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Life on a Climate Roller Coaster

Climate change is radically altering the Earth's plant and animal life. This is due not only to the rise in mean temperatures throughout the world, but also to the changes in temperature variability between both day and night, and summer and winter. **George Wang**, a scientist at the **Max Planck Institute for Developmental Biology**, analyzes climate data with a view to researching the influence of the altered conditions on flora and fauna.

TEXT **UTE KEHSE**

November is not a pleasant month in Germany. It is usually chilly and damp, gray and dismal. The trees lose the last of their leaves, shrubs wither, and many animals seek out a place to hibernate for the winter. In late autumn 2014, however, nature perked up again: forsythia blossomed luxuriously, hedgehogs trotted perkily through gardens, and strawberry plants grew new buds.

What had gone awry? "The unusually mild temperatures sent the wrong signal to the plants," says George Wang. Last year's late autumn had a very spring-like feel to it – possibly indicating that the temperature differences between the seasons are diminishing. In temperate climate zones, however, the temperature is an important indicator for plants when it comes to which season currently prevails. If the thermometer rises above 20 degrees Celsius, the plants assume that spring has arrived, and form blossoms or new shoots, even in November. This is, of course, a poor investment: as soon as the next night frost arrives, the small delicate leaves die. Wang, a biologist at the Max Planck Institute for Developmental Biology in Tübingen, sees the impacts of the weather quirks in late 2014 as indicative of a possible trend that he recently discovered: "We could experience similar events more often in the future," he says.

The correlation between the weather and the physiology of living organisms is George Wang's specialization. He is interested in how climate change affects animals and plants, and what impact it has on evolution. "All physiological processes depend on the temperature," says the American-born researcher with Taiwanese roots. He has been working in Tübingen for four years.

Biochemical processes unfold faster at higher temperatures, so the metabolism of cold-blooded, or poikilothermic, animals accelerates. Populations of

Day and night in the context of global change: Daily temperature variations are rising throughout the world due to climate change. This can have wide-ranging ecological consequences, also for forests.

Sensitive to climate changes: The movements of migratory birds (above) are influenced primarily by the weather and short-term climate variations. The fact that the seasonal temperature differences are declining at temperate latitudes also has an impact on plants: When a frosty snow day follows a warm winter, blossoms, like those of the forsythia bush (below), could succumb to frost more often. The energy the plant invested in flower formation is thus wasted. The energy requirements of tropical organisms can also increase with climate change: even minimal temperature increases cause the metabolic rate of reptiles to rise, for example in the monitor lizard (bottom).

some insects reproduce considerably faster when it is warmer. Other animals don't tolerate high heat at all. As a result, when temperatures change, ecological relations also change – for example, the food available to birds in particular months, or which insect can pollinate a particular flower. Wang discovered an example of this kind of correlation four years ago. With his American colleagues Michael Dillon from the University of Wyoming and Raymond Huey from the University of Washington in Seattle, he calculated how climate change affects the metabolism of poikilothermic animals in the tropics. Their surprising finding: Although temperatures in the tropics have scarcely risen since 1980 – they increased by just a few tenths of a degree Celsius – this small change was sufficient to cause a significant rise in the metabolic rate of reptiles, amphibians and invertebrates. According to the scientists' calculations, it increases just as much as that of animals in moderate climate zones where increases in temperature have been considerably higher. "This is due to the fact that the metabolic rate is exponentially dependent on the temperature," reports Wang. For tropical lizards, amphibians and insects, this means that, as temperatures rise, they need considerably more food and may have less energy available for reproduction.

TEMPERATURE CYCLES IN GLOBAL CLIMATE CHANGE

Dillon and Wang would also like to have studied the future development of the tropical animals' metabolic rate. However, during their work they encountered a typical problem: because the influence of the temperature is non-linear, it is not sufficient to rely on mean temperature forecasts. "If you want to study questions relating to ecology, you must also take tempera-

Photos: iStockphoto - jantrettenero (top), BIOSphoto/images.de (middle), shutterstock (bottom) ture variations into account," stresses Wang. Such studies, however, were rare up to now.

"Some colleagues have studied changes in the case of extreme temperatures, but in that case, too, the values were mostly averaged out," he says. Yet the lives of most animals and plants are influenced mainly by short-term variations, such as the change in temperatures from day to night. The seasons also play an important role for flora and fauna – particularly in the lives of the numerous organisms that exist for only a couple of days or weeks.

To date, very little was known about how these cycles have changed over the course of the global change that has unfolded in recent decades. "Such high-frequency climate variability is difficult to characterize as, in many cases, the resolution of the available data is insufficient, and there is also a lack of suitable analysis techniques," explains Wang.

He had already encountered this problem back in 2007, during his doctoral research at the University of Washington. At the time, he was studying a favorite model animal of biologists, the fruit fly *Drosophila melanogaster*. He wanted to find out how the insect reacts to heat stress – and to predict how its behavior will change as a result of climate change. "But it wasn't possible because the corresponding climate data wasn't available," he reports. Together with Michael Dillon, Wang found a solution to this problem.

The mathematical method of choice for identifying periodic changes in larger volumes of data is the Fourier transformation. "But it only really functions with perfectly sampled data," says Wang. Climate data is notoriously incomplete and inconsistent: one weather station may measure the temperature on an hourly basis, while another may do it only every four hours. In addition, gaps constantly arise in the data because sensors fail or are undergoing maintenance.

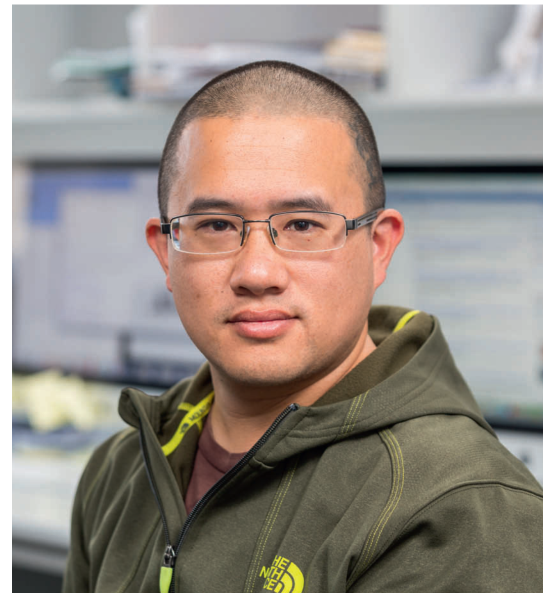
Because similar problems also occur in astrophysics, Wang and Dillon made use of a mathematical model that was previously used mainly in that field to identify the high-frequency cycles in climate data. They presented their findings in the journal Nature Climate Change in September 2014.

DATA FROM ALMOST 8,000 WEATHER STATIONS

The fact that biologists must be able to handle large volumes of data and program them themselves is something that Wang takes entirely for granted: "There is no way around this today." For their study, he and Dillon amassed over one billion temperature measurements. The data originated from almost 8,000 weather stations throughout the world, and had been recorded between 1926 and 2009.

Due to the enormous volumes of data involved in their study, the two researchers had to monopolize several supercomputers in Germany and the US. They started by extrapolating the mean temperatures from the measurements, along with the daily and seasonal temperature variations at different latitudes. The mean temperatures they calculated reflected the Earth's climate zones: In all of the tropics – that is, between the latitudes of 23 degrees north and south of the equator – averaged over the year, the same temperature of around 25 degrees Celsius prevails. The further north or south one moves, the colder the annual mean temperature becomes.

However, the daily temperature variability doesn't follow a clear trend from the equator to the poles: Averaged over the entire period for which the researchers analyzed the weather data, the daily temperature fluctuations were lowest at higher latitudes. In the temperate zones, they reach peak values of up to 15 degrees Celsius. In the tropics, the difference is consistent in all locations, at around 6 degrees.



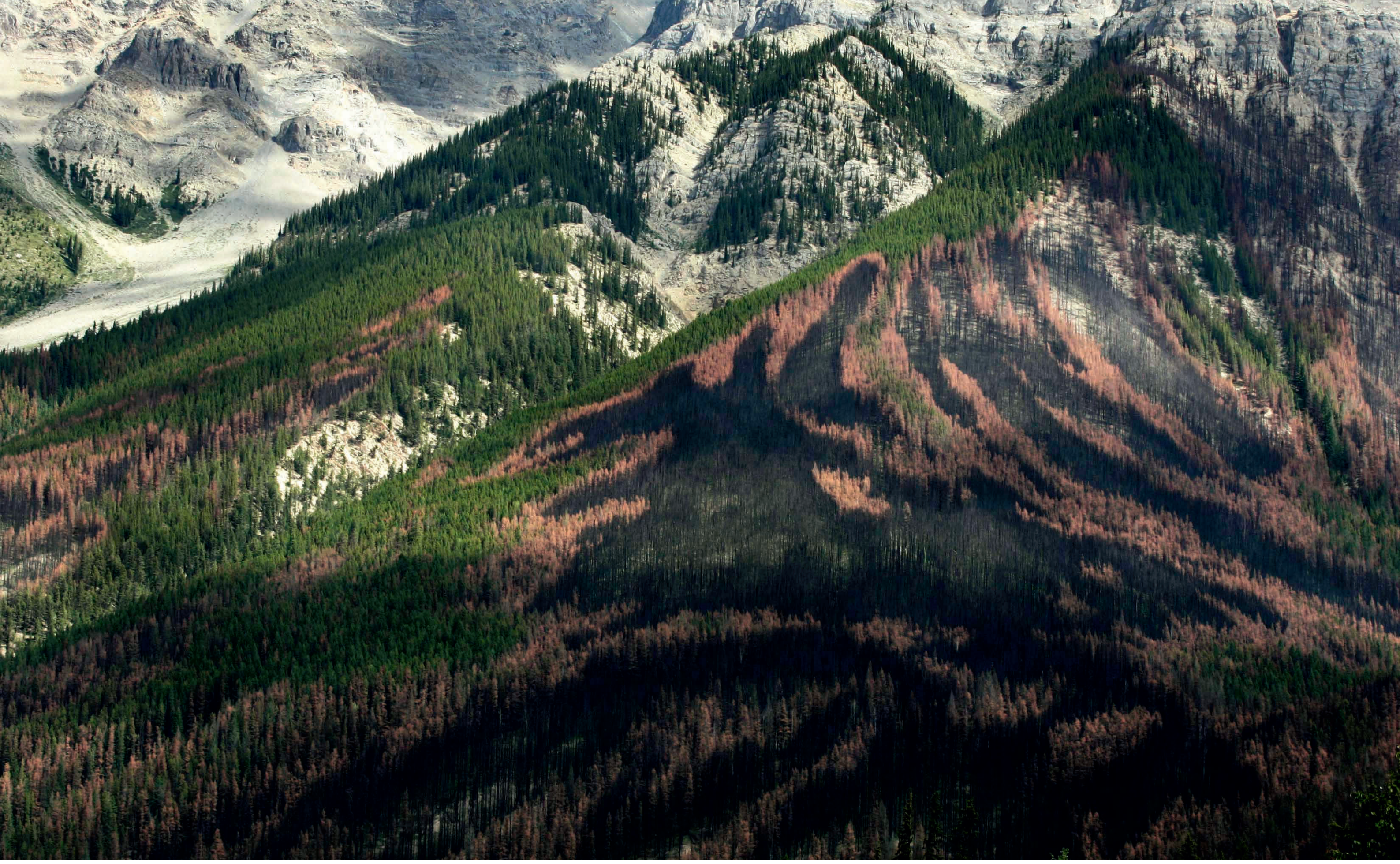
Climate research for biology: George Wang studies global changes in temperature cycles and their impacts on flora and fauna.

The seasonal fluctuations, in contrast, follow a completely different pattern than the daily variability: they are strongest at high latitudes and barely noticeable around the equator. In individual locations in Siberia and Canada, for example, summer and winter temperatures can differ by over 60 degrees Celsius. In the southern hemisphere, temperatures generally fluctuate less between summer and winter – presumably because the land masses there are smaller and the influence of the oceans therefore greater.

In order to identify the latitudes at which the daily and seasonal variability is more significant, Wang and Dillon created a new mathematical parameter that correlates the variability of the two cycles with each other.

As their evaluation showed, the tropics, moderate zones and high latitudes can be differentiated from each other not only on the basis of their mean temperatures, but also through the relationship between their seasonal and daily temperature cycles: the dif-

Photo: Jörg Abendroth for the MPI for Developmental Biology



A bonus for pests: Some animals found at higher latitudes, like the mountain pine beetle, adapt to the rising temperature differences between day and night. They can then tolerate lower temperatures, too. Accordingly, these bark beetles now produce two generations of pests in America each year and damage considerably more trees. To stem the losses, infested forest areas are destroyed in controlled fires.

ference in temperature between day and night in the tropics is greater than that between summer and winter. The seasons thus play a subordinate role for nature here. Plants flourish and blossom all year round, and animals don't undertake any major migrations.

Nevertheless, the calculations revealed that, when considered for an entire year, the temperatures don't follow such a smooth course throughout the tropics as was previously assumed. It is only within a few degrees latitude north and south of the equator that seasonal variability is practically nonexistent.

The further one moves away from zero degrees latitude, the greater the influence summer and winter exert – even if the mean temperature remains as high as it is at the equator. "Our analysis reveals that the seasonal temperature variability within the tropics is changing considerably depending on the latitude – with unknown ecological consequences," says Wang.

FLORA AND FAUNA IN THE RHYTHM OF THE SEASONS

The ratio between seasonal and daily temperature variability is almost exactly reversed at the tropical boundaries: Within the tropics, the variations are more or less equal. In the temperate zones, in contrast, temperatures vary over twice as much over a year than over the course of a day. "In Germany, it's maybe 10 degrees colder at night on average than it is during the day, while the temperature difference between summer and winter is around 25 degrees," reports George Wang. As a result, the animal and plant worlds are subject to distinct seasonal rhythms.

Wang and Dillon then examined how the temperature cycles changed globally between 1975 and 2013. Their data confirmed the already-known global temperature rise: During this period, the greatest temperature increase, 1.2 degrees Celsius, occurred at the poles. Temperatures in moderate climate zones increased by 0.7 degrees, and in the tropics, by just 0.4 degrees.

To the researchers' surprise, daily temperature variability also changed significantly over this period – and it followed the same pattern: The strongest variation also arose at the poles, with the difference between night and day temperatures there having increased by 1.4 degrees Celsius. The cor-

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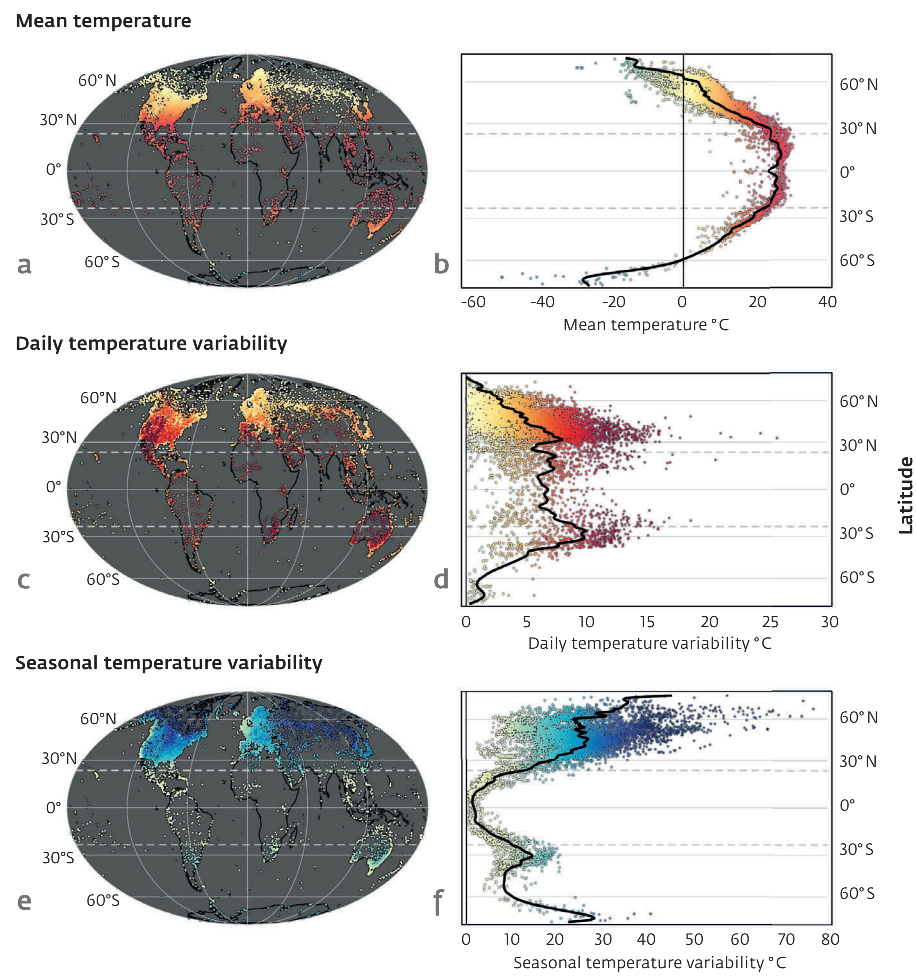
responding increases in the temperate zones and tropics were 1 degree and 0.3 degrees, respectively. In contrast, the seasonal temperature variations at the poles and temperate zones declined until around 2010, and moreover by 1.4 and 0.3 degrees Celsius, respectively. In the last three years of the analysis, the values rose again slightly, while there were few changes in the tropics.

According to Wang and Dillon, their data indicates a shift in the climate zones: "Daily and annual variability at higher latitudes have converged – the temperature variations have become more tropical, as it were," explains Wang. However, this doesn't necessarily mean that the seasons are disappearing, he emphasizes. Overall, the global temperature distribution is flatter – the differences between the different climate zones are diminishing.

The two biologists don't have an explanation for this phenomenon. "We aren't climate researchers," stresses Wang. Whether or not these changes can be explained by global warming thus remains unclear. Long-term shifts in the atmospheric air flows may play a role here, as may a phenomenon known as global dimming. Measurements show that, between 1960 and 1990, there was a progressive decline in the amount of direct solar radiation reaching the soil surface, possibly due to the increase in air pollution.

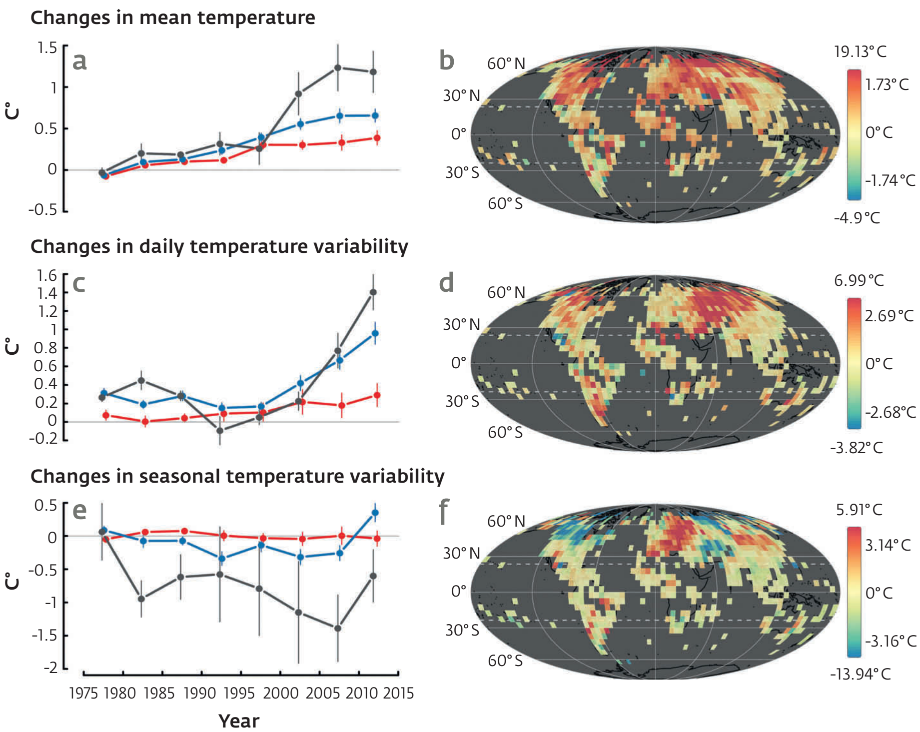
However, this trend has been reversed since 1990, and more sunlight is reaching the soil surface, particularly at higher latitudes. In a comment published in Nature Climate Change, climate researcher Alexander Stine from San Francisco State University suggests that this may have contributed to stronger variations in the daily temperature course.

George Wang is interested in the ecological consequences of these changes. They could be wide-ranging – for humankind, nature and agriculture. For example, it's possible that short-lived insects that emerged only in moderate zones in the warm season could, in the future, thrive throughout the year. "Increasing temperature differences between day and night creates an evolutionary pressure that forces the animals to endure greater temperature variations," explains Wang. "As a result, their physiology could also adapt to the winter weather." In the US, for example, the mountain pine beetle can now produce two generations per year rather than just one, as was previously the case. Consequently, these insects are infesting considerably more trees, and have left a veritable trail of destruction in parts of the Rocky Mountains in recent years. >



A profile of the climate zones: Based on over 7,900 weather records, the scientists examined how the variations in temperature correlate with geographical location. The diagrams on the left present the results per weather station in color. The mean temperature, which declines in the direction of the poles (a,b), was established. In terms of the long-term mean, the temperature variations between day and night are the lowest at the poles and highest at temperate latitudes; they are around six degrees on average in the tropics (c, d). The differences in seasonal variability decline toward the tropics (e, f).

Graphic: Nature Climate Change, 4/2014



Climate change documents: Temperature measurements between 1975 and 2013 reveal different changes in three climate zones: polar region (gray), temperate latitudes (blue) and the tropics (red). The diagrams on the right show the differences between the first and last records in the series. According to the study, the greatest increase in mean temperature (a, b) occurred at the poles, while it scarcely rose at all in the tropics. The rise in the temperature variability between day and night is also highest at the poles and lowest in the tropics (c, d). In contrast, the temperature difference between summer and winter (e, f) at high latitudes has declined considerably since 1975 and remained unchanged in the tropics. The trend at temperate latitudes is not yet clear.

Graphic: Nature Climate Change, 4/2014

The transmission of the malaria pathogen is also dependent on daily variations in the temperature, as a study carried out in 2010 revealed. Another study demonstrated that the movements of migratory birds are influenced mainly by the weather, and less by long-term climate trends. Research has also revealed that the wintering strategy of thale cress, an important model plant studied by biologists, depends on both environmental signals and genetic factors. Thus, greater temperature variability could also generate evolutionary pressure for plants.

Most of the department to which George Wang belongs focuses on the molecular mechanisms that control plant adaptation: “We examine genetic variations at the boundaries of genetics, genomics and ecology,” explains Detlef Weigel, Director of the Molecular Biology Department at the Max Planck Institute in Tübingen. In terms of his research topics, George Wang is something of an exotic species within the group.

The fact that he ended up in Tübingen at all was due to personal reasons: Detlef Weigel brought Wang’s wife, molecular biologist Beth Rowan, to Tübingen in 2009. Wang followed her from Seattle a year later and also found a position in the department. “It’s a large and diverse group. You have a lot of freedom here and can work together with great people,” says Wang.

The biologist, who grew up in Los Angeles, has no regrets about moving from the US West Coast to tranquil Swabia. “Tübingen is wonderful,” he says – and singles out the childcare available in the university town for particular praise. The fact that the temperatures in Germany aren’t as pleasant as those in California – and that winter here sometimes brings snow and double-digit sub-zero temperatures – isn’t a major issue for him. ◂

TO THE POINT

- Climate change has wide-ranging ecological consequences, not only due to the rise in mean temperatures, but also because of changes in the temperature variability between day and night and between the seasons. This can affect the metabolic rate of poikilothermic animals.
- To be able to study the future influence of climate change on flora and fauna in detail, George Wang from the Max Planck Institute for Developmental Biology and Michael Dillon from the University of Wyoming used climate data to analyze high-frequency temperature variability between day and night and summer and winter.
- The different climate zones, namely the tropical, temperate and high latitudes, can differ in terms of both mean temperatures and short-period temperature variations. The influence of the day-night cycle dominates in the tropics, while the influence of the seasons is more important at temperate latitudes and the poles.
- It is assumed that the short-term temperature variability is changing due to climate change: As with mean temperatures, since 1975 the greatest increases in daily temperature variations have been recorded at the poles, and the smallest in the tropics. In contrast, seasonal variability has presumably decreased especially at high, but also at temperate latitudes. Consequently, short-period temperature variations at higher latitudes are converging with the patterns that prevail in the tropics.