Solar UV radiation as a major factor in the premature degradation of plastics in outdoor applications

Plastics are organic materials which age and deteriorate under the influence of temperature, oxidation, mechanical stress or solar radiation. This degradation can affect the surface properties (e.g. discoloration, gloss-change or loss of desired haptics) and in the worst case, weaken mechanical properties (especially impact properties).

From the early stages of the 20th century, material producers and converters held a wish to be able to systematically determine the weathering characteristics of a polymeric material. By doing so, it would enable the appropriate comparison of different stabilization systems and provide an estimate on the achievable lifetime of a given plastic.

Several key players in the value chain began to initiate tests that exposed the materials to the outdoor environment and this created data that was then used for predicting the lifetime of the finished materials. It was soon apparent that the samples weathered at different rates at the different sites. This demonstrated and confirmed the importance of understanding weather conditions in combination with exposure time.

This lead companies began to consolidate testing and focused activity only at sites which were known for their severity of weathering, having similar weather-profiles throughout the year (basically "stable" and "repeatable" weather) as well determining the potential end market for the products.

It is important to identify the targeted market area of the end material when selecting suitable sites and the associated climates for weathering tests. Each class of material is sensitive to a specific group of environmental parameters: humidity (rain or saltwater can cause corrosion of metal). In the case of plastics and coatings, ultraviolet radiation, temperature, and moisture can quickly lead to material degradation.

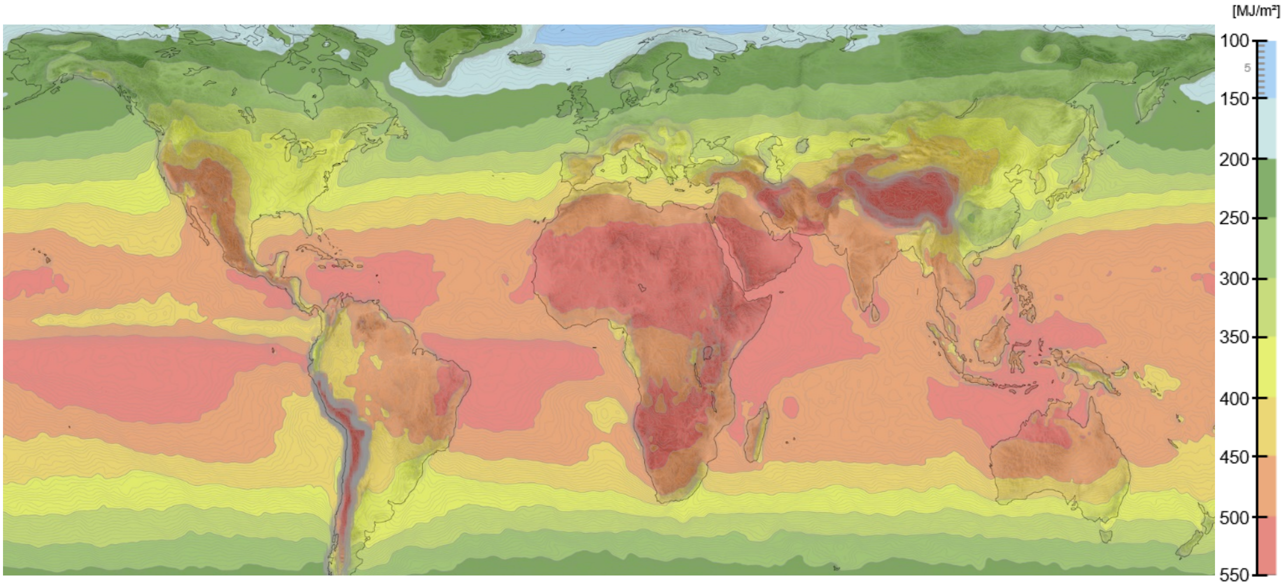

Figure 1: Visualization of the UV-irradiance on the earth-surface in the spectral range of 290 – 400 nm; depicted is the dose of the full year 2015

The experience confirmed that with better evidence of the weathering effect in different climate zones, e.g. tropical areas (hot and humid, e.g. Florida) or arid/desert areas (hot and dry, e.g. Arizona, Kalahari) a clearer understanding of the different failure mechanisms can be achieved. Resulting from this, two standard weathering sites have now been established. Miami, Florida and Phoenix, Arizona have established themselves as THE benchmarks for climate sites due to their stable climatic and weather conditions (summer vs. winter as well as stability over different years).

By measuring the exact spectral solar radiation at these sites, the degradation of the plastic material can then be correlated to the level of solar irradiance. By extrapolating measurements taken from the two reference sites in relation to other locations in the world, the spectral solar irradiance level of the desired target site can be identified or approximated. Solar radiation maps visualize the necessary parameters (Figure 1) and are a major tool for Application Specialists to determine the required stabilizer formulation of a polymers in its final application. It is important, that the irradiance levels from the reference site and the desired application site, are measured in the exact same spectral range, otherwise the “solar load” of the two places cannot be compared.

This is a major drawback of many solar radiation maps, commonly found in books or on the internet. The spectral ranges used to generate these maps are often not disclosed or optimized for a specific application, e.g. solar energy-harvesting. As the spectral sensitivity of a polymer is not identical within the spectral range from which a solar cell generates energy, such solar energy-harvesting maps cannot be used to judge the degradation of a polymer based on solar stress. Only maps which take exactly the area of the solar spectrum that damage a polymer into consideration, can reliably reflect the different lifetimes of a material across different regions of the world.

The capability to interpret durability data obtained on one side of the world and transfer this know-how into adapted products into other markets in other regions is gaining importance. Globalization is impacting all businesses, including the plastic industry. Well established market players are focusing on growth by exploring new opportunities in other regions. UV radiation mapping can help them to fulfil these market needs by adapting their formulations, products and portfolio to the specific local requirements and practices, while avoiding potential issues and remaining economically competitive.

BASF Plastic Additives support customers with global coverage UV-radiation mapping tool

As a leading additive supplier to the polymer industries, BASF continue to develop new products and advance the scientific and technical know-how required for the optimization of stabilizer formulations that shorten the development time for new market solutions.

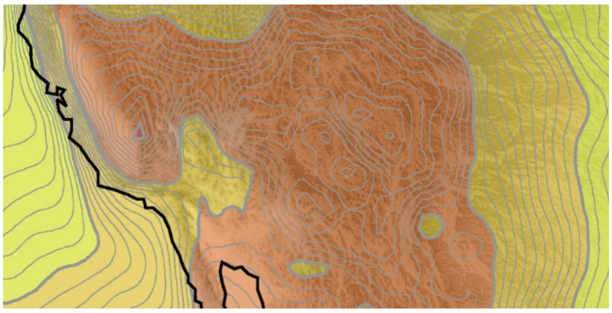

Figure 2: Visualization of the lateral resolution of the UV-radiation map: 1 pixel = 7 km; at this zoom-level the thickness of a thin 5 MJ/m²-iso-line equals 2 pixel
Map shows dose of full year 2015; scale identical to Figure 1

The global UV-radiation mapping tool helps BASF and its customers to predict the local solar UV-radiation for any coordinate on the earth’s surface. With its advanced accuracy, it provides resolution down to city level (5 – 10 km lateral resolution), revealing previously unknown microclimates of elevated UV-radiation (Figure 2). This capability helps the BASF customers to better understand local weathering behaviors and product durability requirements, optimize additive formulations, improve service life prediction and reduce product failures and potential warranty claims.

BASF Plastic Additives collaborated with the German Aerospace Center (DSLR) and NASA Goddard Space Flight Center to create the data required to ensure a high-level accuracy. The leading scientists at the two agencies have created an extensive set of global maps that highlight the radiation levels in all regions of the world.

BASF Plastic Additives' leverages on the Big Data collected from satellite and ground station measurements to create a dynamic UV-radiation specific modeling tool. The current model works on the spectral wavelength of 290 – 400 nm and depicts the UV-irradiance (unit: J/m²). In addition to the state-of-the-art geographical resolution, the map dataset also offers a range of timescales - from days to multiple decades. With this accrued data, the dose of UV-irradiance (accumulated UV-energy from starting point of an outdoor exposure to the end) can be calculated at any one place on earth.

Application Specialists at BASF Plastic Additives are now able to predict the expected UV-radiation dose for an application's intended location and designed lifetime in a very accurate and swift way. This enables BASF's customers to be able to precisely match the required type and concentration of the plastic additive to the predicted intensity of ultraviolet UV-radiation, therefore improving the accuracy of lifetime predictions for the plastic materials. Recommendations are optimized for efficient and robust stabilization systems and the risk of failures and claims can be significantly reduced.

Additional positives that have been derived from the project are increased sustainability benefits. By utilizing less resources and adopting tailored engineering, it is possible to design a specific product that contributes to a more desirable outcome by defining the lifetime of the plastic article.

The data map also works with historical data – going back to the first space programs that kick started the monitoring of the earth's environment in the '70s and '80s – it also helps to understand the unexpected failures from the past and therefore delivers improved designs for new applications – this helps to reduce the required time to market, as less "loops" in the "weathering" stages are required.

Small changes in geography can have a significant impact on UV-radiation and thereby aging performance.

Minor shifts in geographical location can impact the weather significantly (sometimes even the climate), the same material can perform or fail differently at different sites. The following examples illustrate actual cases where the map dataset helped to optimize the formulations both in performance and cost, to achieve the desired commercial outcome required by the customer.

A leading producer of high-end luxury goods received consistent complaints from its Middle Eastern customers. Initially It was unclear if these claims were linked to a performance failure of the material properties or to certain behaviors associated with local market conditions (e.g. frequent cleaning with chemicals). For several years the customer received zero claims from Kuwait but regular claims from Dubai and Abu Dhabi.

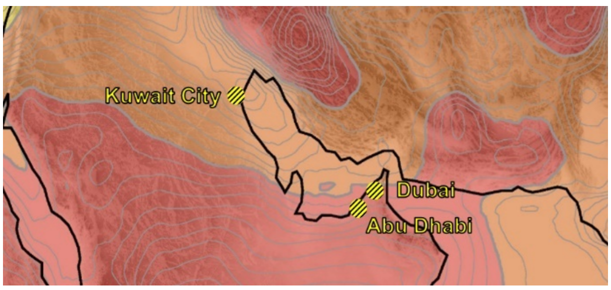

Figure 3: Visualization of the significant differences in UV-radiation between Dubai and Abu Dhabi Map shows dose of full year 2015; scale identical to Figure 1;

The customer turned to BASF Plastic Additives for assistance and by utilizing the data map and analyzing the technical details, it soon became apparent that the claims were linked to a very significant difference of solar stress on the materials. Whilst geographically not so distant, Dubai and Abu Dhabi have significantly higher UV-radiation levels than Kuwait. It was established that the material was under-stabilized to withstand the harsh UV-radiation in both Dubai and Abu Dhabi. Following a re-formulation of the stabilization system, including adjusting the ratio of HALS and UVA, the problems were resolved and the customer has subsequently not received any related claims.

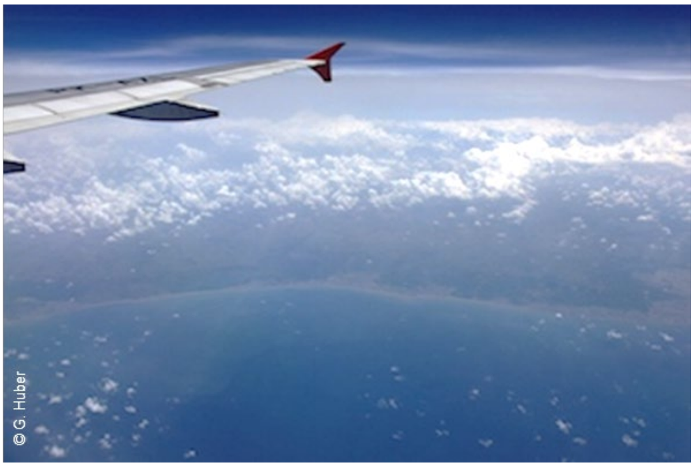

Figure 4: Heavy cloud coverage over land mass, hardly any clouds over sea (Strait of Malacca)

Another well-known phenomenon that can be identified by the map dataset is depicted below in Fig 4. Clouds are formed when moist air above the Ocean hits landmass in conjunction with orographic lift. This often leads to a combination of sun and cloud-free coastal areas (exposed to much higher UV-radiation levels), whereas inland there is heavy cloud coverage.

The lateral resolution from BASF Plastic Additives' map dataset is significantly detailed that its effect can be seen at multiple locations on earth. This is of special relevance, as the earth's population is strongly accumulating in coastal areas (currently about 40% of the world's population lives within 100 kilometers of the coastline). This means that large volumes of material required to be used in these areas are susceptible to higher UV-radiation, much more so than inland. Figure 5 shows an example of this effect for the ASEAN region.

The map dataset is also useful to identify the radiation levels in places which are not commonly considered and/ or from places where the UV-radiation data is not currently, publicly available (example: publications from authorities or airports). By removing misconceptions related to UV-radiation levels it can prevent errors in formulating or incorrectly assigning a material to a certain requirement profile.

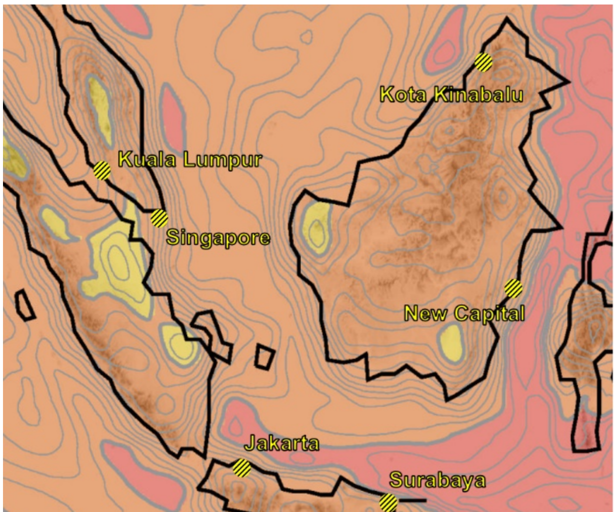

Figure 5: Increased radiation levels can be seen in coastal areas vs. inland. The effect is more pronounced in Philippines, Australia, Florida, California, Korean peninsula and Japan.
Map shows dose of full year 2015; scale identical to Figure 1;

Several years ago, BASF Plastic Additives were involved in a case to solve a problem where the stabilization system was suspected to have failed. The final application was to be used in Greece. Although a high stabilization level had been applied, still some articles were failing. By utilizing the state-of-the-art map dataset, it became easier to identify that the originally assumed UV-radiation level was actually too low. Although there were specific safety elements included in the design formulation, there were still some articles failing.

Today it is obvious that the application used at the time in Crete should have been stabilized based on end use in North Africa rather than Greece. The map dataset below shows clearly that over the last 2 decades, the UV-radiation level of Crete is actually closer to the range of Morocco, North-Algeria or Tunisia (Figure 6).

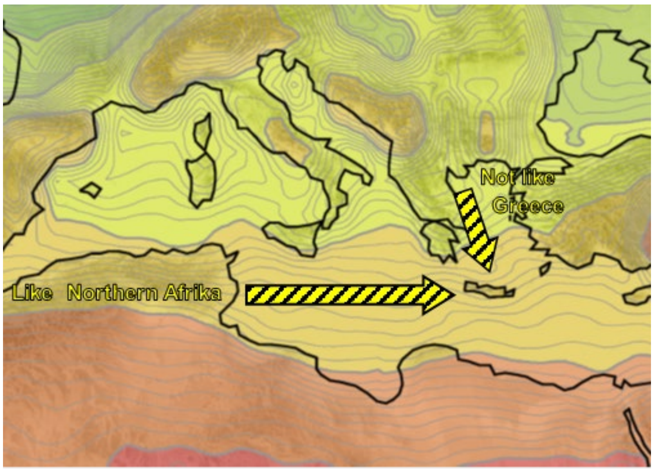

Figure 6: Outdoor applications in Crete need to withstand UV-radiation levels not like the rest of Greece, but like the northern African countries Morocco, North-Algeria or Tunisia.
Map shows dose of full year 2015; scale identical to Figure 1;

For reasons related to functional complexity, BASF Plastic Additives maintains the global UV-radiation map as an in-house technical tool. Additive recommendations utilizing the UV-radiation mapping tool are available for customer specific applications and can be obtained by contacting the local BASF Plastic Additives representative.