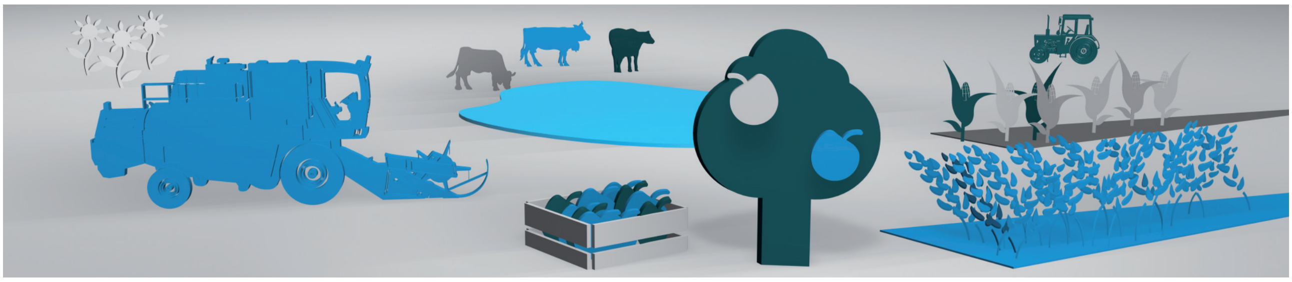
Technical newsletter Avril 2012

Exploring Systemic Weather Risk and the Diversification Possibilities of Agricultural Risks in China

Given the pace of evolution of agricultural production, the rapidly growing demand for agricultural insurance and the weather conditions observed in China, an analysis of systemic weather risk for both insurers and reinsurers active in the agricultural sector seems entirely appropriate.
This paper provides such an analysis, in two parts. The first part gives an overview of agricultural production risk and of recent developments in agricultural insurance in China. The second part consists of an initial investigation into systemic weather risk, conducted over 17 agricultural regions in China. It focuses in particular on the possible spatial diversification of weather risks, and its results reveal a significant spatial diversification effect on a nationwide scale, although at the provincial level the aggregate weather risk remains high.



Agricultural "Production Risk" in China

China has recently become one of the world's largest agricultural producers, with a 19.4% share of global cereal production (FAO, 2010)[1]. For some crop types, China is the top producer – it is the largest producer of rice and wheat and the second largest producer of corn. China is making major efforts to steadily increase its agricultural production, in order to secure its huge food requirements. However, Chinese agricultural production is significantly exposed to pronounced yield risks, particularly caused by weather and climate-related perils. Table 1 shows the main weather risks for key agricultural products in China, along with their geographical distribution.

Table 1: Weather risks affecting major crops

Agricultural Product	Main Producing Area	Main Perils
Paddy rice	Yangtse river basin, north, northeast and southern China	cold spell and heat waves
Wheat	Huang-Huai-Hai plain, Yangtse river basin, Loess plateau, the southwest, the northeast, the northwest, Inner Mongolia, Xinjiang province.	drought, frost and freezing
Corn	The northeast, the northwest, the southwest and Huang-Huai-Hai plain	cold spell, drought and frost
Cotton	Huang-Huai-Hai, Xinjiang, Yangtse river area, Hainan	frost and drought
Rape	South of the Huai river, the northwest, Inner Mongolia, Qinghai/Tibet	freeze and drought
Vegetables	All parts of China	cold spell, frost, freeze and drought
Fruit Trees	North along the Great Wall and in the south	freeze, sprout damage, spring frost, drought, freezing rain

Source: Zheng, 2011[2]

[1] *FAO Statistic Yearbook 2010*
[2] *Zheng, D.-W., 2011.* The Meteorological Risk of China Agriculture. *Presentation at the Guy Carpenter & Company LLC Reinsurance Meeting of 15 September 2011, Hailar, China.*

The statistics for the area of China affected by weather-related perils between 2001 and 2008 are shown in Figure 1a. They show that, of the perils, drought caused the most widespread damage, making up 52% of the total affected area nationwide. Flooding made up around 24% of the total affected area. 13% of the total area was affected by frost, while a similar proportion (11%) was affected by wind and hail. In contrast to above-mentioned perils, flood generally could cause more casualties and property losses than losses for agricultural production.

Figure 1b) shows the fluctuations in both the affected and the actual area damaged by drought over the past 60 years. The frequency of extreme drought events has increased significantly since 1970[3], while flood damage, according to Zheng (2011), peaked in the 1990's. Although the regional climate in China has in general become warmer in the recent past, low temperature disasters have become more severe, while wind and hail has decreased over the past 20 years (Zheng, 2011).

Some fundamental changes in weather phenomena have been observed in China in recent years (Zheng, 2011):

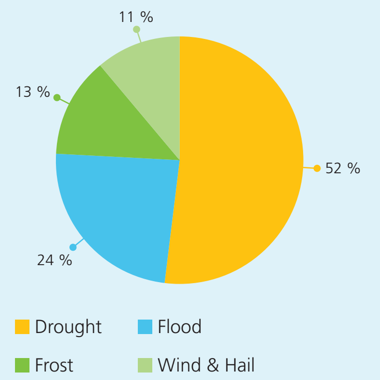
1. The continental monsoon climate has changed significantly between seasons and years.
2. Extreme weather events have been occurring more frequently, especially floods in the south and drought in the north, while seasonal drought in the south has become more severe. More recently, the combination of droughts and high temperatures has caused even more severe damage.
3. The winters are now drier, with lower snowfalls and stronger winds. Damage due to freezing has become less frequent. When it does occur it tends to be more severe, and to cover a larger geographical area.
4. Over the past few years, the areas damaged by flooding have shrunk, benefitting the crop-producing regions of northern China and resulting in an increase in total production yield. In drought years, the agricultural output of the lowlands bordering rivers has increased, but the output of the wider drought-impacted region has decreased, thereby affecting the total crop output negatively.

Additionally, plant diseases and pests are expanding to the north and contamination periods are getting longer and generational overlapping is becoming more serious.

The vulnerability of Chinese agriculture has become more apparent alongside economic growth. Natural resources have become an increasingly sensitive issue, due to ever more intensive utilization since the 1990's. The combination of these factors creates what is commonly referred to as "production risk". For instance, excessive demand for water resources has led to more severe droughts while crops have become more sensitive to local climate changes. Moreover, non-adapted species and intensive farming could make crops even more vulnerable and sensitive to shortages of heat. The combination of factors results in a higher risk.

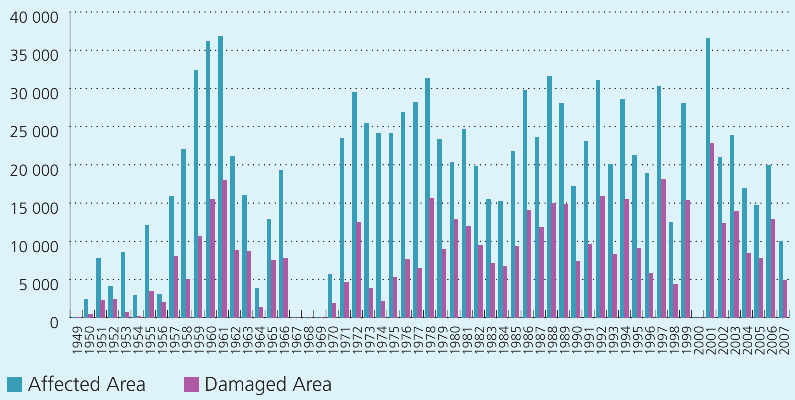
Figure 1: Affected and damaged areas of agricultural production in China

a) Average distribution of weather risks over the affected area between 2001 and 2008



Source: China Meteorological Administration (CMA), 2008[5]

b) Area affected and damaged[4] by drought in China from 1950 to 2007



Source: Chinese Ministry of Agriculture

[3] The increased occurrence of the extreme drought event in the recent past can be regarded as a consequence of the climate change and the long-term influence of human activities, e.g. excessive absorption of the groundwater and dam-building.
[4] Affected area is the area affected by the damage event, but not necessary causes a loss. Damaged area is also the area affected by the damage event, but in contrast to affected area, a certain loss must be able to be measured.
[5] Weather Insurance Pre-feasibility Study, China Meteorological Administration, 2008.
A report for Deutsche Gesellschaft für Technische Zusammenarbeit (GTZ), Beijing, China.

Recent developments in Chinese Agricultural Insurance

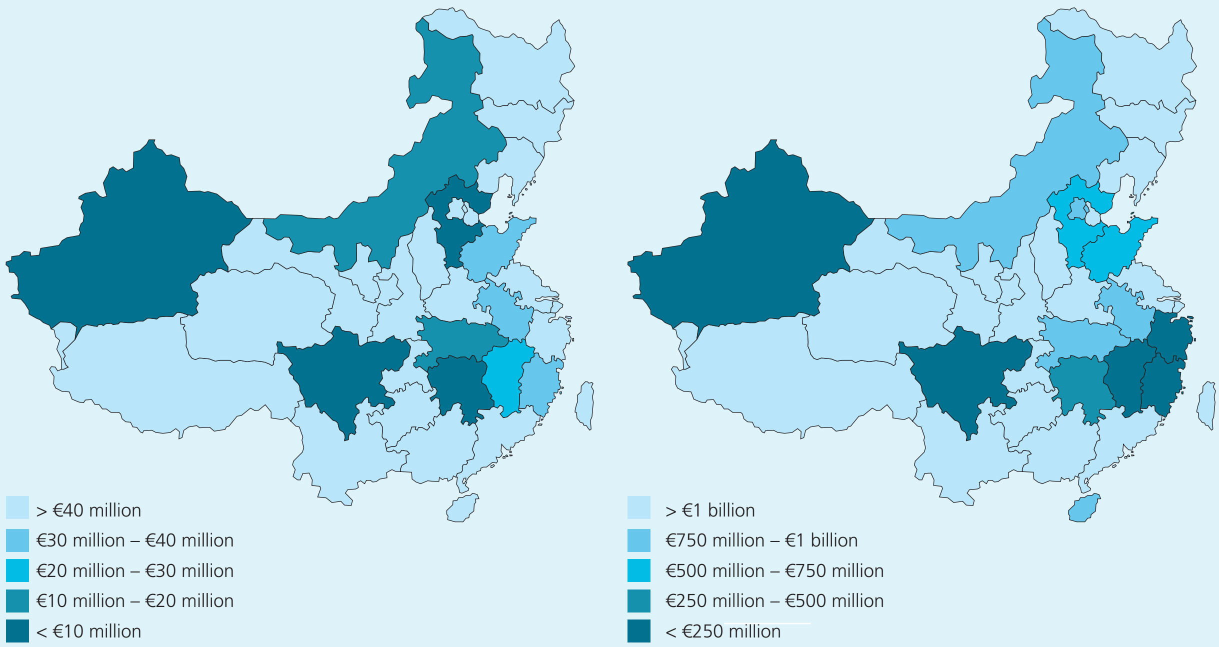
Given the increase in so-called "production risk", the potential value added by agricultural insurance has also increased. Agricultural insurance plays a vital role in terms of stabilizing the agro-food economy, and more precisely in stabilizing farmers' income and stimulating investments in agriculture.
The market for agricultural insurance products took off when the Chinese government began to subsidize insurance premiums in 2007. Governmental subsidies have been growing rapidly: in 2010, subsidies amounted to €678 million, and in 2011 increased by 39% to €940 million. The total volume of agricultural insurance has also increased exponentially: from €80 million in 2007 to €1.36 billion in 2010. According to Aon Benfield China, the Chinese agricultural insurance market is now the second largest in the world after the United States.

Figure 2 illustrates the geographical distribution of premiums and total sums insured per province. Insurance premiums and risks are concentrated in seven provinces: western, northern, middle and eastern China, i.e. where the main traditional crop production regions are located.
Crop insurance makes up the largest share of the Chinese agricultural insurance market (80%). Livestock comes second, representing around 18% of the market, while forestry represents around 2%. The average loss ratio for the entire Chinese agricultural portfolio between 2007 and 2010 was 69%. The market remains concentrated. Although five specialized agricultural insurers and two general P&C insurers operate on the agro risks market, the two largest agro insurers (PICC and China United) still represent 55% of the market.

The combination of huge premium volumes and future development potential is currently generating heavy competition in the Chinese agricultural insurance market. At the same time, increasing insurance penetration and the spread of coverage for crop-producing regions mean that the aggregate risk of possible crop failure due to extreme weather could also be much higher.

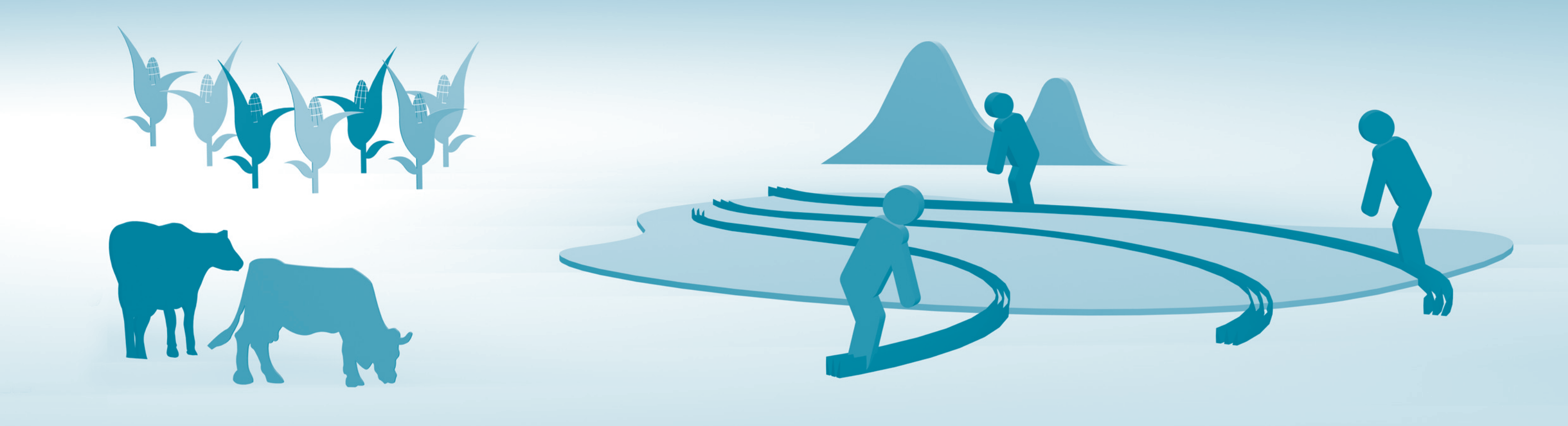
From a risk management point of view, systemic risk becomes an issue when insured areas expand. The spatial development of systemic risk, encompassing the relationship between risk aggregation and spatial diversification effect is relevant for both agricultural insurers and reinsurers in terms of capital, reserves and potential loss payments.

Figure 2: Premiums (left) and total sum insured (right) for crops (including Forestry) by province



Source: The People's Insurance Company of China (PICC), 2011[6]

[6] People's Insurance Company of China (PICC), 2011. China Agricultural Reinsurance Introduction. *Presentation at the Aon Benfield Asia Limited Reinsurance Meeting of 30 August 2011, Beijing, China.*



Definition and studies of Systemic Weather Risk in Agriculture

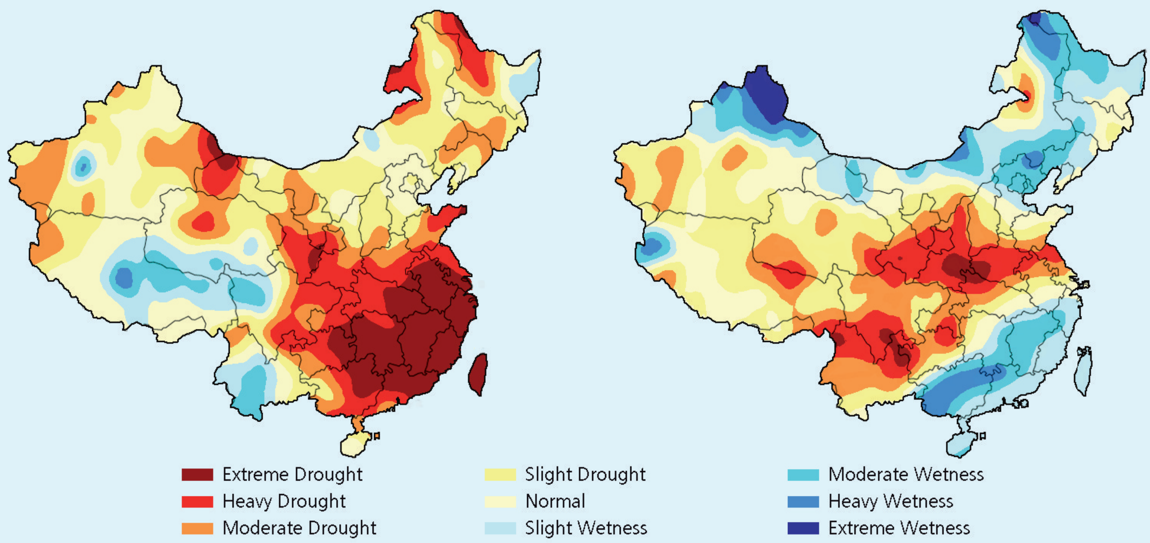
"Systemic risk" is a widely used concept in economics, academic and journalistic financial literature. However, it has a different meaning when applied to agriculture insurance:

In the financial economics literature, systemic risk is defined as the portion of a company's risk associated with the market portfolio (or risk pool). Systemic risk is also known as "undiversifiable risk" or "market risk". Such risk may arise due to the monetary policy of the central bank or to macroeconomic conditions.

In the agricultural insurance literature, the term "systemic risk" (or catastrophic risk) is typically understood as the common portion of underlying risk when losses among insurance units are positively and spatially correlated. In most publications on this topic, the term "systemic weather risk" is commonly applied to extreme weather events. In this article, systemic weather risk denotes the risk of extreme weather events affecting different geographical locations at the same time, thereby causing wide scale damage to agricultural production. Systemic weather risk often leads to major losses that are highly correlated within the affected area, resulting in high aggregate production losses.

For some weather perils such as hail, weather-related losses seem not to be spatially-correlated (at least up to a certain scale of area). However, this assumption does not hold true for other perils, at a regional level at least. Drought and temperature-related risks like frost are examples of perils that could affect a huge area across the country. Examples of this large spatial extent are shown in Figure 3 (left) which illustrates the nationwide distribution of severe-grade drought in China, as measured by the Standard Precipitation Index (SPI) between 23 March and 29 April 2011, while Figure 3 (right) shows the drought situation between 24 December 2009 and 6 February 2010. This system risk is well-known in the literature. Miranda and Glauber (1997) [8] argue that the existence of "systemic weather risk" is the main reason for the failure of private crop insurance markets, unless efficient and affordable instruments for transferring this risk are available. Using spatial statistics, Wang and Zhang (2003) [9] show that yields of wheat, soybeans and corn in the United States are spatially uncorrelated if the distance between fields is larger than 570 miles. They conclude that only a moderate premium loading is necessary to cover systemic yield risk if the risk pool is large enough. Goodwin (2001) [10] reports similar findings, but finds that the correlations between yields fade out more slowly for extreme year than for normal year.

Figure 3: Distribution of drought grade for two periods and area affected in China [7]



Source: National Climate Centre of the China Meteorological Administration (CMA)

[7] *Here the Standard Precipitation Index (SPI) has been used for quantifying the degree of drought. The map on the left shows the period from 23 March 2011 to 29 April 2011 and the map on the right shows the period from 24 December 2009 to 6 February 2010.*

[8] *Miranda, M., and J. Glauber, 1997.* Systemic Risk, Reinsurance and the Failure of Crop Insurance Markets, *American Journal of Agricultural Economics, 79: 206-215.*

[9] *Wang, H., and H., Zhang, 2003.* On the Possibility of a Private Crop Insurance Market: a Spatial Statistics Approach, *Journal of Risk and Insurance, 70: 111-124.*

[10] *Goodwin, B., 2001.* Problems with Market Insurance in Agriculture, American Journal of Agricultural *Economics, 83: 643-649.*

Modelling of Systemic Weather Risk in China

The next part of this article will assess systemic weather risk in China by determining the spatial dependency of weather events in different regions of China and the associated aggregate weather risks. In particular, the effectiveness of risk pooling is investigated when the sample area expands.

The tail behaviour of the joint risk distribution is particularly relevant, because the ruin probability of the aggregate risk is crucial for the insurer and thus for calculation of the premium loading. In the analyses shown, weather variables have been used instead of agricultural yields. This has advantages from a statistical viewpoint, since daily data can be used instead of annual data, resulting in longer time series. Moreover, this approximation is reasonable because the stochastic nature of crop yields is mainly driven by weather events. We focus here on temperature-based weather risks, as recent research asserts that temperature changes cause more crop production uncertainties than changes in precipitation (Lobell and Burke, 2008)[11]. From a statistical perspective, temperature changes are far greater than changes in precipitation when considering standard deviation from the long-term average[12]. With regard to drought, the complex interactions between soil-moisture balance and evaporation are critical for modelling, even though precipitation has a direct and immediate impact on drought damage. This means that temperature dynamics play an essential role in periods of long-term drought and therefore have a key impact on drought damage.

In our analysis of systemic temperature-related risk, we developed and applied the procedure presented in Figure 4.

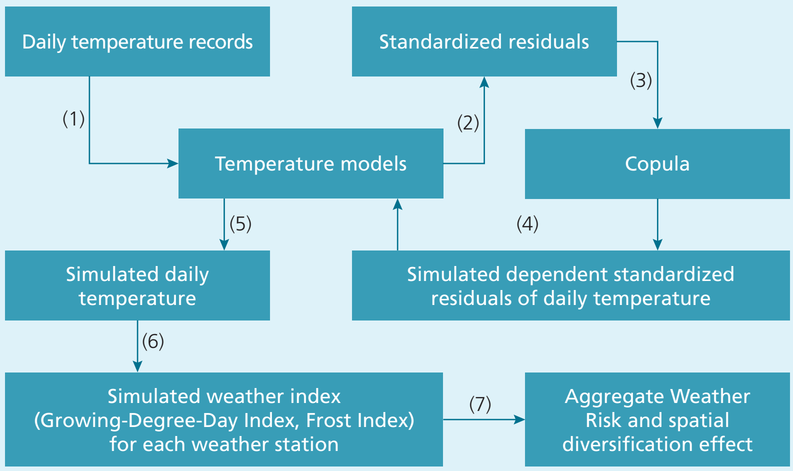
For details on the computational procedure and theoretical background, please see Okhrin, Xu and Odening (2010)[13]. The region analysed covers seven provinces – Neimenggu, Shanxi, Gansu, Shaanxi, Henan, Hubei, and Yunnan – with a total area of 2.67 million km^2, which represents around 28% of China's entire land mass.

The study area is selected on the basis of two criteria:

1. Agricultural production has high economic relevance and
2. Either drought or frost damage is pronounced occurring in this part of the country (The World Bank, 2007[14]).

The study region is divided into 17 homogeneous sub-regions. The differentiation of sub-regions takes into account classifications of ecological zones, temperature zones, and the major farming systems. Each of the homogeneous sub-regions is represented by one centrally-located weather station. The locations of the selected weather stations are depicted in Figure 5[15]. Data for this study was provided by the China Meteorological Data Sharing Service System (http://data.cma.gov.cn/[16]), and is composed of sets of daily average temperature observations covering the period from 1 January 1958 to 31 December 2008.

Figure 4: Flow chart of the computational procedure



Note: "Standardized residuals": See key terms definition p.8.

[11] *Lobell, D. B., and M. B. Burke, 2008.* Why Are Agricultural Impacts of Climate Change so Uncertain? The Importance of Temperature Relative to Precipitation, *Environmental Research Letters, 3: 1-8.*
[12] *Extreme events have already been taken into consideration.*
[13] *Okhrin, O., Xu, W., Odening, M. (2011):* Systemic Weather Risk and Crop Insurance: The Case of China, *Accepted for publication in The Journal of Risk and Insurance.*
[14] *The World Bank, 2007. China: Innovations in Agricultural Insurance – Promoting Access to Agricultural Insurance for Small Farmers.*
[15] *Selected from international weather stations registered with the World Meteorological Organization (WMO), since these stations provide the most reliable data. Weather stations located at high elevations were excluded.*
[16] *China Meteorological Data Sharing Service System, 2009. Daily Weather Data Base: http://data.cma.gov.cn/ (accessed 13 April 2009).*

[Table 2](#) shows the coefficient of the daily temperature for each pair of weather stations. Clearly, significant correlations in temperature exist, even over large distances. In some cases, significant correlations can even be observed over a distance of around 1,000 km (figures marked in blue).

Diversification effect through regional aggregation

To assess the spatial behaviour and the spatial diversification effect of the temperature-related systemic risk, an aggregation scheme is specified and the observed area is expanded step by step until it includes all 17 regions. The result of this aggregation procedure is presented in Table 3, and is also visualized as elliptical circles in Figure 5.

The numbers shown in the Table 3 are the numbers of the region, where the temperature data are collected at a reference weather station (the numbers presented in Figure 5). Table 3 shows the procedure of the regional aggregation. There are seven levels of the regional aggregation. The regions (risk) are aggregated in this way, starting with the region 2 in middle-eastern China, the regions are cumulated step by step, e.g. for the aggregation level 5, the regions 1 to 8 and 15 to 17 are cumulated together considered as an aggregated region which implies an aggregation of the weather risk in different regions. The ellipses in the Figure 5 illustrates the procedure of the regional aggregation which from the lowest aggregation level including region 2 and 3 in the middle-east of China to a countrywide portfolio including all 17 locations for Growing Degree Day Index ("GDD") and 12 locations for Frost Index ("FI") (the three regions 15, 16 and 17 in southern China and two regions 9 and 10 in north-eastern China are excluded, since either no frost occurs or temperatures are typically below zero during the accumulation period).

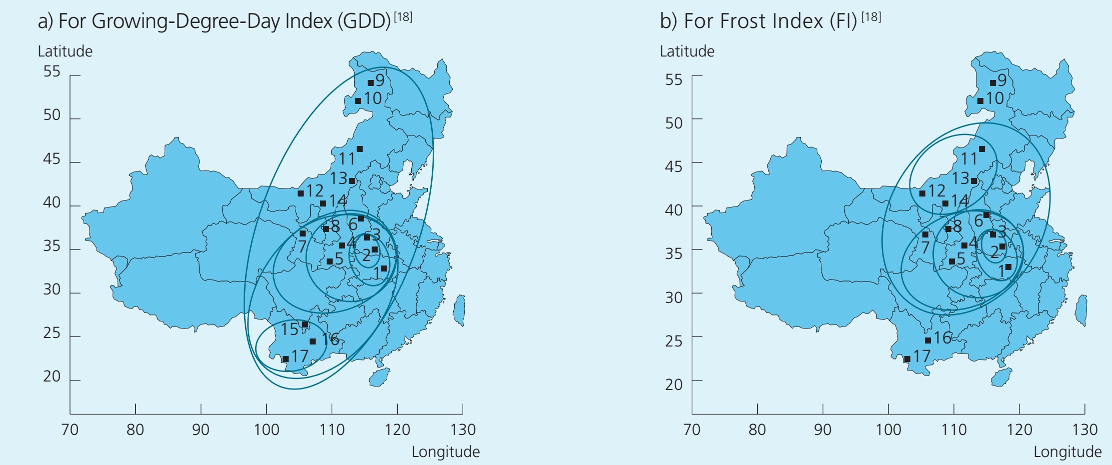
Table 2: Correlation matrix of temperatures at different locations [17]

Weather station	1	2	3	4	5	6	7	8	9	10
4	**0.48**	0.55	0.58	1						
5	**0.38**	**0.28**	0.27	0.57	1					
6	**0.36**	**0.57**	0.66	0.57	0.27	1				
7	**0.29**	**0.22**	**0.19**	**0.31**	0.30	**0.24**	1			
8	**0.42**	**0.45**	**0.42**	0.60	0.44	0.52	0.57	1		
9	0.10	0.16	**0.20**	0.10	0.05	**0.19**	0.10	0.12	1	
10	0.05	0.07	**0.12**	0.04	0.03	**0.13**	**0.12**	0.10	0.71	1
11	0.06	0.09	**0.16**	0.05	0.04	**0.25**	**0.23**	**0.19**	**0.35**	0.53
12	**0.18**	**0.18**	**0.21**	**0.14**	0.09	**0.32**	**0.38**	**0.34**	0.15	**0.21**
13	**0.25**	**0.28**	**0.31**	**0.27**	**0.18**	0.46	**0.38**	**0.41**	0.17	**0.20**
14	**0.20**	**0.23**	**0.24**	**0.17**	**0.12**	0.38	0.46	0.45	0.12	**0.18**
15	**0.13**	0.08	0.08	**0.14**	**0.17**	0.08	**0.13**	**0.14**	0.00	–0.02
16	**0.14**	0.07	0.07	**0.15**	**0.17**	0.10	**0.17**	**0.20**	0.02	0.02
17	–0.01	–0.02	–0.01	0.02	0.01	–0.01	0.03	0.02	–0.02	–0.03

Table 3: Aggregation of investigated regions

Aggregation level	0	1	2	3	4	5	6
Growing Degree Day Index (GDD)	2	2, 3	1-3	1-6, 8	1-8	1-8, 15-17	1-17
Frost Index (FI)	2	2, 3	1-3	1-6, 8	1-8	1-8, 11-14	–

Figure 5: Selected weather stations in china and regional aggregation



[17] This table is an extract of the overall table.
[18] See key terms definition p. 8.

Figure 6 sets out the estimated average temperature-related weather risk per region of both the GDD and FI for different aggregation levels. GDD measures the impact of temperature on the growth and development of crops during a growing season (The World Bank, 2005)[19], while FI indicates the risk of winterkill, i.e. yield losses caused by low temperatures during the winter season (Semenov, 2007)[20]. In order to quantify low probability extreme risk, two scenarios were initially introduced by using two alternative strike levels[21] for each index, namely the 50% and the 15% quantile for the GDD index and the 50% and 85% for the FI. The key element for the GDD index is the part of probability associated with the index value below the strike level, which could damage agricultural production. On the other hand, the key element for the FI is the risk above the strike level, which indicates possible damage. The risk of the extreme weather is estimated at the 5% quantile of the distribution of aggregate damage. Obviously, the average of aggregate risk of temperature per region can be reduced considerably through the aggregation of regions, and is considerably smaller in absolute terms for a strike level of 15% compared to a strike level of 50%. This indicates that the tail of GDD distribution shows a higher dependence than values around the distribution mean. Furthermore,

Figure 6: The Average of aggregate temperature-related weather risk per region for different regional aggregation levels

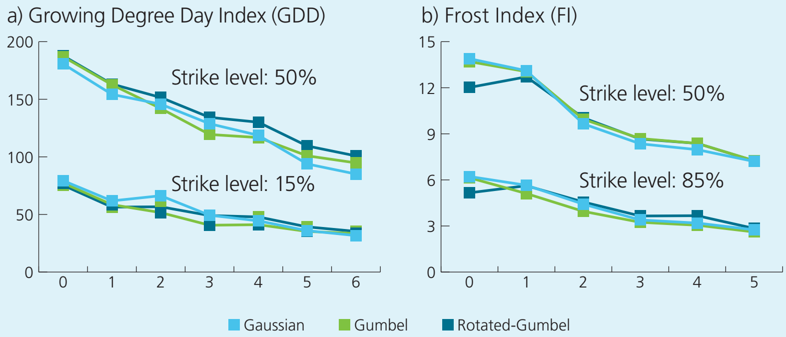


Figure 6a) also reveals that the average of aggregate temperature-related weather risk[22] per region does not continuously decrease with an increasing aggregation level in all cases (e.g. aggregation level 2). This finding can be explained by the heterogeneity of the regions in terms of their local climates.

Table 4 summarizes the diversification effect for the entire area, covering all 17 regions. In the case of normal *i.i.d.*[22] distribution, the average of aggregate risk per region would decrease by a factor of $1/\sqrt{17} = 0.24$. The results presented in the table show a smaller reduction for our calculation than in the case of normal *i.i.d* distribution, which proves that, unlike in the US, a considerable systemic weather risk is present, even for distances far greater than 570 miles. Nevertheless, spatial diversification on a nationwide scale is rather effective in the case of the GDD. The diversification effect of the FI is smaller than that of the GDD, which reveal that the possibility of the regional diversification of temperature-related risk depends also on the crop type and practical production on location.

Table 4: Diversification effects (Entire aggregate area)

Index	Strike Level	Type of Copula		
		Gaussian	Gumbel	Rotated- Gumbel
Growing Degree Day Index (GDD)	50%	0.48	0.54	0.57
	15%	0.43	0.47	0.49
Frost Index (FI)	50%	0.74	0.75	0.78
	85%	0.66	0.65	0.69

[19] *The World Bank, 2005.* Managing agricultural production risk, *The World Bank Report, No. 32727-GLB: http://www.globalagrisk.com/pubs/2005_ESW_Managing_Ag_Risk.pdf (accessed 8 June 2009).*
[20] *Semenov, M., 2007.* Development of High-resolution UKCIP02-based Climate Change Scenarios in the UK, *Agricultural and Forest Meteorology, 144: 127-138.*
[21] *Strike level is defined as a reference value. Once the measured index value is below or above strike level, which depends on the concrete index design, the indemnity will be based on the treaty.*
[22] *See key terms definition p. 8.*

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Conclusions and Outlook

As presented in this study, temperature-related weather risk in China per region has declined by an average of more than 50% as the aggregated area has spread over several provinces. At the same time, systemic weather risk still remains high within a considerable area covering several provinces. The risk dependence of the temperature-related index at different locations becomes smaller if the strike level is reduced. Overall, the findings in this study should be interpreted with care: certain deviations from the results are expected in practice, since certain factors other than weather have not been taken into account - these include differences in soil quality, irrigation systems and the biological resistance of seeds to certain types of natural damage, which may lead to differences in yields even where weather conditions are similar.

This analysis constitutes a first step for a detailed and comprehensive assessment of the features of systemic weather risk in China. More research is still needed with regard to the modelling of aggregate weather damage and cat risk, both for business practice and in general terms. This is becoming increasingly important for risk management in the insurance and reinsurance industries.

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A considerable part of the information in this article, including tables and figures for which no source is mentioned, is based on the author's own publication: Okhrin, O., Xu, W., Odening, M. (2011): Systemic Weather Risk and Crop Insurance: The Case of China. Journal of Risk and Insurance (accepted for publication).

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Key terms definition

Residual

In the time series analysis, the residual of a stochastic model is an observable estimate of the unobservable statistical error which should commonly be standard normal distributed and should follow i.i.d. rule (please see the definition below).

Standardized residuals

The standardized residual is the residual divided by the standard deviation of the residual; this is a residual standardized to have standard deviation of one.

Growing-Degree-Day Index (GDD)

The "Growing Degree Day" index (GDD) measures the impact of temperature on the growth and the development of crops during a growing season; The functional expression is

$$GDD_{i,t} = \sum_{j=\tau_M}^{\tau_0} \max(0, T_{i,t,j} - \hat{T})$$

Herein $T_{i,t,j}$ denotes the daily average temperature in degree Celsius recorded at the location i, in year t and day j. τ_M and τ_0 stand for the first (March 1) and the last (October 31) day of the growing season in year t, respectively. The base temperature $\hat{T}$ is the minimum temperature that has to be exceeded before plant growth is stimulated. Though this threshold is plant specific, we assume a constant value of 5°C.

Frost Index (FI)

FI measures the risk of winterkill, i.e. yield losses caused by low temperatures during the winter season. The FI is defined as the total number of days when minimum temperature is below 0°C during winter; The functional expression is

$$FI_{i,t} = \sum_{j=\tau_N}^{\tau_A} I\{T_{i,t,j} < 0\}$$

where $T_{i,t,j}$ is the daily average temperature in degrees Celsius in location i, in year t and day j. τ_N and τ_A denote the first (November 1) and the last (March 31) day of the winter season in year t, respectively.

i.i.d.

The identical and independent distributed, which is often applied in the statistic and econometric-related articles. In the time series analysis, the residual of the data should be i.i.d. in order to prove the chosen filter (ARMA & GARCH model) is adequate for data.

Aggregate temperature-related weather risk

The aggregation of the risk (e.g. damages or the aggregate probability of the damage), which is caused by temperature-related weather event and the damages distributed in the different locations occur simultaneous which can be measured if the trigger of the local temperature index takes place.

SCOR Global P&C
5, avenue Kléber - 75795 Paris Cedex 16
Editor: Dominique Dionnet
+33 (0)1 58 44 72 62 - ddionnet@scor.com
ISSN: 1967-2136

Design and conception: SCOR Global P&C, Strategy & Development/ sequoia – (04/2012).