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The Human Impact on Climate.
New Evidence from Observations.

As far as we know, we live on a planet which is unique throughout the entire universe. This holds true not only for water and soil but also for the specific characteristics of our atmosphere. These unique components allowed for the development of our climate which is characterized by favourable conditions with respect to temperature and precipitation. This, in turn, allowed for the development of life on Earth in its diversity as we know it today.
However, climate is not a constant. Natural mechanisms like volcanic eruptions, solar activity, or the El Niño phenomenon identifiable by episodic warmings of the tropical oceans, repeatedly caused climate variations. Since the industrial age, which means the past 100 to 150 years, a new global impact on climate was created: mankind. This is due to additional emissions of carbon dioxide and other climate-active trace gases causing in addition to the natural „greenhouse effect" an anthropogenic, that means man-made greenhouse effect.

What does this mean for our climate? Is it possible that the human impact on climate is already more influential than natural climate change? - To answer this extremely difficult question it is broadly accepted to use the most highly sophisticated climate models available at this time. These are models simulating the movement processes within the atmosphere interacting with those of the ocean called „coupled atmosphere-ocean general circulation models".

Such models have been used to compute climate variations due to increased concentrations of „greenhouse gases" within the atmosphere.

However, no model is able to reproduce reality exactly. Rather, it is only possible to more or less approximately simulate the climate response to any forcing. Consequentially, the results of computer climate modelling are not necessarily reliable.

Nevertheless, the results of these simulation modells concur - at least quantitatively - with respect to the following forecast: As a result of the relatively recent man-made "greenhouse-effect" the lower atmosphere will warm up by the end of this century on a global average by a few degrees of centigrade. There is notable consensus amongst experts concerning this assumption.

But is there also consensus regarding the question whether man-made global warming is identifiable in the observations?
To find an answer to this question, the global network of measurement stations was used and it can be stated that there is a fair amount of concurrence between the observed global mean surface air temperature increase and the model projections. It is unlikely that these parallels are purely incidental although it is not yet clearly

understood, to what extent natural climate variability may have contributed to the global warming observed.

If we say that mankind has an influence on the global climate – which is probable, based on the findings so far, - exact quantitative statements are still lacking. And, will global warming happen uniformly or will there be some regional differences? Will global warming even be superimposed by regions which cool due to human impact? What will be the response of climate elements other than temperature? For example, will there be some regions where precipitation increases and other regions where precipitation decreases?

What will be the exact magnitude of man-made climate change, particularly in comparison to natural climate change?
Although these questions cannot, as of yet, be answered unequivocally, even when using the most sophisticated computer-driven climate models. They are however important and urgent with respect to ecological, economic, social and political issues. We therefore cannot wait until the usual climate models are able to provide undoubtely clear and exact answers.

This is why a new research project was initiated by the Institute for Meteorology and Geophysics at Frankfurt University in Germany. Commissioned by the Federal Environmental Agency this research project aims towards answering the following question: Which part of the observed climate variations is caused by which known forcing factors, both natural and anthropogenic?

The scientists performing this study started with the presupposition that different forcing factors of climate change should show particular signs within the time series of overall observed climate change.
On the one hand, these are the effects of known natural forcing like

- solar activity,
- volcanism,
- El Niño, and with respect to Europe also
- the North Atlantic Oscillation specifying the atmospheric circulation pattern in this region.

On the other hand, the effects of known anthropogenic forcing have to be taken into account, in particular

- the anthropogenic greenhouse effect leading - on a global average - to a warming of the lower atmosphere, and
- the anthropogenic effect due to aerosol particles formed by sulphur gases and leading - again on a global average - to a cooling of the lower atmosphere.

A third climate variability component shows some structure so that it is not due to random forcing but the forcing factors are not known.
A fourth and last variability component may be chance. This should be indicated by non-structured climate variations as it is typical for random processes. So, the scientific task to be solved is to consider as many climate element observational time series as possible, to classify them into components which can be related to the different natural or anthropogenic forcing factors. Two components will however remain, one structured but due to unknown forcing and another unstructured and therefore random.

In order to do so, the Frankfurt research group developed a strategy which allows registering the individual as well as the joint effect of different forcing factors on climate by means of common statistical analysis techniques.
This strategy is based directly on the observed time series of surface air tempereature, precipitation and mean sea level pressure.

For example, considering the global mean annual surface air temperature variations since 1899, this classification specifies the variation components

- due to anthropogenic forcing,
- due to natural forcing,
- a structured variation component due to unknown forcing, and
- an unstructured variation component which appears to be random also called “climate noise“ wheras the variation components due to known forcing are called “climate signals“.

Now, it is possible to combine and to compare these different climate variation components. For example, the anthropogenic components and all the natural forcings can be combined and become the explained variance. On the other hand the natural components and climate noise can be combined as well.
In comparing these two combined time-series, it is now possible to tell which part of climate noise differs less from the natural variability than the anthropogenic component.Therefore a measure becomes available which quantifies the anthropogenic signal in observational climate data.

Again let’s take a look at the example of the observed annual global mean temperature variations. In addition, we can see which data appear within particular thresholds of probability. One noticeable result ist that 99% of these interannual data are within the releated thresholds of probability. This means that only once within 100 years are these thresholds exceeded by chance. Corresponding to that, the 99.9% thresholds are exceeded once within 1000 years by chance.
Now, we’ll plot the related temperature curve representing the signal due to the anthropogenic „greenhouse effect“ in red. We recognize that since 1966 this signal time series leads to a temperature increase deviating from the natural temperature behaviour as it occurs by chance only once within 100 years. Since the year 1973 this temperature increase explained by the anthropogenic greenhouse effect has reached a threshold which occurs by chance only once within 1000 years. This means the anthropogenic greenhouse signal is detecteded in the year 1973 at a probability level of 99.9%.
In addition to the greenhouse gases mankind emits sulphur gases in the atmosphere which, as already mentioned, form cooling sulfate particles. The related temperature signal time series is plotted in blue.
If we consider both of these anthropogenic forcings combined, it can be concluded that since 1990 this joint influence exceeds the 99% level of randomness and since 1994 the 99.9% level. The human impact on climate is therefore, clearly identifiable.

Now let’s look at the global surface air temperature pattern which is divided into 80 subregions, each of equal area. For 72 of these subregions the annual means of temperature data cover the period of time from 1894 to 1995. Measurements from the Antarctic region are more recent.

Using additional statistical techniques (called empirical orthogonal functions) it is possible to identify the anthropogenic greenhouse signal within this data field and simultaneously to account for the relationships between these different subregions. Now we'll show the development of temperature change in centigrate due to the anthropogenic „greenhouse effect", the „greenhouse signal".

In nearly all subregions, a warming is detectable due to this effect, reaching in the year 1995 its maximum of 1.7 degrees centigrade in Central Asia. However some cooling also appears, for example in the North Atlantic region.

The striking point, however, at this step of analysis, is: How much do these warmings differ from random change of climate? In other words: How probable is the anthropogenic climate change within each of the subregions of the Earth?
We see that in the year 1967 in one of these subregions the probabilty of 90% is exceeded for the first time.

By the year 1995 a clear picture arises: In 19 out of 72 subregions the probability that a climate change has occurred due to the anthropogenic „greenhouse effect" has reached a level of 99%, in 42 subregions 95%.
It is worth noting that the detection of anthropogenic climate change is not necessarily successful in those subregions where the largest amounts of warming take place, but rather in those subregions where simultaneously random climate variability is small. This is why the highest probabilities of an anthropogenic climate change are located within the oceanic and tropical regions.

Now we'll take close look at Europe. The temperature pattern in this case, is divided into 52 subregions, relating the period of time from1899 to1998.

The developement of the anthropogenic greenhouse effect shows a large-scale warming of increasing magnitude.

It reaches it's height in Northeast Europe in 1998, amounting to nearly 1.7 degrees centigrade. Again, a cooling signal is attributed to the North Atlantic subregion.

How much do these European warmings resulting from the anthropogenic greenhouse effect differ from random variations?
The 90% probability level is exceeded in the year 1985 for the first time.

In 1998, within 11 subregions this probability amounts to 90%, within 4 subregions 95%. This means that on an European scale, anthropogenic climate change is once again detectable in the temperature data. However, not so pronounced as on a global scale.

Finally, we'll take a look at European precipitation. This pattern was analysed with respect to the annual precipitation totals from 1900 to 1998. The data field is divided into 83 subregions.

The development reveals a precipitation increase in widespread parts of Northern Europe. In contrast, more dryness in the Western Mediterranean is observed.

However, due to the fact that in the case of precipitation, climate noise exhibits a very large amplitude, it is not possible to detect the related anthropogenic climate change at an acceptable level of probability. In 1998 this probability exceeds the 90% level in only in 2 out of 83 subregions. But this may be incidental.

Despite all the difficulties and problems remaining, it can be concluded: Human impact on climate is detectable in the observational data of the past with a high level of certainty. Serious risks for the future result. The consequence of this can only be: effective climate protection measures at an international level of cooperation in the near furture. This is our responsibility to the Earth and to mankind's future generations.