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Possible Space Weather Influence on the Earth Wheat Markets

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Abstract. We consider the problem of a possible influence of unfavorable states of the space weather on agricultural market through the chain of connections: "space weather" - "earth weather" - "agriculture crops" - "price reaction". We show that recently discovered new manifestation of the "space weather" - "earth weather" relations allow to revise a wide field of expected solar-terrestrial connections. In the previous works we proposed possible mechanisms of wheat market reaction in the form of price bursts on the specific unfavorable states of space weather.

We point out that implementation of considered "price reaction scenarios" is possible only in the case of the simultaneous realization of several necessary conditions: high sensitivity of local earth weather in a selected region to space weather; state of "high risk agriculture" in the selected agriculture zone; high sensitivity of the agricultural market to a possible deficit of supply. Results of previous works (Pustil'nik, Yom Din, 2004a, 2004b) including application of this approach to Medieval England wheat market (1250-1700) and to modern USA durum market (1910-1992) showed real connections between wheat price bursts and space weather state with high confidence level.

The aim of the present work is to answer the question, why wheat markets in one selected region may be sensitive to space weather factor, while in another region their reaction to this space weather is absolutely indifferent. To this aim we consider the distribution of sensitivity of wheat markets to space weather as a function of their localization in Europe in different climatic zones. We analyze a database of 95 European wheat markets in 14 countries during about 600-year period (1260-1912). We show that the observed sensitivity of the wheat market to space weather effects is controlled, first of all, by the type of predominant climate in different zones of agriculture. Wheat markets in the North and part of Central Europe (England, Iceland, and Holland) shows reliable sensitivity to space weather in minimum states of solar activity, when excess of the high energy cosmic ray stimulate additional cloudiness and precipitation. In the same time wheat markets in the South Europe (Spain, Italy) show reliable sensitivity to space weather state in the opposite (maximum) phase of solar activity when a deficit of cosmic rays input into the atmosphere leads to a decrease of cloudiness and to an increase of the probability of drought weather periods. We demonstrate that a large part of the markets in Central Europe show a lack of any effects of sensitivity to space weather state and show that this asymmetry is in good accordance with model expectation based on the proposed approach. We discuss possible increasing of sensitivity of wheat markets to space weather effects in conditions of fast and drastic change of modern climate, caused by global warming of the Earth atmosphere with fast shift of numerous agriculture regions to the state of "high risk agriculture zone".

Keywords: , solar activity influence, space weather, climate

Introduction

1. Historical introduction:

The problem of the possible influence of solar activity on the agricultural economics through space weather influences on the earth weather has at least 300 years of history and among its adepts are such bright names as the father of European satire Jonathnan Swift (1726) (noted in his "3-d Travel of Gulliver to Laputa" (300 hundreds years ago!!!) that people of Laputa (symbol of scientists of Royal Academy of England) "are under continual Disquietudes … that the Face of the Sun will by Degrees be encrusted with its own Effluvia, and give no more Light to the World"), the father of the European observational astronomy W. Herschel (1801) (who noted after comparison of sunspot variations with wheat price data from Adam Smith "Health of Nations" that "five prolonged periods of few sunspots coincident with costly wheat"), and the father of the Neoclassical Economic Theory and of the idea of Cycles of Economical activity William Stanley Jevons (1878), who proposed a link between sunspot cycles and business cycles…

However, the evident contradiction of the expected "universal" character of this influence to the observed very non-uniform reaction of the markets (when in different regions or in different historical periods, market reaction had opposite signs or even was absent et all) generated global skepticism to the possibility of this effect in principle, and shifted this theme to the field of "pseudo-science" speculations and for a long time prevented the serious analysis of this problem.

2. "Space Weather" introduction

One of the reasons for skepticism is the extremely high stability of the solar irradiance, which as a result was named "solar constant". Only during the last years, high accuracy measurements detected real changes in solar irradiance, related to sunspots, but with extremely low amplitude (about 0.1%). This amplitude of the variability is too low and could not be considered as a real factor of influence.

A drastic change took place in the end of the 20-th century, when it was discovered that a complex of influences, caused by the magnetic nature of solar activity (UV and X-ray emission from solar chromosphere and corona, solar wind pressure on the Earth's magnetosphere, modulation of cosmic ray flux by the solar wind) and identified in the last years as "space weather" is an essential factor influencing the Earth environment and the Earth weather. A great review of these influences and their observed manifestations was presented (Svensmark, H. and Friis-Christensen, 1997; Marsh and Svensmark, 2000; Palle Bago, E., Butler, C.J., 2000, Dorman, 2009). Below we list shortly some observed manifestations of this relation:

2.1. Solar Cycle length - North Hemisphere temperature.

High correlation between solar cycle length and North Hemisphere temperature for 1870-1990 was described for the first time in 1991 by Friis-Christensen and Lassen (1991). This conclusion was confirmed later by an investigation of this relation for historical time interval expanded up to 5 centuries in Lassen and Friis-Christensen, (1995).

2.2. Cosmic Ray Flux (CR) - Cloudiness.

High correlation between fluxes of high energy cosmic rays (CR), penetrating into the Earth atmosphere and ionizing it, with the cloudiness above North Atlantics was discovered by Svensmark and Friis-Christensen (1997) and confirmed later by other researchers (Harrison and Stephenson, 2006; Fastrup et al, 2000). As it was shown by the authors of this discovery, the sensitivity of cloudiness variations to cosmic ray flux is not uniform, but shows compact regions - spots of high sensitivity of cloudiness to CR factor, and wide belts of low or negligible sensitivity. This fact was explained by the authors as a consequence of the threshold type sensitivity of vapor condensation on conditions in the air (vapor density, pressure, temperature). As a result of this "threshold type" nonlinearity, the dependence of vapor condensation on ion concentration (the nucleus of the condensation process) will be high only in the regions with above threshold state of the atmosphere.

2.3. "NAO"-"aa"/"pc" correlation.

A very interesting result in space weather-Earth weather connection was obtained in the last years in a study of how NAO (North Atlantic Oscillation)[1] controls the weather type in the main part of Europe and Mediterranean region. As it was shown in the works of Boberg (2002) and Lukianova and Alekseev (2004), this circulation changes character synchronously with the electric field strength E of the solar wind, the planetary magnetospheric *Kp* index, and the dynamic pressure P of the solar wind, and indices "aa" (level of activity of the magnetosphere controlled by the solar wind) and "pc" (Polar Cap index - measure of the electric field in a disturbed magnetosphere in the polar cap region). Evidently, the magnetospheric variation has energetic level much smaller than the energy of atmospheric mass circulation and cannot pretend on the role of any "driver" for the observed connection. More probably, the correlated variations of aa/pc-indices of magnetospheric disturbances and NAO-index of Atlantic air mass circulation reflect their common sensitivity to some hidden external factor in space weather, which must be identified in the future.

We may summarize here that the investigation of the possible connection between Earth's weather and space weather show that this connection is real and reflects in different manifestations from cloudiness and land temperature up to global circulation of cyclones above North America-Europe-Mediterranean region. We would like to accentuate here that the physical mechanisms of this connections are not understood in details up to now and are being studied widely in different projects (for example "Cloud", Fastrup et al, 2000), but the fact of the existence of the influence of space weather on the Earth's weather is now almost without doubts.

3. "Agricultural production - Earth weather" sensitivity.

The fact of sensitivity of agricultural production to weather condition is trivial. During thousands of years of agricultural history of our civilization, numerous historical cataclysms took place as a result of decreasing of crops caused by climate change. Resulting famines ejected millions of people from their previous environment (which had lost the ability to provide them with food) many times acting as turning points in humanity evolution. Sensitivity of the wheat crop (recently the main source of food in Europe and Mediterranean) to the Earth's weather abnormalities is high too, but depends on the climatic zone. Grain production in the region of Mediterranean climate (warm and dry) is sensitive mainly to drought and deficit of humidity. In the northern region of Europe (England, Iceland, North Russia), the situation is opposite - wheat production has high sensitivity to the deficit of the number of sunshine days, excess of rains, and low temperature which creates "zones of critical agriculture" in weather conditions close to threshold limitations for vegetation. We would like to accentuate here only the following two kinds of negative reaction of wheat crop to weather in these regions[2], which may be interesting for the aims of our research:

[1] NAO is the dominant mode of winter climate variability in the North Atlantic region ranging from central North America to Europe and much into Northern Asia. The NAO is a large scale seesaw in atmospheric mass between the subtropical high and the polar low. The corresponding index varies from year to year, but also exhibits a tendency to remain in one phase for intervals lasting several years. 1. The Positive NAO index phase shows a stronger than usual subtropical high pressure center and a deeper than normal Icelandic low. The increased pressure difference results in more and stronger winter storms crossing the Atlantic Ocean on a more northerly track. This results in warm and wet winters in Europe and in cold and dry winters in northern Canada and Greenland; 2. The negative NAO index phase shows a weak subtropical high and a weak Icelandic low. The reduced pressure gradient results in fewer and weaker winter storms crossing on a more west-east pathway. They bring moist air into the Mediterranean and cold air to northern Europe (http://www.ldeo.columbia.edu/NAO/)

[2] We would like to cite here the following conclusions from a detailed statistical study of the meteorological conditions favorable or unfavorable for the different crops in England (R.H.Hooker, 1907): "the absence of rain in September and October is more important to the wheat crop than rain or

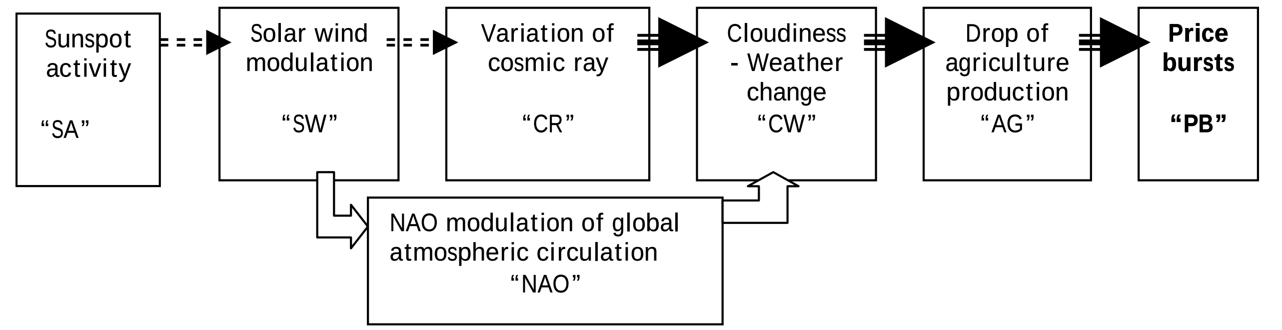


Fig.1. A possible causal connection between space weather and price bursts. For "SA"=>"SW" and "SW" =>"CR" the transition function is linear, for "CR"=>"CW", "CW"=>""AG", "AG"=>"PB" - threshold like transitions with strong non-linearity (marked by bold arrows).

1. Abnormal increasing of cloudiness and rains in summer season in the period of vegetation leads to a drop of crops in England and nearest regions of wheat production in the north of Europe.
2. Abnormal decreasing of cloudiness and precipitations in autumn-winter period leads to dry autumns or snowless severe winters, with catastrophic loss of winter wheat and pasture harvest. Similar catastrophic results for wheat crop may take place in the south regions of Mediterranean and South Russia (Zavolzh'e) as a result of the decrease or absence of cloudiness with drought in hot summers.

One of the first systematic studies on the problem of the influence of the variations of weather phenomena on the yield of crops was the work of Henryk Arctowski (1910). He analyzed annual deviations of wheat yield in 1891-1905 in the USA, Russia and Central Europe. He showed that centers of exceptionally good or bad harvests really exist; the extent of these areas was much smaller than the extent of the studied regions. He claimed that these centers displace themselves following displacing of zones of weather abnormalities (temperatures, rainfalls). Another important aspect of the studied problem is subsistence crises caused by wheat price bursts following low harvest. This problem was studied by Andrew Appleby (1979) for medieval England, France and Scandinavia for the period 1520-1740. He accentuated that from 1590's there were no subsistence crises caused by high wheat prices in England. He explained this fact by the intensive innovation of spring crops (oat, barley) in that period in England. As the result, not all grains failed at the same time. In the same period, no such balance was reached in northern France (for technological reasons), and in northwest of England, in Scotland and Scandinavia (areas that were heavily dependent on spring grains for climatic reasons). These areas suffered terrible starvation several times during the studied period. Thus, under conditions of wide using of alternative crops that reacted in different manner to extreme climatic conditions (we could say "optimal mix of cereals" in the modern language), wheat price bursts did not lead to subsistence crises[3].

temperature at any other period of the year"; and "the advantage of cool weather during spring and summer for the great majority of the crops" is a "a feature [which] stands out with quite unexpected prominence".

[3] As Appleby wrote, "the English poor might not have liked a diet of oats and barley, but this diet sustained life".

4. "Agricultural market" - "crop deficit" sensitivity

It is evident that the agricultural market will show a panic reaction to the deficit of wheat, especially in a situation when wheat is the unique source of muscular energy, food and life itself (like the stock reaction to the deficit of oil-gas today). It is evident too that in conditions of limited abilities of alternative supply of food this reaction will be panic-like, with non-linear reaction in the price of wheat in the free market. We understand that in conditions of a developed transportation system, supplied deliveries from outlying regions (were crop was not suppressed by weather abnormalities), the influence of the local deficit of wheat supply may be depressed – a positive manifestation of the globalization of world economics in modern time. But in a situation when the external market cannot supply enough wheat for the compensation of local deficit, or if transportation expenses of giant volumes of external wheat into sufferer region will increase essentially its price – the natural reaction of the free market to a sudden local deficit of wheat will be price burst. We understand that, in time when wheat was the source of life and energy for workers, wheat price influenced prices of manpower for a wide list of human activities from service up to industry. So, an unfavorable situation due to negative space weather influence on wheat market will be the source of price bursts not only for agricultural production, but for the consumer's basket as a whole.

Evidently, if the negative price reaction of the wheat market on unfavorable space weather is real, we must expect some correlation-synchronization between prices behavior and solar activity - driver of space weather. Our aim in this work is: a) to present a formal description of the expected causal connection "Space weather" - "Wheat Price" and to formulate criteria - necessary conditions for the realization of a scenario with sensitivity of wheat prices to space weather in selected regions; b) to analyze existing data of wheat markets in Europe to test our scheme.

The aim of the work is to test whether these relations are real or it is only a conceptual scheme without any manifestations in reality.

Description of a possible "cause-and-effect" chain from solar activity and space weather to price reaction as a "soft" connection with critical points.

1. Threshold states in soft type connection between "space weather" and "wheat price reaction"

As shown in our previous publications (Pistul'nik and Yom Din 2004.a, hereafter PY 2004-a, and Pistul'nik and Yom Din 2004.b, hereafter PY 2004-b), the possible causal connections between solar activity and wheat prices combine in a complex chain. Its basis is the influence of the solar activity (SA) through solar wind (SW) on the weather state caused by modulation of galactic cosmic rays propagating into the Solar System down to the Earth and penetrating in the Earth atmosphere. Ions and radicals in the air formed by cosmic rays are essential factors of vapor condensation and cloud formation; their modulation can lead to corresponding variations of the earth weather. From the other hand, these cloudiness and weather (CW) abnormalities can lead to drops in agricultural production in regions of high risk agriculture (high sensitive to weather state), with corresponding negative market reactions in the form of price bursts. As a result, a causal chain between solar activity and prices of agricultural products can be presented as a sequence of a number of elements (Fig. 1). Another possible chain is the modulation of the global atmospheric circulation simultaneously with solar wind and magnetosphere activity (Lukianova and Alekseev, 2004)

A main feature of this chain is a nonlinear type of sensitivity of the last elements of this scheme (marked by large bold solid lines arrows). It may lead to step-like transition processes, when small variations of input parameters cause a catastrophe-like transition of the whole system. For example, cloudiness formation caused by the induced vapor condensation in the presence of ions and radicals generated by cosmic rays is very sensitive to vapor concentration, temperature and pressure (like in Wilson camera). This explains the quite inhomogeneous geographical distribution of the sensitivity of "CW" to "CR" (Fig. 1), with few local spots of very high correlation and extended regions of low correlation (see map of sensitivity distribution in Fig.8 in Fastrup et al. 2000). Another element with nonlinear sensitivity is a "CW" - "AG" transition that reflects the reaction of agricultural production to weather abnormalities. This process takes place only in regions of high risk agriculture sensitive to weather states. Additional parameters here are the type of agricultural grain and its dynamical range of sensitivity to weather (oat, for example, is more resistant to weather disturbances than wheat and less sensitive to "CW" - "AG" transition). The market state, in turn, is very sensitive to the last transition element shown in Fig. 1 (price burst reaction to unexpected deficit or excess of agricultural production). We wish to note here that existence of reserves and access to external markets with low transfer costs (global market) will suppress the market sensitivity to disturbances of local supply.

As the result, the multi-element chain of causal connections (Fig. 1) cannot be described by "hard type" models with univocal relations like

$$Y = kX + Noise,$$

or more generally,

$$Y^{(n)} = \sum k_i X^i + Noise,$$

where X_i - input variables (space weather parameters, conditions in the Earth atmosphere, market characteristics,…), Y - the output reaction (market prices, social outcomes, famines), k_i - the coefficients of connections, (n) - the order of derivatives.

On the contrary, this multi-element chain requires "soft type" models for its description when the coefficients of connections k_i depend on the input variables X_i and the output reaction Y:

$$Y^{(n)} = \sum k_i(X,Y) * X^i + Noise.$$

This situation is typical for "catastrophe theory" (Arnold 1992) and requires taking into consideration hidden parameters of the system. The system's behavior is very sensitive to its location in the multi-dimensional space of X^i.

2. Three necessary conditions for the realization of "space weather" - "wheat market" connection

Regarding the problem of space weather influence on wheat prices, the soft type of the relationship leads to high sensitivity of this connection to the following important parameters: distribution of vapor above the earth surface determined by global climate and atmospheric circulation; resistance of the agricultural production to weather conditions (grains and their varieties, agro technique); involvement of local wheat markets in the globalization process (due to cheap shipping costs and low customs). Since all these parameters are very inhomogeneous in space and vary in time on the scale of hundreds of years we can expect that the sensitivity of the market to space weather may be unstable. This sensitivity can take place from time to time in specific regions, when and where all **three necessary conditions** have place simultaneously:

a) **Conditions for vapor condensation in clouds are near the critical state in the atmosphere and, correspondingly, are sensitive to space weather factors (cosmic ray, in particular).**
b) **The region is located in an area of "high risk agriculture" state, sensitive to weather variations.**
c) **Wheat market isolation from external supply must be too high or transportation expenses must be too large to restrict external supply compensation of deficit**.

3. Expected manifestation of "space weather" - "wheat price reaction"

The market behavior expected according to the scheme presented in the Fig. 1 has to demonstrate the following two types of reactions to the unfavorable space weather state:

The burst-like price reaction to the realization of a crucial combination of the above-considered necessary conditions. These price bursts are most probable in specific phases of solar activity (minimum or maximum sunspot number) that lead to the most unfavorable states of weather for the concrete agricultural crops under concrete local market conditions. Possible types of market reactions were discussed in detail in PY 2004 and presented in Fig. 3 and Fig.4 therein.

Min/Max price asymmetry - systematic differences between prices in minimum and maximum states of solar activity, caused by the opposite sign of space weather influence on the market in these opposite states of solar activity.

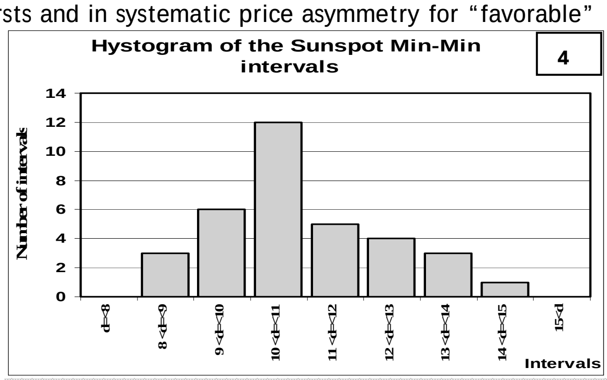
For the analysis of concrete situations in different countries and regions, we have to take into account that global atmospheric circulation may transfer clouds by cyclones from the region of their formation to thousands of kilometers away (for example, from North Atlantic to East Siberia or Near East). This circulation processes may lead to essential weather reaction in these locations to cosmic ray/sunspot activity (with evident time lag) though the atmospheric vapor state above these regions may be very far from the critical state.

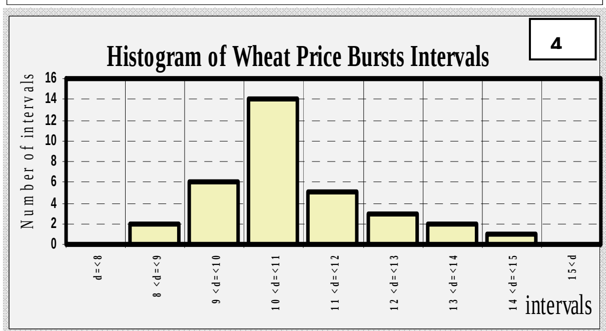
Another factor for the possible increase of price sensitivity to space weather is the compactness of agricultural production zones. Clearly, regional sensitivity of crops to weather conditions is much stronger for those of them that are localized in small and compact regions (hundreds kilometers) than for those dispersed on many thousands kilometers covering different climate zones.

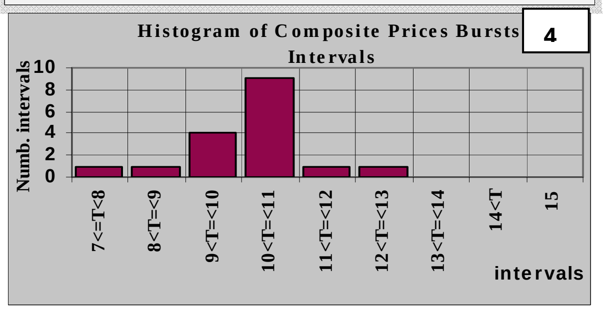
On the base of this description we can conclude that standard methods of statistical inference (regression/correlation, Fourier analysis) may be ineffective for the search of the "space weather - price level" connection, appearing in rare and irregular price bursts and in systematic price asymmetry for "favorable" and "unfavorable" phases of solar activity. Identification of space weather manifestations through Earth markets requires application of another approach based on the "statistics of rare events". As it was shown in the previous part of our work (PY, 2004), adequate methods for this purpose can include (a) statistical study of time intervals between price bursts and (b) search of price asymmetry. In the next chapter we will describe some applications of our approach for identification of market reaction to space weather in different countries and in different historical periods.

Sensitivity of European wheat markets to space weather influences.

1. Preliminary results (Medieval England): In "PY 2004-a" we for the first time applied this approach for identification of possible market reaction to space weather in Medieval England on the basis of wheat prices database from 1250 up to 1700, collected by Prof. Roger based on archives of England monasteries. In the next work we included in our consideration an additional database of price of consumables basket for the same period.







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Database	Median	Average	Standard deviation
Min-Min interval for Sunspots	10.7	11.02	1.53
Wheat Price inter-bursts intervals	11.00	11.14	1.44
Consumable basket inter-bursts intervals	11.00	10.5	1.28

Table. 1. Median, average and standard deviations of time intervals between wheat prices bursts, consumable basket's price bursts and intervals between minimum states of sunspot activity

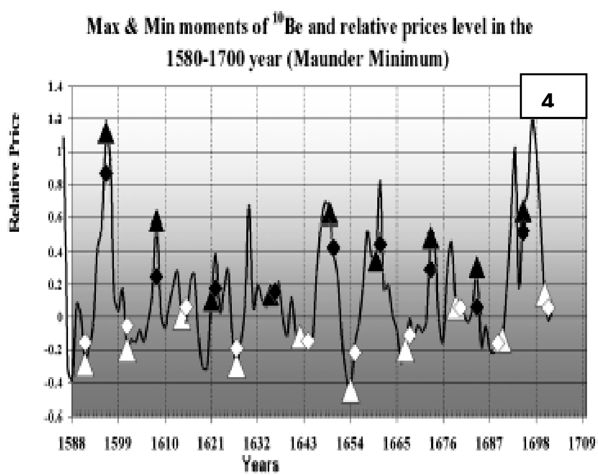

Fig.2.: (a),(b),(c) - distributions of intervals between min-min of solar activity, between bursts of wheat price and composite prices (consumable basket), respectively; (d) - table 1 of medians, averaged, standard deviations for these 3 samples, (e) - asymmetry of wheat prices in 1585-1700 in Medieval England for minimum and maximum states of solar activity.

As a test for identification of real relation we compared time intervals distribution between price bursts and between minimal states of solar activity[4]. Later in "PY 2004-b" we included consumable basket price in the analysis.

We chose Medieval England as a unique region, which in this historical period satisfied all three necessary conditions for the realization of the scenario "space weather - wheat price reaction" (see Chapter II). In reality, this market:

1) is situated in a region of high sensitivity of cloudiness to cosmic rays (see map of sensitivity from Fastrup et al, 2000);

2) is a region of critical wheat agriculture, very sensitive to weather;

3) England wheat market in medieval period was isolated from external wheat supply by geographic conditions and as a result was very sensitive to crop deficit.

We showed for all 3 samples (see Fig.2 and Table 1) that time interval distributions between wheat price bursts and between solar minima are very similar (both for distributions themselves and for statistical parameters: mean, average and standard deviation for different samples).

This means that with high confidence level (>99%; > 99.5%) it is possible to assert that these three different samples formed on the basis of the same quasi-periodical process - solar activity.

Another identification which we made in "PY 2004-a", a test of price asymmetry for opposite states of solar activity (minimum and maximum of sunspot number), shows the same result (see Fig. 2.c. above): with high confidence level (>99.5%) all prices of minimum state of solar activity (black triangles and diamonds) were much higher then the prices in the previous maximum state (the white one).

2. Possible manifestation of space weather effects in European wheat markets.

a. Used database:

To test our model approach we used the database of wheat prices "The IISH List of Datafiles of Historical Prices and Wages", prepared by the International Institute of Social History and published at http://www.iisg.nl/hpw/. This database includes 95 wheat markets from 14 European countries for the period 1260-1912 (different markets in this sample have different times of life and breaks periods. For our analysis we selected the markets with the longest history).

We divided European wheat markets from the database used into 2 groups: first in the zone near the North Atlantic spot of high sensitivity of cloudiness to cosmic ray flux (see map of sensitivity in Fastrup et al, 2000), in "high risk" agriculture zones (sensitive to rainy summer and deficit of sunlight in vegetation period) and with limited access to external suppliers of wheat (England, Ireland, Scotland, Iceland) and nearest continental wheat market, depending on them (Holland). Another group was selected by the opposite criteria - in Mediterranean region with high sensitivity of the crop to deficit of cloudiness and rainfall, with high danger of droughts (Italy, Spain, Sicily). The first group is expected to be most sensitive to the state of minimum of solar activity and solar wind, increased up to maximum cosmic ray ionization in the atmosphere and corresponding input in cloudiness and rain. Oppositely, the second group is expected to be more sensitive to the state of maximum of solar activity, with minimum cosmic ray ionization of the atmosphere with decrease of cloudiness and rain, what may lead to the lost of crops in summer as a result of droughts.

We would like to point here that in regions of threshold state of agriculture, crops may be sensitive to both states of weather abnormalities (high cloudiness and rain in summer on the one side, and cloudless and snow-less winter on the other side). In this situation wheat price may be sensitive to both states of solar activity, both to maxima and to minima of sunspot number, as it described by price reaction IV in Fig. 2.b.

b. Method of analysis:

For detailed analysis we used dummy variable analysis from Suits D. (1957) as most appropriate in our case. Dummy variables are widely used in statistical analysis to capture the influence of qualitative variables. In the note of Suit (1957), one of the first examples of using dummy variables in regression equations is presented. In our work, we used the dummy variables $d_{\min}$ and $d_{\max}$ to measure the effect of the studied years belonging to the periods of minimum or maximum solar activity. Specifically, we were interested to test and compare the existence of this effect and its significance for markets from different European regions. For this purpose, in the regression equation for each of the considered markets the dummy variable $d_{\min}$ received value "one" for years of minimum solar activity, and value "zero" for other years. The dummy variable $d_{\max}$ was defined similarly for years of maximum solar activity. This method is a development of our test of price asymmetry in minimal and maximal states of solar activity, but in this case we used as a quantitative criteria the value of the confidence level of the statement that asymmetry has place.

For our analysis we used the specific period 1590-1702 of the small ice age in Europe (a part of the famous Maunder minimum of solar activity). This choice was determined by the following reasons:

1. During this period the agricultural production in most regions of Europe was shifted to "high risk agricultural state" by the action of long time colds and nips, especially in North Europe;

2. We have for this periods data on solar activity/CR flux, restored by Beer et al. (1998) from data on Be^{10} isotope in Greenland ice - the most adequate proxy of space weather influence in this region in this period;

3. We tested preliminary (PY, 2004-a) price asymmetry in this period for England wheat prices from the database of Prof. Roger (1887) and showed that effects of this asymmetry had place with high confidence

[4] We would like to remind here that the so named "11-year solar cycle" is not really 11-year period. It is quasi-periodical process with low stability of period and phase. Period (interval between minimum states of sunspot number) changes drastically from 8 year up to 17 year.

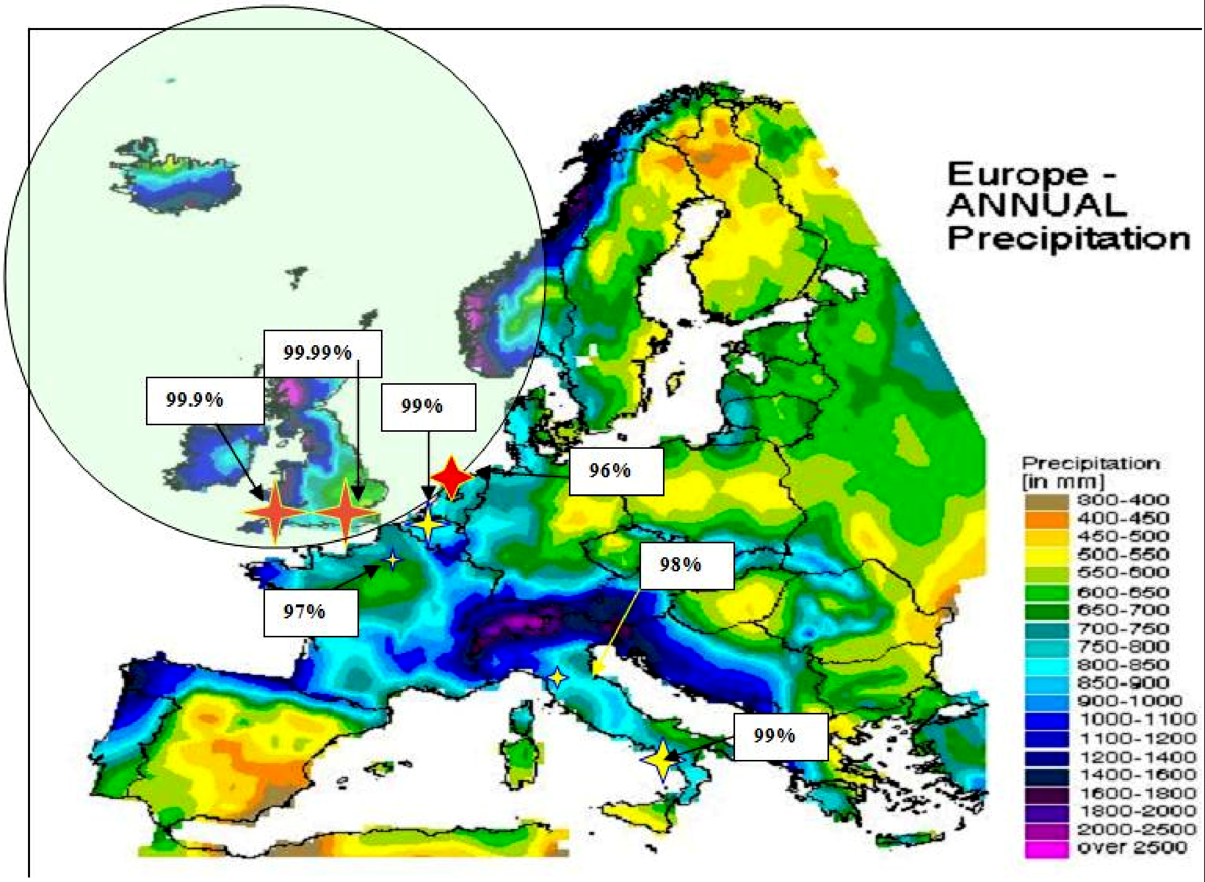

Fig.5. Map of Europe (with distribution of the precipitation) with markets, used for our analysis (marked by stars). In the case of high reliability of the connection between minima of solar activity and wheat prices we used large red marks (London, Exeter-England; Leiden-Netherlands), for similar connections with maxima of solar activity (Napoly, Bassano-Italy) we used yellow stars.

level (99.5%) - in all 9 sunspot cycles of this period, the prices of wheat in minimum of solar activity were essentially (50%) higher then the prices in the moments of the following sunspots maximum.

c. Result of analysis:

We showed the confidence level of the reality of price response on the solar activity state by stars in the Table 2. and on the Fig. 5 (map of Europe) with the size of the star proportional to the confidence level and the color of the star reflecting the sensitivity to maximum (red) or minimum (yellow) states of the solar activity.

As may be seen from the table 2 (where cases of markets sensitive to solar activity state with confidence level >95% are marked by bold), the results of the statistical analysis are in good accordance with our expectations:

- All England wheat markets show high sensitivity to space weather (confidence level > 99.99%) both to maximum and minimum states of solar activity. One Netherlands market (Leiden) shows some sensitivity (>95%) too, but on lower level. The second Netherlands market (Arnhem) shows absence of sensitivity to space weather factors at all. This lower sensitivity of continental markets from the same climatic zone is expected, because the third necessary condition for realization of sensitivity to space weather (limited external supply) for continental markets is not as effective as for England.
- Part of the continental markets show existence of sensitivity to space weather influence in the state of maximum of solar activity (Italy, Spain, France, Belgium). If for Italian and Spain markets it may be naturally explained as a result of the negative influence of the Mediterranean climate with harmful summers and droughts, caused by North Africa influence (with cloudless harmful summer in maximum of solar activity - case II-a from Fig.3, for North European crops markets it may be explained by cloudless and snow-less severe winters in the studied Small Ice Age period.

Discussion.

Possible space weather influence on agriculture economics in present time

The situation considered above and the identified cases of connections of agricultural production and wheat prices with space weather and solar activity are in the past (up to 1700 for Medieval England or up to 1888 for Iceland). Does this connection exist in present time or was it suppressed by the technological development of agriculture production (genetic engineering and using modern herbicides, expanded weather intervals comfortable for the production of the respective grain cultures; globalization of the world agriculture market)?

Table 2. Significance of Min-Max years of solar activities for different wheat markets in 1590-1702

Country	City	Significance as P-value	
		Min SA	Max SA
England	London	**0.0001**	**0.0001**
England	Eton	**0.0001**	**0.0015**
England	Exeter	**0.0474**	**0.0011**
Netherlands	Arnhem	0.3839	0.3488
Netherlands	Leiden	**0.0428**	0.5699
Belgium	Bruges	0.1773	**0.0129**
France	Douai	0.0756	**0.0289**
France	Paris	0.4138	0.1619
France	Toulouse	0.8563	0.4170
France	Angers	0.3227	0.2953
France	Beziers	0.9581	0.7929
France	Grenoble	0.7310	0.5903
France	Strasbourg	0.4748	0.7297
France	Aix en Provance	0.6434	0.9307
Germany	Cologne	0.9546	0.1395
Germany	Wels	0.2881	0.1161
Germany	Wels	0.3126	0.1310
Italy	Bassano	0.5565	**0.0186**
Italy	Siena	0.6837	0.8518
Italy	Naples	0.2190	**0.0085**
Italy	Udine	0.6889	0.0695
Spain	Valence	0.0620	0.6130

As we showed in PY, 2004-b, the situation changed in comparison with the Middle Ages, but some influence of space weather on wheat market continues to be significant. For example, for modern durum market of USA in the 20-th century, price asymmetry for minima and maxima of solar activity is quite real, but the mean amplitude of this asymmetry is lower than for Mediaeval England (20% as compared to 50%, respectively).

The confidence level of this asymmetry for modern USA, estimated by the method of regression of dummy variables is high: p> 99.5%. The main reason of this unexpected result is the very high concentration of USA durum production in a very compact region - 70% of durum is cultivated in 3% of the territory of USA, in a small part of the North Dakota near the border with Canada. Evidently that his compact area, opened for cold winds from the Arctic region, has high sensitivity to weather abnormalities and is able to feel its extreme states, induced by unfavorable states of space weather.

Global warming and space weather effects on agriculture production.

Global warming observed in the last decades may change drastically the conditions for agriculture in many parts of the Earth. Areas that were in the past far from the "threshold state" of agricultural production during short historical time intervals may change their state to more unstable. For these areas the sensitivity to external factors like space weather modulation of cloudiness, rain, and cyclone circulation may increase up to detectable. On the other side, areas of high sensitivity to space weather may lose this sensitivity during the fast climate change due to the disruption of one or more of the 3 necessary conditions for the sensitivity of prices to space weather (sensitivity of local earth weather to space weather, sensitivity of agriculture to earth weather, sensitivity of market to crop decline). A more detailed analysis of the expected change in the sensitivity of local markets to space weather as a result of global warming and climate change is a matter of detailed analysis in a following publication.

Possible scenarios for changes in agriculture, as a result of global climate change, are discussed in scientific literature. One of the conclusions is that crops currently cultivated in specific regions can be no more suitable under changed climatic conditions (Evans 2009 – a study for the Middle East, Fuhrer et al. 2006 – a study for Switzerland).

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