

PUBLIZIERBARER ENDBERICHT

gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Kurztitel:	AgroDroughtAustria
Langtitel:	Trockenheitsmonitoringssystem für die Landwirtschaft in Österreich
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Projekt- und KooperationspartnerIn (inkl. Bundesland):	<ul style="list-style-type: none"> • LFZRG – Landwirtschaftliches Forschungszentrum Raumberg-Gumpenstein • BAW – Bundesamt für Wasserwirtschaft, Petzenkirchen • ZAMG – Zentralanstalt für Meteorologie, Wien • Global Change Research Centre (AS CR v.v.i.), CZ • NDMC – National Drought Mitigation Center, USA
Schlagwörter:	Trockenheit, Trockenstress, Landwirtschaft, Pflanzenproduktion, Monitoring, Vorhersage
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B) Projektübersicht

1 Kurzfassung

Obwohl Österreich überwiegend von humiden oder semi-humiden Klimaten geprägt ist sind die wichtigen Ackerbauregionen in den niederschlagsärmeren Regionen regelmäßig und mit zunehmender Tendenz mit agrarmeteorologischer Trockenheit (oft kombiniert mit Hitzestress bei Nutzpflanzen) konfrontiert, wobei Trockenstress und/oder Hitzebelastung zu deutlichen Ertragseinbußen bei Nutzpflanzen führen. Studien mit Pflanzenwachstumsmodellen zeigen, dass in Mitteleuropa (inkl. der österreichischen Anbauregionen) diese Stresssituationen für Nutzpflanzen unter Klimaszenarien weiter zunehmen werden (Eitzinger et al., 2013; Semenov and Shewry, 2011).

Da es in Österreich noch kein operationelles, nutzpflanzenspezifisches Trockenheitsmonitoringssystem (inkl. Vorhersage) gibt, dass an die österreichischen Verhältnisse und Bedürfnisse der Landwirtschaft angepasst ist, wurde als Hauptprojektziel die Entwicklung eines derartigen Systems definiert, welches als Entscheidungshilfe für produktionstechnische Prozesse und Anpassungen an Trockenheits- und Hitzeeffekte im Ackerbau dienen kann.

AgroDroughtAustria beinhaltete 5 Arbeitspakete (AP). AP1 diente dazu um eine österreichweite Datenbasis für Modelleingabedaten, wie standortspezifische Wetter- und Bodendaten sowie Daten über den Einfluss von Trockenheit auf Nutzpflanzen (Ertragsdaten) zu erstellen. Diese Datensätze wurden in AP2 zur Adaption, Kalibrierung sowie Validierung von Modellen und Algorithmen genutzt, welche das Ertragsrisiko bzw. den Ertragseinfluss bestimmen. AP3 erstellte bzw. adaptierte Wettervorhersageprodukte für die Vorhersageprozedur von Trockenheit. In AP4 wurden schließlich die in AP2 und AP3 entwickelten Methoden in ein operationelles, Geographisches Information System (GIS) basiertes Trockenheitsmonitoringssystem für 4 Nutzpflanzen und Grünland (ADA) implementiert. In AP5 wurde das ADA System anhand von nutzpflanzenspezifischen Ertragsdepressionen mit Beteiligung potenzieller Nutzer getestet.

Das Projekt zielte auf die Entwicklung eines räumlich hoch aufgelösten GIS (500 x 500m) für Trockenheitsmonitoring und Vorhersage ab, das für einen operationellen Einsatz geeignet ist. Um dieses Ziel zu erreichen, wurden vereinfachte Ansätze von Modellen adaptiert und kombiniert - ein Wasserbilanzmodell, ein phänologisches Modell und Modelle für nutzpflanzenspezifische Ertragseffekte für 5 wichtige Kulturen für Österreich (Grünland, Winterweizen, Sommergerste, Mais und Zuckerrübe). Diese methodischen Ansätze wurden mithilfe der erstellten Datenbank kalibriert und getestet.

Zusätzlich wurde das räumlich basierte INCA Produkt täglicher Wetterdaten (inkl. Vorhersagedaten) für einen täglichen Eingabeprozess optimiert. Zur Demonstration operationeller Nutzung der Ausgabedaten des ADA Systems für Österreich wurde ein Internetportal erstellt bzw. entwickelt. Ein Test des ADA Systems im extremen Trocken- und Hitzejahr 2015 zeigte in den meisten Fällen relativ gute Ergebnisse bei der Einschätzung der trockenheits- und hitzebedingten Ertragseinbußen in

einem moderaten Unsicherheitsbereich. Deutliche Abweichungen zeigten sich jedoch an einigen Standorten, welche durch skalenbedingte Abweichungen von realen Standortverhältnissen zu den gitterbezogenen räumlichen Eingabedaten (insbes. Bodencharakteristika, Sortenbedingte Sensitivitätsunterschiede auf Trockenheit und Hitze, Wetterdaten) erklärt werden konnten bzw. können.

Das ADA Trockenheitsmonitoringssystem ist somit als GIS basierte Software für operationelle Nutzung verfügbar. Zur weiteren Verbesserung wird der Test gegenüber realen Bedingungen und erhobenen Daten im Rahmen der Erweiterung des Systems für zusätzliche wetterbedingte Risiken in einem weiteren Projekt (COMBIRISK) fortgesetzt. Auch die Funktionalität muss im weiteren Testbetrieb sowie bei einer operationellen Implementation durch permanente wissenschaftliche Begleitung und Berücksichtigung von Nutzerfeedbacks nachgeschärft werden, wie es auch bei ähnlichen Systemen erfolgreich praktiziert wird. Das Projektkonsortium bemüht sich weiter aktiv einen Weg für eine Umsetzung des operationellen Betriebes des ADA Systems zu finden, damit es für Nutzer dauerhaft zur Verfügung stehen kann.

2 Executive Summary

Although most regions of Austria are humid or semi-humid, main important crop production regions are frequently and with an increasing trend over the past decades affected by agro-meteorological droughts (often combined with heat stress), where water deficit and/or heat effects leads to significant yield decrease of various crops. Crop model studies show that these conditions will accelerate under future climate scenarios in Central Europe including Austrian crop production regions (Eitzinger et al., 2013; Semenov and Shewry, 2011). Based on the lack of an operational drought monitoring and forecasting system specifically designed for the needs of agriculture in Austria the main project goal was therefore the development of such a tool supporting management and mitigation of drought/heat impacts on crops.

AgroDroughtAustria included 5 Work Packages (WP). WP1 was dedicated to establish an Austrian data base on model inputs such as site specific weather and soil conditions and crop drought impacts (yield data) used in WP2 for adaptation, calibration as well as validation of models and algorithms for crop drought stress and yield impact detection. WP3 established and adapted weather forecasting products implemented in the drought forecasting procedure. WP4 implemented the developed methods of WP2 and WP3 into an operational GIS drought monitoring model and tool for 4 agricultural crops and grassland and WP5 was dedicated to test the drought/heat monitoring and forecasting system with stakeholder participation.

In the project a high resolution GIS based crop drought monitoring and forecasting system was developed and designed for operational application. To reach that aim, a simplified crop water balance and a crop phenology model combined with drought and heat stress and yield impact indicators for five main important crops in Austria (grassland, maize, winter wheat, spring barley and sugar beet) were adapted/developed and tested based on collected Austrian data sets. Further, the

spatial INCA product of daily weather data (including forecast) was adapted for daily input use. A Web-portal was developed demonstrating the operational use and presentation of the GIS model outputs for Austria. A test of the model in the drought prone year 2015 demonstrated good performance regarding detected yield impacts of drought and heat stress, considering a certain uncertainty range. However, in some cases significant deviations occurred based on scaling related biases of underlying inputs from real site conditions at small scales (especially on soil conditions, crop cultivar sensitivities to drought, site specific weather parameters).

The ADA drought monitor is therefore available as a GIS based software for operational use. However, the test of the system on real conditions and data sets including the extension for other weather based cropping risks is continued in the further project COMBIRISK. The further development needs permanent scientific supervision and the use of user feedbacks to improve functionality and performance of the system, as it is common for similar monitoring systems. The project consortium is also active in finding and supporting an optimum way to implement the ADA system for operational use to be fully available for stakeholders.

3 Hintergrund und Zielsetzung

In der landwirtschaftlichen Pflanzenproduktion ist die Wasserversorgung ein wesentlicher Faktor für die Ertragssicherheit. Denn Wasser ist eine wichtige Grundlage für das pflanzliche Wachstum und ist v.a. während der Wachstumsperioden der Nutzpflanzen von hoher Bedeutung. Der Wasserverbrauch ist je nach Pflanzenart oder Sorte unterschiedlich. Darüber hinaus hängt er von weiteren Faktoren, wie der Biomasse (und dem damit verbundenen Ertrag) pro Fläche, der Bestandsstruktur, von der Wasserspeicherkapazität des Bodens oder der Bodenbearbeitung ab.

Wesentlich ist jedoch auch der Witterungsverlauf. Bei hohen Temperaturen benötigen (die meisten) Pflanzen besonders viel Wasser, um ihre Blätter durch Transpiration zu kühlen. Darum geht Trockenstress oft mit Hitzestress einher. Wenn es also zu langen Hitze- und Trockenheitsperioden – wie z.B. im vergangenen Sommer – kommt, dann sind Dürre- und Hitzeschäden in der Landwirtschaft häufig die Folge.

Der Klimawandel führt zu einem ganzjährigen Erwärmungstrend und damit nimmt auch das Verdunstungspotenzial zu, was ebenfalls zu schnelleren Wasserverlusten bei Pflanzenbeständen beiträgt. Klimaszenarien lassen darüber hinaus in den nächsten Jahrzehnten in Mitteleuropa zunehmende Winter- und abnehmende Sommerniederschläge erwarten. Hier gibt es allerdings regionale Unterschiede, deren Vorhersagen mit Unsicherheiten verbunden sind.

Grundsätzlich ist jedoch v.a. in schon jetzt niederschlagsarmen Regionen zu erwarten, dass der Wasserbedarf im Sommer im Pflanzenanbau steigt. Dadurch nimmt die Bedeutung von Bewässerung (und v.a. von sparsamen Bewässerungsmethoden) in manchen Regionen auch in Österreich zu. Wichtig ist in potenziell gefährdeten Regionen ebenso die Entwicklung des Grundwassers zu beobachten. Für einige LandwirtInnen und Versicherungen werden Dürreschäden

und deren Vermeidung zukünftig vermehrt eine Herausforderung sein. Eine wichtige Voraussetzung für überlegtes Handeln und Planen und als ein erster Schritt zur Klimawandelanpassung und damit zur effizienteren Wassernutzung und Vermeidung von Dürreschäden ist es, gut und zeitnah über den Stand und weiteren wahrscheinlichen Verlauf der Trockenheit informiert zu sein.

Das in AgroDroughtAustria (ADA) gewonnene Wissen steht LandwirtInnen, Versicherungen und anderen Nutzern im Bereich Landwirtschaft (wie z.B. Landwirtschaftskammern, BMFLUW) zur Verfügung, insbesondere in Form einer sehr wertvollen Informationsplattform - eines operationellen, räumlich hoch aufgelösten „Trockenheitsmonitoringsystems“ spezifisch für verschiedene Nutzpflanzen.

4 Projektinhalt und Ergebnis(se)

The details of the results are presented in English due to the scientific level of the content.

Introduction

Given the considerable uncertainties around projections of climate impacts on agriculture at local and regional scales, there is an evident and urgent need for reliable science-based early warning systems providing timely and understandable information for decision-makers and stakeholders. In our project, we addressed these challenges for agriculture in Austria, by designing and developing a crop specific drought monitoring system for Austria through the achievement of the following objectives:

- 1) Establish a set of calibrated indicators and methods on crop specific drought and heat vulnerability and impacts based on field experiment data and crop model application
- 2) Assess crop drought and heat stress at high spatial resolution by using improved spatial precipitation and temperature input (INCA data)
- 3) Establish a near-time (up to 10 days) forecasting method for drought occurrence
- 4) Adapt and validate methods for crop drought and heat stress detection and yield impact implemented in a GIS-based monitoring system with high spatial resolution (500x500m) for main vulnerable arable crops in Austria
- 5) Test crop specific drought monitoring system for operational use including stakeholder involvement

The above named objectives were addressed by 5 Workpackages, which results are presented below:

WP1: Data base on crop specific drought and heat vulnerability and impacts under Austrian and climate change conditions

In this Work Package the data base was established which was necessary for evaluation of the models and algorithms to be used in the drought monitoring system. The data base was used also for spatial validation and test of the drought monitoring system during the project time period. The data were gathered from

field experiments, statistical reports and other sources of available data. The site and crop specific data include:

- Data on soil conditions of test sites, times series of weather data, soil water content and soil water deficit under various selected crops.
- Crop and management data, describing drought effects on crops and crop stress status (i.e. biomass development, yield and yield reduction).
- Simulated times series of growth and development of the selected crops for development and calibration of a simple crop phenology model by dynamic crop model application.

Milestones:

- Established data bank on drought conditions and drought effects on crops in Austria
- Own additional field measurement stations added to data base
- Data set on simulated drought effects on crops for various periods, sites and crops

The main task of WP 1 was the establishment of the project data base, which is further described under applied methods in Chapter 6.

WP2: Adaptation, calibration and validation of existing methods to detect drought and drought impacts for arable crops and grassland. Test of models and their implementation

Models and algorithms for detecting agricultural drought, soil water deficit and drought effects on crops were evaluated, adapted and calibrated based on the data base established in the WP 1. These included the model SOILCLIM, and a set of algorithms for drought impacts on crops.

The evaluated algorithms describe:

- Soil and crop water deficit on a daily basis and site specific
- Measurable drought and heat effects on the selected crops (i.e. phenology, biomass development, leaf area, yield depression)
- Indicators of heat and drought stress status

Milestones:

- Adapted models and algorithms for GIS implementation
- Calibrated models and algorithms

Soil water balance model

The SoilClim water balance model (Hlavinka et al., 2009) was selected for implementation in the ADA system and tested using the established data base. Figure 1 shows an example of the results achieved by the SoilClim model. It is apparent that at sites with high-quality measurement of soil moisture (where soil moisture is measured at number of replicates and at multiple depths (Hirschstetten and Gumpenstein)) the performance of the SoilClim model is very good and the model correctly depicted both timing and duration of all episodes of low soil

moisture content. There is some concern that the SoilClim model might suffer from too few soil layers that causes later onset of the drought signal in some cases.

A comparison of SoilClim method with the observations and two other means of soil moisture monitoring i.e. process based crop model (DSSAT 4.0.2.0) and remote sensing based method based on the ASCAT instrument was carried out. It is apparent that the agreement of the SoilClim with the observation is lower than shown in Figure 1 but nevertheless the SoilClim method is superior of other two in most of the seasons. At the moment the mean bias of the estimates by SoilClim at the tested sites is between 3-8% and relative root mean square error varies between 15 and 20%. However we are convinced that the ongoing improvements of the SoilClim model utilizing results of over 50 observations sites from the ADA database will improve the performance of the model.

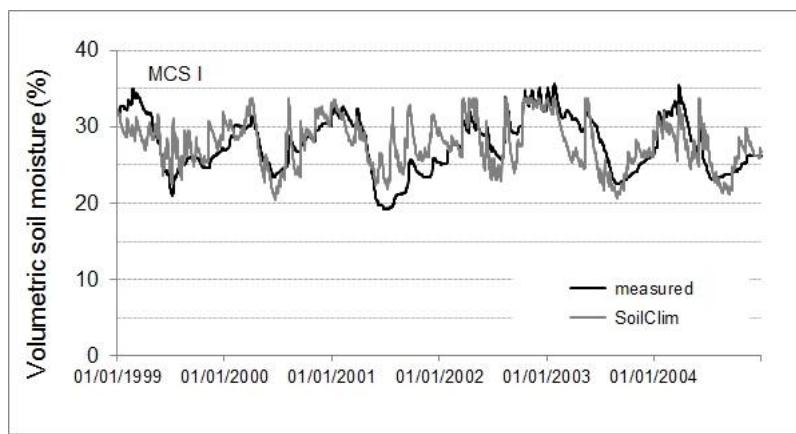


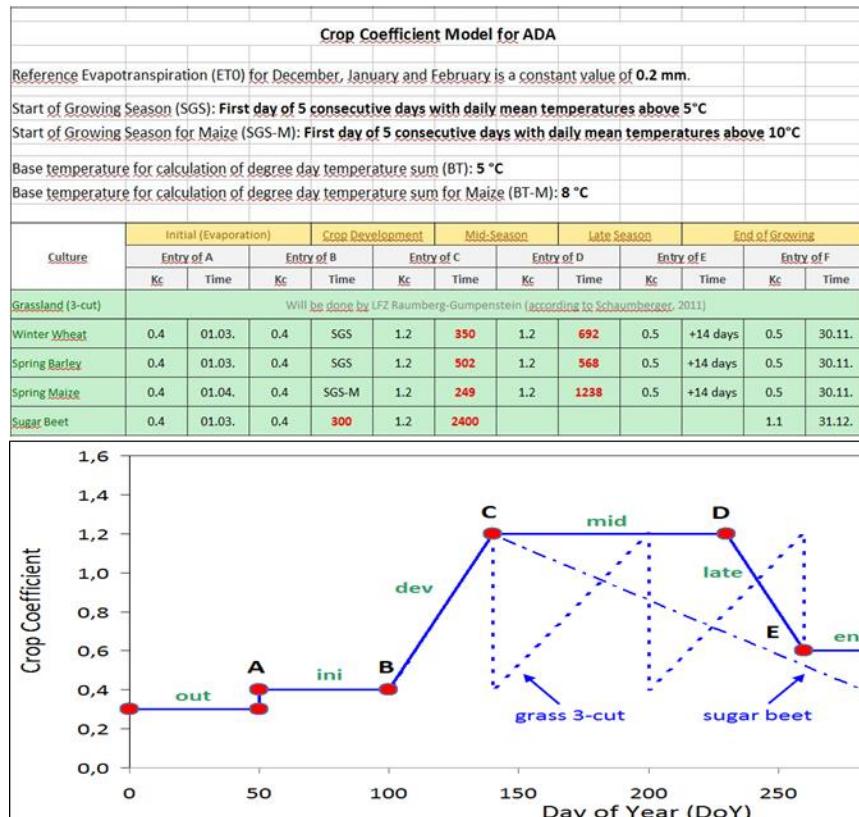
Figure 1. Example of the SoilClim model evaluation at the Hirschstetten site (top layer 0-40 cm).

Crop phenology model

As basis for the crop specific determination of crop water use and soil water depletion a phenology model, calculating the crop phenology related crop water use parameter K_c , was calibrated and implemented into the modeling system in context to the soil water balance model SOILCLIM. K_c is the crop coefficient defined for a given crop and growth stage for calculating actual crop evapotranspiration (=crop water use) from grass reference evapotranspiration (Allen et al., 1998) and is usually determined experimentally. Each agronomic crop has a set of specific crop coefficients which can be used to predict water use rates at different growth stages. Four main crop growth stages can be defined: initial, crop development, midseason, and late season (Fig 2).

For Austria the four crop growth stages as well as the K_c factor were defined for grassland, winter wheat, spring barley, spring maize and sugar beet. As experimental data were not available, calibrated crop growth models were used to determine the crop specific temperature sums required for reaching main development stages and related K_c factors. The DSSAT v4.0.2.0 model was used for maize, winter wheat and spring barley. The simulations were run from 1992-2012, weather station Groß-Enzersdorf, soil Chernozem, rain-fed, fertilization according ÖPUL guideline. On 1st March for winter wheat and spring barley as well as on 1st April for maize started the first stage A (Fig 2). The K_c factor and temperature sum for sugar beet were simulated with the crop model Daisy. For grassland the

approach of the GRAM model is used, which is already available from the partner LFZ and BOKU.



Phenology model

(to be used for evapotranspiration calculation and stress indicators)

Figure 2. Crop growth stages and Kc factor for grassland, winter wheat, spring barley, maize and sugar beet as calibrated for Austrian conditions.

Crop drought/heat stress and yield impact models

Calibration and implementation of quantitative crop drought and heat stress parameters

Based on the crop yield database for the major crops in Austria (established in WP1) such as spring barley, maize, winter wheat and sugar beet and permanent grassland, drought and heat stress impact analysis was carried out using the developed and tested indicators as shown in Table 1.

It shows the best performing indicators which were used for implementation in the ADA GIS system to calculate drought and heat stress related crop yield depletion.

Table 1. Calibrated and statistically significant crop yield impact functions as implemented in the GIS model.

Crop	Daily heat indicator	Daily drought indicator	Daily drought/Heat indicator	Actually implemented yield depression functions		
Grassland 2nd cut		WSI = DR * 100.0 / TAW		YD = 87.53 + (-.0055 *Σ WSI)	Σ 1.5. - cut date	R ² =0.23
Winter Wheat	Σ HDH > 27	WSI = DR * 100.0 / TAW	TM > 26: CSI = WSI * (TM - 25.0) TM < 26: CSI=WSI	YD = 6.64 + (-.000084 *Σ CSI)	Σ 1.3. – harvest	R ² =0.27
Spring barley	Σ HDH > 27	WSI = DR * 100.0 / TAW	WSI > 33 & TM>30: CSI= ((TM-29)*WSI)-33	YD = 5.11 + (-.0002 *Σ CSI)	Σ 1.3. – harvest	R ² =0.20
Maize		WSI = DR * 100.0 / TAW	WSI > 33 & TM>30: CSI= ((TM-29)*WSI)-33	YD = 10.99 + (-.0005 *Σ CSI)	Σ 1.5. – harvest	R ² =0.20
Sugar beet		WSI = DR * 100.0 / TAW	TM > 26: CSI = WSI * (TM - 25.0) TM < 26: CSI=WSI	YD = 89.22 + (-.0008 *Σ CSI)	Σ 1.5. – harvest	R ² =0.41

WSI = water stress indicator [%]
DR = root zone depletion [mm]
TAW = available soil water content at available field capacity [mm]
CSI = combined water and heat stress indicator [-]
TM = maximum daily temperature [°C]
YD = Yield depression relative to not stressed conditions [%]
HDH: Heat Degree Hours [°C]

WP3: Development of drought-specific forecasting products

Reliable meteorological input data is one of the key factors to make useful monitoring and forecasting of drought occurrence. The Zentralanstalt für Meteorologie und Geodynamik (ZAMG) operates and has access to a variety of state of the art analysis and forecasting models that cover forecast ranges from several hours up to few months. These forecast models provide reliable weather forecasts which include drought relevant parameter such as near surface temperature and precipitation. In the framework of the ADA project, special tools have been developed to post-process the model output to drought specific parameters and provide the model data on a common grid and format for downstream applications of the project partners. Although all forecasting models are under continuous development they are affected by a certain degree of uncertainty. To assess these uncertainties probabilistic forecasts are available for all numerical weather prediction (NWP) models in this project. The uncertainties were quantified and evaluated by the use of ensemble forecasting systems. For the ensemble systems operated by ZAMG new methods were developed and tested targeted to improve the probabilistic forecasts especially for drought relevant parameters.

Milestones:

- Interface for model data
- Assessment of forecast uncertainty ready
- Validation results ready

Interface model data

Work package 3 within the ADA project dealt with the preparation of drought relevant meteorological parameters, mainly temperature and precipitation, from

state of the art numerical weather prediction (NWP) and nowcasting models. ZAMG as the Austrian national weather service can provide input for downstream applications from several weather forecasting models varying in horizontal resolution and forecast ranges. The operational model chain includes, among others, the analysis and nowcasting system INCA (Integrated Nowcasting through Comprehensive Analysis) with a horizontal resolution of 1km and the deterministic ALARO model with a horizontal resolution of 4.8km. Since ALARO fields are used as input for INCA both systems provide 'seamless' forecasts from the nowcasting range up to 3 days ahead. ZAMG has also access to forecasts from the European Centre for Medium-Range Weather Forecasts (ECMWF) which global NWP-model covers a forecast range of up to 10 days ahead with a horizontal resolution of 16km.

Since all nowcasting algorithms and NWP forecasts are affected by a certain degree of uncertainty, the importance of ensemble systems for numerical weather forecasts is constantly increasing. At ZAMG there are ensemble counterparts to all deterministic system operationally available. INCA is coupled with the Limited Area Model (LAM) EPS ALADIN-LAEF (Aire Limitée Adaptation dynamique Développement InterNational – LAM) to allow the quantification of uncertainty in the nowcasting range (Ensemble INCA). ALADIN-LAEF can be used to assess the uncertainty in the ALARO forecasts for predictions up to 3 days ahead. The ECMWF ensemble is the counterpart of the ECMWF global model to estimate the uncertainty in the forecasts up to 10 days. For longer lead times ECMWF provides the seasonal forecasting system with a forecast range up to 7 months ahead.

One aim of this work package was the further development of proper methods to quantify the uncertainties of the meteorological input for downstream applications. The tested methods were targeted to improve the forecasts especially for the drought relevant parameter precipitation and near surface temperature. The new methods as well as the existing systems were validated with a focus on drought specific parameter.

For all available models data flow was implemented to enable the use of the data in the GIS system. The model data were post-processed, interpolated to a common horizontal grid and provided to the project partners in the required format.

Uncertainty of INCA analyses and nowcasts

Cross-validation shows that the skill of the precipitation analysis, which combines radar data and surface station data including parameterized elevation dependence, exceeds that of the pure radar data, and is also significantly better than pure station interpolation (Tab. 2).

Table 2. Cross-validation of the INCA 15-min precipitation analysis for different regions and different types of precipitation events.

Period /Type	Validation Area	Number of Analyses	Number of Stations	Relative MAE station interpolation	Relative MAE INCA analysis	Relative improvement
21.11.2008 00-12Z stratiform	Eastern Lower Austria (lowlands)	48	39	45.5%	42.3%	7%
21.11.2008 00-12Z stratiform	Salzburg	48	27	51.2%	46.3%	10%

	(mountainous)					
28.07.2008 15-19Z convective	Salzburg (mountainous)	16	23	104.0%	55.6%	47%
03.06.2008 16-22Z convective	Tyrol (mountainous)	24	29	78.1%	64.6%	17%
04.06.2008 00-24Z strat+conv	Austria	96	260	101.5%	64.5%	36%

As can be seen from Tab. 2, the improvement of INCA compared to station interpolation is most pronounced in convective cases. In stratiform cases, the improvement is smaller because (a) the stations already capture a larger portion of the spatial variance of the precipitation field, and (b) spurious structures in the radar field caused by beam shielding and attenuation, bright band effects, etc. limit analysis quality.

Validation of Ensemble INCA

Several verification scores have been calculated for a period of one month for En-INCA compared to ALADIN-LAEF (Fig. 3). The observations used for verification are taken from surface point observations of TAWES (automatic weather stations in Austria).

The CRPS clearly shows the benefit of the En-INCA, especially during the first 6 hours, but also beyond the nowcasting range. The ensemble dispersion matches the dispersion of the distribution of verifying observations a bit better than ALADIN-LAEF. Also the percentage of outliers is reduced.

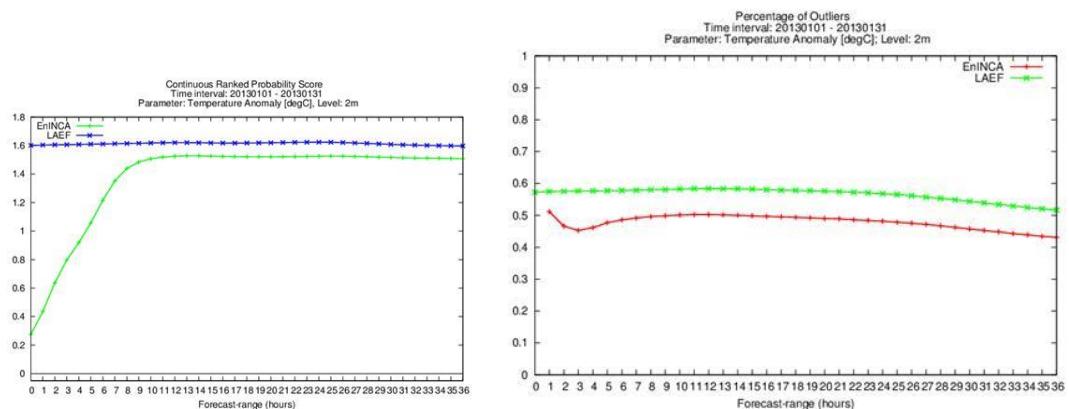


Figure 3. Verification results for a period of one month (January 2013) compared to LAEF for temperature. Left: CRPS (Continuous Ranked Probability Score); Right: percentage of outliers.

Uncertainties in the forecasts

Forecast uncertainties of the operational deterministic NWP model ALARO are assessed by the limited area EPS ALADIN-LAEF. The main uncertainties that exist in regional model forecasts, namely in the initial conditions of the model run, in the boundary conditions and in the model forecast itself, are considered by the breeding-blending method, the use of multi-physics and coupling to ECMWF ensemble.

Most parameters relevant for downstream applications of the drought monitoring system are near surface parameters. Hence the impact of the model surface plays a

key role for the quality of the forecasted parameter since near surface parameter like 2m temperature/humidity are retrieved by interpolating the parameter between the lowest model level and the model surface. In ALADIN-LAEF uncertainties in the uppermost model surface layers are directly perturbed only in the initial conditions of the model but not during the forecast itself. These initial perturbations are retrieved by running the surface assimilation, where randomly perturbed measurements of 2m temperature and 2m relative humidity are assimilated using an Optimum Interpolation method to modify the temperature and humidity of the model surface.

A new approach that was tested in the framework of WP3 is to stochastically perturb physic tendencies in the surface fields of ALADIN-LAEF during the integration. Therefore a so called Stochastically Perturbed Parameterization Tendencies (SPPT) scheme was adapted for model surface fields.

Evaluation of forecast quality

The forecast quality of the drought relevant parameter was evaluated especially in the sense of the appropriate estimation of the uncertainty. The heat wave that occurred over Austria in July 2015 provided a good period for evaluation that could be used to investigate the performance of the involved forecast models and ensemble systems in an extreme weather period compared to the performance in "normal" weather conditions.

July 2015 was the warmest July in Austria in the last 248 years, the period where ZAMG measurements are available in Austria. The mean temperature in Austria was approximately 3 degree warmer compared to the reference period from 1981-2010. Figure 4 shows the predicted monthly mean temperature anomalies of ensemble mean for July 2015 from seasonal forecasts starting in January and July 2015, hence a seven and a one month forecast. The temperature anomalies shows the the predicted temperature anomaly with respect to the model climate.

Both forecasts show a positive temperature anomaly for July 2015 ranging between +0.5 to +1 degree with respect to the climate mean for forecasts from January (Fig. 4). The January forecast is consistent with the forecasts from the seasonal forecasting system of the following months including June 2015. From those forecasts, July 2015 could be expected to be warmer than usual even several months ago, however the ensemble mean didn't indicate an extremely warm month. This changed with the forecasts initialized on 1st of July 2015, where a positive temperature anomaly between 2.5 and 4 degree was predicted for Austria, even slightly overestimating the observed temperatures. The forecasts of precipitation anomalies for July 2015 were very consistent and indicated less precipitation than on average already in forecasts initialized in January 2015 and in the subsequent months. So from the seasonal forecasts July 2015 could also be expected to be drier than on average.

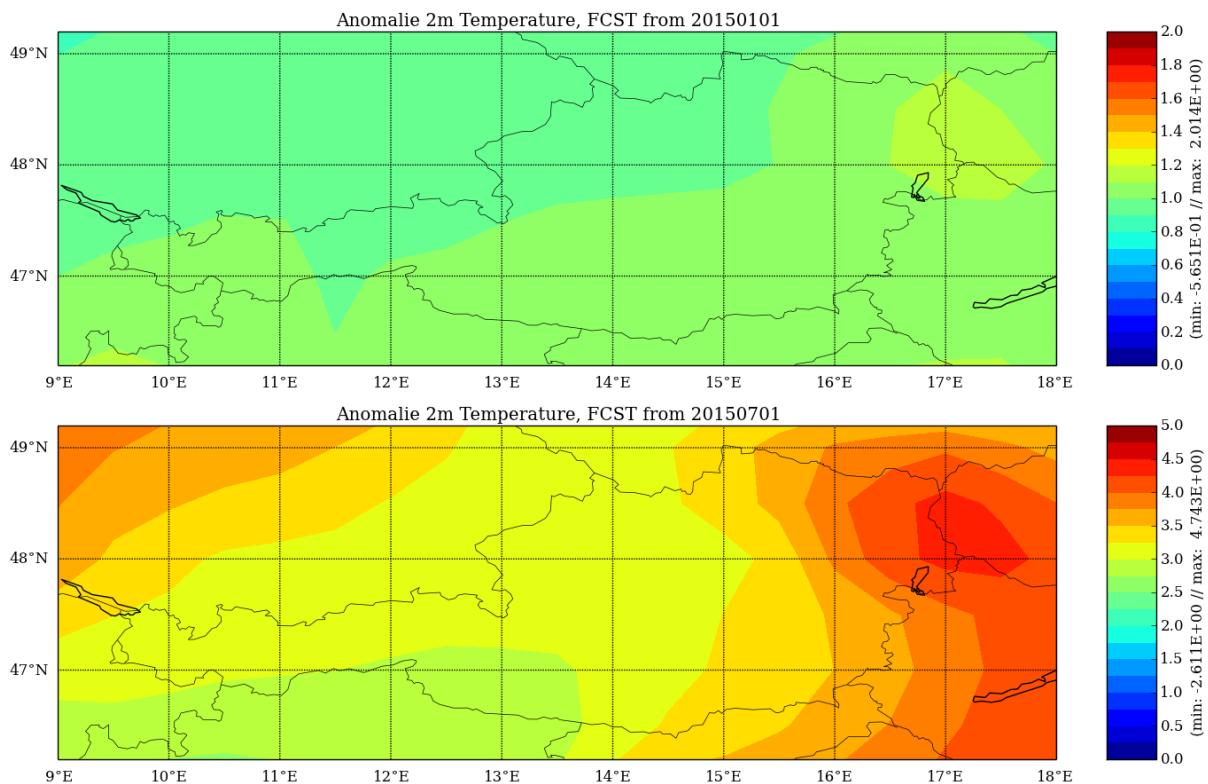


Figure 4. Monthly mean 2m temperature forecasts from ECMWF seasonal forecasts system valid for July 2015. Upper panel shows 2m temperature anomaly of the ensemble mean for forecast initialized on 1st of January 2015, hence a 7 month forecast. Lower panel shows the same field for the forecast initialized on 1st of July 2015.

WP4: Spatial Implementation of drought monitoring on the base of existing GIS with adaptions for Austrian agricultural land

The major focus of work package 4 within the AgroDroughtAustria project is the development of a spatial model denominated ADA-MFS (Agro Drought Austria Monitoring and Forecasting System) for monitoring and forecasting crop specific drought and heat stress parameters. The model covers automated spatial data manipulation, processing, visualization and storage and is mainly implemented through the software package ADIS (Agricultural Drought Information System) as the core component.

Milestones:

- Software and geodata interfaces
- Software for spatial detection of crop and heat stress
- Web-based demonstration of operable drought monitoring system

ADA-MFS (ADIS) and system software

ADIS is based on the already existing models SpatialGRAM (Schaumberger, 2011) and SOILCLIM (Hlavinka et al., 2011) for crop specific drought monitoring and forecasting and was developed within the framework of the project using the

integrated development environment Eclipse¹ and the object-oriented programming language Java². ADIS is designed to work on a Windows Server with Oracle's Java Runtime Environment (JRE) installed and functional. ADIS is integrated in the operable ADA-MFS, which additionally is composed of a FTP (file transfer protocol) component for the download of the meteorological input data and a web based visualisation tool.

The generation of ADA-MFS required several different working steps including the coding of ADIS. The development was accompanied by additional tasks such as the one-time preparation of meteorological, elevation and land use input data, the development and coding of a FTP download tool and of a web page prototype to visualise the results.

The first major working step of ADIS programming was the development and coding of adequate I/O interfaces to allow high performance data access and export. Based on the excellent performance and the relative small size of netCDF data files, the netCDF file format was chosen as main format for the creation, access, and sharing of the data. netCDF is described in more detail in the following chapters.

Due to the existence of the models SpatialGRAM and SOILCLIM and their programmatic implementations, significant time was spent in a second major working step to analyse the methodologies of the two models and to select suitable algorithms for the new software. Appropriate algorithms were, for the most part, transferred unaltered and to a small part adapted to the project specifications. Furthermore new project specific methodologies and algorithms were also developed and implemented.

In the next step a new extensive program logic was coded including the existing and newly developed algorithms. All program features have been implemented as static or instanceable classes in accordance with the object-oriented programming paradigm. All classes with their class methods and the number and types of class variables and, last but not least, the program structure itself have been optimized with regard to a balanced ratio of computer memory consumption and processing speed. Several testing classes have been included to check the program's classes for functionality and correctness. Furthermore various methods have been implemented to export intermediate and final results of crucial calculation steps in ASCII text file format for evaluation and graphical visualisation purposes.

Besides ADIS, a separate application has been developed and coded to allow the download of all necessary meteorological monitoring and forecast files from a download server of the Austrian Central Institute for Meteorology and Geodynamics ZAMG (Zentralanstalt für Meteorologie und Geodynamik). The meteorological files use the netCDF file format, are created on a daily basis and can be downloaded at any time. And last but not least a web page prototype was written to allow the illustration of the computation results. The web page is based on the open source platform MapServer (Univ. of Minnesota, USA), which allows the building of spatially enabled internet applications.

All components of ADA-MFS are located on a Windows server. ADIS and the FTP download tool are triggered and controlled by the Windows task scheduler. The web architecture is depicted in Figure 5.

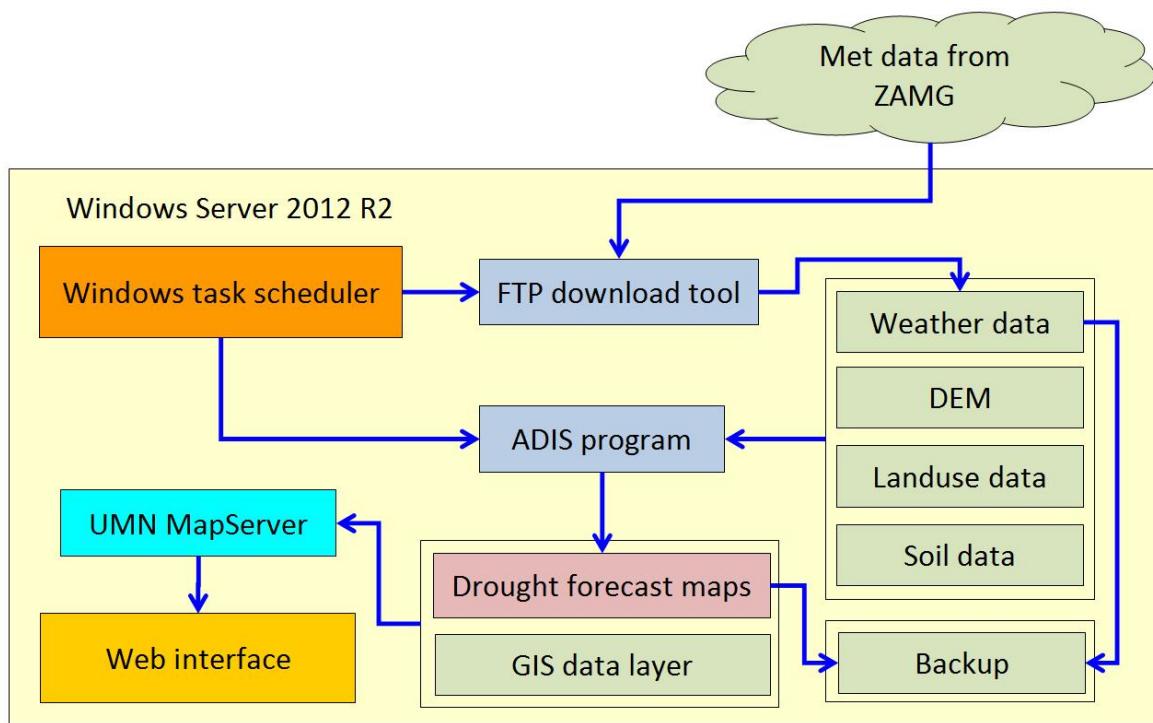


Figure 5. ADA-MFS system web architecture.

Web portal of the monitoring system

The results of the Agro Drought Austria Monitoring and Forecasting System *ADA-MFS* are maps showing the relative soil saturation, drought intensity and crop yield reduction situation over the Austrian territory in a grid resolution of 500 meters for rooting zone layers of 0-40 cm (grassland) and 0-100 cm (winter wheat, spring barley, maize and sugar beet). The maps are visualised in the web page prototype (Fig. 6).

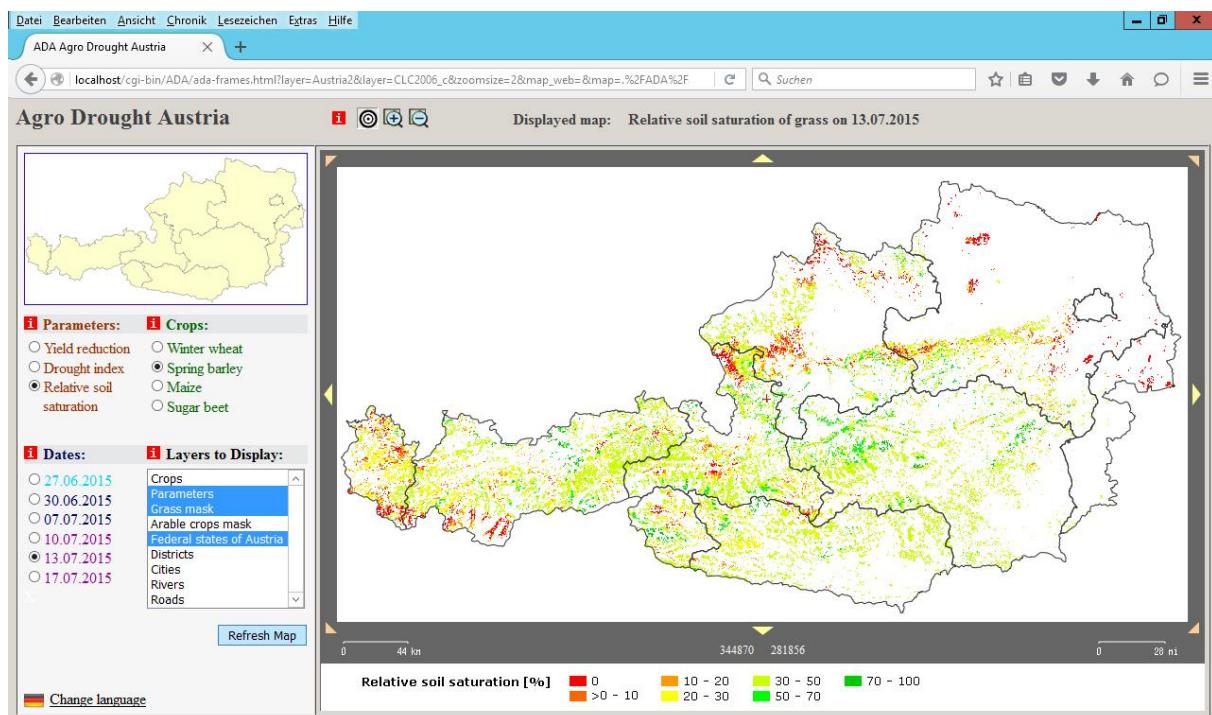


Figure 6. Relative soil saturation distribution of grassland for the Austrian territory on 13.07.2015.

WP5: Test and evaluation of the drought monitoring system with stakeholder participation

Milestones:

- Spatial validation of output parameters of AgroDroughtAustria
- Test of the operational use of AgroDroughtAustria
- Implementation of methodological improvements
- Implementation of stakeholder feedbacks (functionality, presentation)

The involvement of stakeholders included two “levels” of stakeholders. The first group of stakeholders involved can be linked to the “expert” level, i.e. coming from university, agricultural ministry, agricultural chamber, hail insurance, and other institutions. The ADA drought monitoring system was presented to these experts (see presentations as provided at the ADA web page) during the ADA Symposium in November 4th 2015 of about 40 participants. At this meeting via an alternative web portal the functioning of the system was demonstrated. The feedback from the discussions at the meeting was used to improve further the user friendliness for the second group of main stakeholders, which are the farmers. Improvements such as sound explanations of the parameters and methods shown in the web portal and type of useful heat/drought stress parameters to be presented in the web portal were carried out after the meeting.

The operable drought monitoring system “AgroDroughtAustria” was spatially validated and tested over several sites in Austrian crop production regions. For that purpose a questionnaire was distributed and interviews were carried out to gather

independent yield data from farmers from the extreme year 2015 and compared with ADA GIS outputs.

Altogether we received through the questionnaire information from 29 sites over three federal districts on yield impacts of drought and heat stress at field level for 50 fields for the crops considered in ADA including also other crops.

The questionnaire, to be filled for each crop type separately, asked for information on:

- soil type at the field (classified according to water holding capacity)
- dates of adverse weather conditions during the growing season
- yield impact by drought and heat at different reporting dates during the growing season (relative yield depression compared to normal yield level).

Figure 7 shows the results from farm yields from Lower Austria, Burgenland and Styria for the 4 crops. The results show in same cases (i.e. for maize) distinct deviations from farmer reports. These cases could however explained by major small scale deviations in the underlying ADA data base from reality, such as soil conditions or the not considered groundwater impact. Smaller deviations are still common due to natural variations in reality which cannot be caught by the ADA system, such as crop management options, soil cultivation or crop cultivar effects on stress sensitivity. Such deviations should be addressed by applying the pre-defined uncertainty ranges of yield impacts as shown in Figure 8. However, this validation and recalibration activity nee to be continued in the frame of another project beyond the ADA project, and is recommended as an important activity also during operational application for a permanent improvement of a crop drought monitoring systems to meet the stakeholder needs and acceptance.

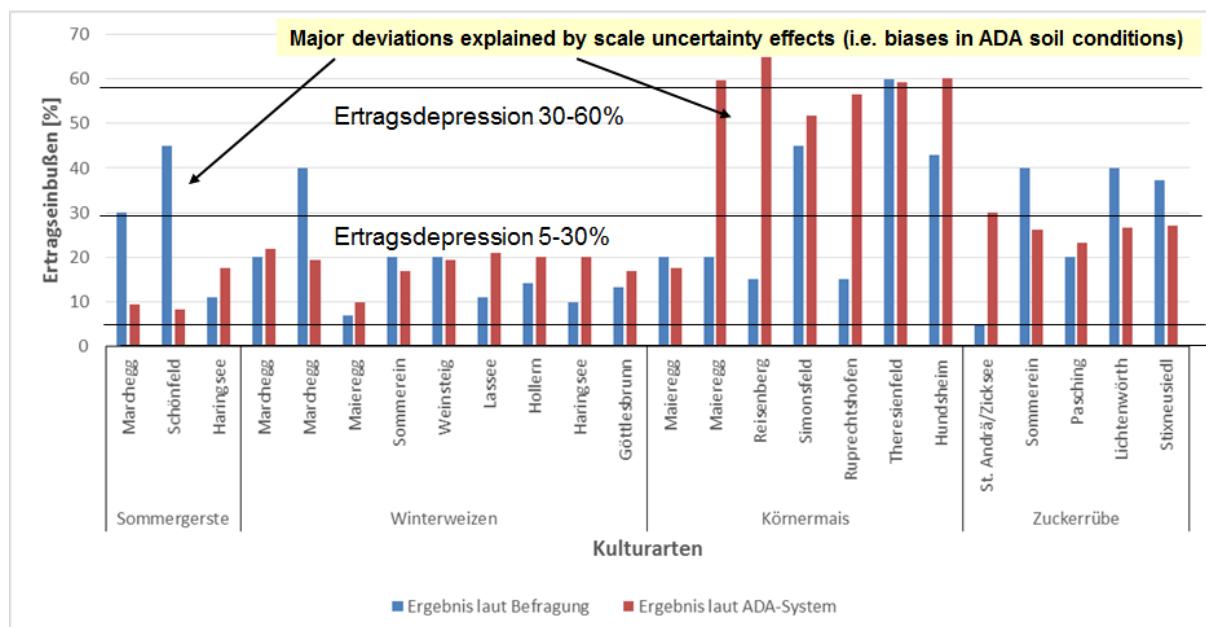


Figure 7. ADA system validation on yield depletion by drought and heat stress in 2015 by farmer inventory in eastern Austria.

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DOI:10.1038/srep00066

5 Schlussfolgerungen und Empfehlungen

Das ADA Trockenheitsmonitoringsystem dient als ein Informations- und Entscheidungshilfetool. Es besteht aus einem nutzpflanzenspezifischen Monitoring (derzeit für Winterweizen, Sommergerste, Mais, Zuckerrübe und Grünland) das die aktuelle Situation von Trocken- und Hitzestress sowie die dadurch abgeschätzte erwartete Ertragsdepression darstellt. Darüber hinaus bietet es die Möglichkeit die vergangene Entwicklung zu betrachten sowie einer Vorhersage über die Situation in den nächsten zehn Tagen und weiter.

Das Monitoring und die Vorhersage basieren auf einem Geographischen Informationssystem (GIS), das in einem Vorprojekt (ClimSoil) entwickelt wurde. So können die Informationen als Karten mit einer räumlich hohen Auflösung (500x500m) abgerufen werden. Die Datengrundlage für das System bilden Bewirtschaftungsdaten (INVEKOS), Bodendaten (Digitale Bodenkarte) sowie aktuelle und Vorhersagewetterdaten (INCA Modell der Zentralanstalt für Meteorologie und Geodynamik Wien). Zur Kalibrierung des ADA Modellsystems wurden Daten von Feldexperimenten (wie Bodenwassergehalte) und statistische Ertragsdaten von Nutzpflanzen aus vergangenen Jahren herangezogen.

Das ADA Monitoringssystem kann über eine Internetseite den Nutzern interaktiv zur Verfügung gestellt werden (siehe Abb. 8). Es ist dabei aber anzumerken, dass der operationelle, dauerhafte Betrieb über die Projektlaufzeit hinaus noch nicht umgesetzt wurde, da dies nur auf institutioneller Ebene (dauerhafter Betreuungsaufwand, Kosten der Wetterdaten usw.) sichergestellt werden kann. Wie auch immer, wird das ADA Monitoringssystem in einem Folgeprojekt des ACRP (COMBIRISK) nun für weitere Wetterrisiken im Pflanzenbau ausgebaut und weiter verbessert.

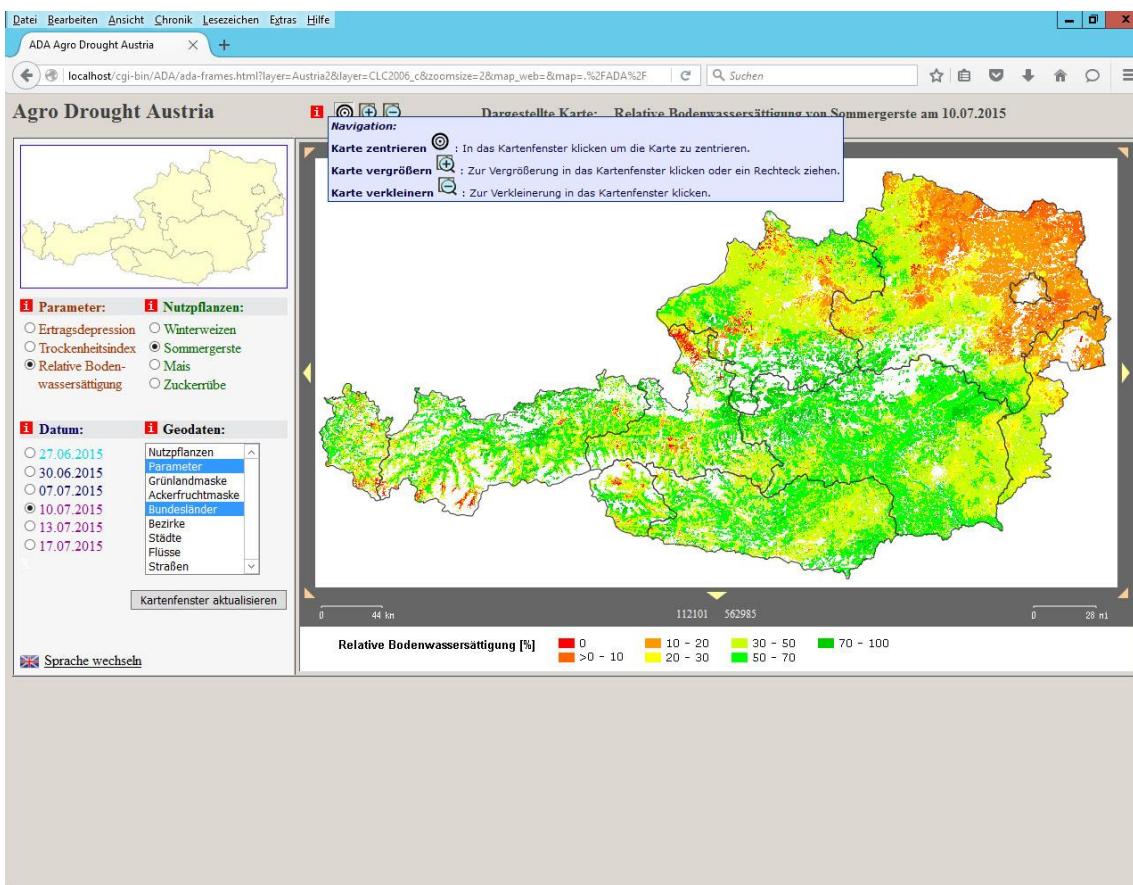


Abbildung 8. Testversion der Webapplikation des nutzpflanzenspezifischen ADA-Trockenheitsmonitoringsystems

Mithilfe einer Fragebogenumfrage wurden für das Jahr 2015 Abschätzungen von ca. 30 Landwirten aus Niederösterreich, Burgenland und Steiermark zu den erlittenen Ertragsdepressionen der jeweiligen Nutzpflanzen an ihrem jeweiligen Standort erhoben und mit dem Ergebnis des ADA Monitoringsystems verglichen. Dabei zeigte sich großteils eine sehr gute Übereinstimmung, allerdings vereinzelt auch größere Abweichungen die meist auf kleinräumige Abweichungen in den Bodenverhältnissen (im Vergleich zur ADA Bodenkarte) zurückgeführt werden konnten. Eine weitere Validierung bzw. Anpassungen in der Funktionalität muss auch während des Testbetriebes bzw. bei einer operationellen Umsetzung betrieben werden. Zum Beispiel, zu einer besseren Berücksichtigung kleinräumiger Besonderheiten (Boden, Grundwasser, usw.), soll eine interaktive Anpassung durch den Nutzer möglich gemacht werden, was im Folgeprojekt berücksichtigt wird.

Wichtigste erreichte Meilensteine:

- Erstes räumlich hochauflösten Trockenheits- und Hitzemonitoringssystem für Nutzpflanzen in der Landwirtschaft Österreichs.
- Überblick über die Situation in der Vergangenheit (seit Inbetriebnahme), der aktuellen Situation und Vorhersage der regionalen Entwicklung von Trockenheit über die nächsten 10 Tage und darüber hinaus.
- Wirksames Entscheidungshilfesystem für die landwirtschaftliche Produktionstechnik (z.B. Bewässerung, Anbauplanung).
- Datenbank zur Sensitivität von Nutzpflanzen gegenüber Trockenheit und Hitze

Empfehlungen und Ausblick aus dem Projekt AgroDroughtAustria:

- Großes Anwendungspotenzial für eine zeitnahe räumliche Übersicht und Vorhersage verschiedenster wetterbasierter Risiken in der Landwirtschaft (Funktionalität laufend erweiterbar für zusätzliche wetterbedingte Anbaurisiken)
- Möglichkeit einer laufenden Verbesserung der Vorhersagegüte durch neue Technologien, wie z.B. Nutzung von Fernerkundungsdaten in hoher räumlicher Auflösung, Berücksichtigung aktueller Landnutzung)
- Möglichkeit einer Berücksichtigung von kombinierten wetterbedingten Einflüssen auf Nutzpflanzen.
- Internationale und interdisziplinäre Kooperation ist Voraussetzung für weitere methodische Verbesserungen, effiziente Ressourcennutzung und robuste Ergebnisse aus dem Modellsystem.
- Eine dauerhafte operationelle Umsetzung erfordert eine permanente wissenschaftliche und technische Betreuung, welche am besten durch institutionelle Kooperationen und Ressourcennutzung (personelle und technische Infrastruktur, Datenbereitstellung, Feedbacknutzung zu Nutzern) sichergestellt werden kann.
- Eine langfristige Ausweitung und Verbesserung zugrundeliegender Eingangsdaten (Wetterdaten, Bodencharakteristika, Nutzpflanzeneigenschaften, Anbaumethoden, usw.) sowie Schadensdatenerhebungen für eine regional geschärzte Kalibrierung können Ergebnisse aus dem Modellsystem weiter verbessern, Unsicherheiten und standortspezifische Abweichungen reduzieren.
- Rückmeldungen von Nutzern zur laufenden Verbesserung der Nutzerfreundlichkeit und Treffsicherheit von Aussagen sind unabdingbar für ein operationelles Monitoringssystem welches Nutzerbedürfnisse erfüllen muss.

C) Projektdetails

6 Methodik

The details of the methods are presented in English due to the scientific level of the content.

WP1: Data base on crop specific drought and heat vulnerability and impacts under Austrian and climate change conditions

The aim of WP1 was to search on information of existing soil moisture monitoring stations in Austria; to check the suitability of the measurement sites for the project purpose; to request the data from data keepers and to merge all the data in one database.

Soil moisture and meteorological data base

For validation of soil moisture model 25 measurement sites were selected. At these sites soil moisture was measured in different soil depths. In order to proof their representativeness for Austrian climates a classification of the available stations was made taking into account the land use and climatic conditions. The stations sea levels vary from 150 to 2010m. From the total of 58 measurement plots, 17 are located on grassland, 36 on arable land and 4 in forest. Taking into account the climatic water balance of regions, one site is situated in the region with negative and 7 with mostly negative water balance. 6 sites are located in regions until 250 mm, 5 until 500 mm, 4 until 1000 mm and 2 until 1500 mm positive water balance.

Data sources

The data were delivered by Institute of Land and Water Management in Petzenkirchen (BAW), Technical University (TU) Vienna, Austrian Agency for Health and Food Safety (AGES) Vienna, Joanneum Research in Graz, L.F.Z. Raumberg - Gumpenstein and Hydrological Services in Styria, Salzburg, Tirol, Vorarlberg, Burgenland and Lower Austria and Institute of Meteorology, BOKU. For each station the data base structure is organised as general station information, land use with crop rotation and yield, soil information with soil type, horizons and soil physical and chemical characteristics as well the soil moisture measured in different depths and weather data.

Data base structure

The data of each site are saved in separate EXCEL files, where the worksheet structure is as follows:

Metadata: General information about the station, soil moisture station and weather station, where one was available in situ.

Crop: information about crop type, crop rotation, begin and end of the crop growth, crop yield.

Soil: Information about soil profile, soil horizon and laboratory analysis of soil parameters.

Water content: Daily soil moisture data of different depths

Weather: Daily weather data: air temperature, air humidity, global radiation, wind velocity, precipitation

Crop data base

The objective of WP1 includes a data base of representative crop yields of the major crops in Austria for the past ten years. Crop and grassland yield data of more than 40 sites were collected including additional weather data from the sites. Grassland yield data of past 12 years were provided from partner LFZRG Gumpenstein from 20 experimental sites.

Crop and yield data were collected from the Chambers of agriculture for several cultivated regions of Austria (Table 3). Analysis was then performed to identify crop yield sensitivity to dry and wet years, pre-crop and cover crop and tillage. Several drought indices have been selected and were tested using this data base in WP2.

Data for the analysis of crop response to climatic stresses comprise yield and management data from farmers' fields and meteorological data for the respective sites. The yield data were obtained from detailed data collections made by the Chamber of Agriculture of Lower Austria within their district level Farmer's Working Groups ("Ackerbau Arbeitskreise"). The data contain all relevant management information and the respective crop yields for individual farmers fields.

Table 3. Farmers' field data base from Chamber of Agriculture Lower Austria. Parameters included in the evaluations with the current project are marked in bold.

Parameter	Unit / Factor levels	Note
Year	2002-2014	Start date: Horn: 2001; Mistelbach and Krems: 2003-2014; Hollabrunn: 2006
Site	Baden, Hollabrunn, Horn, Krems, Mistelbach, Wiener Neustadt	
Pre-crop	Type (Winter cereal, spring cereal, maize, sunflower, rapeseed, legume, sugar beet, others)	
Cover crop	Type (bare soil, legume, brassica, mixture, others)	
Tillage	Type (plough, no plough)	Information collected since 2010 only
Seeding date	Day of year (early, normal, late)	Early=lower quartile; normal=median; late=upper quartile
Yield	t ha ⁻¹ (Crops: Maize, spring barley, winter wheat, sugar beet)	

The total dataset of the four crops evaluated in more detail in this study contained 16.717 entries covering six sites and between nine (Hollabrunn) and 14 (Horn)

years. All yield data were previously checked for plausibility by applying biologically reasonable upper and lower thresholds to exclude outliers from wrong declaration or input errors. For maize the yield data were standardized to 25 % moisture content of grain.

The data do not provide geo-referenced information. Thus the evaluation does not allow an explicit consideration of the influence of soil type on individual yields and provides only information of the average relation between yield and climatic factors for the region under consideration. Still an indirect effect of soil type was obtained by further subdividing the dataset into high and low yielding fields in each individual year using the lower quartile and upper quartile as boundaries for grouping.

WP2: Adaptation, calibration and validation of existing methods to detect drought and drought impacts for arable crops and grassland. Test of models and their implementation

Crop stress indicators

Meteorological information was obtained from local weather stations of ZAMG. From the basic weather data at daily time step, we derived several indices to capture stress periods (Table 4). Some of the indices were obtained by including calculations from other working packages of the ADA project.

Table 4. Meteorological indices used to study crop yield – climate relations.

Indicator	Description
<i>Short term indicators</i>	
Precipitation (P)	Amount (yearly, monthly, critical periods), distribution (in- vs. off-season)
Reference evapotranspiration (ET_0)	Penman Monteith (global radiation, relative humidity, minimum, maximum temperature, wind speed); amount (yearly, monthly, critical periods) and distribution (in- and off-season)
P-to- ET_0	Rainfall deficit
Temperature (T)	Heat days and cumulative temperature above 27°C and 32°C; Heat degree hours (Bristow and Abrecht, 1991)
Combined heat and drought index	Calculated within ADA from heat degree days and soil moisture depletion
<i>Long term indicators</i>	
Palmer Drought Severity Index	Monthly deviation of water supply from 30 year average (Input: precipitation, temperature, soil water storage capacity; Palmer, 1965)
Crop Moisture Index	Weekly deviation of water supply from 30 year average (Input: precipitation, temperature, soil water storage capacity; Palmer, 1968)

Drought and heat indicators were tested according to the following steps:

- Selection of relevant meteorological and crop yield data for the selected crops for representative agricultural regions of Austria,
- Calculation and adoption of drought and heat indicators, and

-Comparison of the impact of drought stress versus the impact of heat stress on crop yields in the region.

Meteorological data were further evaluated to identify the key differences in climatic site conditions. Yield data were analyzed for significant differences in crop yield among sites and years as well as distinct yield stability between single crops constituting the dominant species of the prevailing crop rotations at the investigated sites. Furthermore we analyzed the influence of selected management measures indicated in Table 4 (cover cropping, tillage) on crop yield. Site and year effects on crop yield were determined by a general linear model ANOVA using PROC GLM in SAS. Pairwise comparisons were done using PROC TTEST. For all comparisons we used a Welch test as this procedure allows a robust comparison accounting for inhomogeneous variances which are frequent in datasets not obtained from designed experiments and thus involving mostly unbalanced observations.

A main interest in this WP of ADA was to determine relations among meteorological input parameters (Table 2) and yield data in order to establish the empirical basis for drought and heats stress impact modeling. For this purpose we performed stepwise regressions between yield data and climatic indices using the SAS procedure PROC REG with the MAXR selection method for all available environments constituted by year x site combinations.

WP3: Development of drought-specific forecasting products

Available analysis and forecast data sets for ADA

ZAMG runs their own nowcasting and weather prediction models in an operational mode to provide weather analysis and forecast data up to 3 days ahead to users. In addition ZAMG has access to forecast data from ECMWF which runs global models targeted to provide forecast from medium range up to several months. Below the ZAMG analysis and nowcasting tool and the available NWP models are briefly introduced.

INCA analysis and nowcasting tool

The analysis and nowcasting system INCA (Haiden et al., 2011) algorithmically combines station observations, NWP model output and remote sensing data (radar, satellite) in order to provide meteorological analysis and nowcasting fields at high temporal (5 min) and spatial (1 km) resolution. INCA is used to calculate analyses and forecasts of a variety of parameters.

The INCA analysis and nowcasting system is being developed primarily as a means of providing improved numerical forecast products in the nowcasting range (up to +4 h) and very short range (up to about +12 h) even though it adds value to NWP forecasts up to +48 h through the effects of downscaling and bias correction. INCA algorithmically combines station observations and remote sensing data (radar, satellite) in order to provide meteorological analysis and nowcasting fields at high temporal (5min – 1h, depending on parameter) and spatial (1 km) resolution.

Data

NWP background

For the three-dimensional INCA analyses of temperature, humidity and wind, NWP forecast fields provide the first guess on which corrections based on observations are superimposed. Beginning with 1st of March 2011 a new operational ALADIN configuration named ALARO was set to operations at ZAMG, replacing the old 9.6km version ALADIN-AUSTRIA. The new 4.8km version is coupled to the IFS model and uses the ALARO physics package. However, the INCA analysis and nowcasting methods do not depend critically on the horizontal resolution of the NWP fields and could as well be based on other NWP models.

Surface observations

One crucial data source for the INCA system is the input from surface stations. ZAMG operates a network of approximately 260 automated stations (TAWES) across the country which provides data in high temporal resolution. In addition, a high number of data from other providers such as hydrological services, avalanche warning services etc. are used.

Radar data

The Austrian radar network is operated by the civil aviation administration (Austrocontrol). It consists of five radar stations and ZAMG operationally obtains 2-d radar data synthesized from these five locations, containing column maximum values in 14 intensity categories, at a time resolution of 5 minutes. Ground clutter has already been removed from the data.

Satellite data

The Meteosat 2nd Generation (MSG) satellite products used in INCA are 'Cloud Type' which consists of 17 categories, and the VIS image. Cloud type differentiates between three cloud levels (low, medium, high) as well as different degrees of opaqueness. It also diagnoses whether clouds are more likely convective or stratiform in character. The VIS image is used to downscale the infrared-based (and thus coarser resolution) cloud types during the day.

Elevation data

The 1-km topography used in INCA was obtained through bilinear interpolation from the global 30" elevation dataset provided by the US Geological Survey. The resolution of 30" of the original dataset corresponds to ~930 m in latitudinal, and ~630 m (at 48°N) in longitudinal direction.

INCA and NWP output fields used for ADA

The ADA project partners have been provided with INCA analyses and NWP forecasts for drought specific applications (see Table 5).

Table 5. Summary of the INCA analyses fields, provided to the project partners

Parameter	From year	Forecast (d)	Resolution
Minimum temperature (24 h) [$^{\circ}\text{C d}^{-1}$]	2003	3 bzw. 10	1 km
Maximum temperature (24 h) [$^{\circ}\text{C d}^{-1}$]	2003	3 bzw. 10	1 km
Mean temperature (24 h) [$^{\circ}\text{C d}^{-1}$]	2003	3 bzw. 10	1 km
Daily mean temperature (12 h) [$^{\circ}\text{C d}^{-1}$]	2003	3 bzw. 10	1 km
Global radiation [$\text{MJ m}^{-2} \text{d}^{-1}$]	2003	3 bzw. 10	1 km
Relative Humidity [% d^{-1}]	2003	3 bzw. 10	1 km
Wind [$\text{m s}^{-1} \text{d}^{-1}$]	2003	3 bzw. 10	1 km
Precipitation [mm d^{-1}]	2003	3 bzw. 10	1 km

WP4: Spatial Implementation of drought monitoring on the base of existing GIS with adaptions for Austrian agricultural land

One of the major objectives of work package WP4 within the Agro Drought Austria project is the development of platform independent, well-defined interfaces for the integration of the existing models SpatialGRAM (Schaumberger, 2011) and SOILCLIM (Hlavinka et al., 2009) for crop specific drought monitoring (ADIS). Furthermore new developed and/or adapted methods have to be implemented to monitor and forecast agricultural drought for main crops cultivated in Austria. Using the object-oriented Java programming language, all interfaces, methods and object properties are implemented in various object classes which form the components of the new Java application. For easier operation, a graphical user interface is a further element of the application. The necessary meteorological input data (historical and forecast data) for the test and operational system is supplied by the Austrian Central Institute for Meteorology and Geodynamics (ZAMG) within the framework of WP3 as well as by the Agricultural Research and Education Centre Raumberg-Gumpenstein (AREC) within the framework of WP4. Soil data information has been supplied by the Federal Agency for Water Management (BAW) within the framework of WP1 and 2.

ADIS drought forecast method

Predicting future dry events in a region is essential for finding sustainable solutions to water management and risk assessment of drought occurrences. A drought early warning system with severity and spatial extent in a timely manner provides invaluable information to decision-makers and stakeholders. The drought prediction approach used in ADIS is based on weighted meteorological historical and forecast data for a short-term forecast period of 10 days, on historical meteorological data for medium-term forecast of any number of days and on an averaging process (Figure 9).

The basic approach of the *ADIS* forecast model consists in a repeated calculation of soil water content time series for each historical year and a subsequent arithmetic averaging of the results as shown in Figure 9. The fundamental difference to the swc monitoring option as described before is the differing meteorological input data used in the swc forecast computations.

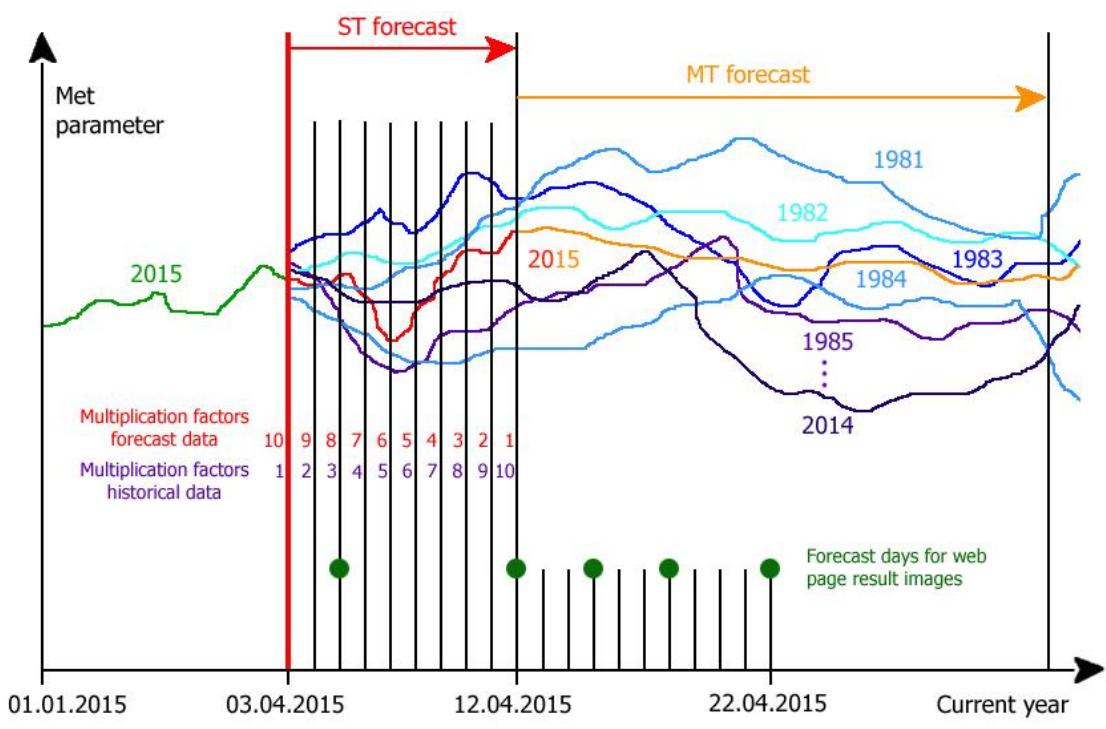


Figure 9. *ADIS* short and medium term combined forecast approach.

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7 Arbeits- und Zeitplan

Tabelle 1. Zeitplan des Projekts AgroDroughtAustria (AP=Arbeitspakete)

AP	Month (0= first month, 36= last month)																	
	0	2	4	6	8	10	12	14	16	18	20	22	24	26	28	30	32	34
1	a					b						c						d
2																		
3																		
4																		
5																		

Projekttreffen:

- a. Kick-Off Treffen
- b. 2. Treffen
- c. 3. Treffen
- d. Letztes Treffen und internationales Symposium

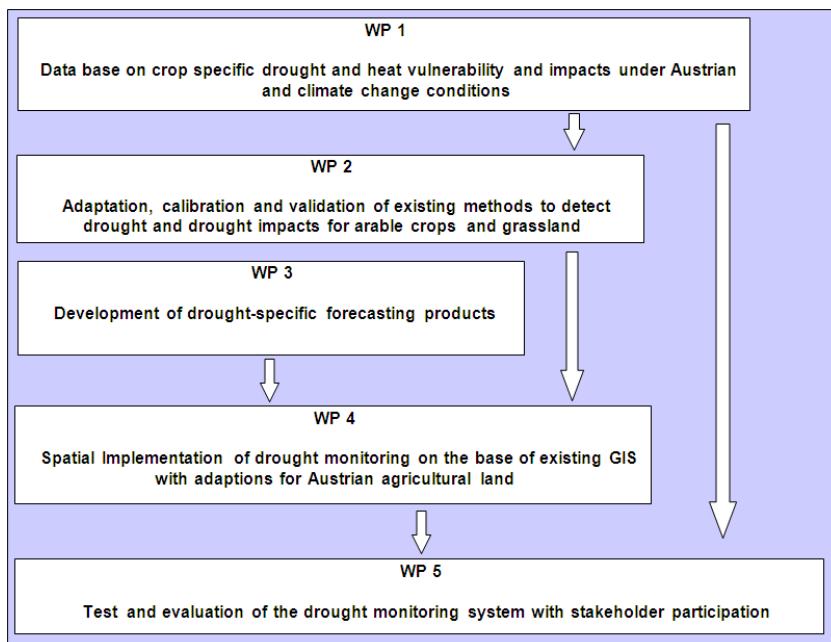


Abbildung 2. Arbeitsablauf von AgroDroughtAustria (WP=Arbeitspaket)

8 Publikationen und Disseminierungsaktivitäten

International publications :

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6 further oral presentations of the partner consortium at the ADA International symposium, Deutsch-Wagram, 4.11.2015:
<https://ada.boku.ac.at/presentations.html>

Web Page:

The AgroDroughtAustria web page (in german) was launched in 2014:
<https://ada.boku.ac.at/>

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