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Verification of wind forecasts for the airports Hammerfest, Honningsvåg, Sandnessjøen, Ørsta, Værnes, Sandane and Narvik

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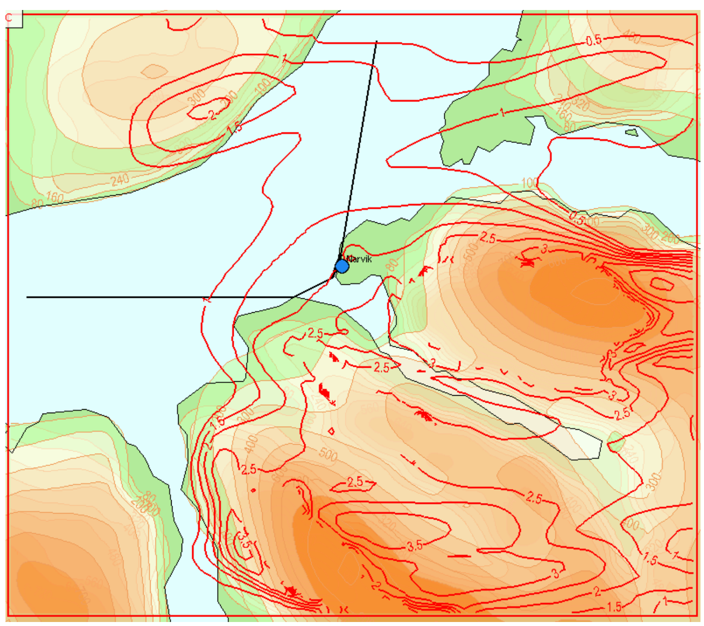

Turbulence forecast for Værnes airport in-flights and runway

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Abstract

Atmospheric turbulence still accounts for a significant percentage of weather-related aircraft incidents in Norway. A turbulence modelling project is run by SINTEF in cooperation with the Norwegian Meteorological Institute. A nested model system designed for forecasting atmospheric turbulence has been developed. From mid 2007 the system has been operated for seven airports in Norway. The present validation report includes a short description of the model system.

We have included verification against surface SYNOP observations for Værnes and all the other six airports the system is operated for.

In the project it has been decided to do a special study for Værnes airport. The airport is chosen as the one of the seven for which there are available AMDAR reports from aircrafts on a regualar basis. In order to study the quality of those observations in more detail, TEMP observations from Ørlandet airport situated some km west of Værnes are used in this study.

The models validated includes HIRLAM 10-km (10-km resolution), UM 4-km and UM 1-km (Unified Model, 4-km and 1-km horizontal resolution) and the SIMRA model (approximately 100m resolution). Verification results from the period 1. September to 15. December 2007 are presented.

Keywords

Turbulence, aviation weather, numerical modeling, verification, aircraft observations

Disiplinary signature	**Responsible signature**

1. Model description

Below is included a rather short description of the model system.

The global ECMWF model provides lateral boundary conditions for the nested turbulence model system. Those boundary values are used for running a HIRLAM hydrostatic 10-km model covering Scandinavia and adjacent sea areas. Nested inside this HIRLAM model is a version of the non hydrostatic Unified Model (UM) developed at Met Office set up with 4-km resolution (see areas in figure 2). The airport specific part of the turbulence system consists of two models covering an area surrounding the airport.

A: 1-km resolution of the Unified Model (UM 1-km)

B: approximately 100-m turbulence model SIMRA

A is nested inside the 4-km run. Initial values and boundary conditions for B is taken from model A. Surrounding the seven airports are set up five 1-km resolution UM models since there is one model for Hammerfest and Honningsvåg and one for Ørsta and Sandane (see figure 2).

All the models involved are regular numerical weather prediction models with exception for SIMRA which is a turbulence model. The model areas for the UM 1-km and SIMRA for Værnes and the other six airports are given in figures 3,4,5,6 and 7. The figures also include model topography and surface projection of the runway, the “flight tracks” and “in-flight sectors” as specified by angles relative to the “flight tracks”.

The UK Met Office Unified Model is a non-hydrostatic numerical weather prediction model. UM (and HIRLAM) uses an Arkawa C grid, where computation points for wind are displaced one half grid length compared to computation points for temperature and moisture. The model has 38 layers in the vertical and a terrain following height based vertical coordinate. Due to semi-implicit time integration and semi-Lagrangian advection the time step is as long as 24 seconds. Physical parameterizations consider influence of gasses and ice crystals on radiation, microphysics in clouds and condensation, 13 layers in the atmospheric boundary layer and 9 different surface types. It is assumed in the 1km resolution models that convection is resolved in the model grid. Moreover orographic influence is assumed to be resolved.

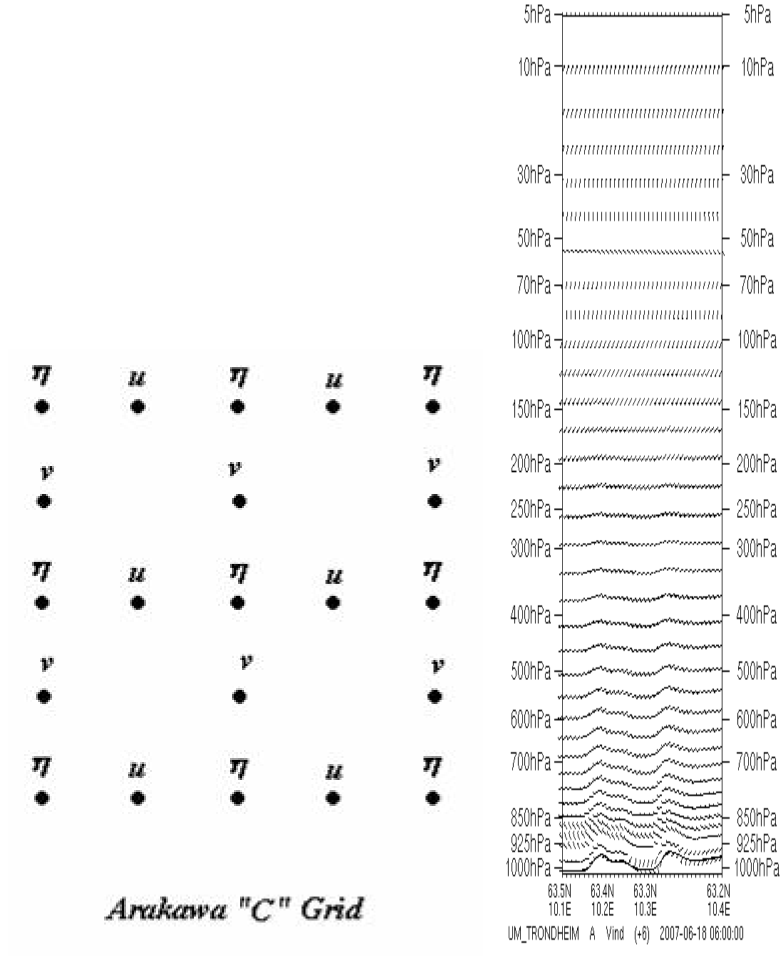


Figure 1 Computation points in the UM. Wind components u and v are computed one half of a grid length displaced compared to ŋ that stands for T, q and ql (left) Distribution of UM vertical layers illustrated with wind arrows in all gridpoints. T, q and ql are computed on the interphases between these layers (right).

In the present model set up input to the SIMRA turbulence forecasts are produced by running UM 1-km model with an interpolated +3 hour forecast from UM 4-km as initial values. Boundary values are specified from the same UM 4-km every hour, and the model is integrated from +6 hours up to + 18 hours. The procedure is repeated based on 4-km forecasts starting at 00UTC and 12 UTC. 1-km model results are produced for both 00UTC and 12 UTC from +6 up to + 18 hours.

Data are interpolated from the spherical rotated UM grid to UTM coordinates used by SIMRA. Vertical interpolation is needed to adapt to the higher resolution topography in the SIMRA model.

Weather parameters transferred from UM to SIMRA are given in the following list:

Surface pressure 2d
Horizontal wind 3d
Potential temperature 3d
Specific humidity 3d
Pressure at model levels 3d

SIMRA is a model based upon Reynolds equations with a standard (K, epsilon) turbulence closure and boundary conditions. It has the capability of predicting flows with separation, attachment, hydraulic transitions and internal wave breaking.

The SIMRA model has a dynamic estimation of turbulent kinetic energy and dissipation, and predicts turbulent kinetic energy (TKE). The square root of TKE has the dimension of velocity and is used as an indicator of turbulence intensity.

Initial data for the SIMRA model are interpolated from the 1-km runs valid every hour (+6, +7, +8,,, +18). For each of those points of time the SIMRA model is run with constant boundaries until a stationary solution is achieved. Rather than an ordinary forecast dataset, SIMRA supplies data that can be used to estimate quantitatively the strength of the turbulence in each time interval (1 hour) (Eidsvik and Utnes, 1997).

The reason for running with a lead time of 6 hours is that the total time from taking the observations up to finished computations is 4 hours at the moment. As the system is operated today, turbulence forecasts valid every hour between +6 and +18 based on 00UTC and 12UTC are available at approximately 04UTC and 16UTC.

During autumn 2007 a new version of the UM1 km is tested in a full parallel set up. This version covers 2 large areas over southern and northern Norway respectively. This has been done in order to be prepared for introducing more airports during early 2008.

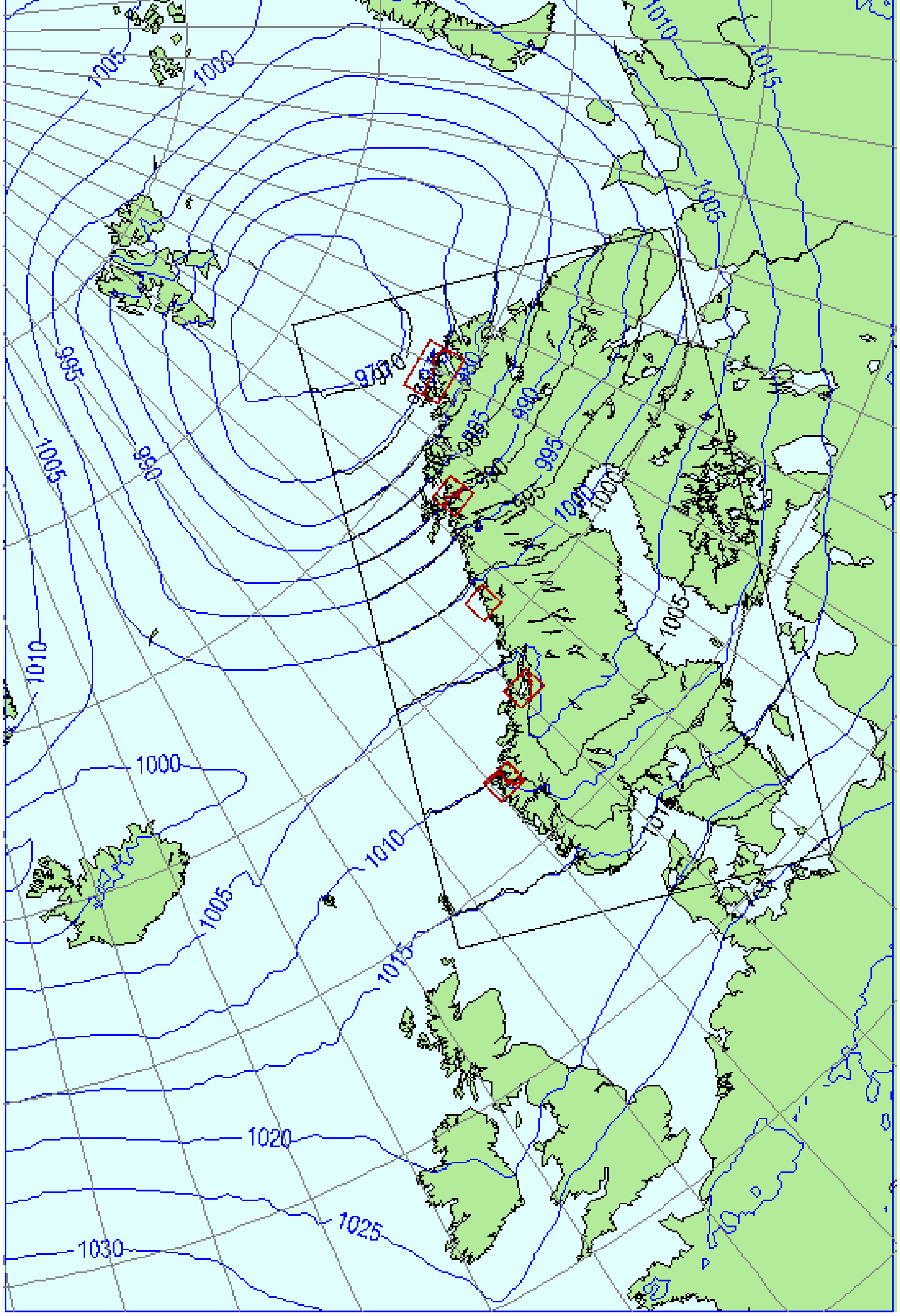


Figure 2 Model domains for (from outer to inner rectangles) Hirlam 10-km, UM 4-km and UM 1-km. The smallest UM 1-km areas cover the airports Hammerfest, Honningsvåg, Narvik, Sandnessjøen, Værnes, Ørsta (Hovden) and Sandane (Anda).

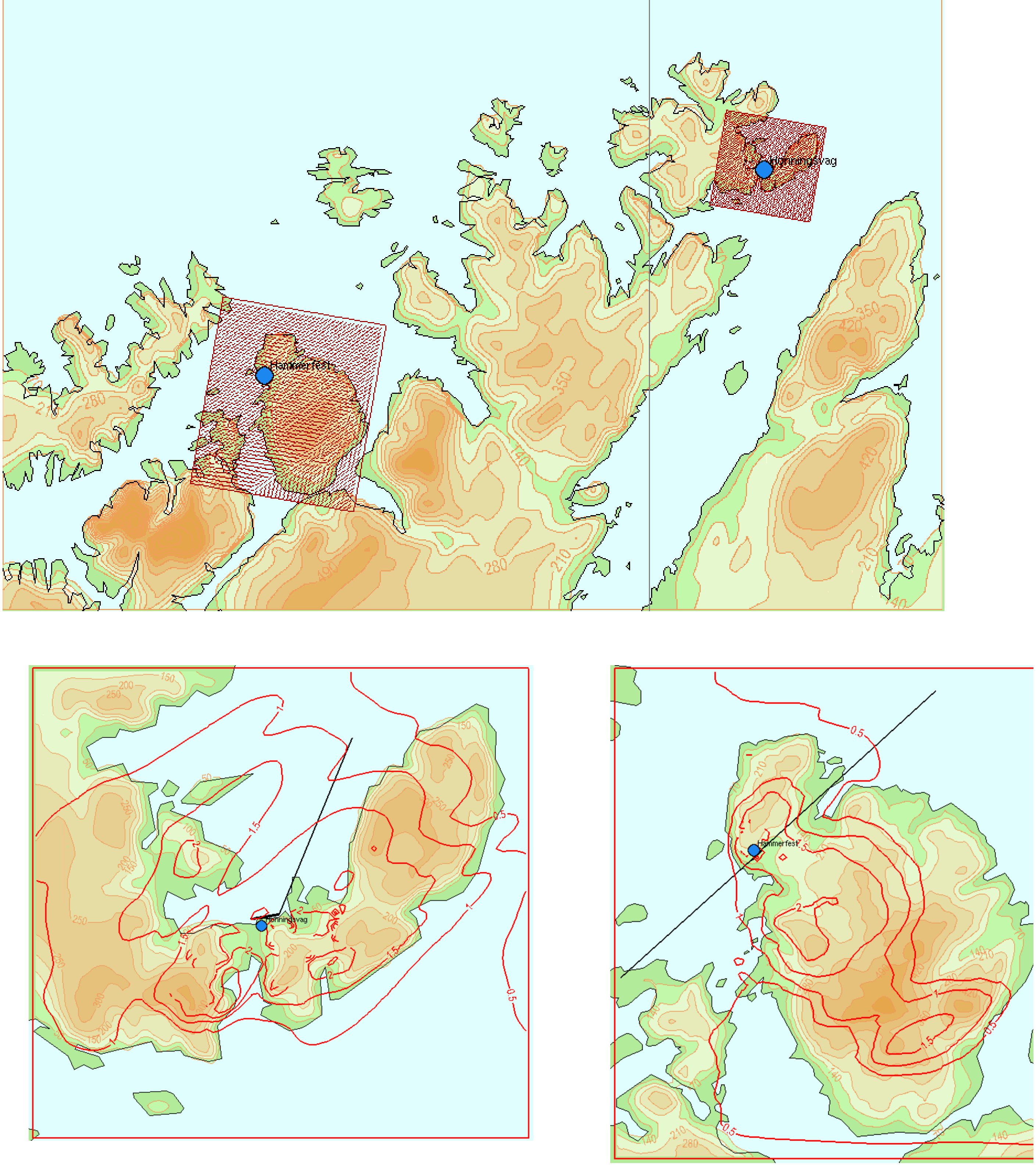
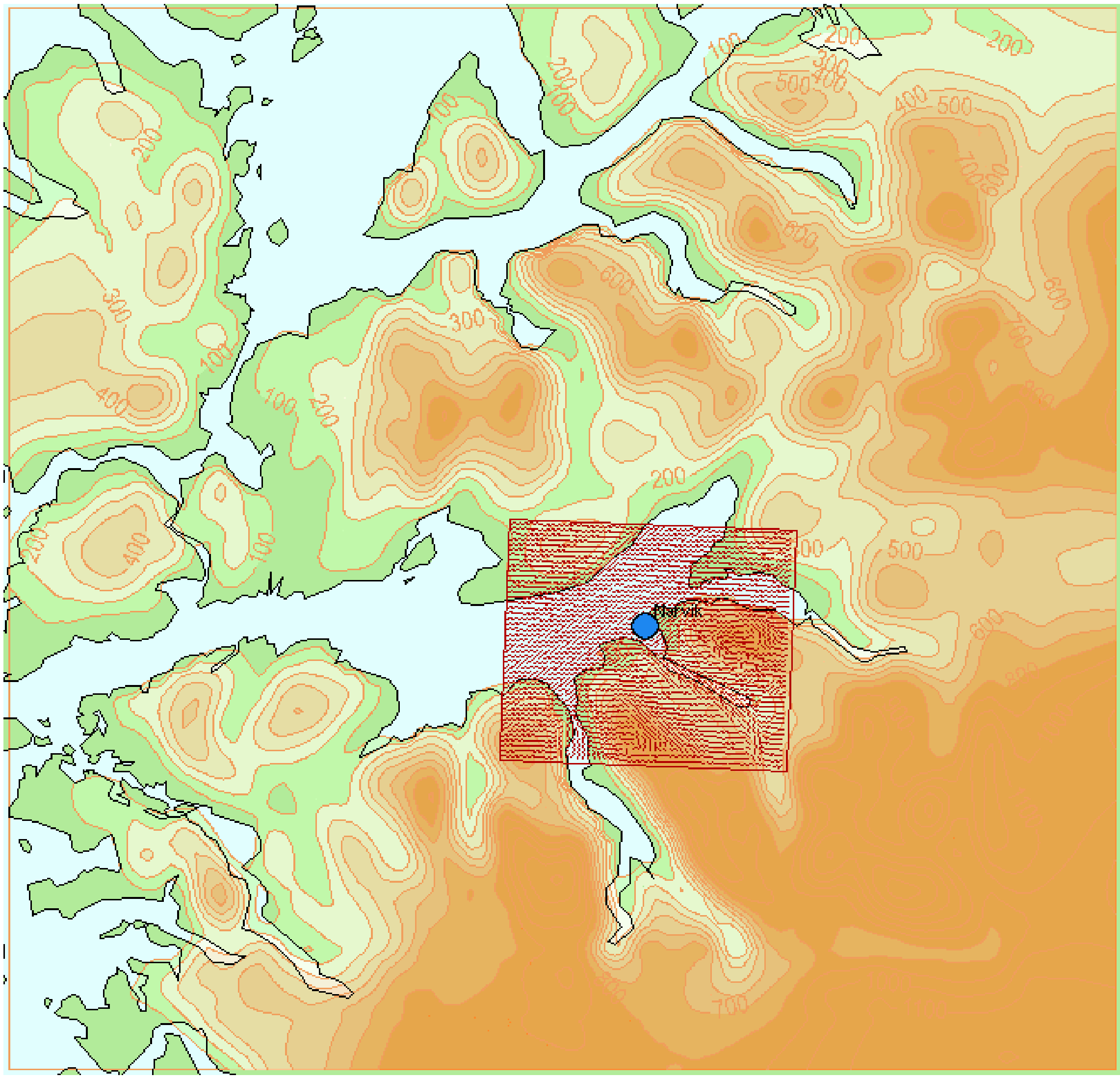


Figure 3 Model domains for UM 1-km for Hammerfest/Honningsvåg airports, topography with 70m spacing between isolines. SIMRA domains are shown with red wind arrows each second grid point (top). SIMRA domains around Honningsvåg (bottom left) and Hammerfest (bottom right). The straight black lines indicate the projection of the sectors for take off and landing. The runway is near the blue dot. The red isolines give turbulence in in-flight levels (arbitrary forecast). The SIMRA topography is shown with 70m spacing between isolines.



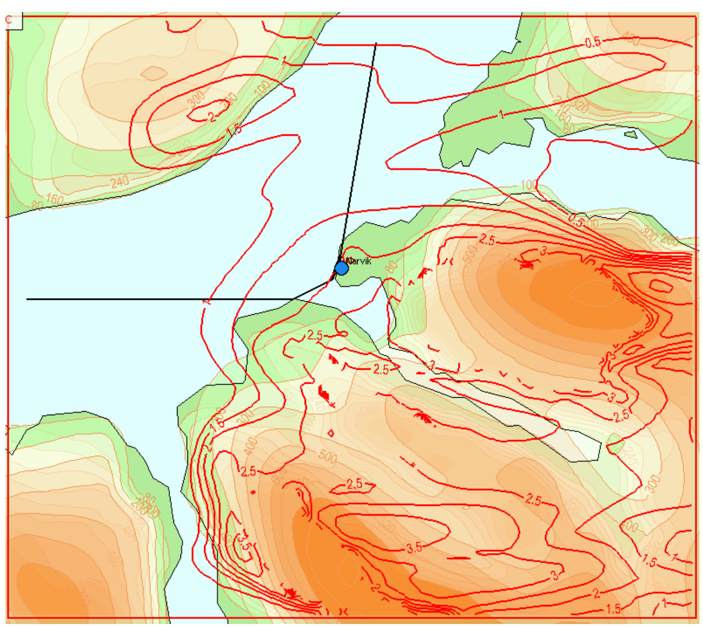


Figure 4 Model domain for UM 1-km for Narvik airport and SIMRA domain around Narvik (bottom). Details as in Figure 3.

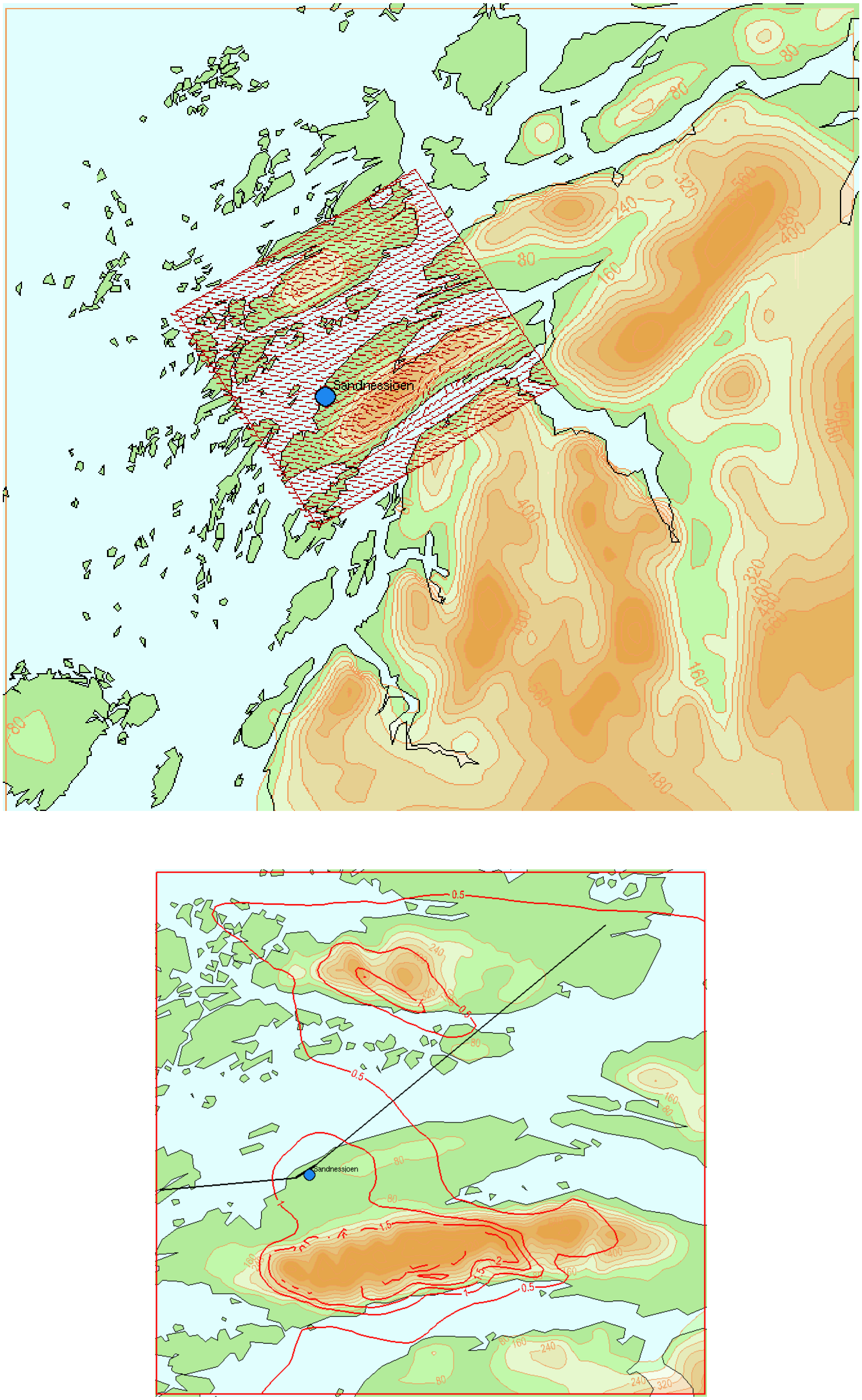
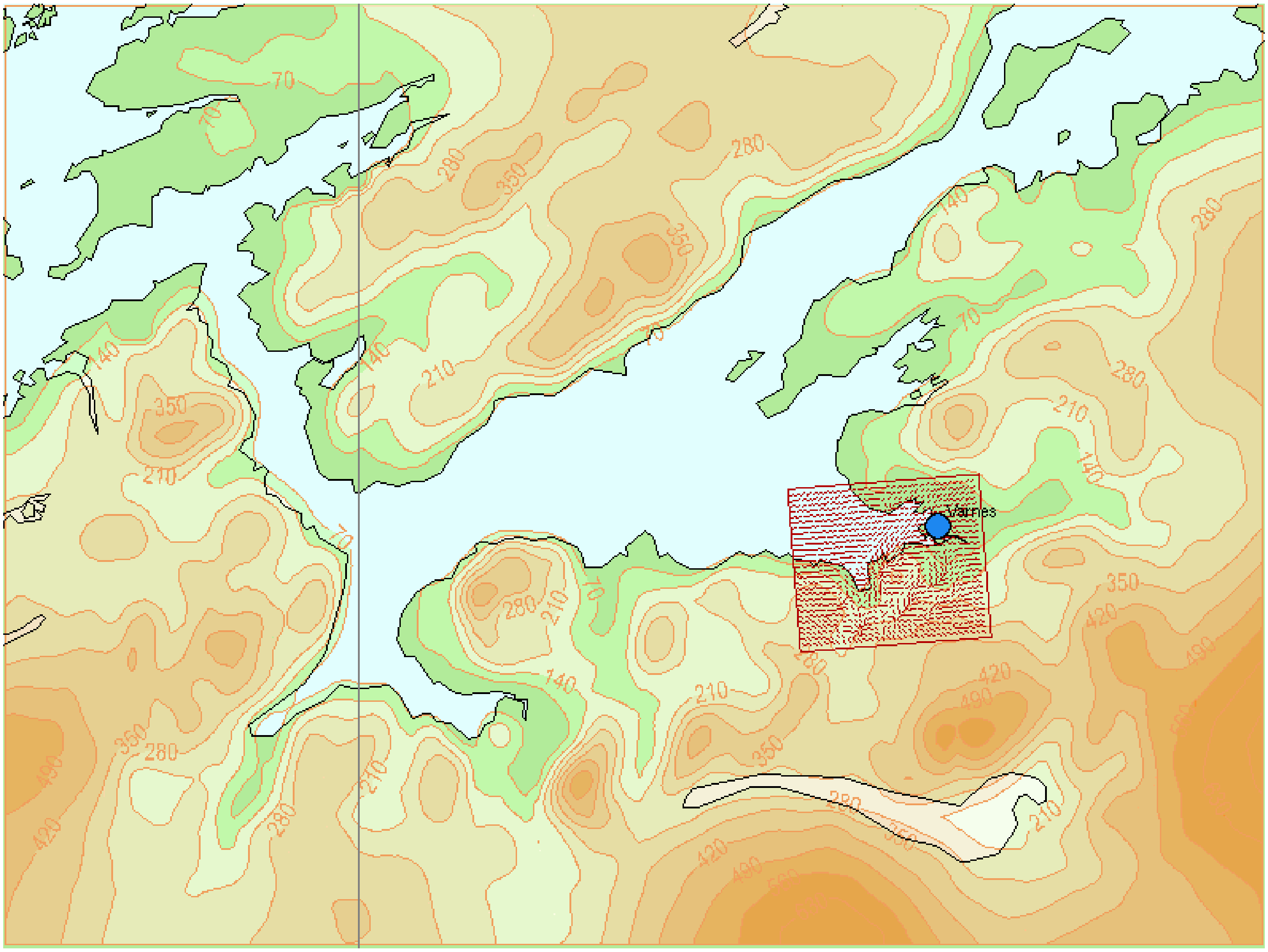


Figure 5 Model domain for UM 1-km for Sandnessjøen airport and SIMRA domain around Sandnessjøen Stokka (bottom). Details as in Figure 3.



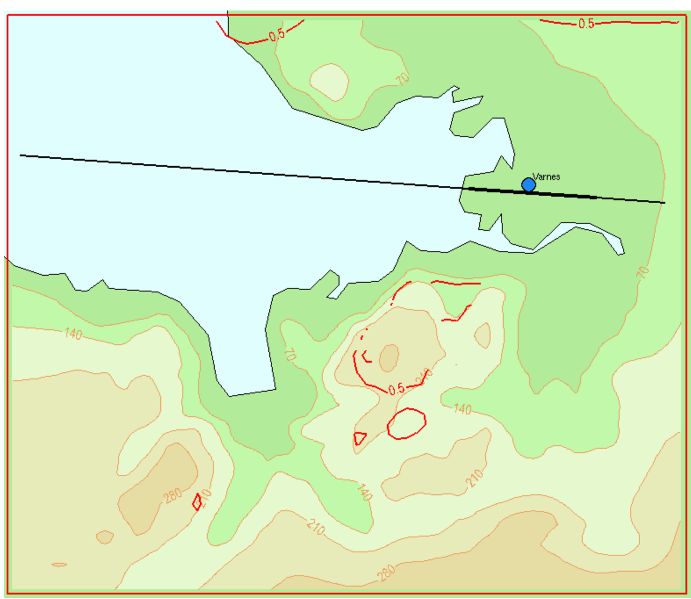


Figure 6 Model domain for UM 1-km for Værnes airport and SIMRA domain around Værnes (bottom). Details as in Figure 3.

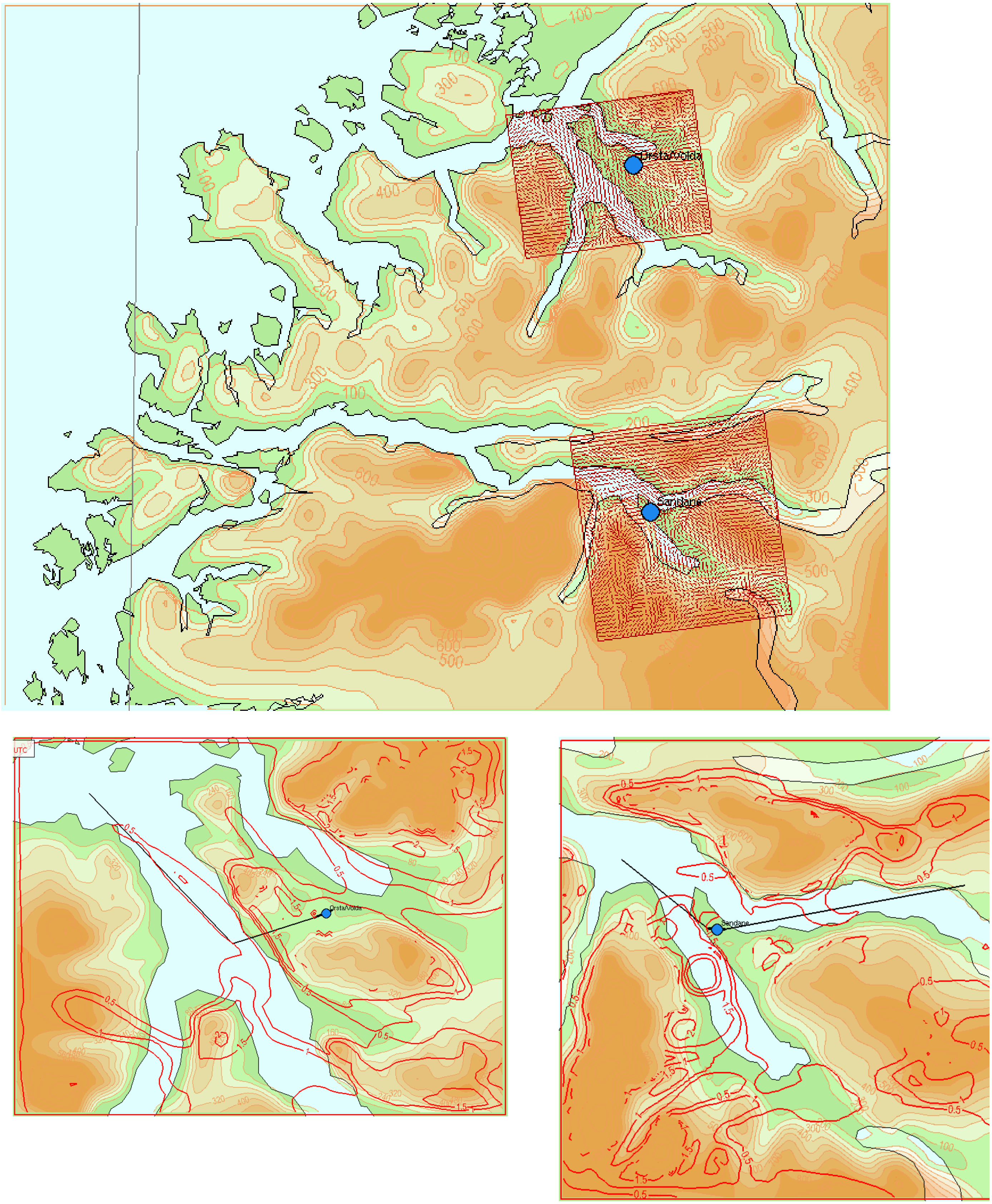


Figure 7 Model domains for UM 1-km for Ørsta and Sandane airports and SIMRA domain around Ørsta Hovden (bottom left) and Sandane Anda (bottom right). Details as in Figure 3.

2. Observations for verification

We have used three standard meteorological observation types in this study. We include a description.

The model system is designed for forecasting turbulent conditions. We have addressed the need for turbulence measurement for verification/validation. An aircraft from Widerøe will now be equipped with recording device so turbulence measurements can be retrieved. So far the data for verification is limited to observations which are unfortunately rather sparse.

2.1 SYNOP

SYNOP is an acronym for surface based reports. A SYNOP report contains wind measurements at 10 meter using standard traditional surface measurements for the airport at standard height 10 meter above land surface.

For the first validation report Midtbø (2006) only SYNOP-code observations were used in the validation.

2.2 TEMP

TEMP is an acronym for vertical soundings as measured from a balloon released and ascending due to lift of the balloon. A measurement device is attached to the balloon. Data are transmitted to the ground from this device in real time. The wind is calculated from the observed drift of the balloon relative to the ground.

The observational error of wind from TEMP reports is of the order of a few m/s.

2.3 AMDAR

There are available data from higher levels in the surrounding areas of some of the Norwegian airports. Some aircrafts are equipped with installations necessary to transmit meteorological observations known as AMDAR (Aircraft Meteorological Data Relay).

The following is referred from AMDAR REFERENCE MANUAL prepared by Derek Painting, World Meteorological Organization (WMO 2003).

"Wind speed and direction are computed by resolution of the vectors:

V = Vg – Va

Where V is the wind vector, Vg (ground velocity) is the velocity of the aircraft with respect to the earth and Va is the velocity of the air with respect to the aircraft. Va is calculated from true airspeed and heading. Heading and ground velocity are derived from the inertial reference unit (IRU).

True airspeed is a function of Mach number and static air temperature. Errors in Mach number are the most significant. For example with a Mach number error of 0.5% at cruise level, airspeed error is some1.2m/s. Thus with zero error from the navigation system, wind vector errors up to 1.2m/s are to be expected and are also dependent on the angle between the wind at flight level and the aircraft heading.

Errors in true airspeed combine with errors from the IRU. The basic calculations assume perfect alignment of the aircraft with the air stream and zero roll, pitch, yaw and perfect inertial platform alignment. At high pitch/roll angles wind vector errors,

which are proportional to true airspeed can be significant. For example at 150kt airspeed with 5 degrees pitch and 10 degrees roll a wind vector error of some 1m/s can be expected regardless of the true wind vector. At low wind speeds vector errors can lead to large errors in wind direction. Thus a more useful indication combining wind speed and direction error as vector error would suggest a typical uncertainty of 2-3m/s."

In the AMDAR format there are possibilities for reporting turbulence measures. Turbulence is reported in one or more out of three ways:

(i)As variation in vertical acceleration experienced by the aircraft.

(ii)As 'derived equivalent vertical gust'.

(iii)As an index related to eddy dissipation rate (EDR).

For more details see the reference manual referred to above.

In Europe quite many AMDAR reports includes the index listed as (iii) above. We have investigated the AMDAR reports presently available from aircrafts operating in Norway for some arbitrary days in January 2008. We have for those aircrafts found only reports with this index given as missing. For the project there would be of great value if actions could be taken to include such an index in the AMDAR reports for Norwegian areas.

3. Measures used for verification

Basis for the verification work at the Norwegian Meteorological Institute is operational storage of both observations and model output in secured data bases. In this way all data for validation and verification is available for further investigation if necessary.

All model data used in the following validation is interpolated horizontally to the position of the observation with Bessel interpolation with good interpolation accuracy. In the vertical data are interpolated as linear in the logarithm of p. To compare with observations at times off the hourly available model data a linear interpolation in time is carried out.

In order to summarize the results for the wind in some way, we have computed the square root (s_{uv}) of the mean of the squared standard deviations of the component errors of the two wind components u and v (s_u *and* s_v). Formula is:

$$s_{uv} = \sqrt{\frac{1}{2} \cdot \left(s_u^{\,2} + s_v^{\,2} \right)}$$

3.1 Verification of horizontal wind forecasts against SYNOP reports for the airports Hammerfest, Honningsvåg, Sandnessjøen, Ørsta, Værnes, Sandane and Narvik.

For Midtbø (2006) only surface based SYNOP reports were available for verification. Results for Hammerfest, Sandnessjøen and Molde were presented in that report. We have in the present report included a table showing the s_{uv} in based on SYNOP reports for all the seven airports. The quality of the forecasts of 10 meter wind is measured by this parameter. We see that the summary given by this parameter indicates that the nested models gives different results for the airports as might be expected.

For Hammerfest UM 1-km and SIMRA are equal and reduce the error compared to UM 4-km.

For Honningsvåg the error is quite large. SIMRA gives the largest error while the two UM give errors almost equal.

For Sandnessjøen there is a gradual decrease in error from Um 4-km down to SIMRA.

For Ørsta UM1-km has smallest errors while UM 4-km and especially SIMRA has larger errors.

For Værnes all three models have relatively equal errors while SIMRA has the smallest.

For Sandane all three models have relatively equal errors (as for Værnes) while UM 4-km now has the smallest error.

For Narvik the error is large. UM 4-km has the smallest error.

As discussed in Midtbø (2006), the results must be used with much care. The model is designed for forecasting turbulence in the upper air. A verification of forecasts of surface winds is quite relevant. It can be argued that good surface wind forecast could be used as an indication of the models wind forecasts in general. This is probably not the case. The forecasts of wind at higher levels are the basis for the turbulence forecasts. In order to say something about the turbulence forecast, wind at higher levels has to be verified.

s_{uv}	UM 4-km	UM 1-km	SIMRA
Hammerfest	2.84	2.25	2.28
Honningsvåg	2.41	2.44	2.61
Sandnessjøen	2.60	2.18	1.99
Ørsta	2.58	2.22	2.97
Værnes	2.05	2.12	2.02
Sandane	1.91	2.05	1.99
Narvik	2.63	3.14	2.88

Table 1 Table showing the parameter s_{uv} for the seven airports Hammerfest, Honningsvåg, Sandnessjøen, Ørsta, Værnes, Sandane and Narvik. For definition of the parameter see chapter 4. Results are computed by comparing model wind forecasts to hourly SYNOP wind observations.

3.2 Verification of horizontal wind forecasts against upper air TEMP reports for Ørlandet airport in Trøndelag

The model system is nested. The quality of wind forecasts in the coarser mesh models are verified against TEMP reports on a routine basis. From those reports we monitor and identify on a routine basis the quality of the models.

The observations can not be viewed upon as what is called the true value for the model data. This is caused by measurements errors and the fact that the model represents a mean value for the model grid box. This last point means that the model represents the grid box and not always the measured quantity regardless of the observation accuracy (small measurements errors).

When we in the following compare the two values (observations and model results) we will in short call the difference for model errors. It should be kept in mind that this error has originates from observational errors and errors connected to difference in what the two values represent as explained above.

We have done a separate investigation of the model errors measured by the TEMP reports for Ørlandet. The reason for this is that we want to find the model error in the Trøndelag area relative to a well known observing system as the TEMP reports. The station closest to Værnes is Ørlandet. As seen in figure 8 this is close to the lateral boundary for the UM 1km model for Værnes and outside the SIMRA area. Out of the results we have chosen to display data for 850 hPa which is a level around 1500 meters above sea level. We have compared the wind from UM 4-km and HIRLAM 10-km to the wind from TEMP reports. UM 1-km results are not displayed as they are quite similar to UM 4-km results.

A selection of verification results are shown in table 2A-D. We have included a table with the parameter S_{uv} in the lowest table 2D as this is a good measure of the wind quality in one parameter. In this table we have included the parameter for the start of the prognosis (+0) together with +12 and +24. We see that the error using this measure at the start is around 2 m/s. As explained above this result is a combination of observation accuracy and the model representing grid boxes rather than the TEMP measurement.

The error increases to 3 m/s after 12 hours. The result shows that the 12 hour prognosis of wind has similar magnitude for the two models. The model with the best results is UM 4-km which has the best resolution. The result justifies the nesting of UM 4-km inside HIRLAM 10-km in order to improve the 12 hour wind forecast in the Trøndelag area.

2A - FF

	UM 4-km	HIRLAM 10-km
ME	-0.1	0.69
MAE	2.2	2.61
RMSE	3.17	3.63
SDE	3.16	3.56

2B - u component

	UM 4-km	HIRLAM 10-km
ME	0.63	-0.17
MAE	2.42	2.65
RMSE	3.27	3.55
SDE	3.21	3.54

2C - v component

	UM 4-km	HIRLAM 10-km
ME	0.36	-0.1
MAE	1.89	2.33
RMSE	2.95	3.36
SDE	2.93	3.36

2D - S_{uv}

	UM 4-km	HIRLAM 10-km
+00	1.93	1.90
+12	3.07	3.45
+24	3.00	3.17

Table 2 A-D Verification results for the period September 1st to December 15th 2007 of interpolated model data compared to horizontal wind from TEMP reports observed at Ørlandet airport. The model data are 12 hour forecasts valid 12 UTC. The models are UM4 (left) and HIRLAM10 (right). The parameters computed are standard statistical parameter for the value of model value minus observation. In the three upper tables values for wind speed (FF), u-component and v-component of the wind are shown. The parameters are mean error (ME), mean absolute error (MAE), root mean square error (RMSE) and standard deviation of error (SDE). The lowest table shows the parameter S_{uv} described in the text. All results are in m/s. Interpolation methods for model data are described in the text. The results are computed for models based on the 00 UTC only. The TEMP reports used for this verification are 102.

5.3 Validation of horizontal wind forecasts against upper air AMDAR reports for the SIMRA Værnes area.

Among the seven airports Værnes airport is the only one where there are available AMDAR reports. The data forming basis for those report are produced continuously during the flight including approach and take off. The observed wind is subject to a sampling procedure and AMDAR reports are produced at certain intervals. An example of measured data is shown in figures 8 and 9. The observed data are irregularly distributed in space and time. The data used for this verification are limited to the volume of the SIMRA model for Værnes which extends up to approximately 1840 meters above sea level. In this way the same observations are used for validating HIRLAM 10-km, UM 1-km and SIMRA.

Results are presented in two similar tables 3 A-D and 4 A-D. The only difference between table 3 and 4 are that the first is for the verification period around 12 UTC and the latter for 00 UTC. For details about the results in the table, see the table text.

The results are as already mentioned confined to the volume box covered by SIMRA. From the previous chapter we have the result that a 12 hour prognosis of horizontal wind has an error of about 3 m/s at 1500 meters height when compared to TEMP reports for Ørlandet. The results in tables 3 and 4 are for forecast lengths of around 12 hours and the errors displayed of the same order of magnitude as the errors compared to TEMP reports. Looking again at the parameter S_{uv} we find that UM 1-km and SIMRA has almost equal errors in both tables, while UM 4-km has somewhat larger error. Based on this verification of horizontal wind alone we can not justify the use o the finer mesh SIMRA model as compared to Um 1-km. Conclusions about the value of the inner SIMRA nest can first be drawn when we have observations of turbulence available for verification.

Værnes is situated closer to the large mountain areas in Southern Norway than Ørlandet. We have seen in the tables 3 and 4 that the errors are on overall a little larger than the errors presented in chapter 5.2. This can be due to effects from the mountains but might also be caused by a somewhat larger observational error in the AMDAR data. The error in AMDAR data might also be somewhat larger at Værnes due to increased errors in the horizontal wind measurements originating from vertical motion and turbulence induced by the mountains.

More distinct conclusion can be drawn by following up this investigation on a larger data set. In a larger data set there also be possible to sample data for more distinct height levels for the AMDAR investigation.

The results shows the view that the UM 1-km and SIMRA are able to reduce horizontal wind error compared to the coarser mesh model HIRLAM 10-km.

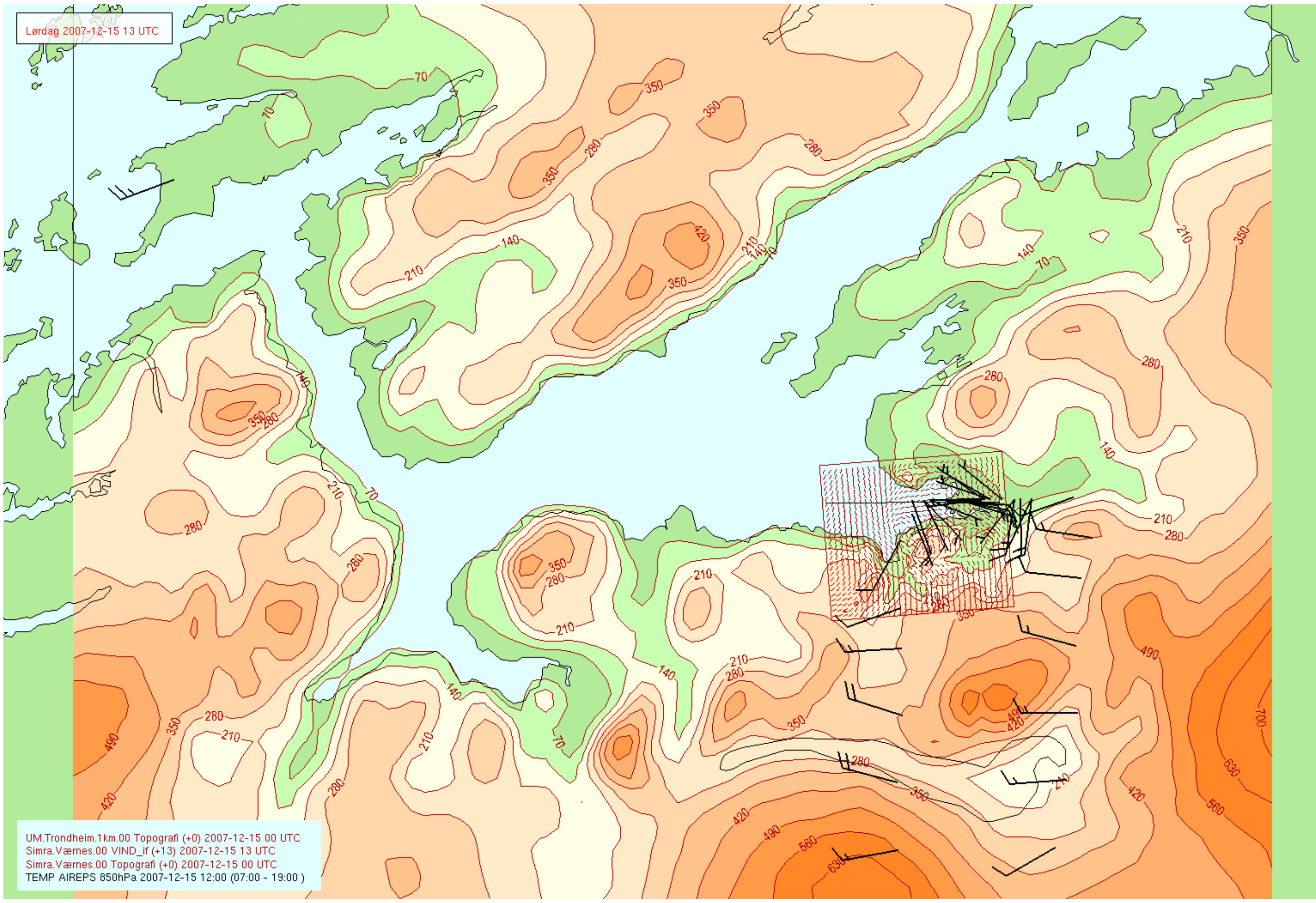


Figure 8. Model domain for UM 1-km for Værnes airport, topography with 70 m spacing between isolines. The SIMRA domain is shown with red wind arrows every second grid point. In black a wind arrow (in 850 hPa) from the radio sounding at Ørlandet airport. Also in black, wind arrows from AMDAR for two different aircrafts.

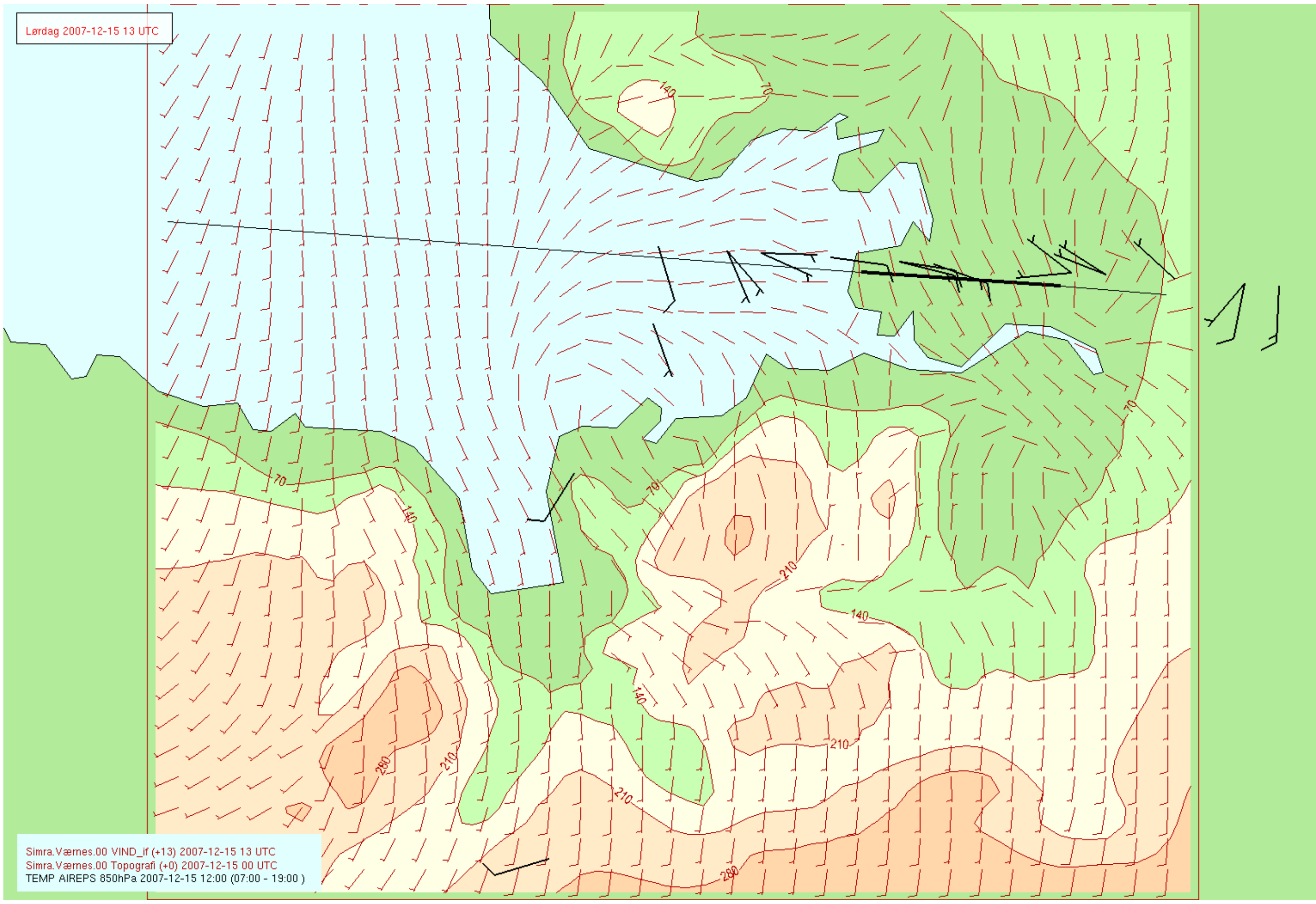


Figure 9. The SIMRA domain around Værnes. The topography is shown with 70 m between isolines. The straight black line indicates the projection of the sectors for take off and landing. The red wind arrows show the wind in the in-flight levels for every second grid point. The black wind arrows are from AMDAR for two different aircrafts.

3A - FF

	HIRLAM 10-km	UM 1-km	SIMRA
ME	1.38	0.54	0.49
MAE	2.87	2.48	2.43
RMSE	3.72	3.17	3.16
SDE	3.46	3.12	3.12

3B - u component

	HIRLAM 10-km	UM 1-km	SIMRA
ME	1.03	0.78	0.65
MAE	3.21	3.07	3.01
RMSE	4.06	3.72	3.71
SDE	3.93	3.64	3.66

3C - v component

	HIRLAM 10-km	UM 1-km	SIMRA
ME	0.79	-0.45	-0.35
MAE	2.47	1.80	1.78
RMSE	3.18	2.44	2.42
SDE	3.08	2.40	2.40

3D - S_{uv}

	HIRLAM 10-km	UM 1-km	SIMRA
S_{uv}	3.52	3.08	3.09

Table 3 A-D. Verification results for the period September 1st to December 15th 2007 of interpolated model data compared to horizontal wind from AMDAR reports within the SIMRA model volume. The model data are +9 to +15 hour forecasts computed based on HIRLAM10 for 00UTC. The models are HIRLAM10, UM1 and SIMRA (left to right). The parameters computed are standard statistical parameter for the value of model value minus observation. In the three upper tables values for wind speed (FF), u-component and v-component of the wind are shown. The parameters are mean error (ME), mean absolute error (MAE), root mean square error (RMSE) and standard deviation of error (SDE). The lowest table shows the parameter S_{uv} described in the text. All results are in m/s. Interpolation methods for model data are described in the text. The number of observed winds used as a basis for the table is 1791

4A - FF

	HIRLAM 10-km	UM 1-km	SIMRA
ME	1.31	0.68	0.52
MAE	2.62	2.48	2.42
RMSE	3.36	3.17	3.09
SDE	3.10	3.10	3.04

4B- u component

	HIRLAM 10-km	UM 1-km	SIMRA
ME	1.00	0.89	0.68
MAE	2.84	2.79	2.73
RMSE	3.48	3.42	3.36
SDE	3.33	3.30	3.29

4C - v component

	HIRLAM 10-km	UM 1-km	SIMRA
ME	0.62	-0.43	-0.27
MAE	2.44	1.91	1.99
RMSE	3.19	2.69	2.75
SDE	3.14	2.65	2.74

4D - S_{uv}

	HIRLAM 10-km	UM 1-km	SIMRA
S_{uv}	3.24	3.00	3.02

Table 4 A-D. Verification results for the period September 1st to December 15th 2007 of interpolated model data compared to horizontal wind from AMDAR reports within the SIMRA model volume. The model data are +9 to +15 hour forecasts computed based on HIRLAM10 for 12UTC. The models are HIRLAM10, UM1 and SIMRA (left to right). The parameters computed are standard statistical parameter for the value of model value minus observation. In the three upper tables values for wind speed (FF), u-component and v-component of the wind are shown. The parameters are mean error (ME), mean absolute error (MAE), root mean square error (RMSE) and standard deviation of error (SDE). The lowest table shows the parameter S_{uv} described in the text. All results are in m/s. Interpolation methods for model data are described in the text. The number of observed winds used as a basis for the table is 1768.

4. Discussion

As discussed above, the modelling of the winds above surface in SIMRA are improved in this nested system when compared to coarser mesh meteorological models.

There is also a need for looking closer into the accuracy of the aircraft data. A study of the effect of mountains on the AMDAR measurements should be carried out at Bodø where the airport and the TEMP observation site are collocated.

What obviously remains is to verify the turbulence itself. Since SIMRA computes the turbulence from wind distribution, a good verification of the wind especially higher up in the atmosphere is a necessary condition for producing good turbulence forecast. Surface wind conditions will in this context be a weaker measure of ability to produce good turbulence estimates. There remains nevertheless to see how good those forecasts are when compared to measurements of turbulence.

This study should indeed be viewed as a start of the system evaluation. In the project we will give high priority to get turbulence reports from the pilots and measurements from the aircrafts flight recorder. Only in this way, we can come further towards the aim of assessing the validity of the model system as a tool for forecasting turbulence close to airports.

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