

Testing efficacy of monthly forecast application in agrometeorology: Winter wheat phenology dynamic

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Abstract. Use of monthly weather forecast as input meteorological data for agrometeorological forecasting, crop modelling and plant protection can foster promising applications in agricultural production. Operational use of monthly or seasonal weather forecast can help farmers to optimize field operations (fertilizing, irrigation) and protection measures against plant diseases and pests by taking full advantage of monthly forecast information in predicting plant development, pest and disease risks and yield potentials few weeks in advance. It can help producers to obtain stable or higher yield with the same inputs and to minimise losses caused by weather. In Central and South-Eastern Europe ongoing climate change lead to shifts of crops phenology dynamics (i.e. in Serbia 4-8 weeks earlier in 2016 than in previous years) and brings this subject in the front of agronomy science and practice. Objective of this study is to test efficacy of monthly forecast in predicting phenology dynamics of different winter wheat varieties, using phenological model developed by Forecasting and Warning Service of Serbia in plant protection. For that purpose, historical monthly forecast for four months (March 1, 2005 - June 30, 2005) was assimilated from ECMWF MARS archive for 50 ensemble members and control run. Impact of different agroecological conditions is tested by using observed and forecasted data for two locations - Rimski Sancevi (Serbia) and Groß-Enzersdorf (Austria).

1. Introduction

Timing and length of plant growing season (GSL) is result of growing plant response on actual weather conditions. Changes in vegetation cover and its time of appearance and duration affect the seasonal changes of energy and water balance as well as aerodynamic conditions at biosphere-atmosphere interface. Notified effects can produce significant impacts on temperature and precipitation, wind share and atmospheric circulation patterns of specific region. Consequently, it additionally affects GSL producing strong feedback between atmosphere and biosphere.



Changes in GSL affect directly or indirectly all aspects of agricultural production including crop management (cropping schedules and rotation, irrigation and fertilisation schedules, timing of harmful organism appearance) and forestry. On longer time scale, permanent increase in GSL affects atmospheric-biospheric carbon budget, too. Linderholm [1] offered excellent overview of studies, covering different periods from 1930 till 2004, reporting shifting in timing and increasing length of the plant growing seasons, based on phenological, climatological and satellite data. Recent trends of winter air temperature anomalies indicate huge increase of winter temperature particularly in the Northern hemisphere mainly affecting Europe and Central Asia but with significant inclusion of USA regions (source: NOAA, Climate monitoring, with respect to a 1981-2010 base period). The most disturbing is the latest anomaly varying from 1.5-2.5 °C in Europe till 5 °C in some regions in Asia.

According to the Index of Early leafing plants used by USA National Phenology network, in the prevailing part of the USA spring 2016 comes 2-20 days earlier in comparison to a 1981-2010 base period (source: USA NPN, Gridded Data Products). In Serbia and many other European countries we are witnessing similar trends. According to recent observations made by observational network of Forecasting and Warning Service of Serbia in plant protection (PIS), in some regions of Northern Serbia (Vojvodina) are registered shifts in phenology varying from - 26 to - 73 days (Table 1). These shifts bear high risk for crop and fruit production from spring frost and early activities of harmful organism. Therefore, strong need is exerted for future more sophisticated forecasting of phenology dynamics based not on fixed phenology calendar (which become less useful under fast changing climate conditions), but on application of numerical weather prediction models in combination with phenological models. Limited number of papers dealing with short-range and monthly weather forecast (MWF) application in agrometeorological and crop forecasting underlining relevance and importance of the topic [2, 3, 4, 5].

Objective of our study is to test efficacy of MWF in predicting appearance of plant growing stages one month ahead in the most important production areas of Austria and Serbia. In this paper are presented results obtained for winter wheat at Rimski Sancevi (Serbia) and Groß-Enzersdorf (Austria) obtained using MWR for March - June 2005.

Table 1. Shift in appearance of "four tillers detectable" - growing stage of winter wheat in Serbia.

Region	Dates	Change (days)
Novi Sad	13.03.2015.	- 58
	14.01.2016.	
Bačka Topola	19.03.2015.	- 58
	20.01.2016.	
Pančevo	12.03.2015.	- 26
	15.02.2016.	
Ruma	22.02.2015.	- 53
	31.12.2015.*	
Sombor	03.03.2015.	- 73
	21.12.2016.*	

2. Material and Method

2.1. Study area

Two locations are selected in most important agricultural production areas in Austria (Groß-Enzersdorf - 48 ° 12' N 16 ° 33' E) and Serbia (Rimski Sancevi - 45 ° 3' N 19 ° 8' E) in which winter wheat is permanently grown as a main crop for many decades. Both locations are situated on flat terrain of southern and south western part of Pannonian lowland, although Groß-Enzersdorf weather is

strongly influenced by presence of Alpine mountains on W and SW. Typical climate of study areas is continental and moderate continental with annual temperature of 11.5°C in Rimski Sancevi and 10.7°C in Groß-Enzersdorf and annual precipitation of 647 mm in Rimski Sancevi and 550 mm in Groß-Enzersdorf for 1981-2010 period.

2.2. Meteorological data

Observed and simulated values of maximum (T_{\max}) and minimum (T_{\min}) air temperatures, for selected locations, are used in this study in order to calculate growing degree-days (GDD) accumulation for winter wheat growing season.

Observed data. Historical records of selected meteorological data for Rimski Sancevi and Groß-Enzersdorf weather stations are obtained from national weather service (Hydrometeorological Service of Republic of Serbia and Central Institute for Meteorology and Geodynamics of Austria (ZAMG)).

Monthly weather forecast (MWF) data. Monthly EPS products of ECMWF (European Centre for Medium range Weather Forecast) for March 1, 2005 till June 30, 2005 in the form of 51-member ensemble (50 ensemble members and control run) are used as boundary conditions for WRF NMM model run. Downscaling was developed using WRF NMM model 3.3 version with horizontal resolution of about 20 km. From the monthly weather forecast variable list, for the purpose of this study were selected maximum and minimum air temperature.

All calculations performed using 50 ensemble members, are averaged in order to obtain ensemble averages and in further text denoted with "EA". Results obtained using observed data and control run are denoted with "OBS" and "CR", respectively.

2.3. Phenology model

Growing stage appearance of selected winter wheat varieties is analysed following phenology dynamic analysis concept designed and conducted by Forecasting and Warning Service of Serbia in plant protection (PIS_PHEN). This concept is based on continuous observation of plant growing stages according to BBCH scale [6]. From 13 winter wheat varieties grown on 58 locations during 2014/2015 growing season, 4 varieties were selected (Zvezda, Apac, Simonida, NS_40s) with the longest time series of observed phenological stages (21-23 during the whole season). At each location was set an automatic weather station equipped with sensors for air and soil temperature, relative air humidity, precipitation and leaf wetness measurements. Selected varieties have been grown at 15 different locations, leaving opportunity to calibrate and validated phenological model even with one-season data. Accumulated growing degree-days (GDD) were calculated using measured temperatures above 0 °C (from emergence) and 5 °C (from beginning of tillering) as a lower threshold temperature what is common practice in calculation of phenology dynamics. (see for example [7]). In further text these low temperature limits will be denoted with GDD_0 and GDD_5, respectively. Phenological analysis was based on BBCH growing stages observations from emergence (9) till ripening (80). Accumulated GDD's are identified for each variety corresponding to specific BBCH growing stage for two lower threshold temperatures. MWF and measured meteorological elements are used for calculation of day of appearance of certain BBCH stage (BBCH_D), for four selected varieties, for Rimski Sancevi and Groß-Enzersdorf locations.

2.4. Verification statistics

The verification methodology, based on RMSE and SPREAD calculation, was used to evaluate, ensemble based, prediction of growing stage appearance. Applying criteria of verification of ensemble based probabilistic weather forecast [8], it quantifies reliability of phenology dynamics simulations obtained using MWF. The differences between results obtained using MWF and observed meteorological data are measured using RMSE of ensemble mean of these products in the form

$$RMSE = \frac{1}{N} \left[\sum_{i=1}^N (\bar{A} - A_{OBS})^2 \right]^{1/2} \quad (1)$$

where $\bar{A} = 1/N \sum_{i=1}^N A(i)$ is ensemble mean, A_{OBS} is observed value of variable of interest, N is number of ensemble members.

The deviation of ensemble forecast from their mean is important attribute of MWF and MWF based calculation of growing stages. From that reason ensemble SPREAD is calculated for both MWF and related products using formula

$$SPREAD = \left[\frac{1}{n-1} \sum_{i=1}^N (\bar{A} - A(i))^2 \right]^{1/2} \quad (2)$$

where $A(n)$ is value of variable of interest for i th ensemble member.

Comparison of Equations (1) and (2) leads to conclusion that an ideal MWF will be expected to have the same size of RMSE and SPREAD since it implies that for each ensemble member, forecasted value is equal to observed ones. According to this conclusion, the simulation is performed more realistic if RMSE and SPREAD values are close to each other.

Relative deviation (RLD) of simulated values can be adequate quantifier of control run forecast data

$$RLD = \frac{|A_{CR} - A_{OBS}|}{A_{OBS}} \cdot 100\% \quad (3)$$

3. Results and Discussion

The verification statistics related to MWF and MWF related products, on longer scale, should provide information on the applicability of MWF for certain purposes. In case of plant phenology dynamics prediction, of particular importance is impact of meteorological elements prediction uncertainty (T_{min} and T_{max} in this case) on calculated values of BBCH_D.

In Tables 2 and 3 are presented verification statistics for T_{min} and T_{max} temperatures for Rimski Sancevi and Groß-Enzersdorf locations from March 1, 2005 till June 30, 2005 obtained using ENS and CR data sets. Negligible difference between RMSE and SPREAD for T_{min} at both locations indicates excellent skill of ensemble forecast in predicting low temperatures. Low performance of ensemble forecast in forecasting T_{max} , particularly in Groß-Enzersdorf is result of two warm advections which were "invisible" in the forecast for March and April. Detailed inspection of grid area from which current forecast is assimilated according to latitude and longitude of weather station indicate that model selected location is set at 218 m altitude, while in reality it is 156 m. In indicated grid area, there are significant differences in the orography resulting in a strong west to east temperature and precipitation gradient, where mountainous hilly regions dominates in the west and flat lowland region in the eastern part of the relevant grid (where the weather station Groß-Enzersdorf is located).

Table 2. RMSE and SPREAD for monthly average maximum and minimum temperatures from March 1, 2005 till June 30, 2005 obtained using 50 ensemble members (Table denotation: M-March, A-April, M-May, J-Jun).

Setting	RMSE (°C)				SPREAD (°C)			
	M	A	M	J	M	A	M	J
T_{min}								
Groß-Enzersdorf	2.9	1.6	1.0	0.8	1.2	1.1	0.9	0.7
Rimski Sancevi	1.3	1.2	1.0	1.6	1.2	1.2	0.9	0.7
T_{max}								
Groß-Enzersdorf	5.1	4.0	2.4	2.8	1.5	1.4	1.3	1.3
Rimski Sancevi	3.0	1.9	1.7	1.5	1.7	1.4	1.4	1.5

Table 3. RMSE and RLD for monthly average maximum and minimum temperatures from March 1, 2005 till June 30, 2005 obtained using control run (Table denotation: M-March, A-April, M-May, J-June).

Setting	RMSE (°C)				RLD (°C)			
	M	A	M	J	M	A	M	J
T_{min}								
Groß-Enzersdorf	2.9	1.3	0.6	1.0	-	19.1	8.0	7.3
Rimski Sancevi	1.8	0.4	0.7	1.7	-	7.9	7.3	9.7
T_{max}								
Groß-Enzersdorf	5.7	4.3	1.9	0.8	24.1	12.0	6.4	3.7
Rimski Sancevi	4.7	2.6	0.2	2.8	20.2	9.0	2.1	6.6

Obtained results indicate much better skill of ensemble forecast for Rimski Sancevi then for Groß-Enzersdorf, but in respect to meteorological elements, results obtained for T_{min} are much better than for T_{max} .

Efficacy of MWF in predicting growing stages is tested by calculating ensemble RMSE and SPREAD for day of appearance (BBCH_D) of BBCH stages from 20 to 99 for Rimski Sancevi and Groß-Enzersdorf using ENS and CR data sets. Low performance of MWF for both threshold temperatures for all varieties can be identified only for Groß-Enzersdorf up to BBCH phase 40 for GDD_0, i.e. BBCH phase 60 for GDD_5. This drop down in MWF skill is caused by forecast deviation from real temperatures in the month March. A month later, rate of GDD accumulation is

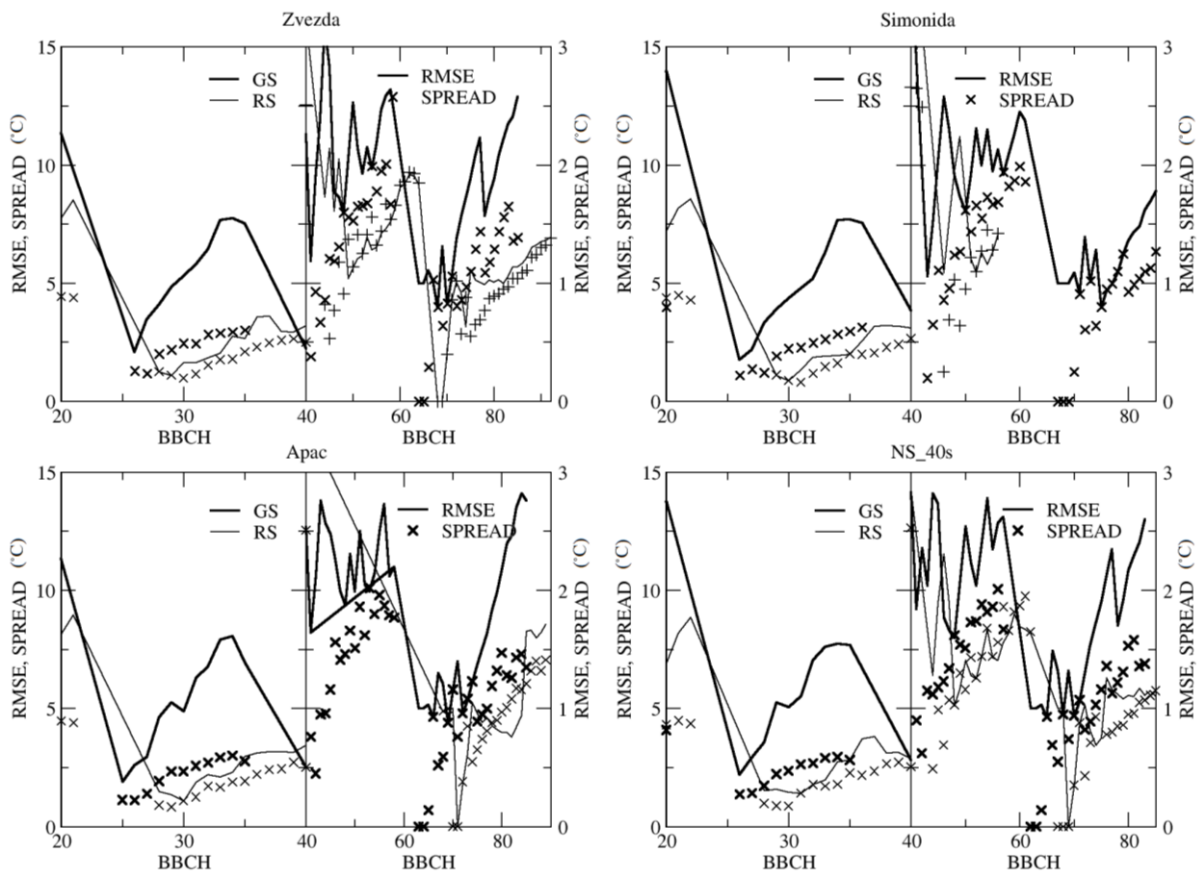


Figure 1. RMSE (line) and SPREAD (cross) of BBCH_D calculated using OBS and ENS data sets for 0 °C lower temperature threshold for Rimski Sancevi (RS) and Groß-Enzersdorf (GS) for the 4 cultivars.

high enough to reduce impact of underestimated GDD during March. Reduction of impact is slower in case of GDD_5 because contribution of period with high deviation of forecast is more pronounced than in case of GDD_0. For the rest of the vegetation period, for all varieties, difference between RMSE and SPRED is negligible, particularly in case of Rimski Sancevi location. More uniform values for RMSE and SPRED of BBCH_D calculated using GDD_5 in comparison to GDD_0 can be result of low temperature effects or photosynthetic radiation limit on crop development (i.e. stopping or delaying these) which are not taken into account. Since these limiting factors on crop development are, however, more pronounced during the winter and early spring months when accumulation of GDD_0 can already take place, variation in BBCH_D forecast quality is more exerted if it is based on GDD_0 than GDD_5.

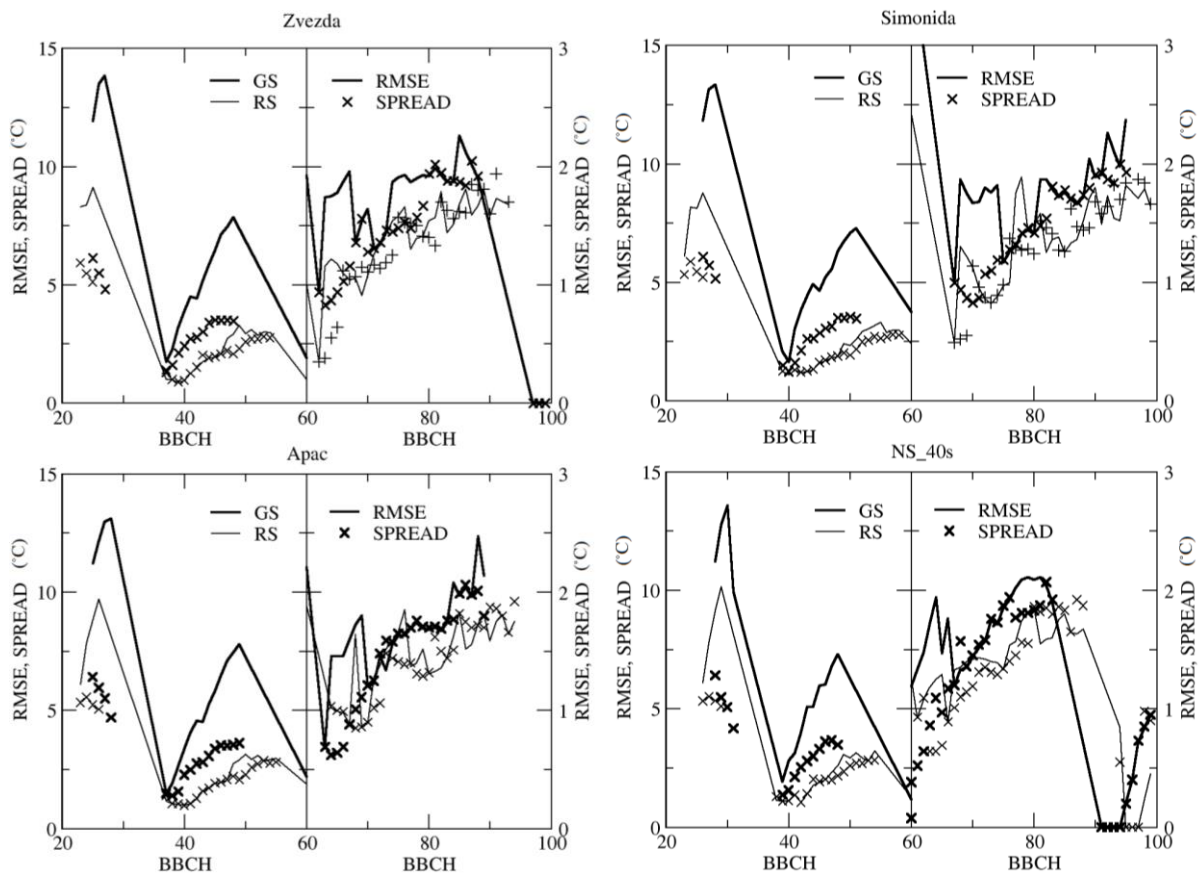


Figure 2. RMSE (line) and SPREAD (cross) of BBCH_D calculated using OBS and ENS data sets for 5 °C lower temperature threshold for Rimski Sancevi (RS) and Groß-Enzersdorf (GS) for the 4 cultivars.

Results obtained using CR data set are analysed by calculating RMSE and RLD for all BBCH stages and threshold temperatures (Figure 3 and 4). RMSE obtained for both threshold temperatures are in order of magnitude of RMSE obtained for ENS data sets for all cultivars. Relative deviation of up to 2% indicates good skill of even control run forecast in predicting growing stage appearance.

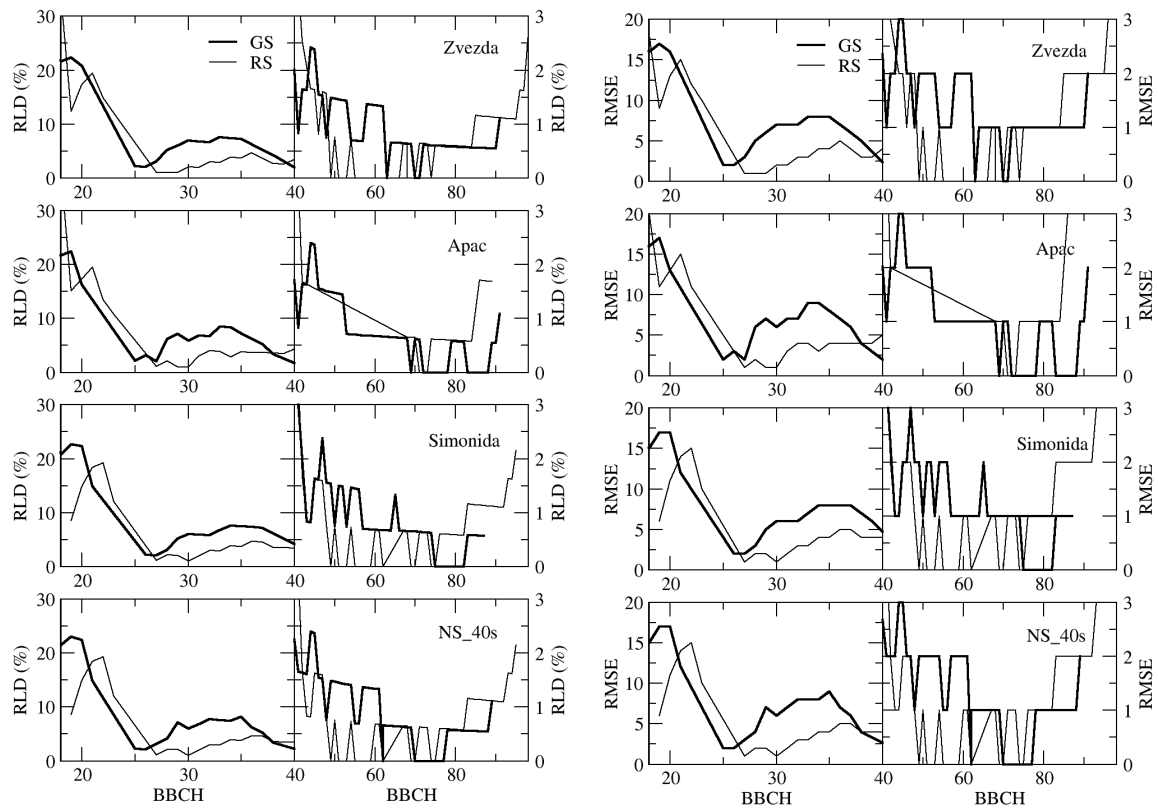


Figure 3. RLD (left) and RMSE (right) of BBCH_D calculated using OBS and CR data sets for 0 °C lower temperature threshold for Rimski Sancevi (RS) and Groß-Enzersdorf (GS) for the 4 cultivars.

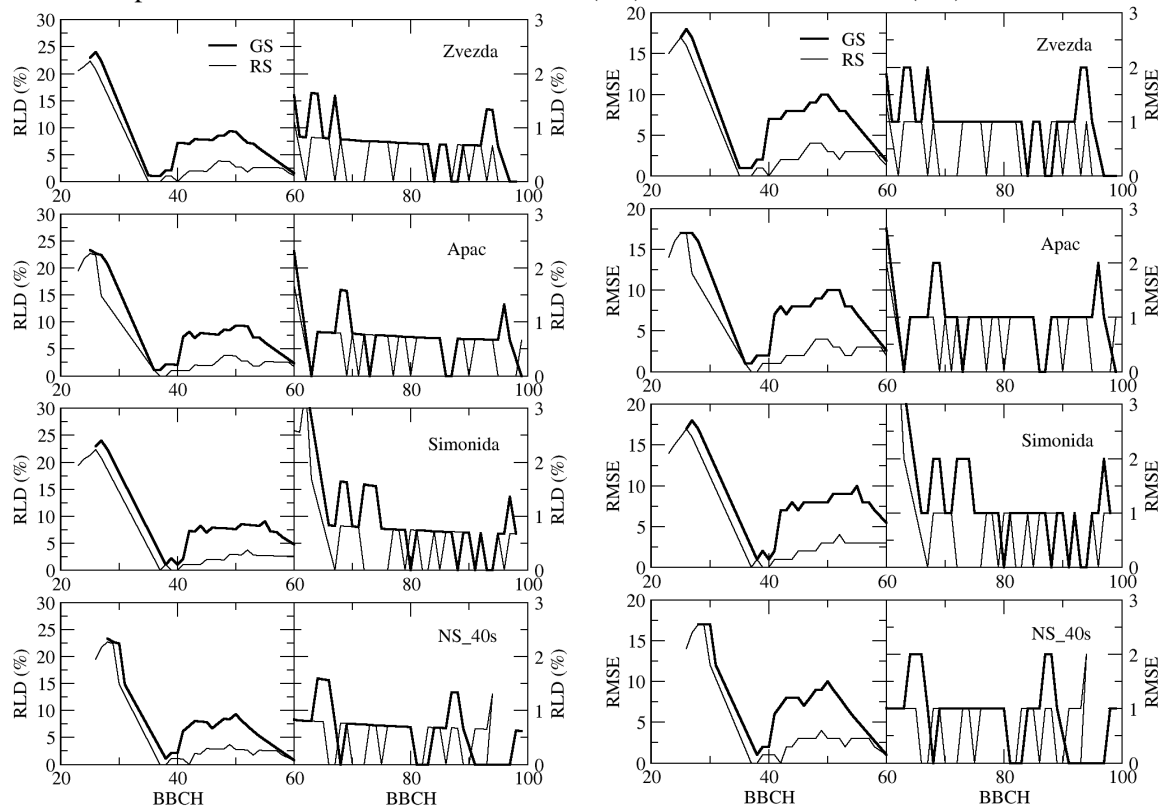


Figure 4. RLD and RMSE of BBCH_D calculated using OBS and CR data sets for 5 °C lower temperature threshold for Rimski Sancevi (RS) and Groß-Enzersdorf (GS) for the 4 cultivars.

4. Conclusions

Every day we are witnessing effects of climate variability and changing climate, expressed as prevailing weather conditions. Important step in adopting to effects of climate variability and change is to provide site specific and reliable information on the future weather conditions at various time scales for stakeholders. Any improvement in long term numerical weather prediction (monthly, seasonal) makes adaptation actions more effective. In case of agriculture, application of monthly and seasonal weather forecast is of particular importance. The best effects of this application can be achieved using long term weather forecast as an input data in well calibrated and validated forecasting tools such as physiological, phenological, agrometeorological, crop yield and pest and diseases models.

Results presented are first outcomes of a strategic study related to modelling phenology dynamics of harmful organism and host plants in order to be used in agrometeorological modelling and integrated pest management of different scales. For that purpose, a current phenological model for winter wheat was applied for two locations in representative agricultural production areas in Serbia and Austria for which MWF for March-June 2005 was available, in order to test efficacy of MWF in comparison to results obtained using observed data.

High skill of MWF in forecasting low temperatures, especially in spring, is promising from frost prediction point of view. Namely, in years with significant shift of phenological phases to earlier time, frost prediction and protection becomes one of the most challenging problems.

Lower performance of MWF in forecasting high temperatures in case of Groß-Enzersdorf is actually result of one warm advection episode which was omitted by the forecasting model. Most probably it is result of difference in altitude between model grid points and exact location of weather station. In order to clarify this problem we are preparing to make more testing, using monthly and seasonal forecast for ten consecutive years.

During the actual growing season of 2016 following a warm winter the system is operationally tested. Up to now, monthly forecast for March and April 2016 for Rimski Sancevi predicted accurately minimum and maximum temperatures and absence of late frost.

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