Royal Netherlands
Meteorological Institute
Ministry of Infrastructure and the Environment

Observations Strategy KNMI

2015 - 2024

De Bilt, 2015 | KNMI-Publication 233

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Buys Ballot, first director of KNMI (1854 – 1890), was co-founder of the network of international observation stations.
Photo Courtesy: Raymond Sluiter

KNMI-Publication 233

Front page photo: The KNMI-observation test site, de Bilt, Netherlands
Photo courtesy: Raymond Sluiter

Content

Executive summary

KNMI is responsible, as laid down in law, to make meteorological observations and to maintain an infrastructure to do so. Exactly which observations are made follows from KNMI's advising and alerting tasks.

This document presents the Observations Strategy* for the period 2015 – 2024. Regular updates of strategic directions for a 10-yr horizon are required to adapt to changes in policy context and to ever changing demands of society. In addition, the continuous improvement to technologies for measuring the atmosphere, and improvements to ways in which information of different (and partly new) data sources can be combined into products requires regular consideration of focus. This document is one of a set of strategy documents in which the institutional strategy is further refined. Other strategy documents cover modeling, data and infrastructure, Earth observation, seismology and international position.

KNMI's mission for the purpose of observations is:

Mission: KNMI performs and collects geophysical observations, and converts these into innovative, high-quality products and services that reduce safety risks, contribute to a sustainable society, and promote economic opportunities.

This mission statement closely follows the institutional mission statement which places an emphasis on reducing safety risks linked to extreme weather, earth quakes, volcanoes, air quality, climate change and on the proper responses to manage such risks.

Starting from an evaluation of existing observation capabilities and a description of trends in society, technology and data products two core directions are identified that are expected to dominate KNMI's observation activities for the next 10 years:

- the transition to an observation network consisting of a set of ground-based reference stations complemented by observations from other sources;
- the development of high-resolution 4-D data products from the integration of different types of measurements and of measurements with atmospheric model analysis.

These directions are demand-driven as society in this densely populated part of Northwestern Europe demands high quality products at all times and all places. They are also supply-driven as the available number of meteorological data sensors is exploding.

The mission statement together with the core directions leads to the formulation of an observations vision statement for the period 2015 – 2024:

Vision: To integrate all observations into optimal products that best represent the state of the atmosphere at any place and at any time [past and present] in three dimensions.

This vision implies that KNMI will be able, among others, to draw detailed pictures of emerging extreme weather events in near real time; to make high quality weather, air quality, pollen and health hazard predictions (and nowcasts) at the level of cities and communities; to make progress in understanding of cloud processes which still form the key uncertainty in predicting future climate; and to use new technologies such as drones to observe the atmosphere at crucial locations for which it proves difficult to derive observational information from existing sources. Achieving this vision requires a focus on four main observational tasks:

- improved and expanded collection and evaluation of 4-D observations;
- programs to integrate measurements provided by different technologies, and measurements with models;
- updated and improved quality management of KNMI observations and Third Party Data;
- Maintaining and updating knowledge.

These tasks are detailed in a number of position and action statements that are listed after this summary [Positions and Actions]. They address the following themes:

- preserving high quality observations;
- dealing with increased availability of Third Party Data;
- shaping R&D towards integrating observation and modeling capabilities;
- structuring the organization in order to carry out the proposed strategy efficiently;
- exchanging data and observations with neighboring countries;
- contributing to the international meteorological and climate research community.

The strategy outlined here, including the ordering of observations into four different classes based on funding and purpose, provides a framework for decisions about future directions regarding the observations infrastructure and regarding resource management.

*Seismic observations are not included; these are part of a separate strategy on seismology.

Positions and Actions

Positions are principles that KNMI will adopt to carry out its observational tasks. Actions are meant to specify general tasks to carry out in pursuit of the vision. Positions and Actions are presented in various Sections of the Observations Strategy document and summarized below.

For the observation network, the vision statement implies the adherence to protocols that are meant to preserve the high standards. These standards are formulated as three positions (P1 - P3).

The positions are to be supported by actions to preserve network quality, including resolution, accuracy and traceability. Also the network needs to be optimized as follow-up actions to earlier network evaluations, and specific observations need to be carried out or explored (A1 – A6).

To achieve the vision, a number of specific R&D programs are defined. These programs are important for the prediction of (severe) weather (NWP and nowcasting) as well as for climatological description of the atmospheric state (A7 – A9).

Essential in evaluating the impact of observations for climate and weather research is their acceptance in national and international scientific communities. To this end it is important to maintain a research activity to interpret observations in terms of atmospheric processes and climate trends, and to improve knowledge on measurement technologies (A10).

The management of Third Party Data requires a shift in activities that are aimed at quality control and assurance. These include the [re]direction of personnel and more specialized actions defined here (A11).

To implement the Observations Strategy the organization needs to be adapted to facilitate the communication and links between Front Office and the Back Office, and reaffirm the responsibilities of the Observations Strategy Committee and the Observations Chain Managers. To this end two actions are defined (A12, A13).

As quality assurance and control of past, present and future observation data streams is central to the role of KNMI as reference institute, it is important to document and (re)evaluate the quality of the observations chains (A14).

Finally , with regard to international coordination there are two positions (P4, P5).

P1	KNMI adopts the Rolling Review of Requirements (RRR) process of the World Meteorological Organization Integrated Global Observing System (WIGOS) as laid down in the Technical Regulations of WMO to support the optimal evolution of all its observing systems.	
P2	The Global Climate Observing System (GCOS) monitoring principles as laid down in the Protocol for Changes in Measurement Infrastructure (PVM) will be applied to manage mutations to climate monitoring network.	
P3	Site optimizations, mutations of the network and other changes to observing systems shall only be accepted after impact studies are performed and evaluated, the new configurations are proven in operation and after proper communication with authorities, clients, stakeholders and the general public.	
A1	The current network configuration shall be evaluated using the formal procedures of RRR, PVM, communication protocols and consideration of impacts.	2015
A2	Studies shall be performed to determine the merit of extensions to the network for specific applications and research (a) in urban centers (b) in the North Sea, Wadden Sea and on Lake IJssel and (c) at the land – sea interface. These studies shall explore the use of mobile AWSs.	a: 2015 – 2017, b: 2018 – 2022, c and d: 2018 and beyond
A3	For observation products (including possible new products) the WIGOS RRR shall be used to make a Critical Review (CR) and a Statement of Guidance (SoG) to describe status, and required or desired developments in the coming 10 years.	2015 - 2017
A4	KNMI will continue to explore new sources of surface climate and meteorological information such as exist in Third Party Data (for example WOW) and other potential Big Data applications.	continuous
A5	KNMI will continue its radiosonde, ozone sonde and NO2 sonde launches and explore new ground-based remote sensing techniques in vertical profiling the atmosphere, and new (Third Party) sources of upper air information such as aircraft observations from AMDAR and MODE-S. The use of drones will be explored for operational boundary layer measurements, research and for use during special weather conditions.	continuous

A6	The need for infrastructure for Cabauw shall be evaluated and prioritized and agreed upon with CESAR partners in order to accommodate the continuation of existing observations of ECV's, the facilitation of studies of atmospheric processes, cloud and radiation, the testing of atmospheric models and possible new extensions of the measurement program into atmospheric chemical composition.	2015 - 2017
A7	A strategic research program is to be set up to merge different data sources into optimal high-resolution data products. Priority examples: a) precipitation intensity from satellite, in situ observations, (c) temperature from the KNMI network and Third Party Data, (d) a cloud product from ceilometer and satellite data. The construction should be explored of (e) potential evaporation from temperature and satellite-derived radiation products, (f) a visibility product from satellite and ground-based observations and , g) aerosols and air quality products from satellite and in situ observations.	2015 - 2018
A8	A strategic research program is to be carried out to test and improve the representation of atmospheric processes, specifically the radiative, thermodynamic, turbulence, cloud, aerosol and chemical composition in models of the atmosphere: the CESAR-test bed to be recognized officially by WMO and other UN bodies.	
A9	A strategic research program is to be carried out to expand near-real-time integration of observations with the HARMONIE 3-D high-resolution atmospheric model and to bench-mark against similar activities elsewhere.	planning 2015 – 2017, execution beyond
A10	Strategic research is to be carried out to a) interpret the (integrated) observations in terms of atmospheric processes and climate trends b) update, improve, understand and manage measurement technologies.	continuous
A11	Third Party Data Stewards will be enlisted to manage the quality of Third Party Data and to evaluate the potential of new data sources and to ensure their inclusion in KNMI 's operational processes. Evaluation tools and automatic data evaluation procedures will be developed to determine quality and usefulness of Third Party Data.	
A12	A governance structure is set up to manage the overlapping structures of Front Office and Back Office with an Observations Strategy Committee (OSC) at the interface.	2015
A13	With the implementation of the Observations Strategy, the role of the Observations Chain Manager (OCM) is reaffirmed. OCMs are assigned for all meteorological variables with a mandate to manage and control the content of observation chains. Their work is supported by a Process Manager.	2015
A14	An internal evaluation of existing observations chains will be performed with the purpose to improve adherence to existing guidelines, their quality and traceability. Actions to improve observation chains will include R&D to improve content, integration and standardization of metadata data and unifying data formats, Quality Control / Quality Assurance (QC/QA) monitoring, validation and documentation. A five year periodic external evaluation and review will be carried out of KNMI's observations chains to assure agreement with international requirements.	first evaluation by 2016
P4	KNMI will continue the efforts to structurally obtain data at a higher spatial and temporal resolution than currently available from neighboring countries' observing systems in the border regions of the Netherlands based on the principles of bilateral international data exchange.	
P5	KNMI will continue to actively participate in international liaison and expert committee functions in order to contribute to coordination efforts of international meteorological organizations. Strategic choices shall be made in which committees KNMI participation is essential.	

Acronyms

ADM-Aeolus:	Atmospheric Dynamics Mission for wind profiling
AMDAR:	Aircraft Meteorological Data Relay (WMO program)
ANSP:	Air Navigation Service Provider
AOPC:	Atmospheric Observation Panel for Climate (WMO-panel)
ARGO:	(Drifting Oceanic Profiling floats)
ASCAT:	Advanced SCATterometer
AWS:	Automated Weather Station
BES:	Bonaire, St Eustatius and Saba (Islands in the Caribbean Sea part of the Netherlands)
BSRN:	Baseline Surface Radiation Network (WCRP project)
CCI:	Climate Change Initiative
CESAR:	The Cabauw Experimental Site for Atmospheric Research (run as a national consortium)
CIMO:	Commission for Instruments and Methods of Observation (WMO-panel)
CR:	Critical Review (part of RRR)
EarthCARE:	ESA's Cloud Aerosol and Radiation mission
EC-Earth:	Global climate model
ECMWF:	European Centre for Medium-range Weather Forecasts
ECOMET:	ECOnomic interest grouping of the national METeorological services of the European economic area
ECV:	Essential Climate Variable
EPS:	EUMETSAT Polar System
EPS-SG:	EPS Second Generation
ERA:	ECMWF Re-Analysis
ESA:	European Space Agency
EU:	European Union
EUCOS:	EUMETNET Composite Observing System
EUMETNET:	EUopean METeorological NETwork
EUMETSAT:	European Organization for the Exploitation of Meteorological Satellites
GCOS:	Global Climate Observing System
GEOSS:	Global Earth Observation System of Systems
GFCS:	Global Framework for Climate Services
GMES:	Global Monitoring for Environment and Security
GNSS:	Global Navigation Satellite System
GOME:	Global Ozone Monitoring Experiment
GRUAN:	GCOS Reference Upper Air Network
GPS:	Global Positioning System
GSM:	Global System for Mobile Communications
GSN:	GCOS Surface Network
GTS:	Global Telecommunication System
HARMONIE:	HiRLAM Aladin Research on Meso-scale Operational NWP in Euromed
ICA&D:	International Climate Assessment & Dataset
ICAO:	International Civil Aviation Organization
INSPIRE:	INfrastructure for SPatial Information in the European Community
ISO:	International Organization for Standardization
JCOMM:	Joint Technical Commission for Oceanography
KDC:	KNMI Data Center
KNMI:	Koninklijk Nederlands Meteorologisch Instituut
LIDAR:	LIght Detection And Ranging
LOTOS-EUROS:	Long Term Ozone Simulation – European Ozone Simulation
LVNL:	Luchtverkeersleiding Nederland (Air Traffic Control the Netherlands)
MAX-DOAS:	Multi-Axis Differential Optical Absorption Spectroscopy
Meteosat:	European geostationary meteorological satellite
MetOp:	European polar orbiting meteorological satellites
MetOp-SG:	MetOp - Second Generation
MODE-S:	Mode Select (Aircraft Transponder)
MSG:	Meteosat -Second Generation
MTG:	Meteosat -Third Generation
NMHS:	National Meteorological and Hydrological Service
NWP:	Numerical Weather Prediction
OCM:	Observations Chain Manager
OGC:	Open Geospatial Consortium
OSC:	Observations Strategy Committee
OSCAR:	Observation Systems Capability Analysis and Review Tool
OMI:	Ozone Monitoring Instrument
PMO:	Port Meteorological Officer
PVM:	Protocol for Changing Measurement Infrastructure
QA:	Quality Assurance
QC:	Quality Control
ODP:	Open Data Policy
R&D:	Research and Development
RACMO:	Regional Atmospheric Climate Model
RBCN:	Regional Basic Climate Network
RBSN:	Regional Basic Synoptic Network
RIVM:	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment)
RRR:	Rolling Review of Requirements
RWS:	Rijkswaterstaat
SAF:	Satellite Application Facility
SCIAMACHY;	SCanning Imaging Absorption spectrometer for Atmospheric CHartographY
SEVIRI:	Spinning Enhanced Visible and Infrared Imager (instrument onboard MSG)
SLA:	Service Level Agreement
SoG:	Statement of Guidance (part of RRR)
(E-)SURFMAR:	EUMETNET SURface MARine program

TCM:	Tropospheric Chemistry Module
TOMS:	Total Ozone Mapping Spectrometer
TOR:	Terms Of Reference
TPDS:	Third Party Data Steward[ship]
TROPOMI:	TROPOspheric Monitoring Instrument
UNFCCC:	United Nations Framework Convention on Climate Change
UV-VIS-NIR:	Ultraviolet-Visible-Near InfraRed
VOS:	Voluntary Observing Ship
WCRP:	World Climate Research Programme
WIGOS:	WMO Integrated Global Observing System
WIS:	WMO Information System
WMO:	World Meteorological Organization
WOW:	Weather Observations Website

Terminology

Actions are general tasks to carry out in pursuit of the vision.

Big Data as a general term refers to the increase of possibilities to generate, share, combine and analyze data leading to new insights. Examples of new data sources are sensors in planes, cars, mobile phones, energy systems, IT infrastructure, the Weather Observations Website-project (WOW), temperature derived from mobile phones and precipitation derived from mobile networks and social media.

Client: Also denoted as 'customer', a party paying for special products.

Complementary Network refers to a network other than KNMI's Meteorological Network such as from RWS or RIVM. These complementary networks issue quality controlled and calibrated data such as air quality data from RIVM, precipitation data from the Water District Boards and hydrological data from RWS.

Meteorological Network refers to a set of automatic weather stations on land and on North Sea platforms, airports and airbases spread out over the Netherlands funded by KNMI, and by KNMI's partners such as the Ministry of Defense, civil aviation and RWS.

Partner: A party that contributes in equal measure with KNMI to establishing and maintaining the essential infrastructure [Ministry of Defense, aviation].

Positions are principles that KNMI will adopt to carry out its observational tasks.

Stakeholder: A not-paying party that attributes high value to, and regularly uses KNMI's observation products.

Third Party Data refers to all data that are not necessarily calibrated and quality controlled up to the standards required by KNMI.

1 Introduction

Background and context

Recently KNMI issued a strategy paper, which outlines its mission and strategy for 2015 – 2024. Its mission statement reads:

“KNMI advises and alerts society to mitigate safety risks of atmospheric or seismic origin. Hereto, KNMI develops state-of-the-art knowledge, makes observations, and converts these into products and services that reduce safety risks, contribute to a sustainable society, and promote economic opportunities.”

The strategy is summarized into three themes:
1) To prepare and to prevent,
2) To alert and to advise,
3) To evaluate and to improve.

A set of requirements and activities evolve from these themes. Aspects of the KNMI-strategy most relevant for the development of an Observations Strategy are:

- **Statutory obligations:** KNMI is responsible for maintaining an infrastructure for geophysical information. This responsibility is laid down in law and emphasizes the importance of safeguarding the Netherlands against the impacts of (un)foreseen geophysical phenomena on its infrastructure.
- **Client awareness:** Clients are essential in shaping KNMI’s services. This requires a continual alertness and a responsive attitude towards clients and their needs.
- **Knowledge:** The importance of knowledge and expertise in asserting an authoritative response to society’s questions and concerns is paramount. Maintaining and developing knowledge is a prime requisite: No knowledge, no authority.
- **Being alert:** Rapid access to existing and new information. Being ‘alert’ also means being alert to new developments, both nationally and internationally. It requires a good network of (inter) national partners and flexibility to improve current standards and services.
- **International context:** We are not alone, and this means that we use other countries’ observations while they use ours. Observational infrastructure is operated in an international context.
- **Communication:** KNMI’s knowledge or products will be evaluated by the general public with KNMI’s communication strategy as an important contributing factor. So, changing or adapting KNMI’s observation network, which are relied upon by diverse authorities, demand excellent communication.
- **Open data.** Society has paid for KNMI’s services. The government requires rapid and open access to all data products and information.

KNMI has an excellent national and international reputation that results from:

a) **Knowledge** about meteorological observations and measurement techniques;
b) **Research** in many areas of observational science;
c) **Strong engagement** and **expertise** from its specialists;
d) **Quality** of the observational products.

Not surprising, there is a match between the reputation of KNMI and the essential elements of the KNMI-strategy. In this document the ideas expressed in the KNMI-strategy document are further developed and the consequences for the management and implementation of observations for weather and climate are described.

Scope

The Observations Strategy is but one of the strategies that follow the KNMI institutional strategy. Other strategy documents cover modeling, data and infrastructure, international positioning, and seismology. Even though satellite observations are discussed here, Earth observation in general is organized in an international context (EUMETSAT, ESA) where KNMI is one of the contributing parties. Furthermore a special Earth Observations Strategy for KNMI is under construction. So with respect to satellite data attention here is restricted to the integration of satellite data with other observations to obtain advanced products for NWP, air quality forecasting, nowcasting and climate.

The document will briefly address the BES-Islands but the emphasis will be on observations for the Netherlands. Of course, as the Netherlands is a small country it is to a large extent dependent upon data from adjacent countries. Therefore this document will reflect also on KNMI efforts to exchange observations and expertise with our neighbors and our international partners. The Terms of Reference (TOR) are given at the end of this document.

2 Mission and Vision Statements

Observations Mission statement

Mission: KNMI performs and collects geophysical observations, and converts these into innovative, high-quality products and services that reduce safety risks, contribute to a sustainable society, and promote economic opportunities.

As the national institute for weather, climate and seismology KNMI is responsible for maintaining a network of reference observations of geophysical quantities in the Netherlands. In addition, KNMI collects meteorological observations of other entities, provides all observations to society, and is the authority on their quality and interpretation. The observations are reliable, and rapidly and easily accessible in order to maximize their usefulness for society, both nationally and internationally. The observations are also the basis for research and innovation in nowcasting and forecasting, climate monitoring, and validation of weather and climate models.

Observations Vision Statement for the years 2015 – 2024

Vision: To integrate all observations into optimal products that best represent the state of the atmosphere at any place and at any time [past and present] in three dimensions.

The general trend is an increasing need for observations as model resolution increases and end users expect more and more (high-resolution) local information, while costs and benefits should be in balance. Society request that such information, on the past and the present, is available near real-time in the highest possible spatial and temporal resolution and that KNMI has authoritative knowledge on the measurements and their derived products, their accuracy and reliability.

3 Observations systems

The observation infrastructure of KNMI is diverse and funded by a mix of national and international initiatives and programs. However, we can broadly identify four different classes with funding base and purpose as the main discriminators.

Class 1. Observations that are deemed vital for safety purposes, such as extreme weather alerts, aviation and defense. Examples of these observations are observations of the Meteorological Network [also at the BES Islands] and from two rain radars. They are funded by Dutch society, specifically observe Dutch climate, but also serve as contributions to international networks (for example Regional Baseline Climate and Synoptic Networks, European network of radar data, CESAR).

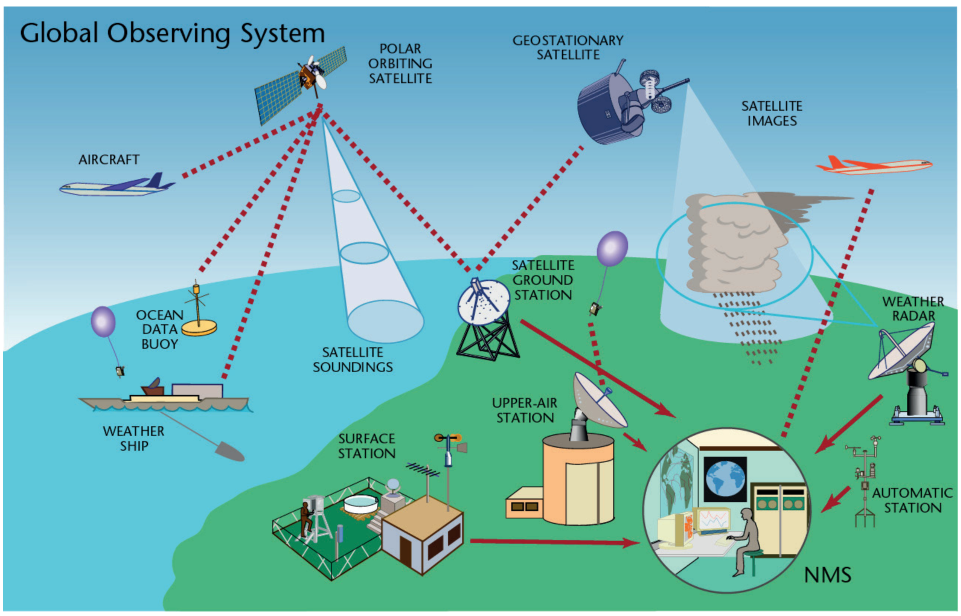
Class 2. Observations that primarily serve economic purposes and observations performed for international NWP and climate programs. They are performed in an international context with significant funding from international funding agencies. KNMI contributions to these observations are to a large extent driven by existing funding opportunities and have led to expertise in technological and scientific matters. Many classes of satellite observations fall in this category.

Class 3. Observations primarily performed in an international context, but with limited international funding. These observations are primarily funded by Dutch society through basic funding to KNMI, and serve as a KNMI contribution to the international community. Examples are the VOS, ARGO floats and the Paramaribo observation station in Surinam.

Class 4. Observations primarily unorganized and without guarantee of continuity but with significant potential to be used as additional source material in the realm of weather and climate. These observations are of divergent aims and funding sources. Examples are the aircraft observations, such as AMDAR and MODE-S, but also the WOW network of commercial weathers stations owned by citizens, GPS-linked temperature sensors and read-out records from automobiles.

The classification above guides future directions regarding observations infrastructure and resource management. Class 1 observations need to be performed by KNMI, and it is not foreseen that these observations will and can be done by international partners. For class 2 and 3 observations this is not necessarily the case. It is however of vital importance that these observations are done, and the Netherlands greatly profits from these observations through international collaboration. For instance, the skill of weather prediction is greatly en hanced by assimilating satellite data in weather prediction models, continuous model improvement is established by means of observations done at Cabauw, and ARGO floats provide essential information on current climate warming. Class 4 observations are not useable in raw form but have the potential to be of interest to the meteorological community after additional processing and quality control.

A more expanded description of the observation system of the Netherlands can be found in Appendix 1.



4 Policy framework

4.1 National

The national policy framework is currently the Law on Tasks on Meteorology and Seismology (2015) where the execution is determined by the 'Rules on governmental care regarding meteorology and seismology'. This is a ministerial ruling which describes the tasks for which the Ministry of Infrastructure and the Environment has responsibility.

The tasks include amongst many others:

a) the collection of geophysical data;
b) maintaining an observation infrastructure;
c) research into climate, technological developments and meteorological observations.

These tasks are delegated to KNMI. There are four regulations that are derived from this Law, namely:

a) on the general weather report (2002);
b) on aviation meteorology (2006, but will be soon derived from the Law on Aviation);
c) on mining (2002);
d) on wind and storm warning services (1972).

Within the Netherlands the most important clients of observations (besides KNMI itself) are the Ministry of Infrastructure and the Environment, Rijkswaterstaat (RWS), the Ministry of Defense, commercial weather providers, national, regional and local authorities, universities and research institutes, business and the general public.

In the past, several strategy papers have been produced regarding the KNMI observations and were consulted in preparation of this document[1].

4.2 International

The weather system is a world-wide system without any national boundary. National Weather Services cannot exist without international and mutual coordination. In particular, the international exchange of observational data is an essential requirement. Most meteorological observations are carried out within international programs. The Netherlands is Member of the World Meteorological Organization (WMO) and the Minister of Foreign Affairs appointed the Director of KNMI as Permanent Representative. KNMI is also the Dutch formal representative to the European Centre for Medium-range Weather Forecasts (ECMWF), ECOMET, EUMETNET, EUMETSAT and KNMI is the designated Air Navigation Service Provider (ANSP) for meteorology. Here the principle of *exchange of observations and knowledge* is the essential element to ensure efficiency and cost-effectiveness.

International scientific and technical coordination and collaboration are achieved through WMO (and its working groups), EUMETSAT, ESA and EUMETNET, SURFMAR, GEO, ICAO, JCOMM, GCOS, and WCRP. Using WMO's Global Telecommunications System (GTS) KNMI observations are made available to the international meteorological community. Furthermore, a number of KNMI stations are part of the Regional Basic Synoptic Network (RBSN) and the Regional Basic Climatic Network (RBCN) of WMO, while a single station (De Bilt) is part of the GCOS Surface Network (GSN).

Several international strategy papers were consulted in preparation of this document[2].

4.3 Quality Assurance and Control

Requirements for the observed quantities, their spatial resolution, representativity for the surrounding vicinity, quality, accuracy and timeliness depend on the client and on the specific application such as climate, NWP or nowcasting. They are defined in:

- internal quality documents and Service Level Agreements (SLA's) under ISO9001 as documented in the KNMI Observations Handbook;
- bilateral agreements with partners such as Air Traffic Control the Netherlands (LVNL) ; Ministry of Defense and RWS;
- requirements, international expert judgment and recommendations such as issued by WMO, ICAO and EUMETNET (e.g. the Rolling Review of Requirements RRR).

The requirements here encompass the entire chain from sensor to the delivery of observation products to the client.

5 Trends

A number of significant trends are visible that demand adaptation of KNMI's strategic direction with respect to observations. Three types of trends are identified:
a) in society,
b) in measurements and
c) in data product supply.

5.1 Trends in Societal Demands

In the last decade, many new small businesses, organizations and the general public as clients for weather and climate information have emerged. Data are increasingly being used and this trend is expected to continue in the near future. This trends is partly driven by the ever increasing accessibility of new electronic communication / registration devices.

The following societal trends are visible:

- **Local information:** Society demands information on the atmospheric conditions in their backyard. More local information means an increasing need for high-resolution data; often such high resolution can only be achieved by integration of observations and model output.
- **Near-real-time and reliable:** Data should be available in real-time and with known uncertainty.
- **Tailor-made:** Society demands that products are tailor-made for each communication device (Smartphone, tablet, related communication channels and social media).
- **Participation:** Society is willing (and government expects this) to contribute to public 'services'. Examples of these are all kinds of Big Data.

The future KNMI Hazard Center will be an important interface to deliver data and information to society.

5.2 Measurement Trends

Parallel to societal trends there are trends in the development of new techniques of observing the atmosphere. Here we discuss the trends in satellite observations, Big Data, observation technologies and data from complementary sources.

5.2.1 Satellite observations

Over the past decades the amount of satellite observations of geophysical parameters has grown tremendously. Nowadays, satellites play a key role in climate monitoring and in NWP and air quality prediction through data assimilation.

The following trends in the field of satellite observations are noted:

- **Increasing resolution.** Nearly all types of satellite observations are characterized by increasing spatial resolution. In addition, the temporal resolution from geostationary platforms is enhanced, while the increasing number of low-earth orbiting platforms also yields higher frequency observations.
- **From research to operations.** An increasing number of sensor types has become mature enough to be included in operational meteorological programs such as Meteosat Second and Third Generation (MSG/MTG) and European Polar System EPS/EPS-SG (Second Generation) also known as Meteorological Operational Satellite Program (MetOp/MetOp-Second Generation). This guarantees the long-term availability of these observations, which is a requirement for climate monitoring. In addition, the Copernicus program will provide operational data for the atmospheric domain through the Sentinel satellites up to 2030.
- **Climate records.** Many types of satellite observations were started around the 1980s and have been continued since then. This allows the generation of time series with sufficient length (~ 30 years) to qualify as climate data records. Over the past years ESA's Climate Change Initiative (CCI) was set up to fully exploit Earth observation for the generation of ECV data records.

5.2.2 Big Data

Big Data refers to the increase of possibilities to generate, share, combine and analyze large amounts data leading to new insights. They are characterized by the 5V's: Volume, Variety, Velocity, Veracity and Value. Examples of new data sources in the domain of observations are sensors in planes, cars, mobile phones, energy systems, IT infrastructure, commercial weather stations owned by citizens (the KNMI Weather Observations Website-project WOW), temperature derived from mobile phones and precipitation derived from mobile networks and social media. Sometimes Big Data directly provide meteorological variables for end users, but most of the time the meteorological observation data have to be extracted from data that were originally intended for other purposes.

Even though these new data sources are promising additions to traditional observation sources they are not expected to be an operational replacement for (part of) the KNMI observation network in the coming 10 years because of data quality issues.

A number of Big Data trends can be identified:

- **Increased availability:** Diverse (real-time) observations and derived products are available and will facilitate Big Data applications.
- **Additions and/or substitute for traditional observations:** Because of the availability of cheap and reliable detectors and of devices from which meteorological information can be derived Big Data can add to or supplement the traditional observations.

The consequence of the availability of Big Data implies a new role for KNMI's traditional network namely that of a reference for these data sources.

5.2.3 Emergence of new observation technologies

Parallel to the increasing volume of new data sources there are new instruments / sensor technologies becoming available which have improved performance over traditional observation systems, are more cost-effective and often add new valuable products.

The technological trends are:

- **Remote sensing of the upper air:** In situ sounding the upper air is expensive. So considerable effort has been made to develop new remote sensing systems: e.g. LIDAR systems for aerosol or volcanic ash detection, wind LIDARs, dual polarization weather radars, improved ceilometers for mixing layer height determination, aerosol plume monitoring and water vapor from Raman LIDAR and different GPS measurements.
- **In situ sensing of the upper air:** There are new developments in upper air measurements of wind, temperature and humidity by means of sensors mounted on commercial aircrafts such as wind derived from aircraft MODE-S transponder signals, increase in aircrafts providing AMDAR data, and advances in AMDAR water vapor measurements.
- **Remote sensing of the local weather:** New optical (video) disdrometers are considered for rainfall intensity measurements and for improvements in the automatic discrimination of the precipitation type. Systems are emerging that extract cloud and visibility information from camera image. (Scanning) pyrometers yield surface and sky temperature measurements and estimates of cloud amount and height. MAX-DOAS are used to observe NO_2 and aerosols.
- **In situ sensing of the local weather:** An emergence of semi-professional compact weather stations in society is evident.

5.2.4 Data from Complementary Networks

In many other applied scientific disciplines networks are developed and maintained. For these networks rapid advances in sensor technology, data sources and data products are manifest. Examples are networks for high-resolution hydrological and agricultural products such as vegetation cover, ground water levels and surface temperature. The trend is to merge hydrological and meteorological data sets in an effort to produce more refined products such as surface heat and moisture fluxes into the atmosphere.

5.3 Data Products and Data Quality Trends

More data are becoming available from in-situ observations, satellite observations and radar observations.
The data product trends are:

- **Development of standards:** In response to the demand for near-real-time and high quality products a WMO-CIMO siting classification scheme is currently used by a number of weather services. At the same time performance classifications (sensor and maintenance) are in development as well as the development of standards for sensor (meta) data.
- **Integration:** Integration / assimilation of data from the different sources will have significant synergistic advances. So-called reanalysis using high-resolution NWP models to develop a comprehensive record of how weather and climate are changing over time provide optimal interpolation tools (see www.reanalysis.org).

6 Strategic Directions

As discussed above the strategic directions of KNMI's observations are founded on: a) the policy (inter)national framework, b) societal demands, c) measurement technology trends and d) data product supplies.

Two core directions emerge that will dominate the period 2015 – 2024:

- the transition to an observation network consisting of a set of ground-based reference stations complemented by observations from other data sources;
- the development of high-resolution 4-D data products from the integration of different types of measurements and of measurements with atmospheric model analysis.

These data products are required for the future Hazard Center and include the following: High-resolution NWP and nowcasting, aviation, wind energy, air quality and pollen forecasts and health applications, evolution of dust plumes and volume radar applications for precipitation types and intensity.

KNMI's Observations Strategy will follow the core directions by means of the four activities listed here:

- Improved and expanded collection and evaluation of 4-D observations;
- Programs to integrate measurements with measurements, and measurements with models;
- Updated and improved quality management of KNMI's observations and Third Party Data;
- Maintaining and updating knowledge.

The four core activities are expanded upon in 6.1 The need for 4-D information; 6.2 The need to integrate; 6.3 The need for improved quality management; and 6.4 The need for knowledge.

6.1 The need for 4-D information

The need for high-resolution 4-D information implies a strategy to maintain a sustained reference observational network that can measure relevant variables in three spatial dimensions over extended periods of time. In addition to providing information directly to KNMI's customers, this network is also used as:

- **reference points** for the ever increasing stream of local weather and climate information;
- **validation points** of satellite observations; and
- **input to high order weather and climate products** obtained from the assimilation of observations into high-resolution weather and air quality models.

6.1.1 The horizontal dimension: The Meteorological Network

The Netherlands possesses an observation network for meteorological observations. It has proven very difficult to answer the question how many such stations there should be to satisfy all client requirements. The current design of the meteorological network of KNMI (station density, measured variables, accuracies, etc.) is mainly a reflection of the needs of the weather and climate department of KNMI and external partners like defense, civil aviation and Rijkswaterstaat (RWS). The network is partly financed by those external parties and may be considered cost-effective. The design is a result of historical continuity, not of repeated verification of its validity. The vision presented in this Observations Strategy combined with the WIGOS RRR (Appendix 2) offers the opportunity to look at the KNMI network design in a new and objective manner.

6.1.1.1 The WIGOS Rolling Review of Requirements

The most objective method, namely a reliance on the WIGOS RRR indicates that while mostly sufficient for disciplines such as global climate monitoring and NWP, the network will remain always insufficiently dense for nowcasting and extreme weather applications at the local scale (See Appendix 2). Overall conclusion is that RRR is a necessary ingredient in evaluating station density but that other criteria (i.e. specific client demands, financial considerations, anticipated usages of stations, length of existing records, and station positioning) will play an important role as well.

In accordance with formal WMO regulations KNMI will start a milestone program to bring the observation activities within the RRR regulations.

Position:

P1. KNMI adopts the Rolling Review of Requirements (RRR) process of the World Meteorological Organization Integrated Global Observing System (WIGOS) as laid down in the Technical Regulations of WMO to support the optimal evolution of all its observing systems.

The use of the RRR will ensure that the following questions are properly addressed:

- What are the needs of the stakeholders, both nationally and internationally?
- Where does KNMI stand with its current capabilities?
- How different are our capabilities with respect to the requirements?
- How do we best manage our technologies?

The capabilities of the KNMI observing systems against user requirements will be evaluated on a regular basis. The gap analysis of requirements versus capabilities for each variable will results in a benchmark, providing objective arguments to plan the evolution of the observing network and to set priorities. As the network is used by a variety of users (weather and climate), it means that the use of the RRR in station evaluation is a contributing element not the deciding element.

6.1.1.2 Network spacing

As the core strategic directions and the vision articulated in the Observations Strategy advocate the integration of observation systems and high-resolution weather models as optimal interpolation tools, this implies a new role for the Meteorological Network namely that of a network of reference observation sites for new data products. This means that changes to network spacing should only be accomplished after a number of formal procedures have been properly followed.

6.1.1.3 Site mutations and network extensions

An earlier evaluation of all network sites has indicated that there are several stations that are not optimally sited, i.e. not representative for the vicinity of their location. Typical examples are Vlissingen and Arcen. If it is not absolutely essential to keep the stations at their current location to preserve continuity for climate records they should be either moved locally, repositioned away from their current locality altogether or closed (in extreme cases) so as to more evenly contribute to a representation of the weather and climate of the region. Other stations are linked to airfields and cannot easily be moved. Research on optimization of site locations is required to improve the design of the network.

Furthermore, the current network configuration indicates a lack of stations covering the sea–land transition, where strong gradients in atmospheric parameters occur, the North Sea, Wadden Sea and Lake IJssel, which are important for the Netherlands. Even though RWS operates some stations near or over water surfaces a better coordination in observations between RWS and KNMI should be achieved. Mobile AWS's could be used to evaluate the need for additional stations or network mutations.

Also, the urban environment is an important topic that merits increased attention in the coming years, because network sites are all located in rural areas.

Position and Actions:

P3. Site optimizations, mutations of the network and other changes to observing systems shall only be accepted after impact studies are performed and evaluated, the new configurations are proven in operation and after proper communication with authorities, clients, stakeholders and the general public.

A1. The current network configuration shall be evaluated using the formal procedures of RRR, PVM, communication protocols and consideration of impacts.

A2. Studies shall be performed to determine the merit of extensions to the network for specific applications and research (a) in urban centers (b) in the North Sea, Wadden Sea and on Lake IJssel and (c) at the land – sea interface. These studies shall explore the use of mobile AWSs.

6.1.2 The horizontal dimension: Satellite measurements

Today, many satellite observations are available in near-real-time. They are of diverse quality and usefulness in providing a comprehensive picture of the climate and weather. In order to incorporate satellite observations in the observational chain as standard products it is important to compare the satellite products with the existing products in order to find out whether they can replace or complement observations from the conventional network stations. Also it needs to be established whether satellite products from new instruments and missions have priority and added value.

Boers et al (2013)[3] have indicated that satellite-derived surface shortwave radiation and cloudiness are promising parameters to complement similar observations of the standard network stations. But satellite observation are not suitable to replace meteorological observations nearby the surface because radiation emanating from the atmosphere close to the ground is orders of magnitude smaller than radiation coming from the ground itself. Therefore the processing of such radiation information to products such as standard state parameters has low accuracy and is only possible under clear sky (i.e. not cloudy) conditions.

6.1.3 The horizontal dimension: Third Party Data

There are a number of initiatives to exploit Third Party Data in meteorological applications. Examples are:

- **The Weather Observations Website (WOW)[4]:** WOW is an initiative of the UK Met Office originally intended as an open platform to use and exchange weather observations from the general public. The main purpose is to increase the spatial and temporal resolution of surface observation data to meet new demands. It has proven useful as an additional source of information in the description of climate and extreme weather events and for forecasters. Many observations under WOW are from commercial weather stations and KNMI is evaluating WOW related observations for its own usage.
- **Cars and traffic:** New efforts are underway at KNMI to evaluate the use of car and traffic information in terms of meteorological parameters. Such efforts are geared towards specific applications such as the easing of traffic congestion and early warning of inclement weather and may hold promise to provide an additional data source for forecasters.

6.1.4 The horizontal dimension: Radar and precipitation

KNMI will acquire two dual polarization radars at the end of 2015/beginning of 2016. The radars will improve the quality of real-time reflectivity composites as well as the quality of current radar products to operationally deliver precipitation type, quantitative precipitation estimates, vertical wind profiles and the radial wind estimates. Merging of radar data with the Dutch ground-based precipitation network is promising.

6.1.5 The vertical dimension: Radiosonde, ozonesonde, NO_2sonde

Today, radiosonde observations are still essential probing the atmosphere in the vertical direction and are required for the Global Reference Upper Air Network (GRUAN). Current measurements of humidity are not yet up to the climate standards as formulated by GRUAN, but can be made to do so requiring only small improvements. Therefore it is important that humidity soundings of the daily radiosonde will be brought to GRUAN standards by performing the required calibration of the humidity sensor.

Given the emphasis of KNMI's satellite observation activities in measurements of atmospheric chemical composition including ozone content the record of ground-based ozone measurements for climate purposes as well as validation for satellite observations should be continued.

Recently, the development of the NO2 sensor at KNMI has led to the capability of measuring NO2 composition from sounding balloons. NO2 is an important component of air quality which is measured from satellites and the weekly launching of these sondes forms a crucial validation source.

6.1.6 The vertical dimension: AMDAR, MODE-S, GPS and Drones

The need to supplement the limited coverage of the in situ data from radiosonde has stimulated a vigorous effort to obtain such information elsewhere. AMDAR and MODE-S obtain profiling information from meteorological sensors and transponders aboard aircrafts particularly during ascent and descent, thus providing information from the top of the troposphere to the surface. Even though such information is limited to the vicinity of airports they have demonstrated significant potential to contribute to the improvement of nowcasting. Also a network of GPSs is used to derive the integrated water vapor at these locations that can be assimilated in NWP models. At the same time it will be important to continue to survey new initiatives such as drones and Third Party Data (for example wind turbines). The use of drones will be explored for operational boundary layer measurements, research and for use during special weather conditions. Drones make it possible to observe the atmosphere at crucial locations for which it proves difficult to derive observational information from existing sources.

Actions:

A4. KNMI will continue to explore new sources of surface climate and meteorological information such as exist in Third Party Data (for example WOW) and other potential Big Data applications.

A5. KNMI will continue its radiosonde, ozone sonde and NO2 sonde launches and explore new ground-based remote sensing techniques in vertical profiling the atmosphere, and new (Third Party) sources of upper air information such as aircraft observations from AMDAR and MODE-S. The use of drones will be explored for operational boundary layer measurements, research and for use during special weather conditions.

6.1.7 The vertical dimension: CESAR

The strong embedding of CESAR within the international atmospheric research community ensures a wide spread use of its data, which over time results in improvements in scientific knowledge which is profitable for both KNMI and the Netherlands in general. A business case for CESAR has been put forward to develop it into a financially sustainable facility (See Appendix 3).

With the strategic goal to observe the atmospheric structure over the Netherlands in four dimensions together with the need for integration of different measurements with each other and with high-resolution models the role of CESAR in the observation network of the Netherlands gains new impetus. Collocation and coherence of observations are the two main strengths of CESAR. In light of the future, the four strategic components driving the programs at CESAR in the next decade will be:

- **Coherent observation of the vertical structure** of the atmosphere, including clouds, radiation, atmospheric composition, temperature, humidity, wind and the interaction with the land surface;
- **Testing and validation of models and atmospheric processes** represented in atmospheric models;
- **Collocated and coherent monitoring of** ECV's within the context of the GRUAN and BSRN programs;
- **Validation and complementation** of satellite observations within the context of atmospheric physics and chemistry processes.

Part of these four strategic components require the maintenance of existing infrastructure such as boundary layer, radiation and remote sensing equipment for measuring clouds and aerosols. Part involves the investment into new equipment and man power such as suggested expansion into chemistry. These efforts will need to be prioritized.

Action:

A6. The need for infrastructure for CESAR shall be evaluated and prioritized and agreed upon with CESAR partners in order to accommodate the continuation of existing observations of ECV's, the facilitation of studies of atmospheric processes, clouds and radiation, the testing of atmospheric models and possible new extensions of the measurement program into atmospheric chemical composition.

6.1.8 The vertical dimension: The ceilometer network

Over the last 10 years the LIDAR technology has gained maturity. This technique uses ground-based remote sensing to observe the atmospheric aerosol / cloud backscatter structure. The technique is now so advanced and robust that it is routinely possible to observe vertical backscatter profiles using a small LIDAR instrument (ceilometer). Hence a ceilometer does not only provide the cloud base, but is also a means to monitor continuously the evolution of the planetary boundary layer, aerosol layers, volcanic ash clouds, and the development of clouds for climate and future assimilation in NWP and air quality models.

It has already been decided that ceilometers yielding cloud and aerosol information up to stratospheric levels will be placed at the 5 main climate stations (De Bilt, De Kooy, Vlissingen, Eelde, and Beek), and on platform A12 on the continental shelf. In fact it proved cost-effective to place such ceilometers at all stations where aviation requires information on the cloud base height. For several purposes including the detection of volcanic ash, the ceilometer data needs to be linked to reference data, for instance vertical profiling from the CESAR station.

6.2 The need to integrate

Central to the KNMI's Observations Strategy is the vision of encapsulating the geographical domain of the Netherlands within a high-density grid of atmospheric observations / data products. The myriad of novel observation techniques and ever increasing capabilities to model the atmosphere with high resolution provide a compelling opportunity to develop new and improved atmospheric data products.

The following steps are envisioned:

- **Integration of information from different observational networks or instruments into optimal products.** This work relies mostly on optimal interpolation techniques and the use of relatively simple physical constraints and models. Work is targeted at providing single atmospheric parameters, like for instance spatial distributions of surface radiation, rainfall or temperature. Here, the more frequent use of Big Data is envisioned (section 6.2.1).
- **A detailed characterization of the state of the atmosphere** (including for instance, clouds, turbulence, radiation, composition) is needed by a mixture of cleverly chosen instruments. Here, the measurement site at CESAR plays a crucial role, and the detailed measurements done there set a standard for model evaluation and development, and satellite calibration (section 6.2.2).
- **Merging information from observational networks with information derived from 4-D modeling of the atmosphere.** The aim here is to provide a full three dimensional picture of the atmosphere that evolves with time. This is typically done by assimilating the observations into a NWP model. The quality of the data may be lower than for direct observations because of model biases. However, the output is complete, available at high resolution and in near-real-time and can be generated for long time periods such as re-analysis products. There is potentially a better consistency between different atmospheric variables (section 6.2.3).

6.2.1 Merging measurements of a single parameter

At the moment the quality of gridded data sets is largely determined by station density. At present data from in-situ observations, satellite observations and radar observations are mostly handled separately. High-resolution spatial patterns can be obtained by integrating data from different observation sources. In order to improve the data products in terms of quality and resolution to meet the demands in the near future strategic research needs to be carried out. There are promising data products that can be generated by combining output from different sensors.

Action:

A7. A strategic research program is to be set up to merge different data sources into optimal high-resolution data products. Priority examples: a) precipitation intensity from satellite, in situ and radar observations; (b) a surface radiation product from a combination of surface and satellite observations, (c) temperature from the KNMI network and Third Party Data, (d) a cloud product from ceilometer and satellite data. The construction should be explored of (e) potential evaporation from temperature and satellite-derived radiation products, (f) a visibility product from satellite and ground-based observations, and g) aerosols and air quality products from satellite and in situ observations.

6.2.2 Observations and model representations

In order to integrate models with available observations it is important that such models represent the atmosphere in the best way possible. Therefore strategic research needs to be carried out with the aim to best represent the essential processes in the models. In the study of atmospheric processes the observed parameters should be coherent with each other. At CESAR coherence is achieved by employing complex instrumentation to study the interaction between aerosol, clouds, radiation, thermodynamic profiles, turbulence and the land surface. An essential element of the CESAR-program is the long-term nature of it. Isolating and resolving complex processes from ambiguous atmospheric signals demands long time series, typically a decade or more. The presence of such long-term programs at CESAR has put CESAR into a unique strategic position in the world, which KNMI intends to exploit for the purpose of improving the representation of atmospheric models.

Action:

A8. A strategic research program is to be carried out to test and improve the representation of atmospheric processes, specifically the radiative, thermodynamic, turbulence, cloud, aerosol and chemical composition in models of the atmosphere: the CESAR-test bed to be recognized officially by WMO and other UN bodies.

Action A8 requires the collaboration of several institutes with KNMI that are joined in the CESAR consortium.

6.2.3 Merging all observations with a 3-D model of the atmosphere

As a final and most complex step of integration it will be necessary to integrate all relevant observations with a 3-D model. Integration/assimilation of the different data sources with models has significant synergetic advantages. In this manner model and/or satellite information are used to deduce high-resolution spatial patterns while the in situ measurements are used to calibrate fields and to provide information on climate variability and extremes. Also data assimilation will lead to higher quality real-time meteorological data products. As a spin-off this work will further enable network optimization using a quantitative approach. In order to achieve the vision of providing KNMI's clients with 4-D atmospheric information at any place and at any time strategic research must be carried out in the field of near-real-time data integration and reanalysis.

Action:

A9. A strategic research program is to be carried out to expand near-real-time integration of observations with the HARMONIE 3-D high-resolution atmospheric model and to bench-mark against similar reanalysis activities elsewhere.

A number of promising approaches with respect to Action 9 have emerged over the last years: a) merging MODE-S data with the high-resolution HARMONIE model demonstrates improvements to nowcasting wind, b) coupling

HARMONIE with hydrological data improves the representation of evaporation, and c) the use of HARMONIE to downscale existing ERA-Interim reanalysis wind data has been used to obtain a high-resolution wind climatology. This last product could be further improved by ingesting data from RWS , the Meteorological Network and possibly wind observations from radars and wind turbines.

6.3 The need for improved quality management

KNMI is responsible for the development, management and maintenance of the network of meteorological observations in the Netherlands. Even though procedures are well documented, quality assurance (QA) and quality control (QC) procedures are to be maintained at the highest levels and continuous improvements should be carried out so that the network preserves its status of a reference network. In light of the trend of increased data streams, new technologies and data products it is expected that high-quality reference observations will increasingly be needed for KNMI to assess the value of new products and the observations of Third Party Data.

6.3.1 Keeping our house in order

The following elements are necessary to assure that the data products from the present infrastructure are always kept to the highest standards:

- **Observations chain management, existing content:** The chain 'production-evaluation-improvement' in the overall KNMI strategy also applies to the existing observation and data product quality and documentation. For each element of the chain the responsible persons need to jointly work on continuous improvement of QA & QC procedures
- **Observations chain management, new content:** R&D will improve content-related QA & QC procedures as the demand for ever increasing timeliness and quality. New quality tests using state-of-the-art techniques will be applied (space and time consistency, NWP outputs, statistical homogeneity testing for several time scales). Brandsma and Van der Meulen (2012)[5] and various KNMI Technical Reports proposed several improvements for content-related QA and QC procedures and will be used as a starting point.
- **Proper management of metadata and data formats:** Metadata and data formats are diverse and often difficult to access or understand by KNMI's clients. Metadata databases will be integrated, readily accessible and directly linked to the data, and based on international standards. Uniform data formats including standard retrieval procedures will be introduced.
- **Using proper network mutation protocol:** The KNMI protocol for changes in the measurement infrastructure (PVM) is based on the GCOS monitoring principles and will be applied rigorously and pro-actively to ascertain the long-term continuity of climate time series (especially of ECVs). Also a protocol needs to be in place to communicate with clients about impending and / or desired changes in infrastructure. The GCOS monitoring principles are related but different from the WIGOS RRR as the former refer to climate observation networks only, while the latter refer to all disciplines within the realm of atmospheric observations.
- **QA/QC for CESAR:** Although the purpose of work at CESAR was originally mostly related to research into the understanding of physical processes, the renewed emphasis on vertical profiling, satellite validation and integration of data from different sources means that further action is needed to envelop CESAR's data into the traditional observation chain of quality management.
- **Historical data, archiving and maintenance:** Meteorological data collected at KNMI goes back many decades, and on some occasion more than a century. Management and archiving procedures are to be dealt with under a separate strategy (Data and Infrastructure Strategy).
- **The BES Islands:** With respect to climatological services there is a backlog that needs to be addressed in the short term (e.g. exchange of historical digital meteorological data for the BES Islands, digitization of hardcopy meteorological data, and knowledge development with respect to the climate of the BES Islands).

Observational chain management is a demanding task which includes a) knowledge of algorithms and implementation, b) insight into the validity of data streams, c) preserving the integrity of data bases and d) the responsibility of making mutations if necessary.

This requires that the Observations Chain Manager be supported by operational and R&D personnel with

Action:

A13. With the implementation of the Observations Strategy, the role of the Observations Chain Manager (OCM) is reaffirmed. OCMs are assigned for all meteorological variables with a mandate to manage and control the content of observation chains. Their work is supported by a Process Manager.

specific knowledge. Existing observation management therefore needs to be evaluated, not only internally, but also externally on a periodic basis (here a five year period is suggested).

Actions and Position:

A14. An internal evaluation of existing observations chains will be performed with the purpose to improve adherence to existing guidelines, their quality and traceability. Actions to improve observation chains will include emphasis on Research and Development (R&D) to improve content, integration and standardization of metadata data base and unifying data formats, Quality Control / Quality Assurance (QC/QA) monitoring, validation and documentation. A five-year periodic external evaluation and review will be carried out of KNMI's observations chains to assure agreement with international requirements.

P2. The Global Climate Observing System (GCOS) monitoring principles as laid down in the Protocol for Changes in Measurement Infrastructure (PVM) will be applied to manage mutations to climate monitoring network.

A3. For observation products (including possible new products) the WIGOS RRR shall be used to describe status, and required or desired developments in the coming 10 years.

6.3.2 Managing the influx of Third Party Data

The increasing use of meteorological data from Big Data sources not managed by KNMI requires KNMI to assess the usability of such Big Data sources for different variables and application areas and perform quality control. KNMI, being the authority of meteorological observations, must assure a certain quality and usability. The new developments require a new area of activities that can be broadly characterized under the name: Third Party Data Stewardship. These activities are necessary to dynamically assess the inflow of new data, their continuity, their possible contribution to KNMI data products and as a means to certify their quality. This work can draw from the 25 year experience handling E-AMDAR data.

Action:

A11. Third Party Data Stewards will be enlisted to manage the quality of Third Party Data and to evaluate the potential of new data sources and to ensure their inclusion in KNMI 's operational processes. Evaluation tools and automatic data evaluation procedures will be developed to determine quality and usefulness of Third Party Data.

6.4 The need for knowledge

6.4.1 Strategy, knowledge development and collaboration

As prerequisite for the execution of any strategy is the development of knowledge. KNMI has developed considerable expertise into the fields of radiation and satellite meteorology (e.g. OMI, SAF, BSRN), model development and parameterizations (EC-Earth, RACMO), chemistry (satellites, TCM, LOTOS -EUROS), ground-based atmospheric sensors and instruments, ground-based remote sensing and boundary layers (Cabauw, weather radar), weather prediction (HARMONIE) and climate change diagnosis.

As the strategy indicates a trend towards integration of different observations with each other and with models, it will be important to facilitate integration of expertise within all of these fields. This implies an emphasis on efforts to stimulate collaboration. Collaboration means a vigorous interaction between KNMI's departments, not only amongst the R&D departments, but also between the operational departments and the R&D departments. A principal requirement would be the optimal planning of capacity between departments to carry out the actions of the Observations Strategy.

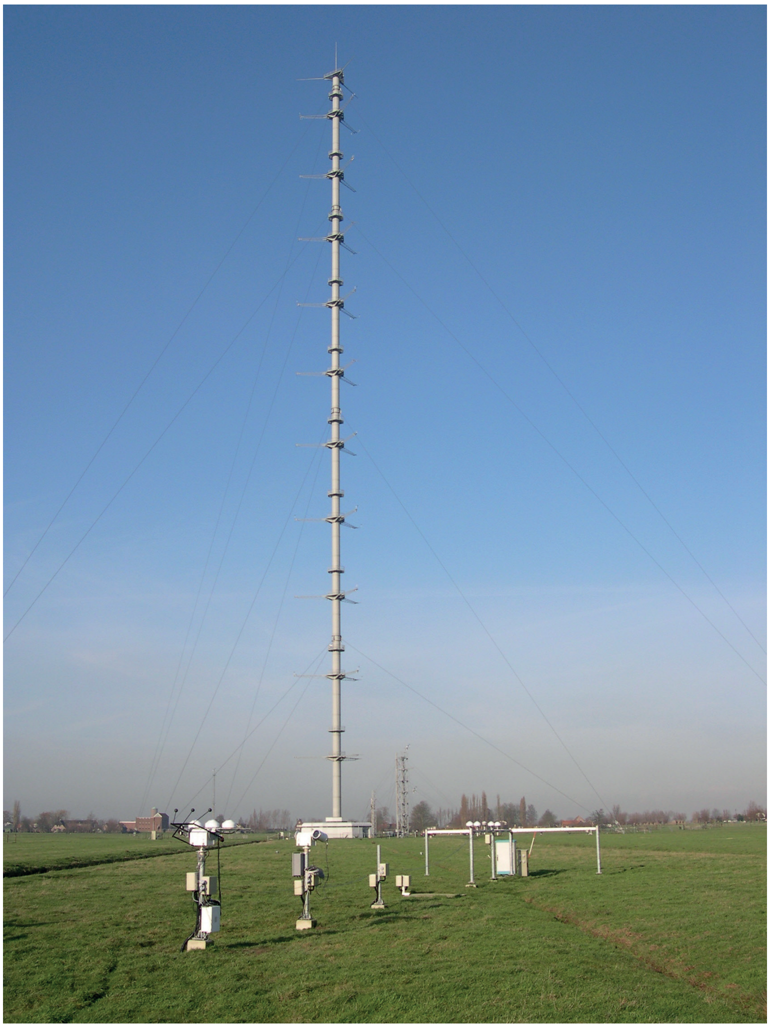
6.4.2 The interplay between research and quality management

Even though the quality management will ensure that the output of KNMI's observation system will meet the required standards, an essential element of (inter) national acceptance of KNMI's observation systems is the physical understanding of output in the context of scientific research pertaining to weather and climate. Such research involves process studies using coherent / linked atmospheric parameters, climatic trend analysis and studies into usages, improvements of measurement technologies. These types of research will deepen our understanding of the output of KNMI's own observation system as it relates to systematic observations elsewhere, and will feed and stimulate the development of improved quality systems, technologies and data products.

On the other hand the cooperation with the international research community will enhance the scientific knowledge which eventually will feed back into benefits for KNMI and the Netherlands as a whole.

Action:

A10. Strategic research is to be carried out to a) interpret the (integrated) observations in terms of atmospheric processes and climate trends b) update, improve, understand and manage measurement technologies.



Cabauw Experimental Site for Atmospheric Research (CESAR). In front KNMI's Baseline Surface Radiation Network site. At the back, the Cabauw observation tower. Photo courtesy: Wouter Knap

7 National and international collaboration and representation

7.1 National Collaboration

Amongst Dutch institutions KNMI is but one that manages a network of observations related to meteorology and climatology. A few examples: RIVM operates an air quality network, RWS operates a network of hydrological observations, Water District Boards measure hydrological and meteorological parameters. Where integration becomes an essential element for future work, it is important to continue to collaborate with such institutions in order to assure that the best quality data from adjacent disciplines can be incorporated into new products.

7.2 International Collaboration

Our closest neighbors: Our observation system is adjacent to those of Germany, Belgium, the UK and France. The Netherlands feeds our neighbors with data, and they feed the Netherlands. Free exchange of data between countries is essential in order that data products mutually benefit in quality and refinement. Station cover on the fringes of the Netherlands is already lower than in the central parts of the Netherlands. For the border regions data from German and Belgium stations are a good addition to the Dutch observation network. In particular there is interest in obtaining data at a higher spatial and temporal resolution than currently available.

Nevertheless foreign stations cannot replace our stations in border regions permanently as measurement methods may differ in some cases, long-term governance is complicated and such a sided strategy is against the principles of international bilateral data exchange.

International programs: International programs in which KNMI contributes serve three purposes:

a) Implementing and maintaining quality and reference standards;
b) Exchange of knowledge;
c) Exchange of data.

EUMETNET: EUMETNET is the most important mechanism for cooperation on the European non-satellite observation network. Many EUMETNET observation programs exist. The list includes E-AMDAR, E-SURFMAR (VOS, drifters and moored buoys) and EUCOS.

Other examples of programs in which international collaboration enhances the national observational efforts are ARGO, surface drifters and VOS (as contributions to world-wide oceanic weather and climate observations), BSRN and GRUAN (as contributions to international networks to standardize radiation and thermodynamic profiling) and many of the satellite programs (contributions to physical and chemical meteorological programs). For the MTG and EPS-SG satellite programs, expert teams have formulated the mission requirements.

Copernicus: KNMI is and will be involved in several projects under the Copernicus service program, in particular the a) Marine, b) Atmosphere and c) Climate Services. The Copernicus program offers KNMI long-term opportunity to contribute its expertise in the construction of an international overarching service provision of climate data to Dutch society.

Capacity building: Together with international partners and WMO KNMI has established the International Climate Assessment and Dataset (ICA&D) project: Data collection centers are established in regions where climate data are scarce and/or difficult to access. In these centers data are stored, digitized and quality controlled. KNMI is involved in three such centers e.g. in Indonesia, Niger and Ecuador as part of the WMO Global Framework for Climate Services (GFCS). In collaboration with the Meteorological Service of Surinam weekly ozone sounding and continuous ozone columnar measurements are taken at the station of Paramaribo.

Position:

P4. KNMI will continue the efforts to structurally obtain data at a higher spatial and temporal resolution than currently available from neighboring countries' observing systems in the border regions of the Netherlands based on the principles of bilateral international data exchange.

7.3 Representation

KNMI maintains an active representation in international working groups and expert teams that deal with observation management, infrastructure and research. Such representation is important for three reasons:

- KNMI is continually fed by important information on all aspects of meteorological observations that can be applied in its own observation management,
- KNMI profits from international coordination and joint observation strategies, e.g. within EUMETNET, and
- KNMI actively contributes to shaping the international knowledge base on observations by freely sharing its own expertise to the international scientific and meteorological community (see KNMI's International Strategy paper).

Nevertheless KNMI's involvement in such committees need to be prioritized as dwindling resources require strategic choices into which committees KNMI's representation is essential and in which it is not.

Position:

P5. KNMI will continue to actively participate in international liaison and expert committee functions in order to contribute to coordination efforts of international meteorological organizations. Strategic choices shall be made in which committees KNMI participation is essential.

KNMI's satellite reception facility.
Photo courtesy: Raymond Sluiter

8 Organization structure to meet the challenge

The KNMI-strategy describes KNMI's organizational structure to be consisting of a Front Office and a Back Office. In mapping this structure onto the Observations Strategy the coupling of clients to the sensor output through the products /geophysical variables is central. Internal and external clients define and express their need for products to the Front Office, which the expertise of the Back Office will provide. Interface management will be needed at the point where Front Office meets Back Office. A suggested framework to do so is expressed through Figure 1. Within both Offices a special role is attributed to the Strategic Business and Account Manager (Front Office) and the Observations Chain Manager (Back Office).

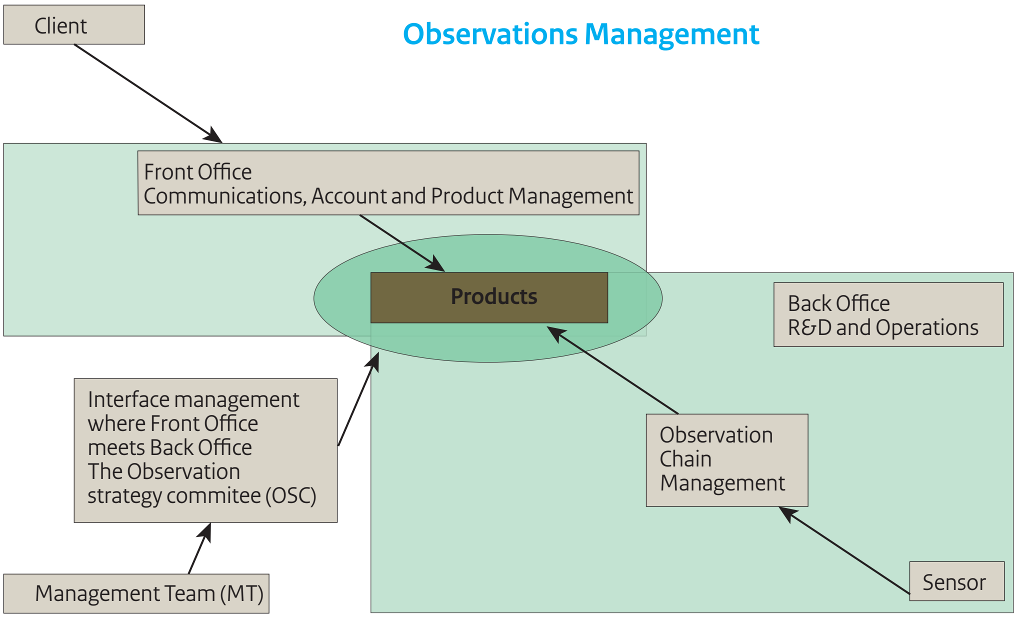


Figure 1: Management structure to couple clients to observations.

Action:

A12. A governance structure is set up to manage the overlapping structures of Front Office and Back Office with an Observation Strategy Committee (OSC) at the interface.

Action A12 is a general action that aims at specifying the tasks and responsibilities of the Front Office and Back Office. However, there are a number of points that will need to be taken into account when providing the governance structure. These points are outlined below:

Front Office: Business / account managers are the eyes and the ears of internal and external clients. Business / Account managers are service-oriented and good communicators as it will be their job to facilitate and articulate the need for products to the Back Office. At the same time they are the first contact for new product emerging from the Back Office.

Back Office: Observations Chain Managers (OCMs) are responsible for observation chains and supervise the conversion of measurements into geophysical products, their quality and traceability.

Interface management: To assure that clients have access to the right products, can give input into the development of new products, or can get exposure to new and potentially promising products that have been developed in the Back Office, the interface between Front Office and Back Office needs to be properly managed. This is facilitated by an Observations Strategy Committee.

Observations Strategy Committee (OSC)
The purpose of the Observation Strategy Committee is to structure the communication between the Business / Account Managers and the Observation Chain Managers.

In order to function effectively it is suggested that the OSC:

a) becomes responsible for implementation of the Observations Strategy;
b) specifies the TOR for the Observations Chain Manager;
c) determines the responsibilities with respect to the improvements to the observation chains;
d) prepares decisions on priorities and resources for the Management Team, and supervises execution of decisions in the Front / Back Offices;
e) becomes responsible for the execution of the multi-year observation infrastructure investment plan
f) becomes responsible for the execution of the research plans related to observations;
g) specifies the TOR of the Third Party Stewards.
h) ensures that the task of the Observations Chain Managers is facilitated by proper collaboration between and support from relevant departments;
i) Ensures that proper resources are available to the OCM.

Observations Chain Manager (OCM)

Observation Chain Managers (OCMs) are responsible for observation chains and supervise the conversion of measurements into geophysical products, their quality and traceability. They will:

a) implement the WIGOS RRR approach;
b) assume responsibility for the documentation of the measurement chain;
c) specify and initiate and approve modifications to measurement chain where necessary;
d) be focal point regarding the measurement products;
e) report on the status of the production chains and are alert on new developments, promising observation techniques.
f) advice the OSC where necessary

Third Party Data Steward (TPDS)

Third Party Data Stewards will manage the quality of Third Party Data and evaluate the potential of new data sources and ensures their inclusion in KNMI's operational chains. They will closely interact with the OCMs in order to enable optimum usage of a Third Party Data.

Process Manager (PM)

Process Managers will assume responsibility of the execution of the process of conversion of measurements into geophysical products, including quality, and traceability. Under authority of the Observations Chain Manager [s]he will be running the daily operational process and implement actions as they devolve from the OCM.

KNMI's Brewer spectrophotometer.
Photo courtesy: Raymond Sluiter

Terms of Reference

Background

Now that the new KNMI-strategy with focus on geophysical safety is completed, it is time to address the observation strategy. Recently the extreme precipitation of 28 July 2014 and accompanying excessive water discharge again demonstrated the importance of good observations. In this example their importance is the diagnosis after the fact of extreme events and dangerous weather. However, maps of the climate atlas and the climate scenarios of KNMI'14 are all dependent upon good observations. Also, KNMI has many data customers and has international obligations towards EUMETNET, EUMETSAT, WMO, GEOSS and UNFCCC with regards to the exchange of data and the knowledge associated with it.

Changes in the basic synoptic and climatic network often have uncorrectable consequences. Therefore decisions about the network have to be made after due and careful consideration. A good observation strategy is essential and leads the way. It is an illusion to think that we can underpin our need for (future) observation precisely, but a strategy can provide the directions from which choices and priorities will follow.

Points of departure

1) The Observations Strategy is a logical consequence of the new KNMI strategy and looks 10 years ahead. Budget reductions are not its impetus: only the optimal use of available means within budget. Because the available budget can grow via special dedicated grants, a minimum / maximum scenario is required. So, the question is in which direction growth is envisioned and in which direction a reduction can be expected.
2) Taking into account the new Law on Meteorology and international commitments and obligations towards EUMETNET-EUCOS, EUMETSAT/ESA, WMO-WIGOS, GEO-GEOSS en UNFCCC-GCOS.
3) Taking into account the different wishes and interests of customers of our observation data (aviation, commercial weather providers, defense, local and regional governments, universities, commerce and the general public) by interviewing them about their future requirements.
4) Giving direction to the question about the quality of observation data and information for different customers and for different applications.
5) Optimal usage of innovations of observation technologies and the development of alternative means of observations such as mobile stations, crowd sourcing, Third Party Data, commercial weather providers, RWS, dykes surveyors, universities, RIVM) en observations from neighboring countries. Giving guidance on expected developments in terms of time and technological advance. Balance between proven technology and early adaptors. The strategy should give guidance on the role of innovations in time.
6) Taking into account the use of observations in KNMI-data products; Observations from different sources and models are all combined for monitoring of safety risks (weather alarm / hazard center), monitoring of climate change, satellite validation, data assimilation in models, development and evaluations of models, the climate atlas and climate scenarios.
7) Define steps to integrate ground-based remote sensing data (radar, LIDAR, ceilometer), satellite data, profiling data (Cabauw, balloon, aircraft) and re-analysis of observations into the most important KNMI products, including a consideration of the implications for our ground-based synoptic network stations.
8) Giving an outline for the justification of the current synoptic network including the balance of costs and profits, and advantages and disadvantages of changing the current network.
9) Determining the minimal set of observations that needs to be maintained in the coming ten years, including the relevant variables and associate quality.
10) Outline where KNMI leads in knowledge development, where our efforts are enhanced by national and international acquisition, and where it is better to purchase expertise from others.
11) Taking into account the communicative issues associated with changing the network.
12) Taking into account Open Data Policy, statutory requirements, rules and regulations (INSPIRE) and standards (OGC and WMO-WIS) en the importance of good archiving and accessibility of the data (KNMI Data Center).
13) Taking into account the conclusions of 'Prioriteiten voor het nationale meteorologische meetnet' van 25 april 2013.

Constraints

1) Most important is the outline, not the precise instruction.
2) Take into account the BES Islands as well.
3) No seismology included.
4) Strategic choices of satellite observations are more or less fixed in the programs of EUMETSAT / ESA and will be used as conditions of usage. Satellite observations will be included to describe synergies with ground-based observations such as integrated products of solar energy from Meteosat.
5) Taking into account cooperation with others.
6) Taking into account, Cabauw, radiosondes/ ozone sondes, radar, AMDAR, VOS/buoys, North Sea platforms and lighting detection.

Appendix 1. The Observations System of the Netherlands

Meteorological Network: The surface Meteorological Network in the Netherlands serves climate and weather purposes and evolved from requirements from divergent interest groups such as weather/climate, water, agricultural, regional and municipal authorities and aviation. It comprises of automatic weather stations on land and on the North Sea platforms , airports and airfields spread out over the Netherlands funded by KNMI, and by KNMI's partners such as the Ministry of Defense, Civil Aviation and RWS.

Radiosonde: At the main synoptic station De Bilt, a radiosonde is launched daily at 00 UTC. Radiosondes provide in situ upper-air observations of atmospheric pressure, air temperature, humidity, wind direction and speed. Additional radiosonde observations are optionally made for nowcasting purposes on request of operational meteorologists.

Aircraft: AMDAR and Mode-S are two methods to obtain temperature and wind profiles from commercial airlines that ascend out of and descend into airports of the Netherlands. KNMI is actively participating in programs to assess the use of these data in complementing the regular radiosonde launch in the acquisition of upper atmosphere profiling data.

CESAR: The Cabauw Experimental Site for Atmospheric Research (CESAR) is the meteorological research site of KNMI and was originally established in 1972. Research work focuses on exchange processes between the earth and atmosphere and on the interaction of clouds, aerosols and radiation, the evaluation of climate and weather models and the validation of satellite retrievals The facility encompasses a land surface flux site, a 200m meteorological tower, a radiation site (BSRN) and a remote sensing site for wind, cloud and aerosol profiling.

Satellite missions: KNMI is and has been an active participant in / developer of products from / consumer of data from many satellite missions that register the state of the atmosphere and surface. The focus is on UV-VIS-NIR spectrometers (e.g., SCIAMACHY, GOME-2, OMI) for atmospheric composition (trace gases, aerosols, clouds), VIS-IR imagers (e.g., Meteosat-SEVIRI) for clouds and radiation, scatterometers (e.g., ASCAT) for winds over sea, and LIDARs (e.g., ADM_Aeolus, EarthCARE) for 3D winds, clouds and aerosols. Furthermore, KNMI is strongly involved in the development of new satellite missions (TROPOMI, Sentinel 4 and 5).

Ozone and NO_2 measurements and sondes: At the KNMI site de Bilt a Brewer Spectrophotometer is operated since 1994 to measure the total ozone column. Additionally, vertical ozone profiles up to an altitude of 34 km have been measured by ozone sondes at weekly intervals since 1992. Ozone measurements are made to validate / calibrate satellite data and obtain a calibrated long-term time series of the profile and total column of ozone. A weekly NO_2 sonde is launched in conjunction with the ozone sonde.

Radar network and (voluntary) precipitation network: KNMI maintains two precipitation radars (De Bilt and Den Helder). Output from the two radars is merged with that from a network of regional European radar stations thus providing precipitation coverage over most of Europe. Also a precipitation network of over 300 voluntary observers exists to complement the radar data.

VOS and SURFMAR: KNMI is participant in the Voluntary Observing Ship program. Under international agreements, a world-wide network of Port Meteorological Officers (PMO's) are involved in keeping the fleet of VOS intact. The duties of the PMO's consist of: a) recruiting new volunteers b) inspection of ships' meteorological equipment and c) instruction to observers. Via SURFMAR KNMI contributes to a network of surface drifters.

ARGO: ARGO is an observation system for the oceans that delivers real-time data for use in climate, weather, ocean fisheries research. Argo consists of a set of robot sondes that are transported by ocean currents all over the world. The Netherlands contribute to the ARGO-project since 2004. Since then 58 more floats have been deployed, all but one in the Atlantic and south-western Indian Oceans.

GPS – GNSS: These observations are used to reduce errors in geodetic and geophysical applications. However, they are also valuable for atmospheric sciences. The GNSS signals are now routinely used in numerical weather forecasting, atmospheric research, and space weather applications. The status of the network is monitored by KNMI, who is also one of the GNSS analysis centers.

Lightning detection network: KNMI has operated an automatic lightning detection system since 1995.

BES Islands: KNMI recently became responsible for the climatological, meteorological, and seismological services on Bonaire, Sint Eustatius and Saba (BES Islands). Since April 2013 an AWS is operational at Bonaire, in the course of 2015 the other two Isles will follow.

Paramaribo observation station in Surinam: KNMI works together with the Suriname meteorologcial service to maintain a Brewer Spectrophotometer and weekly launches of ozone profiles.

Appendix 2. The Rolling Review Requirements

The WIGOS RRR concerns all disciplines in meteorology related to meteo, climate, hydrology for both surface and satellite observations. The RRR uses the Observation System Capability Analysis and Review Tool (OSCAR) which facilitates the comparison, on an international level, of user requirements (technology-free) for horizontal resolution, vertical resolution, observing cycle, timeliness and uncertainty for several application areas with the capabilities (technology-dependent) of present and planned observing systems to provide them. This comparison results in a Critical Review (CR) that is used to prepare Statements of Guidance (SoG) for each discipline. The SoG draws attention to the most important gaps between user requirements and observing system capabilities, in the context of the applications. Implementation of the WIGOS RRR process in the Netherlands, reveals these gaps for KNMI's observing systems and offers the possibility to prepare a SoG for each variable that can be used to make decisions about future network design.

For horizontal resolution expert opinion has determined three quality values per variable and per application:

a) Threshold: This is the minimum resolution needed to be useful;
b) Goal: this is the ideal resolution so that no increase in resolution is necessary;
c) Breakthrough: This is the optimum resolution between threshold and goal seen from a cost – benefit standpoint.

From an economic standpoint, the price – quality balance is optimal for the breakthrough condition.

A first evaluation of the station network of the Netherlands yields ambiguous results:

- For climate Atmospheric Observation Panel for Climate (AOPC, global / climate monitoring) the resolution of the networks for meteorological measurements is sufficient for the 'breakthrough-resolution for all relevant variables. However, on regional scales requirements are not stated in the RRR, and could thus be completely different;
- The ultrafine network resolution specified in RRR for nowcasting and extreme weather is not going to be achievable under any circumstances; For global NWP, it is especially the density of the precipitation network that is insufficient for the breakthrough resolution;
- For the synoptic meteorology the network density of air temperature is insufficient for breakthrough resolution.

In other words the network resolution is good enough for some purposes, but not nearly good enough for others. As the network is used by a variety of users (weather and climate), it means that the use of the RRR in station evaluation is a contributing element but not the deciding element.

Appendix 3. Business case for CESAR

Despite its high international standing, CESAR is under threat due to declining federal budgets and perceived lack of clarity in articulated long-term research and operational goals. Last year, a business case was formulated to underpin CESAR with a new and stable funding structure and a set of strategic goals in the near / intermediate future. The central components of the business case are

- A long-term measurement program of a limited set essential variables for weather and climate and atmospheric composition under federal funding;
- Short term measurement programs funded by government, CESAR consortium partners and third parties;
- International funding (EU, global) as a contribution to international research and monitoring programs.

References

1. National papers consulted here were those of the synoptic observation network (SWANET, 2005), the climate observation network (KWANET, 2005), the earlier KNMI's observation strategy (not accorded by the KNMI directors, 2009), Het KNMI Waargenomen (2009), The National Observation Strategy (2009) and its successor Vervolg NOS (2013, summarized in reference iii, see below) and KNMI's Earth Observation Strategy (2014).
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KNMI's observation test site at De Bilt. At the right KNMI's radiosonde launch facility.
Photo courtesy: Raymond Sluiter

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