DANISH METEOROLOGICAL INSTITUTE

MINISTRY OF TRANSPORT

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Cover picture: DMI automatic V98 weather station in Blaavand, Denmark

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You need to know….

When predicting the weather, you need to know how it is right now. That is why a well planned observation network, along with a thorough knowledge of meteorology, atmospheric physics and numerical analysis, is one of the most important assets of a modern meteorological service.

The Danish Meteorological Institute is responsible for serving the meteorological needs of society within the Kingdom of Denmark (Denmark, the Faroes and Greenland) covering a total of two million square kilometres of land with territorial waters, a geographical area that is second to none on a Western European scale. See figure 1.

It is DMI's strategy to continuously optimise the observation network to support DMI's mainstream products in the most cost-effective way. Like most other countries, Denmark wants to give its citizens value for money, and public services are constantly being challenged to produce better services for less money. In DMI's implementation of this principle this means that, when it comes to the observation network, one needs to:

1. Attain a technical standard that is good enough to support the meteorological products;
2. Concurrently optimise the observation network layout and observation program to yield adequate information about weather and climate;
3. Continuously re-engineer the business processes to cope with financial, political and commercial constraints.

Since 1998 DMI has focused a considerable effort on modernization and automation of the observation service and achieved a cost reduction of almost 30% over five years in the Observation Department. At the same time the observation frequency has been increased from once every 3 hours to once every 10 min for all Danish stations. This has had a substantial effect on the meteorological services provided by DMI, especially nowcasting products that are attracting more and more public attention.

Figure 1. The Kingdom of Denmark consists of Denmark, the Faroes and Greenland. Although Greenland and the Faroes both have home rule, they are still closely connected to Denmark politically, administratively and ecomomi-cally.

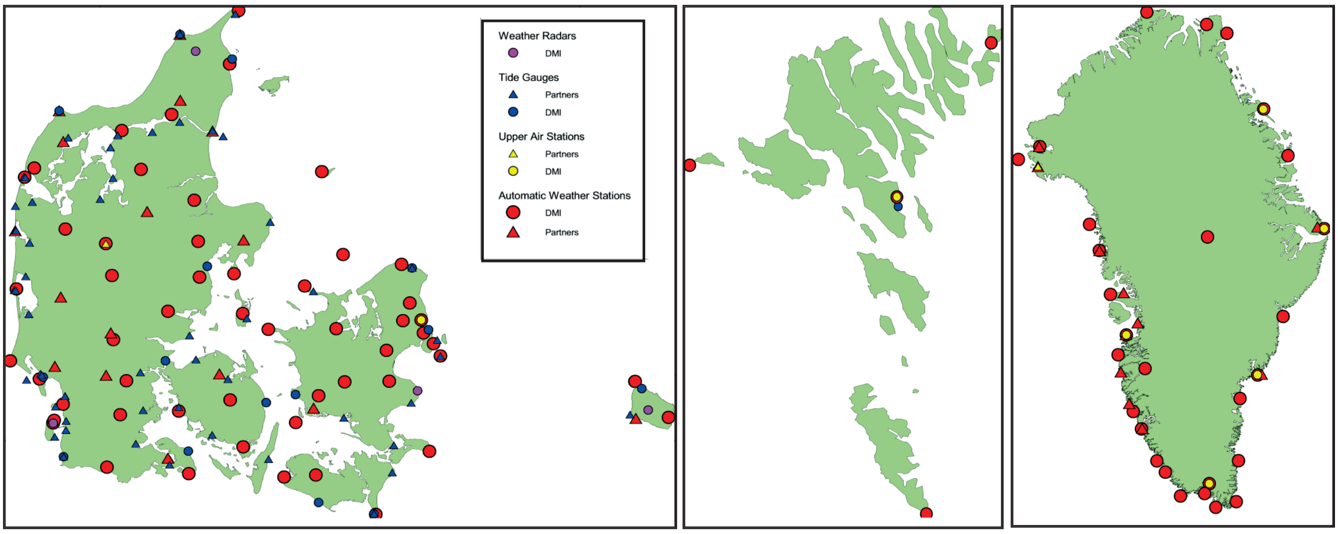


Figure 2. DMI operates 83 synoptic stations, 15 tide gauges, 9 radiosonde stations (including 2 ASAP units), 4 weather radars, 80 automatic precipitation stations, 500 volontary rainfall stations and two surface Ozone stations. The Insti-tute also operates a number of geophysical observatories mainly serving scientific purposes.

Observation network	1999	2000	2001	2002	Accept level
Weather stations	96%	96%	97%	97,0%	95%
Tide gauges	98%	99%	99%	98,9%	98%
Satellite stations					
Denmark	96%	98%	98%	98,3%	95%
Greenland	97%	98%	98%	99,2%	95%
Upper air stations					
Denmark and the Faroes	98%	99%	99%	98,5%	98%
Greenland	99%	96%	96%	97,2%	90%
Weather radars	97%	98%	99%	98,5%	95%

Figure 2. The data availability is monitored continuously and is an important figure of merit for DMI. A data set is considered available if it is received at DMI headquarters in Copenhagen before a certain cut-off time defined for the individual components of the observation network. Data availabilities in the high nineties are achieved for all operational systems.

Automatic Weather Stations

DMI continuously receives observations from 109 automatic weather stations. Out of these stations 83 are owned and operated by DMI, the rest belong to DMI's strategic partners, like private airports, the Danish Coastal Authority and The Danish Institute of Agricultural Sciences. During the winter months additional 300 nonstandard stations owned and operated by municipal and county road authorities are activated as part of the road safety programme.

The automation programme started back in the 1970s with the set-up of approximately 15 remote stations in Greenland. These stations, which were very advanced for their time, communicate their observations via the ARGOS satellite system. They are solar powered, and their batteries can store enough power to operate during the four months of polar winter night at extremely low temperatures. See figure 4. The stations situated at high latitudes are serviced only every second year. Nevertheless, they continue to work perfectly well more than 25 years after their installation. The rest of the stations in Greenland are PC based. Lately all the weather stations on the 11 airports in Greenland have been equipped with a modern DMI developed weather station.

Figure 3. Automatic V98 weather station at Holbaek Airport, Zealand, Denmark. The station is fully equipped with optical sensors for present weather and cloud parameters.

During the last five years the Danish weather station network has been restructured and modernized. All manned stations have been fully automated, except for the airports where observers are still mandatory. To satisfy the airports' special requirements, the airport weather station SAVS2000 has been developed in a fruitful private-public partnership between DMI and Dansk System Elektronik.

Since 1998 DMI has installed more than 40 fully automated stations based on the DMI station called V98 which has a flexible structure allowing configuration for various purposes, such as measuring in coastal regions, measuring parameters of agricultural interest mainly inland, and measuring parameters previously manually reported, like present weather, cloud coverage, etc. The Vaisala Milos 520 data logger is used. See last page for a brief description of DMI's smart sensors used in the V98 programme.

Every ten minutes the V98 station transmits the processed sensor data to DMI Headquarters via the Danish Alarm Net, a proprietary message switched network used for fire alarms, burglar alarms and other forms of critical monitoring. This high priority network yields an unsurpassed data availability.

Voluntary Observing Ships (VOS)

Denmark participates in WMO's VOS (Voluntary Observing Ships) programme with almost 50 ships recruited by DMI and more than 30 ships recruited by other National Meteorological Services.

In 1997 and 2002 DMI collected approximately 28.000 and 24.000 VOS observations respectively. The main effort is concentrated on the waters around Denmark (the Baltic Sea, the Skagerrak and the North Sea), the North Atlantic Ocean around the Faroes, and finally the Greenland waters east, west and south of Greenland.

The percentage of faulty observations is almost constant, just below 2%, whereas the percentage of loss in communication in recent years has declined from approx 4,5% to just above 2%. This reflects the worldwide tendency towards fewer but larger ships carrying modern satellite communication facilities.

Tide Gauges

DMI has continuously monitored the sea level of the Danish waters since 1888. Initially the network consisted of 10 stations equipped with the well-known float gauge in a stilling well, a relatively primitive technical solution. These are very simple to install and operate, but the stilling well involves some undesirable effects, such as trapping of fresh water resulting in erroneous measurements.

Today DMI uses a more sophisticated method based on the measurement of sub-surface pressure by an instrument fixed to the pier below the lowest expected sea level. The instrument also measures temperature and conductivity in order to calculate the

Figure 4. Remote station in Nunarssuit, Greenland. Operating automatic weather stations at remote sites in the high arctics represents a considerable technical and logistic challenge. The stations are solar powered, and during the short summer they need to collect enough energy for the four months of arctic winter night with temperatures below -40^{o}C. The most northern stations are serviced only once every second year.
The remote stations send their data to DMI's satellite receiving stations in Kangerlussuaq, Greenland and Copenhagen via the ARGOS system.

salinity and the density of the water.

New techniques and improved communication have resulted in a fully operational and automated tide gauge network of 15 stations producing real-time data every 10 minutes.

Upper air stations

The purpose of radiosonde launching is to profile the atmosphere with respect to pressure, temperature, humidity, and wind speed and direction. The maximum achievable height is about 5 hPa (35 km). On occasion, special radiosondes are used for measuring ozone or radioactive pollutants.

The Danish upper air network consists of 9 radiosonde stations, five stations in Greenland, one in the Faroes, one in Denmark, and two ASAP (Automated Shipborne Aerological Programme) stations. The two ASAP stations are carried by Royal Arctic Line ships, and soundings are performed by the ships' officers, sailing between Denmark and Greenland along 60° North. The yearly

Sea-level data makes a difference.....

The original purpose of measuring the sea level was to determine a Danish National Vertical Reference System called Dansk Normal Nul (DNN) based on the mean sea level of the seas surrounding Denmark. This original purpose is still a focal point, but during the twentieth century new applications of sea-level data have become obvious.

Warning of storm surges. The storm surge warning service was set up as a result of the severe flooding disaster in Holland in 1953. Like Holland, Denmark has low lying areas protected from the sea only by dikes. Real-time sea-level data in combination with meteorological data and advanced mathematical modelling now yield reliable forecasts of the expected sea level.

Studies of climate and climate changes. Changes in sea level and especially the possible rise in sea level caused by human impact on the climate during the last 30 years are important issues in climate change scenarios both on a global and a local scale.

Navigational safety. It could be disastrous for large cargo ships and oil tankers to navigate the shallow Danish waters without taking account of exact measurements and forecasts of sea level as well as weather conditions. Oil leaks from grounded ships represent a serious threat to the coastal environment.

Geophysical research. The formation of marshes, land uplift or subsidence, the erosion of beaches, salt intrusion into aquifers and surface water are all topics that presuppose a knowledge of sea-level data.

Construction and engineering. The design of dikes and other coastal defences against flooding, implication studies for coastal habitats, the protection of shores against erosion, and construction works in general along the shores or at sea all depend on reliable sea-level data. A recent example is the Copenhagen Metro system which was designed according to historical sea-level measurements for Copenhagen.

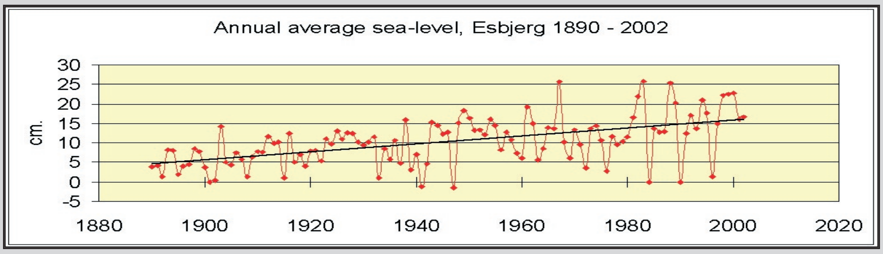


Figure 5. Annual mean sea-level (MSL) from the tide gauge station in Esbjerg calculated from hourly measurements, revealing a positive long time trend with a relative sea level rise of app. 1.01 mm/year.
The relative sea level rise includes the combination of the vertical isostatic and tectonical, movements (uplift and/or depression) in the earth's crust and the actual change in the sea level including the long-term eustatic change. Unfortunately it is not possible to separate these effects directly from the sea level measurements, but it is clearly seen that there is no evidence of an accelerating sea-level rise during the last decades due recent climate changes.

Fig. 6. ASAP unit carried by Royal Arctic Line line ship.

number of radiosonde launches is about 5100 from land stations and about 700 from ASAP ships.

Whenever possible the Loran C navigation system (partly NELS [North European Loran System] and partly a few selected Northwest American chains) is preferred over GPS (Global Positioning System) to measure wind speeds and directions. The reason for this choice is that the Loran radiosondes are less expensive than the GPS radiosondes, the price being about 60 % of the price of a GPS radiosonde. Only in Aasiaat and Narsarsuaq the Loran signals are too weak, and GPS radiosondes are required. The ASAP stations normally carry GPS sondes as well as Loran C sondes in case the Loran signals are unavailable.

RS-90 radiosondes from Vaisala are used at all stations except Torshavn. In Torshavn it has been found that the older RS-80 sonde is more immune to influence from the nearby Loran transmitter station at Ejde. Likewise, all receiving equipment is from Vaisala (MW11 and MW12). Although this type of receiver is from the late 1980's, there has as yet been no incentive to replace the equipment. A prototype of an auto launcher based on a MW11 receiver unit is currently being tested at Jægersborg.

Automatic rain gauge network

In order to increase the knowledge of extreme precipitation in Denmark, the Danish Meteorological Institute in collaboration with the Danish Water Pollution Control Committee established a national automatic rain gauge network in 1979. At present 74 gauges are operated throughout the country, and the longest sequential record includes approximately 23 years of data.

Historical rain series data is used mainly for designing wastewater and drainage systems, and anticipating overflows. Figure 7 shows the location of the rain gauges in the network.

The network consists of rain gauge installations at costumer sites and a data collecting system at DMI. The individual rain gauge is owned by the user, typically the local municipality. The rain gauge used is of tipping bucket RIMCO type. Every time 0.2 mm of rain falls, the bucket tips and the time is recorded. Information about the accumulated number of tippings is collected at DMI via a proprietary message switched network.The strength of this measuring equipment is its high resolution in time and volume providing detailed information about the intensity of a rainfall.

To prevent snow from blocking the funnel in winter, the rain gauge has a built-in heating system. When the temperature falls below 3°C, the heater goes on and melts snow in the funnel.

Voluntary rainfall stations

The Danish and Faroese precipitation climate is supervised closely by a little more than 500 rainfall stations

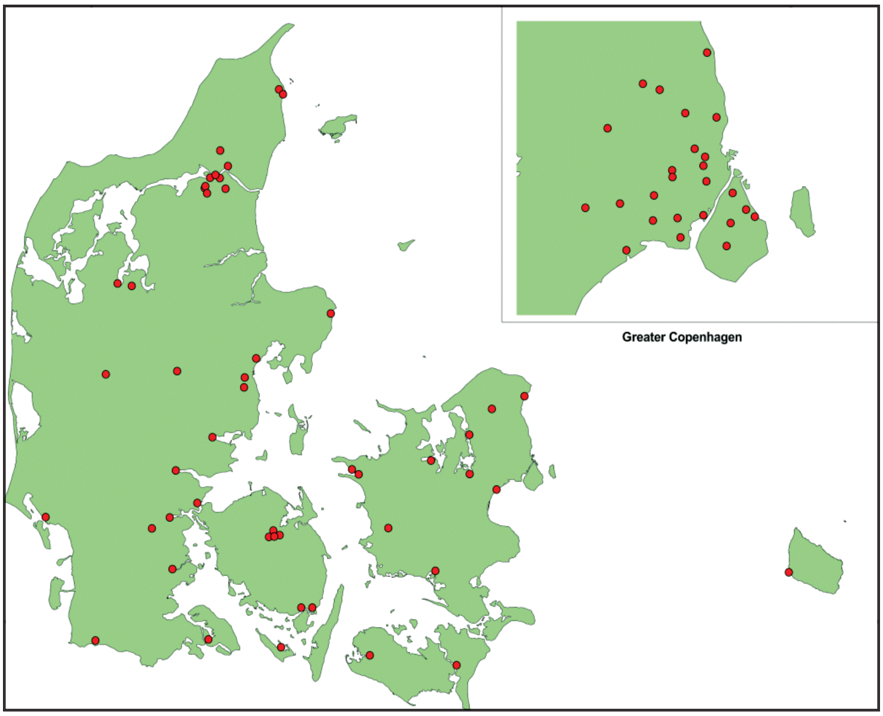


Figure 7. Automatic rain gauge network.

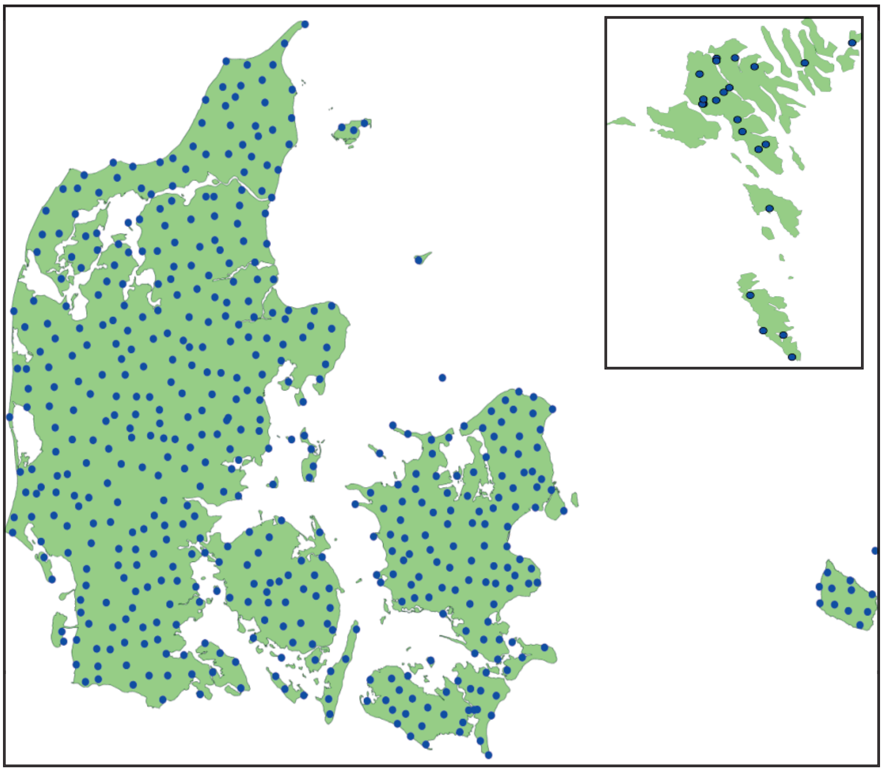


Figure 8. Voluntary rainfall stations in Denmark and the Faroes (insert).

operated by voluntary observers. To provide uniform coverage the Danish stations are placed at intervals of 10 km, and inland and coastal stations cover land areas of 100 km^2 and 50 km^2 respectively. The Faroese topography does not allow a similar regularity.

The precipitation gauge used is of the Hellmann type with a sample area of 200 cm^2. The precipitation is measured every morning at 8 am. Snow, hail and rime frost are melted before measurement. The upper edge of the precipitation gauge is 150 cm above the terrain in order to avoid false measurements, owing to e.g. dirt, leaves or drifting snow in the funnel of the gauge.

Until July 2001 the daily measurements were reported on a monthly precipitation form mailed to The Danish Meteorological Institute at the end of each month. From August 2001 95 stations began to report the daily precipitation measurement via the telephone, and from April 2003 all stations will report in this manner.

Satellite observations

DMI has received and used data from weather satellites since 1965. Today DMI's satellite ground stations in Denmark and Greenland receive data from NOAA and Meteosat operationally. In addition, other types of satellite data are received operationally via the Internet, e.g. data from the Defense Meteorological Satellite Program (DMSP), QuikScat and RADARSAT. Preparations to receive data from Meteosat Second Generation are in progress. The coverage of the two NOAA ground stations is shown in figure 9. Approximately 15 to 20 passages are received daily from operational NOAA satellites by each ground station.

The DMI ground station in Greenland is part of the EUMETSAT ATOVS Retransmission System, and these data are therefore available to all EUMETSAT members and cooperating states.

Images, sounder data and data from data collection platforms are received and processed at DMI and forwarded to DMI's Forecasting Services Department in Denmark, Greenland and the Faeroes for nowcasting purposes. Data are also distributed to DMI's Ice Service and are assimilated into the numerical weather prediction model, HIRLAM.

In addition to DMI's usage, satellite images are also presented to the public, especially on dmi.dk and on television in connection with weather forecasts.

Weather radars

DMI's network of weather radars consists of four radars providing a complete coverage of the precipitation distribution over the entire country.

The radars produce a complete volume scan every ten minutes. The volume scans

Figure 9. Coverage of DMI's NOAA ground stations in Denmark and Greenland.

are converted to Constant Altitude Plan Position Indicator (CAPPI) layers before being communicated to DMI for further processing. The products available are single and multi radar CAPPI and pseudo CAPPI layers showing radar reflectivity factors.

The products are predominately used by DMI's Forecasting Services Department, but also other National Meteorological Services, public authorities and private companies are utilizing the information provided by the network. Furthermore, a subset of the products is presented to the public on dmi.dk and is used as part of the weather forecast presented on television.

During the coming year two of the existing radars will be renewed to improve and ensure a high performance network, to facilitate efficient maintenance and to homogenize the network.

Figure 10. Weather radar situated on Rømø in southern Jutland.

Lightning detection

The distribution and strength of lightning and the extent of thunder storms is monitored from six lightning detection stations located throughout the country to provide a complete coverage of Denmark. The current network, which was established in 2000, detects both cloud to earth and cloud to cloud lightning. The location of lightning strokes (cloud to earth) is determined with an accuracy of 500 to 1000 meters, a considerable improvement compared to an earlyer network. Data from the detectors is communicated to DMI and processed in near real-time. Information about lightning is distributed to DMI's Forecasting Services Department and to the public, e.g. on dmi.dk, and to private institutions such as power companies.

Quality control of synoptical data

DMI performs central on-line quality control of data from the Danish synoptic stations. The main purpose of quality control is to offer better service to both internal and external users by applying quality indicators to all the elements of data. Additionally, there are non-real-time sample quality control procedures which include comparison of observations from adjacent stations, etc.

Automatic real-time data control

The automatic real-time data control runs on-line as a part of the decoding system and monitors all essential parameters, such as temperature, maximum and minimum temperatures, humidity, wind speed and direction, gust, precipitation, precipitation intensity, pressure, barometric tendency, present and past weather, and cloud cover.

The philosophy of the on-line data quality control is that all data are passed unchanged to the user. The quality control only applies a quality index to each parameter that has been checked.

The real-time quality control system consists of three consecutive tests as show in figure 13. There are three levels of data quality in each of the three check categories. The data values are deemed either OK, unusual or extraordinary/physically impossible.

The first check is a range check in which the value under test is compared with the statistics for the actual parameter over the last 20 years. If the value is within the 99.8% central part of the distribution, it is considered OK. If it belongs to the 0.2% fractile, it is considered unusual, while it is

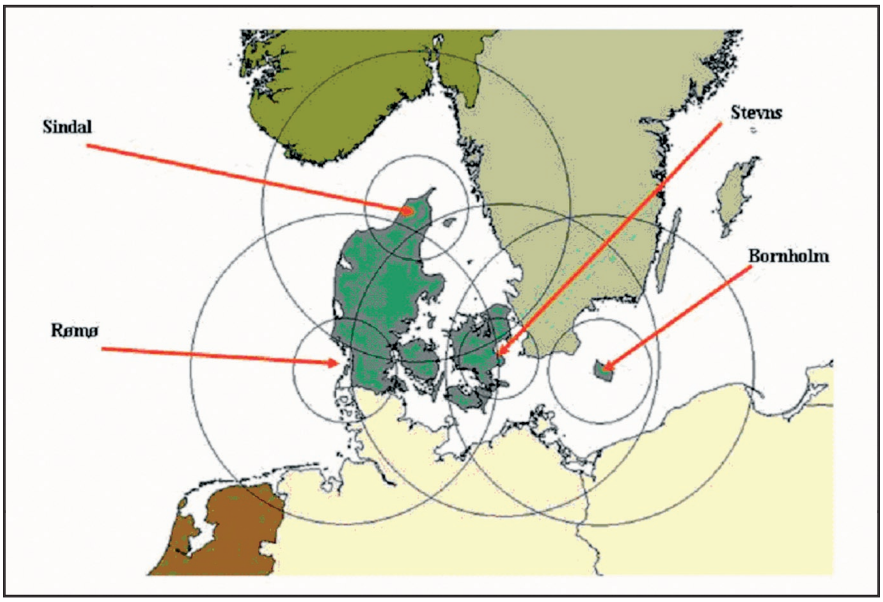


Figure 11. The Danish weather radar network. The circles represent the first and sixth CAPPI layer (height above the ground, 1 km and 6 km respectively) for each of the radars.

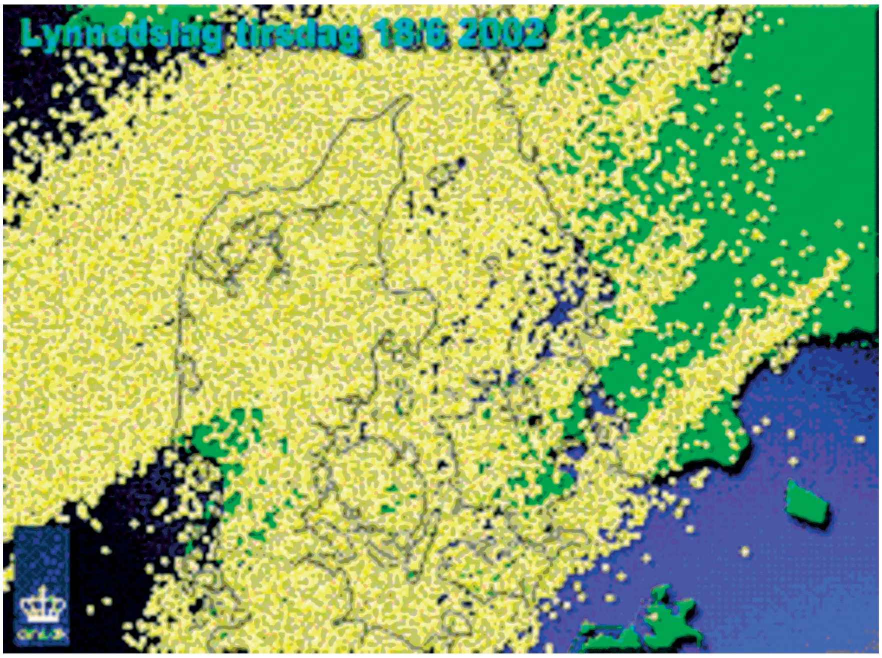


Figure 12. Example of severe summer thunderstorm activity. The map shows detected lightning on 18 June 2002. From www.dmi.dk.

considered extraordinary if it exceeds the most extreme value in the statistical data. The underlying statistics are specific for each of the three regions, Denmark, the Faroes and Greenland, and for each month of the year.

The second test is a similar statistical test in which the increment of the value since last observation is compared with detailed statistics for the actual parameter. Again, the underlying statistics are specific for each of the three regions, Denmark, the Faroes and Greenland, and for each month of the year.

The third test is a consistency check in which various parameters of a single observation are compared for inconsistency. If high temperatures and snow are observed at the same time, for example, the control will note that the parameter is unusual or even physically impossible.

The on-line quality index which is applied to all data elements facilitates on-line rejection of questionable data in real-time applications, like Internet presentations and automatically produ-ced meteorological products. Further, the quality index can be used in off-line tasks, like climatological analysis and observation network maintenance.

Non-real-time sample quality control

I addition to the automatic data control, a scheduled non-real-time sample analysis is carried out on a manual basis.

Several applications are used for this task. The most frequently used one is a graphical user-interface, OBSSHOW, that can display observations over time and space. See the example in figure 14.

For easier detection of minor errors in the parameters in the synoptic code section 1, automatic plotting and Kriging interpolation are done for air temperature, dew point temperature, air pressure, as well as 6 hour and 12 hour accumulated precipitation. This method ensures that the most essential parameters measured at synoptic stations are controlled by manual inspection, giving a clear indication of where the suspicious values are to be found. An example of a plot map is shown in figure 15.

Observations on www.dmi.dk

DMI's Internet pages are among the most popular in Denmark. Monthly polls frequently put DMI on the national top-ten list. Naturally the reason is that the public consider the pages useful in their daily doings. All conventional meteorological parameters

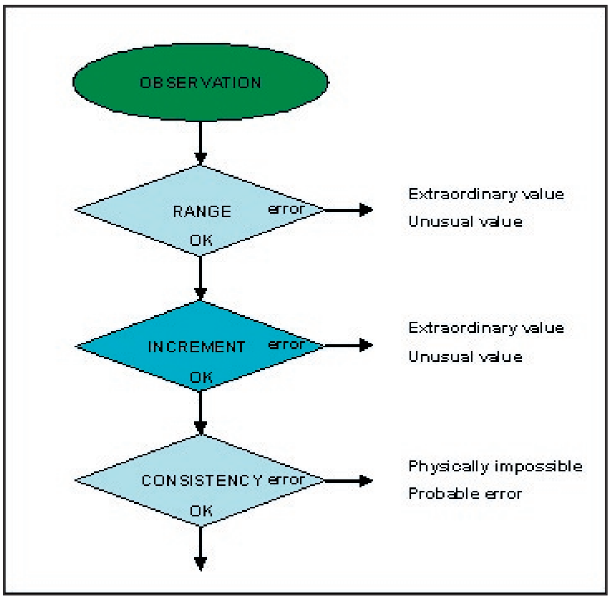


Figure 13. Automatic on-line data control flow chart.

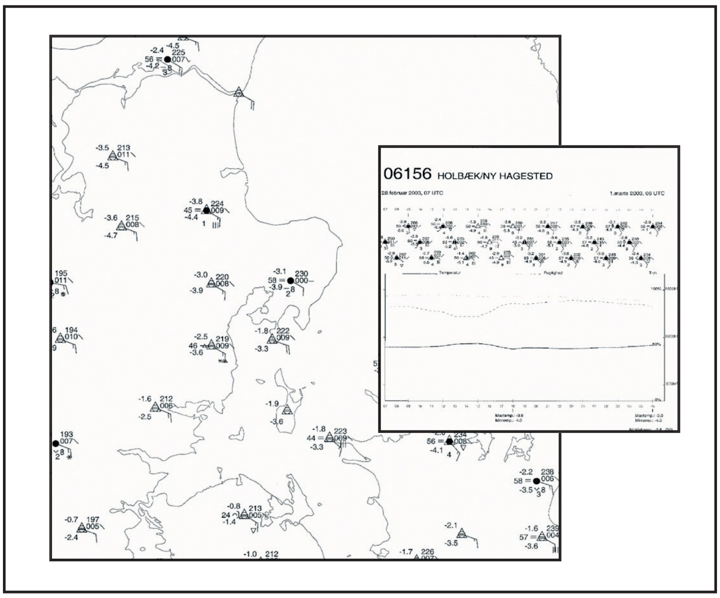


Figure 14. Example of manual sample control.

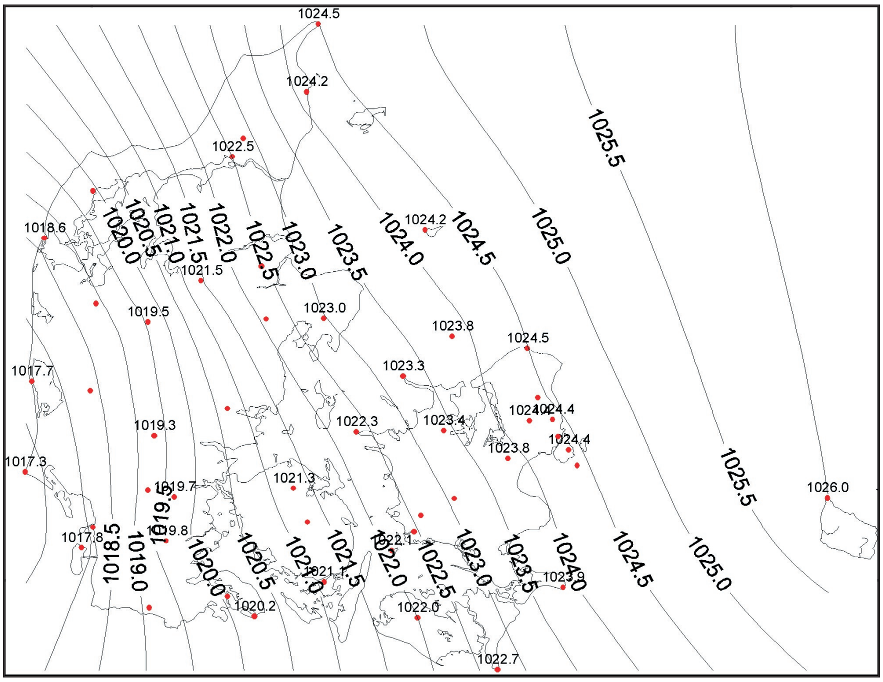


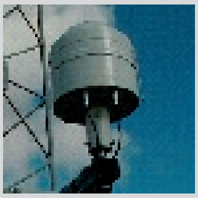
Figure 16. Isobar curves for manual sample control. Iso-curves for a number of important meteorological parameters are drawn automatically by Kriging interpolation. Diverging stations are readily found by visual inspection.

like temperature, wind, wind direction, wind gust, barometric pressure, present weather, etc. are shown for Denmark, the Faeroes and Greenland. The data are mostly hourly. For the Danish area with surrounding waters weather radar images are shown every second hour 8 hours back in time. Lightning is shown for the last three hours, and accumulated lightning maps are shown for the last 7 days. For both Denmark and Greenland satellite images from METEOSAT and NOAA are shown currently. METEOSAT is shown both as still pictures and as animation.

DMI serves as the national hub for all institutions operating tide gauges. Data from more than 100 tide gauges are shown in real time for Denmark, the North Sea and the Baltic. The Danish data are shown together with a high quality prognosis.

Observations without observers.............

Smart sensors facilitate automatic and trustworthy observation at a high observation frequency 24 hours a day. The faulty observations and coding errors of previous times are eliminated and at the same time recognizable savings are achieved.



Global Radiation and Hours of Bright Sunshine

P.H. Schenk Starpyranometer type 8101 with protective housing type 8106. The housing contains an air heater and a blower which keeps the pyranometer dry.

The Milos data logger calculates the hours of bright sunshine based on radiation intensity, time of day and the latitude of the station.

Ceilometer

Vaisala Ceilometer type CT25K measures cloud height up to 25.000 feet using an infrared laser back scatter technique.

Up to three layers are measured simultaneously. A built-in algorithm calculates the cloud amount of those three layers.

In case of low visibility, the vertical visibility is reported.

The sensor runs an extensive test routine reporting any need for service including need for cleaning of the optical parts.

Present Weather Sensor

Vaisala Weather Sensor type FD12P measures visibility using an infrared laser forward scatter technique.

By combining the thoroughly analyzed signal from the forward scatter receiver with the signal from a rain detector, the sensor is able to distinguish different forms of precipitation – liquid as well as solid.

The form and intensity of the precipitation is reported in WMO code.

The sensor runs an extensive test routine reporting any need for service including need for cleaning of the optical parts.

Precipitation Gauge

Geonor type T-200 measures rain and snow. The container is supplied with antifreeze eliminating any need of heating the gauge. A weighing sensor monitors the content of the container enabling the Milos data logger to calculate precipitation intensity and amount. Furthermore a unique algorithm takes advantage of information from the Present Weather Sensor avoiding report of false precipitation events due to vind or temperature variations.