

Comparison of dual Doppler winds with model output of Lokalmmodell

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Abstract. A simple dual Doppler algorithm is developed, producing horizontal wind vectors from the radial wind components measured by two adjacent weather radars. The results from this algorithm are compared with analyses from the Lokalmmodell of German Weather Service.

1 Introduction

Besides the measurements of radar reflectivity, which are used to determine the precipitation intensity, modern operational weather radars provide information on the motion of the atmosphere. This information consists "only" in the radial velocity of the scatterers, i.e. only that single component can be measured, which is the projection of wind speed on the line of sight.

These measurements are commonly evaluated by procedures known as VAD and VVP resulting in vertical profiles of wind velocity. However, corresponding results are valid only at the proximity of the radar site. The advantage of radar measurements to provide areal information remains unused.

In those regions that are covered by two radars the horizontal components of wind speed may be determined from the two independent measured radial velocities. This so called "dual Doppler procedure" is applicable on relatively large areas (cf. Fig. 1) within the German Radarverbund, e.g.

The next section presents a relatively simple dual Doppler algorithm, as it is developed at the Institut für Meteorologie und Klimaforschung. The evaluation of the results from such an algorithm turns out to be difficult, because there are no other independent areal wind measurements available which can be used for comparison. The best suited data set seems to be the analyses of the Lokalmmodell of the German weather service. These data may help to indicate under which circumstances the results of the dual Doppler algorithm are plausible or not. At the same time the wind field produced by Lokalmmodell can be evaluated.

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The data basis for the comparison will be presented in the third section, whereas the results from the comparison are given in the fourth section.

2 The algorithm v_{DD}

Let us assume we had at a certain location \mathbf{r} simultaneous measurements of radial wind velocity of two different radars. This location shall be seen from radar 1 under the azimuth α_1 and the elevation ϕ_1 , from radar 2 under α_2 and ϕ_2 . Then the radial velocity measured by radar i ($= 1, 2$) is given by

$$v_{r,i} = \begin{pmatrix} u(\mathbf{r}) \\ v(\mathbf{r}) \\ w(\mathbf{r}) \end{pmatrix} \cdot \begin{pmatrix} \sin \alpha_i \cos \phi_i \\ \cos \alpha_i \cos \phi_i \\ \sin \phi_i \end{pmatrix} \\ = u \sin \alpha_i \cos \phi_i + v \cos \alpha_i \cos \phi_i + w \sin \phi_i \quad (1)$$

where $\mathbf{v}(\mathbf{r}) = (u, v, w)$ is the wind speed vector. Positive radial velocities indicate increasing distance from the radar.

Obviously this equation system is underdetermined because we want to determine 3 wind components from two (scalar) measurements. That is why for this investigation it is assumed that the vertical component of scatterer velocity w is $w = w_0 = -5$ m/s everywhere. Because the elevation ϕ (and thus $\sin \phi$) is small for most locations, this assumption has hardly any effect on the results of the calculations. To estimate the (small) effect of the assumed vertical component on the derived horizontal velocities, we varied the value of w_0 . In fact, the resulting variations remained rather small (see below).

Solving Eq. (1) for u and v gives

$$u = \frac{w_0(\sin \phi_2 \cos \alpha_1 \cos \phi_1 - \sin \phi_1 \cos \alpha_2 \cos \phi_2) + v_{r,1} \cos \alpha_2 \cos \phi_2 - v_{r,2} \cos \alpha_1 \cos \phi_1}{\sin(\alpha_1 - \alpha_2) \cos \phi_1 \cos \phi_2} \\ v = - \frac{w_0(\sin \phi_2 \sin \alpha_1 \cos \phi_1 - \sin \phi_1 \sin \alpha_2 \cos \phi_2) + v_{r,1} \sin \alpha_2 \cos \phi_2 - v_{r,2} \sin \alpha_1 \cos \phi_1}{\sin(\alpha_1 - \alpha_2) \cos \phi_1 \cos \phi_2}.$$

The denominator of both expressions contains the term $\sin(\alpha_1 - \alpha_2)$, whose value is small near the line of sight

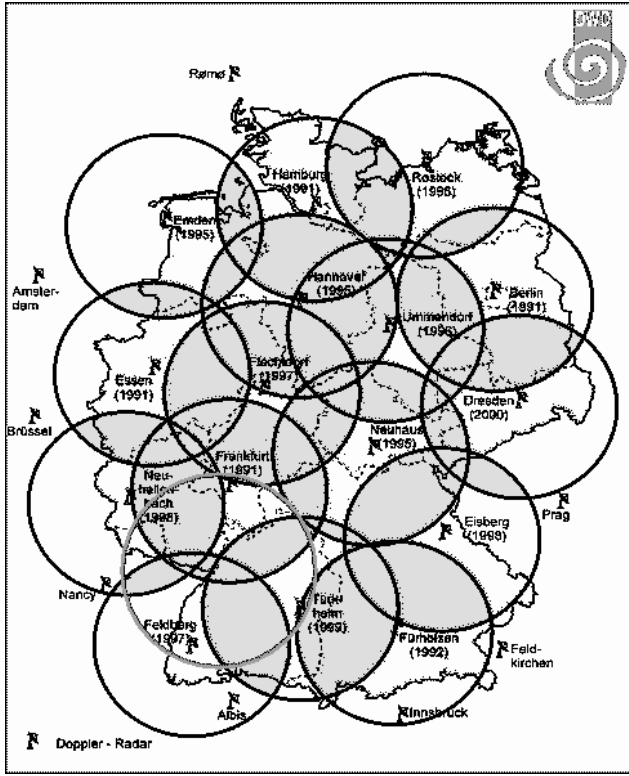


Fig. 1. Radarsites of DWD. Black circles mark the measuring range (120 km) for the quantitative precipitation measurements. Within this range velocity information is gathered with sufficient precision and unambiguous velocity. Regions which are covered by at least two radars are marked gray. The measuring range of the Karlsruhe radar is given by a grey circle.

between the two radars. Here measurements are no longer “sufficiently independent”, i.e. errors within the measurements are strongly amplified. Therefore, no dual Doppler wind speeds are determined, where $|\alpha_1 - \alpha_2|$ is small.

The choice of a reasonable limit value of $|\alpha_1 - \alpha_2|$ is an optimizing problem. Letting the limit for $|\alpha_1 - \alpha_2|$ too small results in “noisy” wind vectors. Choosing it too large rejects measurements although they might be valuable. For this study we rejected wind vectors as long as $|\sin(\alpha_1 - \alpha_2)| \leq 0.3$, which corresponds to a 17° angular difference.

In practice measurements are not available for same location and time. Thus, a new, radar independent target grid is constructed, defining the locations where the (radial) wind velocities will be determined at (cf. Fig. 2). The choice of this target grid is basically arbitrary. For this investigation we used the grid of Lokalmodell, because we wanted to compare with its results.

A temporal interpolation has not been done. The temporarily best suiting data sets of the two radars Karlsruhe and Türkheim have been used, minimizing the time lag between the measurements. Türkheim measurements are repeated every 15 min. and last roughly 13 min. Karlsruhe measurements are started every 10 min. and last roughly 5 min. The analyses of Lokalmodell are available only every hour. Due

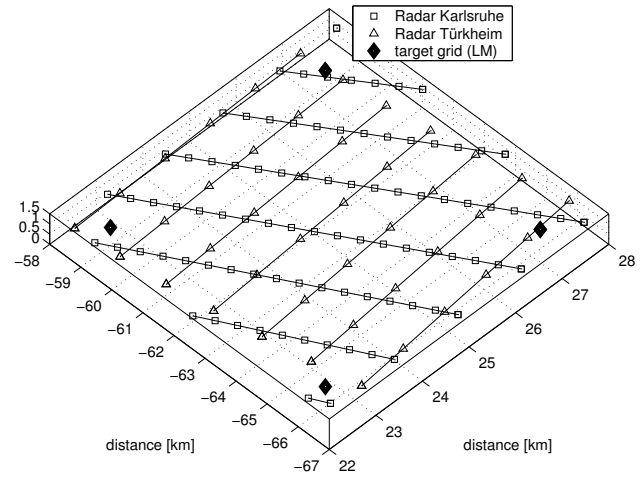


Fig. 2. On the geometry of the different grids. The radar beams of the Karlsruhe (\square) and the Türkheim radar (\triangle) are shown with their relevant bins as well as the grid points of Lokalmodell. This image is reduced to a single elevation for reasons of clarity.

to the fact that the scan strategy of German weather services starts with the (less important) higher elevations, we chose the radar data set that was recorded during the quarter between minute 45 and 60 from Türkheim and the data set from minute 50 to 55 from Karlsruhe. Interpolation in time would be important in case of convective events, because variations of wind velocity are strongest here. But as long as numerical weather models are not able to describe individual thunderstorms, a comparison remains impossible in these cases, anyhow.

The radial velocities at a certain grid point of Lokalmodell are determined from the measured radial velocities taken in the vicinity of that grid point. Those radar bins which are within an ellipsoid of revolution around that grid point contribute to the derived radial velocity at that grid point. The vertical axis of the ellipsoid is in most cases shorter than the horizontal axis. For this investigation 500 m (vertical) and 3500 m (horizontal) have been chosen.

At larger distances from radar, where the vertical distance between two elevations becomes rather large, this definition of the ellipsoid may not contain any radar bins, because the target grid point is located disadvantageously between two elevations. In these cases the vertical axis was elongated to 1.2 times the distance between the two neighboring elevations.

The radial wind velocity at a grid point of Lokalmodell is then calculated as the weighted average of those radial wind speeds, that are measured within the ellipsoid. If no wind speed is measured at a certain radar bin within the ellipsoid (because not enough energy was scattered back from this radar bin) this radar bin does not contribute. Thus, the radial wind speed $v_{r,i}$ at a LM grid point is given as

$$v_{r,i} = \frac{\sum_j g_{i,j} v_{r,i,j}}{\sum_j g_{i,j}}. \quad (2)$$

Table 1. Scan strategies and technical informations of the two radars considered. The distance between the radars is aprox. 113 km.

	Karlsruhe	Türkheim
Institution	Forschungszentrum Karlsruhe Inst. für Meteorologie und Klimaf.	Deutscher Wetterdienst
Location	49° 5' 33" N, 8° 26' 13" E, 148 m asl	48° 35' 8" N, 9° 46' 54" E, 731 m asl
Resolution	500 m and 1°, resp.	1000 m and 1°, resp.
max. range	120 km	128 km ¹
direction of scan	bottom up	top down ¹
Elevations	0.4°, 1.1°, 2°, 3°, 4.5°, 6°, 7.5°, 9°, 11°, 13°, 16°, 20°, 24°, 30°	37°, 29°, 23°, 19°, 17°, 15°, 13°, 11°, 9.5°, 8.5°, 7.5°, 6.5°, 5.5°, 4.5°, 3.5°, 2.5°, 1.5°, 0.5° ¹
Rep. time	10 min.	15 min.

¹ Data of the Türkheim radar where limited to a maximum range of 120 km for this investigation. DWD performs further five elevtions with a reduced unambiguous velocity but an increased maximum range. They are not used here.

The radar bins are counted by j within an ellipsoid, whereas i denotes the radar. The weights g are chosen as the inverse distance between the LM grid point and the radar bin under consideration. (As mentioned above $g_{i,j} = 0$, if there is no radial velocity measured within this radar bin.)

One of the advantages of this procedure is its simplicity. On the other hand, the center of mass of the contributing radar bins, which is determined as

$$\mathbf{r}_i = \frac{\sum_j g_{i,j} \mathbf{r}_{i,j}}{\sum_j g_{i,j}}, \quad (3)$$

is not necessarily close to the LM grid point. Especially close to the ground, when lower elevations are blocked (or even not existent), this can lead to significant errors.

3 Data basis

To apply the algorithm one needs the radial velocities from two radars. To avoid artifacts it is necessary to use raw data in polar coordinates, because derived products (in Cartesian coordinates) are deteriorated by any spatial averaging process.

Besides our own measurements from the Karlsruhe radar, we have roughly 1800 data sets from the radar Türkheim of German weather service available (cf. Fig. 1). 1300 of these data sets are from 20 different days during the year 2000.

Informations on the scan strategies of the two radars are given in Table 1. The hardware is in both cases a Meteor 360 C manufactured by Gematronik.

For validation purposes a reference data set were desirable having an equal (or better) spatial and temporal resolution and a known good accuracy. Such a data set is unknown to us. The best approximation to this optimum are the analyses of the Lokalmodell, which are available on an hourly time basis. Nevertheless, these data are not measurements but modell output, containing their own disadvantages.

The comparison of dual Doppler wind velocities with the results from Lokalmodell cannot be used directly as a criterium of quality. However, a careful investigation of the differences between the two wind fields may give some hints on the strength and weakness of the the two procedures.

From the data sets of the Türkheim radar we chose a subset, such that sufficiently precipitation occurred and thus radial velocity measurements are available. In addition we ensured, that stratiform and convective precipitation events were contained in the data sets. This collection led to 16 cases between May, 15th 2000 and Okt., 10th 2000 and an additional case from June, 19th 2002.

Lokalmodell uses a horizontal resolution of 7 km. The vertical resolution is significantly finer. Nevertheless, grid point heights are (partially) terrain following. Reconstructing this grid for the dual Doppler algorithm would have been rather costly and could easily produce errors. The vertical resolution is further rather fine compared to the radar measurements. Thus, only the heights of 1000 m, 2000 m, 3000 m and 5000 m asl are used for this study.

4 Comparison of dual Doppler wind velocities with results from Lokalmodell analyses

An example of a comparison is shown in Fig. 3. The horizontal wind vectors of Lokalmodell are drawn in blue whereas the dual Doppler winds are red. Vectors are drawn only where the dual Doppler algorithm had radial wind speeds available from both radars.

At a glance an acceptable to good correspondence of the wind fields is visible. Keeping the simplicity of the dual Doppler algorithm in mind this is a very encouraging result.

However, the mismatches are even more interesting and will be discussed below. Differences between Lokalmodell and dual Doppler algorithm are marked by a black dot in Fig. 3 provided the absolute values differ by more than

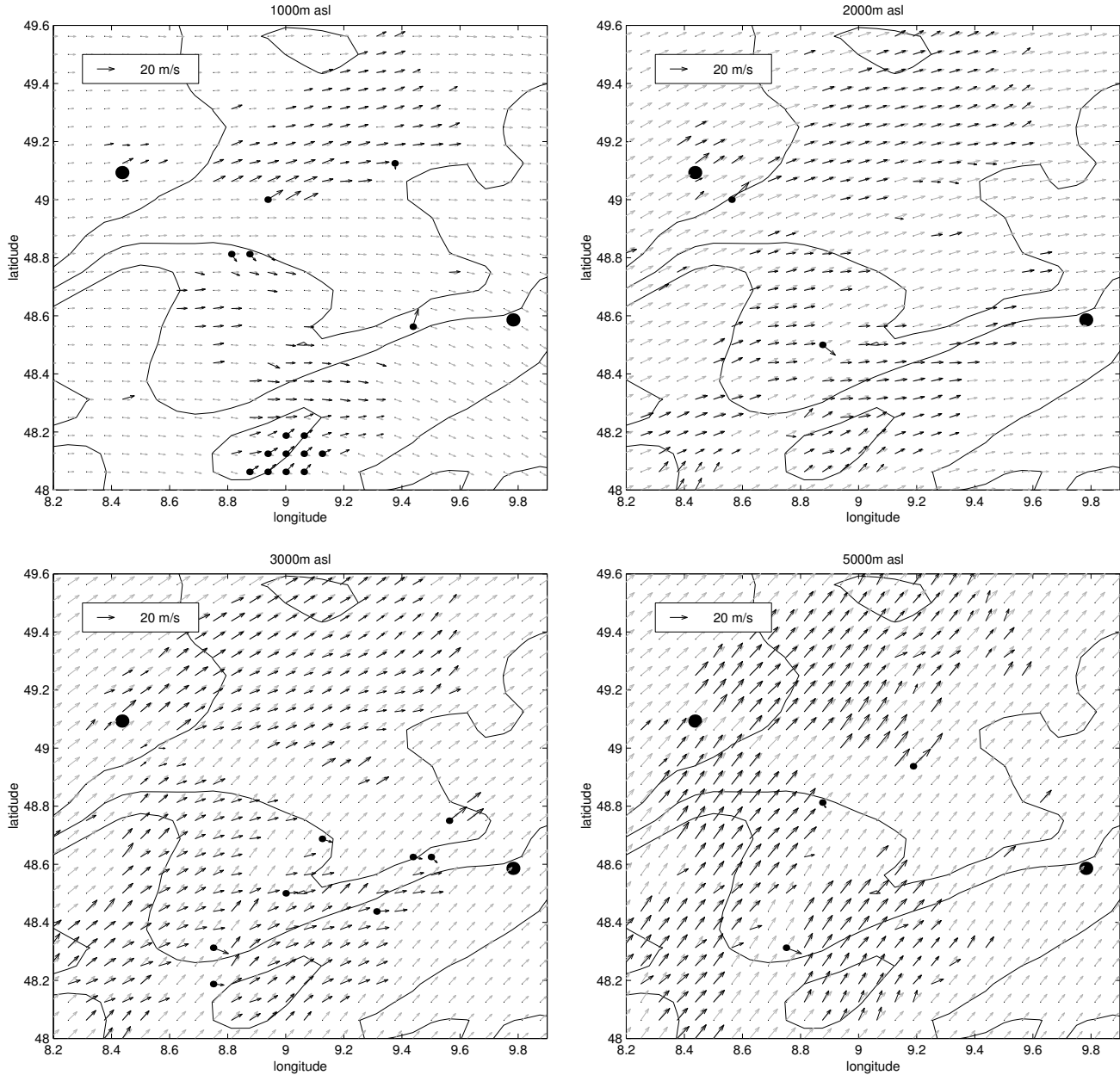


Fig. 3. Comparison of horizontal wind velocities from Lokalmodell (grey) and from dual Doppler algorithm (black) at May, 17th 2000, 18:00 UTC. The orography is shown as a contour plot with 200 m resolution. The two radars are marked as black circles. Black dots indicate those grid points with severe deviations between the two methods.

10 m/s in wind speed or by more than 45° in in wind direction.

4.1 Near the line of sight

As expected there are some strong deviations just around the line of sight between the two radars (the locations of which are marked by two black circles in Fig. 3). As mentioned above, these deviations are caused by the nearly (anti-) parallel measuring directions, producing two measurements of (nearly) the same wind component.

This limitation is system inherent. Finding a compromise between data quality and quantity is a question of the fur-

ther data use, especially. If dual Doppler data are used for automated data processing, the requirements will be chosen rather restrictive. Data sets produced for inspection by eye may be allowed to contain more noisy information.

4.2 Shielding

The calculation of radial wind speeds with Eq. (2) implicitly assumes, that the ellipsoid around a LM grid point is surrounded homogeneously by radar bins, so v_r is representative for the location of the LM grid point. This assumption is not fulfilled at some points. Among them are the grid points at the end of the measuring range (which are easily

identified), but especially also the lowest grid points (close to the ground). It often appears, that radar measurements from at least one radar are available only above a certain minimum height. Radar beams of lower elevations may be shielded or even the lowest elevations is above the desired measuring height.

In our study especially the lowest measuring height of 1000 m asl is affected. The Türkheim radar is located at 731 m asl. Thus, measurements below 1000 m are possible only within a rather short range around the radar. I.e. the calculated radial velocities correspond to locations above the indicated height. At the largest distances from the Türkheim radar the true measuring heights are around 1600 m asl instead of 1000 m.

This problem may be removed by calculating (besides the radial wind velocities with Eq. (2) the true measuring locations by Eq. (3). At grid points with larger deviations of the true measuring location from the LM grid point the measurement of radial wind component could be rejected.

An alternative solution might be, to determine the radial wind speeds not as an average within an ellipsoid, but to assume the radial wind speed can linearly be developed around an LM grid point with the coordinates x_0, y_0, z_0 as:

$$v_r(x_0 + \delta x, y_0 + \delta y, z_0 + \delta z) = v_{r,i} + \delta x \frac{\partial v_r}{\partial x} + \delta y \frac{\partial v_r}{\partial y} + \delta z \frac{\partial v_r}{\partial z}$$

Calculating the radial wind speed $v_{r,i}$ at an LM grid point by this way reduces the “one sided” sampling around that point. Nevertheless, this advantage is paid by a significantly increased amount of computational efforts.

4.3 Errors in radial velocity measurements

At individual points the analyses show unplausible wind vectors caused by unplausible measurements of radial wind velocity. An example is seen in Fig. 3 at 2000 m asl near 8.75° E and 48.28° N. The Karlsruhe radar measured a radial velocity of +13 m/s whereas at the neighbored grid points either no radial velocity at all or weak wind towards the radar are measured (i.e. negative radial wind speeds).

In this special case the error can be traced back to that from 78 radar bins around the LM grid point only 2 contain significant radial wind speeds at all. One of these values is 22.4 m/s and thus obviously erroneous.

Errors like this are significantly reduced by a preprocessing of the radial wind speed fields in polar coordinates. Searching for radar bins with strong deviations from the measurements in their vicinity have to be either removed or have to be replaced by an average from nearby bins.

4.4 Errors of LM

It is striking that, e.g. on May, 17th 2000 in 2000 m asl (Fig. 3) windvectors north from the line of sight between the two radars show a good agreement between the two techniques, whereas in the southern part of the area, especially

downwind from the Black Forest, significant deviations between dual Doppler winds and LM analyses occur. This area is not affected by shielding for both radars, hence we may assume that the dual Doppler winds are quite accurate. Thus, one has to assume that the impact of the Black Forest on wind flow is not properly represented in the Lokalmmodell.

5 On the impact of the presumed vertical velocity w_0

The vertical velocity is presumed to be $w_0 = -5$ m/s within this study. This corresponds roughly to the reflectivity-weighted fall velocity of (strong) precipitation in still air. To investigate the impact of this velocity assumption on the derived horizontal wind components, w_0 was varied between -15 m/s and $+5$ m/s (the latter corresponding to raising precipitation!).

Grid points at higher levels are seen under larger elevations (on the average). Thus, a variation of w_0 influences the horizontal wind speed more significant at higher levels than near the ground. Averaged over the 17 cases, the absolute value of horizontal wind speed in 1000 m/s varied by 0.08 m/s and in 5000 m asl by 0.25 m/s. Wind direction was changed by 0.06° in 1000 m asl and by 0.5° in 5000 m asl.

Keeping in mind, that the Karlsruhe radar measures its radial velocity with a resolution of 0.25 m/s the impact of the presumed vertical velocity may be neglected.

6 Conclusions

Even with quite a simple algorithm dual Doppler wind fields may be derived from the radial wind speed measurements of neighbored radars within their overlapping region – as long as precipitation is recorded. Within radar networks of national and international weather services there is a significant area covered by two or more radars, making the application of such an algorithm possible.

This simple algorithm should be improved (i) with respect to asymmetric distributions of radar bins around a target grid point, with the aim to get more representative radial wind velocities at those grid points, and (ii) by a preprocessor that removes individual radial velocities deviating significantly from their vicinity.

The aliasing problem is not discussed here. We require that this problem is solved by a suited preprocessing of the radial wind velocities. Nevertheless, the derived dual Doppler wind field might be helpful in identifying aliasing.

Operational dual Doppler wind fields might contribute to an evaluation of model outputs or data assimilation, because in opposite to other data they were available with a sufficient spatial and temporal resolution.

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