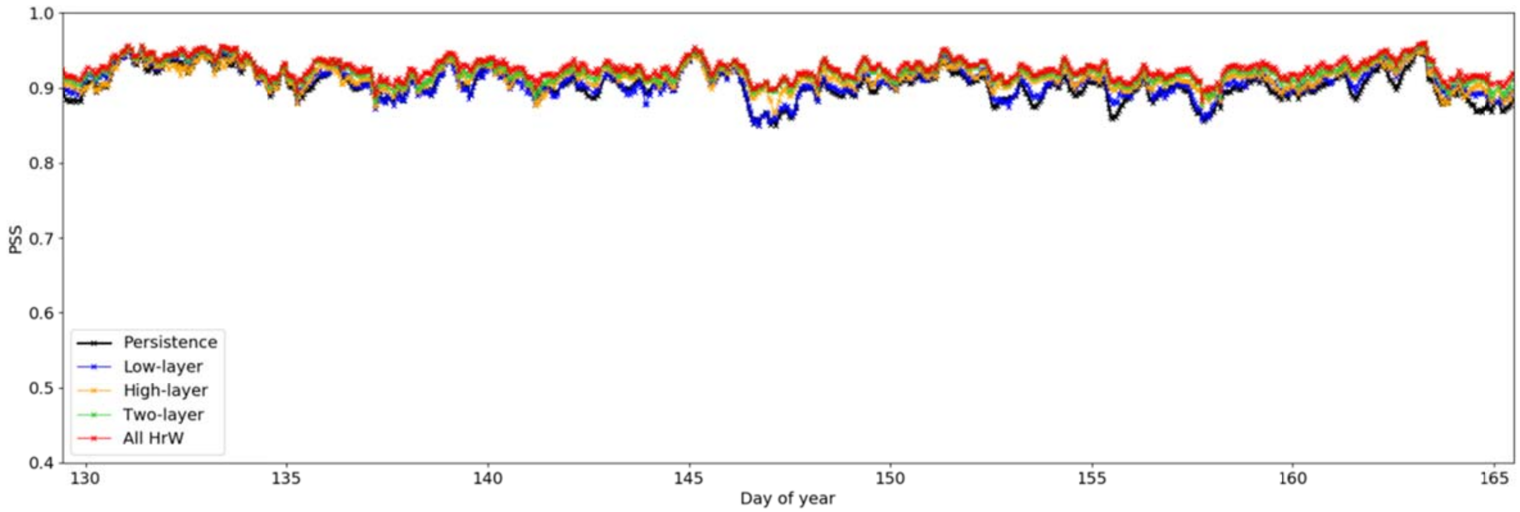
Channel 9.7, 250 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	100.0 / 97.5	100./99.6	94.4 / 77.8	94.4 / 70.7
Best	0.0 / 0.4	100./99.4	0.0 / 0.0	0.0 / 0.2
Second-best	100.0 / 96.7	0.0 / 0.6	0.0 / 0.0	0.0 / 2.7
Third	0.0 / 2.9	0.0 / 0.0	88.9 / 63.8	11.1 / 33.3
Fourth	0.0 / 0.0	0.0 / 0.0	11.1 / 36.2	88.9 / 63.8

Channel 9.7, 250 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 94.9	100./99.2	76.9 / 68.4	100.0 / 70.5
Best	0.0 / 0.0	100./98.6	0.0 / 0.0	0.0 / 1.4
Second-best	100.0 / 94.9	0.0 / 1.4	0.0 / 0.0	0.0 / 3.7
Third	0.0 / 5.1	0.0 / 0.0	69.2 / 56.8	30.8 / 38.1
Fourth	0.0 / 0.0	0.0 / 0.0	30.8 / 43.2	69.2 / 56.8

Channel 9.7, 250 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 86.2	100./95.3	75.0 / 54.3	100.0 / 64.5
Best	0.0 / 2.9	100./93.5	0.0 / 0.0	0.0 / 3.6
Second-best	100.0 / 83.7	0.0 / 6.5	0.0 / 0.4	0.0 / 9.4
Third	0.0 / 13.4	0.0 / 0.0	50.0 / 44.2	50.0 / 42.4

Fourth	0.0 / 0.0	0.0 / 0.0	50.0 / 55.4	50.0 / 44.6



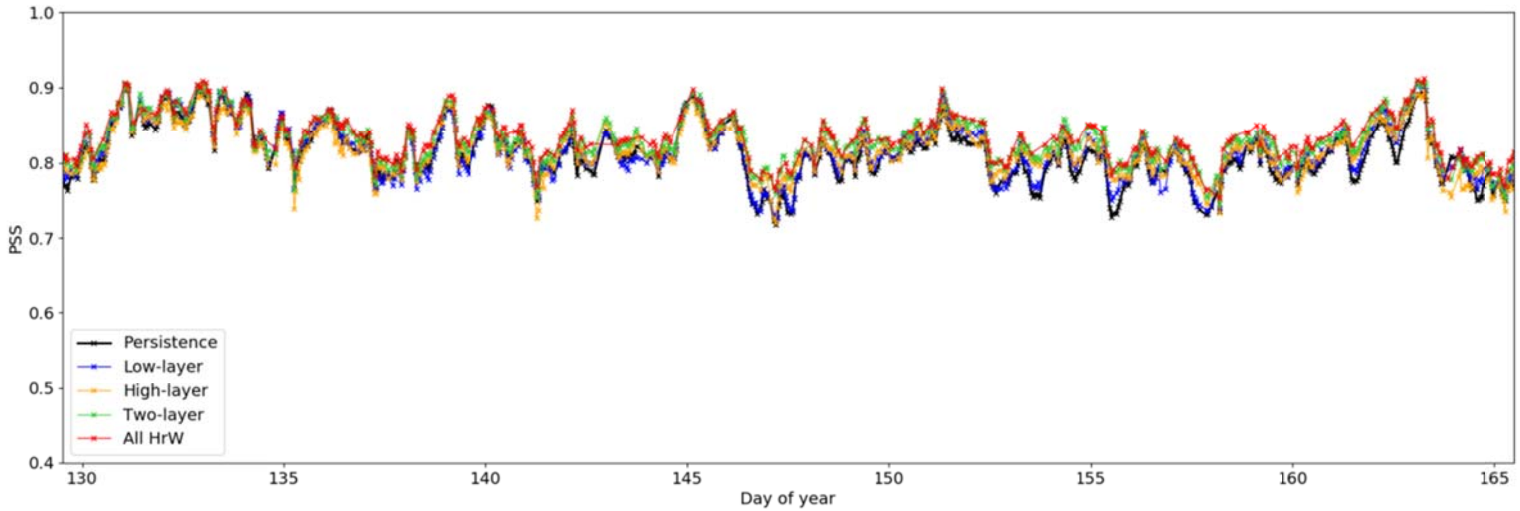


Figure 21: *PSS time series for the IR9.7 250K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 10.8, 240 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100./100.	100./100.	100./99.7	86.1/77.8
Best	2.0 / 8.2	96.0/88.4	2.0 / 3.3	0.0 / 0.0
Second-best	82.1/74.8	3.3 / 9.0	14.6 / 16.3	0.0 / 0.0
Third	15.9/17.0	0.7 / 2.6	83.4 / 79.9	0.0 / 0.5
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 0.5	100./99.5

Channel 10.8, 240 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	100./100.	100./100.	100./99.4	89.3 / 77.1
Best	5.7 / 10.8	90.0/84.7	4.3 / 4.5	0.0 / 0.0
Second-best	75.0 / 71.2	7.9 / 12.2	17.1 / 16.7	0.0 / 0.0
Third	19.3 / 18.0	2.1 / 3.1	78.6 / 77.6	0.0 / 1.2
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 1.2	100./98.8

Channel 10.8, 240 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100./ 99.8	100.0 / 99.0	86.2 / 76.7
Best	12.8 / 17.4	80.7 / 78.7	6.4 / 4.0	0.0 / 0.0
Second-best	74.3 / 67.8	11.9 / 15.6	13.8 / 16.4	0.0 / 0.2
Third	12.8 / 14.8	7.3 / 5.7	79.8 / 77.7	0.0 / 1.8
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 2.0	100.0 / 98.0

Channel 10.8, 240 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 98.9	100.0 / 99.3	100.0 / 97.4	78.9 / 71.2
Best	31.6 / 22.9	63.2 / 72.0	5.3 / 4.4	0.0 / 0.7
Second-best	57.9 / 63.8	21.1 / 20.7	21.1 / 15.1	0.0 / 0.4
Third	10.5 / 13.3	15.8 / 7.4	73.7 / 77.5	0.0 / 1.8

Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 3.0	100.0 / 97.0

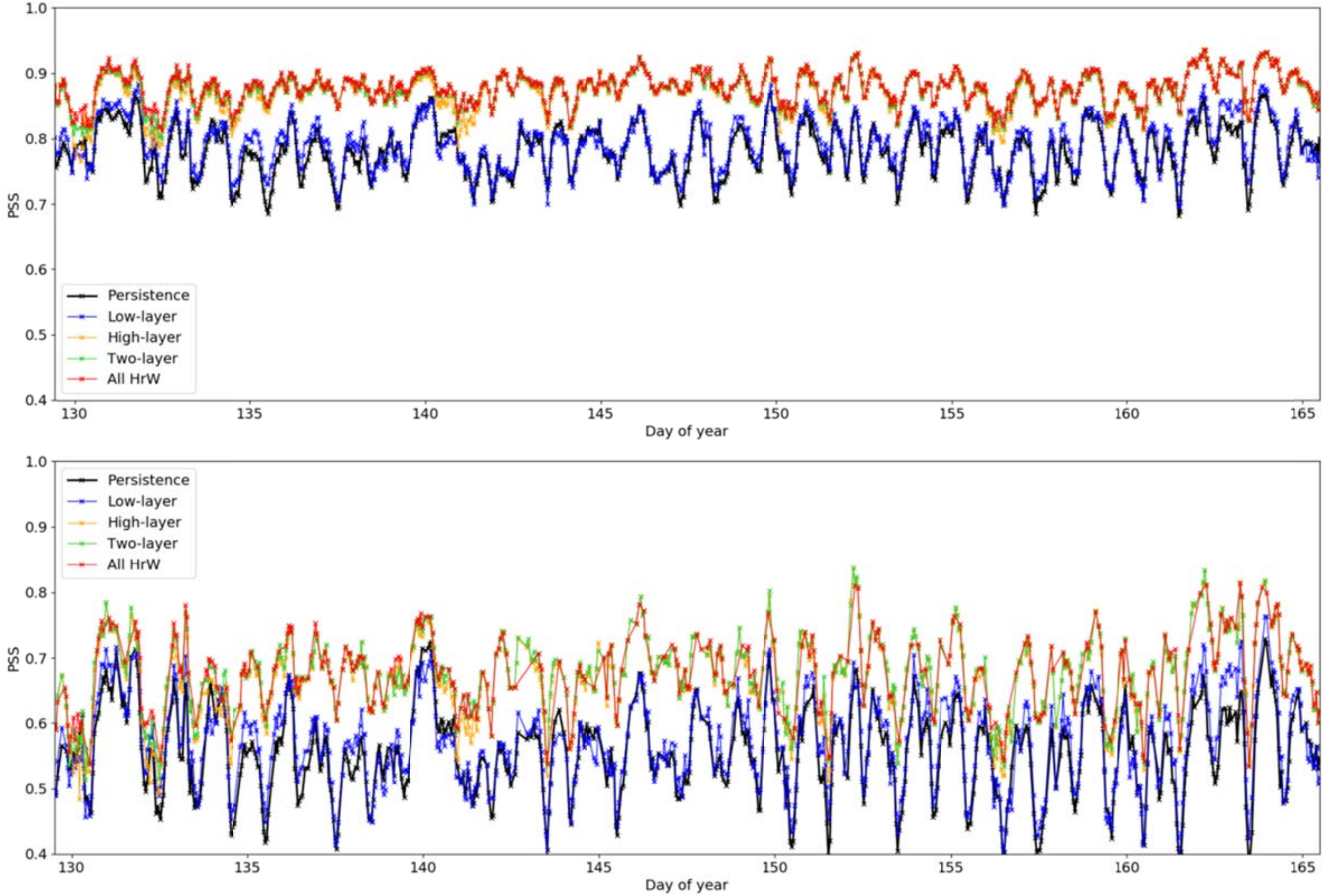


Figure 22: *PSS time series for the IR10.8 240K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 10.8, 270 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100./100.	100./100.	97.4 / 97.7	99.3 / 98.6
Best	0.0 / 0.0	100./99.8	0.0 / 0.0	0.0 / 0.0
Second-best	100./99.8	0.0 / 0.2	0.0 / 0.2	0.0 / 0.0
Third	0.0 / 0.2	0.0 / 0.0	44.4 / 72.9	55.6 / 26.9
Fourth	0.0 / 0.0	0.0 / 0.0	55.6 / 26.9	44.4 / 73.1

Channel 10.8, 270 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	97.1 / 97.6	97.9 / 98.0
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	98.6 / 100.0	0.0 / 0.0	0.0 / 0.0	1.4 / 0.0
Third	1.4 / 0.0	0.0 / 0.0	41.4 / 75.3	57.1 / 24.7
Fourth	0.0 / 0.0	0.0 / 0.0	58.6 / 24.7	41.4 / 75.3

Channel 10.8, 270 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	99.1 / 100.0	100.0 / 100.0	94.5 / 95.1	98.2 / 97.2

Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	99.1 / 99.4	0.0 / 0.0	0.0 / 0.0	0.9 / 0.6
Third	0.9 / 0.6	0.0 / 0.0	37.6 / 74.5	61.5 / 24.9
Fourth	0.0 / 0.0	0.0 / 0.0	62.4 / 25.5	37.6 / 74.5

Channel 10.8, 270 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	94.7 / 91.9	94.7 / 95.2
Best	5.3 / 0.0	94.7 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	84.2 / 98.2	0.0 / 0.0	5.3 / 0.0	10.5 / 1.8
Third	10.5 / 1.8	5.3 / 0.0	36.8 / 68.3	47.4 / 29.9
Fourth	0.0 / 0.0	0.0 / 0.0	57.9 / 31.7	42.1 / 68.3

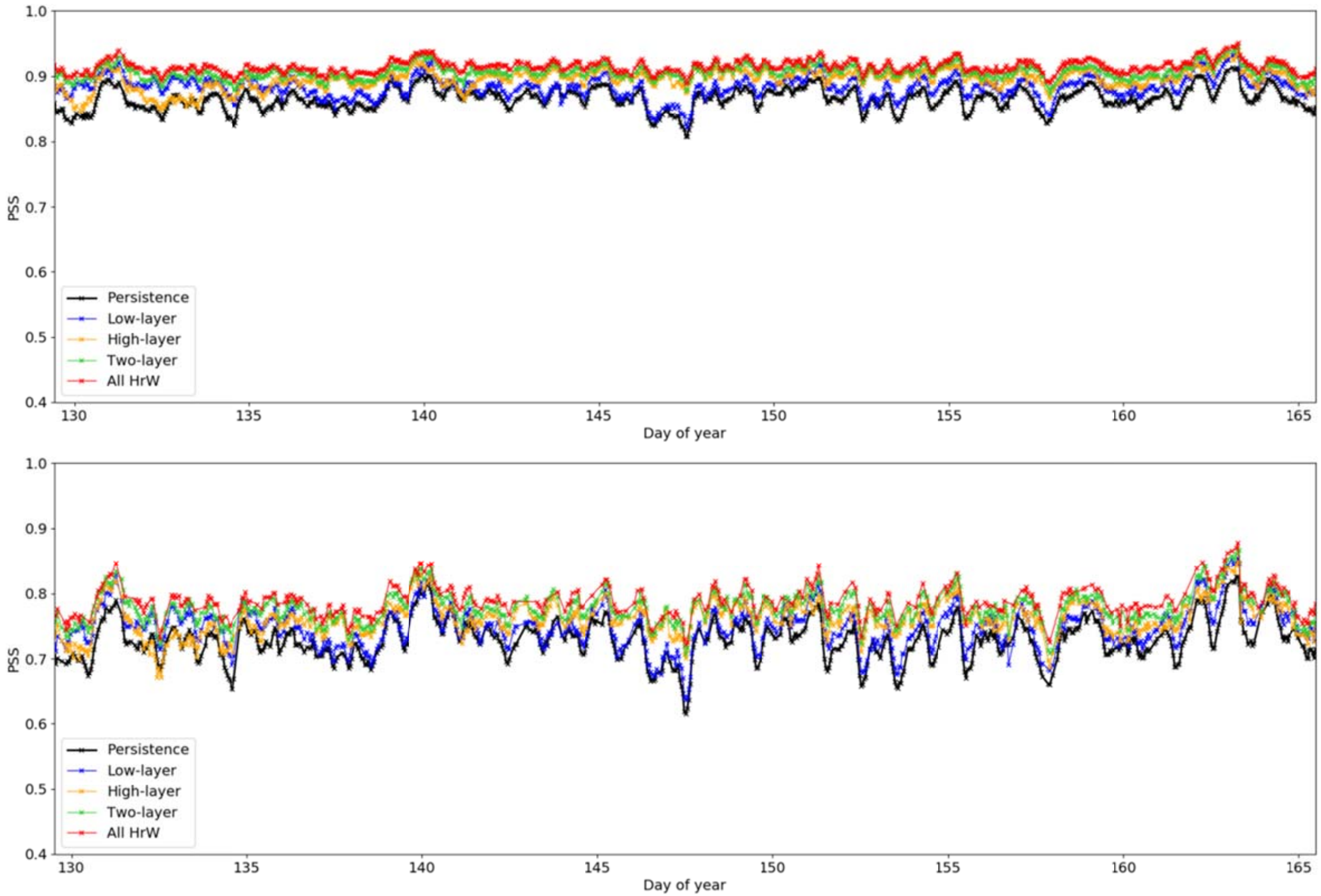


Figure 23: *PSS time series for the IR10.8 270K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

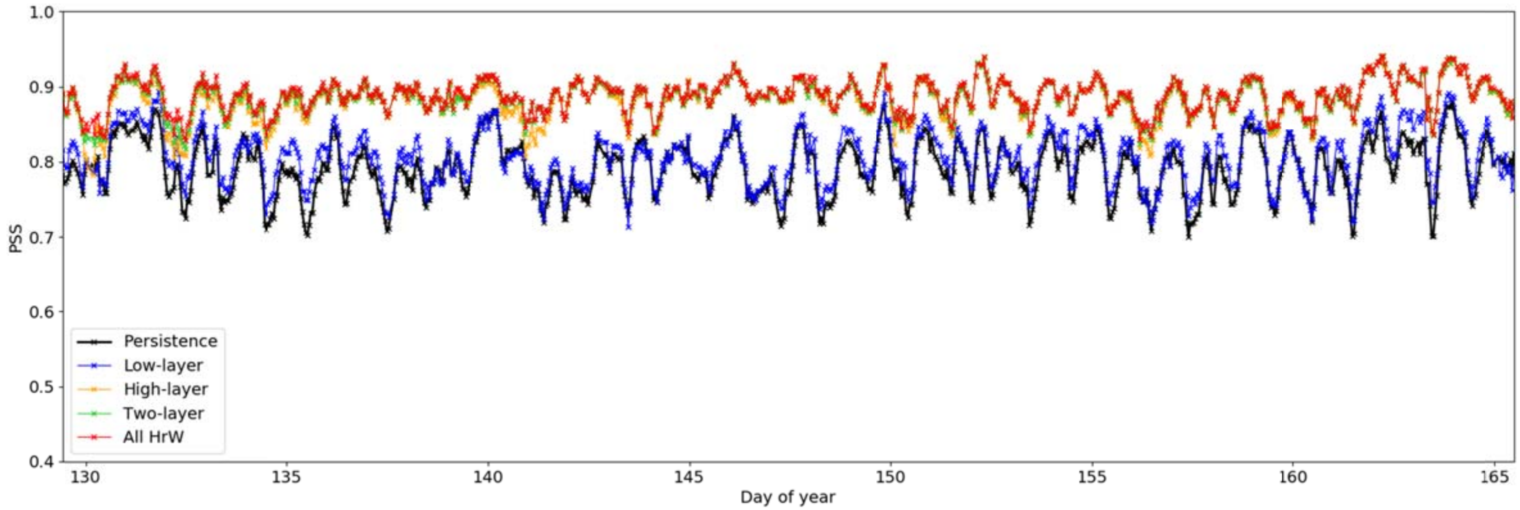
Channel 12.0, 240 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100./100.	100./100.	100./99.7	94.0 / 86.8
Best	2.6 / 10.2	94.7/85.8	2.6 / 3.8	0.0 / 0.0
Second-best	82.1 / 71.7	4.6 / 11.3	13.2 / 17.2	0.0 / 0.0
Third	15.2 / 18.1	0.7 / 3.0	84.1 / 78.5	0.0 / 0.5
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 0.5	100./99.5

Channel 12.0, 240 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	100.0 / 99.4	93.6 / 82.0
Best	7.1 / 11.0	89.3 / 84.1	3.6 / 4.9	0.0 / 0.0
Second-best	75.7 / 72.2	9.3 / 12.5	15.0 / 15.3	0.0 / 0.0
Third	17.1 / 16.9	1.4 / 3.3	81.4 / 78.6	0.0 / 1.2
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 1.2	100.0 / 98.8

Channel 12.0, 240 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	100.0 / 99.4	88.9 / 80.4
Best	12.0 / 15.2	80.6 / 80.2	7.4 / 4.5	0.0 / 0.0
Second-best	75.0 / 70.2	13.0 / 14.2	12.0 / 15.4	0.0 / 0.2

Third	13.0 / 14.6	6.5 / 5.5	80.6 / 77.9	0.0 / 2.0
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 2.2	100.0 / 97.8

Channel 12.0, 240 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 99.3	100.0 / 99.6	100.0 / 98.5	83.3 / 76.8
Best	38.9 / 24.7	55.6 / 71.6	5.6 / 3.0	0.0 / 0.7
Second-best	55.6 / 60.5	22.2 / 21.4	22.2 / 17.7	0.0 / 0.4
Third	5.6 / 14.8	22.2 / 7.0	72.2 / 76.0	0.0 / 2.2
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 3.3	100.0 / 96.7



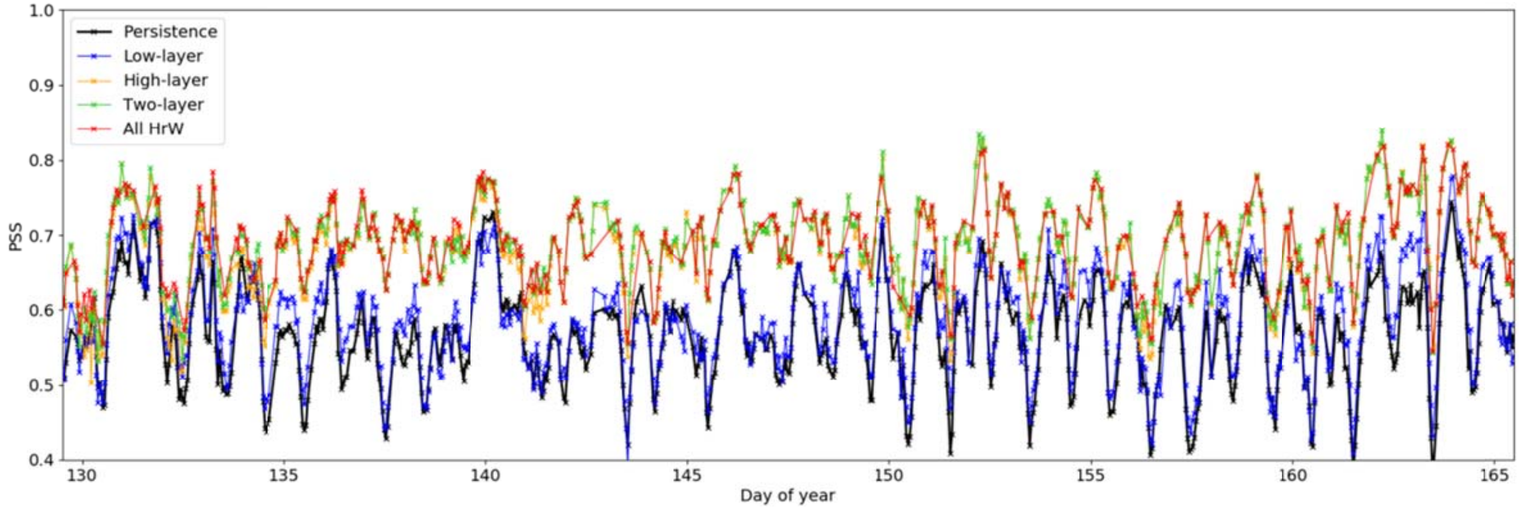


Figure 24: *PSS time series for the IR12.0 240K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 12.0, 270 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100./100.	94.7 / 97.4	99.3 / 98.8
Best	0.0 / 0.0	100./99.8	0.0 / 0.0	0.0 / 0.0
Second-best	100.0 / 99.8	0.0 / 0.2	0.0 / 0.2	0.0 / 0.0
Third	0.0 / 0.2	0.0 / 0.0	45.0 / 72.9	55.0 / 26.9
Fourth	0.0 / 0.0	0.0 / 0.0	55.0 / 26.9	45.0 / 73.1

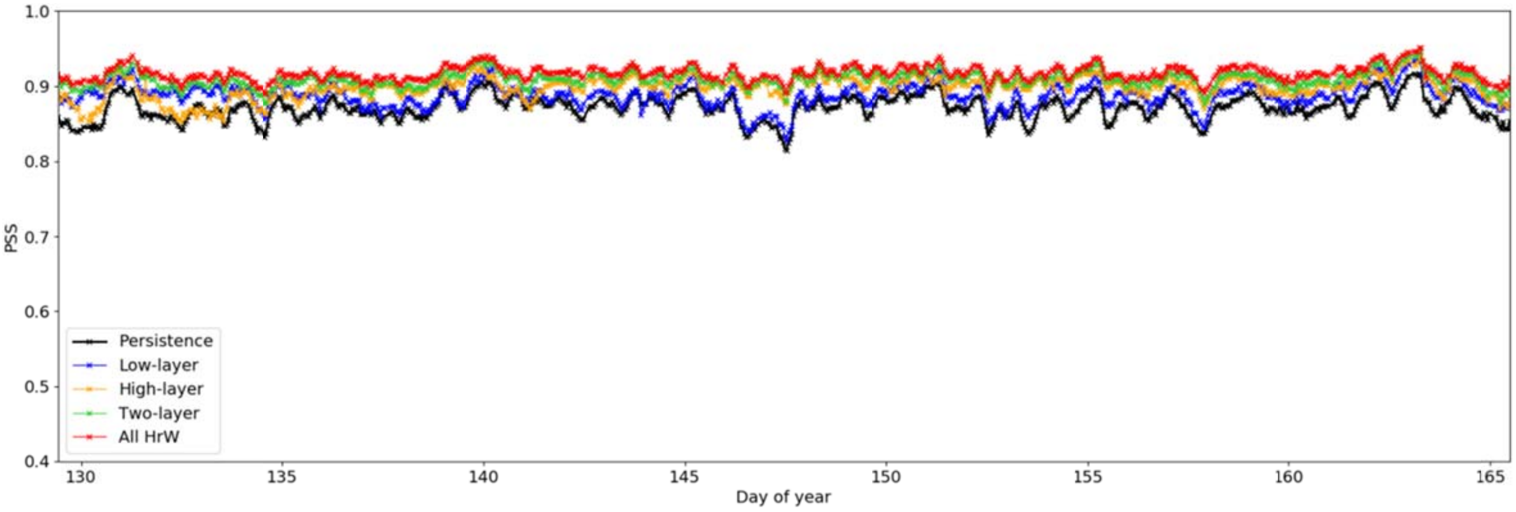
Channel 12.0, 270 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	100.0 / 100.0	100.0 / 100.0	95.0 / 97.1	97.9 / 97.5
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	100.0 / 99.8	0.0 / 0.0	0.0 / 0.0	0.0 / 0.2
Third	0.0 / 0.2	0.0 / 0.0	41.4 / 74.3	58.6 / 25.5
Fourth	0.0 / 0.0	0.0 / 0.0	58.6 / 25.7	41.4 / 74.3

Channel 12.0, 270 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.1 / 100.0	100.0 / 100.0	91.7 / 94.7	97.2 / 97.6
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	99.1 / 99.0	0.0 / 0.0	0.0 / 0.0	0.9 / 1.0
Third	0.9 / 1.0	0.0 / 0.0	38.9 / 74.1	60.2 / 24.9
Fourth	0.0 / 0.0	0.0 / 0.0	61.1 / 25.9	38.9 / 74.1

Channel 12.0, 270 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	88.9 / 91.1	94.4 / 95.9
Best	5.6 / 0.0	94.4 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	94.4 / 97.4	0.0 / 0.0	5.6 / 0.0	0.0 / 2.6
Third	0.0 / 2.6	5.6 / 0.0	38.9 / 69.4	55.6 / 28.0

Fourth	0.0 / 0.0	0.0 / 0.0	55.6 / 30.6	44.4 / 69.4



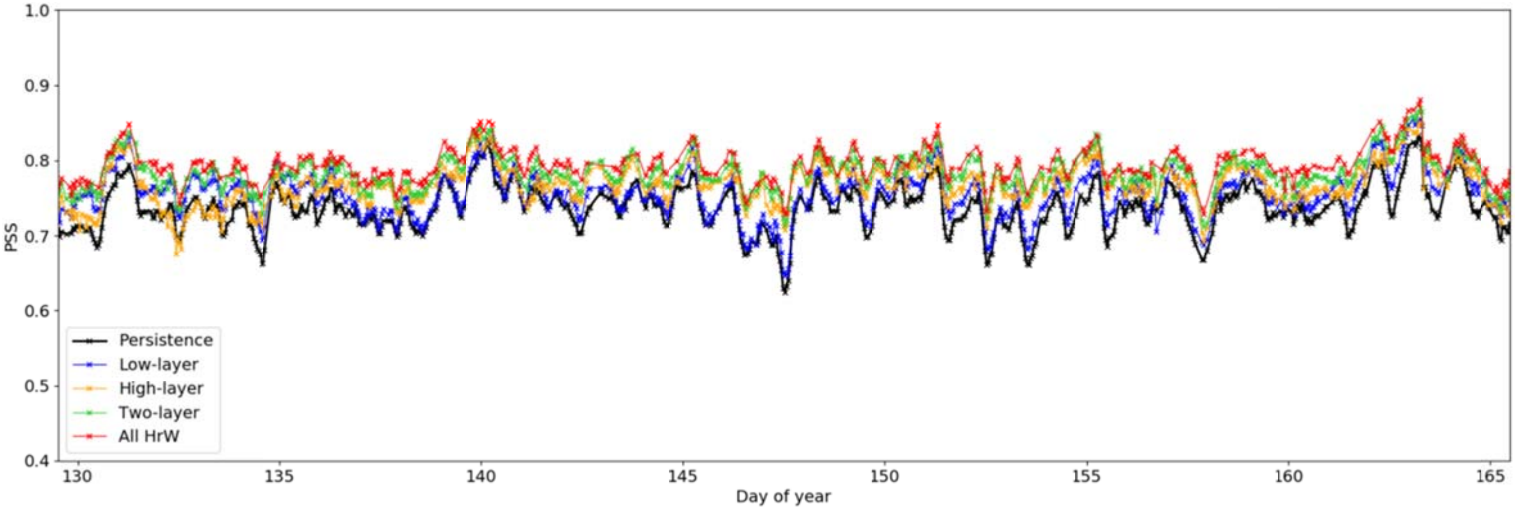


Figure 25: *PSS time series for the IR12.0 270K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 13.4, 240 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100./100.	100./100.	100./100.	99.3 / 95.0
Best	0.7 / 2.1	99.3 / 97.4	0.0 / 0.2	0.0 / 0.0
Second-best	92.7 / 86.5	0.7 / 2.4	6.6 / 11.5	0.0 / 0.0
Third	6.6 / 11.5	0.0 / 0.2	93.4 / 87.5	0.0 / 0.9
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 0.9	100./99.1

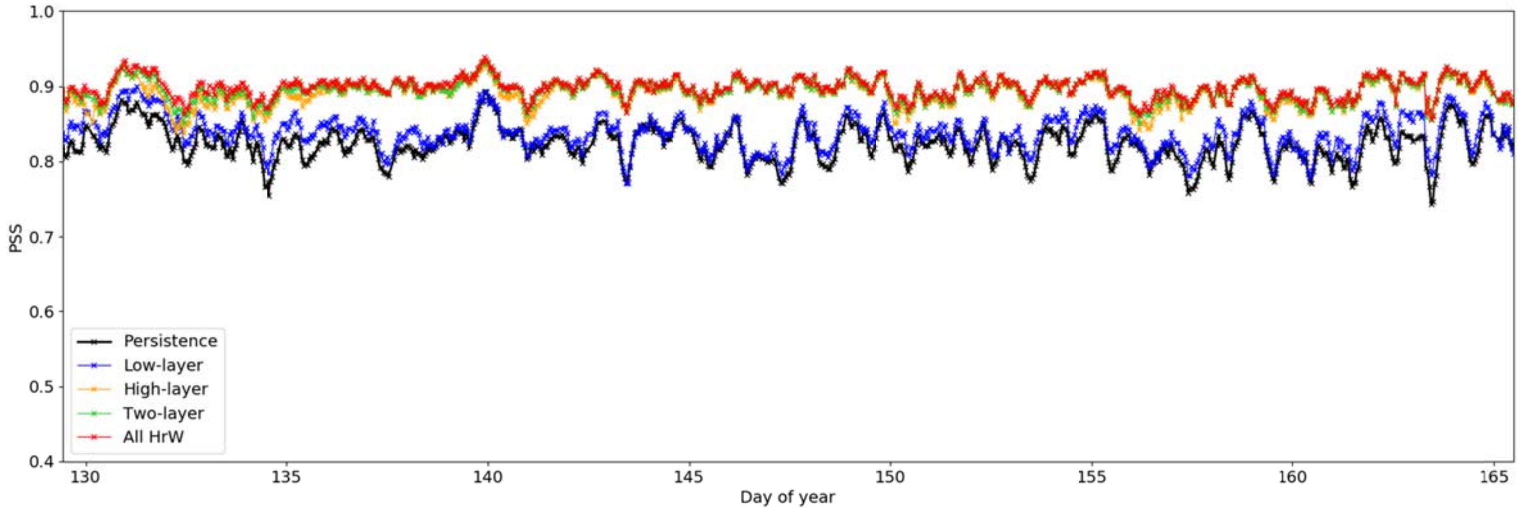
Channel 13.4, 240 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	100.0 / 100.0	100.0 / 100.0	100.0 / 100.0	97.9 / 91.0
Best	0.7 / 2.5	99.3 / 96.9	0.0 / 0.6	0.0 / 0.0
Second-best	92.9 / 86.7	0.7 / 2.5	6.4 / 10.8	0.0 / 0.0
Third	6.4 / 10.8	0.0 / 0.6	93.6 / 87.1	0.0 / 1.6
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 1.6	100.0 / 98.4

Channel 13.4, 240 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	100.0 / 99.4	96.2 / 88.9
Best	1.9 / 4.5	97.2 / 94.1	0.9 / 1.4	0.0 / 0.0
Second-best	96.2 / 86.4	2.8 / 4.3	0.9 / 9.3	0.0 / 0.0
Third	1.9 / 9.1	0.0 / 1.6	98.1 / 87.5	0.0 / 1.8
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 1.8	100.0 / 98.2

Channel 13.4, 240 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	100.0 / 98.5	92.9 / 84.9
Best	7.1 / 11.8	92.9 / 87.5	0.0 / 0.7	0.0 / 0.0
Second-best	92.9 / 77.5	0.0 / 11.8	7.1 / 10.7	0.0 / 0.0
Third	0.0 / 10.7	7.1 / 0.7	92.9 / 85.6	0.0 / 3.0

Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 3.0	100.0 / 97.0



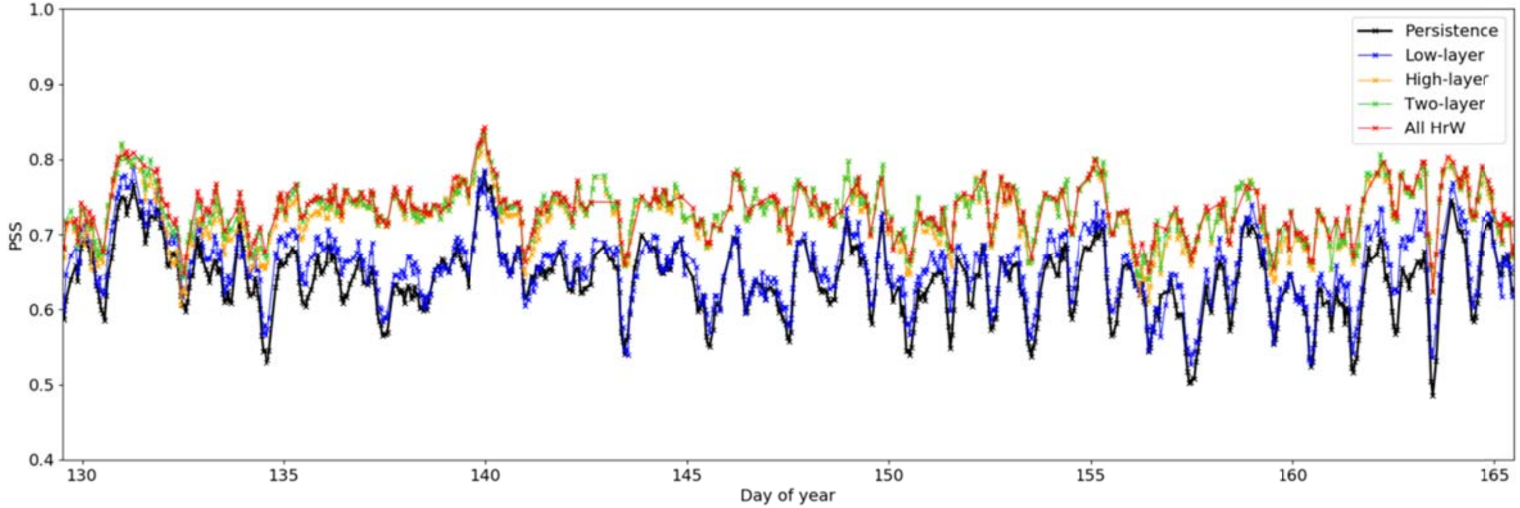


Figure 26: *PSS time series for the IR13.4 240K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 13.4, 250 K, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	100.0 / 100.0	98.0 / 96.4
Best	0.7 / 0.0	99.3 / 99.8	0.0 / 0.0	0.0 / 0.0
Second-best	98.0 / 97.7	0.7 / 0.2	1.3 / 2.3	0.0 / 0.0
Third	1.3 / 2.3	0.0 / 0.0	93.4 / 86.1	5.3 / 11.6
Fourth	0.0 / 0.0	0.0 / 0.0	5.3 / 11.6	94.7 / 88.4

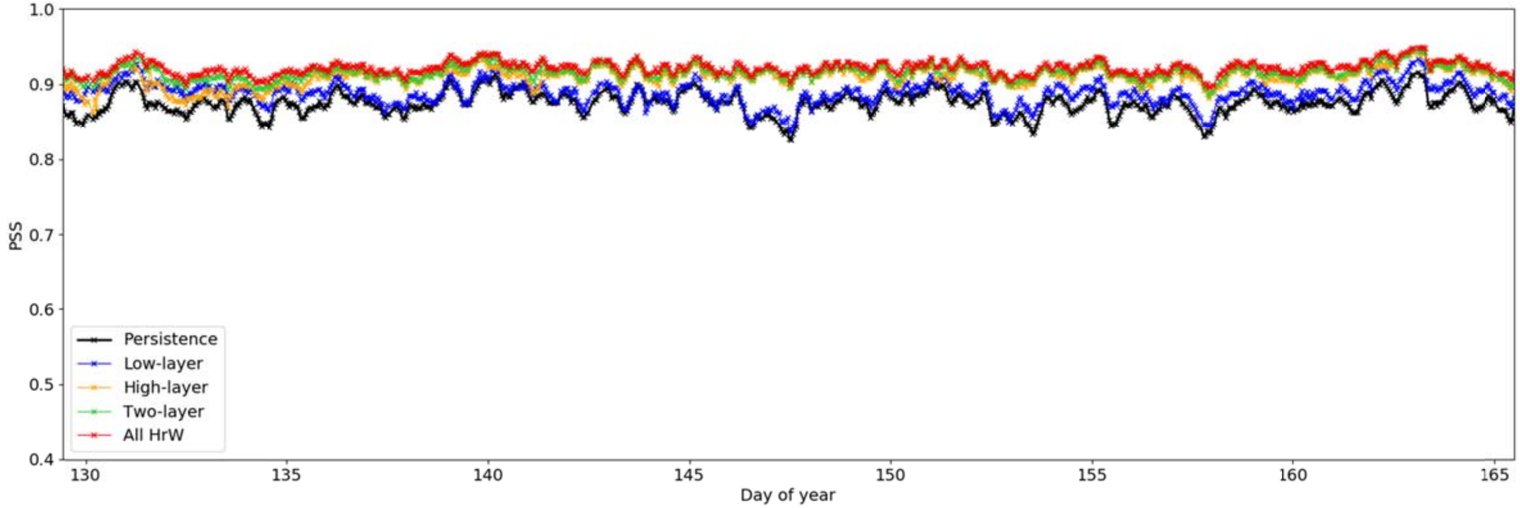
Channel 13.4, 250 K, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	100.0 / 100.0	100.0 / 100.0	100.0 / 100.0	96.4 / 96.5
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	100.0 / 98.8	0.0 / 0.0	0.0 / 1.2	0.0 / 0.0
Third	0.0 / 1.2	0.0 / 0.0	93.6 / 87.8	6.4 / 11.0
Fourth	0.0 / 0.0	0.0 / 0.0	6.4 / 11.0	93.6 / 89.0

Channel 13.4, 250 K, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	100.0 / 99.2	98.1 / 94.7
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	100.0 / 98.0	0.0 / 0.0	0.0 / 1.8	0.0 / 0.2
Third	0.0 / 2.0	0.0 / 0.0	86.8 / 84.6	13.2 / 13.4
Fourth	0.0 / 0.0	0.0 / 0.0	13.2 / 13.6	86.8 / 86.4

Channel 13.4, 250 K, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	100.0 / 97.8	92.9 / 93.4
Best	7.1 / 0.0	92.9 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	92.9 / 97.4	0.0 / 0.0	7.1 / 1.5	0.0 / 1.1
Third	0.0 / 2.6	7.1 / 0.0	78.6 / 79.7	14.3 / 17.7

Fourth	0.0 / 0.0	0.0 / 0.0	14.3 / 18.8	85.7 / 81.2



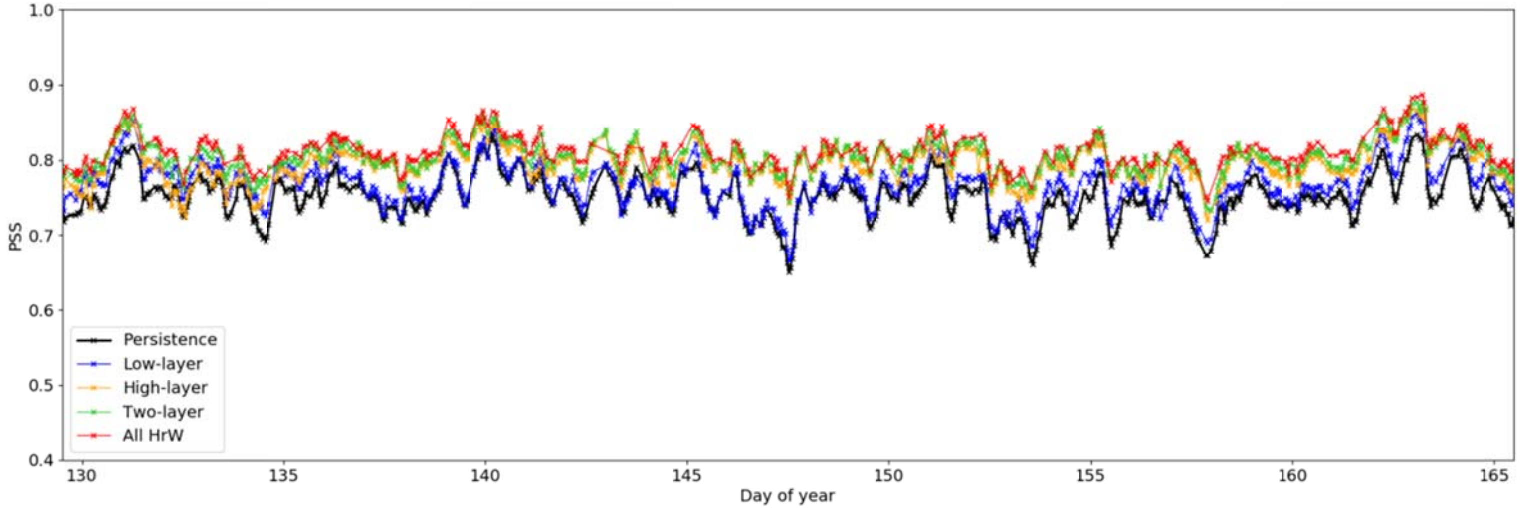


Figure 27: *PSS time series for the IR13.4 250K-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

6.2 VISIBLE CHANNELS

This section presents results for the SEVIRI visible channels 0.6 and 0.8 µm, the evaluations in this case being carried out on the forecasts of the parameter reflectivity (expressed in %). The presentation of results follows the same scheme as for the infrared channels, ch. 6.1.

6.2.1 Disregarding cloudfree areas (=Phase I, 18-30 April 2018)

Channel 0.6, 20 %, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	90.7	98.4	21.7	96.1
Best	0.0	76.0	0.0	24.0
Second-best	43.4	24.0	0.0	32.6
Third	56.6	0.0	6.2	37.2
Fourth	0.0	0.0	93.8	6.2

Channel 0.6, 20 %, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	76.9	85.1	11.6	92.6
Best	0.0	67.8	0.0	32.2
Second-best	31.4	32.2	0.0	36.4
Third	68.6	0.0	5.0	26.4

Fourth	0.0	0.0	95.0	5.0

Channel 0.6, 20 %, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	95.1	96.7	4.9	96.7
Best	0.0	86.9	0.0	13.1
Second-best	31.1	13.1	0.0	55.7
Third	68.9	0.0	0.0	31.1
Fourth	0.0	0.0	100.0	0.0

Channel 0.6, 20 %, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	66.7	91.7	16.7	83.3
Best	8.3	83.3	0.0	8.3
Second-best	50.0	8.3	0.0	41.7
Third	41.7	8.3	16.7	33.3
Fourth	0.0	0.0	83.3	16.7

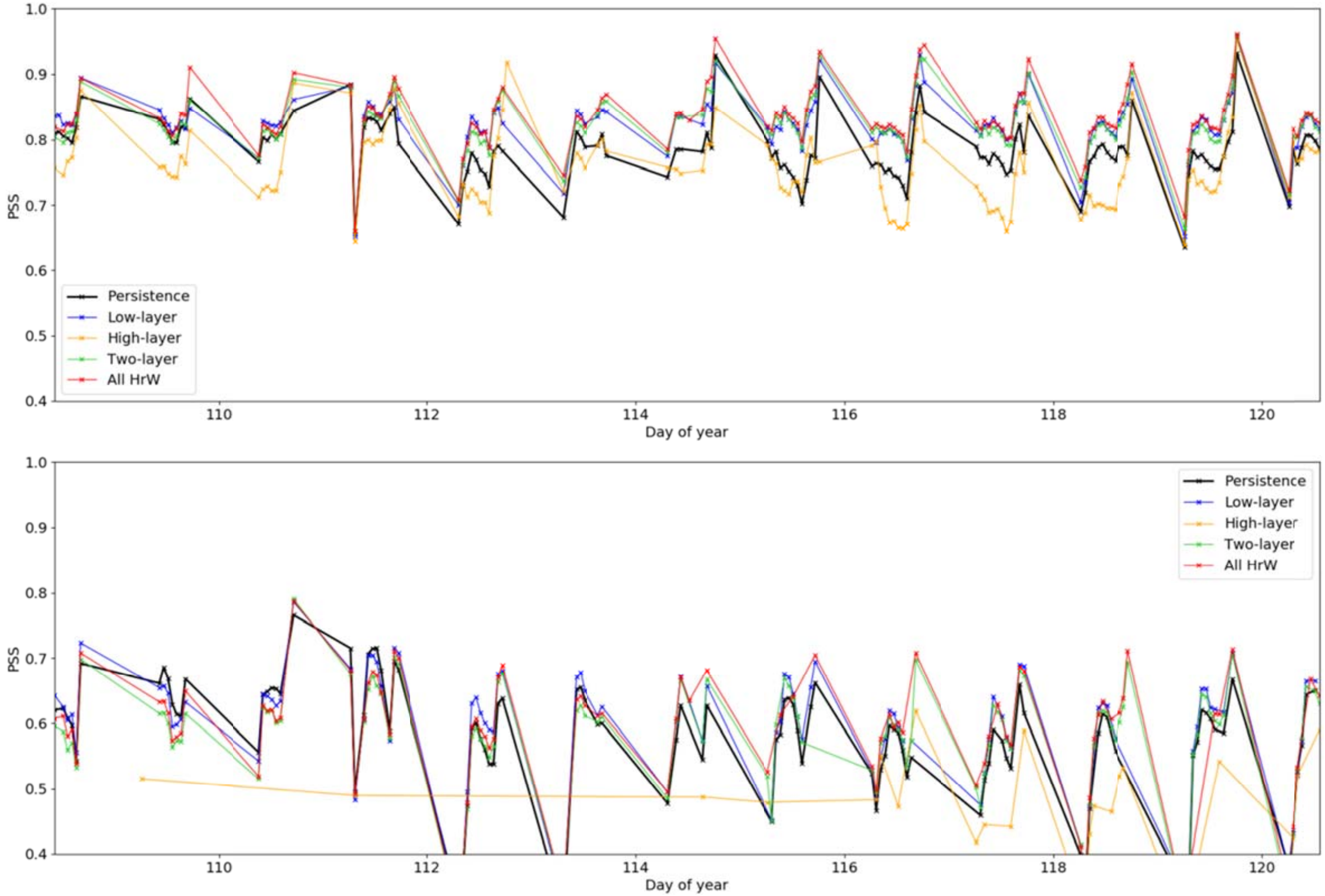


Figure 28: *PSS time series for the VIS0.6 20%-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

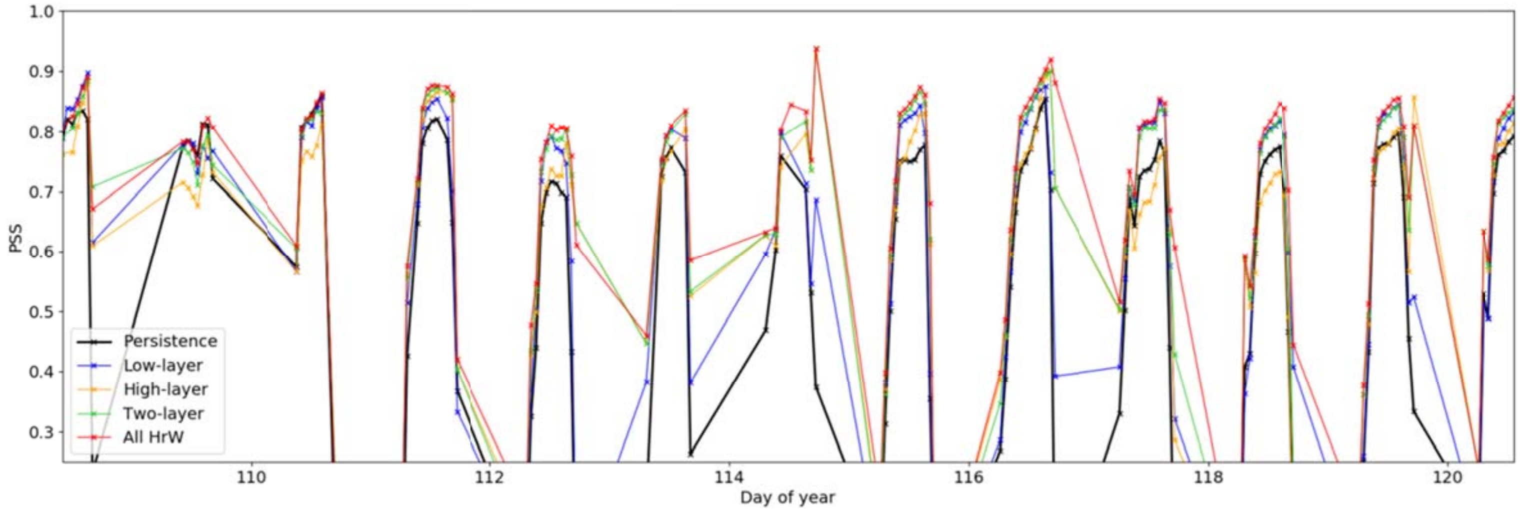
Channel 0.6, 40%, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	90.9	95.0	66.9	86.0
Best	1.7	87.6	4.1	5.8
Second-best	57.0	9.9	9.1	24.8
Third	40.5	2.5	28.9	28.1
Fourth	0.8	0.0	57.9	41.3

Channel 0.6, 40%, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	86.3	90.6	64.1	80.3
Best	5.1	80.3	4.3	10.3
Second-best	53.8	15.4	8.5	22.2
Third	41.0	4.3	24.8	29.9
Fourth	0.0	0.0	62.4	37.6

Channel 0.6, 40%, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	96.3	100.0	51.9	81.5
Best	5.6	85.2	0.0	9.3

Second-best	57.4	11.1	7.4	24.1
Third	33.3	3.7	24.1	38.9
Fourth	3.7	0.0	68.5	27.8

Channel 0.6, 40%, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0	90.9	72.7	54.5
Best	18.2	63.6	9.1	9.1
Second-best	54.5	27.3	9.1	9.1
Third	27.3	9.1	54.5	9.1
Fourth	0.0	0.0	27.3	72.7



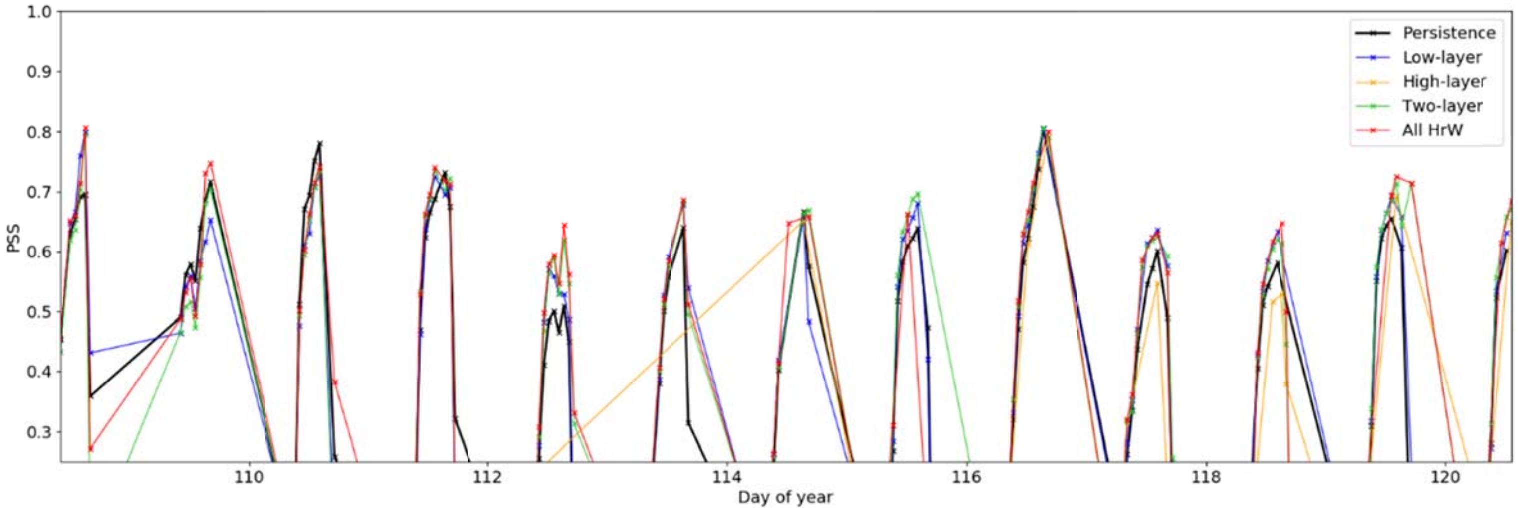


Figure 29: *PSS time series for the VIS0.6 40%-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 0.8, 20%, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	84.7	87.9	16.1	98.4
Best	0.0	62.1	0.0	37.9
Second-best	37.9	37.9	0.0	24.2
Third	62.1	0.0	4.0	33.9
Fourth	0.0	0.0	96.0	4.0

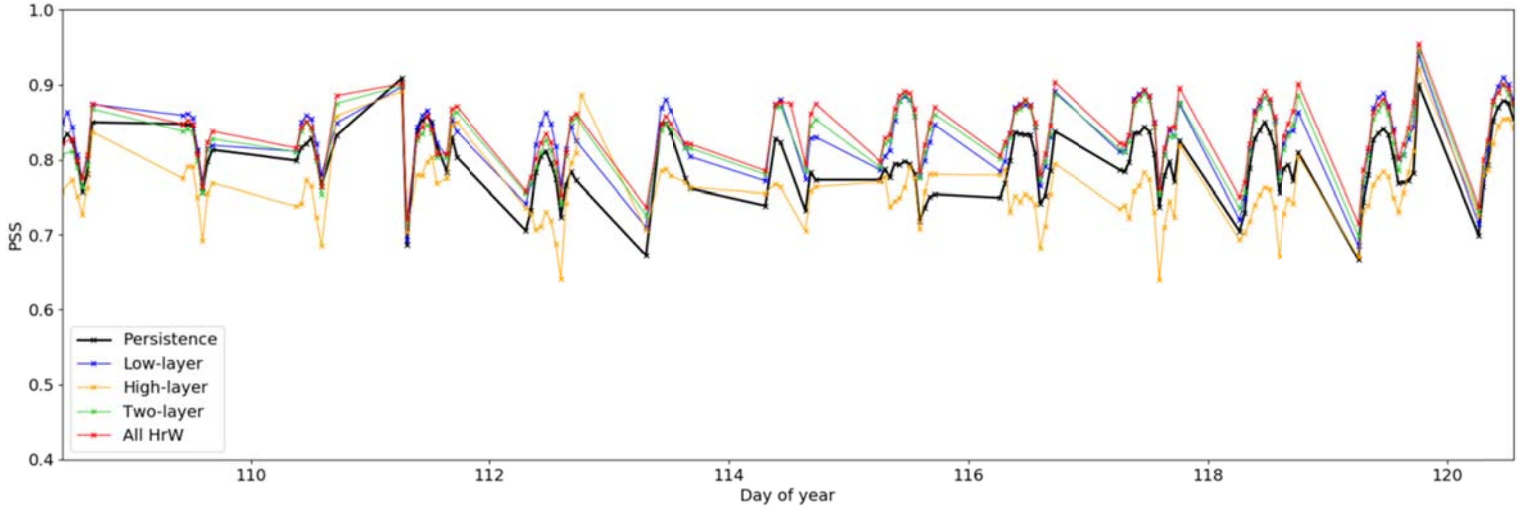
Channel 0.8, 20%, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	69.4	78.5	9.9	91.7
Best	0.0	52.1	0.0	47.9
Second-best	25.6	47.9	0.0	26.4
Third	74.4	0.0	2.5	23.1
Fourth	0.0	0.0	97.5	2.5

Channel 0.8, 20%, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	62.7	73.5	2.4	89.2
Best	0.0	39.8	0.0	60.2
Second-best	13.3	59.0	0.0	27.7
Third	86.7	1.2	0.0	12.0
Fourth	0.0	0.0	100.0	0.0

Channel 0.8, 20%, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	44.0	48.0	4.0	72.0
Best	12.0	20.0	4.0	64.0
Second-best	16.0	68.0	0.0	16.0
Third	68.0	12.0	4.0	16.0

Fourth	4.0	0.0	92.0	4.0



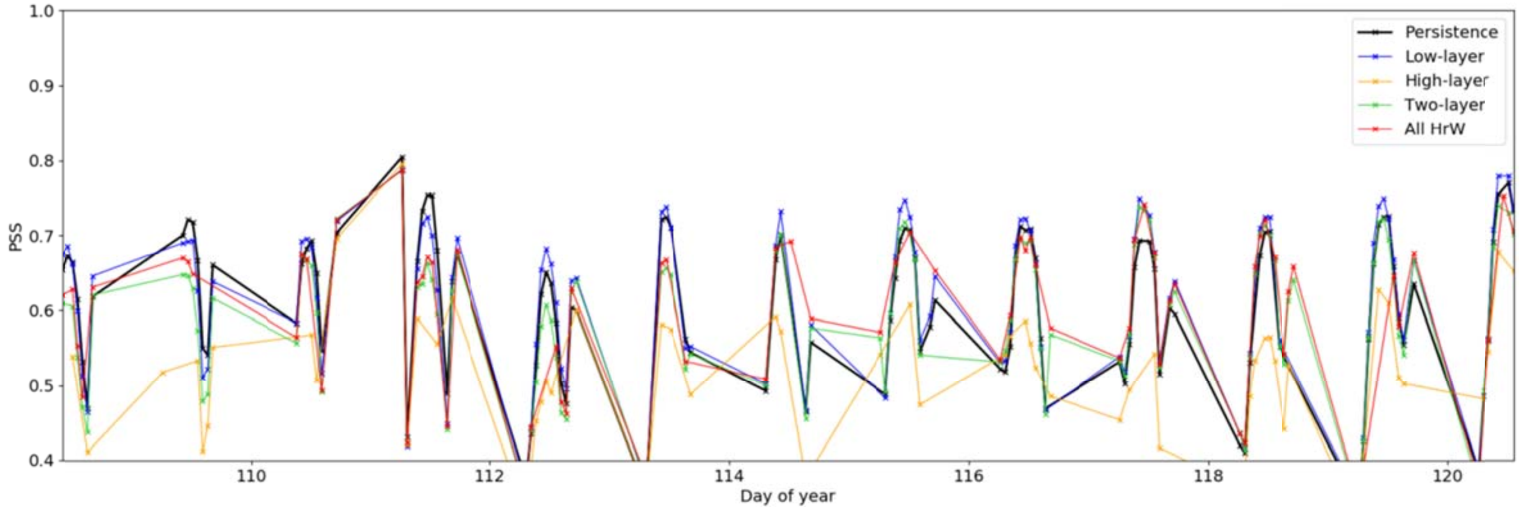


Figure 30: *PSS time series for the VIS0.8 20%-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 0.8, 40%, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	87.1	94.4	52.4	87.9
Best	2.4	87.9	1.6	8.1
Second-best	50.8	10.5	8.1	29.8
Third	46.0	0.8	26.6	27.4
Fourth	0.8	0.8	63.7	34.7

Channel 0.8, 40%, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	83.5	89.3	48.8	81.0
Best	0.8	81.0	2.5	15.7
Second-best	49.6	17.4	7.4	25.6
Third	47.1	0.8	24.0	28.1
Fourth	2.5	0.8	66.1	30.6

Channel 0.8, 40%, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	85.5	89.2	34.9	79.5

Best	2.4	77.1	0.0	20.5
Second-best	42.2	22.9	3.6	31.3
Third	51.8	0.0	21.7	26.5
Fourth	3.6	0.0	74.7	21.7

Channel 0.8, 40%, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	72.0	76.0	32.0	68.0
Best	16.0	64.0	4.0	16.0
Second-best	36.0	28.0	8.0	28.0
Third	48.0	8.0	20.0	24.0
Fourth	0.0	0.0	68.0	32.0

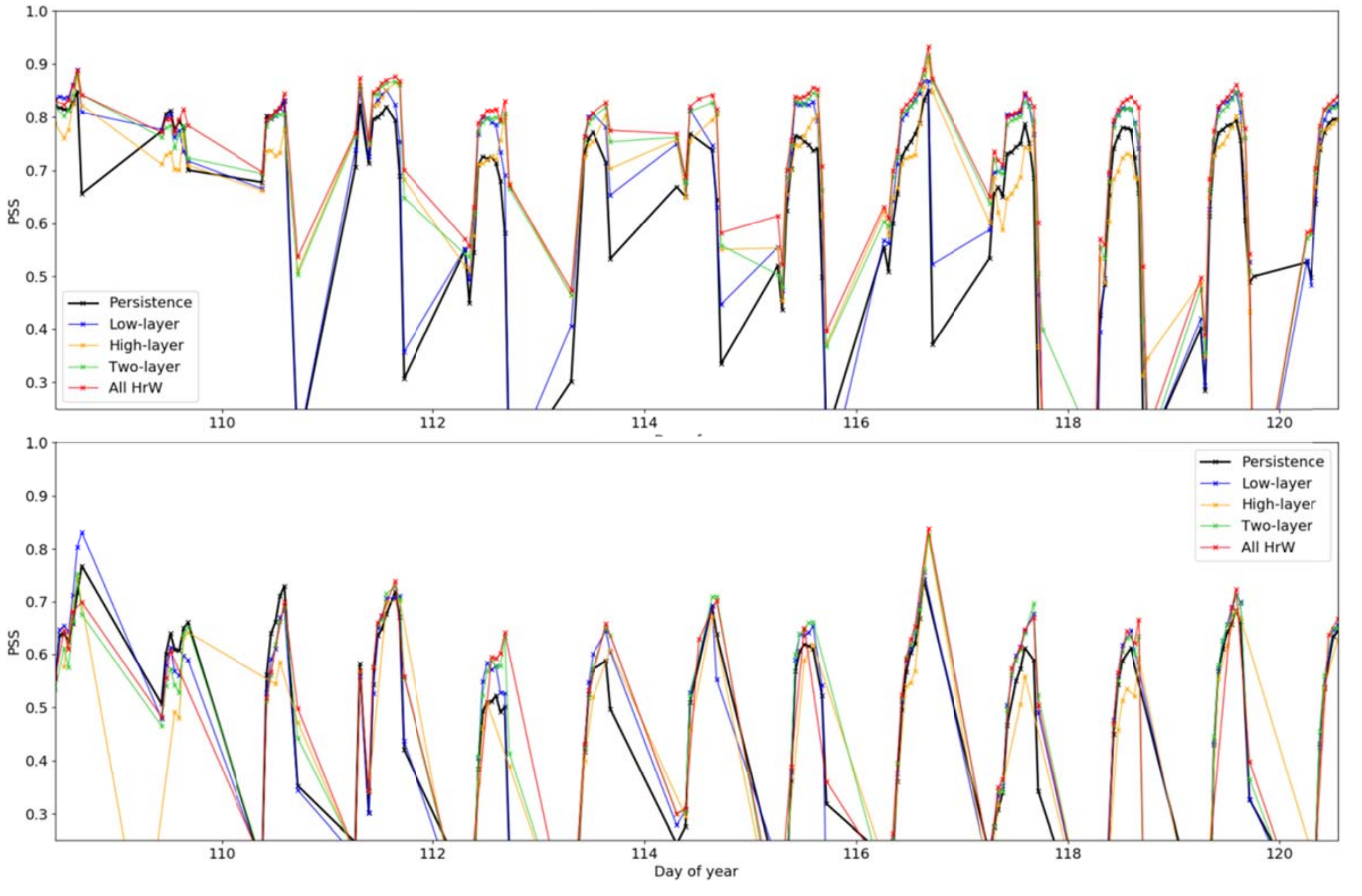


***Figure 31:** PSS time series for the VIS0.8 40%-isoline forecasts, Phase I. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

6.2.2 Under inclusion of cloudfree areas (Phases II and III, 8 May – 6 June 2018)

In the following tables, the first number in each cell refers to phase II (1-8 May), the second number is from phase III (9 May – 6 June) (cf. the definition of phases in section 2.4). As the number of cases in phase III is considerably higher and the two-layer approach ran in its corrected form including HRVIS vectors, the second number is better substantiated. On the same grounds, it was deemed appropriate to present only the phase-III results in the diagrams included in this section.

Channel 0.6, 20%, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	61.6 / 80.8	67.9 / 86.7	22.6 / 38.9	71.1 / 83.3
Best	2.5 / 4.9	55.3 / 68.7	1.9 / 2.7	39.6 / 23.7
Second-best	33.3 / 52.7	32.7 / 21.9	1.9 / 4.0	32.7 / 21.2
Third	57.2 / 39.7	9.4 / 7.7	14.5 / 17.8	18.9 / 34.8
Fourth	6.9 / 2.7	2.5 / 1.7	81.8 / 75.4	8.8 / 20.2

Channel 0.6, 20%, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	56.6 / 75.4	67.6 / 85.3	16.6 / 27.0	69.0 / 78.1
Best	1.4 / 5.7	52.4 / 65.0	2.8 / 2.1	43.4 / 27.2
Second-best	37.2 / 49.3	33.8 / 24.2	0.0 / 3.4	29.0 / 23.1
Third	56.6 / 42.3	7.6 / 7.9	13.1 / 12.7	22.8 / 37.1
Fourth	4.8 / 2.6	6.2 / 2.8	84.1 / 81.9	4.8 / 12.7

Channel 0.6, 20%, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	46.0 / 64.5	65.9 / 76.9	14.3 / 20.0	60.3 / 70.2
Best	6.3 / 5.6	43.7 / 57.8	3.2 / 3.7	46.8 / 32.9
Second-best	26.2 / 45.3	42.9 / 27.5	1.6 / 3.5	29.4 / 23.6
Third	64.3 / 46.3	7.9 / 9.3	9.5 / 10.1	18.3 / 34.3
Fourth	3.2 / 2.7	5.6 / 5.4	85.7 / 82.8	5.6 / 9.1

Channel 0.6, 20%, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	34.4 / 52.3	46.9 / 61.2	15.6 / 18.9	50.0 / 63.7
Best	3.1 / 10.7	40.6 / 38.1	3.1 / 4.3	53.1 / 47.0
Second-best	31.2 / 37.4	37.5 / 39.9	3.1 / 4.3	28.1 / 18.5
Third	65.6 / 47.7	18.8 / 15.3	3.1 / 12.8	12.5 / 24.2
Fourth	0.0 / 4.3	3.1 / 6.8	90.6 / 78.6	6.2 / 10.3

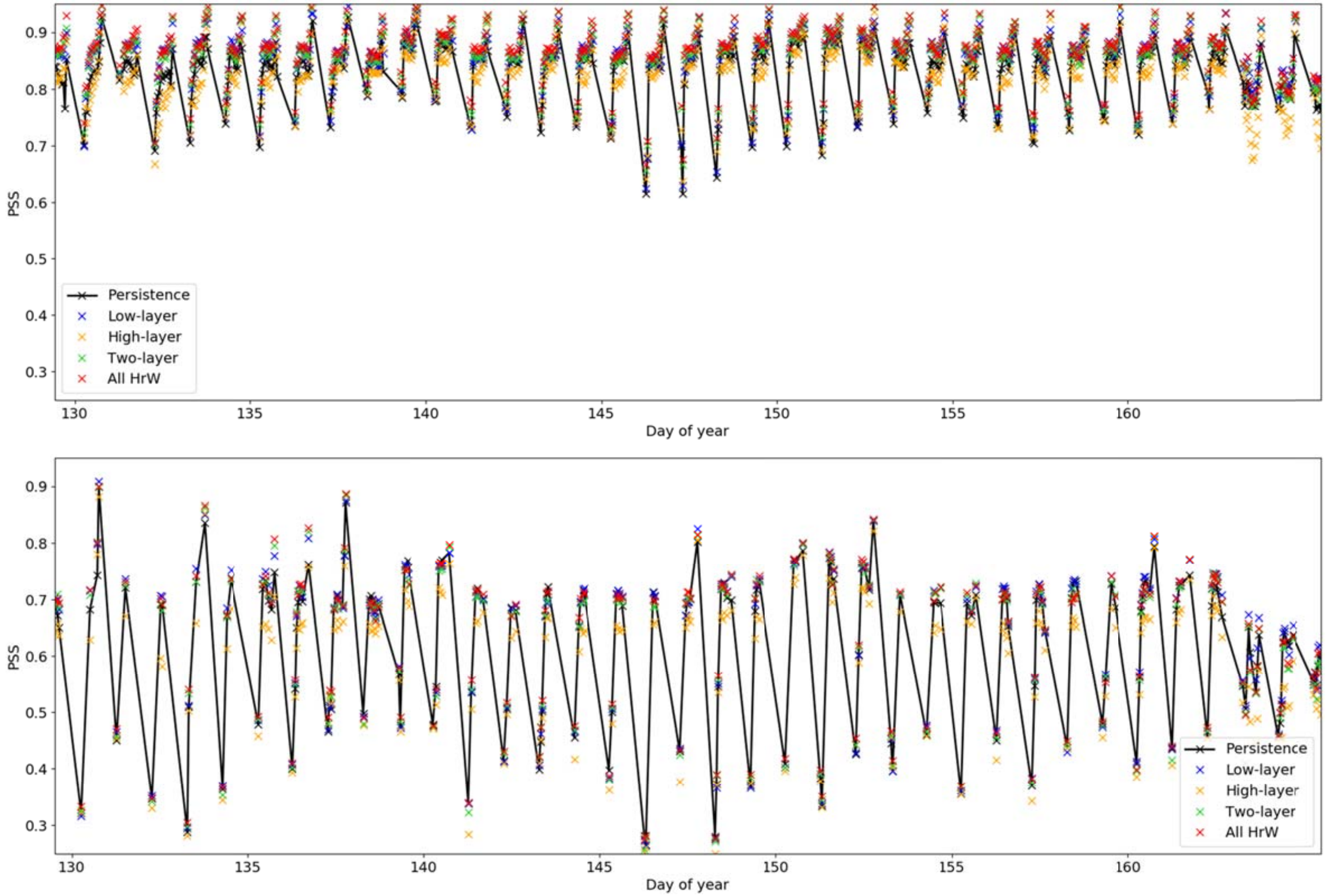


Figure 32: *PSS time series for the VIS0.6 20%-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

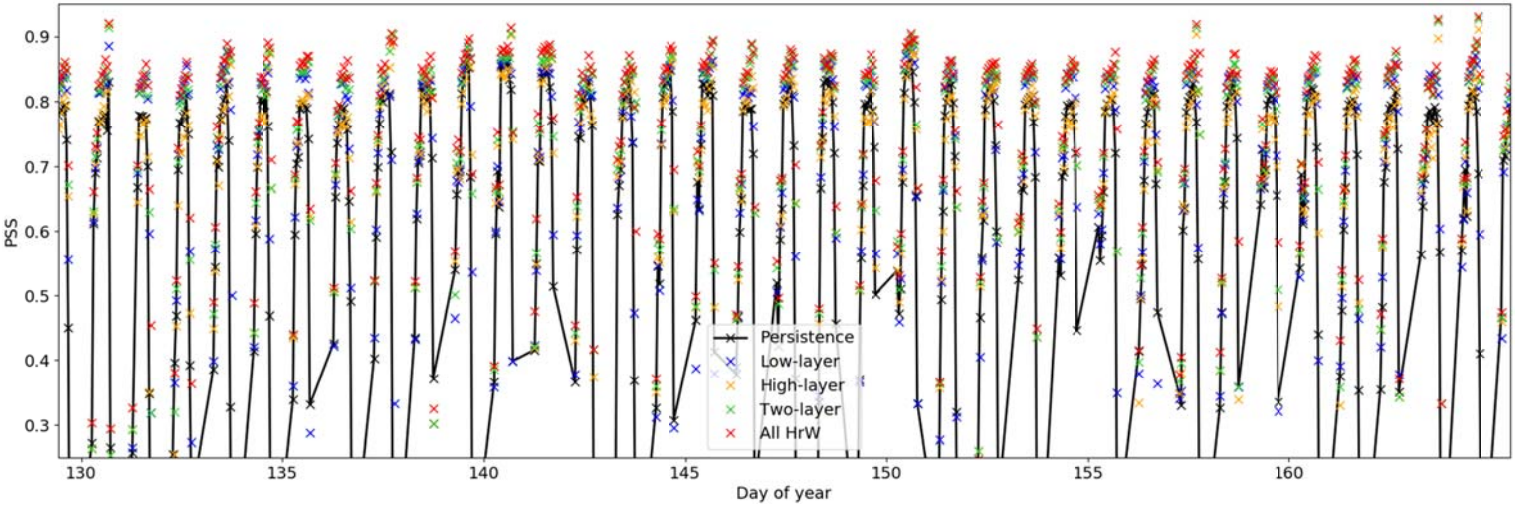
Channel 0.6, 40%, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	71.1 / 78.3	74.6 / 80.4	43.9 / 53.8	67.5 / 70.8
Best	7.0 / 3.2	64.0 / 69.6	7.0 / 8.9	19.3 / 16.8
Second-best	45.6 / 60.9	20.2 / 15.0	14.0 / 9.3	22.8 / 13.0
Third	41.2 / 32.0	11.4 / 9.1	24.6 / 28.5	21.9 / 33.0
Fourth	6.1 / 4.0	4.4 / 6.3	54.4 / 53.4	36.0 / 37.2

Channel 0.6, 40%, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	73.5 / 78.1	81.4 / 80.3	44.1 / 53.5	65.7 / 68.1
Best	7.8 / 6.4	65.7 / 70.8	3.9 / 8.8	19.6 / 12.8
Second-best	40.2 / 61.7	14.7 / 11.5	14.7 / 8.0	30.4 / 18.8
Third	49.0 / 27.2	11.8 / 10.4	24.5 / 29.0	16.7 / 33.8
Fourth	2.9 / 4.6	7.8 / 7.3	56.9 / 54.2	33.3 / 34.5

Channel 0.6, 40%, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	64.7 / 76.4	80.0 / 78.7	40.0 / 49.3	67.1 / 66.7
Best	4.7 / 8.0	63.5 / 64.4	5.9 / 9.4	24.7 / 17.7

Second-best	42.4 / 59.6	18.8 / 17.0	16.5 / 10.3	21.2 / 13.5
Third	49.4 / 26.8	9.4 / 11.2	18.8 / 25.2	23.5 / 36.2
Fourth	3.5 / 5.5	8.2 / 7.3	58.8 / 55.0	30.6 / 32.6

Channel 0.6, 40%, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	63.2 / 67.1	63.2 / 75.0	47.4 / 40.7	63.2 / 60.2
Best	10.5 / 17.1	36.8 / 45.8	10.5 / 10.6	36.8 / 26.4
Second-best	52.6 / 46.8	21.1 / 26.9	21.1 / 11.6	10.5 / 14.8
Third	31.6 / 28.7	26.3 / 13.4	15.8 / 26.4	26.3 / 31.5
Fourth	5.3 / 7.4	15.8 / 13.9	52.6 / 51.4	26.3 / 27.3



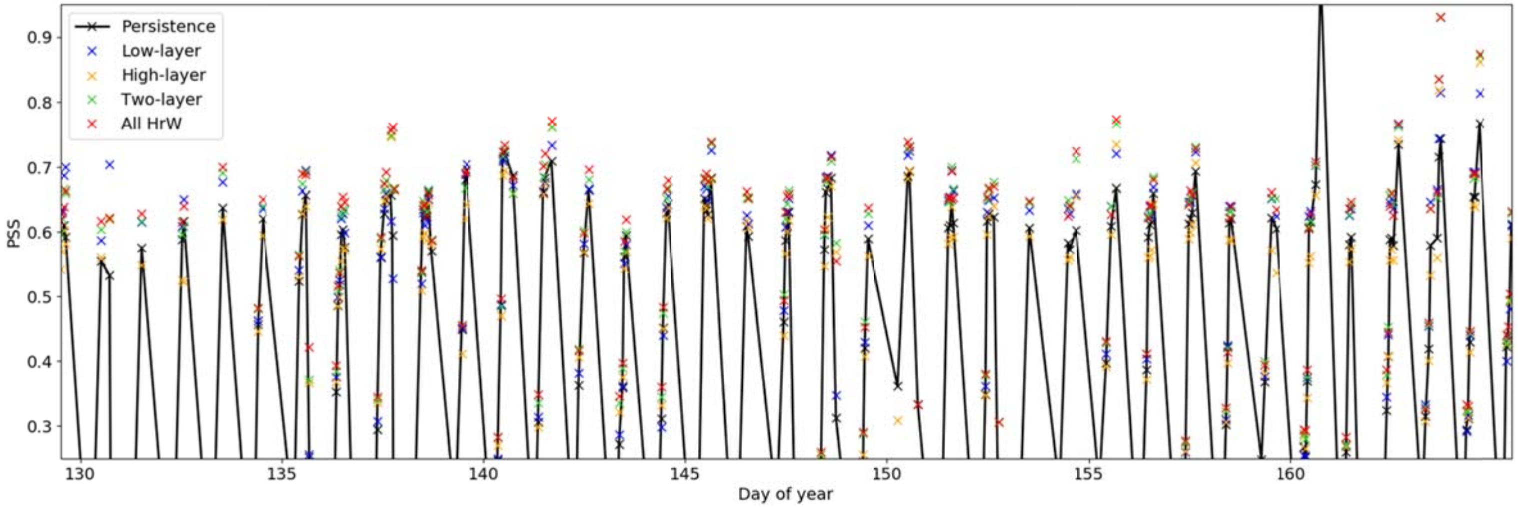


Figure 33: *PSS time series for the VIS0.6 40%-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 0.8, 20%, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	49.7 / 63.1	65.4 / 69.5	23.5 / 35.8	66.7 / 63.1
Best	2.6 / 3.1	52.3 / 65.0	1.3 / 2.2	43.8 / 29.7
Second-best	32.0 / 53.0	37.3 / 26.4	1.3 / 3.4	29.4 / 17.2
Third	62.7 / 41.7	6.5 / 6.2	13.7 / 18.9	17.0 / 33.3
Fourth	2.6 / 2.2	3.9 / 2.4	83.7 / 75.5	9.8 / 19.9

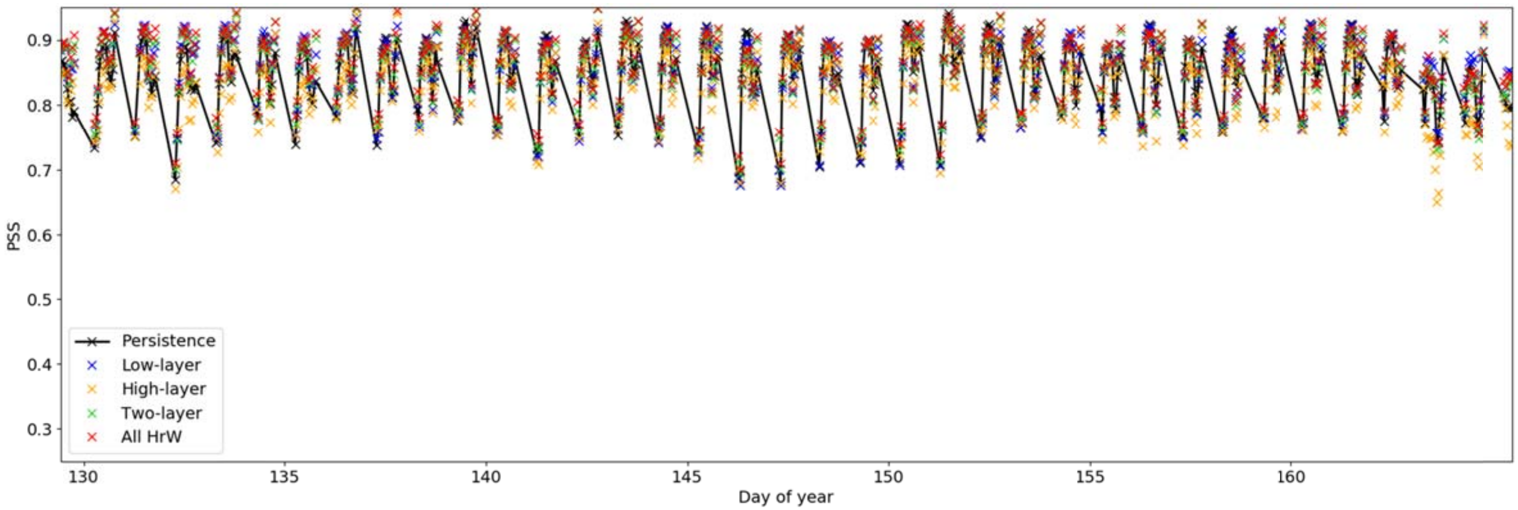
Channel 0.8, 20%, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	48.9 / 59.2	67.4 / 66.9	17.7 / 24.5	71.6 / 64.7
Best	0.7 / 4.4	43.3 / 52.4	0.0 / 1.5	56.0 / 41.6
Second-best	31.9 / 44.1	46.8 / 36.8	0.0 / 3.5	21.3 / 15.6
Third	65.2 / 50.7	8.5 / 8.1	9.9 / 11.4	16.3 / 29.9
Fourth	2.1 / 0.8	1.4 / 2.7	90.1 / 83.6	6.4 / 12.9

Channel 0.8, 20%, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	32.5 / 49.4	54.2 / 57.3	9.2 / 17.3	60.8 / 58.0
Best	2.5 / 5.3	37.5 / 41.0	0.8 / 1.8	59.2 / 52.0
Second-best	21.7 / 36.1	53.3 / 45.5	1.7 / 3.3	23.3 / 15.1
Third	73.3 / 56.3	5.8 / 9.4	8.3 / 10.8	12.5 / 23.5
Fourth	2.5 / 2.4	3.3 / 4.1	89.2 / 84.1	5.0 / 9.4

Channel 0.8, 20%, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	21.6 / 36.5	37.8 / 43.9	16.2 / 15.9	54.1 / 52.4
Best	5.4 / 7.7	21.6 / 30.3	5.4 / 2.6	67.6 / 59.4
Second-best	21.6 / 37.6	62.2 / 43.2	2.7 / 5.2	13.5 / 14.0
Third	70.3 / 50.6	13.5 / 20.3	2.7 / 11.4	13.5 / 17.7

Fourth	2.7 / 4.1	2.7 / 6.3	89.2 / 80.8	5.4 / 8.9



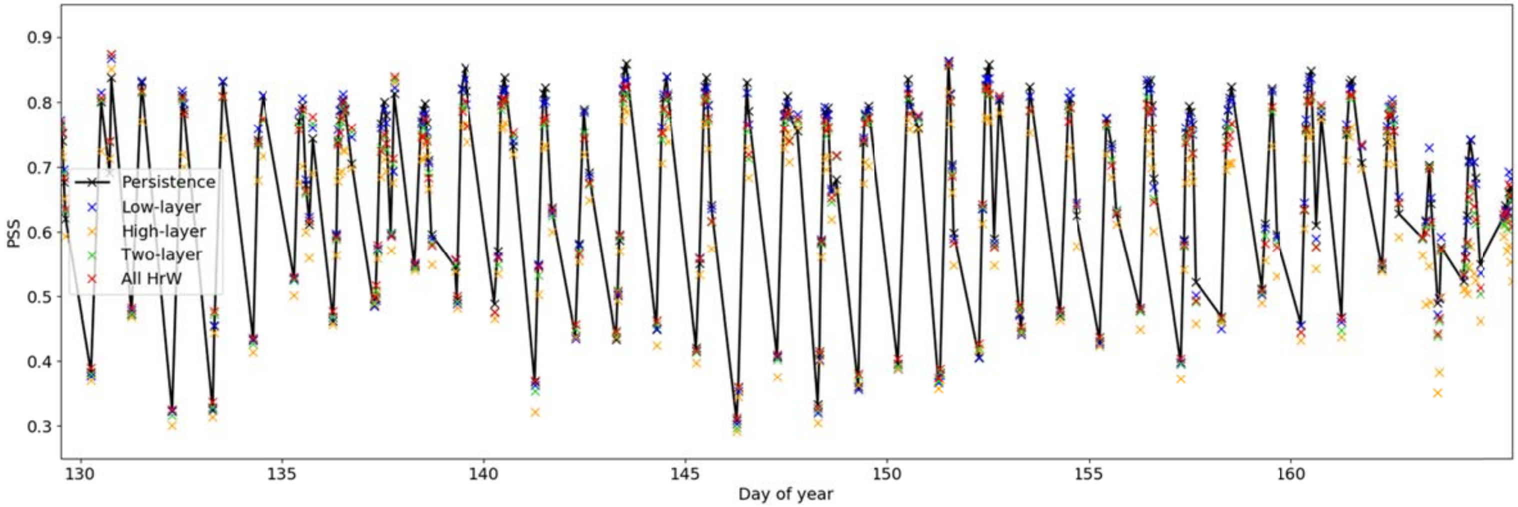


Figure 34: *PSS time series for the VIS0.8 20%-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

Channel 0.8, 40%, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	60.5 / 73.9	66.7 / 76.1	36.1 / 44.3	63.9 / 65.5
Best	3.4 / 7.4	63.9 / 68.4	4.8 / 4.0	27.9 / 19.9
Second-best	42.2 / 58.1	16.3 / 17.5	14.3 / 6.9	25.9 / 17.4
Third	49.0 / 31.6	11.6 / 11.0	23.1 / 29.0	17.7 / 28.7
Fourth	5.4 / 2.9	8.2 / 3.1	57.8 / 60.1	28.6 / 34.0

Channel 0.8, 40%, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*

better than persistence [%]	64.0 / 71.7	69.9 / 76.9	37.5 / 40.8	64.0 / 62.4
Best	9.6 / 6.4	58.8 / 69.0	5.9 / 5.6	25.0 / 18.9
Second-best	36.0 / 60.3	20.6 / 16.2	14.0 / 4.6	30.1 / 18.9
Third	45.6 / 28.3	9.6 / 9.2	25.0 / 30.1	19.9 / 32.6
Fourth	8.8 / 5.0	11.0 / 5.6	55.1 / 59.7	25.0 / 29.7

Channel 0.8, 40%, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	53.8 / 70.0	67.5 / 74.7	31.6 / 38.6	60.7 / 59.0
Best	6.0 / 7.6	52.1 / 64.7	6.8 / 5.5	35.0 / 22.2
Second-best	37.6 / 56.5	30.8 / 18.6	12.0 / 8.2	19.7 / 16.7
Third	47.0 / 32.2	9.4 / 9.0	19.7 / 24.1	23.9 / 34.5
Fourth	9.4 / 3.7	7.7 / 7.6	61.5 / 62.2	21.4 / 26.7

Channel 0.8, 40%, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	47.2 / 59.8	55.6 / 67.2	36.1 / 35.1	50.0 / 54.6
Best	11.1 / 14.0	41.7 / 45.4	8.3 / 12.5	38.9 / 28.0
Second-best	27.8 / 48.0	38.9 / 27.3	11.1 / 7.7	22.2 / 17.0
Third	50.0 / 31.7	11.1 / 17.3	30.6 / 21.4	8.3 / 29.5

Fourth	11.1 / 6.3	8.3 / 10.0	50.0 / 58.3	30.6 / 25.5

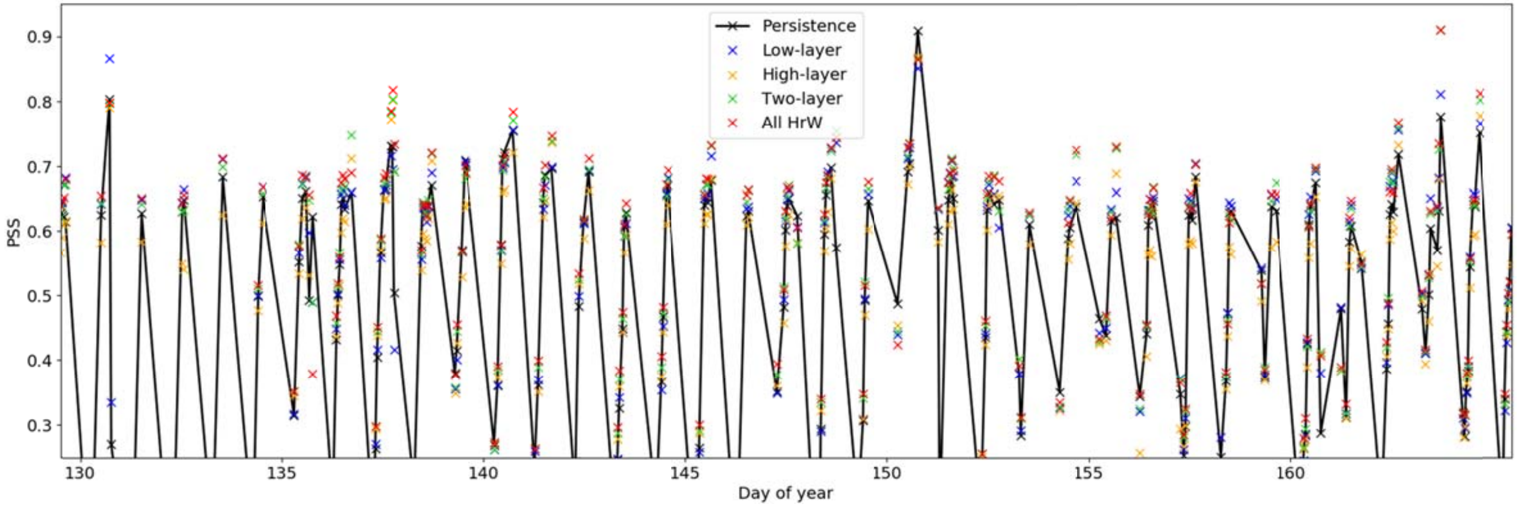


***Figure 35:** PSS time series for the VIS0.8 40%-isoline forecasts, Phase III. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

6.3 Thermal Channels: Water Vapour

Figure 36 - Figure 39 show the time series plots for the period 18 April – 8 May 2018, where WV evaluations were run (cf. 2.4). As explained in the main chapter 3.3, the evaluations compared just a sort of "All HrW" scheme (using all vectors derived from the channel itself) with persistence.

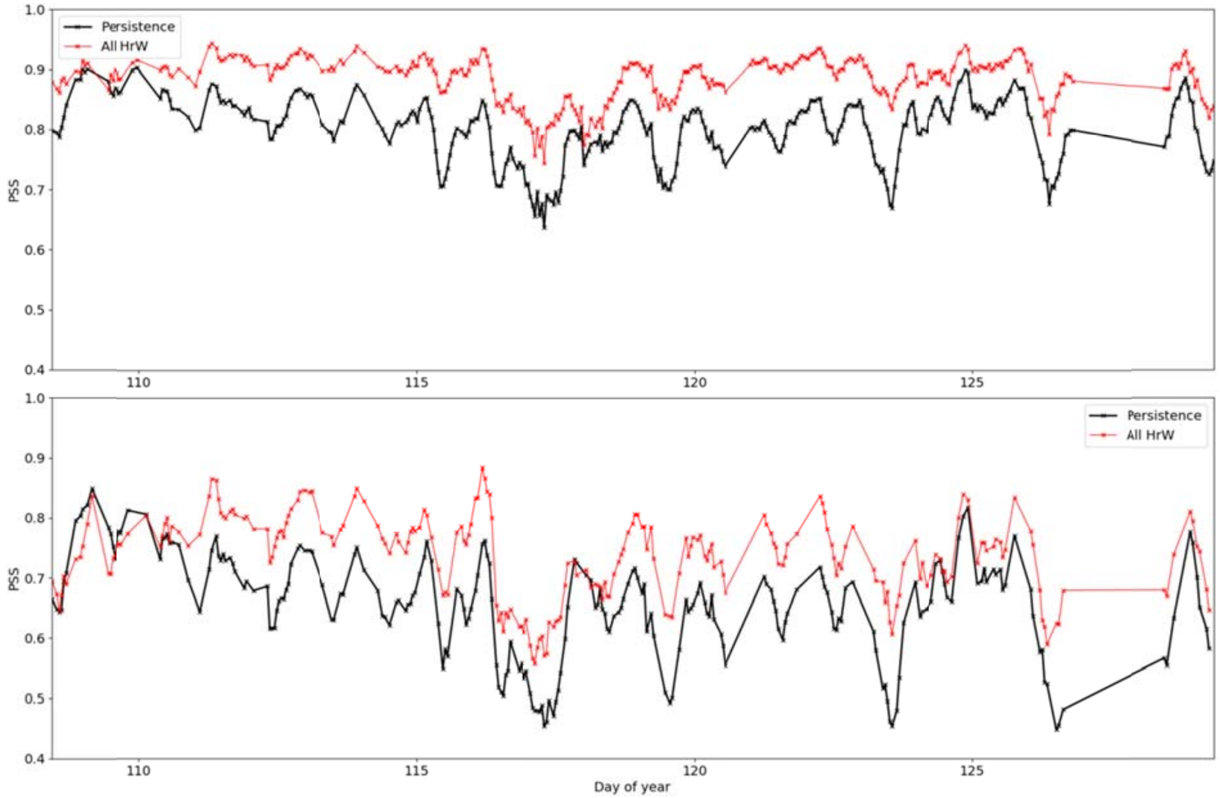


Figure 36: *PSS time series for the EXIM WV6.2 225 K-isoline forecast (red) vs. persistence (black). Upper panel: 15-minute forecasts; lower panel: leadtime 60 minutes.*

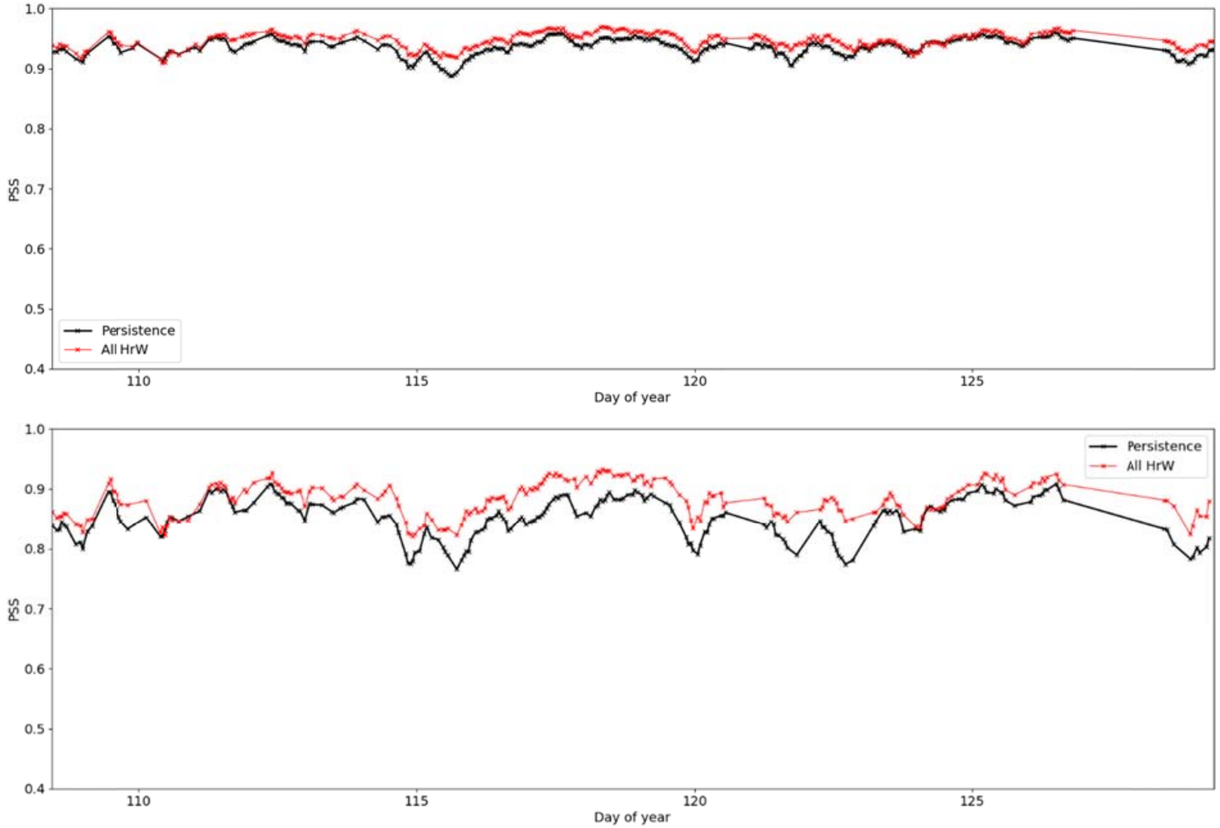


Figure 37: *PSS time series for the EXIM WV6.2 235 K-isoline forecast (red) vs. persistence (black). Upper panel: 15-minute forecasts; lower panel: leadtime 60 minutes.*

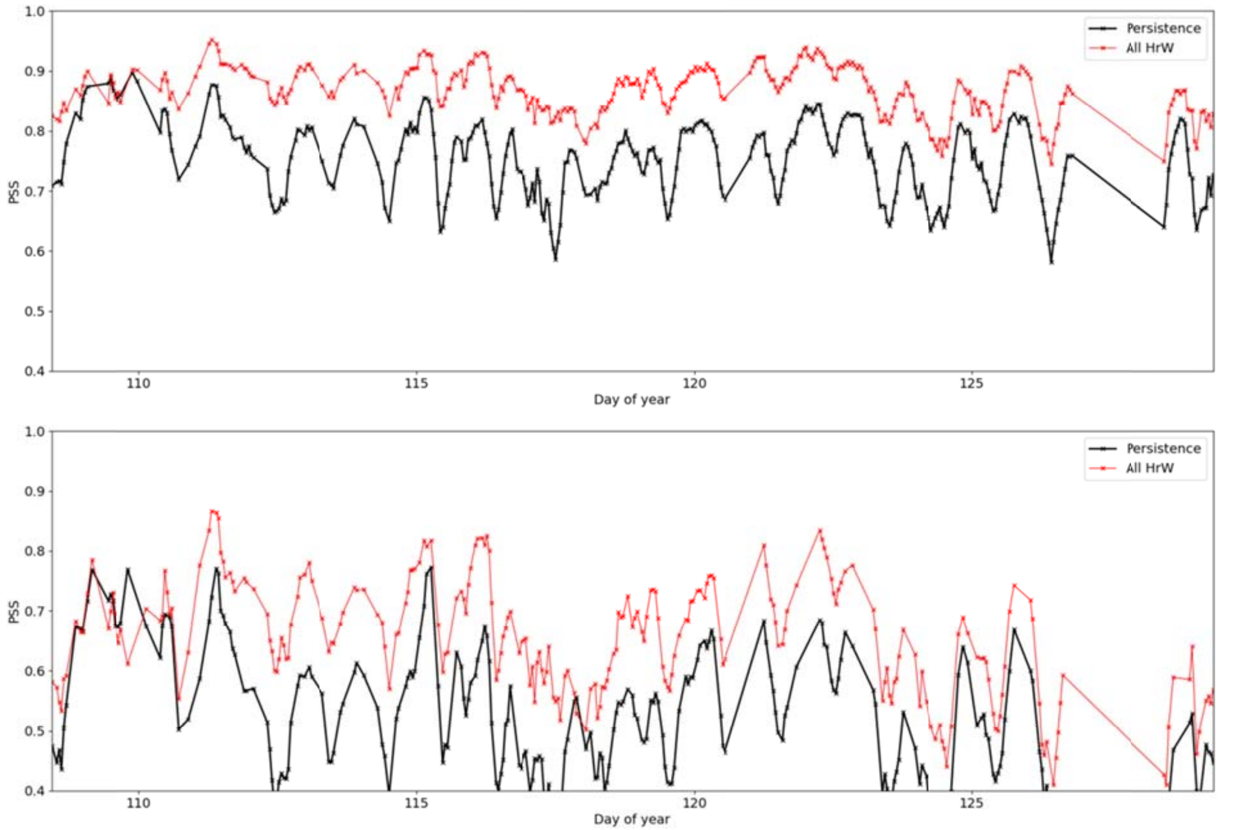


Figure 38: *PSS time series for the EXIM WV7.3 230 K-isoline forecast (red) vs. persistence (black). Upper panel: 15-minute forecasts; lower panel: leadtime 60 minutes.*

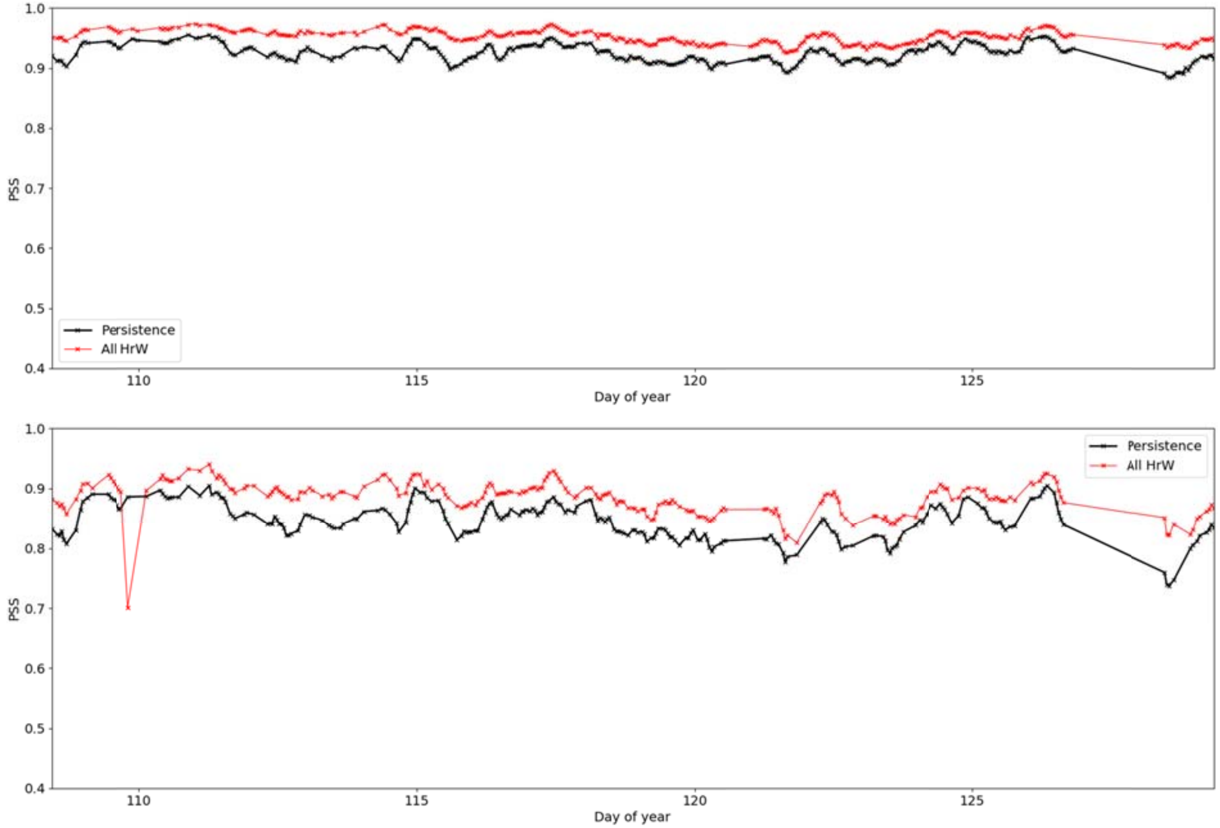


Figure 39: *PSS time series for the EXIM WV7.3 250 K-isoline forecast (red) vs. persistence (black). Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes.*

6.4 NWCSAF/GEO PRODUCTS

For the extrapolated NWCSAF products, there is no option of cloud screening (in most cases it is in fact implicitly done during the product generation), hence we can join the cases of phase I and phase II into one larger group (18 April – 8 May 2018; the first number in each cell of the following tables refers to this sample whereas the second number is from phase III (9 May – 6 June 2018); cf. the definition of validation phases in section 2.4). For the sake of conciseness, all three phases are presented together in the *PSS* time series diagrams.

6.4.1 CMa: Cloud Mask

+ 15 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	91.1 / 79.6	98.7 / 93.3	21.1 / 25.5	87.2 / 71.5
Best	1.0 / 0.2	98.4 / 96.1	0.0 / 0.0	0.7 / 3.7
Second-best	78.3 / 76.2	1.6 / 3.9	0.0 / 0.0	20.1 / 19.7
Third	20.7 / 23.6	0.0 / 0.0	4.3 / 11.6	75.0 / 65.0
Fourth	0.0 / 0.0	0.0 / 0.0	95.7 / 88.4	4.3 / 11.6

+ 30 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	74.3 / 56.3	86.6 / 72.0	10.3 / 12.1	66.4 / 46.4
Best	0.4 / 0.0	96.4 / 92.6	0.0 / 0.0	3.2 / 7.4
Second-best	69.6 / 67.9	3.2 / 7.4	0.0 / 0.0	27.3 / 24.7
Third	30.0 / 32.1	0.4 / 0.0	3.2 / 6.0	66.4 / 61.8
Fourth	0.0 / 0.0	0.0 / 0.0	96.8 / 94.0	3.2 / 6.0

+ 45 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	62.6 / 46.9	79.4 / 62.9	8.0 / 6.9	58.4 / 38.3
Best	0.8 / 1.1	91.2 / 86.6	0.0 / 0.0	8.0 / 12.3
Second-best	64.3 / 58.0	8.8 / 13.1	0.0 / 0.0	26.9 / 28.9
Third	34.9 / 40.9	0.0 / 0.3	2.9 / 4.9	62.2 / 54.0
Fourth	0.0 / 0.0	0.0 / 0.0	97.1 / 95.1	2.9 / 4.9

+ 60 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	60.8 / 30.3	67.8 / 45.0	9.1 / 0.9	55.2 / 28.4
Best	5.6 / 5.5	81.8 / 69.7	0.0 / 0.0	12.6 / 24.8
Second-best	65.0 / 56.0	13.3 / 17.4	0.0 / 0.0	21.7 / 26.6
Third	29.4 / 38.5	4.9 / 12.8	4.2 / 1.8	61.5 / 46.8
Fourth	0.0 / 0.0	0.0 / 0.0	95.8 / 98.2	4.2 / 1.8

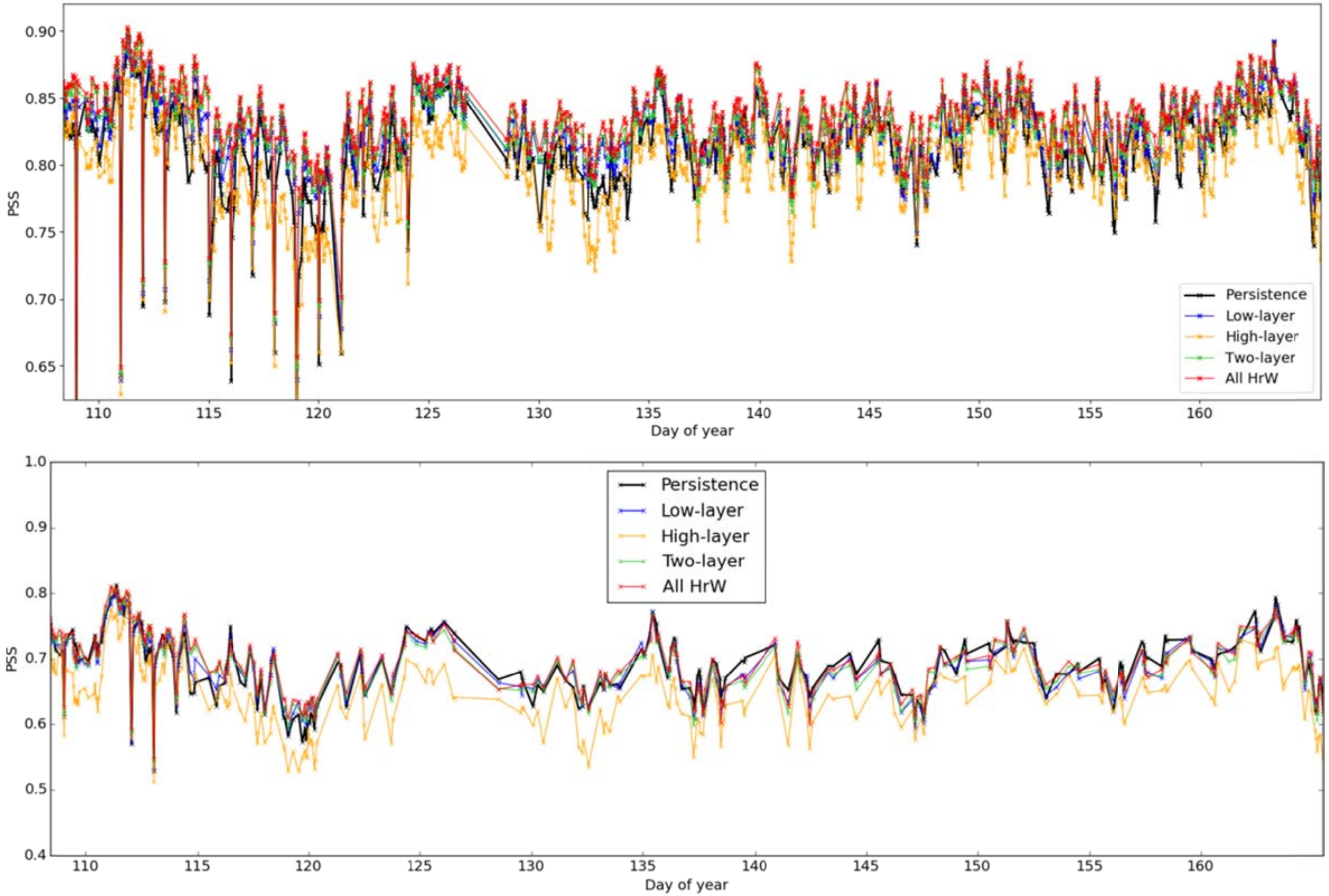


Figure 40: *PSS time series for the CMa forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends. Note that the range of the y-axis was chosen differently for readability purposes.*

6.4.2 CT: Cloud Type

+ 15 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	56.4 / 73.1	99.0 / 91.7
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	99.3 / 99.5	0.0 / 0.0	0.0 / 0.0	0.7 / 0.2
Third	0.7 / 0.5	0.0 / 0.0	17.4 / 50.5	82.0 / 49.3
Fourth	0.0 / 0.0	0.0 / 0.0	82.6 / 49.5	17.4 / 50.5

+ 30 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.4 / 100.0	99.6 / 100.0	41.3 / 51.9	94.1 / 81.6
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	98.4 / 99.5	0.0 / 0.0	0.0 / 0.0	1.6 / 0.5
Third	1.6 / 0.5	0.0 / 0.0	11.0 / 38.2	87.4 / 61.3
Fourth	0.0 / 0.0	0.0 / 0.0	89.0 / 61.8	11.0 / 38.2

+ 45 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	94.1 / 99.7	97.9 / 100.0	28.9 / 36.9	89.1 / 77.4

Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	92.5 / 97.7	0.0 / 0.0	0.0 / 0.0	7.5 / 2.3
Third	7.5 / 2.3	0.0 / 0.0	5.4 / 27.7	87.0 / 70.0
Fourth	0.0 / 0.0	0.0 / 0.0	94.6 / 72.3	5.4 / 27.7

+ 60 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	86.8 / 98.2	91.7 / 100.0	19.4 / 22.0	81.2 / 62.4
Best	2.8 / 5.5	95.8 / 94.5	0.0 / 0.0	1.4 / 0.0
Second-best	86.8 / 89.0	4.2 / 5.5	0.0 / 0.0	9.0 / 5.5
Third	10.4 / 5.5	0.0 / 0.0	3.5 / 19.3	86.1 / 75.2
Fourth	0.0 / 0.0	0.0 / 0.0	96.5 / 80.7	3.5 / 19.3

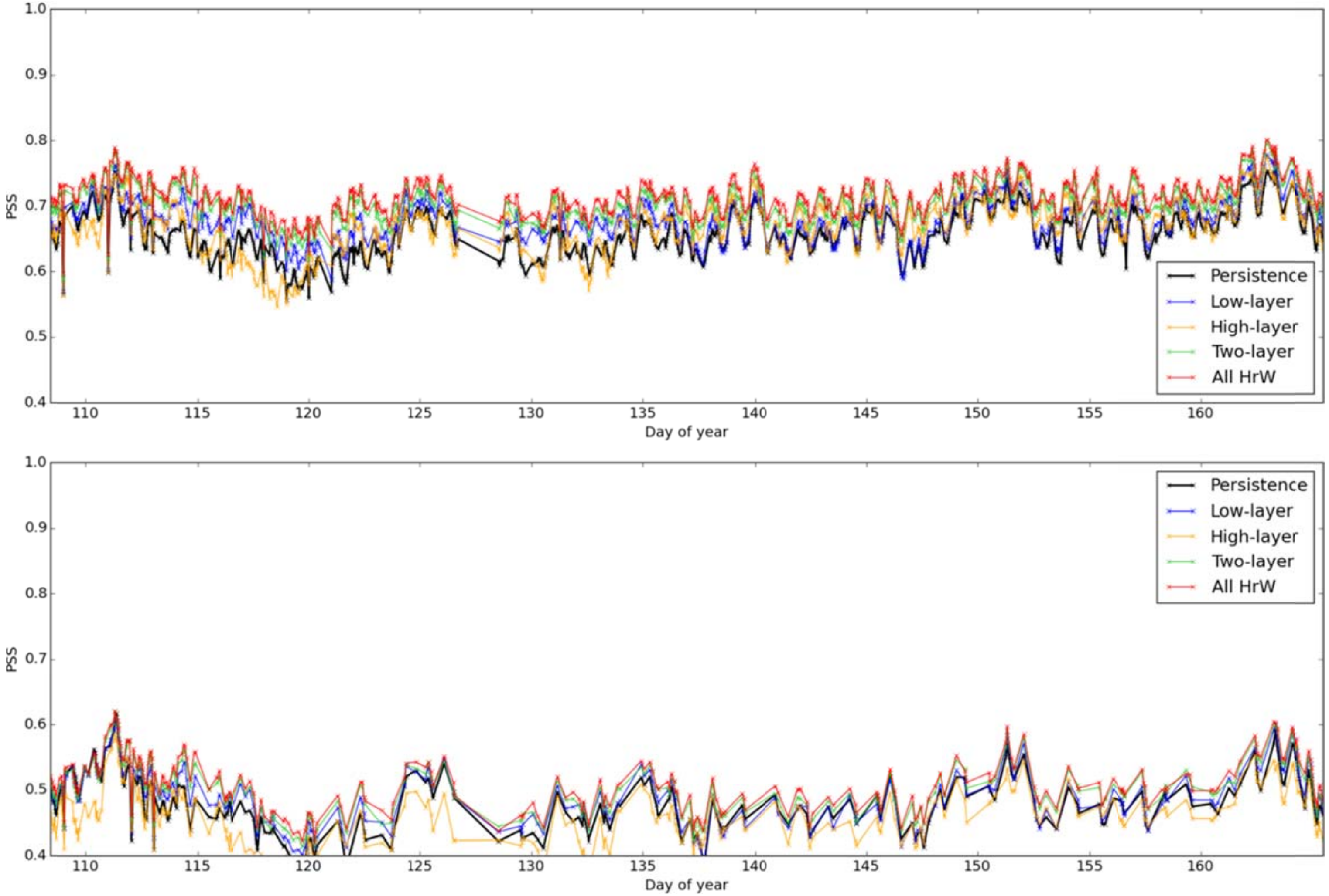


Figure 41: *PSS time series for the CT forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

6.4.3 CTTH: Cloud Top Temperature and Height

Height 4000m, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 99.8	100./100.	79.3 / 95.4	97.4 / 94.7
Best	0.0 / 0.0	100./100.	0.0 / 0.0	0.0 / 0.0
Second-best	98.0 / 97.2	0.0 / 0.0	0.0 / 0.7	2.0 / 1.9
Third	2.0 / 2.8	0.0 / 0.0	40.5 / 65.0	57.6 / 32.5
Fourth	0.0 / 0.0	0.0 / 0.0	59.5 / 34.3	40.5 / 65.7

Height 4000m, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	99.2 / 99.7	100.0 / 100.0	79.8 / 96.2	97.2 / 94.8
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	94.9 / 97.0	0.0 / 0.0	0.0 / 1.1	5.1 / 1.9
Third	5.1 / 3.0	0.0 / 0.0	34.8 / 60.4	60.1 / 36.5
Fourth	0.0 / 0.0	0.0 / 0.0	65.2 / 38.5	34.8 / 61.5

Height 4000m, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	99.2 / 99.7	100.0 / 100.0	79.0 / 93.7	94.5 / 95.7
Best	0.4 / 0.0	99.6 / 100.0	0.0 / 0.0	0.0 / 0.0

Second-best	94.5 / 95.4	0.4 / 0.0	0.0 / 1.7	5.0 / 2.9
Third	5.0 / 4.6	0.0 / 0.0	30.3 / 57.0	64.7 / 38.4
Fourth	0.0 / 0.0	0.0 / 0.0	69.7 / 41.3	30.3 / 58.7

Height 4000m, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	95.1 / 99.1	99.3 / 100.0	74.1 / 93.5	94.4 / 95.4
Best	0.7 / 2.8	98.6 / 97.2	0.0 / 0.0	0.7 / 0.0
Second-best	88.8 / 92.6	0.7 / 2.8	0.7 / 0.9	9.8 / 3.7
Third	10.5 / 4.6	0.7 / 0.0	21.0 / 58.3	67.8 / 37.0
Fourth	0.0 / 0.0	0.0 / 0.0	78.3 / 40.7	21.7 / 59.3

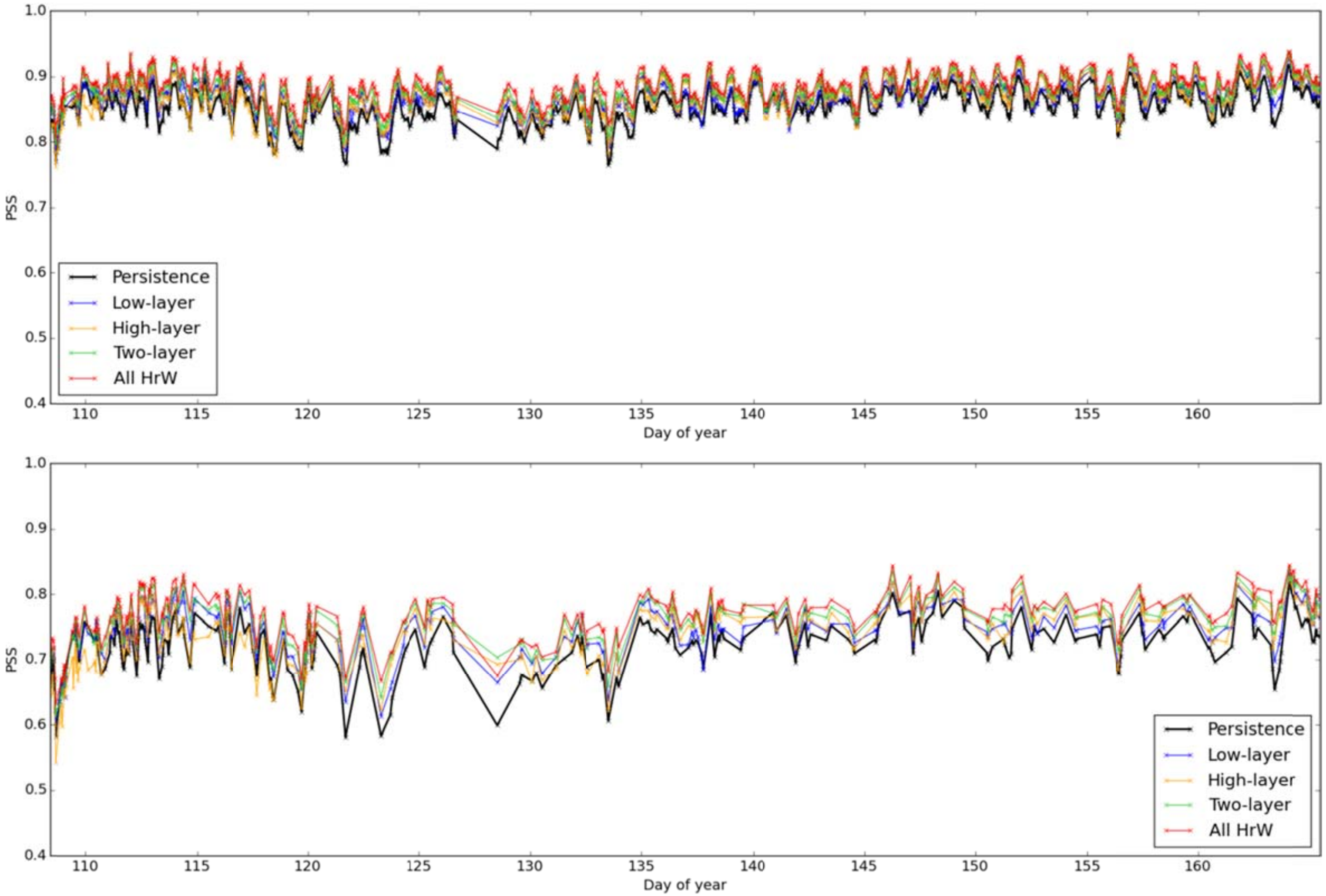


Figure 42: *PSS time series for the CTTH 4000m-isoline forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

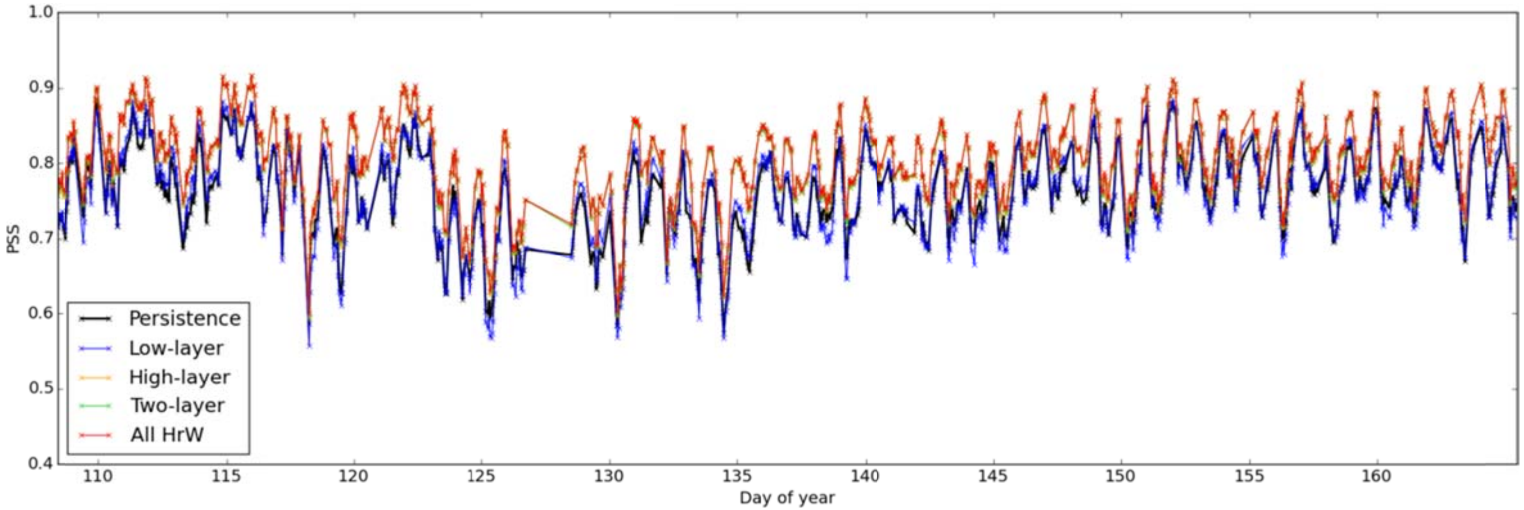
Height 8000m, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 98.8	100.0 / 99.3	100.0 / 98.8	60.2 / 50.3
Best	8.6 / 3.7	88.8 / 94.9	2.6 / 1.4	0.0 / 0.0
Second-best	72.7 / 78.7	8.9 / 4.4	18.4 / 16.7	0.0 / 0.0
Third	18.8 / 17.6	2.3 / 0.7	78.9 / 81.9	0.0 / 0.0
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 0.0	100.0 / 100.0

Height 8000m, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	99.2 / 99.2	100.0 / 99.5	98.0 / 98.4	64.0 / 59.1
Best	13.8 / 4.4	78.7 / 88.7	7.5 / 6.6	0.0 / 0.3
Second-best	70.4 / 76.4	15.0 / 8.8	14.6 / 14.8	0.0 / 0.0
Third	15.8 / 19.2	6.3 / 2.5	77.9 / 77.7	0.0 / 0.5
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 0.8	100.0 / 99.2

Height 8000m, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	96.2 / 98.6	97.5 / 98.3	95.8 / 98.0	63.9 / 60.5
Best	27.3 / 17.5	63.4 / 75.6	9.2 / 6.3	0.0 / 0.6

Second-best	58.0 / 64.8	23.5 / 19.2	18.5 / 15.8	0.0 / 0.3
Third	14.7 / 17.8	13.0 / 5.2	72.3 / 76.2	0.0 / 0.9
Fourth	0.0 / 0.0	0.0 / 0.0	0.0 / 1.7	100.0 / 98.3

Height 8000m, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	92.3 / 98.1	93.7 / 98.1	93.0 / 98.1	60.8 / 60.2
Best	37.1 / 33.3	49.7 / 55.6	13.3 / 9.3	0.0 / 1.9
Second-best	48.3 / 53.7	32.2 / 31.5	18.9 / 14.8	0.7 / 0.0
Third	12.6 / 13.0	18.2 / 13.0	67.1 / 74.1	2.1 / 0.0
Fourth	2.1 / 0.0	0.0 / 0.0	0.7 / 1.9	97.2 / 98.1



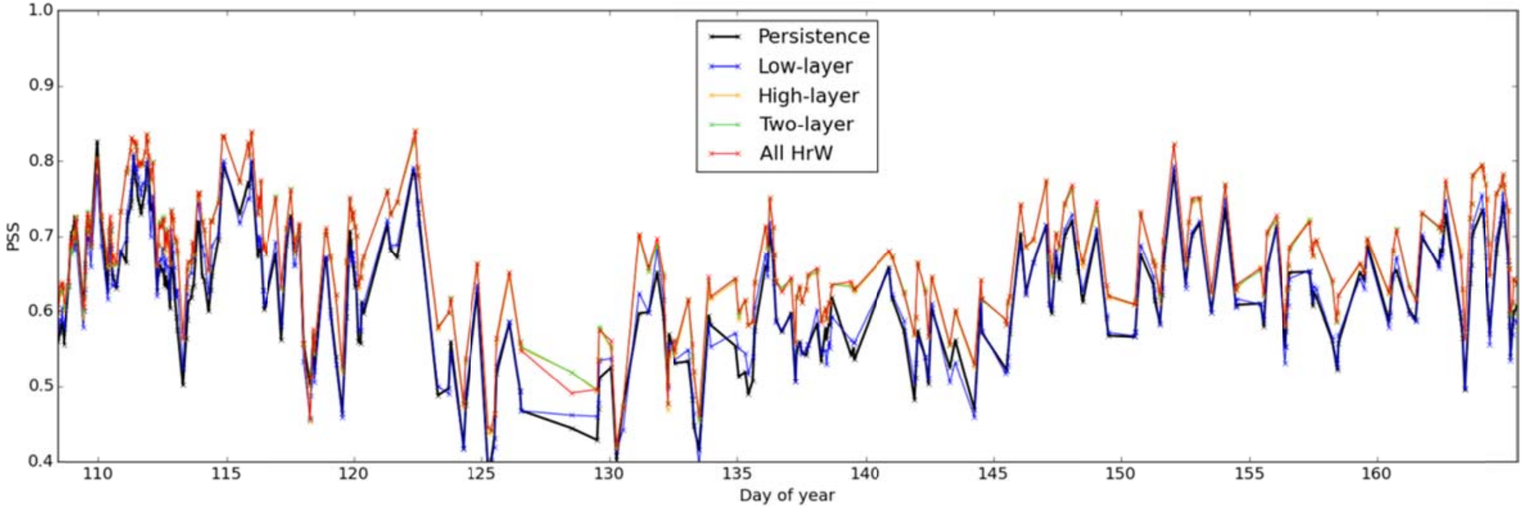


Figure 43: *PSS time series for the CTTH 8000m-isoline forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

6.4.4 CMIC: Cloud Microphysics

For “cloud optical thickness” and “ice water path”, only tables of reduced content (and no diagrams) are presented hereafter as the unconvincing results of comparing with persistence renders a comparison between the four extrapolation approaches irrelevant.

6.4.4.1 “Cloud optical thickness”

COT=25, +15 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	57.6 / 63.7	68.6 / 72.8	34.5 / 24.5	28.4 / 31.5

COT=25, +30 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	49.5 / 67.0	60.2 / 75.3	27.0 / 29.6	22.4 / 36.1

COT=25, +45 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	40.7 / 62.2	55.7 / 69.7	20.4 / 23.5	17.4 / 32.0

COT=25, +60 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	35.0 / 51.6	44.0 / 59.1	19.0 / 20.4	14.0 / 15.1

6.4.4.2 “Ice water path”

0.5 kg m^{-2}, +15 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	63.3 / 56.6	71.3 / 64.1	54.9 / 51.1	35.4 / 19.9

0.5 kg m^{-2}, +30 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	57.8 / 62.2	67.3 / 66.8	49.2 / 56.3	33.2 / 23.1

0.5 kg m^{-2}, +45 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	57.4 / 55.4	63.9 / 60.5	49.1 / 50.0	30.8 / 25.3

0.5 kg m^{-2}, +60 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	58.4 / 48.9	63.4 / 56.4	49.5 / 44.7	33.7 / 23.4

6.4.4.3 "Cloud phase"

Cloud phase, +15 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	37.3 / 50.8	98.6 / 88.0
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	94.2 / 97.8	0.0 / 0.0	0.0 / 0.0	5.8 / 2.0
Third	5.8 / 2.2	0.0 / 0.0	5.8 / 32.7	88.4 / 65.3
Fourth	0.0 / 0.0	0.0 / 0.0	94.2 / 67.3	5.8 / 32.7

Cloud phase, +30 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	95.1 / 99.0	99.6 / 100.0	27.8 / 34.7	91.5 / 75.4
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	94.7 / 98.2	0.0 / 0.0	0.0 / 0.0	5.3 / 1.8
Third	5.3 / 1.8	0.0 / 0.0	4.9 / 25.9	89.8 / 72.4
Fourth	0.0 / 0.0	0.0 / 0.0	95.1 / 74.1	4.9 / 25.9

Cloud phase, +45 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	92.5 / 97.0	97.2 / 100.0	22.6 / 27.8	84.9 / 68.9
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0

Second-best	91.3 / 95.4	0.0 / 0.0	0.0 / 0.0	8.7 / 4.6
Third	8.7 / 4.6	0.0 / 0.0	3.2 / 21.1	88.1 / 74.3
Fourth	0.0 / 0.0	0.0 / 0.0	96.8 / 78.9	3.2 / 21.1

Cloud phase, +60 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	83.1 / 95.3	91.6 / 100.0	18.8 / 22.0	79.2 / 59.1
Best	1.9 / 7.9	96.1 / 92.1	0.0 / 0.0	1.9 / 0.0
Second-best	85.1 / 88.2	3.9 / 7.9	0.0 / 0.0	11.0 / 3.9
Third	13.0 / 3.9	0.0 / 0.0	1.9 / 22.0	85.1 / 74.0
Fourth	0.0 / 0.0	0.0 / 0.0	98.1 / 78.0	1.9 / 22.0

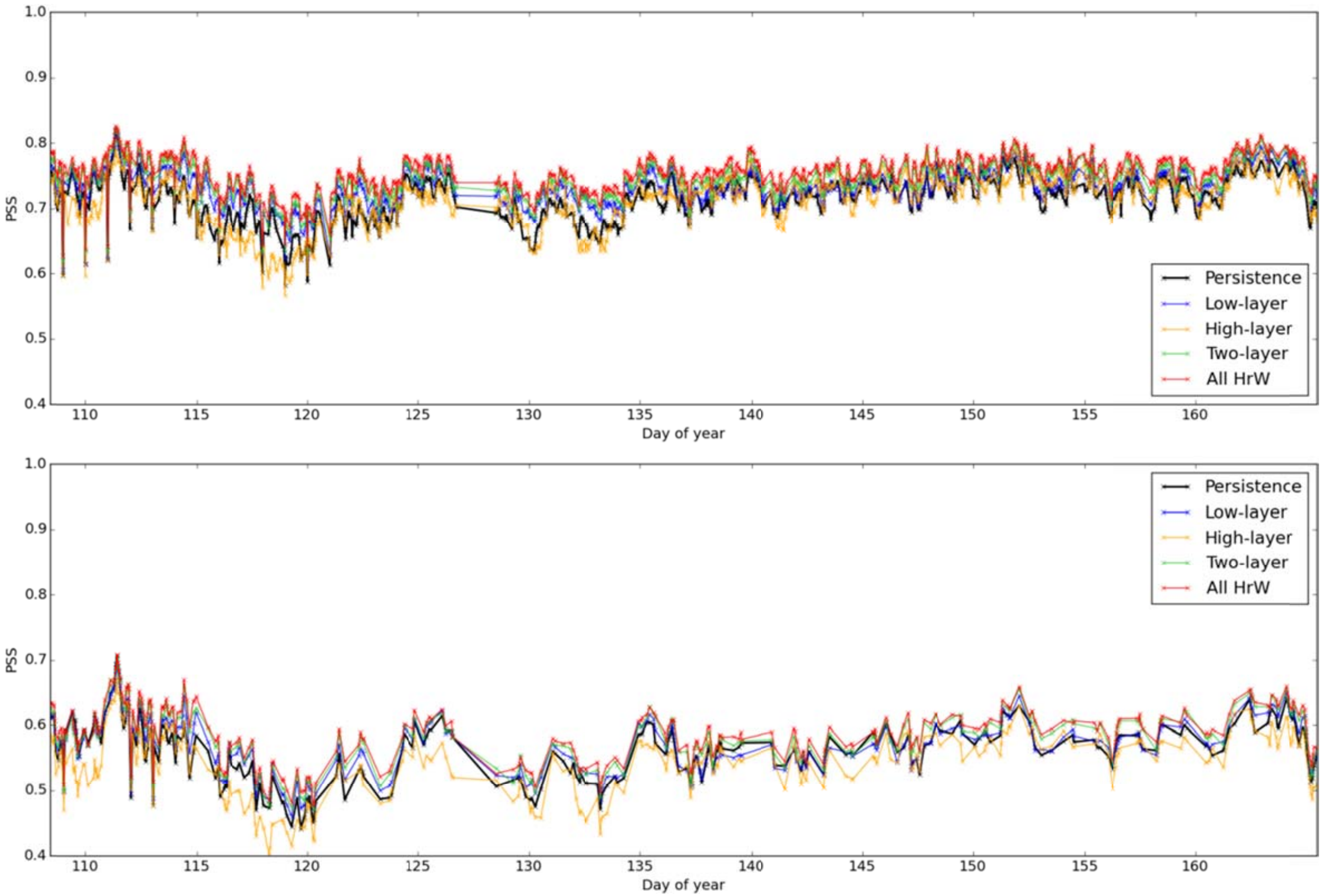


***Figure 44:** PSS time series for the CMIC cloud phase forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

6.4.5 CRR: Convective Rainfall rate

0.2 mm/h, +15 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	99.7 / 99.6	97.1 / 98.9
Best	10.7 / 17.7	78.0 / 72.6	11.0 / 9.7	0.0 / 0.0
Second-best	58.9 / 59.6	15.2 / 16.3	26.2 / 23.8	0.0 / 0.0
Third	30.4 / 22.7	6.8 / 11.0	62.1 / 66.0	0.6 / 0.4
Fourth	0.0 / 0.0	0.0 / 0.0	0.6 / 0.4	99.4 / 99.6

0.2 mm/h, +30 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 99.7	100.0 / 100.0	98.8 / 98.7	91.8 / 90.2
Best	14.5 / 15.2	76.1 / 77.1	9.4 / 7.7	0.0 / 0.0
Second-best	54.5 / 64.9	16.9 / 12.8	28.2 / 22.1	0.4 / 0.0
Third	31.0 / 19.9	7.1 / 10.1	59.6 / 68.1	2.4 / 2.1
Fourth	0.0 / 0.0	0.0 / 0.0	2.7 / 2.1	97.3 / 97.9

0.2 mm/h, +45 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	99.2 / 98.9	99.6 / 99.7	96.7 / 97.0	80.8 / 83.5

Best	13.8 / 14.9	75.4 / 77.1	10.4 / 7.7	0.4 / 0.3
Second-best	59.6 / 66.1	18.3 / 14.0	20.8 / 19.0	1.2 / 0.8
Third	26.7 / 19.0	6.2 / 8.8	63.8 / 69.7	3.3 / 2.5
Fourth	0.0 / 0.0	0.0 / 0.0	5.0 / 3.6	95.0 / 96.4

0.2 mm/h, +60 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	96.6 / 100.0	98.6 / 100.0	91.8 / 96.5	80.8 / 80.5
Best	15.1 / 27.4	67.1 / 61.9	17.1 / 9.7	0.7 / 0.9
Second-best	52.7 / 54.9	22.6 / 21.2	21.2 / 23.0	3.4 / 0.9
Third	30.1 / 16.8	10.3 / 16.8	53.4 / 63.7	6.2 / 2.7
Fourth	2.1 / 0.9	0.0 / 0.0	8.2 / 3.5	89.7 / 95.6

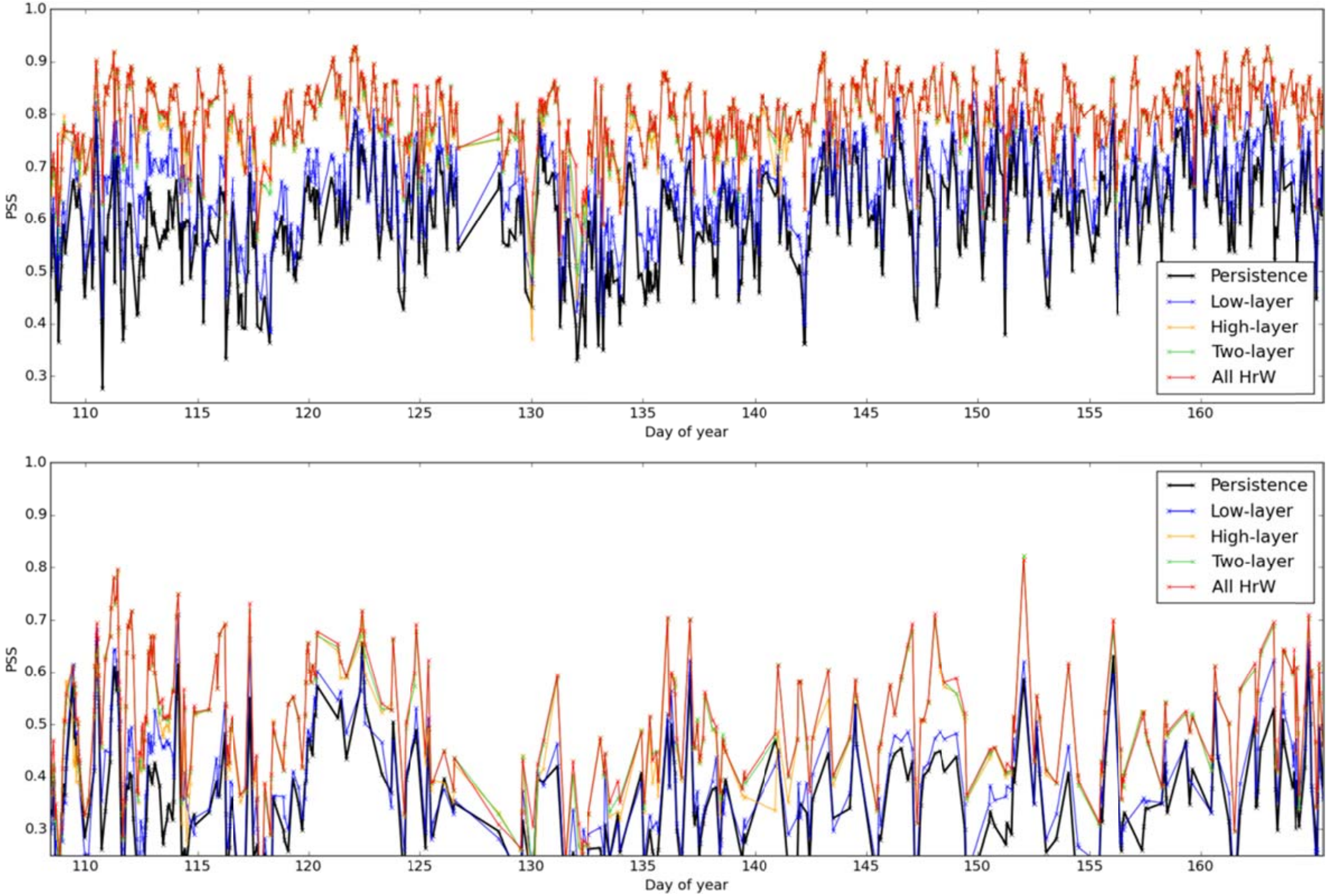


Figure 45: *PSS time series for the CRR 0.2mm/h-isoline forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

5 mm/h, +15 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	96.1 / 99.3	96.8 / 99.6	95.8 / 99.1	74.8 / 83.5
Best	21.7 / 29.3	50.5 / 52.4	26.2 / 17.6	1.0 / 0.2
Second-best	44.0 / 47.4	27.5 / 21.6	27.5 / 31.1	1.0 / 0.2
Third	33.7 / 23.1	21.4 / 25.8	42.7 / 49.3	2.9 / 2.0
Fourth	0.6 / 0.2	0.6 / 0.2	3.6 / 2.0	95.1 / 97.6

5 mm/h, +30 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	94.1 / 98.9	94.9 / 99.2	94.5 / 98.4	69.0 / 76.7
Best	21.2 / 23.9	53.3 / 55.4	22.7 / 19.9	2.4 / 0.5
Second-best	45.5 / 52.8	25.1 / 17.0	27.8 / 30.2	1.2 / 0.3
Third	33.3 / 22.5	20.4 / 27.3	45.1 / 47.5	2.0 / 2.7
Fourth	0.0 / 0.8	1.2 / 0.3	4.3 / 2.4	94.5 / 96.6

5 mm/h, +45 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	92.1 / 95.3	91.7 / 96.4	90.0 / 94.0	61.2 / 69.8
Best	32.5 / 29.4	46.2 / 51.4	17.1 / 17.9	4.2 / 1.4

Second-best	41.2 / 49.2	27.5 / 18.1	29.2 / 31.6	2.1 / 1.1
Third	23.3 / 20.3	24.6 / 29.9	49.2 / 45.6	2.9 / 4.1
Fourth	2.9 / 1.1	1.7 / 0.5	4.6 / 4.9	90.8 / 93.4

5 mm/h, +60 minutes	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	91.1 / 92.1	91.1 / 93.9	85.6 / 89.5	66.4 / 64.9
Best	26.7 / 33.3	46.6 / 45.6	22.6 / 18.4	4.1 / 2.6
Second-best	42.5 / 42.1	25.3 / 17.5	24.7 / 38.6	6.8 / 1.8
Third	28.8 / 24.6	26.7 / 36.0	41.1 / 34.2	4.1 / 5.3
Fourth	2.1 / 0.0	1.4 / 0.9	11.6 / 8.8	84.9 / 90.4

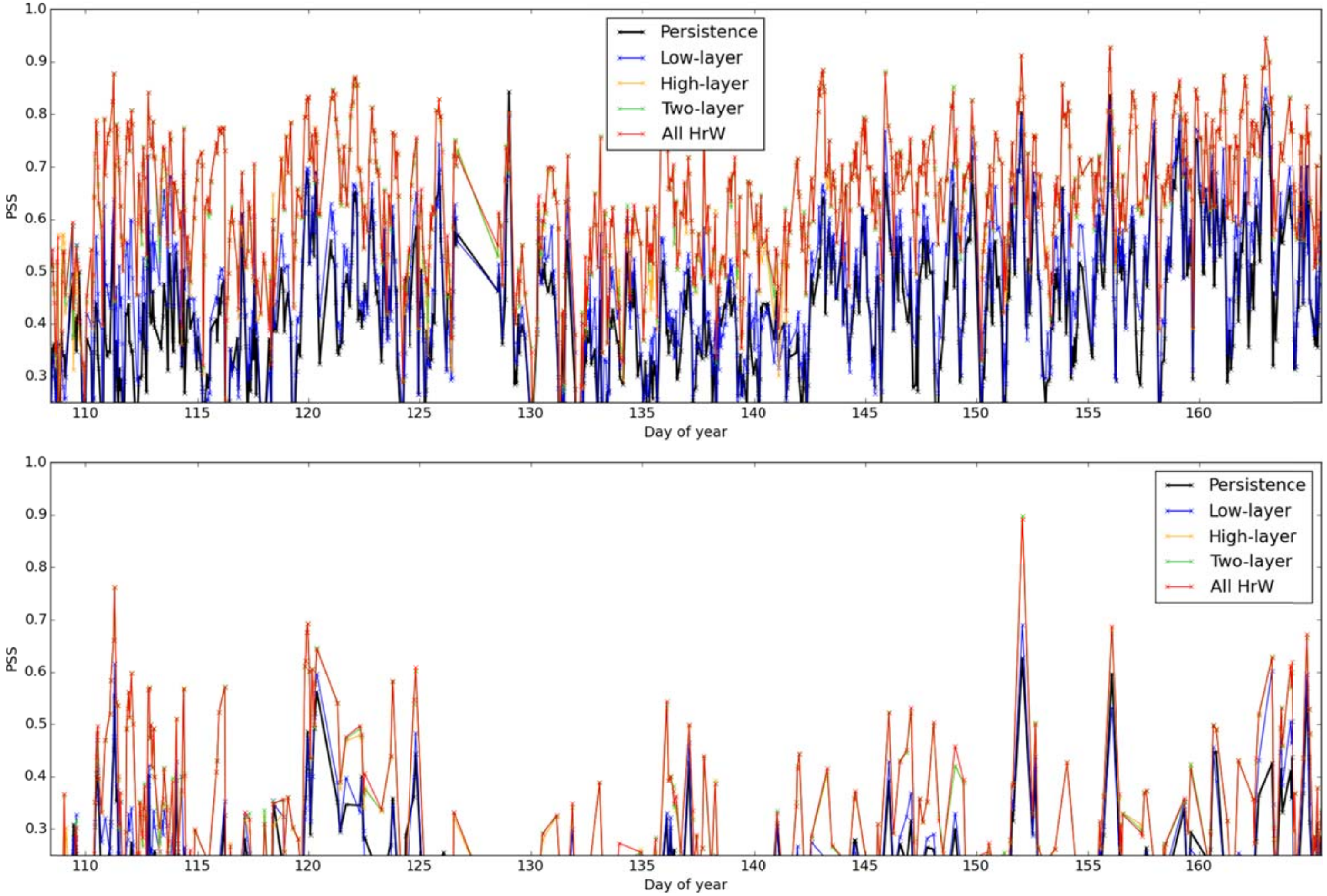


Figure 46: *PSS time series for the CRR forecasts of the 5 mm/h-isoline. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

6.4.6 CRR-Ph: Convective Rainfall Rate from Cloud Physical properties

0.2 mm/h, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 99.4	100.0 / 100.0	98.1 / 98.5	88.9 / 90.0
Best	5.0 / 8.1	91.0 / 87.3	3.7 / 4.7	0.3 / 0.0
Second-best	79.6 / 76.9	7.1 / 8.1	12.7 / 14.9	0.6 / 0.0
Third	15.2 / 15.1	1.9 / 4.7	80.2 / 76.2	2.8 / 4.2
Fourth	0.3 / 0.0	0.0 / 0.0	3.4 / 4.2	96.3 / 95.8

0.2 mm/h, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	97.8 / 98.7	99.6 / 99.5	95.5 / 98.9	84.3 / 85.8
Best	5.2 / 7.2	88.4 / 88.5	5.2 / 4.0	1.1 / 0.3
Second-best	71.5 / 79.6	10.1 / 6.2	17.6 / 14.2	0.7 / 0.0
Third	22.5 / 12.9	1.1 / 5.4	72.7 / 78.8	3.4 / 2.9
Fourth	0.7 / 0.3	0.4 / 0.0	4.5 / 2.9	94.8 / 96.8

0.2 mm/h, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	97.1 / 98.6	99.2 / 99.4	95.5 / 97.8	83.5 / 83.1

Best	9.5 / 6.1	83.9 / 88.6	5.0 / 5.0	1.7 / 0.3
Second-best	69.0 / 76.5	12.8 / 7.5	16.1 / 15.5	2.1 / 0.6
Third	21.5 / 17.2	3.3 / 3.9	72.7 / 75.3	2.5 / 3.6
Fourth	0.0 / 0.3	0.0 / 0.0	6.2 / 4.2	93.8 / 95.6

0.2 mm/h, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	93.1 / 96.5	97.2 / 98.2	88.3 / 92.1	75.2 / 78.9
Best	17.2 / 14.9	73.1 / 80.7	7.6 / 2.6	2.1 / 1.8
Second-best	56.6 / 75.4	16.6 / 12.3	22.1 / 11.4	4.8 / 0.9
Third	23.4 / 8.8	10.3 / 6.1	60.0 / 81.6	6.2 / 3.5
Fourth	2.8 / 0.9	0.0 / 0.9	10.3 / 4.4	86.9 / 93.9

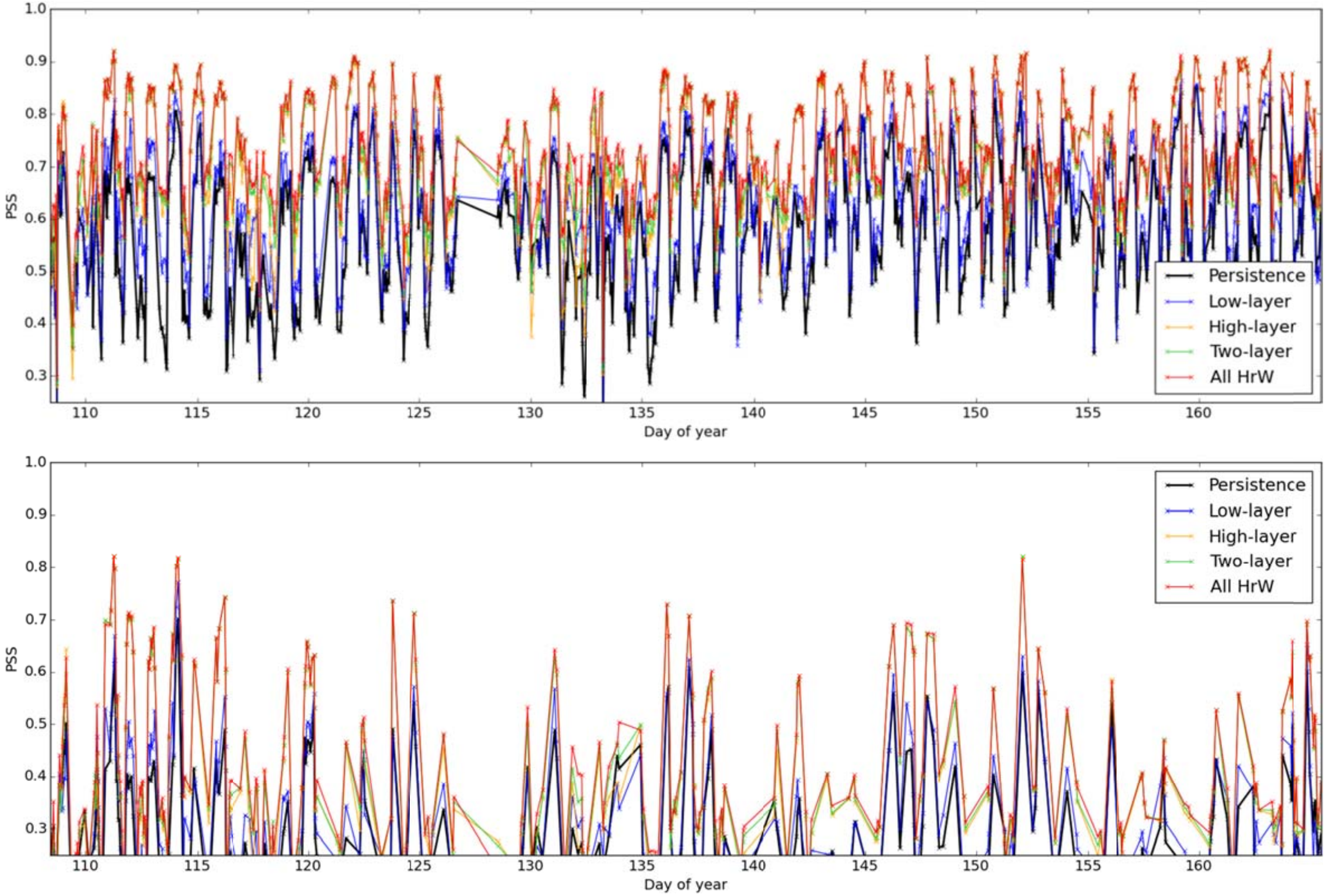


Figure 47: *PSS time series for the CRR-Ph 0.2mm/h-isoline forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

2.2 mm/h, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	92.6 / 92.2	95.5 / 92.8	88.7 / 90.9	62.7 / 46.3
Best	14.5 / 13.9	62.4 / 70.0	14.1 / 7.8	4.5 / 2.4
Second-best	58.5 / 61.3	21.5 / 15.2	19.6 / 25.7	2.9 / 2.2
Third	25.7 / 24.6	16.1 / 14.1	54.3 / 59.8	5.8 / 3.7
Fourth	1.3 / 0.2	0.0 / 0.7	11.9 / 6.7	86.8 / 91.7

2.2 mm/h, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	89.6 / 91.8	91.9 / 94.8	86.2 / 87.5	64.2 / 55.2
Best	19.2 / 14.9	60.4 / 73.1	13.1 / 6.5	6.5 / 4.9
Second-best	51.2 / 58.4	24.2 / 15.2	20.8 / 22.8	3.8 / 3.8
Third	28.1 / 24.5	15.0 / 11.1	47.3 / 58.4	10.4 / 6.2
Fourth	1.5 / 2.2	0.4 / 0.5	18.8 / 12.2	79.2 / 85.1

2.2 mm/h, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	86.1 / 87.0	89.9 / 90.4	81.9 / 81.6	61.2 / 57.1
Best	23.6 / 15.0	54.9 / 65.3	12.2 / 10.2	8.9 / 8.8

Second-best	43.5 / 49.7	27.0 / 16.1	22.8 / 28.2	6.8 / 6.8
Third	27.8 / 30.2	16.9 / 15.5	43.5 / 47.2	12.2 / 7.1
Fourth	5.1 / 5.1	1.3 / 3.1	21.5 / 14.4	72.2 / 77.4

2.2 mm/h, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	80.0 / 82.0	82.9 / 84.7	73.6 / 79.3	64.3 / 55.0
Best	24.3 / 27.0	41.4 / 48.6	17.1 / 10.8	17.1 / 12.6
Second-best	37.9 / 44.1	31.4 / 16.2	22.9 / 31.5	7.9 / 8.1
Third	32.9 / 24.3	22.1 / 27.9	35.7 / 41.4	9.3 / 7.2
Fourth	5.0 / 4.5	5.0 / 7.2	24.3 / 16.2	65.7 / 72.1

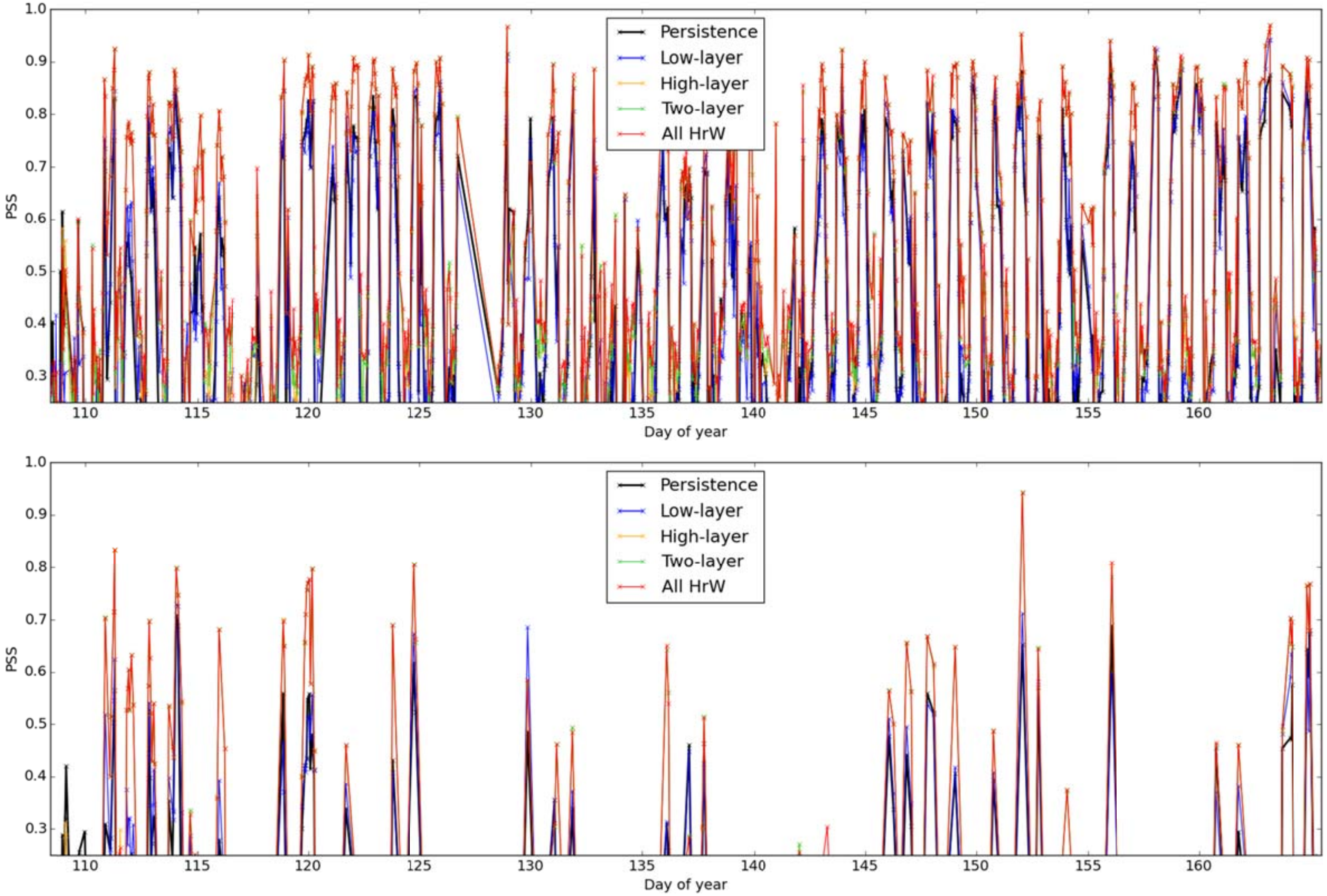


Figure 48: *PSS time series for the CRR-Ph 2.2mm/h-isoline forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

6.4.7 PC: Precipitating Clouds

10% probability, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	92.2 / 99.5	99.7 / 100.0	70.1 / 92.0	77.3 / 63.9
Best	0.0 / 0.0	100.0 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	98.7 / 98.6	0.0 / 0.0	0.0 / 0.7	1.3 / 0.5
Third	1.3 / 1.4	0.0 / 0.0	54.5 / 87.2	44.2 / 11.6
Fourth	0.0 / 0.0	0.0 / 0.0	45.5 / 12.1	54.5 / 87.9

10% probability, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	89.0 / 99.5	97.6 / 100.0	69.4 / 92.3	81.6 / 72.1
Best	0.0 / 0.0	99.6 / 100.0	0.0 / 0.0	0.0 / 0.0
Second-best	93.7 / 98.4	0.0 / 0.0	0.4 / 0.8	6.3 / 0.8
Third	5.9 / 1.6	0.0 / 0.0	48.2 / 84.4	45.5 / 14.0
Fourth	0.4 / 0.0	0.4 / 0.0	51.4 / 14.8	48.2 / 85.2

10% probability, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	89.5 / 98.3	95.4 / 100.0	64.9 / 89.5	79.5 / 71.7

Best	0.4 / 0.0	97.9 / 100.0	0.0 / 0.0	1.7 / 0.0
Second-best	92.5 / 97.2	2.1 / 0.0	0.0 / 1.7	5.4 / 1.1
Third	7.1 / 2.8	0.0 / 0.0	42.3 / 81.3	50.6 / 15.9
Fourth	0.0 / 0.0	0.0 / 0.0	57.7 / 17.0	42.3 / 83.0

10% probability, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	82.1 / 98.2	90.3 / 99.1	51.7 / 88.2	71.7 / 83.6
Best	1.4 / 0.0	94.5 / 99.1	0.0 / 0.0	4.1 / 0.9
Second-best	85.5 / 94.5	4.8 / 0.9	2.1 / 1.8	7.6 / 2.7
Third	13.1 / 5.5	0.7 / 0.0	32.4 / 78.2	53.8 / 16.4
Fourth	0.0 / 0.0	0.0 / 0.0	65.5 / 20.0	34.5 / 80.0

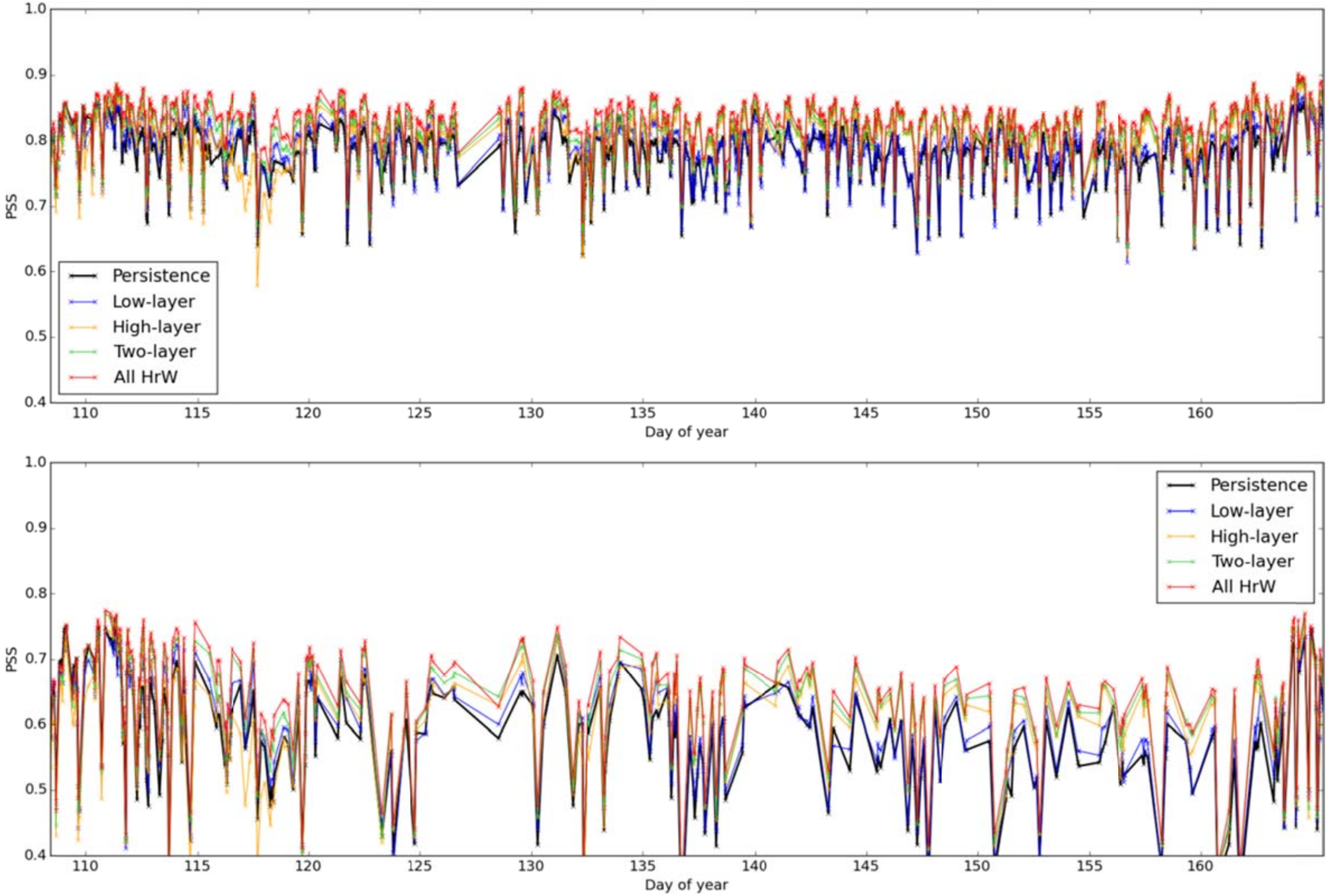


Figure 49: *PSS time series for the PC 10%-isoline forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

30% probability, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	85.4 / 85.2	89.6 / 87.2	74.7 / 82.2	53.2 / 39.5
Best	7.8 / 8.4	89.0 / 87.2	2.9 / 3.2	0.3 / 1.1
Second-best	81.5 / 80.4	9.1 / 8.2	7.8 / 10.3	1.6 / 0.9
Third	10.4 / 10.5	1.9 / 3.2	70.8 / 77.6	16.9 / 8.9
Fourth	0.3 / 0.7	0.0 / 1.4	18.5 / 8.9	81.2 / 89.0

30% probability, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	83.9 / 84.4	88.6 / 85.8	74.5 / 81.1	58.8 / 48.8
Best	7.1 / 7.7	87.5 / 86.3	2.7 / 1.6	2.4 / 4.4
Second-best	76.9 / 77.5	9.8 / 10.1	7.5 / 10.4	6.3 / 1.9
Third	13.3 / 13.2	2.4 / 2.7	70.6 / 74.8	13.3 / 9.3
Fourth	2.7 / 1.6	0.4 / 0.8	19.2 / 13.2	78.0 / 84.4

30% probability, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	81.2 / 80.7	85.4 / 83.6	76.6 / 74.8	59.0 / 48.7
Best	10.0 / 9.3	82.8 / 81.3	2.1 / 2.3	5.0 / 7.1

Second-best	71.5 / 72.8	15.1 / 11.6	9.2 / 10.2	4.2 / 5.4
Third	15.9 / 15.6	1.7 / 4.8	68.2 / 68.8	14.2 / 10.8
Fourth	2.5 / 2.3	0.4 / 2.3	20.5 / 18.7	76.6 / 76.8

30% probability, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	73.8 / 78.2	81.4 / 79.1	65.5 / 69.1	49.7 / 53.6
Best	9.7 / 11.8	79.3 / 76.4	3.4 / 3.6	7.6 / 8.2
Second-best	66.9 / 69.1	15.2 / 15.5	11.7 / 10.0	6.2 / 5.5
Third	20.0 / 17.3	5.5 / 8.2	54.5 / 62.7	20.0 / 11.8
Fourth	3.4 / 1.8	0.0 / 0.0	30.3 / 23.6	66.2 / 74.5

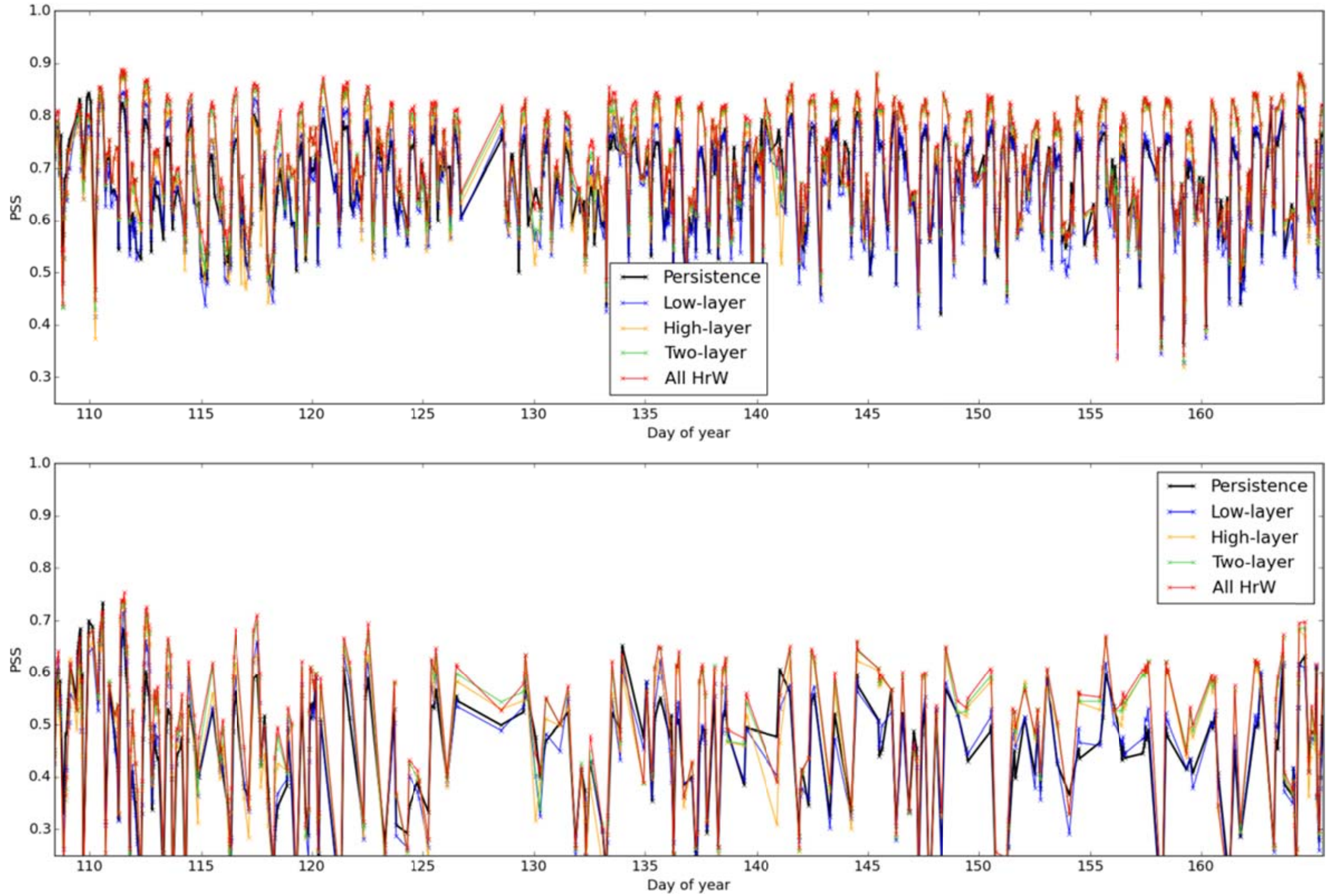


Figure 50: *PSS time series for the PC 30%-isoline forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

6.4.8 PCPh: Precipitating Clouds from Cloud Physical Properties

1% probability, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	100.0 / 100.0	100.0 / 100.0	97.2 / 100.0	100.0 / 99.8
Best	0.6 / 0.0	99.2 / 100.0	0.0 / 0.0	0.3 / 0.0
Second-best	95.0 / 97.3	0.8 / 0.0	1.1 / 2.5	3.0 / 0.0
Third	4.4 / 2.7	0.0 / 0.0	57.7 / 76.9	37.8 / 20.6
Fourth	0.0 / 0.0	0.0 / 0.0	41.2 / 20.6	58.8 / 79.4

1% probability, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.6 / 100.0	100.0 / 100.0	94.4 / 100.0	99.6 / 99.5
Best	0.4 / 0.3	98.2 / 99.7	0.0 / 0.0	1.4 / 0.0
Second-best	96.1 / 97.5	1.8 / 0.3	0.4 / 2.3	1.8 / 0.0
Third	3.5 / 2.3	0.0 / 0.0	65.5 / 79.4	31.0 / 18.3
Fourth	0.0 / 0.0	0.0 / 0.0	34.2 / 18.3	65.8 / 81.7

1% probability, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.4 / 100.0	99.6 / 100.0	93.7 / 99.5	97.2 / 99.5

Best	0.4 / 0.0	97.2 / 99.7	0.0 / 0.0	2.4 / 0.3
Second-best	95.2 / 96.5	2.8 / 0.3	0.4 / 2.7	1.6 / 0.5
Third	4.4 / 3.5	0.0 / 0.0	67.9 / 80.5	27.8 / 15.9
Fourth	0.0 / 0.0	0.0 / 0.0	31.7 / 16.8	68.3 / 83.2

1% probability, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	97.4 / 100.0	98.1 / 100.0	89.0 / 98.4	95.5 / 100.0
Best	3.2 / 7.1	94.2 / 92.1	0.0 / 0.0	2.6 / 0.8
Second-best	91.6 / 87.4	4.5 / 7.9	1.9 / 1.6	1.9 / 3.1
Third	5.2 / 5.5	1.3 / 0.0	65.6 / 73.2	27.9 / 21.3
Fourth	0.0 / 0.0	0.0 / 0.0	32.5 / 25.2	67.5 / 74.8

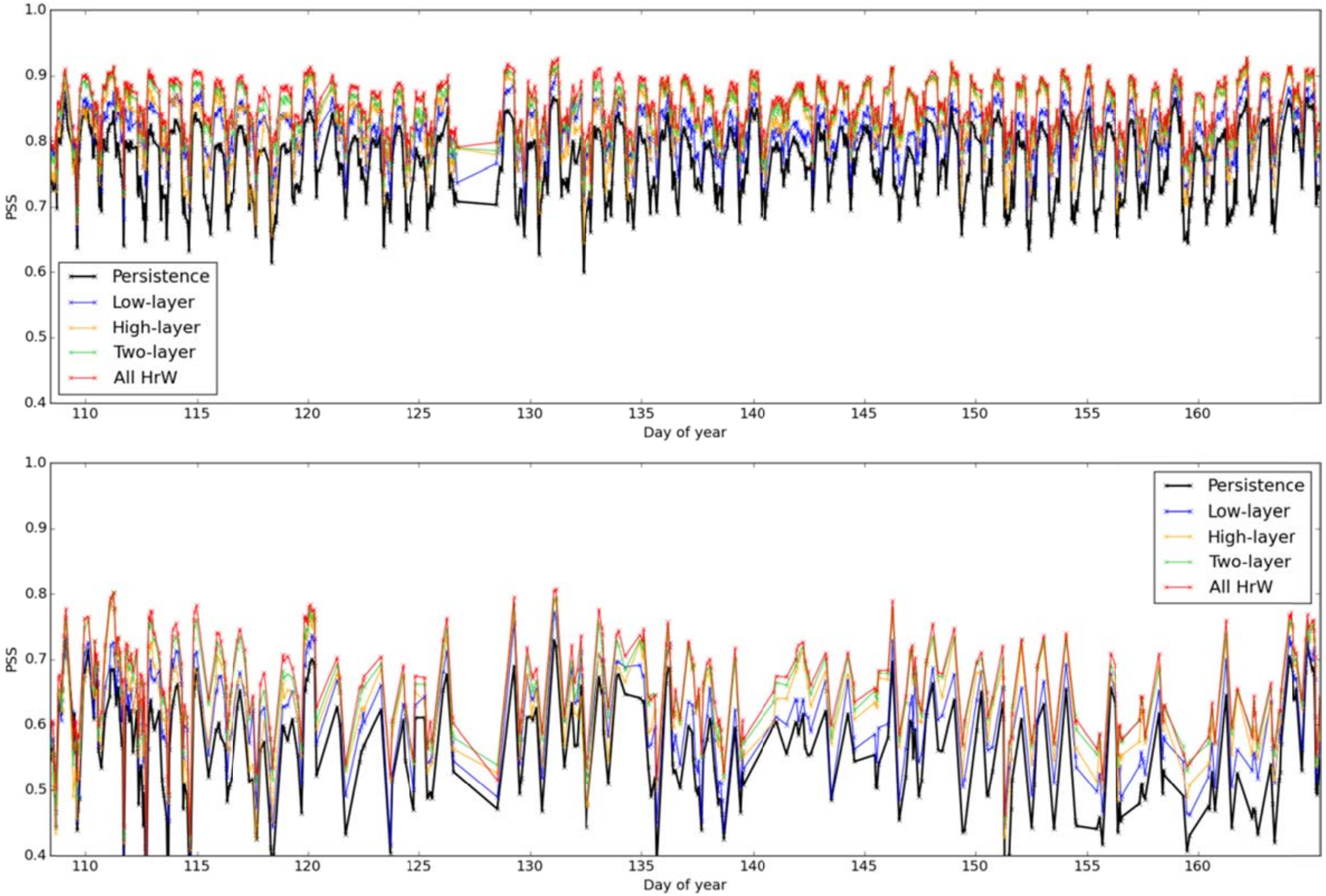


Figure 51: *PSS time series for the PCPh 1%-isoline forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*

21% probability, +15 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	98.9 / 99.8	100.0 / 100.0	97.0 / 97.8	86.5 / 89.2
Best	1.1 / 1.8	98.6 / 97.5	0.3 / 0.8	0.0 / 0.0
Second-best	92.8 / 89.0	0.8 / 2.0	5.8 / 8.8	0.6 / 0.0
Third	6.1 / 9.2	0.6 / 0.6	88.7 / 83.7	4.7 / 6.7
Fourth	0.0 / 0.0	0.0 / 0.0	5.2 / 6.7	94.8 / 93.3

21% probability, +30 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	97.2 / 99.7	100.0 / 100.0	95.1 / 98.7	85.6 / 83.9
Best	2.1 / 2.3	96.5 / 96.5	1.1 / 1.3	0.4 / 0.0
Second-best	85.9 / 89.2	2.8 / 3.0	10.2 / 7.8	1.1 / 0.0
Third	12.0 / 8.5	0.7 / 0.5	82.7 / 85.4	4.6 / 5.5
Fourth	0.0 / 0.0	0.0 / 0.0	6.0 / 5.5	94.0 / 94.5

21% probability, +45 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	96.0 / 99.7	98.8 / 100.0	94.8 / 97.6	80.2 / 81.6
Best	3.6 / 2.2	95.6 / 96.5	0.8 / 1.4	0.0 / 0.0

Second-best	85.7 / 85.1	3.6 / 2.2	9.9 / 12.2	0.8 / 0.5
Third	10.7 / 12.4	0.8 / 1.4	83.7 / 80.8	4.8 / 5.4
Fourth	0.0 / 0.3	0.0 / 0.0	5.6 / 5.7	94.4 / 94.1

21% probability, +60 min	*Two-layer model*	*All HrW*	*High-layer HrW*	*Low-layer HrW*
better than persistence [%]	92.9 / 97.6	96.8 / 99.2	90.9 / 92.9	77.3 / 76.4
Best	6.5 / 14.2	90.9 / 81.9	1.9 / 2.4	0.6 / 1.6
Second-best	79.2 / 77.2	7.1 / 12.6	9.7 / 10.2	3.9 / 0.0
Third	13.6 / 8.7	1.9 / 5.5	79.9 / 79.5	4.5 / 6.3
Fourth	0.6 / 0.0	0.0 / 0.0	8.4 / 7.9	90.9 / 92.1

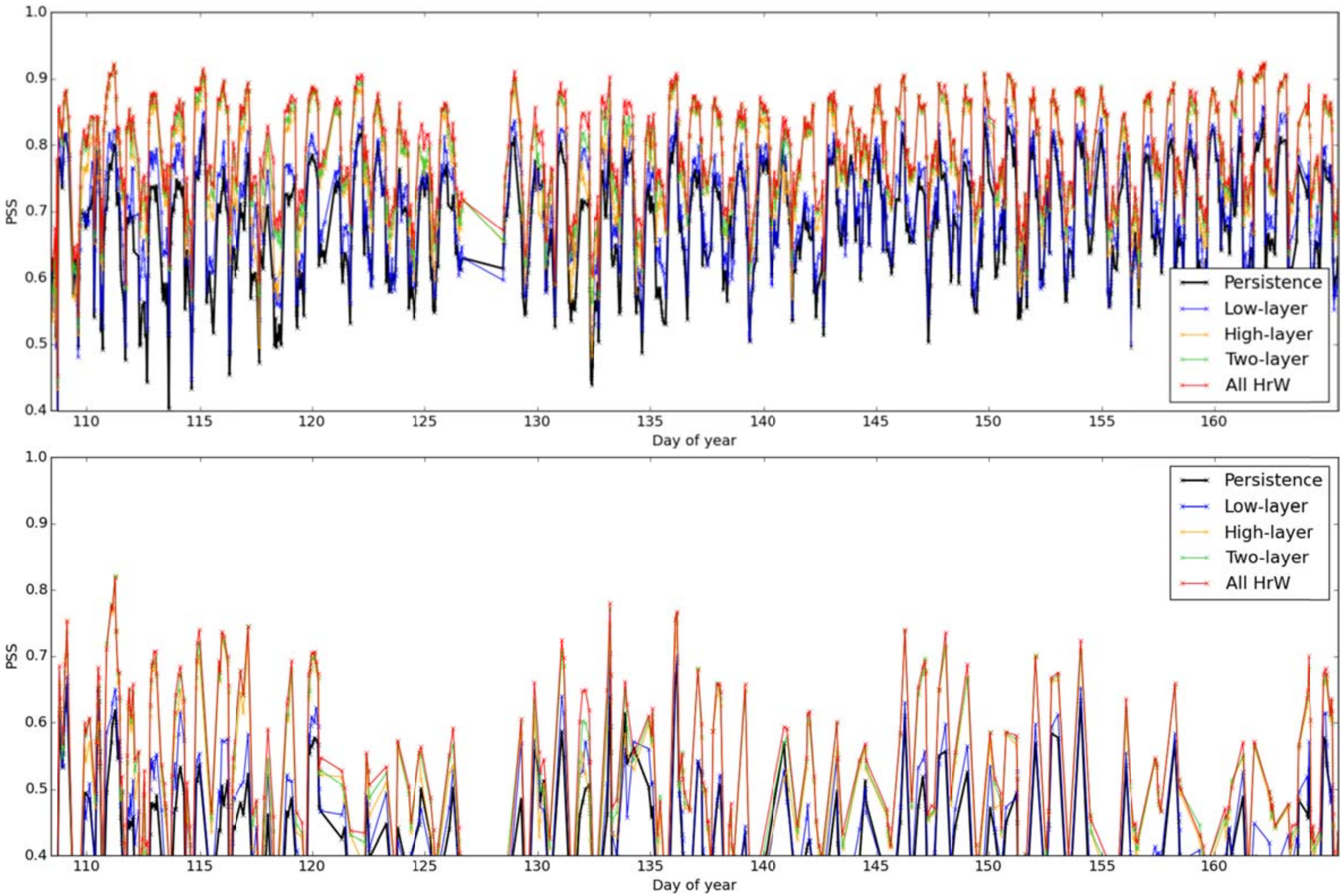


Figure 52: *PSS time series for the PCPh 21%-isoline forecasts. Upper panel: leadtime 15 minutes; lower panel: leadtime 60 minutes; forecasting methods distinguished through colour coding, cf. inserted legends.*