New developments and operational experience with surface observation technology and national networks

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ABSTRACT

In this paper new developments on surface measurements are discussed. Reference is made to historic and nowadays trends of users' interests and demands. The increasing diversity of available observation technologies and specific user requirements will become a great challenge for observation system developers, especially due to integration of the various observing systems. Moreover, quality control, data management and standardization will become key issues due to complexity and indirect measurement practices.

Historic Background

Monitoring the weather and the desire to integrate earth-observing systems seems to be the trend of today but has in fact a long history. In the begin of the 17^{th} century the city of Florence asked Galileo to invent a system to pump up fresh water to the city. In that time the existence of vacuum and air pressure was not well accepted or understood and water pumps suffered from pumping up water. Galileo died before he found a solution and Evangelista Torricelli was asked to continue the job. Instead of water he used mercury and created a sustained vacuum to prove its existence. As a consequence he discovered the principle of a mercury barometer (fig. 1) and also the fact that air has a density ρ or mass. Also the variability in time of air pressure was discovered.

Figure 1

Torricelly demonstrating vacuum using a mercury barometer

Around 1650 experimenters like Blaise Pascal and Robert Boyle did field research and Pascal discovered using a mercury barometer that air pressure decreased with altitude and Boyle the relation between pressure and the volume of a gas. More than a century after these experiments geo-physical research came back into focus, especially the studies on the earth electromagnetic field. For these studies dense networks were established in the first half of the 18^{th} century. That time is characterized by the interest in and discovery of environmental phenomena. Use of mathematics was not popular; the idea was that phenomenological research would give the answer and solution to most questions, *i.e.* a theory based on the experiment. A well-known discoverer was Alexander von Humboldt, who investigated the air temperature as a function of altitude (like Pascal did for air pressure some 150 years earlier). In fact he is the personification of this type of phenomenological studies with a deterministic approach. Typically after 1850 the use of mathematics came into practice and the experiments produced quantitative data to prove any theory.

At some stations to measure the geological behavior of the earth electromagnetic field also barometers and thermometers were placed to analyze any correlation between the variability of the field and atmospheric pressure. Note that this type of research is focused on discovery and purely phenomenological oriented. A major success of this approach was the discovery of the relation between wind and the gradient in surface air pressure. Moreover he ability to forecast weather with a barometer stimulated the establishment of many autonomous "weather stations" (fig 2).

Fig. 183. — Baromètre de Bourdon.

Figure 2

Bourdon type barometer, used in the 19th century as a tool to forecast weather - still populair today at home.

After the invention of the telegraph it became possible to communicate in "near real time" giving an extremely important impulse for synoptic meteorology. This new data communication facility made it possible to obtain an instantaneous overview on a map of the measured quantities like pressure, wind, temperatures and also the state of the weather, expressed in more qualitative terms. Thus in the second half of the 19th century networks already provided meteorological information, suitable for forecasting practices. At that time geo-physical research came at a stage where the behavior of the atmosphere was tried to be expressed on a more theoretical base and especially with a mathematical approach. Even more, in the begin of the 20th century it was postulated that hydrostatic formulas could be used to describe the current state of the atmosphere and for forecasts. This idea was found correct but impossible to develop because of the infinite amount of arithmetics required for a three dimensional approach. Only in the second half of previous century with the introduction of supercomputers it became possible for the NWP community to produce forecast data within a processing interval shorter than its forecast range. A forecast for UTC + 24H came available after a processing period less then 24 H, essential for any forecast.

It is interesting to see that both science and operational services dealing with meteorology, climatology, *etcetera* are oriented today on both discovery of weather phenomena (the classic deterministic approach) and on validation and analyzing NWP models, based on modern thermodynamics with plenty of mathematics. This statement not only holds for *in situ* measurements but also for remote sensing and especially for observations from satellites.

Therefore the functional specifications of networks and weather stations have a complex background. Such a network should provide numerical data, *i.e.* quantitative physical variables, and present weather information expressed in pre-defined parameters, like type-of-cloud, special phenomena, type-of-precipitation, icing. Although the background looks complex it is simple compared to the present needs of the multiform disciplines in meteorology and the available technologies of observation, both *in situ* and remotely sensed.

Systems development and functional requirements

Nowadays we see a strong trend in the development of observing *systems*, in particular those systems based on satellite born remote sensing. Many satellite missions have a 'discovery' entity, *i.e.* are explorer missions, the other mission are for operational practices to monitor the earth and to support the services in meteorology. Most of these new products are geographical oriented, *i.e.* reflects the average state of an area, whereas the classical *in situ* observations are typically point measurements. Moreover, satellite based observations produce data from anywhere on the earth, whereas the classical regional synoptic and climate networks are identified by extreme variability in density or coverage (see fig. 3 to 5 and refs. [1], [2]).

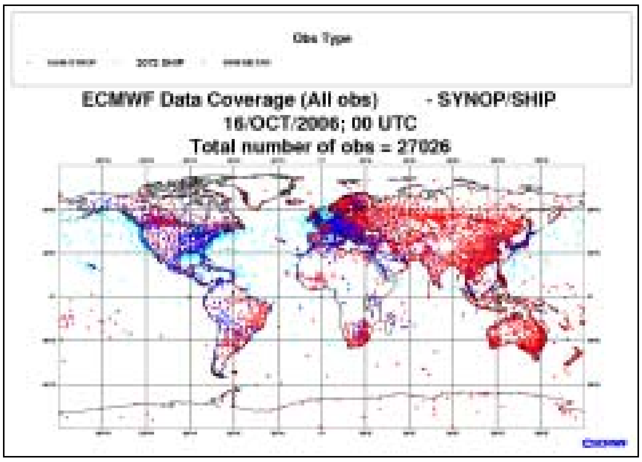


Figure 3 Data Coverage of all synoptical observations recieved at ECMWF (presented are SYNOP, SHIP and METAR data)

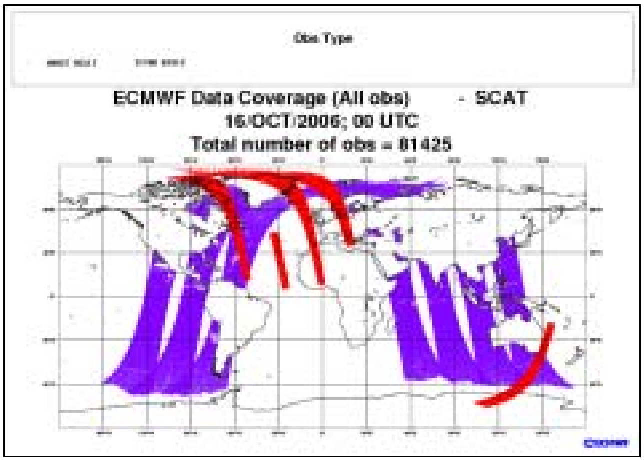


Figure 4 Data Coverage (6H) of wind-scatterometer data (observed by ERS-2 and QuickSCAT)

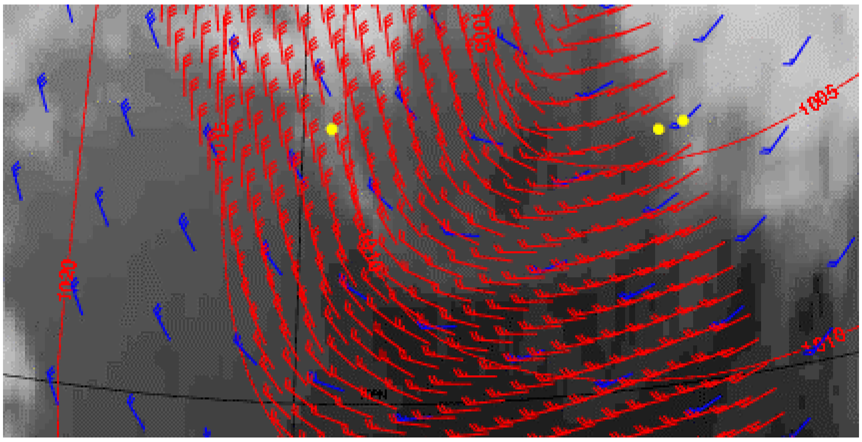


Figure 5

Example of wind derived from theERS-2 scatterometer (see ref. [2])
Location:South- east of Greenland, 2006-10-15 21:30 UTC

On the other hand the user communities representing the various disciplines in meteorology, climatology, hydrology, *etc.* expressed an increasing demand on observational data and with discipline specific conditions. Such demands refer to alternative or new observations, performance, representativety and frequency of observations. As a result we see that there is a strong increasing diversity in both the users' requirements and in observation technology (see fig. 6 and refs. [5], [6]).

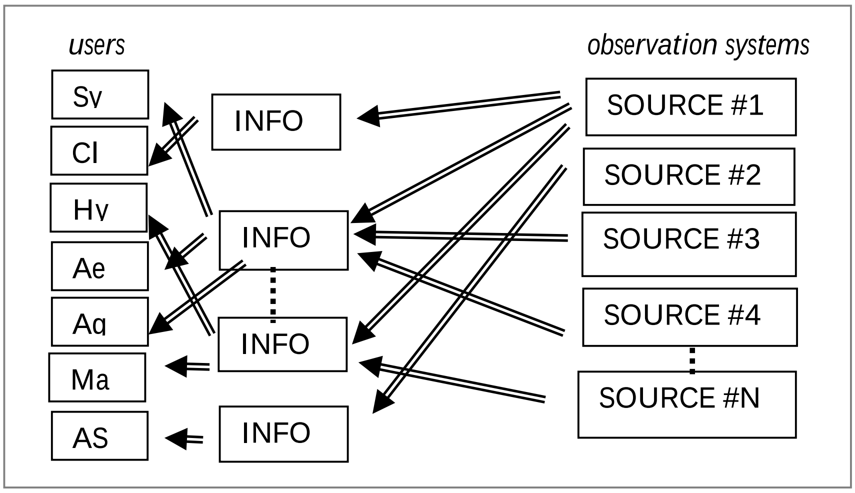


Figure 6
Data sources (observations), application & informations systems and the user community show has become a complex network

[Sy] Synoptical Meteorology,
[Cl] Climatology,
[Hy] Hydrology,
[Ag] Agro-meteorology,
[Ae] Aeronautical meteorology,
[Ma] Marine meteorology,
[AS] Sciences of the atmosphere

Although the new data sources imply new challenges for the various communities, the classical observing systems are changing as well and causing other types of challenges. In the first place a continuing trend in complete automation is significant. Note that the idea to automize the observation of present weather (PW), the outmost challenging development, came already into practice some 20 years ago. As a consequence many manned weather stations are replaced already by automatic weather stations (AWS). However, automated observations of present weather of phenomena at or in the vicinity of a site are still a matter of concern because of the many complaints. Those complaints are usually expressed in terms of '*low hit rates*' (event misses) and '*false alarms*'. Note however that requirements on the *performance* of these type of observations (detecting phenomena) are still subject to continuous discussion, an action item for the CBS expert team on AWS (see ref. [7]). Research to improve the performance of PW observing technology is ongoing but only with step-by-step successes (see refs. [4] and [5]).

On the other hand users are trying to fulfill their increasing needs with alternative tools. A typical example is the technique of "down scaling". For this technique a high-resolution limited area model is used with short distance grid points and a high update frequency. It uses a detailed orographic database (relief map) in combination with climate data. This technology provides a resolution of an order of magnitude higher than that of a standard observation network see fig. 7). This now-casting technology is very promising, but we have to understand that use is made of a theoretical model on the interaction between atmosphere, the relief of the earth surface and historic data. In fact we get "virtual reality".

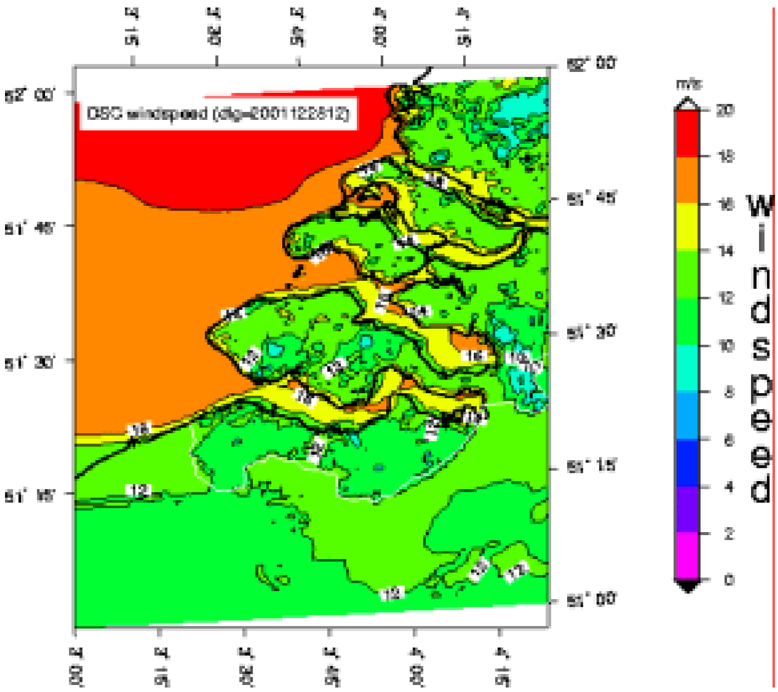


Figure 7

Example of down scaling: Wind speed data obtained using a high resolution limited area model (HiRLAM), orographic data and a network of wind measuring devices (location: Coast of Zeeland, Netherlands and Flanders, Belgium)

50 km

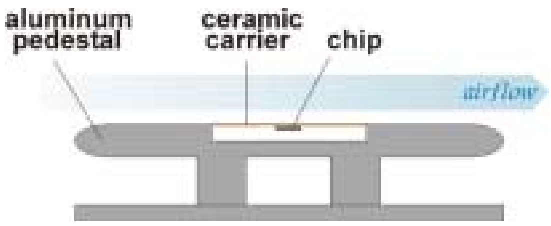
Not only data is manipulated at then users' side but also at its source (by the observing system). Automatic Weather Stations and in particular Present Weather-systems use sophisticated, but very diverse algorithms to determine the weather and to report it in a standard code format. Because many weather phenomena cannot be measured directly, use is made of empirical relations. By measuring specific any characteristic behavior, the reported weather phenomenon is derived according to well-known correlations. In fact, reported data is not always based on a direct measurement. Typical examples are the determination of under-cooled precipitation based on air and wet-bulb temperature, solid precipitation based on air temperature, identification of precipitation based on hydrometeor size and falling speed or visibility. But also new alternative techniques are in practice now, like hail detection using Doppler weather radars and empirical determined correlations. Nevertheless, such methods to 'detect' hail are very useful, because hail from showers is always on a very small scale and the change to detect hail using point measuring devices is extremely small.

Such algorithms to derive parameters enable to 'tune' performances. By modifying some constants, the performance of the observing system can be optimized, which means that its output becomes more in line with reality. Constraints for tuning these values are the required 'skill scores' or 'hit and false alarm rates' (see ref. [5]). It is found that tuning these values may be related to a region (or specific climate) or to a season (in regions where winter-weather differs significantly from summer-weather). Although we can put questions marks around these "methods of observation", the user shall be pleased as long as the weather reports confirm to the stated requirements. However, appoint of serious concern is the lack of appropriate quality evaluation and insecure data-management. The performance of observing systems can only be indicated after data evaluation using the real world as reference and the management of the data processing facilities is only successful if the implementation of the algorithms is well described and understood. In fact lack of reference data and knowledge of data processing applications are the real bottleneck of a modern data observing and processing system. Some regulations, *e.g.* in line with ISO 17025 (quality standard for calibration and testing laboratories) should be developed and recommended.

Development and new design of instruments

For manned weather stations, the instruments were designed as a tool for the observer to generate the weather report. Many of the instruments described in the CIMO Guide, like the mercury barometer, are such types of instruments. Moreover, the layout of a weather station is designed to comfort the manual observations. Although many weather stations are not well sited due to constraints like accessibility or common infrastructure, the layout of these stations comply with recommendations as stated in the CIMO Guide or Guide on the GOS. However, due to forth going automation we see a trend where many sensors are combined into one close environment. Although such designs provide efficient maintenance and quick installation, mutual impacts by the instruments on the measurement and other siting impacts may reduce the measurement uncertainty and representativety on a rather uncontrolled manner. On the other hand, new sensor developments, especially based on microelectronics is a remarkable development.

Micro-sized systems with 'multi-sensors on a single chip' might look futuristic but these developments started in the 1980's and mass production may be expected soon. Examples of commercially available micro sensors are there for wind (fig. 8) or pressure (fig. 9). The latter is already in common use in radiosondes. Cost effectivety is the major pushing force for further development and it will be a challenge to find an optimal layout for this new generation of sensors, taking into account siting and representativity conditions. Measuring the environment will always suffer from natural, unconditioned impacts caused by the same environment and designing an optimal solution is never straightforward.



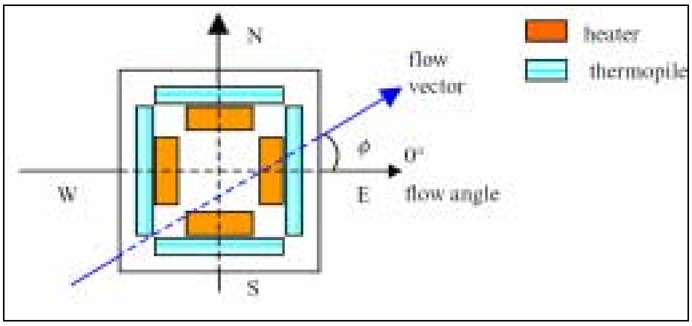


Figure 8 - design of a wind sensor using a microsized chip

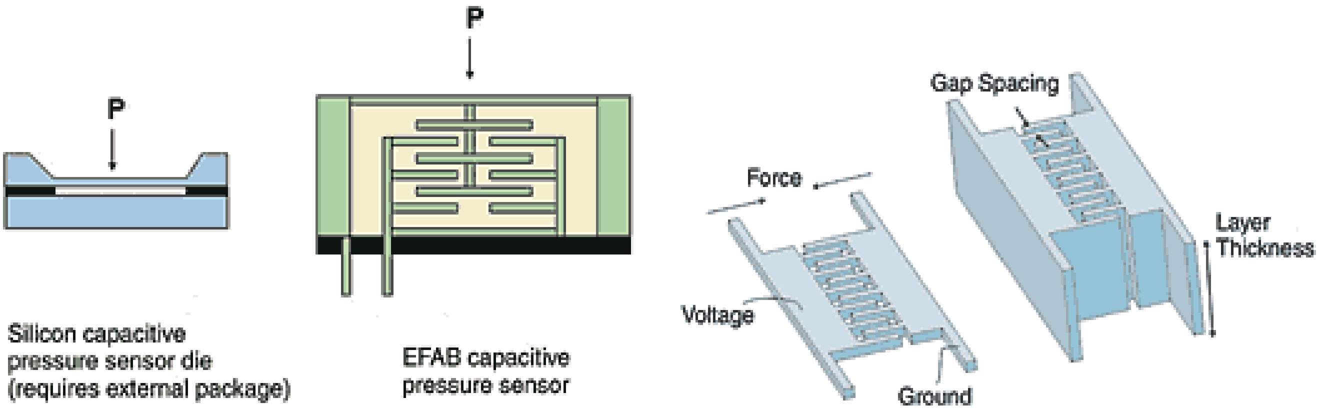


Figure 9 Old and new type microscopic IC based pressure sensors. The new type is based on a multilayer concept with high accuracy specifications.

Although new sensor technologies will evaluate and may introduce new revolutionary concepts, experiences with current systems still require improvements or alternative approaches. In particular present weather observing systems, based on a multi-sensor approach do not meet the required targets during specific weather events (*e.g.* freezing phenomena). Alternative solutions or extra dedicated sensors may be beneficial, although experiences are limited and acceptance criteria subject to discussion. Examples of some new techniques are shown in figs. 10 to 12 (see ref. [3] and [4]).

Figure 10

Examples of holograms containing in-focus and out-of-focus freezing drizzle drops (from Lawson et al., Atm. Res.(1998)181)

Figure 11

Example of an monostatic radar system to determine drop size distribution and falling speed from the back scatter profile (Metek PreWeS-24 – under test by DWD)

Figure 12

Example of a so called 'Hotplate snowgauge' (NCAR, USA)

Trends and criteria for further development, a conclusion

During the last decades a clear trend is observed in the development of methods of observation and measurement devices. First there is a strong push from the satellite community using remote sensing techniques to observe the whole earth. Also the ongoing automation of weather stations is remarkable. Essential however is that in the past most networks and stations were used first for observing the weather on a rather deterministic manner and transformed later on into instrument oriented facilities producing geo-physical quantities.

Measurement uncertainty was subject to research itself and the users trusted that this research would improve the quality of the data. Nowadays, users of various and different disciplines in meteorology state their own requirements and confirm to data, not directly measured but derived from alternative techniques. For this practice efficiency and cost reduction are relevant targets.

So, in fact functional requirements and demand have become increasingly complicated but a great challenge for developers to design observing systems, which will meet these requirements. Also a huge variety of sources of observational data are available today to support many users. Within this context the important issue of standardization and uniformity remain a serious key issue. If the various disciples in meteorology will forward specific, non-uniform requirements or data providers supply products generated for special applications only, the endorsed standardization will decrease and confusion will enter. Examples of this trend are the introduction of 'visibility for aeronautical purposes', which differs from the well-defined 'visibility' and a number of variables, indicated as identifiers in binary code reports, which are not traceable to a unique definition.

For surface observations technologies, the focus is on the ability to determine specific weather phenomena. In particular those present weather data, crucial for safety and warnings (*e.g.* freezing phenomena) are in focus, but also the improvement to measure cloud coverage is an item for research and development. To improve cloud coverage determinations use should be made of a combination of surface, upper-air and satellite measurements. This type of integration will become more and more common practice for all type of surface measurements. Measuring the performance of such a solution will be challenging, especially for dangerous but infrequent phenomena. For establishing suitable performance requirements, a suitable strategy on the introduction and use of 'skill scores' should be developed and recommended. Such scores can be used for further quality evaluation, which is essential for integrated observations systems.

references

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