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College on Soil Physics: Soil Physical Properties and Processes under Climate Change

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Paleopedology and Paleoclimate

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PALEOPEDOLOGY AND PALEOCLIMATE

Lecture Notes for ICTP College on Soil Physics: *Soil Physical Properties and Processes under Climate Change*. Trieste, August/September, 2010.

I. False Hypothesis?

II. Consequences for Soil Physics

I. False Hypothesis?

INTRODUCTION

Since the very beginning of the Earth, its global atmospheric conditions have never been spatially or temporally constant - all of them are variable regardless of location and time. The detection of their variation depends upon the intervals of both time and location during which they are measured.

It is common to talk about the weather. We readily accept the notion that weather is the changing conditions of the atmosphere at a specified geographic location over a short period of time - yesterday it rained and today the sun is shining. Yesterday the temperature was 16^o C, today it's 20^o C. We expect the weather to change from day to day. We also expect annual fluctuations in weather - this year we had a cool spring and the harvest of maize was delayed for a week. Last year when the spring was much warmer, the maize harvest was a week earlier than usual. Changes in weather are usually based on mean values of data recorded over approximately 150 to 250 years with most persons not knowing the exact period of time from which the average "norm" is calculated.

Climate is the behavior of the forever fluctuating atmospheric conditions during much longer periods of time. Hence, when we talk about climate, we refer to "long-term" averages of weather - the climate of Iceland is cooler than that of Sri Lanka. Most persons do not recall or even know just the opposite - when or for how long Iceland was warm and Sri Lanka cool. Nor do they know why crocodiles and dinosaurs first appeared on Earth about 240 million years ago with crocodiles still surviving today after major changes in global climate while dinosaurs have long been extinct.

Quantification of climate at prescribed geographic locations and specific geologic times is somewhat complex and difficult to achieve - yet scientific progress is continuing to be made.

Quantifying the rate of climate change in and during the recent or geologic past is still more complex and remains as an infant far from the maturity of an adult. Hypotheses for the causes of various kinds of climate changes are being continually developed. In the first lecture, the discipline of soil science is linked with other scientific disciplines to understand the development of hypotheses of climate change. In the second lecture, two kinds of climate change are singled out for the consideration of soil physicists - global warming and increasing CO_2 concentration in the atmosphere.

I. HYPOTHESES OF CLIMATE CHANGE

1.Soil Genesis

1.1.Soil Forming Factors (Dokuchaev, 1983, Jenny, 1941):

Parent Material
Climate
Organisms
Terrain relief
Man´s activity
Time

Dokuchaev considered climate and vegetation as the most important.
Hilgard (1906) emphasized the relationship between soils and climate

1.2. Soil Forming Processes

Physical weathering
Chemical weathering. Clay minerals.
Biological weathering
Humus formation
Transport. Eluvial and illuvial horizons
Soil Profile

1.3. Soils Classification

Examples of soil types

2. Paleosols

Paleosols of past geological periods and epochs were detected from Kambrium (540 – 488 mil. years = myear BP) up to start of Holocene (11,500 years BP). Buried and fossile soils, or their horizons are used as indicators of the past climate of all geological periods and epochs.

Our study: **Pleistocene** (2.588 – 0.0115 myear BP):

In the second half of Pleistocene:
Glacials, each about 100,000 years (= 100 kyr).
Between glacials are **interglacials**, each about 12,000 years.
100 kyr cycles up to cca 1 myr BP. Earlier (1to 2.5 myr BP) were 41 kyr cycles

Loessical deposits – cooling, **glacials.**
A, or A, A/B horizons between loessical layers – relative warm **interglacials.**

NAMES OF LAST FOUR GLACIALS

Cca kyr BP	Alps	US
440-340	Günz	Nebraskan
325-230	Mindel	Kansan
220-130	Riss	Illinoian
110-11.5	Würm	Wisconsinan

INTERGLACIALS

340-325	Günz-Mindel	Aftonian
230-220	Mindel-Riss	Yarmouthian
130-110	Riss-Würm (Eem)	Sangamonian

3. Paleosols as Indicators of Paleoclimate in Last Interglacials

Paleosols as indicators of paleoclimate - methods: Sheldon and Tabor (2009).

Riss/Würm (Eem) interglacial

Paleosol – Chernozem in loess (PCh), slight (B) horiz.; clay fraction – increased percentage of montmorillonite (Smolíková, 1990) compared to recent Ch; i.e. warmer and slightly more humid climate. It lasted for thousands years.

Paleosols – Terra Rossa, less frequent Terra Fusca on limestone and on travertine: Mediterranean climate in central Europe (Smolíková, 1990).

Ložek (1964) according to molluscs associations and paleosols: climate was warmer.

Achyuthan, H. (2007) stabile isotopes in soil carbonates below the Tsar desert cover are typical for more humid climate.

River Ob: in Riss/Würm (Eem interglacial) was steppe, up to early Würm (75,000 years BP). Würm (last glacial) – climate oscillations. Recent Holocene is tundra (Nývlt et al., 2003). I.e. the last interglacial was warmer than our Holocene climate.

The longest interglacial in Late Pleistocene, China loess (500,000-470,000 BP) temperature by 4° C to 6° C higher than recent (Zhao, 2003).

Paleosols of Vertisol type and their CaO and MgO indicate the climate change, especially its mean annual precipitation in Late Pleistocene and in transition to Holocene. Several wet and dry periods were detected (Nordt and Driese, 2010).

Stable C isotopes are measured in soil organic matter in order to determine the ratio of C_3/C_4 plants as indicators of climatic conditions in early Holocene and in late Pleistocene (Kelly et al., 1998), where the role of CO_2 was found as negligible.

Last interglacial Riss/Würm (Eem): Temperature was higher by at least 3°C than in our recent interglacial (Holocene), lasting for more than thousand years. CO_2 concentration was below 300 ppm.

4. Ten Additional Proxy Methods of Climate Change (Proxies)

1.Concentration changes of isotopes ^{2}H, ^{18}O in core drillings in glaciers. $^{18}O/^{16}O$ is lower in cold climates.
2. Concentration change of the isotope ^{10}Be in sediments or ice, solar activity.
3. Ratio of stable isotopes in soil organic matter.
4. Pollen analysis (palynology) - the dominant plants – long lasting climatic conditions.
5. Tree-ring width and density records (dendrochronology).
6. Isotopic ratios of corals - surface sea temperature.
7. Change in annual lake sediments (varves).
8. Change in growth of stalagmites in karst caverns and isotopic ratios.
9. The size of lichens.
10. Buried fossils of mammals, some insects related to climatic zones.

5. Climate of the Pleistocene

The Milankovitch cycles had the dominant influence upon the change of glacial/interglacial periods. Deep ice drilling (Antarctic glacier: Vostok, EPICA and Greenland glacier) show that the peak of CO_2 was delayed – arriving every time after the peak of the temperature. The CO_2 concentration rose by 80 up to 100 ppm (from 180 up to 290 ppm) with a time delay up to 600 ± 300 years during the last four interglacials.
EPICA to the depth related to 820,000 years BP, 9 glacials.
25 climate oscillations in the last Würm (Wisconsinan) glacial.

Temperature/climate oscillations were caused by other factors than CO_2 change.

E.g. According to Vostok data in the last 400,000 years:

CO_2 falling, T const – two times
CO_2 rising, T const – two times

CO_2 const, T falling - once
CO_2 const, T rising - once

6. Climate of the Holocene (11,500 BP up to present)

Transition from the last glacial to our recent interglacial (Holocene) was realized in several steps: 1. Warming about 15,000years BP.

2. Cooling, Older Dryas.
3. Warming after Older Dryas was 0.79^{o}C/100 years. Twice more than the recent rate.
4. Cooling, Younger Dryas.
5. Final warming and start of Holocene, 11,500 years BP.

Dates locally shifted, regional slight variations.

Holocene climate: variation of warm and cool periods. In Greenlands ice cores:
20-years averages: 13 warm periods, frequent doubling of temperature peaks.
500-years averages: 8 warm periods, 8 cool periods.

7. Eight Factors Involved in Climate Change

Astronomic factors: Milankovitch cycles.
Astronomic factors: Solar activity.
Continental drift .
Greenhouse gases.
Thermo-haline circulation.
Aerosols, volcanoes, asteroids
Vegetation cover
Earth´s magnetic field

8. Conclusions on the Greenhouse Hypothesis

Based on climate experiments performed by nature itself in Late Pleistocene and the Holocene, the Greenhouse Hypothesis was found to be not valid.

The CO_2 air concentration never rose above 300 ppm in the 8 Holocene warm periods with average temperatures above the recent maximum. Factors other than the greenhouse effect played a role in the warming. Therefore, the hypothesis on dominant influence of greenhouse gases upon the global warming has to be rejected.

This rejection scientifically holds even for recent warming.

We accept the existence of the influence of greenhouse gases upon global warming but only as one of many other factors and provided that it is not considered as dominant.

Indeed, the contemporary global warming is a return to roughly the average global temperature of Holocene after the cold oscillation in Little Ice Age.

II. Consequences for Soil Physics

II. GLOBAL WARMING AND RISING CO_2 CONCENTRATION IN THE ATMOSPHERE

1.Characteristics of Recent Global Warming

Graphs from IPCC and from satellite observations are demonstrated and discussed.

CO_2 concentration in the atmosphere: continuous records by Charles D. Keeling (1928-2005) started 1957 at Mauna Loa in Hawaii and in Antarctica at the South Pole. In the 50-year period between 1958 and 2008, the carbon dioxide concentration in the atmosphere increased from 316 ppm to 385 ppm.

The satellite data on global temperature exist from 1979. The correlation between smooth regular rise of CO_2 and the global temperature is poor and in the last decade there was no correlation at all.

2. Climate Change and Ancient Societies

Due to the continental drift a Great Rift Valley in East Africa originated and the climate change caused extinction of tropical rain forest, which was replaced by savanna: one of the important impulses for the evolutionary steps in the direction of Hominids (5-2 myr BP) and finally of Homo (Homo habilis 2.5 myr BP, Homo sapiens cca 0.25 myr BP).

Ancient Egypt

Sahara desert extended more to the south in the last glaciation.
1. But a savanna with plenty of game occupied the region of recent Sahara desert 9,000 to 6,500 years BP due to global warming after the last glaciation. Agriculture started in oasis when savanna was gradually transformed due to climate change into desert (cooling, aridization) between 7,000 to 5,000 years BP. Predynastic Period in the Nile valley (largest nand richest permanent „oasis“), 7,500 to 4,900 years BP.
2. Early dynasties 4,900 to 4,650 years BP. Protection of unified settlements. Start of the hierarchical structures. Urbanisation (= control of the population) was accelerated with. simple writing (hieroglyphs).
3. Old Kingdom.4,650 – 4,150 years BP. Egypt unified. Pyramids: The Step Pyramid symbolised a staircase to the stars. Later the ‚smooth' pyramid was a symbol of sun.
4. First Intermediate Period 4,150 – 3,980 years BP. Weakening of the central power started from the 6th dynasty. Impact of an asteroid. Cooling. Decrease of the Nile floods. Together with weak government resulted in famines and general disorder. Attacks of nomads.
5. Middle Kingdom from 11th dynasty, 3,980 – 3,760 years BP. Nile floods are back. Mild global warming.

Ancient Mesopotamia

First settlements cca 7 kyr BP. Short arid and cool climate oscillation about 7.5 kyr BP was one of the impulses for the migration from the hilly country of the north. Start of agriculture, and irrigation in southern Mesopotamia.
Early Dynastic Period: transformation of pictograms to syllabic writing. Cuneiform writing. Kingdom of Uruk. Aridization and extreme salinization about 4 kyr BP caused the collapse of the state systems. Chaos (Analogy to ancient Egypt).

3. Hydrologic Consequences of Global Warming?

Flooding

River Vistula (Poland), CF catastrophic flood (Cyberski et al.,2008): most frequent catastrophic floods 1840-1905.

Spain in last millennium: most frequent floods 1550-1650 and 1750-1900.

River Vltava in Prague:
During 45-year period (1845-1890 AD), 3 floods greater than 100-year flood.
During the next 110-year (1891-2001 AD) **no** 100-year flood.
But next year in 2002 a 500-year flood!

Common scientific mistake: The natural processes behave like a "roulette wheel"
Not true: Events are clustered, neither normally nor log-normally (etc. of distribution patterns) distributed in time, especially under the observed change of climate.

Additionally: the classical downscaling methods are not applicable due to the non-stationarity of processes.

Damage by floods
The river morphology (regular bed) is determined by relatively low flows ($T \approx 1$-2 years).
Areas close to the regular riverbed, but within the flood plain ($T > 2$ years), have been regarded as safe lands for housing and other activities.
Thus, even moderate flood events (e.g.10-year flood) cause big destructions due to mistaken planning.

4. Evapotranspiration When CO_2 is Increased

Photosynthesis: carbon dioxide (CO_2) and water (H_2O), in the presence of light and chlorophyll form sugar ($C_6H_{12}O_6$) and oxygen (O_2)

$$6CO_2 + 6H_2O \xrightarrow[\text{chlorophyll}]{\text{light}} C_6H_{12}O_6 + 6O_2$$

Role of stomata:
1.Conductivity, resistance
2.Number
3.Transpiration

Examples of experiments (M.B.Kirkham, 2010):
Role of CO_2 concentration (= partial pressure) upon 1.conductance 2.assimilation of CO_2.
Role of CO_2 concentration upon diffusion resistance and transpiration.
Stomatal density has decreased as CO_2 concentration in the atmosphere has increased.

5. Desertification

Extension of deserts in Pleistocene is closely correlated with the global cooling of the climate. Examples:
Existence of Sahara desert in the past and now.
Tsar desert on Indian subcontinent.

6. Implications and Goals for Soil Physicists

Global warming will continue, climate oscillation periods may occur.
Annual precipitation values shall tend to increase if global warming persists.
Traditional rainfall distribution patterns statistically characterized for last two centuries may change.
The consequent change of subtypes of soil water regime is probable.
Cluster linking as well as frequency scaling in soil water regime are not applicable due to the non-stationarity of boundary conditions.
The consumptive use of water by C_3 plants will be reduced provided that CO_2 concentration continues to increase and global warming continues, too.
The scarcity of good quality water induced by humans may contribute to reduced use of irrigation systems.
Concepts and methodology of soil physics research shall change:
We expect decreasing use of randomly treated small plots on selected soil domains.
We expect increasing use of measurements of soil, plants and environment across the landscape at different scales of space and time

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