*Final Report*

# Joint project Climate Adaptation: Increasing Climate Resilience in Central Asia - Sustainable Rural Development through the Introduction of Innovative Agricultural Insurance Products (KlimALEZ)

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## Imprint

Final Report: Collaborative Project Climate Adaptation: Increasing Climate Resilience in Central Asia - Sustainable Rural Development through the Introduction of Innovative Agricultural Insurance Products (KlimALEZ)

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Figure Cover: Dr. Ihtiyor Bobojonov launching a drone for remote sensing data collection © Lena Kuhn, 2020.

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| | |
|---|---|
| CHIRPS | Climate Hazards Center InfraRed Precipitation with Station Data |
| CSM | Crop Surface Model |
| DMKNL | German-Mongolian Cooperation Project Sustainable Agriculture |
| EVI | Enhanced Vegetation Index |
| EVT | Extreme Value Theory |
| GCI | Green Chlorophyll Index |
| GCVI | Green Chlorophyll Vegetation Index |
| GEE | Google Earth Engine |
| GLDAS | Global Land Data Assimilation System |
| GSMaP | Global Satellite Mapping of Precipitation |
| HR | Hanover Re |
| HUB | Humboldt University Berlin |
| IAMO | Leibniz Institute for Agricultural Development in Transition Economies |
| LAI | Leaf Area Index |
| NDVI | Normalized Differentiated Vegetation Index |
| PSM | Propensity Score Matchings |
| SCCCI | Simplified Canopy Chlorophyll Content Index |
| UAV | Unmanned Aerial Vehicles |
| UNDP | United Nations Development Programme |

## 1. Brief description

### 1.1. Task

The overall objective of the KlimALEZ project was to increase the resilience of the Central Asian agricultural sector to climate risks through innovations in agricultural insurance markets. Climate change threatens agricultural production and livelihoods of the rural population in the region. Agricultural insurance is an important tool for climate risk management. Payments made in the event of a loss not only secure the livelihood of producers, but also provide incentives for investment in modern and efficient production. Agricultural insurance should be seen as complementary to climate adaptation and other risk management tools, as payouts compensate only part of the losses suffered. While traditional insurance products make payouts dependent on the assessment of agronomists, index-based insurance uses regional crop, weather, or vegetation indices for valuation.

At the start of the project, agricultural insurance markets in the region were still poorly developed. Kazakhstan and Uzbekistan had only conventional, less effective insurance markets at the time the project started. Mongolia had a well-functioning index insurance program for livestock, but not for crop production. In Kyrgyzstan, there were no agricultural insurance markets at all. In cooperation with regional insurance companies and a German reinsurer, the project was therefore designed to develop an index-based agricultural insurance program for various Central Asian countries, implement it in a small pilot project, and measure its impact on socioeconomic development and strategic business decisions.

### 1.2. Procedure of the project

For the planning and preparation of the project, several trips were made to the region even before the start of the project. As the first official activity of the project, a kick-off meeting was held in December 2017 at Humboldt University with the German project partners. After the recruitment of project staff, the first full project workshop with all participating partners, including several Central Asian project partners, took place in April 2018.

The starting point of the project was the comparative analysis of challenges and successes of index-based insurance pilots worldwide. A comprehensive literature review was followed by the creation of a database on existing projects. To complement publicly available data, interviews were conducted with experts and project leaders of different case studies. As a result, we were able to collect information on 110 insurance pilots or programs in 47 countries. This information was used to fine-tune project implementation and better prepare for the widespread application of activities.

The second work package consisted of investigating the suitability of various indices for different regions of Central Asia. Particular attention was paid to the selection of suitable indices to reduce the basis risk, which is the probability that a loss will occur but no compensation will be paid by the insurance company (Elabed et al., 2013). Another challenge was the pricing of the insurance products, taking into account drought risk and economics, since no subsidy was available for the pilot. Additional adoption factors were collected and evaluated through economic decision experiments. This work took place from the spring of 2018; an initial product was fully developed in the summer of 2018. Adjustments and further developments took place in the following years. From summer 2018, concrete work followed on piloting the developed product. In summer 2018 and spring 2019, so-called insurance games were held in Kyrgyzstan and Uzbekistan to test basic interest and innovation determinants. An initial small-scale pilot in Uzbekistan followed in 2019, followed by a larger pilot in Mongolia in 2020. Larger-scale farm data collection on climate risks, climate risk management, demand for agricultural insurance, and climate change perceptions of farmers also took place in Kyrgyzstan, Uzbekistan, and

Mongolia in 2020/2021. Toward the goal of further refining vegetation indices, several collections of high-resolution drone imagery took place in mid-2020 and 2021.

The work of the third work package, exploring the influence of insurance, started with hypothetical experiments in 2019 among Uzbek farmers. Subsequently, with the larger pilot in Mongolia in 2020 and the subsequent farm data collections in 2021, farm data were available for the first time to verify the de facto influence of insurance on farm parameters.

In parallel to the substantive work, extensive dissemination activities took place. This included bilateral meetings with decision-makers such as the Deputy Minister of Agriculture of Uzbekistan or the Board of Directors of the state insurance company Agrosugurta, capacity building activities with insurance company staff and ministries in Mongolia, Uzbekistan and Kazakhstan, major stakeholder workshops, and the presentation of project results at scientific conferences. Another focus was the creation of digital dissemination materials and outputs, including tutorial videos, an Android app, and three desktop applications for policy and business decision makers, as well as recordings of workshops and seminars.

### 1.3. Main results

Overall, the project was successful in driving the development of modern insurance markets in the region. At the time of reporting, Kazakhstan had a successful, state-supported system of index-based agricultural insurance in which the project partner Hannover Re is involved. In Uzbekistan, project efforts resulted in a law introducing index-based agricultural insurance markets. At the time of reporting, IAMO was in contact with various stakeholders regarding the scaling of credit-linked index insurance. In Mongolia, the successful project pilot in 2020 also prompted a revision of the law on index-based agricultural insurance. Currently, IAMO, in cooperation with the "German-Mongolian Cooperation Project on Sustainable Agriculture" (DMKNL), is in contact with decision-makers in order to make the pilot permanent once the administrative processes have been completed.

At the start of the project, the majority of index insurance policies worldwide included weather indices, i.e. precipitation and/or temperature indices based on data from weather stations or satellites, or vegetation indices based on satellite data. The particular improvement of our pilot product was the introduction of so-called *Cropland Masks* to reduce the basis risk. Here, index values are calculated only for the area that is actually planted with crops. Existing indices often form regional averages, which also include built-up areas or other cultivated land and thus significantly cloud the accuracy of the index. Scientifically, the project provided impetus for the selection of different vegetation indices (Eltazarov et al., 2021), artificially increasing the resolution of available satellite data (Eltazarov et al., 2023a), or analyzing the effect of different indices on risk mitigation potential (Eltazarov et al., 2023b). In the area of innovation adoption, our research was the first known study to simultaneously address ex-ante and ex-post evaluation (Moritz et al., 2023c). Furthermore, we made a methodological contribution to the state of the art in research with the further development of so-called *framed field experiments* (Moritz et al., 2023a).

## 2. In-depth presentation

The project consortium consisted of three German project partners, the Leibniz Institute of Agricultural Development in Transition Economies (IAMO), the Humboldt University of Berlin (HUB), and Hannover Re (HR), as well as a larger number of local cooperation partners (see **Error! Reference source not found.**).

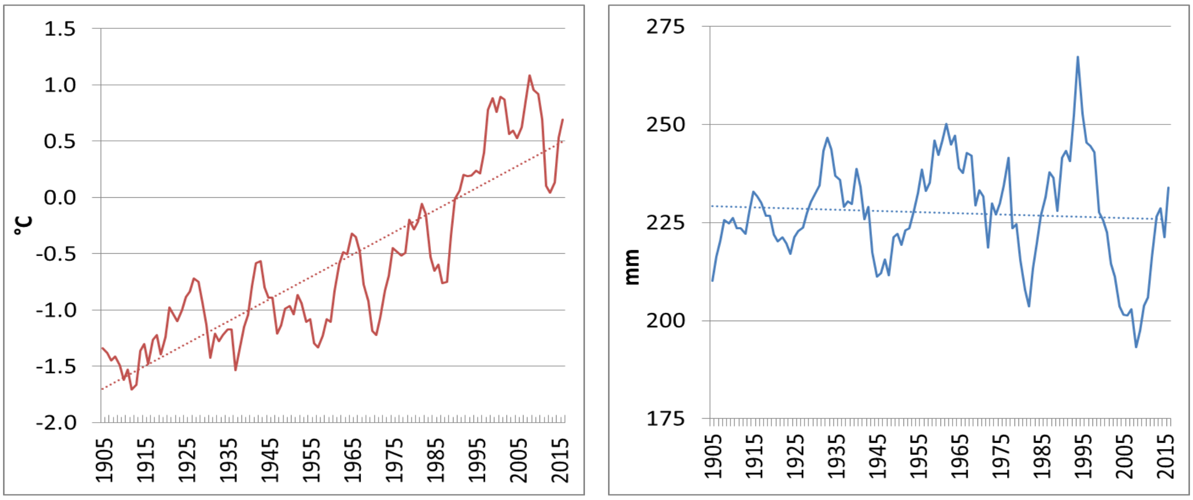

**Figure 1: Overview project consortium**

The overall objective of the KlimALEZ project was to increase the resilience of the Central Asian agricultural sector to climate risks through innovations in agricultural insurance markets. Climate change threatens agricultural production and livelihoods of the rural population in the region. Agricultural insurance is an important tool for climate risk management. Payments made in the event of a loss not only secure the livelihood of producers, but also provide incentives for investment in modern and efficient production. Agricultural insurance should be seen as complementary to climate adaptation and other risk management tools, as payouts compensate only part of the losses suffered. While traditional insurance products make payouts dependent on the assessment of agronomists, index-based insurance uses regional crop, weather, or vegetation indices for valuation.

The project's target countries were selected from the Central Asia region, whose agricultural producers have been increasingly exposed to weather risks over the past two decades. For example, in Mongolia, producers face sharply increasing average temperatures (>2°C since 1905) as well as a decrease in average annual rainfall with increasing annual variability (see Figure 1). Climate change therefore poses a high risk not only to regional food security but also to rural incomes, due to the high dependence on agricultural incomes in many parts of the country.

To achieve this overall goal, the project had set three work objectives: a) to develop an index-based agricultural insurance program, b) to roll out said program in a small pilot in one or more of the target countries, and c) to measure the impact of index insurance on socioeconomic and farm parameters.

In the following, the activities of the partners are shown in detail. First, the three main objectives of the original project application are discussed, followed by the two secondary objectives, the scaling of the smaller pilots and the measures for dissemination of the project results.




a) Temperature (in °C) b) Precipitation (in mm)

**Figure 1: Changes in average temperatures (a) and annual precipitation (b) Mongolia, 1906-2015 (5-year average).**

*Source: Own representation, data from World Bank (2019)*

### 2.1. Development of an index-based agricultural insurance program

All three German project partners were involved in the activities of this main objective. The work built on existing research activities of the project partners, for example in the area of climatic risks to agriculture (Odening et al., 2008), as well as approaches to address the basis risk (Ritter et al., 2014), systemic risk (Xu et al., 2010), and challenges in implementing index insurance (Odening & Shen, 2014). Other existing work addressed the basic feasibility of using remote sensing data (Bobojonov et al., 2014), as well as a study of prevailing political conditions in insurance markets of CIS countries. (Bobojonov & Goetz, 2015).

The distribution of roles in the work planning was as follows: The project coordinator IAMO developed practical index solutions for the target market together with HR, with the project partner HR being responsible for pricing. The project partner HUB provided support, as did the project team at IAMO, through accompanying scientific research. In parallel to the implementation of the pilot project, work was carried out on the methodological foundations in order to apply the results and experience to insurance products and projects in the future.

#### 2.1.1. Analysis of success factors of index insurance pilots

The work began with a detailed analysis of existing insurance pilots. We then compiled a database of all known implementation activities in the area of index-based insurance programs. This data collection was done with an extensive literature and internet search. Specifically, we searched the *Science Direct* and *EconLit* online databases for the keywords "index," "climate," and "insurance" (linked to "AND" in the advanced search). In the second step, the keyword "climate" was replaced with "weather" and "index insurance." To narrow the results, the terms "index insurance," "demand," and "distribution" were added. Additional information on current index insurance projects was researched on the *Global Index Insurance Facility* website. In addition, the literature review was supplemented by bilateral and multilateral exchanges with a variety of stakeholders as part of the activities of the KlimALEZ research project. The systemic literature search was complemented by another literature search based on the bibliography of selected case studies.

In addition, interviews with experts who were involved in the piloting process of the respective insurance product complement the analysis of the case studies. In particular, we tried to contact those responsible for the piloted insurance product who had the most comprehensive insight into the project processes. Two different interview methods were used: the written expert interview with a self-completed questionnaire and the verbal telephone interview via Skype. The expert interview was sent to the interviewees as an online survey. In addition to answering the questions from the questionnaire, the interview partners were able to provide further information about their research activities in the index insurance field.

As a result, we were able to gather information on 110 insurance pilots or programs in 47 countries. This information was used to fine-tune project implementation and better prepare for the widespread application of activities. A key challenge in existing projects proved to be the low level of expertise of the producers to be insured and the resulting low level of trust, including low acceptance of insurance. Other neuralgic points were low chances of success of pilots that relied purely on meteorological stations. Pilots with strong premium subsidies or high premium support from project funds were often not very sustainable, as demand dropped radically after subsidies were removed and premiums increased. Projects with linkages to credit lines, subsidized input prices, or other benefits that served as an additional incentive had a high success rate. Almost all projects reported a high need for dissemination and training among both the target group of farmers and the local stakeholders involved.

This information was used to fine-tune project implementation and better prepare for the widespread application of activities (see Figure 2). The database is available for download by interested parties in the download area of the project page: https://www.klimalez.org/resources/

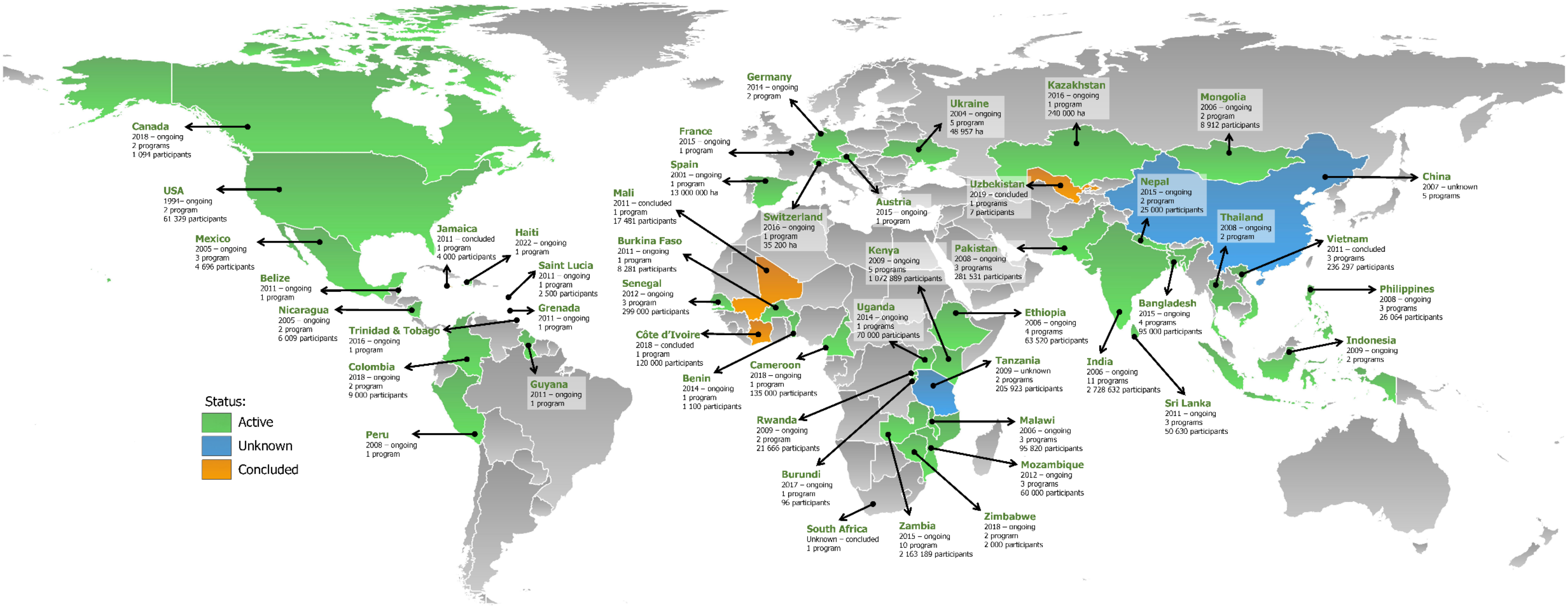



**Figure 2: Database index insurance programs**

*Source: Own representation*

To verify the - so far only qualitative - evaluation of the database, we carried out quantitative analyses of adoption factors within the framework of insurance experiments (so-called *framed field experiments*) as a next step. This special type of study enables the investigation of decision behavior of study groups within the framework of an artificial decision experiment under conditions that are as realistic as possible. This idea gave rise to two studies: one with 144 farmers in Kyrgyzstan and another with 199 farmers in Uzbekistan. The Kyrgyz study explored the influence of the insurance behavior of a peer group (other farmers) on individual demand for three marketable and unsubsidized crop index insurance options. It also examined the personal influence of trust and understanding on insurance demand. Econometric calculations show statistically significant and economically relevant imitation effects, i.e., the individual imitates the group behavior in adopting innovative index insurance (see **Figure 3**). These imitation effects decrease with increasing individual insurance experience and with receipt of an insurance payout as a result of a drought. However, imitation of the comparison group (peers) increases with increasing peer group size, own insurance confidence, and practical insurance understanding. Ceteris paribus, own insurance confidence increases insurance demand, and insurance understanding gains relevance only in the dynamic perspective.

This study highlights the importance of community-based extension services, where farmers can learn from each other, and individual trust for the adoption of innovative agricultural technologies in the initial dissemination phase (Moritz et al., 2023a). A similar study in Uzbekistan underscores the validity of our findings from the first study across national sample boundaries. In a direct comparison of different size- and distance-specific definitions of the comparison group, this study adds that a sense of social acceptance seems to be more dominant for an individual decision than the detailed consideration of the behavior of the comparison group. A critical but more superficial peer mass is required to establish credible innovation strategies. In addition, borrowing, higher insurance confidence, and practical insurance understanding may increase the adoption of index insurance. These findings imply that community-based extension activities in larger groups and credit-linked products can increase the diffusion of innovations and improve rural climate resilience (Moritz et al., 2023c). Both studies have a clear message: economic and social factors are important determinants in the index insurance decision. Their interaction can be expected to overcome the barriers to adoption in practical implementation that have been observed in many places. In concrete terms, this means for future pilot projects that the adoption of innovative risk management solutions can be significantly strengthened by the observability of innovation decisions, for example via social media.

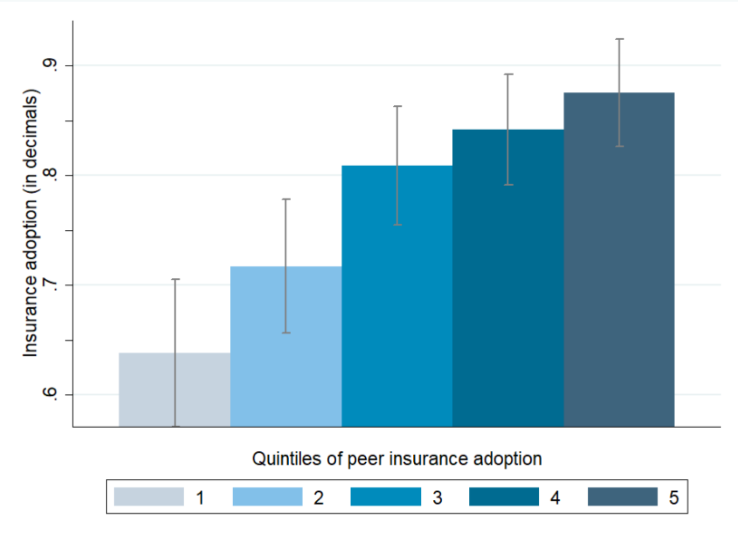



**Figure 3: Individual insurance uptake depending on that of the comparison group**

Source: Own data.

### 2.1.2. Accompanying research on the development of index insurance

The project partner HUB supported the KlimALEZ project with accompanying scientific research. Parallel to the implementation of the pilot project, work was carried out on the methodological foundations in order to apply them in insurance products and projects in the future. In particular, the project partner was able to contribute scientific results on the following topics:

**Consideration of extreme weather events in the modeling of index insurances**

Weather risks from rare but extreme weather events are expected to increase in intensity and frequency in the future due to climate change and thus represent a growing challenge for farmers, insurers and reinsurers, among others. Although they occur only rarely, they often lead to high losses and correspondingly high insurance claims. When modeling weather events, the values that occur most frequently in a distribution are estimated as accurately as possible. However, this is often done to the detriment of correctly representing extreme weather events that are located at the edges of distributions. These values are central to designing index insurance as accurately as possible, and this is where extreme value theory comes in. By applying this methodology, it is possible to model very high historical values as well as much more extreme values that have never occurred historically. Since not only the frequency but also the intensity of extreme weather events is expected to increase due to climate change, it is even more important to model these potential future values. The aforementioned methodology was used to model the distribution edges for two relevant weather indices. First, a *dry-degree-day* index was calculated. Here, dry periods are defined as the sum of all consecutive days without rainfall. On the other hand, a heavy rain index was evaluated. Here, extreme daily rainfall amounts are mapped. These indices were chosen because both weather events (dry periods and heavy rainfall) are expected to become more extreme and frequent in the future, leading to significant crop damage. Also, basis risk is still a major hurdle to accurate index design. Here, the inclusion of spatial and temporal parameters in the extreme value distributions should reduce the basis risk. The results offer added value to both the scientific community and the insurance industry, as the issue of predicting extreme weather events using extreme weather theory in the context of index insurance still represents a research gap. In this respect, this project has made a sound contribution to the further development of index-based insurance.

**Reducing basis risk by more accurately estimating weather and yield data.**

In addition to better availability of weather as well as yield data and more accurate consideration of phenological phases, improving the index design is one way to reduce basis risk. To model this non-linear weather-yield relationship, various methods can be used. For some time, classical regression methods have been used for this purpose. For example, in Vedenov and Barnett (2004), multiple regressions are used, or 'quantile regressions' in Conradt et al. (2015). However, these classical statistical models have weaknesses in modeling non-linear relationships. Machine learning methods with their data-driven and non-linear approach are supposedly better able to model more complex relationships. Neural networks in particular can model complex relationships such as the weather-yield relationship due to their large number of trainable parameters.

This approach was taken up as part of this project. A comprehensive yield data set was available for this purpose, comprising data from 1,000 farms in Germany over a period of 16 years. The goal of this work was to investigate which type of data, which level of aggregation of weather data, and which regional breakdown is beneficial for applying machine learning. To this end, three hypotheses were made: First, the flexibility of machine learning allows it to fit the yield data better than traditional regression models. Second, disaggregated weather data have a higher information content than aggregated weather variables, so better results can be obtained based on them. Third, regional models may lead to better results. To test these hypotheses, a classical regression model was compared with a neural network. The neural network used in the paper is capable of modeling the weather-yield relationship with both daily weather data and monthly averages. Due to the architecture of the network, the neural network can also model non-linear relationships, which can be inferred from the respective datasets (Sharma et al., 2017).

A challenge in this work, besides the technical implementation of the neural network and the training of several hundred different configurations, was the measurement of the basis risk. Following Teh and Woolnough (2019) and Benami et al. (2021), this variation is split into *downside basis risk*, i.e., a situation in which a loss of revenue is realized $(\Delta y_{it} < 0)$ but a positive value is predicted $\left(\widehat{\Delta y_{it}} > 0\right)$, and the *upside basis risk*, where a negative value is predicted $\left(\widehat{\Delta y_{it}} < 0\right)$ but a positive value is observed $(\Delta y_{it} > 0)$. A downside basis risk increases the risk of loss, while an upside basis risk increases the cost of premiums. The occurrence and magnitude of upside and downside basis risk are determined. Complementing the *Root Mean Square Error* and *Normalized Root Mean Square Error,* both categories of basis risk (upside and downside basis risk) are used as additional metrics for comparing models, and the proportions of misclassified observations are evaluated as realizations of the corresponding basis risk. By exploring different ways to use and aggregate weather data, the focus is on production or design risk. These evaluation options allow for both the assessment of the level of basis risk and an analysis of whether the model correctly classifies yield deviations. In combination, both metrics are suitable for assessing the quality of the models.

Another essential point in the implementation and application of neural networks is *hyperparameter tuning*. Hyperparameters can be understood as default settings or configurations of the model. The performance of a neural network depends significantly on these settings. These can be, for example, the step size in the training process (*learning rate*) or the number of observations processed in parallel by the network (*batch size*). In order to ensure a regular and reproducible procedure for the selection of hyperparameters, the so-called *grid search* was used in this study, in which certain configurations are evaluated with each other in a predefined search space. Based on the best *out-of-sample* performance (i.e., accuracy of estimation outside the original sample) on the validation dataset, a configuration was then chosen. A final performance and comparison between models was then undertaken in the test data set. This division of the data sets is also known as *cross-validation.* It is used to avoid overfitting the chosen model to the training dataset. Since neural networks tend to adapt very strongly to the training data, a very high estimation accuracy may be achieved within the sample with which the model was trained, but a significantly poorer performance away from this data set.

The first hypothesis could be confirmed within the scope of the work. The neural network based on daily data outperforms the results of the initial model in all regions of Germany. A neural network with monthly data, on the other hand, leads to a higher *root mean square error* (RMSE) and thus to poorer mapping quality. This also confirms the second hypothesis: With the help of disaggregated weather data, a better performance of the models can be achieved, both compared to the neural network with monthly data and the classical regression model. The third hypothesis can only be partially confirmed. In some regions, the use of regional models leads to an improvement of the results. In other regions, however, there is a significant deterioration of the results. A closer look at the specific regions reveals that the regions in which the results deteriorated have only a small amount of data. It can thus be concluded that data availability is of particular importance when using regionalized models. This is particularly interesting in light of the research question and motivation of this project. Finally, it can be stated that despite an improvement of the results compared to the classical regression model, there are still considerable error rates. Therefore, it is advisable to further specify the application of machine learning methods to the insurance case in further research and to consider it in the network architecture. Detailed results can be found in Schmidt et al. (2022).

### 2.1.3. Improvement of the data base

The data base is limited in many locations in the pilot region, a deficit that has significant implications for the accuracy of crop estimates, as shown above. Acquiring historical meteorological data is therefore a top priority for effective insurance. At the outset of the project, available data from meteorological stations were collected and transferred to a common database. However, initial analysis of the available data revealed that ground-based meteorological stations were too sparsely distributed in the study region to provide data with sufficient precision for insurance design (see **Figure 4**). Much of the grain-growing region was too far away (>20km) from weather stations for crop estimates based purely on ground-based data to be made with acceptable precision. The acceptable distance is even lower for regions with high spatial variability of weather events, for example in mountainous areas.

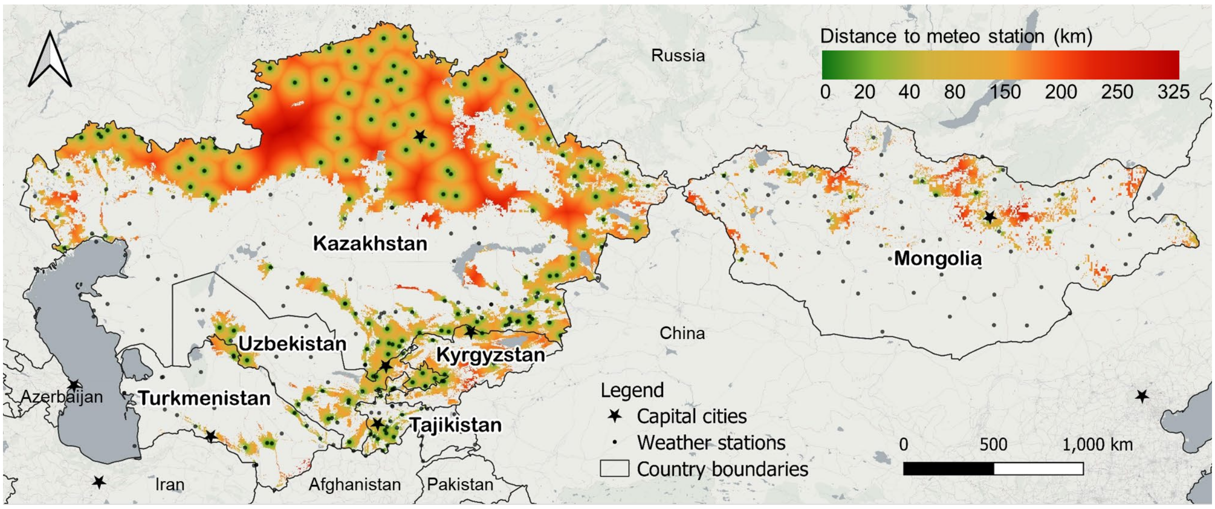



**Figure 4: Geographic distribution of weather stations in grain-growing regions of Central Asia and Mongolia.**

Source: Own representation, based on data from Teluguntla et al. (2015) and NCEI (2019).

In principle, satellites provide data of sufficient geographic and temporal resolution, but they are usually only available as raw data. Processed data, on the other hand, are usually subject to a charge or are only made available with a certain time delay, which in practice would lead to unsustainable, expensive product solutions. Even if data costs are absorbed by project funds in the context of research or development projects, high product costs after project funding has expired are a frequent obstacle to subsequent commercialization and scaling, even in international comparison (see database). As a practical solution to this data problem, the IAMO team developed two desktop applications that are also available to external users:

The freely available SATWEX platform was developed for automated point-by-point daily data collection using the *Google Earth Engine* (GEE) JavaScript API. GEE is an open-source planetary-scale satellite imagery and geospatial dataset analysis platform that aims to increase the quality and time efficiency of spatial analysis for research, commercial, and government users and is free for academic and scientific use. Currently, SATWEX allows for the extraction of daily satellite-based temperature data from the *Global Land Data Assimilation System* (GLDAS) and precipitation data from the *Global Satellite Mapping of Precipitation* (GSMaP) and the *Climate Hazards Center InfraRed Precipitation with Station Data* (CHIRPS). The user selects a time period and desired location by either manually entering the coordinates or clicking on the desired area on the map. SATWEX generates daily GSMaP precipitation data from the original hourly data, daily GLDAS maximum (Tmax) and minimum (Tmin) temperatures from the original three-hourly data, and CHIRPS data originally at the daily scale. For a detailed description of the functions of SATWEX, we refer the reader to Eltazarov et al. (2021).

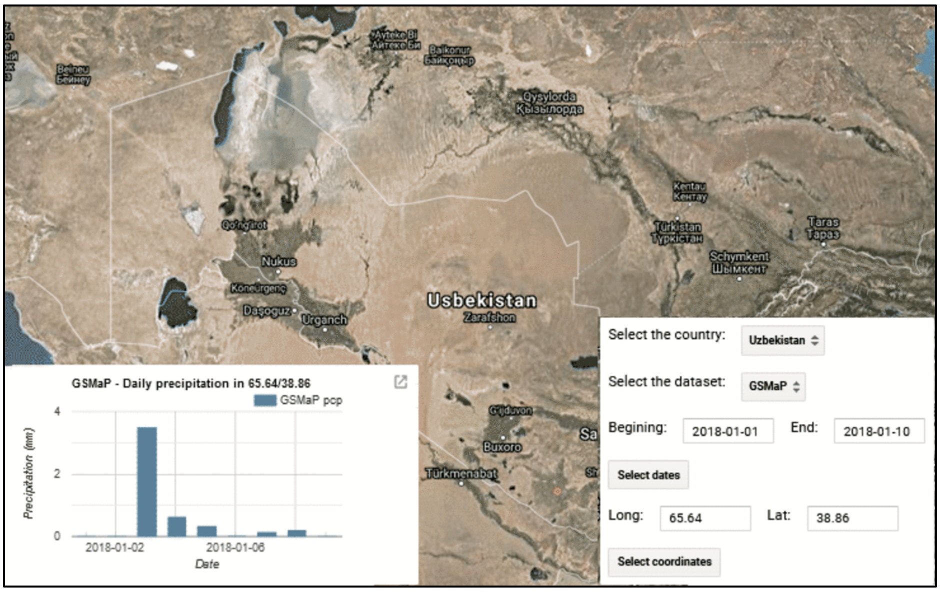



**Figure 6: User Interface SATWEX**

The VEWEX platform allows the selection, processing, and download of county-level satellite data (i.e., in aggregated format, which is much more commonly used for insurance solutions). This platform was also developed for researchers and stakeholders in industry and government to access weather and vegetation data without knowledge of remote sensing data collection and processing. Users select the area of interest for satellite data extraction. In addition to retrieving aggregated data at the level of administrative regions, this feature also provides the option to extract satellite data for cropland only and exclude other land use/cover types in the given county. This feature is a technical innovation that allows for more precise crop estimation and thus indices even in regions with mixed land use.

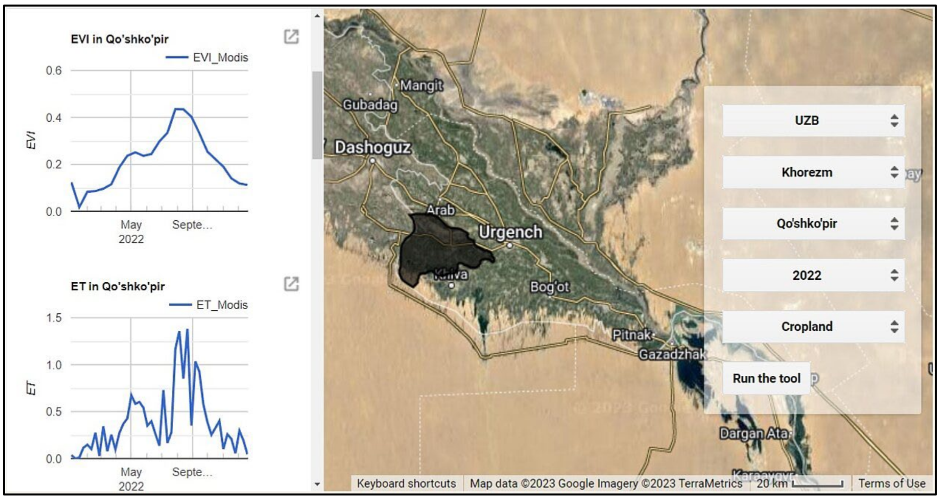



**Figure 7: User Interface VEWEX**

### 2.1.4. Practical development and pricing

Building on the basic and accompanying research mentioned above, the project coordinator IAMO, together with the project partner HR, developed several market-ready index solutions for piloting in the target region.

From February to March 2018, a small preliminary study was conducted in the three project countries by local project partners. The contents of this preliminary study included the demand for and basic willingness to pay for insurance products. However, it quickly became apparent that realistic product examples were necessary for a realistic assessment of demand and its determinants. To conduct the following insurance experiments, HR developed an index product, set the price and provided the necessary product descriptions.

Based on the experience gained during the experiment, a new index product for the pilot regions in Chui Province (Kyrgyzstan) was developed starting at the end of 2018, in a collaboration of IAMO and the local primary insurer *Jubilee Kyrgyzstan Insurance Company,* with the pricing done in collaboration with HR. This was a drought product that insured policyholders against insufficient rainfall throughout the growing season. The growing season in this case was defined as the period from April 1, 2019 to August 31, 2019, and an insufficient amount of precipitation was defined as any amount of precipitation below 70% of the long-term average in the growing season for the region in question. Accordingly, a payout from the insurance product is generated as soon as the 70% of the long-term mean is fallen short of.

In the project year 2019, another product was developed for the Uzbekistan market based on the experience gained here. Once again, this was a drought product that insures policyholders against insufficient rainfall during the growing season. After testing various available indices, HR and the IAMO team jointly agreed on a cumulative precipitation index. This index was also chosen to make the product transparent and understandable to end users, as comprehension issues were known from our database research to be the main implementation barrier. The cumulative precipitation index refers to a critical period in the growing season, which was defined as April 1, 2019 to May 31, 2019. Inadequate precipitation was defined here as any precipitation below 70% of the long-term average during the critical period for the region in question. The growing seasons of these and all other indices were defined on the basis of expert interviews and analysis of long-term operational data in the region. According to the product design, a payout is generated from the insurance product as soon as the rainfall falls below 70% of the long-term mean.

For the generation of the indices, we only used freely accessible weather data such as precipitation values based on remote sensing (CHIRPS; GSMAP) or vegetation indices such as the *Normalized Difference Vegetation Index* (NDVI) as well as aggregated yield data, which were processed by IAMO from freely accessible sources and made available for the development of indices. Furthermore, at the beginning of the project, HR system accesses (cost-neutral for the project) were used via an independent platform of a fee-based provider.

In the third year of the project, the project team developed an index product for Mongolia based on the experience gained previously. While drought-only products have the advantage of transparency and ease of understanding for users, they turned out not to be suitable for minimizing basis risk in the context of our study (see also Sect. 2.1.2). In particular, three papers of the KlimALEZ project, which have already been published in scientific journals, led to a significant improvement of the product:

The first major task was to evaluate different satellite products for yield estimation. Eltazarov et al. (2021) contribute by systematically analyzing the accuracy of some globally available satellite data (GSMPaP, CHIRPS, GLDAS) compared to ground-based weather information for 14 different indicators in the case of Uzbekistan. The analysis showed that these sources can provide the necessary data for an accessible and adequate climate service. However, depending on the source of the satellite data, there is a significant risk of overestimation or underestimation, especially for precipitation data under Central Asian conditions. Among the datasets tested, GSMaP showed relatively better performance than CHIRPS in precipitation estimation for drought and flood detection. Further, the study noted that to reduce estimation errors and thus the suitability of satellite weather products for index insurance, temporal aggregations (e.g., monthly, seasonal) need to be considered. Globally available climate data could serve for the introduction of index insurance products in Central Asia; however, careful selection of source and index is required (Eltazarov et al., 2021).

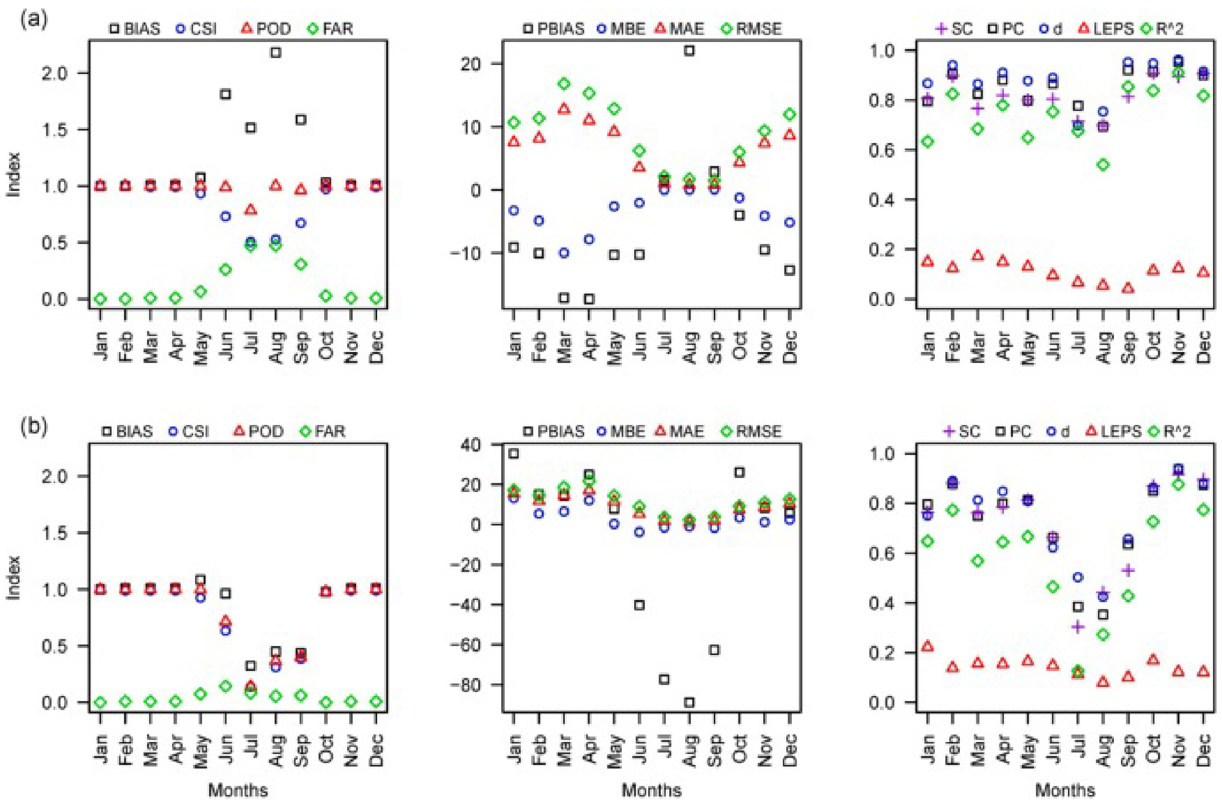


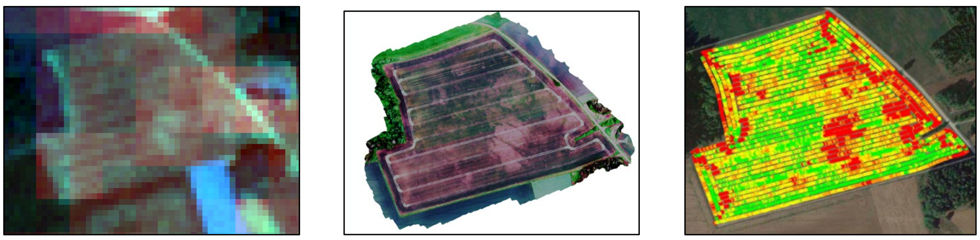

**Figure 5: Average classification, quantification and agreement accuracy of monthly precipitation.**
Comparison of (a) GSMaP and (b) CHIRPS with weather stations.

*Source: Eltazarov et al (2021).*

Another innovation was the introduction of *cropland masks* to reduce basis risk (see also above). In this study, potential accuracy gains from land use classification are analyzed, allowing indices to be developed specifically for cropland and wheatland. The validity of this approach is tested against conventional satellite-based products, including NDVI and land surface temperature (LST), as well as indices not yet widely used in the crop insurance industry, such as the *Enhanced Vegetation Index* (EVI), *Green Chlorophyll Index* (GCI), and *Leaf Area Index* (LAI). The study includes 2060 yield observations from 152 districts in Central Asia and Mongolia with irrigated, mixed, and rainfed wheat cropping systems. The results show that most of these indices are suitable for detecting wheat yield variability in rainfed and mixed crops, although they are not unambiguous in irrigated crops. Classifying land use and developing indices based on cropland and wheat area significantly improves the relationship between the indices and wheat yields in rainfed and mixed crops. In particular, the LAI and GCI outperform other well-known indices. Overall, freely available satellite data could be a good source for introducing index insurance products in Central Asia and Mongolia. Nevertheless, careful evaluation and selection of the index and land use classification is essential (Eltazarov et al., 2023b).

A third practical contribution was the development of ways to subsequently increase the resolution of available satellite data. Open-access climate data are a good potential data source for designing and operating index insurance in regions with limited data. However, index insurance requires climate data with long historical records, global geographic coverage, and at the same time fine spatial resolution, which is almost impossible to meet, especially for open-access data. In Eltazarov et al. (2023a) we computed gridded climate data (precipitation, temperature, and soil moisture) at coarse spatial resolution with globally available long-term historical records to finer spatial resolution using satellite-based data and machine learning algorithms. We then examined the effect of index insurance contracts based on downscaled climate data to hedge spring wheat yields. For this study, we used county-level spring wheat yield data between 1982 and 2018 from a total of 56 counties in Kazakhstan and Mongolia. The results show that in the majority of cases (70%), the hedging effectiveness of index insurance increases when climate data are spatially downscaled using a machine learning approach. These improvements are statistically significant ($p \leq 0.05$). For other climate data, further improvements in hedging effectiveness were observed when the insurance design was based on downscaled temperature and precipitation data. Overall, this study highlights the benefits of downscaling climate data for insurance design and operation (Eltazarov et al., 2023a).

Fourth, the accuracy of vegetation indices was compared with site-specific crop data and drone data: Improving crop yield accuracy during the growing season plays an important role in national food security, land management, and the establishment of early warning systems. Unmanned aerial vehicles (UAVs), with their high-resolution data (**Figure 6**) and their flexibility, are widely used for yield estimation based on physical or spectral information about crops in agriculture and for monitoring crop health in both large and small areas. The aim of Khodjaev et al. (2023b) was to evaluate the effectiveness of wheat yield estimates based on the integration of vegetation indices (VIs) and plant height (CH) traits. VIs are calculated based on multispectral images obtained from UAV-based imagery for the selected study areas. Wheat plant height features were extracted from the UAV-based plant surface model (CSM) for our area. The suitability of different indices such as the NDVI, the NDRE, CIred-edge, the *Simplified Canopy Chlorophyll Content Index* (SCCCI), the *Green Chlorophyll Vegetation Index* (GCVI), and the *Enhanced Vegetation Index* (EVI) based on multispectral UAV imagery were tested. The accuracy of the estimates is analyzed by comparing the estimated yields with the actual yields. Fields in the southern part of Germany were the subject of the study (due to travel restrictions in 2020 and import restrictions, measurements could not be acquired in our actual study region). A highly significant relationship was found between the combination of CHs variables and the NDRE index ($R2=0.72$, adj $R2=0.71$, $RMSE=0.58$ for CHs and for the NDRE index). Linear regression and quantile regression models were used for the analysis. According to our analysis, integration of the NDRE index value and the wheat height parameter resulted in an increase in the accuracy of wheat yield prediction by up to 10-15+ %, compared to the separate use of each index (Khodjaev et al., 2023b).



a) b) c)

**Figure 6: Comparison of the resolution of different data sources**

(a) satellite imagery, (b) drone imagery, (c) site-specific crop coverage (crop cut).

*Source: Own representation*

A final scientific contribution aimed to investigate in perspective the suitability of index-based agricultural insurance for other local crops such as cotton. Precise satellite-based yield estimates are already established for important food crops such as maize and wheat. However, for many crops such as cotton, the accuracy of satellite-based yield estimation has not been scientifically tested, mainly due to the low correlation between biomass and yield. In Khodjaev et al. (2023a) we investigated the suitability of several vegetation indices based on Sentinel-2 imagery for estimating farm-level yields for one such crop, cotton. We estimated several vegetation indices associated with cotton crop phenology for the selected study area and compared them with farm-level panel data (n=232) for 2016-2018, which we had obtained from a statistical agency in Uzbekistan. Overall, we tested the suitability of the NDVI, the *Modified Soil Adjusted Vegetation Index 2* (MSAVI2), the *Red-Edge Chlorophyll Index* (CIred-edge), and the *Normalized Difference Red-Edge Index* (NDRE). Of these indices, the NDRE index showed the highest agreement with actual cotton yield data. These results indicate that accurate yield estimation is possible even for crops with low biomass-yield correlation and support the NDRE index as a powerful metric for determining cotton yields of irrigated cropping systems such as in Uzbekistan (Khodjaev et al., 2023a).

### 2.2. Introduction of the developed products in a pilot project

In 2019, a product developed by Team KlimALEZ was launched on the market in Uzbekistan for the first time. Due to the finding that many projects lose trust with insured farmers by scaling prematurely, a pilot with a very limited scope was initially planned. HR played an important role in cooperating with the local primary insurer. Commercial discussions on contract terms between local primary insurers and HR also took place in advance of the pilot. As described above, the first product was drought insurance based on a rainfall index. What was initially tested were the factual demand, the transparency and comprehensibility of the product for the insured farms, but also the role of IAMO as settlement agent. In this role, IAMO used the satellite data on which the index was based to determine the insured farms' claims experience, while also determining the amount of claims payments. This relationship was contracted with HR support, and IAMO executed its role accordingly. In this initial pilot, we gathered several insights: First, many farmers expressed a desire to insure not only against lack of rainfall, but also against other crop failure triggers, particularly high temperatures and drying winds. This feedback was incorporated into the design of the second index product. Furthermore, it was decided to offer future products with a link to loans to provide further incentives to farmers for this otherwise unsubsidized product. This decision was also taken largely on the basis of the experience gained from the projects listed in the database, but also at the suggestion of our regional cooperation partners, who had been increasingly approached with such inquiries.

In 2021, many years of dissemination activities in Mongolia paid off. After various bilateral discussions, workshop contributions and training sessions for local stakeholders, the Mongolian Ministry of Agriculture decided to make a planned agricultural credit program conditional on agricultural insurance. The product proposal of the KlimALEZ project was selected for this purpose. Mongolian Re served as the local partner. In cooperation with this reinsurer, video materials were developed in Mongolian (see **Error! Reference source not found.**), which provide detailed information on the benefits and function of index insurance. These video materials were aired on several national television channels. The vegetation index described above was used for the pilot. 387 farms with a total of 225,000 acres purchased the innovative index insurance. Regional coverage of farmers with insurance coverage from the pilot is shown as a graphic in **Error! Reference source not found.**. In addition to developing the index and assisting Mongolian Re in the technical planning of the pilot, IAMO also served as the settlement agent.

In this role, IAMO used the satellite data to determine the payouts to be made to insured farmers within the critical assessment period.


**Figure 10: Marketing video of the insurance partners in Mongolia**

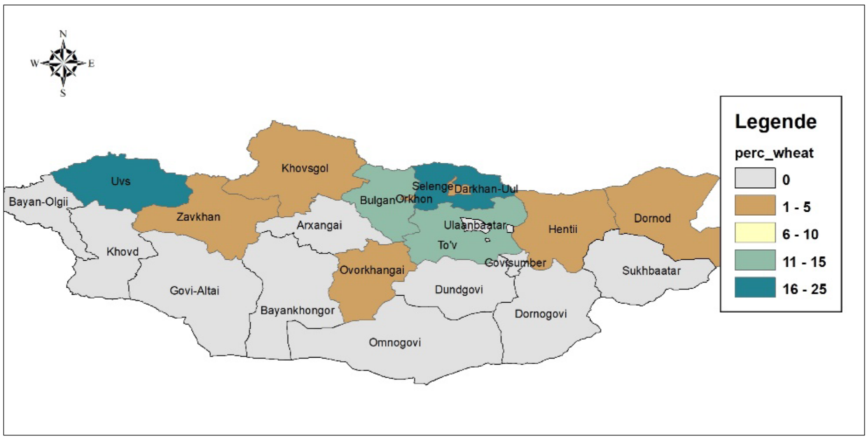



**Figure 11: Coverage of the 2020 pilot, in % of wheat area at provincial level**

### 2.3. Influence of Index Insurance on Socio-economic and Entrepreneurial Indicators

The impact of index insurance on socioeconomic development and strategic business decisions was measured on both a hypothetical basis and in practical implementation.

First, an analysis on the impact of hypothetical insurance purchases on socioeconomic and farm target parameters was conducted with 199 Uzbek farmers in 2019. For this, a marketable and non-subsidized index insurance option was developed by the local insurance company, and its effectiveness for farmers was studied in a *framed field experiment* conducted in parallel with the first real market implementation. These studies were not only of high practical relevance, but also made a valuable scientific contribution with their methodology and findings. While research has already gained good insights into the general effects of agricultural insurance, there is often a lack of a clearer distinction between ex-ante effects (pure effect of the insurance even before the loss occurs) and ex-post effects (after the payout). In order to fully understand the effects and benefits of agricultural insurance, the impact on the different production stages needs to be investigated. Using *framed field experiments,* this study analyzed the impact on welfare in non-irrigated agriculture (risky but profitable fertilizer use, consumption, and net income) as well as its financial resilience (borrowing).

The study results suggest that index-based crop insurance implies ex-ante and ex-post welfare gains and thus significantly strengthens post-drought climate resilience. Pure insurance status and the associated protection for potential drought damage were associated with higher investment in consumption, fertilizer, and savings. Following an insured drought, the insurance payout was able to increase farmers' consumption investments and savings, reduce borrowing, and thus increase net income. These effects are strongest in the period immediately following the drought. However, positive implications are still visible up to three periods later. Thus, an insurance payout has an impact on farm orientation in the short to medium term. On the practical side, our results contribute twofold to the evaluation of the effectiveness of crop index insurance and its positive impact on rural welfare: Firstly, positive effects may arise directly through insurance coverage, and secondly, indirectly through a narrative that stimulates adoption of crop index insurance. In times of climate change, farmers need to choose a risk management portfolio that is appropriate for them, for which index insurance is an important element (Moritz et al., 2023b). It remains clear that a high basis risk reduces the positive effects of insurance and thus the willingness to adopt, an effect that could not be accounted for in our hypothetical study due to the practical limitations of the experimental design. This makes the science-based development of new insurance solutions to reduce basis risk, as conducted in our technical research articles (see Section 2.1), all the more important.

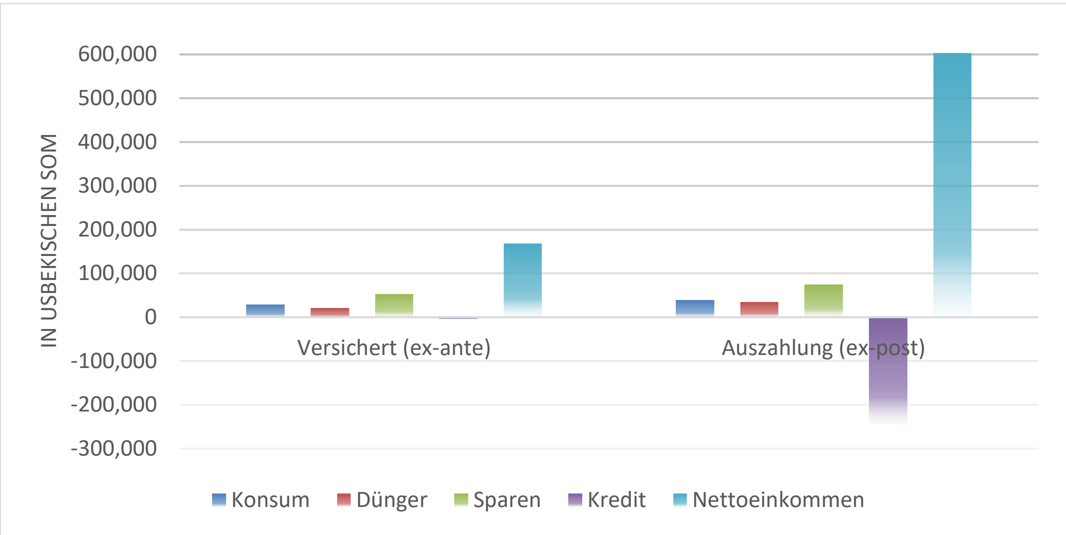



**Figure 7: Average investment decision based on insurance status**

Source: Own data, 2020.

Based on the successful pilot in Mongolia, it was also possible to survey the impact of practical adoption of crop insurance on business decisions in 2020 in the following season (2021). The sample included 94 uninsured farms and 232 of the insured farms. Since randomization of treatment groups was not possible due to the linkage of insurance to a universally available subsidized loan program, econometric methods of *propensity score matching* (PSM) were used instead for causality tests. In the previous studies, no direct effects on productivity or resource use could be measured, which is certainly due to the short-term nature of the program. Therefore, since no second wave of implementation could be carried out due to the COVID-19 crisis, no learning effects could set in (Bobojonov & Kuhn, 2023). An important finding of the preceding, qualitative research was that a learning effect occurs only after several repetitions of rounds. However, an important effect that emerged directly was the use of agricultural land: apparently, access to credit made possible by insurance conditioned an expansion of agricultural production on additional land. This result flanks findings from previous research that illustrated the importance of risk management motives on credit demand (Kuhn & Bobojonov, 2023).

### 2.4. Scaling

In particular, the bonus work packages focused on scaling up practical project results through a) expansion to irrigated agriculture, b) support for national dissemination activities, and c) cross-regional scaling.

As part of the extension of an index-based drought index to irrigated agriculture, the suitability of crop estimation for cotton production was scientifically investigated. One challenge here is that yields depend less on local rainfall and more on the availability of surface or groundwater for artificial irrigation. The only possible approximation, therefore, are vegetation indices, which also correlate closely with crop yields. A classic irrigated crop in the region is cotton, for which the accuracy of satellite-based yield estimation had not been scientifically tested. A key challenge is the low correlation between biomass and yield, which makes it difficult to develop an index product. Scientific works have examined the suitability of several vegetation indices based on Sentinel-2 imagery for estimating farm-level yields for cotton crops. The results of these studies indicate that accurate yield estimation is possible even for crops with low biomass-yield correlation (Khodjaev et al., 2023a). Based on this and other research, indices for irrigated agriculture were developed, which, to reduce moral hazard, particularly the reduction of irrigation by insured farmers, makes insurance payouts dependent on regional averages rather than farm-specific vegetation development.

### 2.5. Dissemination

For the purpose of regional and transregional scaling, the results of the above activities were disseminated to potential stakeholders through various dissemination activities. Classic dissemination formats included bilateral meetings with decision-makers such as the Deputy Minister of Agriculture of Uzbekistan or the Board of Directors of the state insurance company Agrosugurta, capacity building activities with insurance company staff and ministries in Mongolia, Uzbekistan, and Kazakhstan, organizing or participating in larger stakeholder workshops, and presenting the project at the COP24 - UN Climate Change Conference in 2018 (see Figure 8).

Other activities include the publication of reports and a policy brief on the topic (Kuhn et al., 2018). Furthermore, numerous participations in scientific conferences should be highlighted, for example, the annual conferences of the Development Economics Committee - Verein für Socialpolitik in 2023, *the Agricultural and Applied Economics Association* (AAEA) in 2022, the *European Assocation of Agricultural Economists* (EAAE) and *International Association of Agricultural Economists* (IAAE) in 2021, but also regional conferences such as the *Life in Kyrgyzstan* conference in 2020. An overview of selected dissemination activities can be found in the appendix.

Furthermore, the project revealed particular needs for capacity building among local insurance partners. Models for evaluating weather risks often process a large amount of data, such as weather information, yield data, prices, or even soil properties. The problem with this approach is that interdisciplinary discourse and exchange of views can become difficult due to the strong complexity. Often, the black-box nature of the models interferes with integrating the expertise of farmers, consultants, or insurance industry experts, among others, in the analysis and evaluation of insurance as a risk management tool. A particular difficulty is communicating the concept to farmers who either have no experience with agricultural insurance at all or are accustomed to the concept of traditional insurance markets that pay claims based on actual, measured loss.


**Figure 8: Seminars and exchanges with political stakeholders**

(Clockwise from top left: Training Ministry of Agriculture Uzbekistan 2022, Meeting Minister of Agriculture Uzbekistan 2018, IAMO Director Thomas Glauben with Minister of Agriculture Uzbekistan 2020, Stakeholder Seminar Mongolia 2020.)

*Source: Projekt KlimALEZ*

As a consequence of these findings, the project team is working on technical solutions to improve the transparency and acceptance of index-based insurance products. In the first step, the project partner HUR developed a web app for an interactive data presentation and processing form. The novelty is that data can be presented and prepared in a simpler and more transparent way, especially for less knowledgeable individuals. This also makes the app directly applicable as a learning tool for farmers and could reduce farmers' reluctance to adopt new technologies and insurance products in the pilot region. Via the *Smart Small Farmer App*[1] , data located on servers can be structured and linked to own

[1] https://wayne1030.shinyapps.io/SmartSmallFarmerApp/

data by simple means. The desktop application allows the retrieval of weather data for any location worldwide. It is also possible to compile one's own individual weather index and validate this index with one's own individual crop yield data. This app is also suitable for training and illustration purposes.

In the second step, some aspects of this desktop app were taken up and implemented for a simplified Android app for the target group of producers. The multilingual app *FarmPulse* is designed to support farmers in the target region in their daily decisions related to field management as well as risk management measures. The app has three functions: First, users can retrieve field-specific data on vegetation indices and thus draw conclusions for their operational decisions, such as site-specific fertilizer use. Furthermore, historical data on weather and vegetation indices are also available, which creates a higher transparency also in the context of financial risk management tools. At the same level of the app, farmers have the option of direct management of index-based agricultural insurance, from information and contract conclusion to settlement in the event of a claim.

Third, further accompanying scientific research had shown the positive influence of mobile weather information on climate risk perceptions (Emileva et al., 2023). For this reason, a third feature was also included in the app, namely location-based, up-to-date weather information (cf. Figure 9).

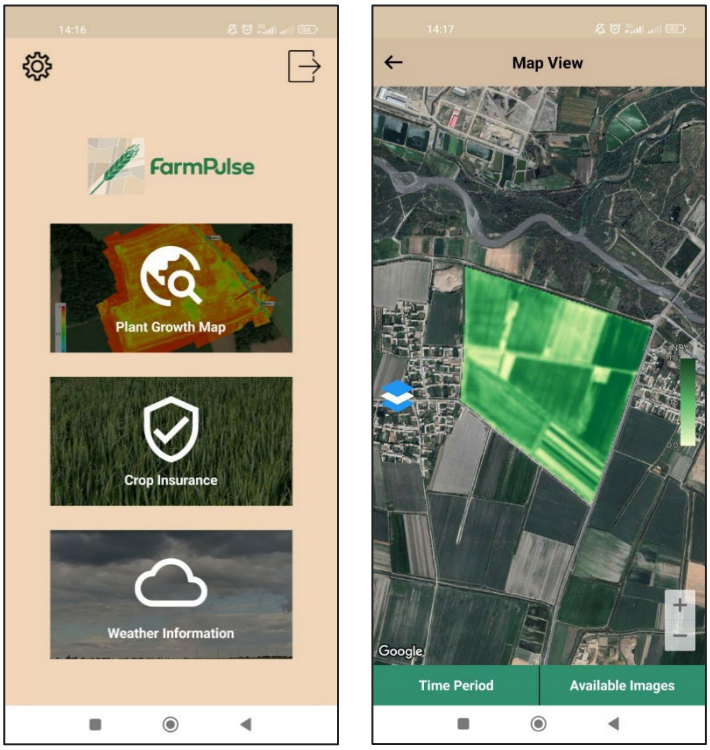



**Figure 9: Retreiving vegetation data in the FarmPulse app**

Furthermore, the desktop platform "KlimALEZ Toolbox" was developed for the dissemination of scientific findings in insurance design. This application allows users to design index-based climate insurance policies and then analyze their climate risk mitigation potential. The app is user-friendly and requires no knowledge of statistics or programming languages. After entering the desired time period, crop yields, and index information, the web app designs index-based climate insurance products based on the data entered. In addition, the app calculates descriptive statistics and carries out a performance analysis (Figure 10).

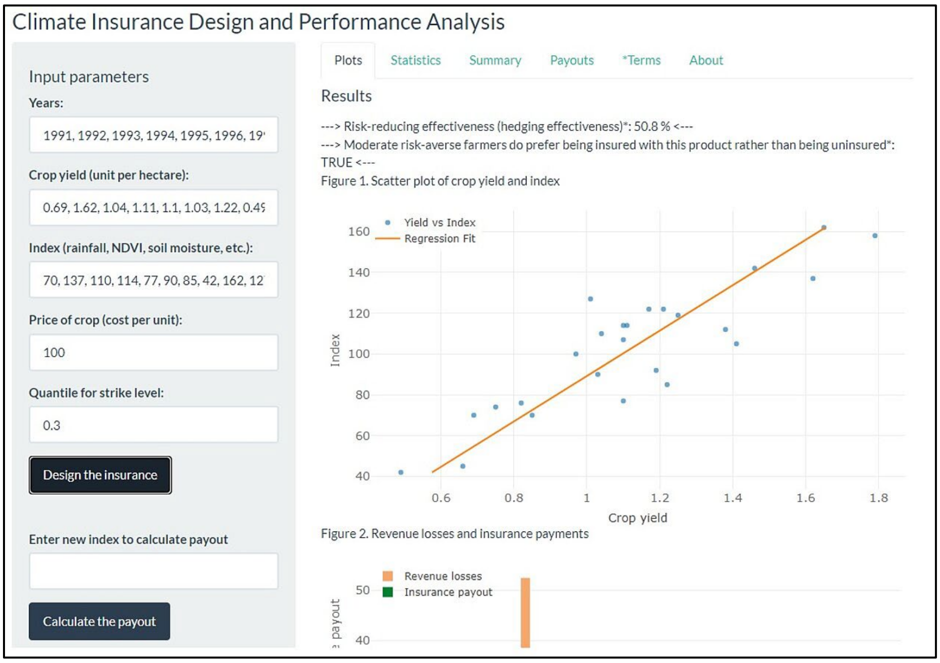



**Figure 10: Desktop application KlimALEZ Toolbox**

*Source: Projekt KlimALEZ*

Another focus was the creation of digital dissemination materials and outputs, including the FarmPulse Android app described above and three desktop applications for policy and business makers (SATWEX, VEWEX, and the KlimALEZToolbox) including associated tutorial videos. These materials are offered collectively on a digital information platform on our project homepage[2] (Figure 12). Furthermore, recordings of workshops and seminars are offered on the Youtube channel of the project[3] (Figure 11). For a detailed description of the data platforms mentioned, please refer to Section 5 (Benefits and Usability of the Results).

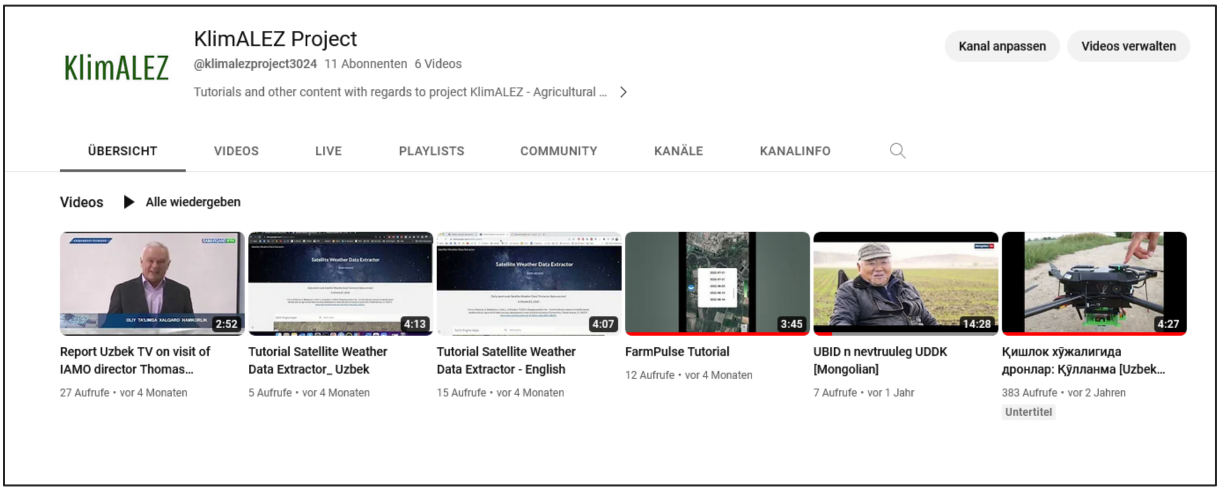



**Figure 11: Youtube chanel of the project**

[2] https://www.klimalez.org/resources/
[3] https://www.youtube.com/@klimalezproject3024

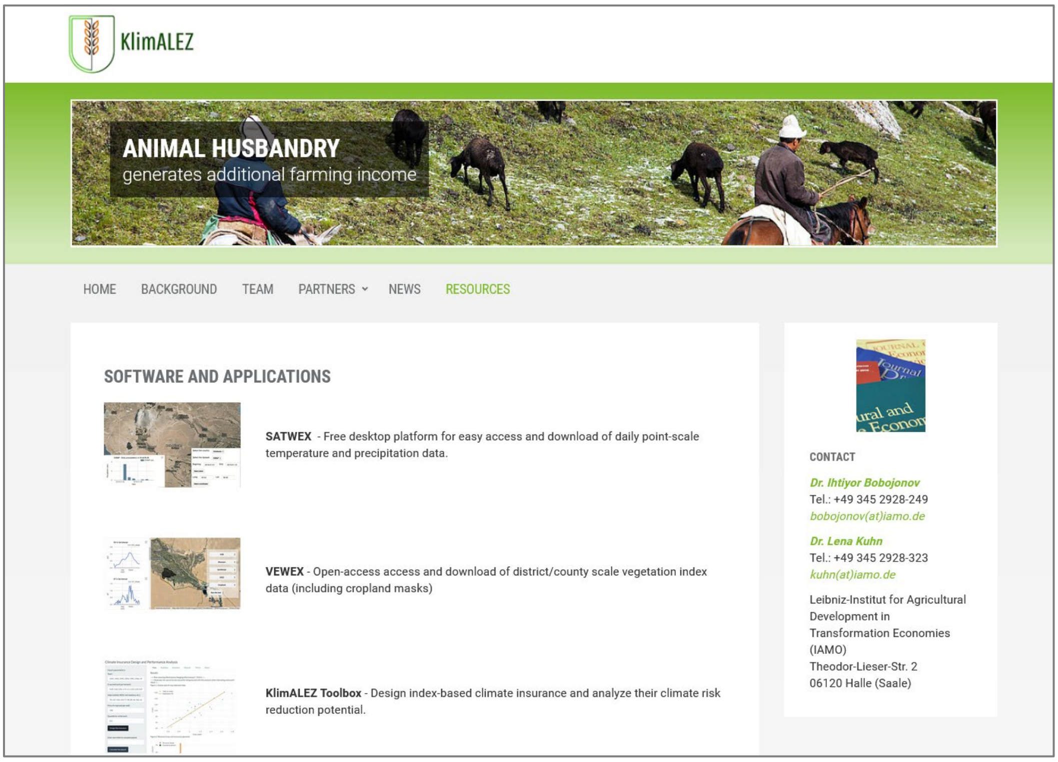



**Figure 12: Digital information platform KlimALEZ homepage**

### 3. Numerical evidence and use of financial resources

The approved funds were used as planned and most of them were consumed. IAMO spent 99.9% of the approved funds, HUB called 100% of the funding. The project partner HR spent only 58.44% of the approved funds, because no administrative costs were used due to external factors and the budget in the item data purchases could be saved by using freely available data as well as data accesses of HR.

A large part of the funds was allocated to scientific staff at IAMO and the HUB, including three junior scientists and two project coordinators (partially financed). At the project partner HR, three positions with different employment levels (details can be found in the HR reports) were budgeted for the project. Further personnel costs were incurred for the financing of scientific assistants at the project partner IAMO. Furthermore, larger sums were spent on the awarding of contracts. The largest cost items here related to the implementation of several surveys in the target countries in 2019-2021 and the programming of the FarmPulse app.

Some travel and dissemination activities in the field were not feasible due to travel restrictions during the COVID-19 crisis. Corresponding shifts and adjustments in activities are also reflected in the use of financial resources. For example, more staff funds were spent than originally planned to advance digital dissemination tools and the expansion of a digital knowledge platform. Correspondingly, fewer funds were used for business trips and the awarding of contracts as well as other administrative expenses/costs.

At the request of the network coordinator, a multiple extension of the original processing period was applied for and approved by the project management organization. The reason for this was in particular the desire to accompany the piloting for a further period as a scientific observer. The goal was a sustainable transfer of the pilot activities to private-sector or state actors. The scientific project team of the HUB was mainly active in an advisory capacity and limited itself to scientific observation, evaluation and the preparation of recommendations for action during the extension period.

## 4. Necessity and adequacy of the work performed

The development and establishment of a regionally adapted insurance offer is intended to contribute to increasing the resilience of agricultural enterprises to climate events, an increase in investments in sustainable agriculture and an increase in the prosperity of small farmers in the region. In this way, the project not only contributes to addressing the challenges of climate change in the agricultural sector, but also strengthens cooperation with emerging and developing countries in research and development for sustainable socio-economic growth.

The need for the work performed arose from the complexity of a project that had to deal with the political circumstances and structures of four different transition economies, technical possibilities of crop estimation, market demands, as well as individual demand factors of producers. In addition, there were challenges of a political nature (e.g. political tensions in Kyrgyzstan), travel restrictions during the COVID crisis, and downstream political and economic realignments in some of the project countries.

For a sustainable paving of the way for the implementation of modern agricultural insurance markets, an inter- and transdisciplinary task planning and very high flexibility in the chosen methods was therefore necessary. In particular, adjustments to the work plan as well as an expansion of the project countries are due to these requirements for flexibility and adaptations to current circumstances. For example, we decided to make adjustments to the transfer concept. These adjustments were conditioned on the one hand by COVID contact and travel constraints, but also on the other hand by the experience that for sustainable scaling, even stronger activities in the area of basic local capacity building are necessary: Thus, a stronger focus than originally planned was placed on digital transfer channels, including mobile application development and digital content. This decision was also made against the backdrop of personnel fluctuation among regional contacts, which made isolated person-based capacity-building measures less sustainable. In this context, tutorials and online resources that can be viewed by a larger group of people at any time were seen as more useful. Another example was the decision to triangulate satellite-based crop estimates with data from ground-based, site-specific crop survey and drone data: Given the importance of building confidence by reducing basis risk, the team decided on this extension of the original work plan. Local harvest data were available, but the accuracy of the chosen indices still needed to be confirmed using data from area-specific harvest data and high-resolution drone imagery.

## 5. Benefits and usability of the results

As shown in the elaborate database and hypothetical as well as practical implementation studies, the demand for insurance and its practical utility for farmers depends on product design, transparency and communication of how the product works, as well as hedging effectiveness, which is largely due to the control of basis risk. Many of our project results are directly applicable to solving the above problems:

### 5.1. Mobile apps and transfer concepts to increase transparency

A key reason for the rejection of index insurance is its complex structure, which is sometimes difficult to understand. This was also evident in the feedback from the second major pilot in Mongolia.

In particular, the *Small Smart Farmer* app and the *FarmPulse* app are suitable for reducing the black-box nature of index insurance. The *Small Smart Farmer* app allows the use of own yield data to calculate four different indices that protect against frost, high temperatures and drought. This increases understanding in terms of how these insurance policies work. Also, the different metrics, such as trends of the farm yield data, help the user understand the structure of an insurance policy step by step. The calculated insurance parameters can also be changed manually afterwards. This allows the effect of individual parameters on the final insurance product to be clearly illustrated. Therefore, the *Small Smart Farmer* app *is* not only suitable as a decision tool for insurers and potential policyholders, but also for training purposes. Step by step, the structure and influence of individual insurance parameters can be presented dynamically and in a practical manner. The *FarmPulse* app, on the other hand, is tailored specifically to farmers in the study region, both in terms of user language and app complexity. Here, farmers can track vegetation development for their own cultivated areas, retrieve historical index values and thus assess the sense of insurance for their individual situation. Furthermore, the complete claims process can be carried out via the app. So far, the project has relied on regional partners to distribute the app. The reason for this is that a minimum level of orientation in map systems is required for the creation of user accounts and, in particular, the creation of the areas for which relevant index values are later retrieved. This practical challenge will be addressed in future versions of the app.

However, these apps are no substitute for direct consulting services. A core problem of previous pilots was that when modern insurance markets are established by one provider, various competitors usually quickly follow into the market, benefiting from the consulting services of the *first mover.* Therefore, in practice, there is little incentive for companies to overinvest in the commons of insured farmers' expertise. To reduce extension spending by farmers, the KlimALEZ project has therefore started to create multilingual information videos, which can also be accessed via the *FarmPulse* app or directly via our homepage or YouTube channel.

Third, as part of the hypothetical impact analysis, the team developed an innovative transfer concept called interactive extension seminars. As was shown in Mongolia, conventional sales activities with little emphasis on capacity building easily lead to farmers' comprehension problems and a reduction in demand in subsequent years. Participants in interactive extension seminars, on the other hand, were able to play insurance games to test the principle and operation of modern insurance products. This also provided an opportunity to enter into a neutral exchange with the researchers and thus open up to the topic of index insurance in a protected setting. The concept and materials are ready developed and have already been applied in the pilot regions of Kyrgyzstan (07/2018) and Uzbekistan (04/2019). If needed, they can be easily transferred to other (local) contexts.


**Figure 13: Interactive consulting seminars**

### 5.2. Innovative methods to reduce the basis risk

Several research findings within the project are applicable to insurance design practice:

Of immediate use for insurance design in the Central Asia region is an examination of the available indices in terms of their accuracy in estimating crop and drought events. As shown in Eltazarov et al. (2021), data from the GSMAP satellite are particularly suitable for assessing drought or flood events in the region. Eltazarov et al. (2023b) in turn investigated the suitability of various weather and vegetation indices for crop estimation in wheat production in the region. Among a variety of studied indices, LAI and GCI showed the highest accuracy. Another contribution of the research is the development of an algorithm for classifying grain growing regions. As described above, the accuracy of crop estimation and thus the basis risk suffers from the use of vegetation indices which are estimated for regions independent of land use type. The work of the researchers is practically immediately usable, since mentioned index data are made available for download on the above described platform VEWEX, including the option of classification into grain growing regions.

Scientific benefits also arise from the accompanying research of the HUB: Climate change and the resulting increase in weather extremes can lead to increased *risk loading* for insurance companies. Extreme weather events can lead to high economic losses, and thus high insurance sums. In the future, these extremes are expected to increase, but the uncertainty in this context remains high. This means that insurance companies could shift this uncertainty to policyholders, at least in part, by making insurance more expensive. To reduce this uncertainty, and thus not increase insurance prices, insurers can apply extreme value theory (EVT). Since EVT focuses only on the edges of distributions, and thus only on the extreme events, this methodology is suitable in this context. By relating EVT parameters to time and space in this work, the geographic basis risk can be reduced and insurance can be offered in locations where there are no, or few, weather stations. The temporal component captures the advancing climate change.

Schmidt et al. (2022) show that the use of neural networks can lead to a better fit to the yield data than traditional regression models, due to their flexibility. Since the most accurate representation of yield data is central to insurance design, the use of this methodology is of particular interest to insurance companies. The use of disaggregated weather data also leads to better yield estimation, due to its higher information content (see **Figure 14**). Thus, daily weather data are preferable to monthly weather data. It is important to note that neural networks only lead to an improvement over the baseline model in regions where enough regional data are available. Under the mentioned conditions, the application of this methodology in insurance design is reasonable.

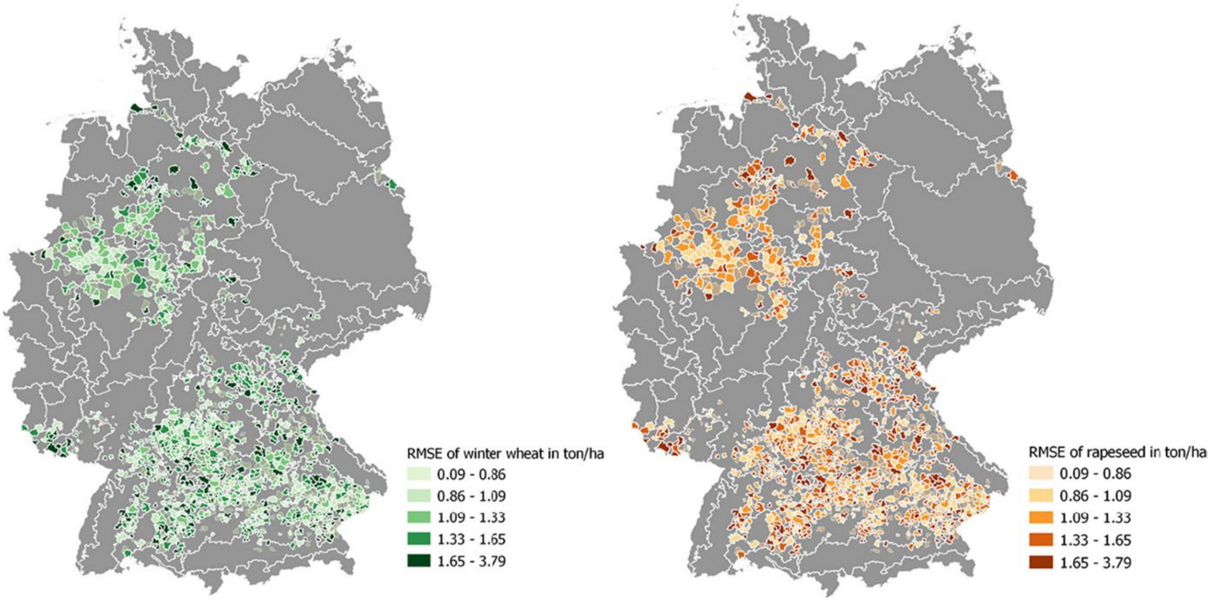



**Figure 14: Accuracy of harvest estimation using ANN at county level.**
Source: Schmidt et al. (2022)

Having the most accurate data possible, preferably at the farm level, is essential for accurate insurance design. Nevertheless, county-level (or even higher levels of aggregation) data are more readily available than operational data and are therefore far more commonly used for product design. When county-level data are used, idiosyncratic risk (i.e., unsystematic risks such as management errors at the farm level) is not factored in. Thus, the overall risk is underestimated and so-called *aggregation bias* occurs, the deviation of the estimated risk from the actual risk due to the aggregation of the underlying estimated data. So-called *relational data matching* models can be used to disaggregate county-level data to the farm level. By using this model, insurance companies reduce the risk of underestimating operational risk. Especially in regions where data is very scarce, especially at the farm level, this methodology can make a significant contribution to insurance design.

### 5.3. Artificial intelligence and desktop applications to improve the data base

A major problem in the design of index insurance, especially in smallholder agriculture, is the still too low resolution of available satellite-based indices. This is especially true for those indices with sufficient time series that must rely on older satellite data, which by their nature are only available at much lower resolution than products of more recent origin. In Eltazarov et al. (2023a) the utility of machine learning to increase the resolution of existing satellite data was explored. Comparison of high-resolution and artificial augmented satellite data and crop data from our research region showed a significant increase in hedging effectiveness by augmentation in 70% of cases. The effects of such augmentations (*downscaling*) are shown in **Figure 15**. Such methods could directly inform the design of new products.

The desktop applications SATWEX and VEWEX, as described above, serve to improve access to already existing data. These applications are aimed directly at insurance companies and reduce both the workload and the cost of obtaining data, which could have a direct impact on reducing insurance premiums. The applications are open and accessible free of charge.

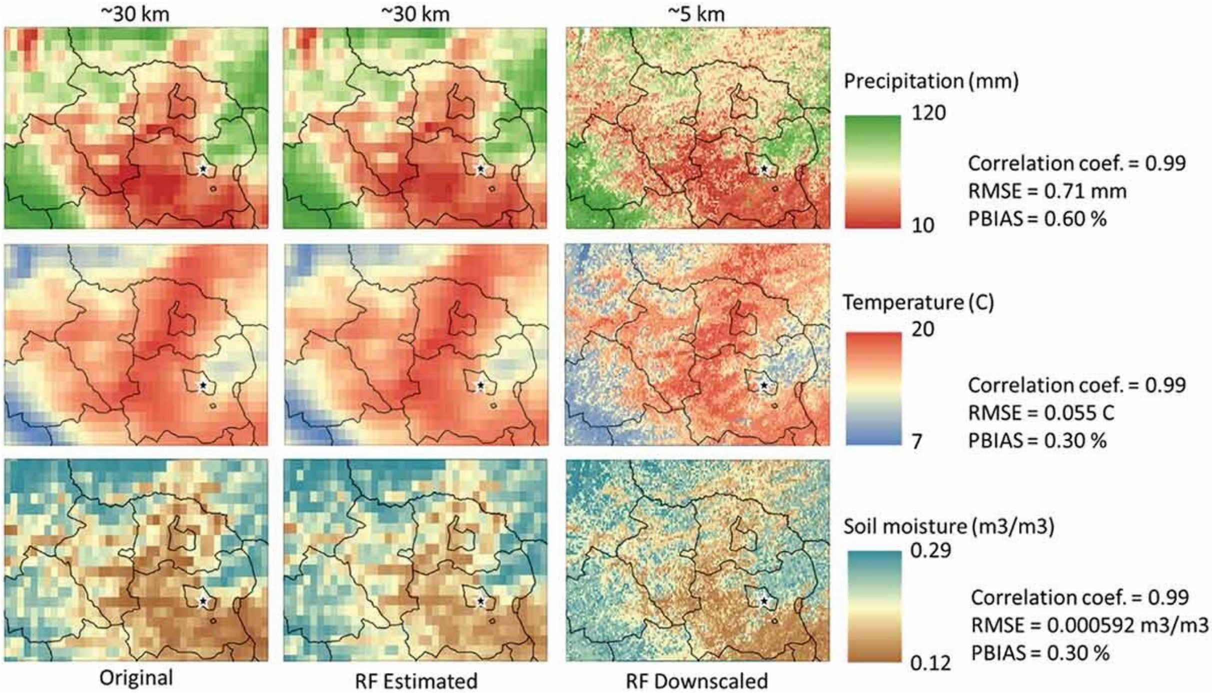



**Figure 15: Downscaling of precipitation, temperature and soil moisture data.**
Source: Eltazarov et al (2023a).

## 6. Progress with other agencies during the project processing period

Currently, we are aware of several index insurance activities in the region that are relevant to the KlimALEZ project. Although these activities are not carried out under this project, some synergies and spillover effects may have been created by the project. For example, Swiss Re and UNDP are implementing a pilot fruit insurance project in the Fergana Valley in Uzbekistan. Although currently based on conventional insurance methods, the project is similar to the KlimALEZ project in terms of participation of local and international insurance companies. Efforts to establish an index insurance market are also underway in Tajikistan, initiated by the World Bank and other international organizations, and KlimALEZ scientists have been asked to advise on several occasions. Similar feasibility studies are also being conducted in Armenia and Georgia, studies in which the project team is indirectly involved. In addition, Azerbaijan has established an operational insurance pool where index insurance can also be purchased. Project staff have also made several presentations in Azerbaijan and met with several government agencies during the project period.

Scientific research progressed at various points during the project: For various reasons, the piloting within the KlimALEZ project relied on individual contracts. Recently, so-called *group collective index insurance* has been increasingly discussed. This group collective index insurance is an alternative to individual index insurance and aims at reducing the basis risk through group-internal informal transfers. Current research (Santos et al., 2021) shows, however, that collective index insurance introduces a coordination dilemma: socially optimal outcomes are achieved when everyone takes out insurance; however, a minimum proportion of contributors is required before the impact of basis risk can be offset and individuals have an incentive to take out insurance. Collective index insurance is, in principle, a potential tool for improving the sustainability of insurance solutions in developing countries. However, the research highlighted above implies that more empirical research and improvements to the concept are needed before practical implementation in our study region seems advisable.

Other methodological contributions sought to get to the bottom of the puzzle of the persistently low demand for index insurance despite the advancing climate change, which we also found in our implementation. Dougherty et al. (2020) estimated a structural learning model around separate learning effects and biased perception of time-shifted effects (*recency bias*). Taking these and other cognitive effects into account, the authors were actually able to demonstrate a reduced demand for agricultural insurance under climate change conditions. This research confirms the importance of tools to objectify climate change by communicating climate data, such as those provided by our mobile and desktop applications.

Further recent research confirmed our perception of the advantageousness of linked insurance products. Ankrah et al. (2021) attested to a low level of knowledge among agricultural producers about agricultural insurance products and therefore also recommend linking agricultural insurance to credit or inputs to increase adoption and demand.

Scientific research within the KlimALEZ project focused intensively on technical innovations to reduce basis risk. These efforts have now been validated by empirical research that confirmed the sensitivity of producers to basis risk: as Janzen et al. (2021) have shown, experimental experience and knowledge about how index insurance works could only slightly reduce producers' demand for index insurance in the presence of basis risk. This research shows that dissemination is important, but continued strong focus should be placed on sustained reduction of basis risk through technical improvements.

Our empirical findings on the effect of index insurance have also been confirmed by research elsewhere: First, recent research provided evidence of ex-ante effects on investments in higher-yielding production (Bulte et al., 2020; Haile et al., 2020). Further, there was evidence of positive pooling effects between certified seed and index insurance (Bulte et al., 2020), which is consistent with the KlimALEZ project's experience with bundled products. Bulte et al. (2020) further found evidence of a complementary effect between index insurance and other diversification measures such as income from non-farm activities. Most recently, Noritomo and Takahashi (2020) have found that payouts from index insurance (i.e., ex-post impact) kept poorer pastoralists in Kenya from falling below the poverty line. Thus, this study was the only research that, similar to the KlimALEZ project (Moritz et al., 2023b), controlled for both ex-ante and ex-post impacts.

Overall, recent progress in practice and research confirmed the results and findings of our project. There remains a great need for further work in the area of index-based agricultural insurance. Future efforts should focus in particular on further dissemination and capacity building, as well as technical reduction of basis risk through even more accurate index products.

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**Appendix : Selected project activities over time**

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| 07.12.2017 | Preparatory meeting of the project partners (Berlin) |
| 28.01.2018 | Meeting with Uzbekistan's Vice Minister of Agriculture and Water Resources at the Green Week in Berlin (IAMO) |
| 23.02.2018 | Meeting of the project partners in Berlin to prepare the kick-off workshop |
| 9.-10.04.2018 | Kick-off Workshop KlimALEZ (Halle) |
| 04/2018 | Preliminary study in Kyrgyzstan and Uzbekistan |
| 07/2018 | Data collection ("Framed Field Experiment") in Kyrgyzstan |
| 22.08.2018 | Defense of the master thesis "Design of Weather Index-based Insurance in Kyrgyzstan". |
| 10/2018 | Presentation of project results at the International Symposium on Water and Land Resources in Central Asia, Almaty, Kazakhstan. |
| 13.12.2018 | Project presentation in the CLIENT II side event at UNFCCC COP 24 in Katowice, Poland |
| 25.01.2019 | Jour Fixe of the specialist area in Berlin: "The Prediction of Climatic Extremes by means of Extreme Value Theory". |
| 04-05/2019 | Baseline data collection (Kyrgyzstan: n=471; Uzbekistan: n=700). |
| 05.-13.04.2019 | Data collection ("Framed Field Experiment") in Uzbekistan |
| 17.06.2019 | KlimALEZ workshop at Tashkent State Economic University; presentation of the web app "Small Smart Farmer"; discussion with experts of the insurance company Gross Insurance |
| 07.01.2019 | Presentation of the project at the UNFCCC COP 24 |
| 24.01.2019 | Presentation of initial project results at the Global Forum for Food and Agriculture 2019 |
| 03/2019 | Piloting index insurance in Uzbekistan |
| 17.06.2019 | Interim Workshop in Uzbekistan |
| 02.08.2019 | Policy consultation results in presidential decree on insurance sector reform |
| 01.11.2019: | Jour Fixe of the specialist area in Berlin: "The estimation of trends in weather Extremes by means of Extreme Value Theory". |
| 01/2020 | Defense Master thesis Christine Köchy |
| 16.01.2020 | United Hail Insurance Experts Meeting, Title: "Improvement of Weather-Based Index Insurance Design through Extreme Value Theory." |
| 16.01.2020 | Meeting with Minister of Agriculture of Uzbekistan, Jamshid Khodjaev |
| 05.03.2020 | Request for cost-neutral extension up to and including November 2021 |
| 19.03.2020 | Online project meeting between HUB and IAMO |
| 03/2020 | Piloting in Mongolia |
| 05/2020 | Project presentation at the lecture series "Virtual Seminars on Applied Economics and Policy Analysis in Central Asia". |
| 12.06.2020: | Jour Fixe of the specialist area in Berlin: "The Estimation of Tail Probabilities in Weather Extremes by Means of Extreme Value Theory " |
| 24.06.2020 | An organized session of the KlimALEZ project at the IAMO Forum 2020 "Digital transformation - towards sustainable food value chains in Eurasia". |
| 11.11.2020 | Defense of the master thesis "Applying Machine Learning to estimate weather-induced yield losses". |

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| 18.12.2020 | Jour Fixe of the specialist area in Berlin: "The Spatial and Temporal Estimation of Tail Probabilities in Weather Extremes by Means of Extreme Value Theory, Part A". |
| 03/2021 | Operational data collection Mongolia (n=542) and Kyrgyzstan (n=1200), Uzbekistan (n=1088). |
| 04.06.2021 | Jour Fixe of the specialist area in Berlin: "The Spatial and Temporal Estimation of Tail Probabilities in Weather Extremes by Means of Extreme Value Theory, Part B" |
| 08/2021 | Presentation of project results at the International Association of Agricultural Economics, New Delhi/online. |
| 18.11.2021 | KlimALEZ Dissemination Workshop (online) |
| 24.05.2022 | Visit of Mongolian delegation at IAMO/MLU |
| 18.-19.10.2022 | Participation in the CASIB Regional Stakeholder Conference |
| 04/2022 | Presentation of project results at the Annual Conference of The Agricultural Economics Society (AES), Leuven / Belgium |
| 07/2022 | Presentation of project results at the annual meeting of the Agricultural & Applied Economics Association (AAEA), Anaheim, USA |
| 09/2022 | Presentation of project results at the annual meeting of the European Association of Agricultural Economics (EAAE), Zagreb, Croatia |
| 10/2022 | Presentation of the project's digital applications at the Geo for Good Summit 2022, California, US. |
| 19.10.2022 | KlimALEZ Dissemination Workshop (hybrid) |
| 06.04.2023 | Submission of the PhD thesis "Index insurance for agriculture: Adoption behavior and its impact in Central Asia" (Laura Moritz) |
| 25.05.2023 | Submission of the PhD thesis "The potential of satellite-based data to detect weather extremes and crop yield variation for hedging agricultural weather risks in Central Asia and Mongolia: Three essays" (Sarvarbek Eltazarov) |