Obtaining data for wind farm development and management: the EO-WINDFARM project

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Abstract: The life cycle of a wind farm is a long process starting from site selection and running until decommissioning. The different steps in the process are site selection, feasibility study, design, construction, operation and monitoring, and decommissioning. All these steps are requesting data and specially geo-information. Finding the relevant information with good accuracy for the right area is a long and costly task. In this huge task, Earth Observation (EO) satellites can help. EO sensors are designed for delivering geophysical parameters over large spatially distributed areas. In order to help the offshore and onshore wind industry to access the relevant data, the EO-WINDFARM (www.eo-windfarm.org) project is developing a single-stop shop to obtain a set of geophysical parameters. This project is based on a consortium composed of EO service providers, wind energy market players and end-users such as electricity companies. It is supported by the European Space Agency within the Earth Observation Market Development program. The set of data comprises offshore wind, waves and tides information and onshore orography and terrain roughness maps. In this paper, the approach chosen to select the relevant geophysical parameters, is described. It is based both on information requirements from potential end-users and consultants and on the real potential of EO satellites. Then, the data that can be accessed through the EO-WINDFARM project is described. Perspectives of development of these EO-based services are evoked.

Introduction

The Kyoto objectives are stated into the White Book of the European Community (United Nations, 1997). The goal is to reduce the greenhouse gases emissions of 15 % by 2010, compared to the level of 1990. This can be partly managed by using renewable sources for producing electricity. For Europe, the part of renewable energy sources in electricity production should then increase from 6 % to 12 % in 2010.

While Europe is not rich in oil, gas and coal, there are huge wind resources and European companies are world leaders at converting it into electric power. Wind power and other renewables provide economic growth, security of energy supply, employment, and technology development, which do not come at the expense of the environment. Exploitation of wind energy will therefore help to stagnate the release of dangerous waste (from other non-renewable energy sources). That sector has a mean growth rate of 30% for the last two years. The total installed wind power capacity objective for 2010 in Europe amounts to 75 GW (EWEA, 2004). The total power currently installed (mid 2004) in Europe is 42 GW.

In order to help the offshore and onshore wind industry to access the relevant data, EO-WINDFARM aims at providing Earth observation (EO) data for the development of the wind sector. In remote areas and particular offshore there is an urgent need for data. Using EO data can help in solving the lack of data and possibly increase the cost-effectiveness when siting, constructing and operating wind farms. In EO-WINDFARM, a service will be set up where relevant EO-based products can be integrated with existing products for wind farm management. The service will be thoroughly tested and validated for cost-effectiveness.

Analysis of wind farm life cycle

Wind energy is a growing business world-wide powered by the need in many countries to shift partly to “green” energy. In many regions, particular in Europe, the best land-based wind farm sites are often already in use and new regions are found offshore. Placing wind turbines on shallow coastal shelves has been done e.g. at the 166 MW Nysted Havmøllepark in Denmark (the world’s largest offshore wind farm). The advantages of offshore sites are many, e.g. higher wind energy potential and less conflict with other interests.

The energy production of a wind farm is closely connected to the wind climate, and accurate measurements are needed when planning new sites. Traditionally, a mast with anemometers measures wind for at least one year in order to estimate the local wind climate. Offshore meteorological mast are very expensive (typically 1M€ for 100 m mast) and only produces data-sets for a single geographical position. An innovative and potentially important application of high spatial resolution Synthetic Aperture Radar (SAR) is for wind energy mapping in coastal regions worldwide. This will contribute to the exploitation and promotion of wind energy. However, wind data is only one of many parameters that are needed during the life cycle of a wind farm.

The different phases of wind farms development are indicated in Figure 1. The service defined in this document aims at providing relevant EO-data for help in the different stages of the life cycle of a wind farm.

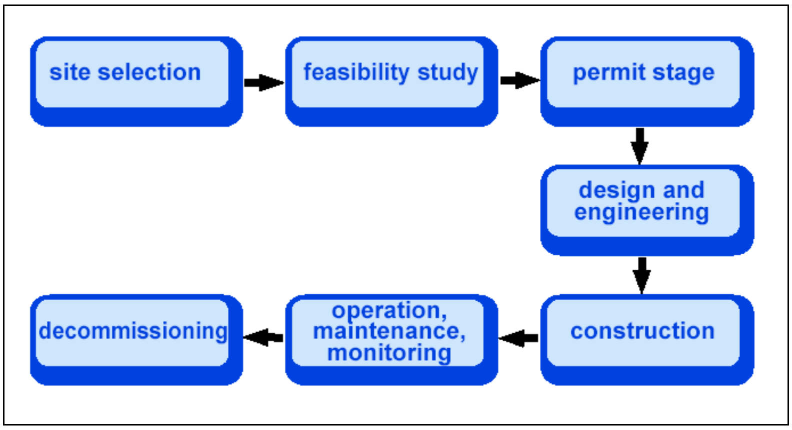

Figure 1. The seven phases in the life cycle of a wind farm. The phases from site selection to operation are numbered I-VI. The decommissioning phase is not considered in this project.

The service will provide different products for different regions, e.g. for offshore sites EO wind mapping will be an important product, while for land sites other EO products such as roughness mapping will be more relevant.

The service will benefit citizens of Europe, through improved cost-effective pre-siting, constructing and operating wind farms.

In the first phase of the project a limited number of products will be included in the service. To aid in the planning and construction of offshore wind farms, tidal heights and tidal currents at any coastal location worldwide will be provided based on a shallow water model assimilating altimeter and station data. Offshore wind resource information based on a combination of scatterometer and SAR will be available for inclusion in the micro-siting model WAsP© (Wind Atlas Analysis and Application Program) together with available in situ data. For land based sites terrain roughness maps useful in modelling of the airflow are created from a combination of a set of calibrated SAR images and classification of visible data. Orography is also planned for inclusion, but in this first phase only as a service providing the data from the Shuttle Radar Topographic Mission.

Potential of Earth Observation for wind farm

In the first phase of the EO-Windfarm project a restricted list of parameters and services that can be delivered from EO, has been selected. The different products are presented in the following section.

Products and services

Winds

Offshore wind resources climatology is available from a combination of different radar satellite data. The temporal resolution is ensured by scatterometer and altimeter data, while coastal details in the mean wind speed are given by high spatial resolution Synthetic Aperture Radar (SAR) images (Figure 2).

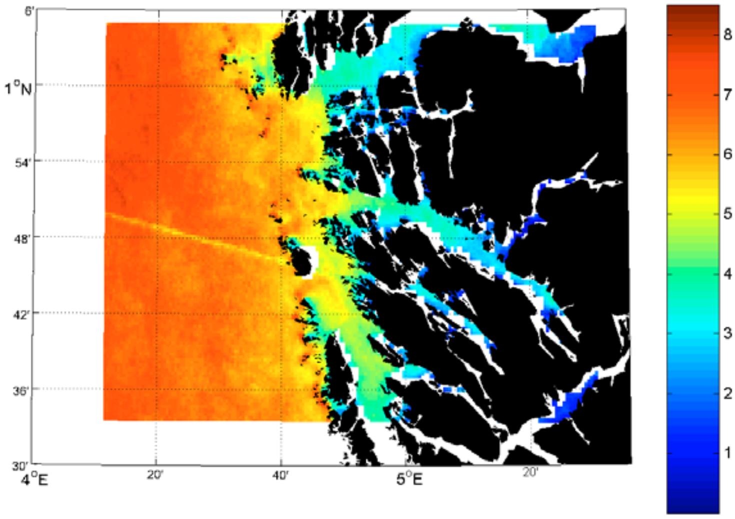

Figure 2. Mean wind speed distribution at the Norwegian west coast based on scatterometer, altimeter and SAR data. Data Credit: ESA.

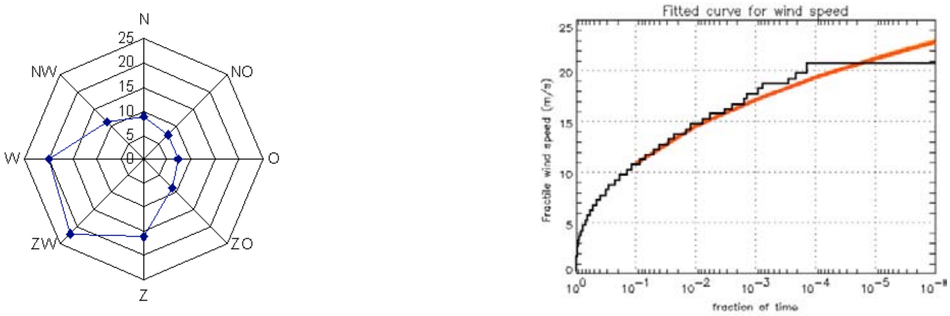

Figure 3. Wind rose and accumulated Weibull distribution for a location in the North Sea (54° 00'N, 0° 00'E).

10 years of quality checked scatterometer and altimeter data are available online for use in the offshore wind resource assessment worldwide. The data has a resolution of 50 km with a relative error of about 10 to maximum 17% and absolute error of about 1.4 m/s compared to local measurements. The mean (average) wind depends on the number of observations but this will reduce by the square root of observations. In the case of 5000 measurements the error of the mean wind speed is about 0.02 m/s.
Offshore wind roses and Weibull distributions are calculated from these data (Figure 3). Closer to an offshore site of interest a weighting function based on SAR data can be applied to the mean wind speed to transfer the information closer to the coast with higher spatial detail. The resulting coastal mean wind speed distribution for an area of the Norwegian west coast is shown in the Figure 2. In this example the weighting function is based on 48 ERS SAR images, each of them calibrated before the wind was retrieved using CMOD-IFR2 (Quilfen et al 1998). The mean wind speed from the images is normalised with the highest wind speed making a weighting function for the area with 1 where the wind speed is highest and 0 where it is lowest. Multiplying with the statistically more reliable mean wind speed from the scatterometer data, we get the detailed wind speed map is shown in Figure 2. The approach is presently being validated at Arklow Bank, Ireland.

Waves

Information of wave statistics is needed for planning, building and operating offshore constructions. Significant wind and waves joint occurrence is not only relevant for estimation of weather imposed downtimes but also for design purposes when calculating joint wind-wave loading. Information of swells are highly desirable for estimating the loads on the tower (the fatigue).

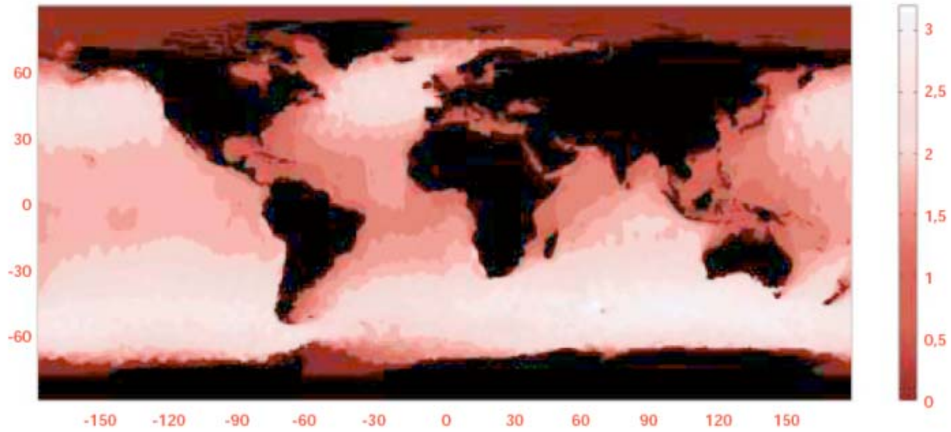

Figure 4. Annual mean significant wave height of swells only, in meters.

Satellites orbiting the Earth collect the wind and wave measurements that are the basis of the service that is offered (Figure 4). They use radar technology, allowing them to sense the sea surface under all weather conditions. Data from three different types of sensors is used: radar altimeter measuring significant wave height and wind speed, scatterometer measuring wind vectors, and imaging radar (SAR). The combination of data from these sensors allows for a complete picture of the wind and wave climate. World-wide satellite data on the offshore wind and wave climate is made available through this system on the Internet and for almost all offshore areas in the world.

The service includes information about significant wave height, mean period and direction of the entire sea-state, and also separately of wind and swell. Furthermore, statistical information of the combination of extreme wind speed and wave height is available. This degree of detail is obtained from radar image (SAR) spectra, analyzed by a method developed by the EO WINDFARM partner ARGOSS over the last five years. The resulting wave spectra are merged with coincident wave model data to improve the information on short waves. The method and the resulting dataset have been thoroughly checked against wave buoy data.

Tides

Detailed information on tidal heights and currents is important for design purposes and to support offshore and coastal operations. Tides are to be considered, as the waves do not break at low or at high tide for a given site. The fatigue loads are not located at the same height of the tower at low or high tide. The construction constraints are then influenced by the tides.

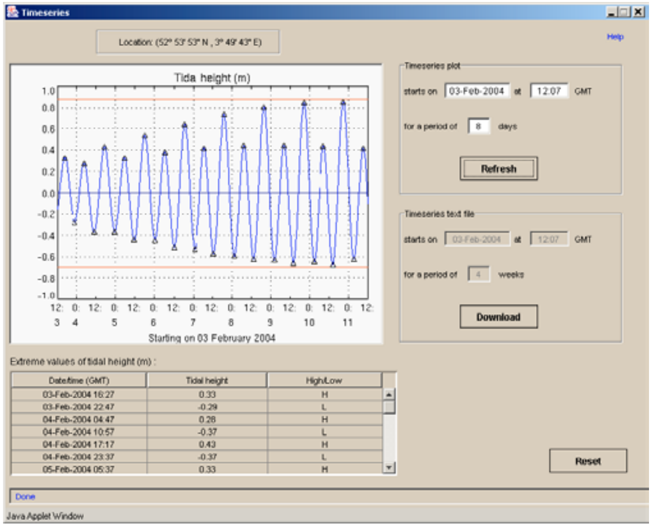

Figure 5. Water level changes due to tide at a location in the North Sea (52°53'53"N, 3°49'43"E).

The tidal information is computed by assimilating measurements obtained from satellite borne radar altimeters and from coastal stations in a shallow-water tidal model. The satellite measurements give a good overview of the tide offshore, whereas the local stations give accurate local information for locations close to the shore. The combination of the two, assimilated in a tidal model, provides good information in shallow seas and coastal areas, where tidal effects are most prominent. Time series of tidal height, tidal current speed or current direction are available at a ten-minute interval, starting from a user specified time/date, and cover a full tidal cycle of four weeks (Figure 5). Statistical information comprises of histograms (tidal height and current speed, Figure 6), and of scatter diagrams (e.g. current speed versus current direction). All information can be viewed on-screen and can be downloaded for further processing.

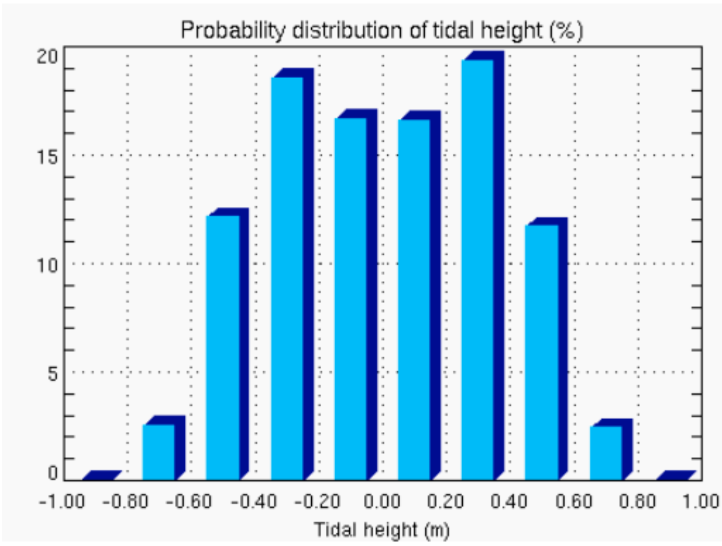

Figure 6. Probability distribution of tidal height at 60°46'00"N, 4°45'00"E. ©ARGOSS, May 2004.

The overall accuracy of the computed harmonics (compared to local measurements) is between 5-10 % for the tidal height and between 10-15% for the tidal currents. Information is standard provided worldwide at an effective resolution of around eight kilometers. However, on request more detailed information can be provided.

Terrain Roughness

Terrain roughness is an important parameter for the evaluation of the land use impact when modelling the air flow in the atmospheric boundary layer. The larger this parameter, the more the airflow is disturbed at a given altitude.

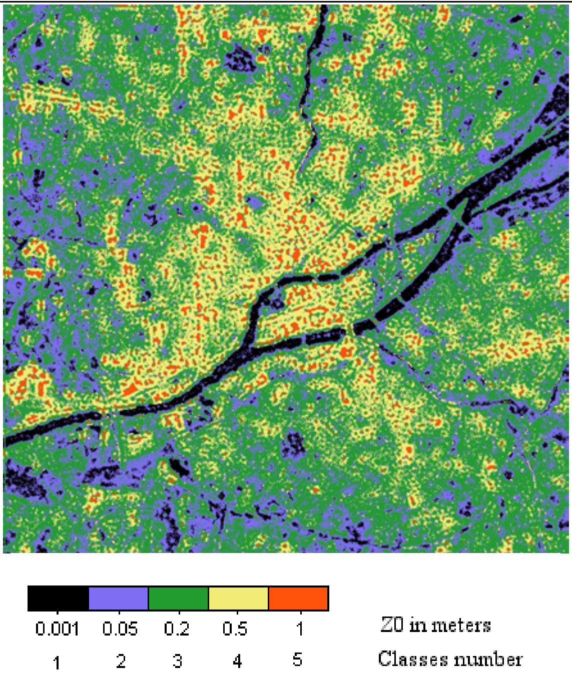

Figure 7. Terrain roughness separated into five classes over the city Nantes in France based on radar images.

Satellite data allow the mapping of the terrain roughness, through land cover and land use mapping. Usually, classification of optical data is used for land use mapping and attribution of roughness length to classes (Hasager *et al.*, 2003, Basly, 2000). The terrain roughness is a key parameter for evaluation of the wind resource for a given site. Two products are available through EO WINDFARM based on satellite data. Within EU 15 European countries (apart from Sweden and Finland) a 250 m cell-size roughness map derived from the CORINE land-cover data is available. On request, a high-resolution (30 m cell-size) roughness map derived from advanced processing of Synthetic Aperture Radar (SAR) images (Basly, 2000; Basly *et al.* 1999) is offered. The advantage of this type of map is that the roughness is calculated directly, possibly reducing the need for site visits.

Orography

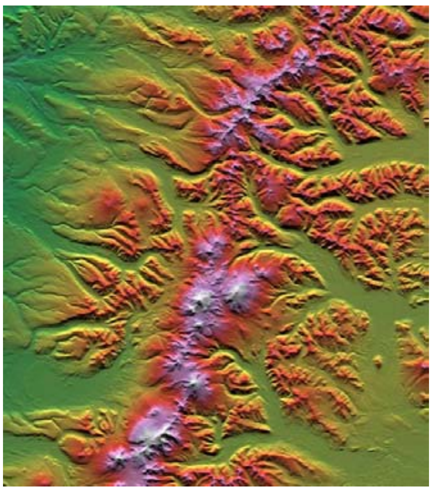

Figure 8. Example of shaded and coloured elevation over the Kamchatka peninsula provided from the SRTM. Image Credit: NASA/JPL/NIMA.

Orography is the average height of land, measured in geopotential meters, over a certain domain. In geoscientific models, orography defines the lower boundary (except over ocean, of course). Because orography is spatially averaged, for example the height of the Himalaya mountains will depend on

horizontal resolution. The higher the horizontal resolution, the better the orography will follow the actual terrain.
The orography of the land site has a strong impact on the local wind climate. Much work can be saved from having access to digital maps from the area of interest. Orography is available from a digital elevation model based on data collected during the Shuttle Radar Topography Mission (SRTM). The image above covers 93 km x 105,7 km over the Kamchatka Peninsula in eastern Russia. Elevations here range from near sea level up to 2,618 meters. The quality of the data is 3.3 m rms over open landscape and the maximum systematic shifts detected are 4-6 m. The SRTM data covers the entire landmass of the Earth between 60°N and 57°S with a spatial resolution of 1 arc sec (~30 m) for U.S. use or 3 arc sec (~90 m) for all other uses.

Operational use of products

The RWT software

The RWT software developed at Risoe National Laboratory is used to assess the wind climate from satellite SAR images. IT is an add-on of the WASP software. The SAR images are calibrated in the BEST software from ESA, then calculated into wind speed and wind direction maps from the WEMSAR tool developed by NERSC (Furevik and Espedal, 2002; Johannessen *et al.*, 2001). The RWT tool is based upon footprint modelling for an optimal area-averaging of the spatial wind information (Hasager *et al.*, 2004a). This is to obtain a time-series as similar as possible to classical meteorological observations. Furthermore RWT offers the opportunity to estimate the Weibull A and k parameters as accurately as possible keeping in mind the low number of samples and the fact that the data are censored (Hasager *et al.*, 2004b). *I.e.* some data may be missing in the time-series due to the validity range of the geophysical model function. CMOD4 e.g. only is valid in the wind speed range from 2 to 24 m/s. Finally maps of the wind resource statistics are generated. The number of satellite SAR (or scatterometer or altimeter) observations necessary for a reasonable estimate on the wind resources is investigated in detail (Barthelmie and Pryor, 2003;Pryor *et al.*, 2004). Using satellite SAR as stand-alone for offshore wind resource mapping is not recommended, however the data source is seen as a very promising new technology in combination with classical observations and wind resource modelling.

Offshore

The wind data provided by EO-WINDFARM allow the establishment of the long term wind rose (combined wind speed wind direction distribution) for projected sites offshore. These wind roses are essential to estimate the long-term annual energy output of projected offshore wind farms. The scatterometer, altimeter and SAR based data provide information on the wind climate at 10 m above sea level. These data still have to be extrapolated to the relevant height (wind turbine hub height) with the help of suitable physical models. In principal, commercial wind farm design tools such as WAsP provide this vertical extrapolation facility. The EO-WINDFARM data are intended to be used as input data for such design tools.
In coastal areas however, tailor made solutions are necessary to appropriately take into account the coastal effects on the vertical gradient of the atmospheric flow. In general, the wind farm design tools should allow for taking into account the adjusted (improved) parameters for the vertical extrapolation.
A specific advantage of the SAR based wind is the fact that it provides information on the spatial distribution of the wind field. This can be very useful for evaluating the resource in sea areas where the flow is influenced by land effects, e.g. in regions with islands. Another interesting use of the SAR wind is the evaluation of the ‘shadow’ behind existing wind farms. This is an important factor for determining the optimal distances between various offshore wind energy projects. The main limitation of the present use of the data is that the related uncertainties are still too high for studies on bankability of offshore wind projects. Their value lays mainly in the support they can deliver for decisions in the early planning stages of the projects. These decisions are related to siting, general dimensioning of main wind farm components, choice of operational concepts etc.
Another unique application is the use of EO-WINDFARM data to establish the combined wind and wave climate. The design of the offshore wind turbine construction needs site specific input data about wind and waves to calculate the effects of their combined dynamic loading on the construction. EO-WINDFARM can provide wind and wave statistics for user specified sites and in a range of desired

formats. The information includes both the long-term statistics on averages and on extreme wind and wave design situations.
In addition, EO-WINDFARM can provide site-specific information on tidal heights and currents. Such information has several applications, both in the design phase and the operational phase of offshore wind farms. For example, in some areas, the tidal height variations can be quite significant (> 10 m). In such cases the position of the wind turbine in the atmospheric boundary layer is shifted. This causes a variation in the mean wind speed and also a variation of the wind shear across the wind turbine rotor.

Onshore
The environmental data services of EO-WINDFARM for onshore wind energy applications are mainly oriented to the provision of suitable terrain data as input for wind farm design tools (such as WAsP, WindPro, Windfarmer etc.). Basically all these models need maps of terrain elevation and terrain roughness in an area of a few tens of kilometres around the projected wind farm. In several areas of the world, such maps are not readily available for the wind farm 'explorer'. In such cases, EO-WINDFARM can provide such maps in formats compatible with the current wind farm design tools. One striking advantage is that first site explorations can be done in a cost-effective way without the need for a local survey. In a further stage of the explorations, the maps allow a more efficient and well-prepared execution of the site survey, which is needed anyway in order to correctly describe the terrain around the future wind farm.

Conclusions and Perspectives

The proposed products and services are in a validation phase that will be achieved before the end of 2004. They are representing the up-to-date services available for the delivering of information to the on-shore and offshore wind farms developers and managers. In the second phase of the project, enhanced services will be developed in collaborations with selected end-users and new products will be prepared for satisfying the need of data of the wind farm industry.

Acknowledgements

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