Numerical Modeling of Climate (on Yakutia example)

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Abstract. Numerical modeling of time series of observations of Yakutsk meteorological station was used for the first time to construct a model of heat and moisture climate variability over the course of a century cycle of solar activity (SA). The lag of precipitation relative to temperature for ¼ of the rhythmic wave was revealed. Consecutive change of climatic phases: cold-wet (CW) warm-wet (WW), cold-dry (CD) and warm-dry (WD) has been established. The nonlinearity of the solar-tropospheric relations at level of intra- and secular oscillations is confirmed. The trends and anomalies of climate changes and permafrost response for the next decades and the current century as a whole are determined.

1. Introduction
The problem of climate change is debatable. Both anthropogenic and natural factors are cited as the main cause of warming. The gas concept of warming is dominant, which based on theory of greenhouse gas emissions of anthropogenic origin. But climate is a global process associated primarily with position of earth in solar system and with the sun influence. This is evidenced by fundamental research of Anatoly V. Dyakov [1], MorisS. Eigenson [2] and Boris A. Sleptsov-Shelevich [3]. Dyakov's climate forecasts for any point of Northern Hemisphere were remarkably accurate (3-6 months ahead). They were based on the energy-climatological basis and were justified by 80-90% [1]. All this data causes interest to the problem of solar-tropospheric relations, and modeling of long-term series of meteorological observations takes a key place.

2. Statement of the problem
The series of meteorological observations of annual surface air temperature mean and atmospheric precipitation on HMS (Hydro-Meteorological Station) Yakutsk (Central Yakutia) were taken as inputs. They originate from May 1829 (Figure 1 [4]). However, the presence of significant interruptions in 1850s - 1870s limited the beginning of continuous series to 1882 (138 years).

Choice of Yakutsk meteorological station is due to not only the maximum duration of observations for Eastern Siberia, but also to its geographical location. Station is located on the Central-Yakutian plain, framed from the east and south by a chain of mountains, blocking incursions of air masses from
Pacific Ocean. It is also significantly remote from warm Atlantic air masses and has a good response to changes in solar activity (SA)[2]. Our studies of the Siberian anticyclone and modern Global warming showed that the observational series of HMS Yakutsk are highly representative not only for most of Central Siberian plateau, but also for the entire Northern Hemisphere [5].

The Zurich series of Wolf numbers lasting more than 300 years was used as an indicator of SA.

Purpose of work: by methods of numerical modeling of non-stationary processes in HMS Yakutsk series of meteorology (mean of annual temperature and atmospheric precipitation) and Wolf numbers to study the solar-tropospheric relations with climate variability at level of hundred-year rhythm oscillations and provide the long-term climate and permafrost forecasts.

Objectives:
- To clarify trends in climate and solar activity over the last century by calculating linear trends in series of weather observations and Wolf's numbers;
- To model the heat and moisture supply curves of the climate over a hundred-year rhythm, using the moving-average method;
- To study regularities of climate fluctuations under influence of global atmospheric circulation factor and SA harmonic oscillations;
- To determine the most probable changes and future climate anomalies as an appendix to long-term climate and permafrost forecasts.

Figure 1. The graph of average temperatures in Yakutsk from 1830 to 2016 [5].

3. Results and discussion
Calculation of linear trends in series of temperature and atmospheric precipitation of Yakutsk station in graphical comparison with the linear trend of Wolf numbers for the twentieth century showed that the increase in temperature was only slightly behind the positive trends of atmospheric precipitation and Wolf numbers, which have close values for the period under consideration (Figure 2 and 3).
This indicates unified trends in Sun activity and dynamics of tropospheric-climatic processes. Solar activity, as was shown by Eigenson [2], is able to modulate not only climate fluctuations at level of harmonics of 11-year cycle of SA, but also longer - on a long term basis. In particular, Eigenson writes: "...the root cause of some post-glacial warm "seasons" - as well as all other paleoclimatically analogous warm "seasons" - can or should be the same as the modern warming. And this root cause is now quite well known. It lies in intensification of solar activity. Cold planetary paleoclimate "seasons" are, generally speaking, only a cyclically inevitable counter-phase for the corresponding warm "season" in a given climatic cycle. Hence the geophysical cause of cold paleoclimatic "seasons" may be epochs of long negative anomalies of atmospheric circulation energy, and the cosmic root cause of this negative anomaly of terrestrial circulation and climate is a similar negative solar circulation and "climate", i.e. the decline of solar activity" [2, p. 246].

Coincidence of linear trends of temperature, atmospheric precipitation and Wolf number in our models may testify in favor of SA influence on global climate, including process of modern warming development.

Modeling of series of meteorological elements by methods of Fourier and Wavelet analysis has shown the presence in their structure of oscillations close to known periodicities of solar rhythmic. All
revealed modes - 11, 22, 36, 48, 72 years - are comparable with the solar-conditioned oscillations of Schwabe-Wolf, Hall, Brickner, half-century and double Brickner [4, 6]. However, a direct graphical comparison of Fourier curves of studied series and Wolf number curve showed that the response of Fourier harmonics in meteorological element series to 11-year SA oscillations over the course of hundred-year rhythm was ambiguous. In some cases, positive anomalies of temperature and atmospheric moisture coincided with the maximums of 11-year SA cycles, in others - with the minimums, or occupied an intermediate position, gravitating either to upward or downward branch of 11-year cycle (Figures 4 and 5).

Figure 4. The curve of air temperature in Yakutsk with the harmonics of Fourier analysis in direct comparison with the Wolf number (w) fluctuations.

Figure 5. The comparison of precipitation dynamics (a) and solar activity (b).

The nonlinear character of solar-tropospheric relations is evident. It is manifested in a stable phase lag of harmonic oscillations in series of meteorological elements relative to anomalies of 11-year cycle (maximums and minimums): by 1/4 for temperature and 1/2 for precipitation. The entire spectrum of rhythmic, uncovered by us in meteorological series of HMS Yakutsk, is subordinate to this pattern.

In general, the results obtained reveal the great influence of solar rhythms on dynamics of annual temperature mean and the regime of atmospheric precipitation. The phase lag in response of anomalies of meteorological elements to SA anomalies may indicate in favor the presence of inertia in response of atmosphere to external energy impacts.

At the same time, it is known that the climatic conditions of the Earth in general, as well as of any region in particular, are set by combination of heat and moisture. Therefore, the most important task is
to determine variability of heat and moisture of climate along the hundred-year rhythm. To solve this problem, the series of annual temperature mean and atmospheric precipitation were smoothed by moving average method (Fig. 6).

The resulting model (see Figure 6) showed the most important fact in development of secular warming wave. Temperature peaks manifested in Yakutsk in twentieth century were ahead of humidification peaks by $\frac{1}{4}$ of wave of secular rhythm. This led to a successive alternation of cold-wet (CW) warm-wet (WW), cold-dry (CD) and warm-dry (WD) climatic phases here.

The lag of humidification peaks in relation to temperature peaks on $\frac{1}{4}$ rhythmic wave was discovered during paleogeographical reconstructions of the structure of long-periodical rhythms - 40700-year of Milutin Milankovitch and 1850-year of Arseny Shnitnikov - by Evgeny Maximov and called by him the Iversen - Grichukrule [7]. It seems that this phenomenon has a universal character in climatic regime of the Earth. Its essence, in our opinion, can be explained by two facts: disproportion of land and ocean area on the Earth and a huge area of cryolithozone [8].

With a 2.5-fold excess of ocean area over the land area in Northern Hemisphere and with the cryolithozone clearly dominating there, water and ice intercept most of the solar heat and inhibit a sharp warming course. As the land area increases, the gap between temperature and moisture peaks should shrink according to the Iversen-Grichuk rule. Apparently, this pattern was characteristic of early Pleistocene, when the excess of the land area over the ocean in Northern Hemisphere created an incredible scale of continentality and ensured the dominance of steppe and African mammalian appearance all the way to the shore of the Arctic Ocean.

Correction of the Iversen-Grichuk rule by humidification conditions can be seen at present on the example of melting glaciers of Suntar-Khayata and Chersky Mountains. In Chersky Mountains, located in a more continental part of north-east Asia, the losses of glacier area during the modern warming are twice higher of Suntar-Khayata. The south-eastern tip of Suntar-Khayata faces the Pacific Ocean, humidification of which protects this mountains from Global warming much more effectively than the continental climate of Chersky Mountains.

Another example is given by Little Ice Age. It is separated from the present only by a century, but differs sharply from it in terms of moisture conditions. At maximum area of Arctic ice fields and mountain glaciation at the peak of Little Ice Age in 1840-60, the moisture content of the Earth was
minimal [6]. This is especially evident in "failure" of precipitation course in the peak of Little Ice Age in Yakutia and in Altai Mountains [8]. Main reason for this phenomenon is increase in the area of sea ice. Ice has created the effect of an increase in the land area and, consequently, a sharp increase in continentality of the climate. As a result, humidification could not restrain the increase in July temperatures during the peak of Little Ice Age in 1840-60 as successfully as it did during the warming of 1970s – 2000s, when the sea ice and mountain glaciation approached their minimum and humidification approached its maximum. The braking effect of these factors, as formulated by the Iversen-Grichuk rule, is effectively dampening catastrophic "explosion" the Earth's warming climate today. Corrections to the sea ice extent of the World Ocean should be introduced in paleoclimatic reconstructions and interpretation of the temperature and humidity variations in rhythmic models.

At the same time, judging by the course of temperature and Wolf number curves in our model, the main warming waves manifested themselves at the beginning and end of SA hundred-year rhythm, coinciding with the beginning and end of the twentieth century, while the maximum of cold return, in contrast, manifested itself at the maximum of hundred-year rhythm in 1957 (see Figures 1 and 6). Figure 6 shows that the causes of cooling in the middle of last century are related to weakening of global atmospheric circulation in Northern Hemisphere, which manifested itself during the maximum of hundred-year rhythm in 1957, coinciding with the maximum of entire series of SA. The cooling developed at the transition of global atmospheric circulation from the zonal type to a more efficient meridian type (see Figure 6a). Thus, the climate response to development of the SA secular cycle in Yakutsk was nonlinear and similar to that previously observed by Alexander Chizhevsky [9] for 11-year cycle. The process anomalies gravitated to branches of cycle rise and fall - minimum and maximum.

At the same time, in spite of seemingly fast, abrupt changes in the course of natural processes, they require a long preparation for overcoming the inertia of the environment. A good example of this is the current melting of ice in Arctic, where after three decades of warming the Arctic Ocean lost 25% of its ice cover in 2007 alone. The process had reached a tipping point with enormous Arctic melt resistance, but once there, it was moving forward by leaps and bounds. It must be remembered that the presence of natural ice in permafrost, with its tendency to phase transitions, its huge mass and inertia to melt, poses a catastrophic threat, capable of manifesting itself with extraordinary force at the most inopportune moment.

The overcoming of cold inertia in Little Ice Age–by warming – has evolved over more than one century.

So what should we expect in future?

The warm and dry phase of the climate that unfolded on the plains of Yakutia at the beginning of this century will continue in future for at least the other two or three decades. Severe droughts similar to those in 1920s which caused the famine and coincided with the Spanish pandemic and other infectious diseases (typhoid, smallpox, cholera, etc.), may intensify their dynamics in very near future (2021-2025), as well as in 2040s and 2070s. This is evidenced by both the evolving current deep warm-dry climatic anomaly and the entire climatic structure of previous hundred-year rhythm. We are now at the beginning of second wave of 11-year cycle along the course of new century, which we entered 12 years ago (in 2009).

A hundred years ago, the Spanish pandemic, which may have returned to us today in the guise of Covid-19, unfolded in the world. At that time in Yakutiathe forests were burning, dangerous cryogenic processes increased their dynamism, the regime of ice, flood waves, floods, and seismic activity was transformed...

Development of the current warm and dry climate phase will also modulate, in the very near future, activation of large-scale forest fires and dangerous cryogenic phenomena and processes, associated with melting of strata and vein ice, area spreading of thermokarst, strengthening the dynamics of solifluction, waterlogging processes, etc. Besides, we may expect a burst of dangerous hydrological, hydro-geological and seismotectonic manifestations, especially at moments which are close to the tipping points of solar cycles.
4. Results and discussion

Results of analysis of solar-tropospheric relations at the level of linear trend models and cyclicity of nonstationary processes in multi-year series of weather observations of Yakutsk station (temperature and atmospheric precipitation) in graphic comparison with the course of Wolf numbers showed the unity of trends in solar activity and dynamics of investigated tropospheric-climatic processes. Nonlinearity of harmonic oscillations on the Sun and in atmosphere should be noted as an important regularity. A stable phase lag of 1/4 period - temperature, and 1/2 - precipitation, relative to anomalies of 11-year SA cycle (maximums and minimums) has been revealed. The reason for this phenomenon seems to be in inertia of response inherent in all geospheres of geographical shell to influence of external energy impulses.

Not less interesting is the intra-annual variability of the heat and moisture of climate over the course of hundred-year rhythm. It is manifested in fact that temperature peaks were ahead of moisture peaks by ¼ of the rhythmic wave and created conditions for alternation of cold-wet (CW) warm-wet (WW), cold-dry (CD) and warm-dry climatic intervals.

According to identified heliogeophysical preconditions, severe droughts should be expected from the first half to the middle of 2020s (2021-2025), as well as in 2040s and early 2070s. They will alternate with seasons characterized by heavy precipitation. These phenomena will modulate the periodicity of large-scale forest fires and dynamics of entire spectrum of dangerous cryogenic exogenic geological processes. At time ranges close to minimums and maximums of 11-year cycle, we should also expect bursts of dangerous hydrological, hydrogeological and seismo-tectonic manifestations.

If we discuss the trends of global climatic changes, for today there are no grounds to expect a transition to global cooling. This follows from general trend of strengthening of SA regime for more than three hundred years. However, periodic returns of cold weather are quite probable. They can occur both at sharp increases or decreases of SA during secular cycles, influencing the atmospheric circulation regime, and in form of return discontinuous or compensatory currents of cold air from polar latitudes.

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